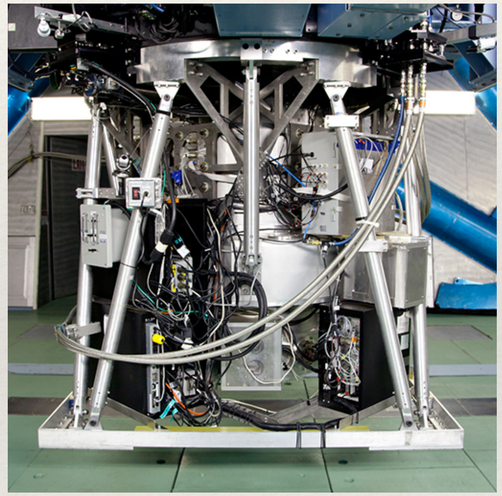
MOIRCS confirmation of super-Eddington accretion in an extremely X-ray loud radio quasar at z=3.4 in the eROSITA/eFEDS field

(Submitted to ApJ)

Sakiko Obuchi (小渕 紗希子)

Waseda University



Collaborators :

Kohei Ichikawa (Waseda University), Ingyin Zaw (NYUAD), Bovornpratch Vijarnwannaluk (ASIAA), Andrea Merloni (MPE), Yuxing Zhong (Waseda University), Satoshi Yamada (Tohoku University), Kosuke Takahashi (Tohoku University), Naoki Matsumoto (Tohoku University)

Motivation

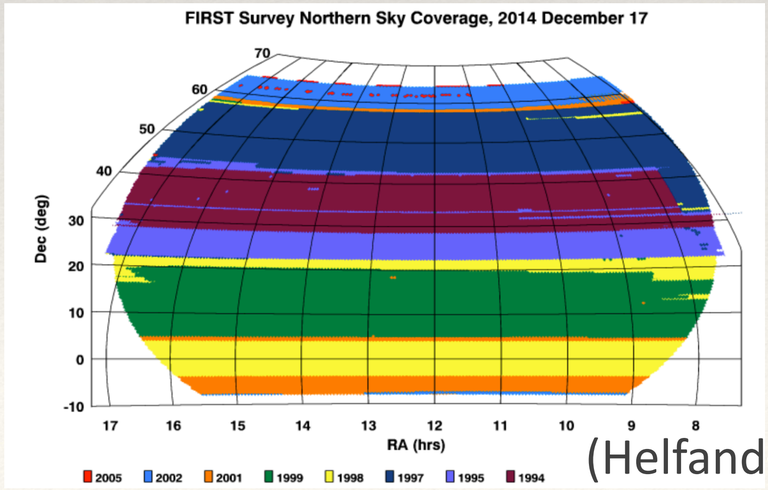
Credit: STScI

Radio AGN

- AGN : gas accreting event into supermassive black holes (SMBHs)
- 10% of AGN are **radio AGN = key population for AGN feedback**
- radio AGN : known to be low Eddington ratio in local universe (e.g., Ivezic+02, Ho 2008)

VLA/FIRST wide-area radio survey

(v=1.4 GHz, $f_{v,lim}$=1 mJy, >10^4 deg^2)

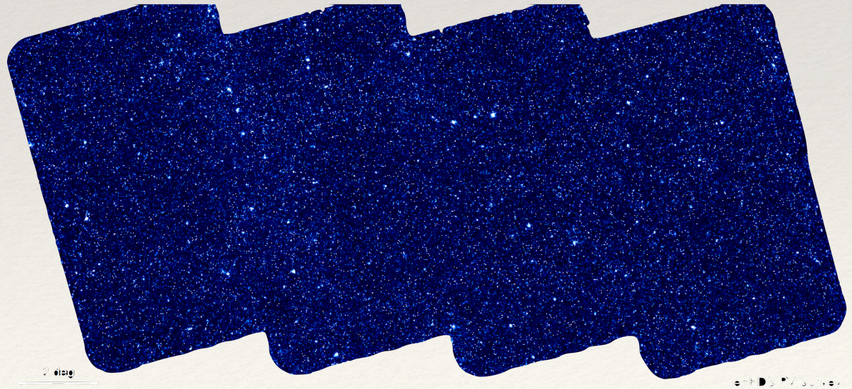


(Helfand+15)

×

eROSITA eFEDS wide-area X-ray survey

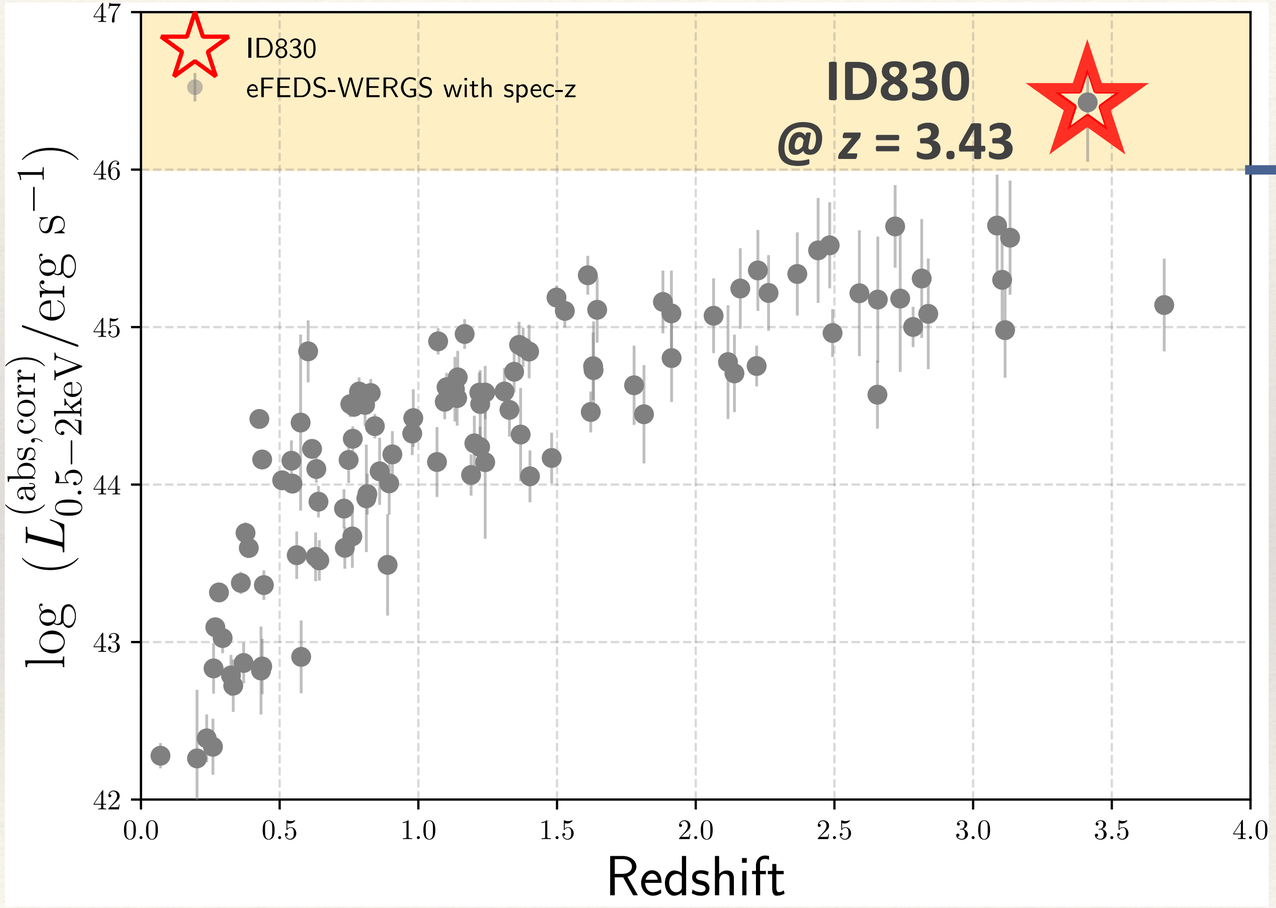
(0.5-2 keV band, 140 deg^2)



(Brunner+22)

Discovery of extremely X-ray luminous radio AGN

From the eFEDS-WERGS catalog (Ichikawa+23), we selected spec-*z* objects with $L_{0.5\text{-}2\mathrm{keV}} > 10^{46.0}$ erg s^{-1}.



$$L_{0.5-2\,\mathrm{keV}} > 10^{46}\,\mathrm{erg\,s^{-1}}$$

↓

$L_{\mathrm{bol,X}} \approx 10^{48}\,\mathrm{erg\,s^{-1}}$ (Marconi et al. 2004)

↓ If we assume the mass-limit $M_{\mathrm{BH}} = 10^{10}\,M_{\odot}$ ...

↓

$\lambda_{\mathrm{Edd}} \approx 1$

A prominent candidate of super-Eddington AGN w/ radio-jet!

M_{BH} measurement from Subaru/MOIRCS J-band spectrum

We conducted *J*-band spectroscopic observations to cover the MgIIλ2800 emission line

(S25A-0040N; 2025/3/15)

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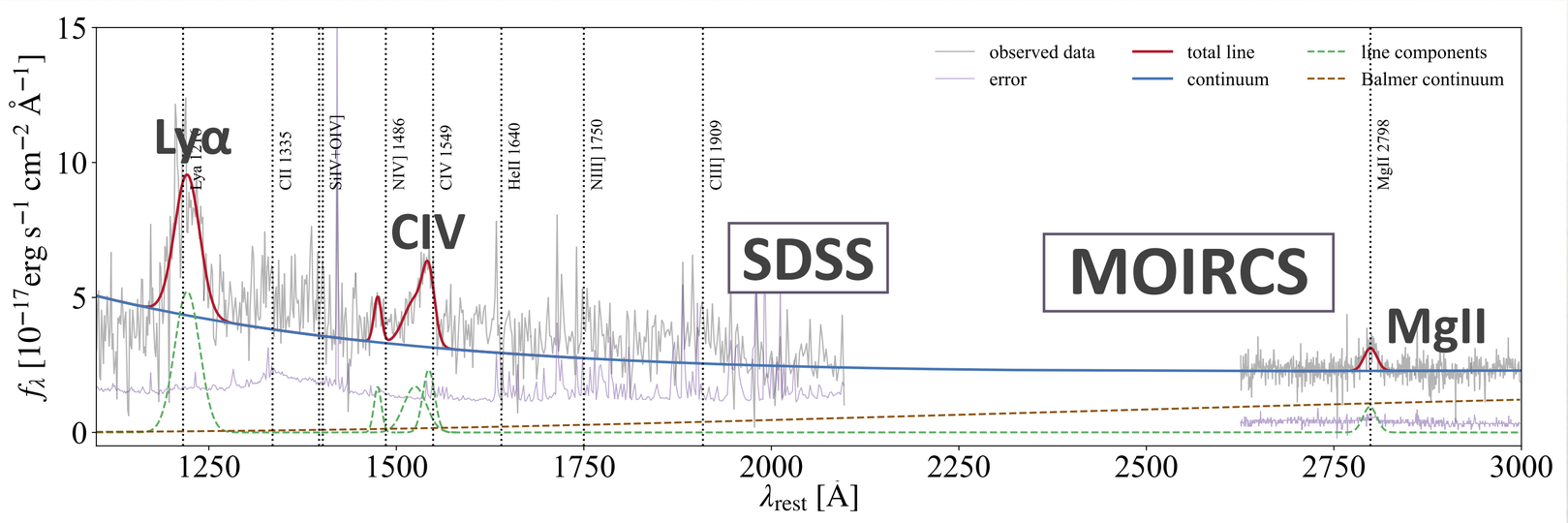

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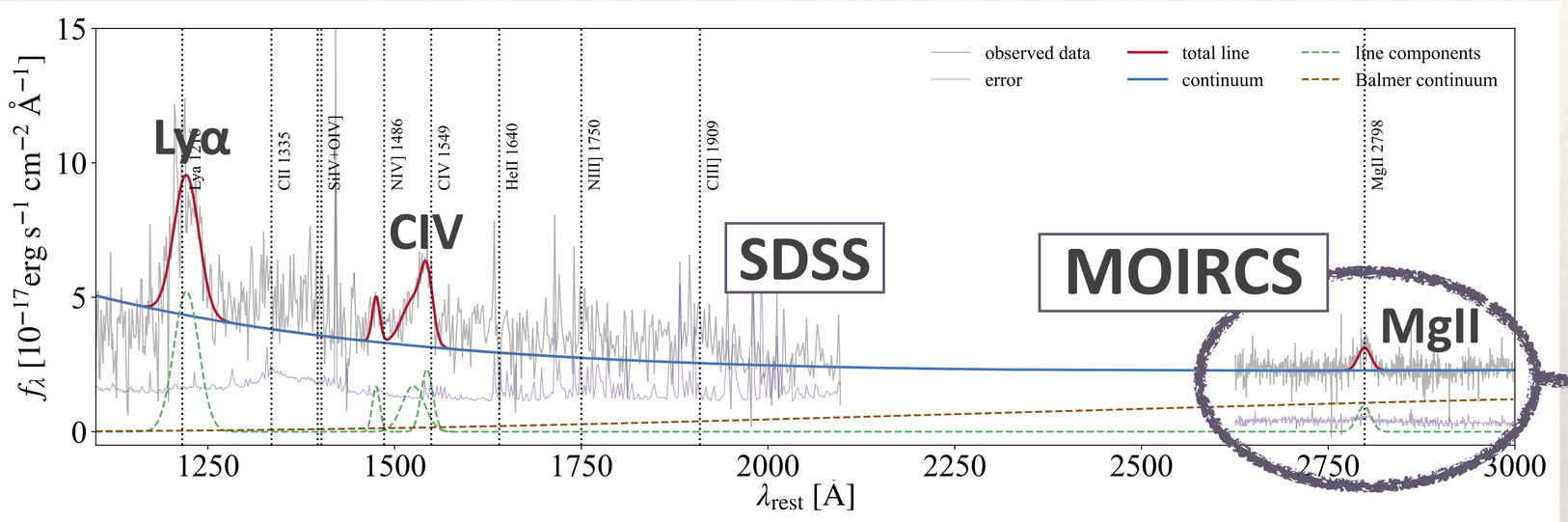

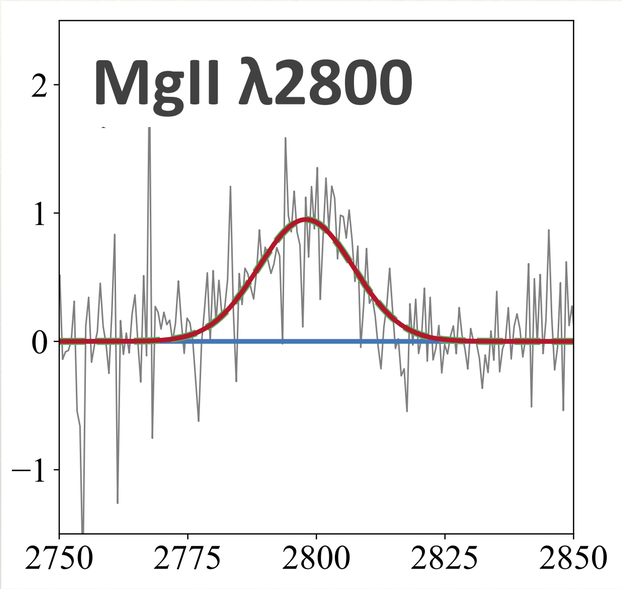

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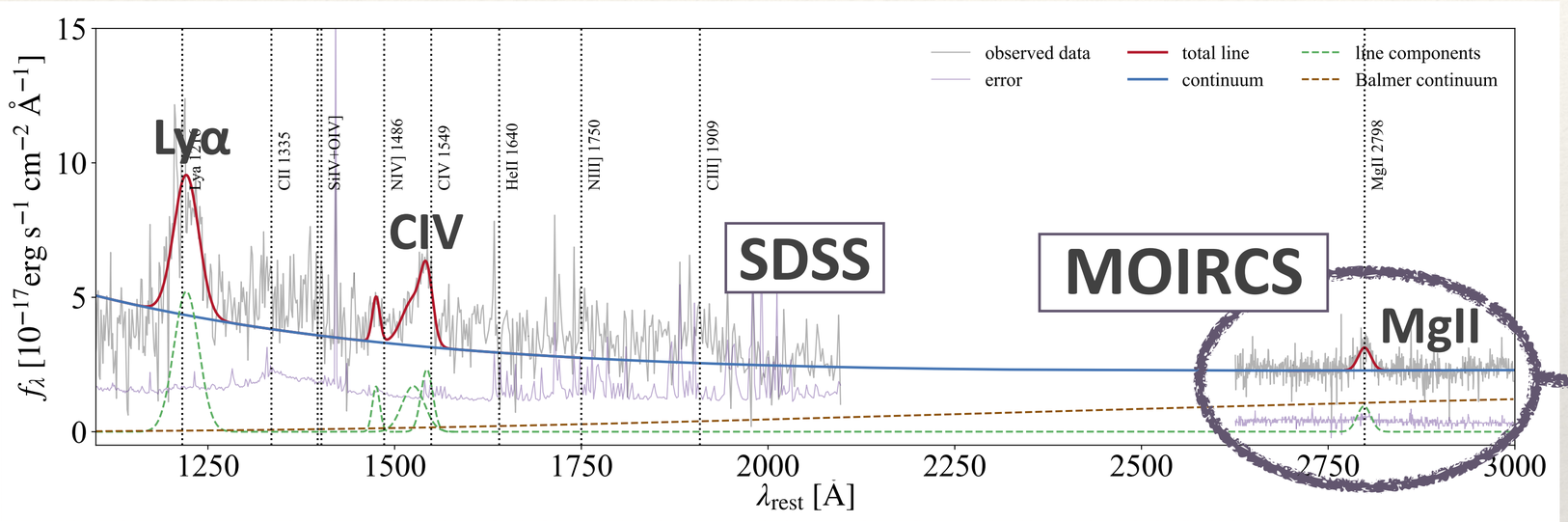

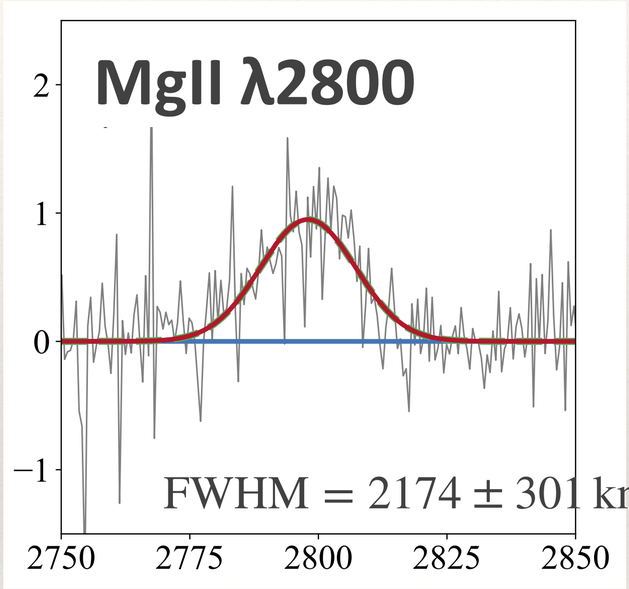

$$M_{\rm BH} = (4.40 \pm 0.72) \times 10^8\, M_\odot$$

$$L_{\rm bol,3000Å} = (7.62 \pm 0.31) \times 10^{46}\, {\rm erg\ s^{-1}}$$

(*A*v=0.386, *R*v=3.27 ; Gordon+16)

$$\lambda_{\rm Edd} = 1.44 \pm 0.24$$

super-Eddington!

