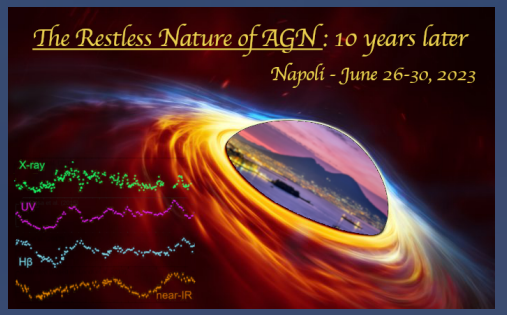

The Optical-to-X-ray continuum variability of AGN: thermal fluctuation rather than reprocessing?

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in collaboration with

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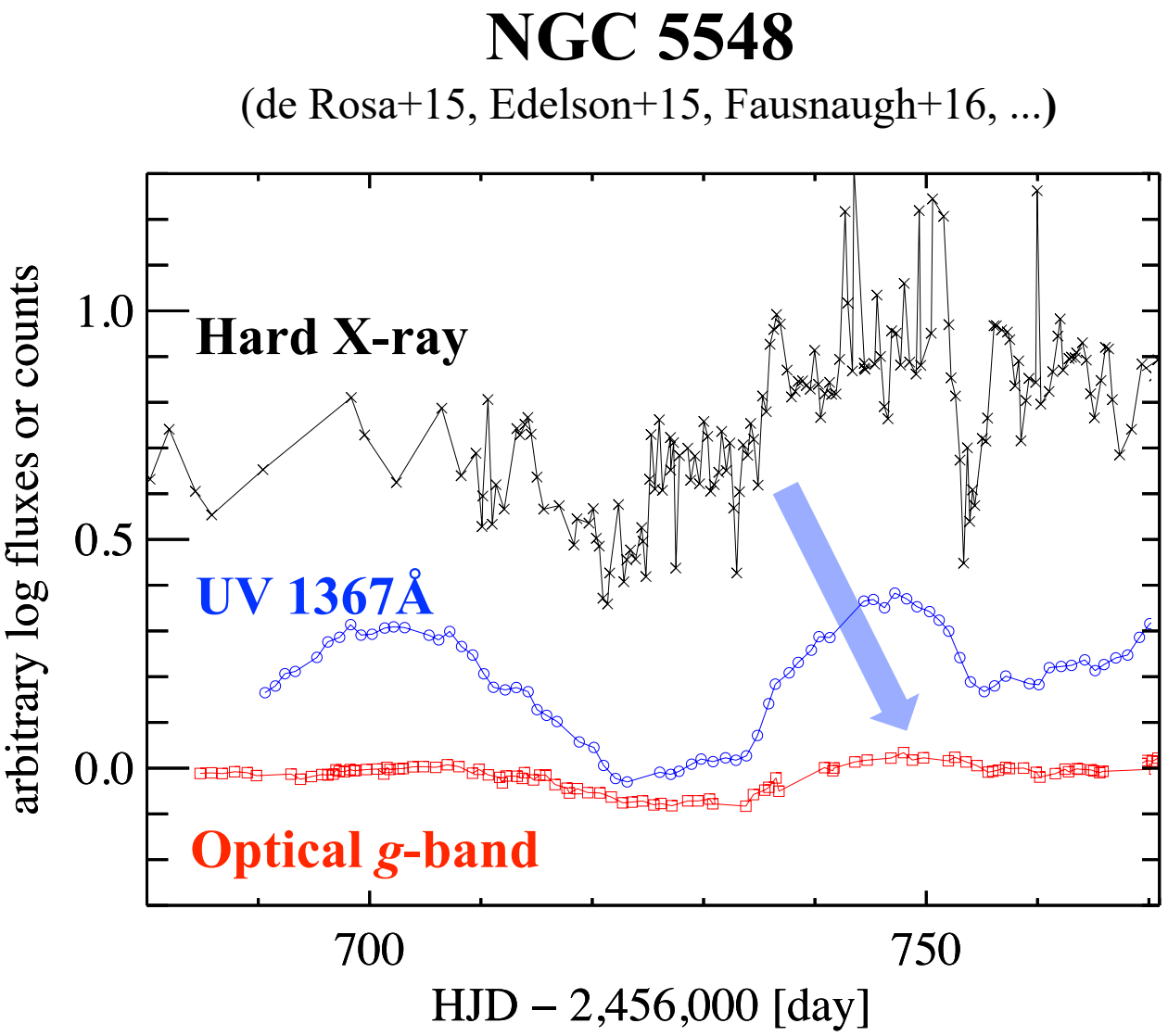
XMU: Mou-Yuan SUN, Wei-Min GU
ZHU: Xin-Wu CAO
SHAO: Feng YUAN
...

26 Jun 2023 @ Napoli

Outline

- **AGN variability & Reprocessing**
- Thermal fluctuation scenario & New origin of continuum lag
- More questions & Summary

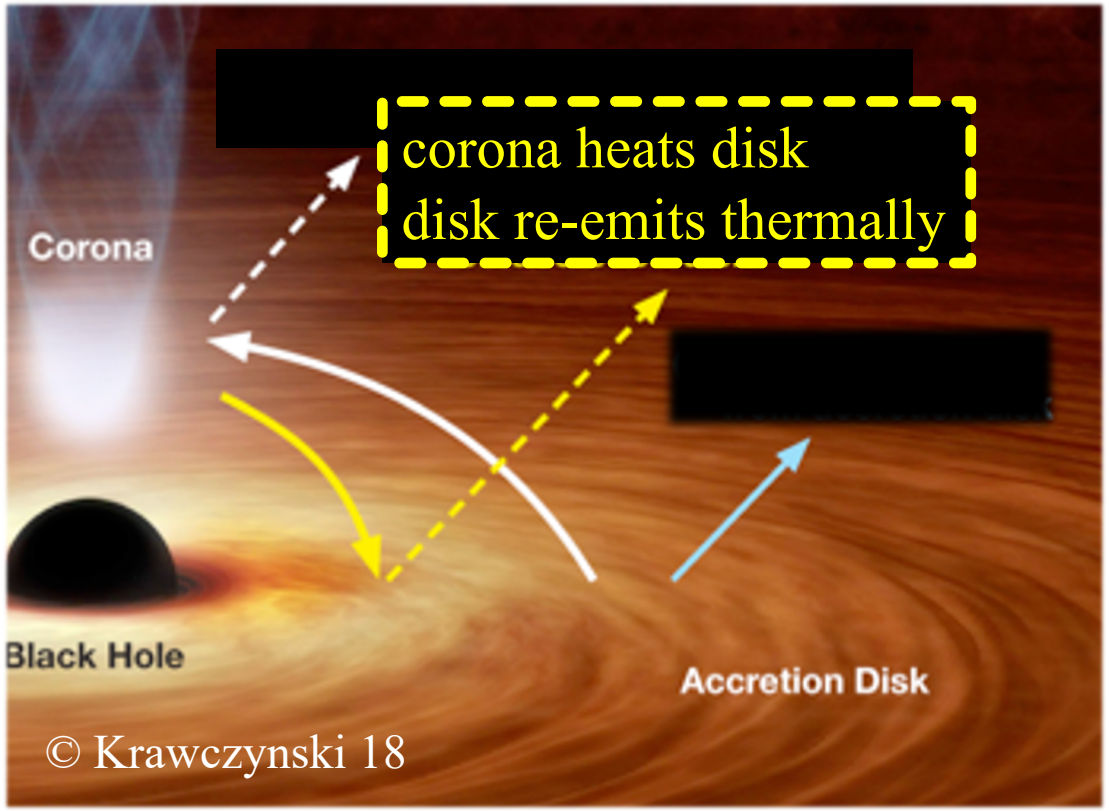
Ubiquitous variations: from optical to X-ray



- larger at shorter wavelength
- nicely correlated
- bluer-when-brighter in UV/optical
  (since Cutri+85, ..., Sun+14, Zhu+16,+18, Cai+19)
- lag for longer wavelength
  (since Wanders+97, ..., Fausnaugh+16, ...)

