A tale of radiation pressure dominated disks: theory, observations, and cycles of life.

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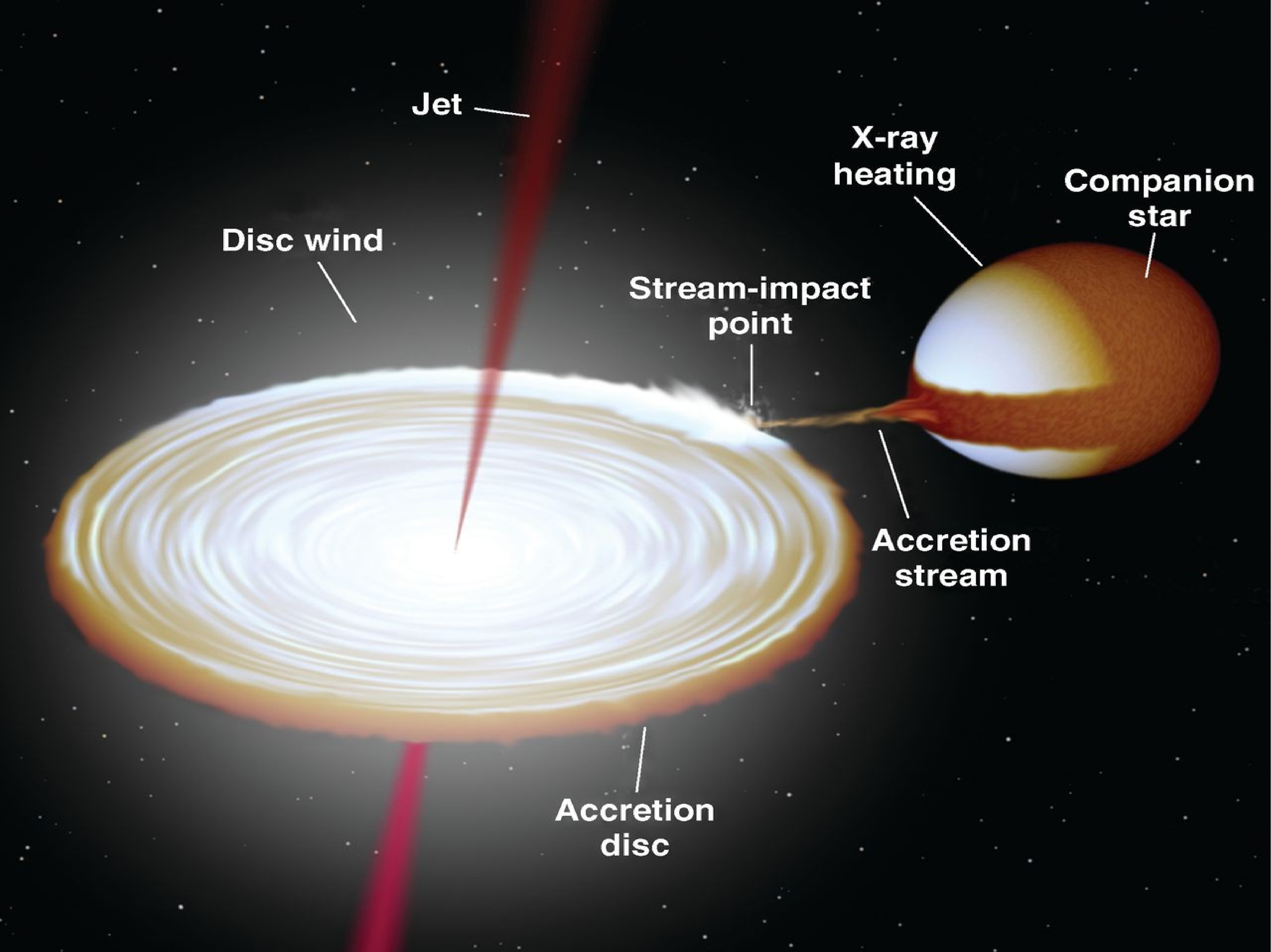
THE ROYAL SOCIETY

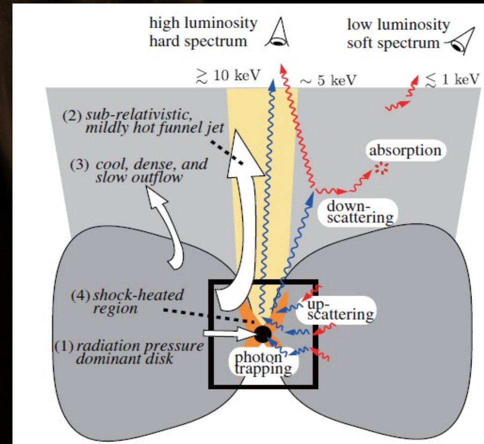

Jet
X-ray heating
Companion star
Disc wind
Stream-impact point
Accretion stream
Accretion disc

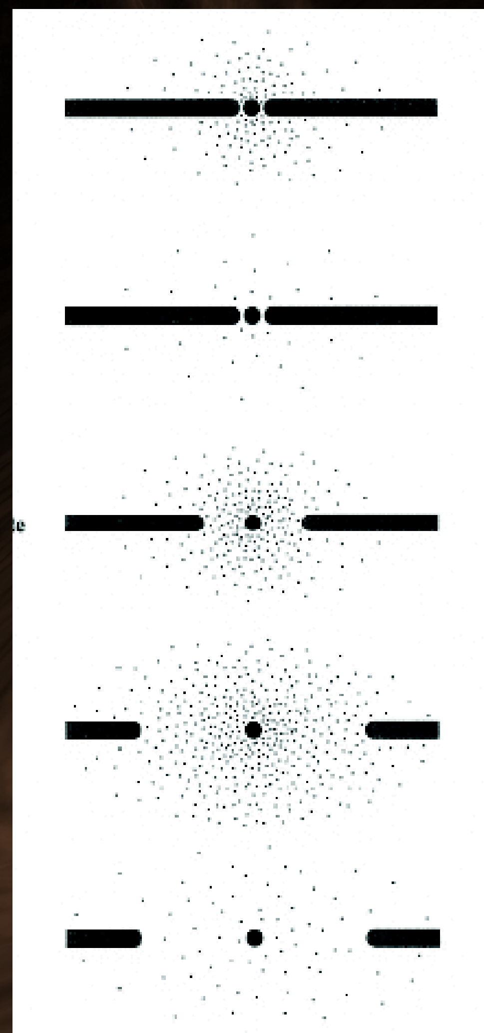
The Eddington Limit

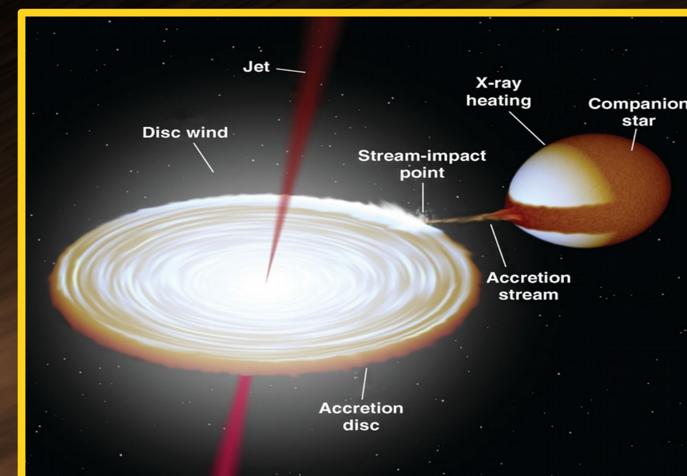
- steady spherically symmetrical accretion
- Fully ionized hydrogen
- Radiation exerts force on the electrons via Thomson scattering

$$L_{edd} = 1.2 \times 10^{38} \left(\frac{M}{M_\odot} \right) \quad \text{erg/sec,}$$

