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# Pulsations in stars with abundance stratifications: the case of the chemically peculiar HgMn stars

Satenik Ghazaryan

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# THÈSE

En vue de l'obtention du  
**Diplôme de Docteur « Astronomie et Astrophysique »**  
délivré par  
**L'Observatoire de Paris**

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Présentée et soutenue par:

**Satenik Ghazaryan**

le mardi 12 novembre 2013

Titre:

**Les pulsations dans les étoiles avec stratifications d'abondance: le cas des étoiles  
chimiquement particulières HgMn**

*Pulsations in stars with abundance stratifications: the case of the chemically peculiar  
HgMn stars*

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# Résumé

La modélisation des processus de diffusion microscopiques et de la stratification des abondances dans les étoiles a fait de grands progrès dans les années récentes. Les données observationnelles ont fait de leur côté un bond très important, notamment en astérosismologie grâce au satellite CoRoT. Parmi les résultats relativement anciens, on sait que la diffusion de l'hélium (sédimentation gravitationnelle) dans les étoiles d'environ deux masses solaires permet de comprendre l'absence de pulsations dans la grande majorité des étoiles de type Am alors que ces pulsations sont présentes dans les delta Scuti (même région du diagramme HR). De même, cette diffusion permet de comprendre les abondances anormales de certains métaux dans les étoiles Am. Dans le présent travail de thèse, on considère le cas des étoiles chimiquement particulières plus chaudes que les Am, de masses autour d'environ trois à quatre masses solaires: les étoiles HgMn. Leur photosphère est caractérisée par de très fortes anomalies d'abondance pour de nombreux métaux (par exemple le mercure peut atteindre un facteur  $10^6$  de surabondance par rapport à l'abondance cosmique).

Plusieurs observations montrent que certaines étoiles HgMn présentent une variation photométrique monopériodique (Alecian et al. 2009, Morel et al. 2013). La question est alors de savoir si cette variation qui semble bien intrinsèque à l'étoile est une pulsation ou une modulation rotationnelle. Les études théoriques montrent que les HgMn peuvent développer des pulsations du même type que les étoiles SPB, cependant les HgMn ne sont que très marginalement dans cette bande d'instabilité des SPB et, peut-être même en dehors. Par ailleurs les périodes observées (de l'ordre de un à quatre jours) sont également compatibles avec une modulation rotationnelle et certains auteurs proposent de les relier à des taches superficielles.

L'objectif de la thèse est d'étudier plus avant les variations photométriques observées dans les étoiles connues pour avoir des stratifications d'abondances et notamment les étoiles HgMn, d'abord en améliorant l'analyse des courbes de lumières fournies par CoRoT, puis en complétant les premières mesures publiées par Alecian et al. 2009 par l'étude d'autres étoiles HgMn.

La thèse comprend donc une partie consacrée au développement d'une nouvelle procédure, puis une application de cette procédure au traitement des courbes de lumières fournies par CoRoT. Ce travail de thèse contient aussi un volet sur une tentative de détection de la granulation à partir de la courbe de lumière d'une étoile HgMn brillante, cela dans le but de confirmer par l'observation directe l'absence de convection superficielle. En effet, la stabilité de

l'atmosphère des HgMn, qui est une hypothèse forte du modèle de diffusion, n'a jamais été établie par une observation directe. Enfin, la thèse reprend aussi une étude sur la statistique des anomalies d'abondances mesurée à la surface des HgMn depuis l'année 1993. Une des motivations principales de cette étude est de vérifier si les abondances mesurées par des techniques plus précises que celles d'avant 1993 montrent le même niveau de dispersion. Le fait que cette dispersion ne soit pas due aux erreurs de mesure est important pour les modèles théoriques.

# Abstract (english)

Modeling of atomic diffusion and abundance stratification processes in stars progressed significantly in recent years. Observational data, on their side, have made a major leap, namely for asteroseismology thanks to the CoRoT satellite. From older studies, one knows that atomic diffusion of helium (gravitational settling) in stars having about 2 solar masses, allows to explain the lack of pulsations in most of Am stars, whereas these pulsations are present in the delta Scuti stars (in the same region of the HR diagram). Atomic diffusion allows also to understand the abundance anomalies for many metals determined in stars hotter than Am stars, with masses of about three to four solar masses: the HgMn stars. The photosphere of these stars is characterized by very strong abundance anomalies for many metals (for instance, mercury can be up to 106 times overabundant with respect to cosmic abundances).

Several observations show that some HgMn stars present a monophasic photometric variation (Alecian et al. 2009, Morel et al. 2013). So, one problem is to check if this variation, which seems intrinsic to the star, is a pulsation or a rotational modulation. Theoretical studies show that HgMn stars could have pulsations in the same type as SPB type stars, although HgMn stars are very marginally in the SPB instability strip, or even outside. On the other hand, observed periods (about one to four days) are also compatible with a rotational modulation, and some authors propose that they could be related to superficial spots.

The aim of this thesis is to study further the observed photometric variations in these stars known to have stratified abundances, and especially HgMn stars, by improving the analysis of the light curves provided by CoRoT, then, by considering additional measures to those published by Alecian et al. 2009, and by considering other HgMn stars.

The thesis is composed of a part devoted to the development of a new method, and by the application of it to the corrections of light curves provided by CoRoT. This thesis is also composed by a work corresponding to an attempt in detecting granulation signal from the light curve of a bright HgMn stars. This is to confirm the lack of superficial convection zone from a direct observation. Indeed, the stability of atmospheres of HgMn stars is an important hypothesis of the diffusion model, and this hypothesis was never confirmed by a direct measurement. Finally, the thesis contains a statistical study of abundance anomalies measured at the surface of HgMn stars and published after 1993 (another study of the same kind existed for data published before this date). This study aims to check if the abundances measured with

much better and accurate techniques than those before 1993, so the same scatter. Such a scatter appears not to be due to measurement errors, and this is an important observational fact for theoretical modeling.

# Contents

<b>ACKNOWLEDGEMENTS</b> .....	<b>9</b>
<b>INTRODUCTION (FRANÇAIS)</b> .....	<b>11</b>
<b>INTRODUCTION</b> .....	<b>15</b>
<b>1 - THE SCIENTIFIC CONTEXT</b> .....	<b>19</b>
1.1 HgMn stars .....	19
1.2 A theoretical model for HgMn stars.....	21
1.3 The CoRoT space mission .....	24
<b>2 - METHODS FOR CORRECTING COROT LIGHT CURVES</b> .....	<b>28</b>
2.1 The CDA Algorithm .....	30
2.2. The COLIGCOR procedure .....	33
2.2.1 The test-case S3 (CoRoT ID_0102685695).....	36
2.2.2 The case of S1 (CoRoT ID_0102694749) .....	38
2.2.3 The case of S2 (CoRoT ID_0102647589) .....	40
2.2.4 The case of S4 (CoRoT ID_0102874481) .....	42
2.2.5 The case of S5 (HD175640).....	43
2.2.6 The case of S6 (HD 45975).....	44
<b>3 - GRANULATION</b> .....	<b>47</b>
<b>4 - ABUNDANCES OF ELEMENTS IN HGMN STARS</b> .....	<b>55</b>
<b>CONCLUSION</b> .....	<b>67</b>
<b>CONCLUSION (FRANÇAIS)</b> .....	<b>69</b>
<b>PUBLICATIONS</b> .....	<b>71</b>
<b>APPENDIX A (COLIGCOR)</b> .....	<b>73</b>



<b>APPENDIX B1</b> .....	<b>87</b>
<b>APPENDIX B2</b> .....	<b>93</b>
<b>APPENDIX B3</b> .....	<b>97</b>
<b>REFERENCES</b> .....	<b>103</b>

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# Introduction (français)

Ce projet de recherche est consacré à investiguer plus avant les variations photométriques observées dans les étoiles HgMn, à les caractériser, et plus généralement à apporter des connaissances supplémentaires utiles à l'étude des étoiles chimiquement particulières HgMn de la séquence principale. Pour cela, nous avons d'abord développé une procédure numérique pour l'étude des courbes de lumière obtenues par le satellite CoRoT (Convection Rotation and planetary Transits), et nous avons ensuite appliqué cette procédure pour plusieurs étoiles HgMn. Nous avons également tenté de détecter le signal de granulation dans la courbe de lumière d'une HgMn brillante observée par CoRoT. Enfin, nous avons réalisé une étude statistique à partir de publications récentes d'abondances dans les étoiles HgMn et que nous avons comparées à des études plus anciennes.

Généralement, les étoiles Am jeunes ne montrent pas de variabilité, mais des variabilités peuvent apparaître quand ces étoiles évoluent. Des observations récentes ont montré toutefois, que certaines étoiles Am peu évoluées peuvent être variables, contrairement aux prédictions qui situent les Am variables plutôt à proximité du bord rouge de la bande d'instabilité (là où se situent les plus évoluées). Ceci est cohérent avec l'observation des étoiles variables de type Delta Delphini et des Am à anomalies modérées. Le phénomène Am est une conséquence de la diffusion microscopique dont l'efficacité est plus grande dans ces étoiles en raison d'une épaisseur de la zone convective externe plus faible que dans les étoiles dites normales. Cette faible épaisseur de la zone convective est due à la diminution de la concentration de l'hélium dans les couches externes en raison de la sédimentation gravitationnelle de cet élément (diffusion dominée par l'action de la gravité). Lorsque l'épaisseur de la zone convective se réduit, la diffusion des métaux sous cette zone convective devient plus efficace (Baglin, 1972 ; voir Turcotte et al., 1998 pour les modèles récents). Les étoiles HgMn sont parmi les plus calmes de la séquence principale, notamment, leur atmosphère est supposée très stable. On considère qu'elles sont apparentées aux étoiles Am, mais avec des températures effectives et des masses plus élevées. Très récemment des variations photométriques ont été détectées dans des étoiles HgMn par le satellite CoRoT (Alecian et al., 2009). Ces variations peuvent être dues à des pulsations, mais cette conclusion doit être confirmée par d'autres études tant que l'effet des modulations rotationnelles ne sera pas exclu.

Dans le premier chapitre, nous présentons une brève description des étoiles HgMn. Puisque cette thèse est essentiellement basée sur des données CoRoT, nous donnons aussi une brève description de cette mission spatiale.

Pour mieux comprendre les courbes de lumière CoRoT, nous avons développé une méthode de correction des courbes de lumières fournies par le pipeline N2 de CoRoT. Ceci est décrit dans le second chapitre où nous discutons de l'algorithme CDA de Mislis et al. (2010), et ensuite notre procédure ColiGcor. Dans un premier temps nous avons en effet essayé d'utiliser une méthode déjà publiée, et réécrit celle proposée par Mislis et al. (2010). Cette méthode est supposée corriger les perturbations observées dans les courbes de lumière CoRoT. Mais, comme nous l'expliquons dans un second temps, la méthode présentée dans leur article contient des erreurs. Il apparaît donc que cette méthode plutôt destinée à traiter les cas avec des transits ne peut pas répondre à nos besoins. Nous avons donc décidé de développer notre propre procédure. Cette nouvelle procédure, que nous avons appelée ColiGcor, permet de supprimer les sauts qui sont dus principalement à des pixels « chauds », et de corriger des pentes anormales typiques qu'on trouve dans les données CoRoT (notamment dans les données obtenues par le canal dédié aux exoplanètes). Cette procédure, écrite en langage IDL, nous permet donc d'analyser les données N2 et d'obtenir des courbes de lumière corrigées où une grande partie des perturbations a été enlevée. L'ensemble de cette procédure IDL est présenté dans l'appendice A. L'analyse de Fourier et l'extraction des fréquences ont été réalisées avec le software Period04 (Lenz & Breger, 2005). Ce code nous permet d'analyser facilement le spectre de Fourier, mais du fait que Period04 ajuste, la phase, l'amplitude et la fréquence de chaque pic du spectre après chaque identification, les fréquences extraites peuvent changer légèrement après chaque ajustement. Par ailleurs, si le nombre de points de mesure est très grand, la fréquence de Nyquist sera également très grand, ce qui peut donner des erreurs durant le calcul FFT. A noter que, puisque Period04 a été initialement développé pour les pulsateurs de type Delta Scuti, il n'est pas très bien adapté aux étoiles de type solaire où le nombre de fréquences à identifier est grand.

Dans la section 2.2.6, nous avons considéré l'étoile HgMn HD 45975 (dans le cadre d'une grande collaboration Morel et al, 2013). Une variation photométrique a été trouvée dans cette étoile HgMn par CoRoT. Des observations au sol ont montré que cette étoile est membre d'un système binaire spectroscopique à longue période. Notre contribution a été de réaliser le traitement de la courbe de lumière et l'analyse du spectre de Fourier. Nous avons identifié une fréquence dominante. Cette étude ne permet pas encore de décider si la variation photométrique est due à des taches d'abondance dans l'atmosphère ou à une pulsation.

Dans le troisième chapitre, nous décrivons notre recherche d'un signal de granulation dans la courbe de lumière d'une étoile HgMn bien connue (HD175640) observée par CoRoT (canal « astero »). Pour cela, après avoir corrigé la courbe de lumière avec notre procédure ColiGcor, nous avons calculé (après avoir réalisé une FFT) le spectre puissance de la courbe de lumière corrigée. Parmi les différents arguments nécessaires à apporter pour confirmer les modèles théoriques, l'observation directe d'une indication de stabilité de l'atmosphère des HgMn serait particulièrement importante. Cependant, il s'agit d'un véritable défi pour les observateurs, et nous avons essayé plus modestement de vérifier si la signature de la granulation peut être détectée dans la courbe de lumière CoRoT d'une HgMn brillante. Nos résultats montrent que nous ne détectons pas de signature de granulation dans la courbe de lumière de cette étoile. Ce résultat est cohérent avec les modèles d'étoiles Ap qui supposent que leur atmosphère doit être stable. Toutefois, de futures observations avec une meilleure sensibilité pourraient permettre d'apporter une confirmation plus solide.

Le dernier chapitre de la thèse est consacré à l'étude statistique des abondances dans les étoiles HgMn, à partir de la compilation des articles que nous avons trouvés et qui ont été publiés depuis 1993. Les abondances de la quasi-totalité des observations spectroscopiques d'HgMn publiées ont donc été combinées et comparées avec la revue de Smith (1996). Nous avons présenté et discuté en détail nos résultats.



# Introduction

This research project is devoted to further investigations of photometric variations observed in HgMn stars, their characterization, and more generally, to bring more knowledges useful in the study of the main sequence chemically peculiar HgMn stars. For this purpose, we have first developed a numerical procedure to study the light curves obtained from the CoRoT satellite (Convection Rotation and planetary Transits), and we applied this procedure for several HgMn stars. We have also tried to detect the granulation signal in the light curve of a bright HgMn star observed by CoRoT. Finally, we have realized a statistical study from recent publications of chemical abundances determined in HgMn stars, and we have compared them to previous studies.

Generally, pulsations are shown to be excluded for young Am stars but may exist when these stars undergo evolution. Recent observations show, however, that some not evolved Am stars may be variable. The predicted variable metallic A stars lie towards the red edge of the instability strip (where they are more evolved), in qualitative agreement with the observed variable delta Delphini and mild Am stars. The Am phenomenon is the consequence of atomic diffusion, which is more efficient in these stars because of a smaller external convection zone than those of “normal” stars. This smaller convection zone is due to a lower concentration of helium in external layers due to its gravitational settling (atomic diffusion dominated by gravity). When the lower boundary of convection zone is at a higher layer, atomic diffusion of metals below this convection zone is more efficient and produces significant abundance anomalies (Baglin, 1972; see Turcotte et al., 1998 for recent models). HgMn stars are among the quietest stars of the main sequence, namely, their atmospheres are supposed very stable. These stars are considered as related to the Am stars category but with higher effective temperatures and larger masses. Very recently, photometric variations have been detected by the CoRoT satellite in HgMn stars (Alecian et al., 2009). These variations could be the result of pulsations but this conclusion has to be confirmed by further studies as far as rotational modulation effect cannot be excluded.

In the first chapter a brief description of HgMn stars is presented. Because this thesis is mostly based on CoRoT data, we give also a brief description of this space mission.



To better understand CoRoT light curves, we developed a method for correcting the light curves provided by the N2 pipeline of CoRoT. This is described in the second chapter where we discuss the CDA algorithm of Mislis et al. (2010), and then, our ColiGcor procedure. Indeed, we first tried to use published methods, and re-write the one suggested by Mislis et al. (2010). This method was supposed to correct effects perturbing CoRoT light curves. But, as we discuss later, the method presented in their paper contains errors. Therefore, it appeared that this method, rather aimed to correct light curves presenting transits, cannot meet our needs. We therefore decided to write our own procedure. The new developed procedure, which we call ColiGcor, removes the jumps caused mostly by hot pixels and to correct systematic trends encountered in typical CoRoT data (especially in data provided by the exochannel, the channel used to detect planets transits). This procedure, which is written with the IDL software, allows us to analyse CoRoT N2 data and to obtain light curves where most of the perturbations are suppressed. The whole procedure is presented in Appendix A. Fourier analysis and frequencies extraction have been done with the Period04 software (Lenz & Breger, 2005). This software allows us to do frequency Fourier analysis easily, but because Period04 fits the phase, the amplitude and the frequency of each identified peak after each identification, the extracted frequencies may slightly change after each fitting. On another hand, if the number of points is huge the Nyquist frequency will be quit huge, which can give errors during FFT calculations. There may be also a problem with the phase calculations. Notice that, because Period04 was developed originally for Delta Scuti type pulsators, it is not well fitted for solar type ones where a large number of frequencies have to be identified.

In the Section 2.2.6, we consider the HgMn star HD 45975 (in the framework of a large collaboration Morel et al., 2013). A photometric variation was found in the light curve of this star by CoRoT. Ground based observations show that this target is a long-period and single-lined binary. Our contribution was to realize the treatment of the light curve and the analysis of the Fourier spectra. We identified the dominant frequency. It is not yet possible to clearly determine if the photometric variation is due to spots of some elements in the atmospheres of the star, or due to a pulsation.

In the third chapter, we describe our search of granulation signal in the light curve of a well known HgMn stars (HD175640) observed by CoRoT (in “astero” channel). We applied the correction procedure ColiGcor and we computed the power spectrum of the corrected light curve after Fast Fourier Transform. Among the various arguments for the consolidation of the theoretical models for these stars, a direct observational indication of the stability of their

atmosphere would be very important. However, this is a difficult challenge for the observers and in the present work we would like more modestly to check if a granulation signature may be detected in the light curve of a bright HgMn star observed by the CoRoT satellite. The results show that we do not detect any granulation signature in the light curve obtained for this star. This result is consistent with the usual model for Ap stars, which assumes that their atmospheres are stable. However, further observations with higher sensitivity could give stronger support to his assumption.

The last chapter of the thesis is devoted to the statistical study of chemical abundances in HgMn stars from a compilation of all the papers we have found and which were published since 1993. The abundances of nearly all spectroscopically determined (and published) HgMn stars were combined and compared with the Smith's review (1996). We present and discuss our results in detail.



# 1 - The scientific context

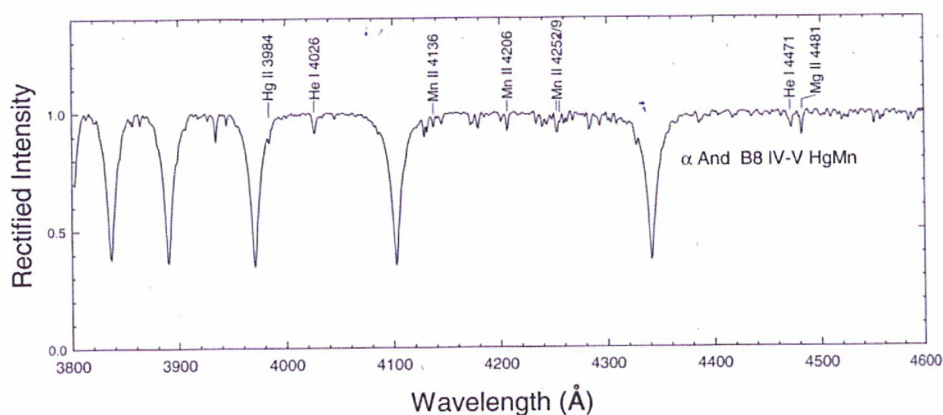
At the end of the nineteenth and at the beginning of the twentieth century's the American researchers Annie Jump Cannon and Antonia Maury noticed that in the spectra of some stars, some atomic spectral lines were abnormally strong or weak as compared to typical (or normal) stars (see the book of Francis LeBlanc, 2010). These main-sequence stars present strong abundance anomalies in the atmospheres, and they are commonly called chemically peculiar stars. They are classified in several groups and subgroups (AmFm, magnetic Ap, HgMn, etc.). The HgMn stars were first recognized as a group (the "manganese" stars) by Morgan (1931), although at that time the HgII  $\lambda 3984$  (in angstrom) line was unidentified. This line was first identified to be a HgII line by Bidelman (1966), who also suggested the presence of isotopic anomalies in mercury in the HgMn stars (see Whitford 1962). Their effective temperatures of HgMn stars lie in the range of about 10 000 K- 16 000 K.

## 1.1 HgMn stars

Ap stars are divided into nonmagnetic and magnetic groups. The HgMn stars are the main sequence chemically peculiar nonmagnetic stars typically found in the spectral-type range from approximately A2 to B5, and have luminosity types from V to IV. They are characterized by unusually strong lines of HgII and MnII. HgII can be detected only at  $\lambda 3984$ , whereas enhanced MnII is most readily seen at  $\lambda 4136$ ,  $\lambda 4206$  and  $\lambda 4252$  (see Grand, et al 2009). For some stars HgII line is not seen. In such case the star is referred to as "manganese" star. It is also possible that in other stars manganese is normal and mercury is enhanced. The HgMn stars often show mild helium deficiencies, but the helium abundance is difficult to measure. For instance, the well-studied HgMn star  $\chi$  Lupi A (Leckrone et al. 1999) shows marked overabundances for most elements with  $Z \geq 38$  (strontium and heavier elements; manganese has a near-normal abundance) including overabundances of 2 dex and greater for the rare earths, and very large overabundances of platinum, gold and mercury. In the *IUE* ultraviolet data, these stars show a marked flux deficiency, presumably due to added line blanketing and bound-free continuous

opacity. HgMn stars also show significant isotopic anomalies for platinum and mercury. Fig. 1.1 shows the optical spectrum of a prototypical HgMn star,  $\alpha$  And, in the blue-violet.

HgMn stars are considered as nonmagnetic chemically peculiar stars, although this physical picture has been discussed recently. For instance, Mathys & Hubrig (1995) mentioned a magnetic field strength of the order of 1 kG for oPeg, and similar fields have been detected in a number of other HgMn stars. However, the existence of magnetic field is still controversial (see Wade et al. 2006). The fact that some HgMn stars show periodic spectral variations (for instance, profile changes in HgII  $\lambda$ 3984 in  $\alpha$  And) is also suggestive of a nonuniform distribution of abundances on the stellar surface, and thus the presence of weak magnetic fields may be suspected from theoretical considerations (Alecian et al. 2011).



**Fig.1.1** A blue violet spectrum of the mercury-manganese star  $\alpha$  And. The most prominent lines of Hg II and Mn II are marked; the Mn II  $\lambda$ 4252 line may be blended with Ga II in  $\alpha$  And. Spectrum obtained at the Dark Sky Observatory. (see the book of Grand, O. R. et al. 2009)

An interesting study has been implemented recently on the connection between the HgMn stars and the hot-Am stars (those with early-A hydrogen-line types). Adelman, Adelman & Printado (2003) have suggested that there is a direct evolutionary connection between the HgMn stars and Am stars. The coolest HgMn stars and the hottest Am stars are found on the same stellar evolutionary tracks and a cool HgMn stars must evolve into hot Am stars. HgMn stars have a high incidence of binarity like Am stars (more than 50%, according to Mathys & Hubrig 1995), with many of the companions possible Am stars (see Ryabchikova 1998).

Very recently, photometric variations have been detected by the CoRoT satellite (Alecian et al. 2009) in HgMn stars, and, as we discussed above, these variations could be due to pulsations. Recently, Morel and his collaborators (2013) investigated HD 45975, a HgMn star observed by CoRoT and with several ground-based telescopes. The obtained results show that

this star is a long-period, single-lined binary. For this target we did a Fourier analysis and calculated the Fourier spectrum. We identified a single period, with the software Period04 (Lenz & Breger, 2005). The frequency at  $0.7572 \text{ d}^{-1}$  can be explained by the existence of spots of some elements at the stellar surface (rotational modulation), but it may also be due to a pulsation which is compatible with theoretical models discussed in Alecian et al (2009). For this purpose further studies need to be done (see Section 2.2.6 for more details).

## 1.2 A theoretical model for HgMn stars

Many atomic and nuclear theories were invoked to explain chemically peculiar stars. One of them, which was proposed by the canadian astrophysicist Georges Michaud (for more details see Michaud, 1970) suggests that the abundance anomalies determined in chemically peculiar stars are the result of atomic diffusion provided that radiative acceleration is taken into account. This explanation is presently well admitted by the stellar community. The role of the radiative acceleration can be simply explained in the following way. When an atom absorbs a photon (as the result of a photo excitation or photo ionisation) the momentum of the photon is transferred to the atom and leads to a radiative force on the atom. Because the net radiation flux inside the star is in the direction of the surface, this elementary process pushes in average the atom toward the surface, whereas the stellar gravity acts in the opposite direction. To summarize: when the radiative force, which depends on the atomic properties of ions, is locally larger than gravity, atoms diffuse toward the surface of the star, while they fall toward the centre when gravity dominates (in this case one often speaks of gravitational settling). This leads elements to accumulate at certain depths according to the balance between gravity and radiative acceleration.

Modeling individual stars is a quite complex problem. Classically, it is assumed that the atmosphere of a star consists of plane-parallel homogeneous layers, in steady state and in hydrostatic equilibrium. These assumptions are often enough for a rough description of stellar atmospheres, but in many cases they cannot allow to understand the details of many observations of real stars. Mass motions, like turbulence, stellar wind, pulsations, are often present. Rotation also has to be taken into account. Strong magnetic field may be present in the

atmospheres of some stars. When atmospheres are stable (without mixing process), another physical process must be considered: atomic diffusion, which produces transport of individual species and leads to a stratification of abundances.