The traditional X-ray reprocessing scenario

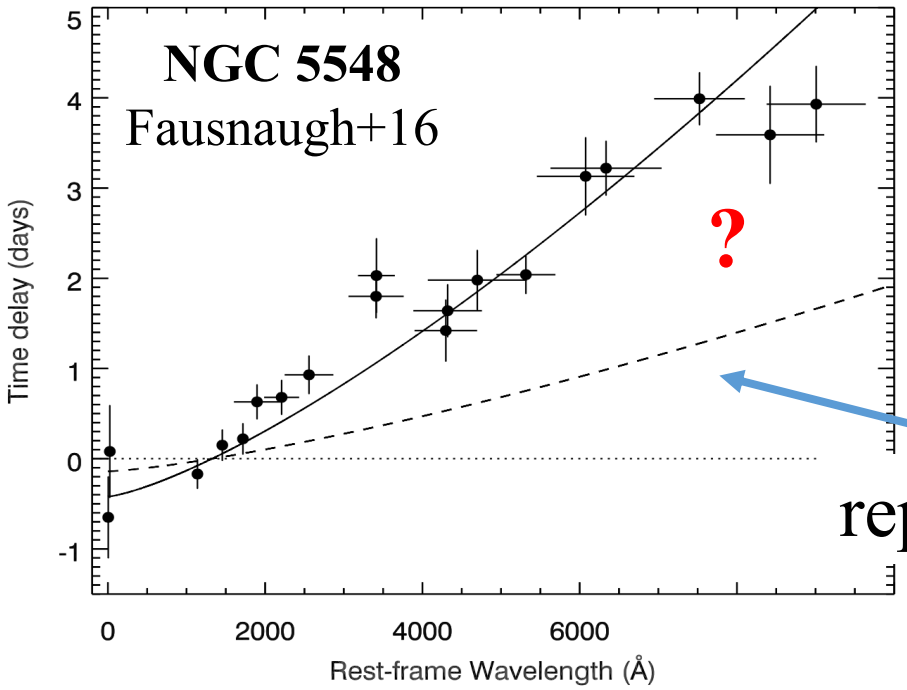
since Guilbert & Rees 88, Krolik+91, ...



Seemingly, AGN world is more complicated than reprocessing thought!

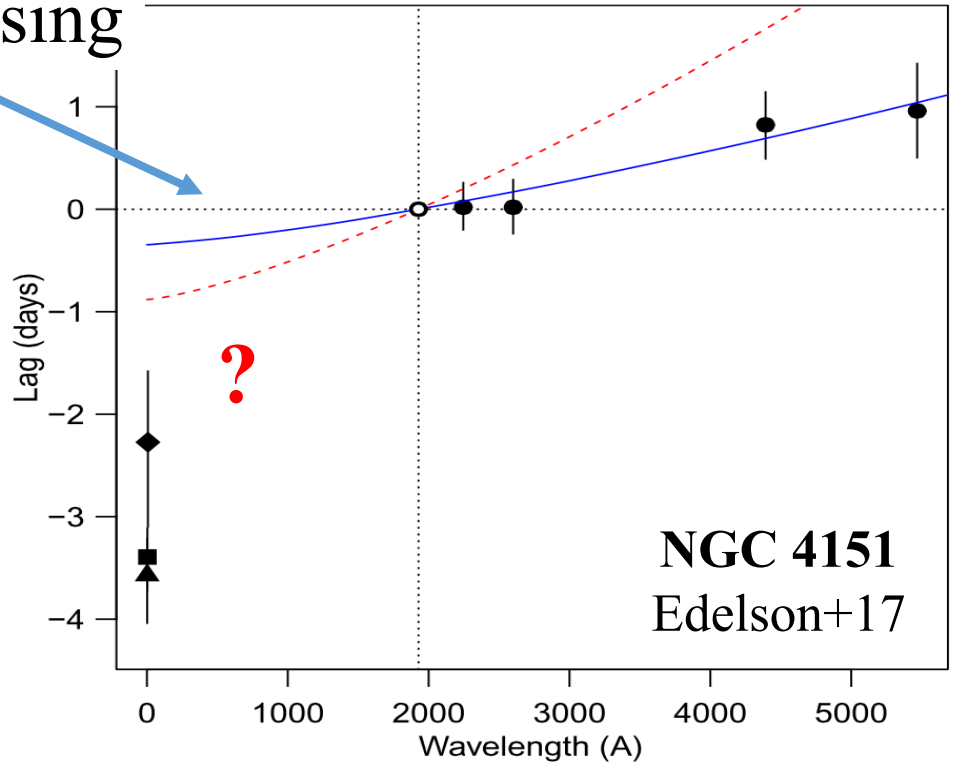
- naturally predicts
  - nice co-ordination
  - lag-wavelength relation of $\tau \sim \lambda^{4/3}$
- but challenged by
  - un-correlated X-ray and UV/optical (Lira+15, Xin+20, Sou+22)
  - faint X-ray corona (Kara+23)
  - UV/optical leads X-ray (Edelson+19, Kara+23)
  - too much UV/optical power (Gardner & Done 17)
  - **too small** lags (Fausnaugh+16, Edelson+17, ...)
  - **too weak** *timescale-dependent* bluer-when-brighter (Zhu+18)

Lag challenge against X-ray reprocessing



observed
too large
Optical to X-ray lag

reprocessing

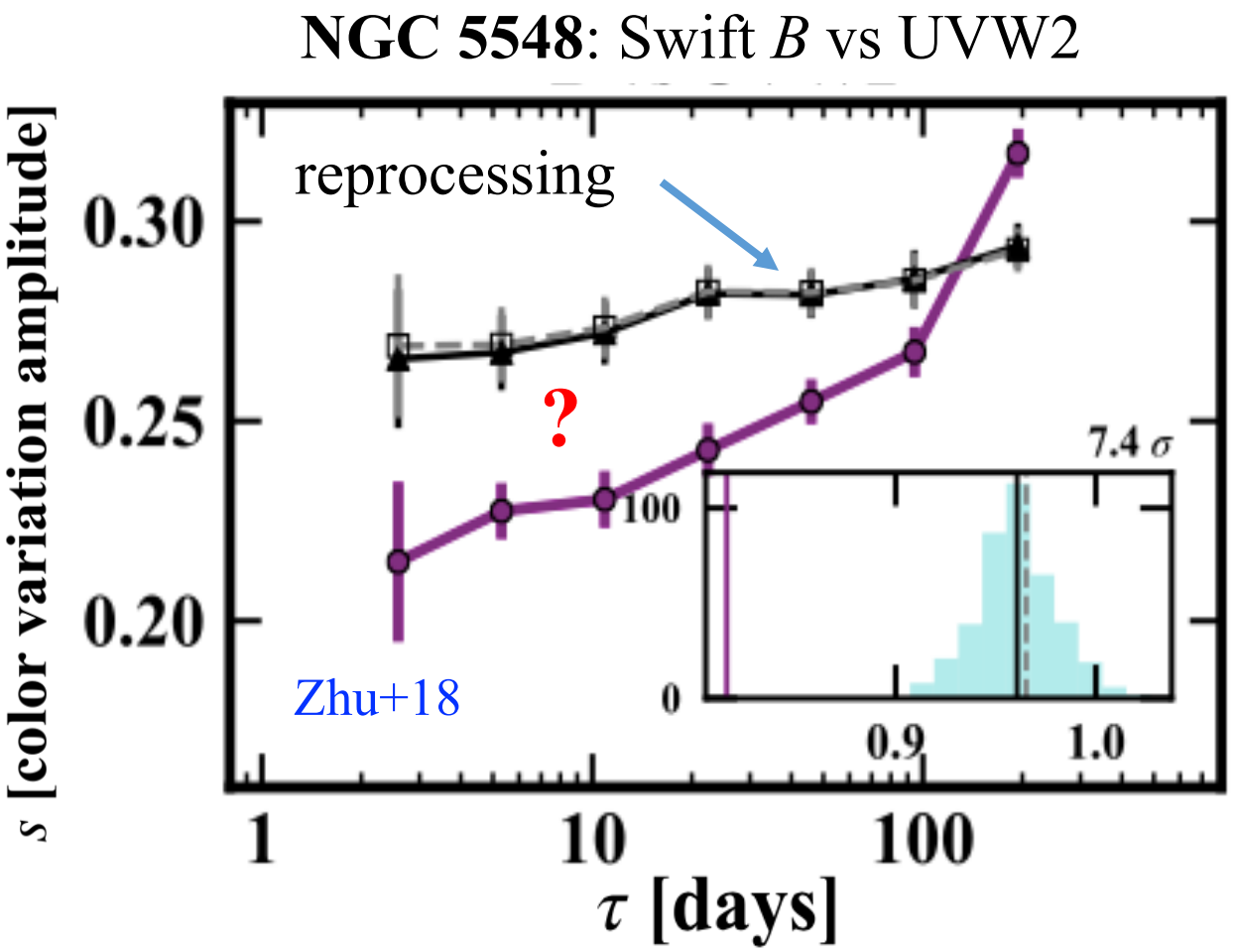


- **lag-wavelength relation**

observed
too large
UV to X-ray lag

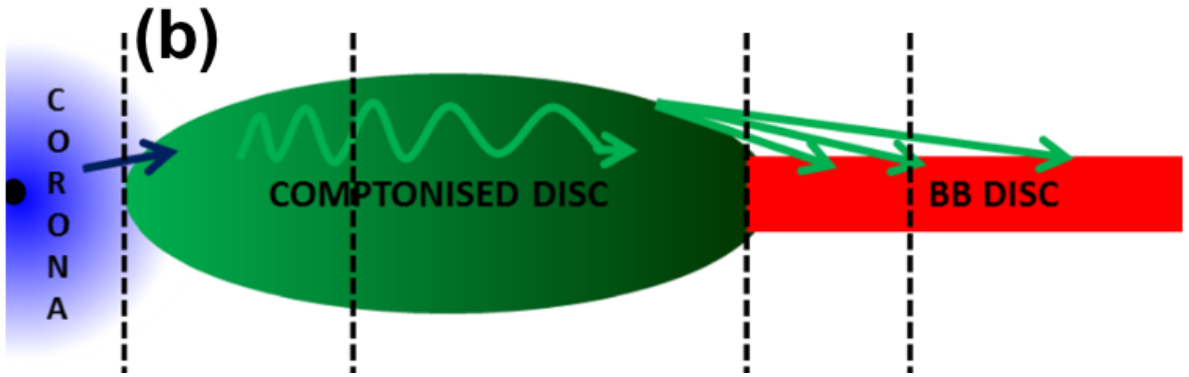
Color challenge against X-ray reprocessing

