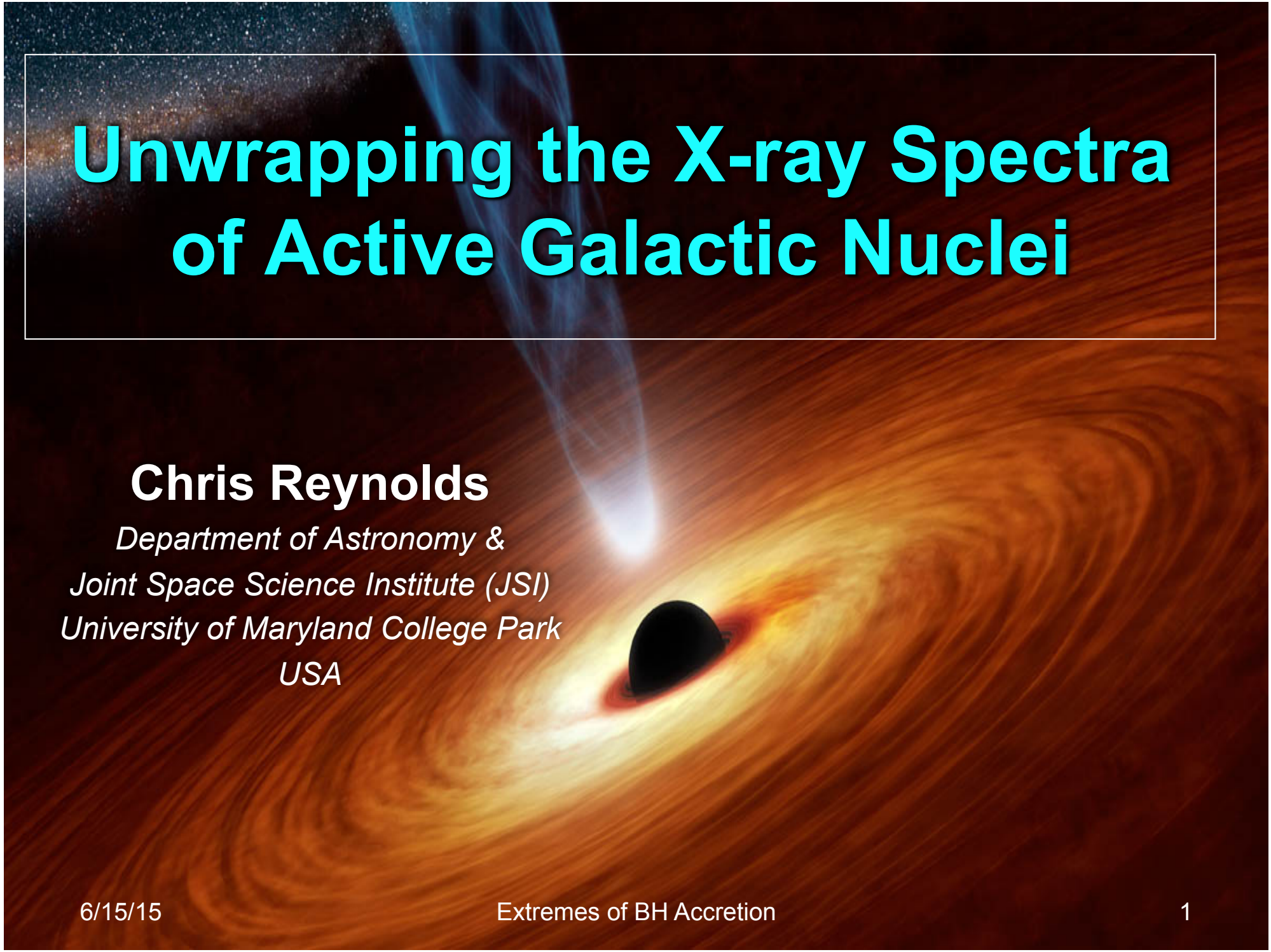
Unwrapping the X-ray Spectra of Active Galactic Nuclei



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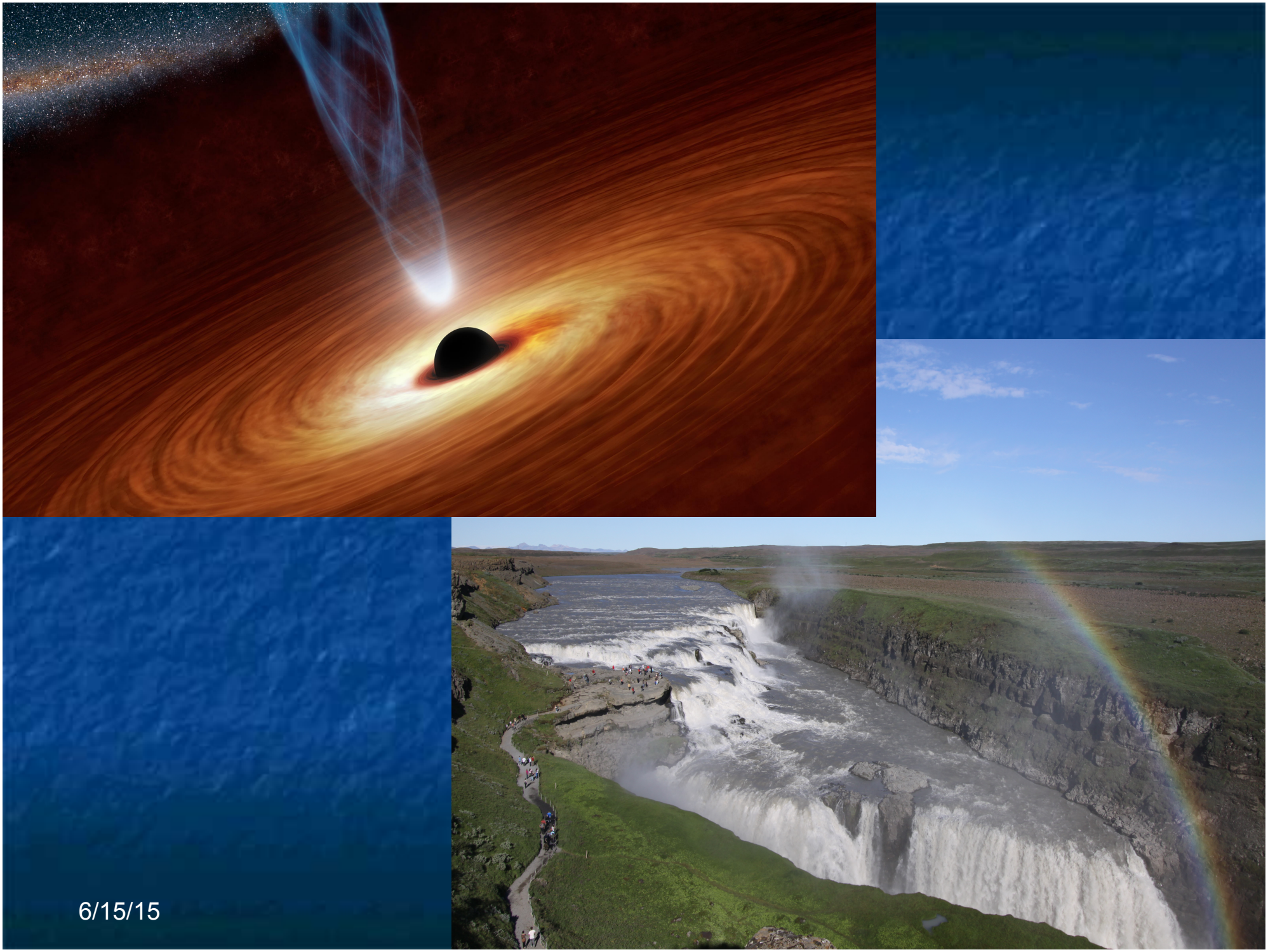
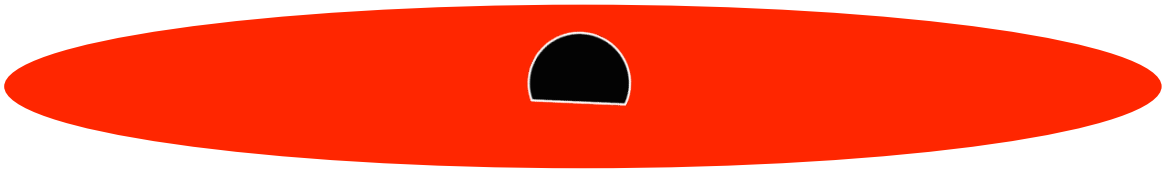
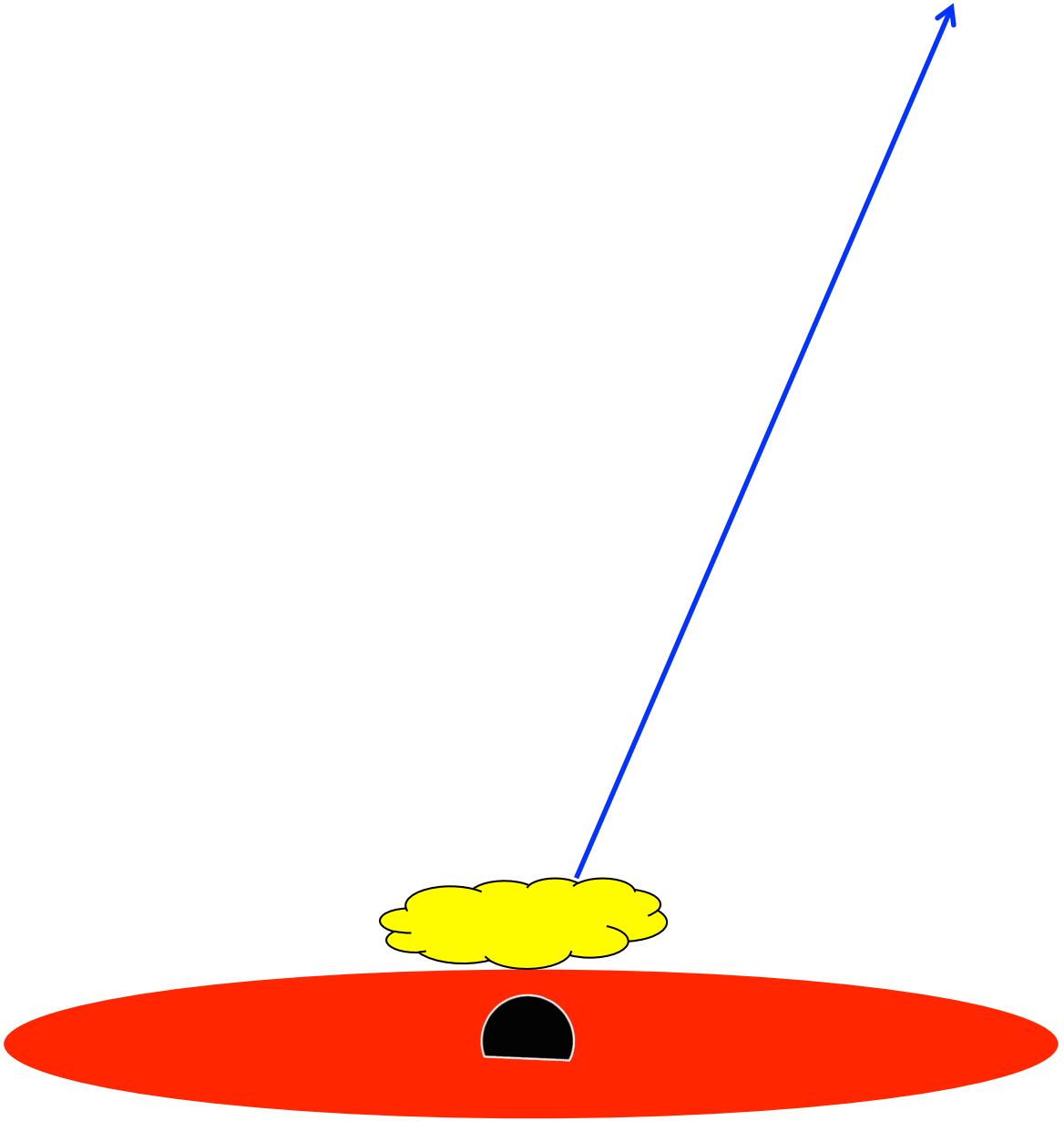


