The Disk-Jet-Spin Connection in Active Galactic Nuclei

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With…
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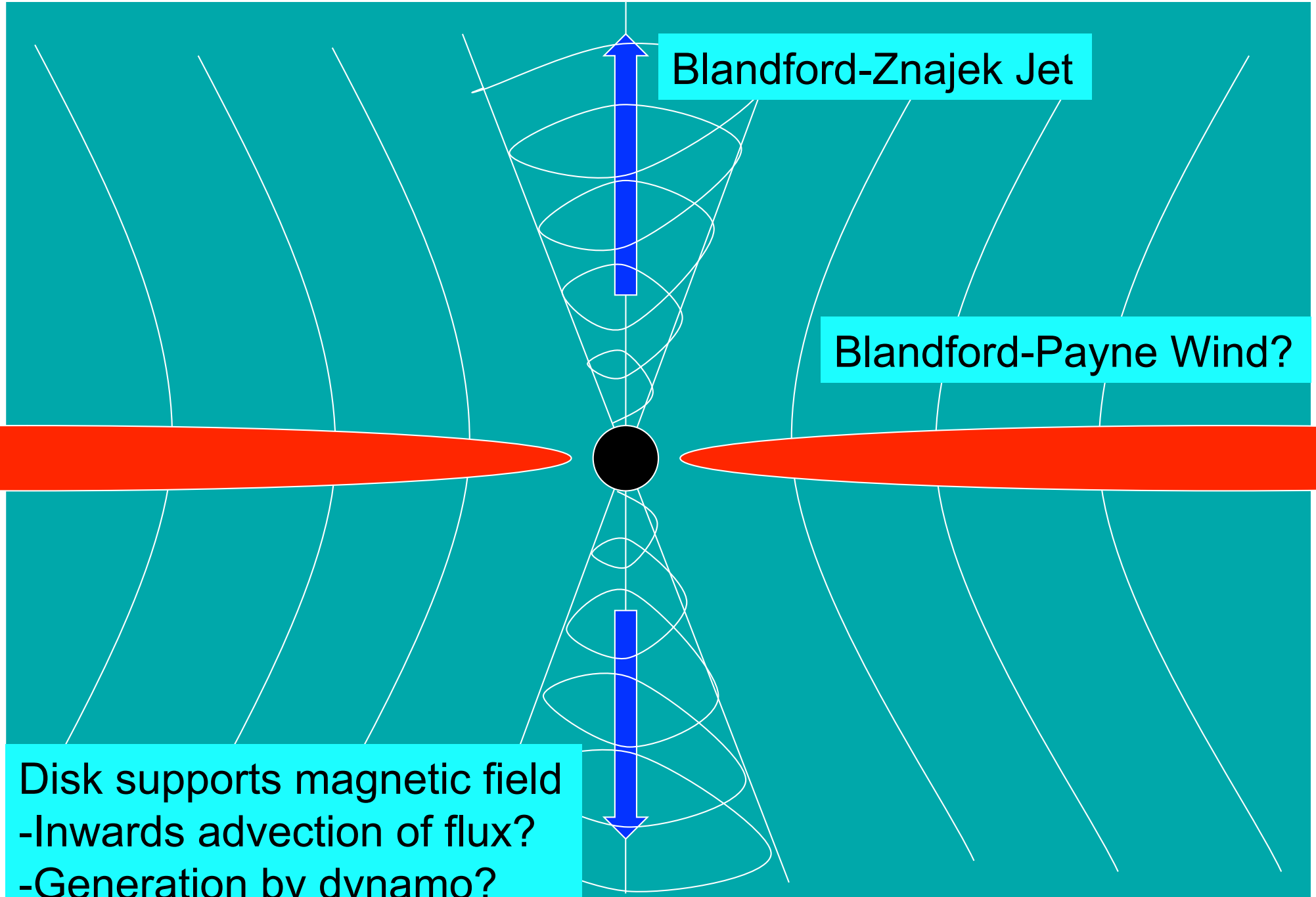
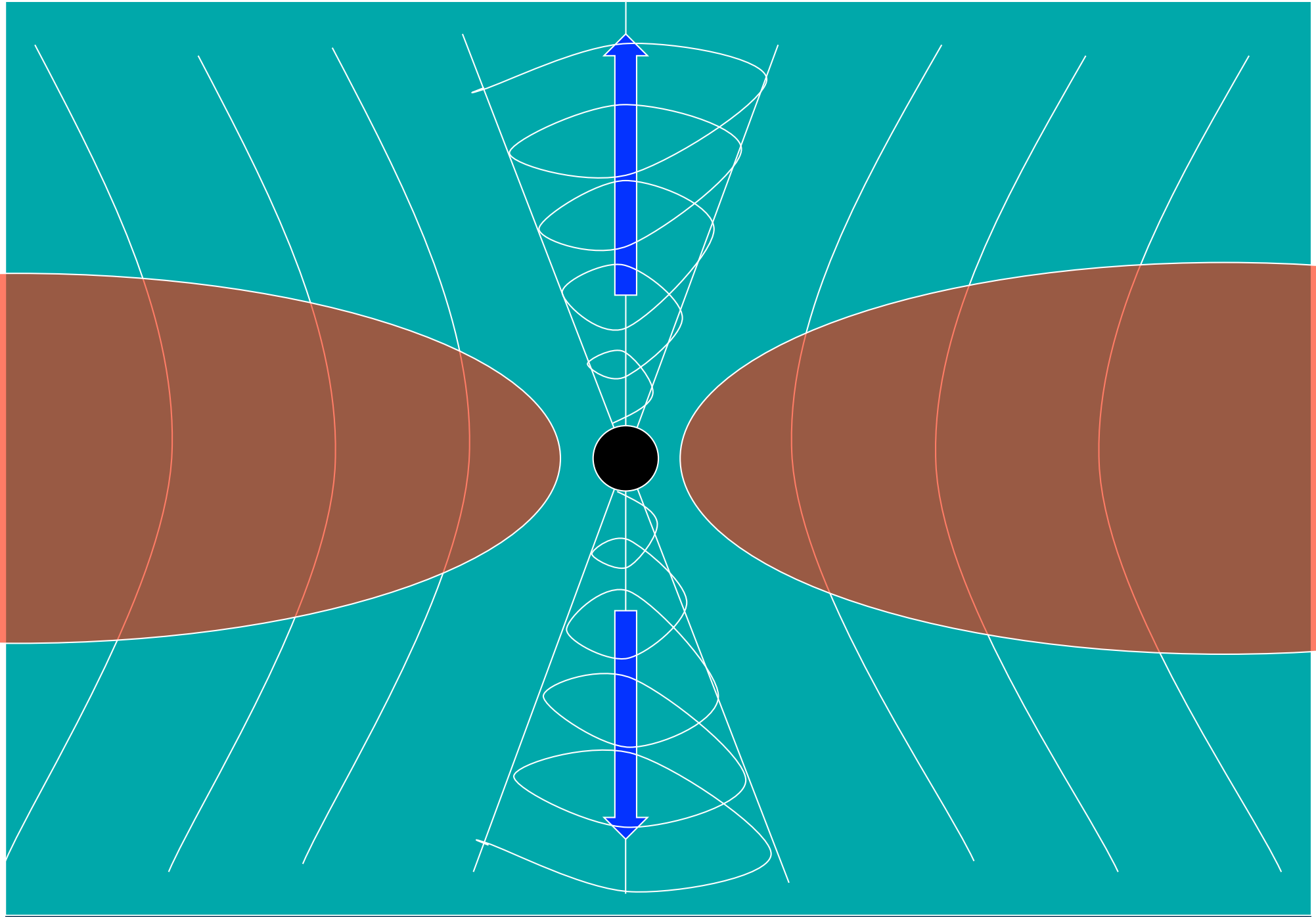
Anne Lohfink
Alan Marscher
Abdu Zoghbi

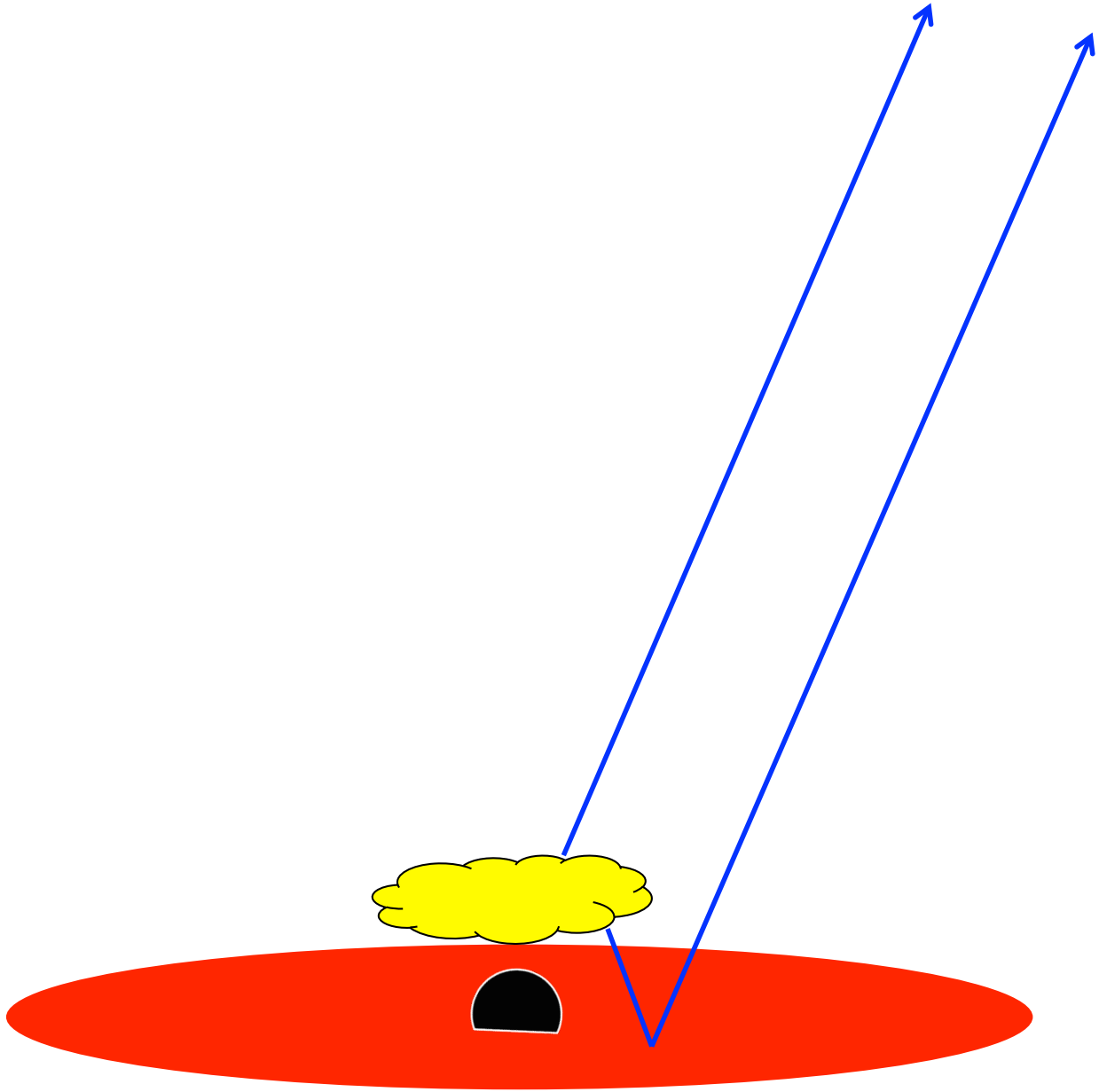

Blandford-Znajek Jet
Blandford-Payne Wind?
Disk supports magnetic field
-Inwards advection of flux?
-Generation by dynamo?

