Super-Critical Accretion in AGN and Quasars

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Outline

- Are there super-Eddington AGN?
- X-ray ray spectral/timing of the innermost accretion flow for high accretion rate AGN
  - Moderately high accretion rates: modified “disk lines”
  - Very high accretion rates: lines from outflow/funnel geometry

I : Are there super-critical AGN?

$$\dot{m} = \frac{L_{\rm bol}}{L_{\rm Edd}} = \frac{\eta \dot{M} c^2}{L_{\rm Edd}}$$

Fundamentally, this is the limit that Prof. Eddington cared about!

In principle, directly follows from two observables, L_{bol} and M

In practice, L_{bol} hard to measure since much of the luminosity expected to emerge in FUV

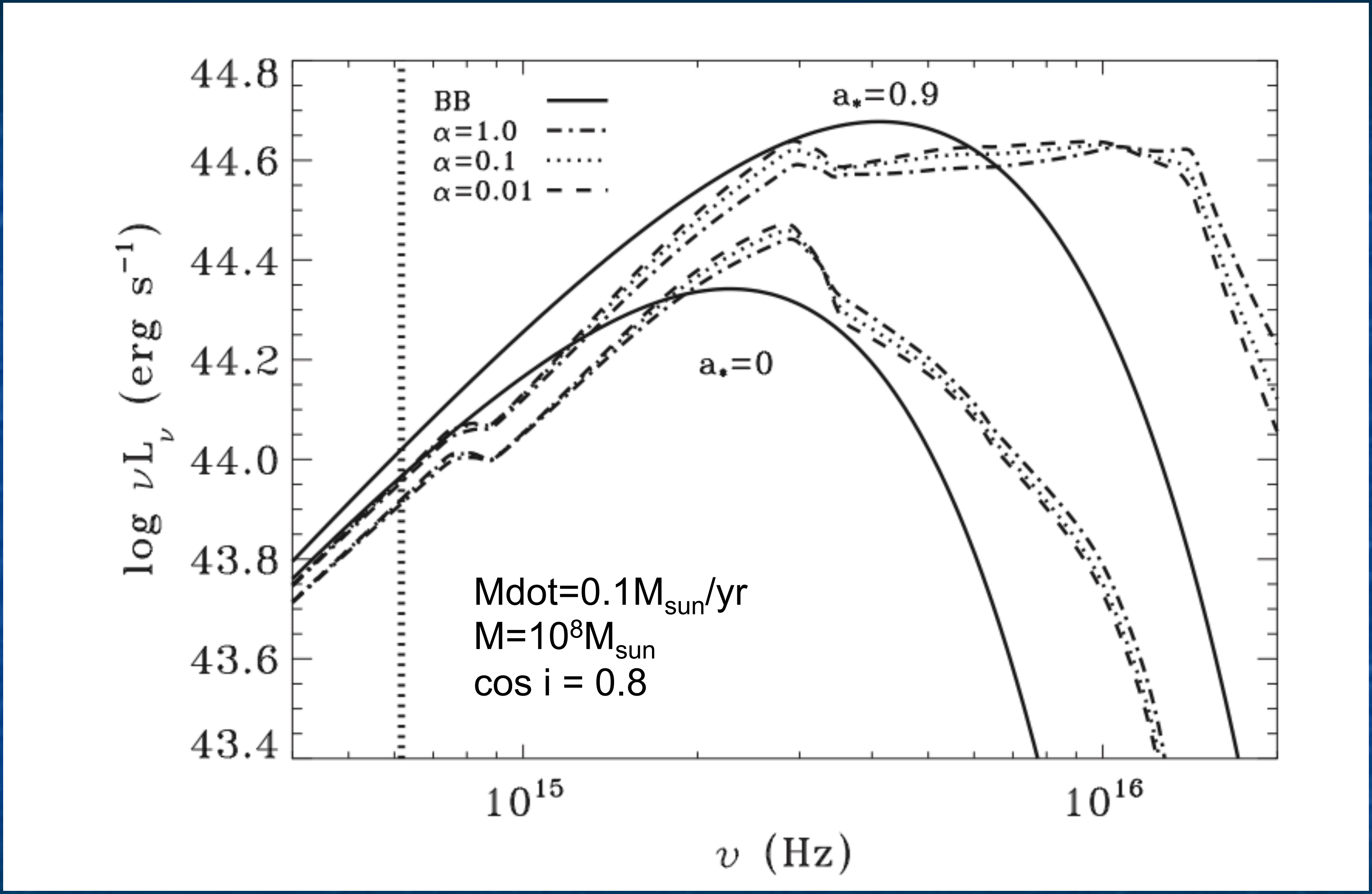
I : Are there super-critical AGN?

$$\dot{\mathcal{M}} = \frac{\dot{M} c^2}{L_{\rm Edd}}$$

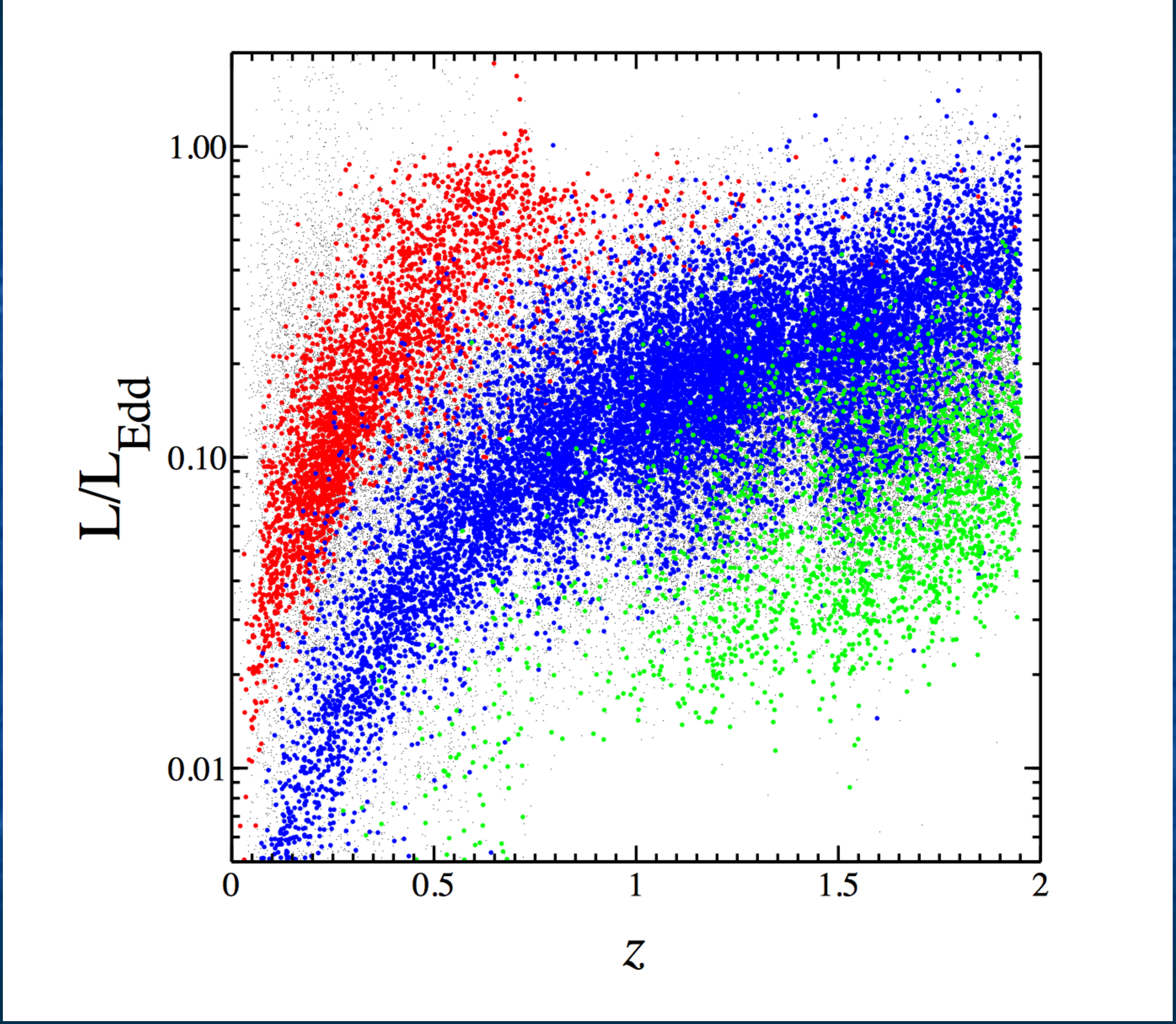
Fundamentally, this is the quantity relevant to the growth timescale of black holes.

Need a model to extract mass accretion rate from observations.

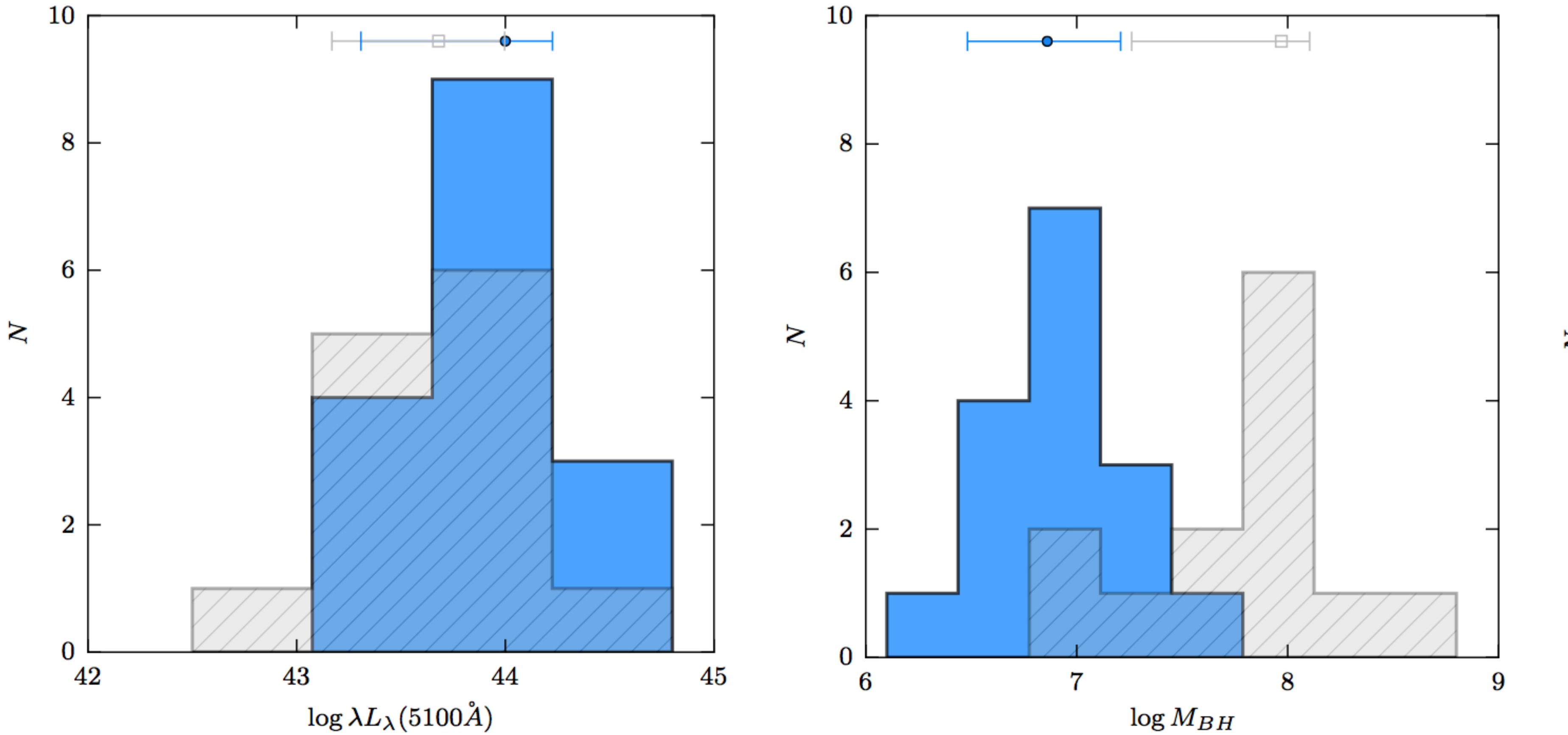
Davis & Laor (2011)



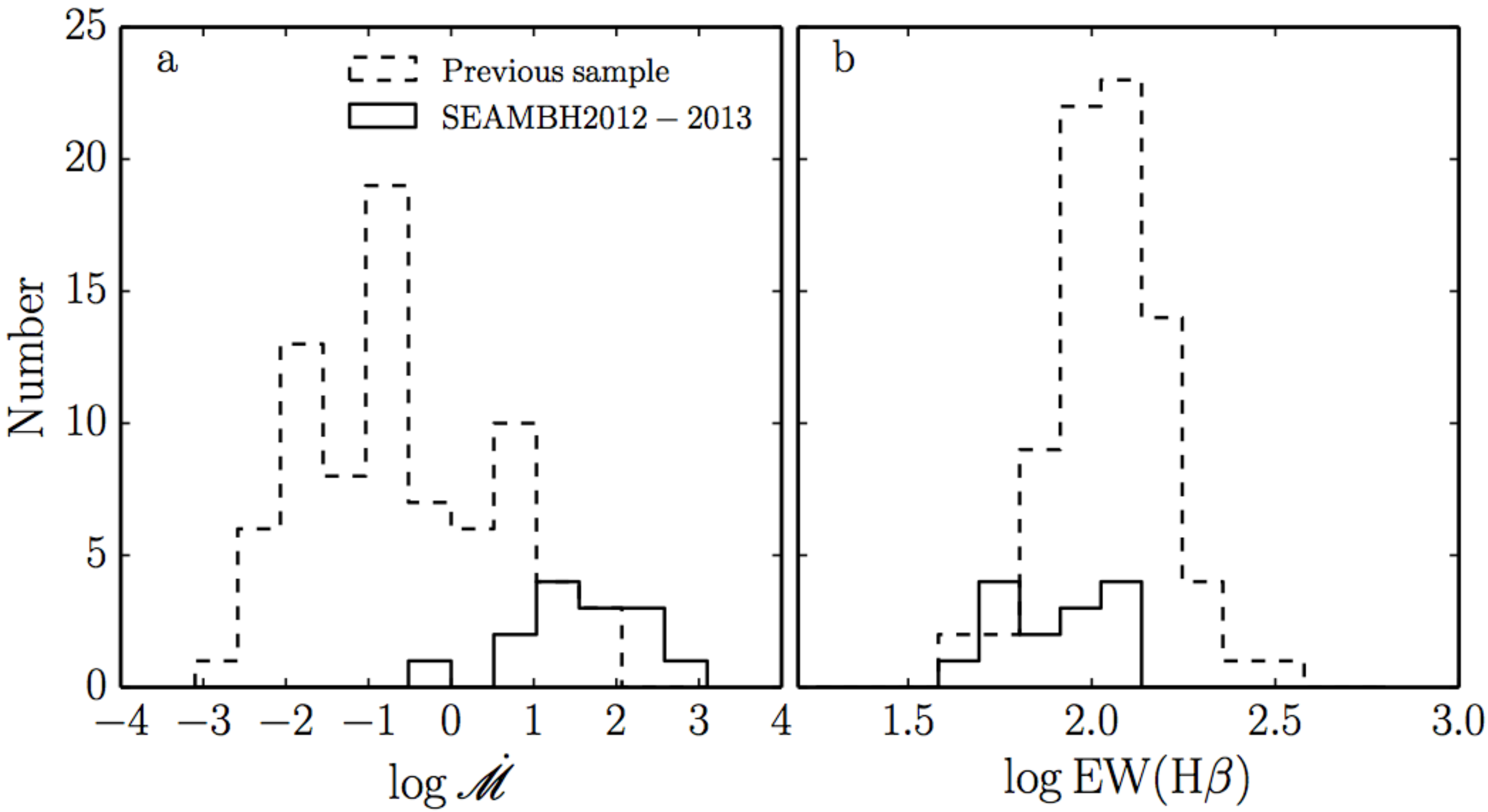
Trakhtenbrot & Netzer (2012)