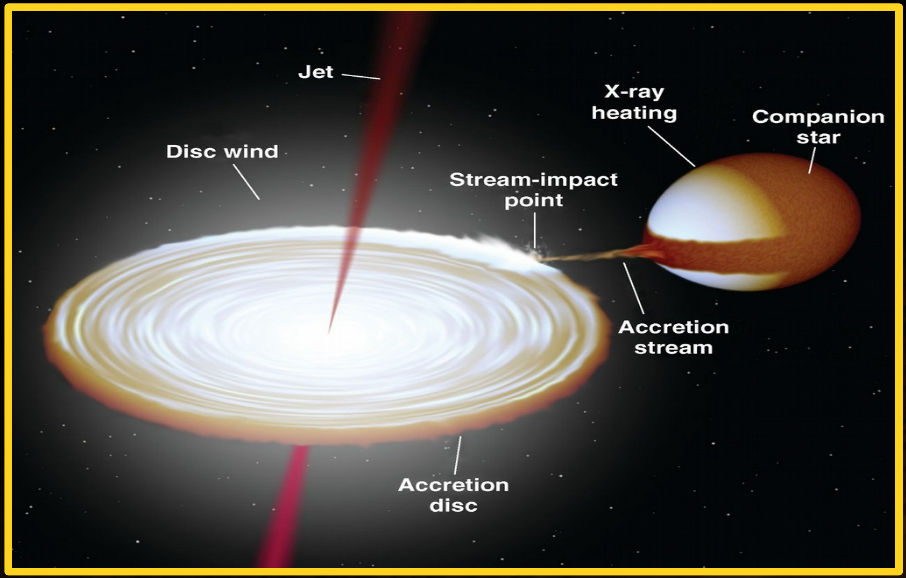
Accretion Rate



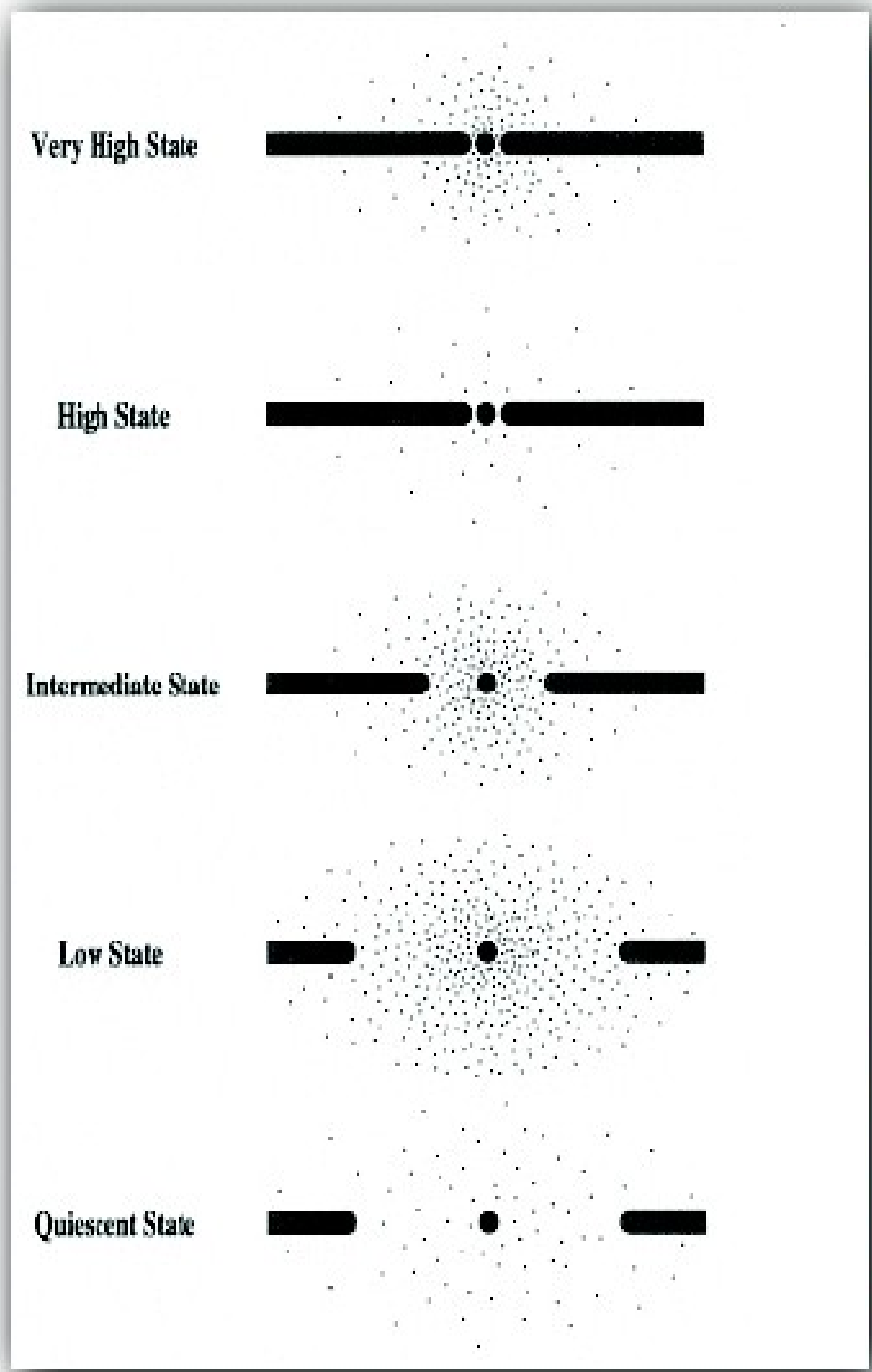


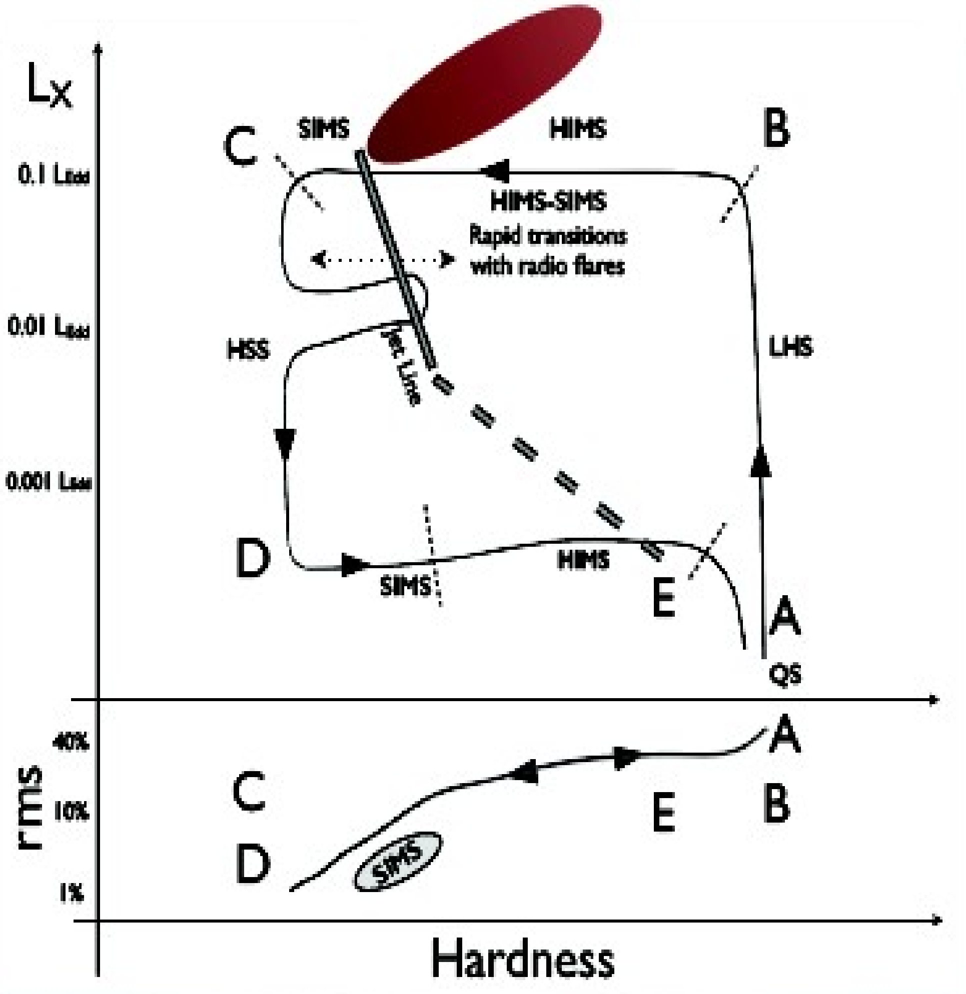


Assumptions:



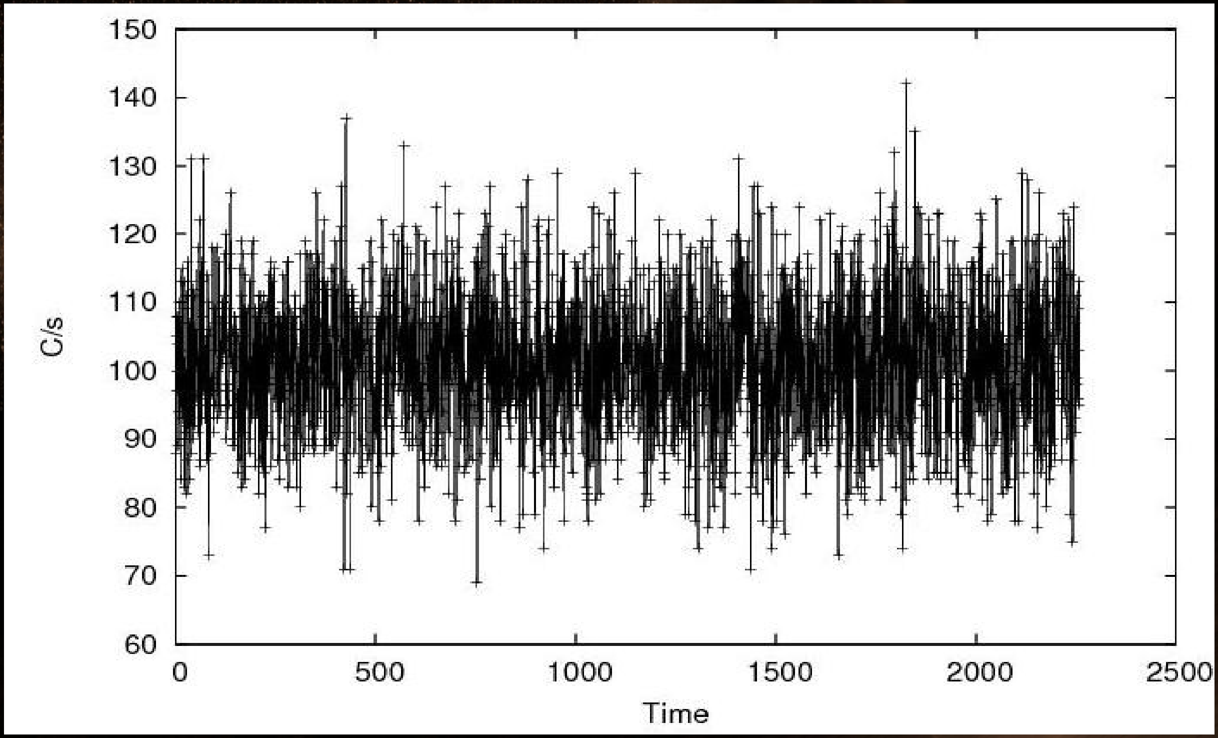
- Spherical accretion (??)
- Close enough to the compact object, all disks are the same! (?)
- There should be no difference in the macro-physics of accretion onto a BH and a NS. (???)
- Inclination is not an issue (????)
  - or we accept that we cannot do much about it


Very High State
High State
Intermediate State
Low State
Quiescent State

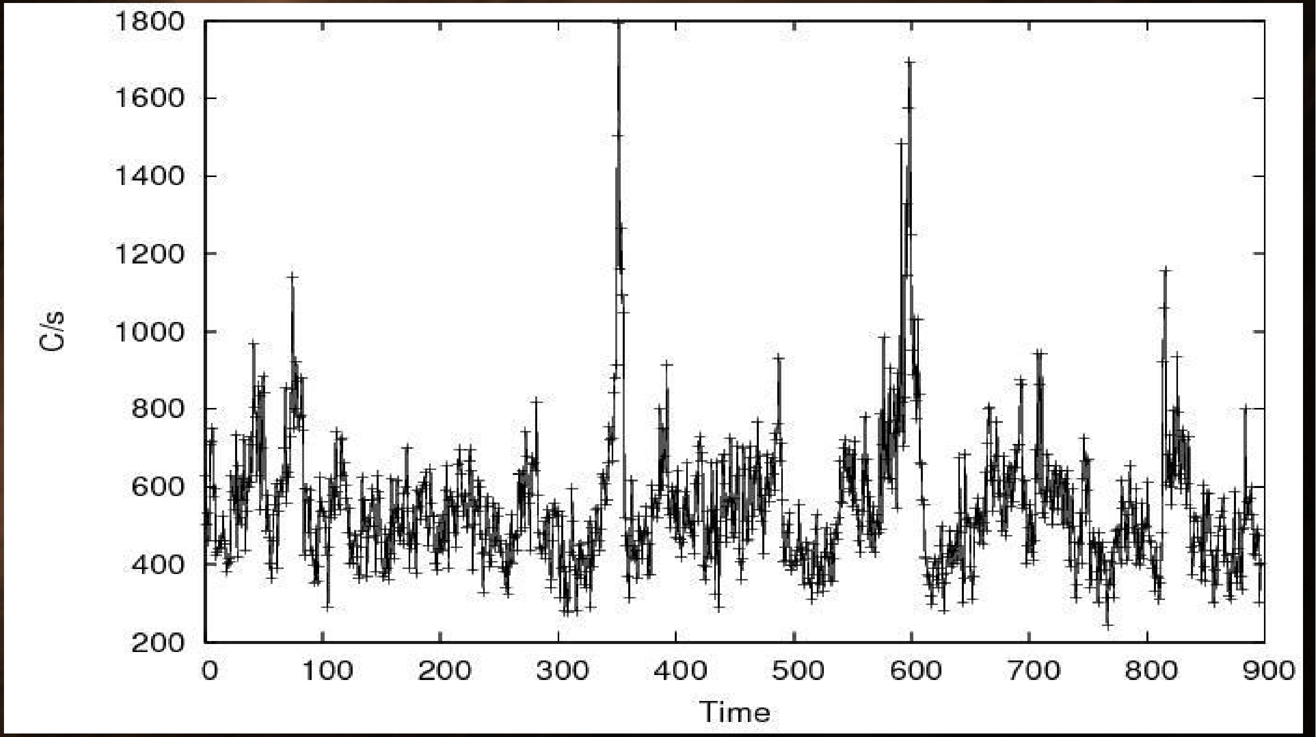

Lx
0.1 LEdd
0.01 LEdd
0.001 LEdd
C
SIMS
HIMS
B
HIMS-SIMS
Rapid transitions
with radio flares
HSS
Jet Line
LHS
D
SIMS
HIMS
E
A
QS
rms
40%
10%
1%
A
C
E
B
D
SIMS
Hardness

Disk is unstable when you reach Eddington....

- Actually, the disk becomes thermally unstable at around a few % Eddington! thanks to radiation from the inner parts of the disk.
- Many theoretical work on this subject. Prediction: limit cycles (Honma et al. 1992;Szuszkiewicz & Miller 1998; Janiuk et al. 2002; Li et al. 2007)
- Have we seen disk instabilities?



C/s
Time



C/s
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Disk is unstable when you reach Eddington....

