Magnetic fields and outflows in X-ray binaries and changing look AGNs

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Outline

1. **Magnetic fields in accretion disks and outflows**

2. **Evidence of magnetic arrested disk (MAD) in MAXI J1820+070**

3. **Changing look AGNs (CLAGNs)**

    3.1 timescale of variabilities in CLAGNs
    3.2 quasi-periodic eruptions (QPEs)
    3.3 TDE triggered CLAGN

1. Magnetic fields in accretion disks and outflows

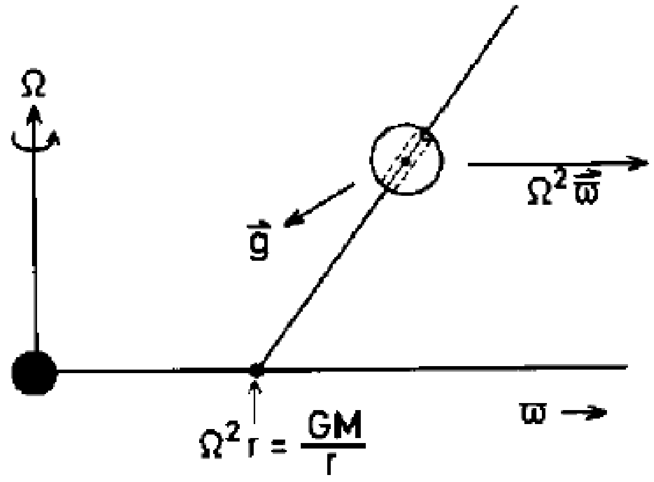
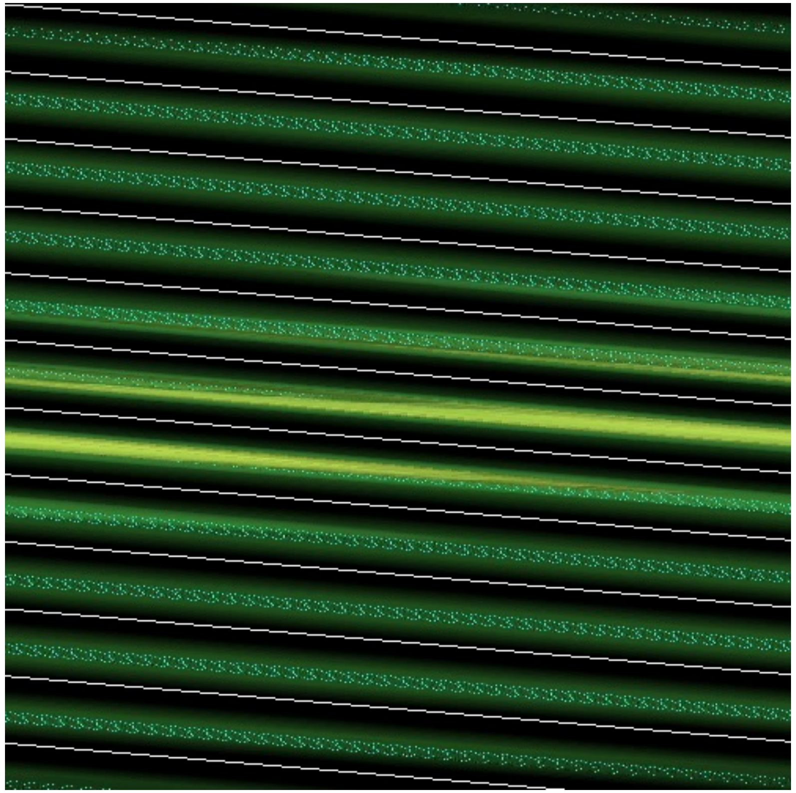


Figure 2: Bead-on-a-wire analogy for centrifugal acceleration by a magnetic field.

(Spruit 1996, astro-ph/9602022)



Kuwabara+

Origin of large-scale magnetic fields in accretion disks

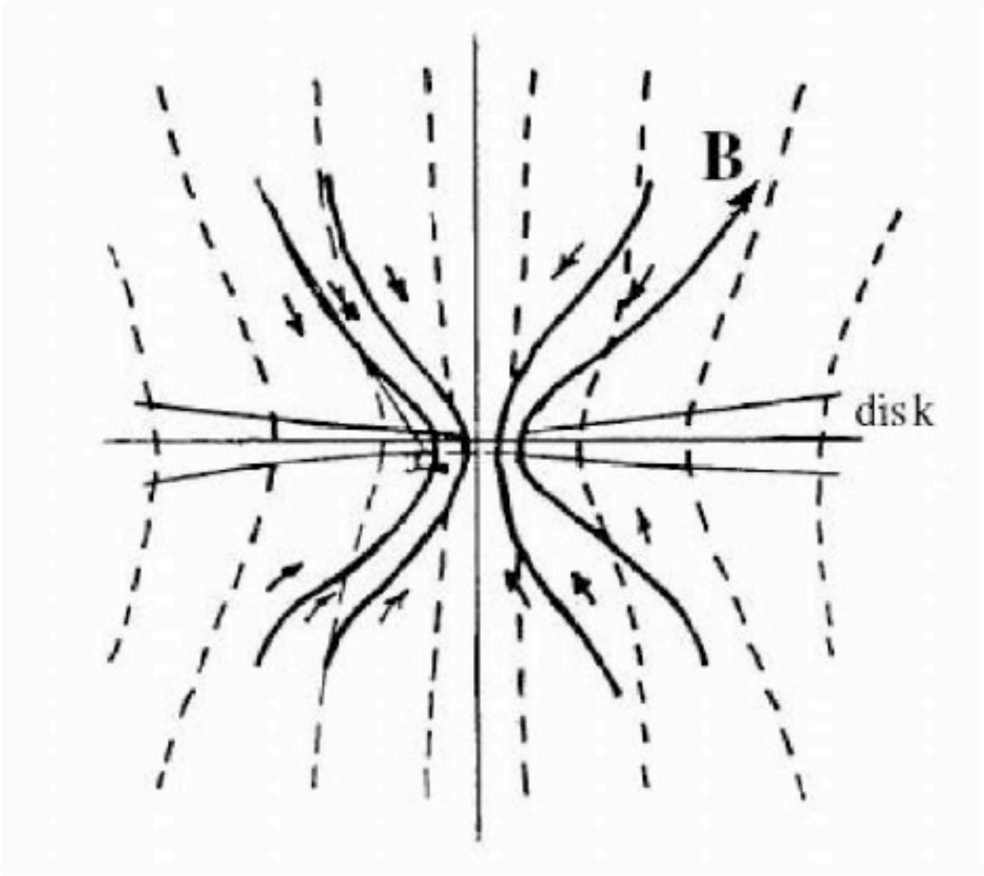
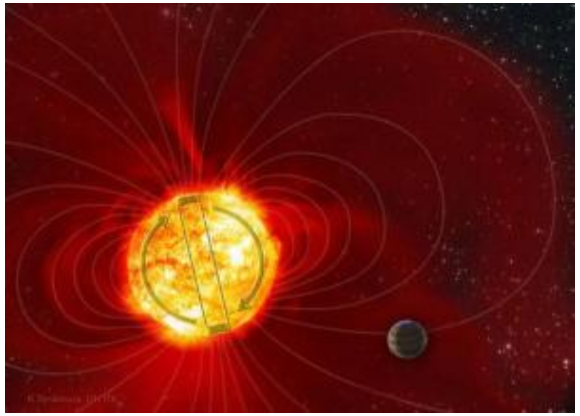
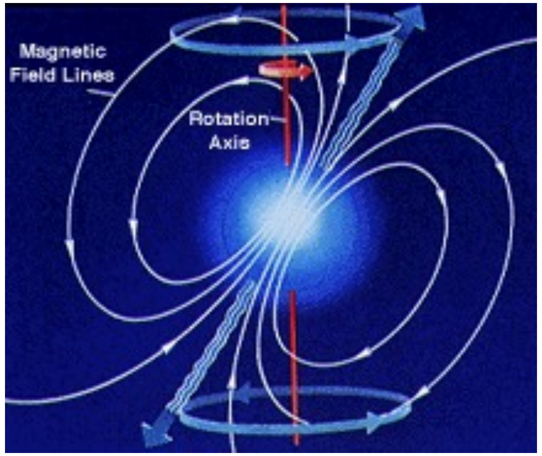


FIG. 1.—Sketch of the poloidal magnetic field threading an accretion disk (from Bisnovatyi-Kogan & Ruzmaikin 1976). The field strength increases with decreasing radius owing to flux freezing in the accreting disk matter.



collapse!



Magnetic field advection/diffusion in accretion disks

Field advection in a thin turbulent disk is inefficient!

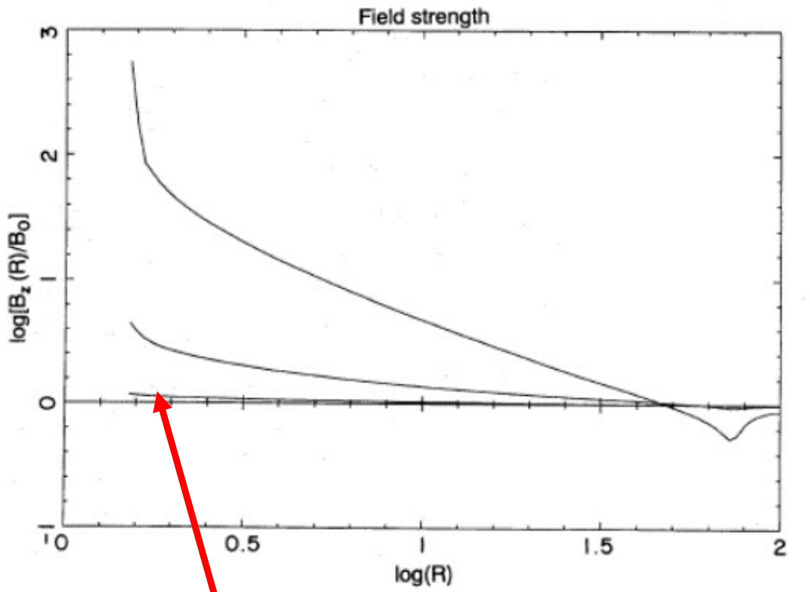


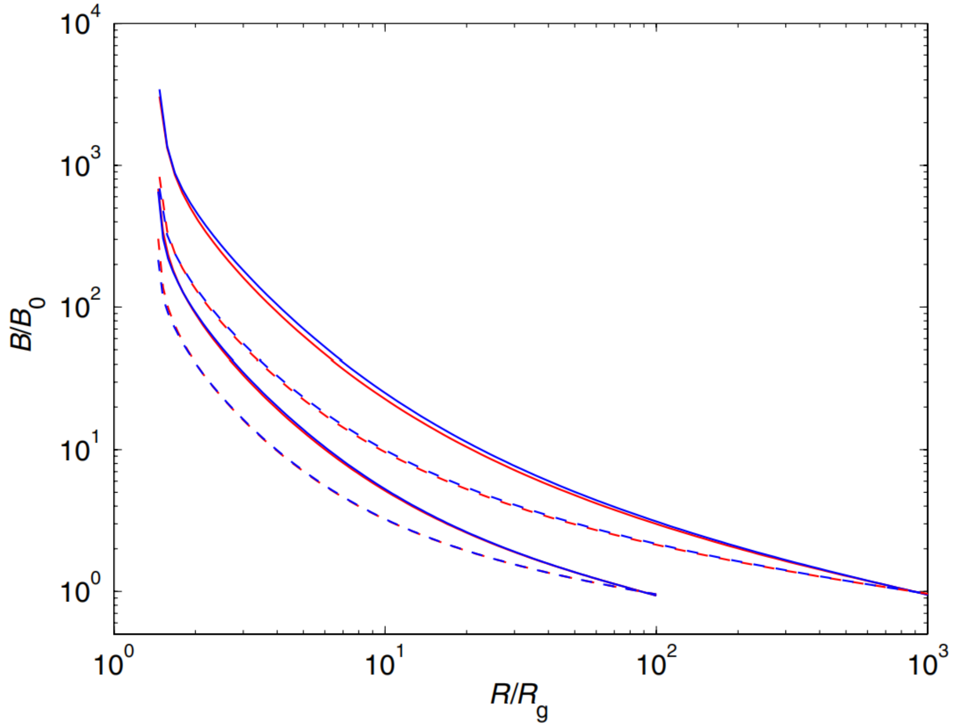
Figure 1. Plot of $\log[B_z(R)/B_0]$ versus $\log R$. Each curve corresponds to a constant value of $\mathscr{D}$. The highest curve for small R corresponds to $\mathscr{D}=0.2$, the intermediate curve to $\mathscr{D}=2.0$, and the flattest curve to $\mathscr{D}=20$.

$$\mathscr{D} \equiv (R/H)\mathscr{P}.$$

$\mathscr{P} \equiv \eta/\nu$ is the magnetic Prandtl number.

