

Recent time domain advances in AWD research brings more questions!

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Overview

1) How have time-domain observations shifted in AWD research?

1) Recent (and biased!) time-domain discoveries in AWDs
   - Broad-band aperiodic variability (a.k.a. flickering)
   - Magnetically gated bursts
   - Mode switching
   - Micronovae
   - X-ray fireball flash in novae

1) What observations/theory are critical to unravel the physics?

2) A very biased wish-list!

Astro 2020 Science questions:

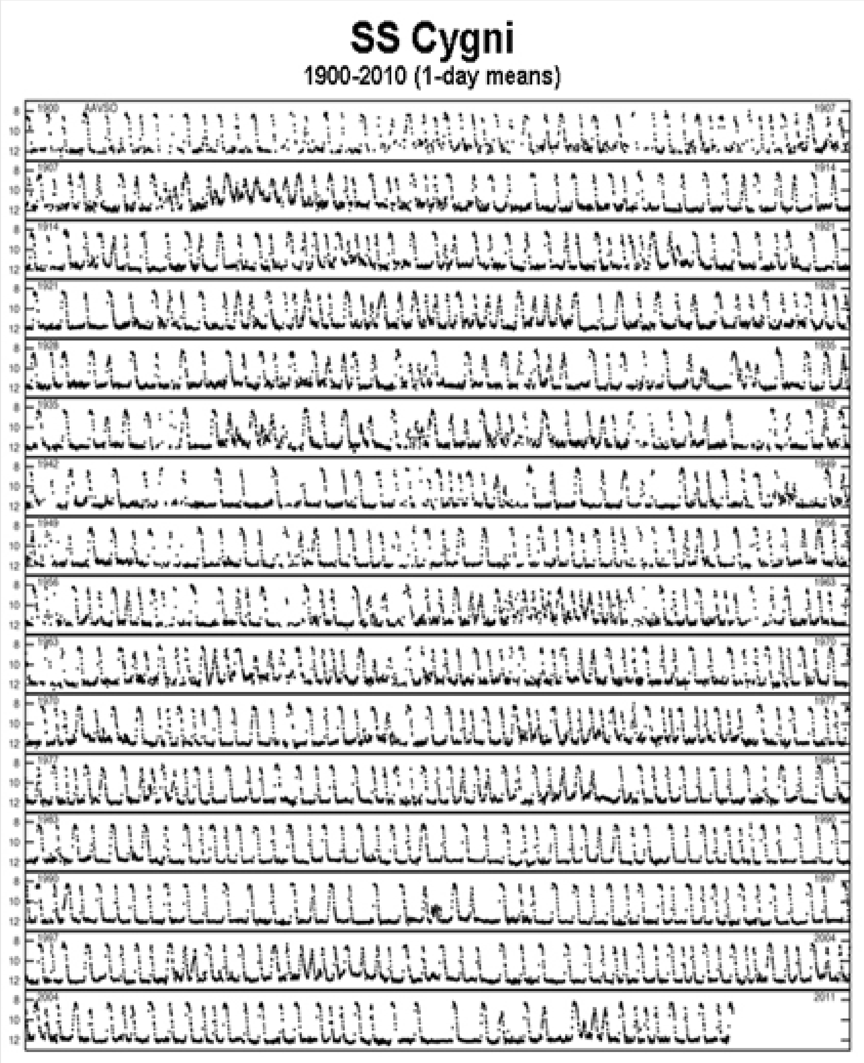
B-Q2. WHAT POWERS THE DIVERSITY OF EXPLOSIVE PHENOMENA ACROSS THE ELECTROMAGNETIC SPECTRUM?

B-Q2a. When and How Are Transients Powered by Neutron Stars or Black Holes, OR White Dwarfs?

B-Q2c. When and How Are Transients Powered by Radioactivity?

B-Q2d. What Are the Unexplored Frontiers in Transient Phenomena?

Accretion disk instabilities



Broad-band variability

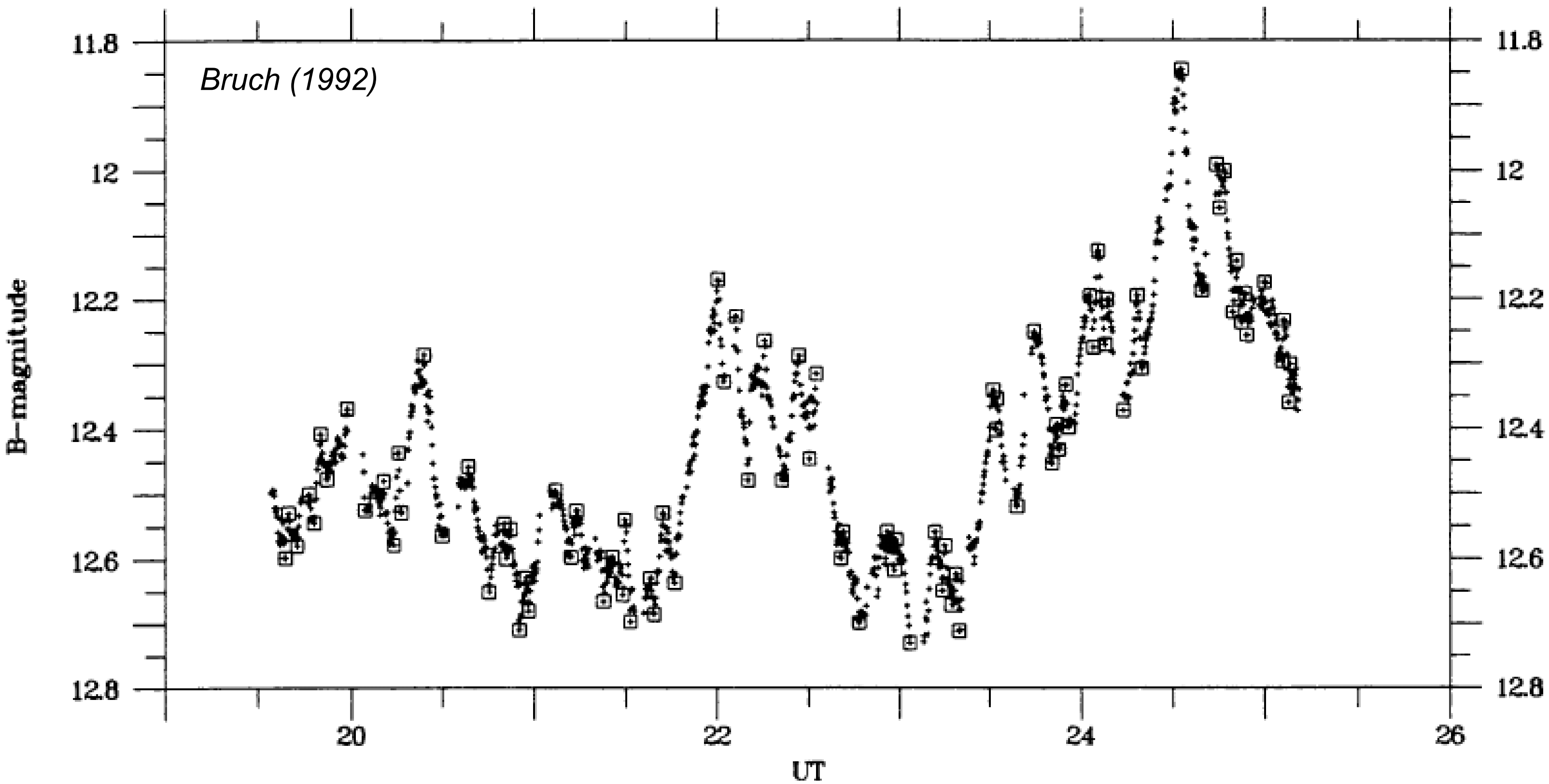
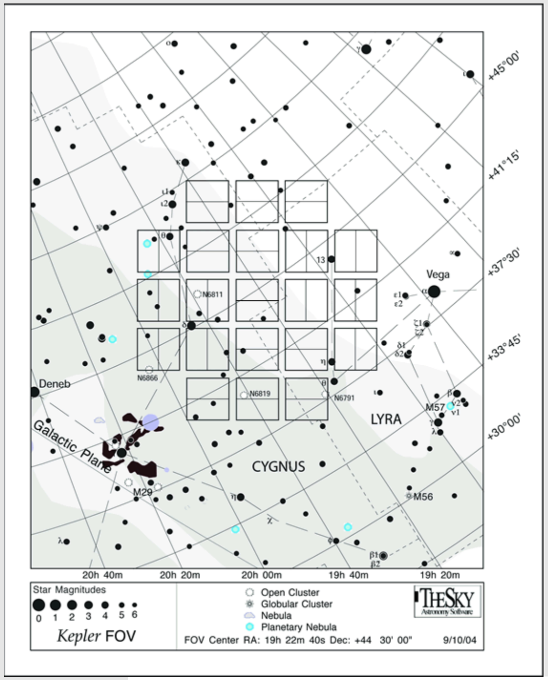
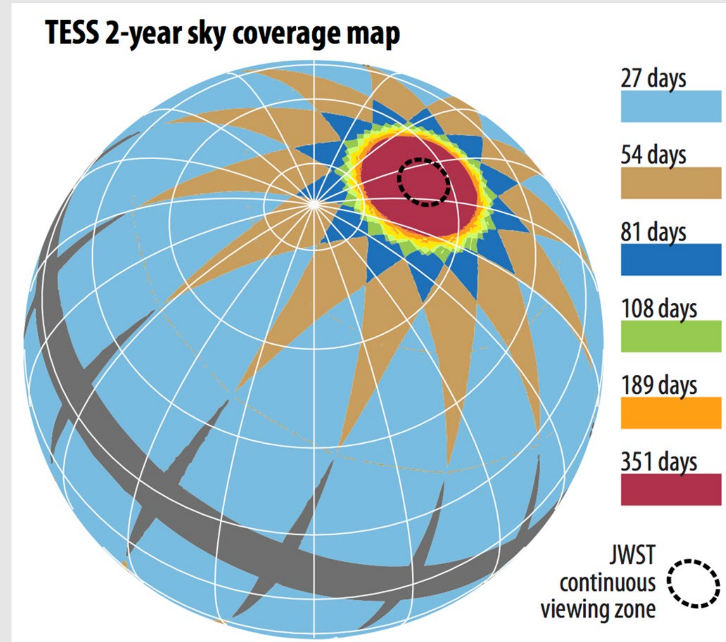


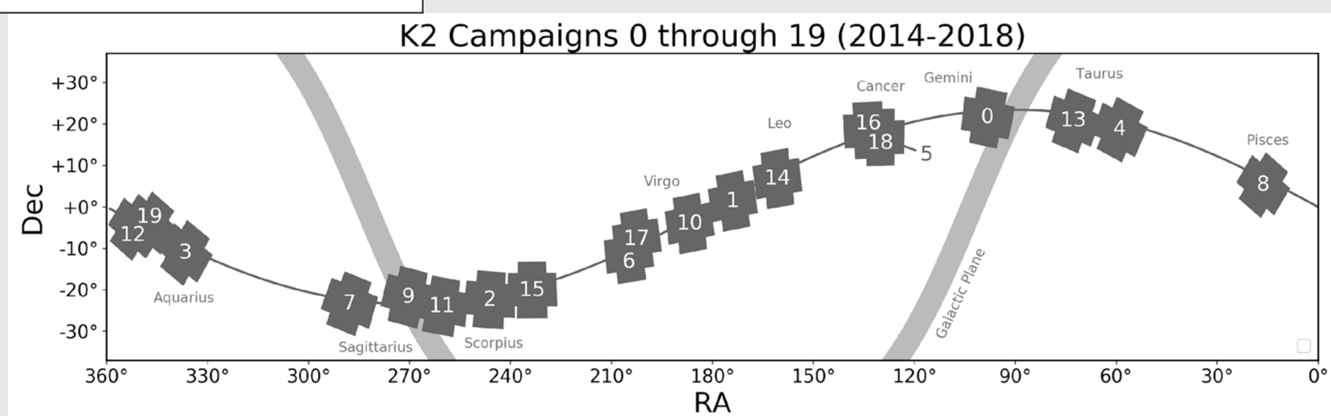
FIG. 1: Light curve of SS Cyg of 1983, Aug. 12, as an example for the formal definition of flickering flares. The base points and peaks of individual flares recognized as significant are marked by squares. The limiting amplitude for a flare was chosen to be $0^{\mathrm{m}}.03$.



Vega
Deneb
Galactic Plane
LYRA
CYGNUS
M29
M56
M57
N6811
N6866
N6819
N6791
+45°00'
+41°15'
+37°30'
+33°45'
+30°00'
20h 40m
20h 20m
20h 00m
19h 40m
19h 20m
Star Magnitudes
0 1 2 3 4 5 6
Kepler FOV
Open Cluster
Globular Cluster
Nebula
Planetary Nebula
FOV Center RA: 19h 22m 40s Dec: +44 30' 00"
9/10/04
TheSky



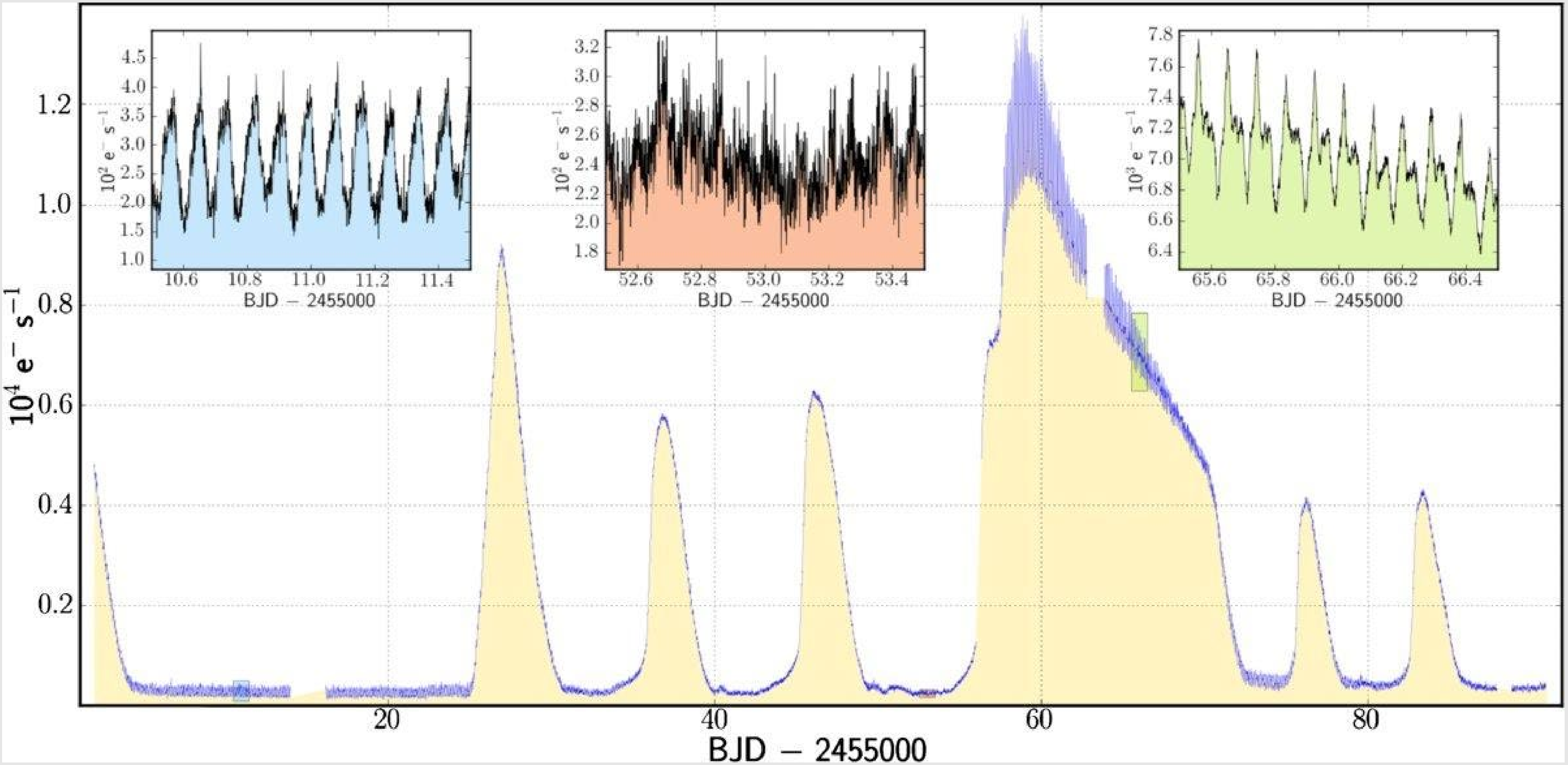
TESS 2-year sky coverage map
27 days
54 days
81 days
108 days
189 days
351 days
JWST continuous viewing zone



K2 Campaigns 0 through 19 (2014-2018)
Dec
RA
+30°
+20°
+10°
+0°
-10°
-20°
-30°
360°
330°
300°
270°
240°
210°
180°
150°
120°
90°
60°
30°
0°
Aquarius
Sagittarius
Scorpius
Virgo
Leo
Cancer
Gemini
Taurus
Pisces
Galactic Plane
19
12
3
7
9
11
2
15
17
6
10
1
14
16
18
5
0
13
4
8

Accretion disk instabilities

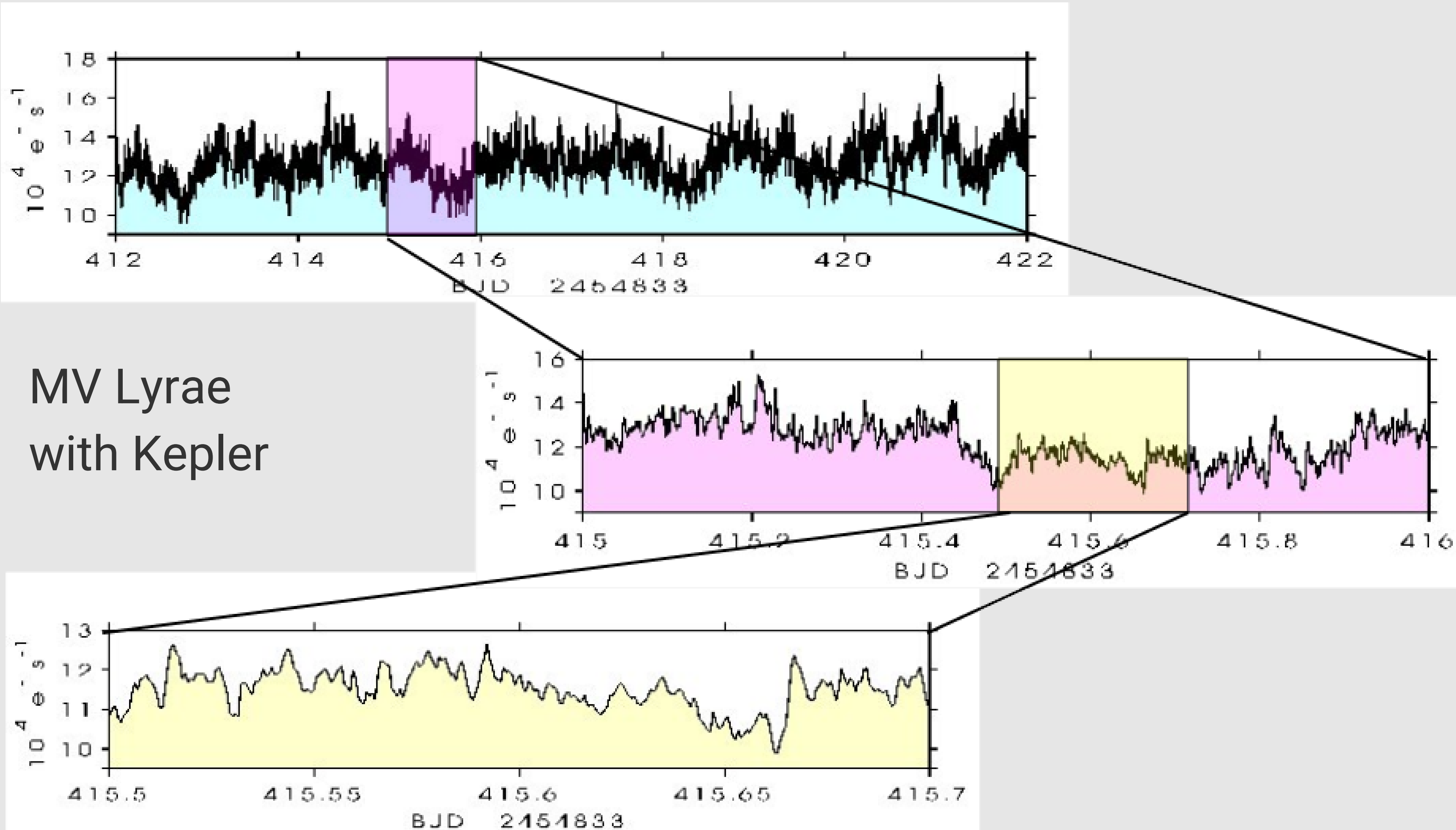
V344 Lyrae with Kepler



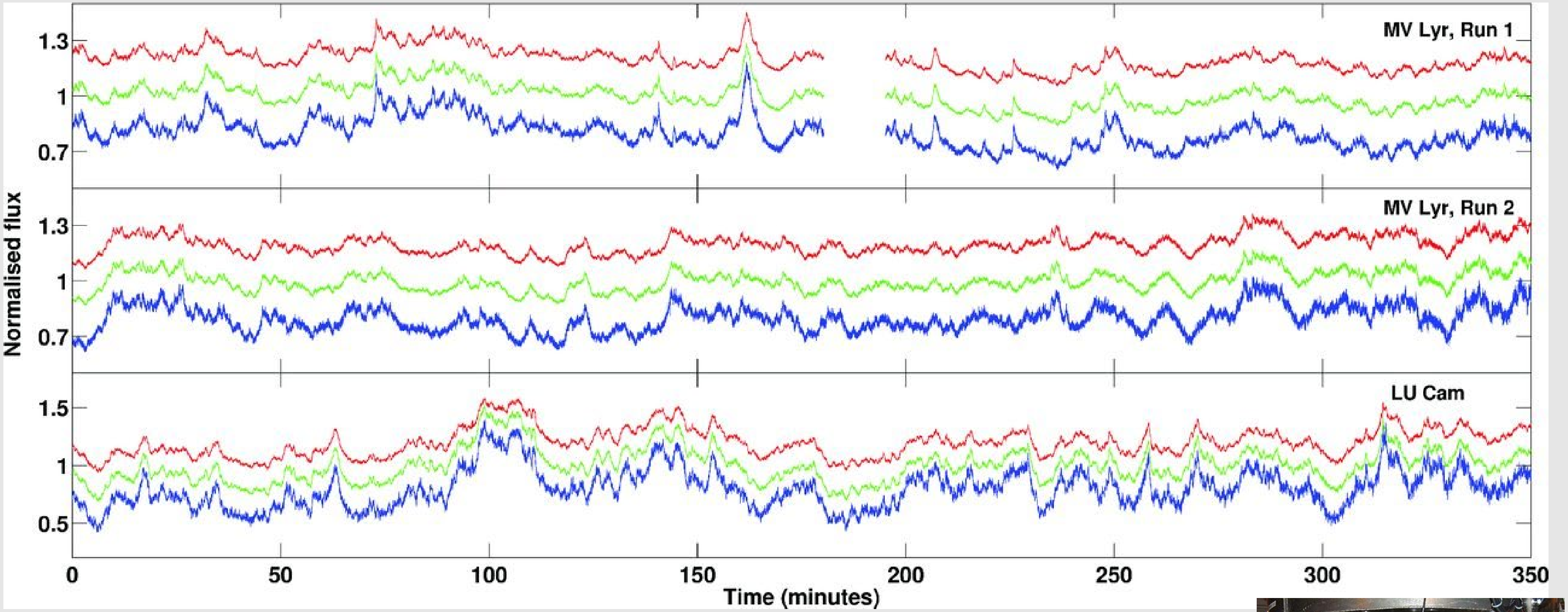
Still+ (2010)

Broad-band variability

MV Lyrae
with Kepler

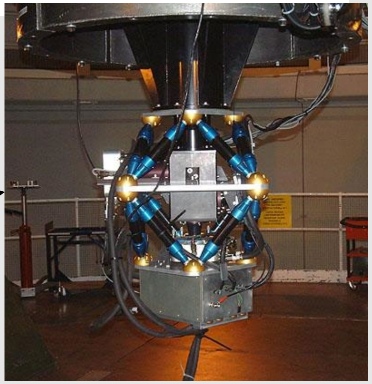


Broad-band variability
…from the ground



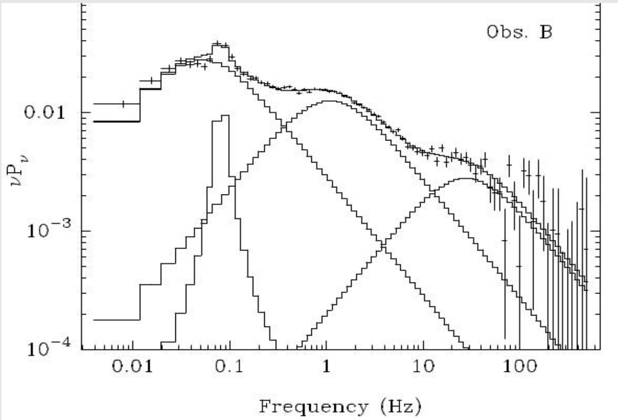
Ask me about Fourier time-lags and what we can learn from them

ULTRACAM on the WHT

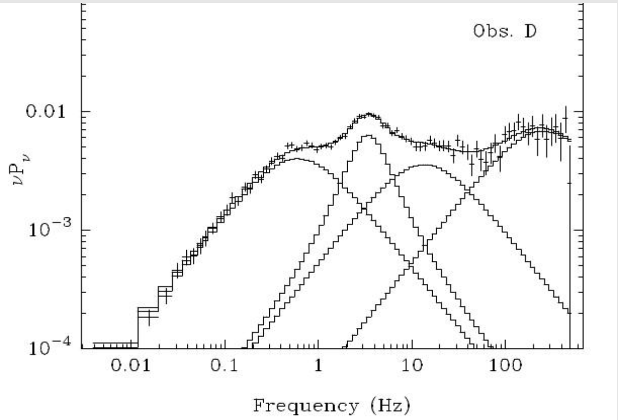


Broad-band variability common across the scales

Black hole XRB

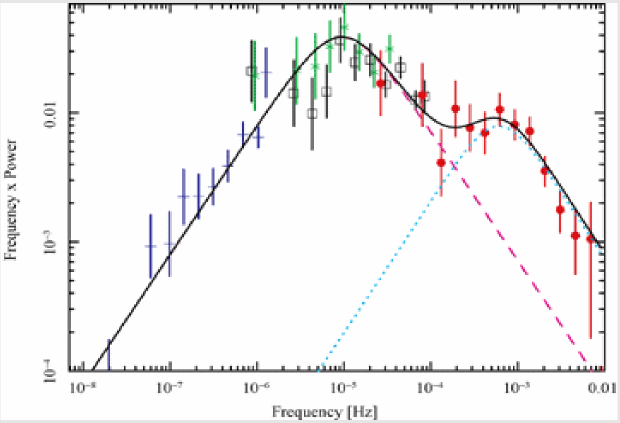


Neutron star

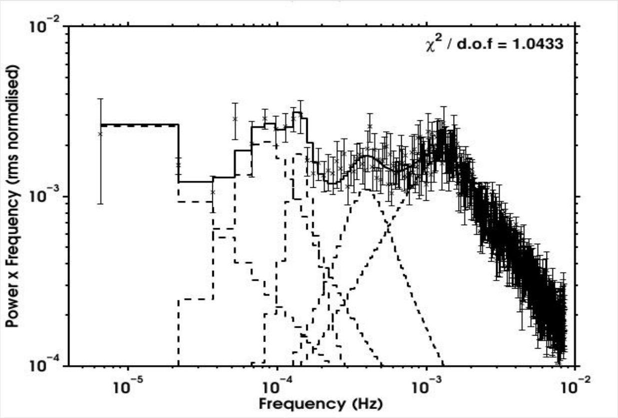


Belloni+ (2002)
McHardy+ (2007)
Scaringi+ (2012b)

