ProDiMo – ***New Disk Models for GASPS***

Peter Woitke(1), Inga Kamp(2), Wing-Fai Thi(3), and Michiel Hogerheijde(4)

(1) UK Astronomy Technology Centre, Edinburgh, UK (2) Institute for Astronomy, Edinburgh, UK (3) University of Groningen, The Netherlands (4) Sterrewacht Leiden, The Netherlands

Introduction to “ProDiMo”

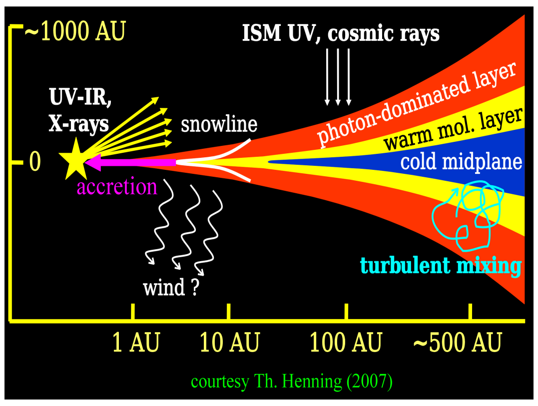

FIGURE 1: Sketch of disk structure.

Protoplanetary disks are readily detectable in the dust continuum. However, 99% of their mass is gas. With the launch of ***HERSCHEL*** we will be able to study far IR gas emission lines from protoplanetary disks, which allows us to explore the physical (e.g. gas temperature) and chemical structure of the disks.

In the ***GASPS*** open time key programme (PI B. Dent), we will observe fine structure lines of CII and OI, as well as rot. lines of CO and H2O that probe the photon-dominated surface layer and the warm molecular layer, respectively (see Fig.1).

This poster reports on recent work on models for the gas in disks called ***ProDiMo*** (**PRO**toplanetary **DI**sk **MO**del) which will be used for the interpretation of the ***GASPS*** observational data.

What's inside?

chemistry	User-specified selection of elements, chemical species, and reactions. Selection for the model shown on the r.h.s comprises 9 elements (H,He,C,N,O,Mg,Si,S,Fe), 71 species (including excited H2* and 5 ice species), and 950 reactions. Reaction data include UV photorates mainly taken from the UMIST 2006 compilation **(Woodall et al. 2007)**. Special treatment of CO and H2 photodissociation, and neutral C photoionisation including detailed photo-cross sections and self-shielding **(Kamp & Dullemond 2004)**. H2* chemistry is from (**Tielens & Hollenbach 1985)**. Ice formation and evaporation according to **Aikawa (1996)**. H2 formation on grain surfaces from **Cazaux & Tielens (2004)** with latest updates (S. Cazaux, priv. comm.).
heating	**photoeffect** on grains, **PAH** heating, heating by **H2 formation** on grains, **H2*** collisional de-excitaion, **H2 dissociative** heating, **viscous/accretion heating** (switched off in the r.h.s. model), **thermal accomodation.** **IR and optical pumping** by absorption of stellar and dust continuum radiation in spectral lines (see cooling).
cooling	**OI** fine-structure (3 levels, 3lines, 5 coll. partners), **CII** fine-structure (2 levels, 1 line, 3 coll. partners), **CI** fine-structure (3 levels, 3 lines, 6 coll. partners), **CO rotational & ro-vibrational** (110 levels, 243 lines, 6 coll. partners) **o/p-H2O rotational** (45/45 levels, 258/257 lines, 1 coll. partner), **o/p-H2 quadropole** (80/80 levels, 803/736 lines, 4 coll. partner), **MgII** resonance lines (8 levels, 12 lines, 1 coll.partner), FeII fine-structure, semi-forbidden and permitted lines (80 levels, 477 lines, 1 coll. partner), **SiII** semi-forbidden (15 levels, 35 lines, 1 coll. partner), **SII** semi-forbidden (5 levels, 9 lines, 1 coll. partner), Ly alpha cooling, OI 6300A cooling, thermal accomodation. Non-LTE treatment with radial and vertical **escape-probabilities.**
radiative transfer	2D ray-based **dust continuum radiative transfer** with **isotropic scattering, accelerated Lambda method.** Used to determine Tdust, local UV field, and background mean intensities for the non-LTE modelling.
dust opacities	**Mie theory** with **effective medium** treatment for volume-mix of solids for spherical grains. Arbitrary **size-distribution**.
hydrostatics	vertically upward **numerical integration of pressure stratification** p(z) for given sound velocity structure cT(z). **Normalisation** of vertical column density to given radial law. Solution of chimistry and heating/cooling balance for **fixed pressure p**, which renews cT(z). Global iteration.
open issues	**X-ray** heating and chemistry, dust in **escape probability**, **mixing**, **dust** and **SED** modelling, ...