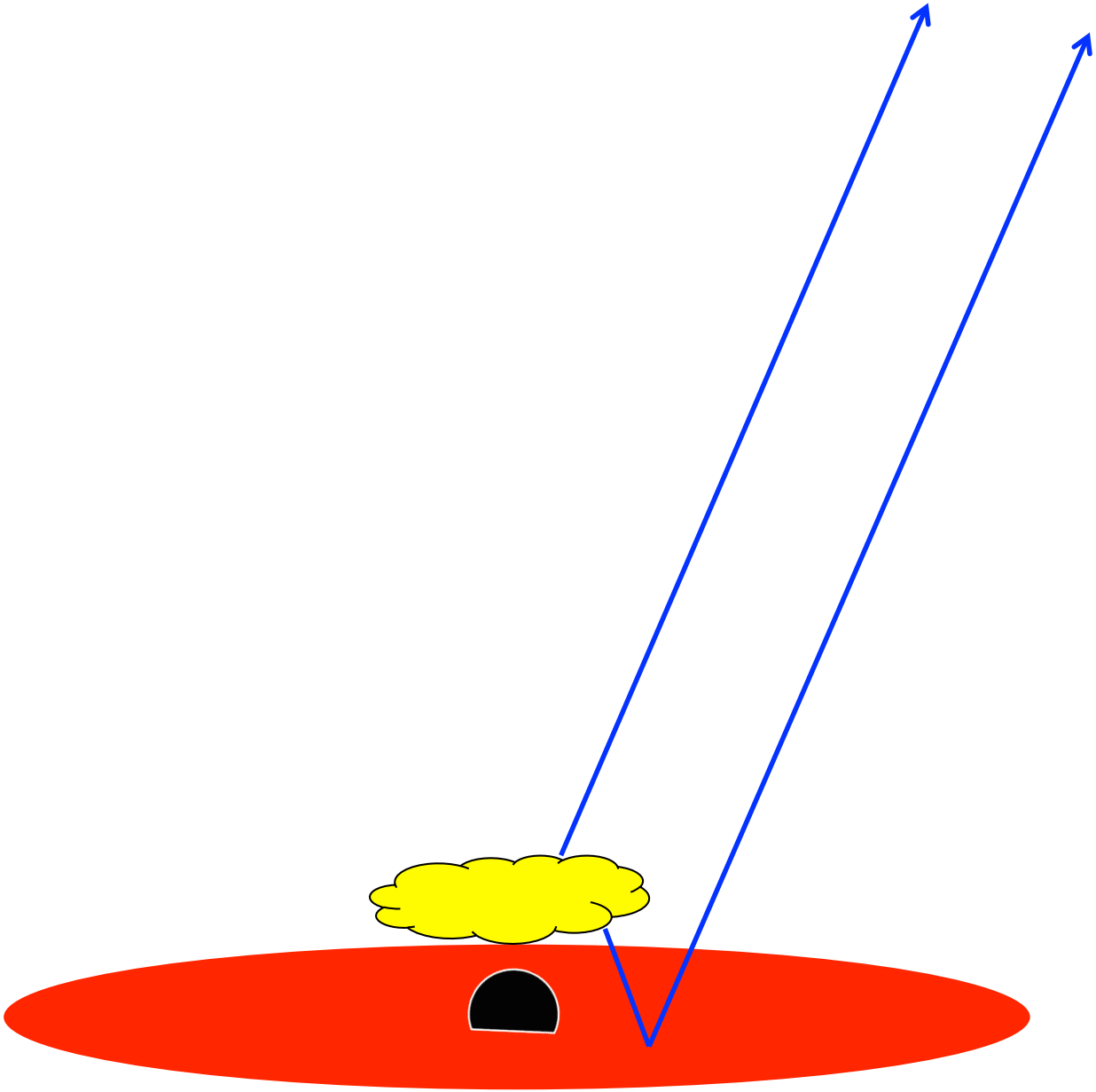
6/15/15

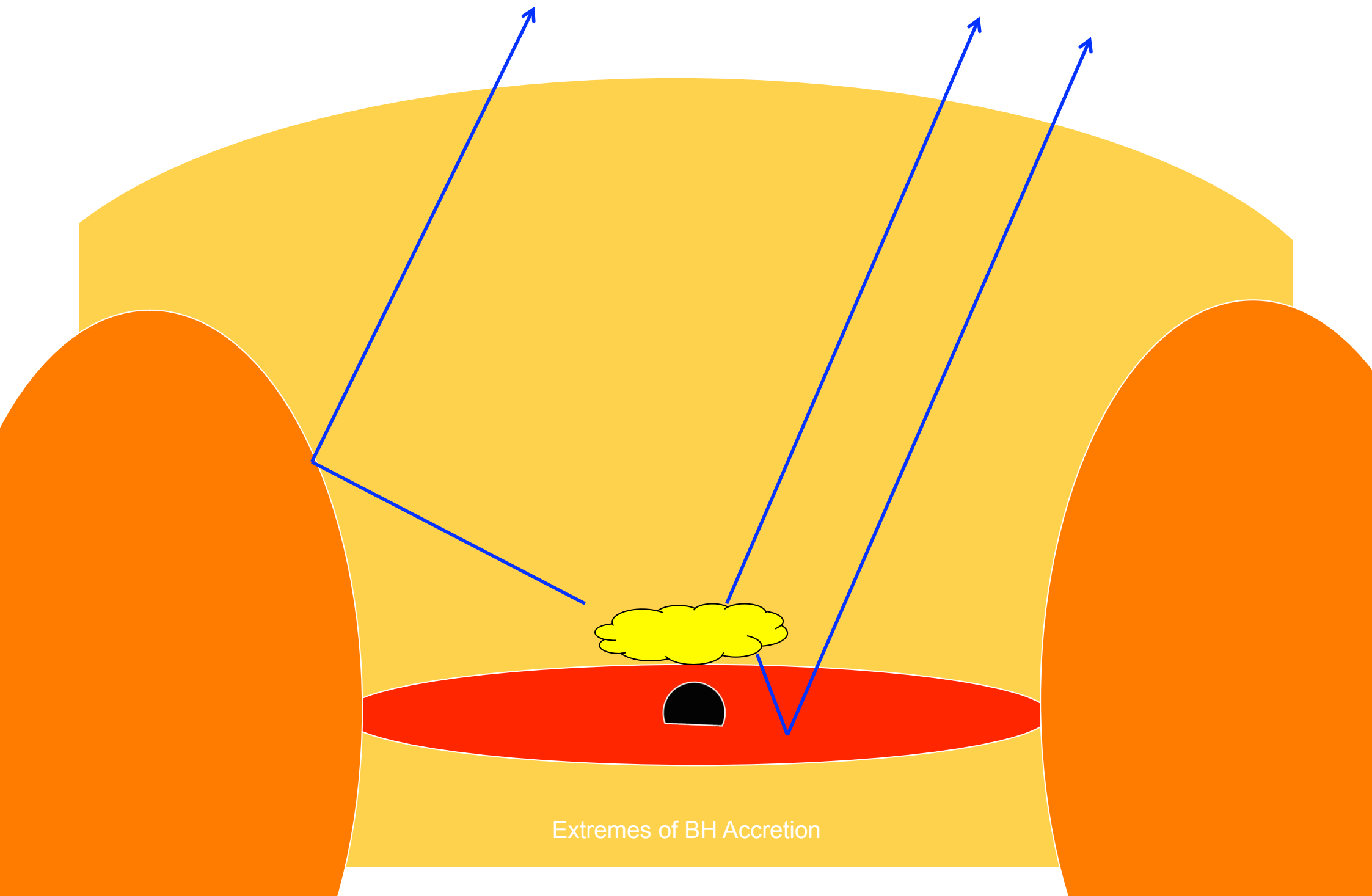
Outline

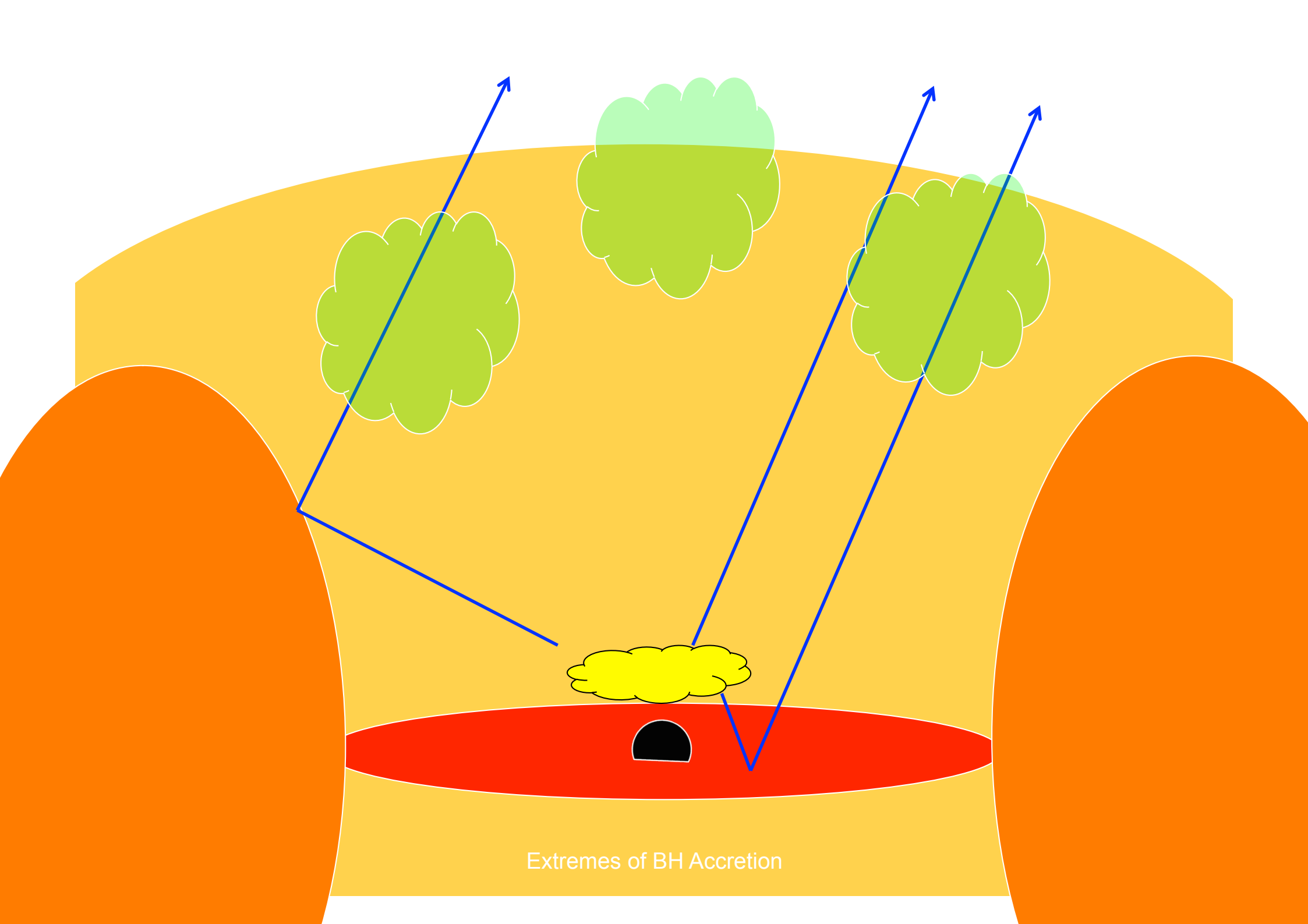
- The components of an AGN X-ray spectrum
- Some highlights in recent studies of…
  - Physics of X-ray coronae
  - Black hole spin
  - Fast winds and “quasar-mode” feedback
- Setting scene for talks to follow…

