Episodic Accretion in Young Stars

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Magnetic Fields: From
Core Collapse to YSOs
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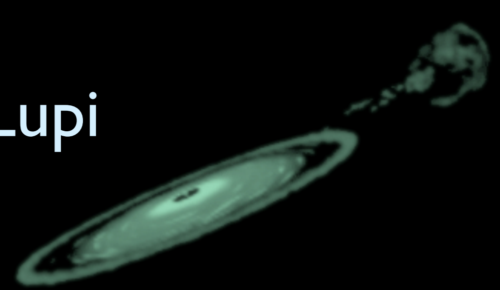
Talk Outline

- Evidence of magnetic activity in TTauri stars, "EXors"
- Review of magnetically-regulated accretion, accretion and propeller
- Model: two new regimes of magnetically-controlled accretion:
    - Quiescent disks
    - Episodic outbursts via disk instability
- Results of Simulations
- Observational Prospects; Application to EX Lupi [Preliminary!]
- Conclusions and Future Work

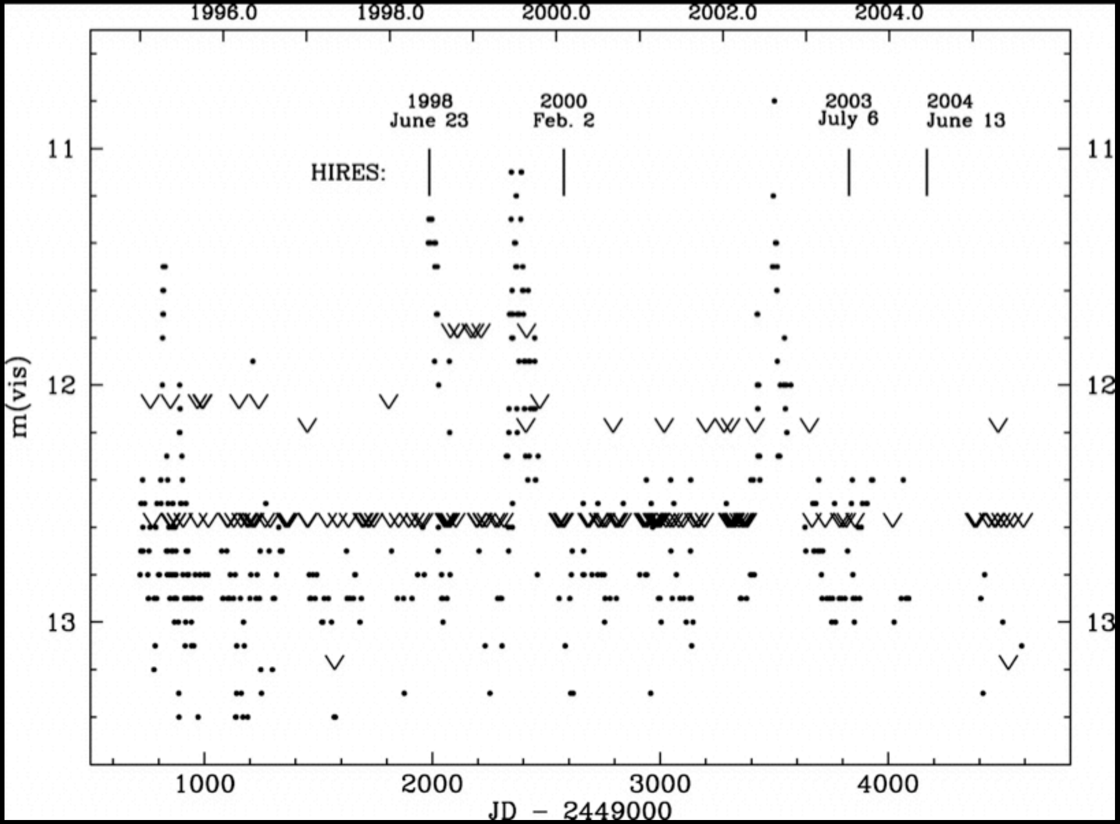


Magnetic Fields in TTauri Stars

- TTauri stars are fully convective, often have high surface magnetic fields (~100-1000G)
- Strong magnetic field can regulate accretion flow in innermost regions of star
- Evidence for magnetic activity:
  - Jets and outflows
  - Variability
  - Spin regulation
  - Direct field measurements

EXors

- small class of T Tauri stars that show repeated, major increases in brightness (between 1-4 magnitudes)
- In quiescence have late-type dwarf spectra, in outburst see veiling of spectra, inverse P-Cygni profiles (evidence of accretion)
- Recurrent outbursts on timescale of several years (suggests regulation from accretion disk)



[Herbig 2008]

Changes in luminosity in EXor prototype, EX Lupi [1994-2006]

