Possible Observable Signatures of Classical T Tauri Stars Accreting in an Unstable Regime

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Abstract

Classical T Tauri stars (CTTSs) are variable in different time-scales. One type of variability is possibly connected with the accretion of matter through the Rayleigh-Taylor instability that occurs at the interface between an accretion disc and a stellar magnetosphere. In this regime, matter accretes in several temporarily formed accretion streams or `tongues' which appear in random locations, and produce stochastic photometric and line variability. We use the results of global three-dimensional magnetohydrodynamic (MHD) simulations of matter flows in both stable and unstable accretion regimes to calculate time-dependent hydrogen line profiles and study their variability behaviours. We use multiple-time slices of the MHD simulations in radiatilve transfer models. This allows us to study "intrinsic varibility", which should be differentiated from the rotationally induced variability, caused by the flows associated with the instability. Our main findings are summarized in *Summary* section at the bottom of this poster. This work is based on Kurosawa & Romanova, 2013, MNRAS, 431, 2673.

Method

Outline

(1). Run MHD simulations, and find both stable and unstable accretion flows onto CTTSs (e.g. Kulkarni & Romanova 2008)

(2). Map MHD data (density, velocity and temperature to radiative transfer model grid.

(3). Find the source function (non-LTE level populations) using the Sobolev approximation

(4). Compute the observed flux as a function of frequency (profile calculations).

(5). Repeat (2)--(4) for different rotational phases, and for 3 rotational phases.

MHD Models

- Two regions: (1). low density corona region and (2). accretion disk region (using α viscosity: Shakura & Sumyaev 1973).
- Numerical code: MHD in 3D. Uses "cubed sphere" grid (Koldoba et al. 2002). Riemann solver similar to Powerll et al. (1999)
- Initial B field: a stellar dipole field

==> $B = [3(\mu \cdot r)r - \mu r^2]/r^5$

But the magnetic dipole moment is inclined by Θ with respect to the stellar (and disk) rotation axis.

- In general, flows becomes unstable for 1, larger α, 2. smaller Θ and 3. slower stellar rotation rate (Ω_*).

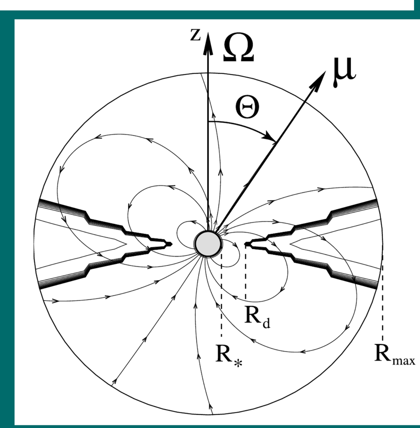
Radiative Transfer Models

- The multi-dimensional non-LTE radiative transfer model with the Sobolev approximation in the source function calculation, as described in Kurosawa et al. (2011) is used.
- Atomic models. H I (20 levels), He I (19 levels, up to n=4), He II (10 levels).
- Stellar continuum sources: (1) Photosphere --> T_{eff}=4000 K and log g_*=3.5 (cgs), and (2). Accretion hotspots included.
- The sizes and shapes of the hot spots on the stellar sizes are adjusted based on the the energy fluxes of the accretion flows at the stellar surface.
- Line broadening effects (Stark, van der Waals, turbulence) included for some lines

Model Parameters

	M_* ($M_\odot$)	R_* ($R_\odot$)	B_{eq} (G)	r_{cor} (R_*)	P_* (d)	Θ (−)	α (−)
Stable	0.8	2	10^3	5.1	4.3	30°	0.02
Unstable	0.8	2	10^3	8.6	9.2	5°	0.1

