
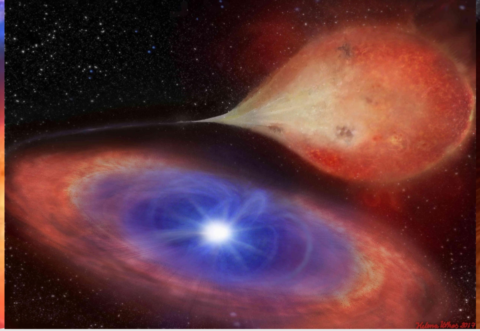


Optical variability properties of accreting white dwarfs

Tomaso’s legacy beyond X-ray binaries

Simone Scaringi

simone.scaringi@durham.ac.uk

Letter to the Editor

ROSAT observation of the boundary layer between the white dwarf and the accretion disk of VW Hydri

T. Belloni[1], F. Verbunt[1,2], K. Beuermann[1,3], W. Bunk[1], C. Izzo[1], W. Kley[4], W. Pietsch[1], H. Ritter[5], H.C. Thomas[5], and W. Voges[1]

[1] Max-Planck-Institut für Extraterrestrische Physik, W-8046 Garching bei München, Federal Republic of Germany
[2] Astronomical Institute, Postbox 80000, NL-3508 TA Utrecht, The Netherlands
[3] Institute of Astronomy and Astrophysics, Hardenbergstraße 36, W-1000 Berlin 2, Federal Republic of Germany
[4] Board of Studies in Astronomy and Astrophysics, University of California, Santa Cruz, USA
[5] Max-Planck-Institut für Astrophysik, W-8046 Garching bei München, Federal Republic of Germany

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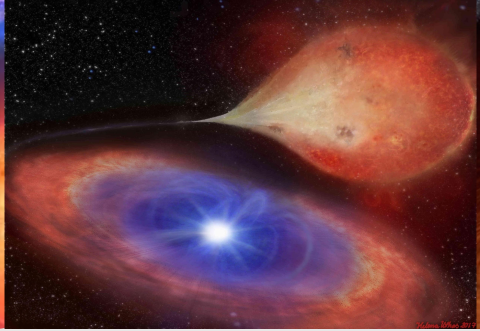
Abstract. We present first results of an observation of the dwarf nova VW Hyi, in its quiescent state between outbursts, with the Position Sensitive Proportional Counter on board of *ROSAT* . The dwarf nova was detected at a countrate of 1.26 ± 0.01cts/s. Its spectrum is that of an optically thin plasma at a temperature of ~ 2.2 KeV, and the flux in the X-ray band is smaller than the flux observed in the optical and far ultraviolet by almost an order of magnitude. We can put a 2-σ upper limit of 5% to amplitudes of sinusoidal flux variations at periods between 13-15 sec.

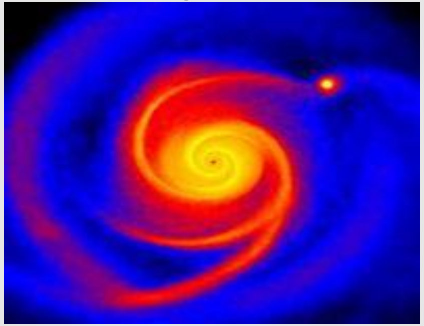




TIME DOMAIN TELESCOPE

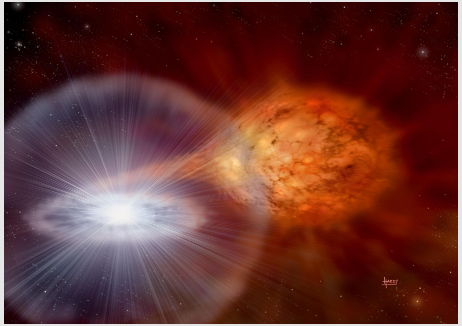
Why accretion?

Accretion regulates the growth and evolution of most objects in the Universe

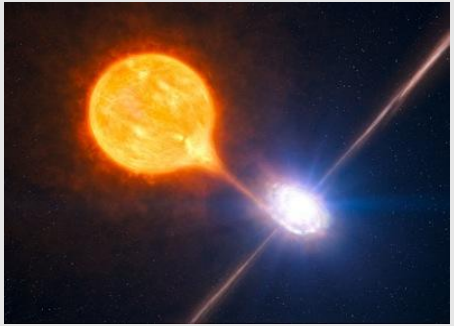
Young stellar objects



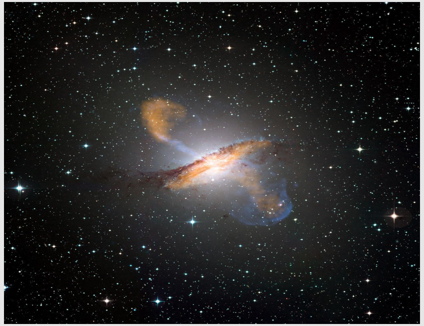
White dwarfs



Neutron stars & Black holes



Active Galactic Nuclei



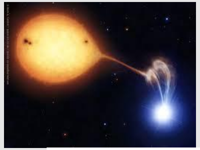
~0.1 - 100$M_\odot$ | ***<1.4 $M_\odot$*** | ***$1<M_\odot<20$*** | ***$10^6<M_\odot<10^9$***

Accreting White Dwarfs

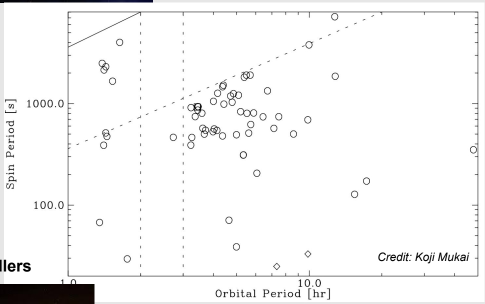
of the Cataclysmic Variable type

…AWDs are nature's minimal reproducible example for debugging our understanding of accretion disks…