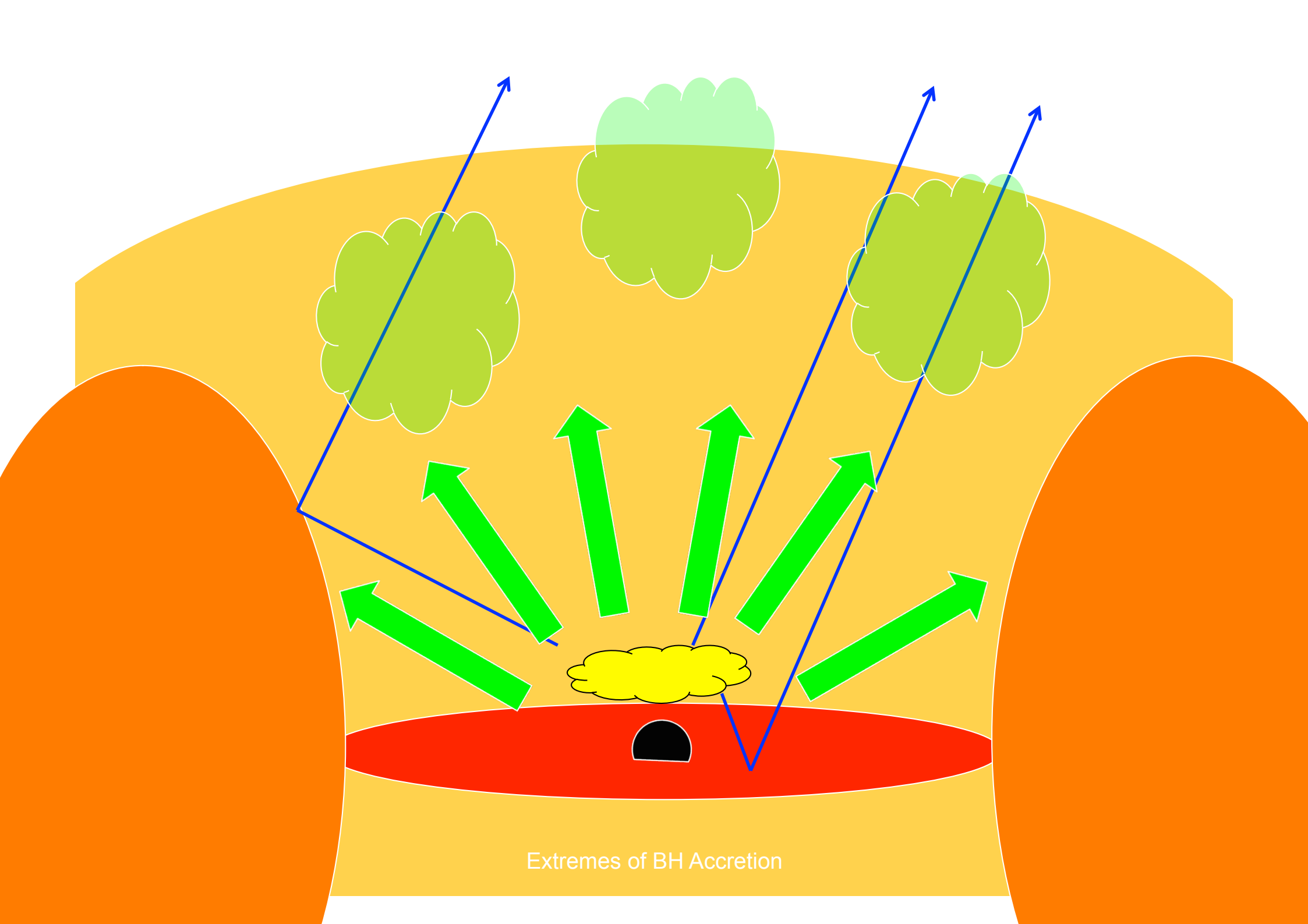


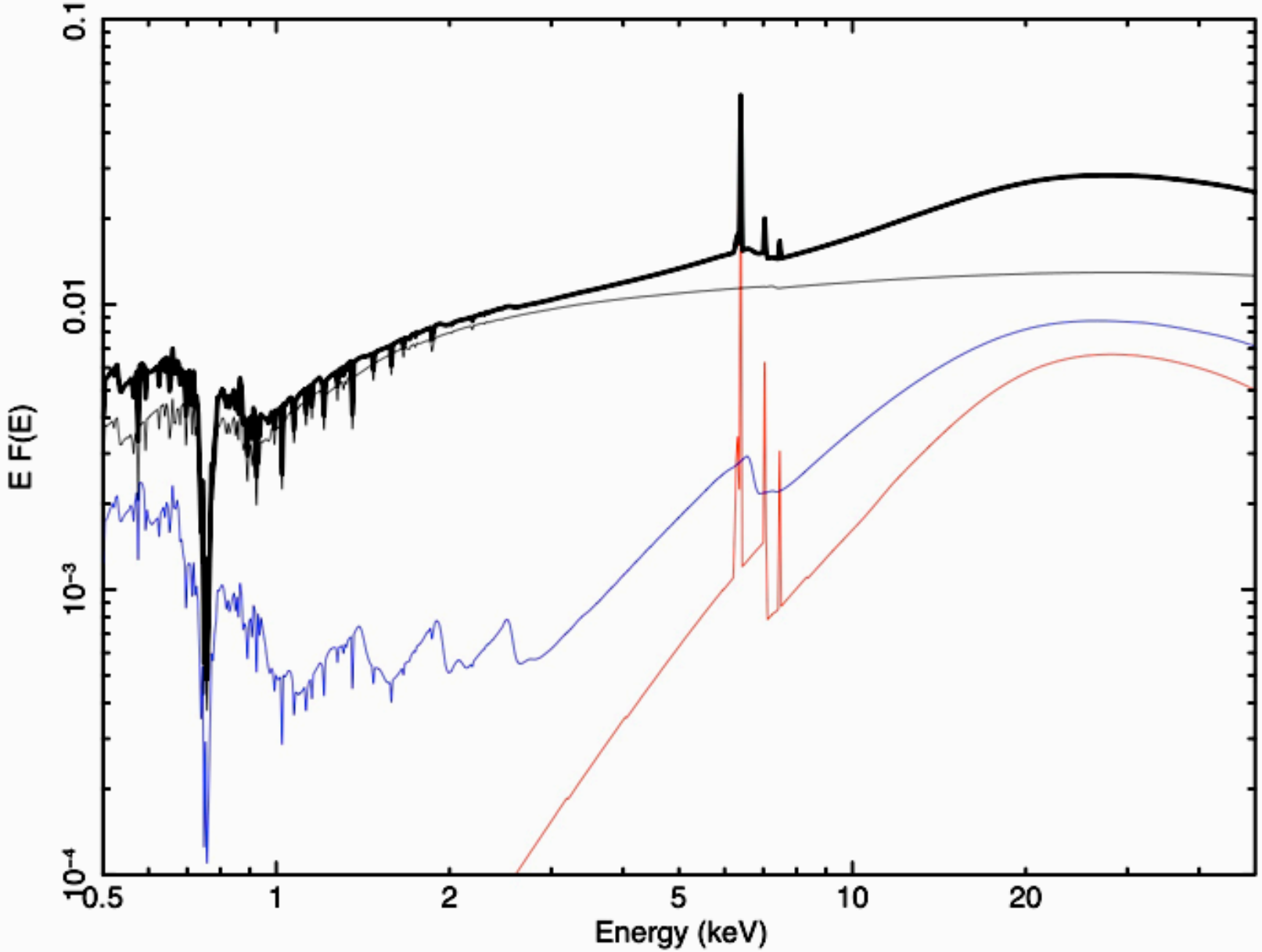




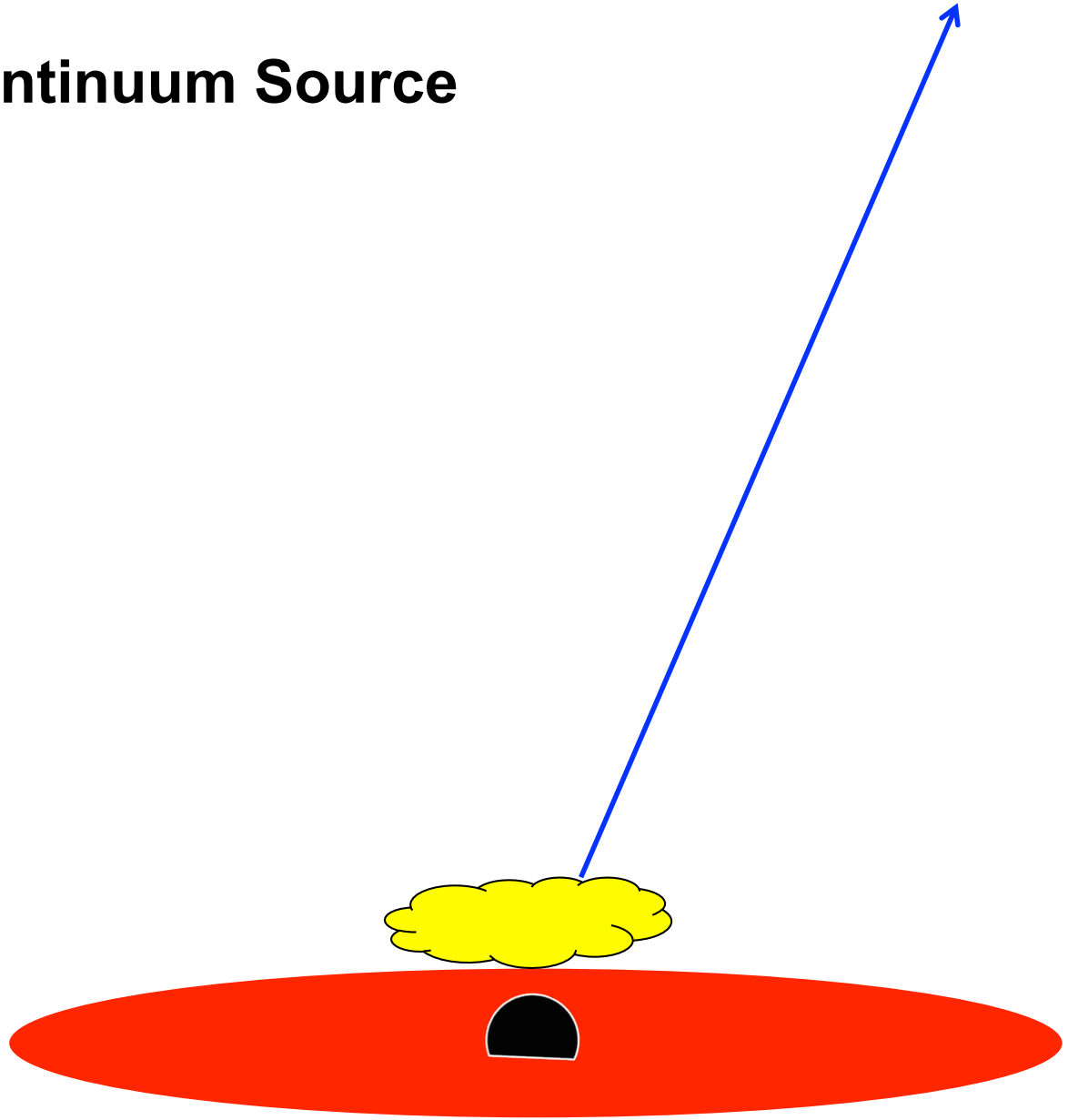

Extremes of BH Accretion


Extremes of BH Accretion


Extremes of BH Accretion


0.1
0.01
10^{-3}
10^{-4}
E F(E)
0.5
1
2
5
10
20
Energy (keV)

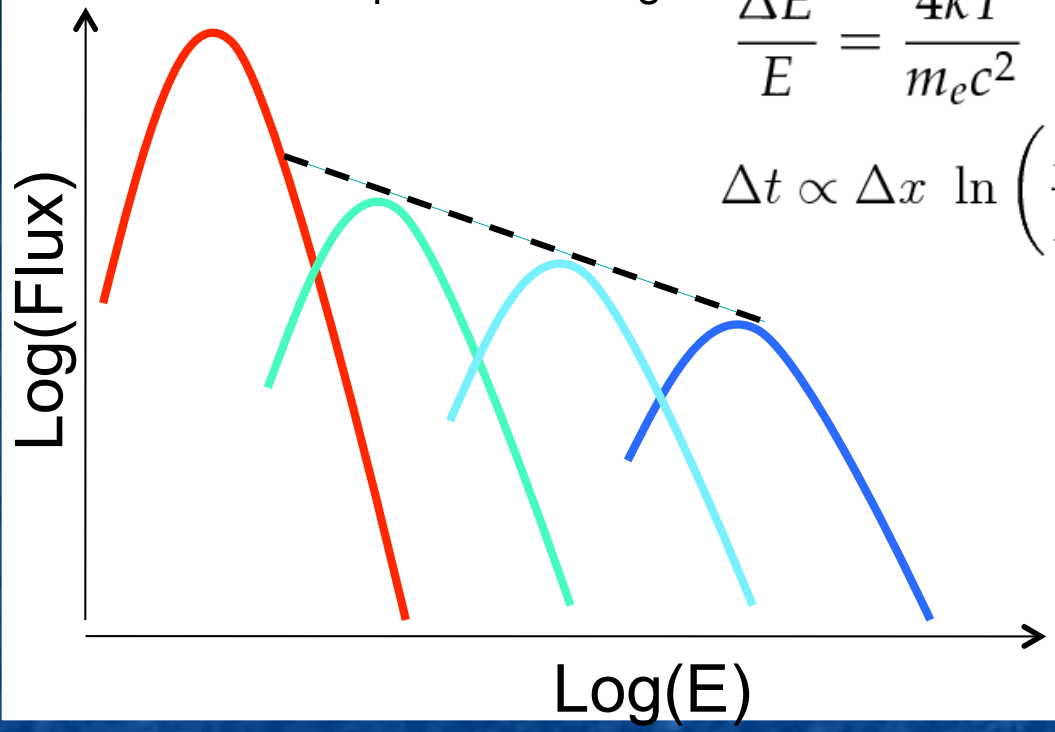
I : The Continuum Source



Inverse Compton scattering

$$\frac{\Delta E}{E} = \frac{4kT}{m_e c^2}$$

$$\Delta t \propto \Delta x \ \ln\left(\frac{E_2}{E_1}\right)$$



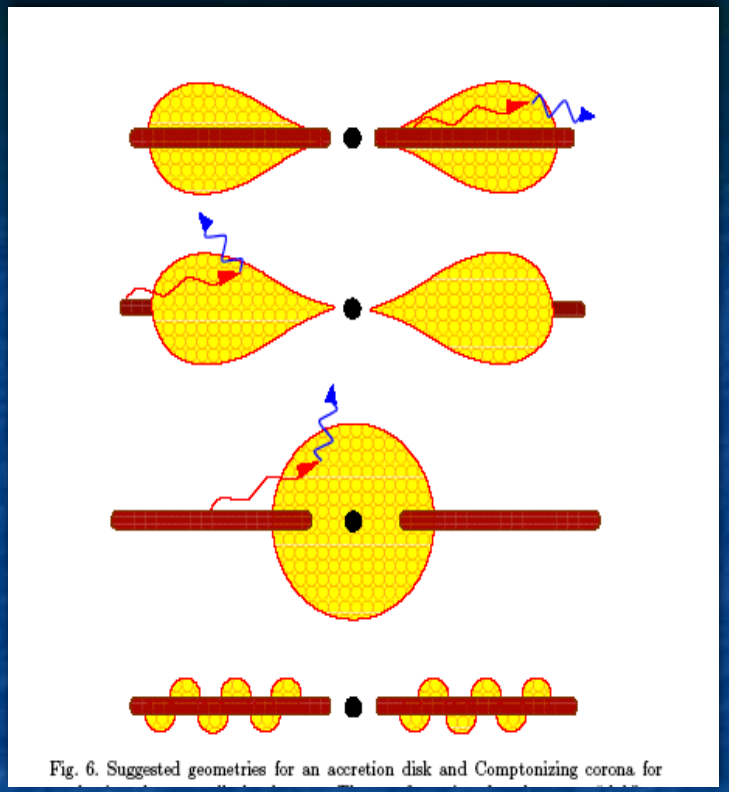
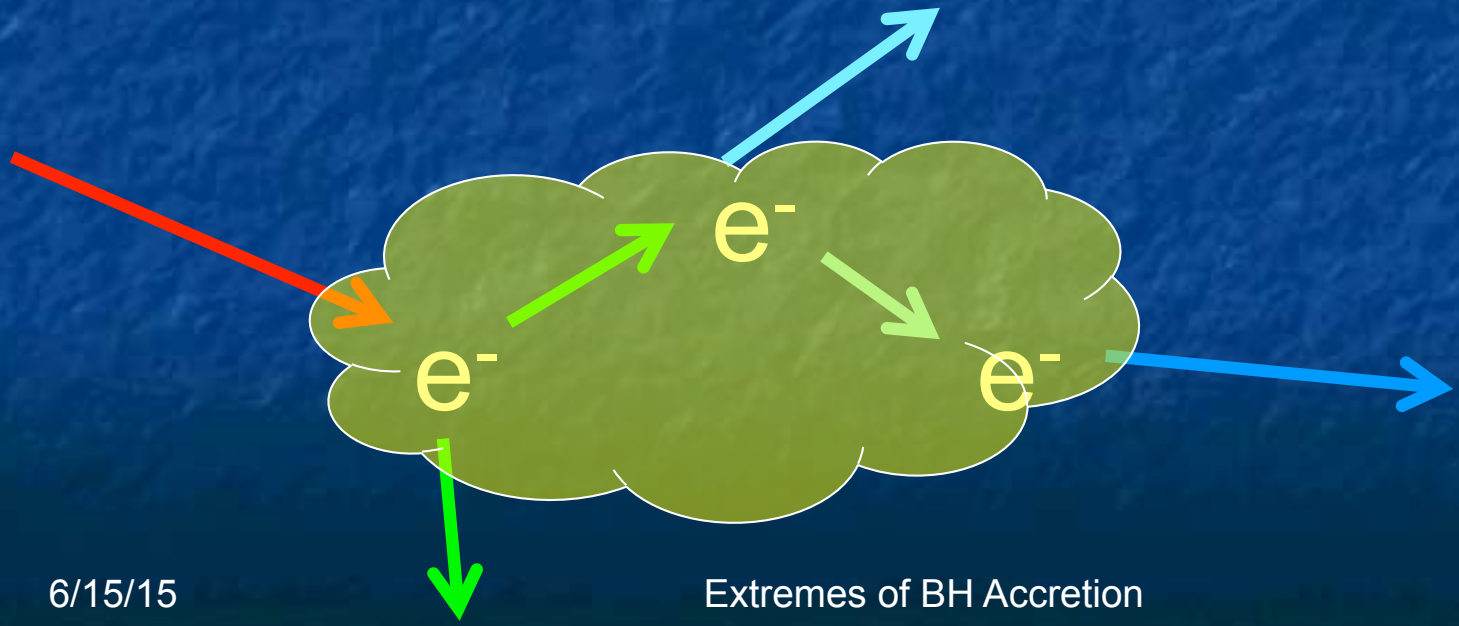
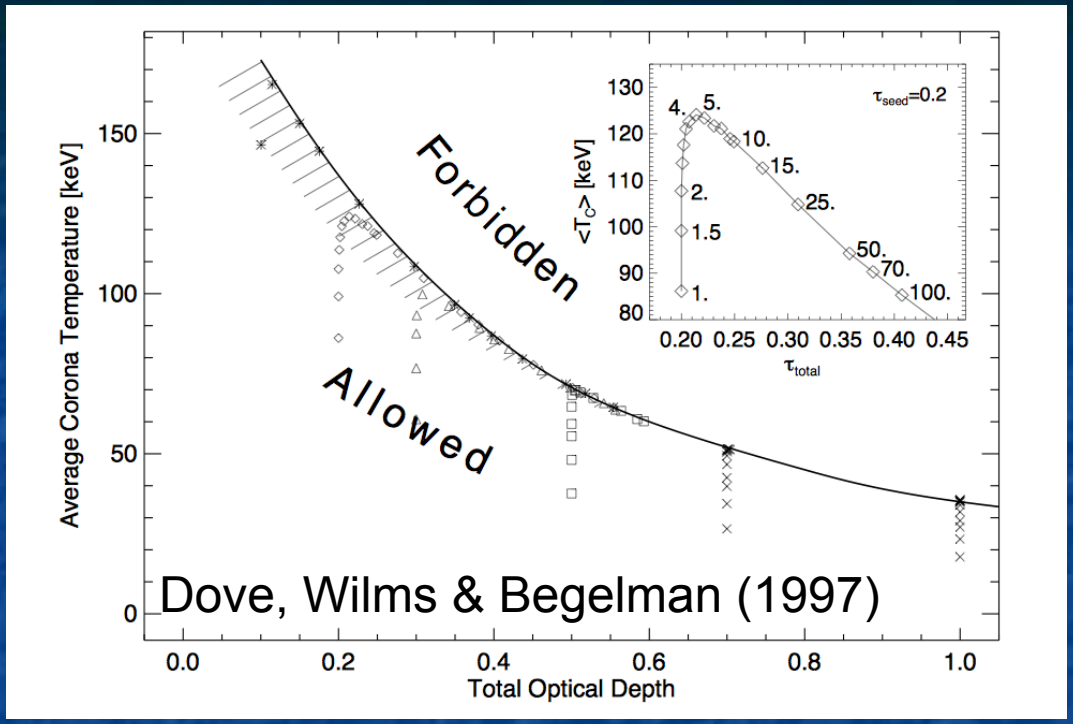


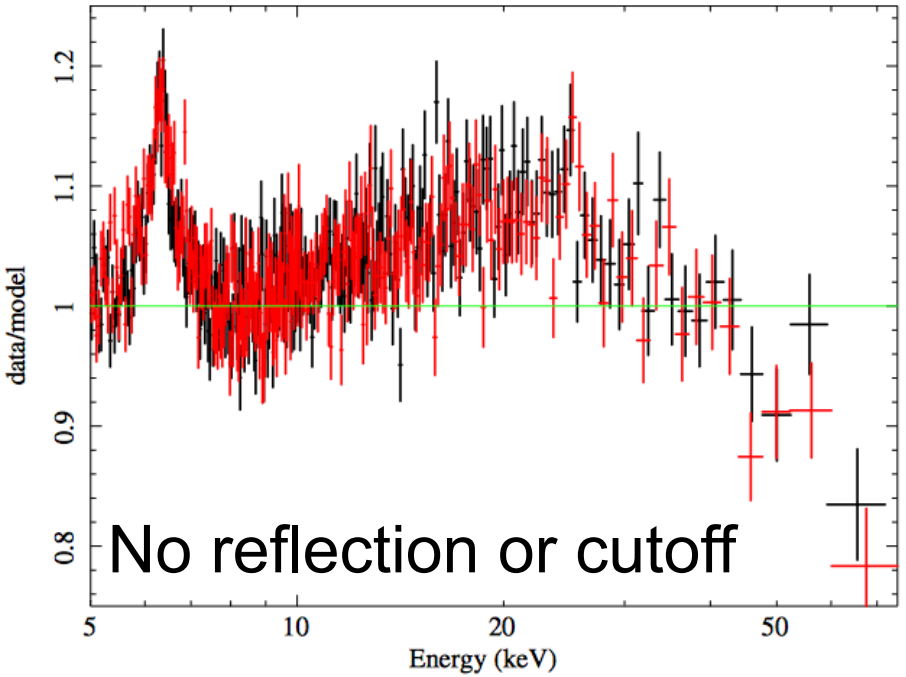
Fig. 6. Suggested geometries for an accretion disk and Comptonizing corona for

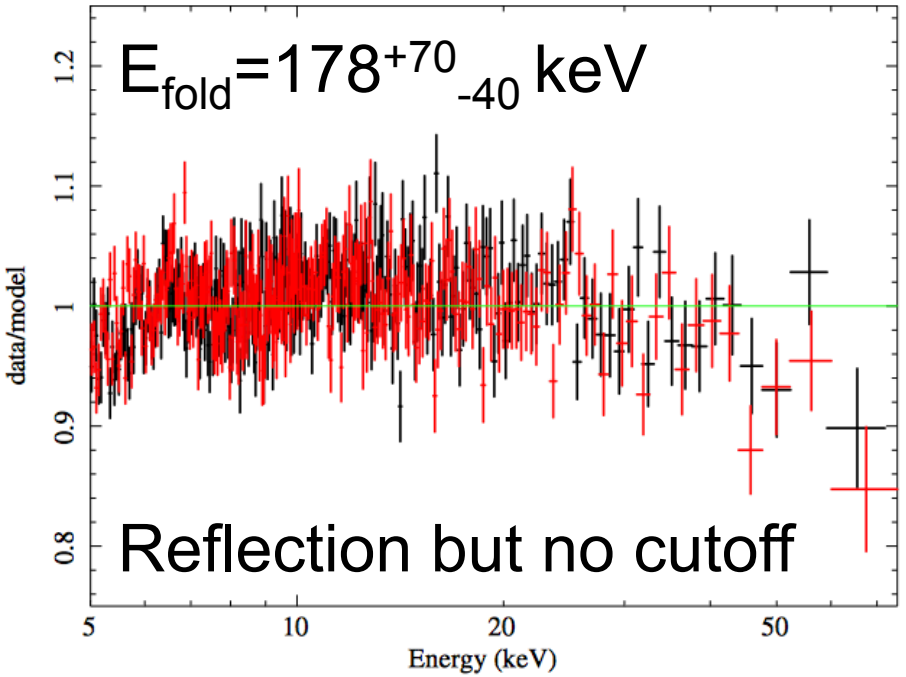




Pair production acts as a natural thermostat for corona (Svenson+84)

