The accretion-ejection process in young stars

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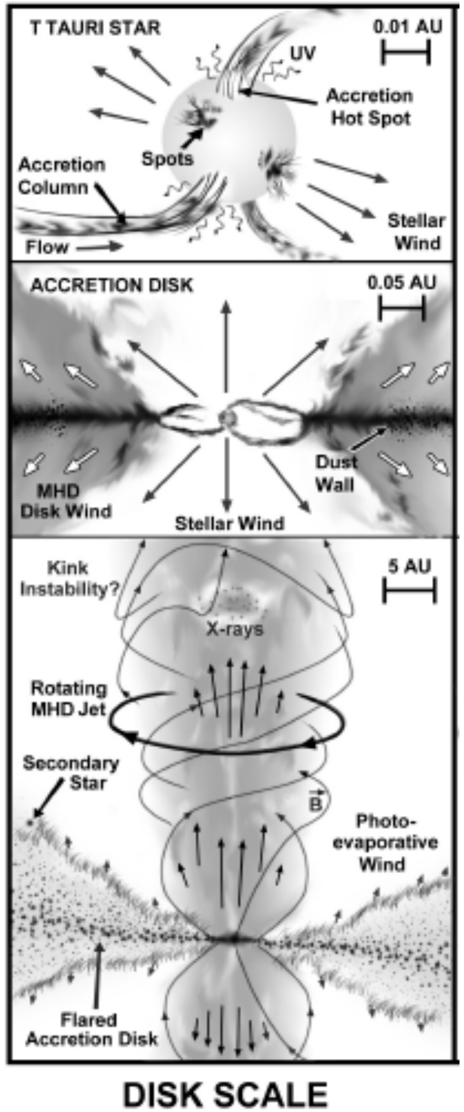
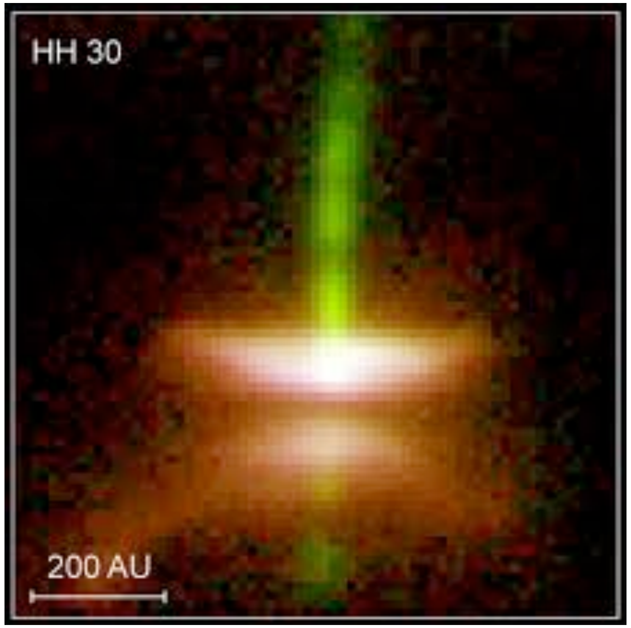
an IPAGocentric (re)view…

A few keys issues

- How are ejection and accretion processes physically related? How do they vary in time?
- How do these processes scale with stellar parameters (e.g., mass)?
- How does accretion proceed from the inner disk onto the star? Are there different accretion/ejection regimes?
- How does accretion impact onto early stellar evolution?

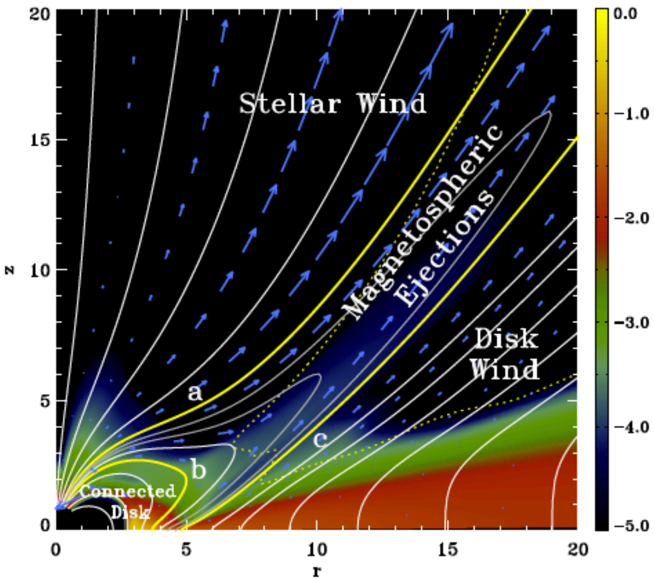


Franck et al. 2014, PPVI

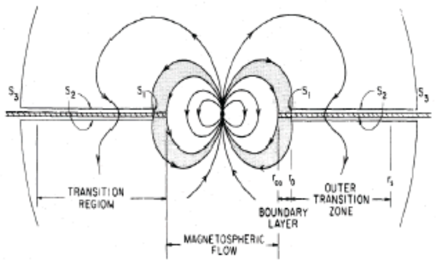


THE ACCRETION-EJECTION CONNECTION

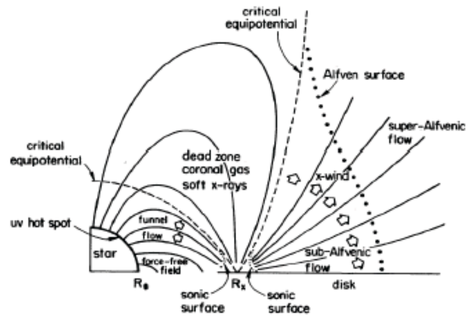
Ejection process : stellar winds, interface winds, disk winds