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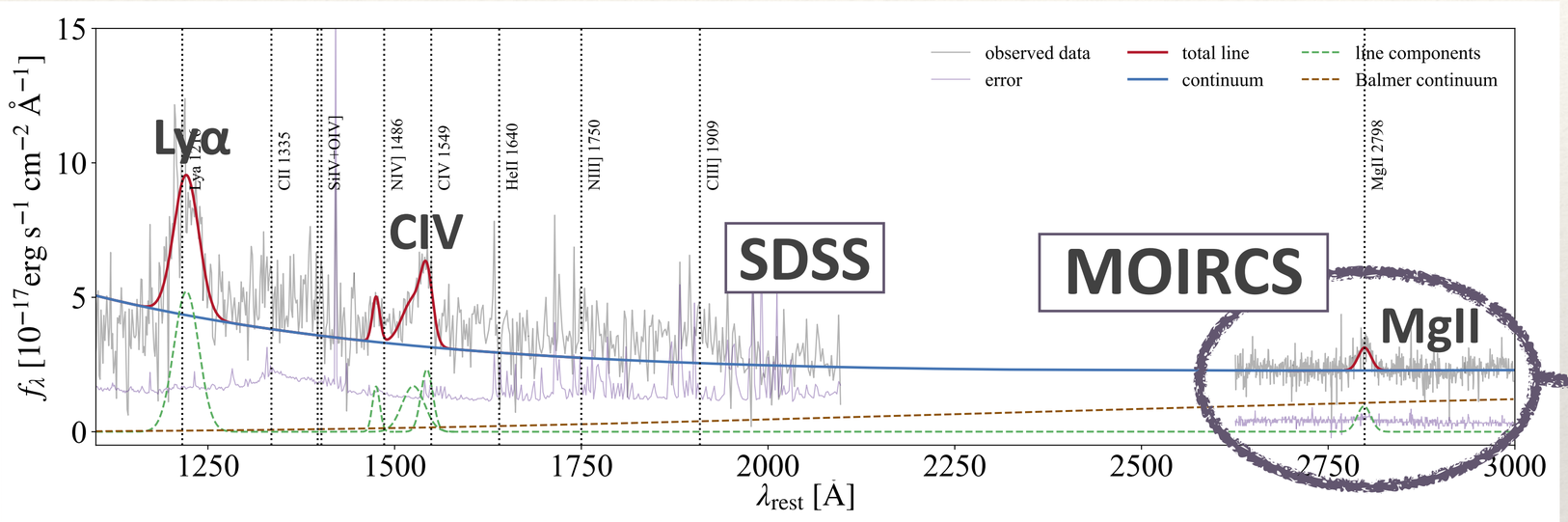

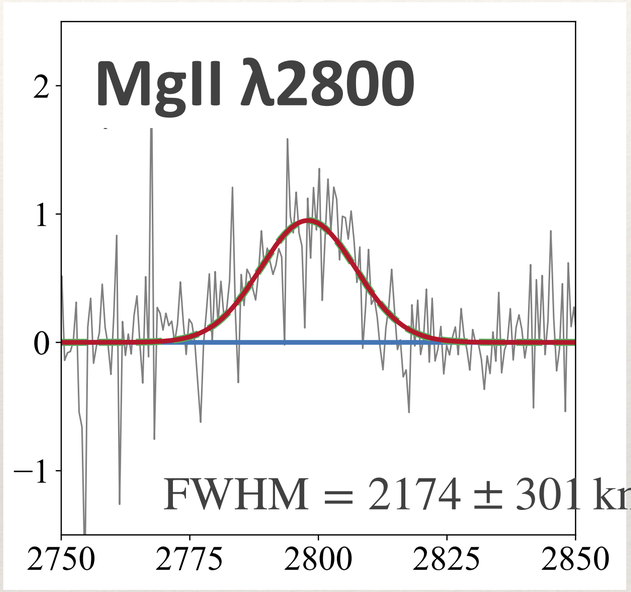

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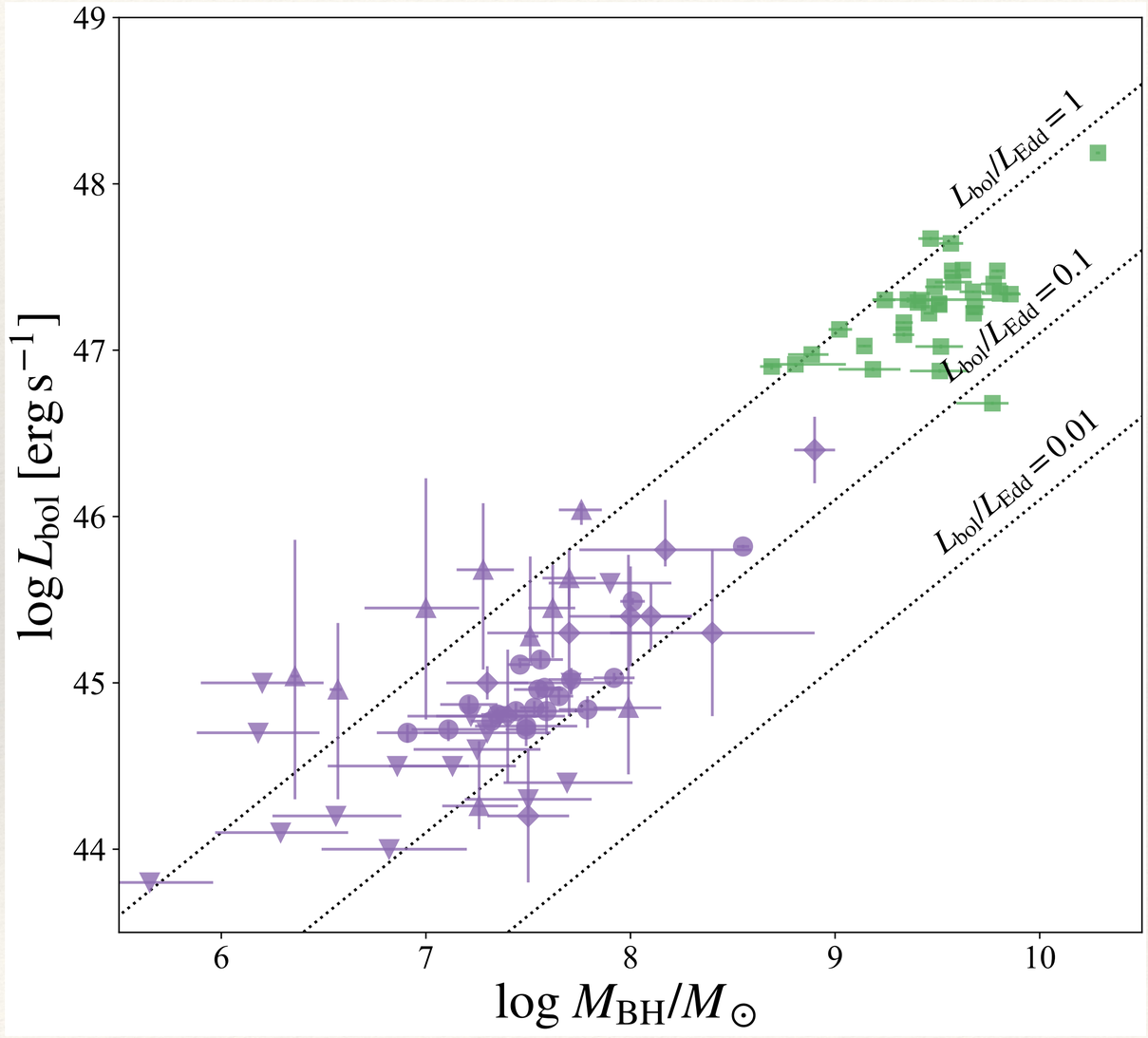
➡ $\lambda_{\rm Edd} = 1.44 \pm 0.24$ **super-Eddington!**

AGN bolometric luminosity: X-ray-derived vs UV-derived



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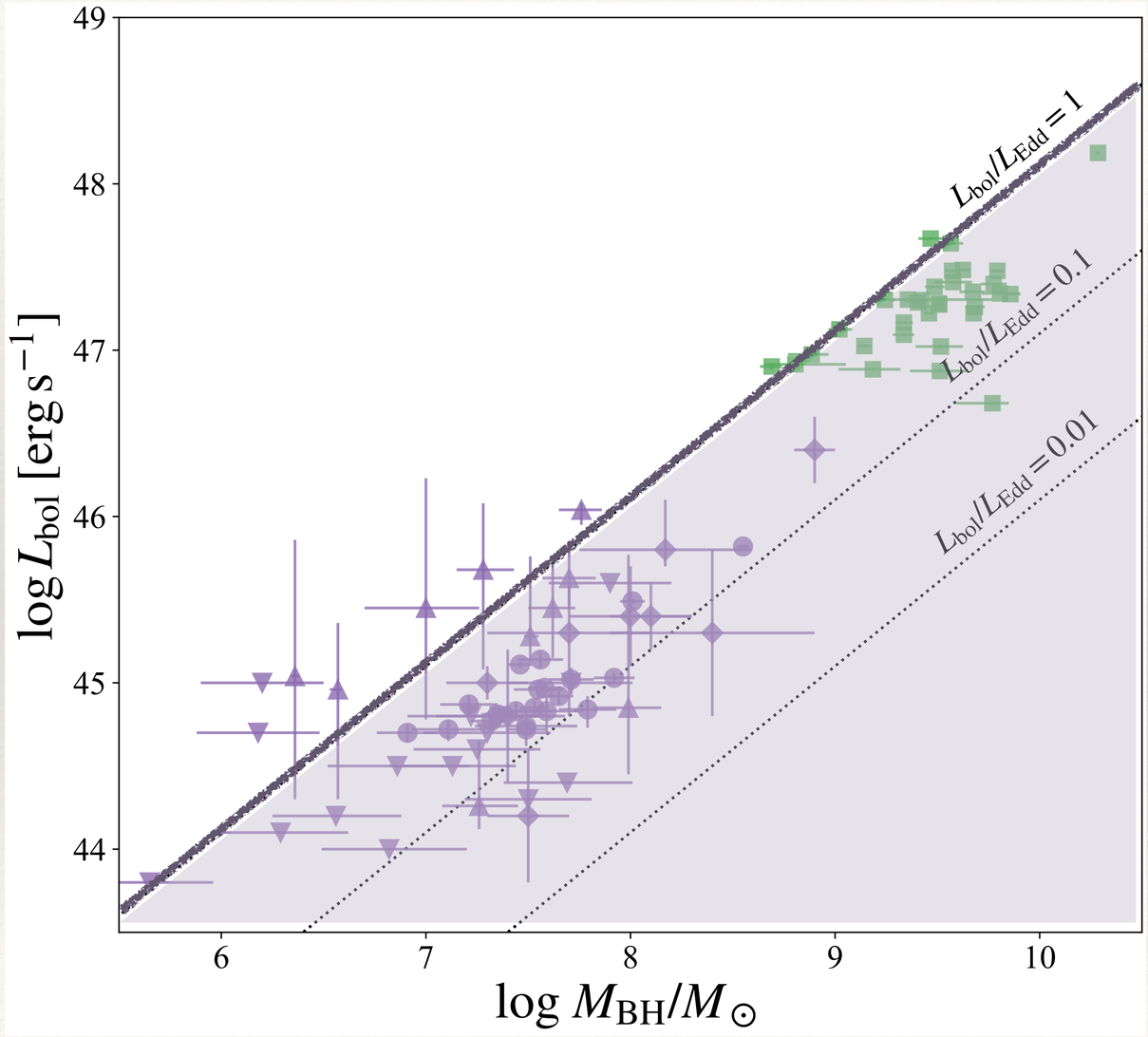

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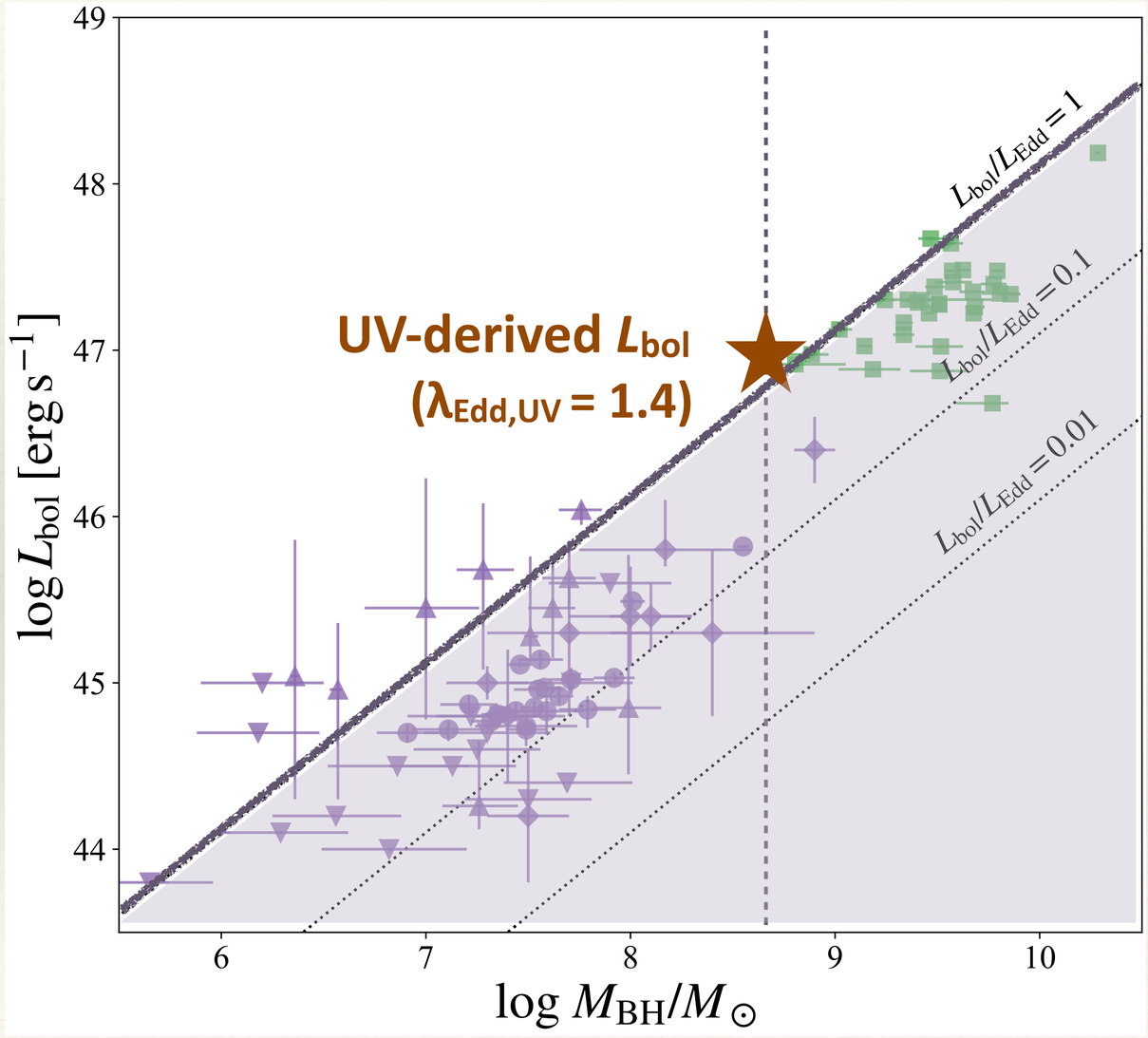