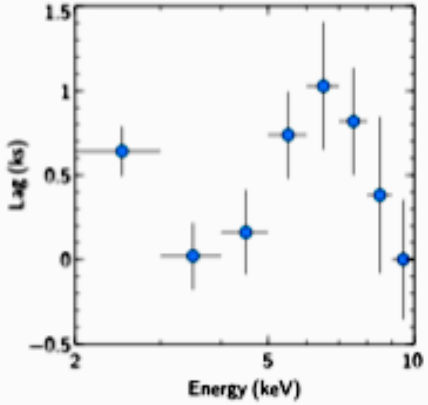
NuSTAR detection of cutoff in IC4329A (Brenneman et al. 2014)

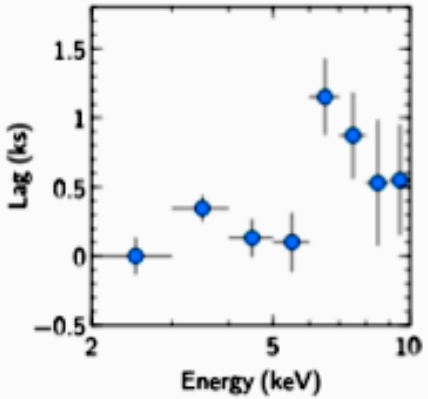


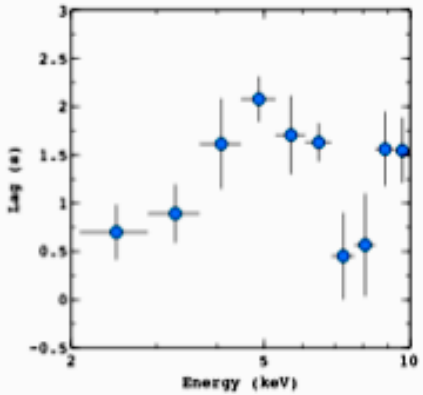


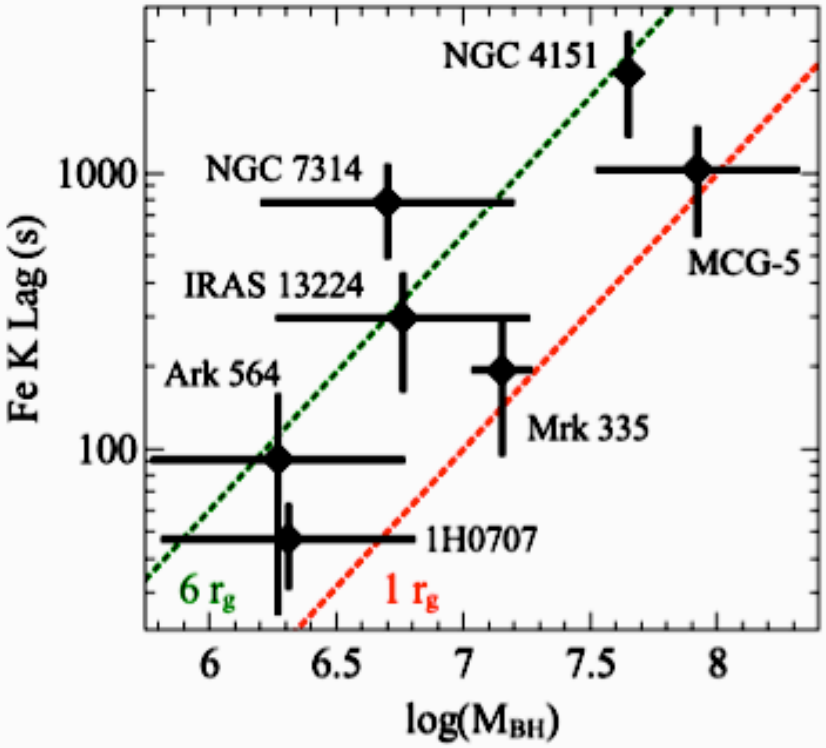
Observed Iron K lags

The reverberation lag scales with black hole mass.

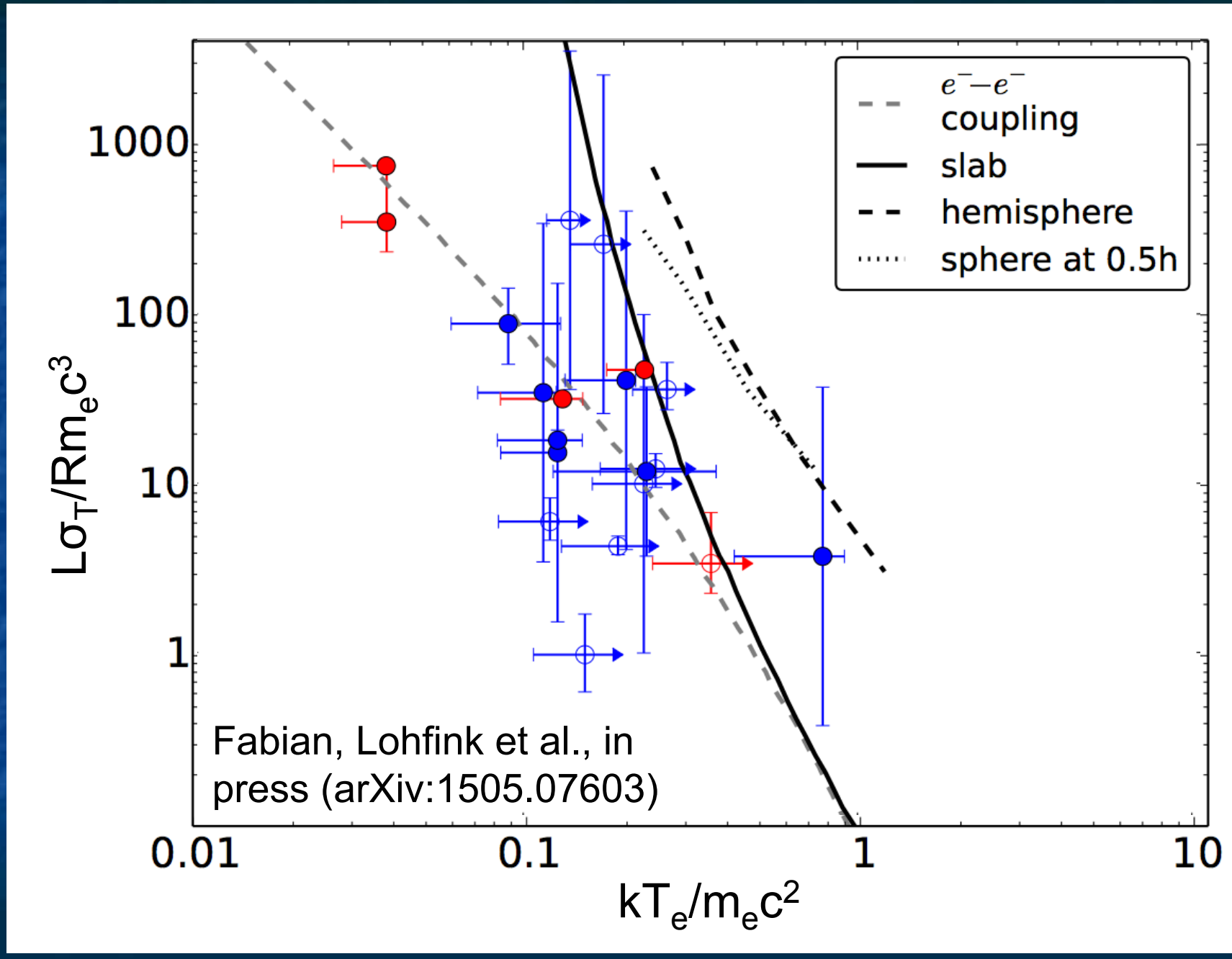




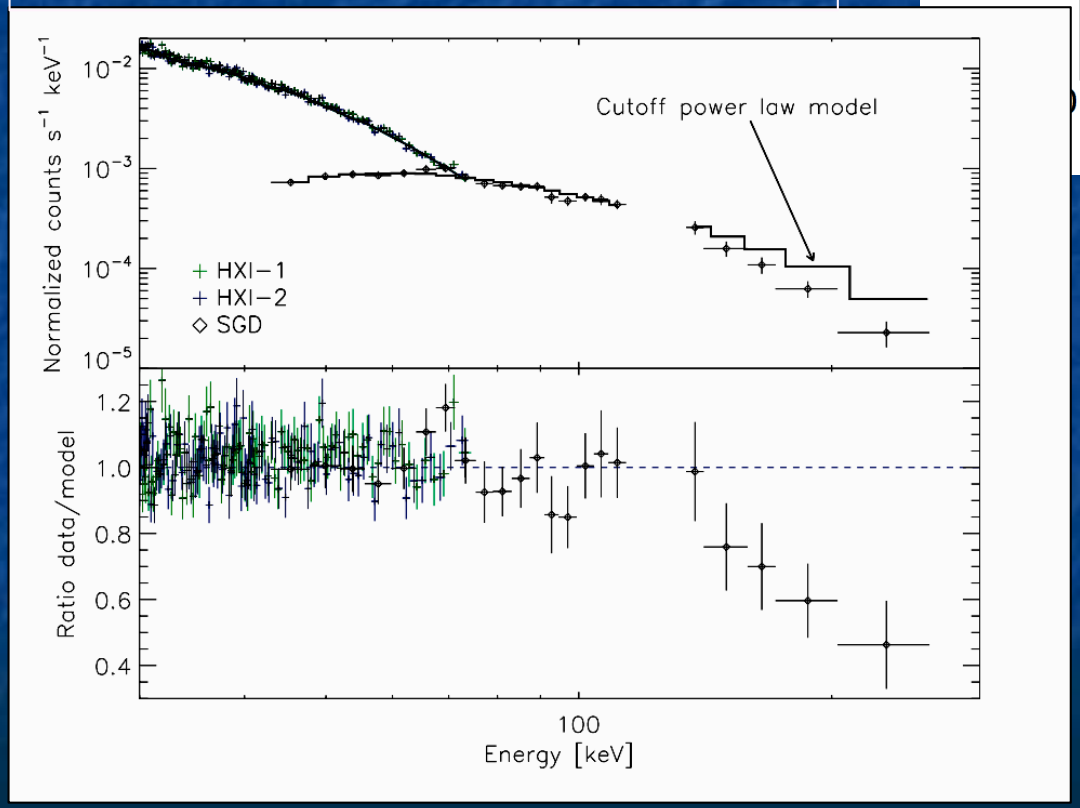


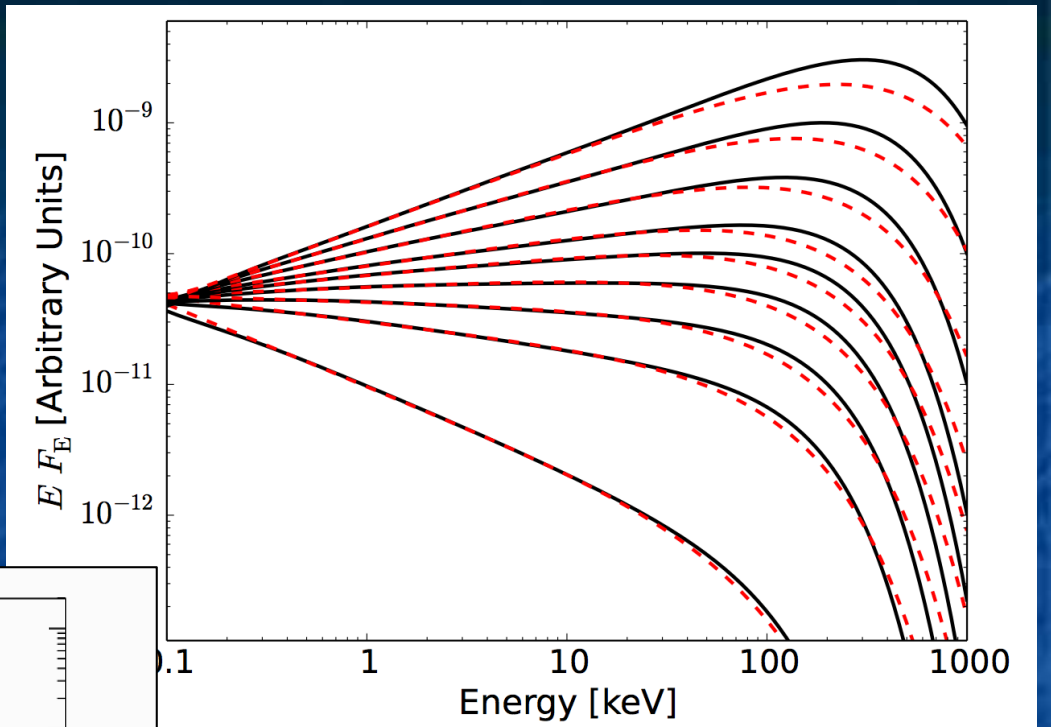


Zoghbi+12,13. Kara+13


e^-–e^- coupling
slab
hemisphere
sphere at 0.5h
1000
100
10
1
0.01
0.1
1
10
$L\sigma_T/Rm_ec^3$
kT_e/m_ec^2
Fabian, Lohfink et al., in press (arXiv:1505.07603)

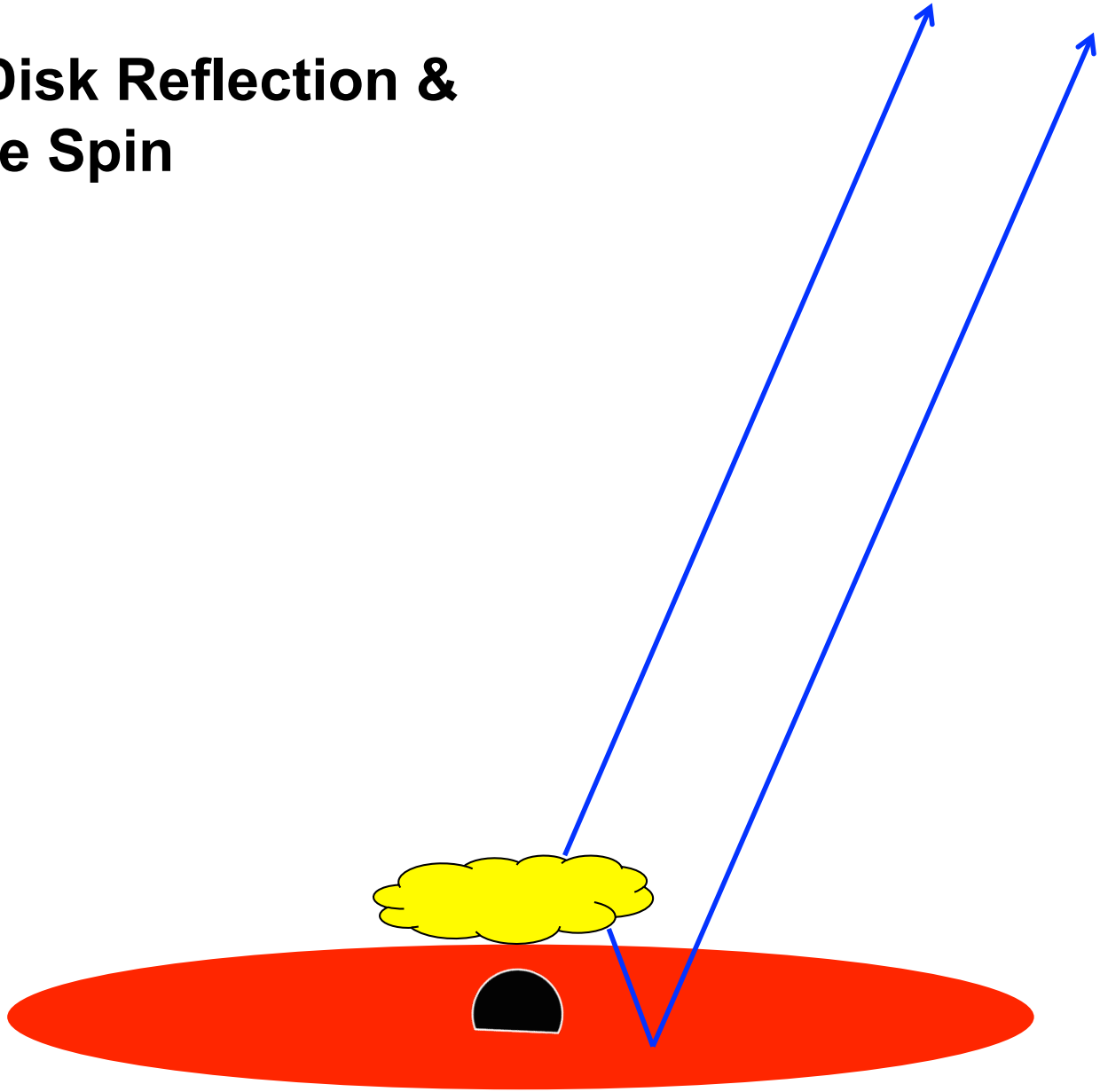
Simulated 100ks Astro-H simulation of NGC4388 (kT=50keV)
Reynolds, Ueda et al. (2014)





