

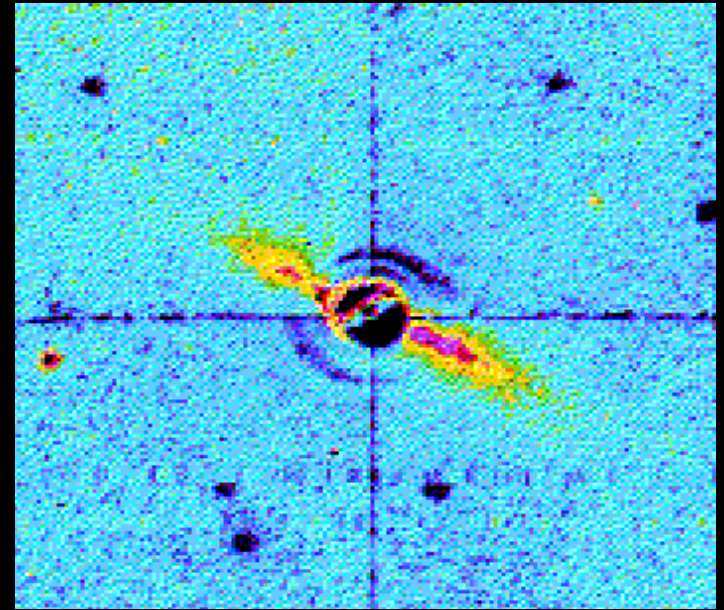
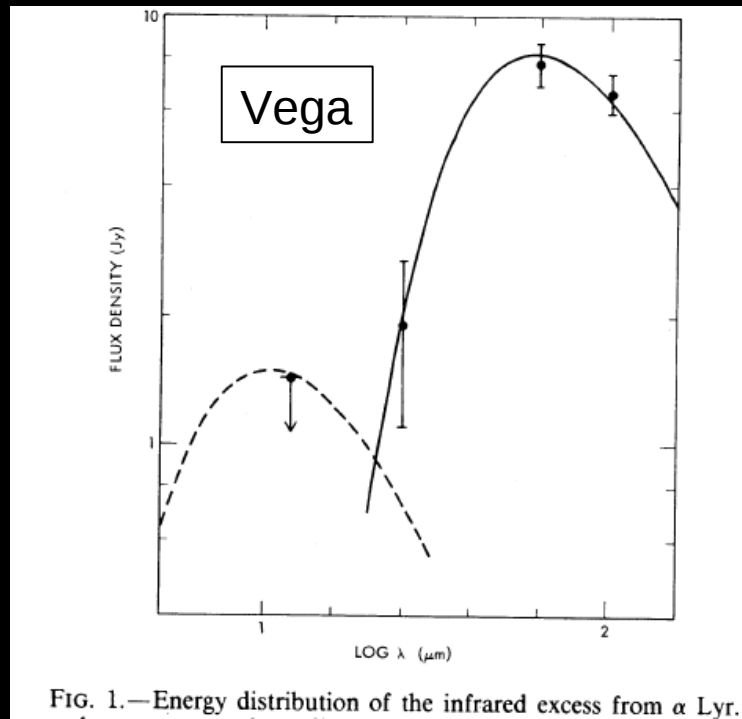
The β Pictoris system : disk, gas, and planet

*A.-M. Lagrange**

J. Milli, A. Boccaletti, G. Chauvin, M. Bonnefoy, D. Mouillet, J. Girard, H. Beust, N. Meunier, M. Sterzik, D. Apai, D Rouan, D Ehrenreich, S Lacour

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OPSII– march 2012



Aumann et al. (1984): Vega

Smith & Terrile (1984)

flattened disk => planet formation

Aumann (1985): IR excesses
 Vega, α PsA, ϵ Eri, β Pic

Small, short lived grains => replenishment from larger bodies

<1mic

1-3 mic

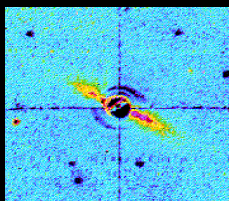
8-25mic

60 mic

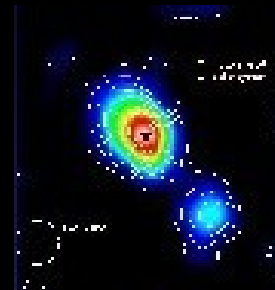
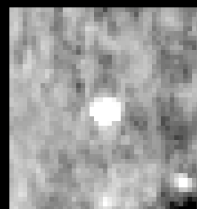
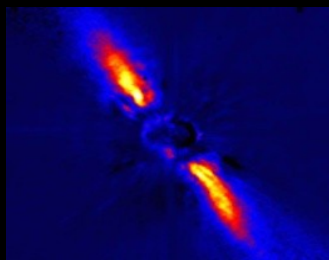
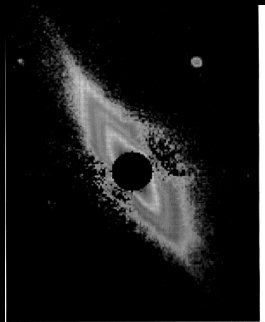
850mic

1.3mm

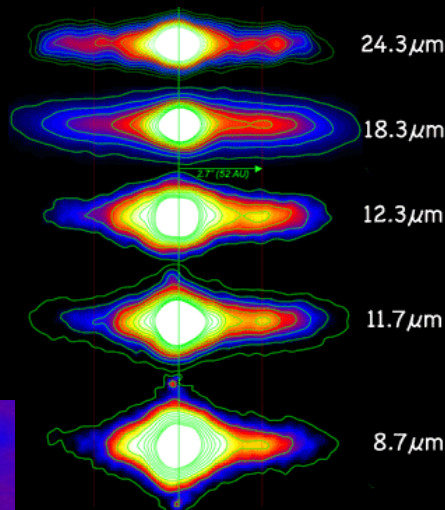
1985



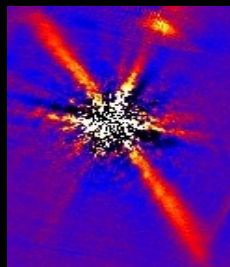
1995



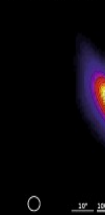
2000



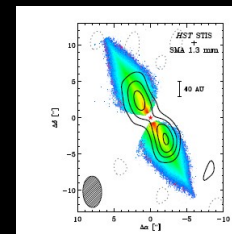
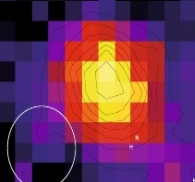
2010



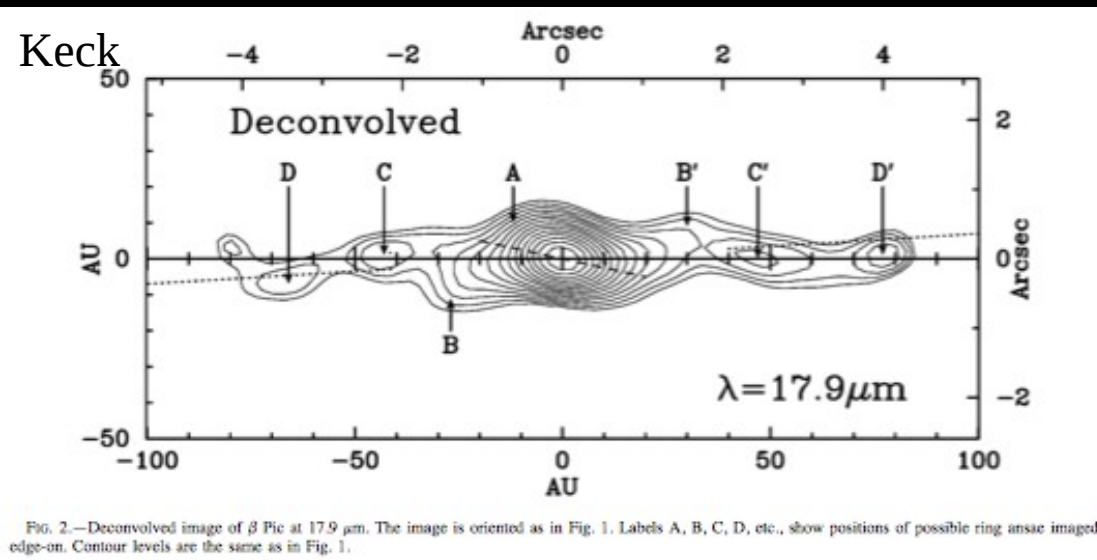
Beta Pic & PSF 70um



Beta Pic 500um



Gaps, belt-like structures (thermal IR)

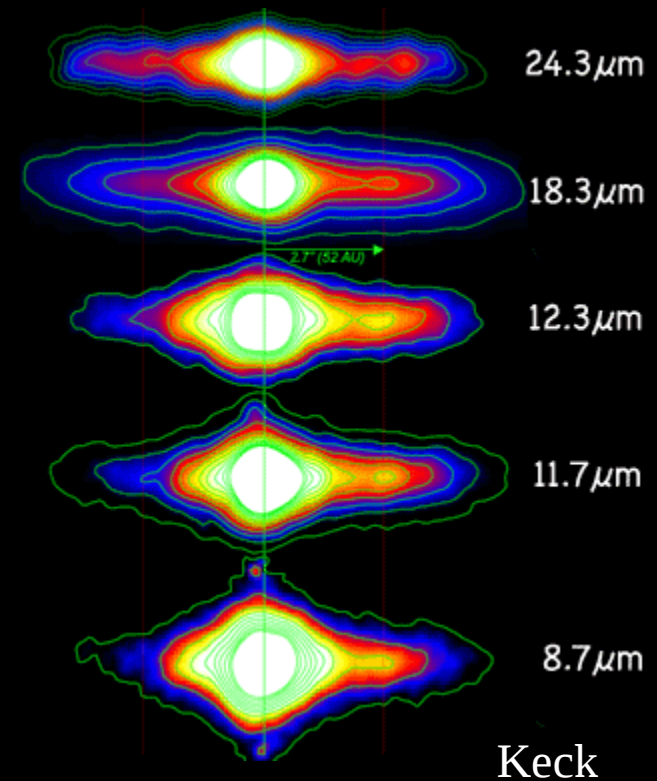


Wahhaj et al (2002)

