Protoplanetary disks including radiative feedback from accreting planets

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Introduction and objectives

While recent observational progress is converging on the detection of compact regions of thermal emission due to embedded protoplanets, further theoretical predictions are needed to understand the response of the parent disk to the planet formation radiative feedback.
We use 2-D hydrodynamical simulations to follow the evolution of a viscous protoplanetary disk in which there is embedded a luminous Jupiter-mass planet.
The impact of the radiative feedback is quantified for a Jupiter-mass planet emitting at $10^{-4}L_{sun}$, kept at 68 au of a Solar-mass star, and meant to approximate the conditions of HD100546b, where a planet in formation is suspected to lies (Quanz et al. 2013b).
The feedback increases the luminosity of a 10 au circumplanetary region from 1.3×10^{-5} (when there is no feedback) to $1.3 \times 10^{-3}L_{sun}$. The changes produced by the radiative feedback are mainly due to the local pressure work done by the planet radiation onto the gas. This pressure work stimulates a local enhancement of the accretion rate through the disk in the vicinity of the planet, producing a hotter and more luminous disk.

Model

We modify a beta release of the public two-dimensional hydrodynamics code called FARGO (Masset 2000) dedicated to planet–disk interactions by solving the Navier- Stokes and continuity equations.

We implement into the energy equation:
- A radiative cooling function, assuming that the disk radiates locally as a blackbody.
- The radiative feedback of the planet, ranging from $10^{-5} – 10^{-3}$ L_{sun} (Mordasini 2013)

Planet feedback:

The energy from the planet is distributed in a region with area πH_p^2, therefore:

$$Q_p^+ = \frac{L_p}{\pi H_p^2}$$

Total dissipation: Viscous dissipation + planet dissipation

$$Q^+ = Q_v^+ + Q_p^+$$

Results

Temperature profile

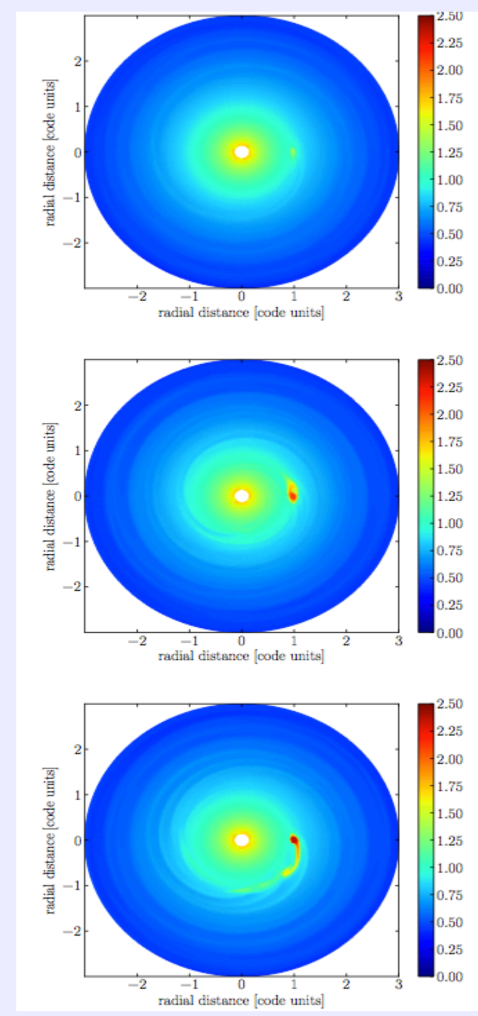

Figure 1. From top to bottom; the first figure corresponds to Lp = 0, the second one to Lp = $10^{-4}L_{sun}$, the third corresponds to Lp = $10^{-3}L_{sun}$. The corresponding temperature peaks at the planet location are; T = 10 K (top figure), T = 130 K (second figure), and T = 241 K (bottom figure).
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Spectral signature

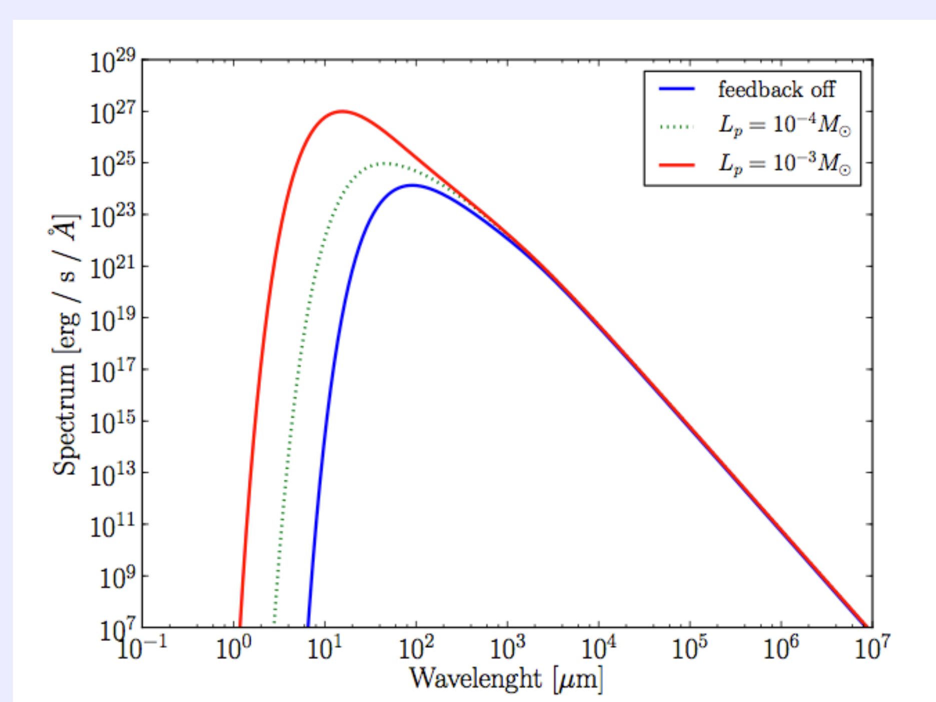

Figure 2. Spectrum of the disk after 600 orbits. We compare the cases with: Lp = 10^{-4}, Lp = 10^{-3}, and Lp = 0 L_{sun}.

