The effect of multi grain network in chemical composition in the ISM

A study of dense clouds using Nautilus multi grain code

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Introduction

Many chemical reactions occur at the surface of interstellar dust grains, producing a large diversity of molecules more or less complex. Most current astro-chemical models include only a single size of grains (0.1 micron representing most of the mass of silicate grains) to study the formation and destruction of molecules on the dust surface. We have studied the effect of considering a distribution of grain sizes on the chemical evolution of various complex molecules in cold clouds in the ISM.

Methods

We used two different types of grain size distributions, MRN (Matthis et al. 1977) and WD (Weingartner & Draine 2001). We divided the grain radii range of 0.005 micron to 0.25 micron into 10, 30 and 60 bins. Each bin has its own characteristic grain size and corresponding grain number density which comes from either MRN or WD distribution. Other important parameters such as grain surface temperature, or cosmic ray induced desorption rate also vary with grain sizes.

Some important characteristic of Nautilus multi grain model

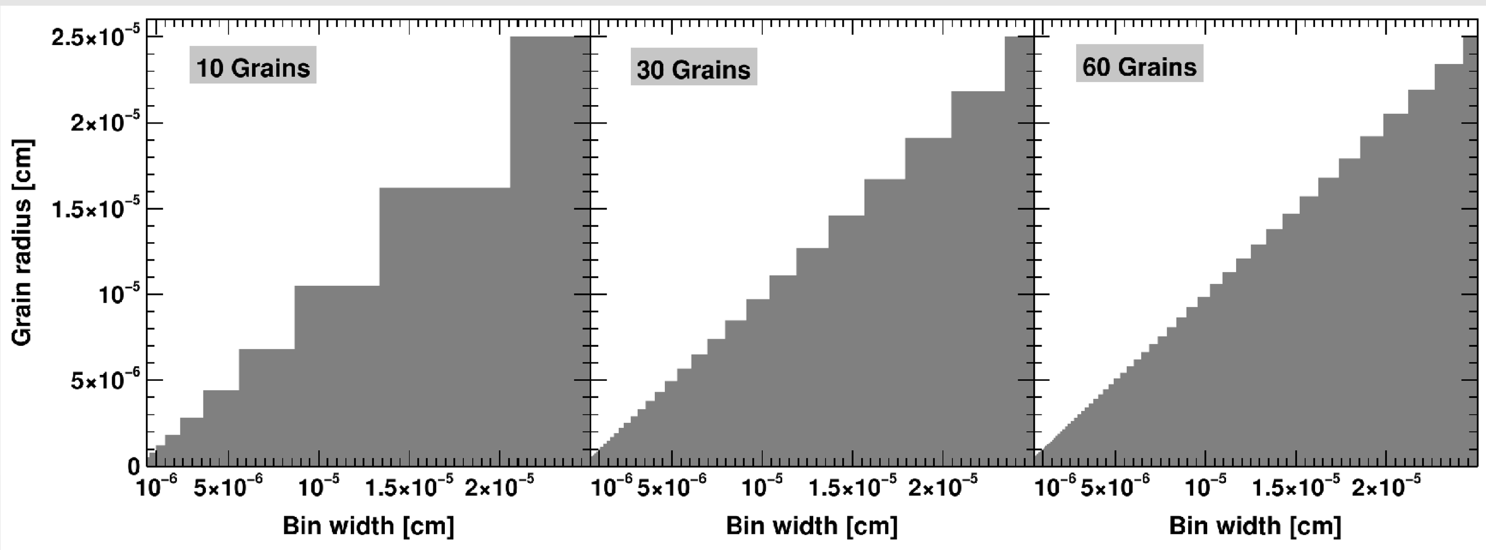

Figure 1: Bin width as a function of grain radius. The width of each vertical column represents bin width and the height of each vertical column represents the radius of the representative grain.