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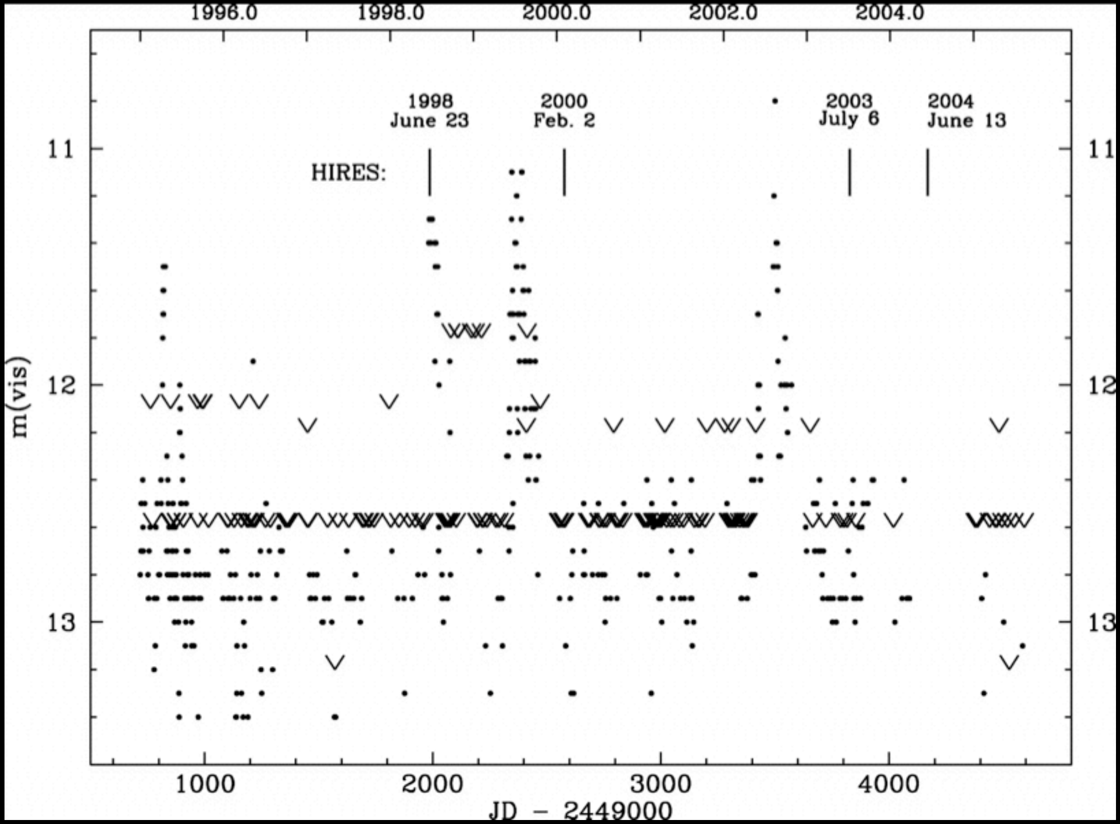

[Herbig 2008]

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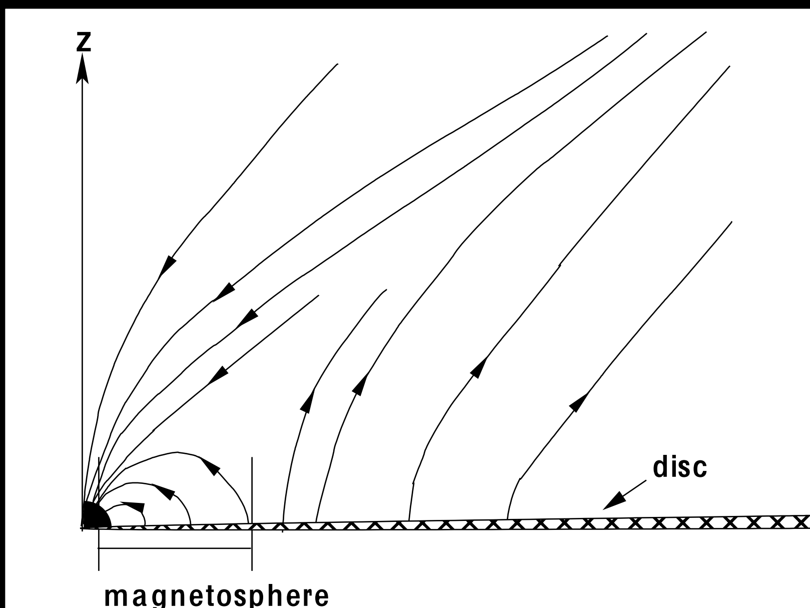
Present here a model for *periodic, magnetically-controlled accretion* that could explain episodic accretion bursts in EXors

