# X-ray irradiated gaseous protoplanetary disks

## 2D photoionisation & dust RT models with MOCASSIN


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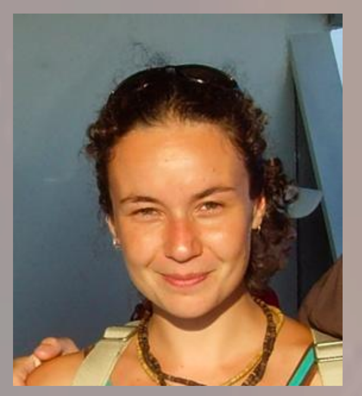
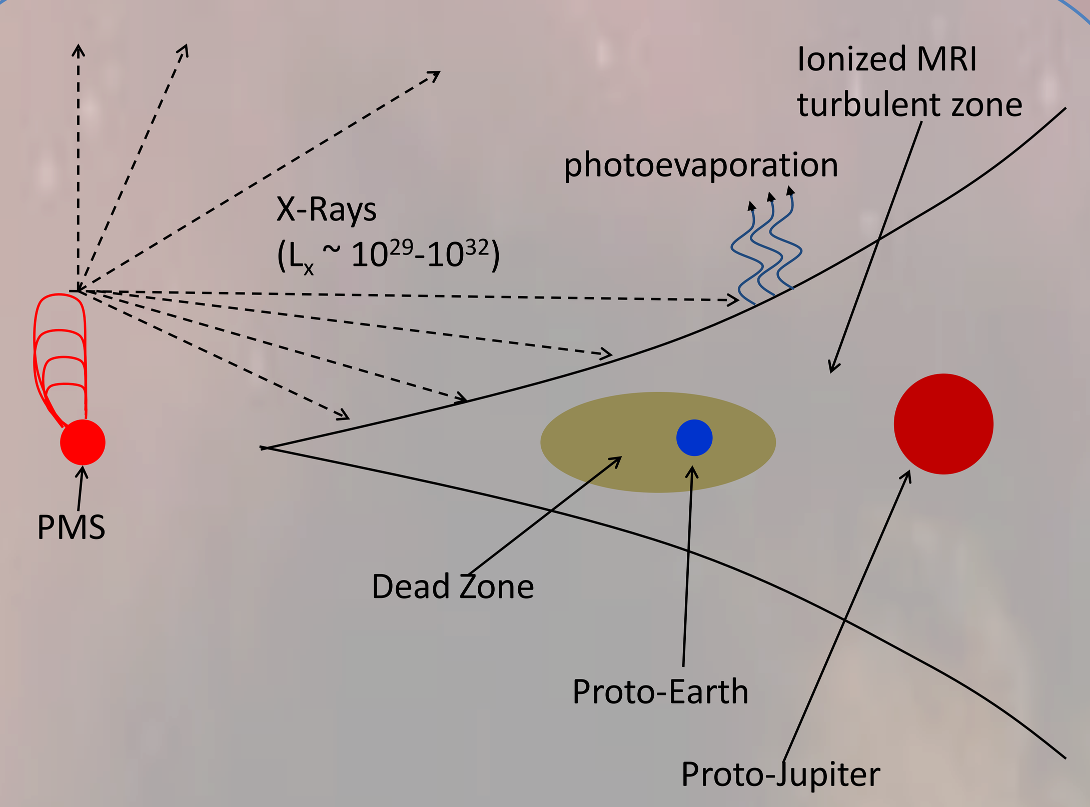


## Background




The evolution of protoplanetary disk and of its planetary progeny is controlled by heating and irradiation from the central star—from IR to X-rays. In particular X-rays with their large penetration depth can warm, ionise and photoevaporate a disk during its entire lifetime - *even when an optically thick wind may prevent EUV radiation from reaching the disk surface.* Furthermore, the large penetration depths of X-radiation may provide ionisation of the disk interior – an ingredient necessary to explain accretion via magneto-rotational instabilities (MRI). Indeed understanding X-ray irradiation provides constraints on the size and location of the 'dead zone' where terrestrial planets may form.