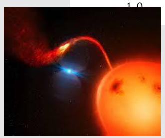
Polar



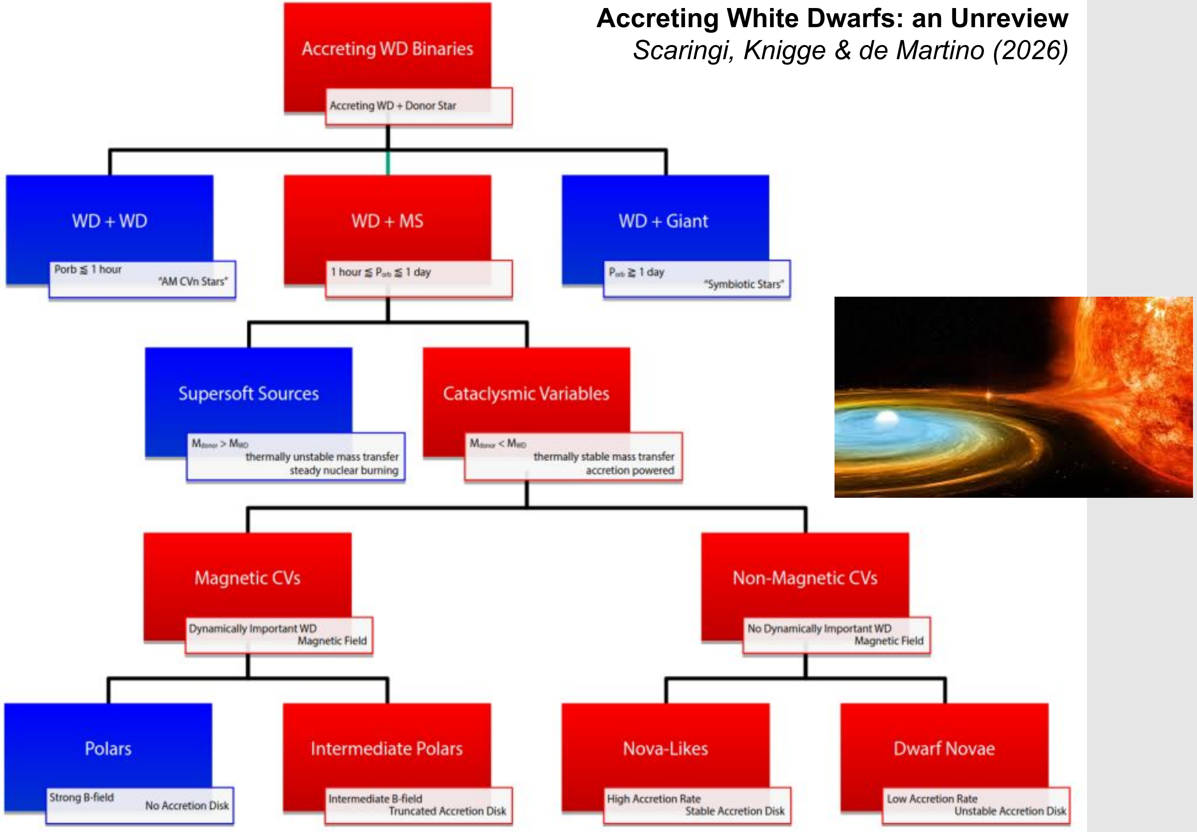
Intermediate Polar



Propellers



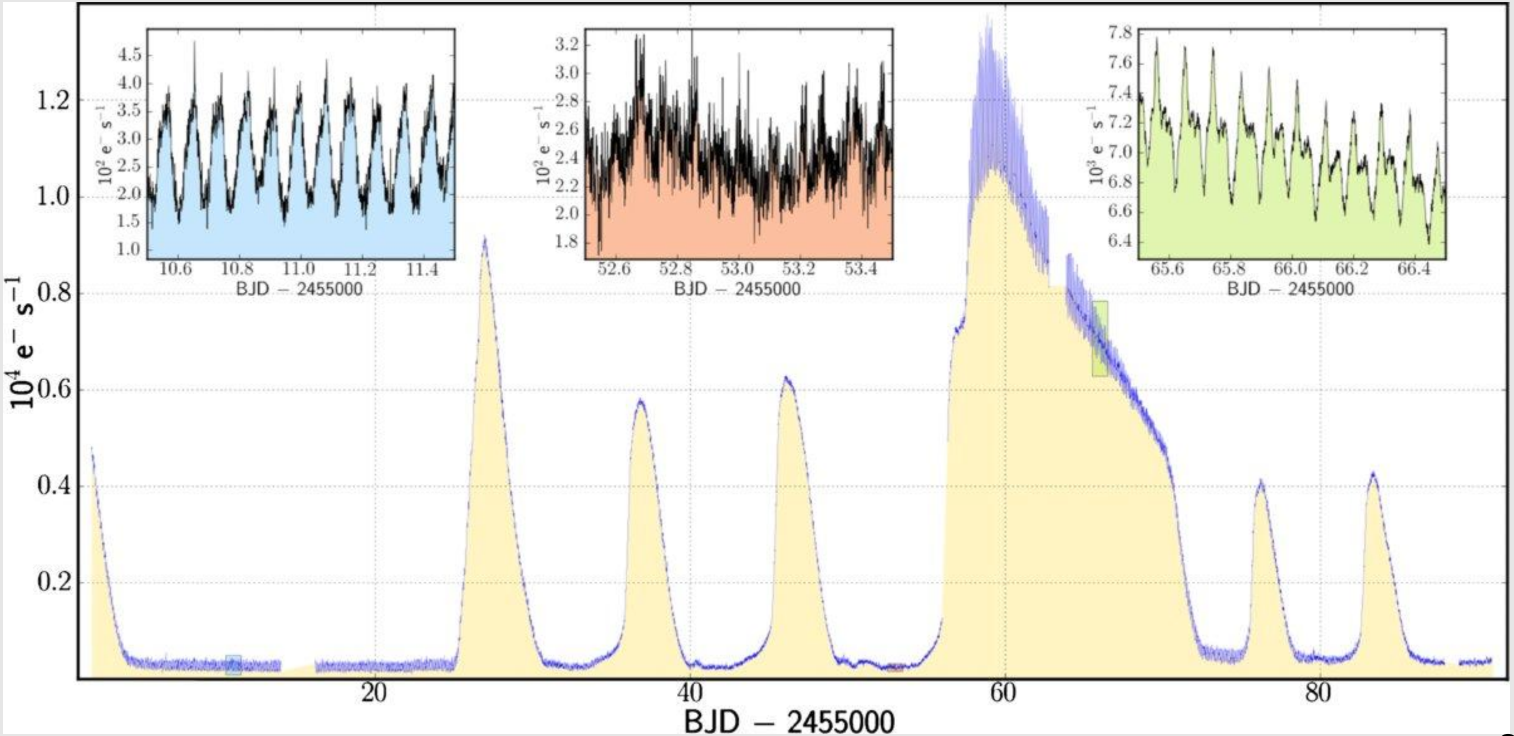
Accreting White Dwarfs: an Unreview
Scaringi, Knigge & de Martino (2026)



Aperiodic variability in AWDs:

The *Kepler* revolution

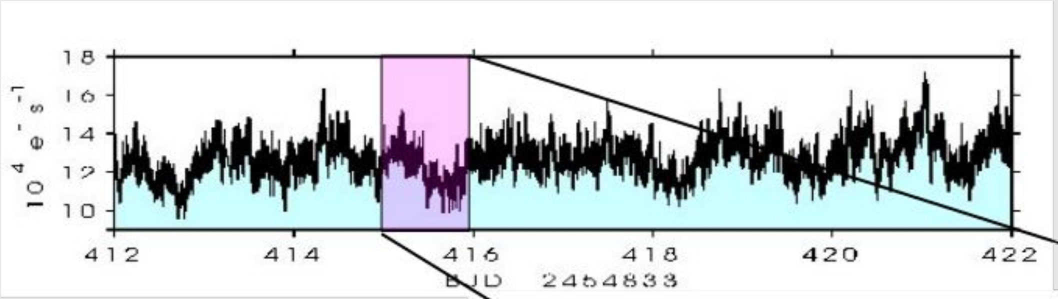
V344 Lyrae



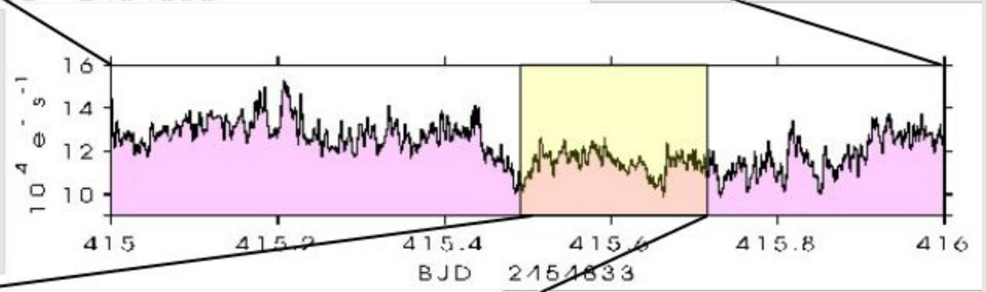
Still+ (2010)

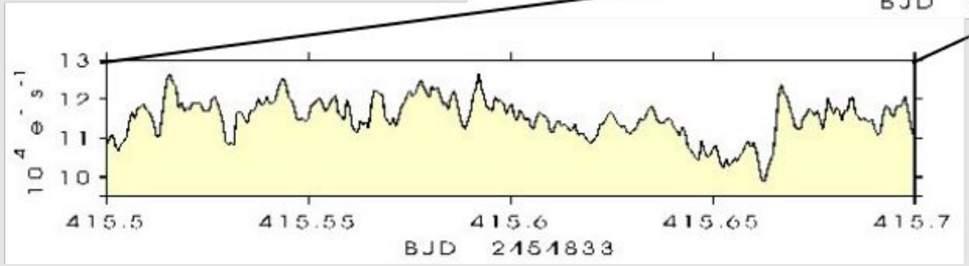
Aperiodic variability in AWDs:

The *Kepler* revolution



MV Lyrae
with Kepler





“I need to learn Fourier methods AFAP” (as fast as possible)

An empirical model for a unified description of the power spectra of accreting SYSTEMS

A UNIFIED DESCRIPTION OF THE TIMING FEATURES OF ACCRETING X-RAY BINARIES

Tomaso Belloni
Osservatorio Astronomico di Brera, Via E. Bianchi 46, I-23807 Merate (LC), Italy; belloni@merate.mi.astro.it
Dimitrios Psaltis
School of Natural Sciences, Institute of Advanced Study,
Princeton, NJ 08540; dpsaltis@ias.edu
Michiel van der Klis
Astronomical Institute "Anton Pannekoek", University of Amsterdam and Center for High-Energy Astrophysics,
Kruislaan 403,NL 1098 SJ Amsterdam, the Netherlands; michiel@astro.uva.nl
Resubmitted to ApJ: February 11, 2002

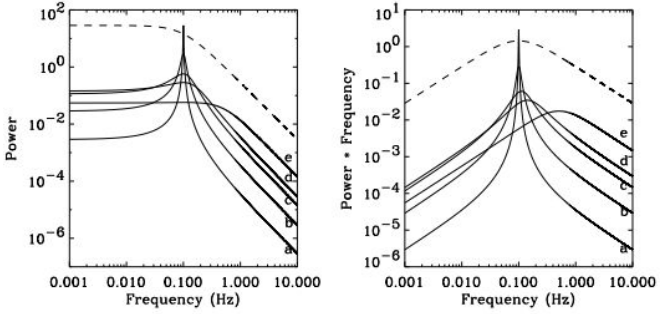


Fig. 1.— Examples of Lorentzian models. Left panel: P_ν representation; right panel: νP_ν representation. Solid lines represent Lorentzians with ν_0=0.1 Hz and different Q values: the spectra labeled a, b, c, d and e correspond to Q=50, 2, 1, 0.5 and 0.1, respectively. The dashed line is a zero-centered Lorentzian with Δ=0.1 Hz.

