# CONSTRAINTS ON THE NATURE OF THERMONUCLEAR BURST OSCILLATIONS

**Feryal Özel**

**Institute for Advanced Study, Princeton**

**Collaborators: Mike Muno and Deepto Chakrabarty (MIT)**

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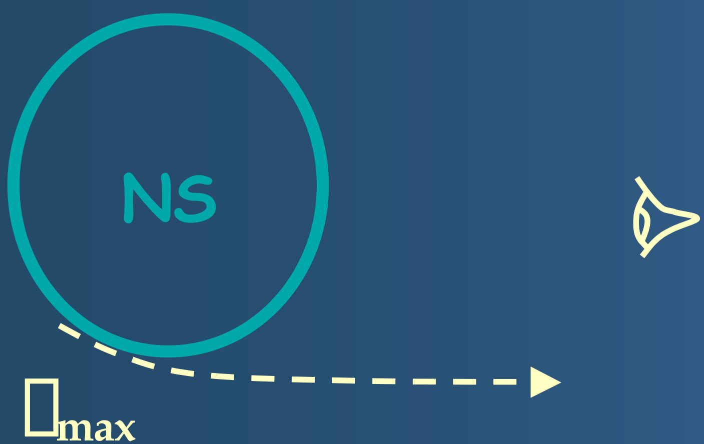
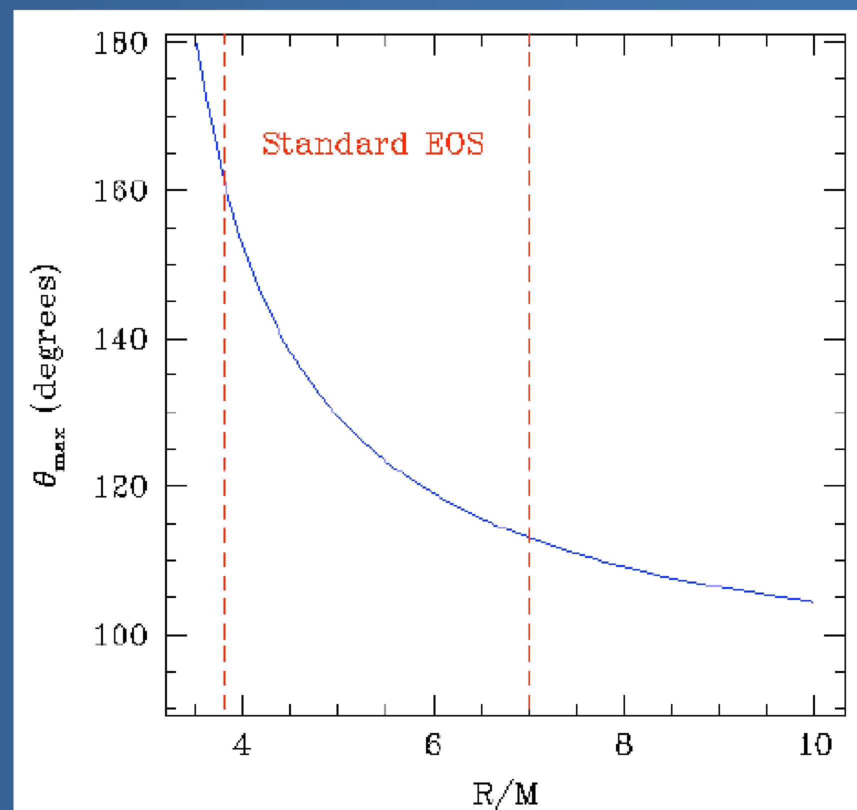
**Pavlin Savov**
**Dimitrios Psaltis**

# Neutron Star Self-Lensing

**The Schwarzschild metric:**

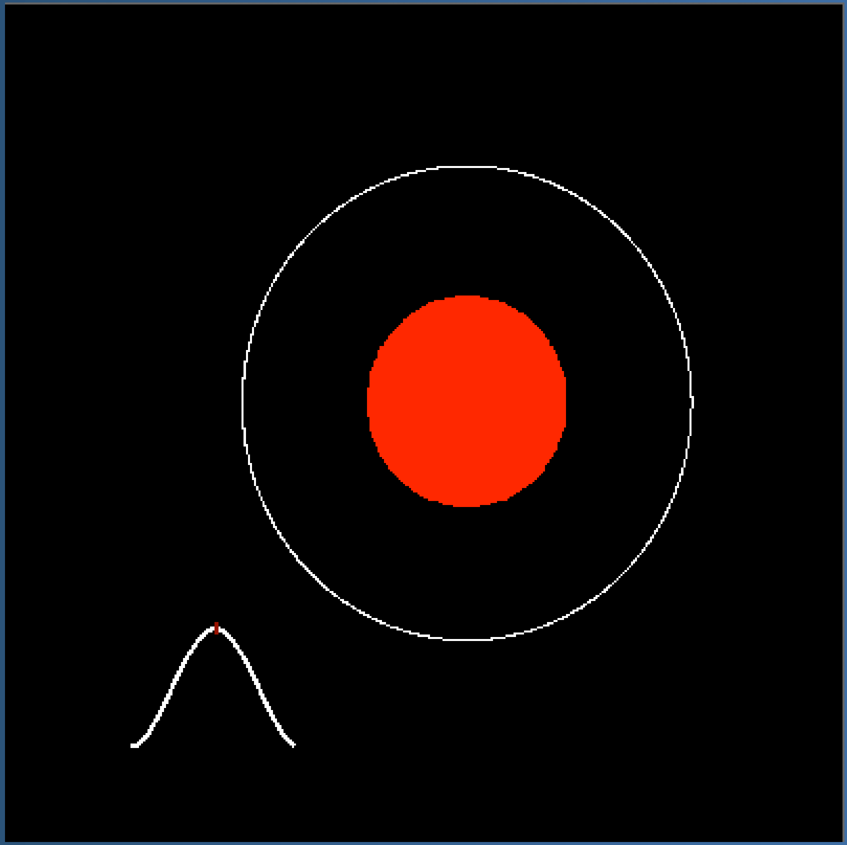
$$ds^2 = dt^2\left(1-\frac{2M}{r}\right) - dr^2\left(1-\frac{2M}{r}\right)^{-1} - f(\theta,\phi)$$



