

# The Grid to model the Interstellar Medium

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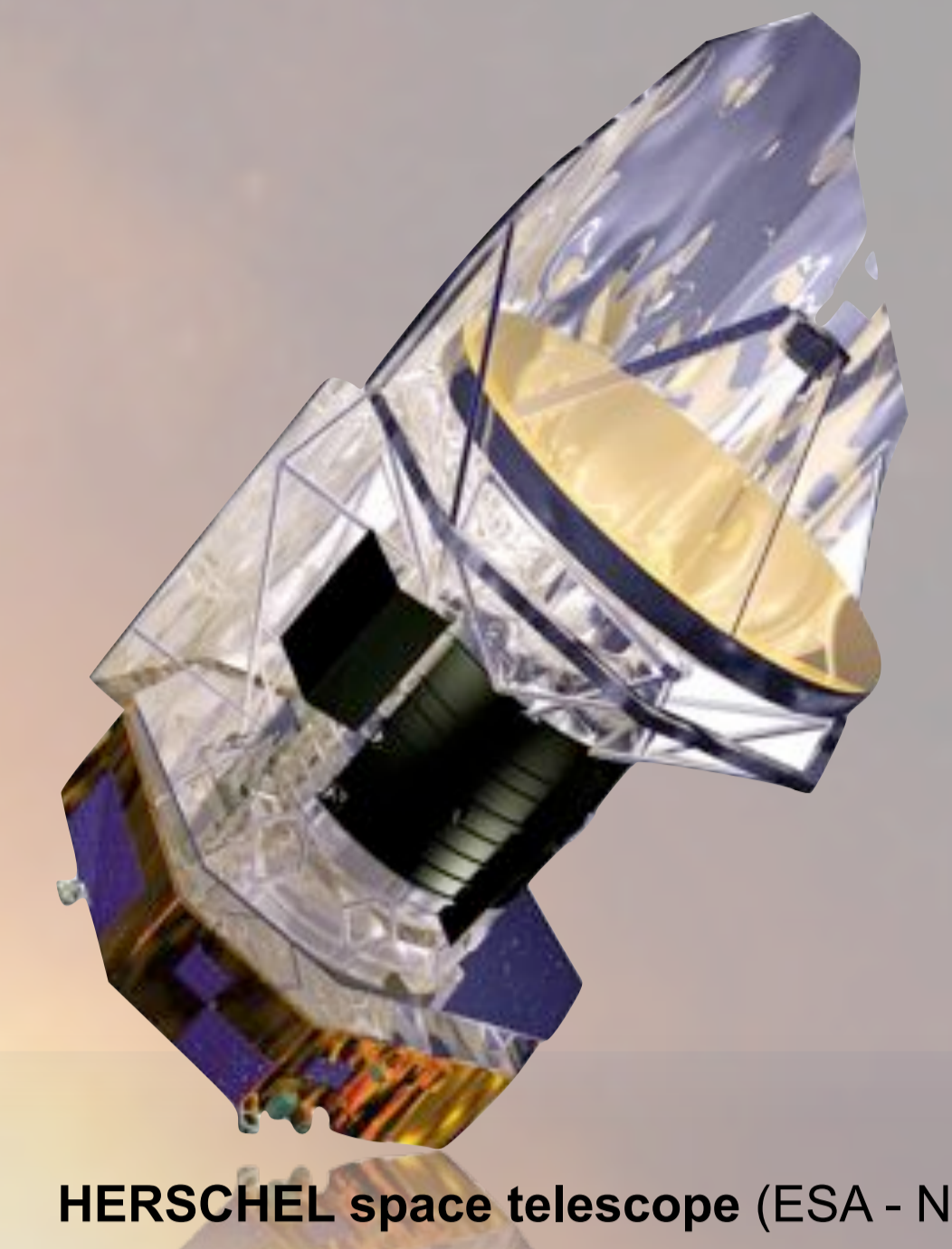


## Introduction

Large instruments as the space telescope HERSCHEL and the radio-telescope array ALMA (under construction) allow the astrophysicists to study the interstellar medium (ISM). The hot-topics in this field of research are the comprehension of the star formation mechanisms from the interstellar gas and, in return, the impact of stars on the interstellar medium by their radiation, wind and explosions in supernovae.

Observations of these regions are done thanks to spectrometers. These observations are interpreted by numerical models that compute the chemical and thermal structure of interstellar clouds. Because of the increase of the resolution (spectral and spatial) of the instruments, the physics implemented in these numerical models have to be treated with deeper details. As a consequence, the number of parameters in models increases and large computing resources are required to explore the parameter space.