## What is MOCASSIN?

MOCASSIN is a 3D photoionisation and dust radiative transfer code that uses a Monte Carlo approach to the transfer of radiation. It can calculate gas and dust temperature, ionisation structure, SEDs and line emission for arbitrary geometries and illumination source(s).

The code is public and it is fully parallelised using the MPI standard. Please contact Barbara Ercolano (be@ast.cam.ac.uk) for more information or look at Ercolano et al. (2003, 2005, 2008a)

## Conclusions, limitations, future

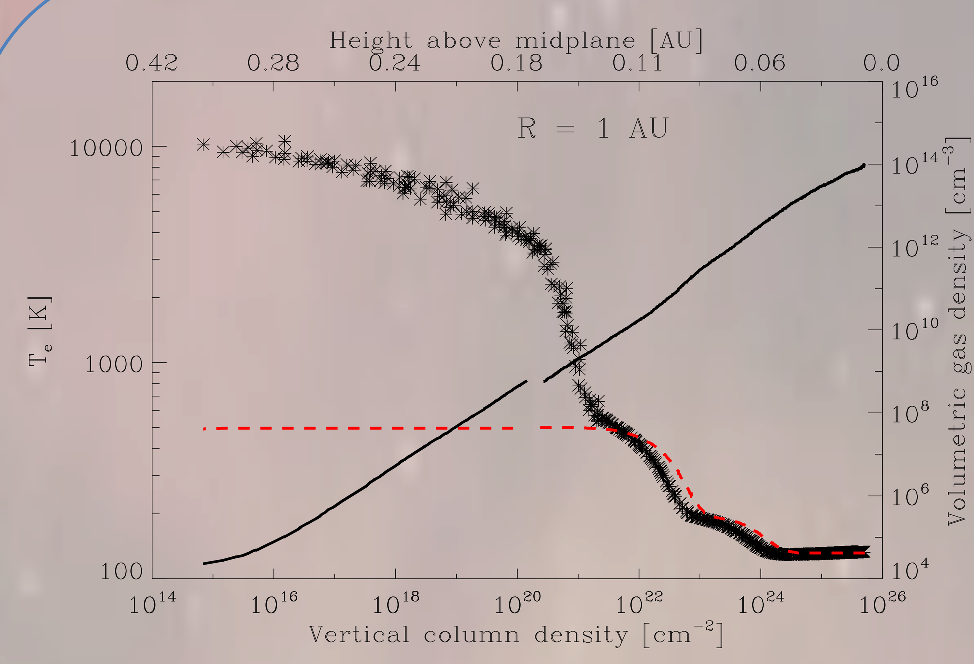
•Our results suggest that X-ray photoevaporation may play an important role in disk dispersal. Our rates are larger than those calculated by Gorti & Hollenbach (2008b) and this discrepancy needs to be investigated. A more detailed comparison is however premature at this stage given the crude methods used to estimate mass loss rates from a temperature and density structure. A careful assessment of the erros (by comparison with the results of hydrodynamical simulations) is needed.

•In the final stages of disk evolution accretion is nearly shut off and therefore a strong FUV flux (above the photospheric FUV) is not expected, however at this stage, optically thick winds will have also disappeared and EUV photons may therefore reach the disk surface. We are currently in the process of estimating the combined effects of EUV and X-ray irradiation on disk dispersal.

