

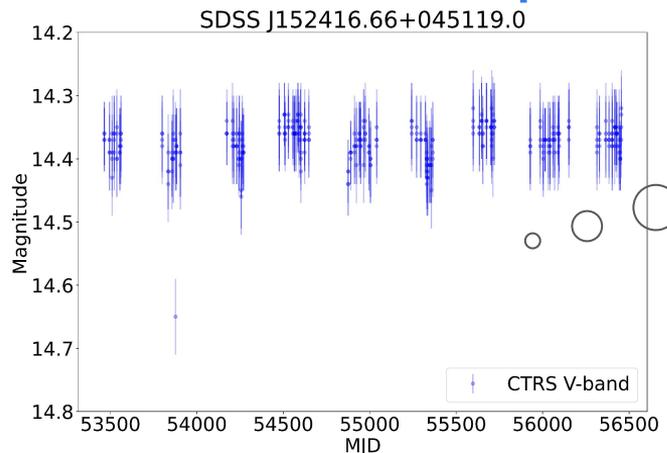
# Recurring flares in Active Galactic Nuclei and peculiar optical emission lines

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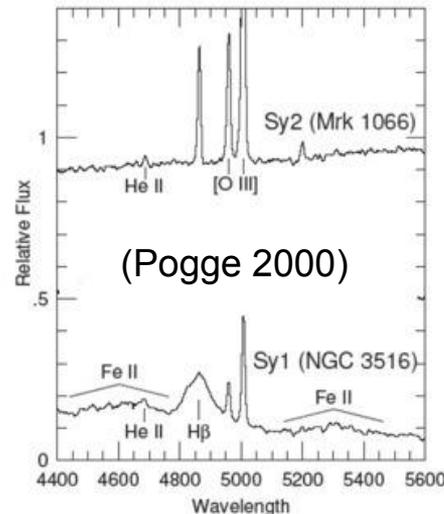
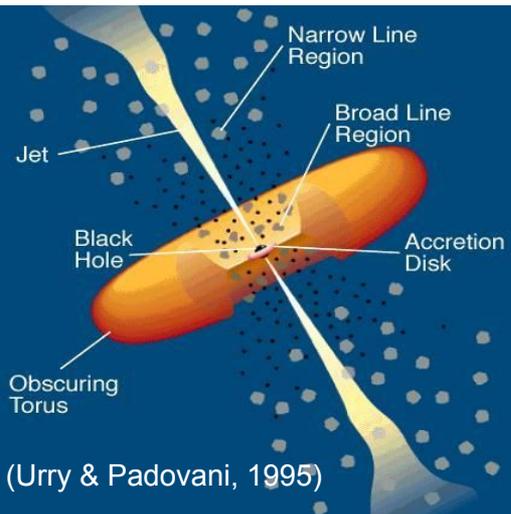
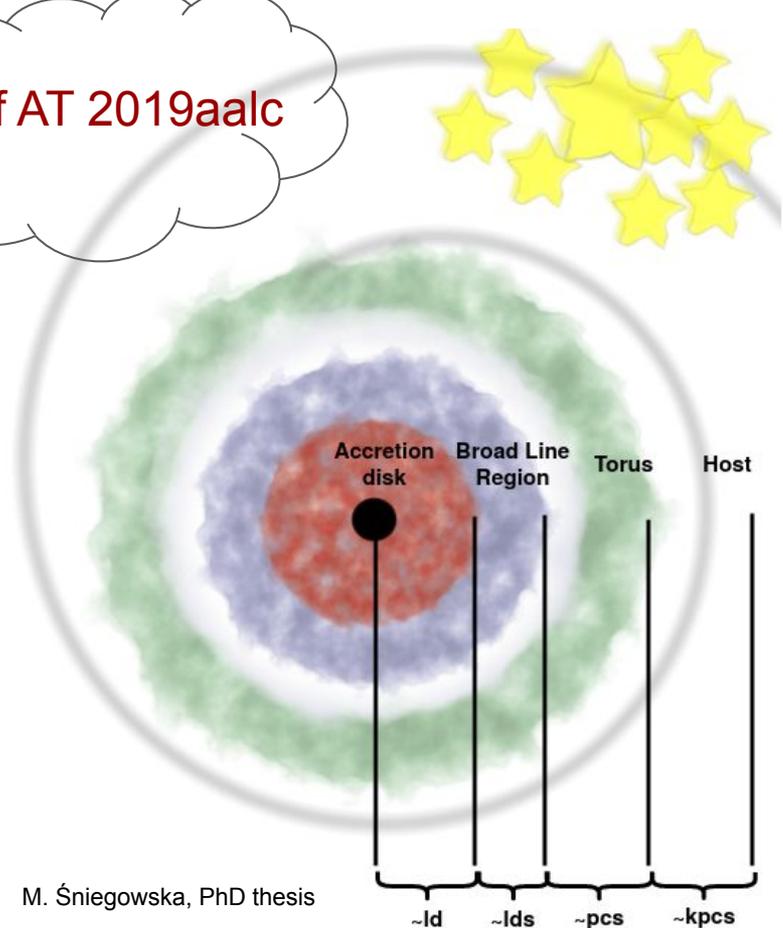
Marzena Śniegowska (AV ČR), Benny Trakhtenbrot (Tel Aviv),  
Lydia Makrygianni (Lancaster), Iair Arcavi (Tel Aviv), Claudio Ricci (UDP),  
Sarah Faris (Tel Aviv), Biswaraj Palit (CAMK, Warsaw),  
Agnieszka Janiuk (CTP, Warsaw), Bożena Czerny (CTP, Warsaw),  
and many others!



# Motivation - Time-dependent phenomena in AGN



host of AT 2019aal

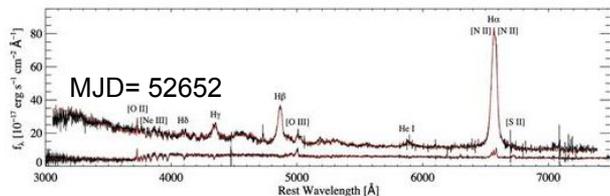


M. Śniegowska, PhD thesis

# Supermassive black hole related transients

## Changing look AGN

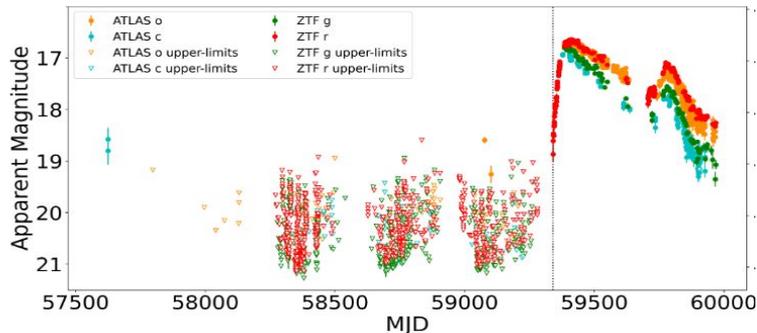
Months-years?



MJD= 57073

## Peculiar events in AGN

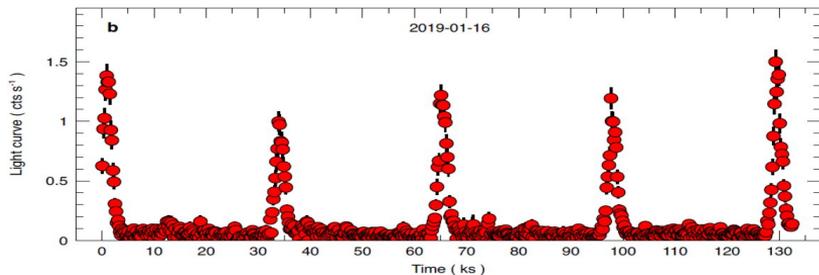
Months-years?



