Multi-wavelength Observations of the *super-Eddington* Accretion Flow in Narrow-line Seyfert 1 Galaxies

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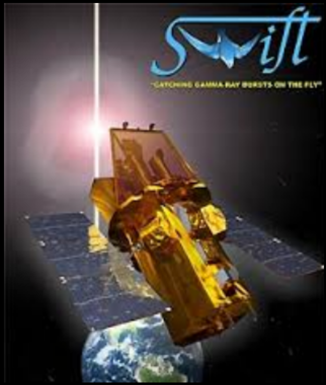
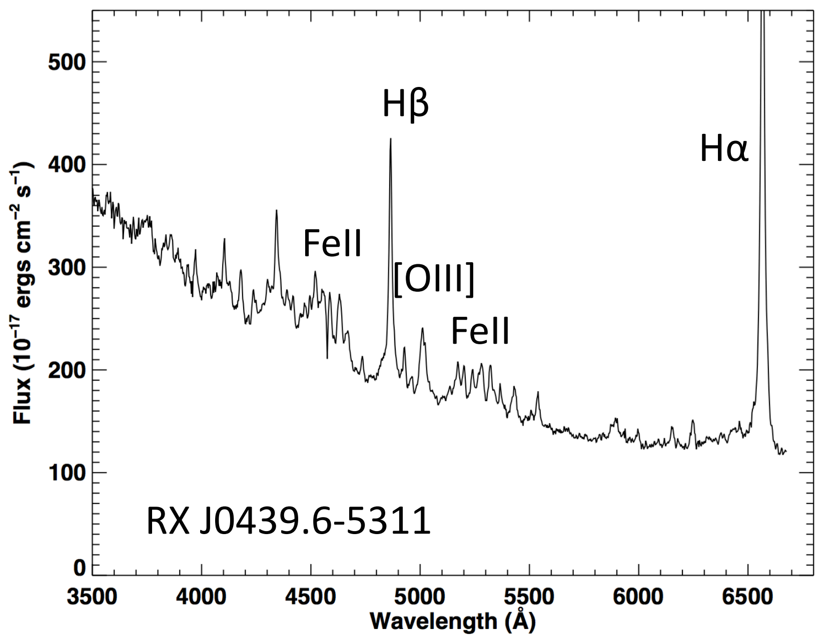
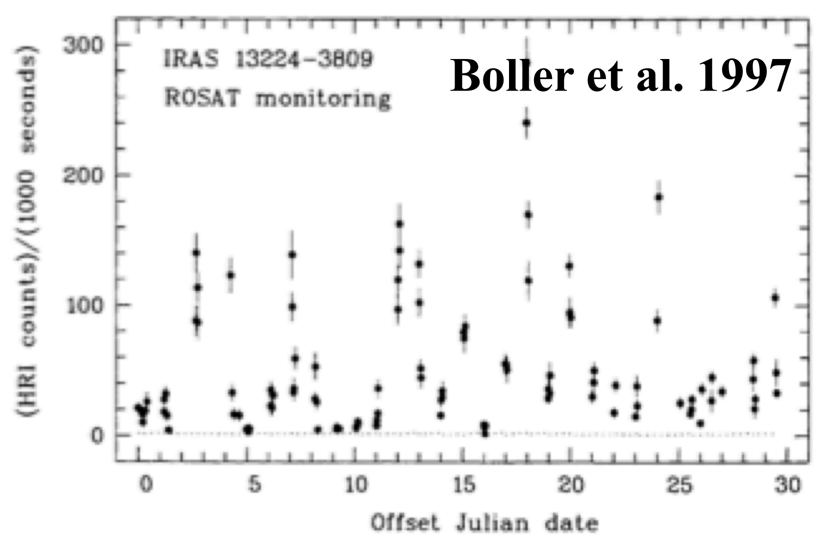
Guilin, 24/09/2019



Narrow-line Seyfert 1 Galaxies

1. Hβ FWHM < 2000 km s^{-1}
2. [OIII] 5007 / Hβ < 3 (Goodrich 1989)
3. Strong FeII emission lines
4. Steep X-ray spectra ($\Gamma > 2$), a prominent soft X-ray excess (e.g. Boller, Brandt, Fink 1996)
5. Low black hole mass (10^5-10^7 $M_\odot$), and high mass accretion rate close to Eddington (Komossa 2008)
6. Strong X-ray variability, but weak optical/UV variability (Leighly 1999)





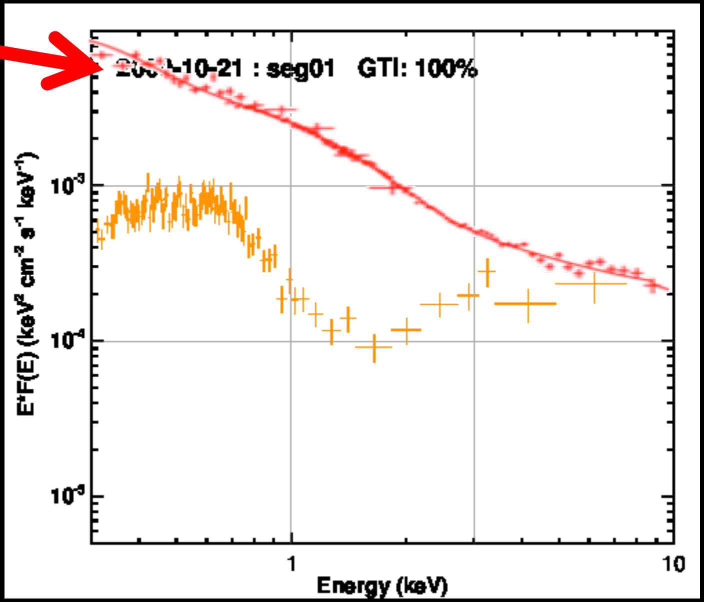
Boller et al. 1997

Narrow-line Seyfert 1 Galaxies

Complexities in the NLS1s

1. Not all have simple steep X-ray spectra (cold/warm absorption, partial covering, reflection, etc.)

Gallo 2006:
X-ray ‘simple’ and X-ray ‘complex’ NLS1s

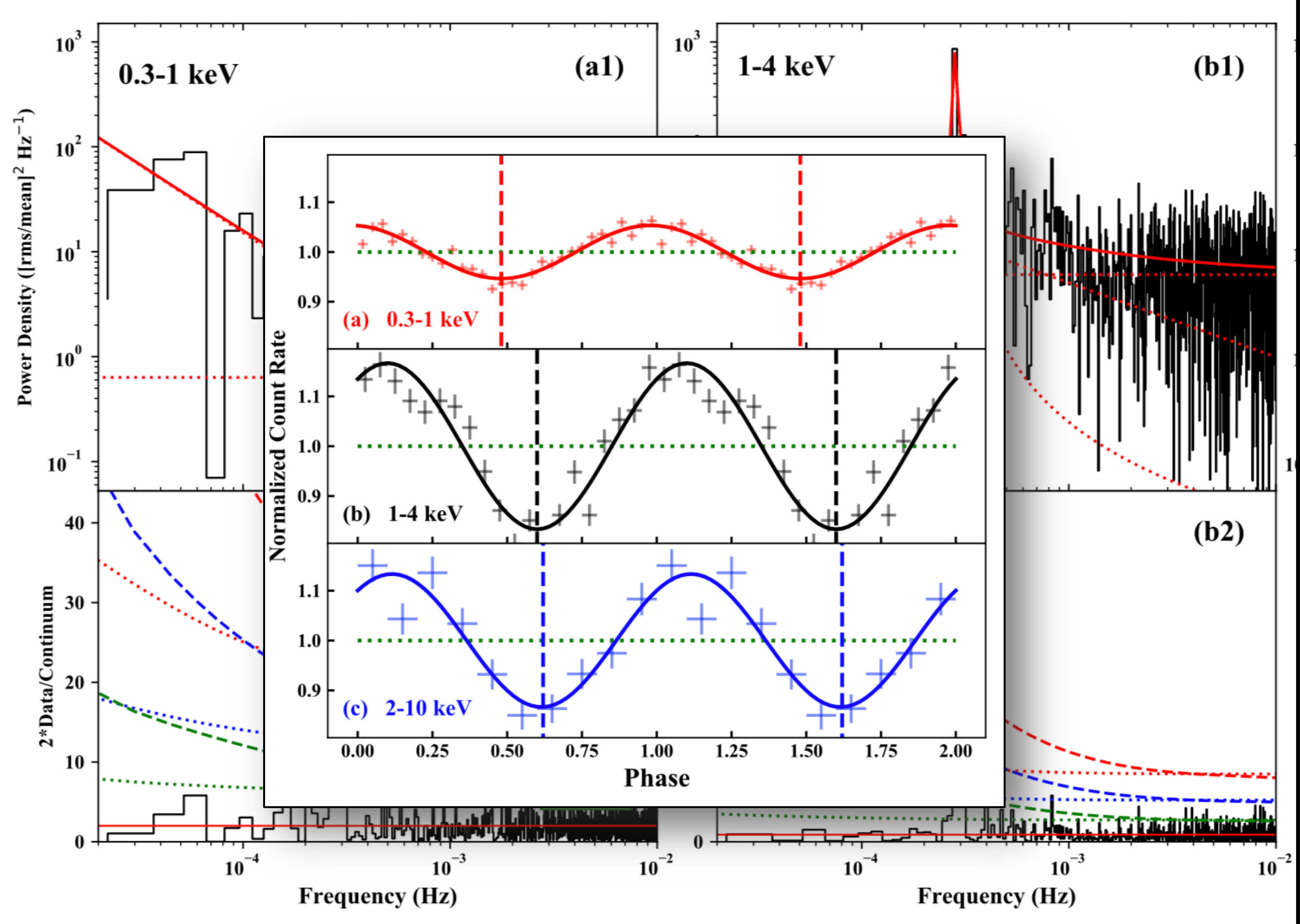


2. Not all have high mass accretion rates: NGC 4395, M~$5\times10^5 M_\odot$, $L/L_{Edd} < 0.01$ (Vasudevan & Fabian)
3. Black hole spin (Reynolds et al. 2013; Done & Jin 2016)
4. Radio-loudness (Merloni, Heinz & Di Matteo 2003)
5. Can show AGN X-ray QPO!