The Meudon PDR code, is one of the public code used by the community to interpret such observations. It has been gridified on the EGI-InSpire infrastructure and is used to interpret HERSCHEL observations



HERSCHEL space telescope (ESA - NASA)

**The Meudon PDR code** is a 1D stationary plan-parallel model of interstellar clouds. It solves consistently :

- **Radiative transfer**

Radiative transfer is solved from the far UV to sub-millimeter taking into account absorption in lines (H, H<sub>2</sub>, CO) and by dust.

- **Chemistry**

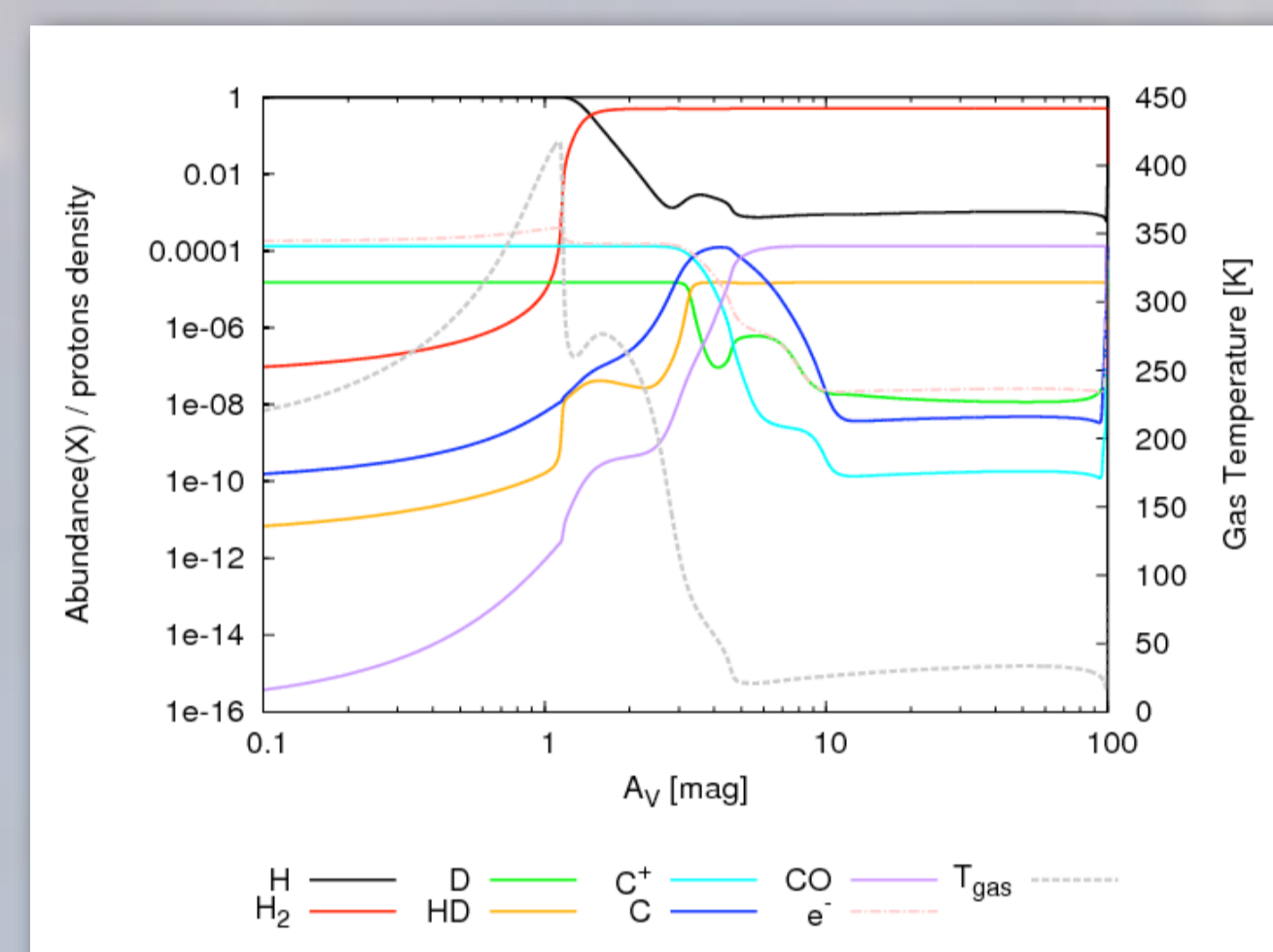
Typically a few hundred species linked by a network with 10 times more chemical reactions is used.