See also *Okamoto et al (2003)*: Subaru $10 \mu\text{m}$ spect

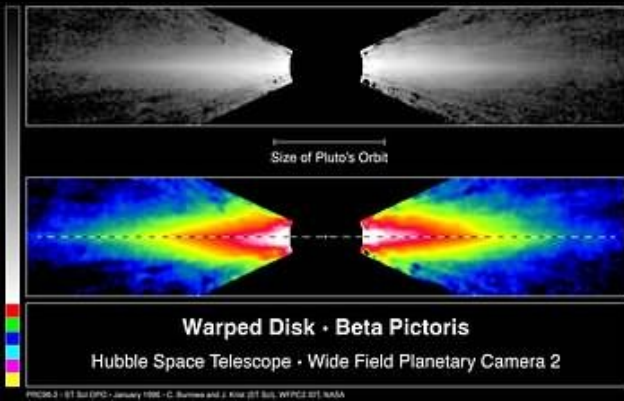
Origin of the clumps:

- on-going destruction of a large body?
- planet sculpting? *Freistetter (2007)*: EGPs 12-25-44AU

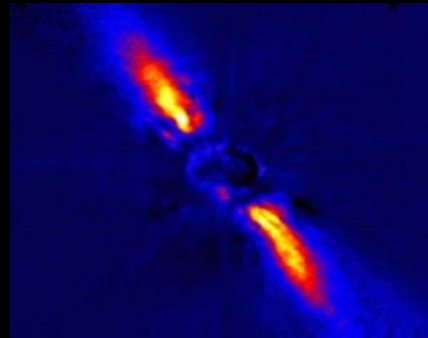


Telesco et al (2005)

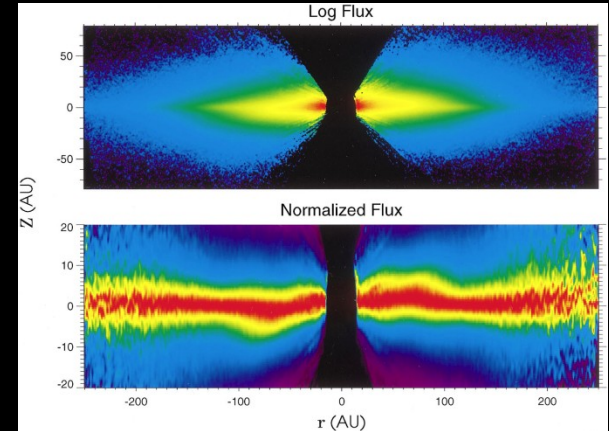
Inner (< 200 AU) disk shape



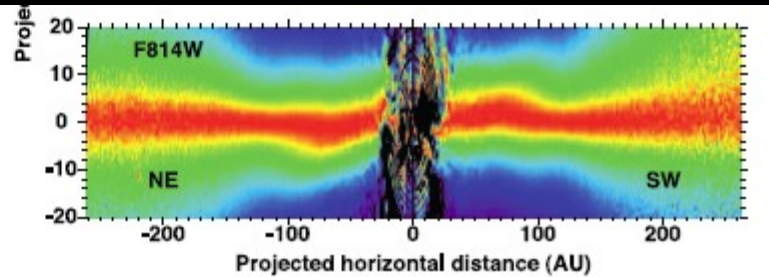
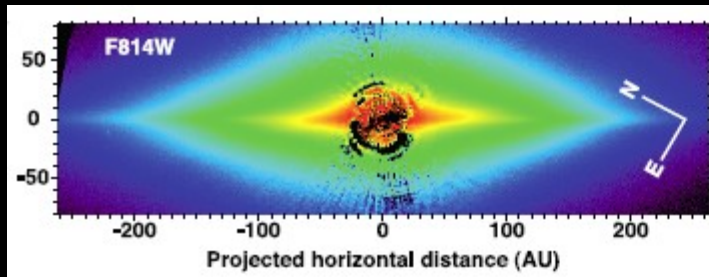
Burrows et al (1997)



Mouillet et al (1997)

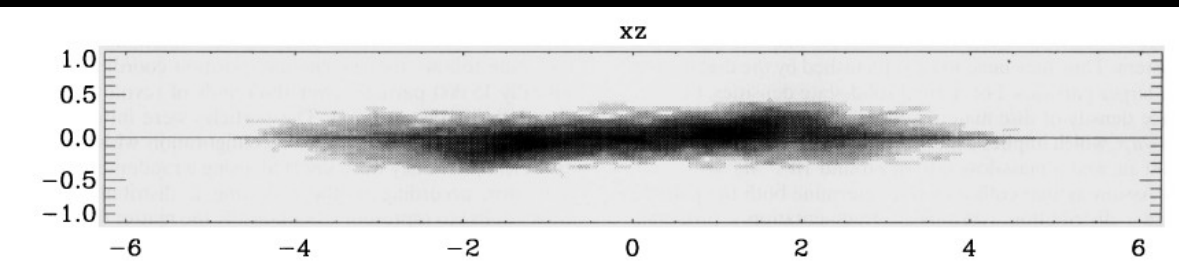
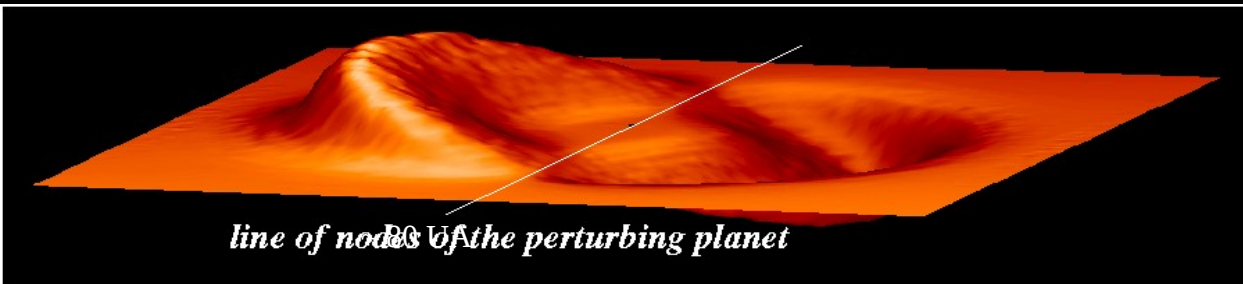
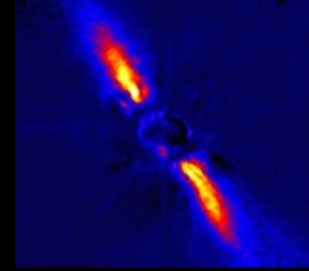


Heap et al (2000)

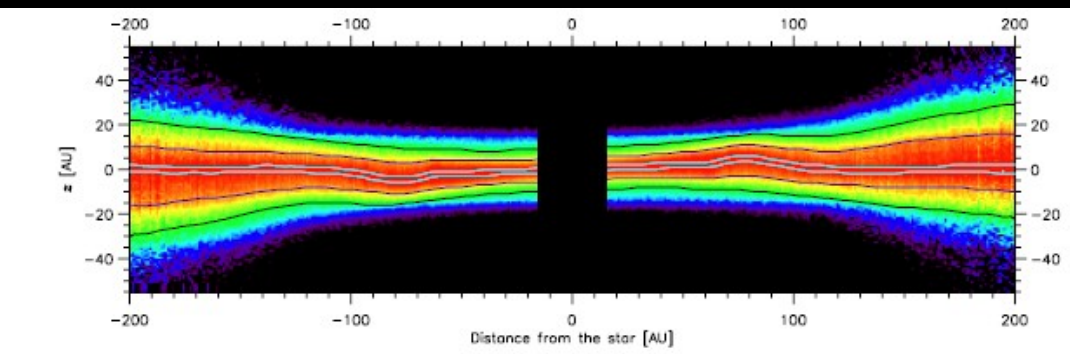


HST/ACS Golimowski et al (2006)

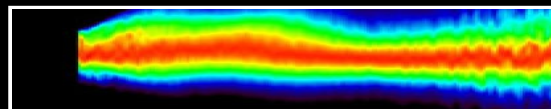
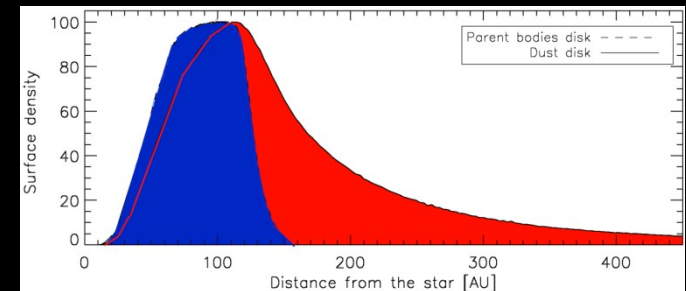
Planet on a 5° inclined orbit,
+ disk of planetesimals (70-150AU)



