Accreting X-ray Pulsars

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January 5, 2009

Science Questions

- How does matter behave in environments with extreme magnetic and gravitational fields?
- Why are accretion disks stable in some systems but highly unstable in others?
- How does emergent radiation affect the accretion flow?

How do we address these questions for accreting pulsars?

- Observations
  - Measure cyclotron lines.
  - Monitor phase connected spin parameters.
  - Determine precise fluxes during and between outbursts.
  - Track pulse profile variations.
  - Search for QPO.
- Instrument needs
  - Broad energy range
  - Good timing capability
  - Regular monitoring observations
  - Quick ToO activation
  - Very high count rate statistics
  - Imaging/small fov

Magnetic Field Measurements

There are three ways to constrain a pulsar's B field:

1) Measure the lowest cyclotron absorption line energy

$$E_{cyclotron} \approx 11.6 \text{ keV } (B/10^{12} \text{ G}) (1+z)^{-1}$$

where B is the magnetic field and z is the gravitational redshift at the emission region.

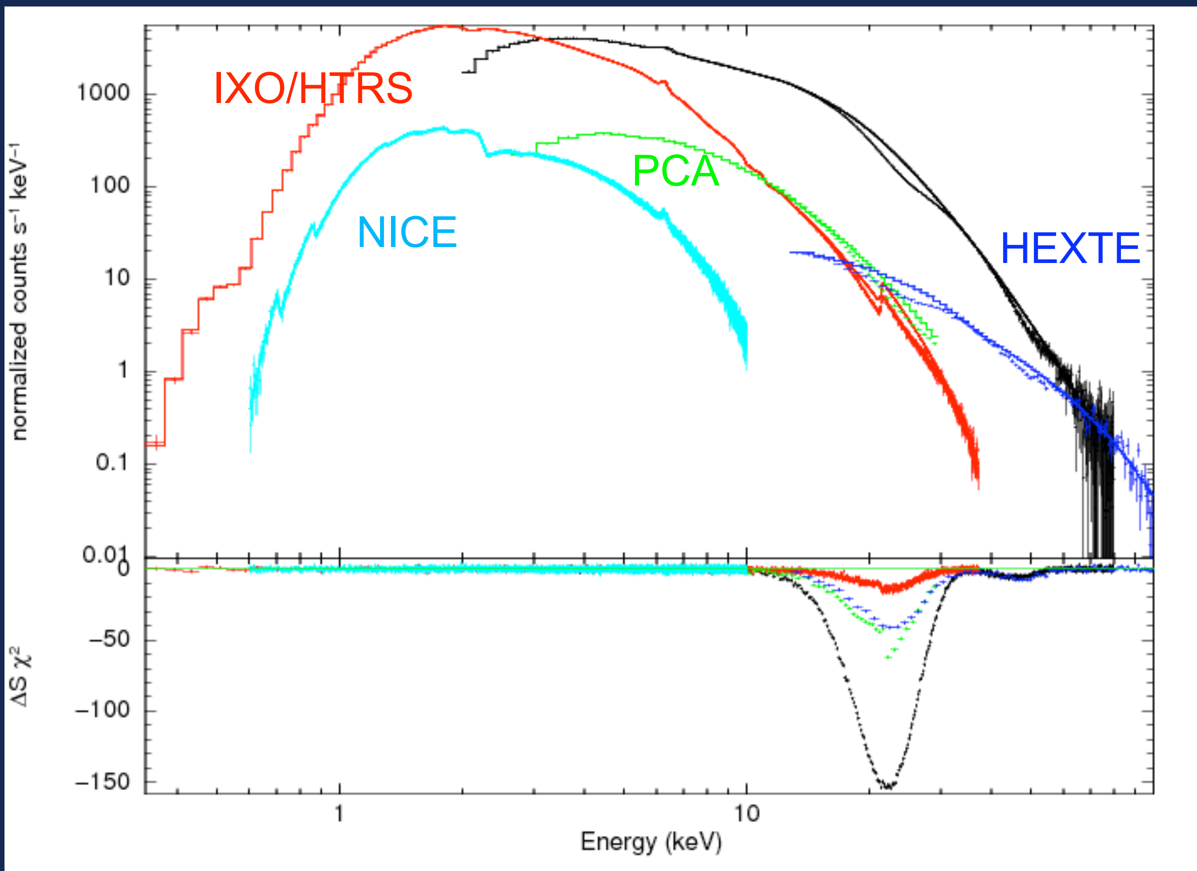
2) Observe the cutoff of accretion due to centrifugal inhibition:

$$L_{cutoff} \approx 2\times10^{38} (\mu/10^{30} \text{ G cm}^3)^2 (P/1\text{s})^{-7/3} \text{ erg s}^{-1}$$