Initical Configurations



Results

MHD Similations

Stable Case

Unstable Case

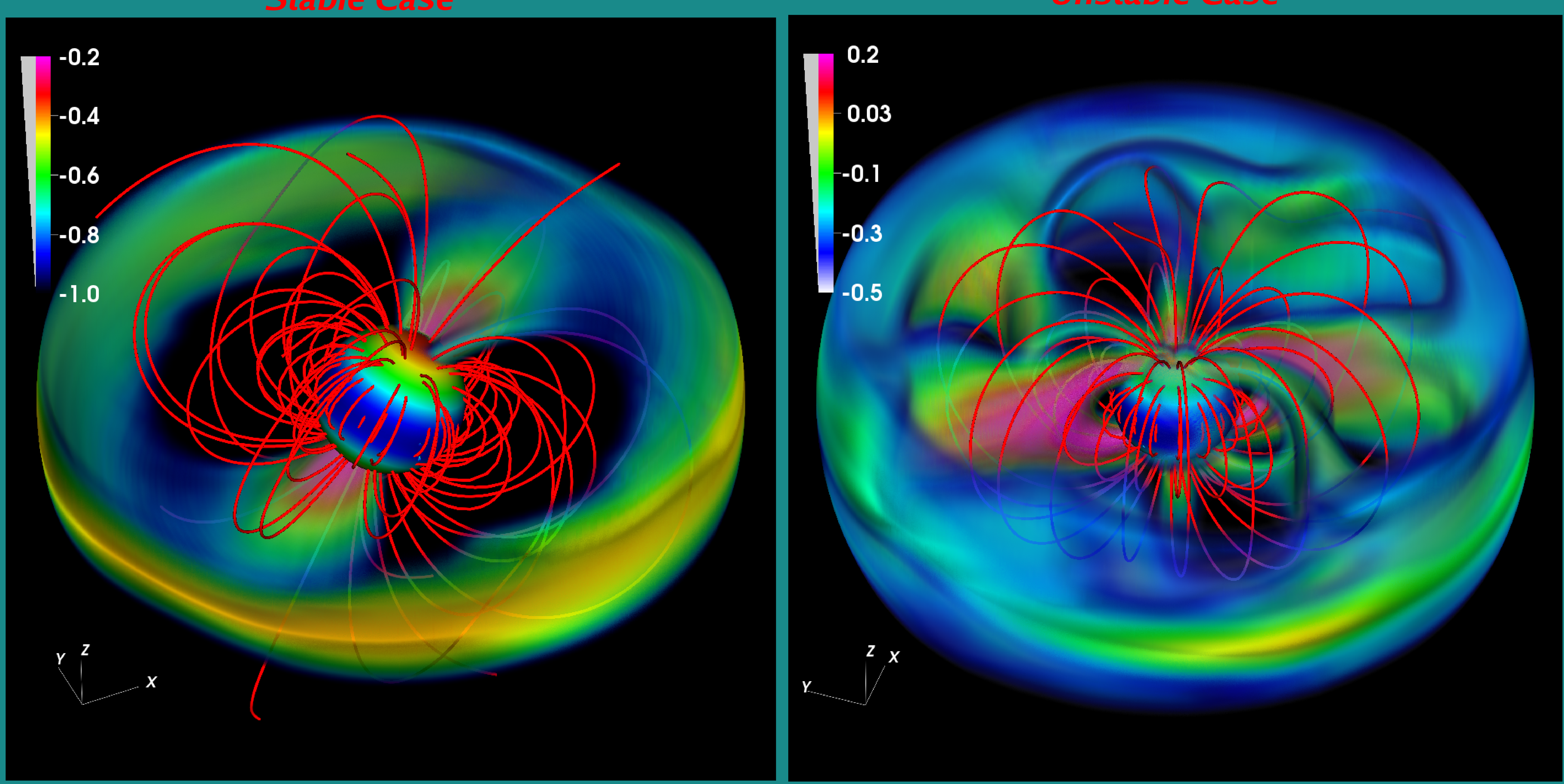


Figure 1. Examples of the magnetospheric accretions in a stable (left panel) and an unstable (right panel) regimes. The background colours show the volume rendering of the density (in logarithmic scales and in arbitrary units). The sample magneticfield lines are shown as red lines. Similar 3D MHD simulartions can be found in e.g. Romanova et al. (2008), Kulkarni & Romanova (2008).

Time-Dependent Hδ (410.2nm) Profile (Models)