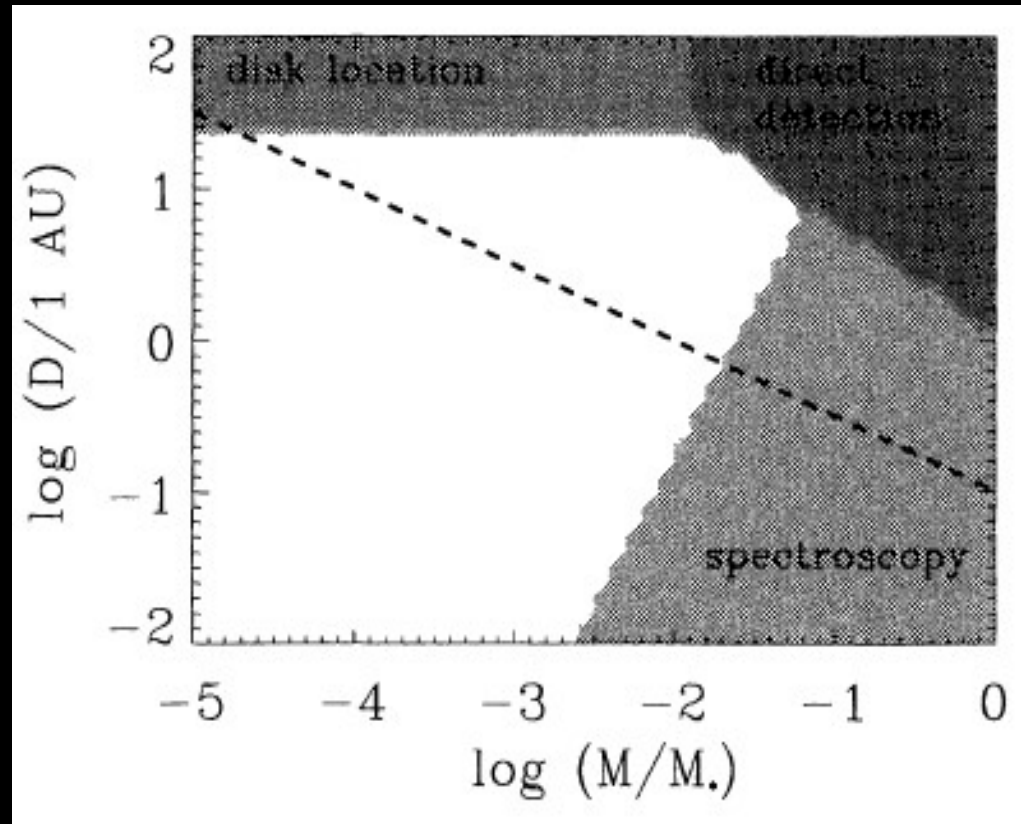
Mouillet et al. (1997)



Augereau et al. (2001)



Modeling the warp

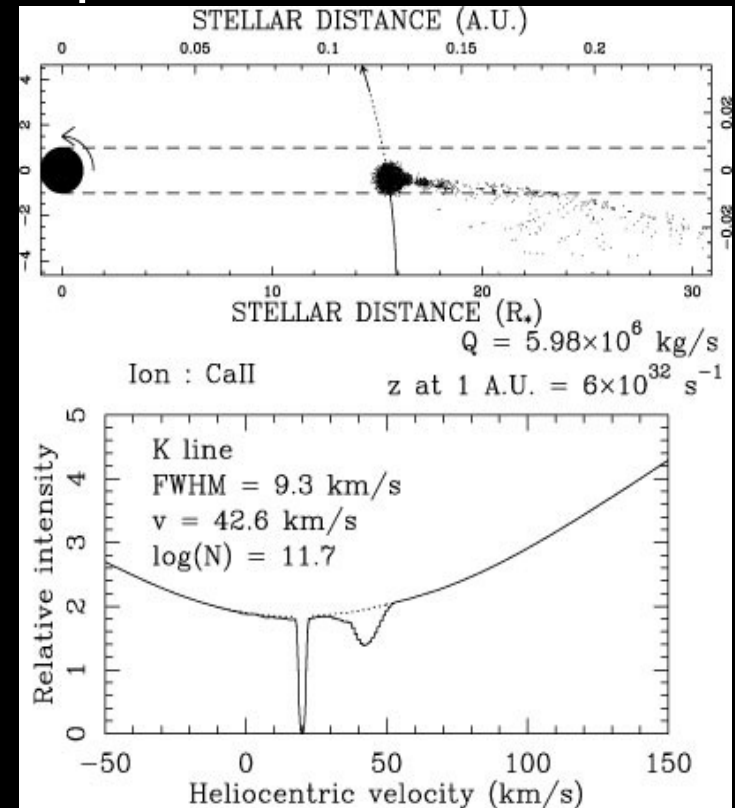
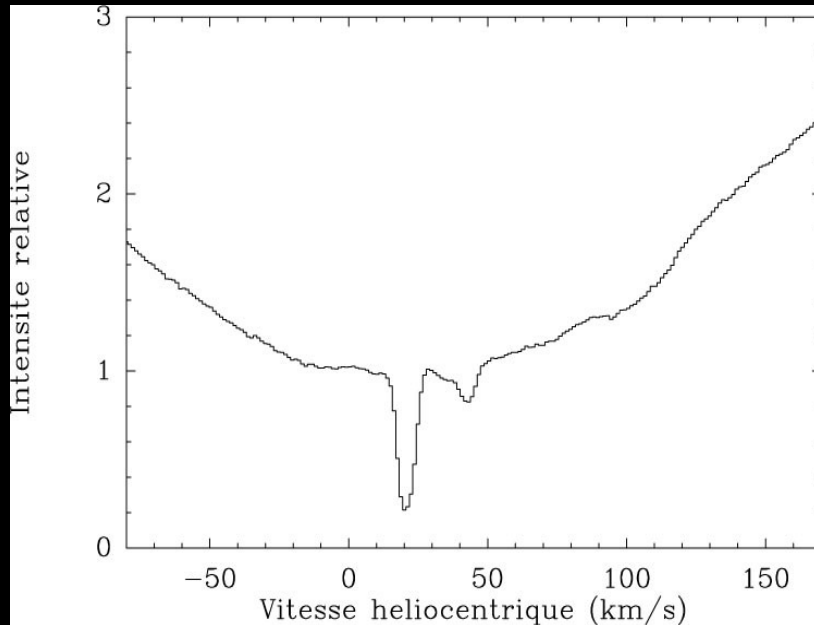


Mouillet et al. (1997)

$$\log \left(\frac{R_w}{10 \text{ AU}} \right) = 0.29 \log \left(\frac{M}{M_*} \left(\frac{D}{10 \text{ AU}} \right)^2 \frac{t}{t_{\text{unit}}} \right) - 0.2.$$

Late 80's: Falling Evaporating Bodies on β Pictoris

=> indirect evidence for planet ?



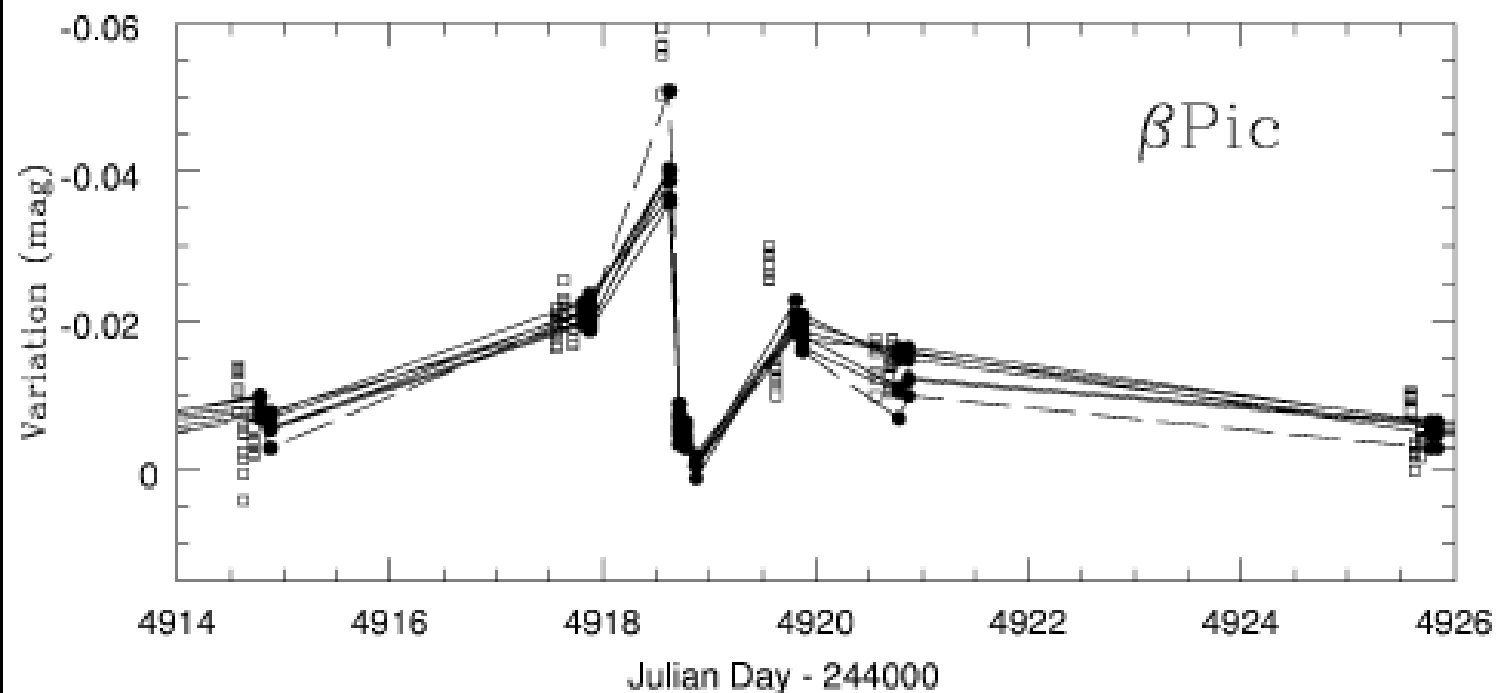
*Vidal-Madjar, Lagrange, Roberge
Beust, Morbidelli, etc*

