Disrupted Stars and/or Unstable Disks?: Two Challenging AGN Transients

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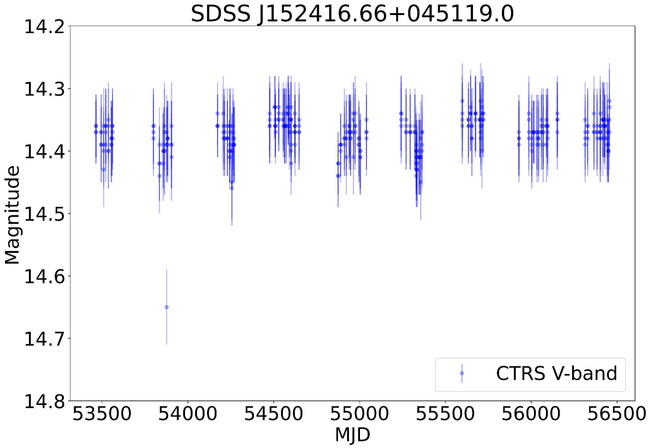
Taj Jankovic (FZU, Prague), Tanja Petrushevska (Nova Gorica), Dragana Ilic (Belgrade)
Agnieszka Janiuk (CTP, Warsaw), Bożena Czerny (CTP, Warsaw),
and many others!

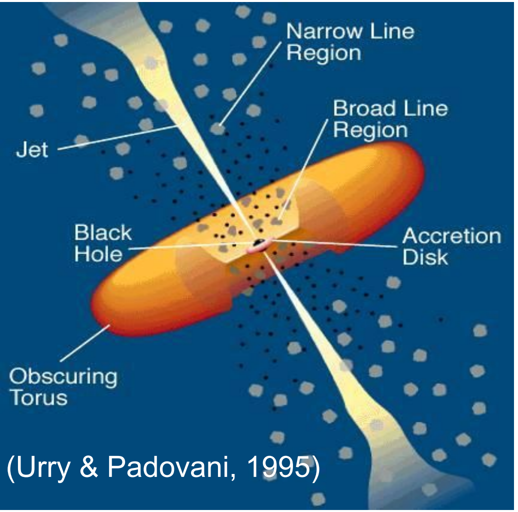
Astronomical Institute of the Czech Academy of Sciences

POSTDOC INDIVIDUAL FELLOWSHIP

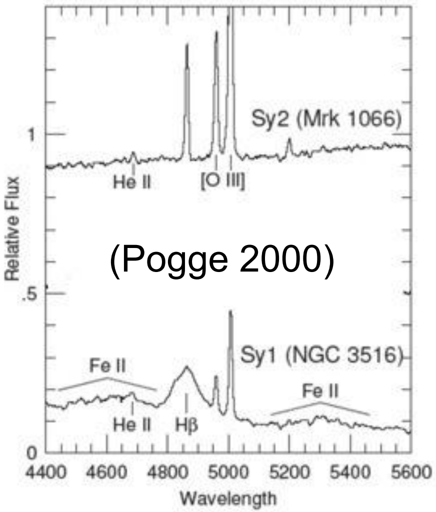
GAČR GRANTOVÁ AGENTURA ČESKÉ REPUBLIKY

Motivation - Time-dependent phenomena in AGN

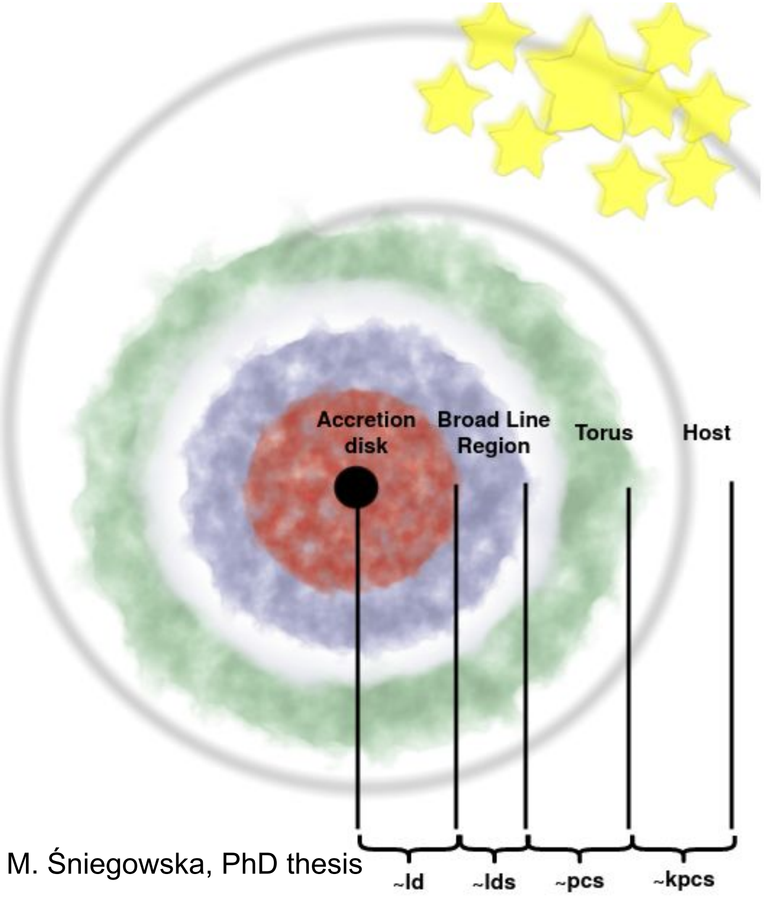




(Urry & Padovani, 1995)



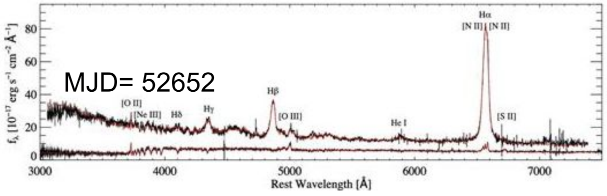
(Pogge 2000)



M. Śniegowska, PhD thesis

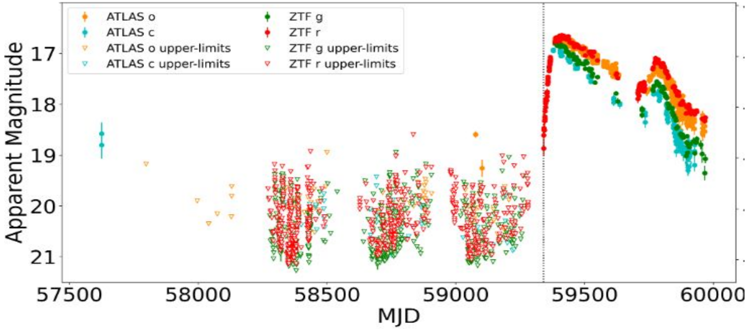
Supermassive black hole related transients

Changing look AGN
Months-years? **recurring?**



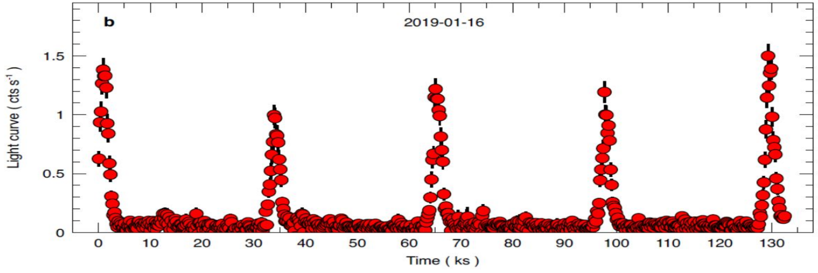
Runnoe+2016

Peculiar events in AGN
Months-years? **recurring?**



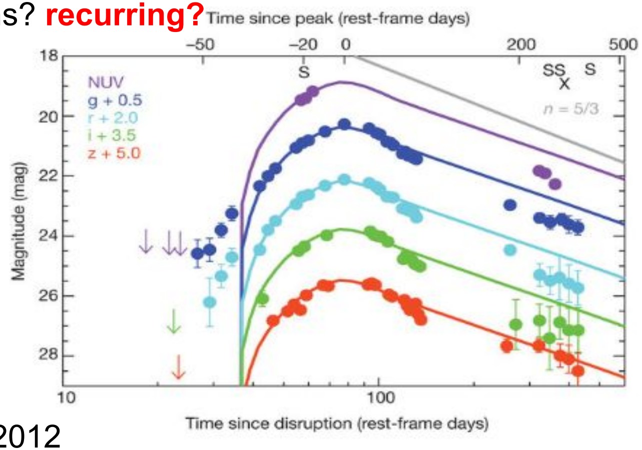
Makrygianni+2023

Quasi periodic eruptions
hours? **recurring?**



Miniutti+19; 23a,b

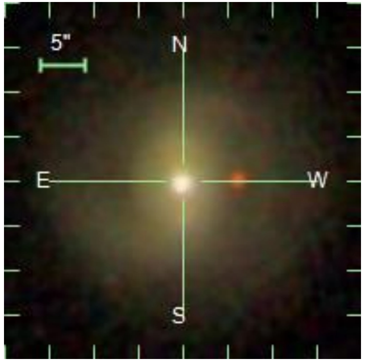
Tidal disruption events
Months? **recurring?**