- **Thermal balance**

Heating mechanisms take into account photo-electric effect on grains, cosmic rays, exothermal reactions ...

Cooling mechanisms take into account line emission of C<sup>+</sup>, C, O and the most important molecules CO, H<sub>2</sub>O, OH, ...

The code computes at each point of the slab of dust and gas the abundances of species, the temperature of gas and grains, the excitation in the levels of the most important species, ...



Post-processing provides column densities and lines intensities and is used to interpret observations.

The code is public and can be downloaded at : <http://pdr.obspm.fr>

Language : Fortran 90  
Libraries : LAPACK, BLAS, CFITISO  
Execution Time : A few hours to several days  
Memory : 2 Gb

## Gridification

The code has been gridified on the EGI-InSpire infrastructure.

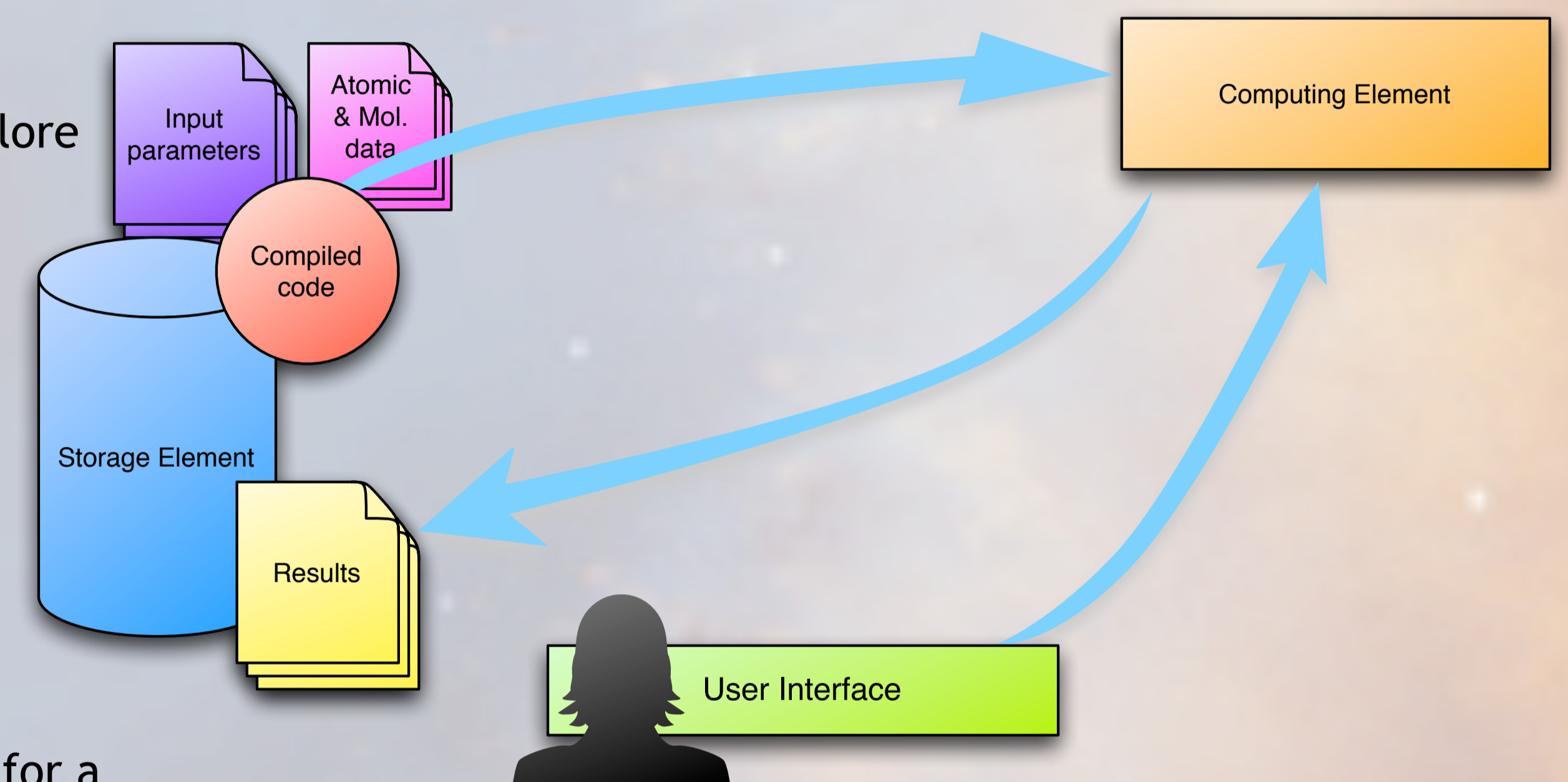
Jobs submitted to the Grid use the parametric mode to run large amount of models and so to explore the parameter space.