$a \sim 10 \text{ AU}; 0.05 < e < 0.1$

FEB in 4:1 or possibly 3:1 resonance

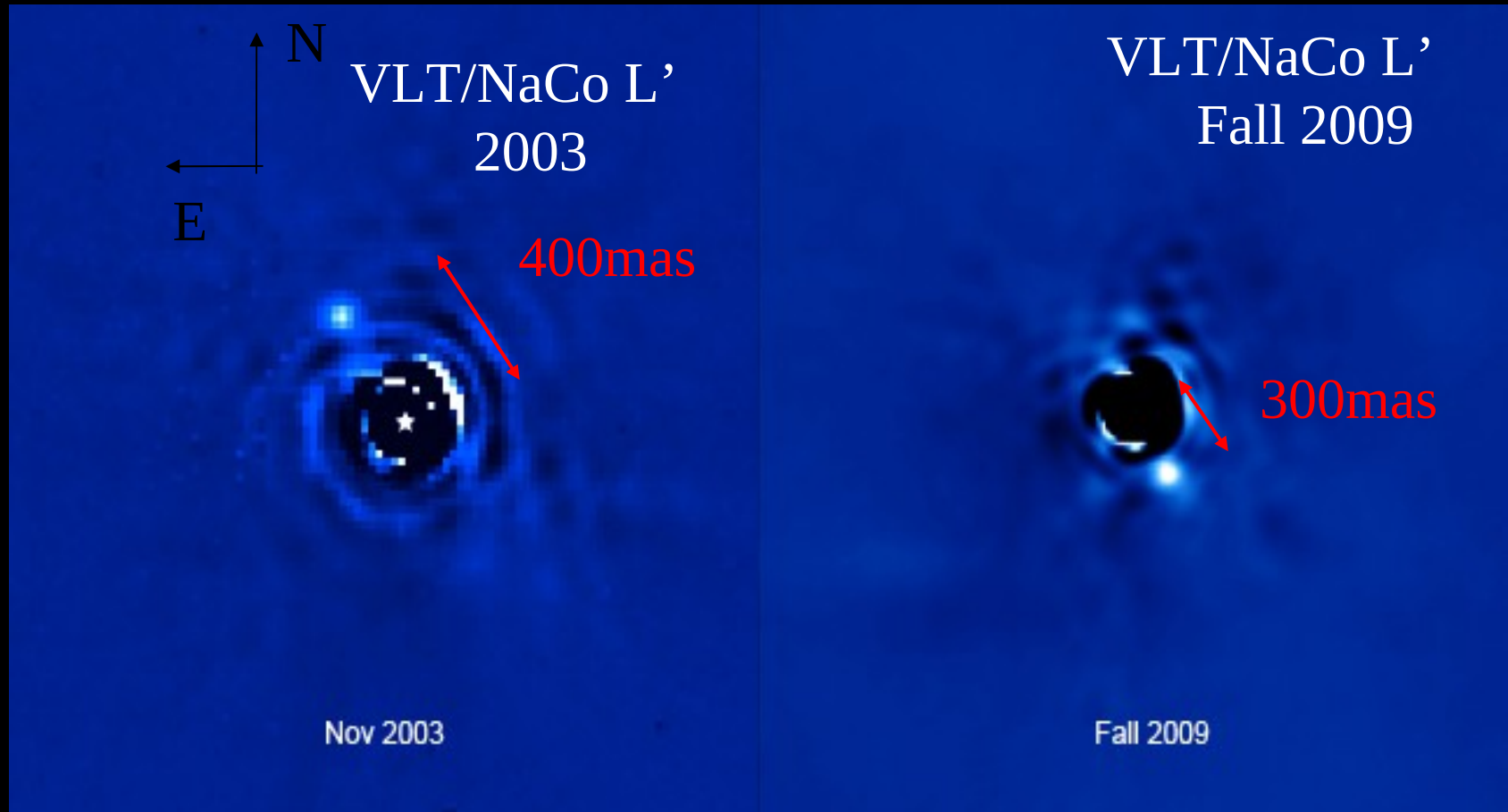
Total mass evaporated : a few Earth masses

B Pic light variations (Nov. 10, 1981)



Lecavelier et al (1995, 1997)

Planet around β Pictoris



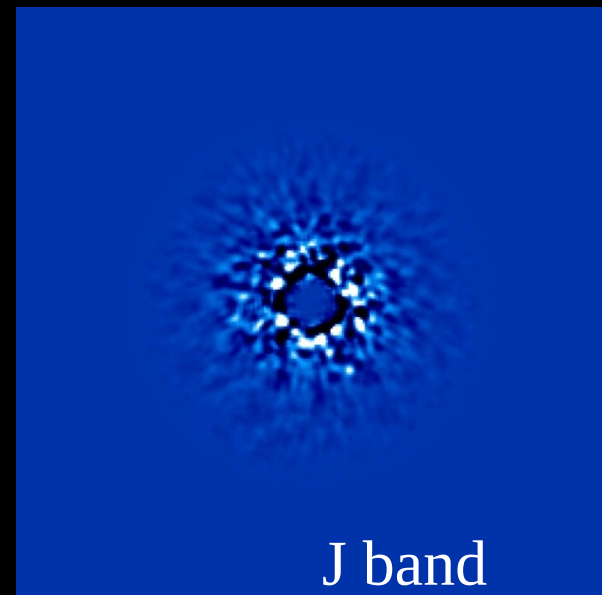
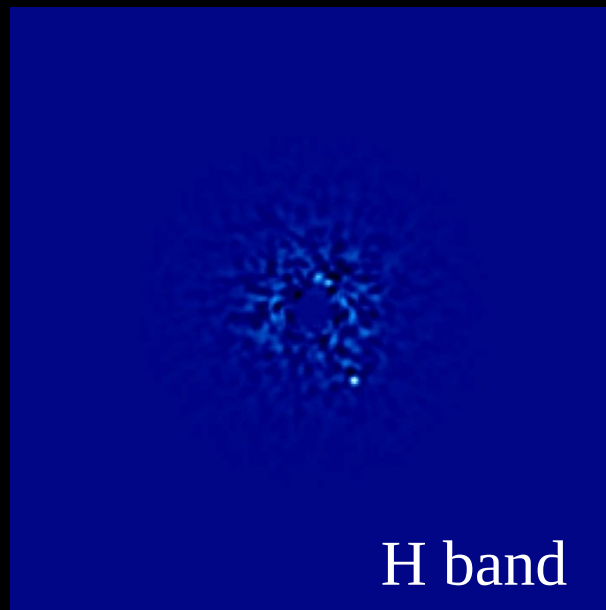
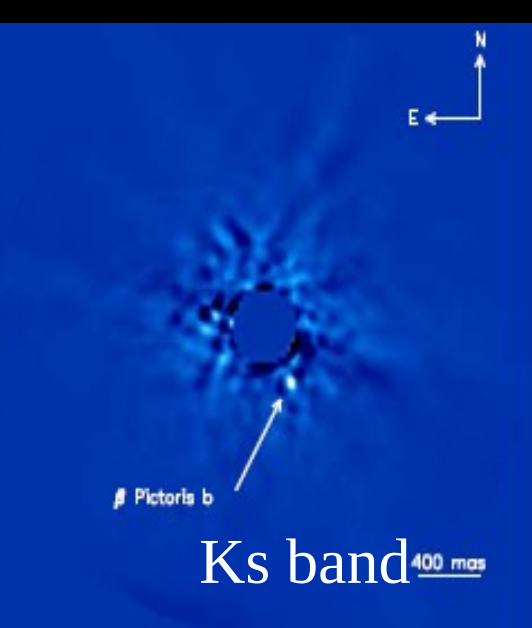
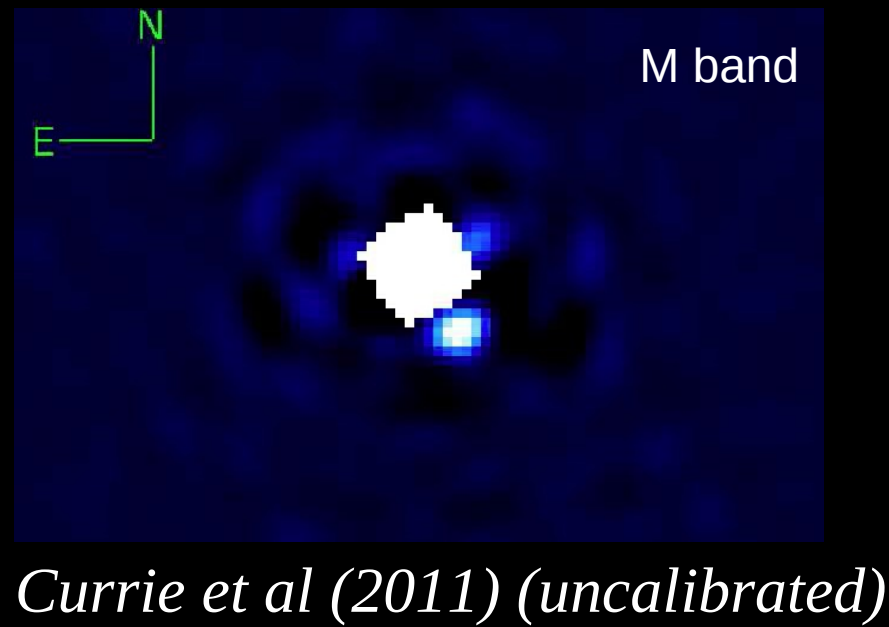
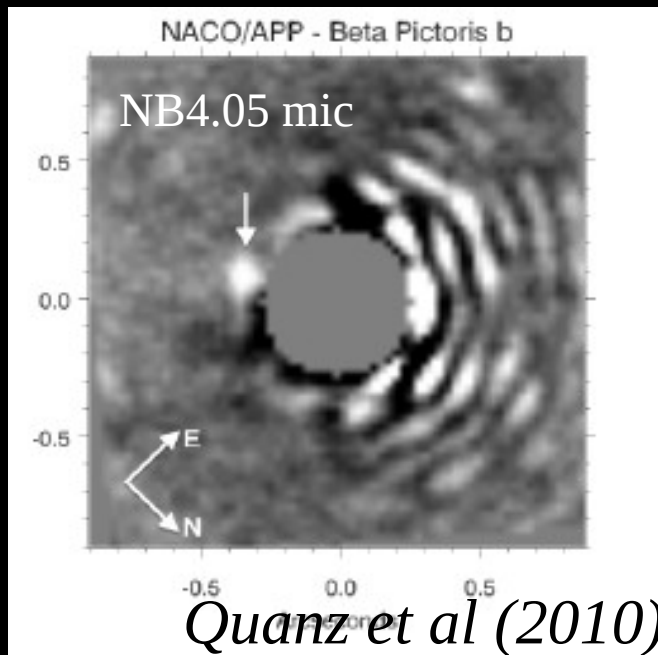
Lagrange et al (2009)

