Black holes: Theory and Observations

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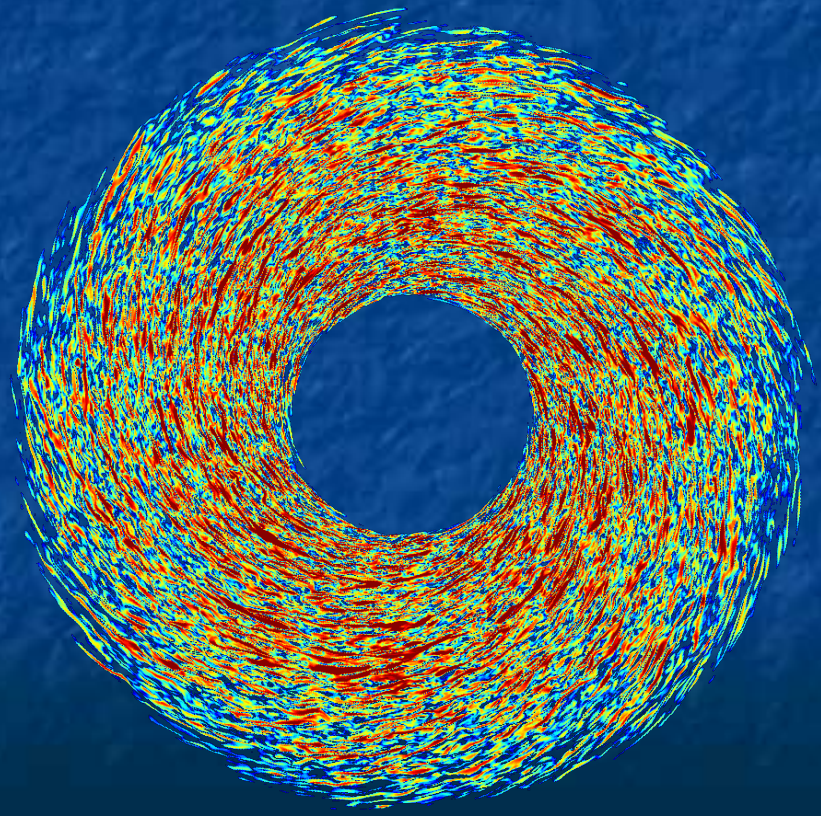
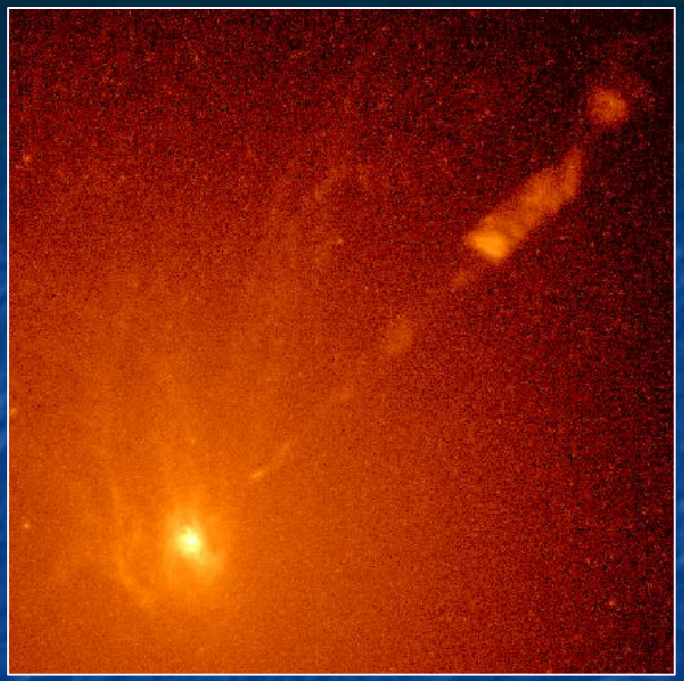
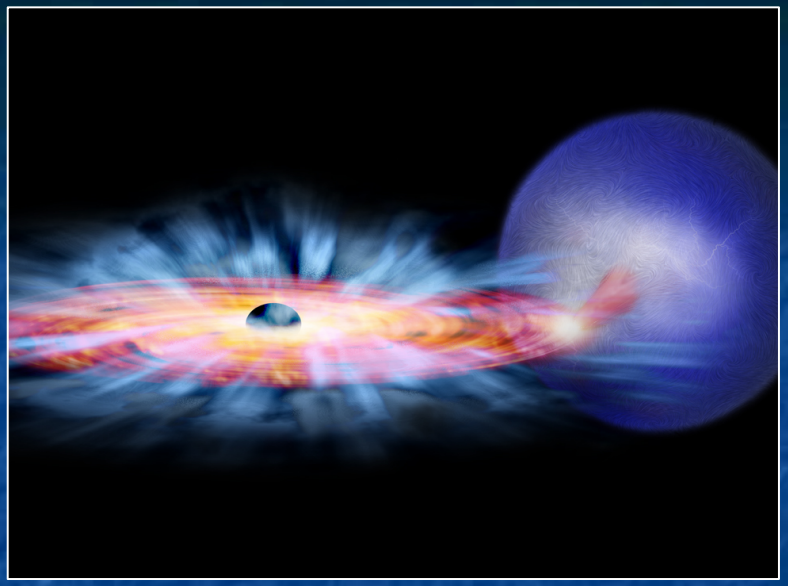
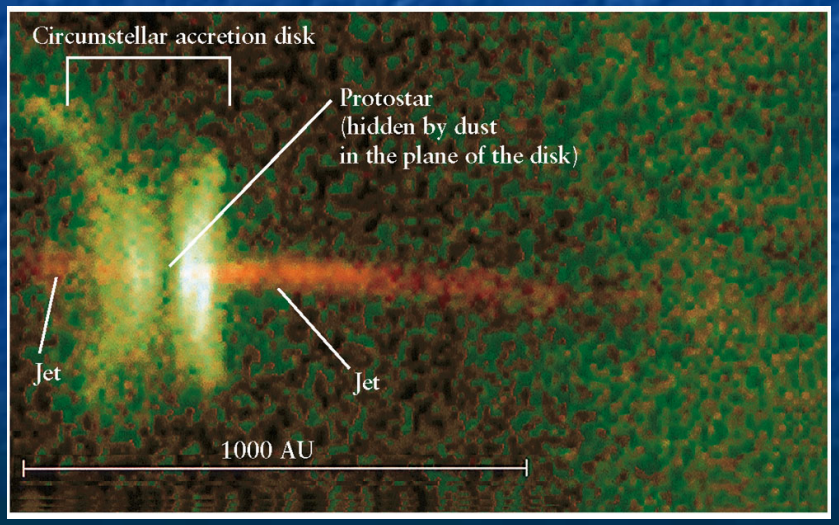
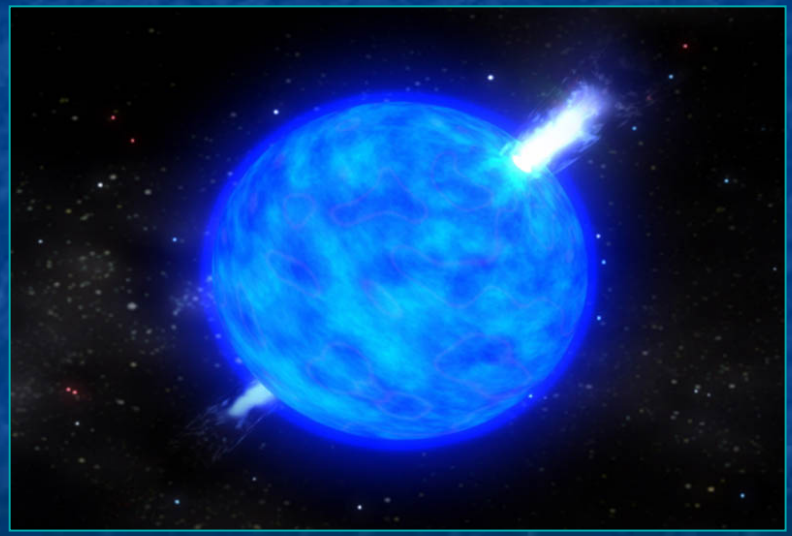






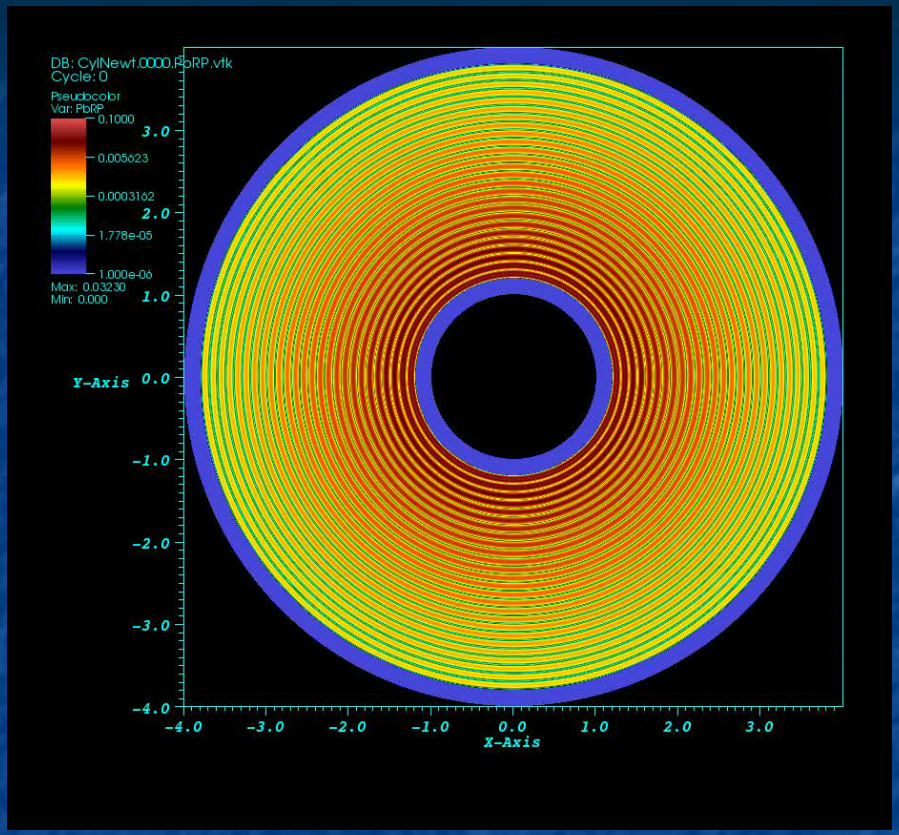

Circumstellar accretion disk
Protostar
(hidden by dust
in the plane of the disk)
Jet
Jet
1000 AU



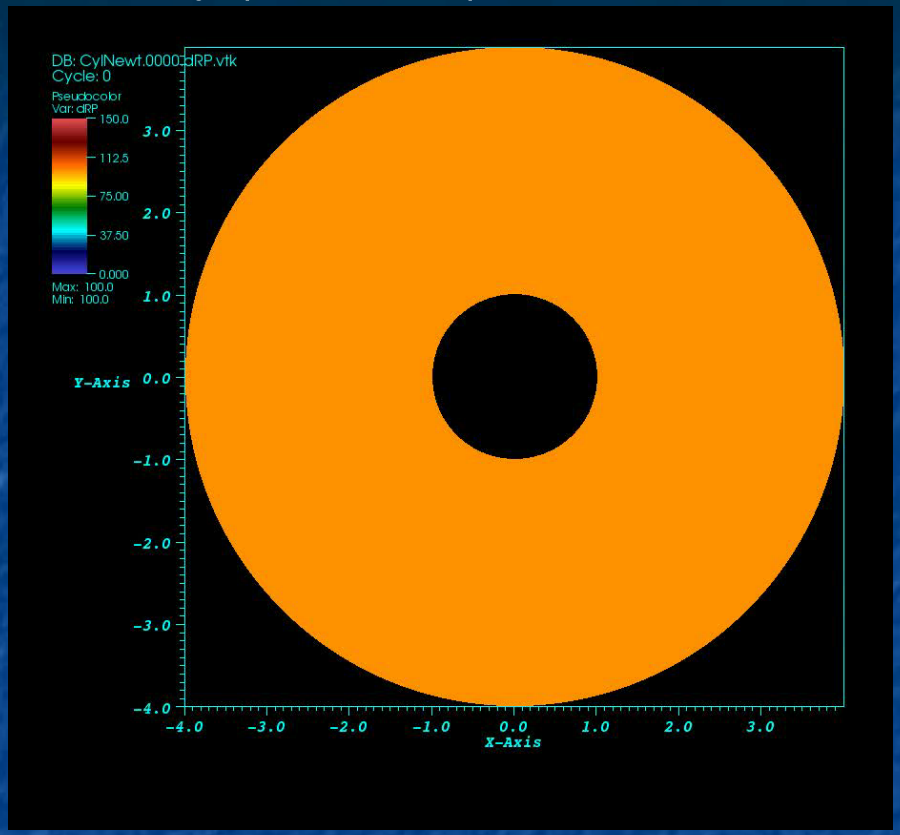
Theory…

- Why do accretion disks actually accrete?
  - MHD turbulence paradigm for angular momentum transport
- Why are accreting systems so variable?
  - Aperiodic and quasi-periodic phenomena
- Why do some black holes produce powerful jets whereas others do not?
  - Generation of large scale magnetic field