AGN

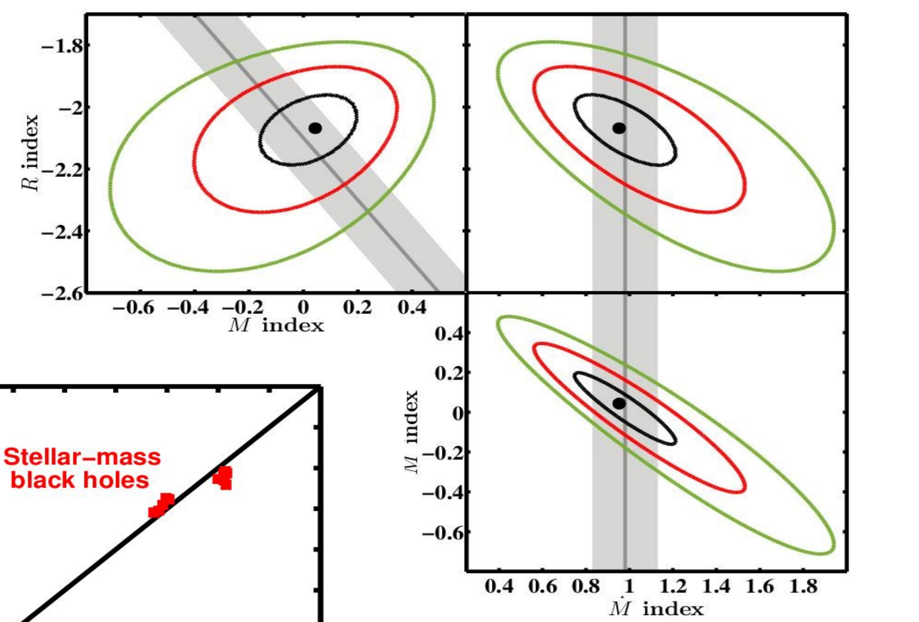


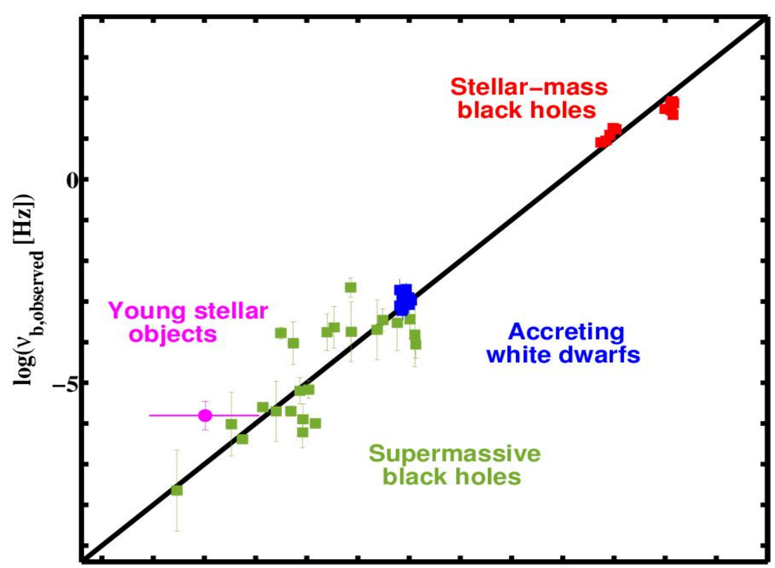
White dwarf



The accretion variability plane

$$\log \nu_b = A \log M + B \log R + C \log \dot{M} + D$$





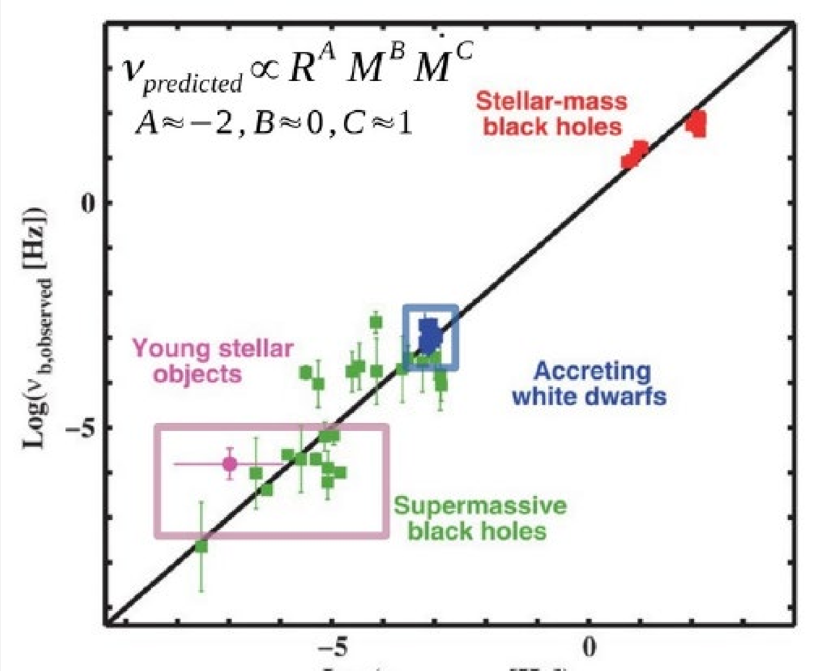
Scaringi+ (2015b)

Caveat:

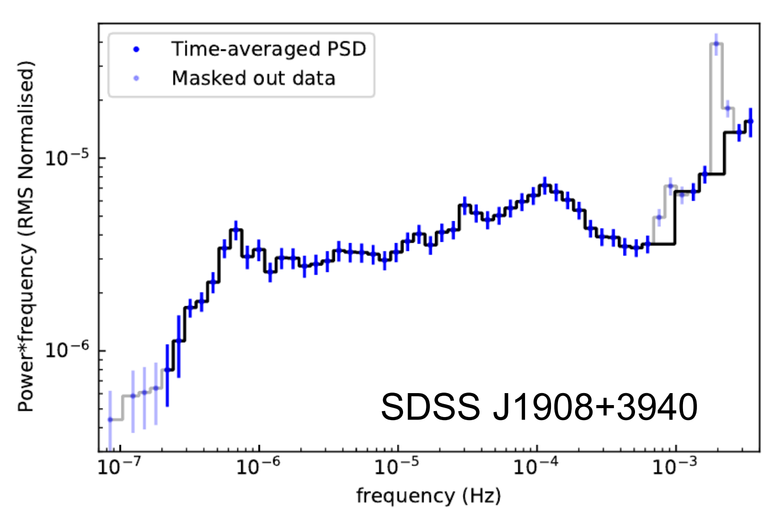
Frequency breaks can be wavelength dependent

The accretion variability plane

1) Need both novalikes (high Mdot) **and** dwarf nova in quiescence (low Mdot)
2) Where are the low frequency breaks?
   -> Need longer obs.



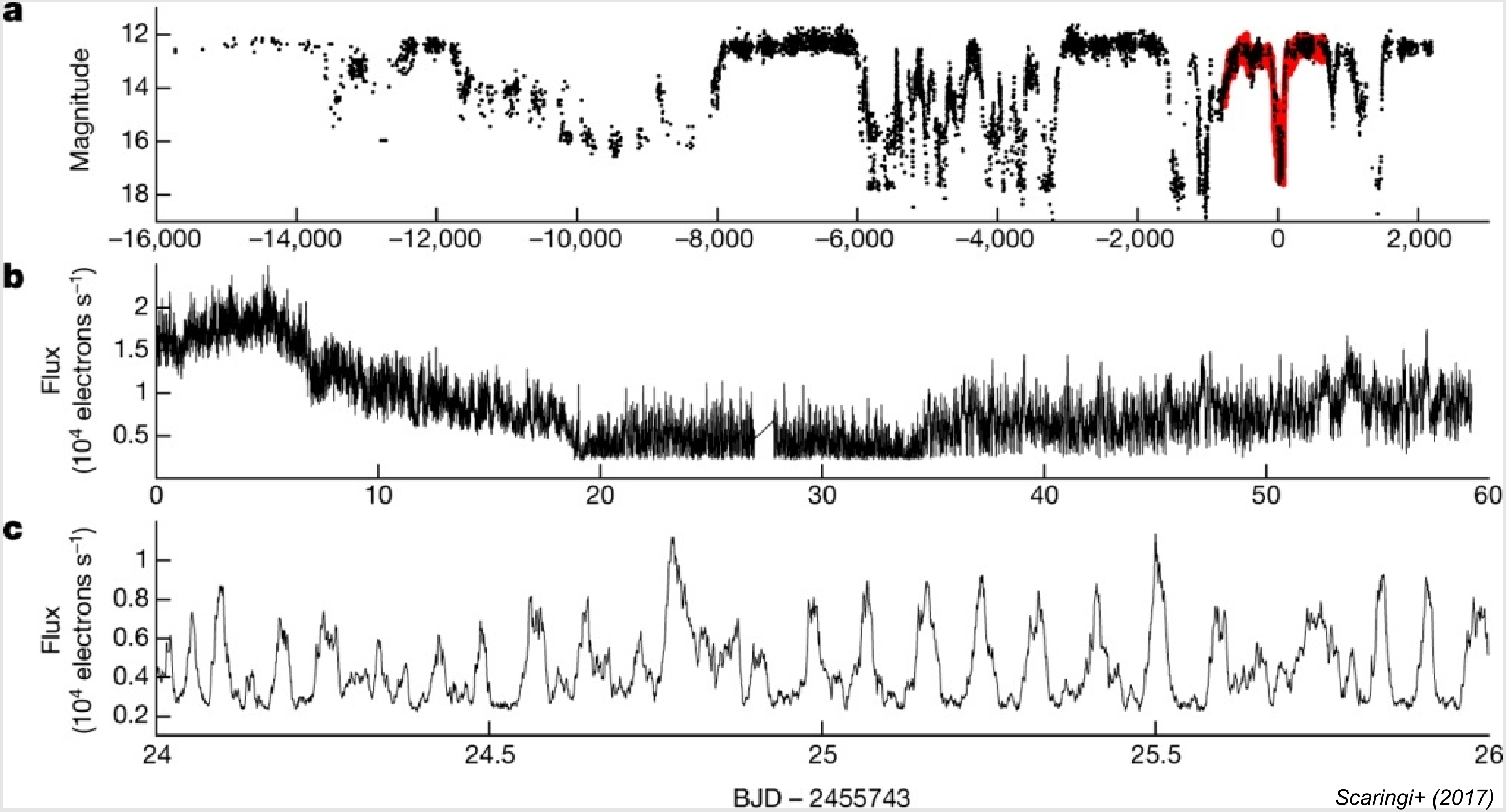
Scaringi+ (2015b)



Veresvarska & Scaringi (2022, submitted)

Figure 1. Time-averaged PSD of SDSS J1908+3940 with the segment length of 60 days and masked out periodic signals in the white noise dominated high frequency regime and low frequency masked out data below the segment window length limit.

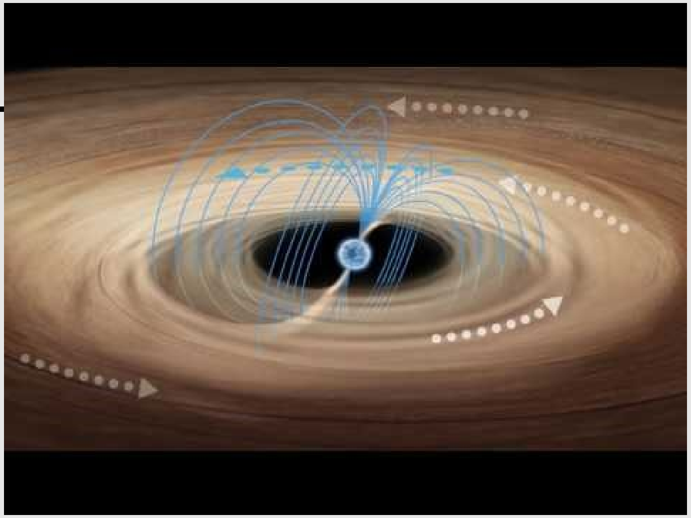
Magnetically gated accretion



Scaringi+ (2017)

Magnetically gated accretion

Type-II burst equivalent in XRBs

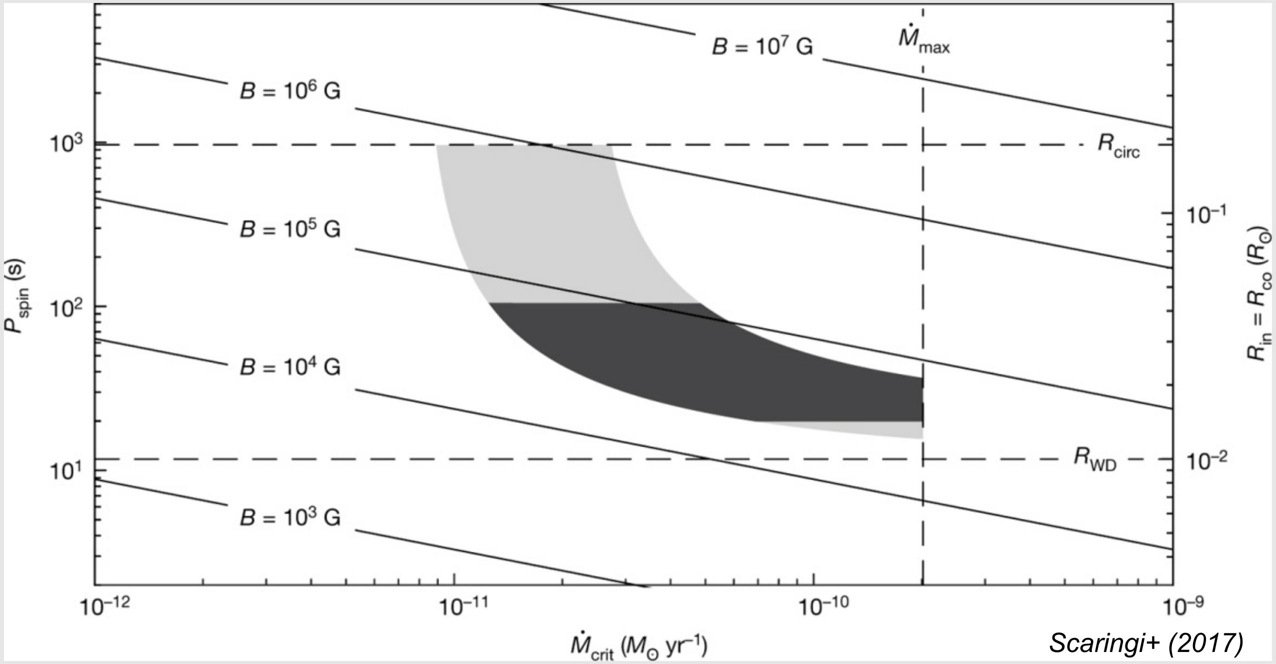


Disk-WD co-rotation radius

$$P_s^2 = \frac{4\pi^2 R_{co}^3}{GM_{WD}}$$

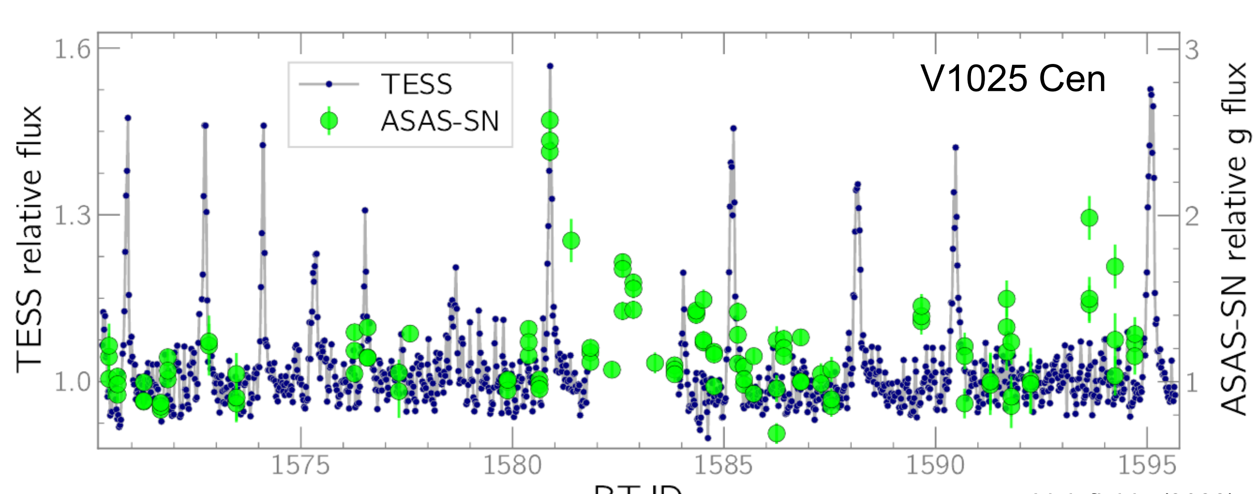
Critical mass transfer rate

$$\dot{M}_{crit} = \frac{\eta\mu^2 P_s}{8\pi R_{in}^5}$$

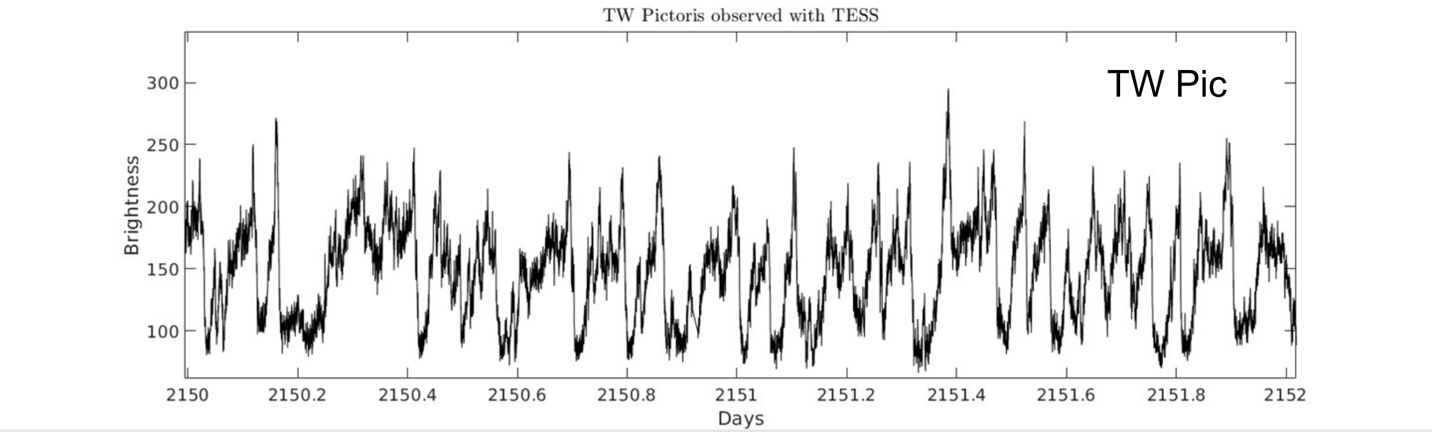


Scaringi+ (2017)

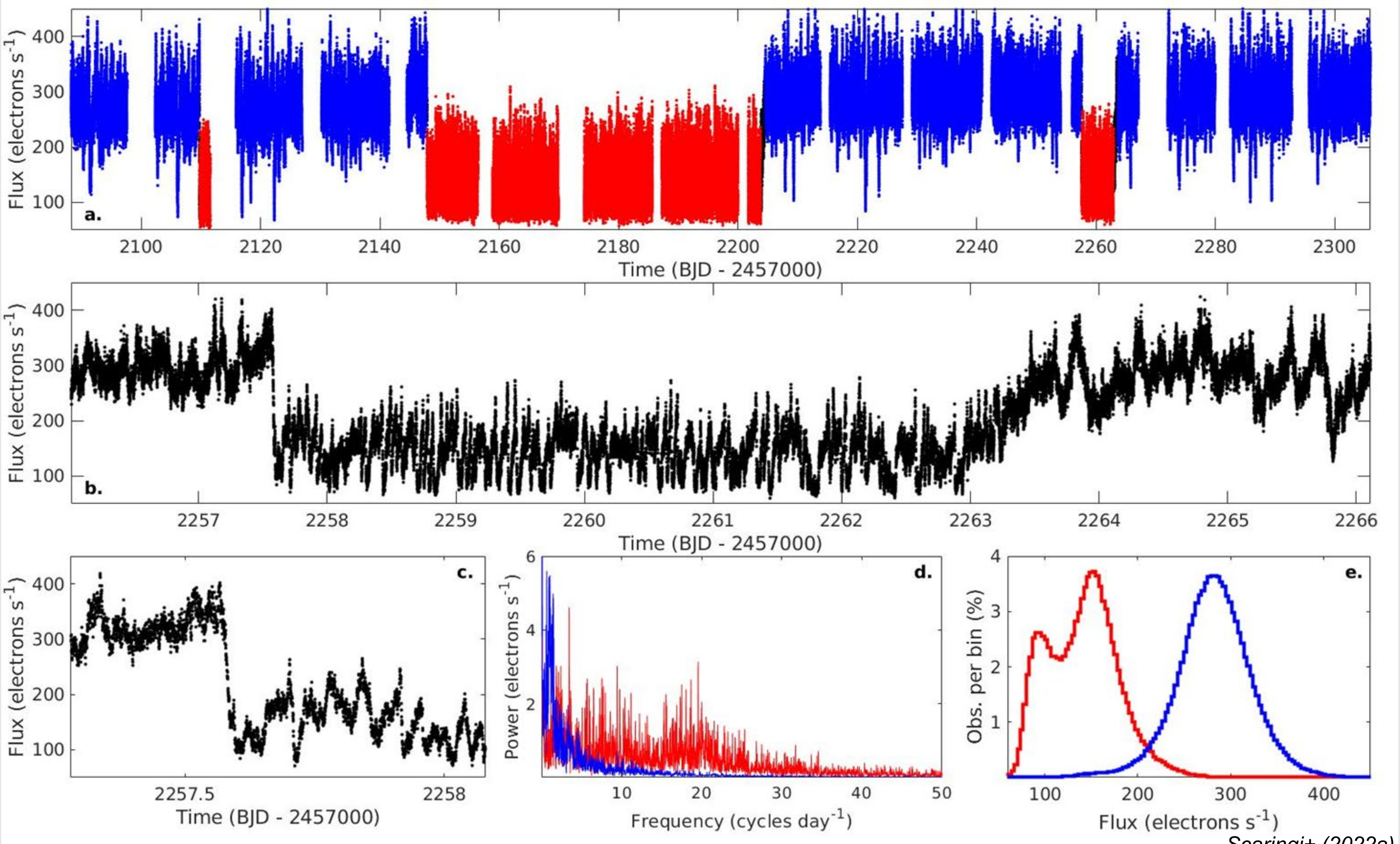
Magnetically gated accretion



Littlefield+ (2022)



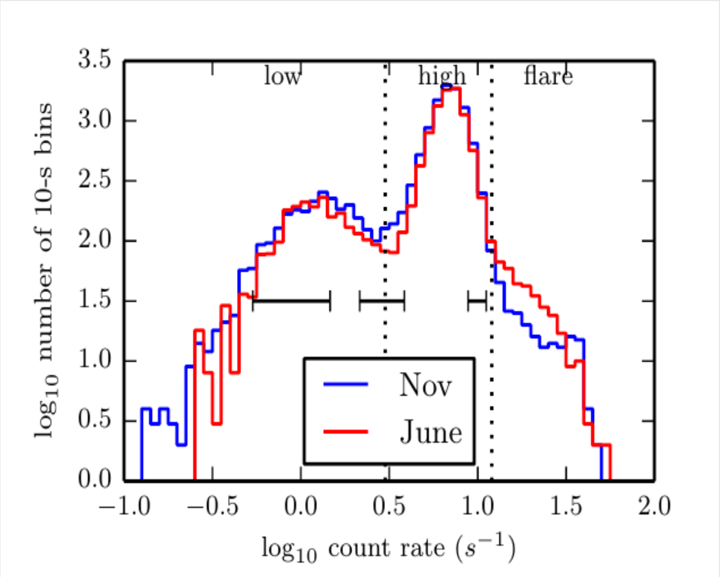
TW Pictoris

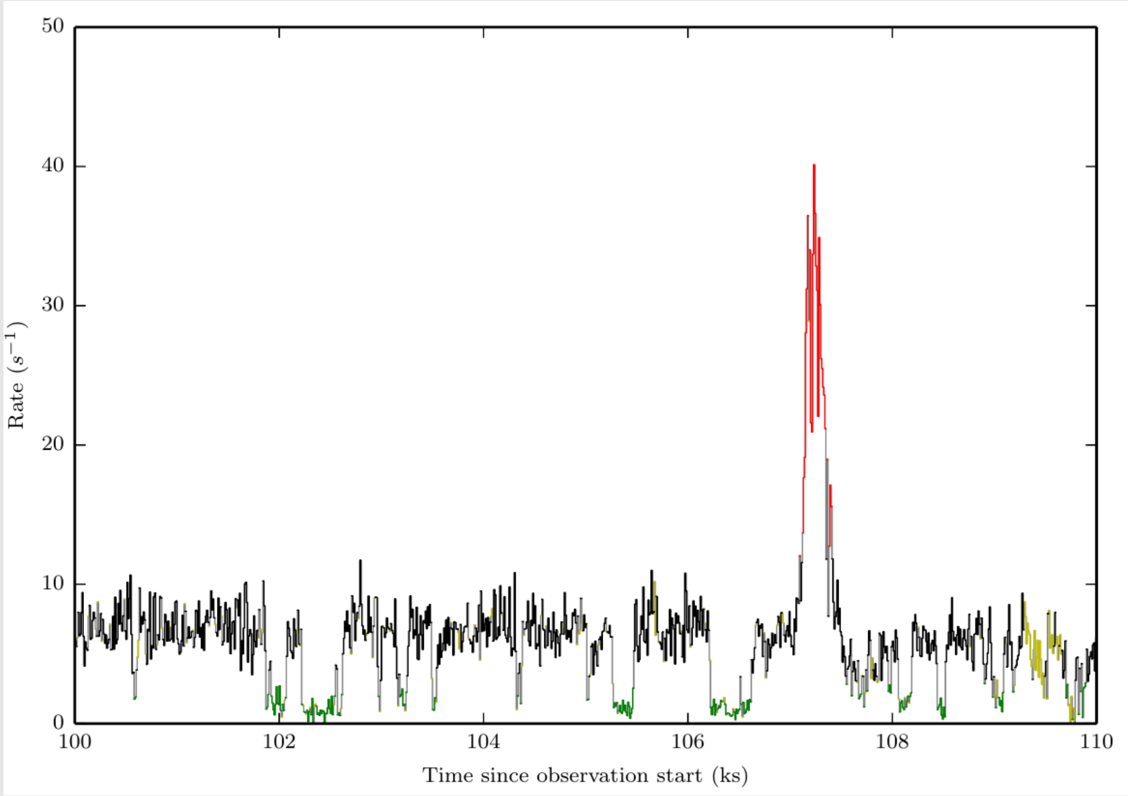


Scaringi+ (2022a)

PSR J1023+0038

Moding caused by accretion on/off state

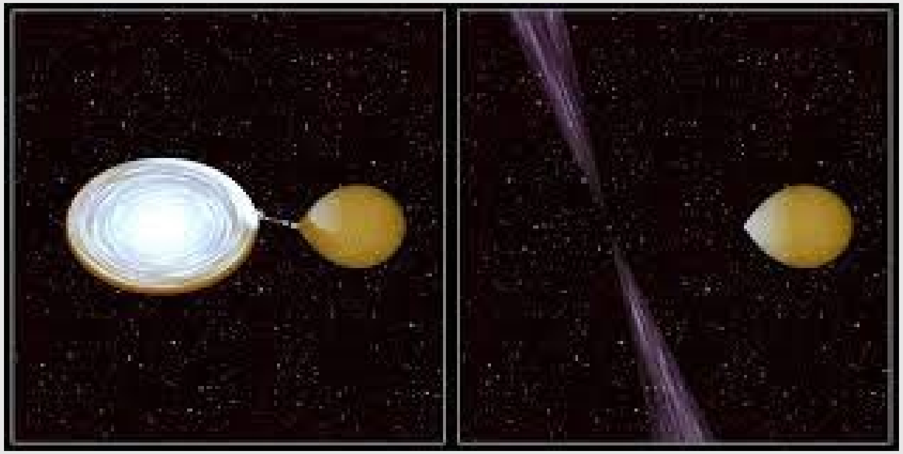




e.g. Archibald+ (2015)

transitional Accreting White Dwarfs (tAWDs)
vs.
transitional Millisecond Pulsars (tMSPs)

???