$$P(\nu) = \frac{r^2\Delta}{\pi}\frac{1}{\Delta^2 + (\nu - \nu_0)^2}$$

$$\nu_{max} = \sqrt{\nu_0^2 + \Delta^2} = \nu_0\sqrt{1 + 1/(4Q^2)}$$

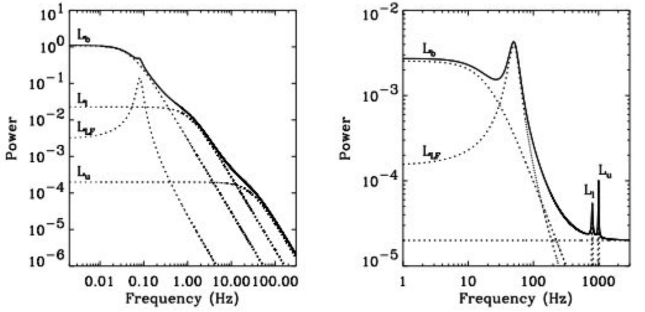
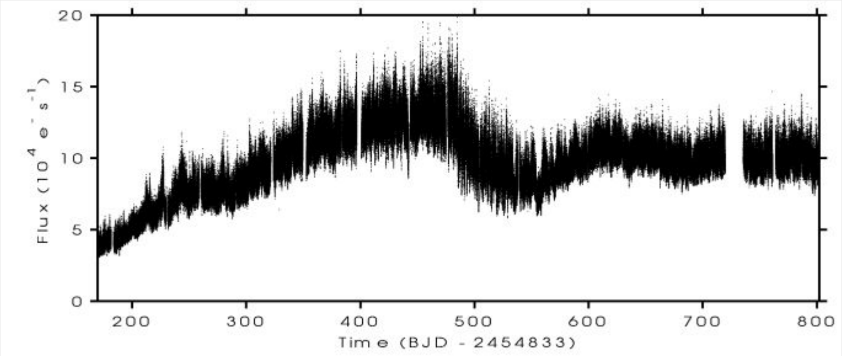
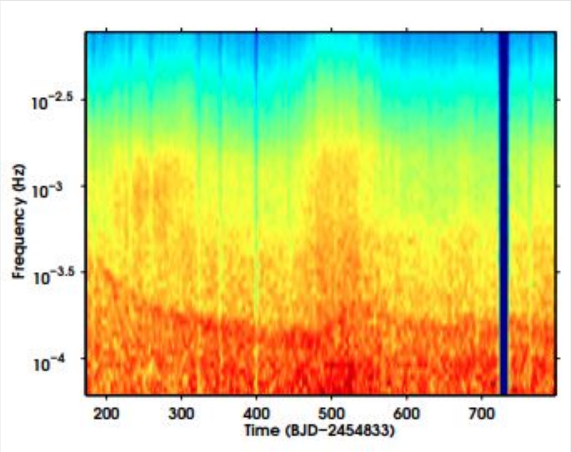


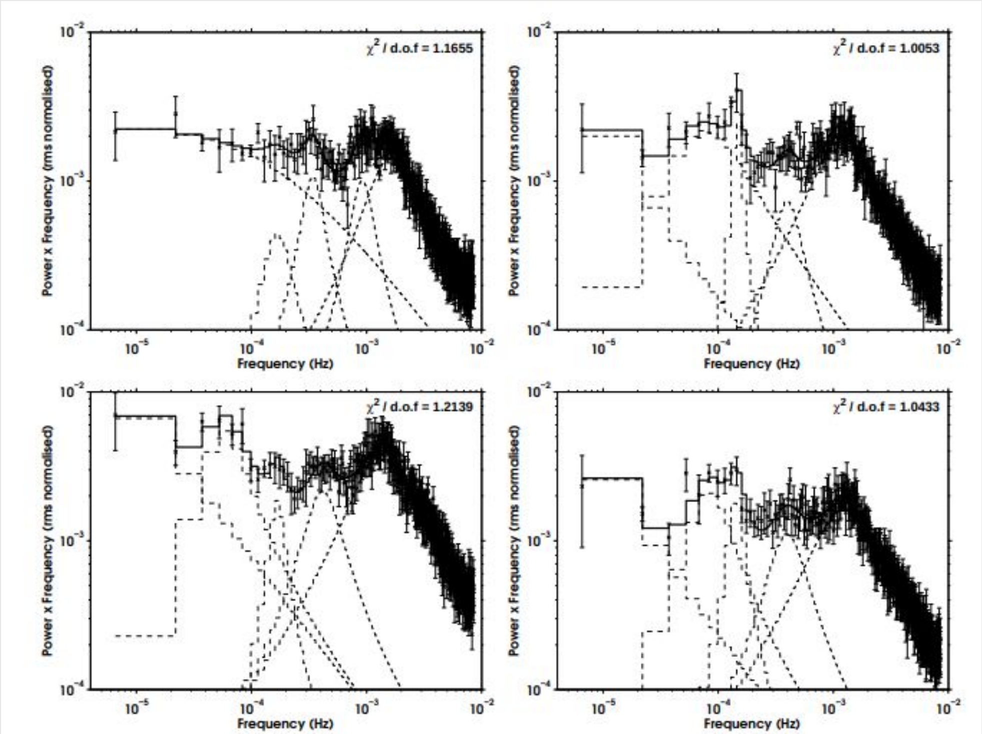
Fig. 2.— Left panel: model decomposition for XTE 1118+480. Right panel: the same four Lorentzian components but with characteristic frequencies corresponding to the high-frequency end of the WK99 and PBK99 correlations and narrower widths for the two high-frequency components.

The case of MV Lyrae

(i.e. my first application of Tomaso's methodology)



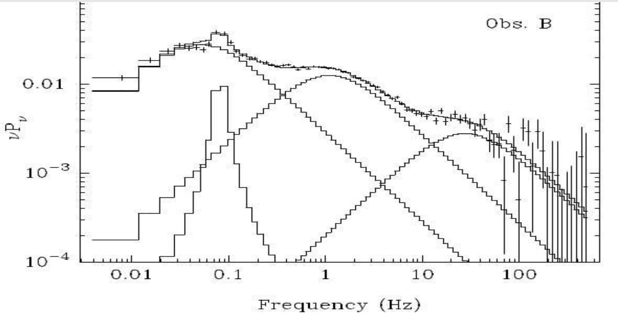




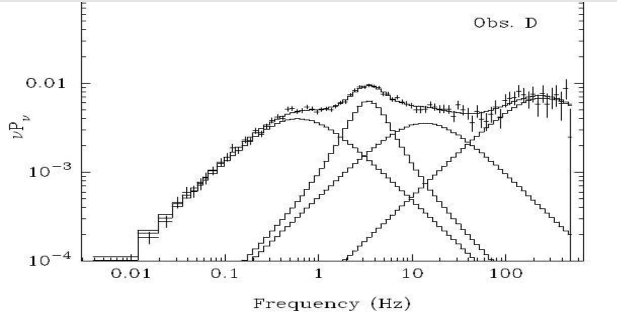
Scaringi+ (2012b)

Power spectral densities:
some examples

Black hole XRB

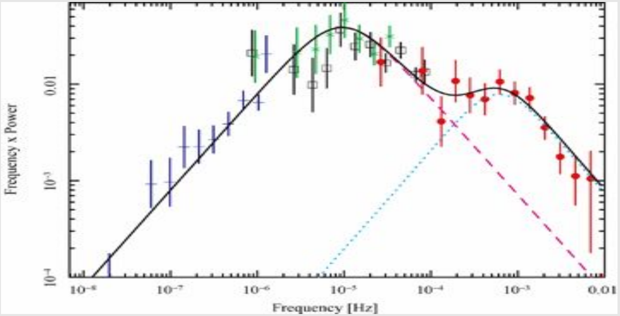


Neutron star

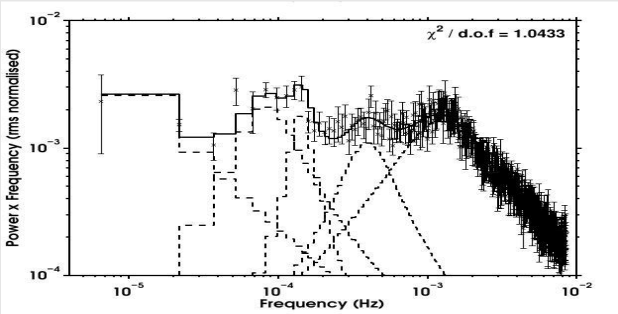


Belloni+ (2002)
McHardy+ (2007)
Scaringi+ (2012b)