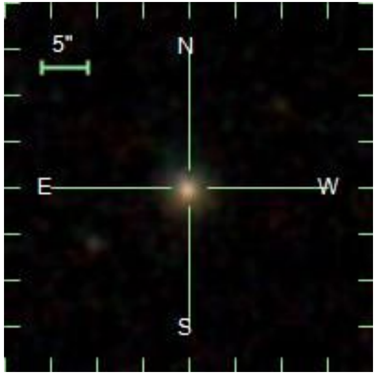
Gezari+2012

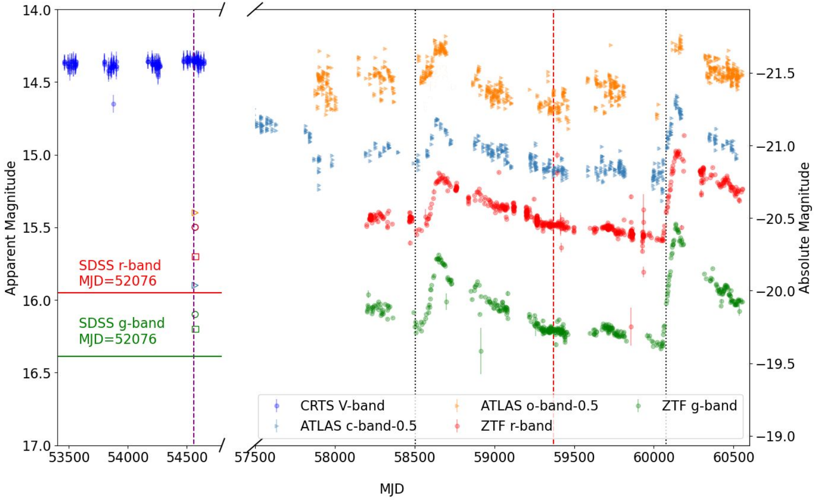
Time-dependent phenomena in AGN

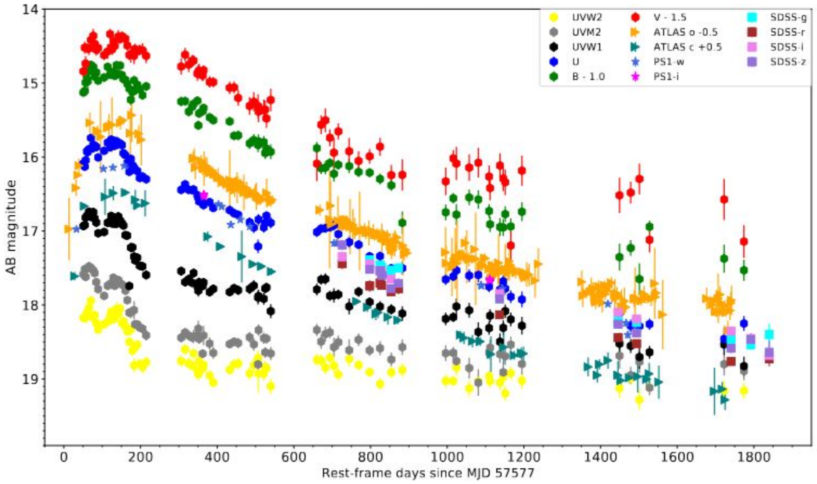
AT 2019aalc



PS16dtm

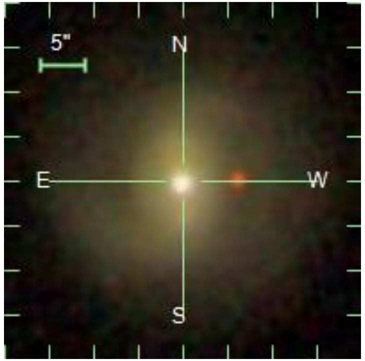


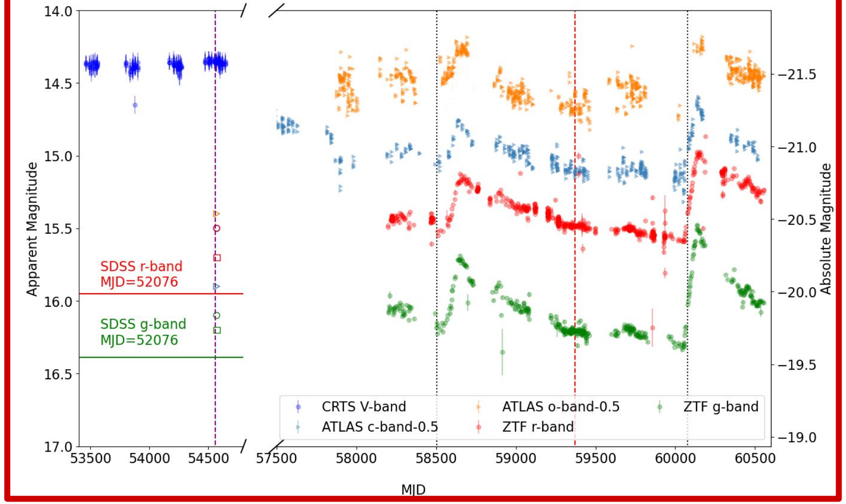




Time-dependent phenomena in AGN

AT 2019aalc





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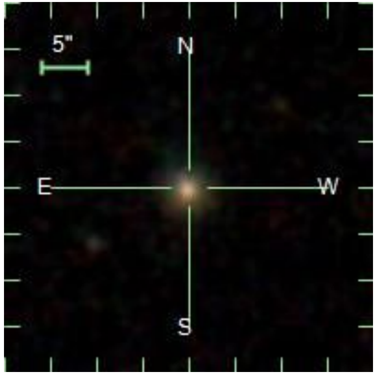
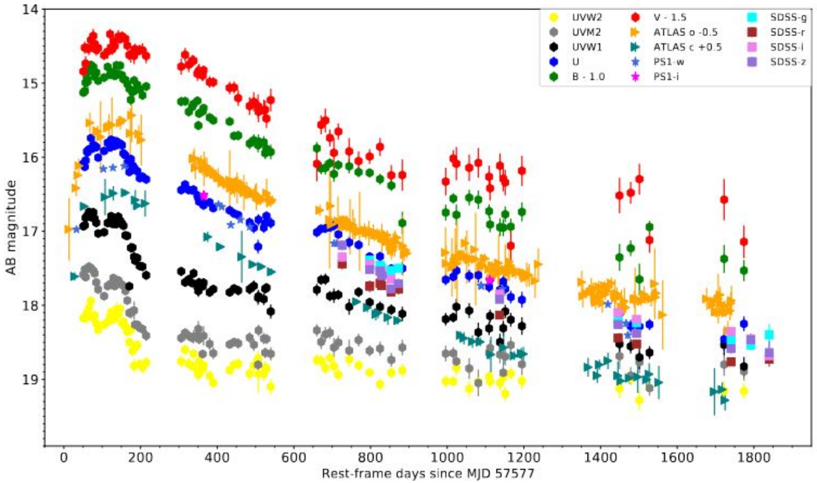
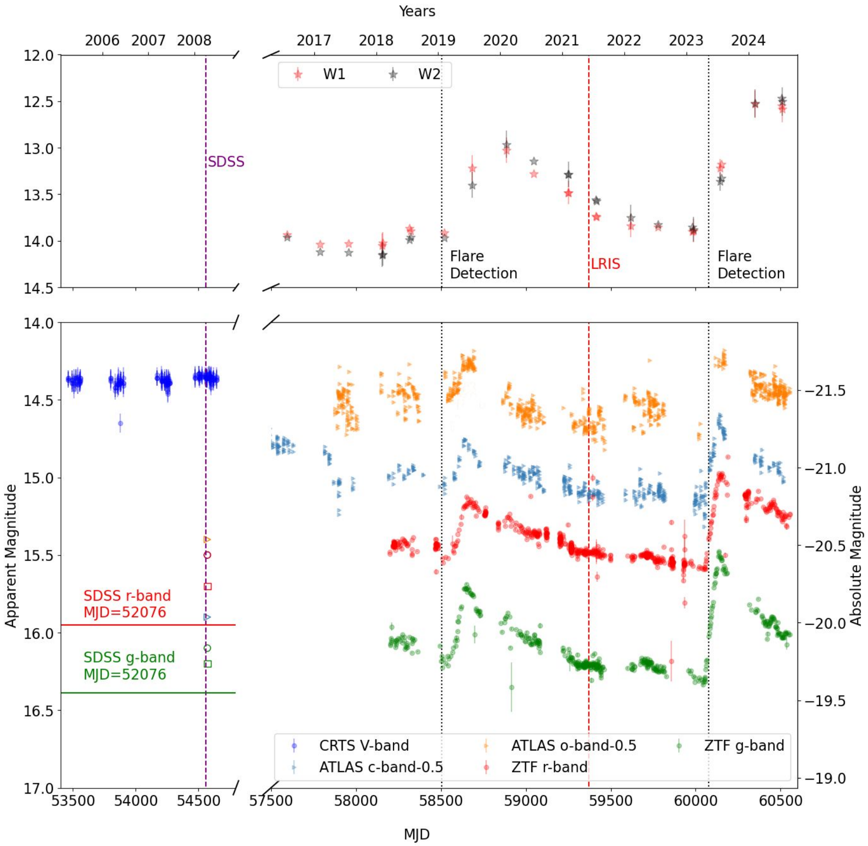
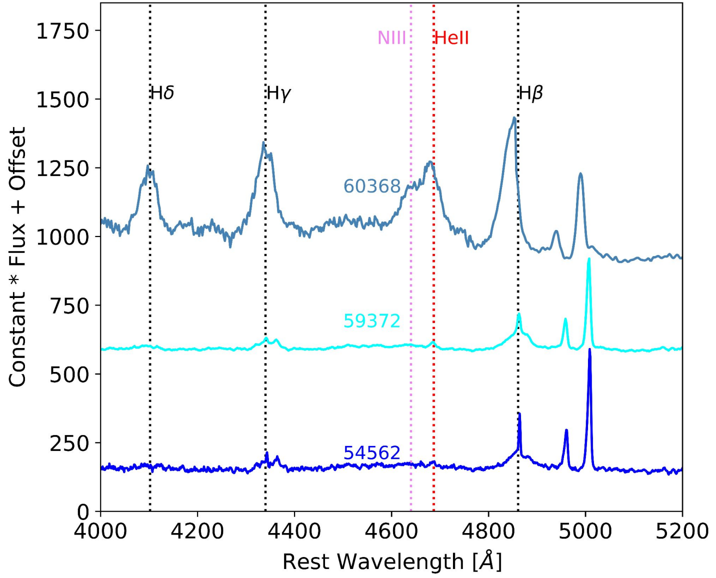




Recurring flaring event in an AGN - AT 2019aalc

(Śniegowska+2025, Veres+2026)



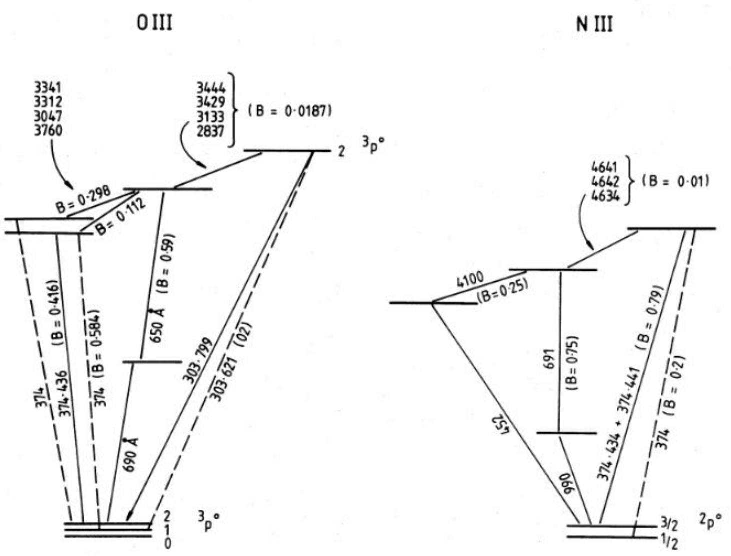


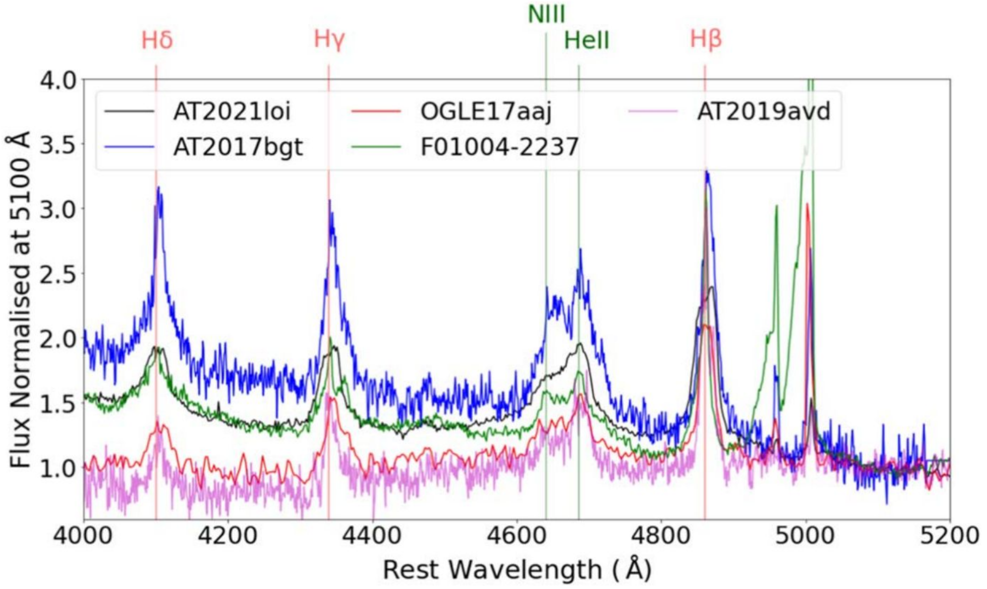
- NUV increased by x10
- double flare in AGN
- appearance of Bowen Fluorescence lines

Broad Bowen Fluorescence lines in AGN

Netzer+1985

- High energy photons
- Dense material
- Those lines should be comparable to Hβ!

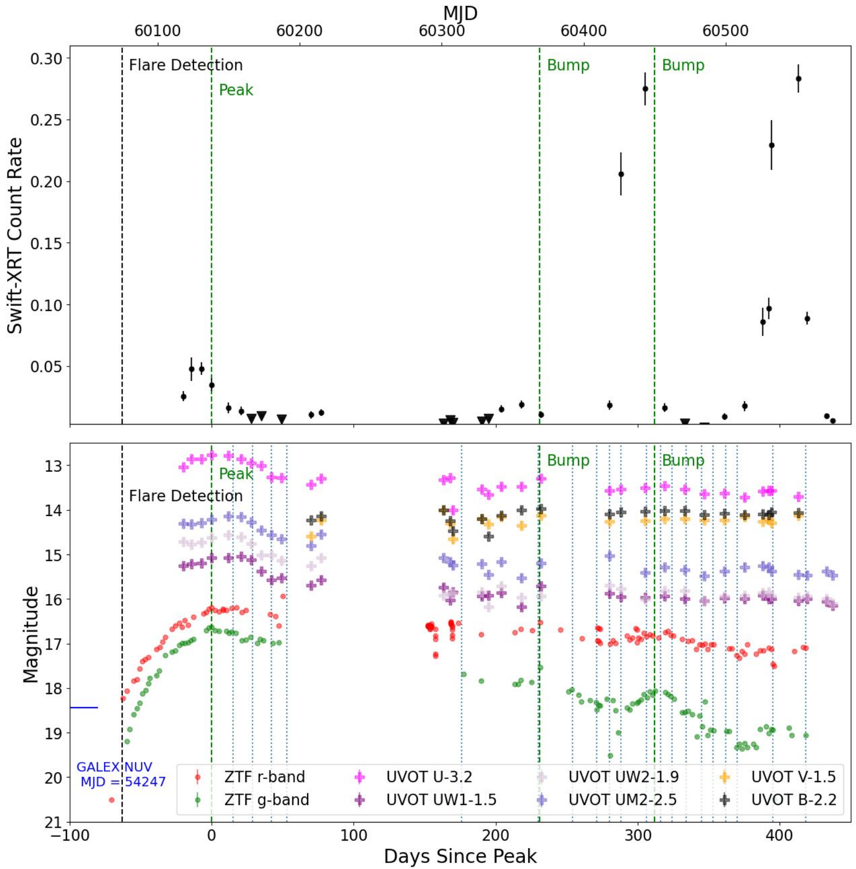


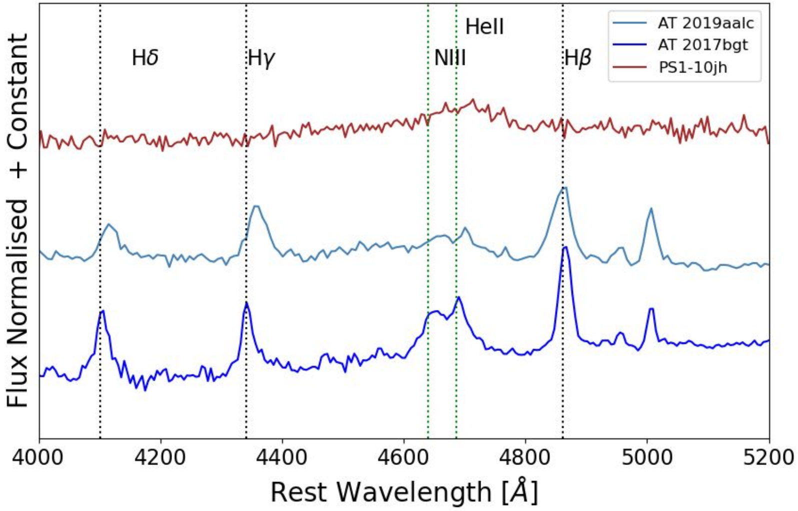


Trakhtenbrot+2019,
Makrygianni+2023

Recurring flaring event in an AGN - AT 2019aalc

(Śniegowska+2025, Veres+2026)