In cool B-type, A-type and cooler stars hydrogen and helium are, with a significant proportion, partially ionized in external layers. Due to this partial ionization there is a superficial convection zone (see the book of Sidney C. Wolff, 1983), which in “normal” stars, mixes the external layers (atmosphere plus upper envelope) and ensures homogeneous abundances. In chemically peculiar stars, and according to the standard diffusion model, this superficial convection zone is smaller (Am stars) or inexistent (ApBp stars). This is due to the lower helium concentration in the external layers. Because chemically peculiar stars are slow rotators, large scale circulations (meridional circulation for instance) are weak or inexistent, and so, mixing below the superficial convection zone is supposed to be weaker than in normal stars when these stars arrive on the main-sequence. Due to the weaker mixing, atomic diffusion at the bottom of the convection zone is more efficient than in normal stars, and so gravitational settling of He can lead to a decrease of the helium concentration in external layers. This decrease in He concentration implies the decrease or the disappearance of the convection zone, which allows atomic diffusion to work in higher layers, with more efficiency (smaller the local mass density, larger the diffusion velocity). Since ApBp stars (including HgMn stars), have higher effective temperature (H and He are more ionized), the lower concentration of He is supposed to lead to the complete disappearance of the superficial convection zone. For these stars, atomic diffusion is then able to stratify the abundances even inside their atmospheres, which is not the case of Am stars, for which the atmosphere remains convective.

To be able to describe the chemical peculiarities found in the atmospheres of HgMn stars one needs to take into account fundamental parameters:  $T_{\text{eff}}$ ,  $\log g$ , age, mass, metallicity and rotation. There is no magnetic field, or very weak and not detected in these stars. Elements, such as boron (see Borsenberger et al. 1984), rare earths, and generally elements which are pushed outward in most of their states of ionization. They should leave the star except if there is a weak horizontal magnetic field. The only elements that would be noticeably overabundant in the nonmagnetic stars would be those on which the radiative accelerations are large in the atmosphere, but decrease at some point above the line-forming region (see G. Alecian and G. Michaud 1981 for more details), or if a weak horizontal magnetic field forces the diffusion velocity to decrease.

Beryllium, barium and magnesium abundances determined in the atmospheres of HgMn stars may be understood by computing radiative accelerations assuming NLTE effects (Borsenberger et al., 1984). Be, B are found overabundant, and Mg underabundant.

The abundance anomalies are different according to the effective temperatures ( $T_{\text{eff}}$ ), and in some cases, there are clear correlations between the anomalies and  $T_{\text{eff}}$ . This is the case of manganese anomalies in HgMn stars. The abundance anomalies determined for Mn in HgMn stars were explained in the framework of atomic diffusion (Alecian & Michaud, 1981). According to the radiative accelerations for Mn computed by these authors (with an estimate of NLTE effects), manganese should accumulate in stars with  $T_{\text{eff}} \leq 15\,000\text{ K}$ . Above this temperature, radiative acceleration is so large that Mn atoms could leave the star. For effective temperature larger than about 18000K, the stellar wind velocity is large enough to prevent the abundance stratifications. At lower temperatures (lower than 11000K) there is a cutoff on the Mn overabundances, which may be due to the existence of a superficial convective zone. Alecian & Michaud, (1981) have also shown that the overabundance of Mn should be correlated with the effective temperature: Mn overabundance should increase with the effective temperature. This prediction was later confirmed in observed stars by Smith & Dworetsky (1993).

New numerical calculations by Alecian & Stift (2007, 2010) have been carried out for magnetic Ap stars and for non-magnetic HgMn stars also. These calculations are much more accurate than the previous ones and use large atomic databases for radiative accelerations. These authors propose equilibrium solutions for abundance stratifications in Ap stars atmospheres. These solutions are such that the diffusion flux of particles is zero (radiative acceleration is equal and opposite to the gravity). Other works are in progress for solutions obtained by solving the continuity equation (Alecian et al. 2011). Alecian & Stift (2010) propose also bi-dimensional calculations to explain abundance in magnetic Chemically Peculiar stars.

As discussed above, the large abundance anomalies found in ApBp stars (including HgMn stars) are due to the various abundance stratifications in their atmospheres. However, beside the effects of atomic diffusion in the atmospheres, one must also consider atomic diffusion in the interiors. Indeed, a large fraction of the outer envelopes of these stars is also radiative (without convection). So, atomic diffusion is also efficient in these layers, even if diffusion velocities are smaller and diffusion timescales much larger than in atmospheres. Calculations by Turcotte & Richard (2003) show that the iron concentration increases in some layers in the envelope of HgMn stars (namely at the iron bump position, close to layers with



$\log T = 5.3$ ). According to the models, this increases the local opacity, and therefore, allows oscillations to be driven by  $\kappa$ -mechanism, as in SPB stars (see also Alecian et al. 2009). But, such pulsations in HgMn stars were never observed before CoRoT measurements. With CoRoT some HgMn stars have been found with monophasic photometric variation, and major part of the work presented in this thesis tries to contribute to the search of such pulsation signal in HgMn stars.

## 1.3 The CoRoT space mission

The **CoRoT**<sup>1</sup> satellite, which stands for **C**onvection, **R**otation and planetary **T**ransits, is a space telescope dedicated to stellar seismology and the search for extrasolar planets. This space mission was developed and is operated by the French space agency CNES, with participation of ESA's RSSD and Science Programs, Austria, Belgium, Brazil, Germany, and Spain. The development of the spacecraft began in October 2000 and the satellite was launched on December 27<sup>th</sup> 2006 (see Baglin A. et al. 2006). The satellite stopped working at the end of 2012.

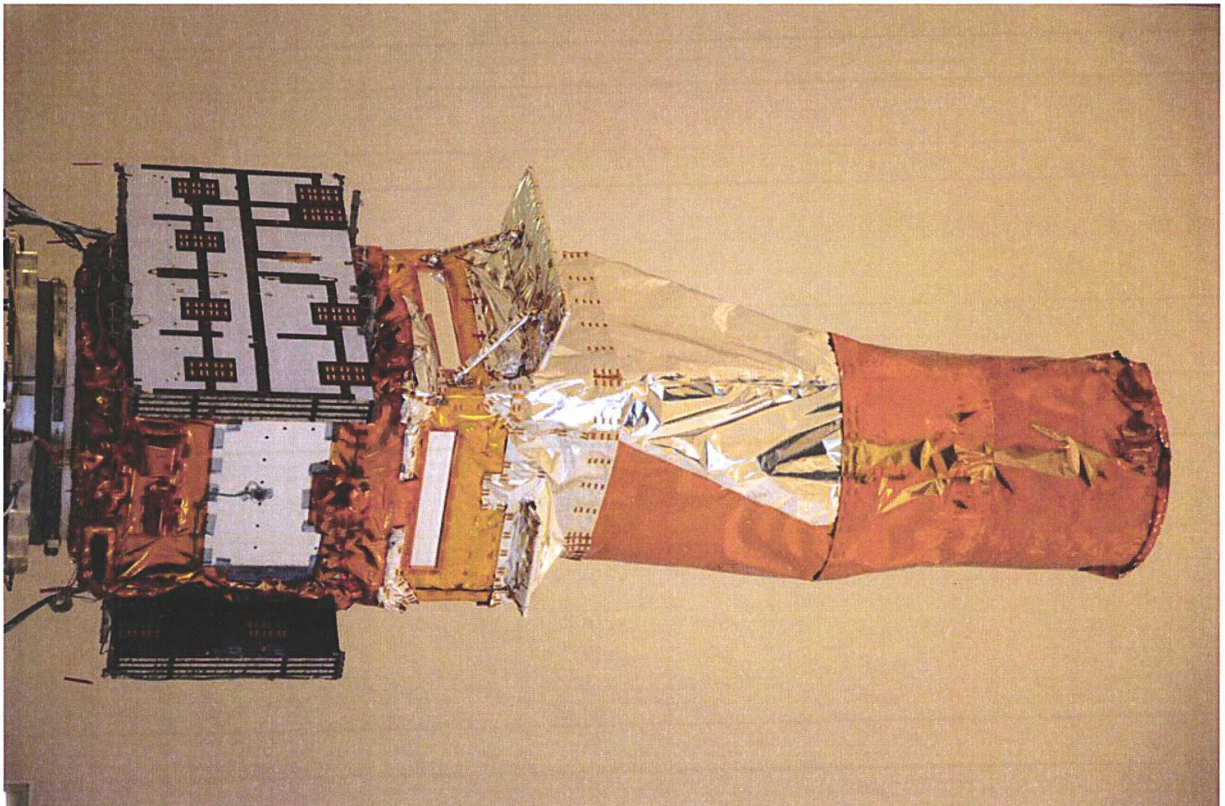
As mentioned above, CoRoT had two main objectives: stellar seismology and the search for extrasolar planets. For both programmes a very high photometric precision is needed. An accuracy of less than 1 ppm is expected for 6<sup>th</sup> magnitude stars and of a few  $10^{-4}$  for stars with magnitude ranging from 11.5 to 16. On the other hand, the major characteristic of CoRoT was the possibility to perform very long observations of the same targets (up to 150 days). In addition, the expected duty cycle excluding short and long interruptions was  $\approx 94\%$ , which was much better than what can be obtained for ground-based data. The fields in the sky which can be seen by CoRoT (the eyes of CoRoT) were two circles in the Galactic Centre and Anticentre centred at  $\alpha = 18^{\text{h}}50^{\text{m}}$ ,  $\delta = 0^\circ$  and  $\alpha = 6^{\text{h}}50^{\text{m}}$ ,  $\delta = 0^\circ$ , each having a radius of  $10^\circ$ .

CoRoT had a small 27 cm mirror. The focal plane was composed of four 2048 x 2048 Marconi MPP CCDs, working in frame transfer, at  $-40^\circ\text{C}$ . Two CCDs were dedicated to the seismology programme (stars with  $5.7 \leq m_v \leq 9.5$ ) and the other two to the exoplanet programme (stars with  $11.5 \leq m_v \leq 16$ ). After 4 years of nominal work, one of the acquisition chain stopped

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<sup>1</sup> <http://smc.cnes.fr/COROT/Fr/>

working (only half of these CCDs were used after that event). During a Run, and using asterochannel it was possible to obtain the light curves of about 10 bright targets. The exochannel allowed to obtain the light curves of about 4000 faint targets per CCD. The time sampling for the data acquisition of these two channels was different: 1 second for the asterochannel (re-sampled to 32 seconds in the delivered N2 data), and 32 seconds or 512 seconds for the exo-channel. In the exochannel, the 32 seconds sampling can be used for a limited number of targets (these targets are selected before and during a run according to their scientific interest).



*Fig. 1.2 CoRoT satellite © Thales Alenia Space/JL*

A star is a self gravitating object, in global equilibrium, but it is subject to various motions inside. For many types of pulsating stars the sound waves and the gravity waves make the star periodically swell and contract locally, get hotter and cooler locally. Telescopes and associated instruments allow us to detect these effects: the periodic changes in the star's brightness and the periodic motion of its surface moving up-and-down, back-and-forth. These

variations cause photometric variations, which are detected by instruments like CoRoT, and doppler effects of spectral lines are detected by spectrographs (radial velocity measurement). Investigations of these effects are used by asteroseismology which probes the stellar interiors through the study of surface pulsations (for more details see Aerts book in Asteroseismology, 2010). The analysis of a seismology spectrum makes possible to estimate for instance the energy spent across a region of acoustic stationary modes, the chemical composition near the stellar core or the distance at which convective heat transport becomes preponderant over radiative heat exchanges.

The observations of stars from space (with a precision and over time scales out of reach from the ground) are very much needed to improve the modelling of the internal structure and evolution of stars.

The stars in the asteroseismology channel of CoRoT, must have a magnitude less than 9.5. The main target usually addressed in this channel are solar-like pulsators, classical pulsators as  $\delta$  Scuti,  $\gamma$  Dor and  $\beta$  Ceph stars, and stars known as variable from the ground (peculiar metallic stars, sub-dwarfs of B type, Be stars etc.). Nine stars could be observed in this channel at each run.

Several shorter runs were devoted to the exploratory program of seismology. Their aim was to widen the variety of targets (from B to K spectral types up to magnitude 9.5), to sample correctly the HR diagram. With this shorter time window, the resolution of the frequencies falls to 0.6  $\mu$ Hz, but it is sufficient to produce statistical data about the excitation of the oscillating modes, as a function of mass, age, rotation speed and metallicity.

The CoRoT planet-finding programme aimed at detecting the presence of extrasolar planets when they transit in front of their parent star. This programme was performed during especially the long runs, for which the maximum length is 180 days. Ideally to detect a planet candidate in complete confidence, the phase must stay coherent over 3 observed periodic transits. So planets detected by CoRoT should have a period smaller than 60 days. In order to partly overcome this limitation, a dispersion device was placed in front of the exoplanet CCD matrices, providing a three-colour signal which helps to make the difference between planetary transits (achromatic events) and stellar activity (highly chromatic due to temperature variations at the surface of the star). Studies show that the use of this coloured information improves the detection and will contribute to widen the detection domain to cases where a run is not long enough to show three periods. In addition to hot Jupiters, few terrestrial planets should be

detectable, but not in the "habitable zone" (compatible with liquid water), depending on hypotheses about accretion models and the existence of planets. It must be mentioned that the detection of planetary bodies in the habitable zone is most likely to occur for cold dwarfs of K, M types because the contrast of the transit is better when the radius of the star is small (habitable zone closer to the parent star, between 0.2 and 0.5 a.u) (see L. Boissard and M. Auvergne 2006).

The additional programme of CoRoT allowed the astronomical community to propose observations devoted to specific target fields to address scientific cases different from the core programme, as for instance stellar activity (surface magnetism), binary systems, pulsating stars beyond the instability strip, search for Kuiper belts objects (KBO) etc. With this program it was possible to do asteroseismology in CoRoT exochannels (see Weiss, 2004).

Most of the Data are reachable through a web interface. There are 4 types of data:

- N0: Time-stamped raw data, processed and archived by CNES.
- N1: Data corrected from main instrumental effects, available upon request, through the Science archive, then the Long Term Archives.
- N2: Scientific labelled data, available through the Science archive then the Long Term Archives.
- N3: Standard scientific products labelled by the Scientific Committee: frequencies, line-widths, amplitudes, classification of variables etc. is available through the Science archive then the Long Term Archives (presently these data have a restricted access).

The Science Archive is located at Institut d'Astrophysique Spatiale, Orsay, France. Two Long Term Archives are foreseen, one at CDS Strasbourg, France and one at LAEFF, Spain (see Baglin A. et al. 2006).

## 2 - Methods for correcting CoRoT light curves

The raw data acquired by the CoRoT satellite are, as for any other instrument, subject to many various kinds of instrumental artefacts, defects, and also subject to several kinds of perturbations due to the environment (Auvergne et al. 2009). Among the most common instrumental effects, one may quote for instance, thermal adjustments of the instruments after a change of the telescope orientation, small motions of targets images on the detector, long term drifts of the sensitivity due to normal aging of instruments, etc. Since the CoRoT satellite is a very high performance instrument, and since its aim is to measure very small variations of the light coming from stars, and since its orbit is relatively close to the Earth (900 km), it is extremely sensitive to several perturbations due to the environment, such as Earth emission (day/night, clouds, etc.), Earth (and Sun) infrared emissivity, and other straylights (zodiacal light, for instance), and so on. Among the prominent environmental perturbations, there is the South Atlantic Anomaly (SAA) essentially due to protons with relatively high energies, trapped by Earth's magnetic field in a certain location which is crossed by the satellite during the orbit.

Most of these artefacts/perturbations are well identified, and they are corrected/removed by the standard data treatment pipeline. Therefore, the N2 data, which are released through the official CoRoT archiving system (<http://idoc-corot.ias.u-psud.fr/>), are usable safely by the scientific community. However, some of the perturbations affecting the N2 light curves are not corrected because they are not systematic enough (or they are too badly understood) to be corrected without the risk of removing real astrophysical signal coming from the observed targets (future releases of the data could include corrections of some of these defects). Among this kind of perturbations, and especially in the light curves provided by the exo-channel, there are often random jumps (discontinuities followed by an increase of the flux level followed by a slow decrease). They are due to what is called “hot pixels” caused by energetic particles (generally protons impacts) falling randomly (and outside SAA crossing) on some parts of the detector. According to the case, the corresponding pixels may, or may not, recover a regular state after some time (typically about 1day). This “relaxation” time can be as long as a significant fraction of the duration of an observing run. On another hand, each target forms an image on the detector that covers several pixels (Point Spread Function). Due to a prism in front

of exo-CCDs', images from the exochannel, are roughly separated in three colours (red, green, blue) to improve transits discrimination. Because hot pixels may overlap the borders of the colour zones (or the edge of images), they affect each colour in a different way. These three fluxes are later combined to give the white flux (provided in recent releases of N2 data) that we use for asteroseismology, and there should not be residual effects on jumps due to the colours separation.

When jumps are too numerous, they could prevent the using of the full light curve of a target, which implies the lost of the benefit of a run for the target, or a significant increase of the noise level in the frequency spectra (see, for instance, the jumps in the light curve of Fig 2.3). Since, most of the light curves considered in this work come from the exo-channel (in the framework of the additional programs), we first considered the problem of correcting the light curves from the random jumps, together with the associated abnormal slopes.

## 2.1 The CDA Algorithm

We started by looking for the methods already proposed by other teams, and published in the relevant literature. The method published by Mislis et al. 2010 seemed to meet our needs. It is called CoRoT Detrended Algorithm (CDA) and the main idea of this method is to use the cleanest filter as a proxy for the whole light curve provided by the exochannel (for more details see Mislis et al. 2010). The algorithm of this method is as follows:

- Removing "bad" points;
- Creating "60 sub-light curve" in each colours (white fluxes were not provided in N2 data at the date when the algorithm was prepared);
- Normalizing each "sub-light curve" (for all these sub-light curves the average levels were set to 1.);
- Extracting 5 random packages of 20 adjacent points in each sub-light curve;
- Calculating the mean standard deviation (MSD ) of each package;
- Comparing MSD with the standard deviation in each colour;
- Computing the relative standard deviation (RSD) of each colour;
- Calculating a new mean light curve using base (min RSD) and target (max RSD);
- Re-normalize the light curves by the raw mean value;
- Apply this procedure for all sub-light curves and then put all of them together.

We made an attempt of rewriting this algorithm with IDL to use it for our purposes but encountered some errors in the algorithm.

It appeared that the random packages creation process was not well explained in the published algorithm. Indeed, it is mentioned in the article that only five random packages had been taken for analysis. However, after private discussion with the principle author it appeared that these 5 random packages had been chosen for each sub-light curve. So this does mean that in total there are 300 random packages chosen for the whole amount of sub-light curves.

The second issue to be clarified appeared to be in the second equation where the authors define the mean value of these five packages of each filter as the mean standard deviation, where NF is normalized flux.

$$MSD_{R,G,B} = \frac{1}{5} \sum_{j=1}^5 \frac{1}{20} \sqrt{\sum_{i=k_j}^{k_j+20} (NF_{R,G,B,i} - Mean_{min})^2},$$

where the indices  $k_j$  denote to 5 different random data points of the light curve and  $min$  index in  $Mean_{min}$  is not the minimum value of the mean values. Here instead of  $Mean_{min}$  should be  $Mean_{mean}$ , where  $mean$  index means that the mean of the mean values should be used.

The third inaccuracy appears in the eq. 4 where the authors calculate the standard deviation of each filter TSD defined by the expression

$$TSD_{R,G,B} = \frac{1}{N} \sqrt{\sum_{i=1}^N (NF_{R,G,B,i} - Mean_{min})^2} .$$

Since the all sub-light curves used in this equation are already normalized there should be 1 instead of  $Mean_{min}$ .

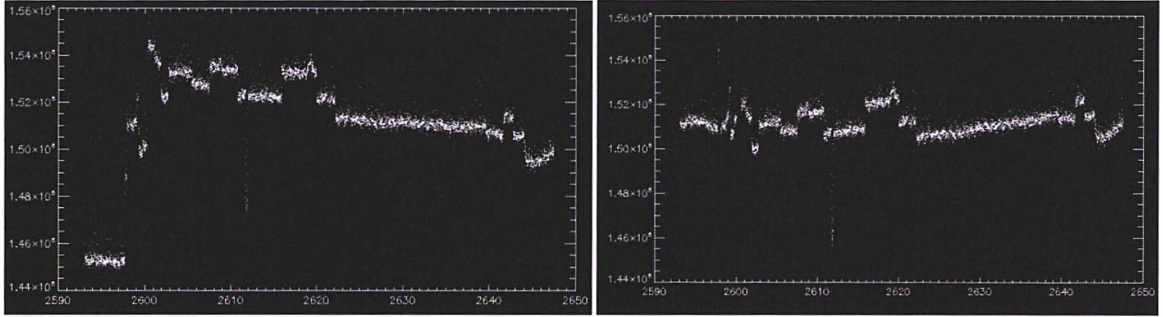
In equation number 7 the authors of the algorithm make an attempt to re-normalize the target channel to the raw mean value using the assumption (NR is the normalized red flux):

$$NFR_{final} = NR * NF_{R,i},$$

but instead of  $NR$ ,  $MR$  (mean read flux) should be used here. It was calculated earlier (mean value of each sub-light curve).

After the detailed discussions of all these misprints and errors with the main author of the algorithm we tried to apply the procedure on a CoRoT target which was observed by them also. The CoRoT ID of that observed target is 102874481. The original light curve and the final fitted ones are presented here (Fig 2.1 and Fig 2.2) to show the results obtained from the procedure application. In the figures showing the CoRoT light curves, the photon flux (measured in electrons) is plotted versus the CoRoT Julian days (JD). It is clear that we did not obtain the same results as the authors (see Fig. 6 in Mislis et al. 2010 paper). So, we decided to stop using this procedure.





*In Fig. 2.1 and Fig. 2.2 the original lightcurve of S4 target and the treated one after applying the CDA algorithm are presented. The left axis is the photon flux (in electrons) and the bottom axis is the CoRoT Julian days.*

In any case, our targets were observed during 120 days and this means that we have 120 sublight curves and 600 random packages in total with CDA. With such a large amount of loops and running the code for all of them would mean spending a too long computing time on the observation of just one target. Also, because of the large number of averaging in this method, we think that there is a risk to lose the real signal during the correction process. We conclude that the corrected CDA algorithm, rather aimed to correct light curves presenting transits, cannot meet our needs. We decided to develop our own procedure ColiGcor (see next section).

## 2.2. The COLIGCOR procedure

It is quite difficult to describe all the features perturbing CoRoT light curves, since the perturbations have many different origin. Moreover, the problem is really complicated because we do not know a priori which light curve features are real signals (real transits, real flares etc.) and which ones are only instrumental/environmental effects. As the satellite orbit is at an altitude about 900 km, the Earth influences the satellite and introduces perturbations on three characteristic time scales; the orbital time (and harmonics), the day (and harmonics) and the seasons. As partly mentioned at the beginning of Chapt.2, the main perturbations are *eclipses (transition light/penumbra/shadow)*, *gravity field and Earth's magnetic field which perturb the satellite attitude*, *the South Atlantic Anomalies (SAA)*, *Sun and Earth infrared emissivity*, *Earth albedo*, *objects in LEO* (for more details see Baglin, A. et al. 2009; Auvergne et al. 2009).

To remove instrumental useless features, the package ColiGcor uses only white light curves (three colours plus white are provided by exochannel pipe line). This procedure consists of three subroutines - *lect\_fits.pro* or *lectaster\_fits.pro* (depending on the CoRoT channel), *jump\_det.pro*, and *lapgf.pro*. With the small *lect\_fits.pro* and *lectaster\_fits.pro* codes we firstly read the FITS files obtained with CoRoT channels devoted to the search of exoplanets and asteroseismological observations respectively. We first extract the Julian days, the white flux and the status flag of measured points. Later on, we remove all "bad points" (points flagged to have high noise, the interpolated points and the ones corresponding to South Atlantic Anomalies). These points have a "status" different from 0. To remove abnormal features that appear on CoRoT light curves, first, we do smoothing, then we detect the jumps positions to remove them, and finally we correct abnormal trends. Presently, our code allows us to detect up to about 100 jumps (see the beginning of Chapt.2 about the origin of jumps) during an observation run of about 120 days (this is done by *jump\_det.pro* subroutine).

To correct the light curves, we proceed in three main steps :

- We create sub-light curves;
- we correct the sub-light curves for abnormal slopes, with second degree polynomial fitting.
- We realign sub-lights to reconstruct the whole corrected light curve.

The first sub-light curve starts from the first point of the time series and ends at the point where the first jump starts, the second sub-light curve starts from the end of the first jump and

ends with the second jump starting point, etc. The flux during a jump changes from a given level to another one, but the exact position and the width of a jump cannot be known because of the noise. That transition points may be removed by the code according to the choice of the user, however this creates a gap. We do not fill the gap with interpolated points in the present version of the procedure.

The method used to detect a jump, starts by computing for each flux point (after normalization of the flux and smoothing) the difference of the average level of the flux from the right and from the left of each point. This gives a new curve (with respect to the time) presenting peaks at jump positions. The heights of the peaks, which depend on the size of the averaging windows (left and right) and the importance of each jump, are compared to the standard deviation  $\sigma$  of the flux noise. The user may adjust the detection criterion in  $\sigma$  unit. The shape of the peaks due to transits, are different from those due to jumps. The procedure recognizes this particular shape due to transits to not treat them as jumps. Notice however, that light-curves with transit are rather rare (about 4000 light curves are acquired at each observation run).

After the detection of jumps and determination of the sub-lights, a second degree polynomial fit is done for each sub-light curve to correct the abnormal slope due to the relaxation of the hot pixels event. Because CoRoT light curves typically have thousands of data points, and because our sub-light curves are large enough, the polynomial does not fit short-term variations such as transits. We have checked on some light curves with known transit, that short-term variations (like transits) are preserved. We thus write

$$Whiteflux = a + b * JD + c * JD^2$$

where  $JD$  is the Julian date (normalized to range  $-1 \leq JD \leq 1$ ) and  $a, b$ , and  $c$  are the fitting parameters for the second degree polynomial. At the end of this step we have detrended white sub-light curves.

As a final step, ColiGcor reconnects all sub-lights (with average level normalized to 1) and rescale the normalized flux to the average level of the original light curve.

ColiGcor has two possibilities - using expert mode or not. Using expert mode gives the possibility to choose (among other options) a  $\sigma$  level for detection sensitivity of jumps, and to force a width for jumps (gap size). If one does not choose expert mode, one is able to change only the  $\sigma$  level. At the end of the treatment we obtain a corrected light curve from which it is possible to extract the frequencies using, for instance, Period04 software of Lenz & Breger (2005).