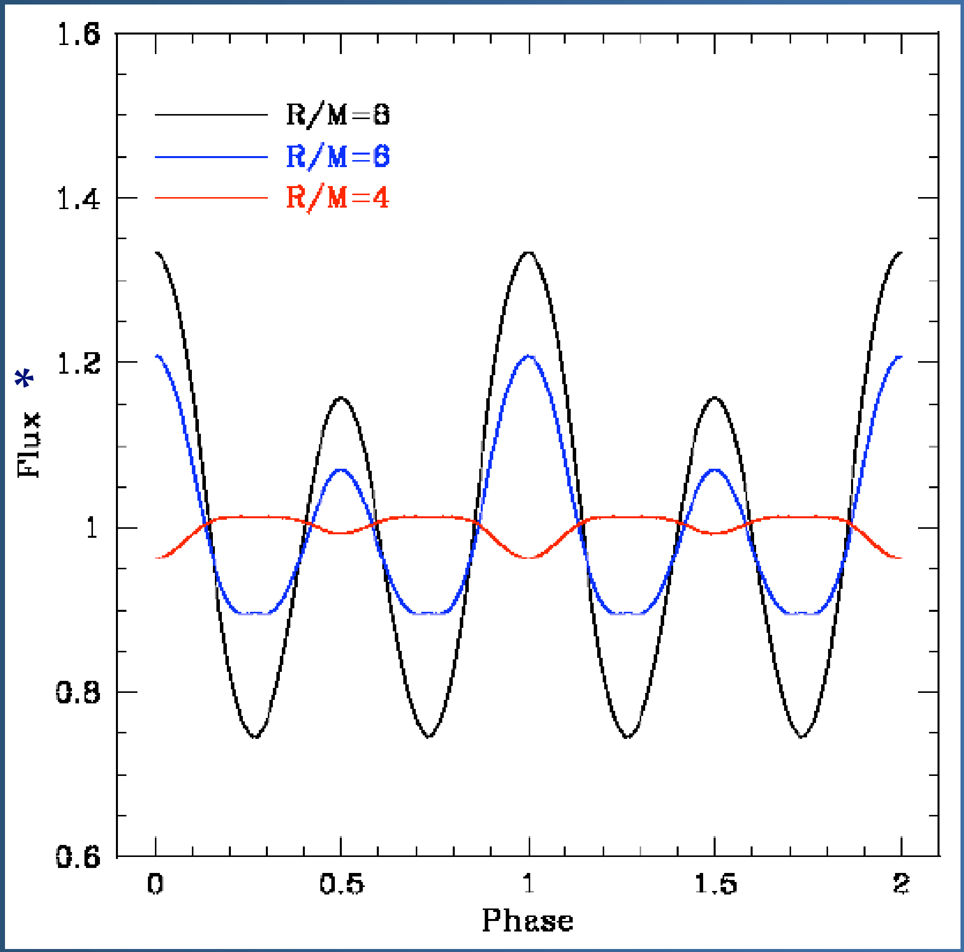




A perfect ring of radiation:
➔ R/M = 3.52

# General Relativistic Effects

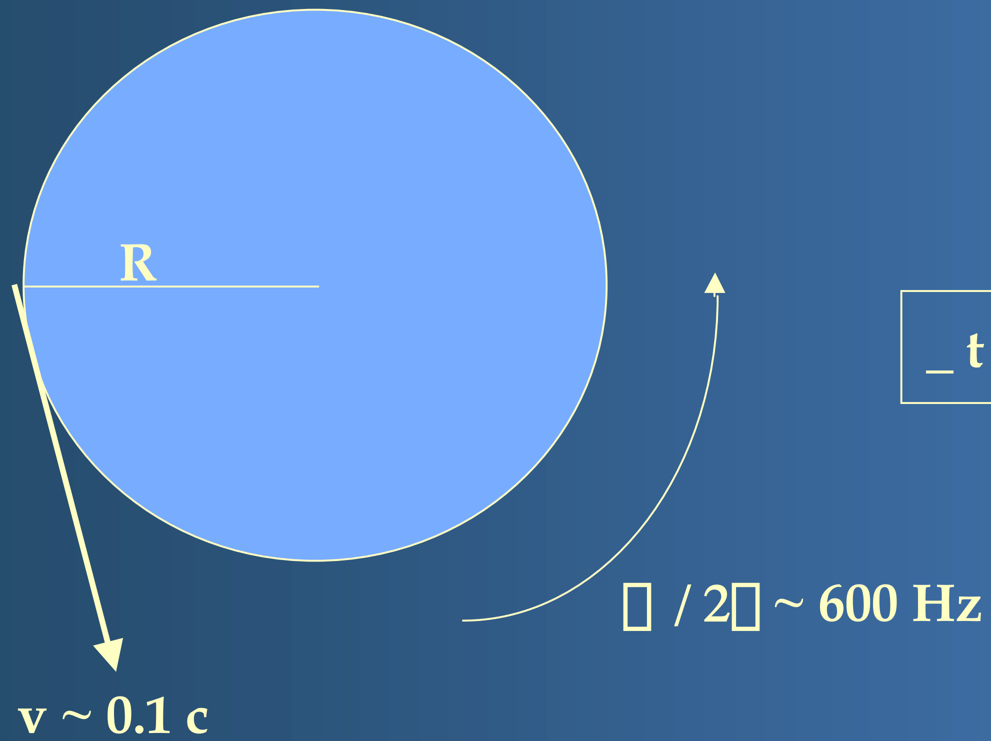


# Pulse Amplitudes




* Normalized to average

# What if the star is rotating rapidly?




**Time delays**

_ t = □/□ □ □ R/c

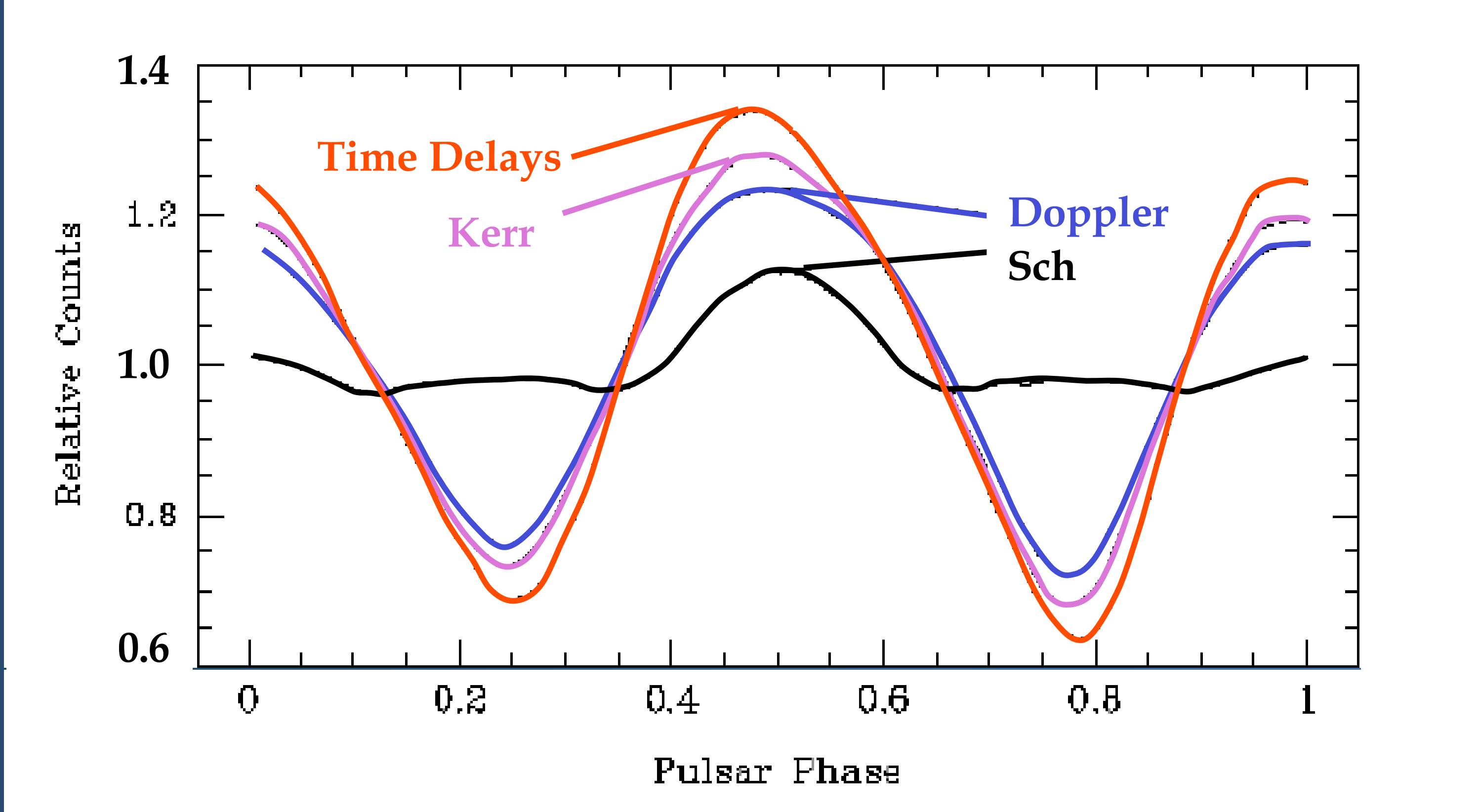
Light travel time

NS half period

E =$E_0$ □(1+□ R/c)