Magnetospheric Accretion in a Disk

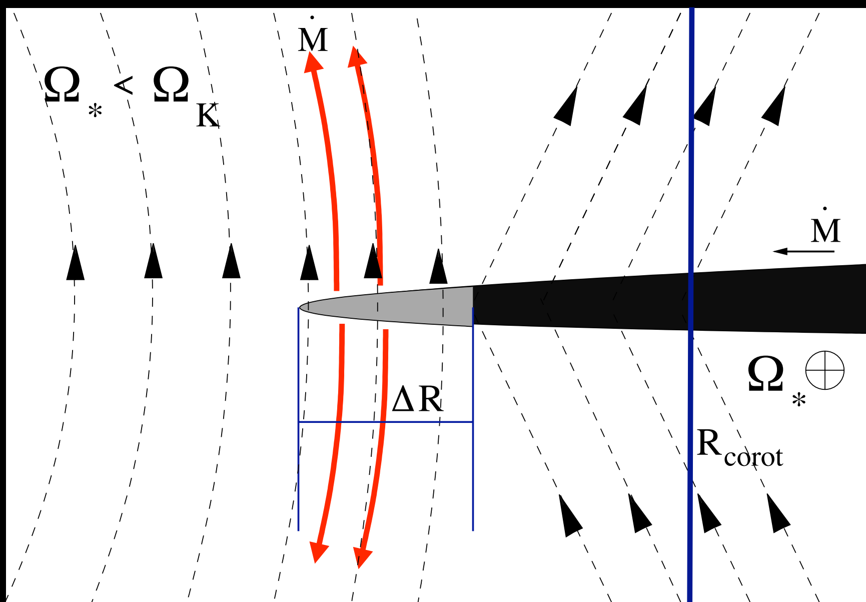
$$R_m = (8GM_*)^{-1/7} \mu^{4/7} \dot{M}^{-2/7}$$

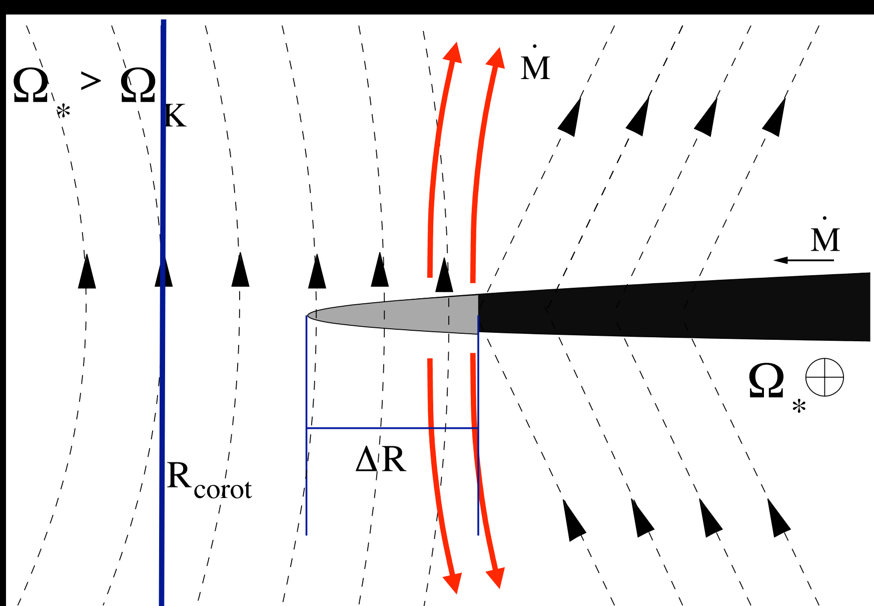


$$R_{corot} = \left(\frac{GM_{star}}{\Omega^2_{star}} \right)^{1/3}$$

- Strong magnetic fields regulate accretion near star, leading to region of closed field lines
- Define inner edge of thin disk as *magnetosphere radius*, edge of closed field line region
- Outside R_m field lines open up and reconnect: region of interaction $\boldsymbol{\Delta r}$ between the disk and field is small
- Magnetic coupling allows *transfer of angular momentum (dJ/dt) between disk and star*
- Sign depends on *corotation radius*, where spin frequency of star equals Keplerian velocity in disk