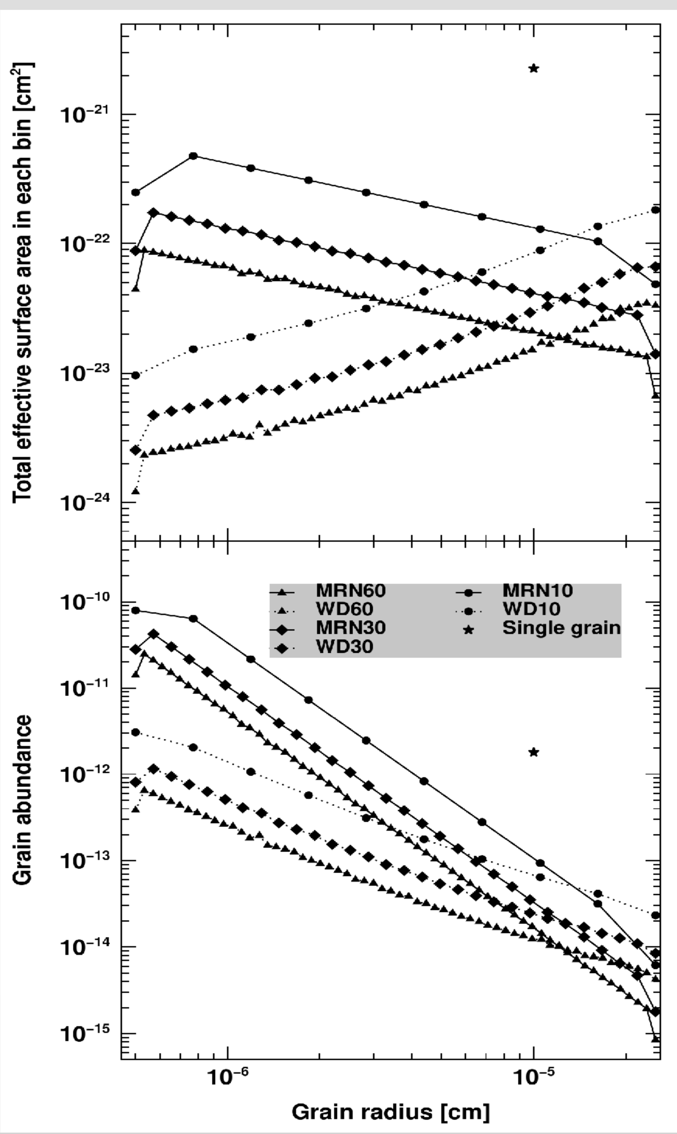

Figure 2: Bottom panel, grain abundance in each bin plotted against the grain radius. Top panel, the total effective grain surface area (in cm^2) of each bin for different models plotted against the grain radius.

