SOXS WG2

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INAF
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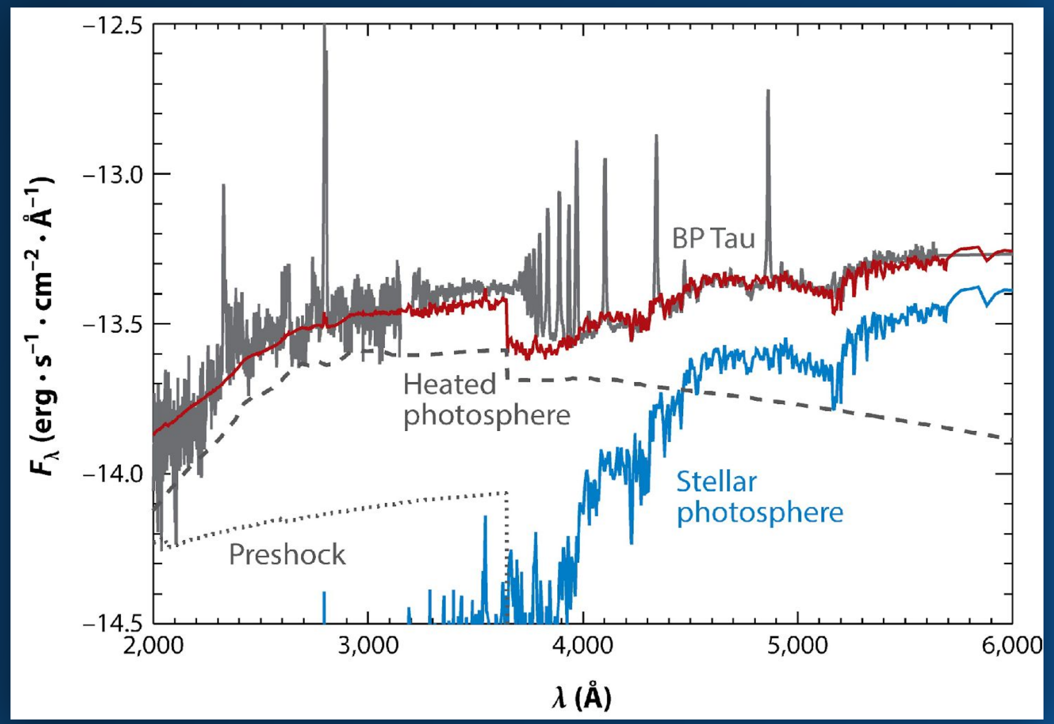
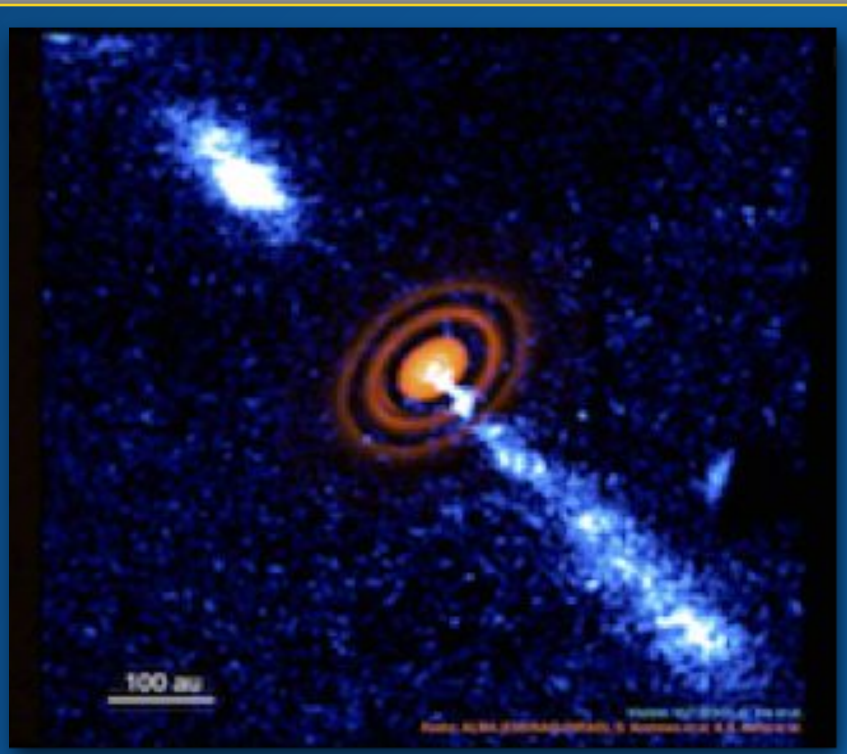
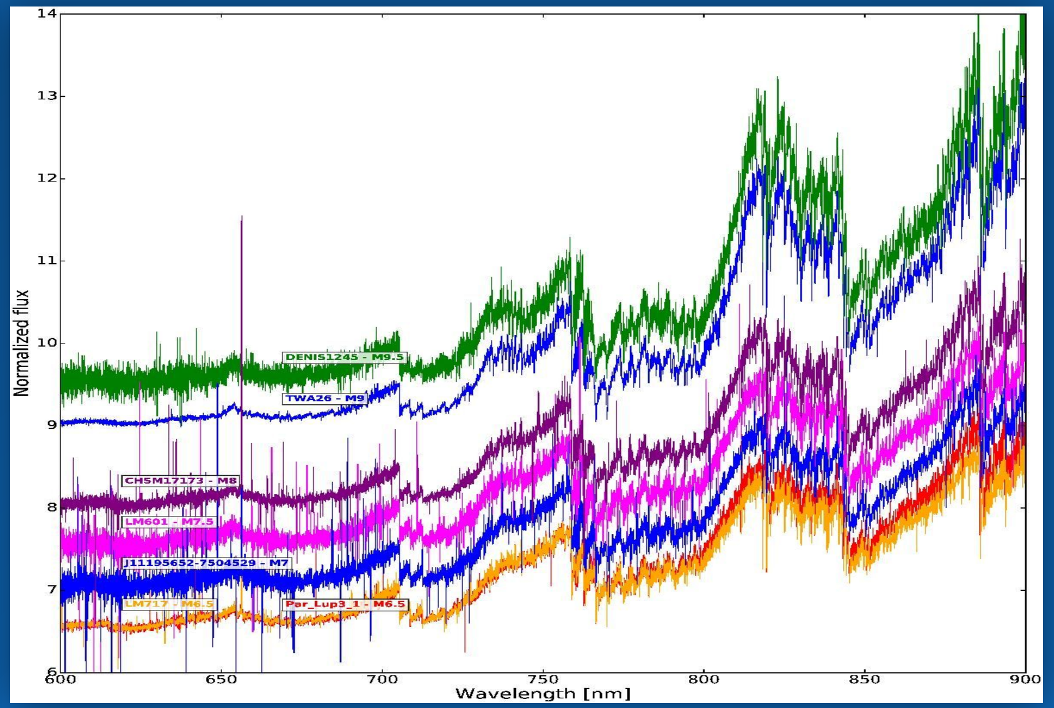
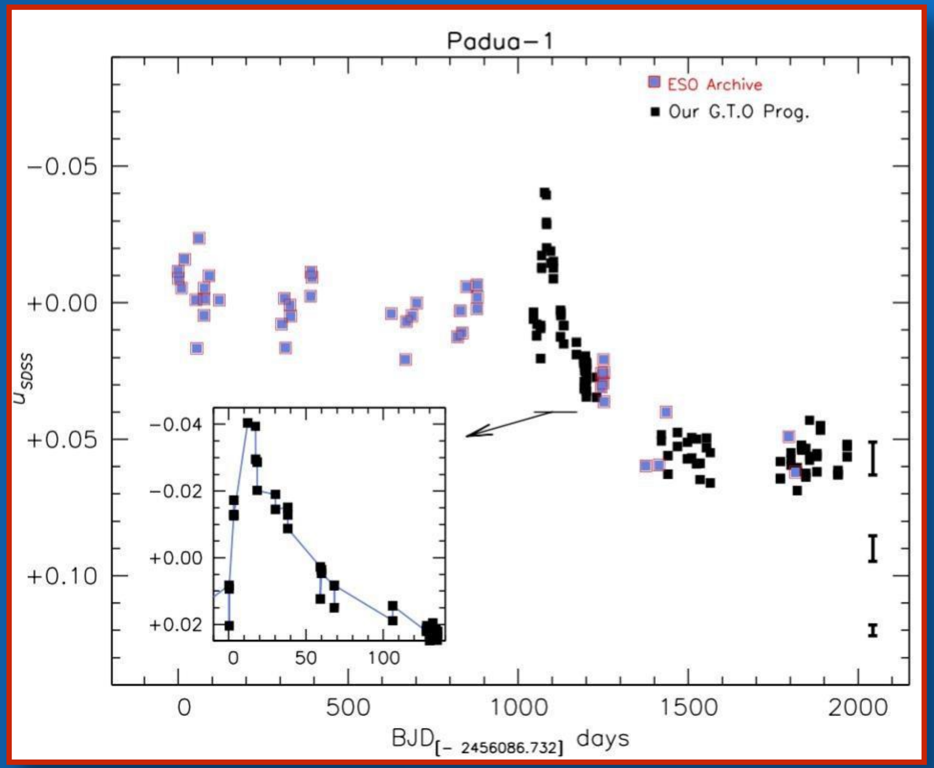