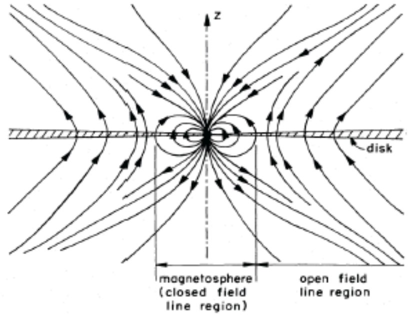
Zanni & Ferreira 2013



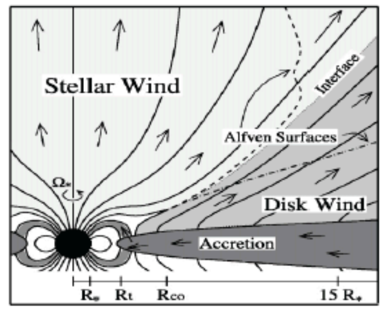
Ghosh & Lamb 1979



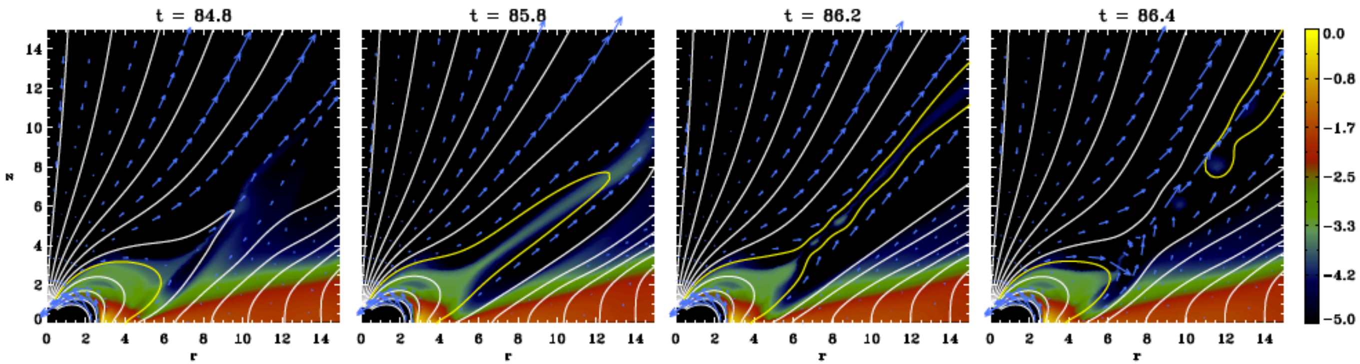
Shu et al. 1994



Lovelace et al. 1995



Matt & Pudritz 2005

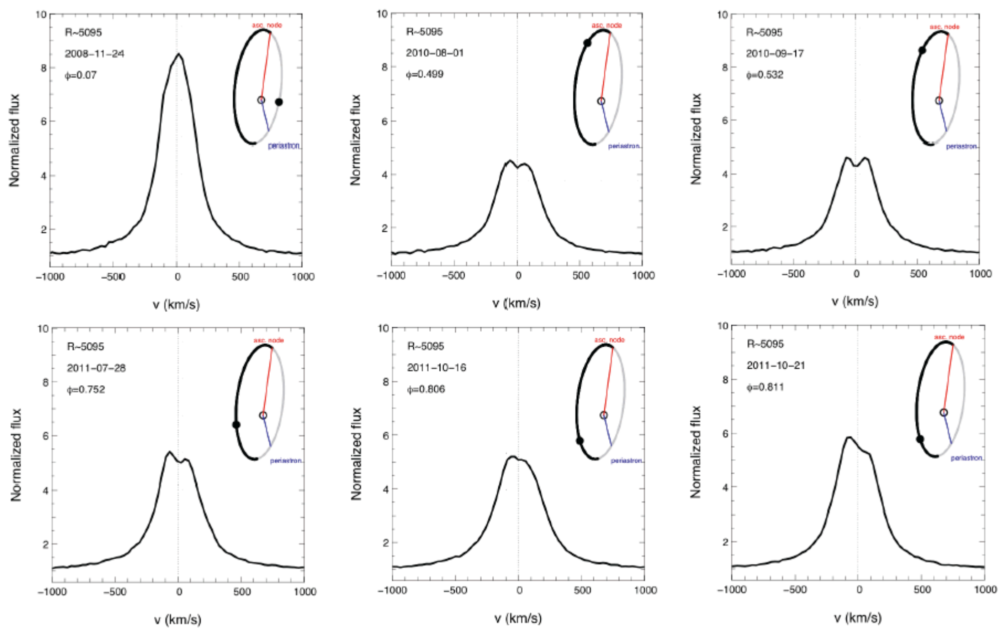


Lai 2013

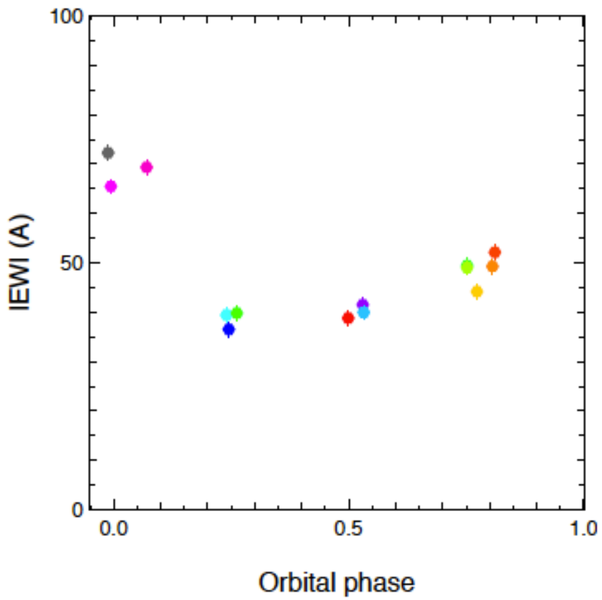
Tidally triggered accretion/ejection in young binary systems

- HD200775 (B2+B?); $P_{orb} \approx 3.6$ yr
- Separation = 15mas (≈5 A.U.)
- Tidally truncated disk
- Spectro-interferometry (VEGA/CHARA)

Benisty et al. 2013 (+Perraut, Le Bouquin)



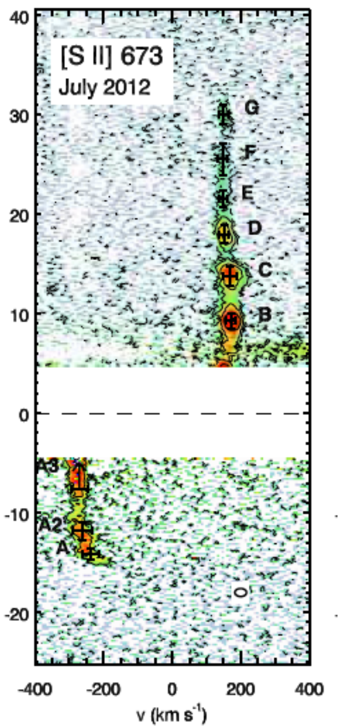
Hα increases at periastron both in flux and in the size of the emitting region