Typical values: P~1, H/R~0.05, D~20

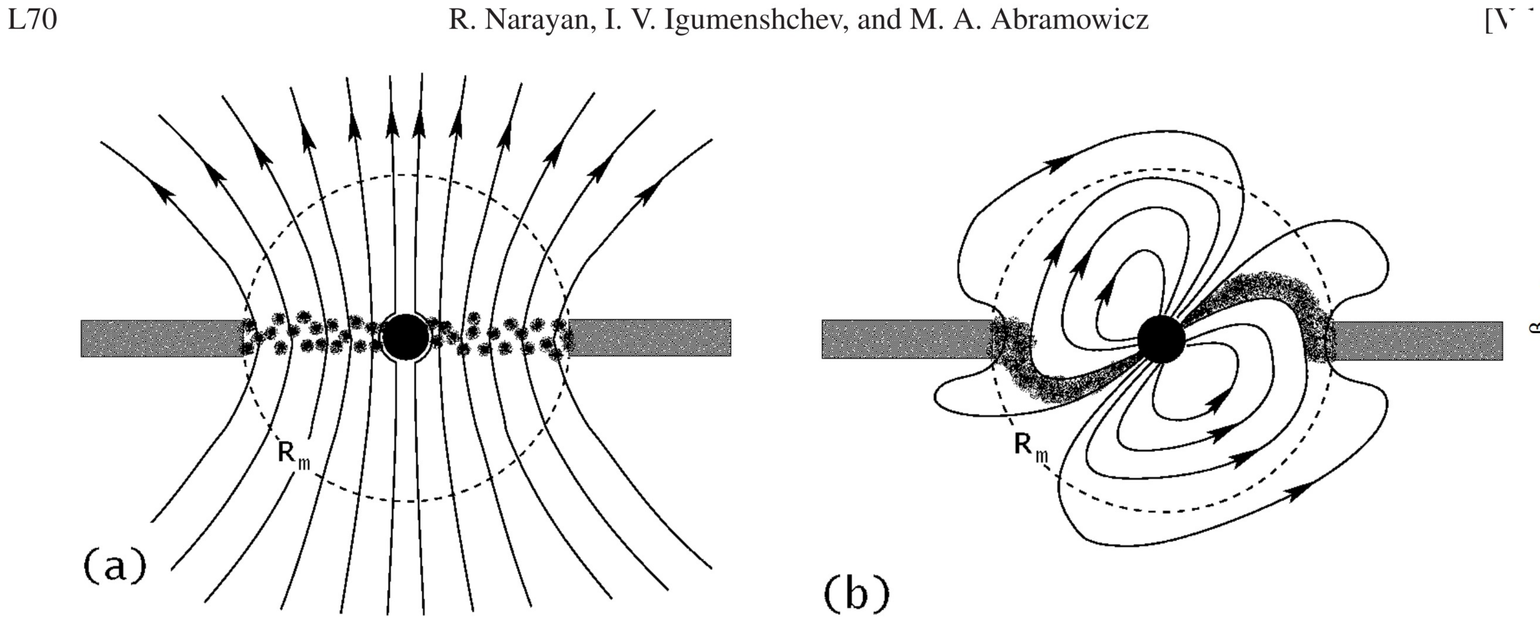
Lubow et al. 1994, MNRAS, 267, 235

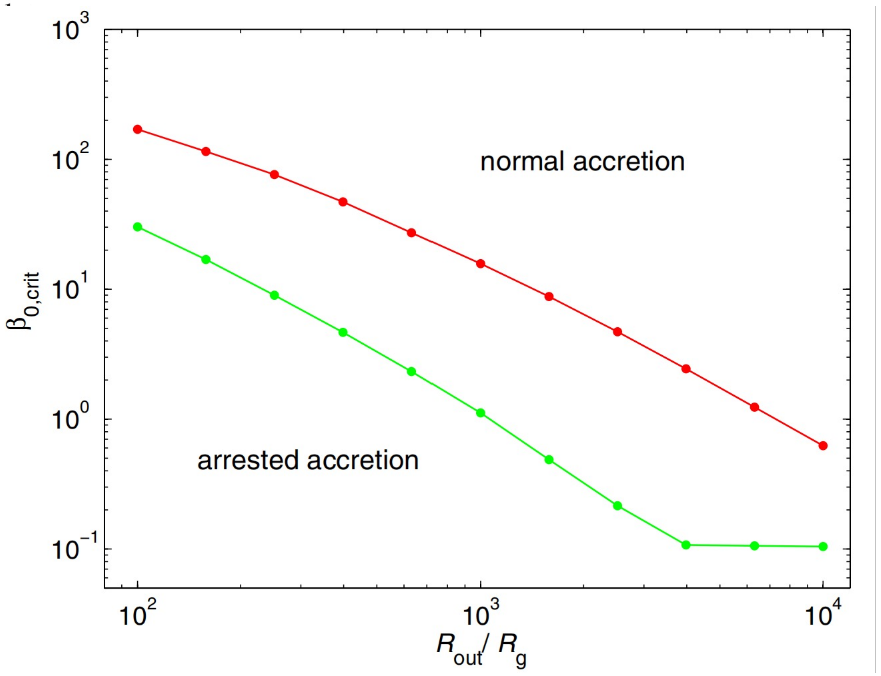


Field amplification in an ADAF increases with its size!

Cao 2011, ApJ 737, 94

The disk may be arrested if the field is sufficient strong, i.e., magnetically arrested disk (MAD)





P_m=1(red); 1.5(green)

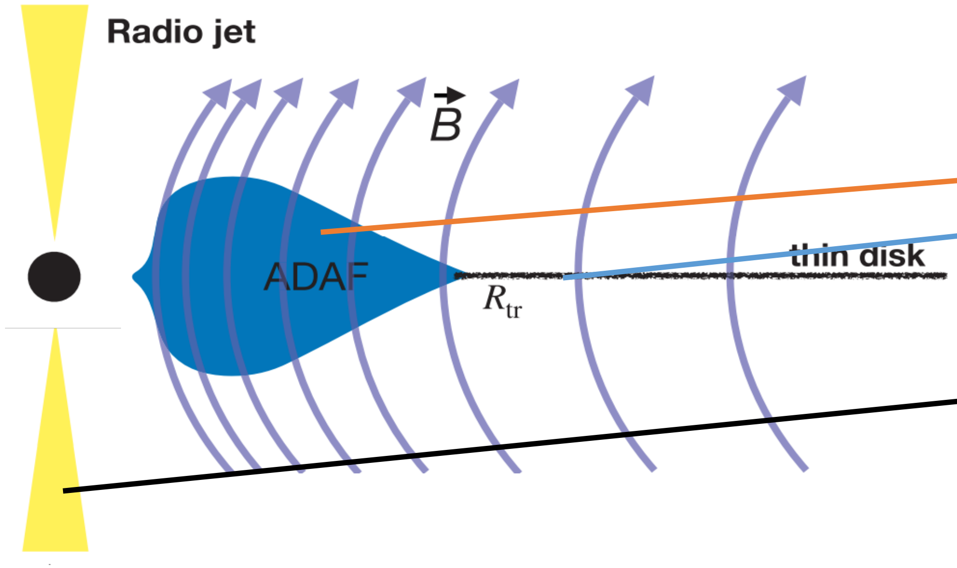
Narayan+ 2003

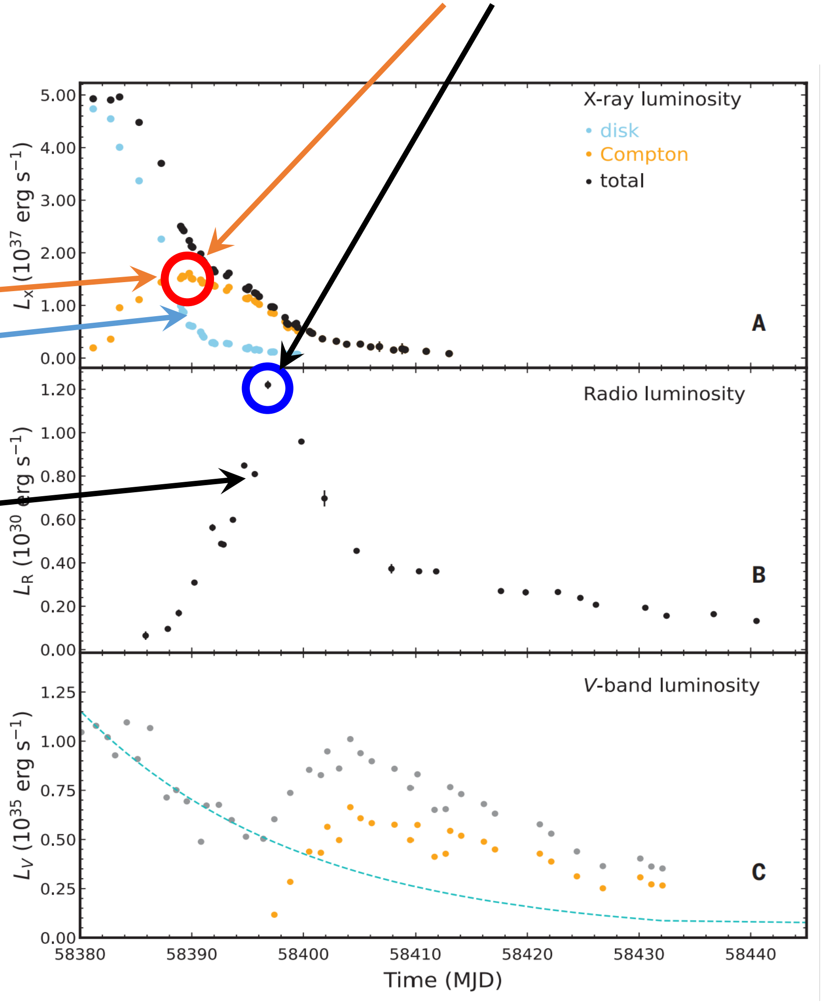
Cao 2011, ApJ 737, 94

2. Evidence of magnetic arrested disk (MAD) in MAXI J1820+070

Its radio flux was delayed compared with hard X-ray flux by 8 days!

8 days

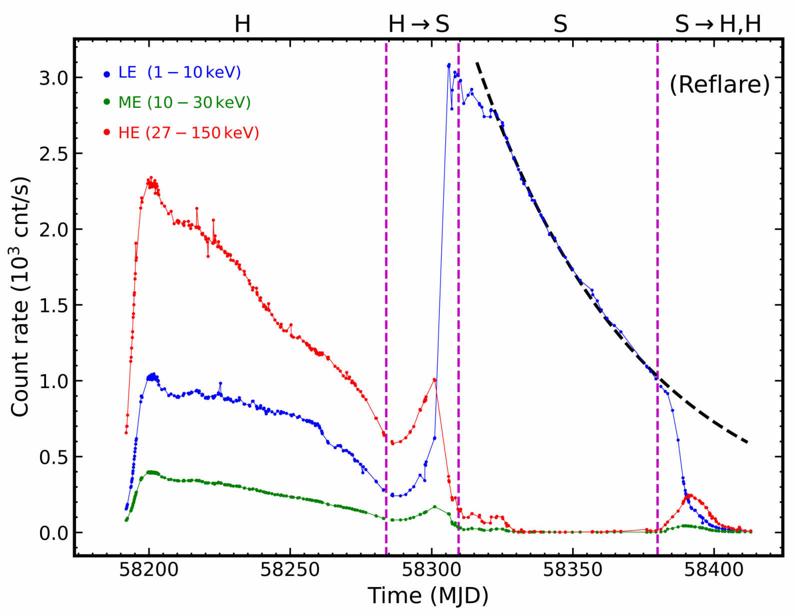




BH size is ~30km
hard X-ray emission region ~300km!