- **timescale-dependent bluer-when-brighter (or color variation)**

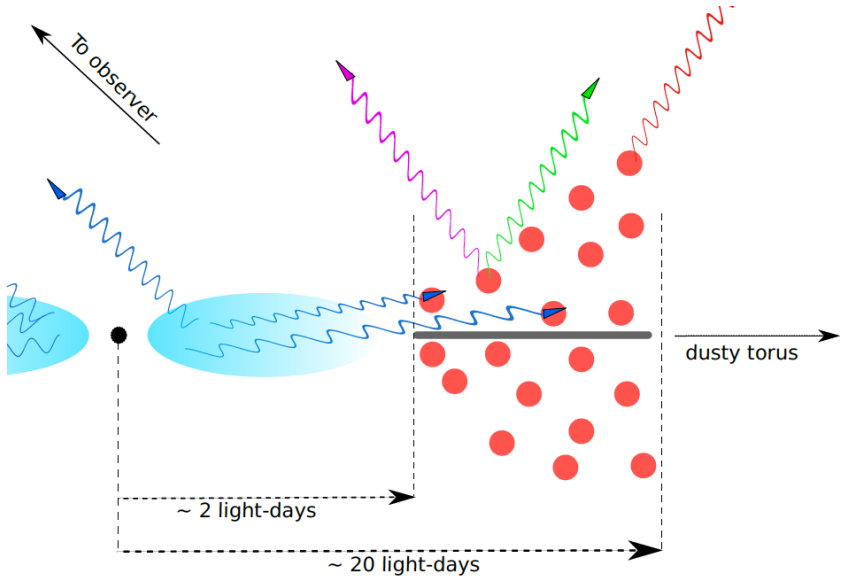


observed
stronger dependence
in timescale

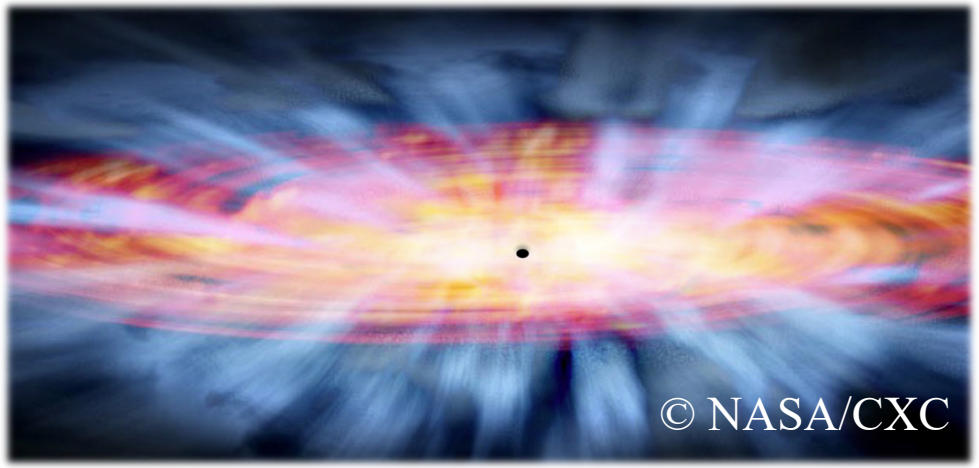
More ideas extending reprocessing



EUV/FUV reprocessing
(Gardner & Done 17)



reprocessing of clouds in broad-line region
(Mahmoud & Done 19, Chelouche+19, Montano+22, ...)



reprocessing on windy disk (Sun+19)

reprocessing on rimmed/rippled disk
(Starkey+23)

On origin of AGN variability and the continuum lag

Does **X-ray** (**EUV**/**FUV**) drive UV/optical variation?

Is there ***other origin*** for UV/optical variation?

Does lag relate to **light travel difference**?

Is there ***other origin*** for continuum lag?

Outline

- AGN variability & Reprocessing
- **Thermal fluctuation scenario & New origin of continuum lag**
- More questions & Summary

Thermal fluctuation for AGN UV/optical variation

ARE THE VARIATIONS IN QUASAR OPTICAL FLUX DRIVEN BY THERMAL FLUCTUATIONS?

Kelly+09

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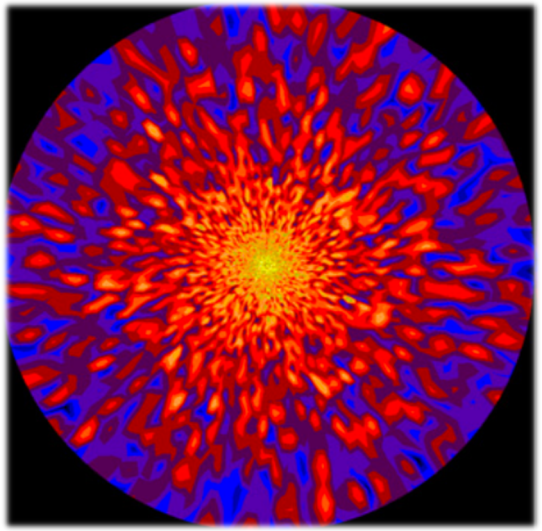
Received 2008 November 16; accepted 2009 April 3; published 2009 May 26

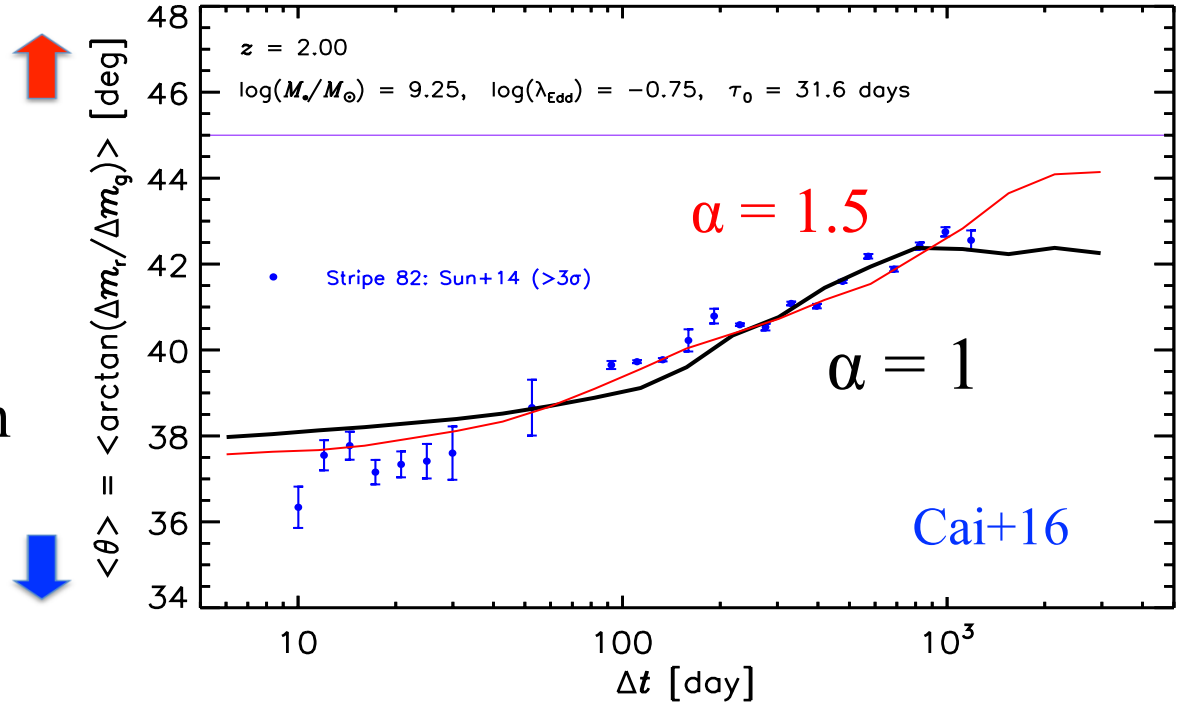
- empirically described by damped random walk
- damping timescale should depend on radius: $\tau = \tau_0 (r/r_{\rm in})^{\alpha}$