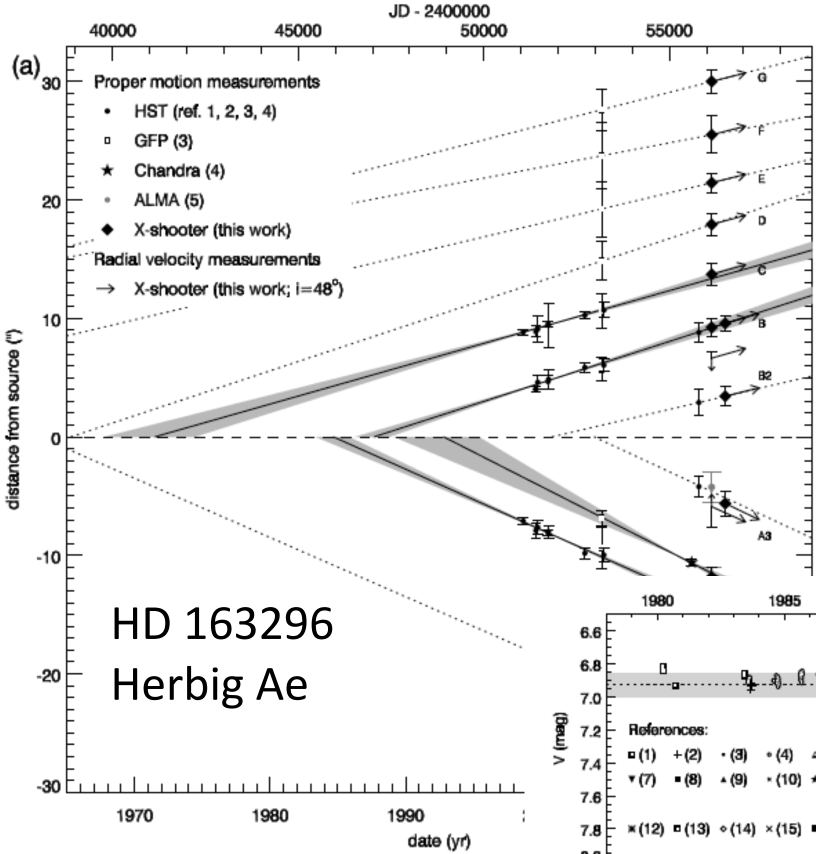


Suggests accretion outburst close to periastron followed by wind enhancement

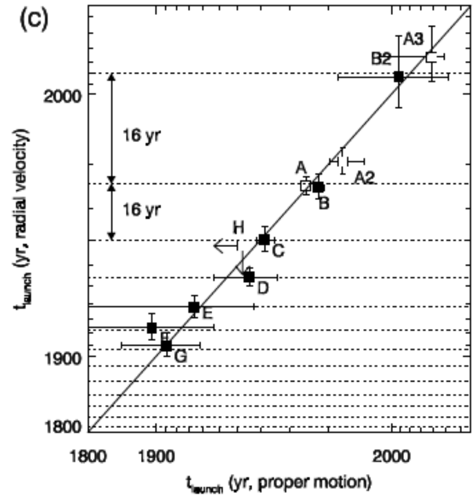
Long-term time variability of the accretion-ejection process

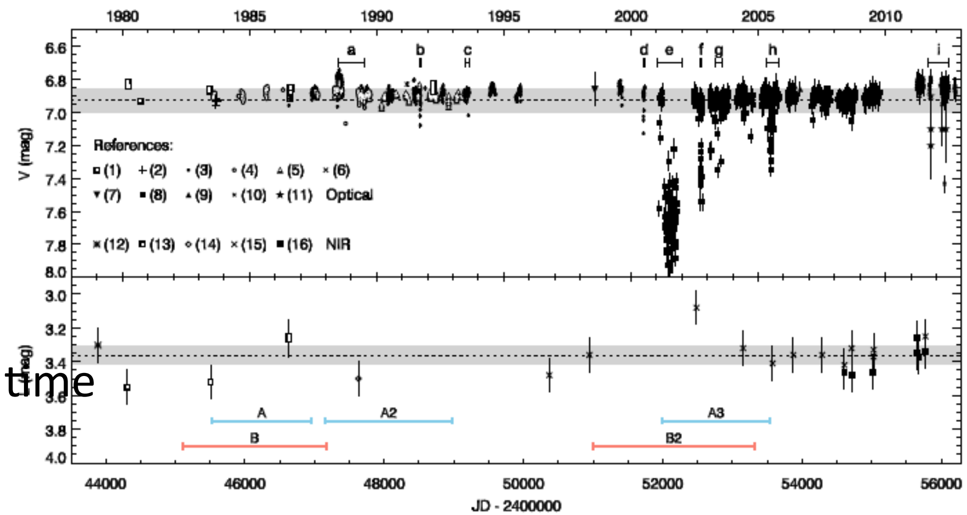
Jet knots





HD 163296
Herbig Ae





Tracing back the launch epoch of jet knots
Compare with photometric activity at launch time

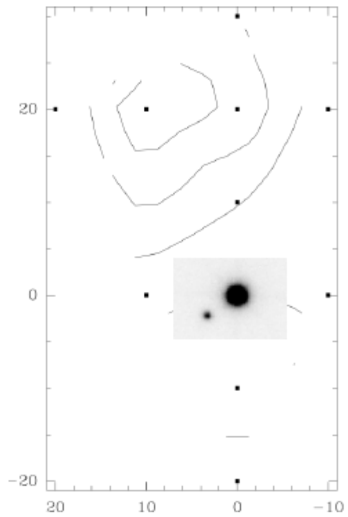
Ellerbroek et al. 2014 (+Dougados, Cabrit)

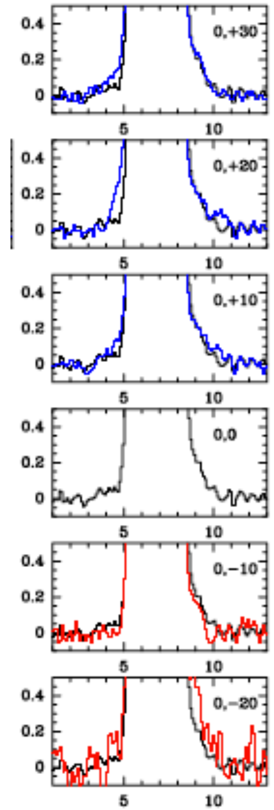
Accretion-ejection process in young brown dwarfs

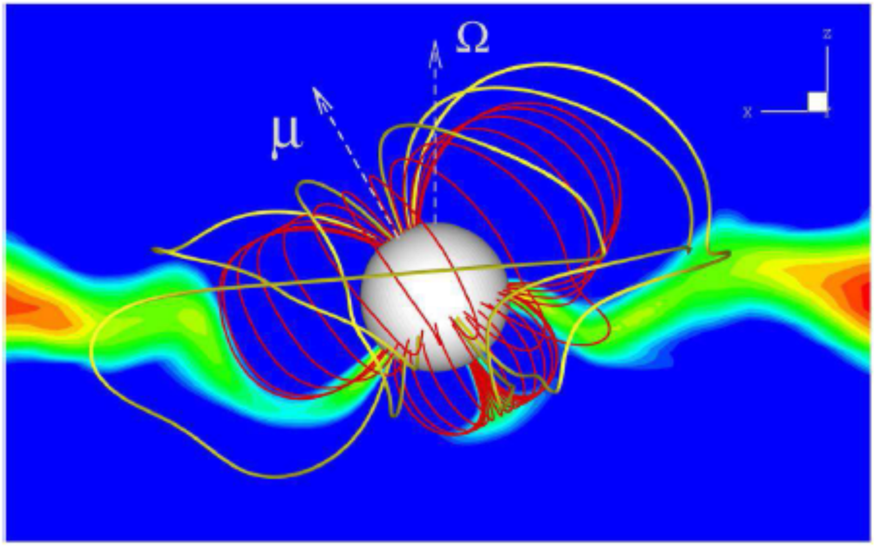
- A molecular outflow driven by the young BD binary FU Tau
- IRAM 30m CO(2-1) mapping
- Mass loss rate ≈ 6 10^{-10} $M_{\odot}$/yr

Monin et al. 2013 (+Lefloch, Dougados)

Suggestive of a scaled-down version of the accretion-ejection process seen in T Tauri stars