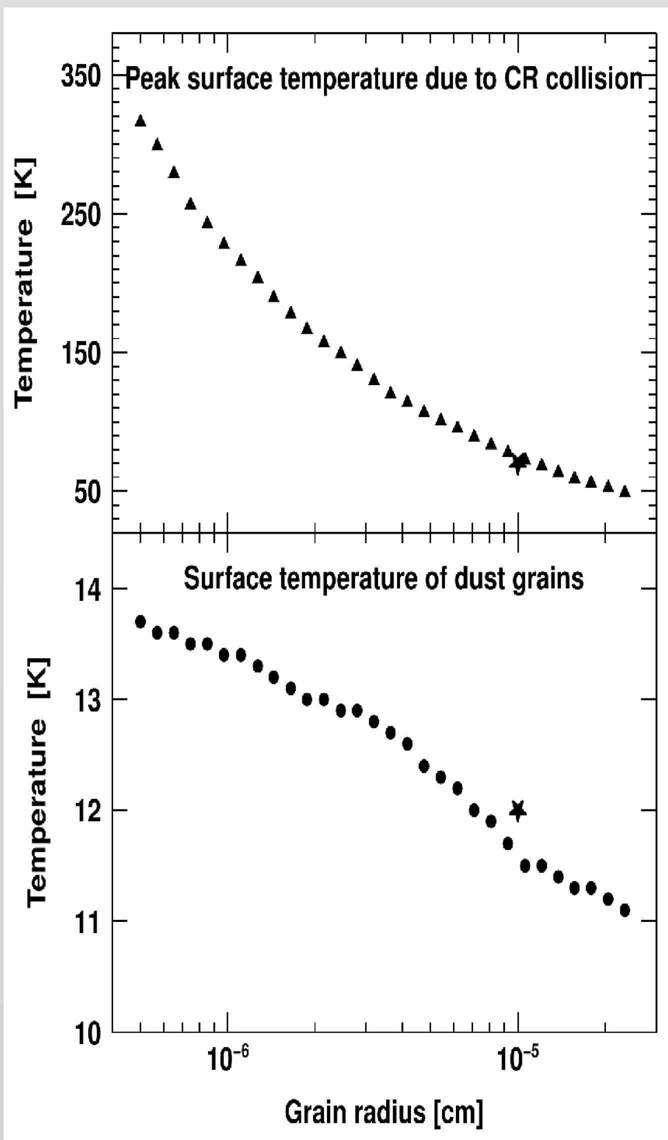

Figure 3: Bottom panel: grain temperature as a function of grain radius. Top panel: Peak surface temperature due to collision with cosmic rays as a function of grain radius. Star for single-grain model.

Important results

We present abundance of various molecules including some complex molecules in gas phase and also on the surface of dust grains at different time interval during the simulation. We also compare our results with observed abundances in TMC-1 and L134N. We show how a multi grain model can be a better tool in explaining the observed abundances in these cold dense clouds.