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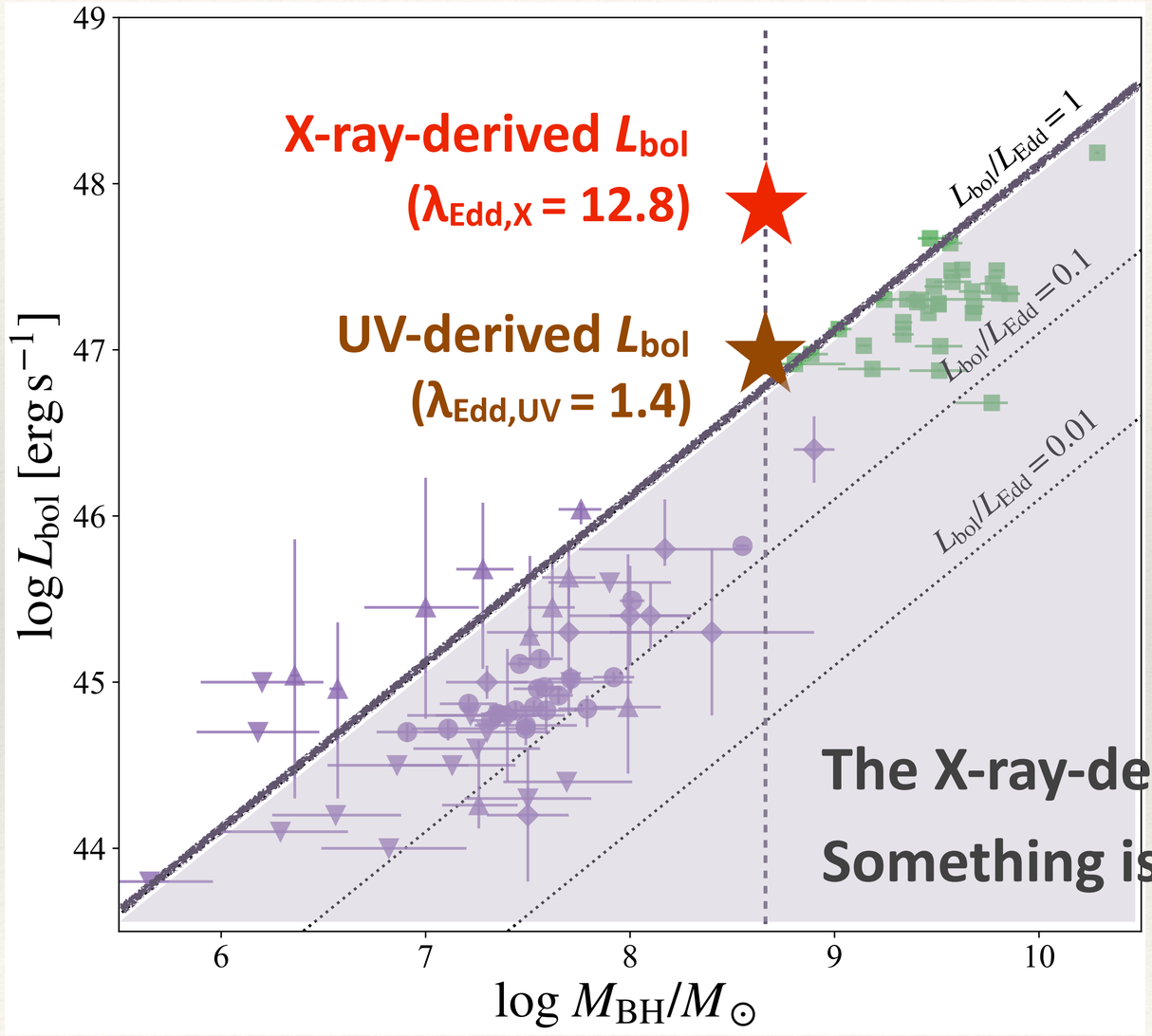

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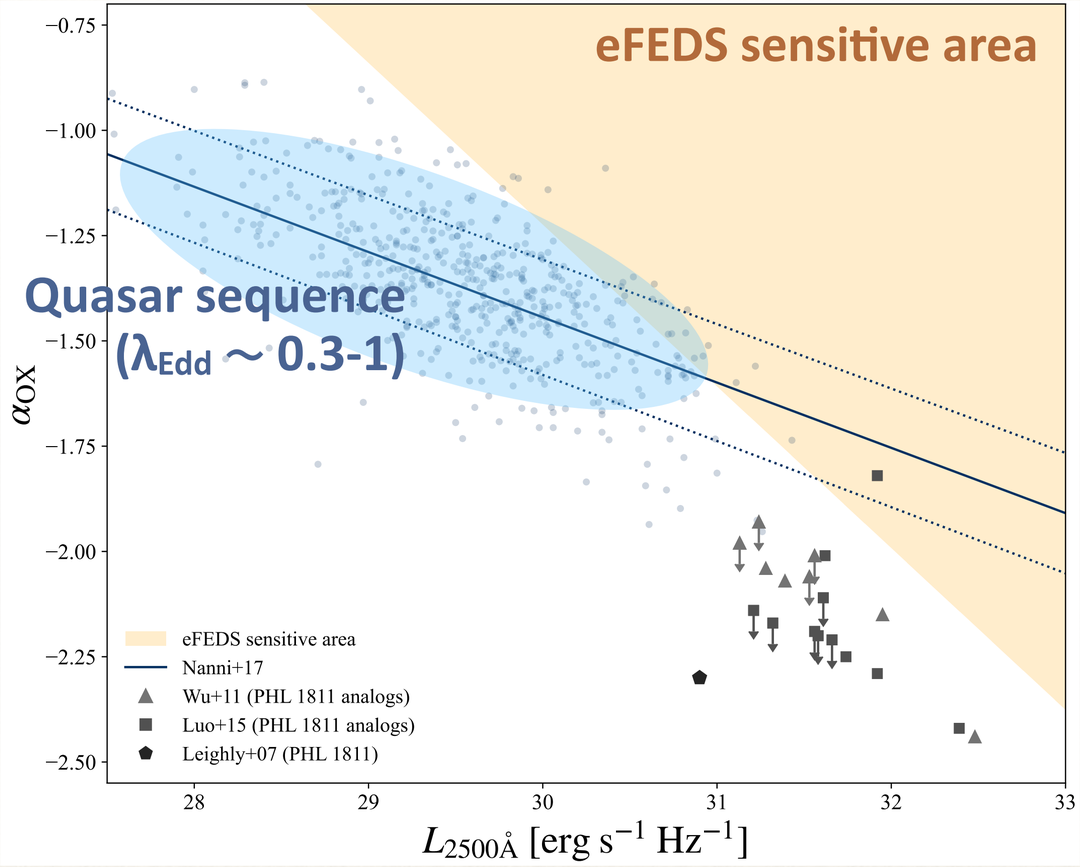
The X-ray-derived and UV-derived L_{bol} are inconsistent…

Something is happening in this source??

How unique is this X-ray brightness? — X-ray properties : α_{OX} vs $L_{2500Å}$

α_{OX} : the ratio of UV to X-ray luminosities (Tananbaum et al. 1979)



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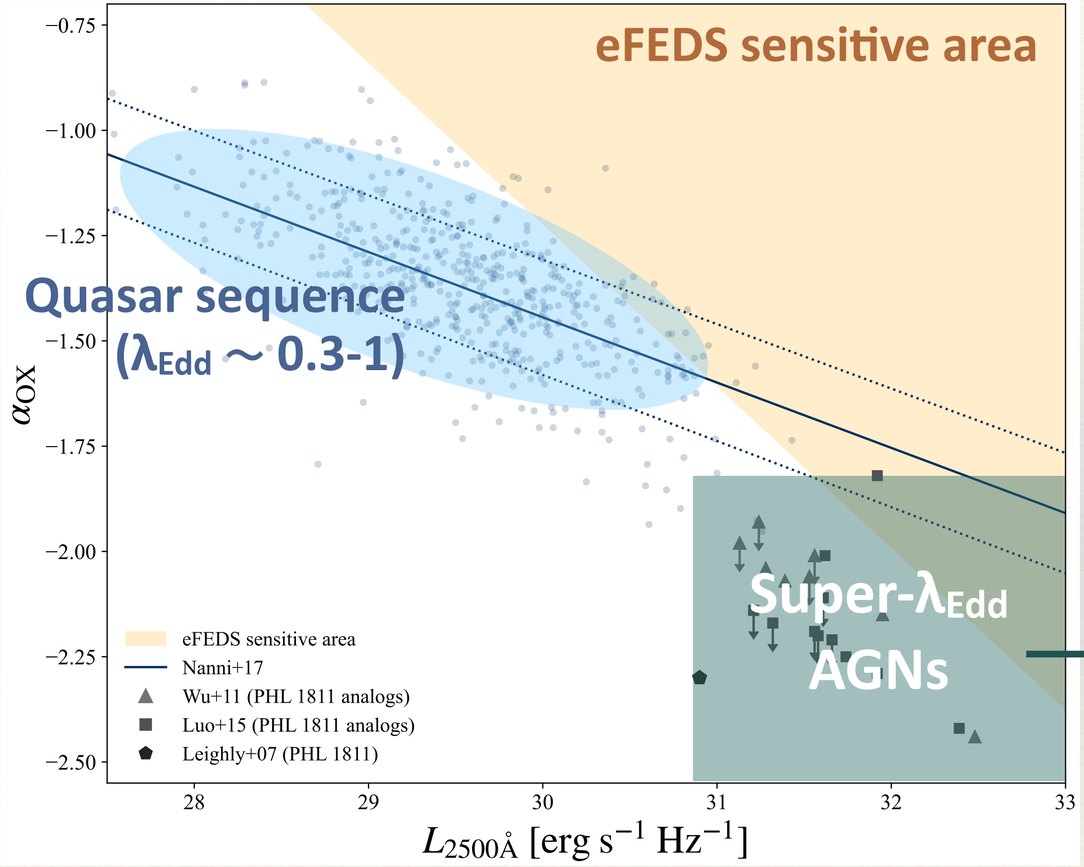

→ typically X-ray weak

$(\alpha_{OX} \lesssim -1.8)$

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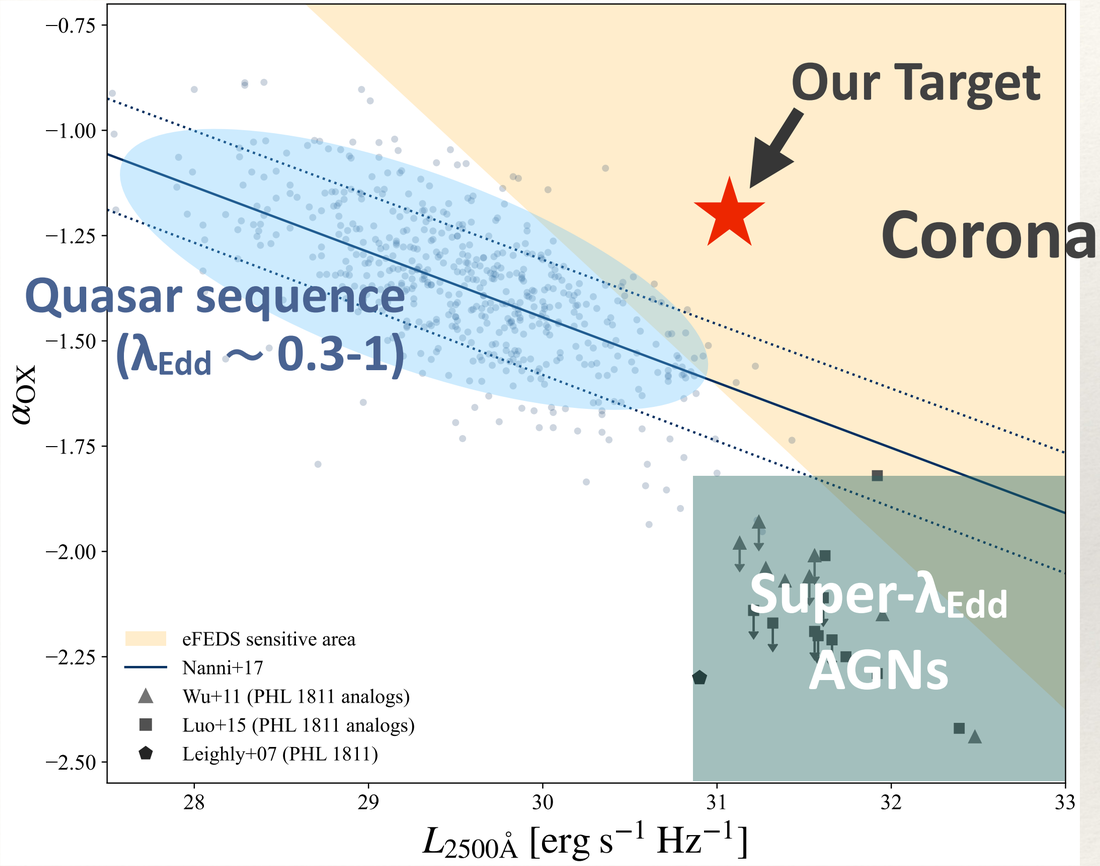


Corona is unquenched!

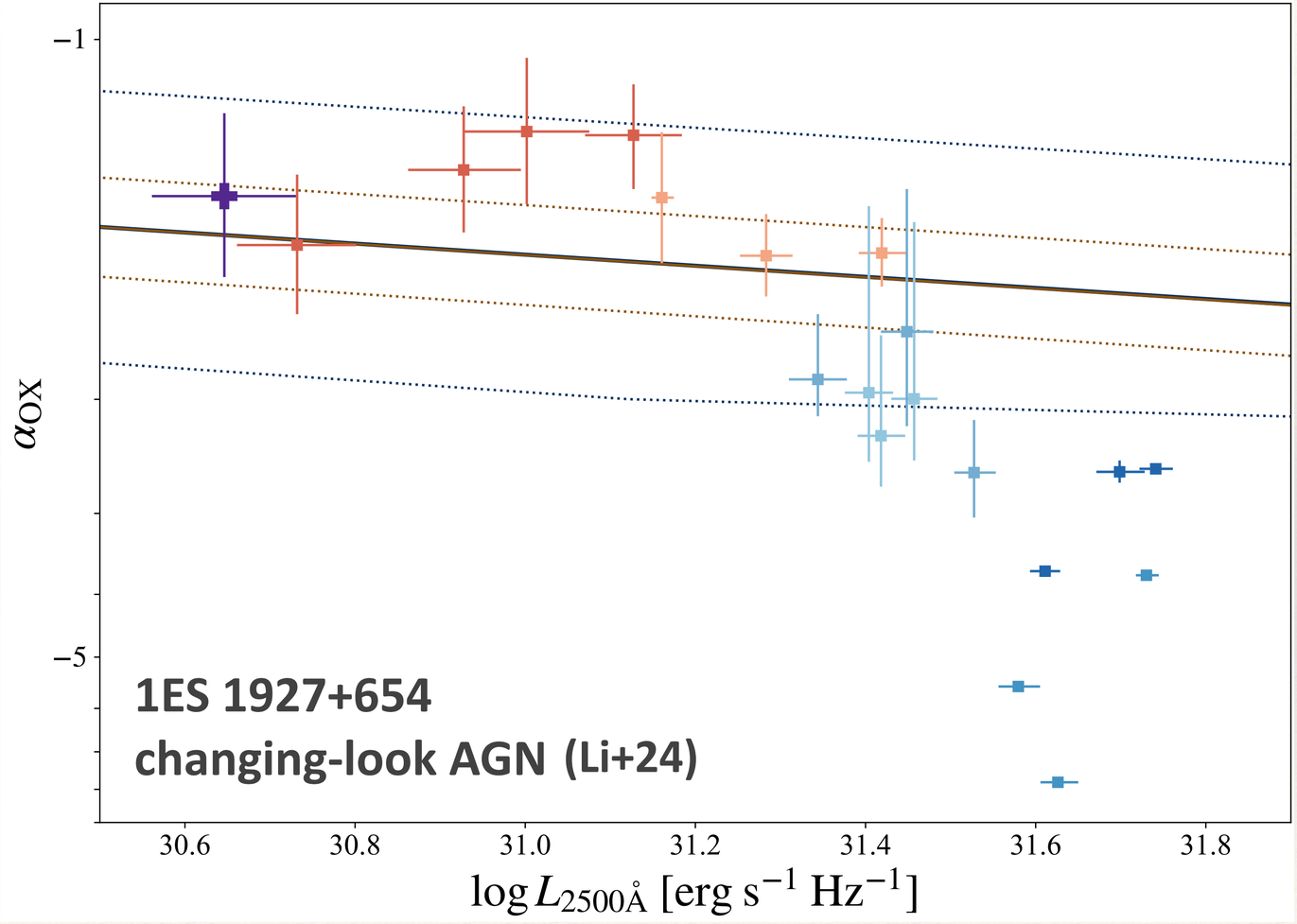
- higher α_{OX} at super-Eddington
- Opposite trend compared to “X-ray deficit”

(Kawaguchi+00, Luo+13,+15)

This super-λ_{Edd} AGN has a different mechanism compared to typical super-λ_{Edd} AGNs?

