Accretion and outflow on the late phases of Pre-main sequence evolution

Ilya S. Potravnov

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"The UX Ori type stars and related topics"
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Introduction

- During the first few Myr of their life young stars are surrounded by accretion disks rich in gas (∼99% by mass) and small dust.
- Accretion processes probe the gas content of the inner <1 AU of the disk.
- Magnetospheric accretion model. Applicable to TTS & HAe(?) stars

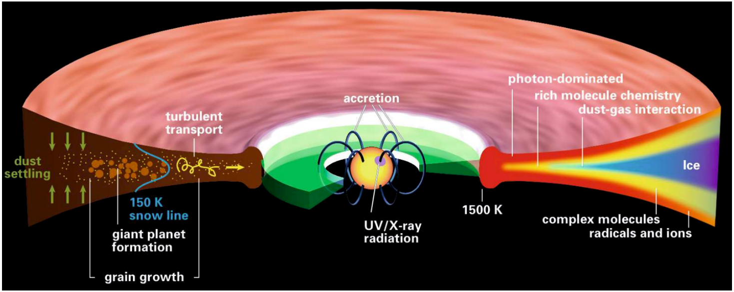


Figure: Henning&Semenov, 2013

CS disks evolution

From gas-rich protoplanetary to dusty debris disk

Disk clearing mechanisms:

- Accretion + wind
- Photoevaporation
- Planets formation

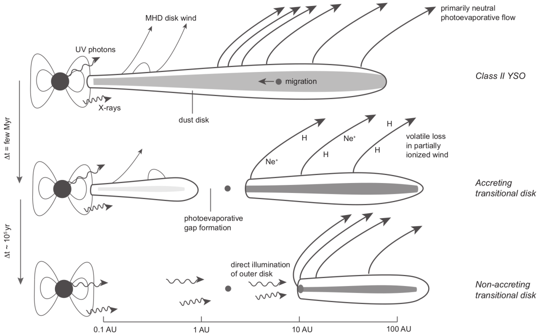


Figure: Alexander et al., 2014 PP VI

Inner disk clearing → Accretion and wind decay

Accretion lifetime

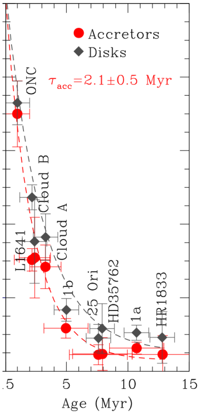


Figure: Briceño et al., 2019

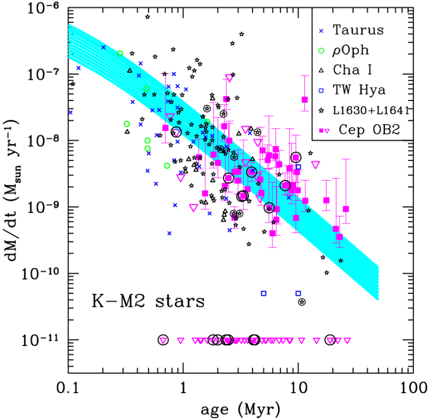


Figure: Sicilia-Aguilar et al., 2010

General trend is decrease both fraction of accretors and M_{acc} with age. But there is significant scatter in M_{acc} at each given age.

Accretion lifetime

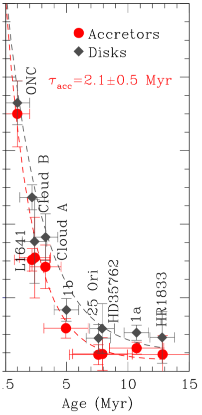


Figure: Briceño et al., 2019

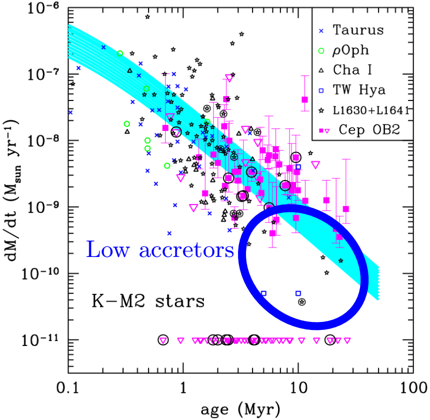


Figure: Sicilia-Aguilar et al., 2010

General trend in decrease both fraction of accretors and M_{acc} with age.
But there is significant scatter in M_{acc} at each given age.