Stable Case

Unstable Case

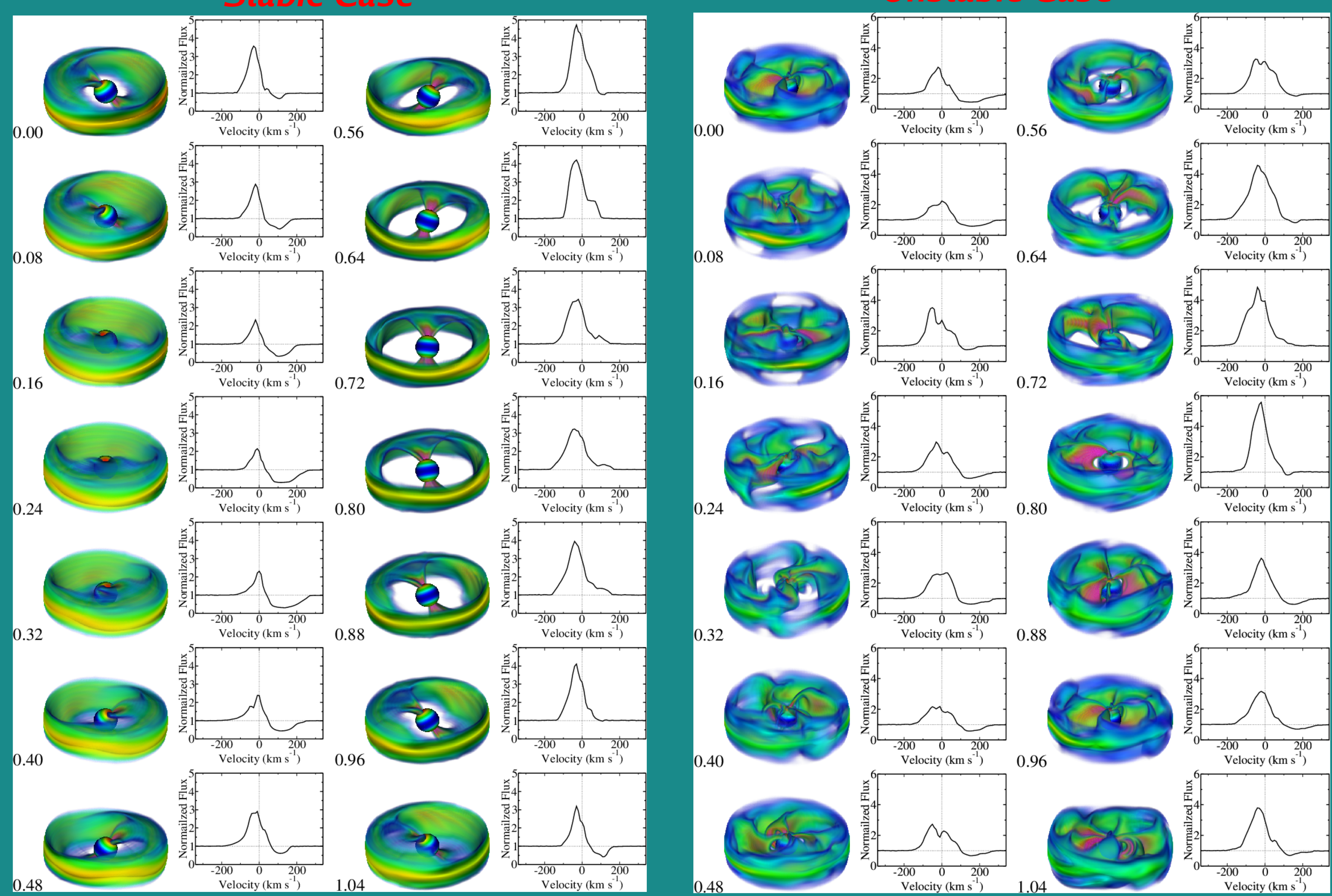


Figure 2. Magnetospheric accretion in the stable (left) and unstable (right) regimes. The corresponding Hδ model profiles are shown at different rotational phases (indicated at the lower-left corner of each panel; with 0.08 interval). Only a subset (only for about one rotation period of the star) of the MHD simulations and model profiles is shown. The volume rendering of the density shown in colour (in logarithmic scale) at each phase are projected toward an observer viewing the system with its inclination angle i=60°. The model profiles are also computed at i=60°

Light Curves and Line EW (Models)

