Doppler Tomography of accretion disks in compact binaries

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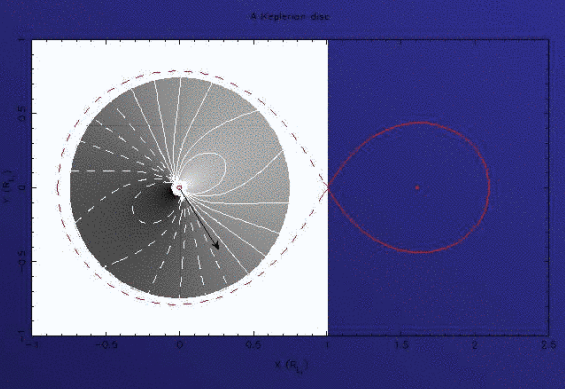
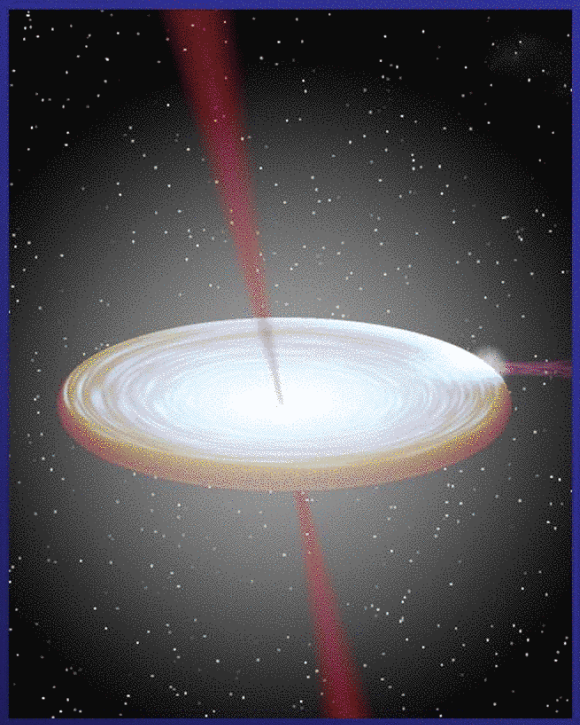
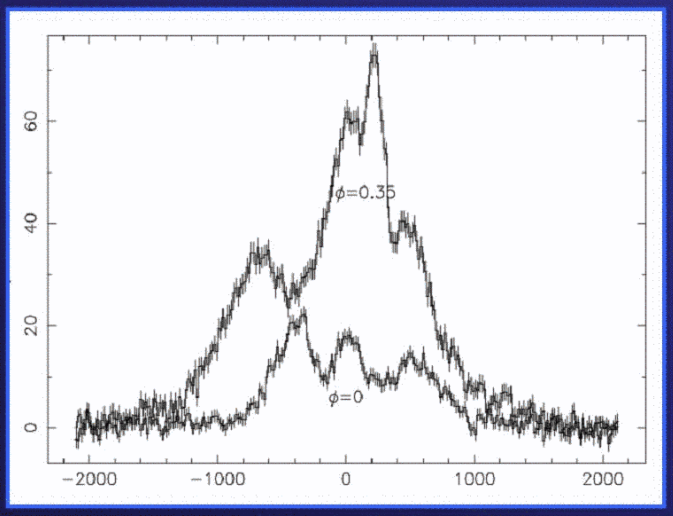
Emission lines from a disk

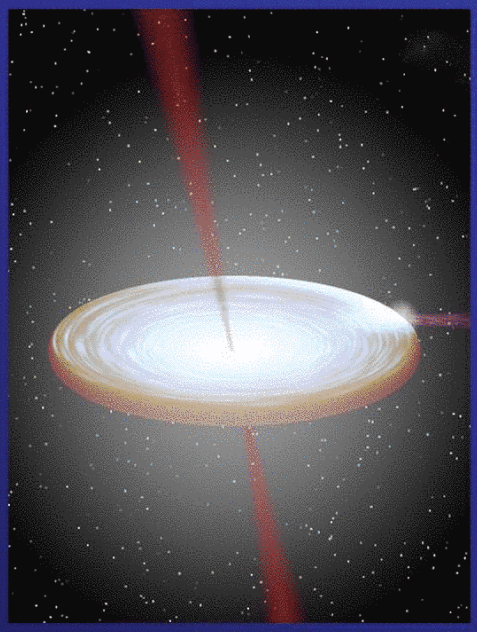




Emission line diagnostics

The presence of strong and Doppler broadened emission lines is indeed a key characteristic of accretion flows





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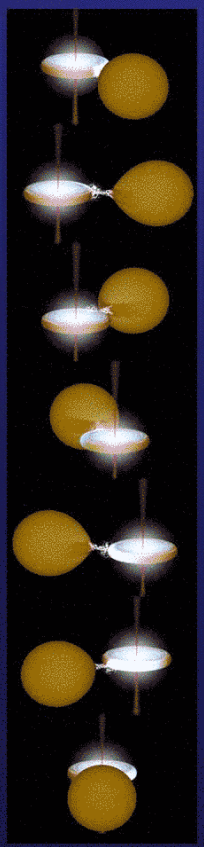
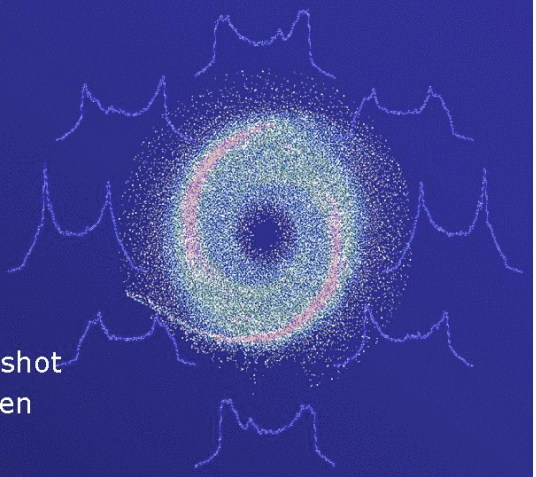
Doppler tomography using line profiles