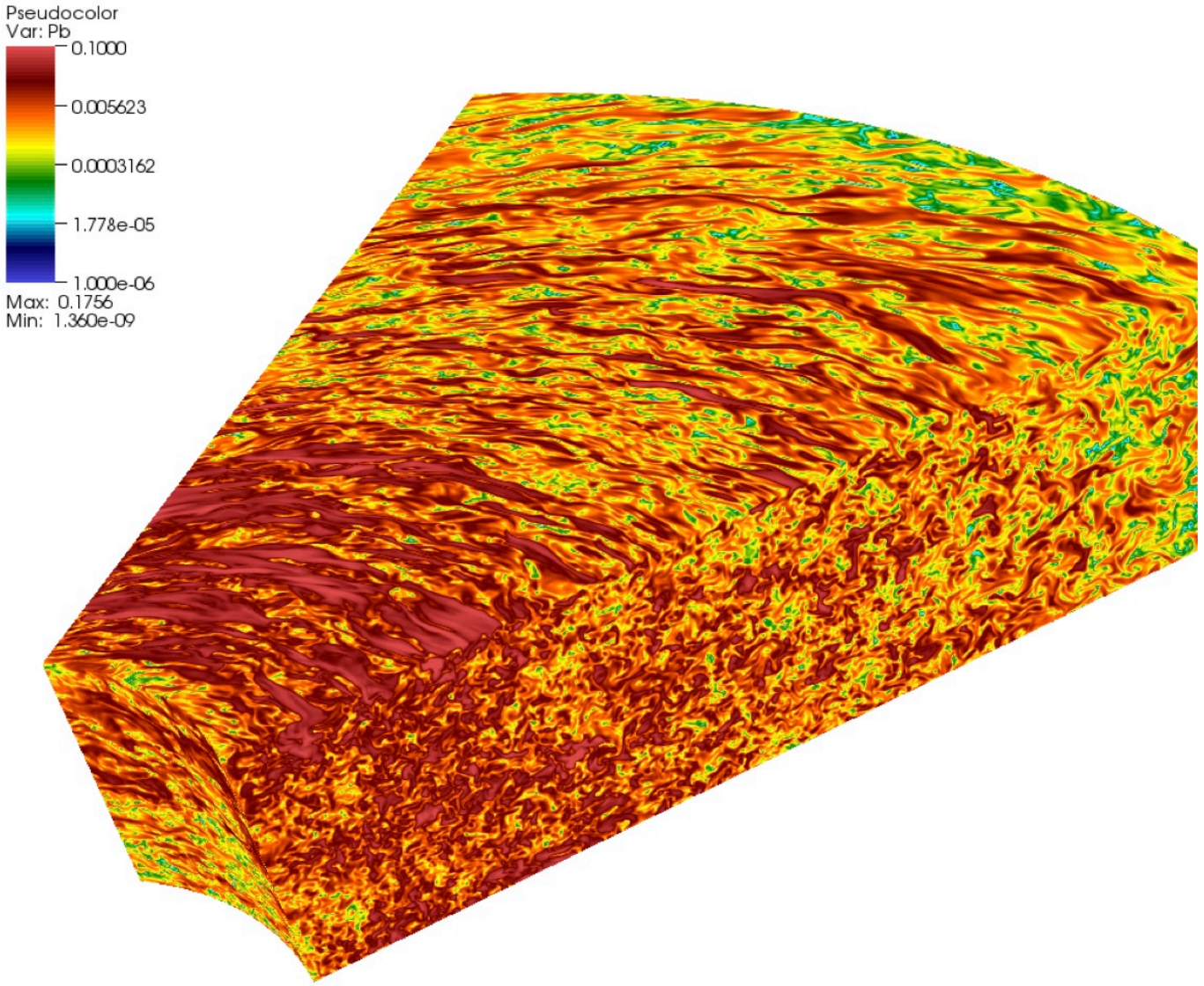
Magnetic Pressure (midplane)

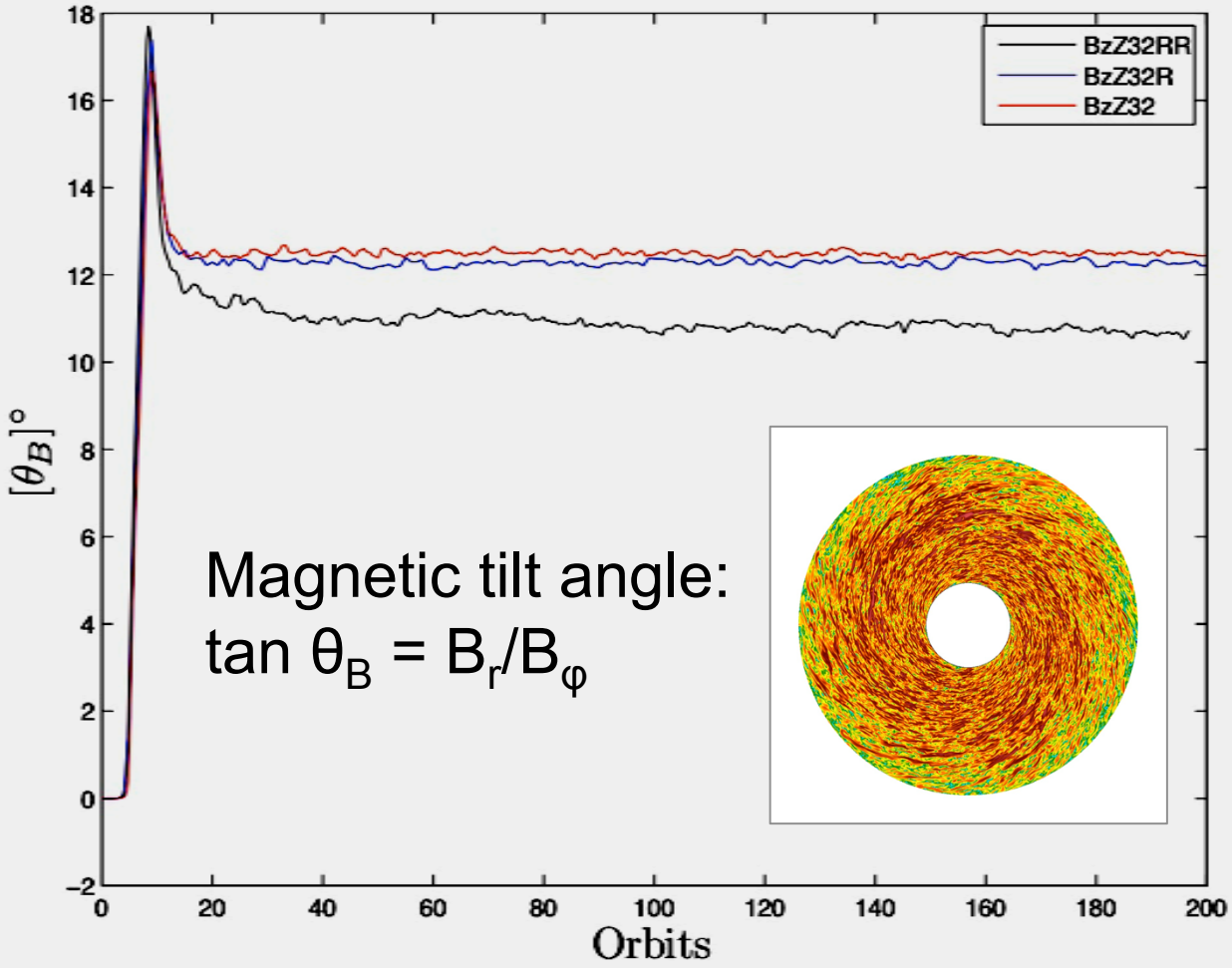


Density (midplane)

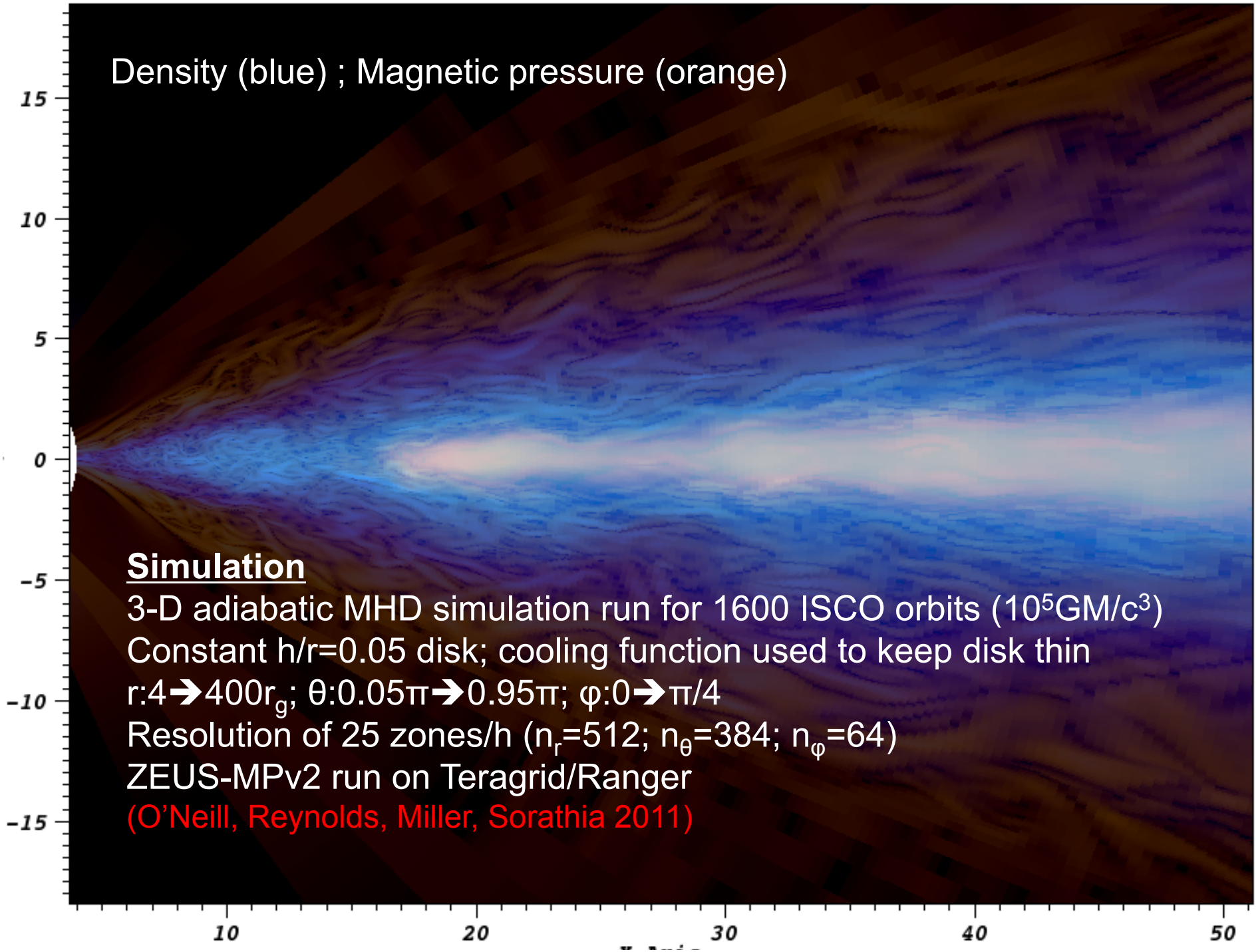


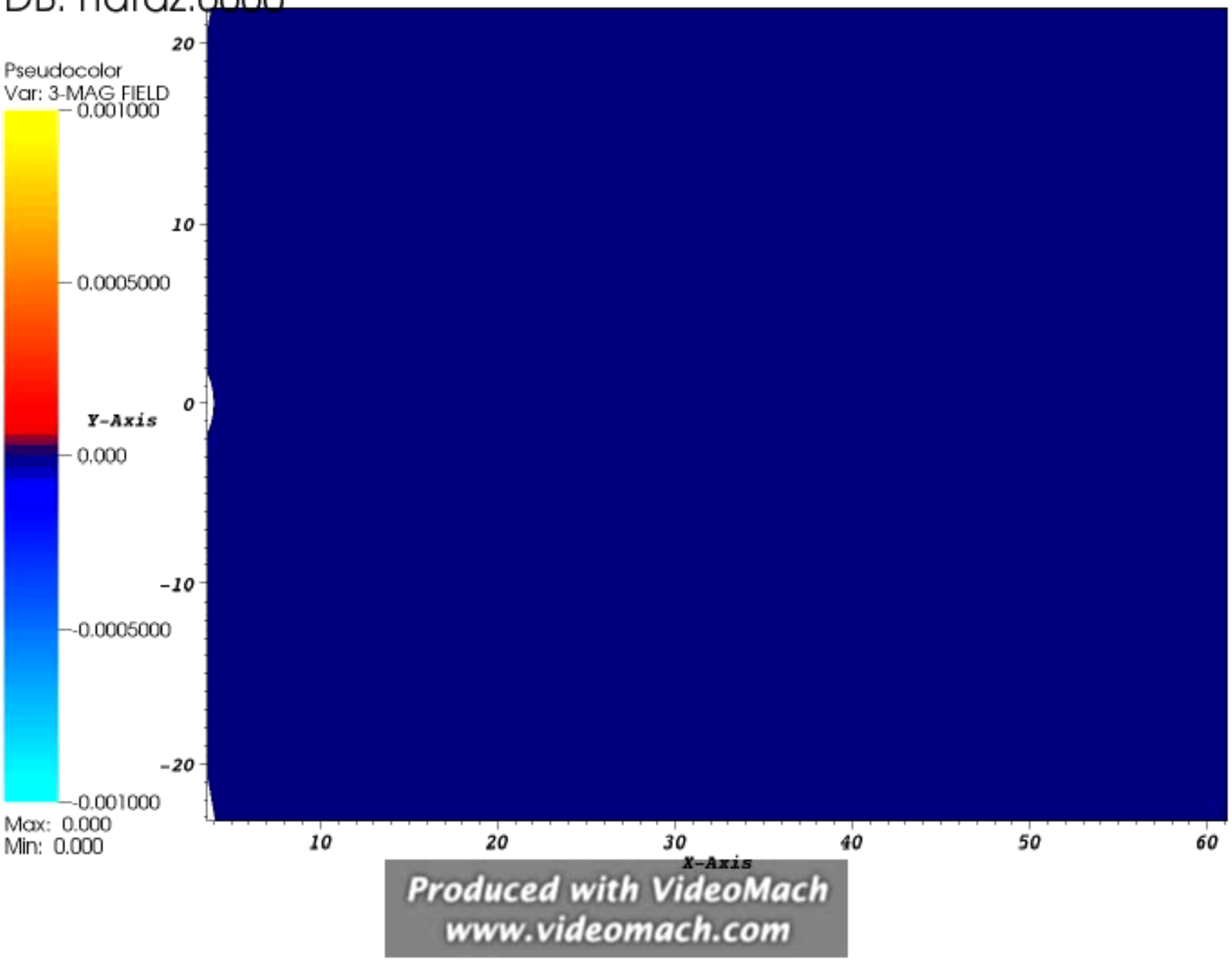
- Global convergence study of vertically unstratified Newtonian disks
- Implement orbital advection in Athena; speed up calculation by factor 20
- **Effective h/r=0.1; 8/16/32/64 z-zones/h at the fiducial radius**
- First models to achieve high resolution in vertical direction AND not cheat in terms of azimuthal resolution (Sorathia, Reynolds et al. 2011)