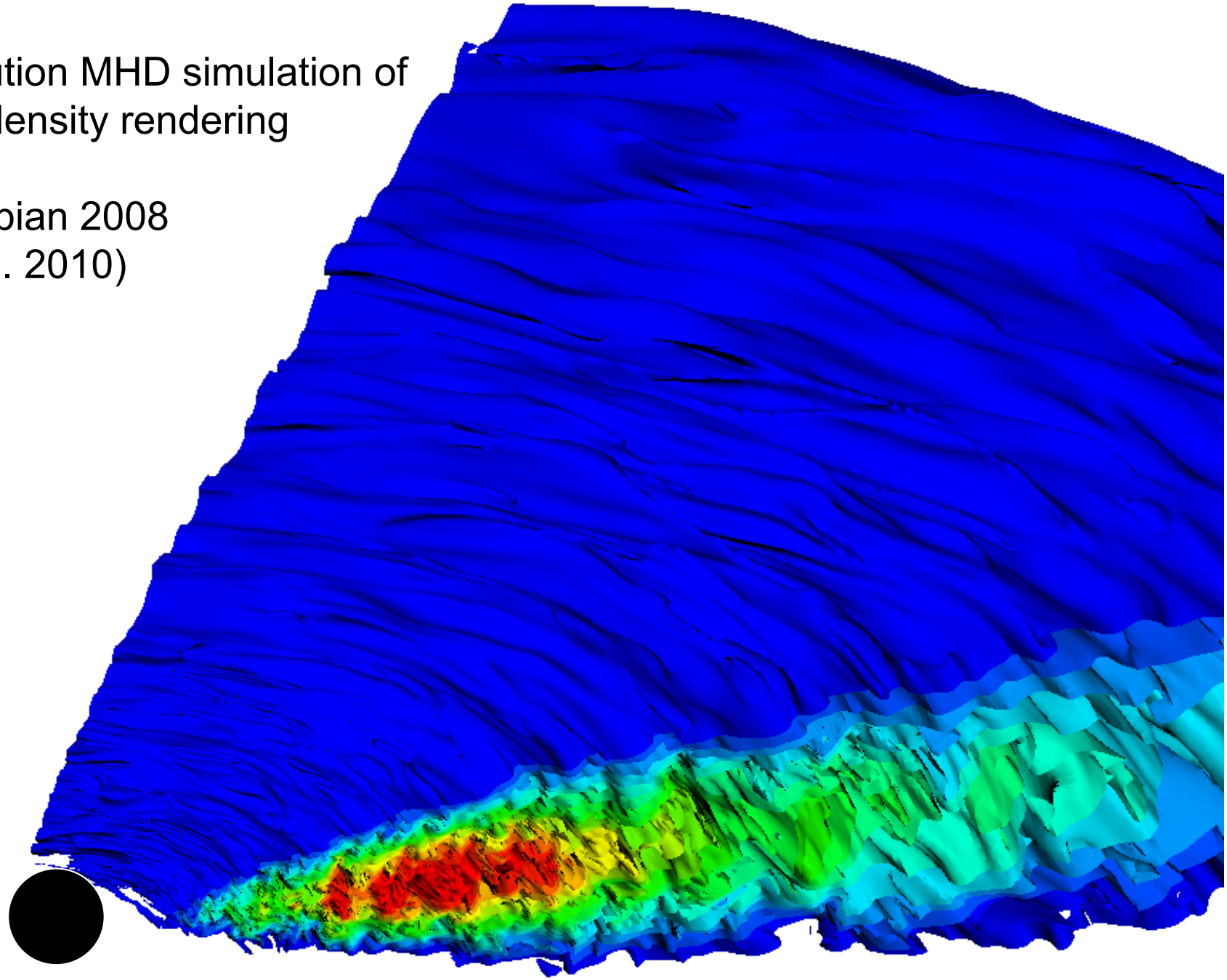
Difference of Comptonization model (black) & exp model (red)
Fabian+15

II : Inner Disk Reflection & Black Hole Spin

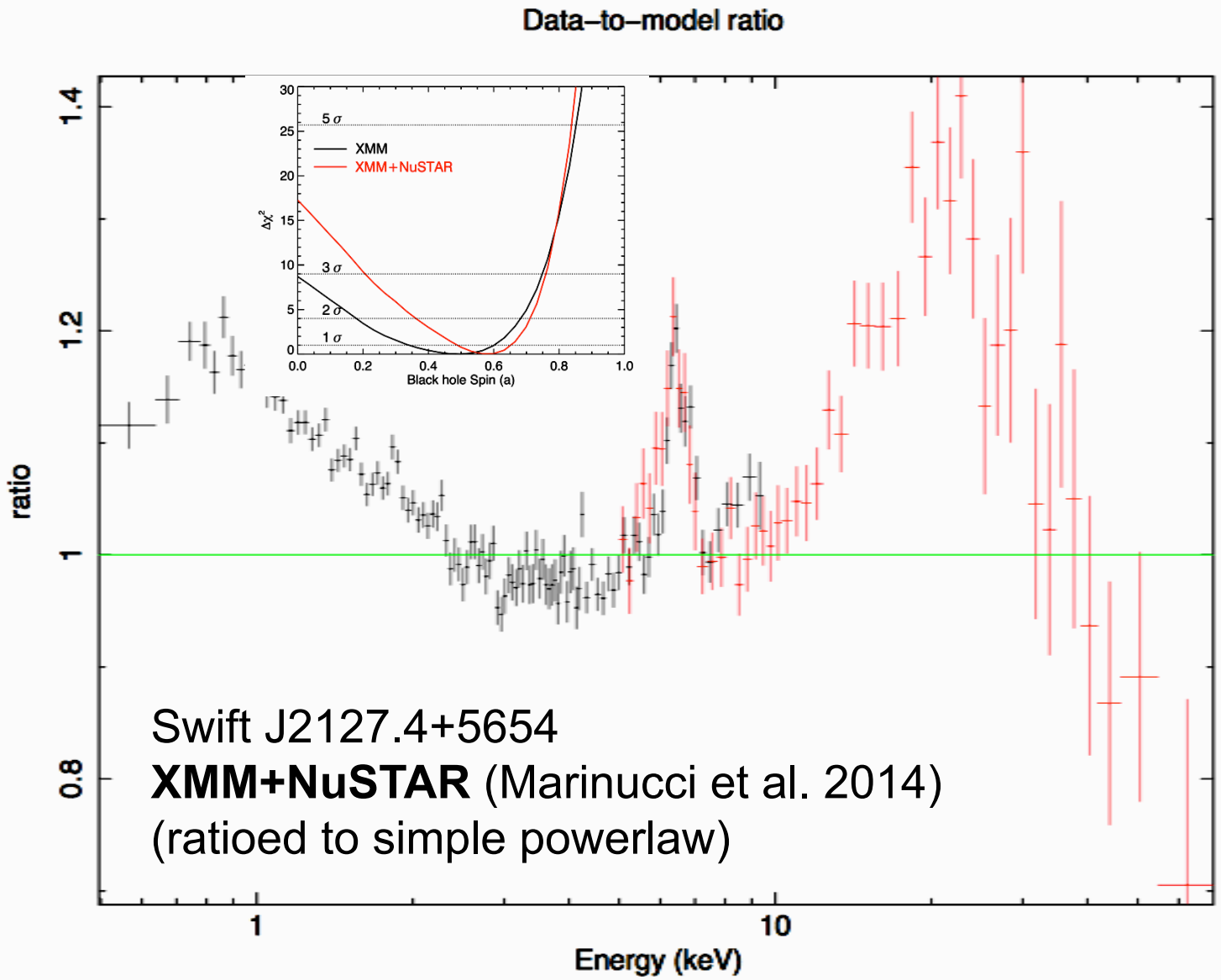


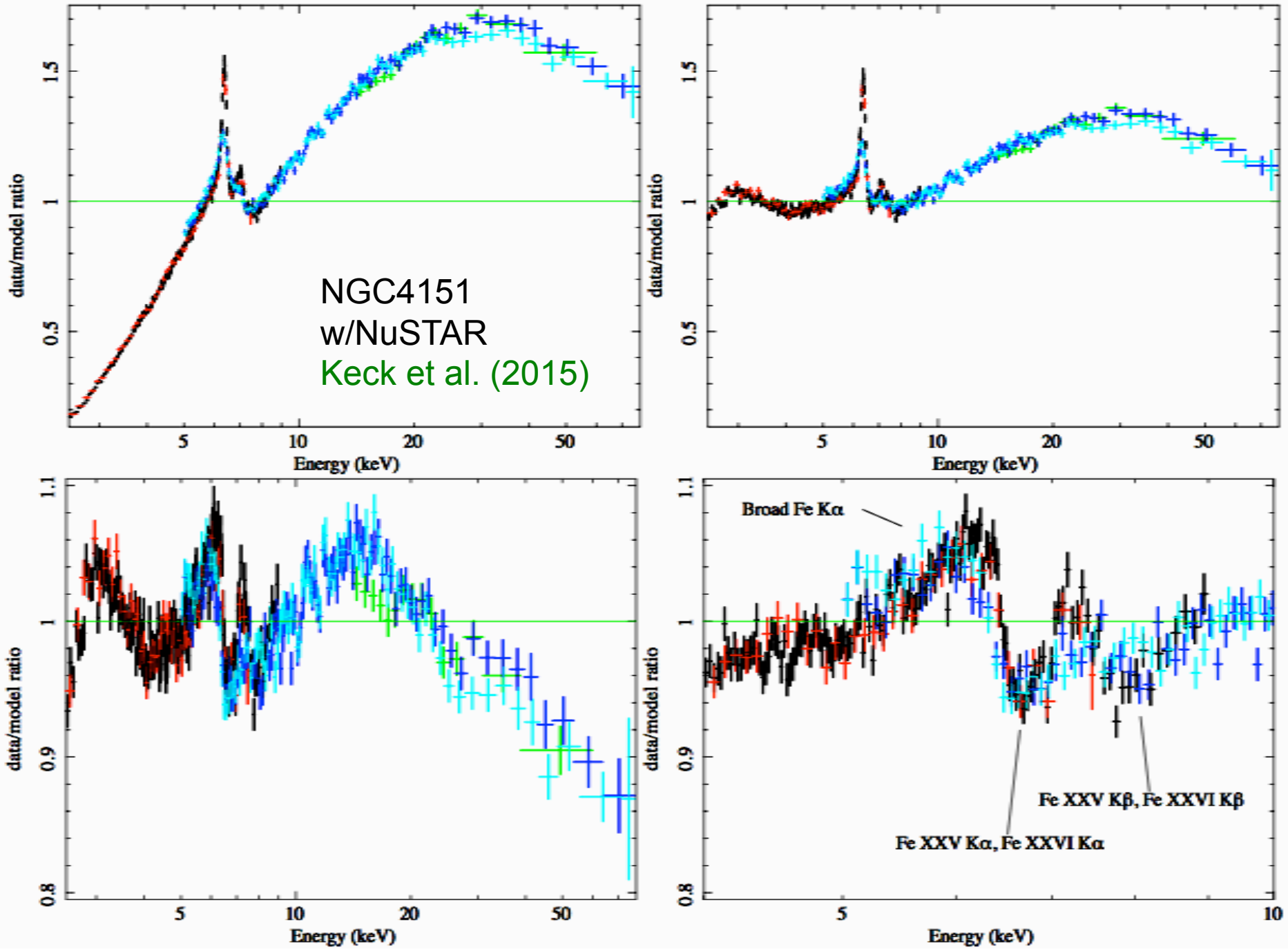
High-resolution MHD simulation of thin-disk / density rendering

(CSR & Fabian 2008
Penna et al. 2010)

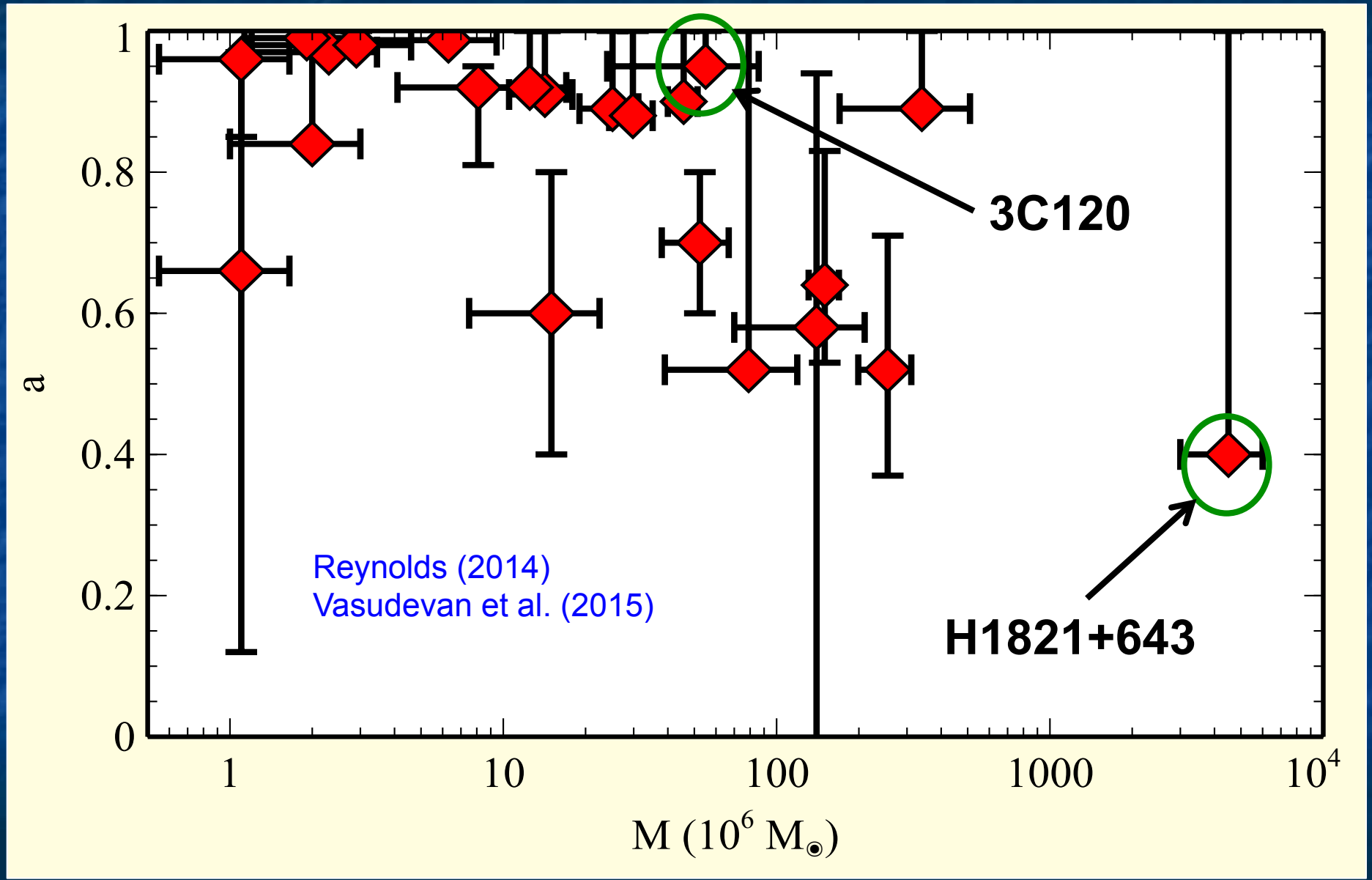


Bare Seyfert galaxy SWIFTJ2127.4+5654 (z=0.014)