- Time-dependent line profiles provide a powerful diagnostic as the binary components go through their orbits
- Each spectrum provides a snapshot of the binary dynamics at a given orbital phase = orientation
- Phase-resolved spectroscopy can build up a dataset of line profiles that contain sufficient information to invert these into images resolving the dynamics of accretion = image reconstruction through (de)projection = tomography



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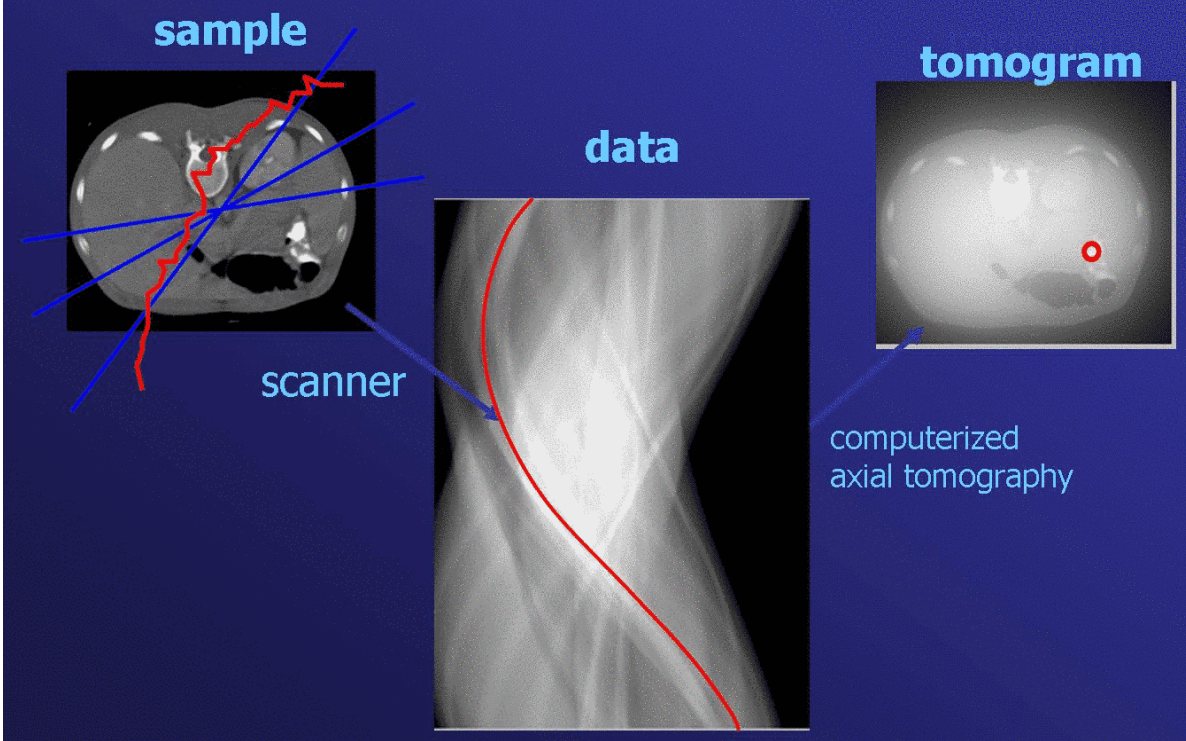
Medical CAT: from sample to tomogram



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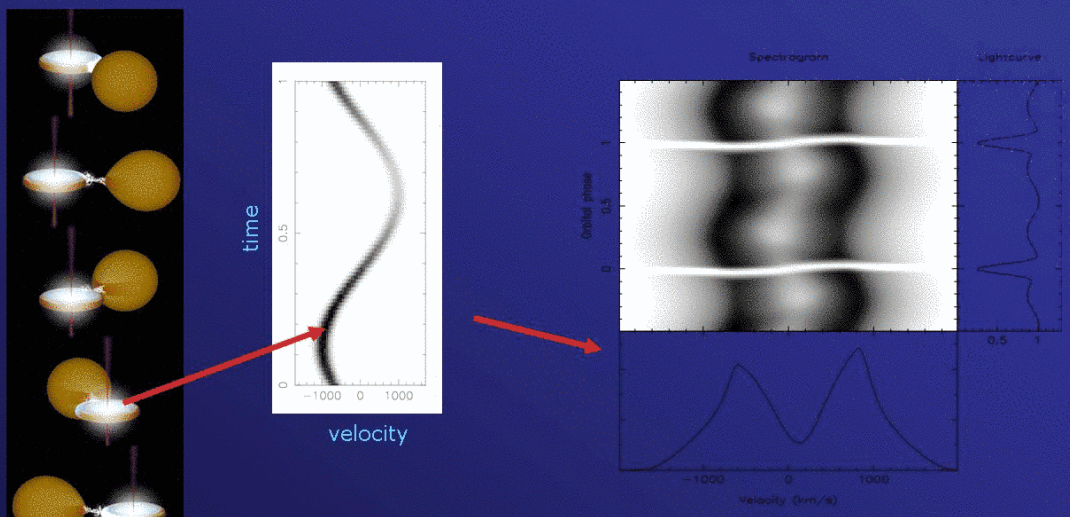
Imaging through spectroscopy



we can observe the time dependent line profiles as a function of the binary orbit