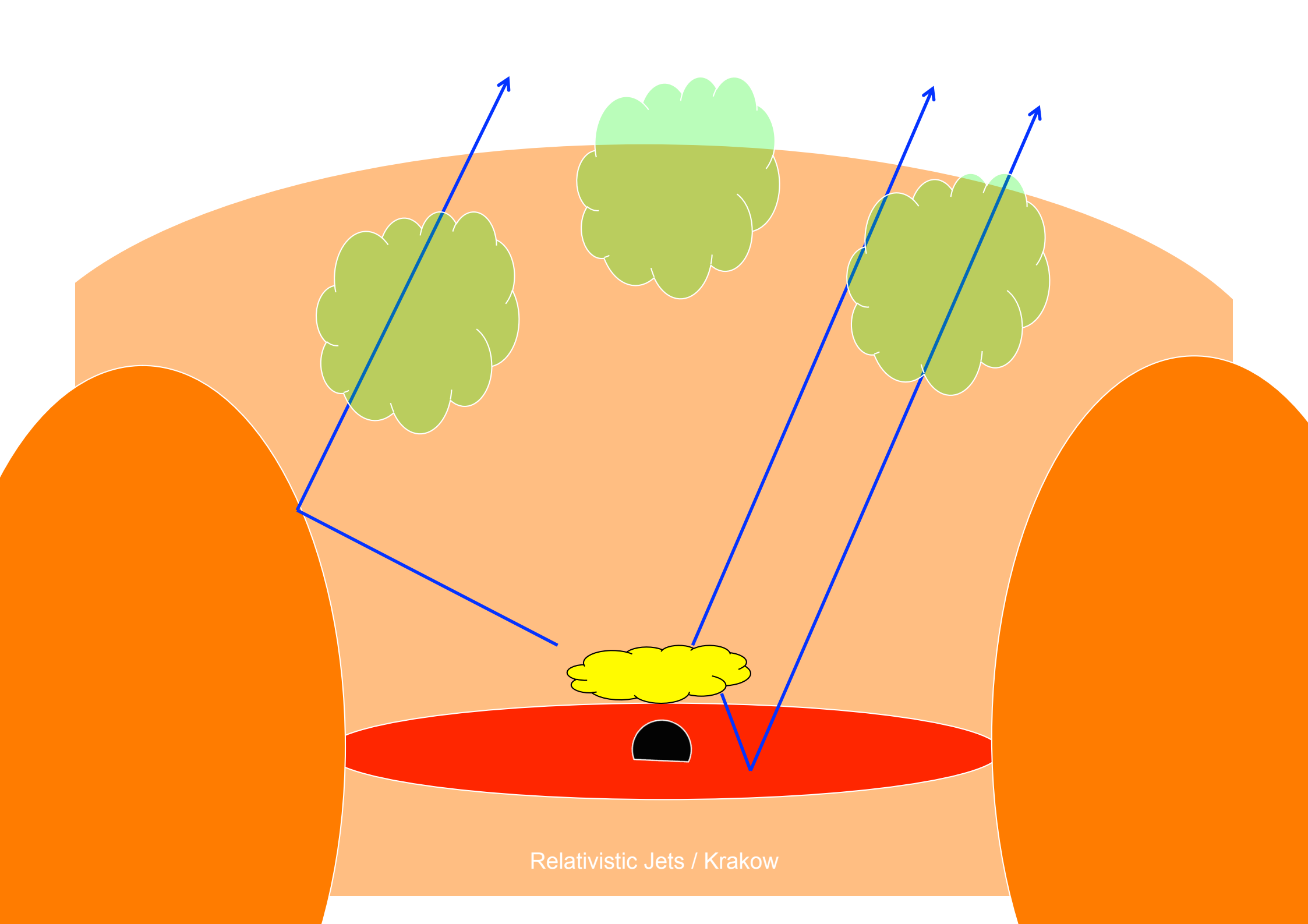


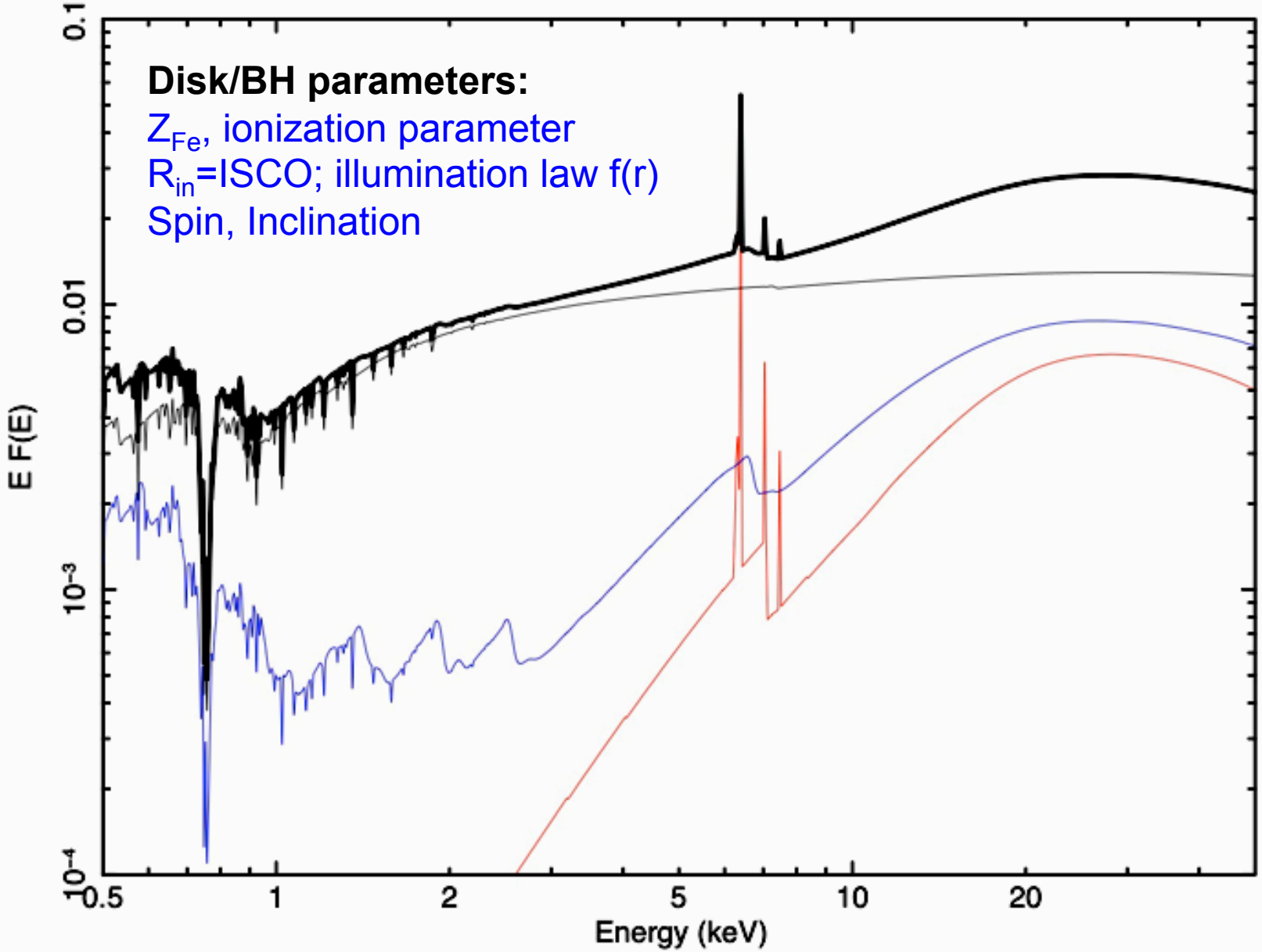
This talk…

- Black hole spin measurements find population of high-spin, radio-quiet AGN
  - Existence of jets depends on more than spin!
- Some powerful jetted AGN show radiatively-efficient thin-disks down to ~ISCO
  - May break the analogy between AGN and stellar-mass BHs
- Broad-line radio galaxies give a direct view of the time-dependent disk-jet connection
  - Cyclical “disappearance” of the innermost accretion disk
- X-ray reverberation studies are suggesting non-obvious geometries for the X-ray source in Seyfert galaxies
  - Evidence of BH magnetospheric processes?

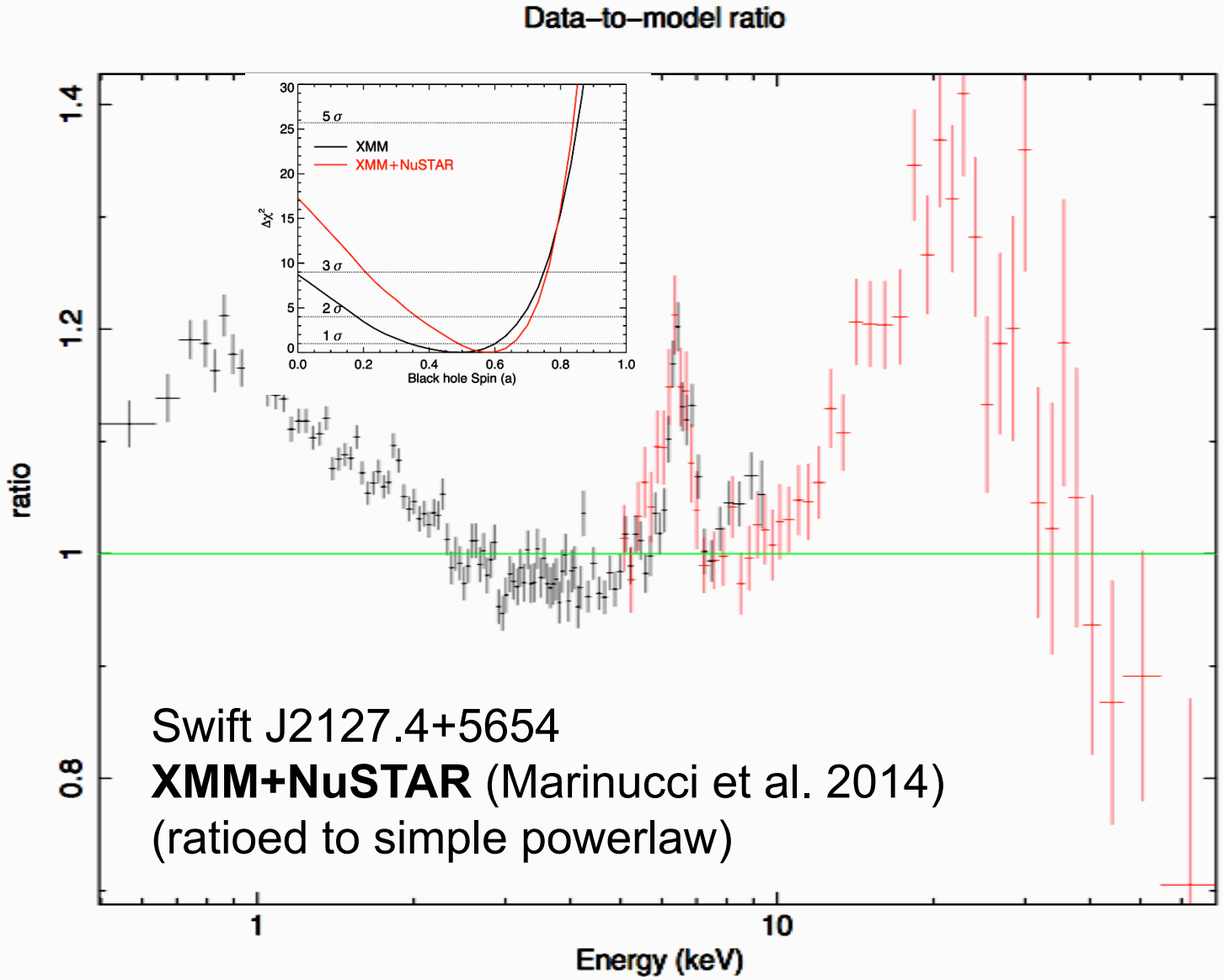
I : Black Hole Spin Measurements




Relativistic Jets / Krakow

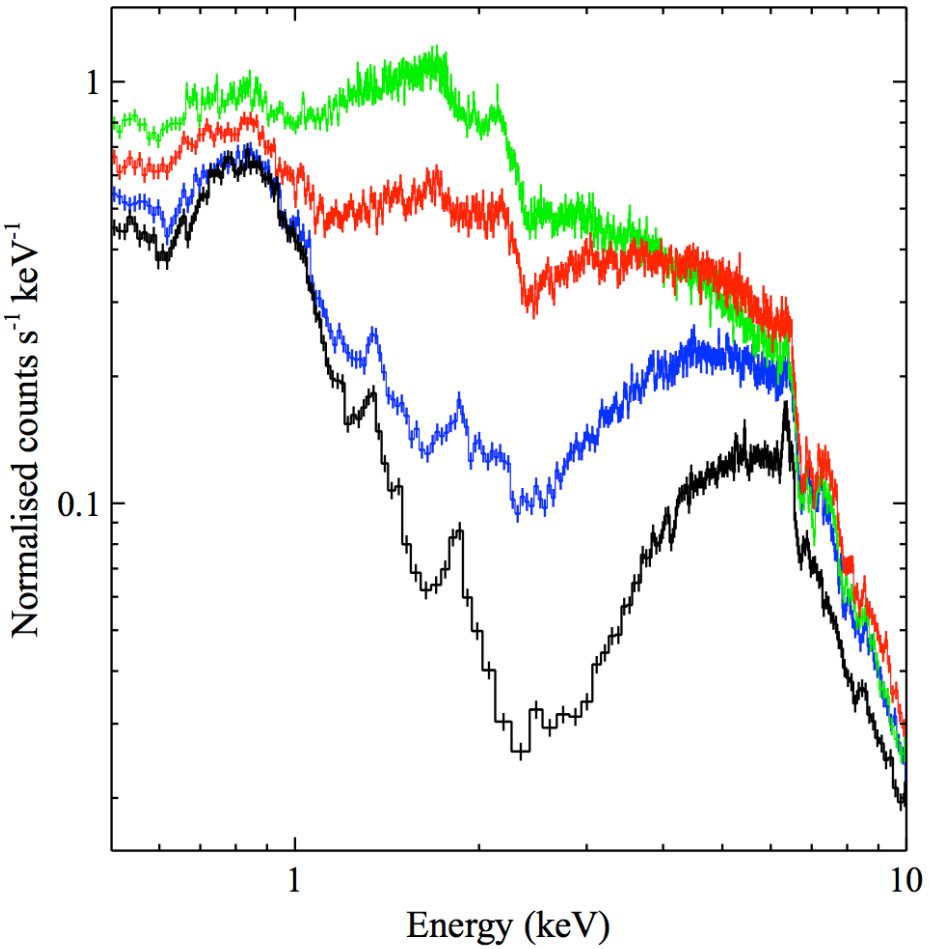

Disk/BH parameters:
Z_{Fe}, ionization parameter
R_{in}=ISCO; illumination law f(r)
Spin, Inclination
E F(E)
0.1
0.01
10^{-3}
10^{-4}
0.5
1
2
5
10
20
Energy (keV)