TV Columbae

…a brief history…

THE ASTROPHYSICAL JOURNAL, **280**:729–733, 1984 May 15

AN UNPRECEDENTED UV/OPTICAL FLARE IN TV COLUMBAE

PAULA SZKODY[1] AND MARIO MATEO[2]
Department of Astronomy, University of Washington
Received 1983 August 8; accepted 1983 November 23

ABSTRACT

We report a surprising, 2 mag, short time scale (hr) outburst of TV Col (2A 0526−328) observed simultaneously at *IUE* and optical wavelengths in 1982 November. During this "flare," the *IUE* emission lines of N v λ1240, C IV λ1550, and He II λ1640, intensified by more than an order of magnitude and developed P Cygni profiles, indicating mass loss. Continuum fits with a power law plus a blackbody from the UV through the optical showed a steepening of the UV power-law component and an increase in the temperature and size of the blackbody component during the flare activity. We discuss this unusual behavior in terms of an accretion disk instability.

Subject headings: stars: accretion — stars: dwarf novae — stars: flare — stars: individual — ultraviolet: spectra

TV Columbae

…a brief history…

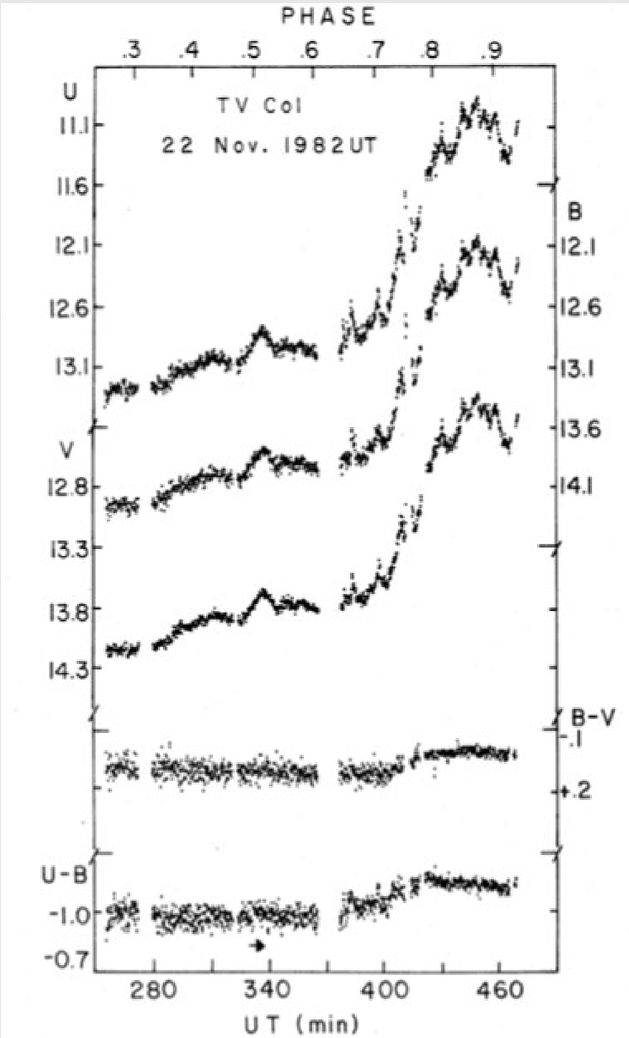
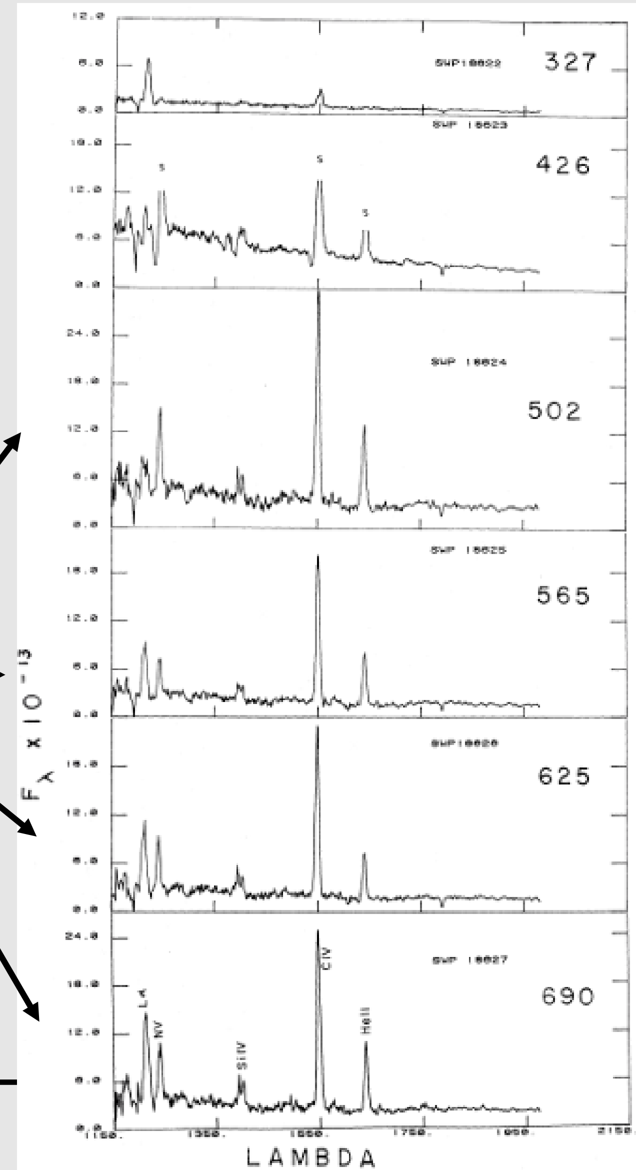


FIG. 1.—Simultaneous *UBV* photometry for 1982 November 22 UT. Each point is a 10 s integration with statistical uncertainty of less than 0.02 mag. *IUE* coverage began at the arrow and continued past the end of the optical data. Phases at the top are for the photometric variation according to the ephemeris by Hutchings *et al.* (1981).

Pre-burst

Burst maximum

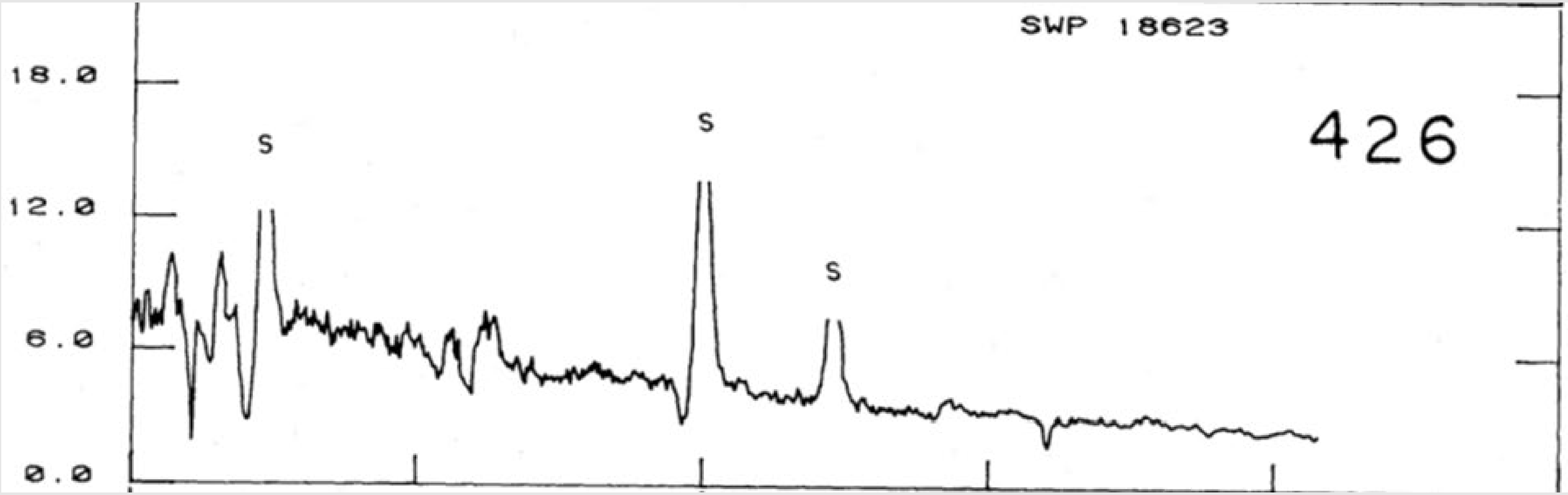
Post-burst



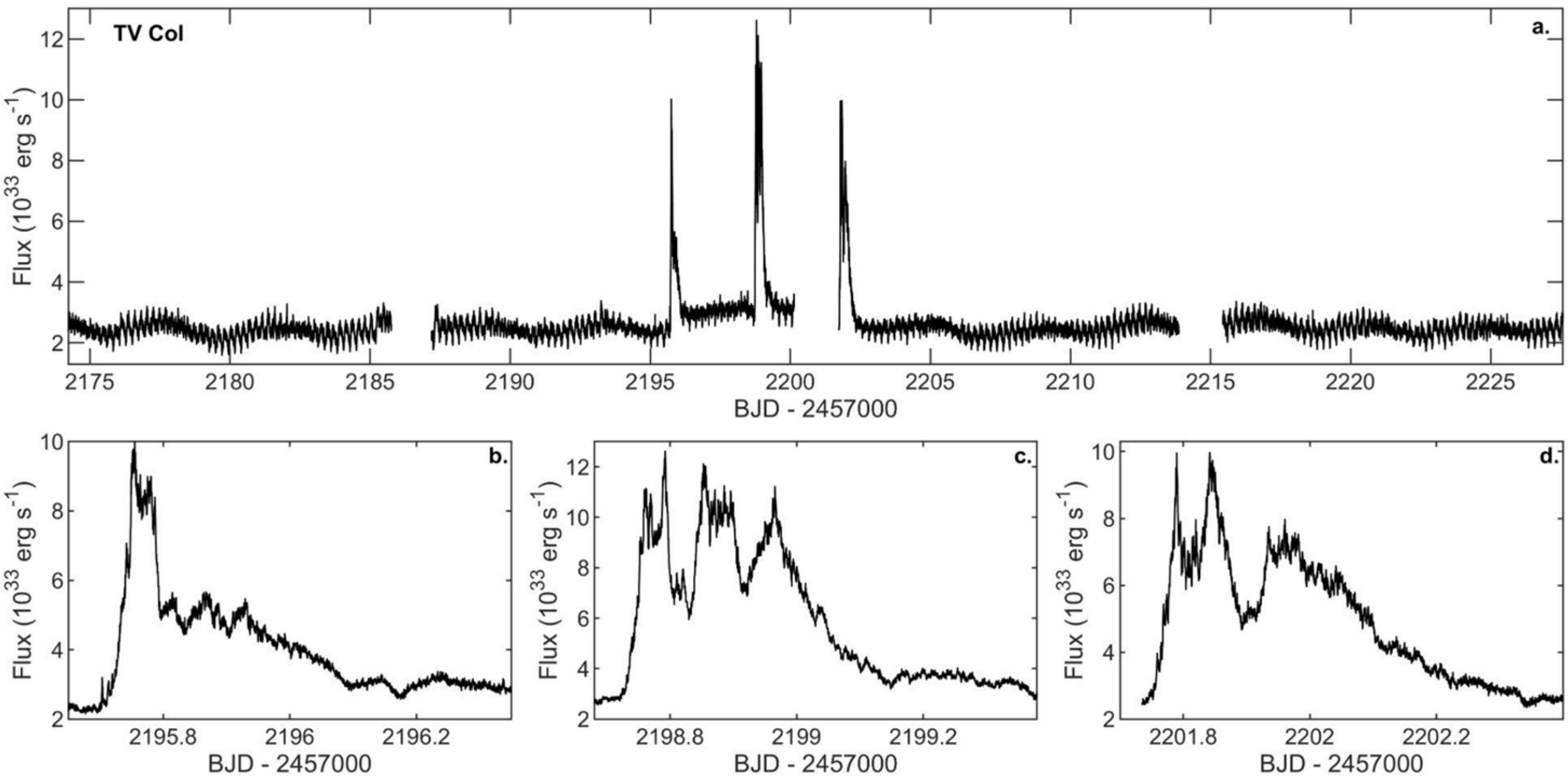
TV Columbae

…a brief history…

- High ionisation HeII and NV lines appear during burst and persist for ~1 month
- P-Cygni profile suggests outflows of >2500 km/s only at peak luminosity



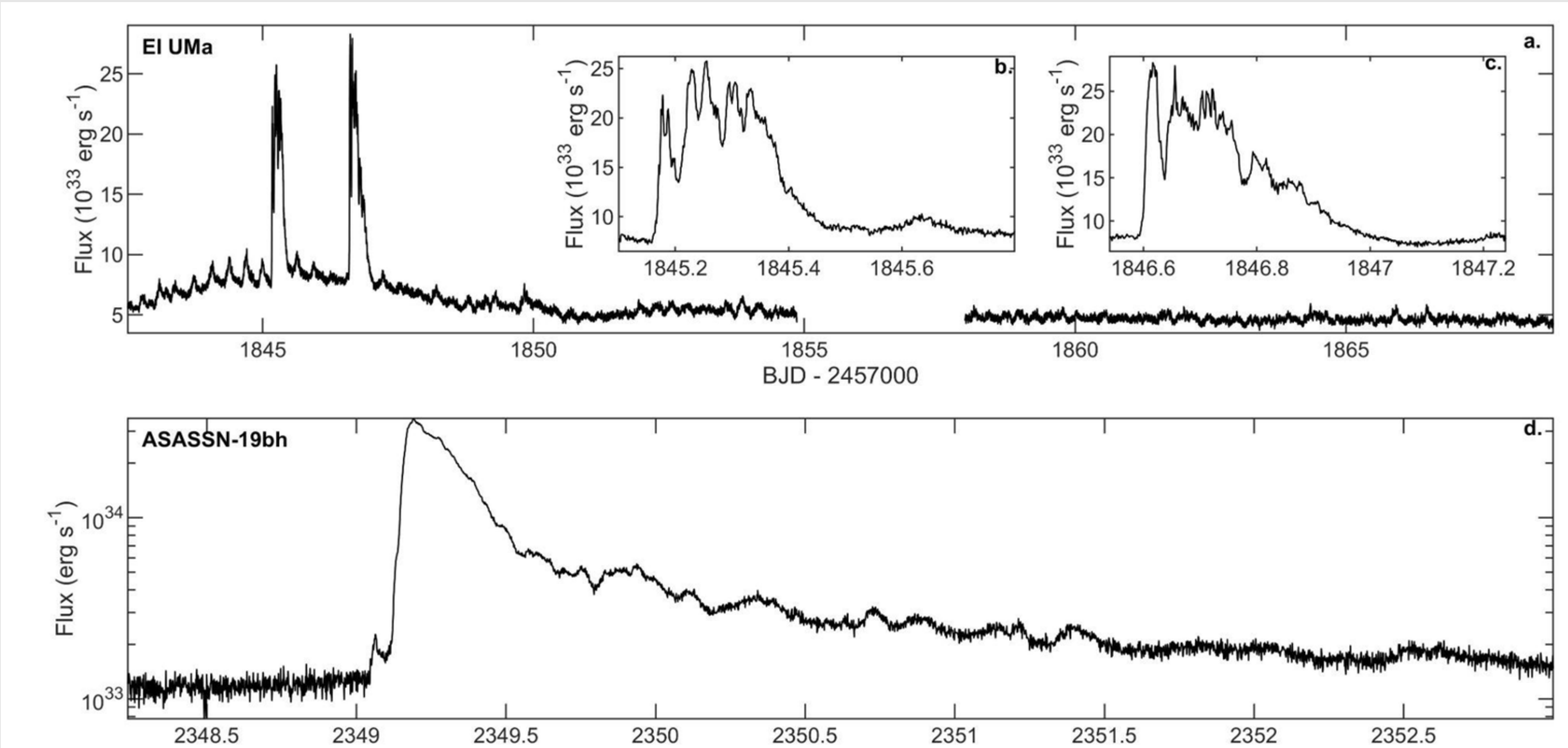
TV Columbae
…with TESS…



Scaringi+ (2022b)

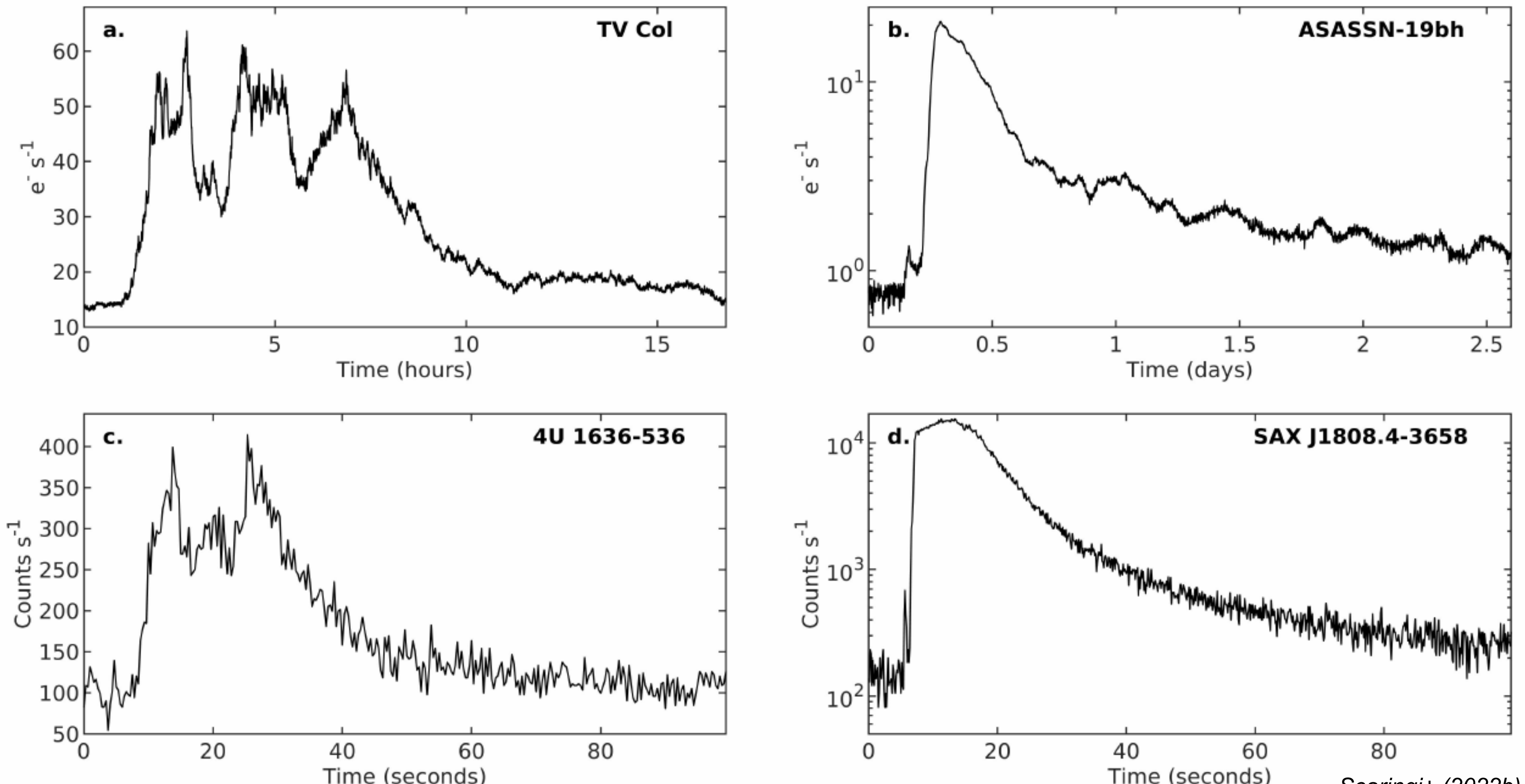
EI UMa and ASASSN-19bh

…with TESS…



Scaringi+ (2022b)

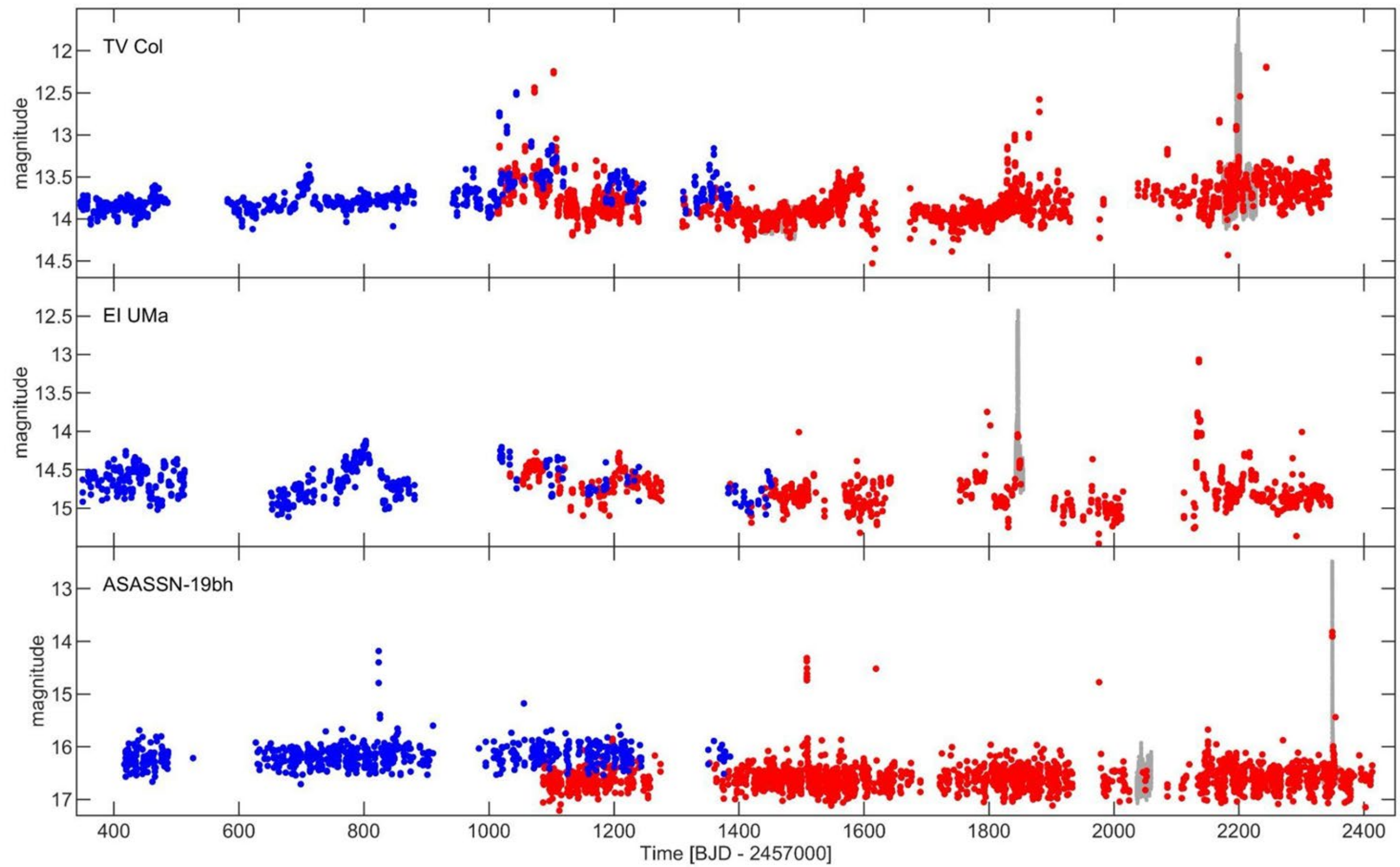
Micronovae vs. Type I X-ray bursts



Scaringi+ (2022b)