! The tomogram reconstructs the mean emission line distribution in the co-rotating frame

Since our diagnostic is Doppler shift, our projection space is in velocity and not Cartesian coordinates

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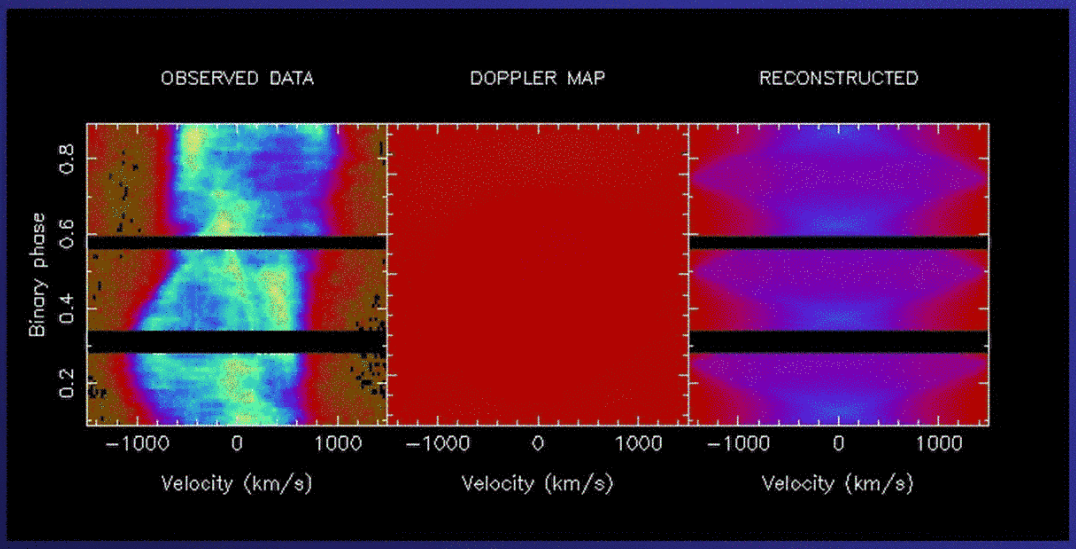
From 2D data to 2D image



maximum (image) entropy serves as our Occam's razor in regularising the fit

minimisation problem: $Q^2 = \chi^2 - \alpha S$

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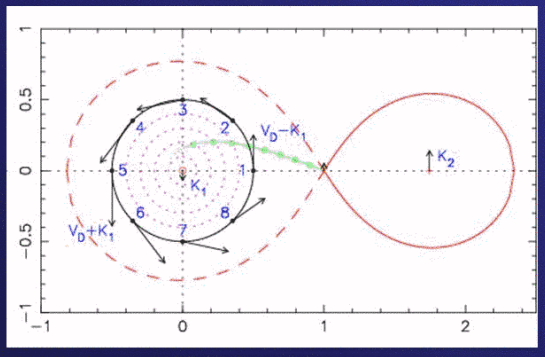
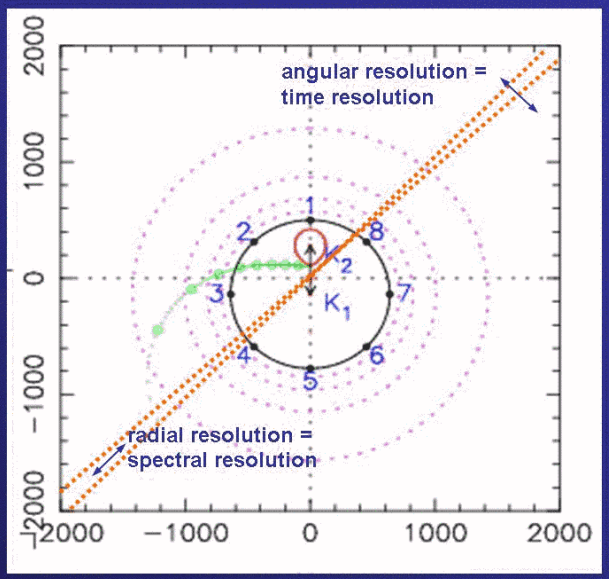
Doppler coordinates