Narrow-line Seyfert 1 Galaxies

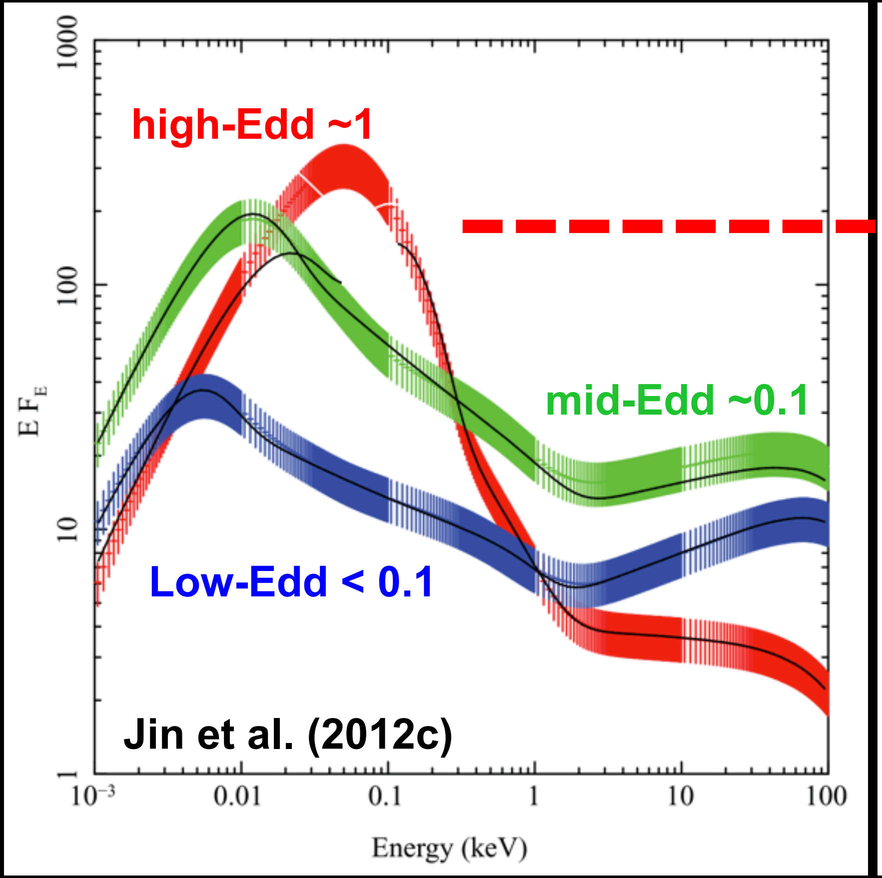
RE J1034+396:

An X-ray QPO lasts for more than one decade! (Jin et al. in prep.)

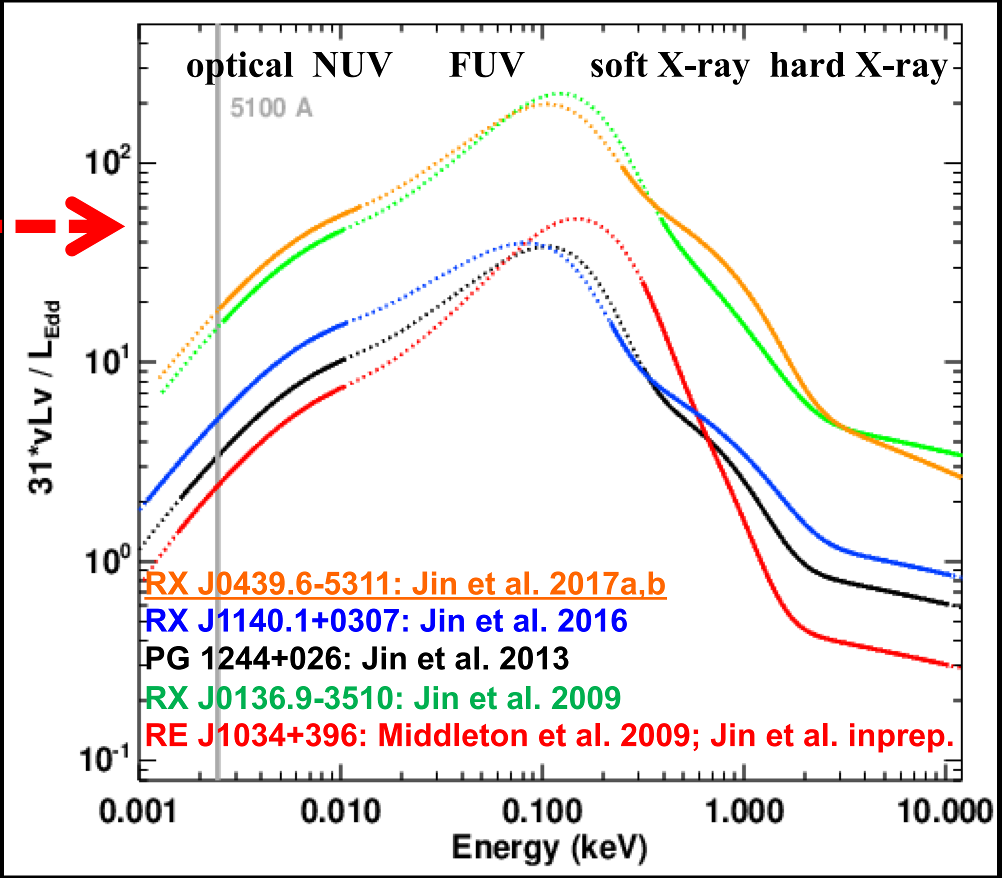


The Extremes: Super-Eddington NLS1s

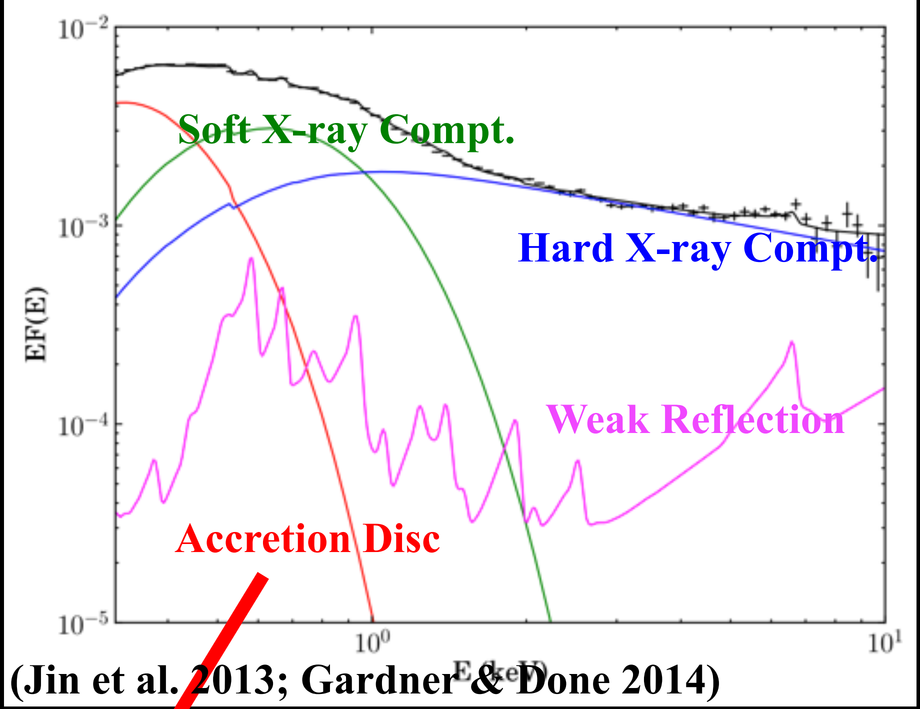
Type-1 AGN Mean SED Evolution



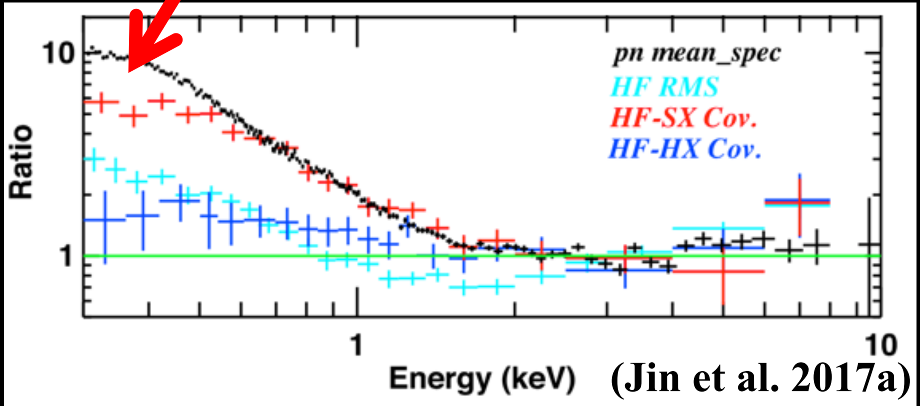
Super-Eddington NLS1 SED



X-ray Spectral Decomposition



(Jin et al. 2013; Gardner & Done 2014)



(Jin et al. 2017a)

- Soft excess: low-T, optically thick Comptonisation:

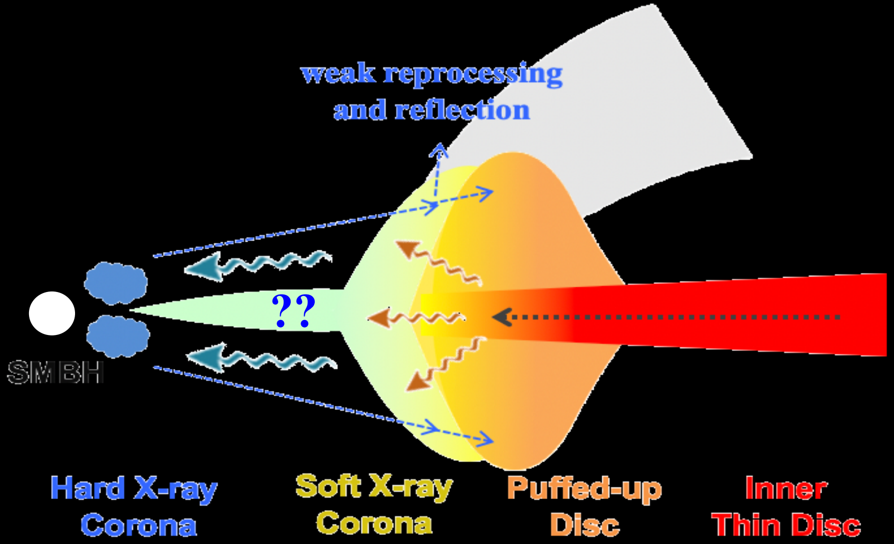
  extended corona
- Narrow Iron line, weak reflection component:

  low black hole spin
- *Inner disc component in the soft excess*

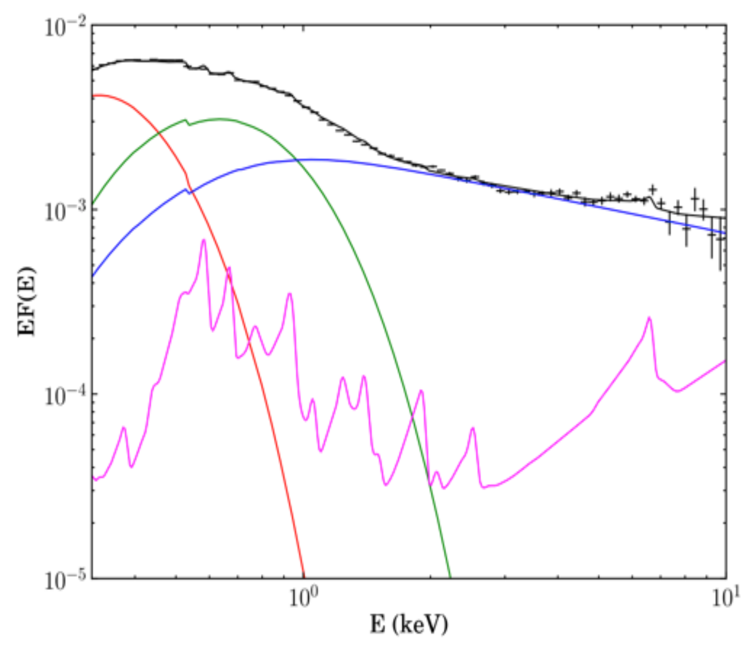
Examples:

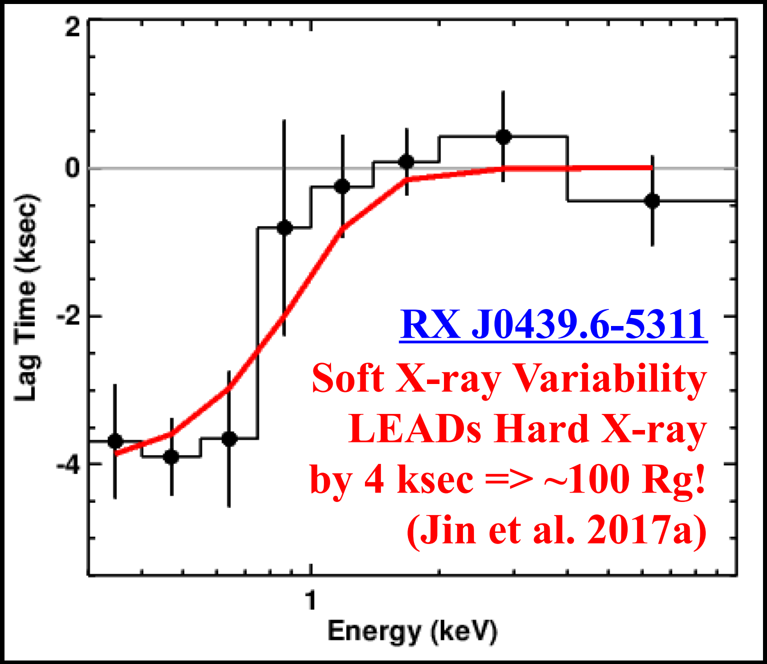
- ✓ PG 1244+026 (Jin et al. 2013; Gardner & Done 2014)
- ✓ RX J0439.6-5311 (Jin et al. 2017a)
- ✓ Ark 564 (Kara et al. 2018)
- ✓ Ton S180 (Parker et al. 2018)

Inner Accretion Disc Structure inferred from Observations



(Jin et al. 2017a)





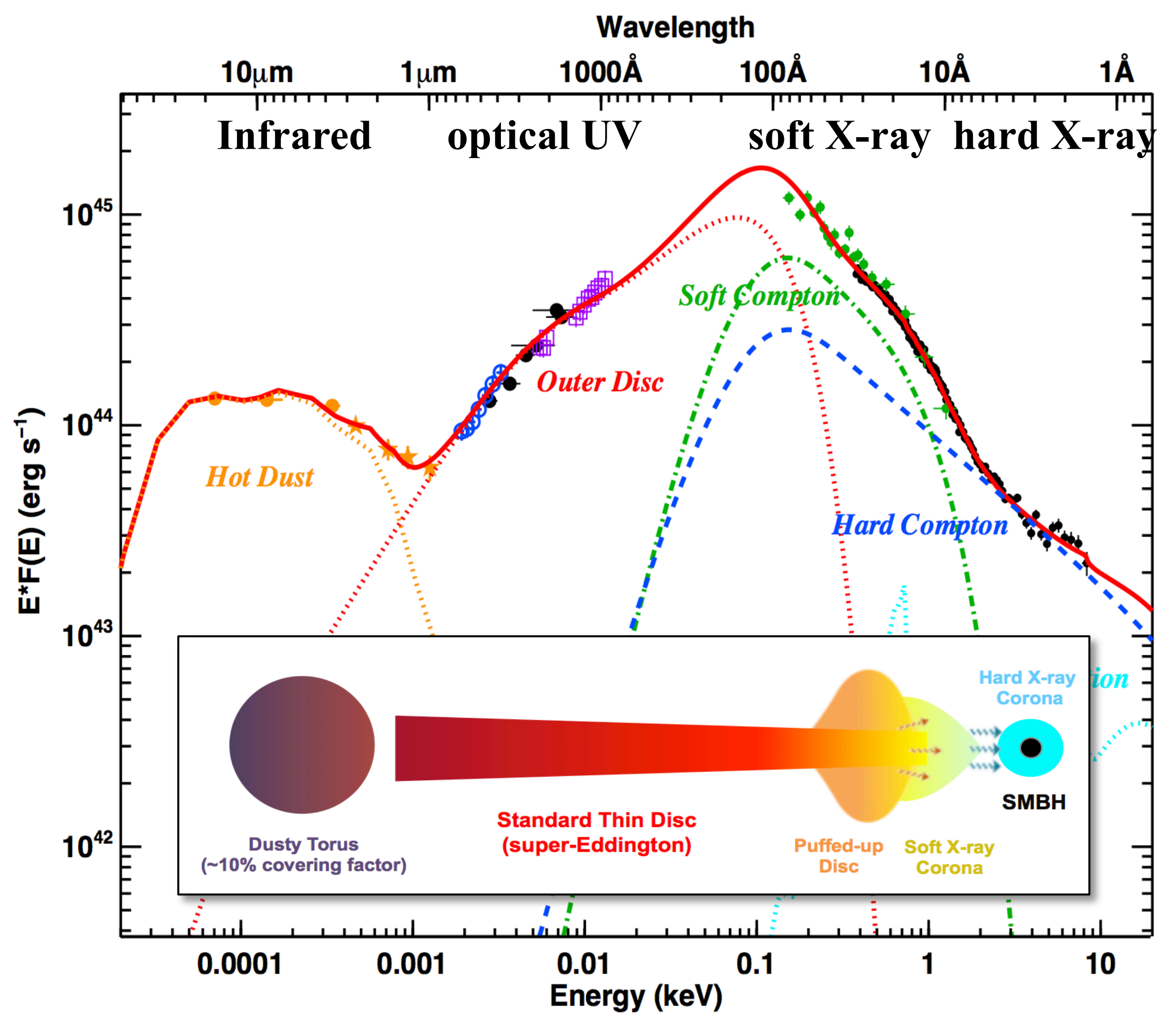
RX J0439.6-5311

Soft X-ray Variability LEADs Hard X-ray by 4 ksec => ~100 Rg!

(Jin et al. 2017a)

Broadband Spectral Energy Distribution of the NLS1 RX J0439.6-5311

the so-far most robust super-Eddington NLS1



$M = 7x10^6 M_\odot$

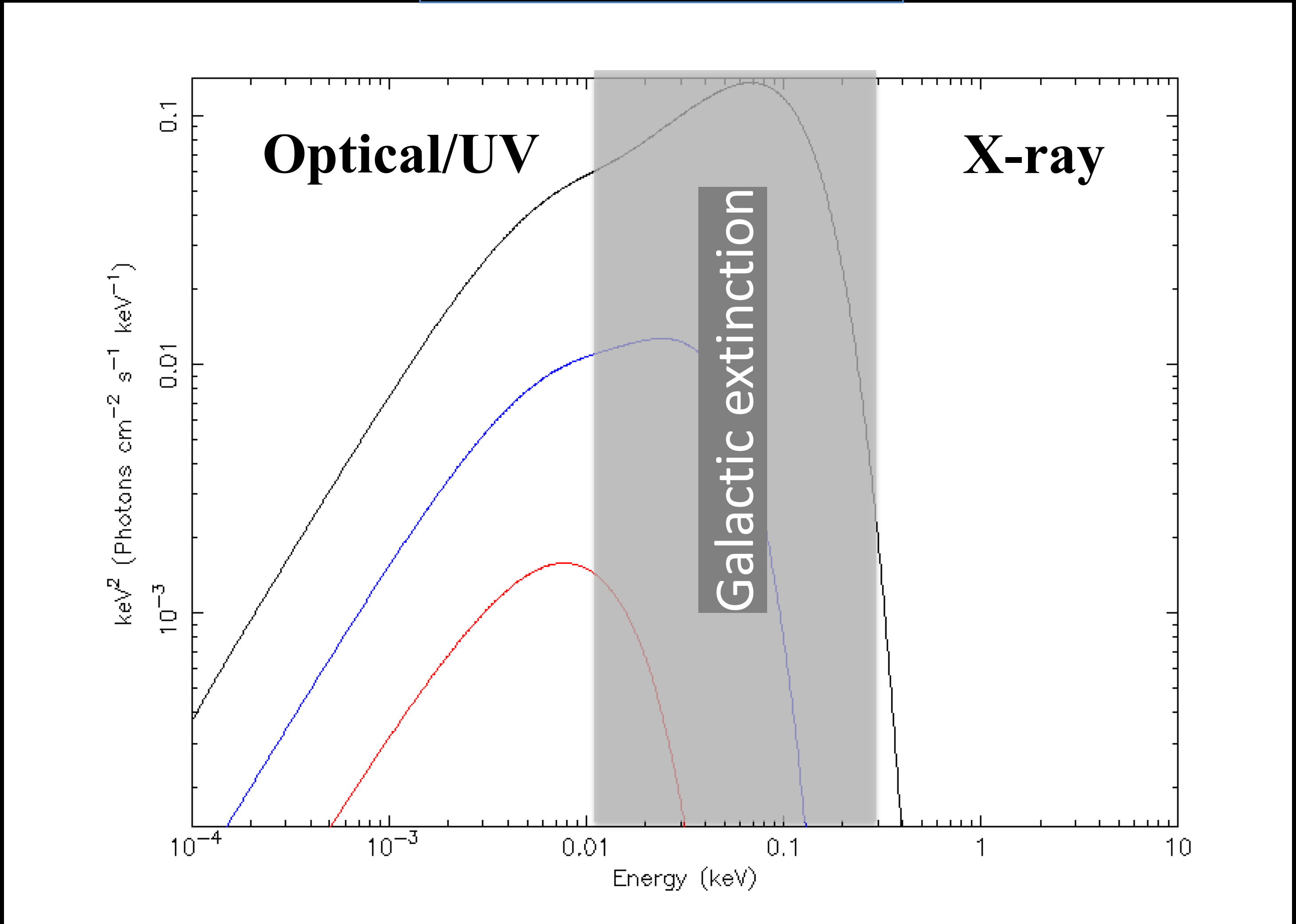
$L/L_{Edd} = 4.6$

mdot = 12.1

Jin et al. (2017b)

