Multi-wavelength study of the debris disk of βPic

Miriam Keppler, Anne-Marie Lagrange, Julien Milli, Jean-Charles Augereau, and Hervé Beust

IPAG Institut de Planétologie et d'Astrophysique de Grenoble

ESO

1. Introduction

Since its discovery in 1984 (Smith&Terrile,1984), the debris disk of βPic has been studied extensively from the ultraviolet to millimeter wavelengths. Its nearly edge-on appearance allows in particular to examine the disk's vertical structure which reveals several asymetries (Kalas & Jewitt (1995), Pantin et al. (1997), Mouillet et al. (1997a), Heap et al. (2000)). Dynamical modeling (Mouillet et al. (1997b), Augereau et al. (2001)) showed that the inner warped disk (~70-150 au) can be explained by the gravitational influence of a planet. This theory could be confirmed by the discovery of a massive (8-14 MJup) planet, βPic b, orbiting the central star at 8-9 au on an inclined orbit by 3° with respect to the disk midplane (Lagrange et al. (2009), Lagrange et al. (2012)).

2. Multi-wavelength study

Aims:

- Revisit models of the debris disk of βPic (i.e. Augereau et al.. (2001)).
- Constrain system parameters such as age, planet mass and orbital parameters, dust grain properties

Method:

- Simulate numerically the dynamical evolution of the debris disk, taking into account the known orbit of planet βPic b
- Produce synthetical images in scattered light and thermal emission and reduce them from the point of view of an observer
- Adapt simulation parameters comparing to observation data in multiple wavelength ranges (e.g. Telesco et al. (2005), Golimowski et al. (2006), Lagrange et al. (2012), Apai et al. (2014), Dent et al. (2014), Milli et al. (2014)) to find best fitting model

3. Generating synthetical images

The model

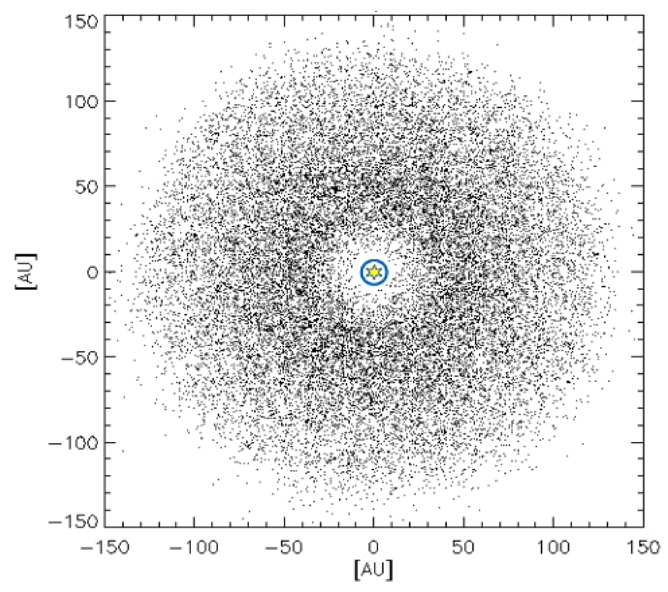
- The debris disk is considered to consist of two populations: Parent bodies (PB) and dust grains with sizes between ~ 1 and 1000 microns which are continuously generated by mutual collisions between PB
- Dust particles are subject uniquely to gravitation and radiation pressure

$$\beta_{pr} \equiv F_{rad}/F_{grav}$$

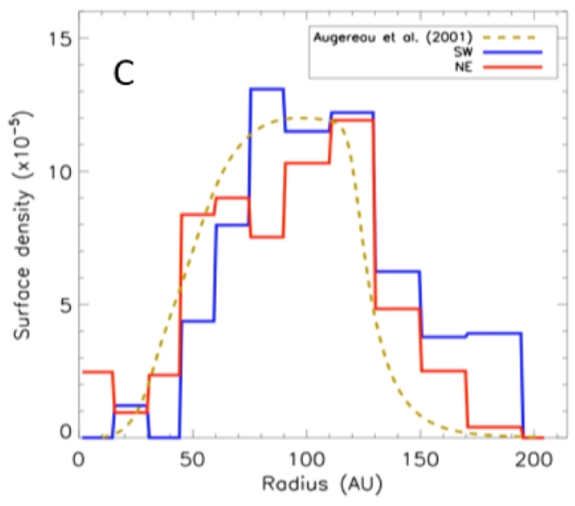
- The two components are simulated separately in 3 steps, our model consists in 4 steps: 1) dynamical evolution of the PB (N-Body simulations) under the gravitational perturbation of a planet, 2) analytical computation of dust distribution, 3) computation of emitted and scattered light and 4) simulation of real observation