Stable Case

Unstable Case

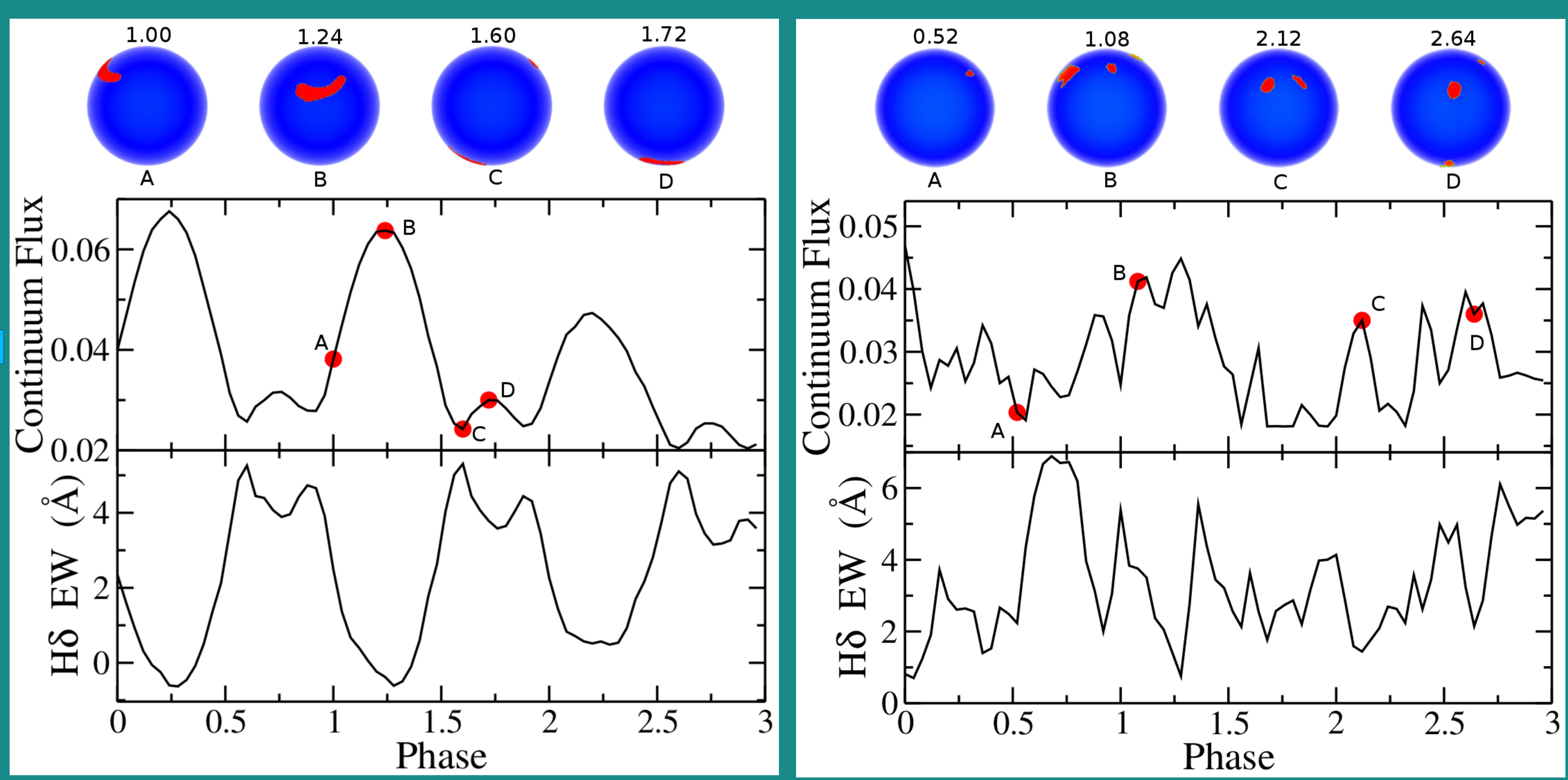


Figure 3. The maps of hot spots, as seen by an observer at the inclination angle i=60°, at four different rotational phases (top panels), the light-curves calculated at the wavelength of Hδ (middle panels; flux in arbitrary units) and the line equivalent widths (EWs) of model Hδ profiles (lower panels, in Å) are shown for the stable (left panels) and unstable (right panels) regimes of accretions. The hot spots are assumed to be radiating as a blackbody with T=8000K, and are shown for representative moments of time which are marked as red dots in the light curves.

Periodic Light Curve (Observation)

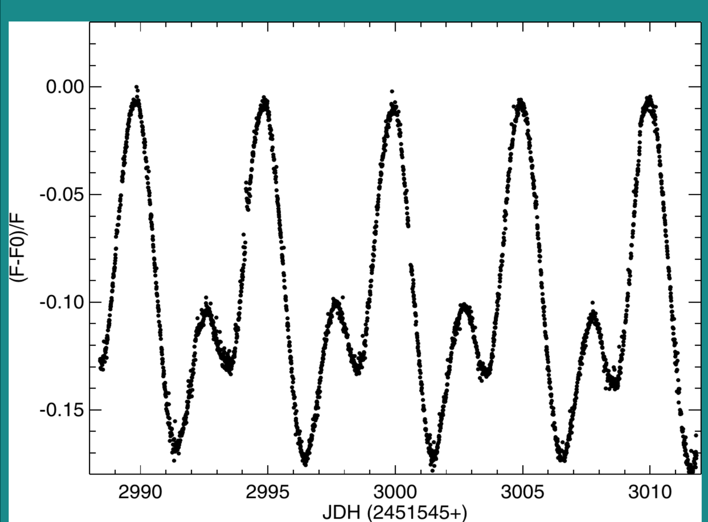


Figure 4. A periodic light-curve (in `white light' broadband) of a CTTS in NGC 2264 obtained by *CoRoT* satellite (from Alencar et al. 2010). About 30% of CTTSs samples show this type of regular/periodc light curves, which are likely caused by stellar spots and stellar rotations.