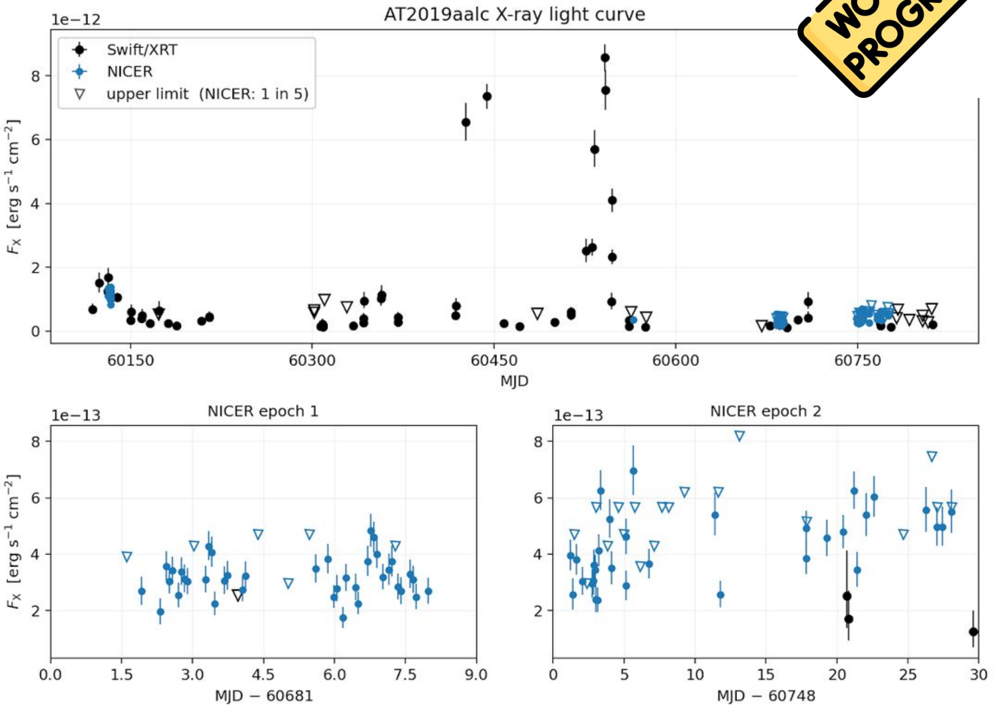


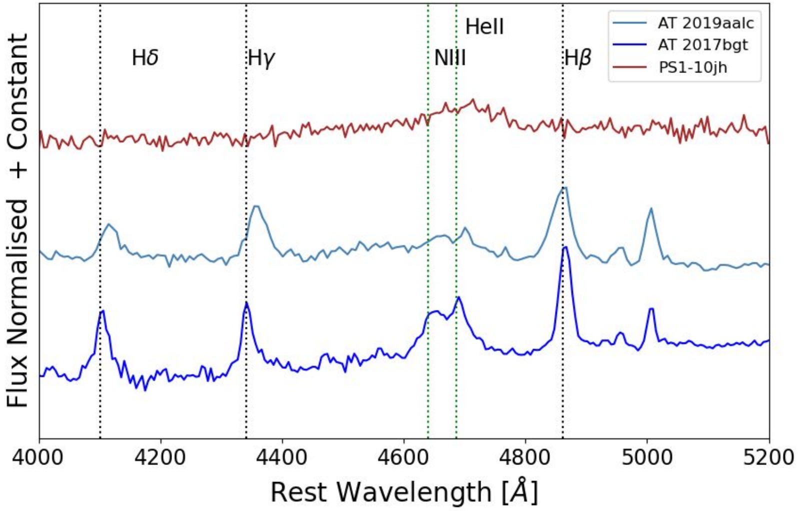


- NUV increased by x10
- double flare in AGN
- appearance of Bowen Fluorescence lines

- a separate double flare in X-rays
- Different from normal TDEs
- Similar to other BFFs

Recurring flaring event in an AGN - AT 2019aalc



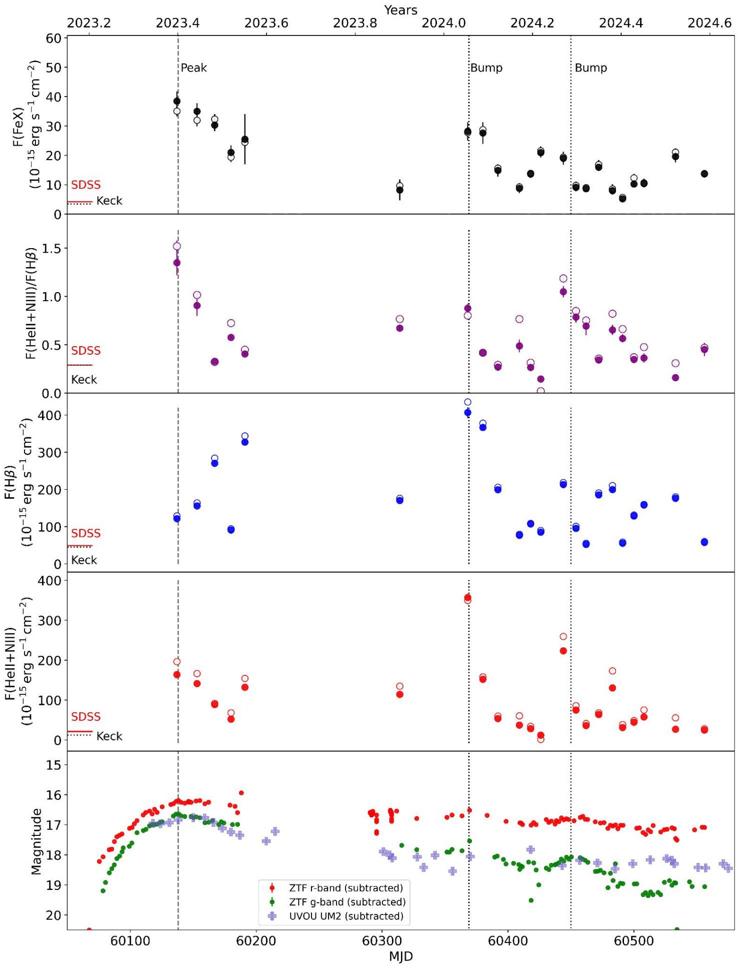


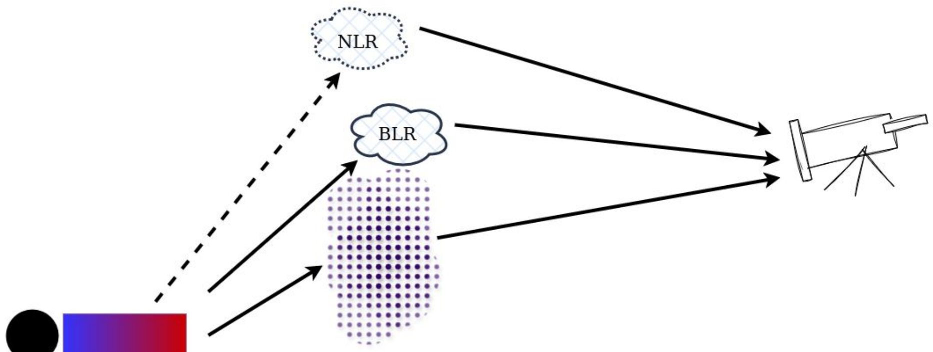
Where are those flares?!

- NUV increased by x10
- double flare in AGN
- appearance of Bowen Fluorescence lines

- a separate double flare in X-rays
- Different from normal TDEs
- Similar to other BFFs

Recurring flaring event in an AGN - AT 2019aalc



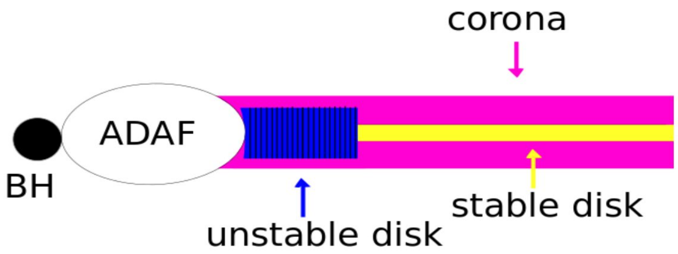


- Rich temporal variations
- Lines respond fast for the luminosity changes
- Line emission significantly enhanced during the peak of the flare
- Further enhancement during optical bumps
- *Strong SED variations during the flare and decline?*

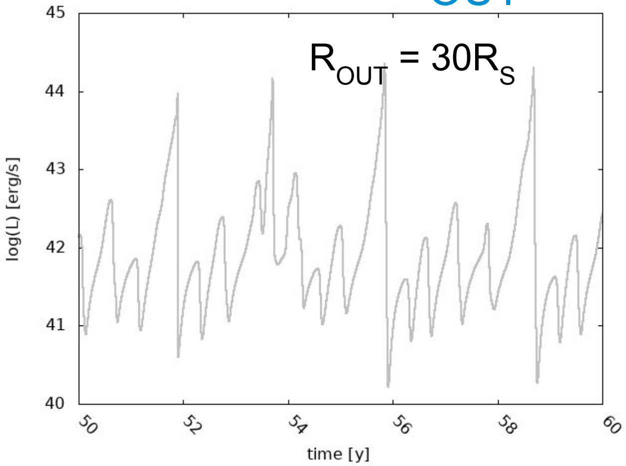
Examples of the light curves with small R_{OUT}

Radiation pressure instability in the central parts of the AD (Pringle+1973; Lightman & Eardley 1974; Nayakshin+2000; Janiuk+2000, 2002).

$$\left.\begin{aligned} \frac{\partial \Sigma}{\partial t} &= 0 \\ \frac{\partial T}{\partial t} &= 0 \end{aligned}\right\} \longleftarrow \text{stationary solution}$$



(Śniegowska+2023)

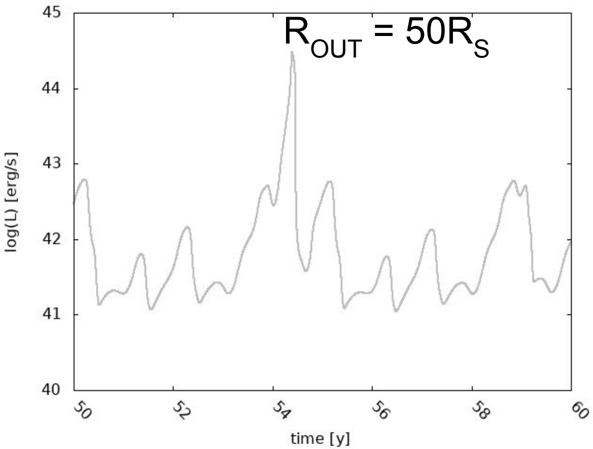


$\log(M_{BH}) = 7$

$\alpha = 0.01$

$R_{IN} = 3R_S$

Challange:
they seem to rise slowly and drop quickly



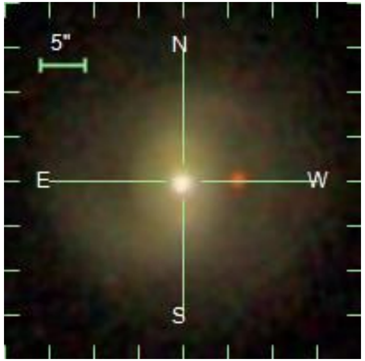
- ★ Recurring flares in an AGN disk
- ★ Years timescales
- ★ Rich structure
- ★ In UV-optical part

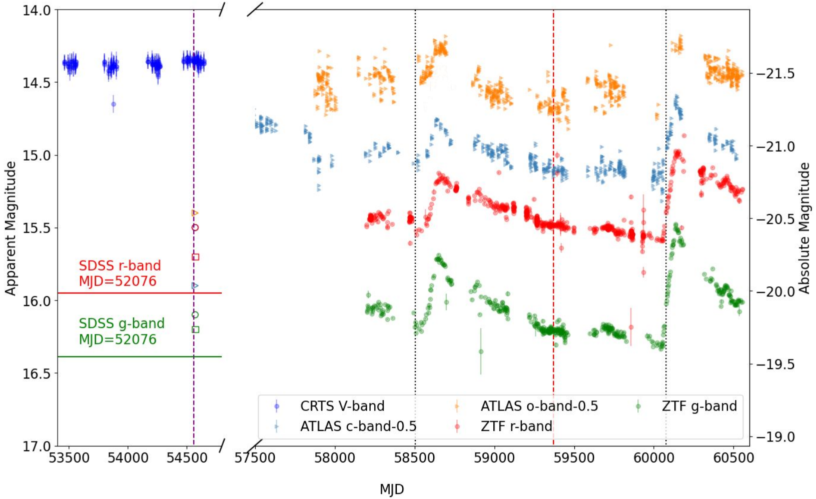
Take-home message 1/2

- ★ Large amplitude, long-term QSO variability with follow-up spectroscopy gives us new insights into accretion physics
- ★ We observed AGN with recurrent extreme-UV flares in the inner disk
- ★ Strong, persistent broad Bowen lines
- ★ Related to radiation pressure instability?