AGN



White dwarf

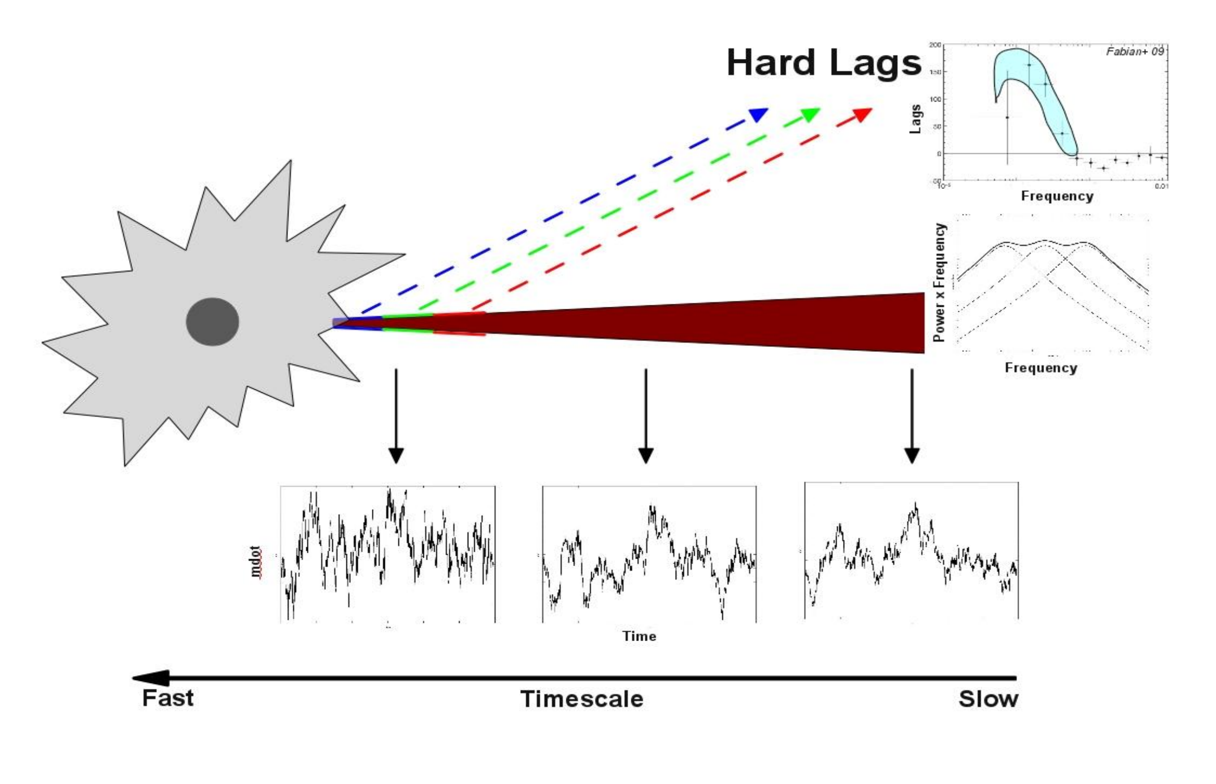


Fluctuating Accretion disks

Mass transfer rate modulated on the *local* viscous timescale

$$\nu_{visc}(r) = \alpha (H/R)^2 \nu_{dyn}(r),$$

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



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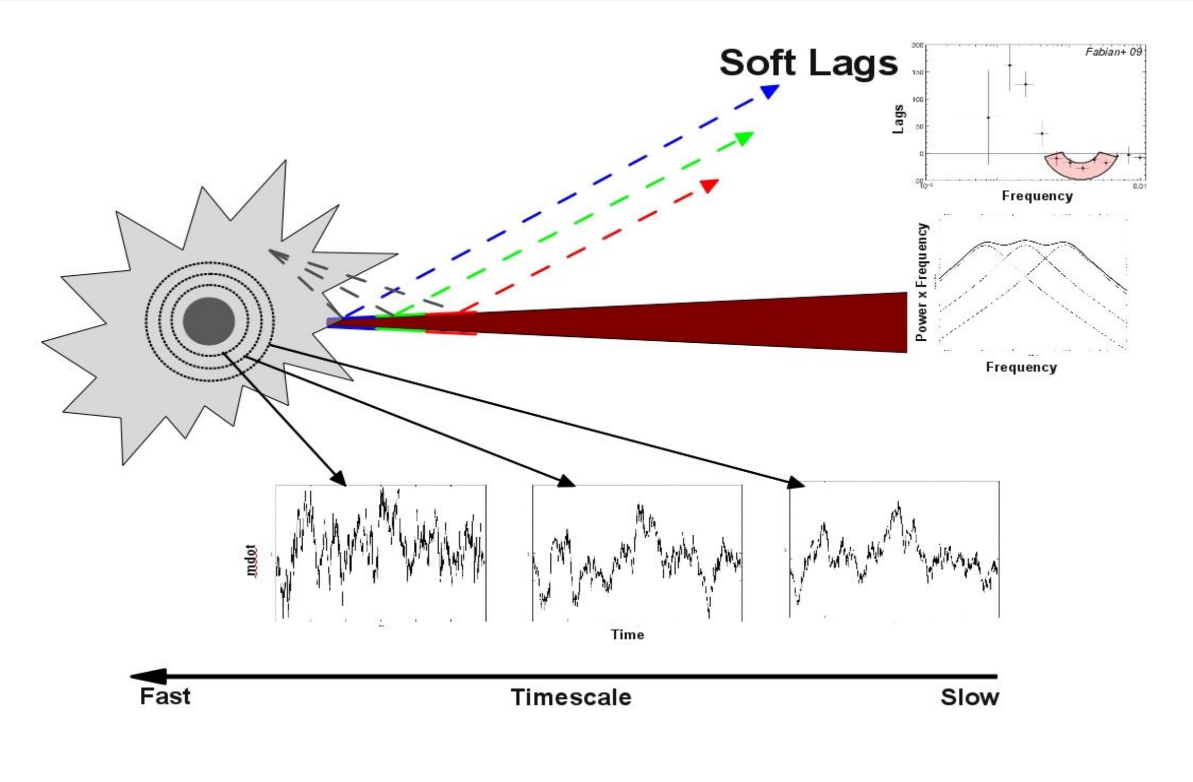
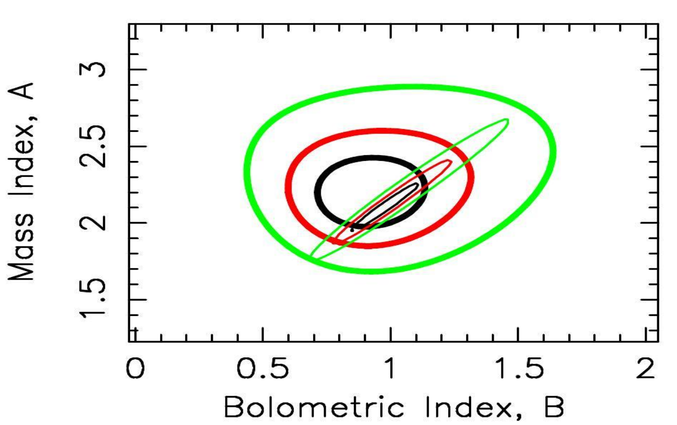
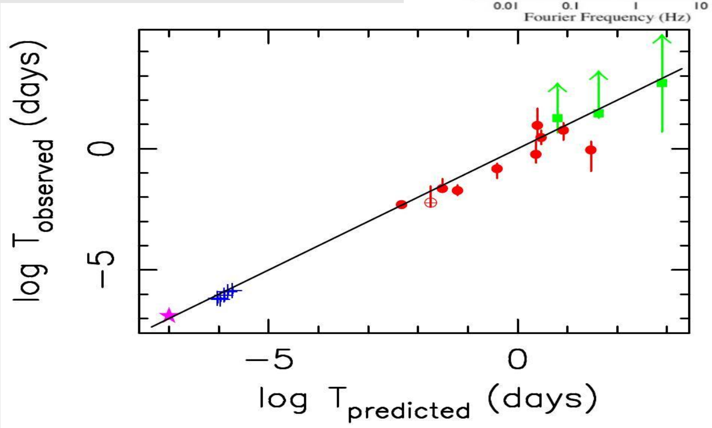
etc...

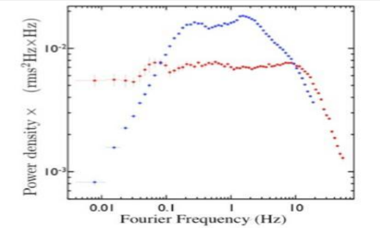


Galactic BH as scaled down AGN?

$$\log \nu_b = A \log M + B \log L_{bol}$$







...for BH however...

Mc Hardy+ (2006)
Koerding+ (2007)
Gonzalez-Martin & Vaughan (2012)

$$R_s = \frac{2GM}{c^2}$$

Galactic BH as scaled down AGN?

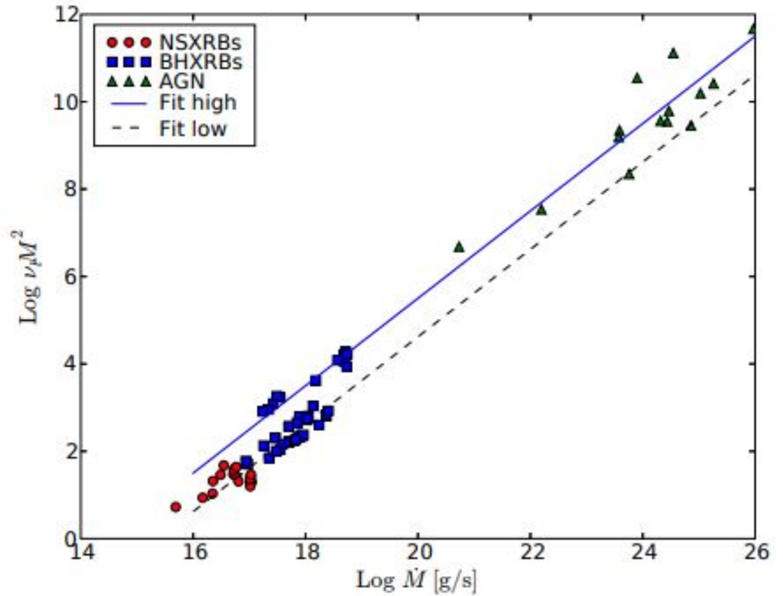


Figure 4. Edge-on projection of the variability plane including AGN, stellar BHs and NSs with directly measured ν_l.