Pseudocolor
Var: Pb
0.1000
0.005623
0.0003162
1.778e-05
1.000e-06
Max: 0.1756
Min: 1.360e-09

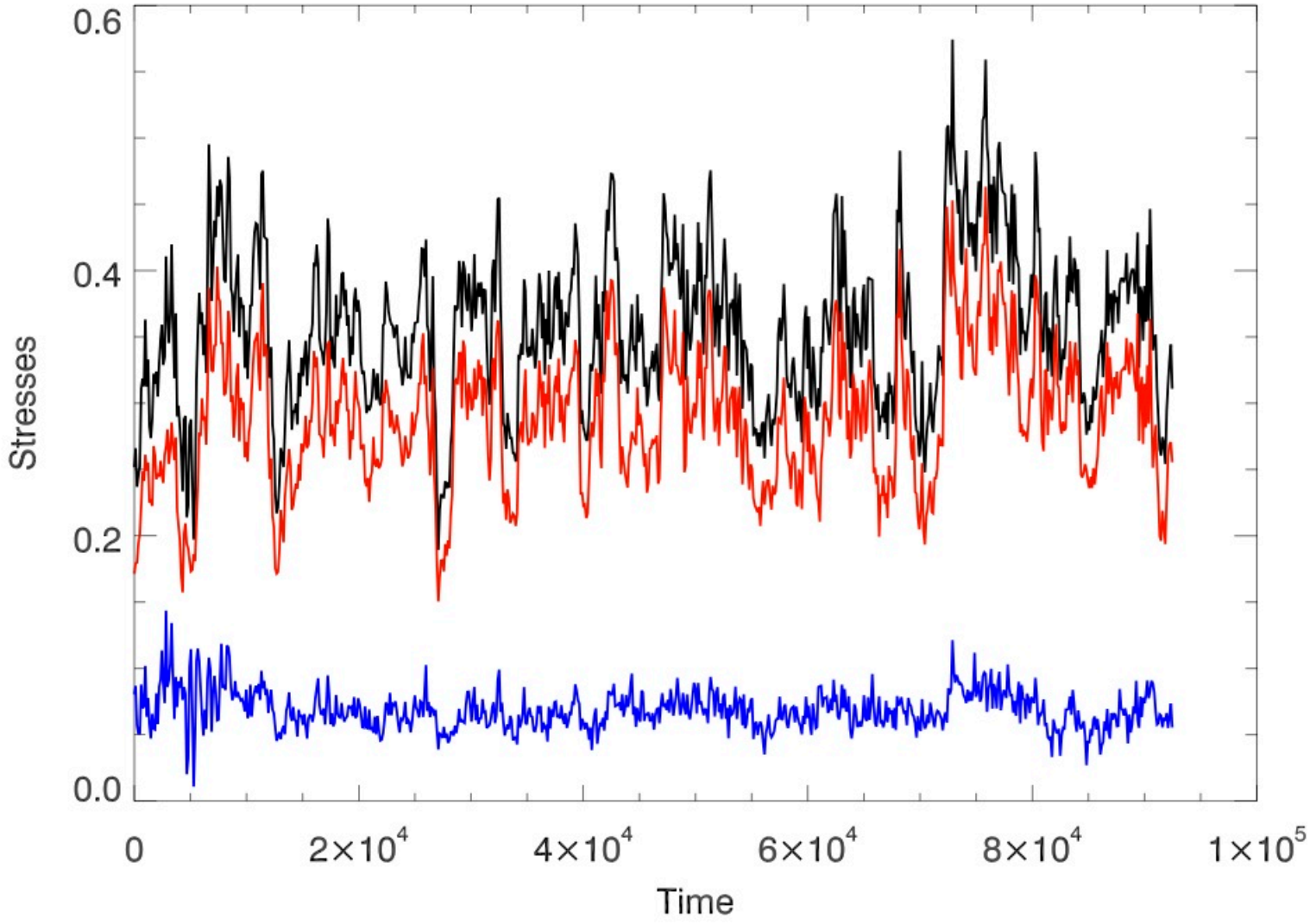


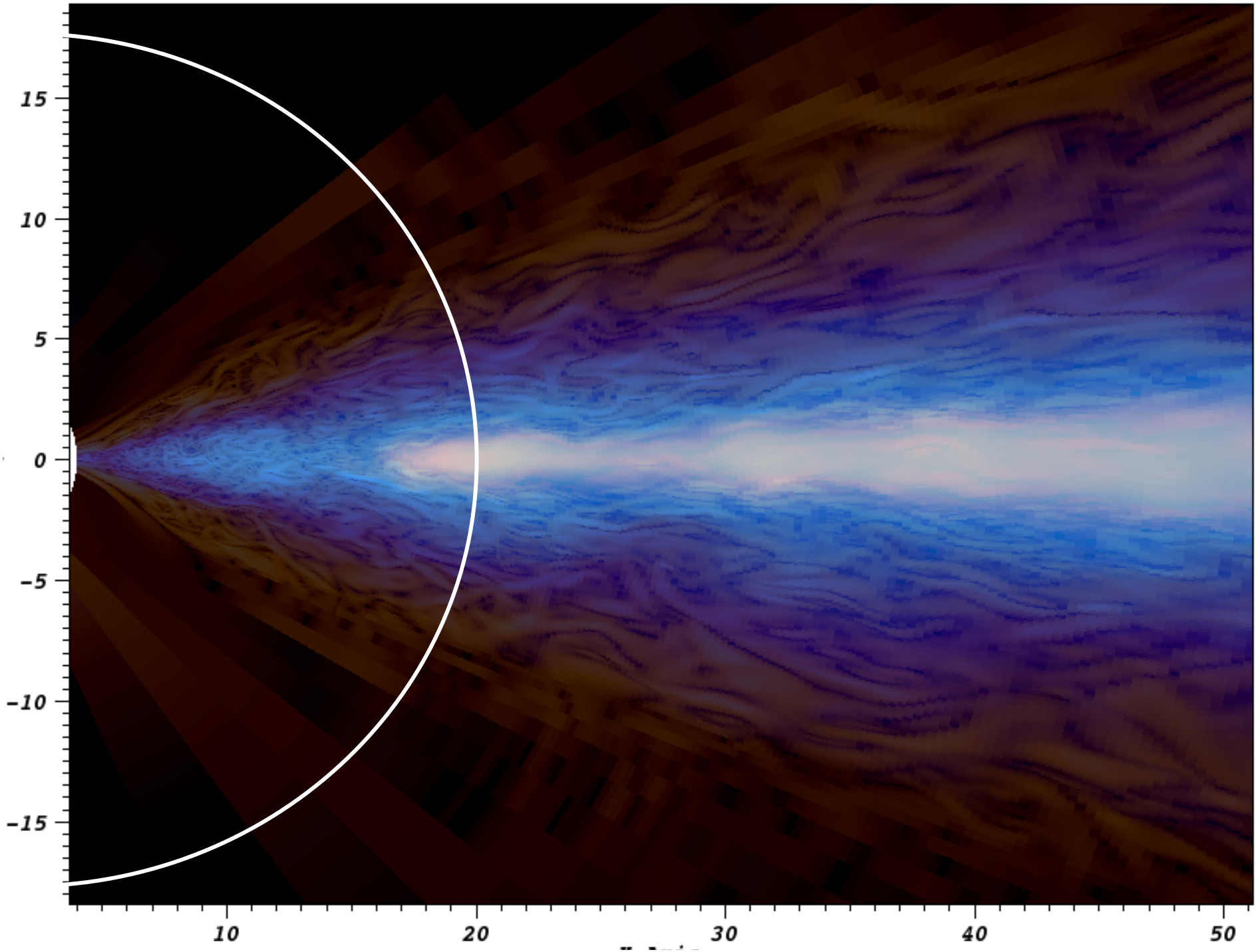
Sorathia et al. (in prep)


Density (blue) ; Magnetic pressure (orange)
15
10
5
0
-5
-10
-15
10
20
30
40
50
Simulation
3-D adiabatic MHD simulation run for 1600 ISCO orbits ($10^5 GM/c^3$)
Constant h/r=0.05 disk; cooling function used to keep disk thin
r:4➔400r_g; θ:0.05π➔0.95π; φ:0➔π/4
Resolution of 25 zones/h (n_r=512; n_θ=384; n_φ=64)
ZEUS-MPv2 run on Teragrid/Ranger
(O'Neill, Reynolds, Miller, Sorathia 2011)

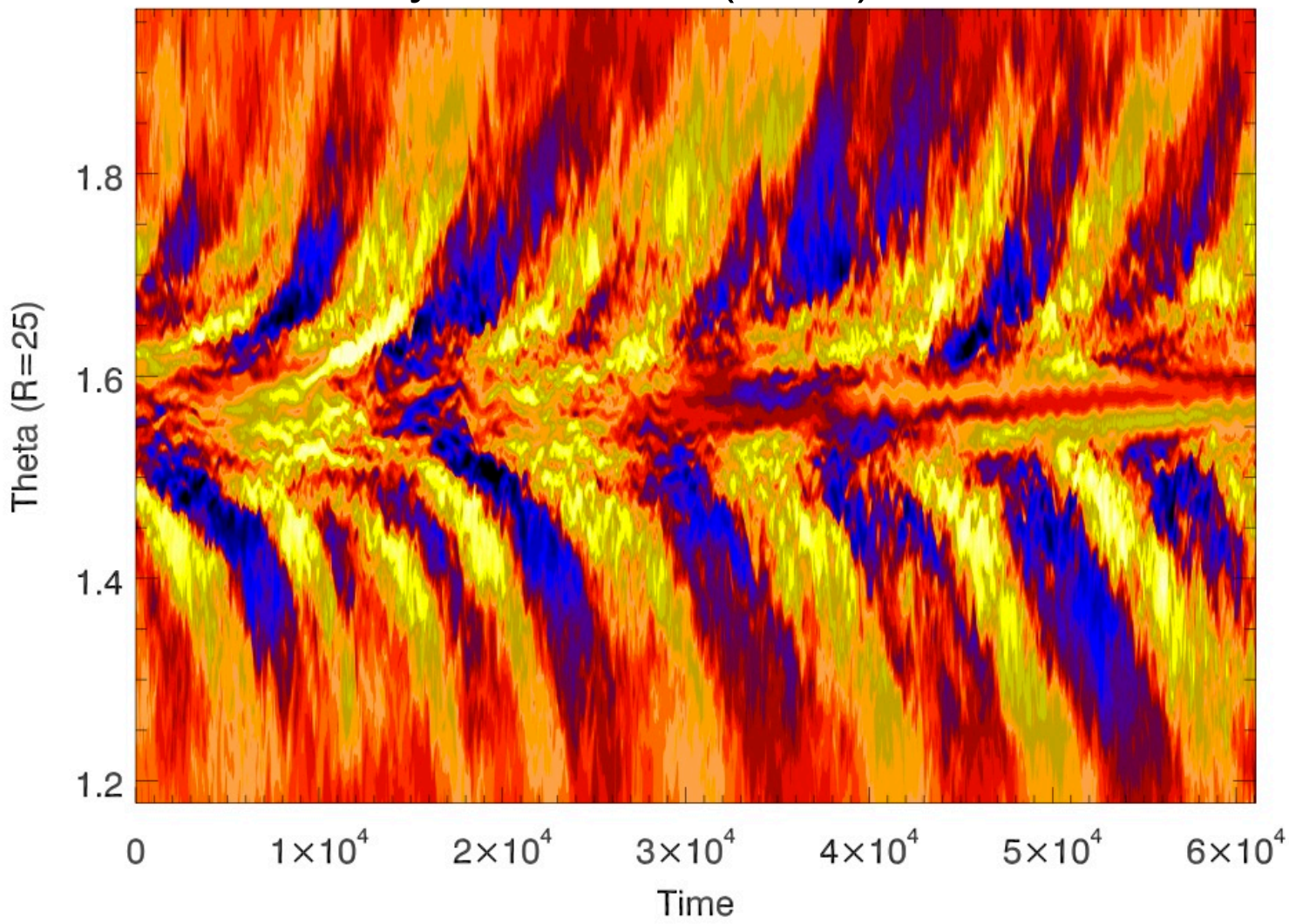

DB: hdfaz.0000
Pseudocolor
Var: 3-MAG FIELD
0.001000
0.0005000
0.000
-0.0005000
-0.001000
Max: 0.000
Min: 0.000
Y-Axis
20
10
0
-10
-20
10
20
30
40
50
60
X-Axis
Produced with VideoMach
www.videomach.com