The final step could be a binning to 512 seconds, if one needs to reduce the number of points. As an output result we can obtain the binned and well detrended light curve, which is easy to use in further computations. The whole algorithm is presented in Appendix A.

To illustrate the algorithm with real light curves we applied ColiGcor to CoRoT five targets: S1 = CoRoT ID\_0102694749, S2 = CoRoT ID\_0102647589, S3 = CoRoT ID\_0102685695, and S4 = CoRoT ID\_0102874481 observed by CoRoT exochannels, and S5 = CoRoT ID\_07569 and S6 = CoRoT ID\_01824 observed by CoRoT asterochannel.

Stars S1, S2 and S3 were selected as CoRoT exochannel targets by Alecian et al. (2009) after a ground based survey with the multiobject spectrograph VLT-GIRAFFE. These authors have identified these faint stars as HgMn stars. However, the fundamental parameters are not known with good accuracy, because they were determined from low-resolution spectra ( $R=6400$ ).

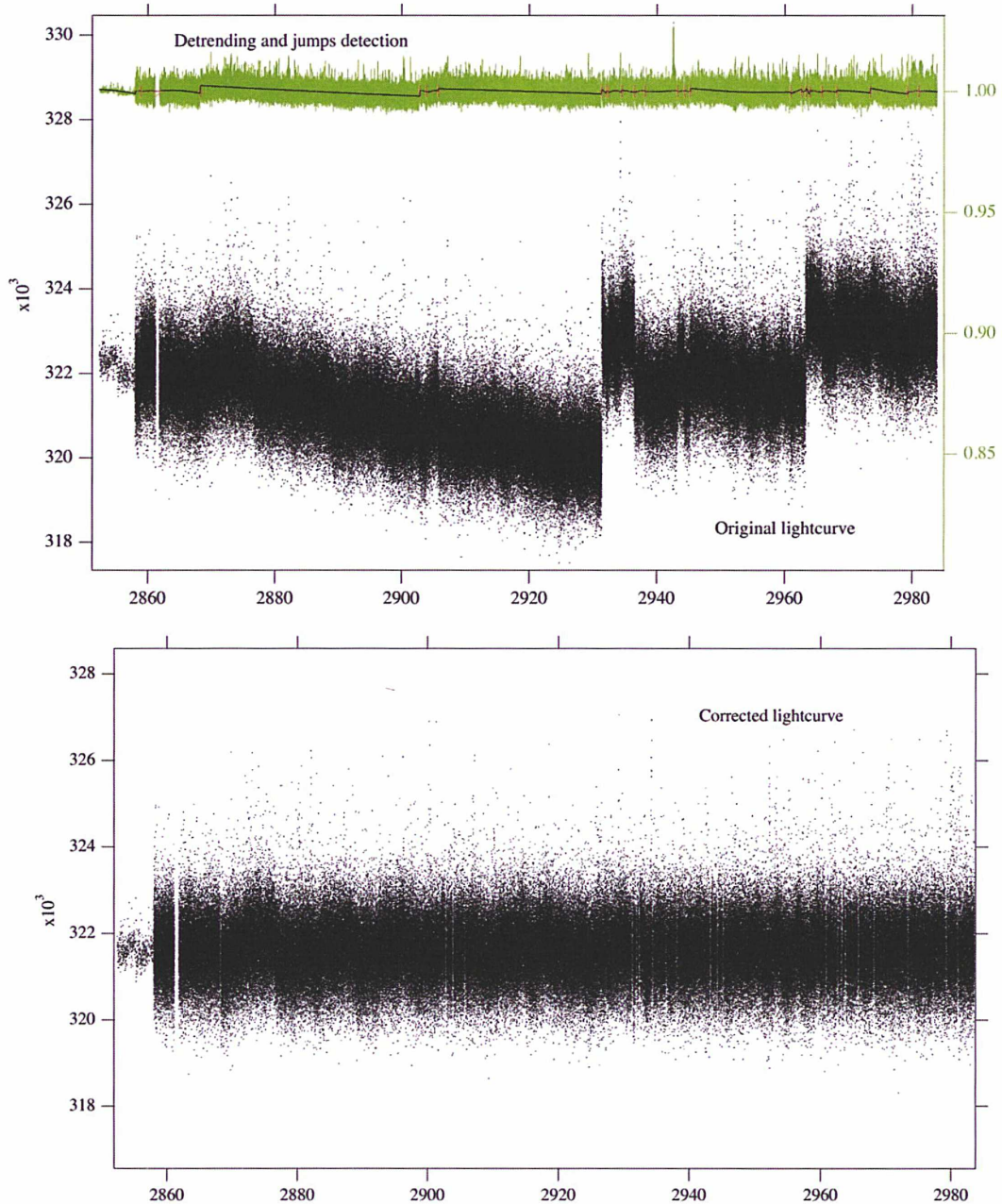
The corrected light curves and Fourier spectra of these targets are briefly discussed in next subsections. First, we describe S3 target. The light curve of this star is full of jumps, it is noisy, and for these reasons it was used by Alecian et al. (2009) partially. With our procedure ColiGcor we succeeded to remove the jumps and all perturbations and were able to use the whole light curve. Later on, we present the all targets in the right order. S5 has been chosen to investigate granulation problem in HgMn stars (see Sec. 3, fundamental parameters from Hubrig et al 1999). S6 has been chosen in the framework of the collaboration with Thierry Morel and collaborators to investigate photometric variations in this HgMn star. This star will be discussed in Sec. 2.2.6. The main characteristics of all six targets are given in Table 1.

**Table 1:** Main characteristics of our studied targets, with the published parameters (see sections 2.2.1 to 2.2.6). All these stars are HgMn stars, excepted S4 which is a test case with a transit.

Star	CoRoT ID	USNO -A2 or HD Number	Mass ( $M_{\star} M_{\odot}$ )	Radius ( $R_{\star} R_{\odot}$ )	$T_{\text{eff}}$ (K)	$m_v$	v.sini ( $\text{km s}^{-1}$ )
S1	0102694749	0825-03036752	-	-	$13500 \pm 500$	12.05	$35 \pm 5$
S2	0102647589	0825-03028353	-	-	$12500 \pm 500$	13.01	$50 \pm 8$
S3	0102685695	0825-02993210	-	-	$11750 \pm 500$	13.18	$50 \pm 8$
S4	0102874481	-	2.8	4.4	-	13.84	-
S5	07569	HD 175640	-	-	$11958 \pm 100$	6.21	2.5
S6	01824	HD 45975	$\sim 3.0$	$1.8 \pm 0.5$	$12250 \pm 500$	7.45	$61 \pm 2$

## 2.2.1 The test-case S3 (CoRoT ID\_0102685695)

Firstly we present the case of the star S3 which has a very perturbed light curve, and gives a good illustration of ColiGcor ability in correcting the light curves. In Fig.2.3, we show the white light curve, which includes a long-term phenomenon and jumps, and the final light curve after applying ColiGcor. The example of S3 target shows how ColiGcor works and how it removes the jumps from a distorted light curve.

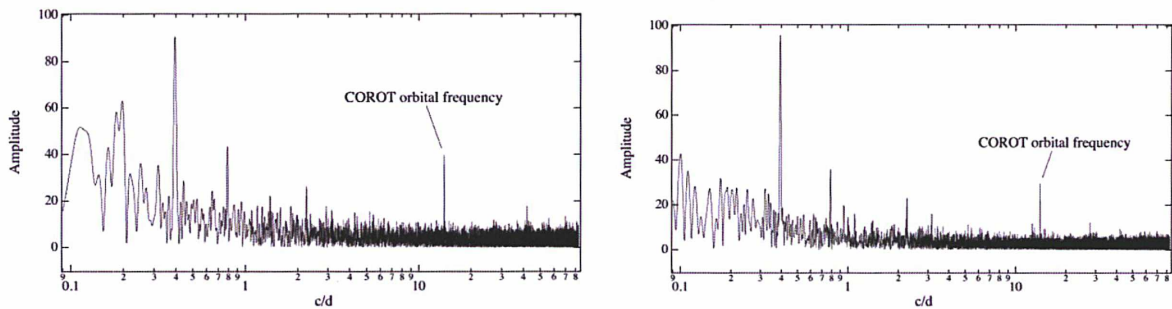


**Fig. 2.3** The correction process for S3 target. The left axis is the photon flux (in electrons) and the bottom axis is the CoRoT Julian days.

In the top panel of Fig. 2.3 the normalized original light curve is plotted in green. The red crosses represents jumps positions. The black lines show the second order polynomial fits of each sub-light curves. In the bottom the corrected light curve of S3 target is presented. As we see from the figure ColiGcor is able to remove the jumps and abnormal slopes encountered in typical N2 data of CoRoT light curves.

To do the Fourier analysis on the corrected light curve and to extract main frequencies, we have used the Period04 software (see Lenz and Breger, 2005). The Fourier spectrum

obtained after using our procedure, is plotted below in the left panel. It is compared to the one derived by Alecian et al. (2009). The comparison shows that ColiGcor does not affect the main frequency peaks (here in cycles per day: c/d), and the noise is significantly lower (mainly because we are able to use the whole signal acquired during the observation run). The CoRoT main orbital frequency (13.97 c/d) and its harmonics (27.94, 41.915 c/d) may be seen in the spectra. Still at low frequencies, the signal-to-noise ratio remains high but as we see from comparison of the spectra, it is much higher than in Alecian et al. (2009). There are clearly two peaks above the noise, the first one at  $0.395 \pm 0.01$  c/d (period  $P \approx 2.53$  days) and the second one at  $0.789 \pm 0.01$  c/d, which is the first harmonic ( $P/2$ ). There is a peak around 0.19 c/d, but as one can see in more detail in Fig. 2.4, it does not emerge from the surrounding patterns as clearly as the previous peaks. Another isolated peak emerges around 2.24 c/d (0.446 day), it is more significant in our new spectra than it was in the one of Alecian et al. (2009).

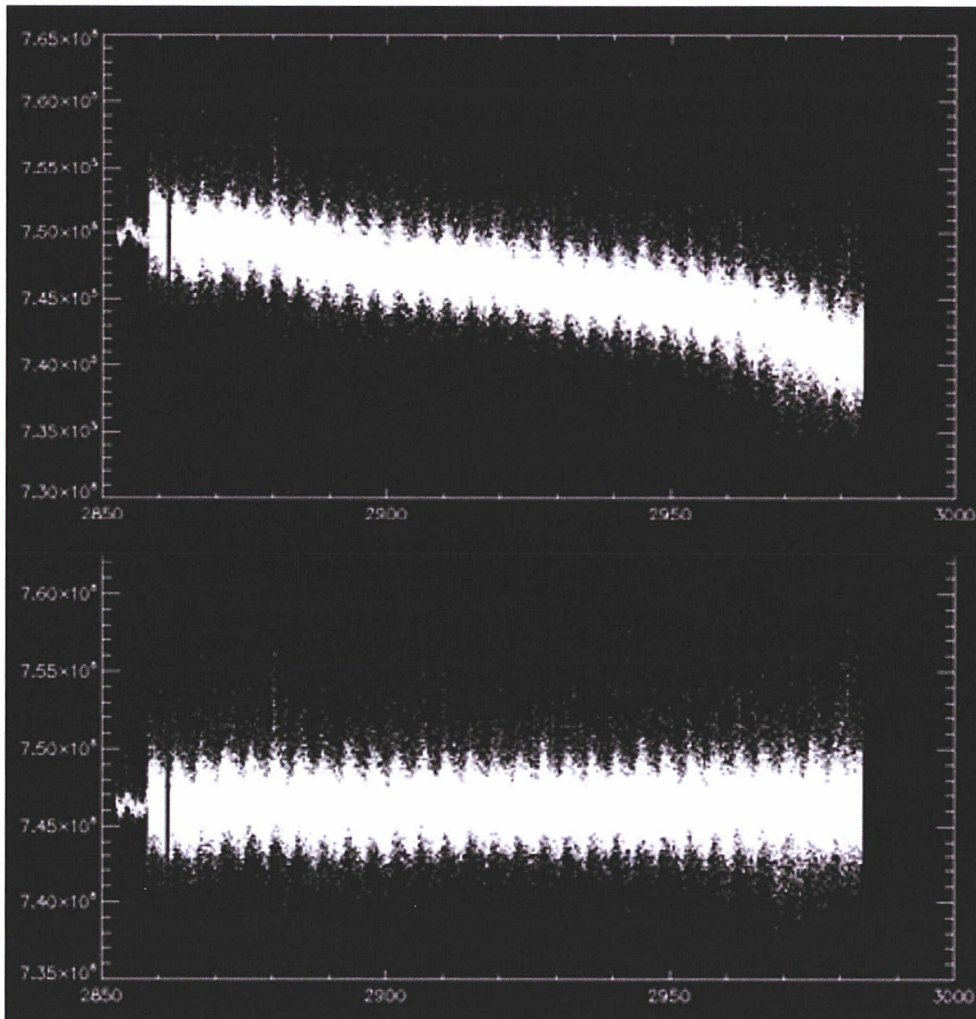


**Fig. 2.4** The left panel shows the full Fourier spectrum (amplitude vs. cycle per day) of S3 target obtained by Alecian et al. (2009). The right panel show the Fourier spectrum after applying our procedure ColiGcor. Both spectra are calculated with Period04. The CoRoT main orbital frequency is marked on the two plots.

## 2.2.2 The case of S1 (CoRoT ID\_0102694749)

This target is the less noisy one investigated by Alecian et al. (2009). ColiGcor succeeds removing small random jumps and instrumental trends. The original light curve and the final detrended light curve are shown in Fig. 2.5. The comparison of the Fourier spectra obtained by Alecian et al. (2009) and the one derived by applying our procedure ColiGcor are compared.

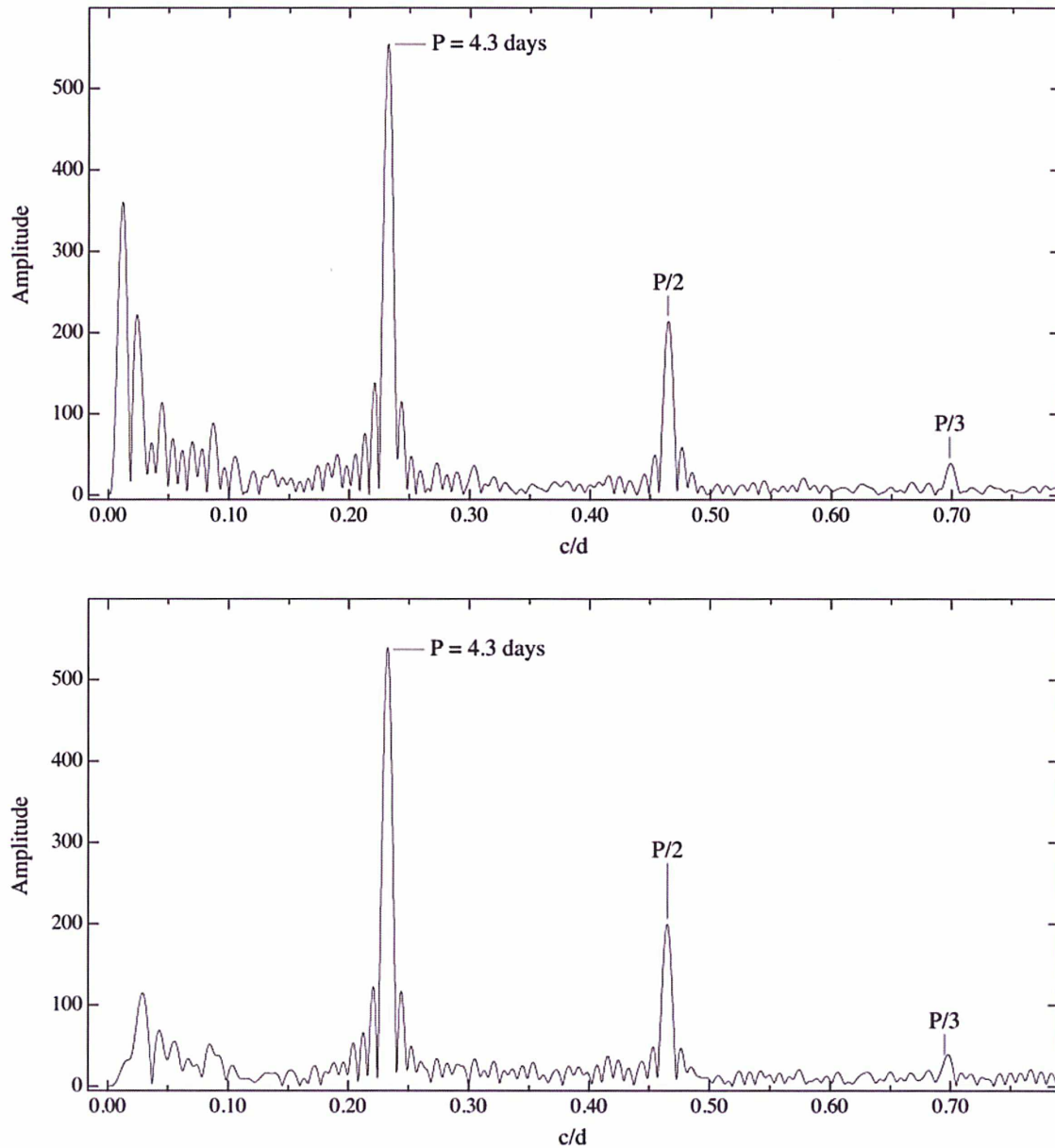
The spectrum obtained with our method is less noisy, especially at low frequency and better detrended.



**Fig. 2.5** The original S1 light curve and final detrended light curve. The left axis is the photon flux (in electrons) and the bottom axis is the CoRoT Julian days.

The noticeable low frequencies around 0.01 c/d are related to long-term variations in Fig. 2.6. We cannot interpret with confidence these long-term variations, which have periods comparable to the run duration. They do not correspond to known instrumental effects and can be due to an insufficient corrections of abnormal trends, even if they are significantly lower in our corrected light curve. Fig. 2.6 presents the detailed spectrum around 0.23 c/d. The features around the peaks are due to the spectral window. The period  $P \approx 4.3$  days, with two harmonics ( $P/2$ ,  $P/3$ ) is interpreted by Alecian et al (2009) as an intrinsic variation of star S1, since there is no known instrumental frequency in around  $P$ . (see Alecian et al. 2009 for more details). Its amplitude ( $\Delta m/m$ ) can be estimated to be about 1.6 mmag.

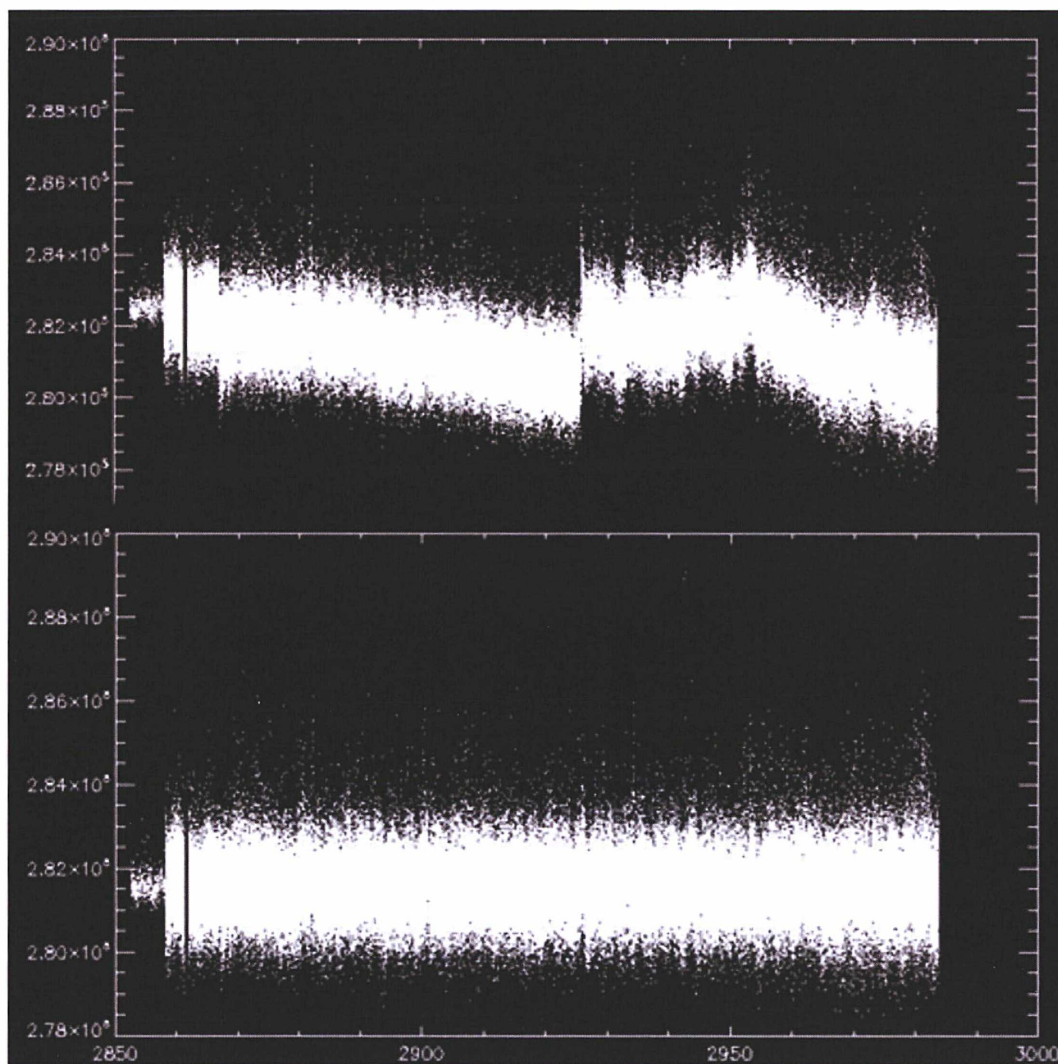




*Fig. 2.6. The comparison of zoomed Fourier spectra for S1 target.*

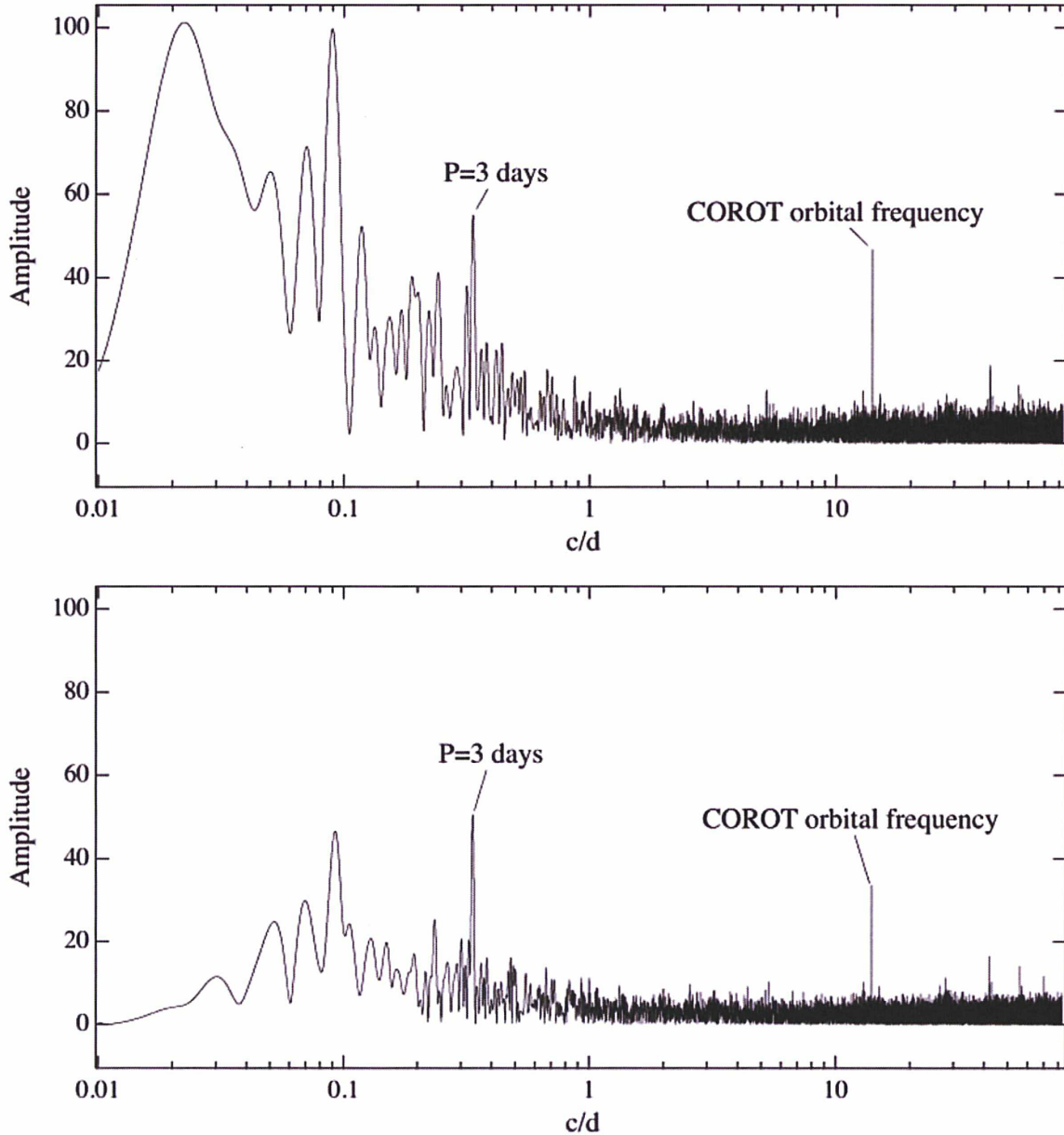
### 2.2.3 The case of S2 (CoRoT ID\_ 0102647589)

In Fig. 2.7 the original white light curve and the final light curve obtained by ColiGcor are presented. As can be seen, for this case also we succeed to remove all random jumps and instrumental trends.



**Fig. 2.7** *The original S2 light curve and final detrended light curve. The left axis is the photon flux (in electrons) and the bottom axis is the CoRoT Julian days.*

The comparison of the Fourier spectra is presented in Fig. 2.8. Again, the CoRoT orbital frequency (and harmonics) dominates at 13.97 c/d (and above). The only other significant peak is for  $0.337 \pm 0.01$  c/d, very close to a period of 3 days, which may be related to the 1 day period often present in CoRoT data. From these rather poor data, we cannot identify with confidence if there is a significant signal intrinsic to the star S2 (for more details see Alecian et al. 2009). Here also the comparison shows that our method is efficient in reducing the noise.