What causes the X-ray excess? — α_{OX} transition with an accretion burst

The dramatic flux variation of a changing-look AGN driven by an accretion burst shows **α_{OX} transition.**



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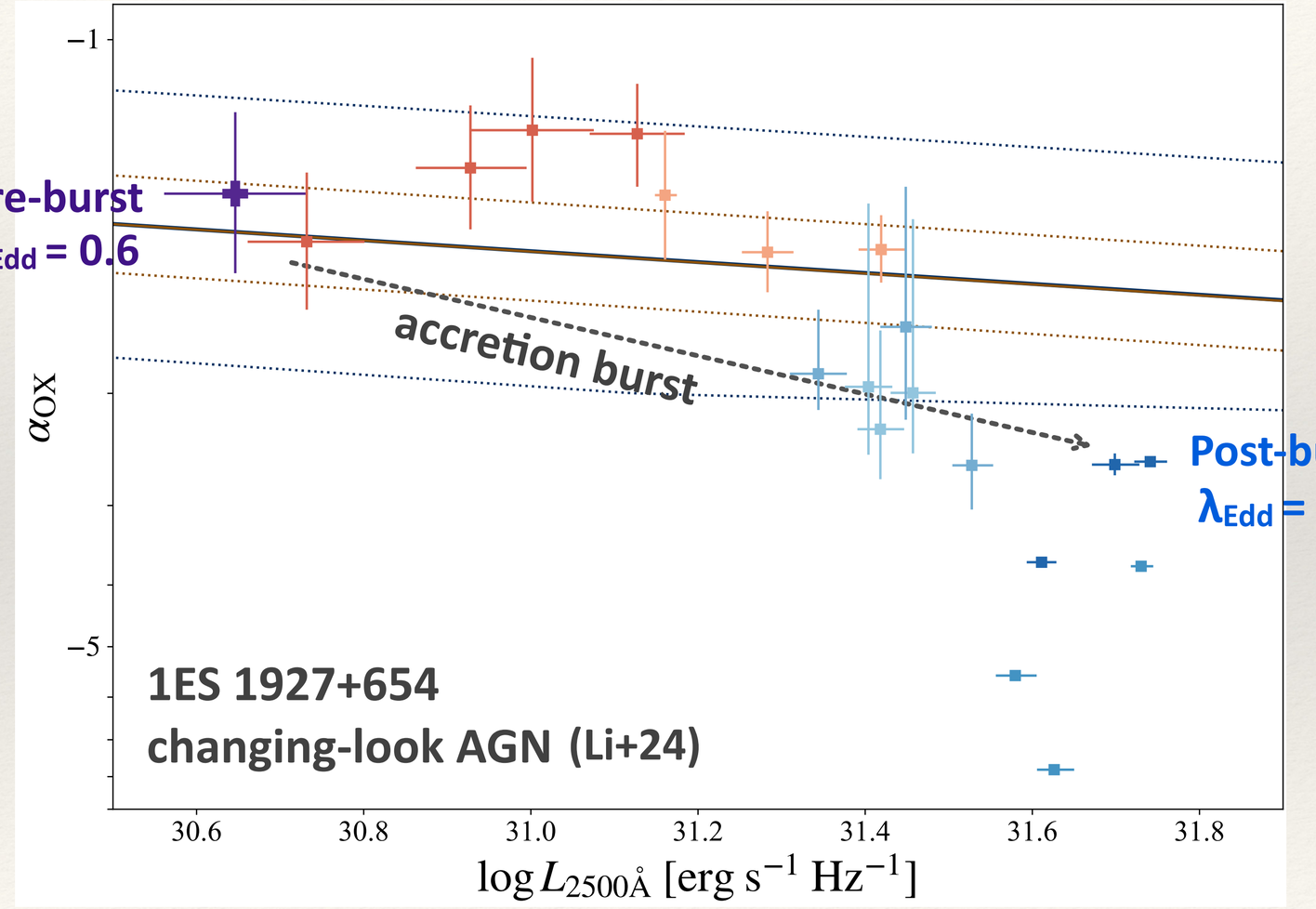

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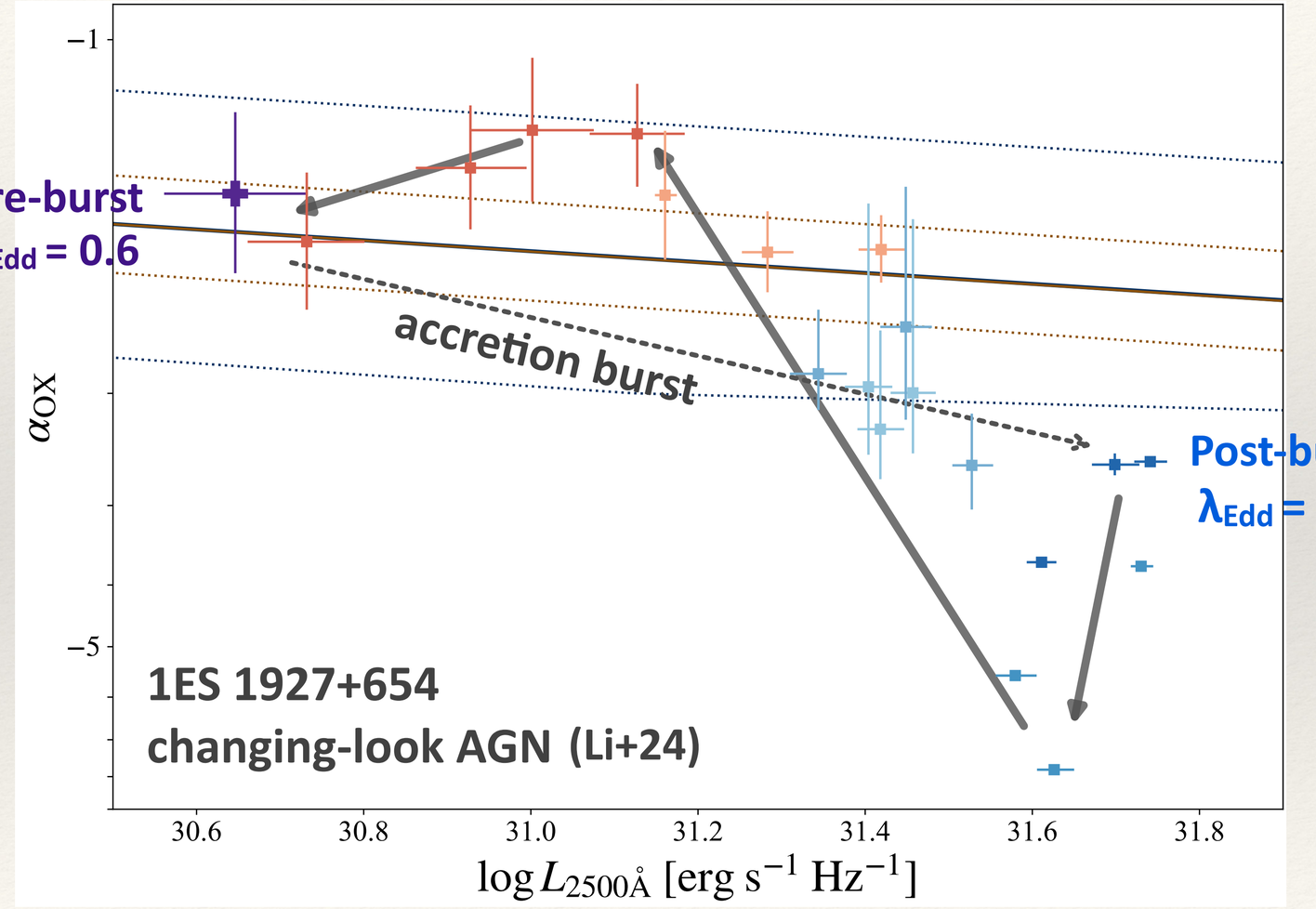

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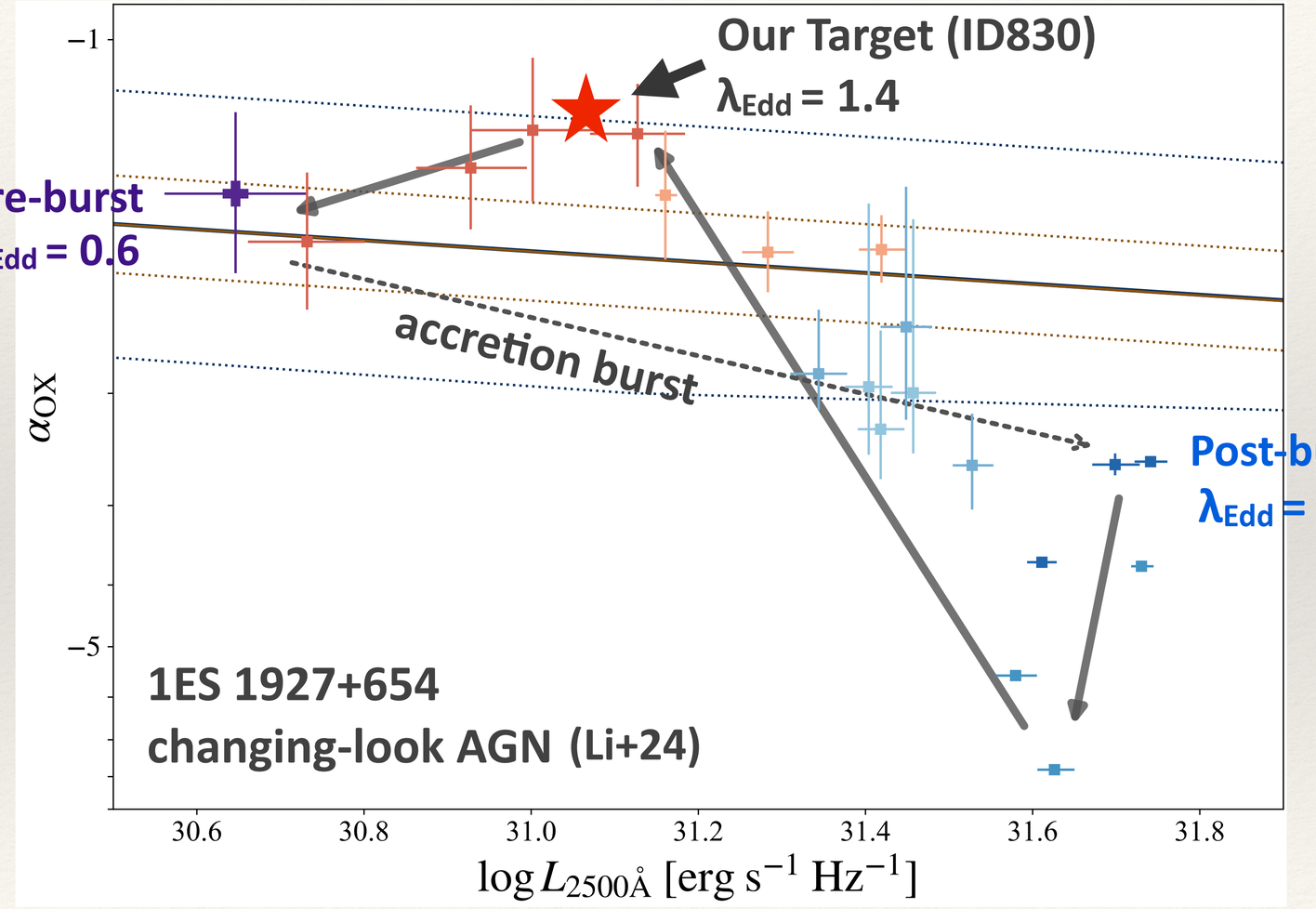

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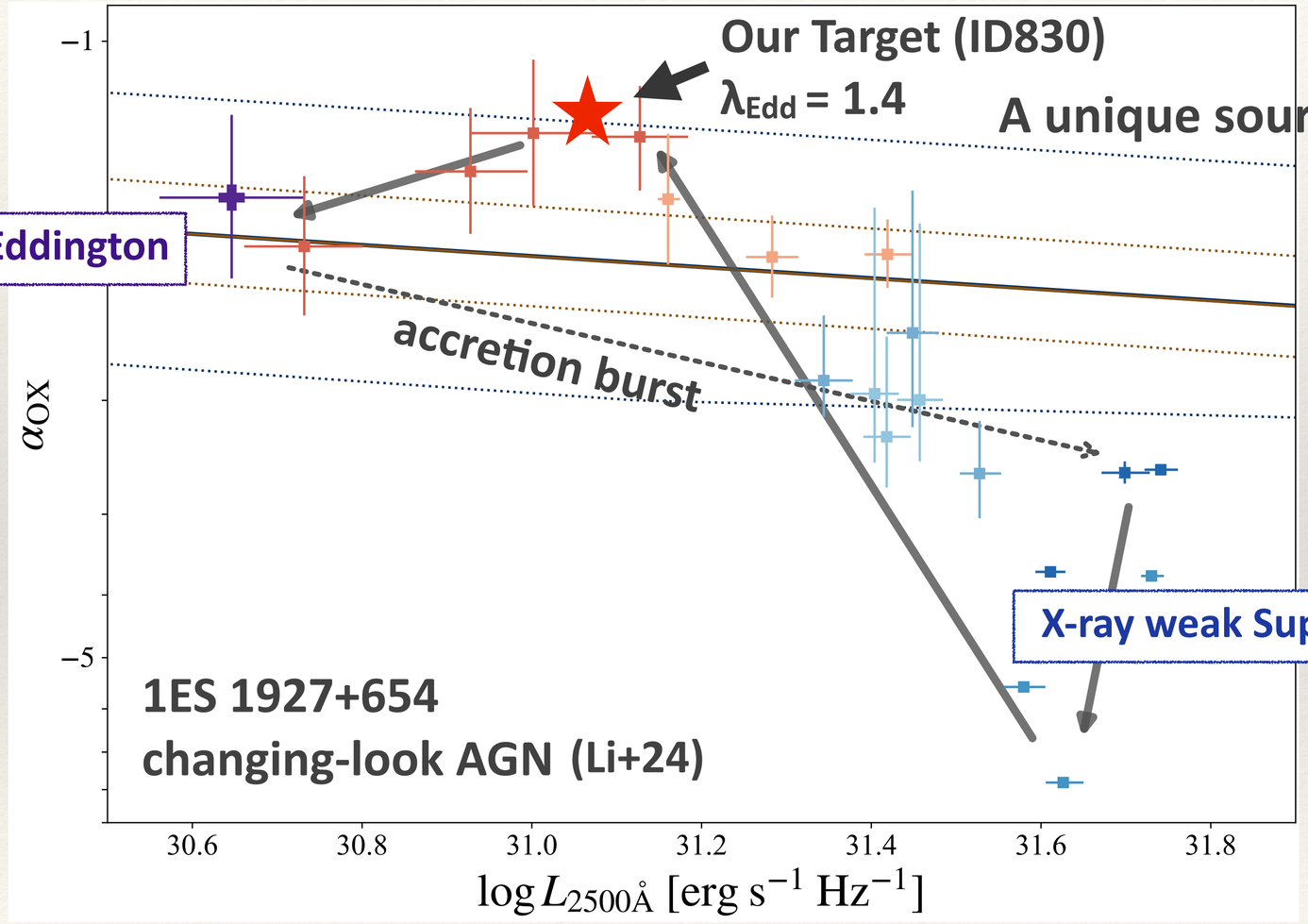

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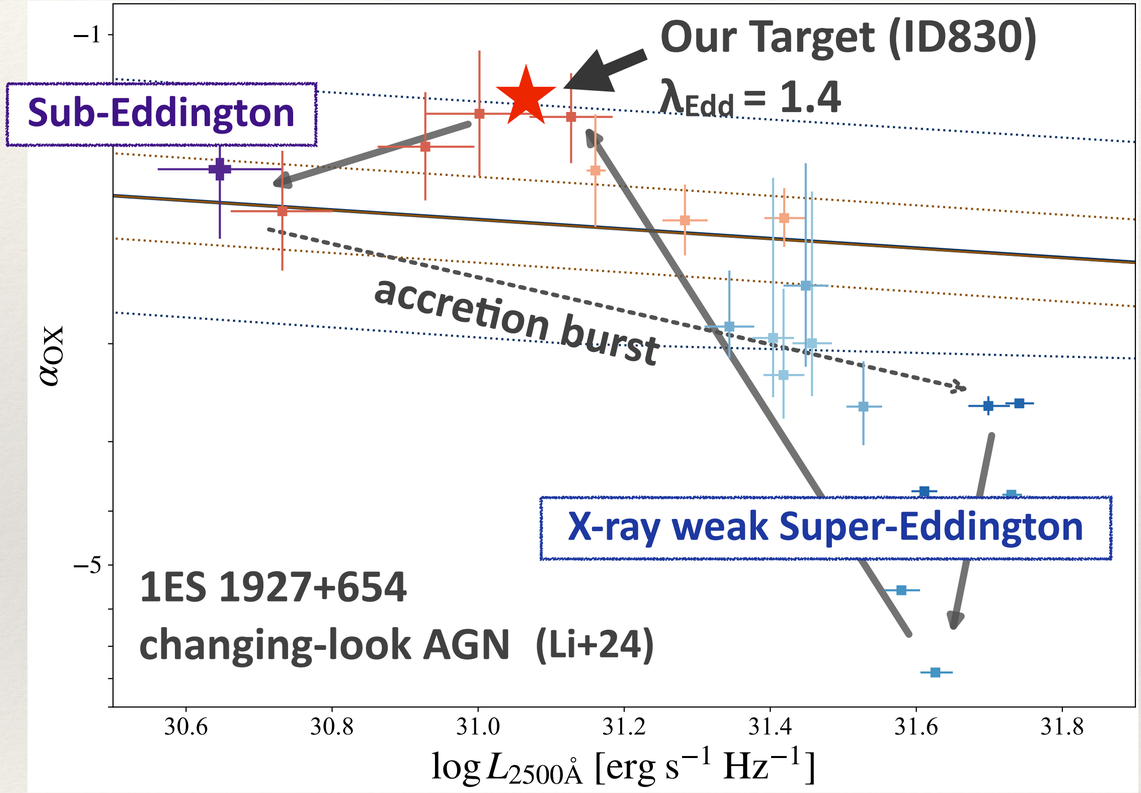
The transition of 1ES 1927+654 lasted for **3 years**. ⟶ What is the timescale of the transition in our target?