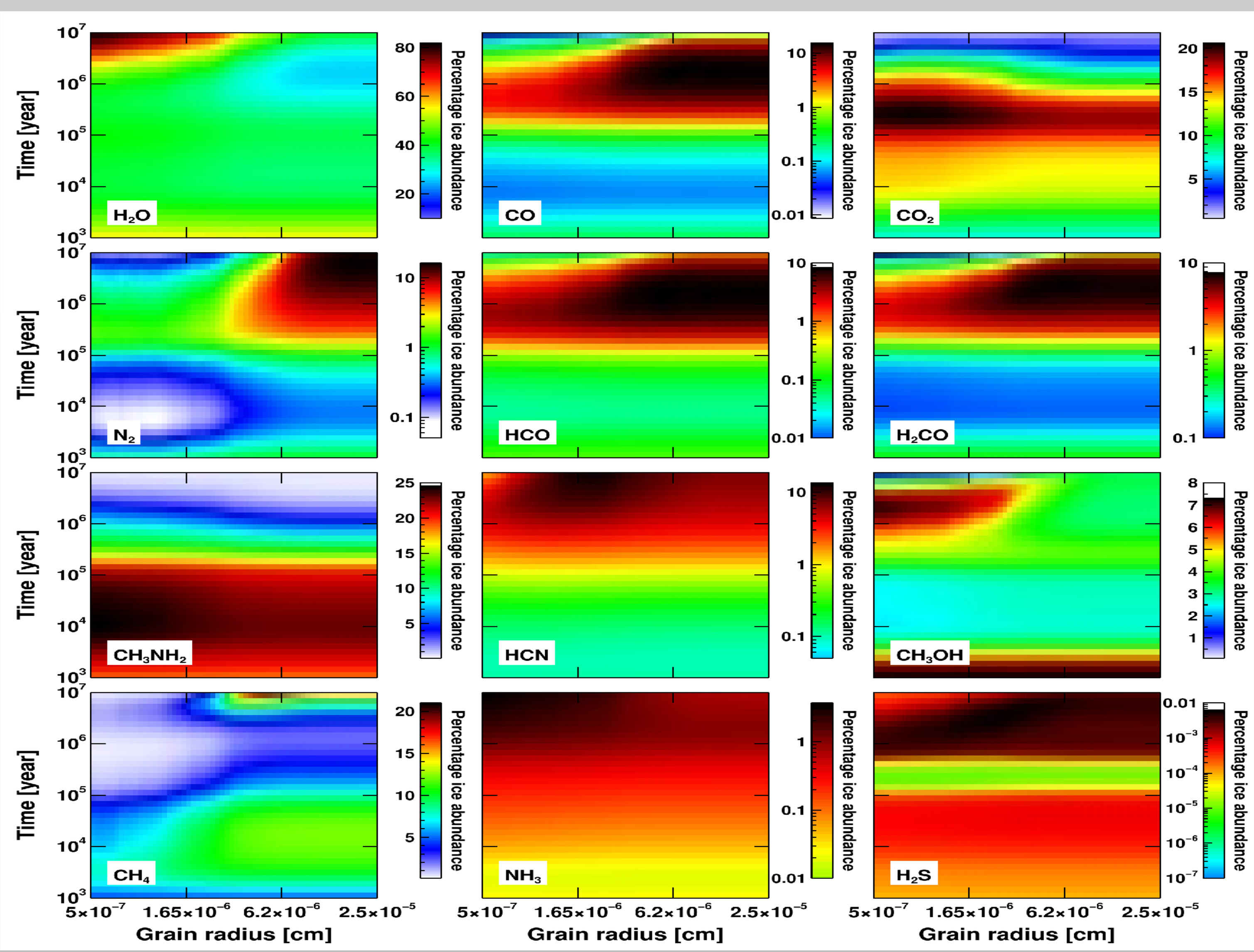

Figure 4: Percentage ice abundance of the most abundant species.

