E-ELT/HIRES
Disk-Star Interactions
at the epoch of planet formation

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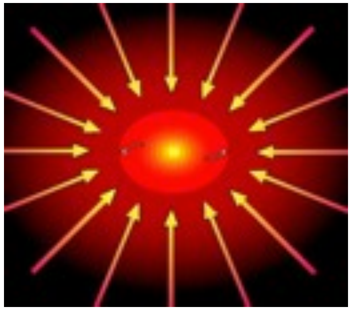
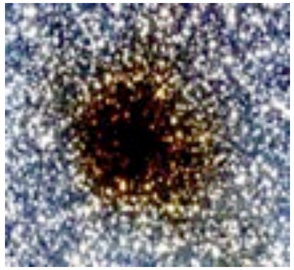
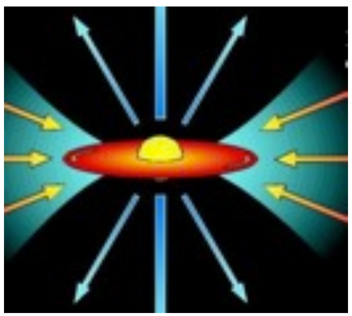
From Cores to Planetary Systems

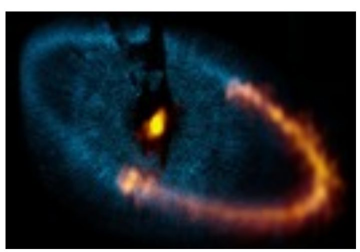




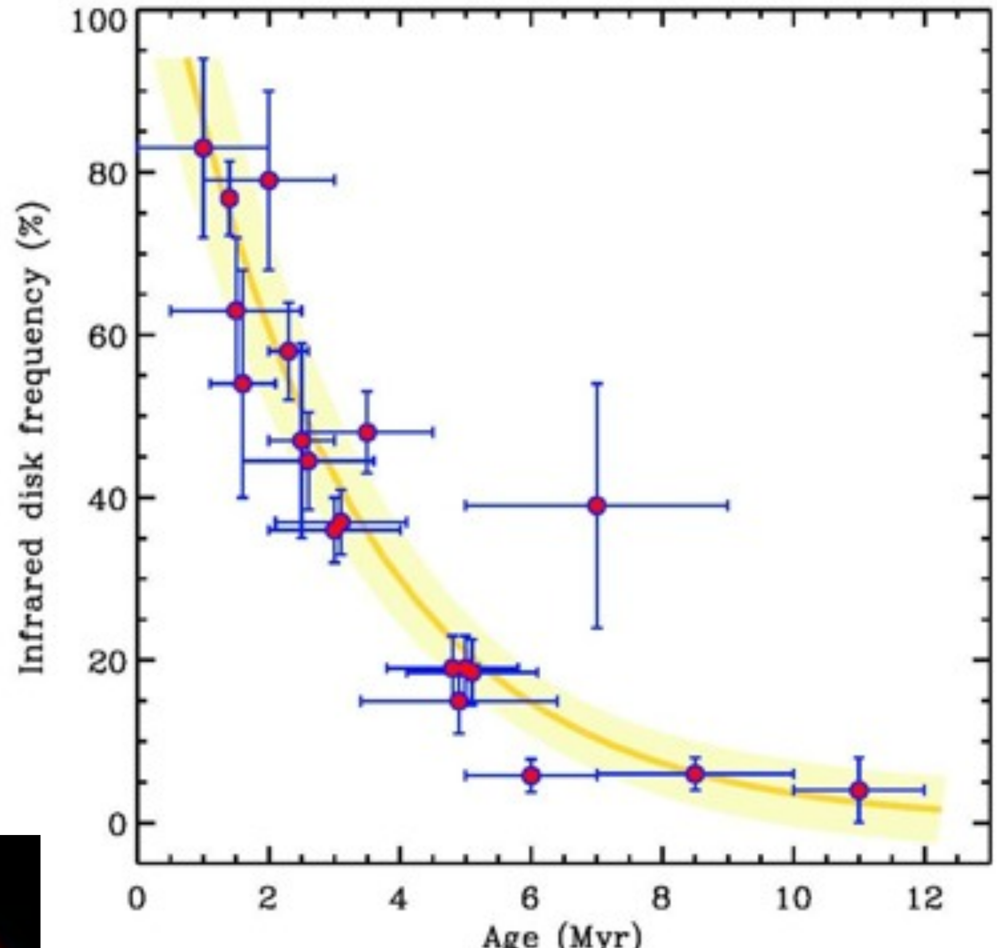
Core



Disk



Debris Disk

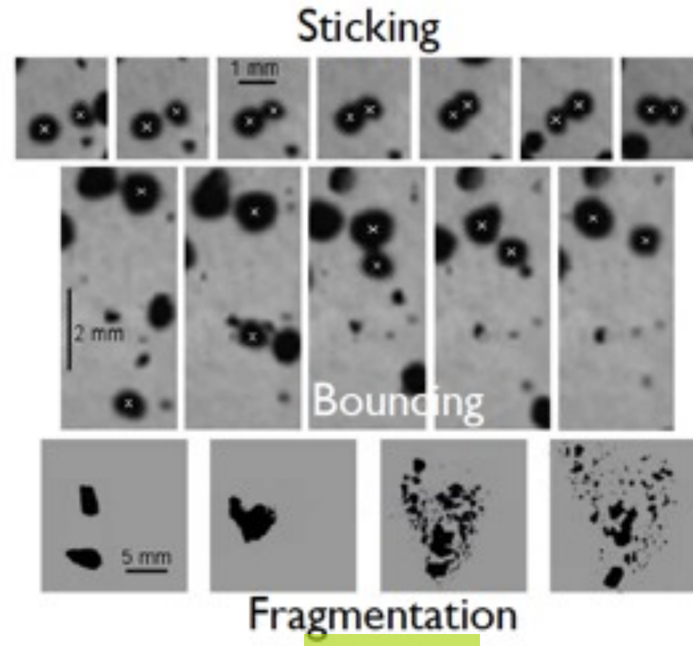


(Hernandez et al. 2007)

Inner disk clearing:
e-folding time t~2-3 Myr

Grain Growth the Dawn of Planets

- The core-accretion scenario
  - Dust growth and planetesimals formation
  - Formation of rocky cores
  - Gas accretion from disk



Directly observable through IR and mm observations

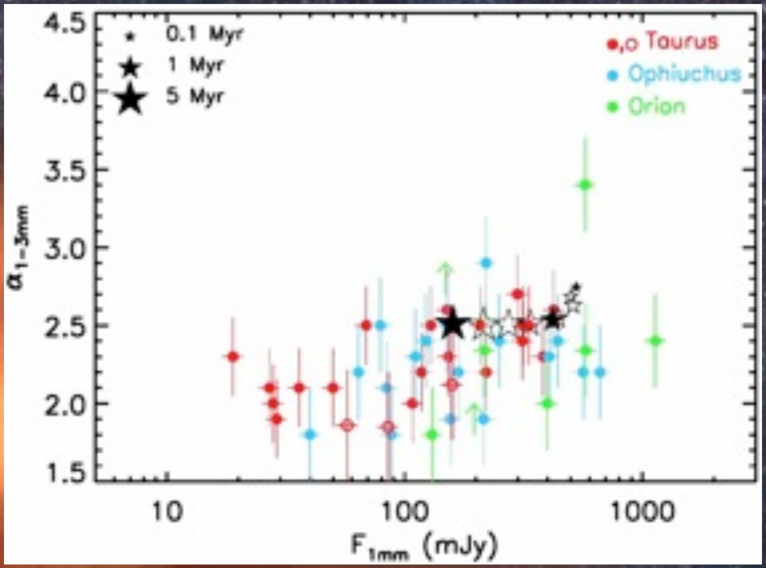
hic sunt dracones (models)

End State Exo-planets

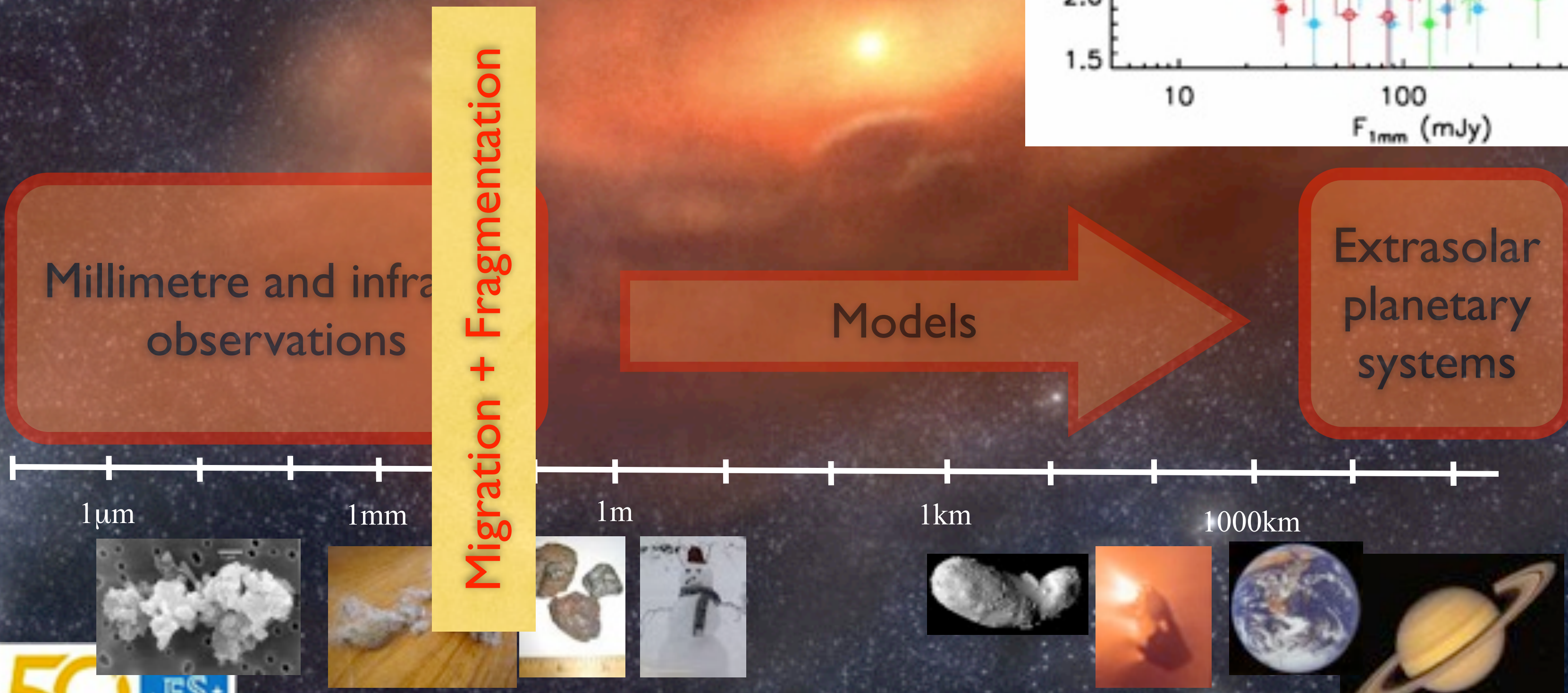
Solar system constraints (but only 1 object! Snapshot 4.5 billion years after the fact!)

