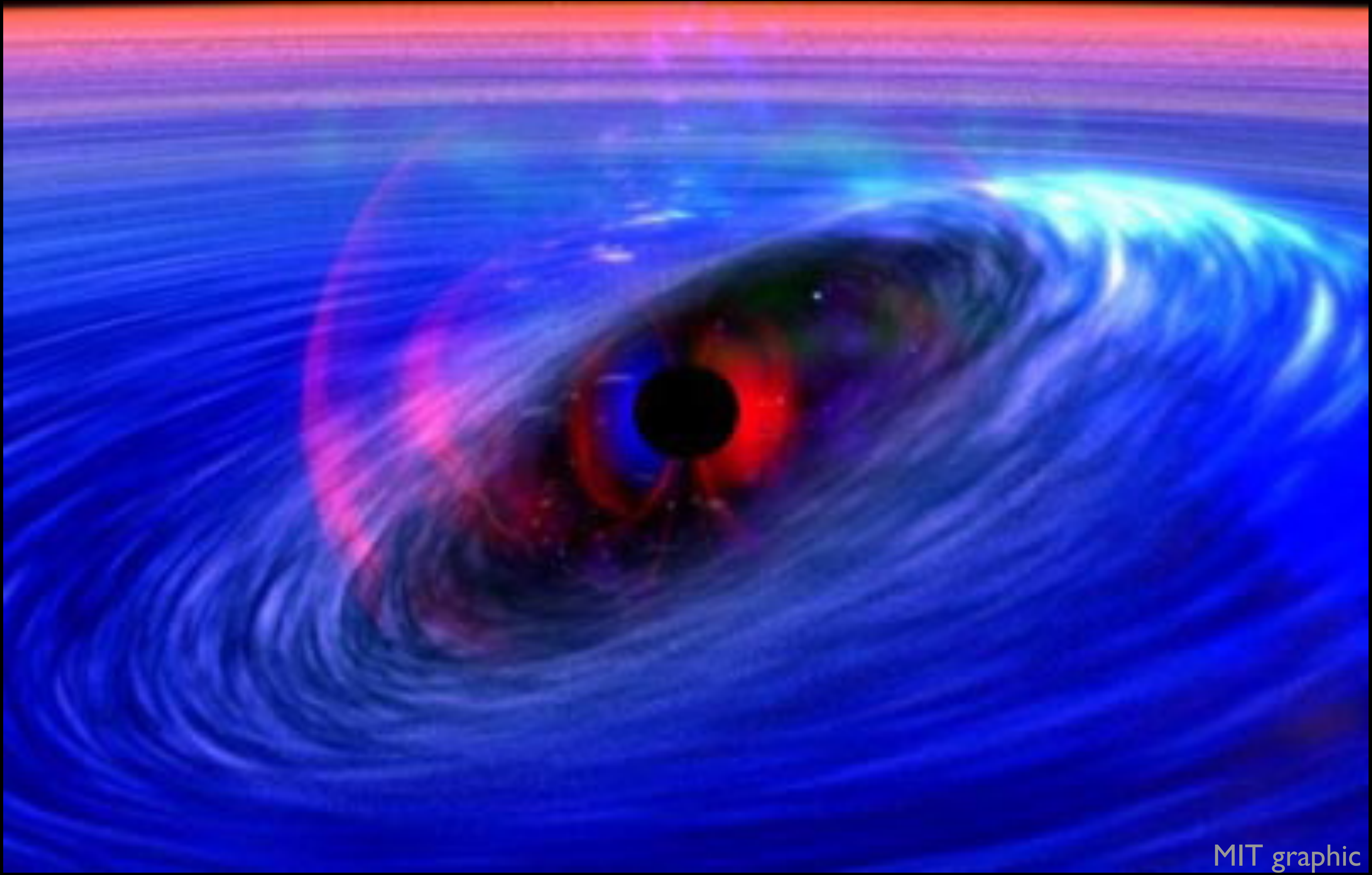
Probing strong gravity with ASTROSAT



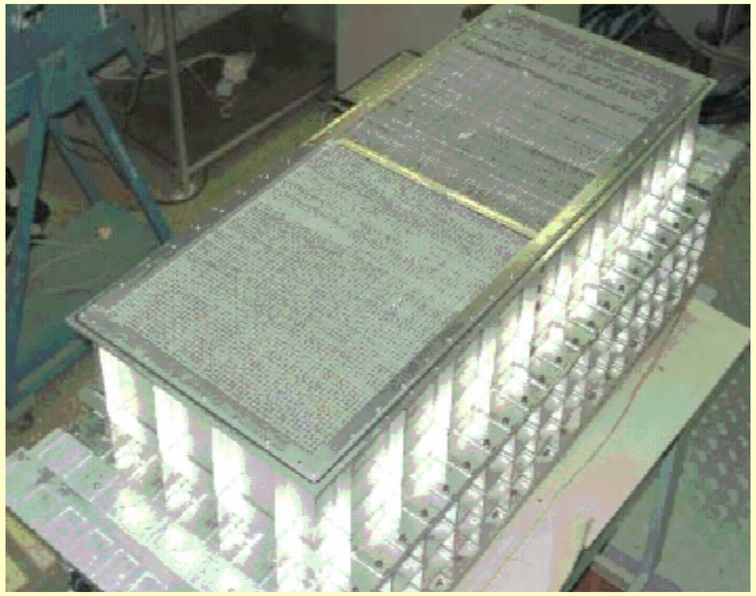
Dipankar Bhattacharya
IUCAA, Pune

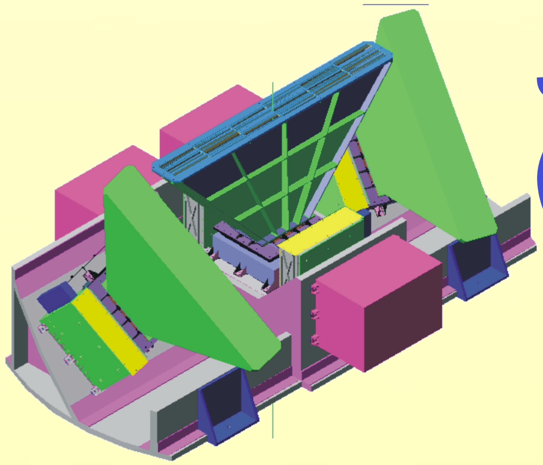
ASTROSAT is an Indian satellite scheduled for launch in 2009

It will carry five astronomy payloads covering optical, UV, soft-X ray and hard X-ray bands

ASTROSAT INSTRUMENTS

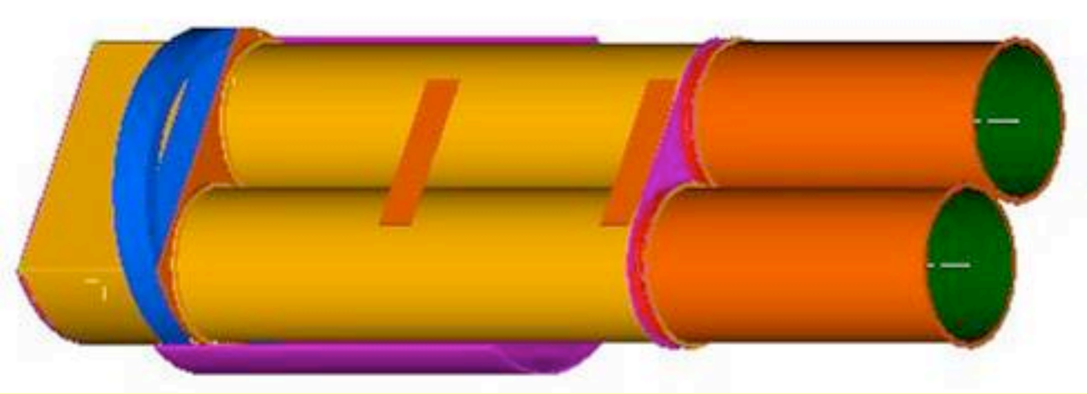
Large Area X-ray Proportional Counter (LAXPC)

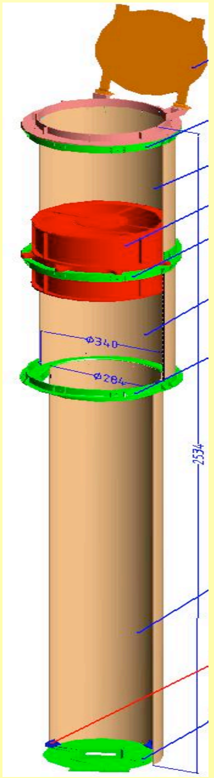




Scanning Sky Monitor (SSM)

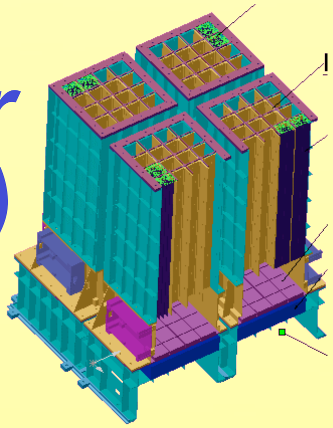
UV Imaging Telescope (UVIT)

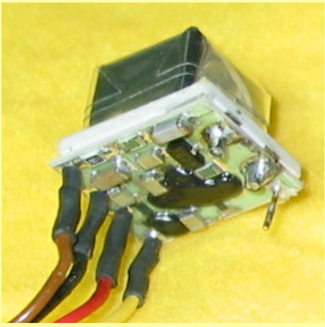




Soft X-ray telescope (SXT)

Cadmium Zinc Telluride Imager (CZTI)





Charged Particle Monitor (CPM)

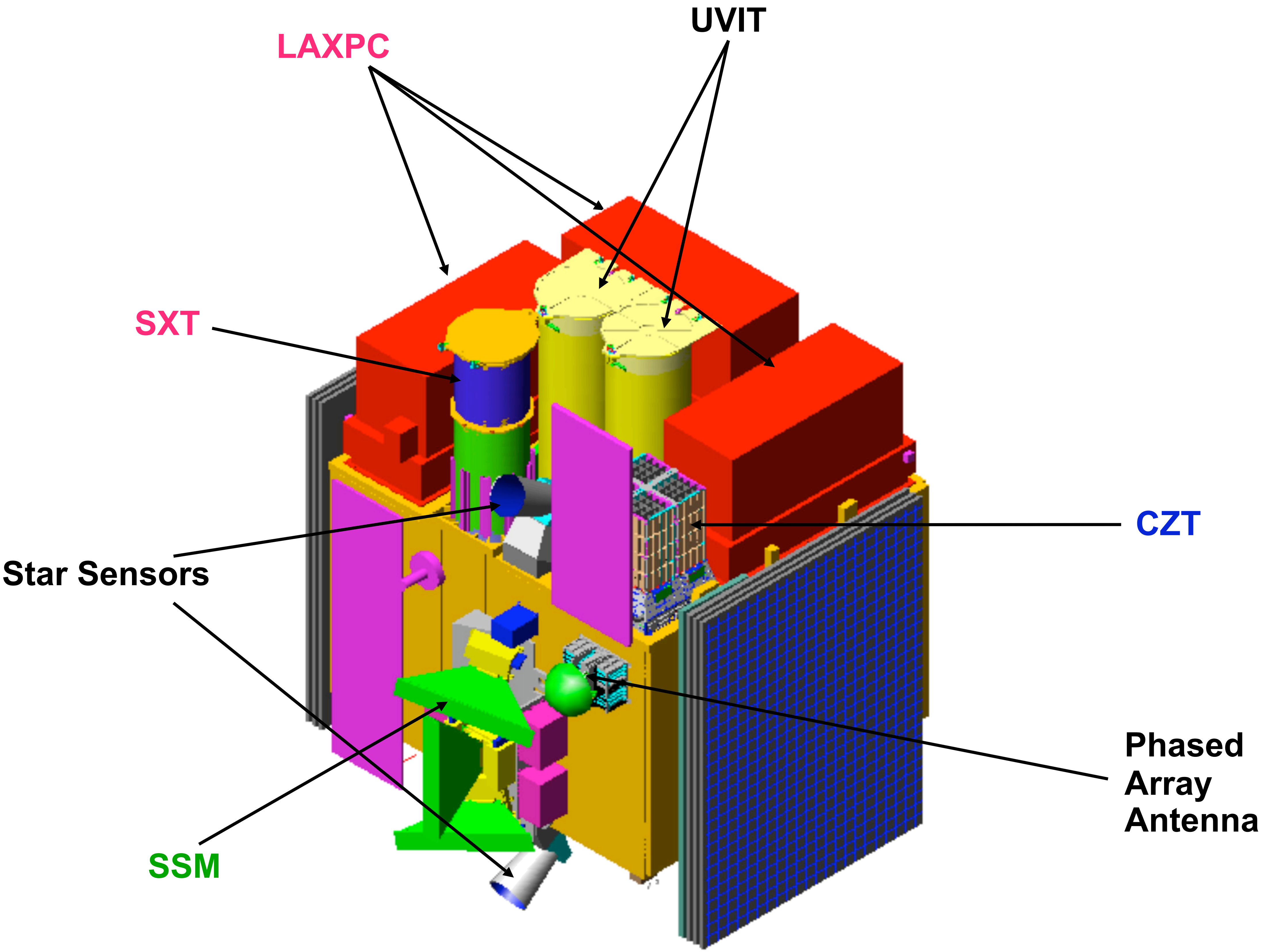
ASTROSAT

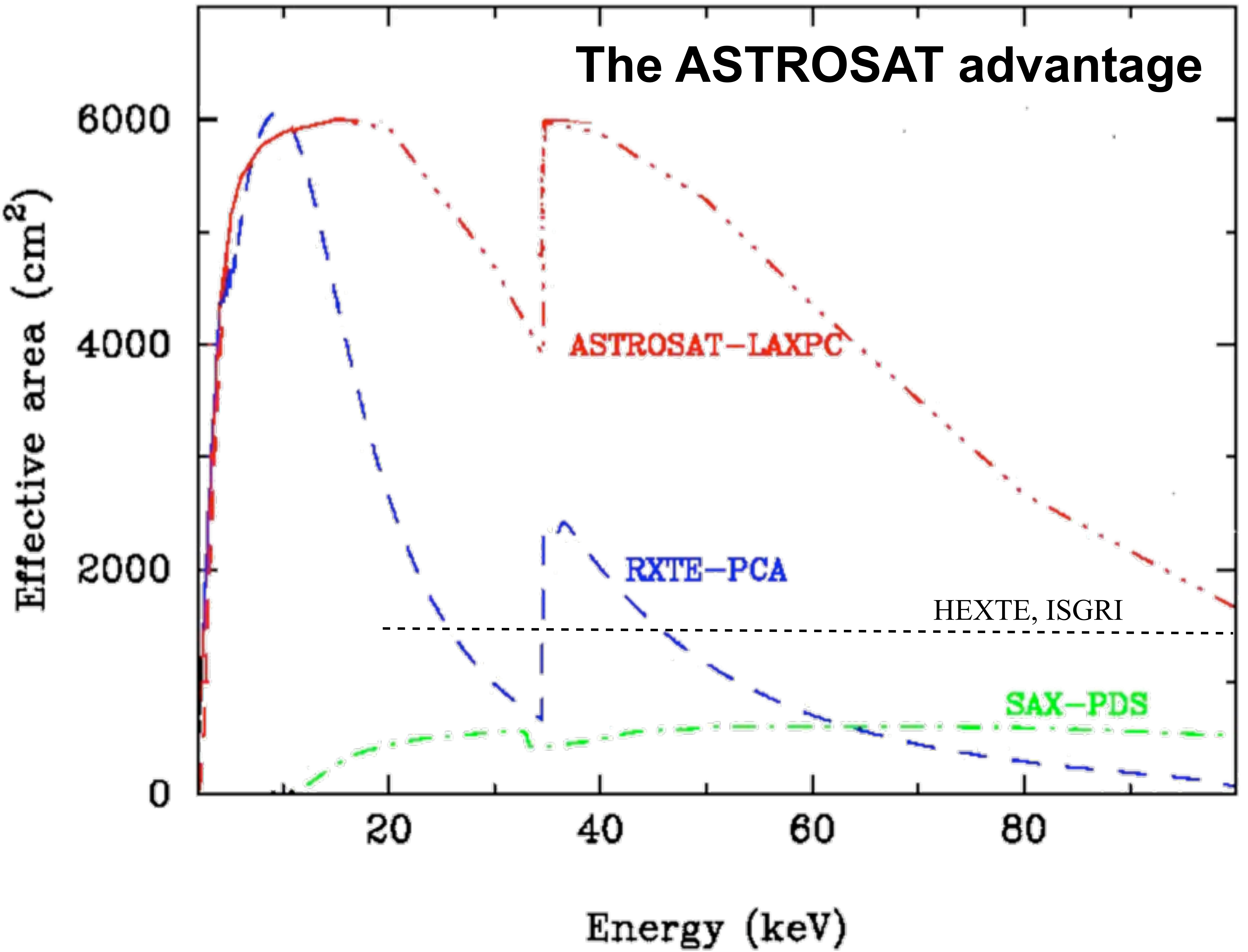
5 instruments

LAXPC, CZTI, SXT, UVIT : co-aligned

SSM : orthogonal to the rest, large-FOV monitor

ASTROSAT configuration




The ASTROSAT advantage
Effective area (cm²)
6000
4000
2000
0
20
40
60
80
Energy (keV)
ASTROSAT-LAXPC
RXTE-PCA
HEXTE, ISGRI
SAX-PDS

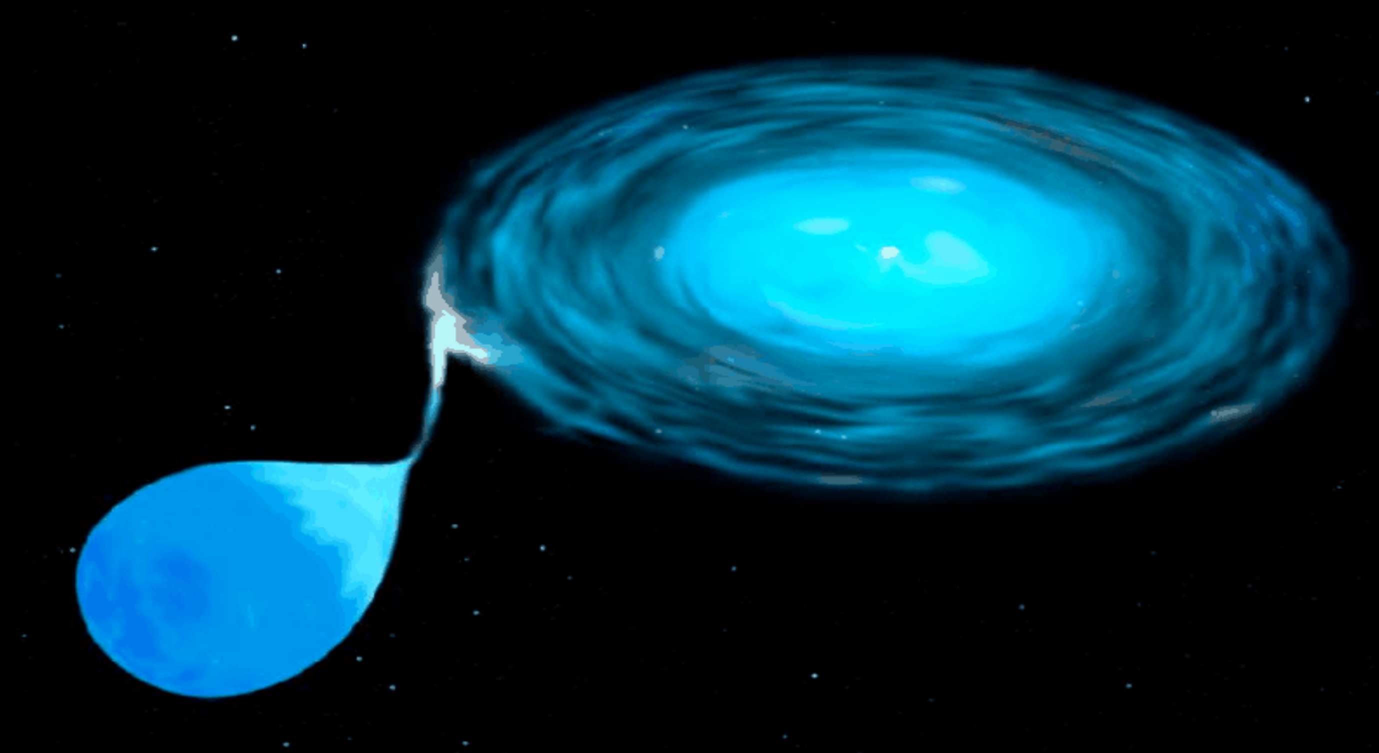
Observable signatures of strong gravity

- Luminosity production by matter accretion
- High frequency intensity variations
- Gravitational redshift
- Light bending
- Lense-Thirring effect
- Geodetic precession
- Post-Keplerian binary orbit
- Gravitational Radiation (and its reaction)

Applicable sites are collapsed objects

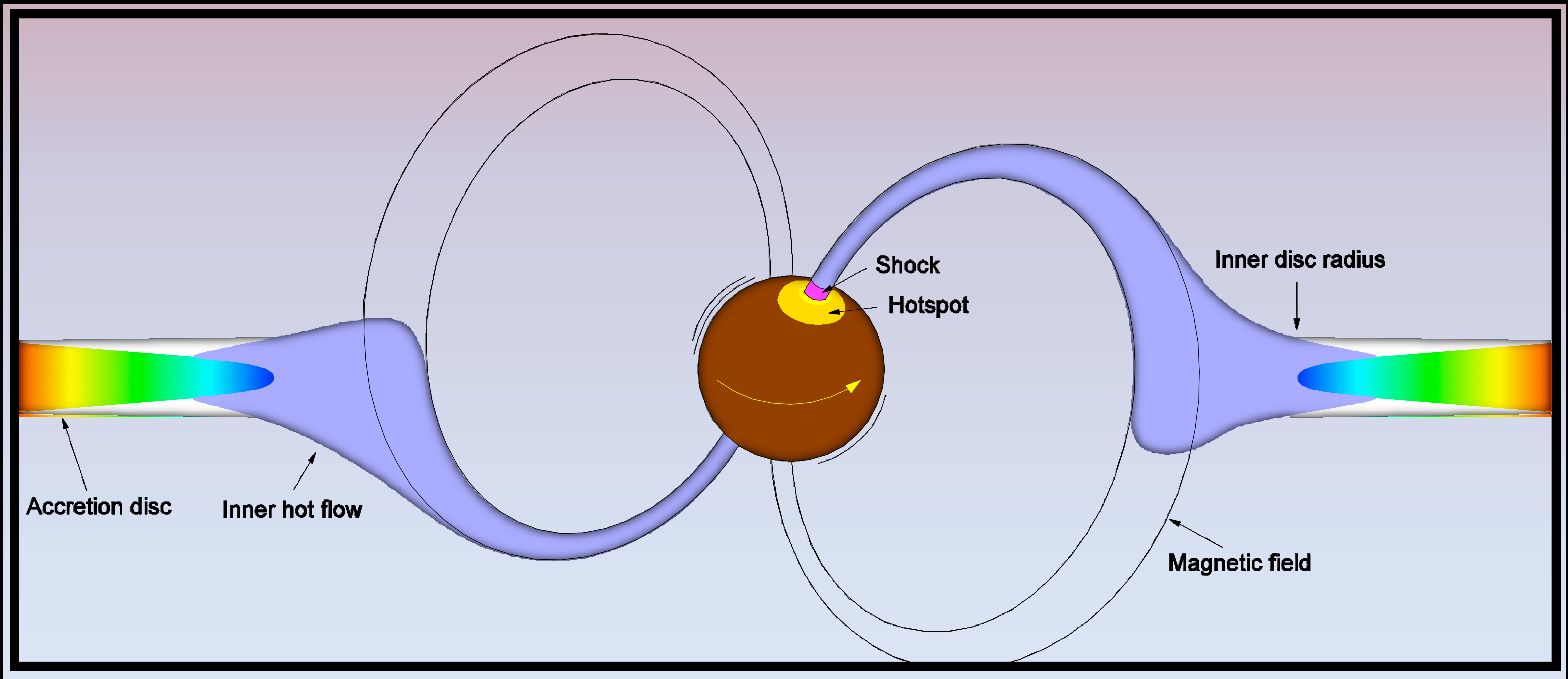
- Neutron Stars: *stellar mass*
- Black Holes: *stellar mass – supermassive*