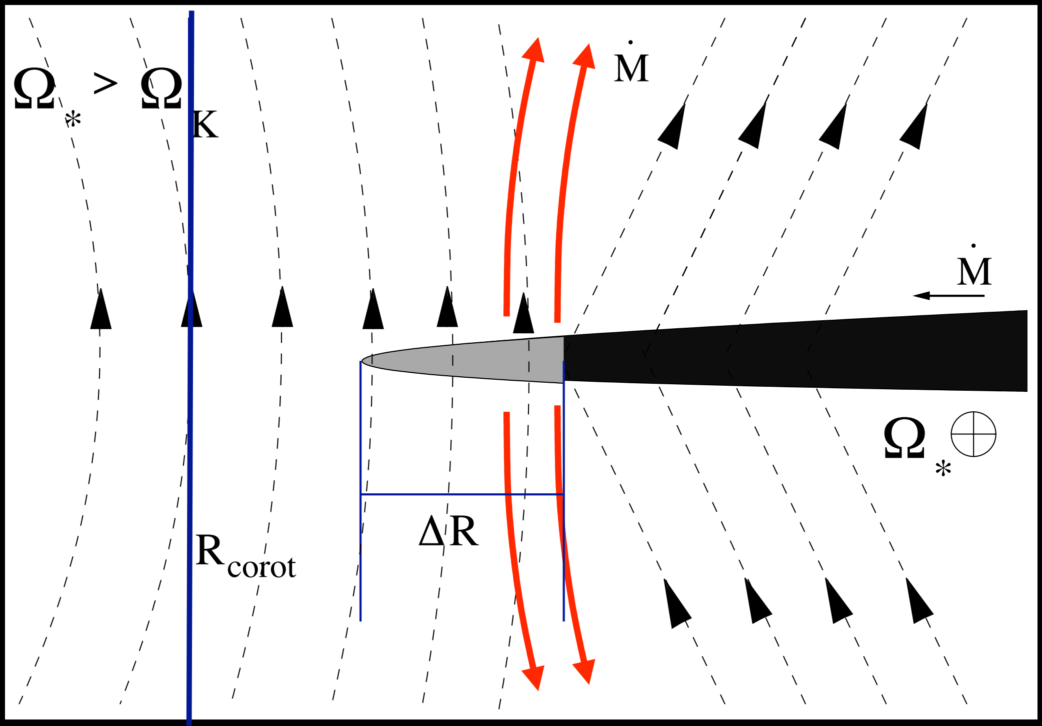
Accretion or Propeller?





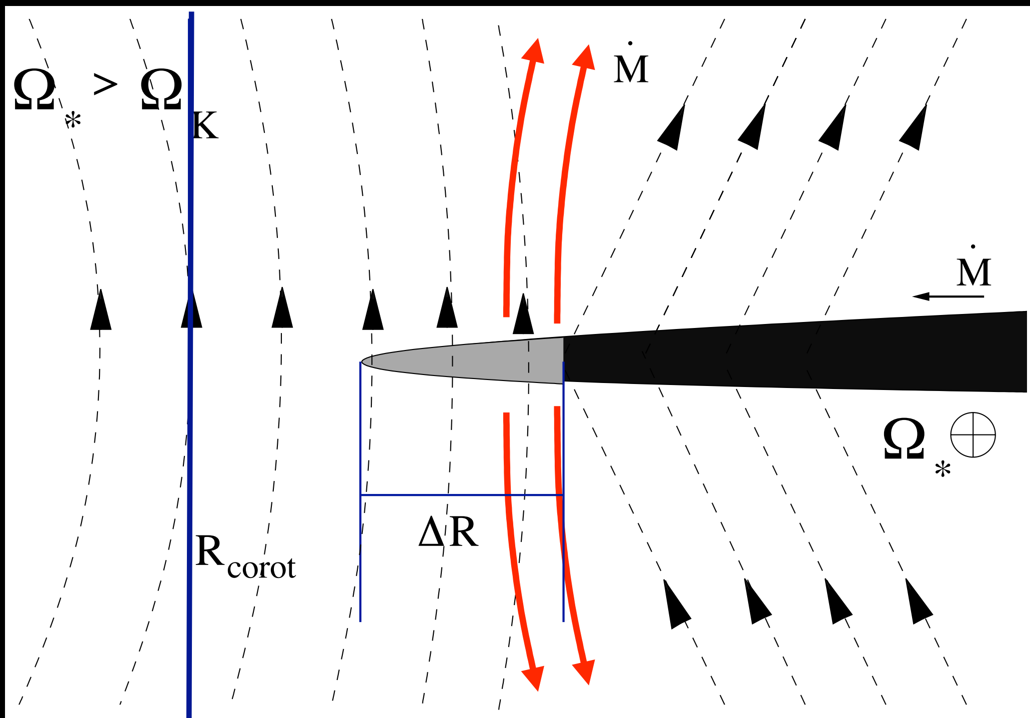
- If disk is truncated inside R_{corot}, angular momentum is *extracted* from the disk, and the disk accretes
- If disk is truncated outside R_{corot}, angular momentum is *added* to the disk, and matter is expelled ("propeller" regime)

Quiescent Disks



- For R_{in} < 1.3 R_{corot}, energy transfer between magnetic field and disk is not enough to expel much gas from system
- Gas piles up near inner regions
- If angular momentum can be absorbed at the outer edge of the disk, dM/dt from large distances is very small
- Can get a massive disk with little or no accretion or outflow: a stationary "accretion disk"!