Stresses (Reynolds, Maxwell, Total)

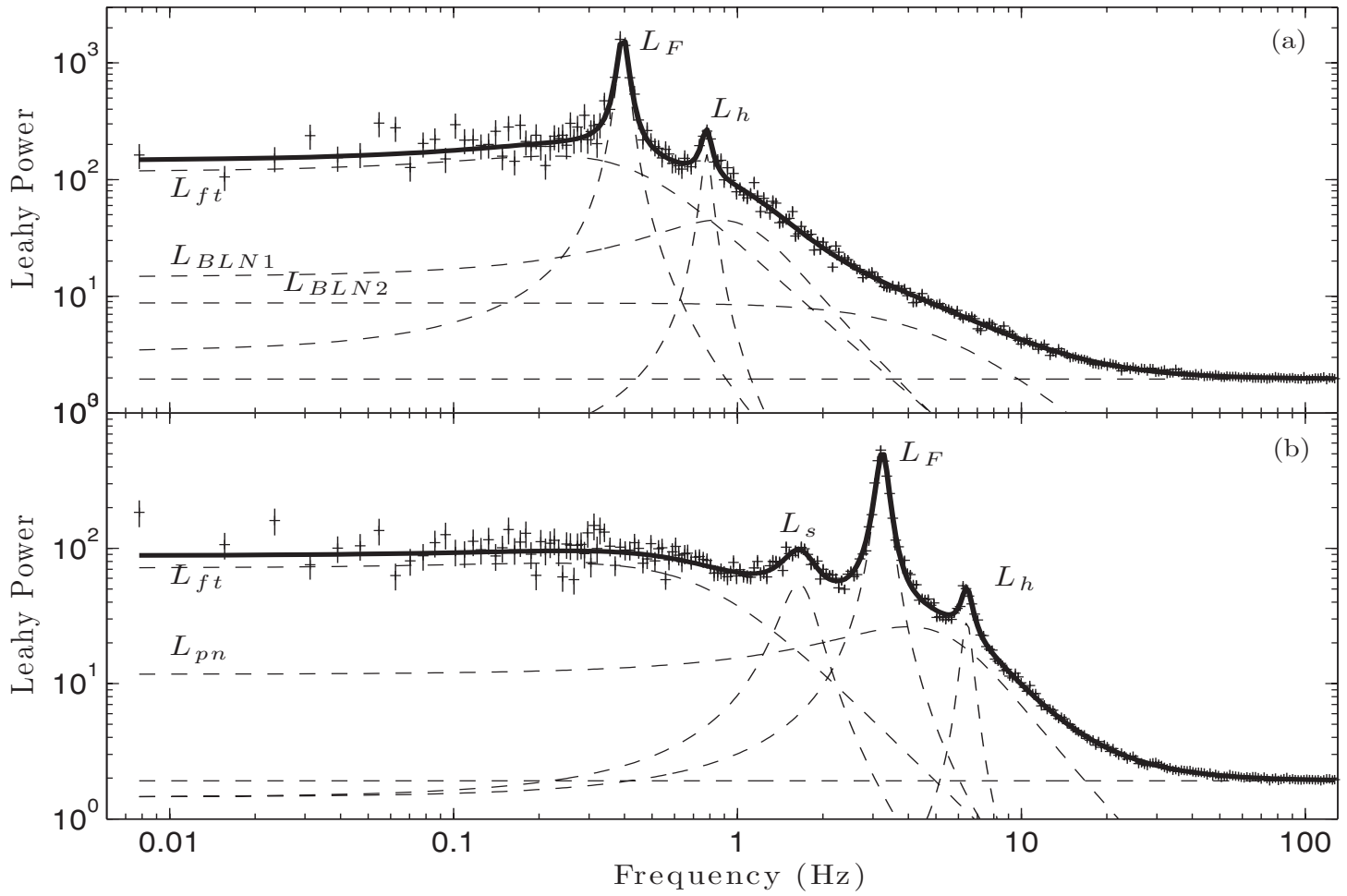


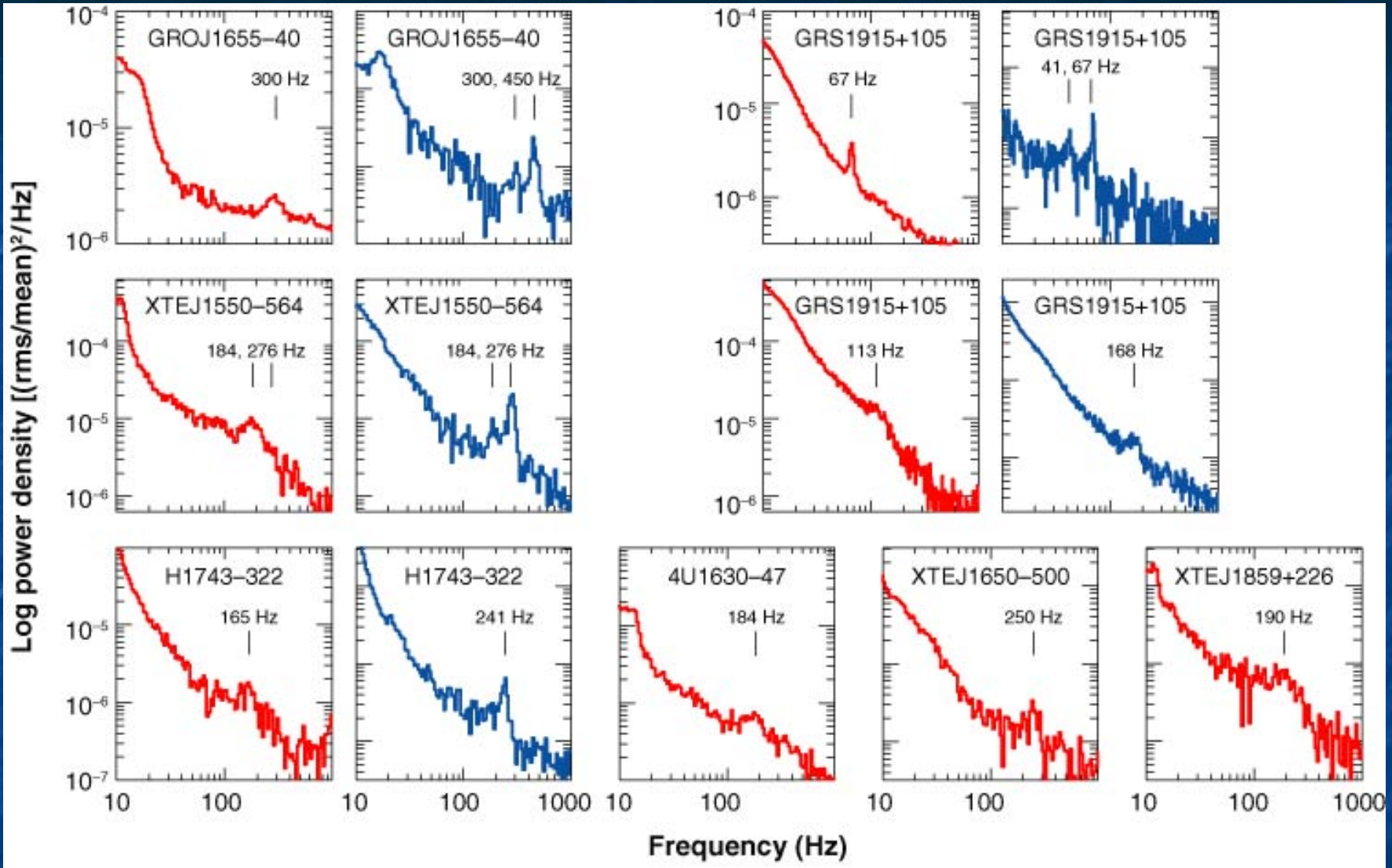

15
10
5
0
−5
−10
−15
10
20
30
40
50

O’Neill, Reynolds et al. (2011)



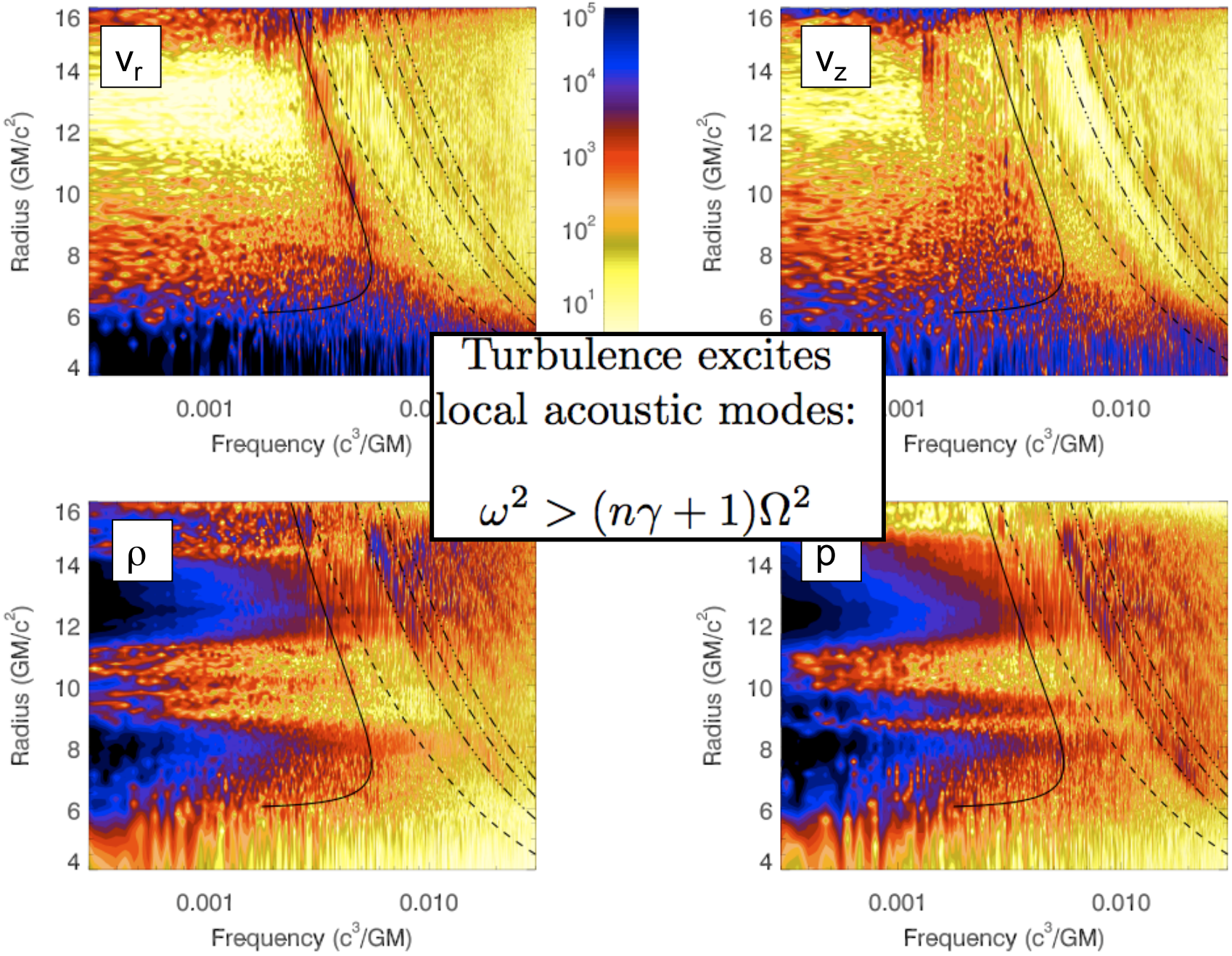
XTEJ1550-564; Rao et al. (2010)