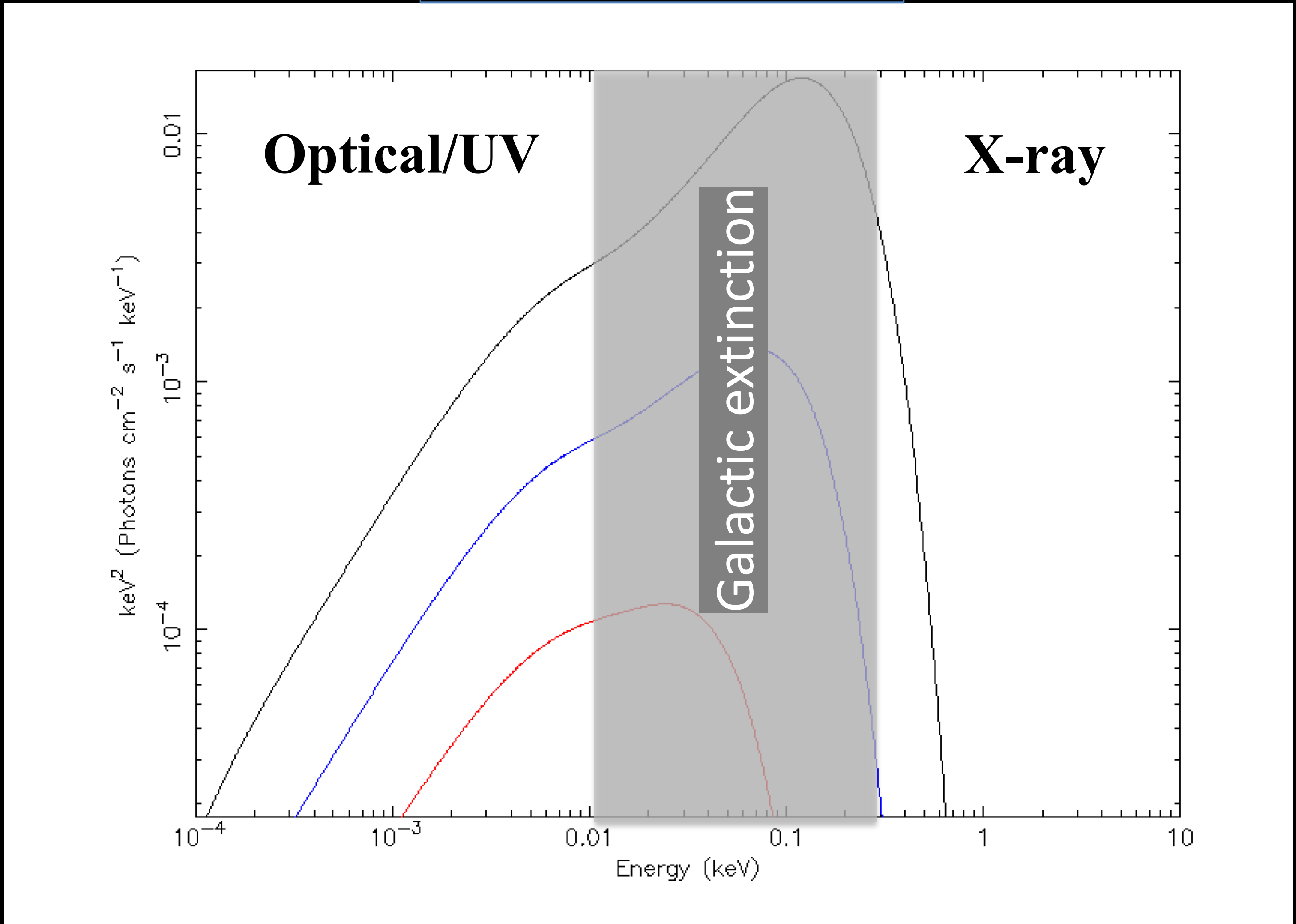
Standard Accretion Disc Spectrum

$M = 10^8 M_\odot$



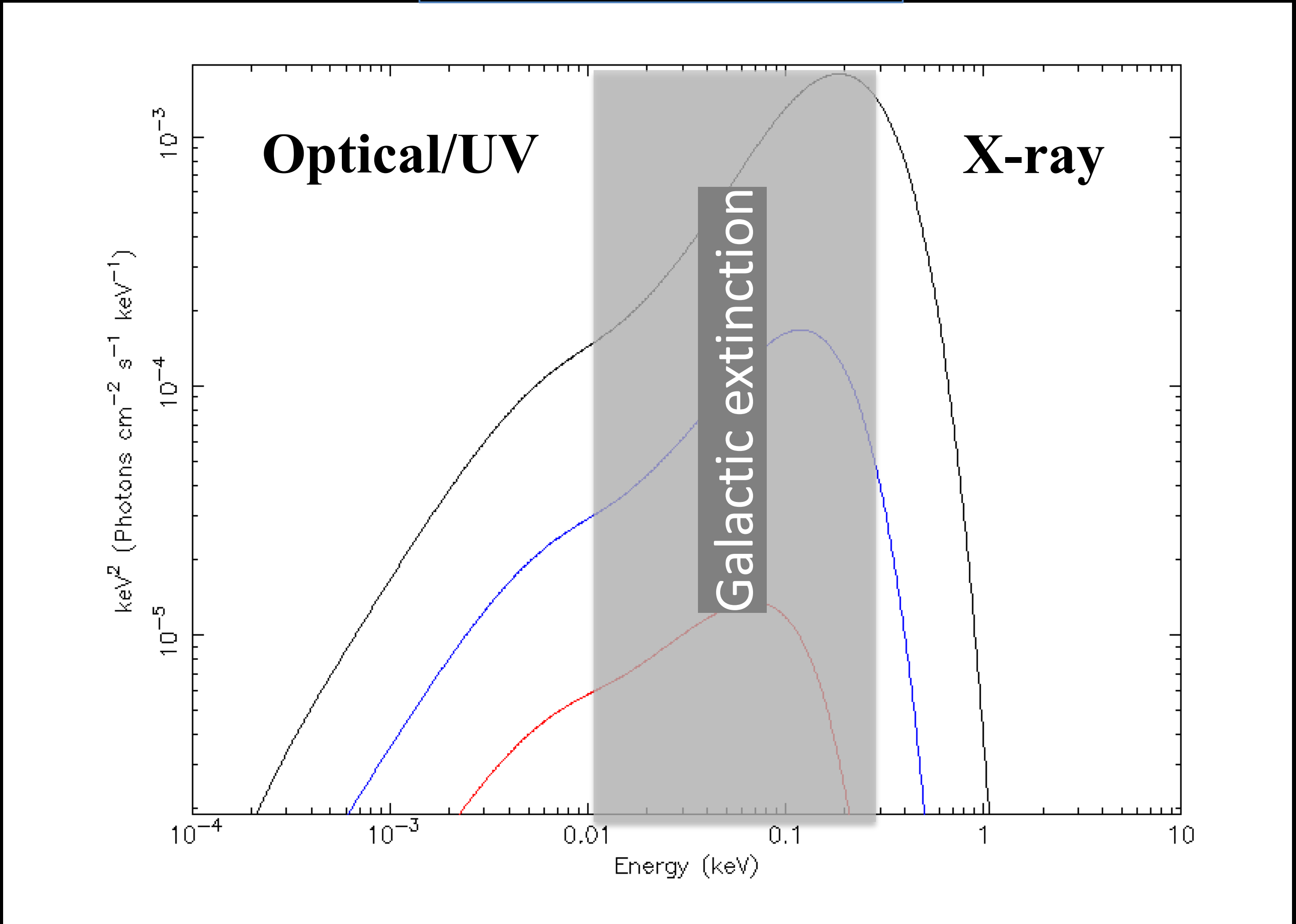
Standard Accretion Disc Spectrum

$M = 10^7\ M_\odot$



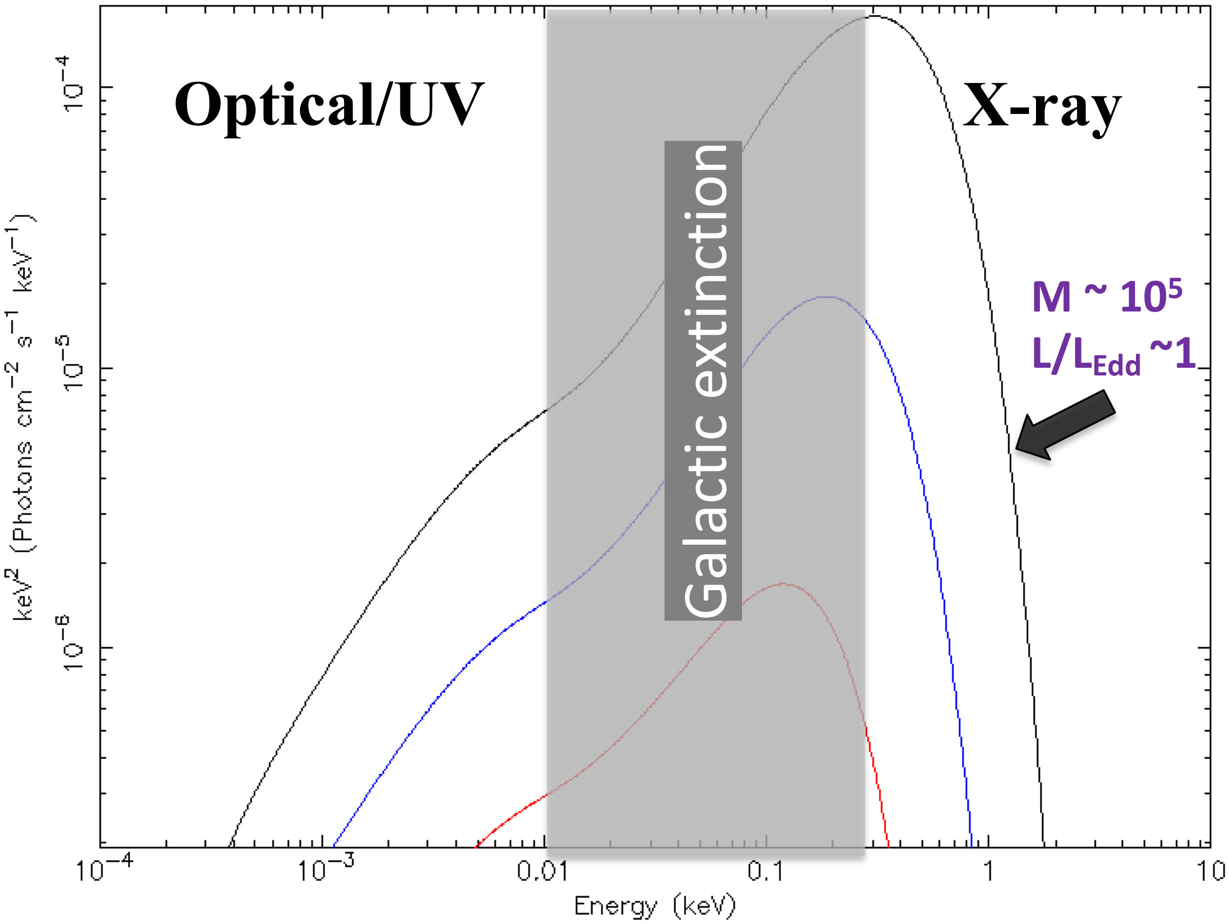
Standard Accretion Disc Spectrum

$M = 10^6\ M_\odot$



Standard Accretion Disc Spectrum

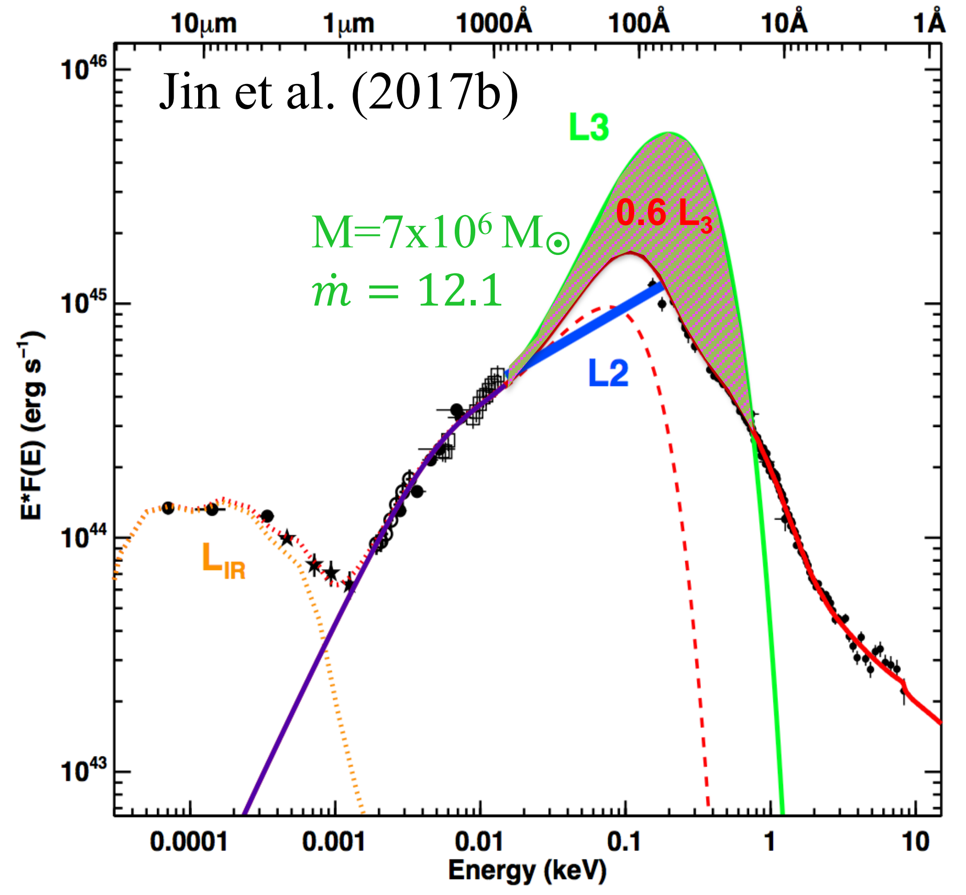
$M = 10^5 M_\odot$



Energy Budget and Radiation Efficiency

Most robust super-Eddington NLS1: RXJ0439.6-5311

$L_1 = 1.2\ L_2 = 0.4\ L_3 = 10.8\ L_{IR}$

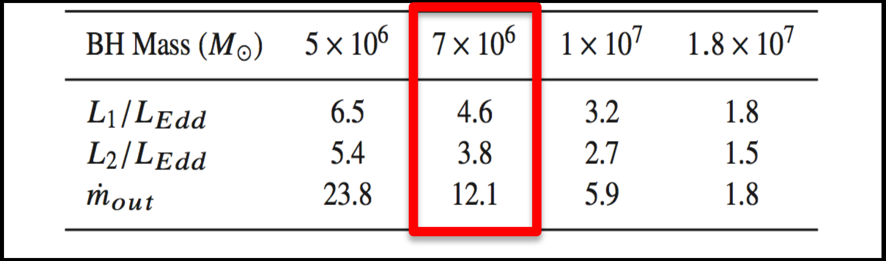


Black Hole Mass:

1. X-ray RMS: 0.8-3 $\times 10^6\ M_\odot$