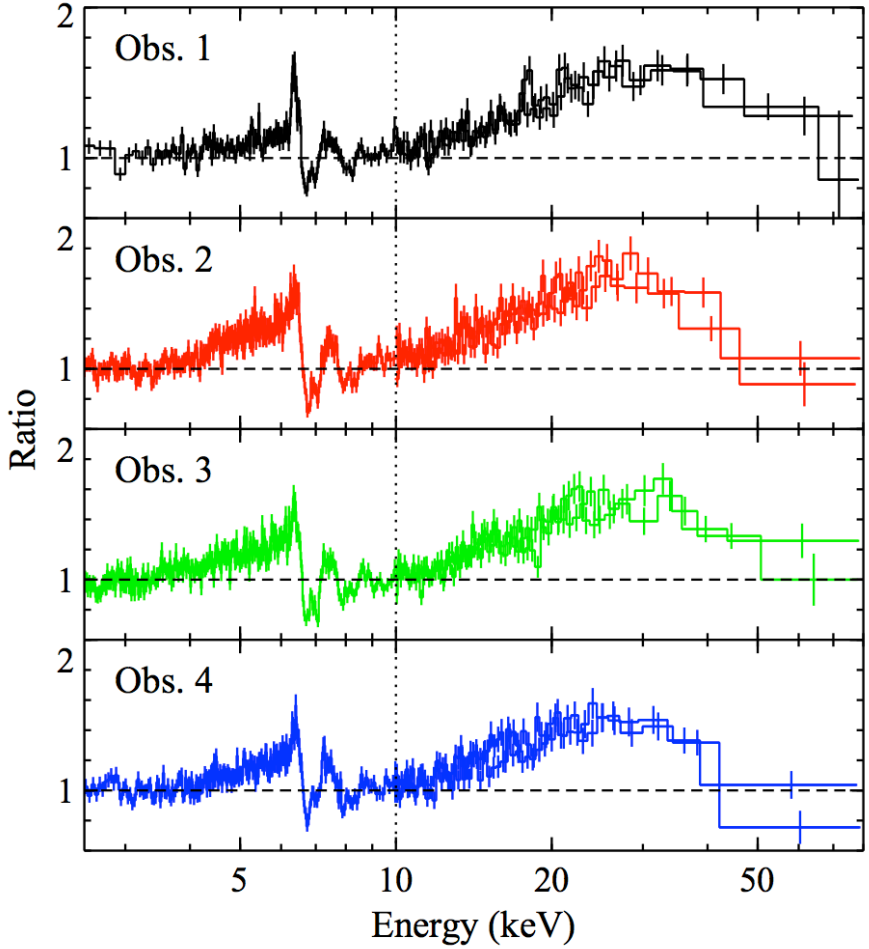
Bare Seyfert galaxy SWIFTJ2127.4+5654 (z=0.014)



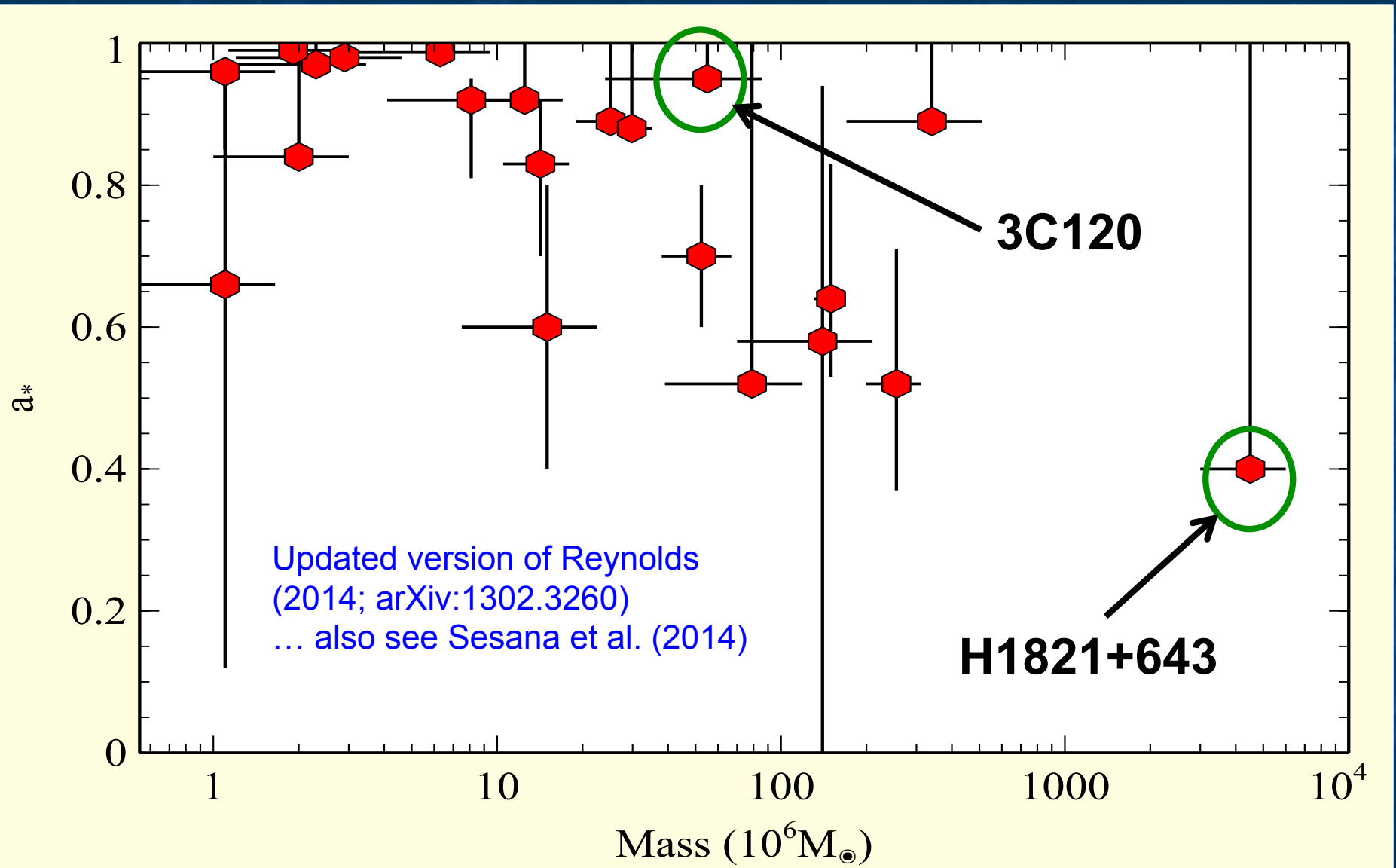
What about complicated absorption?

NGC1365 with XMM+NuSTAR (Walton et al. 2014)



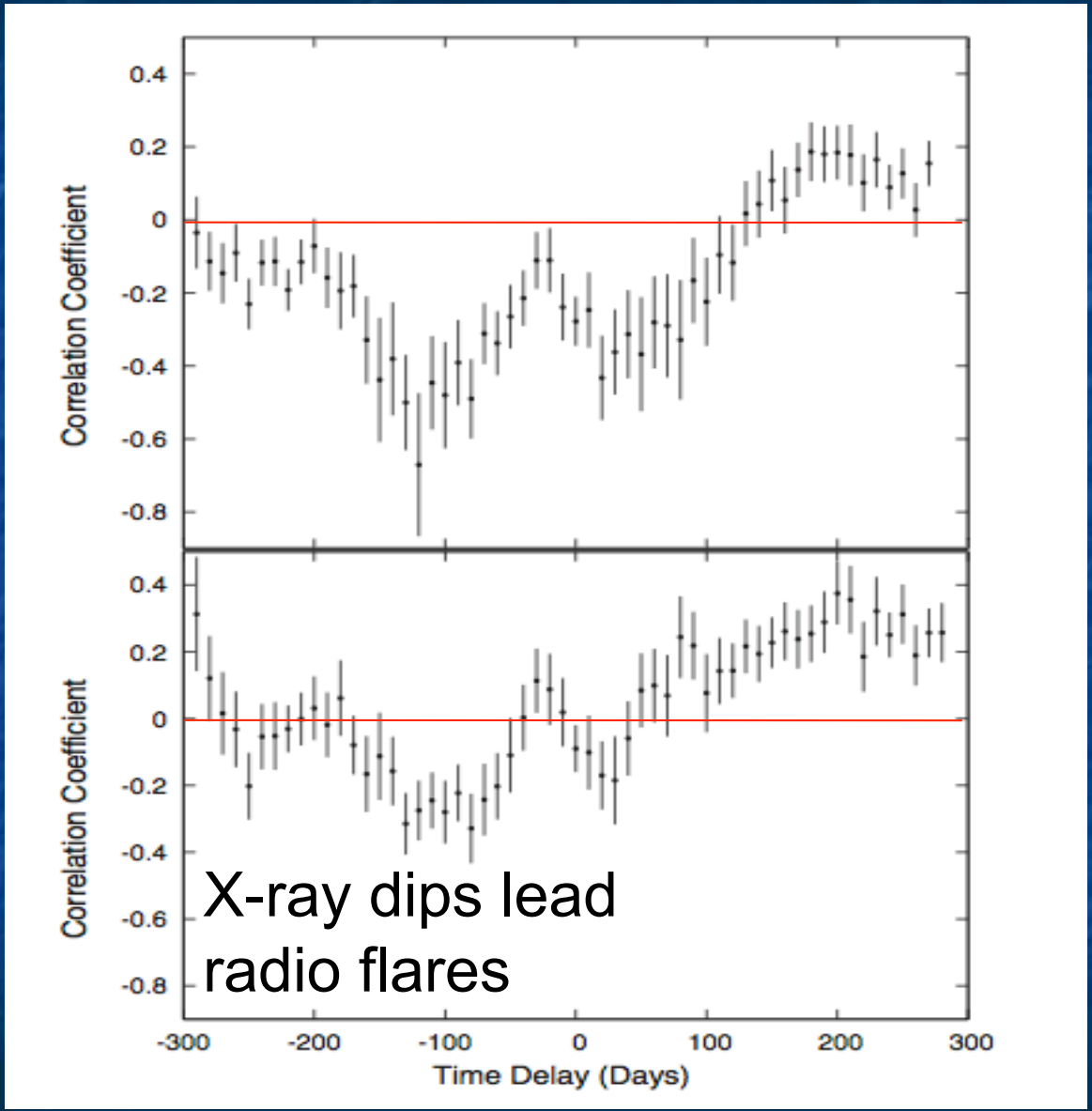


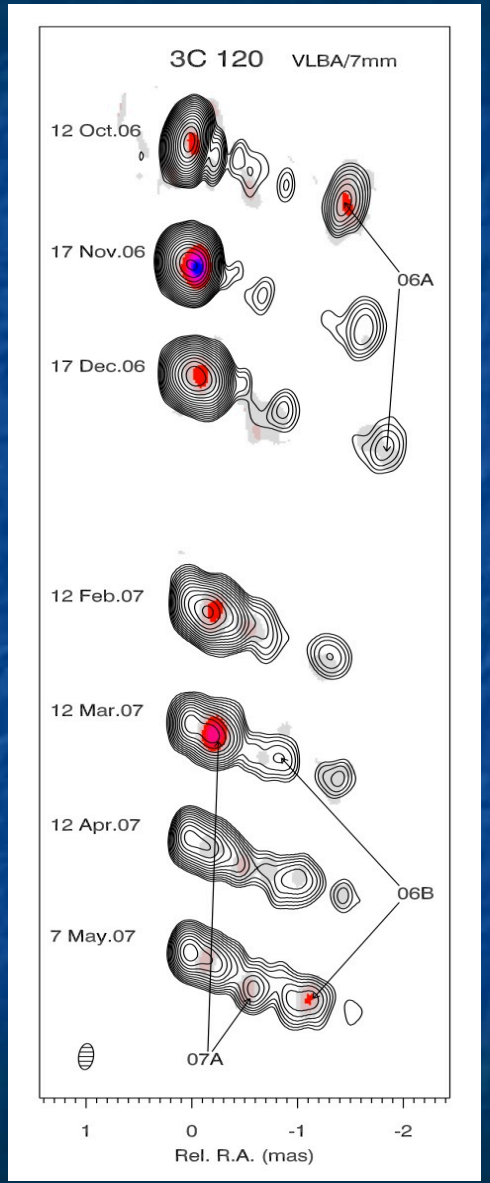
Compilation of spin constraints



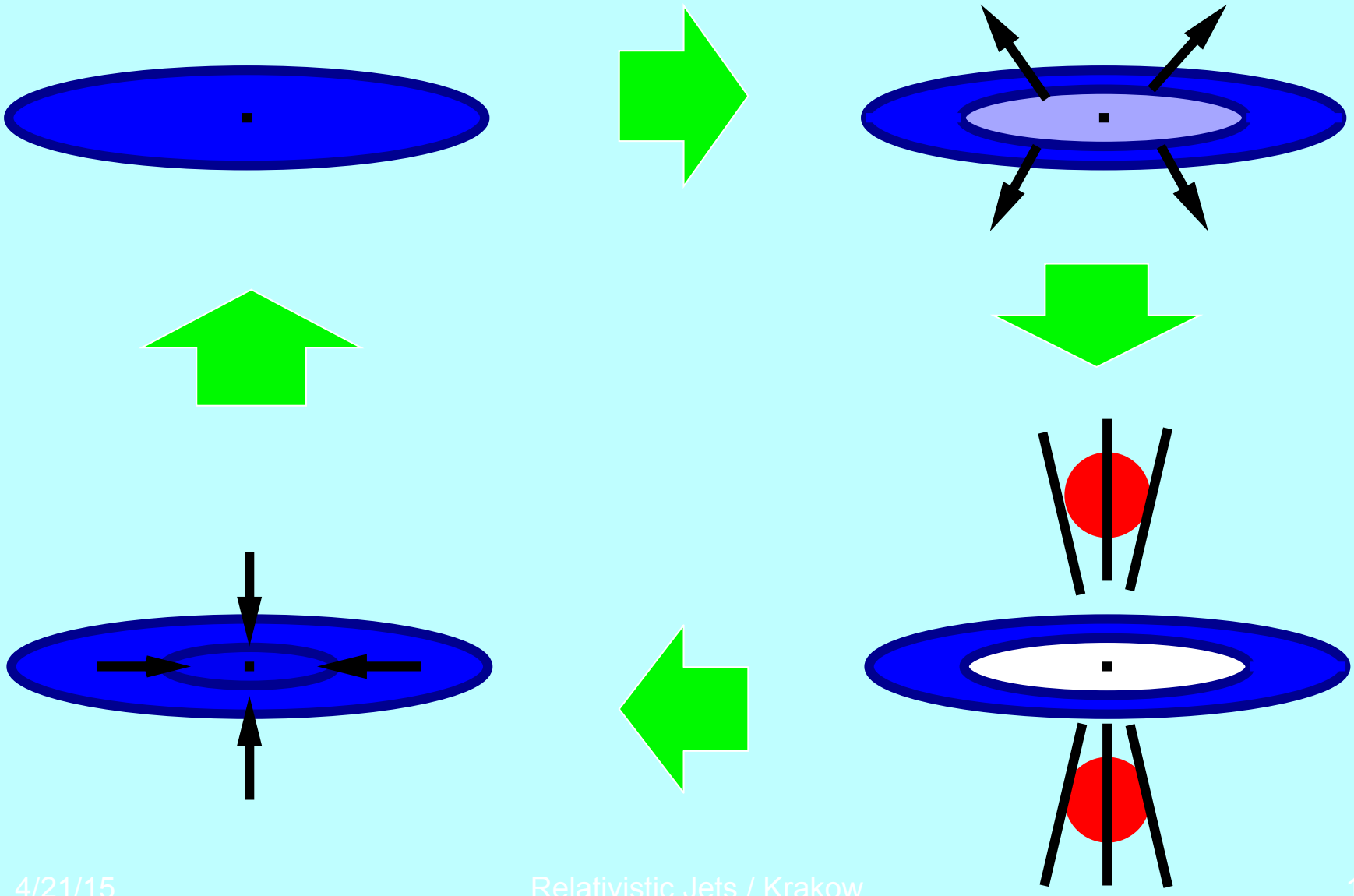
II : Nature of the accretion disk, and disk-Jet interactions in broad line radio galaxies

