Spin-orbit alignment in resolved debris disks

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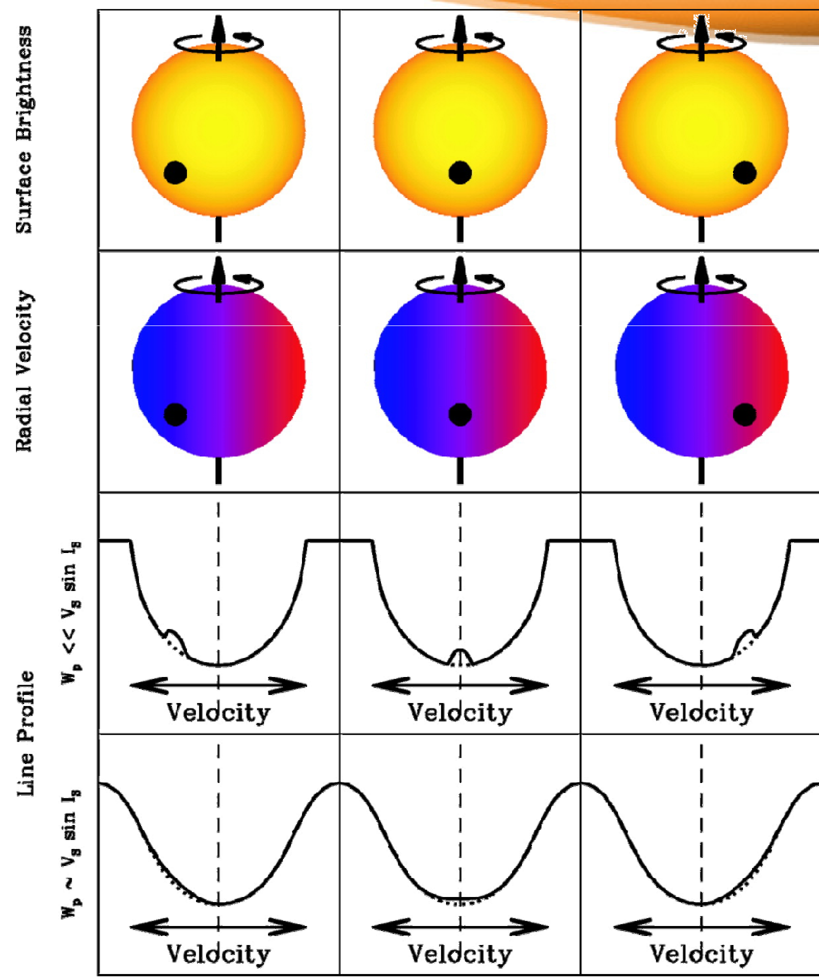
The Rossiter-McLaughlin effect