2. X-ray HFB: 3-6 $\times 10^6\ M_\odot$
3. Opt. Spec: 5-9 $\times 10^6\ M_\odot$
4. SED: 1.8 $\times 10^7\ M_\odot$

$$F_{\rm opt} \propto \cos i\, (M\dot{M})^{2/3}$$

Davis & Laor (2011)

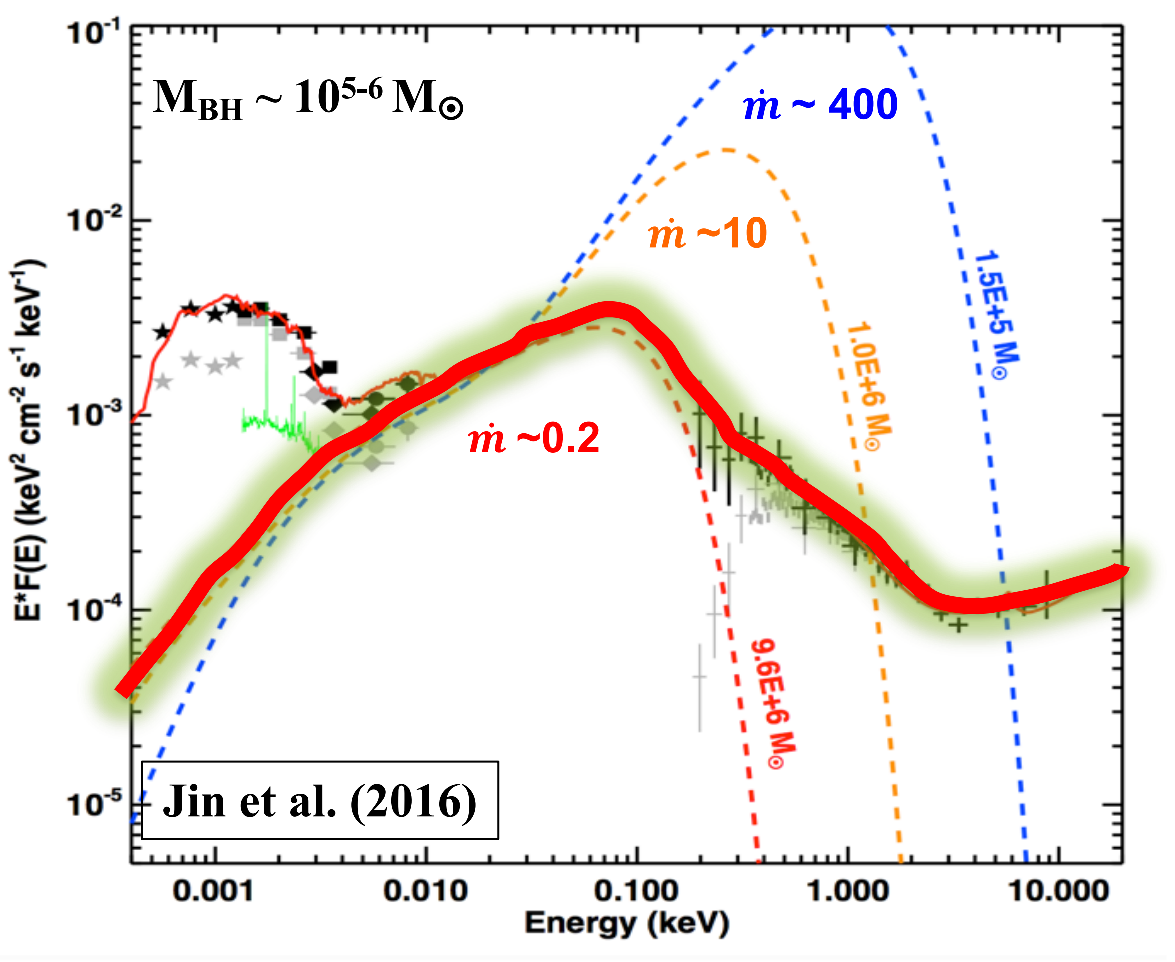


BH Mass ($M_\odot$)	5×10^6	7×10^6	1×10^7	1.8×10^7
L_1/L_{Edd}	6.5	4.6	3.2	1.8
L_2/L_{Edd}	5.4	3.8	2.7	1.5
$\dot{m}_{out}$	23.8	12.1	5.9	1.8

Energy Budget and Radiation Efficiency

SED discrepancy: Intermediate Mass black hole: RX J1140.1+0307

An Extreme Case!

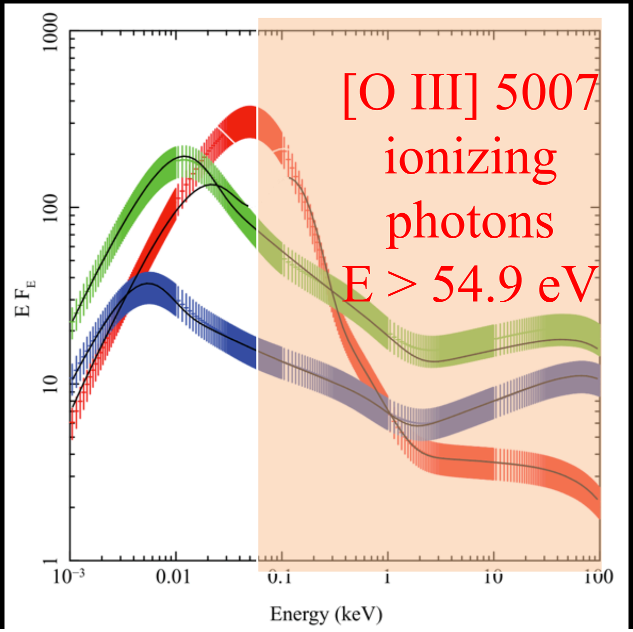


$M_{BH} \sim 10^{5\text{-}6}\,M_\odot$

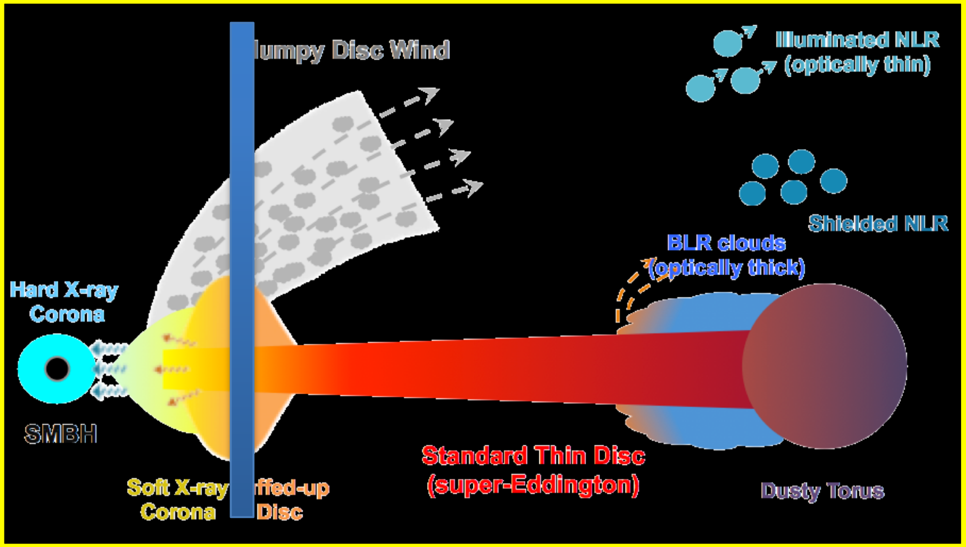
Jin et al. (2016)