3) Measure the spin-up rate at high luminosity:

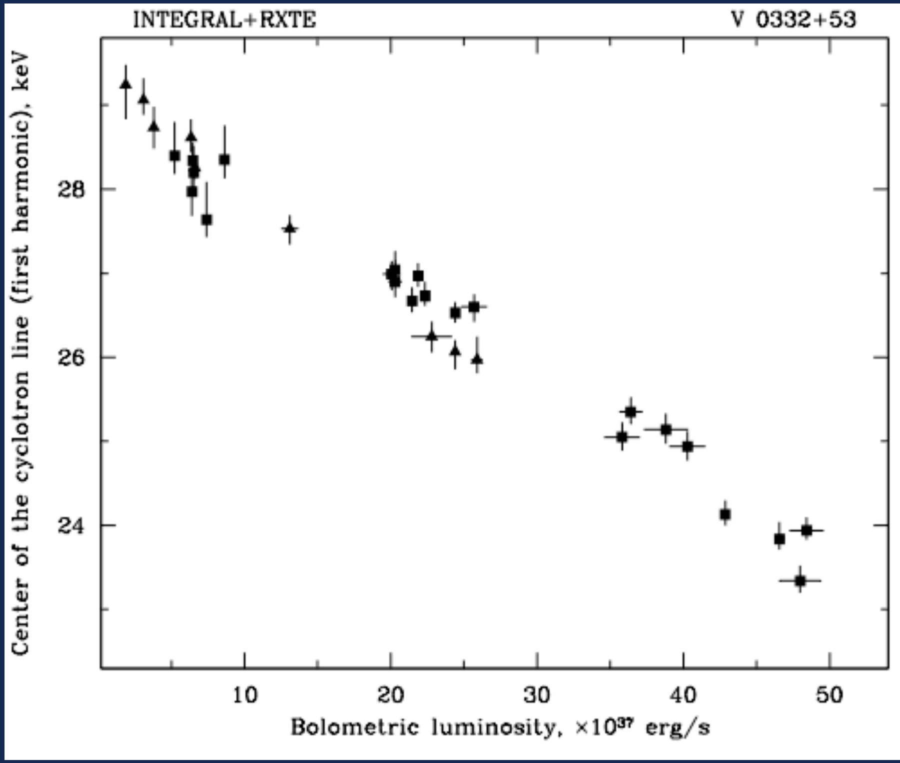
$$\dot{\nu} \approx 1.7\times10^{-11} (\mu/10^{30} \text{ G cm}^3)^{2/7} (L/10^{38} \text{ erg s}^{-1})^{6/7} \times(I/10^{45} \text{ gm cm}^2)^{-1}$$

Cyclotron line simulations



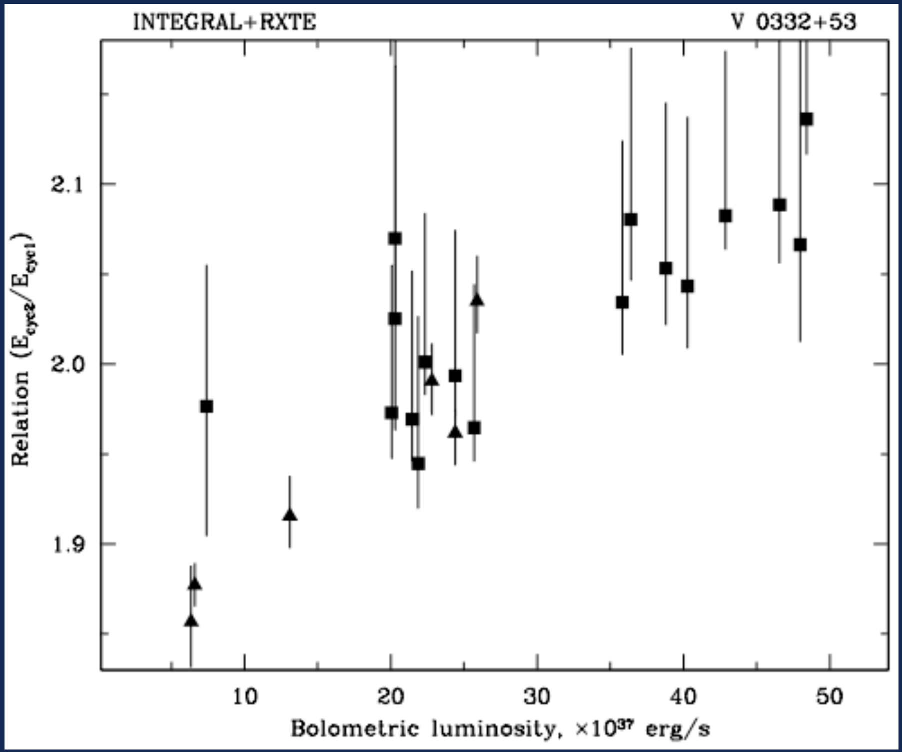
- A0535+26 RXTE observation Aug 28, 2005
- Line detected at 48 keV
- PLCUT model for continuum: index = 1.02, Ecut = 12.6 Efold = 20.6
- Added line @ 24 keV with V0332+53 parameters