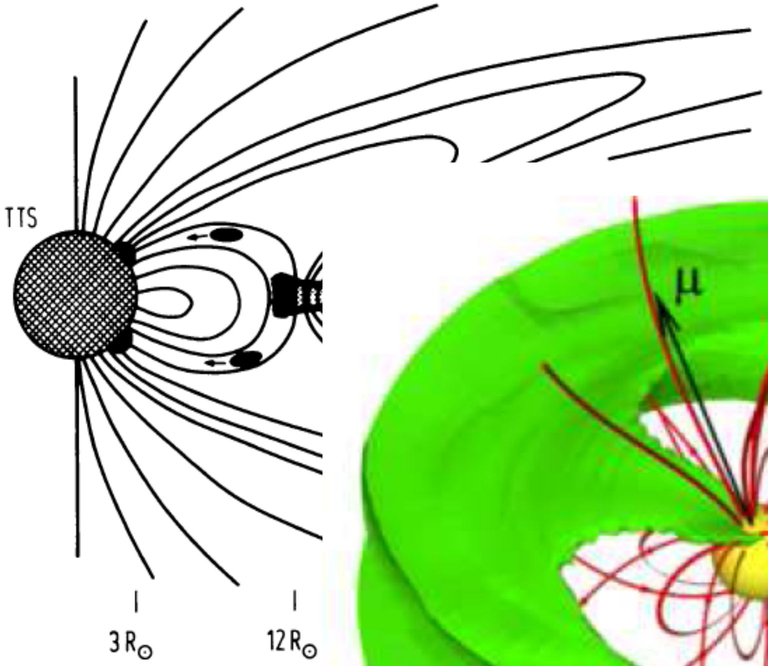




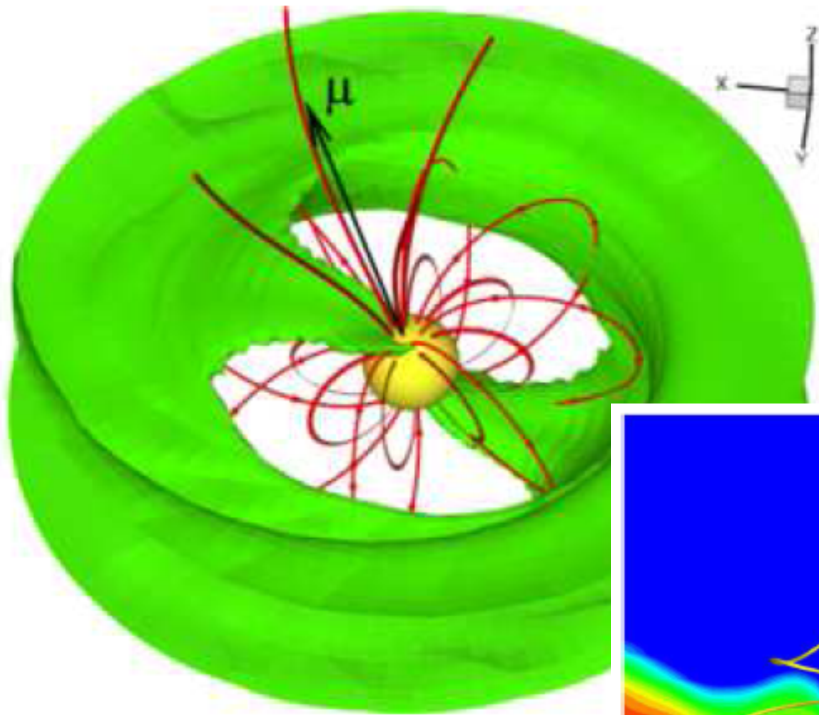
ACCRETION FROM THE INNER DISK TO THE CENTRAL STAR

Magnetospheric accretion on complex magnetic fields

(cf. J.-F. Donati's talk)

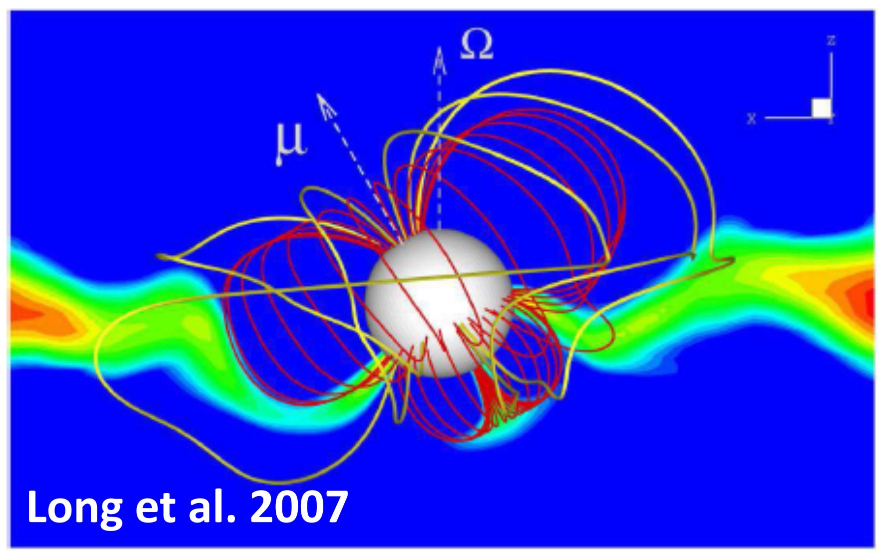


Camenzind 1990



Romanova et al. 2003

≈ a few R* (<0.1AU)

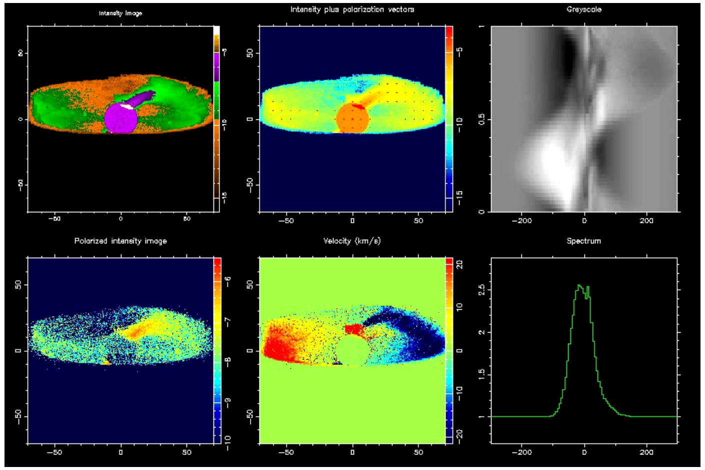


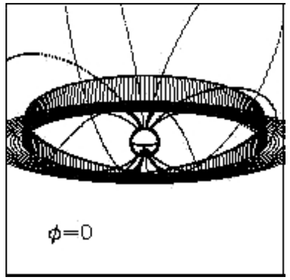
Long et al. 2007

Line profile variability from inclined magnetospheres: explore the time domain

3D MHD simulations of accretion onto an inclined dipole
3D radiative transfer of rotationally-induced line variability (e.g. Paβ)