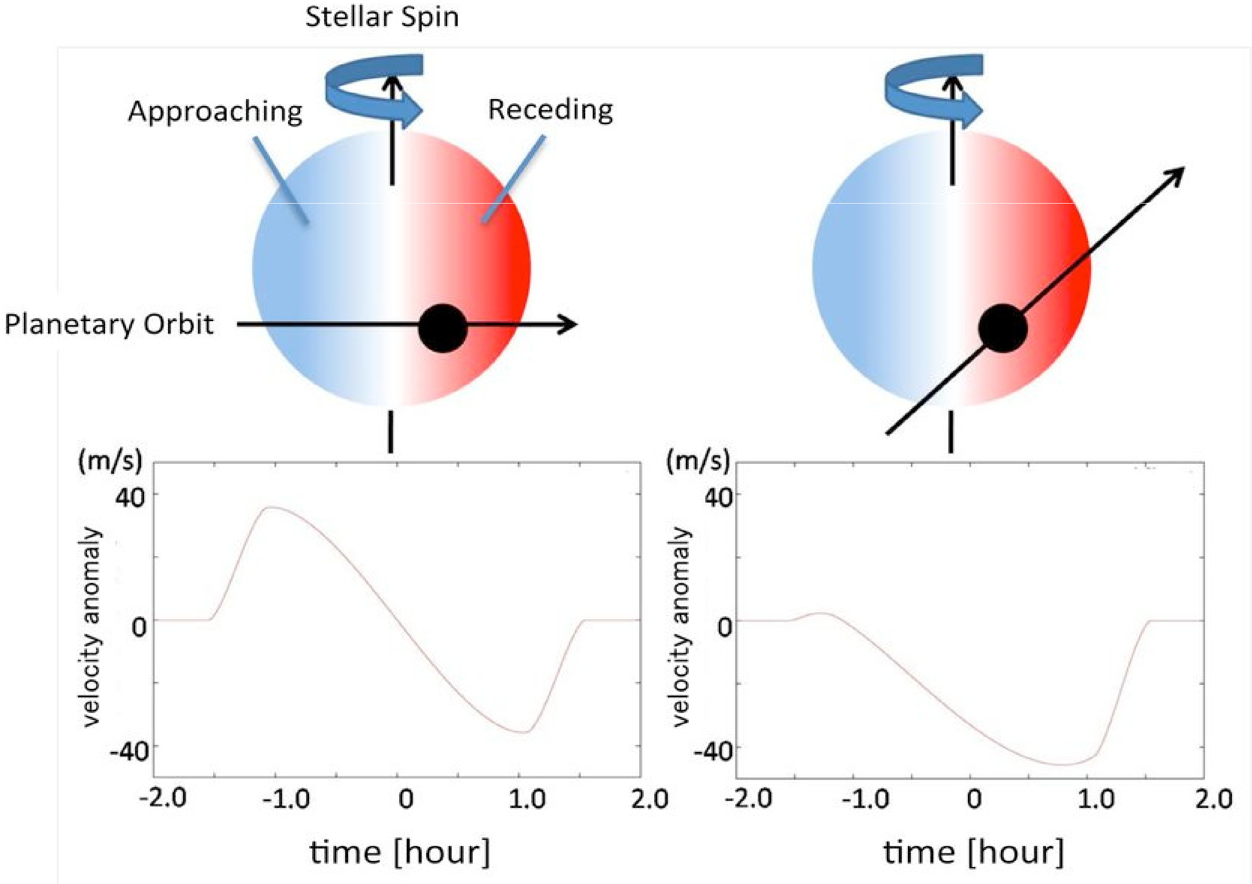
- Takes place during (planetary) transit
- Planet hides small fraction of one velocity component on photosphere
- Small bump moves through spectral line
- Creates RV anomaly



Gaudi & Winn 2007

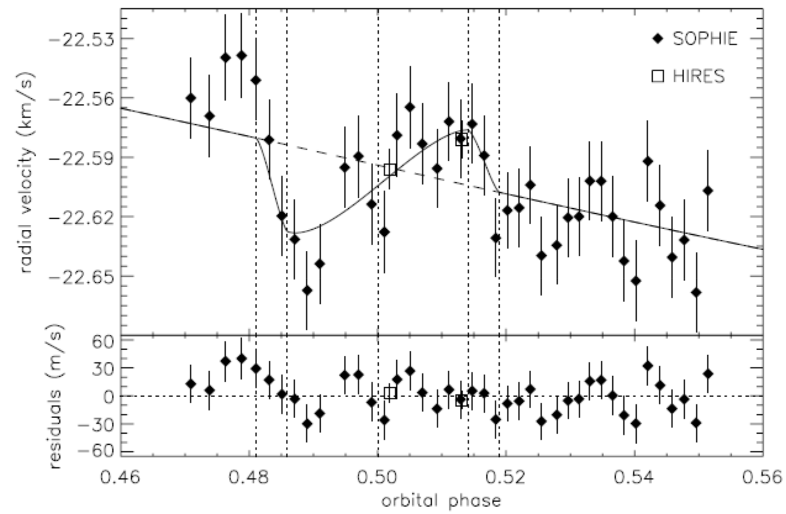
The Rossiter-McLaughlin effect

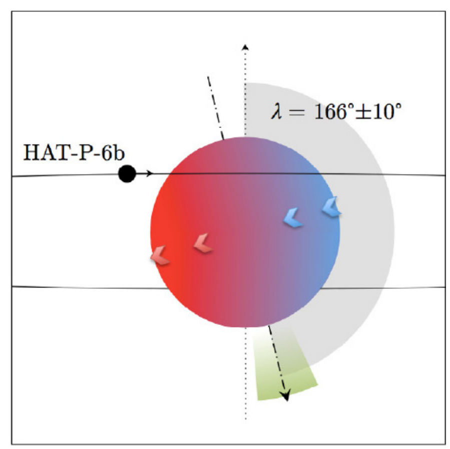
- Access to **projected** star/orbit inclination



