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## THE MISTRAL SPECTROGRAPH AT OHP

C. Adami<sup>1</sup>, S. Basa<sup>1</sup>, J.C. Brunel<sup>2</sup>, V. Buat<sup>1</sup>, N. Clerc<sup>3</sup>, M. Dennefeld<sup>4</sup>, F. Dolon<sup>2</sup>, A. Le van Suu<sup>2</sup>,  
F. Moreau<sup>2</sup>, S. Perruchot<sup>2</sup> and J. Schmitt<sup>2</sup>

**Abstract.** We present in this contribution the expected MISTRAL characteristics and operation modes as well as examples of science applications which can be performed by the instrument, in terms of variable sky and non transient objects.

Keywords: OHP, MISTRAL, spectrograph, GRBs, SNs, variable sky

### 1 Introduction

With the advent of new sky surveys, both from the ground and from space, the exploration of the variable sky is entering a new era. The high cadence of those surveys, and the large area covered allow a much larger coverage of the physical parameter space than ever before. As a result, a wealth of new phenomena and classes of objects are discovered, enlarging the physical diversity, and the statistics of previously known, but rare phenomena is greatly improved. On the high-energy side, Gamma-Rays bursts (GRB's) are now observed in large numbers, and classified into two categories, the short- and long-duration GRB's. On the Supernovae (SNe) side, it appears that stellar explosions are not just core-collapse, or thermonuclear explosions of CO white dwarfs, but new categories are discovered, from "ultrabright SNe" to faint and fast decaying type I SNe, and passing through He detonations, Ia objects or luminous red novae. The range of underlying physical mechanisms must therefore be much more diverse than previously thought, but is still not understood. On a somewhat "quieter" side, Luminous Blue Variables, or numerous peculiar binaries await a better understanding too. What is most necessary to progress is enough ground-based observing time to follow the variations of a series of representative examples of all those categories, both in photometry, and, even more so, in spectroscopy and in near infrared (Y band) spectroscopy: only with long time-series of spectroscopic variations, accompanying the light-curves, we will understand the underlying physical mechanisms. "Small to medium" sized telescopes are best suited for that, being now more available than before (with 8m telescopes) provided they are equipped with efficient versatile spectro-imagers. It is the purpose of the MISTRAL (Multi-purpose InSTRument for Astronomy at Low-resolution) instrument to be mounted at the 1.93m telescope of OHP. With a possibility of rapid changeover from the other available instrument (SOPHIE), it will allow fast response to transient objects.

MISTRAL will also help to follow non transient targets in the framework of spatial missions covering fields as galactic HII regions and their exciting and triggered stars (e.g. Herschel) or nearby contributions to extragalactic surveys as for example XXL (see recent ESA Press Release: <http://sci.esa.int/xmm-newton/60686-tracing-the-universe-x-ray-survey-supports-standard-cosmological-model/>) or XCLASS (XMM-Newton). Having access to MISTRAL-type instrument with reasonable pressure is crucial for these subjects. MISTRAL is expected to be available at the end of 2019 or beginning of 2020.

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<sup>1</sup> Aix Marseille Univ, CNRS, CNES, LAM, Marseille, France

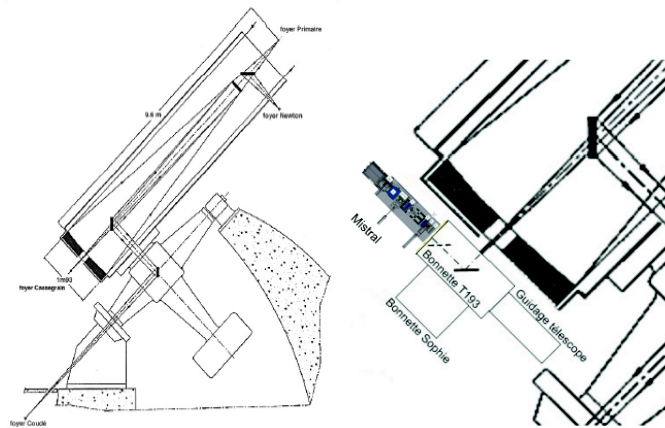
<sup>2</sup> Aix Marseille Univ. CNRS/INSU, OSU PYTHEAS (France)