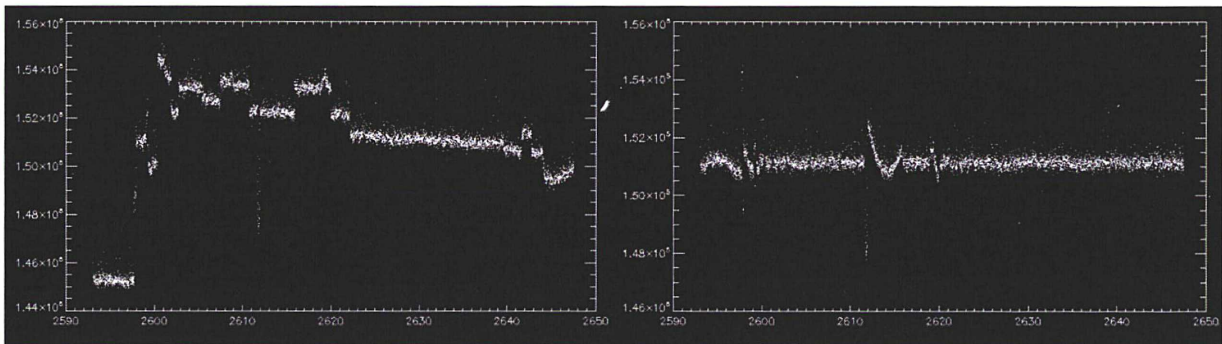
*Fig. 2.8. The comparison of full Fourier spectra for S2 target.*

## 2.2.4 The case of S4 (CoRoT ID\_ 0102874481)

The extreme case is S4, the light curve of which is affected by many jumps. In this case it is really difficult to distinguish real events from instrumental ones. Around  $JD \sim 2612$  there is an identified transit which the depth is  $\sim 0.036$  (see Mislis et al., 2010). According to the CoRoT team, the host star's spectral type is A0IV. Assuming the typical radius and mass of this star to be  $R_S = 4.4 R_\odot$  and  $M_S = 2.8 M_\odot$  and assuming the transiting object to be an exoplanet,

Mislis and his colleagues determine the planet's radius to  $R_p = 4.28 R_J$ , where  $R_J$  is the radius of Jupiter and  $R_p$  is the radius of the planet.

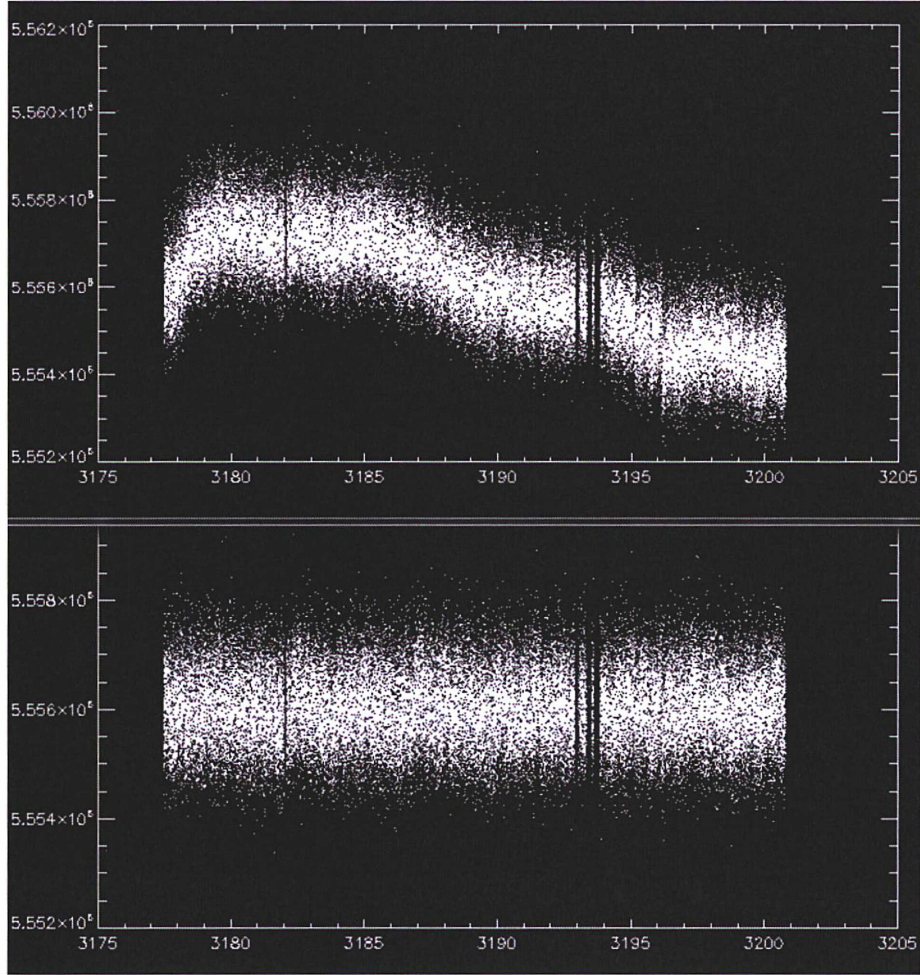
This target was treated without using the expert mode. We have chosen a  $\sigma$  level of 0.4. As can be seen from Fig.2.9, in the final light curve, the transit is preserved. There remain some problems (insufficient corrections of the sub-light curves) just in the first part of the light curve. This is due to a wrong correction of the slope of sub-light curves. We did not tried to correct this problem because our purpose was to study pulsation signals in HgMn stars. We intend to consider improving our procedure for such cases in the near future.



*Fig. 2.9 The original S4 light curve with a transit, and final detrended light curve where transit is preserved. Notice the bad corrections of sublights curve slopes. The left axis is the photon flux*

## 2.2.5 The case of S5 (HD175640)

To check if our procedure can be potentially useful for the analysis of CoRoT targets observed by Astero channel, we applied it on the CoRoT\_ID\_07569 (HD175640). Later on, we deeply investigated this target to search for granulation signature in HgMn stars as well (see Section 3 for more details). As it is clear from Fig. 2.10 it perfectly works for this star also. The procedure is able to remove the random jumps (less jumps than in lightcurves of exochannel) and instrumental effects from this target also. So we can conclude that ColiGcor can be used not only for CoRoT N2 Exo data but also for CoRoT N2 Astero data.



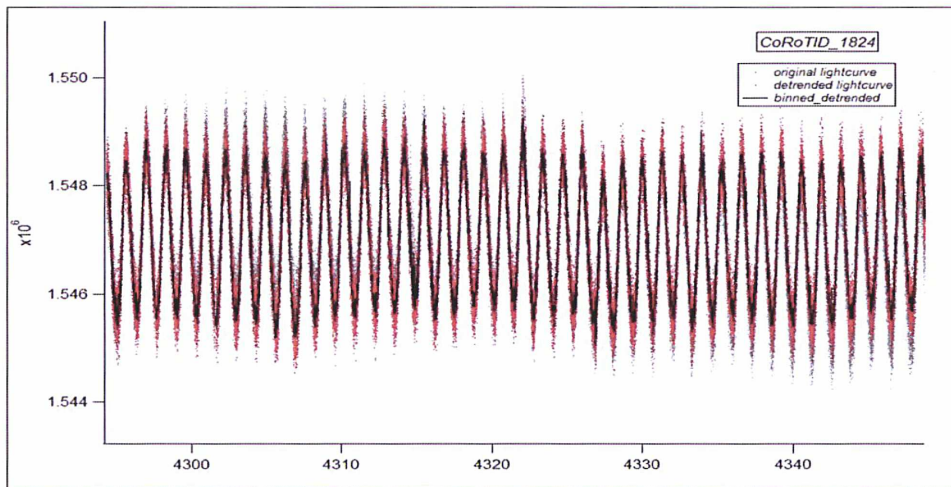
*Fig. 2.10* The original S5 light curve and final detrended light curve. The left axis is the photon flux (in electrons) and the bottom axis is the CoRoT Julian days.

## 2.2.6 The case of S6 (HD 45975)

Recently photometric variations have been detected by the CoRoT satellite in HgMn stars (see Alecian et al. 2009). These variations could be pulsations. But this has to be confirmed by further studies because rotational modulation cannot yet be excluded. Indeed, the detected frequencies by Alecian et al. (2009) are compatible with both processes. The stars they studied being faint stars ( $m > 12$ ), they had only medium resolution optical spectra, and therefore very low accuracy for *v.sini*.

The HgMn star HD 45975 (S6, CoRoT ID\_ 01824) is among the very few bright HgMn stars in the CoRoT “eyes”. Actually, only two confirmed HgMn stars are known: this one and HD175640 (S5). This B9-V type star was observed by CoRoT (astero channel) in 2011 during

the Short Run SRa04 with 53 days observational period and 32 seconds time sampling. To check the existence of photometric variability in this HgMn star and to disentangle pulsations and rotational modulation, Morel et al. (2013) lead multisite spectroscopic observations (with high spectral resolution and much better S/N than Alecian et al 2009) from the ground simultaneously with the CoRoT observations. After the beginning of the data acquisition by CoRoT, it comes out that the light flux could be affected by a faint contaminating star lying about 35" to the North of HD 45975 (see Fig. 1 of Morel et al. 2013). By analyzing the "imassettes" given by the CoRoT team it appeared that the lightcurve of HD 45975 is not affected by this contaminating star.

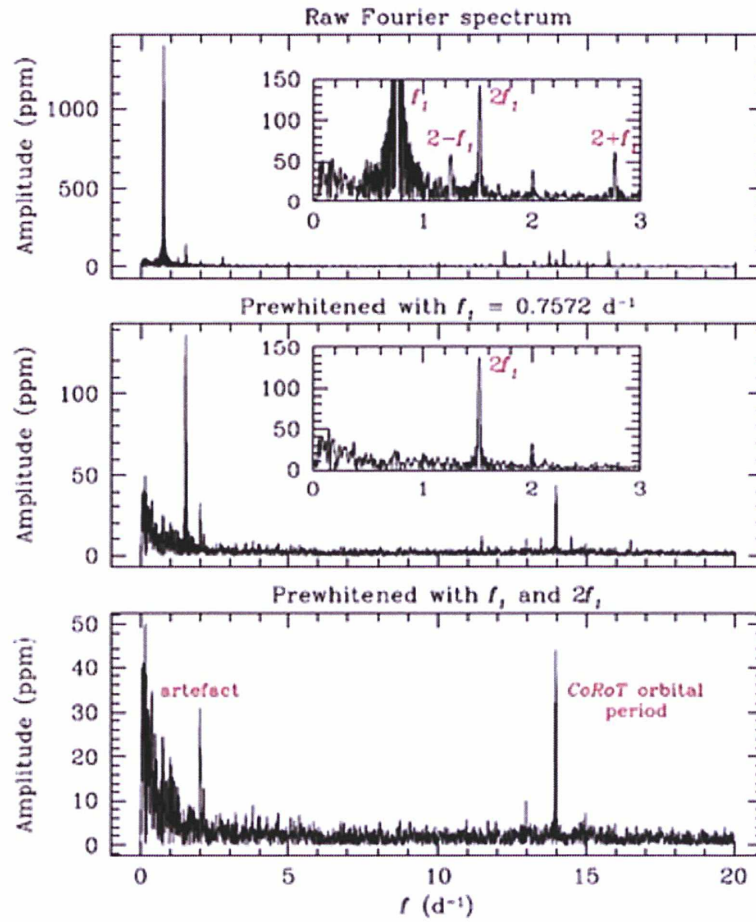


**Fig. 2.11** The original light curve (gray points), the detrended lightcurve before binning (red points) and after binning (solid line). The left axis is the photon flux (in electrons) and the bottom axis is the CoRoT Julian days.

My investment in this big collaboration was the treatment of the light curve of HD 45975 and the frequency analysis using software Period04. The treatment was done using our procedure ColiGcor (see Fig. 2.11 and Appendix B for more details).

The obtained Fourier spectrum is presented in Fig. 2.12 (See Fig. 4 in Morel et al. 2013 paper). The main frequency peak with its harmonics and aliases are presented in the figure. The aliases are caused by the peak at 2 c/d (1 day overtone) which is found in most of CoRoT light curves and due to Earth infrared emissivity (as explained by Auvergne et al. 2009, the Earth's infrared emission produces temperature variations on time scales of orbits and days). The Fourier spectra has been analysed by Period04. As usual, Period04 allow to remove identified frequencies one by one, and compute a new spectra from the residual (prewhitening). The spectra after prewhitening with  $f_1$ , and then with  $f_1$  and  $2 f_1$  are displayed in the middle and bottom panels of Fig. 2.12, respectively. CoRoT main orbital frequency at  $13.97 \text{ d}^{-1}$  is marked in the

bottom the figure as well. There is no evidence of frequency peaks with amplitudes lower than about 50 ppm.



**Fig.2.12** Raw Fourier spectrum (upper panel) and after pre whitening with  $f_1$  (middle panel) and with  $f_1$  and  $2 f_1$  (bottom panel).

An independent frequency analysis was carried out by M. Briquet, who confirmed our conclusions regarding to the monoperiodic nature of variations and the frequency value.

Multisite ground based observations shows that HD 45975 is a long-period, single-lined binary. Observed pulsations in this star may be due to the spots of some elements at the stellar surface, or pulsation.

# 3 - GRANULATION

The history of the observations of the granulation begins at the end of 18<sup>th</sup> century when William Herschel (1801) discovered that the solar disk was covered by corrugations, which he said, 'I call that very particular and remarkable unevenness, ruggedness, or asperity, which is peculiar to the luminous solar clouds, and extends all over the surface of the globe of the Sun. As the depressed parts of the corrugations are less luminous than the elevated ones, the disk of the Sun has an appearance which may be called mottled'. Later on, in 1862 the English engineer James Nasmyth, who used his largest fifty centimeters Cassegrain - Newtonian telescope to observe sunspots and the solar photosphere, announced that the Sun's surface was actually covered by a compact pattern of the thin bright filaments shaped much like 'willow-leaves'. The English astronomer William Huggins described visually the photospheric fine structure. He showed that the grains, which he preferred to call granules, as suggested by Dawes in 1864, were distributed over the entire solar surface. They were approximately round or oval in shape, or sometimes irregular. The granules diameters which he estimated, were in the range of 1"-1.5" ( $\approx 1000$  km), which is in a good agreement with present observations. His results, published in 1866 in MNRAS, ended the controversy about Nasmyth's 'willow-leaves' (for more details see Bray et al., 1984).

As we know, Sun is a G2-type dwarf star. If we were able to observe the surface of other stars belonging to the same spectral class, we would see the phenomena of granulation and super granulation at their surface. It is believed that the Sun has no convective core. A stars have thin hydrogen convection zones and also helium ones below, whereas early B stars have thin helium convective zones, which carry negligible heat. In 2008 Eric Michel and the CoRoT team announced that CoRoT was able to detect granulation effects in stars hotter than the Sun. All three targets, which were investigated, HD 49933, HD 181420, and HD 181906, were F-type stars noticeably hotter than Sun (see Michel et al. 2008). Later on, in 2010, Kallinger and Matthews announced that granulation effects may be detected in  $\delta$ -Scuti (early A-type) stars as well. These works open a way for us to investigate this problem in HgMn stars also.

HgMn stars and magnetic ApBp stars are affected by atomic diffusion processes (see Sec. 1.2). To be efficient, this process requires that the atmospheres of these stars are stable.

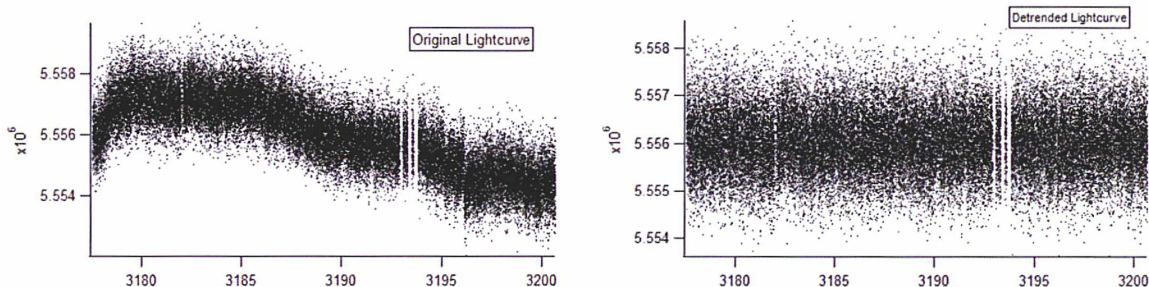


Due to the effective temperature and He gravitational settling the superficial convective zone is supposed to have disappeared in these stars (Michaud et al. 1976, Alecian and Michaud 1981; Smith and Dworetzky 1993). Among the various arguments to consolidate the theoretical models for these stars, a direct observational indication of the stability of their atmosphere would then be very important. However, this is a difficult challenge for the observers and in the present work we would like more modestly to check if a granulation signature may be detected in the light curves of a bright HgMn star observed by the CoRoT satellite. With the data obtained through CoRoT satellite's channel devoted to asteroseismology, it is possible to deeply investigate the modes penetrating to different depths in the stars, to do frequency Fourier analysis in which granulation signature could be found. According to the theoretical model for HgMn stars one does not expect to detect any granulation signal, but if a signature was indeed detected, it would be very constraining for the theoretical models. The absence of granulation signal in HgMn stars may give a new indication to support the absence of superficial convection zones in these stars.

Because the observation fields by CoRoT are small (two  $10^\circ$  cones toward galactic center and anticenter), there are very few well identified and well studied chemically peculiar stars in them. The fact to have a bright and well-known HgMn star in the CoRoT eyes is a chance. The observation of HD175640 by CoRoT in the asteroseismology channel, is a great opportunity to search for granulation signature. This star is a well-known bright HgMn star (see Castelli and Hubrig 2004; Landstreet et al. 2009), and it was measured by CoRoT during the second Short Run in the direction of the galactic center. Because of the existence of trends and jumps in the light curve we used our procedure ColiGcor (described in Chapter 2) to obtain a corrected light curve. The frequency analysis using Period04 software (Lenz and Breger 2005) is presented below.

The HgMn star HD175640 (the CoRoT-ID is 7569), is a bright B9-V type star with 6.21 apparent magnitude. It was well identified as belonging to the HgMn group and studied in detail through high resolution UVES-VLT spectra by Castelli and Hubrig (2004) who adopted the following parameters:  $T_{\text{eff}} = 12000\text{K}$ ,  $\log g = 3.95$ , with the rotational velocity  $v \sin i = 2.5 \text{ km/s}$ . This star was also studied by Landstreet et al. (2009) using Aurelie and Gecko spectrographs on the 1.52 m telescope at the Observatoire de Haute Provence (OHP) in France and at the 3.6 m Canada-France-Hawaii telescope (CFHT), respectively. The stellar parameters  $T_{\text{eff}} = 12000\text{K}$ ,  $\log g = 4.0$ , with the rotational velocity  $v \sin i = 1.5 \text{ km/s}$ , obtained by these authors, are in good agreement with those obtained by Castelli and Hubrig.

This star was observed by the CoRoT satellite's channel devoted to asteroseismology during the second short run (2008 from Sept. 12 to Oct. 6, SRc02, in the galactic center direction). The original and detrended light curve of HD 175640 is presented in Fig.3.1.



*In Fig. 3.1 we present the original light curve of HD 175640 obtained by CoRoT and the corrected one (before the 512 sec. binning), which was obtained by our procedure ColiGcor. As we see from the figures, the original light curve of HD 175640 presents weak jumps and long term variations often related to the jumps. From the corrected light curve, we do not detect any flare or transit-like variations in the light curve. The left axis is the photon flux (in electrons) and the bottom axis is the CoRoT Julian days.*

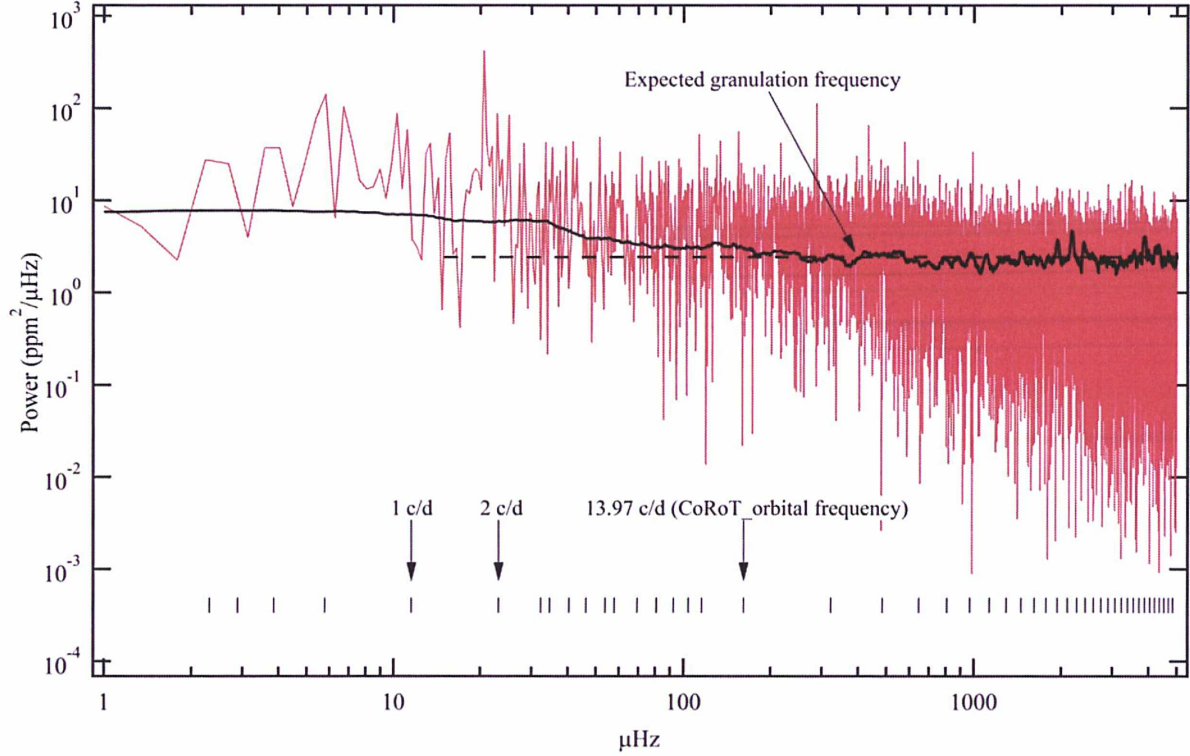
The power spectral density has been obtained from the corrected light curve and is presented in Fig.3.2. This spectrum is computed through an IDL procedure with the fast Fourier transform function and after normalization to satisfy the Parseval's theorem for FFTs. We list in Table 2 the main peaks in the spectrum as they have been extracted using Period04 software (Lenz and Breger 2005). This software identifies the peaks one by one, starting with the highest one. After each identification of a periodic signal, Period04 calculates a theoretical light curve with all the identified frequency peaks (with a minimization procedure of the residual involving all the fitted frequencies, amplitudes and phases). This calculated light curve is subtracted from the original one, and one obtains a residual light curve in which we look for the next periodic signal. In other words, the signals with the identified frequencies are removed one by one from the light flux, and a new spectrum is computed from the residual light curve to search for the next highest peak. Notice that the value of these frequencies may slightly differ at each iteration because Period04 fits the phase, the amplitude and the frequency of all the identified peaks after each identification, to minimize the difference between the observed spectrum and the one calculated with identified frequencies. We have not listed in Table 2 the frequencies smaller than 0.5 c/d because these signals with large periods are very doubtful: they are too close to the duration of the acquisition (about 20 days) and they can be due to an insufficient correction of the original light curve by ColiGcor. Indeed, as it can be seen in the top panel of Fig.3.1, the original light curve is affected by numerous fluctuations due to several kind of perturbations

(see Chapter 2). In Table 2, one can recognize the 1 cycle per day frequency (number 3) and its harmonics (number 4, 6, 7 and 8), and also the usual CoRoT orbital frequency (13.97 c/d, number 9) and its harmonics (number 10, 11, 12). The other peaks (number 1, 2, 5) do not correspond to these well-known artifacts, however, their amplitudes are very close to the noise average amplitude estimated to be about 12.6 by *Period04* around the corresponding frequencies.

Number	c/d	$\mu\text{Hz}$	Amplitude
1	0.544	6.30	32.0
2	0.674	7.80	26.4
3	0.997	11.55	31.5
4	2.006	23.22	79.0
5	2.429	28.12	24.7
6	3.013	34.88	10.8
7	4.016	46.48	23.0
8	4.977	57.61	7.5
9	13.968	161.67	19.7
10	27.945	323.43	40.4
11	41.924	485.23	14.8
12	55.887	646.84	18.5

**Table 2.** *Significant fitted frequencies in different units, and the amplitudes extracted from *Period04*.*

It is not surprising that one does not find solar-type oscillations in a CP star, but one could expect to find a pulsation signal of the type of what is observed for SPB stars (as suggested by Alecian et al. 2009). The lack of significant pulsation signal in such a bright and typical HgMn star shows that, even if some stars belonging to this group present periodic photometric variations (see the paper accepted by T. Morel et al. 2013), pulsation does not exist systematically in HgMn stars.



**Fig. 3.2.** The power spectrum of HD 175640. The dotted red curve is the spectrum for the light curve after correction with ColiGcor. In the bottom of the figure we show with small vertical bars: the 1 c/d, the orbital frequency at 13.97 c/d, and their harmonics. The solid black line is the smoothed spectrum (50  $\mu\text{Hz}$  boxcar) obtained for the residual light curve after removal of the discussed frequencies. The black dashed line is the average white noise level ( $\approx 2.43 \text{ ppm}^2/\mu\text{Hz}$  between 0.015 and 5 mHz).