RM detected for hot Jupiters

- First detection by Queloz et al. (2000)
  - HD 209458b aligned
- 40 systems observed
  - 18 significantly misaligned
  - 9 on retrograde orbits
- Detection not easy
  - Significant error bars (~10°) on relative inclination



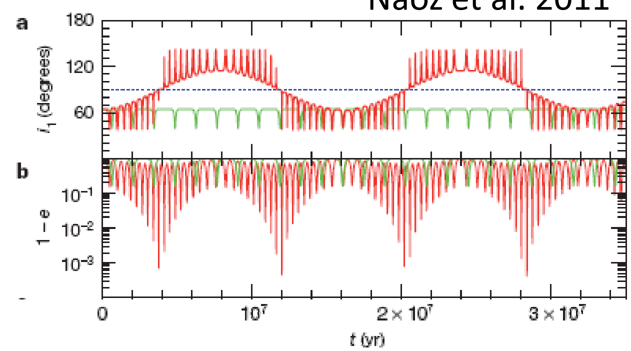


Example: HAT-P-6b (Hébrard et al. 2011)

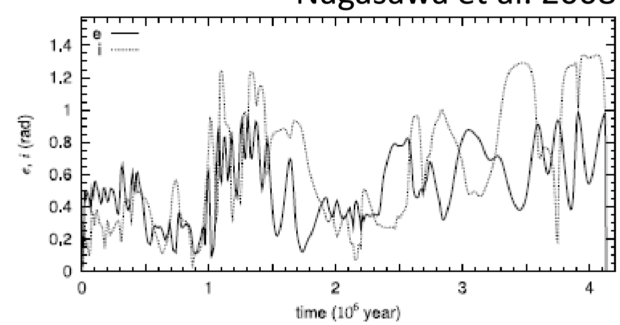
Possible explanations

- Disk-driven migration not possible
- Kozai mechanism
  - Requires distant 3rd body on inclined orbit (40° < i < 140°)
  - Secular oscillations of eccentricity and inclination for inner planet
  - Circularisation by tidal friction
- Planet-planet scattering
  - Instabilities in multiple (packed) planetary systems
  - Orbital crossing → high eccentricities / inclinations
  - Circularisation by tidal friction