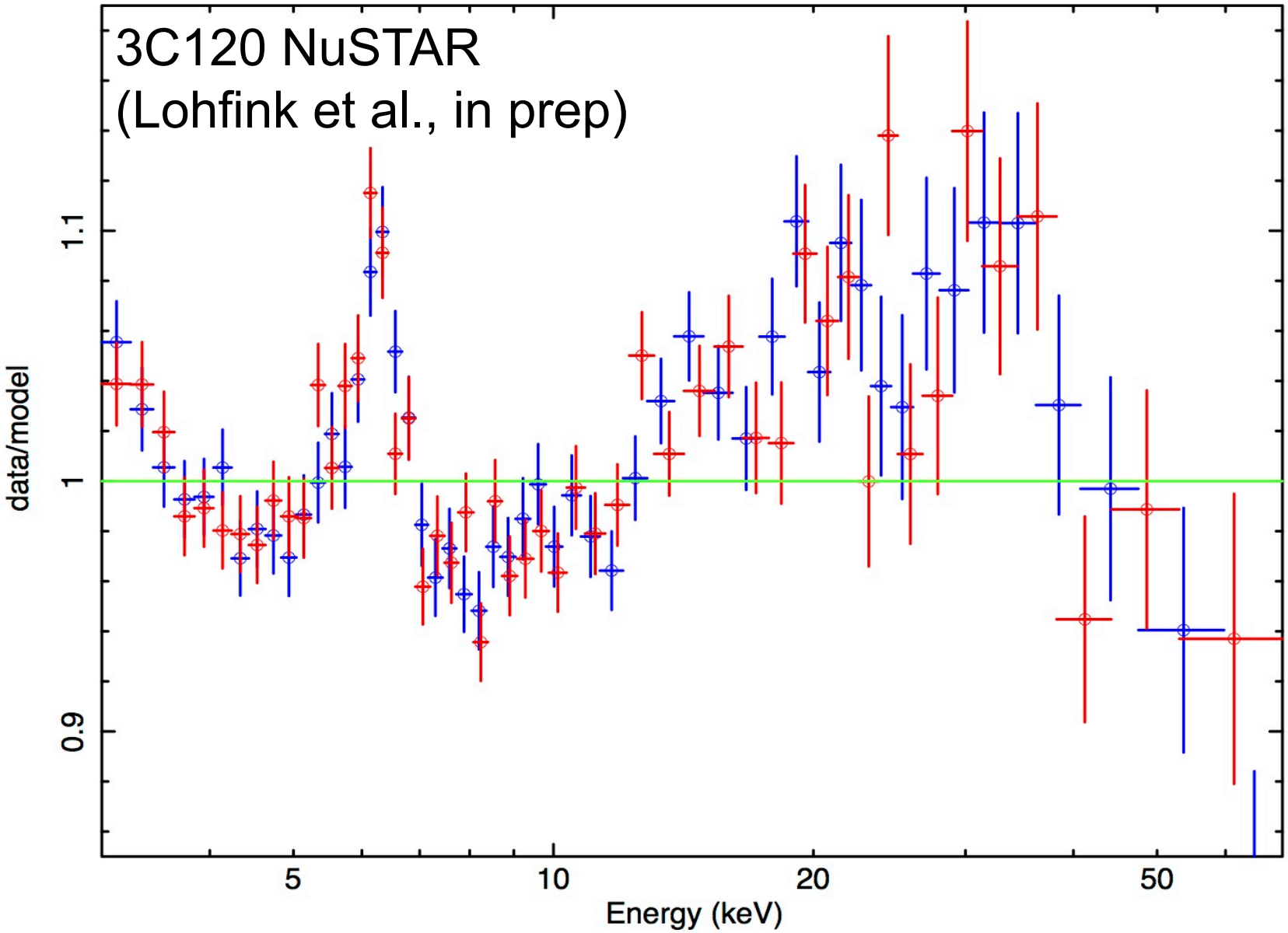
Broad line radio galaxy 3C120

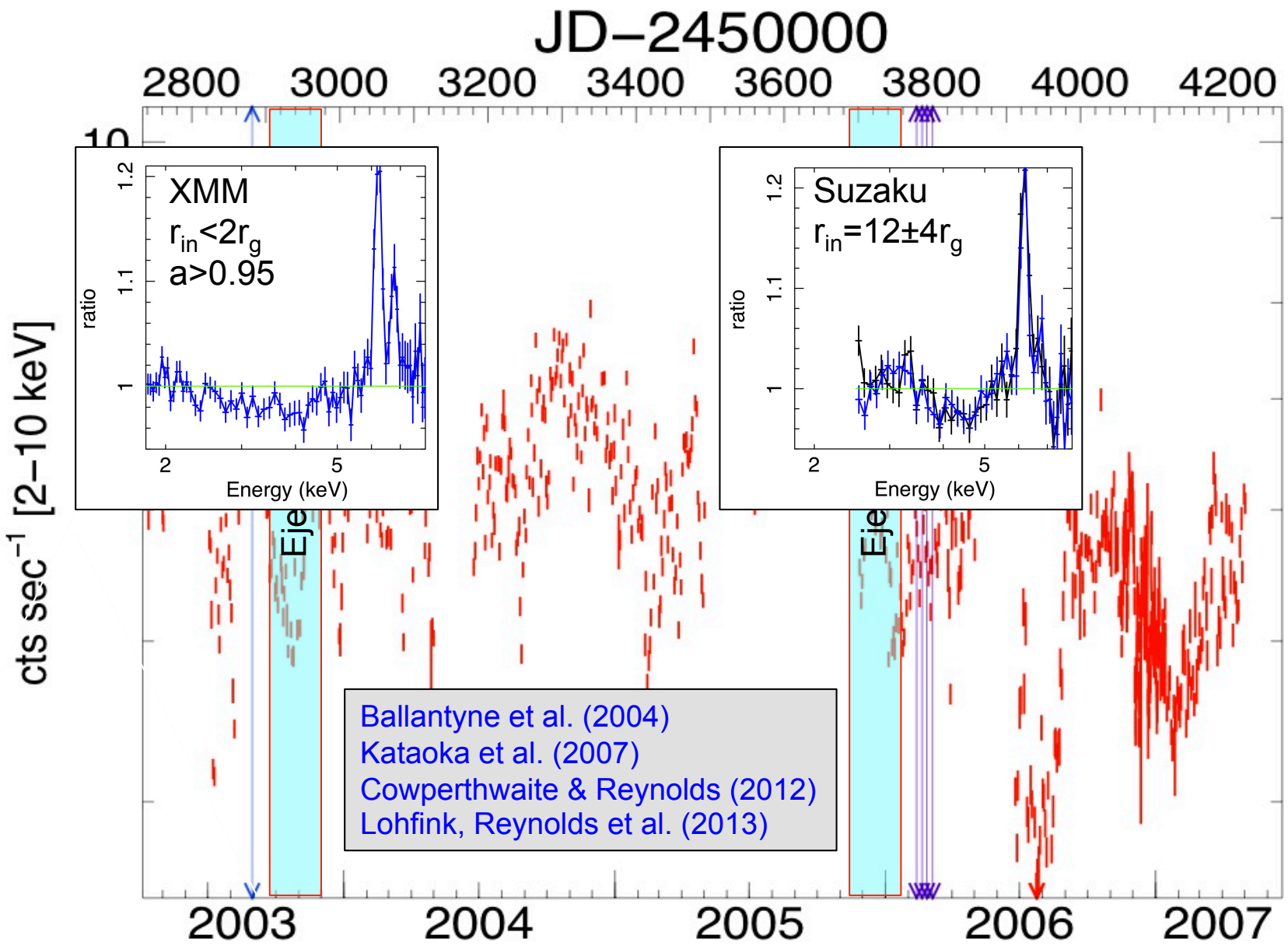


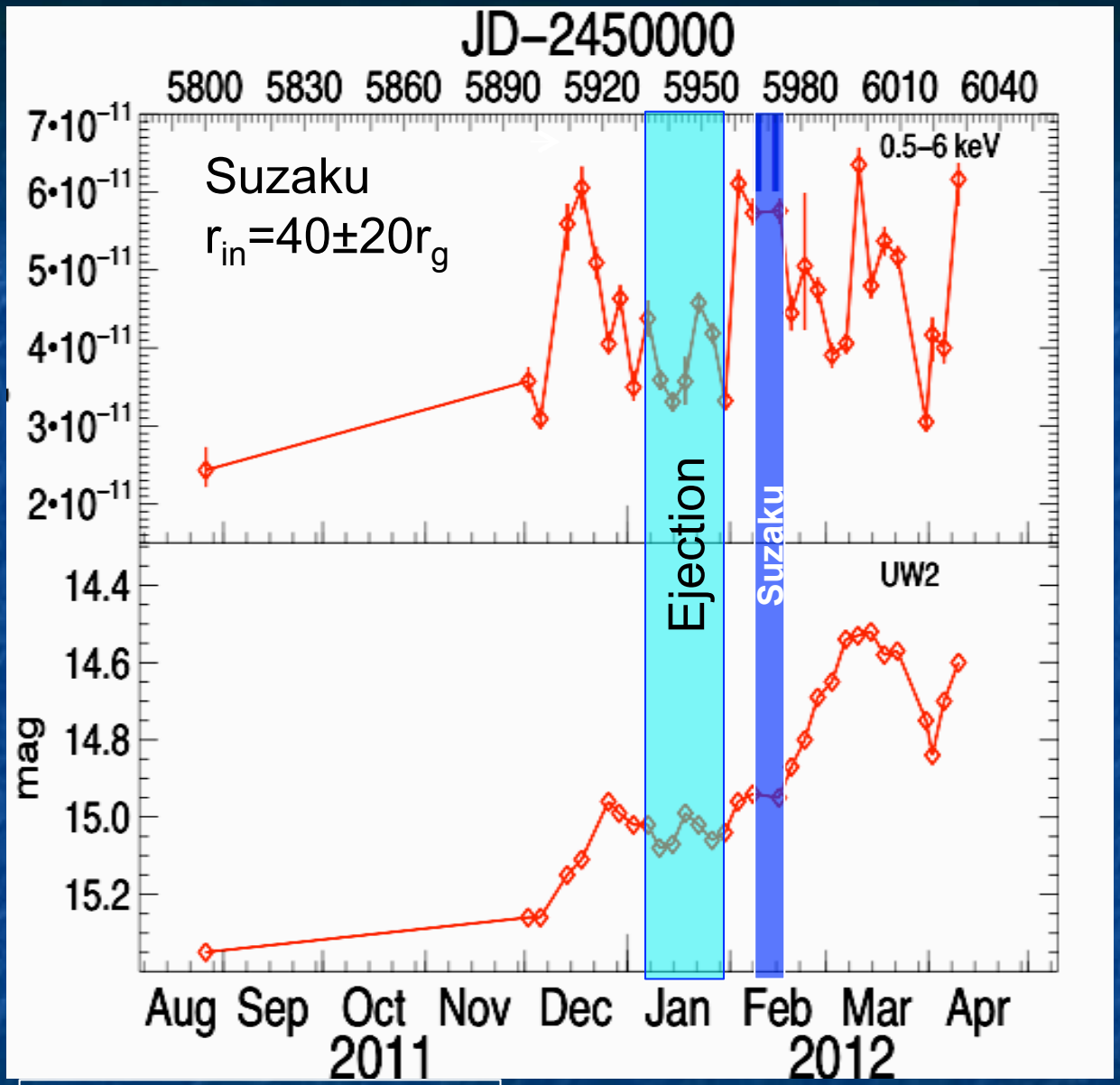


The Jet Cycle…

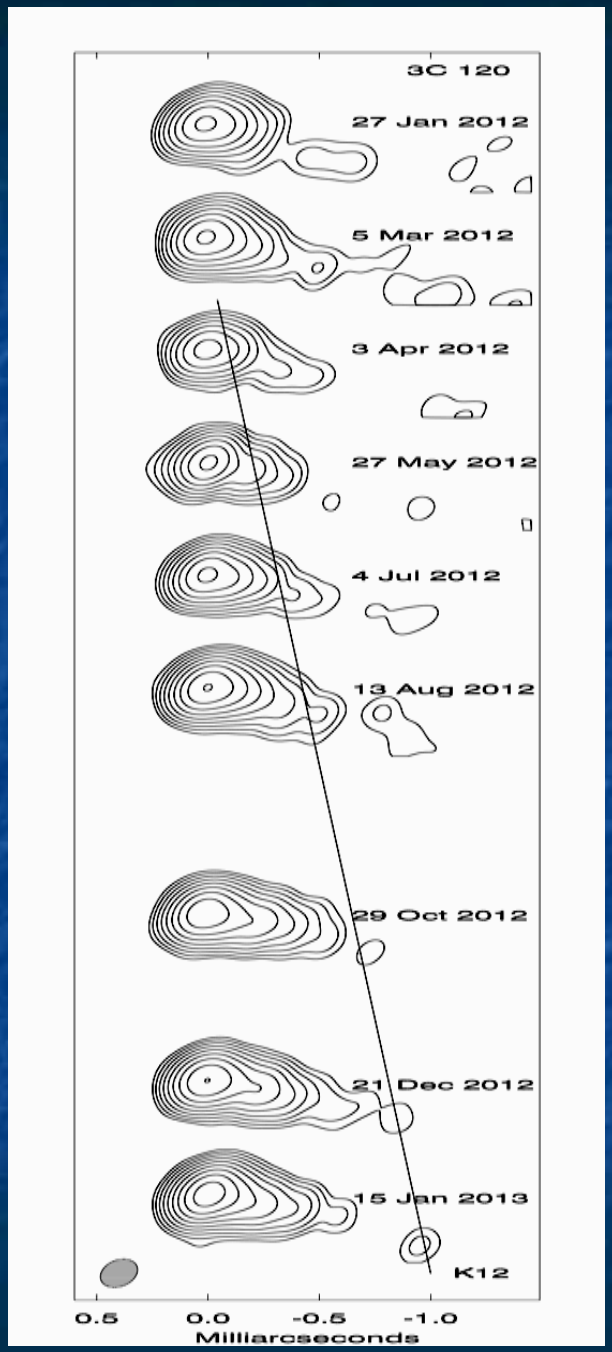



3C120 NuSTAR
(Lohfink et al., in prep)
data/model
0.9
1
1.1
5
10
20
50
Energy (keV)