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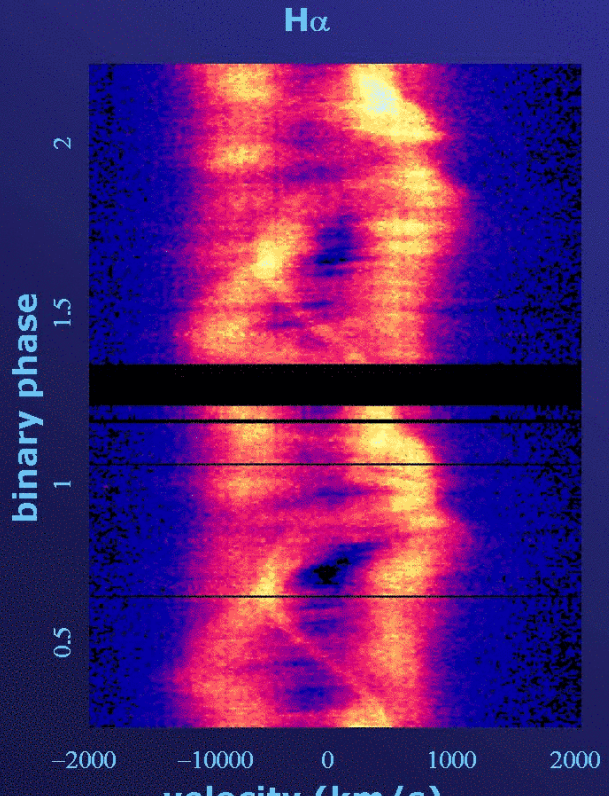
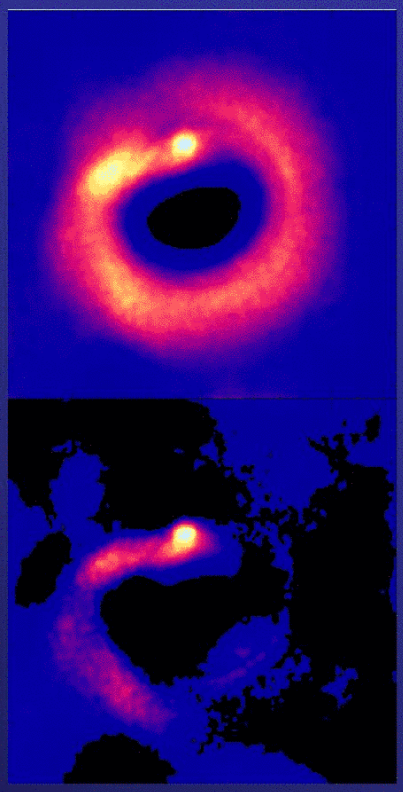
Mapping the accretion flow; a 'low-α' disk





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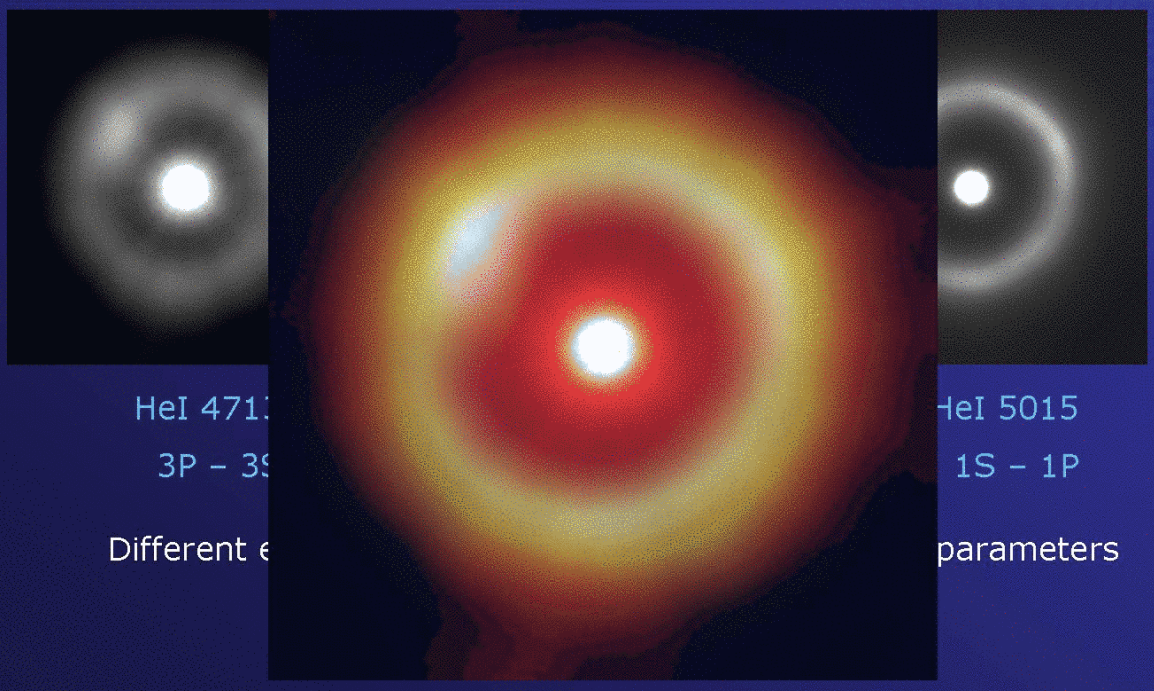
Multi-line diagnostics

The hydrogen-deficient accretion disk in the ultra-compact double white dwarf binary GP Com



HeI 471 — HeI 5015

3P – 3S — 1S – 1P

Different ε — parameters

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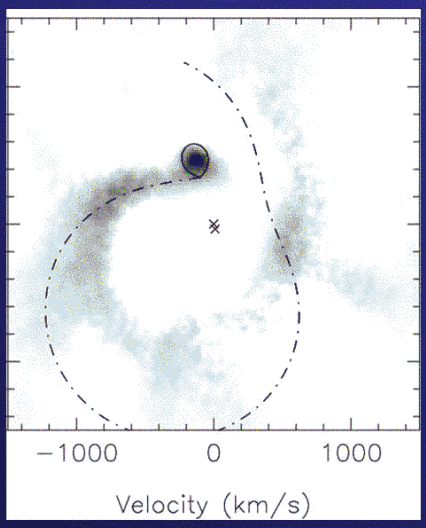
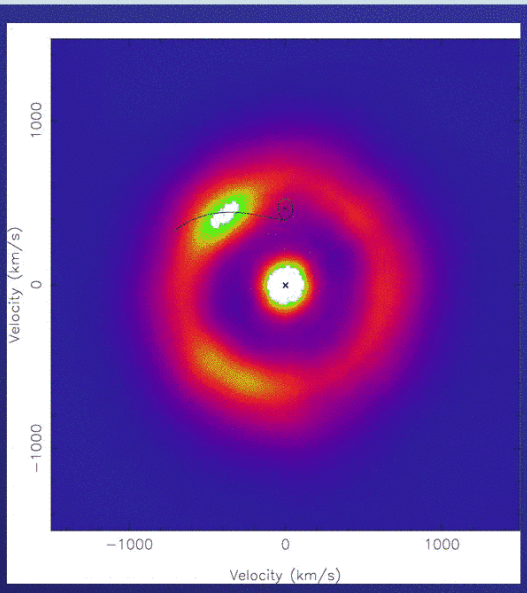
System parameters through tomography