TV Col, EI UMa and ASASSN-19bh

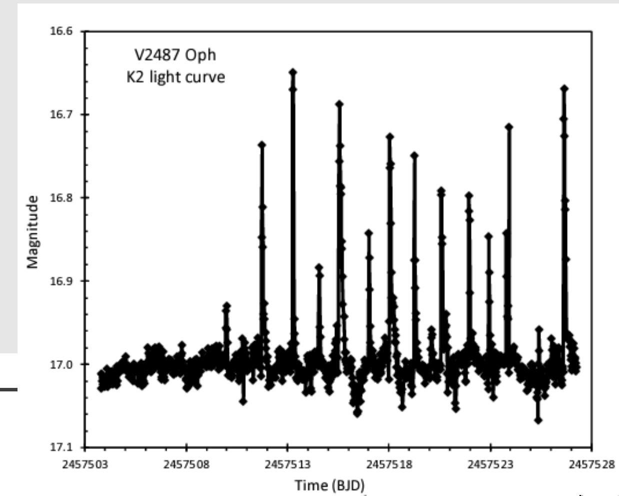
…with ASASSN…

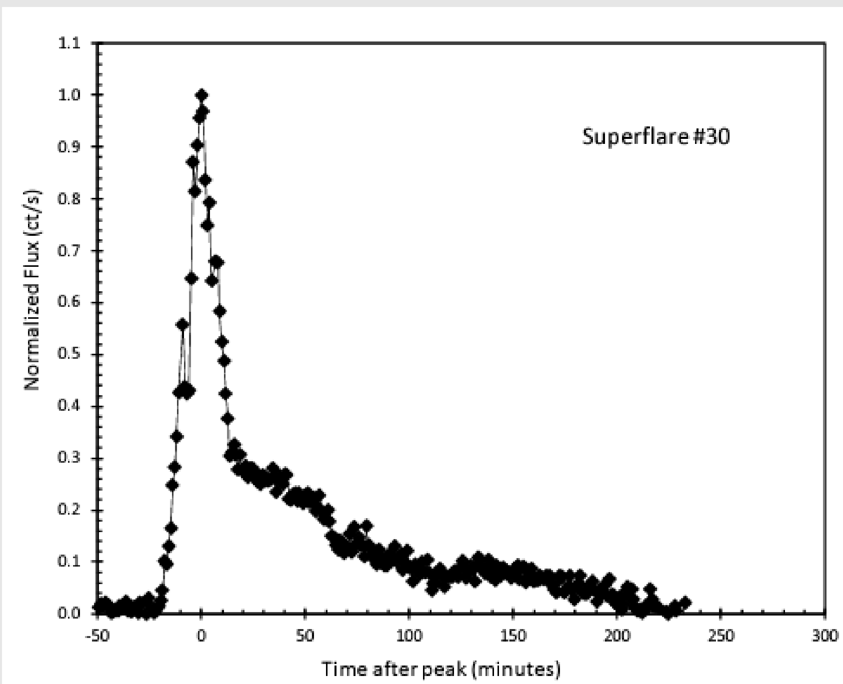


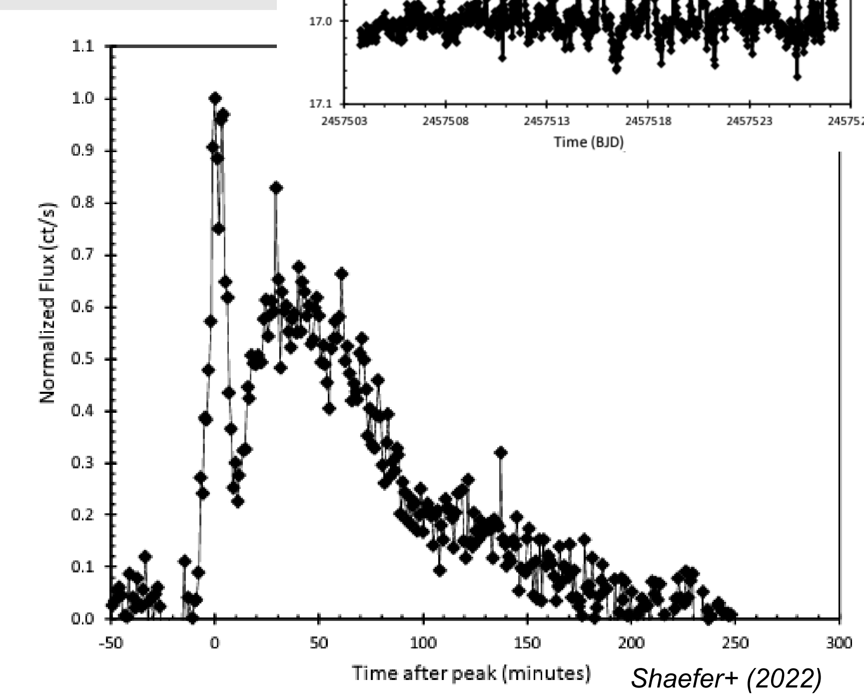
Scaringi+ (2022b)

V2487 Oph
…with Kepler…

- **About 60 bursts observed in a Recurrent Nova**
- **Explained through mag. reconnection?**

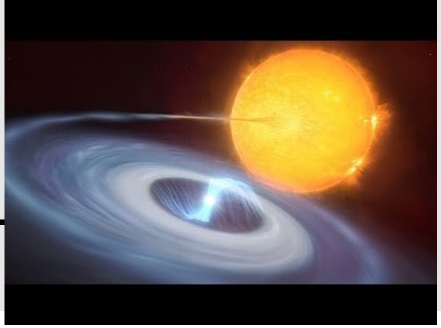






Shaefer+ (2022)

How to trigger micronovae?

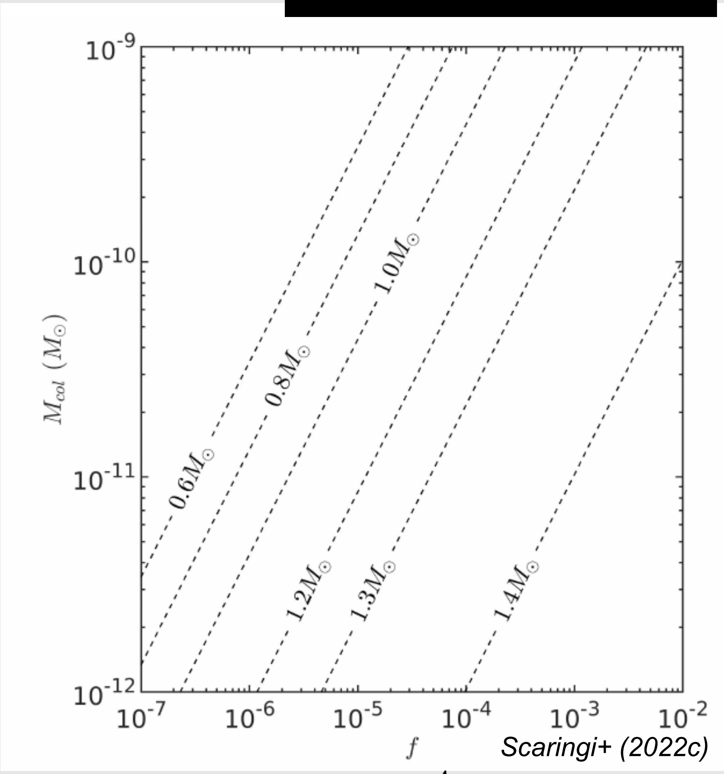


To ignite, we require:

$$P_{col} \approx P_{crit} > 10^{18} dyn\, cm^{-2}$$

As long as magnetic confinement of material holds:

$$t_{rec} = \frac{M_{col}}{\dot{M}_{acc}}$$



$$f = \frac{A_{col}}{A_{WD}}$$

Problem:

As column pushes into WD, at what depth do triggering conditions occur? (spoiler: maybe too deep)

Fireball phase in classical novae

- Bright X-ray flash ~11hr before optical brightening
- X-ray flash lasting <8hr

-> <u>Requirement</u>: large FOV at both X-ray and optical

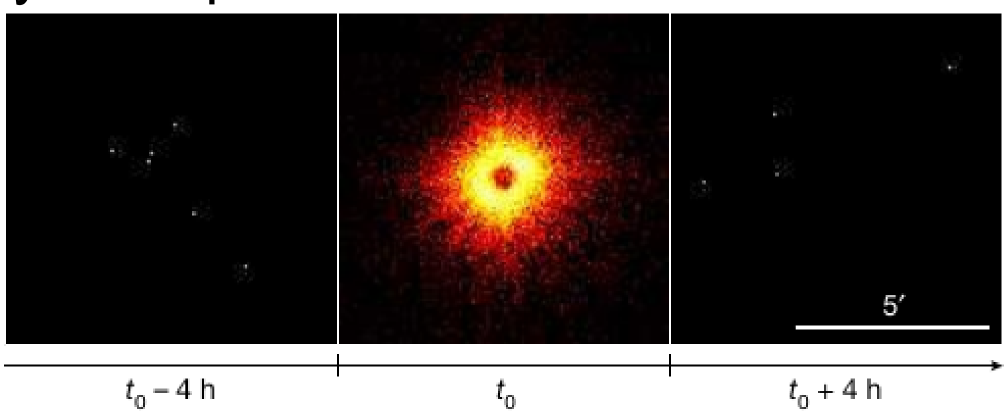
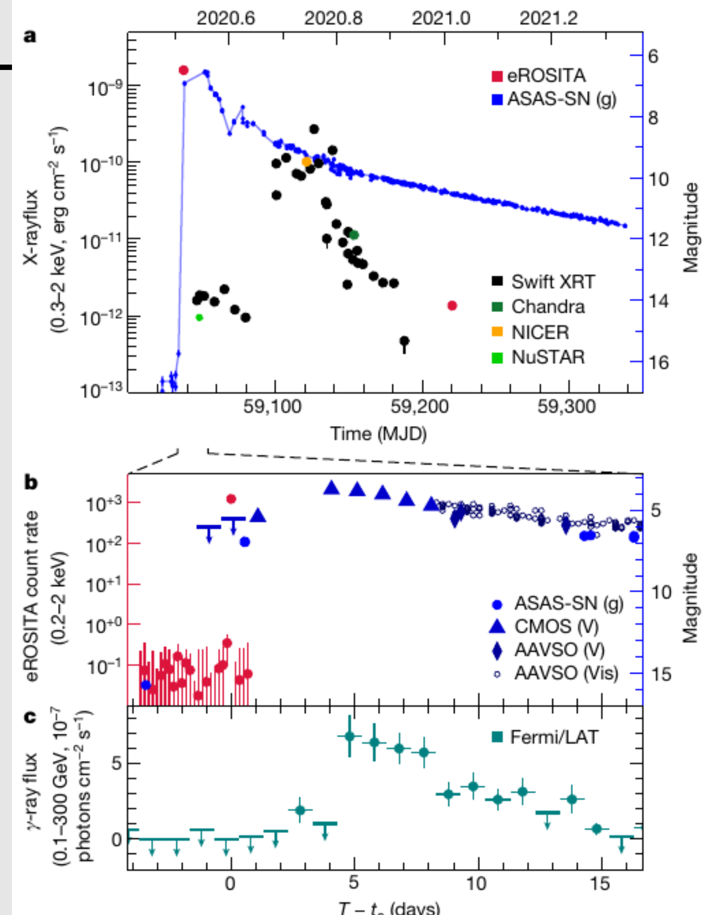


Fig. 1 | Sky images of all seven eROSITA cameras combined (0.2–0.6 keV). On t_0 = 2020 July 7, 16 h 47 min 20.64 s TT, during the second all-sky survey, eROSITA detected a bright, new, soft X-ray flash that was severely affected by pile-up. No source can be seen in the scans 4 h before and after the event.



Koening+ (2022)

Fig. 2 | Multi-wavelength light curve of YZ Ret. Error bars denote 1σ confidence levels. **The top x-axis shows the fractional time of the year.** **a**, Long-term evolution tracing the absorbed X-ray flux and the optical flux from the flash through the supersoft state using eROSITA, Swift, NICER and Chandra data. The extrapolated NuSTAR flux[14] is multiplied by 100 for visibility. **b**, Short-term light curve before and after the X-ray flash showing the eROSITA count rate and the subsequent optical brightening. **c**, Fermi/LAT light curve showing the γ-ray activity starting a few days after the flash.

A new parameter space for time-domain research

What we have ("workhorses")

1) Long-term monitoring

   (>1 month)

1) Fast cadence

   (~1 min)

1) Consistent monitoring

   (very few data gaps and quasi-consistent cadance)

1) Large optical FOV

   (TESS ~24^o x 96^o)

What more we'd like! ("workunicorns")

1) Longer monitoring

   (> 1 year)

1) Faster cadence

   (but not necessary <5sec)

1) Rapid response

   (both ways in/out)

1) Simultaneous multi-wavelength

   (multi-opt + X-ray + radio + UV on selected targets)

1) Any UV observatory: Please!

A new parameter space for time-domain research

What we have

1) TESS
2) eROSITA (?!?)
3) MAXI - NICER
4) INTEGRAL – Swift
5) Fermi
6) …

What's to come!

1) Nancy Grace Roman Space Telescope

   (every ~15min for bulge – 5day high latitude)

1) PLATO

   (multi-band 25s or 2.5s)

1) GRINTA (?)

   (5-400 keV, large FOV)

1) ngVLA

Open questions

Broad-band variability

- **How does disk geometry/viscosity change with Mdot and radius? Do AWDs have an analogous "corona" as seen in XRBs?**

Mag. Gating

- **Why only a handful of AWDs show this? What are the "optimal" parameters to initiate mag. Gating? Does it happen in a specific evolutionary phase?**

tAWD

- **What causes the abrupt drops in luminosity/sudden reduction in Mdot? Can we make direct analogies to tMSPs? How are these related to mag. Gatiting and/or evolution?**

Micronovae

- **What triggers these, and how common are they? What are the implications of common micronovae to chemical enrichment and multi-messenger emission?**

Nova fireball

- **How long do they last and how much energy is released? Do all events show this?**

Extra slides…

How to trigger micronovae?

Scaringi+ (2022c)

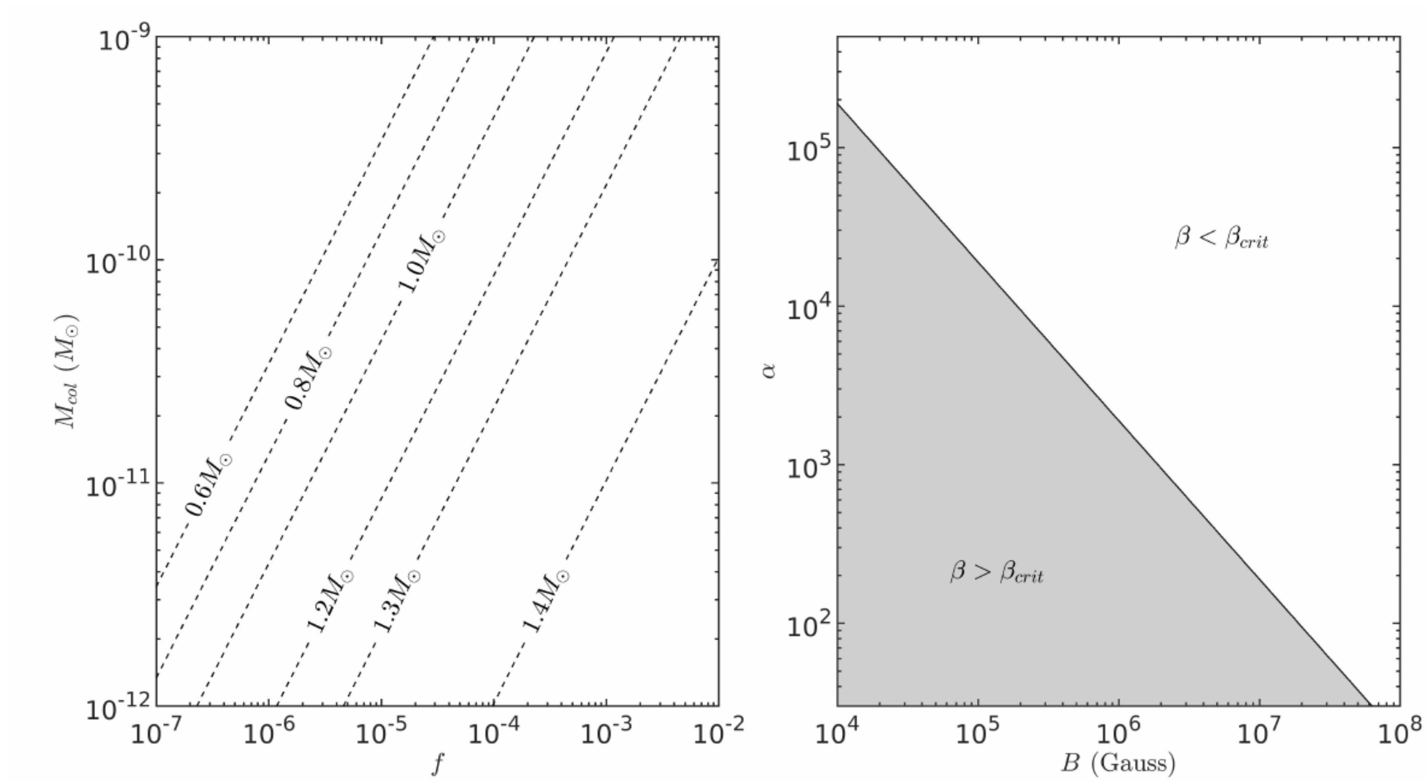
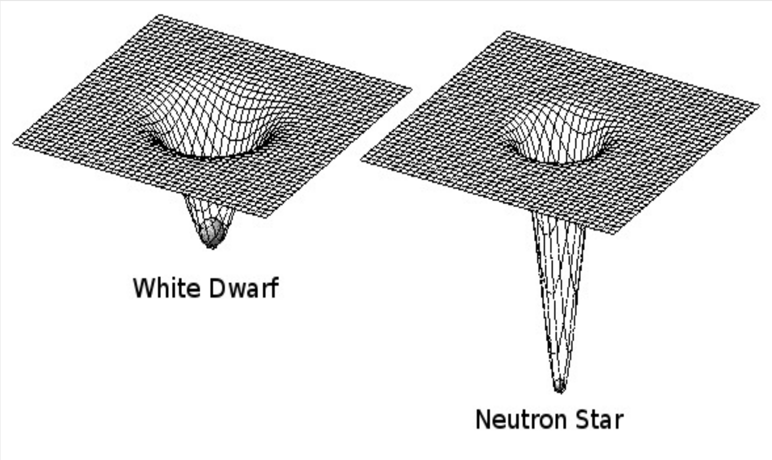


Figure 1. Left-panel: Range of column masses (M_{col}) required to reach $P_{base} \approx P_{crit} \approx 10^{18}$ dyn cm^{-2}. The plot has been computed with a range of WD masses as indicated by the dashed lines. Right-panel: Constraint on keeping the accretion column magnetically confined up to $P_{crit} = 10^{18}$ dyn cm^{-2}. Gray shaded region shows regions where the column pressure will be too high and break the magnetic confinement.

Accretion across the scales

- Disk theory supposedly the same across different system types
- Disk dynamics governed by the embedded gravitational potential:



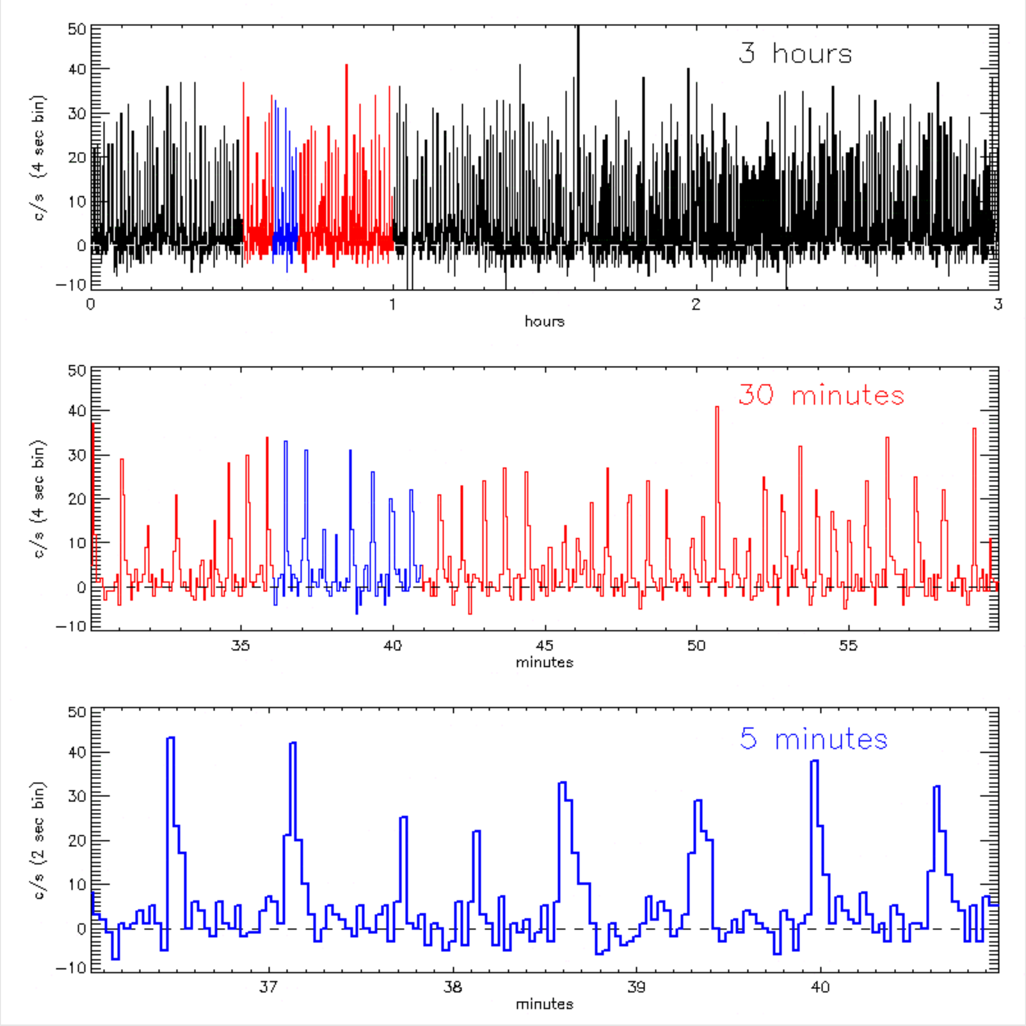
	BHs/NSs (XRBs)	WDs (CVs)	YSOs	AGN
Surface	~ km	~ thousand km	~ 10 million km	~ 10 million km
Emission	X-rays	Opt/UV	IR/Opt	UV/X-rays
t_{dyn}	~1 millisecond	~10 seconds	~2 days	~2 days
Dynamic Range	$\sim 10^7$	~300	$\sim 10^6$	$\sim 10^8$

Rapid Bursters

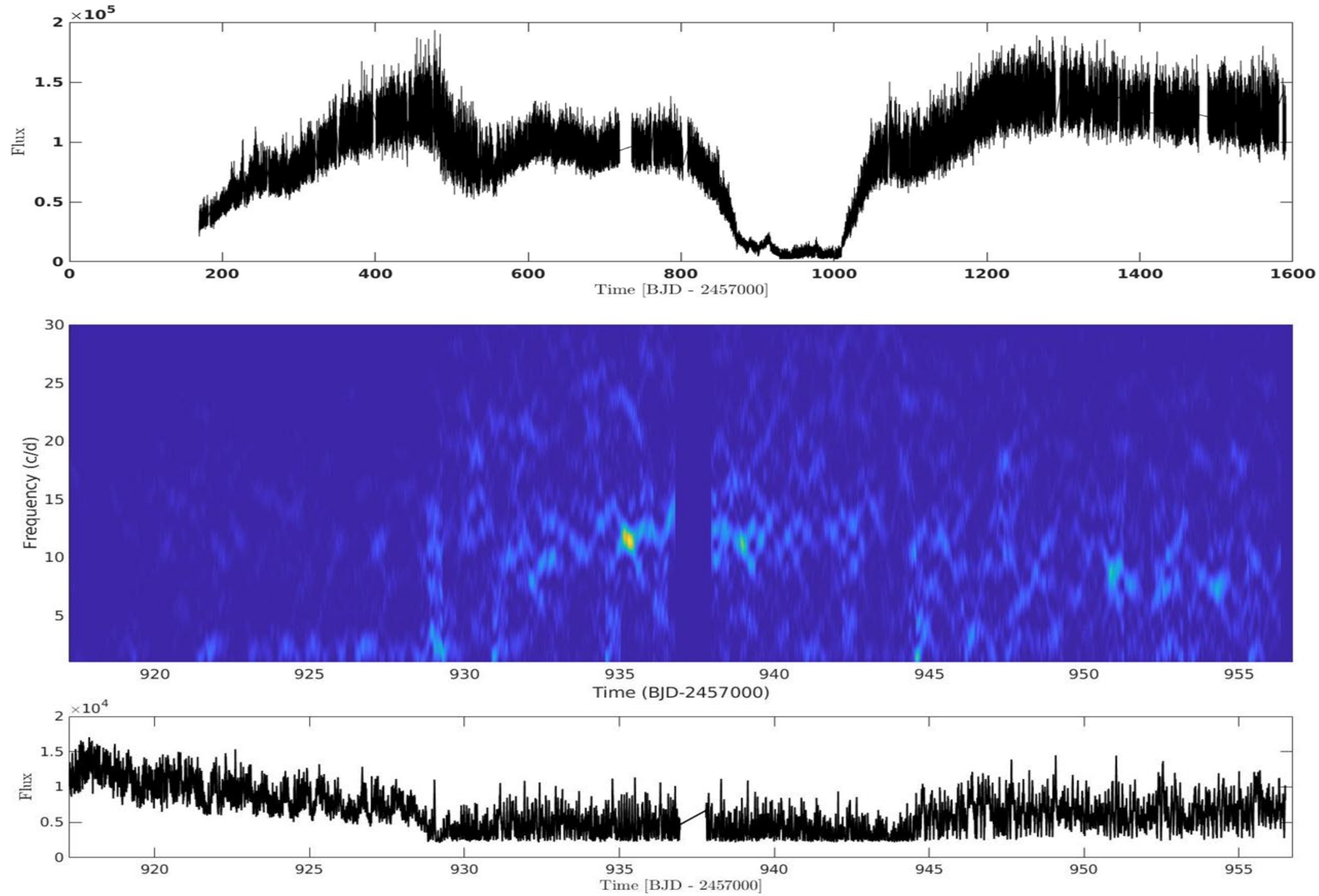
- Accreting neutron stars with excess power in the kHz regime
- Only ~5 known to date
- Very short bursts (few seconds)
- Best explained through magnetically gated accretion

Spruit & Taam (1993), Patruno+ (2009), D'Angelo & Spruit (2010,2012), Patruno & D'Angelo (2013), Bagnoli+ (2015), van den Eijnden+ (2016), Kuulkers+ (200), etc...*