Compact Star in accreting binary system

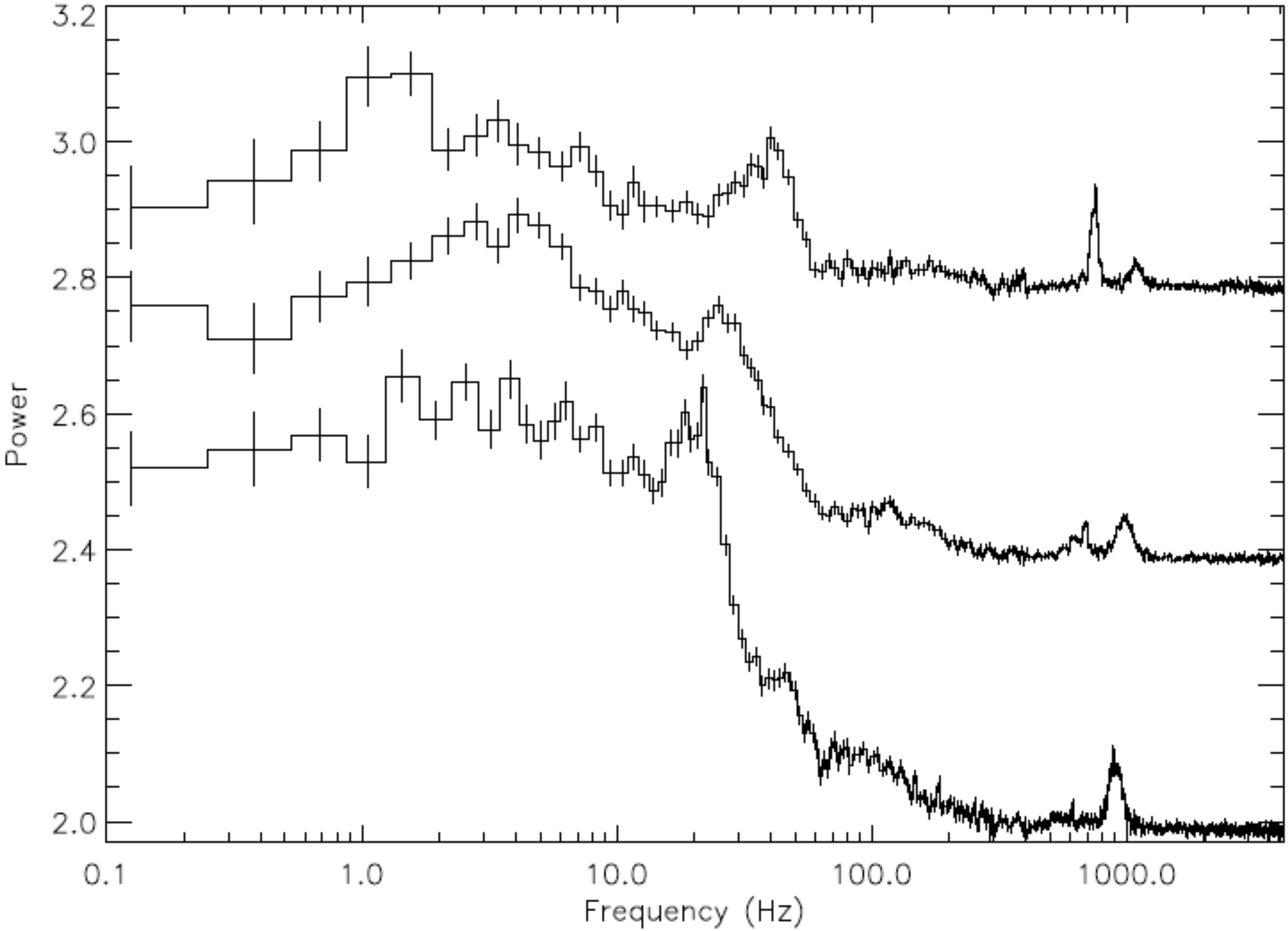


- Matter accretes in the form of a disk
- X-rays are generated by accreting matter
- Outer parts of the disk radiate in UV/optical

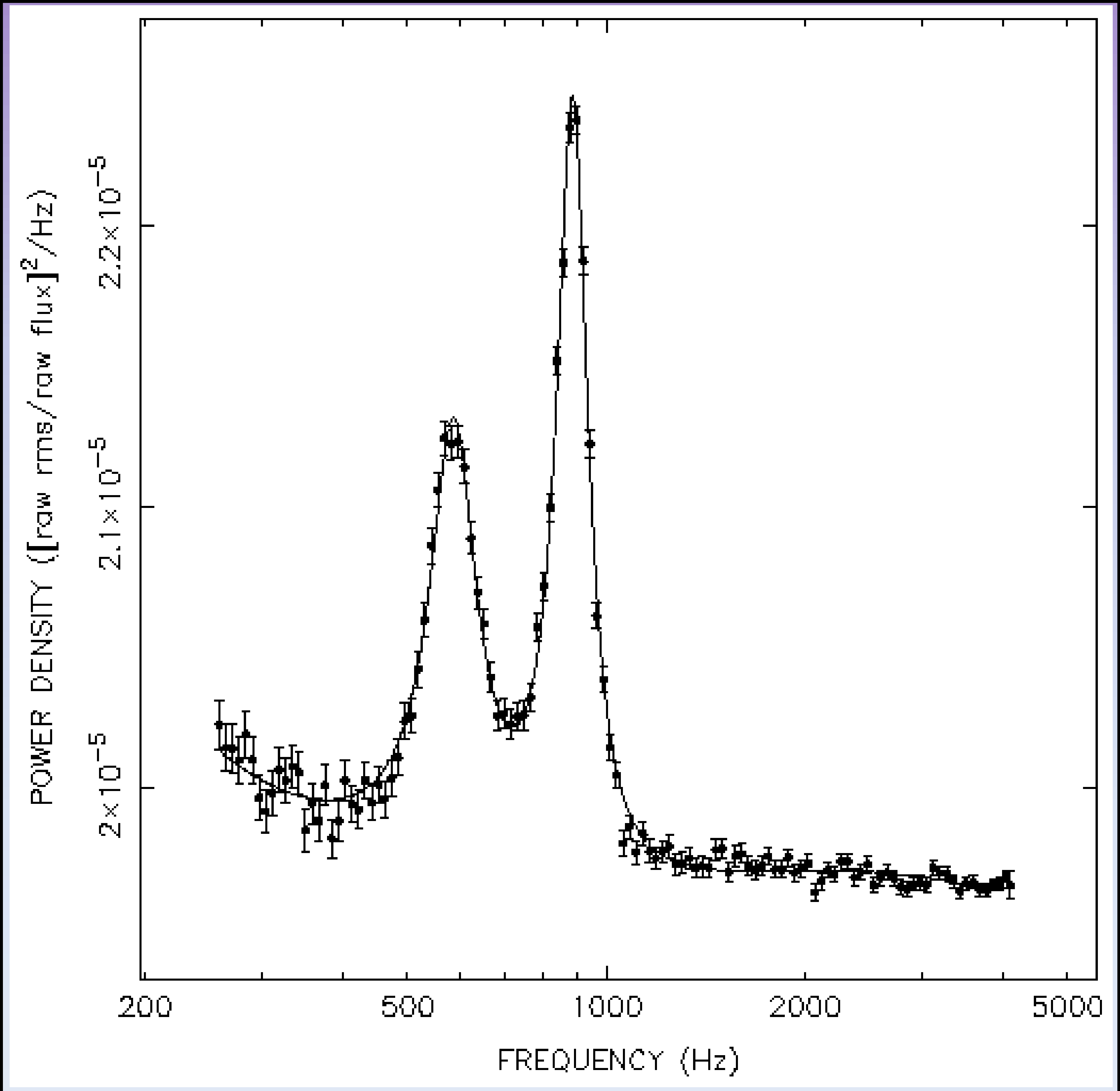
Accretion on a magnetized neutron star



Stellar spin + polar hot spot => pulsar activity (needs B > 10^9 G)
Complex structure in X-ray intensity variations, even for low B
X-ray timing rich source of information; key strength of ASTROSAT

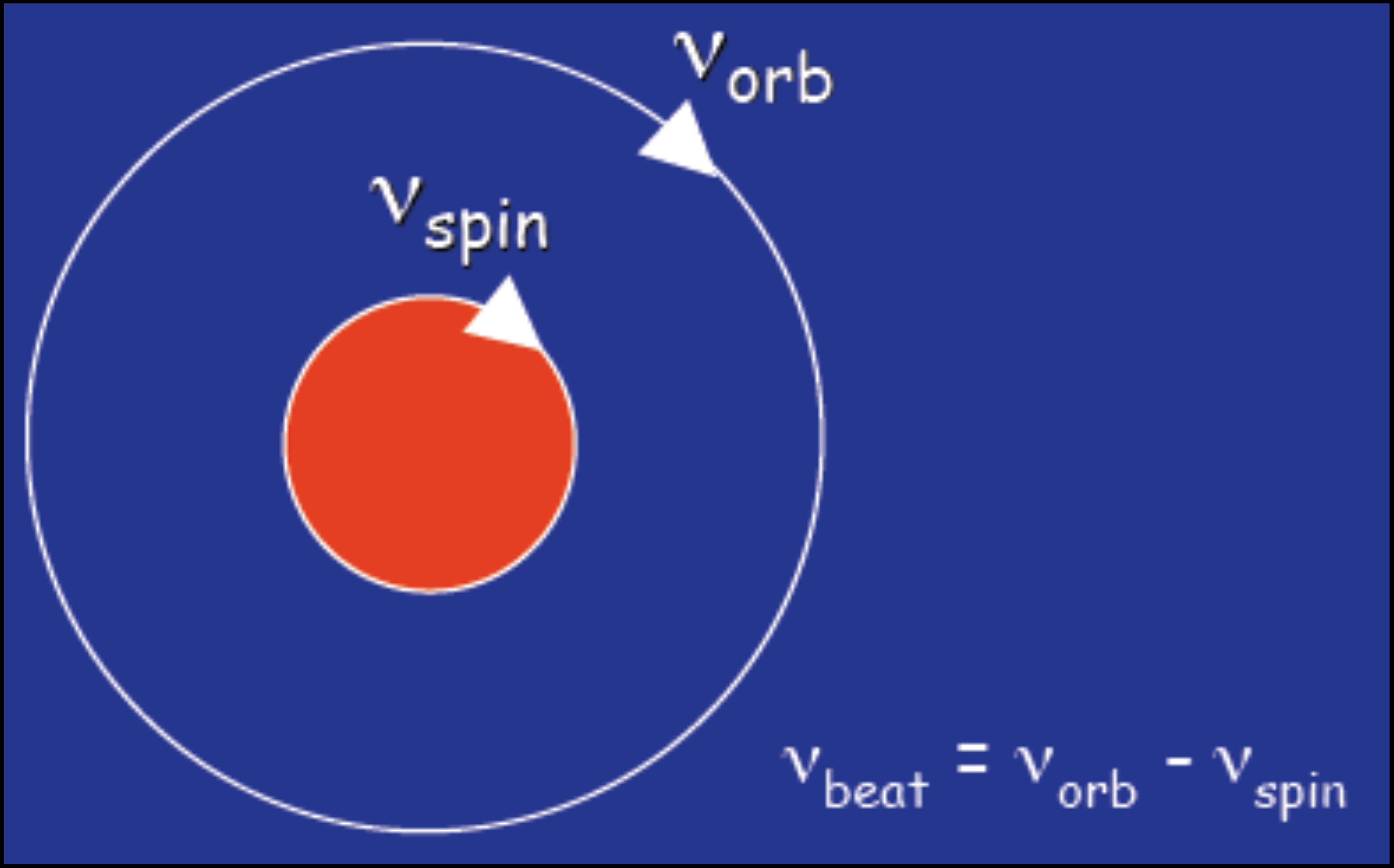


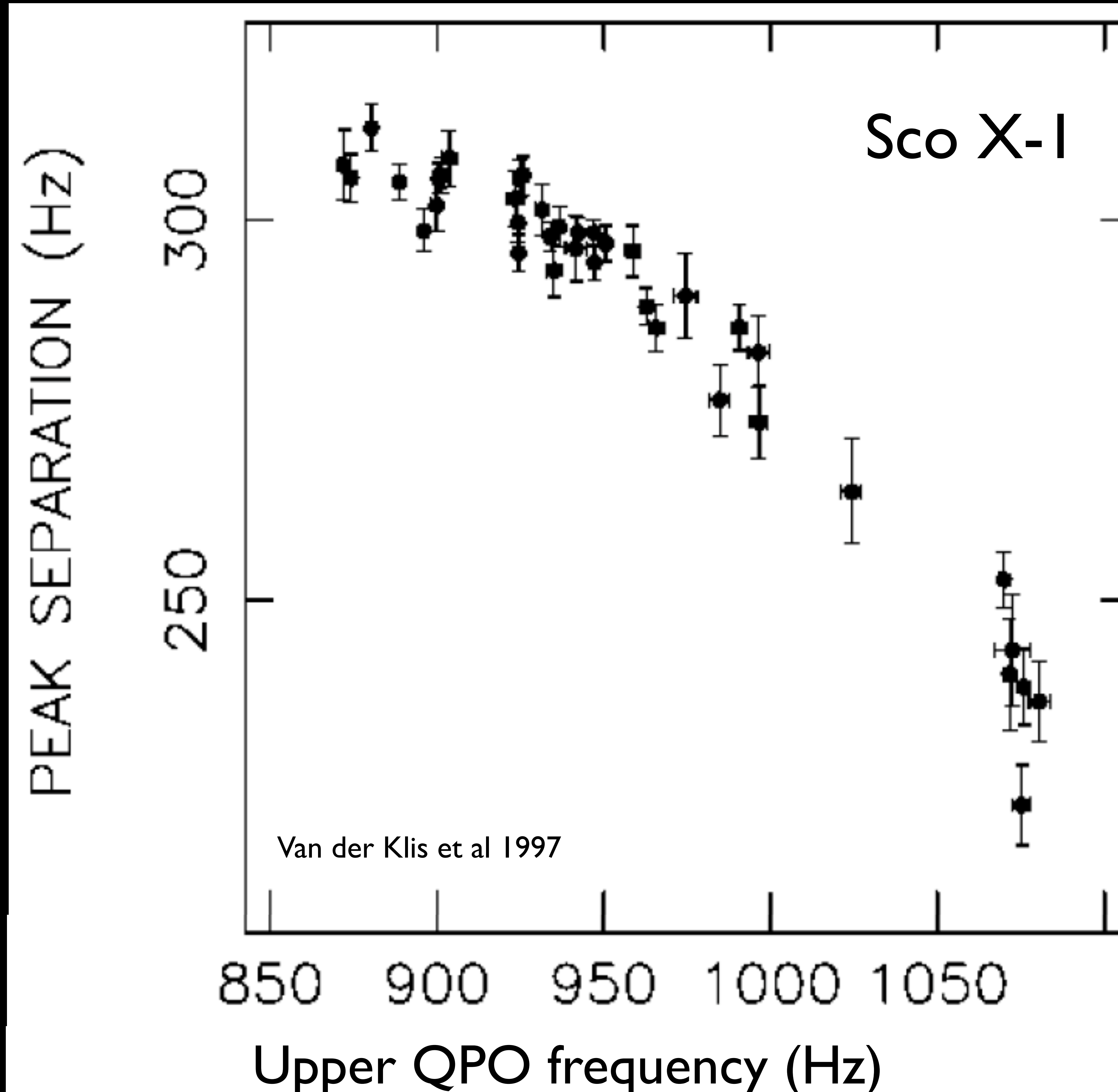
3.2
3.0
2.8
2.6
2.4
2.2
2.0
Power
0.1
1.0
10.0
100.0
1000.0
Frequency (Hz)



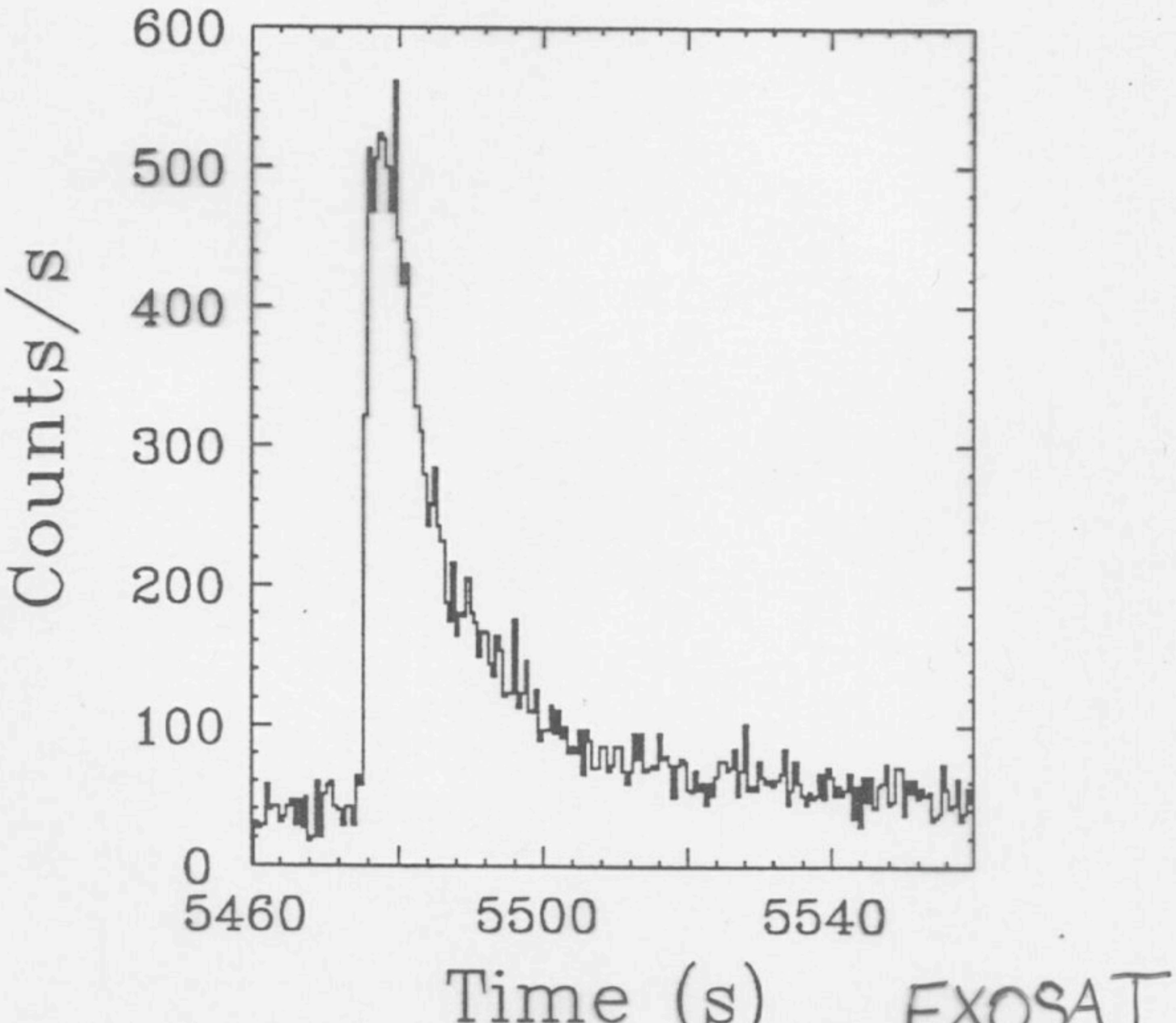
POWER DENSITY ([raw rms/raw flux]^2/Hz)
2.2×10^{-5}
2.1×10^{-5}
2×10^{-5}
200
500
1000
2000
5000
FREQUENCY (Hz)

Beat frequency model for twin QPO

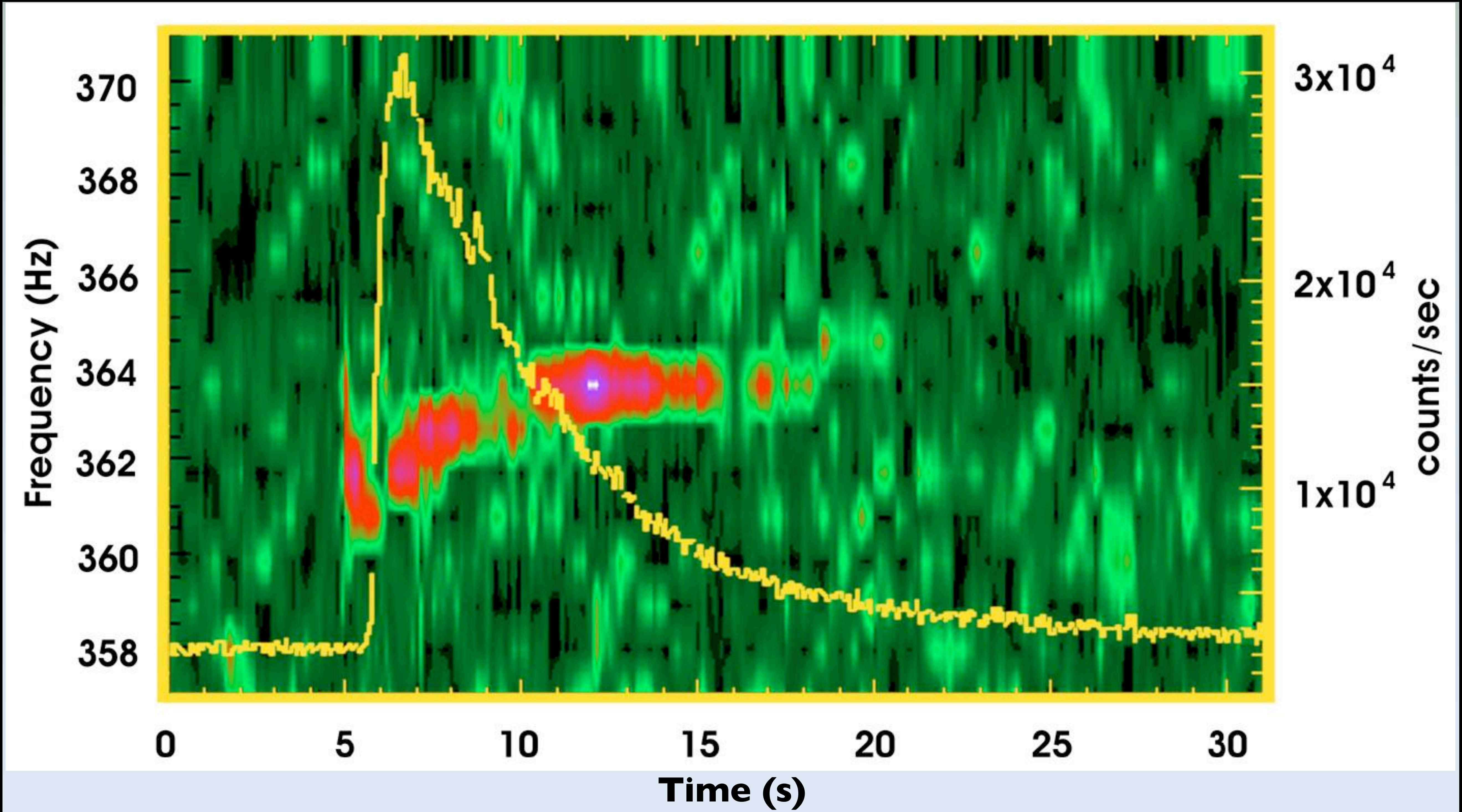



Sco X-1
PEAK SEPARATION (Hz)
300
250
Van der Klis et al 1997
850
900
950
1000
1050
Upper QPO frequency (Hz)