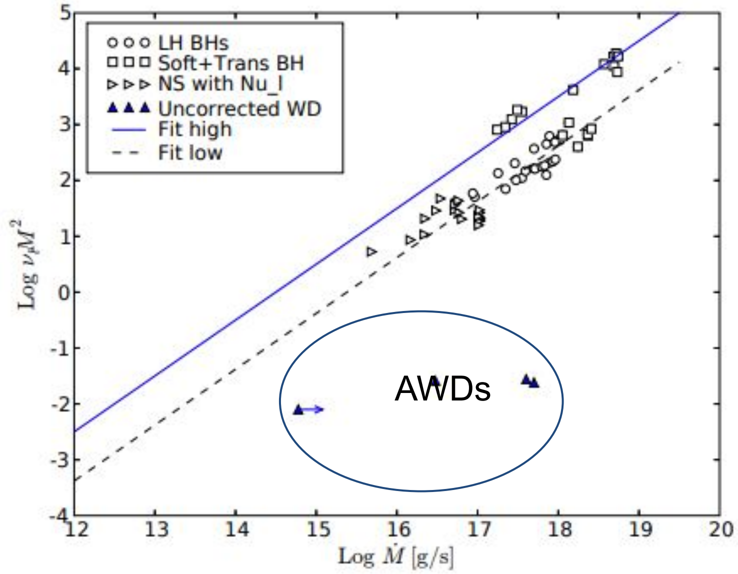
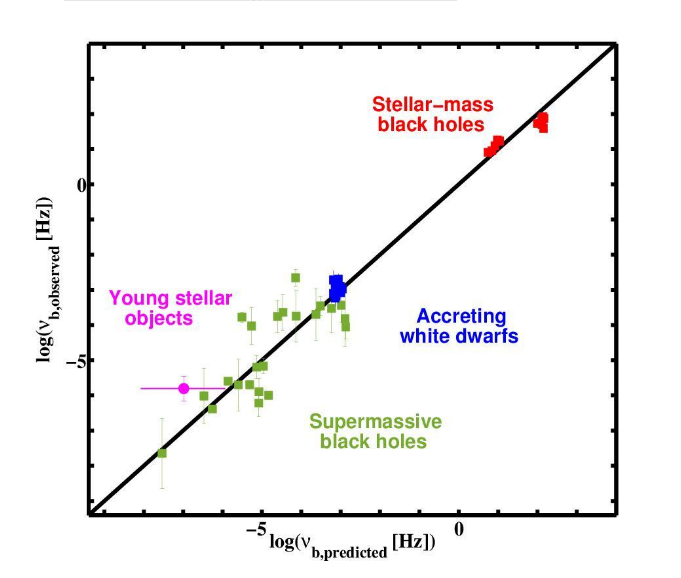


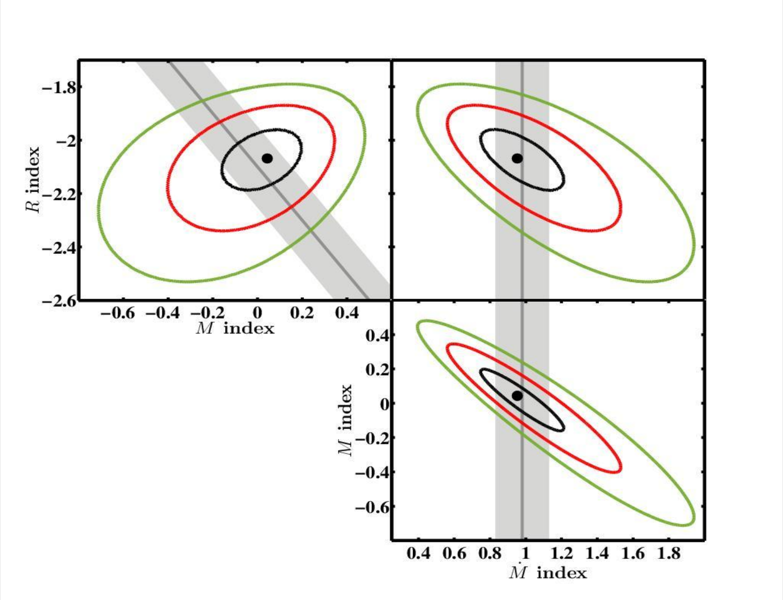
Figure 5. Edge-on projection of the variability plane compared to our sample of WDs. The uncertainty on the accretion rates in a factor 2-3, so in logspace 0.3-0.5 dex.

Koerding+ (2007)

The accretion variability plane

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



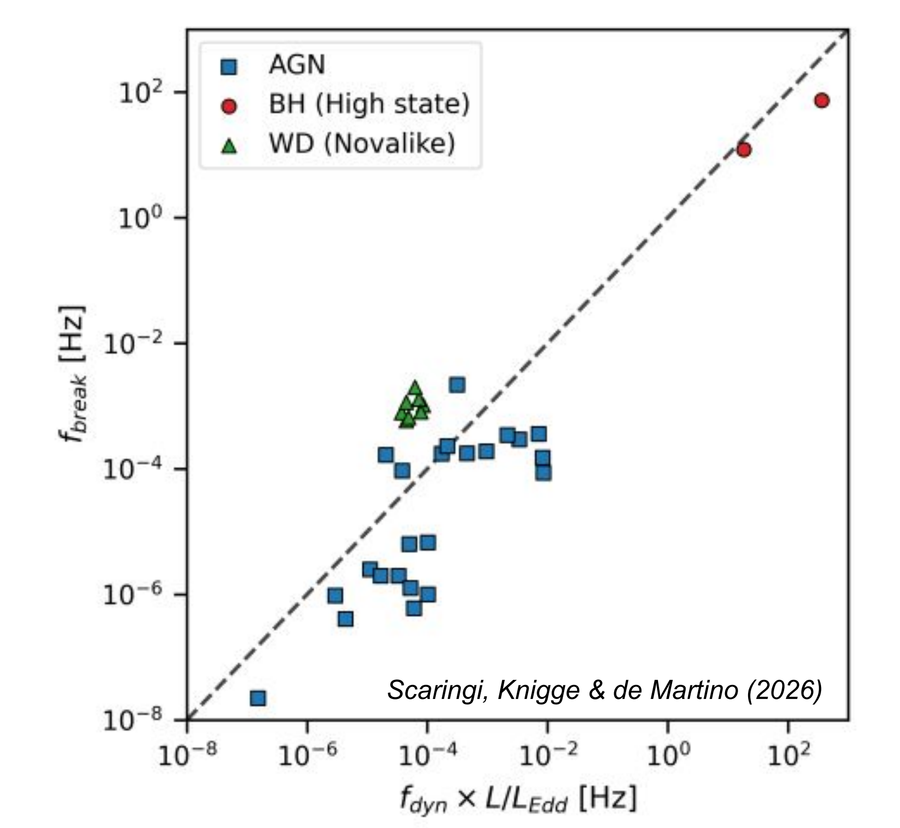


Caveat:

Frequency breaks are wavelength dependent

Scaringi+ (2015b)

The accretion variability plane



Is the break frequency a tracer of Eddington ratio?

$$\frac{f_\mathrm{b}}{f_\mathrm{dyn}} = \frac{L_\mathrm{acc}}{L_\mathrm{edd}} = \frac{\dot{M}}{\dot{M}_\mathrm{edd}}$$

← at R_{in}

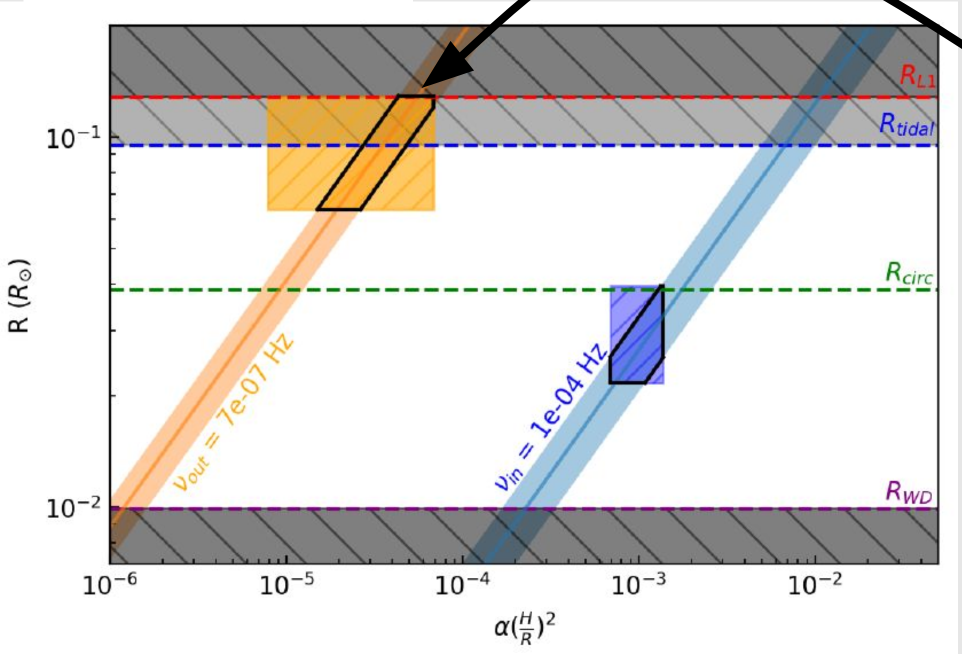
$$f_\mathrm{b} = \frac{\sigma_\mathrm{T}\sqrt{G}}{8\pi^2 m_\mathrm{p} c} M^{\frac{1}{2}} R^{\frac{-5}{2}} \dot{M}.$$

Or is this just “cosmic coincidence”?