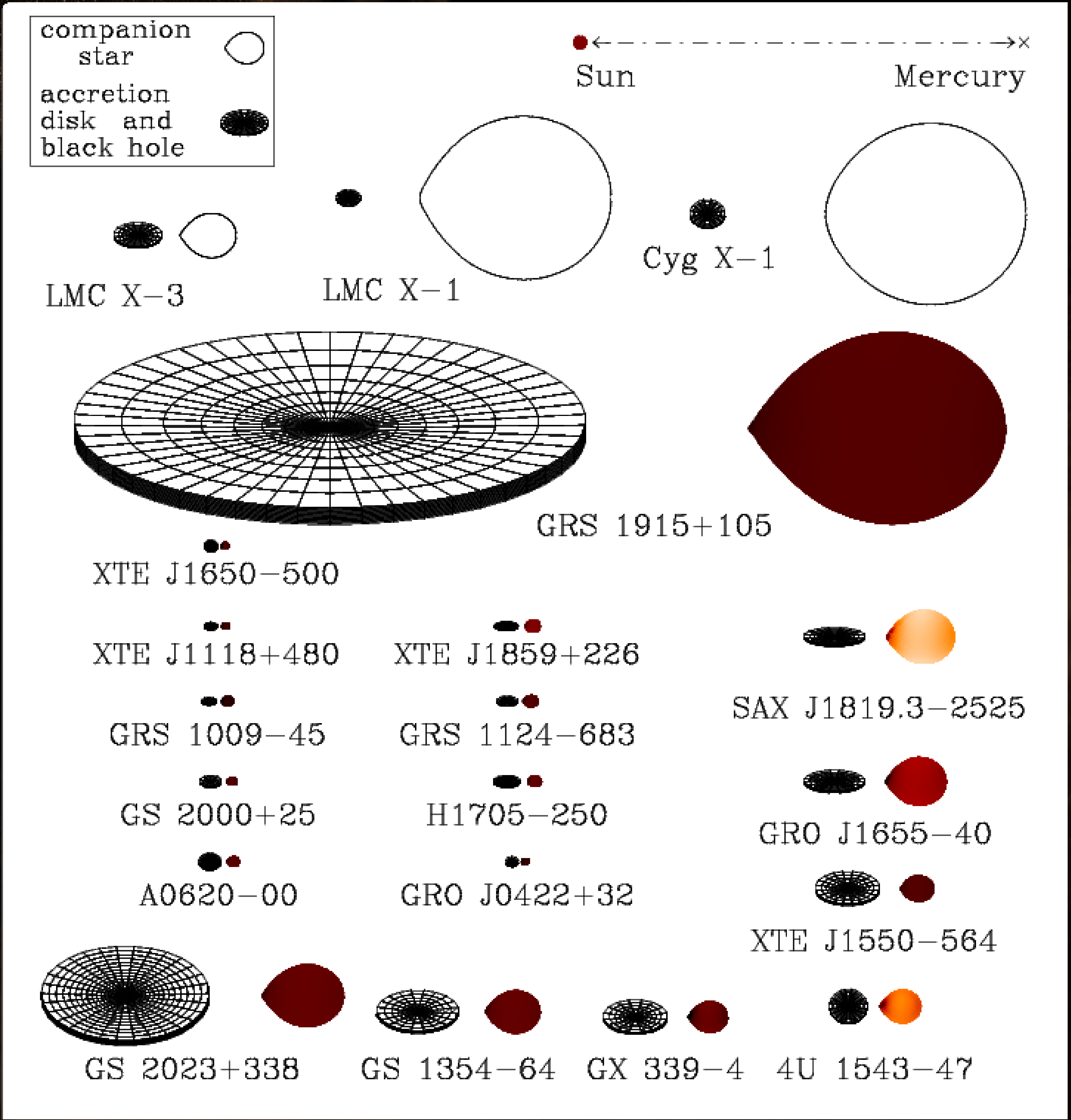
- Actually, the disk becomes thermally unstable at around a few % Eddington! thanks to radiation from the inner parts of the disk.
- Many theoretical work on this subject. Prediction: limit cycles (Honma et al. 1992;Szuszkiewicz & Miller 1998; Janiuk et al. 2002; Li et al. 2007)
- Have we seen disk instabilities? Yes... for many years... but in one single source:

  GRS 1915+105

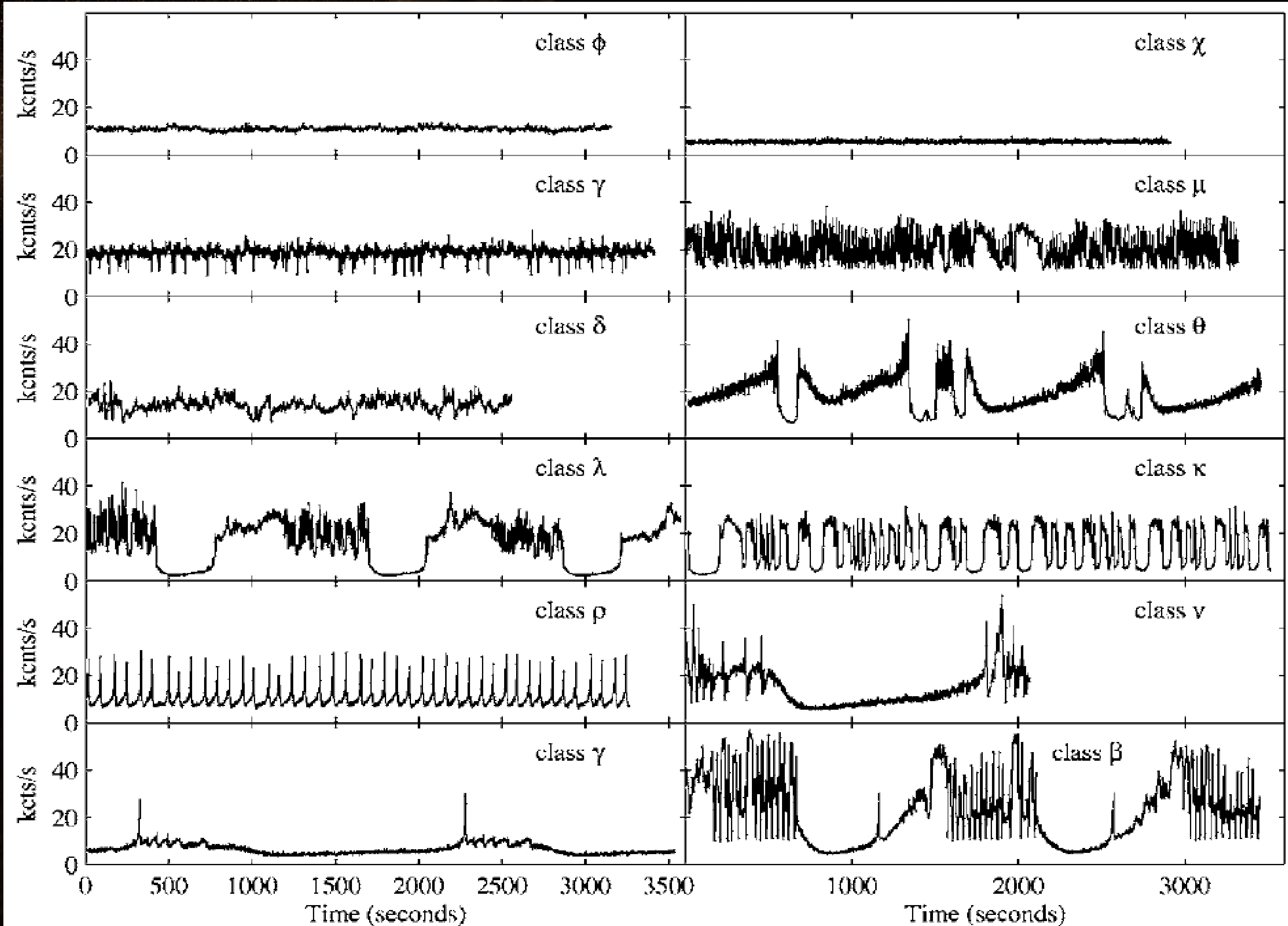
GRS 1915+105

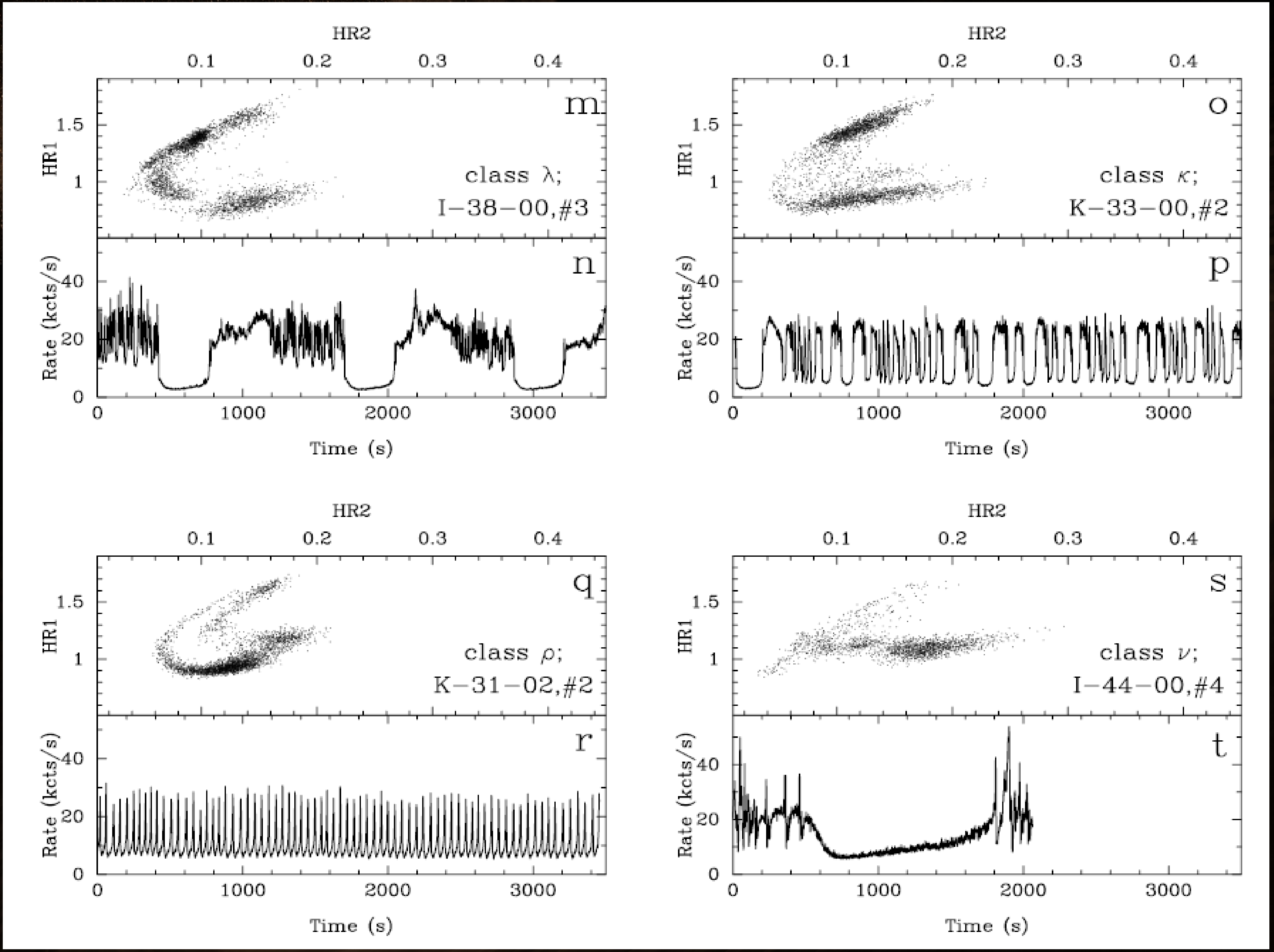
- Discovered in August 1992

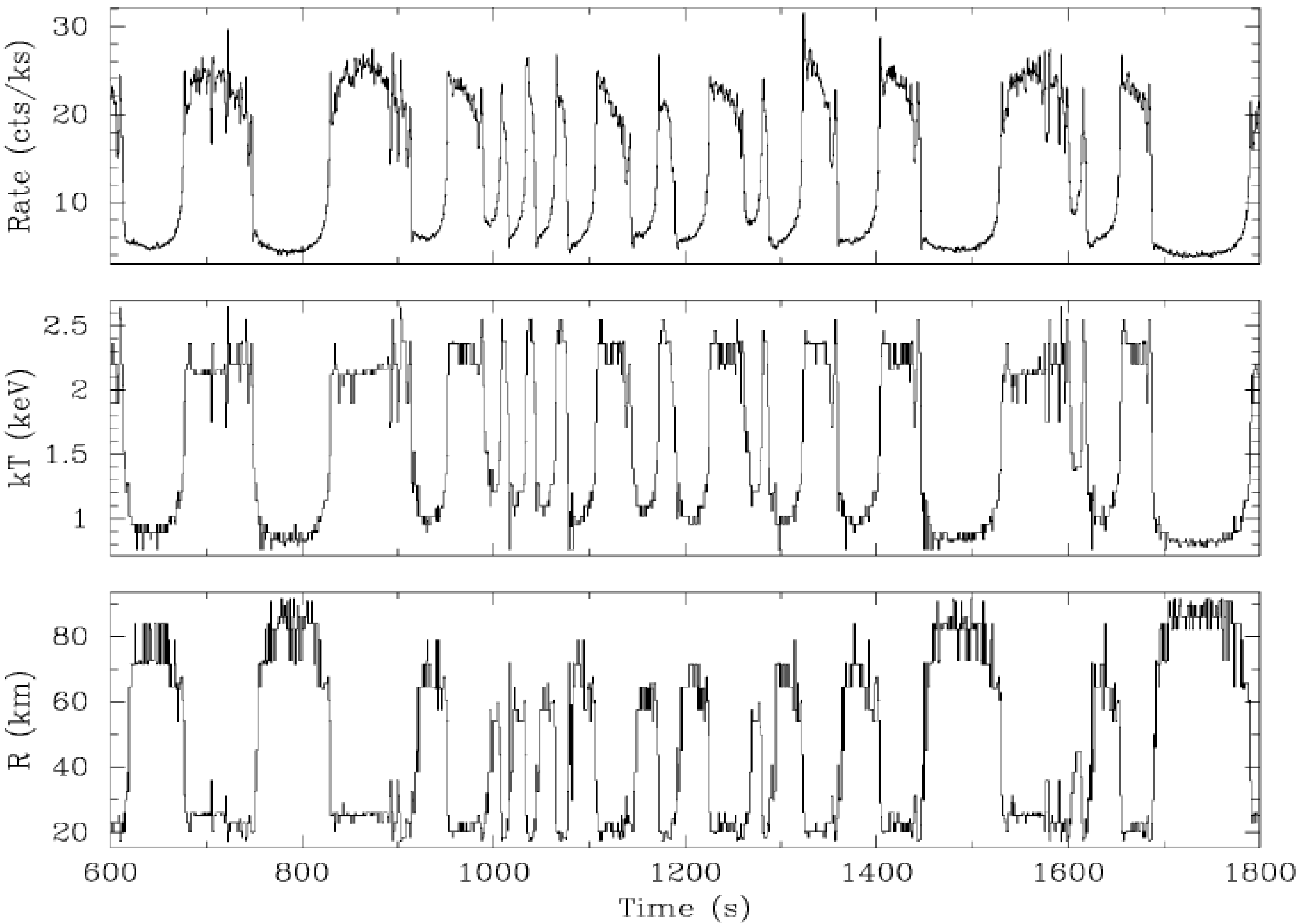
  ("GRS" stands for "GRANAT source")
- ~10 M_o Black hole
- ~10 kpc
- ~ 33 days orbital period
- ~1.2 M_o K-M III companion star
- Often at L_{Edd}



companion star
accretion disk and black hole
Sun
Mercury
LMC X−3
LMC X−1
Cyg X−1
GRS 1915+105
XTE J1650−500
XTE J1118+480
XTE J1859+226
SAX J1819.3−2525
GRS 1009−45
GRS 1124−683
GS 2000+25
H1705−250
GRO J1655−40
A0620−00
GRO J0422+32
XTE J1550−564
GS 2023+338
GS 1354−64
GX 339−4
4U 1543−47