$\Delta L' = 7.8 \pm 0.2$ mag

Sep = 298 ± 16 mas

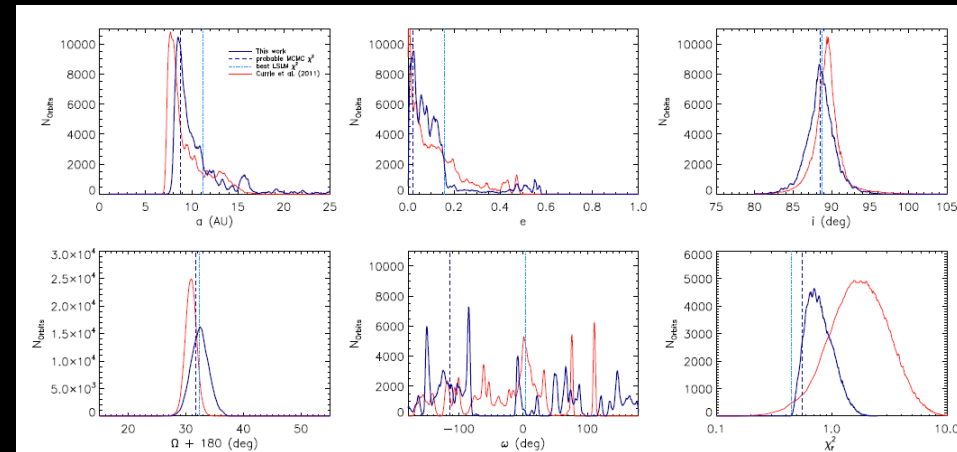
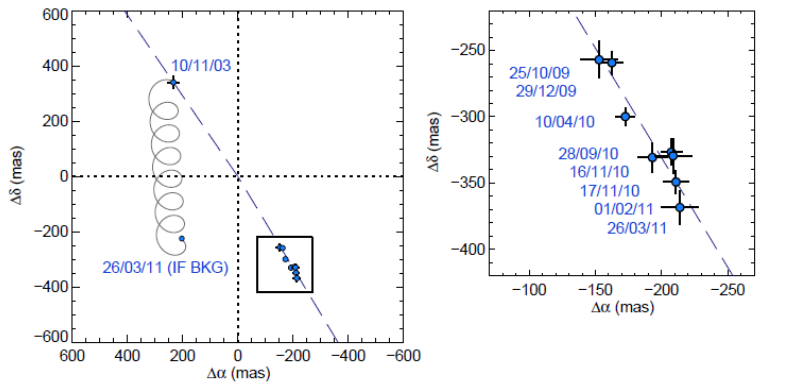
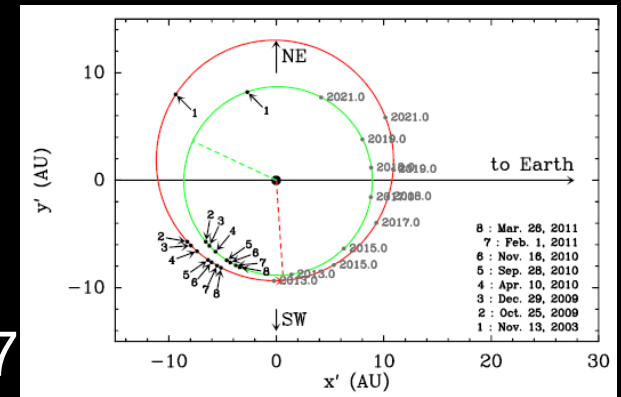
PA $\sim 210.6 \pm 3.6^\circ$

Lagrange et al (2010)