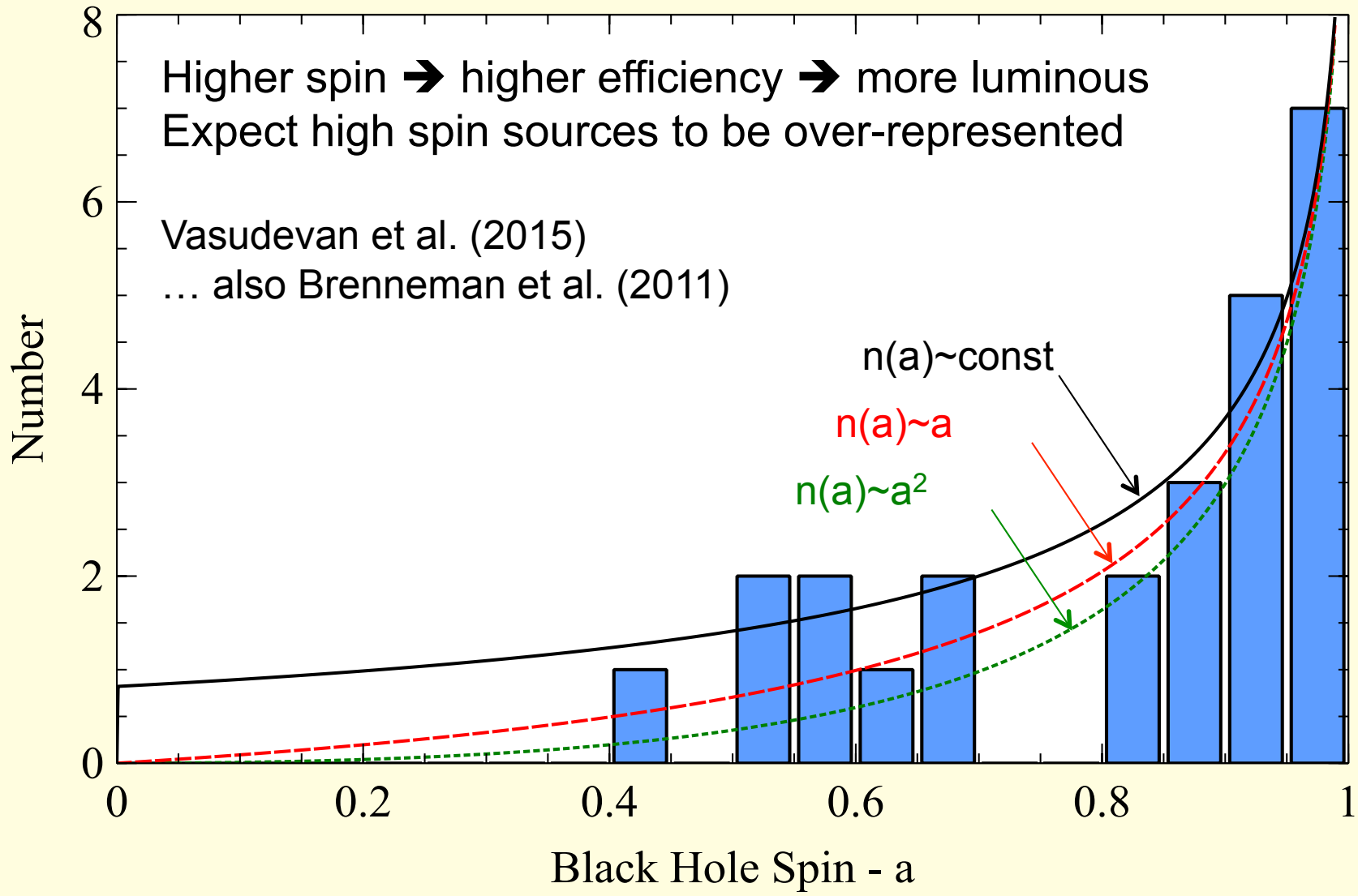


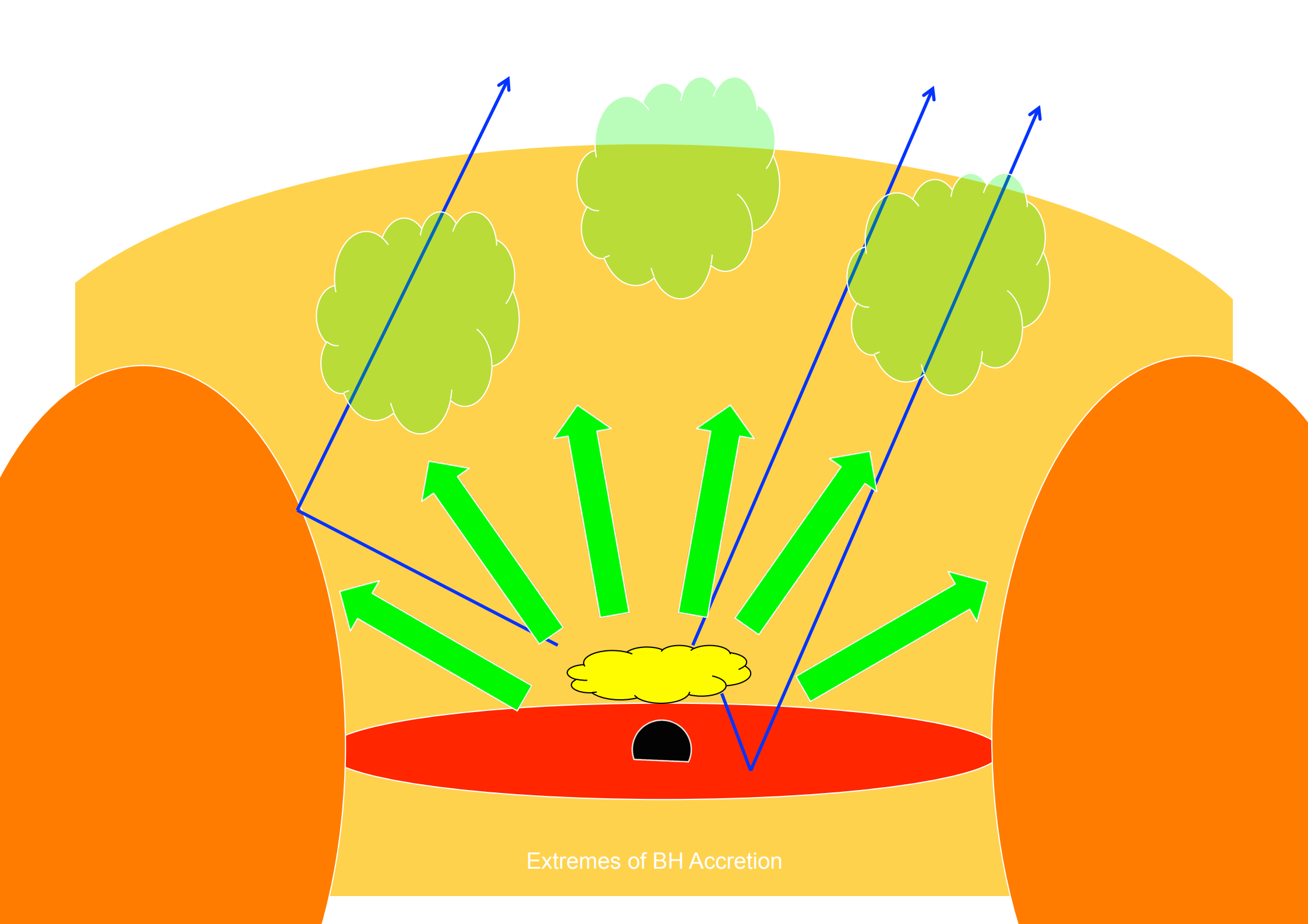

NGC4151
w/NuSTAR
Keck et al. (2015)
data/model ratio
Energy (keV)
Broad Fe Kα
Fe XXV Kβ, Fe XXVI Kβ
Fe XXV Kα, Fe XXVI Kα

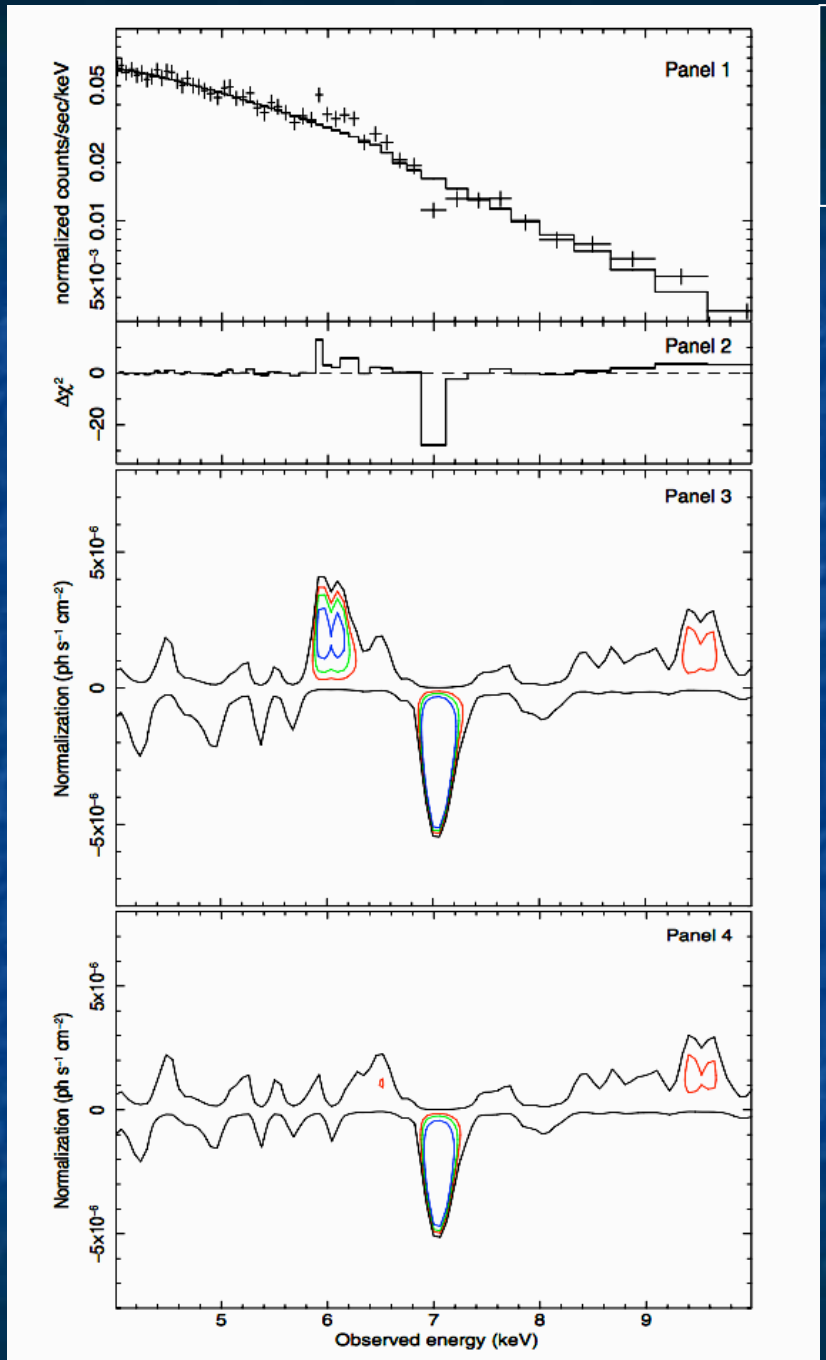
Compilation of spin constraints



Spin Bias

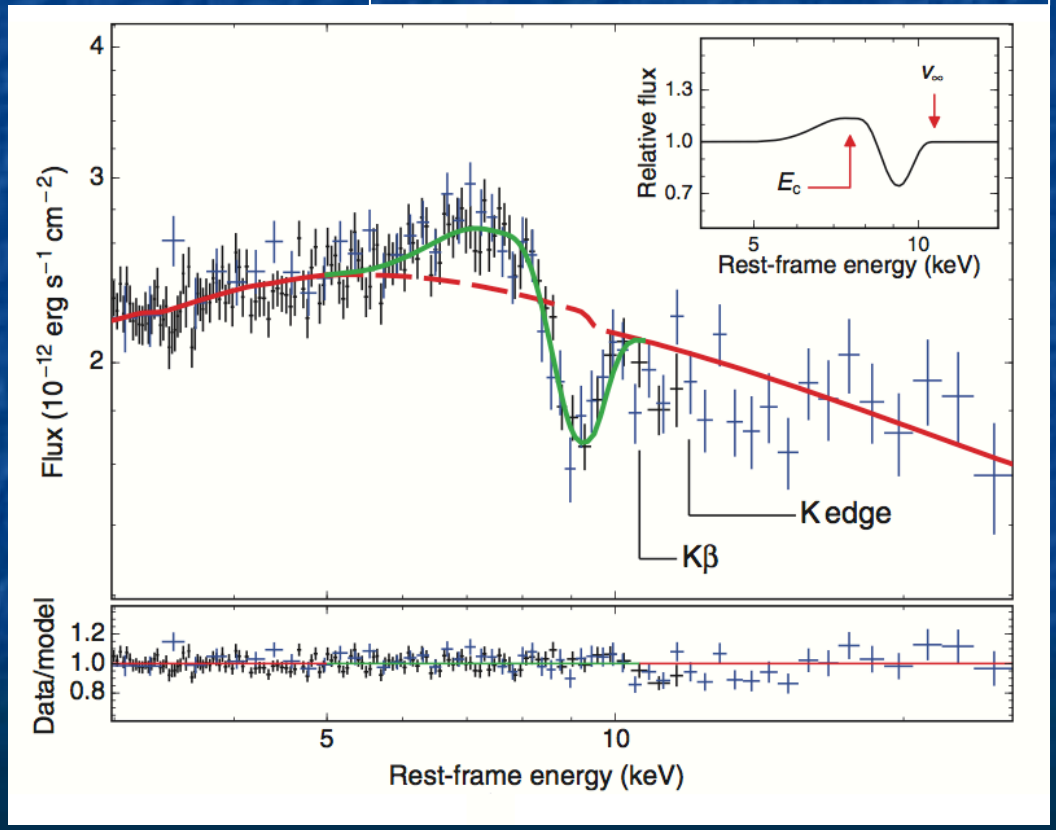

Higher spin ➔ higher efficiency ➔ more luminous
Expect high spin sources to be over-represented
Vasudevan et al. (2015)
… also Brenneman et al. (2011)
n(a)~const
n(a)~a
n(a)~a²
Number
Black Hole Spin - a
0
2
4
6
8
0
0.2
0.4
0.6
0.8
1