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
0
20
40
0
500
1000
1500
2000
2500
3000
3500
Time (seconds)


HR2
HR1
Rate (kcts/s)
Time (s)
m
n
class λ;
I−38−00,#3
o
p
class κ;
K−33−00,#2
q
r
class ρ;
K−31−02,#2
s
t
class ν;
I−44−00,#4



Rate (cts/ks)
30
20
10
kT (keV)
2.5
2
1.5
1
R (km)
80
60
40
20
600
800
1000
1200
1400
1600
1800
Time (s)


And about the models....

TIME-DEPENDENT DISK MODELS FOR THE MICROQUASAR GRS 1915+105

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luminosity of the source is near the Eddington luminosity. The inclusion of a jet allows us to reproduce several additional observed features of GRS 1915+105. We conclude that the most likely structure of the accretion flow in this source is that of a cold disk with a modified viscosity law, plus a corona that accounts for much of the X-ray emission and unsteady plasma ejections that occur when the luminosity of the source is high. The disk is geometrically thin (as required by the data) because most of the accretion power is drained by the corona and the jet.

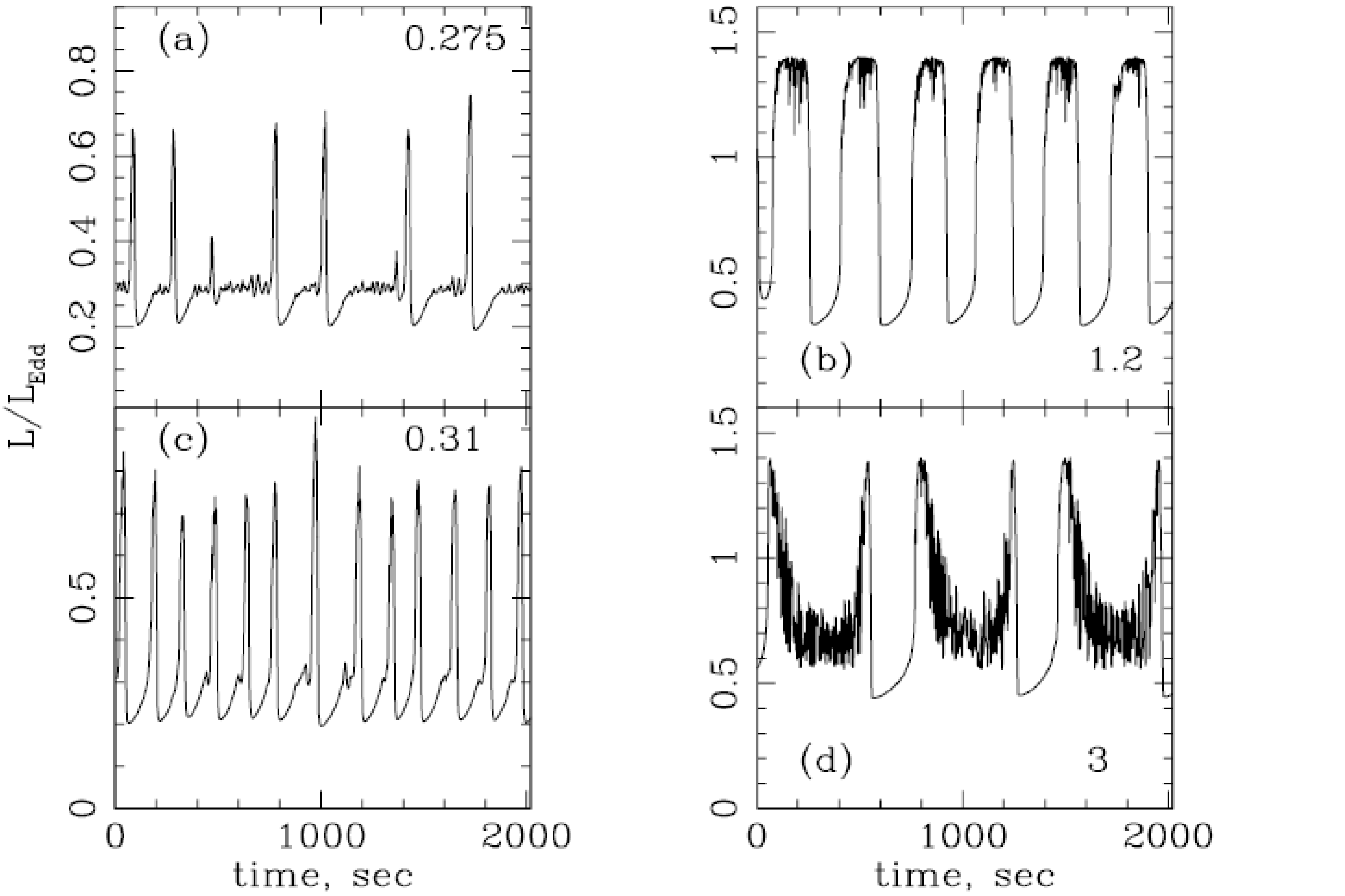
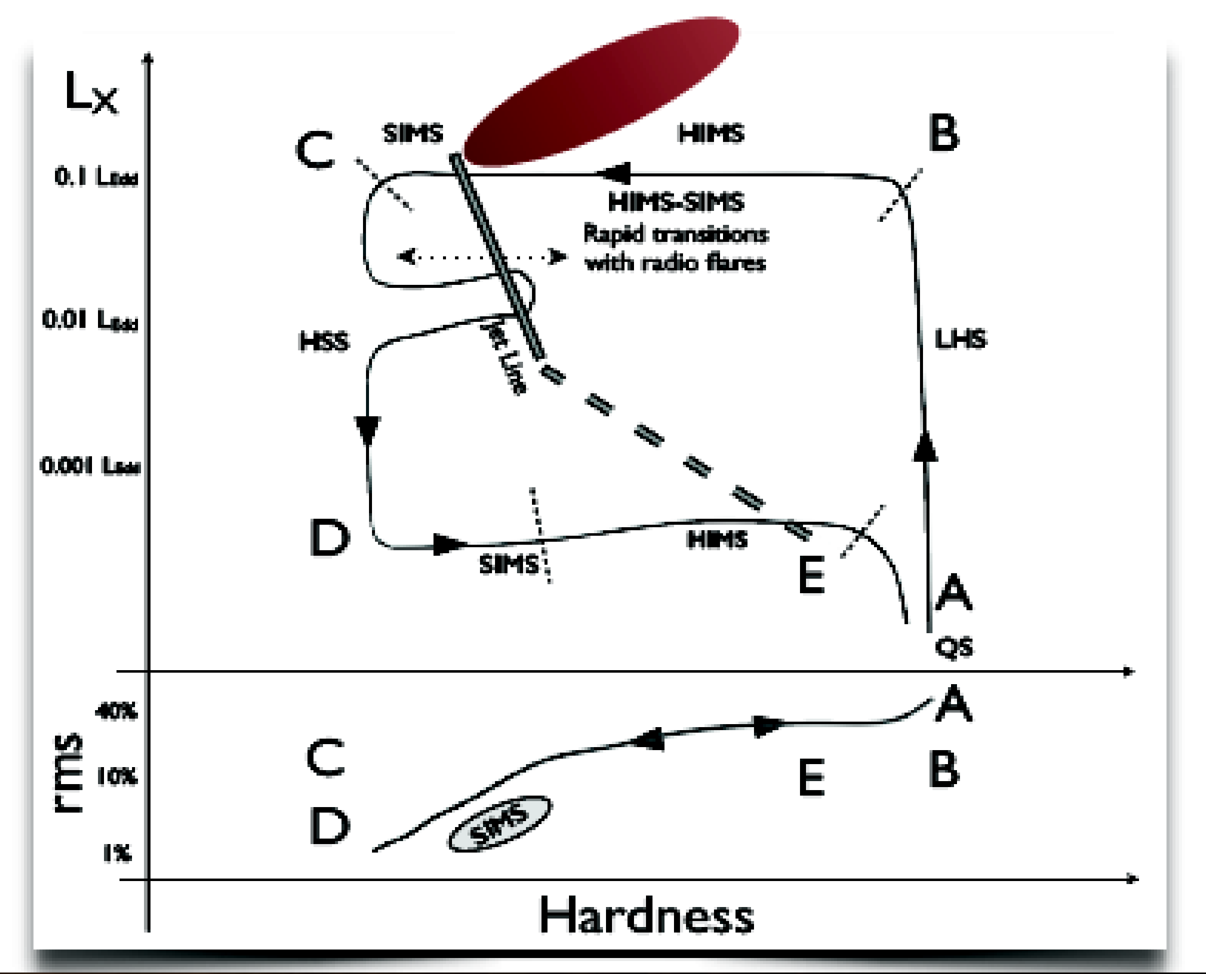


FIG. 9.—Light curves for unstable accretion disk with a viscosity prescription given by eq. (12), and with a fluctuating corona and plasma ejections. The fraction f is given by eq. (18), $\alpha_0 = 0.008$, and $\xi_0 = 8$ for all the panels. The dimensionless accretion rate $\dot{m}$ is shown in the upper or lower right-hand corner of each panel.

TIME-DEPENDENT DISK MODELS FOR THE MICROQUASAR GRS 1915+105, NAYAKSHIN et al. 2000

So although theory predicted disk instabilities starting at few % Eddington, we only see them at ~L_{edd}

(so far in one source)