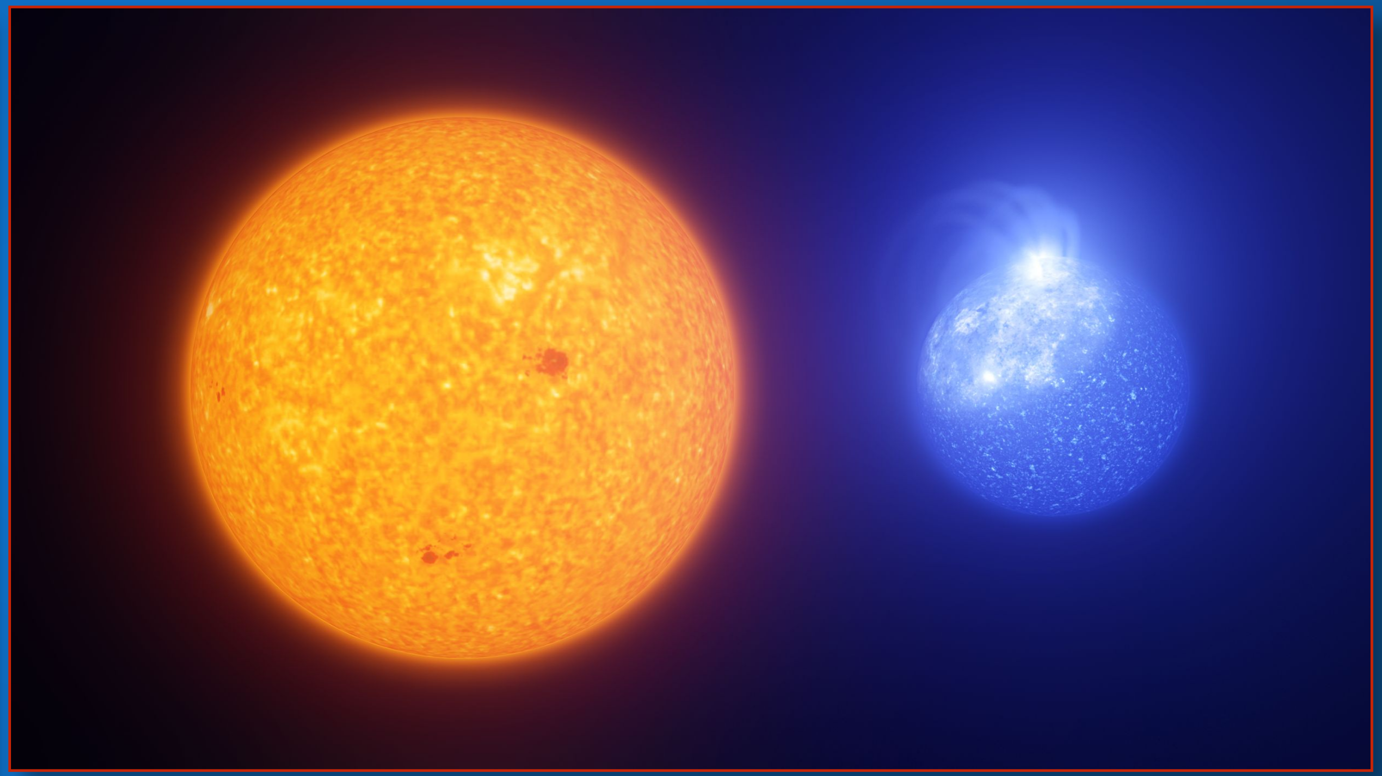


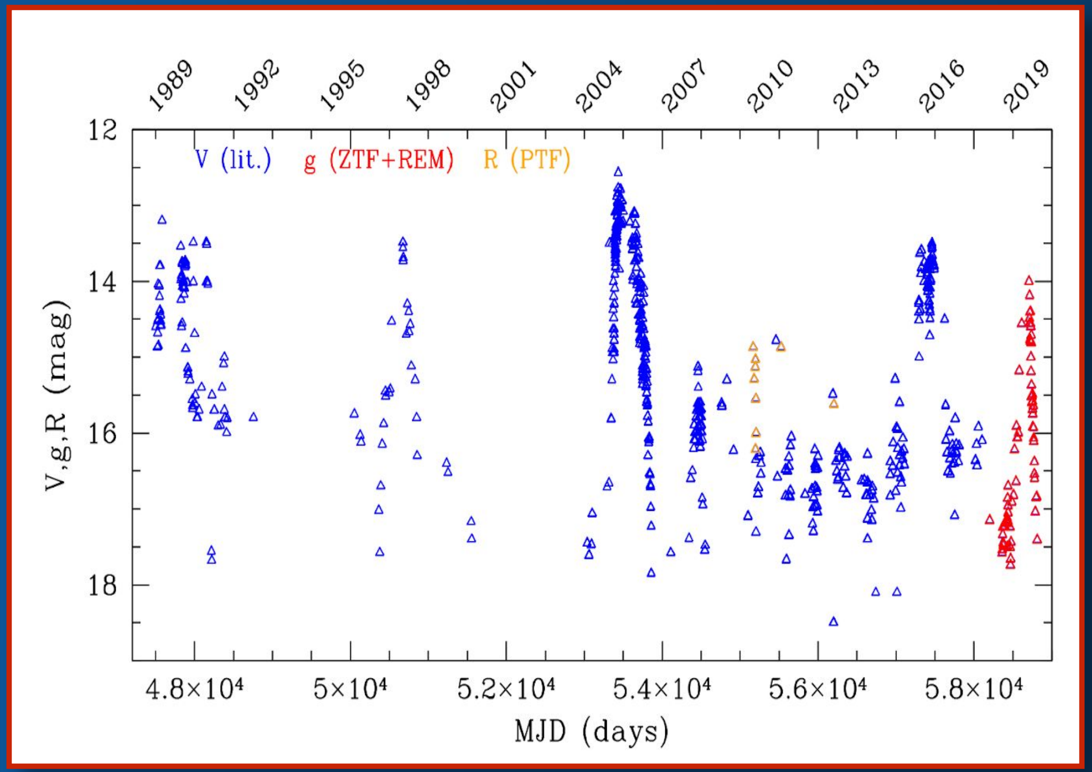


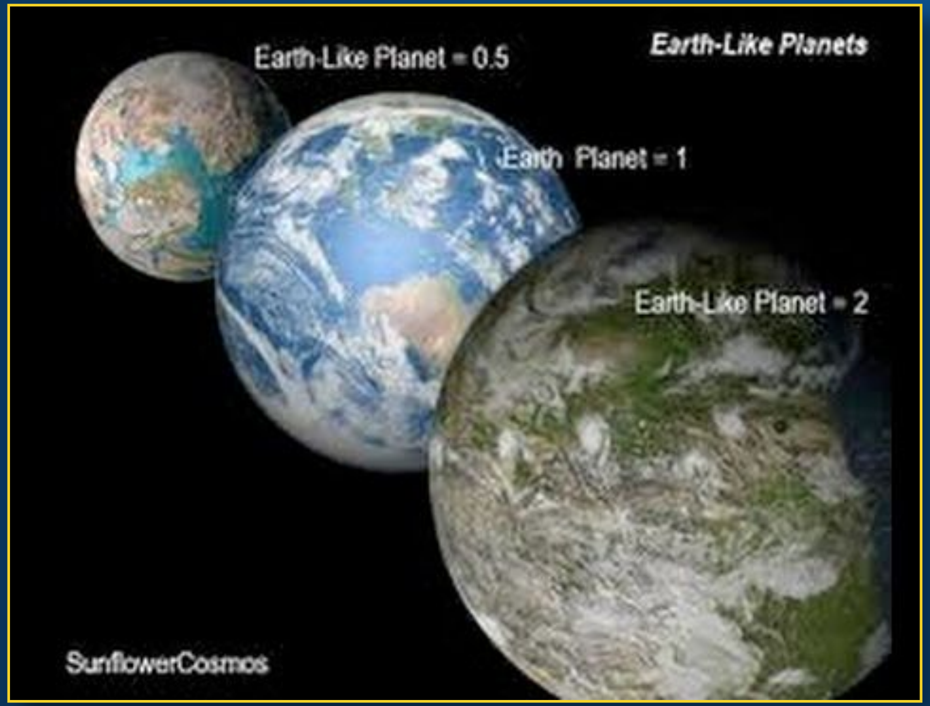
Young Stellar Objects

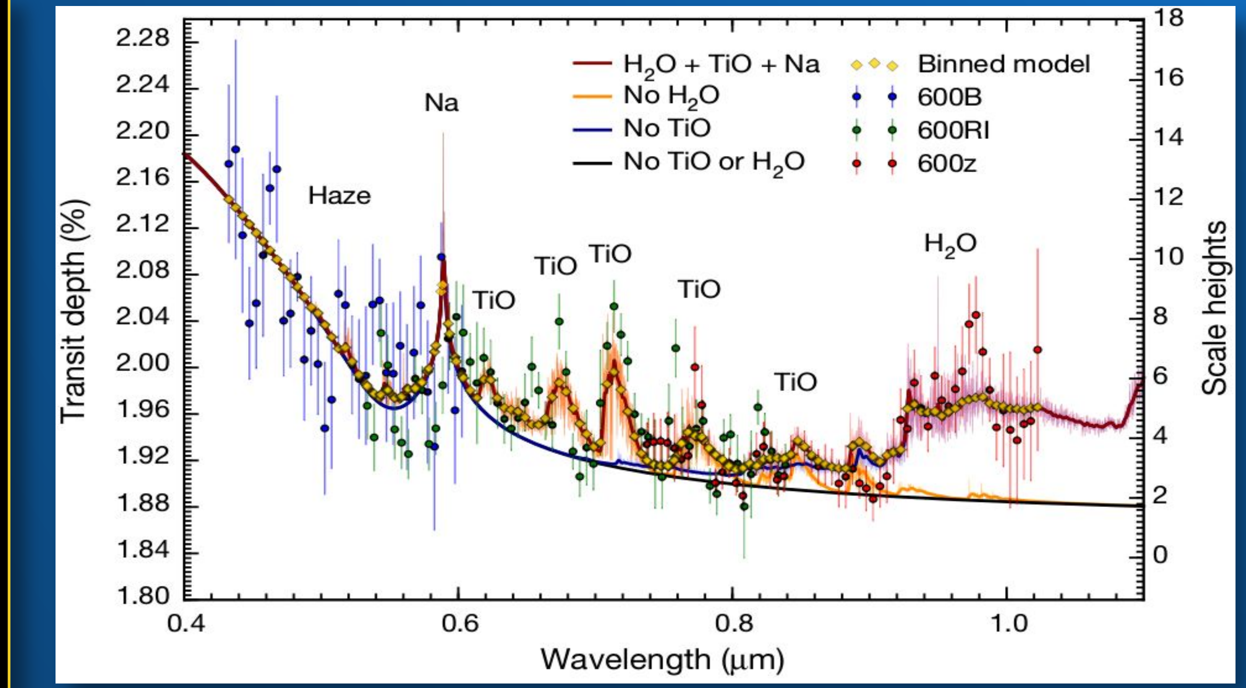
Variable Stars

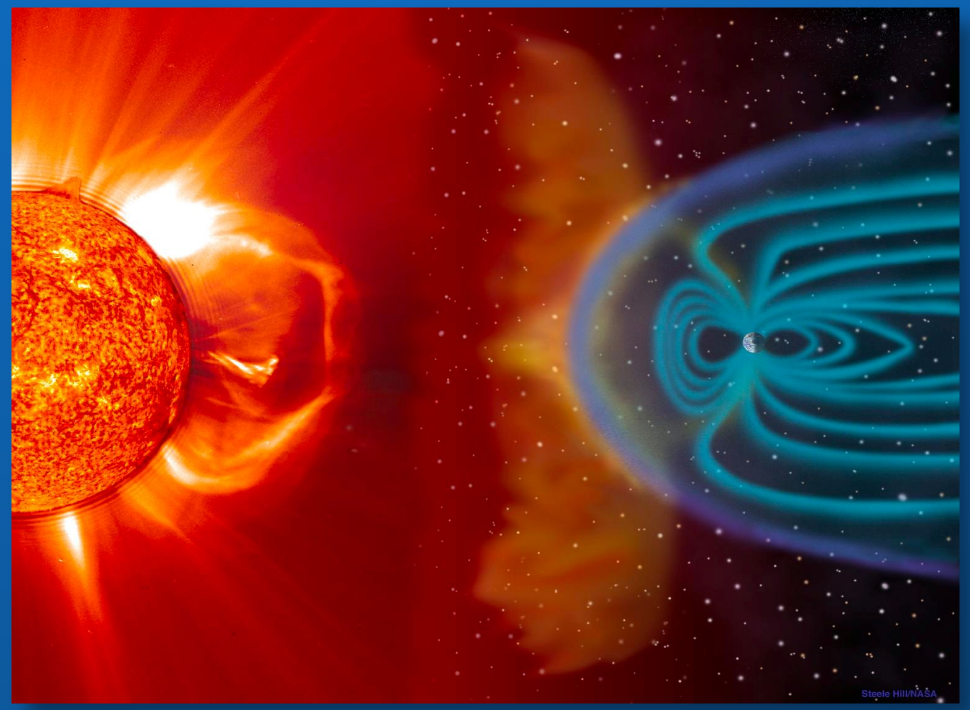












Exoplanets

SOXS and YSOs

Characterization of EXor and FUor erupting variables

Teresa Giannini (OA Roma)

collaborators

Consortium Cols:

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External Cols:

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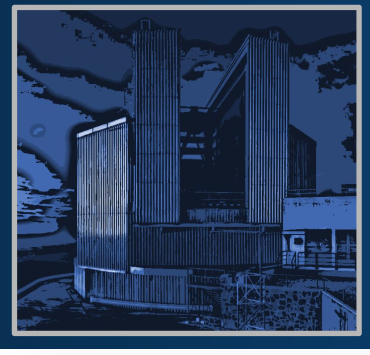
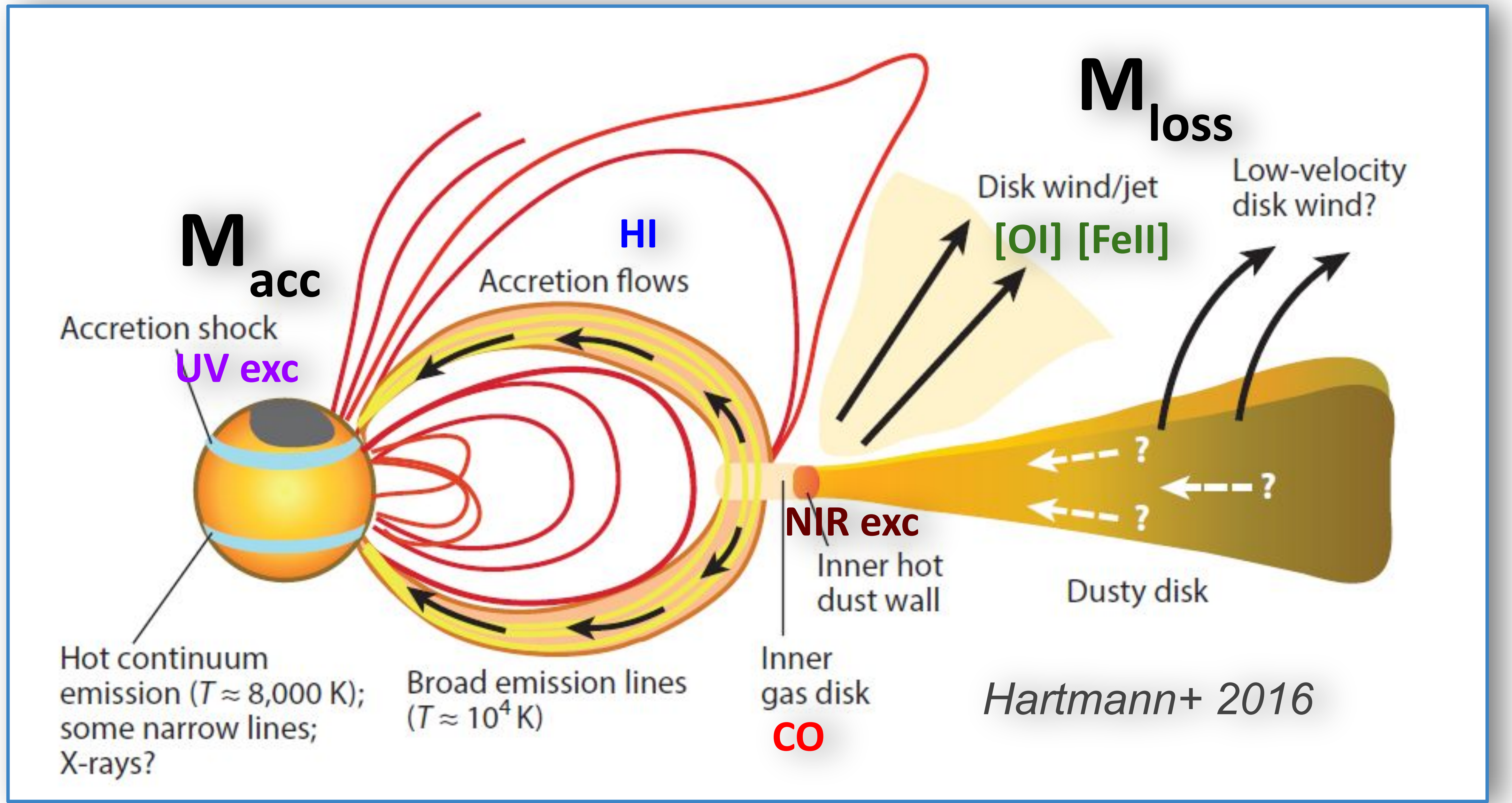


YSO UBV-VIS-NIR spectrum

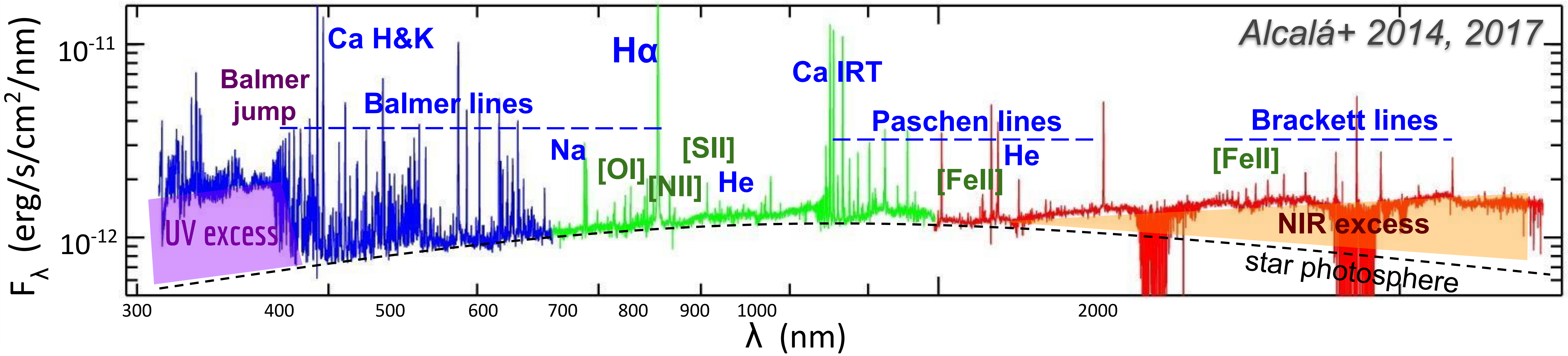


- UV-Optical continuum excess emission →*accretion shock*
- HI & other permitted lines (HeI, CaI, CaII, FeI, NaI, …)
  → *accretion columns, winds*
- Forbidden lines ([FeII], [OI], [SII], [NII], …)
  → *winds, atomic jet diagnostics*
- NIR excess
  → *inner disk*
- Photospheric absorption features
  → *spectral type, veiling, abundances, v sin i*

SOXS simultaneous UVB-NIR coverage: ideal instrument to fully characterize YSOs

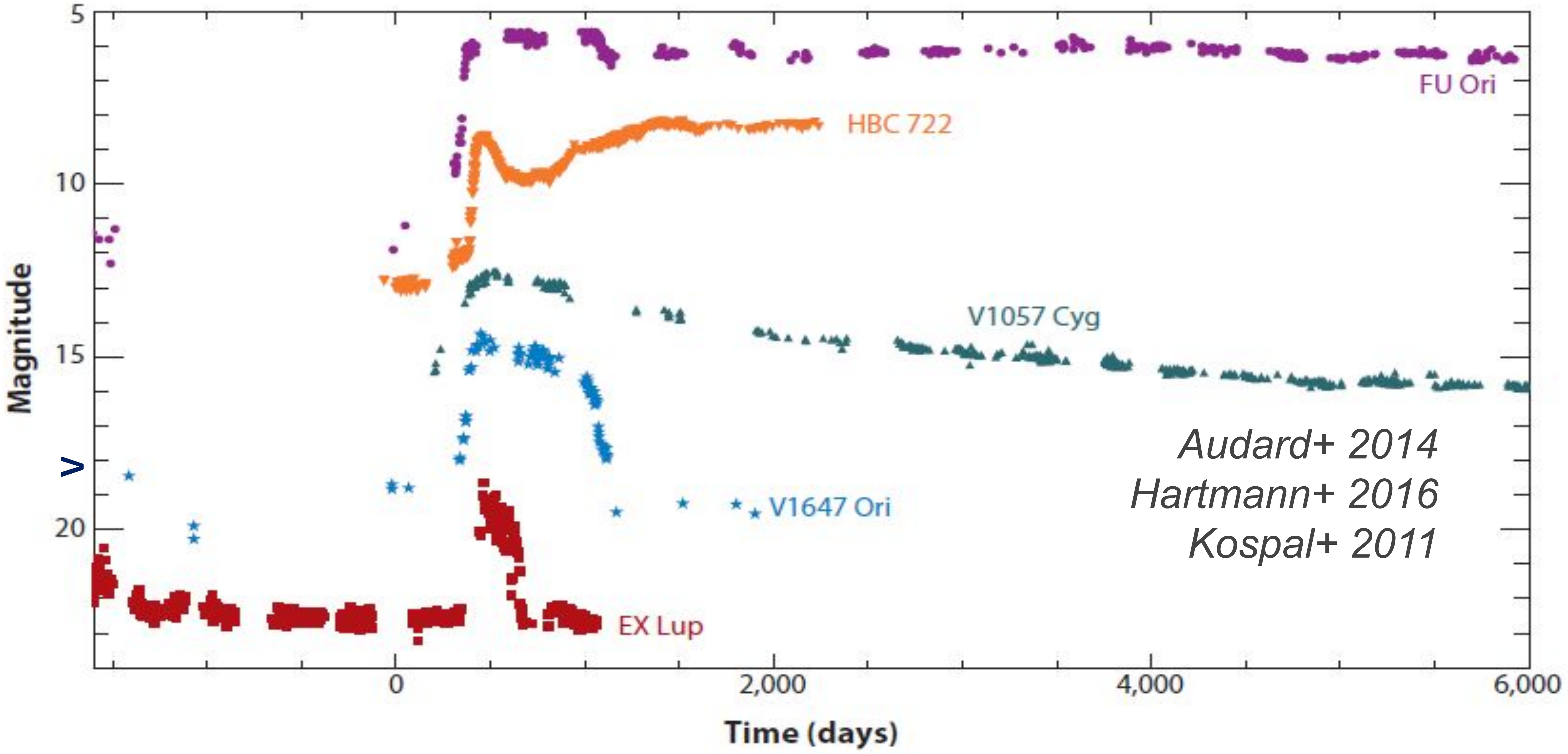
→ *star, accretion, winds/jets, inner disk*