Rapid disk evolution in dence clusters? Prolonged accretion lifetime in loose environment?
(Pfalzner et al., 2014)

Fraction of K-type accretors in Sco-Cen subgroups: US (10±3 Myr), UCL (16±2 Myr), LCC (15±3 Myr) (Pecaut&Mamajek, 2016)

Band/Criteria/Disk Type	US	UCL	LCC
EW(Hα)	6/84 ($7.1^{+3.9}_{-1.9}$%)	5/145 ($3.4^{+2.2}_{-1.0}$%)	4/119 ($3.4^{+2.5}_{-1.0}$%)

Some individual long-lived accretors

- MP Mus, sp:KIVe, 10-20 Myr (Mamajek et al., 2002)
- WISE J0808-6443, sp:M, 40 Myr (Murphy et al., 2018)
- RZ Psc, sp:K0IV, 20 Myr (Grinin et al., 2010; Potravnov et al, 2019)

Prospects in GAIA era: disclosure low-mass content of OB associations

Low accretors

At last stages of active accretion star becomes a "low accretor":
$M_{acc} < 10^{-11} M_\odot$ yr^{-1} ($H\alpha$ surveys detection limit)

$M_{wind}/M_{acc} \sim 0.01$ (Hartigan et al., 1995): Low accretion ⇒ even lowest wind.

Highlights from studying of low accretors:

1. How the accretion/outflow and their observational tracers decays?
2. Does the MA act with the same efficiency at the all accretion phases?
3. Could be any alternative/complementary mechanisms of star-disk interaction?

The case study: RZ Psc

- High-latitude UXOR, $b = -34°$ (Grinin et al.,2010)
- sp: K0 IV (Herbig, 1964)
- No notable emission-line spectrum (Herbig, 1964; Grinin et al., 2010)
- mid-IR excess ($\lambda \gtrsim 5\mu$m): $L_{IR}/L_{bol} \sim 8\%$ (de Wit et al., 2013)
- Age $t = 20^{+3}_{-5}$ Myr; probable member of Cas-Tau OB ass. (Potravnov et al., 2019).

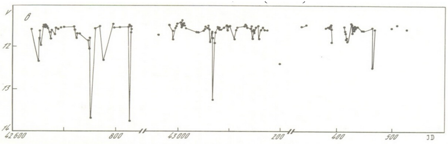


Figure: Zajtseva, 1985

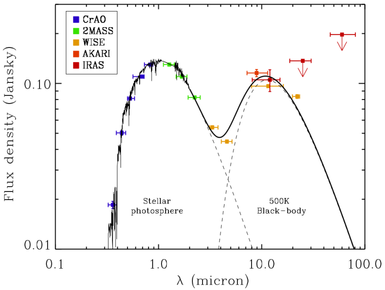


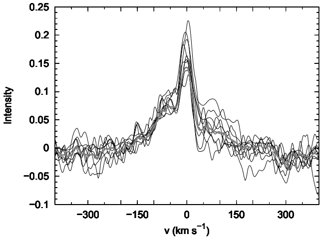
Figure: de Wit et al., 2013

RZ Psc: spectroscopy

From medium resolution spectra:

- $H\alpha$ profile: filled-in by very weak variable emission
- Variable blueshifted absorptions (BACs) are almost permanently presented in NaI D, IR CaII and KI lines

Residual emission at $H\alpha$: EW $\sim$ 0.5 Å



$$M_{acc} \sim 7 \cdot 10^{-12} M_{\odot}\ \mathrm{yr}^{-1}$$

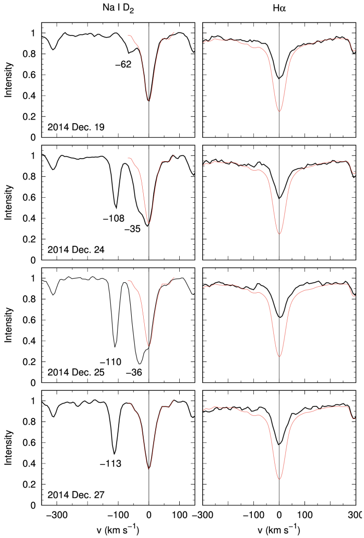


Figure: Potravnov et al., 2017

BACs in spectra of young stars

BACs at NaI D are presented in spectra of several young stars: CTTS NY Ori & V1118 Ori (Herbig, 2008), HAe MWC 480 (Kozlova et al., 2003), FUOR BBW 76 (Reipurth et al., 2006)

- All of this stars are actively accreting objects.
- RZ Psc is only exception - low accretor.