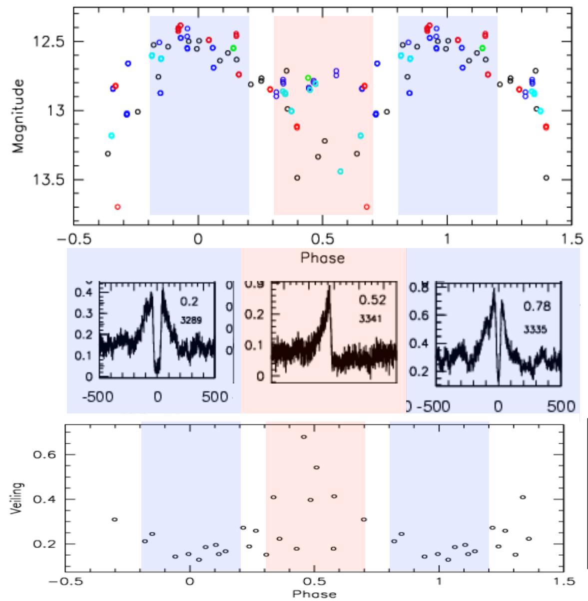
Kurosawa, Romanova, Harries 2008





Bouvier et al. 2007

Inclined magnetospheres : AA Tau



Periodic eclipses

(disk warp)

(P=8.22d)

Balmer lines

(accretion funnel)

Veiling

(accretion shock)

Supports inner disk warp resulting from inclined stellar magnetosphere + accretion columns + accretion shock

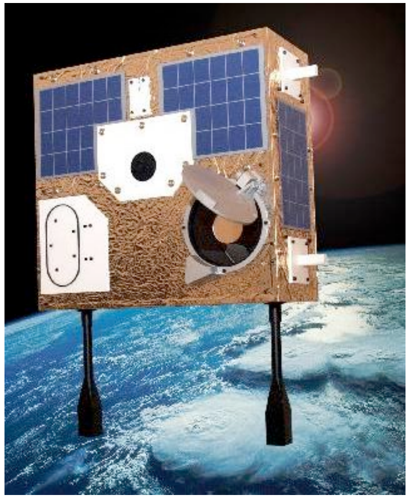
Coordinated Synoptic Investigation of NGC 2264

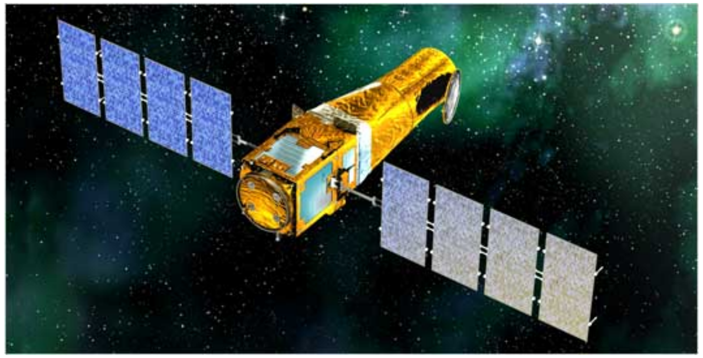
A revolution in space based Monitoring of young stars

(December 2011)

P.I. J. Stauffer, G. Micela

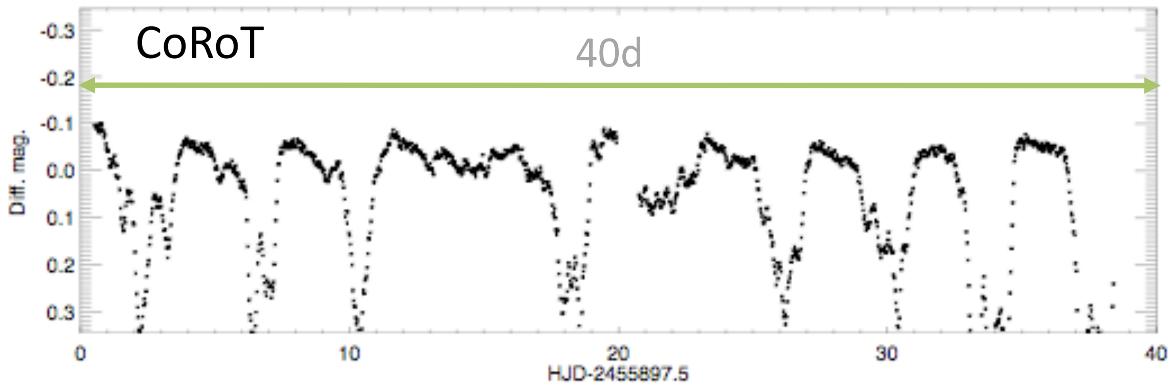
- Spitzer: 30d @ 3.6, 4.5 µm
- CoRoT: 40d, optical
- Chandra/ACIS: 300ks (3.5d)
- MOST: 40d, optical
- VLT/Flames: ~20 epochs
- Ground-based monitoring
  U-K bands: ~3 months





(includes CFHT/MegaCam
u + r-band monitoring)

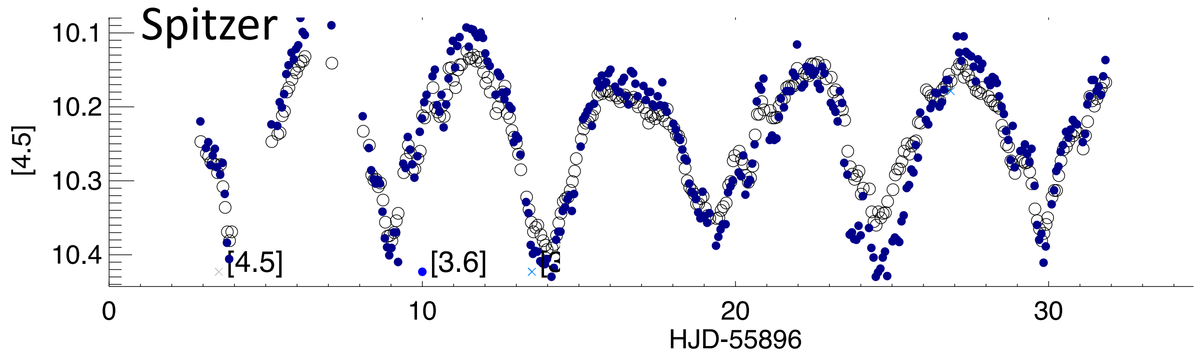
Light curves display distinct patterns...



0.5 mag

“AA Tau’s”

(~25%)



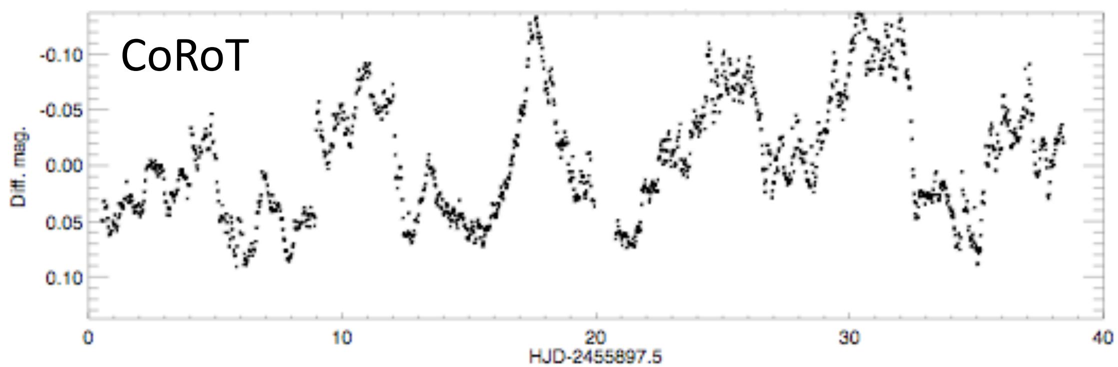
30d

Dust obscuration?