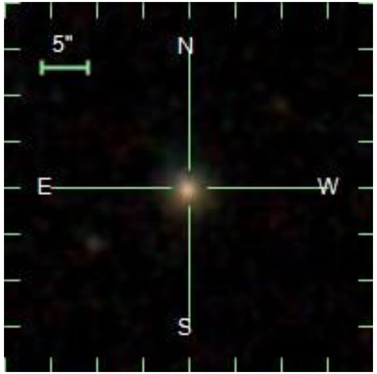
Time-dependent phenomena in AGN

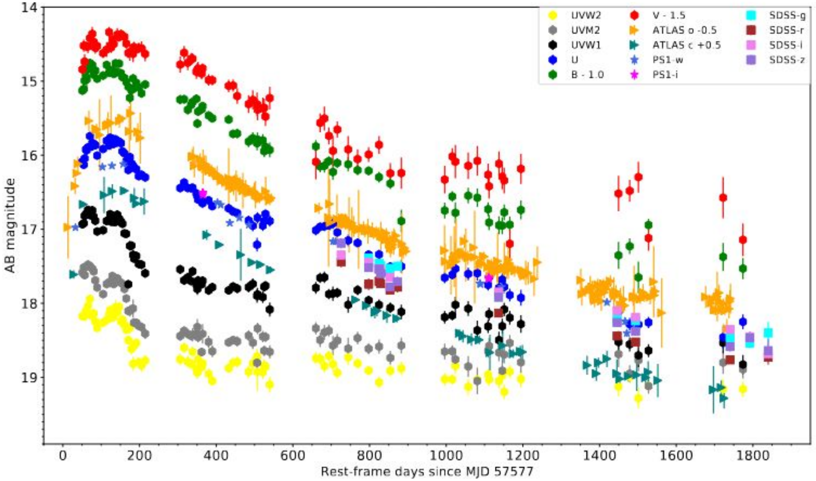
AT 2019aalc





PS16dtm



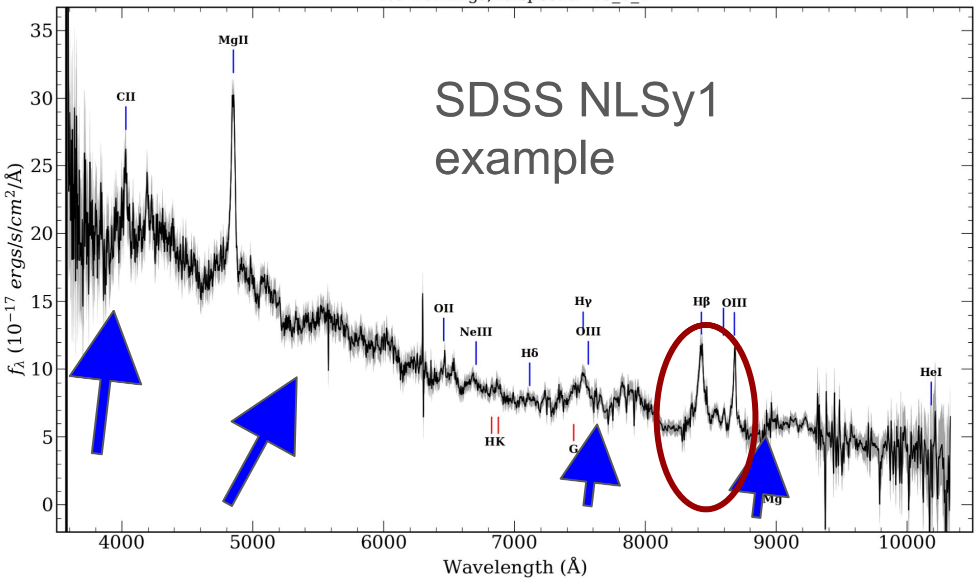


NLSy1s galaxies

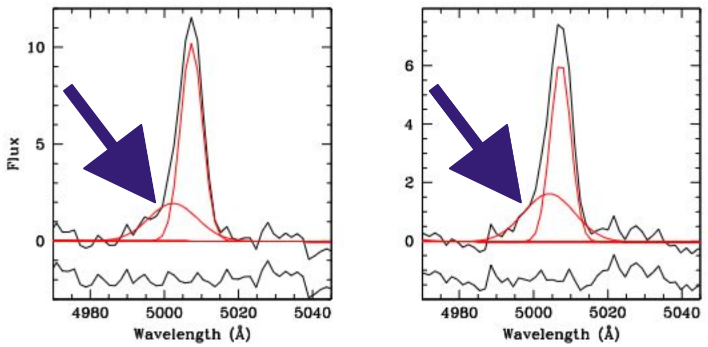
The most important features of NLSy1s:

- ★ **FWHM (Balmer lines) < 2000 km/s (Osterbrock & Pogge1985; Goodrich 1989)**
- ★ **Strong Fe II emission (optical/UV) (Véron-Cetty et al. 2001)**
- ★ **Stronger [OIII] line asymmetries (Schmidt et al. 2018)**
- ★ Lower-luminosity AGN
- ★ Strong soft excess (Pounds et al. 1995, Done et al. 2007)
- ★ Stronger X–ray variability (Boller et al. 1996, Ding et al. 2022)

- ★ Peculiar Hβ lags (Du et al. 2015, 2016; Wang et al. 2014)



Zw049.106 SDSSJ134524.70−025939.8



Schmidt et al. 2018

NLSy1s galaxies

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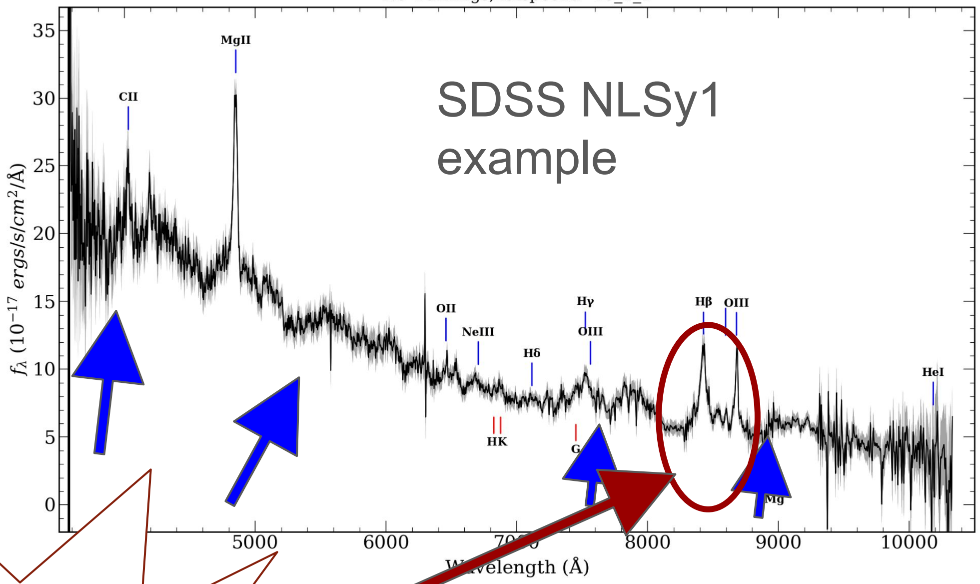
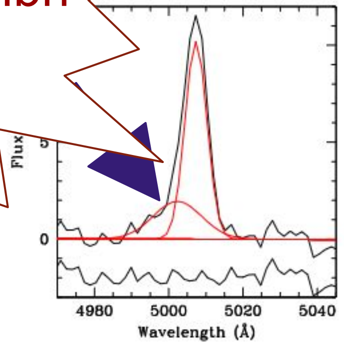
★ Peculiar Hβ lags (Du et al. … Wang et al. 2014)



Hβ line used for Mbh estimation

…49.106



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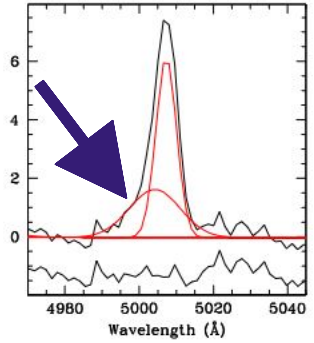
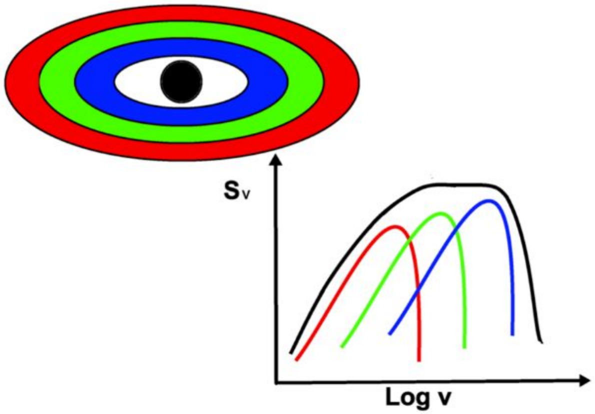
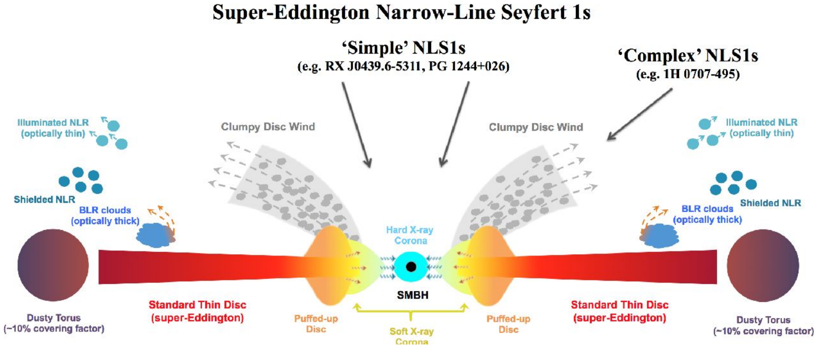


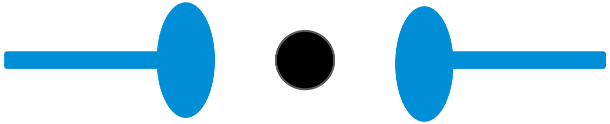
Schmidt et al. 2018

Sub-Eddington vs Super Eddington accretion





Jin et al. (2017b)



- geometrically thin, optically thick (Shakura & Sunyaev 1973)

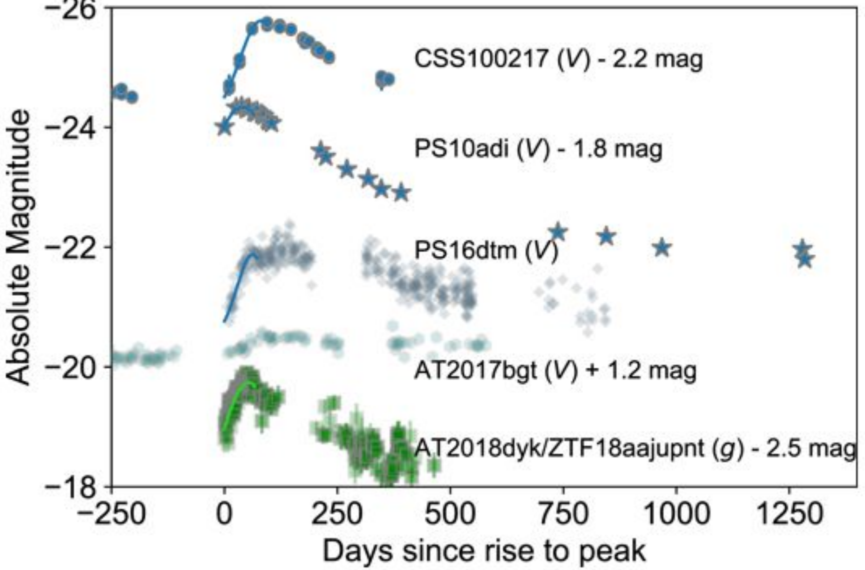
- geometrically thicker
- we expect outflows

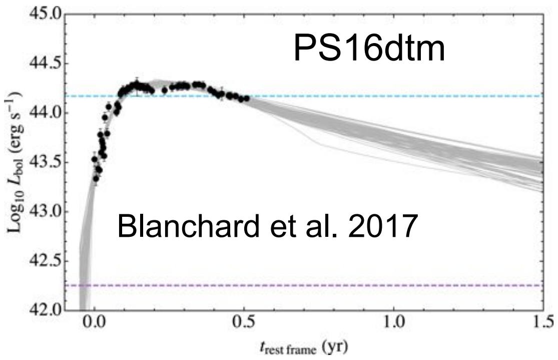
see: http://www.scholarpedia.org/article/Accretion_discs

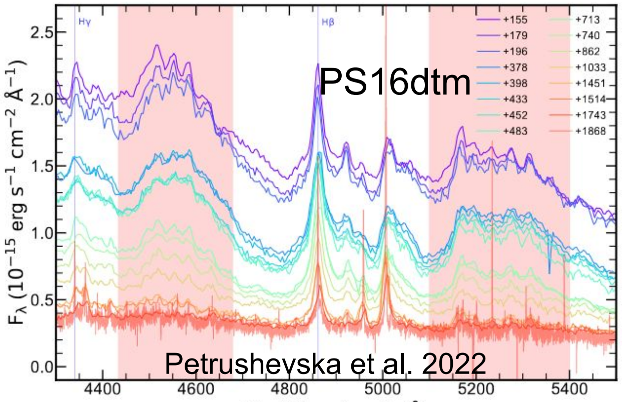
NLSy1-related flares

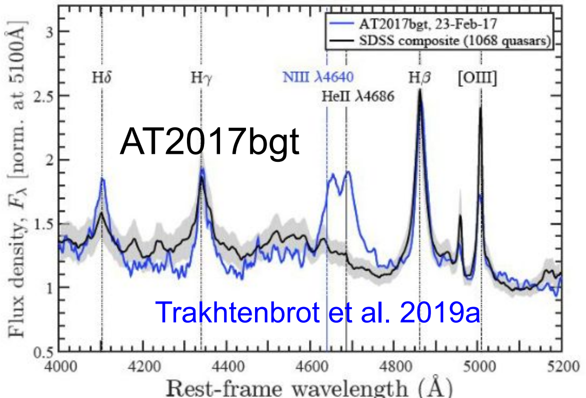
★ CSS100217 accompanied by broad Hα and was interpreted either as a Type IIn SN (Drake et al. 2011) or a TDE (Saxton et al. 2018)
★ PS10adi (Kankare et al.2017, Jiang et al. 2019)
★ PS16dtm - a nuclear outburst in a NLSy1 (Blanchard et al. 2017, Petrushevska et al. 2022)
★ AT2017bgt - Broad Bowen Fluorescence lines (Trakhtenbrot et al. 2019a)
★ ZTF18aajupnt/AT2018dyk (Frederick et al. 2019) - first LINER changing look to a NLSy1