Naoz et al. 2011

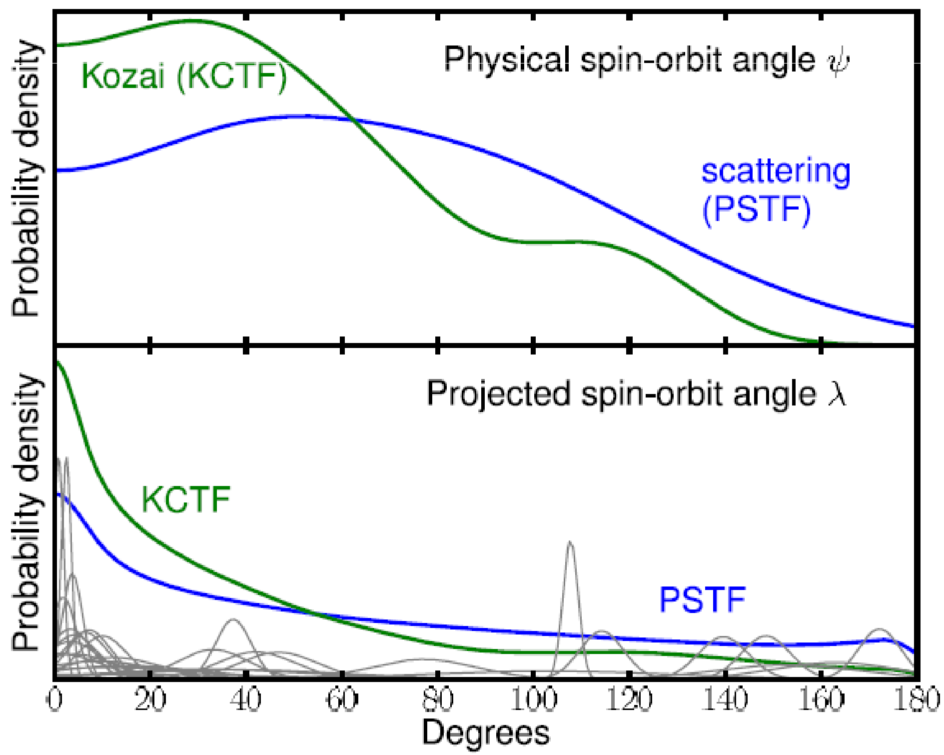


Nagasawa et al. 2008



Kozai or scattering?

- Strongly debated issue (Morton & Johnson 2011)
  - Need 2× more observed systems to conclude



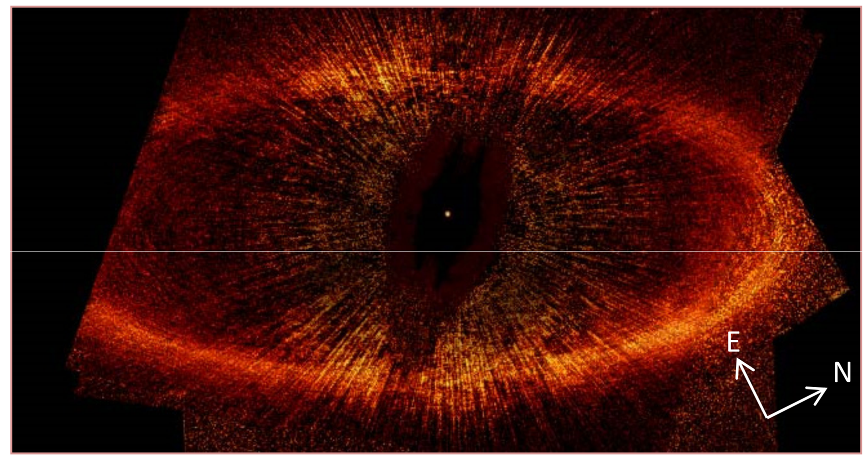
Alternative scenarios

- Misalignment may date back to proto-planetary disk phase
- Early stellar encounter (Bate et al. 2010)
  - Stellar cluster → chaotic environment
  - Interactions → misalignment + truncation
    - Enough mass left for planets?
- Magnetosphere-disk interactions (Lai et al. 2011)
  - Magnetic protostar exerts warping/precessional torque on disk inner region
  - Disk resists warping → back-reaction torque

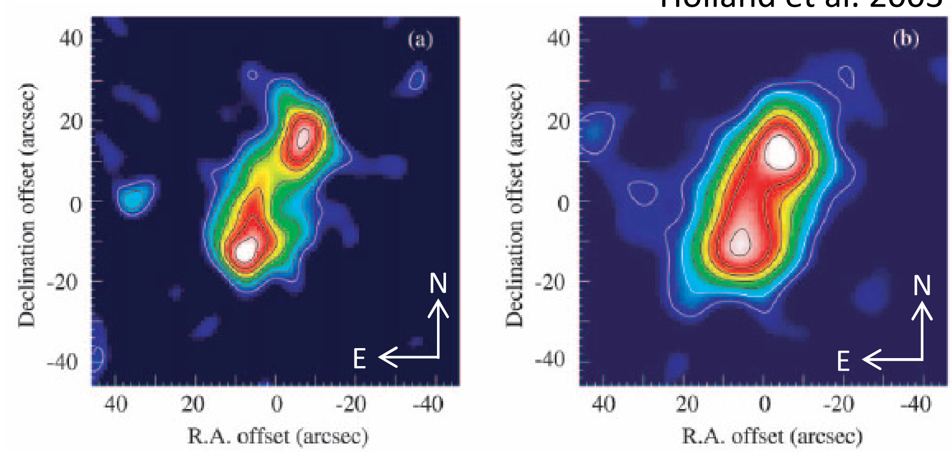
How to discriminate?