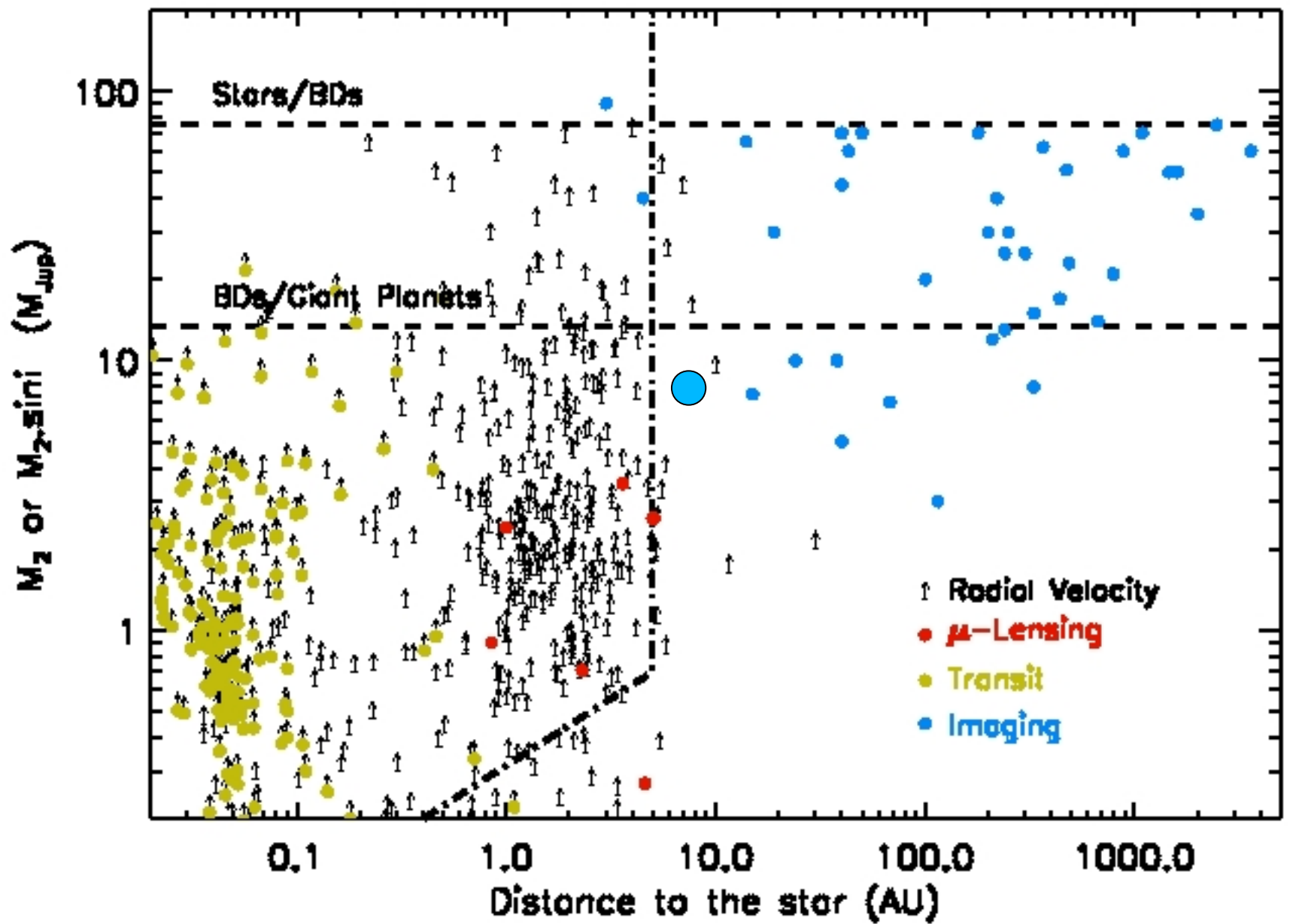
β Pic b properties

- Orbit: $a=8-9$ AU; $e < 0.17$; $i \sim 88.5 \pm 1.7$



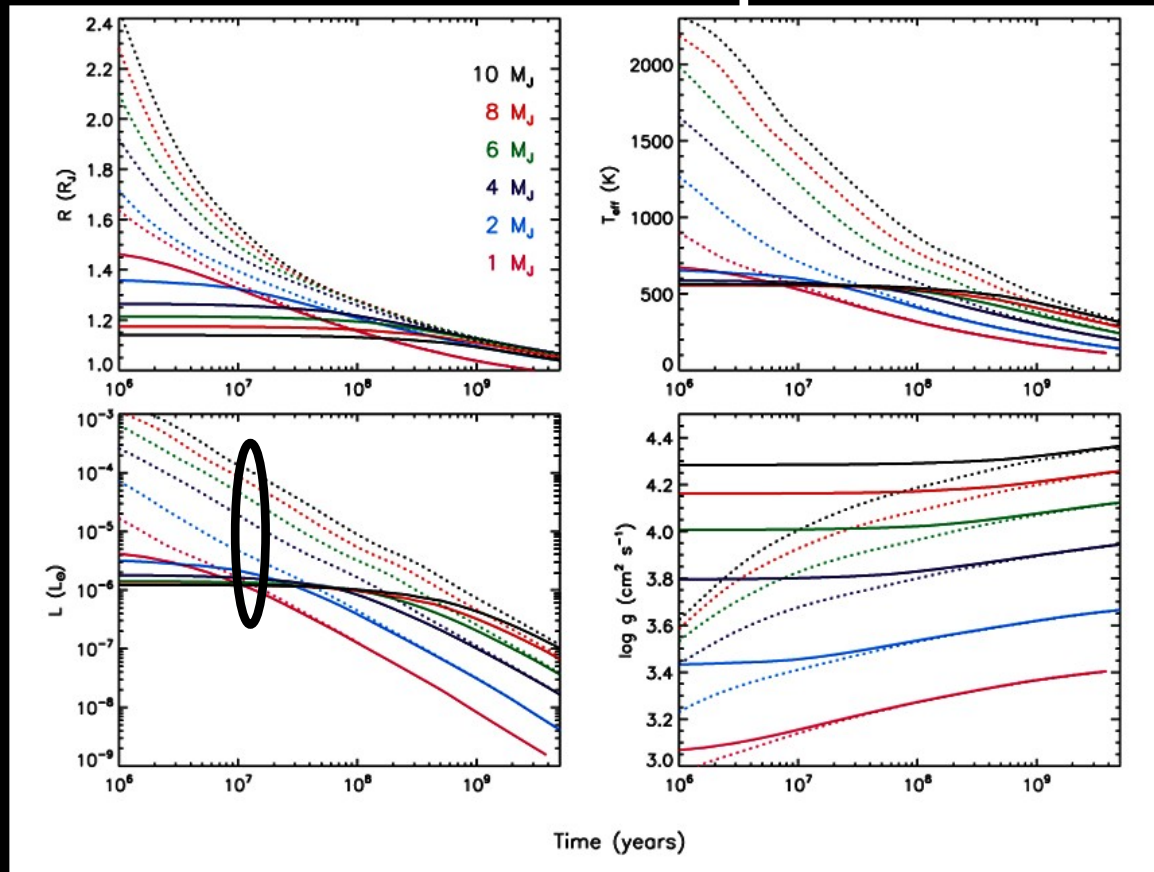
Chauvin et al (2012; arXiv:1202.2655)

- $T_{\text{eff}} \sim 1500\text{K}$ (L' data); $T_{\text{eff}} = 1600 \pm 200\text{K}$ (Ks data)
(cf M. Bonnefoy Friday's talk)
- $M \sim 9M_{\text{Jup}}$ (COND models)



Could be formed by Core Accretion (Kennedy & Kenyon, 2008)

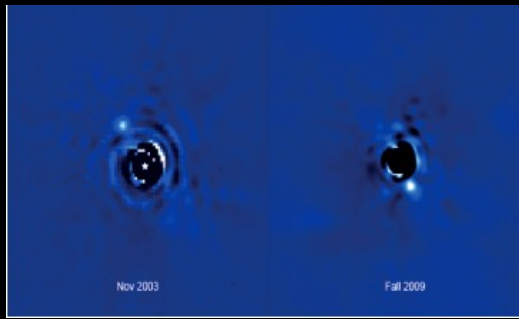
Mass estimates from imaging are model-dependant



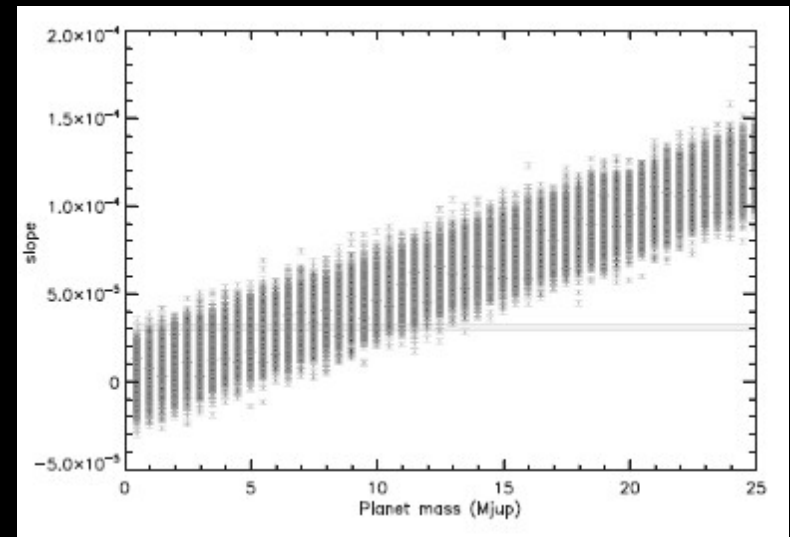
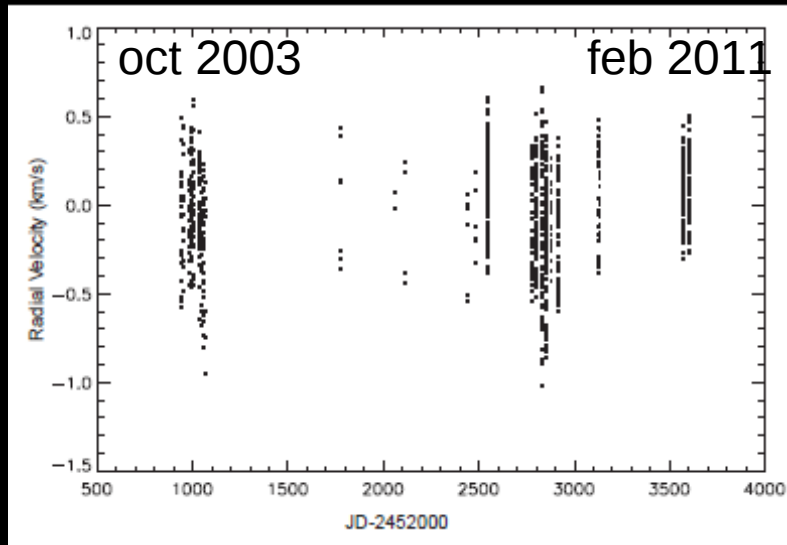
Need for dynamical masses *Fortney et al (2008)*