It is believed that the characteristic time of the matter motions producing granulation should be scaled with the ratio of the cell size, which is undertaken to be inversely proportional to the atmospheric pressure scale height  $H_p$  to the average velocity in the cell, which is proportional to local sound speed  $c_s$ . Under the assumption of an ideal adiabatic gas, the granulation frequency should scale as  $\nu_{gran} \propto c_s/H_p$  (see Huber et al. 2010). In solar-type pulsators the oscillation frequencies are almost symmetrically distributed around dominant frequencies which is also proportional to the  $c_s/H_p$ . Following the Kjeldsen and Bedding (1995) paper, it can be assumed that

$$\nu_{gran} \propto \nu_{max} \propto M/(R^2 \sqrt{T_{eff}}), \quad (1)$$

(see the Eq.2 of Kallinger and Matthew 2010). Taking into account the same parameters for HD175640 as given by Thiam et al. (2010):

$$M/M_{\odot} = 3.21 \pm 0.1, R/R_{\odot} = 2.66 \pm 0.28, \quad (2)$$

and

$$T/T_{\odot} = 2.03 \pm 0.1. (3)$$

We evaluate the ratio of Eq.1 around  $0.316 \pm 0.08$ . This value (and the error) is computed using the fundamental parameters (and the errors) mentioned above in solar units. Using the scaling proposed by Kallinger and Matthew (2010) in their Fig.3, we deduced for HD 175640 a granulation maximum frequency around 400  $\mu\text{Hz}$ . The position of this maximum frequency is shown with the arrow labeled "Expected granulation frequency" in our Fig.3.2.

The signal of solar granulation and mesogranulation was studied by Frohlich et al. (1997) from observations with various instruments: SOHO/VIRGO/PMO6 (bolometric variations), and for different band pass by SOHO/VIRGO/SPM (photon counting). From this study and using techniques provided by Kjeldsen et al. (2005), Michel et al. (2009) have estimated the expected signal from CoRoT data for solar-like stars. These estimates show that the granulation frequency in solar type stars should be over 1 mHz, which is in good agreement with values evaluated by Aigrain et al. (2004), and with the scaling of Kallinger and Matthew (2010) we use for HD 175640. To check the existence of the granulation signature we consider the detrended power spectrum shown in Fig.3.2. We have first removed from this spectrum all the frequencies listed in Table 2, and compute the spectrum of the residual light curve using Period04. This residual spectrum has been smoothed with a 50  $\mu\text{Hz}$  boxcar (500 frequency points). This smoothed spectrum is the solid black line in Fig.3.2. Around the expected position of the granulation signature (400  $\mu\text{Hz}$ ), we notice a small increase (close to 1  $\text{ppm}^2/\mu\text{Hz}$ ) of the smoothed spectrum. However this increase has an amplitude of only about  $1\sigma$  above the noise ( $\approx 0.83 \text{ppm}^2/\mu\text{Hz}$ ), which is not large enough to be considered as a detection. Moreover, the signal level remains at the level of the noise (the dashed line) and could be interpreted as a recovery of the average level after the small dip around 360  $\mu\text{Hz}$ . We can see in Fig.3.2, that we are not far from the limit of detection of a small power excess around 400  $\mu\text{Hz}$ . However, we cannot confirm an additional power emerging from the noise, and we cannot consider that a granulation signal can be identified in this power spectrum.

Main-sequence stars inside the effective temperature range of HgMn stars, are generally not solar type pulsators. There is no theoretical model describing what could be the amplitude of a granulation signal for "normal" stars in that  $T_{\text{eff}}$  range. So, we cannot assure from our result that the absence of mixing in the atmosphere is confirmed for HgMn stars. We say that, considering what is known for stars where granulation signal has been detected, and considering the best light curve of an HgMn star presently available, we do not find any power excess indicating the presence of granulation.

On another hand, we have not found clear pulsation signal (beside some few uncertain peaks in the spectrum). This suggests, that even if pulsations may exist in some HgMn stars (as for instance in S1 or S6), they should not exist systematically in all HgMn stars.



# 4 - Abundances of elements in HgMn stars

HgMn stars, as a subgroup of Chemically Peculiar stars, are characterized by unusually strong lines of HgII and MnII. They often show mild helium deficiencies, and sometimes the presence of other peculiarities, for instance, isotopic anomalies in platinum, mercury, gallium and in other elements, which means that some rare isotopes are more abundant than those that are usually found in the atmospheres of those stars.

To see the trends of chemical abundances in HgMn stars and to be able to do statistical analysis of them, I compiled nearly all elements and ions abundances published in the literature since 1993 and I created a database of physical and chemical properties of these stars. Such type of research was done by Preston (1974), and later by Smith (1996). For this research more than 130 stars and around 50 papers were considered. All abundances have been plotted versus atomic numbers. The elements and ions abundances are rescaled assuming the solar values given by Asplund et al. (2009) (see Fig. 4.1). To be able to compare our results with the work done nearly twenty years ago (see Smith 1996) I took the average of all the ions abundances and I created the same plot as a function of the atomic numbers of the elements. The final plot and the figure taken from Smith's outcome are given below (see Fig. 4.2 and Fig. 4.3). In these plots each point for a given element, represents one star.

The comparison results show that the **helium** underabundance is less pronounced than in Smith's outcome. The dispersion of He values is quite large and equal to 3 dex. It comes out that the hotter HgMn stars have stronger He deficits than the cooler HgMn stars (see Dworetzky, 2004).

**Berillium** and **boron** abundances are available only for HD71066 and  $\chi$ LupA (see Yüce et al. 2011, and Leckrone et al. 1999, respectively). Unfortunately, we could not find any other papers relevant to Be and B abundances. Some HgMn stars are Be- rich, others are essentially normal. The same may be stated for the case of boron. It is overabundant in about 20% of HgMn stars, normal in a handful cases, and deficient in the rest (see Smith, 1996). These abundances were observed before 1993, which is the reason why we do not have more Be and B abundances in our compilation. However, this is just a preliminary conclusion. We need to investigate this problem more deeply.



For a few HgMn stars **carbon (C)** seems overabundant, for others is underabundant, but mostly the relative amount of carbon in the atmospheres of these stars is normal. In Smith's compilation there is no HgMn star which shows carbon overabundance.

**Nitrogen (N)** underabundance is more pronounced than in Smith's compilation. There are two HgMn stars, HD 168932 and HD179761, which show nitrogen overabundance in their atmospheres (for more details see Niemczura et al. 2009). It is important to note that the dispersion value of carbon and nitrogen is nearly 3 dex for both of them.

The abundance of **oxygen (O)** in HgMn stars is normal and it is not highly dispersed. This result is in a good agreement with Smith's compilation.

On the average, the **neon (Ne)** and **sodium (Na)** abundances are normal. Just a few percent of HgMn stars show underabundances of neon. Neon and sodium abundances are absent in Smith's outcome.

The comparison of the two compilations shows that in our outcome the underabundances (**aluminum (Al)** and **silicon (Si)**) are less pronounced (as in the case of helium) and there is a huge dispersion of these elements as well, nearly 3.2 dex and 3.6 dex, respectively. Nearly for 75 percent of HgMn stars silicon abundances are normal, and for the others Si is overabundant or underabundant. The highest overabundance and underabundance values of Si are 1.36 and -2.10 dex for HD 45583 and HD 35548 (see Niemczura et al. 2009 and Smith 1993, respectively). Another light element, **magnesium (Mg)**, is mostly underabundant. For a few HgMn stars, the abundances overlay solar values.

**Phosphorus (P)** is overabundant in almost all HgMn stars. It is underabundant only in the atmosphere of 46 Dra B. The exceptional underabundance value of phosphorus goes down to -0.4 dex.

**Sulphur (S)** is underabundant in most HgMn stars. The largest deficiency of sulphur appears in the atmosphere of HD 55362 (see Niemczura et al. 2009) and reaches to -2.0 dex.

**Chlorine (Cl)** abundances are available only for two targets - HD 46886 and  $\chi$ LupA and are equal to -0.36 and -1.40 dex respectively (see Niemczura et al. 2009 and Leckrone et al. 1999). Because of the lack of abundance values it is hard to speak about dispersion of this element in the atmospheres of HgMn stars.

**Potassium (K)** abundances seem to be normal in HgMn stars. In any case, this is a preliminarily conclusion, because the abundance values are given just for HD 153720A and HD

153720B (see Yushchenko et al. 2004). It is important to mention that chlorine and potassium abundances are absent in Smith's compilation also.

The dispersion of **Ca**, **Sc** and **V** is quite large, nearly 3 dex or slightly more. Unusual **calcium** underabundances are determined in the atmosphere of HD49935 (see Niemczura et al. 2009) which reaches -1.66 dex. The measured underabundances of **vanadium** in the atmospheres of HD 71066, HD 11753, and HD 175640 (see Yüce et al. 2011, Makaganiuk et al. 2012, Castelli and Hubrig 2004) need further studies as well.

**Titanium (Ti)** is mostly overabundant in HgMn stars. In the atmospheres of several HgMn stars it is underabundant. The overabundances of titanium are slightly larger than in Smith's compilation.

The iron-peak elements (**Cr**, **Mn**, **Fe**, **Co**, and **Ni**) are broadly scattered around the solar abundances. It is worthwhile to note, that two stars in the HgMn group,  $\chi$ Lup and 36 Lyn, have less **manganese** abundances compared with the solar properties. These observational results seem to confirm Cowley's (1980) suggestion that there is a separate group of hot, mild HgMn stars, which are difficult to identify by usual classical observational techniques. The total range in **iron** abundance determined in this HgMn sample is around 2.5 dex, which is greater than that measured for any other group of chemically peculiar stars (see Ptitsyn and Ryabchikova, 1980). HgMn stars are generally Co-deficient, although there are some examples with overabundances respect to solar values. The unusual overabundance is determined in the atmosphere of HD 143807 (see Ryabchikova, 1998) which needs further detailed investigations. The HgMn stars are generally Ni-deficient although there are some examples with abundances higher with respect to solar properties (see Smith and Dworetsky, 1993). Although the high dispersion of iron-peak elements, heavy elements are more overabundant in the atmospheres of HgMn stars.

**Copper (Cu)** is overabundant in most HgMn stars and is underabundant only in few cases. **Zinc (Z)** is typically deficient in those stars, despite the fact that in some cases it is overabundant with respect to solar values or essentially equal to solar abundances (see Smith, 1994).

One should mention that there are some rare elements, namely, **Ge**, **As**, **Br**, **Mo**, **Ru**, **Rh**, **Pd**, **Cd**, **Sn**, **Sm**, **Os**, **Sb**, **Pr**, **Eu**, **Gd**, **Dy**, **Er**, **W**, **Re**, **Ir**, **Au**, **Tl**, **Pb**, **Bi** and **U**, which are not represented in Smith's compilation. From these elements only **germanium** and **lead** are underabundant, the others are overabundant in the atmospheres of HgMn stars. The abundances of **praseodymium**, **gadolinium** and **dysprosium** are given for dozens of HgMn stars while the

other rare elements' abundances are available for one or two targets. **Germanium**, **molybdenum**, **ruthenium**, **cadmium**, **stannum**, **antimony**, **europium**, **tungsten**, **ruthenium**, **iridium**, **lead** and **bismuth** abundances are given for  $\chi$ LupA only (see Leckrone et al. 1999). **Bromine** abundance is available for HD 175640 (see Castelli and Hubrig, 2004), while the **erbium** and **uranium** abundances are given for HD 193452 in Hubrig et al. (1999). **Arsenic** abundance is available for HD 71066 (see Yüce et al. 2011) and  $\chi$ LupA only (see Leckrone et al. 1999). The abundances of **rhodium**, **osmium** and **palladium** are determined in the atmospheres of HD 175640 and  $\chi$ LupA (see Castelli and Hubrig, 2004 and Leckrone et al. 1999, respectively), the **thallium** abundance - in HD 193452 and  $\chi$ LupA only (see Wahlgren et al. 2000 and Leckrone et al. 1999, respectively). **Samarium** abundance is determined in the atmospheres of HD 158704 and HD 193452 (see Hubrig et al. 1999).

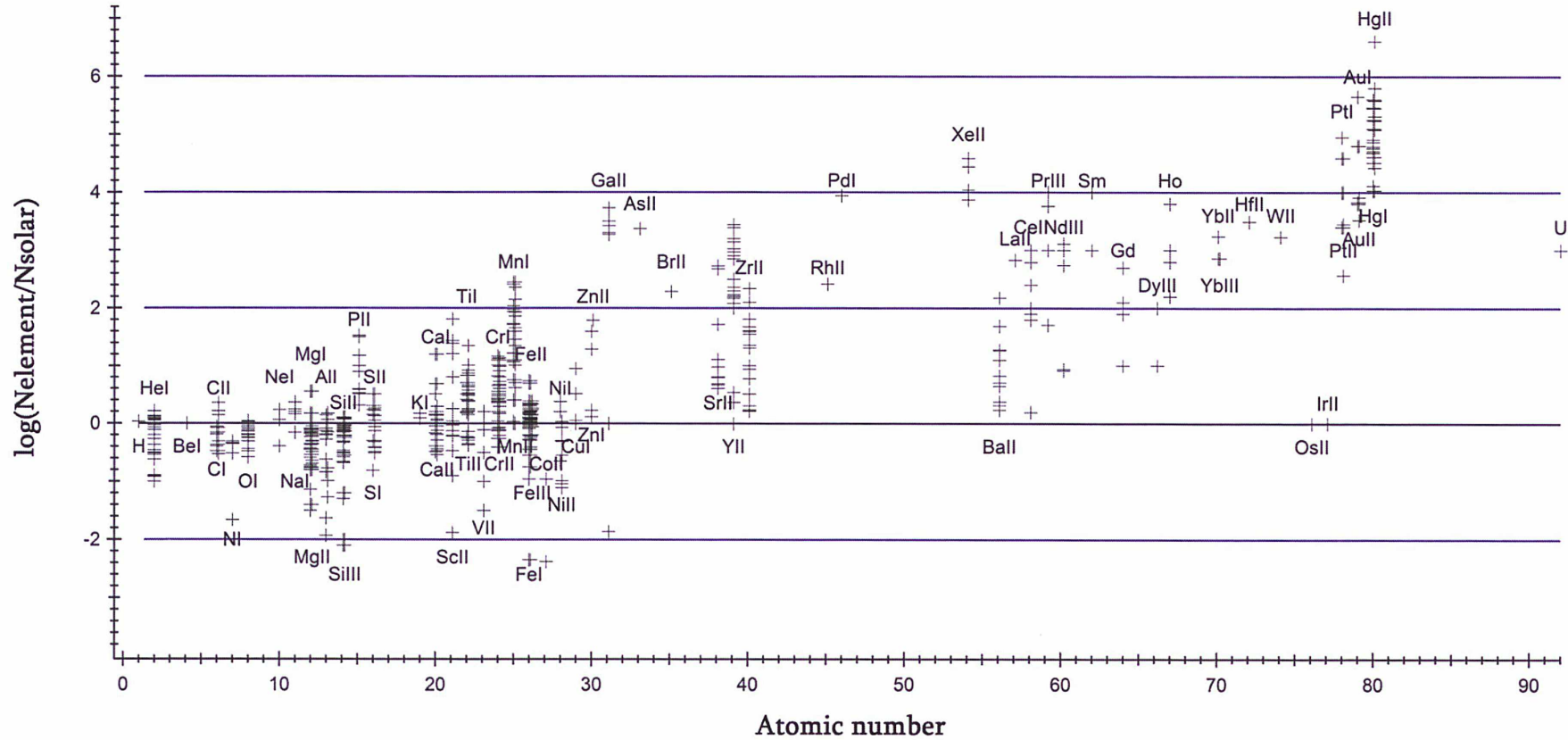


Fig. 4.1 Compilation of abundances (relative to the Sun) for Hg-Mn stars versus atomic numbers. Abundances are from the following papers: Adelman et al. 1996; Adelman, Gulliver and Rayle, 2001; Adelman et al. 2001; Adelman et al. 2006; Alecian et al. 2009; Anders and Grevesse 1988; Asplund et al. 2009; Bohlender et al. 1998; Castelli and Hubrig 2004; Catanzaro et al 2003; Catanzaro et al 2006; Catanzaro 2010; Cowley et al. 2007; Dolk et al. 2002; Dolk et al. 2003; Dworetzky et al. 1998; Dworetzky and Budaj 2000; Dworetzky 2004; Dworetzky et al. 2008; Fossati et al. 2011; Hubrig et al. 1999; Jomaron et al. 1999; Khokhlova et al., 1995; Kochukhov et al. 2005; Leckrone et al. 1999; Niemczura et al. 2009; Pintado and Adelman 1996; Ryabchikova et al. 1996; Ryabchikova 1998; Ryabchikova et al. 1999; Saffe et al. 2011; Savanov and Hubrig 2003; Smith 1993; Smith and Dworetzky 1993; Smith 1994; Smith 1996; Smith 1997; Tkachenko et al. 2013; Usenko et al. 2001; Wahlgren et al. 2000; Wahlgren and Hubrig 2000; Woolf and Lambert 1999; Woolf and Lambert 1999a; Yüce et al. 2011; Yushchenko et al. 1999; Yushchenko et al. 2004 and Zavala et al. 2007.

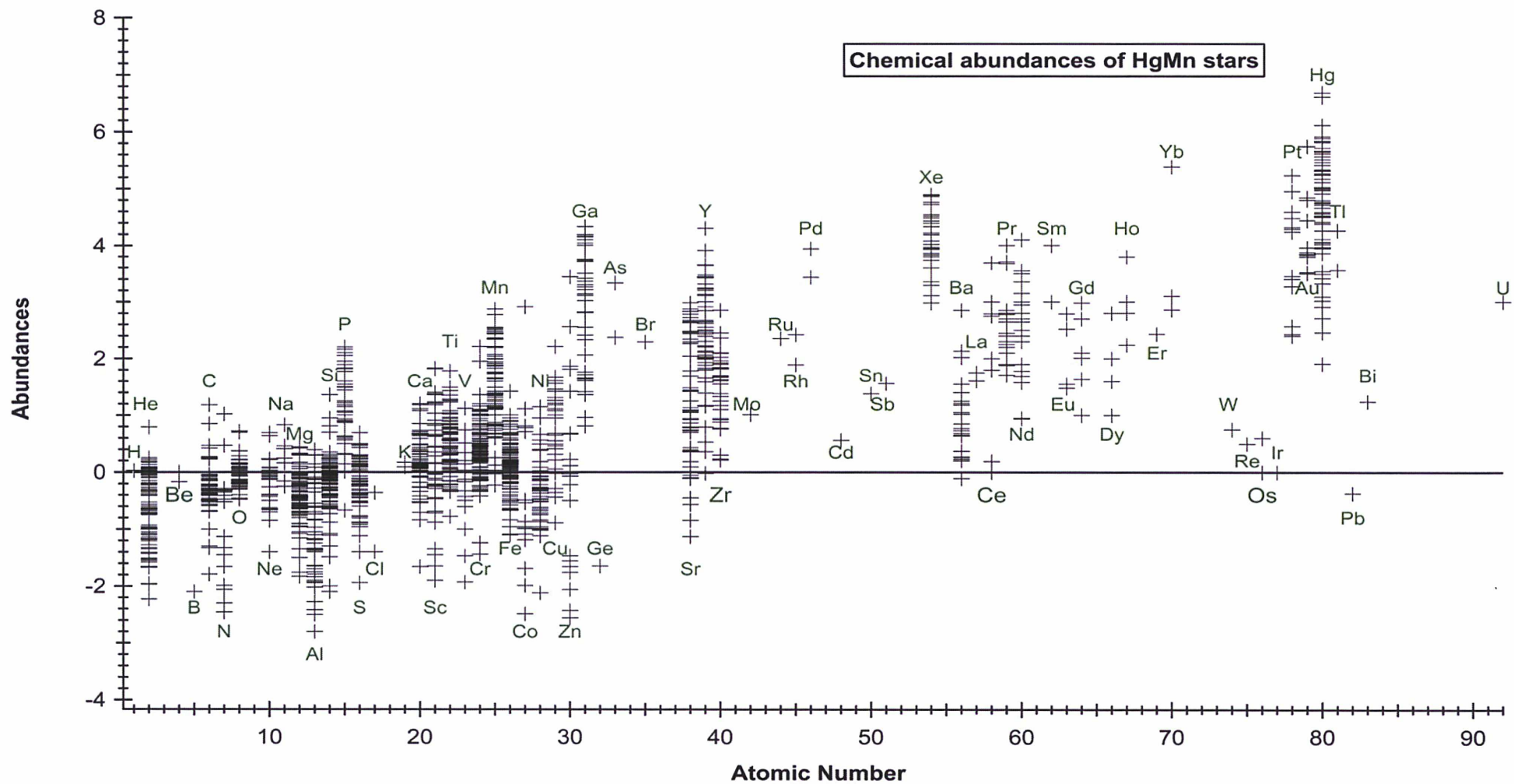


Fig. 4.2 Mean abundances (relative to the Sun) versus atomic numbers. Abundances are from the same authors as in Fig.4.1

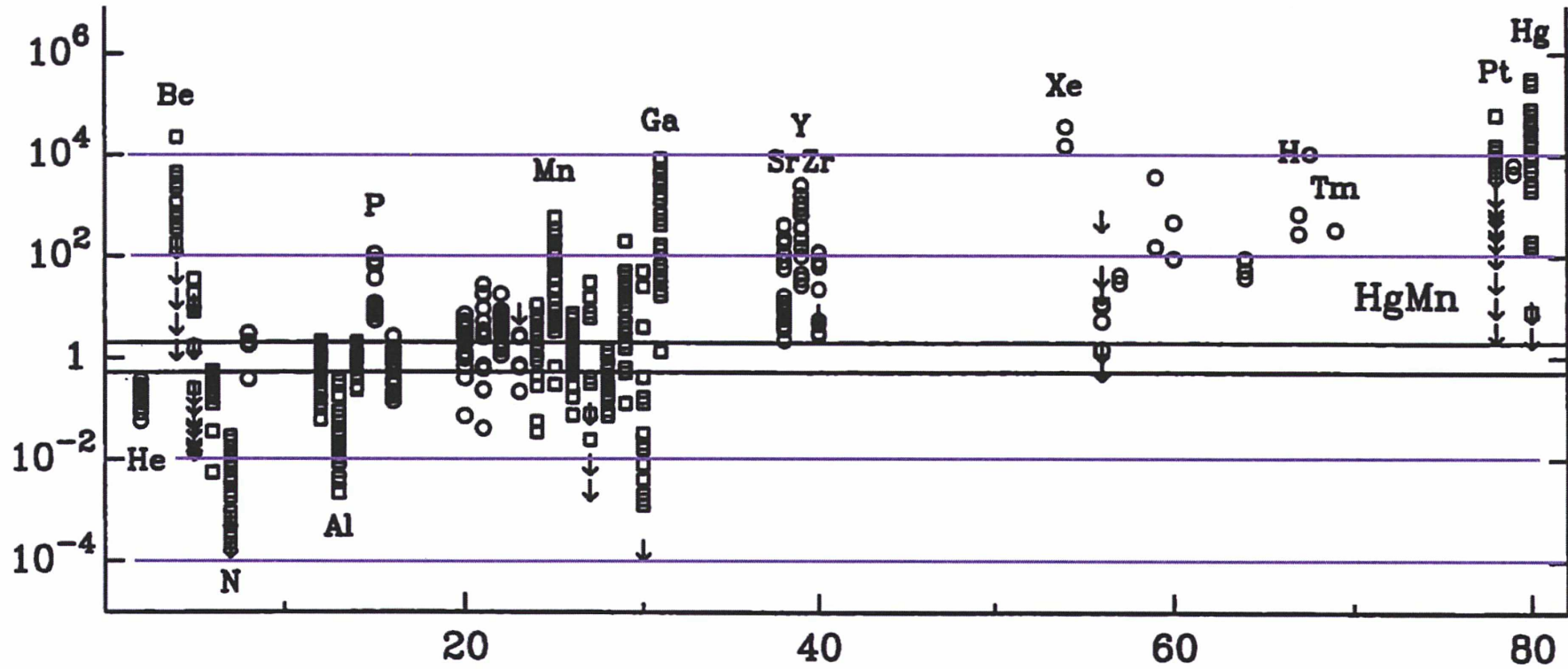


Fig. 4.3 Figure 5 of Smith 1996. Abundances (relative to the Sun) versus atomic numbers. Pairs of horizontal lines denote a range of  $\pm 0.3$  dex in which most normal stars lie. Circles denote abundances obtained from optical-region spectra; squares and arrows denote abundances and upper limits obtained from IUE spectra.

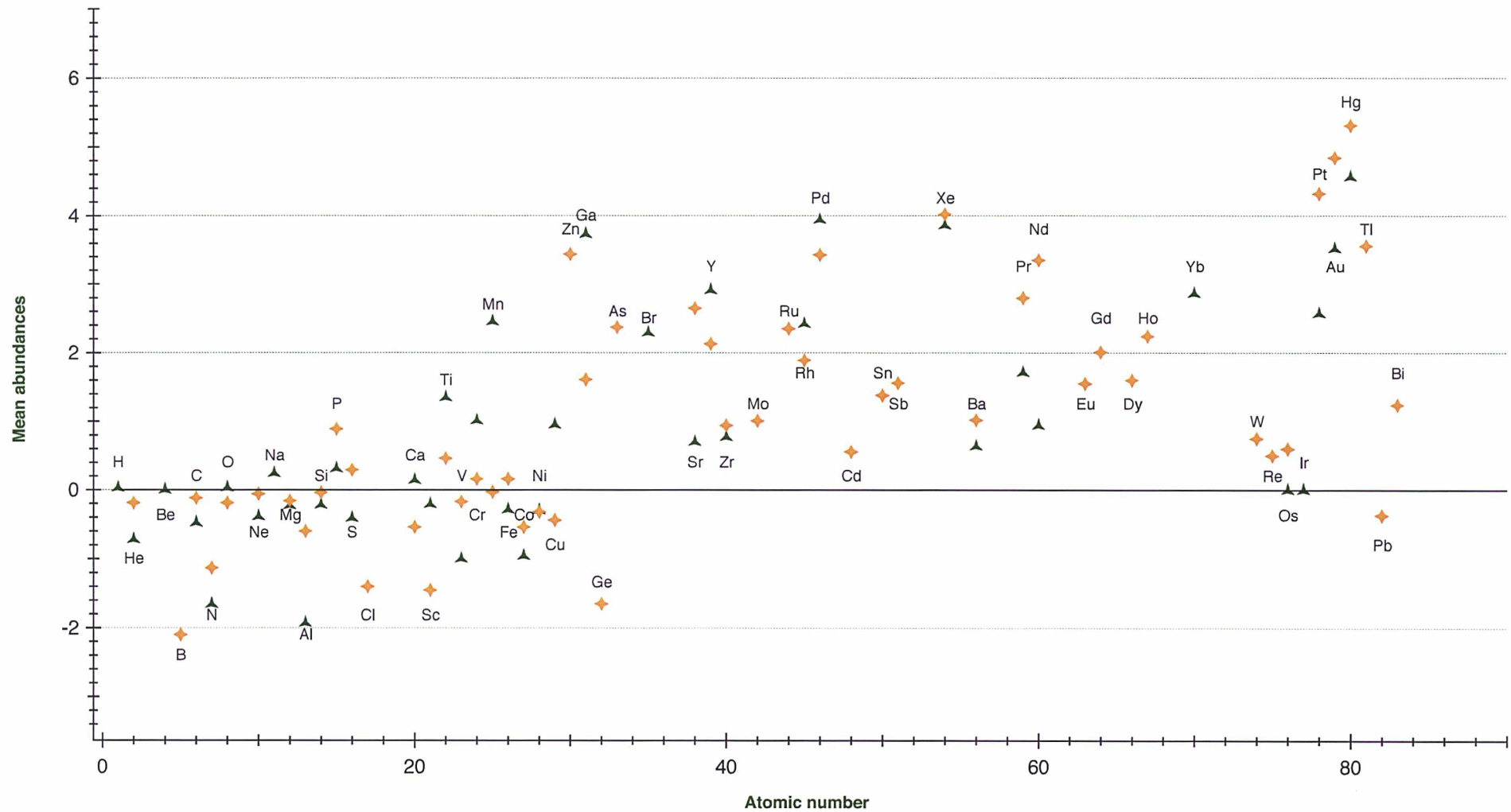


Fig 4.4 - Abundances (relative to the Sun) for two HgMn stars: HD 175640 and  $\chi$  Lupi A. The green triangles are for HD 175640, the yellow crosses are for the abundances of  $\chi$  Lupi A. The abundances are obtained from Castelli and Hubrig 2004; Yüce et al. 2011; Dworetsky et al. 2008; Dolk et al. 2003, and Dworetsky 2004 (for HD 175640); Dworetsky et al. 2008; Catanzaro et al. 2003; Jomaron et al. 1998; Ryabchikova 1998; Leckrone et al. 1999; Pintado and Adelman 1996; Adelman et al. 2001; Wahlgren et al. 2000; Dolk et al. 2002; Dworetsky and Budaj 2000; and Smith 1994 (for kappa Lupi A).