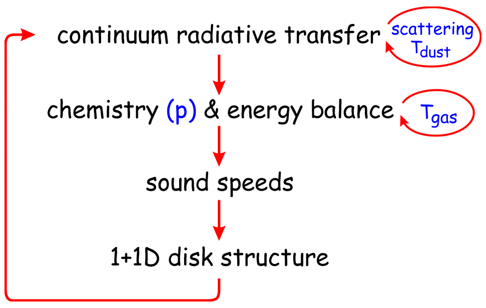
continuum radiative transfer
scattering T_{dust}
chemistry (p) & energy balance
T_{gas}
sound speeds
1+1D disk structure

FIGURE 2: Iterative scheme to solve the chemistry and thermal balance of the gas consistently coupled to the dust continuum radiative transfer, and the vertical disk structure.

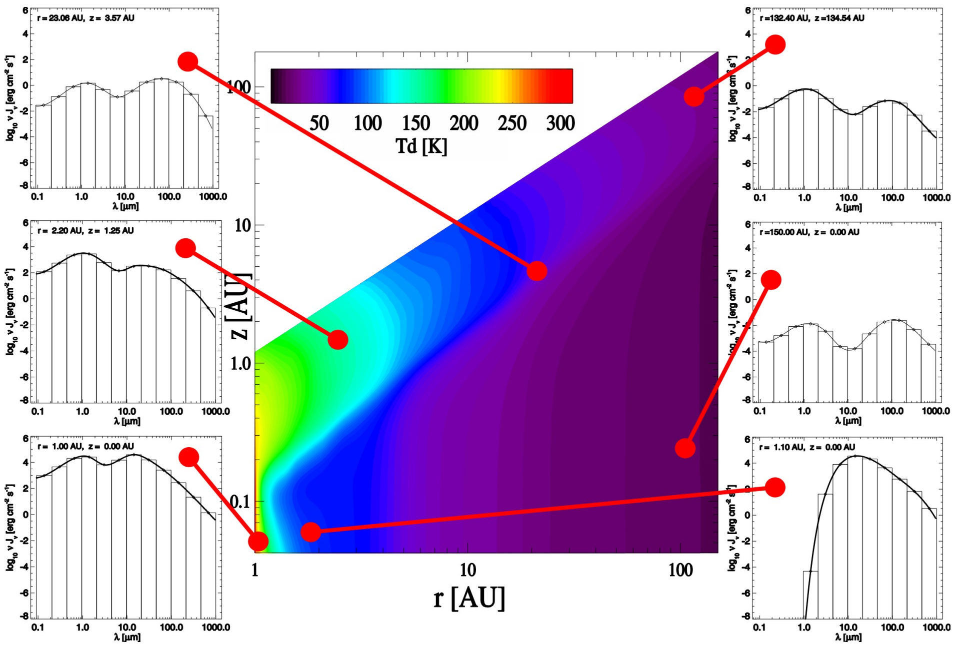

FIGURE 3: Dust continuum radiative transfer as input for non-LTE modelling. The figure shows the calculated “background” mean intensity $J_\nu^{back}(r,z)$.

Physical Disk Structure

The following figures show some results of a model for the T Tauri disk LkCa15 with parameter $M_*=0.8\ M_{sun}$, $L_*=0.5\ L_{sun}$, $T_{eff}=4400$ K with added UV from the measured chromospheric flux of “young sun” HD 129333 (Dorren & Guinan 1994). Disk mass is $2\times10^{-2}\ M_{sun}$, $R_{in}=1$AU, and $R_{out}=425$ AU. Grains are assumed have uniform size distribution $f(a)\sim a^{-3.5}$ between 0.1 μm and 100 μm, and to have astronomical silicate optical properties (Draine & Lee 1984).

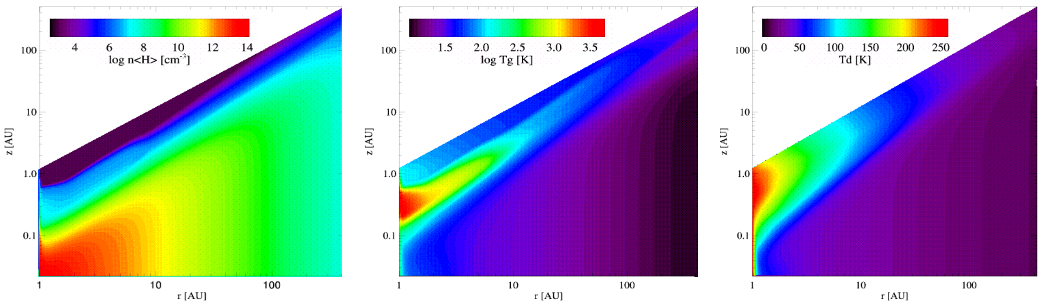

FIGURE 4: The UV irradiation causes a hot surface layer with Tgas >1000 K inside of about 10 AU, where the gas is thermally decoupled from the cooler dust. These high gas temperatures cause a puffed-up inner rim and an extended vertical stratification. The gas in these regions is H-rich (H2-poor) and contains hot molecules like CO2 and H2O, which can be expected to cause near IR iine emissions. At larger distances, the disk is flared. ***ProDiMo*** grid is 100x100.