Close planets needed

See also *Spiegel & Burrows (2011)*

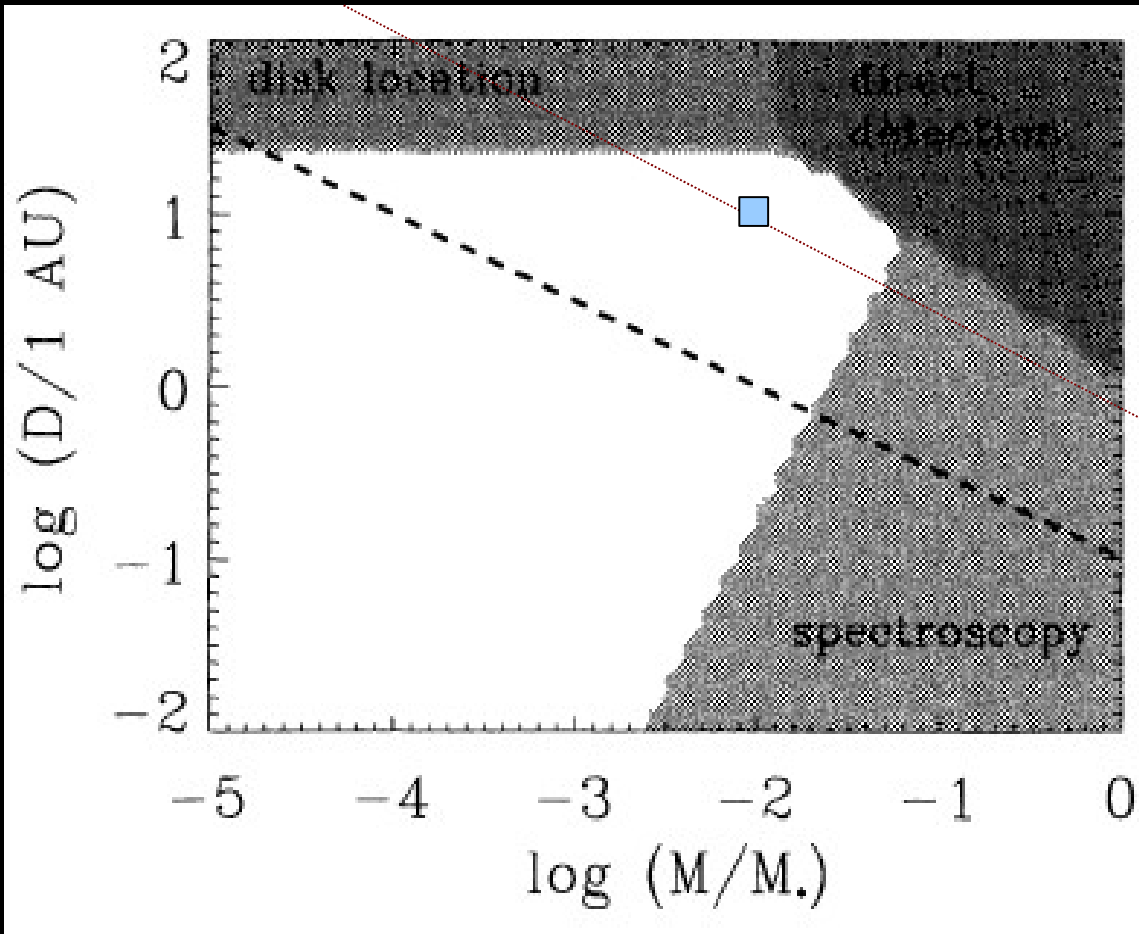


Mass of β Pic b



For $a = 9$ (resp. 8, 10, 12) AU, $M < 12$ (resp. 10, 16, 25) MJup
Lagrange et al (2012b; 2012arXiv1202.2579)

Planet and warp



A massive GP at ~10AU explains also:

- the FEBs
- the photometric event

Right mass, right separation, but
should be inclined wrt the main disk!

Where is β Pic b?

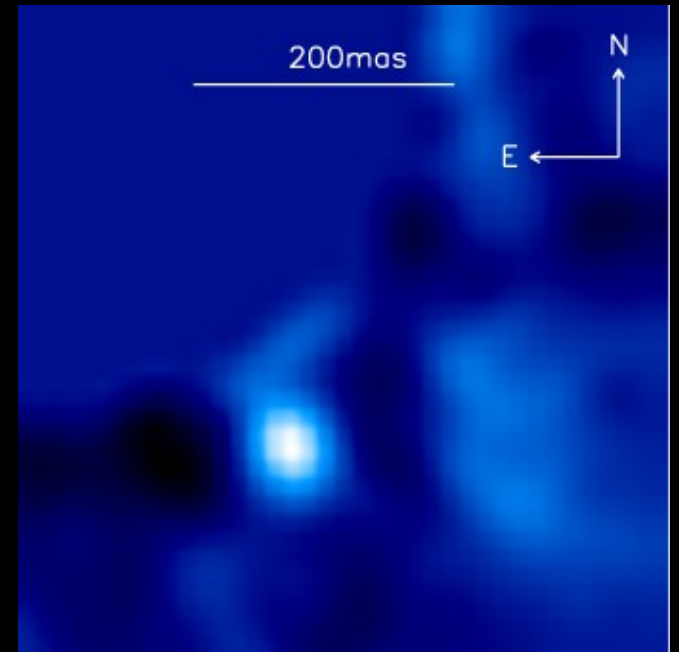


larger FoV Ks, data
detailed error budget

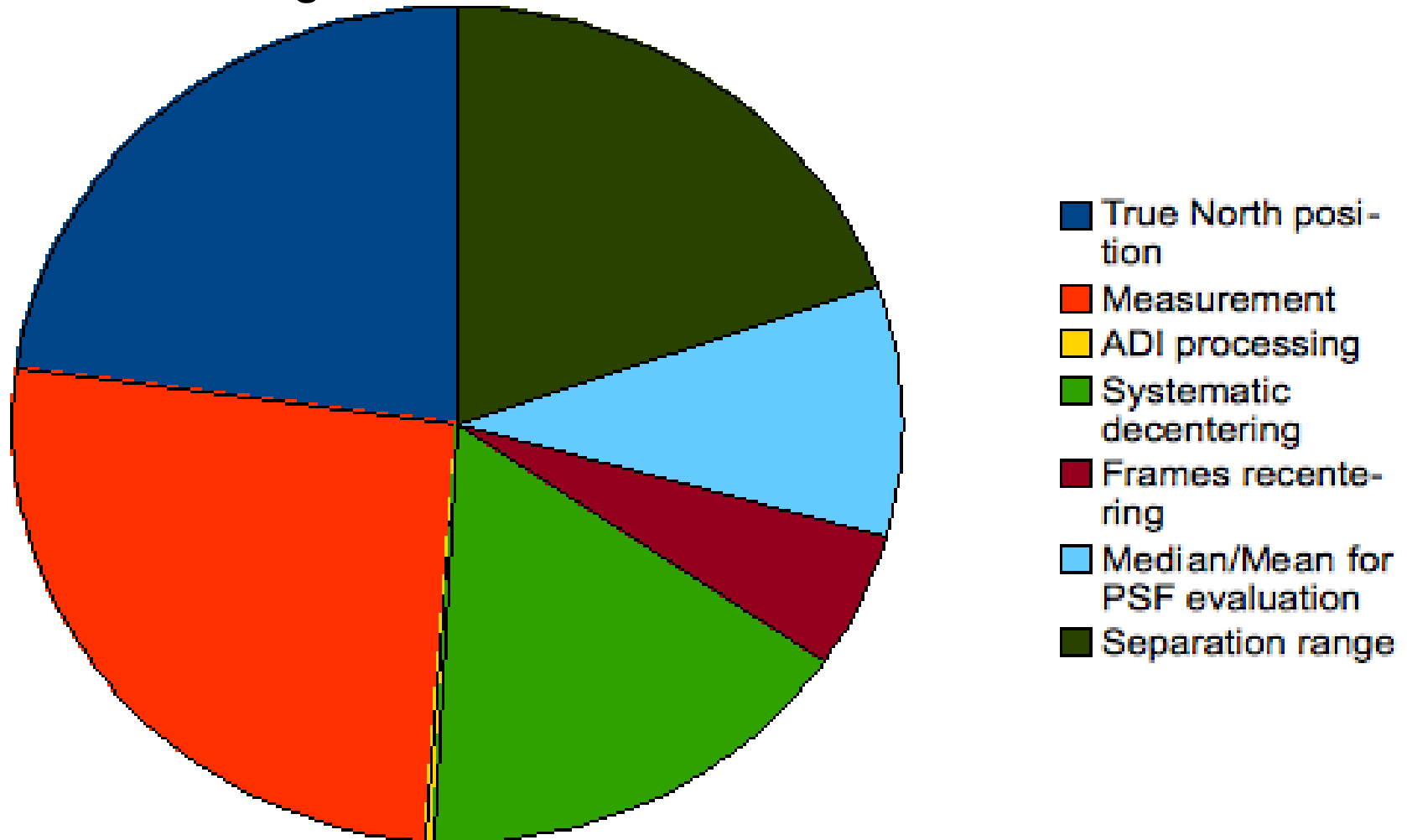
(see J. Milli's talk for ADI impact on disks p