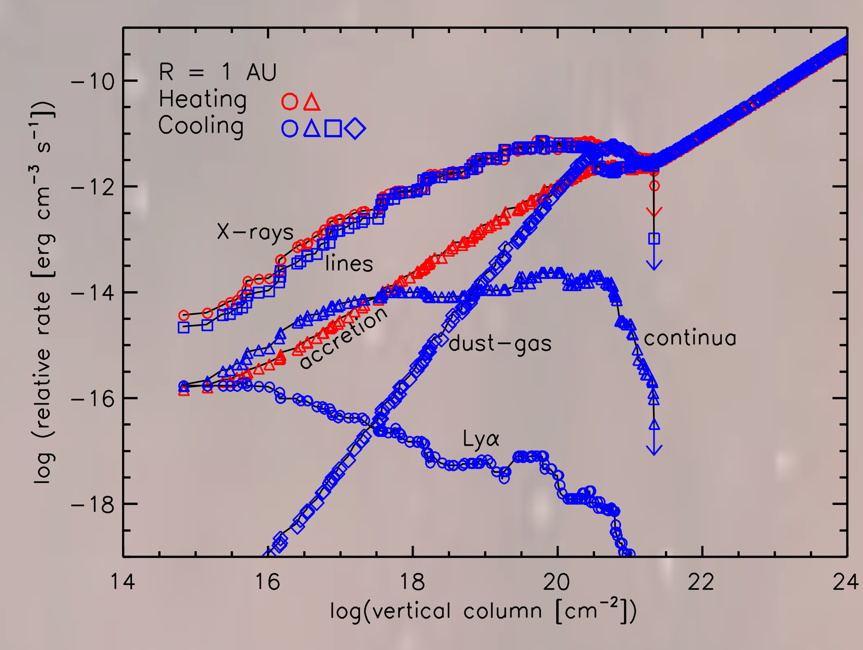
•An updated emission line spectrum will be published in the near future for the hydrostatically converged models.

•Future models will include a small chemical network.

