European Research Council

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AGN coronae

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STRONGGRAVITY

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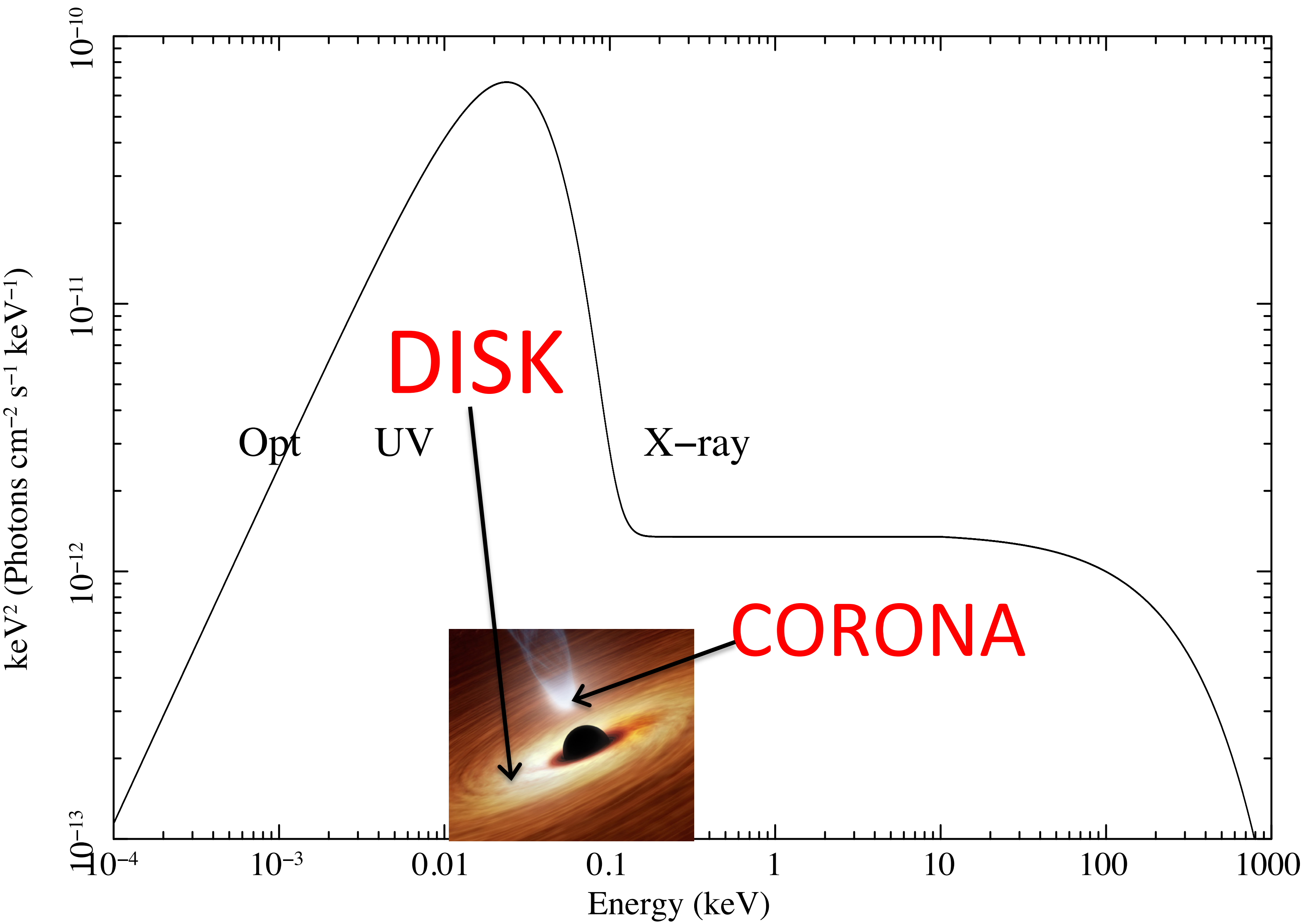
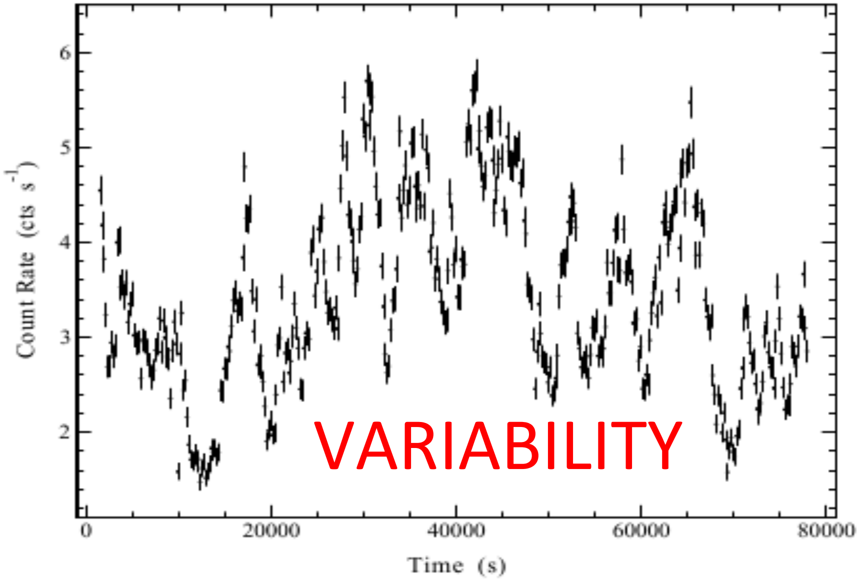
2013 - 2017

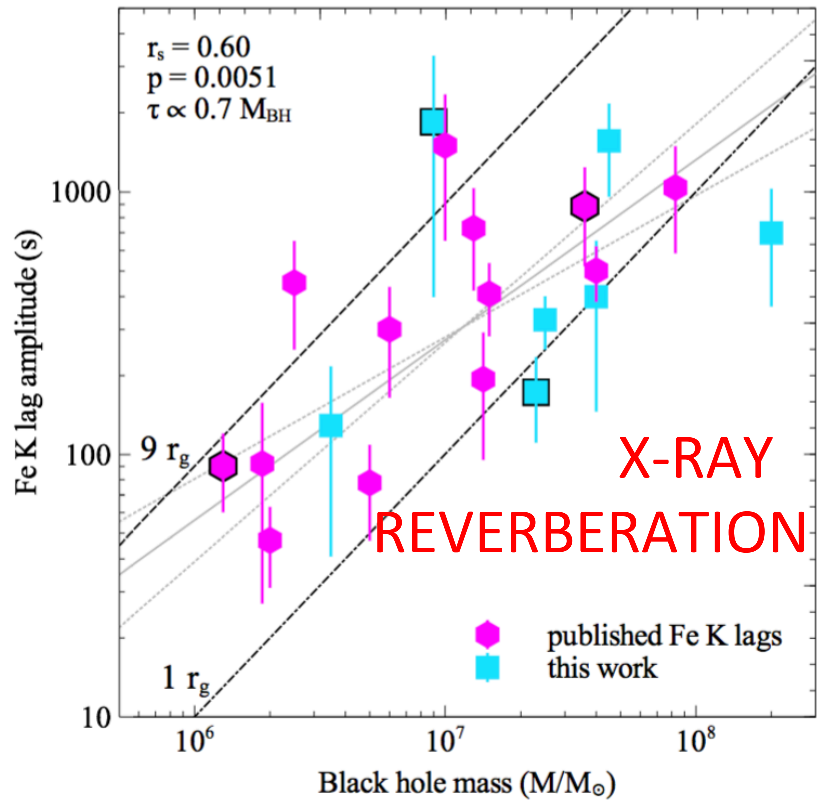

DISK
CORONA
Opt
UV
X–ray
keV² (Photons cm⁻² s⁻¹ keV⁻¹)
Energy (keV)
10⁻¹⁰
10⁻¹¹
10⁻¹²
10⁻¹³
10⁻⁴
10⁻³
0.01
0.1
1
10
100
1000

How to constrain geometry of corona

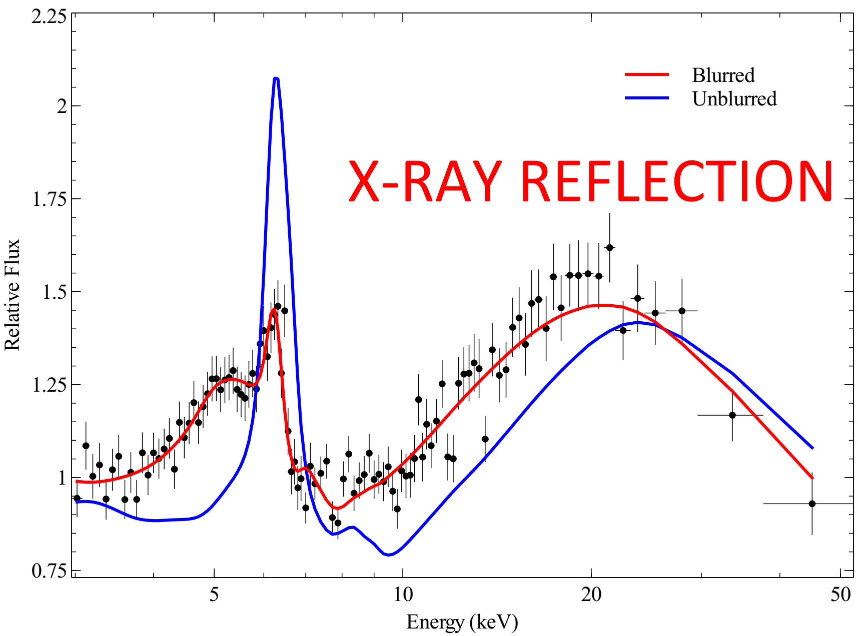
- Variability
- Reflection
- Reverberation
- Emissivity profiles
- Gravitational microlensing
- Occultations