A degenerate donor star in WZ Sge

M_1~1.0$M_\odot$, M_2~0.08$M_\odot$ (Steeghs et al. 2001)

The stripped 5M_J donor of CE-315 (Steeghs et al. 2004)

Dynamic mass estimates of compact objects and faint donors

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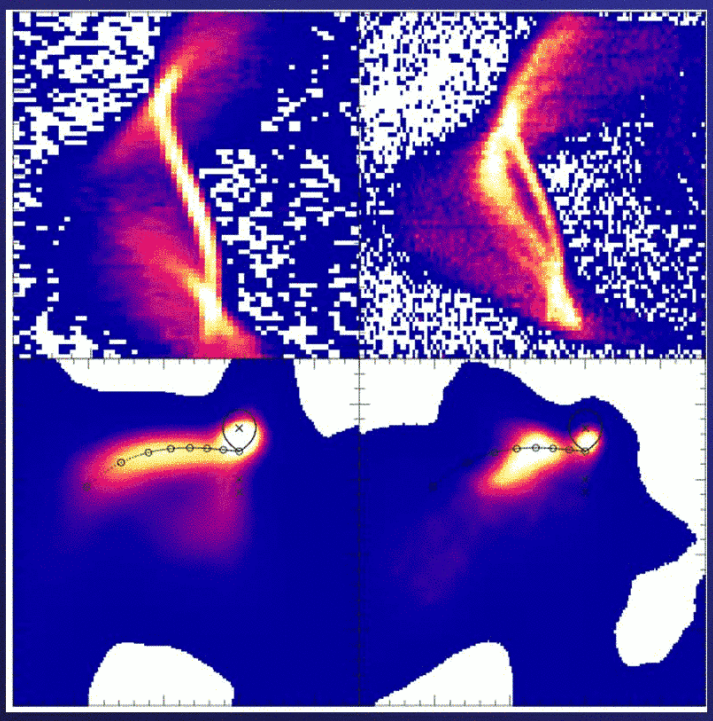
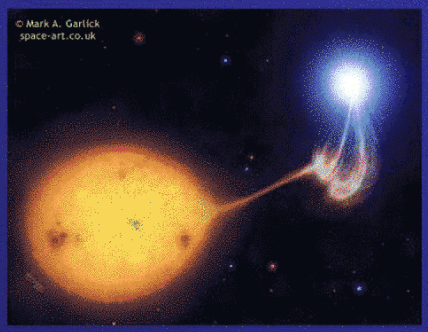
Non-disk flows





Magnetically controlled accretion onto a magnetized primary (Schwope 2004)

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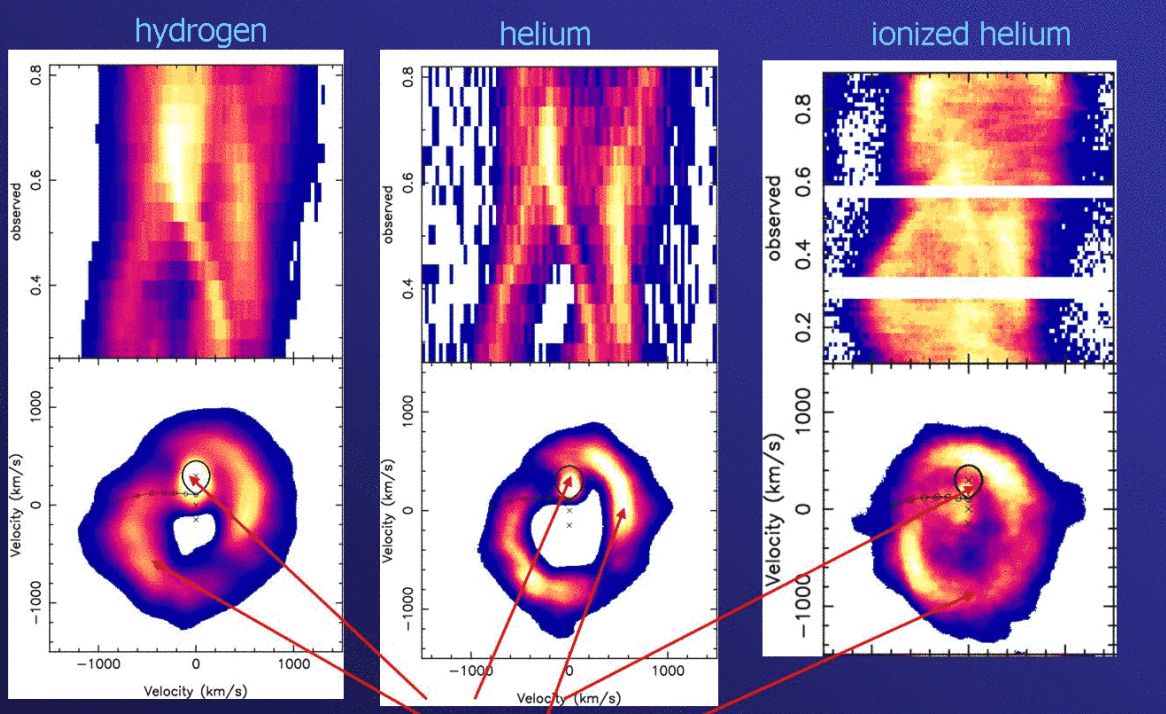
An accretion disk in outburst