JD−2450000
2800
3000
3200
3400
3600
3800
4000
4200
cts sec^{-1} [2−10 keV]
XMM
r_{in}<2r_g
a>0.95
ratio
Energy (keV)
Suzaku
r_{in}=12±4r_g
Ballantyne et al. (2004)
Kataoka et al. (2007)
Cowperthwaite & Reynolds (2012)
Lohfink, Reynolds et al. (2013)
2003
2004
2005
2006
2007

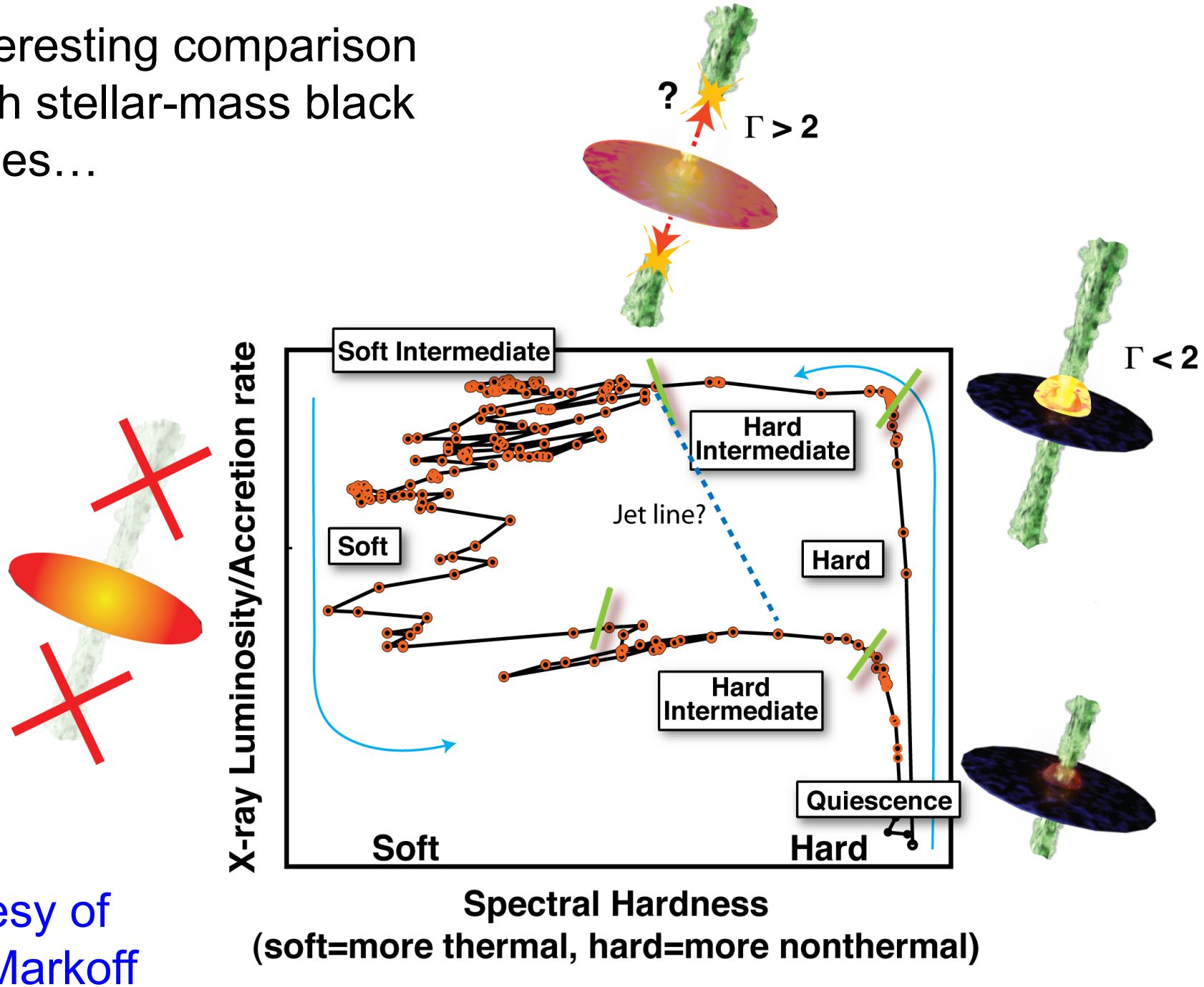


Lohfink et al. (2013)



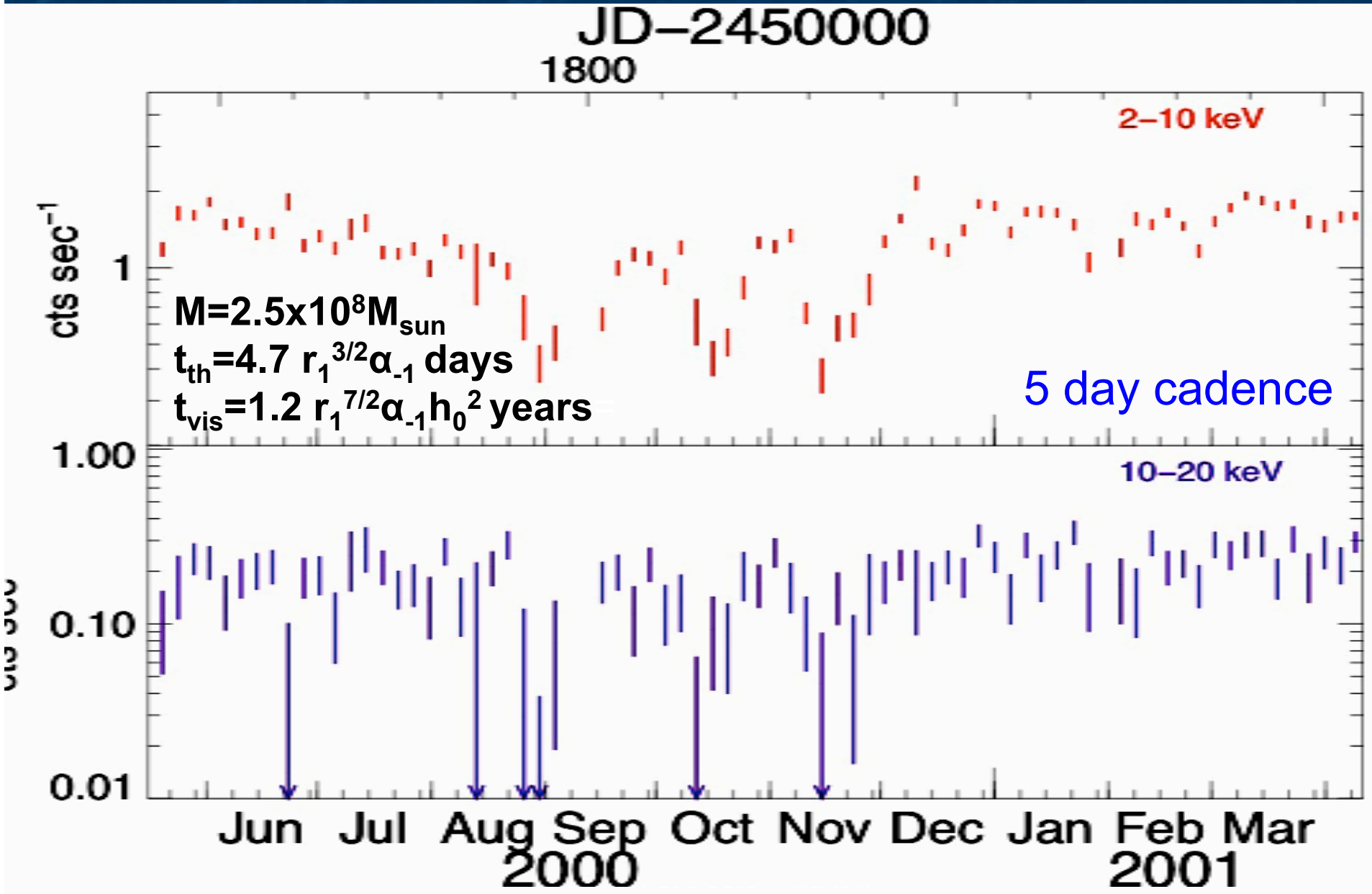
- Prior to jet-ejection event, 3C120 has an optically-thick, geometrically-thin disk
- During jet-ejection event, disk truncates to ~10-40r_g and then refills

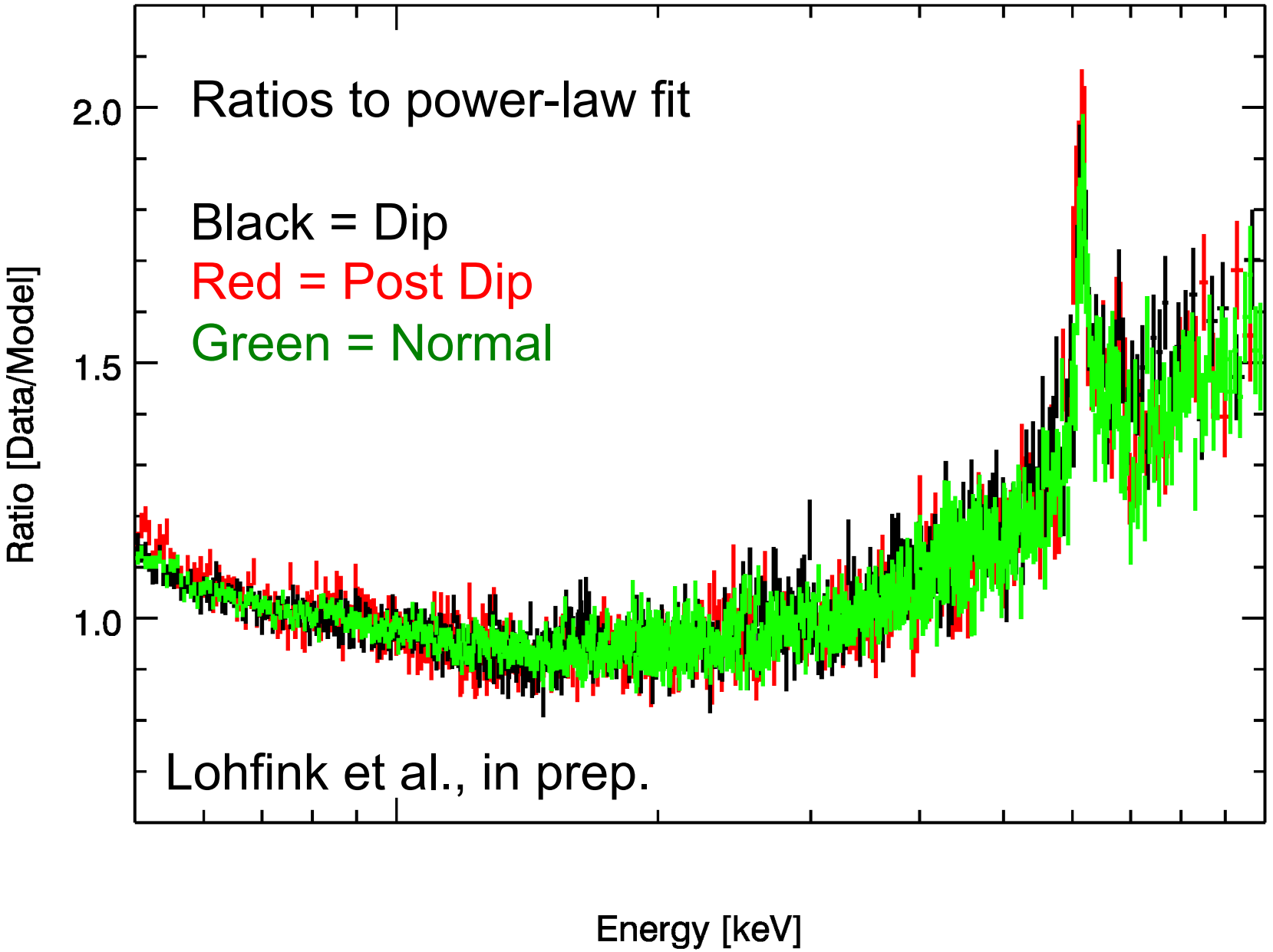
Interesting comparison with stellar-mass black holes…