Quiescent Disks



Consequences:

- Spin regulation of star?
- Influence planet formation?
- Force gas to persist in disk for long time

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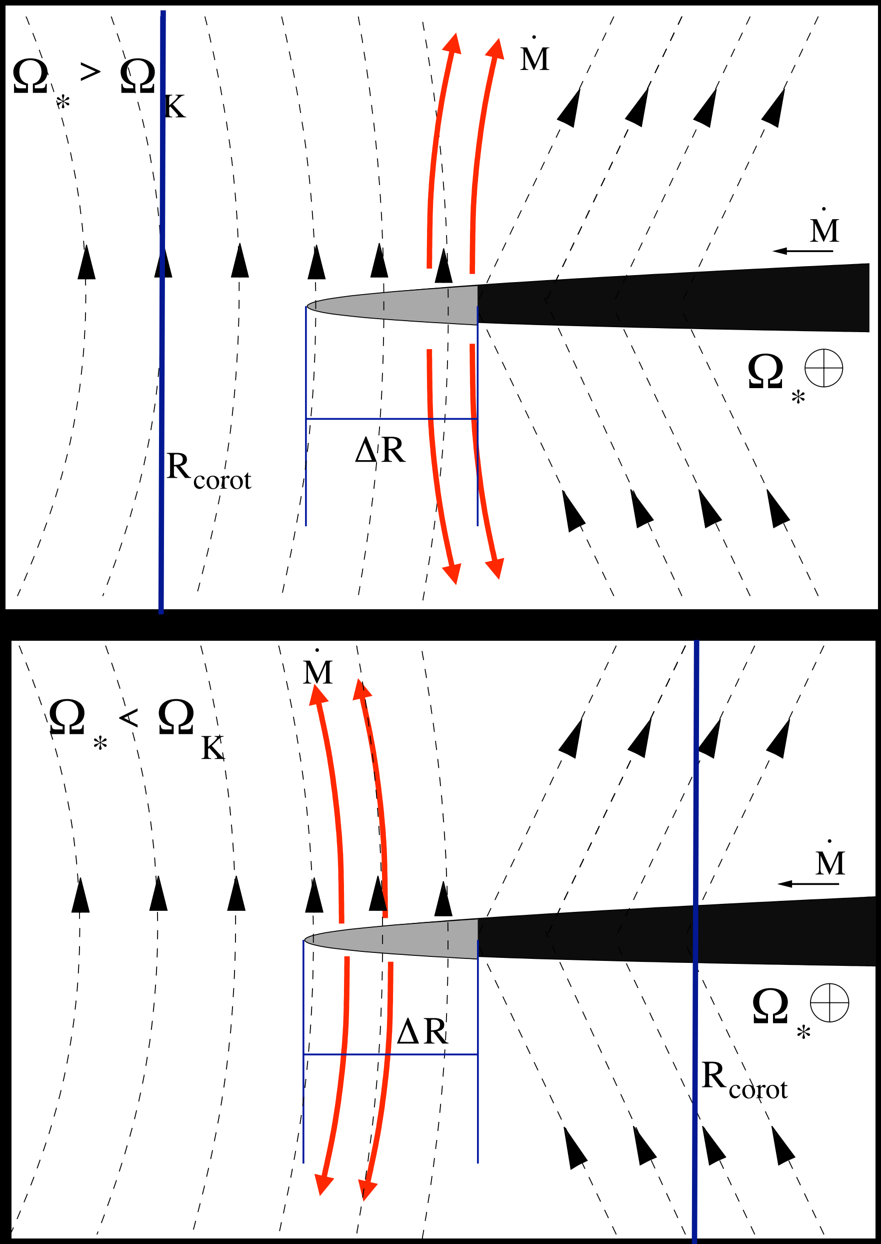
Instability: $R > R_{corot}$