1. Step: N-Body simulations

- Dynamical evolution of planet and 25000 massless test particles representing the PB during simulation lifetime (25 Myr) using the RMVS (Regularized Mixed Variable Symplectic) integrator (Levison&Duncan, 1994)
- Initial conditions of PB: Surface density from Augereau et al. and consistent with ALMA observation data (Dent et al., 2014)
- Planet is set on circular, inclined orbit



Ole-on view of the system at t=0: star, planet (blue orbit) and test particles representing the PB disk



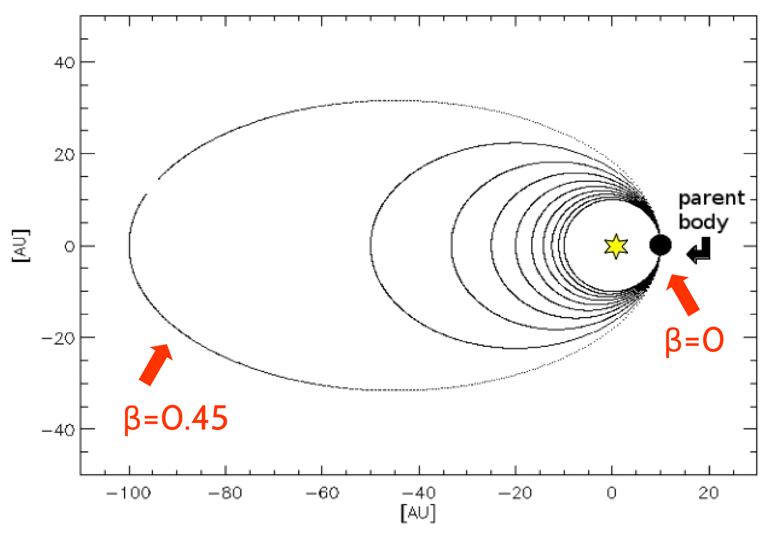
PB surface density of ALMA observations and modeled by Augereau et al. (2001) (Dent et al., 2014)

2. Step: Dust distribution

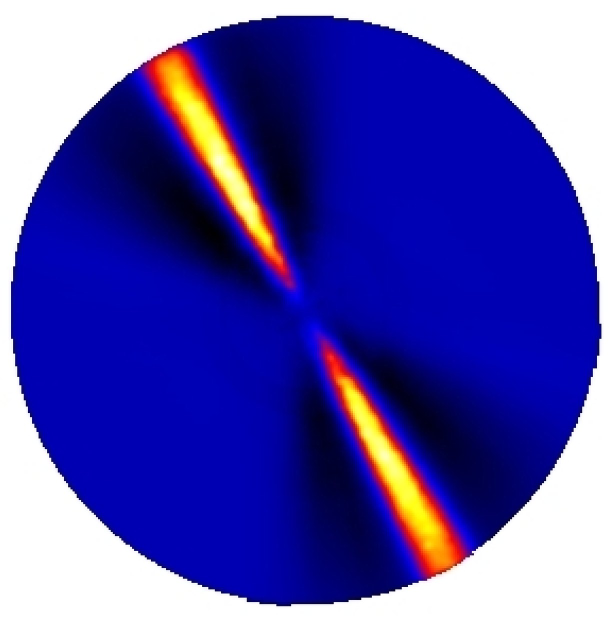
- Assuming that every PB in final configuration produces dust grains of different grain sizes corresponding to different values of beta
- Orbital parameters (e.g. eccentricity) for grains depending on beta and on current distance of its PB to the star
- Calculate orbits for each PB and each considered beta
- Fill these orbits with quantity dust grains

3. Step: Flux maps

- Computate flux emitted by dust grains in scattered light and thermal emission using GraTeR (Augereau et al., 1999)
- Quantitative ponderation of flux emitted by different grain sizes respects the distribution of local collisional equilibrium
- Flux maps can be computed at any spatial projection



Examples of orbits of dust grains at different beta prodices by a PB on a circular orbit



Synthetical image of the disk at 3.8 microns reduced by the PCA method (cf. Milli et al. (2014))