Frederick et al. 2021



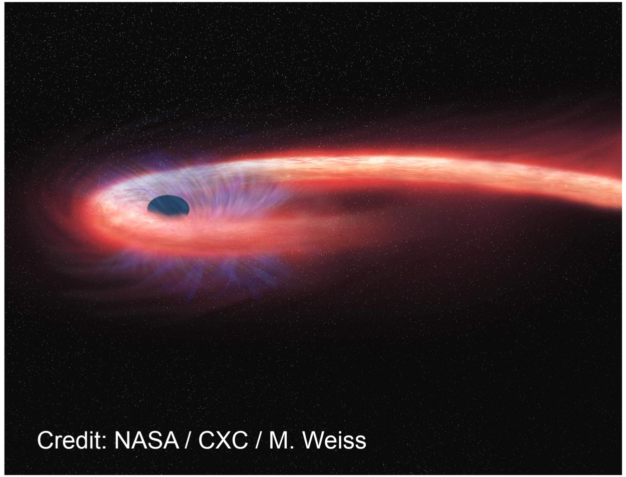


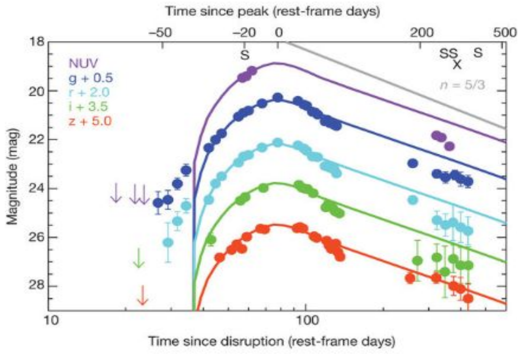




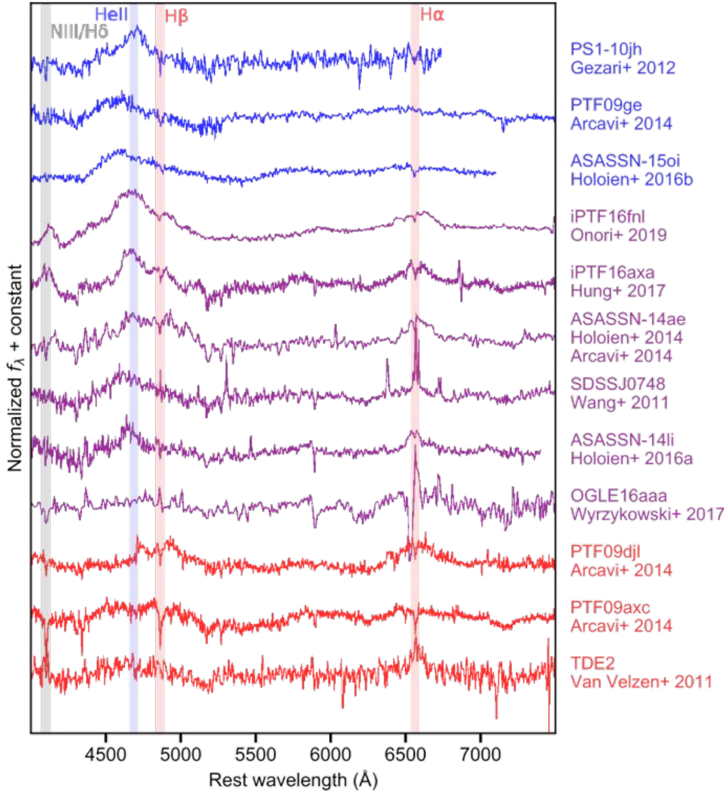
Tidal disruption events

- Luminous in optical/UV, blue, with broad H and/or HeII
- In galaxy centers
- More luminous than SNs
- spectra different than SNs
- We do not have preexisting accretion disc


Credit: NASA / CXC / M. Weiss

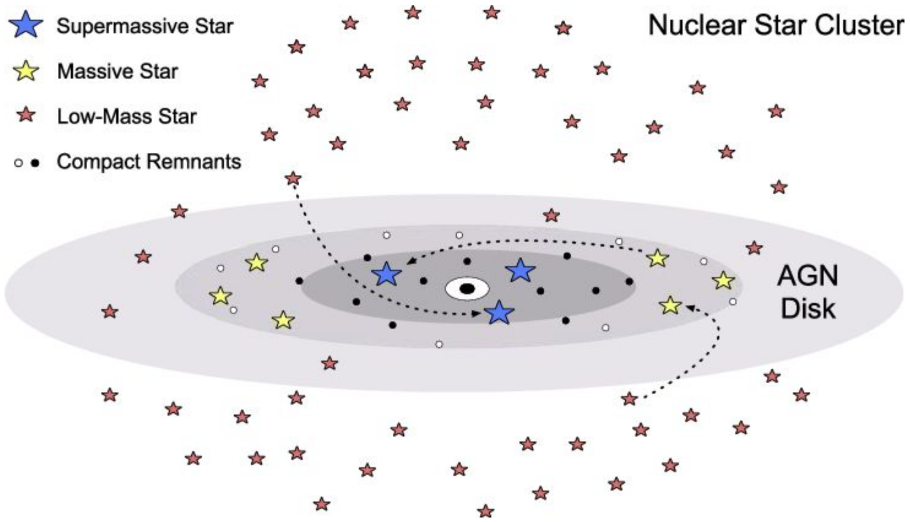


Gezari et al. 2012

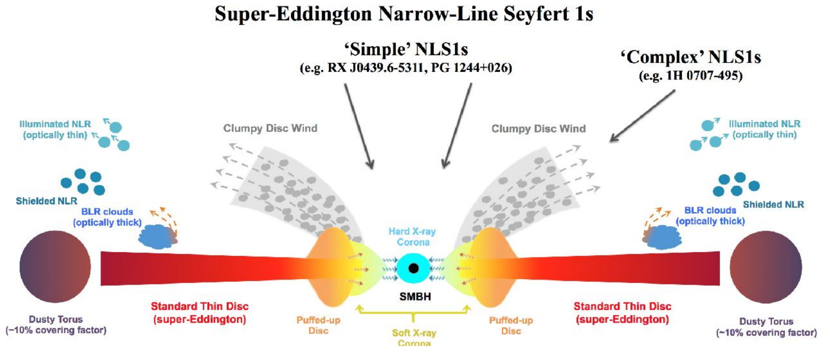


van Velzen et al. 2020

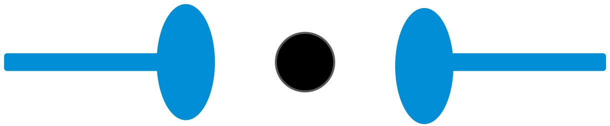
In NLSy1 we have accretion disc already!



(Cantiello et al. 2021)



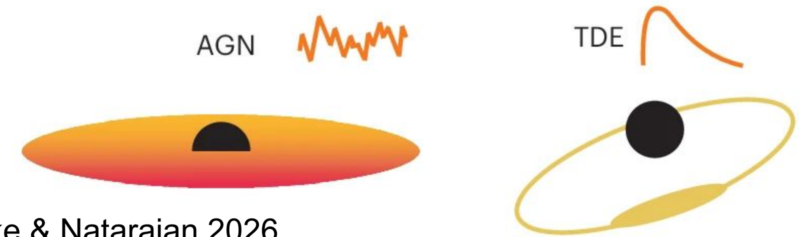
Jin et al. (2017b)