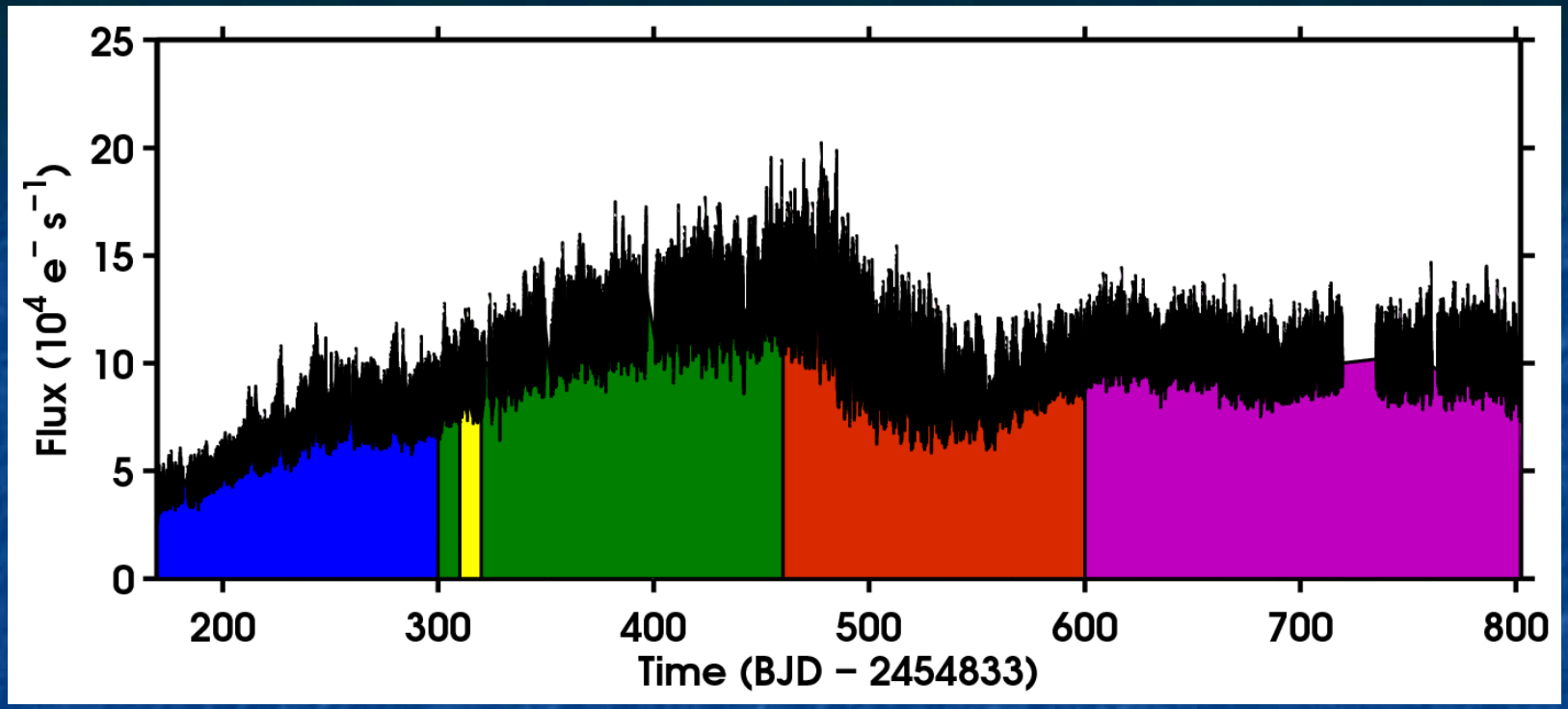


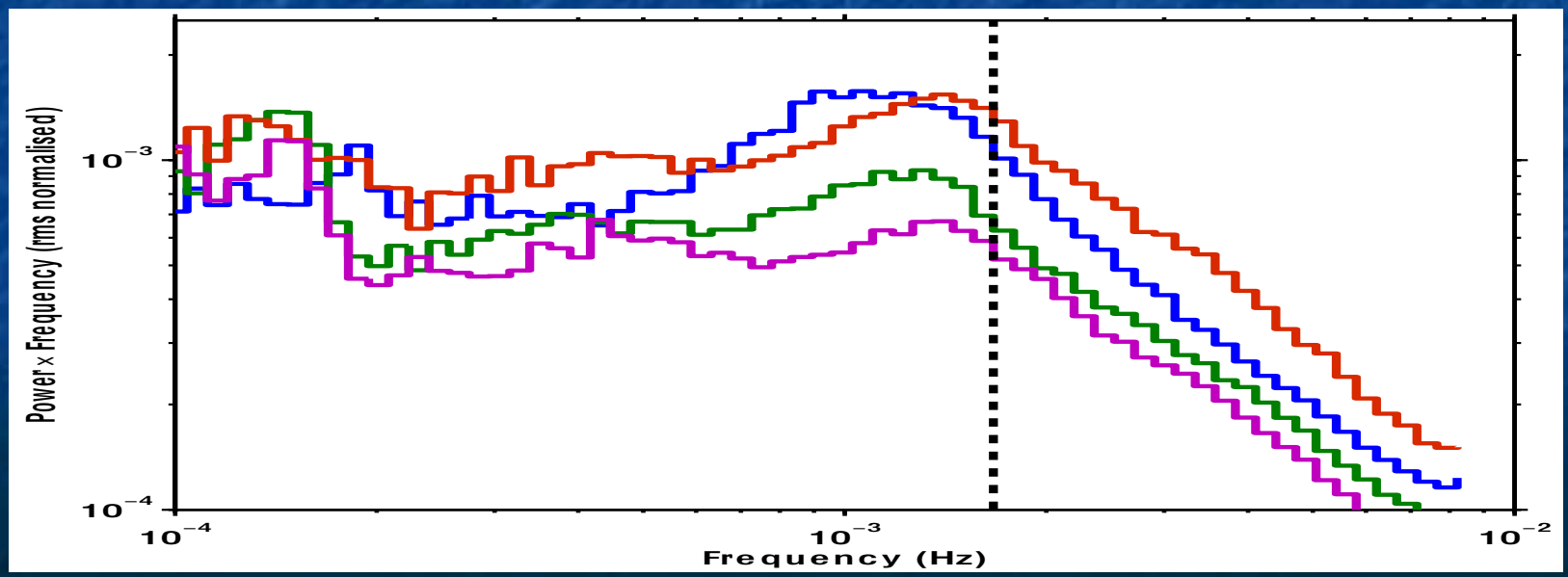


Remillard RA, McClintock JE. 2006.
Annu. Rev. Astron. Astrophys. 44:49–92

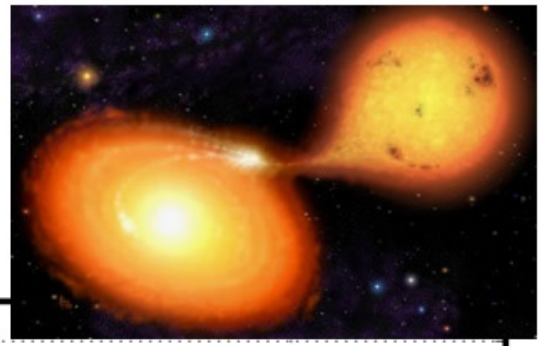
High-frequency QPOs

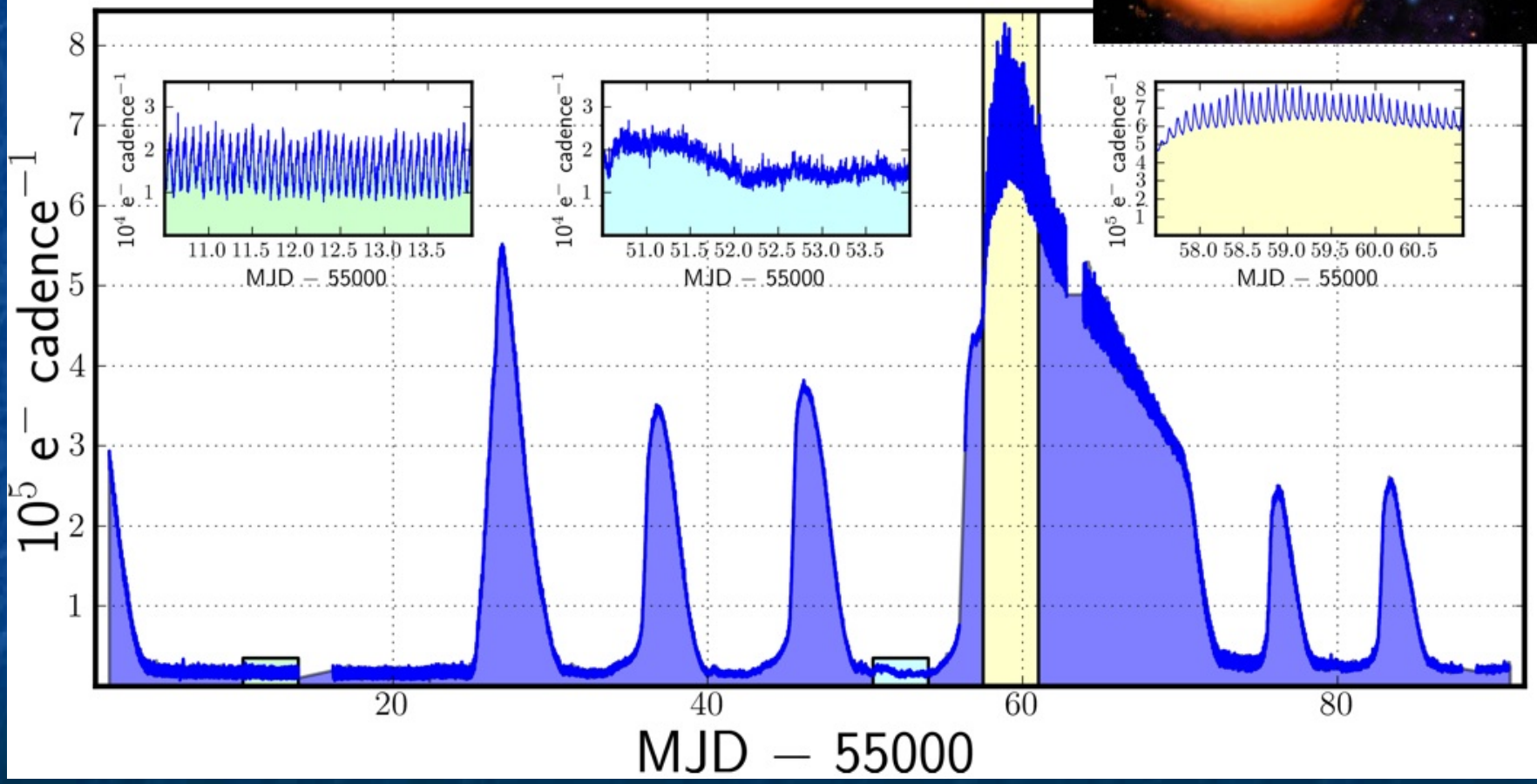

v_r
v_z
ρ
p
Radius (GM/c^2)
Frequency (c^3/GM)
0.001
0.010
Turbulence excites local acoustic modes:
$\omega^2 > (n\gamma + 1)\Omega^2$


25
20
15
10
5
0
Flux (10^4 e$^-$ s^{-1})
200
300
400
500
600
700
800
Time (BJD – 2454833)


Power x Frequency (rms normalised)
10^{-3}
10^{-4}
10^{-4}
10^{-3}
10^{-2}
Frequency (Hz)

EXAMPLE: V344 LYR (DWARF NOVA)

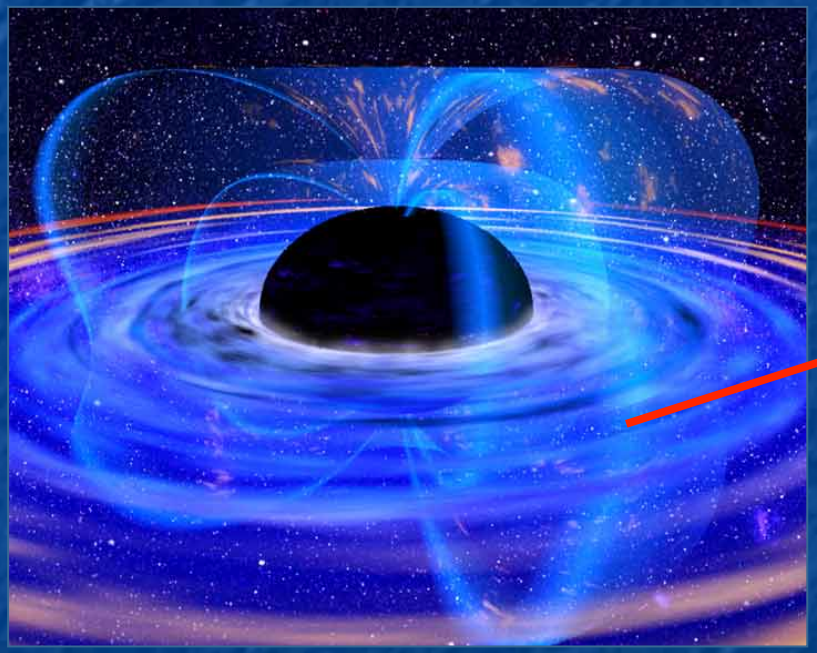


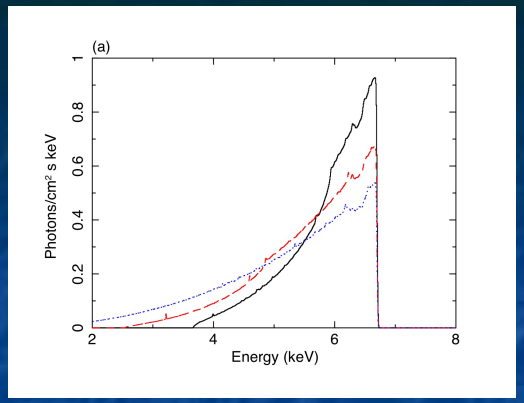


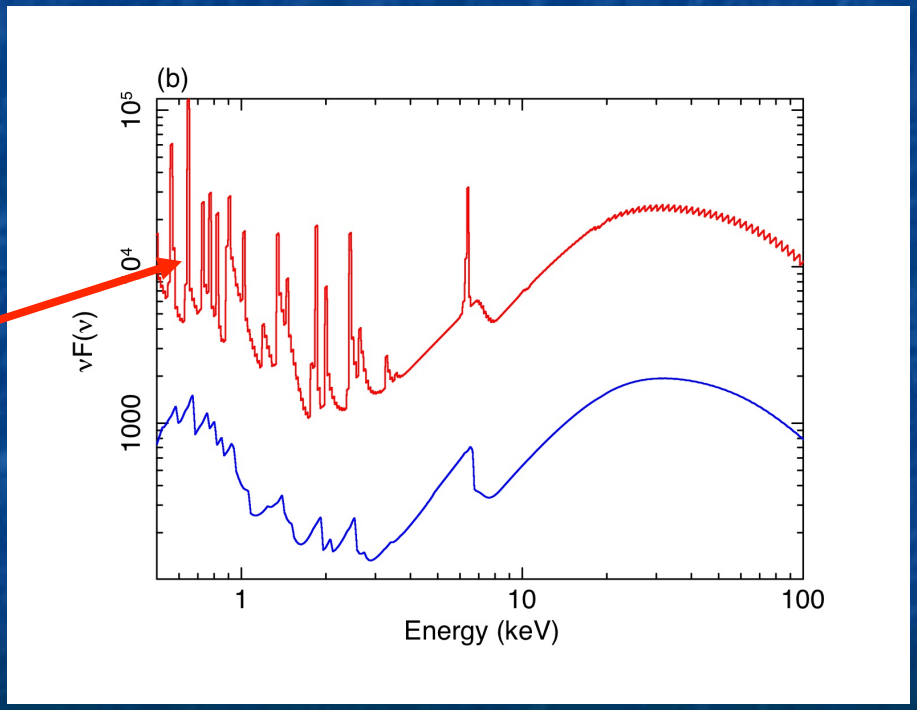
Observations…

- How quickly do supermassive black holes spin?
  - What does this tell us about SMBH formation?
  - Is spin necessary for jet production?
- Why do AGN emit X-rays?
  - What is the nature of the X-ray source?
- What is the physics of jet production?
  - How do the jet and the disk interact?
  - How important is environment for jet production?