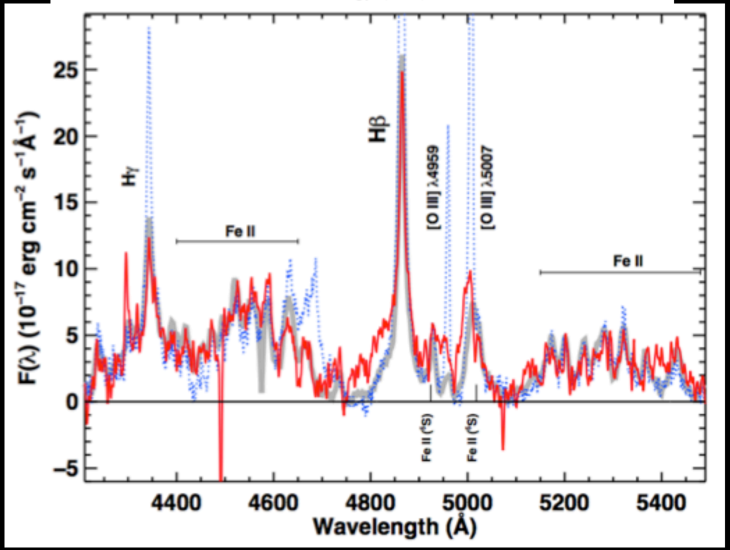
The Accretion Disc Structure

- ✓ Energy loss through the disc wind and/or advection:
  slim disc (e.g. Abramowicz et al. 1988)
  puffed-up disc (Jiang et al. 2014)
- ✓ Energetic soft excess, but weak [OIII] 5007 in the NLR:
  shielding mechanism
- ✓ BLR and NLR outflows



[O III] 5007 ionizing photons E > 54.9 eV





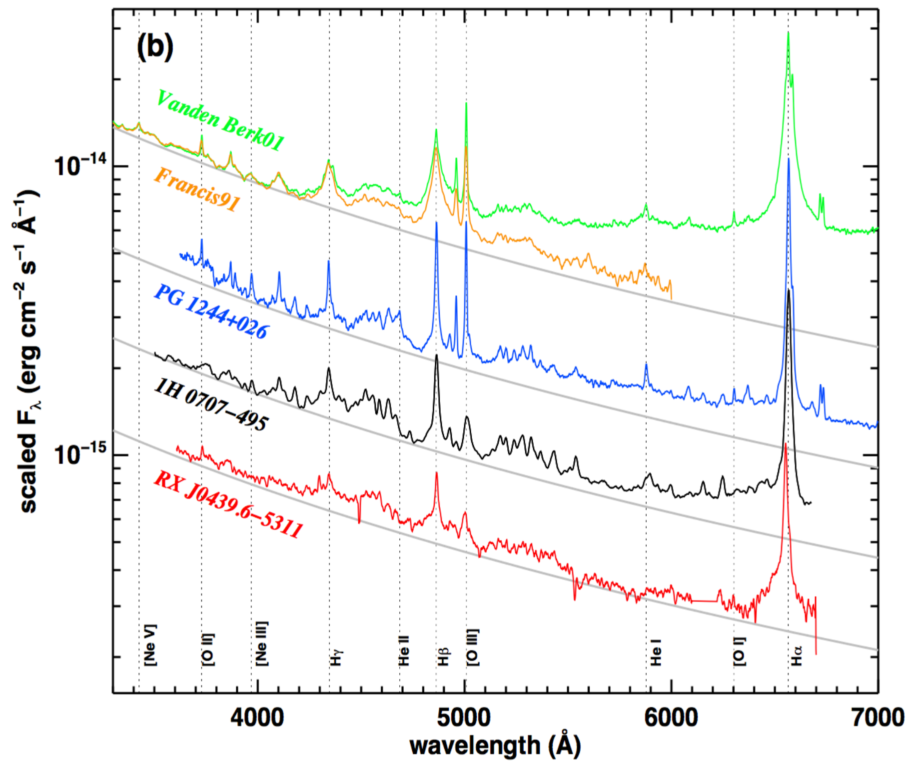
A Unified Picture for the Accretion Flow in all *Super-Eddington* NLS1s

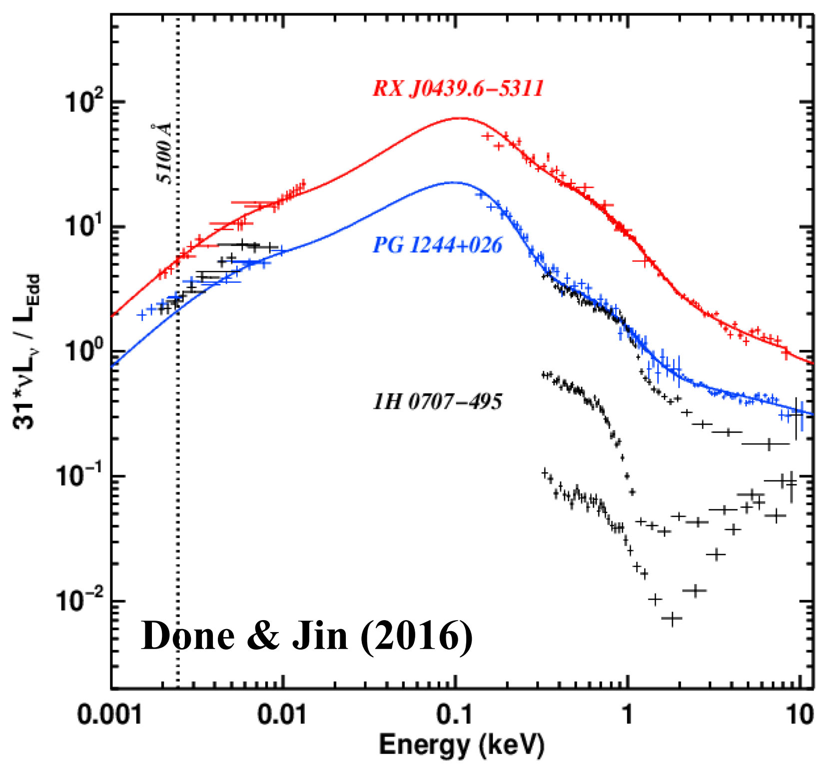
RXJ0439.6-5311, PG 1244+026, 1H0707-495

Similar black hole mass, mass accretion rate;

Similar optical/UV continuum and line emission;

but totally different X-ray spectral variability?! (viewing angle effect)



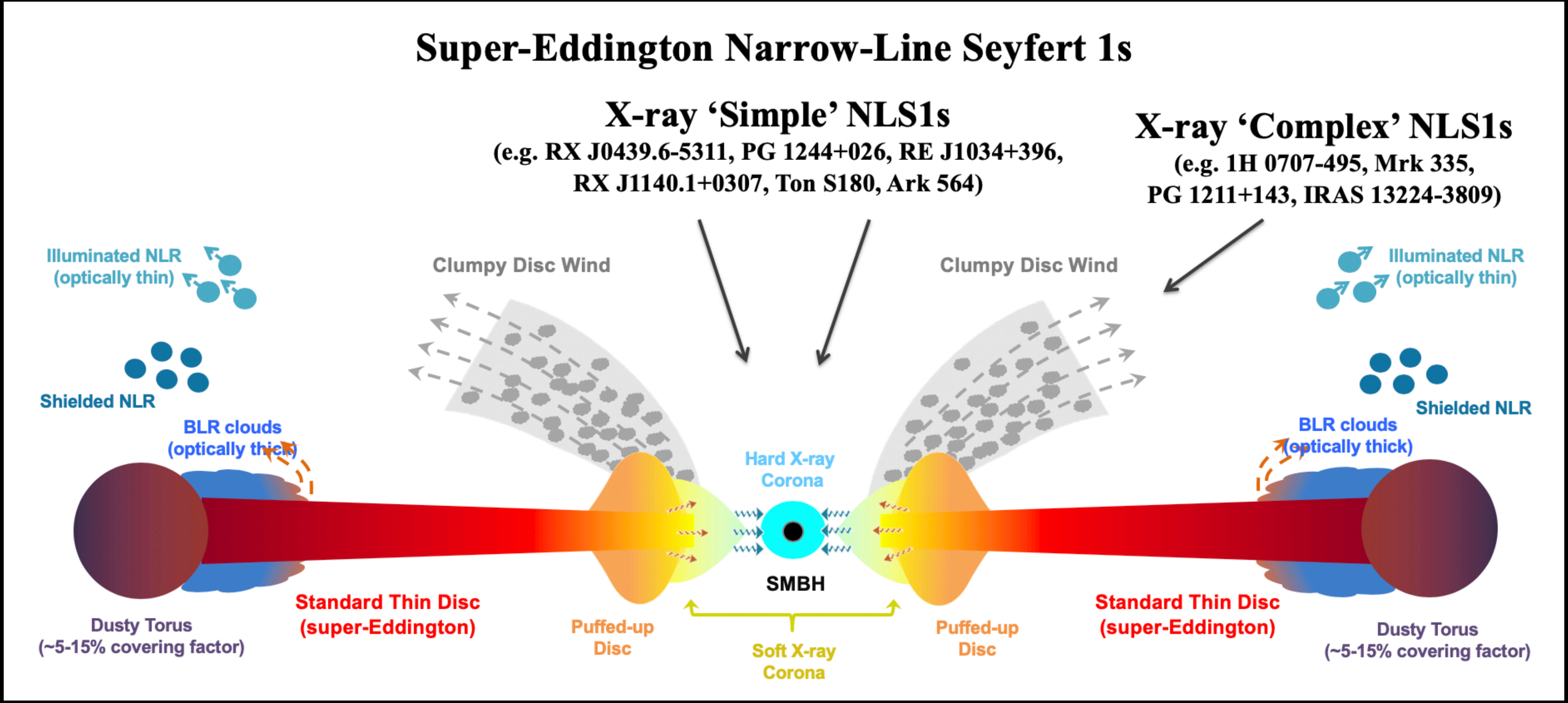


Done & Jin (2016)

A Unified Picture for the Accretion Flow in all *Super-Eddington* NLS1s

the **viewing angle effect** relative to the clumpy disc wind

Hagino et al. (2016); Done & Jin et al. (2016); Jin et al. (2017b)



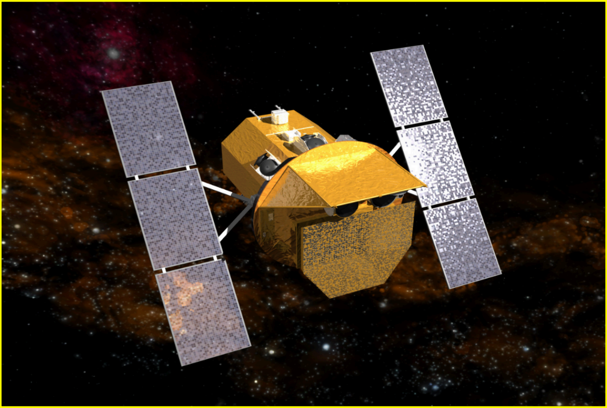
Jin et al. (2017b)