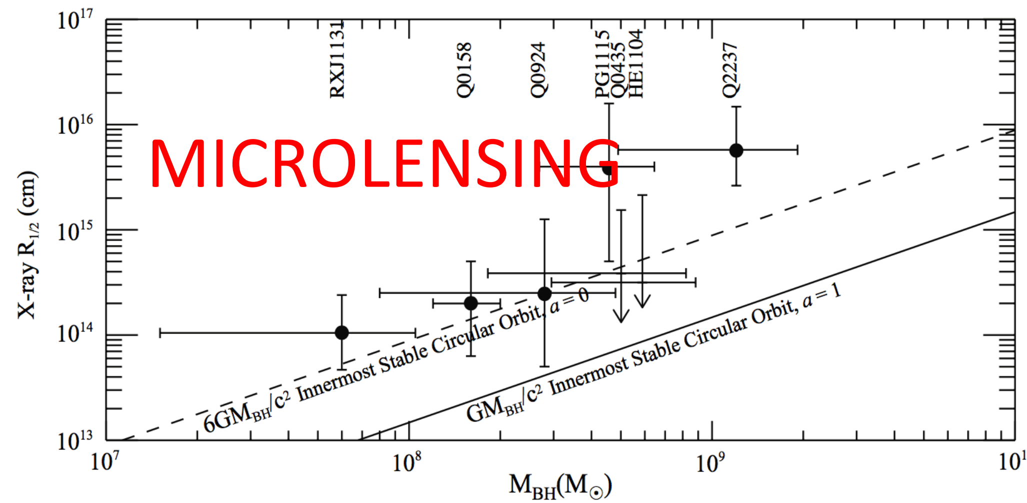
- Brightest parts of the Universe immediately next to the darkest parts





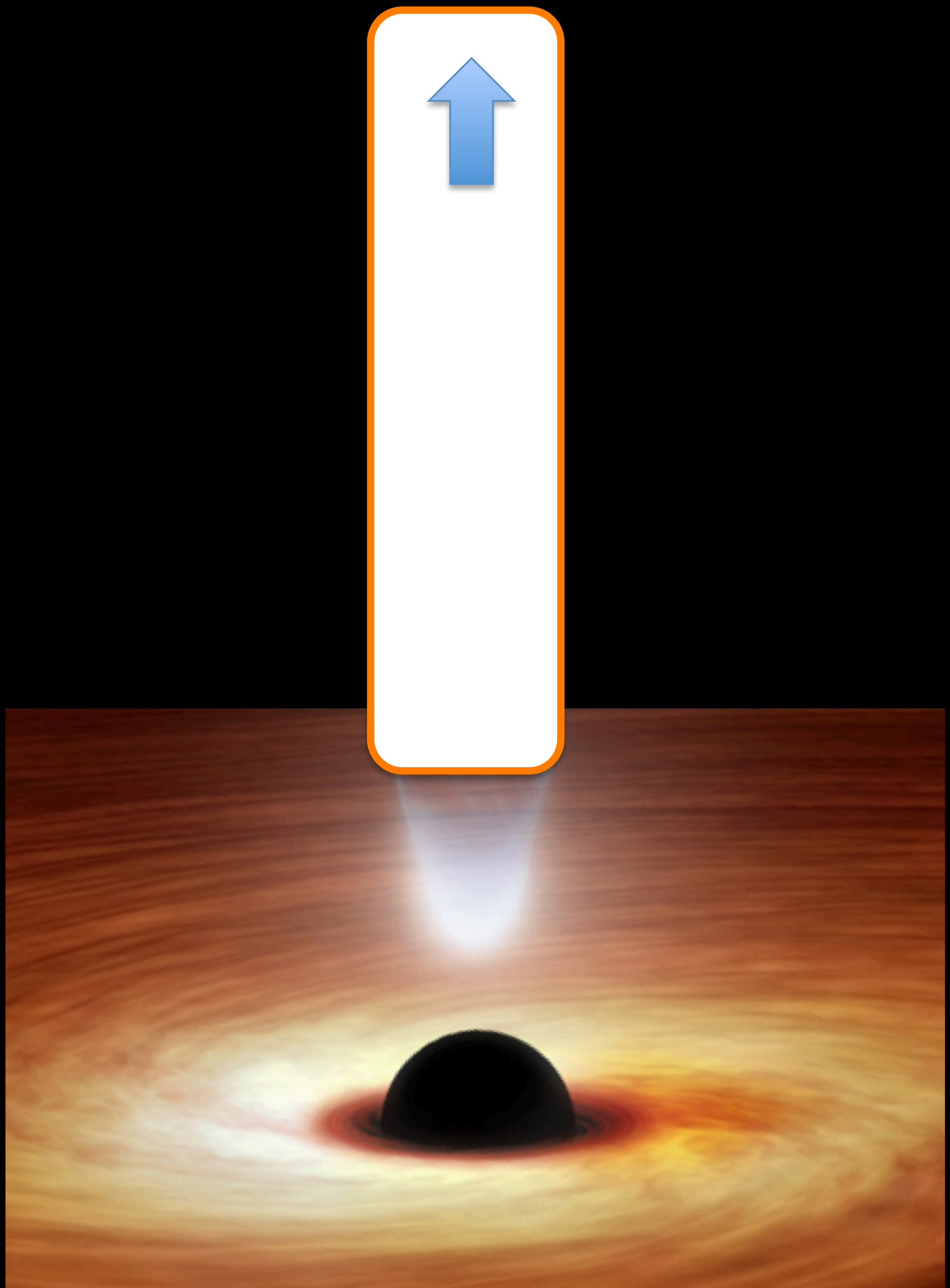
CORONAL SIZE CONSTRAINTS





Coronal properties

- $15<kT<150$ keV, most 50-100 keV
- $R<10\ r_g$ for much of the power
- Some could be outflowing (Beloborodov99, Malzac+01, Wilkins+14)
- Probably not static!
- Lowest part of corona dominates reflection, outflowing upper part dominates observed powerlaw



WHAT DETERMINES CORONAL TEMPERATURE?

WHAT DETERMINES CORONAL TEMPERATURE?

ITS COMPACTNESS

Concept of Compactness introduced in 1980

EXTREME NONTHERMAL RADIATION FROM ACTIVE GALACTIC NUCLEI

A. CAVALIERE AND P. MORRISON

Received 1979 September 24; accepted 1980 February 29

ABSTRACT

The physics of emission from the powerful continuum sources within active galactic nuclei can be characterized by the parameter L/R, a measure of compactness. For values of L/R exceeding some 10^{30} ergs s^{-1} cm^{-1} energy losses by relativistic electrons are so rapid that they must come into general balance with simultaneous processes of energy gain.

The ratio L/R determines the photon collision analog of the optical depth for an emitting electron

Photon number density proportional to L/R^2 so L/R is proportional to the column density of photons in the source

CORONA IS RADIATIVELY COMPACT

Dimensionless compactness parameter, GuilbertFabianRees83

$$\ell = \frac{L}{R}\frac{\sigma_T}{m_e c^3}.$$

$$l = \left(\frac{m_{\mathrm{p}}}{m_{\mathrm{e}}}\right)\left(\frac{R}{R_{\mathrm{S}}}\right)^{-1}\left(\frac{L}{L_{\mathrm{Edd}}}\right)$$

For AGN, ℓ typically 10-1000

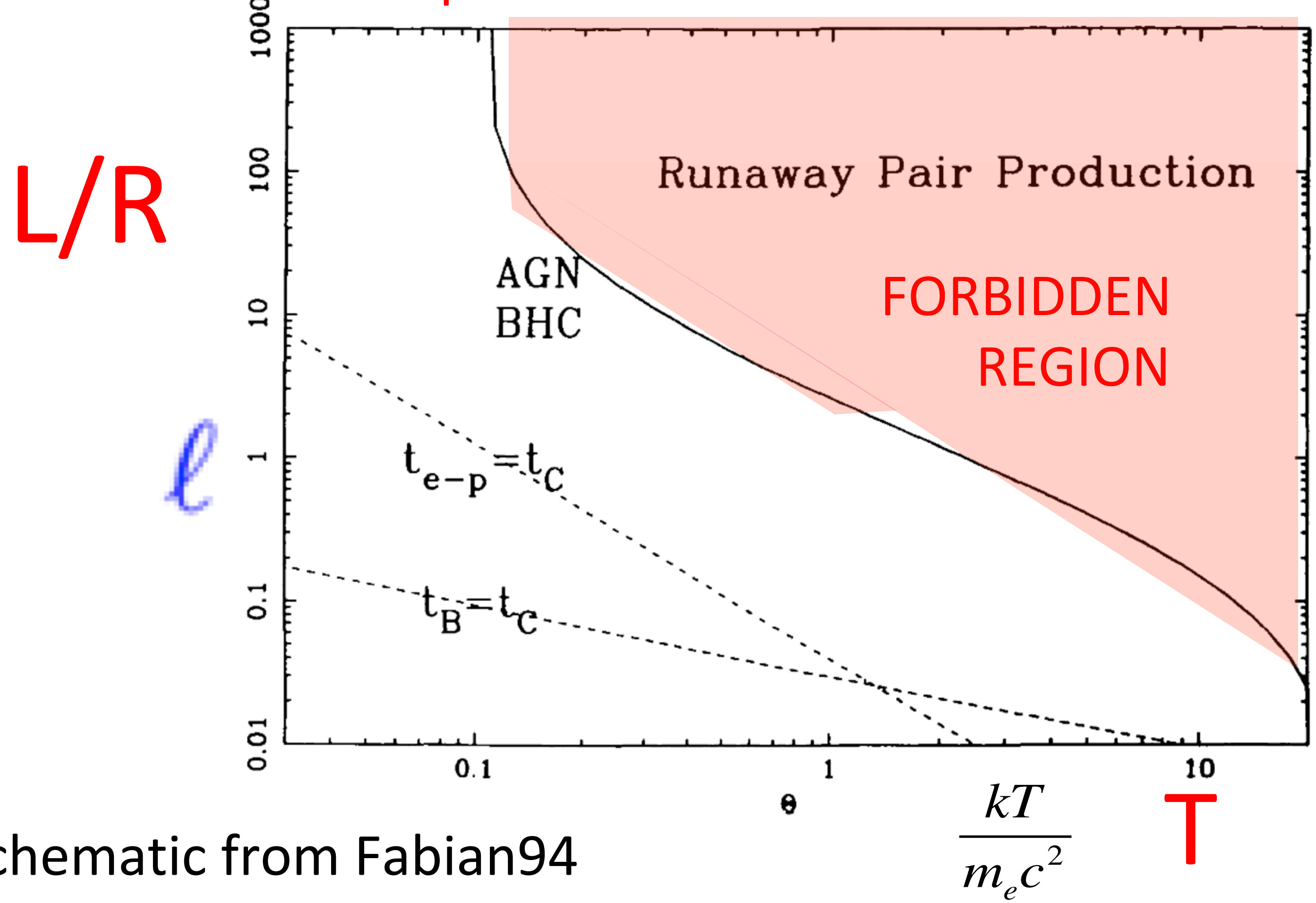
Compton cooling time < light crossing time