0.2 mag

“bursters”

(~10%)



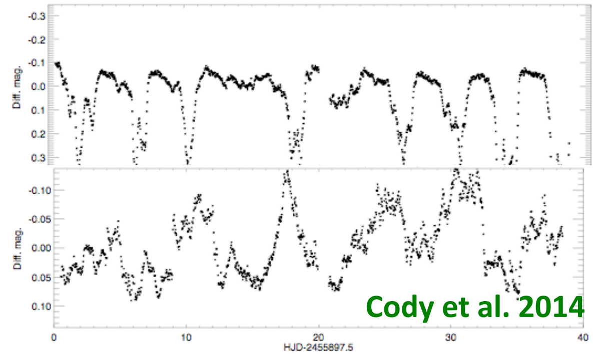
40d

Accretion bursts?

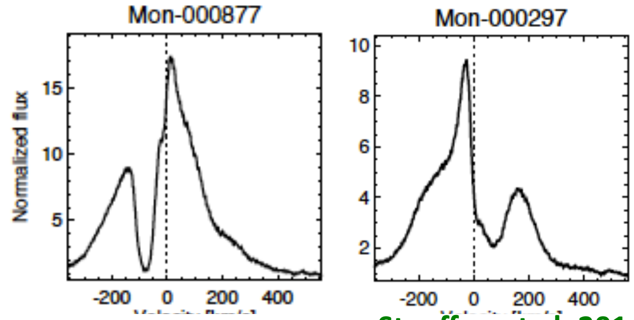
0.1 mag

Evidence for different accretion-ejection regimes in young stars?

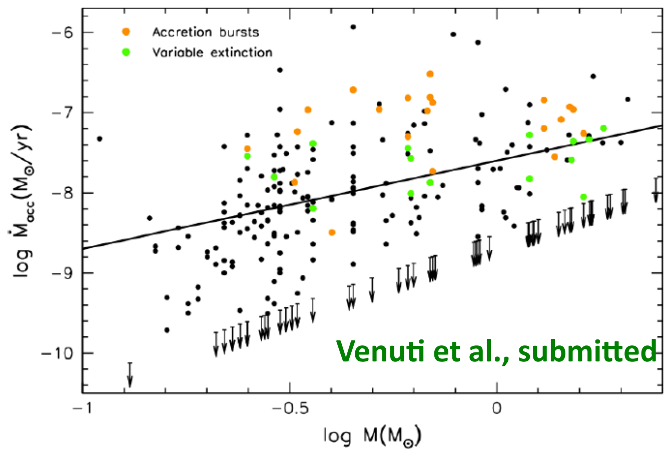
- *AA Tau's* and *bursters* have different light curves: magnetospheric vs. stochastic accretion?
- They have different Hα line profiles (strong redshifted absorptions vs. strong blueshifted absorptions): different outflow structure?
- They have different mass accretion rates: *bursters* have larger M_{acc} than *AA Tau's*



Cody et al. 2014



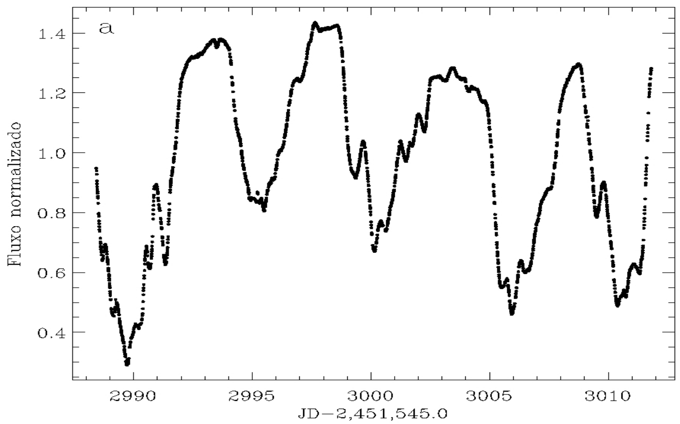
Stauffer et al. 2014



Venuti et al., submitted

The dynamics of magnetospheric accretion

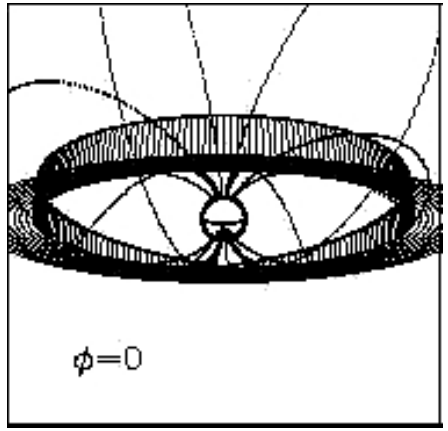
V354 Mon (K4) CTTS
P= 5.26 ± 0.50 days



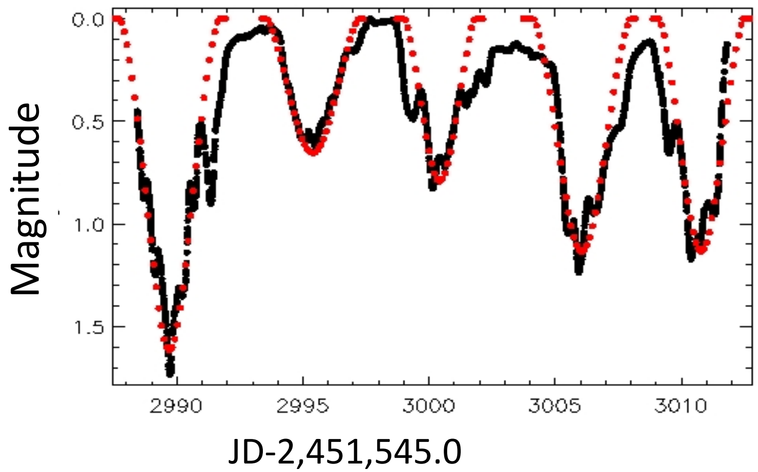
Occultation by a non axisymmetric disk warp