V0332+53: Cyclotron Line Evolution on Outburst Decline



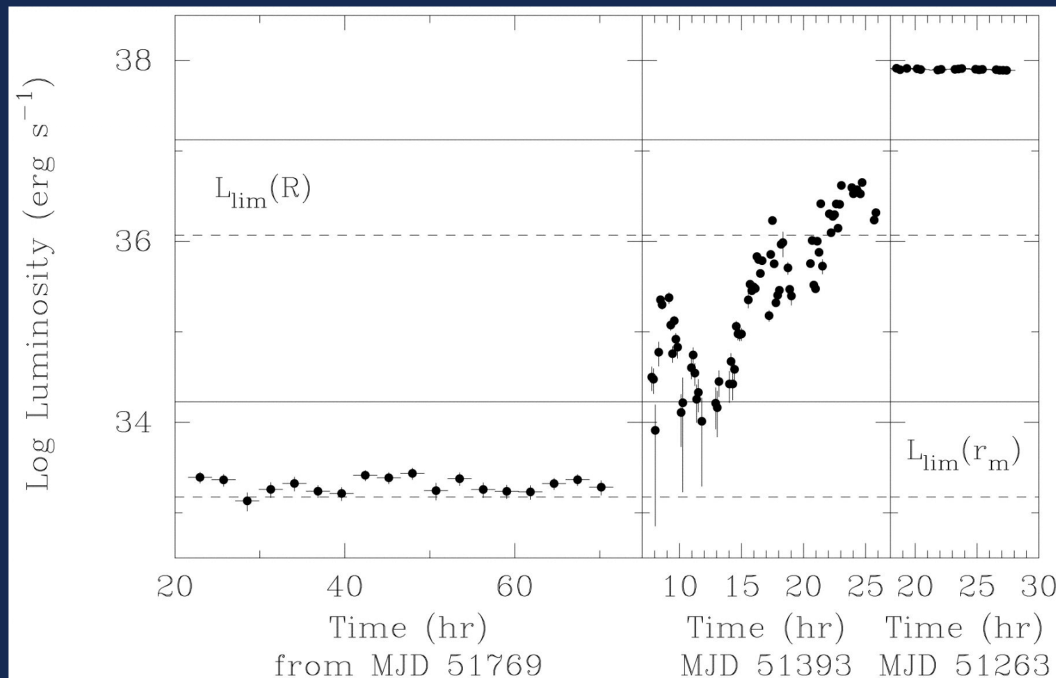
1st cyclotron line energy vs. luminosity. Squares RXTE, triangles INTEGRAL. From Tsygankov et al. (2005).

Explained by increase of shock height with increasing luminosity.



Ratio of 2nd to 1st cyclotron line energy vs luminosity. From Tsygankov et al. (2005).