Chemical Disk Structure

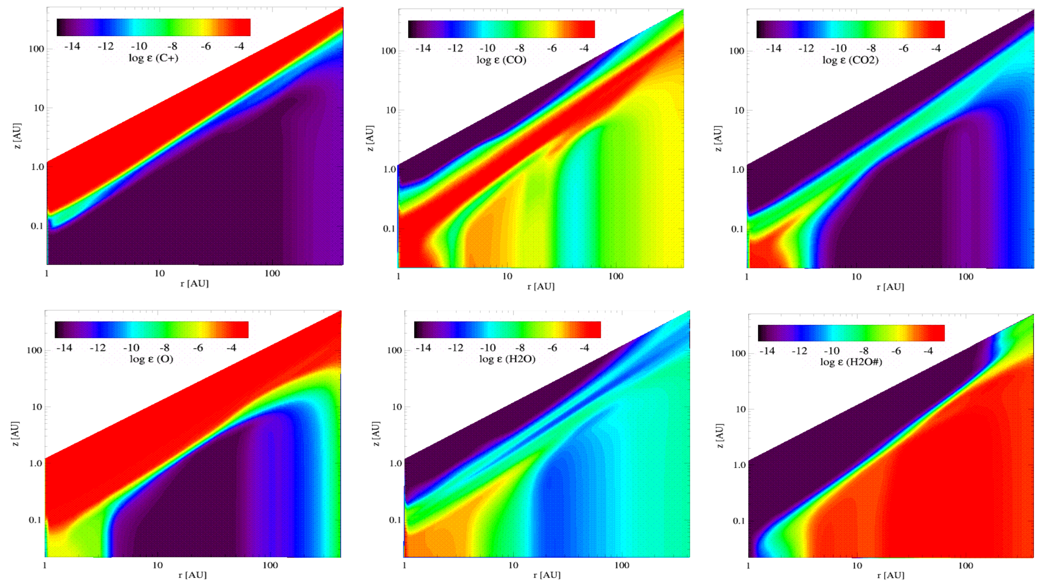

FIGURE 5: At large distances from the star, the vertical chemical structure resembles very much the results of 1D slab PDR-modelling with simple atoms/ions at the top and increasing chemical complexity and ice towards the midplane. However, the inner parts of the disk are so dense, that thermo-chemical equilibrium is reached approximately, resulting in e.g. high H2O abundances. The “snow-line” (see H2O ice concentration in the lower right plot) is located at about r=3.5 AU in this model in the midplane, but as extended as r=20 AU at a height of z=1AU.

Non-LTE line radiative transfer

The calculated particle densities, gas and dust temperatures, and the dust opacity serve as input for non-LTE line transfer calculations to predict line fluxes, profiles and images. We use the accelerated Monte-Carlo code ***RATRAN*** (Hogerheijde & van der Tak 2000) for this purpose.

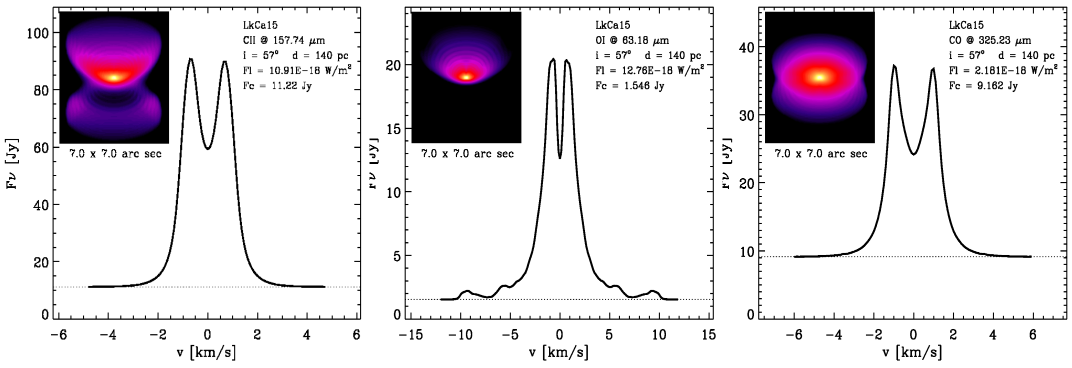

FIGURE 6: Line flux predictions for Herschel GASPS, using a 40x20 ***RATRAN***-grid. The OI 63μm line is usually the strongest line with emphasis on the central regions. The CII 158μm line originates from the surface and the CO J=8→7 325.23μm line probes the deeper layers (for higher J, the CO lines vanish quickly in the continuum!). These complimentary informations can be used to attack various long-standing astrophysical questions. For example, we intend to determine the disk gas mass independently of the dust using line ratios, which would allow to determine ρ_{gas}/ρ_{dust}.

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