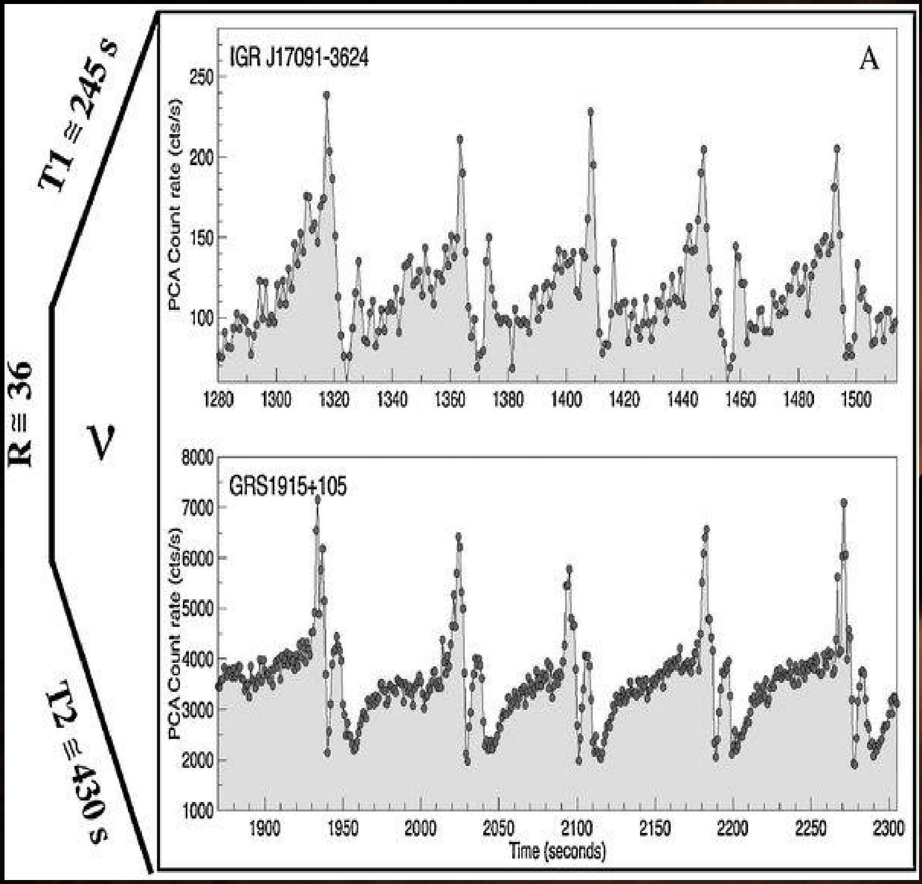


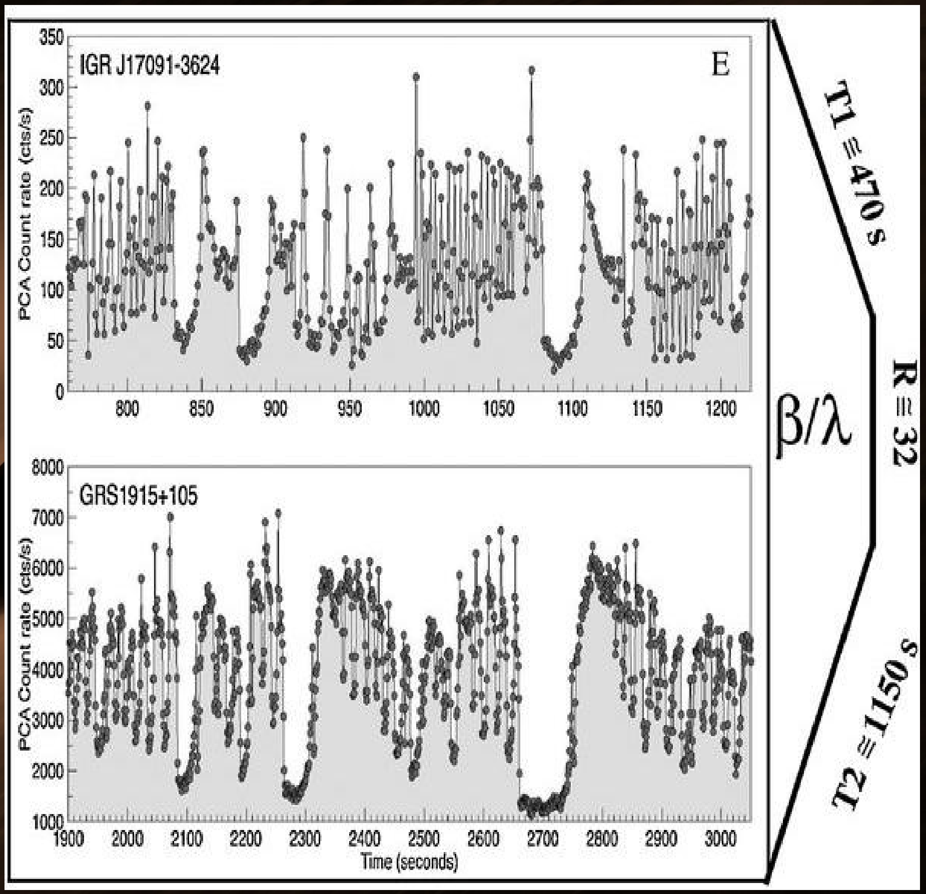
What makes the disk stable at high accretion rates?

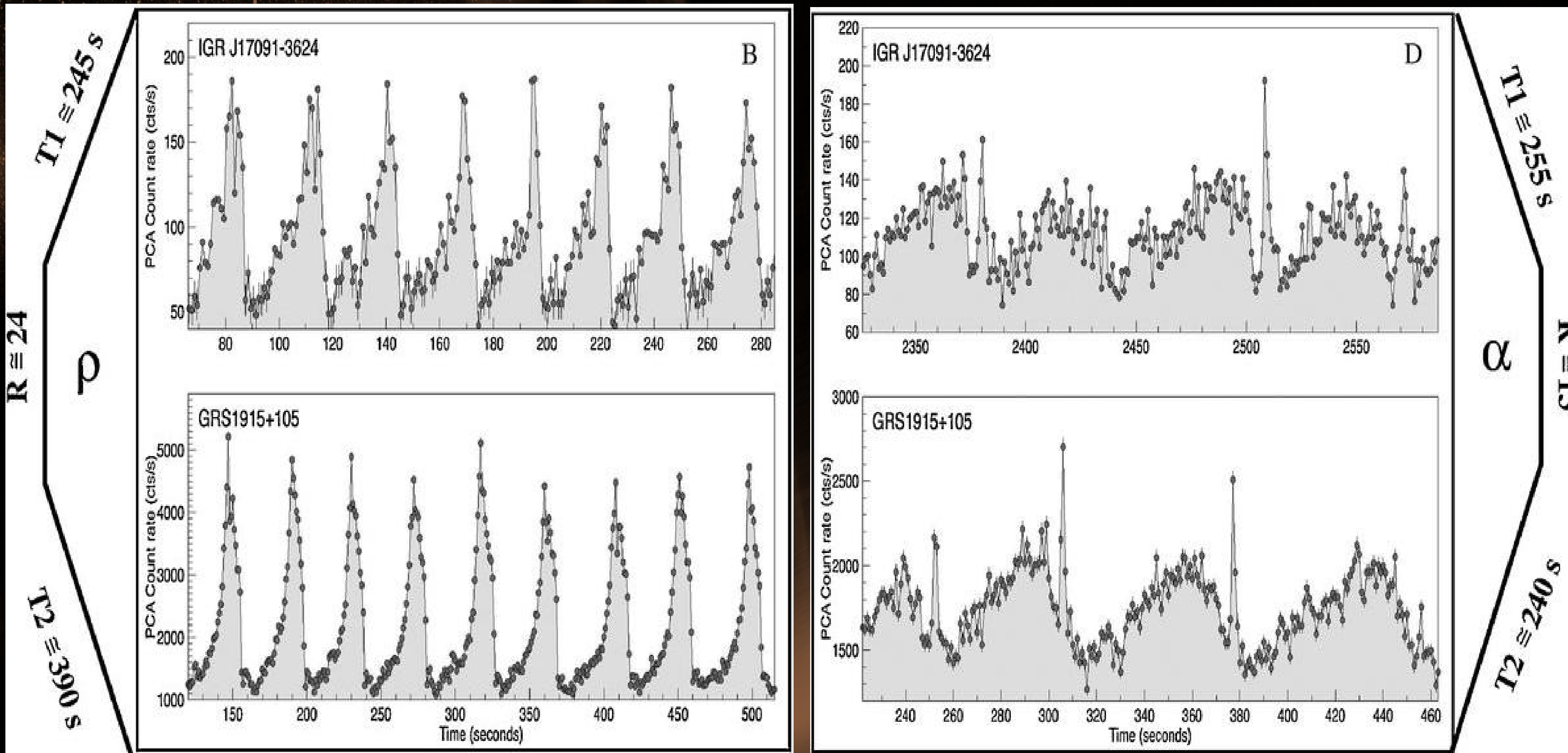
- Advection cooling? (Abramowicz et al. 1988)
- Energy is channeled to corona/winds/jet/others? (e.g., Svensson & Zdziarski 1994)
- Alternative parametrization of the viscosity ? (e.g.,Lightman & Eardley 1974; Stella & Rosner 1984)
- Stochastic variations in the viscous parameter (Janiuk, A. & Misra, R. 2012)

Are numerical simulations the solution?

IGR J17091-3624
vs
GRS 1915+105

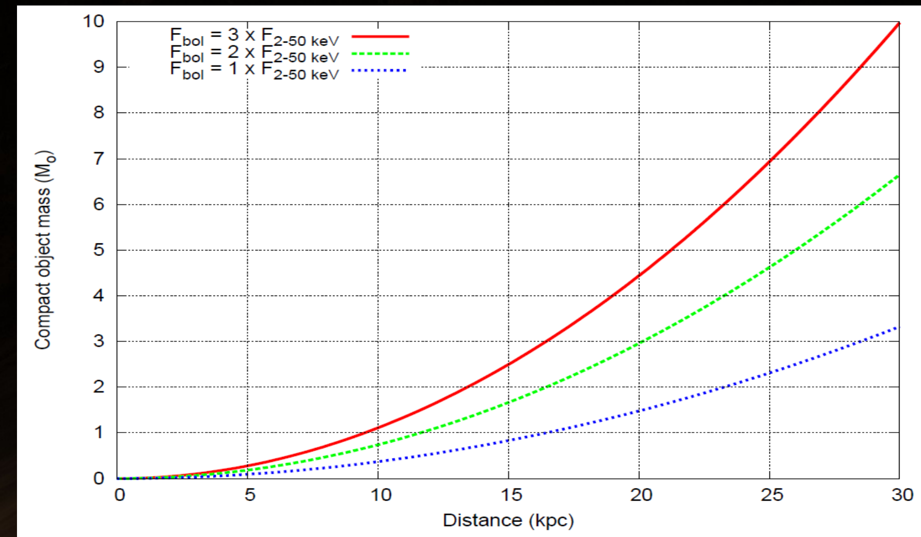


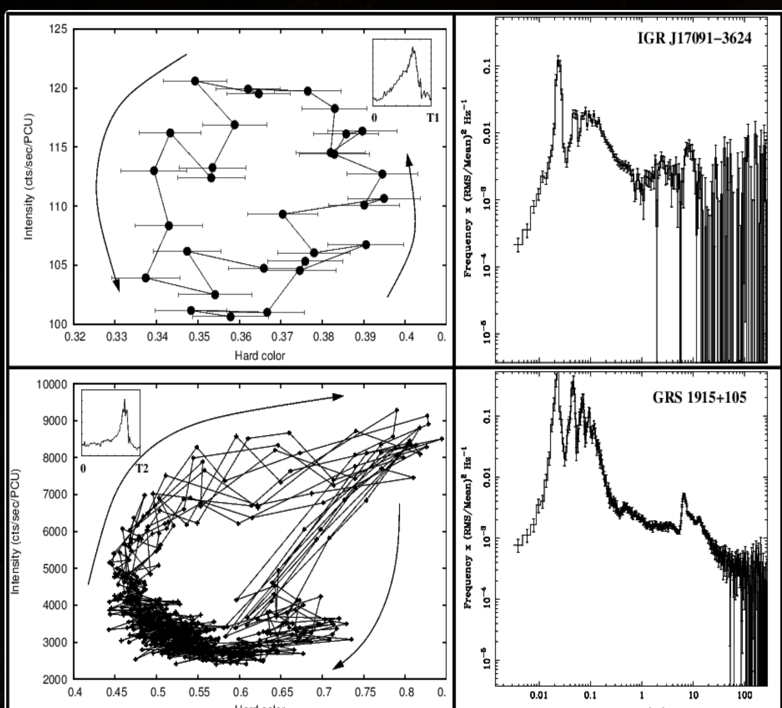


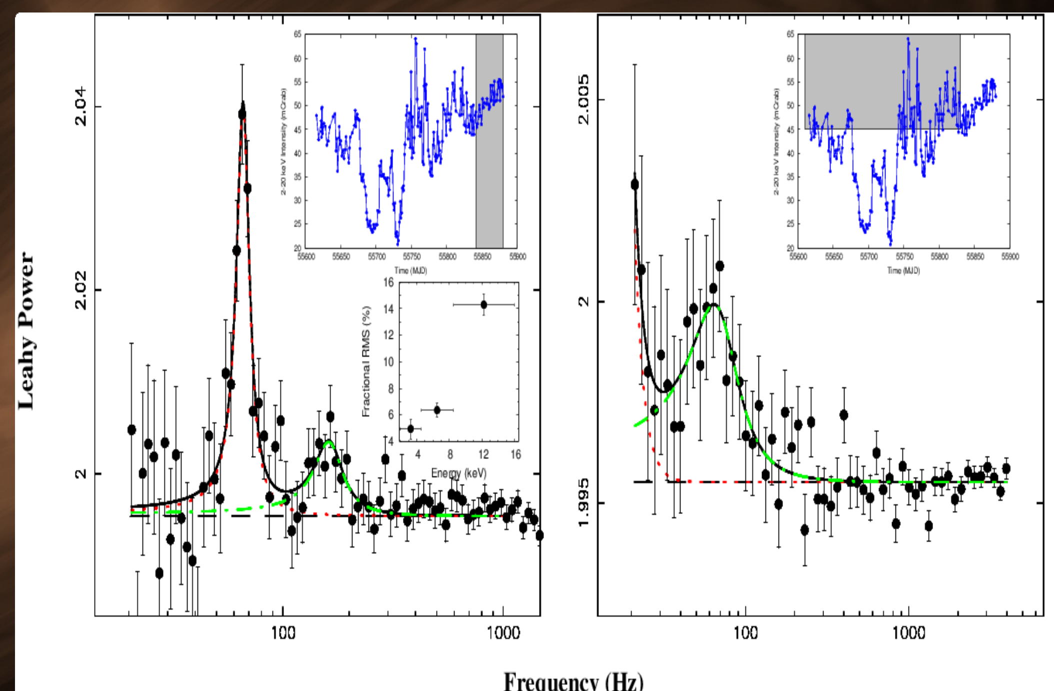


IGR J17091-3624
vs
GRS 1915+105

IGR J17091-3624 vs. GRS 1915+105







What about NSs?