<sup>3</sup> CNRS, Université de Toulouse, UPS-OMP, IRAP, Toulouse (France)

<sup>4</sup> Sorbonne Université, CNRS, UMR 7095, Institut d'Astrophysique de Paris, 98bis Bd Arago, 75014, Paris, France

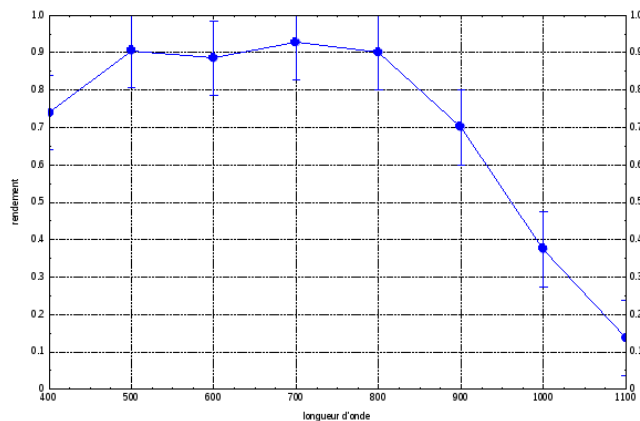
## 2 MISTRAL characteristics

MISTRAL is a spectro-imager fully funded by the OSU Pytheas. It will be mounted at the Cassegrain focus of the T193 telescope (see Fig. 1), on the Cassegrain adapter in parallel with the SOPHIE adapter's housing. A 45deg mirror needs to be installed to send the beam in one of the output sides. The advantage is to be independent from the SOPHIE adapter and to allow a rapid switch-over (faster than 30 min).



**Fig. 1.** Instrument at bottom of the T193. Left: general design of the T193. Right: zoom on the MISTRAL location.

MISTRAL is equipped with an ANDOR deep depletion CCD  $2k \times 2K$  camera (iKon-L DZ936N-BEX2DD CCD-22031). This camera was tested at OHP in October 2018. It shows no dead column, and only 2 lines with an efficiency lower than the mean by 5 to 10 %. The cooling is made by a 5-layers Peltier device. The operating temperature can reach  $-95$  to  $-100$  °C (with a chiller and water between  $18$  and  $30$  °C). The dark current proved to be lower than 3 electrons/hour/pixel at  $-95$  °C. The measured reading noise is 3.7 electrons at 50 kHz (with gain #4). We also measured the response curve (Fig. 2) and it shows the expected  $\sim 35\%$  response at  $1 \mu\text{m}$ .



**Fig. 2.** CCD response curve at  $-95$  °C.

The expected design of MISTRAL is shown in Fig. 3. It will host 3 dispersors (*Prisme* in Fig. 3) plus an empty slot on a mobile plate. The first two (to be installed at the beginning of the operations) will cover the full spectral range with a resolution of the order of 600. A third one will be added later, with a reduced spectral range, but a resolution of the order of 2000. An FLI filter wheel will offer 12 slots for 50 mm filters. Finally, a mobile fixed aperture slit will allow to switch between imaging (left of Fig. 4) and spectroscopic (right of Fig. 4) mode when empty slot is chosen for the mobile plate. The imaging field of view will be  $\sim 5' \times 5'$ .