X-ray burst from the LMXB 1702-429

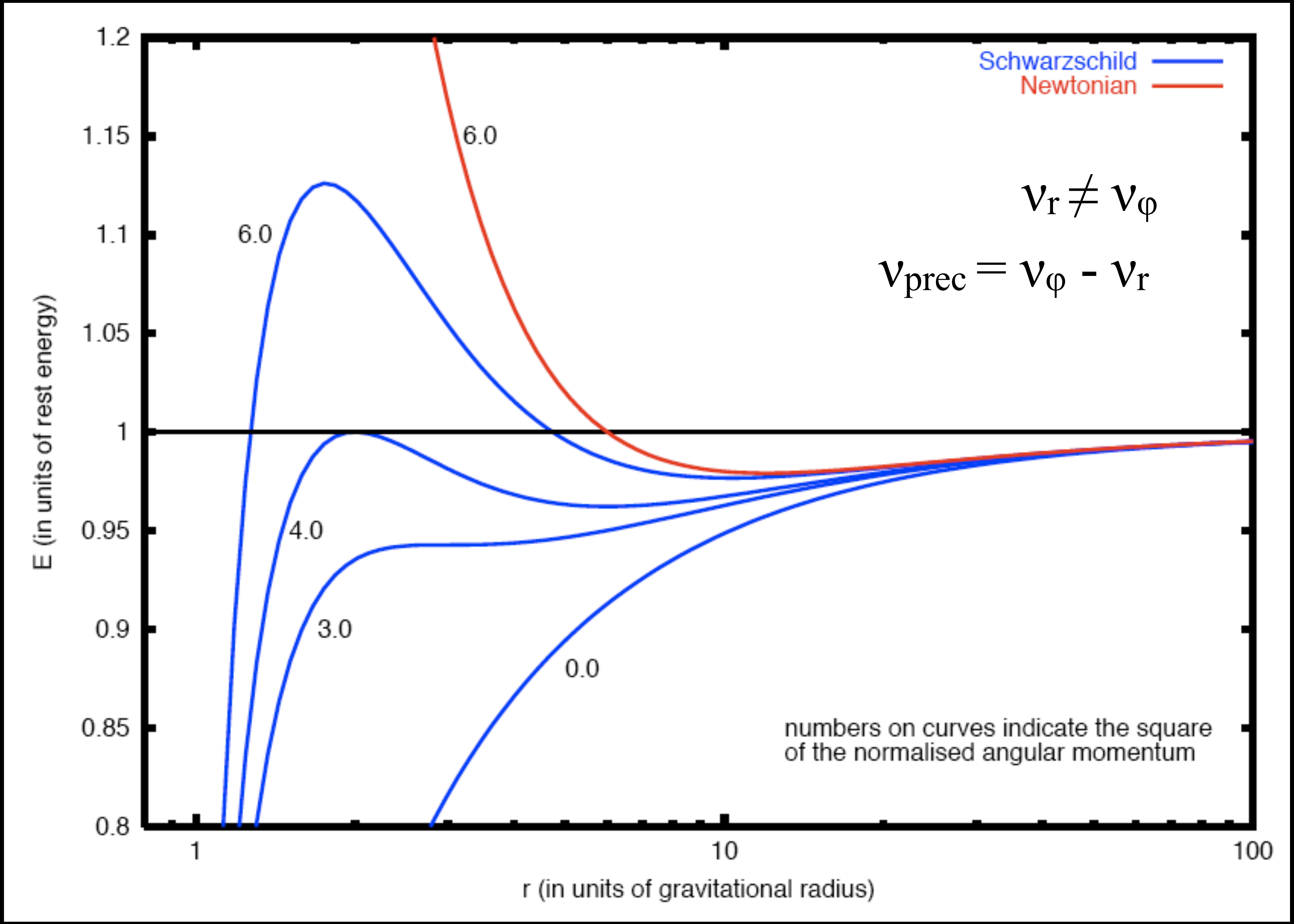


Burst Oscillations



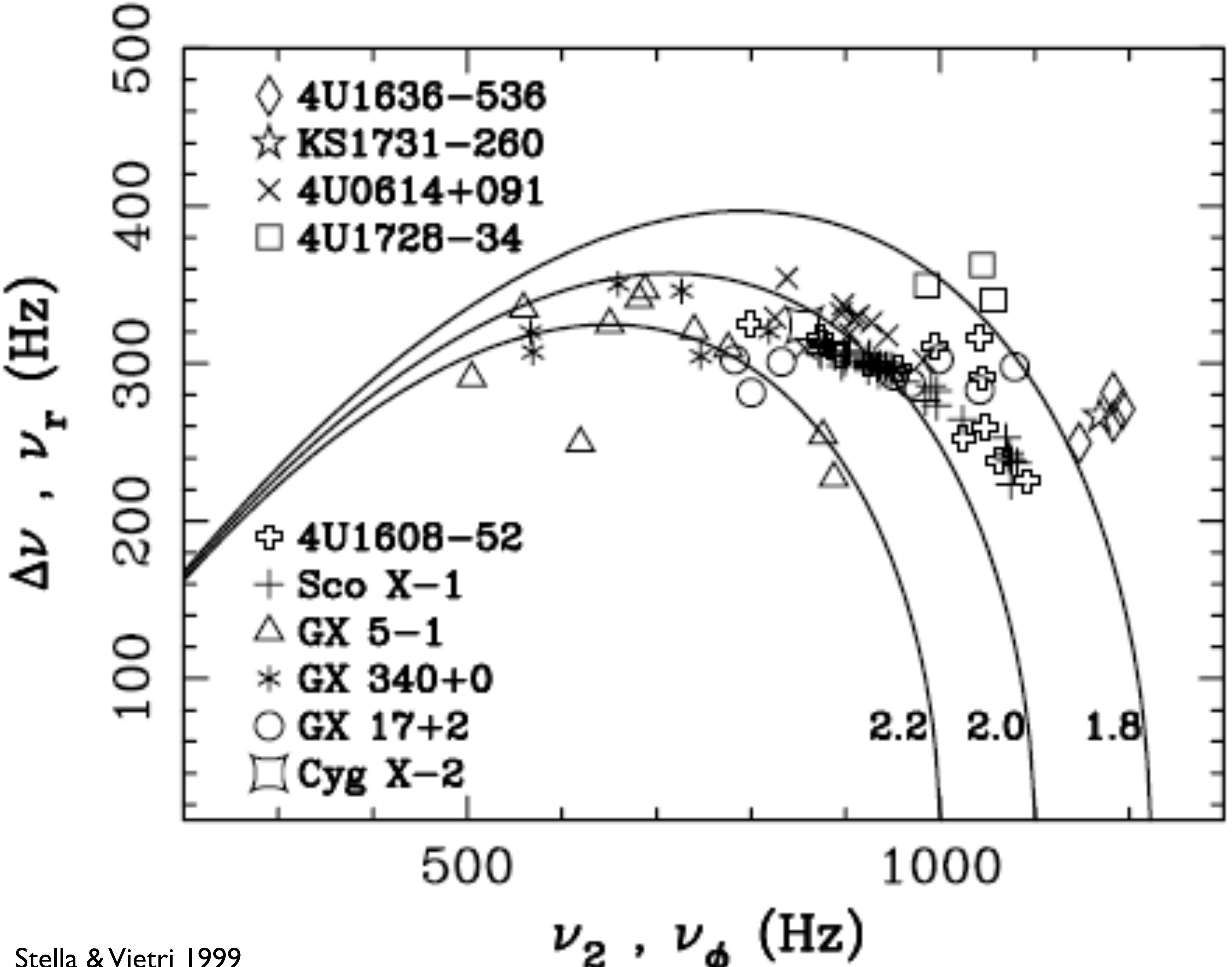
T. Strohmayer 1996

Relativistic precession model



$\nu_{upper} = \nu_\varphi$ $\nu_{lower} = \nu_{prec}$ $\Delta\nu = \nu_r$

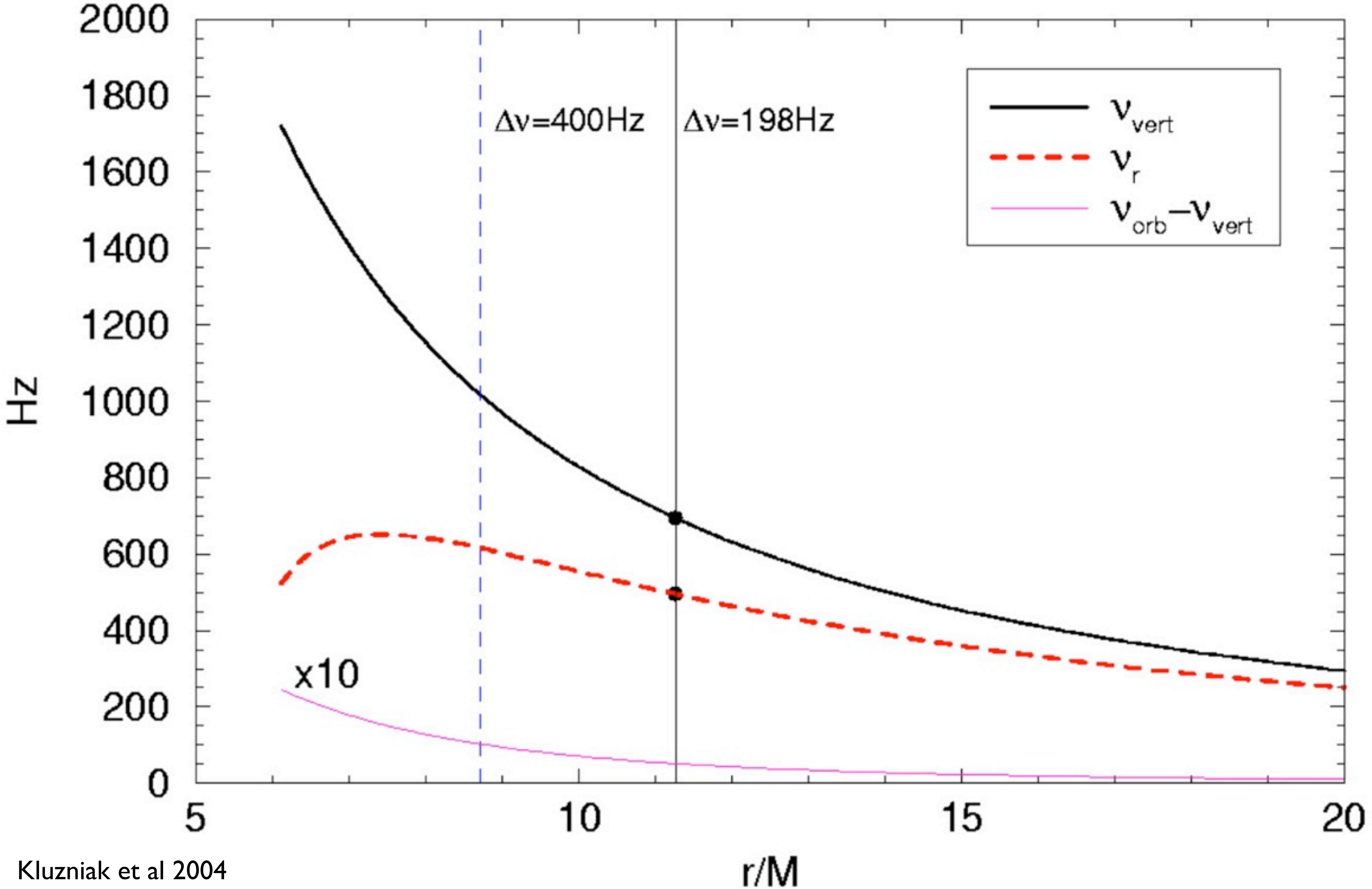
at the inner edge of the disk



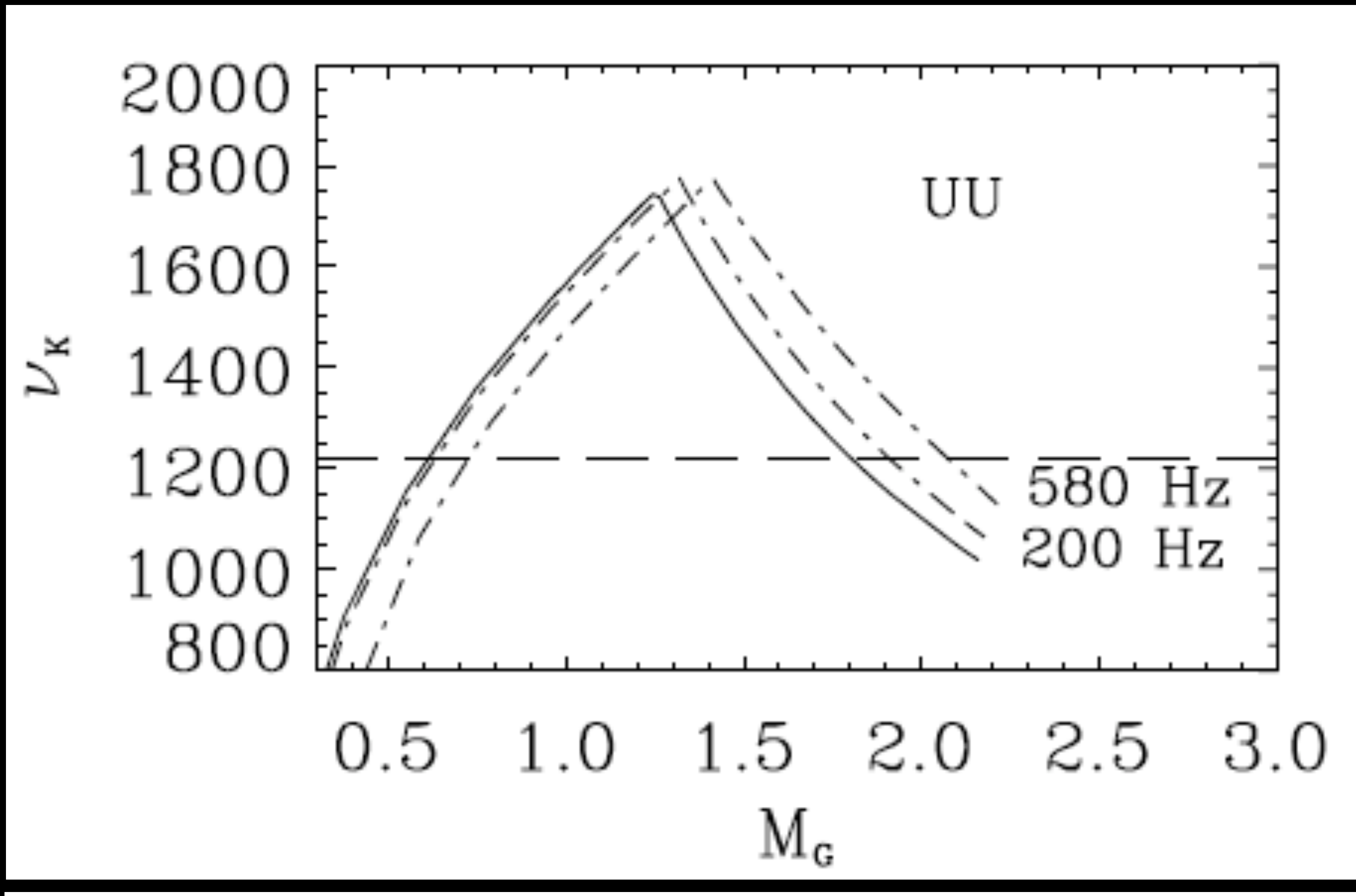
Stella & Vietri 1999

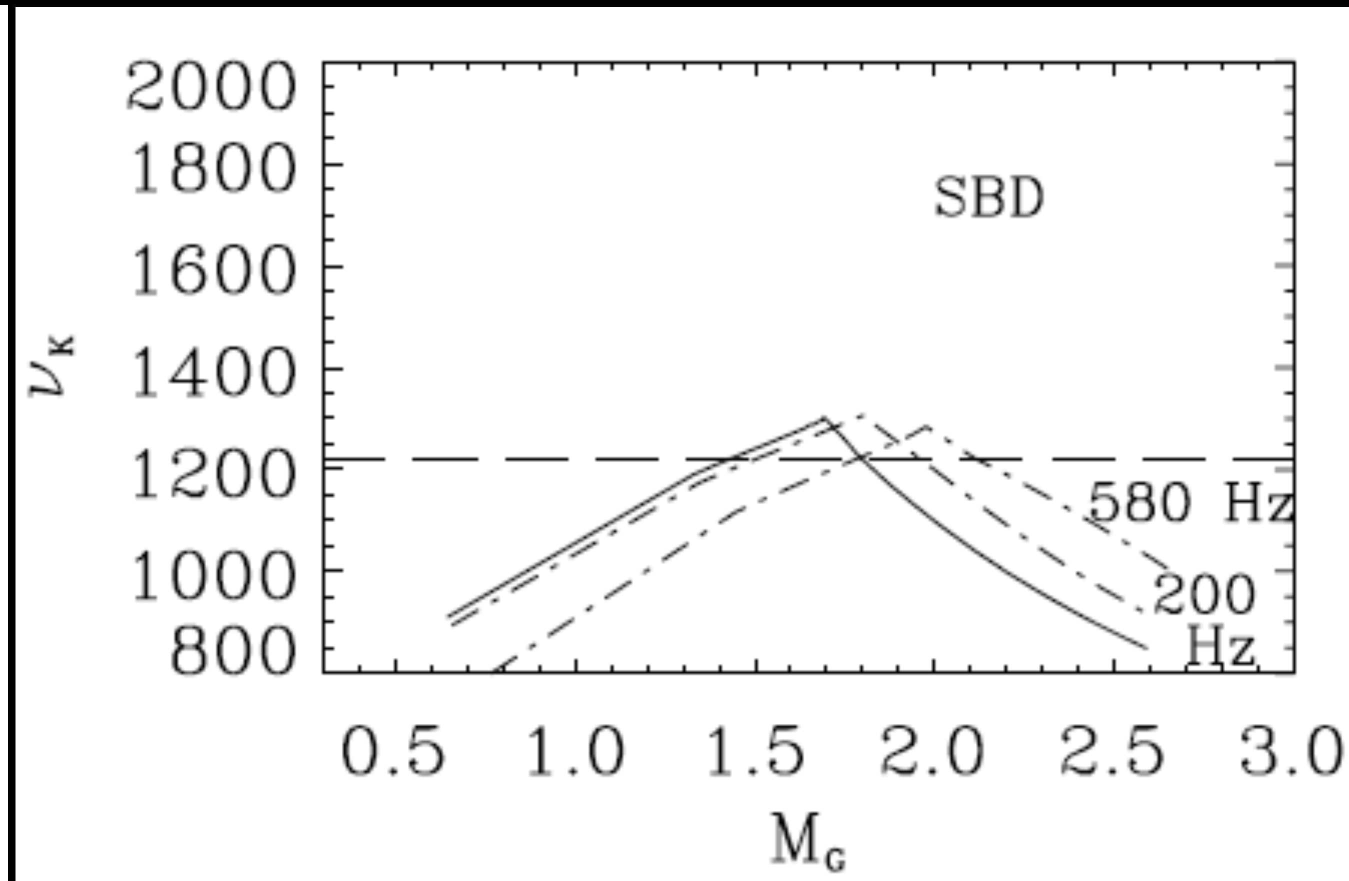
For spinning neutron stars, gravitomagnetic effect will modify frequencies

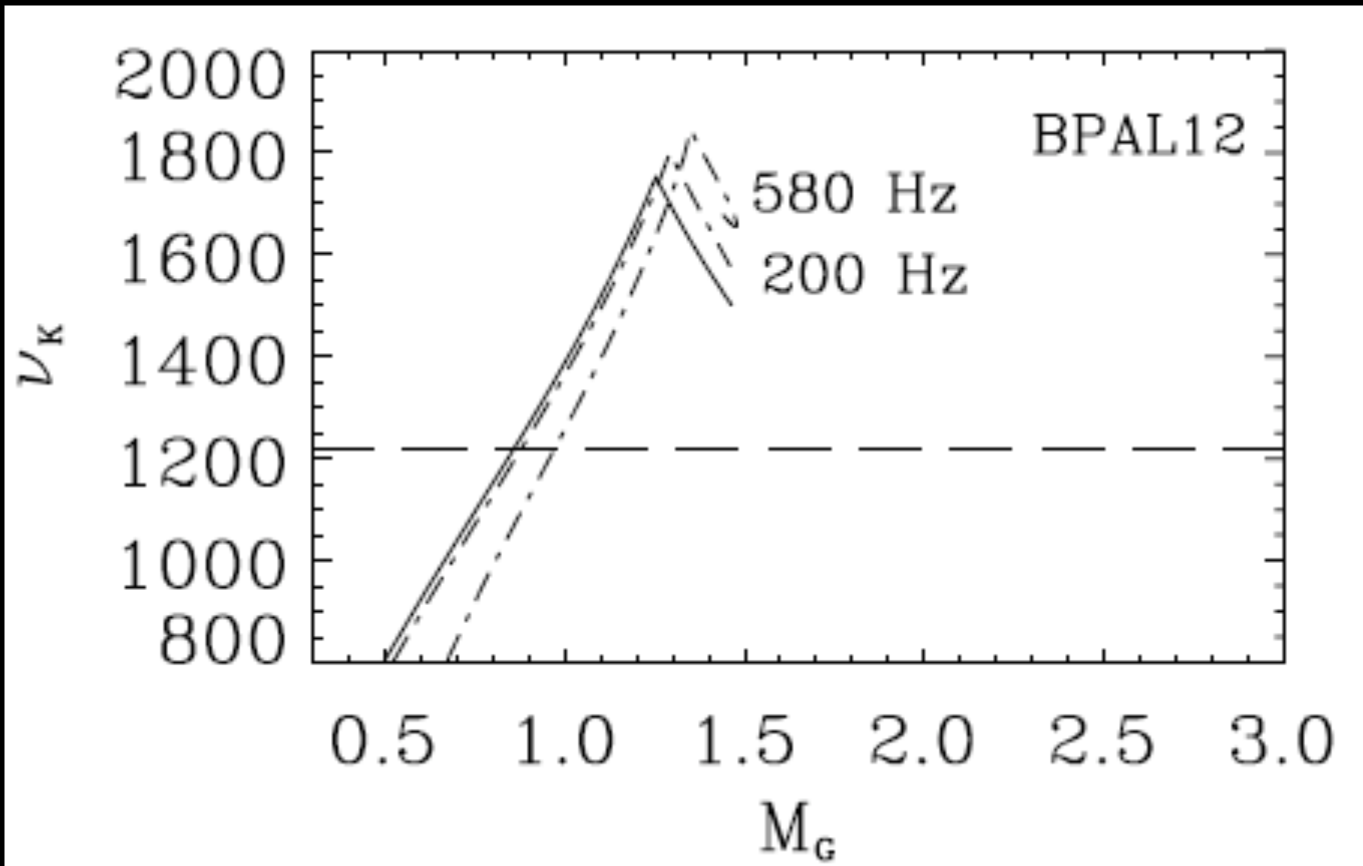
Epicyclic Resonance in disk oscillation: vertical/radial