Makrygianni+2023

## Quasi periodic eruptions

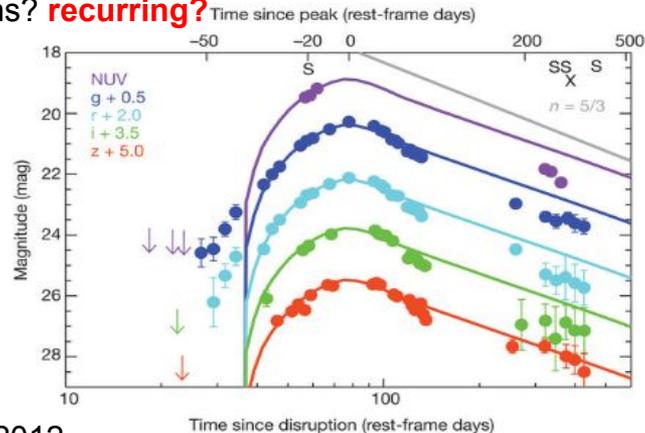
hours? **recurring?**



Miniutti+19; 23a,b

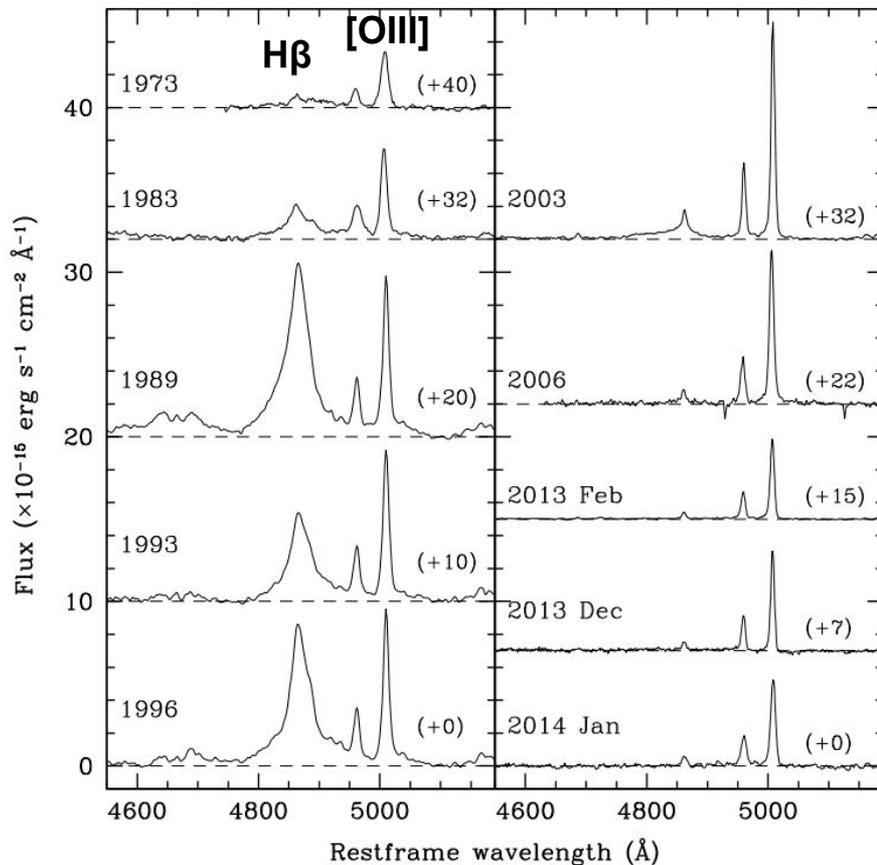
## Tidal disruption events

Months? **recurring?**



Gezari+2012

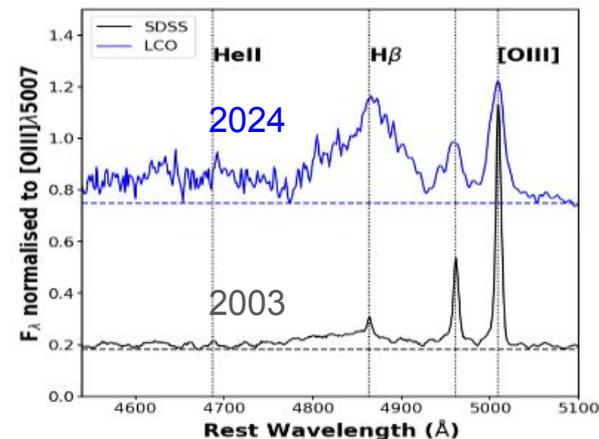
# Balmer line (dis)appearance - CL AGN



Mrk 590 (Denney+ 2014)

- ★ In some of the Changing Look AGN (CL AGN), a broad line disappears
- ★ In others, a broad line appears
- ★ and sometimes disappears again

Mrk 590 (Palit+ 2025)

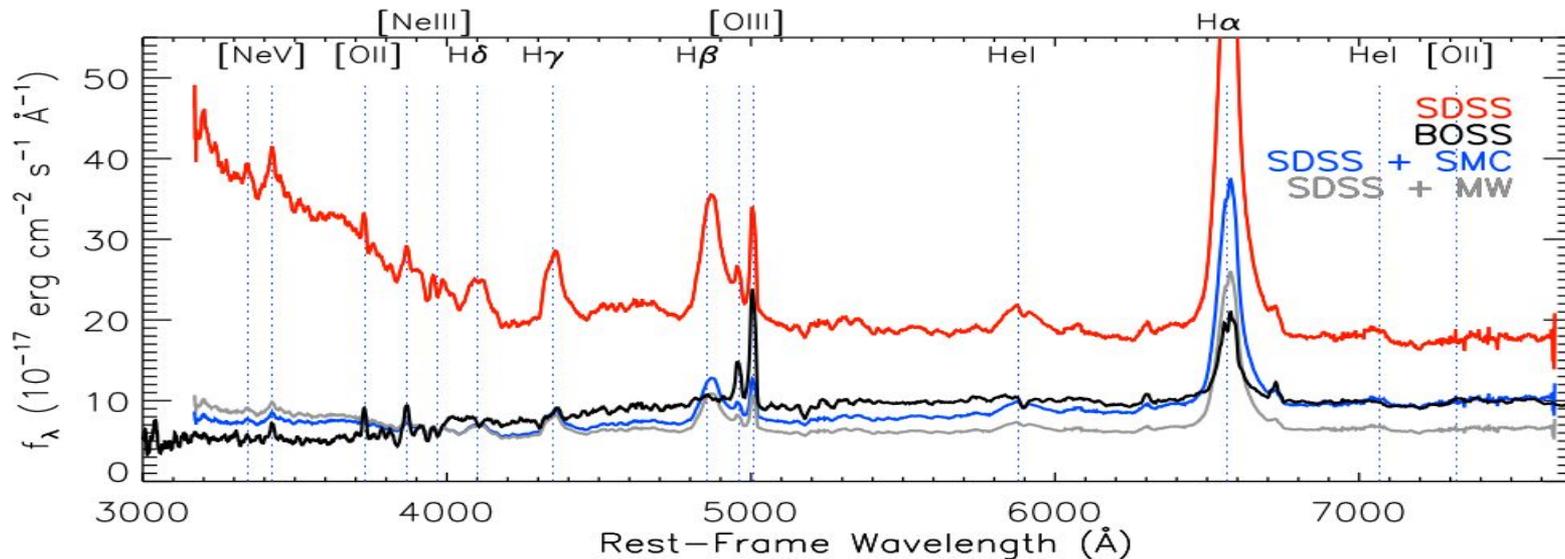


# Why do we study flaring AGN?

- Many flaring AGN have been detected recently. It is difficult to explain the reason of the change
- A challenge of the unified model
- Host galaxies of luminous AGN: essential for studying the coevolution of SMBH & its host
- State transitions can provide new insights into AGN physics

# A systematic search of the SDSS MacLeod+ 2016

- First systematic search for changing-look quasars
- Using data from the SDSS and PS1 3 $\pi$
- Visual identification of 10 unknown changing-look quasars
- Extending the population of changing-look AGN to  $z = 0.63$ .



# More CL AGN Searches (Selected)

A systematic search in CRTS  
(Graham+2020)

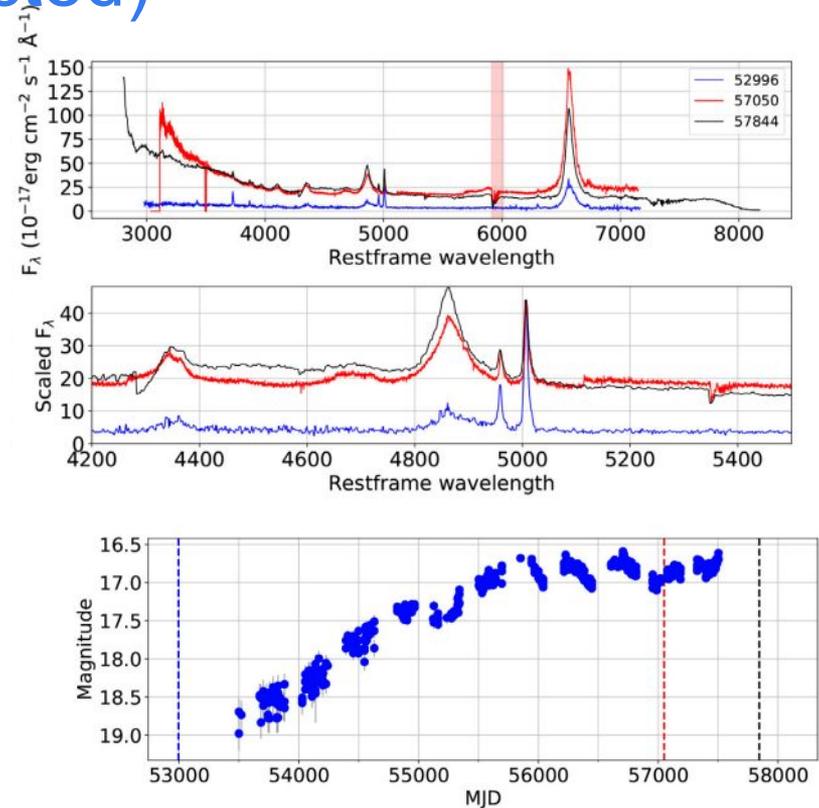
- 111 sources with specific patterns of optical variability