Results continue

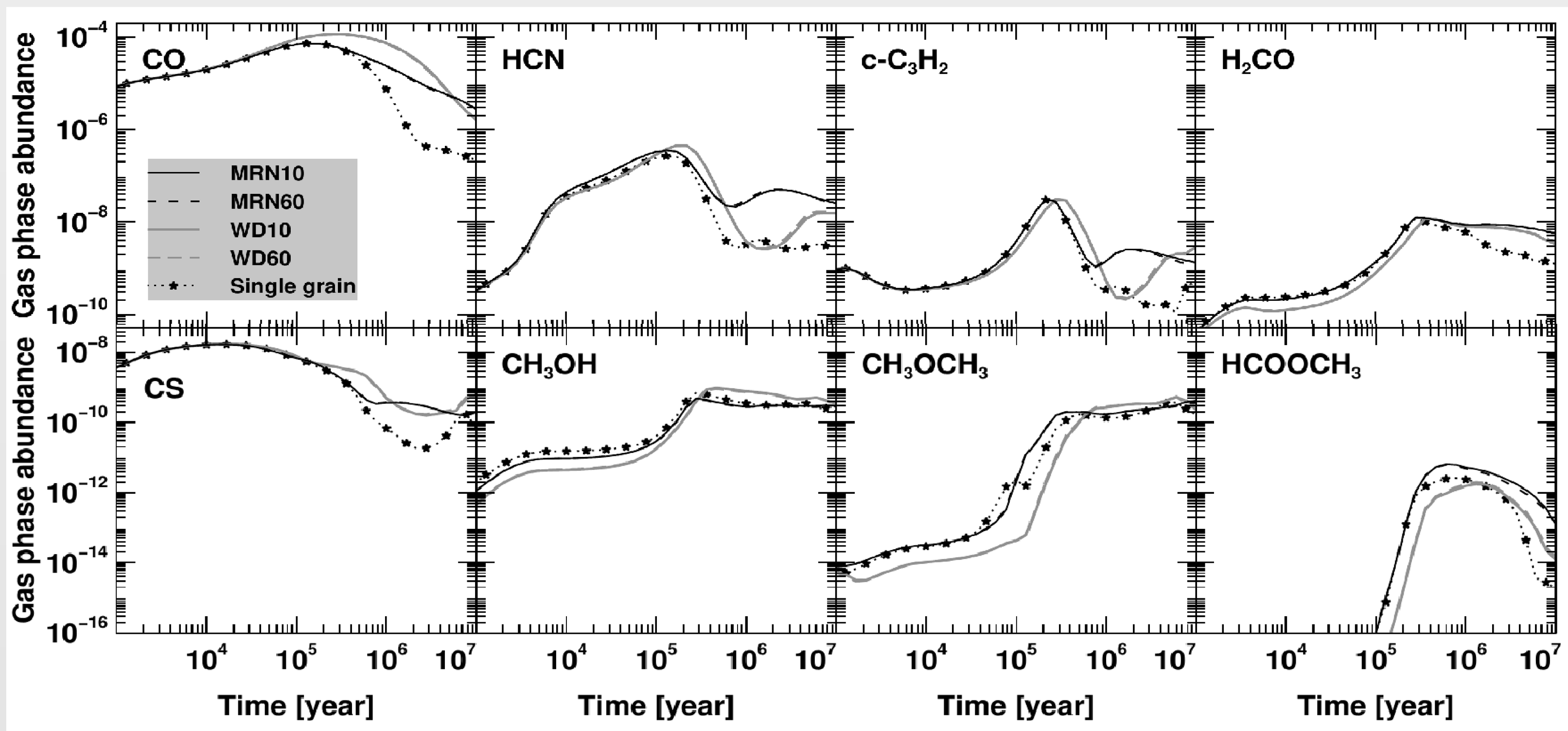

Figure 5: Gas phase abundances of selected species as a function of time for models with different grain size distributions. Grain temperature is non-uniform in the multi-grain models and in the single-grain model surface temperature is 12K. This legend applies to all panels.