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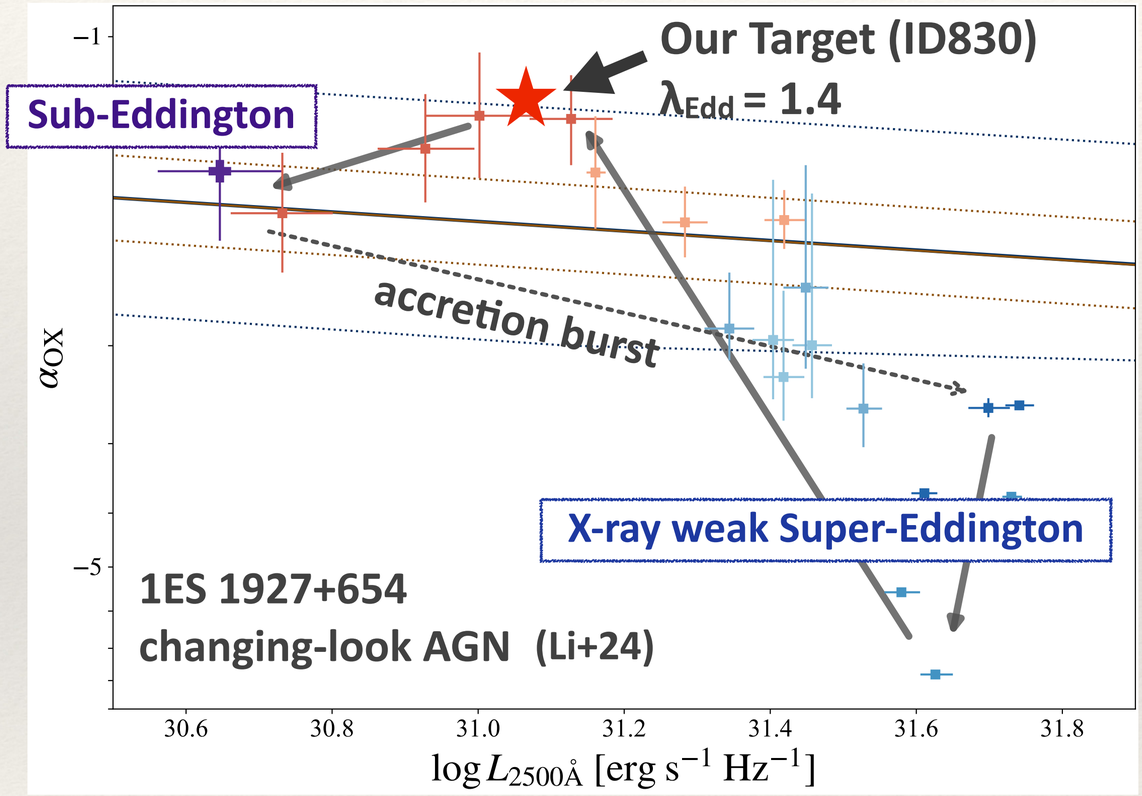

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- $M_{BH} = 4.40 \times 10^8\, M_\odot$
- $z = 3.43$

⟷

1ES 1927+654

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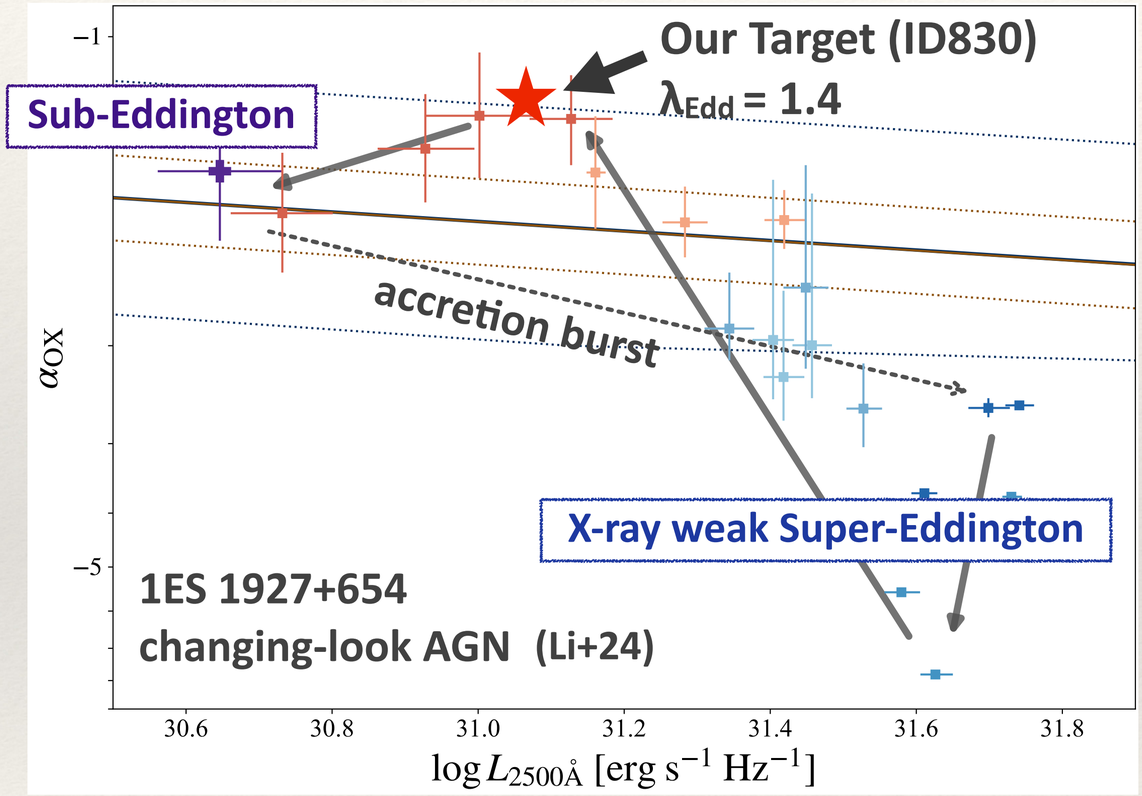

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On larger scales…

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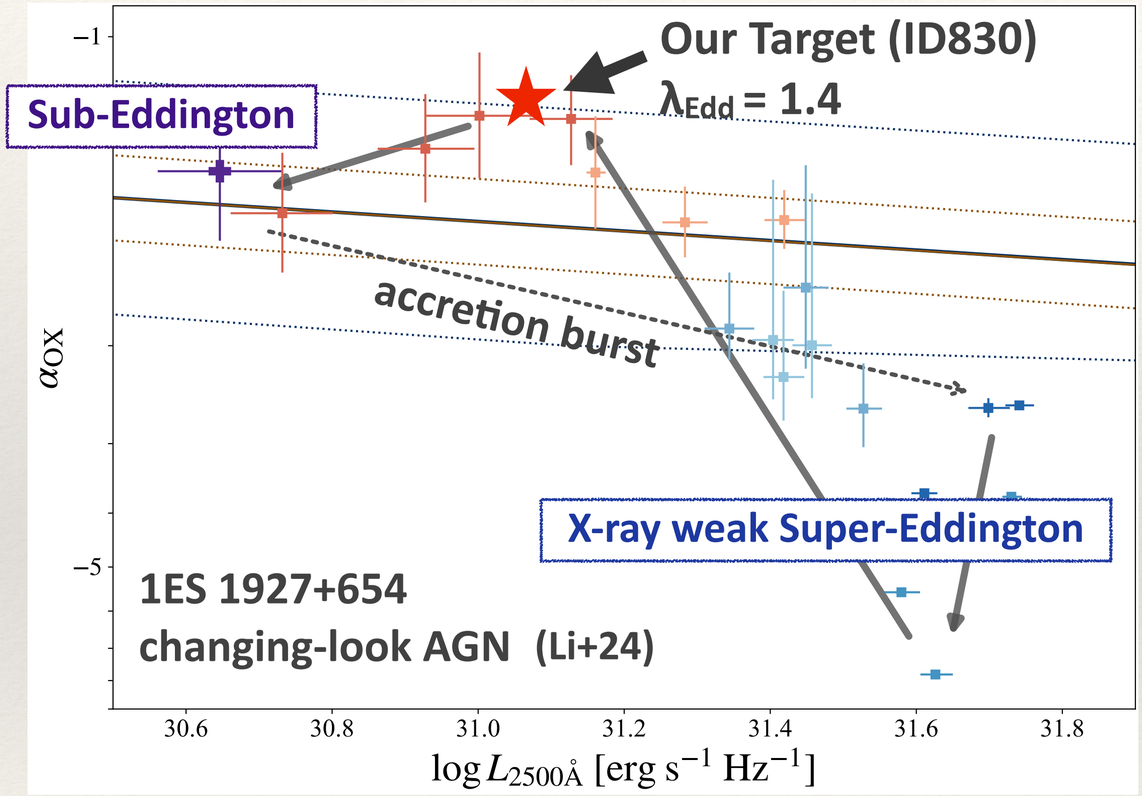

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Considering cosmic dilation…

→ $t_{\rm ID830,obs} = t_{\rm ID830} \times (1 + z_{\rm ID830}) \approx \mathbf{300\,yr}$

This source may allow us to observe the transitional phase over ~300 yr!

Summary

Motivation

- VLA/FIRST wide-area radio survey × eROSITA eFEDS wide-area X-ray survey

⟶ A prominent candidate of **super-Eddington AGN w/ radio-jet**

Results

- $M_{BH} = 4.40\times10^{8}\,M_{Sun}$, $\lambda_{Edd,UV}$ =1.44 / $\lambda_{Edd,X}$ =12.8 ⟶ **super-Eddington AGN w/ radio-jet**!
- **higher α_{OX} = unquenched** at super-Eddington ⟶ **transitional phase after an accretion burst**?

Future works

- confirm the transitional phase from super-Eddington phase to sub-Eddington phase

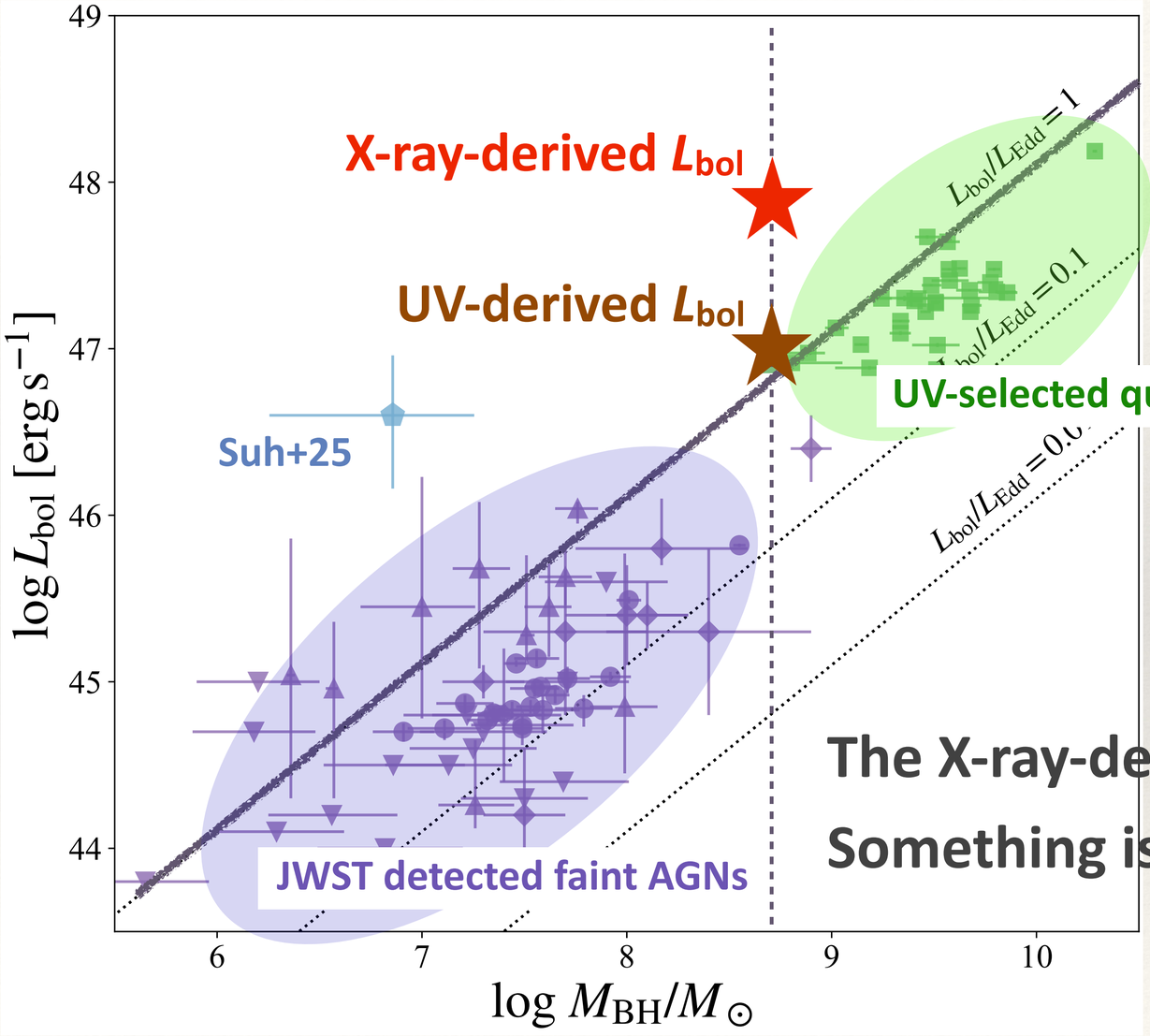
⟶ Further observations targeting **larger-scale structures = past bright phase**

- unclear mechanism of the super-Eddington AGNs jet emission

⟶ Need to know **the jet scale by radio observations**

Appendix

AGN bolometric luminosity: X-ray-derived vs UV-derived



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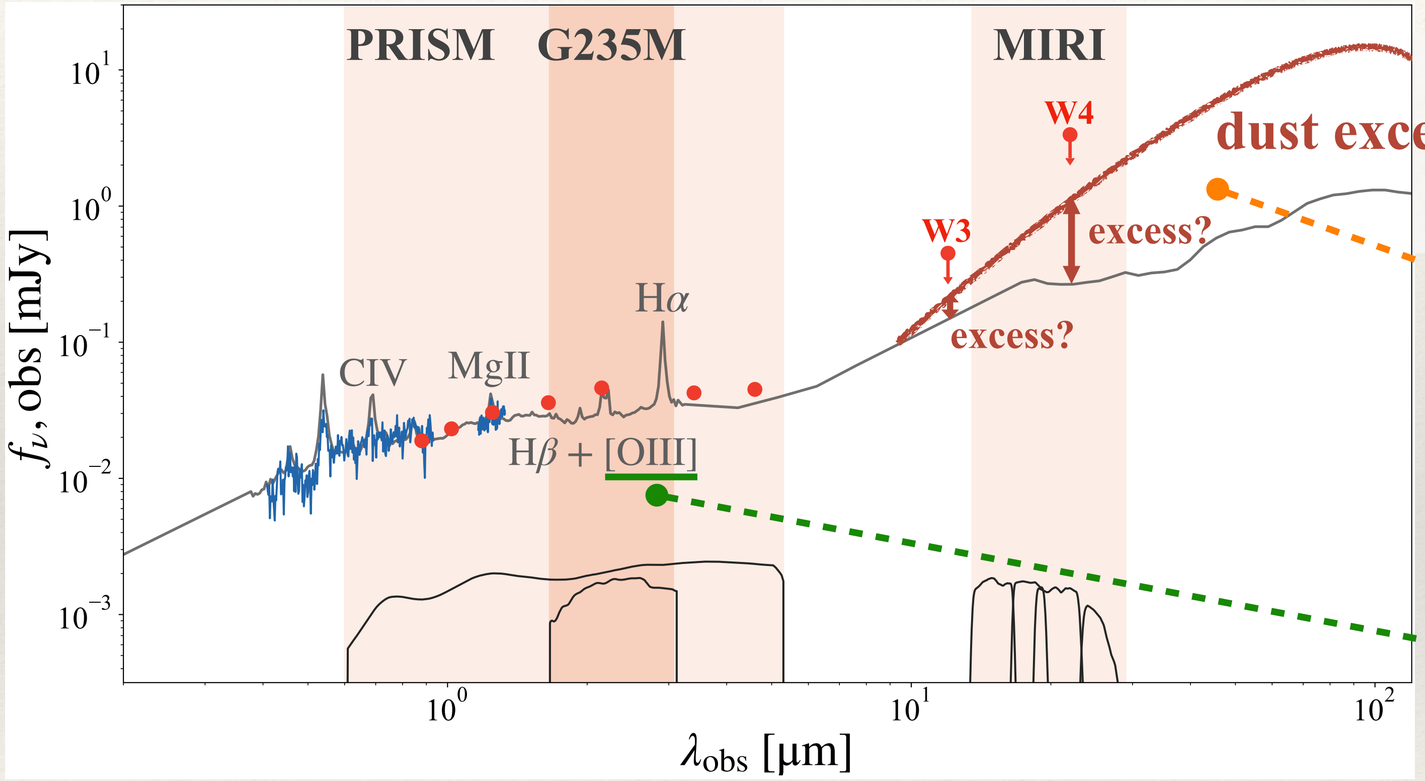
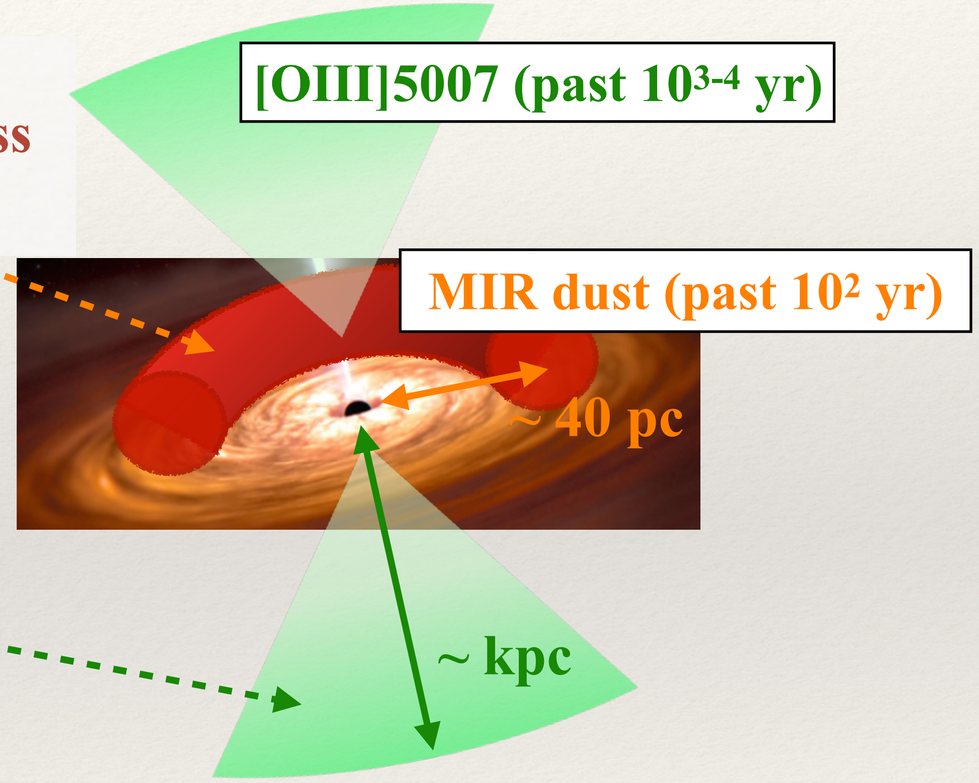
JWST Cycle5 MIRI+NIRSpec observation





JWST further observations can trace “dust echo” and “ionized gas echo” in the traditional phase

