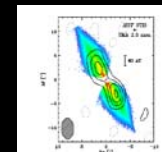
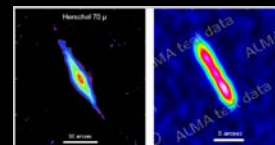
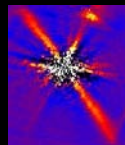
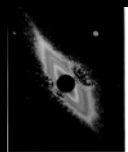


β Pictoris b a proxy for planet formation studies

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G. Chauvin, D. Apai, et al*

**Institut de Planétologie et d'Astrophysique de Grenoble, France*



Signposts of exoplanets -- October 2011

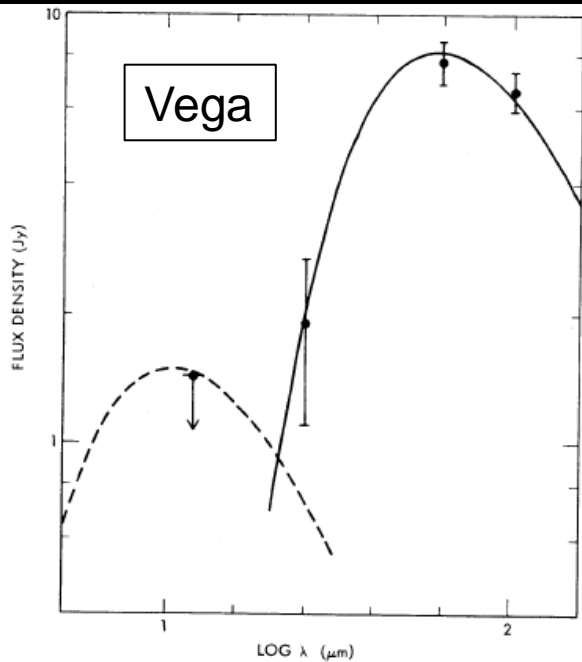
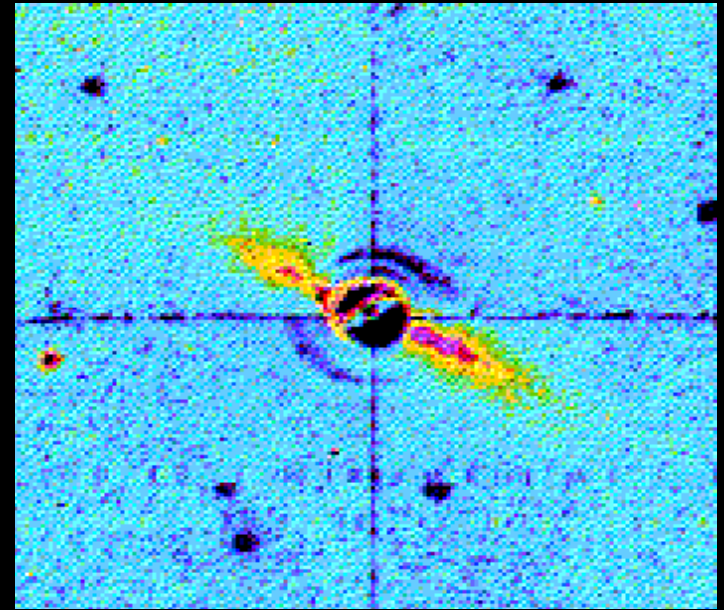


FIG. 1.—Energy distribution of the infrared excess from α Lyr.



Smith & Terrile (1984)

flattened disk => planet formation

Aumann et al. (1984): Vega

Aumann (1985): IR excesses

Vega, α PsA, ϵ Eri, β Pic

Small, short lived grains => replenishment from larger bodies

<1mic

1-3 mic

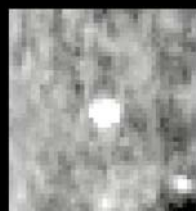
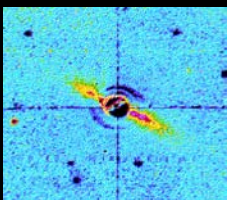
8-25mic

60 mic

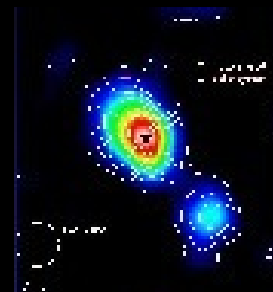
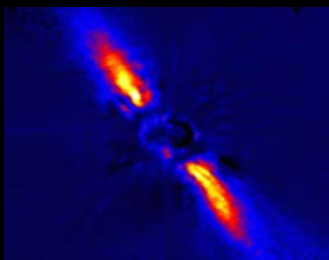
850mic

1.3mm

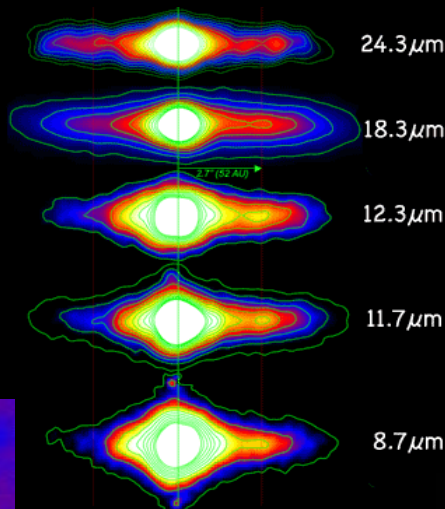
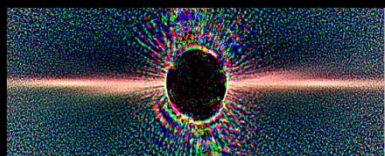
985



995



000



24.3 μm

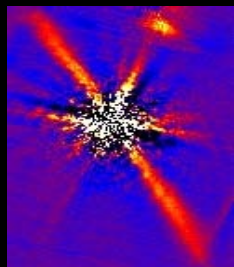
18.3 μm

12.3 μm

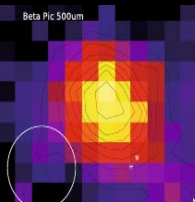
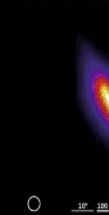
11.7 μm

8.7 μm

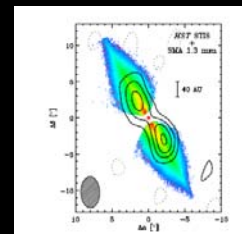
010



Beta Pic & PSF 70um

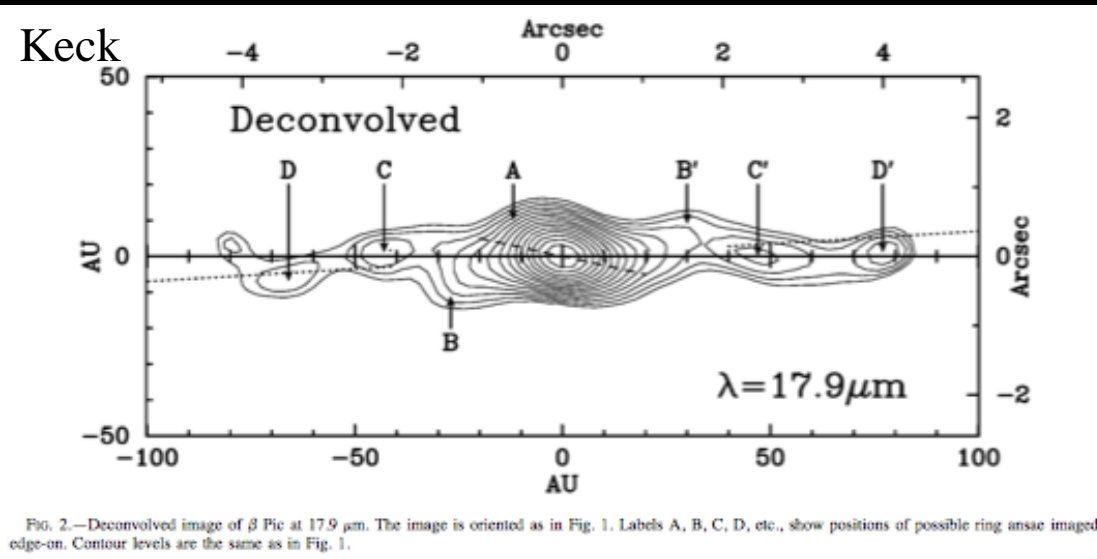


Beta Pic 500um



Beta Pic 1.3 mm

Gaps, belt-like structures (thermal IR)

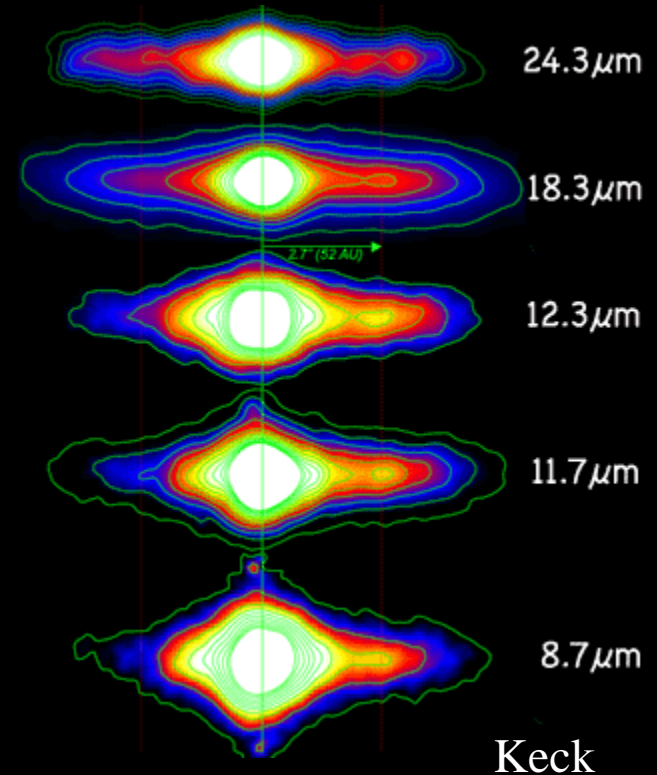


Wahhaj et al (2002)

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

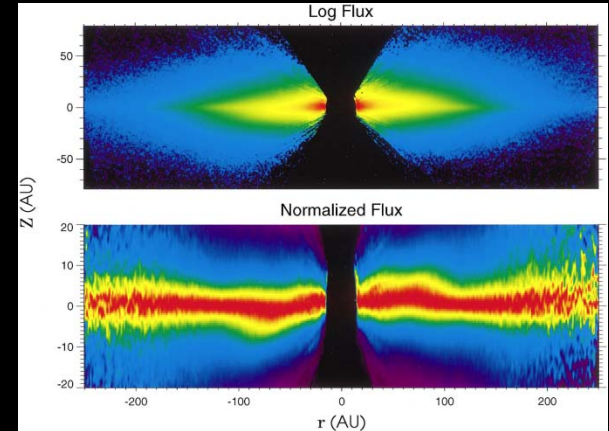
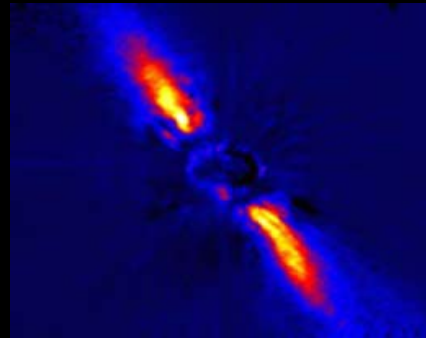
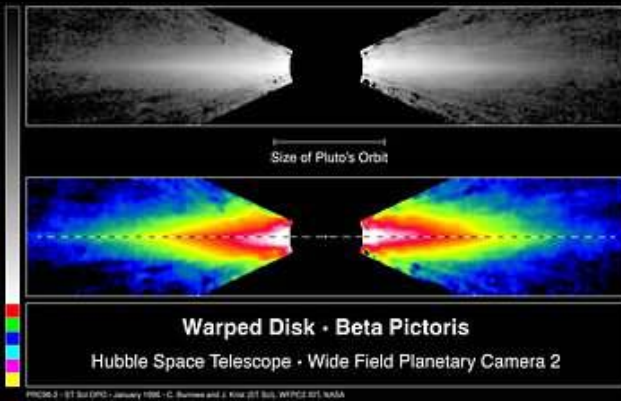
Origin of the clumps:

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



Telesco et al (2005)

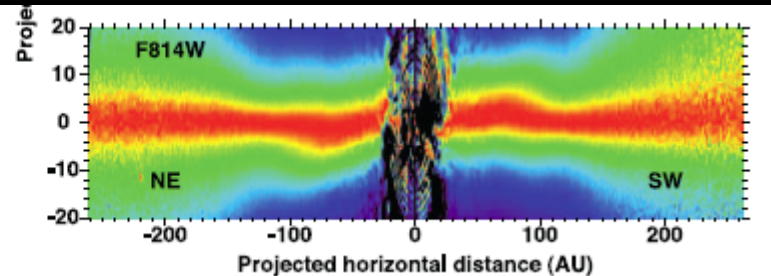
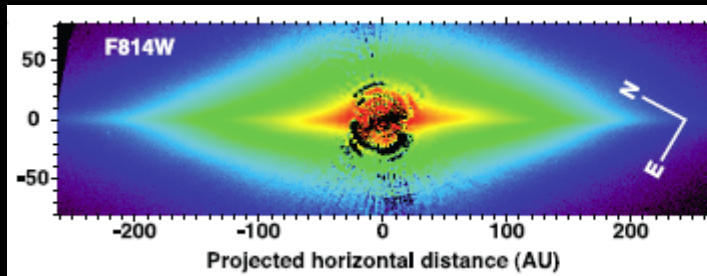
Inner (< 200 AU) disk shape



Burrows et al (1997)

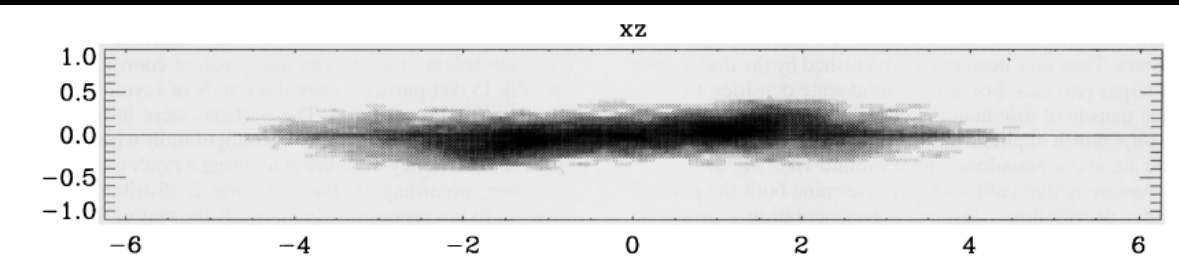
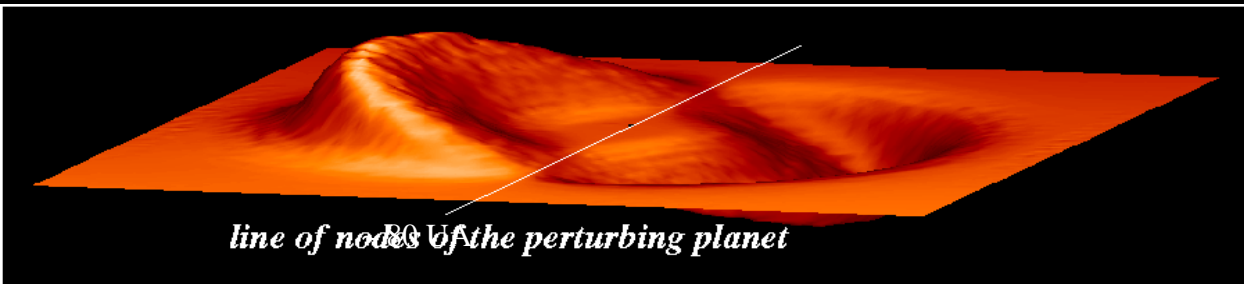
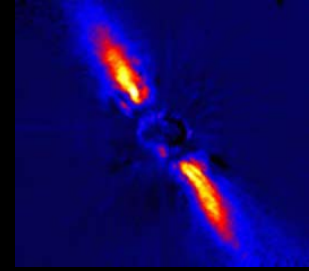
Mouillet et al (1997)

Heap et al (2000)

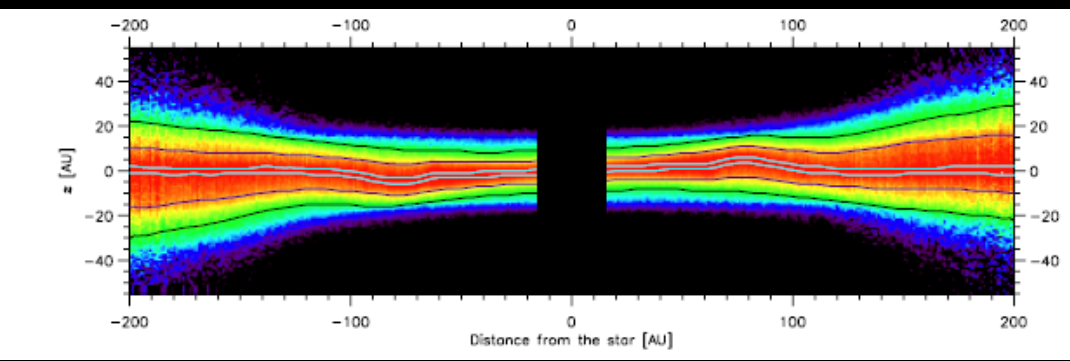


HST/ACS Golimowski et al (2006)

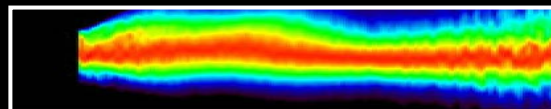
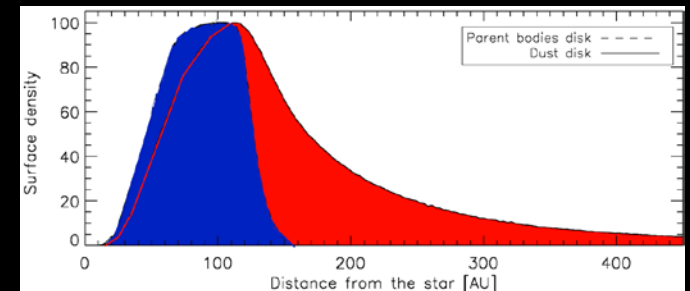
Planet on a 5° inclined orbit, + disk of planetesimals (15-150AU)



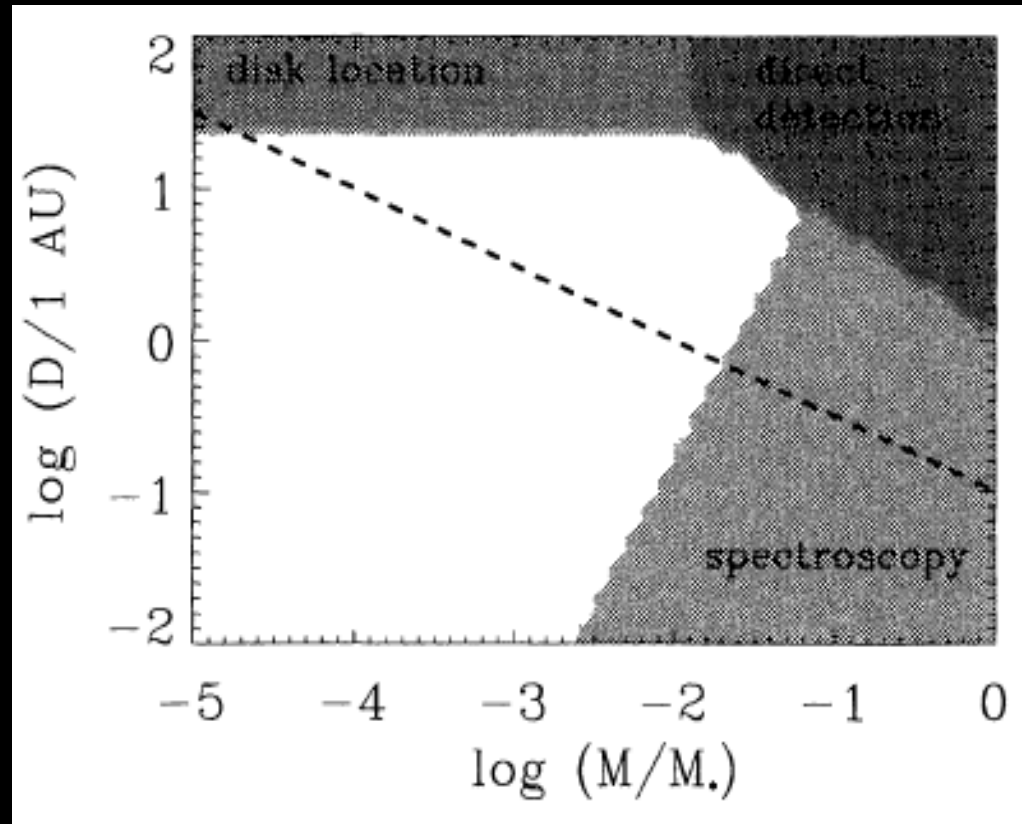
Mouillet et al. (1997)



Augereau et al. (2001)