PAIR PRODUCTION: electron-positron pairs form when photons and/or particles collide at energies $> m_e c^2 = 511 keV$

photon-photon collisions: $\gamma + \gamma \rightarrow e^{\pm}$ requires $\frac{\epsilon_1}{m_e c^2} \frac{\epsilon_2}{m_e c^2} > 2$

Svensson, 82,84, Zdziarski 85, many other papers and workers 80s + 90s

Concept of PAIR THERMOSTAT introduced



Schematic from Fabian94

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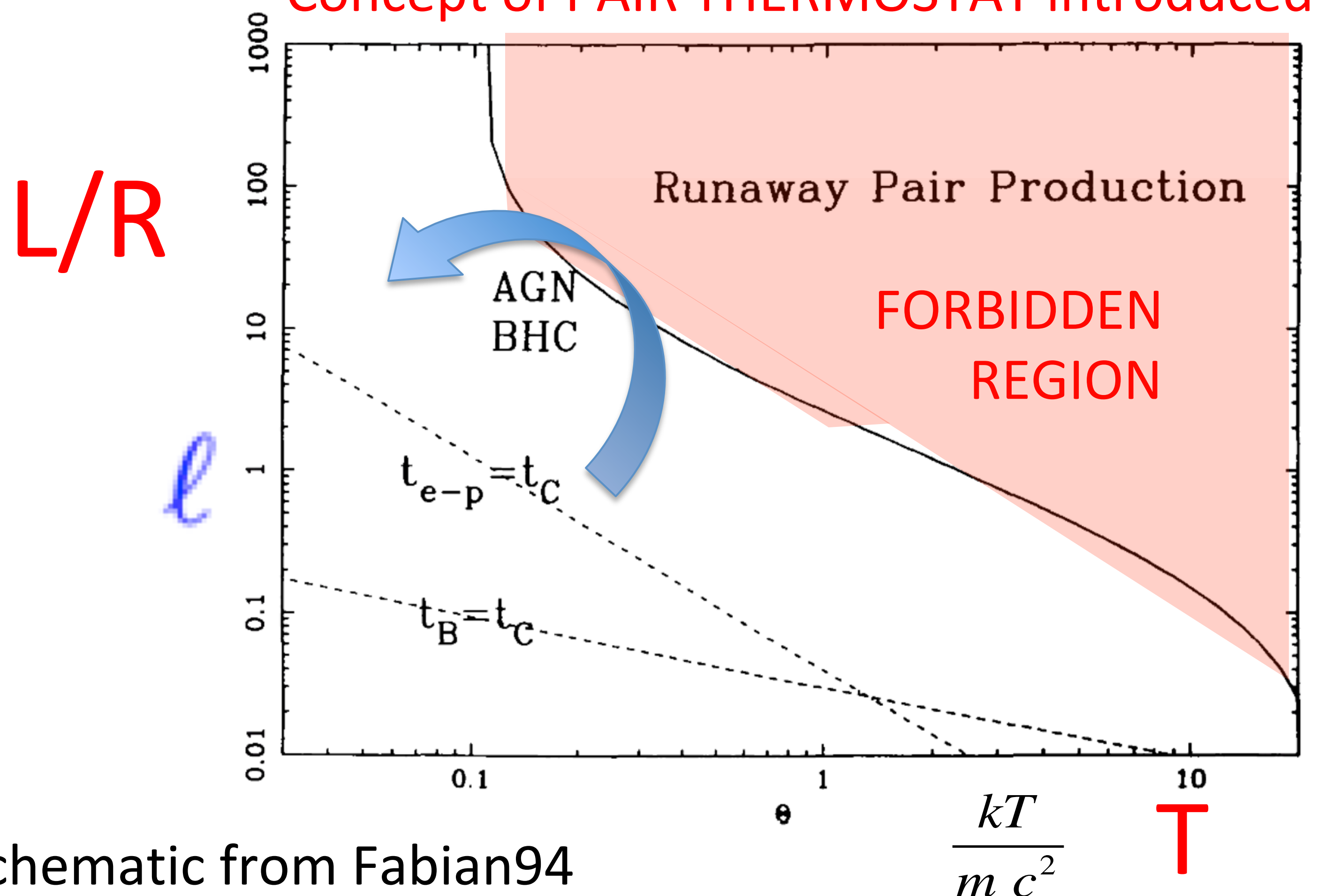
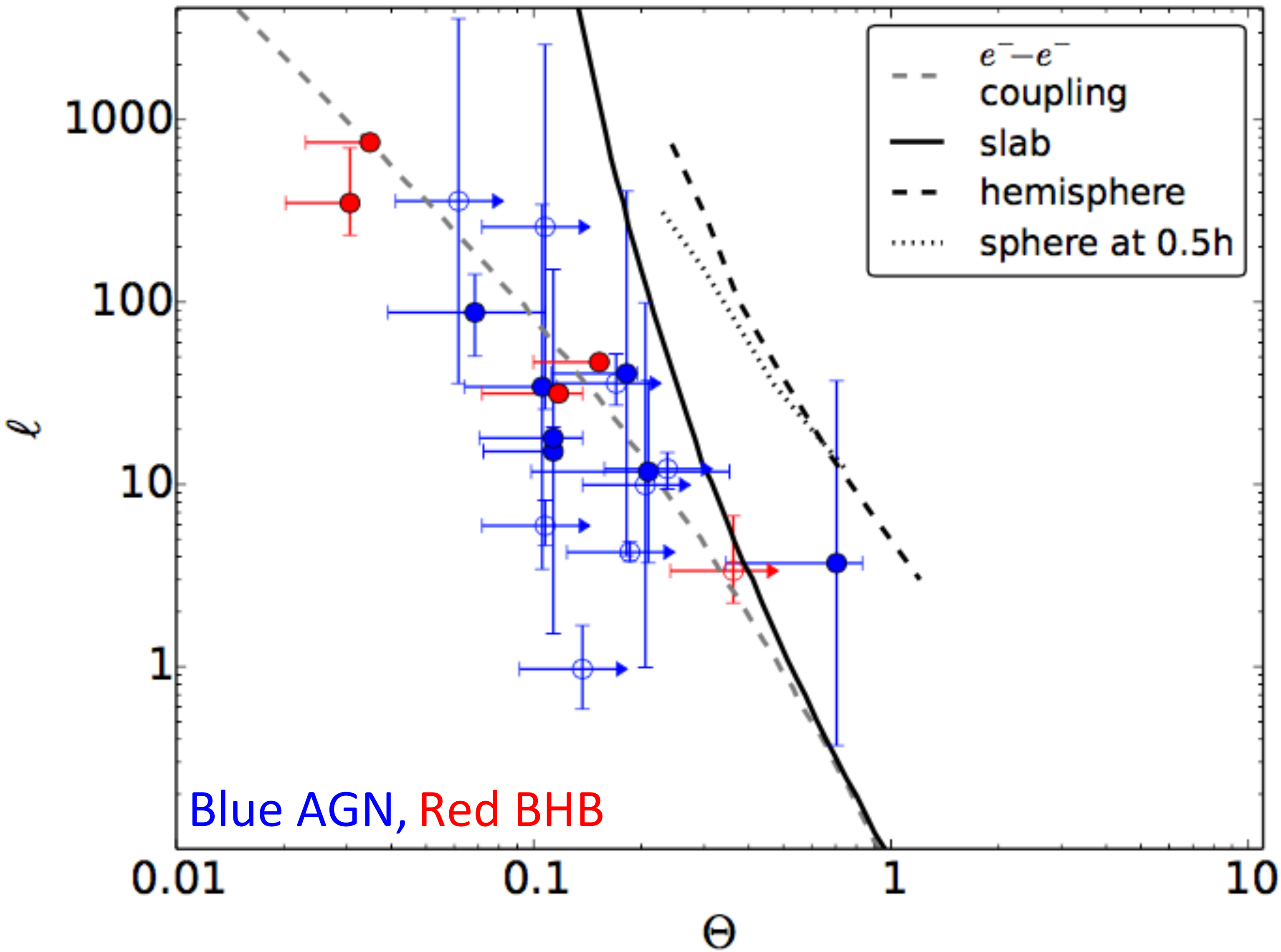