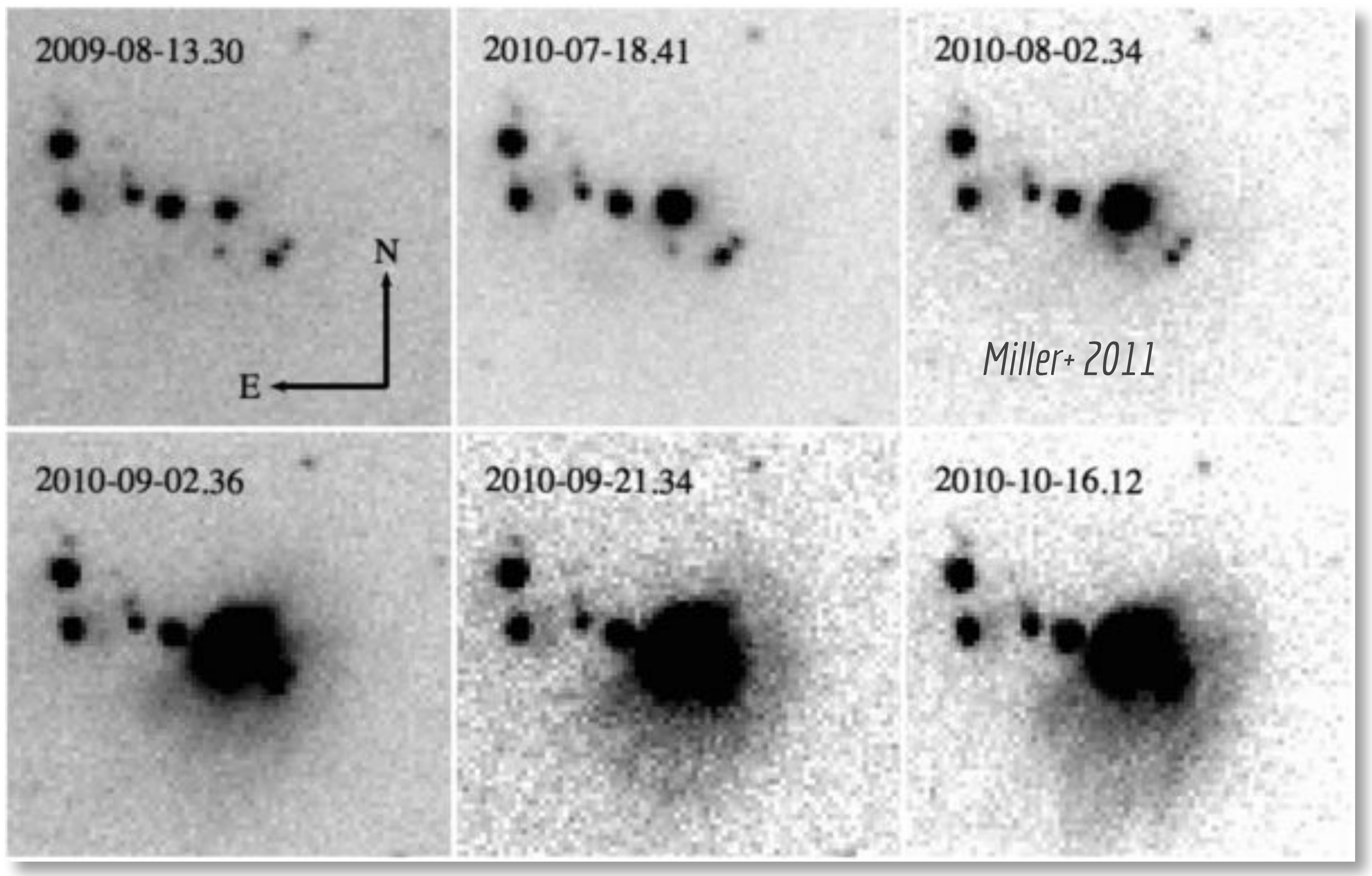
X-Shooter spectrum of RU Lup



EXors and FUors

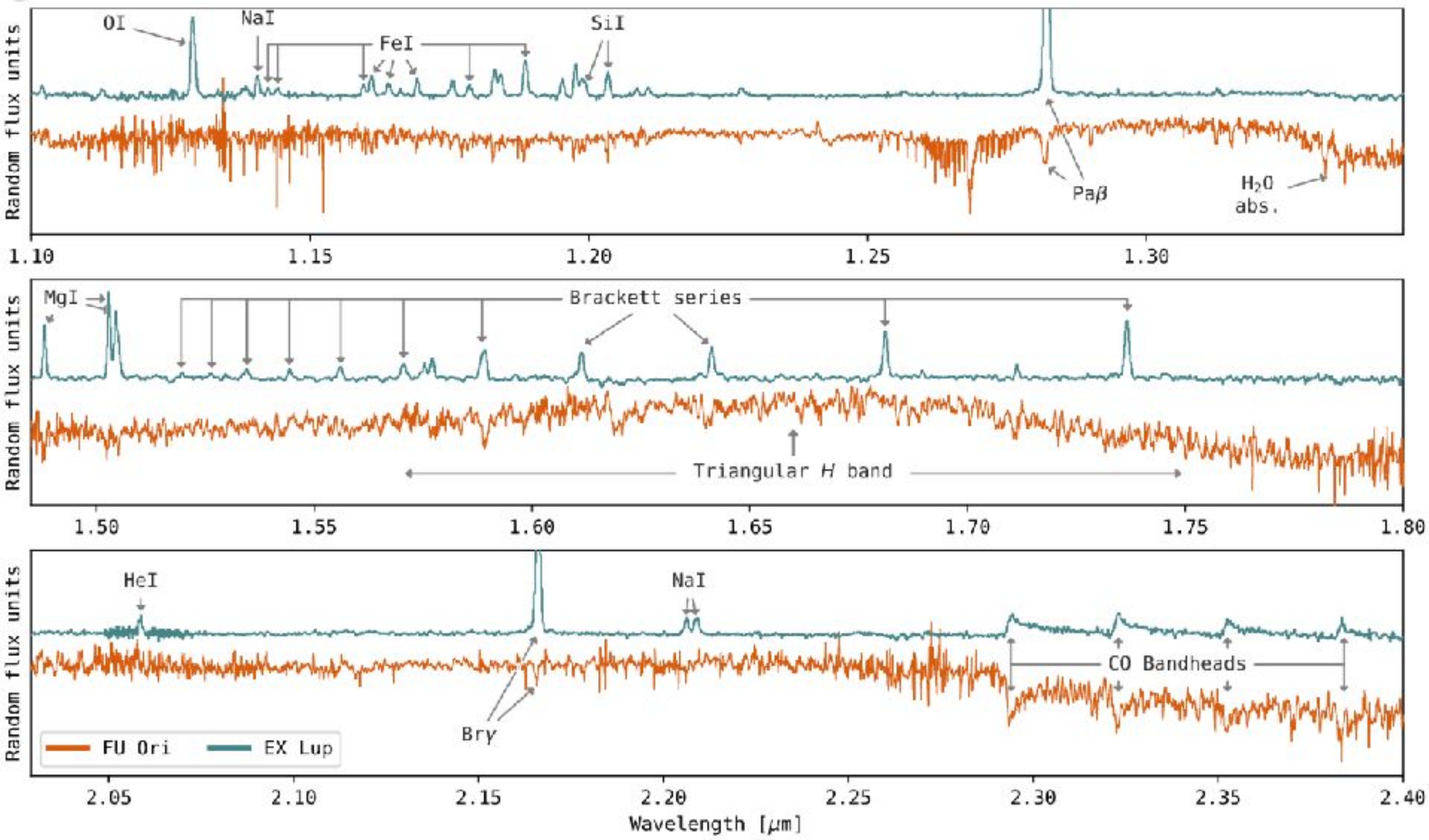
Some YSOs show recurrent accretion outbursts, classically detected in the optical: FUor and EXor events





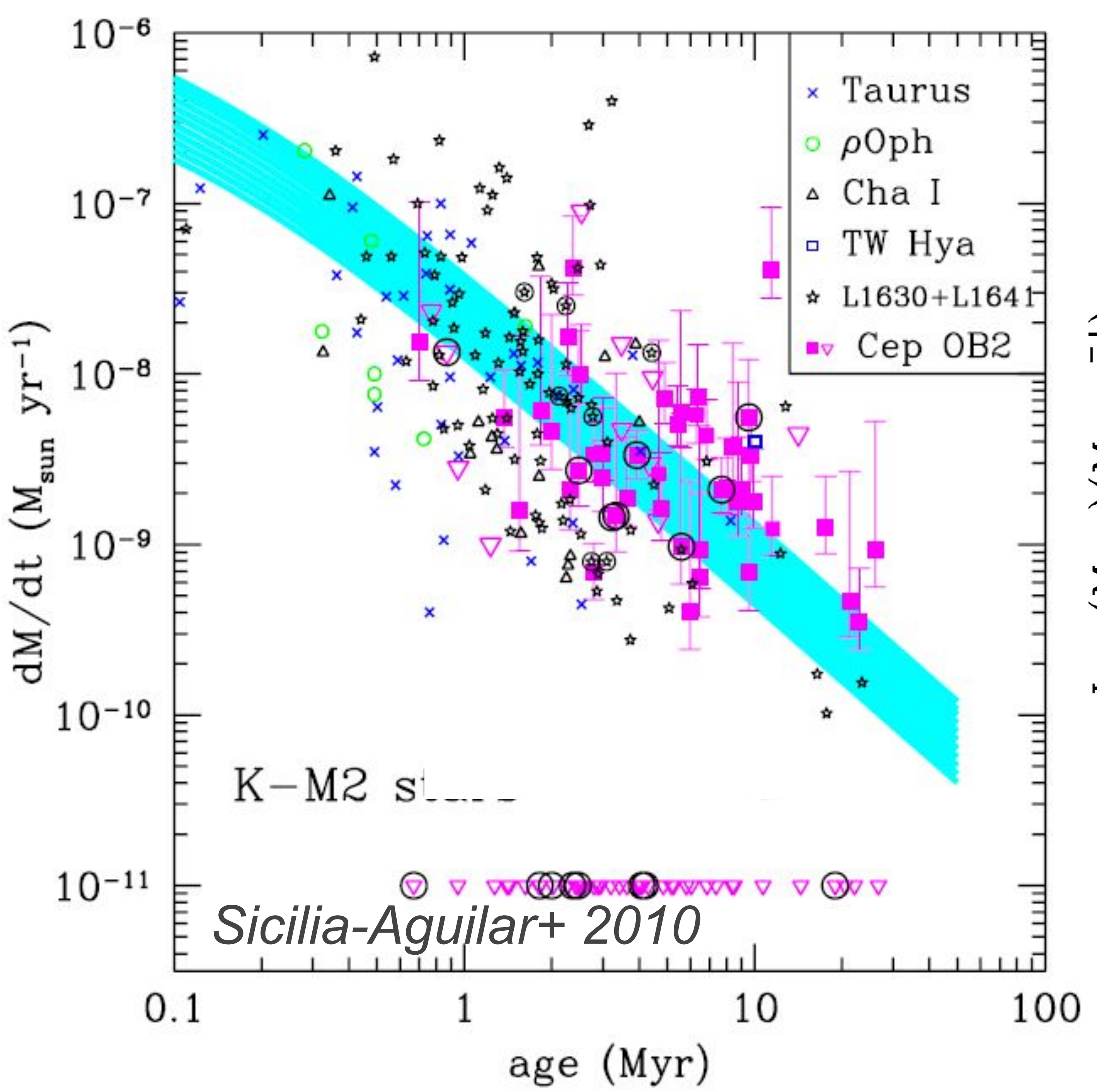
	ΔV	duration/recurrence	M_{acc}	obs
EXors	2-4 mag	months/several years	10^{-7}- 10^{-5} M_{sun}/yr	emission lines
FUors	5-7 mag	tens of years/?	10^{-5}- 10^{-4} M_{sun}/yr	absorption lines

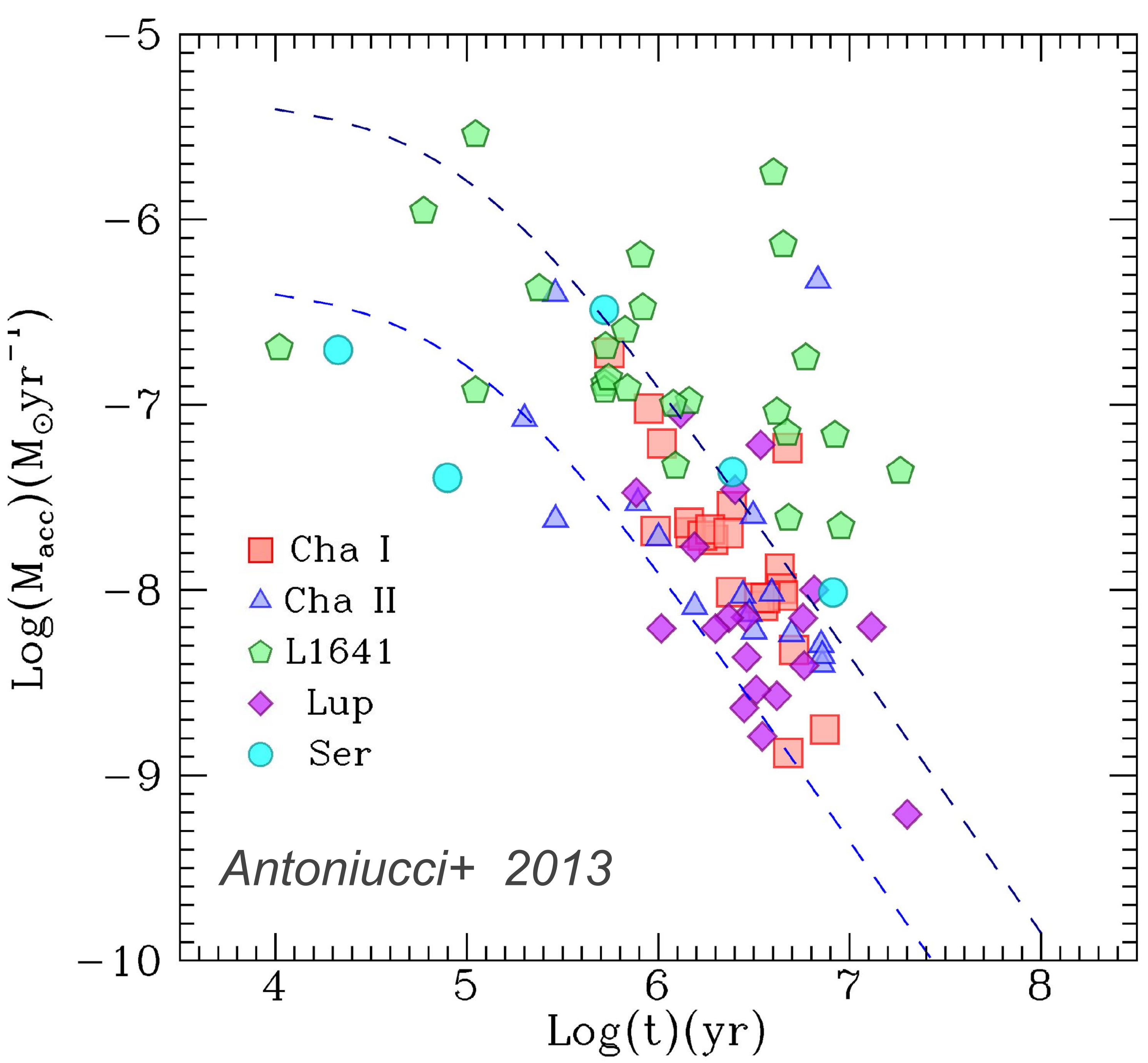
EXors vs. FUors: NIR spectral features

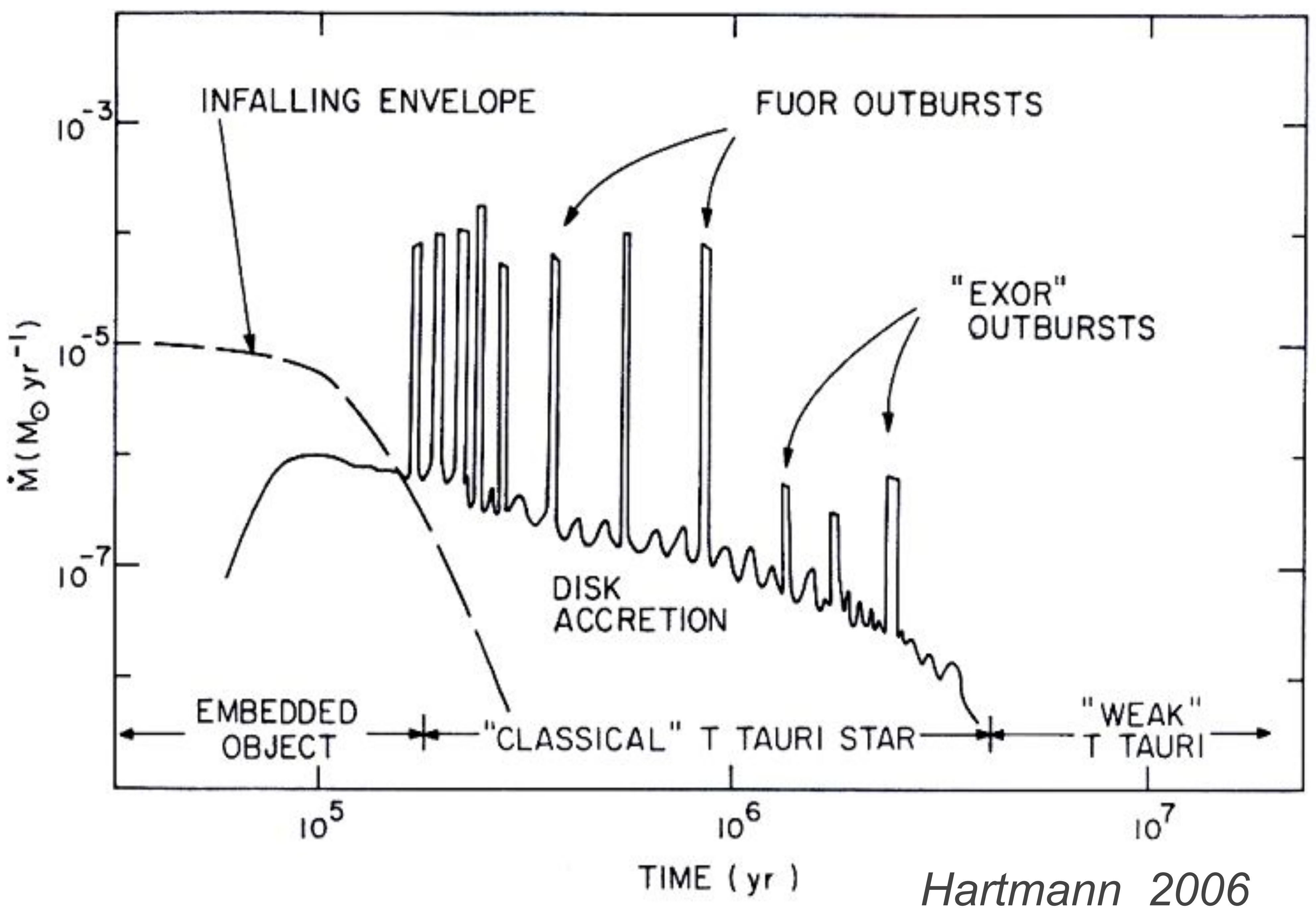


Up to now sparse observations, poor monitoring → **only few tens of such objects are genuine eruptive variables**

Accretion evolution and outbursts







- **Quasi-stationary accretion scenario: low-mass stars form in 1-10 Myr with M_{acc} that declines from $10^{-5,-4}$ to $10^{-10,-9}$ M_{sun}/yr**
- **But this scenario predicts much higher accretion luminosity than observed (luminosity problem)**
- **Assuming short outbursts of enhanced accretion like in EXors and FUors can solve the luminosity problem**

- is the FUor/EXor phase a common stage for all YSOs?
- what is the outburst trigger mechanism?
- are there outbursts even in the embedded phase?