Dust trapping in pressure maxima

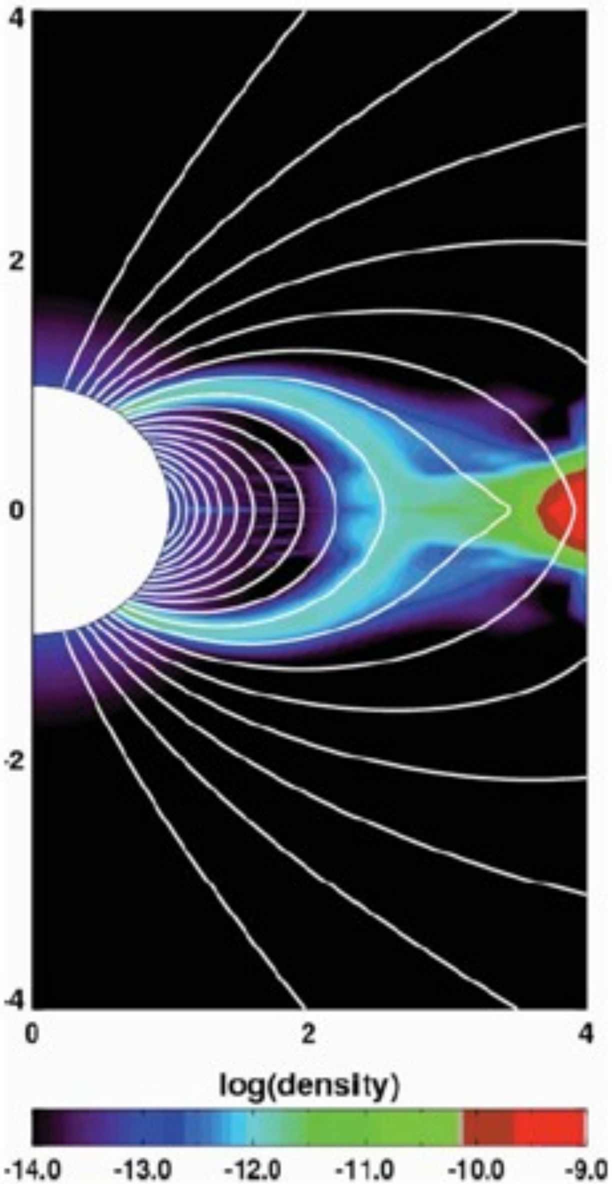
- Pressure maxima in disks (arms, vortices...) can efficiently trap large particles allowing grains to growth and stay in the disk for long times



(Pinilla, Birnstiel, Ricci et al. 11, Ricci et al. 11)



Disk-Star Interaction Region

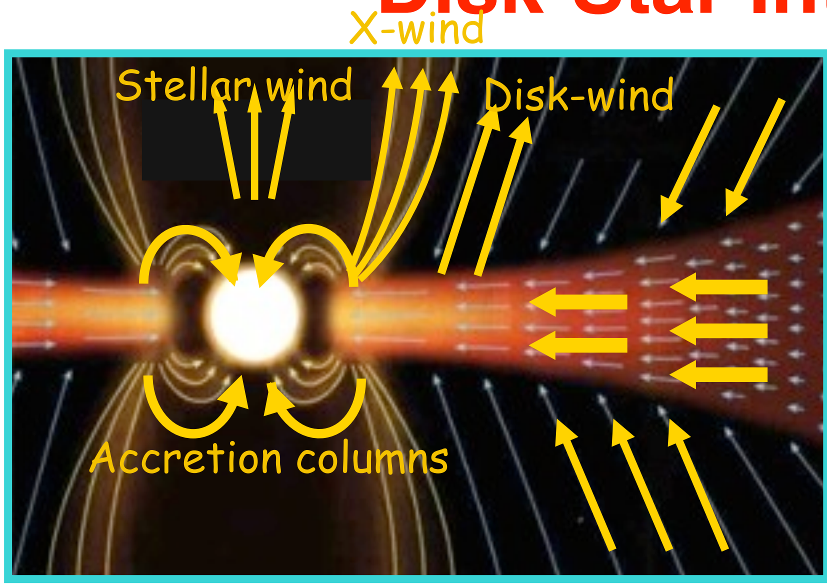


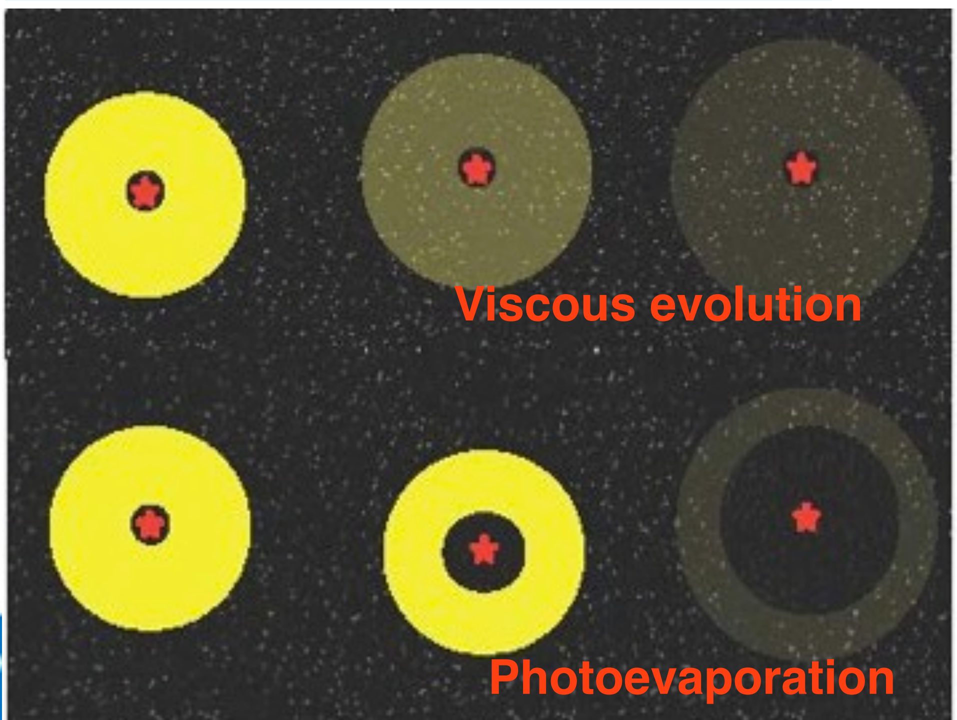
- Ingredients:
  - Young (evolving) stellar photosphere
  - Magnetic Field
  - Dusty disk evolving
  - Gaseous inner disk accreting/outflowing

- What we know:
  - Evolution of the star is tightly coupled to the disk and vice versa
  - Very little on magnetic fields
  - Gas (chemistry) and dust (size distribution) evolve with time and are affected by the star
  - Structure (and its evolution) of the inner disk is critical for outcome of planet formation (planets in habitable zone and their characteristics)

- 1 AU @ 150pc = 7 mas

Disk-Star Interaction Region



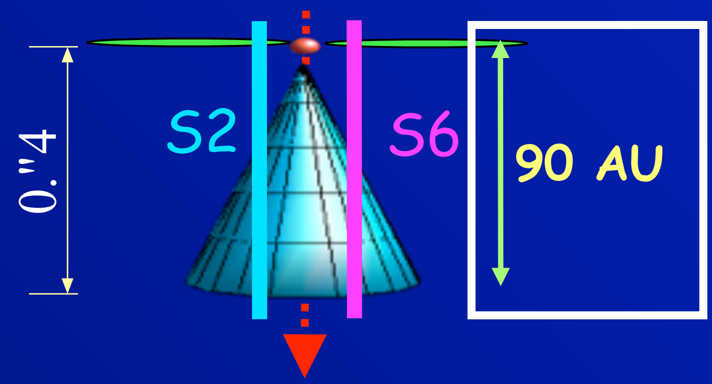


- Accretion is driven by viscosity
  - Accretion is linked to the inner stelalr and/or “X-”wind.