Modeling the warp

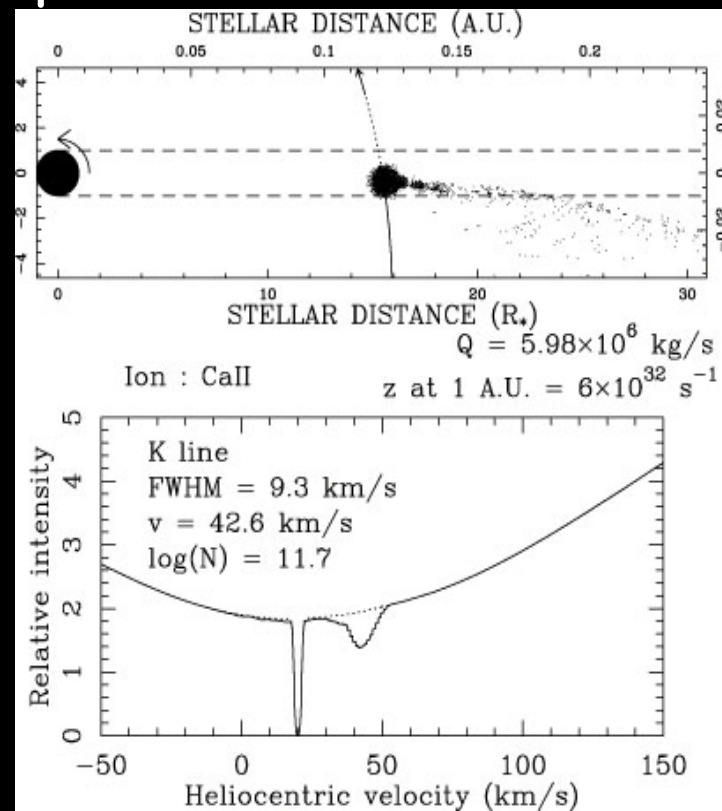
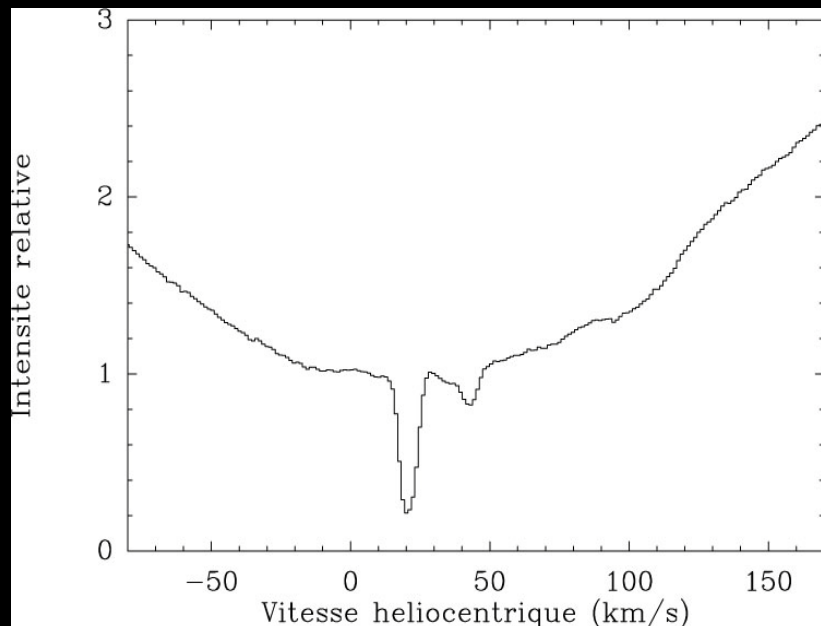


Mouillet et al. (1997)

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

Late 80's: Falling Evaporating Bodies on β Pictoris

=> indirect evidence for planet ?



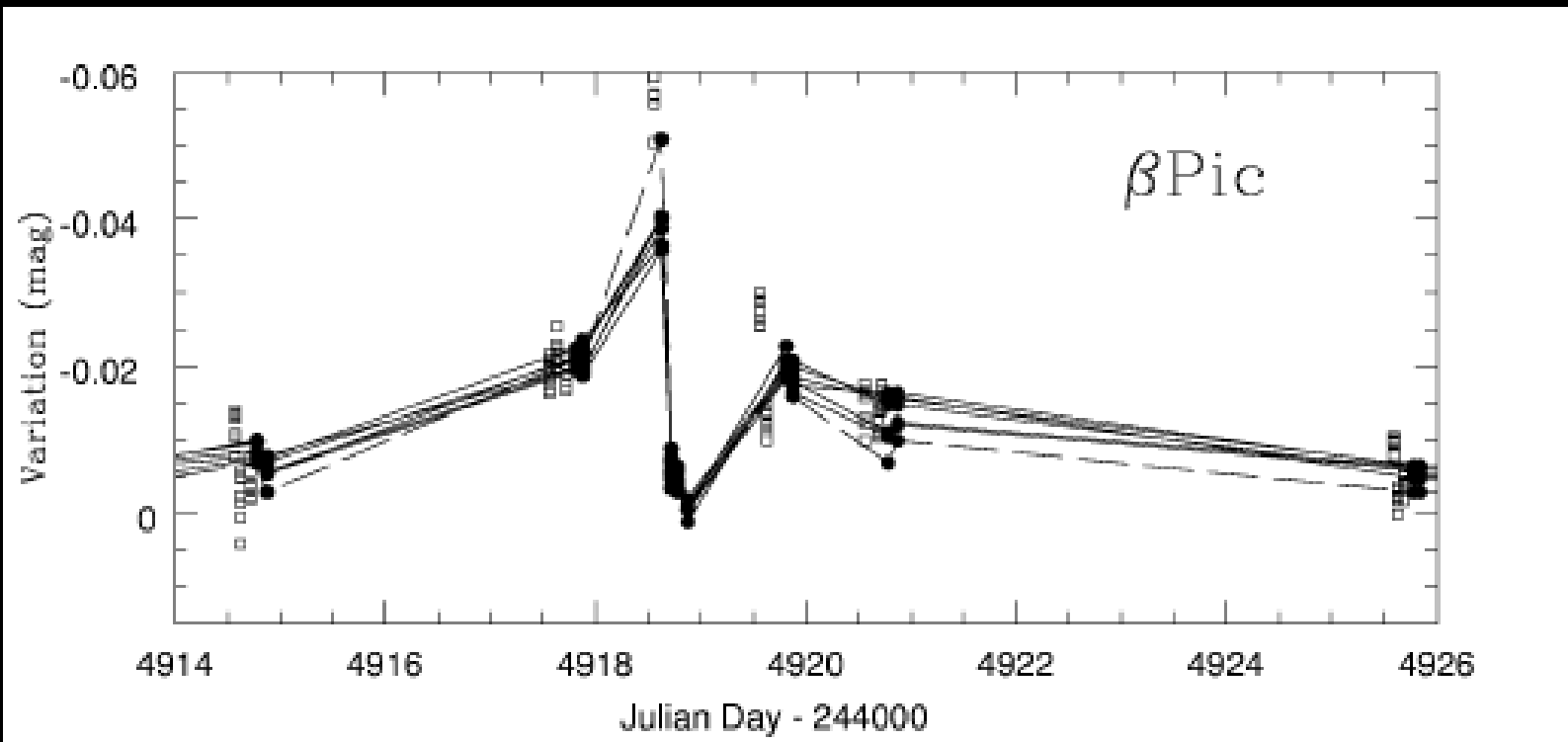
*Vidal-Madjar, Lagrange, Roberge
Beust, Morbidelli, etc*

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

FEB in 4:1 or possibly 3:1 resonance

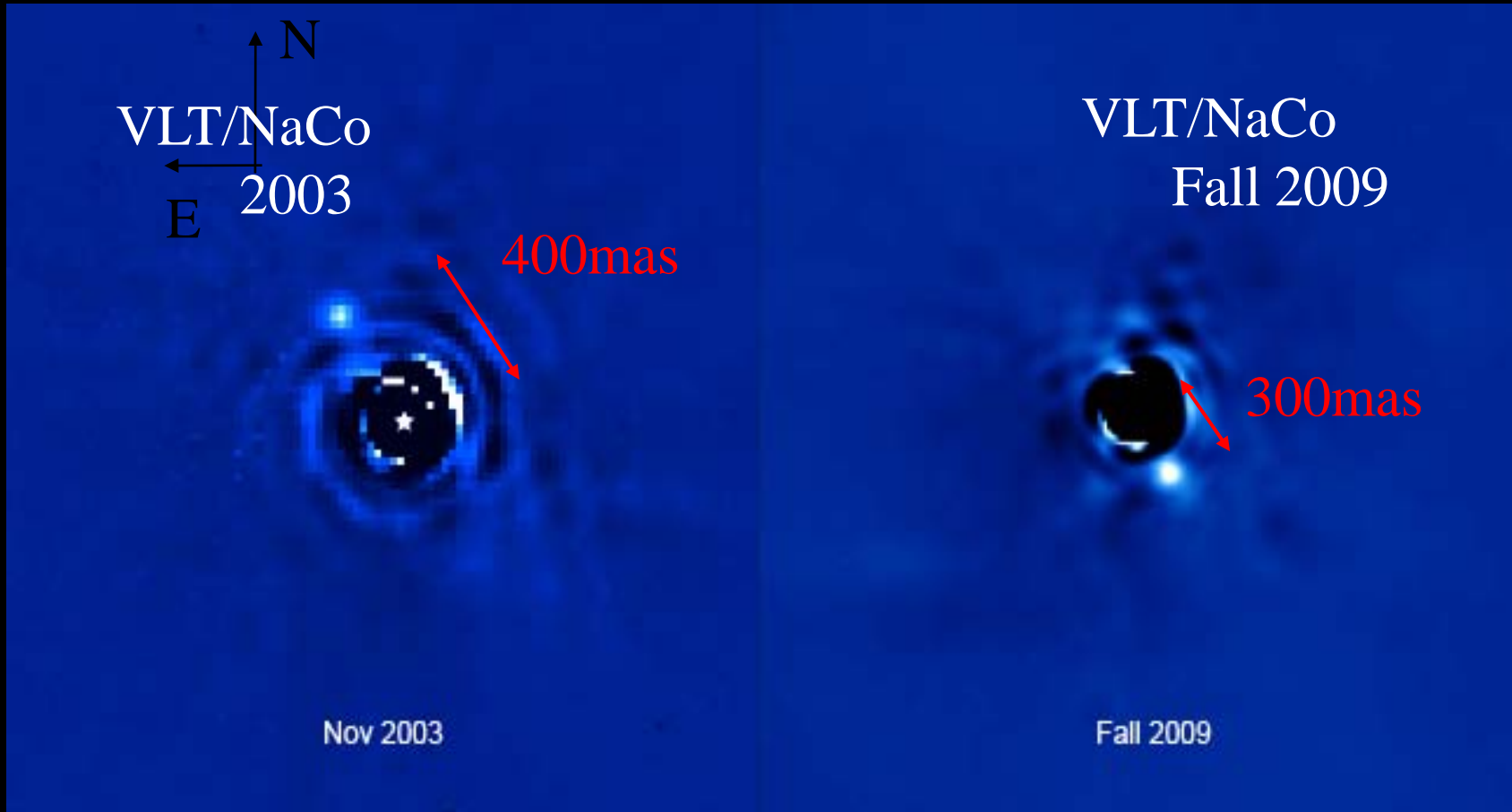
Total mass evaporated : a few Earth masses