Schematic from Fabian94

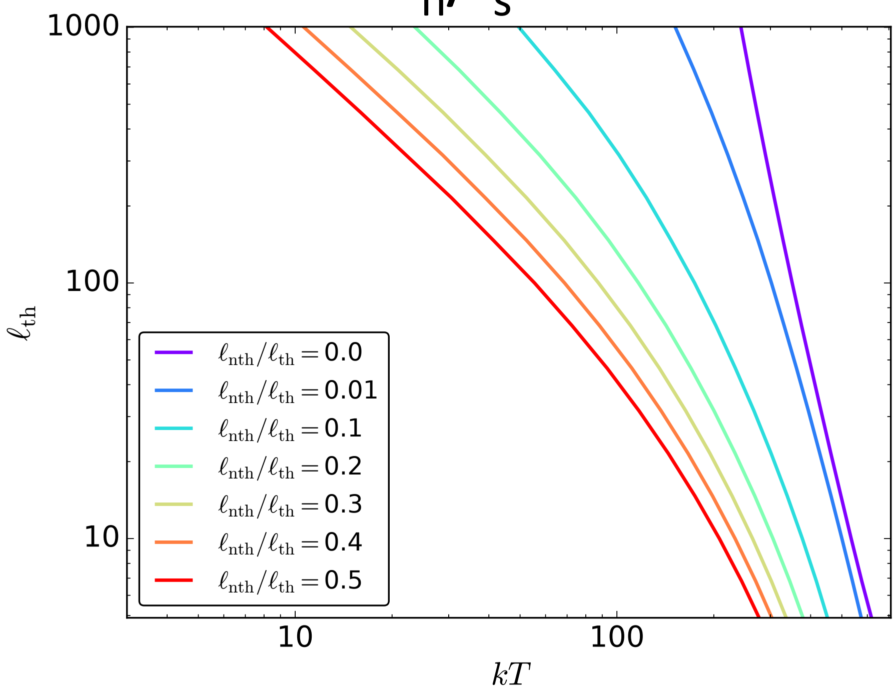
NuSTAR results



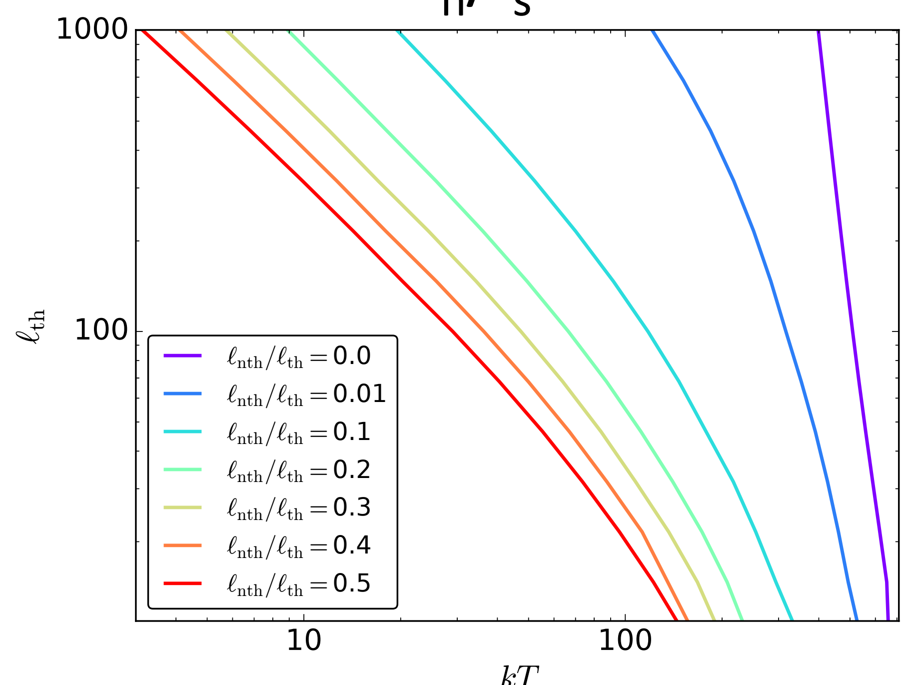
R=10r_g unless indications otherwise   Fabian+15