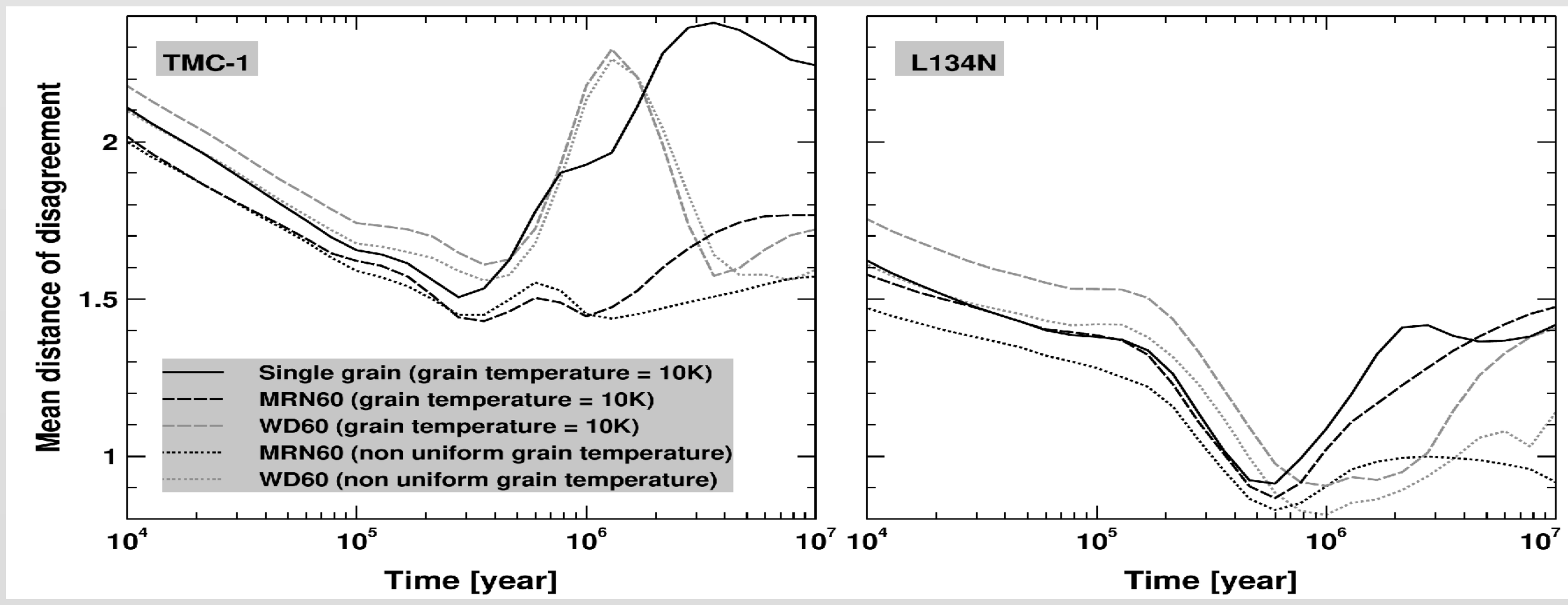

Figure 6: Mean distance of disagreement for dark clouds TMC-1 network and L134N.

Conclusions

- Results from the single-grain and multi-grain models both using the MRN distribution are very close and are similar in absence of the cosmic rays provided all grains are at the same surface temperature.
- The collisions of the cosmic ray particles with the small grains (< 0.04micron) causes the evaporation of a large portion of the ices from the surfaces. This results in a significant reduction in the ice thickness on these grains.
- The choice of the MRN or the WD distributions strongly affects the abundances of most of the species. The cosmic-ray-induced desorption is the most effective in the MRN distribution case. Most of the species have smaller ice abundances in the WD case due to a lower number density of dust grains as compared to the MRN distribution.
- Ice composition depends on grain size. Ices on the small grains contain a small percentage of lighter molecules, such as CO, HCO and N_2, and a larger percentages of more strongly bound species, such as water and CO_2.
- Considering a non-uniform surface temperature for the different grain sizes strongly impacts the overall gas and ice compositions. The difference in the chemical compositions between the small and big grains is even stronger.
- The MRN distribution gives a better agreement with TMC-1 observations whether the dust temperature is uniform or not, while both the MRN and the WD distributions give a better agreement with L134N when dust temperature is non-uniform.

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References

Ruaud, M., Wakelam, V., & Hersant, F. 2016, MNRAS, 459, 3756
Mathis, J. S., Rumpl, W., & Nordsieck, K. H. 1977, ApJ, 217, 425
Weingartner, J. C., & Draine, B. T. 2001, ApJ, 548, 296
Acharyya, K., Hassel, G. E., & Herbst, E. 2011, ApJ, 732, 73
Hasegawa, T. I., Herbst, E., & Leung, C. M. 1992, ApJS, 82, 167
Hasegawa, T. I., & Herbst, E. 1993, MNRAS, 261, 83
Hasegawa, T. I., & Herbst, E. 1993b, MNRAS, 263, 589
Iqbal, W., Acharyya, K., & Herbst, E. 2014, ApJ, 784, 139
Mathis, J. S., Mezger, P. G., & Panagia, N. 1983, A&A, 128, 212
Draine, B. T., & Lee, H. M. 1984, ApJ, 285, 89 (erratum 318, 485 [1987])
Herbst, E., & Cuppen, H. M. 2006, Proc. Natl Acad. Sci., 103, 12257
Wakelam, V., Herbst, E. 2008, ApJ, 680, 371
Jenkins, E. B. 2009, ApJ, 700, 1299
Hincelin, U., Wakelam, V., Hersant, F., Guilloteau, S., Loison, J. C., Honvault,
Graedel, T. E., Langer, W. D., Frerking, M. A., 1982, ApJS, 48, 321
Pauly, T., Garrod, R. T., 2016, ApJ, 817, 146
Ge, J. X., He, J. H., Li, Aigen, 2016, MNRAS, 460,L50
Garrod, R. T., 2008, A&A, 491, 239
Wakelam, V., Smith, I. W. M., Herbst, E., et al. 2010, SSRv, 156, 13
Léger, A., Jura, M., Omont, A., 1985, A&A, 144, 147