(from Steeghs, 2001)

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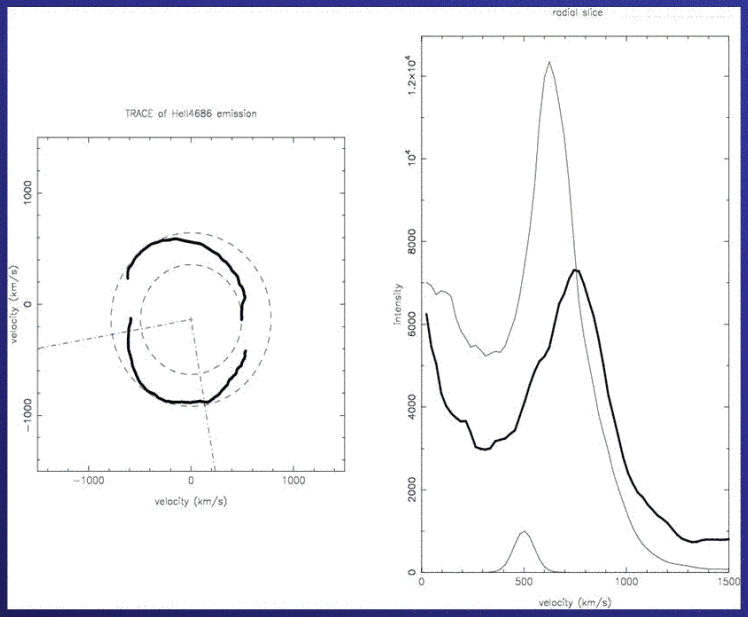
Global disk asymmetries

- Two-armed asymmetry can be traced for almost 180 degrees and shifts from 500-800 km/s with respect to the white dwarf as a function of azimuth

  = geometric spiral

- These velocities correspond to radii between 0.3 and 0.9 times the distance of the L1 point assuming Keplerian velocity field



(Steeghs 2001)

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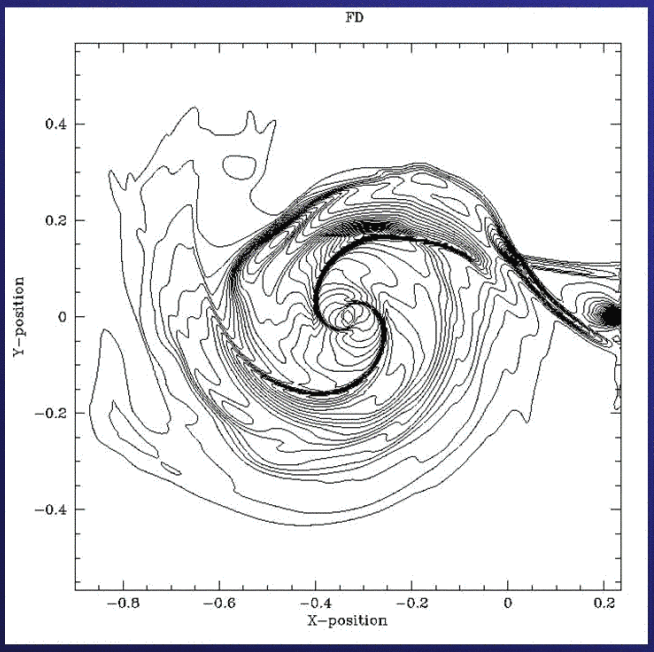
Spiral arms through tides?