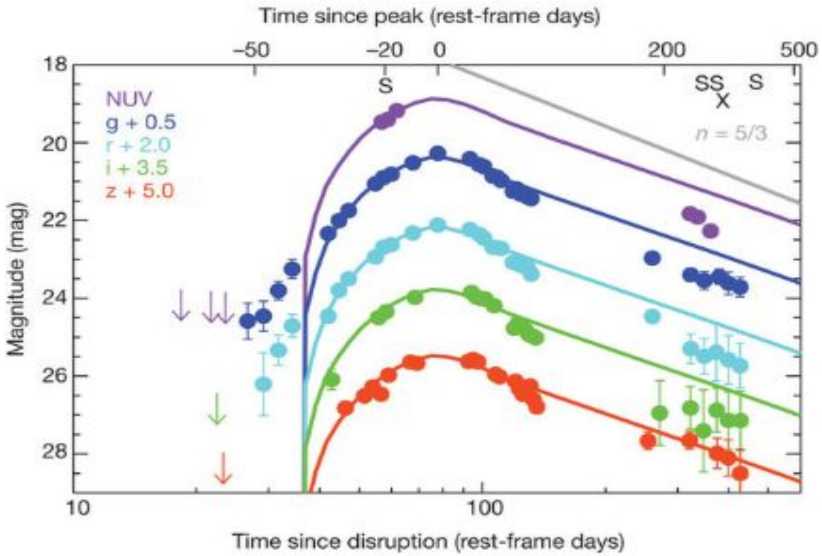
we also have stars there…

- geometrically thicker
- we expect outflows

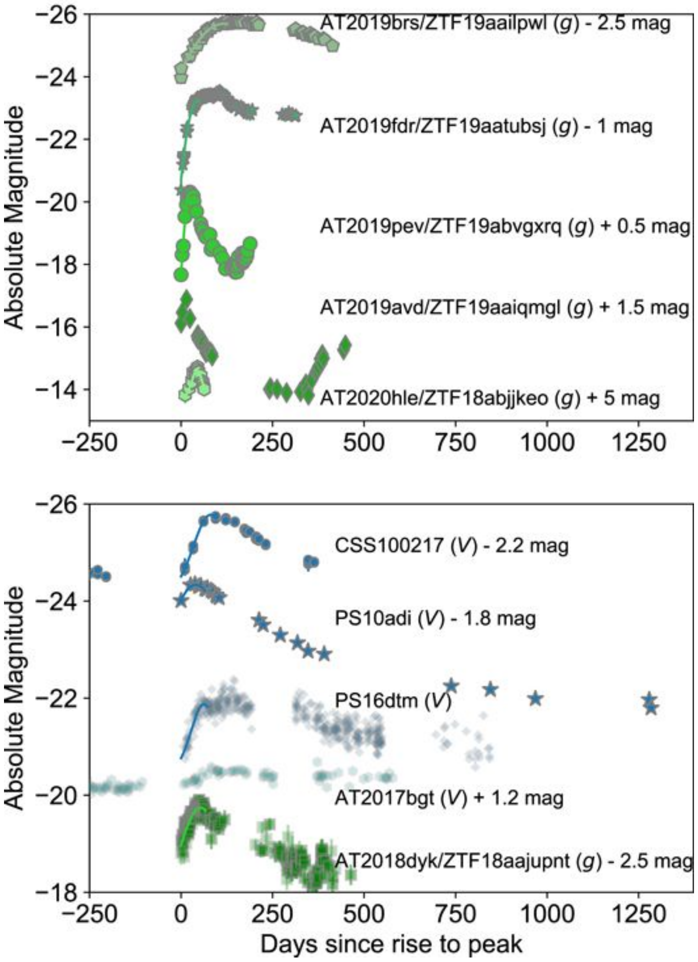
Transients zoo in NLSy1



Burke & Natarajan 2026

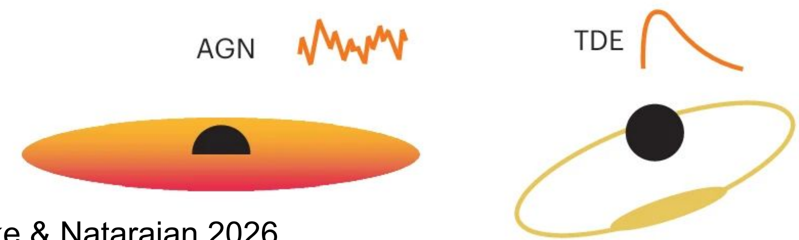


Gezari et al. 2012

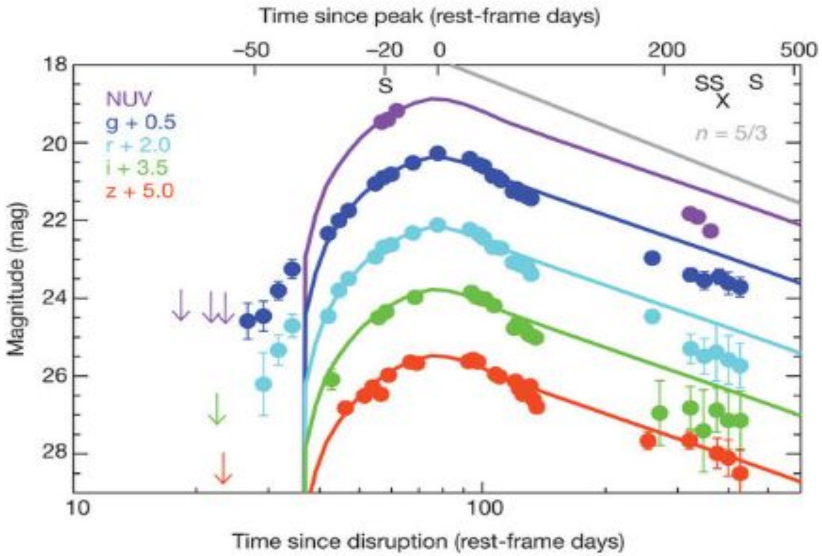


Frederick et al. 2019

Transients zoo in NLSy1



Burke & Natarajan 2026



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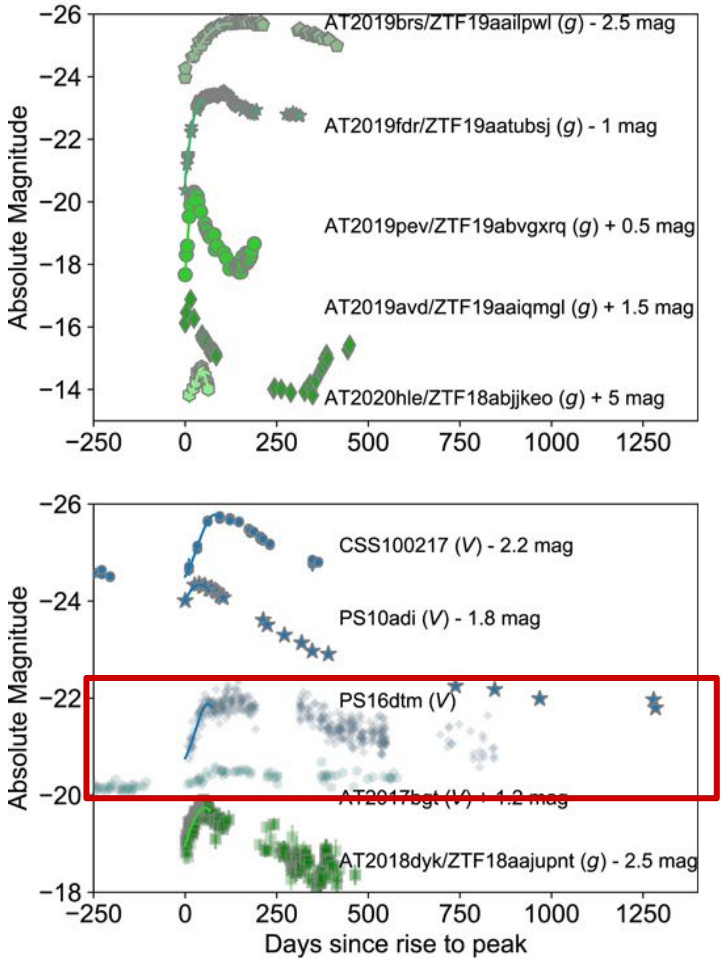
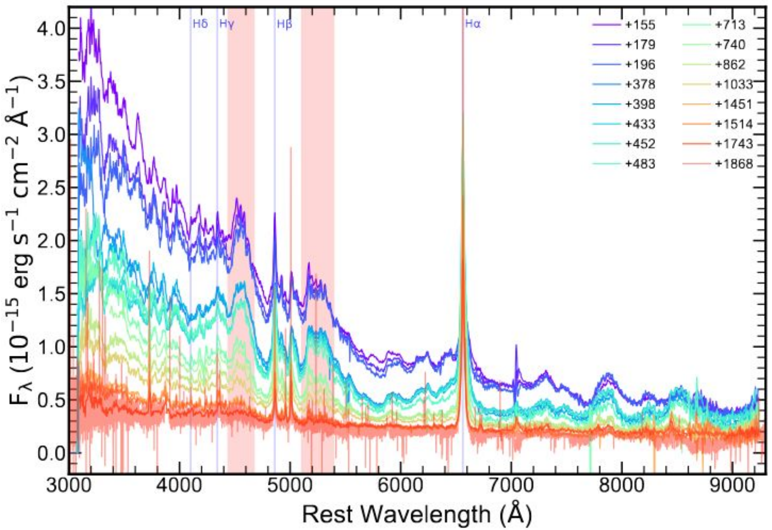
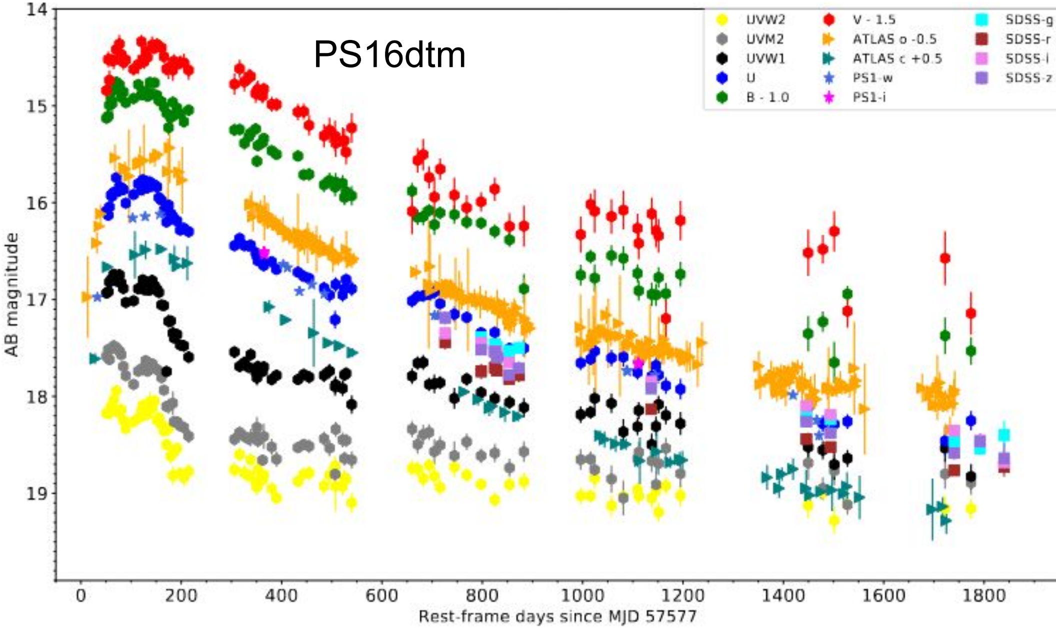


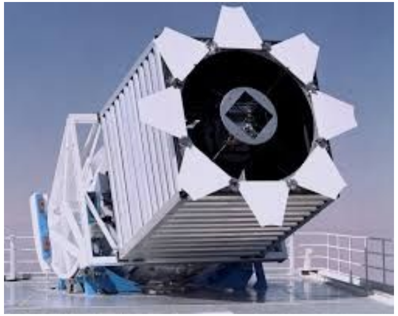
Frederick et al. 2019

Exploring PS16dtm flare

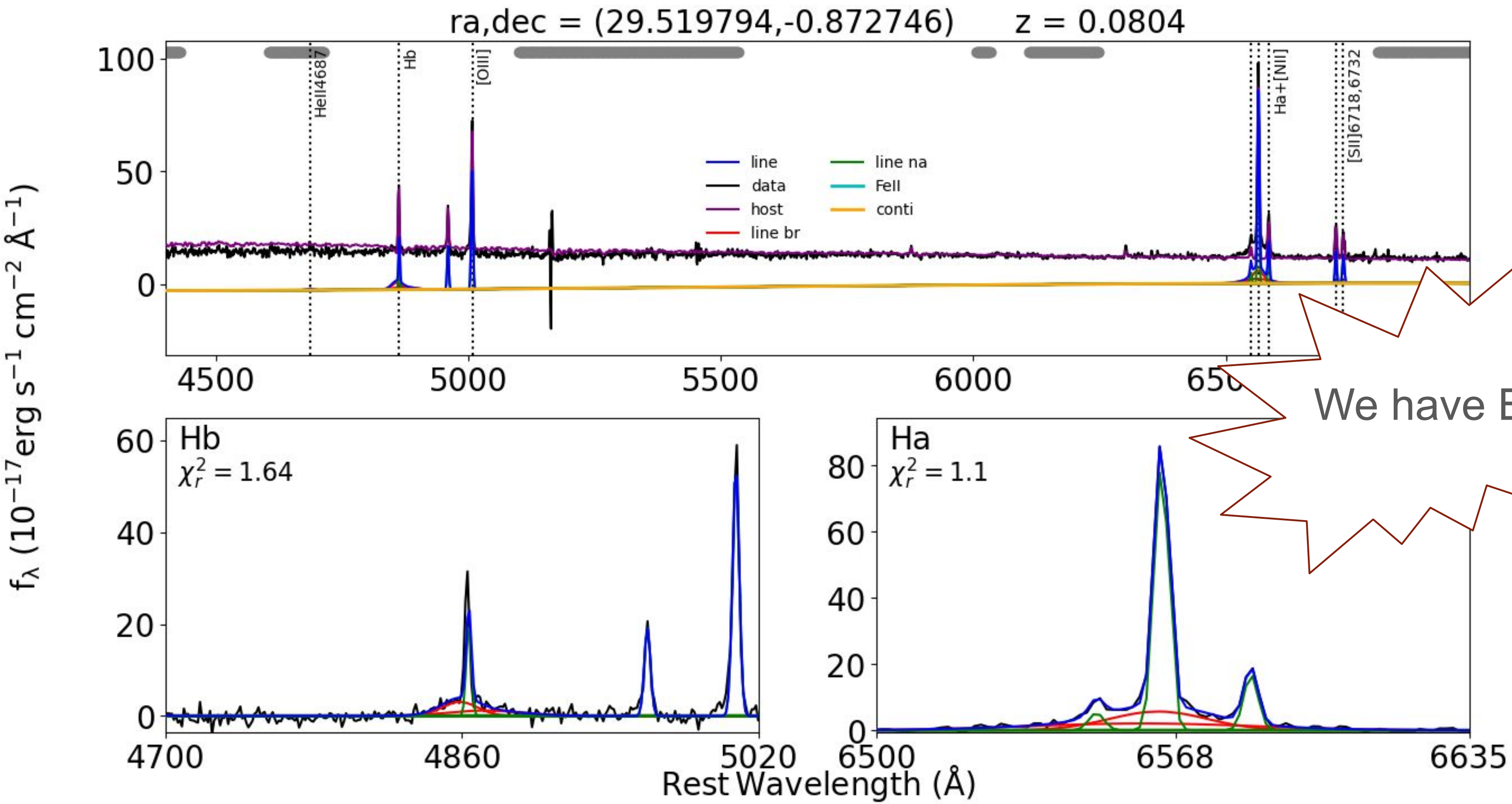




Blanchard et al. 2017, Petrushevska et al. 2023



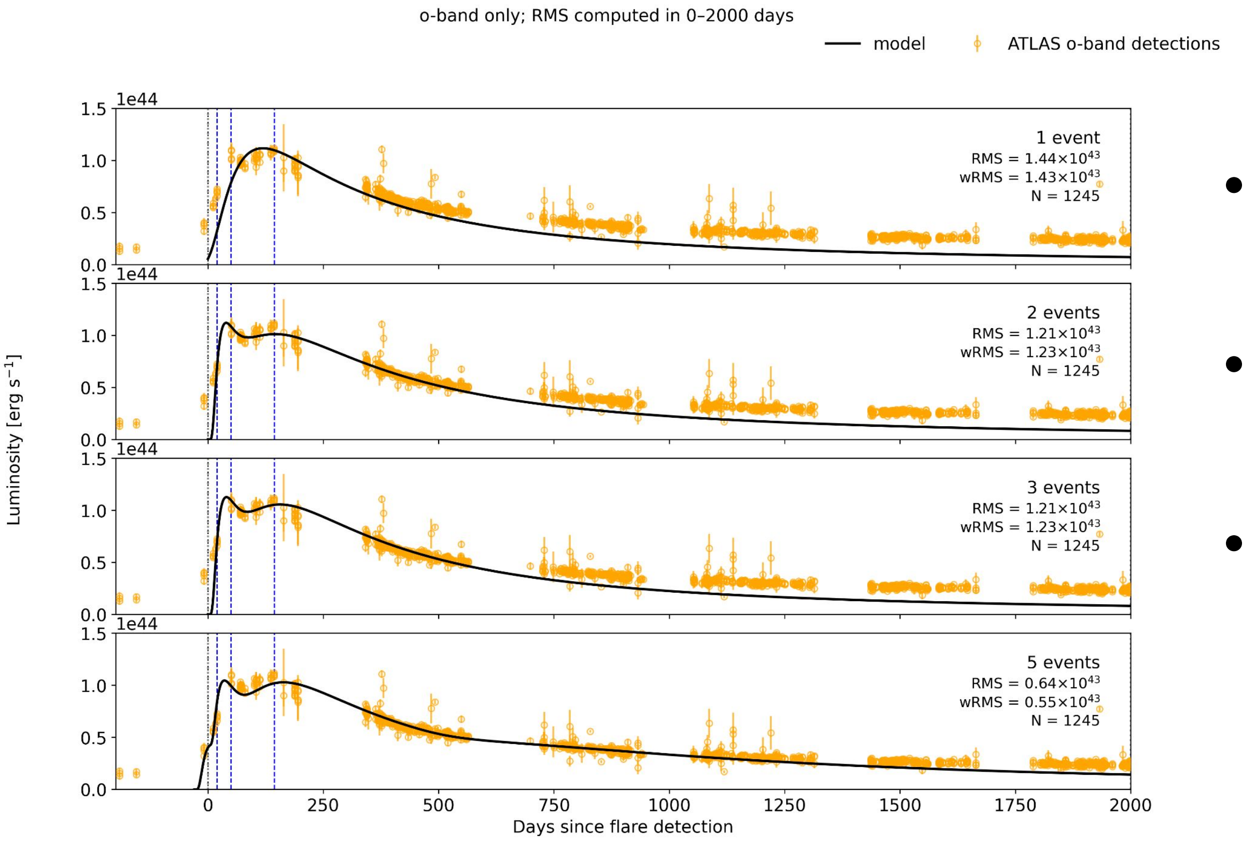
Exploring PS16dtm flare - Before the event



We have BLR

Sniegowska et al. 2026

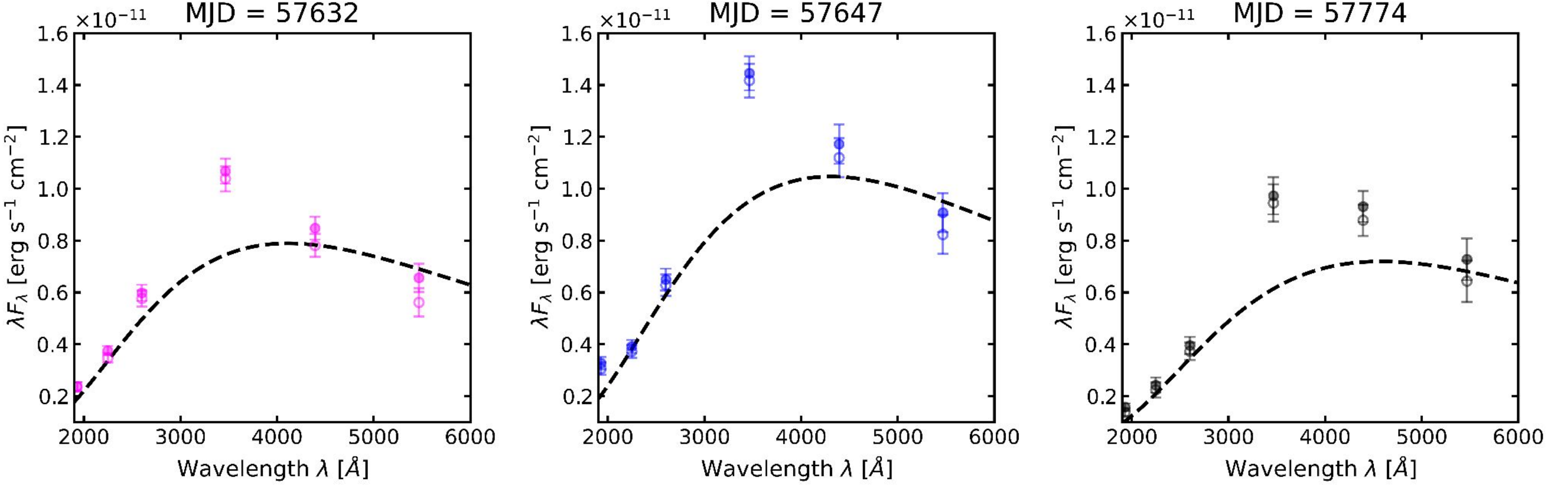
Exploring PS16dtm flare - During the event