(Green+2022)

- 61 newly discovered CLQ candidates using the Time Domain Spectroscopic Survey of the SDSS IV

(Zeltyn+2024)

- 113 newly discovered CL AGN using SDSS V



Graham+ 2020

# Possible scenarios

Variation of obscuration  
(Extrinsic)

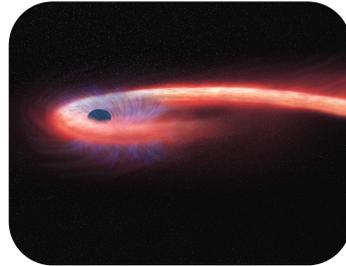
Inconsistent with broad line  
dimming and timescales



Credit: NASA/SOFIA/Lynette Cook

Tidal disruption event  
(Intrinsic)

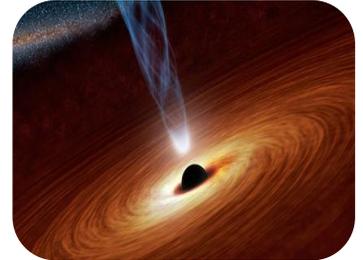
The flares are longer-lived  
than the typical TDE



Credit: NASA / CXC / M. Weiss

Changes in accretion rate  
(Intrinsic)

Distinct physical processes  
from the rest of quasars



Credit: NASA/JPL-Caltech

# Possible scenarios

## Variation of obscuration (Extrinsic)

Inconsistent with broad line  
dimming and timescales



Credit: NASA/SOFIA/Lynette Cook

- Low level of polarization in CL AGN argues against the scattering (and obscuration) scenario (Hutsemekers+ 2019)
- Strong changes are also seen in the IR, where the obscuration should not play a role (Sheng+ 2017; Stern+ 2018)
- Complex multi-band recovery, inconsistent with obscuration (e.g. Mathur+ 2018)

# Possible scenarios

- In some cases perhaps TDE provides the answer
- In sources with repeated events the TDE is statistically unlikely

Tidal disruption event  
(Intrinsic)

The flares are longer-lived than the typical TDE

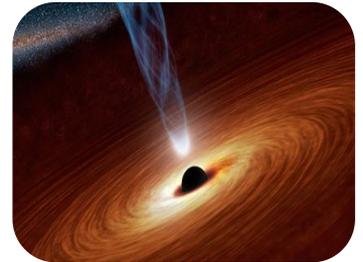


# Possible scenarios

- What process would start instability?
- What instability would give us the expected timescales?
- Need of additional angular momentum loss (e.g., waves in inner disk, hydromagnetic winds)?

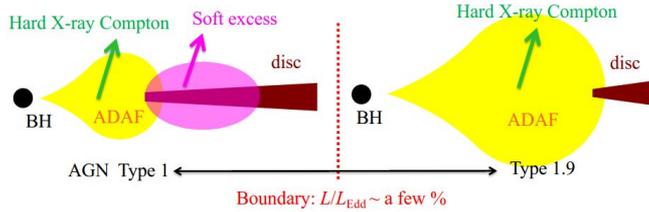
Changes in accretion rate  
(Intrinsic)

Distinct physical processes  
from the rest of quasars

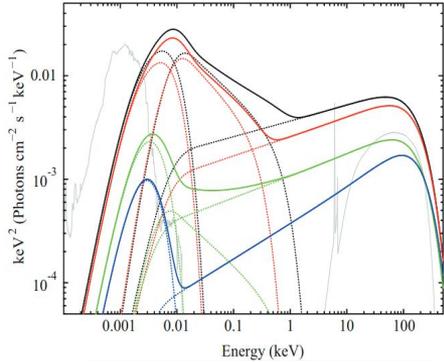


Credit: NASA/JPL-Caltech

# Changes in accretion rate (Intrinsic)



Noda & Done 2018

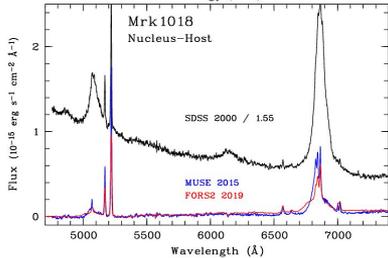


2008 Aug

2008 Jun

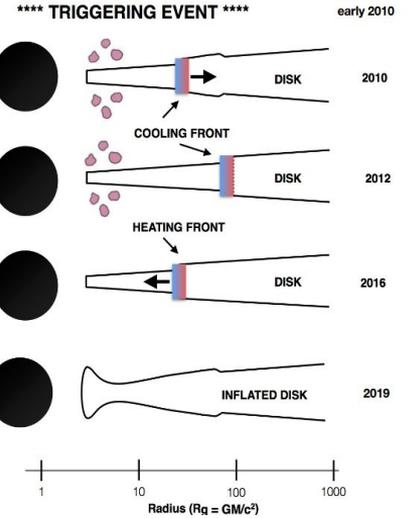
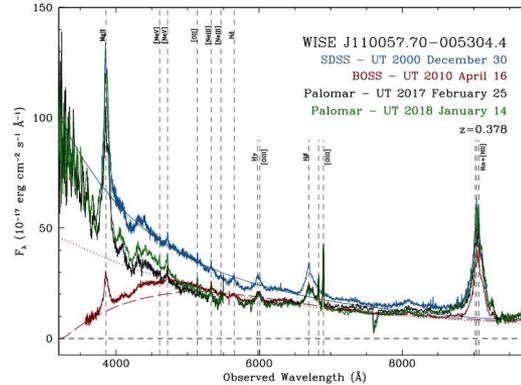
2013

2016



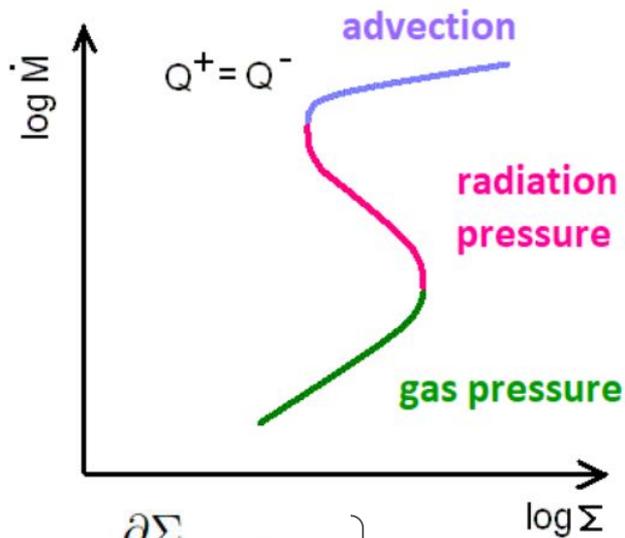
Hutsemékers+ 2020

- 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

# Intrinsic changes - Instability of radiation pressure dominated Keplerian disk



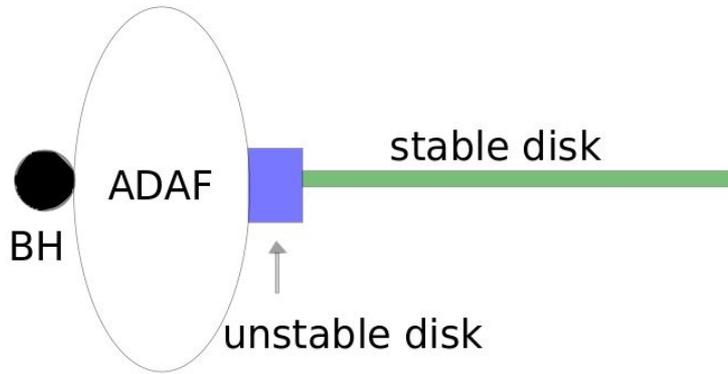
## Shakura-Sunyaev disk model:

- ★ 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

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

← stationary solution

# A possible mechanism for **multiple** CL events in Active Galactic Nuclei (*Śniegowska+ 2020*)



- ★ a 3-component, computational toy model
- ★ followed the time-dependent evolution of a single zone
- ★ Viscous timescales scale with  $\Delta R/R$

$$\tau_{\text{vis}} = \tau_{\text{visSS}} \Delta R/R$$

# Our model

- The model is sensitive to the adopted parameters
- The zone structure may be easily affected by local phenomena

The default parameters are:

$\dot{m}=0.0122$ ,

$\alpha=0.02$ ,

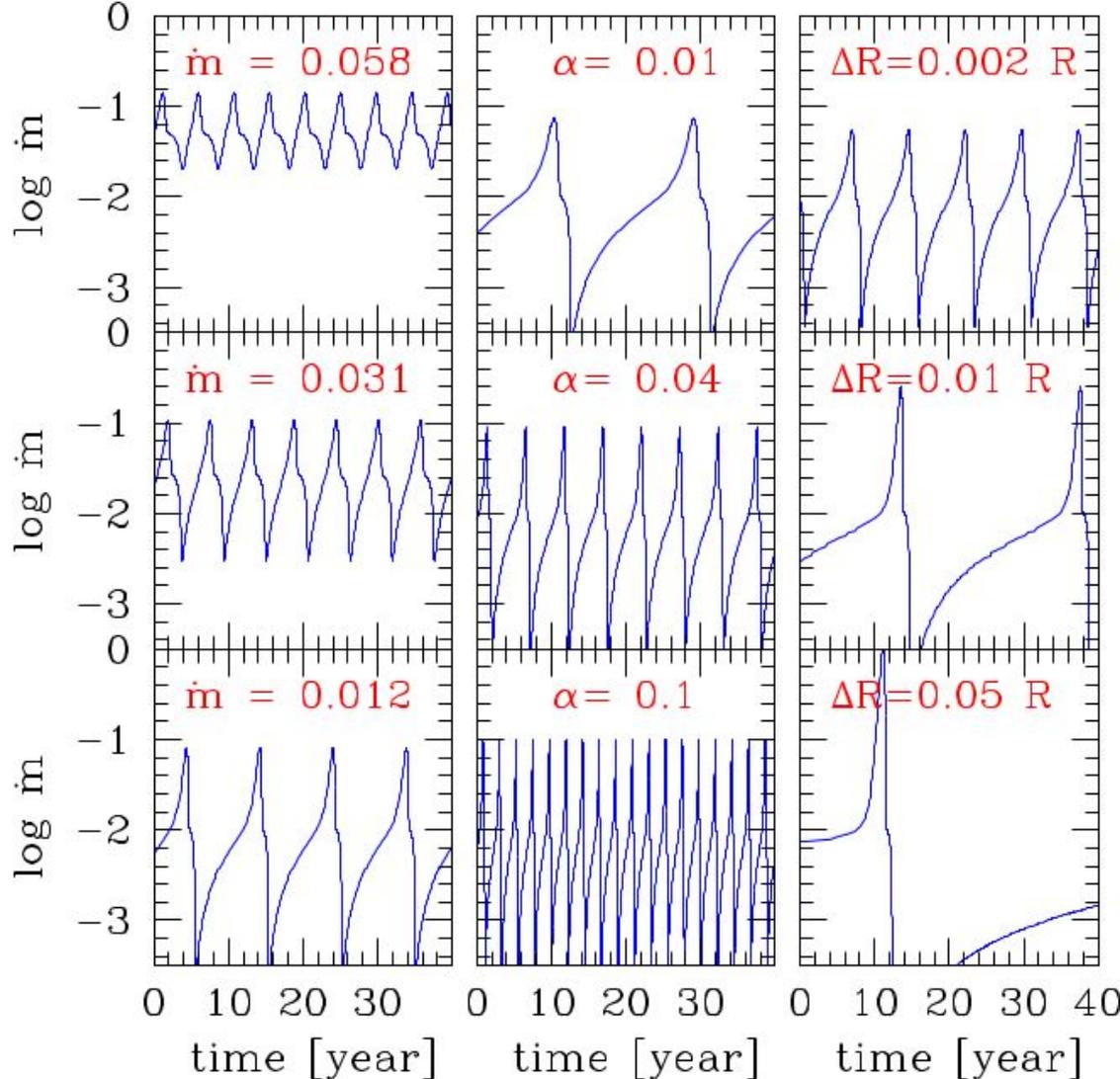
$\Delta R=0.003R$ .

Fixed parameters:

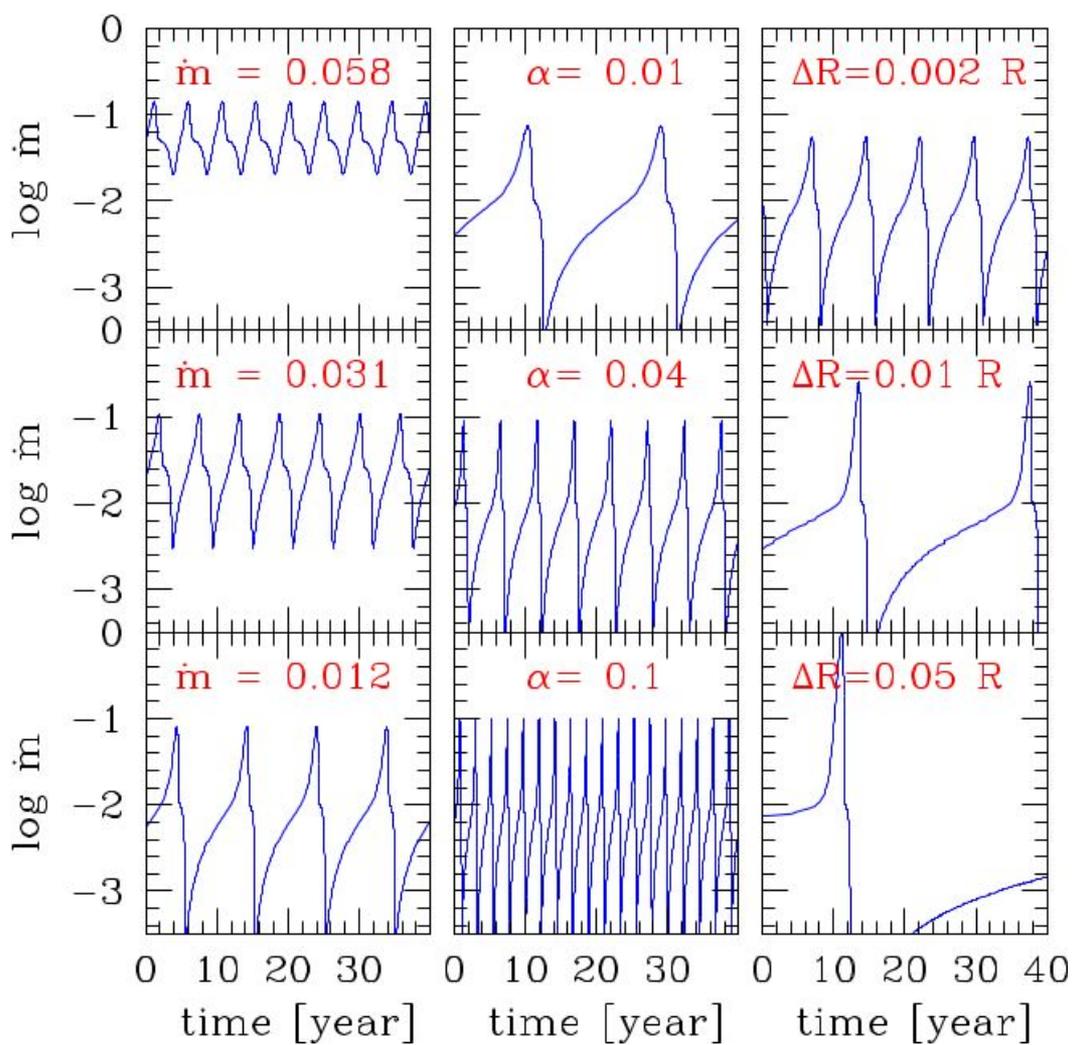
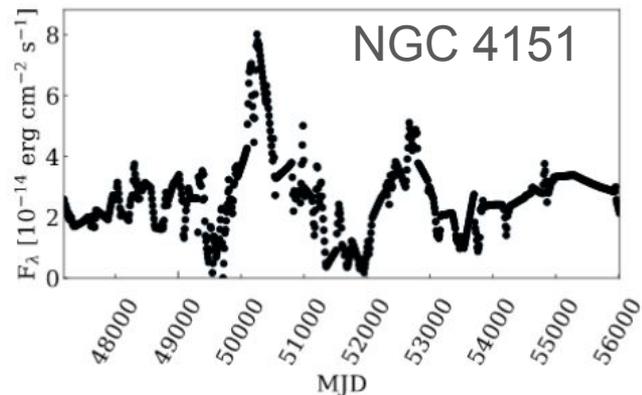
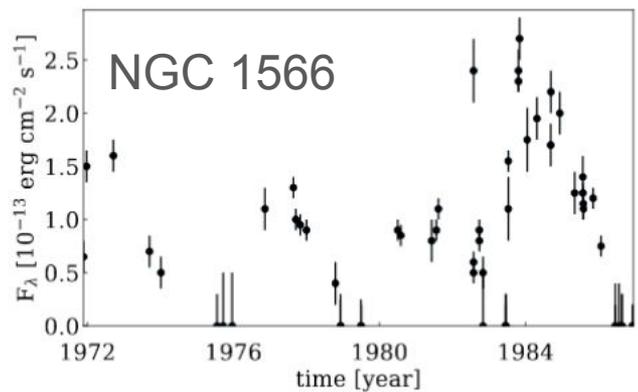
$\log M=6.92$  (like in NGC 1566),