Table 3 – Details of the abundances displayed in Fig 4.4, with uncertainties as published in the given references.

Elem.	Solar abundance	HD175640			$\chi$ Lupi A		
		$\log(N_{el})$	$[N_{el}]$	Reference	$\log(N_{el})$	$[N_{el}]$	Reference
H	12.00	-0.008163	0.02	Castelli & Hubrig (2004)	-	-	-
He	$10.93 \pm 0.01$	$10.21 \pm 0.05$	-0.72	Dworetsky (2004)	$10.73 \pm 0.20$	-0.20	Dworetsky (2004)
Be	$1.38 \pm 0.09$	-10.64	0.02	Castelli & Hubrig (2004)	-	-	-
B	$2.70 \pm 0.20$	-	-	-	<0.6	-2.48	Leckrone et al. (1999)
C	$8.43 \pm 0.05$	-4.08	-0.51	Castelli & Hubrig (2004)	-3.46	-0.03	Ryabchikova et al. (1998)
N	$7.83 \pm 0.05$	-5.78	-1.61	Castelli & Hubrig (2004)	6.7	-1.34	Leckrone et al. (1999)
O	$8.69 \pm 0.05$	$(-3.18) \pm 0.11$	0.13	Castelli & Hubrig (2004)	-3.48	-0.17	Ryabchikova et al. (1998)
Ne	$7.93 \pm 0.10$	-4.35	-0.28	Castelli & Hubrig (2004)	7.87	-0.06	Dworetsky & Budaj (2000)
Na	$6.24 \pm 0.04$	-5.47	0.24	Castelli & Hubrig (2004)	-	-	-
Mg	$7.60 \pm 0.04$	$(-4.69) \pm 0.07$	-0.23	Castelli & Hubrig (2004)	-4.48	-0.08	Catanzaro et al. (2003)
Al	$6.45 \pm 0.03$	-7.50	-1.93	Castelli & Hubrig (2004)	-6.18	-0.63	Ryabchikova et al. (1998)
Si	$7.51 \pm 0.03$	$(-4.71) \pm 0.06$	-0.22	Castelli & Hubrig (2004)	-	-0.10	Leckrone et al. (1999)
P	$5.41 \pm 0.03$	$(-6.28) \pm 0.08$	0.31	Castelli & Hubrig (2004)	6.3	0.89	Leckrone et al. (1999)
S	$7.12 \pm 0.03$	$(-5.12) \pm 0.03$	-0.41	Castelli & Hubrig (2004)	7.40	0.28	Leckrone et al. (1999)
Cl	$5.50 \pm 0.30$	-	-	-	<4.1	-1.20	Leckrone et al. (1999)
Ca	$6.34 \pm 0.04$	$(-5.54) \pm 0.25$	0.14	Castelli & Hubrig (2004)	5.8	-0.54	Leckrone et al. (1999)
Sc	$3.15 \pm 0.04$	$(-9.08) \pm 0.15$	-0.21	Castelli & Hubrig (2004)	1.7	-1.45	Leckrone et al. (1999)
Ti	$4.95 \pm 0.05$	$(-5.67) \pm 0.11$	1.35	Castelli & Hubrig (2004)	5.4	0.45	Leckrone et al. (1999)
V	$3.93 \pm 0.08$	-9.04	-1.00	Castelli & Hubrig (2004)	3.85	-0.17	Leckrone et al. (1999)
Cr	$5.64 \pm 0.04$	$(-5.36) \pm 0.08$	1.01	Castelli & Hubrig (2004)	$5.7 \pm 0.2$	0.16	Smith & Dworetsky (1993)
Mn	$5.43 \pm 0.04$	$(-4.20) \pm 0.06$	2.45	Castelli & Hubrig (2004)	-	-0.06	Khokhlova (1995)
Fe	$7.50 \pm 0.04$	$(-4.83) \pm 0.11$	-0.29	Castelli & Hubrig (2004)	7.66	0.16	Leckrone et al. (1999)
Co	$4.99 \pm 0.07$	-8.08	-0.96	Castelli & Hubrig (2004)	-	-0.56	Leckrone et al. (1999)
Ni	$6.22 \pm 0.04$	$(-6.09) \pm 0.16$	-0.30	Castelli & Hubrig (2004)	5.90	-0.32	Leckrone et al. (1999)
Cu	$4.19 \pm 0.04$	-6.52	0.95	Castelli & Hubrig (2004)	$3.83 \pm 0.4$	-0.36	Smith (1994)
Zn	$4.56 \pm 0.05$	-	-	-	2.5	2.06	Smith (1994)
Ga	$3.04 \pm 0.09$	$(-5.43) \pm 0.04$	3.73	Castelli & Hubrig (2004)	$4.65 \pm 0.15$	1.61	Smith (1996a)
Ge	$3.65 \pm 0.10$	-	-	-	<2.0	-1.65	Leckrone et al. (1999)
As	-9.63	-	-	-	4.7	2.33	Leckrone et al. (1999)
Br	-9.63	$(-7.12) \pm 0.04$	2.29	Castelli & Hubrig (2004)	-	-	-
Sr	$2.87 \pm 0.07$	3.53	0.66	Dworetsky et al. (2008)	5.48	2.61	Dworetsky et al. (2008)
Y	$2.21 \pm 0.05$	5.12	2.91	Dworetsky et al. (2008)	4.34	2.13	Dworetsky et al. (2008)
Zr	$2.58 \pm 0.04$	$(-8.67) \pm 0.17$	0.77	Castelli & Hubrig (2004)	3.46	0.88	Leckrone et al. (1999)



Mo	1.88 ± 0.08	-	-	-	2.89	1.01	Leckrone et al. (1999)
Ru	1.75 ± 0.08	-	-	-	4.10	2.35	Leckrone et al. (1999)
Rh	0.91 ± 0.10	-8.50	2.42	Castelli & Hubrig (2004)	2.80	1.91	Leckrone et al. (1999)
Pd	1.57 ± 0.10	(-6.41) ± 0.30	3.94	Castelli & Hubrig (2004)	5.00	3.43	Leckrone et al. (1999)
Cd	-10.24	-	-	-	2.32	0.56	Leckrone et al. (1999)
Sn	2.04 ± 0.10	-	-	-	<3.42	1.38	Leckrone et al. (1999)
Sb	-10.96	-	-	-	2.6	1.56	Leckrone et al. (1999)
Xe	2.24 ± 0.06	-5.90 ± 0.17	3.86	Yüce et al. (2011)	6.26 ± 0.07	4.02	Dworetzky, Prsaud and Patel (2008)
Ba	2.18 ± 0.09	-9.27	0.64	Castelli & Hubrig (2004)	3.2	1.02	Leckrone et al. (1999)
Pr	0.72 ± 0.04	-9.62	1.71	Castelli & Hubrig (2004)	2.80	2.08	Dolk et al. (2002)
Nd	1.42 ± 0.04	(-9.57) ± 0.08	0.97	Castelli & Hubrig (2004)	3.35	1.93	Dolk et al. (2002)
Eu	0.52 ± 0.04	-	-	-	2.07	1.55	Leckrone et al. (1999)
Gd	1.07 ± 0.04	-	-	-	3.08	2.01	Leckrone et al. (1999)
Dy	1.10 ± 0.04	-	-	-	2.70	1.60	Leckrone et al. (1999)
Ho	0.48 ± 0.11	-	-	-	2.72	2.24	Leckrone et al. (1999)
Yb	0.84 ± 0.11	(-8.10) ± 0.1	2.86	Castelli & Hubrig (2004)	-	-	-
W	0.85 ± 0.12	-	-	-	<1.6	0.75	Leckrone et al. (1999)
Re	-11.73	-	-	-	<0.77	0.50	Leckrone et al. (1999)
Os	1.40 ± 0.08	-10.55	0.00	Castelli & Hubrig (2004)	-	0.53	Wahlgren et al. (1998)
Ir	1.38 ± 0.07	-10.65	0.00	Castelli & Hubrig (2004)	-	-	-
Pt	-10.20	-7.63	2.57	Castelli & Hubrig (2004)	6.00	4.20	Leckrone et al. (1999)
Au	0.92 ± 0.10	(-7.51) ± 0.06	3.52	Castelli & Hubrig (2004)	5.77	4.85	Adelman et al. (2004)
Hg	-10.91	5.65	4.56	Dolk et al. (2003)	-5.60	5.31	Catanzaro et al. (2003)
Tl	0.90 ± 0.20	-	-	-	4.66	3.76	Leckrone et al. (1999)
Pb	1.75 ± 0.10	-	-	-	1.52	-0.23	Leckrone et al. (1999)
Bi	-11.29	-	-	-	2.1	1.39	Wahlgren et al. (1998)

Table 3 - Continued

**Gallium (Ga)** is overabundant in HgMn stars. In both compilations Ga abundances are larger compared with the solar abundance. In this sample gallium overabundance reaches to 4.4 dex which is a bit different from Smith's outcome value. The largest gallium overabundance in Smith's outcome is essentially equal to 4 dex.

**Yttrium (Y)**, **zirconium (Zr)** and **cerium (Ce)** are overabundant in all HgMn stars. **Strontium (Sr)** is overabundant in nearly all HgMn stars as well. Just in a few cases it seems deficient in those stars. It is important to note that all these abundances are broadly scattered above the solar abundances.

In our compilation **xenon (Xe)**, **barium (Ba)**, **lanthanum (La)**, **holmium (Ho)**, **praseodymium (Pr)** and **neodymium (Nd)** overabundances have nearly the same values as in Smith's compilation. **Thulium (Tm)**, **platinum (Pt)**, **gold (Au)** and **mercury (Hg)** abundances are given in Smith's outcome, but overabundances are smaller than in ours. In Smith's compilation **platinum** tend to solar abundance but in our sample it is broadly overspread with respect to solar values. **Mercury** abundances, which defining feature of those stars, reaches up to 6.7 dex in the atmosphere of HR 8937 (see Saffe et al. 2011).

The compilation confirms that the overabundances in the atmospheres of HgMn stars increase for heavy elements with atomic numbers. The main conclusion we could draw from this compilation is that the large scatter of the abundances cannot be due to errors of measures. This scatter existed already in the compilation of Smith 1996, and it is still present in the present compilation, despite of the progress in measurement techniques. It is due to a large variety of abundance anomalies from star to star. To illustrate this statement, we have chosen two HgMn stars (HD 175640 and  $\chi$ Lupi), which were measured by different techniques and different methods, and we have plotted them in the same plot (Fig. 4.4). As we can see, both stars show very different patterns of abundances. Such a large scatter of abundances of heavy elements in the atmospheres of HgMn stars, supports the unstable scenario of abundance stratifications build-up proposed by Alecian (1998) and Alecian et al. (2011).



# Conclusion

In this work we first present a new procedure (called *ColiGcor*) written in IDL. It is aimed to treat the light curves obtained through CoRoT "astero-" and "exo- channels". This procedure allows to correct abnormal effects not removed by the automatic treatment of light curves provided in N2-data. Our quasi- automatic procedure is able to detect nearly 100 jumps and to treat the light curve in few minutes for a middle-power desktop computer. The method clearly improved the light curves. This is visible when the Fourier spectra are compared with the ones obtained by Alecian et al. (2009) from the same data. We have checked that this method could be applied also on targets showing transits, however, after some adjustments which remain to be done.

We have considered the case of the well-known HgMn star HD 175640 observed with *CoRoT* with the asteroseismology channel. After applying our correction procedure, we analyzed the frequency power spectrum to search for granulation signal and pulsations. We have not found any granulation signal, at this level of sensitivity. Hence, the consistency with the usual model with atomic diffusion to explain the strong abundance anomalies that characterize HgMn stars, is preserved. On another hand, we have not found any clear periodic photometric variations (besides some few uncertain peaks in the spectrum). This suggests that, even if pulsations may exist in some HgMn stars (as perhaps in HD45975 to the study of which we have participated), they should not exist systematically in all HgMn stars. The Kepler's data, which we plan to study in near future, could help us to understand deeper these problems and give some new insights.

For a better understanding of the details of the physical processes affecting the atmosphere of HgMn stars, we have compiled the chemical abundances measured and published since 1993 for HgMn stars are compiled. We compared them to the data presented in Smith's review (1996). The results of this compilation show how the heavy elements are systematically overabundant in HgMn stars (see Preston, 1974 and Smith, 1996). The underabundance of He seems less pronounced than in Smith's review. The overabundances in the atmospheres of HgMn stars increase with atomic mass for heavy elements. The scatter of abundances is not due to the errors of measures. It is due to a large variety of anomalies from star to star. For some heavy elements no abundances have been shown by Smith while for the

others, the results are mostly the same. However, it is important to know that the created database is not homogenous because the HgMn stars were observed by different techniques and diverse methods. Consequently, to give the precise values of abundances all uncertainties need to be recalculated. The database will be supplemented in near future and a deeper study of HgMn stars will be done. We plan to extend this study to the other kinds of A and B stars to be able to do improve the statistical analysis.

# Conclusion (français)

Dans ce travail, nous avons présenté d'abord une procédure (appelée ColiGcor) écrite en langage IDL. Elle est destinée à traiter les courbes de lumières CoRoT obtenues par les canaux « astéro » et « exo ». Cette procédure permet de corriger des effets anormaux qui subsistent après le traitement automatique des courbes de lumière fournies dans les données N2. Notre procédure quasi-automatique est capable de détecter et corriger environ 100 sauts anormaux et de traiter la courbe de lumière en quelques minutes sur un ordinateur de bureau de puissance moyenne. La méthode améliore clairement les courbes de lumière comme l'a montré la comparaison des spectres de Fourier avec ceux obtenus par Alecian et al. (2009) à partir des mêmes données. Nous avons vérifié que cette méthode pourrait être employée pour des cibles présentant des transits, toutefois après quelques ajustements qui restent encore à faire.

Nous avons considéré le cas de l'étoile HgMn bien connue HD 175640 observée par CoRoT dans le canal dédié à l'asterosismologie. Après avoir appliqué notre procédure de correction, nous avons analysé le spectre de puissance pour rechercher un signal de granulation et des pulsations. Nous n'avons pas trouvé de signal de granulation à ce niveau de sensibilité. Par conséquent, la cohérence avec le modèle habituel incluant la diffusion microscopique pour expliquer les fortes anomalies d'abondance qui caractérisent les étoiles HgMn, est préservée. Par ailleurs, nous n'avons pas trouvé de variation photométrique périodique (à part quelques pics non significatifs dans le spectre). Cela suggère que, même si des pulsations existent dans certaines étoiles HgMn (comme peut-être dans HD45975 à l'étude de laquelle nous avons participé), elles n'existent pas de façon systématique dans toutes les étoiles de ce type. Les données de la mission Kepler que nous avons pour projet d'étudier dans un futur proche pourraient aider à mieux comprendre ces problèmes et donner quelques nouvelles indications.

Pour une meilleure compréhension du détail des processus physiques affectant l'atmosphère des étoiles HgMn, nous avons compilé les abondances mesurées et publiées depuis 1993 pour les HgMn. Nous les avons ensuite comparées aux données présentées dans la revue de Smith (1996). Le résultat de cette compilation montre la façon dont les éléments

lourds sont systématiquement surabondants, avec des valeurs croissantes avec la masse atomique, dans les étoiles HgMn (voir Preston, 1974 et Smith, 1996). La sous-abondance de He semble moins prononcée que dans la revue de Smith. Les surabondances dans l'atmosphère des étoiles HgMn augmentent avec la masse atomique pour les éléments lourds. La dispersion des abondances n'est pas due aux erreurs de mesure, mais elle est due à la grande variété des anomalies d'étoile à étoile. Pour certains éléments lourds, la mesure d'abondance est manquante chez Smith, alors que pour d'autres les mesures sont semblables. Toutefois, il est important de noter que cette base de données n'est pas homogène, car les étoiles HgMn ont été observées par des techniques différentes, et l'analyse des données réalisée avec des méthodes différentes. Par conséquent, pour avoir des estimations plus précises des abondances il faudrait recalculer les incertitudes. La base de données sera complétée dans un avenir proche et une étude plus approfondie des étoiles HgMn sera faite. Nous envisageons aussi d'étendre cette étude aux autres types d'étoiles A et B afin de pouvoir améliorer l'analyse statistique.

# Publications

1. Satenik Ghazaryan, Georges Alecian and Hayk Harutyunian (see Appendix B1)

"Attempt to detect the granulation signature in the HgMn star HD175640 from CoRoT\* light curves".

*Monthly Notices of the Royal Astronomical Society, 2013, Vol. 435, Issue 3, p. 1852-1856*

2. Satenik Ghazaryan (see Appendix B2)

"On the question of detecting granulation signal in A and B star's CoRoT light curves".

*Advances in Astronomy and Space Physics, 2013, Vol. 3, page 20-22*

3. T. Morel, M. Briquet, M. Auvergne, G. Alecian, S. Ghazaryan et al.

"A search for pulsations in HgMn stars with CoRoT observations of HD 45975".

*Astronomy and Astrophysics, 2013, accepted*

*2013arXiv1311.4370M*

4. Satenik Ghazaryan

"Physical properties of HgMn stars on the basis of the available data".

*Poster in Proceedings of Roscoff conference, 27 - 31 May 2013, Roscoff, in press, and*

*Astrophysics, 2013, accepted*

5. Satenik Ghazaryan, Georges Alecian and Hayk Harutyunian (see Appendix B3)

"Analysis of CoRoT\_ N2-light curves corrected with a new quasi-automatic procedure.".

*Poster in Proceedings of the 2nd CoRoT symposium, 14 - 17 June 2011, Marseille and*

*Refereed article in Proceedings of the YSCC, November 2011, Yerevan*





# Appendix A (COLIGCOR)

## lect\_fits.pro

```
; Name:
; lect_fits (The procedure which read the FITS files)
; Purpose:
; To read fits file by IDL and to extract needed information easily.
; Inputs:
; fits file
; Output:
; Txt files of mean values.
; Keywords:
; None.
; Author and history:
; S. Ghazaryan, G. Alecian 4/July/2011.
;-----
; Reading the FITS file.
targetname = "
  PRINT
  PRINT, " What is the target's name? ", targetname
  READ, targetname
result = MRDFITS (targetname, 2)

; Checking the header of the fits file.
HELP, /STRUCTURES, result

; Reading the number of points from the fits file
jd = result.DATEJDHEL
PRINT, N_ELEMENTS(jd)

; Reading statuses and creating new ASCII files which contains zero status julian_days and
whitefluxes.
n = N_ELEMENTS(jd)
st = result.STATUSHEL
wf = result.FLUXHEL
OPENW, hunit, 'jd_status0.txt', /GET_LUN
OPENW, munit, 'white_status0.txt', /GET_LUN
OPENW, lunit, 'status0.txt', /GET_LUN
FOR i = 0L, n-1L DO BEGIN
  IF(st(i) EQ 0) THEN BEGIN
    PRINTF, hunit, jd(i), FORMAT = "(F18.8)"
    PRINTF, munit, wf(i), FORMAT = "(F18.8)"
    PRINTF, lunit, st(i), FORMAT = "(I3)"
```

```
    ENDIF
  ENDFOR
  FREE_LUN, hunit
  FREE_LUN, munit
  FREE_LUN, lunit
END
```

## jump\_det\_gf

```
PRO jump_det_gf, n, wf, jd, sigmalevel, fenetre_H, transdet, jwfactor, exitstat
;+
; Name:
; jump_det_g (automatic determination of jumps)
; Inputs:
; sigmalevel
; Output:
; Txt files of mean values.
; Keywords:
; None.
; Author and history:
; G. Alecian (18 February 2011) version 1
; G. Alecian (20 April 2011) version 2 (ignore transits in jumps)
;-----
; Analyze of the sampling frequency (512s or 32s) just at the beginning of the Corot run.
PRINT
PRINT, "===== entering jump_det_gf (v2)"
PRINT
mini = 33
i_32sec = 0L
i = 0L
WHILE ( (86400 * (jd(i+1) - jd(i))) GT mini ) DO BEGIN
  i = i + 1
  IF(i GE n-1) THEN BREAK
ENDWHILE
i_32sec=i
PRINT, '32 sec from i=', i_32sec
; Smoothing the whitecurve and writing the smoothed values in the 'white_medsmooth.txt'
file.
; Equivalent average number of points
fenetre = n/((24./fenetre_H) *(jd(n-1) - jd(0)))
n_points = 2*FIX(fenetre/2) + 1 ; odd
half = 2*FIX(n_points/4) ; pair
quarter = 2*FIX(n_points/8) ; pair
jump_width = FIX(jwfactor*quarter/2)
IF (jump_width LT 3) THEN jump_width = 3
PRINT, 'fenetre = ', fenetre
PRINT, 'n_points = ', n_points
PRINT, 'half = ', half
PRINT, 'jump_width = ', jump_width
wms = DBLARR(1, n)
wms = MEDSMOOTH(wf, n_points)
wms = SMOOTH(wms, half+1)
left = DBLARR(1, half)
right = DBLARR(1, half)
wdiff = DBLARR(1, n)
FOR i=LONG(half),LONG(n-half-1) DO BEGIN
```

```

        wdiff(i)=MEAN(wf(i-half:i-1))-MEAN(wf(i+1:i+half))
ENDFOR
wdiff = ABS(wdiff)
wdiff = SMOOTH(wdiff, half+1)
result = MOMENT(wdiff)
PRINT, 'Mean: ', result[0] & PRINT, 'Standard deviation: ', SQRT(result[1]) & $
PRINT, 'Skewness: ', result[2] & PRINT, 'Kurtosis: ', result[3]
; Analyze jumps
sigma_x = sigmalevel * SQRT(result[1])
jumps = DBLARR(1, n)
mask = INTARR(n)
mask(*) = 1

; It is assumed that one has less than 100 jumps
diffmax = FLTARR(100)
imax = LONARR(100)
jpb = LONARR(2,100) ; jpb: jump boundaries
diffmax(*)=-1.
iflag = 0
k = 0
FOR i=0L,n-1L DO BEGIN
    IF (wdiff(i) GE sigma_x ) THEN BEGIN    ;begining of a jump or inside a jump
        jumps(i) = sigma_x
        mask(i) = 0
        IF(iflag EQ 0) THEN jpb(0,k)=i
        IF(wdiff(i) GT diffmax(k) ) THEN BEGIN ; looking for the max of wdiff
inside the jump
            diffmax(k) = wdiff(i)
            imax(k) = i
            iflag=1
        ENDIF
    ENDIF ELSE BEGIN ; end of the jump
        IF(iflag EQ 1 ) THEN BEGIN
            jpb(1,k)=i-1
            k=k+1
            IF(k GE 100) THEN BEGIN
                PRINT
                PRINT, 'TOO LARGE NUMBER OF JUMPS DETECTIONS
!'
                PRINT, 'Try another value for detection level..'
                PRINT
                exitstat=1
                RETURN
            ENDIF
            iflag=0
        ENDIF
    ENDELSE
ENDFOR
; jumps(i) is a curve =sigmax (constant value) inside the interval containing the jump, =0
elsewhere.