m=2 trailing spiral due to tidal torques driven in the outer disk

Sawada et al. 1986

Spruit 1987, Larson 1989

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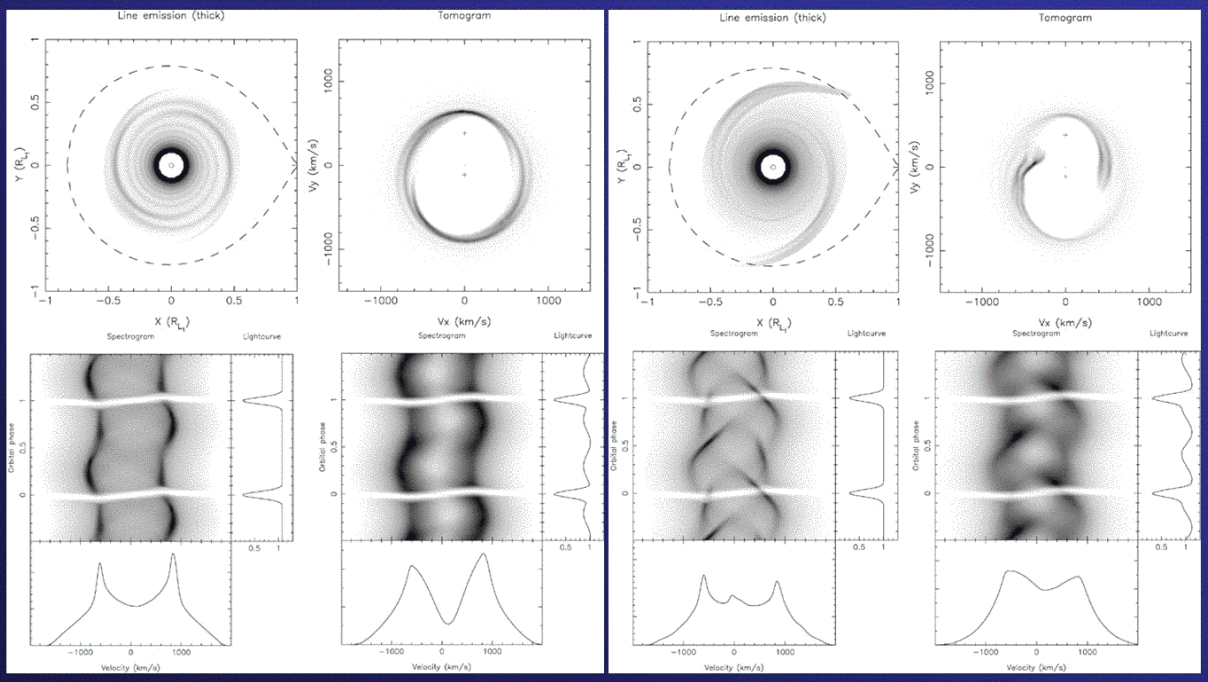
Interpreting Doppler maps in detail

Modeling in Doppler-space



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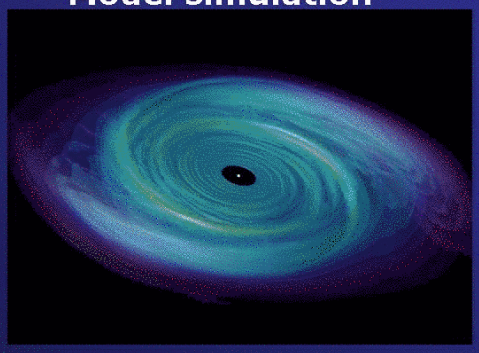
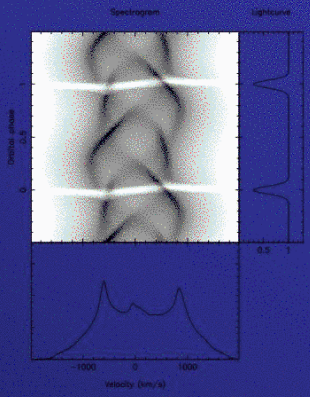
The dynamics of accretion disks ; tidal spirals

Model simulation

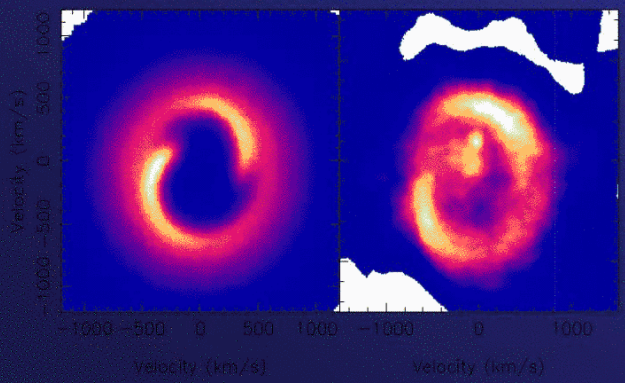


Synthetic data



from Steeghs & Stehle (1999)

Model versus observations



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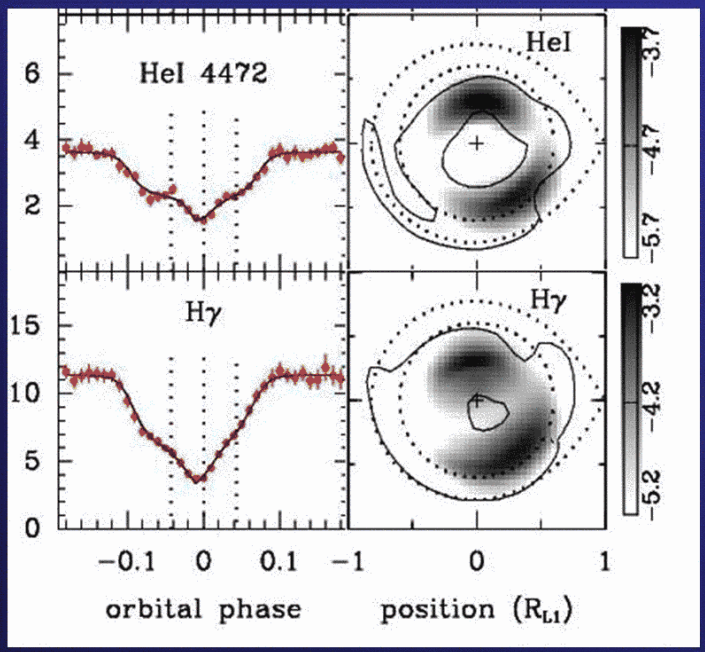
Independent eclipse constraints for IP Pegasi



Reconstructing the disk emissivity using the eclipse shape reveals the two-armed assymmetry in the eclipses of the lines and continuum

Correlating velocities as measured in the Doppler images with radii as reconstructed from the eclipse also confirms sub-Keplerian velocity field in these outer disk regions

