Evolution of gas in debris discs - Application to β Pictoris

UNIVERSITY OF CAMBRIDGE
Institute of Astronomy

Quentin Kral, Mark Wyatt, Jim Pringle

IoA - University of Cambridge, UK

Gas in debris discs

Observations of gas in debris discs are becoming astonishingly common, in part thanks to ALMA high resolution and sensitivity as well as the Herschel mission. Study of gas in these environments is still in its infancy as one did not expect gas to be present around such old systems as it should be long gone, either accreted onto the star or photoevaporated.

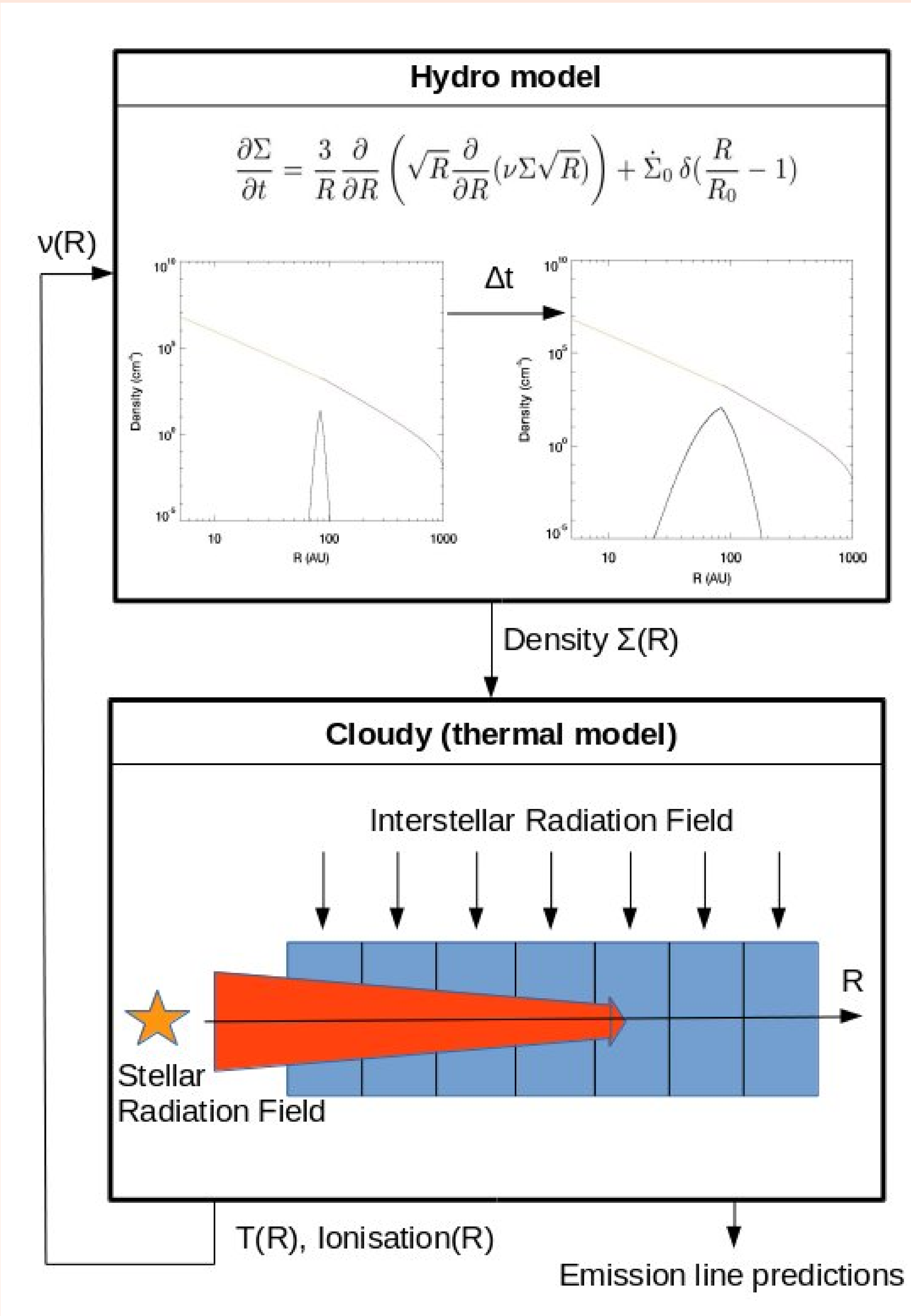
The observed **gas is most probably secondary and created in rocky or icy (more likely) planetesimal belts** but the details of its origin are still to be defined. Molecular (CO) and atomic species (C, O, Fe, Ca) are observed at different locations pointing out to a distinct dynamical evolution.