You, **Cao,** Yan et al. 2023, Science 381, 961

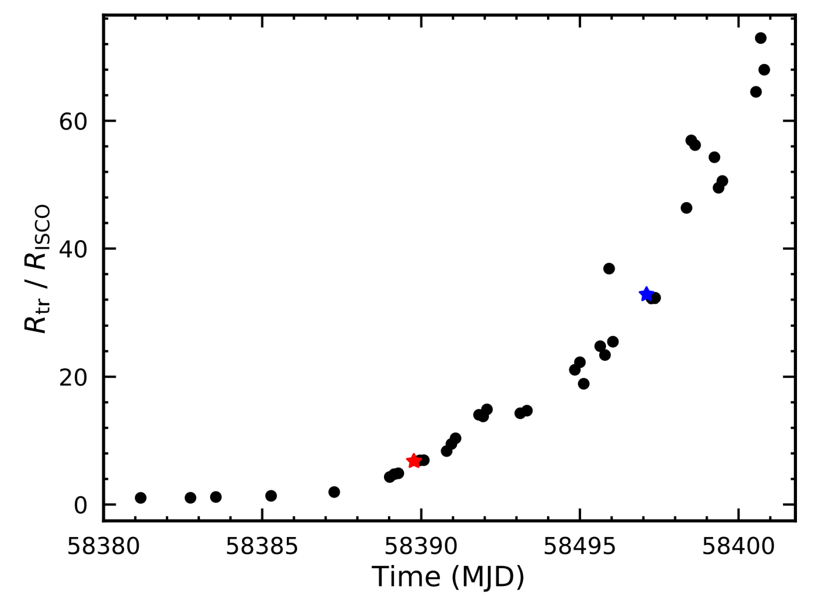
$\tau = 57.61$ days

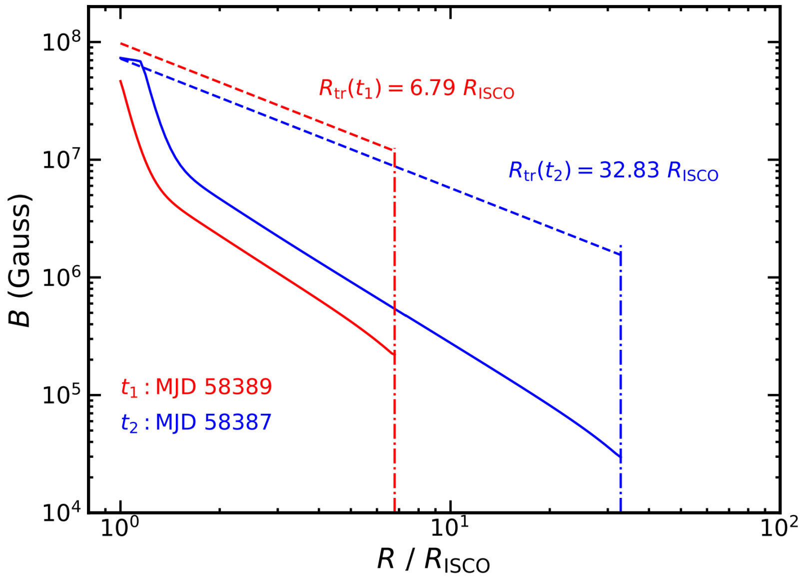


$$M_h = \frac{\rho R_h^3}{3} \exp(-3\nu t / R_h^2)$$

$$\tau = \frac{1}{3} t_{visc} \sim \frac{R_0^2}{3\nu} \sim 40 \text{ d}$$

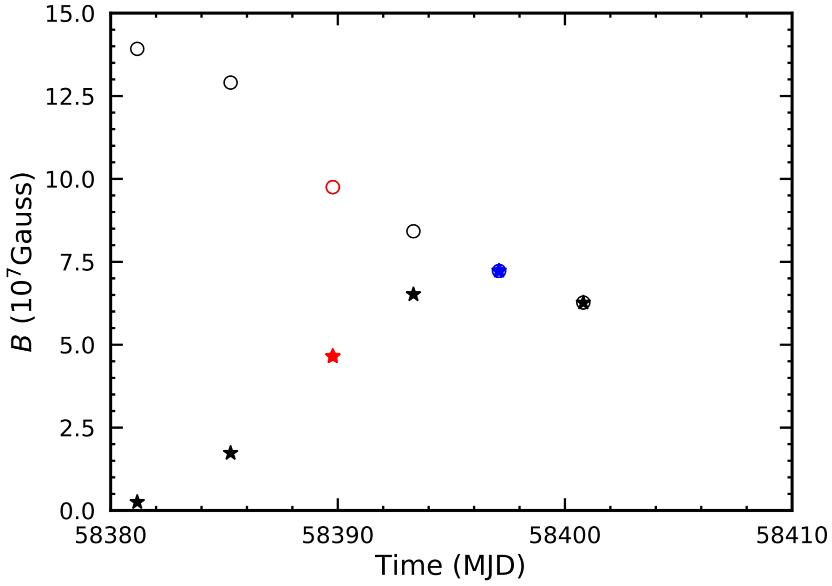
King & Ritter 1998





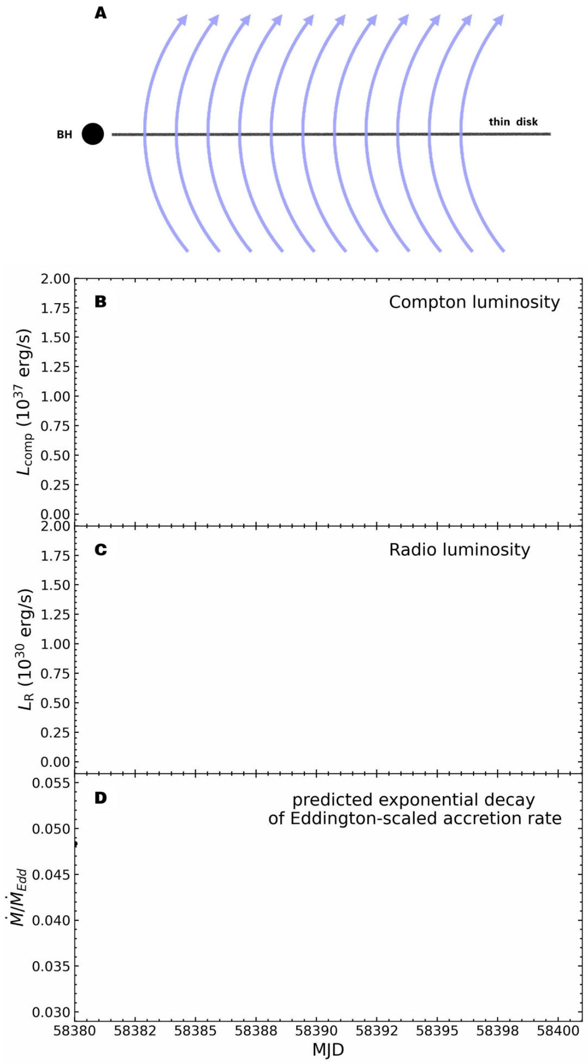
Red: peak of X-ray

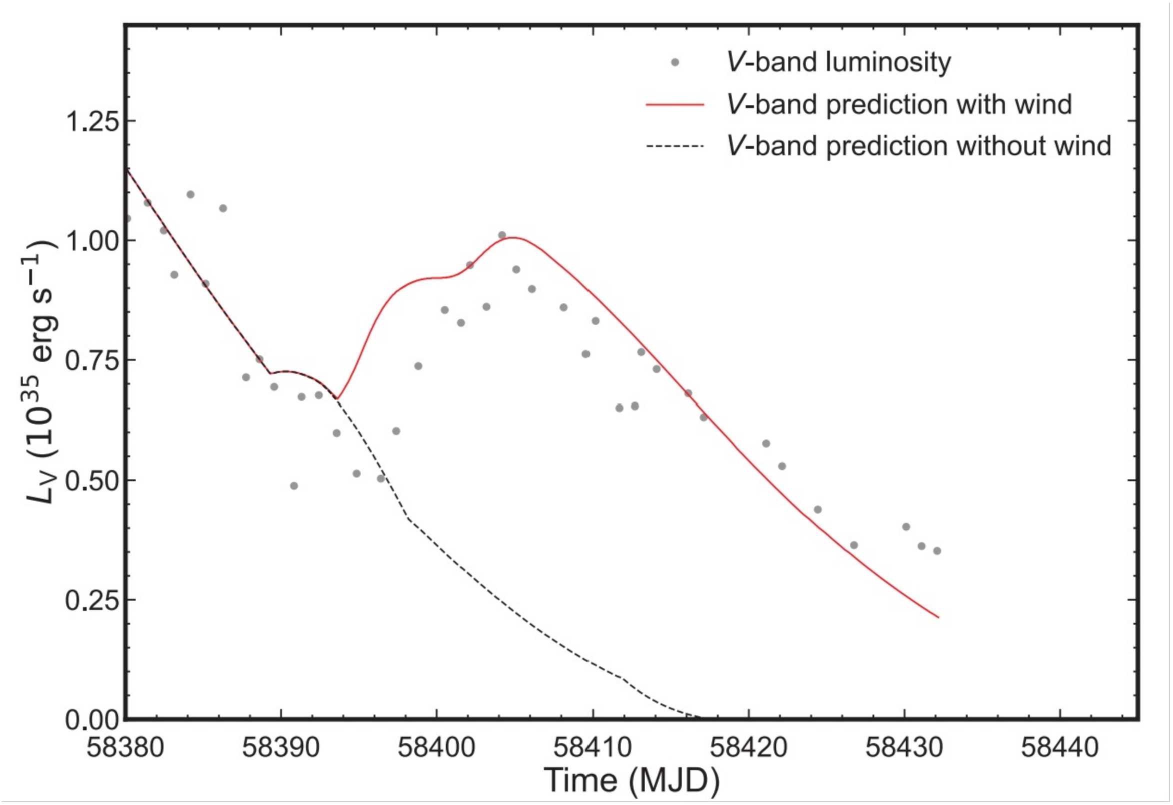
Blue: peak of radio



Dashed: minimal field strength for MAD

Figure S5: The strength of the magnetic field of the ADAF at R_{ISCO} varies as a function of time. The star points indicate the simulated magnetic strength advected by the ADAF, and the circle points are the MAD criterion. The red and blue colors represent the epochs corresponding to the



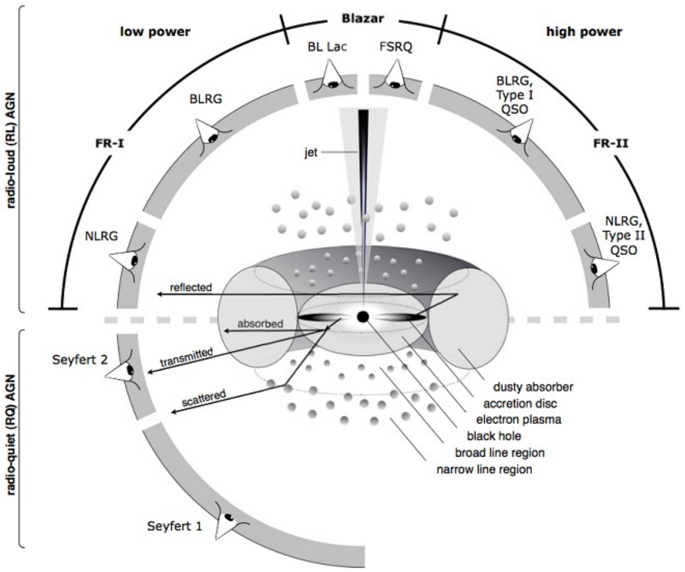


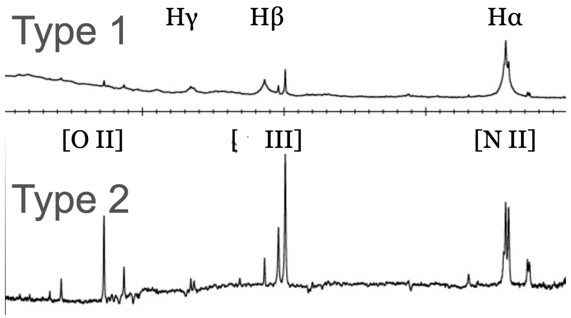
The X-ray flare heats up the outer thin disk, reviving the thermal-viscous instability in the thin disk, which produces a delayed optical emission.

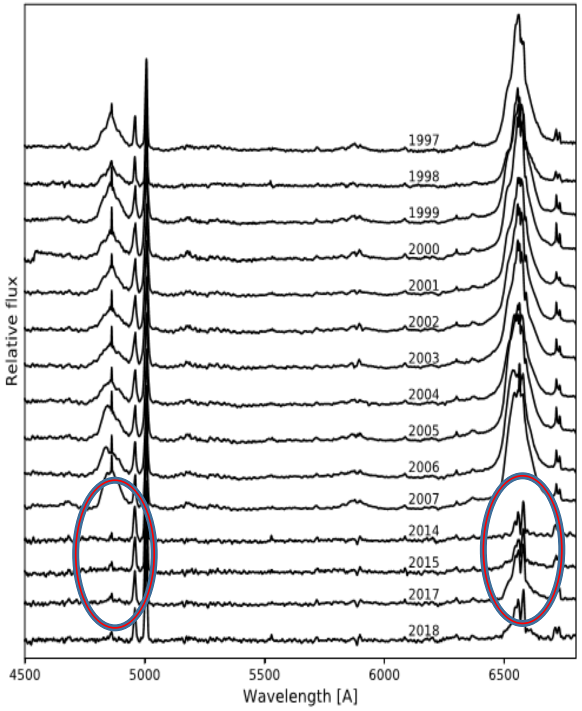
3. Changing look AGNs (CLAGNs)

3.1 timescale of variabilities in CLAGNs

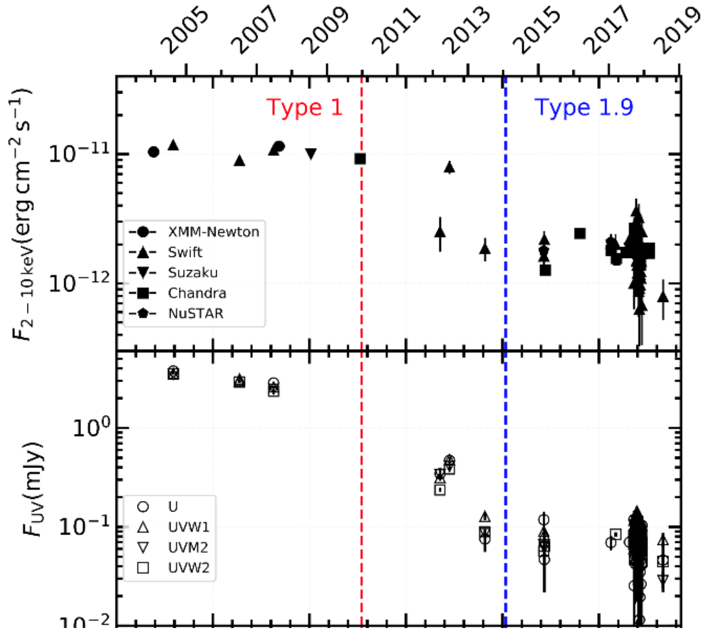
The timescales of the variabilities in CLAGNs are usually on the order of years to tens of years (some of them are even shorter than one year).







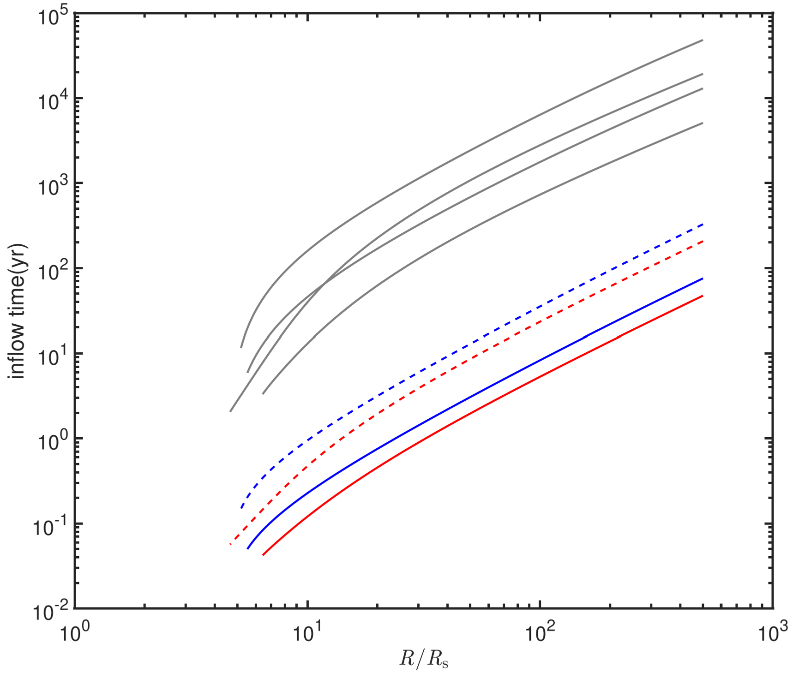
Mrk 590 Denney et al. 2014



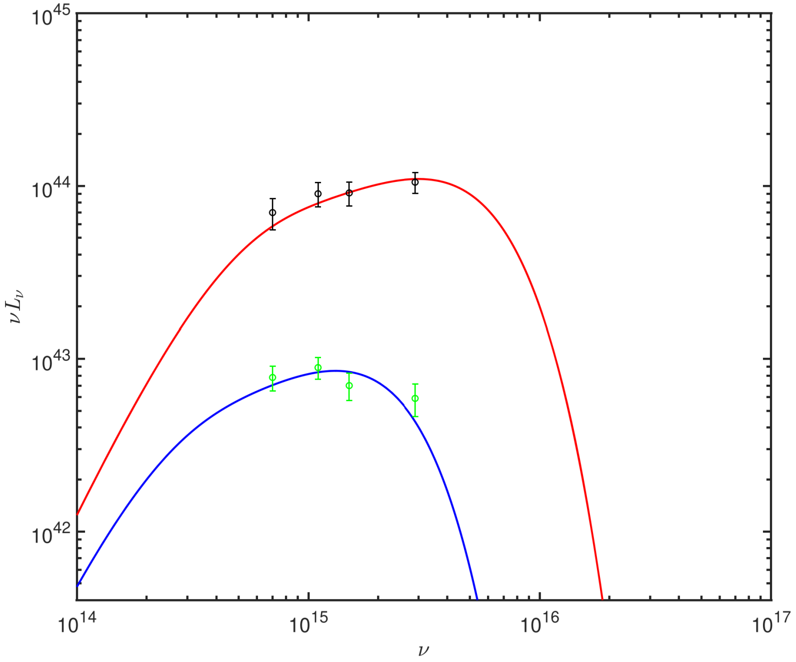
A CLAGN: Mrk1018

It is much shorter than the viscous timescale of a standard thin disk.