inner radius of the unstable zone in disk

$R=30 R_{\text{Schw}}$



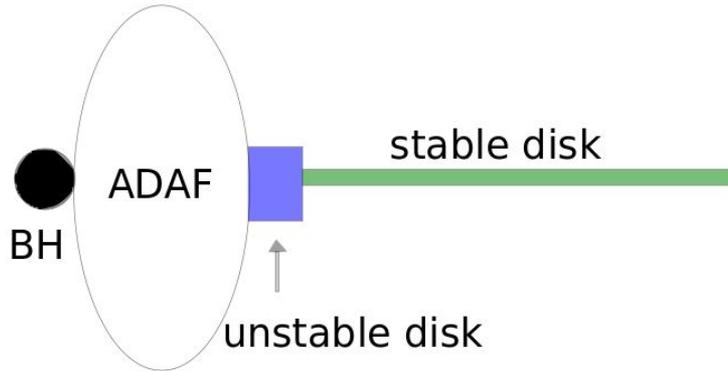
# Our model



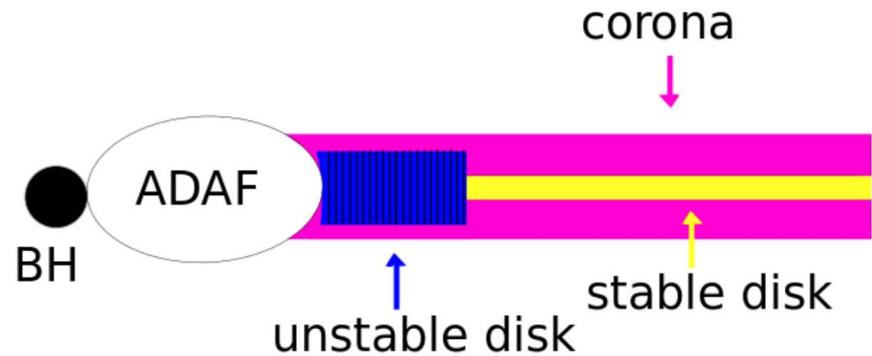
# Let's try something more realistic...

GLADIS: GLocal Accretion Disk Instability Simulation Code (Janiuk 2019)

(Śniegowska+ 2020)



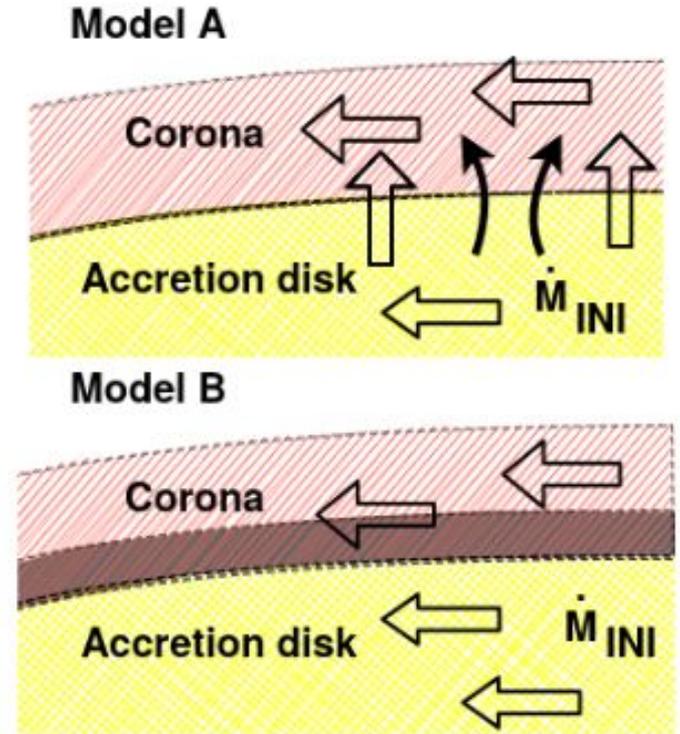
(Śniegowska+ 2023)



Timescales in Grzędzielski et al. 2017 for  $M = 10^7 M_{\text{sun}}$  are  $\sim 1000$ s years.

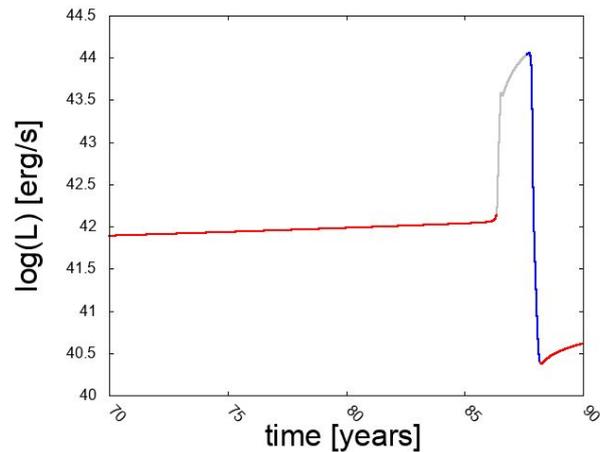
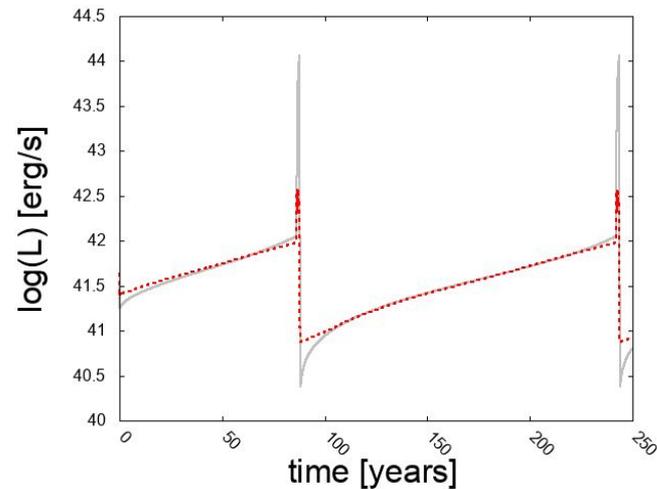
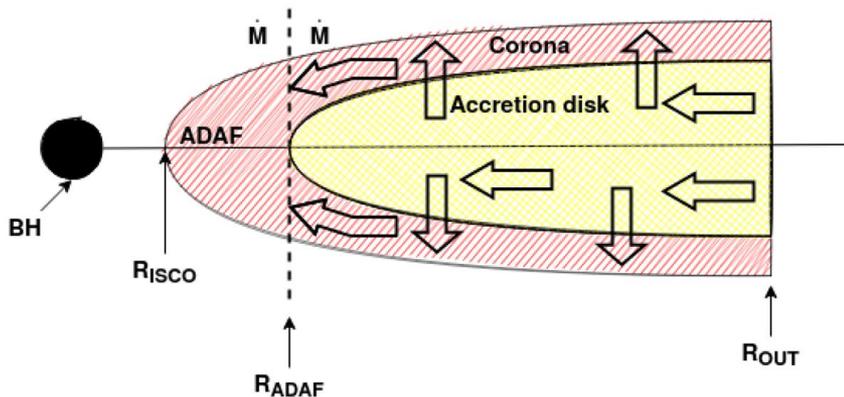
With reduced  $R_{\text{OUT}} = 80 R_{\text{S}}$  we obtain timescale of 85 years.