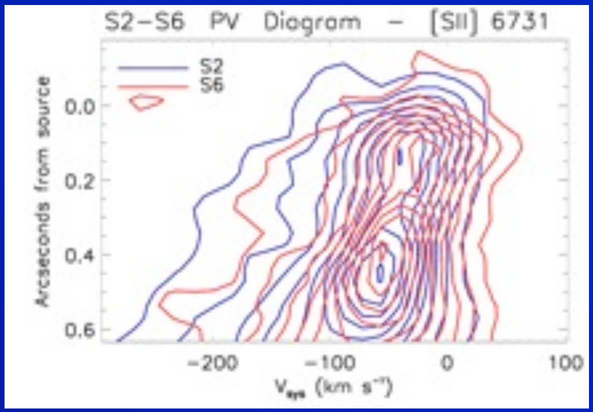
- What we know:
  - Photoevaporation removes the disk inside-out

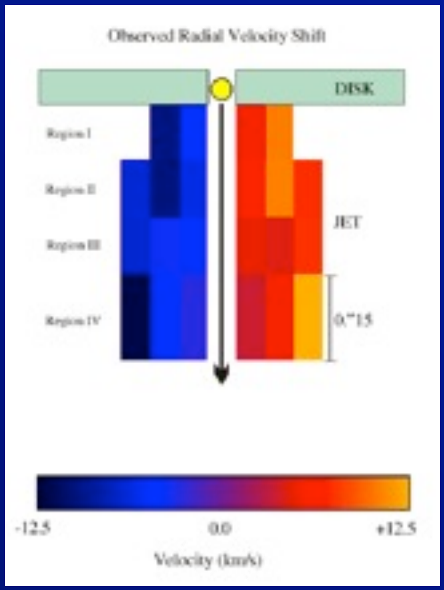
- Planet formation “competes” for resources with these two processes and interacts with them

First detections of jet base rotation : DG TAU, RW AUR



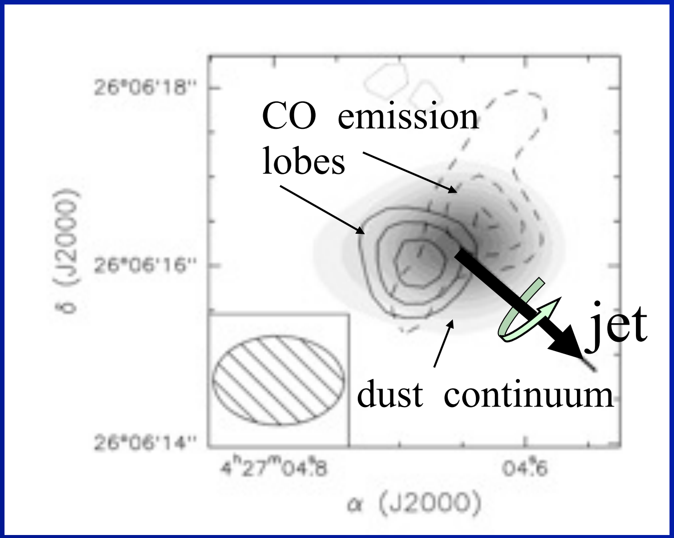
Small VELOCITY SHIFT
in symmetrically opposed slits (in all lines, corrected for uneven slit illumination)





30 AU

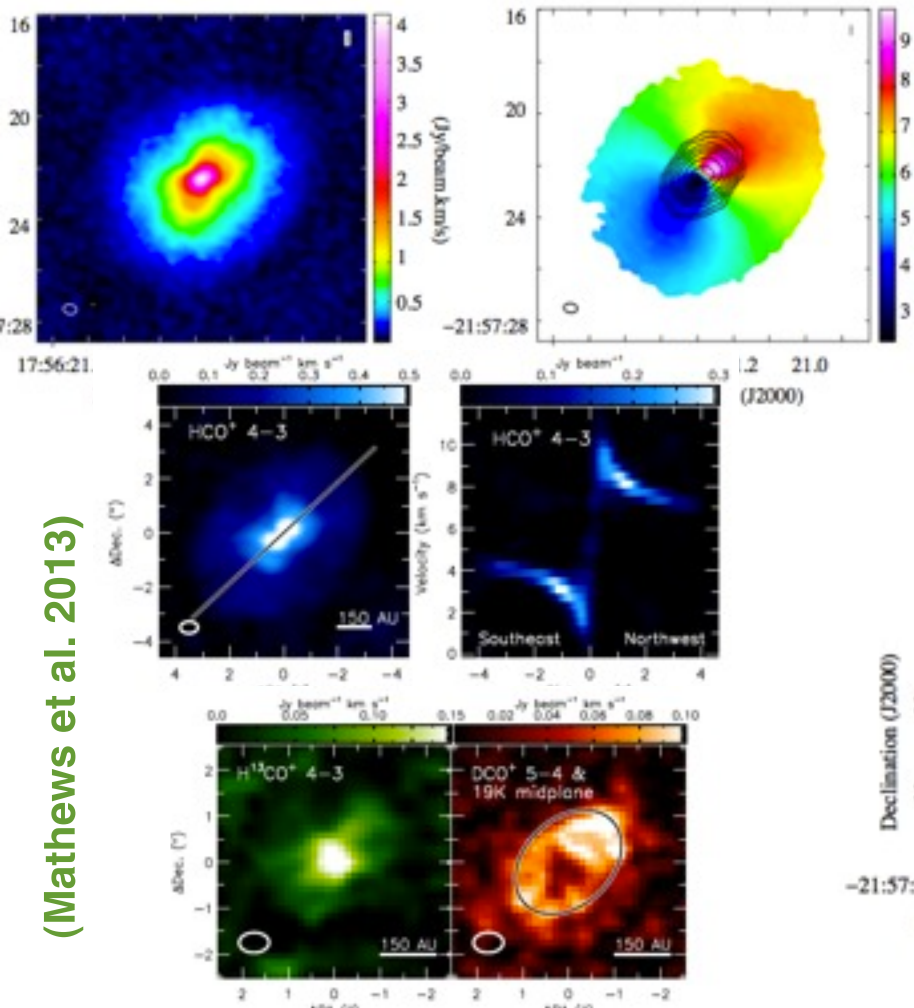
Bacciotti et al, 2002 ApJ



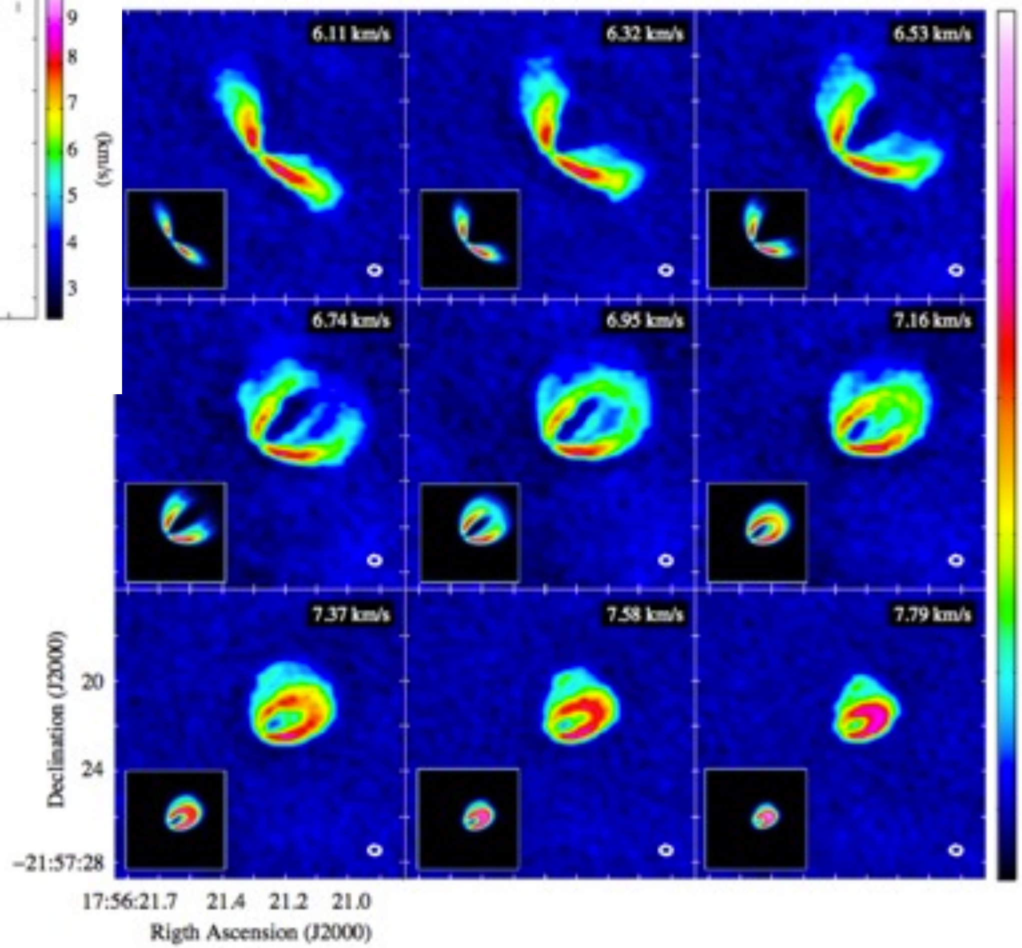
DG Tau disk rotates in the same sense and along the same rotation axis