The variabilities of CLAGNs cannot be reproduced by varying the mass accretion rate of a standard thin disk!



CLAGN Mkn 1018

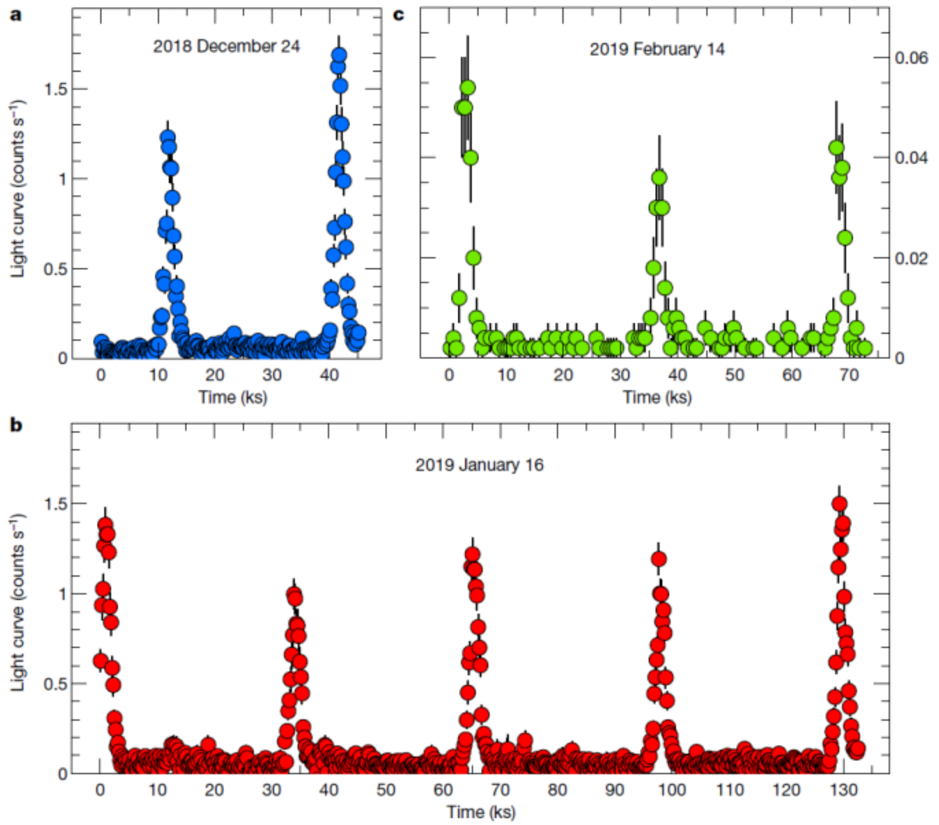


We suggest that most angular momentum of the gas in the disk is carried away by magnetic outflows, and therefore its radial velocity can be substantially higher than that of a conventional viscous disk.

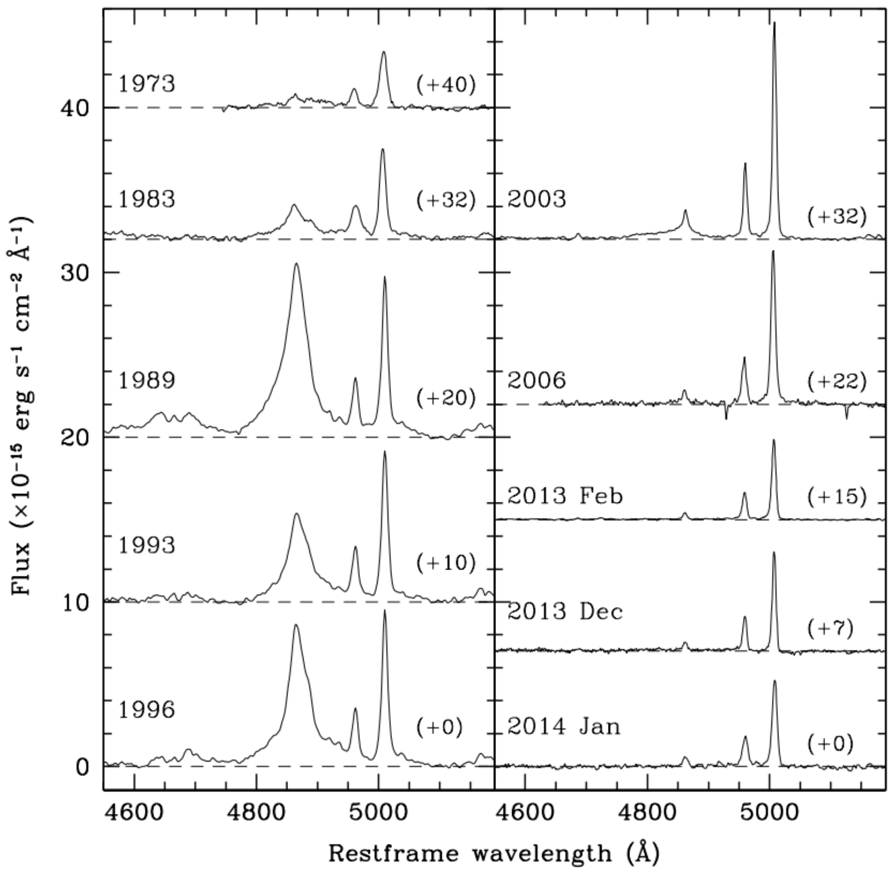
Feng, **Cao** et al. 2021, ApJ, 916, 61

3.2 quasi-periodic eruptions (QPEs)

GSN 069

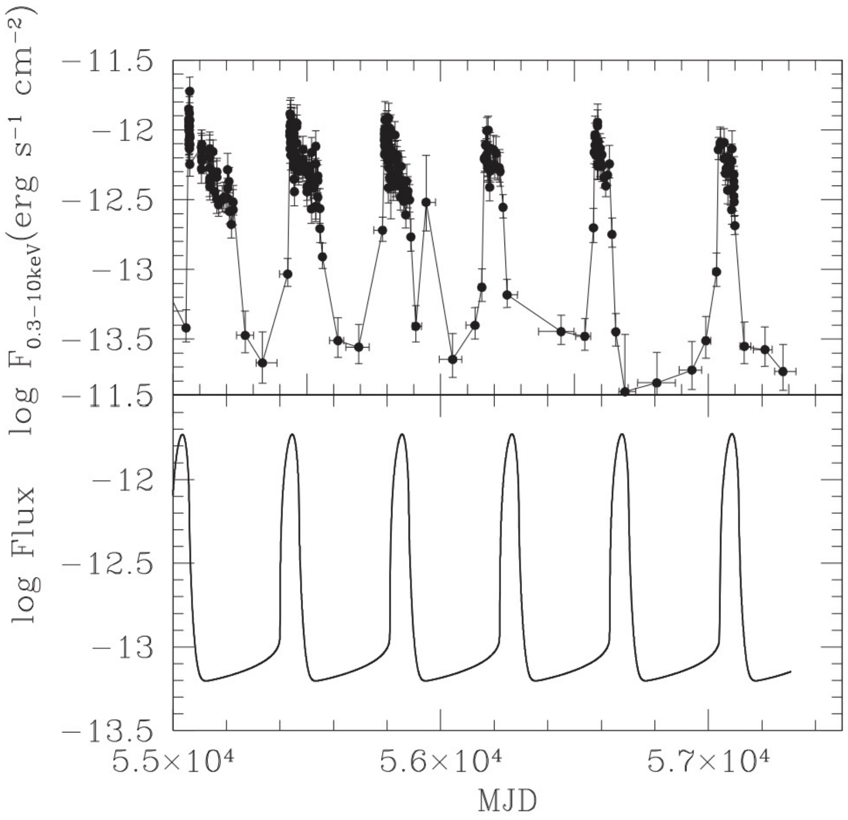


Miniutti et al. 2019,Nature



Denney et al. (2014)

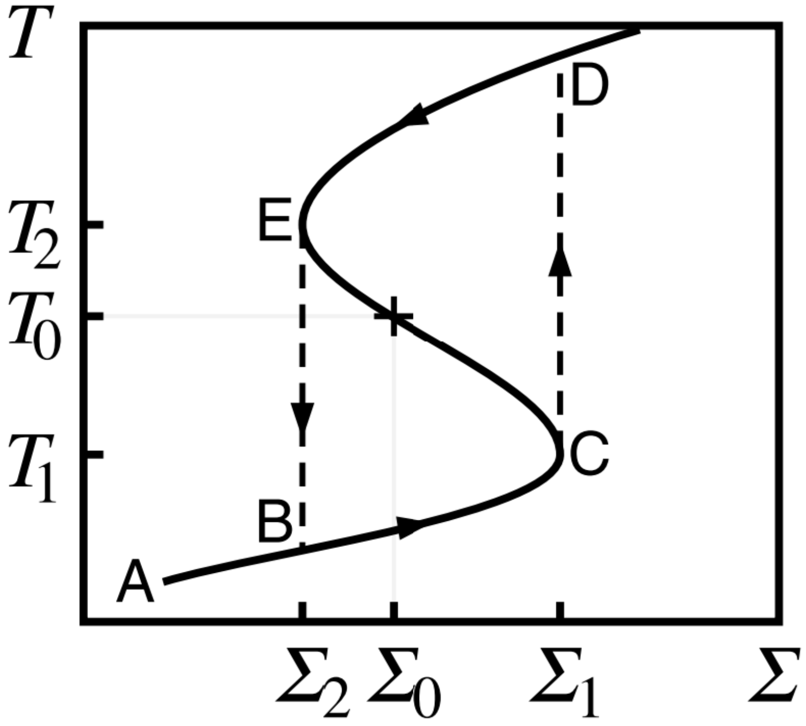
HLX-1



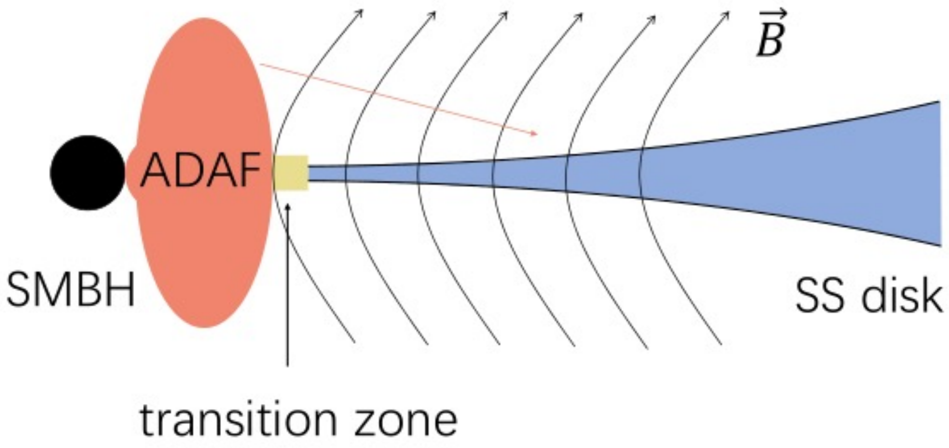
Observed light curve of hyperluminous X-ray source and modeled curve (disk instability model)