Baptista et al. 2000; 2005

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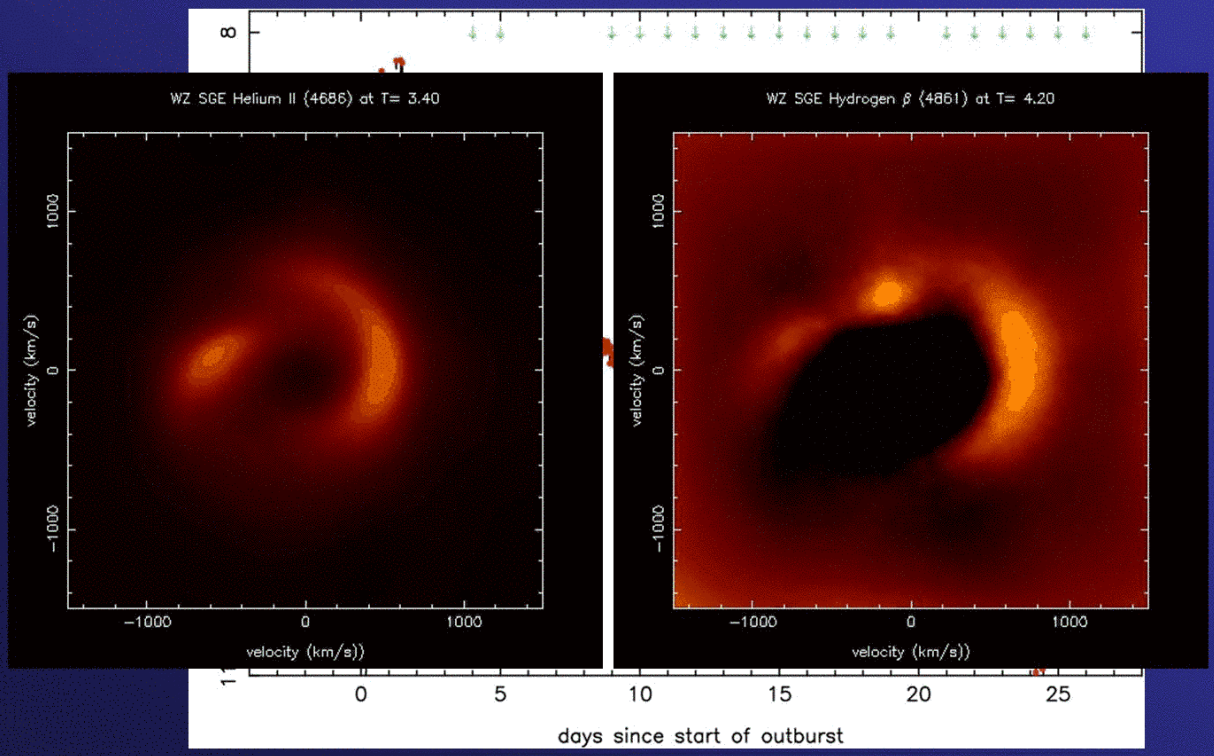
Time-lapsed Doppler movies of WZ Sge



time

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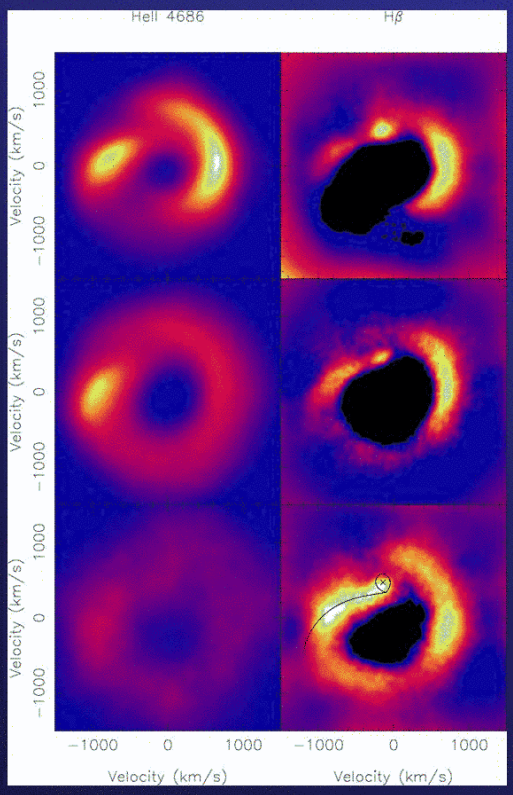
Global disk geometry, tides and angular momentum



- Tides can drive strong spiral asymmetries in the disks surrounding compact objects
- The angular momentum budget is an interplay between local α-type viscosity processes and non-local processes associated with tides, density waves and shocks
- Global disk changes driven by modulations in local α/MRI-style viscous transport
- Doppler imaging can map this interplay and constrain the MRI turbulence through its effect on the overall disk geometry and the properties of the transient tidal arms

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Summary and Outlook

- Doppler tomography resolves the accretion flow around objects in detail
  - the donor star and its accretion stream
  - interaction between mass transfer and outer disk
  - non-disk components, propellors, magnetic streams
  - reconstruct the real-time viscous evolution of disks
  - established the critical role of tides in the outer disk
- Extend line tomography to new wavebands and new objects
  - cool disks in the IR
  - hot inner disk regions in the UV/X-ray
- Match observations to global disk simulations
  - dynamics
  - study interplay between local and global angular momentum
  - line emission thermodynamics
- Time-lapsed tomography of transient accretors
  - accretion states and the disk geometry
  - tides and angular momentum

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