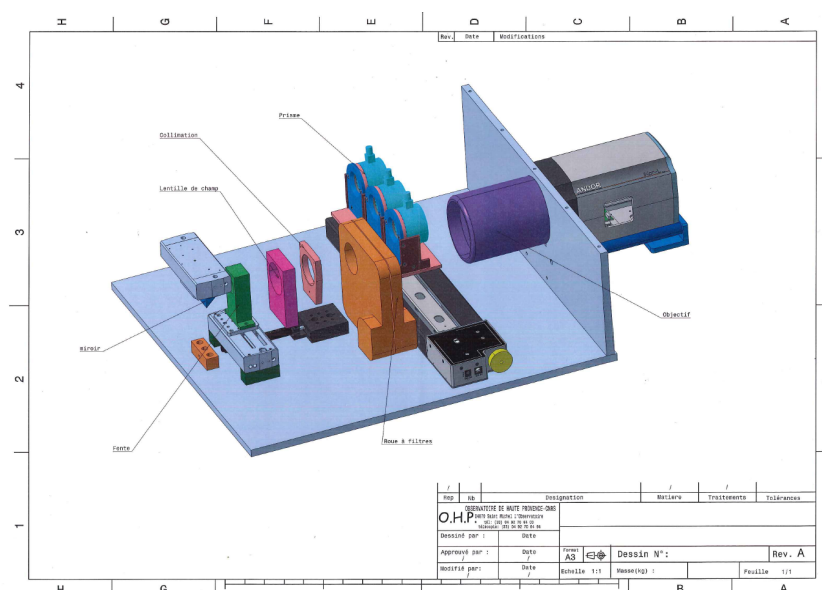


Fig. 3. Expected MISTRAL design.

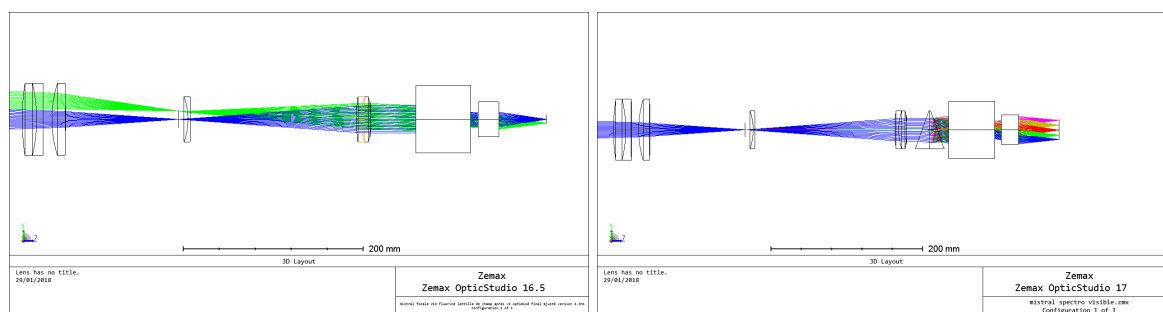


Fig. 4. MISTRAL optical design in the imaging (left), and spectroscopic mode (right).

### 3 Operating modes

MISTRAL should offer two operating modes, following the INSU recommendations of the 2015-2020 colloque de prospective: regular observing runs in visitor mode and Target of Opportunity in service observing mode for fast transients. Targets of Opportunity will be activated under triggers and should not occupy more than 2 hours per night, and should not occur more than once every 3 nights while the total initial MISTRAL allocation (ToO + regular) is planned not to exceed 15% of the total T193 nights available for observations.

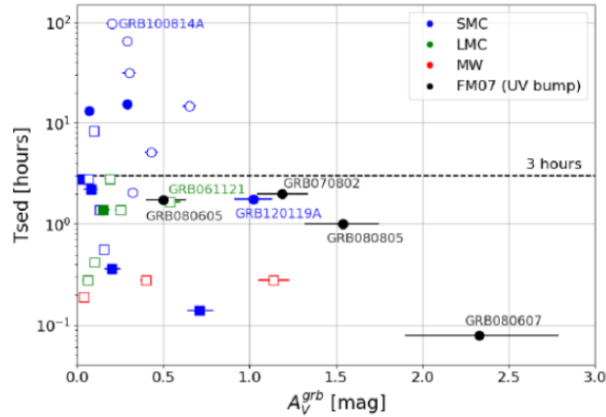
### 4 Examples of science applications

Directly derived from the SPRAT (at the Liverpool 2m telescope) spectrograph, MISTRAL should have similar performances in spectroscopy (see also the SPRAT ETC at <http://telescope.livjm.ac.uk/TelInst/calculator/>). We expect to reach in 1 hour exposures  $R \sim 20$  (resp. 19) at  $S/N \sim 3$  (resp. 10).