```

```

; imax(k) is an attempt to find the exact position of the jump n°k (the position of the
max(wdiff) inside the jump.
nbpics=k
IF(nbpics EQ 0 ) THEN BEGIN
    GOTO, TheEnd
ENDIF
; checks that successive imax are separated by more than jump_width
FOR k=0,nbpics-2 DO BEGIN
    IF (imax(k+1)-imax(k) LE jump_width) THEN BEGIN
        PRINT
        PRINT, 'DETECTED JUMPS ARE TOO CLOSE !', k,imax(k),imax(k+1)
        PRINT, 'Try another value for detection level...'
        PRINT
        exitstat=1
        RETURN
    ENDIF
ENDFOR

```

```

IF(transdet EQ 0) THEN BEGIN
    mask(*) = 1
    GOTO, output
ENDIF
IF(transdet EQ 2) THEN BEGIN
    GOTO, output
ENDIF

```

```

; looking for strong transits (wdiff is double-peaked inside the jump).
; Need to analyze what happens inside intervals where jumps(i)=sigmax.
transits = LONARR(10)
kt = 0

```

```

FOR k=0,nbpics-1 DO BEGIN
    peak=0
    diffpeak=0.
    iflag = 0
    FOR i=jpb(0,k),jpb(1,k) DO BEGIN
        IF(wdiff(i) GT diffpeak ) THEN BEGIN
            diffpeak=wdiff(i)
            iflag=1
        ENDIF ELSE BEGIN
            IF(iflag EQ 1 ) THEN BEGIN
                iflag=0
                peak=peak+1
            ENDIF
            diffpeak=wdiff(i)
        ENDELSE
    ENDFOR
    PRINT, 'jump k=',k,', imax=',imax(k)', boundaries=',jpb(0,k),jpb(1,k)', peak=',peak
    IF (peak GT 1) THEN BEGIN
        PRINT,'===== > TRANSIT detection for jump n°',k
        transits(kt)=k
    ENDIF

```

```

        kt=kt+1
    ENDIF
ENDFOR

IF (kt GT 0) THEN BEGIN ; remove strong transits from jumps
    PRINT, '***** remove transits'
    FOR m=0,kt-1 DO BEGIN
        k=transits(m)
        PRINT,'erase jump from ',jpb(0,k),' to ',jpb(1,k)
        FOR i=jpb(0,k),jpb(1,k) DO BEGIN
            jumps(i)=0.
        ENDFOR
        WHILE (k LE nbpics-2) DO BEGIN
            imax(k)=imax(k+1)
            diffmax(k)=diffmax(k+1)
            jpb(0,k)=jpb(0,k+1)
            jpb(1,k)=jpb(1,k+1)
            k=k+1
        ENDWHILE
        nbpics=nbpics-1
        IF(kt-1 GT m) THEN BEGIN
            FOR mm=m,kt-1 DO BEGIN
                transits(mm)=transits(mm)-1
            ENDFOR
        ENDIF
    ENDFOR
    FOR k=0,nbpics-1 DO BEGIN
        PRINT, 'jump k=',k,', imax=',imax(k)', boundaries=',jpb(0,k),jpb(1,k),'
    ENDFOR
ENDIF
    PRINT, '***** END of jumps detection !'
;===== outputs
OPENW, aunit, 'jump_igor.txt', /GET_LUN
PRINTF, aunit, 'wms wdiff jumps'
FOR i=0L,n-1L DO BEGIN
    PRINTF, aunit, wms(i),wdiff(i), jumps(i), FORMAT = "(F18.8, 3X, F18.8, 3X,
F12.5)"
ENDFOR

OPENW, bunit, 'jumps_pics.txt', /GET_LUN
PRINTF, bunit, 'imax deb fin jdmax diffmax'
FOR k=0,nbpics-1 DO BEGIN
    PRINTF, bunit, imax(k), jd(imax(k)-jump_width), jd(imax(k)+jump_width),
jd(imax(k)), diffmax(k), FORMAT = "(I7, 3X, F18.8, 3X, F18.8, 3X, F18.8, 3X, F12.5)"
ENDFOR

OPENW, cunit, 'auto_boundaries_sublights.txt', /GET_LUN
IF (i_32sec GT 0) AND (i_32sec LT imax(0)) THEN BEGIN
    PRINTF, cunit, 0, i_32sec-1, FORMAT = "(I7, 3X, I7)"
    PRINTF, cunit, i_32sec, imax(0), FORMAT = "(I7, 3X, I7)"

```

```

ENDIF ELSE BEGIN
    PRINTF, cunit, 0, imax(0), FORMAT = "(I7, 3X, I7)"
ENDELSE
FOR k=1,nbpics-1 DO BEGIN
    PRINTF, cunit, imax(k-1)+jump_width, imax(k)-jump_width, FORMAT = "(I7, 3X,
I7)"
ENDFOR
PRINTF, cunit, imax(nbpics-1)+jump_width, n-1, FORMAT = "(I7, 3X, I7)"

OPENW, dunit, 'mask.txt', /GET_LUN
FOR i=0L,n-1L DO BEGIN
    PRINTF,dunit,mask(i), FORMAT = "(I2)"
ENDFOR
FREE_LUN, aunit
FREE_LUN, bunit
FREE_LUN, cunit
FREE_LUN, dunit

END

```



## lapgf.pro

```
PRO lapgf, n, wf, jd, n_reduced, jd_reduced, w_detrended, fenetre_H
;+
; Name:
; NEW_LAP(The new lightcurve analysing program)
; Purpose:
; Analysing CoRoT white lightcurve (exochannel).
; Inputs:
; n,wf,jd.
; Output:
; Txt files of mean values.
; Keywords:
; None.
; Author and history:
; S. Ghazaryan, 2010.
; G. Alecian, 18 Feb 2011 (run first jump_det_g.pro)
; G. Alecian (21 April 2011) version 2 (masking)
;-----
PRINT
PRINT, "===== entering lapgf (v2)"
PRINT
mask = INTARR(n)
OPENR, 5, 'mask.txt'
READF, 5, mask
CLOSE, 5

OPENR, 5, 'auto_boundaries_sublights.txt'
n_subl=0L
WHILE NOT EOF(5) DO BEGIN
    READF, 5, A
    n_subl=n_subl+1
ENDWHILE
CLOSE, 5
PRINT, 'n_subl',n_subl
i_first = LONARR(n_subl)
i_last = LONARR(n_subl)
subl_boun = LONARR(2, n_subl)
OPENR, 5, 'auto_boundaries_sublights.txt'
READF, 5, subl_boun
i_first = subl_boun[0, *]
i_last = subl_boun[1, *]
i=0L
PRINT
PRINT, 'jump#',0
PRINT, 'i_first=', i_first(i)
PRINT, 'i_last =', i_last(i)
PRINT
```

```

n_reduced = 0L
sub_pos = LONARR(n_subl-1)
n_reduced = n_reduced + i_last(0) - i_first(0) + 1
FOR i=1L, n_subl-1L DO BEGIN
    sub_pos(i-1) = n_reduced
    n_reduced = n_reduced + i_last(i) - i_first(i) + 1
    PRINT, 'jump#',i
    PRINT, 'i_first=', i_first(i)
    PRINT, 'i_last =', i_last(i)
    PRINT, 'sub_pos=', sub_pos(i-1)
    PRINT
ENDFOR
CLOSE, 5

```

; n\_reduced is the new total number of points  
; sub\_pos give the positions of the first points after the jumps  
; n\_subl is the number of sublights (for instance: n\_subl=3 for 2 jumps)

```
PRINT, 'n_reduced', n_reduced
```

; Printing all sublightcurves in one file.

```

OPENW, kunit, 'jd_reduced.txt', /GET_LUN
w_reduced = DBLARR(1, n_reduced)
w_masked = DBLARR(1, n_reduced)
jd_reduced = DBLARR(1, n_reduced)
k = 0L
nm=0L
FOR j = 0L, n_subl - 1L DO BEGIN
    FOR i = i_first(j), i_last(j) DO BEGIN
        w_reduced(k) = wf(i)
        w_masked(k) = wf(i)*mask(i)
        jd_reduced(k) = jd(i)
        PRINTF, kunit, jd_reduced(k), FORMAT = "(F18.11)"
        k = k + 1
    ENDFOR
ENDFOR

```

```
ENDFOR
```

```
FREE_LUN, kunit
```

; Equivalent average number of points

```
fenetre = n_reduced/((24./fenetre_H) *(jd_reduced(n_reduced-1) - jd_reduced(0)))
```

```
n_points = 2*FIX(fenetre/2) + 1 ; odd
```

```
half = 2*FIX(n_points/4) ; pair
```

```
quarter = 2*FIX(n_points/8) ; pair
```

```
wmsr = DBLARR(1, n_reduced)
```

```
wmsr = MEDSMOOTH(w_reduced, n_points)
```

```
wmsr = SMOOTH(wmsr, half+1)
```

; linear interpolation between boundaries of masks (using the index rather the jd)

```

imask1=0L
imask2=0L
iflag=0
ik=0L
k=1L ; This section assumes that 2 first points and 2 last points of w_mask are different from
0.
WHILE (k LE n_reduced-1L) DO BEGIN
    IF(w_masked(k) EQ 0) THEN BEGIN ; start of a mask
        iflag=1
        imask1=k-1
        k=k+1
    WHILE (w_masked(k) EQ 0) AND (k LE n_reduced-1L) DO BEGIN ;still in the
mask
        k=k+1
    ENDWHILE
    IF (iflag EQ 0) THEN BEGIN
        ENDIF ELSE BEGIN ; still in the mask
        ENDELSE
    ENDIF
    IF (iflag EQ 1) THEN BEGIN ; we are just leaving a mask
        imask2=k
    PRINT, 'imask1,imask2 ',imask1,imask2 ; the two non-zero boundaries of the mask
    PRINT, ' wmsr1, wmsr2 ',wmsr(imask1),wmsr(imask2)
    aw = (wmsr(imask2)-wmsr(imask1))/(jd_reduced(imask2)-
jd_reduced(imask1))
    bw = wmsr(imask1)
    FOR ik=imask1+1,imask2-1 DO BEGIN
        w_masked(ik) = aw*(jd_reduced(ik)-jd_reduced(imask1)) + bw
    ENDFOR
    iflag=0 ; remains=0 until the next mask
    ENDIF
    k=k+1
ENDWHILE
av_reduced = MEAN(w_masked)

; Processing the sublightcurves

w_detrended = DBLARR(1, n_reduced)
cpw = DBLARR(1, 3)

OPENW, funit, 'w_detrended.txt', /GET_LUN
OPENW, gunit, 'igor_verif.txt', /GET_LUN

PRINTF, gunit, 'jd_reduced wmsr w_detrended w_masked w_temp w_poly'

p_first=0L
FOR j = 0L, n_subl - 1L DO BEGIN
    IF(j EQ n_subl - 1L) THEN BEGIN
        p_last = n_reduced - 1
    ENDIF ELSE BEGIN

```

```

        p_last = sub_pos(j) - 1
ENDELSE
print, 'p_first, p_last:', p_first, p_last
aver=MEAN(w_masked(p_first:p_last))
PRINT, 'average=', aver

w_temp = DBLARR(1, p_last - p_first + 1)
w_tempmask = DBLARR(1, p_last - p_first + 1)
w_poly = DBLARR(1, p_last - p_first + 1)
jd_temp = DBLARR(1, p_last - p_first + 1)

w_temp = w_reduced(p_first:p_last)/aver
w_tempmask = w_masked(p_first:p_last)/aver
jd_temp = jd_reduced(p_first:p_last)
cpw = POLY_FIT(jd_temp, w_tempmask, 2, /DOUBLE)
a = cpw(0)
b = cpw(1)
c = cpw(2)
d = 0.
w_poly = a + b * jd_temp + c * jd_temp^2 + d * jd_temp^3
av_poly = MEAN(w_poly)
k=0L
FOR i=p_first, p_last DO BEGIN
        w_detrended(i) = (w_temp(k) - w_poly(k)/av_poly + 1.) * av_reduced
        PRINTF, gunit,
jd_reduced(i), wmsr(i), w_detrended(i), w_masked(i), w_temp(k), w_poly(k)/av_poly,
FORMAT = '(F18.8, 3X, F18.8, 3X, F18.8, 3X, F18.8, 3X, F18.8, 3X, F18.8)'
        PRINTF, funit, w_detrended(i), FORMAT = '(F18.8)'
        k=k+1
ENDFOR

        p_first = p_last + 1
ENDFOR

FREE_LUN, funit
FREE_LUN, gunit

END

```

## Main code (coligcor.pro)

```
; Main code for CoRoT lightcurve corrections called 'coligcor.pro'
; white_status0.txt, jd_status0.txt must exist in the directory
;
; Inputs:
; None.
; Output:
; Txt files of mean values.
; Keywords:
; None.
; Author and history:
; G. Alecian (5 April 2011).
; S. Ghazaryan
; G. Alecian (21 April 2011) version 2 (masking)
;-----
PRINT, 'CoRoT lightcurve corrections v2.2'
;===== outputs
OPENW, ujob, 'coligcor_job.txt', /GET_LUN
PRINTF, ujob, SYSTIME()
OPENR, 1, 'jd_status0.txt'
A=""
n=0L
WHILE NOT EOF(1) DO BEGIN
  READF, 1, A
  n=n+1
ENDWHILE
CLOSE, 1

PRINT, 'n=',n

wf = DBLARR(1, n)
OPENR, 7, 'white_status0.txt'
READF, 7, wf
CLOSE, 7

jd = DBLARR(1, n)
OPENR, 4, 'jd_status0.txt'
READF, 4, jd
CLOSE, 4

expert = ''
READ, expert, PROMPT='Expert mode? (y/n): '
PRINTF, ujob, 'expert=',expert

tracer = 'y'
IF(expert EQ 'y') THEN READ, tracer, PROMPT='plot? (y/n): '
IF(tracer EQ 'y') THEN BEGIN
  window, 0
```

```

        PLOT, jd,wf, psym=3,YRANGE=[MIN(wf),MAX(wf)]
ENDIF

fenetre_H = 12
;-----
        FREE_LUN, ujob
        iteration=0
NEWITER: iteration = iteration + 1
OPENW, ujob, 'coligcor_job.txt', /GET_LUN, /APPEND
PRINTF, ujob, '======'
PRINTF, ujob, 'iteration=',iteration

        PRINT
        PRINT, "Iteration number ",iteration
        PRINT

; Detection level
sigmalevel = FLOAT(5.0)
PRINT
PRINT, 'Detection level (default= 5 sigma).!'
READ, sigmalevel, PROMPT='Number of Sigma (type 0 for the default value):'
IF(sigmalevel EQ 0) THEN BEGIN
        sigmalevel = 5.0
ENDIF
IF(sigmalevel LT 0) THEN BEGIN
        PRINT, 'Stop requested by the user!'
        STOP
ENDIF
PRINT, sigmalevel, FORMAT = "('sigmalevel=',F7.3)"
PRINT
PRINTF, ujob, sigmalevel, FORMAT = "('sigmalevel=',F7.3)"

transdet=0
IF(expert EQ 'y') THEN READ, transdet, PROMPT='Activate transits detection and/or
masking? (0=no, 1=yes, 2=only masking):'
PRINTF, ujob, 'transits detection and/or masking=',transdet

jwfactor=FLOAT(1)
IF(expert EQ 'y') THEN READ, jwfactor, PROMPT='Change jump_width by factor? (1 is
the default value):'
PRINT, jwfactor, FORMAT="('jump_width factor=',F7.3)"
PRINTF, ujob, jwfactor, FORMAT="('jump_width factor=',F7.3)"

; Correction processes
;-----
exitstat=0

; Jumps detection and sublights determination
        JUMP_DET_GF,n,wf,jd,sigmalevel,fenetre_H,transdet,jwfactor,exitstat ; <-----
---
```

```

IF(exitstat EQ 1) THEN GOTO, NEWITER

; Detrending
LAPGF,n,wf,jd,n_reduced,jd_reduced,w_detrended,fenetre_H ; <-----
IF(tracer EQ 'y') THEN BEGIN
    window, 1
    PLOT, jd_reduced,w_detrended,
psym=3,YRANGE=[MIN(w_detrended),MAX(w_detrended)]
ENDIF

FREE_LUN, ujob
question=' '
READ, question, PROMPT='Try another detection level ? (y/n): '
IF(question EQ 'y') THEN BEGIN
    ERASE
    jd_reduced=0
    w_detrended=0
    GOTO, NEWITER
ENDIF
PRINT, 'STOP'
END

```

# Appendix B1

## **1. Satenik Ghazaryan, Georges Alecian and Hayk Harutyunian**

"Attempt to detect the granulation signature in the HgMn star HD175640 from CoRoT\* light curves".

*Monthly Notices of the Royal Astronomical Society, 2013:  
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# Attempt to detect the granulation signature in the HgMn star HD 175640 from *CoRoT*<sup>★</sup> light curves

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## ABSTRACT

HgMn stars are affected by atomic diffusion processes. Because theoretical models based on atomic diffusion require that the atmospheres of ApBp stars have to be much more stable than those of normal stars, the detection or the absence of detection of granulation in them should be an interesting information for the modelling. We would like to address the question of the stability of the atmospheres of HgMn stars by analysing the light curves provided by the *Convection Rotation and planetary Transits (CoRoT)* satellite. We used the *CoRoT* light curves of the bright HgMn star HD 175640 observed through asteroseismology channel, to look for granulation signature. We have developed a new quasi-automatic IDL procedure, which allows us to correct abnormal jumps and variations which exist in *CoRoT* N2 data. The earlier results show that this procedure is an appropriate tool for the analysis of data obtained through asteroseismology and exoplanet channels. Calculations we carried out for this target show that granulation signature in this HgMn star is not detected from *CoRoT* light curves. On the other hand, we do not detect clear pulsation signal for this star. That shows that even if some HgMn stars are pulsating, this is not a general property of the group.

**Key words:** asteroseismology – methods: data analysis – stars: individual: HgMn stars.

## 1 INTRODUCTION

Hot chemically peculiar (CP) stars of the main sequence, i.e. the magnetic ApBp stars and the HgMn stars, are affected by atomic diffusion (first proposed by Michaud 1970). To be efficient, this process requires that the atmospheres of these stars are stable. HgMn stars are expected to be among the quietest stars of the main sequence. Due to the effective temperature and He gravitational settling, the superficial convective zone is supposed to have disappeared in those stars (Michaud et al. 1976; Alecian & Michaud 1981; Smith & Dworetzky 1993). Among the various arguments to consolidate the theoretical models for these stars, a direct observational indication of the stability of their atmosphere would then be very important. However, this is a difficult challenge for the observers and in this work, we would like more modestly to check if a granulation signature may be detected in the light curves of a bright HgMn star observed by the *Convection Rotation and planetary Transits (CoRoT)* satellite. So one expects rather to not detect

granulation signal, but if detected, this could be very constraining for the theoretical models.

Granulation is the result of convective motions leading to upward flow of hot plasma and downward flow of cooler plasma in the photosphere. With the data obtained through *CoRoT* satellite's channel devoted to asteroseismology, it is possible to deeply investigate the modes penetrating to different depths in the stars, to do frequency Fourier analysis in which granulation signature has been found: several works were already published about granulation detection by *CoRoT* (see Kallinger & Matthews 2010).

First, we consider HgMn stars that are expected to be among the quietest stars of the main sequence. HgMn stars are the late B-type CP stars whose effective temperatures range from 10 000 K to 16 000 K. They are characterized by large over abundances of Hg (up to 6 dex) and Mn (Heacox 1979, see also the review by Smith 1996). HgMn stars are slow rotators, often binaries and the existence of a weak magnetic field in their atmospheres is still a subject of debate (Wade et al. 2006). Some of them show periodic photometric variations which could be pulsations (Alecian et al. 2009), but this has still to be confirmed. Because of their high effective temperatures, the HgMn stars should not host hydrogen convective zones in their upper layers, and their low He abundances (depletion due to gravitational settling) may lead to the disappearance of the He convective zone as well. Such quiet external layers allow atomic diffusion to proceed and so, explain the observed abundance

<sup>★</sup>The *CoRoT* space mission was developed and is operated by the French agency CNES, with participation of ESA's RSSD and Science Programs, Austria, Belgium, Brazil, Germany and Spain.

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anomalies (Alecian & Michaud 1981; Smith & Dworetzky 1993). The absence of granulation in HgMn stars will give a new indication about the absence of superficial convection zones in these stars, which is important for understanding the inner structure of these stars.

Because the accessible observation fields by *CoRoT* are small (two  $10^\circ$  cones towards Galactic Centre and Anticentre), there are very few well-identified and well-studied CP stars in them. So, to have a bright and well-known HgMn star among the *CoRoT* targets is very rare. The observation of HD 175640 by *CoRoT* in asteroseismology channel is a great opportunity to search for granulation signature. This star is a well-known bright HgMn star (see Castelli & Hubrig 2004 and Landstreet et al. 2009), and it was measured by *CoRoT* during the second Short Run in the direction of the galactic centre. Because of the existence of trends and jumps in the light curve, we used our procedure COLIGCOR (described in Section 3) to obtain a corrected light curve. The frequency analysis using PERIOD04 software (Lenz & Breger 2005) is presented in Section 4.

## 2 OBSERVATIONAL DATA

The HgMn star HD 175640 (the *CoRoT*-ID is 7569) is a bright B9-V type star with 6.21 apparent magnitude. It was well identified as belonging to the HgMn group and studied in detail through high-resolution UVES-VLT spectra by Castelli & Hubrig (2004) who adopted the following parameters  $T_{\text{eff}} = 12\,000$  K,  $\log g = 3.95$ , with the rotational velocity  $v \sin i = 2.5 \text{ km s}^{-1}$ . This star was also observed by Landstreet et al. (2009) using Aurelie and Gecko spectrographs on the 1.52 m telescope at the Observatoire de Haute Provence in France and at the 3.6 m Canada–France–Hawaii telescope, respectively. The stellar parameters  $T_{\text{eff}} = 12\,000$  K,  $\log g = 4.0$ , with the rotational velocity  $v \sin i = 1.5 \pm 1 \text{ km s}^{-1}$ , obtained by these authors, are in good agreement with those obtained by Castelli & Hubrig.

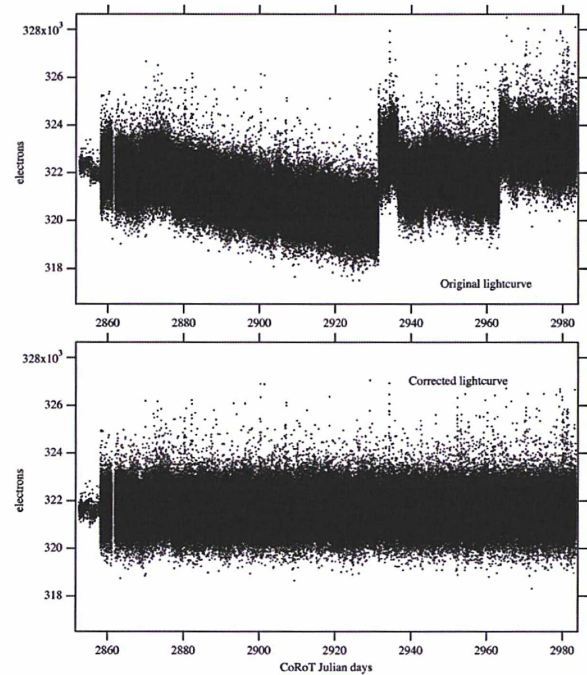
This star was observed by the *CoRoT* satellite’s channel devoted to asteroseismology during the second Short Run (2008 from September 12 to October 6, SRc02, in the galactic centre direction).

The *CoRoT* light curves are affected by several instrumental and astronomical effects. Most of them are corrected by the standard *CoRoT* post-processing software packages before their delivery for scientific use (the N2 data<sup>1</sup>). However, to avoid any true signal removal, this post-processing corrects only well-identified/characterized defects, and therefore some of the perturbations in the light curves remain in the N2 data. They have to be treated by the end user. In the next section, we describe the post-processing procedure we developed. It can be applied on the light curves both from exoplanet and asteroseismic channels.

## 3 THE CORRECTION PROCEDURE: COLIGCOR

The package COLIGCOR written for IDL environment, uses the white light flux provided in the N2 data. Its purpose is to remove the numerous jumps affecting light curves that are generally due to hot pixels which appear on the detector during the exposure, and to correct the abnormal slopes of the light flux (see the black dots of the test case shown in the top panel of Fig. 1) due to instrumental effects.

The first step consists in removing all ‘bad points’. These points are flagged with *status* different from 0, because they are considered



**Figure 1.** Test of COLIGCOR efficiency on the star S2 studied by Alecian et al. (2009). The original white light curve is shown in top panel (only points with *status* 0), electrons versus *CoRoT* Julian days (origin 2000 January 1 12:00:00). The final light curve after applying COLIGCOR, and before the binning, is shown in the bottom panel.

as unreliable by the standard post-processing (for instance, points which are affected by the crossing of the South Atlantic Anomalies). The second step consists in detecting jumps through a statistical analysis of the points distribution. The detection threshold may be fixed by the user, but there is a default value based on the standard deviation of the measurements. The detected jumps determine a series of sub-light curves which are corrected individually, and re-aligned. The first sub-light curve starts from the first point and ended in the place where the first jump starts, the second sub-light curve starts at the end of the first jump and ended with the second jump starting point, etc. At the position of a jump, there are generally more than one points affected by the jump. These points (at least three) are simply removed from the data (we do not add interpolated value). This may create gaps in the data; however, the user may decide to constrain the gap to its minimum value.

We use a second-order polynomial to fit each sub-light curve and correct the trends:

$$\text{Whiteflux} = a + b \times \text{JD} + c \times \text{JD}^2, \quad (1)$$

where JD is the Julian date normalized to the range

$$-1 \leq \text{JD} \leq 1, \quad (2)$$

and  $a$ ,  $b$  and  $c$  are the fitting parameters for the second-degree polynomial. At the end of this step, we have corrected the slope of white sub-light curves.

We limit the number and the density of detected jumps, so we have sub-light curves each covering large enough time intervals to avoid the removal of a true signal: the second-order polynomials do not fit short-term variations such as transits. We have verified for stars known to have light curve with a transit that such short-term signals are not removed with our procedure.

<sup>1</sup> <http://idoc-corot.ias.u-psud.fr/>

After this step, COLIGCOR is able to correct all sub-light curves, keeping the average level of the original light curve.

The final step may be a binning (to 512 s for instance). At the end we have satisfactorily corrected *CoRoT* light curves from which it is possible to extract the frequencies using Lenz & Breger's software PERIOD04 (see Lenz & Breger 2005).

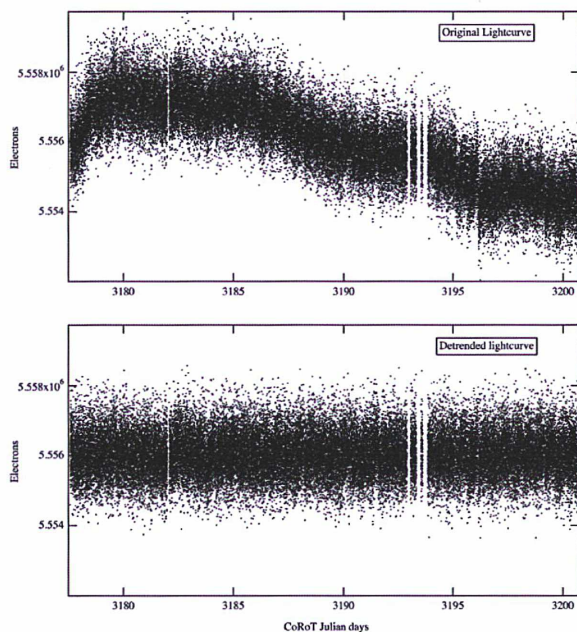
To show the efficiency of our method for the treatment of *CoRoT* light curves, we applied COLIGCOR to the star CoRoT-ID 102685695. This star is the faint 'S2' star studied by Alecian et al. (2009) and identified as HgMn. It was observed by *CoRoT* in the exoplanet channel during the first long run towards the galactic anticentre in 2007. In Fig. 1, we present the raw white light curve, which includes long-term variations (assumed not to be a true signal from the star) and jumps, and the final light curve after applying COLIGCOR. Ghazaryan, Alecian & Harutyunian (2012) have compared the frequency spectrum obtained after this treatment to the one published by Alecian et al. (2009), and the result has clearly been improved.