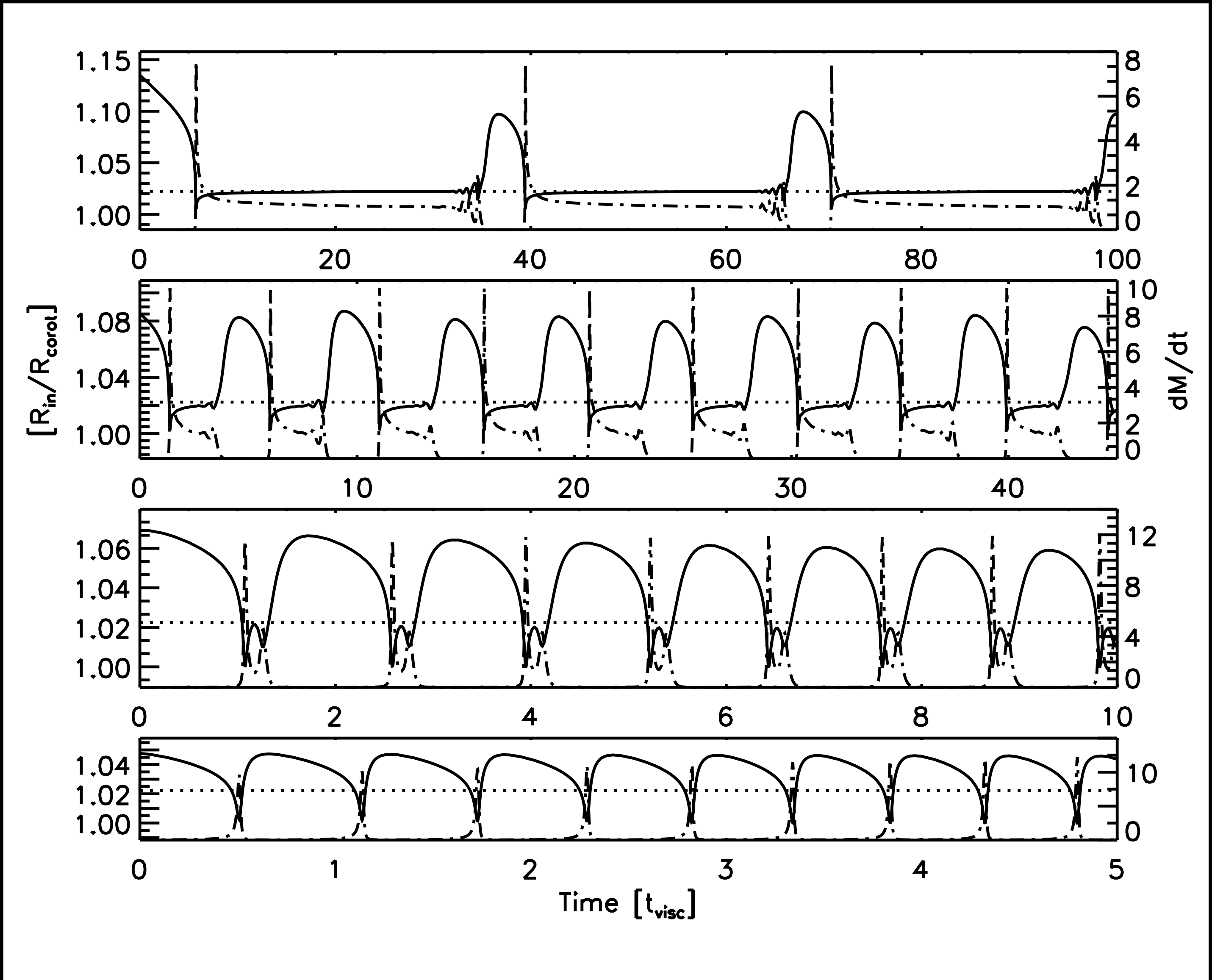


- If accretion rate is set at large distances, can get cycles of accretion
- matter builds up at the inner edge of the disk, until disk slowly pushes inside R_{corot}
- Once inside R_{corot}, excess mass is accreted until inner edge is outside corotation, where cycle starts again

Simulation

- Studied instability by modelling interaction using 1-D numerical simulation for diffusive disk:
  - assume angular momentum vectors of disk and star aligned with each other and star's magnetic dipole field
  - parameterise viscosity in disk using Shakura-Sunyaev α-viscosity model
  - assume interaction region is small: $\Delta r/r < 1$
- Parameterised interaction with magnetic field, imposed as boundary conditions at inner edge of disk:
  - For $R_{in} > R_{corot}$, angular momentum and mass conservation set surface density and radial velocity at inner edge
  - For $R_{in} < R_{corot}$, inner radius is magnetospheric radius
- Introduce (artificial) smooth transition between two boundary conditions
- Free parameters are $\Delta r/r$, smoothing length for boundary transition, average accretion rate

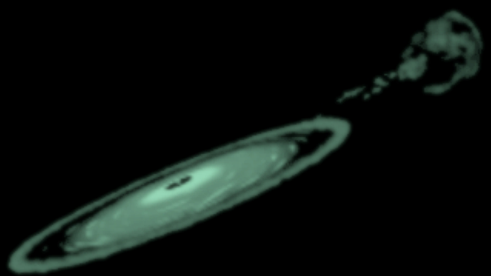
Range of Accretion Profiles



[D'Angelo & Spruit 2010]

T_{visc} = 4.3 years

$dM/dt = 10^{-8}\ M_{sun}\ yr^{-1}$

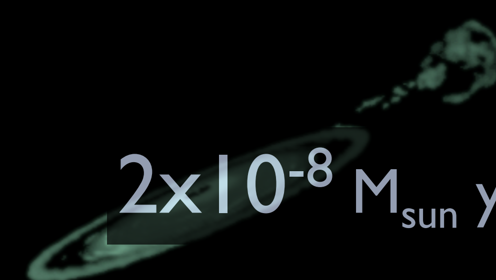


Changing dM/dt

Average accretion rate:

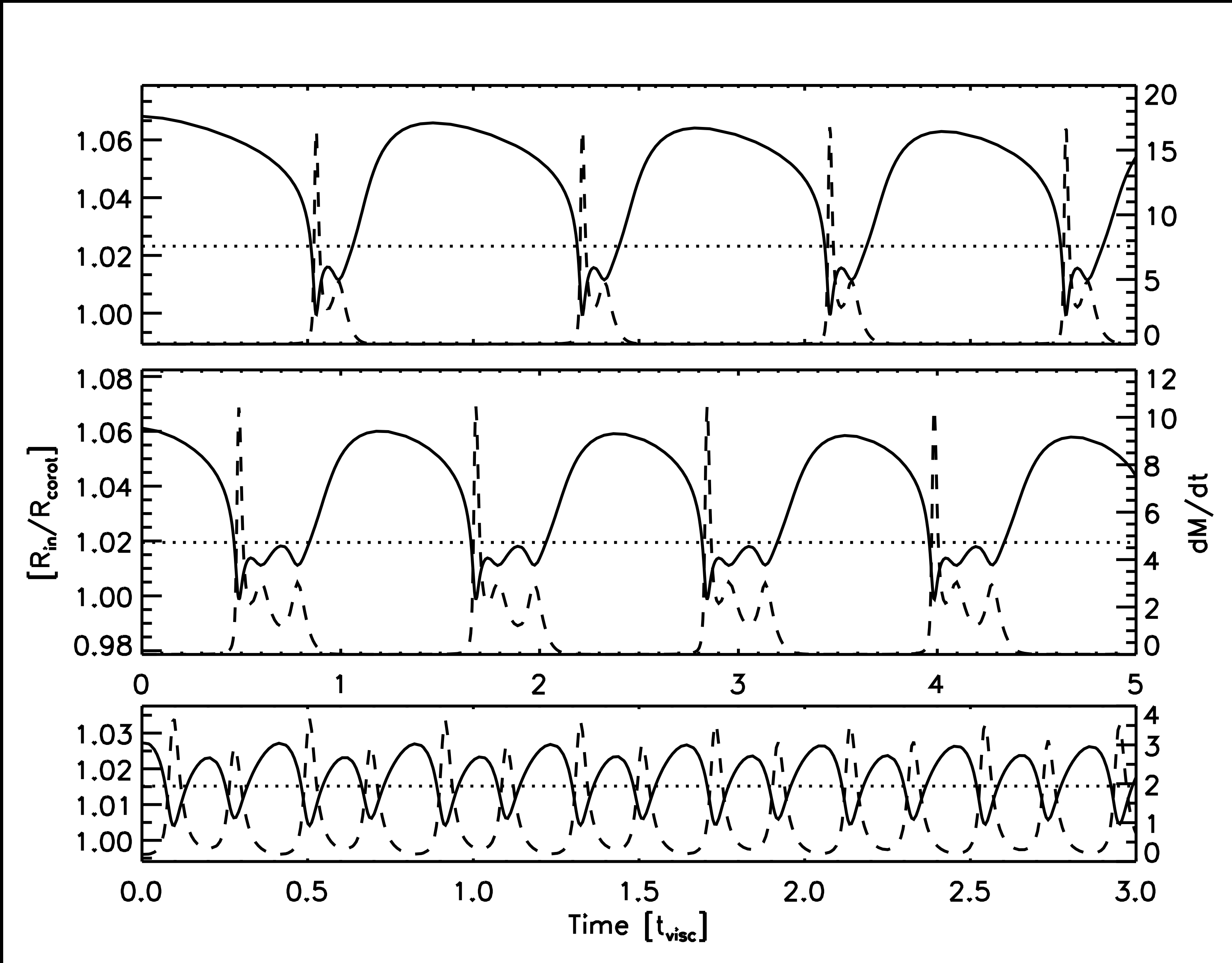
$7 \times 10^{-9}\ M_{sun}\ yr^{-1}$

$10^{-8}\ M_{sun}\ yr^{-1}$



$2 \times 10^{-8}\ M_{sun}\ yr^{-1}$

Changing dM/dt



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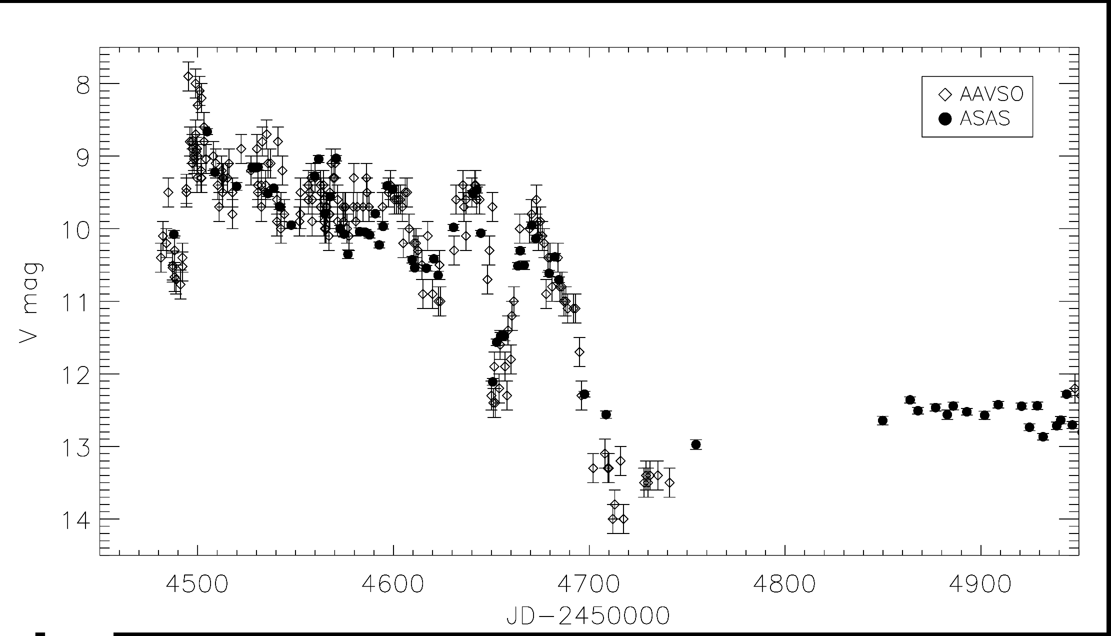
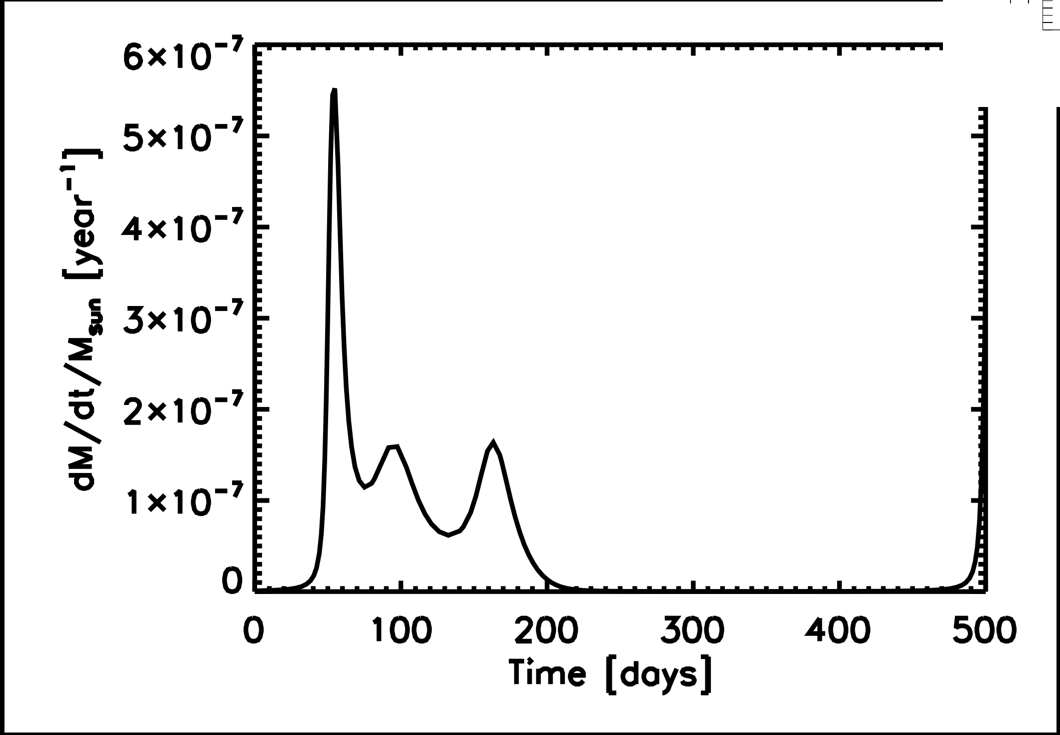
EX Lupi: 2008 outburst

• Jan. 2008: EX Lupi V 10 mag (quiescent: 13-14)
• Rises to V 8 mag before dropping to quiescence in August
• Undergoes several shorter timescale oscillations



[Attila Juhasz *private comm.*]



• Magnitude corresponds to dM/dt ~ 10^{-6} /yr
• End of outburst marked by outflow (seen also in V1115Cyg, another EXor, V1647 Ori -- [propeller?])
• Model qualitatively fits, working on more quantitative comparison

Conclusions and Future Work

- Requires **strong** magnetic field, fairly fast-spinning star, low-accretion rate to truncate the disk outside co-rotation
- **Low accretion rate does not mean tenuous disk!** Disk stays truncated close to co-rotation even in quiescence (is this observable?)
- Wide range of frequencies (~0.1-50 years for proto-stellar disk) and outburst shapes (relaxation oscillator, sub-oscillations)
- Solutions also depend on physics in outer disk (sets accretion rate, angular momentum transport); instabilities appear over two orders of magnitude in accretion rate
- Mechanism could also have implications for long-term evolution of star (working on now!)
- Early results suggest mechanism could explain variability in TTauri class "EXors"