Castello-Mor, Netzer & Kaspi (2016)
Using reverberation mapped sample of Du et al. (2015)

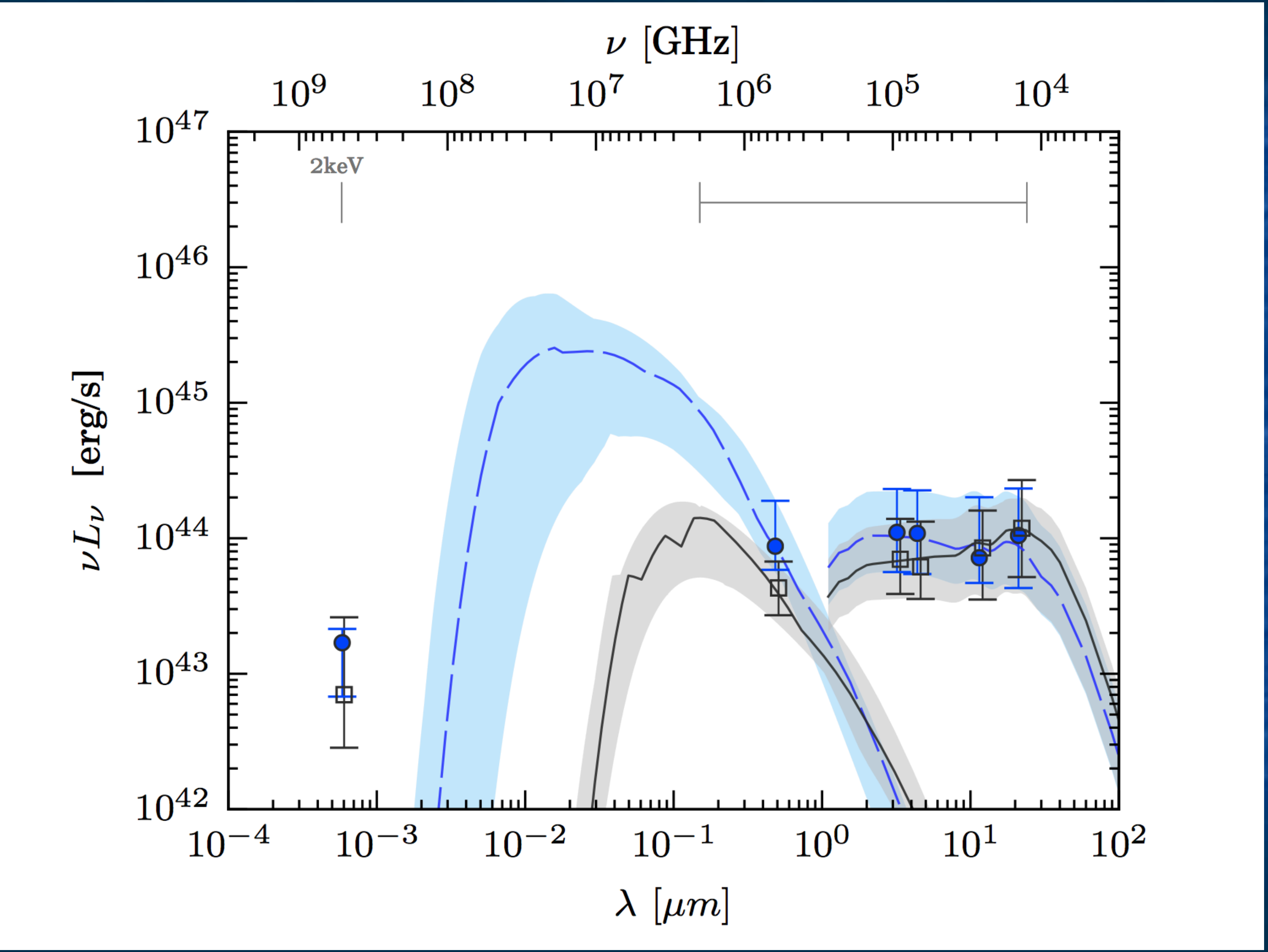


Du et al. (2015)

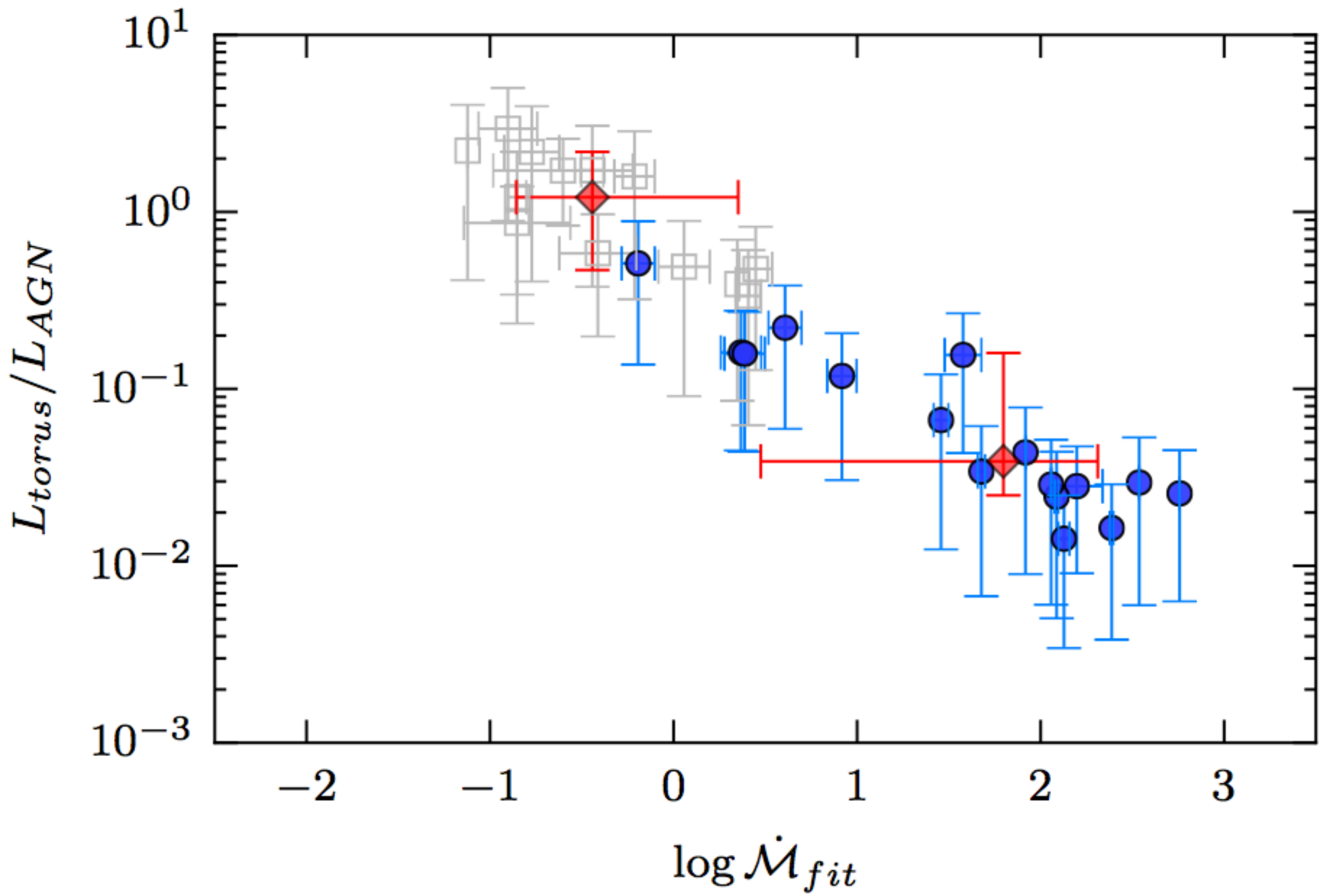


a
b
Previous sample
SEAMBH2012 – 2013
Number
25
20
15
10
5
0
−4
−3
−2
−1
0
1
2
3
4
1.5
2.0
2.5
3.0
log $\dot{\mathscr{M}}$
log EW(Hβ)

Castello-Mor, Netzer & Kaspi (2016)



Castello-Mor, Netzer & Kaspi (2016)

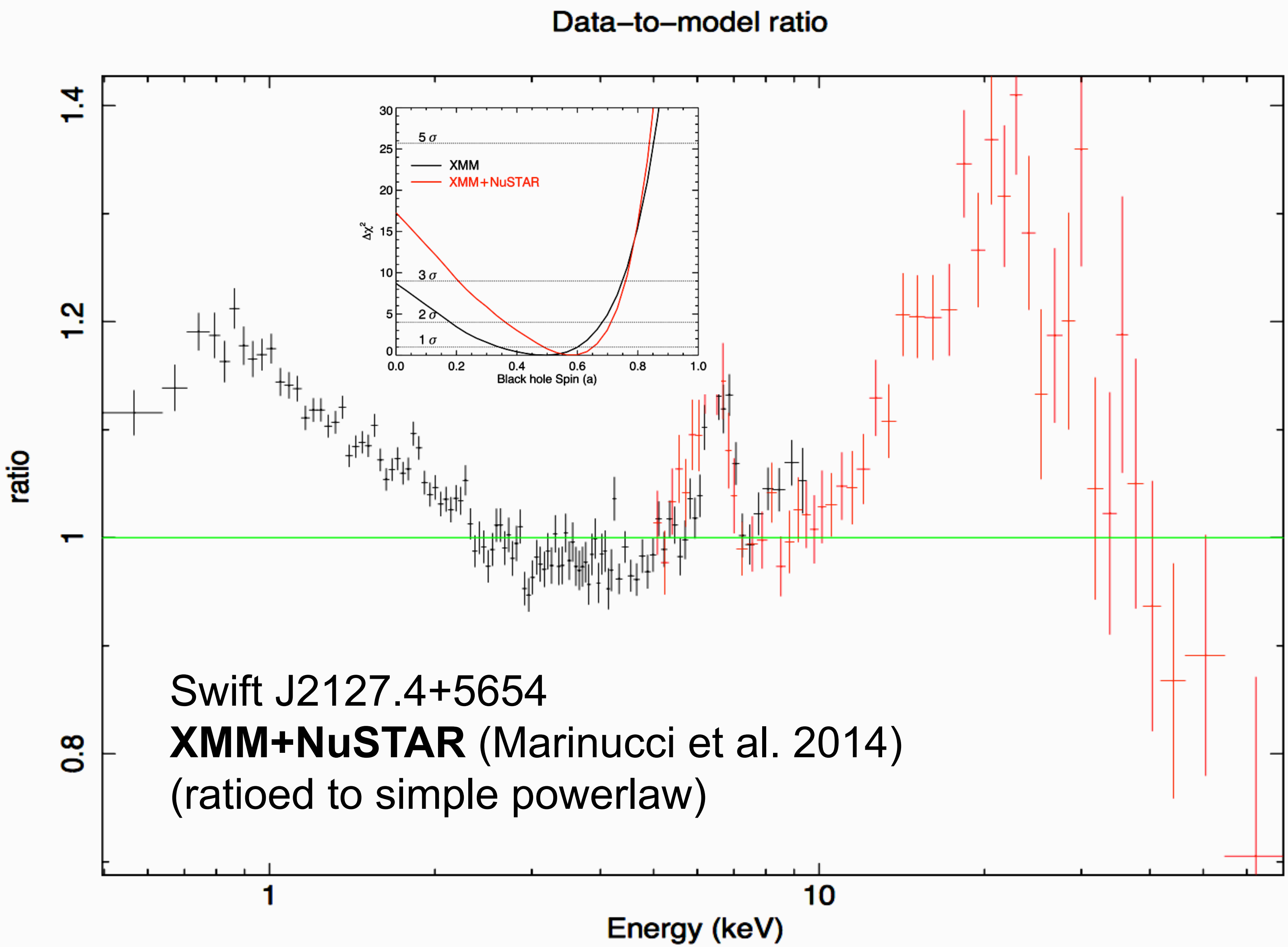


Concerns…

- IR/optical ratio same for sub/super-Eddington samples (Castello-Mor, Netzer & Kaspi 2016)
  - IR from torus which acts as a calorimeter
  - Would need conspiracy between Eddington rate and torus opening angle.
- Mass estimates do not include radiation forces. Naively, BLR clouds will see effective mass $M_{eff}=M(1-L/L_{Edd})$.
  - Are marginally critical AGN masquerading as super-critical AGN?
- Models assume continuity of mass flux down to BH
  - Maybe a lot of mass never makes it? Gets blown off in a UV-driven wind? One possible explanation for the 1000 Angstrom break (Laor & Davis 2014)
  - Would invalidate extrapolation of optical spectrum to FUV

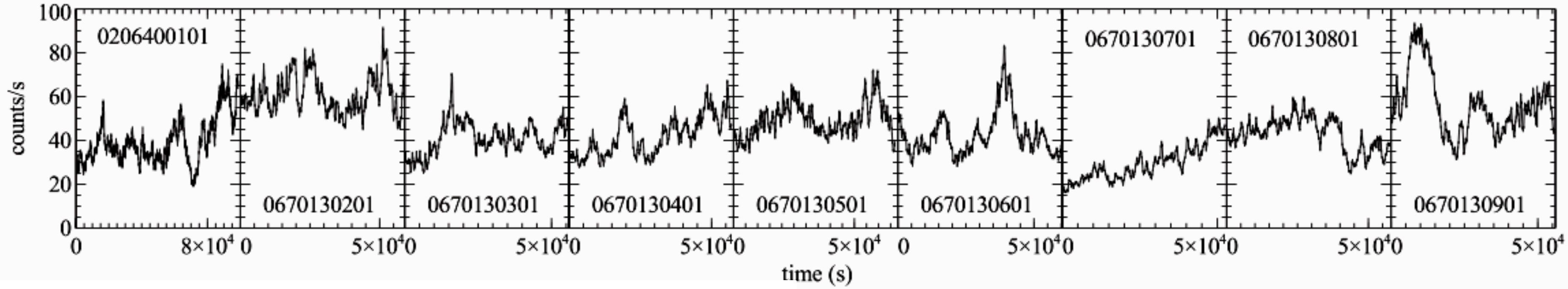
X-ray probes of the innermost accretion flow

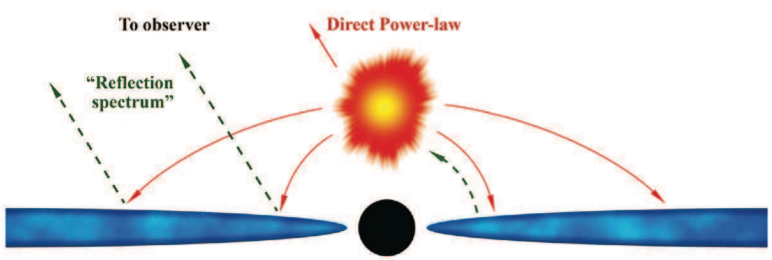
Bare Seyfert galaxy SWIFTJ2127.4+5654 (z=0.014)