VLT/NaCo Ks
Nov. 2010

140AU



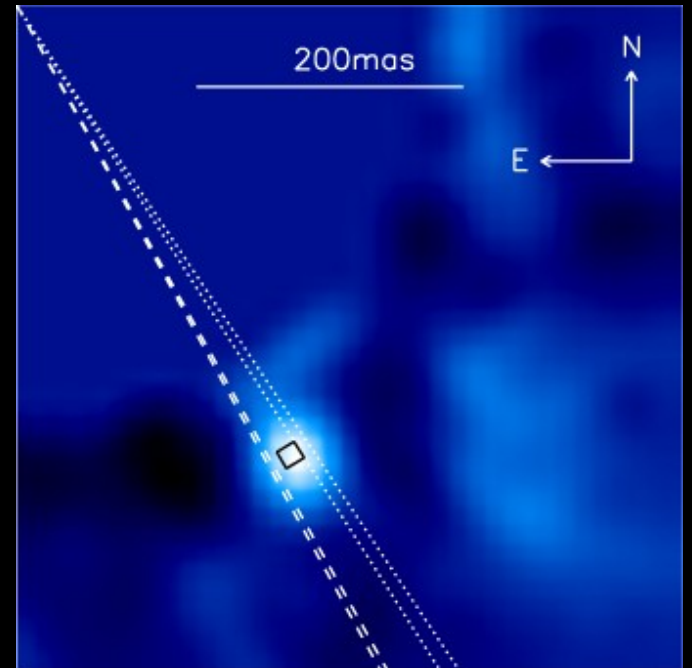
Disk PA error budget

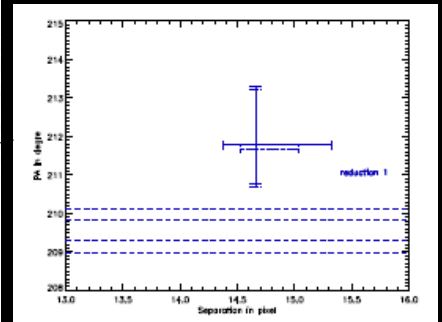
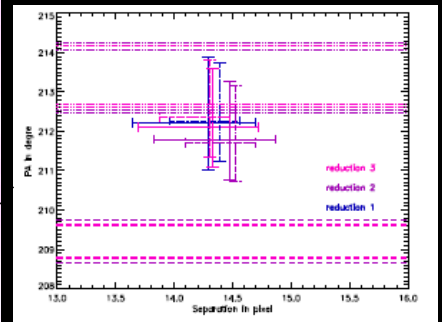
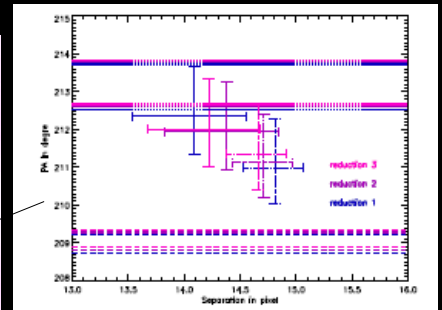
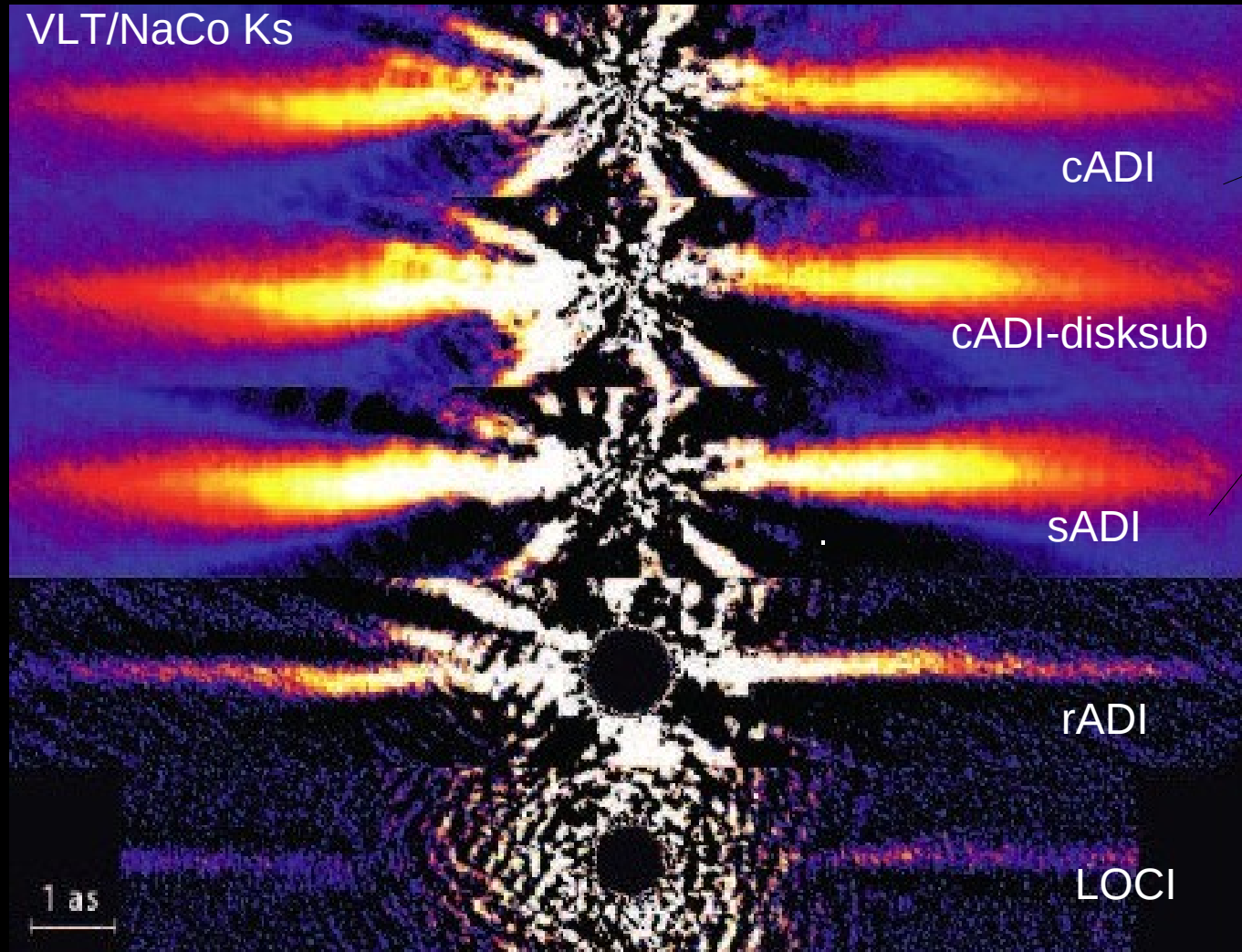


total error = 0.14° (internal error) (up to 0.35°)

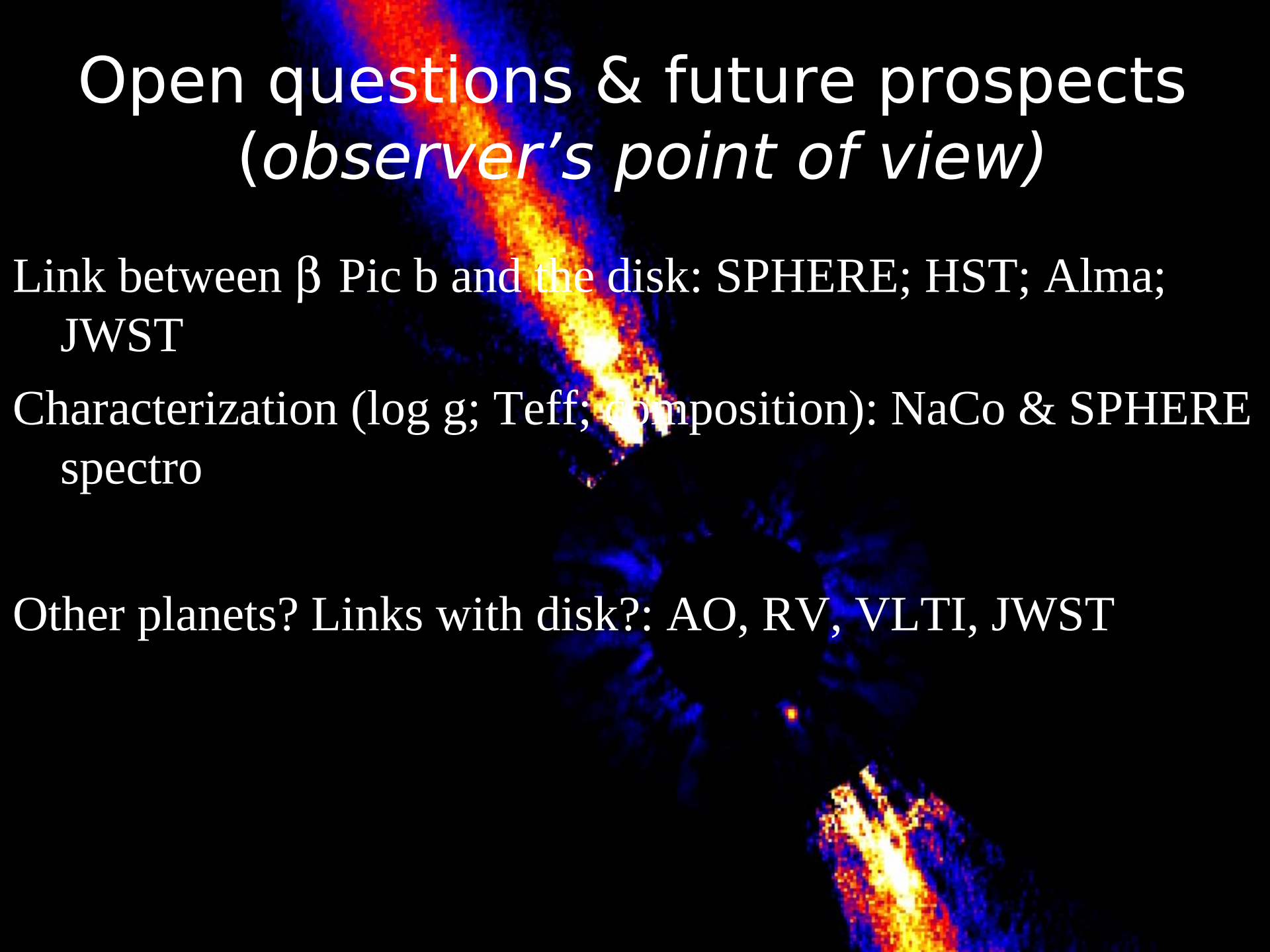
VLT/NaCo Ks
Nov. 2010

140AU





β Pic b projected position is not in the main disk
 β Pic b de-projected position is not in the main disk
 (Lagrange et al, 2012a, arXiv:1202.2578)



Open questions & future prospects (*observer's point of view*)

Link between β Pic b and the disk: SPHERE; HST; Alma;
JWST

Characterization (log g; T_{eff} ; composition): NaCo & SPHERE
spectro

Other planets? Links with disk?: AO, RV, VLTI, JWST