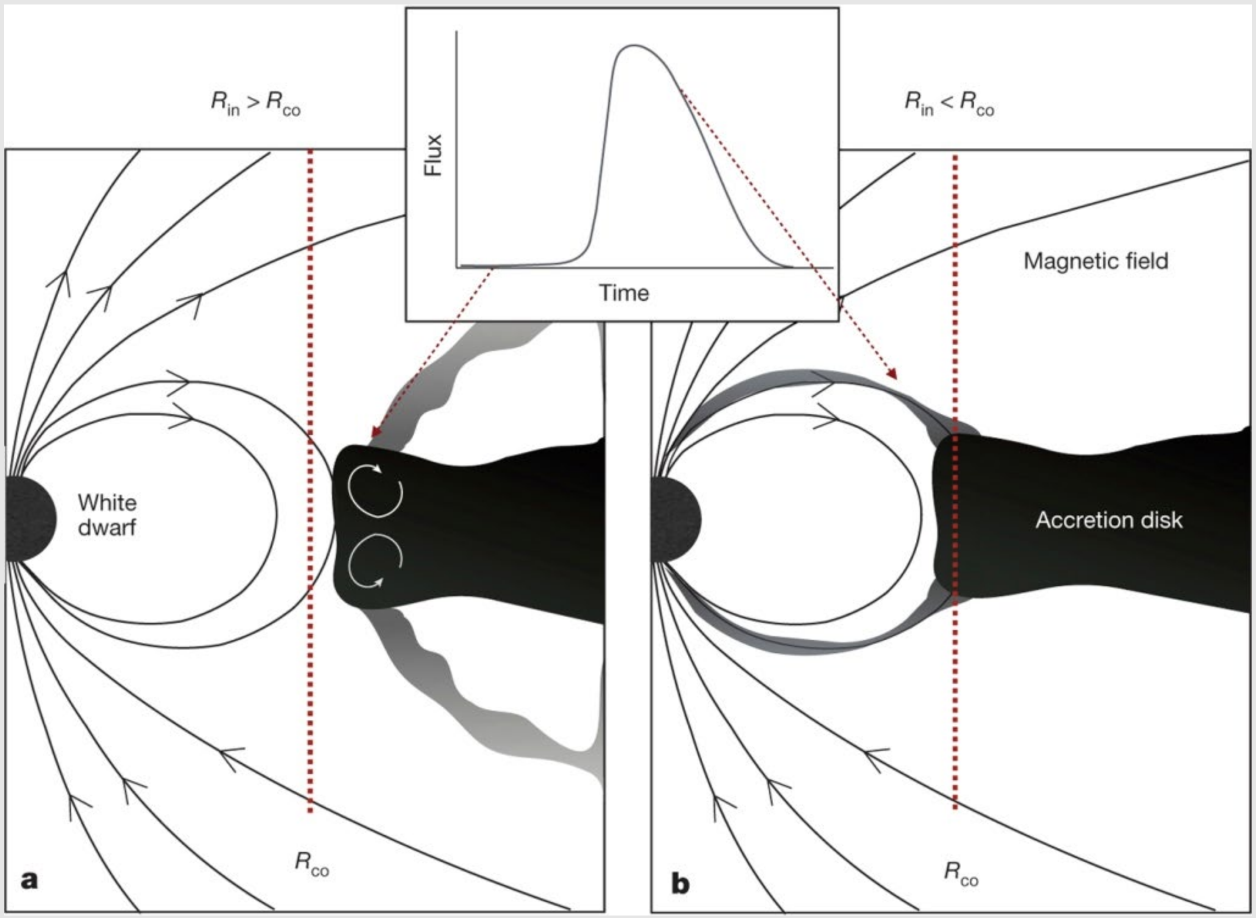
MXB 1730-335



Magnetically gated accretion

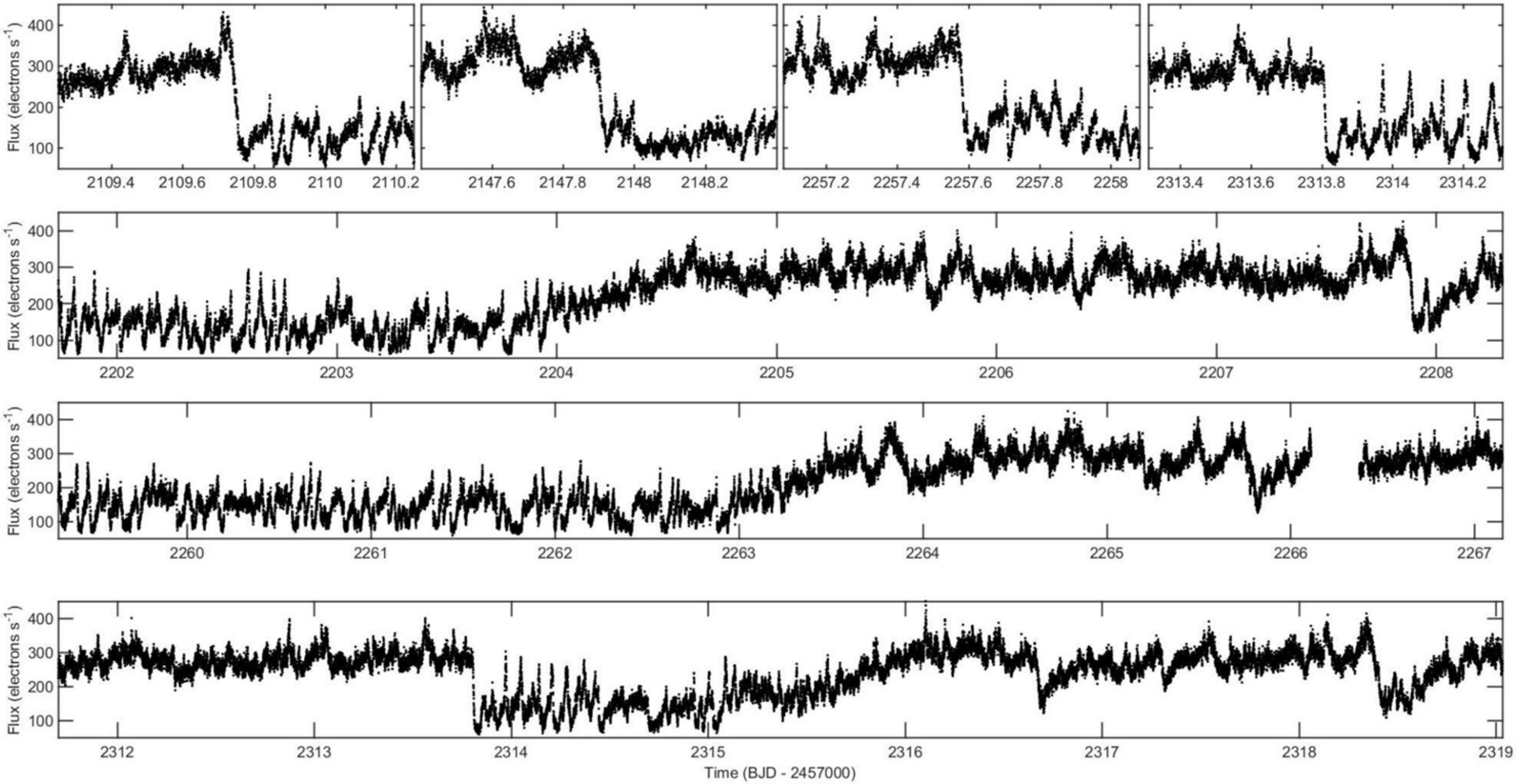


Magnetically gated accretion



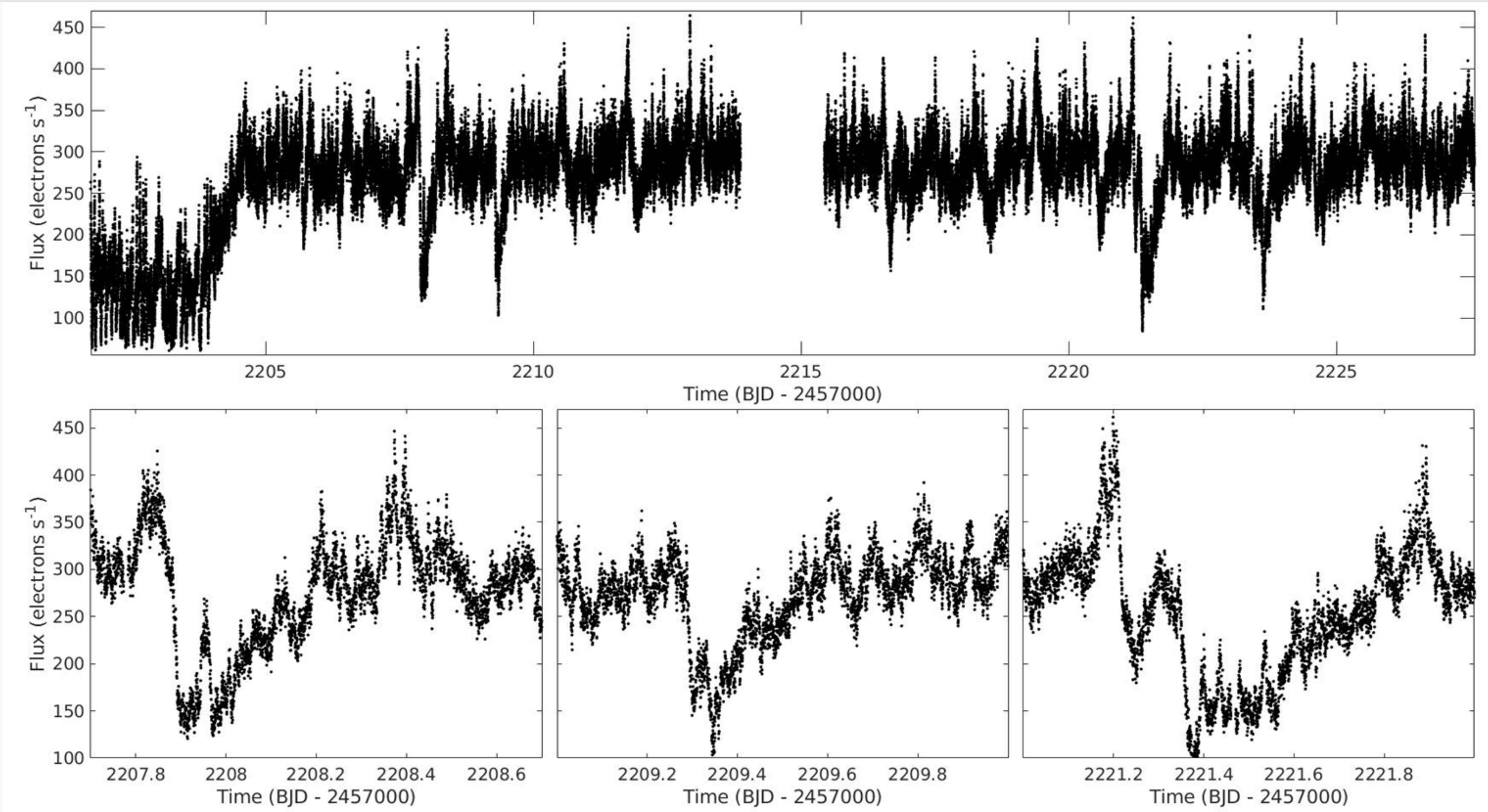
Scaringi+ (2017)

TW Pictoris



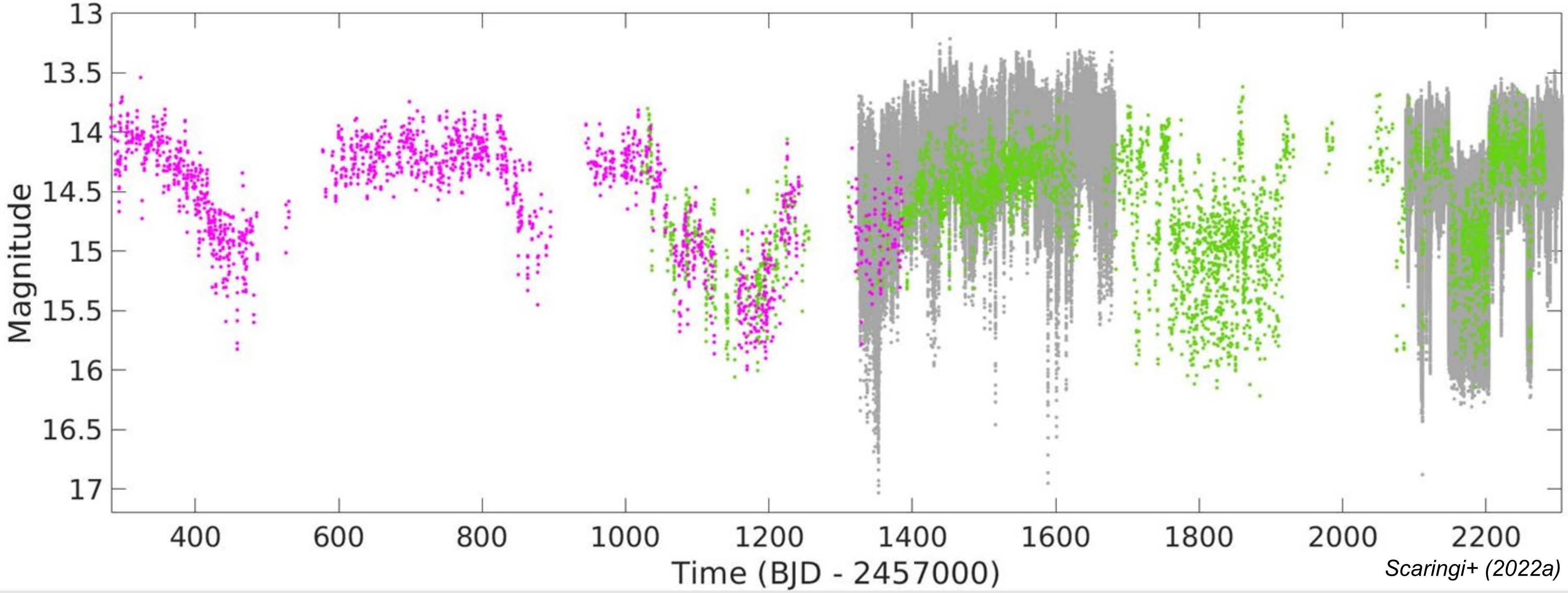
Scaringi+ (2022a)

TW Pictoris



Scaringi+ (2022a)

TW Pictoris
including Cycle 1 and ASAS-SN



Scaringi+ (2022a)

DW Cnc

…IP…

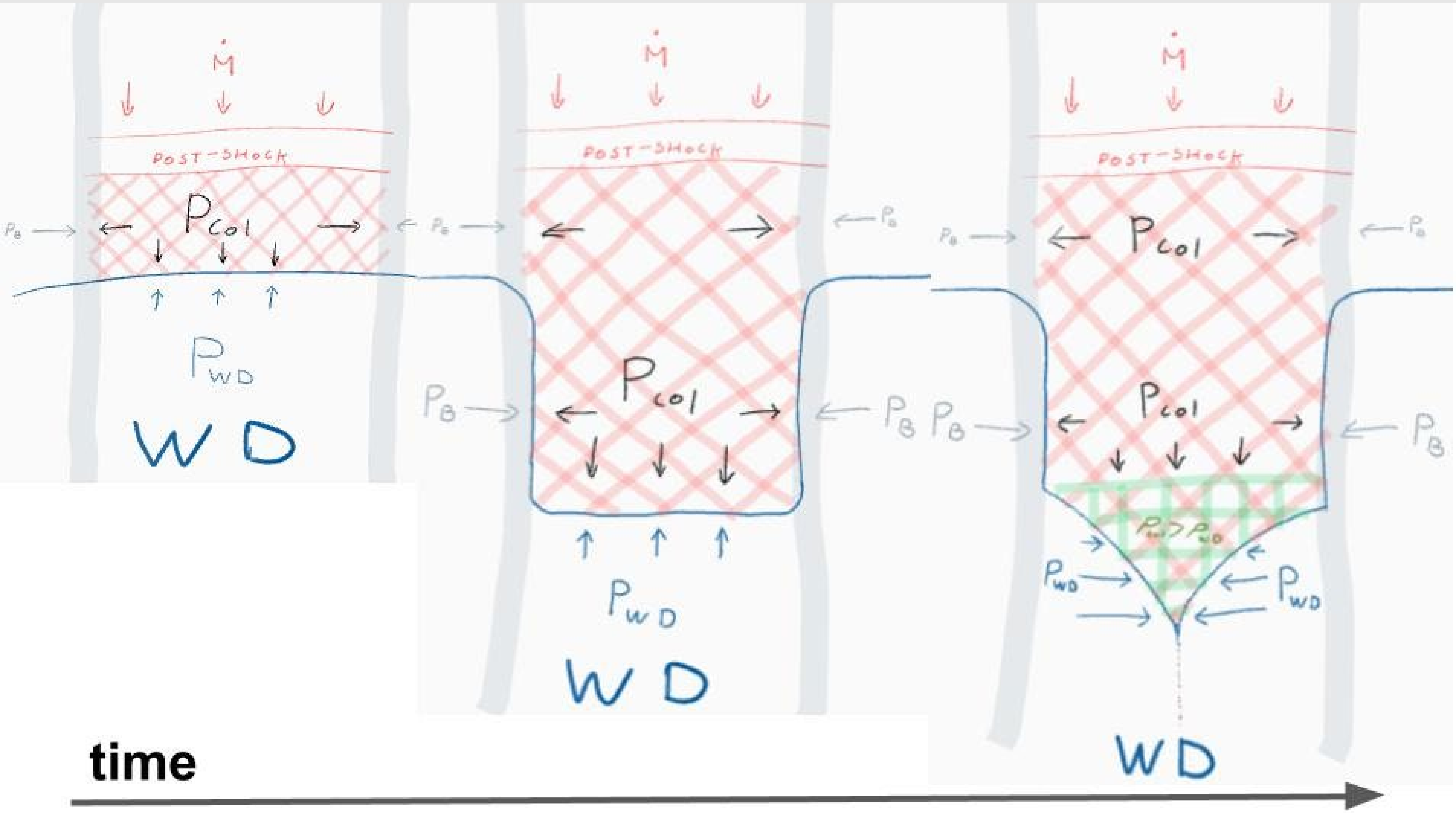
The return of the spin period in DW Cnc and evidence of new high state outbursts

C. Duffy,[1,2★] G. Ramsay,[1] D. Steeghs,[2,8] M. R. Kennedy,[3,4] R. G. West,[2] P. J. Wheatley,[2] V. S. Dhillon,[5,6] K. Ackley,[2,7,8] M. J. Dyer,[5] D. K. Galloway,[7,8,9] S. Gill,[2] J. S. Acton,[10] M. R. Burleigh,[10] S. L. Casewell,[10] M. R. Goad,[10] B. A. Henderson,[10] R. H. Tilbrook,[10] P. A. Strøm,[2] D. R. Anderson [2]

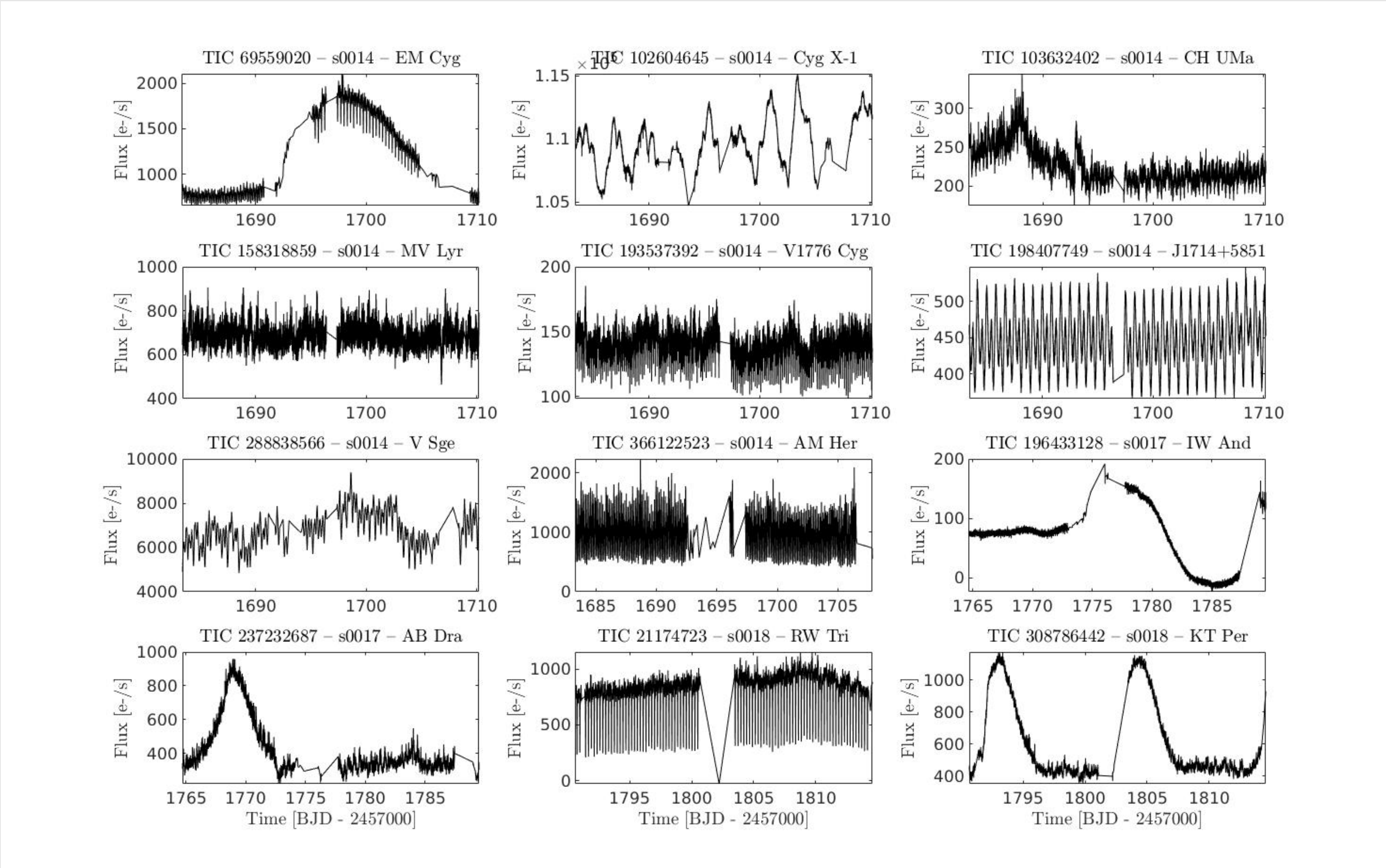
ABSTRACT

DW Cnc is an intermediate polar which has previously been observed in both high and low states. Observations of the high state of DW Cnc have previously revealed a spin period at ~ 38.6 min, however observations from the 2018/19 low state showed no evidence of the spin period. We present results from our analysis of 12 s cadence photometric data collected by NGTS of DW Cnc during the high state which began in 2019. Following the previously reported suppression of the spin period signal we identify the return of this signal during the high state, consistent with previous observations of it. We identify this as the restarting of accretion during the high state. We further identified three short outbursts lasting ~ 1 d in DW Cnc with a mean recurrence time of ~ 60 d and an amplitude of ~ 1 mag. These are the first outbursts identified in DW Cnc since 2008. Due to the short nature of these events we identify them not as a result of accretion instabilities but instead either from instabilities originating from the interaction of the magnetorotational instability in the accretion disc and the magnetic field generated by the white dwarf or the result of magnetic gating.

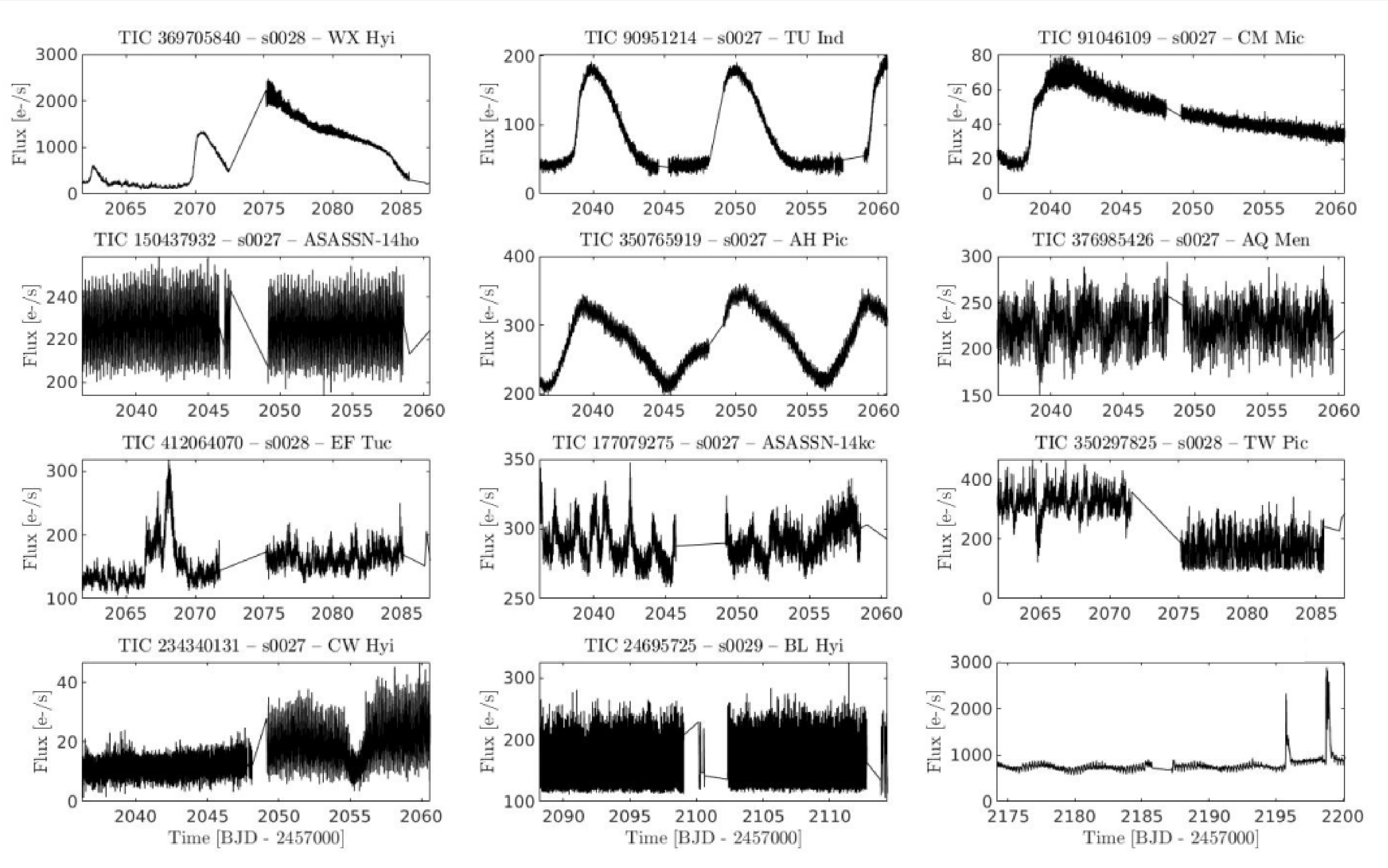
Density-driven Instabilities?