- We use GLADIS: GLocal Accretion Disk Instability Simulation Code
- We model luminosity changes for objects with  $10$ ,  $10^5$ ,  $10^7$  solar masses
- We use the time-dependent evolution of a black hole accretion disk unstable due to the dominant radiation pressure
- We add boundary condition between ADAF and outer flow
- We add extra cooling component based on presence of magnetic field

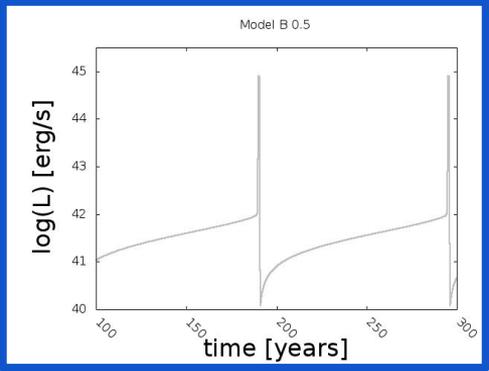
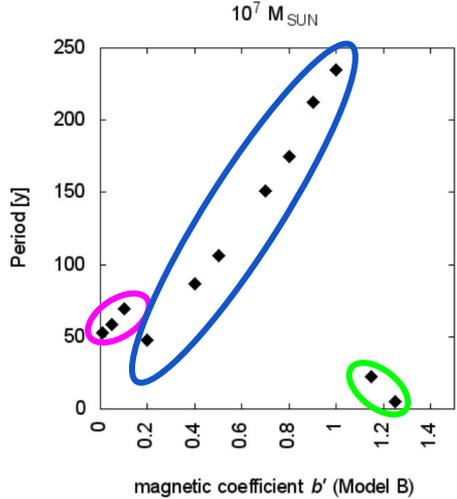


# Our results

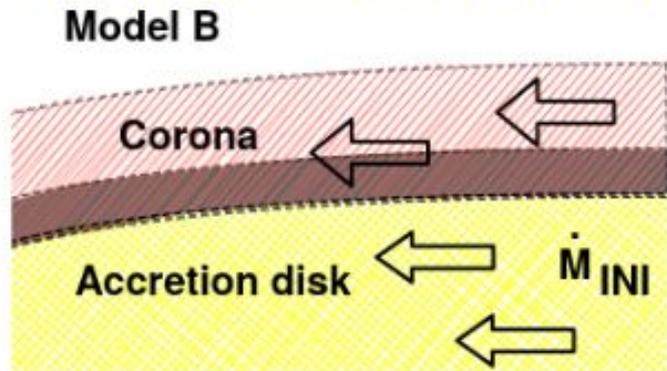
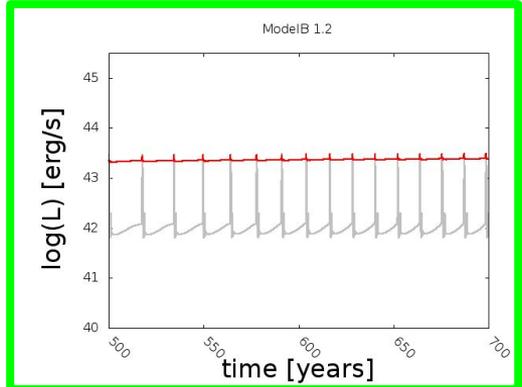
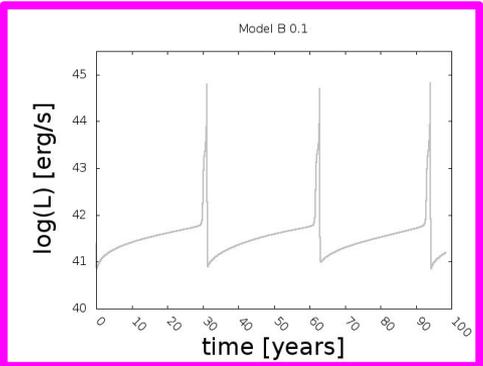
- $\log(M) = 6.92$
- $\text{Alpha} = 1.e-2$
- $R_{\text{ADAF}} = 20.0$
- $R_{\text{OUT}} = 100.0$
- 3-phases cycle behaviour



# Dependences of the duration of the limit cycle



- ★  $\log(M_{\text{BH}}) = 7$
- ★  $\alpha = 0.01$
- ★  $R_{\text{IN}} = 3R_{\text{S}}$
- ★  $R_{\text{OUT}} = 100R_{\text{S}}$

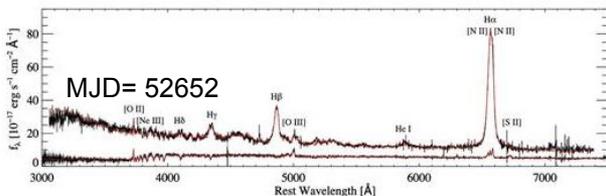
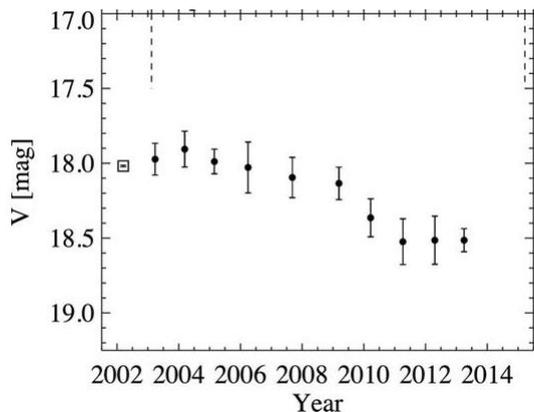


idea from Begelman+ 2015

# Supermassive black hole related transients

## Changing look AGN

Months-years? **recurring?**  
blue continuum and broad lines on/off

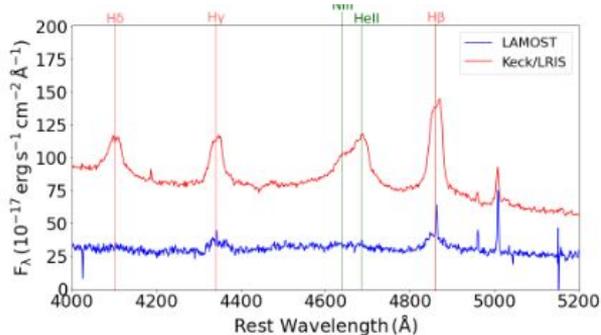
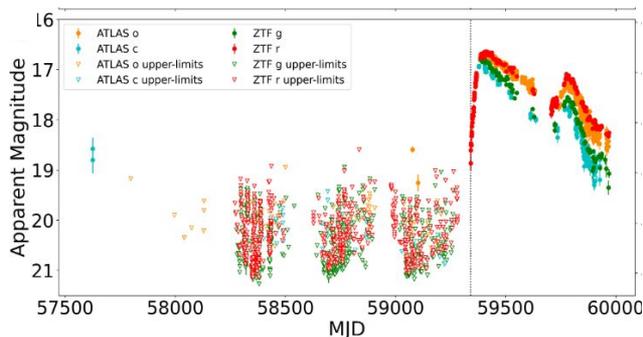


MJD= 57073

Runnoe+ 2016

## Peculiar events

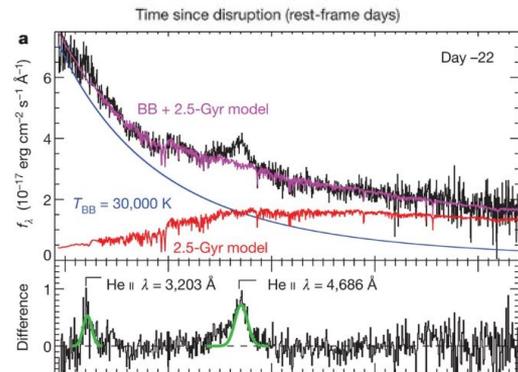
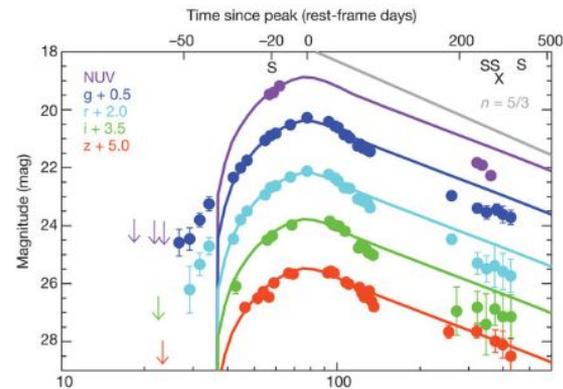
Months-years? **recurring?**  
broad HeII + NIII



Makrygianni+ 2023

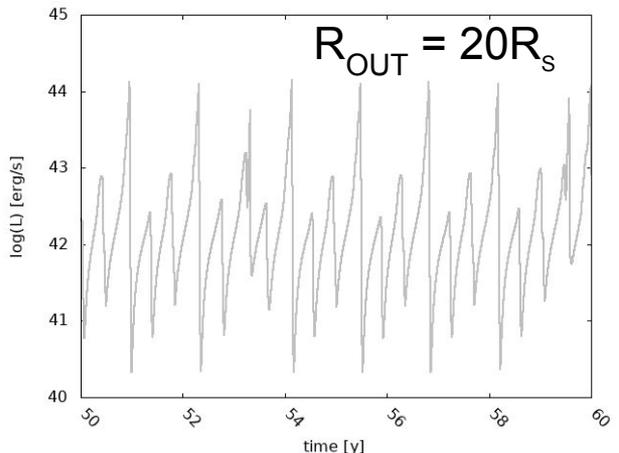
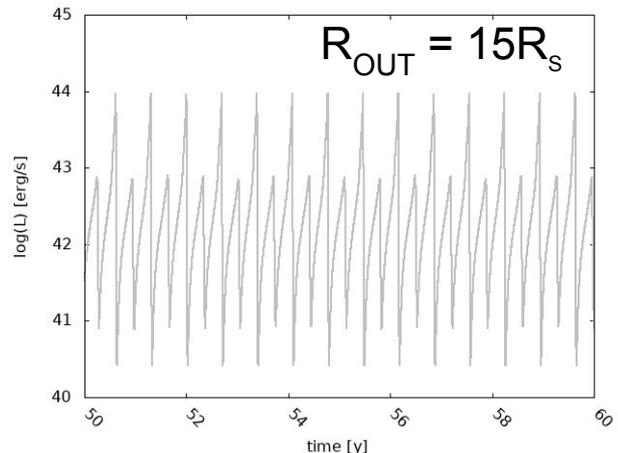
## Tidal disruption events