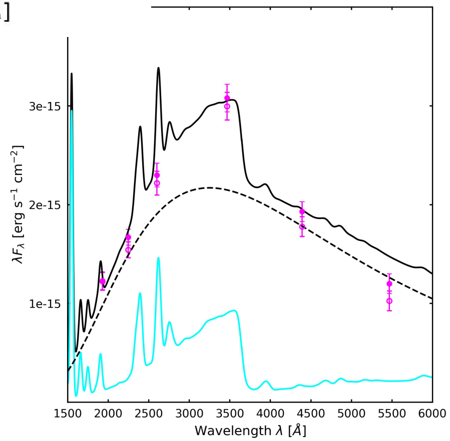
- Single or multiple accretion events Zdziarski et al. (2009); Czerny et al. (2013),
- Single deposit cannot reproduce plateau + double hump
- Total injected mass remains **~0.3 M⊙**

Sniegowska et al. 2026

Exploring PS16dtm flare - During the event



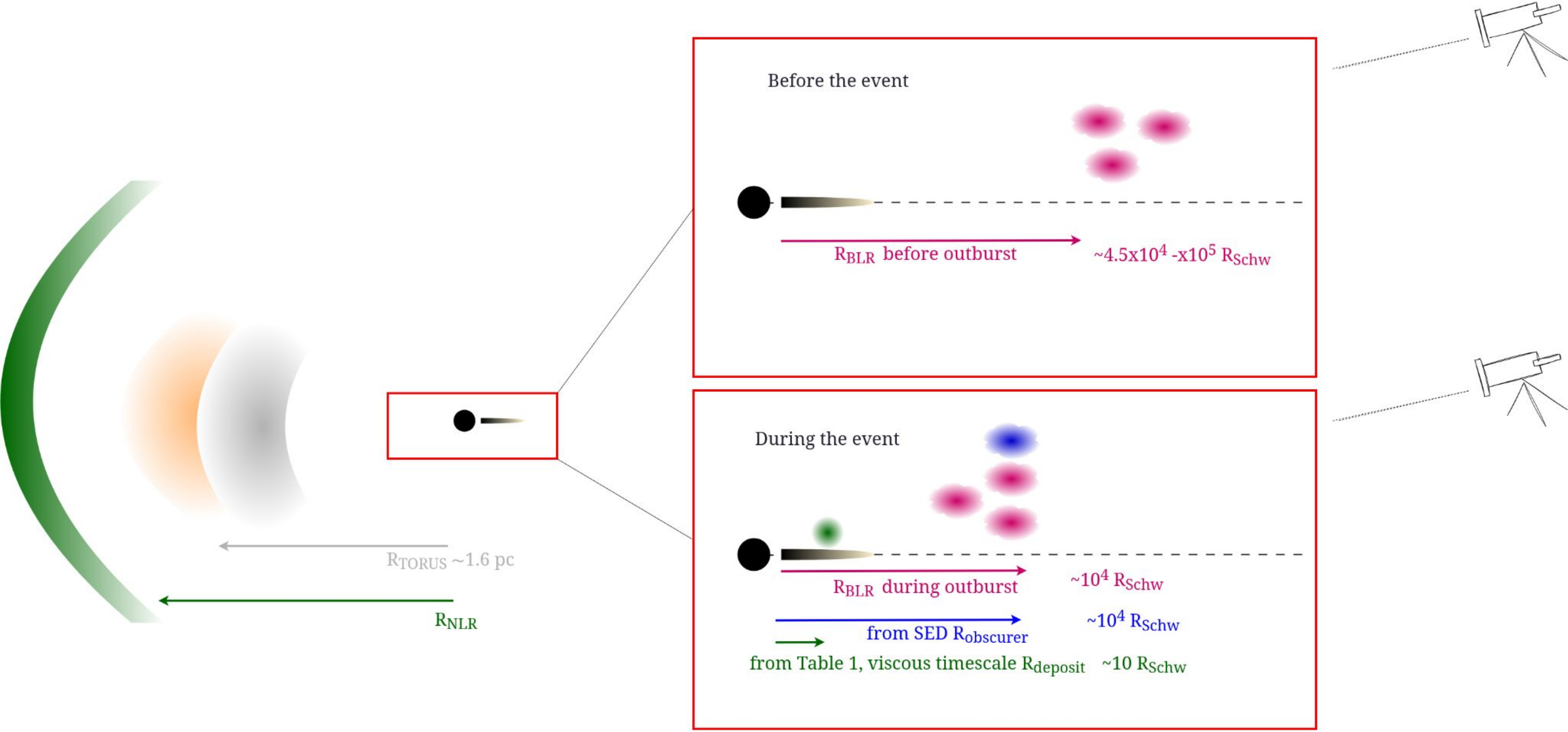
8900K (left), 8500K (middle), and 8000K (right)



A blackbody near **8,000–8,900**K fits the observed shape, but this is likely not the inner-flow temperature. It points to a large reprocessing layer.

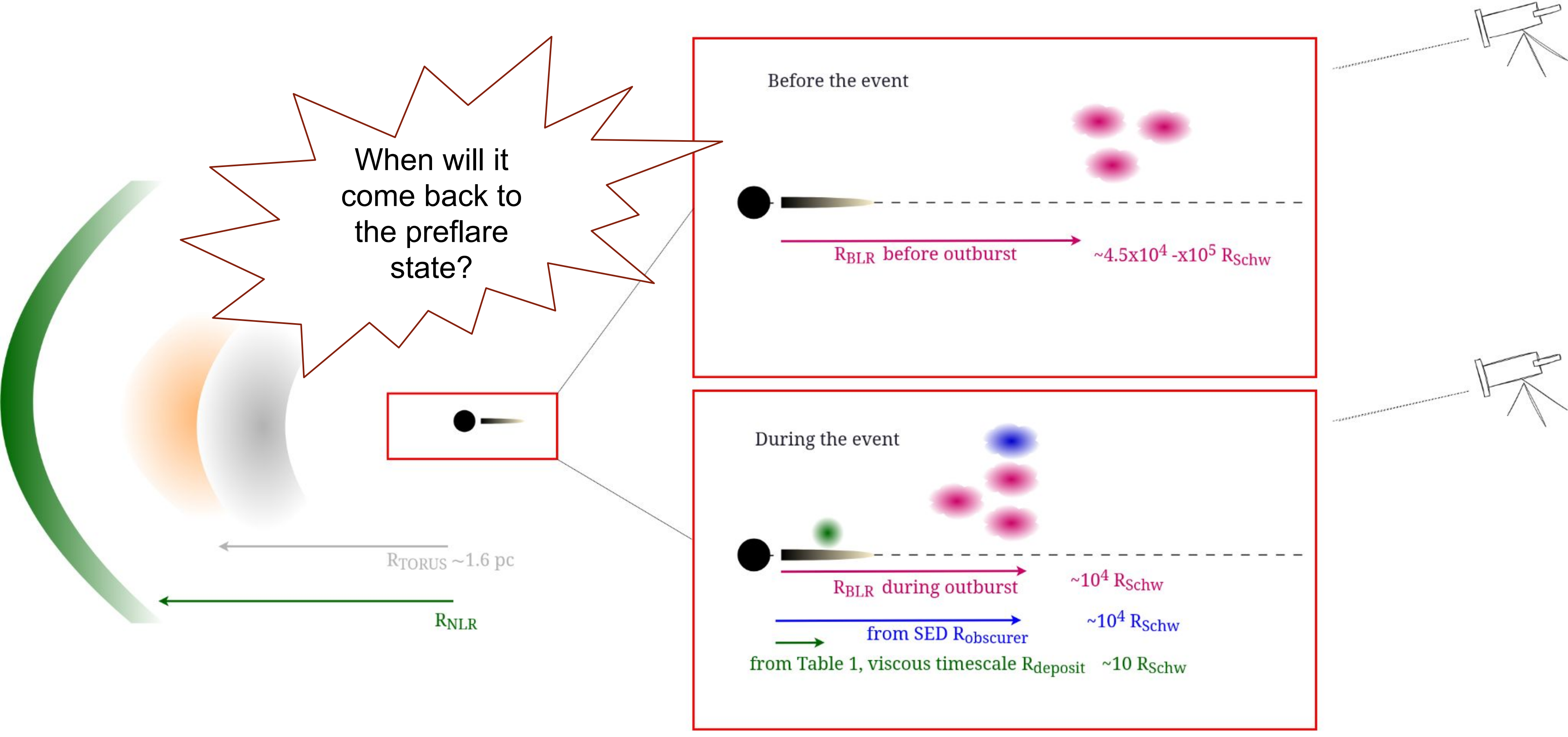
Sniegowska et al. 2026

Exploring PS16dtm flare - During the event



Sniegowska et al. 2026

Exploring PS16dtm flare - During the event



Sniegowska et al. 2026

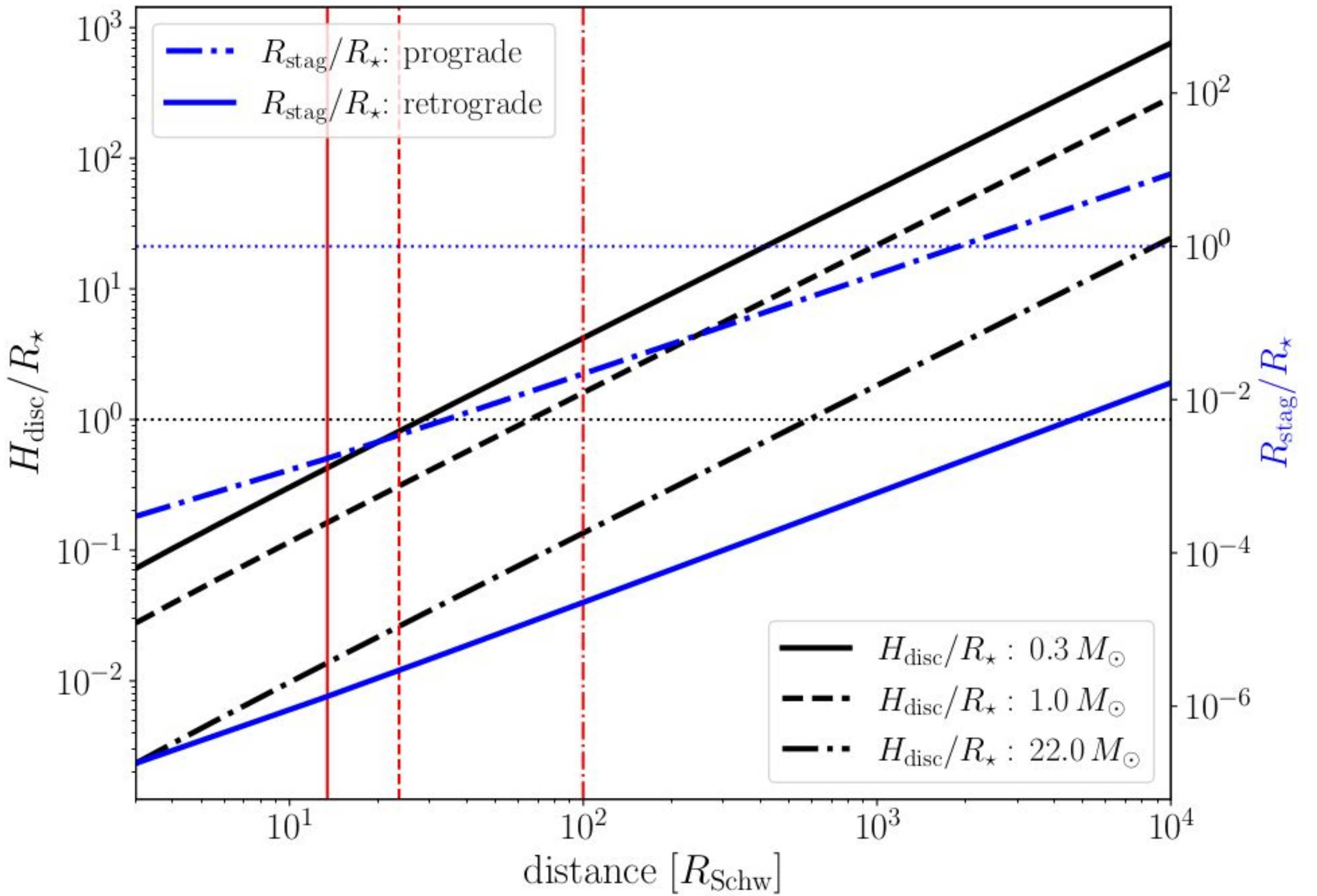
Take-home message 2/2

- ★ The host galaxy was already an **active AGN** before the outburst, so the event happened inside a pre-existing accretion disc
- ★ Total injected mass remains ~0.3 $M_\odot$
- ★ There appears to be a preference for multiple, at least two accretion events separated by ~ 4 days