$$h(\phi) = h_{max} \left| \cos \frac{(\phi - \phi_0)}{2} \right|$$

AA Tau's model

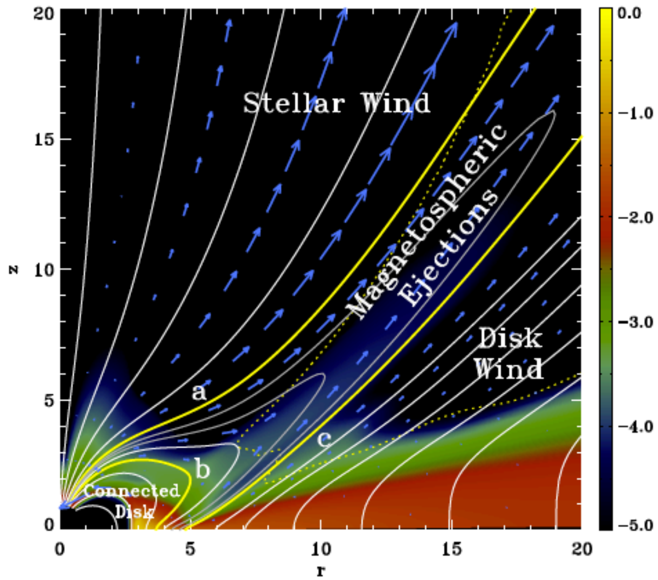


Varying h_{max} and extension



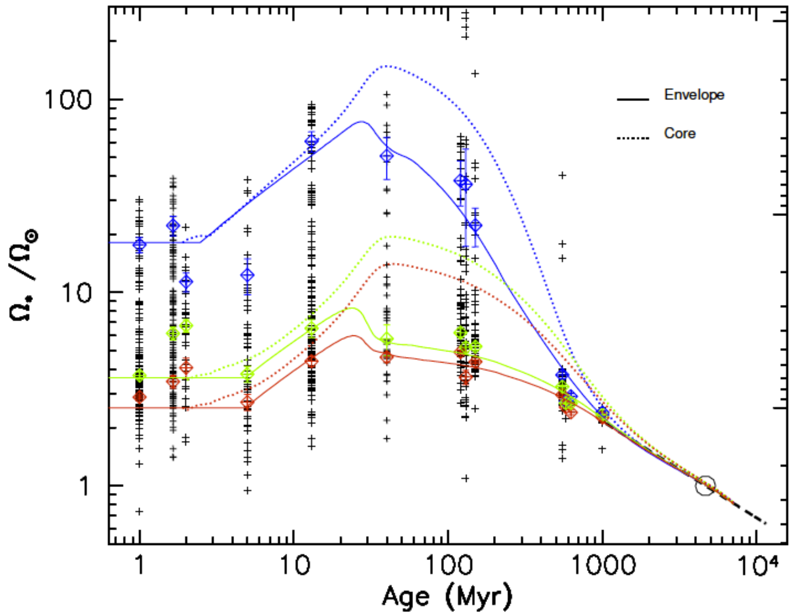
h_{max} (r_c)	azim. ext. (º)
0.31	320
0.23	320
0.25	240
0.28	320
0.28	280

Fonseca, Alencar, Bouvier (2014)



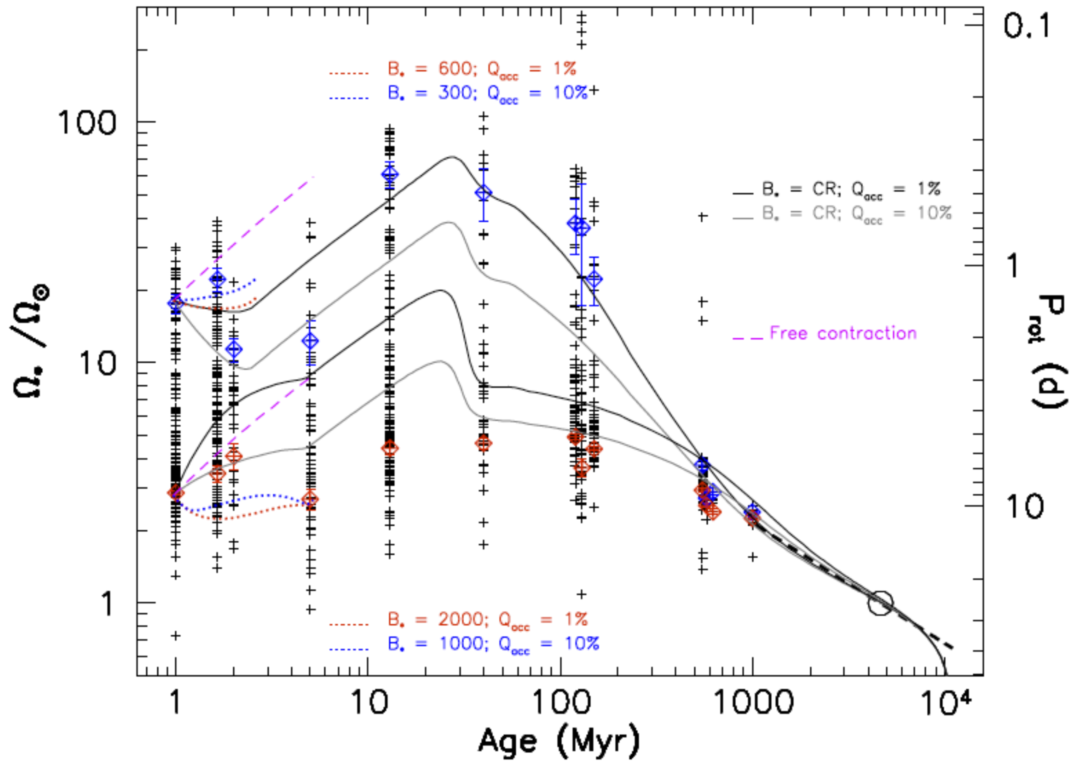
IMPACT ON ANGULAR MOMENTUM EVOLUTION

Star-disk interaction and early angular momentum evolution



Gallet & Bouvier 2013

Star-disk interaction:
assumes constant rotation rate as accretion proceeds



Gallet & Zanni, in prep.