**Doppler Boosts**

# Lensed Lightcurves




Braje, Romani, & Rauch 01; Muno, Özel, & Chakrabarty 02

- ✓ Non-sinusoidal lightcurves
- ✓ Higher amplitude oscillations

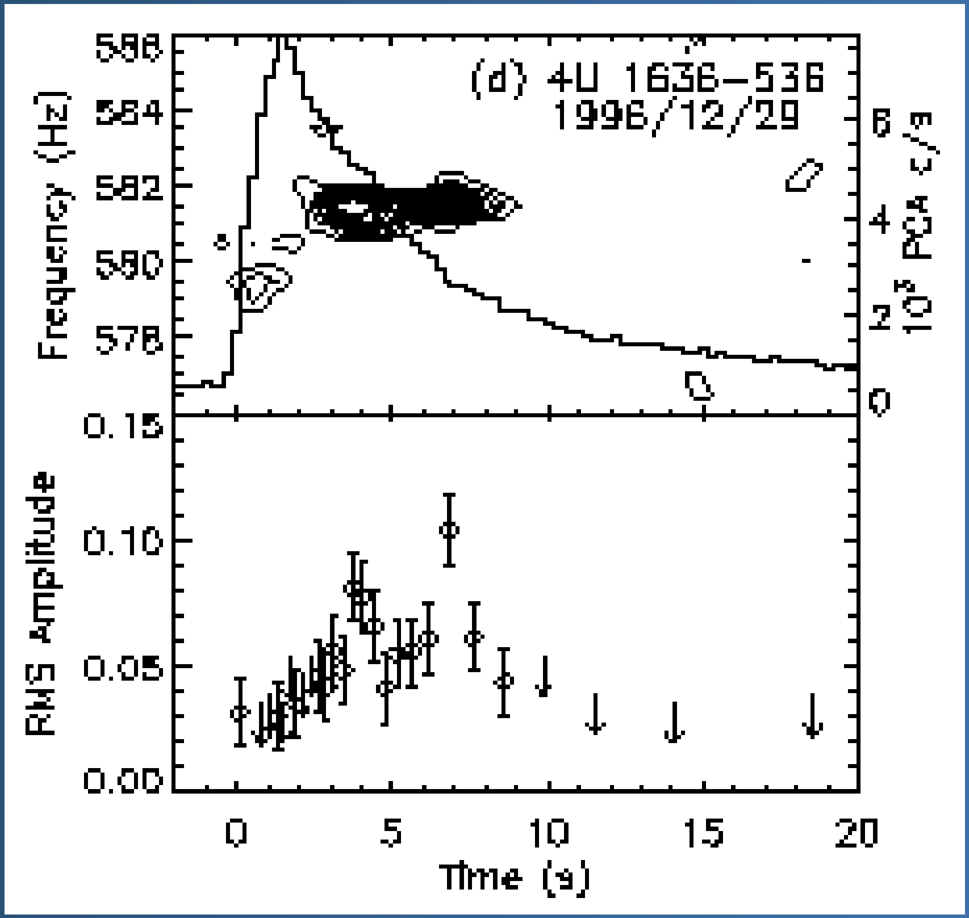
# What does this have to do with bursts?

- Thermonuclear bursts occur on the surface
  → GR effects important
- Oscillations are one of the most powerful probes
- Use pulse profiles to constrain
  the burst or neutron star properties