Kluzniak et al 2004





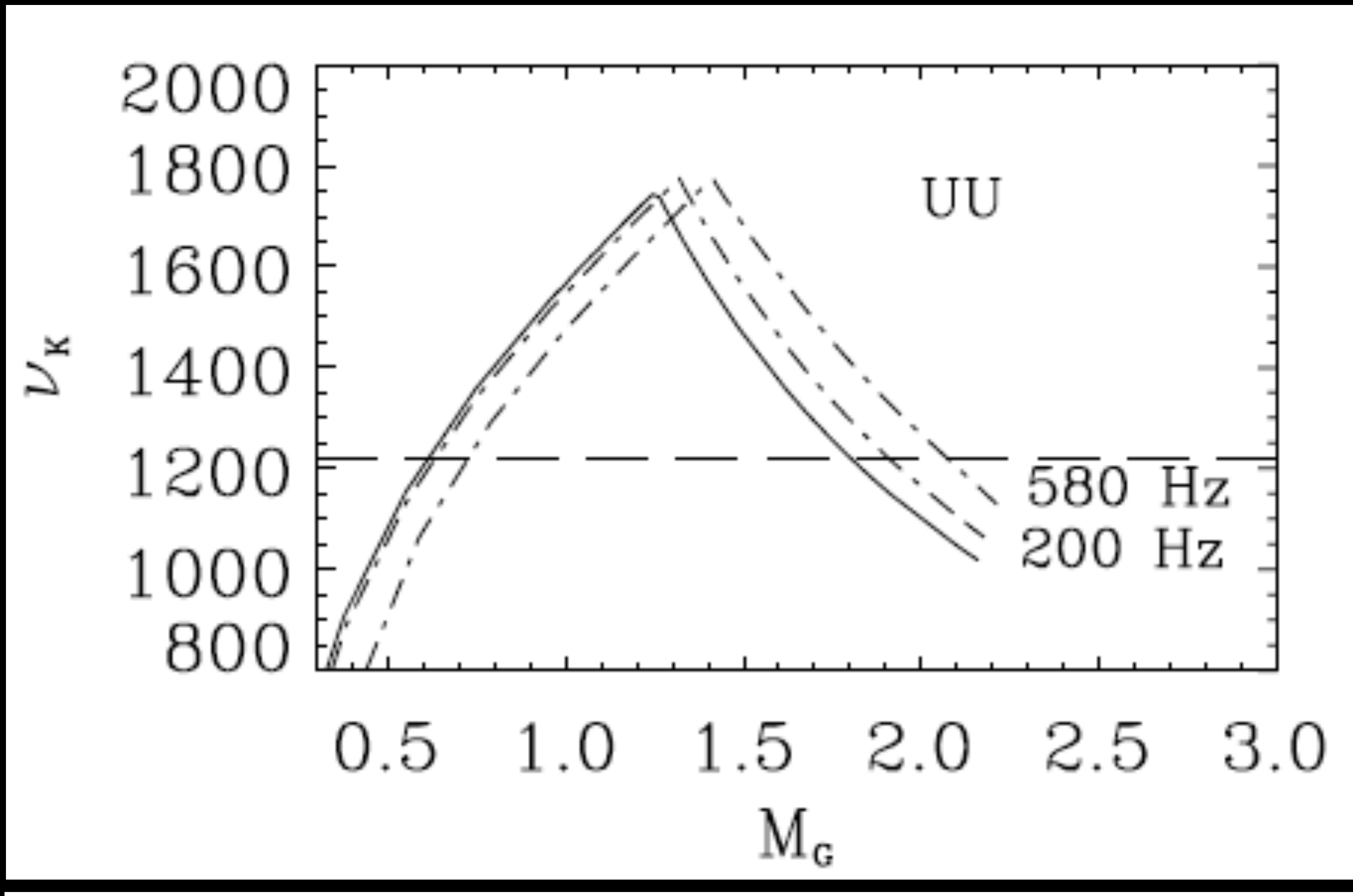


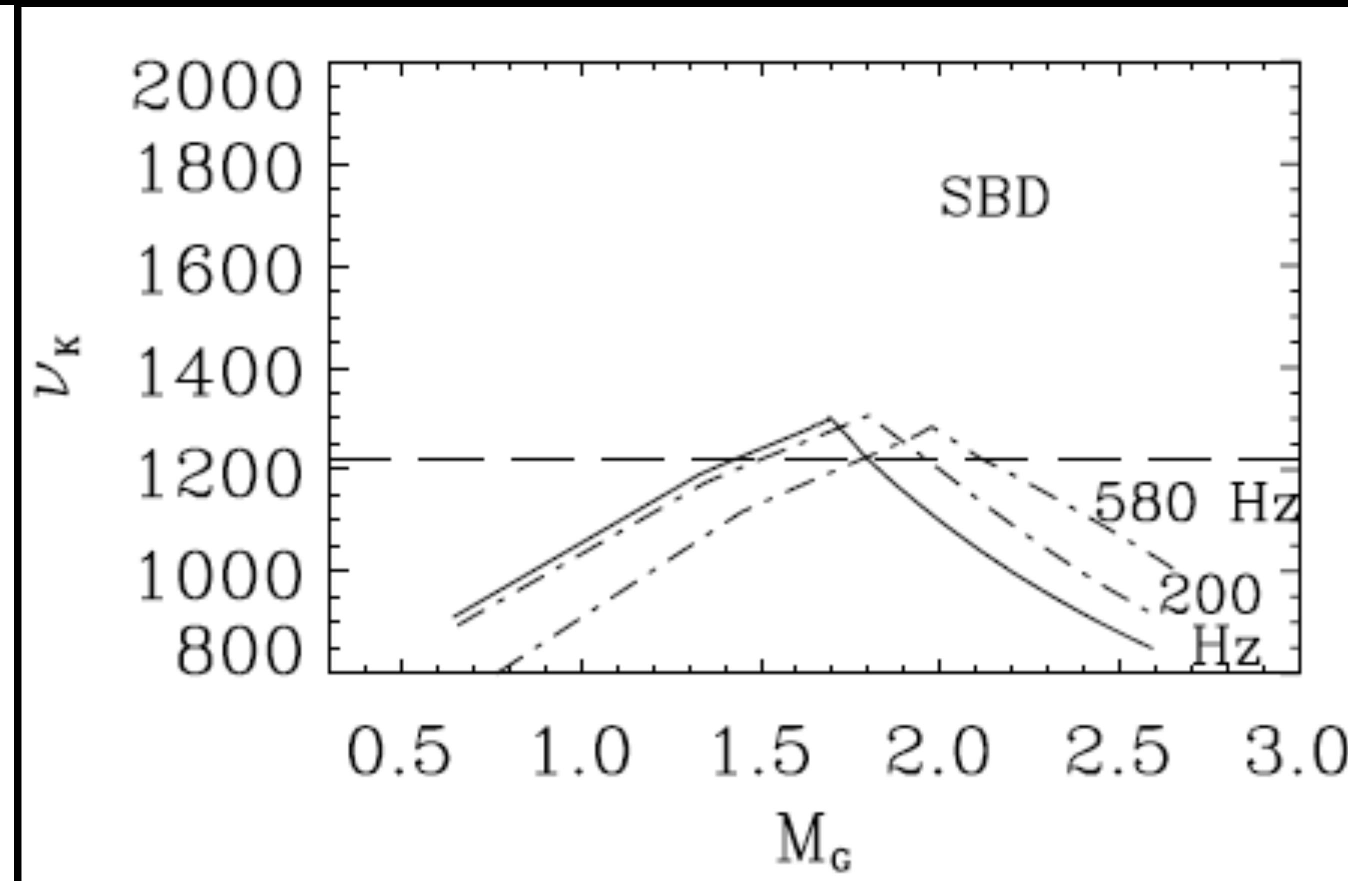
Thampan, Bhattacharya, Datta 1998

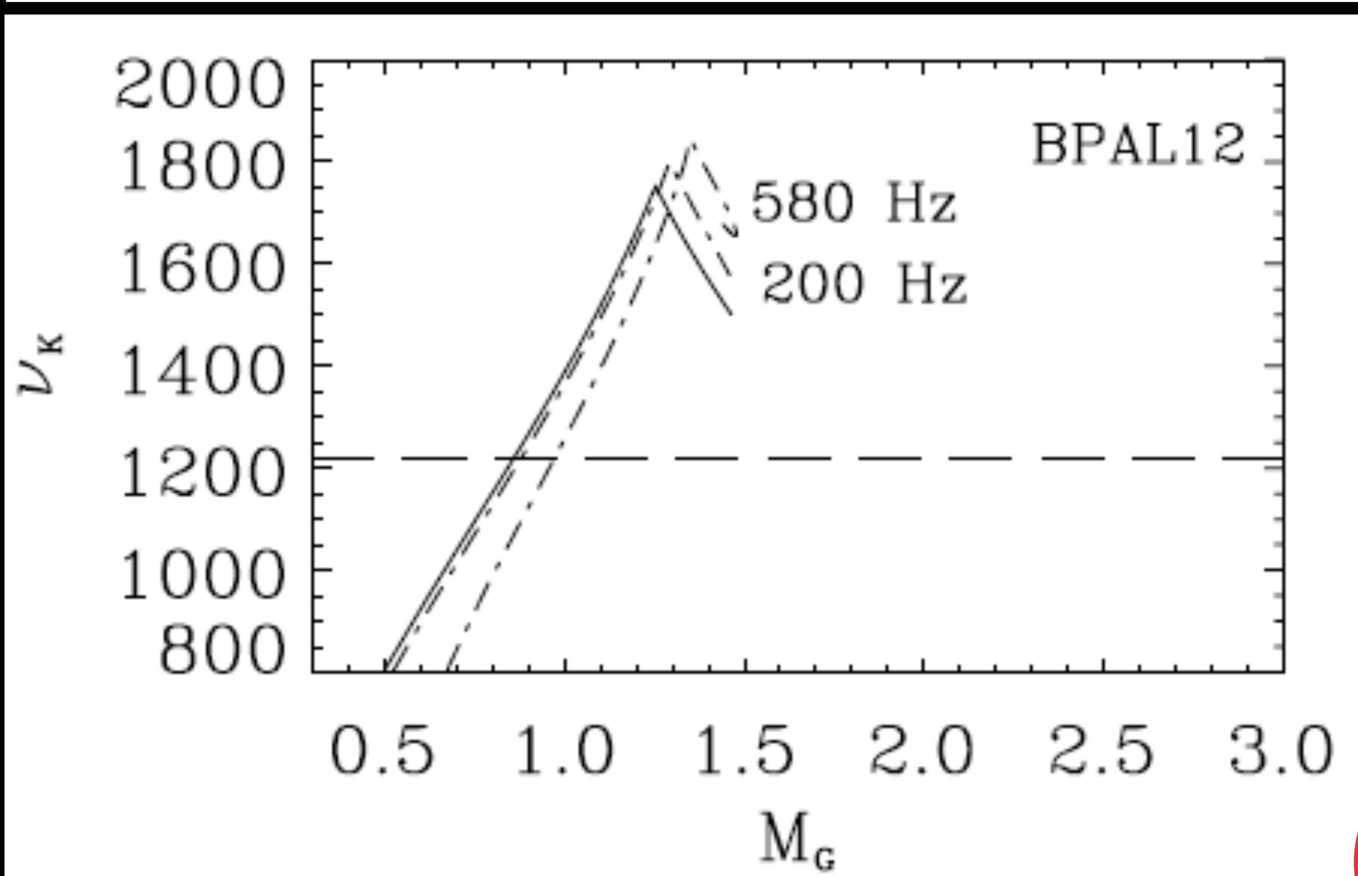
Upper QPO frequency from innermost allowed orbit:

ISCO / NS radius

=> Constraints on NS EOS







Thampan, Bhattacharya, Datta 1998

Upper QPO frequency from innermost allowed orbit:
ISCO / NS radius

=> Constraints on NS EOS

Astrosat will be able to study KHz QPOs in unprecedented detail

Thermal spectrum from accretion disk

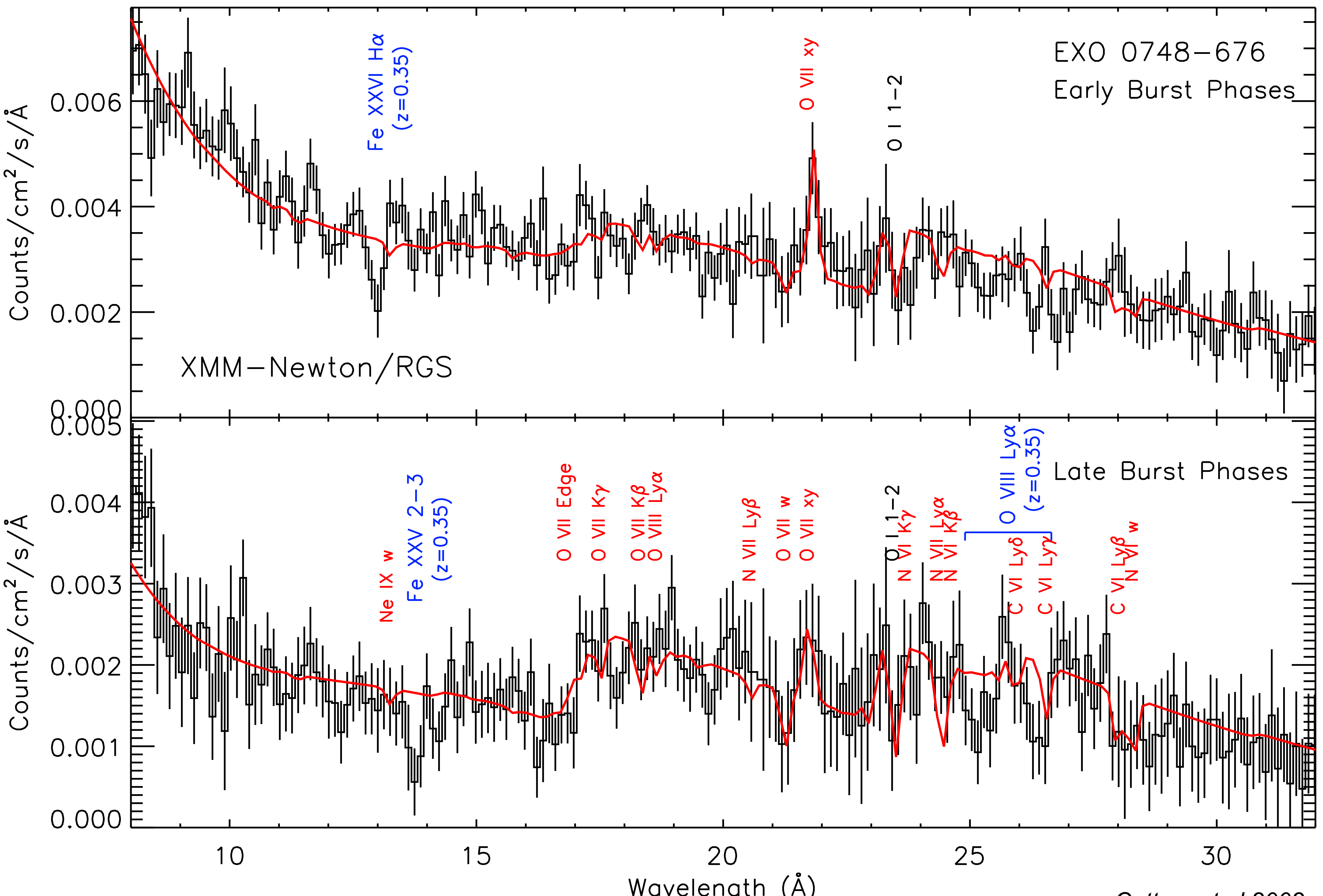
Multicolour Blackbody : *T (r)* : inner disk hotter