Centrifugal Inhibition



Campana et al. 2001

4U0115+634: Period = 3.62s, distance = 8kpc, B=1.3x10^{12}G

$F_{cutoff} \approx 1 \times 10^{-9}$ erg cm^{-2} s^{-1}

Period=10 s, distance = 5 kpc

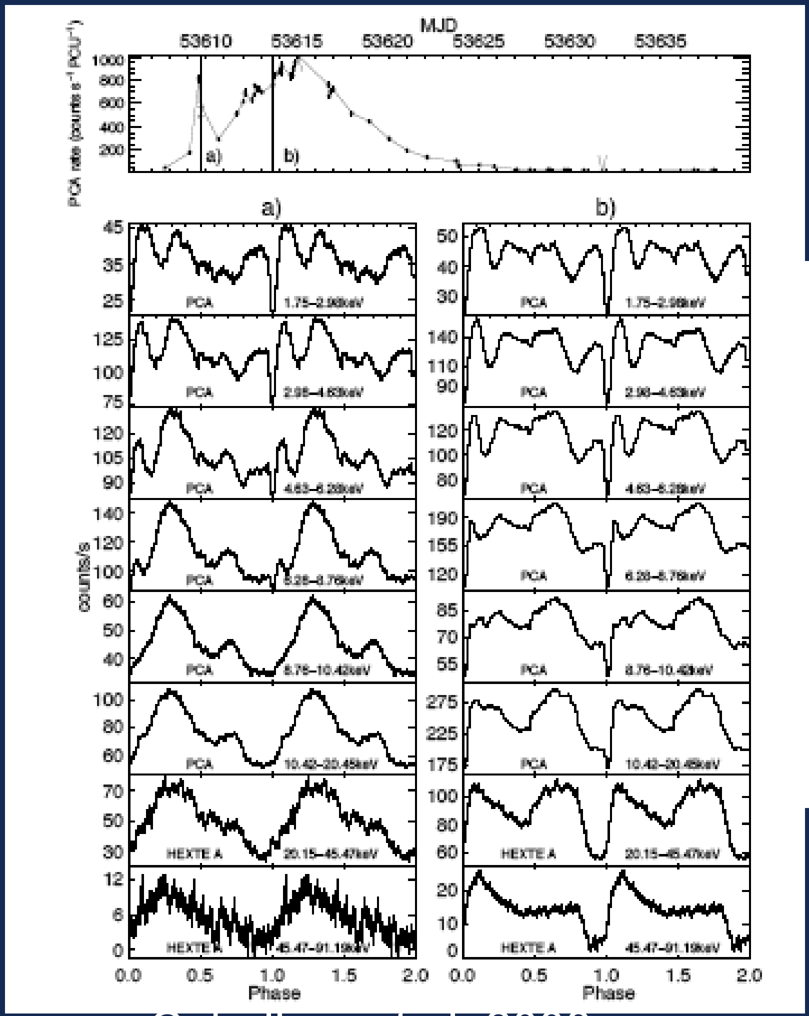
$F_{cutoff} \approx 3 \times 10^{-10} (\mu/10^{30}$ G cm$^3)^2$ erg cm^{-2} s^{-1}

Period=100 s, distance=10 kpc

$F_{cutoff} \approx 4 \times 10^{-13} (\mu/10^{30}$ G cm$^3)^2$ erg cm^{-2} s^{-1}

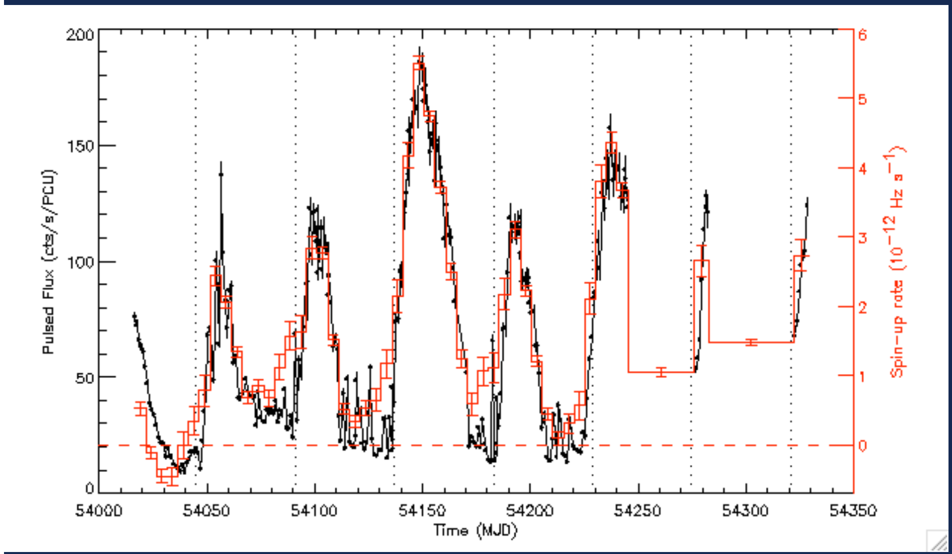
Magnetospheric Instabilities?