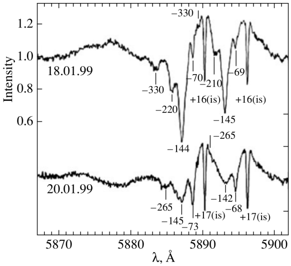


Figure: HAe MWC 480

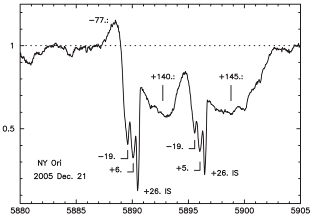


Figure: CTTS NY Ori

What is their origin?

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Original Russian Text © V.P. Grinin, I.S. Potravnov, I.V. Ilyin, S.G. Shulman, 2015, published in Pis'ma v Astronomicheskiĭ Zhurnal, 2015, Vol. 41, No. 8, pp. 444–454.

Magnetic Propeller Effect in the Spectra of Young Stars

V. P. Grinin[1,2*], I. S. Potravnov[1], I. V. Ilyin[3], and S. G. Shulman[1,2]

[1]Pulkovo Astronomical Observatory, Russian Academy of Sciences, Pulkovskoe sh. 65, St. Petersburg, 196140 Russia

[2]Sobolev Astronomical Institute, St. Petersburg State University, Universitetskii pr. 28, St. Petersburg, 198504 Russia

[3]Leibnitz Institute of Astronomy, 14482 Potsdam, Germany

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Abstract—The origin of the blueshifted narrow absorption components in the resonance sodium doublet lines observed in the spectra of some young stars is discussed. Such components are assumed to be formed by the interaction of the circumstellar gas with the stellar magnetosphere in the magnetic propeller regime. The results of observations for the post UX Ori star RZ Psc are discussed in detail. This star shows distinctive signatures of mass outflow in the absence of any clear accretion signatures. Such a picture is quite possible in the magnetic propeller regime. Estimates show that for this regime to be realized, the star must have a surface magnetic field of $\sim$1 kG at an accretion rate that does not exceed $10^{-10} M_\odot\,\mathrm{yr}^{-1}$.

Magnetic propeller effect

Regime of interaction between magnetised star and its disk depends on relation between the corotation (R_{cor}) and magnetosphere's truncation (R_{tr}) radii.

$$R_{tr}/R_* = 7.1 B^{4/7} \dot{M}_{-8}^{-2/7} M_{0.5}^{-1/7} R_2^{5/7}$$

$$R_{cor} = (GM_*/\omega^2)^{1/3}$$

Magnetospheric accretion (MA)

$$\boxed{R_{tr} < R_{cor}}$$

Matter is accreted onto the star

Magnetic propeller (MP)

$$\boxed{R_{tr} > R_{cor}}$$

Matter is expelled outward by rotating magnetosphere

TTS in MP regime

- Theory (MHD simulations): Romanova et al., 2004; 2018
- Observations: AA Tau, V2129 Oph and LkCa15 (Donati et al., 2010; 2012; 2019).

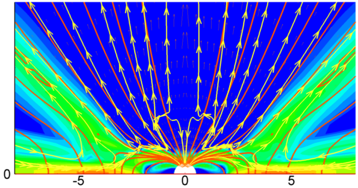


Figure: Romanova et al., 2018

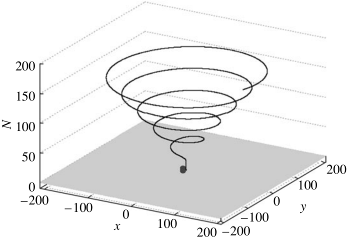


Figure: Shulman, 2015; Grinin et al., 2015

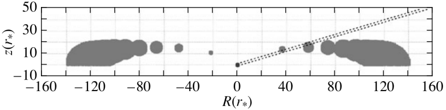
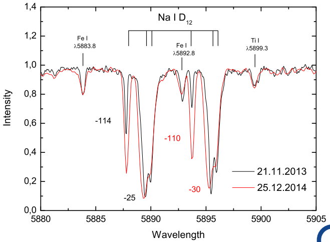