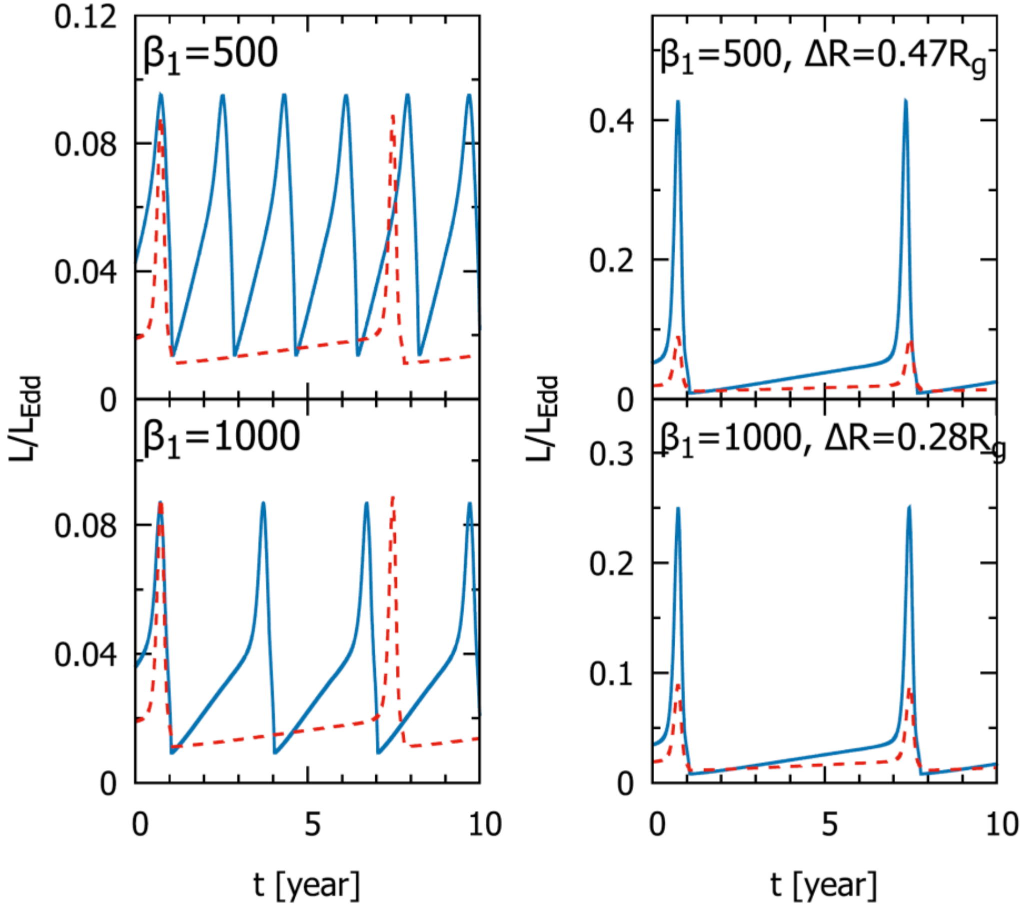
Wu+ 2016, ApJ 833, 79

Disk instability model



Effective temperature–surface density diagrams

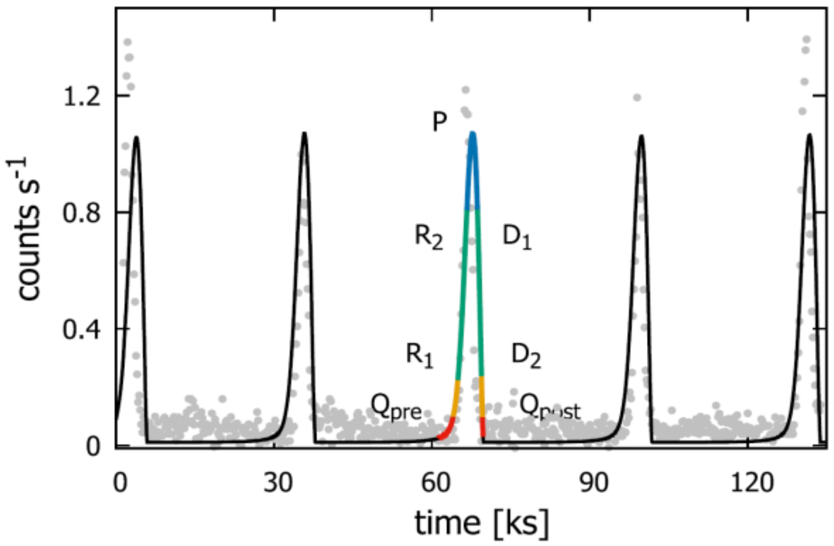




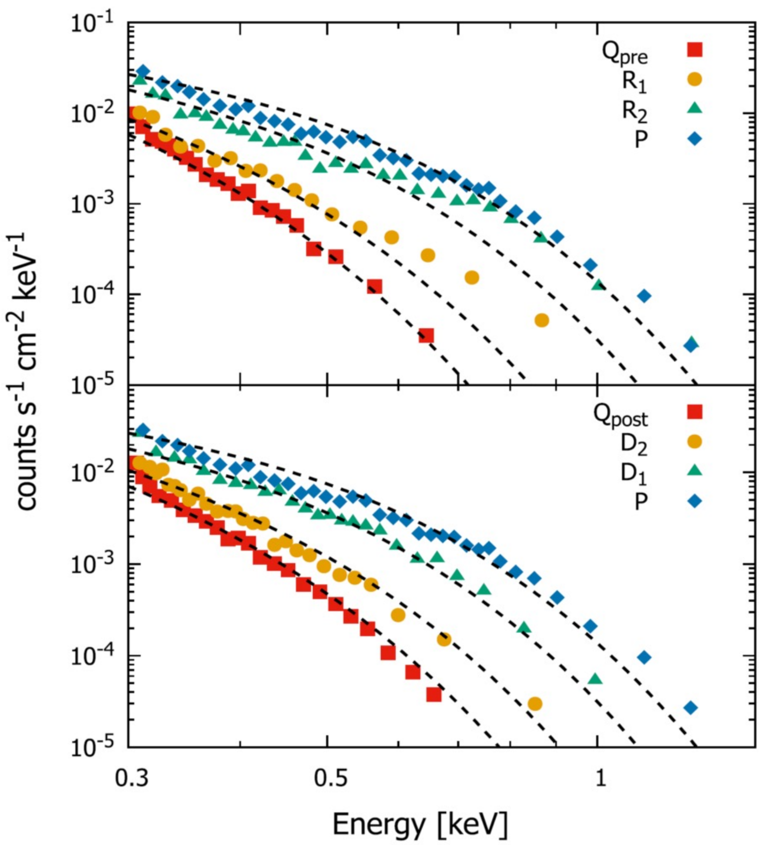
The outer blue region represents a stable thin disk dominated by gas pressure and the inner orange region is the unstable zone dominated by radiation pressure.

Pan, Li, **Cao** et al. 2022, ApJ, 928, L18

GSN 069



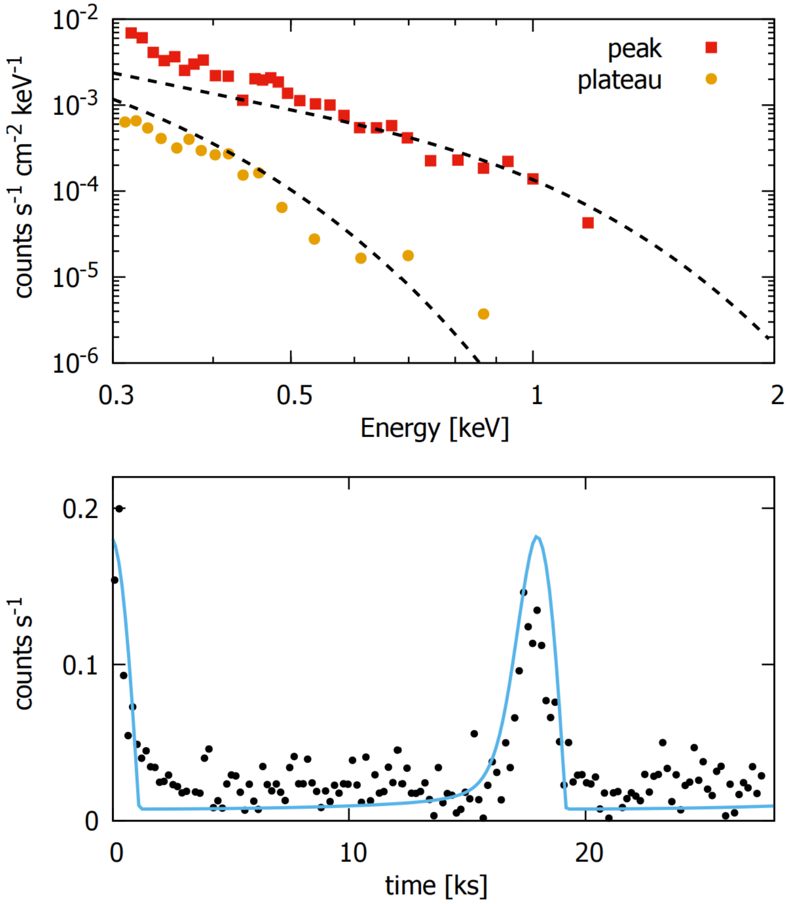
counts s^{-1}
1.2
0.8
0.4
0
0
30
60
90
120
time [ks]
P
R$_2$
D$_1$
R$_1$
D$_2$
Q$_{pre}$
Q$_{post}$



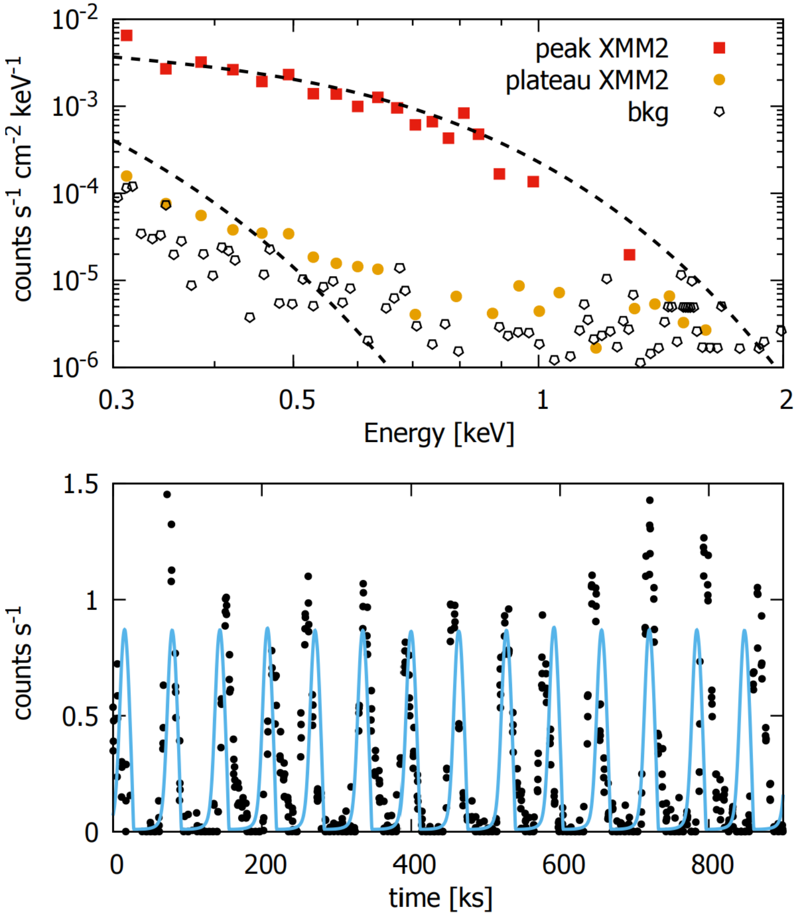
counts s^{-1} cm^{-2} keV^{-1}
10^{-1}
10^{-2}
10^{-3}
10^{-4}
10^{-5}
Q$_{pre}$
R$_1$
R$_2$
P
Q$_{post}$
D$_2$
D$_1$
P
0.3
0.5
1
Energy [keV]