Months (late radio flares?) **recurring?**  
broad HeII 4686 line

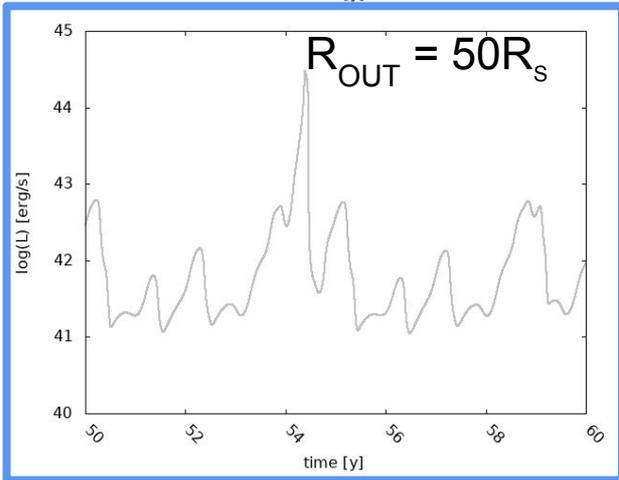
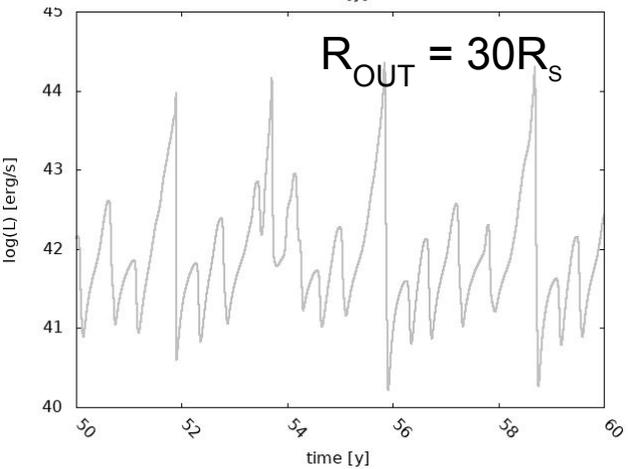


Gezari+ 2012

# Examples of the light curves with small $R_{OUT}$



$\log(M_{BH}) = 7$   
 $\alpha = 0.01$   
 $R_{IN} = 3R_s$

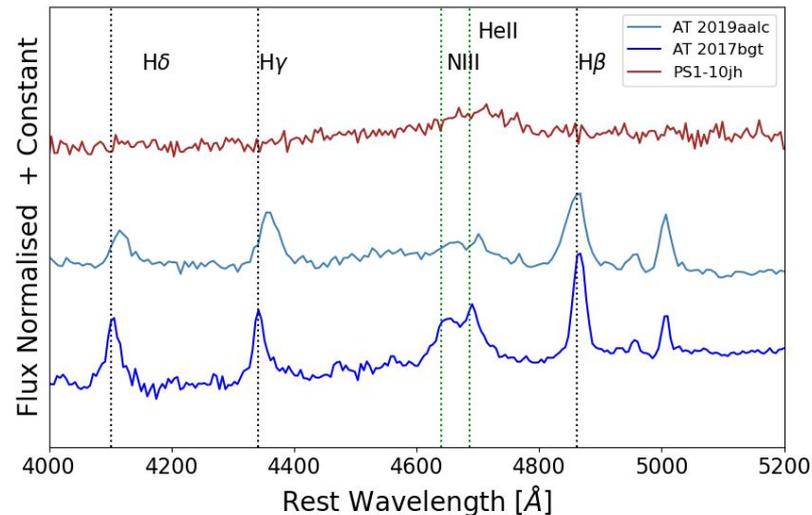
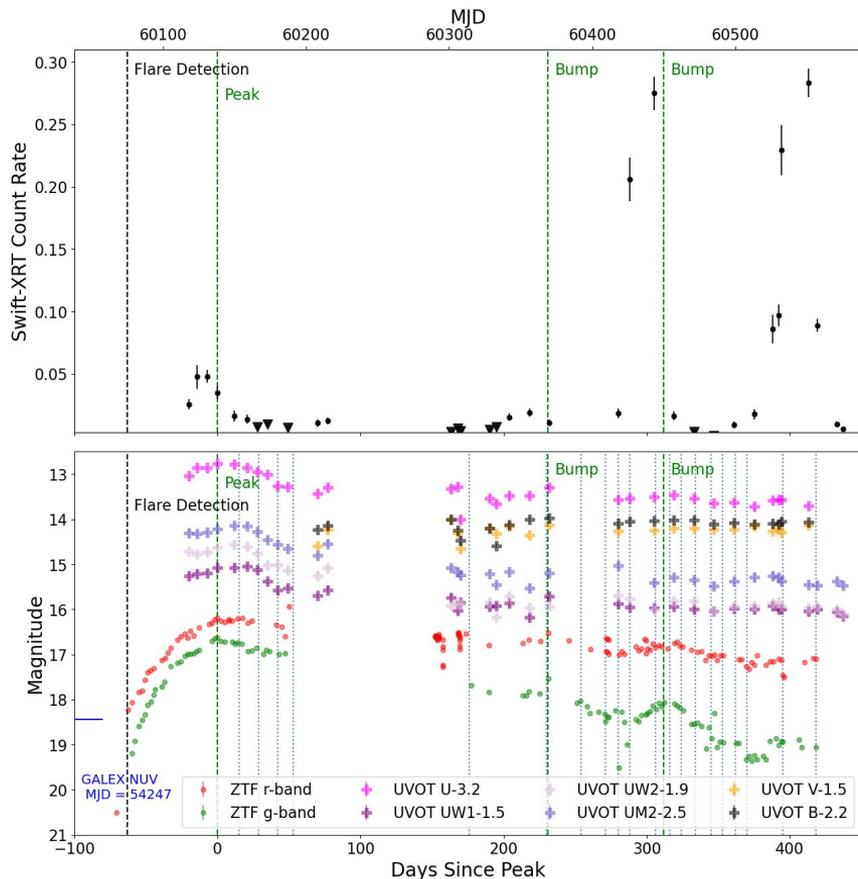


- ★ Recurring flares in an AGN disk
- ★ Years timescales
- ★ Rich structure
- ★ In UV-optical part



# Recurring flaring event in an AGN - AT 2019aalc

(Veres+2024, Śniegowska+2025)



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

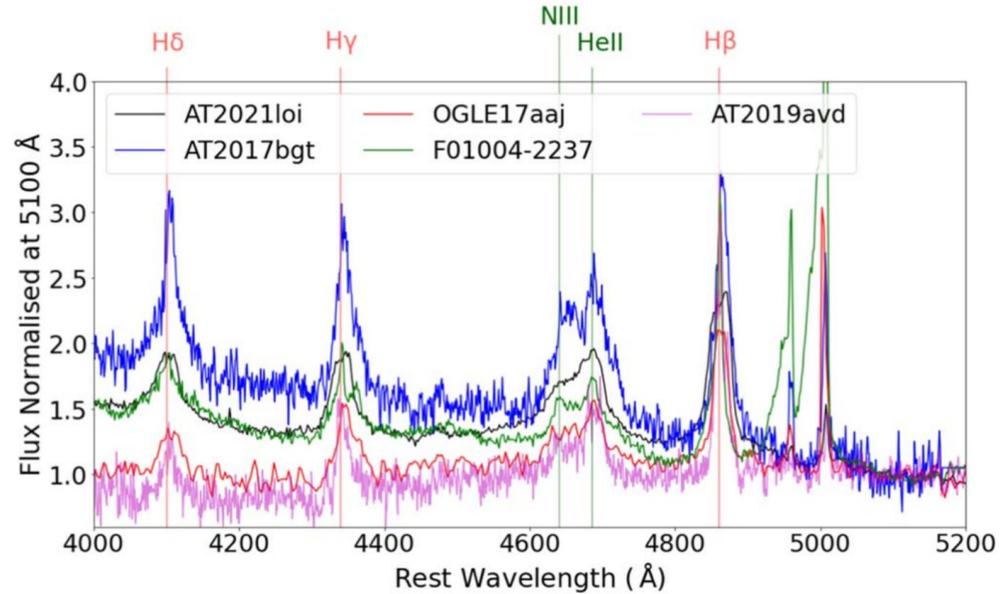
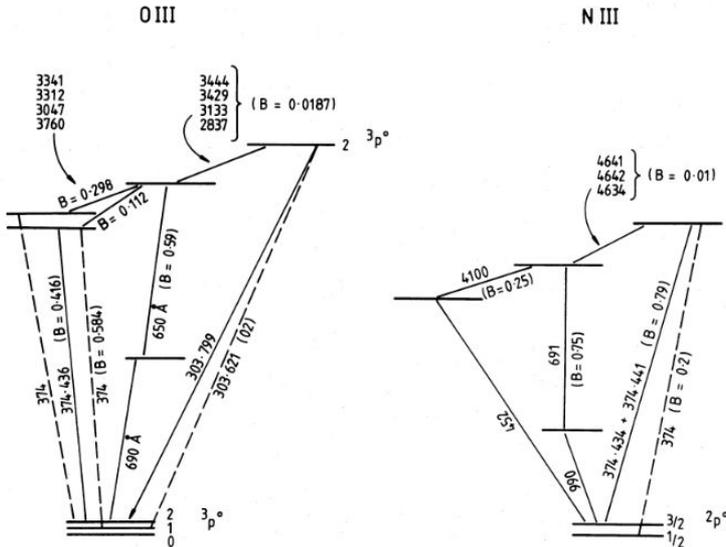
arxiv:2505.00083