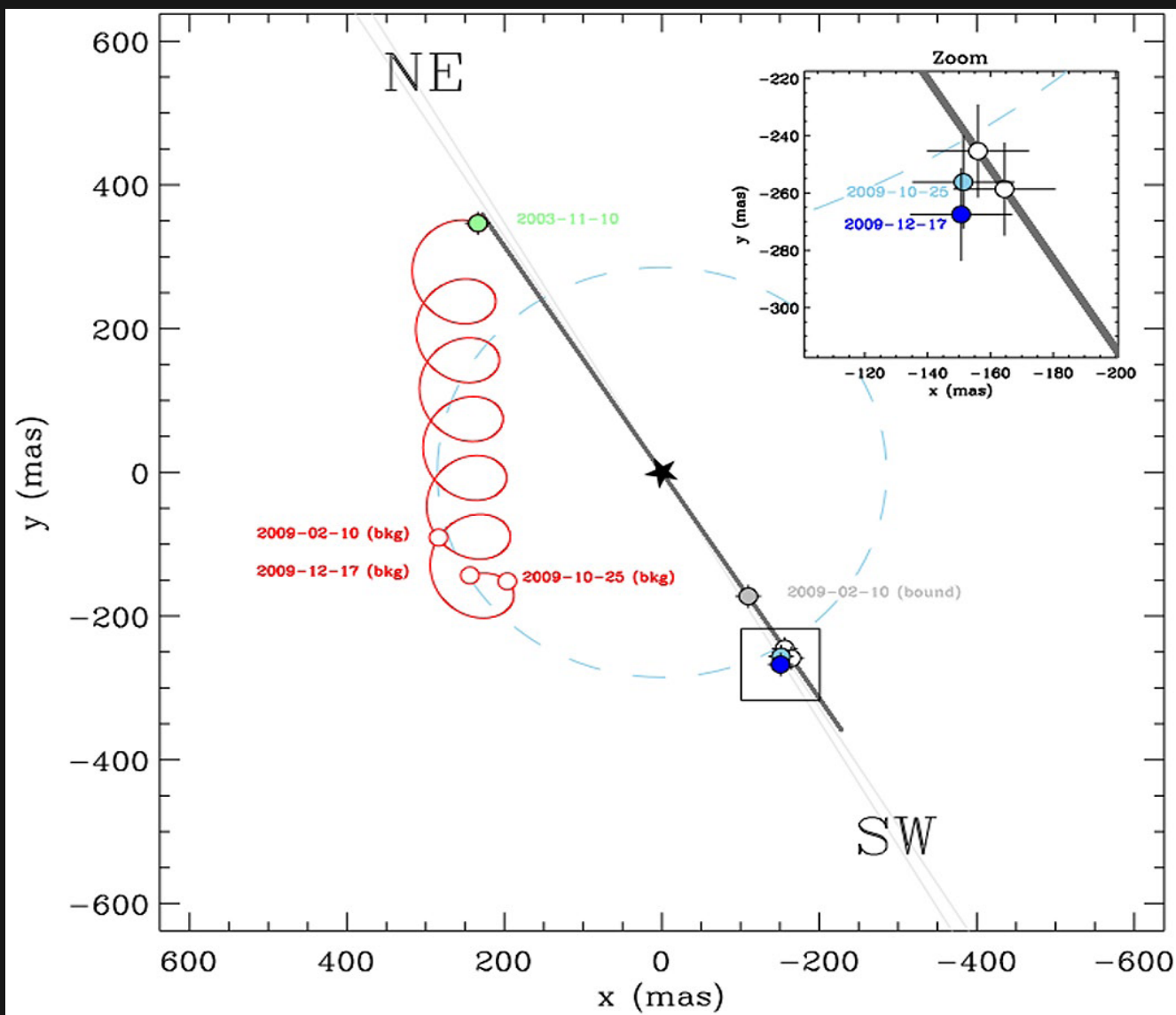
B Pic light variations (Nov. 10, 1981)



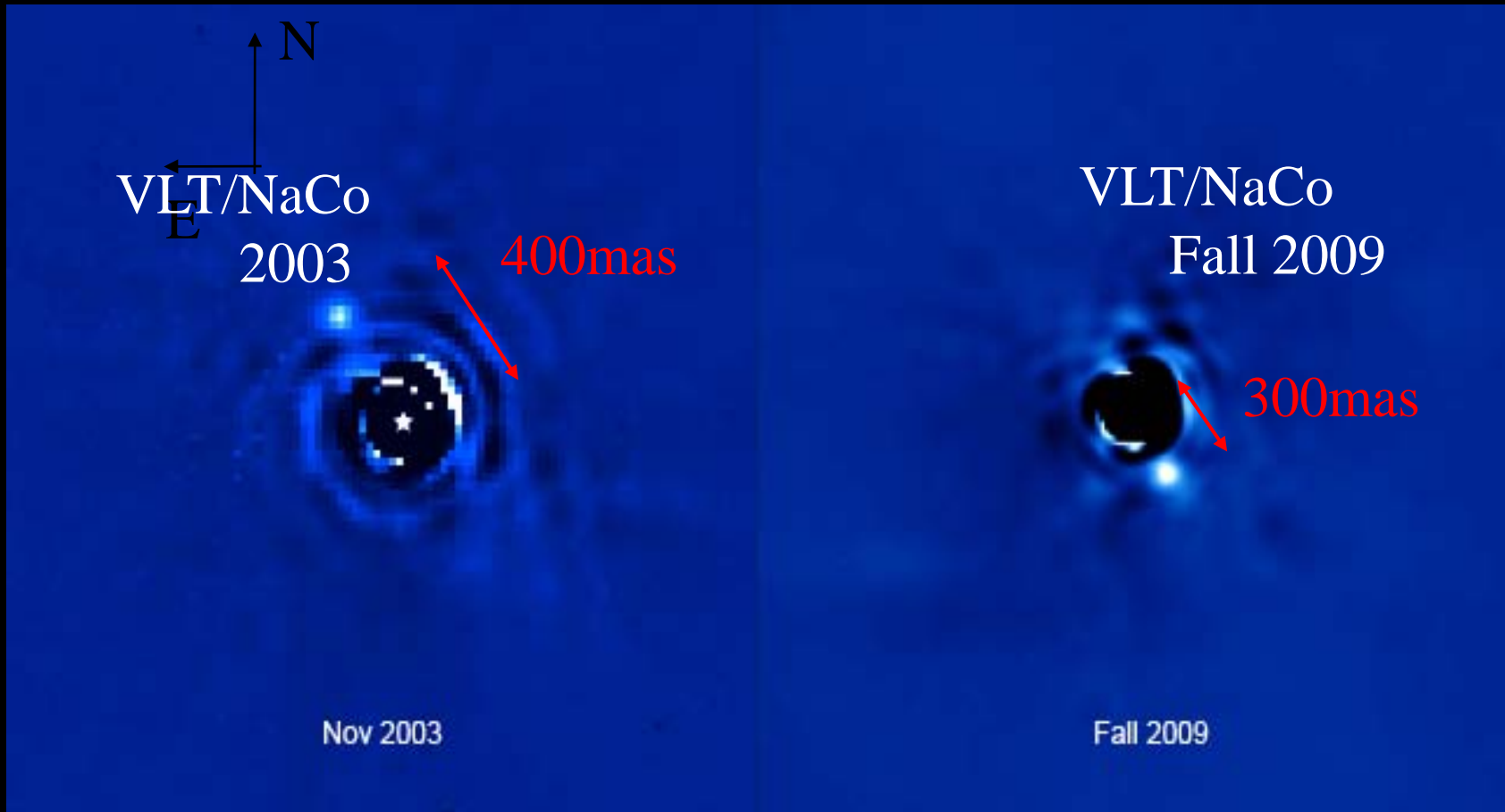
Lecavelier et al (1995, 1997)

Planet around β Pictoris





Planet around β Pictoris



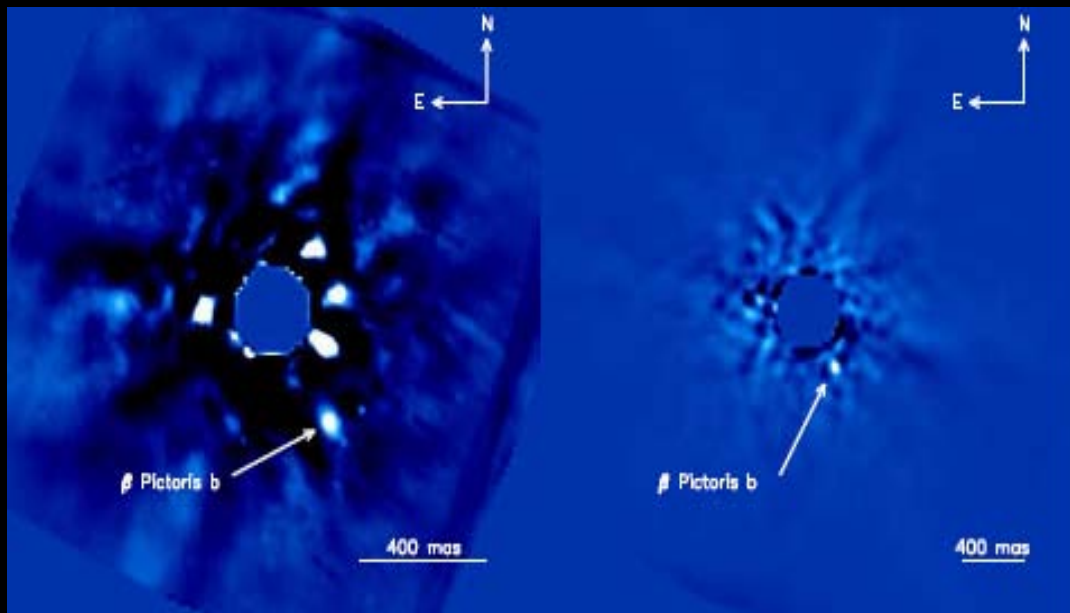
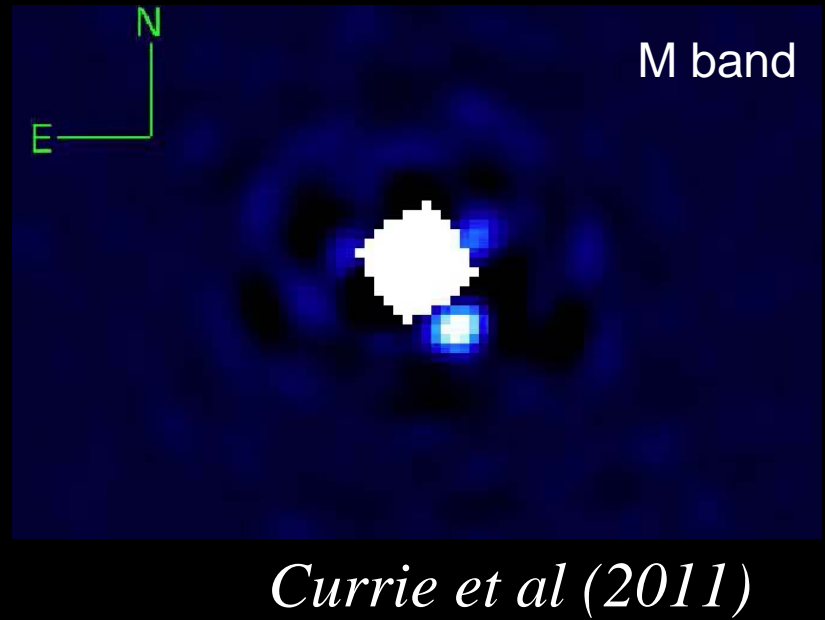
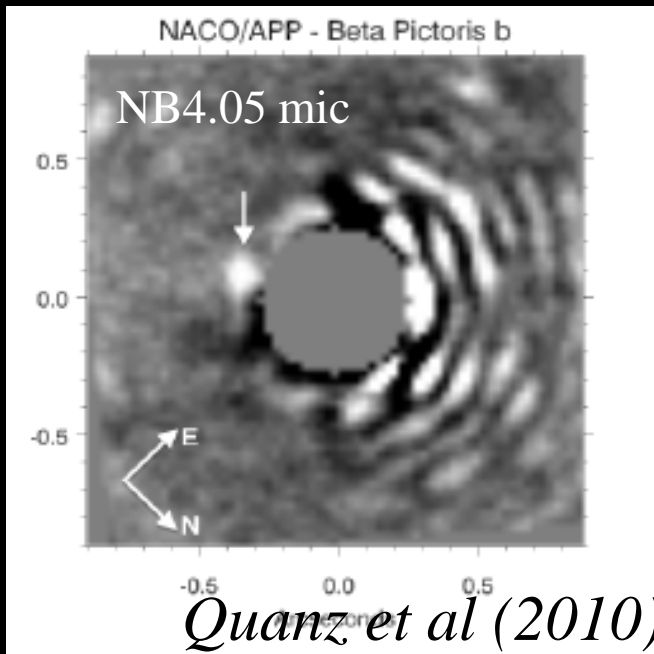
$T_{\text{eff}} \sim 1500\text{K}$; $M \sim 9M_{\text{Jup}}$ (Lyon's group models)