The case of type II bursts (the release of gravitational potential energy due to spasmodic accretion onto a compact object) in

(I) Bursting Pulsar

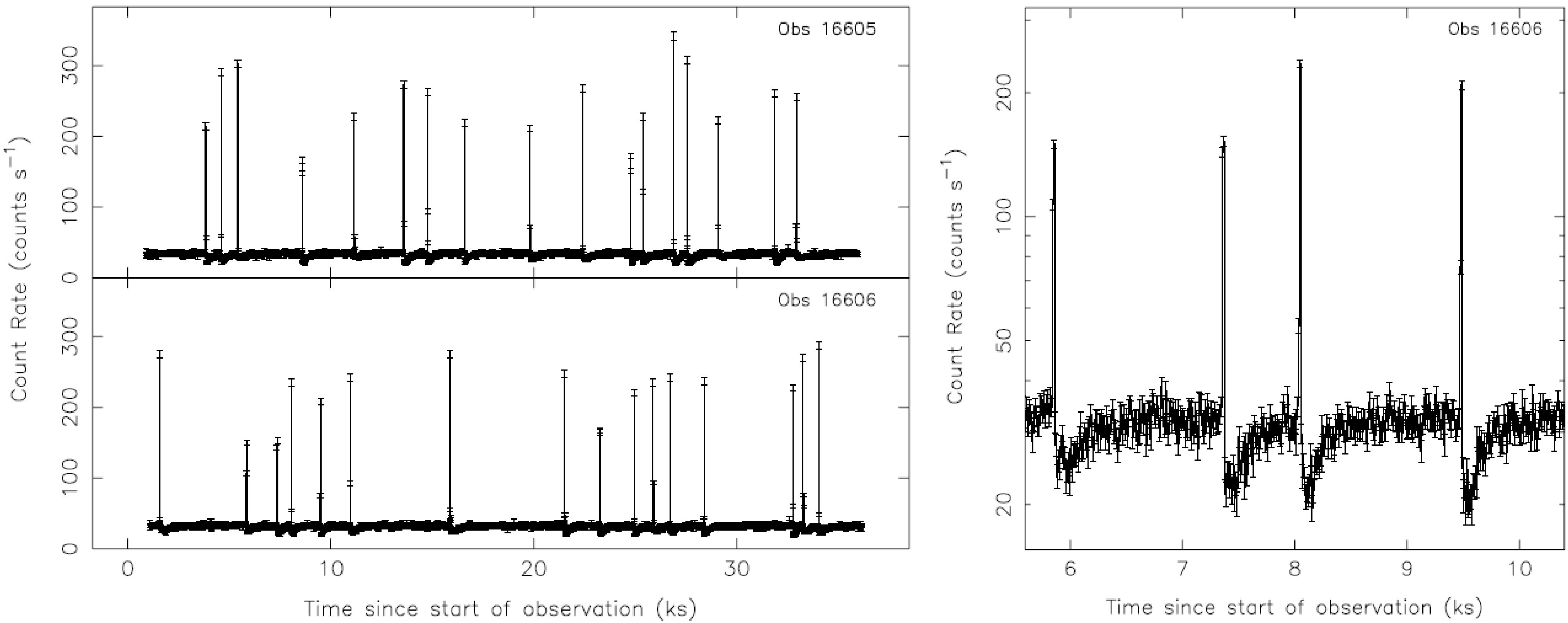
(ii) the Rapid Burster

Bursting pulsar

– NS as it shows pulsations (but no thermonuclear bursts)

– distance NOT known

– Spin: 0.467 s, 11.8 days orbital period, B=10^10 – 10^11 G


Obs 16605
Obs 16606
Count Rate (counts s⁻¹)
Time since start of observation (ks)
Obs 16606
Count Rate (counts s⁻¹)
Time since start of observation (ks)

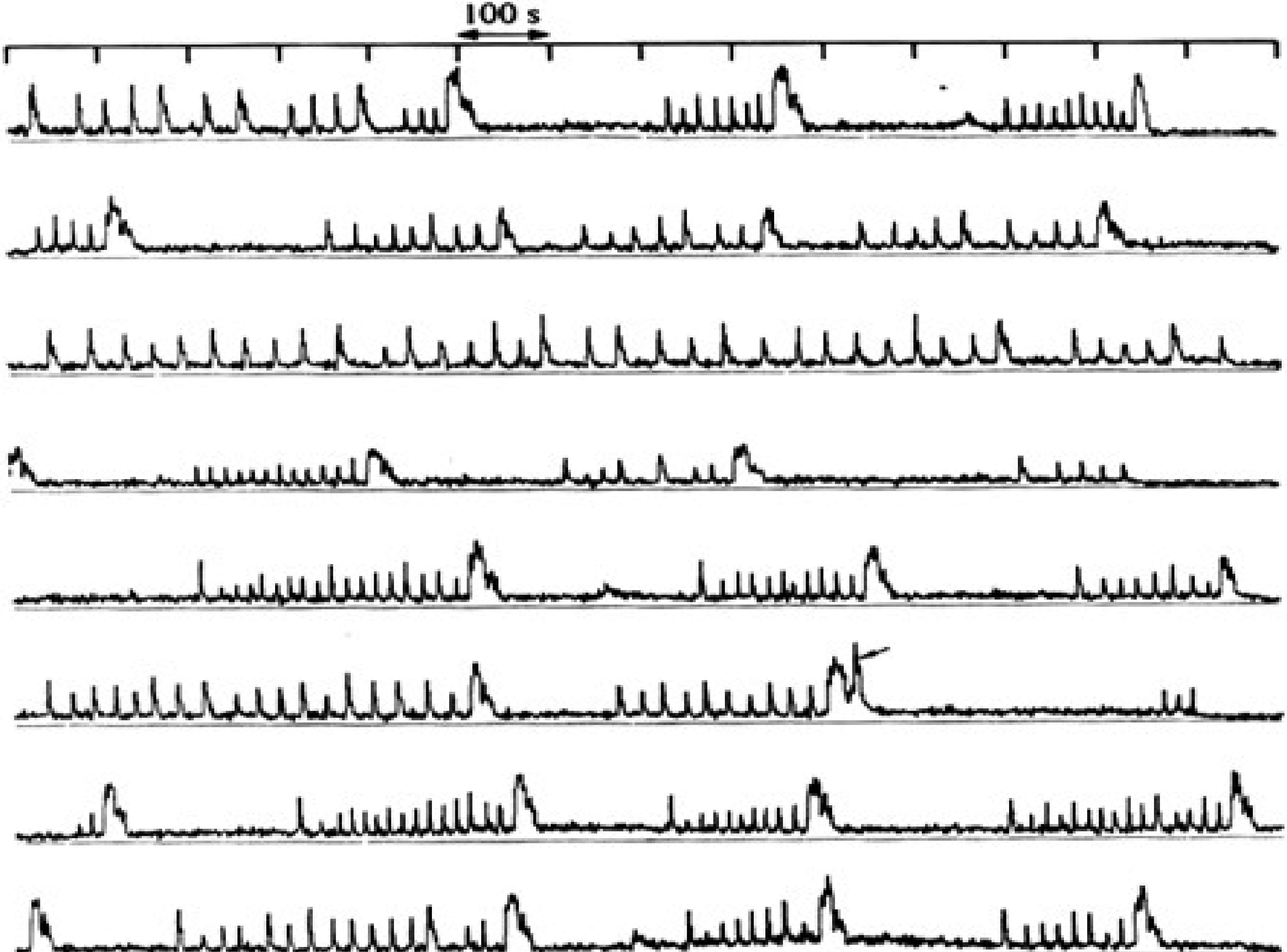
Of course the instabilities are …
different …
(or are they not?)