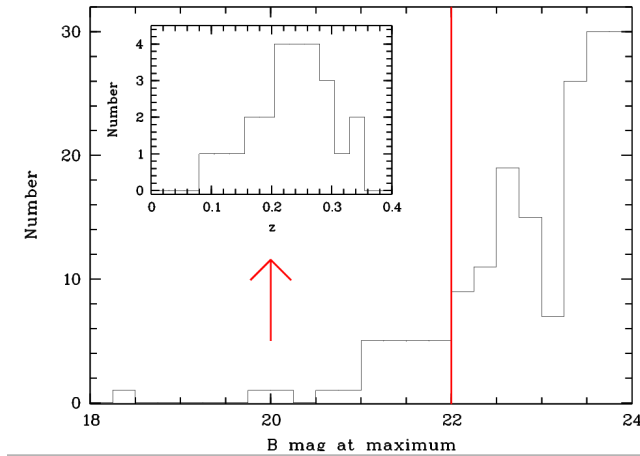
#### 4.1 Variable sky

These performances should allow to catch optical afterglows of GRBs up to  $z \sim 1$  in the framework of spatial missions as SVOM. Following the SWIFT experience, such GRBs visible from OHP should occur once or twice a month. An example of science application for this kind of object would be the measure of the extinction curves of the host galaxy. MISTRAL will complete the target spectroscopy 3 hours after the burst. This is crucial to detect obscure bursts and to avoid to be biased toward SMC curves as seen on Fig. 5 and in

Corre et al. (2018). Similarly, MISTRAL will be efficient to spectroscopically observe supernovae up to  $z \sim 0.4$  (see also the talk by M. Dennefeld in these proceedings). Assuming the SNLS survey ([http://irfu.cea.fr/dap/Phoce/Vie\\_des\\_labos/Ast/ast\\_technique.php?id\\_ast=430](http://irfu.cea.fr/dap/Phoce/Vie_des_labos/Ast/ast_technique.php?id_ast=430)) supernovae population and a MISTRAL expected magnitude limit (B band) of 22 for these objects, Fig. 6 shows the typical expected redshift histogram (embedded sub-figure). MISTRAL will also be very efficient to search for optical counterparts of gravitational wave events.



**Fig. 5.** Time after the burst versus attenuation for the GRB host for different GRBs. Color code gives the type of curve.