$\Delta L' = 7.8 \pm 0.2 \text{ mag}$

$\text{Sep} = 298 \pm 16 \text{ mas}$

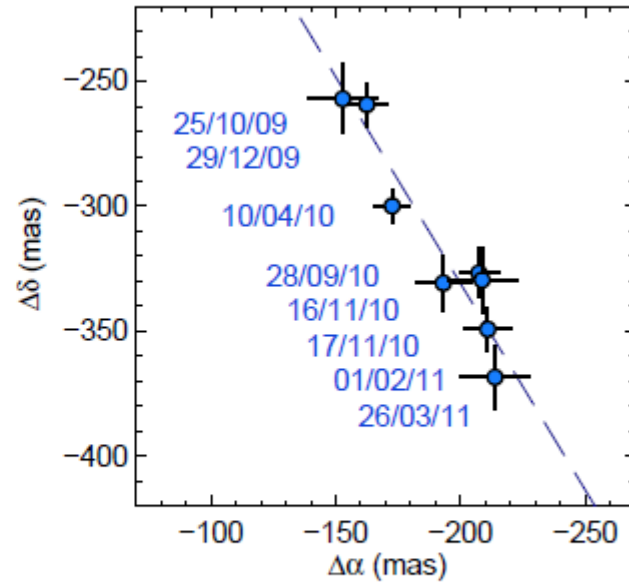
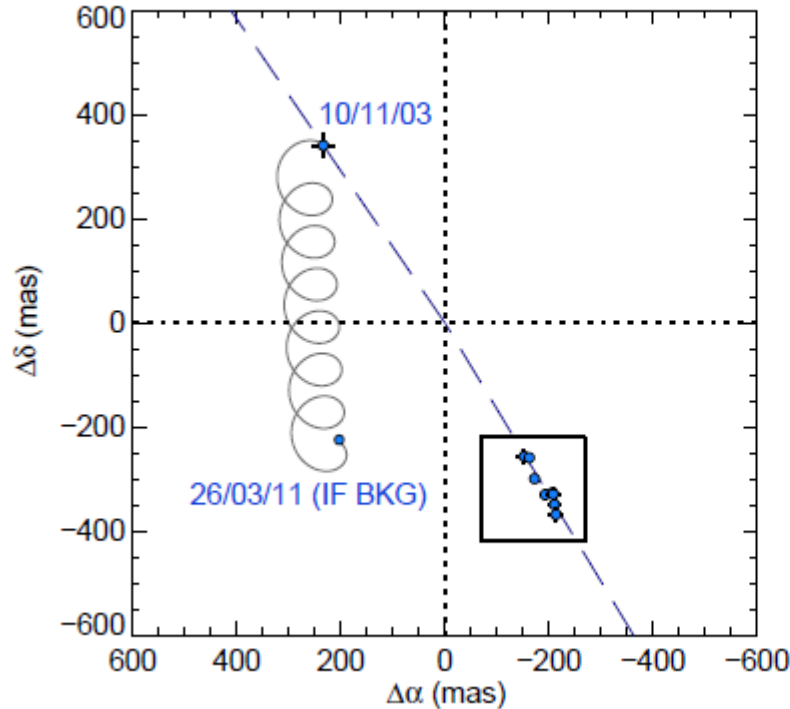
$\text{PA} \sim 210.6 \pm 3.6^\circ$

Lagrange et al (2010)



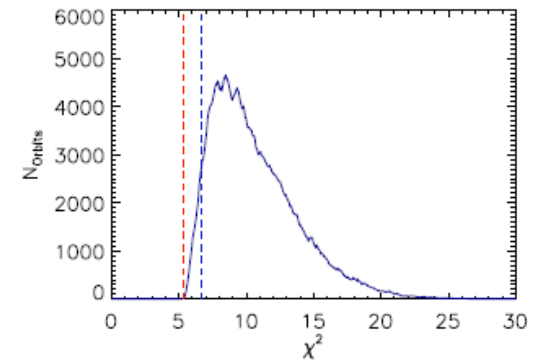
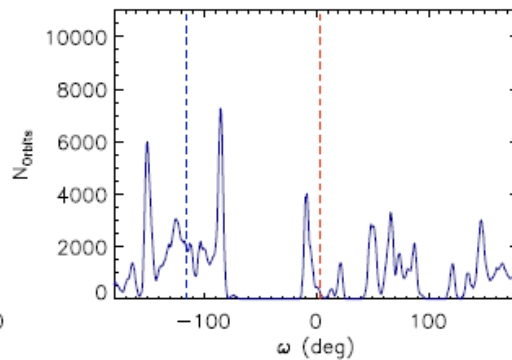
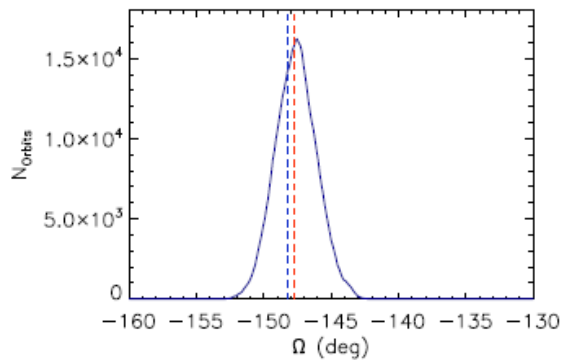
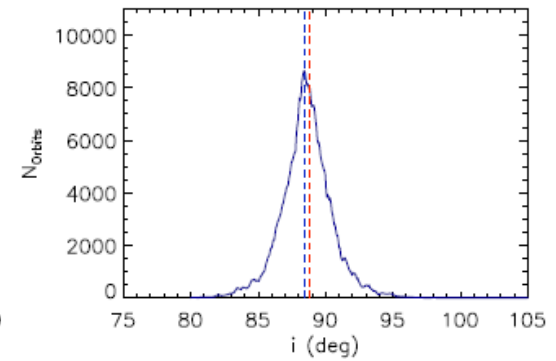
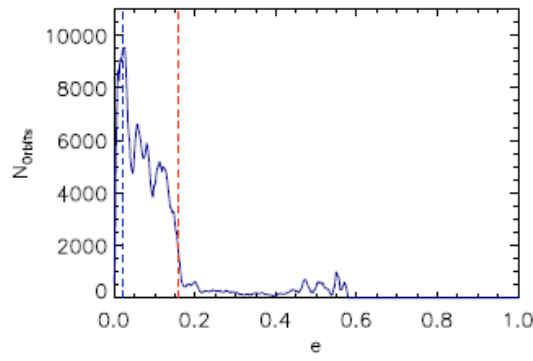
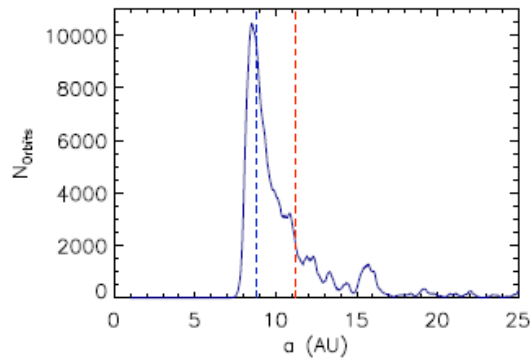
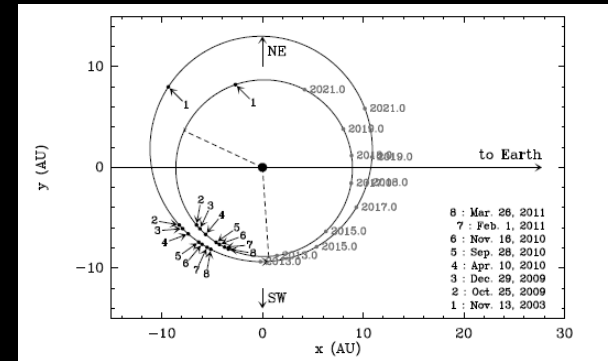
$T_{\text{eff}} = 1600 \pm 200 \text{K}$

Orbit of β Pic b



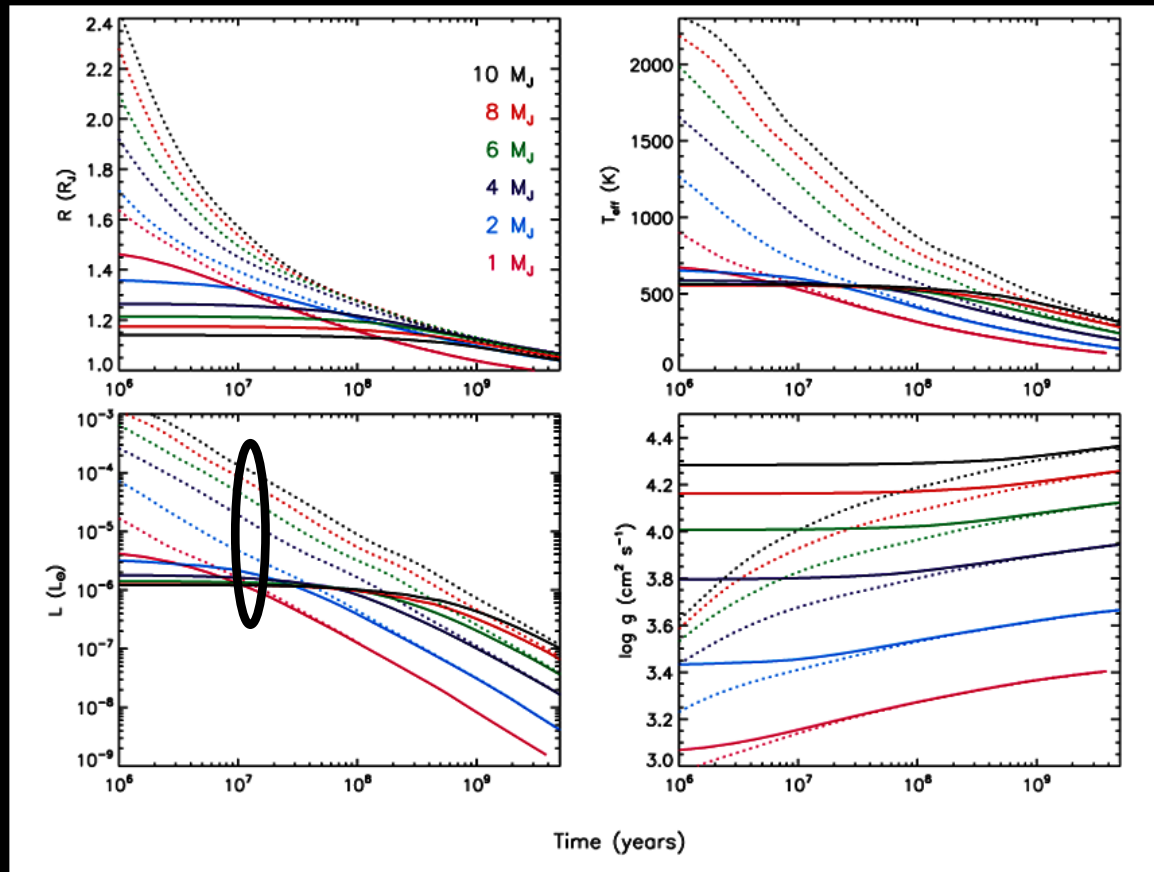
Special care for calibrators (FoV orientation) *Chauvin et al (2011a)*

Orbit of β Pic b



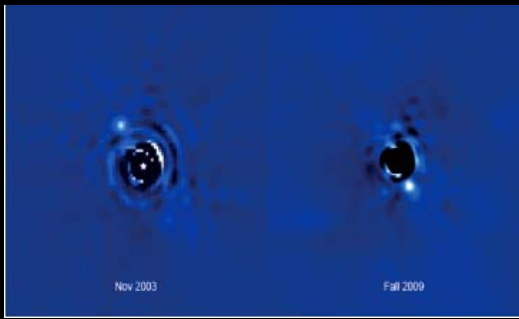
Chauvin et al (2011a); see also Currie et al (2011)

Mass estimates from imaging: model-dependant and uncertain!