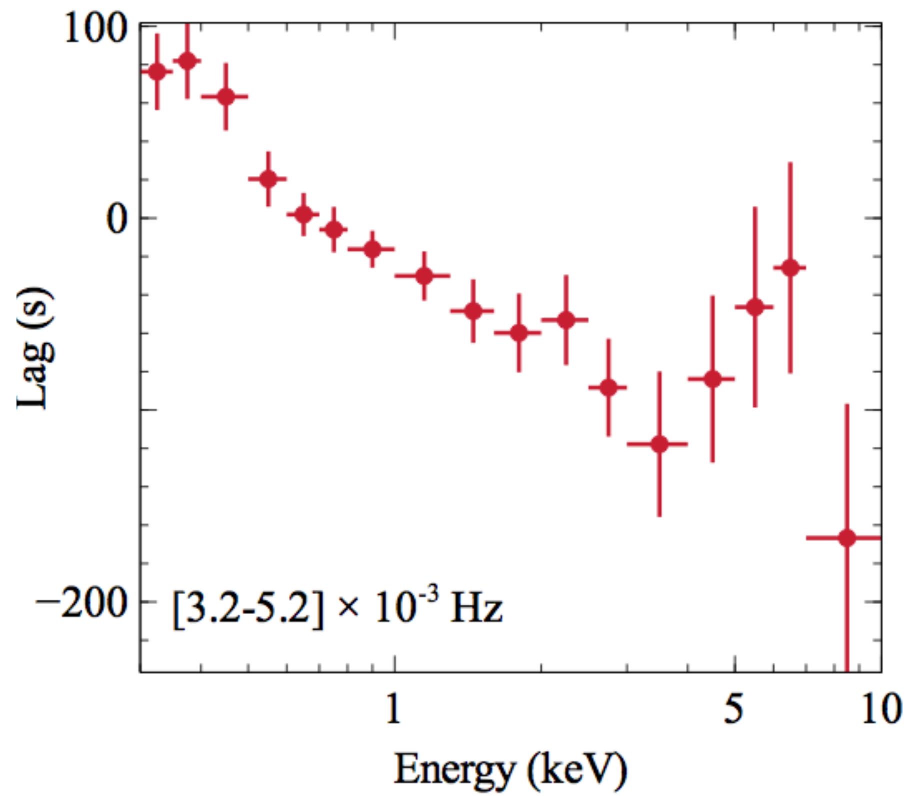


Swift J2127.4+5654
XMM+NuSTAR (Marinucci et al. 2014)
(ratioed to simple powerlaw)

Seyfert galaxy Ark564 (XMM-Newton)

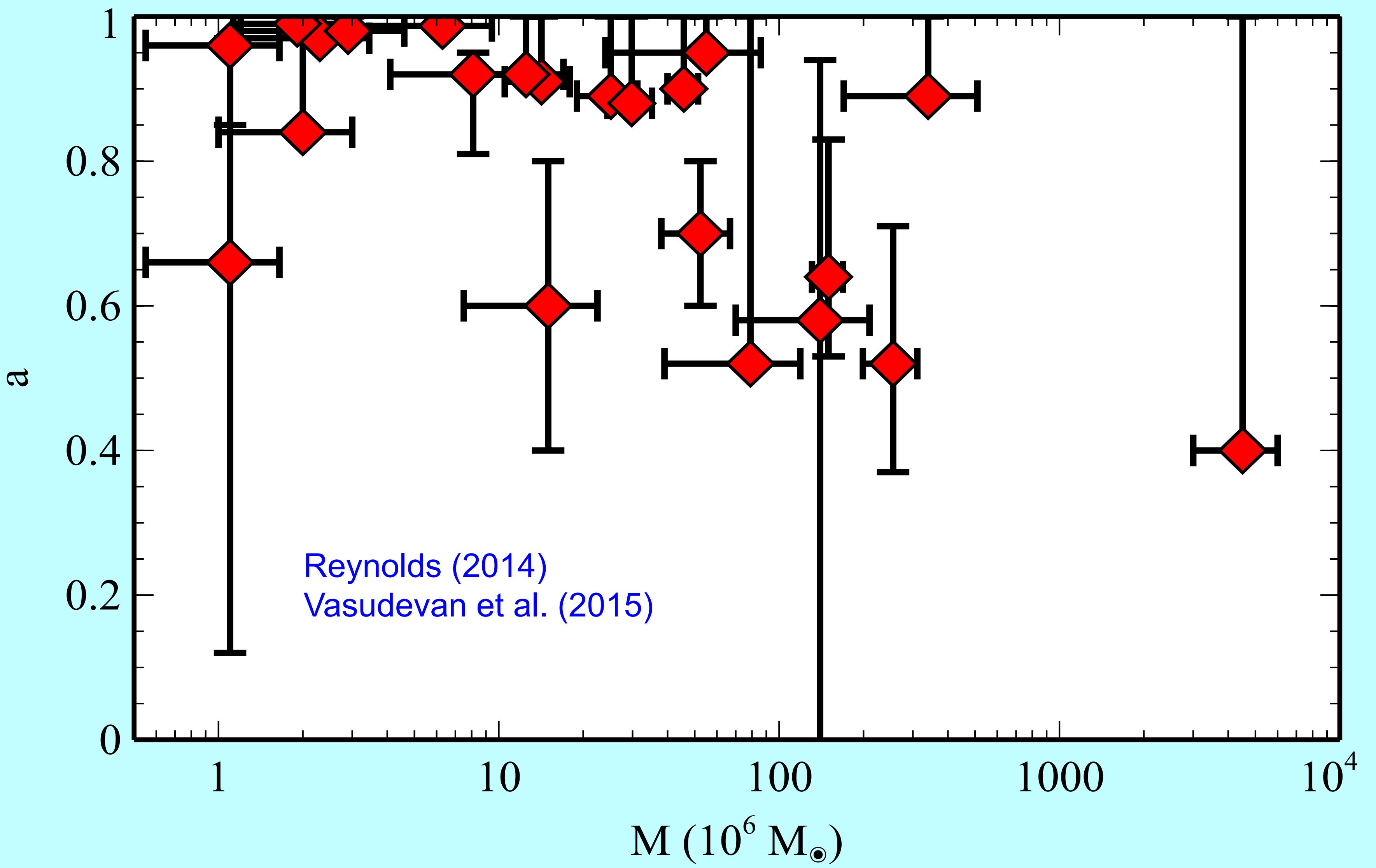




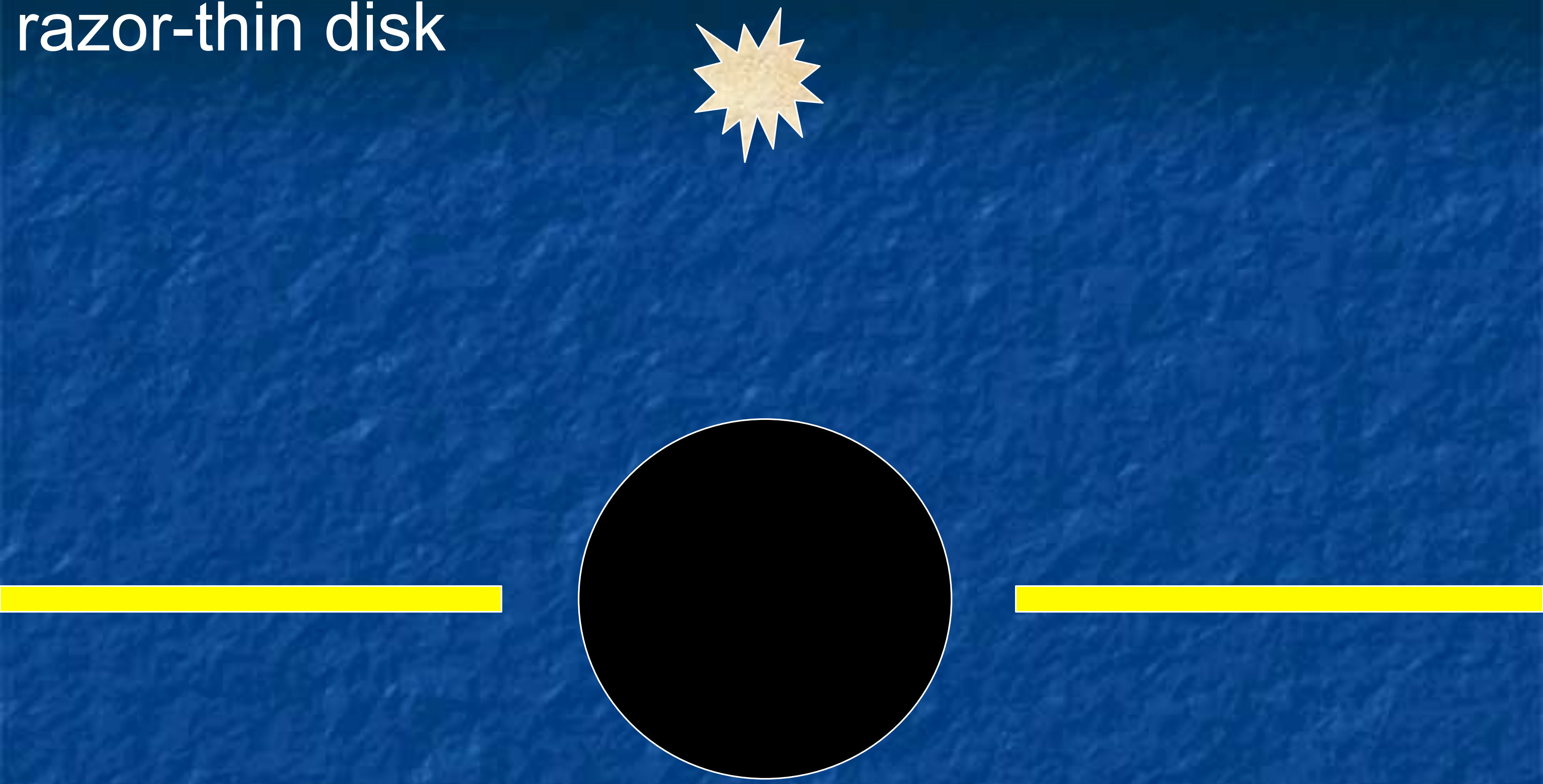


Kara et al. (2013)