Effect of addition of nonthermal particles - Hybrid Plasma

l_h/l_s=1



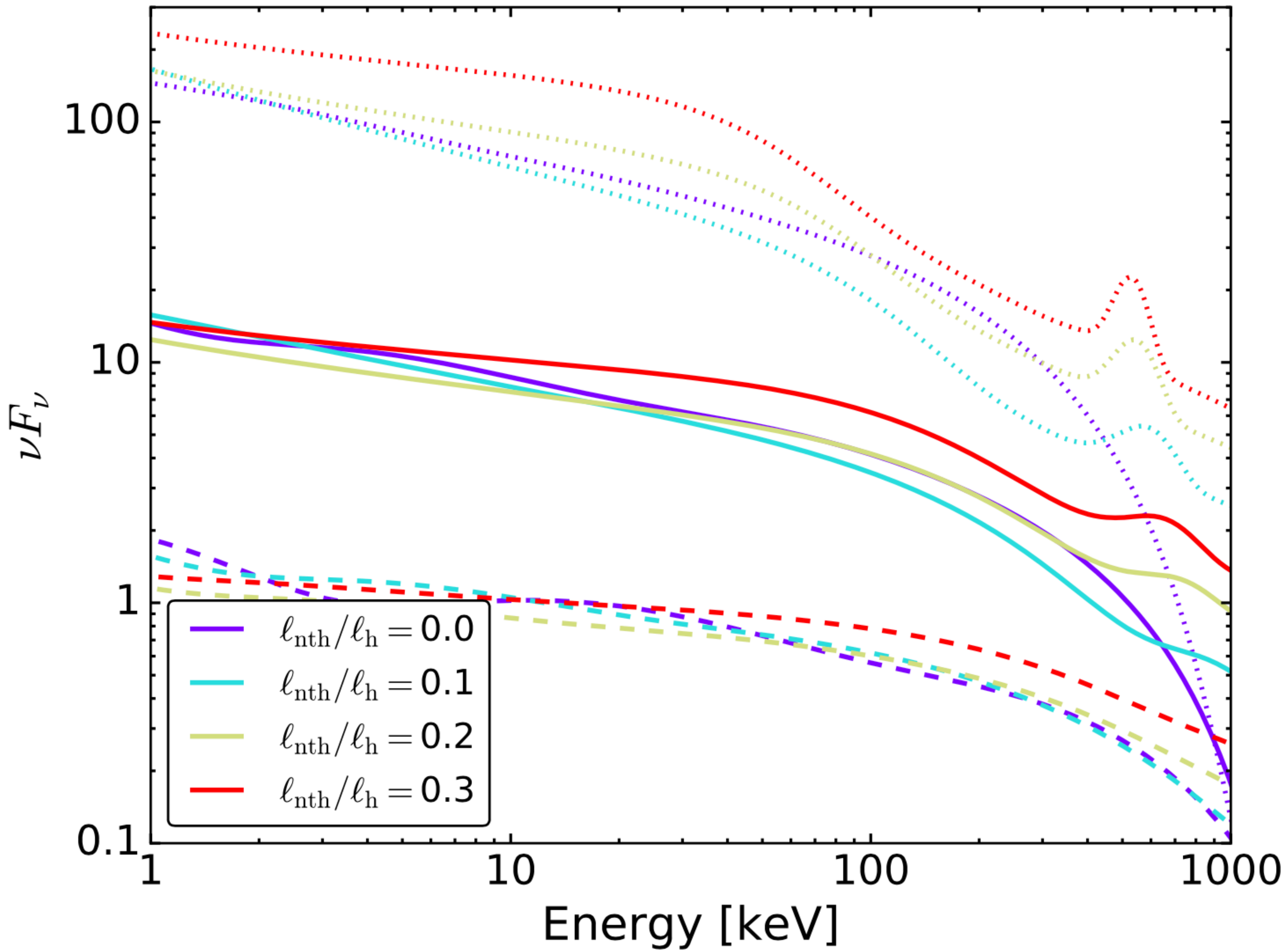
l_h/l_s=0.1



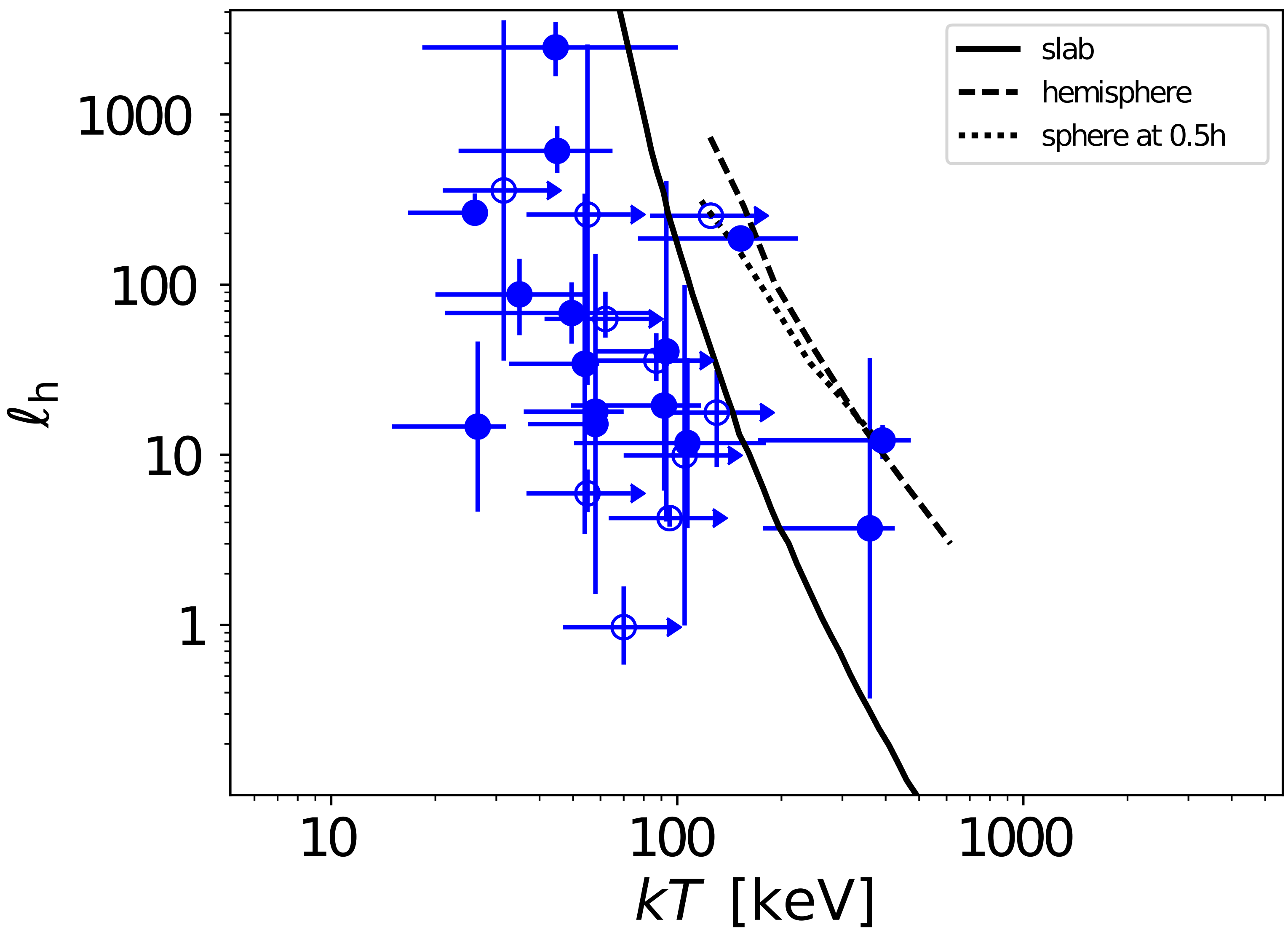
Uses BELM, similar results for EQPAIR

Fabian, Lohfink, Belmont, Malzac, Coppi 17

See Zdziarski+93, Ghisellini+93, Coppi99…

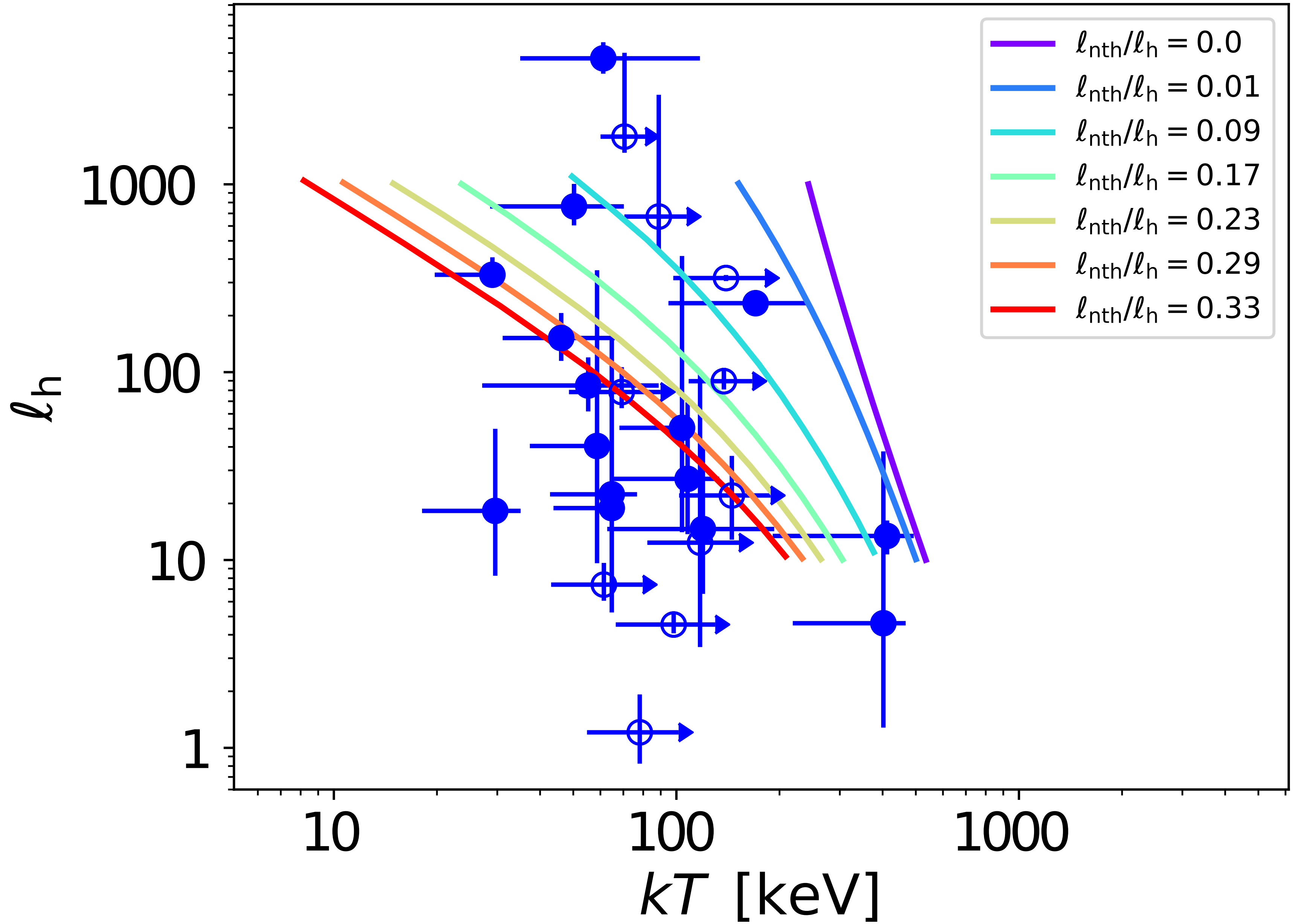


100
10
1
0.1
νF_ν
1
10
100
1000
Energy [keV]
$\ell_{\rm nth}/\ell_{\rm h} = 0.0$
$\ell_{\rm nth}/\ell_{\rm h} = 0.1$
$\ell_{\rm nth}/\ell_{\rm h} = 0.2$
$\ell_{\rm nth}/\ell_{\rm h} = 0.3$