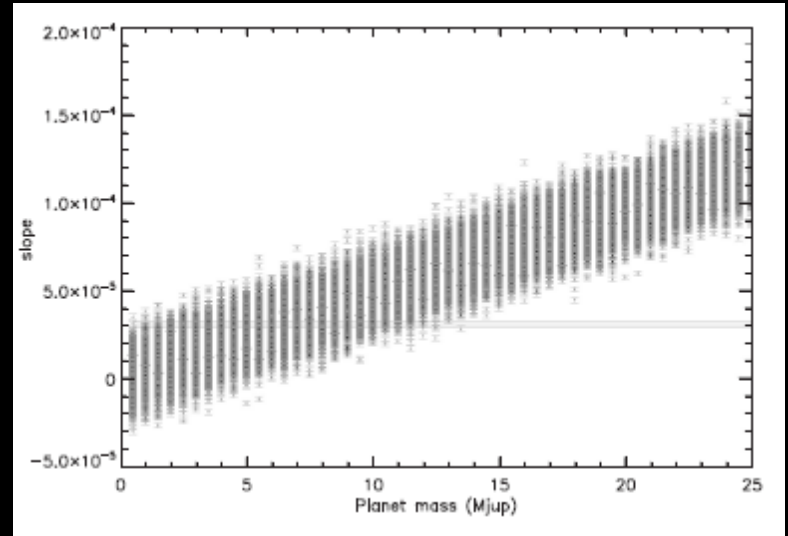
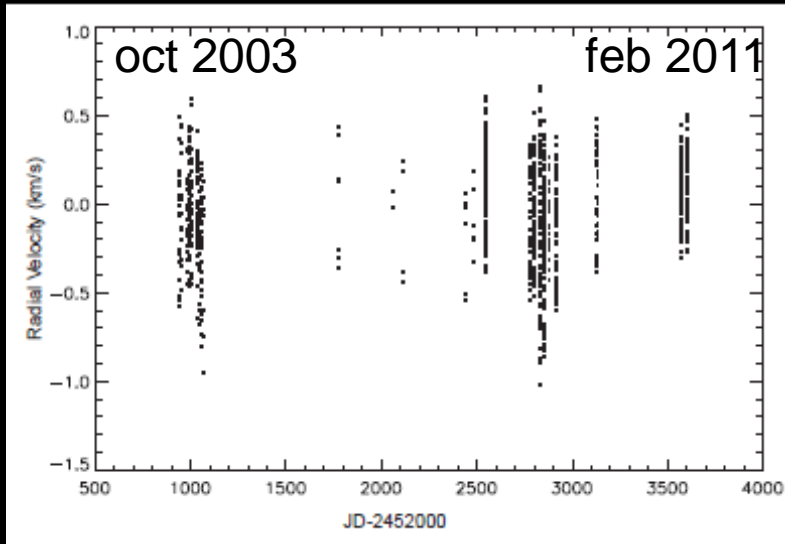


Need for dynamical masses
Close planets needed!!

Fortney et al (2008)
See also *Spiegel & Burrows (2011)*

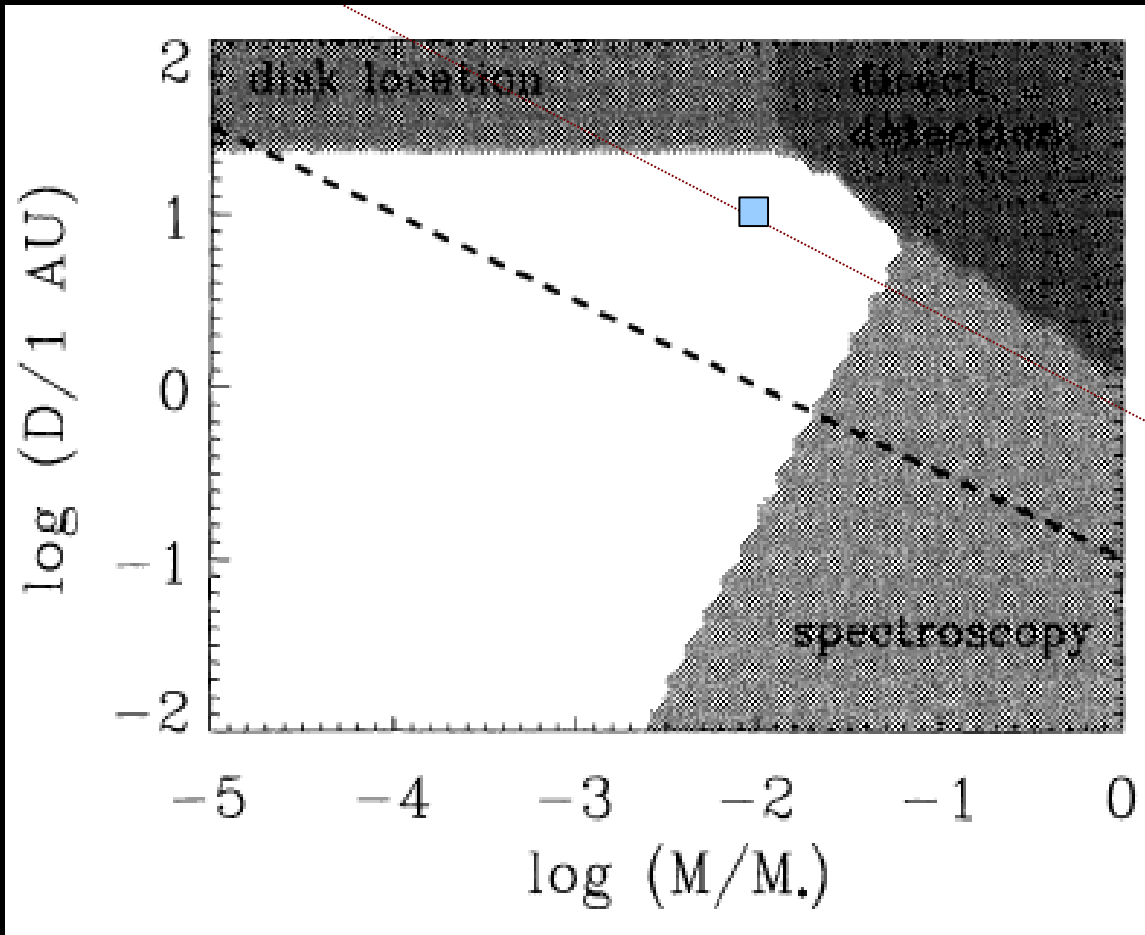


Mass of β Pic b



for $a = 9$ (resp. 10, 12) AU, $M < 12$ (resp. 16, 25) MJup
Lagrange et al (2011a)

Planet and warp



A massive GP at ~10AU explains also:

- the FEBs
- the photometric event

should be located in the warped disk
(but see also T Currie's talk)

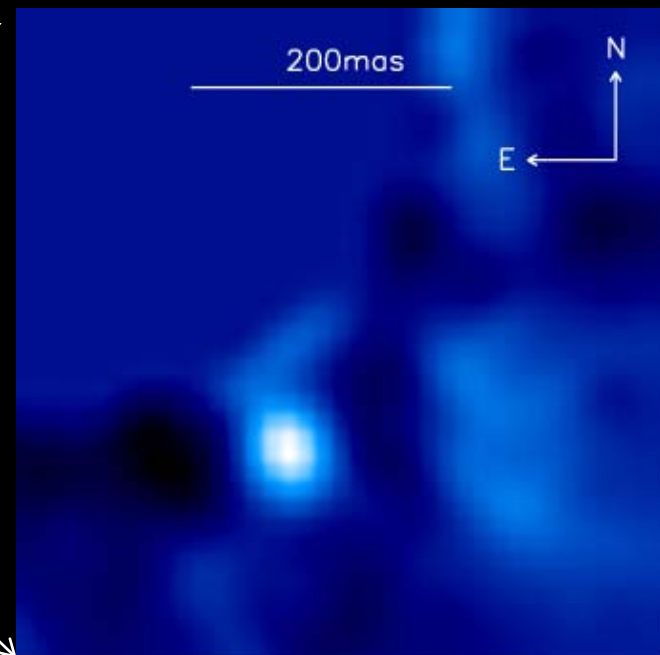
Where is β Pic b?