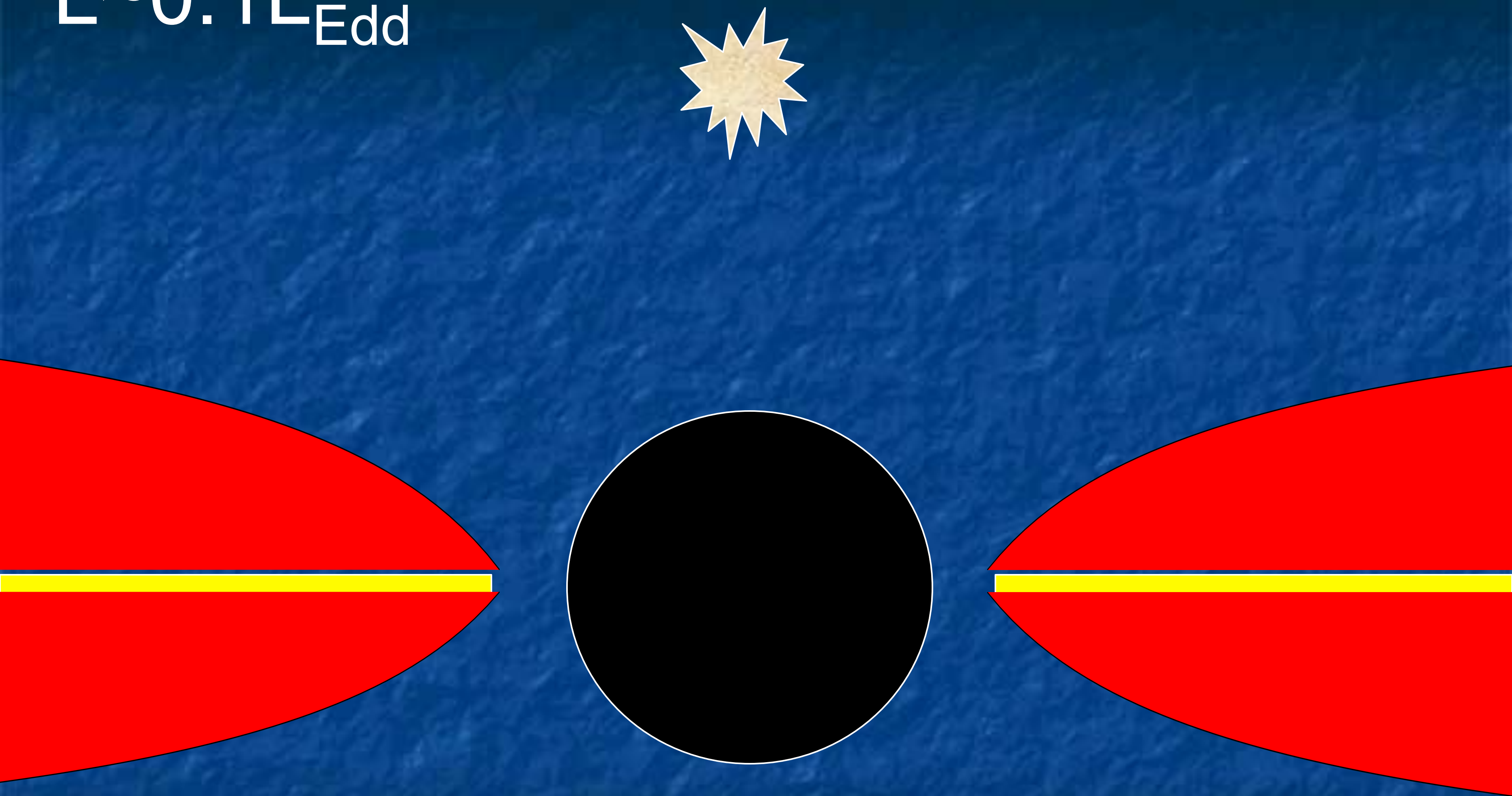
Compilation of spin constraints



Models assume razor-thin disk

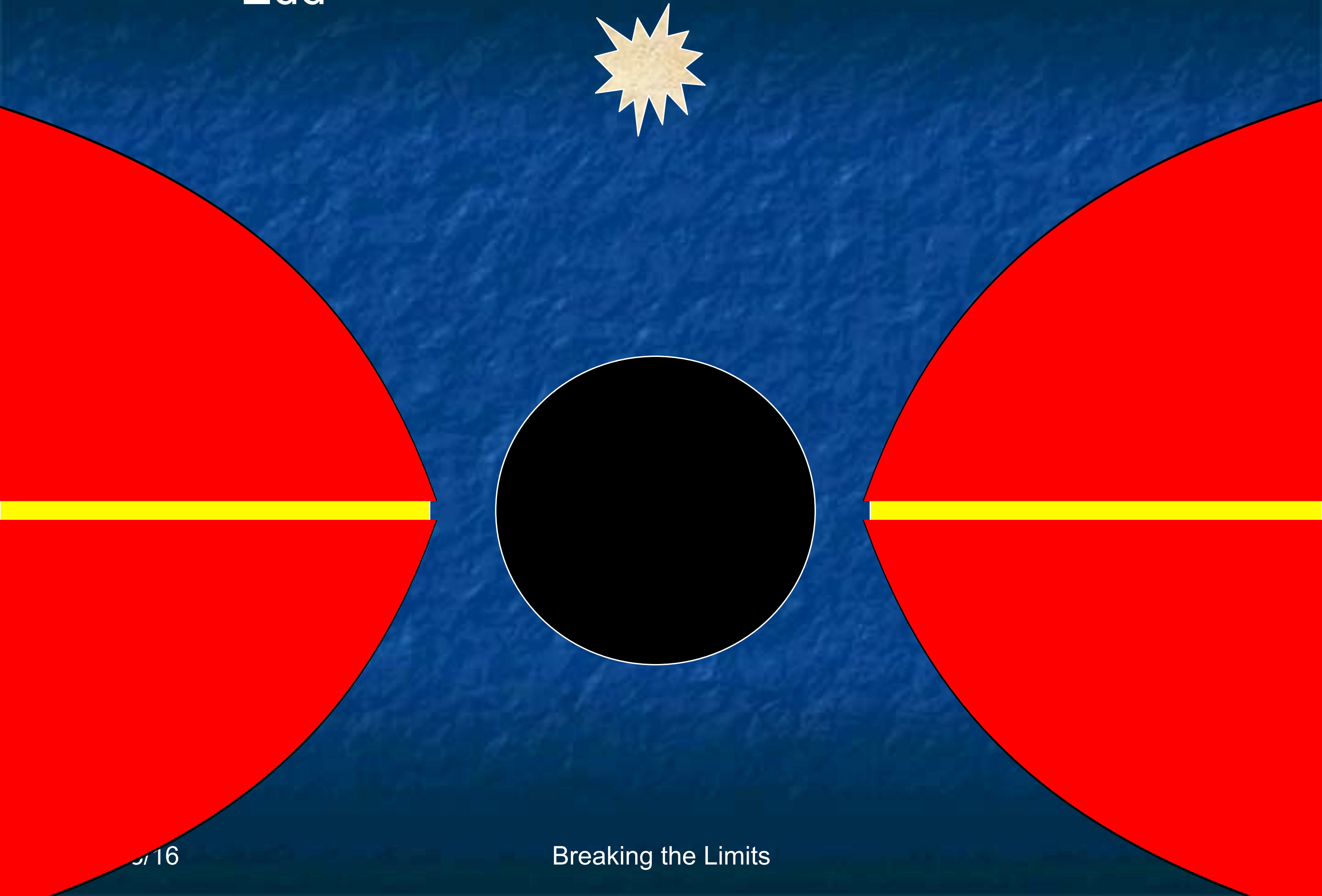


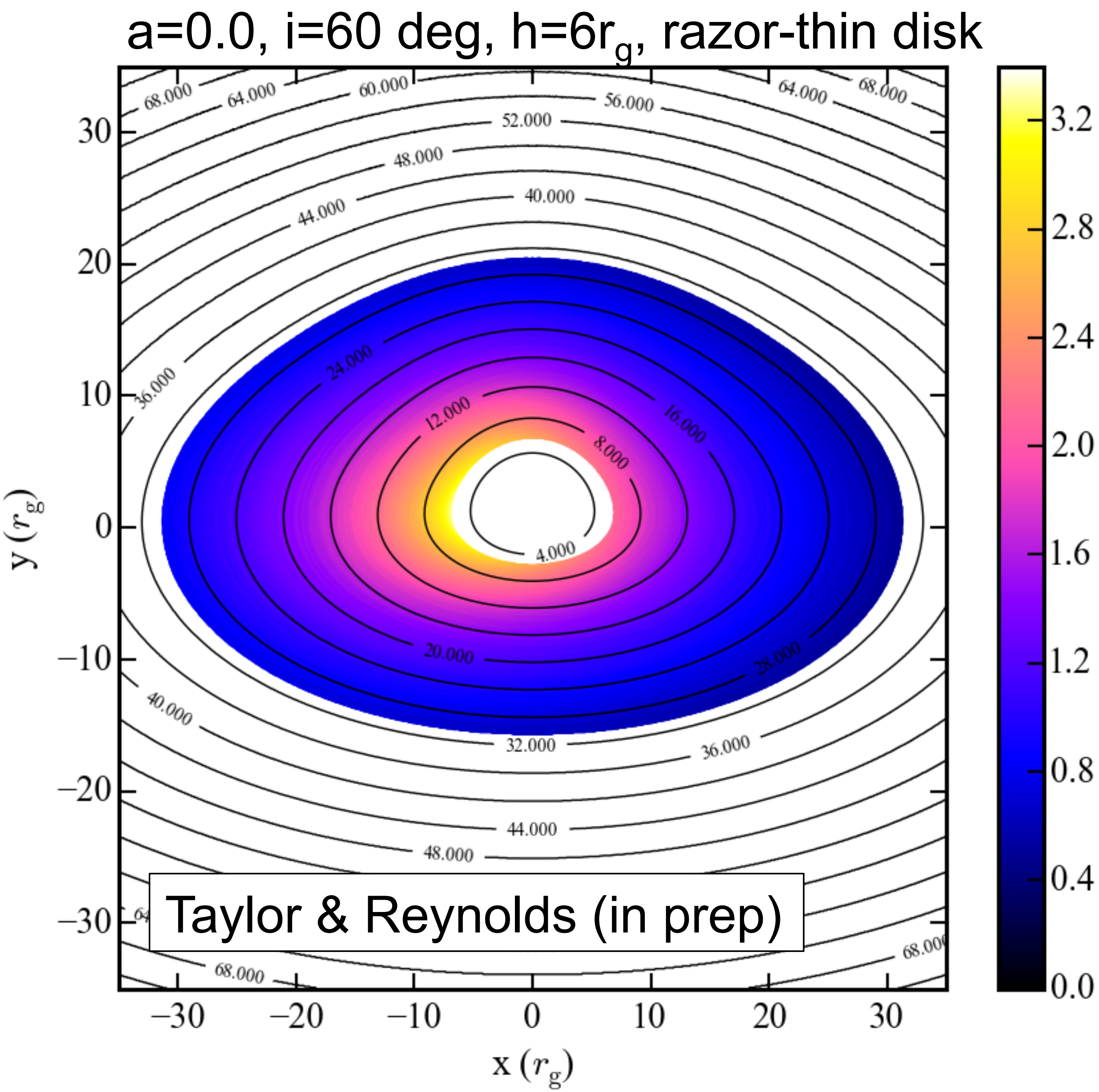
$L \sim 0.1 L_{Edd}$



$$h = \frac{3}{2\eta}\frac{L_{\rm bol}}{L_{\rm Edd}}\left[1 - \left(\frac{R_{\rm isco}}{R}\right)^{1/2}\right] r_g$$

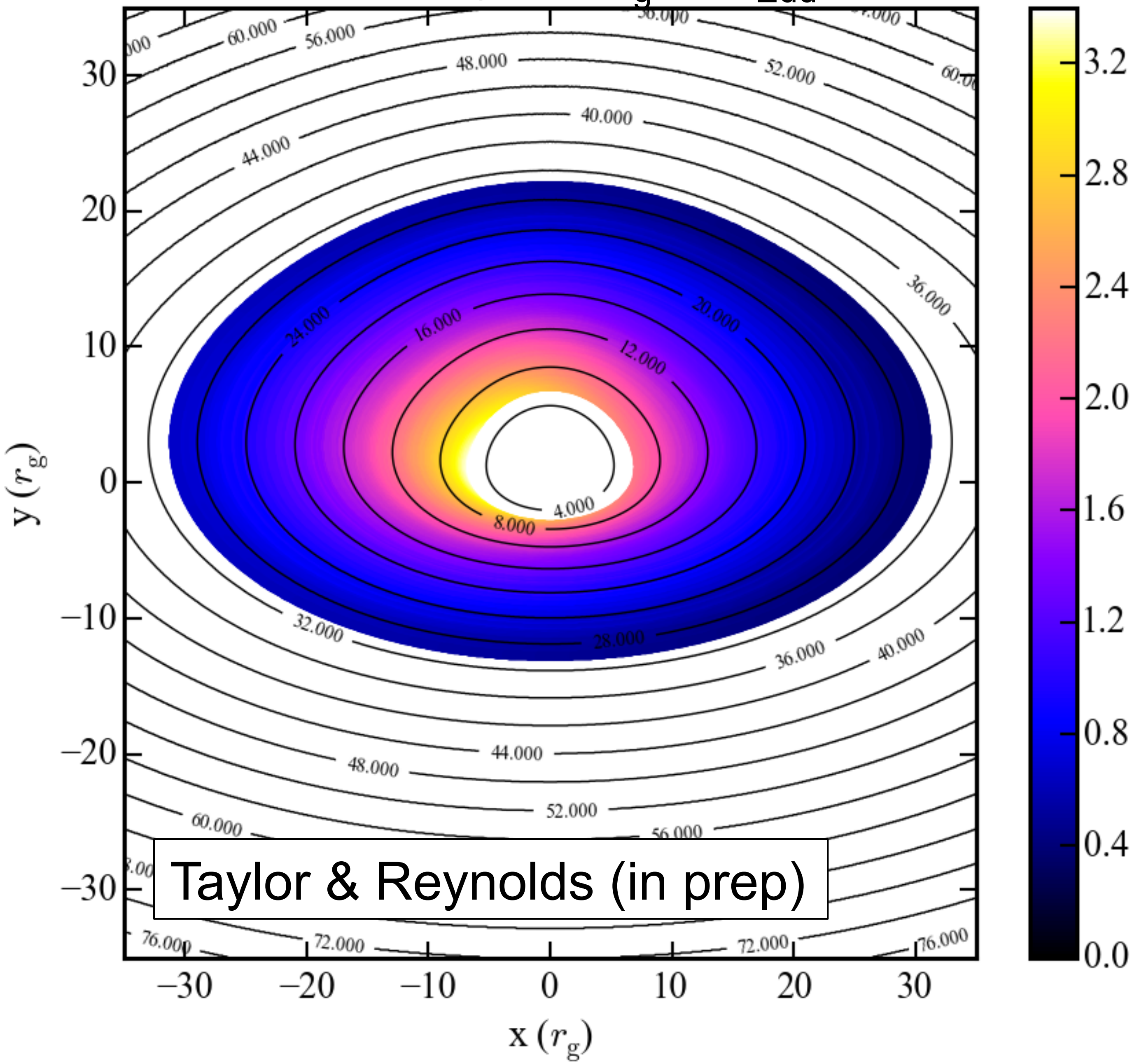
$L \sim 0.3 L_{Edd}$



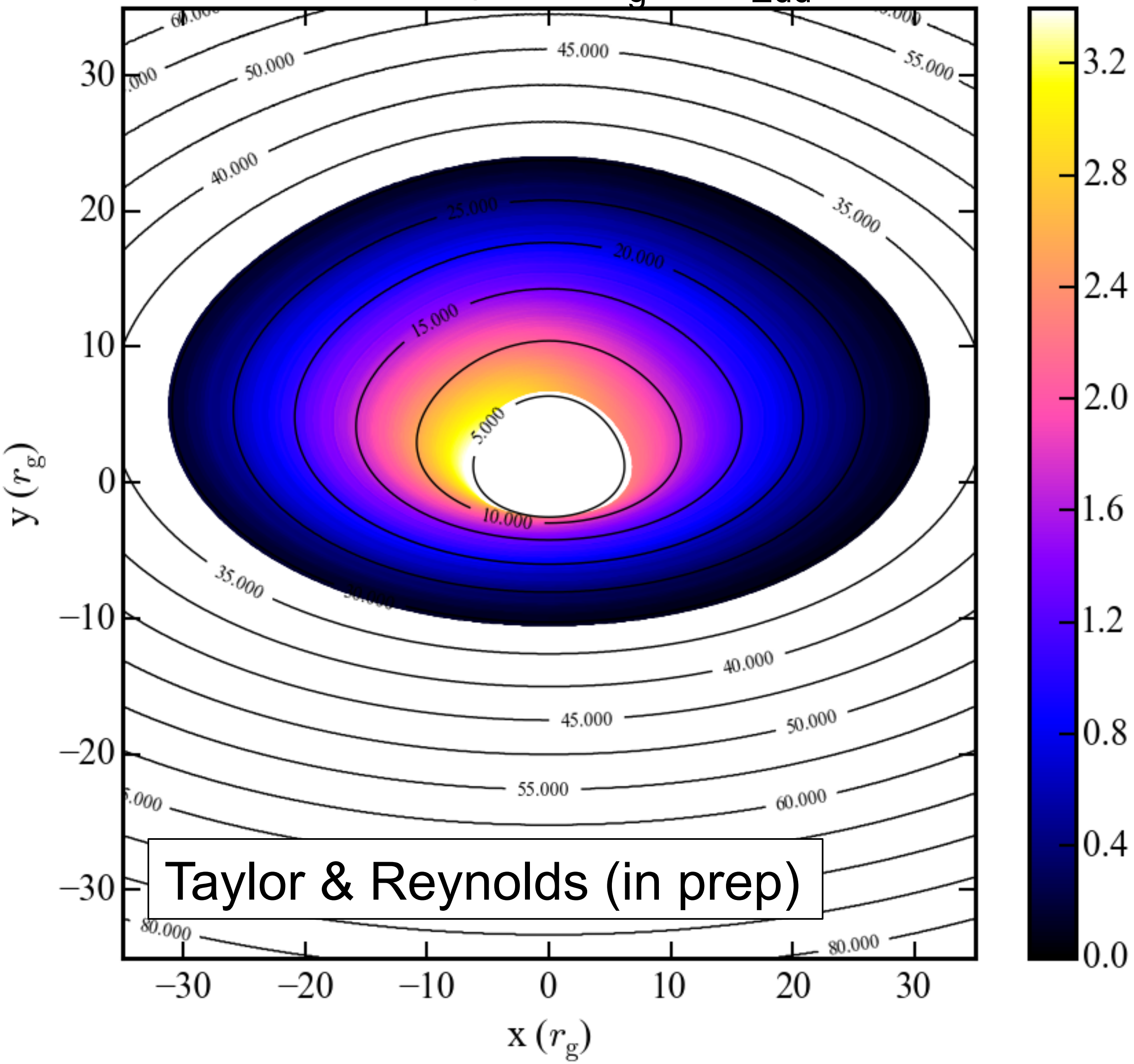


a=0.0, i=60 deg, h=6r_g, razor-thin disk
68.000
64.000
60.000
56.000
52.000
48.000
44.000
40.000
36.000
24.000
12.000
16.000
8.000
4.000
20.000
28.000
32.000
30
20
10
0
−10
−20
−30
y (r_g)
x (r_g)
3.2
2.8
2.4
2.0
1.6
1.2
0.8
0.4
0.0
Taylor & Reynolds (in prep)