The fortran code is pre-compiled and is stored, with the input parameters and the atomic and molecular data, on a storage element.

Simple scripts have been developed to manage the jobs :

- send jobs to the Grid (by packs of 500 to the maximum) : download the files from the S.E. where they are stored, run the jobs, send the results to a S.E.
- identify the failures
- re-submit the failed jobs

This procedure has been used for 2 projects with several thousands jobs (about 10 hours per job) for a total of about 40 000 CPU-hour. Jobs failure rate was a few %. Failed jobs were re-submitted to the Grid or to a local cluster.



## Application : Formation of H<sub>2</sub> in the interstellar medium

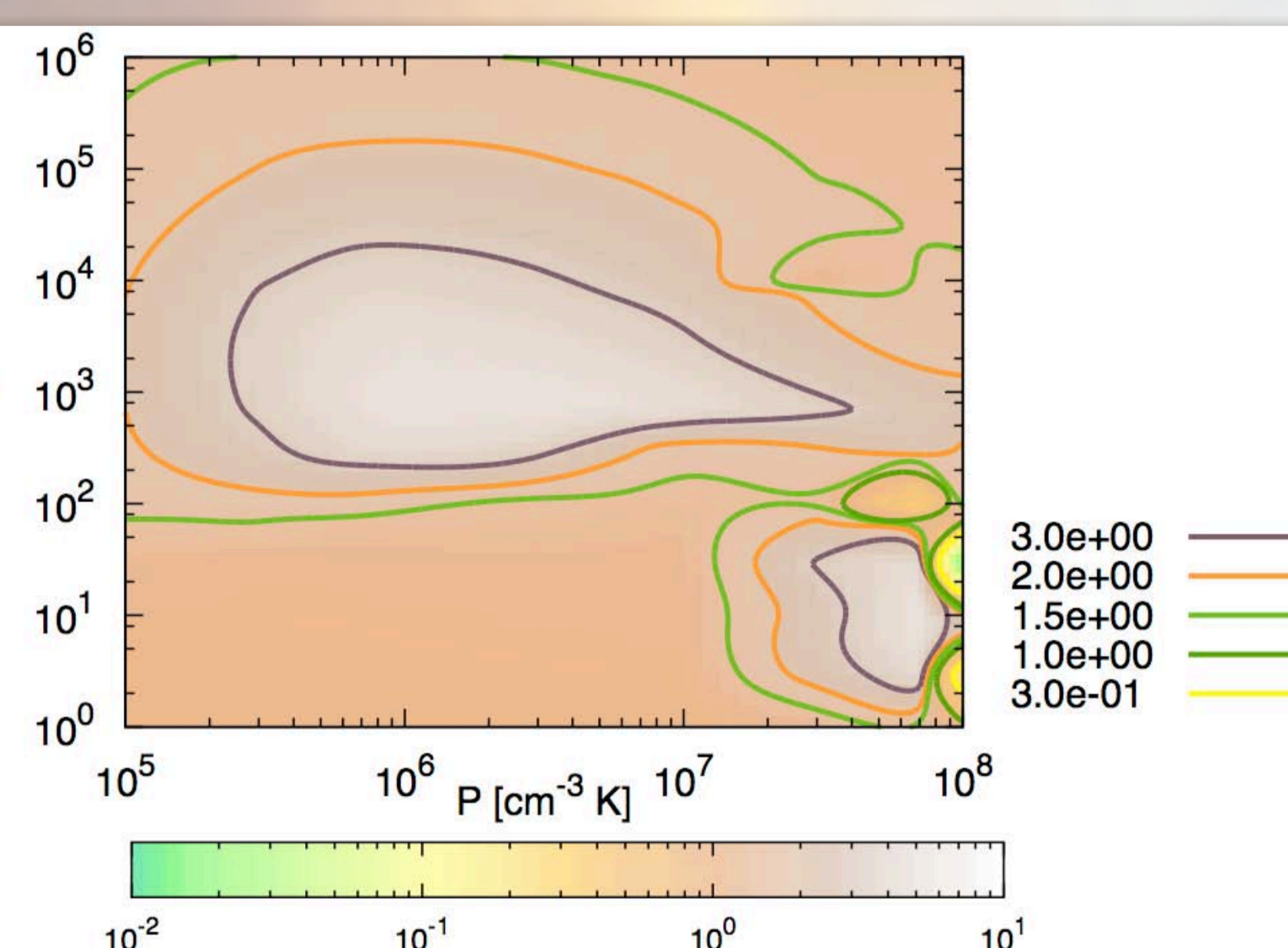
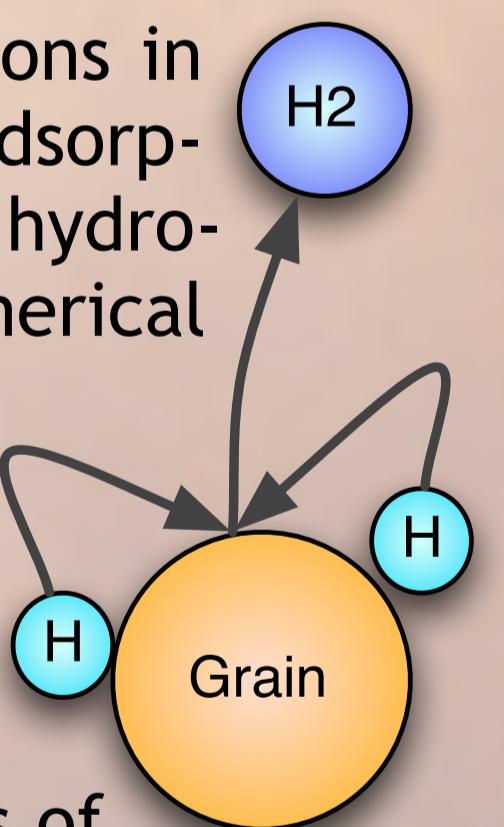
We used the Grid for two projects. One of them is related to the interpretation of HERSCHEL observations in the interstellar medium and more specifically to grain surface reactions. Molecules as H<sub>2</sub> are formed by adsorption of atomic hydrogen of the gas phase on interstellar grains. They can then react with other adsorbed hydrogens atoms or with H from the gas phase. The way such fine chemical processes are implemented in numerical codes affect the interpretation of the observations.