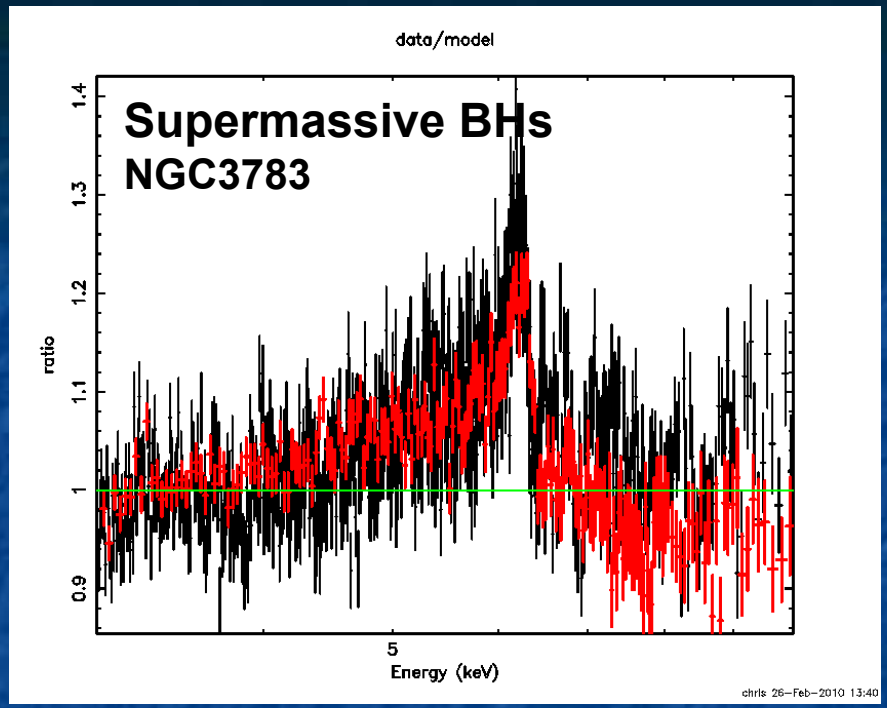
X-rays from corona/jet irradiate accretion disks… creates a backscattered spectrum rich in spectral features

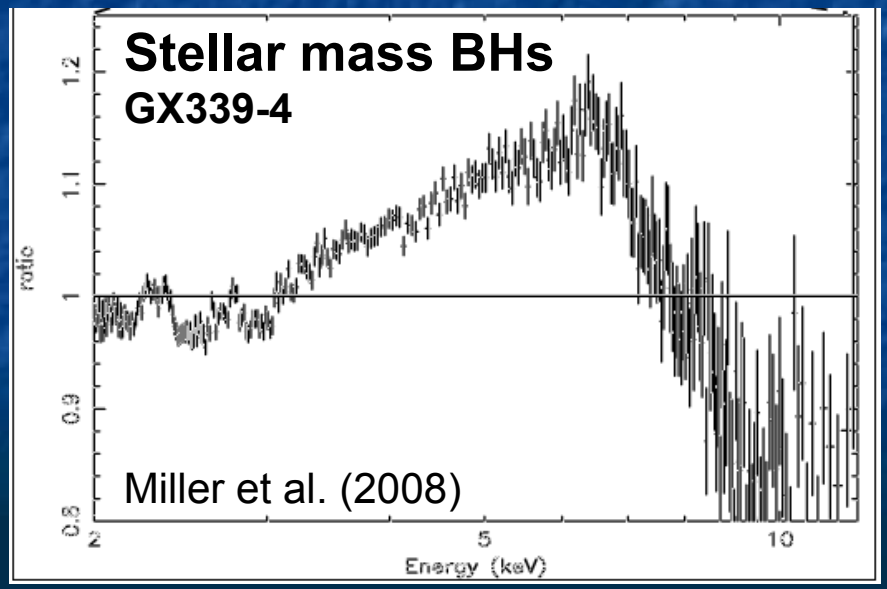




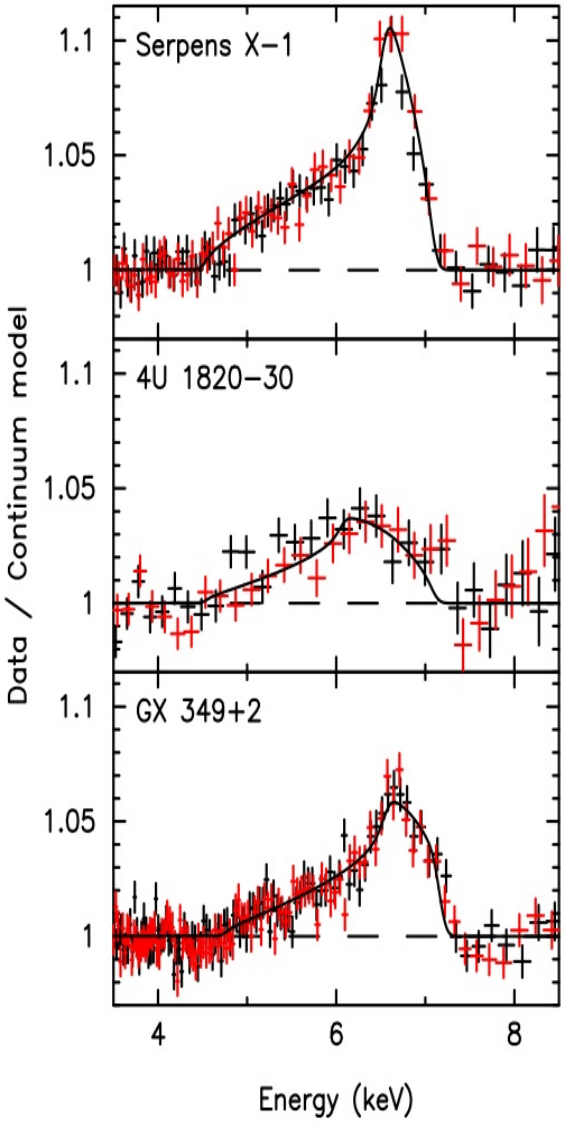


Calculations of spectrum emitted by accretion disk in response to X-ray irradiation (Ross & Fabian 2005)



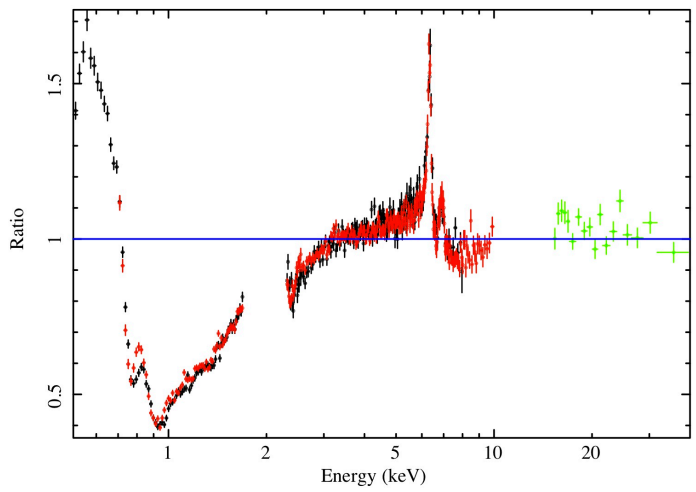


Neutron stars



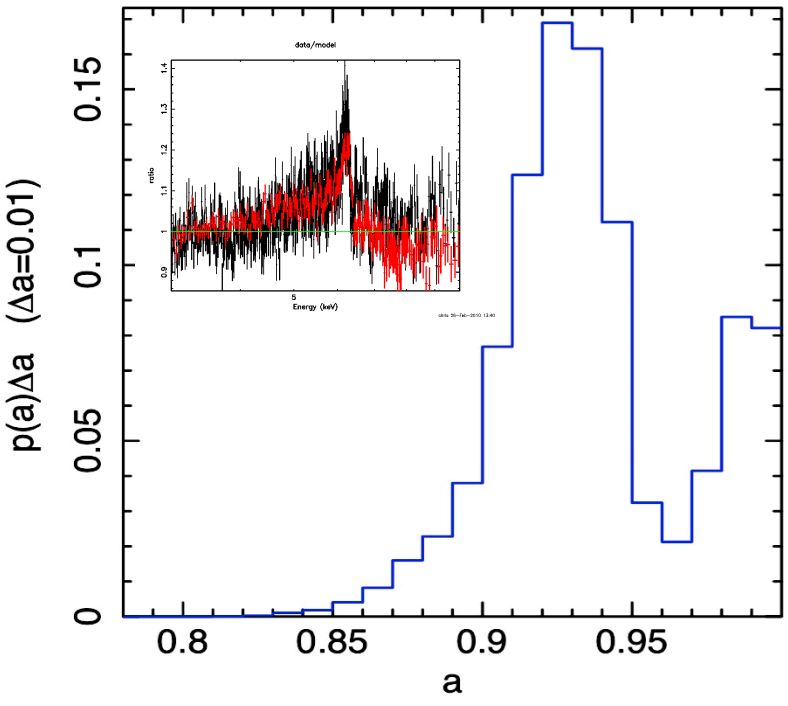
Courtesy of E.Cackett

Seyfert 1.5 nucleus in NGC3783 (z=0.0097)



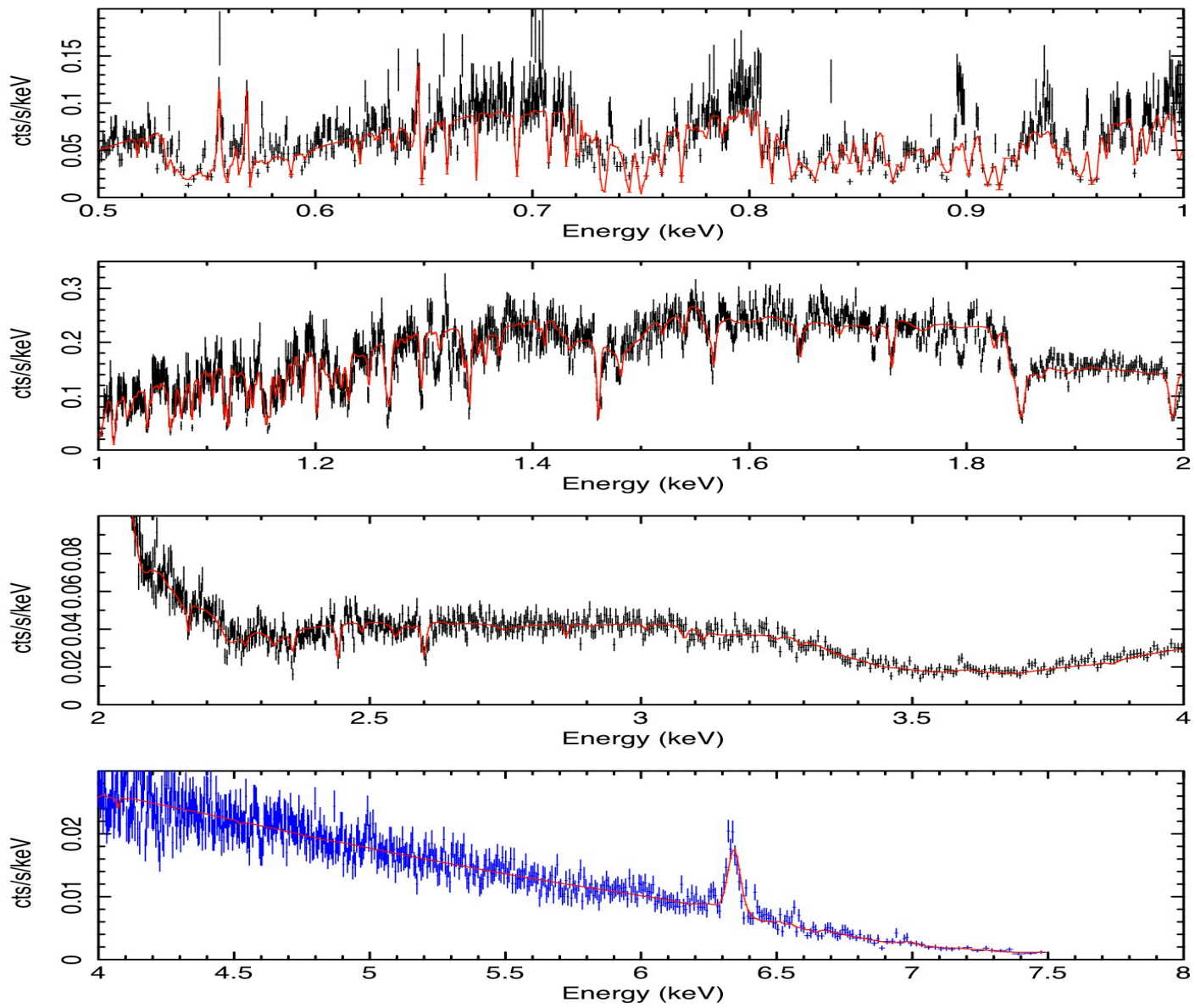
Suzaku XIS+PIN spectrum ratioed against simple power-law. A global model of this spectrum requires multi-zone ionized absorption, reflection from distant matter, and reflection from inner accretion disk