independent
local fluctuations



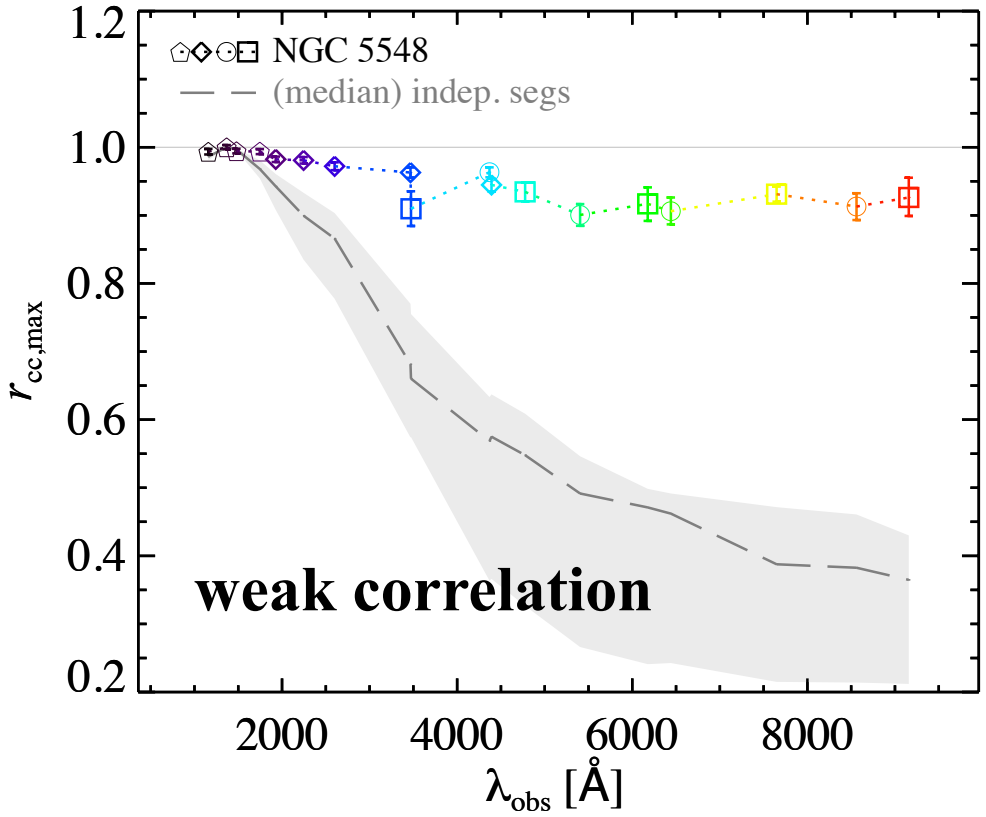
Dexter & Agol 11

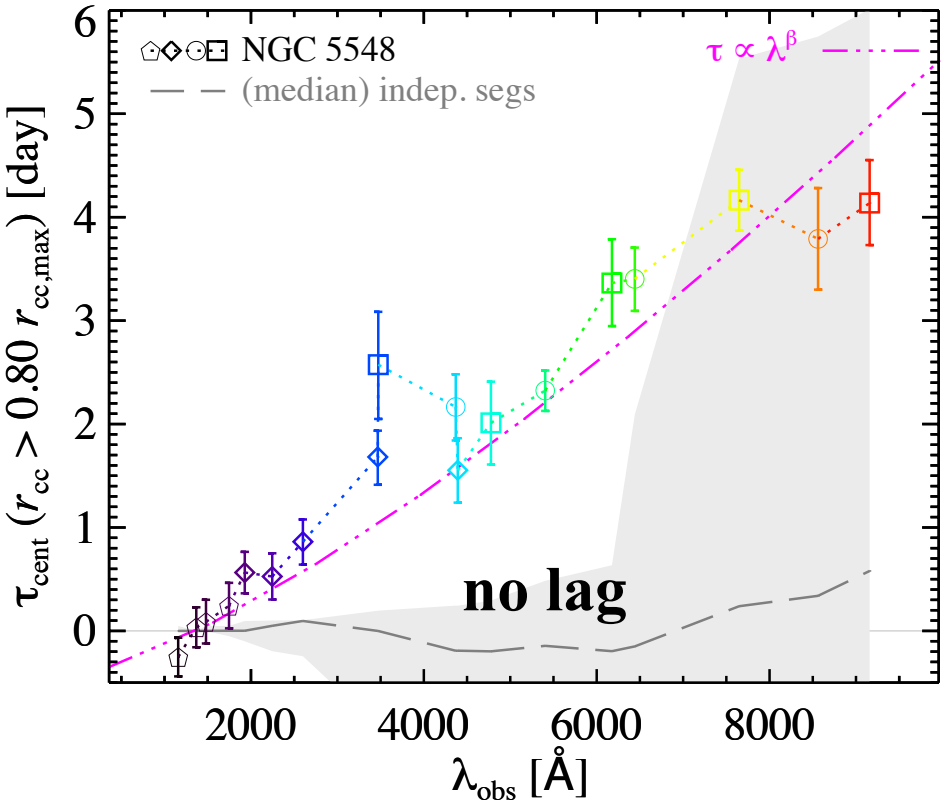
timescale-
dependent
color variation



But … weak correlation and no lag

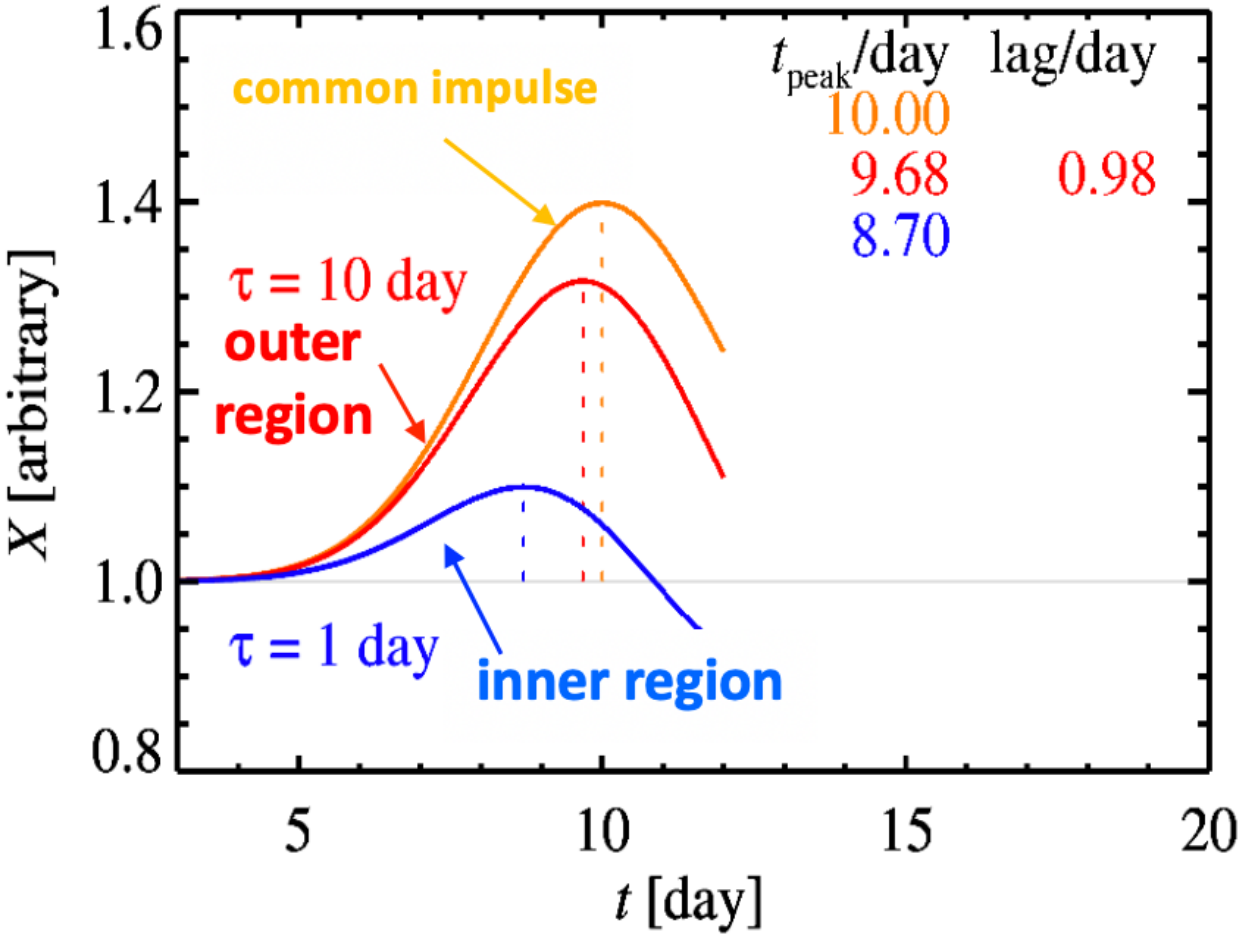
- old thermal models assume ***independent local*** **fluctuations**
  (Dexter & Agol 11, Ruan+14, Kokubo 15, Cai+16)





Speculate a large-scale common fluctuation

➢ introduce interaction between *local* and *large-scale* fluctuations (Cai+18)