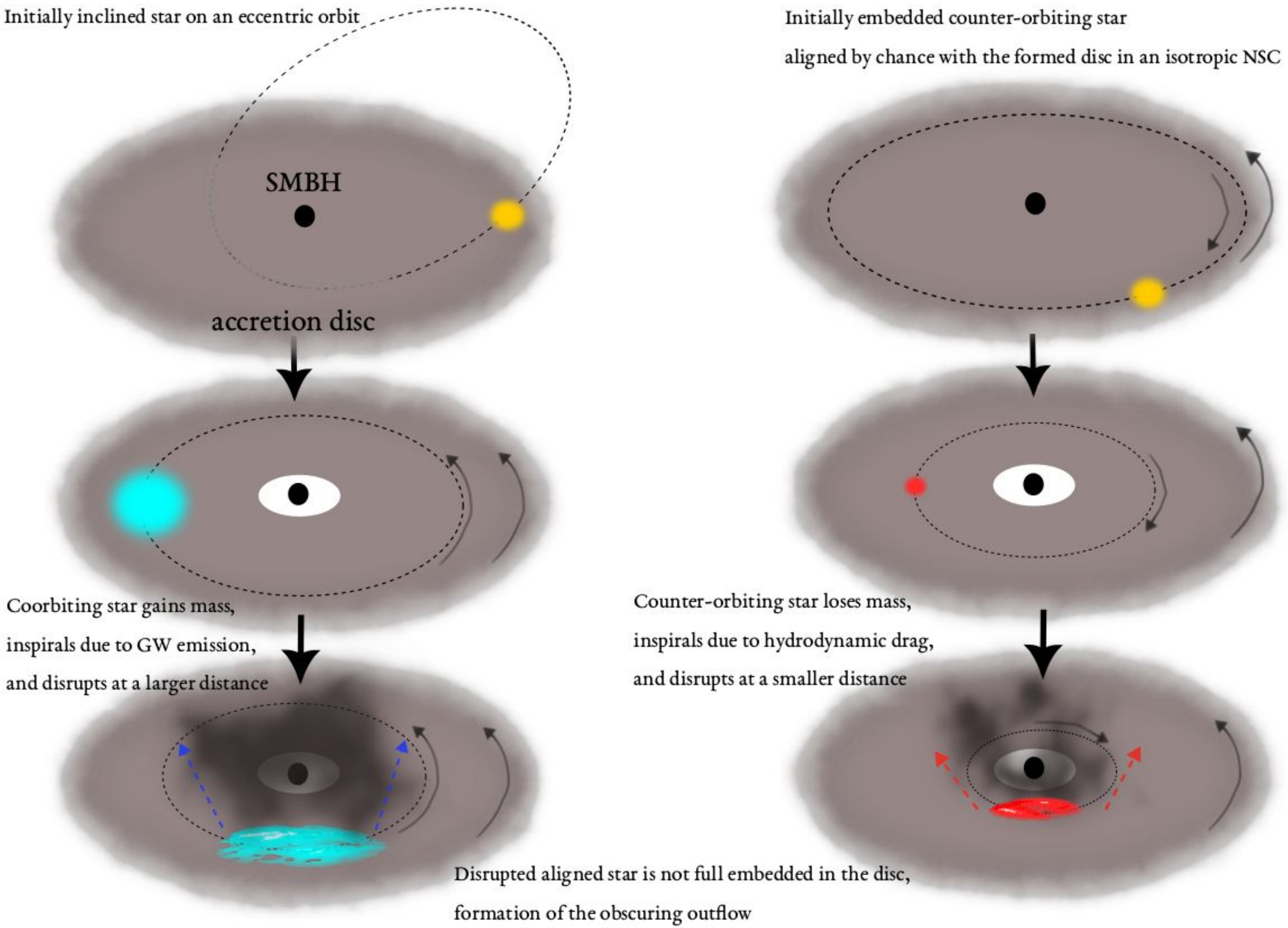
Did it come back to the pre-flare state?

How common are similar TDEs hidden inside AGN discs?

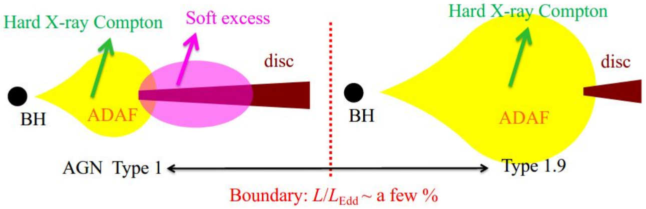
Thank you!



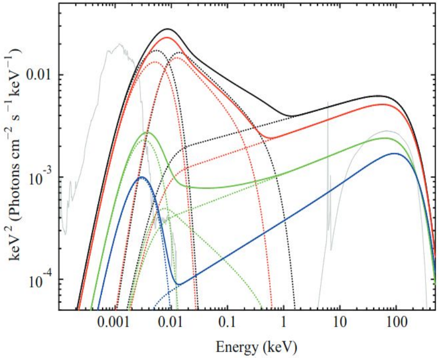
$R_{\rm stag}/R_\star$: prograde
$R_{\rm stag}/R_\star$: retrograde
$H_{\rm disc}/R_\star$: $0.3\,M_\odot$
$H_{\rm disc}/R_\star$: $1.0\,M_\odot$
$H_{\rm disc}/R_\star$: $22.0\,M_\odot$
$H_{\rm disc}/R_\star$
$R_{\rm stag}/R_\star$
distance $[R_{\rm Schw}]$
10^{-2}
10^{-1}
10^0
10^1
10^2
10^3
10^4
10^{-6}
10^{-4}


Initially inclined star on an eccentric orbit
SMBH
accretion disc
Initially embedded counter-orbiting star
aligned by chance with the formed disc in an isotropic NSC
Coorbiting star gains mass,
inspirals due to GW emission,
and disrupts at a larger distance
Counter-orbiting star loses mass,
inspirals due to hydrodynamic drag,
and disrupts at a smaller distance
Disrupted aligned star is not full embedded in the disc,
formation of the obscuring outflow

Changes in accretion flow (Intrinsic)



Noda & Done 2018

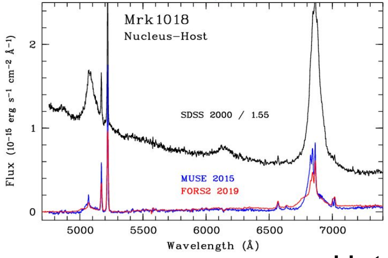


2008 Aug

2008 Jun

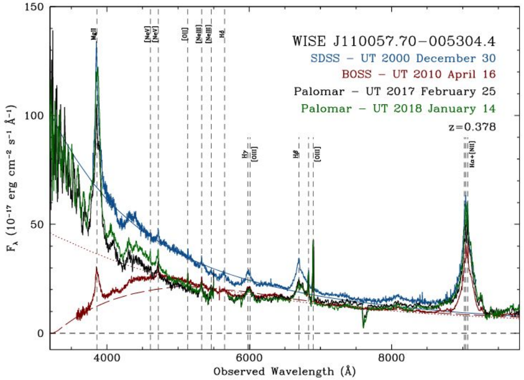
2013

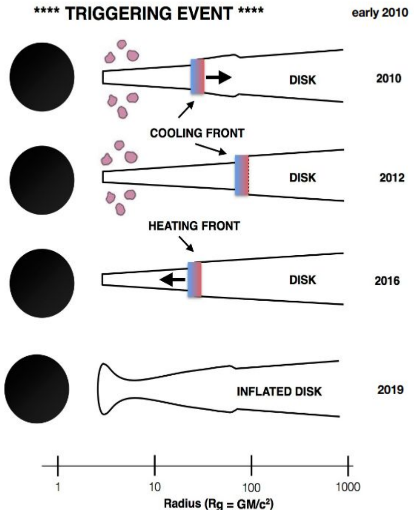
2016



Hutsemékers+2020

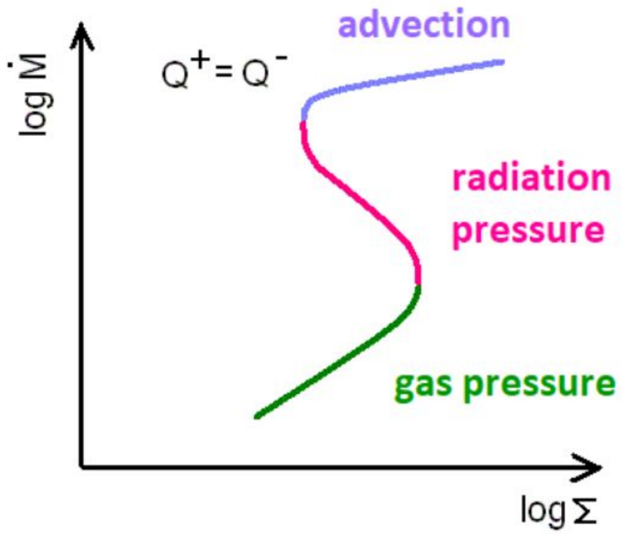
- The explanation of the unusual spectral evolution of J1100-0053
- The triggering event occurs, possibly due to a shift in the magnetic field configuration





Ross+2018

Instability of radiation pressure dominated Keplerian disk



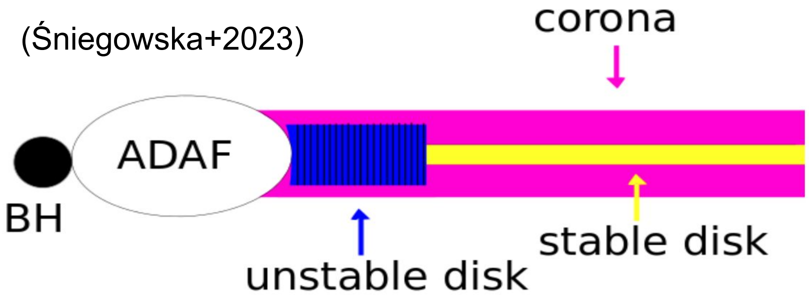
Shakura-Sunyaev disk model:

- ★ the radial momentum equation (Keplerian flow)
- ★ azimuthal one (radial transport of angular momentum)
- ★ vertical one (hydrostatic balance)
- ★ continuity equation (mass conservation)
- ★ energy equation (local balance)
- ★ equation of state

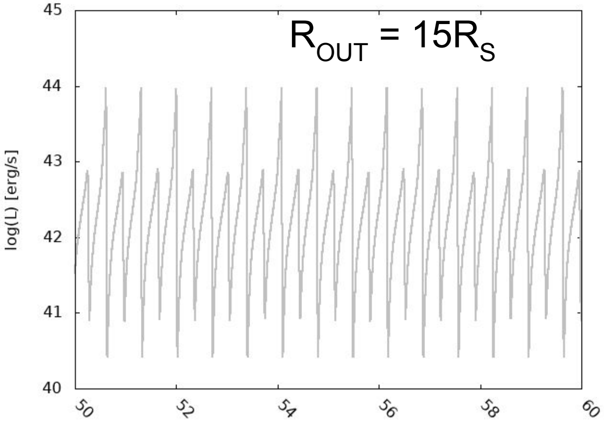
Radiation pressure instability in the central parts of the AD (Pringle+1973; Lightman & Eardley 1974; Nayakshin+2000; Janiuk+2000, 2002).

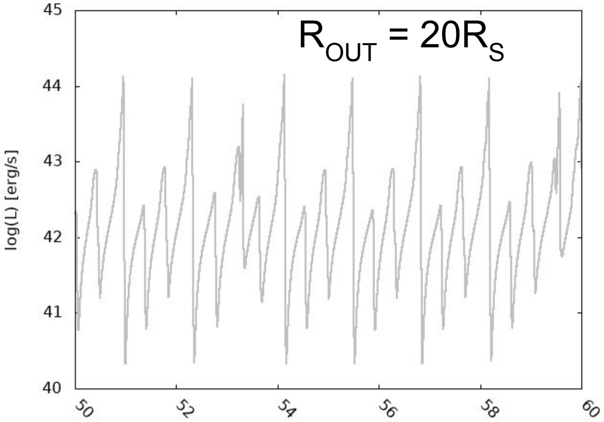
$$\left.\begin{aligned} \frac{\partial \Sigma}{\partial t} &= 0 \\ \frac{\partial T}{\partial t} &= 0 \end{aligned}\right\} \longleftarrow \text{stationary solution}$$

(Śniegowska+2023)



Examples of the light curves with small R_{OUT}



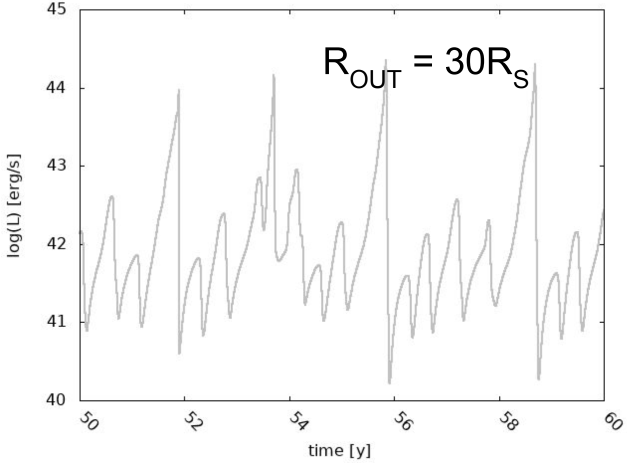


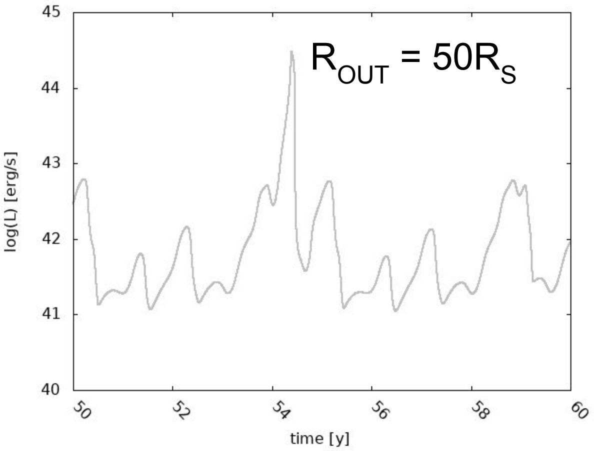
$\log(M_{BH}) = 7$

$\alpha = 0.01$

$R_{IN} = 3R_S$

Challange:
they seem to rise slowly and drop quickly





- ★ Recurring flares in an AGN disk
- ★ Years timescales
- ★ Rich structure
- ★ In UV-optical part