Figure: Shulman, 2015; Grinin et al., 2015



Weak propeller simulations

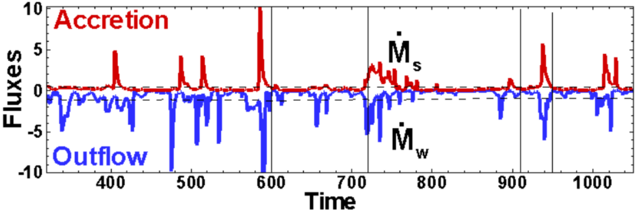


Figure: Romanova et al., 2018

- Even at low M_{acc} accreting matter sometimes accumulates in the inner disk and penetrates the magnetocentrifugal barrier.
- Short-lived accretion "flares" should be observable sometimes.
- Nevertheless, wind dominates in observational statistics of MP regime.

Is RZ Psc accreting object?

Answer from high-resolution spectroscopy: yes!

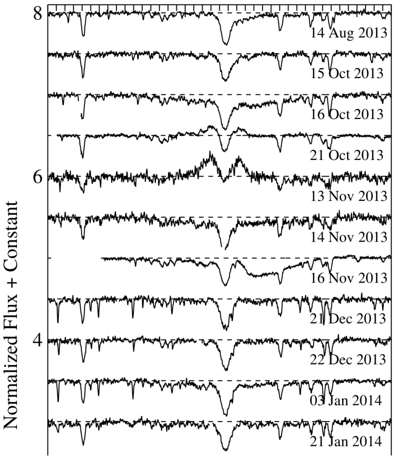
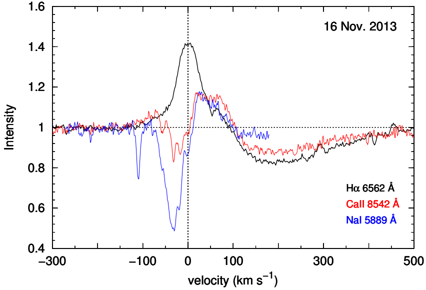


Figure: Punzi et al., 2018

HIRES spectrum 16.11.2013:

- IPC profile at $H\alpha$ and IR CaII $\Rightarrow$ infall from R_{cor}.
- Identical BACs at IR CaII and NaI D lines $\Rightarrow$ wind acceleration from magnetosphere's boundary.

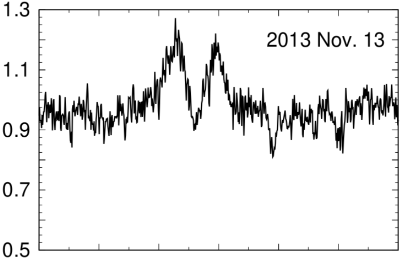


Potravnov et al.,2019

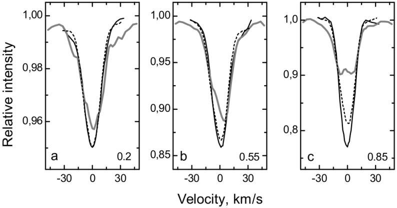
RZ Psc in the deep photometric minimum

Unique high-resolution spectrum of RZ Psc was obtained 13.11.2013 at its deep UXOR minimum ($\Delta V \approx 1.^m4$) (Punzi et al., 2018; Potravnov et al, 2019)

$H\alpha$ line appeared in double-peaked emission



LSD profiles of photospheric lines. Light gray- in eclipse.



"Coronographic effect" revealed the emission cores in metallic lines ("line-dependent" veiling) attributed to radiation of the accretion hot spot.

Summary

1. Stars at last stages of active accretion (low accretors) are promising for the investigation of the mechanisms of star-disk interaction in details.
2. UXOR orientation gives the unique opportunity for spectroscopic probe of the accretion/outflow even at very low accretion rates.
3. Magnetic propeller regime is realised in young stars and could play the important role at the latest stages of accretion activity.
4. BACs at NaI D and IR CaII lines could be important observational tracers of MP regime.

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