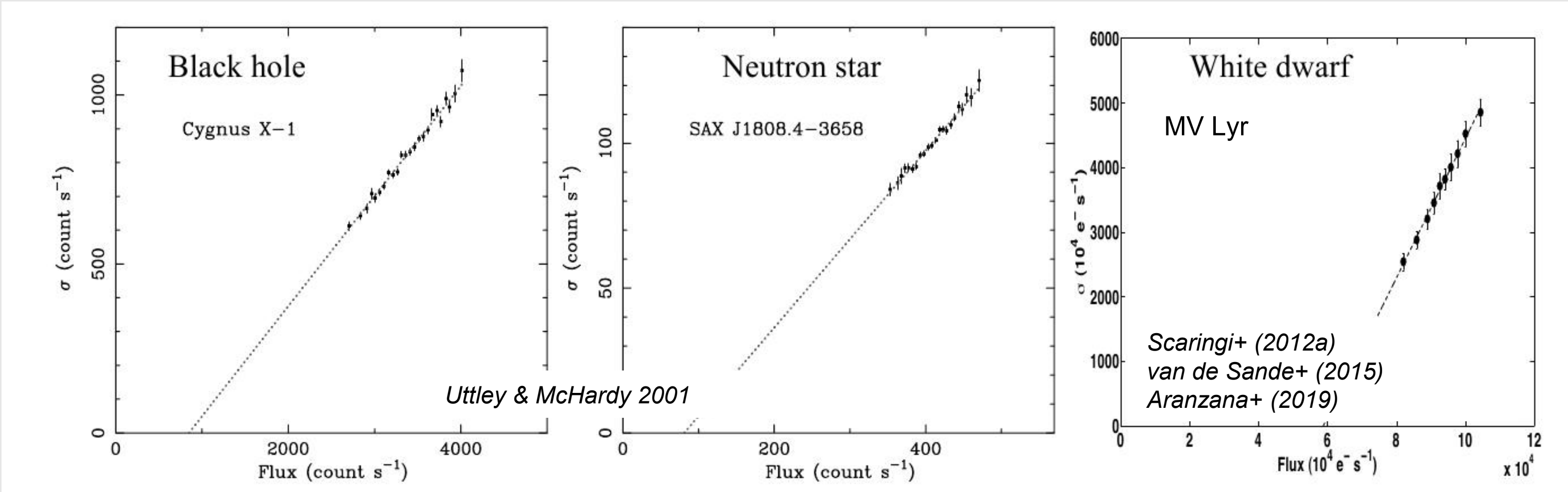
TESS atlas of AWD – Cycle 2



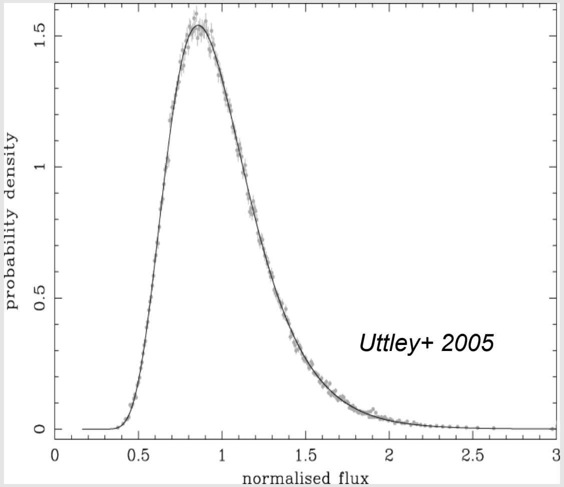
TESS atlas of AWD – Cycle 3



The rms-flux relation

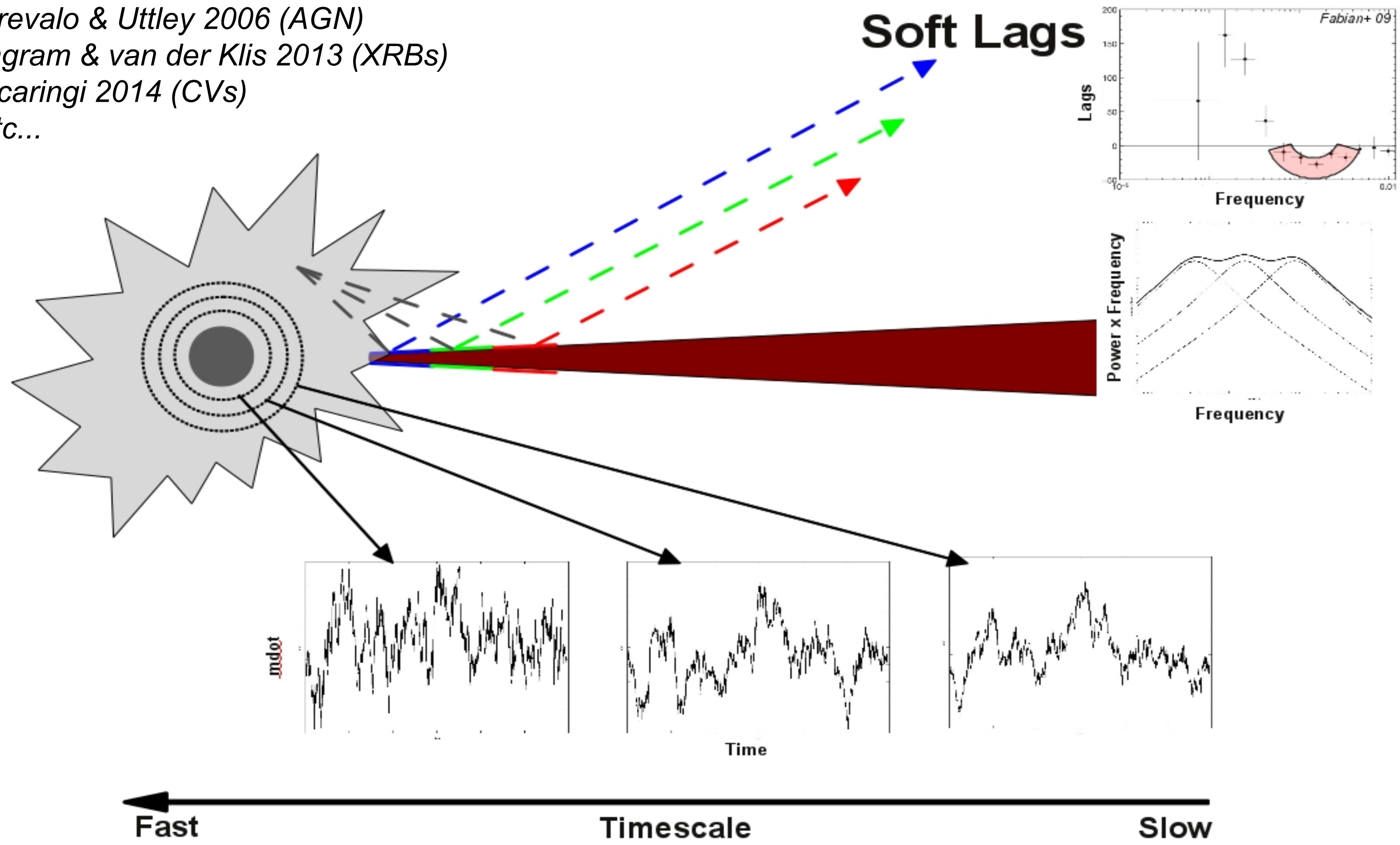


- Flux distributions are log-normal
- → Additive processes ruled out!
- Observed lightcurves must be the result of *multiplicative* processes

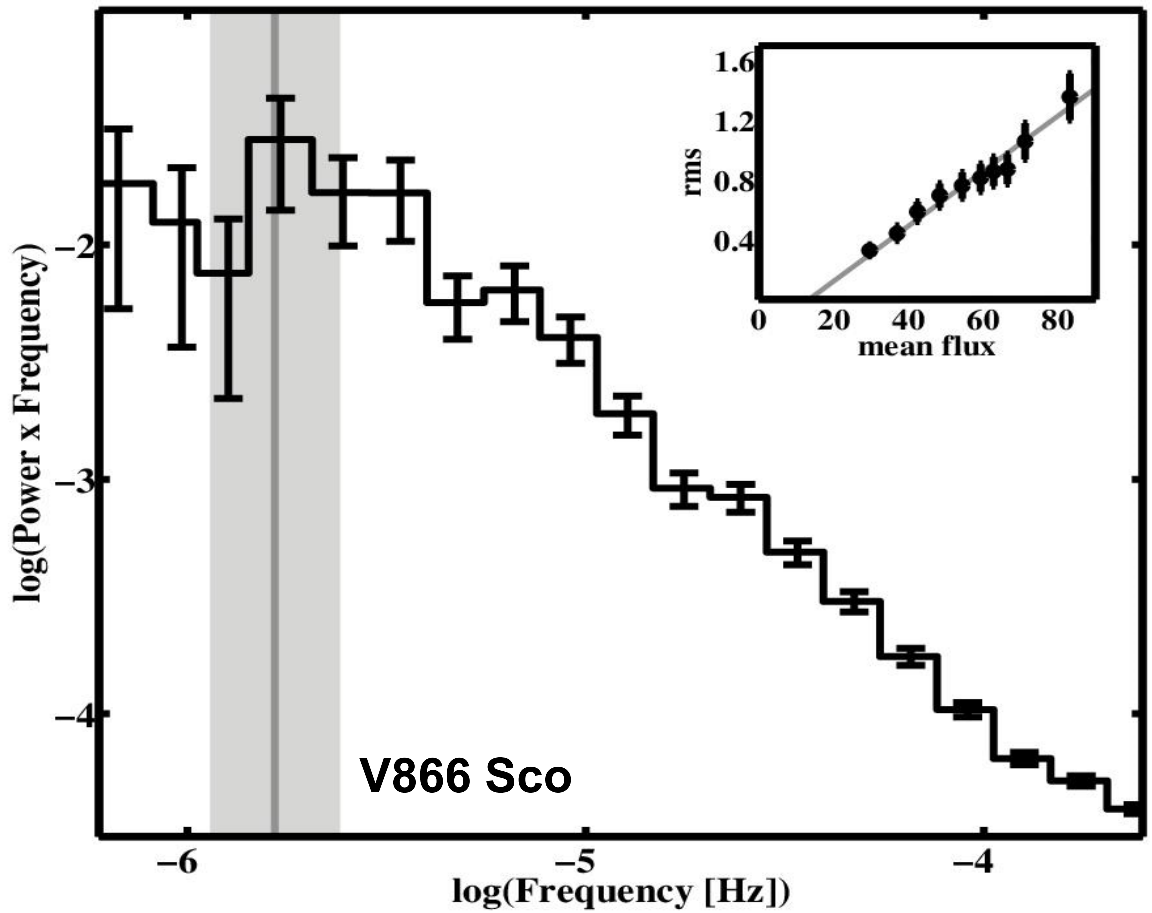


Fluctuating Accretion disks

Lyubarskii 1997
Arevalo & Uttley 2006 (AGN)
Ingram & van der Klis 2013 (XRBs)
Scaringi 2014 (CVs)
etc...

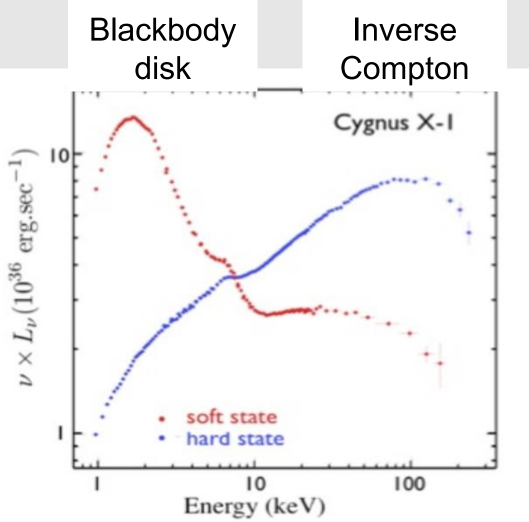


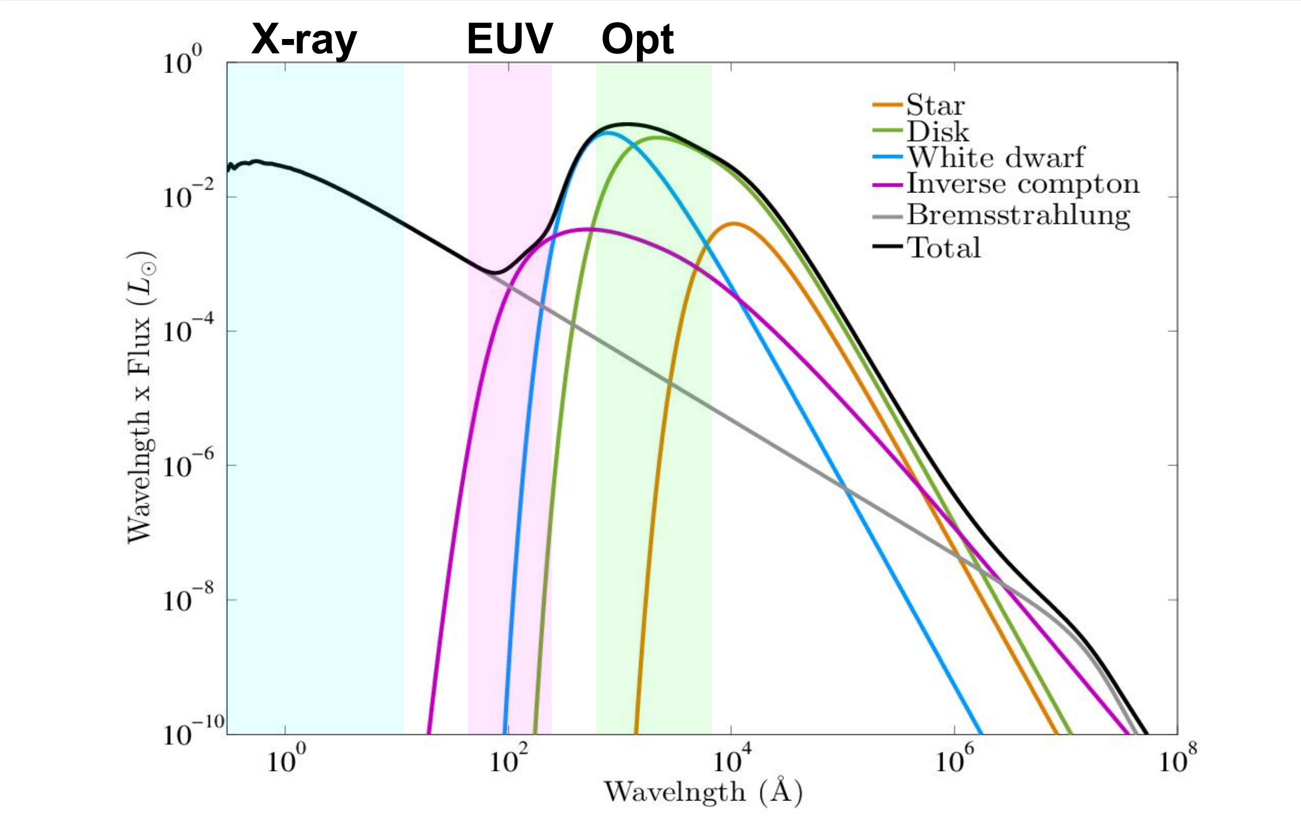
YSOs join the family!



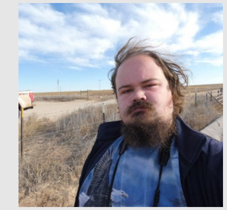
Scaringi+ (2015b)

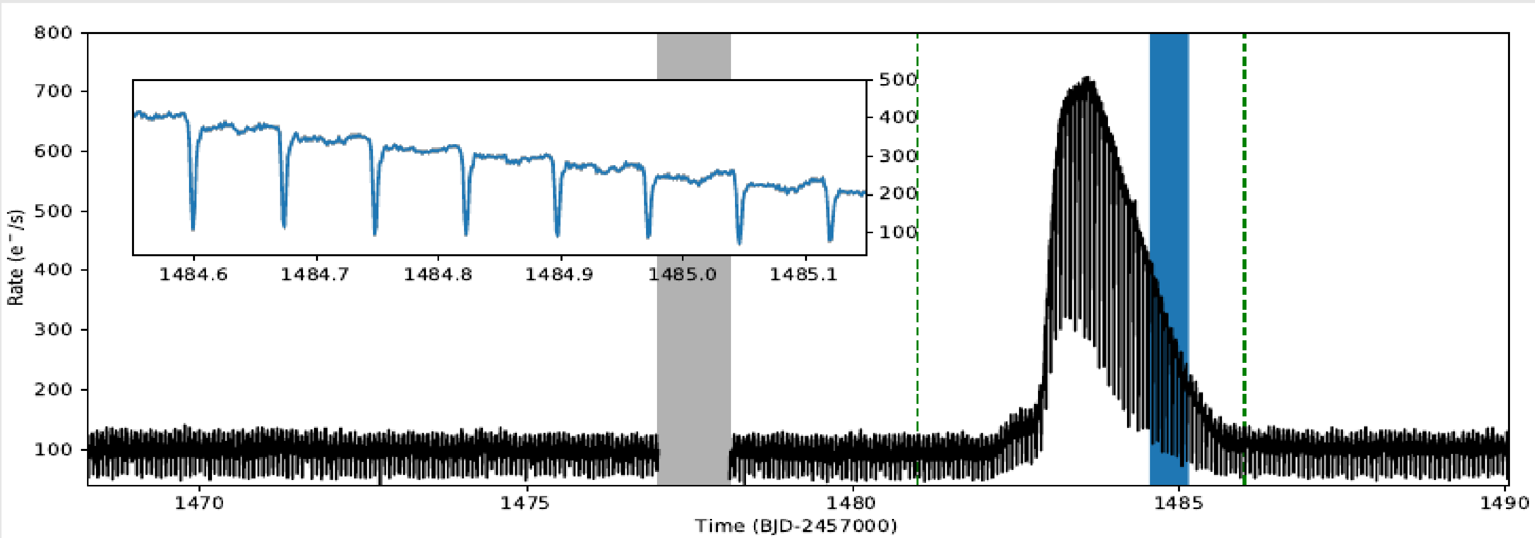
Fluctuating Accretion disk:
how can we test for "corona" in CVs?





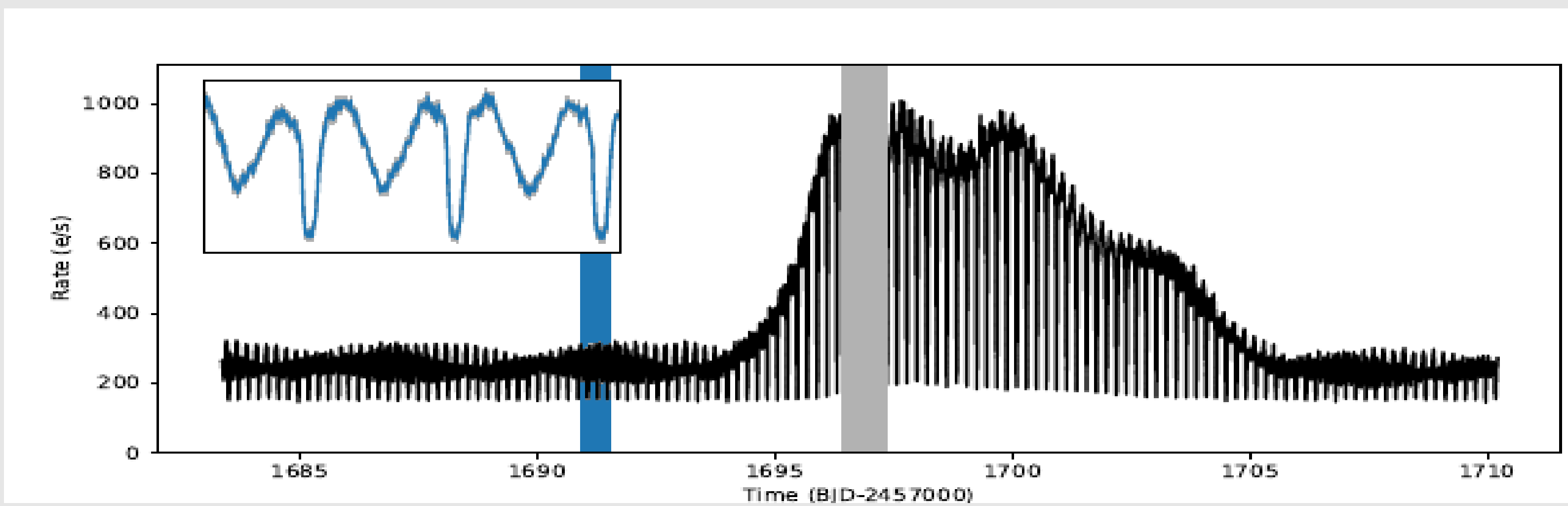
Z Cha & EX Dra





Z Cha

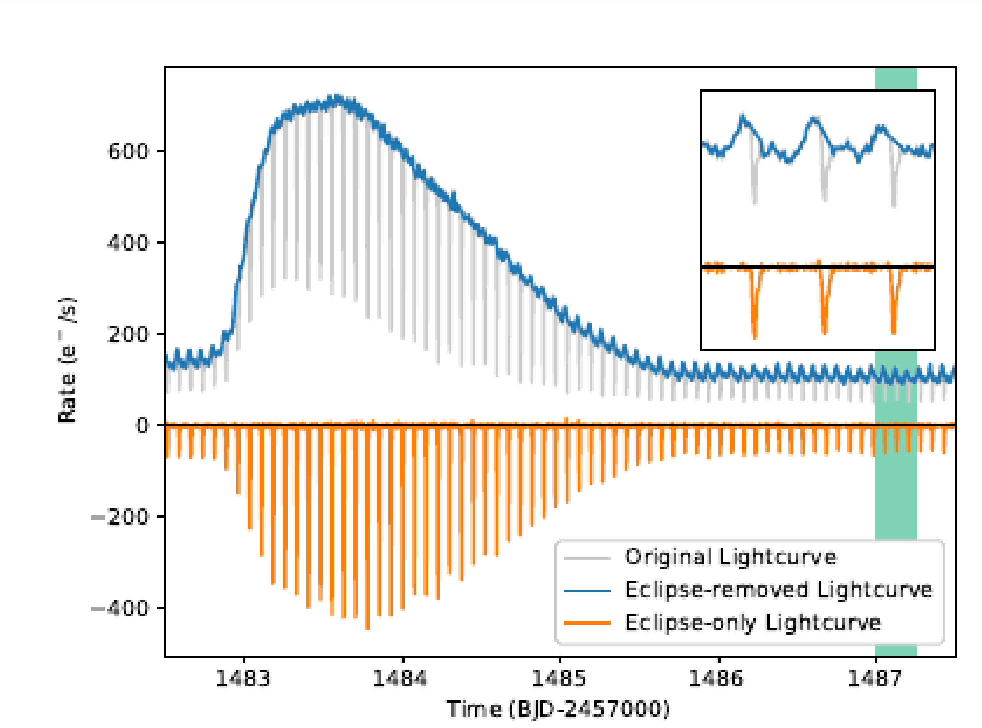
EX Dra



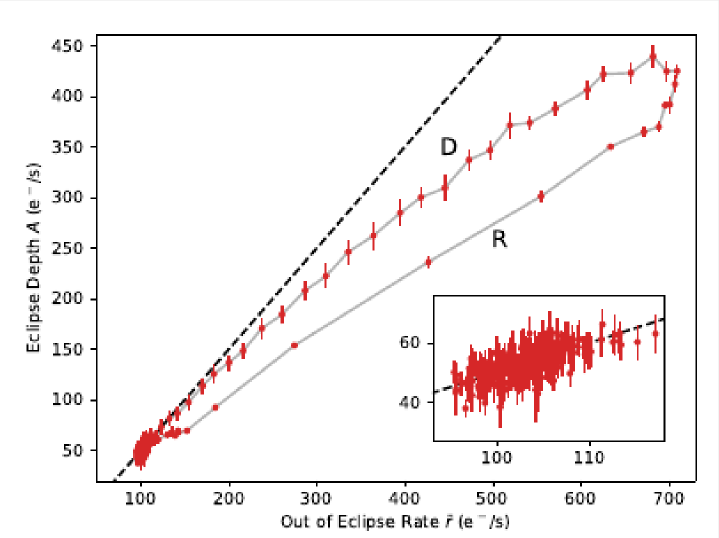
Court+ (2019)
Court+(2020)

Z Cha

Outside-in outburst evolution



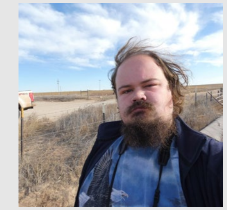
Clear hysteresis during dwarf nova outburst evolution

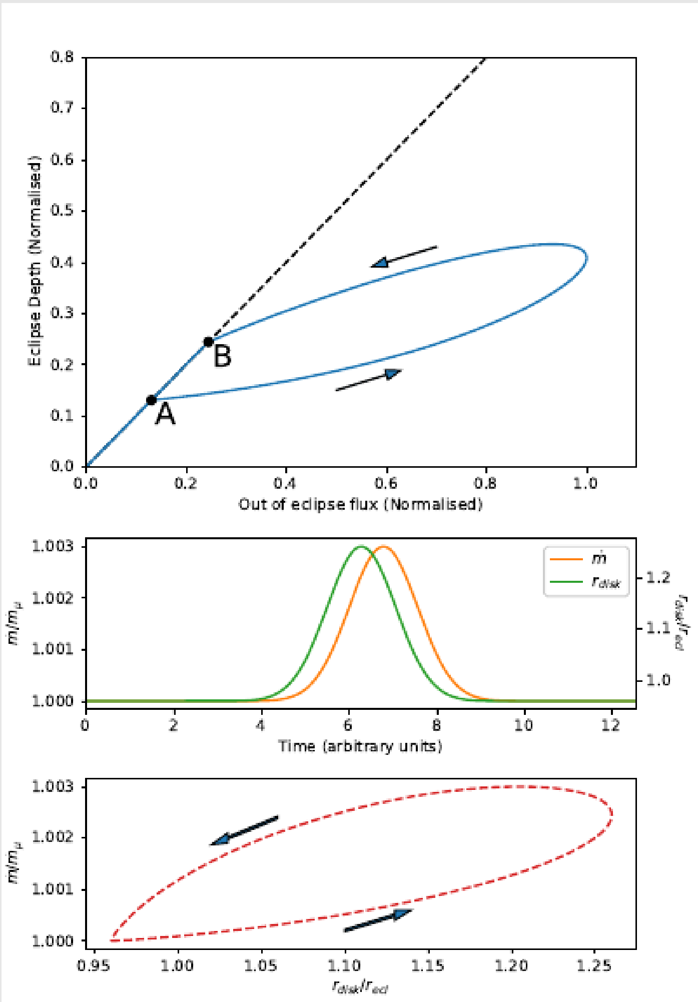


Court+ (2019)
Scaringi+ (2013)

Z Cha

Outside-in outburst evolution





$$L(\dot{M}, R_{\rm out}) = \frac{1}{2}\int_{R_{\rm in}}^{R_{\rm out}} \sigma 2\pi R T^4(R)\,{\rm d}R$$