NB: Frequency breaks are wavelength dependent

Variability from the disk outer-disk edge

$$\nu_{visc}(r) = \alpha(H/R)^2 \nu_{dyn}(r),$$



3 years of *Kepler* data
@ 1 minute cadence

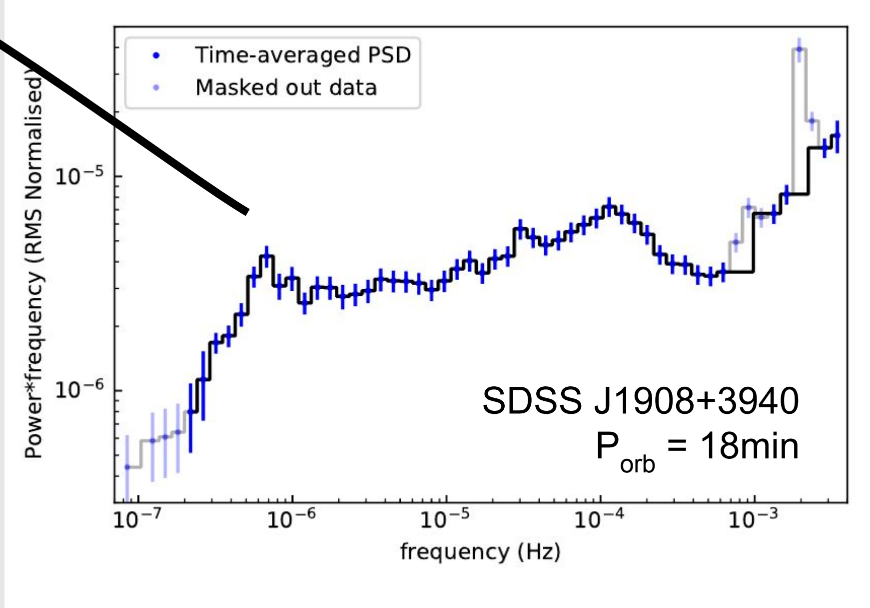
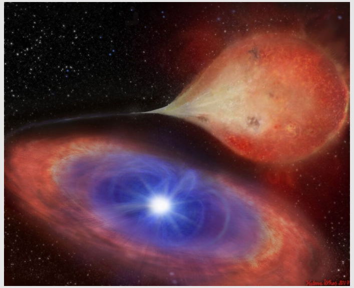


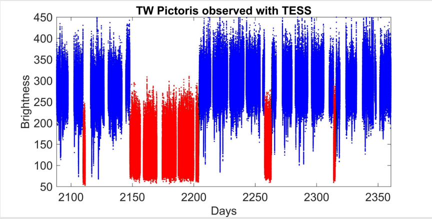
Figure 1. Time-averaged PSD of SDSS J1908+3940 with the segment length of 60 days and masked out periodic signals in the white noise dominated high frequency regime and low frequency masked out data below the segment window length limit.

Veresvarska & Scaringi (2023)

Phenomenological similarities:
are XRBs self-similar to AWDs?

1) **Linear RMS-flux relation**
   [Scaringi+ 2012, van de Sande+ 2013]
2) **Fourier soft-lags are observed in AWDs at optical wavelengths**
   [Scaringi+ 2013, Bruch 2015, Aranzana+ 2018, Irving+ 2026 in prep.]
3) **Type-II bursts observed in NS are seen in AWDs as “magnetic gating”**
   [Scaringi+ 2017, Scaringi+ 2022a, Littlefield+ 2022, Covington+ 2022, Hamneury+ 2022, Joshi+ 2026]
4) **tMSPs find a direct analogue (one?) in AWDs: TW Pic**
   [Scaringi+ 2022a]
5) **Type-I bursts observed in NS are seen in AWDs as micronovae**
   [Scaringi+ 2022b, Scaringi+ 2022c, Iłkiewicz+ 2024, Veresvarska+ 2024a, Veresvarska+ 2025, Irving+ 2024, Mendelsohn+ 2026, Oliveira+ 2026]
6) **Type-C (?) QPOs are now confirmed in AWDs**
   [Veresvarska+ 2024b]





QPOs in XRBs

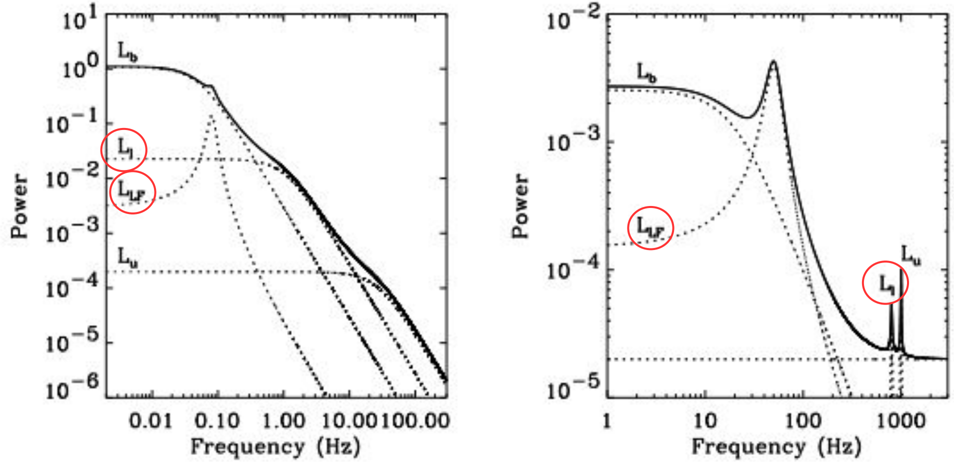
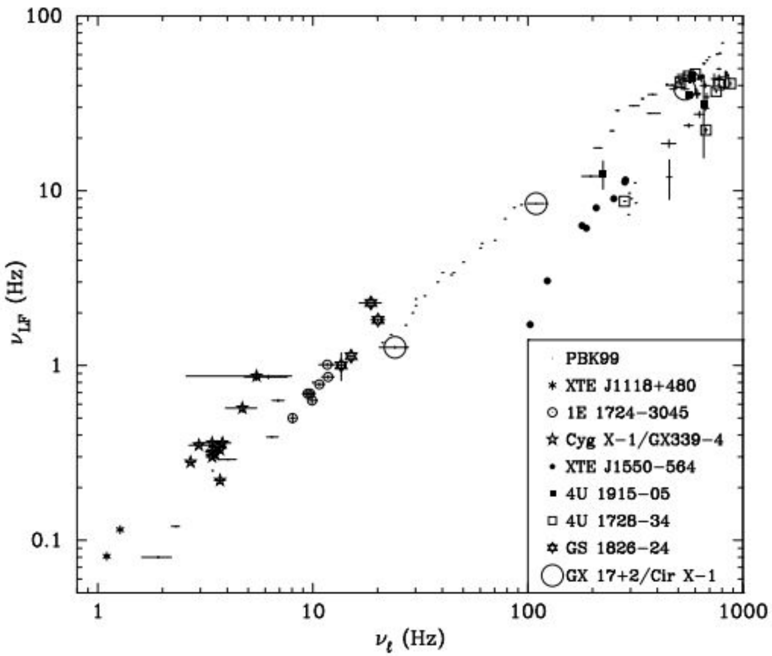


FIG. 2.— Left panel: model decomposition for XTE 1118+480. Right panel: the same four Lorentzian components but with characteristic frequencies corresponding to the high-frequency end of the WK99 and PBK99 correlations and narrower widths for the two high-frequency components.



Belloni, Psaltis & van der Klis (2002)

QPOs in AWDs

In the early 2000s

Peculiar: if AWDs follow this same relation than the disk dynamics CANNOT (?) be dominated by GR effects.

But clearly the inner regions of BHs ARE governed byu GR!

This needs fact-checking…

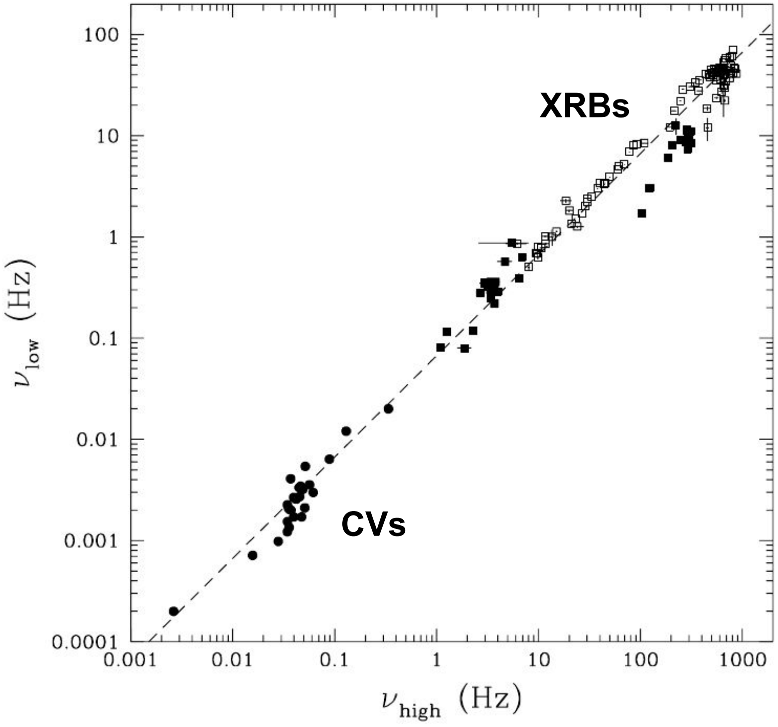


Figure 30. The Two-QPO diagram for X-Ray binaries (filled squares: black hole binaries; open squares: neutron star binaries) and 26 CVs (filled circles). Each CV is only plotted once in this diagram. The X-Ray binary data are from Belloni et al. (2002) and were kindly provided by T. Belloni. The dashed line marks $P_{QPO}/P_{DNO} = 15$.