Temperature depends on
- compact object mass
- accretion rate

Observed emission modified by
- gravitational redshift
- light bending

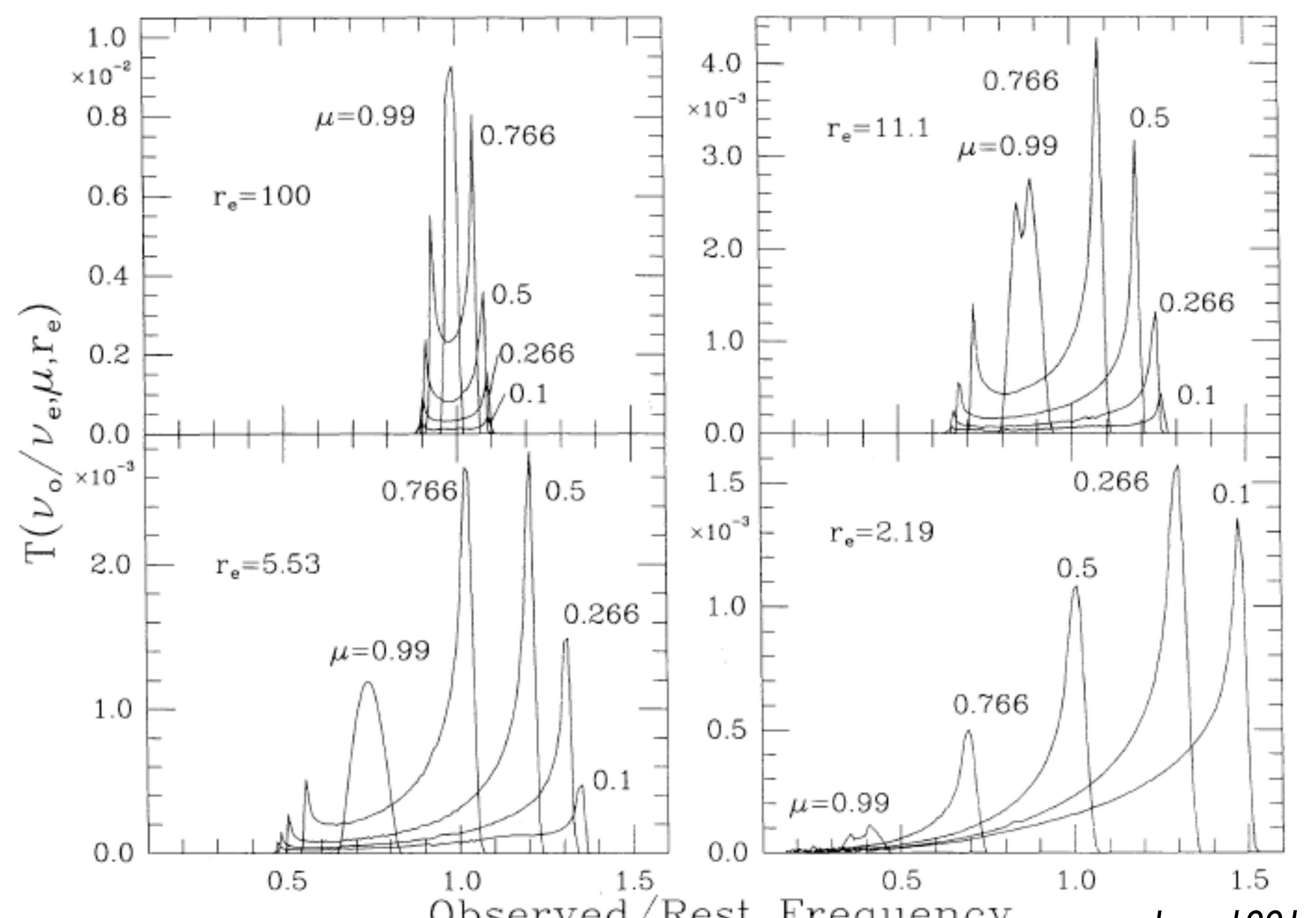
In presence of BH horizon: ADAF

Gravitational Redshift from NS surface



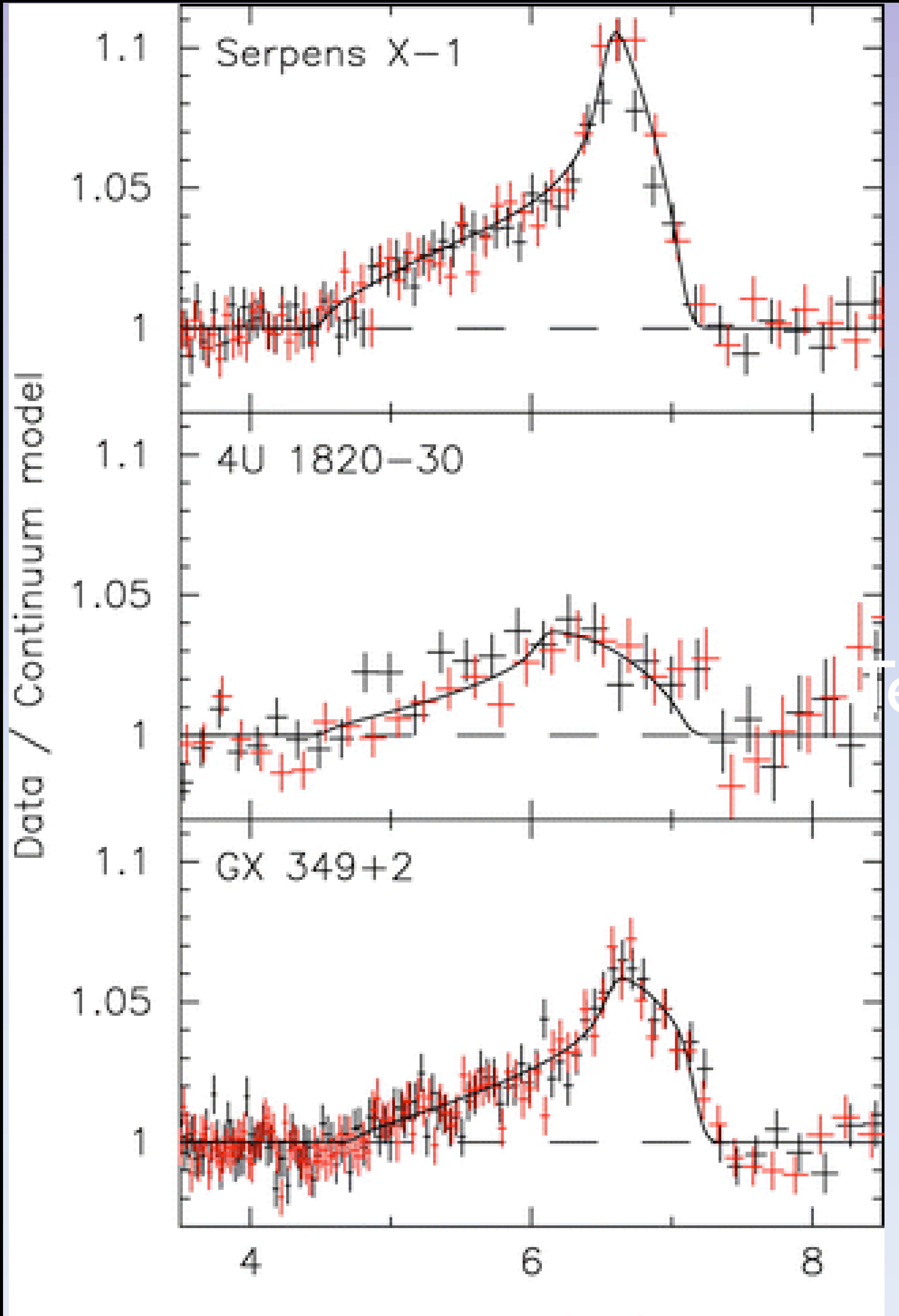
Cottam et al 2002

Gravitational Redshift from the Accretion Disk: Fe Kα line

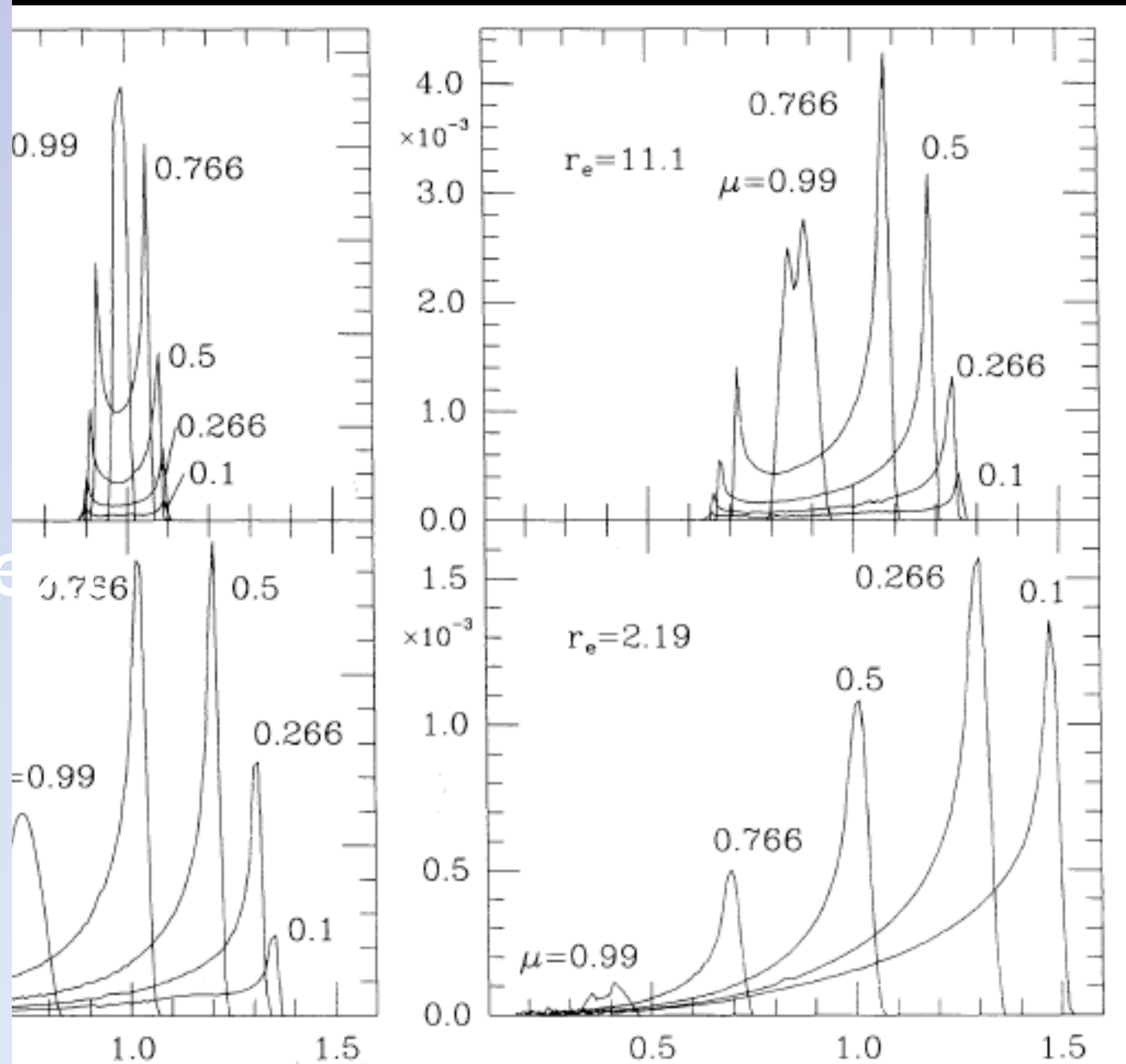


Laor 1991

Gravitational Redshift from the Accretion Disk: Fe Kα line

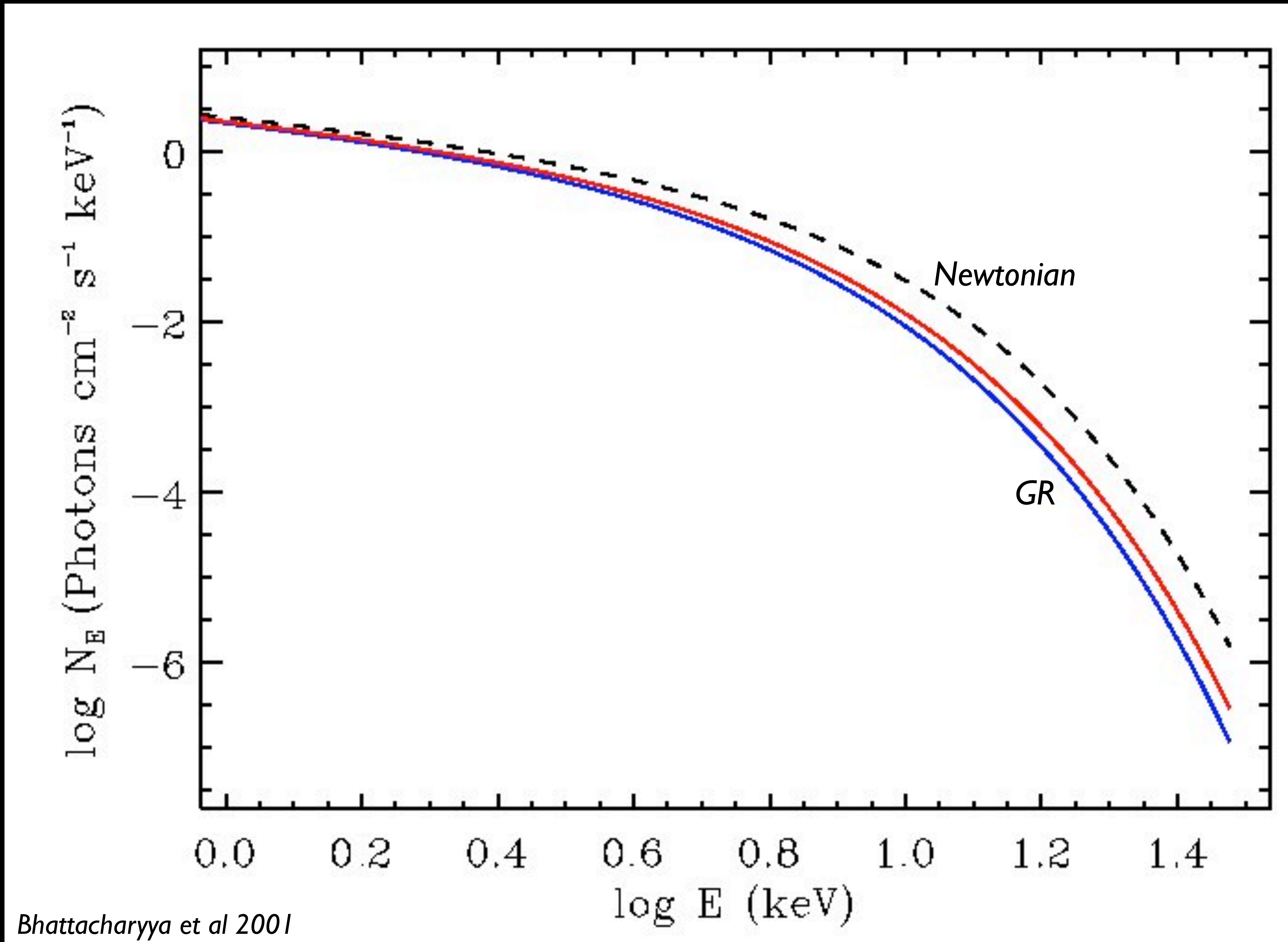


Cackett et al 2008



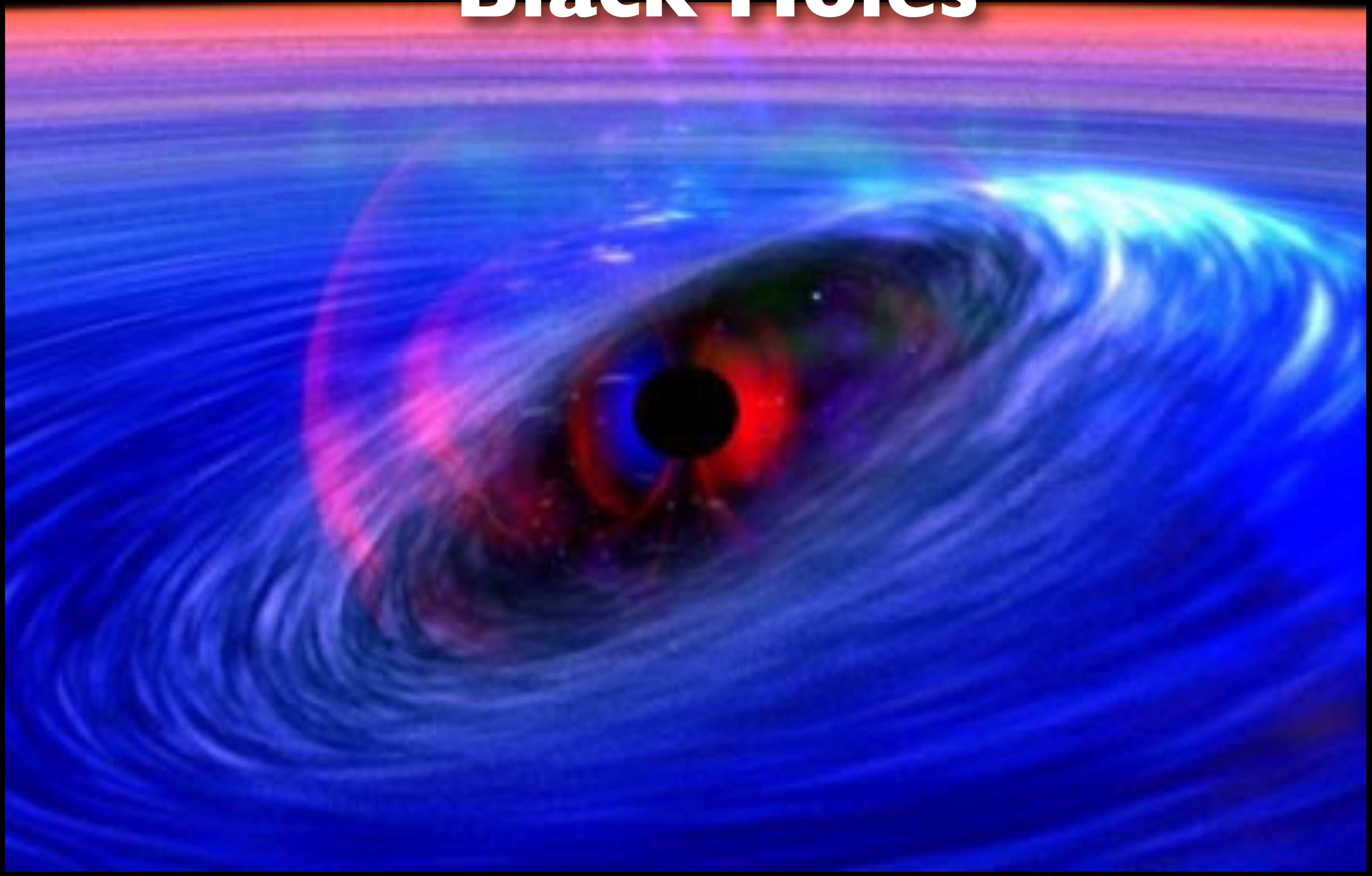
Laor 1991

Observable signatures of strong gravity



Accretion Disk Thermal Spectrum

Black Holes



Black Hole is fully characterized by M, J

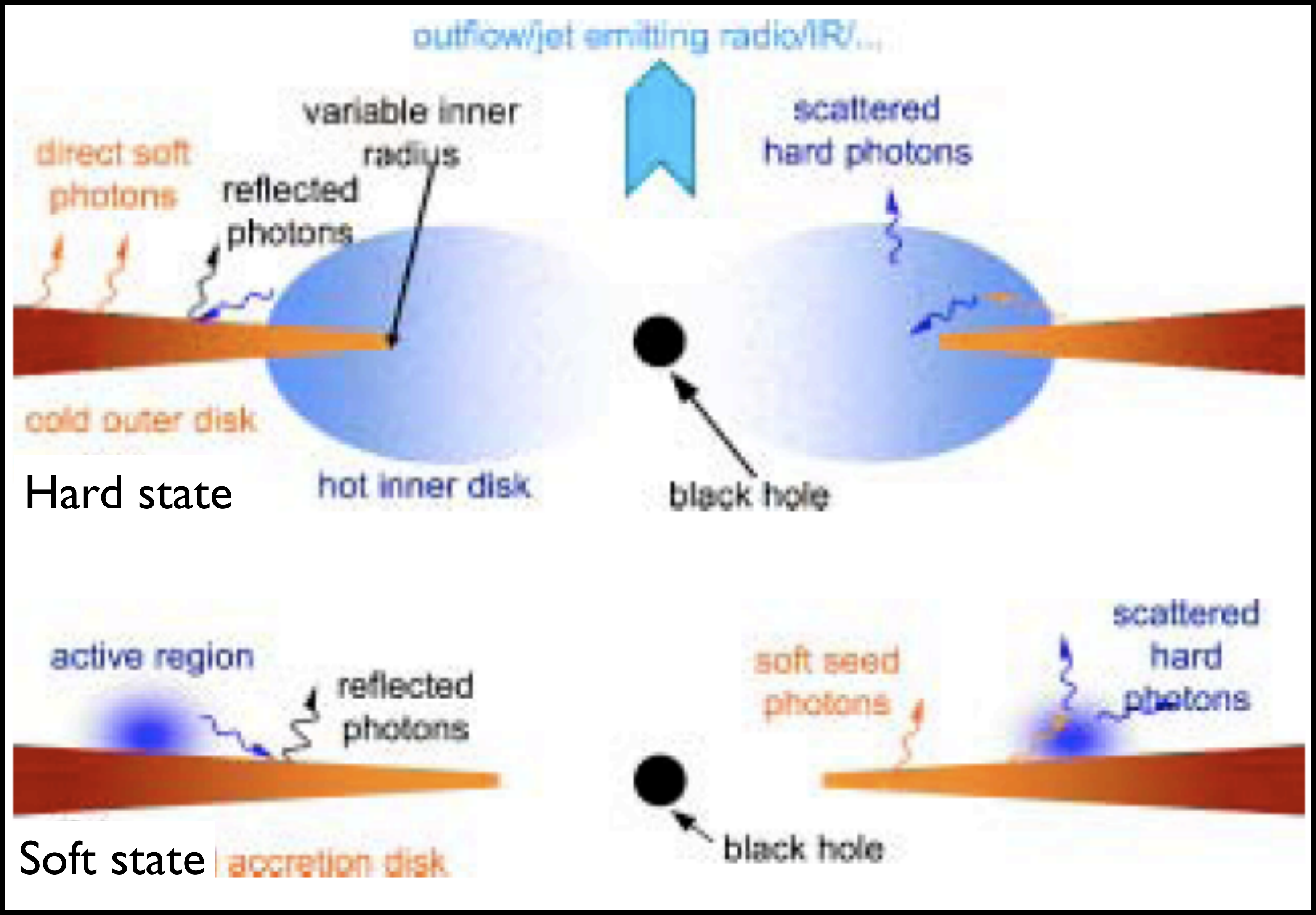
Does not radiate by itself.

Studied through influence on its surroundings

Accretion flow entering the BH samples regions nearest to it. Matter approaches the BH in a disk, gets hot and radiates up to 50% of the rest mass of accreted matter

Study of the accretion flow is one of the most important ways to study Black Holes

Accreting Black Hole: Radiation Components



- *Thermal disk radiation (soft) - matter closest to BH hottest : ISCO*
- *Compton upscattered hard photons from hot electrons*
- *"Reflected" hard photons from the accretion disk*
- *Fe K-α line*
- *Jets and outflows, non-thermal synchrotron*

Smaller for
- lower M
- higher J

DW jets: launching mechanism

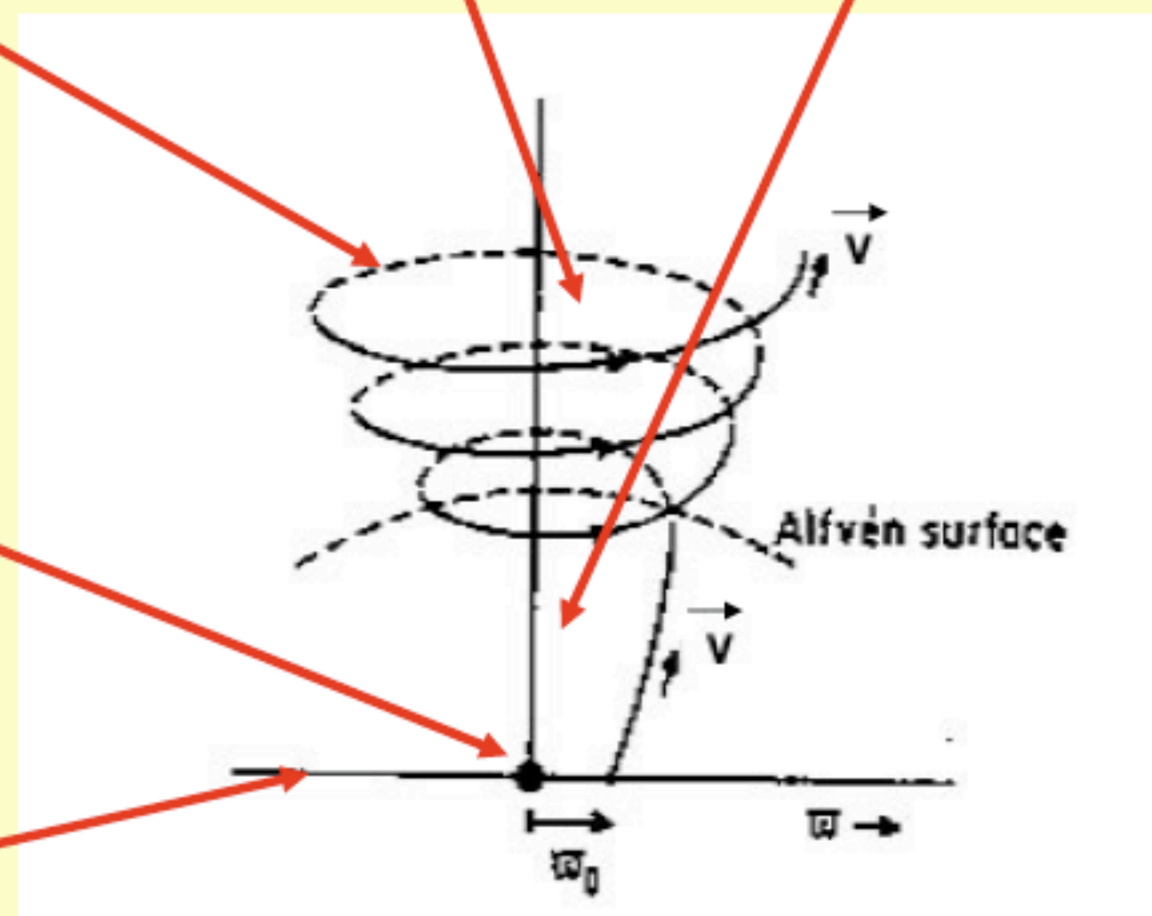
Collimation:
Magnetic tension
(Hoop-stress)

Acceleration:
Magnetic pressure
gradient

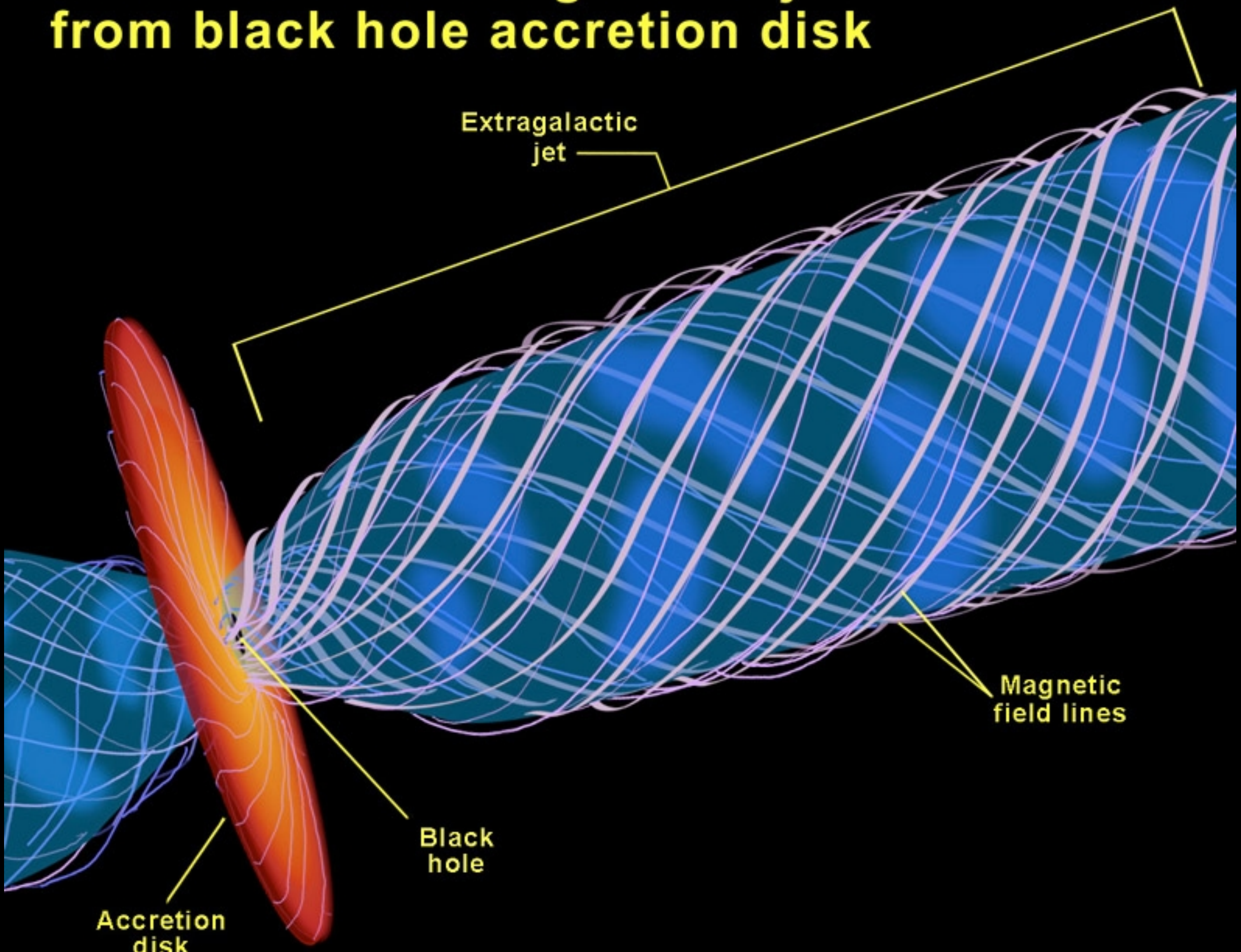
Acceleration:
centrifugal

Central object

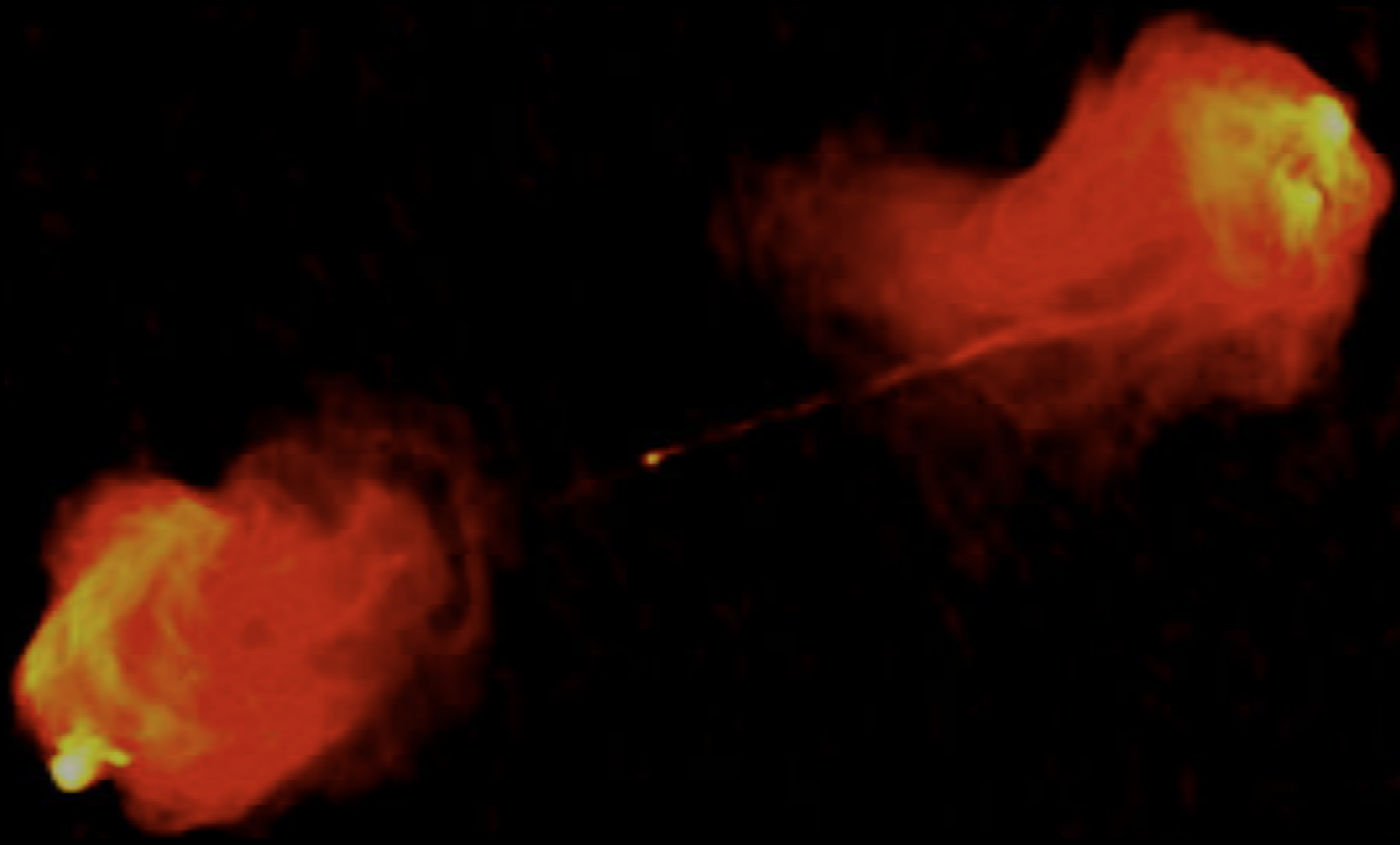
Disk



Formation of extragalactic jets from black hole accretion disk



Radio Galaxy Cygnus X-1



Black Hole studies with ASTROSAT

Stellar Mass Black Holes

Luminosity/Spectral state change monitoring (SSM)

Broadband spectra (SXT, LAXPC, CZTI)

Timing, fluctuation spectra - QPO, LFN (LAXPC)

Multi-wavelength campaign: jet launch in microquasars

Ultra Luminous X-ray Sources

Broadband spectra and timing/QPO : mass estimates

Active Galactic Nuclei

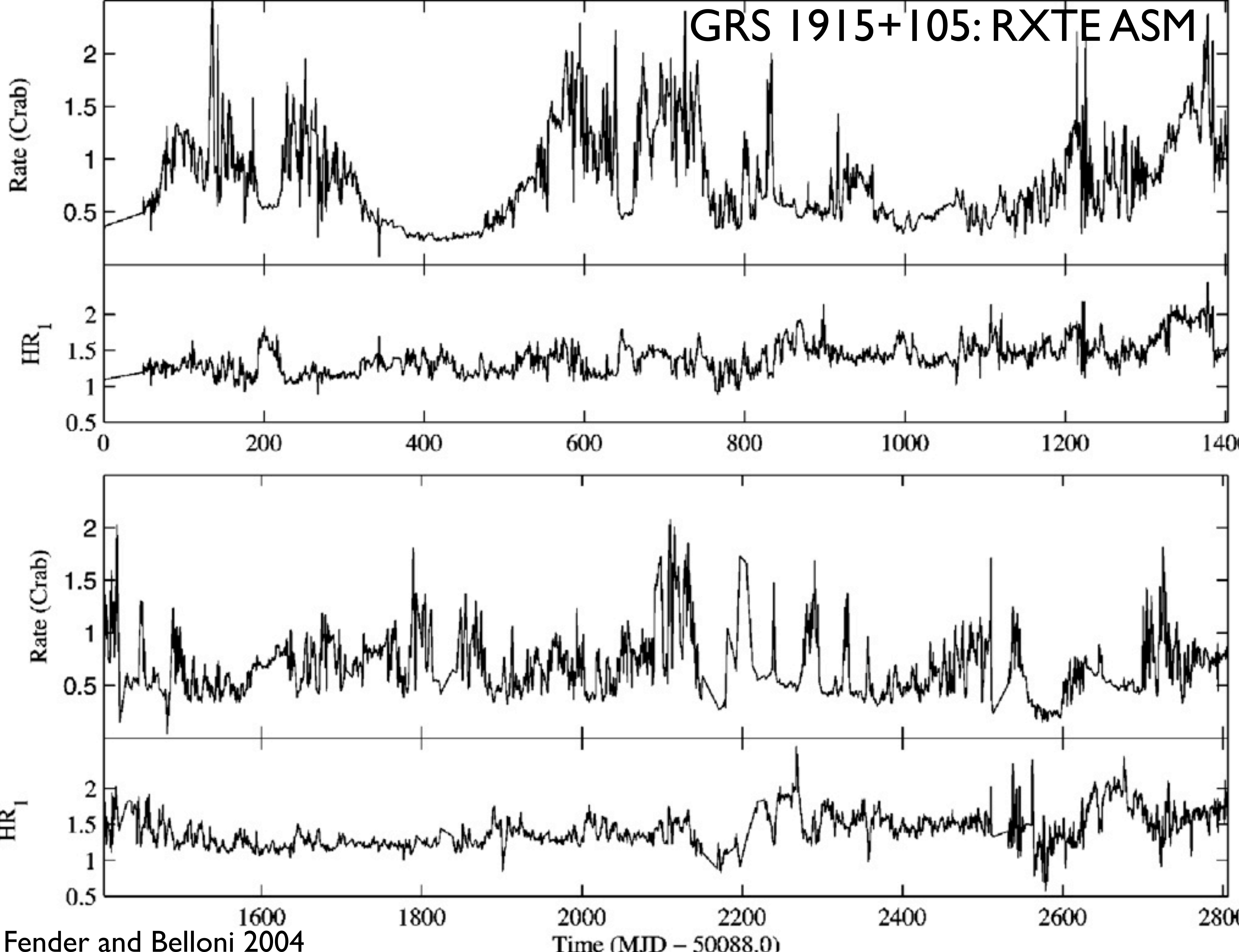
Simultaneous multi-wavelength monitoring plus

Broadband (Opt/UV-hard X-ray) spectra:

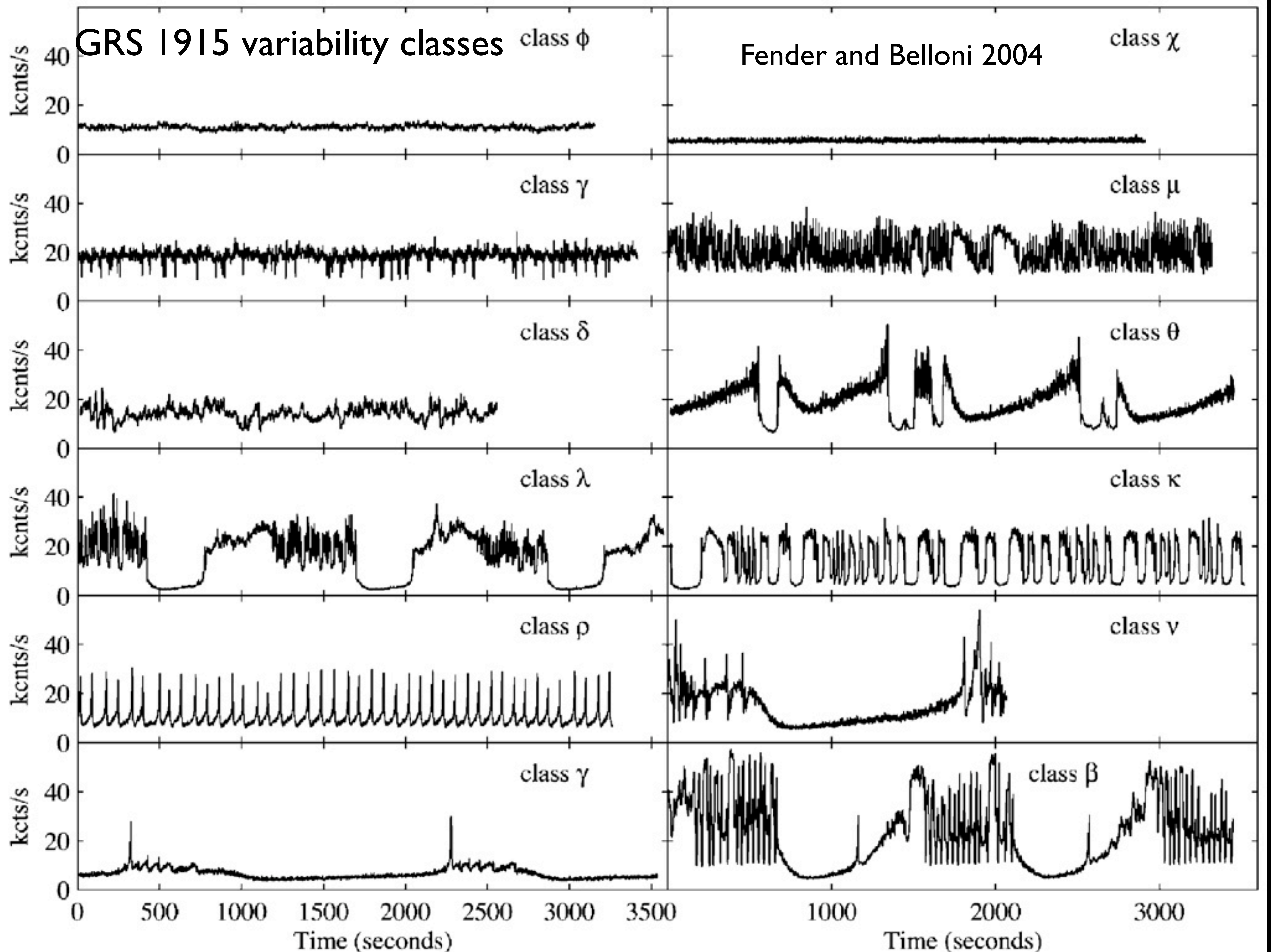
tests of Comptonization model

Possible QPOs in AGNs

GRS 1915+105: RXTE ASM



Fender and Belloni 2004



GRS 1915 variability classes
Fender and Belloni 2004
class φ
class χ
class γ
class μ
class δ
class θ
class λ
class κ
class ρ
class ν
class γ
class β
kcnts/s
kcts/s
Time (seconds)