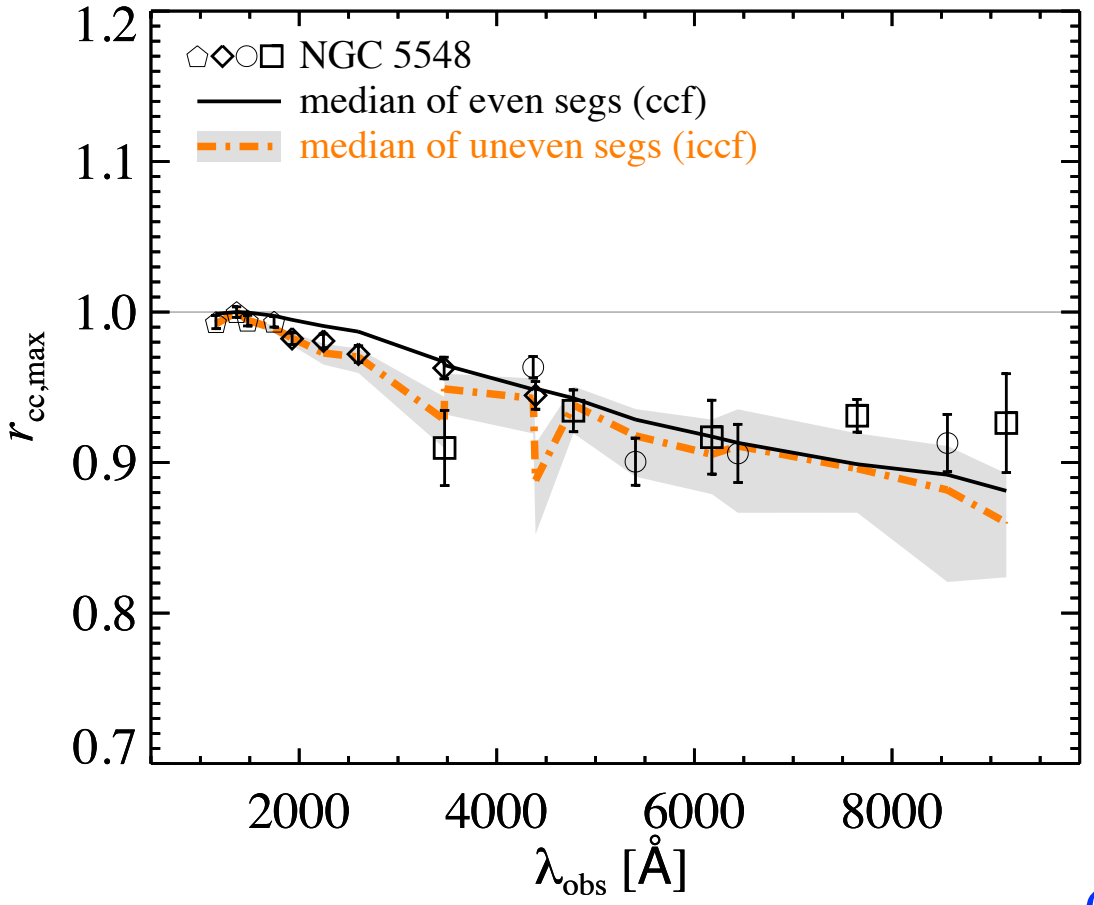
lag due to differential regression capability

- responding to common fluctuation, inner region with *smaller damping timescale* returns quicker
- **UV** from inner region leads **Optical**

New origin of the continuum lag!

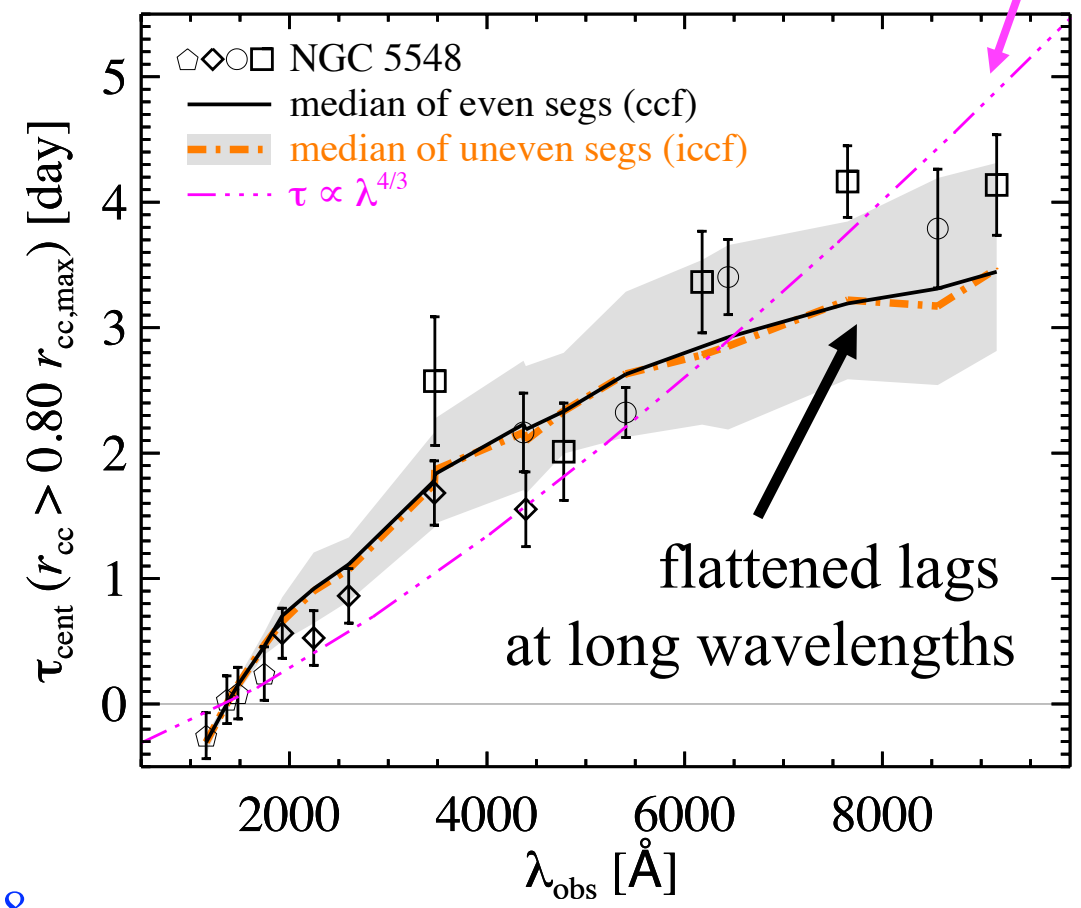
Achieve correlation and lag for NGC 5548