We implemented detailed treatment of H<sub>2</sub> formation taking into account binding and desorption energy thresholds on interstellar grains determined in laboratory experiments. Thanks to the Grid, we have been able to run a large number of models (~1000 models) to investigate the space-parameter of astrophysical conditions (gas pressure and intensity of the incident radiation field) and study the consequences of a detailed treatment compared to a rough one. We showed that some astrophysical parameters deduced by rough models can be wrong by several order of magnitudes.

### Comparison of H<sub>2</sub> line intensity 0-0 S(2)

We ran on the Grid isobaric models with different gas pressures and UV radiation fields with 2 prescriptions for H<sub>2</sub> formation : a) detailed H<sub>2</sub> formation mechanisms , b) constant formation rate at  $R = 3 \cdot 10^{-17} \text{ cm}^3 \text{ s}^{-1}$  (mean interstellar value determined from Copernicus and FUSE observations of diffuse clouds - Jura 1974, Gry et al. 2002).

This plot represents the ratio of H<sub>2</sub> line intensity 0-0 S(2) obtained by models a and b. We see that in some domains, the differences reach a factor 3. As a consequence, attempts to interpret observations of such H<sub>2</sub> lines in these domains of parameters by un-detailed models of H<sub>2</sub> formation would introduce an error by a factor 10 to 100 on the intensity of the incident radiation field on the cloud.



## Towards a platform of theoretical services

The Astronomy and Astrophysics community develops from 2002 standards to publish results of simulation codes. These works are done in the context of the Virtual Observatory, an international project which aims to share observations from large instruments in an interoperable way. Recent works are also done to standardize the way codes can be available online.

In this effort, we are trying to build a platform of theoretical services devoted to the interpretation of observations of the interstellar medium. This will contain interoperable databases of numerical simulations (two have been developed yet : pdr.obspm.fr and starformat.obspm.fr) as well as online codes. These codes will require computing resources. The EGI InSpire grid infrastructure could be a solution that will be investigated. In this case, solutions will have to be found to make Virtual Observatory protocols and the Grid compatible.