Testi, Bacciotti et al. 2002, A&A

HD163296 as seen by ALMA



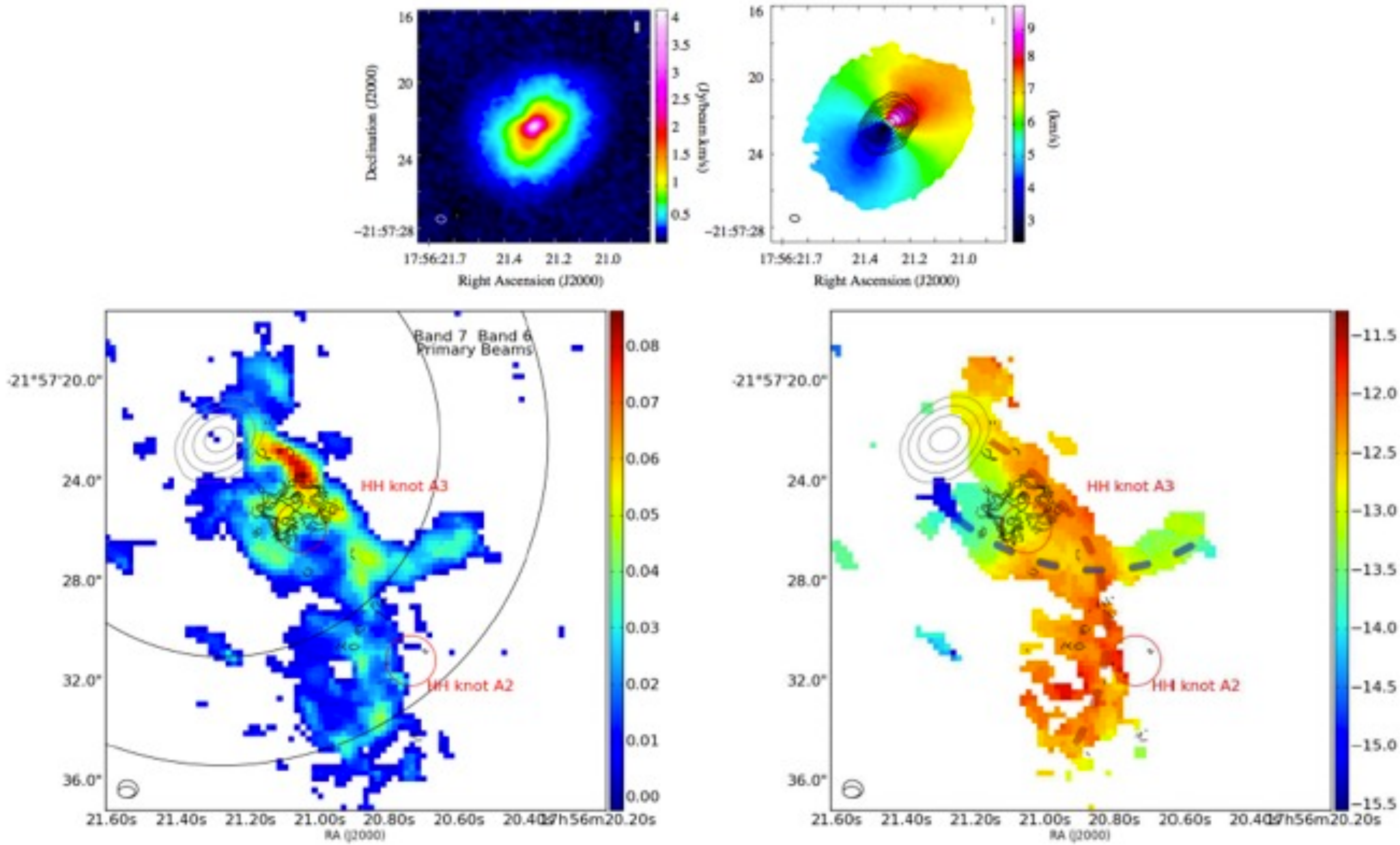
(Mathews et al. 2013)



(de Gregorio Monsalvo et al. 2013)

- Dust vs. gas disk, freeze-out and deuteration, flaring geometry

HD163296 as seen by ALMA



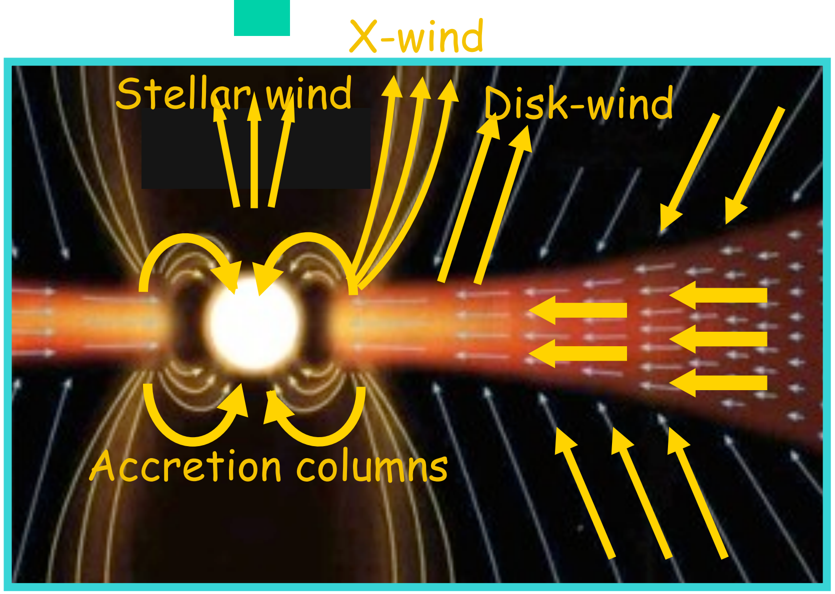
(Klaassen et al. 2013)

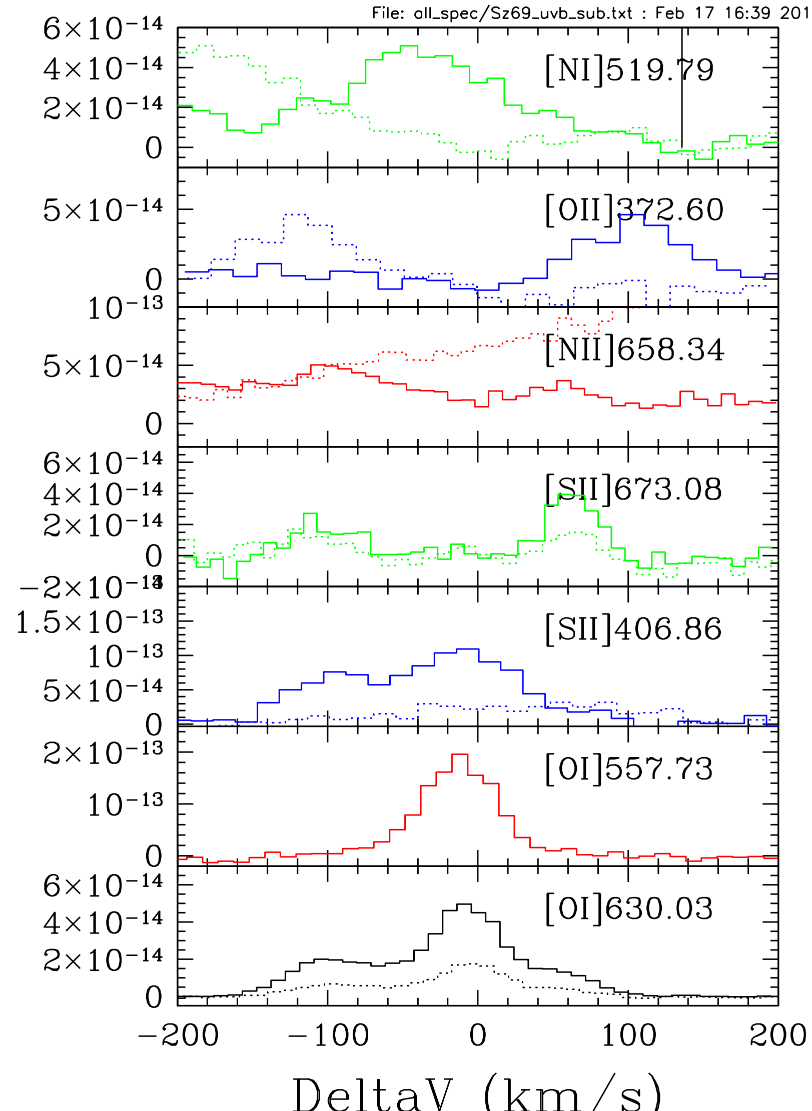
- ✦ CO disk wind

Winds in optical forbidden lines

High Velocity “jet”