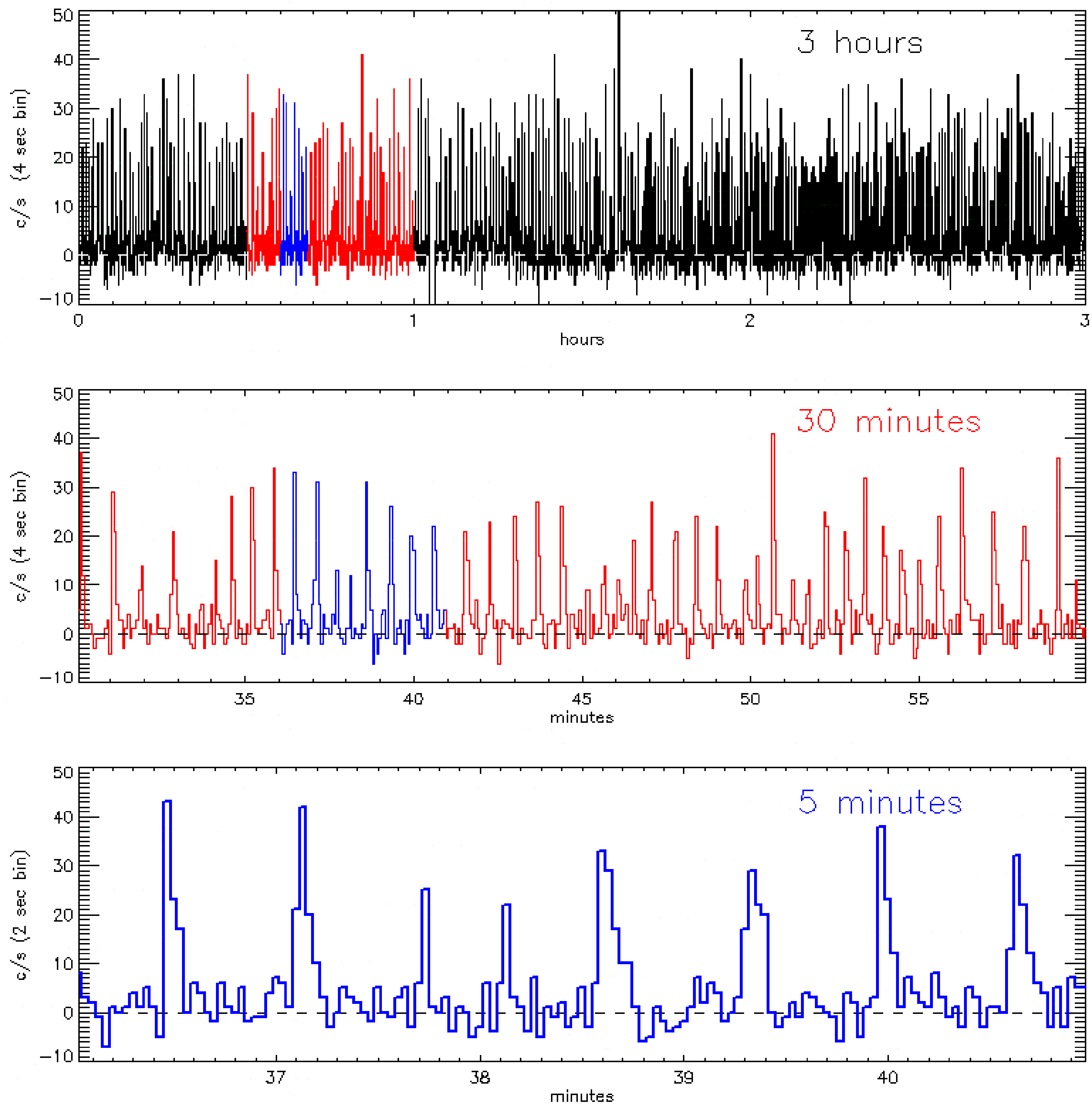
Rapid burster

– NS as it shows thermonuclear x-ray bursts

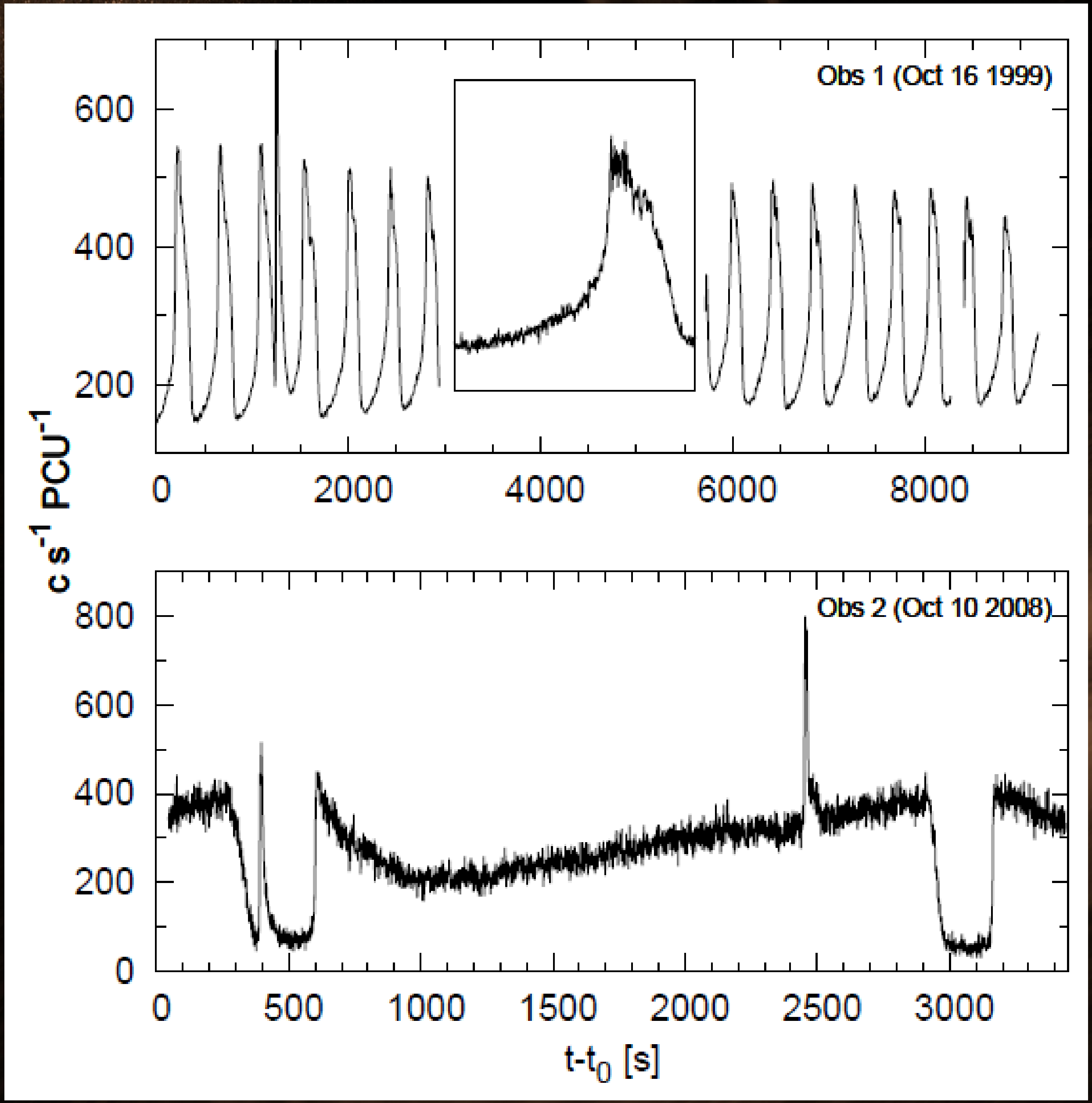
– Distance known (in a globular cluster)

– NO spin, B or system parameters measured so far.


100 s


3 hours
c/s (4 sec bin)
50
40
30
20
10
0
−10
0
1
2
3
hours
30 minutes
c/s (4 sec bin)
50
40
30
20
10
0
−10
35
40
45
50
55
minutes
5 minutes
c/s (2 sec bin)
50
40
30
20
10
0
−10
37
38
39
40
minutes

And a few weeks ago...



Rapid Burster
- NS
- B < 10^8G
- Suggested low spin

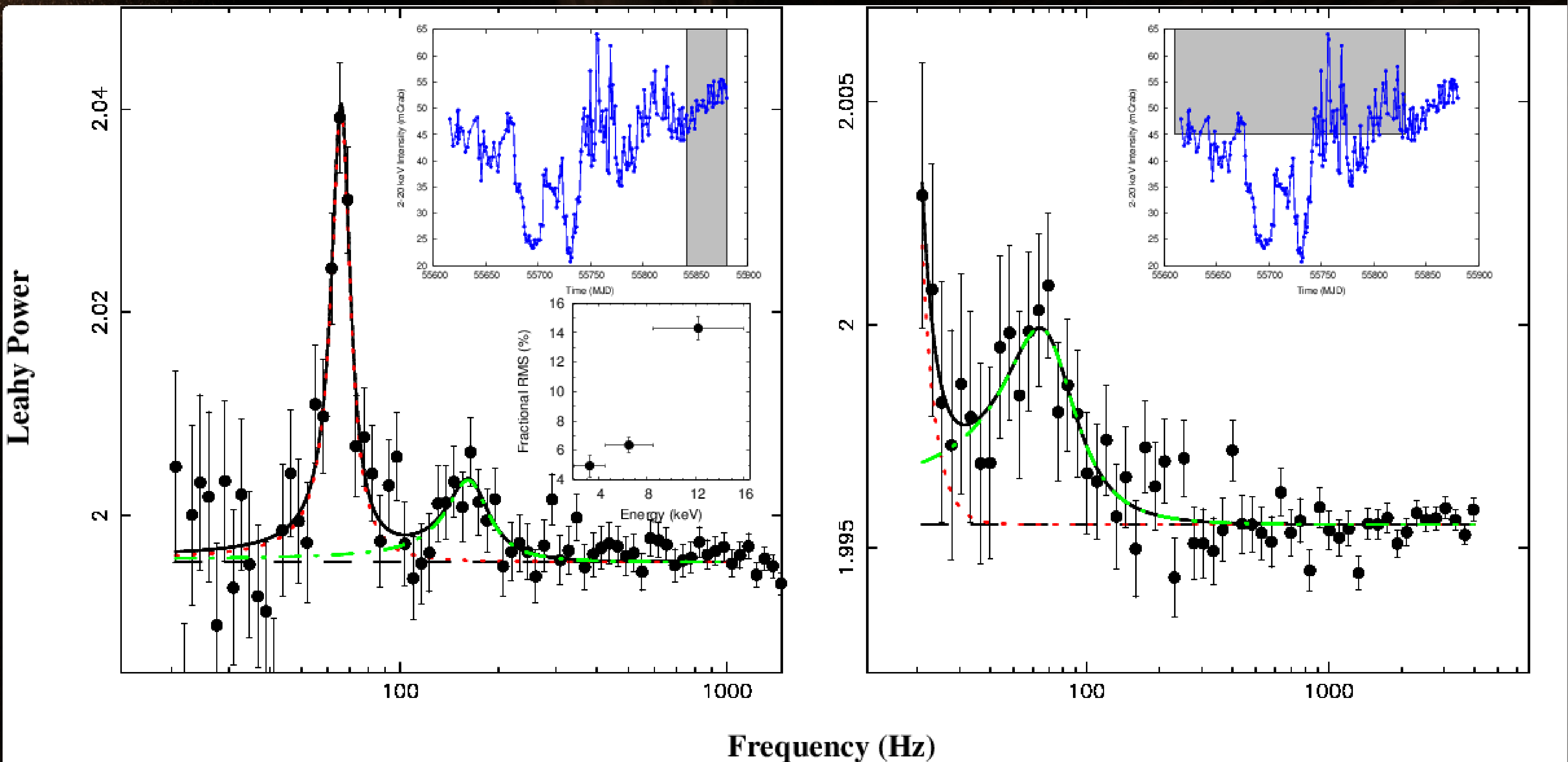
Bagnoli & in't Zand 2015


The Cycle
of
Life!

Can it be that we are seeing the same instability in both BHs and NSs ?

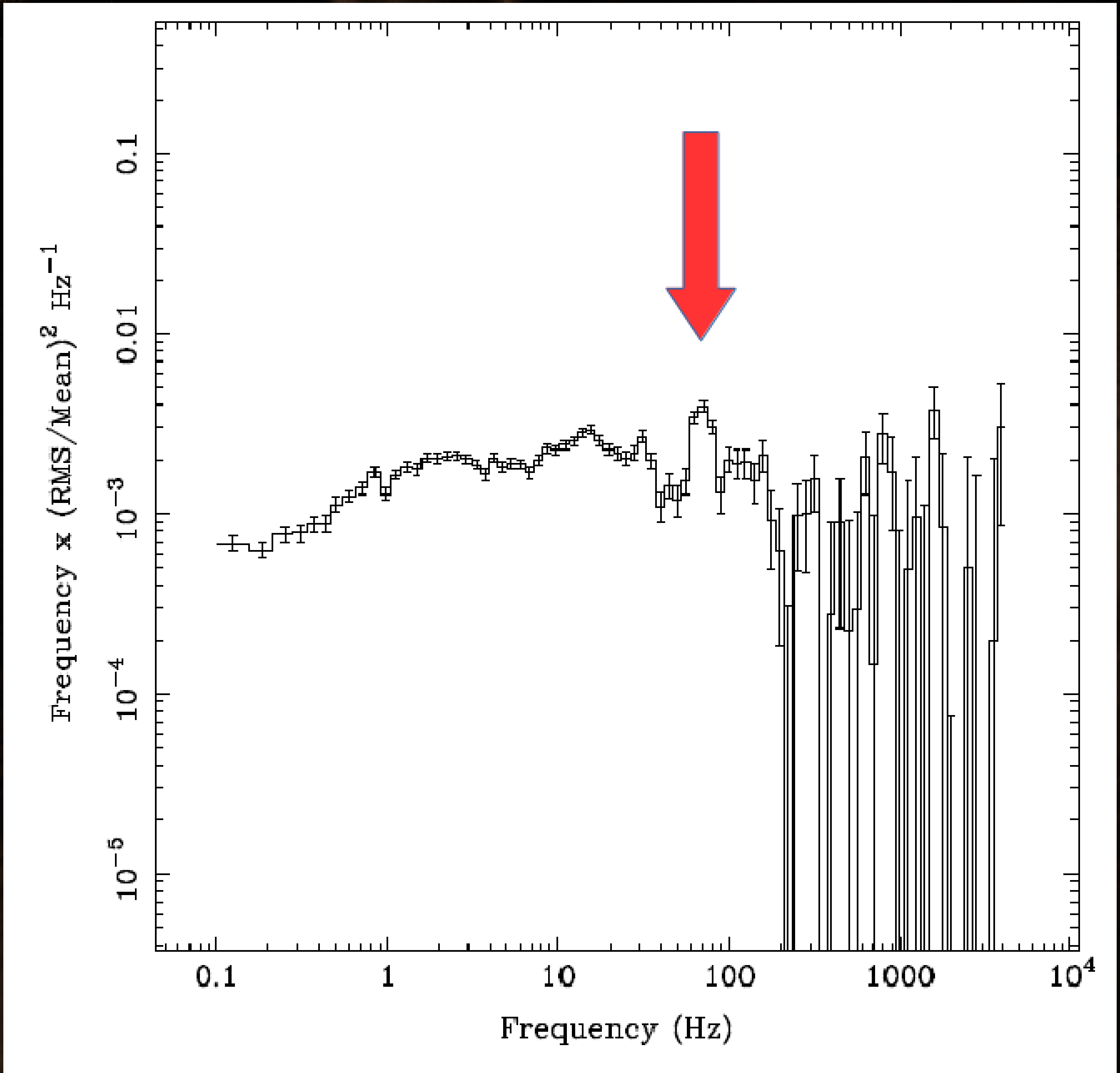
Despite the differences?