A 0535+26



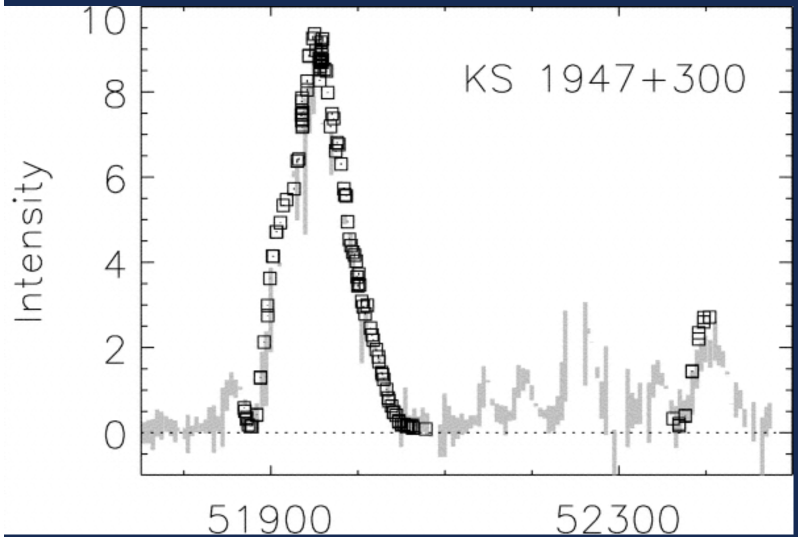
Caballero et al. 2008

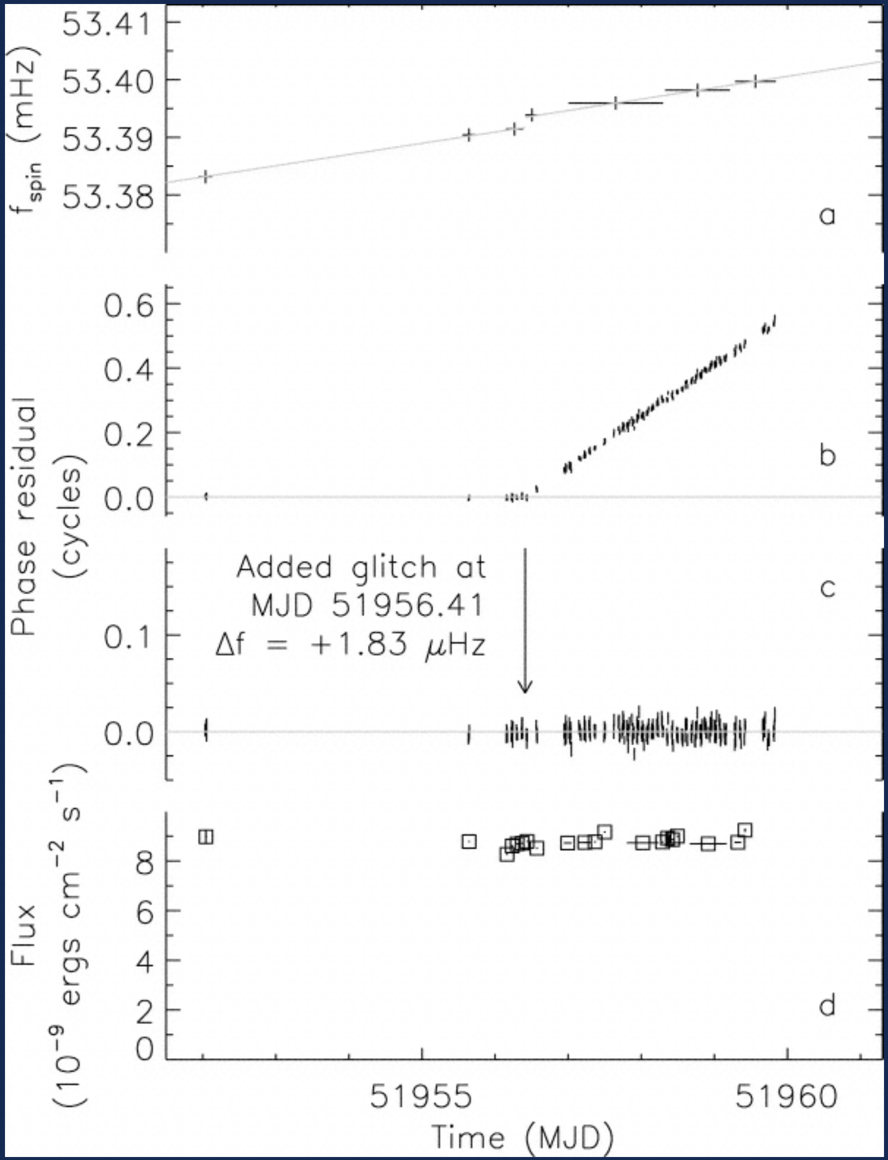
EXO 2030+375



Wilson et al. 2008

A Glitch in an Accreting Pulsar?