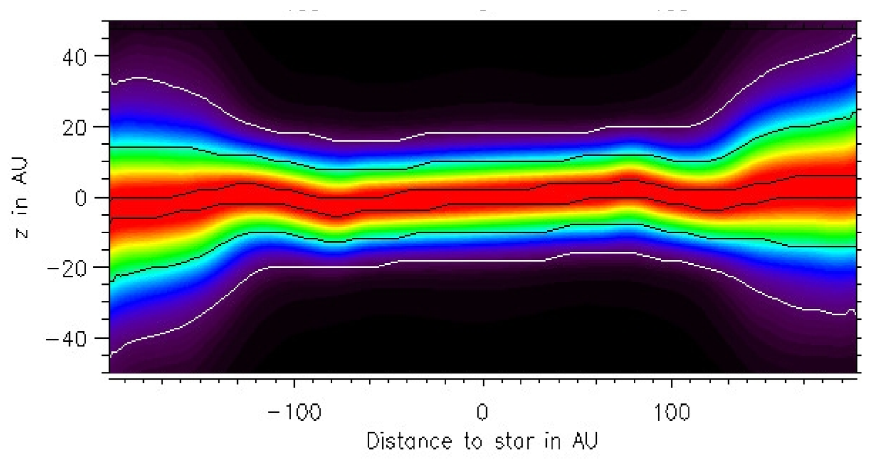
4. Step: Accounting for instrumental PSF and reduction biases

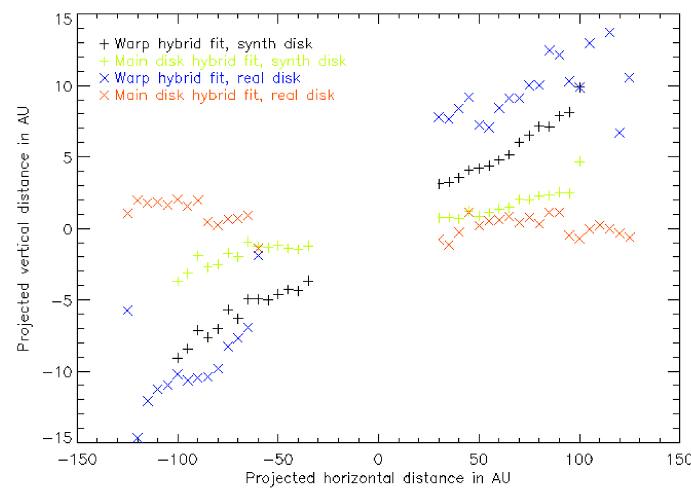
- To compare with real observation data, convolution of synthetical image with considered instrument PSF
- Using the same reduction procedures (PCA, cADI,...) to compare with observation data under same hypothesis

Poster by J. Milli on ADI reduction at Lp

4. Measurements

- Examination of the disk's vertical profile normalized to its midplane (cf. Augereau et al. (2001), Golimowski et al. (2006))