ToO SoXS proposal

Photometric trigger by Gaia/LSST

1. Mag variation alert (e.g. Δmag > 2)
2. Location in a SFR or (embedded) cluster
3. SED typical of YSO (rising with λ)
4. Lightcurve (and colours)

→ **candidate eruptive YSOs**

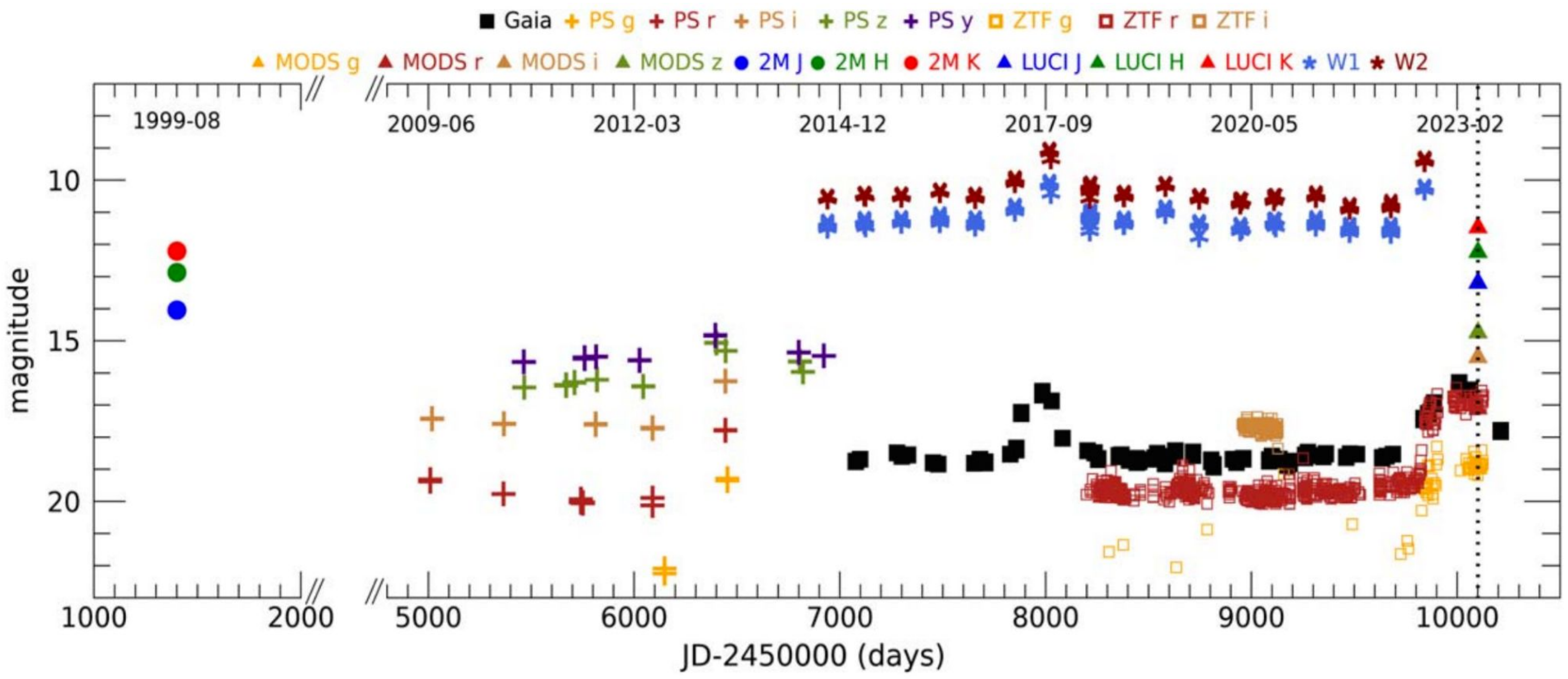
SoXS

1. examine spectral features (EXor/FUor/New)
2. derive parameters (star, M_{acc}, M_{loss})

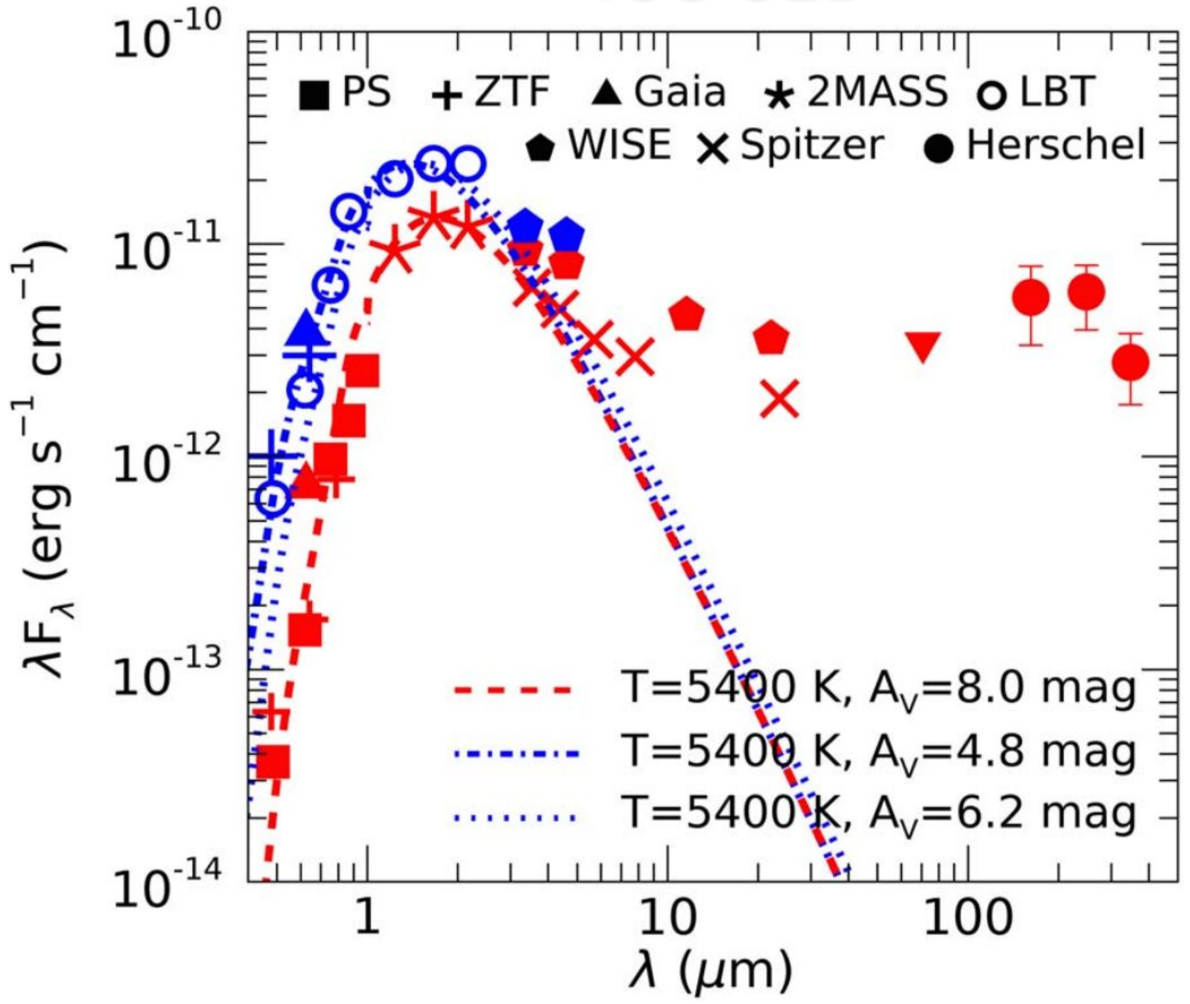
→ **confirmed outbursting YSOs**

- **Expected triggers : 30 objects per year**
- **Monitoring period of 6 months (4 observations)**
- **130h of telescope time per year / ~ 16 nights per year**

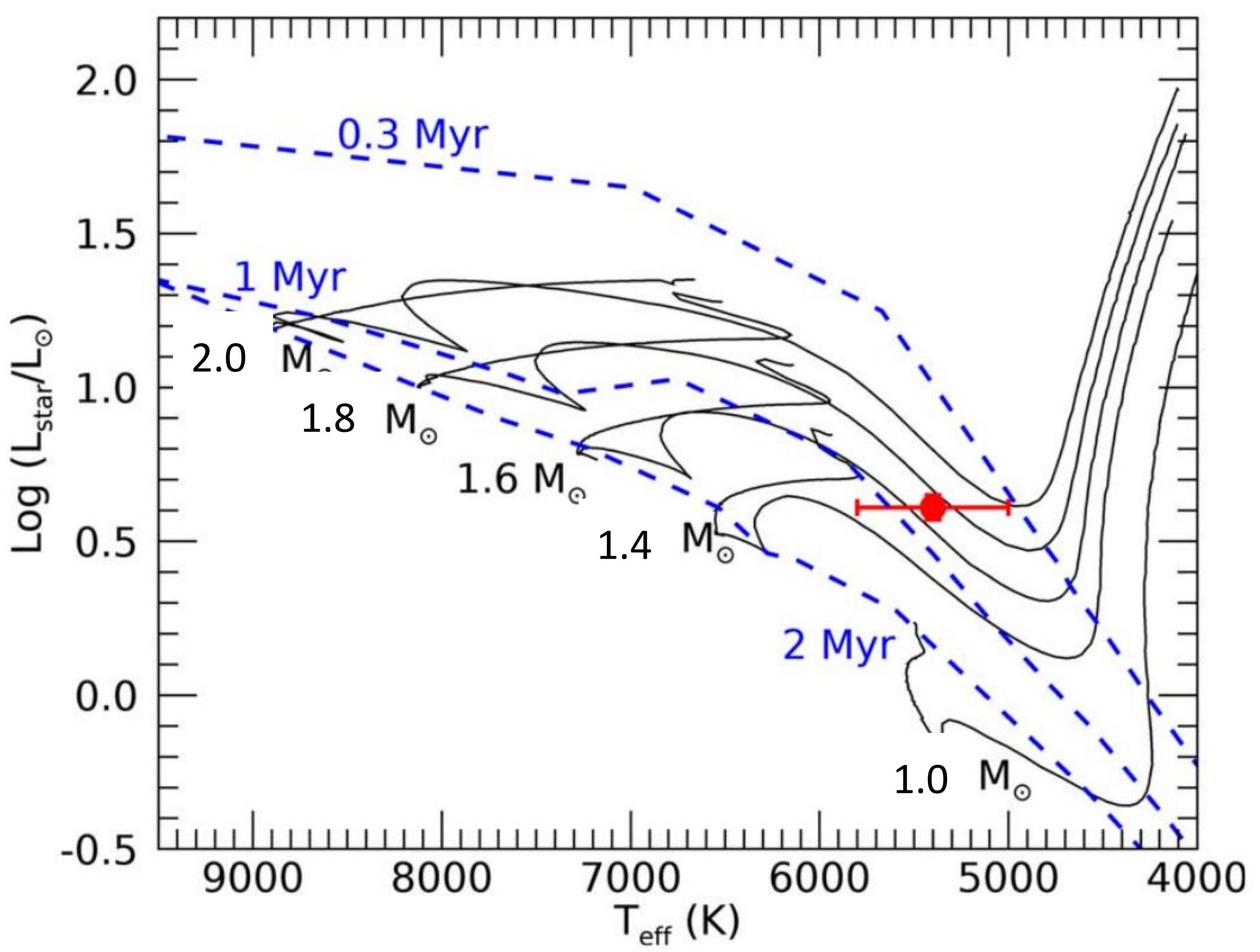
Example Gaia alert: EXor Gaia23bab (Giannini+2024)