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

# Broad Bowen Fluorescence lines in AGN

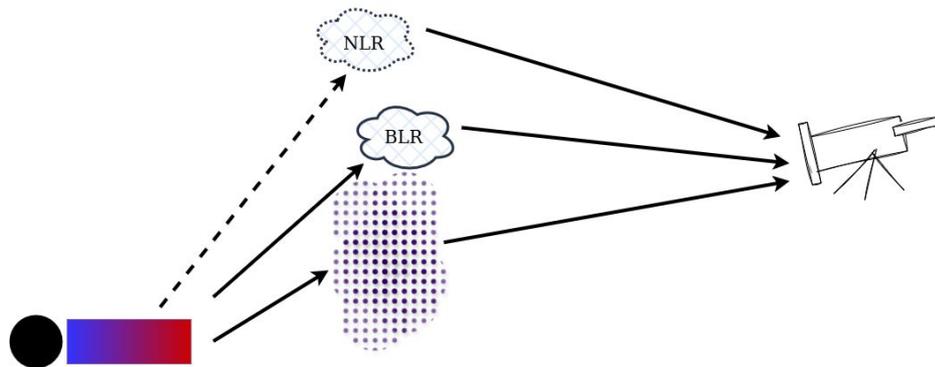
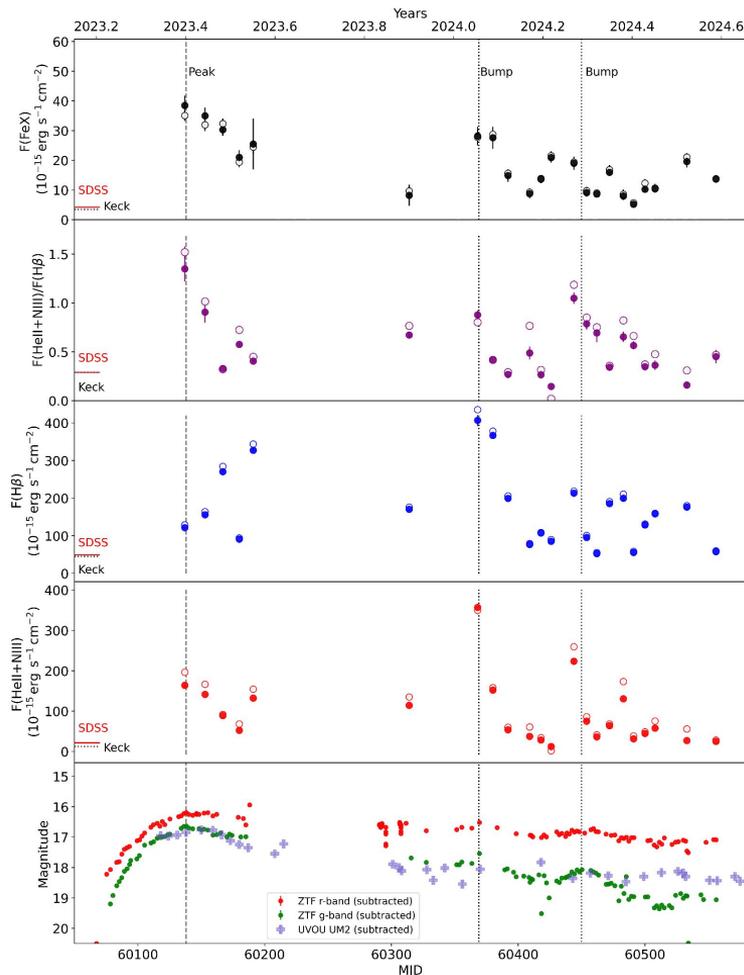
Netzer+1985

- High energy photons
- Dense material
- Those lines should be comparable to H $\beta$ !



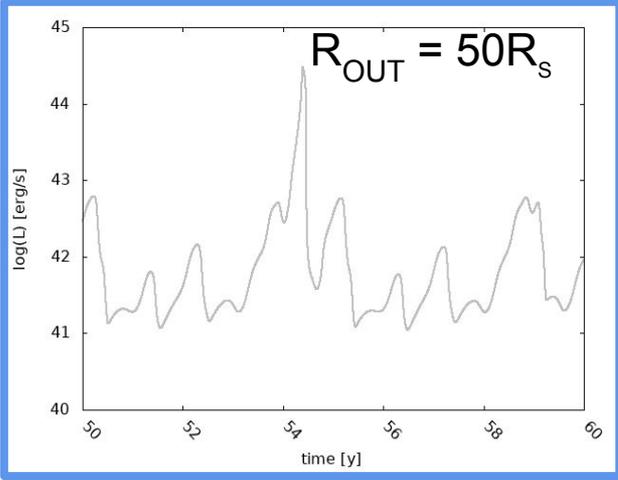
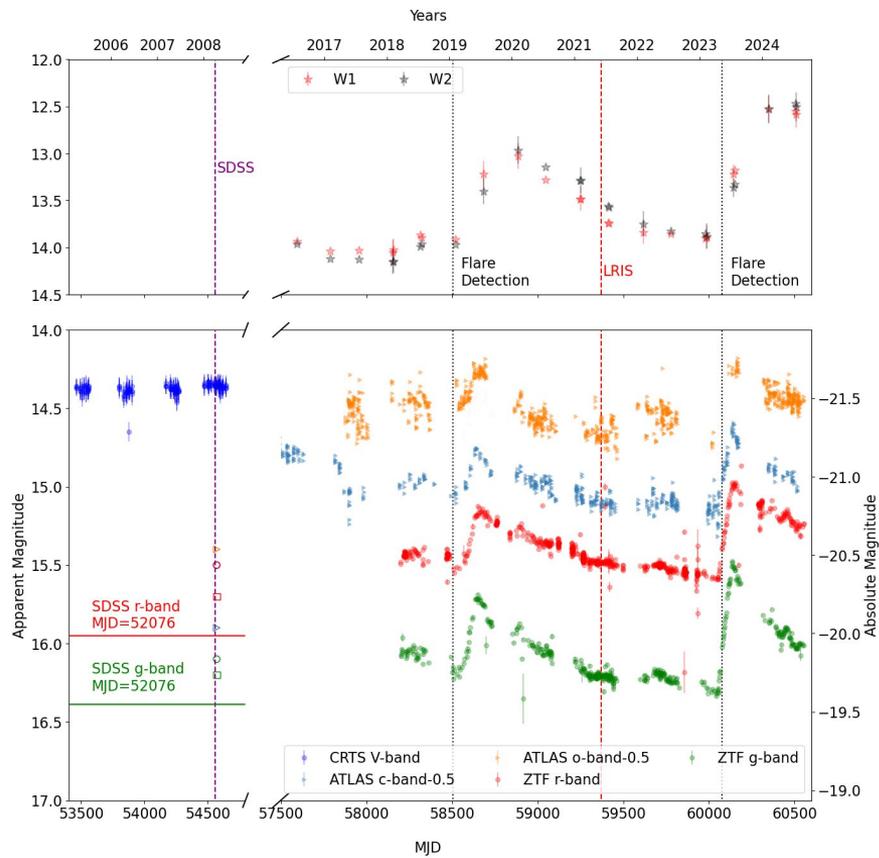
Trakhtenbrot+2019,  
Makrygianni+2023

# 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?*

# Recurring flaring event in an AGN - AT 2019aalc



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

# Conclusions

- 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
- Possible mechanism can be related to radiation pressure instability, but we need small  $R_{\text{OUT}}$
- Spectroscopic and multi- $\lambda$  follow-up is key
- Broad Bowen lines - Linked to TDEs? maybe TDEs-in-AGN? recurring tidal events?

Thank you!