- Use debris disks
  - 2nd generation dust created by small bodies
  - Equivalent to Kuiper belt
- Resolved image
  - Inclination / position angle easy to measure
  - Materialises the plane of planetary formation

Kalas et al. 2005



Holland et al. 2003

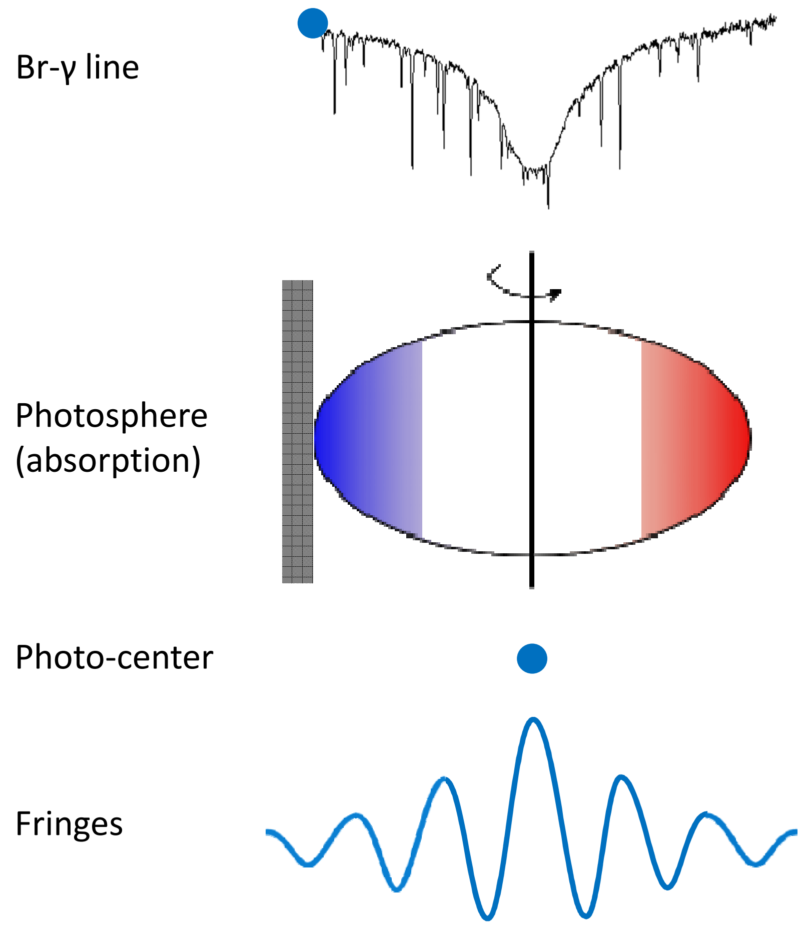


Need stellar orientation

- Inclination from $P_{rot} \times v \sin i / 2\pi R_*$ (Watson et al. 2011)
  - v sin i from high resolution spectroscopy
  - P_{rot} from photometry or Ca II lines (low precision)
  - R_* from spectra, interferometry, …
  - Result: no misalignment in 8 systems (FGK stars)
    - BUT: final error bars generally ≥ 10°
- Position angle from spectro-interferometry
  - Only for rapidly rotating stars (A / early F)
  - Subject of this talk