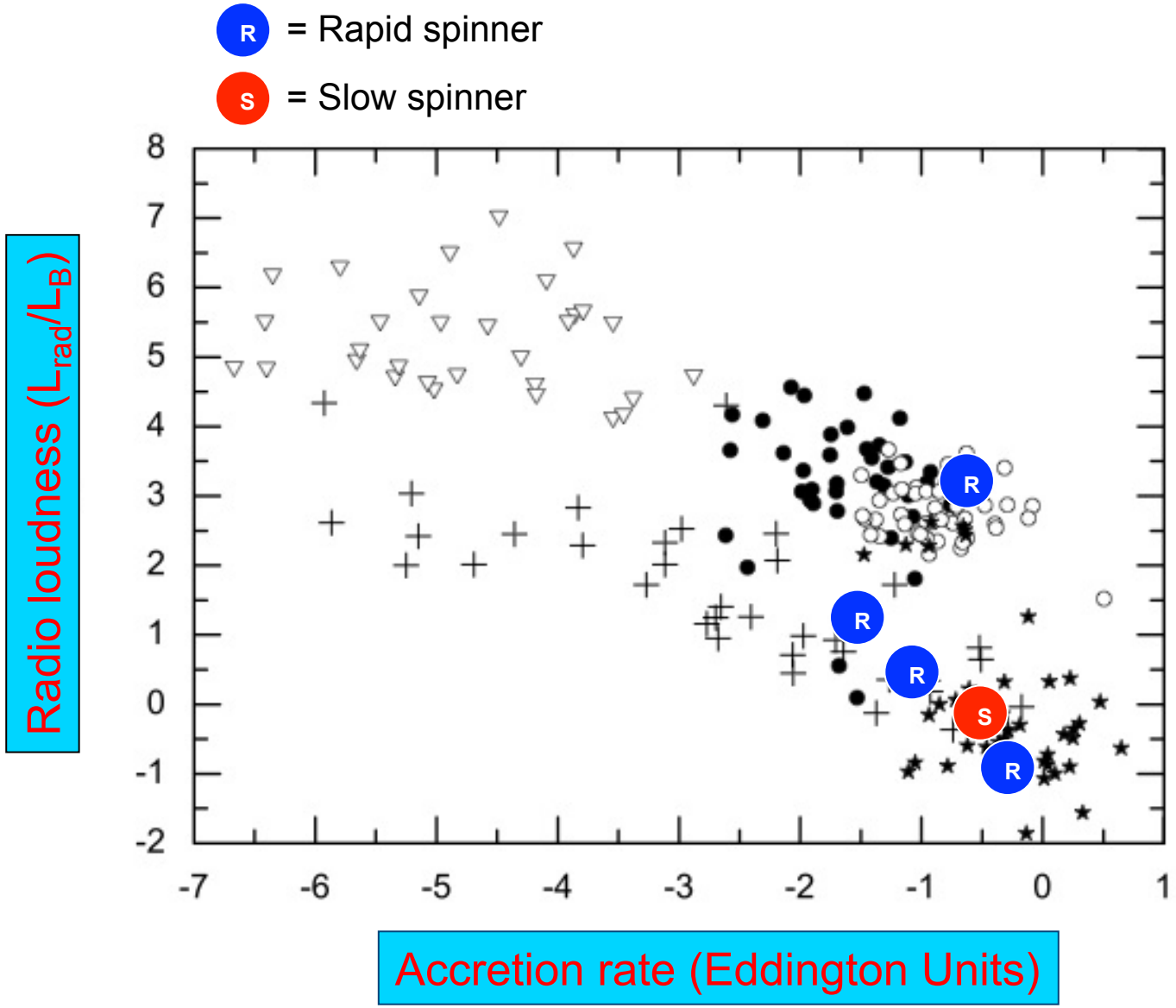
MCMC ➔ high spin (a>0.88 at 90% CL). This includes all uncertainities associated with ionized absorption, irradiation profile of inner disk, iron abundance, and treatment of PIN background.



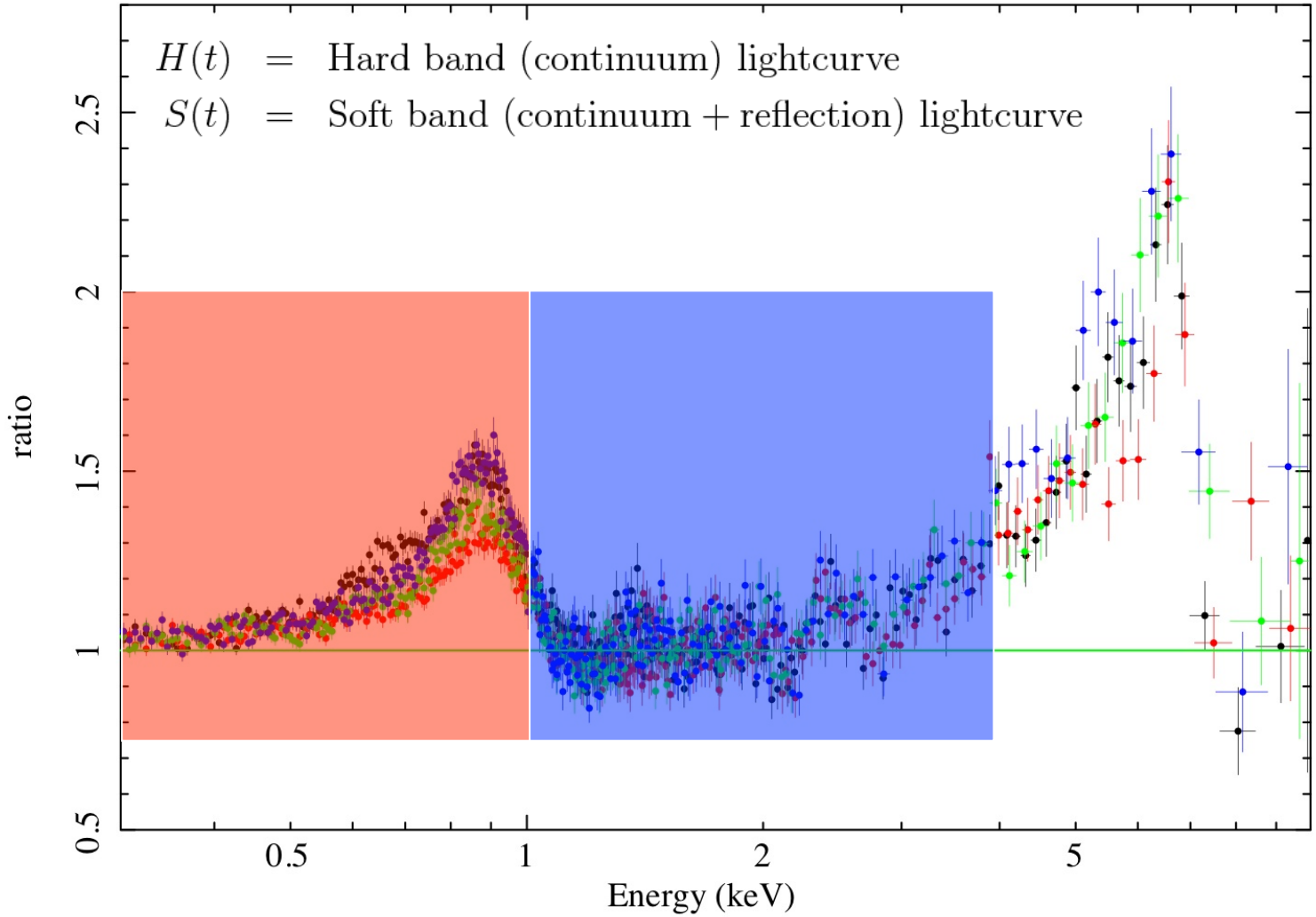
Brenneman et al. (2011)
Reis et al. (2012)
Reynolds et al. (2012)

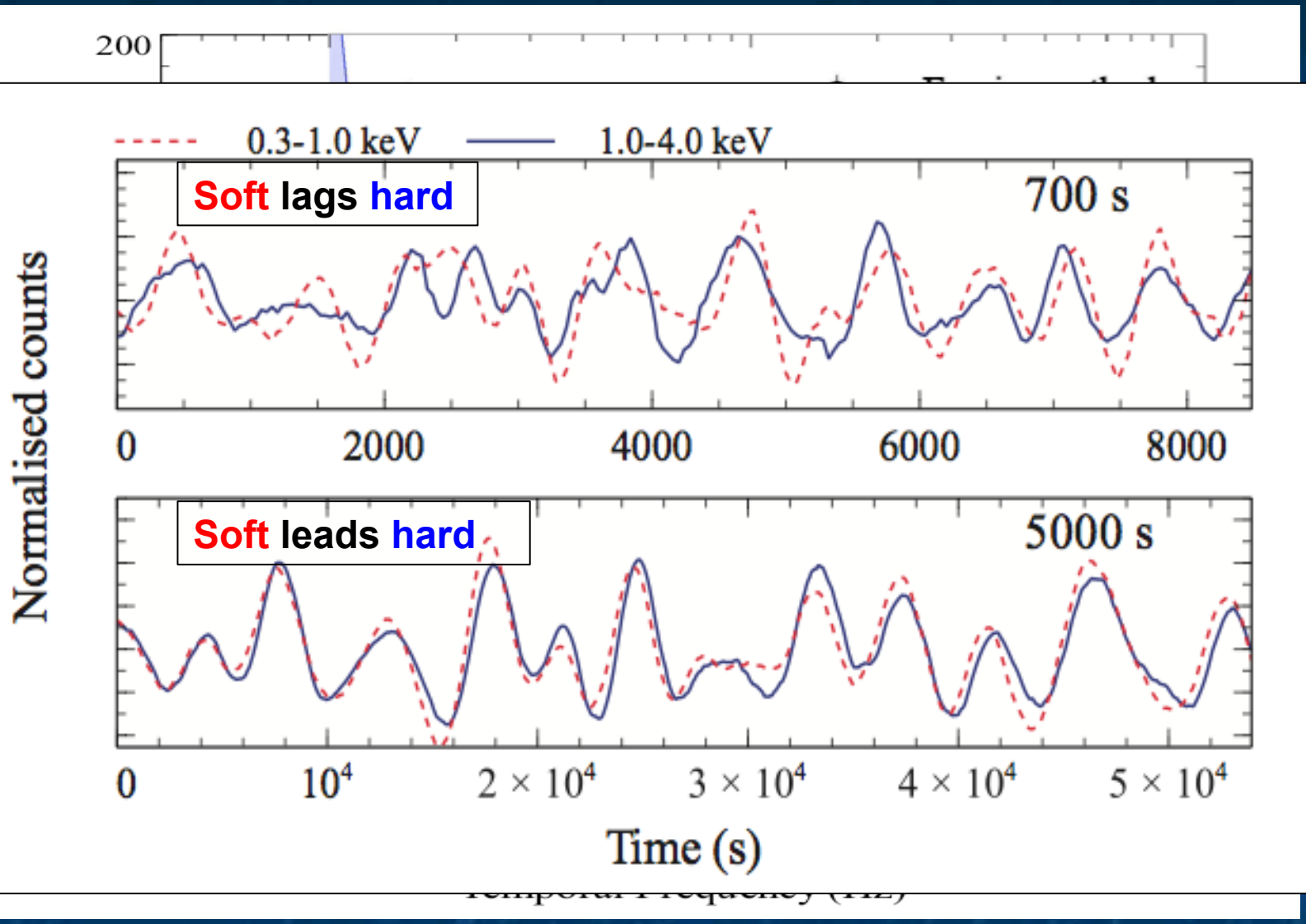
900ks Chandra/HETG (e.g. see Krongold et al. 2003, Netzer et al. 2003)