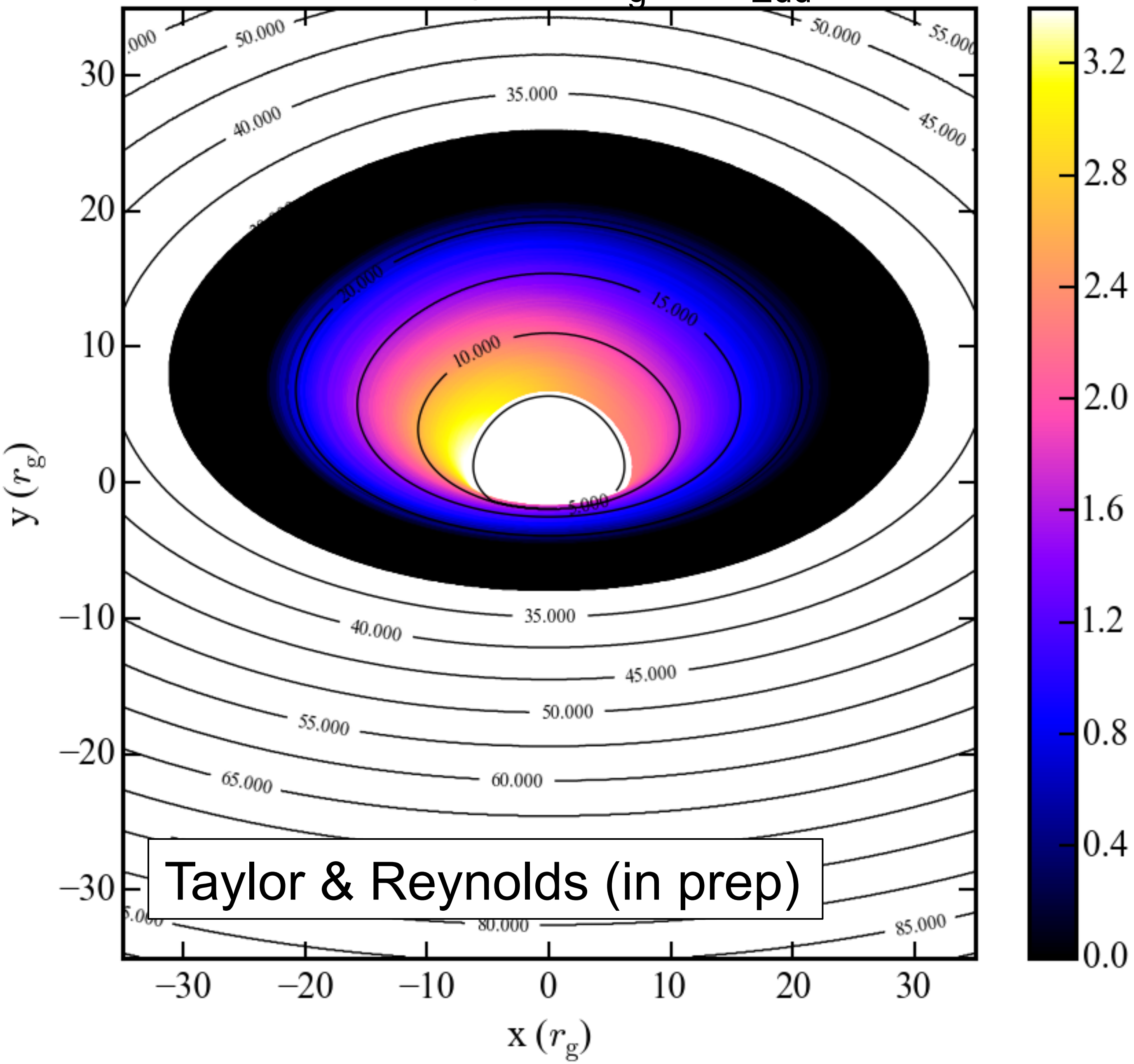
a=0.0, i=60 deg, h=6r_g, L/L_{Edd}=0.1



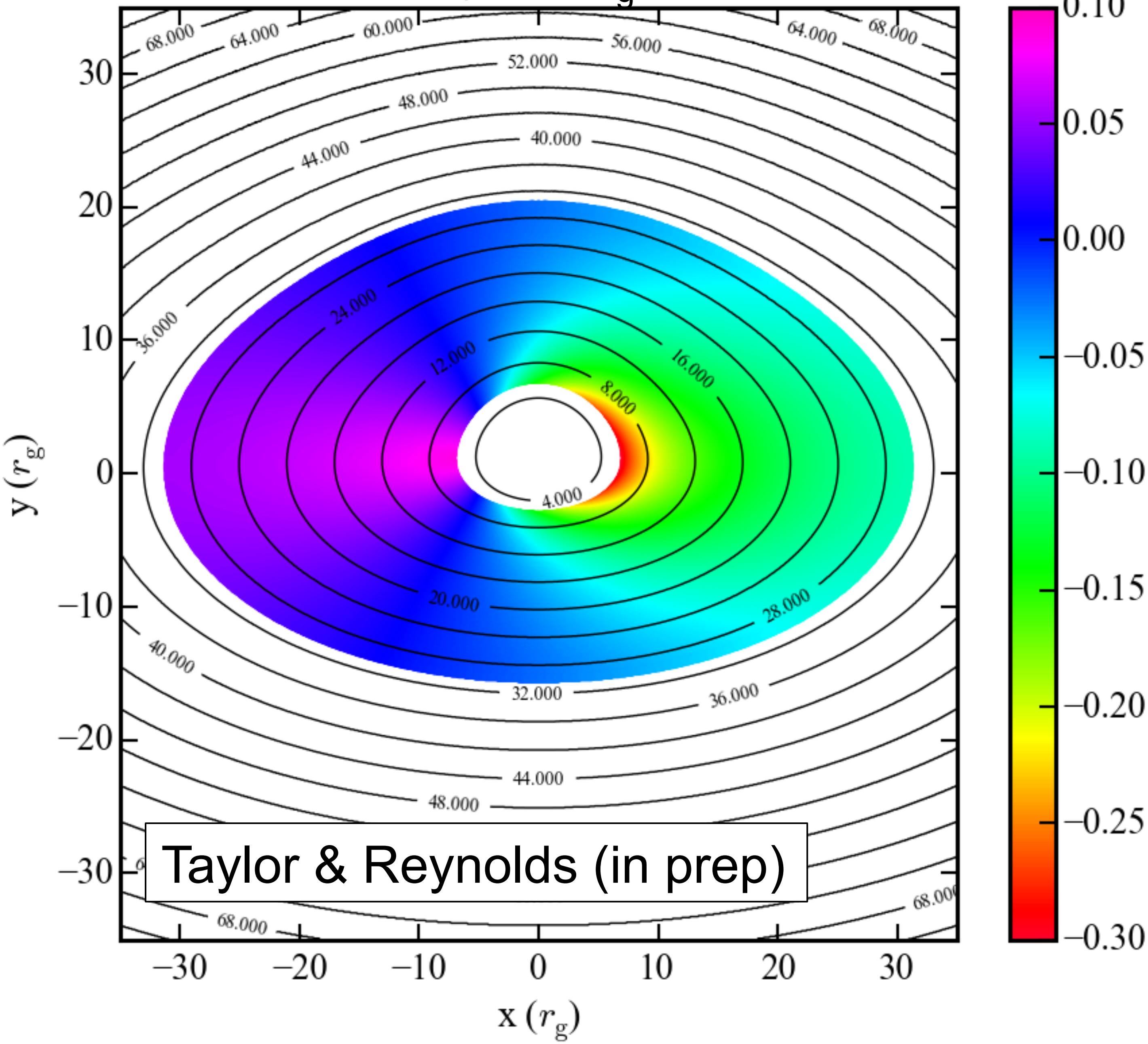
a=0.0, i=60 deg, h=6r_g, L/L_{Edd}=0.2



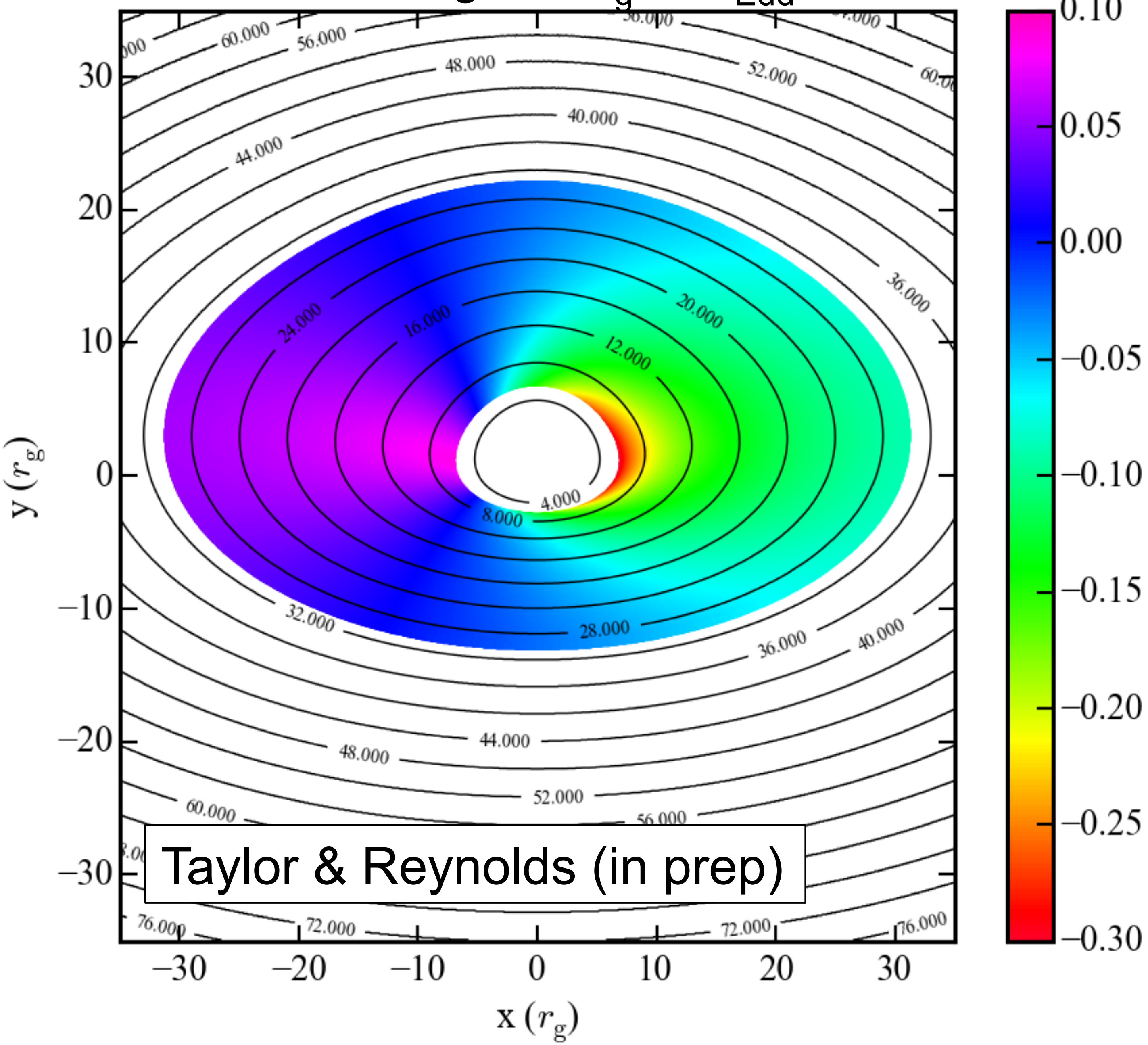
$a=0.0$, $i=60$ deg, $h=6r_g$, $L/L_{Edd}=0.3$



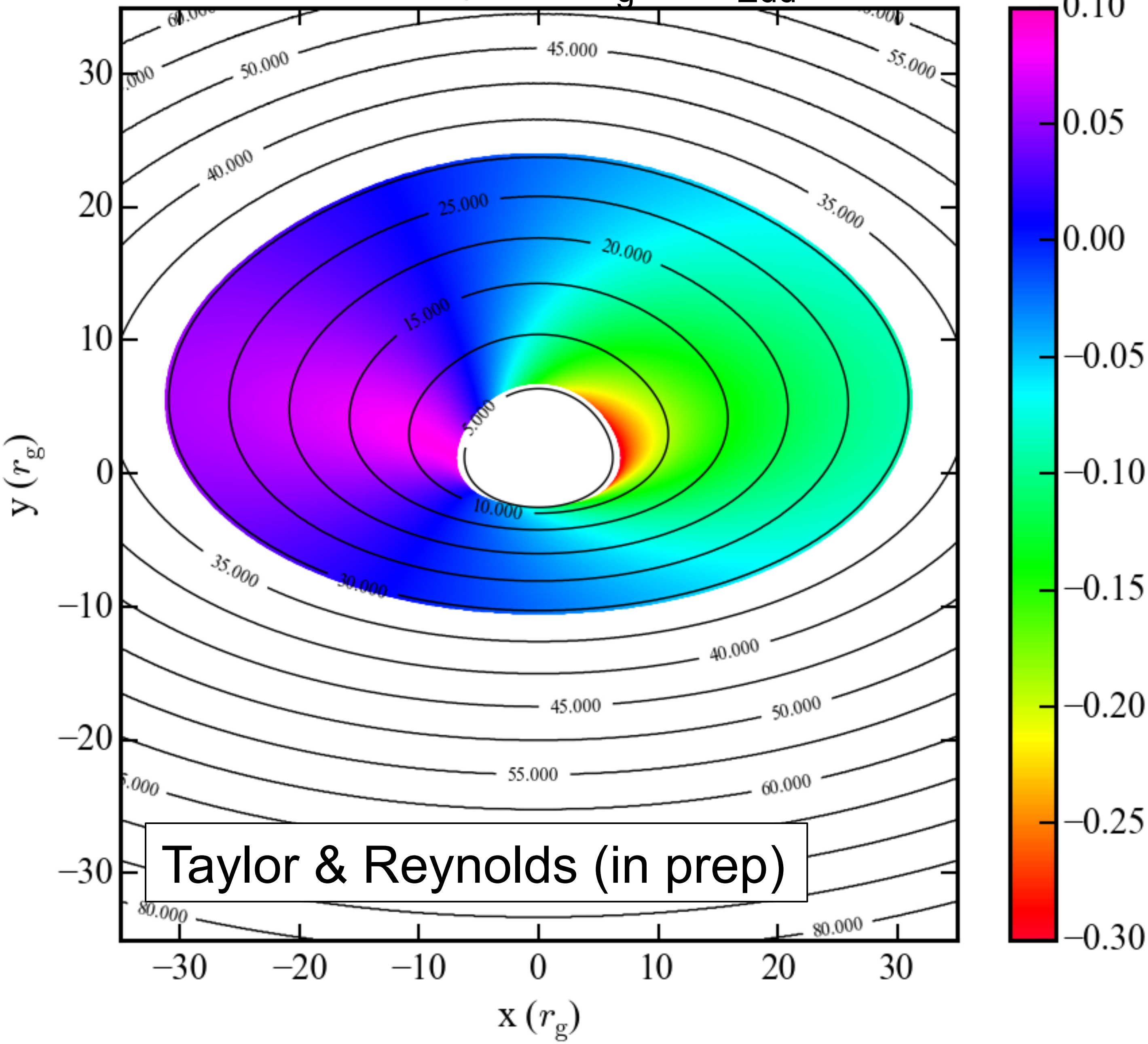
a=0.0, i=60 deg, h=6r_g, razor-thin disk