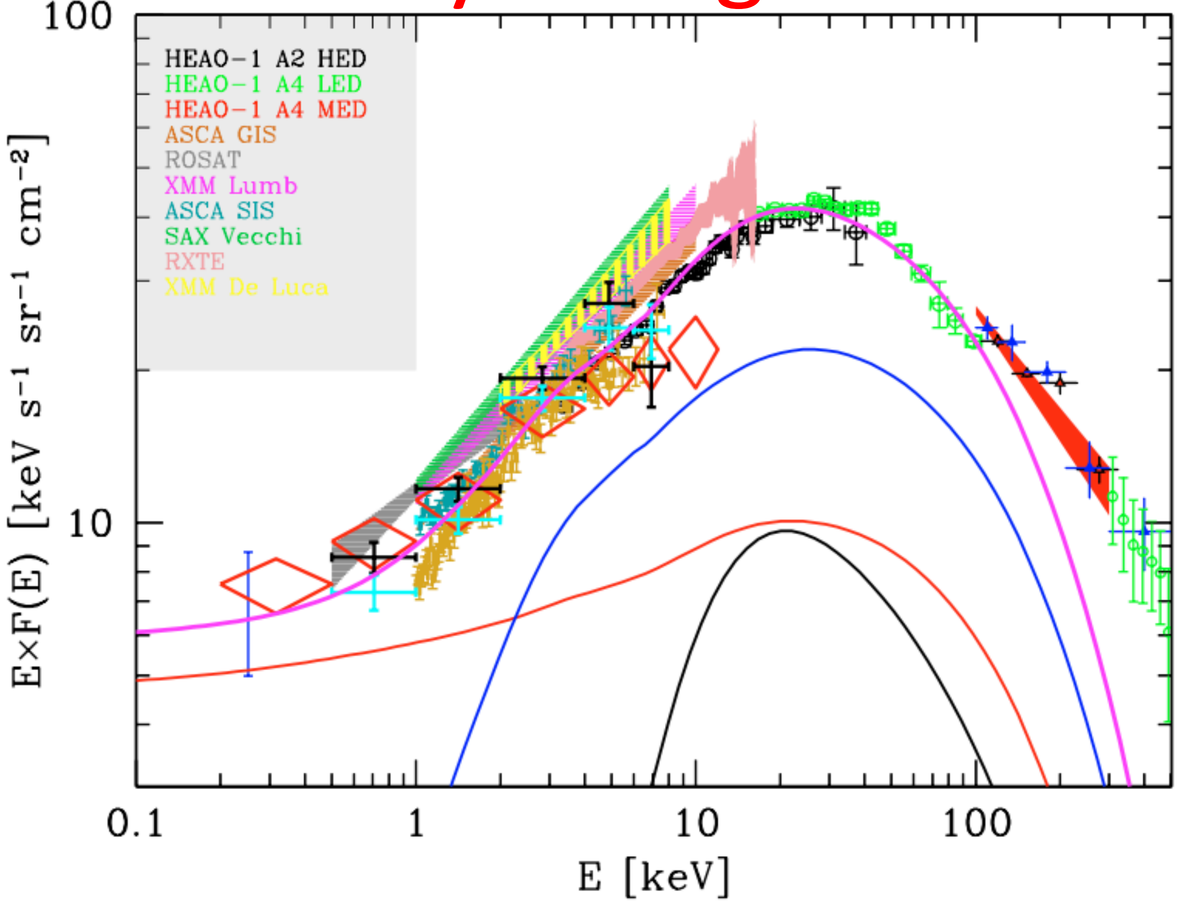
Updated by Anne Lohfink

With GR corrections

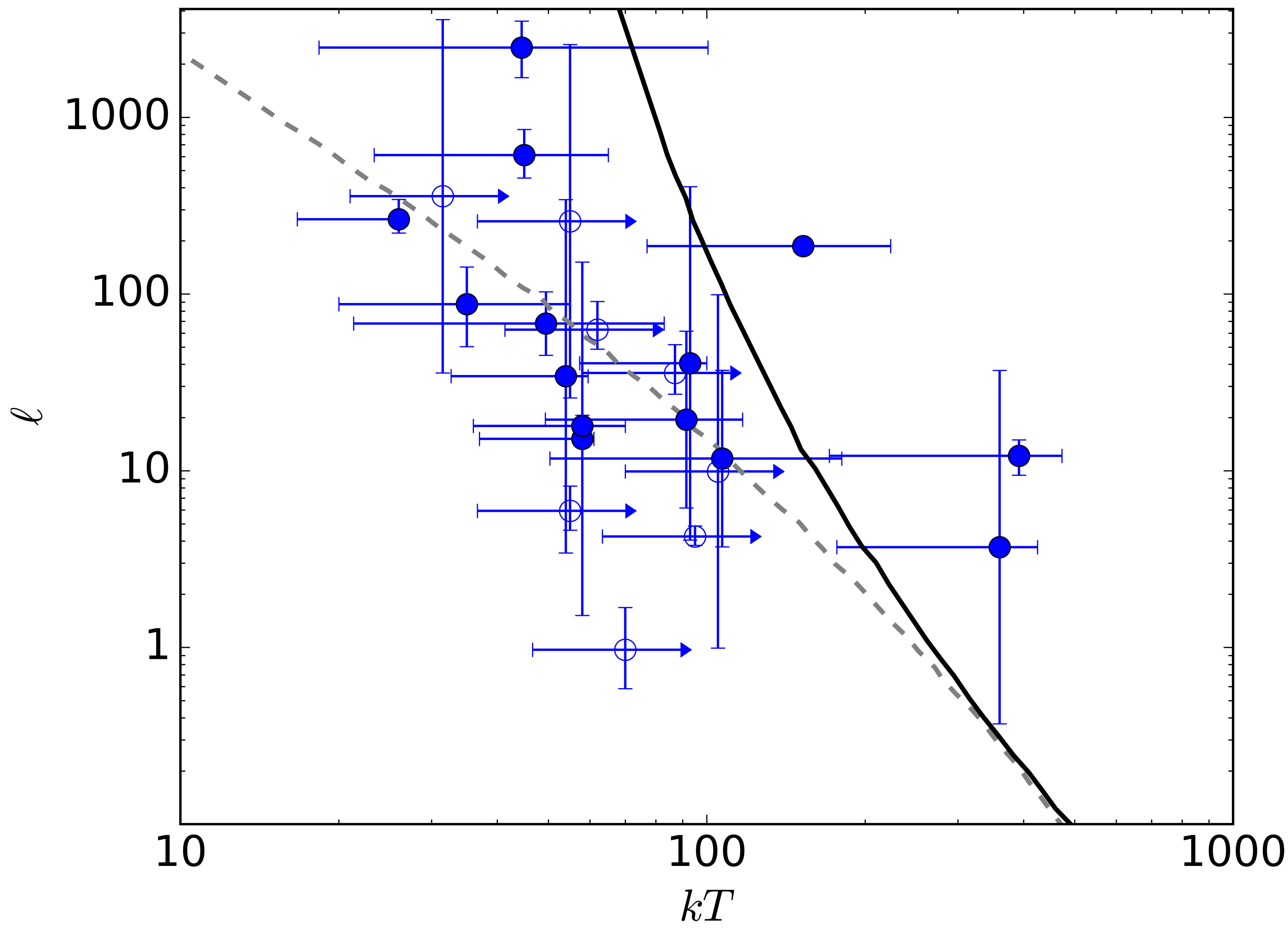


E_{cut} = 200 keV in Gilli+07 models.
XRB exceeded if much higher → average kT<100 keV.

X-ray Background



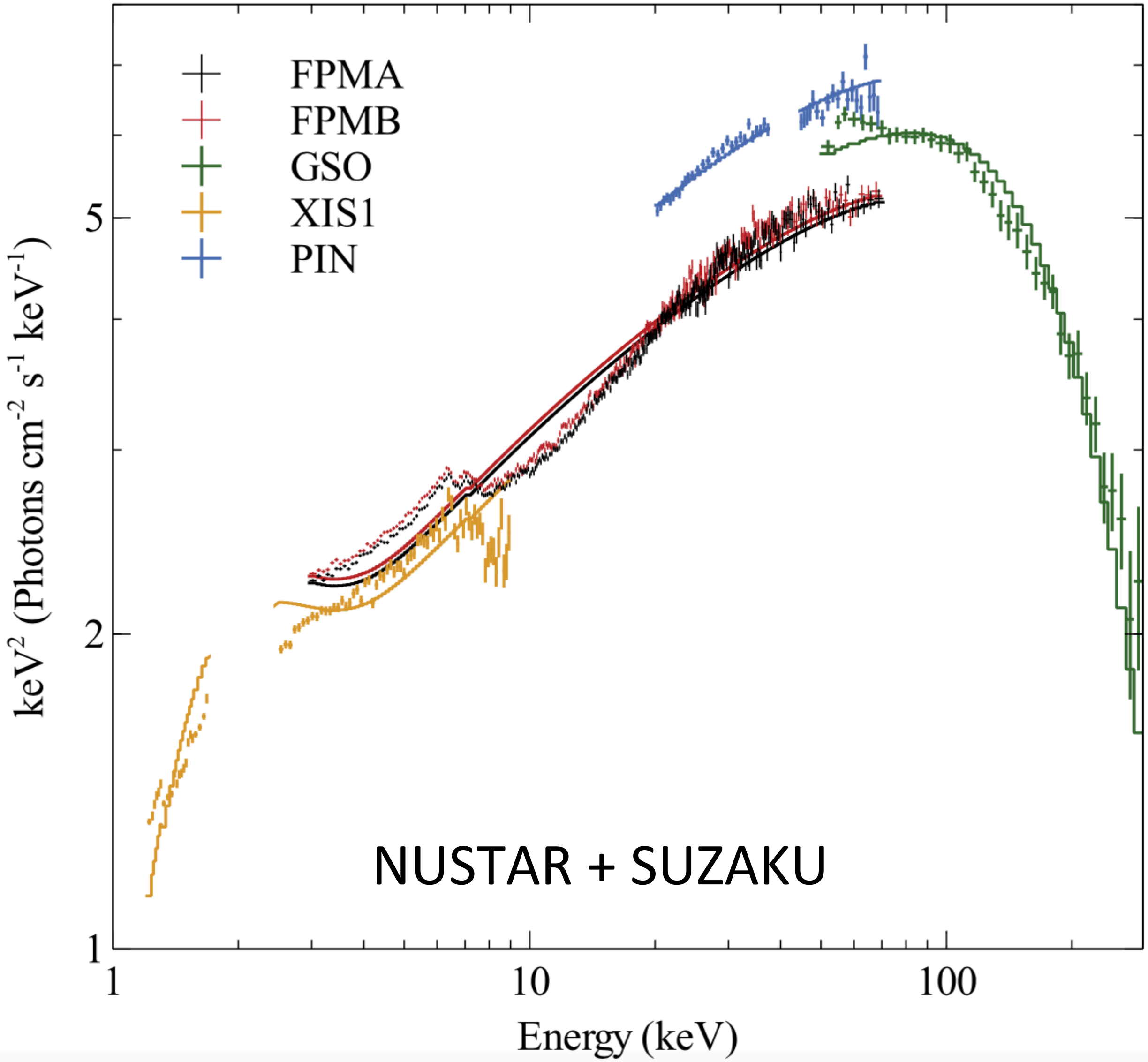
NuSTAR AGN updated with all published results
Rough agreement with Integral (Lubinski+16)