Application of the disk instability model to all Quasi-Periodic Eruptions

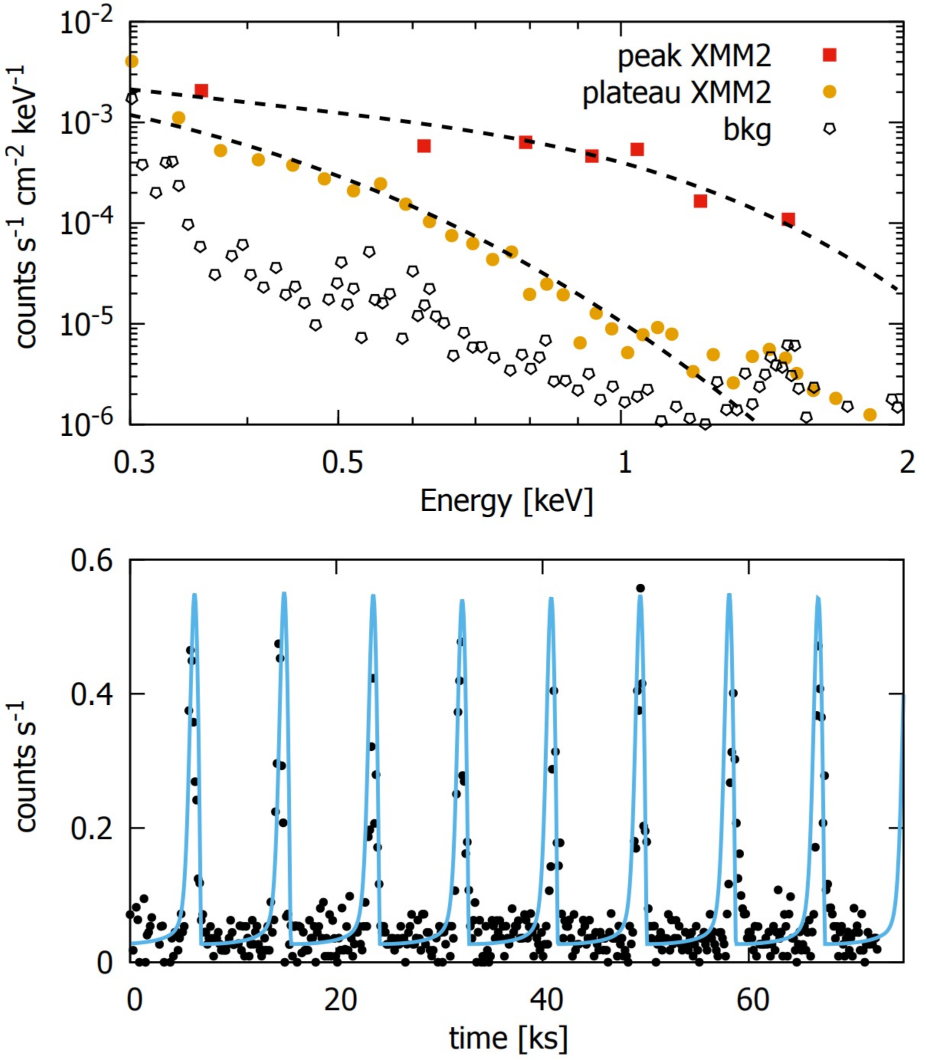
RX J1301.9+2747



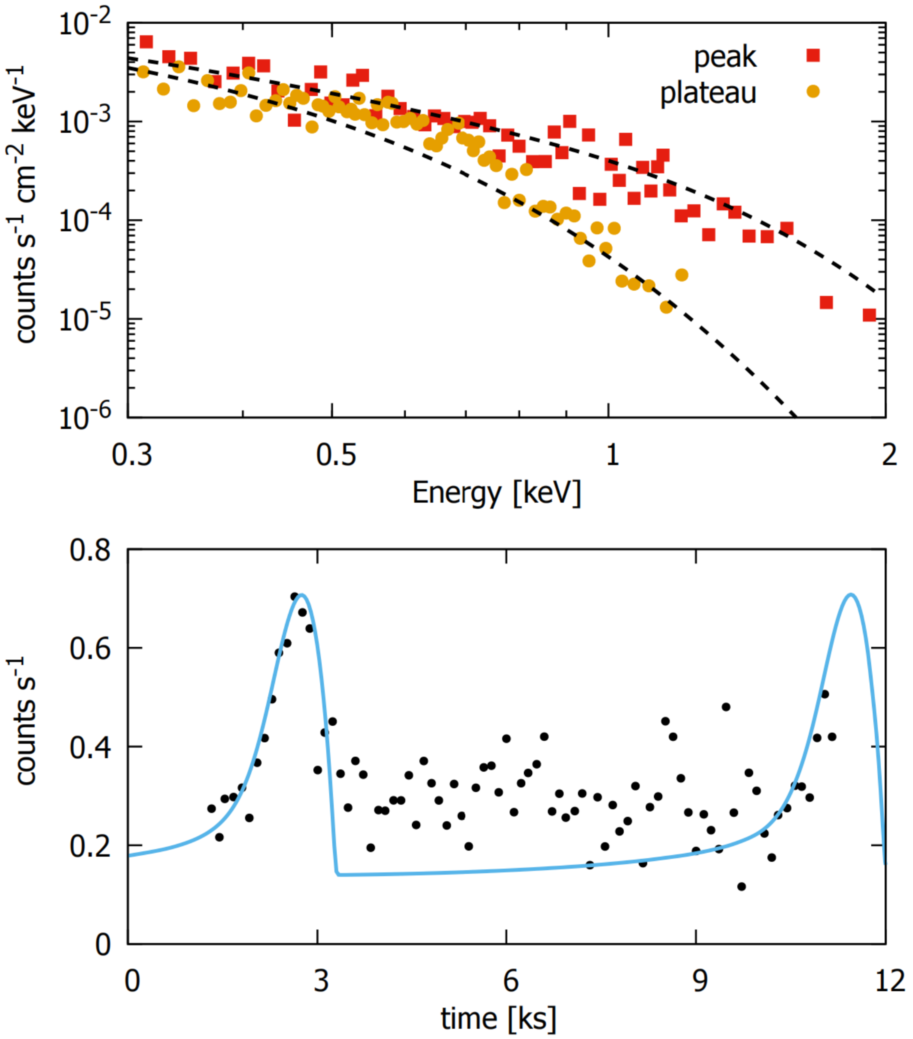
eRO-QPE1



Pan, Li, & **Cao,** 2023, ApJ 952, 32



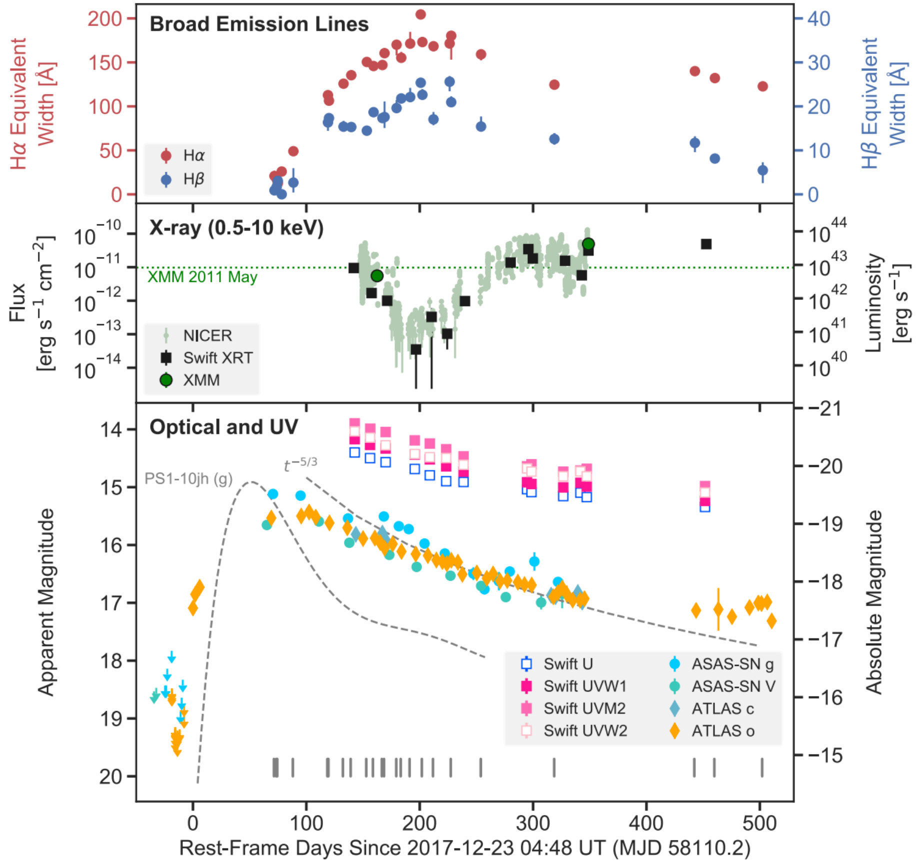
eRO-QPE2

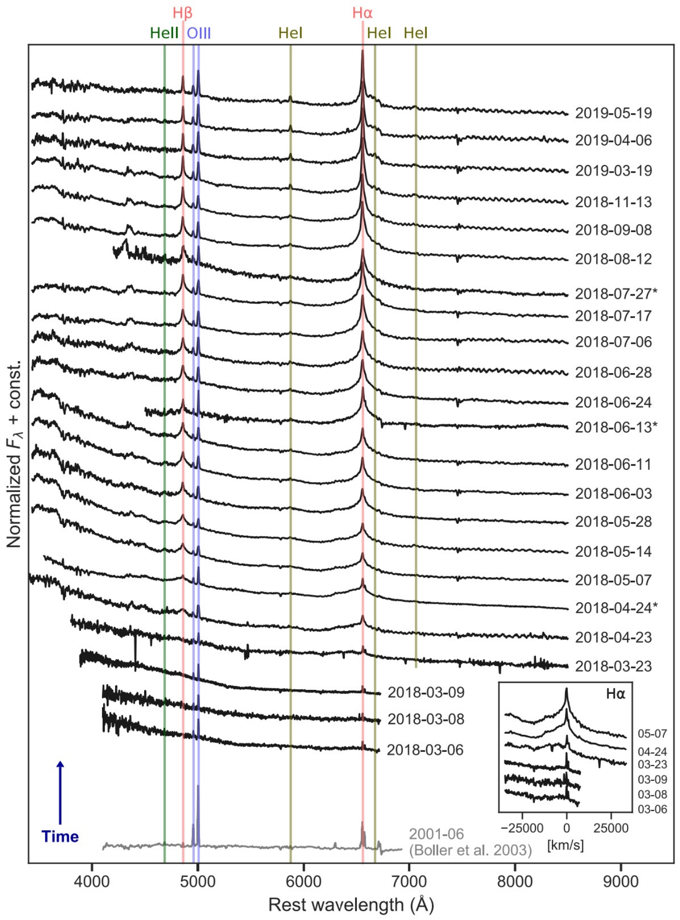


XMMSL1 JJ024916.6-041244

3.3 TDE triggered CLAGN 1ES 1927+654

It was a narrow-line Seyfert galaxy before the UV/optical outburst in 2017 z = 0.019422

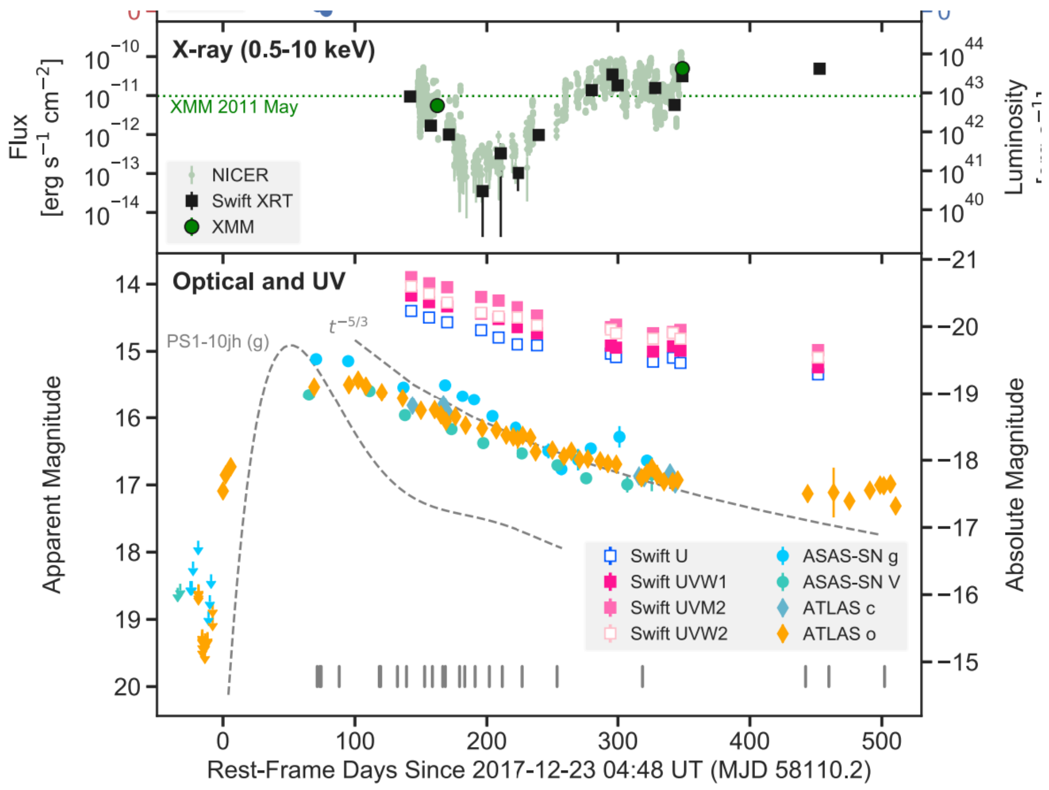


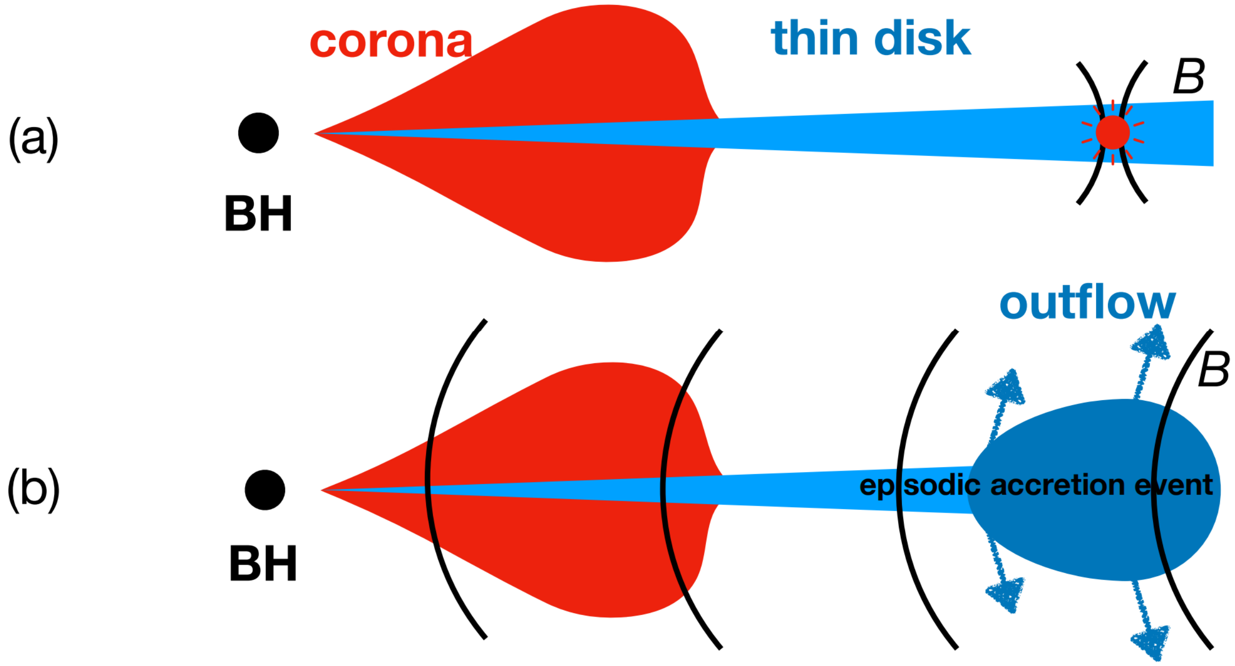


Trakhtenbrot+ 2019, ApJ, 883, 94

Model

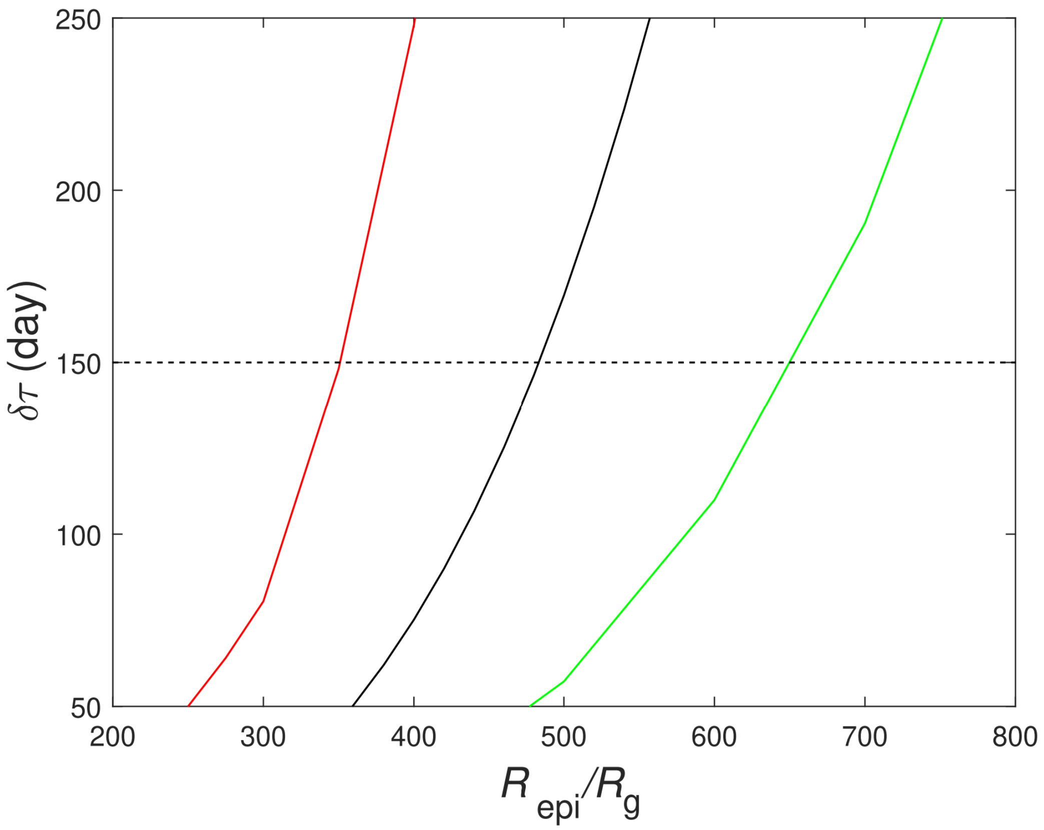
We assume that a TDE takes place in the outer region of the disk that emits UV/optical photons