## Fixed density grid models

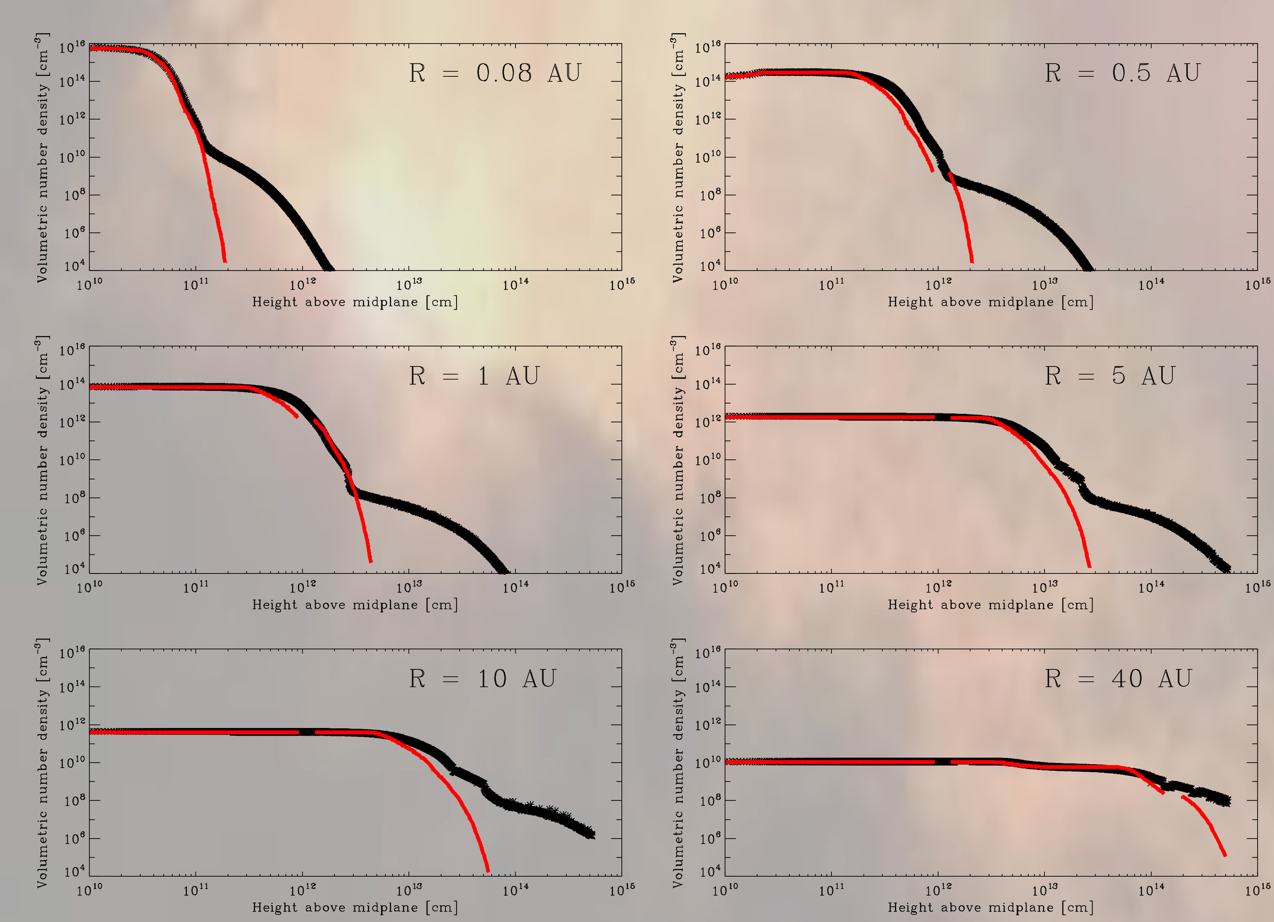



Vertical gas temperature distribution (asterisks) at a radial distance of 1AU. The red dashed line shows the dust temperature distribution. These early models (Ercolano et al. 2008b) used the gas density model of D'Alessio et al. (2001, solid line), which assumed full thermal coupling between dust and gas. The figure above clearly shows that this assumption is not justified (temperatures diverge at a column of $10^{21}$ $cm^{-2}$). A better approach is to impose hydrostatic equilibrium.




We have modelled the temperature and ionisation structure of a typical protoplanetary disk around a 0.7 $M_{sun}$ star. Our gas thermal balance includes X-ray photoionisation from the central PMS star, viscous accretion, Ly-α emission, free-free and free-bound continua and dust-gas collisions. The figure above shows the main cooling and heating channels as a function of vertical column at a radial distance of 1AU for the fixed grid models.