Extremes of BH Accretion

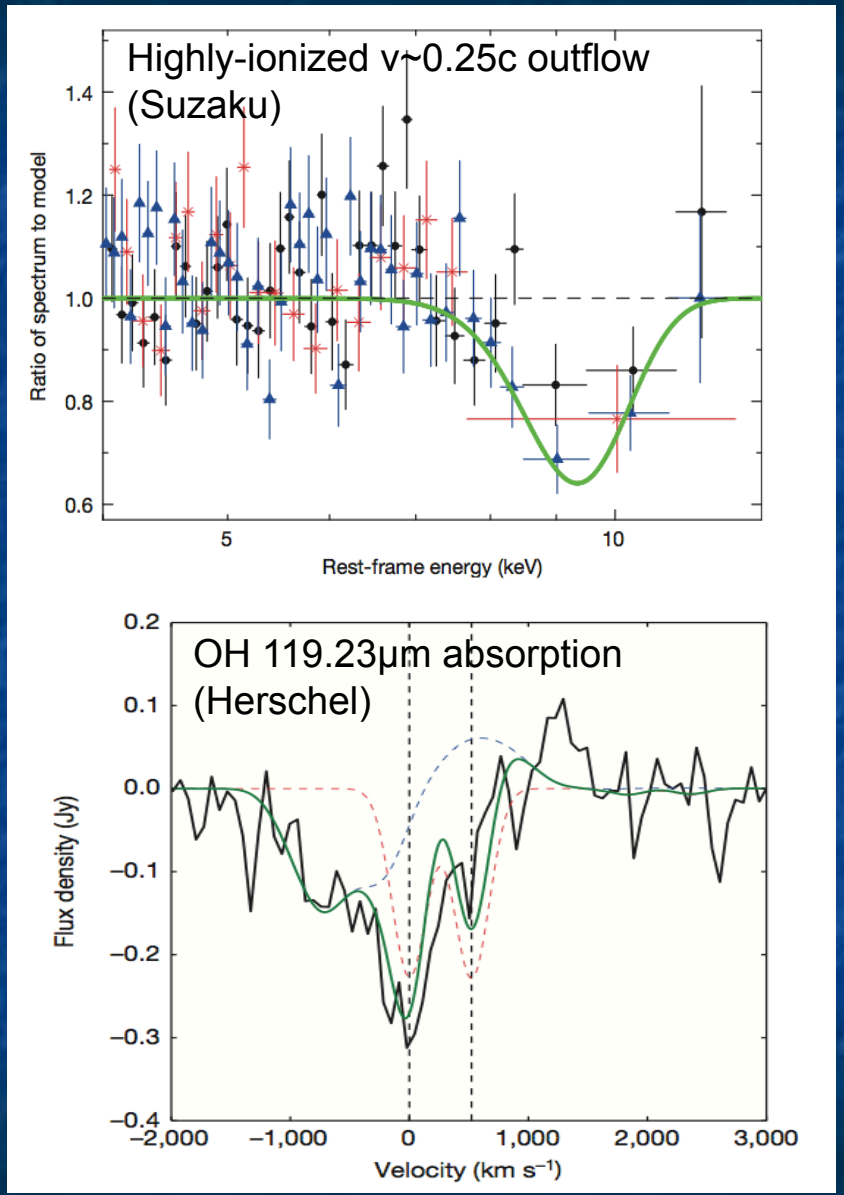


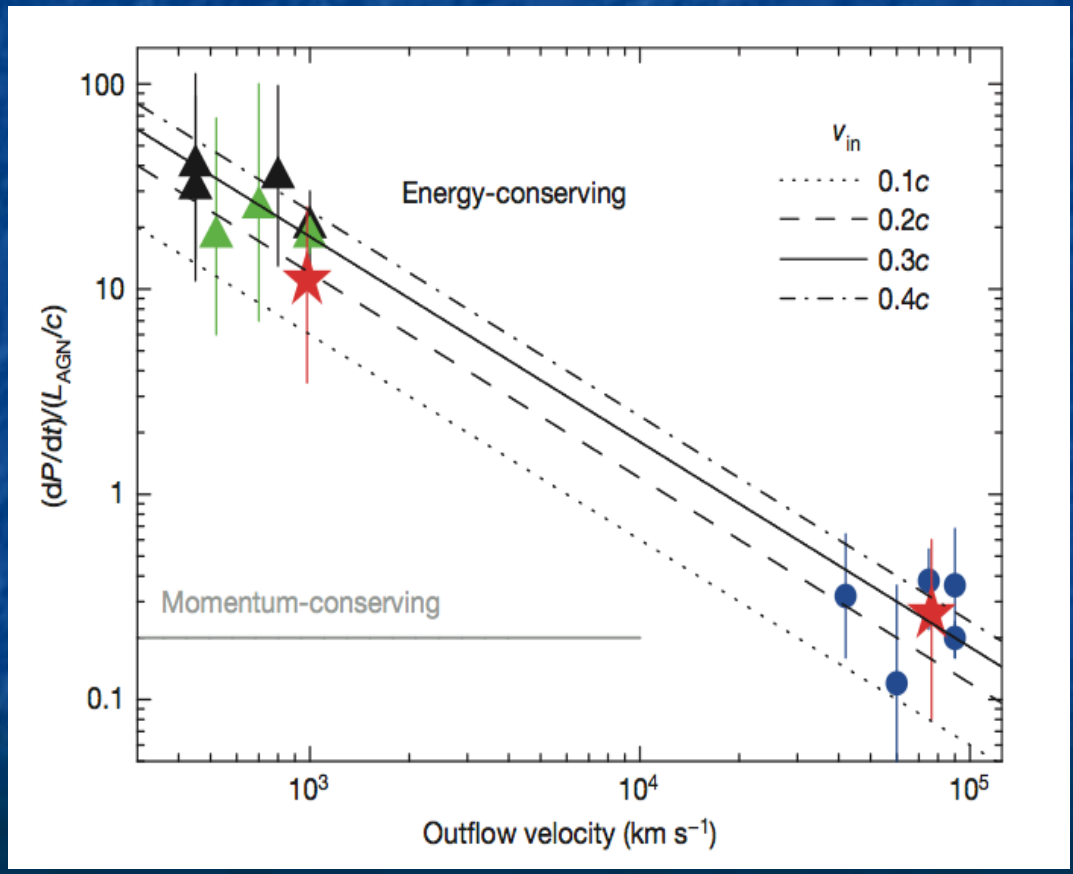
PG1211+143 w/XMM : Absorption line from v~0.1c outflow (Tombesi+2010; Pounds+2003)

PDS456 w/NUSTAR : P-Cyg profile from v~0.3c outflow (Nardini+ 2015)

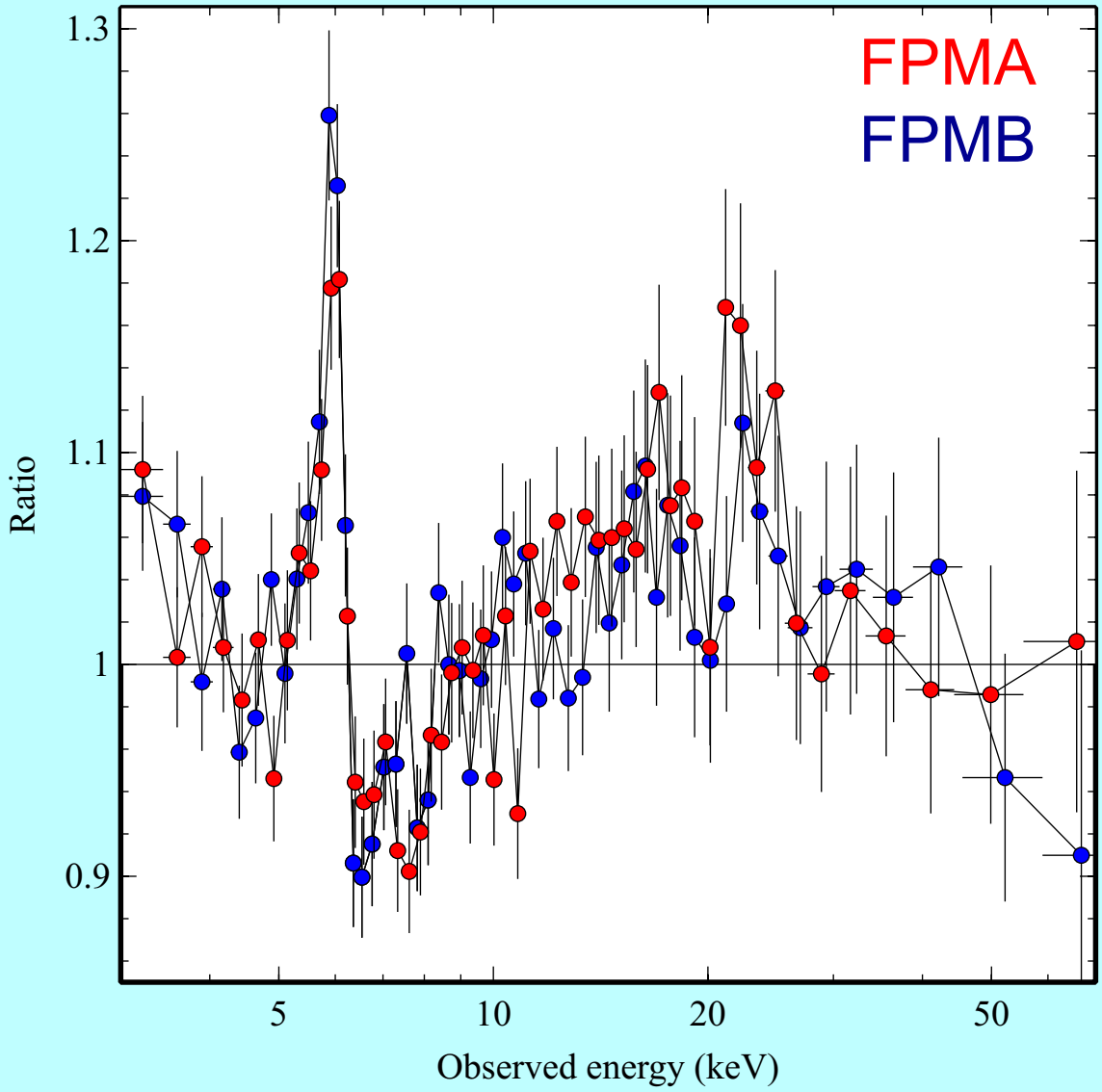


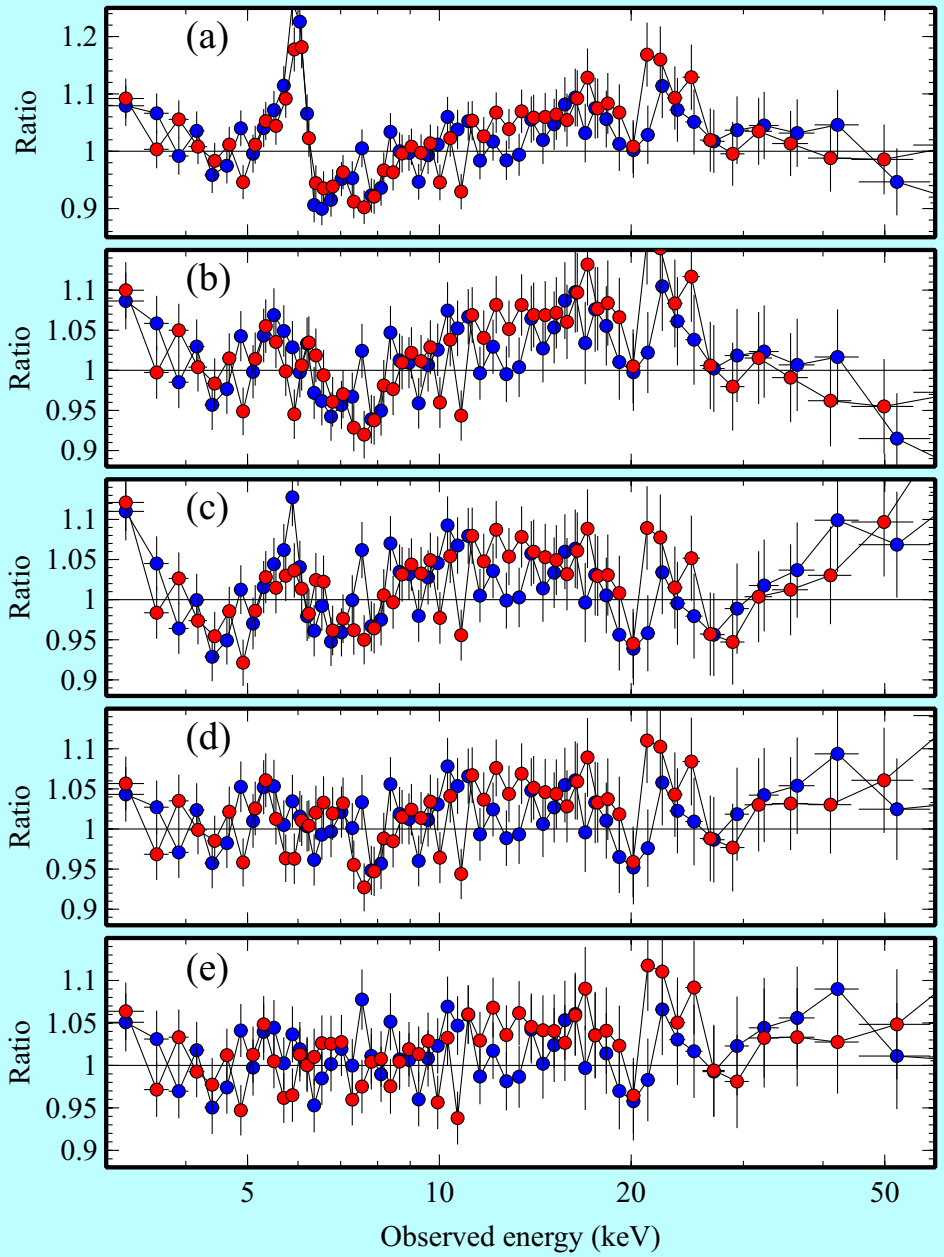
The ULIRG IRASF1119+3257 (Tombesi et al. 2015)





Cygnus A w/NuSTAR (Reynolds et al., submitted)





ICM + cABS(PL)

ICM + cABS(PL+emLINE)

ICM + cABS(PL+REFL)

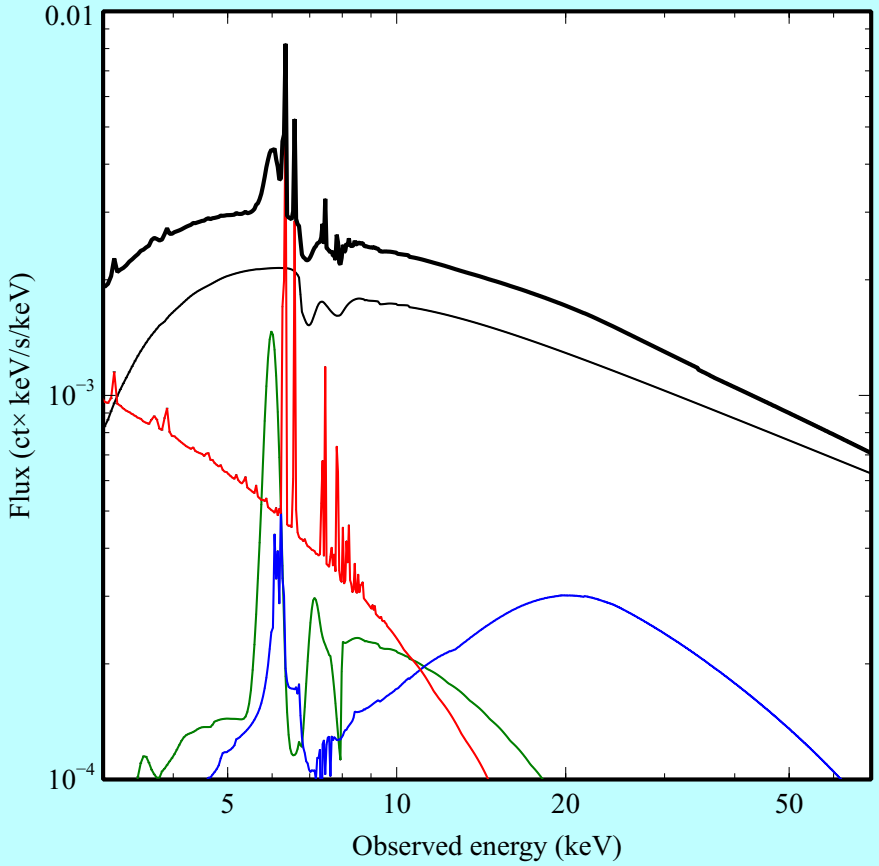
↓ $\Delta\chi^2=74(5)$

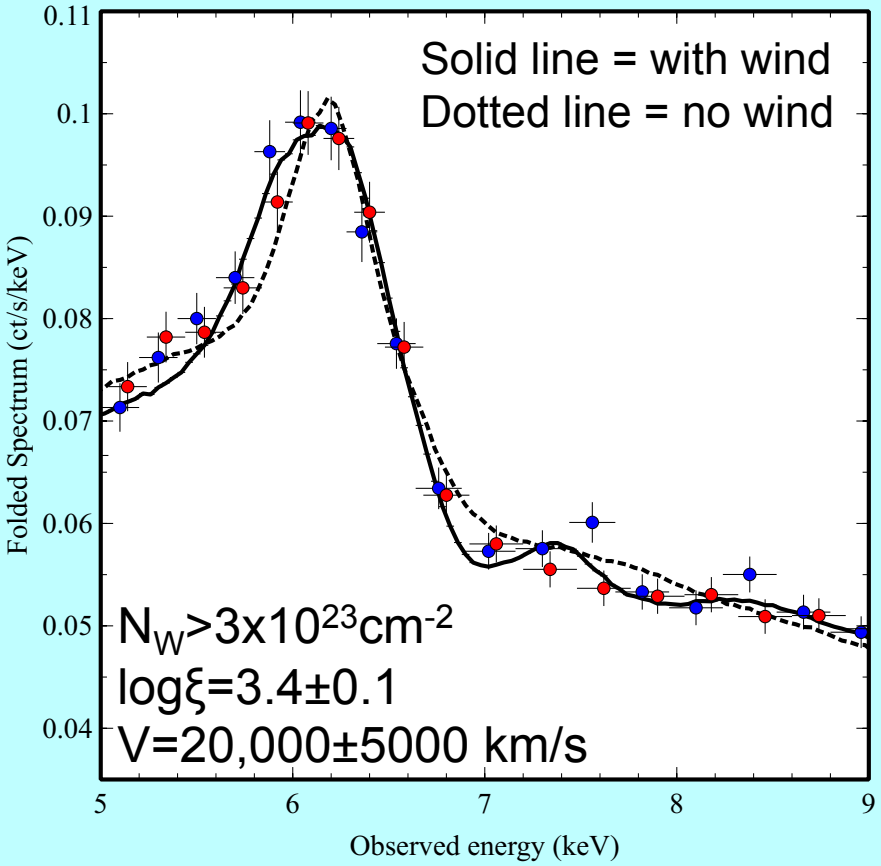
ICM + cABS(PL+PCYG)