Warner, Woudt & Pretorius (2003)

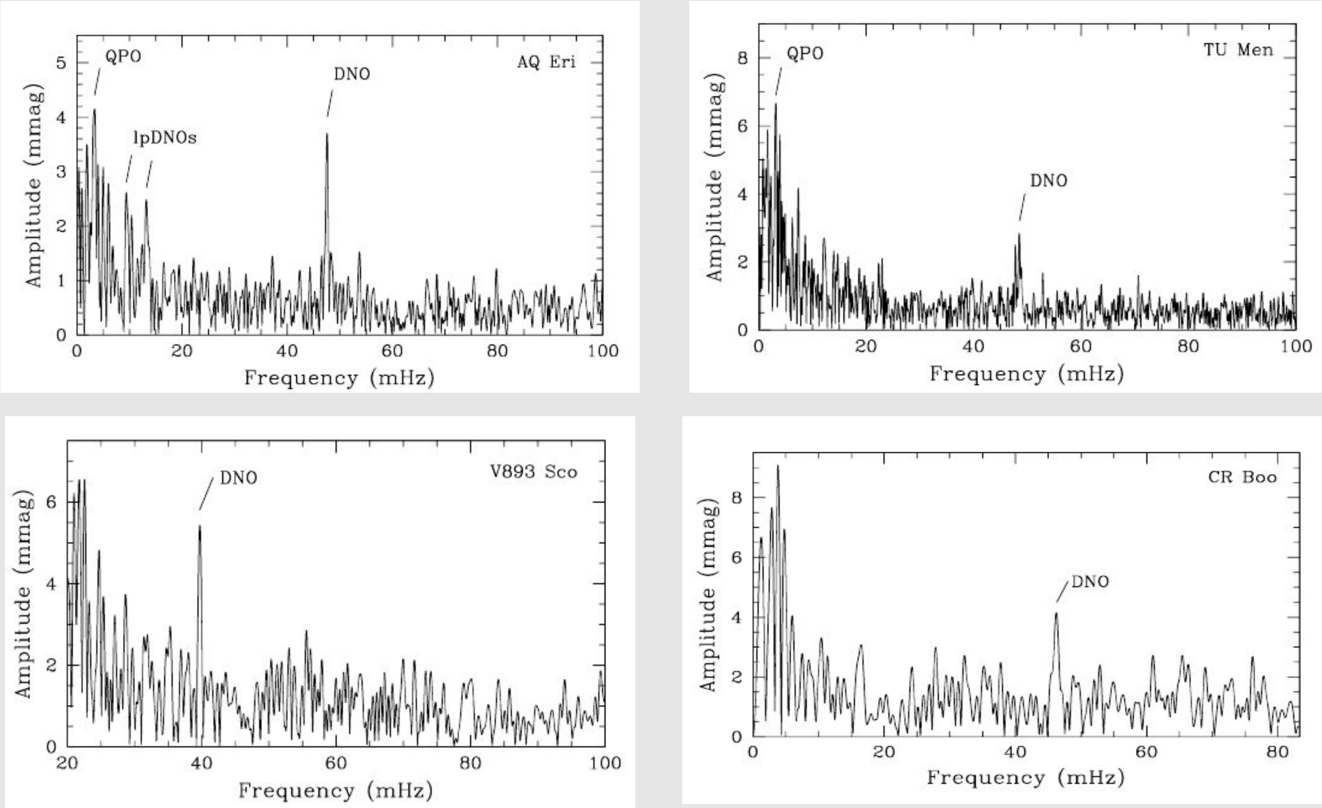
QPOs in AWDs

In the early 2000s

Final judgment on significance of detection is left with the audience.

After years of mining Kepler + TESS data I could not confirm these signals.

I will assumes these are all red-noise spikes.



Warner, Woudt & Pretorius (2003)

QPOs in AWDs

The case of CP Pup

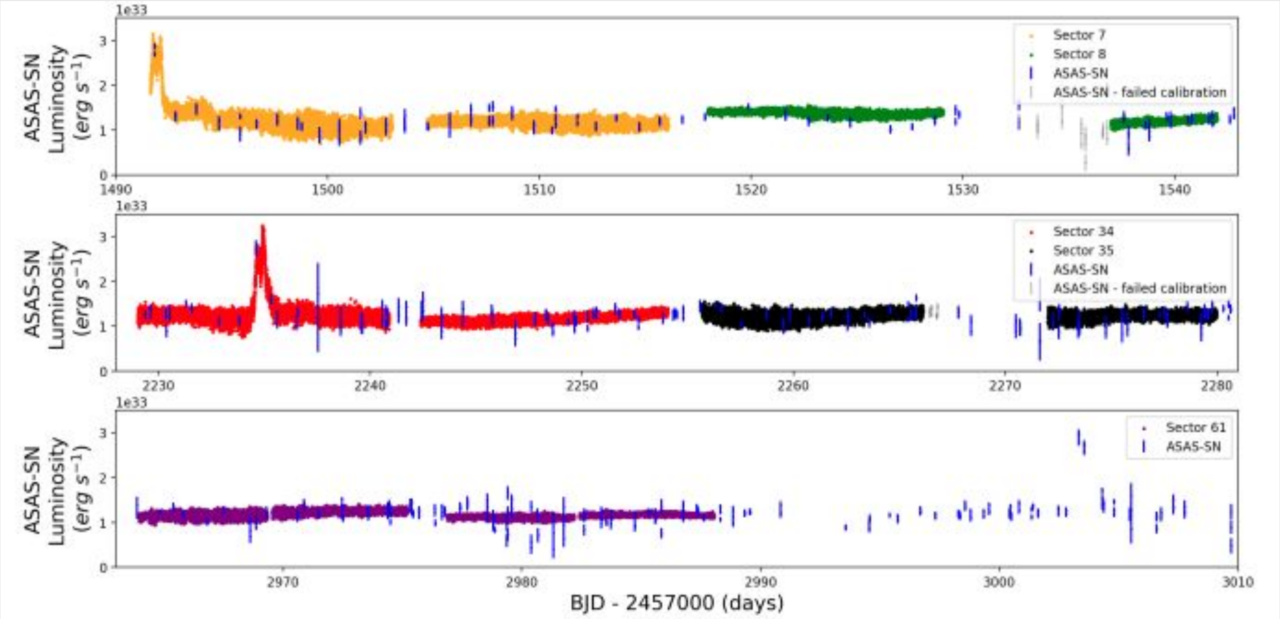
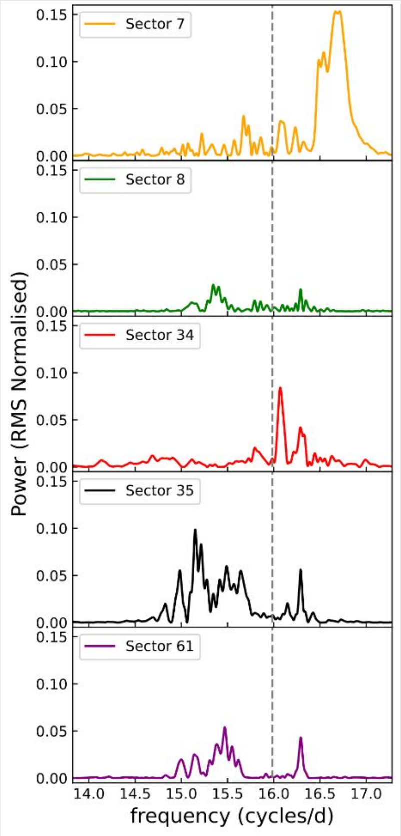


Figure 1. Light curve of CP Pup showing all 5 sectors of *TESS* data as described in Table 1 (orange, green, red, black and purple consecutively for sectors 7, 8, 34, 35 and 61). Overlaid (in blue) is the *ASAS-SN* light curve used for calibration. The grey points are data from *ASAS-SN* for which calibration failed and hence were excluded. The flux of both *TESS* and *ASAS-SN* light curves is converted to erg s^{-1} using the *Gaia* parallax.

Veresvarka+ (2023a)



Incoherent signal “moving around” in CP Pup

QPOs in AWDs

Self-similar to Type-C QPOs in XRBs?

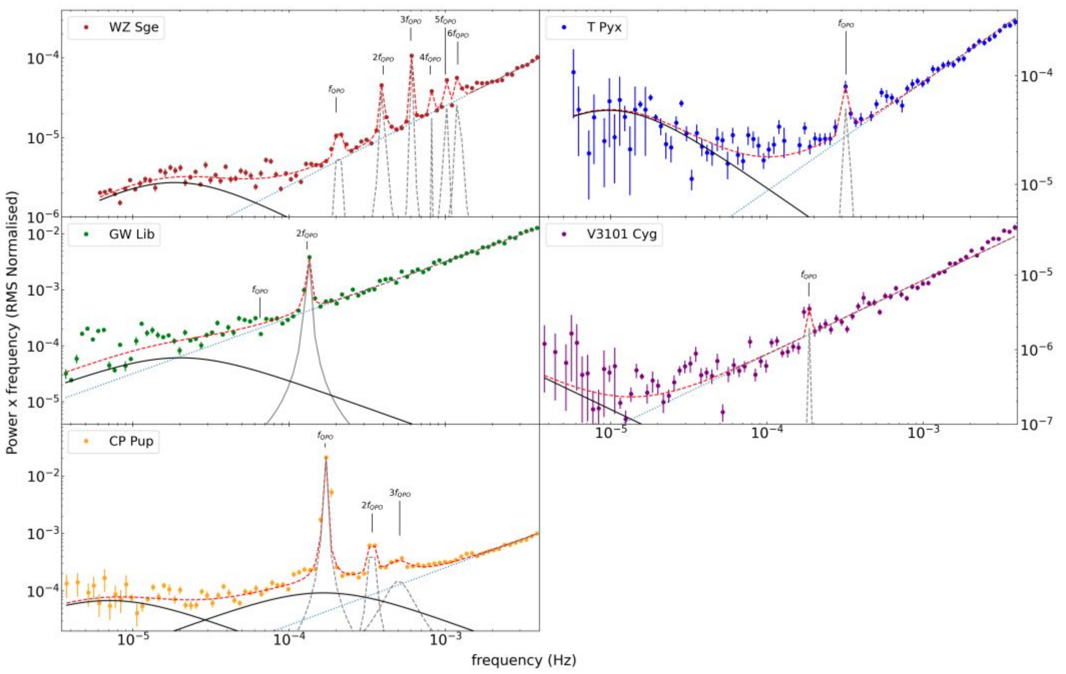
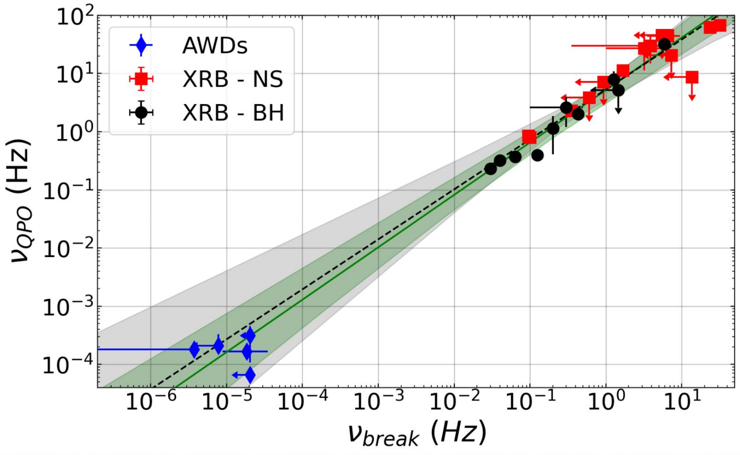