Irregular Light Curve and EW (Observation)

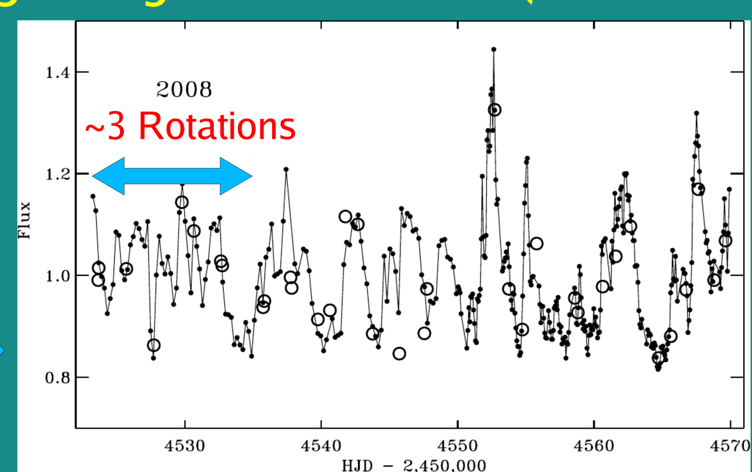


Figure 5. The irregular light-curve of TW Hya (in the broadband between V and R) obtained by *MOST* satellite (from Rucinski et al. 2008). About 40% of CTTSs samples in Alencar et al. (2010) show irregular light curves.

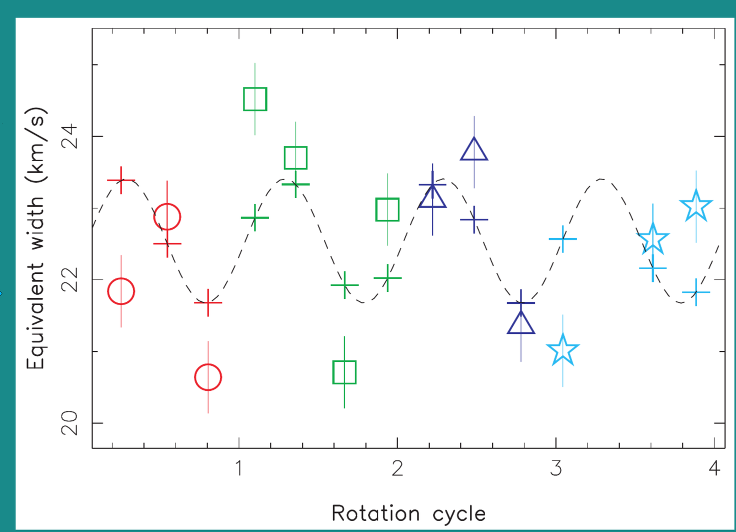


Figure 6. Line EW (Ca I IRT) of TW Hya, observed as a function of rotational phase (from Donati et al. 2011), shows significant amount of "intrinsic" variability.

Summary

- In the stable regime, some hydrogen lines (e.g. Hβ, Hγ, Hδ, Paβ and Brγ) show a redshifted absorption component only during a fraction of a stellar rotation period, and its occurrence is periodic.
- in the unstable regime, the redshifted absorption component is present rather persistently during a whole stellar rotation cycle, and its strength varies non-periodically.
- In the stable regime, an ordered accretion funnel stream passes across the line of sight to an observer only once per stellar rotation period while in the unstable regime, several accreting streams/tongues, which are formed randomly, pass across the line of sight to an observer. The latter results in the quasi-stationarity appearance of the redshifted absorption despite the strongly unstable nature of the accretion.
- In the unstable regime, multiple hot spots form on the surface of the star, producing the stochastic light curve with several peaks per rotation period. This study suggests a CTTS that exhibits a stochastic light curve and a stochastic line variability, with a rather persistent redshifted absorption component, may be accreting in the unstable accretion regime

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