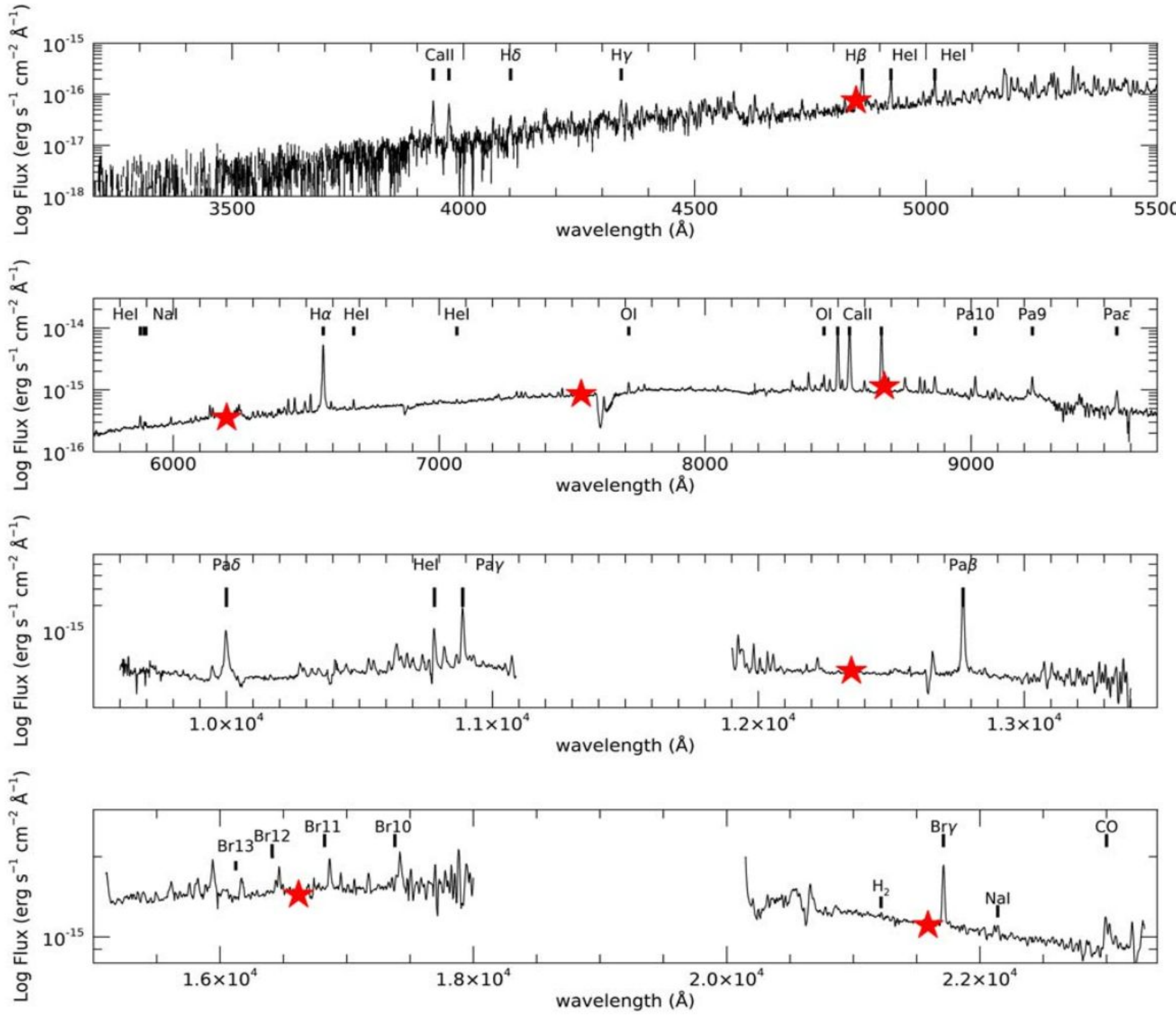
YSO SED

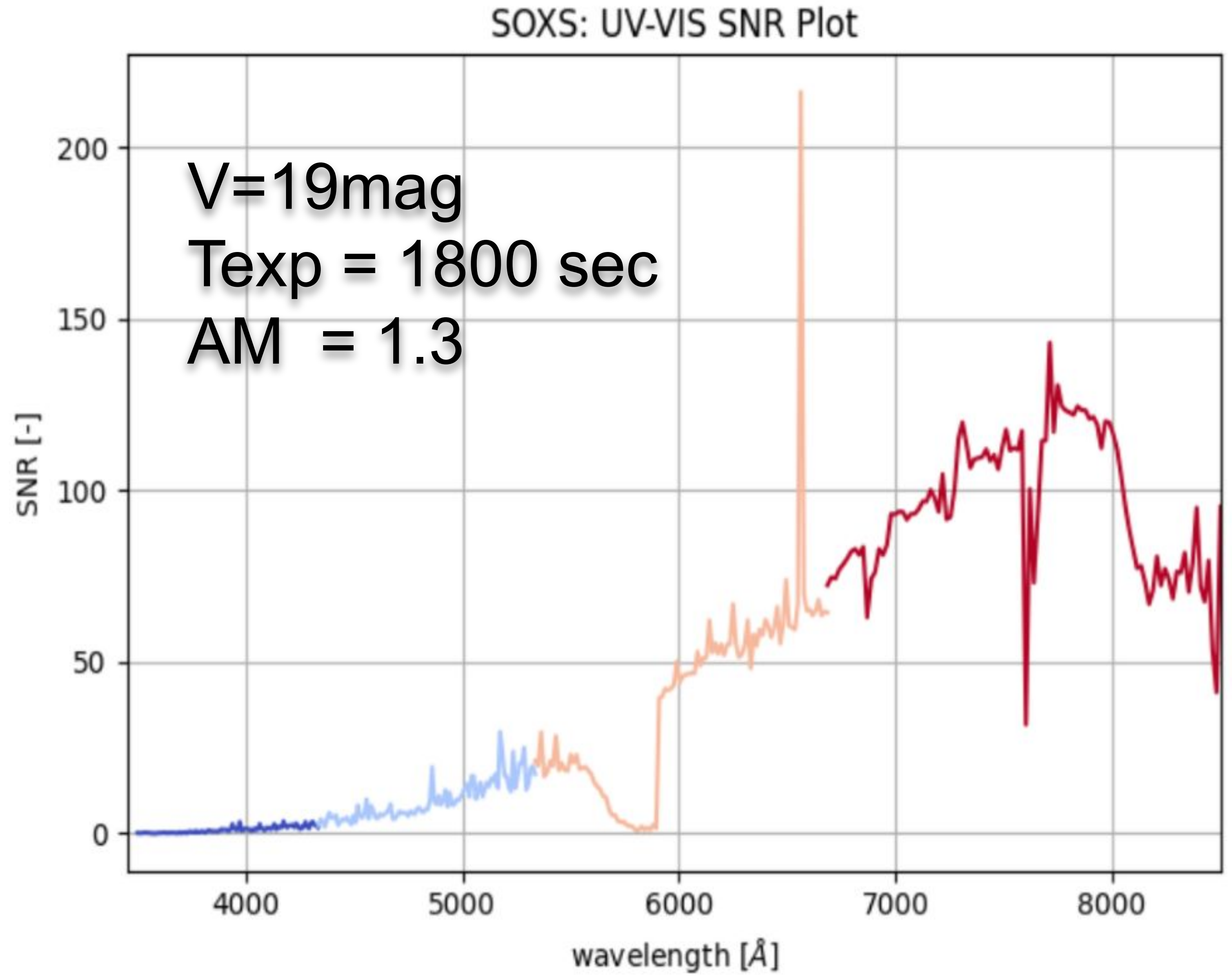


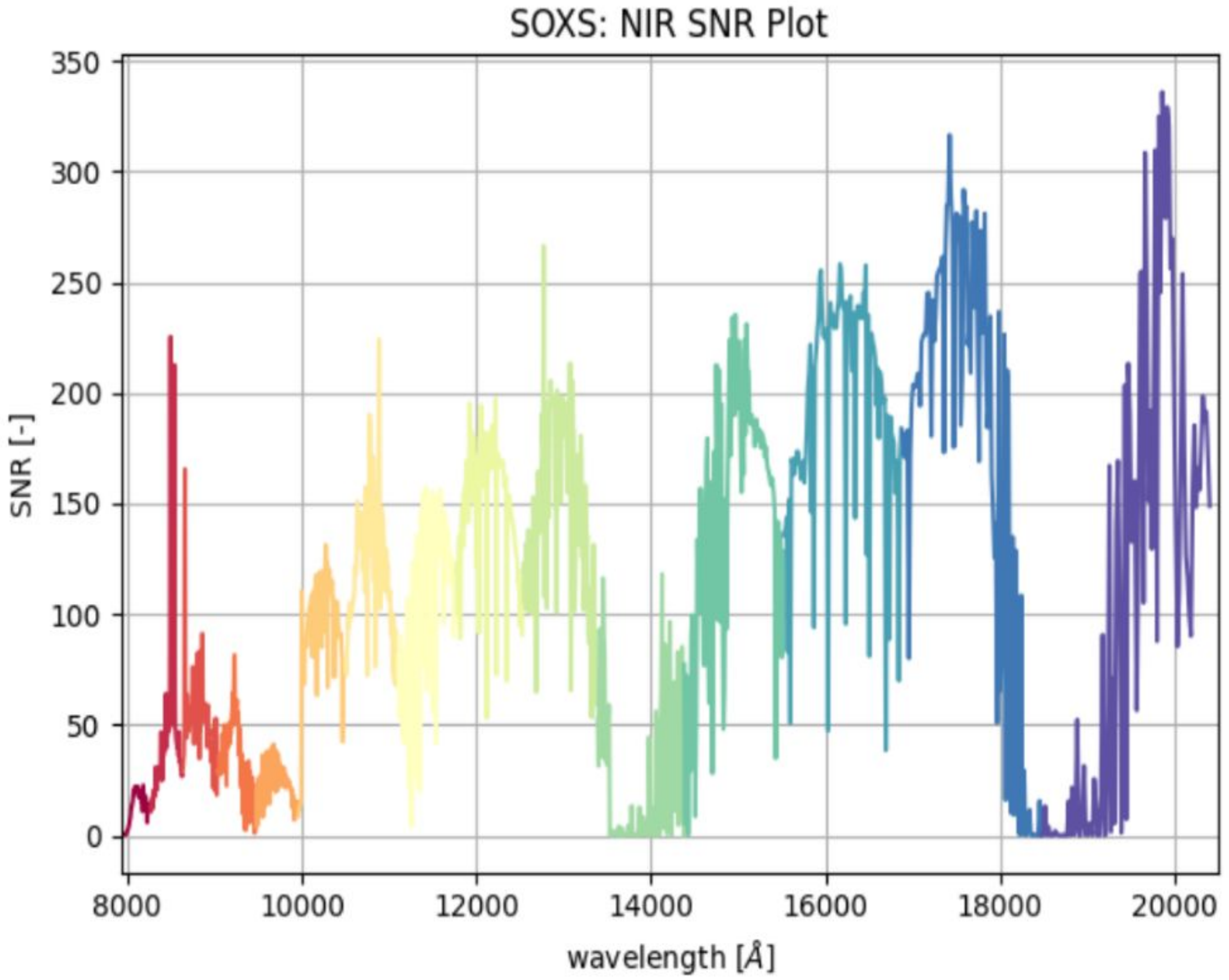
M~1.6Msun ; t~1Myr



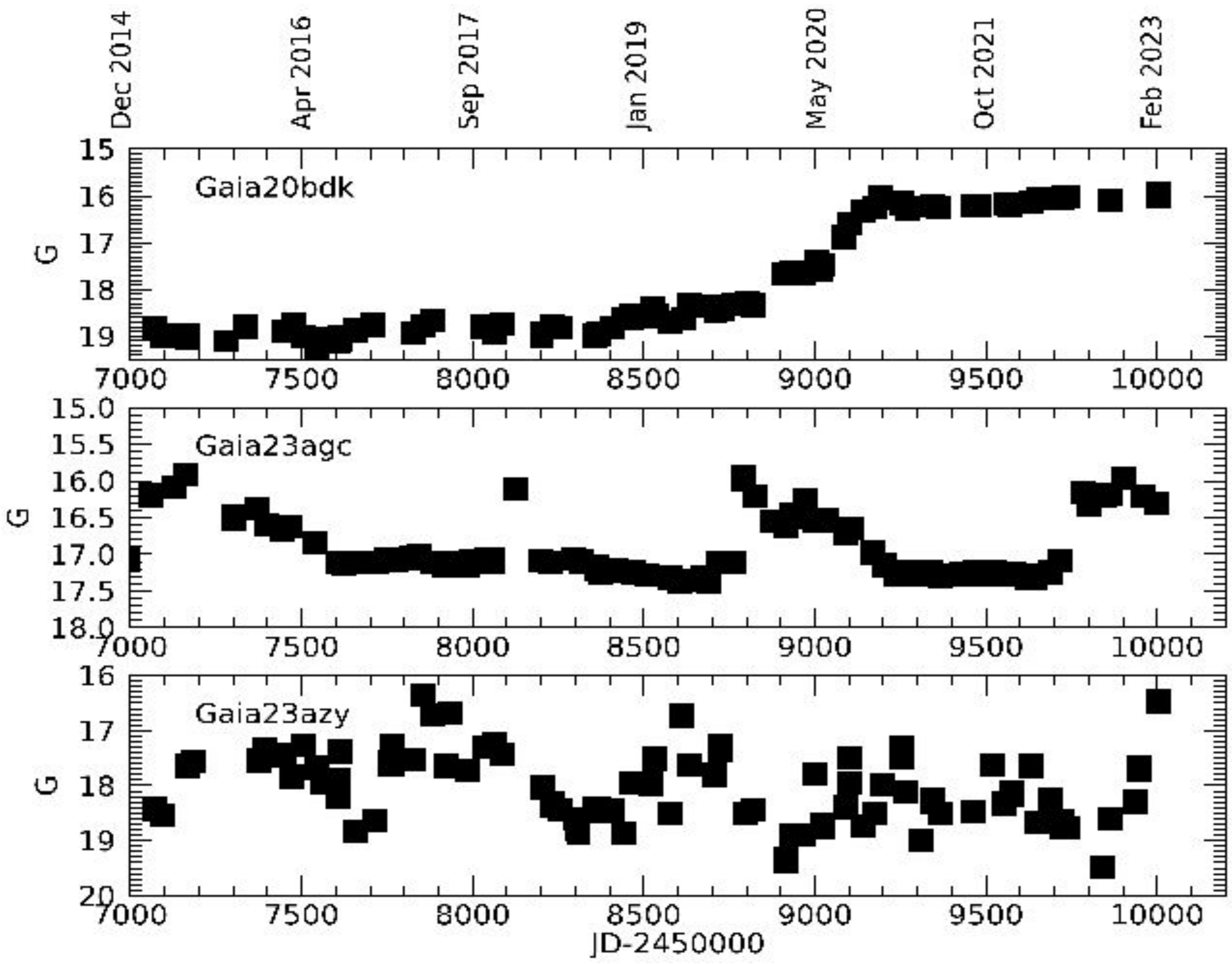
LBT MODS-LUCI spectrum







ToO SoXS proposal : triggering light curves



FUor

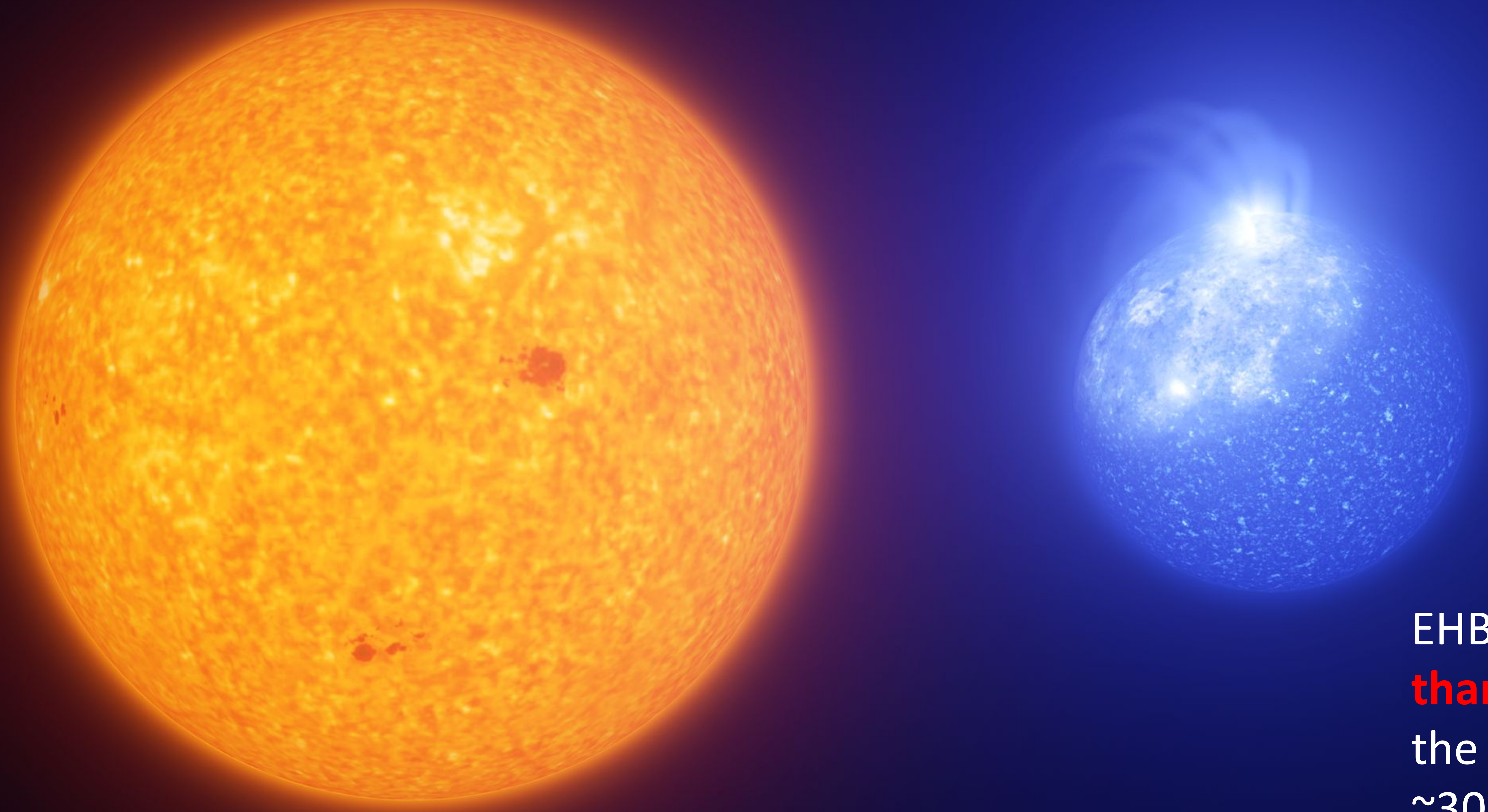
EXor

New class ?

SOXS characterization of EHB Padua variable stars in globular clusters

S. Zaggia, Y. Momany,L. Monaco, M. Gullieuszik, I. Saviane

Momany et al. (2020, Nature Astronomy, 4, 1091) have recently demonstrated that, at the end of their life, low-mass (like our Sun) suffer “A plague of huge magnetic Spots” during the so-called Extreme Horizontal Branch phase. Thus, a glimpse of the future evolution of our Sun. Stellar Spots trace their Magnetic activity.



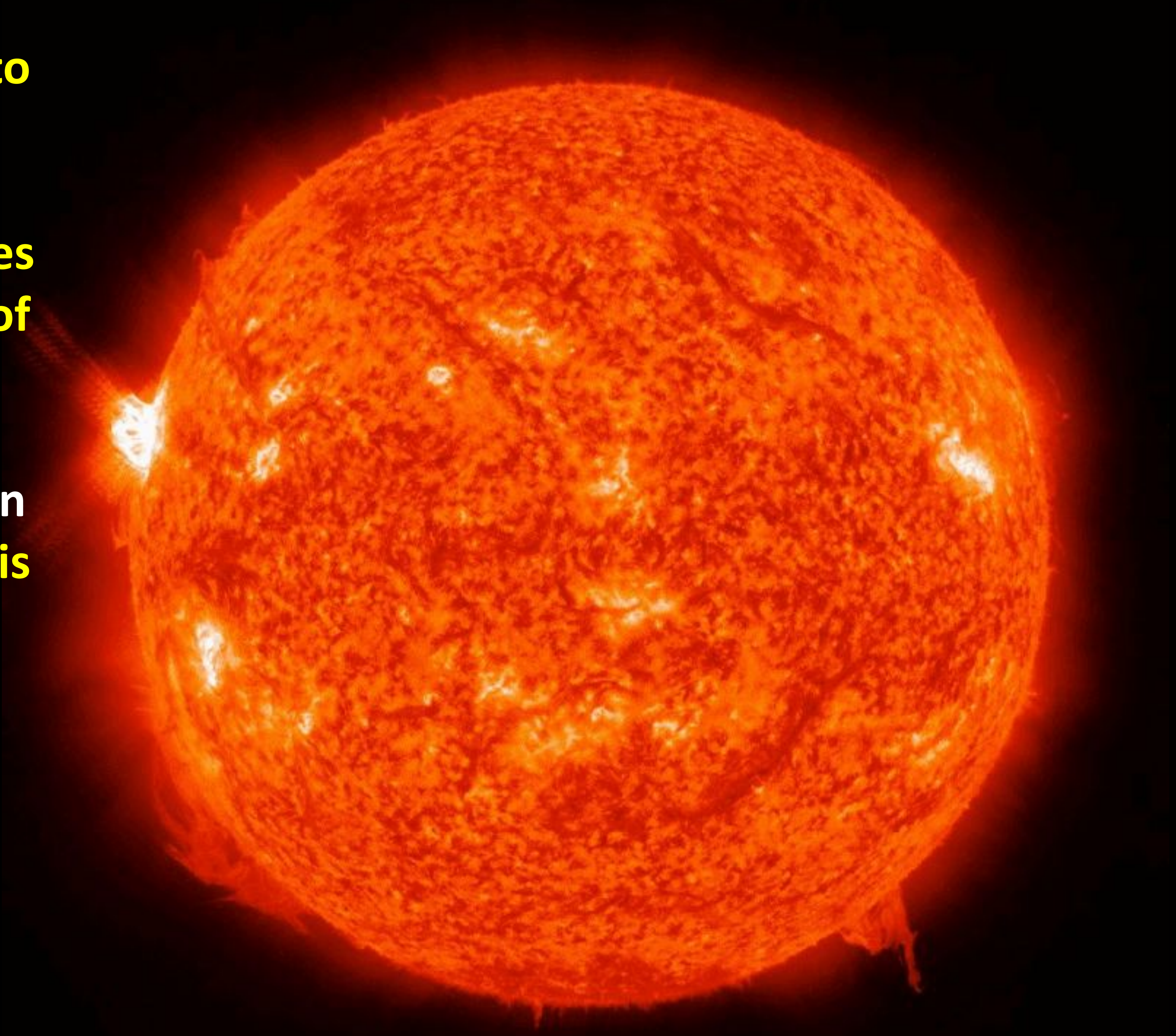
The Sun is relatively cool (5778 K) & moderately old (4.6 Billion years) showing dark **spots** (typically Earth-sized).