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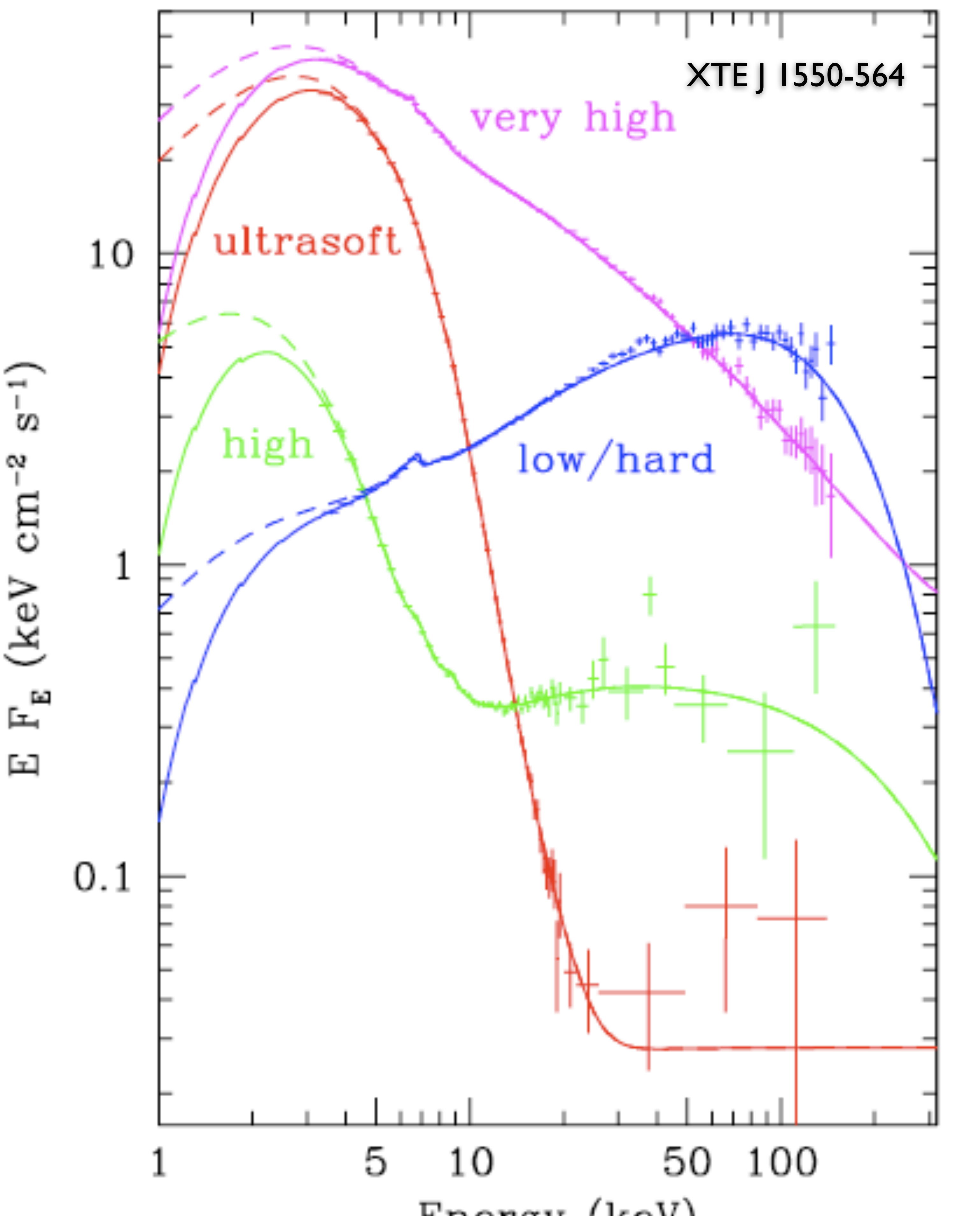
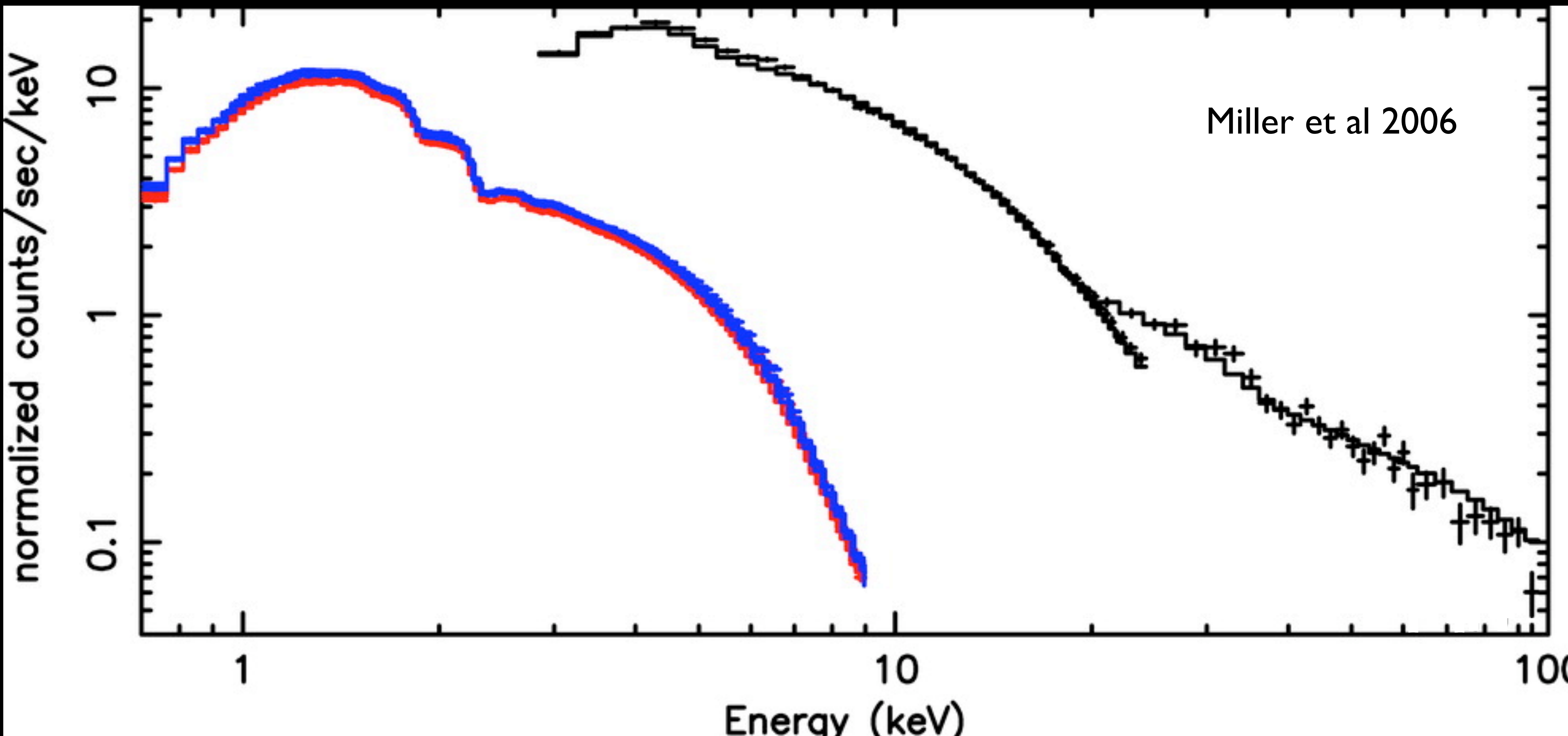
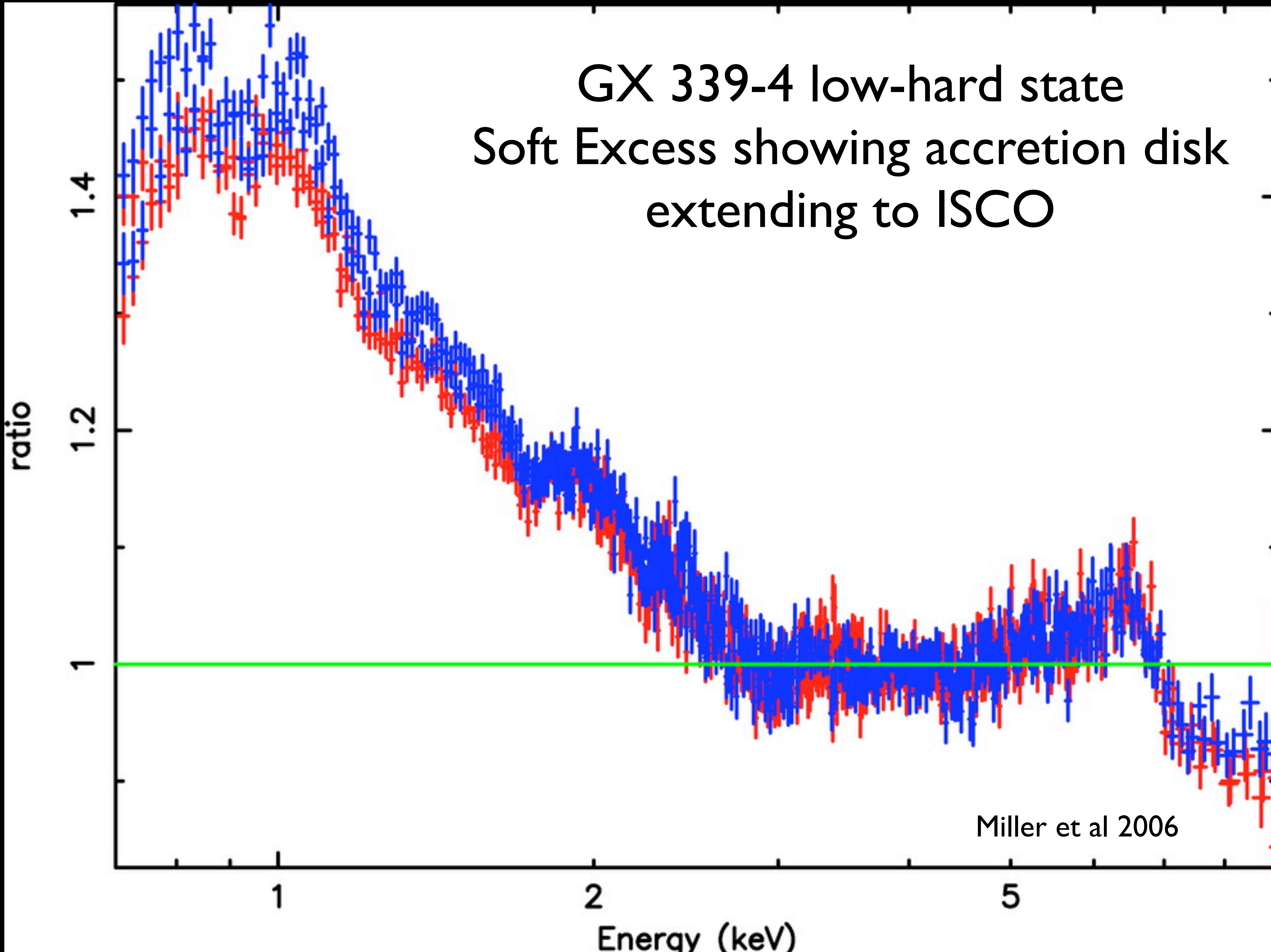


Spectral / Luminosity states of accreting BH

Zdziarski & Gierlinski 2004

GX 339-4 low-hard state
simultaneous XMM - RXTE spectrum





GX 339-4 low-hard state
Soft Excess showing accretion disk
extending to ISCO
Miller et al 2006
ratio
1.4
1.2
1
1
2
5
Energy (keV)

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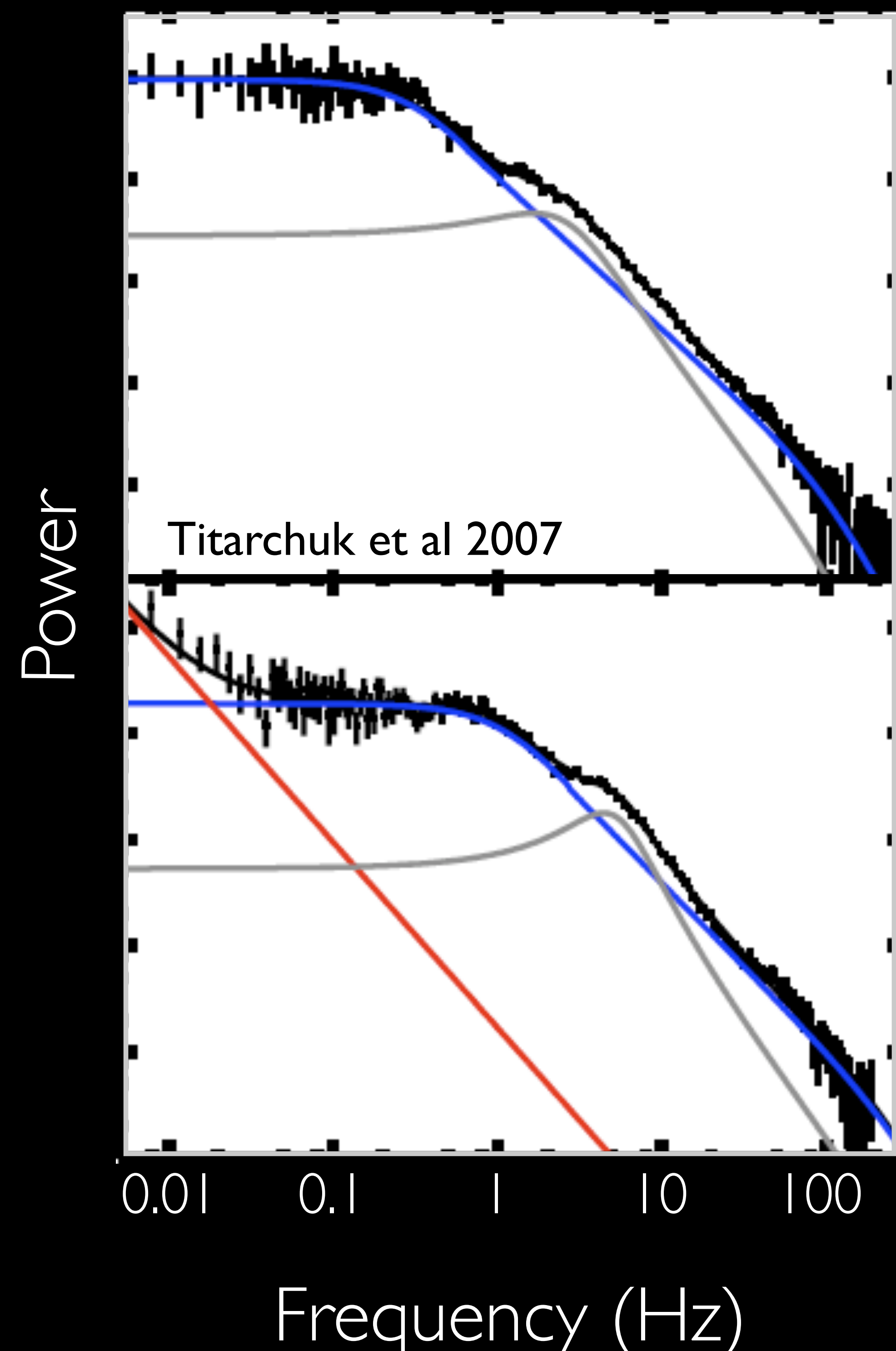
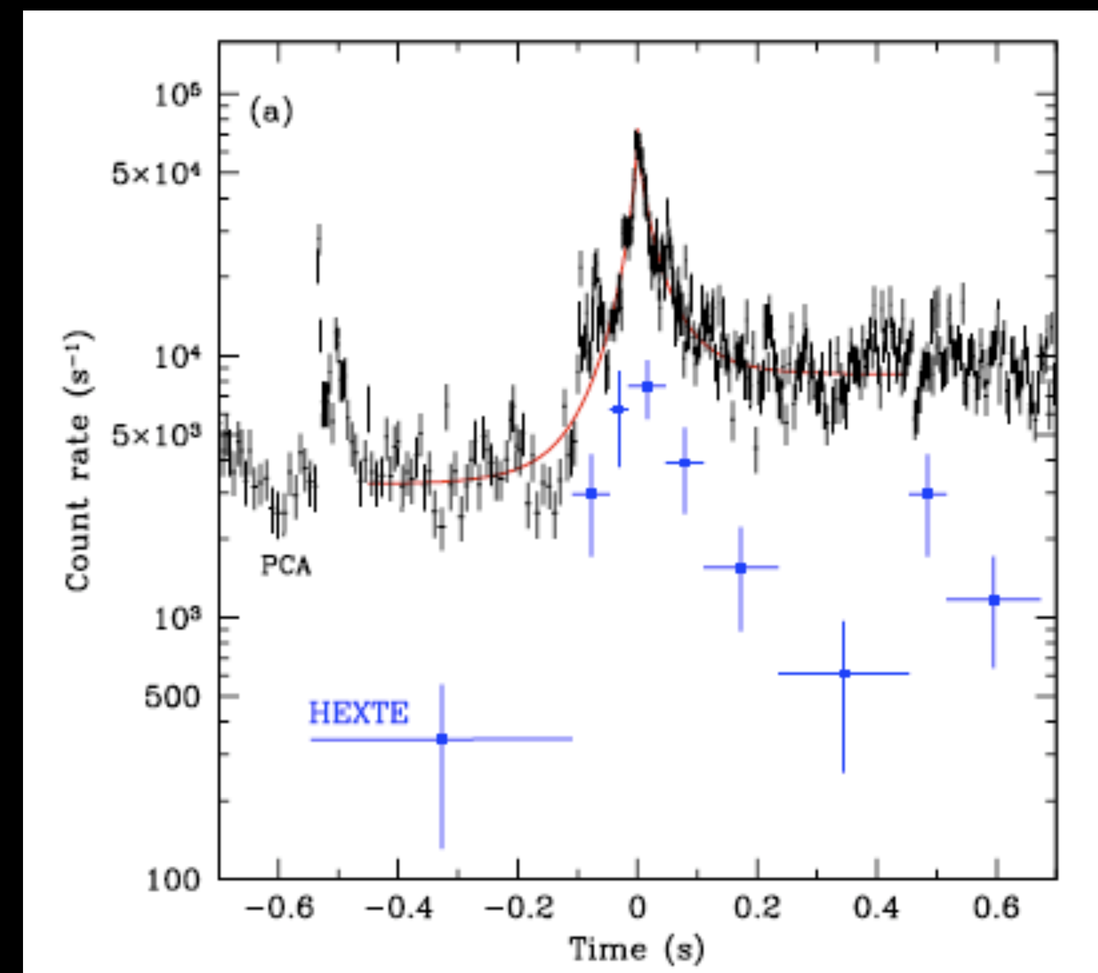
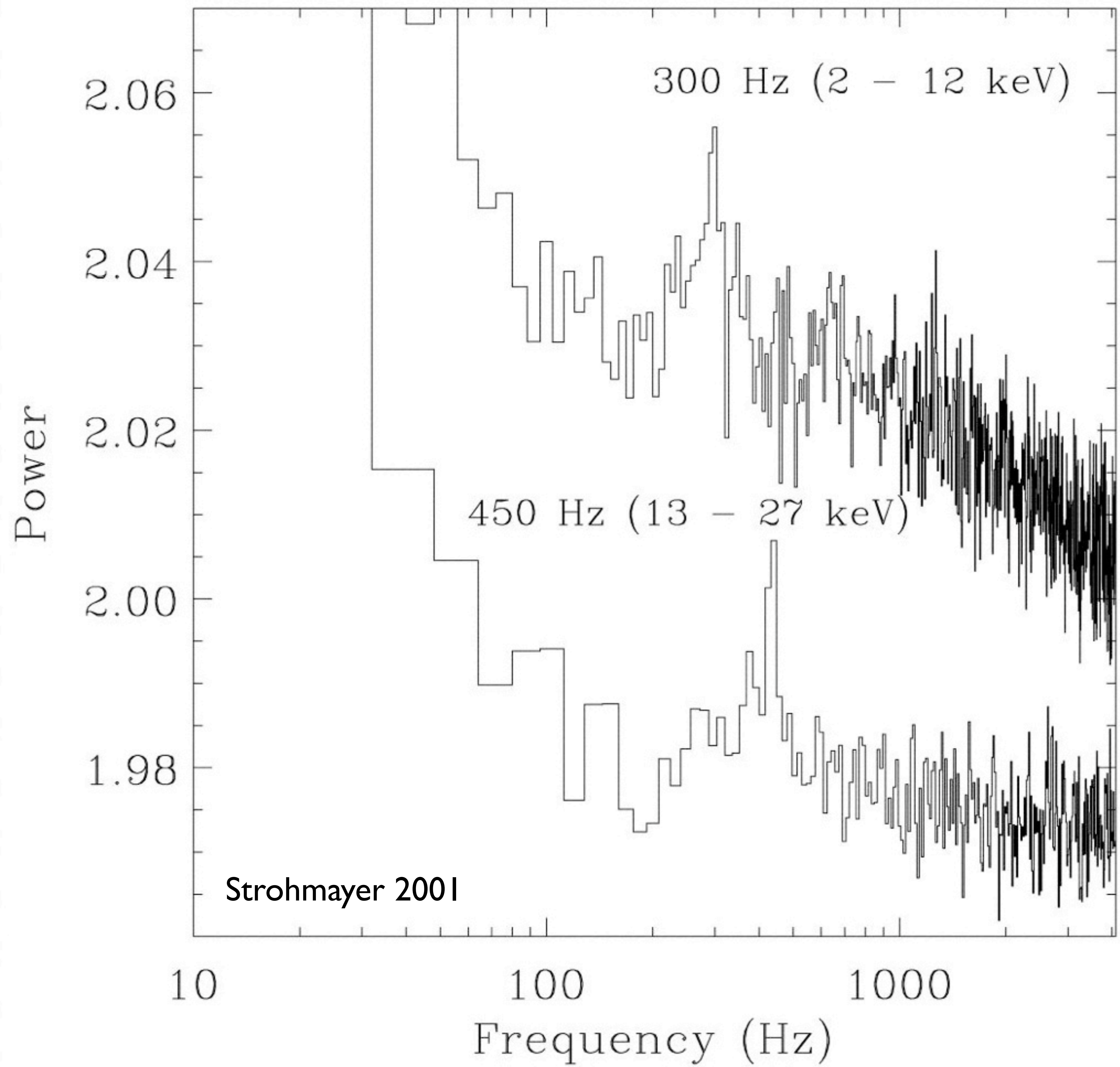
Cygnus X-1: variation of Power Density Spectrum