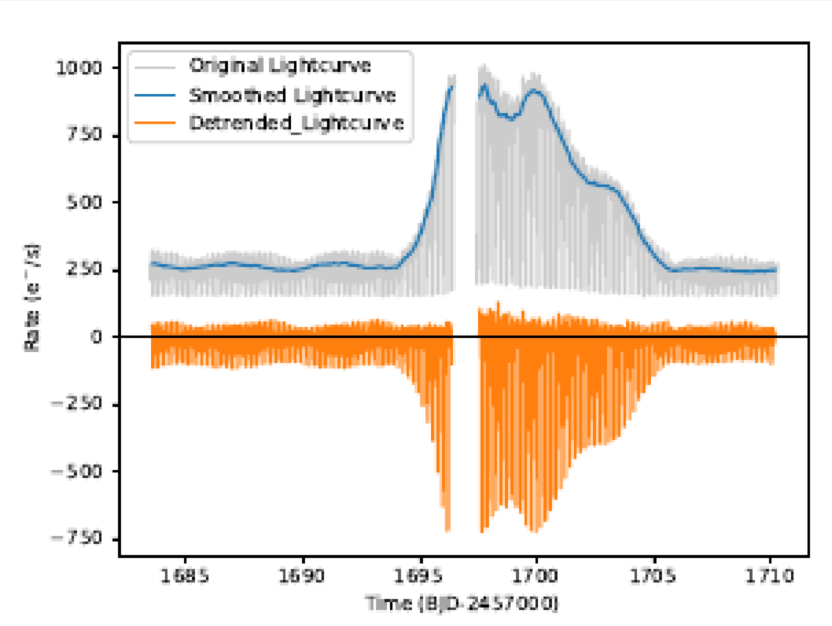
$$\propto \dot{M}\left(\frac{2\sqrt{R_*}}{3R_{\rm out}\sqrt{R_{\rm out}}} - \frac{1}{R_{\rm out}} + \frac{1}{3R_*}\right)$$

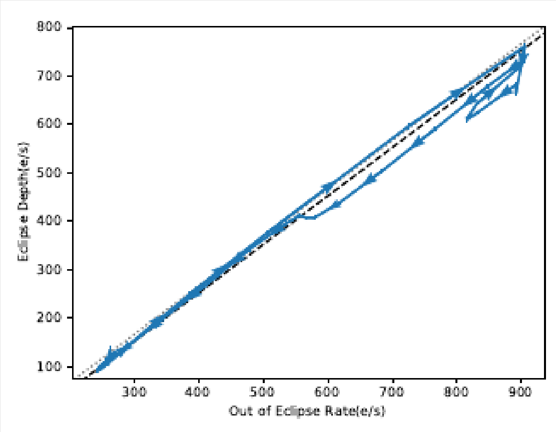
Hysteresis must be caused by outer disk size increasing **before** mass transfer rate increase
→ outside-in outburst

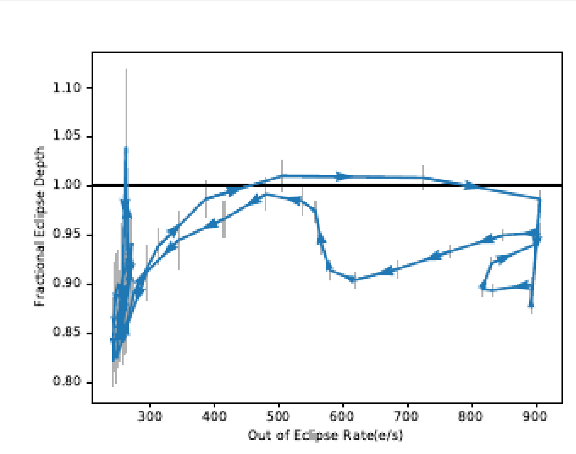
Court+ (2019)

EX Dra

Inside-out outburst evolution



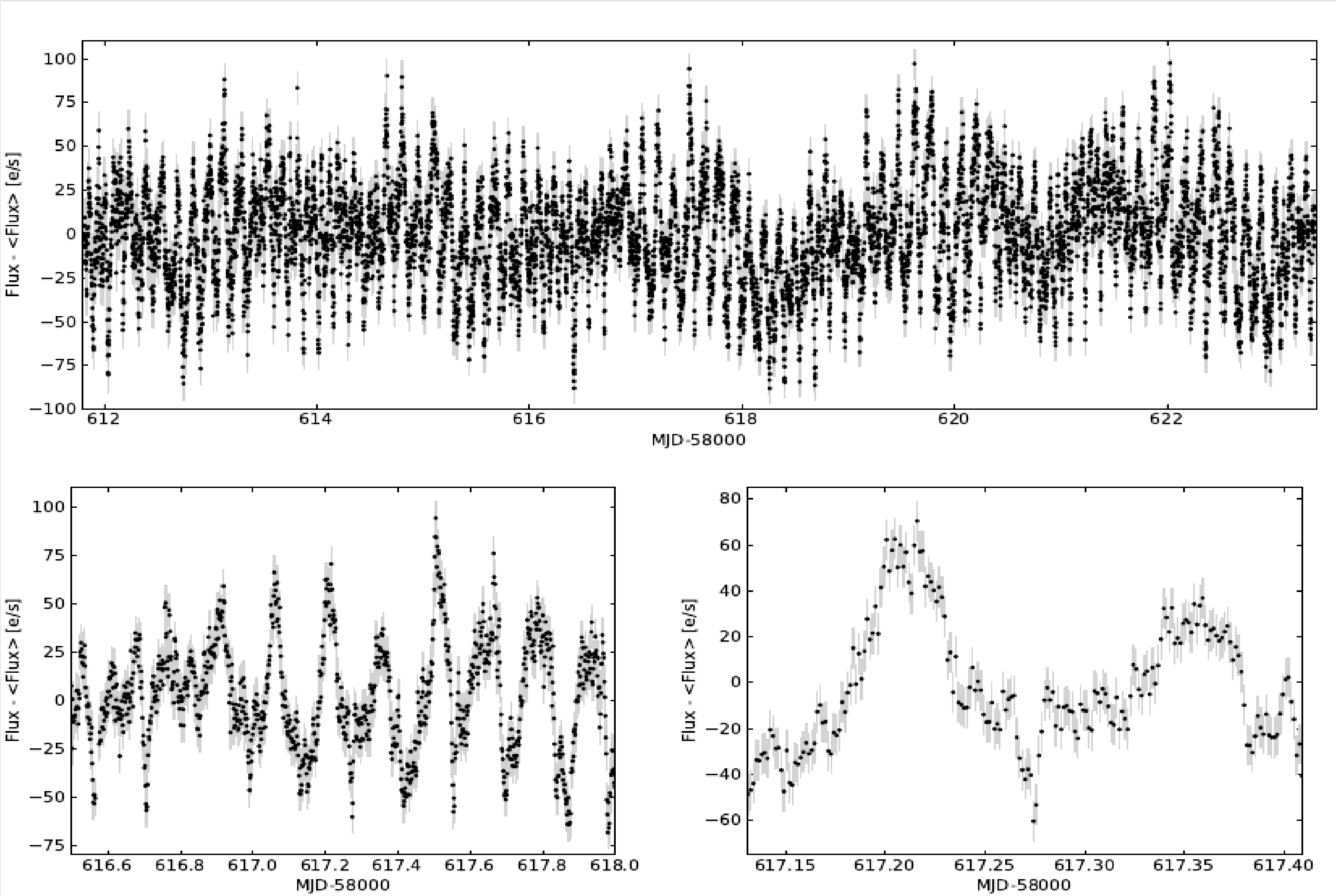




Hysteresis must be caused by mass transfer increasing **before** outer disk radius
→ inside-out outburst

Court+ (2020)

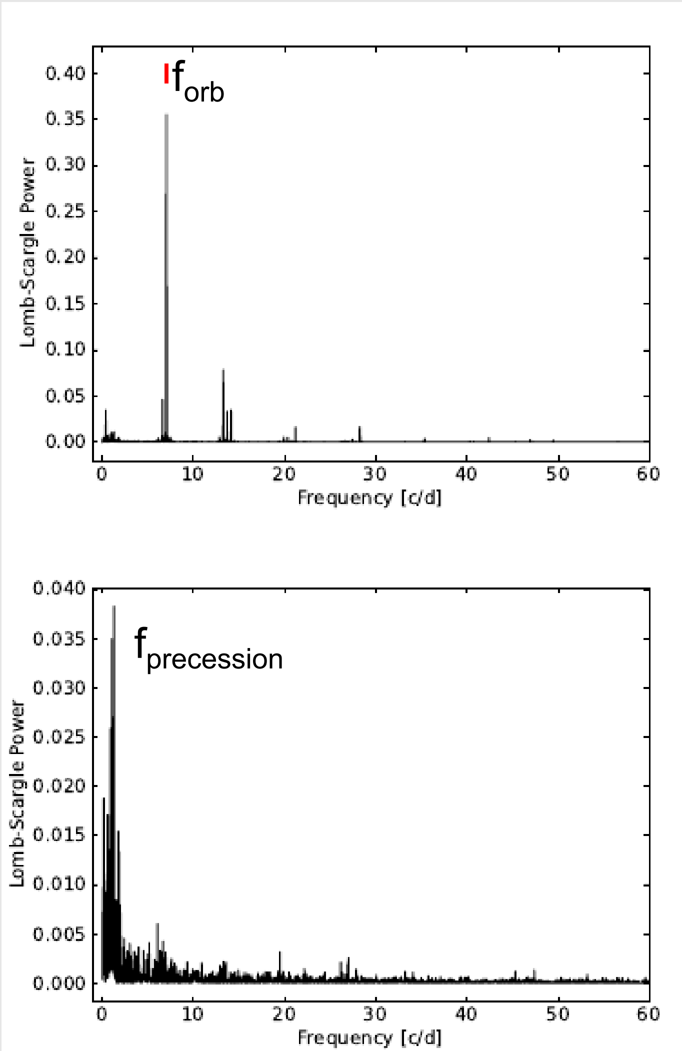
AQ Men
exploring the tilted disk



Ilkiewicz+ (2021)

AQ Men

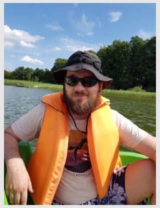
exploring the tilted disk

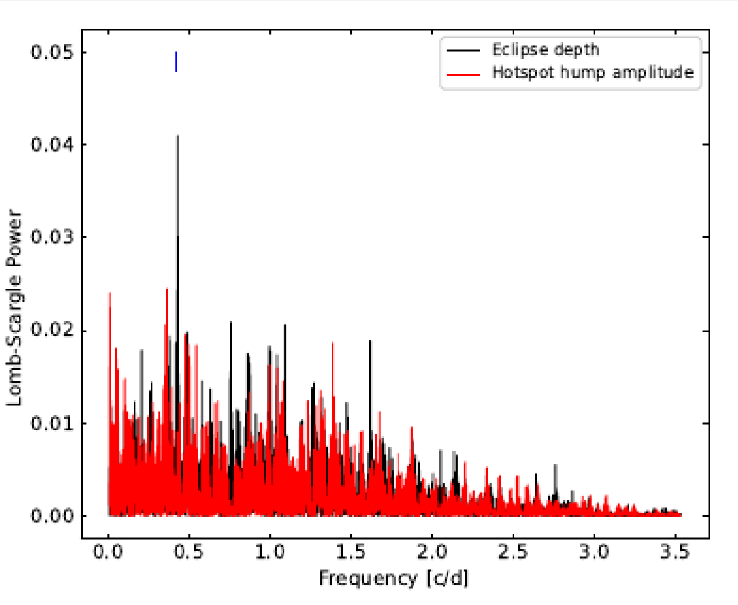


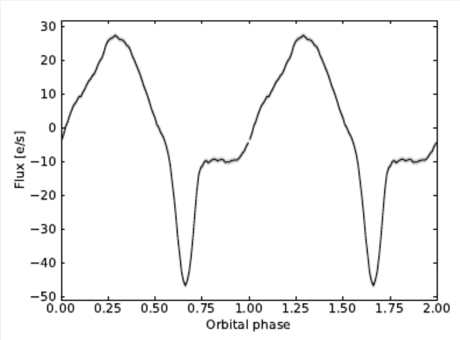
ID	Frequency [c/d]	Amplitude [e/s]	MJD_0
ω_0	7.06869(13)	24.66(17)	58667.68379(16)
$2\omega_+$	13.29413(28)	11.25(17)	58667.67647(18)
ω_+	6.64591(34)	9.42(17)	58667.71802(42)
N	0.42093(41)	7.78(17)	58668.449(8)
$2\omega_0$	14.13860(41)	7.70(17)	58667.64725(24)
$2\omega_0$-N	13.71513(44)	7.28(17)	58667.70072(27)
$4\omega_0$	28.27526(60)	5.29(17)	58667.68000(18)
$3\omega_0$	21.20627(62)	5.10(17)	58667.69222(25)
ω_-	7.4890(10)	3.42(17)	58667.69220(11)
$2\omega_0$-3N	12.8742(11)	3.08(17)	58667.7019(7)
$3\omega_+$	19.9415(11)	3.11(17)	58667.65870(43)
$3\omega_0$-2N	20.3658(11)	2.91(17)	58667.69293(45)
ω_0-2N	6.2228(12)	2.84(17)	58667.7486(15)
$6\omega_0$	42.4152(12)	2.71(17)	58667.66454(24)
$5\omega_0$	35.3431(13)	2.56(17)	58667.67009(30)
$4\omega_0$-2N	27.4305(14)	2.32(17)	58667.68465(42)
$7\omega_0$-6N	46.9523(15)	2.11(17)	58667.68200(27)
$7\omega_0$	49.4830(17)	1.89(17)	58667.68073(29)
$2\omega_0$+N	14.5574(19)	1.68(17)	58667.6597(11)
$4\omega_+$	26.5834(21)	1.53(17)	58667.68059(65)
$3\omega_0$-N	20.7830(21)	1.51(17)	58667.67364(84)
$6\omega_0$-5N	40.3054(24)	1.36(17)	58667.66312(49)
$8\omega_0$	56.5535(29)	1.09(17)	58667.67454(44)
$6\omega_0$-4N	40.7268(32)	0.99(17)	58667.66489(66)

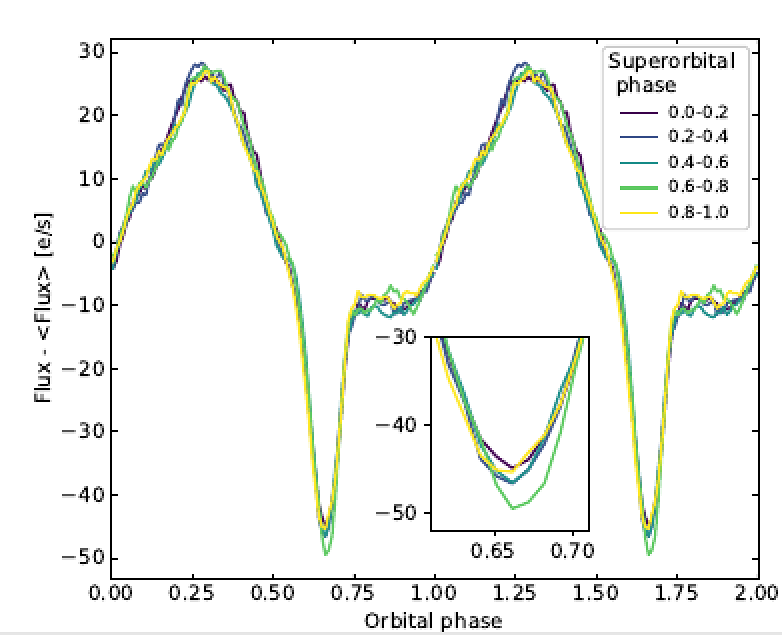
Ilkiewicz+ (2021)

AQ Men
exploring the tilted disk









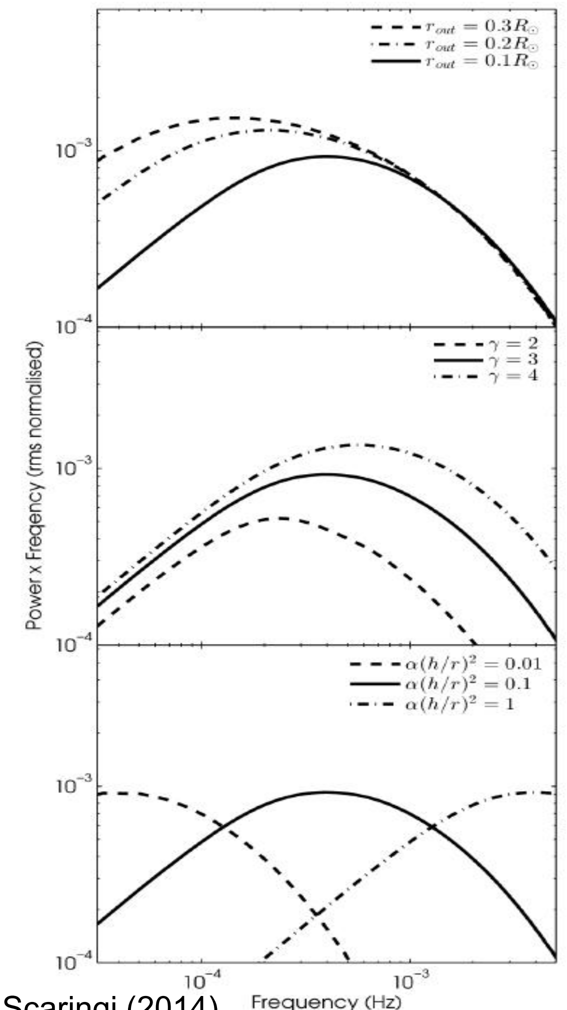
Eclipse depth variations on tilted disk precession period

Ilkiewicz+ (2021)

Fluctuating Accretion disks

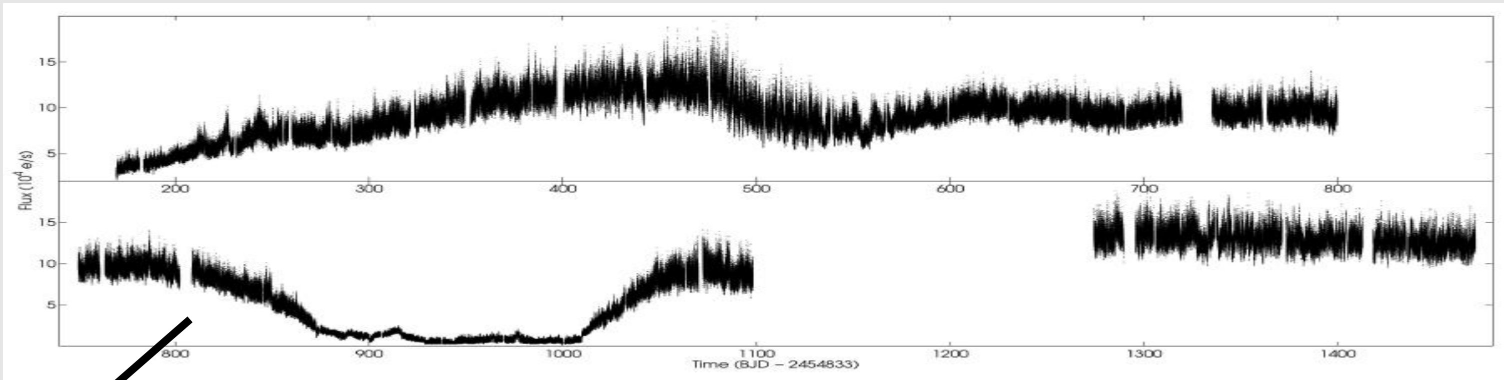
1) Fix $M_{WD} \rightarrow R_{WD}$ (mass-radius relation)
2) Set $r_{in} = R_{WD}$
(assume disk extends to WD surface)
3) Fit **4 free parameters**:

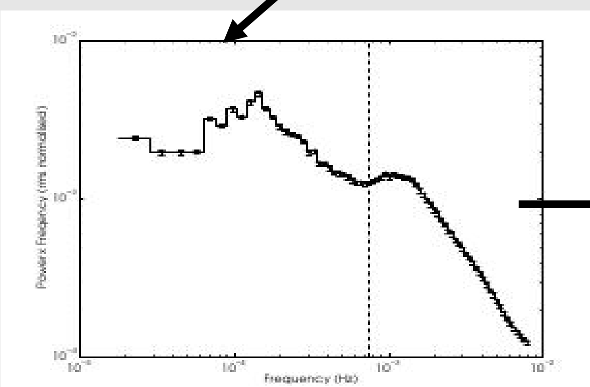
r_{out} = outer disk radius
$\alpha(h/r)^2$ = viscosity and disk scale height
γ = emissivity index
F_{var} = fractional variability per radial decade

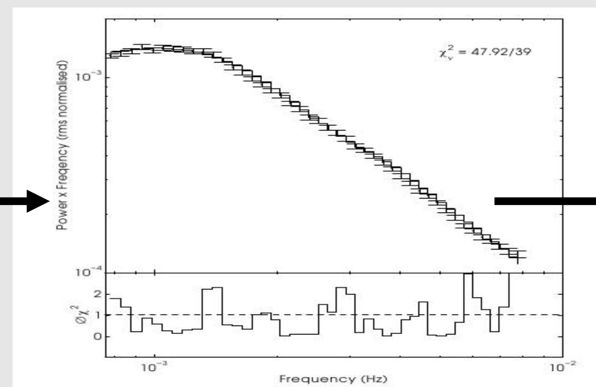


Scaringi (2014)

Fluctuating Accretion disk:
what generates the variability?







$M_{WD}(M_\odot)$	$\equiv 0.73$
$r_{in}(R_\odot)$	$\equiv 0.0105$
$r_{out}(R_\odot)$	$0.117^{+0.029}_{-0.020}$
γ	$0.853^{+0.047}_{-0.041}$
$\alpha(h/r)^2$	$0.705^{+0.289}_{-0.182}$
F_{var}	$0.220^{+0.001}_{-0.001}$

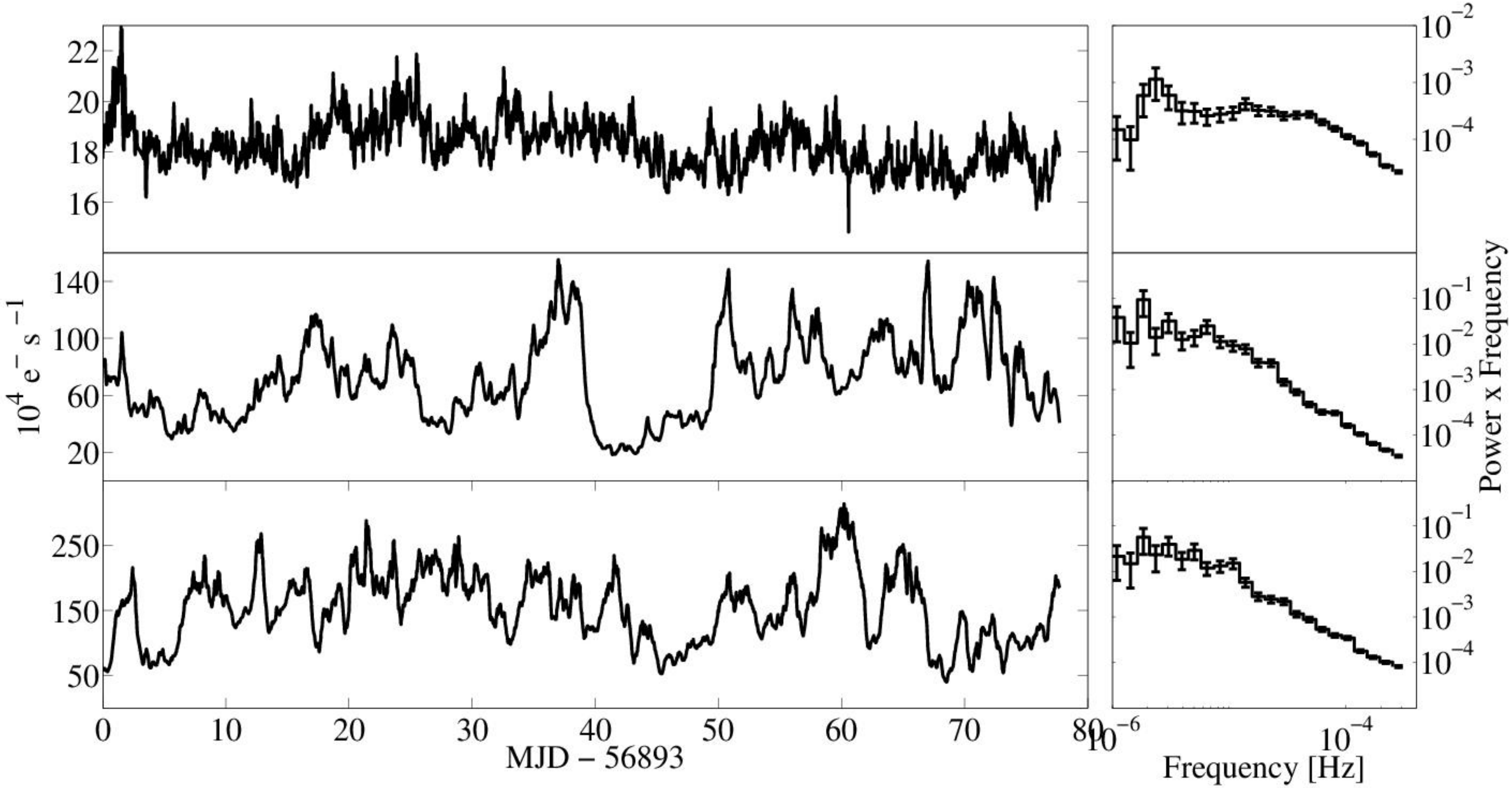
Scaringi (2014)
see also Dobrotka+ (2015,2016)

Geometrically thick disk close to the WD with large viscosity parameter?

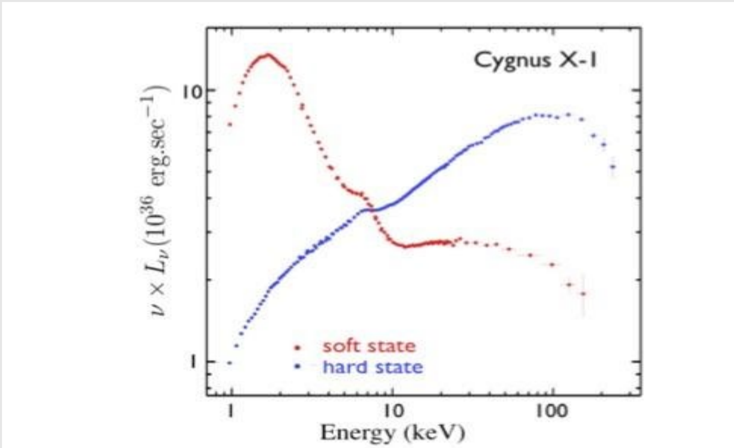
also inferred from eclipse mapping studies:

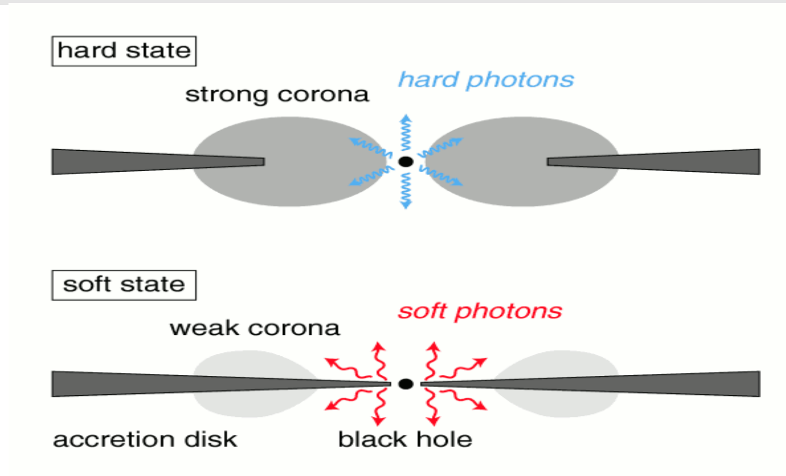
Feline+ (2005), Wood+ (1986,1992), Groot+ (2000,2004), Baptista&Bortoletto (2004), etc...