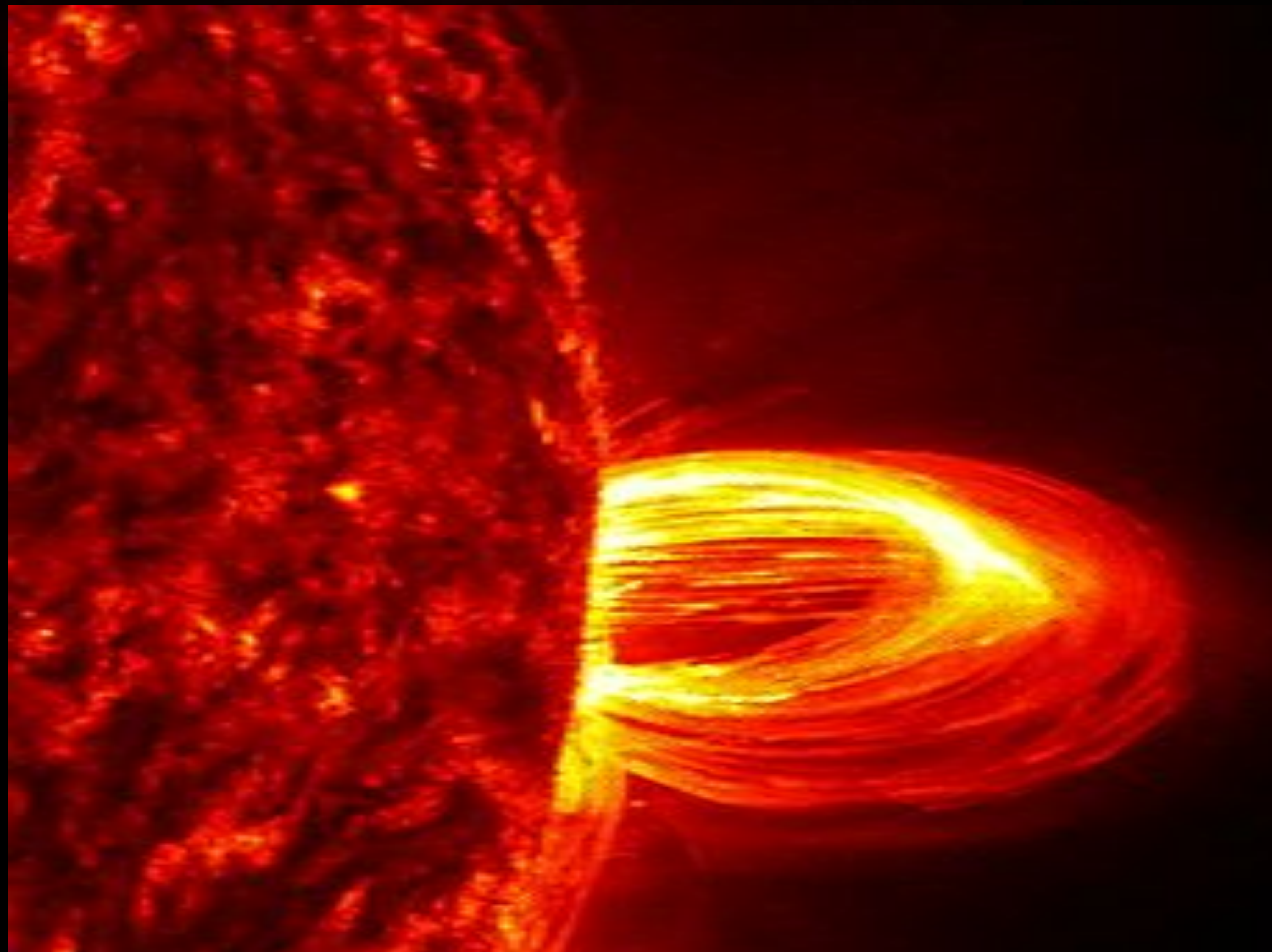
EHB stars are **twice older and 5-6 times hotter than our Sun.** Close to their death, EHBs have half the Sun’s radius but the spots are **bright** and are ~3000 times larger (covering 25% of their surface). Thereby EHBs show stronger magnetic activity.

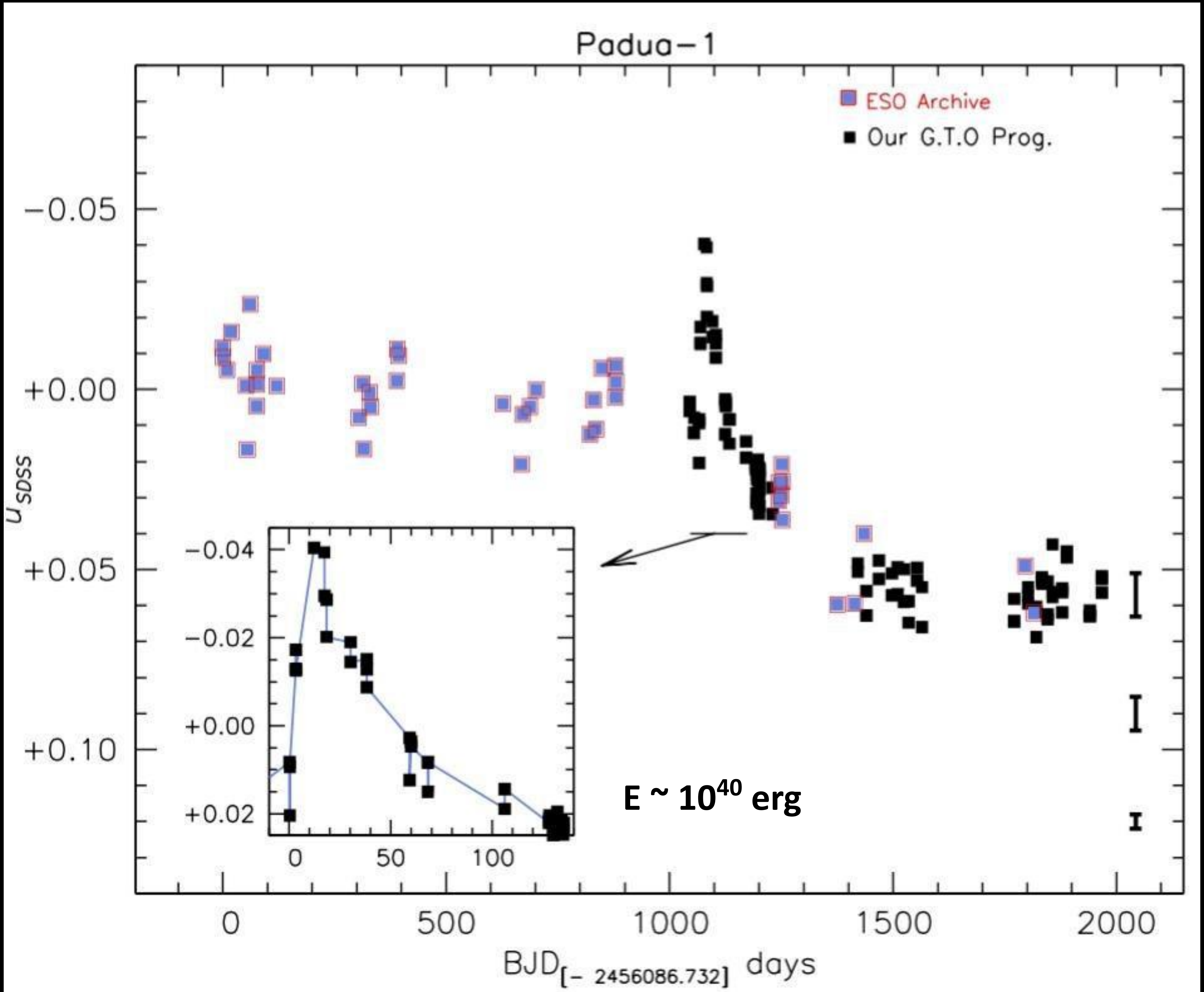
Having detected Stellar-Spots, especially giant ones, it is inevitable to detect the eruptive “face” of magnetic fields.

Solar Flares: sudden and unpredictable ejections of plasma & particles into outer space. Violent release of energy (10^{32} erg) in the vicinity of sunspots, lasting up to few hours.

We have detected two superflare events in EHB stars that are 10 milion times more energetic than typical solar flares, lasting for ~80 days. This is a new class of transient objects (we call Padua variables).







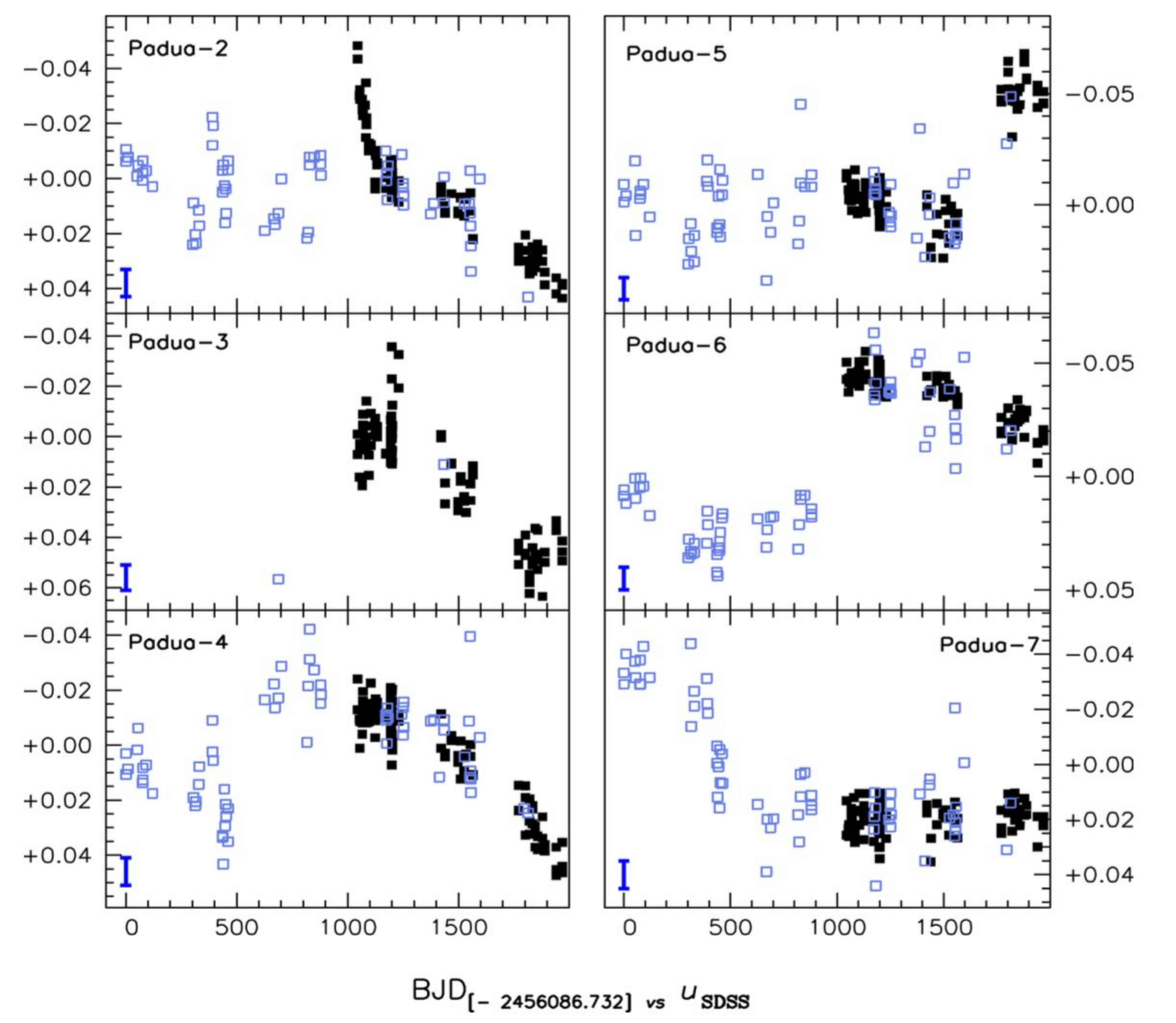
Six years monitoring of ~70 EHBs stars in the Globular Cluster NGC6752 allowed us to detect a full superflare event.

Padua-1 displayed almost constant luminosity for ~years, then had a mini-burst (~0.05 mag) that yet traces a violent release of energy (10^{40} erg) in these hot stars. Following the mini-burst, Padua-1 faded slightly, and returned to display a constant luminosity.

EHBs in Globular Clusters are certainly NOT binary systems, adding more interest to how they trigger the superflare events.

In particular, the long-duration of these mini but highly energetic bursts are likely to trace a rotating magnetosphere disk that outshines the star during the superflare event.

There are ~20 Globular Clusters in the Southern-hemisphere which posses ~50-100 EHB stars, each. We expect to detect at the very least 1 superflare event, per year, per cluster. However, continuous monitoring is mandatory (looking forward for the LSST).



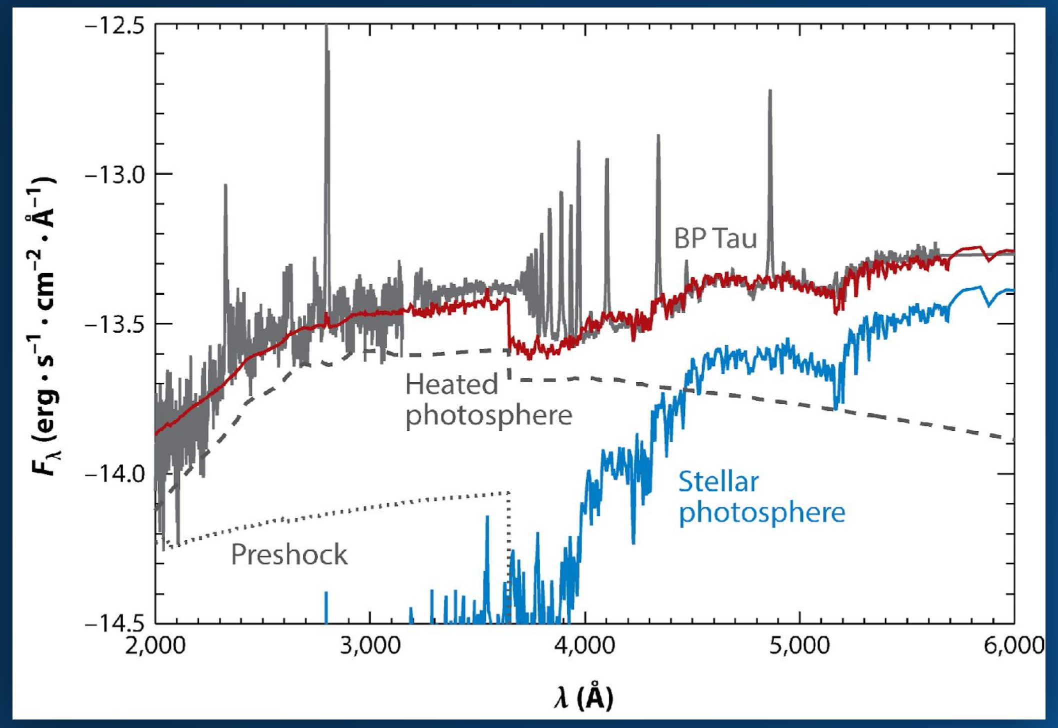
We have missed the rising phase of the Padua-2 superflare event. Hence, continuous monitoring of these extremely peculiar EHB stars is important to trigger the ToO events.

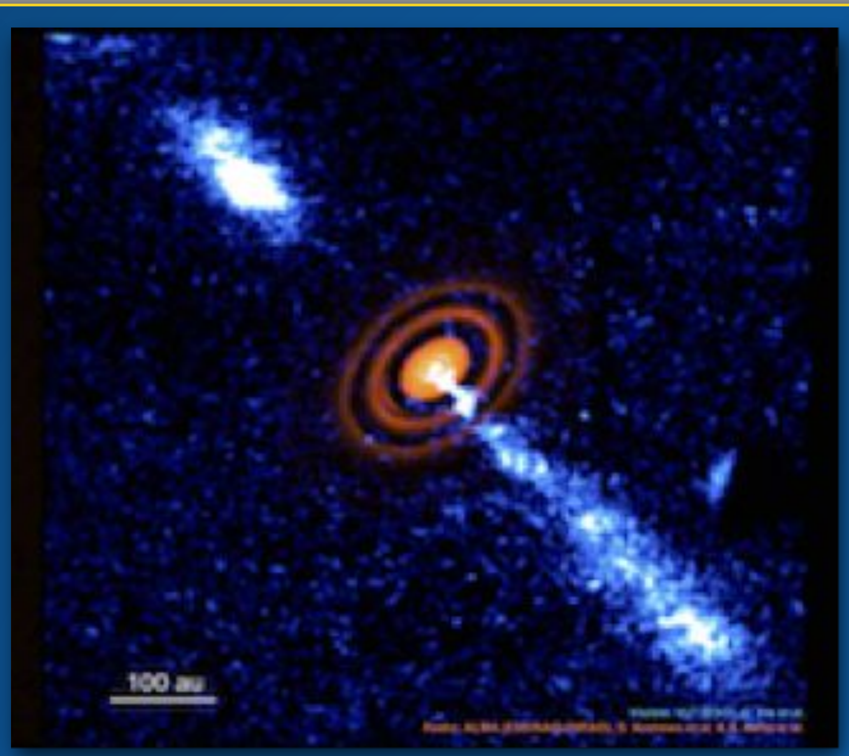
Thanks to having detected/sampled the full mini-burst in Padua-1, we know that the luminosity "jumps" of these EHB stars (occurring on timescales of few hundred days) are preceded by a mini-burst (as can be seen also in Padua-2).