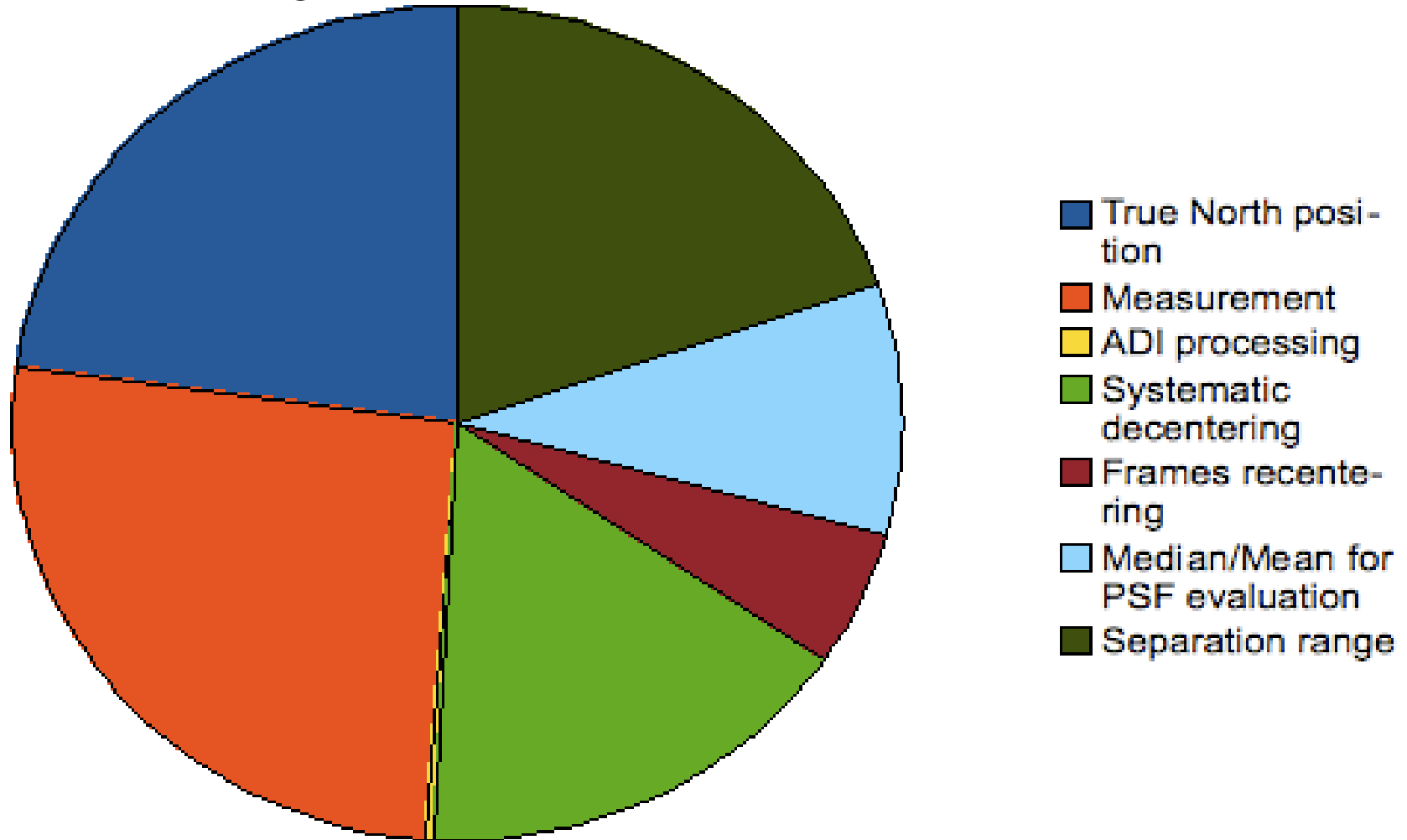
larger FoV Ks, data
detailed error budget

VLT/NaCo Ks
Nov. 2010

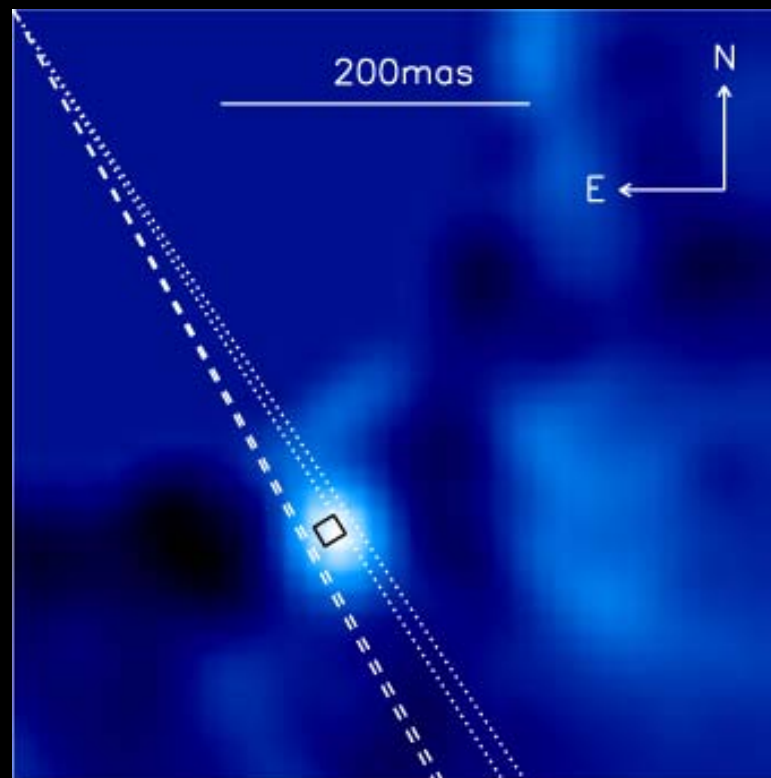
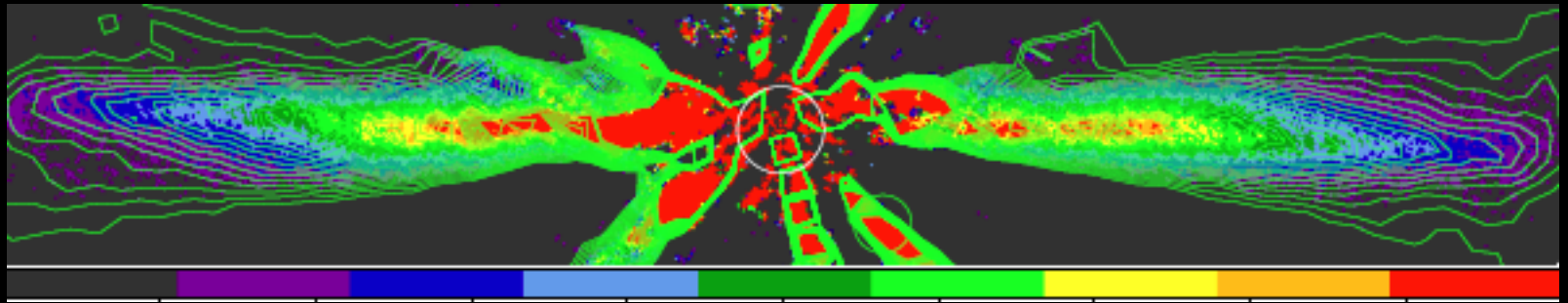
140AU

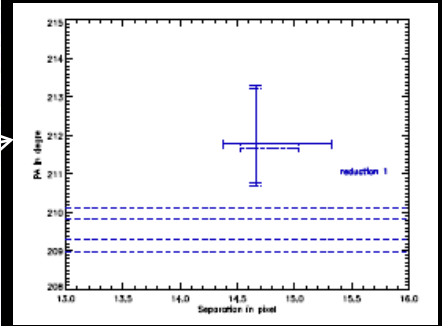
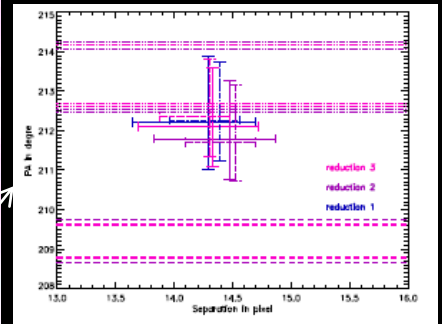
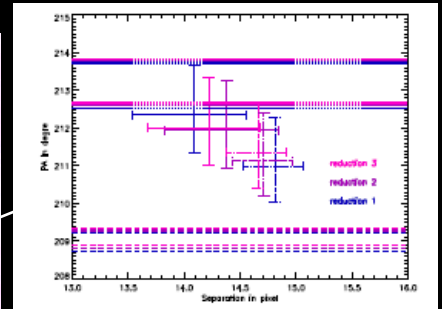
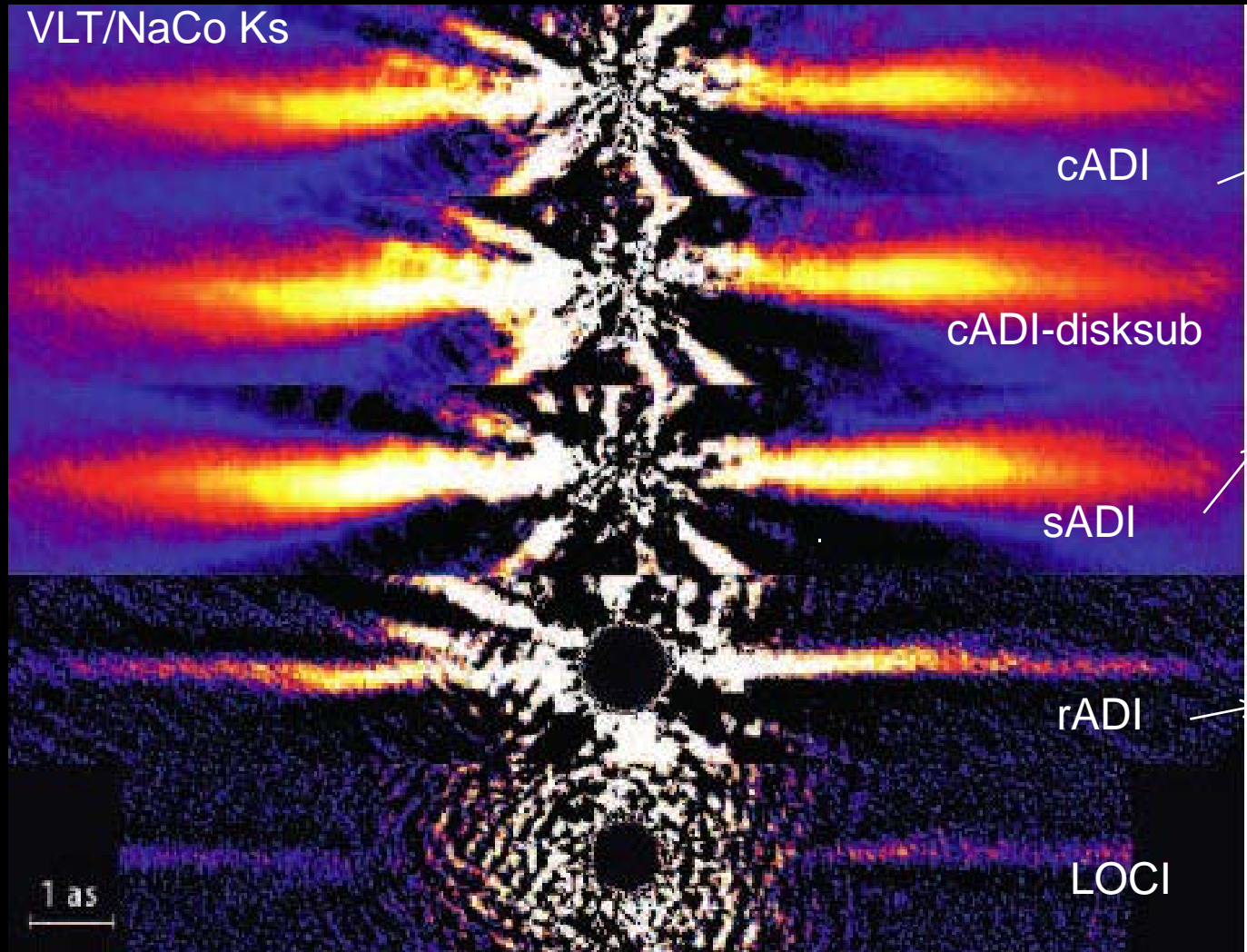


Disk PA error budget



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





β Pic b projected position is not in the main disk
 β Pic b de-projected position is not in the main disk