In this poster, we propose a self-consistent scenario that **produces CO from the belt that gets quickly photodissociated in C and O, which in turn evolves due to viscous spreading**. Eventually, we test our model on the most observed system, **β Pictoris**.

A new dynamical/thermal gas model

In our model, **some gas is input at a location R_0** (where the belt is located) and we solve its viscous evolution using an α **prescription** (see equation in the diagram below). This hydro evolution needs to know the viscosity and so the temperature needs to be determined at every point in the gas disc. The temperature, ionisation profile and emission line predictions are solved using **Cloudy** (Ferland et al. 2013), a PDR-like thermal model. The process is described on the diagram below.

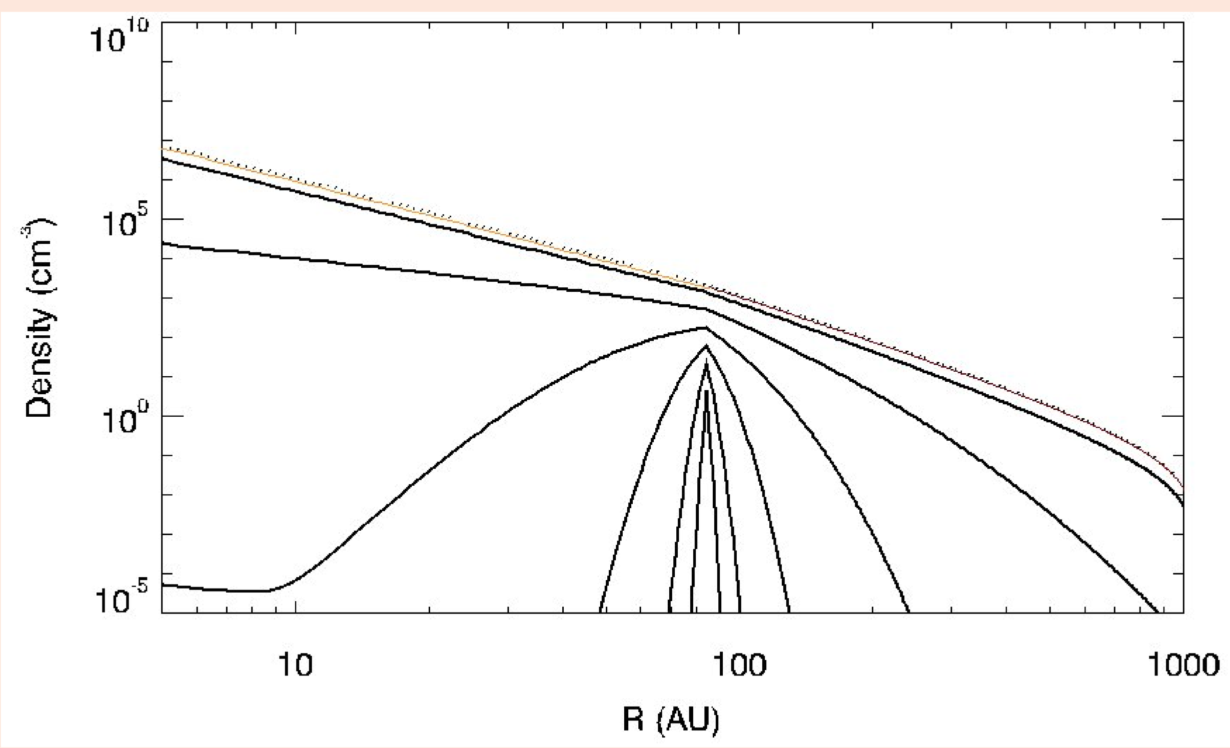
The **free parameters are α, the input rate $\dot{M}$, the input location R_0 and the impinging radiation field**. Some dust can be included as well in the thermal model to account for photoelectric heating.