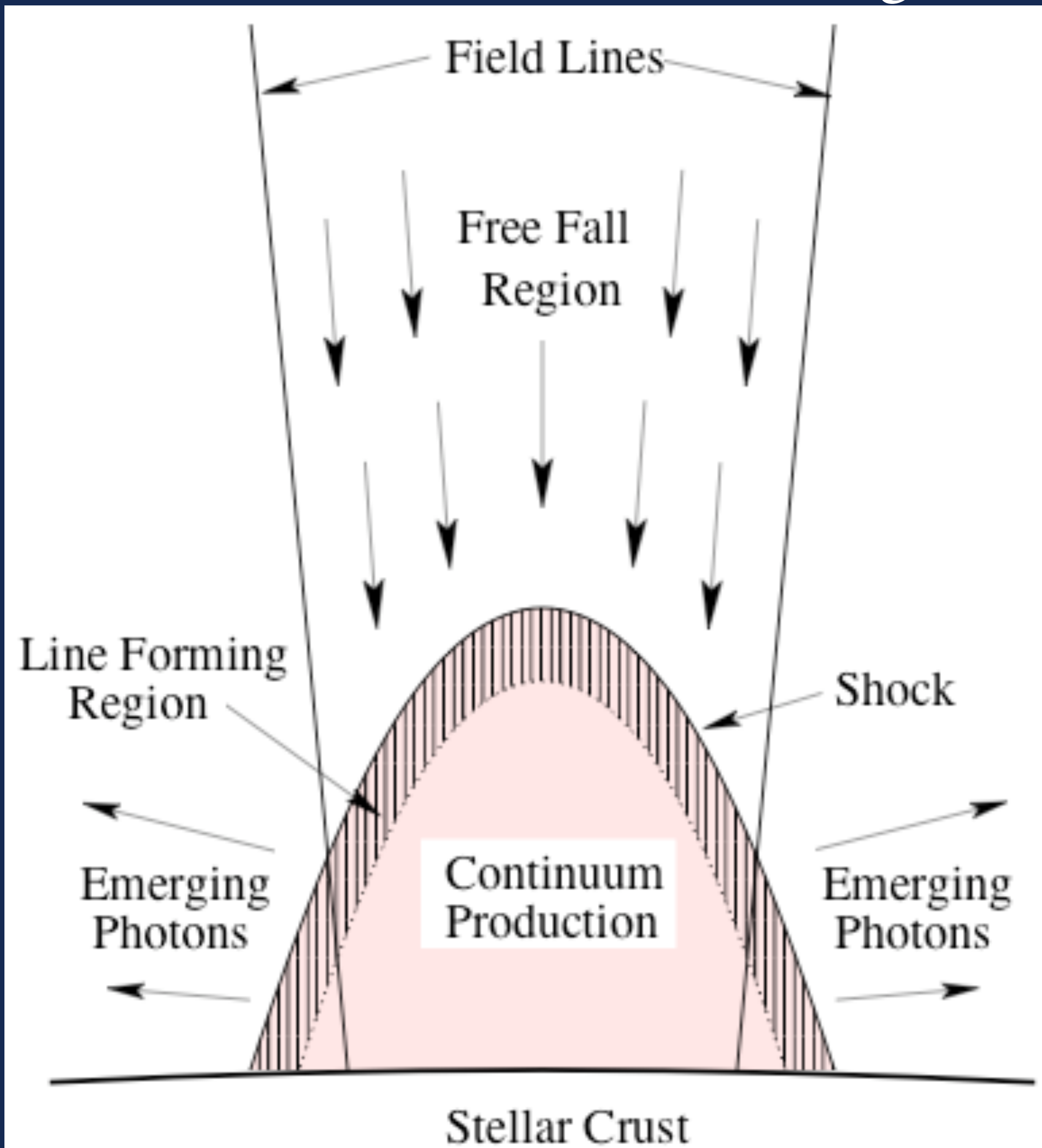
Galloway et al. 2004

Fig. 5.— Pulse frequencies, phase residuals, and X-ray intensities around the time of the glitch. (a) Measured pulse frequency corrected for the binary orbit with error bars corresponding to 3 σ confidence intervals. (b) Phase residuals calculated from a best-fit model that does not include a component representing the glitch. (c) Phase residuals from a full model that does include a component representing the glitch. Note the difference in scale between (b) and (c). (d) The 2–60 keV band source flux.

Additional Science Topics

- Beat frequency QPOs
- Millisecond Accreting X-ray pulsars
- Supergiant Fast X-ray Transients
- Workhorse science
  - Orbital elements
  - Tracking phase connected spin-frequency models

Emission Region Geometry



From Heindl et al. (2004).

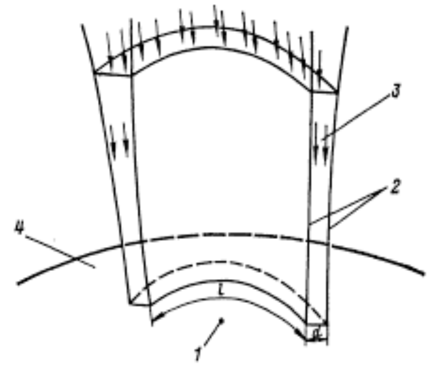


FIG. 1. The geometry of an accretion column, according to the Basko–Syunyaev model [1]: 1) a neutron-star magnetic pole; 2) magnetic field lines; 3) the accretion channel; 4) the neutron star surface.

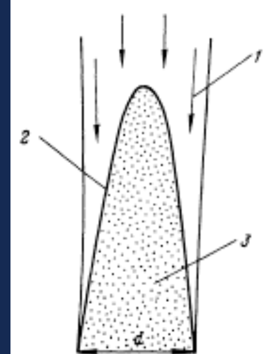


FIG. 2. A cross section of the accretion column: 1) free-falling plasma; 2) the deceleration zone; 3) gradual settling.