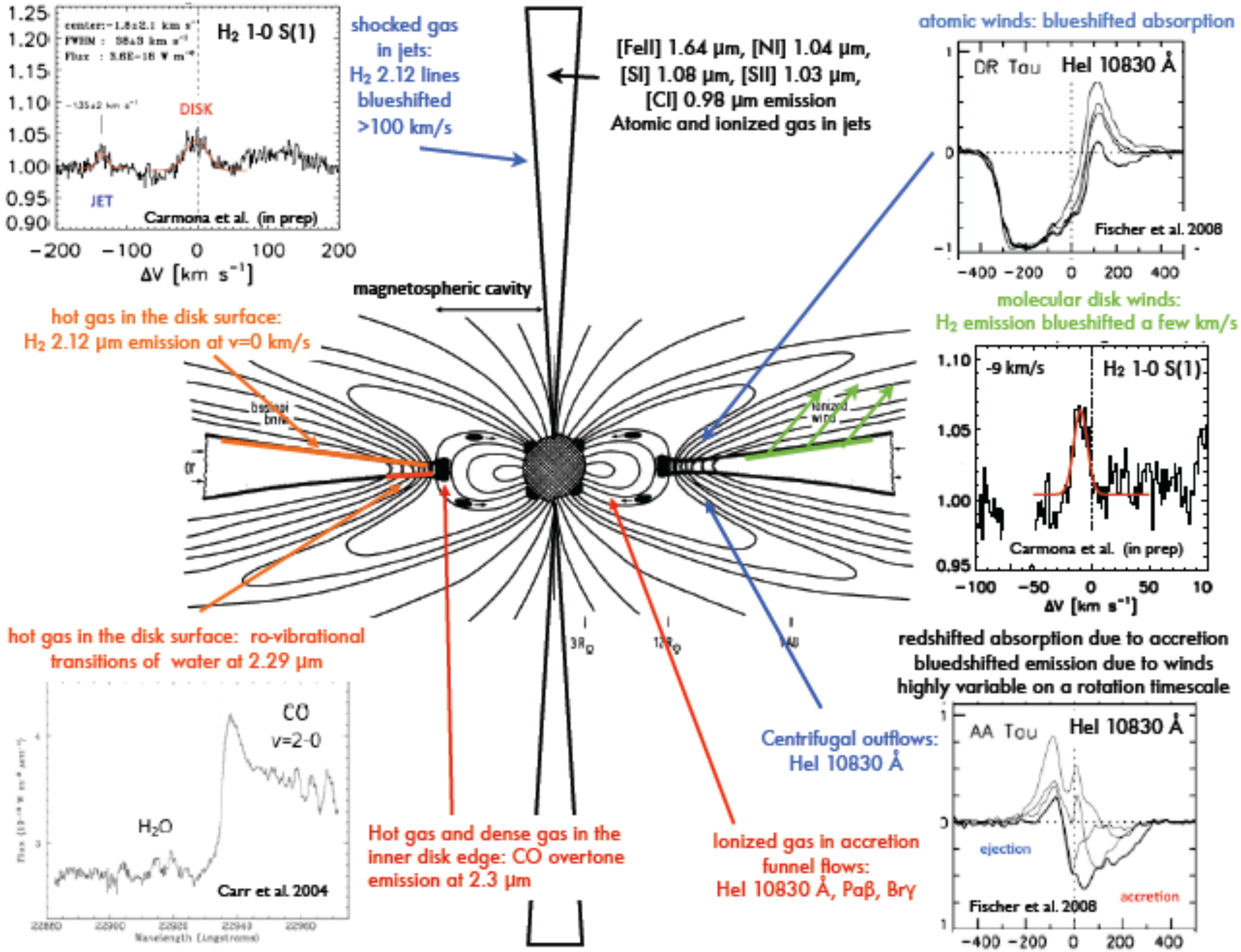
Includes magnetospheric ejections and accretion-driven stellar winds

$$\tau_{ME} \propto \frac{B_p^2 R_*^6}{R_t^3}\left[K_{rot} - \left(\frac{R_t}{R_{co}}\right)^{3/2}\right] \qquad \dot{M}_{wind} = Q_{acc}\dot{M}_{acc} \qquad \tau_{wind} \propto \Omega_* \dot{M}_{wind} r_A^2$$

PROSPECTS

Prospects : time domain spectroscopy

(e.g., VLT/Xshooter, CFHT/Spirou)



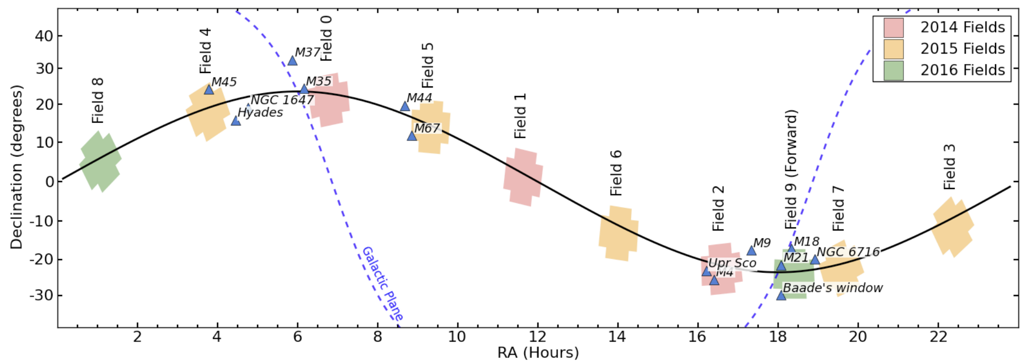
Carmona, Bouvier, Delfosse 2013

Prospects: spaceborn photometry

Long-term (few months) photometric monitoring

– Kepler 2-wheels: 10 fields, 75 days each, FOV 115 sq.deg.

2014-2015



– **Plato (2024)**: 2-5 months monitoring, FOV 2300 sq.deg.(!)

+ Gaia for a complete census of YSOs in SFRs

Prospects : high sensitivity spectro-interferometry

Goal: direct imaging of the magnetospheric cavity

- ✓ 2-3 magnitudes gain required in H_α and near-IR
- ✓ Resolution ≤ 100 μas (or better)

➔ VLTI/Gravity? Next generation interferometers?

Prospects: numerical tools

Modeling and interpreting the observations

- ✓ 3D MHD star-disk interaction numerical models
- ✓ 3D radiative transfer models (lines + continuum)

➔ strong need for rapid developments

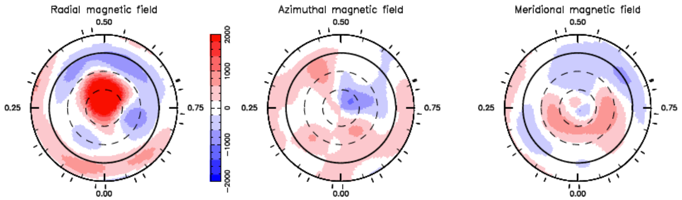
Thank you!

- Priorities:
    - Optical-NIR high resolution spectroscopic monitoring
    - Long-term continuous photometric monitoring
    - Improved sensitivity/resolution spectro-interferometry
    - 3D MHD + 3D RT numerical models

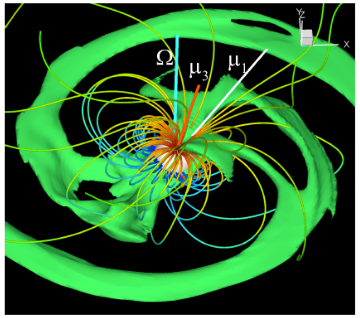
Star-disk interaction: the magnetospheric accretion process

e.g., V2129 Oph

CFHT/ESPaDOnS spectropolarimetry yields:
2.1 kG octupole + 0.9 kG dipole



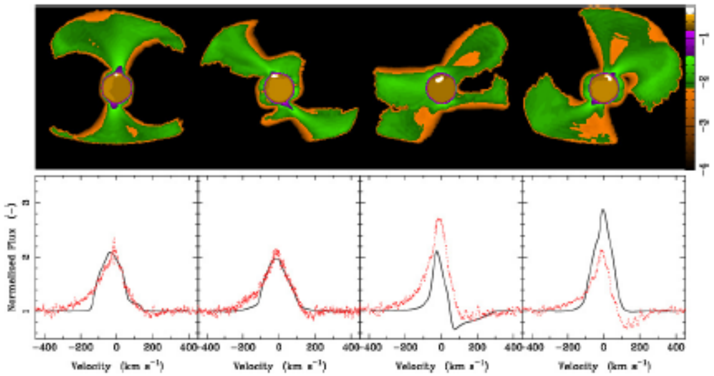
Donati, Bouvier, Walter et al. (2011)



3D MHD simulations predict the accretion flow geometry

Romanova, Long, Lamb et al. (2011)

ESO/Harps line profile variability + 3D RT models reveals accretion dynamics



Alencar, Bouvier, Walter et al. (2012)

Chandra X-ray monitoring reveals accretion shock

Argiroffi, Flaccomio, Bouvier et al. (2011)