Cyg X-1

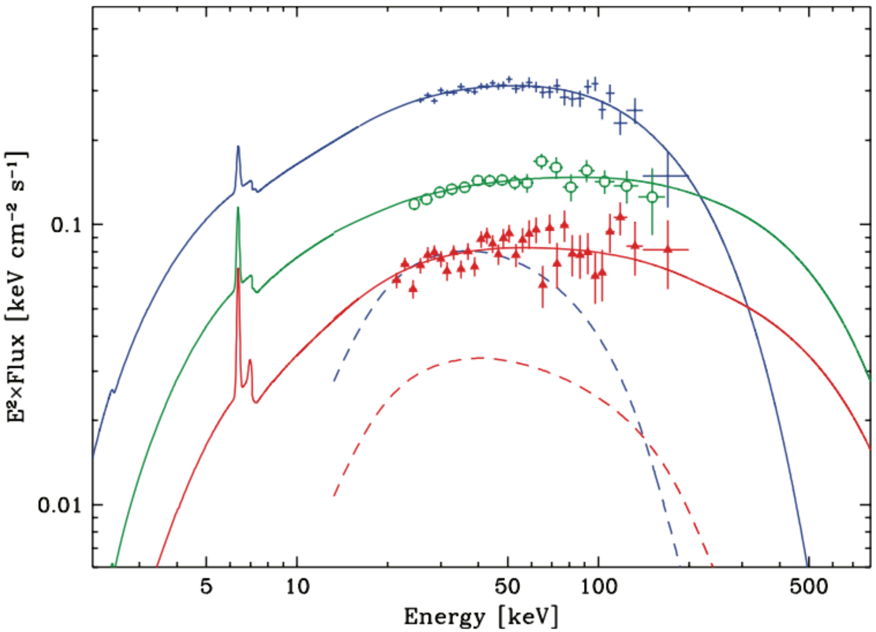
REMINDER

Parker et al. 2015

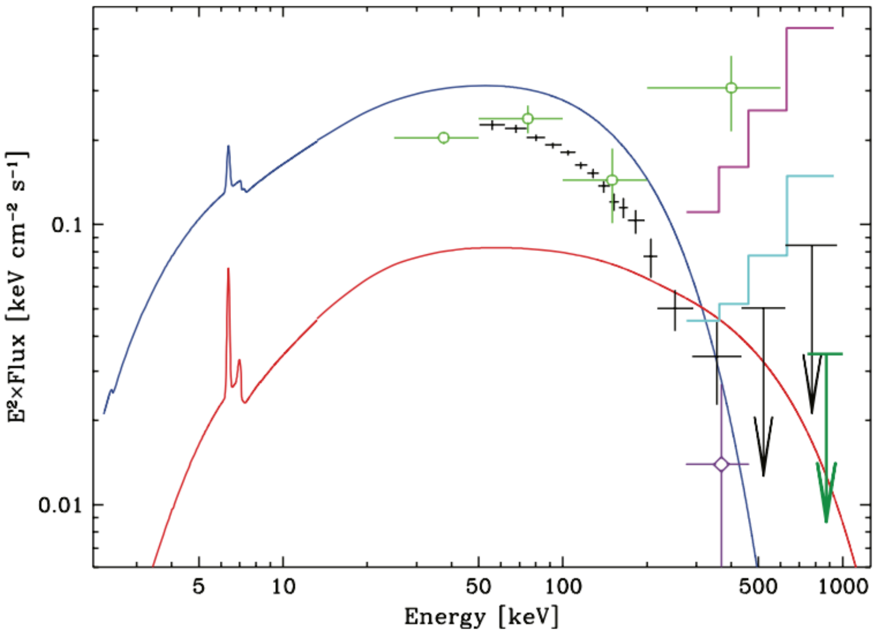


also Gilfanov+00, Wilms+06, Novak+11

NGC4151



Extreme flux states of NGC 4151 1859



INTEGRAL

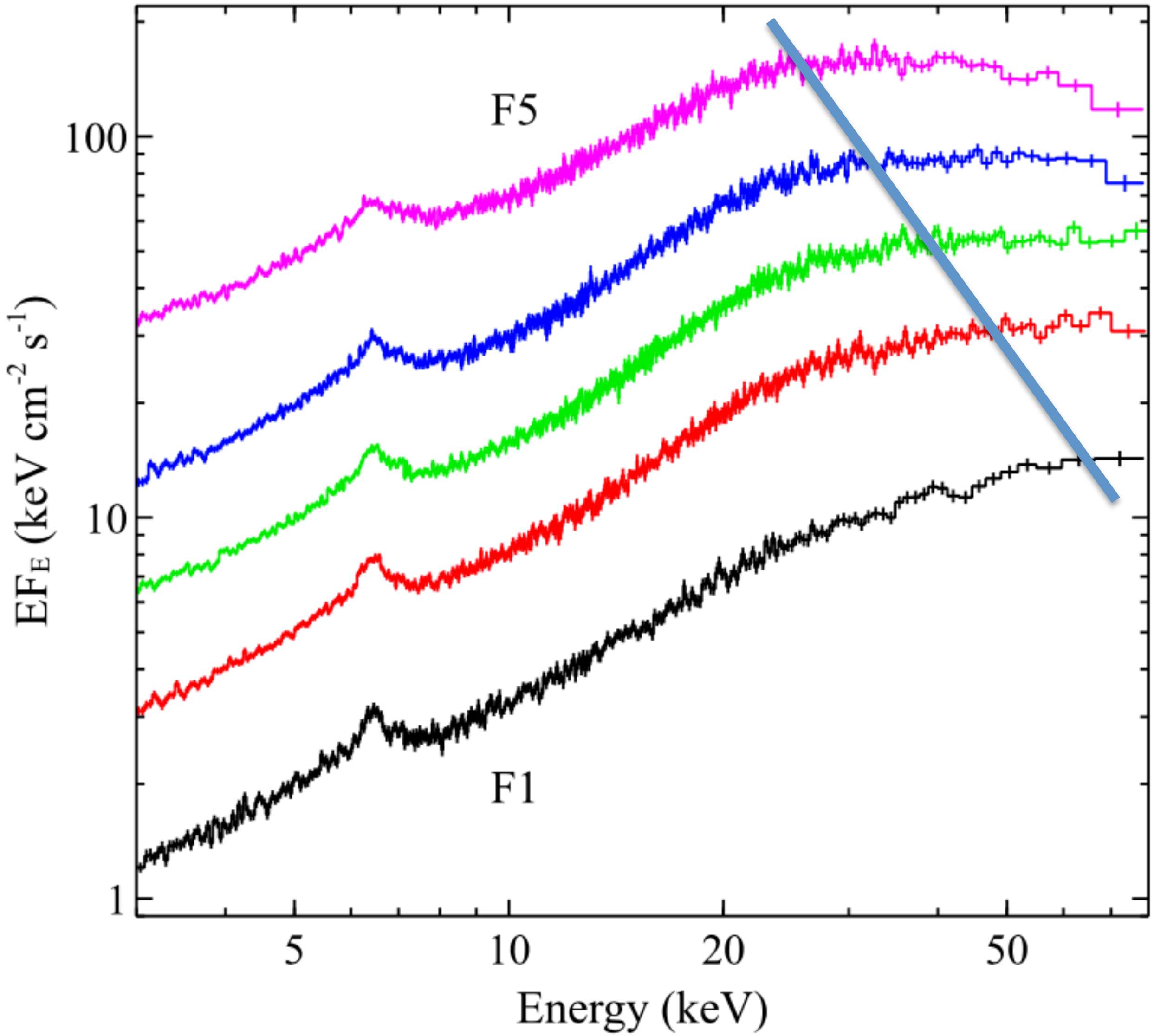
OSSE, Comptel

INTEGRAL/PICsIT SPI

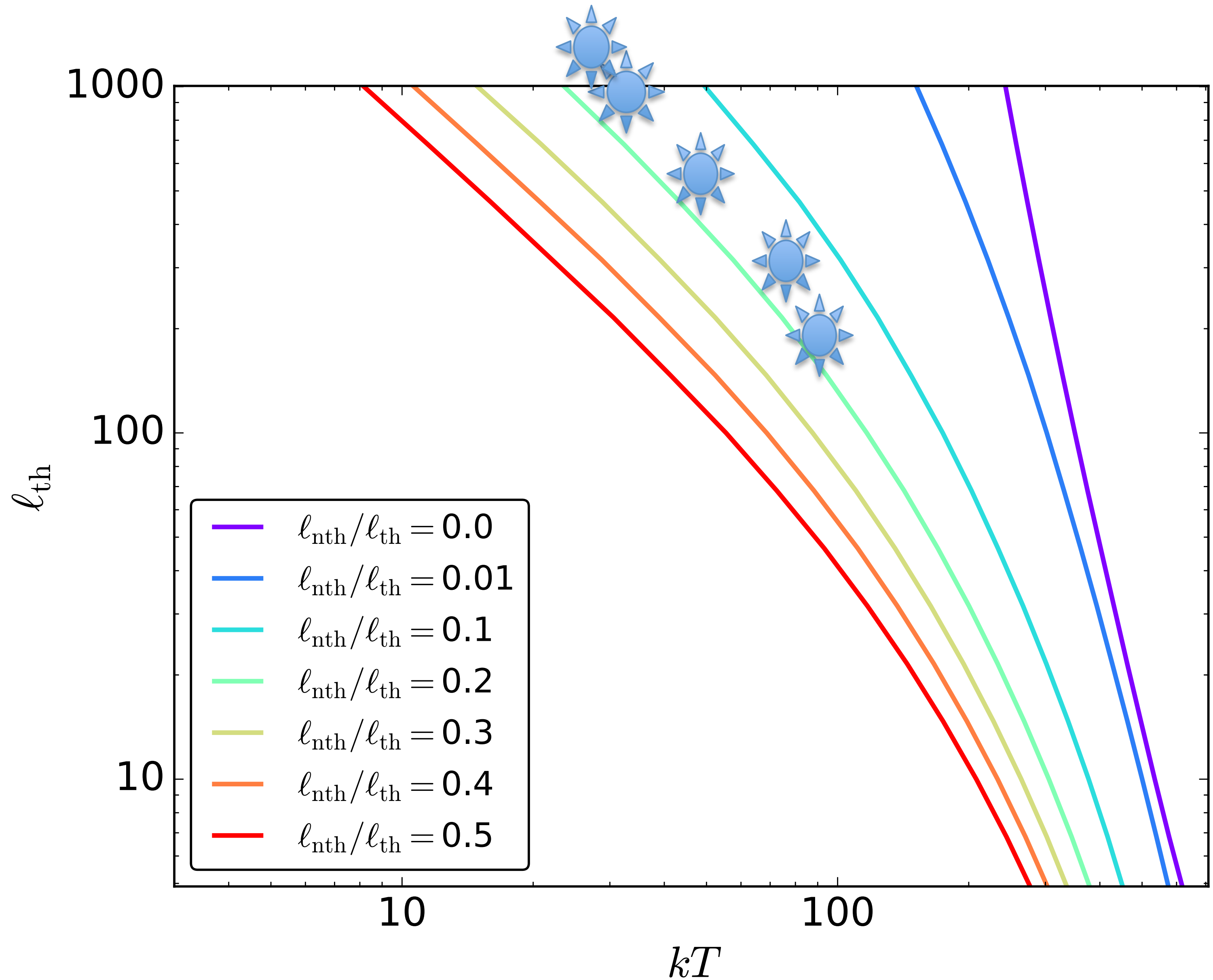
Lubinski+10 see alsoKeck+15, Beuchert+17

V404 Cyg NuSTAR

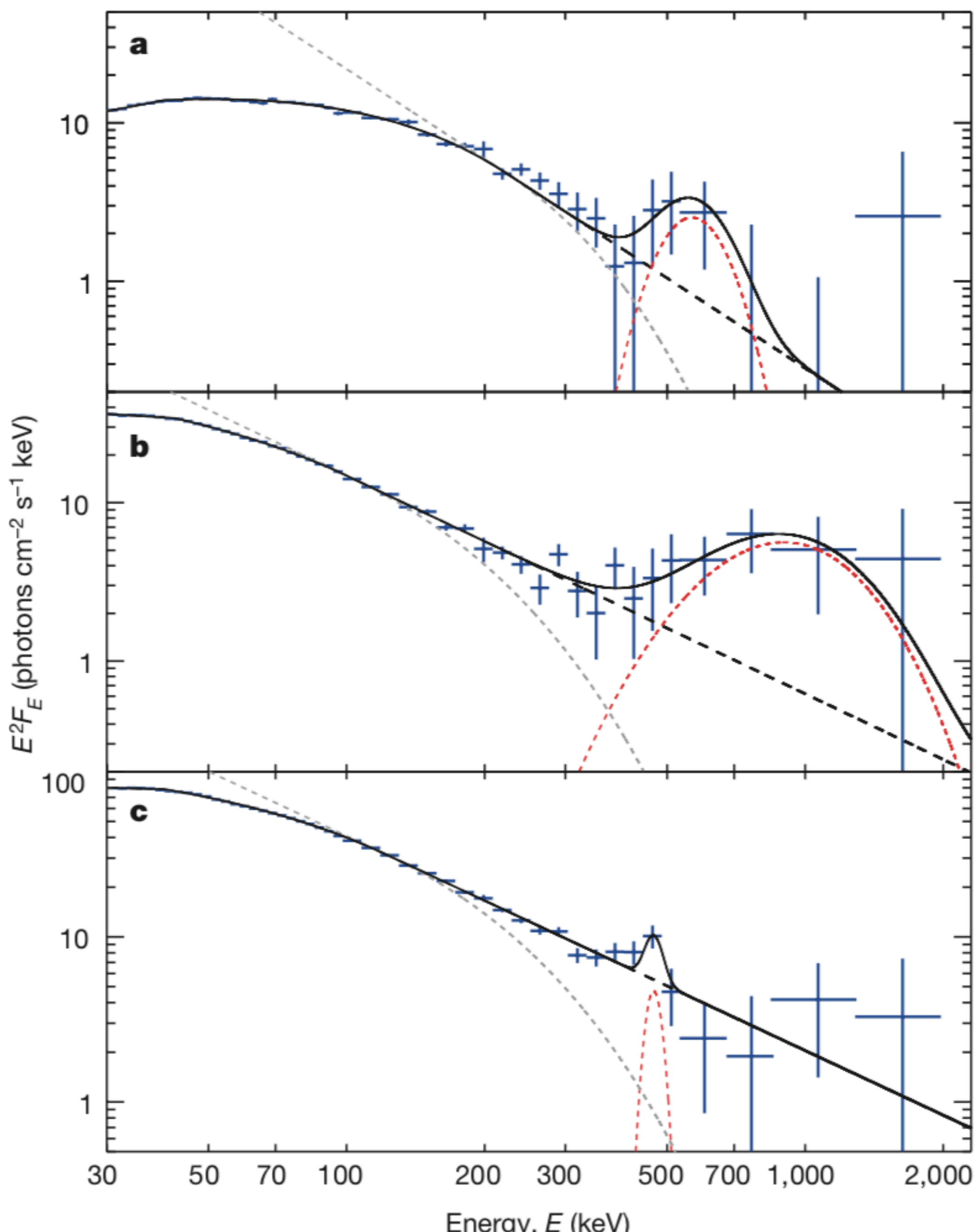
Walton et al.