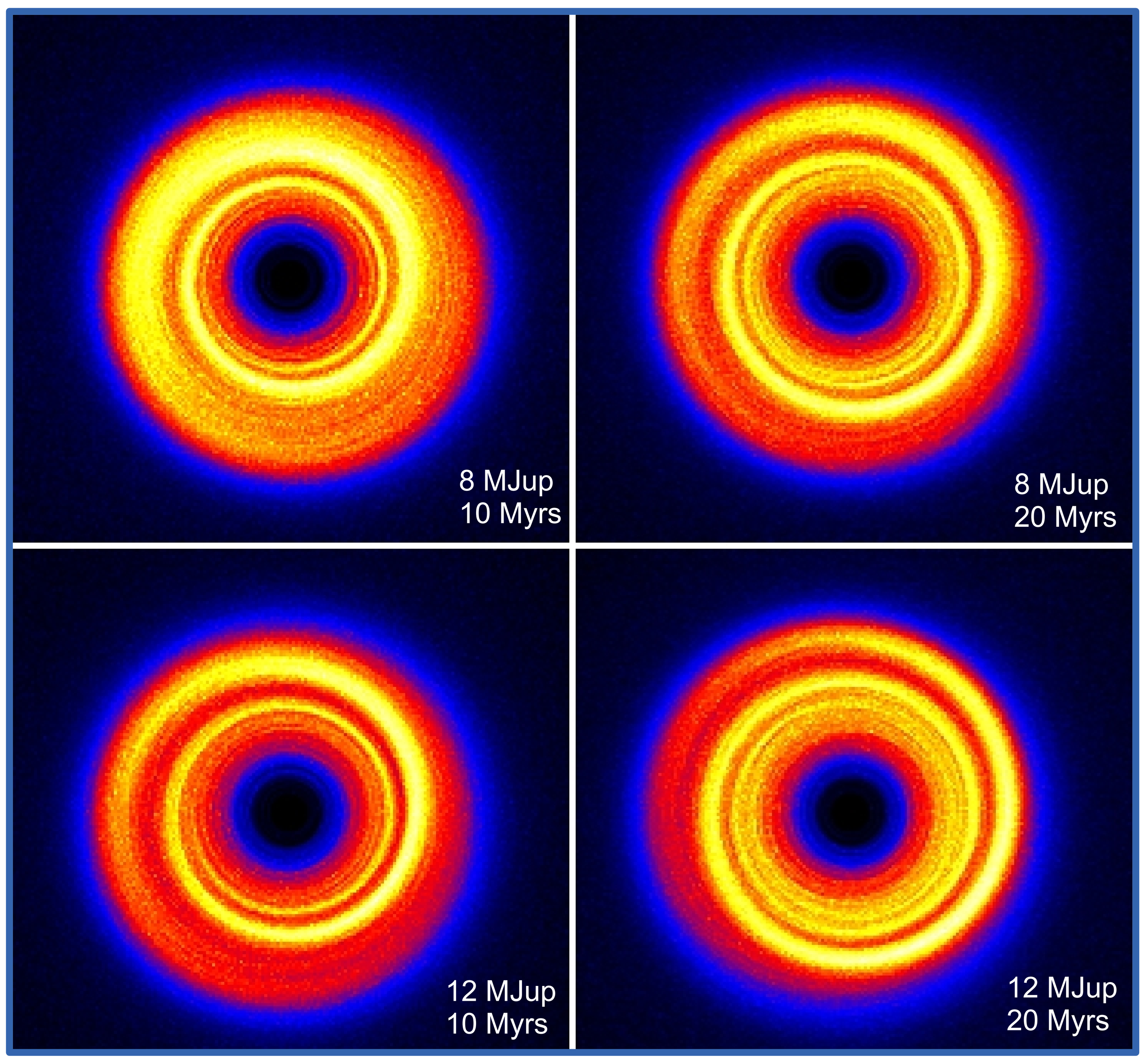




- Measurement of disk and warp centroids, position angle and surface brightness distribution via single lorentzian fitting and hybrid fitting methods (cf. Lagrange et al.. (2012))

5. Results

- PB disk shows spiral structure, even with planet on circular orbit which breaks the initial cylindrical symetry
- Spiral structure also seen on synthetical images in scattered light and thermal emission
- Structure and extension depending on planet mass and evolution time



Can spiral structure account for radial asymmetries on the both NE and SW sides of the observed disk and could it be an alternative explanation therefore without introducing any additional planet?

6. Conclusions and outlook

- Simulations reproduce consistently warped feature in inner (70-150 au) disk range
- Spiral structure has to be tested about its influenced on the flux maps seen in scattered light and thermal emission
- New SPHERE observations at different wavelengths can bring information about the dust color

References

Augereau, J. C., Lagrange, A. M., Mouillet, et al. 1999, A&A, 348, 557
Augereau, J. C., Nelson, R. P., Lagrange, A. M., et al. 2001, A&A, 370, 447
Apai et al, 2014, ApJ, submitted
Dent, W. R. F., Wyatt, M. C., Roberge, A., et al. 2014, Science, 343, 1490
Golimowski, D. A., Ardila, D. R., Krist, J. E., et al. 2006, AJ, 131, 3109
Heap, S. R., Lindler, D. J., Lanz, T. M., et al. 2000, ApJ, 530
Kalas, P., & Jewitt, D. 1995, AJ, 110, 794
Lagrange, A.-M., Gratadour, D., Chauvin, G., et al. 2009, A&A, 493, L21
Lagrange, A.-M., Boccaletti, A., Milli, J., et al. 2012a, A&A, 542, A40
Levison, H.F. & Duncan, M.J. 1994, Icarus, 108, 1
Milli, J., Lagrange, A.-M., Mawet, D., et al. 2014, A&A, 566, 91
Mouillet, D., Lagrange, A. M., & Beuzit, J.-L. 1997a, A&A, 324, 1083
Mouillet, D., Larwood, J. D., Papaloizou, J. C. B., & Lagrange, A.-M. 1997b, MNRAS, 292, 896
Pantin, E., Lagage, P.-O., & Artymowicz, P. 1997, A&A, 327, 1123
Smith, B. A. & Terrile, R. J. 1984, Science, 226, 1421
Telesco, C. M., Fisher, R. S., Wyatt, M. C., et al. 2005, Nature, 433, 13