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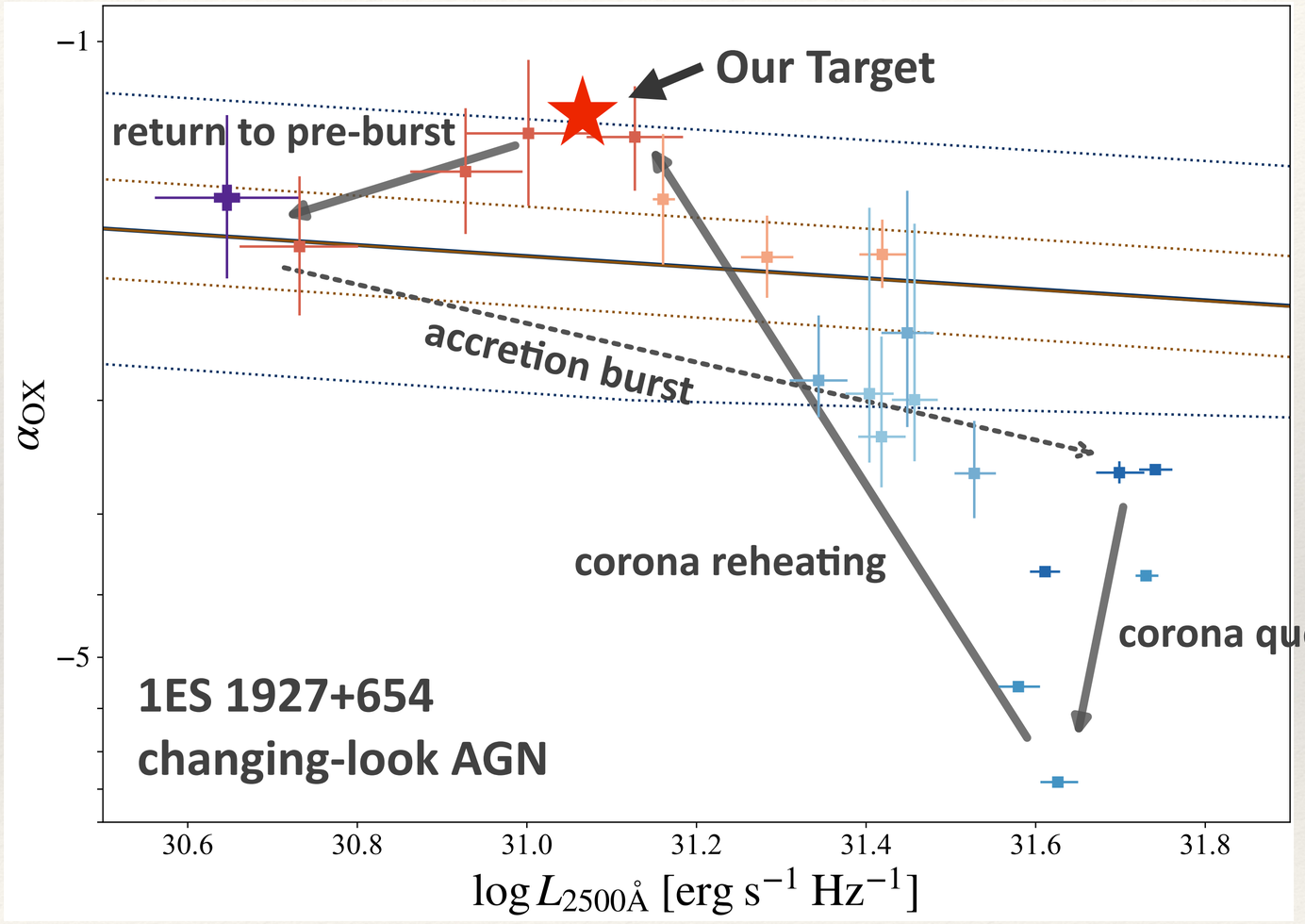

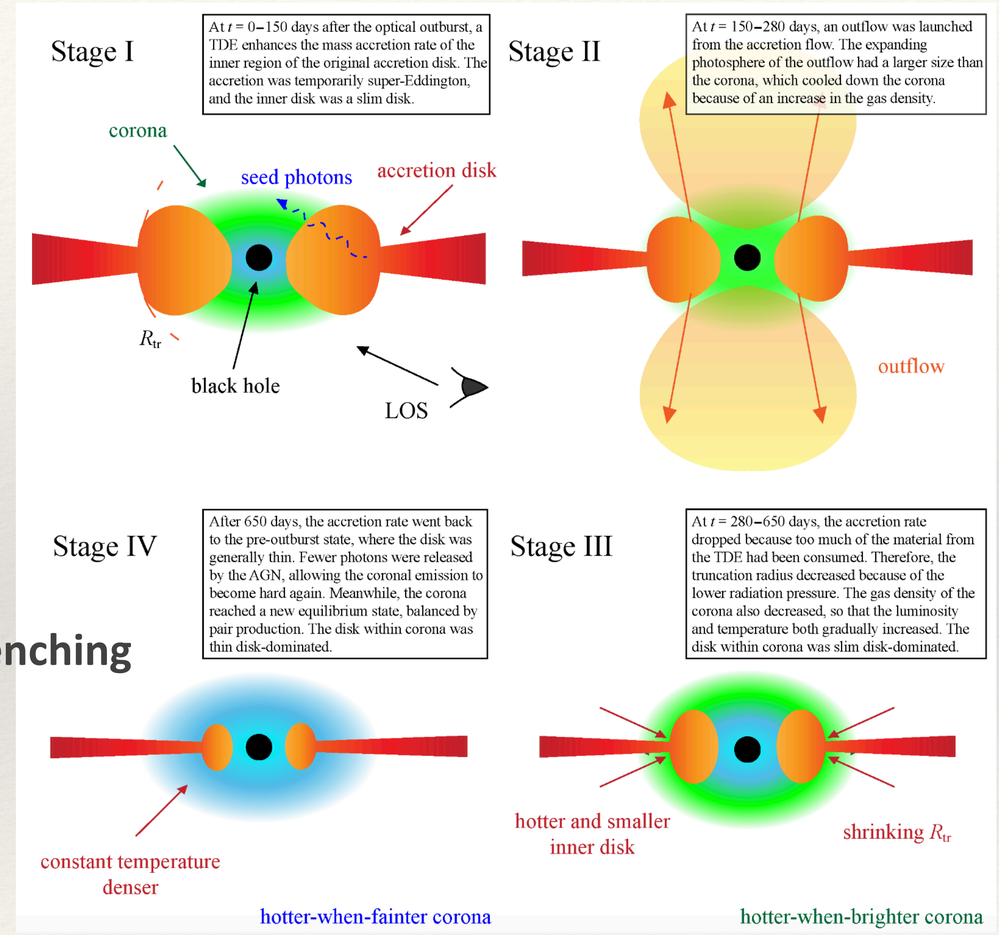

Li+24

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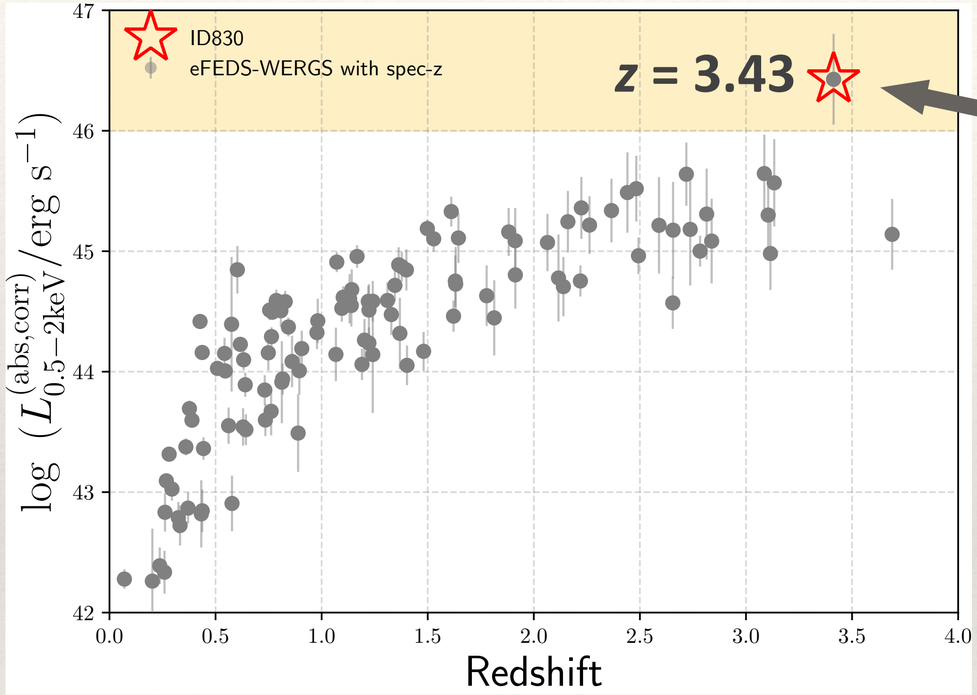

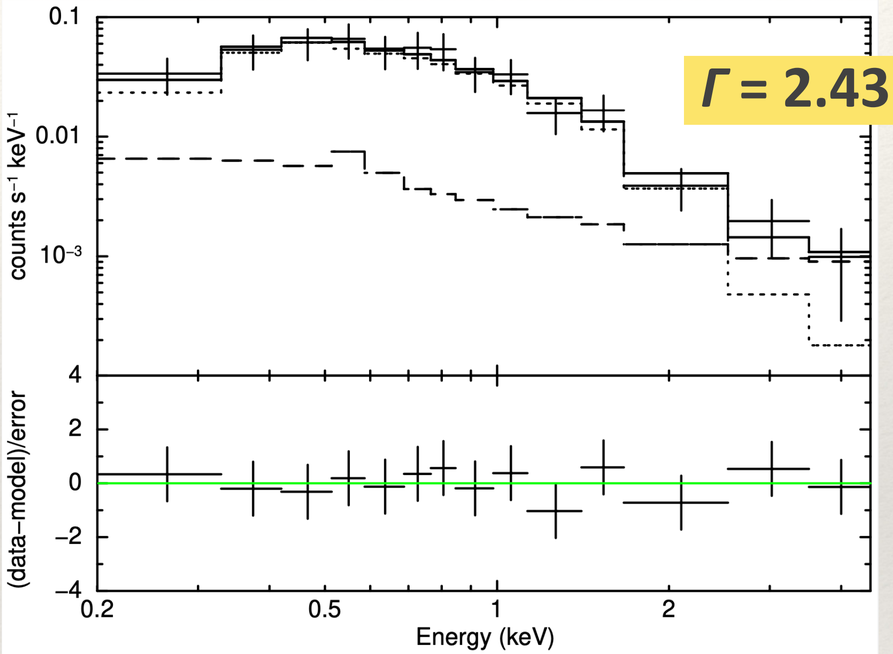

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(Marconi et al. 2004)

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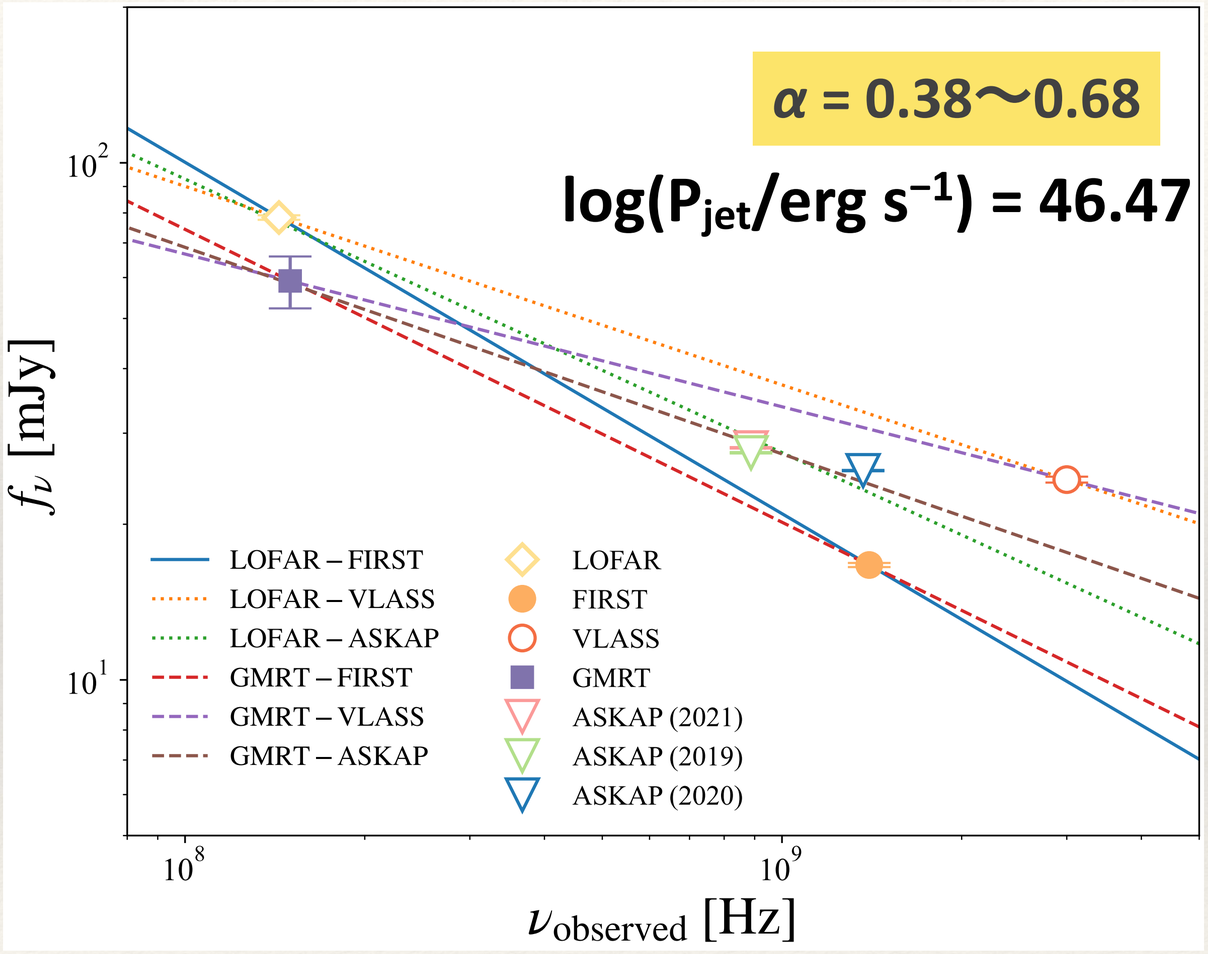
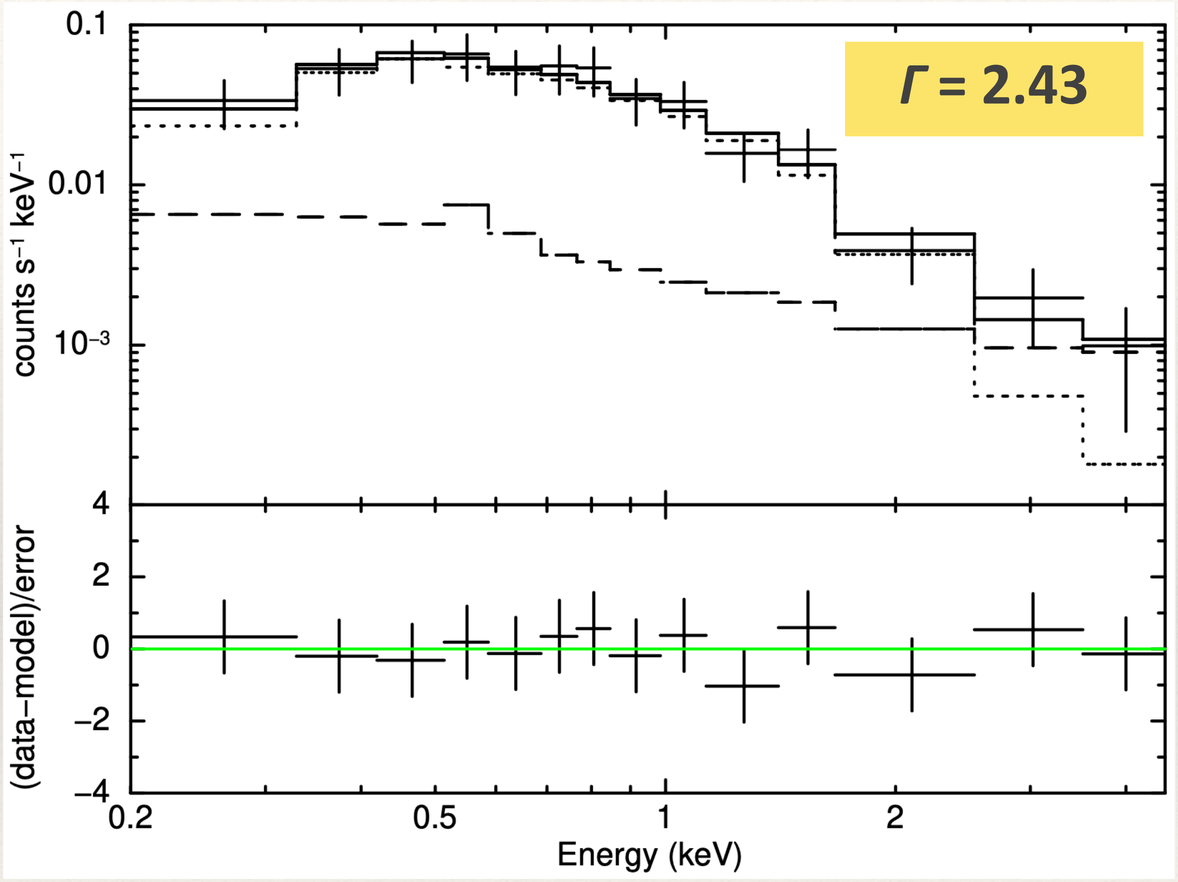
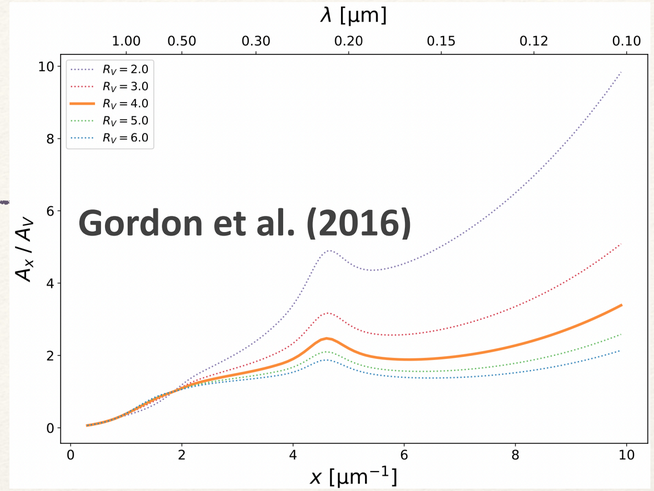
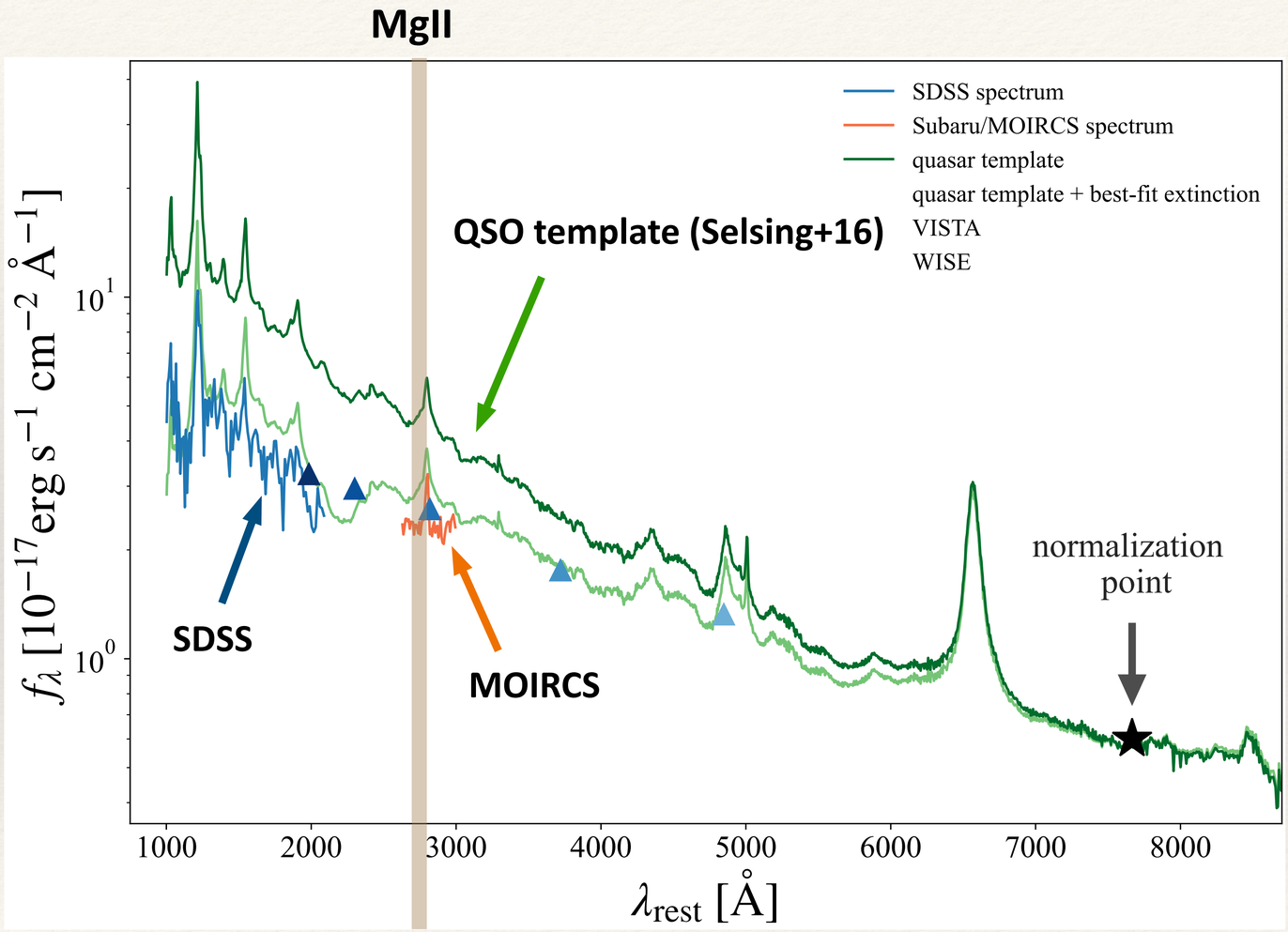
Radio and X-ray spectra