Courtesy of Sera Markoff

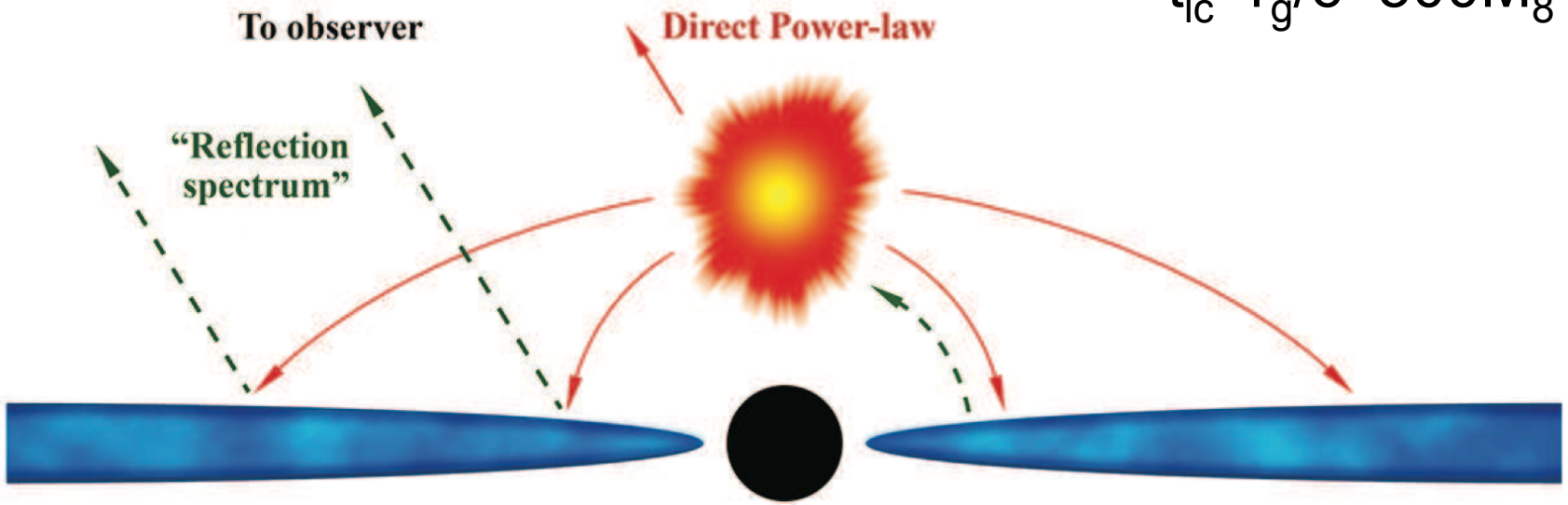
RXTE lightcurve of Fairall 9 (Lohfink, Reynolds et al. 2012)

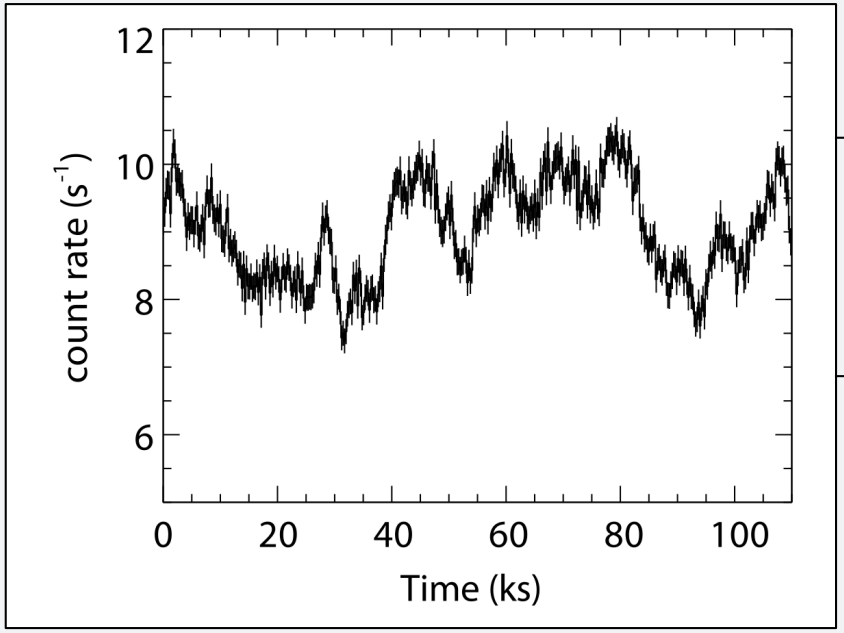



Ratios to power-law fit
Black = Dip
Red = Post Dip
Green = Normal
Lohfink et al., in prep.
Ratio [Data/Model]
2.0
1.5
1.0
Energy [keV]

III : Nature of the X-ray source BH magnetospheric activity?

$t_{lc}=r_g/c=500M_8$ s





Reference (broad) band

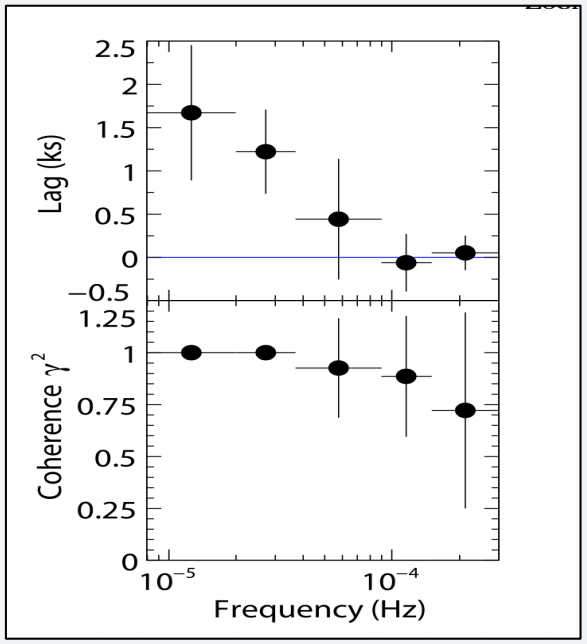
$$R(t) \rightarrow \tilde{R}(\omega) \equiv |\tilde{R}| e^{i\phi_R(\omega)}$$

Specific (line) band

$$L(t) \rightarrow \tilde{L}(\omega) \equiv |\tilde{L}| e^{i\phi_L(\omega)}$$

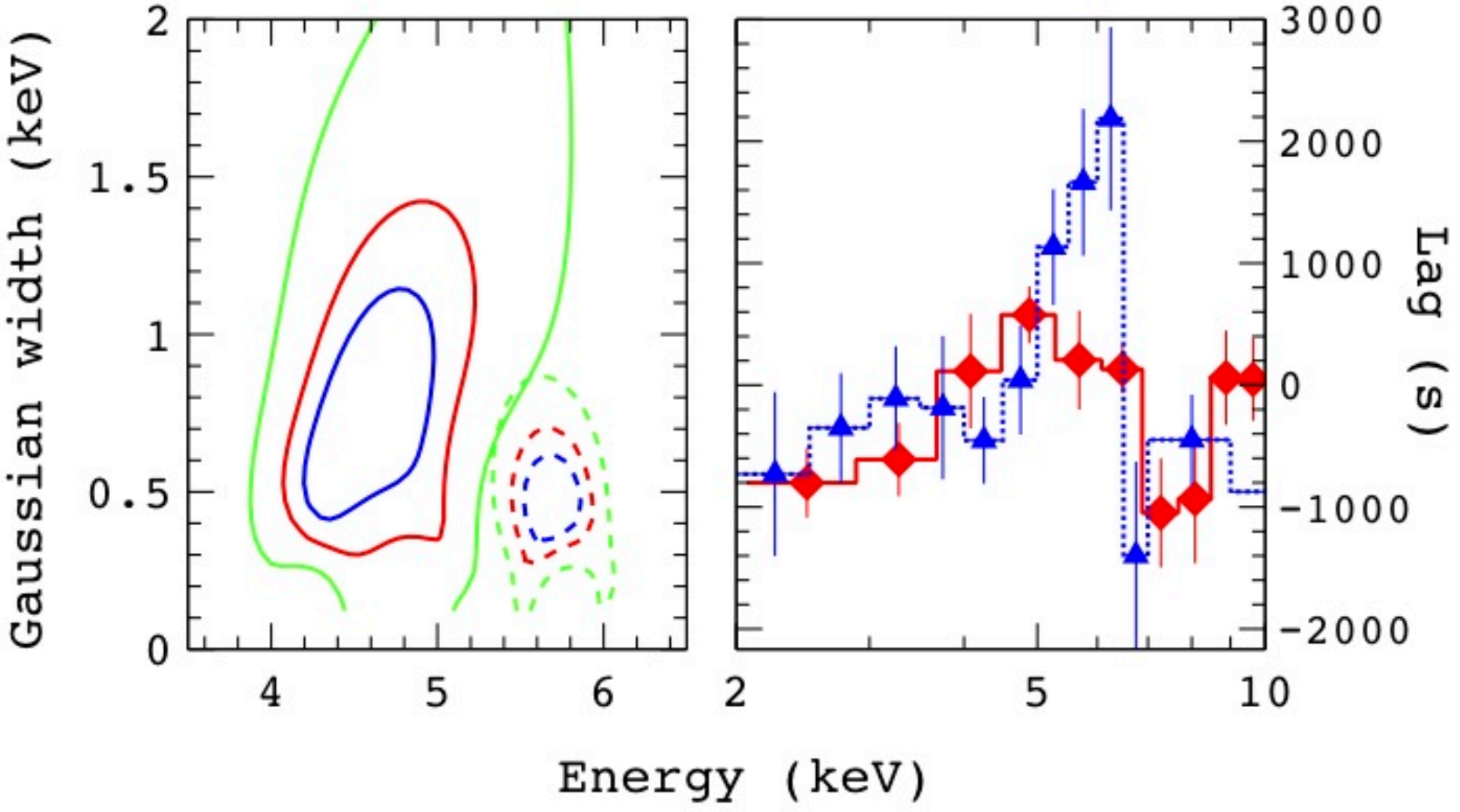
$$\mathcal{C}(\omega) := \tilde{R}^* \tilde{L} = |\tilde{R}||\tilde{L}| e^{i\Delta\phi(\omega)}$$

$$\text{Define } \Delta t(\omega) = \frac{\Delta\phi(\omega)}{\omega}$$



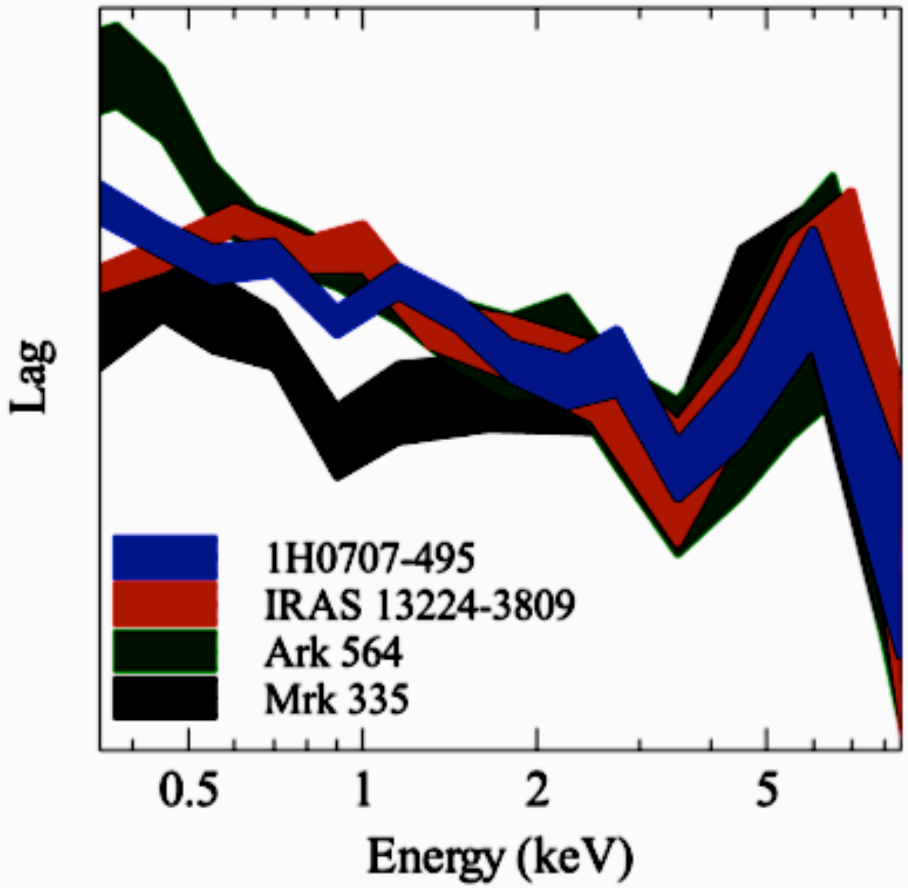
MCG-5-23-16
Zoghbi et al. (2013)

Iron line reverberation in NGC4151 (Zoghbi et al. 2012)



Observed Iron K lags

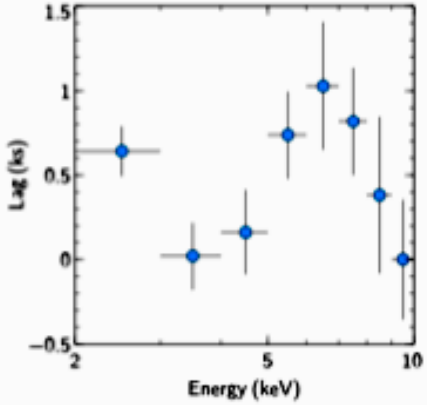
The whole lag spectrum.