Schematic description of the gas model coupling the dynamical and thermal evolution of atoms.

An example of a gas disc evolution till steady state

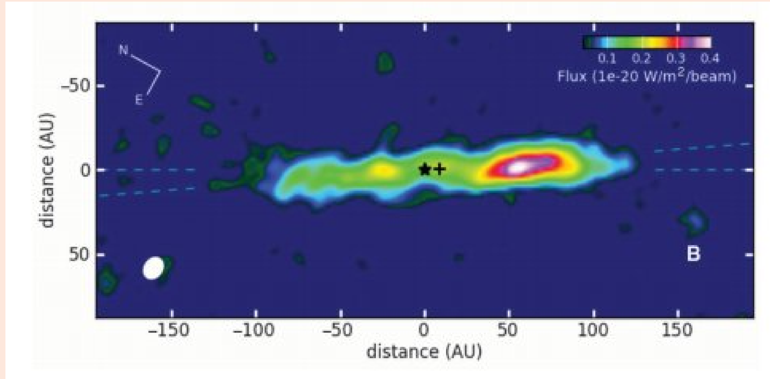
- Gas evolution simulation with our new dynamical/thermal model up to steady state :



Gas is input at **85AU** at a rate $\dot{M} = 0.1M_\oplus$/**Myrs**. T is chosen to be a power law to extract the physics clearly, although this is calculated with Cloudy elsewhere in the poster. An **accretion disc forms inwards** and a **decretion disc outward**. The gas piles up until

β Pic observations of gas

- C, O, Na, Mg, Al, Si, S, Ca, Cr, Mn, Fe, Ni detections in UV absorption (Roberge et al. 2006)
- **O I** detected with Herschel/PACS
- C II observed with Herschel/HIFI (Cataldi et al. 2014)
- CO observations by **ALMA** :

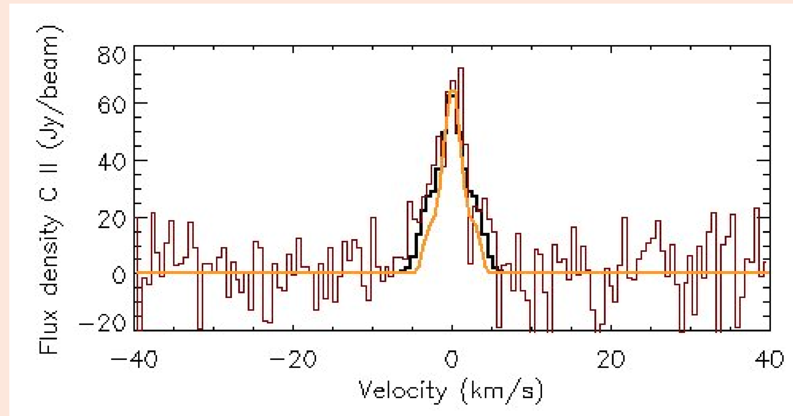


$$\Longrightarrow \left\{ \begin{array}{l} \text{CO gas at 85AU} \\ \dot{M} = 0.1M_\oplus/\text{Myrs} \end{array} \right.$$

CO J=3-2 ALMA observations in β Pictoris (Dent et al. 2014).