correlation



lag

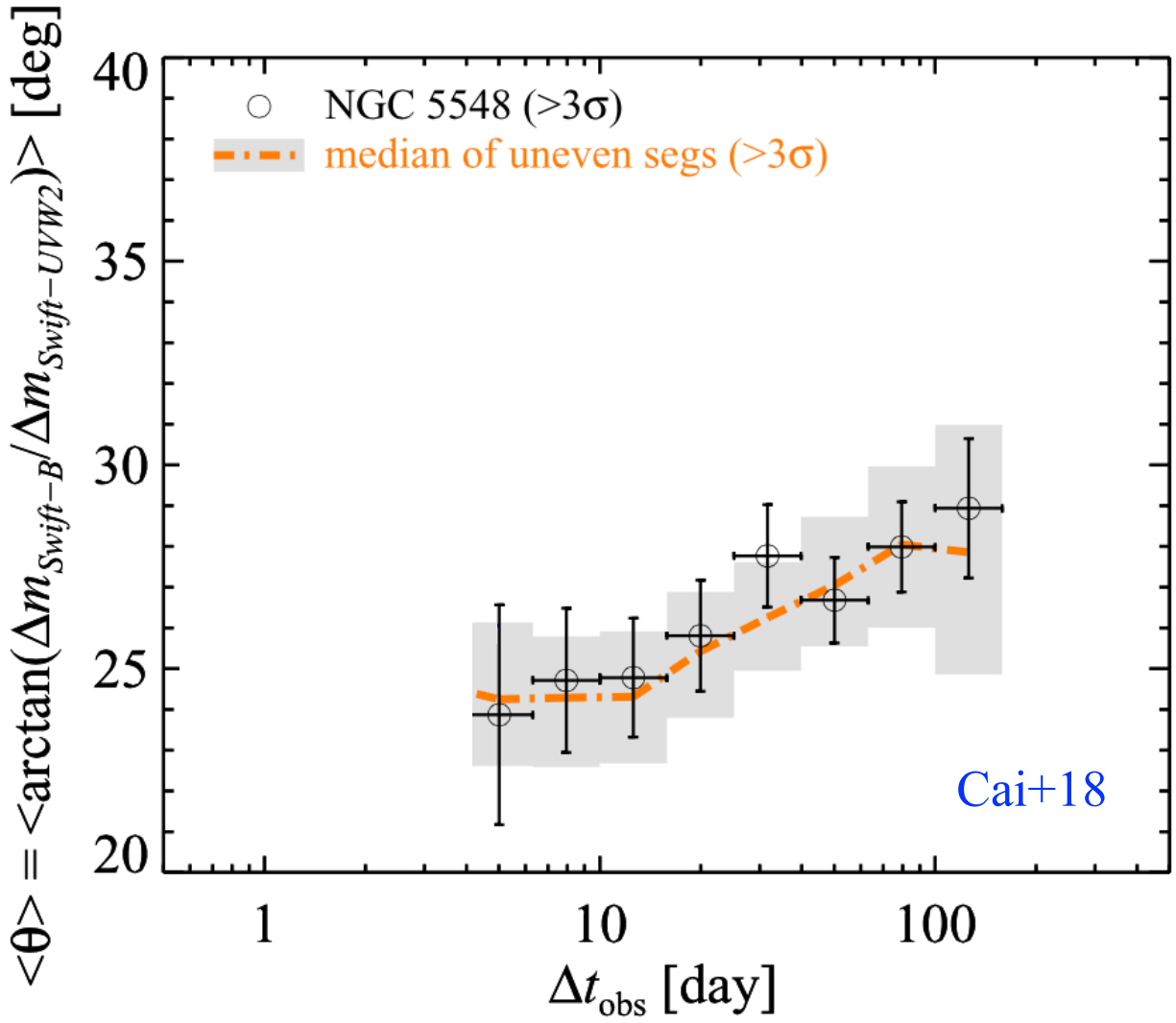
reprocessing



Cai+18

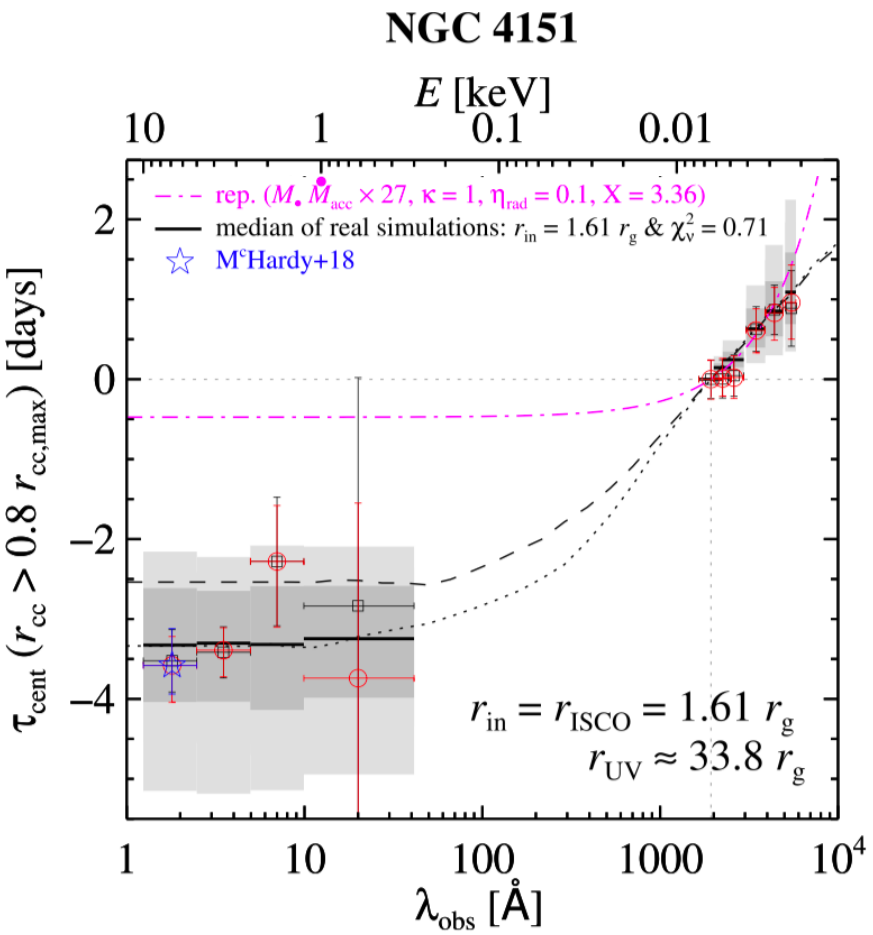
Still preserve timescale-dependent color variation

Swift
B vs UVW2



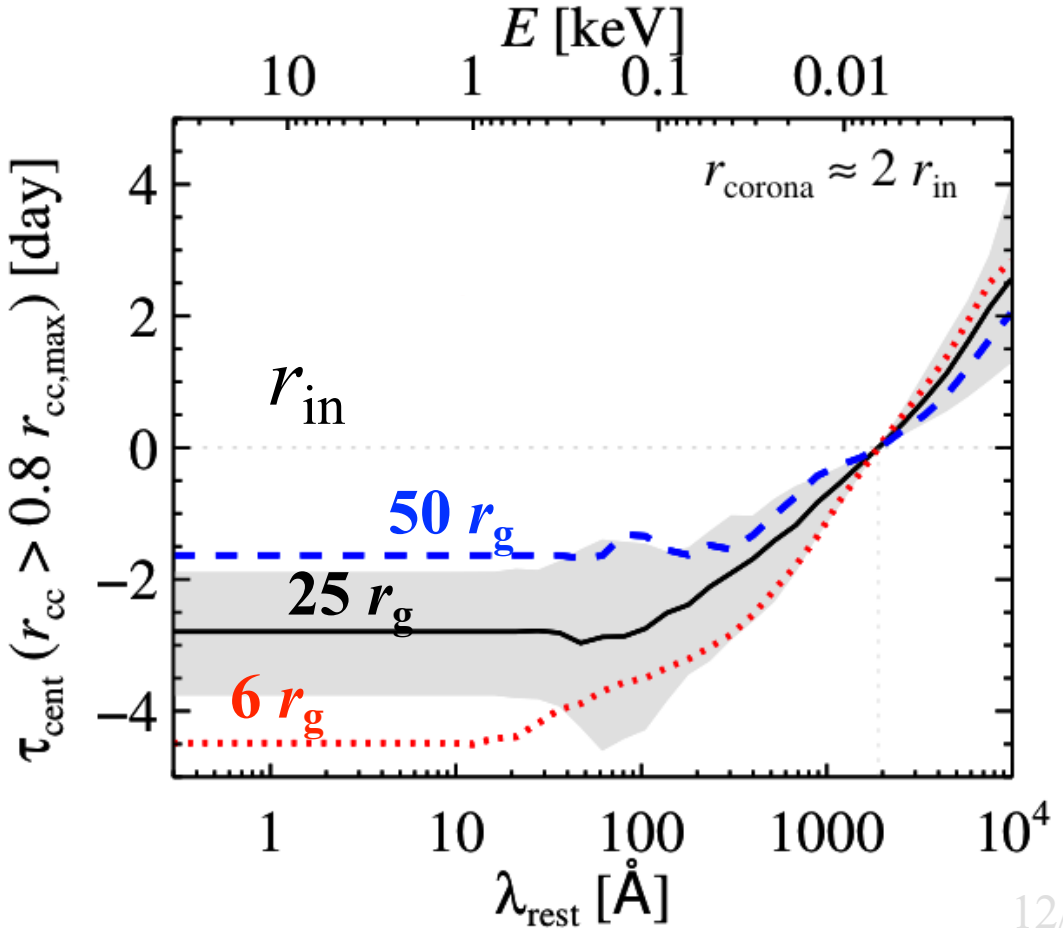
Account for the puzzling large UV to X-ray lag

- assuming corona heating is associated with turbulences in the inner disk (Kang+18 and see Kang's talk)



Cai+20

- larger r_{in} of cold disk, smaller UV to X-ray lag



Physical origin for the large-scale common fluctuation?

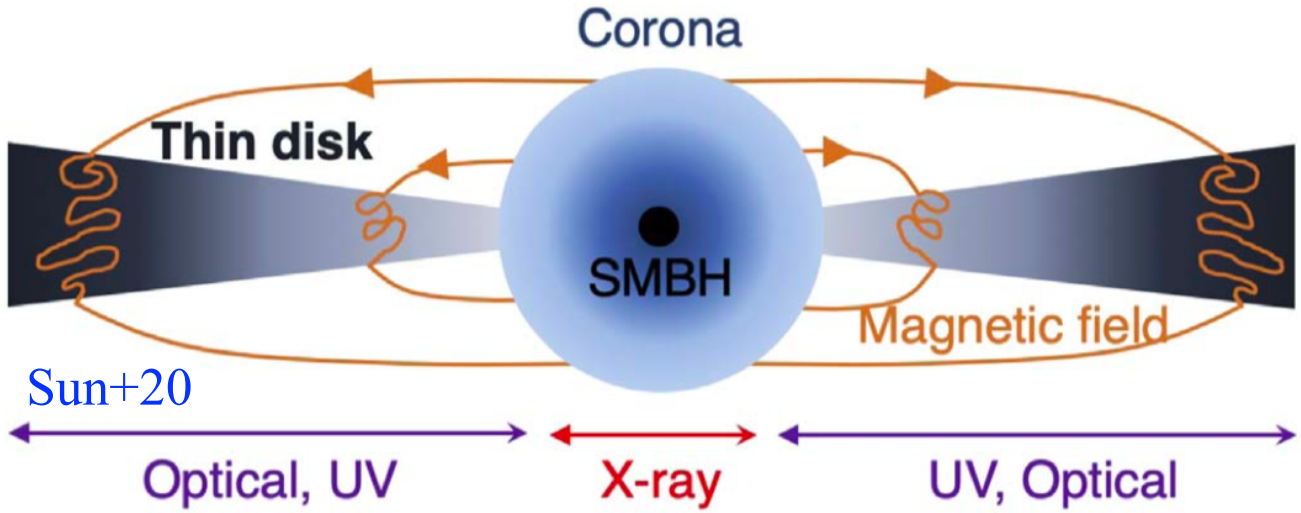
common fluctuation → magnetic corona heating