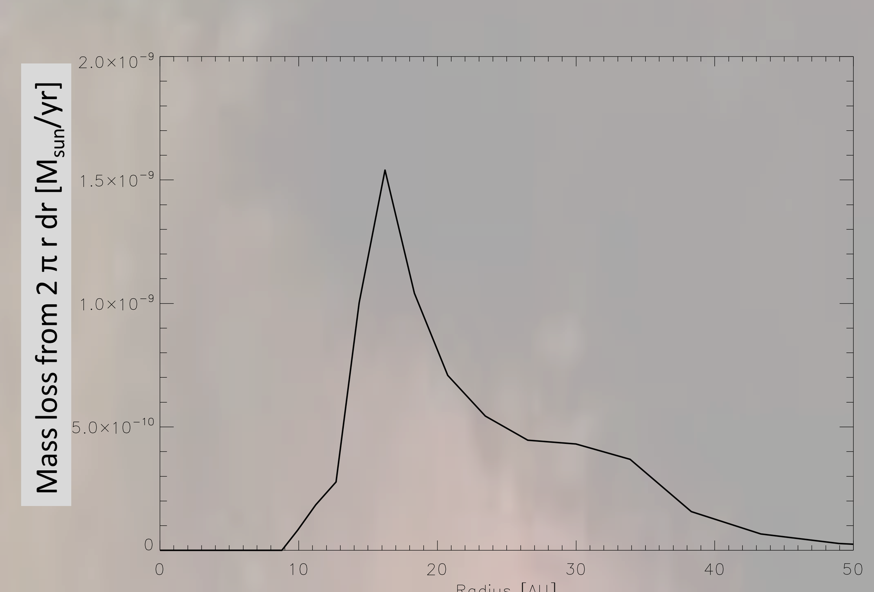
## Models in Hydrostatic Equilibrium



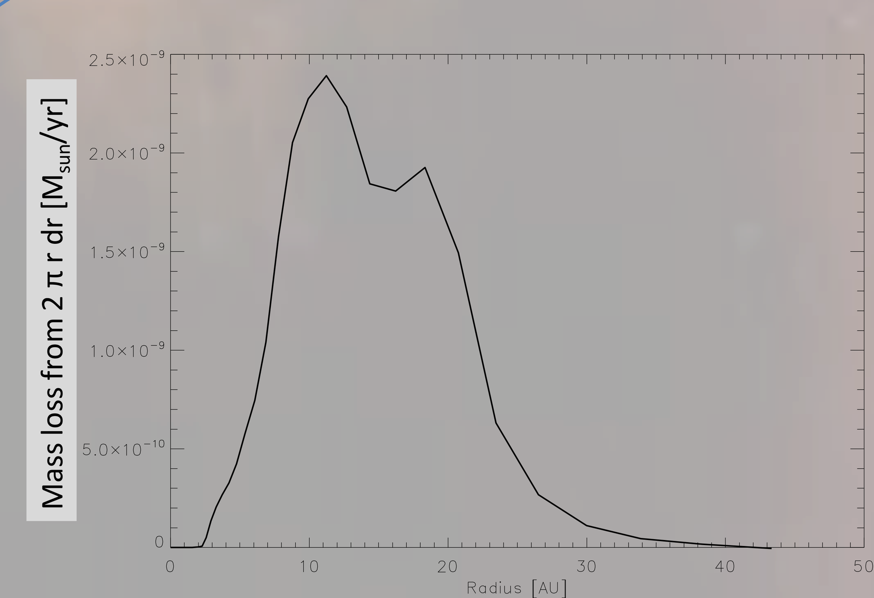

The vertical gas density distribution from the hydrostatic equilibrium calculations (black asterisks) compared to the original density distribution of D'Alessio et al. (2001) calculated under the assumption of thermal coupling between dust and gas.

We employed the formalism of Alexander, Clarke & Pringle (2004) in order to calculate the density distribution resulting from the X-ray heated disk. Convergence of hydrostatic and thermal solutions ensure a self-consistent result.

## Disk Dispersal by Photoevaporation




Substantial photoevaporation rates result from X-ray irradiation of a fixed gas density structure. The rates shown in the figure above as a function of radial distance from the star correspond to a total disk photoevaporation rate of **~$10^{-8}$ $M_{sun}$/yr**. Photoevaporation rates are not sensitive to the viscous accretion rate (for accretion rates lower than $10^{-8}$ Msun/yr) and only vary by a factor of two when different grain models are used (e.g. MRN or evolved size distribution).




Total disk photoevaporation rates from hydrostatic equilibrium models are 5 times larger than those of a fixed density model with the same parameters. This is a result of the 'puffing up' of the material in the hot inner disk which finds itself at a lower escape velocity due to the increased distance from the star. The figure shows that substantial photoevaporation rates are achieved in the region between ~5 and 25 AU from the star. As for the fixed density model these rates imply a disk dispersal timescale of a few Myr.

## Also Read:


Alexander, Clarke & Pringle 2004, MNRAS 354, 71; D'Alessio et al. 2001 RMxAc 11, 177; Ercolano et al. 2003 MNRAS 340 1136; 2005 MNRAS 362, 1038; 2008a ApJS 175, 534; 2008b ApJ in press; Glassgold, Najita & Javier 2004, ApJ 615, 972; Gorti and Hollenbach 2008a ApJ 683, 287, 2008b ApJ in press.