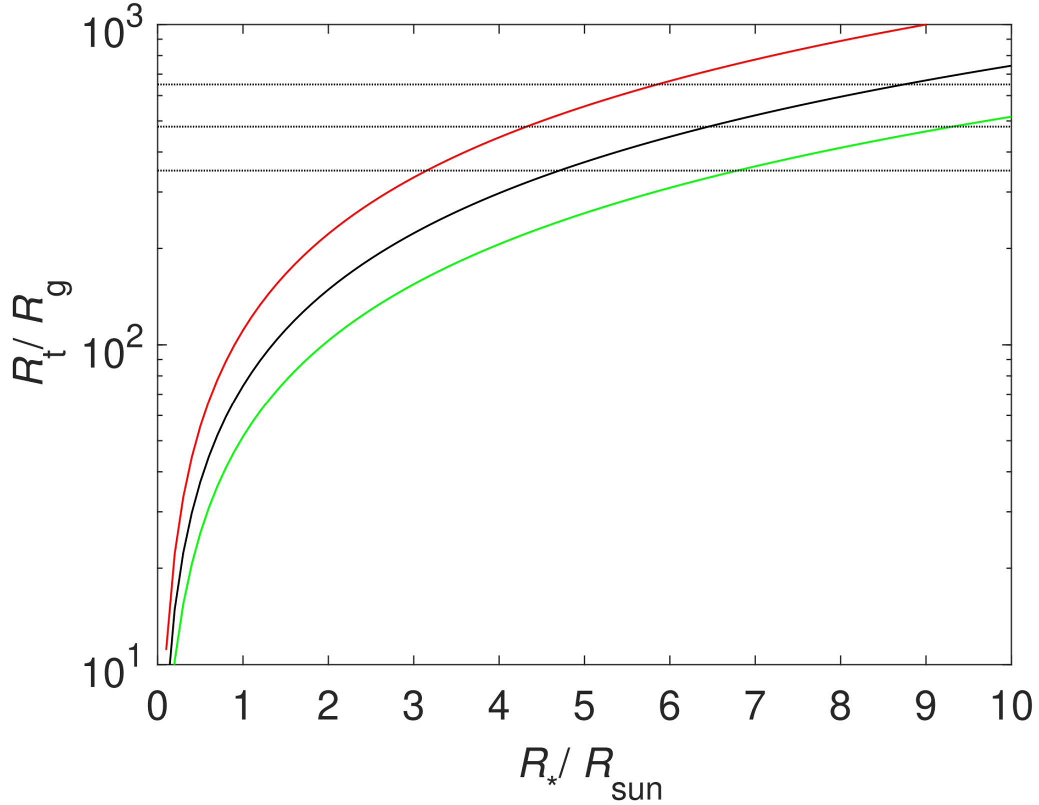


Cao, You, & Wei 2023, MNRAS, 526, 2331

The inner thin disc with corona is completely swept by the accretion event when the gas reaches the innermost circular stable orbit (~150 days after the TDE).



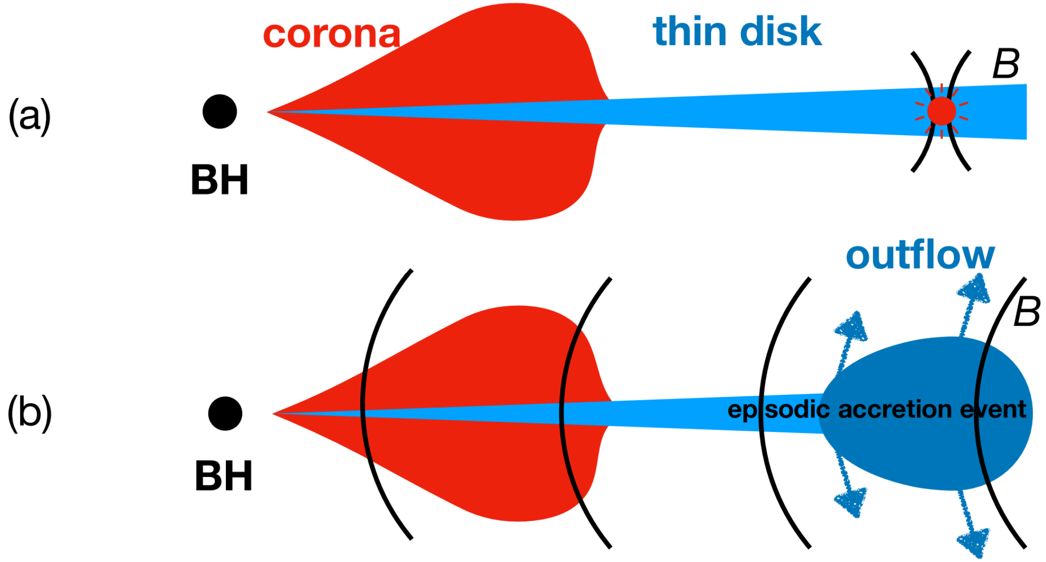
$\alpha = 0.03$ (red), 0.1 (black), and 0.3 (green)

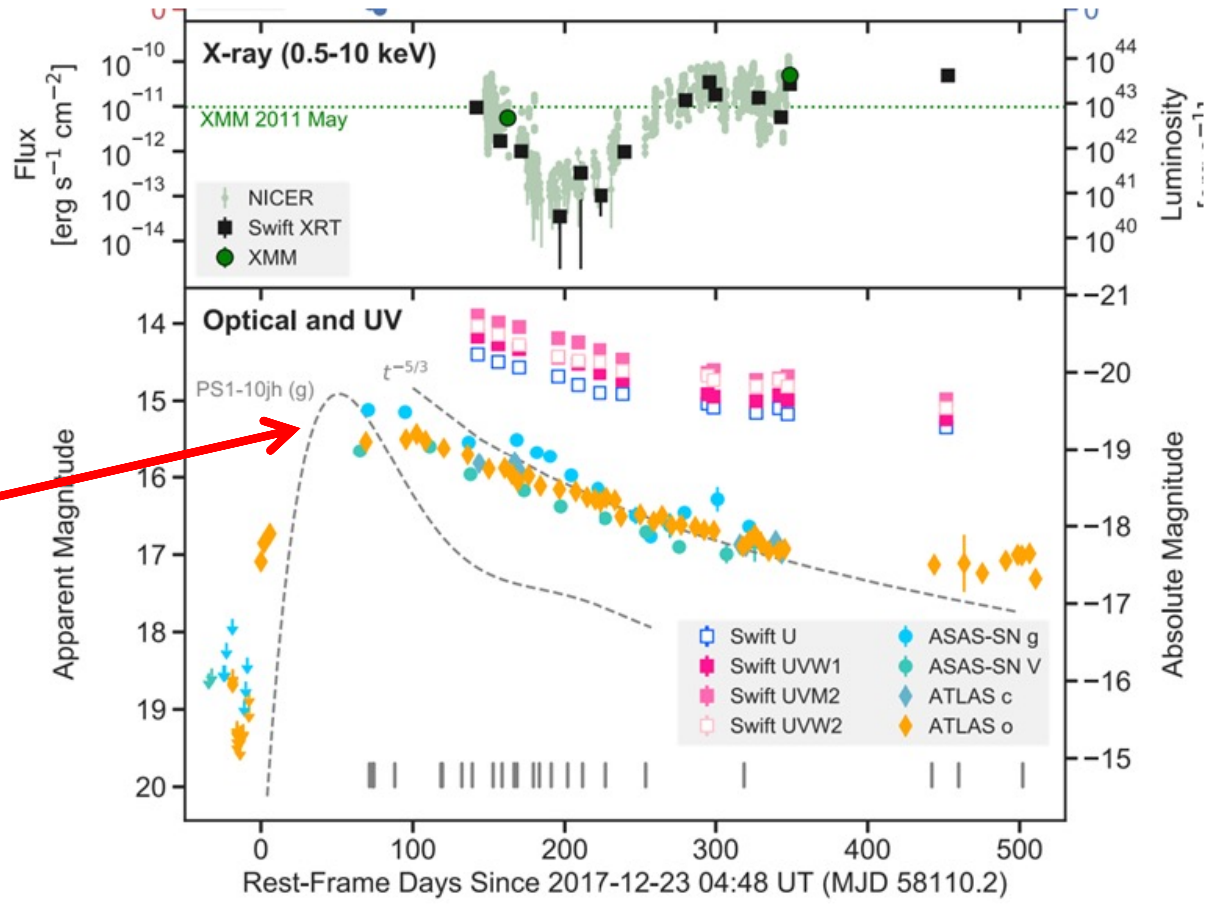


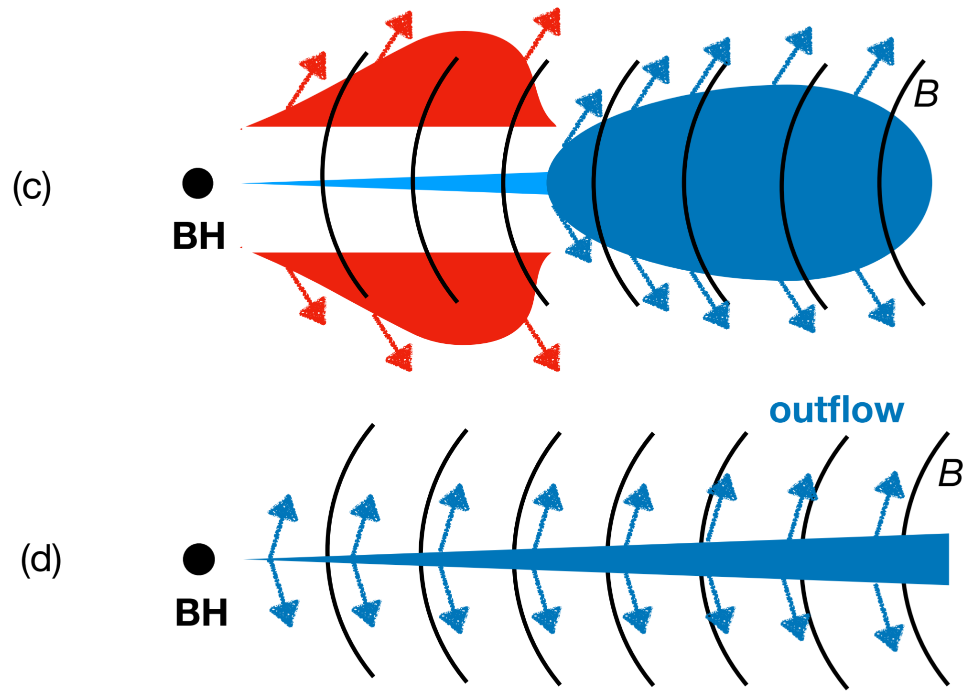
The tidal disruption radius R_t versus the star radius with different star masses (red: $0.3M_\odot$, black: $1M_\odot$, and green: $3M_\odot$). The horizontal dotted lines denote $R_t = 350R_g$, $480R_g$, and $650R_g$, respectively.

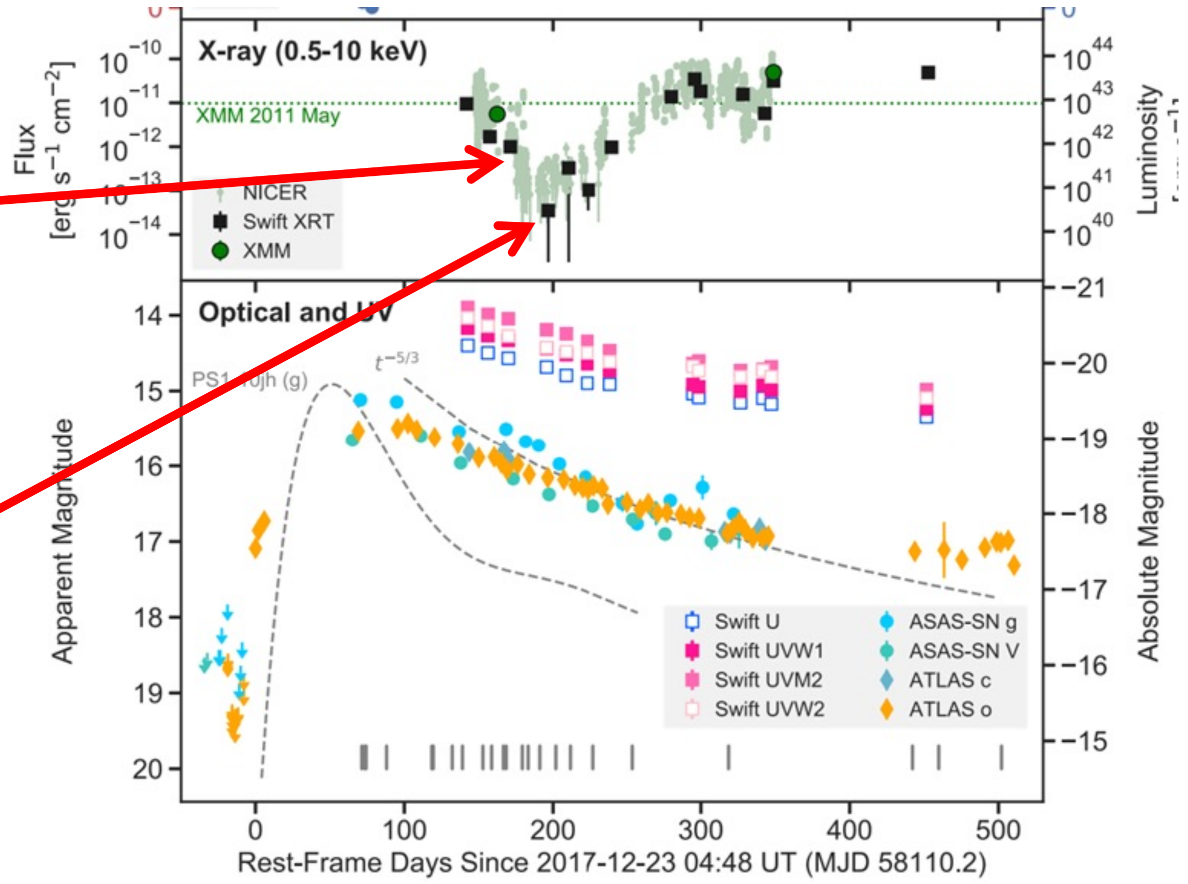
We suggest a solar-mass red giant star is disrupted in the outer region of the accretion disk!

The magnetic field of a giant red star is very strong!