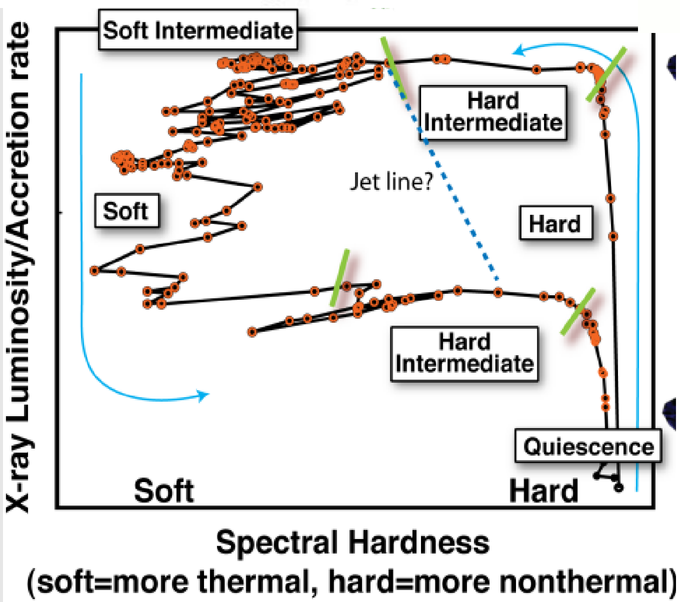
Accretion-driven flickering:
YSO variability

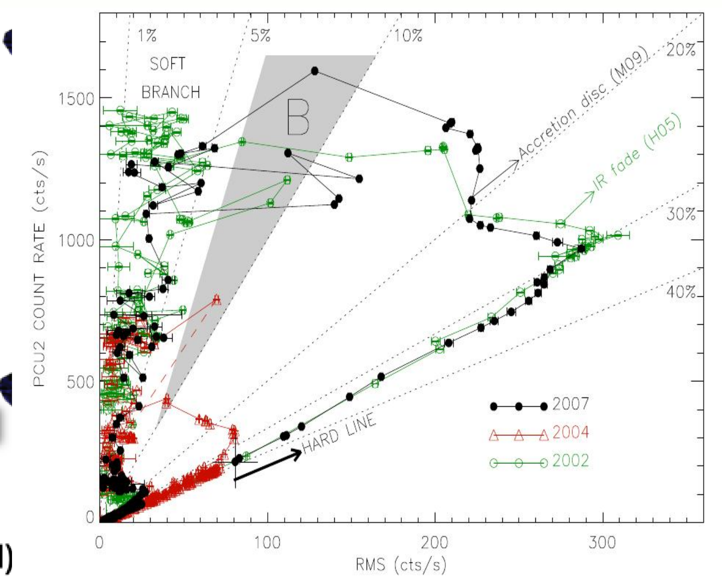


Fluctuating Accretion disk:
what generates the variability in XRBs?

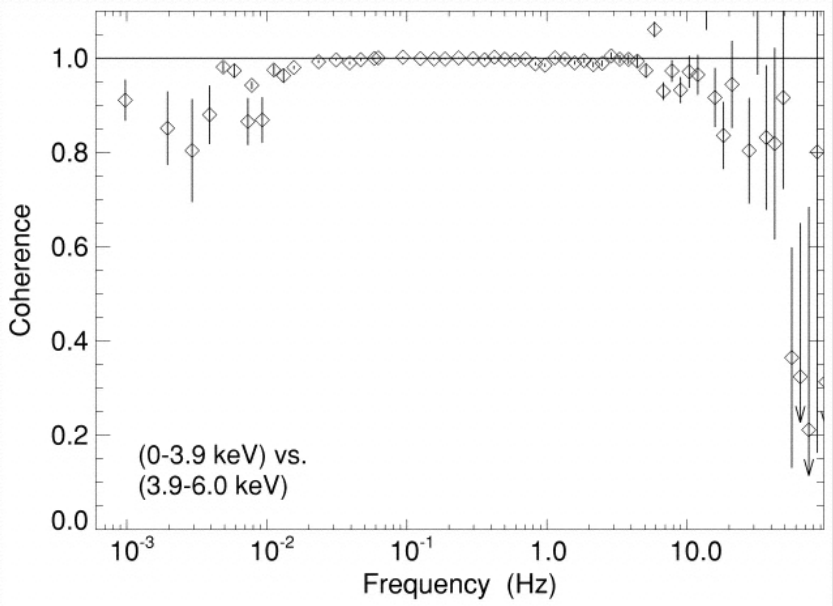


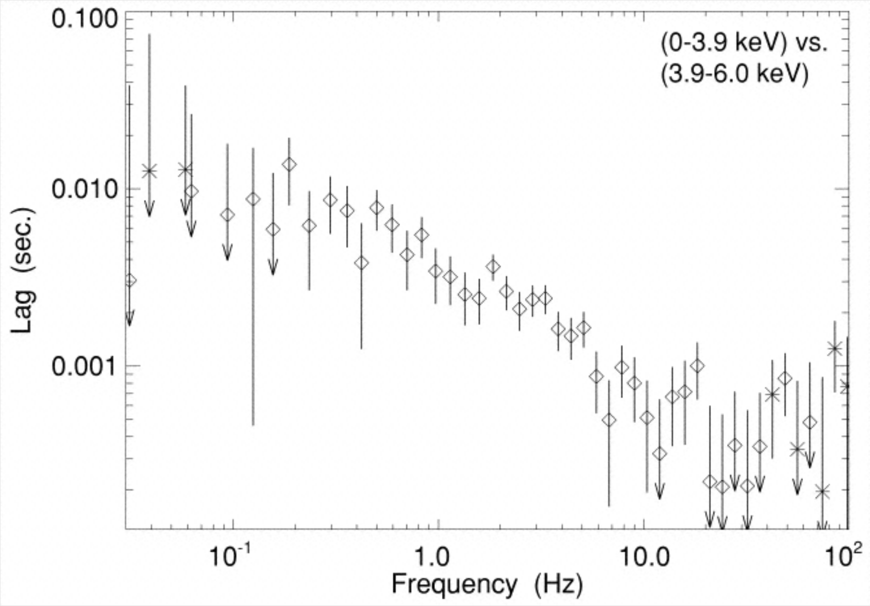






Coherence & Fourier-dependent lags



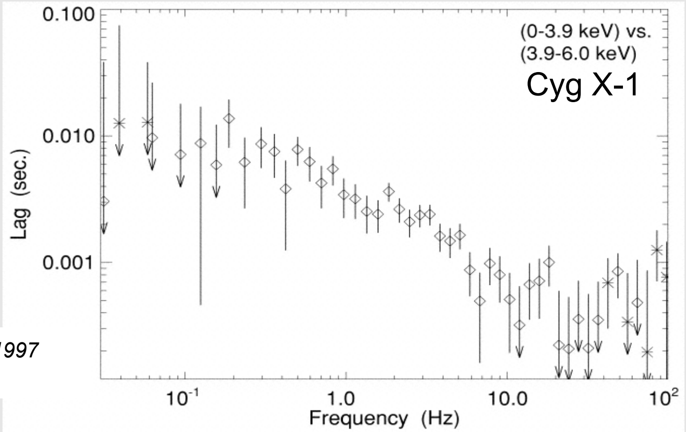


Fourier frequency-dependant measure of the linear correlation between 2 time series observed simultaneously in two energy channels

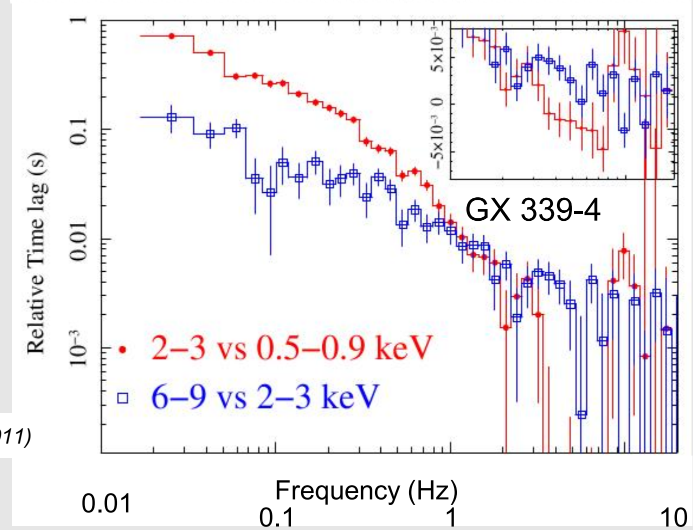
Nowak & Vaughan 1997
Nowak+ 1999

Fourier-dependent time lags

XRBs

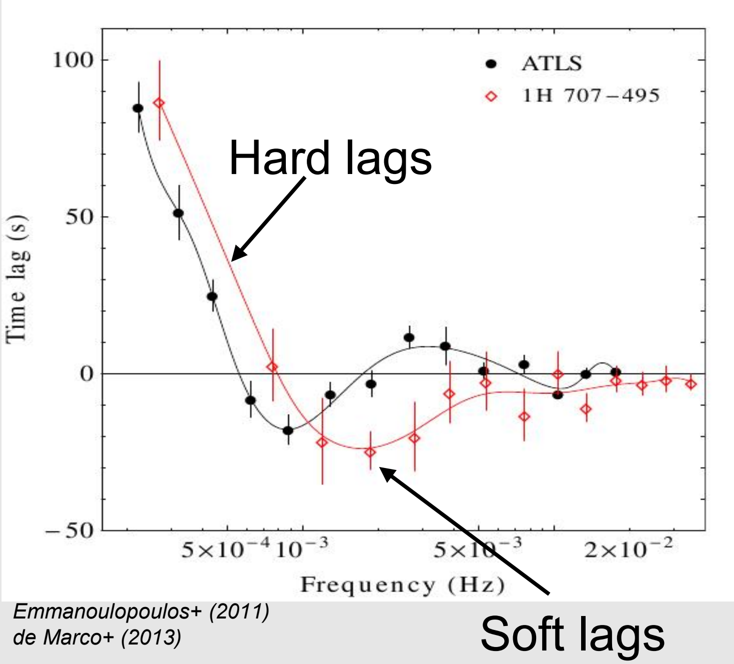


Nowak & Vaughan 1997
Nowak+ 1999



Uttley+ (2011)

AGN

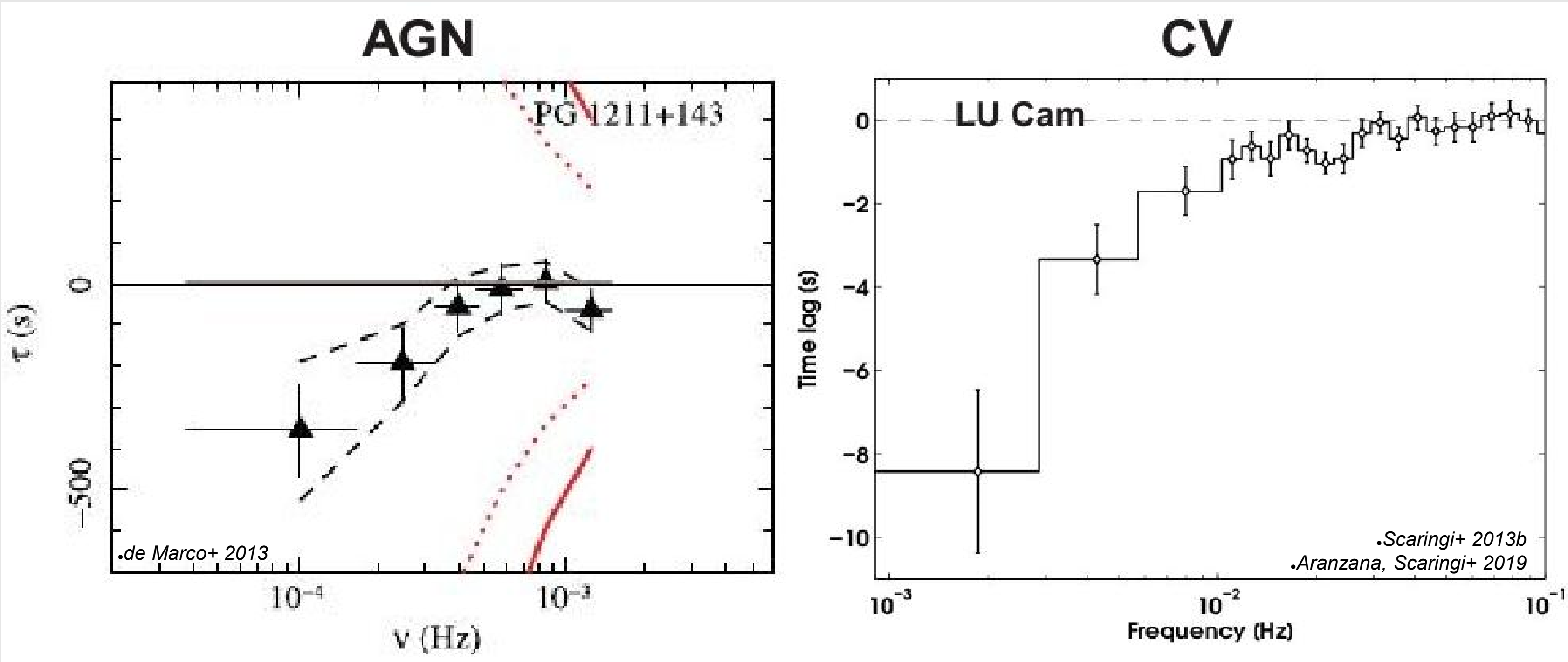


Emmanoulopoulos+ (2011)
de Marco+ (2013)

Fourier time-lags in CVs

Soft lags hard

Red lags blue

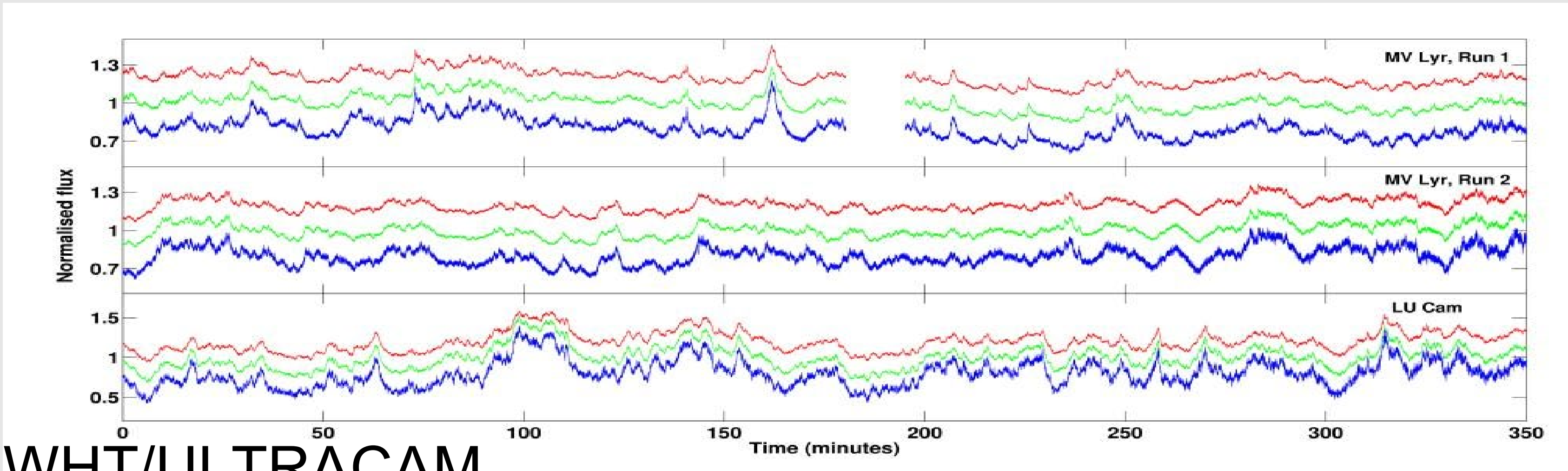


Time-scale consistent with time-travel delay

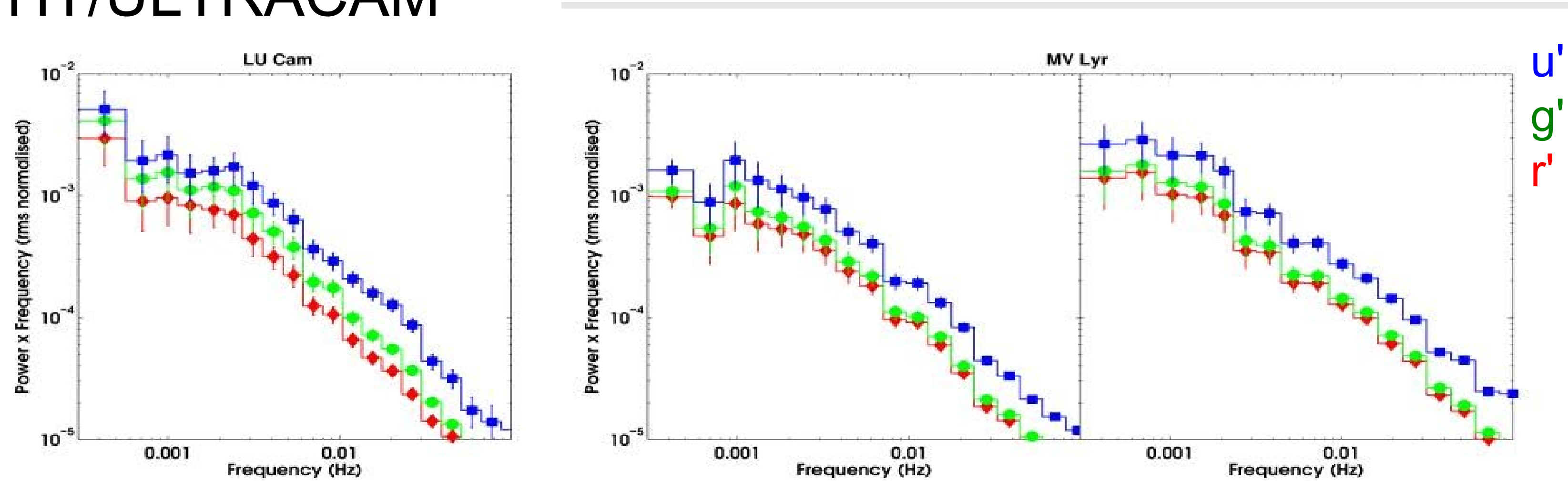
Time-scale longer than time-travel delay: *disk thermal reprocessing?*

•...see also Bruch 2015

Fourier time-lags in CVs

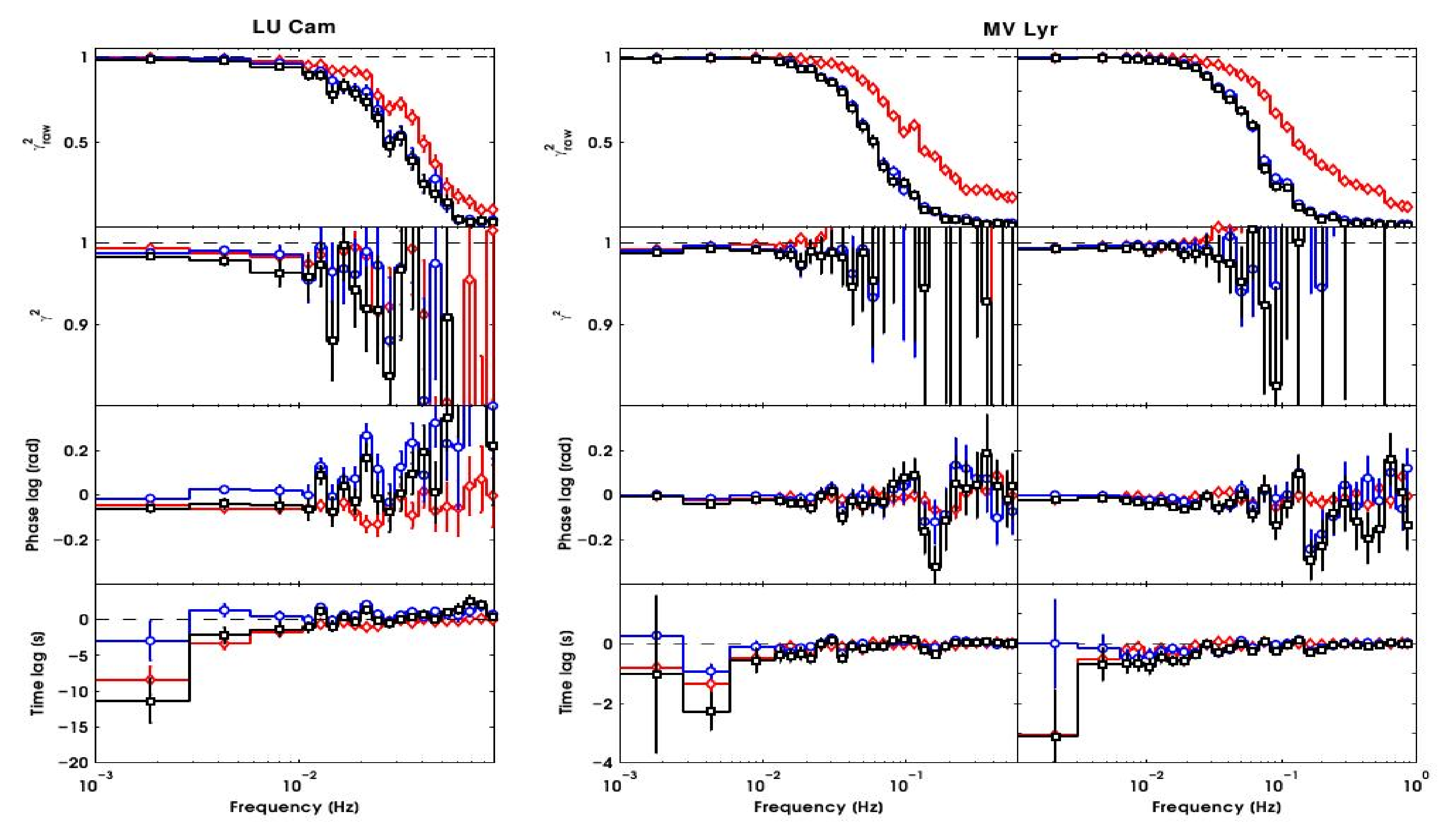


WHT/ULTRACAM



Scaringi+ 2013b

Fourier time-lags in CVs

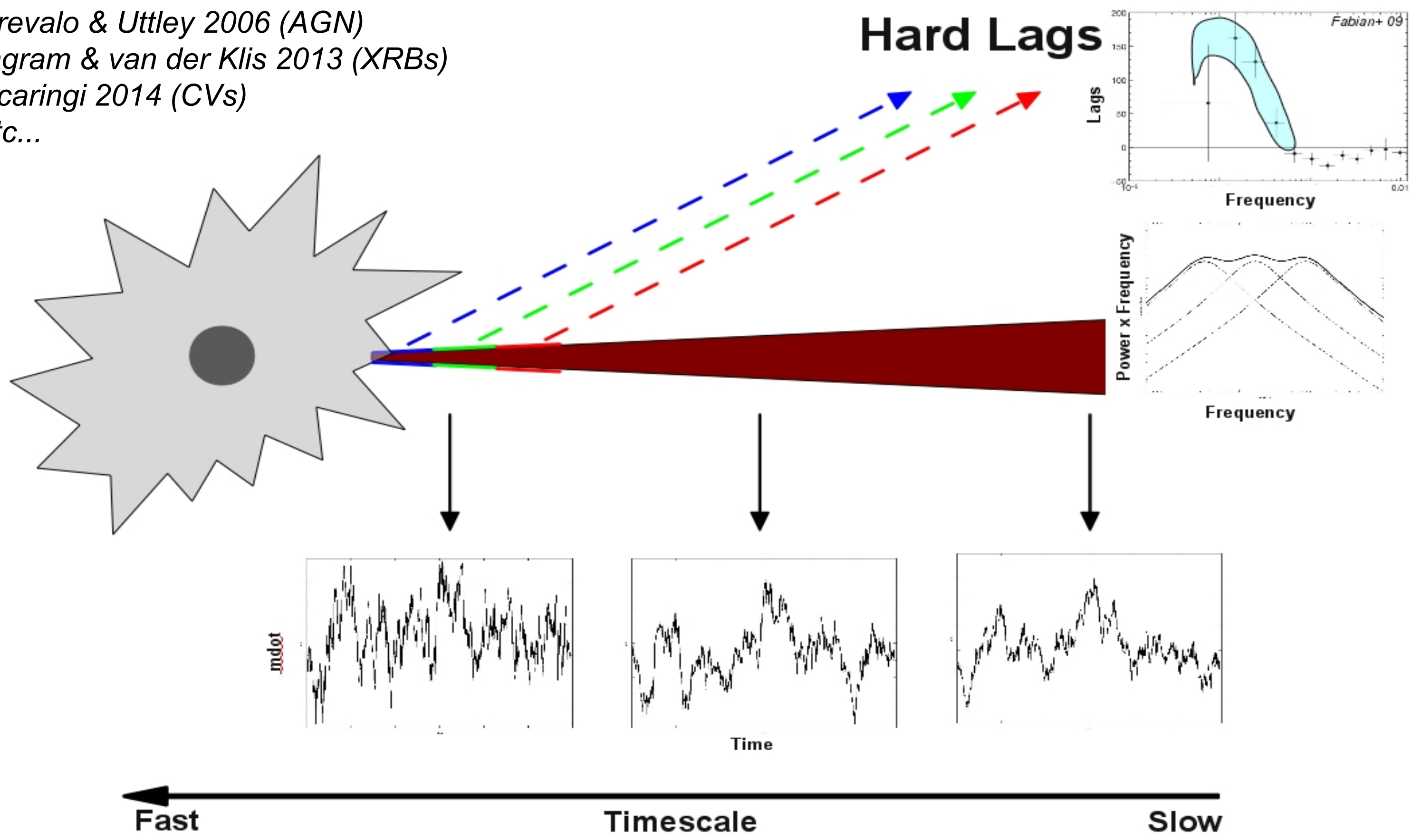


u'-r' g'-r' u'-g'

Scaringi+ 2013b

Fluctuating Accretion disks

Lyubarskii 1997
Arevalo & Uttley 2006 (AGN)
Ingram & van der Klis 2013 (XRBs)
Scaringi 2014 (CVs)
etc...



Fluctuating Accretion disks

Emmanoulopoulos+ 2014
Gardner & Done 2014
Scaringi+ 2013
etc...