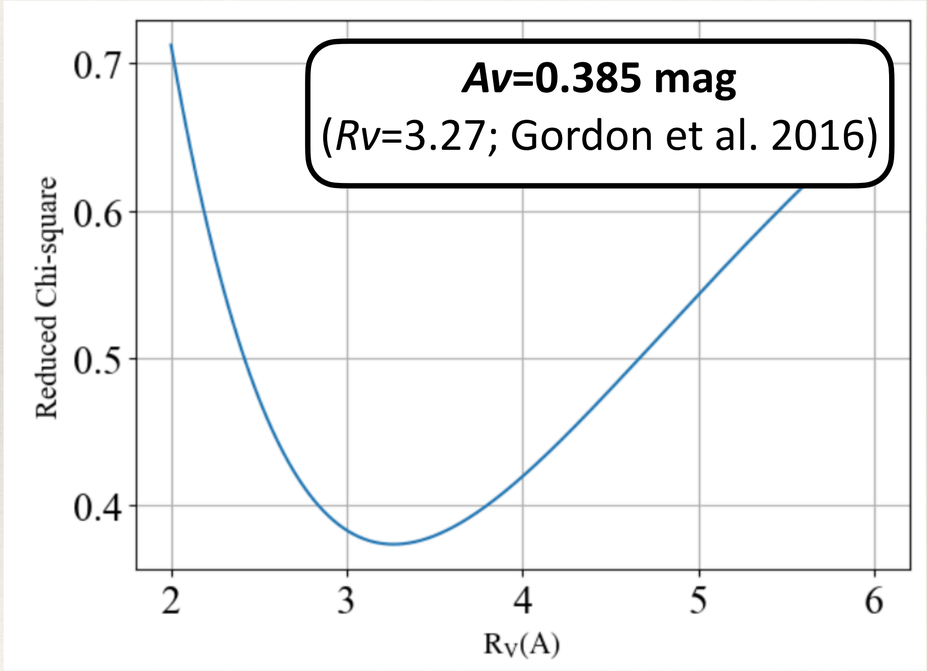




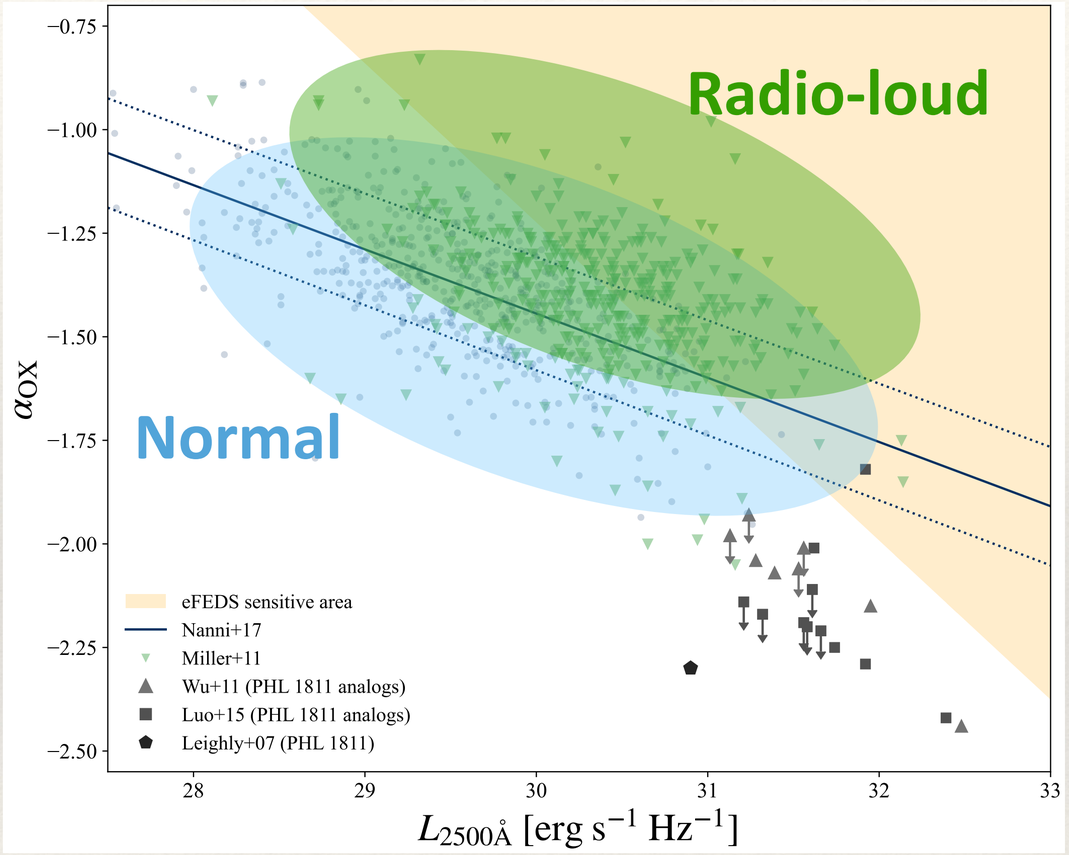
M_{BH} measurement from UV+optical spectra







What causes the X-ray excess? — contamination from the jet



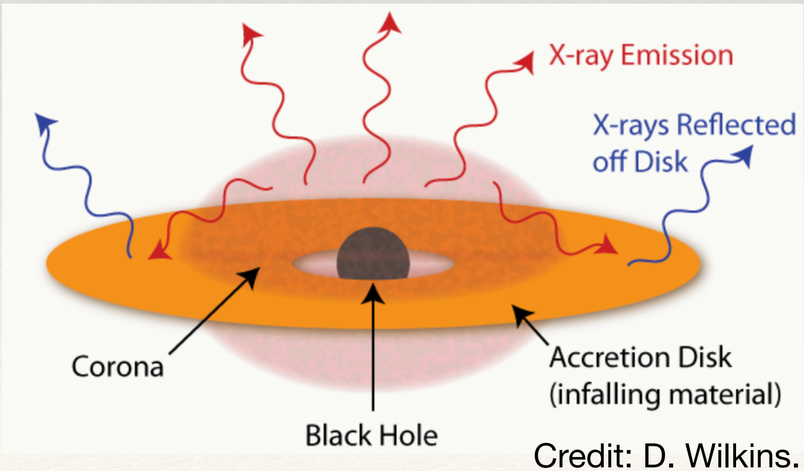
The X-ray emission generally arises from a hot “corona”

(e.g.,Haardt & Maraschi 1991)

⬇ for radio-loud quasars…

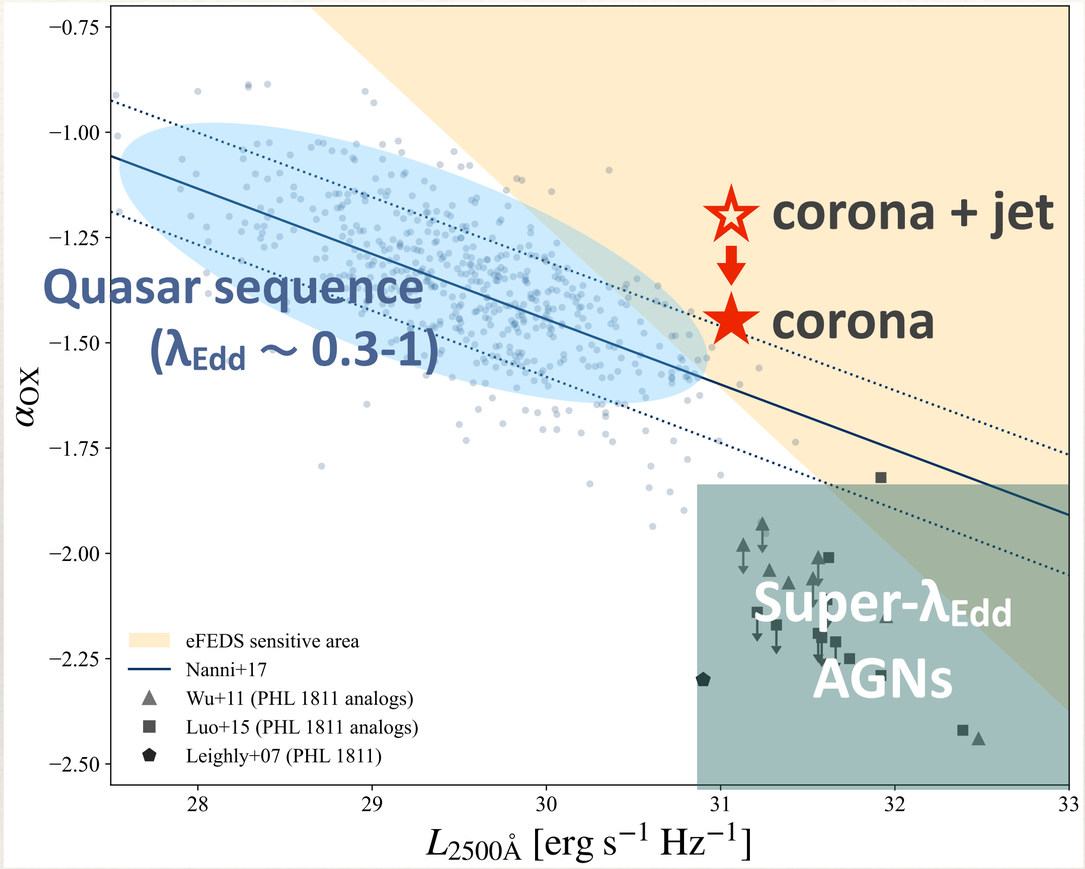
jet-linked X-rays may contaminate

(Synchrotron self-Compton; SSC or external-Compton; EC ?)



Credit: D. Wilkins.

What causes the X-ray excess? — contamination from the jet



The X-ray emission generally arises from a hot “corona”

(e.g.,Haardt & Maraschi 1991)

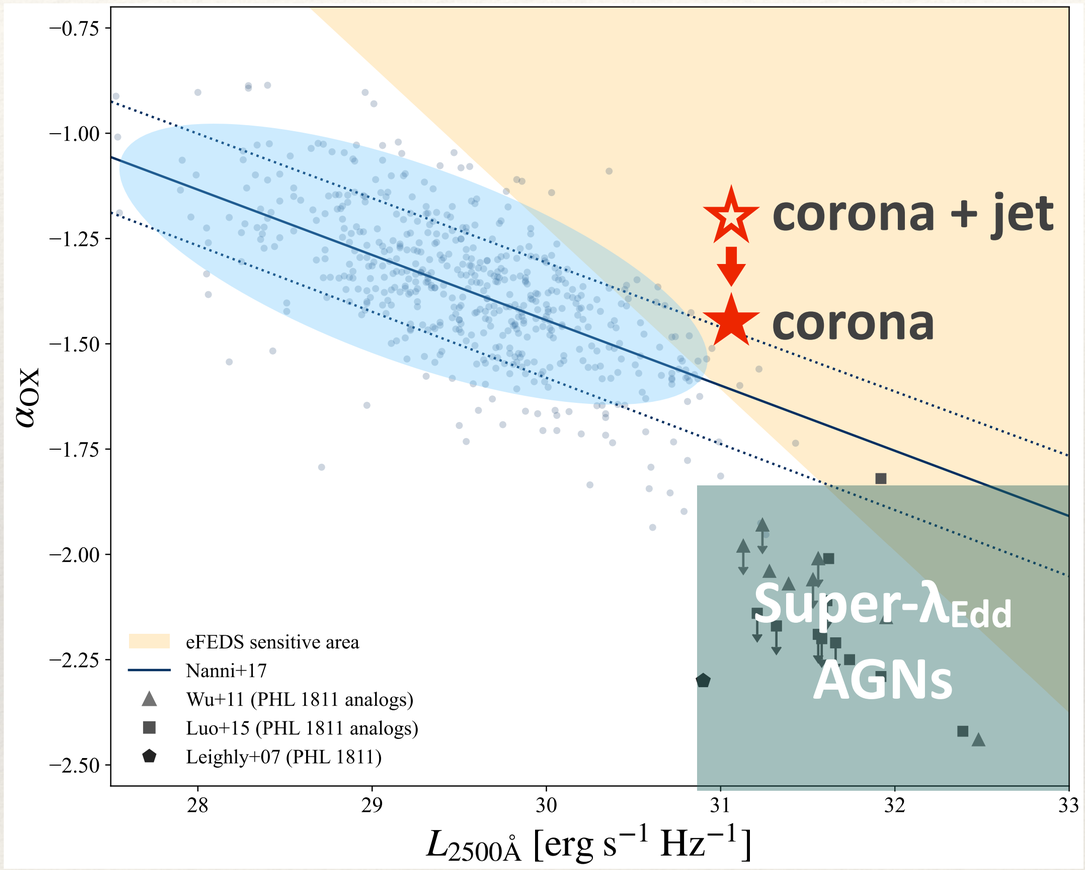
⬇ for radio-loud quasars…

jet-linked X-rays may contaminate

(Synchrotron self-Compton; SSC or external-Compton; EC ?)

Even after removing the jet contamination, the X-ray luminosity is still high…

What causes the X-ray excess? — contamination from the jet



The X-ray emission generally arises from a hot "corona"

(e.g.,Haardt & Maraschi 1991)

⬇ for radio-loud quasars…

jet-linked X-rays may contaminate (SSC or EC ?)