β Pic best-fit model

- χ^2 analysis gives the following best fit model :

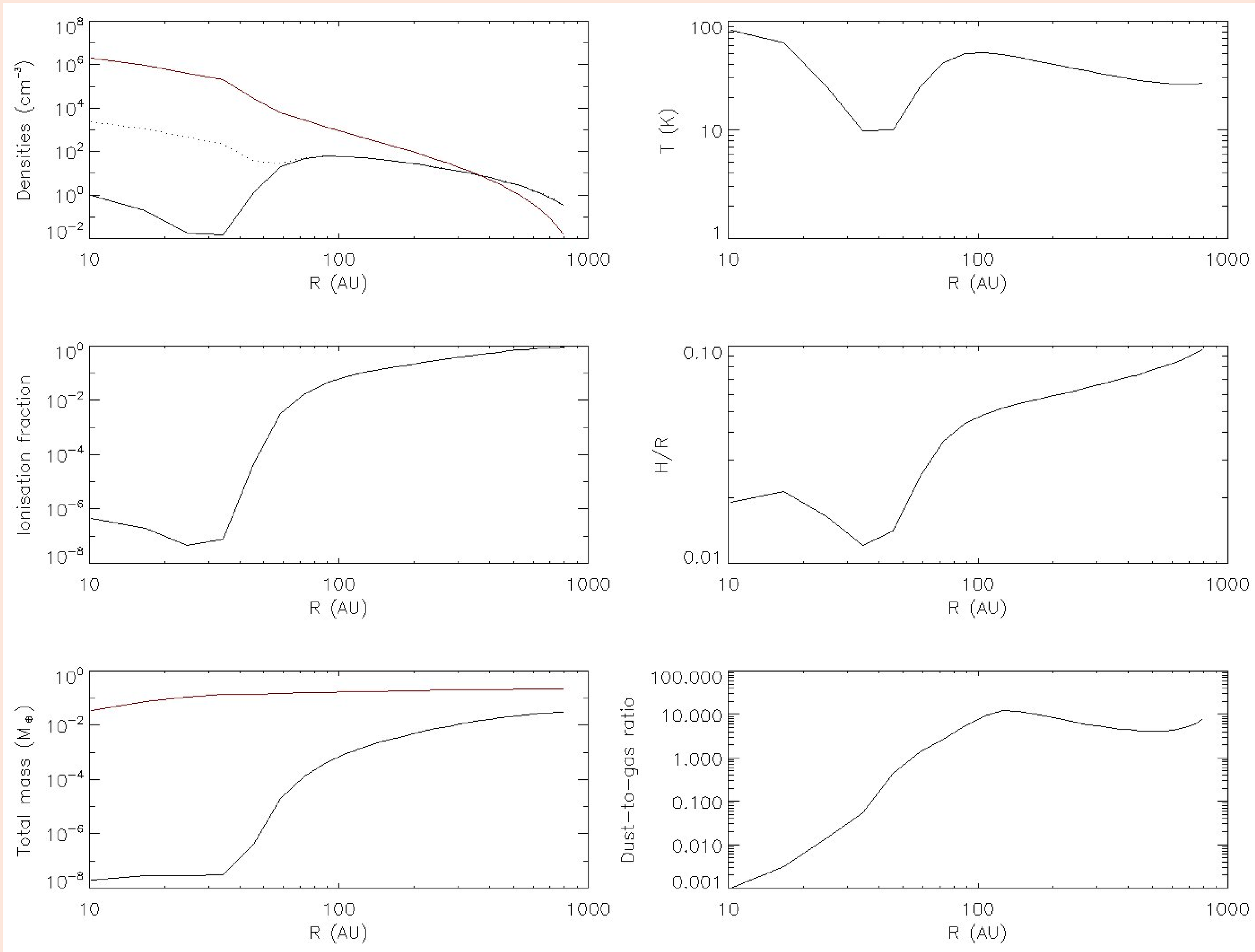


Our best fit model in black superimposed on the observed C II spectrum in red (Herschel).