Low Velocity wind

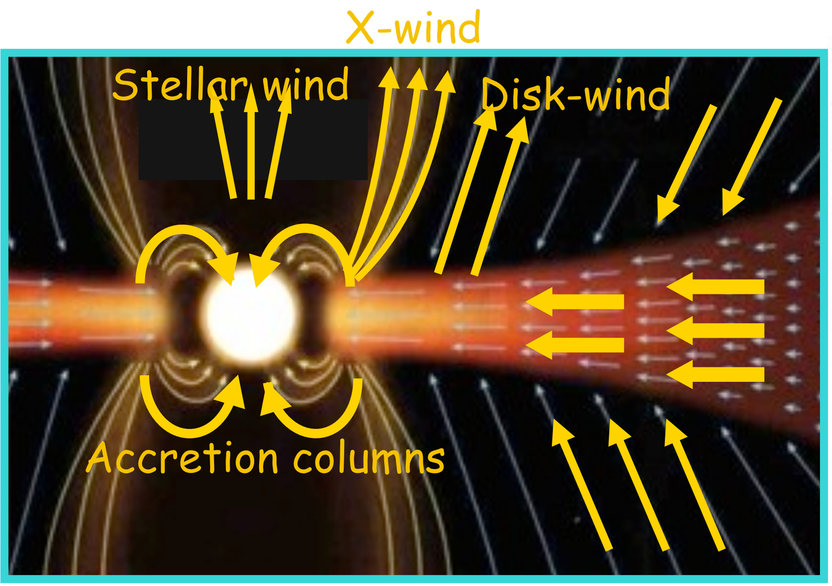


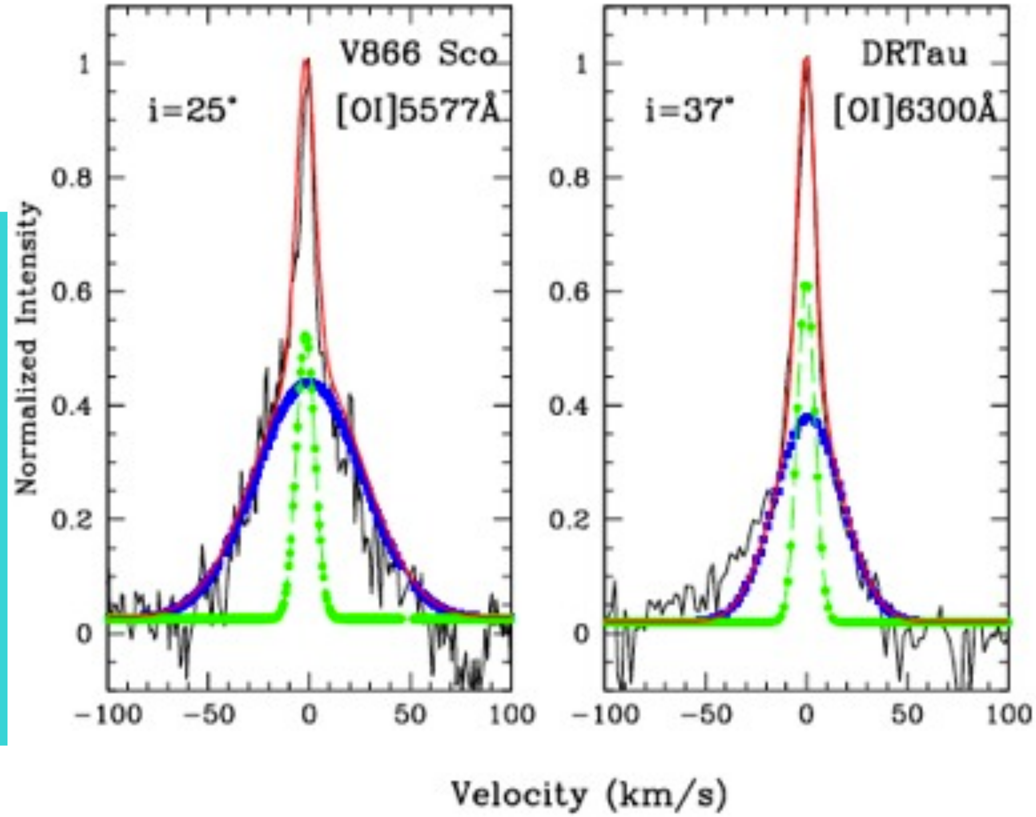


(Natta et al. 2013)

Winds in optical forbidden lines

Low Velocity Component

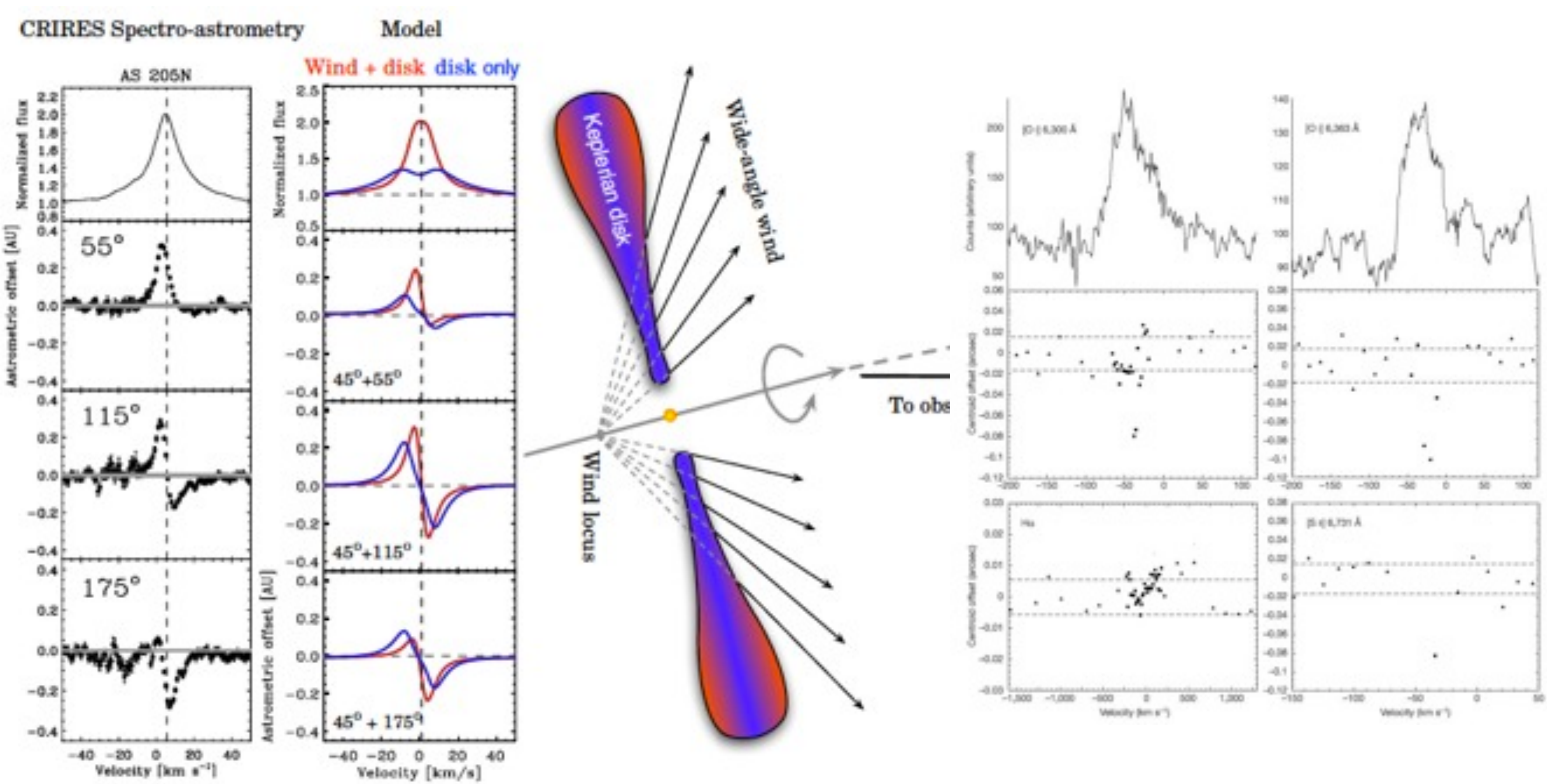




(Rigliaco et al. 2013)

- Working hypothesis:
  - Narrow component is the real wind from outer disk
  - broad component is photodissociated upper layer of the inner disk

Spectroastrometry



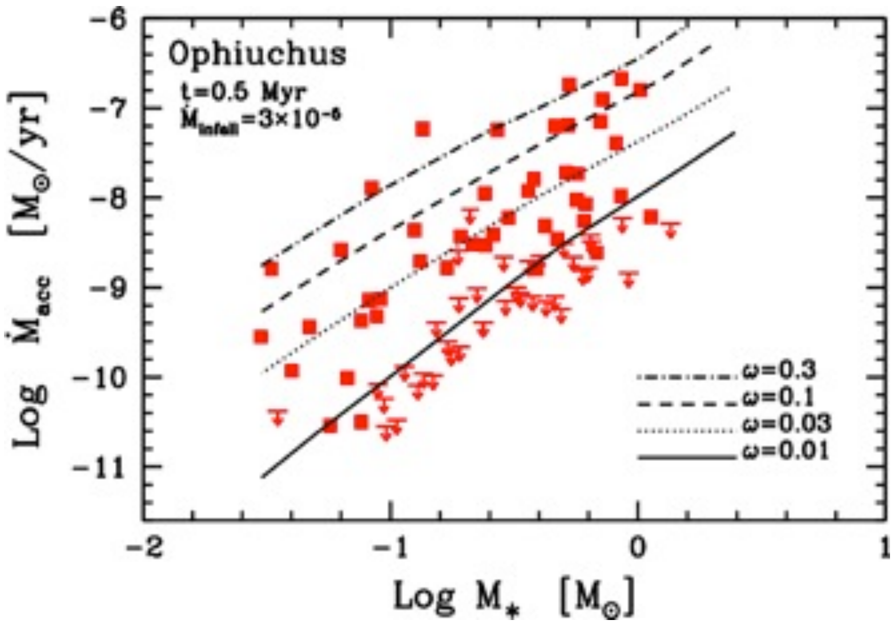
(Pontoppidan et al. 2011)

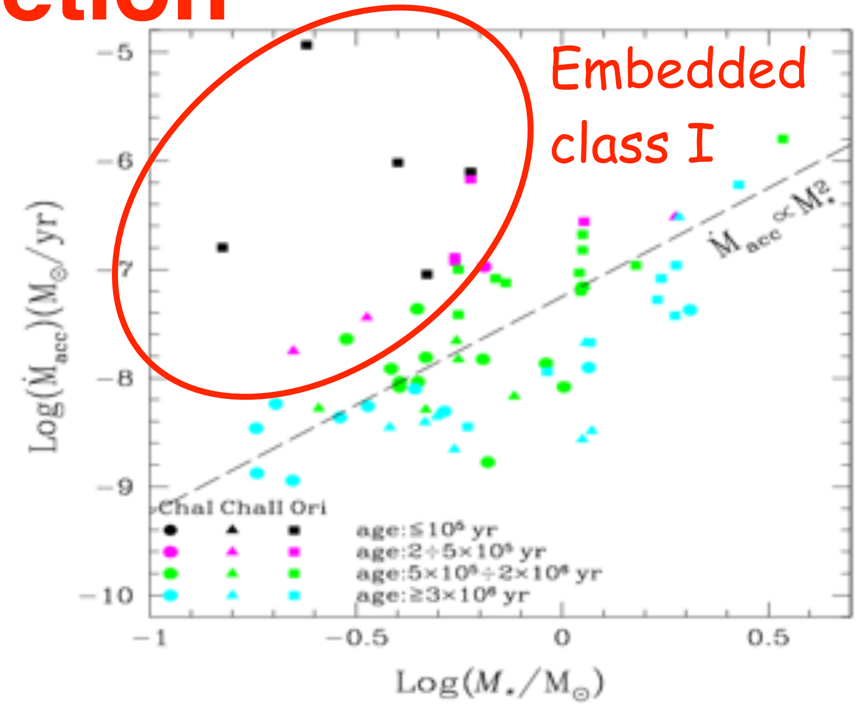
(Whelan et al. 2005)