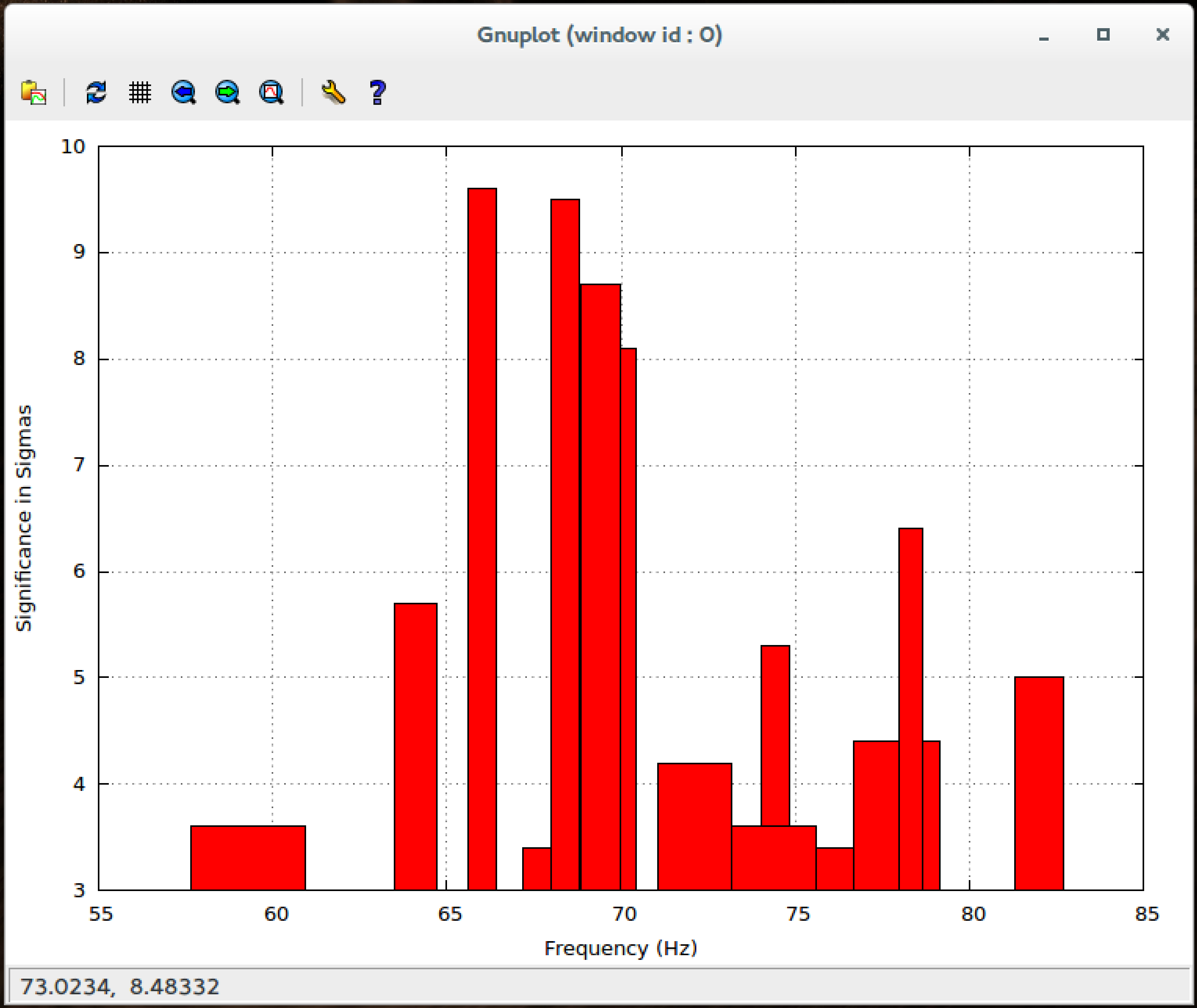
First hint
(observations vs. observations)?

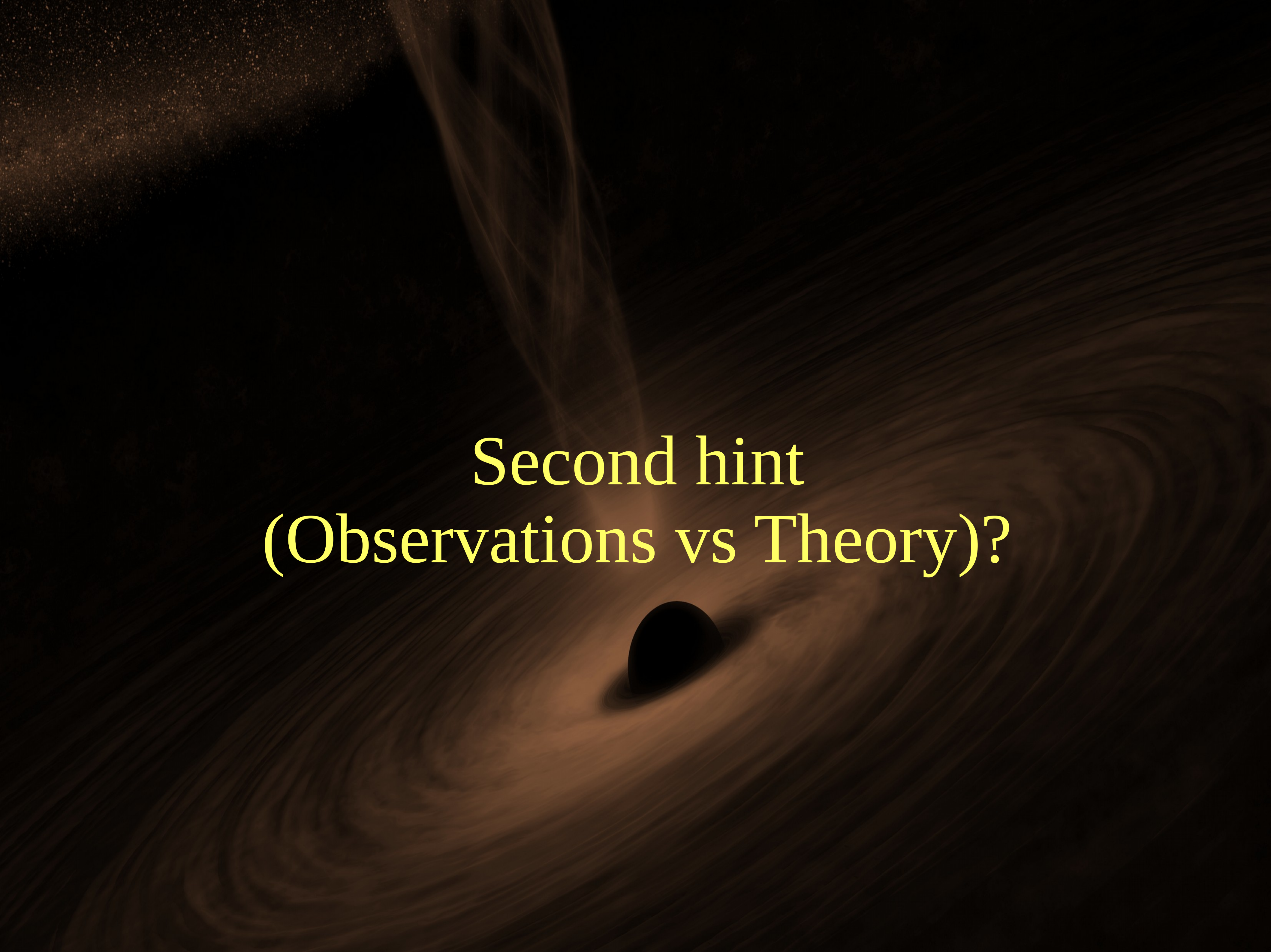


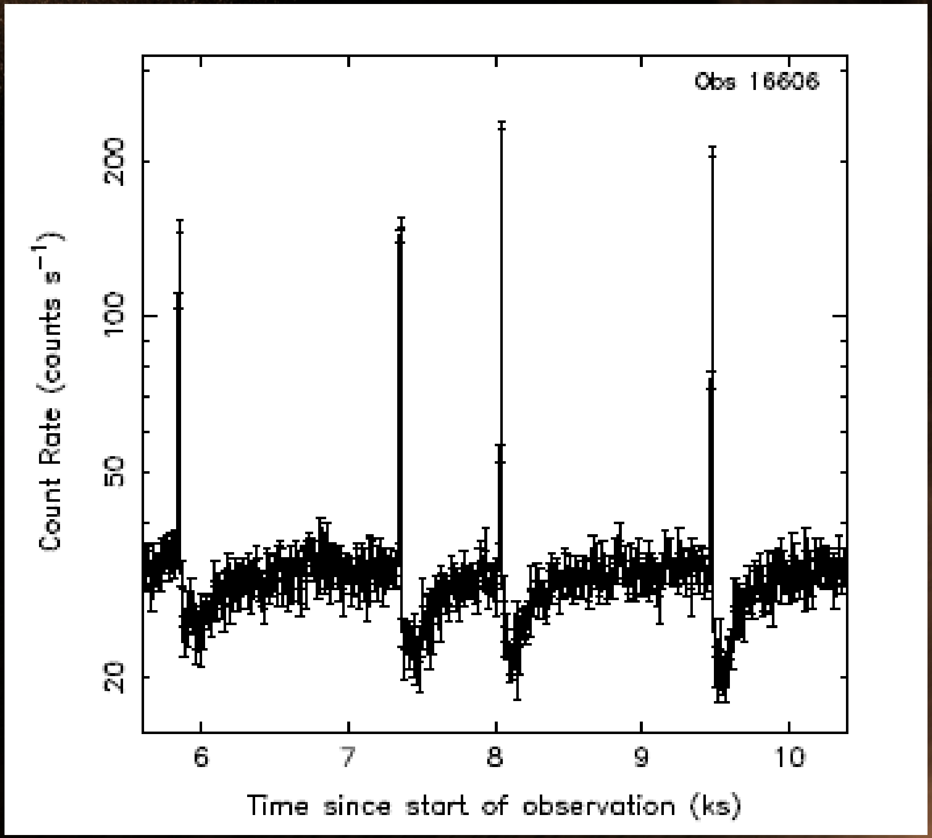
Leahy Power
Frequency (Hz)
2.04
2.02
2
100
1000
2-20 keV Intensity (mCrab)
Time (MJD)
Fractional RMS (%)
Energy (keV)
2.005
2
1.995

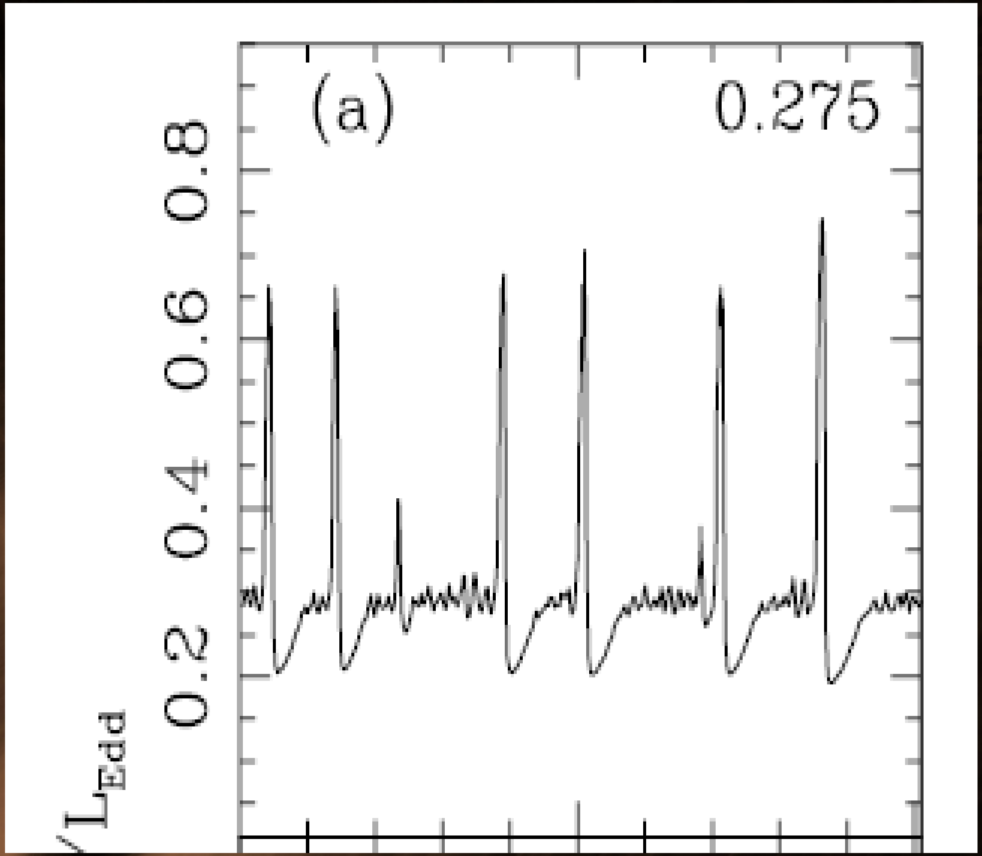
Rapid burster




Gnuplot (window id : 0)
Significance in Sigmas
Frequency (Hz)
10
9
8
7
6
5
4
3
55
60
65
70
75
80
85
73.0234, 8.48332


Second hint
(Observations vs Theory)?


Obs 16606
Count Rate (counts s^{-1})
20
50
100
200
6
7
8
9
10
Time since start of observation (ks)


(a)
0.275
L_{Edd}
0.2
0.4
0.6
0.8

Summary

- Theory predicts that radiation dominated disks should be thermally unstable unless you have a way to dissipate the extra energy.
- Do we see systems showing “expected” instabilities? Yes, the 4 weirdest sources out there!
- So why are these sources different? For good or for bad, the news are that you can have a BH and a NS showing very similar instability.
- The question still remains: why only 4! when there are many systems out there which look exactly the same.

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