PA from spectro-interferometry

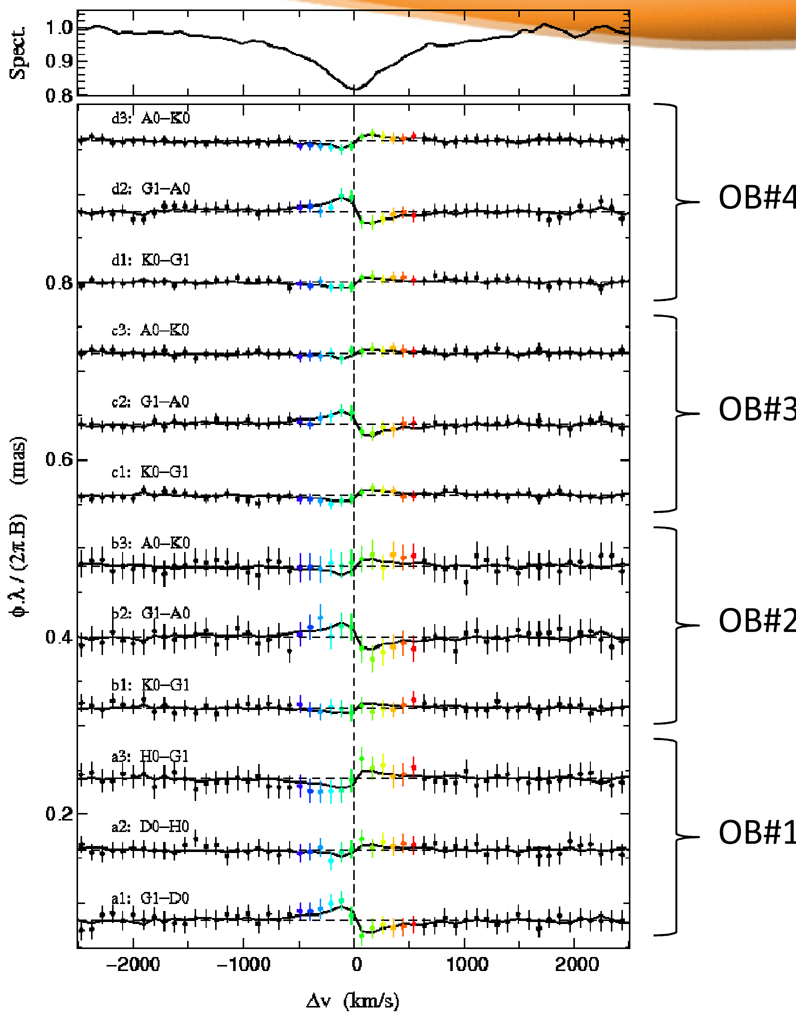
- Requirements
  - Rapidly rotating star
  - Deep absorption line
  - Marginally resolved photosphere (~1 mas)
- Displacement of photocenter across the Br-γ line
  - Signature in fringe phase versus wavelength
  - 2D phase → position angle



Fomalhaut with VLTI/AMBER

- AMBER
  - 3 × Auxiliary Telescopes
  - Baselines: ~100m
  - Medium spectral resolution (R=1500) in K band
- Fomalhaut
  - A4V star at 7.7 pc
  - v sin i = 93 km/s
  - Angular diam: θ = 2.2 mas
- Measure wavelength-differential phase
  - Deduce 2D differential astrometry