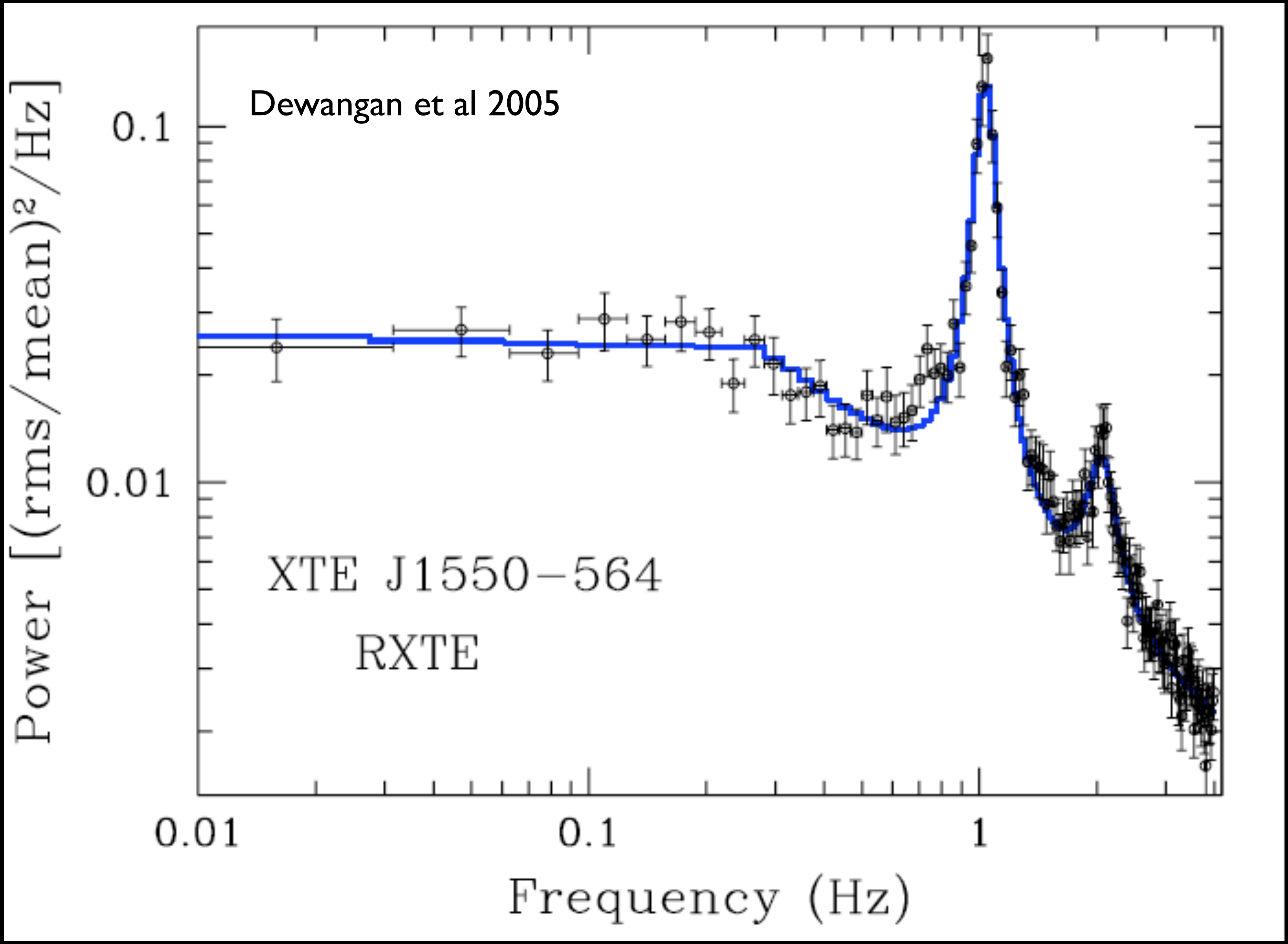
ms X-ray flare from Cyg X-1





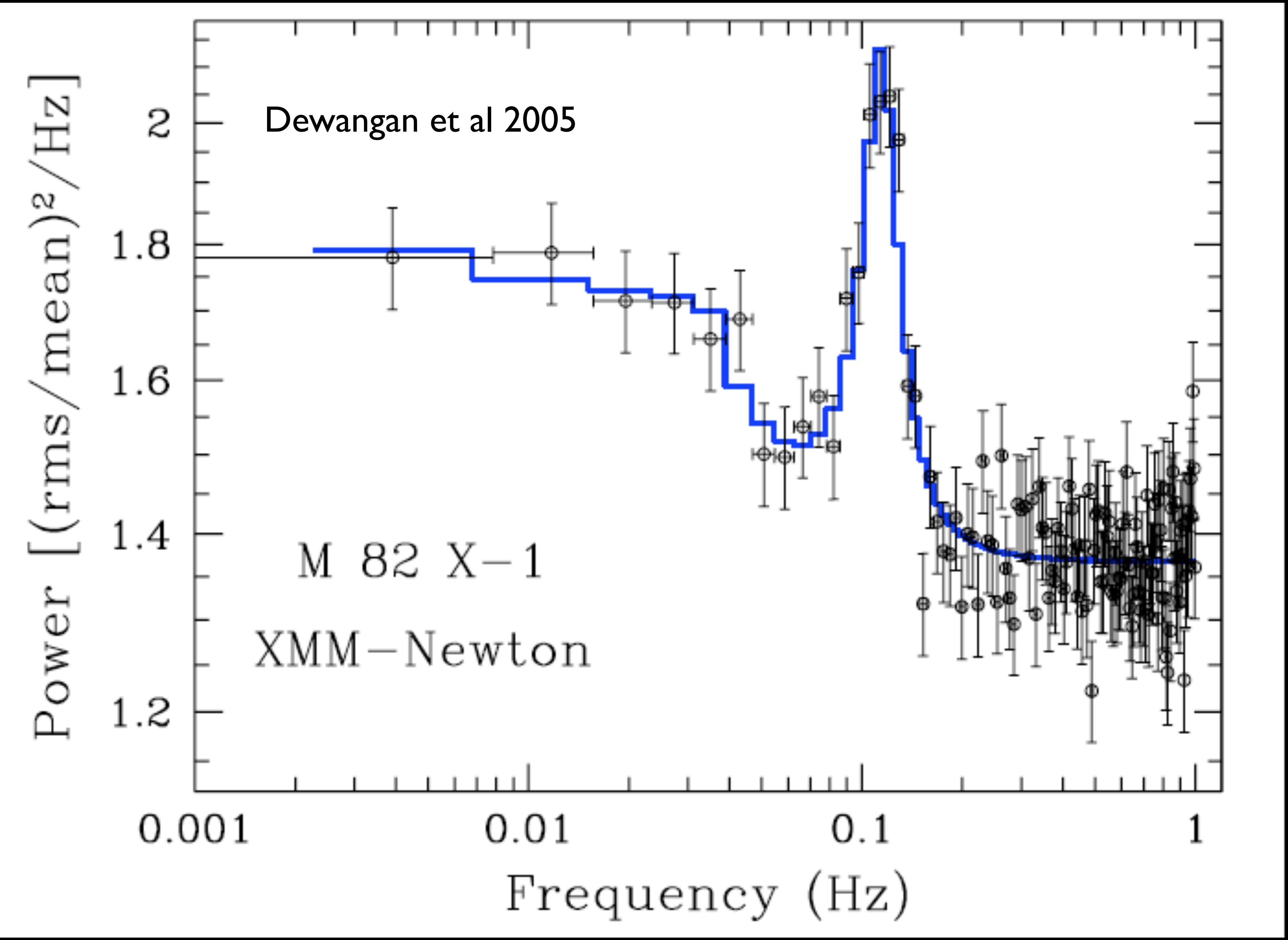
Black Hole twin QPO

GRO J1655-40

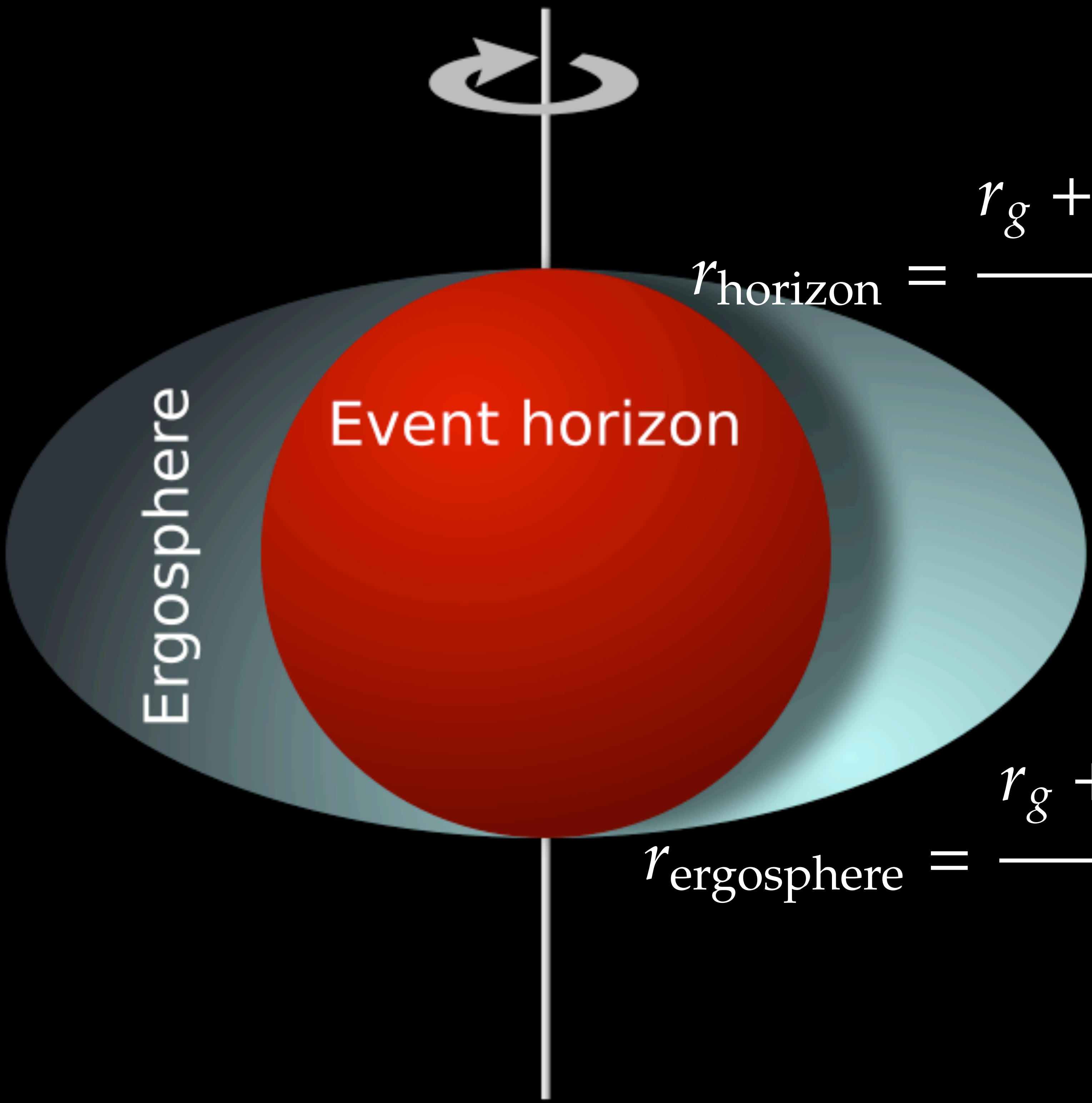


Dewangan et al 2005
XTE J1550−564
RXTE
Power [(rms/mean)²/Hz]
0.1
0.01
0.01
0.1
1
Frequency (Hz)

M82 ULX: Intermediate Mass Black Hole



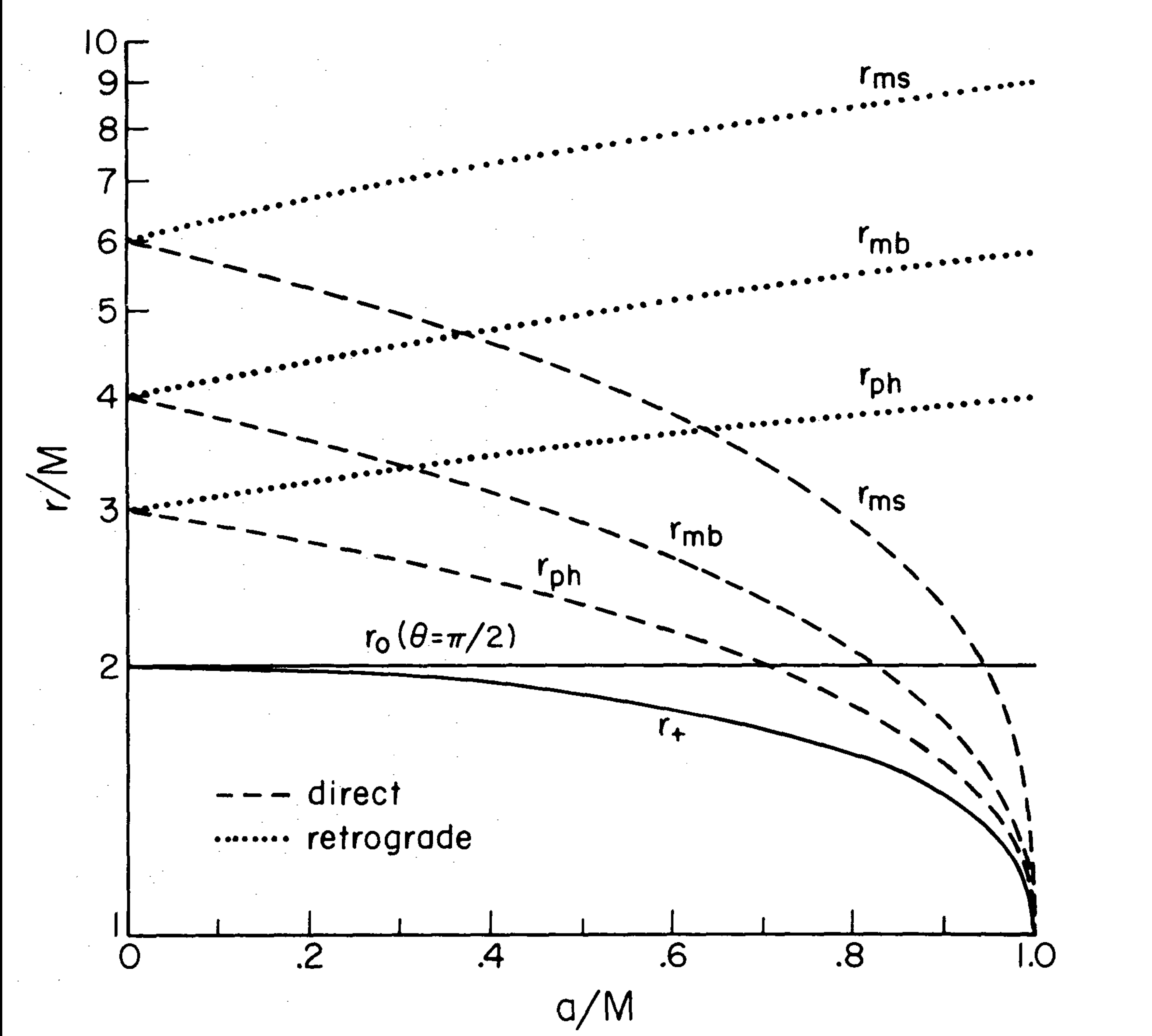
Kerr Black Hole



$$r_{\text{horizon}} = \frac{r_g + \sqrt{r_g^2 - 4\alpha^2}}{2}$$

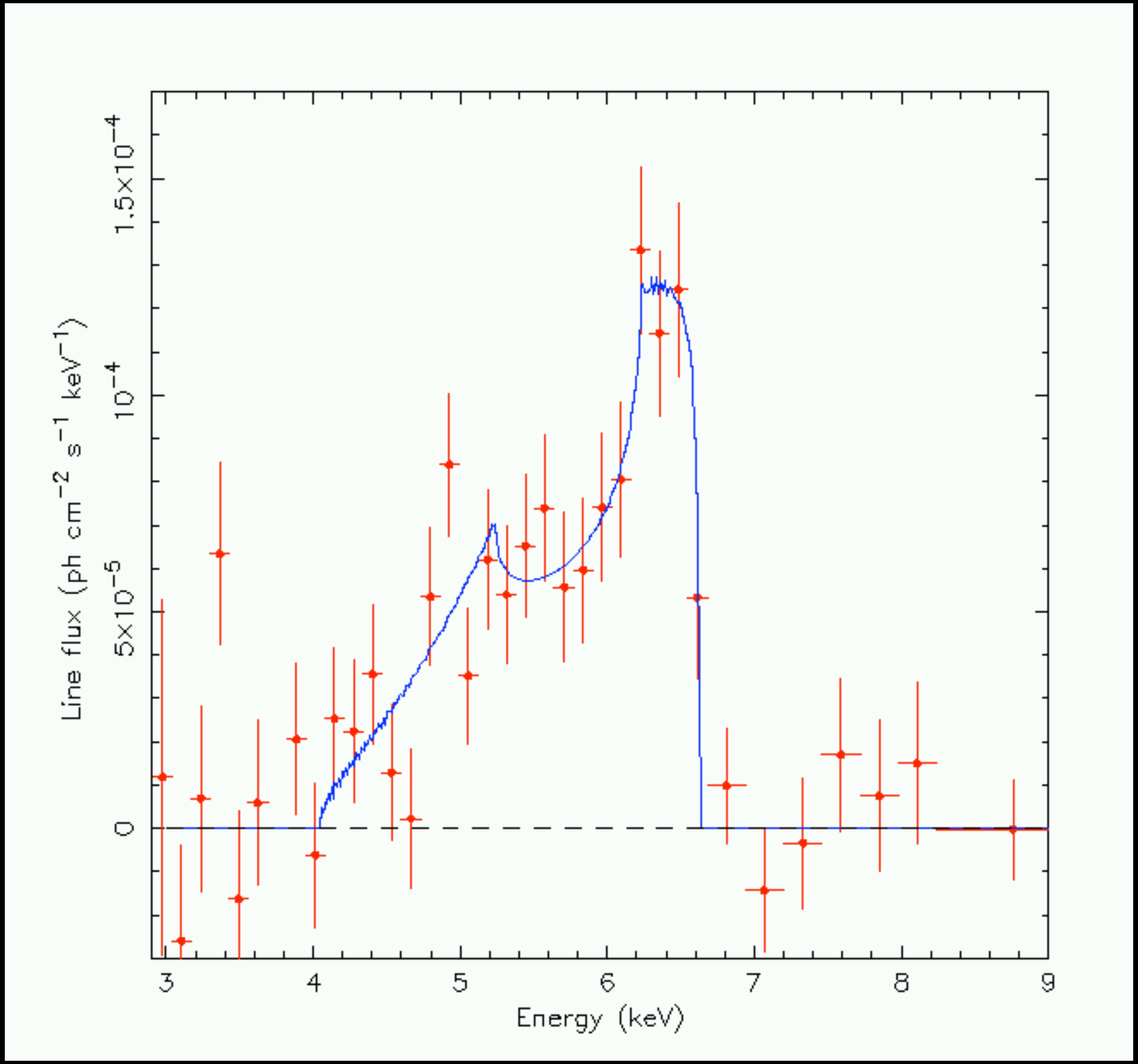
$$\alpha = \frac{J}{Mc}$$

$$r_{\text{ergosphere}} = \frac{r_g + \sqrt{r_g^2 - 4\alpha^2 \cos^2 \theta}}{2}$$

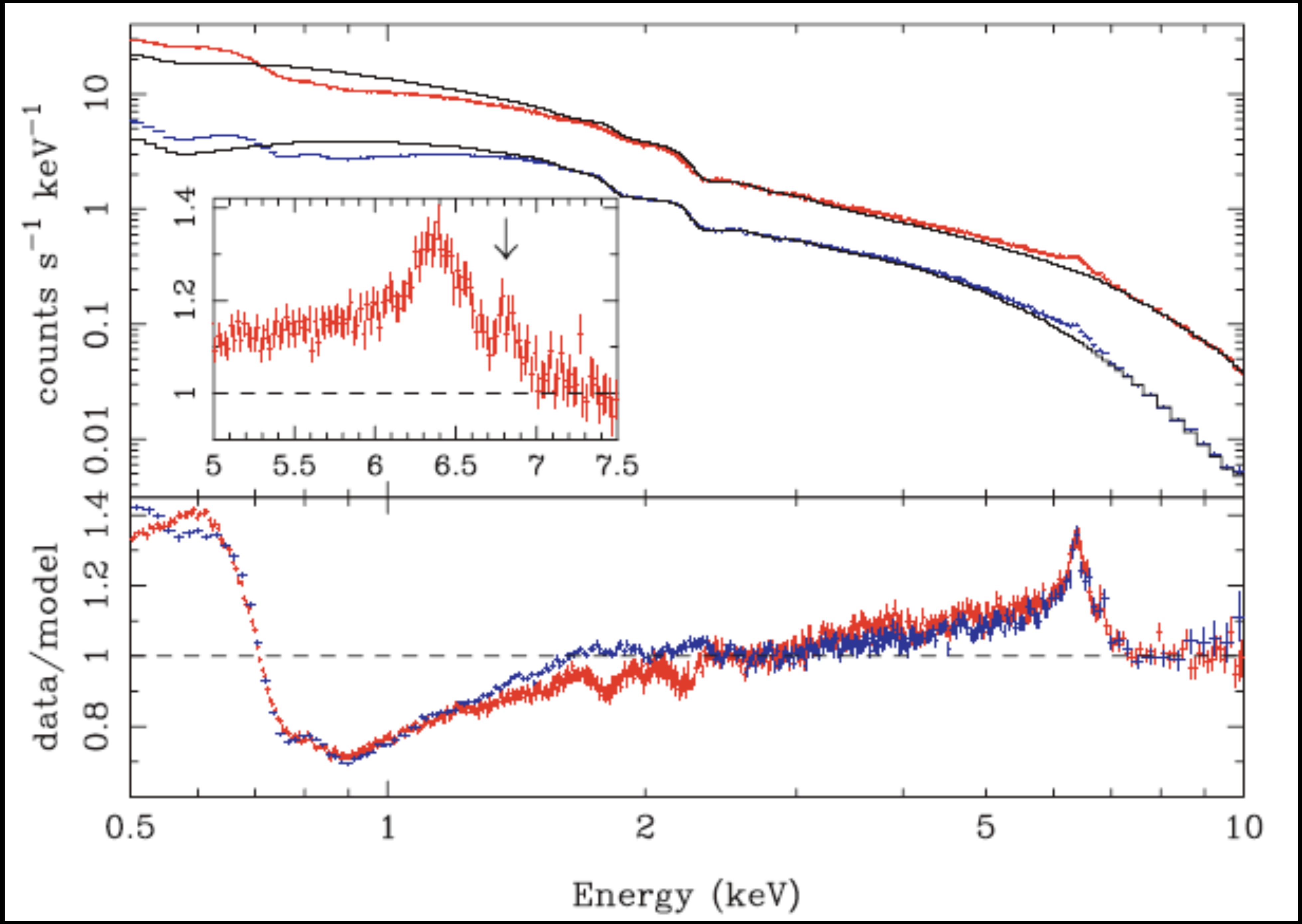


10
9
8
7
6
5
4
3
2
1
r/M
0
.2
.4
.6
.8
1.0
a/M
r_{ms}
r_{mb}
r_{ph}
r_{ms}
r_{mb}
r_{ph}
$r_0(\theta=\pi/2)$
r_+
direct
retrograde