damping time → thermal timescale

common fluctuation

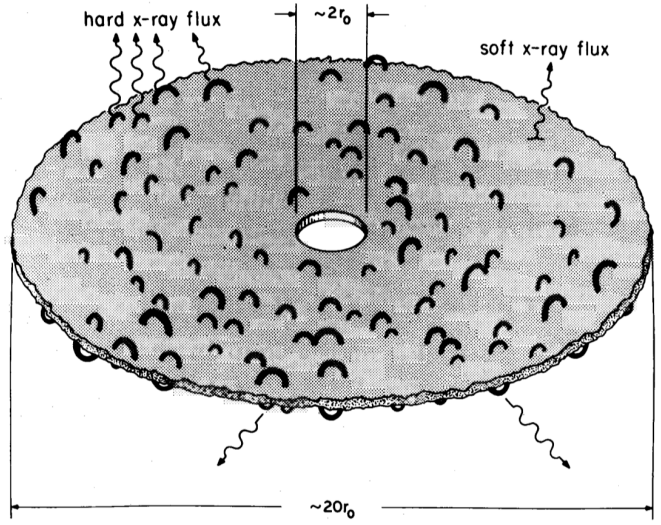
⇳

propagate quickly enough



possible physical origins

- propagation in corona atop disk
- ionized outflows/winds
- corona heats disk through X-ray photons (reprocessing)
- corona heats disk through **magnetic fields** (Sun+20)
- disk blanketed by **magnetic fields** (e.g., Galeev+79)
- ...



Galeev+79

Outline

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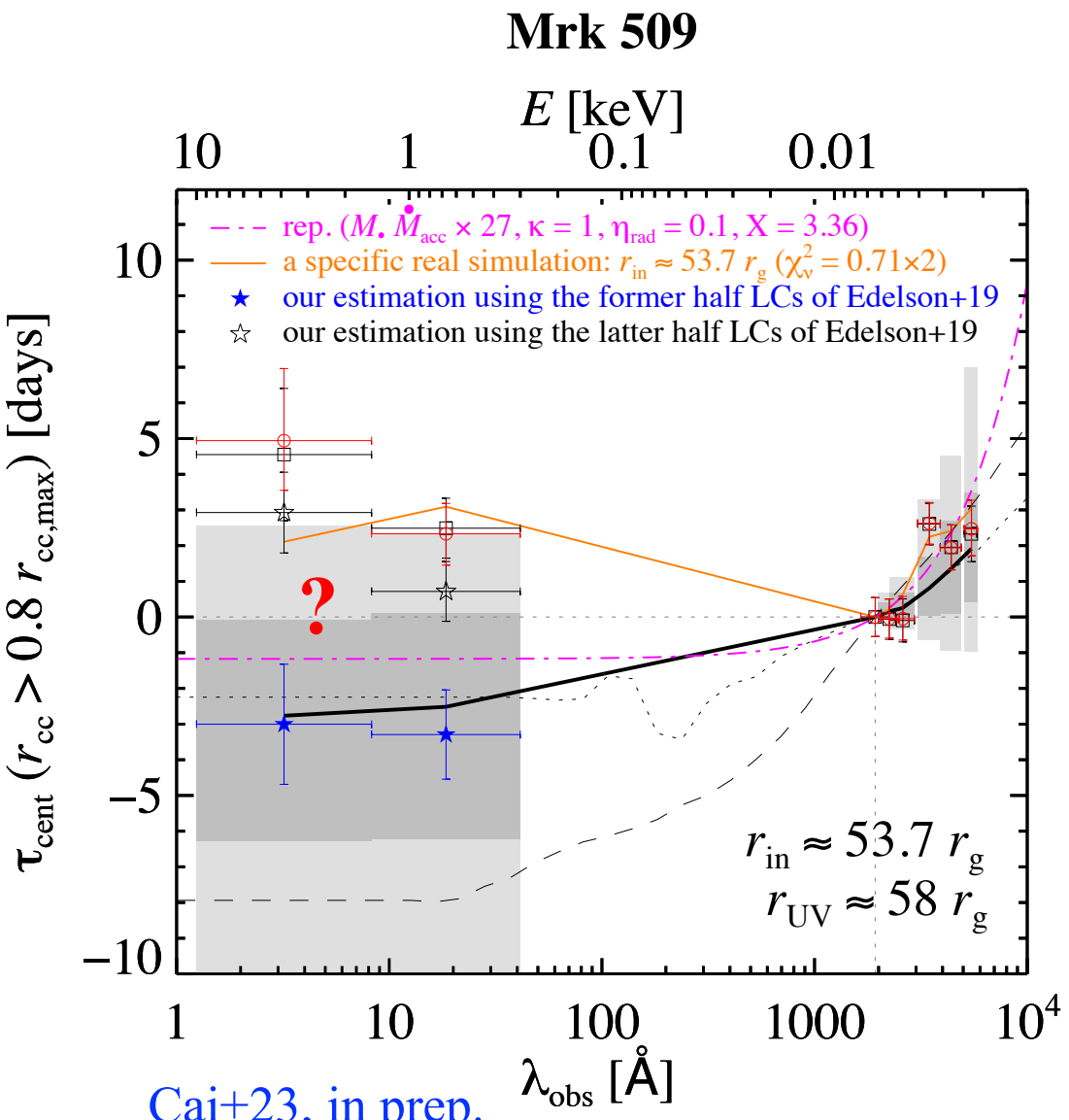
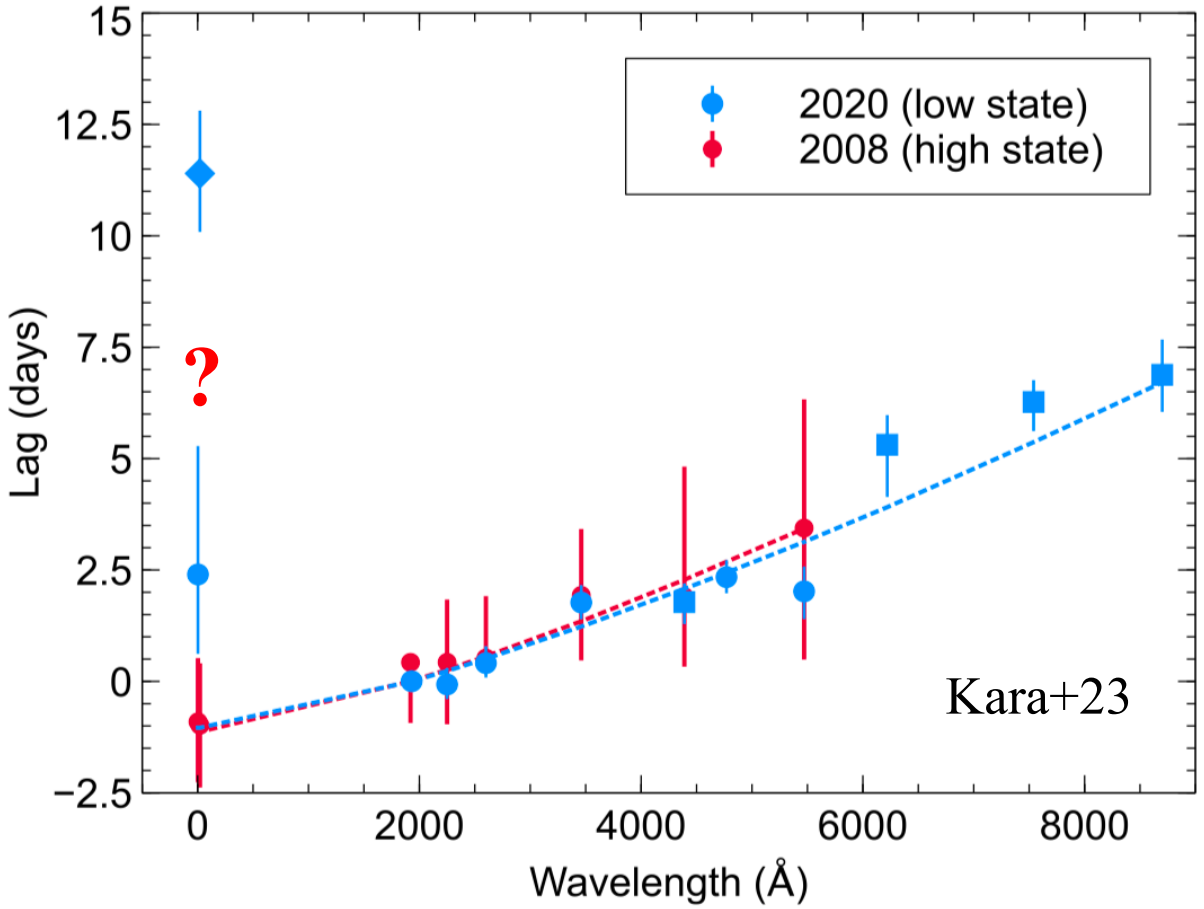
- **More questions & Summary**

UV leads X-ray? The role of X-ray heating?