↓ $\Delta\chi^2=19(2)$

ICM + cABS(PL+PCYG +absLINE)

Best fitting NuSTAR model to Cygnus-A

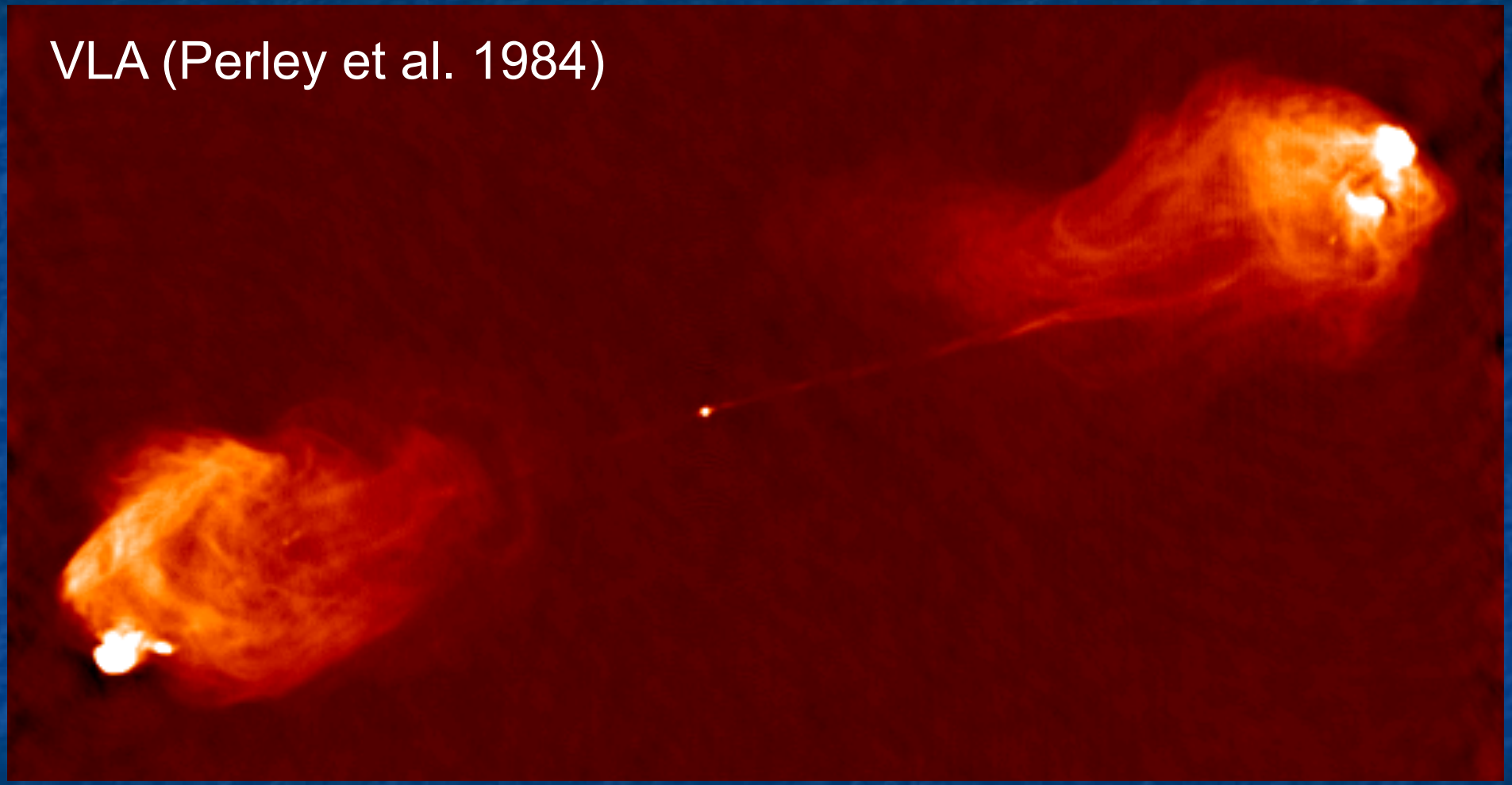


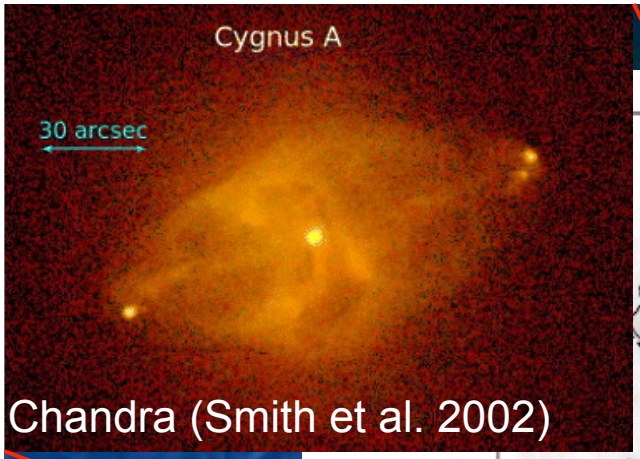


The wind…

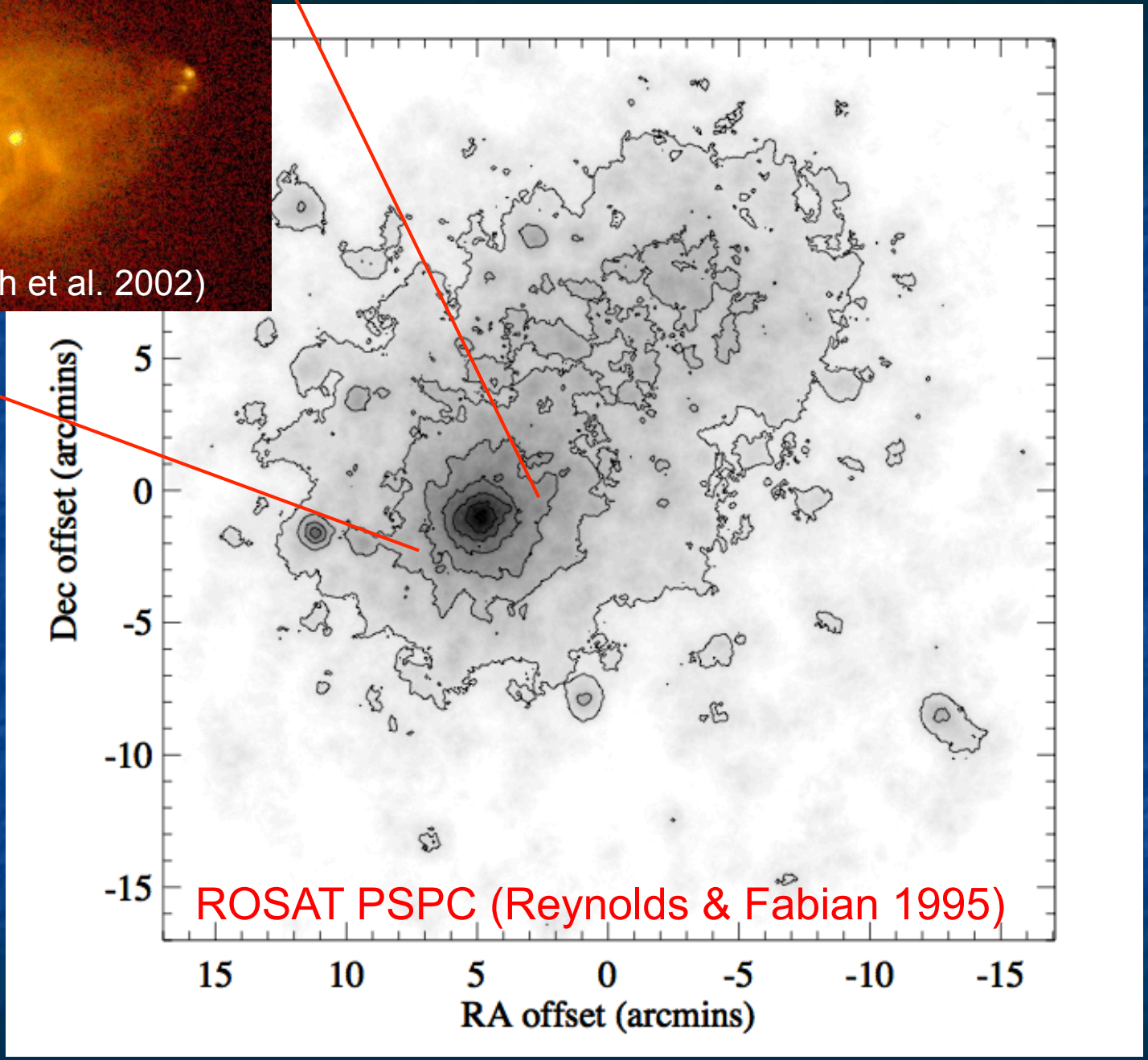
- Assume
  - Wind subtends $\Omega=\pi$ of the sky as seen by source
  - Velocity is escape speed at launching site
- Then
  - Mass flux… $M_{dot} = 110\ (L_{bol}/c^2)$
  - Momentum flux… $P_{tot} = 10\ (L_{bol}/c)$
  - Kinetic energy flux… $L_K = 0.42\ L_{bol}$

VLA (Perley et al. 1984)





Chandra (Smith et al. 2002)

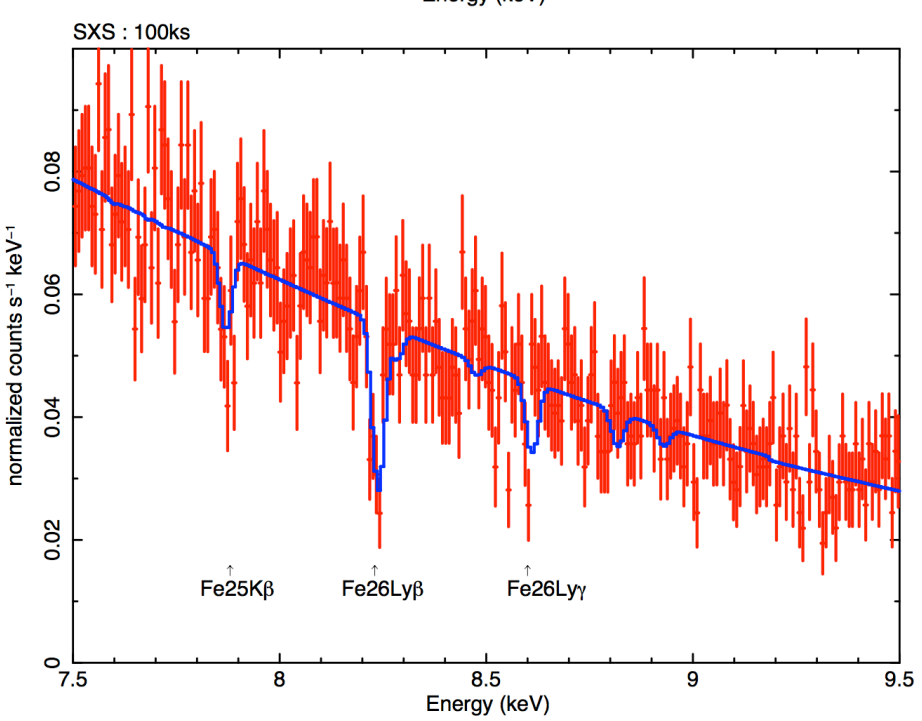


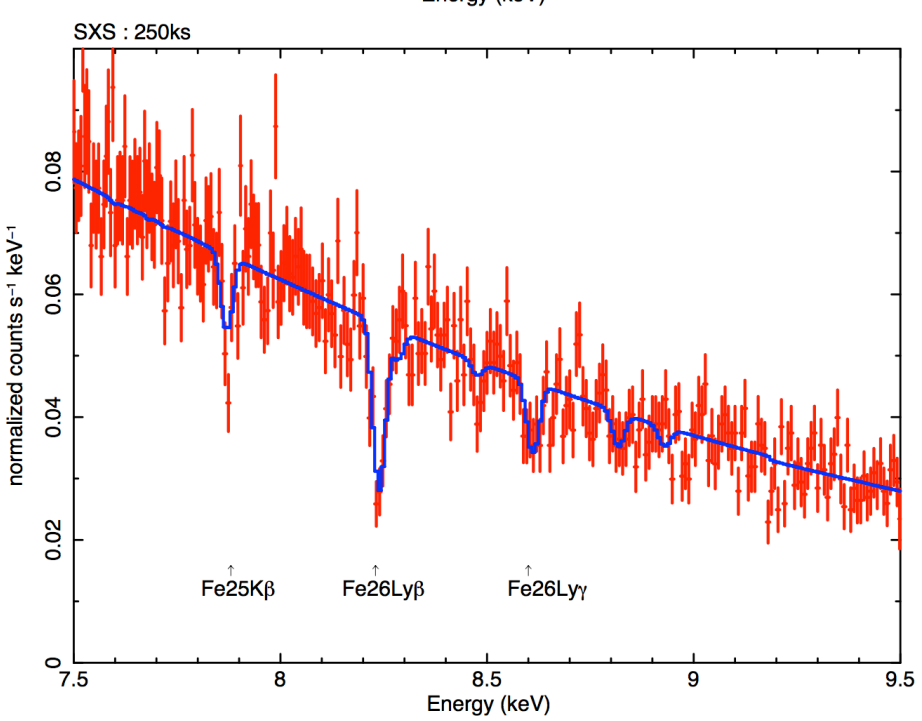
ROSAT PSPC (Reynolds & Fabian 1995)

The wind in Cygnus A…

- Assume
  - Wind subtends $\Omega=\pi$ of the sky as seen by source
  - Velocity is escape speed at launching site
- Then
  - Mass flux… $M_{dot} = 110\ (L_{bol}/c^2)$
  - Momentum flux… $P_{tot} = 10\ (L_{bol}/c)$
  - Kinetic energy flux… $L_K = 0.42\ L_{bol}$
- Appear to have a strong wind (possibly exercising feedback on galaxy) at same time as we see strong jets (feeding back on cluster)

Simulated Astro-H Observation of MCG-6-30-15





Conclusions

- Selected highlights from AGN/X-ray spectroscopy
  - Evidence for pair-regulated coronae
  - Samples of black hole spin; even measure in complex cases
  - Prevalence of high-spin sources may be largely efficiency bias
  - Fast powerful disk winds and feedback on host galaxy
- May of these advances enabled by high-s/n and wide-bandpass possible with joint XMM+NuSTAR (or Suzaku +NuSTAR)
- Looking forward to Astro-H era