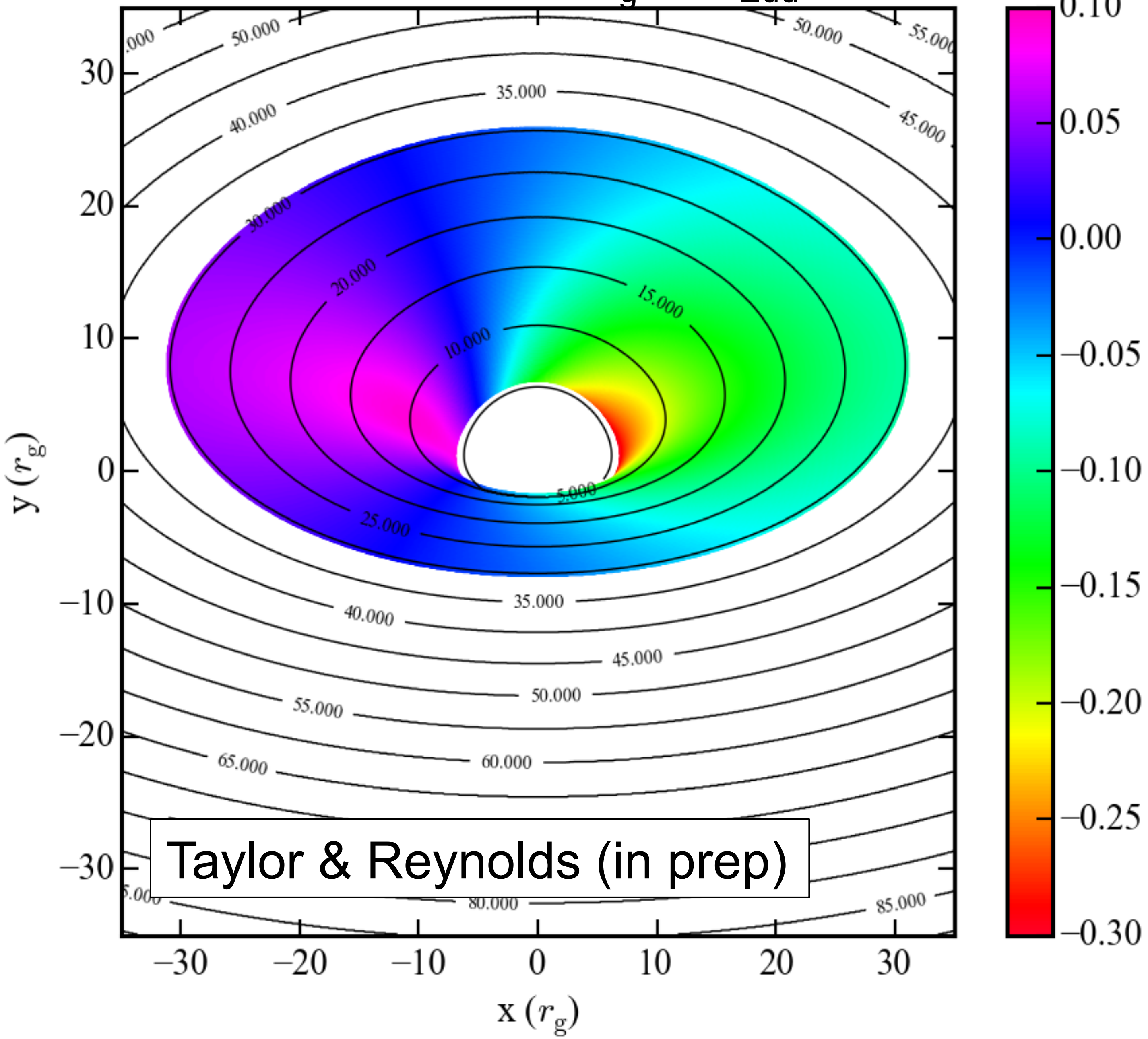
a=0.0, i=60 deg, h=6r_g, L/L_{Edd}=0.1

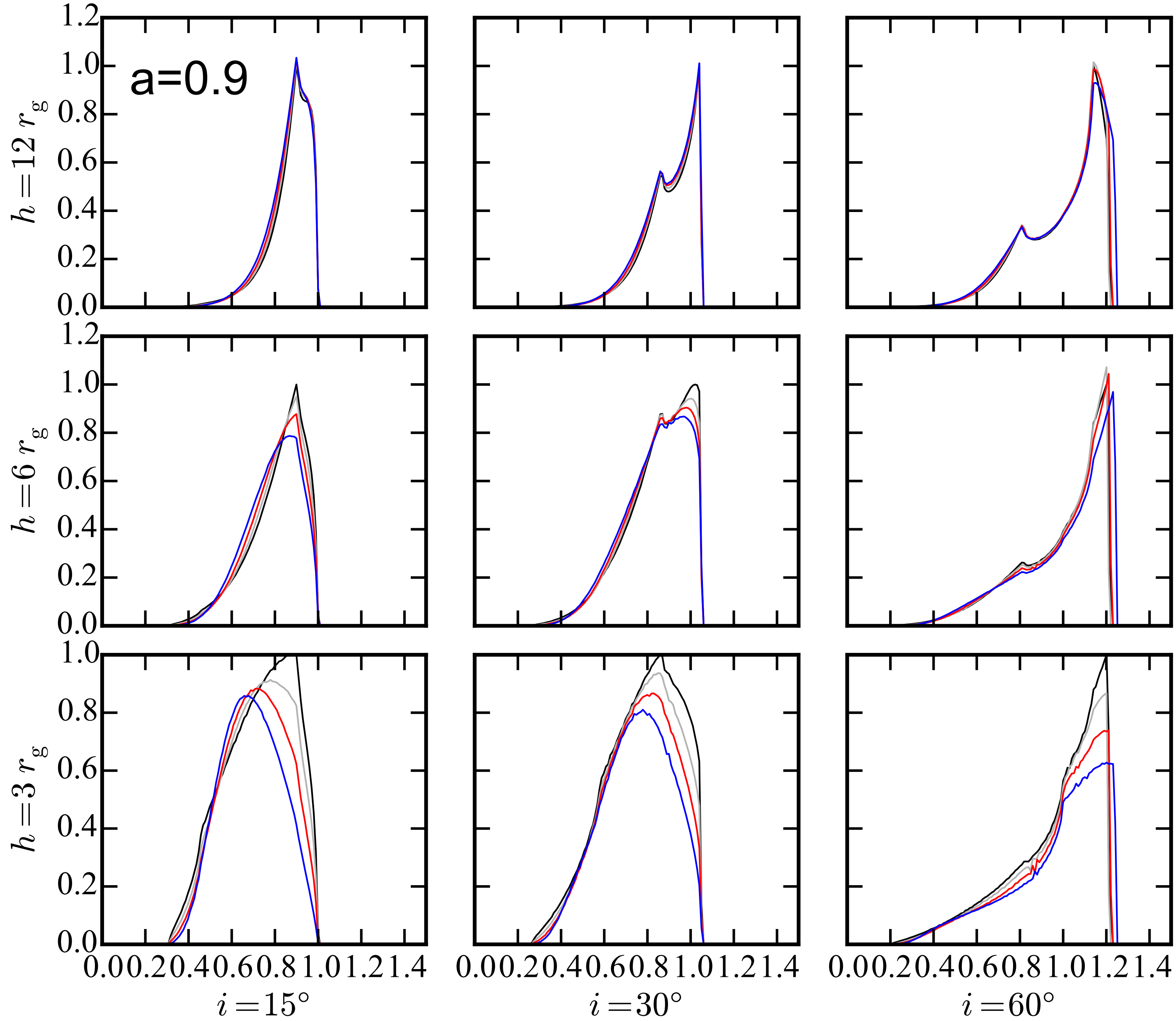


a=0.0, i=60 deg, h=6r_g, L/L_{Edd}=0.2

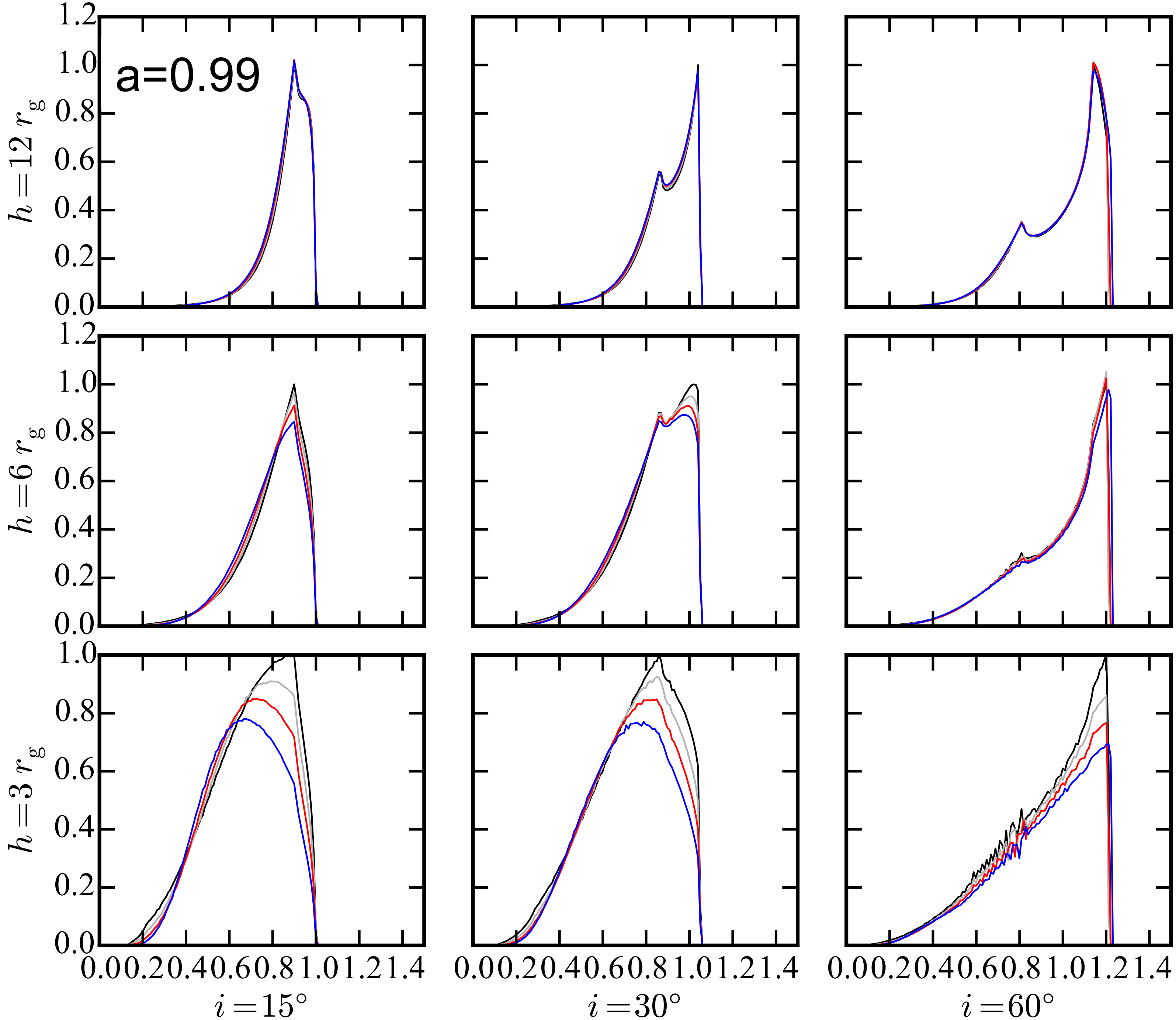


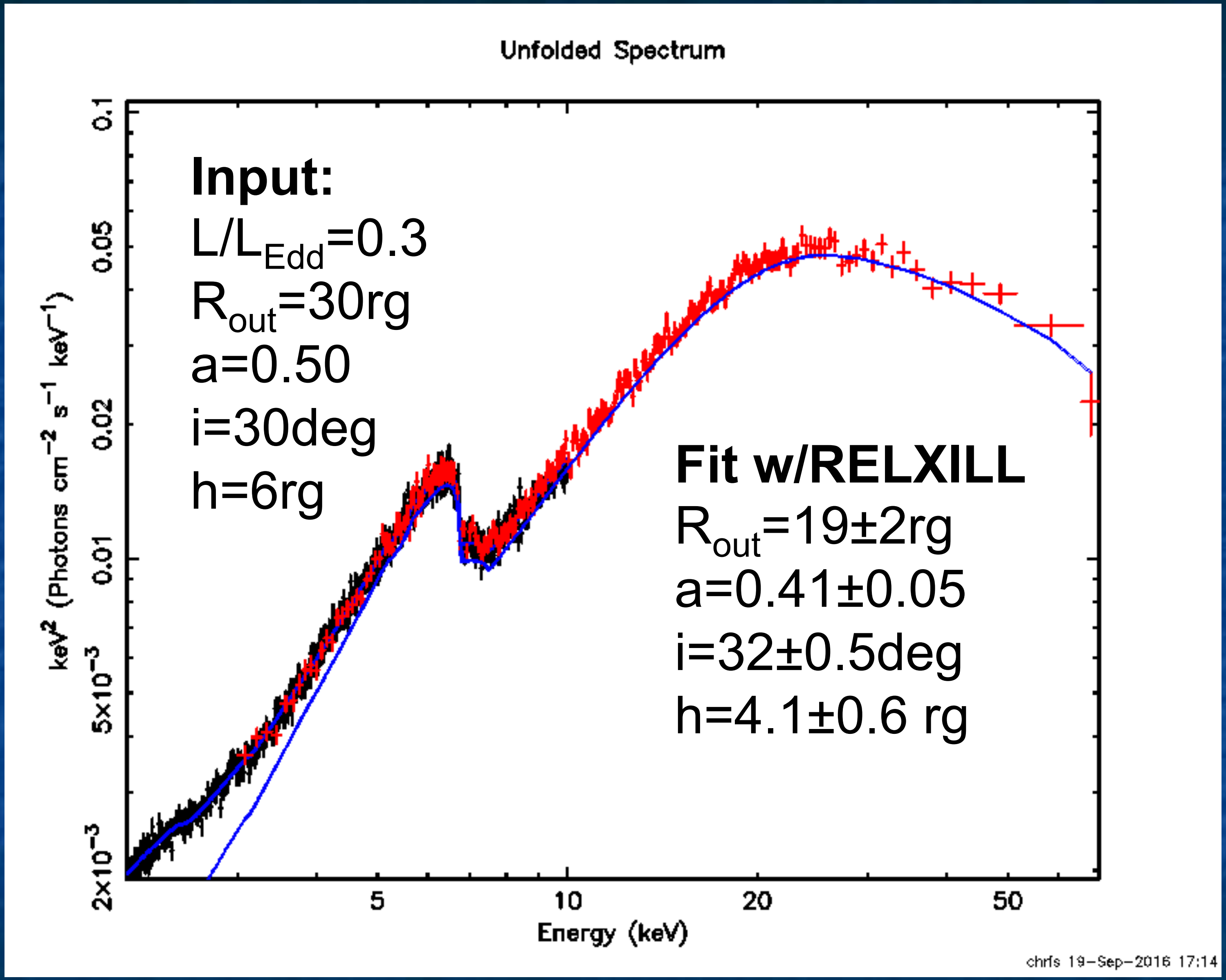
a=0.0, i=60 deg, h=6r_g, L/L_{Edd}=0.3

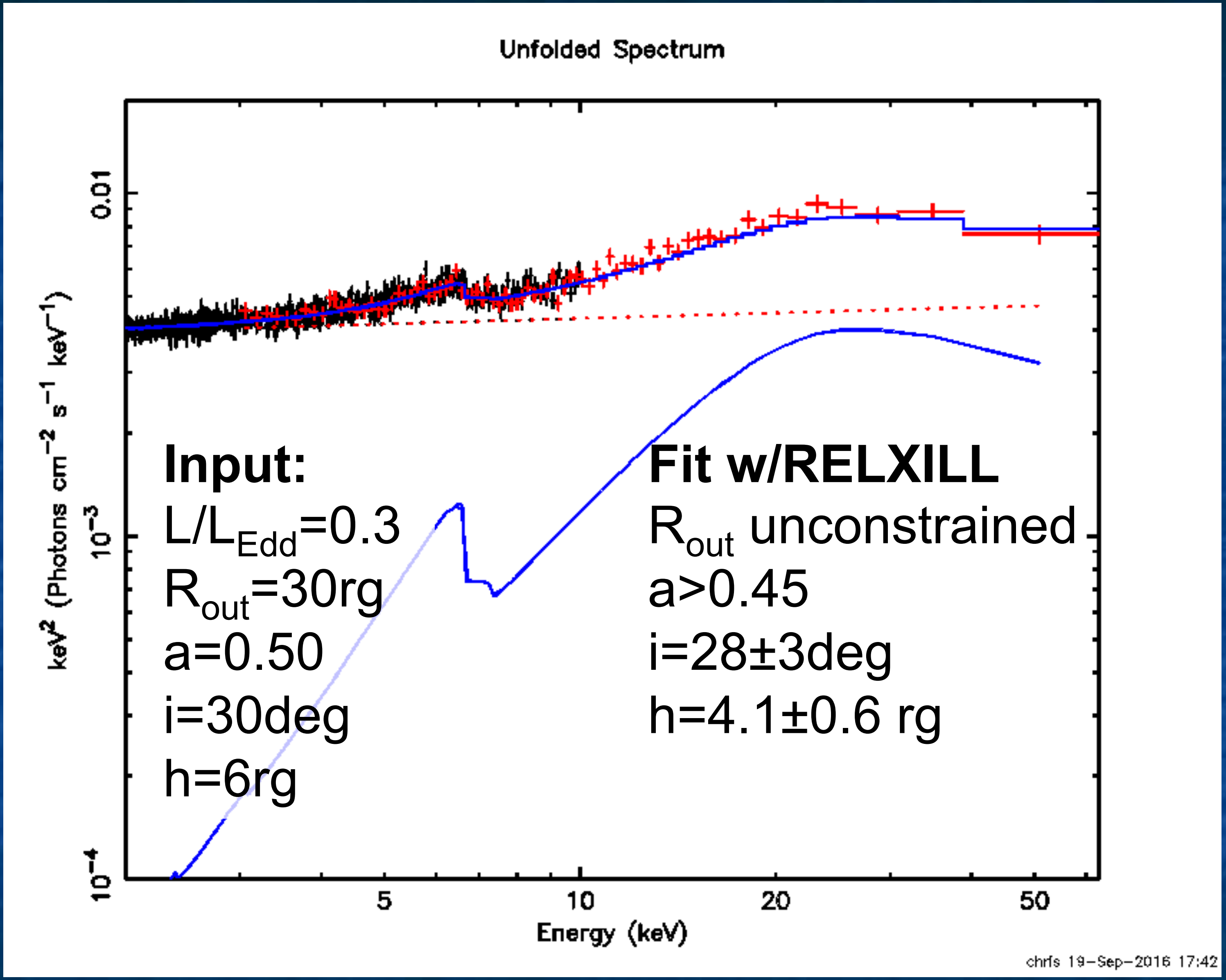




a=0.9
h = 12 r_g
h = 6 r_g
h = 3 r_g
i = 15°
i = 30°
i = 60°

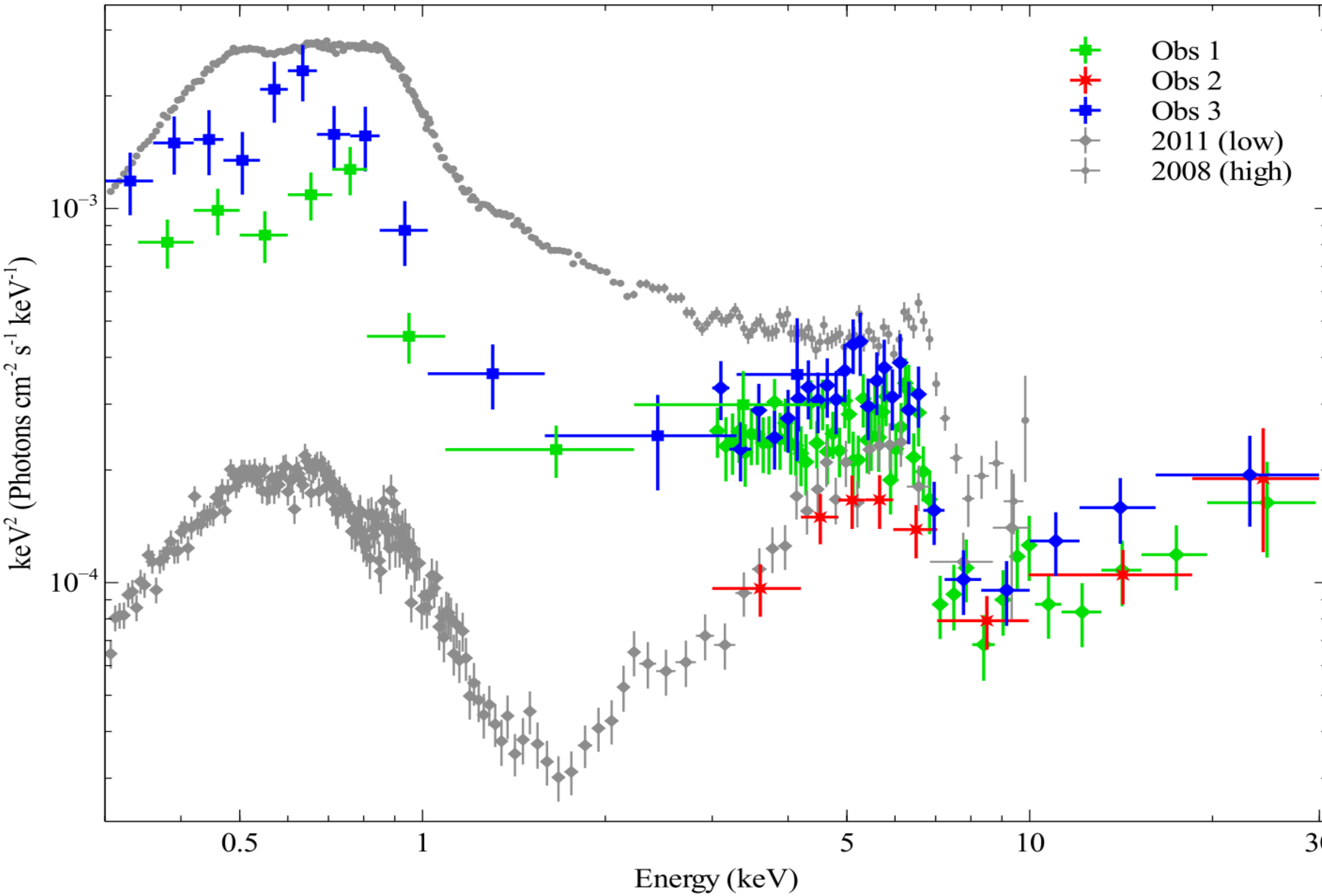

a=0.99
$h = 12\,r_{\rm g}$
$h = 6\,r_{\rm g}$
$h = 3\,r_{\rm g}$
0.0 0.2 0.4 0.6 0.8 1.0 1.2
0.0 0.2 0.4 0.6 0.8 1.0
0.0 0.2 0.4 0.6 0.8 1.0 1.2 1.4
$i = 15^\circ$
$i = 30^\circ$