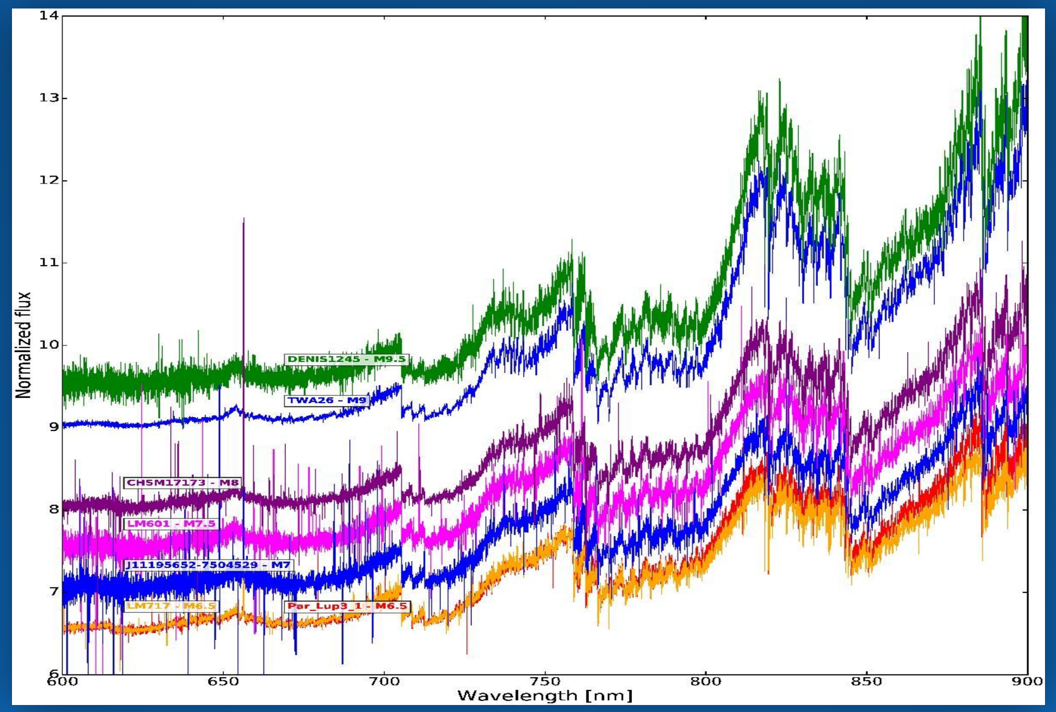
IN CONCLUSION

- RATE: We expect 1 event per year/per cluster.
- TRIGGERING: via active photometric monitoring either via VST on-going GTO programme or via LSST when available.
- NUMBERS: Active monitoring of the globular clusters with extended HB (30% of the ~100 visible from the South) will allow to have ~30 events per year or 15 per semester.
- TIME: faintest EHB have magnitude V~20, brightest V~16. With 1h exposure we will be able to get a S/N~25 and S/N~175 respectively, in the UV/VIS part considering the high Teff~20000 K of these stars. After triggering we will need at least 1 spectrum per day first week and 1 every 3 days per 3 weeks for a total of 14h per event
- We will select only the more promising and the best and brightest events. In total we may expect to request 30 hours per semester.