Weinberg, Miller, & Lamb 01
Nath, Strohmayer, & Swank 02

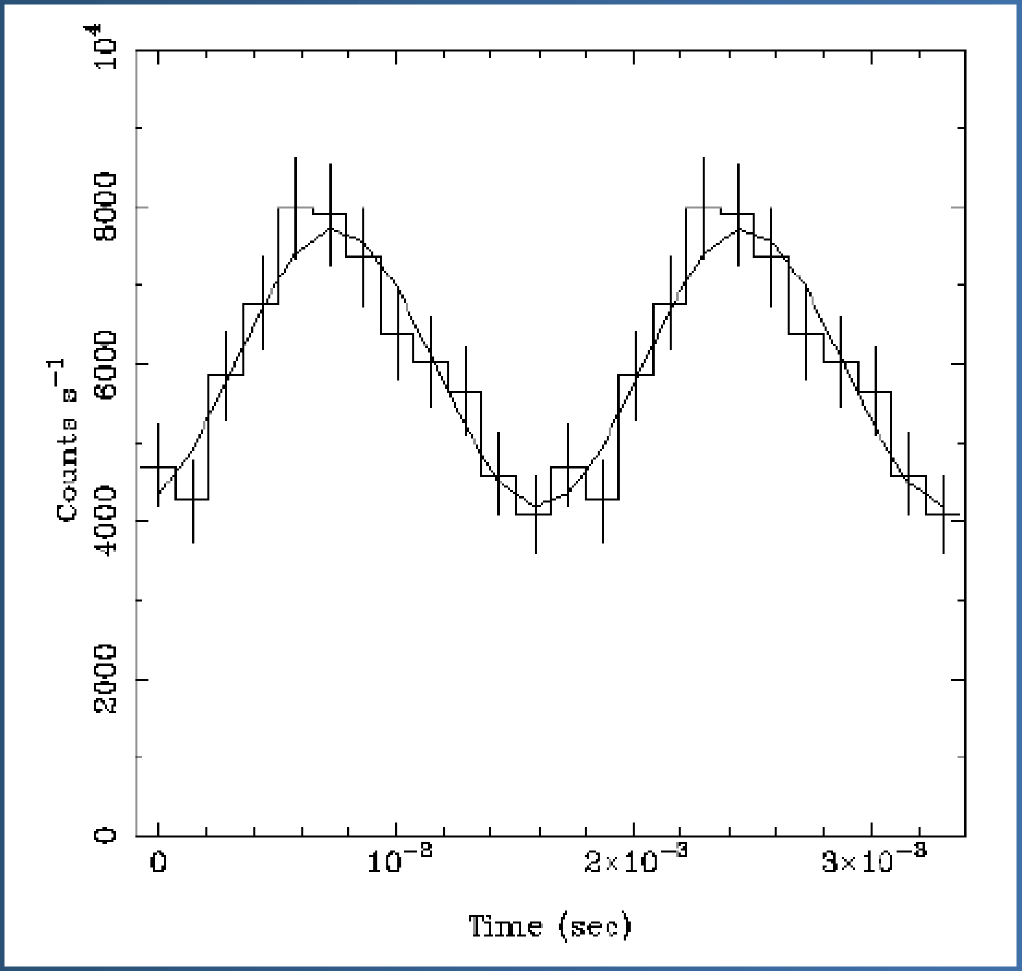
# Burst Oscillations

## Oscillations observed during tails of thermonuclear bursts



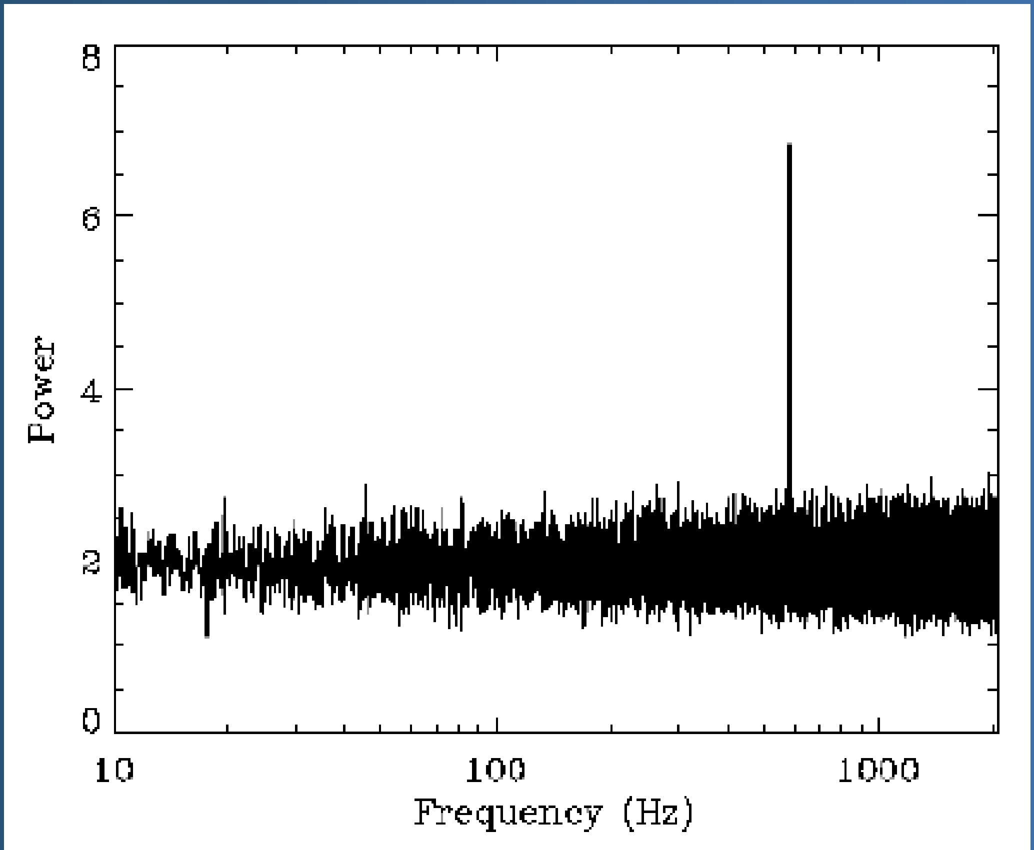

Strohmayer 98; Muno et al. 02