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

Orbit of β Pic b

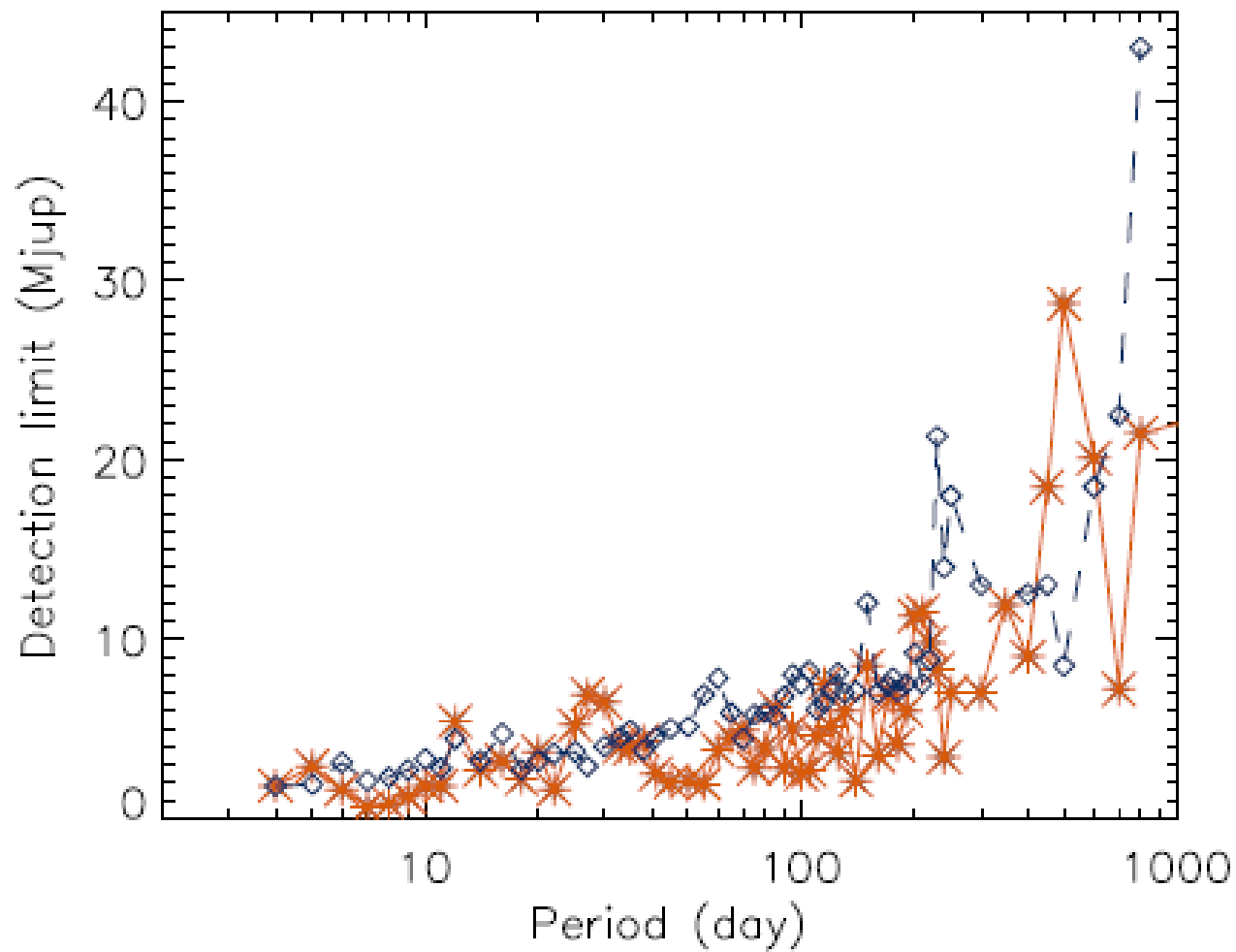
Link between β Pic b and the disk: XAO imaging; HST; Alma; JWST

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

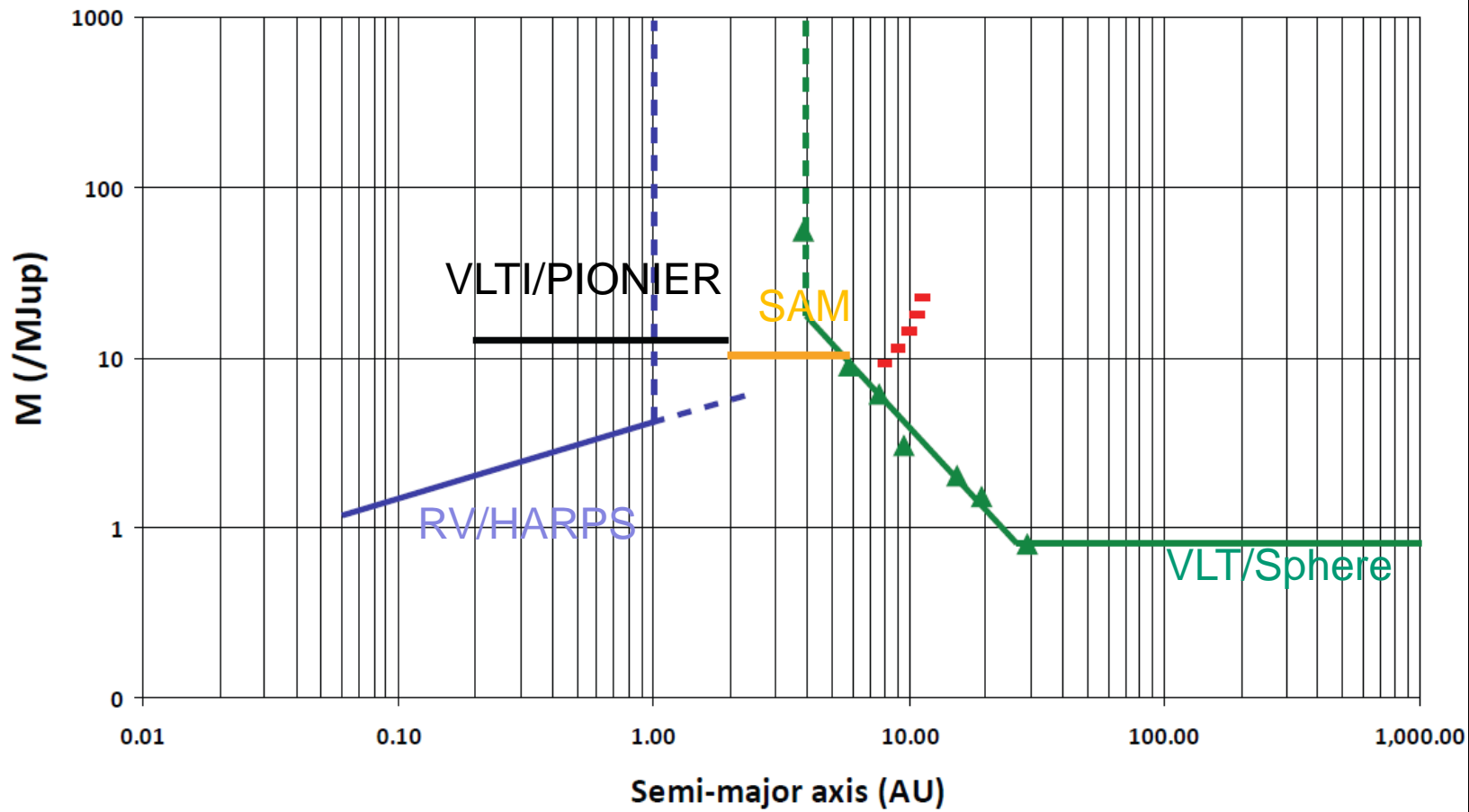
Other planets?: AO, RV, VLTI, JWST

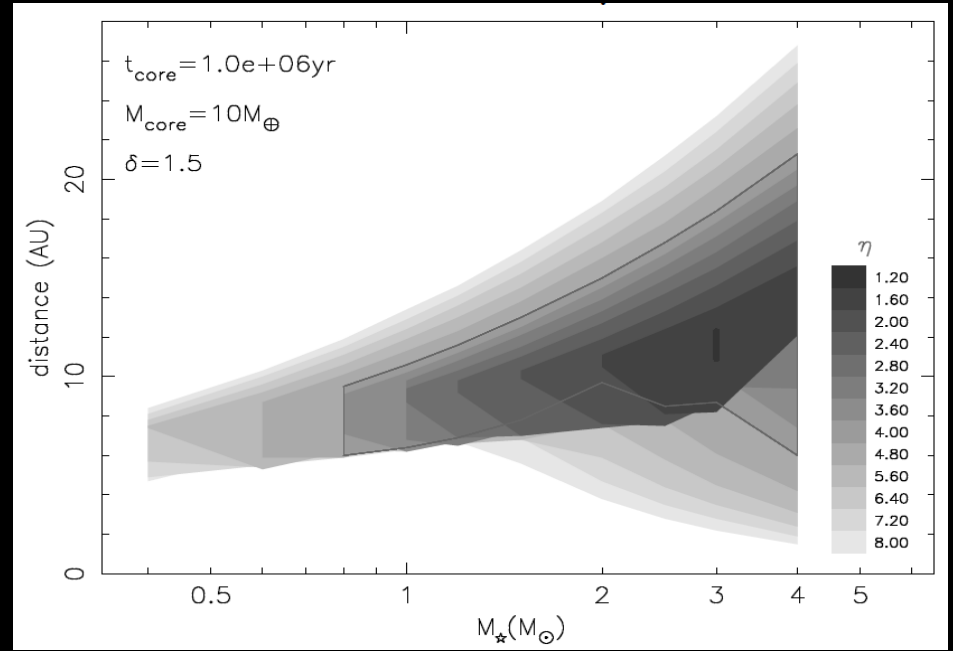
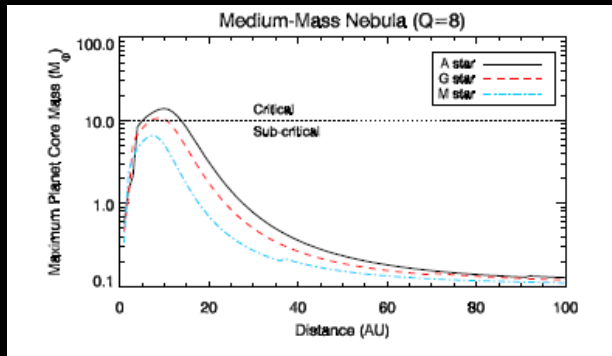
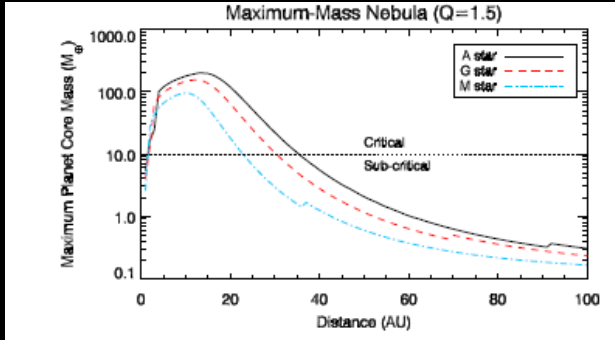
Disk: secondary or warped ? Other origins for the β Pic warp?

Formation process: CA (possible) or GI (can GI produce massive EGP at 10 AU ?)? => observe other planets in resolved disks



3.6m/Harps *Lagrange et al (2011a)*





Dodson-Robinson et al, (2008)

Kennedy & Kenyon (2008)