Multi-wavelength Variability Studies

XMM-Newton

t: min~hours

Swift

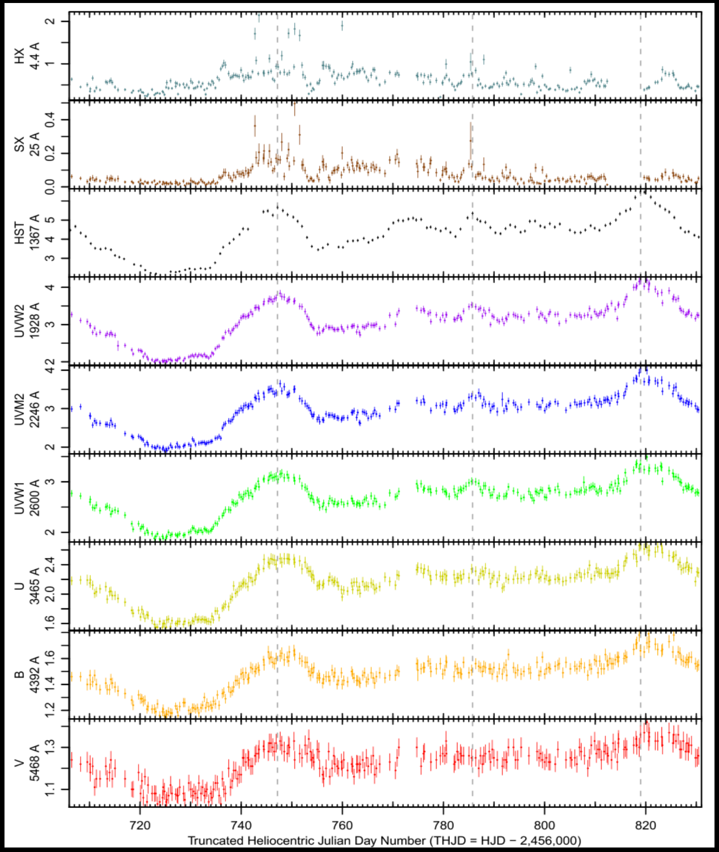


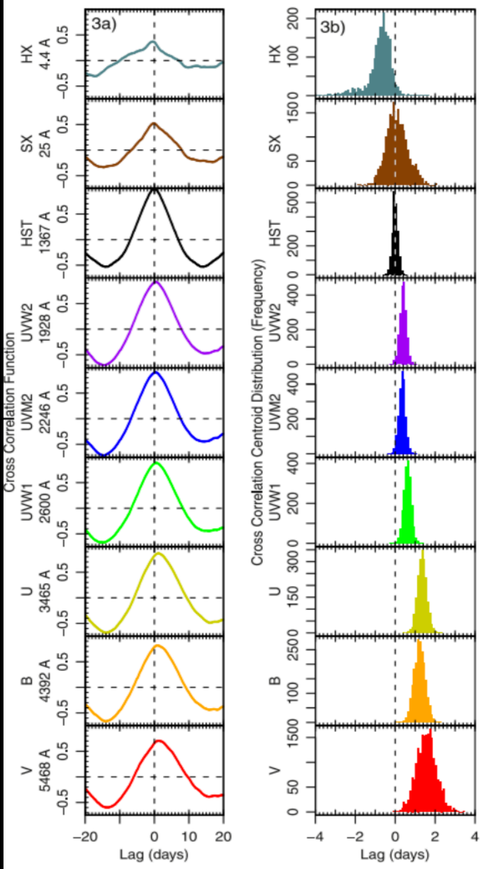
t: day~month

Correlations between the Optical, UV and X-ray Variability

X-ray leads UV, UV leads Optical

X-ray radiates the outer disc and gets reprocessed

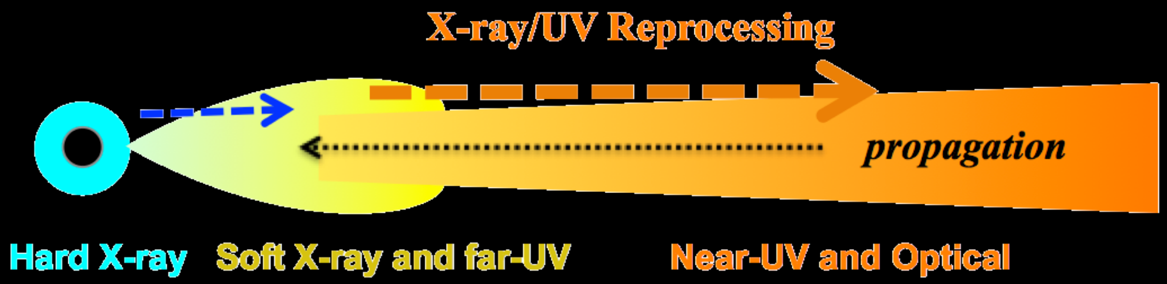




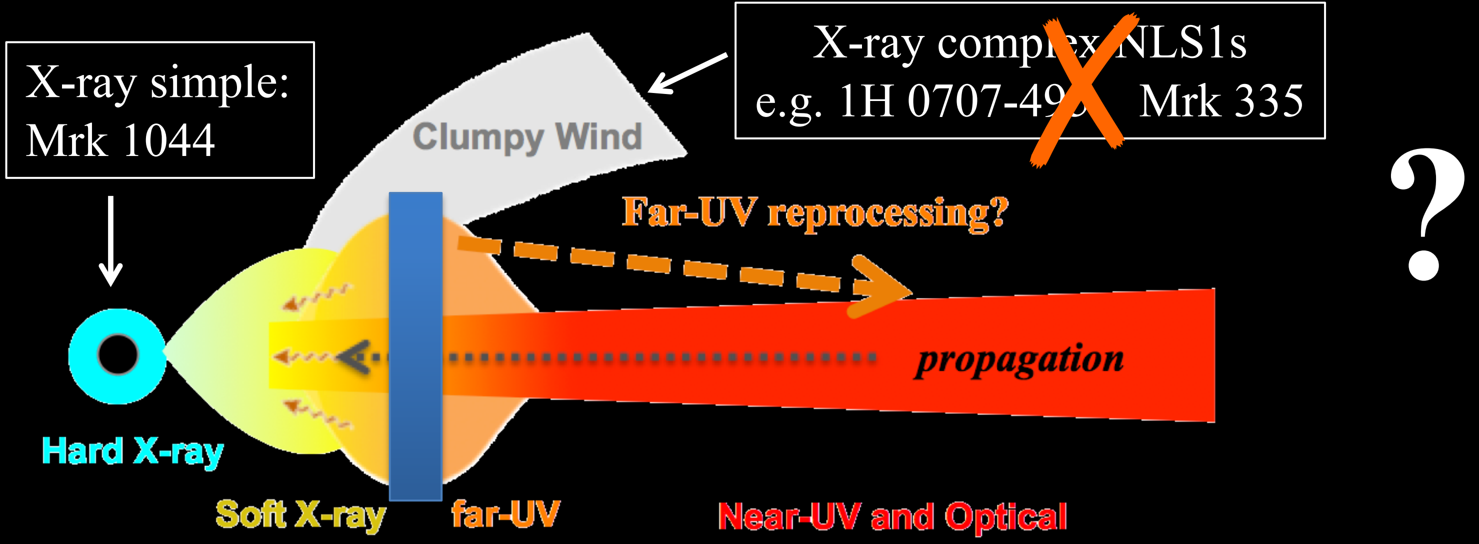
NGC 5548 (Swift & HST: 125 days' monitoring campain): Edelson et al. (2015)