Comparison with observations

Quanz et al. (2013) calculated the luminosity of the hot spot around the candidate HD100546b, assuming a point source embedded in a region of 0.1 arc- sec (~ 10 au) located at 68 au from the central star, reporting an emission of about $10^{-3}L_{sun}$ that can be compared with our model.

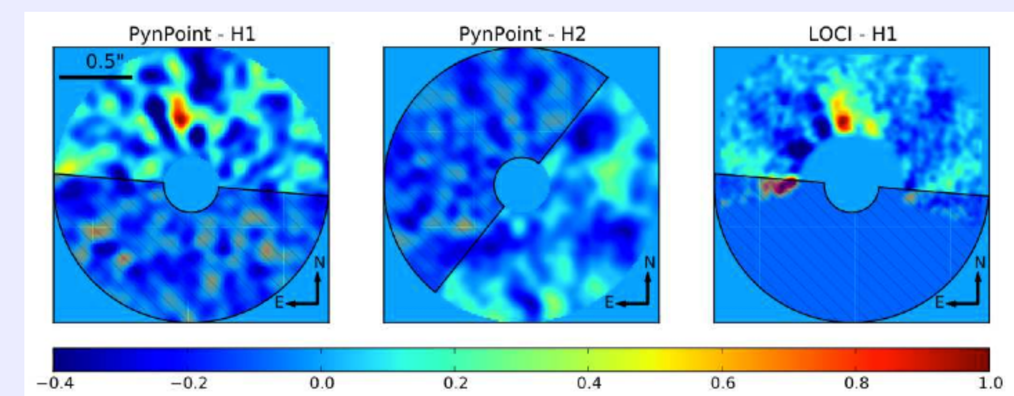

Figure 3. NACO/APP L′ images of the circumstellar environment of HD100546. From left to right: Final PynPoint images of hemisphere 1 and hemisphere 2 and final LOCI image of hemisphere 1. An emission source is clearly detected in left and right panel. The shaded area indicates the region that was only covered by the low sensitivity hemisphere of the APP. The images are scaled with respect to their peak flux. Credit: Quanz et al 2013

Accretion rate

The feedback increases the luminosity of a 10 au circumplanetary region from 1.3×10^{-5} (when there is no feedback) to $1.3 \times 10^{-3}L_{sun}$, and the spectral maximum is shifted from 76 to 24 microns.

The luminosity can be associated to the accretion rate, therefore an excess of luminosity should have a concomitant enhancement of the accretion rate.

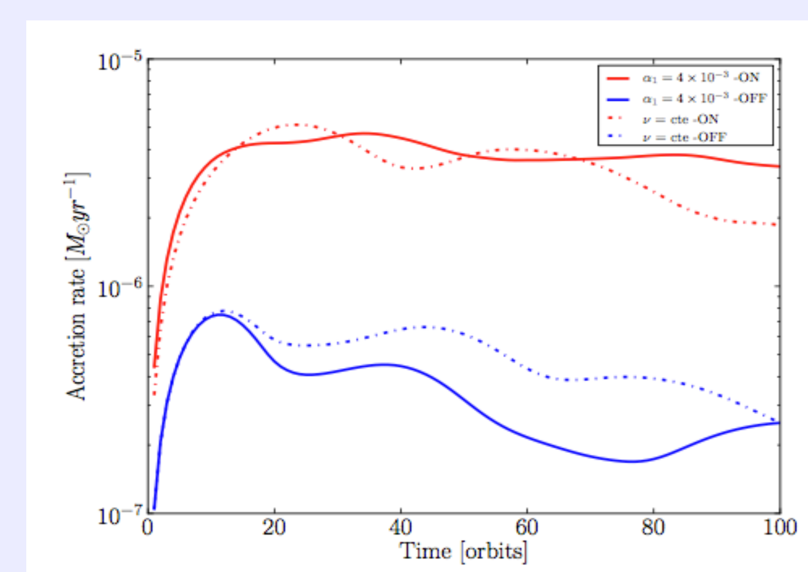

Figure 4 Accretion rate at the planet location. when the feedback is activated, the accretion rate in the circumplanetary orbit is enhanced by at least one or- der of magnitude, independent of the viscosity prescrip- tion.

Conclusions

We find that planet luminosities below Lp < $10^{-4}L_{sun}$ barely modify the disk physics: the cavity formed by the planet does not show any noticeable modification when compared with the feedback-off case and the emitted spectrum of the disk remains practically unchanged.

When we include more energetic planets, e.g., Lp >~ $10^{-4}L_{sun}$, changes in the disk are easily observed: the additional energy input from the planet heats up the disk, enhancing the accretion rate and the energy output of the disk in a non-linear process. The changes produced by the radiative feedback are mainly due to the local pressure work.

Consequently, the spectrum and luminosity of the disk are modified, shifting the emissions to higher amplitudes and shorter wavelengths.

Finally, we build a model for the system around HD 100546 (Quanz et al. 2013), reproducing quite well the observed luminosity of the region around the accreting candidate planet HD 100546b

Our model indicates that this system contains a forming planet with a luminosity of ~ 10−4 $L_\odot$.

Literature cited

Quanz et al. ApJ, 766L, 1Q

Mordasini, C. 2013 A&A, 558, 1

Masset, F. 2000, A&AS, 141, 165

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