- Spectroastrometry can “resolve” the inner regions of disks in the Gould Belt star forming regions
- Probe the kinematics and gas content of the inner disk and jet-outflow

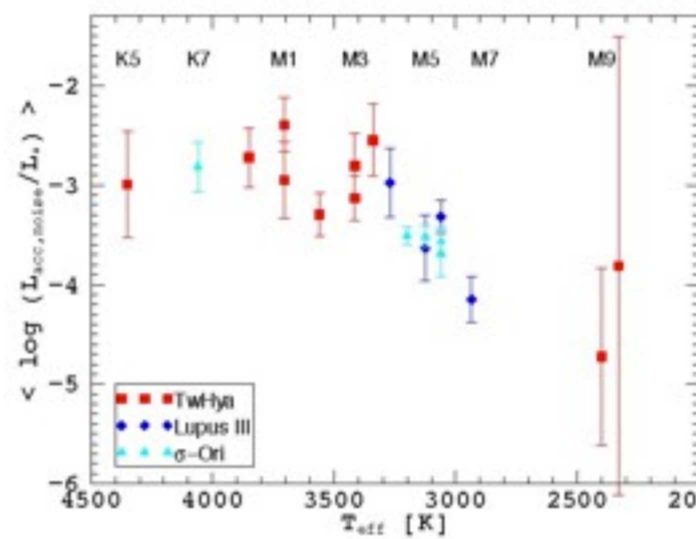
Accretion

(Dullemond, Natta & Testi 2006; Natta, Testi, Randich 2006)





(Antoniucci et al. 2011; Caratti o Garatti et al. 2011)

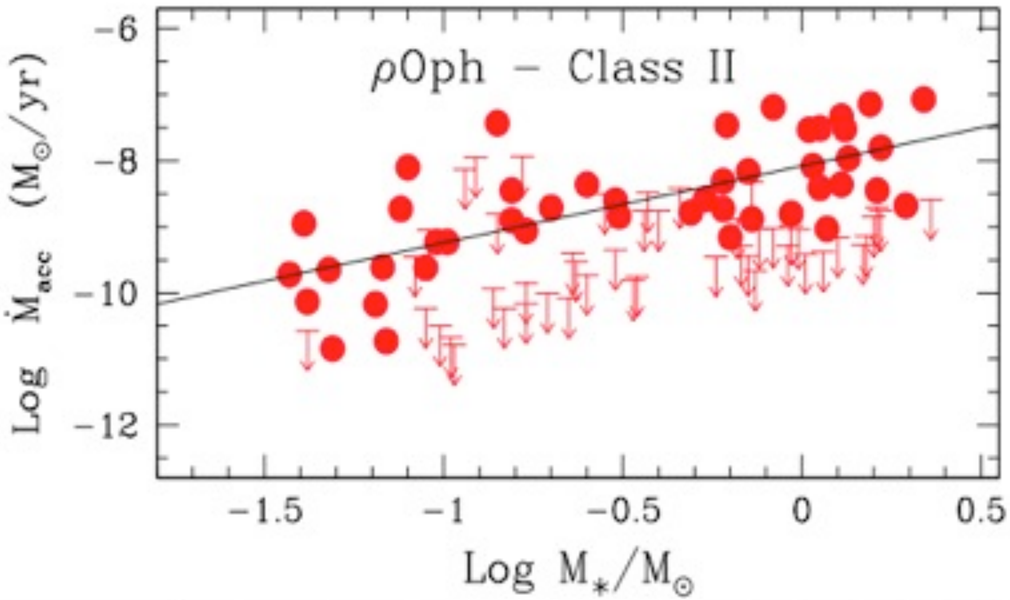


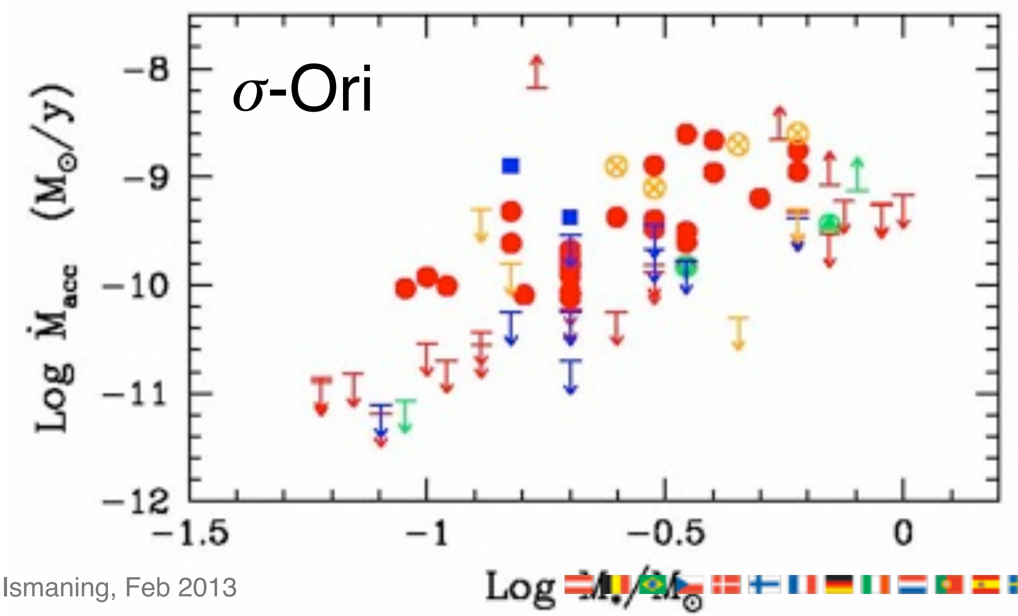
(Manara et al. 12)

- Accretion evolution
- Accretion in BDs and below
- Limit may be reached by our knowledge of chromospheric activity in young stars without disks
- Significant effort ongoing with VLT/ XShooter in characterizing these effects

Accretion vs mass/age

- ρ-Oph vs σ-Ori
- ~0.5-1Myr vs ~3-5Myr





(Rigliaco et al. 11)

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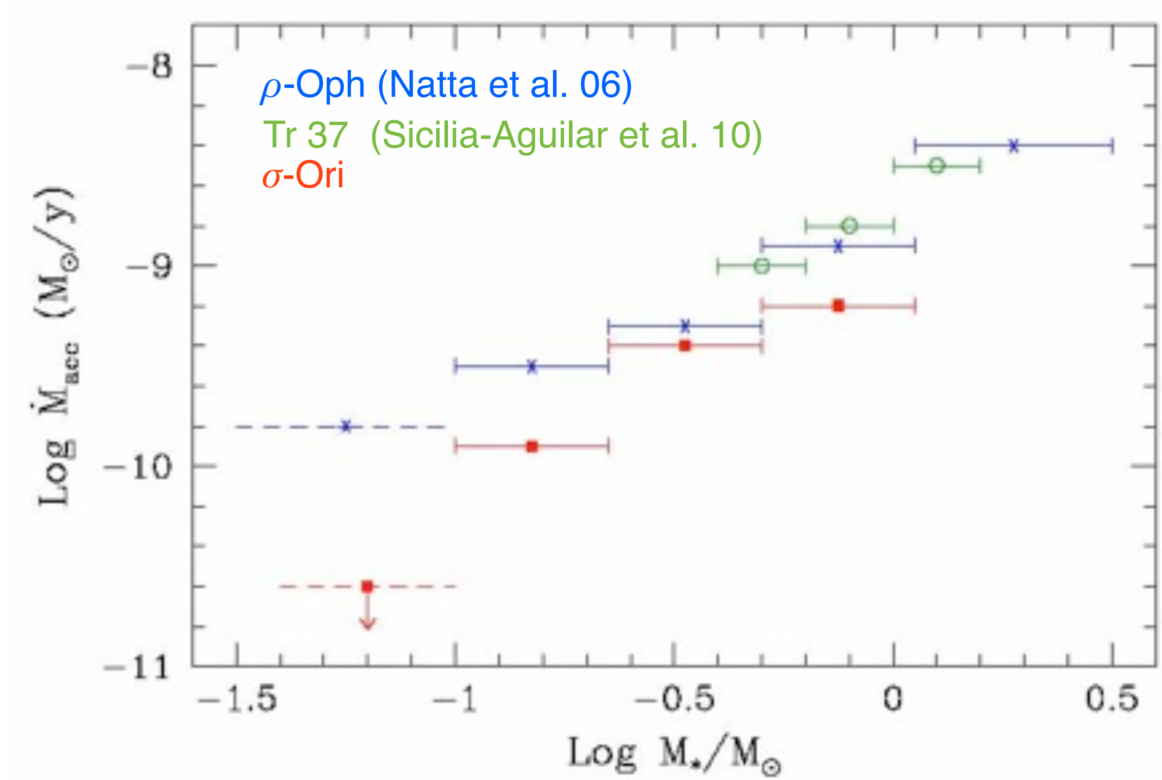
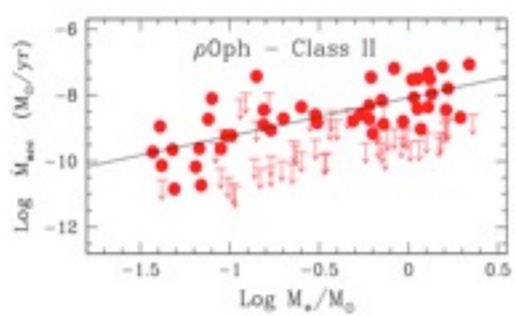
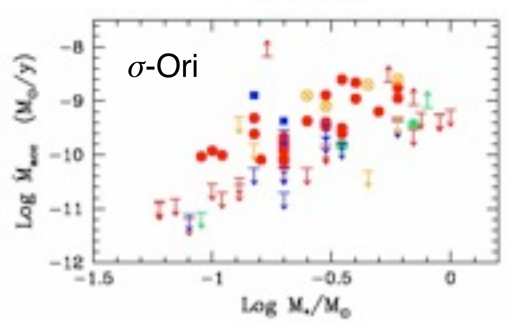