SOXS WG2

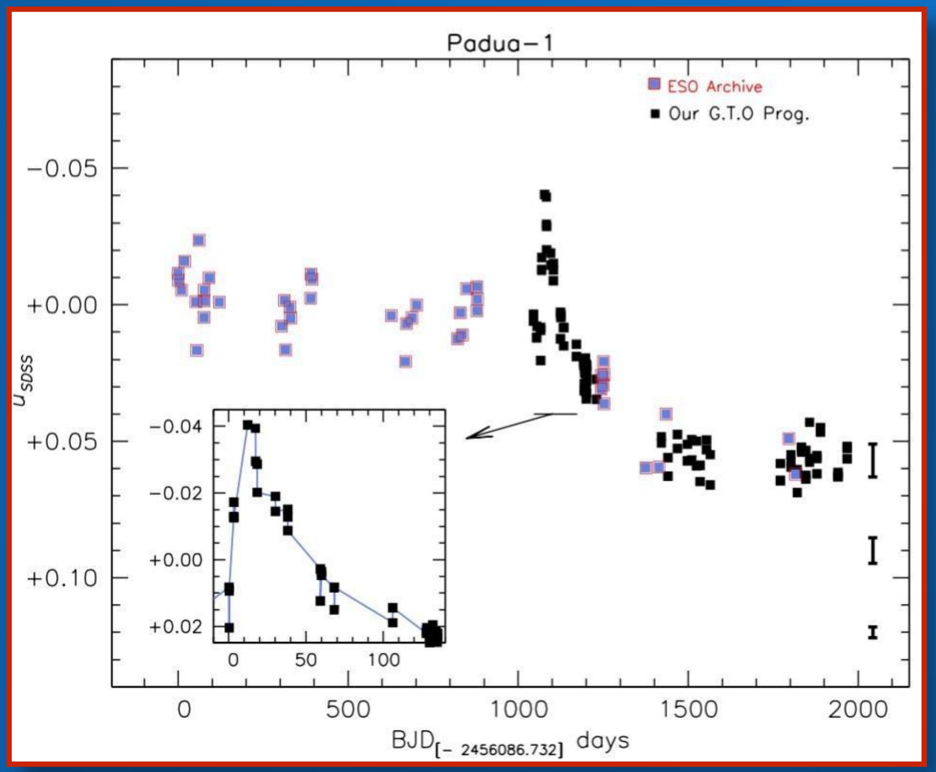


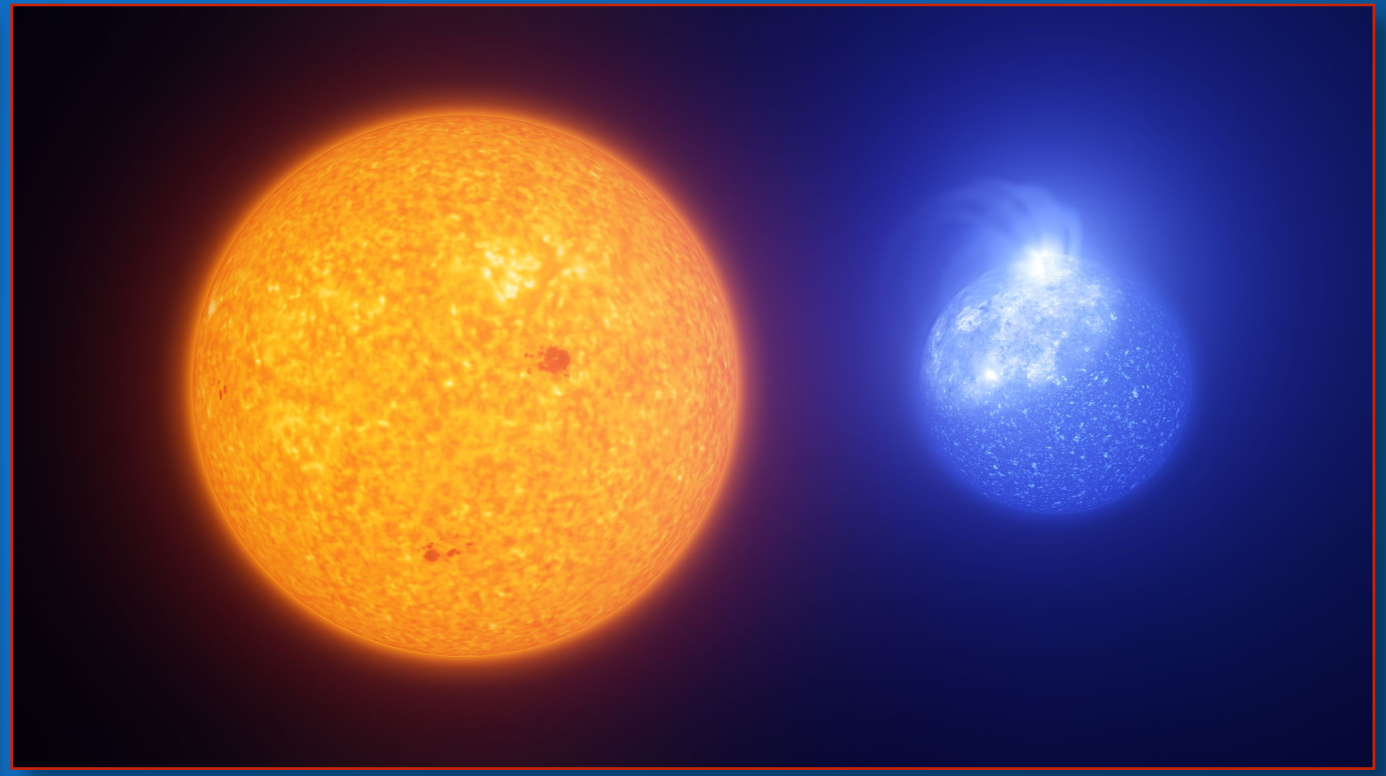


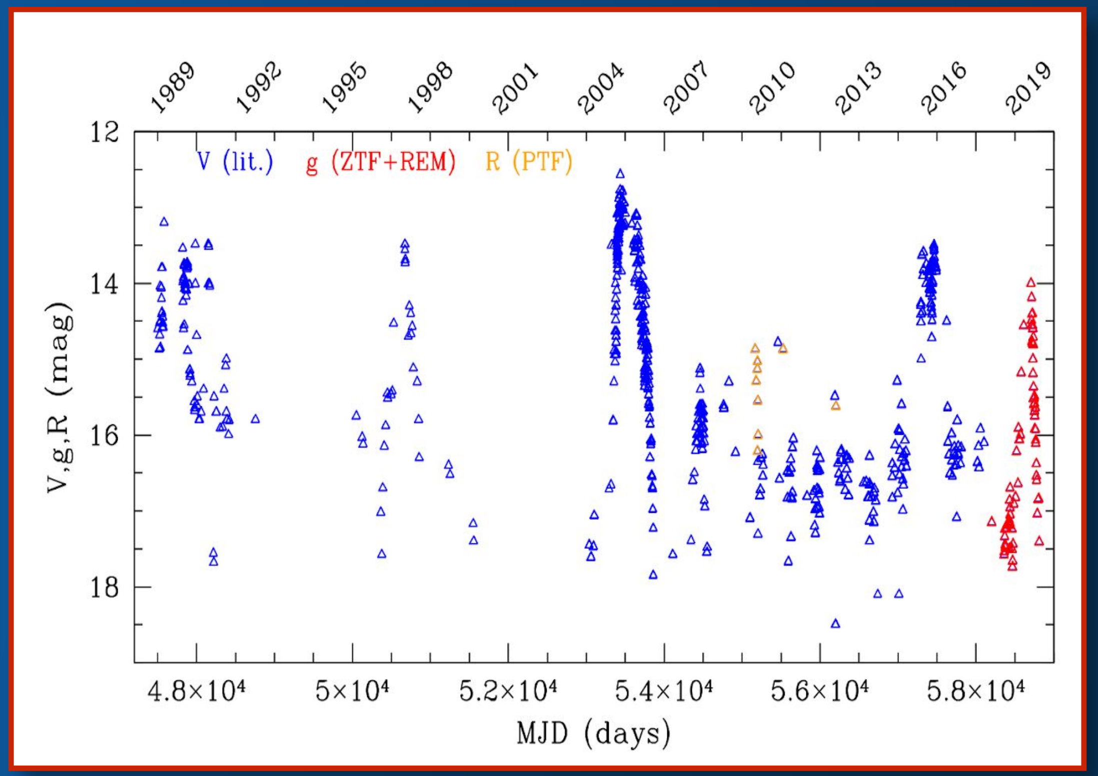


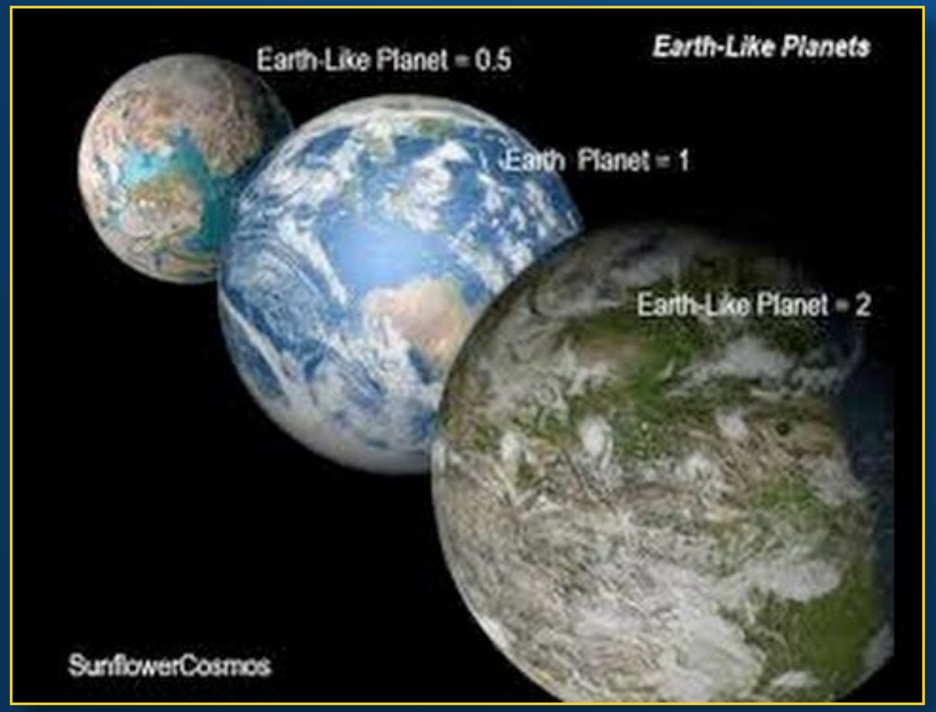
Eruptive YSOs
130 h/yr

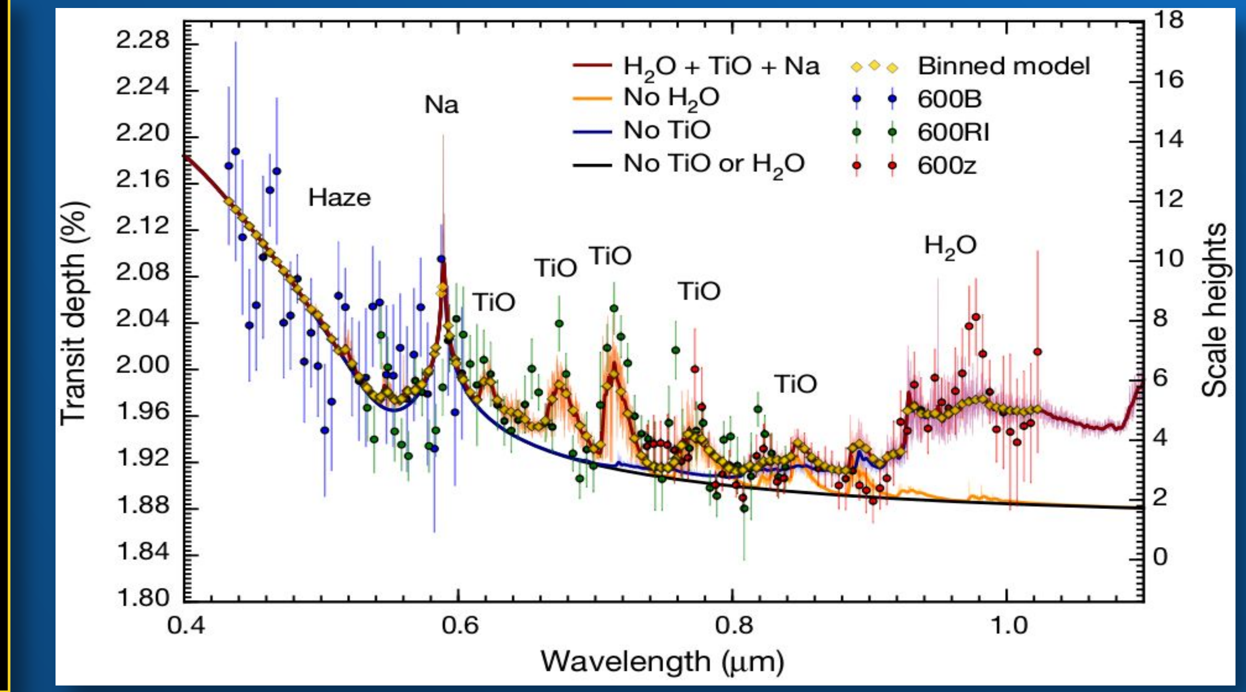
EHB stars
60 h/yr

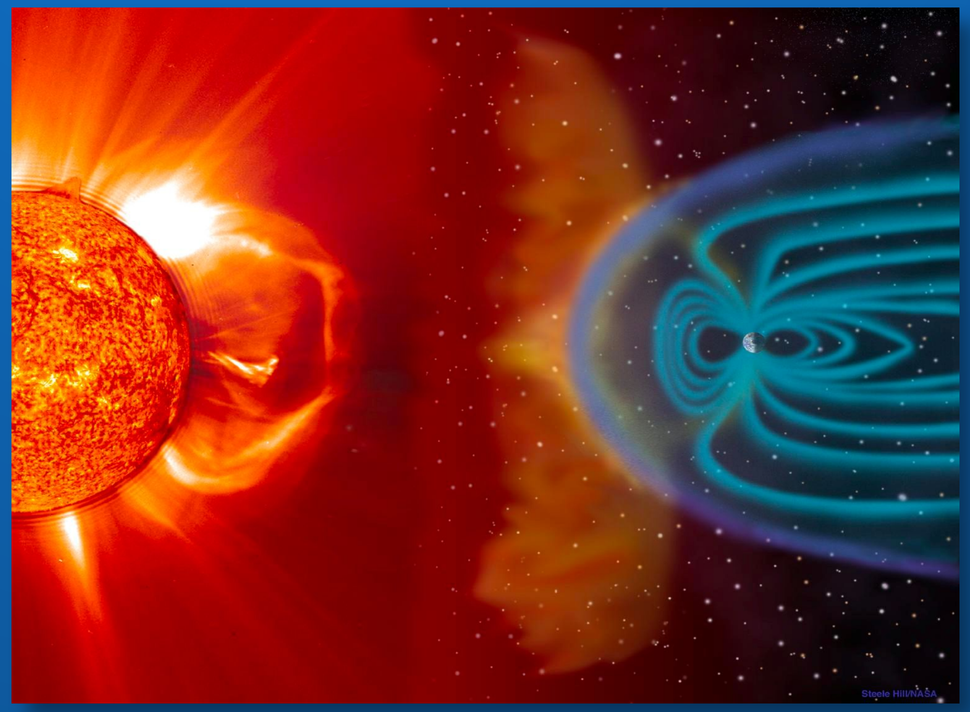






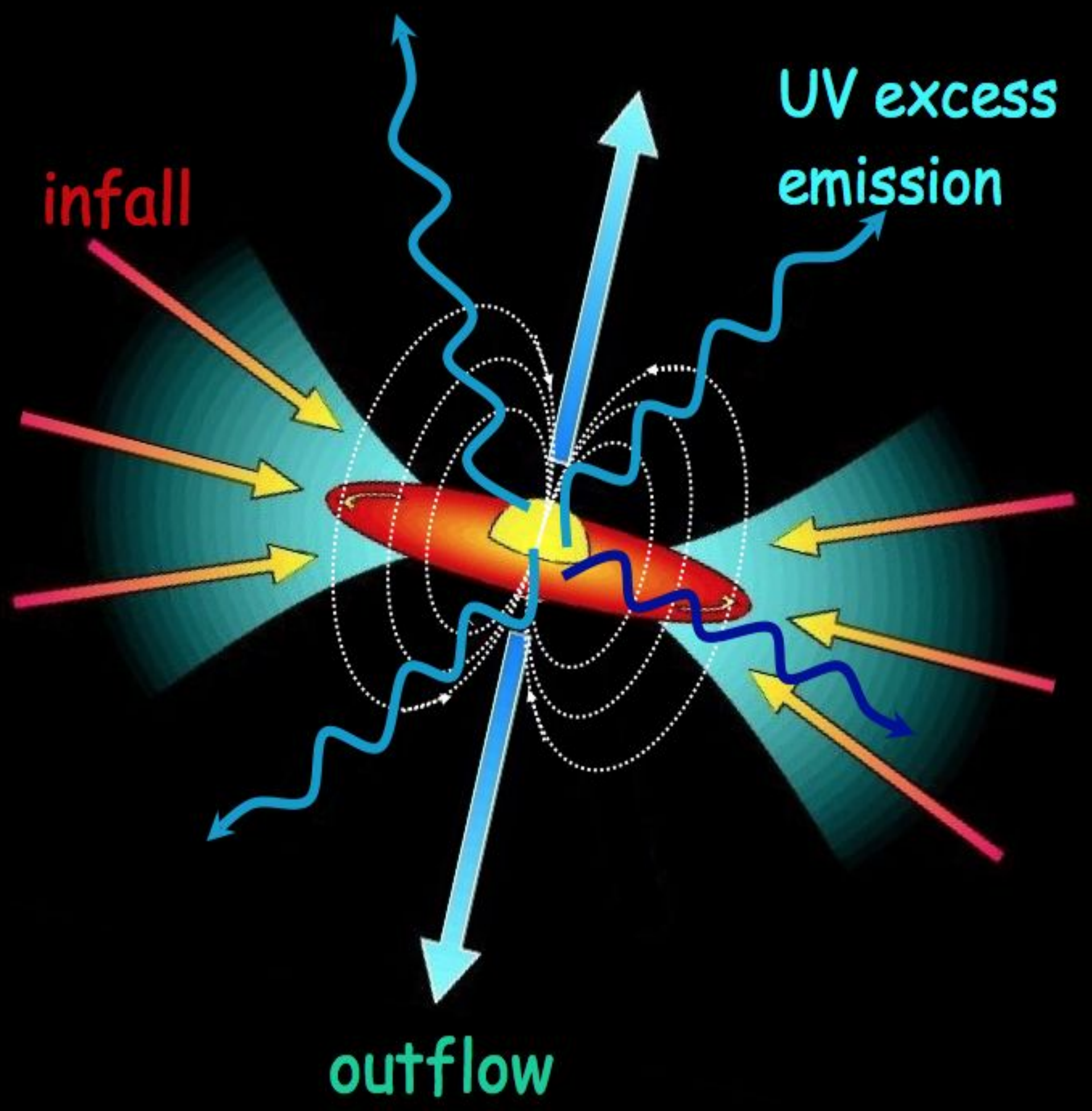






Exoplanets
Isabella…

Accretion luminosity: Lacc

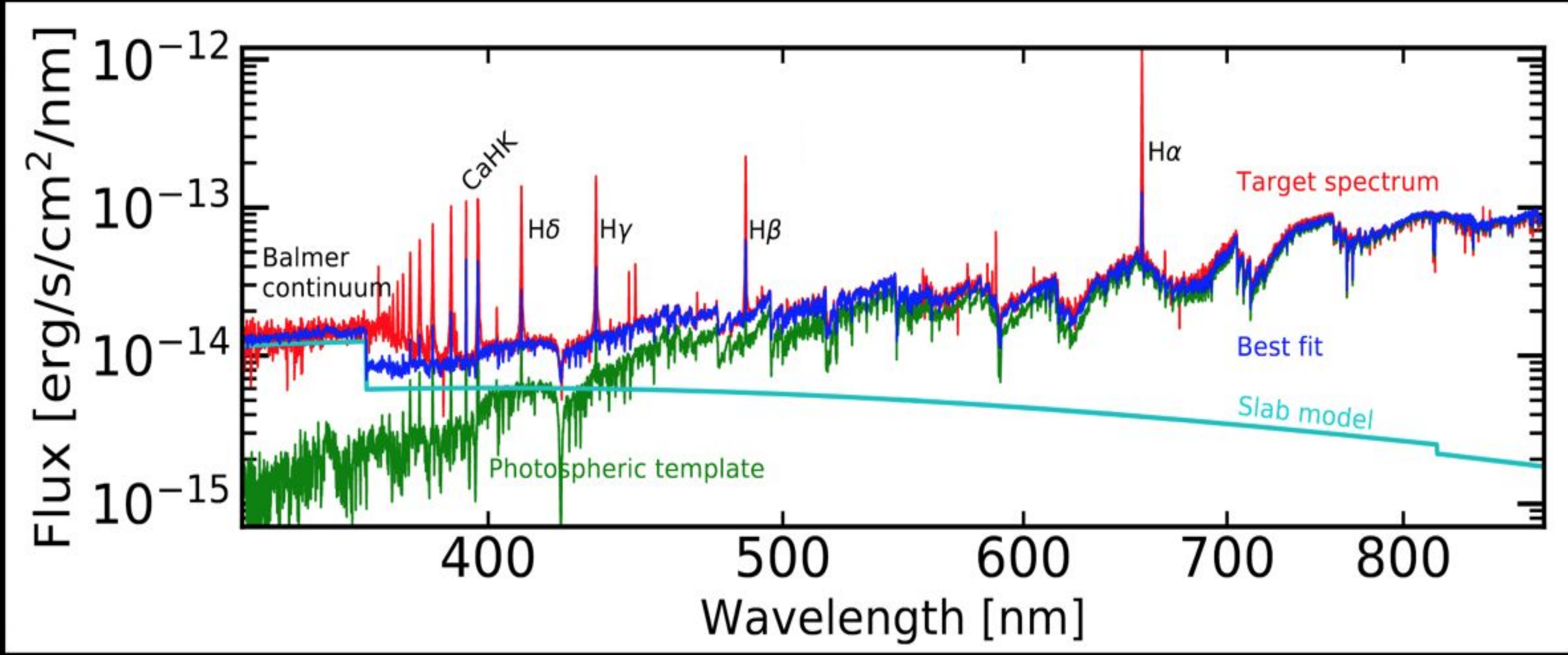


- hydrogen slab in LTE : continuum excess emission

$T_{gas} \approx 6000 - 10^4$ K

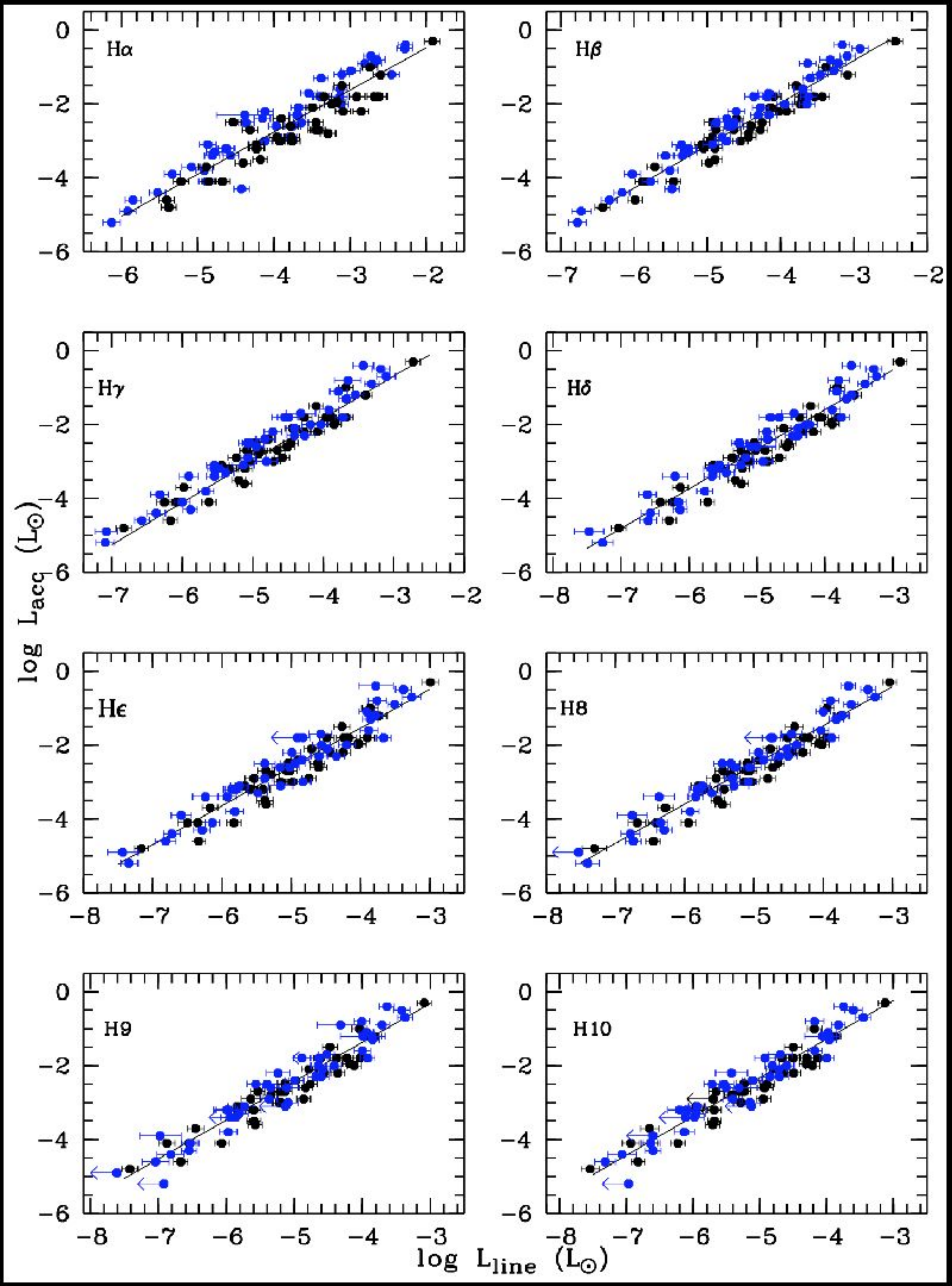
$n_e \approx [10^{13} : 10^{14}]$ cm^{-3}

$l \approx 10^7$ cm



$$L_{acc} = \frac{G M_\star \dot{M}_{acc}}{R_\star} \left(1 - \frac{R_\star}{R_{in}}\right)$$

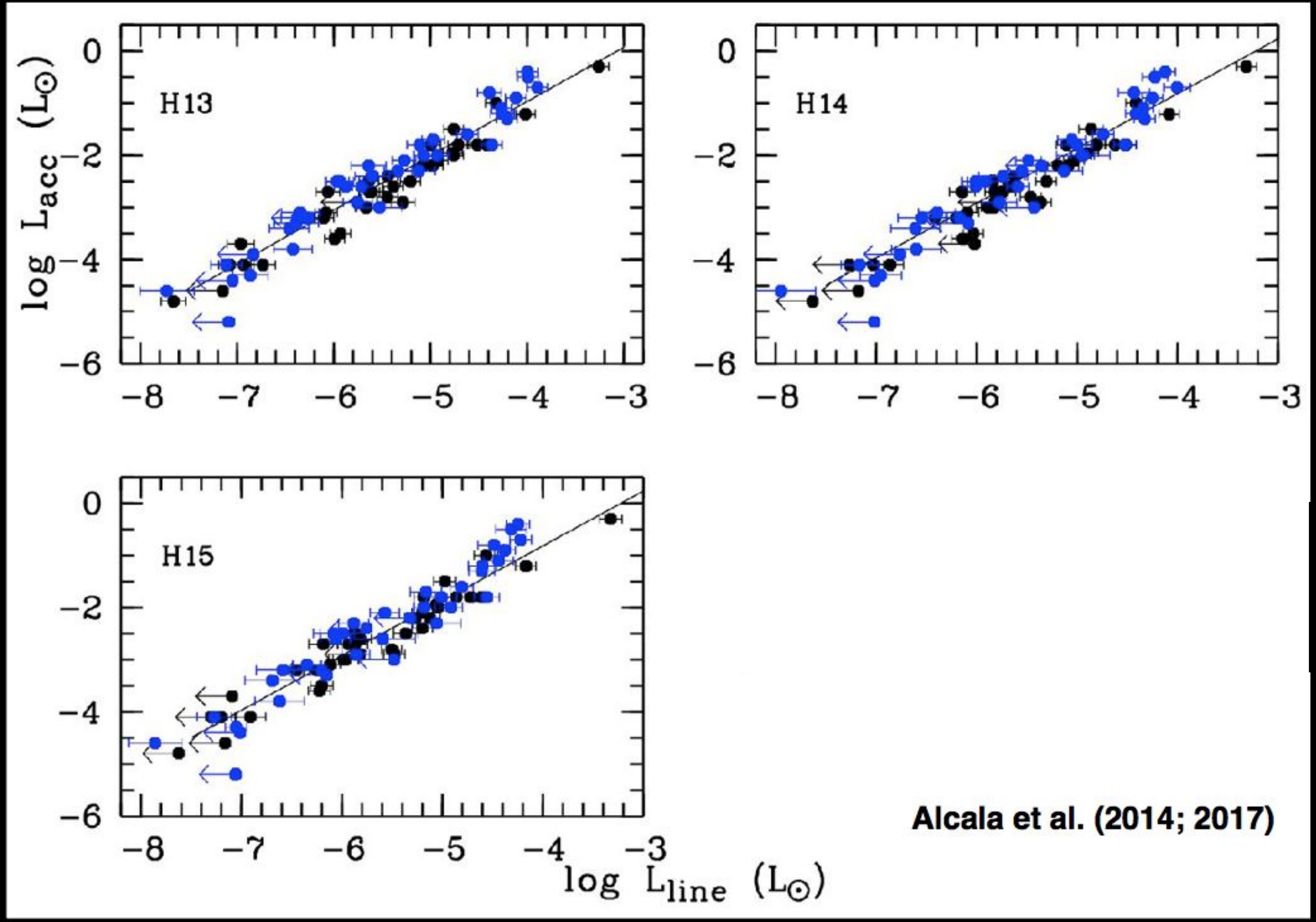
- modelling continuum excess emission is best to estimate L_{acc}
- all parameters (A_V, T_{eff}, $L_\star$, etc.) self-consistently derived
- good absolute flux cal. (<15%) & widest possible wave. range



L_{acc} vs. L_{line} relationships: 40 diagnostics

L_{acc} α L_{line}^{η} (0.9 < η < 1.18)
to zero order linear over 5 orders of mag. in L_{acc}

- Balmer lines up to H15
- Pa5 - Pa10 & Br7
- He I & He II (10 lines)
- Ca II (H & K, IRT)
- Na I D lines



Alcala et al. (2014; 2017)