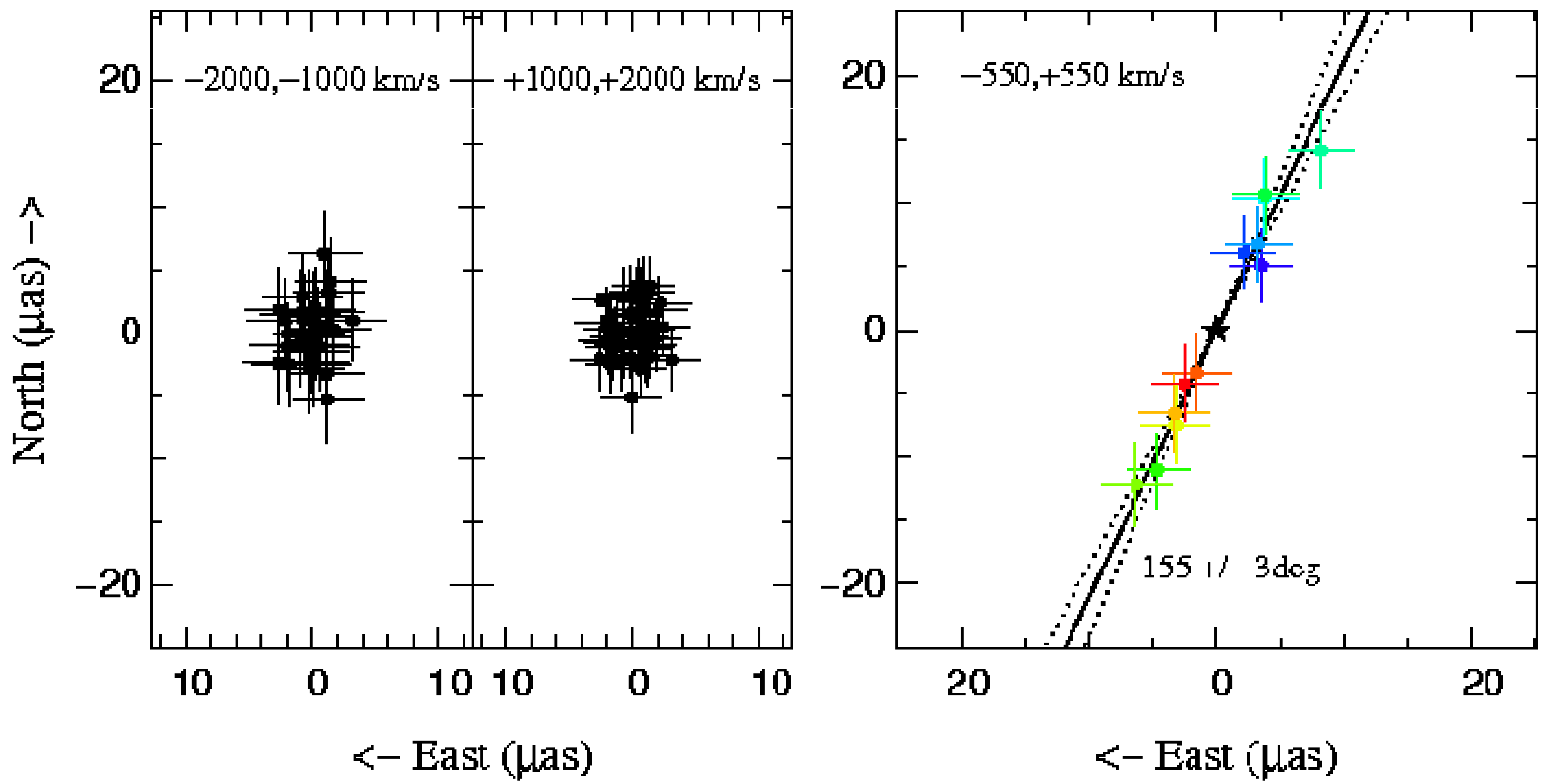
Le Bouquin et al. 2009



2D differential astrometry

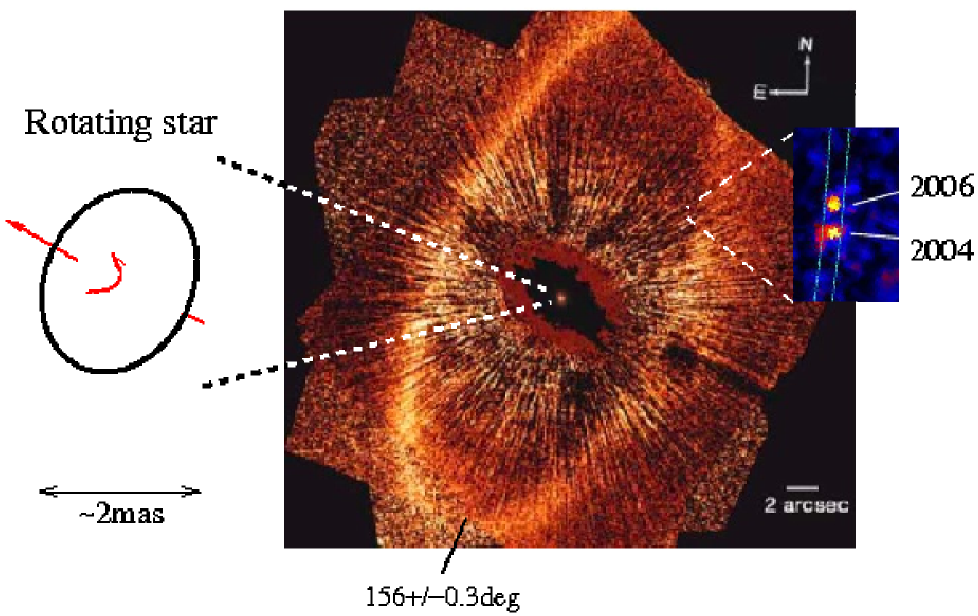
- Clear signature inside Br-γ line
  - Precision: ~3 μas