(Rigliaco et al. 11)





- Possible evidence for a change of slope with stellar mass
- possible evidence for a faster evolution at the low mass end

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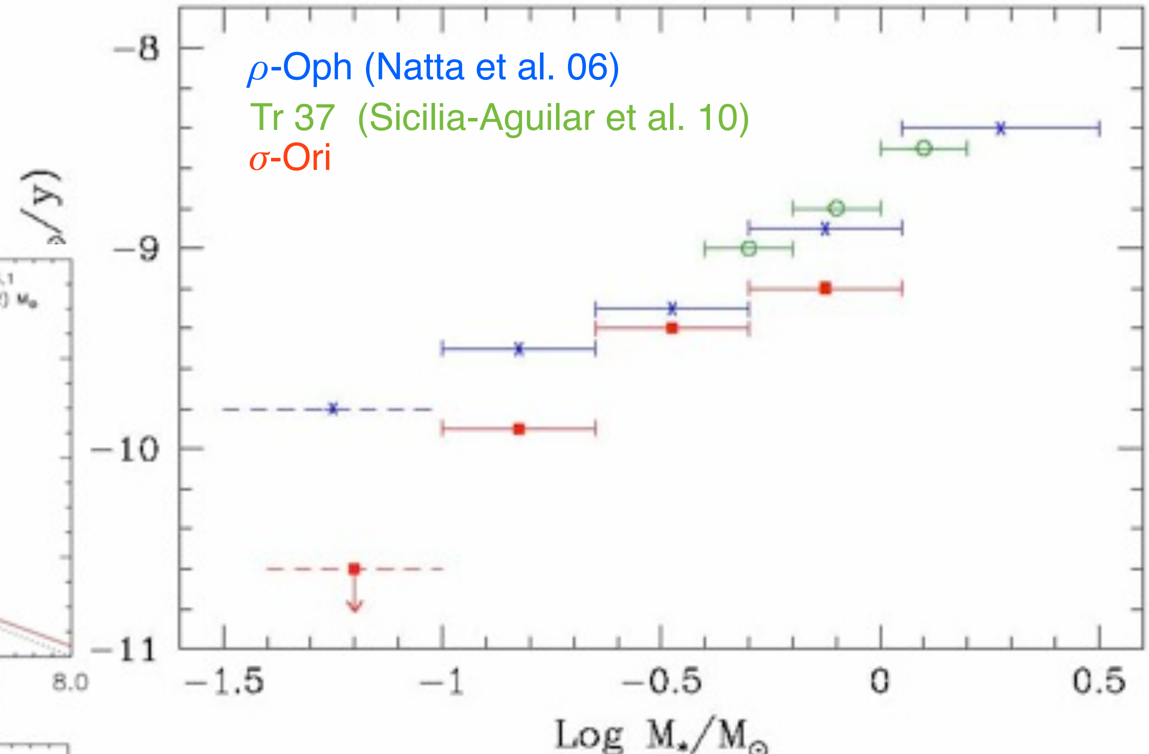
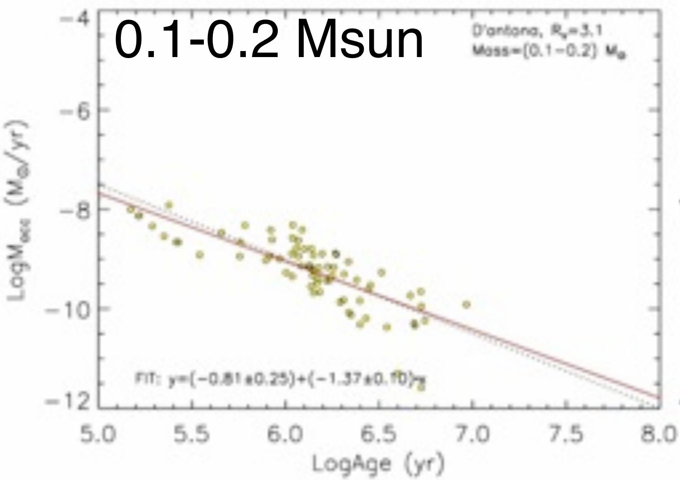
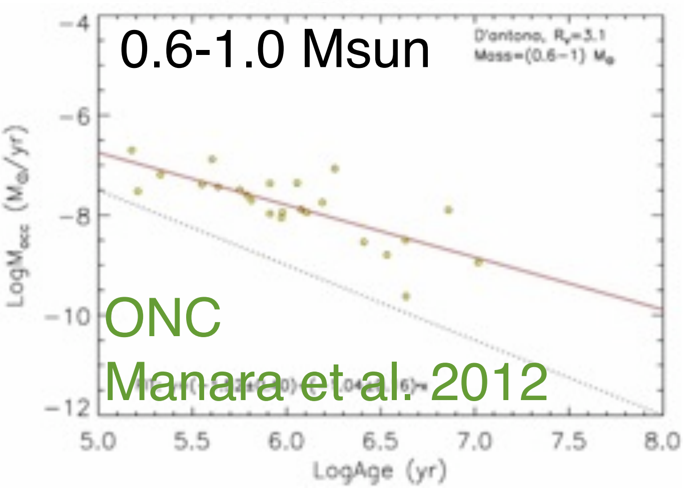


(Rigliaco et al. 11)





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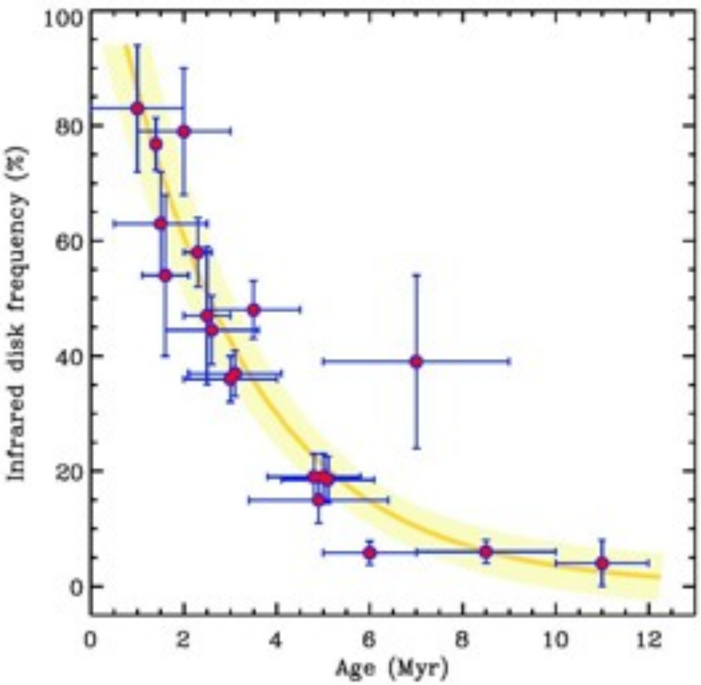
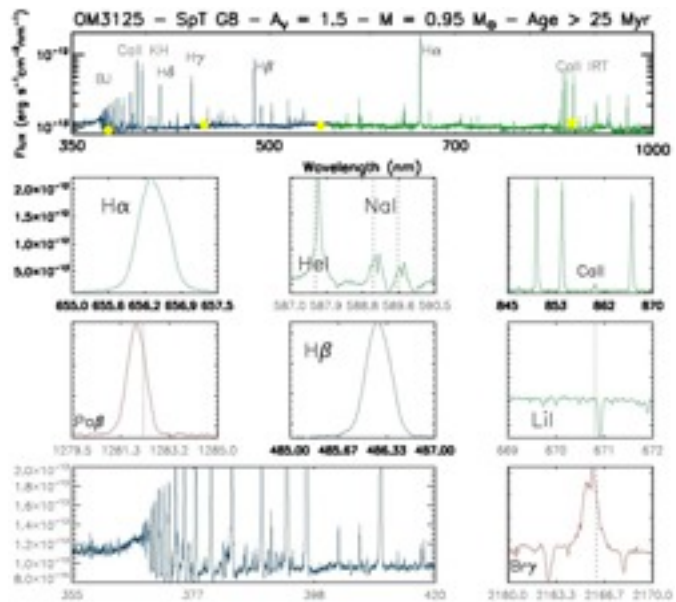
The puzzle of Old Accretors

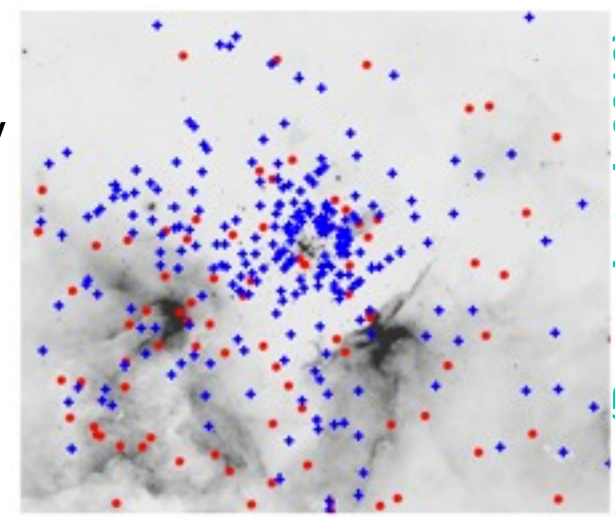


(Hernandez et al. 2007; Fedele et al. 2011)