# Pulse Profiles



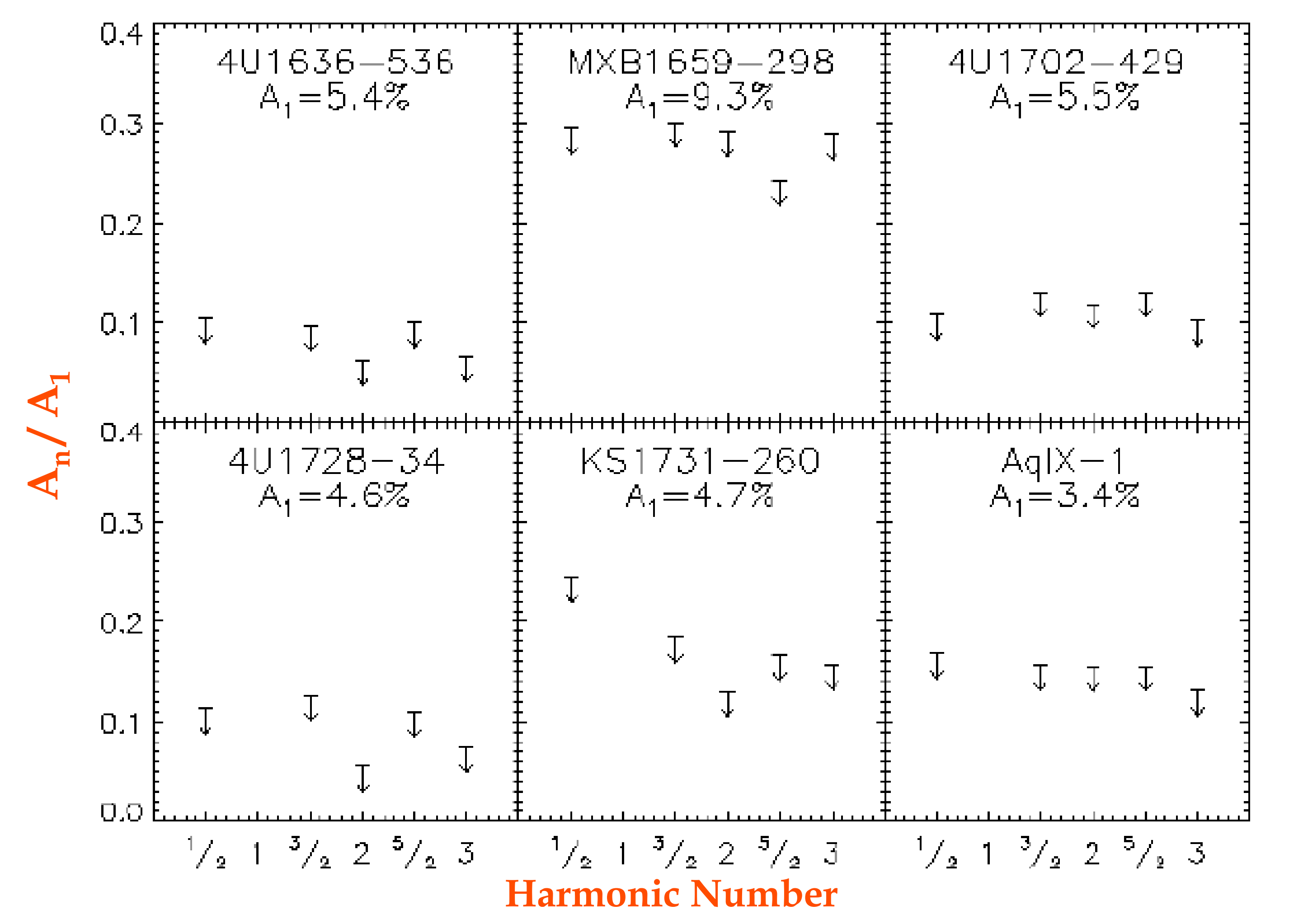

Muno et al. 02

# Harmonics?




Muno et al. 02

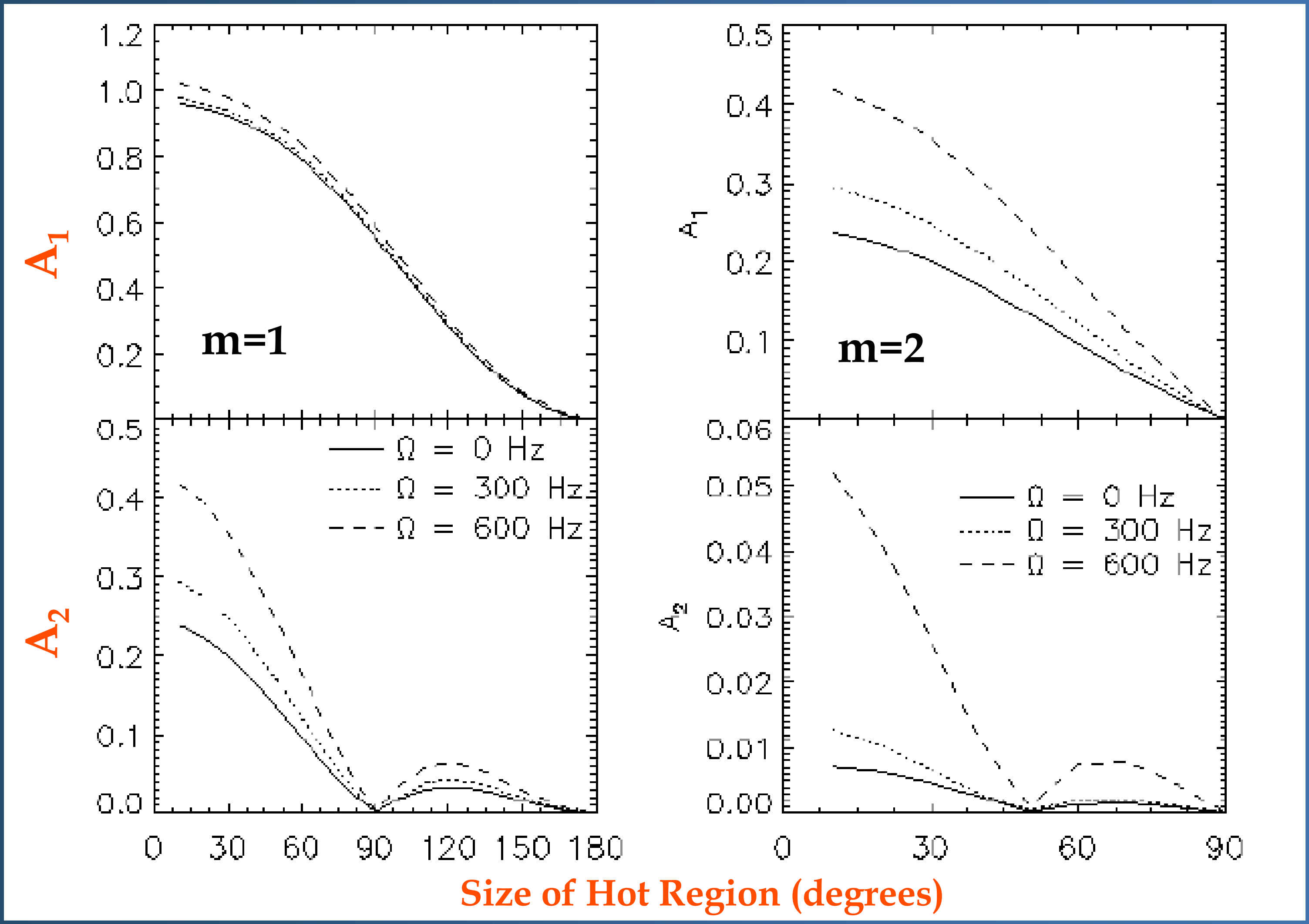
# Not really…



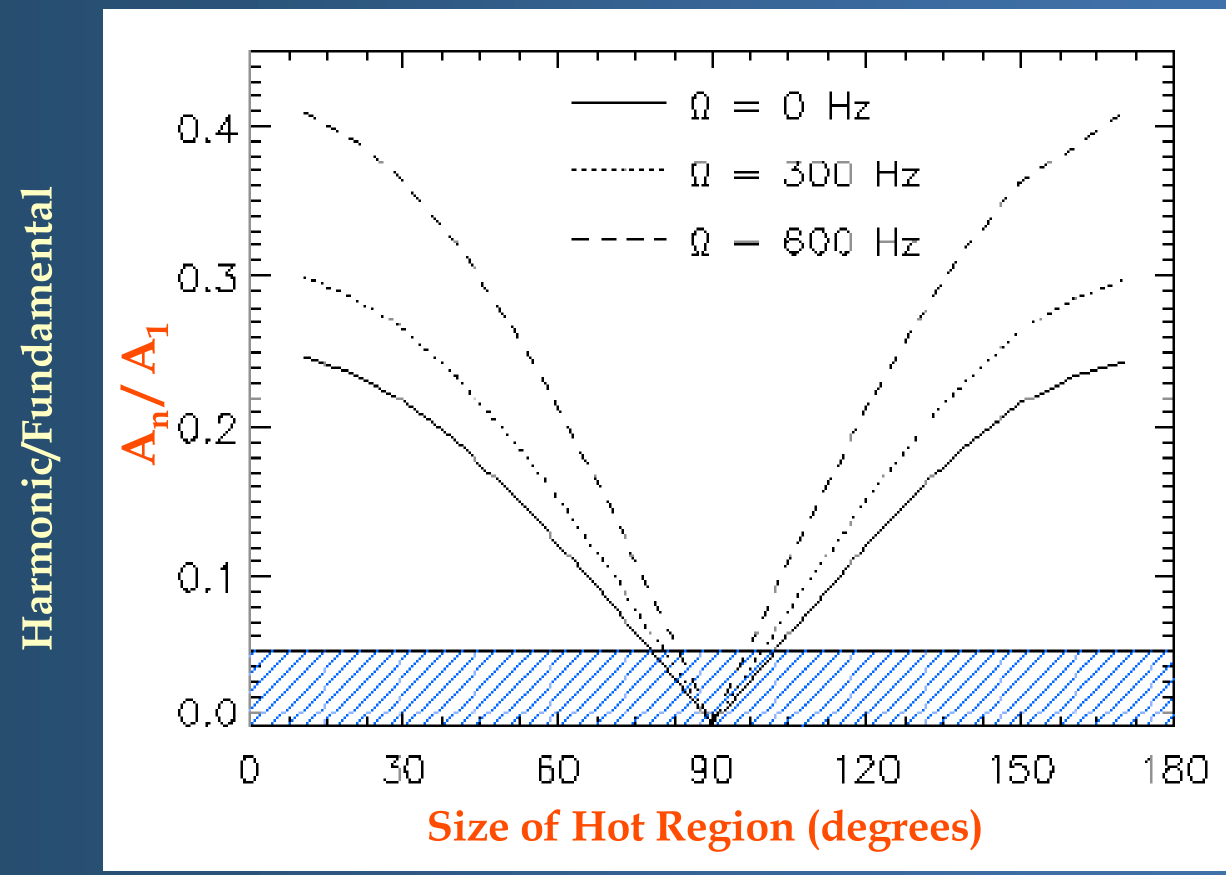

Muno, Özel, & Chakrabarty 02

**Stringent upper limits on harmonic amplitudes**

# Effects of