$i = 60^\circ$


Unfolded Spectrum
Input:
L/LEdd=0.3
Rout=30rg
a=0.50
i=30deg
h=6rg
Fit w/RELXILL
Rout=19±2rg
a=0.41±0.05
i=32±0.5deg
h=4.1±0.6 rg
keV2 (Photons cm-2 s-1 keV-1)
0.1
0.05
0.02
0.01
5×10-3
2×10-3
5
10
20
50
Energy (keV)
chrfs 19-Sep-2016 17:14

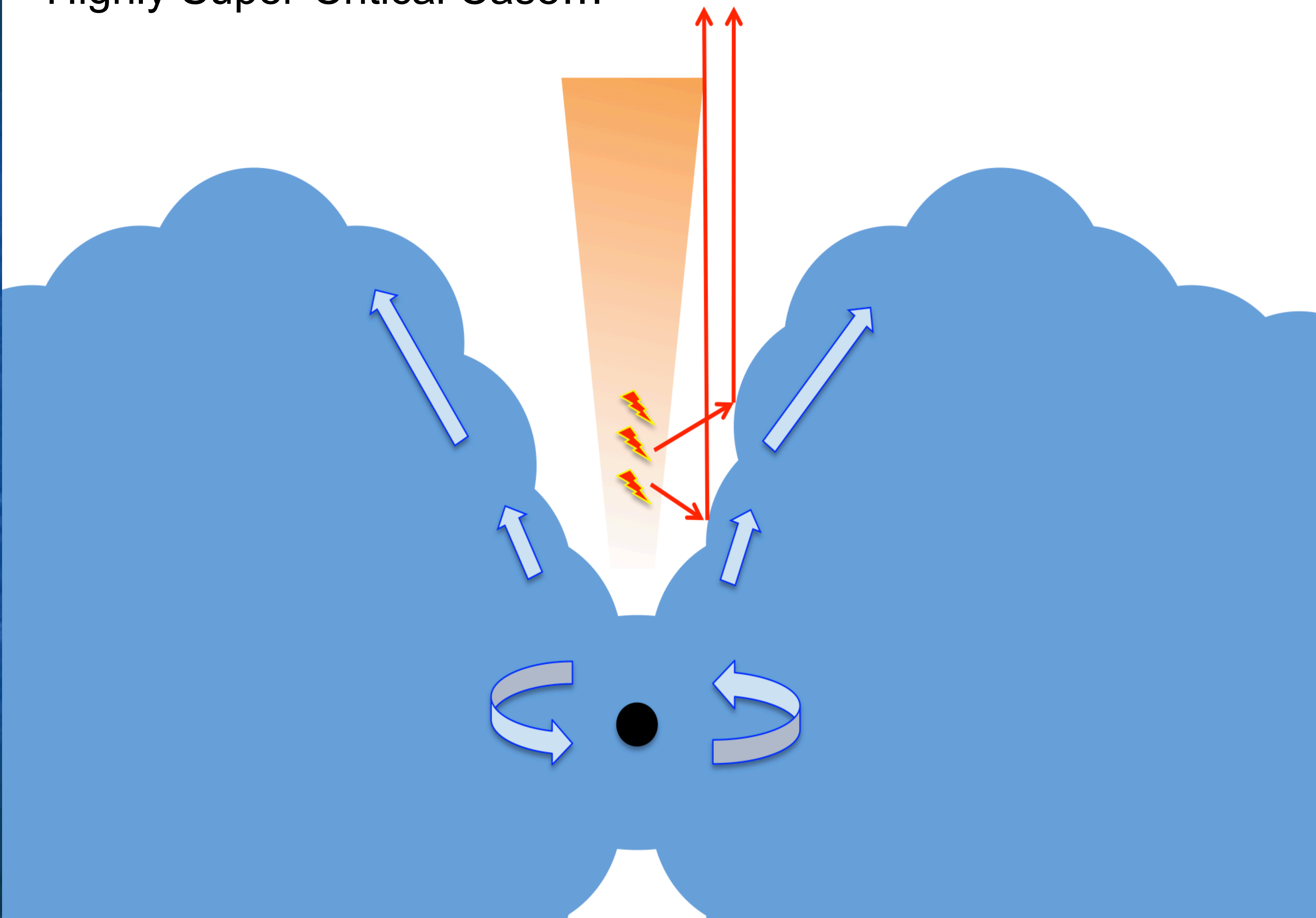


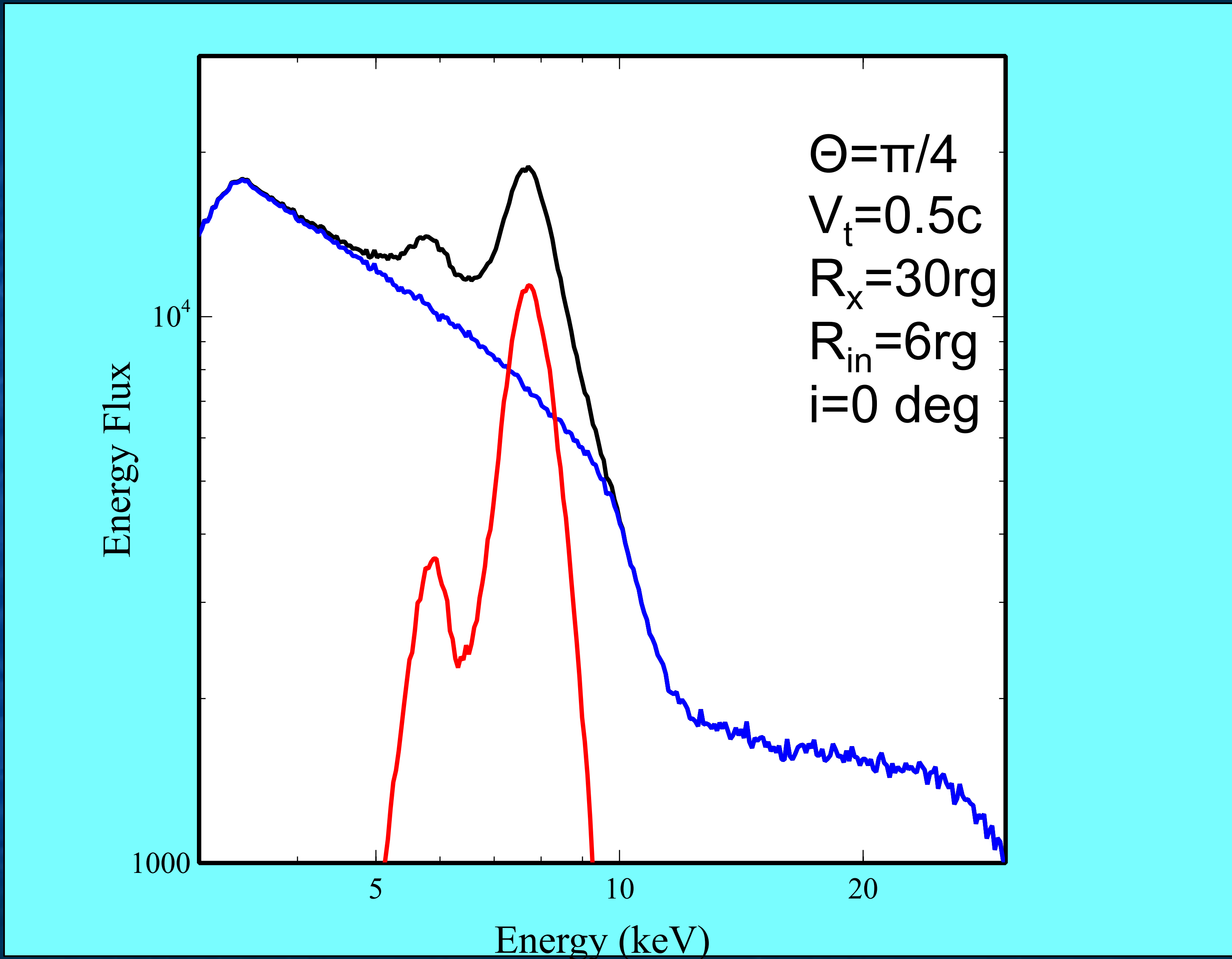
Unfolded Spectrum
keV^2 (Photons cm^{-2} s^{-1} keV^{-1})
0.01
10^{-3}
10^{-4}
5
10
20
50
Energy (keV)
chrfs 19–Sep–2016 17:42
Input:
L/L_{Edd}=0.3
R_{out}=30rg
a=0.50
i=30deg
h=6rg
Fit w/RELXILL
R_{out} unconstrained
a>0.45
i=28±3deg
h=4.1±0.6 rg

1H0707-495 (Kara et al. 2015)