V404 Cyg (GR corrections included)

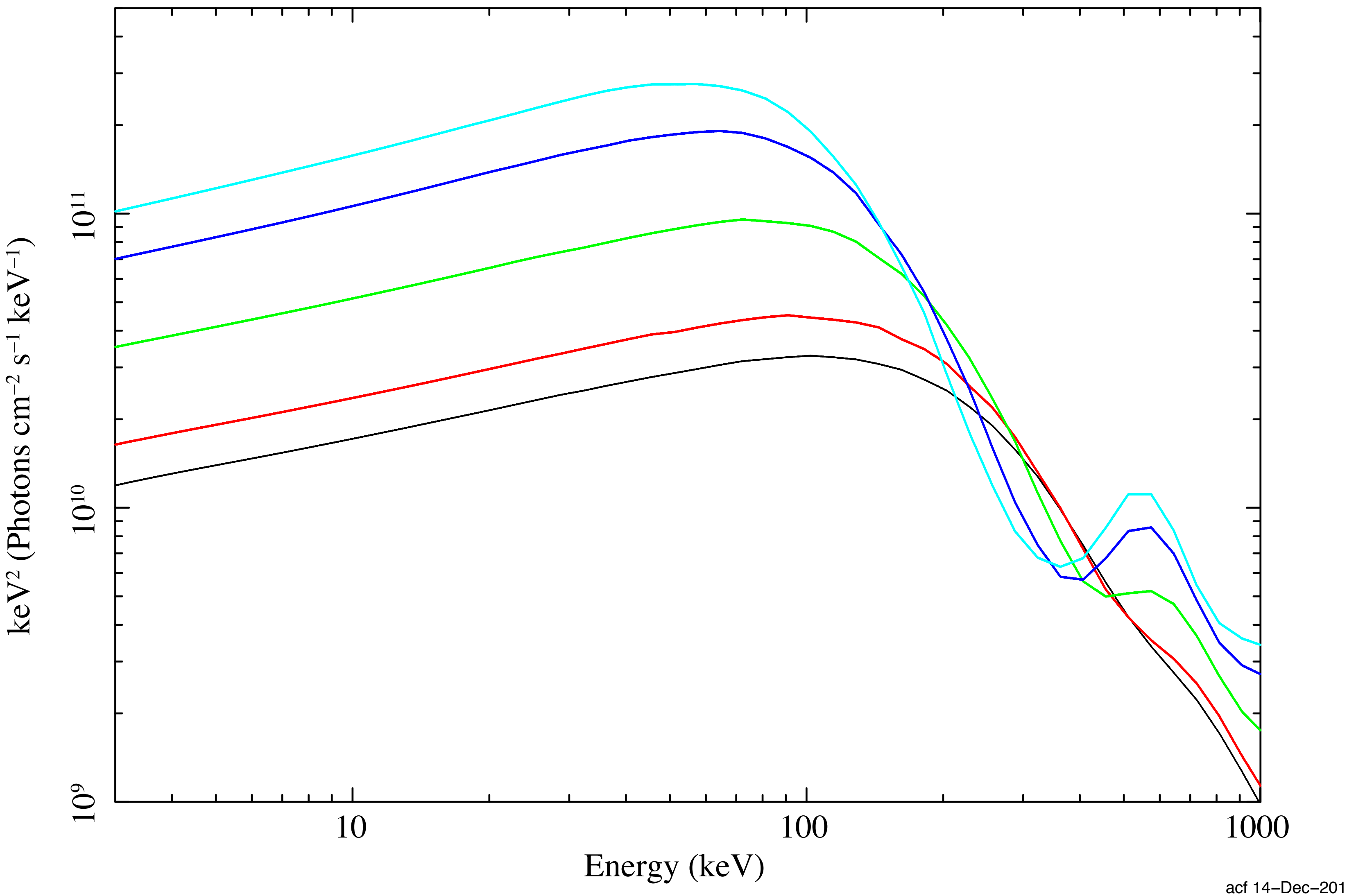


D Walton



INTEGRAL   Siegert+16

V404 Cyg Simulation



EQPAIR

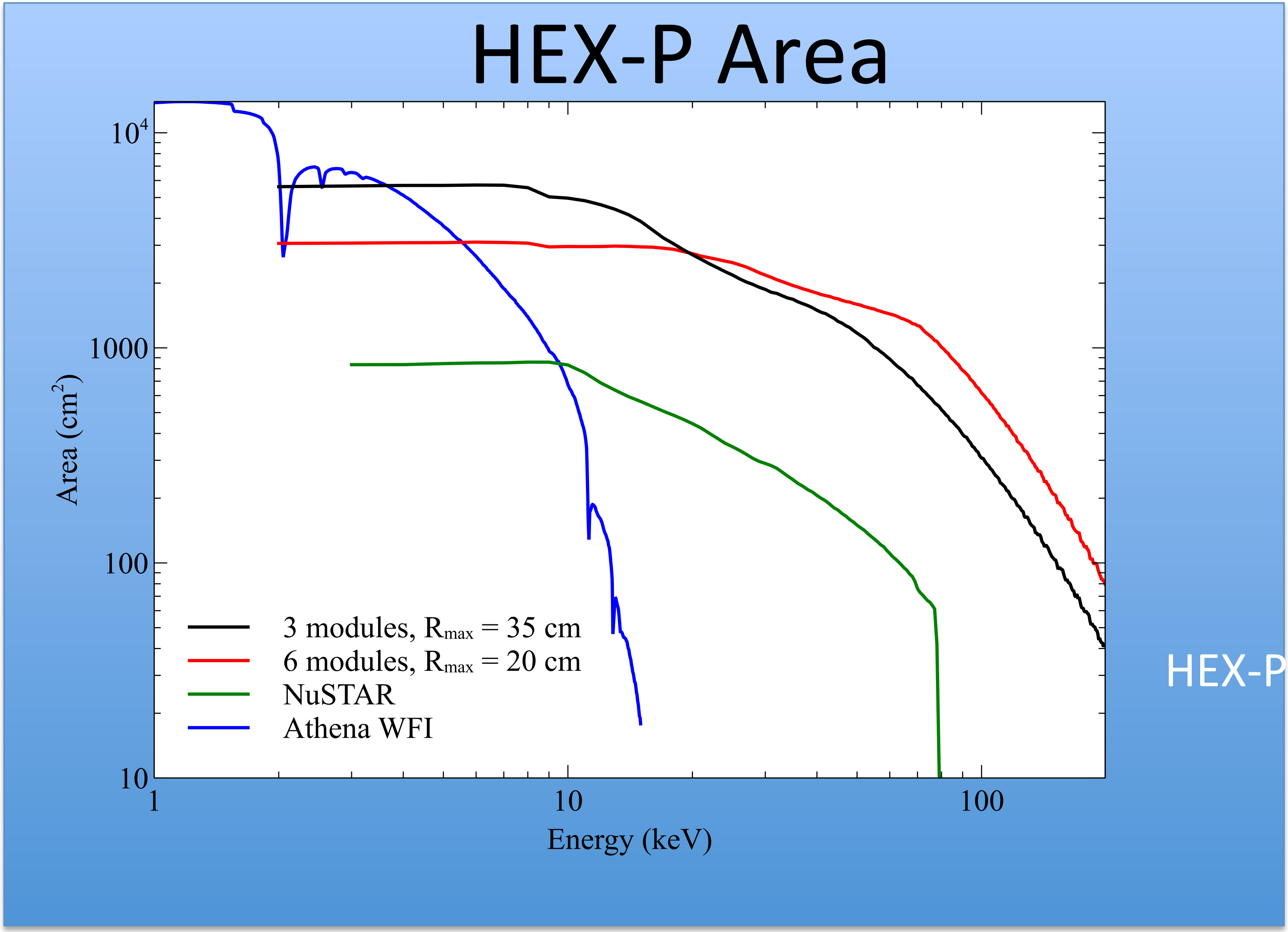
Cautionary Notes

- Most hard X-ray spectra cover many dynamical times and many many cooling times
- Characterizing a corona by a single T, tau etc could be misleading
- Measured compactness values are probably underestimates
- Converting E_{cut} (exponential cutoff) to kT unreliable

The AGN Corona is

- Compact
- Highly magnetized
- Close to the black hole along spin axis
- Probably dynamic, possibly containing outflowing plasma
- Probably contains a significant fraction of electron-positron pairs + nonthermal particles
- Annihilation line expected (broad)
- Corona controls ~10-50% of the power
- Related to jets?
- All probably true also of BHB coronae

The Future?


HEX-P Area
10^4
1000
100
10
1
10
100
Area (cm^2)
Energy (keV)
3 modules, R_{max} = 35 cm
6 modules, R_{max} = 20 cm
NuSTAR
Athena WFI
HEX-P

HEX-P Performance

Parameter	*NuSTAR*	*Athena*/X-IFU	*HEX-P*
bandpass	3-79 keV	0.2-12 keV	2-200 keV
angular resolution	60″	10″	15″
spectral resolution [FWHM]	600 eV @ 6 keV 1.2 keV @ 60 keV	2.5 eV below 7 keV	200 eV @ 6 keV 0.8 keV @ 60 keV
timing resolution	1 μsec	10 μsec	1 μsec
field of view	13′ × 13′	5′ diameter	13′ × 13′

Table 1. *Key performance parameters. Angular resolution is half-power diameter (HPD).*