Emitting Area

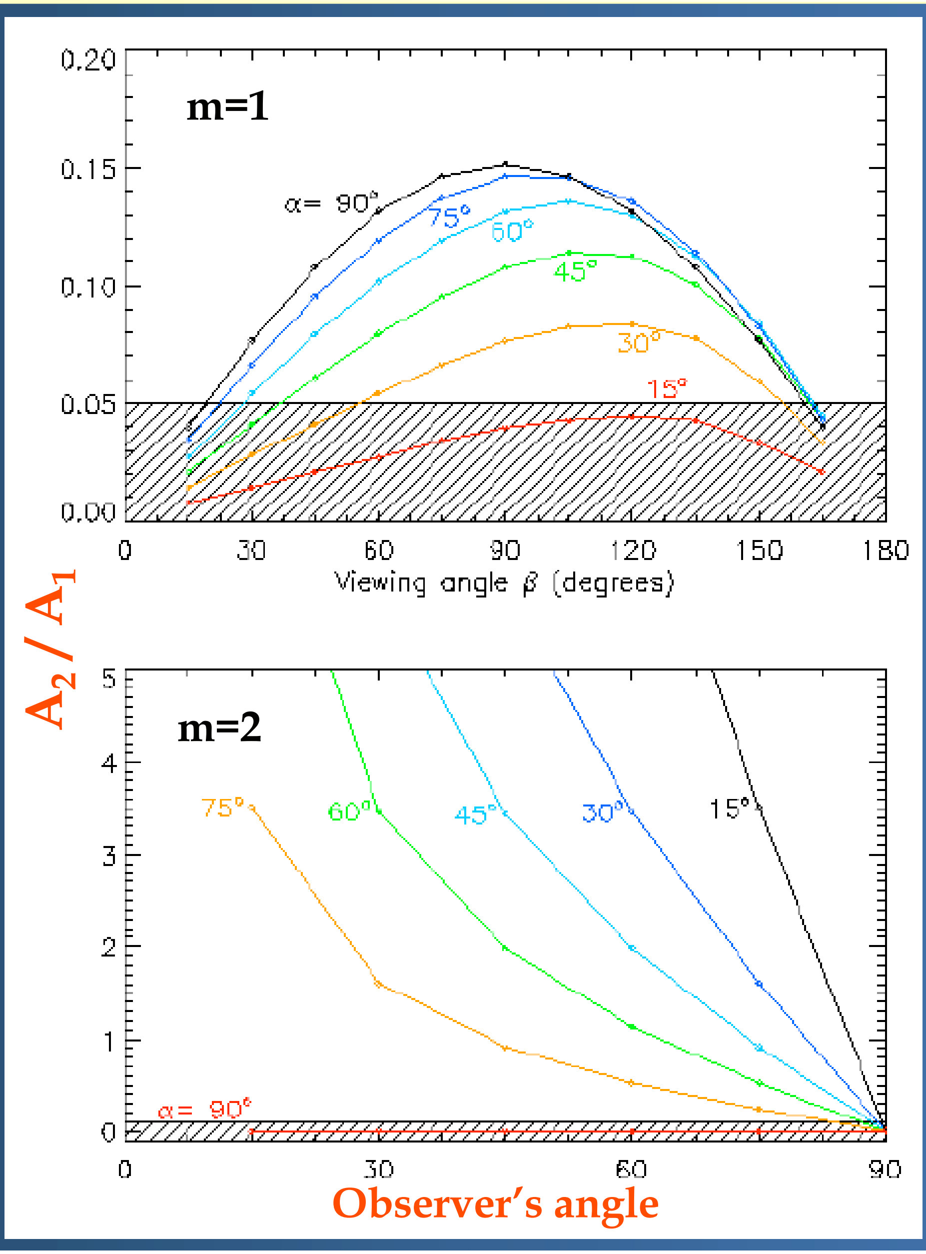


# Where Does the Emission Come from?




Muno, Özel, & Chakrabarty 02

# Constraining Location on the Neutron Star



# Possibilities

**One hot region must be localized near the rotational pole**

***or***

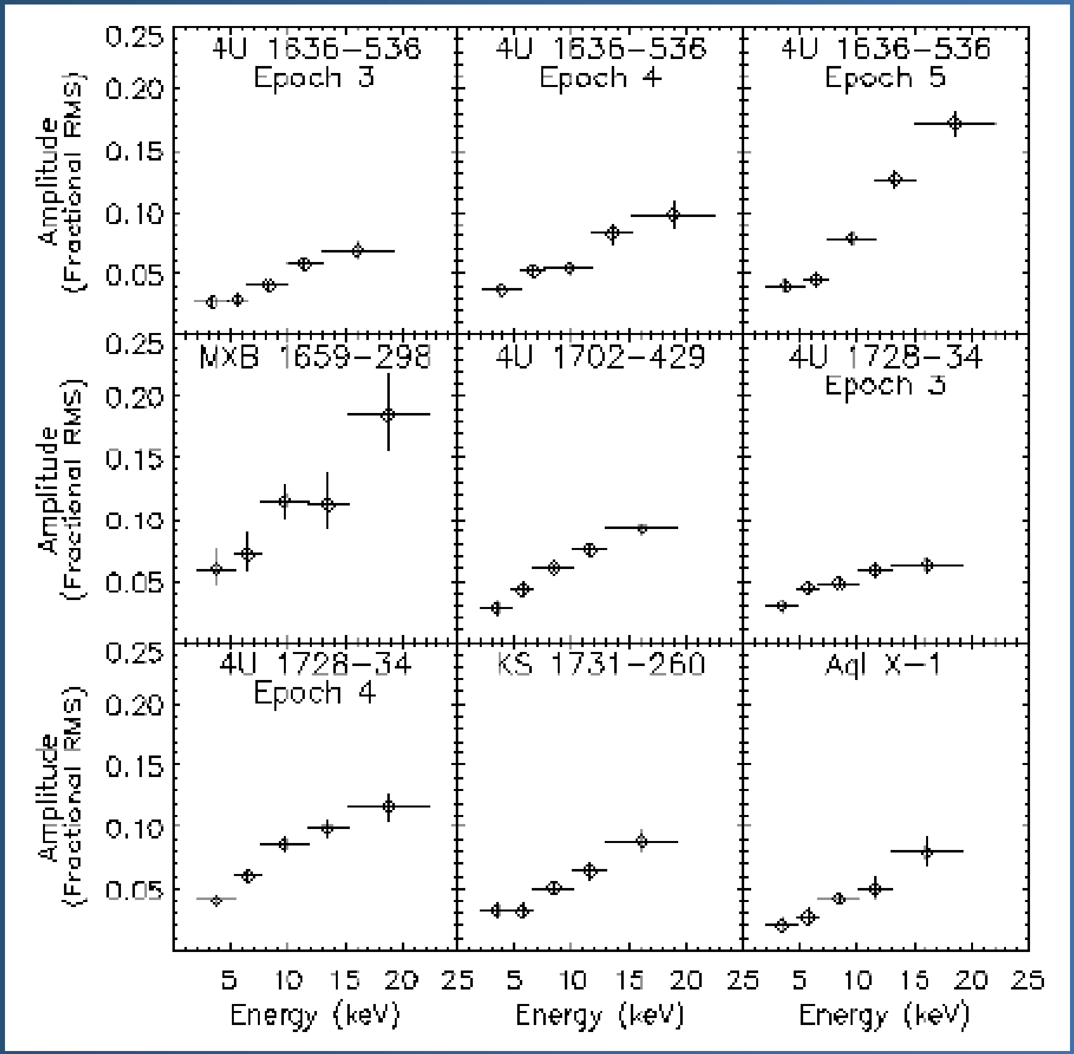