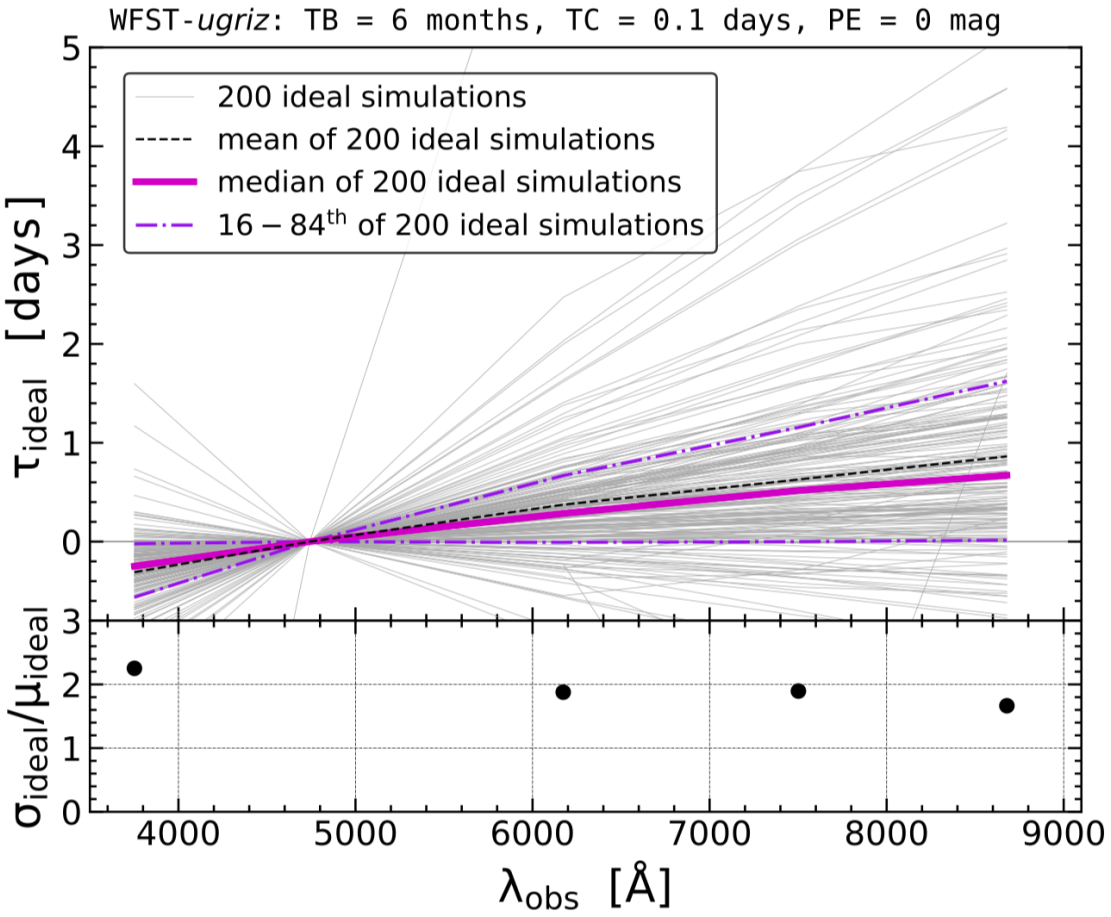
Cai+23, in prep.

Mrk 335
a faint X-ray corona



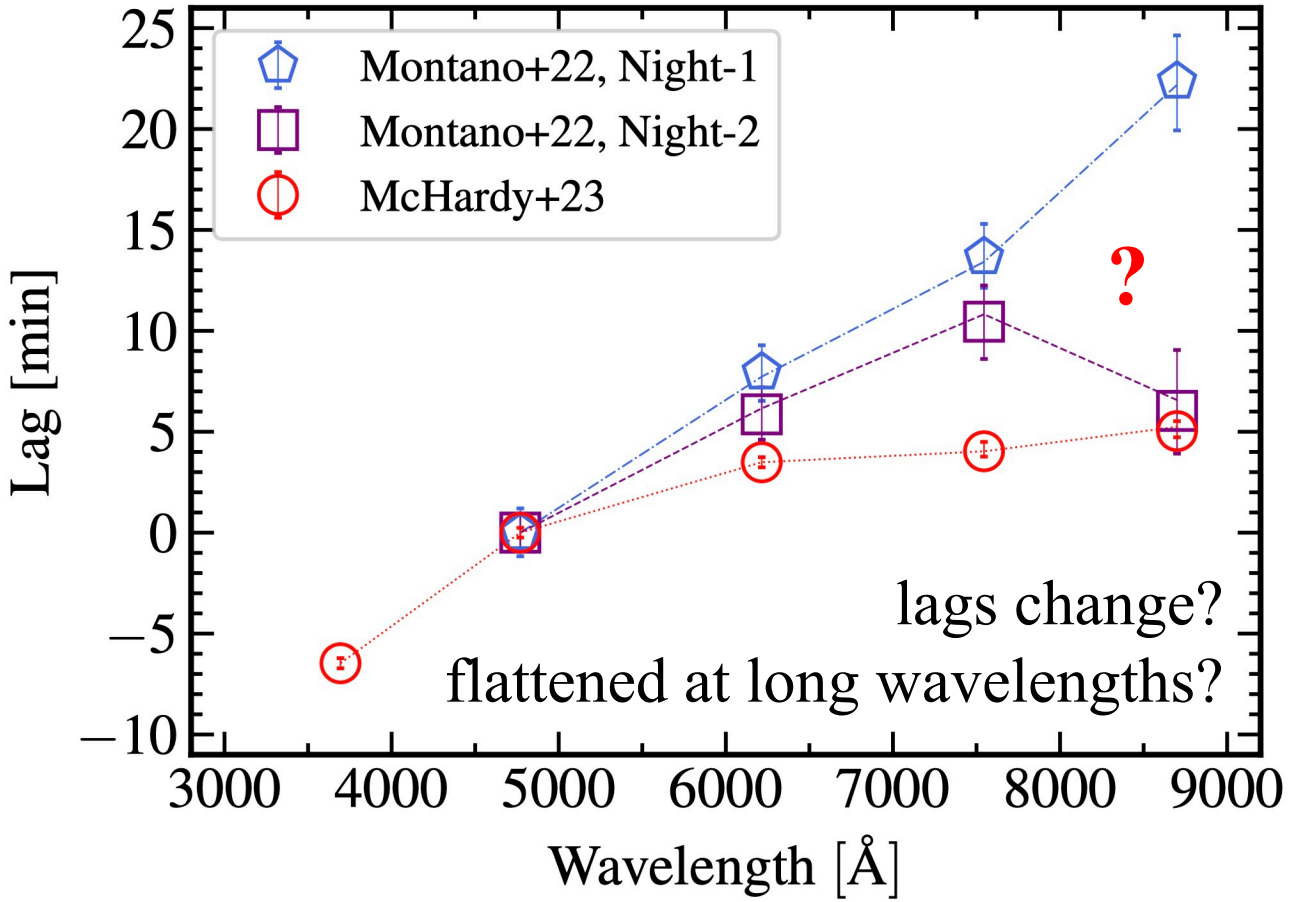
Randomness of lag? Or just observational issue?

random lags predicted for **NGC 5548**



Su+23, in prep.

NGC 4395



Summary

- **Thermal fluctuation scenario** could be responsible for the AGN continuum variations across UV/optical to X-ray.
- **New origin of the continuum lag**, as a result of differential regression between different disk regions.
- More observations on AGNs in the time-domain era would shed light on the nature of AGN UV/optical variability, e.g., the role of corona, randomness, etc.

Thanks for your attention!

Blue references cited in this talk

- timescale-dependent color variation
  - Sun et al. 2014, ApJ, 792, 54
  - Zhu et al. 2016, ApJ, 832, 75
  - Zhu et al. 2018, ApJ, 860, 29
  - Cai et al. 2019, SCPMA, 62, 069511
- relation between X-ray and UV
  - Sou et al. 2022, MNRAS, 512, 5511
- thermal fluctuation model (EUCLIA)
  - Cai et al. 2016, ApJ, 826, 7
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- corona-heated accretion-disk reprocessing (CHAR)
  - Sun et al. 2020, ApJ, 891, 178