Le Bouquin et al. 2009



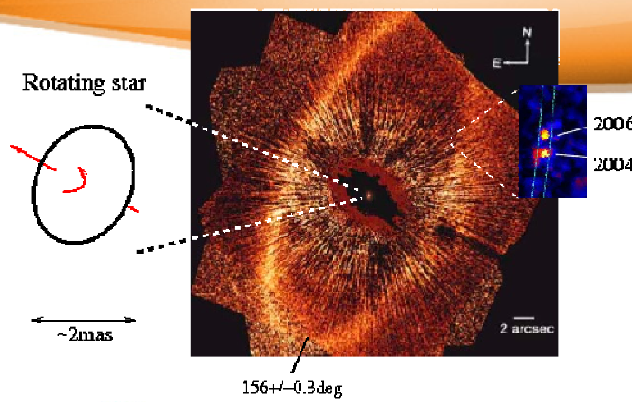
Spin-orbit alignment

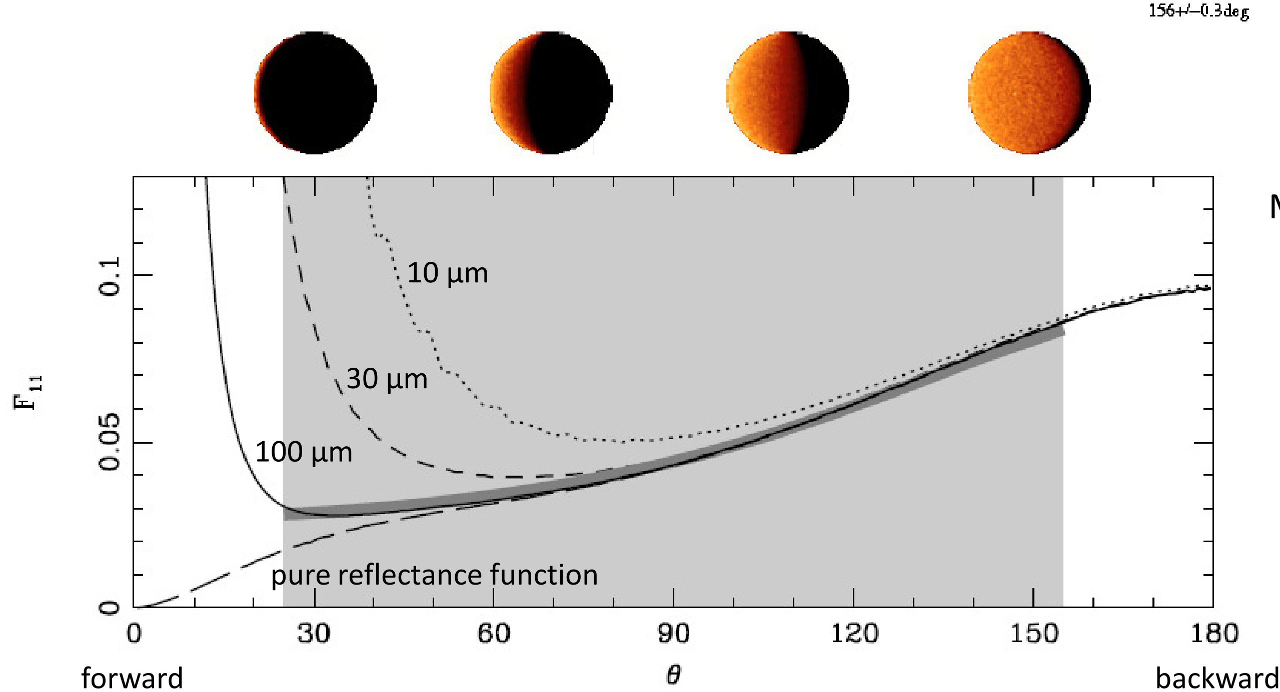
- Photosphere position angle: 155° ± 3°
  - But inclination not constrained (needs advanced model)
- Disk position angle: 156.0° ± 0.3°
- By-product: discriminate front side / back side
  - Assuming planet prograde and stellar spin not flipped



Backward scattering dominant?

- Possible only with big grains
  - Similar to lunar phases
- Small grains ejected?
  - What about further collisions?





Min et al. 2010

Future work

- 10 potential targets
  - Out of 25 resolved debris disks
- Zeta Leporis
  - Position angle retrieved while θ = 0.75 mas only
- Beta Pictoris
  - Star aligned with inner or outer disk?