Different Accretion Disc Structure under Different Mass Accretion Rates

Low-Eddington AGN: e.g. NGC 5548, NGC 4151, NGC 4051… （e.g. Edelson’s talk）



Super-Eddington NLS1



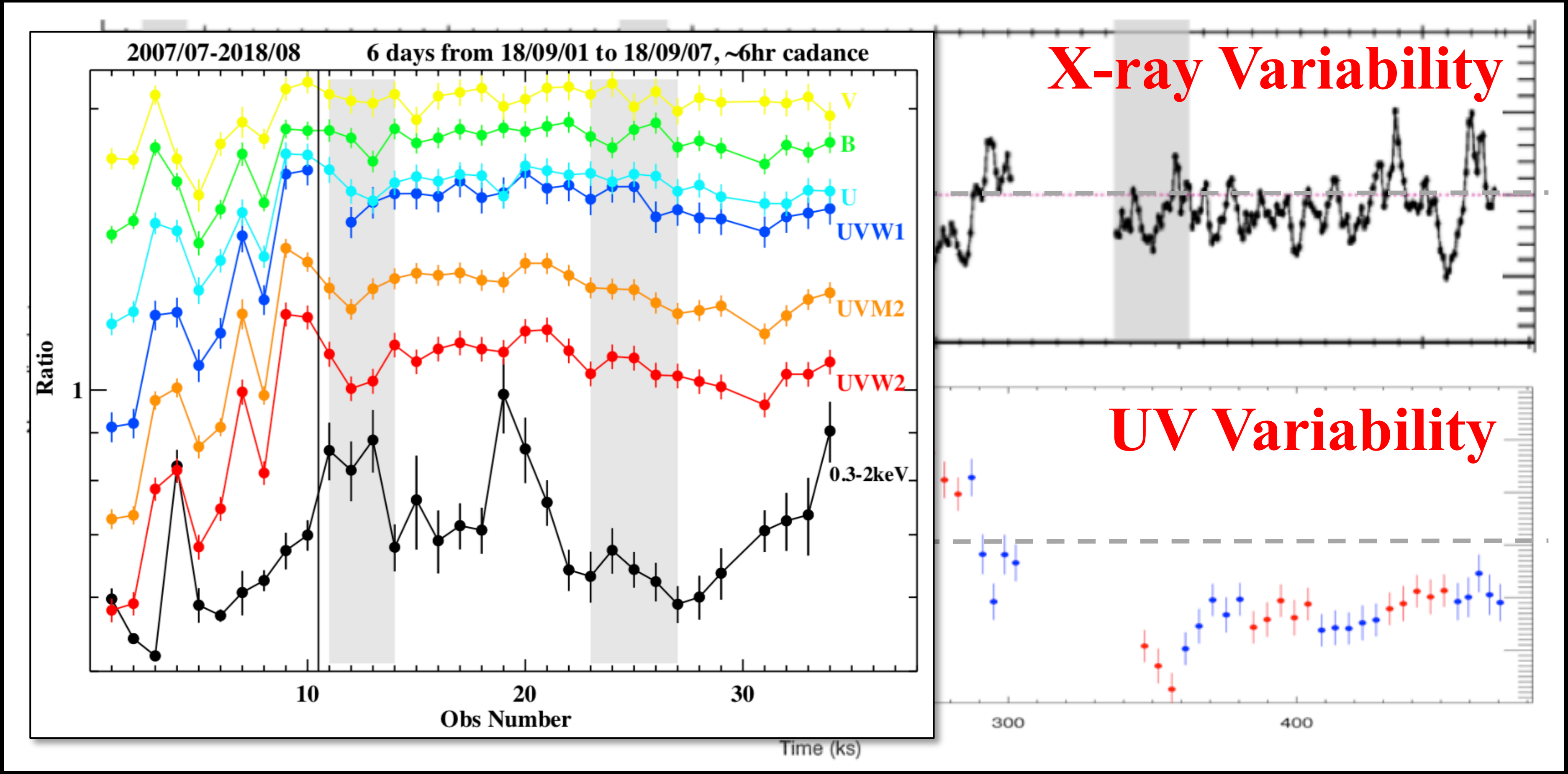
X-ray simple:
Mrk 1044

X-ray complex NLS1s
e.g. 1H 0707-495, Mrk 335

Recent Large XMM-Newton/NuSTAR Program
（PI: C. Jin）

Mrk 1044: 420 ksec, simultaneous UV (2600A) , 0.3-79 keV obs

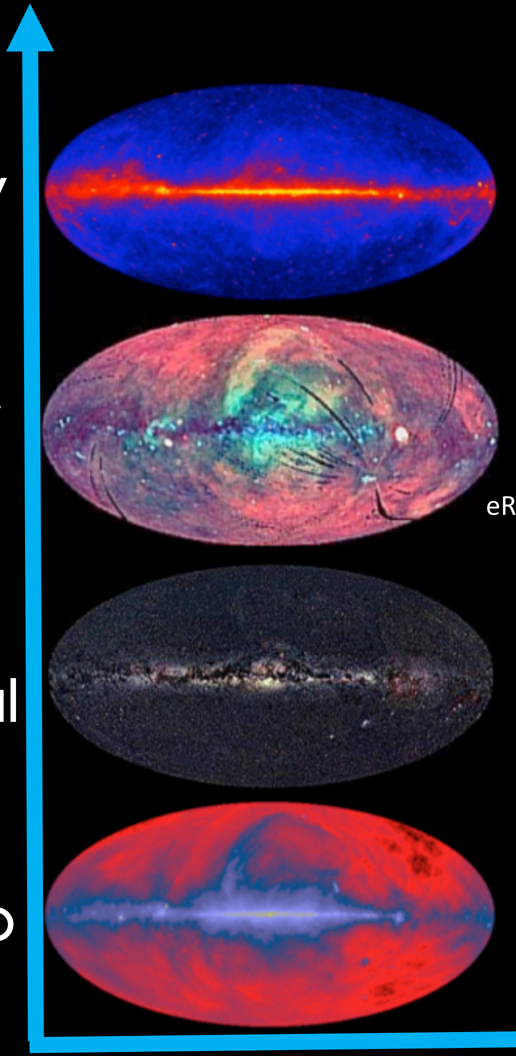
no correlation is found, as predicted by the puffed-up disc scenario



The Future
of AGN Multi-wavelength Observations

The Future: time-domain astronomy

Multi-wavelength



γ-ray

X-ray

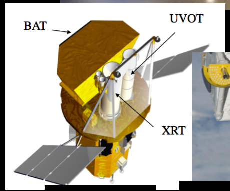
UV
Optical
IR

radio

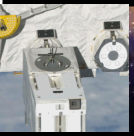
Time

Fermi

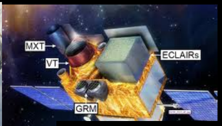
INTEGRAL



SWIFT

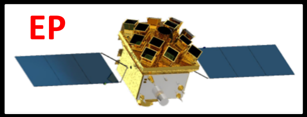


MAXI



SVOM

eROSITA



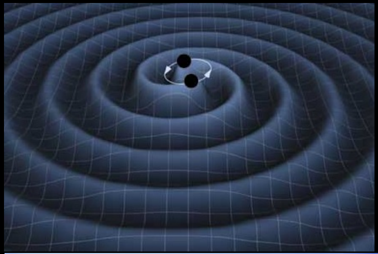
EP

LSST

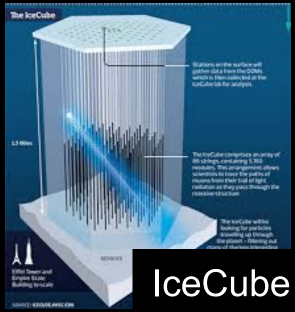
LOFAR、 SKA

Multi-messenger

GW, neutrino



LIGO/VIRGO/Kangra

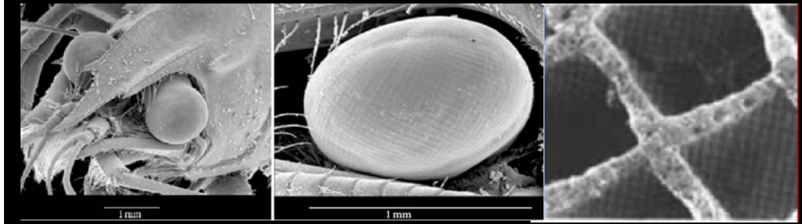


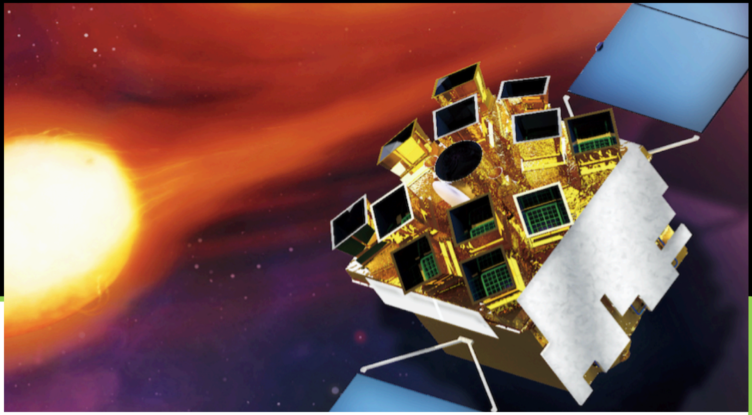
IceCube

The Einstein Probe (EP) mission

The first Lobster-eye soft X-ray all-sky monitor:

- Approved in 2017/Dec, fully funded in the space science programme of CAS (2nd phase)
- Expected launch: 2022/Dec
- Lifetime: 3 years (5 years goal)



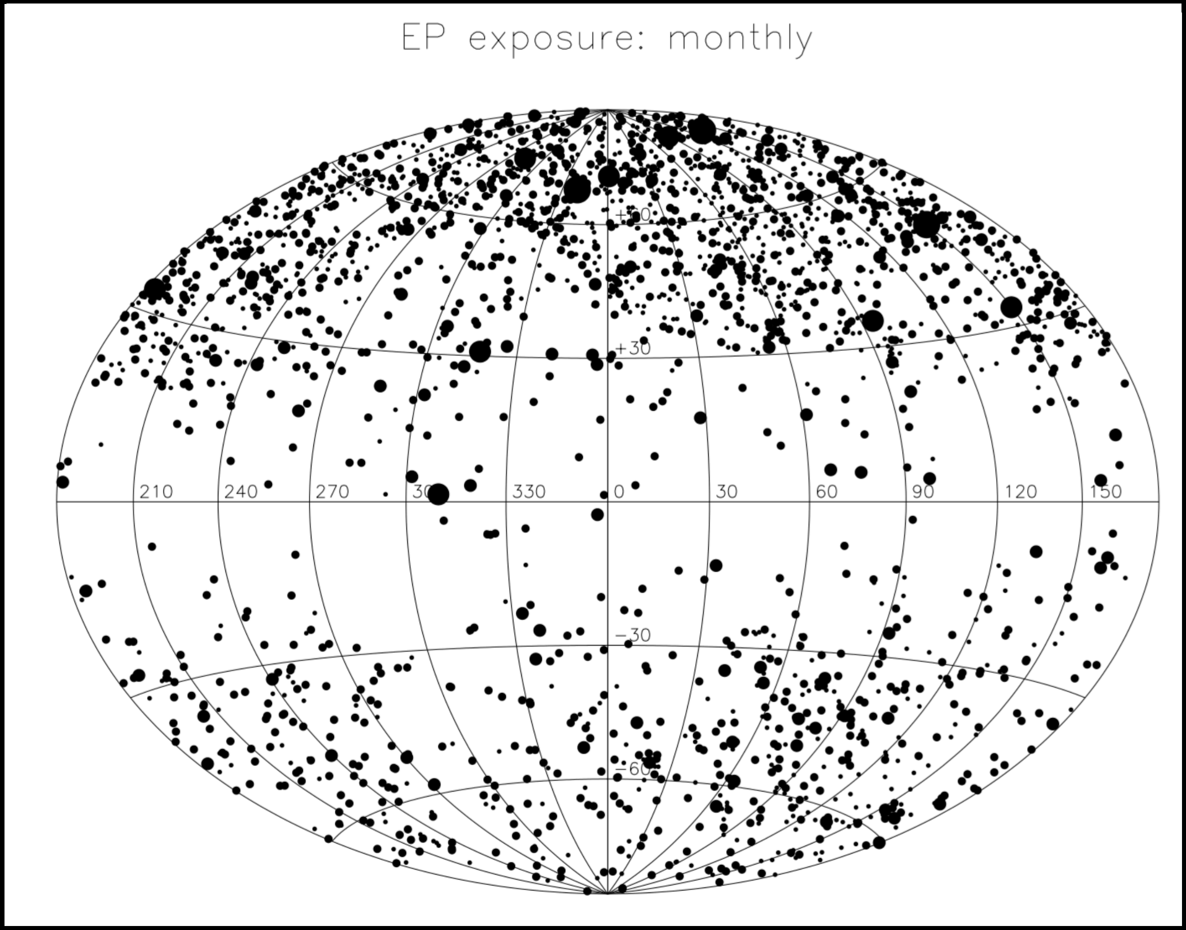


- Large Field of View 3600 sq. deg.
- Monitoring: soft X-ray band: 0.5-4 keV
- Sensitivity: > 1 order of magnitude higher than those in orbit
- Good angular resolution (~5’ fwhm) and positioning accuracy (<1’)
- Autonomous X-ray follow-up (<10 arcsec localisation; 0.3-10keV)
- Fast alert data downlink and (possible) fast uplink (ToO)

AGN Observation of EP

By-product science: Large samples of AGN can be monitored at various cadence

- Monitoring variability on long timescales



~140 AGN detectable (5 sigma) in one day data taking
(normal survey mode)

~700 AGN detectable weekly

~1,600 AGN detectable monthly

AGN Observation of EP

AGN Study in the time domain:

1. <u>AGN X-ray Long-term monitoring (WXT)</u>

- ➢ AGN X-ray Variability and Power Spectrum
- ➢ Most Extremely Variable AGN: AGN outbursts, flares, state transition (?), duty cycle (?)
- ➢ Multi-wavelength variability study

etc…

2. <u>ToO Observations (FXT)</u>

- ➢ Deep Following-up observations of unusual AGN behaviors

etc…

Conclusions

1. NLS1s are complex sources: X-ray simple & X-ray complex
2. The X-ray spectrum can be decomposed into a hard X-ray Compt., soft X-ray Compt., inner disc and a weak reflection, which is supported by detailed X-ray spectral-timing analyses;
3. The optical/UV of the broadband SED is dominated by the disc emission plus the host galaxy
4. A large fraction of the energy in the flow must be taken away by the outflow and/or advection rather than all being radiated
5. Viewing angle effect plays an important rule in producing the diversity of multi-wavelength properties
6. Multiwavelength monitoring of unobscured super-Edd NLS1s is also very important for understanding the AGN accretion
7. Much more multiwavelength monitoring data are expected in the future with large surveys and all-sky monitors

Thank you!

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