**Two hot regions must be centered on the equator**

***or***

**Half of the neutron star or equatorial band**
**must be hotter than the other half**

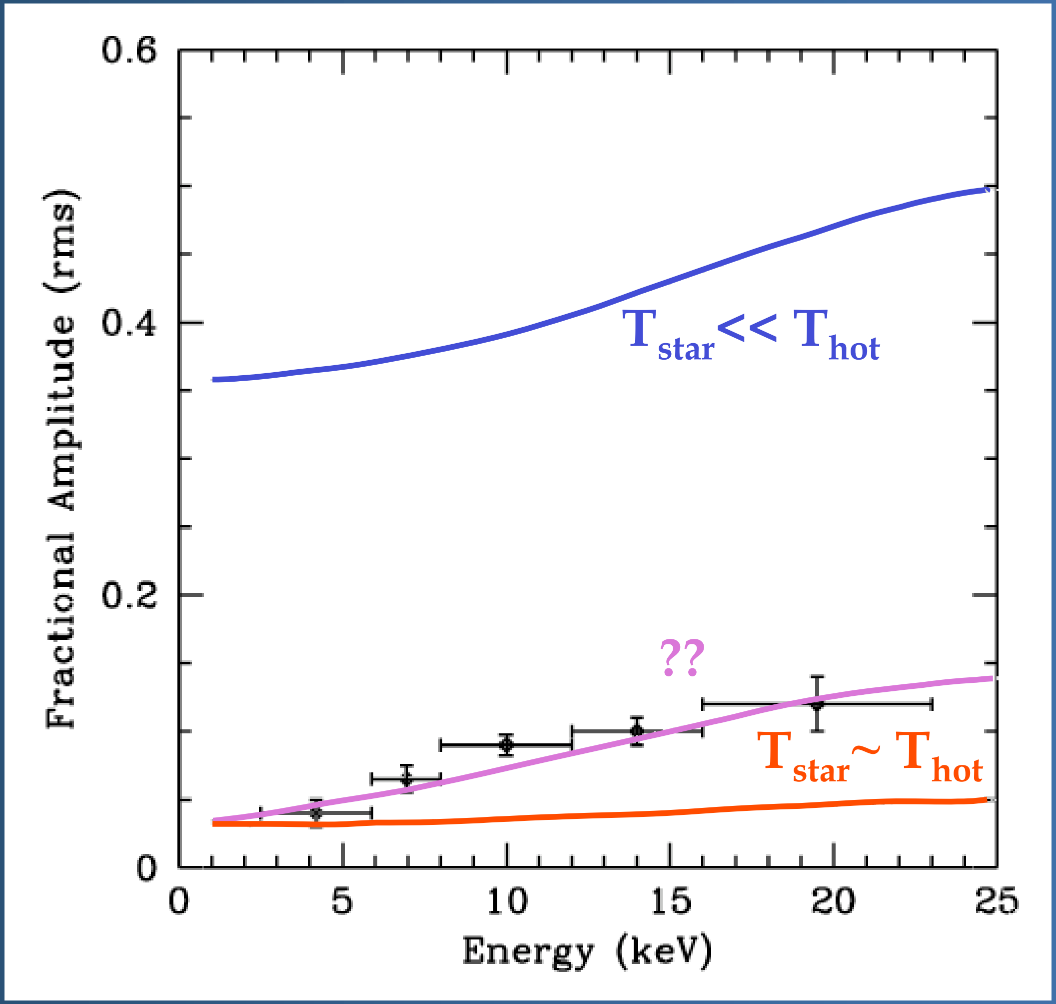
- **A highly organized pattern or mode on the stellar surface**