Corona + jet

Radio-loudness

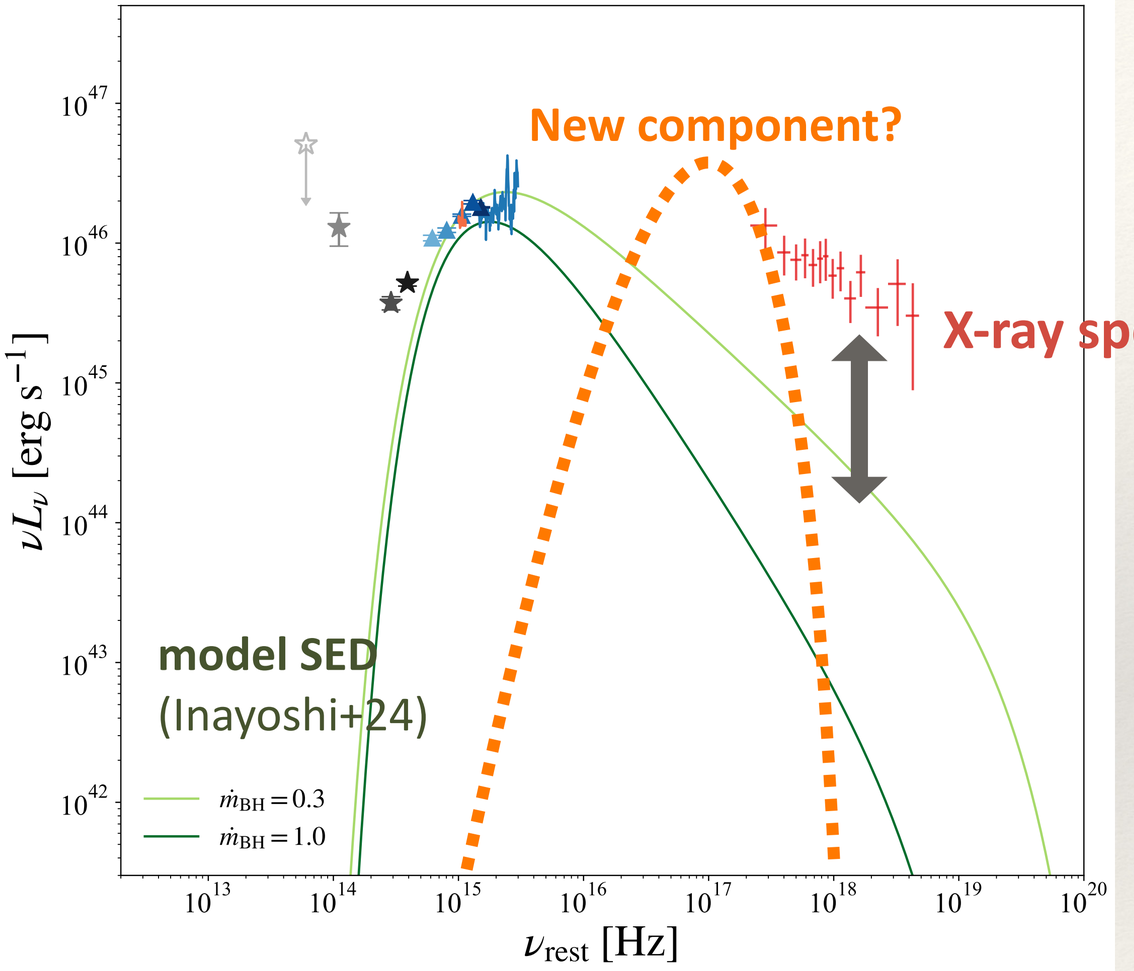
$$\log\left(\frac{L_{\mathrm{X,RLQ}}}{L_{\mathrm{X,RQQ}}}\right) = (-0.354 \pm 0.050) + (0.352 \pm 0.039)\ \log R$$

(Miller+11)

Only Corona

Even after removing the jet contamination, the X-ray luminosity is still high…

What causes the X-ray excess? — “soft excess” component



The most similar one is…

“Soft X-ray excess” in super-Eddington NLS1s

(e.g., Jin+17)

NLS1s ⟶ low-z, low-$M_{\rm BH}$ ($\sim 10^6\ M_{\rm Sun}$)

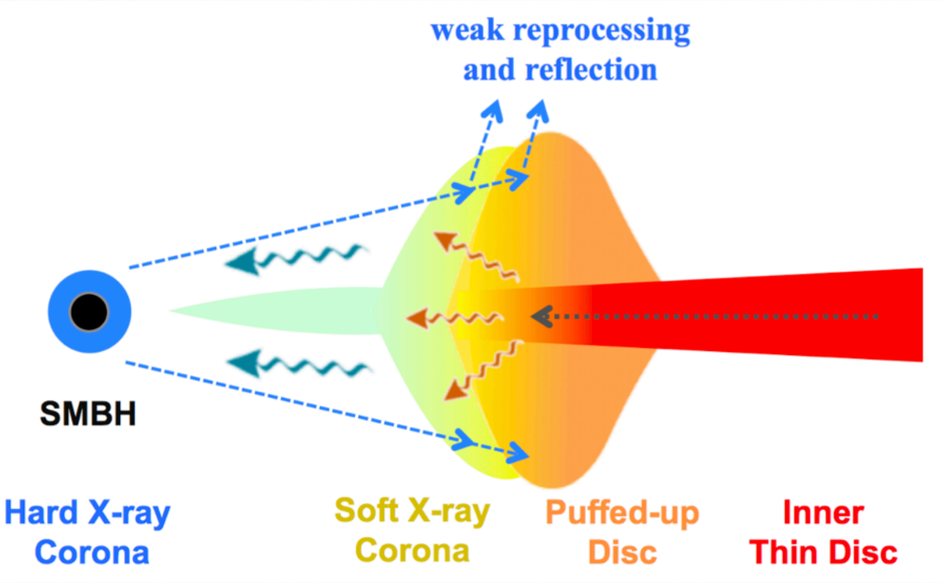
our target ⟶ high-z, high-$M_{\rm BH}$ ($\sim 10^8\ M_{\rm Sun}$)

Even at high-z and with high-$M_{\rm BH}$, a “soft excess” component may be required?

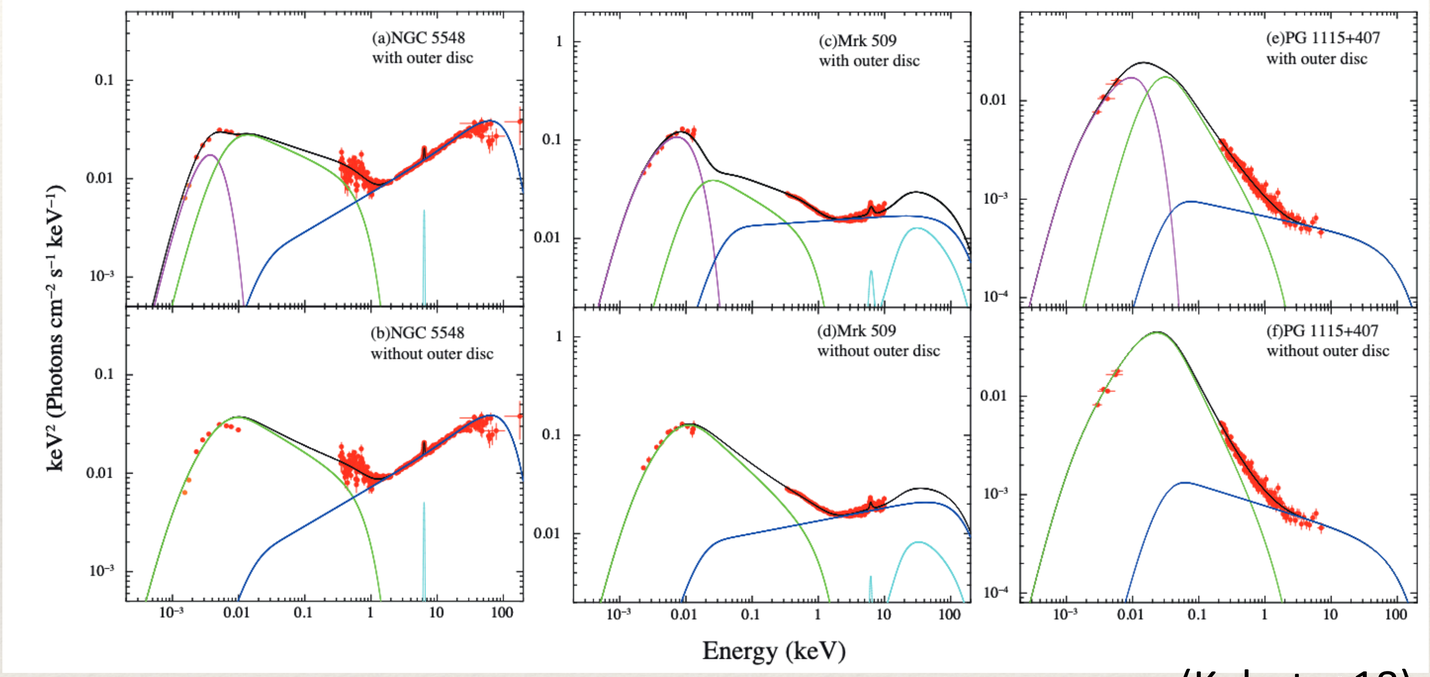
What causes the X-ray excess? — “soft excess” component

super-Eddington NLS1s with the soft X-ray excess

$\dot{m}$

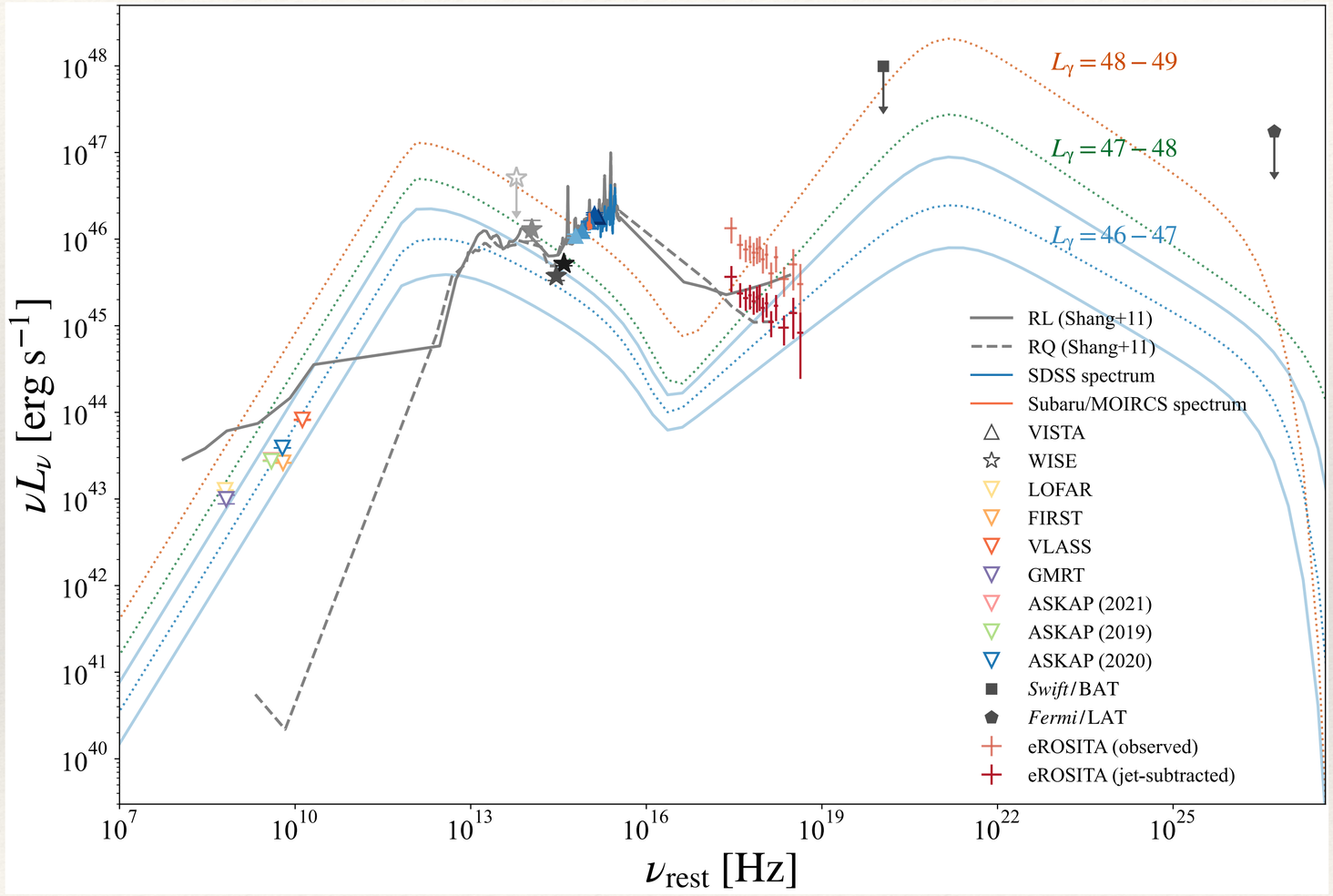


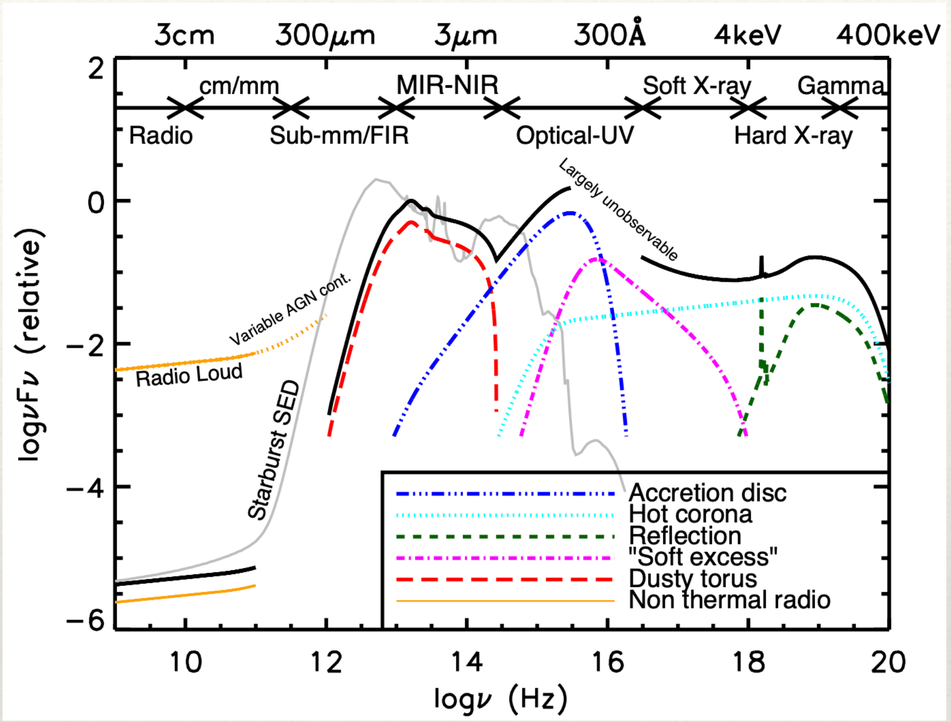
(Jin+17)



(Kubota+18)

Broad-band spectral energy distribution (SED)

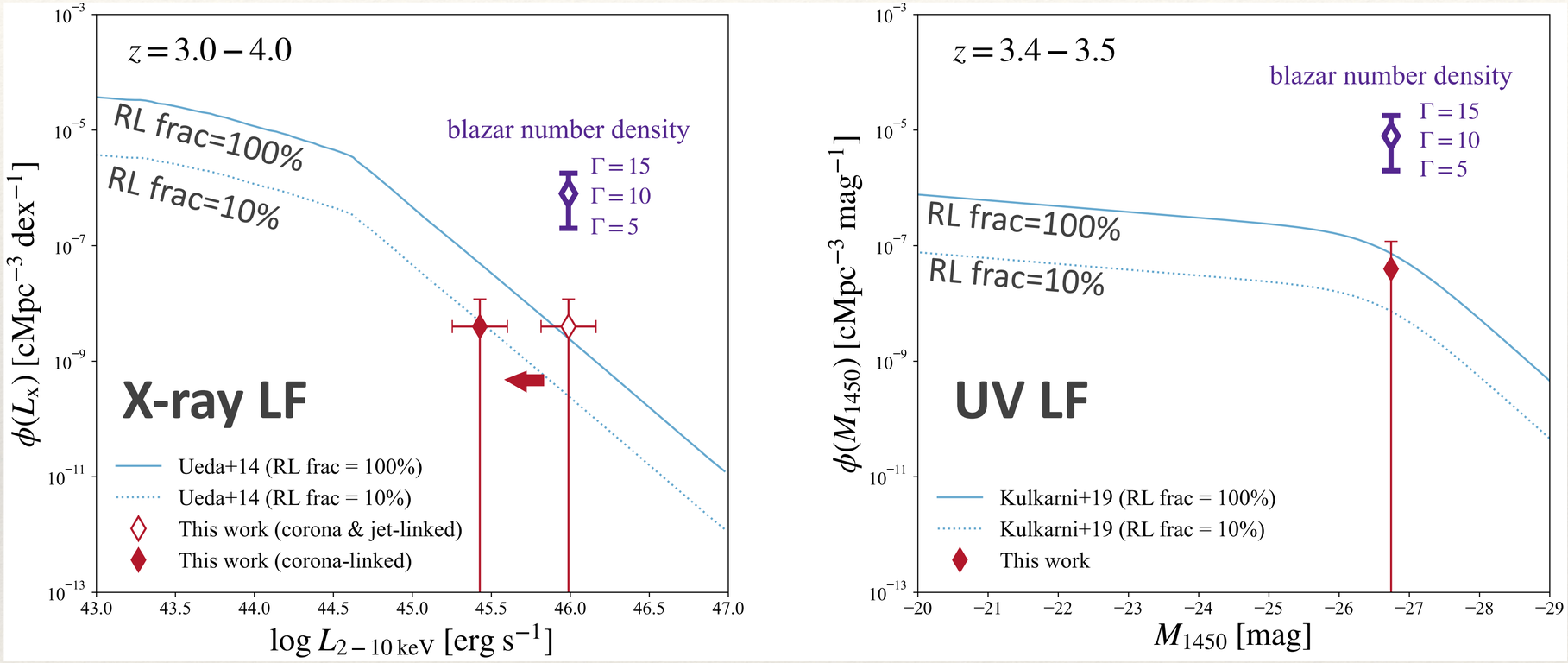




(Hickox & Alexander 2018)

Number density of radio AGNs at z=3.4

Based on the eFEDS survey field and the spec-*z* bias, we estimate the number density of radio-loud quasars.



For the UV-based number density, the radio-loud fraction is 57 %, which exceeds the expected threshold 10 %.

The number density of radio-loud quasars at *z*~3-4 may be underestimated in existing UV selected quasar samples!