MCG 6-30-15 ASCA



MCG 6-30-15 XMM



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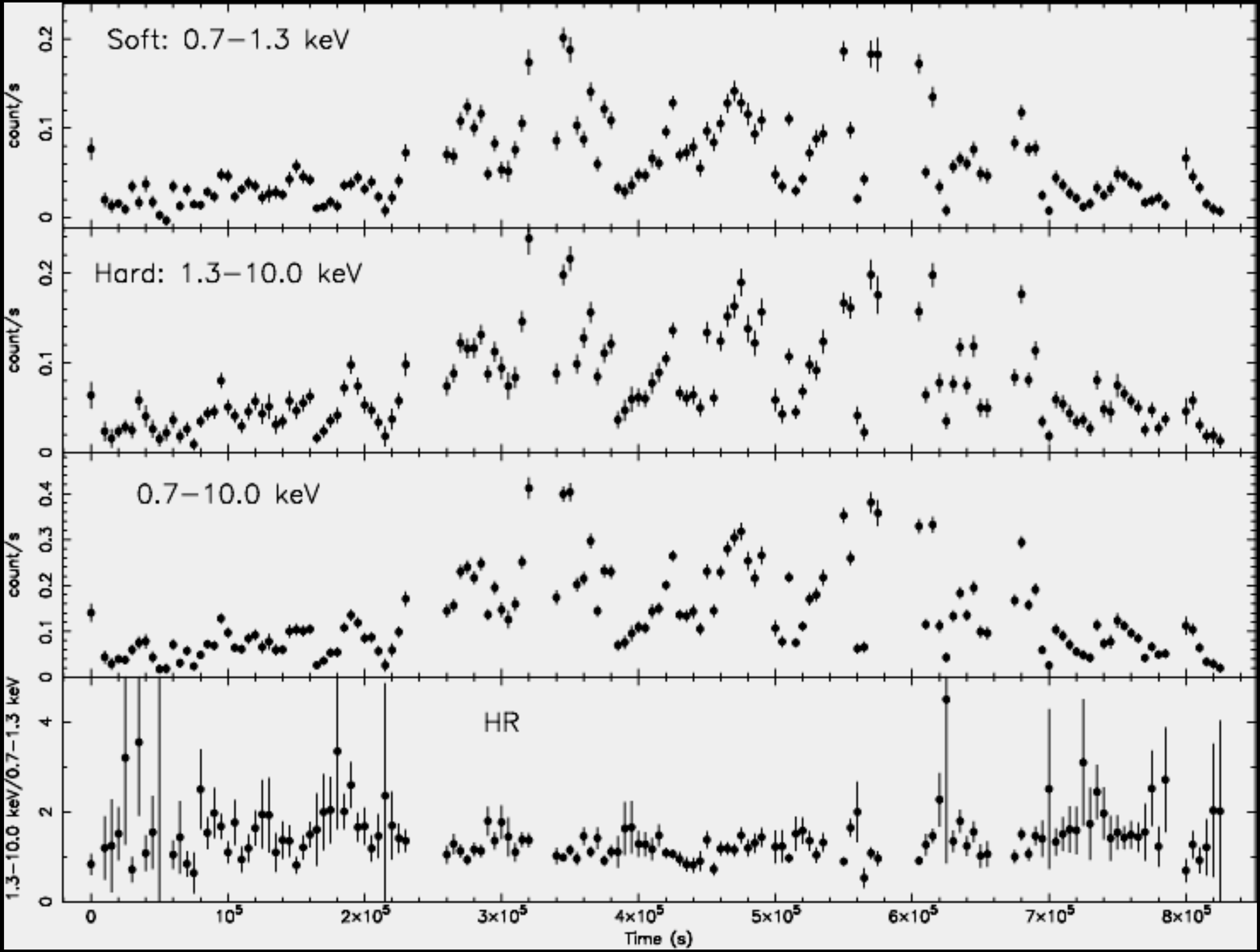
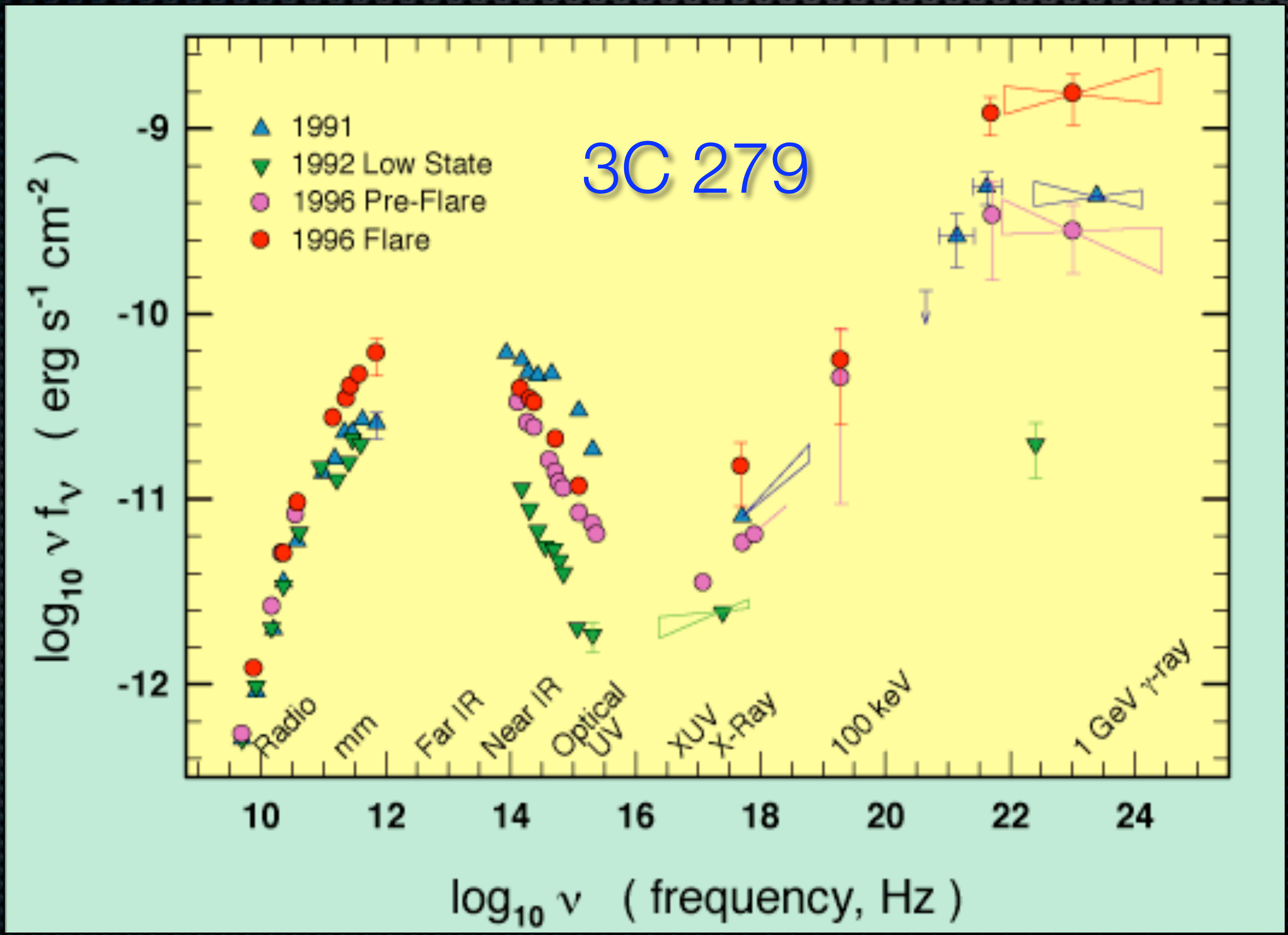
tests of Comptonization model
Possible QPOs in AGNs



Rapid X-ray variability in Seyfert 1 galaxy IRAS 13224-3809 observed from the ASCA satellite

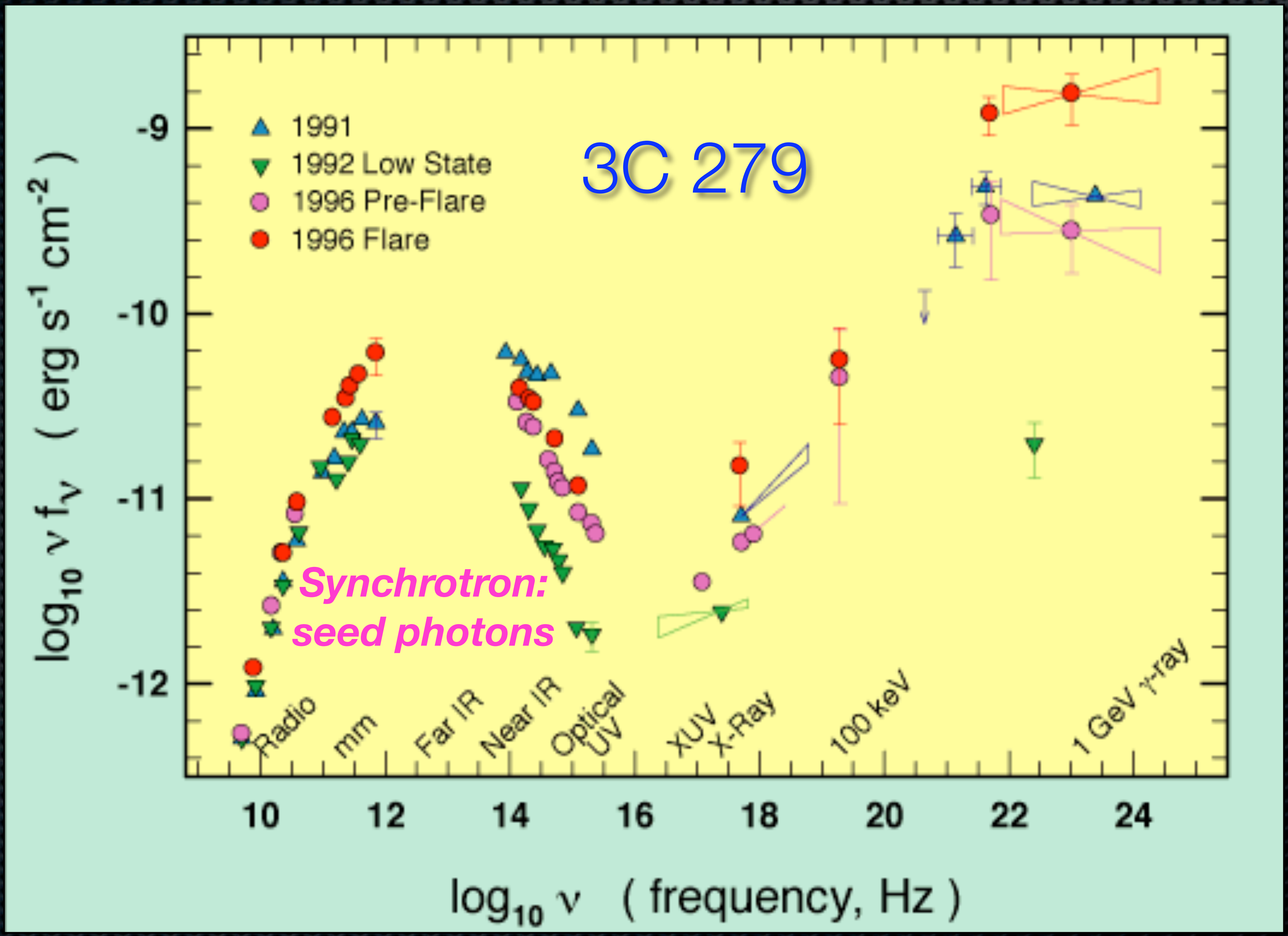
(Dewangan et al 2002)

Multiwavelength science:
AGN :: Blazars

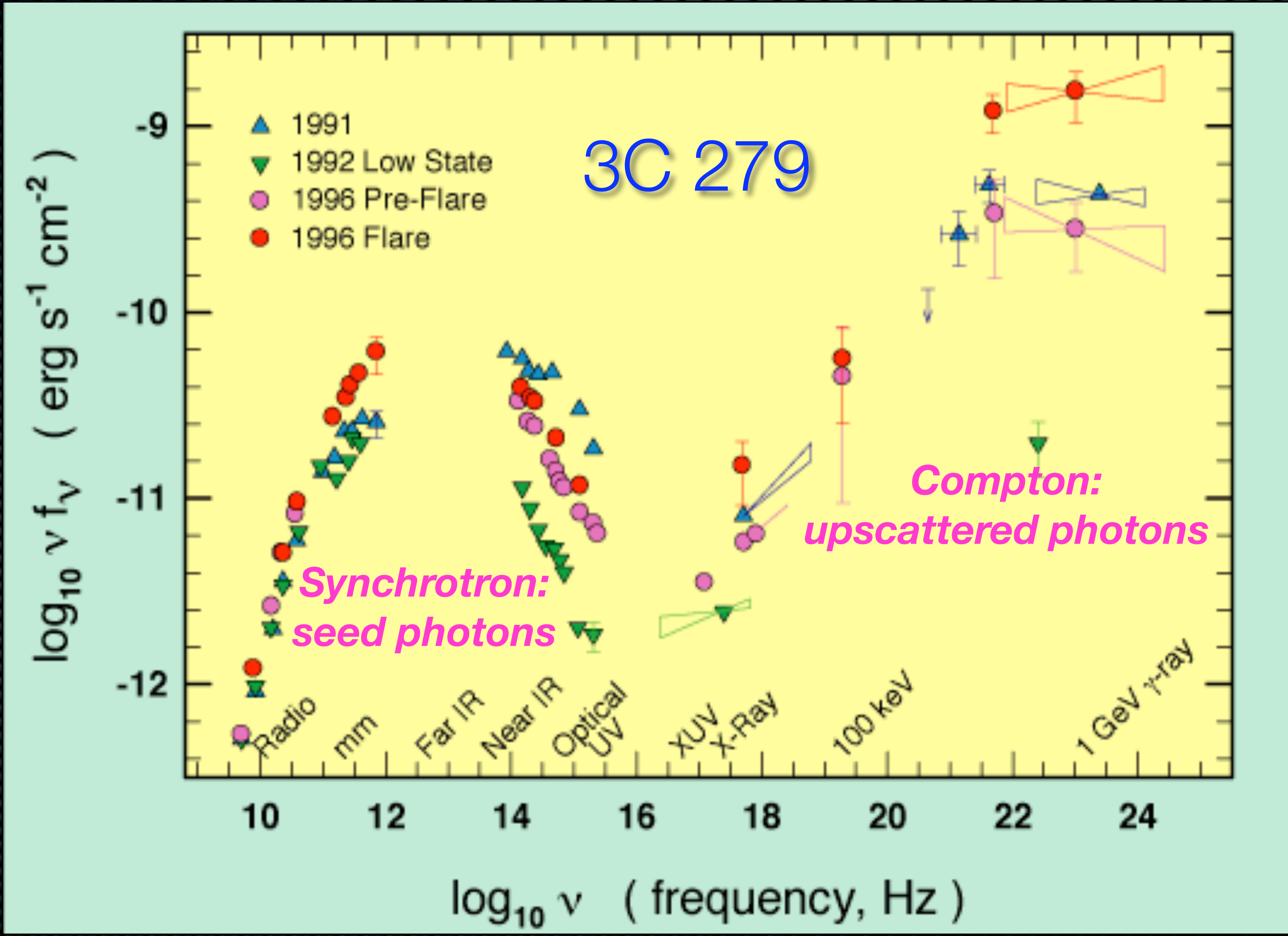


Multiwavelength science:

AGN :: Blazars

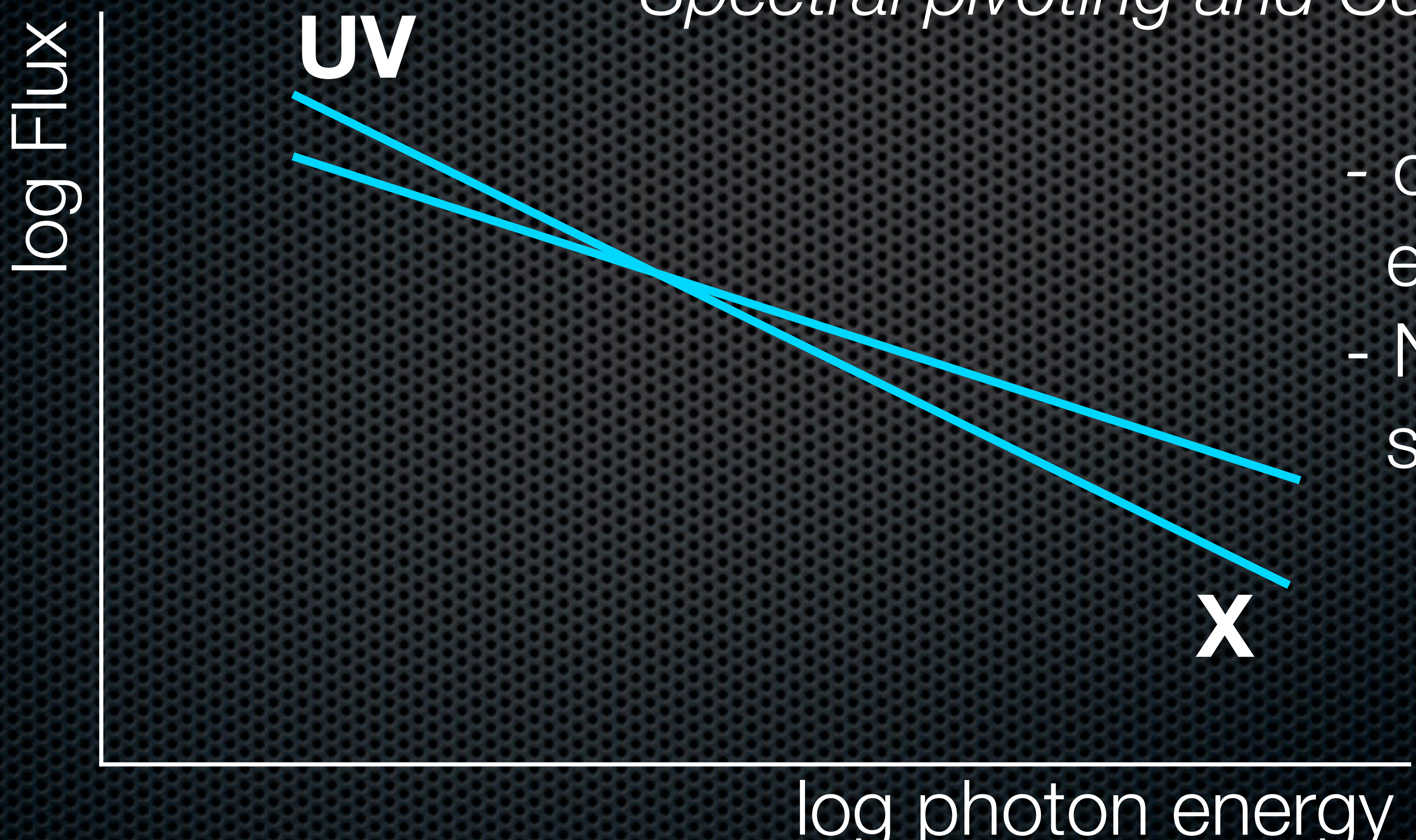


Multiwavelength science:
AGN :: Blazars



Multiwavelength science:
AGN :: Disk photons+Compton

Spectral pivoting and Comptonization cycle

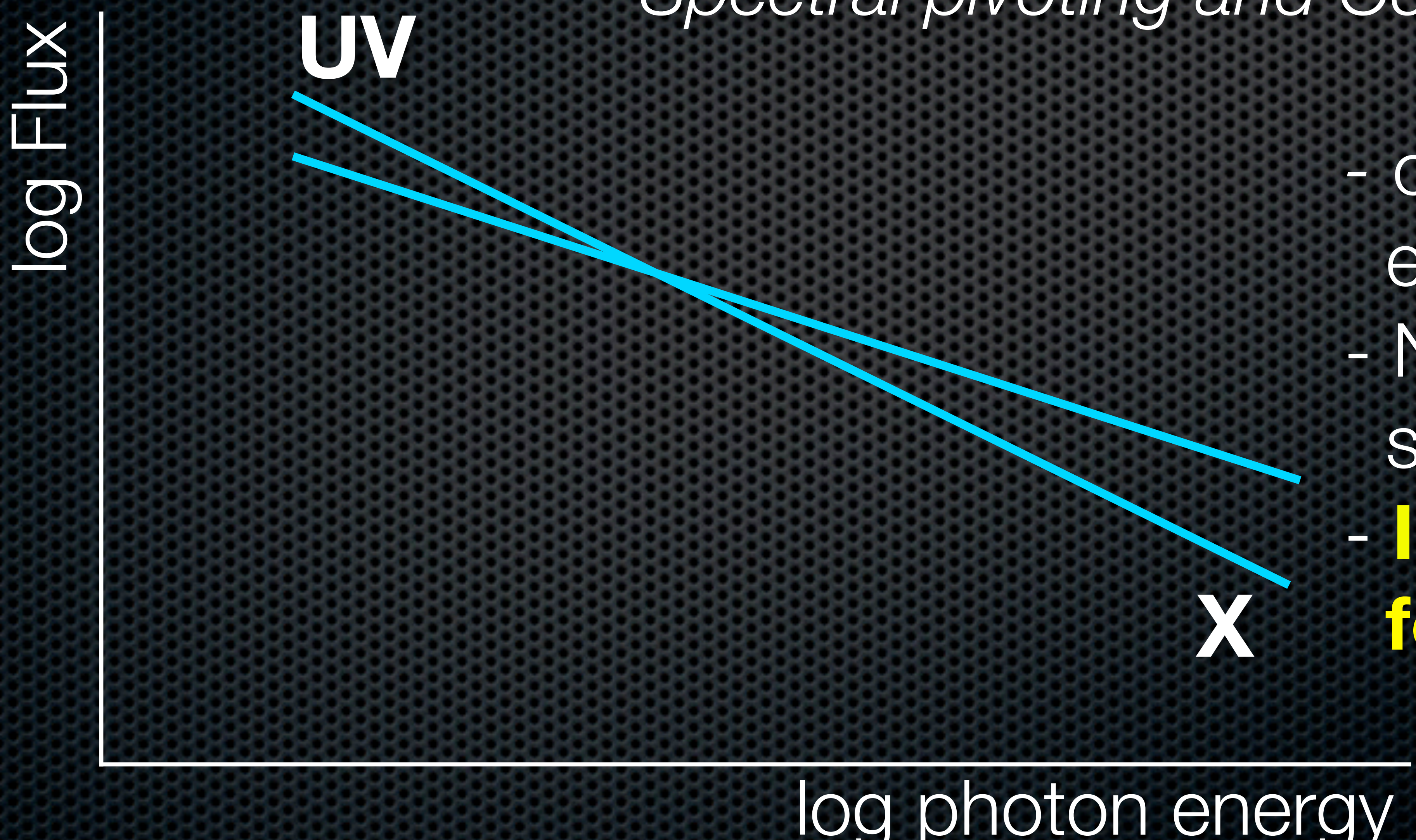


- correlated variability expected
- No detailed study so far

Multiwavelength science:

AGN :: Disk photons+Compton

Spectral pivoting and Comptonization cycle



- correlated variability expected
- No detailed study so far
- **Important niche for ASTROSAT**

ASTROSAT will be a multi-purpose observatory.
Will operate via AO, proposals

Proposals may be made for one or more of the co-aligned instruments

Proposals will be peer reviewed.
Acceptance will be decided by the ASTROSAT time allocation committee

Rights to data obtained with the instruments asked for in the proposal will rest with the PI of the proposal for 18 months. Public release of data after the expiry of the lock-in period.

ASTROSAT time allocation

T0 +	1st yr	2nd yr	3rd yr	4th yr
Instrument teams	6m - PV 6m - GT	50%	30%	-
CSA		3%	3%	3%
Leicester		3%	3%	3%
Open IND	-	35%	45%	65%
Open Intl	-	-	10%	20%
TOO	-	5%	5%	5%
Calib	-	4%	4%	4%

Summary

- ASTROSAT will provide an important platform to study regions of strong gravity.
- Large fraction of ASTROSAT observing time will be open to the Indian community.
- Project ideas are welcome. For details/discussions/assistance contact any of us in the ASTROSAT community.

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http://meghnad.iucaa.ernet.in/~astrosat/

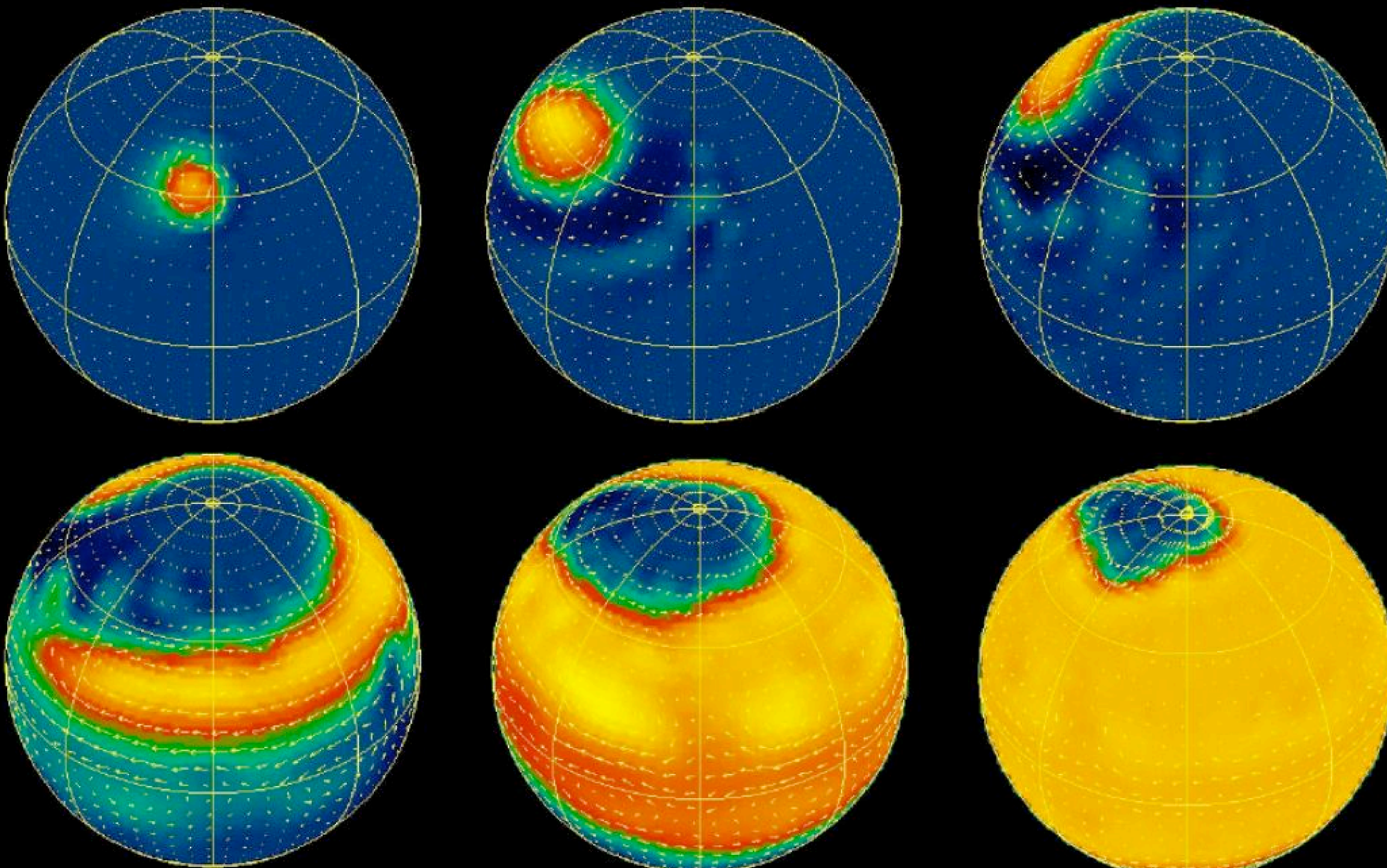
Thank you

ASTROSAT

	Energy range	Description	Angular resolution	sensitivity
SXT	0.3 – 8 keV	Focussing X-ray mirror + CCD (39 shells) FOV=42’	3 – 4 arcmin	~0.01milliCrab (10,000 sec)
LAXPC	2 – 80 keV	Large proportional counters (3)	1 deg collimator	0.1 milliCrab (1000 sec)
CZTI	10 – 150 keV	CZT array (hard X-ray imager)	8 arcmin	0.5 milliCrab (1000 sec)
SSM	2 – 10 keV	All sky monitor (3) on a rotating platform	5 – 10 arcmin	30 milliCrab (300 sec)
UVIT	1300 – 6500 Ang	Twin RC telescopes – 40 cm each (NUV,VIS, FUV)	1.8 arc sec	21 magnitude (1800 sec)

Ignition and spreading

2D shallow water model on a sphere
ν=300 Hz; 200 revolutions



Spitkovsky, Levin, & Ushomirsky (2002)