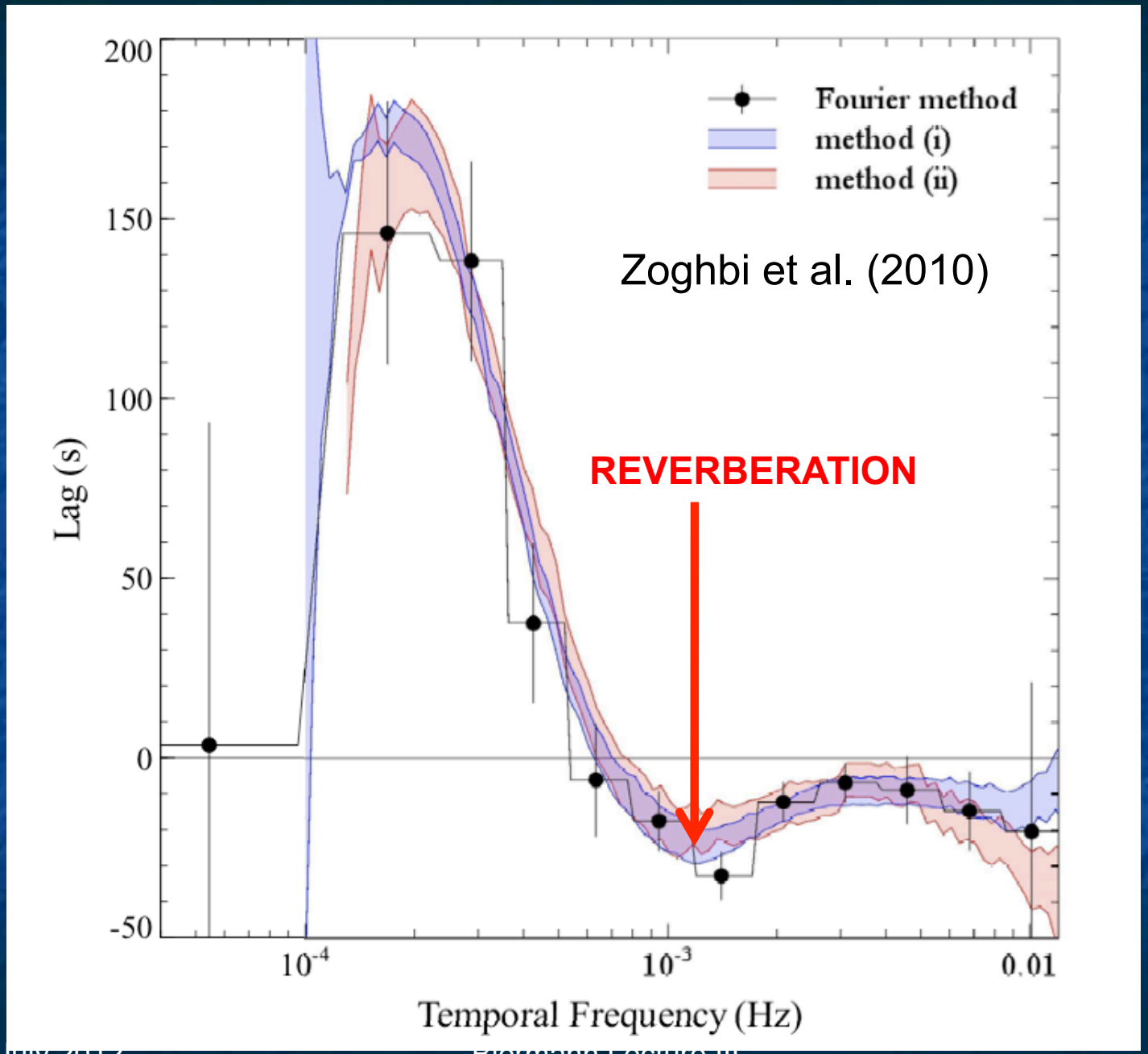


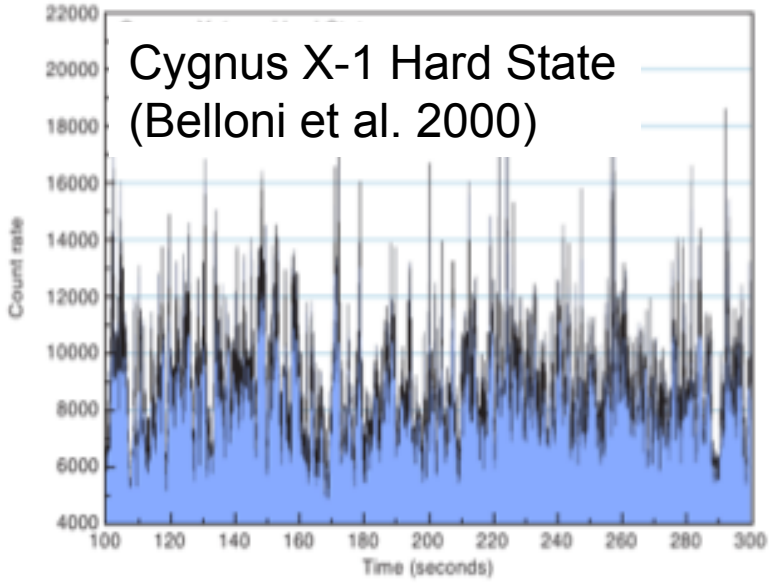
Sikora et al. (2007) + Spin results


$H(t)$ = Hard band (continuum) lightcurve
$S(t)$ = Soft band (continuum + reflection) lightcurve
ratio
0.5
1
1.5
2
2.5
0.5
1
2
5
Energy (keV)

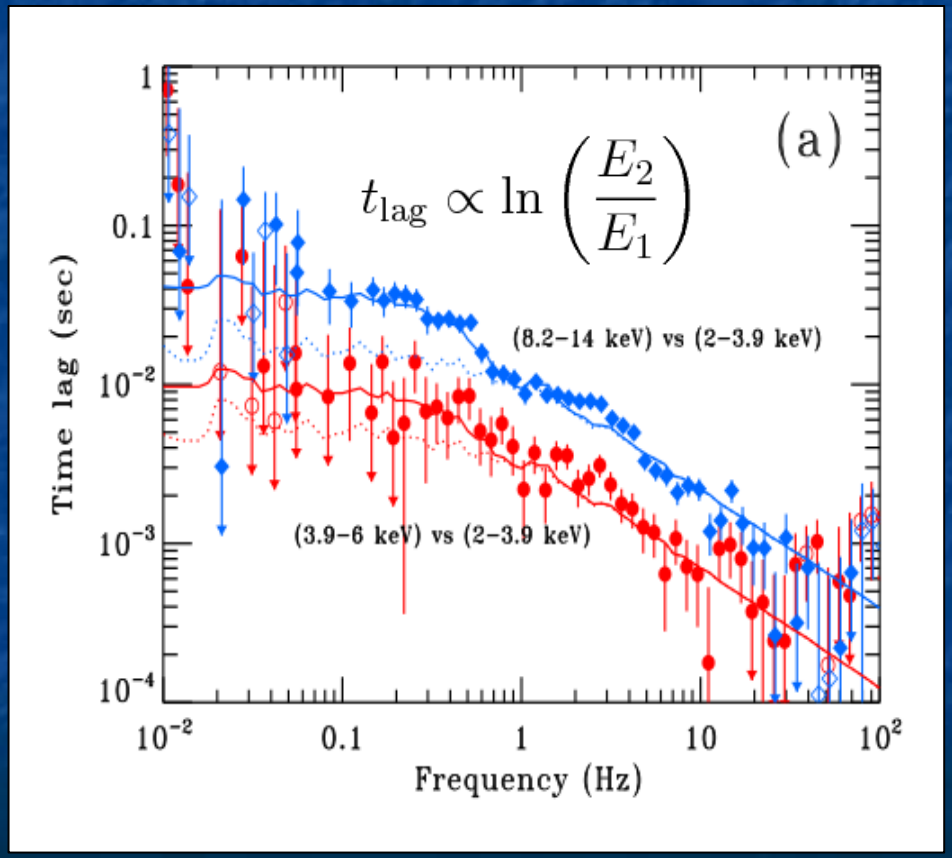


1H0707-495/XMM (Zoghbi et al. 2010)


200
150
100
50
0
-50
Lag (s)
10^{-4}
10^{-3}
0.01
Temporal Frequency (Hz)
Fourier method
method (i)
method (ii)
Zoghbi et al. (2010)
REVERBERATION



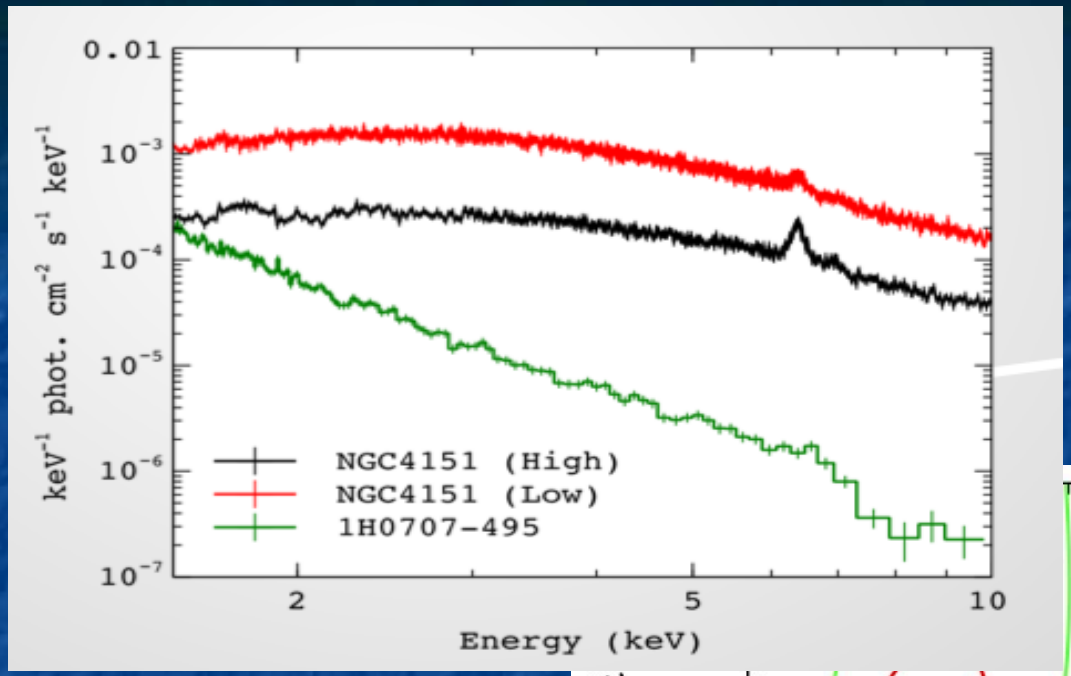
Poutanen (2000); Gilfanov et al. (2000); Nowak (2000); Uttley et al. (2011)

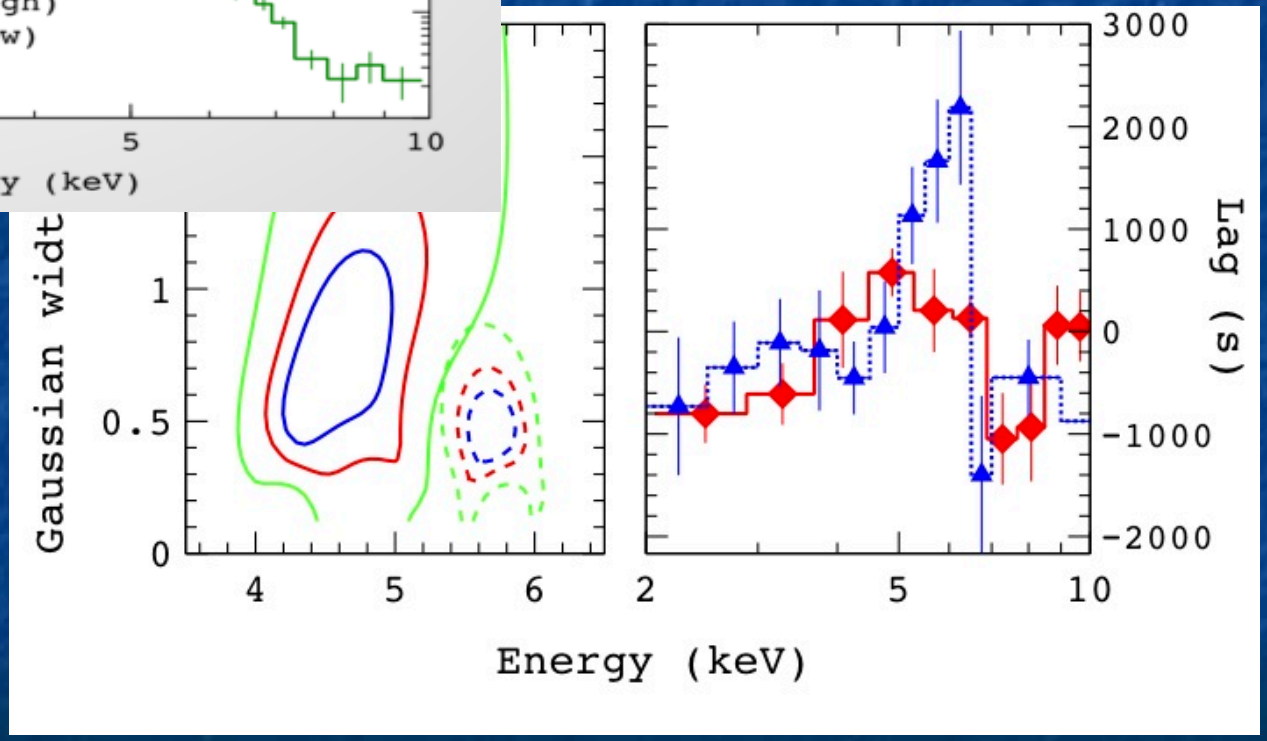


Findings:

- Frequency dependent time lags (almost constant phase)
- Time lags can get very long (for $M=10M_{sun}$, $10^{-2}s \cong 200r_g/c$)
- Often see log-normal variability

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





Source located 2-4r_g from disk

Confirmation of the relativistic iron line paradigm