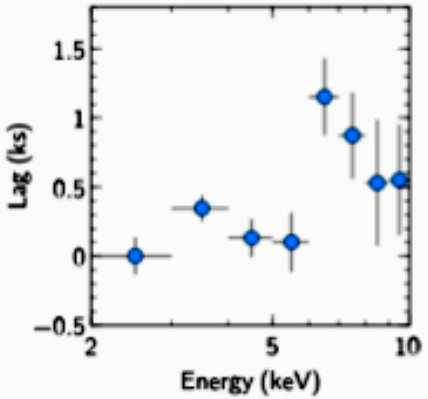


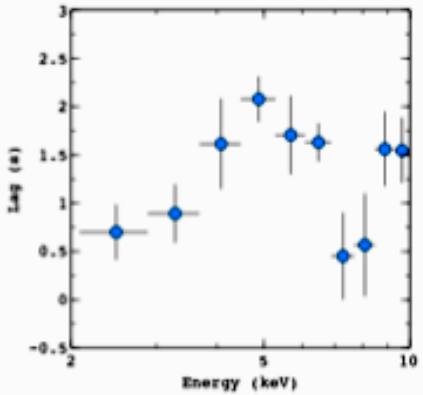
Kara+13

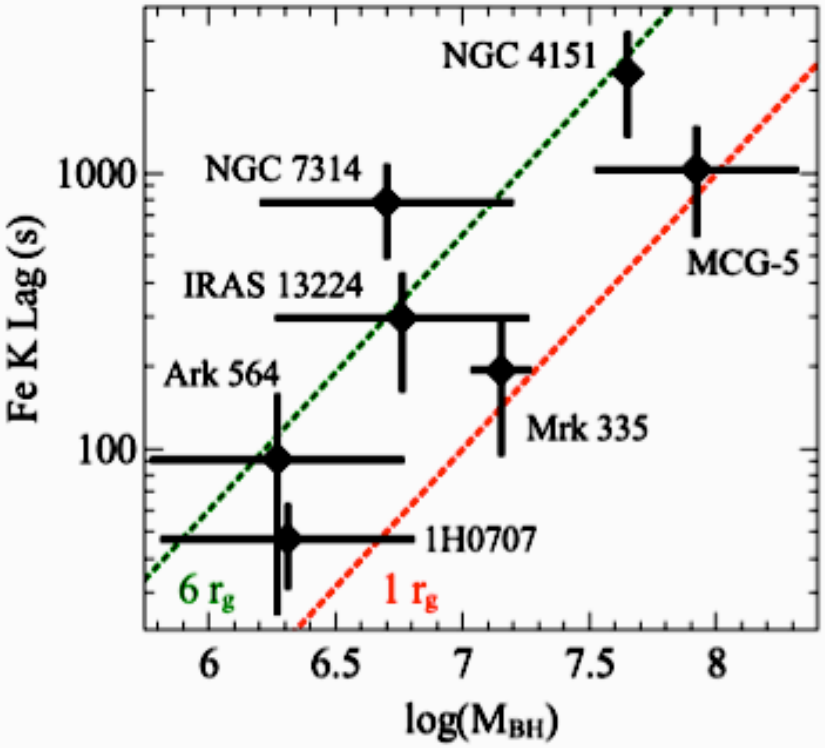
Observed Iron K lags

The reverberation lag scales with black hole mass.