#### 4 THE CASE OF HD 175640

In Fig. 2, we present the original light curve of HD 175640 obtained by *CoRoT* and the corrected one (before the 512 s binning), which was obtained by our procedure COLIGCOR. As we see from the figures, the original light curve of HD 175640 presents weak jumps and long-term variations often related to the jumps. From the corrected light curve, we do not detect any flare or transit-like variations in the light curve.

##### 4.1 Frequency analysis

The power spectral density has been obtained from the corrected light curve and is presented in Fig. 3. In this case, we did not proceed to a binning (we have kept the 32 s sampling) and the gaps in the time series were filled by linear interpolation (as in Kallinger & Matthews 2010). This spectrum is computed through an IDL procedure with



**Figure 2.** Original white light curve (top panel) of HD 175640 obtained by *CoRoT* (only points with *status* 0). The final light curve after applying COLIGCOR, and before the binning, is shown in the bottom panel.

the fast Fourier transform (FFT) function and after normalization to satisfy the Parseval's theorem for FFTs.

We list in Table 1, the main peaks in the spectrum as they have been extracted using PERIOD04 software (Lenz & Breger 2005). This software identifies the peaks one by one, starting with the highest one. After each identification, the signal with the corresponding frequency is removed from the light flux, and a new spectrum is computed from the residual light curve to search for the next highest peak. Note that these frequencies may slightly differ from their real value because PERIOD04 fits the phase, the amplitude and the frequency of all the identified peaks after each identification, to minimize the difference between the observed spectrum and the one calculated with identified frequencies. We have not listed in Table 1, frequencies smaller than  $0.5 \text{ cycle d}^{-1}$  because these signals with large periods are very doubtful: they are too close to the duration of the acquisition (about 20 d) and they can be due to an insufficient correction of the original light curve by COLIGCOR. Indeed, as it can be seen in the top panel of Fig. 2, the original light curve is affected by numerous fluctuations due to several kind of perturbations (see Section 2). In Table 1, one can recognize the  $1 \text{ cycle d}^{-1}$  frequency (number 3) and its harmonics (number 4, 6, 7 and 8), and also the usual *CoRoT* orbital frequency ( $13.97 \text{ cycle d}^{-1}$ , number 9) and its harmonics (number 10, 11, 12). The other peaks (number 1, 2, 5) do not correspond to these well-known artefacts; however, their amplitudes are very low compared to the noise.

It is not surprising that one does not find solar-type oscillations in a CP star, but one could expect to find a pulsation signal of the type of what is observed for SPB stars (as suggested by Alecian et al. 2009). The lack of significant pulsation signal in such a bright and typical HgMn star shows that, even if some stars belonging to this group present periodic photometric variations (see Morel et al. 2013), pulsation do not exist systematically in HgMn stars.

##### 4.2 Looking for a granulation signature

It is believed that the granulation time-scale should be scaled with the ratio of the cell size, which is expected to be inversely proportional to the atmospheric pressure scaleheight  $H_p$ , and the cell velocity, which is proportional to local sound speed  $c_s$ . Under the assumption of an ideal adiabatic gas, the granulation frequency should scale as  $\nu_{\text{gran}} \propto c_s/H_p$  (see Huber et al. 2010). In solar-type pulsators, the oscillation modes almost symmetrically divided around the maximum oscillation power frequency,  $\nu_{\text{max}}$ , which is also proportional to the  $c_s/H_p$ . Taking into account the Kjeldsen & Bedding (1995) paper, it can be assumed that

$$\nu_{\text{gran}} \propto \nu_{\text{max}} \propto M/(R^2 T_{\text{eff}}^{1/2}) \quad (3)$$

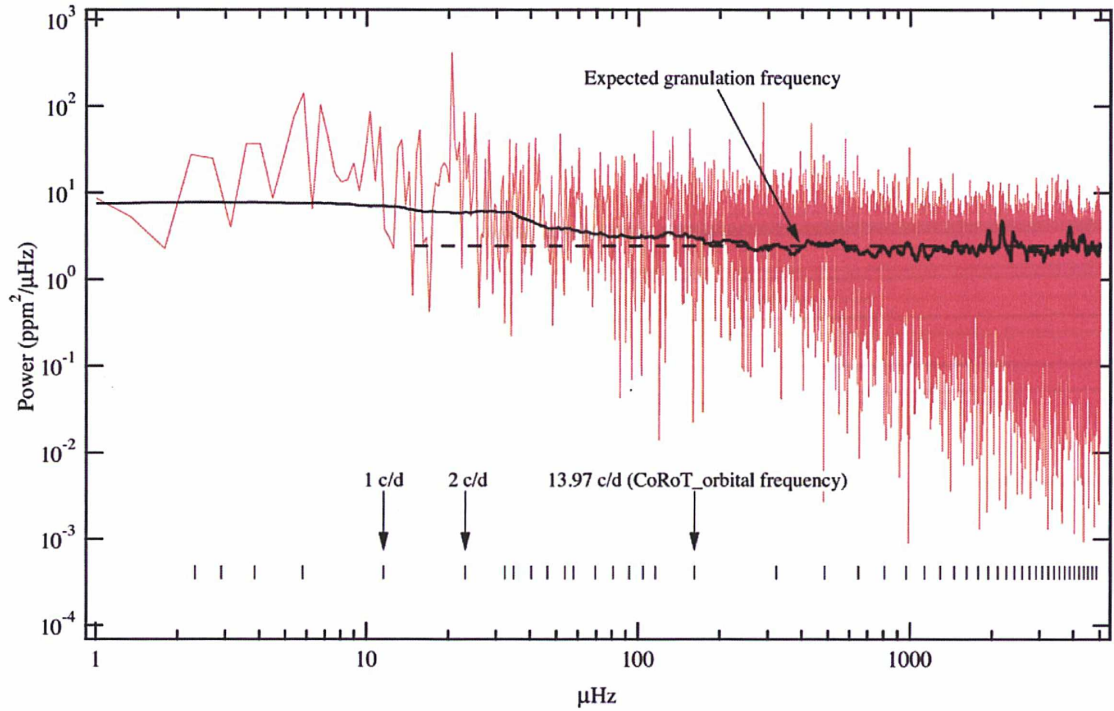
(see the equation 2 of Kallinger & Matthews 2010). Taking into account the same parameters for HD 175640 as Thiam et al. (2010):

$$M/M_{\odot} = 3.21 \pm 0.1, R/R_{\odot} = 2.66 \pm 0.28, \quad (4)$$

and

$$T_{\text{eff}}/T_{\text{eff}\odot} = 2.03 \pm 0.1. \quad (5)$$

We evaluate the ratio of equation (3) to around  $0.316 \pm 0.08$ . This value (and the error) is calculated using the fundamental parameters (and the errors) mentioned above in solar units. Using the scaling proposed by Kallinger & Matthews (2010) in their fig. 3, we deduced for HD 175640 a granulation frequency around  $400 \mu\text{Hz}$ . The position of this frequency is shown with the arrow labelled 'Expected granulation frequency' in our Fig. 3.



**Figure 3.** The power spectrum of HD 175640. The dotted red curve is the spectrum for the light curve after correction with COLIGCOR. In the bottom of the figure, we show with small vertical bars: the 1 cycle  $d^{-1}$ , the orbital frequency at 13.97 cycle  $d^{-1}$  and their harmonics. The solid black line is the smoothed spectrum (50  $\mu\text{Hz}$  boxcar) obtained for the residual light curve after removal of the frequencies discussed in Section 4.1. The black dashed line is the average white noise level ( $\approx 2.43 \text{ ppm}^2 \mu\text{Hz}^{-1}$  between 0.015 and 5 mHz).

**Table 1.** Significant fitted frequencies in different units, and the amplitudes extracted from PERIOD04.

Number	cycle $d^{-1}$	$\mu\text{Hz}$	Amplitude
1	0.544	6.30	32.0
2	0.674	7.80	26.4
3	0.997	11.55	31.5
4	2.006	23.22	79.0
5	2.429	28.12	24.7
6	3.013	34.88	10.8
7	4.016	46.48	23.0
8	4.977	57.61	7.5
9	13.968	161.67	19.7
10	27.945	323.43	40.4
11	41.924	485.23	14.8
12	55.887	646.84	18.5

The signal of solar granulation and mesogranulation was studied by Frohlich et al. (1997) from observations with various instruments: SOHO/VIRGO/PMO6 (bolometric variations) and for different band pass by SOHO/VIRGO/SPM (photon counting). From this study and using techniques provided by Kjeldsen et al. (2005), Michel et al. (2009) have estimated the expected signal from *CoRoT* data for solar-like stars. These estimates show that the granulation frequency in solar-type stars should be over 1 mHz, which is in good agreement with values evaluated by Aigrain, Favata & Gilmore (2004), and with the scaling of Kallinger & Matthews (2010) we use for HD 175640.

To check the existence of granulation signature, we consider the detrended power spectrum shown in Fig. 3. We have first removed from this spectrum all the frequencies listed in Table 1, and com-

puted the spectrum of the residual light curve using PERIOD04. This residual spectrum has been smoothed with a 50  $\mu\text{Hz}$  boxcar (500 frequency points). This smoothed spectrum is the solid black line in Fig. 3. Around the expected position of the granulation signature (400  $\mu\text{Hz}$ ), we notice a small increase (close to  $1 \text{ ppm}^2 \mu\text{Hz}^{-1}$ ) of the smoothed spectrum. However, this increase has an amplitude of only about  $1\sigma$  around the average noise ( $\approx 0.83 \text{ ppm}^2 \mu\text{Hz}^{-1}$ ), which is not large enough to be considered as a detection. Moreover, the signal level remains at the level of the noise (the dashed line) and could be interpreted as a recovery of the average level after the small dip around 360  $\mu\text{Hz}$ . We can see in Fig. 3, that we are not far from the limit of detection of a small power excess around 400  $\mu\text{Hz}$ . However, we cannot say that an additional power emerges from the noise, and we cannot consider that a granulation signal can be identified in this power density spectrum.

## 5 CONCLUSION

In this article, we present a post-treatment procedure for the analysis of *CoRoT*N2 light curves obtained by both the channels devoted to asteroseismology and to search for exoplanets transits. Our procedure COLIGCOR remove the jumps in the light curve and abnormal flux variations. To verify the efficiency of this procedure, we have compared the light curve of a star studied previously by Alecian et al. (2009), to the one obtained with our new treatment and noticed a significant improvement.

We have considered the case of the well-known HgMn star HD 175640 observed with *CoRoT* in its asteroseismology channel. After applying our correction procedure, we analysed the frequency spectrum to search for granulation signal and pulsations. We have not found granulation signal, that is, consistent with the usual model including atomic diffusion to explain the strong abundance

anomalies that characterize HgMn stars. On another hand, we have not found clear pulsation signal (besides some few uncertain peaks in the spectrum). This suggests that, even if pulsations may exist in some HgMn stars, they should not exist systematically in all HgMn stars.

#### ACKNOWLEDGEMENTS

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# Appendix B2

## 2. Satenik Ghazaryan

"On the question of detecting granulation signal in A and B star's  
CoRoT light curves".

*Advances in Astronomy and Space Physics, 2013, Vol. 3, page 20-*

*22*

# On the question of detecting granulation signal in CoRoT light curves of A and B stars

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We applied the procedure written by us to HgMn targets observed both through CoRoT astero and exo channels to check its usefulness for search of possible existence of solar-type granulation signature in their power spectrum. The point is that many articles appeared very recently considering this problem but, we did not find any paper on this issue in relation to chemically peculiar main-sequence stars. Because theoretical models based on atomic diffusion require that the atmospheres of ApBp stars have to be more stable than those of normal stars, presence or absence of granulation on their surfaces should be an interesting information for modelling. The earliest results show that our method is appropriate for analysis of data obtained through astero and exo channels. Nowadays, solar-type granulation effect most likely has not been seen within CoRoT data for the stars we considered. This issue needs further consideration.

**Key words:** asteroseismology, HgMn stars, granulation

## INTRODUCTION

CoRoT (Convection, Rotation and Transits)<sup>1</sup>, a satellite with 27 cm mirror, was successfully launched on the 27th of December 2006. This instrument allows to probe stellar interiors via variations of the light curves which can be studied using the frequency spectra. It provides a tool for deeper understanding of internal structure of stars. Namely, if a large number of modes penetrating to all possible depths can be observed on the surface, than it is possible to “invert” the observations to make a map of the sound speed throughout the star, and then to deduce the temperature profile, with reasonable assumptions about the chemical composition. Thus asteroseismology lets us literally to see the interior of stars because different modes penetrate to different depths. With the data obtained through CoRoT Astero channel we are able to study the modes more carefully, to do frequency Fourier analysis which allows us to have some idea about signature of solar granulation effect in many stars. Granulation, as we know, is a result of convection motions leading to upward flows of hotter plasma and downward flows of cooler plasma.

The discovery of global oscillations in the Sun by Claverie et al. in 1979 [2] and Grec in 1980 [4] opened a way for the new solar observations, for measuring, for example, the depth of solar convection zone and rotation of the Sun at different depths and lat-

itudes. However, there is still a debate on the question which type of oscillations can be hidden by stellar granulation and the examination of solar granulation effect signature is not well done. Solar-like oscillations have been detected from the ground in radial velocity in several stars but because of high uncertainties of the ground based observations it is preferable to do high-precision photometry from the space. In 2008 CoRoT team announced detection of the solar-like oscillations and granulation in stars hotter than the Sun. In the paper, published in Science, they claim for the presence of these effects in three main-sequence F-type stars (see [9] for more details). The solar granulation frequency reaches up to 2 mHz for all of them. In 2010 Kallinger and Matthews [6] announced possible existence of solar granulation in early A-type stars. They presented evidence for this effect in two  $\delta$  Scuti stars of spectral type A2: HD 17493 and HD 50844. That is why we decided to search for signature of this effect also in HgMn stars.

HgMn stars are the late B-type Chemically Peculiar stars, the effective temperature of which is ranging from 10 000 K and 16 000 K. They are characterized spectroscopically by large overabundances of Hg (possibly up to 6 dex) and Mn (possibly up to 3 dex, [1]). Overabundances greater than 2 dex of Be, Ga, Y, Pt, Bi, Xe, Eu, Gd, W, and Pb are frequently observed in these stars, while He, N, Mg, Al, Ni and Zn often are underabundant by more than 0.5 dex

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<sup>1</sup>The CoRoT space mission is developed and operated by the French Space Agency CNES, with participation of ESA's RSSD and Science Programmes, Austria, Belgium, Brazil, Germany, and Spain.

[10]. The elements C, O, Si, S, Ca, V, Cr and Fe usually show only modest peculiarities, with abundances within 0.5 dex of their solar one (classified as “normal type” elements in [10]). HgMn stars are slow rotators, often binaries, and the existence of a weak magnetic field in their atmospheres is still a subject of debate. Because of their high effective temperatures, the HgMn stars should not host hydrogen convective zones in their envelopes, and their low He abundances may reduce the importance of He convective zones as well. Such a quiet external layers allow atomic diffusion to proceed and hence to explain the observed abundance anomalies [8]. The absence of granulation in HgMn stars will give a new way to prove the absence of convection zones in these stars which is extremely important for understanding the inner structure of these stars.

## SELECTED TARGETS AND ANALYSIS

The first step of analysis was to select a target which was observed by CoRoT Astero channel. The selected target is HD 175640 (the CoRoT ID is 7569). It was observed in 2008 during the SRc02, which means that the observations were done during the second Short Run to the Galaxy centre direction. This is a bright B9-type star with 6.21<sup>m</sup> apparent magnitude and it belongs to the third Luminosity class targets. The light curve of CoRoT7569 is a combination of strong trends and weak jumps (Fig. 1). The raw light curve of CoRoT7569, which was obtained using our own procedure [3] written in IDL language, does not show any transits (Fig. 2). It is well detrended and there is no clear evidence for granulation. To prove the absence of signature of solar granulation in HgMn stars we calculated the power spectrum of the light curve using `Period04`, software written by Lenz and Breger in 2005 [7]. And then, the same calculations were performed for the original light curve. These two spectra are presented in Fig. 3. The CoRoT orbital frequencies are also overlotted on the graph.

To calculate the solar granulation frequency we used the second equation given in [6]:

$$\nu_{gran} \propto \nu_{max} \propto M \cdot R^{-2} \cdot T_{eff}^{-1/2}, \quad (1)$$

where the mass, radius and effective temperature are taken in solar units.

Assuming that

$$\begin{aligned} M/M_{\odot} &= 3.36, & R/R_{\odot} &= 2.55, \\ T_{eff}/T_{eff,\odot} &= 2.03, \end{aligned} \quad (2)$$

we mean that granulation frequency is  $\nu_{gran} \sim 440 \mu\text{Hz}$ . As one can see from in Fig. 3 there are no changes in the spectrum. It is almost flat which means that there is no sign of granulation.

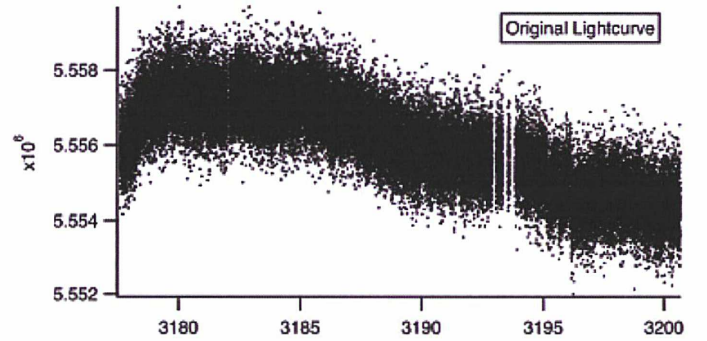


Fig. 1: Original light curve of CoRoT7569 obtained through CoRoT Astero channel.

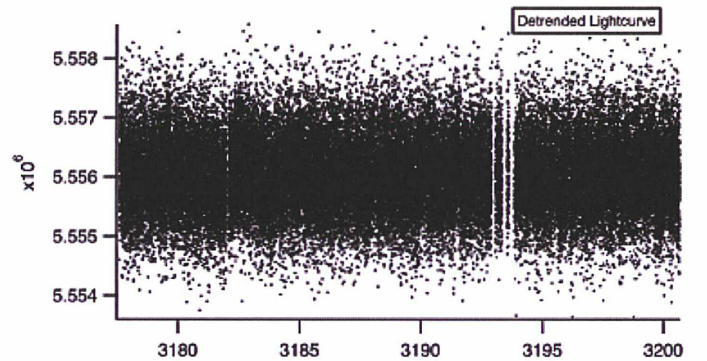


Fig. 2: Detrended light curve obtained through ColiCor.

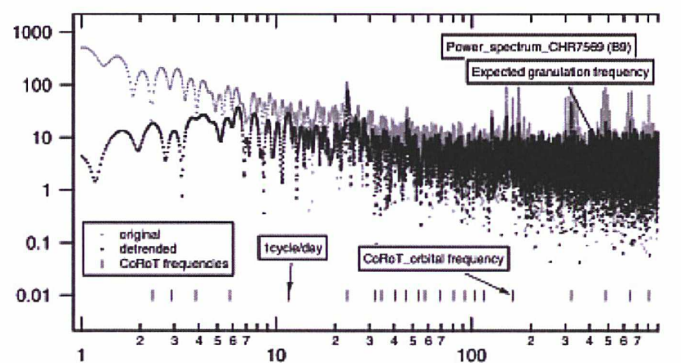


Fig. 3: Power spectra of the original and detrended CoRoT7569 calculated with `Period 04`. The grey and black curves correspond to the original and detrended light curves, respectively. The frequencies marked below the diagrams present the CoRoT orbital frequencies.

## ACKNOWLEDGEMENT

I would like to express my gratitude to my supervisors Georges Alecian and Hayk Harutyunyan for their valuable directions and hearty guidance during my PhD study.



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# Appendix B3

## **5. Satenik Ghazaryan, Georges Alecian and Hayk Harutyunian**

"Analysis of CoRoT\_ N2-light curves corrected with a new quasi-automatic procedure"

*Poster in Proceedings of the 2nd CoRoT symposium, 14 - 17 June  
2011, Marseille and*

*Refereed article in Proceedings of the YSCC, November 2011,  
Yerevan*

## **Analysis of CoRoT\* N2-light curves corrected with a new quasi-automatic procedure.**

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*\* The CoRoT space mission was developed and is operated by the French agency CNES, with participation of ESA's RSSD and Science Programs, Austria, Belgium, Brazil, Germany and Spain.*

### **Abstract**

This work is devoted to the analysis of CoRoT light curves to which we apply a new quasi-automatic procedure we have developed. This IDL procedure corrects the abnormal jumps and the instrumental drifts which survived in N2-exoplanet data.

The method we present can be used for the CoRoT targets observed through exoplanets channel. In this work we study 3 stars already considered by Alecian et al. (2009) who used less sophisticated methods for corrections, and used an older release of the N2 data. With our method we succeed to remove random jumps and systematic trends encountered in typical CoRoT data. In this article we describe the algorithm and compare our new results to the old ones published in 2009.

### **Анализ N2 кривых блеска, полученных с помощью CoRoT\* и исправленных новой, квази-автоматической программой.**

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Эта работа посвящена анализу кривых блеска, полученных с помощью космического телескопа CoRoT, для которых мы разработали новую, квази-автоматическую программу. Эта программа, написанная на IDL, исправляет все аномальные скачки и инструментальные сдвиги, которые присутствуют во втором издании данных, полученных с помощью экзопланетного канала CoRoT.

Метод, представленный нами здесь, может быть использован для анализа кривых блеска, которые были получены по экзопланетному каналу CoRoT. В данной работе мы обработали данные тех 3 звезд, которые уже были опубликованы в 2009 году Алесианом и его коллегами, которые использовали не очень сложный метод исправления и старую версию данных. С помощью нашего метода мы смогли избавиться от всех произвольных скачков и систематических ошибок, присутствующих во всех данных, полученных телескопом CoRoT. В этой статье мы описываем алгоритм этой программы и приводим сравнение новых результатов со старыми, опубликованными в 2009 году.

## Introduction

This article describes a numerical tool in view of a systematic study of light curves obtained through CoRoT (Baglin 2006) exoplanet camera in the framework of the Additional Programme procedure (Weiss 2006). It is quite difficult to describe all the features perturbing CoRoT light curves (exo-channel) with a given function, since there are many different shapes of jumps with many different functional forms. Furthermore, the problem is complex, because we do not know a priori which ones of light curve features have stellar origin. Our IDL macros start with the white light curve provided by N2 data archive for each star, and considered to be completed with a new light curve from which jumps have been removed.

## Method

The first step of our treatments consists in the jumps detecting. Generally, jumps are characterized by signal level and slope discontinuities in light curves. Our procedure uses this property to identify the jumps (after smoothing and slope variations analysis). The method is not fully automatized because there is certain detection level around a default value proposed by the code to be adjusted only by the user according to the star properties. Generally, this method has a capacity to detect up to 30 jumps only inside a light curve for a 120 days run of

observation. The second step consists in correcting the light curve itself. For this purpose the light curve is shared out into a family of sub-light curves delimited by the jumps' moments. A fixed (and adjustable) number of points can be removed inside the jumps. The shape of each sub-light curve is corrected after giving a good fit with a second order polynomial, and the level adjusting to the average level of the original light curve. The last step of the light curve analysis is a binning to 512s. We usually extract the frequencies with Period04 (Lenz and Breger 2005).

## Results

To illustrate the method, it is applied to three CoRoT light curves: ID-102694749(S1), ID-102685695(S2), and ID-102647589(S3), which had been already analyzed by Alecian et al.(2009). We present in Fig.1 a comparison of the light curves, before and after the application of our method for the star S2 (the original light curve has many jumps). We compared also the resulting spectra with the ones by Alecian et al. (2009). The quality of the spectra is improved definitely: the signal to noise ratio is higher for low frequencies ( $c/d < 13.9$ ) and the stellar signal is not affected by our treatment. We tried to check the method for a star exhibiting a transit. The method could work because it does not destroy the information on the transit. However some additional efforts are still needed before proposing these macro for such cases. In practice, only a few minutes per light curve are needed to apply the procedure.

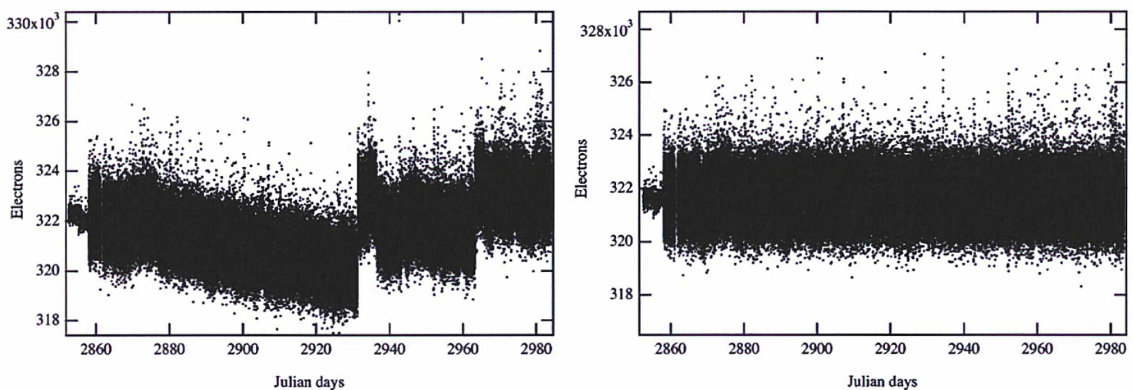


Figure 1. *The light variation of S2. The original N2 data are shown in the left panel, and the one corrected with the present method is shown in the right panel.*

We applied also this procedure to a HgMn target observed through CoRoT astero channel to check its usefulness for looking for possible existence of solar-type granulation signature in their power spectrum. The point is that many articles have been appeared very recently considering this problem but no paper was found on this issue in relation to HgMn stars. Therefore this problem seems to remain a subject of further debates. On the other hand the earliest results show that our method is an appropriate tool for the analysis of data obtained through astero channel and nowadays in HgMn stars solar-type granulation effect most likely could not be seen with CoRoT data. This issue needs of further consideration.

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