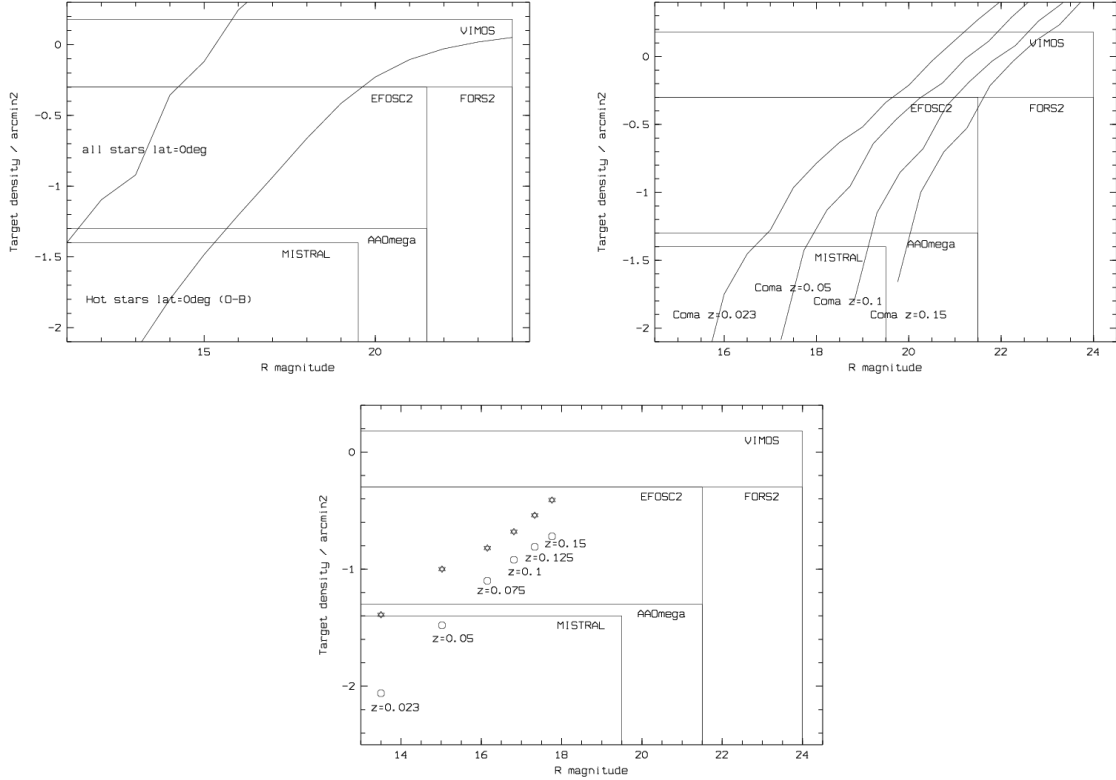


**Fig. 6.** B band magnitude histogram of the SNLS supernovae population. Red line marks the MISTRAL expected limiting magnitude. Objects to the left are used to draw the embedded graph which shows their redshift distribution.

#### 4.2 Non transient objects

MISTRAL is also planned to search for hot exciting stars in HII regions in particular the ones observed by Herschel. Assuming the Besançon model (<http://model.obs-besancon.fr/>) for galactic hot stars and for the whole population of stars, we show in Fig. 7 that MISTRAL is well adapted to measure the full sample of hot stars in its field of view down to magnitude of  $R \sim 16$ . It will also allow to observe nearby galaxies. For example, it will allow to confirm nearby cluster of galaxies candidates detected by XMM-Newton or to study the environment of fossil groups of galaxies. The galaxy magnitude and number density on the sky for this kind of targets is well adapted to the MISTRAL capabilities (see Fig. 6). Assuming the Coma cluster population (Adami et al. 2006) and shifting it at different redshifts, we show in Fig. 7 that MISTRAL is well adapted to measure the redshift of the cluster BCG up to redshift of  $\sim 0.125$  (or higher for the BCGs still forming stars). Assuming similarly the fossil group described in Adami et al. (2012) and shifting it at different redshifts, we

show in Fig. 7 that MISTRAL is well adapted to spectroscopically measure the galaxy members of such a structure (down to  $M_{BCG}+2$ ) up to  $z \sim 0.025$ , and well adapted to study the cosmic bubble of the fossil group (measuring galaxies brighter than the fossil group BCG) up to  $z \sim 0.075$ . One may argue that such tasks could be handled using photometric redshifts, but at these redshifts, this requires good quality U-band observations, and this is very difficult to get given the generally poor CCD efficiency at these wavelengths (see e.g. Rykoff et al. (2014); Clerc et al. (2016)), where photometric and spectroscopic redshift estimates differ at  $z \leq 0.05$ ). Similarly, large all-sky-type spectroscopic surveys (as SDSS) are generally avoiding this kind of targets because they are often too bright. This was for example the case for several nearby clusters in the XCLASS survey (<http://xmm-lss.in2p3.fr:8080/14sdb/>).



**Fig. 7.** Upper left: star target density versus R magnitude from the Besançon model inside the galactic plane for the whole galactic star population and for hot stars (O-B types). Upper right: galaxy target density versus R magnitude to reach in order to confirm the cluster of galaxies as function of redshift. Bottom: galaxy target density versus R magnitude to reach in order to study fossil group galaxy population (open stars) and fossil group environment (circles) as function of redshift. The domain covered by different spectrographs is shown for the three figures.

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