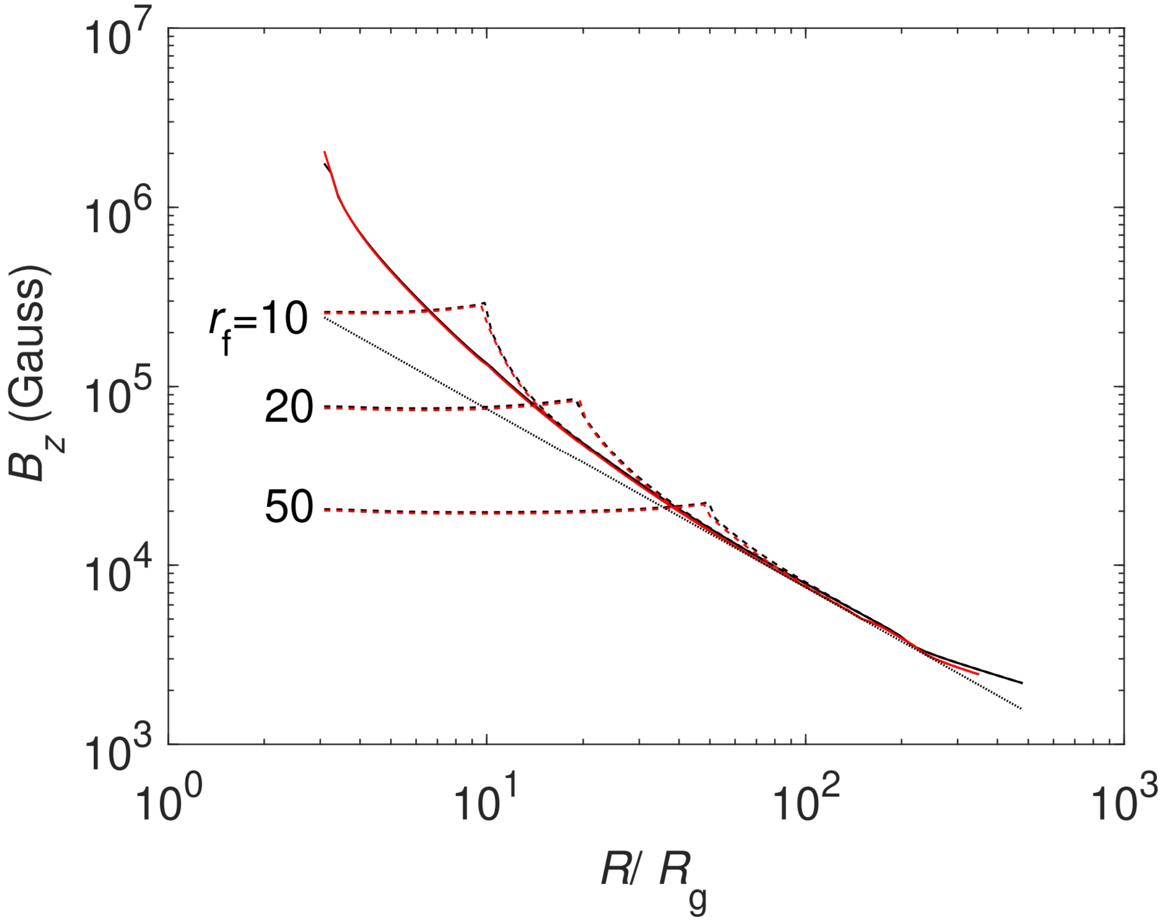




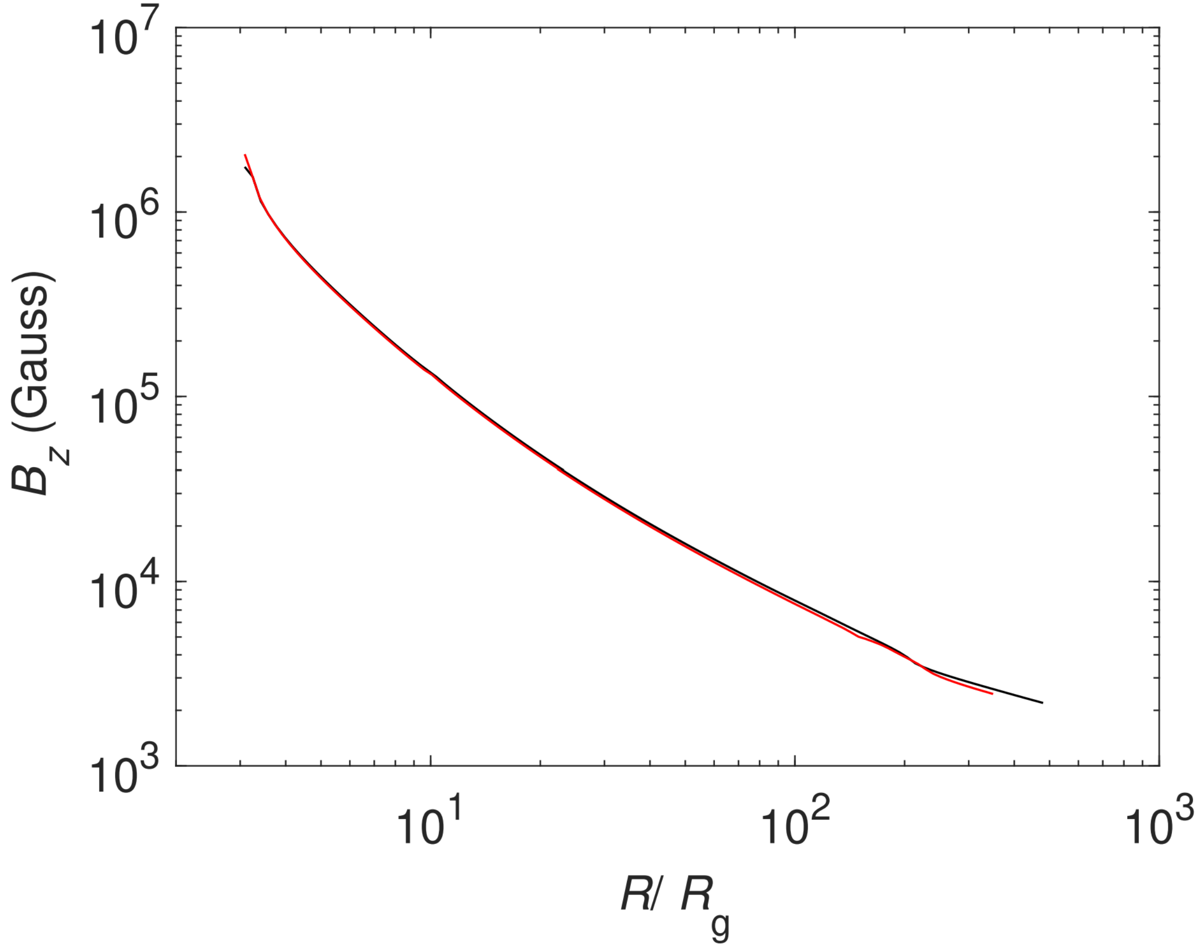


1. The field threading the disrupted star is dragged inwards by the disk formed after the TDE, which accelerates the corona from the disk.

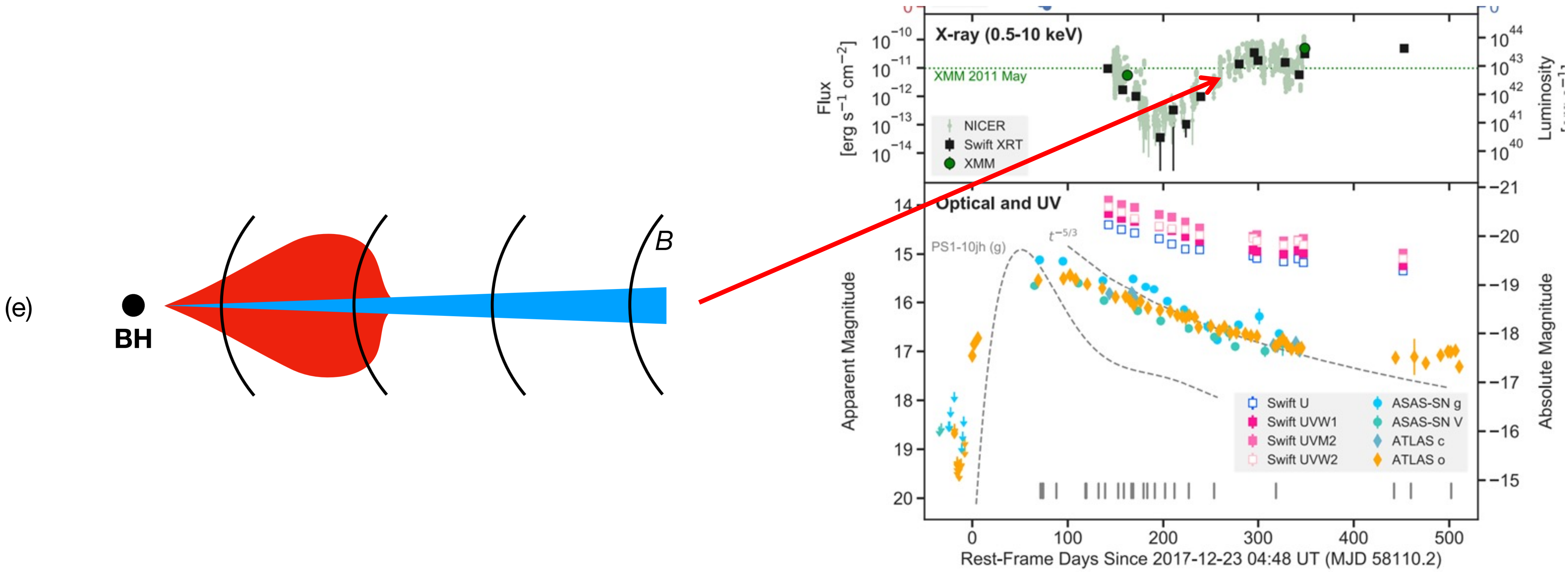
2. The disk dimmed since a large fraction of the energy released in the disk is tapped into the outflows.



Black line: the minimal magnetic field required to accelerate the corona into outflows



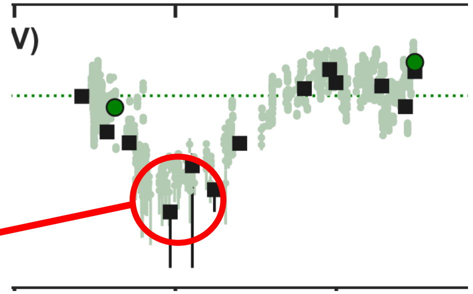
The field of the TDE disk extends to the ISCO.



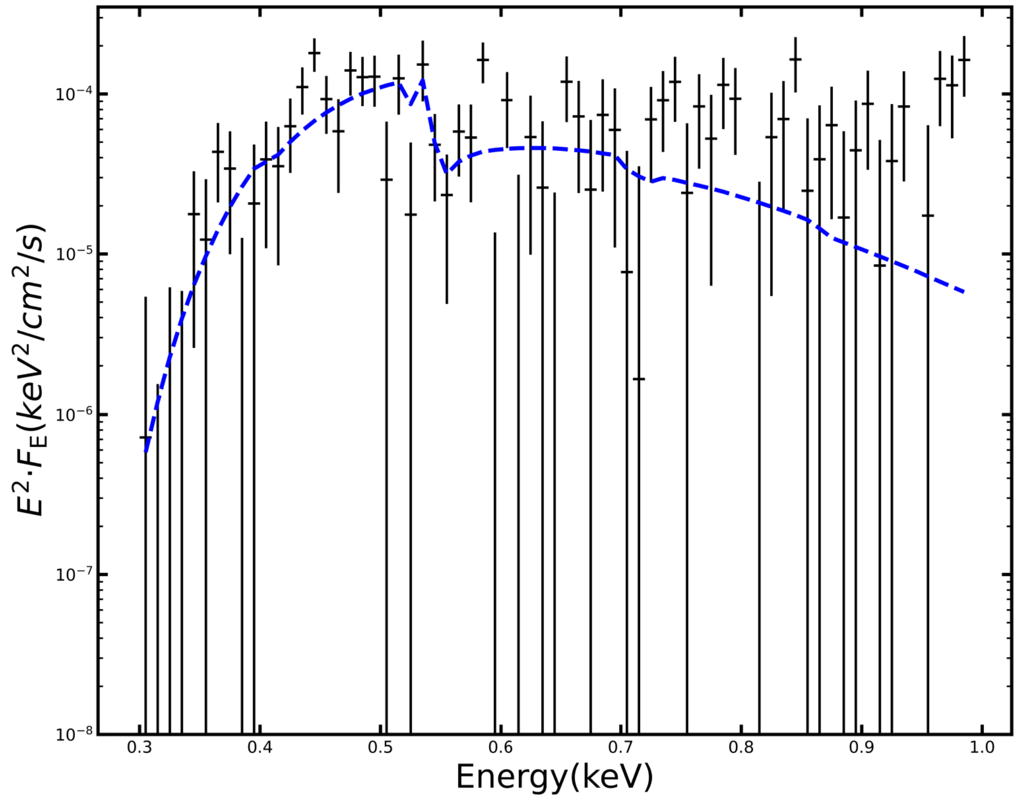
1. The accretion rate of the TDE declines, and ultimately it turns out to be a thin disk, which is inefficient for field advection, and the outflows are switched off.

2. A thin disk with corona reappears later after the outburst.

Model fitting of the X-ray spectra



We use our model to fit the X-ray spectra during the X-ray dip.



$\alpha = 0.1$

Two epochs: MJD 58323 (Obs ID: 1200190151) and MJD 58325 (ObsID: 1200190153). The spectra of these two epochs are then combined for better statistics using the tool addspec.

We note that, the best-fitting values:

Bext =2.19e3 Gauss (βext = 85.5)

Typical field strengths of red giant stars are several thousand Gauss in their envelopes, or ~10^5 Gauss in the cores of the red giant stars.

Summary

1. The external field is substantially enhanced in an ADAF due to its large radial velocity;

2. Evidence of MAD in MAXI J1820+070 derived from its light curves;

3. Main observational features of CLAGNs can be naturally explained in the frame of magnetic disk-outflow models.

Thanks!

Observational features:

1. L(0.3-10keV)=6.81e42 erg/s (observed in 2011 as a Seyfert 2 galaxy);

2. A UV/optical outburst was observed in the end of 2017:

   a. peak emission is about four magnitudes brighter than that in the pre-outburst state
   b. UV/optical emission declined slowly, similar to a typical light-curve of a TDE

3. X-ray dip:

   a. flux declines rapidly with the power-law component completely disappearing while the X-ray emission reached its lowest level (about several ten days after the UV/optical peak)
   b. With the soft X-ray emission increasing from the lowest flux, the power law X-ray emission reappeared and backed to (or even brighter than) the flux before the X-ray dip within the next ~100 days