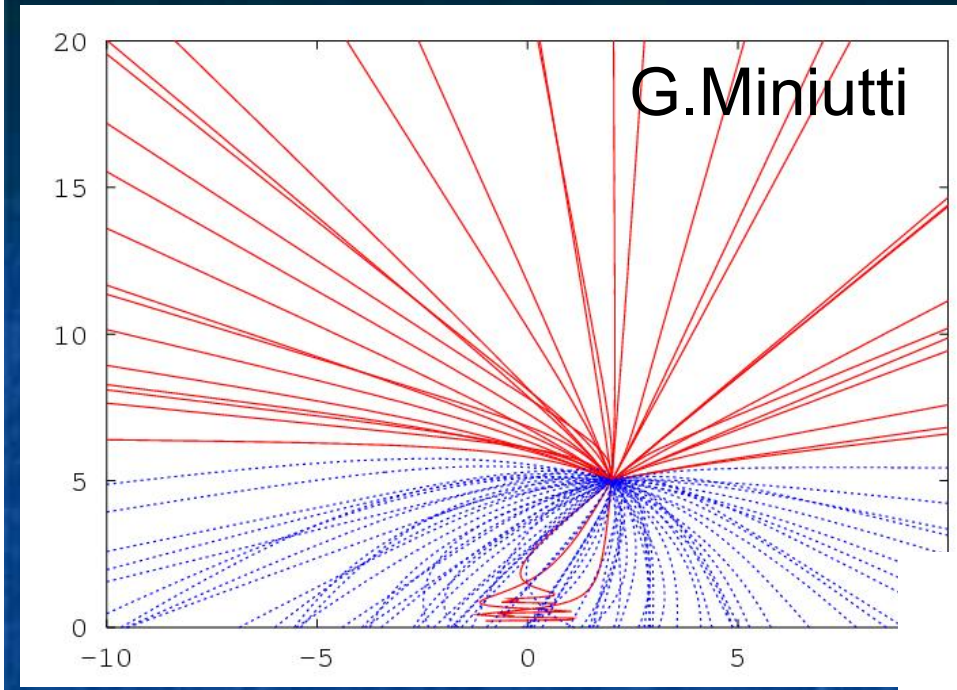


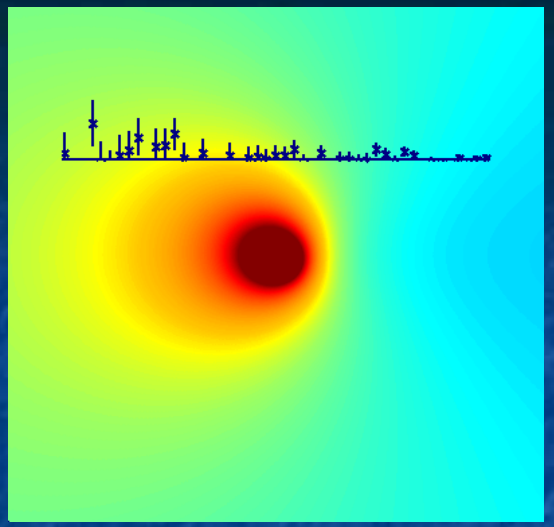


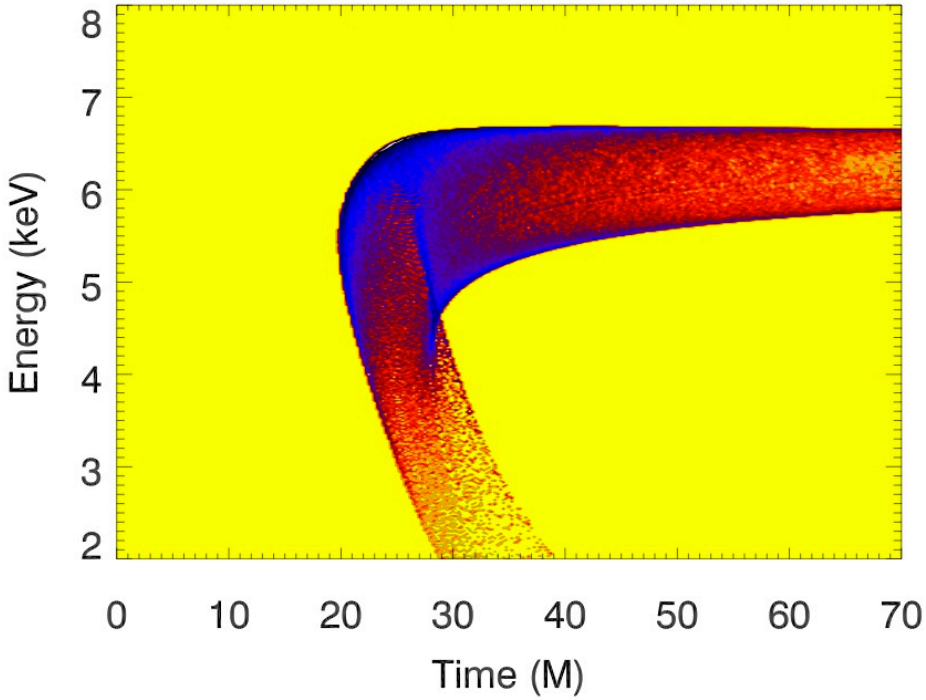




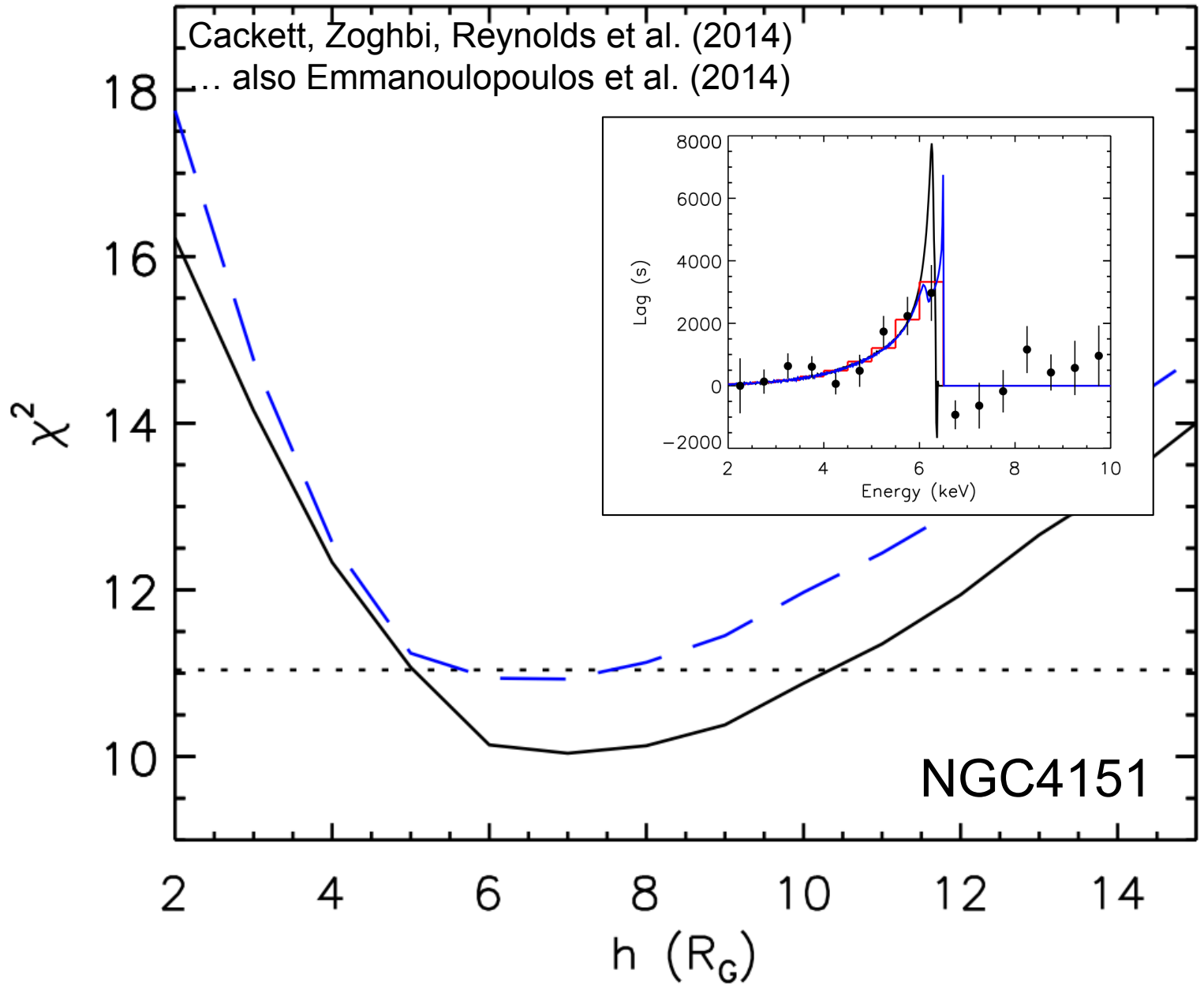
Zoghbi+12,13. Kara+13

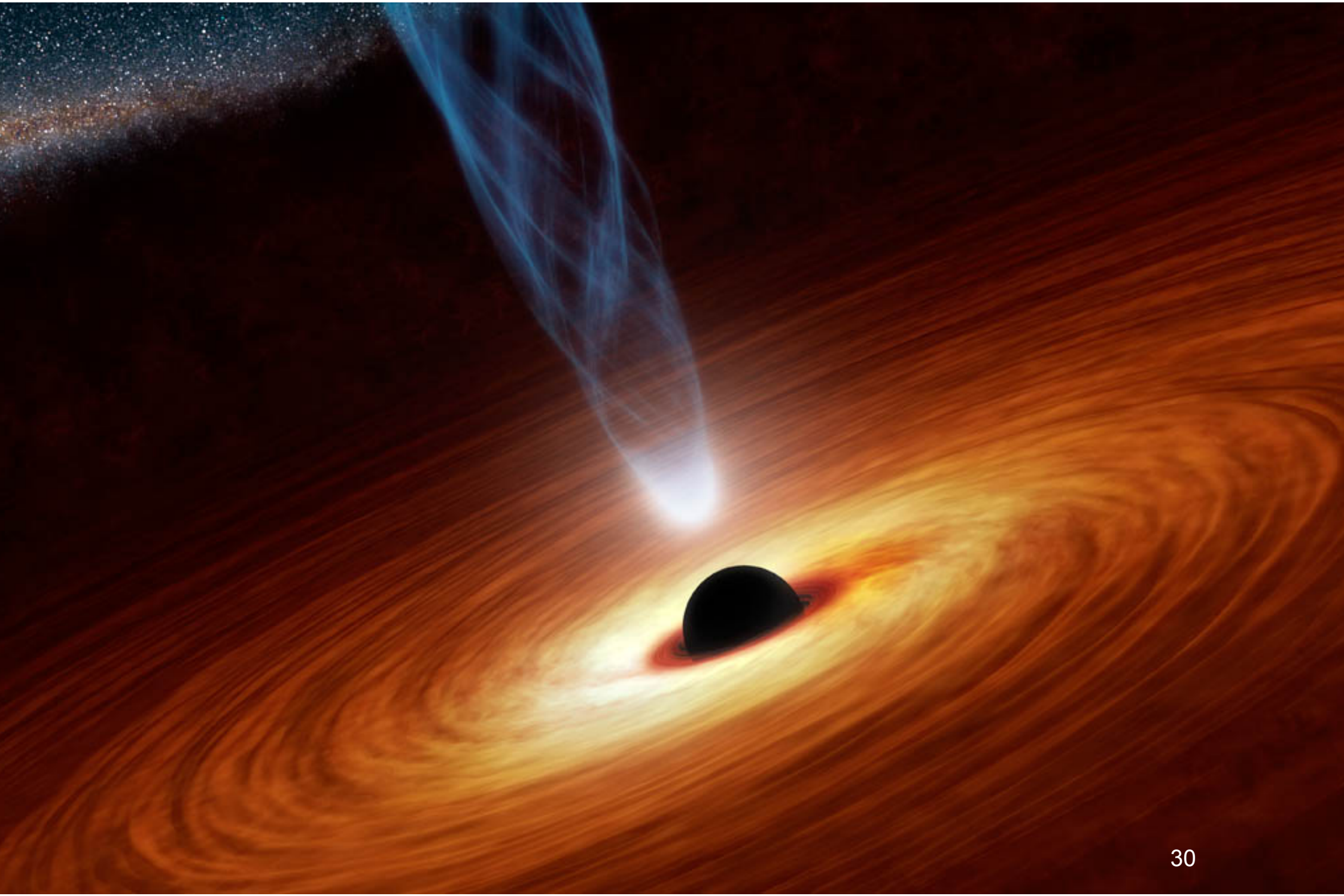




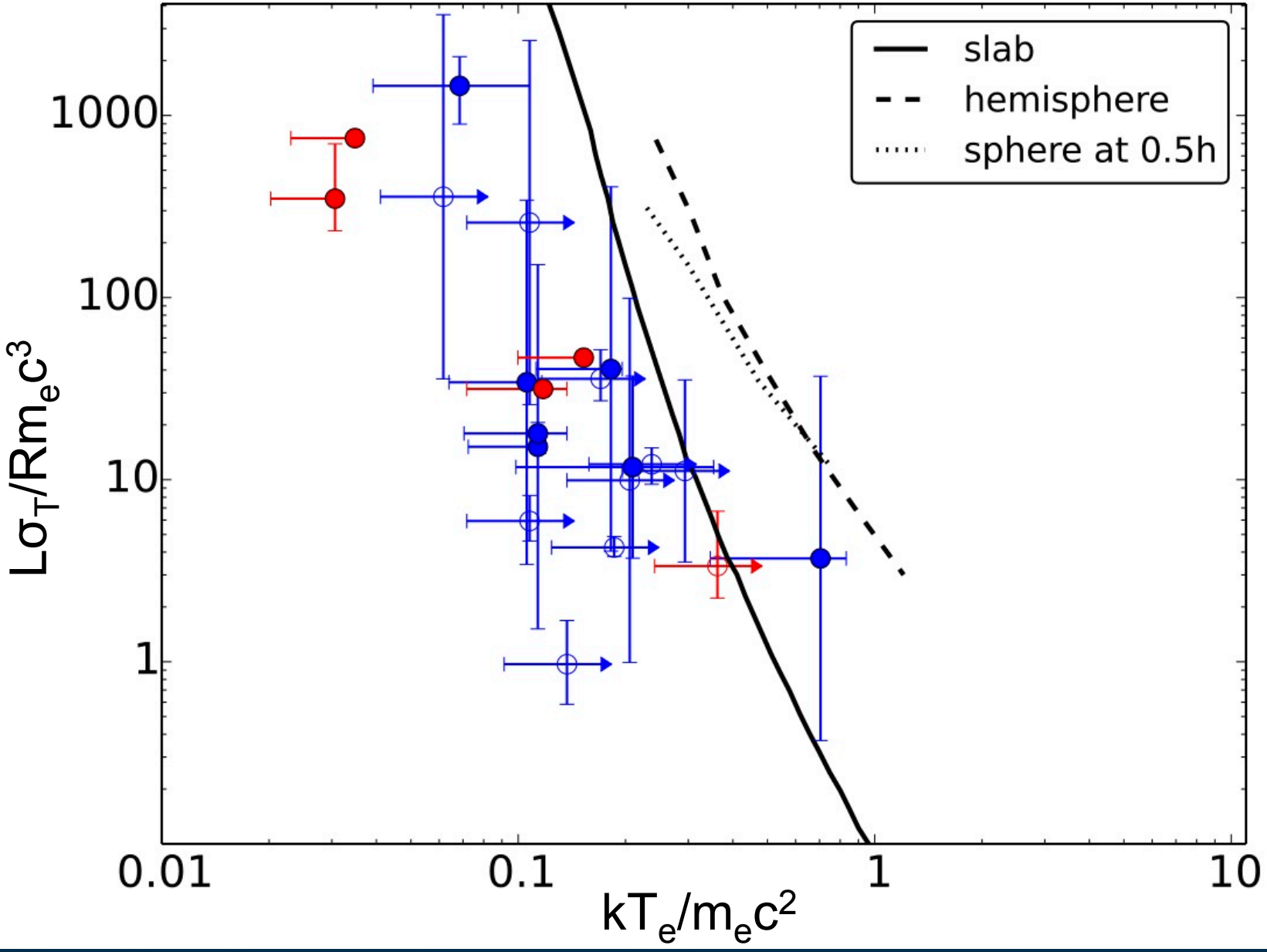


Reynolds et al. (1999)
Young & Reynolds (2000)


Cackett, Zoghbi, Reynolds et al. (2014)
… also Emmanoulopoulos et al. (2014)
χ^2
18
16
14
12
10
2
4
6
8
10
12
14
h (R_G)
NGC4151
Lag (s)
8000
6000
4000
2000
0
−2000
2
4
6
8
10
Energy (keV)



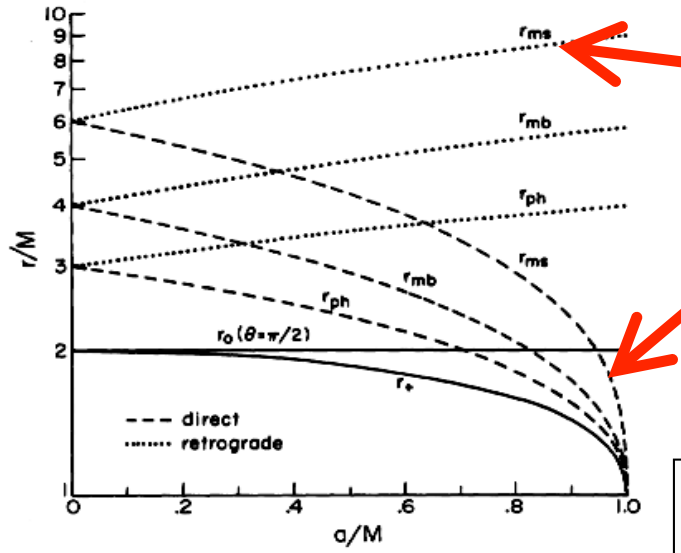
Fabian, Lohfink et al. in preparation



Conclusions

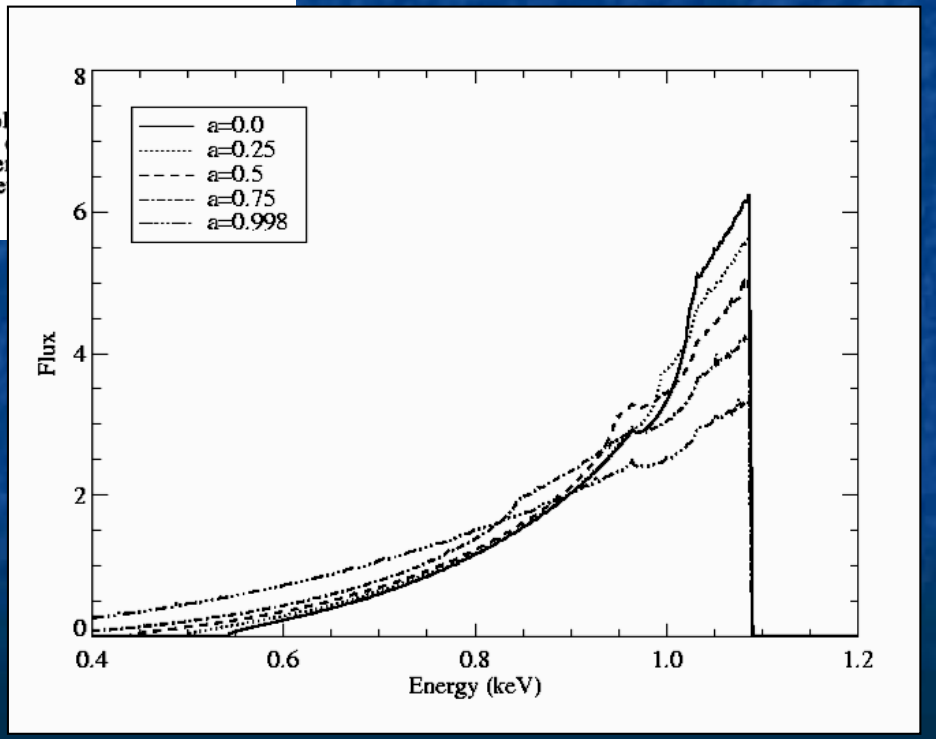
- Find population of radio-quiet AGN with rapidly-spinning black holes ➔ rapid-spin may be necessary but is not sufficient for creation of jets
- Jetted AGN can have optically-thick, geometrically-thin (radiatively-efficient) disks ➔ break analogy with BHBs?
- AGN give us view of dynamical timescale disk/jet interactions ➔ in BLRGs, find disapperance of inner disk associated with ejection event
- Reverberation suggests “high-altitude” X-ray source ➔ magnetospheric activity? But what about finite disk thickness effects?

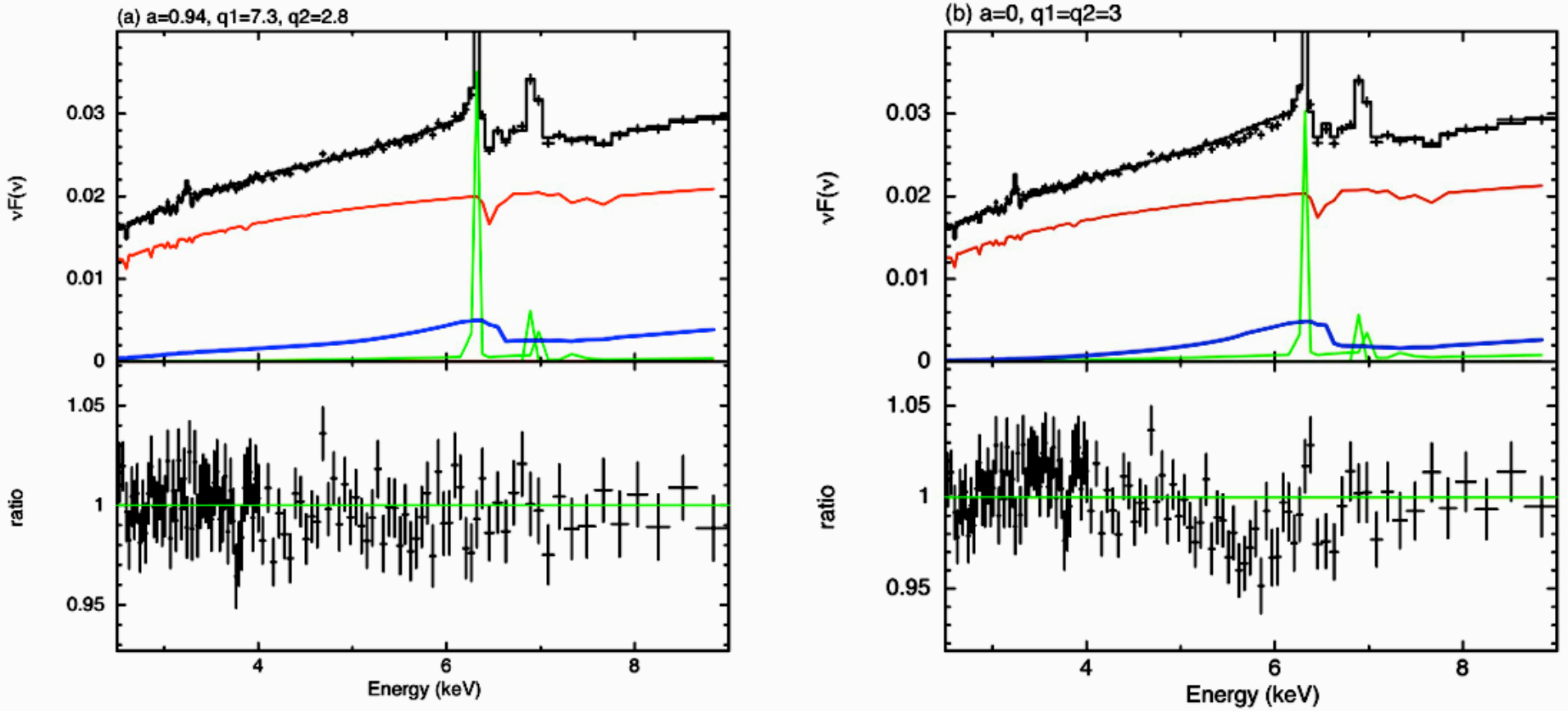
[1972ApJ...178..347B]



ISCO

FIG. 1.—Radii of circular, equatorial orbits around a rotating black hol
functions of the hole's specific angular momentum *a*. Dashed and dotted
and retrograde orbits) plot the Boyer-Lindquist coordinate radius of the inne
innermost bound (mb), and photon (ph) orbits. Solid curves indicate the e
and the equatorial boundary of the ergosphere (r_0).





Reynolds et al. (2012)

$L \sim 0.1 L_{Edd}$