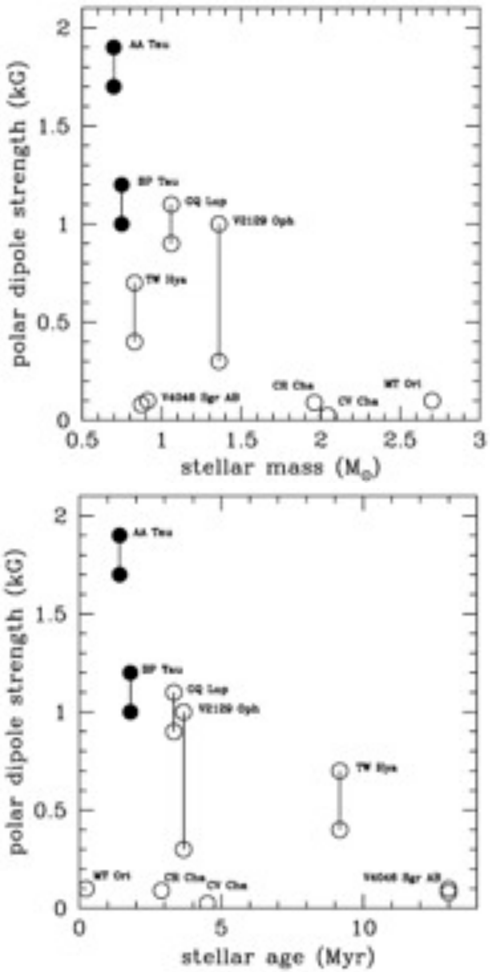
(Manara et al. 13)

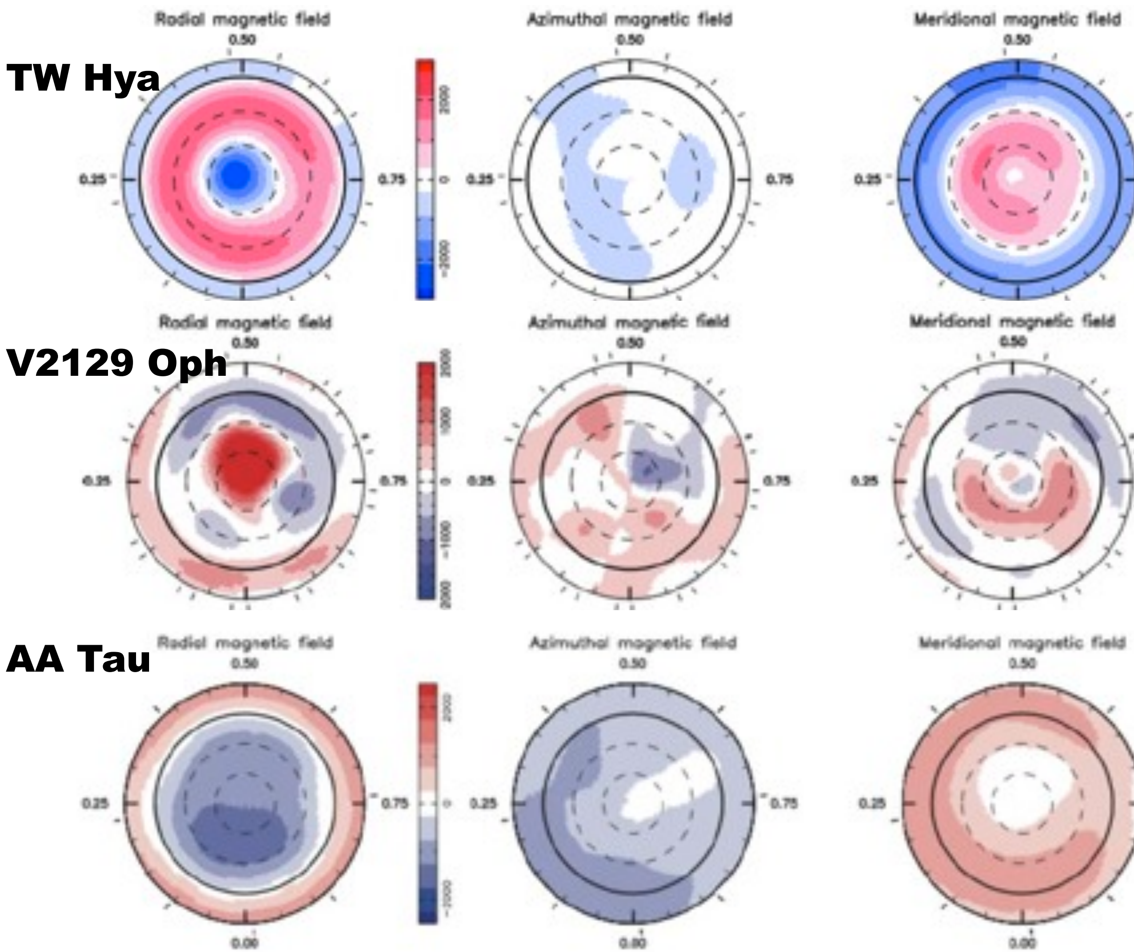
- ✦ Inner disc/accretion e-folding time: 2-3 Myr
- ✦ Population of Old Accretors discovered photometrically
- ✦ 2 candidates in ONC not confirmed spectroscopically
- ✦ Large populations in Galactic clusters and LMC/SMC can only be followed up with the EELT
- ✦ Can the inner disk be reactivated?
- ✦ Is there an alternative channel for planet formation?



(Beccari et al. 2010)

Magnetic Fields



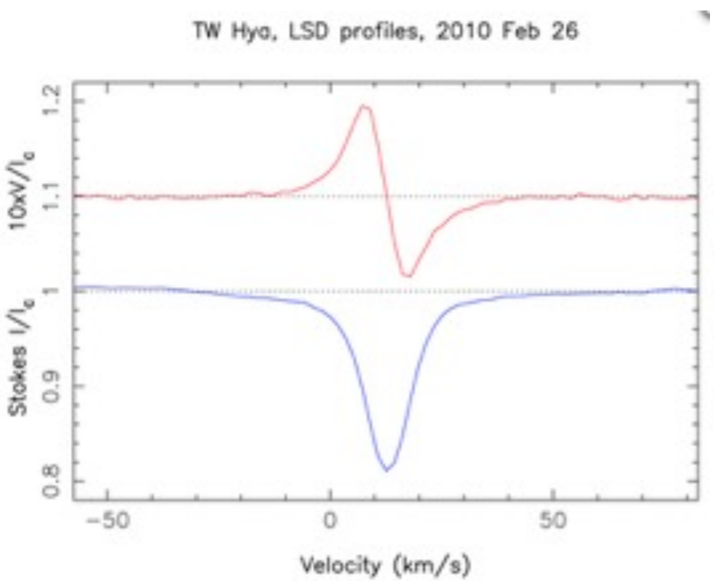


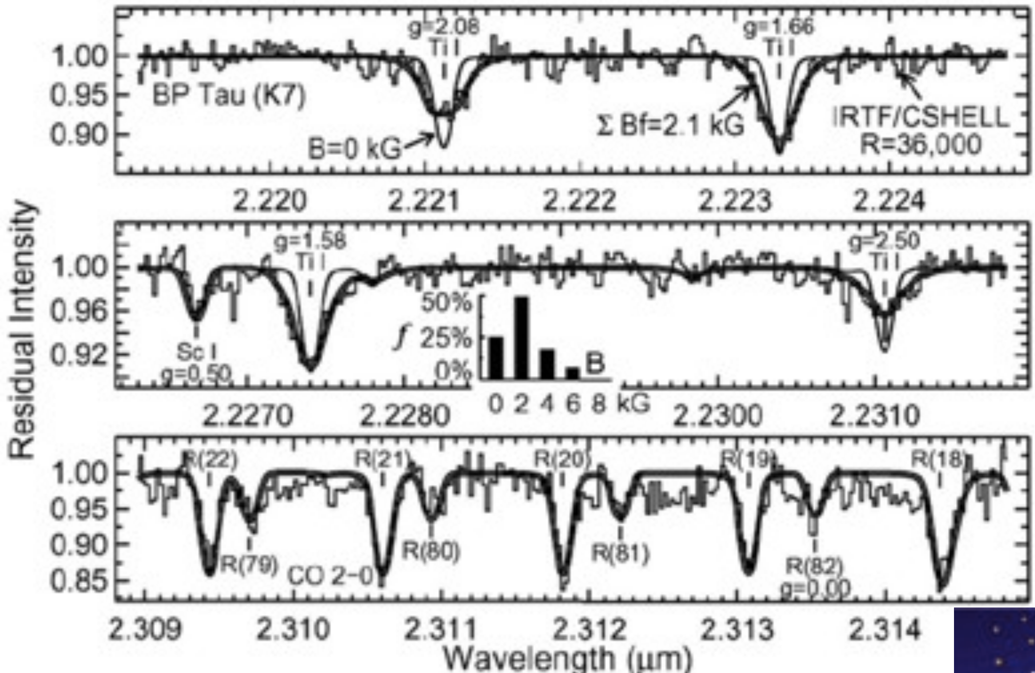
(Donati et al. 11, Gregory et al. 2012, Hussain 2012)

- Very few measurements, brightest objects
- Real population studies critical to understand the impact on disk and stellar evolution

Magnetic Fields

- Requirements:
  - High Spectral Resolution: R >= 100000
  - Polarization
  - High sensitivity
  - Broad spectral coverage





Summary of Requirements

- Jets/outflows/photoevaporation
  - Resolution: 10^4-10^5; Optical-NIR; AO mode; slit or IFU
- Inner disk/wind spectroastrometry
  - IFU ~20x100mas; 10^4-10^5; AO mode; Optical-NIR
- Accretion
  - Resolution: >10^4; Optical-NIR; NIR critical for young sources
  - IFU and AO mode would be good to try to connect to the inner disk/wind
- Magnetic fields
  - High resolution: 10^5; Polarization; Optical-NIR; Seeing limited ok
- Synergy with ALMA and high resolution thermal infrares is critical to connect to the outer disk evolution and the large scale outflow