# Energy Dependence of Amplitudes




Muno, Özel, & Chakrabarty 03

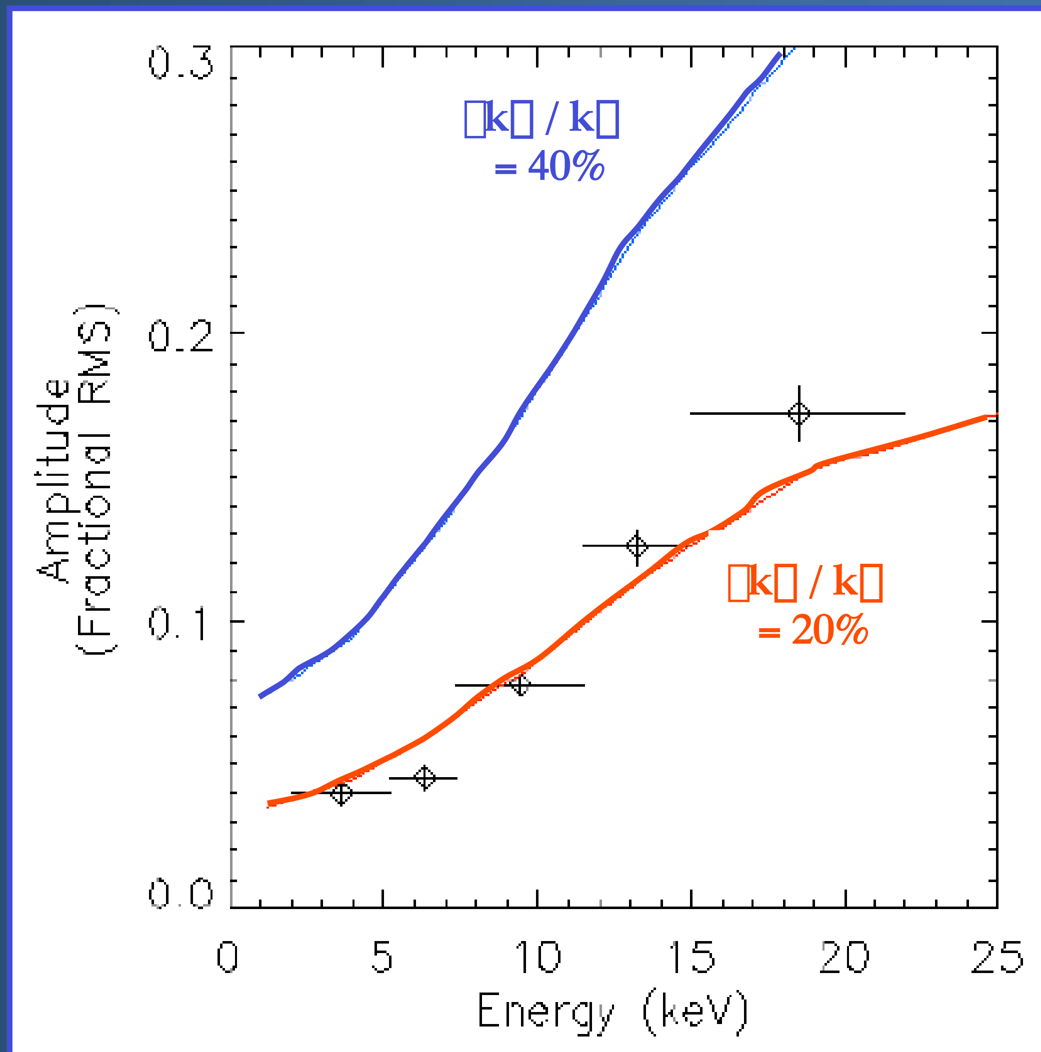
# What affects the Energy Dependence ?




→ Rest of the star must emit within the PCA band

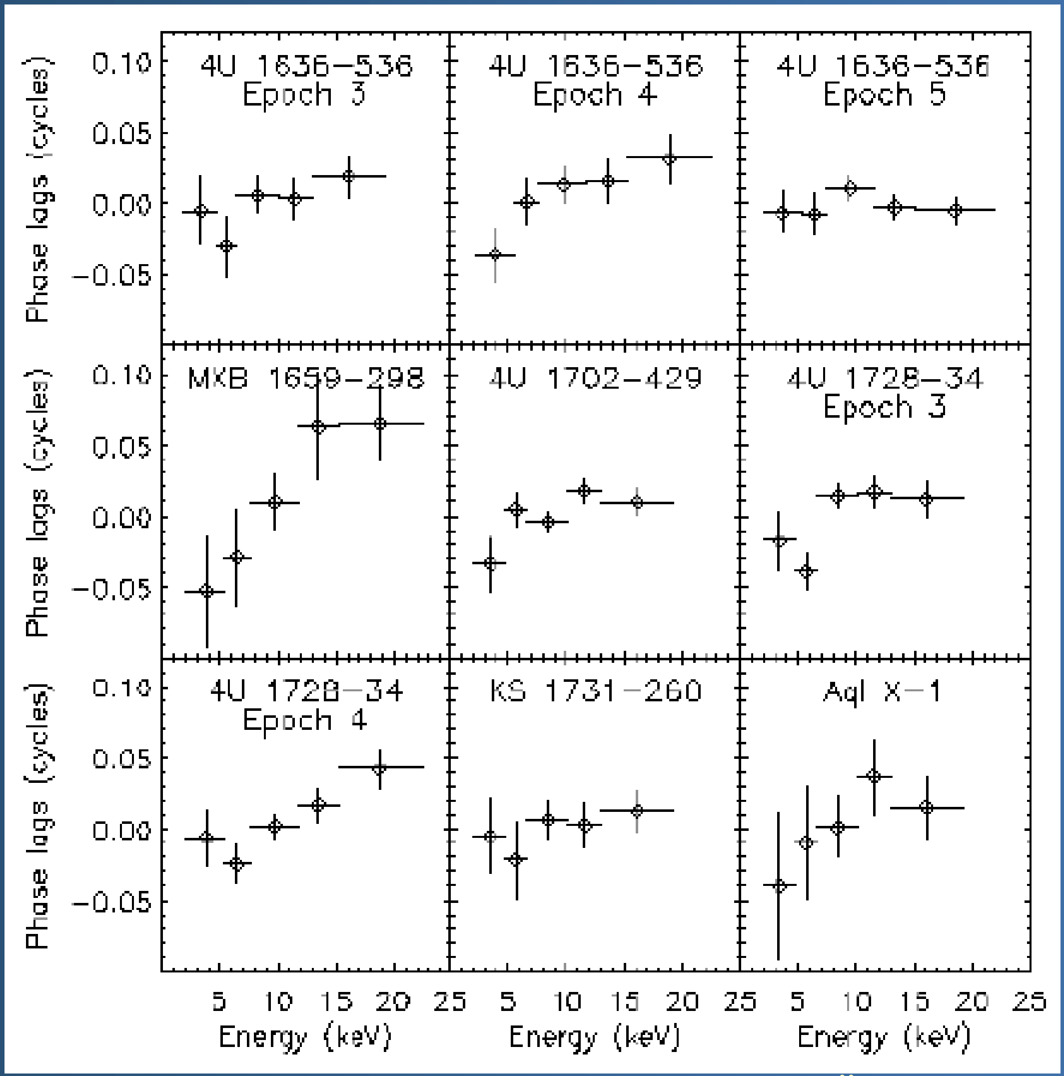
# Further Constraints

for □ = 90,
□ = □ = 90




Muno, Özel, & Chakrabarty 03

# Time Lags




**Muno, Özel, & Chakrabarty 03**

- Expect soft lags from Doppler boosts
- Observed: hard or no lags

→ A scattering corona may induce hard lags

# Conclusions

- ✓ Bursts excite a (non-radial) mode on the NS
- ✓ m=1, m=2 patterns seem to match the observations

Photon diffusion time ~ 1 s.
Higher frequency modes trapped in burning layer filtered out?

**And many questions:**

- ✓ Need models of a scattering corona during bursts
- ✓ Modes, but which modes? (Spitkovsky, Lamb)
- ✓ How does the frequency evolution fit in with modes?

# Thoughts on Scattering Coronae

- Need □□3 to reduce $A_n / A_1$ to observed levels but this also reduces the fundamental significantly
- Harmonic ratios don't change with photon energy band but different energy photons should undergo different number of scatterings