- C II spectrum reproduced by our gas model setting the free parameters to the right injection rate $\dot{M}$ from CO observations (see above) and a high α value ($\alpha \sim$ **0.3**).

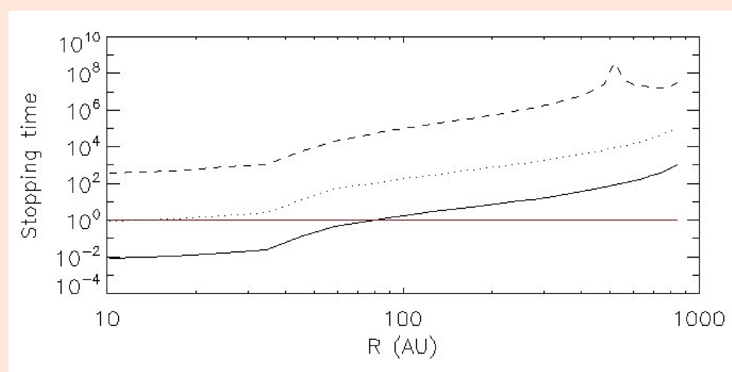
Model predictions for β Pic

- Best-fit model predictions :

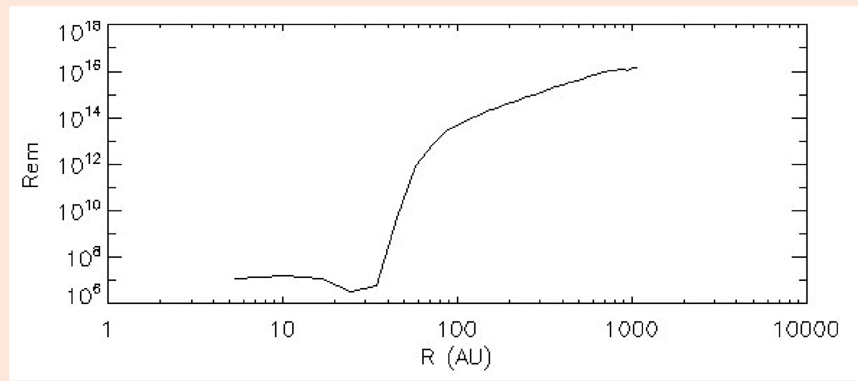


β Pic best-fit model predictions. When two colours, red is C I, black is C II. **R** is the radial distance to the star.

- Gas drag in the inner regions of β Pic ? **MRI** at play ?



β Pic : Dimensionless stopping time versus **R** for 3 different grain sizes 0.5 (solid), 5 (dotted) and 100 microns (dashed).



β Pic : Magnetic Reynolds number with $\mathrm{Re_M} = \mathbf{c_s H}/\eta$, where η is the Ohmic resistivity $\propto \sqrt{\mathbf{T}}/\mathbf{f_e}$

Take-away messages

- Model assumes that CO gas is created in the belt, photodissociated quickly and resulting atoms evolve viscously with an α prescription.
- **This new self-consistent thermo-dynamical gas model explains β Pic** gas observations.
- High α value required + carbon high ionisation fraction –> First **MRI** detection ?
- Gas drag may explain the detection of submicron grains in the inner part of β Pic.
- Model can be used more **generally** to learn about gas in **debris discs**.

Summary and Conclusion

This poster describes the development of a new gas model coupling viscous and thermal evolution in debris discs. It is applied to β Pic and can explain the gas observations in a self-consistent fashion. The proposed scenario is that CO is created in icy belts (collisions, photodesorption), photodissociates and C and O evolve viscously with an α prescription. Carbon is found to be highly ionised due to FUV radiation from the interstellar radiation field. β Pic gas observations are well explained with a high α value. Many **predictions of the gas state** are given (density, temperature, ionisation fraction...) for β Pic. This model could be used on a larger sample or even to understand debris disc gas in general. It also gives potentially some insights on MRI that could lead to further developments.

ERC funded project through grant number 279973

Contact: qkral@ast.cam.ac.uk