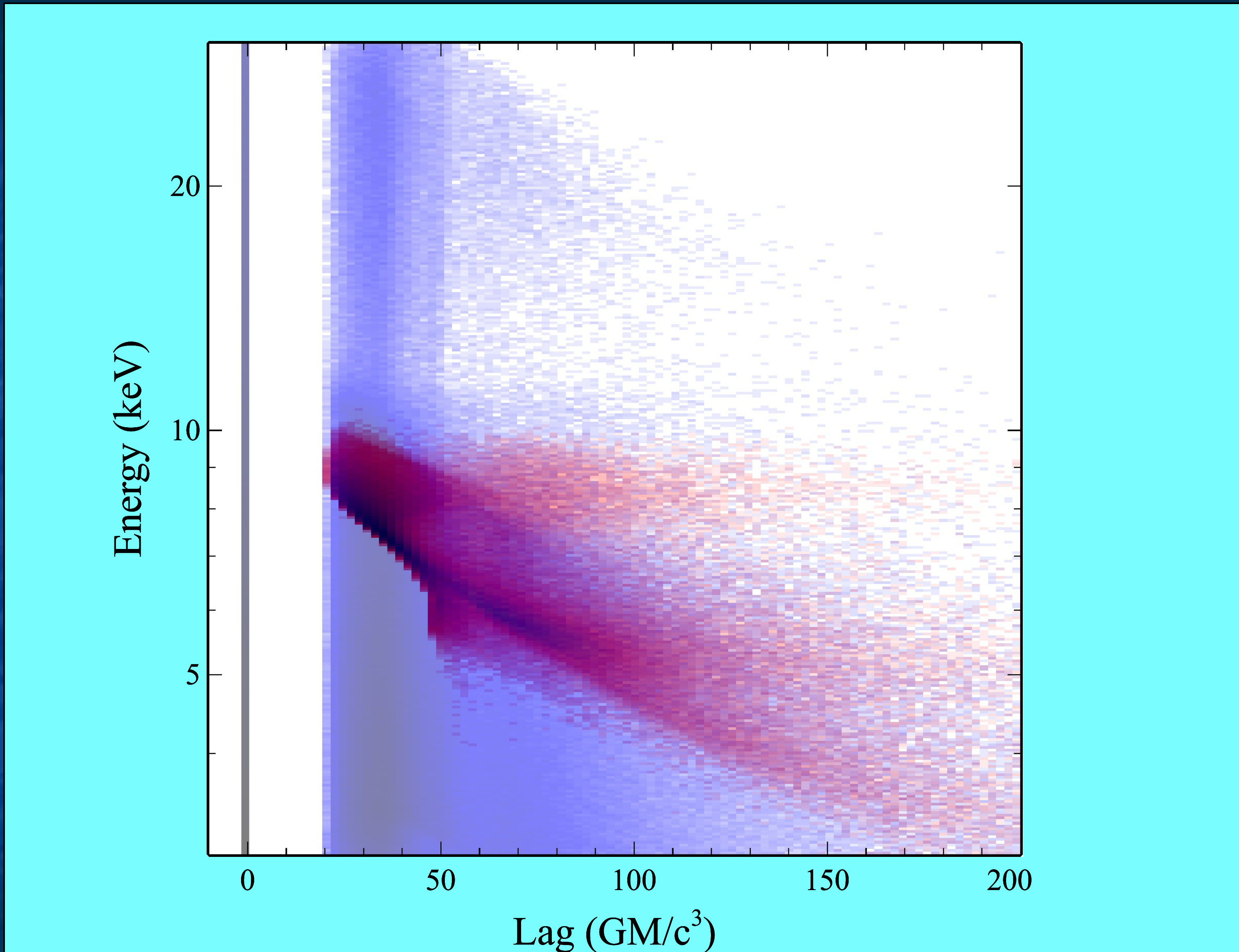


Highly Super-Critical Case…



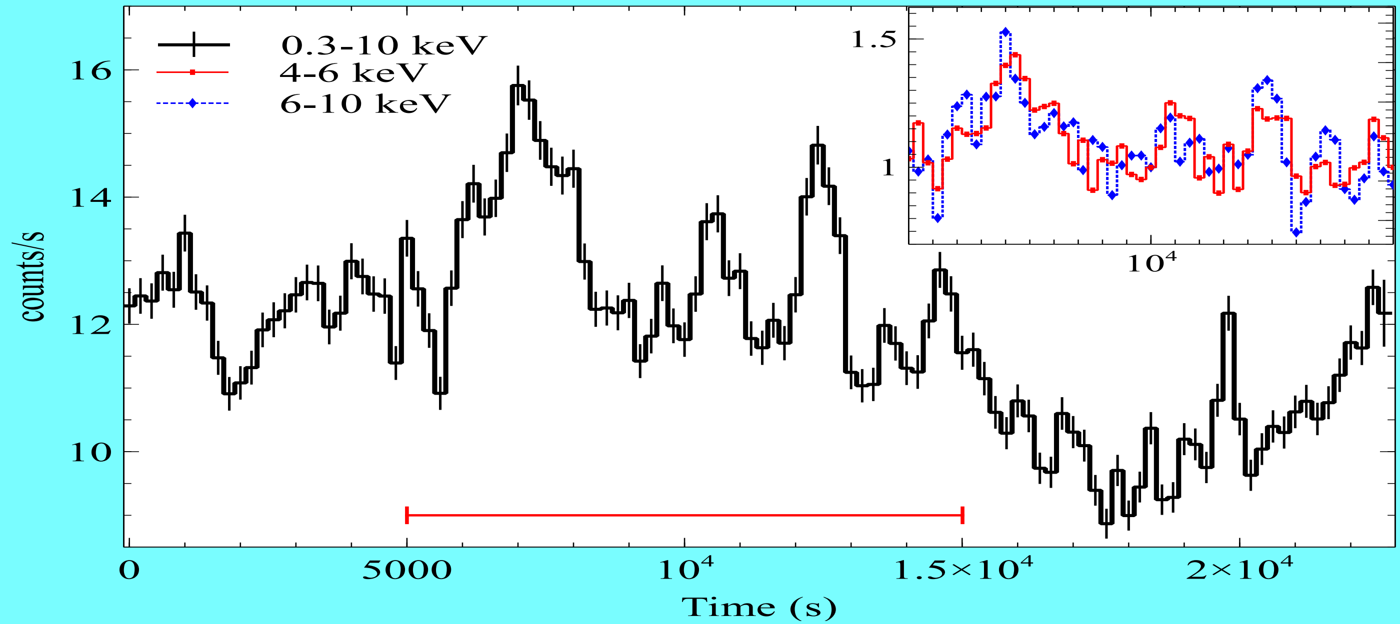


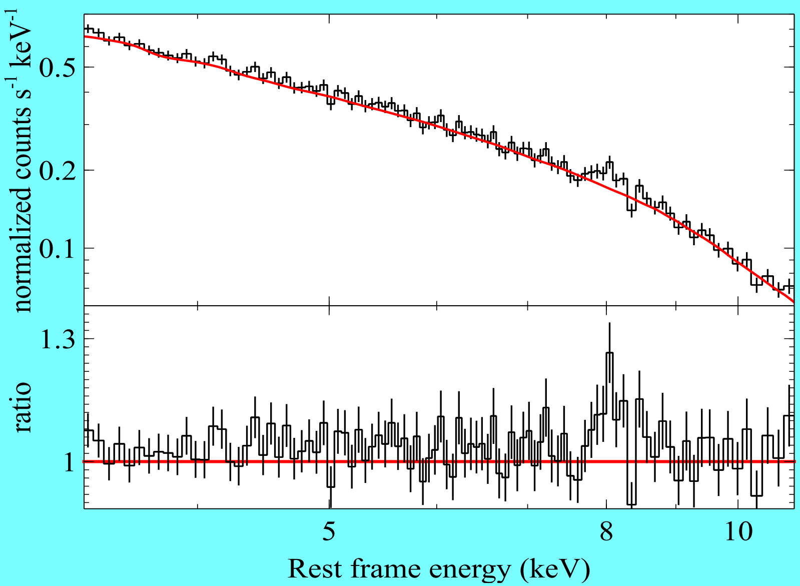
Θ=π/4
V_t=0.5c
R_x=30rg
R_in=6rg
i=0 deg
Energy Flux
10^4
1000
5
10
20
Energy (keV)

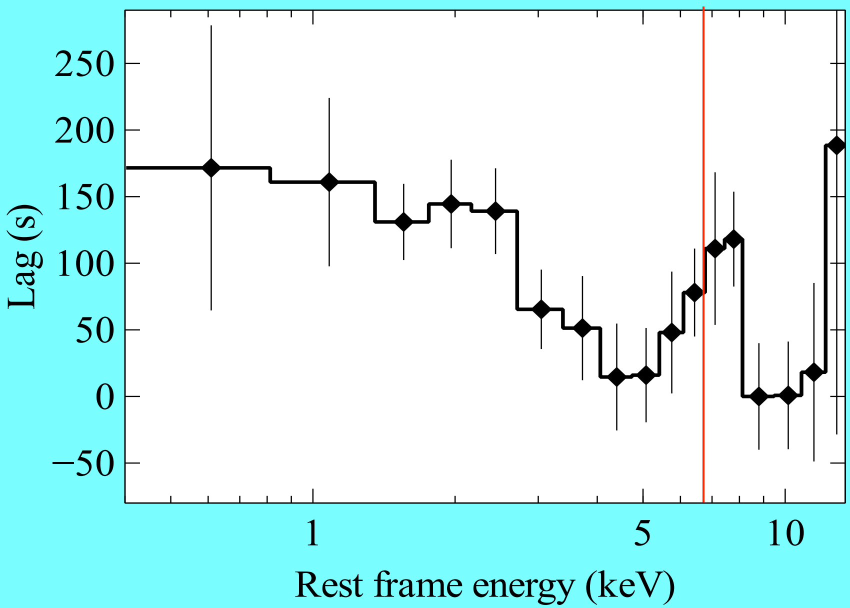


Energy (keV)
20
10
5
0
50
100
150
200
Lag (GM/c3)

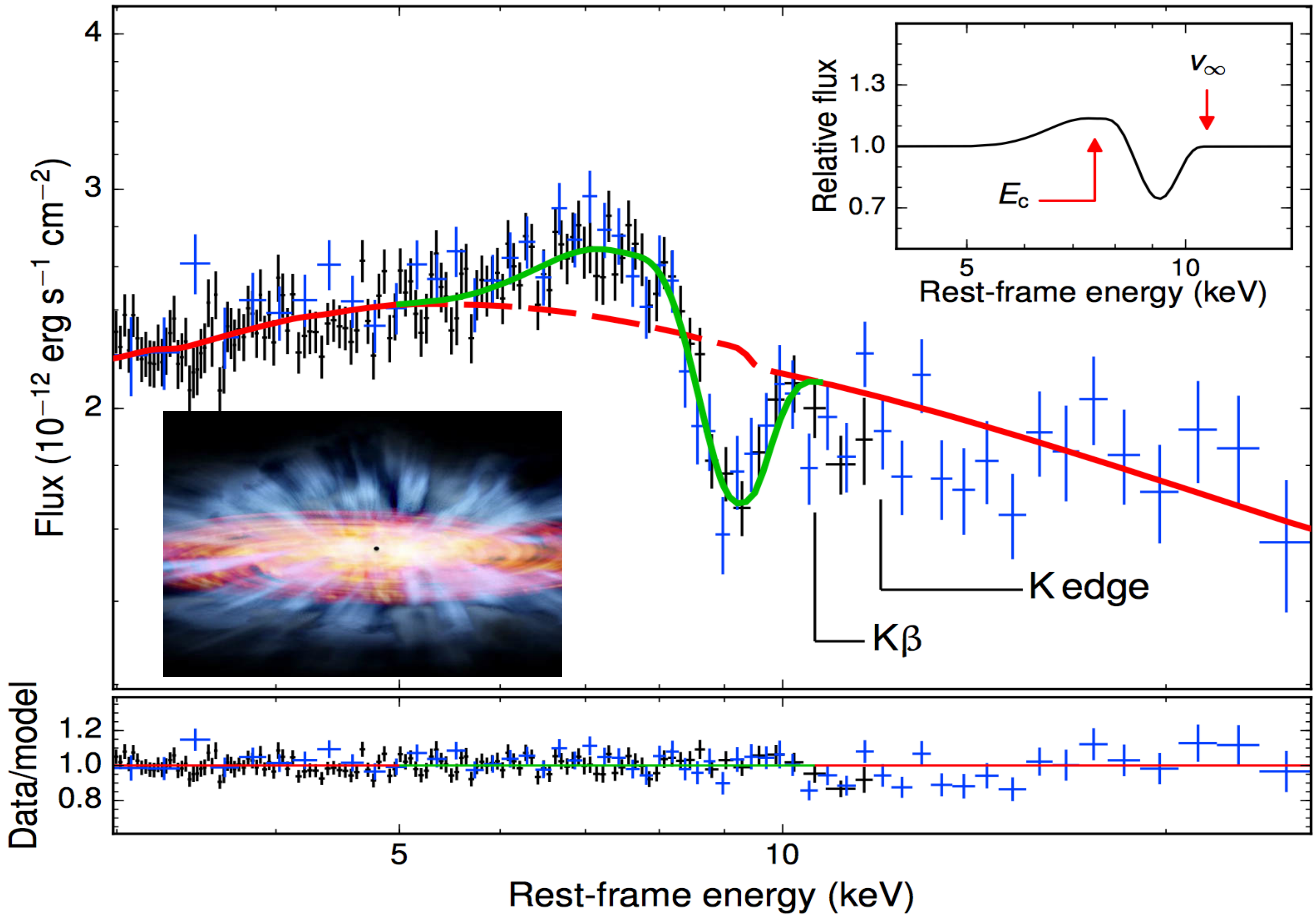
Kara, Miller, Reynolds & Dai (Nature, 2016)

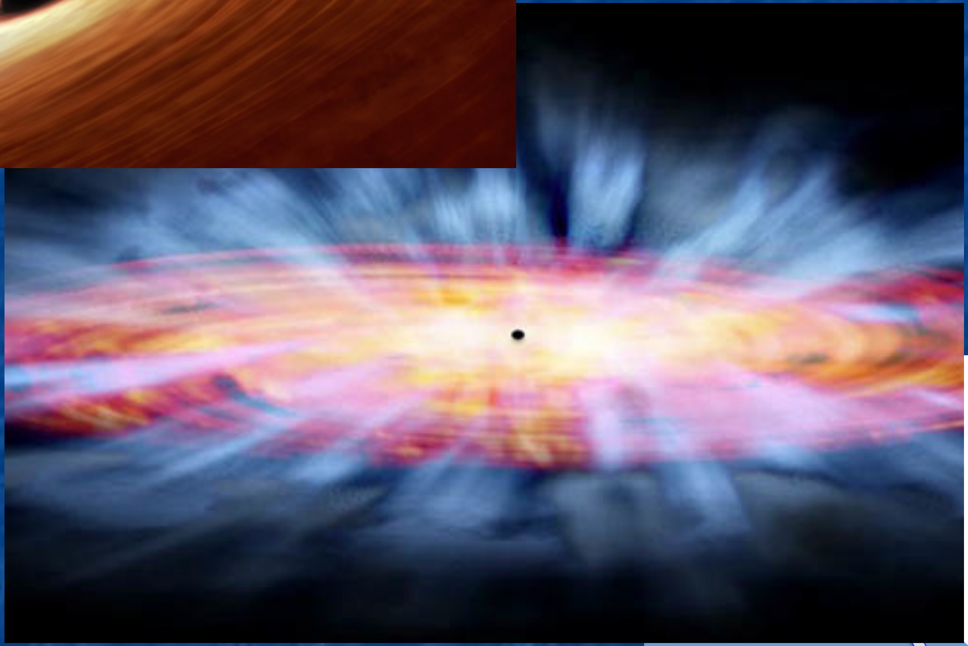


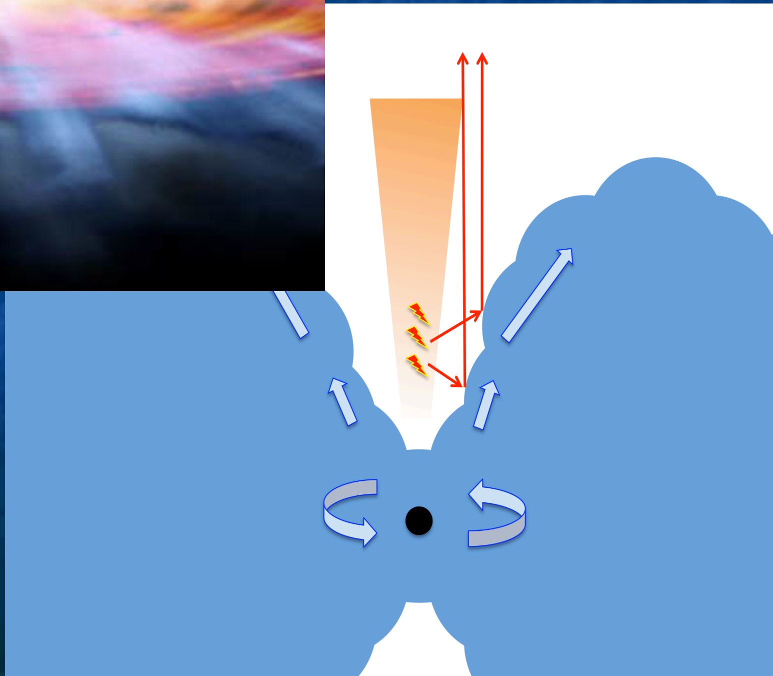




PSD456 (Nardini et al. 2015)







Conclusions

- Case for highly super-Eddington AGN is still open.
  - Are masses reliable as L approached L_{Edd}?
  - Is the optical light a good proxy for mass accretion rate?
- Even for L~0.1-0.3L_{Edd}, geometric thickness of inner disk important for X-ray reflection features
  - If not accounted for, may introduce modest systematic error into measures of spin and coronal height.
  - May explain shifting blue wing in, e.g., 1H0707-495
- TDE (Sw1644) shows that true super-Eddington accretion can create reflection/reverberation signatures in iron
  - Shifts likely dominated by outflow
  - Could be important probe of such sources