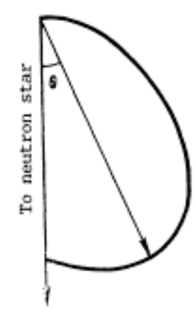
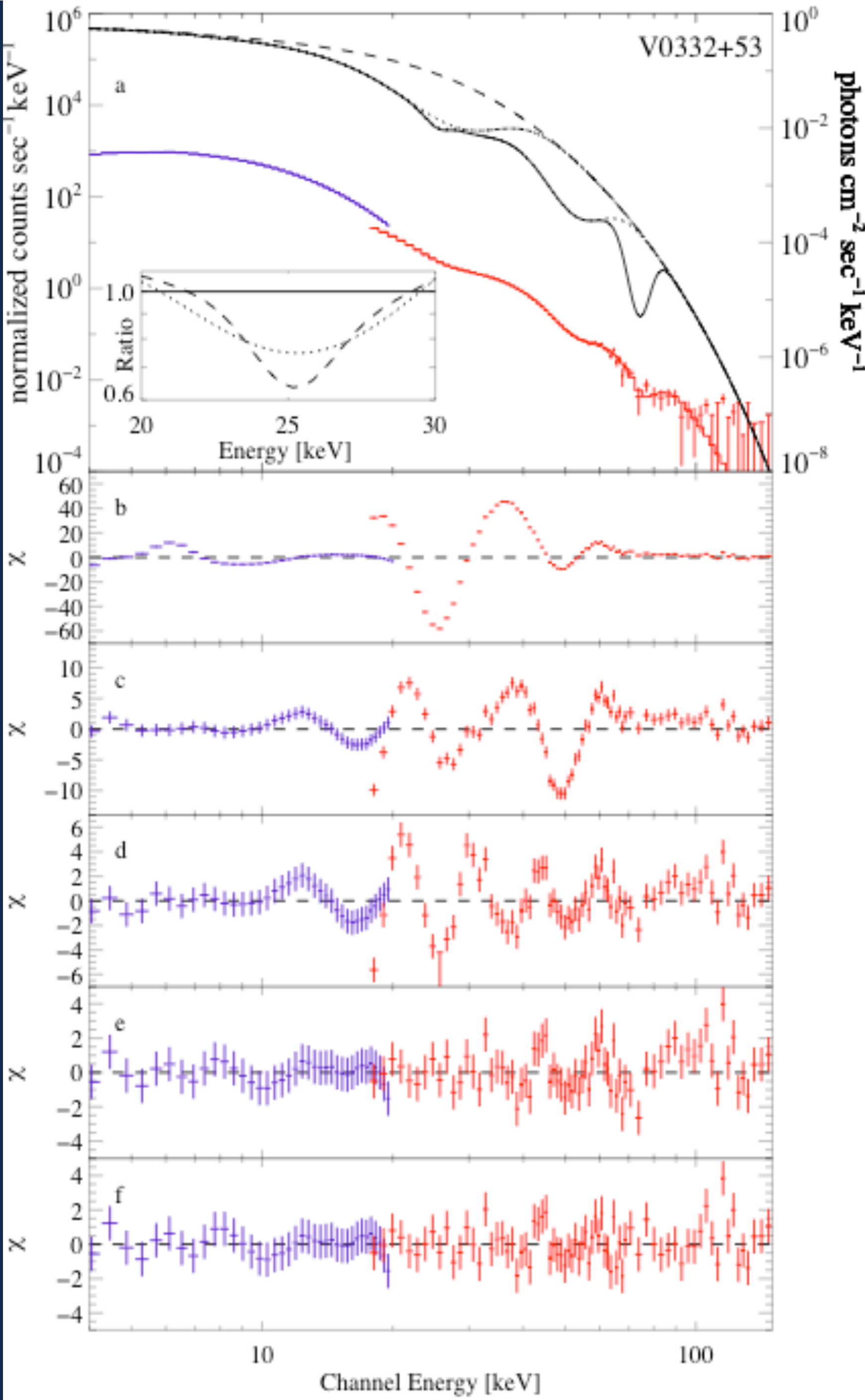


FIG. 3. A beam of radiation emerging from the accretion column.

From Lyubarskii & Sunyaev (1988).



Cyclotron Lines in V0332+53

Analyzing RXTE data near the outburst peak Pottschmidt et al. (2005) find cyclotron lines at 26.3, 51.3, and 73.7 keV They show that these energies are consistent with the relativistic formula for the line energies,

$$E_{C,n} = \frac{2nE_F}{1+z}\left(1+\sqrt{1+2n\frac{E_F}{m_e c^2}\sin^2\theta}\right)^{-1}$$

(with E_F = 11.6 keV ($B/10^{12}$ G), z the redshift and θ the angle between the incident photon and the magnetic field), for B = 2.7×10^{12} G, z = 0.3, and θ near 90°.

These cyclotron lines were also found with INTEGRAL.

Cyclotron Line Measurements

Class	Name	E_{cyc} (keV)	Reference
Be/X-ray	EXO 2030+375	10.5	Wilson et al. 2007
	4U 0115+63	11.5	White, Swank & Holt, 1983
	V 0332+53	28.5	Makishima et al., 1991
	X Per	28.6	Colburn et al., 2001
	Cep X-4	30.0	Mihara et al. 1991
	XTE J1946+274	34.9	Heindl et al. 2001
	MX 0656-072	36.0	McBride, V.A. et al., 2005
	A 0535+26	47.0	Caballero et al 2007
Disk Fed	Cen X-3	30.0	Burderi et al., 2000
	4U 1626-67	39.0	Coburn et al. 2000
	Her X-1	42.0	Manchanda, 2003
Wind Fed	4U 1907+09	18.3	Cusumano et al. 1998
	4U 1538-52	20.7	Robba et al. 2001
	2S 0114+65	22.0	Bonning et al. 2005
	Vela X-1	23.3	Kreykenbohm et al., 2002
	4U 2206+54	32.0	Blay et al., 2006
	GX 301-2	42.4	La Barbera et al. 2005