Figure 1. TPS of WZ Sge, GW Lib, T Pyx, V3101 Cyg and CP Pup averaged on the segment lengths specified in Table 1 with 90 logarithmicaly spaced bins. The empirical fit of the PSD is included here and comprises a Poisson noise power law (dotted line) in the high frequencies, one (in the case of WZ Sge, GW Lib, T Pyx and V3101 Cyg) or two (CP Pup) zero-centred Lorentzians (solid line) representing the broad band PSD structure and Lorentzians representing the QPOs and their harmonics (dashed line).



If the target is bright enough and observed for long enough, we see QPOs in AWDs
(2 AWDs in the sample are the closest known ones)

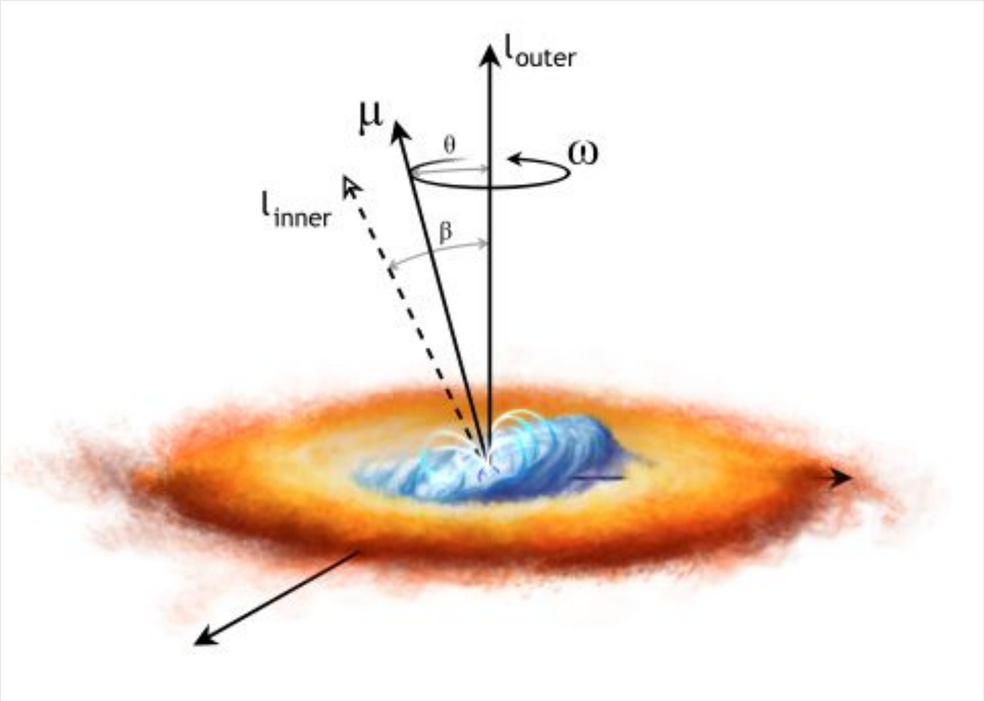
Veresvarka+ (2024b)

QPOs in AWDs
magnetically-driven QPOs?

From Lai (1999) and Pfeiffer & Lai (2004):

The QPOs could be generated by magnetically-driven precession of the inner disk around the spin axis of the accretor. This model was developed for NS and YSOs.

$$\nu_{QPO} = A\nu_p(r) = \frac{A}{2\pi^3}\frac{\mu^2}{r^7\,\Omega(r)\,\Sigma(r)}\frac{F(\theta)}{D(r)},$$



See Veresvarska & Imbrogno et al. 2025 for application of the model to ULXs

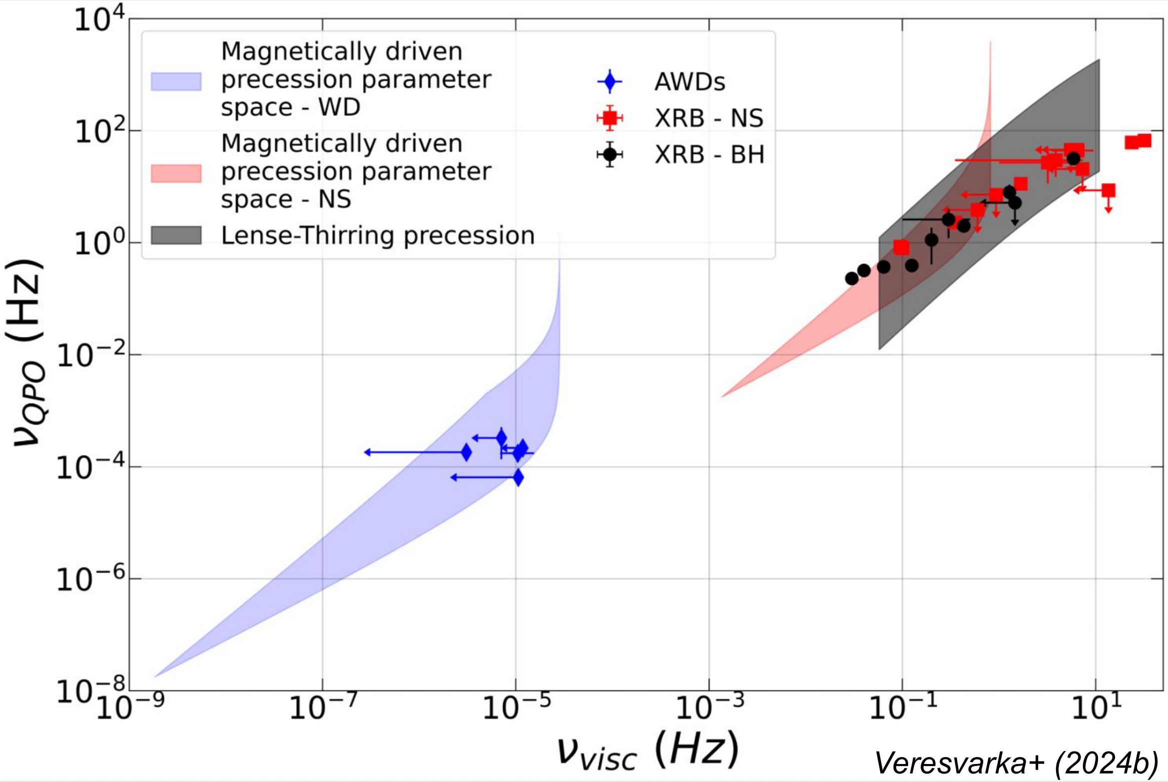
Veresvarka+ (2024b)

QPOs in AWDs
magnetically-driven QPOs?

For AWDs:
We assume the break frequency is related to the viscous frequency at the truncation radius of the disk where the accretor B-field begins to affect the accretion flow.

For BHs:
The break frequency is related to the viscous frequency at the truncation radius where Lense-Thirring precession becomes dominant.

For NSs: ???

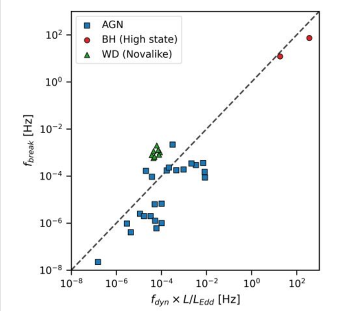


Veresvarka+ (2024b)

My three main open questions

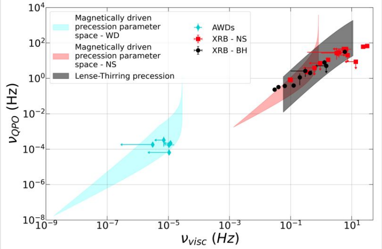
Testing self-similar accretion physics has brought many more questions than answers:

1) Fluc. Prop explains high-amplitude fast variability via a geometrically extended hot-flow (corona) in XRBs. Do AWDs also have a hot-flow? Where is it?



2) Is the "analytical" accretion variability plane physically motivated?

3) Are the QPOs in AWDs somewhat self-similar to LT QPOs in XRBs?



Thanks Tomaso!