

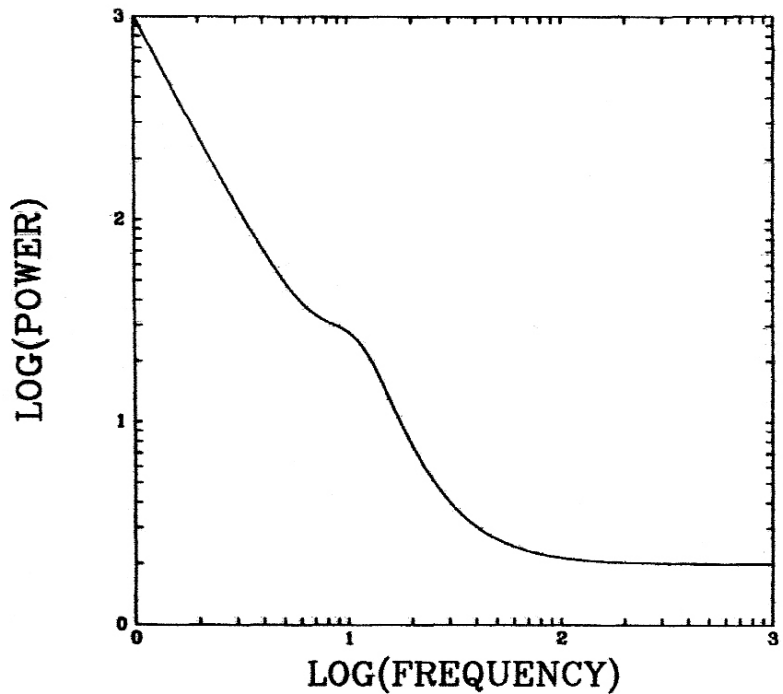
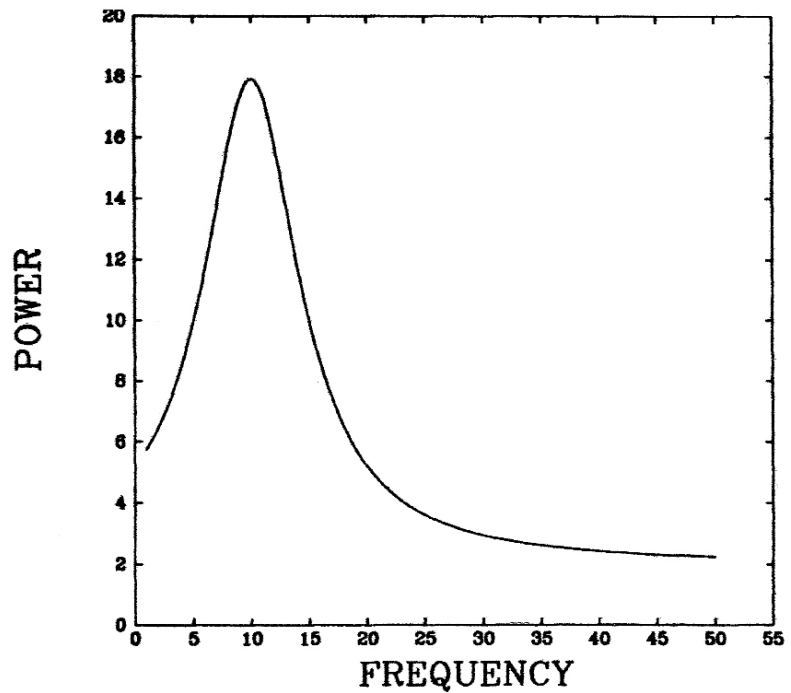
# Quasi-Periodic Oscillations

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# Topics

- Quasi-periodic Oscillations in general
  - What are QPOs?
  - Classification
  - Sources where QPOs were observed
- QPO Spectra
- Methods to detect QPOs
- Theoretical Models to explain QPOs

# What are QPOs



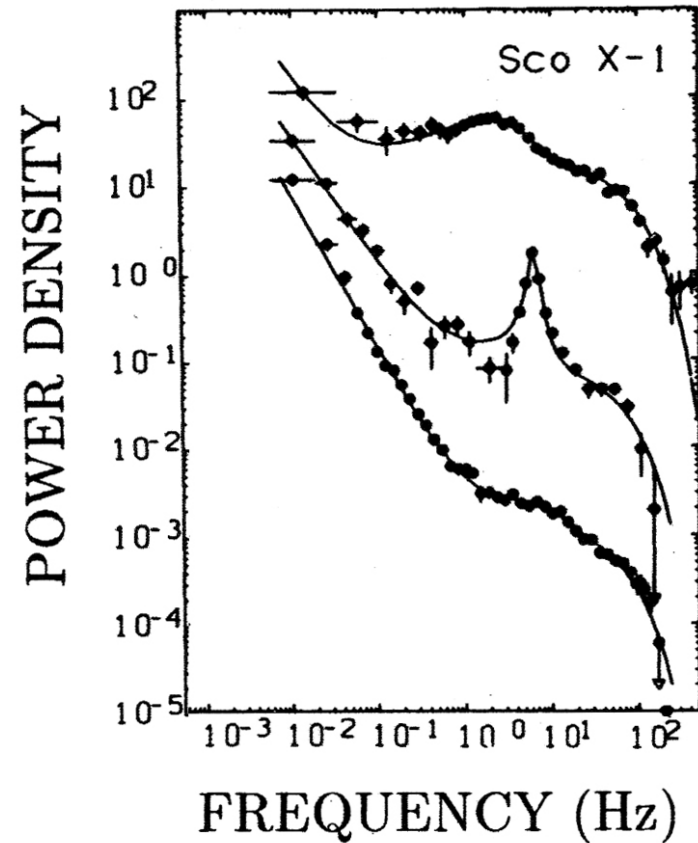
Hasinger, van der Klis 89

# Classification

- "Normal" QPOs
- High Frequency QPOs
- Burst Oscillations
  
- Z-Shape Sources
- Atoll Shaped Sources
  - Banana Shaped Sources

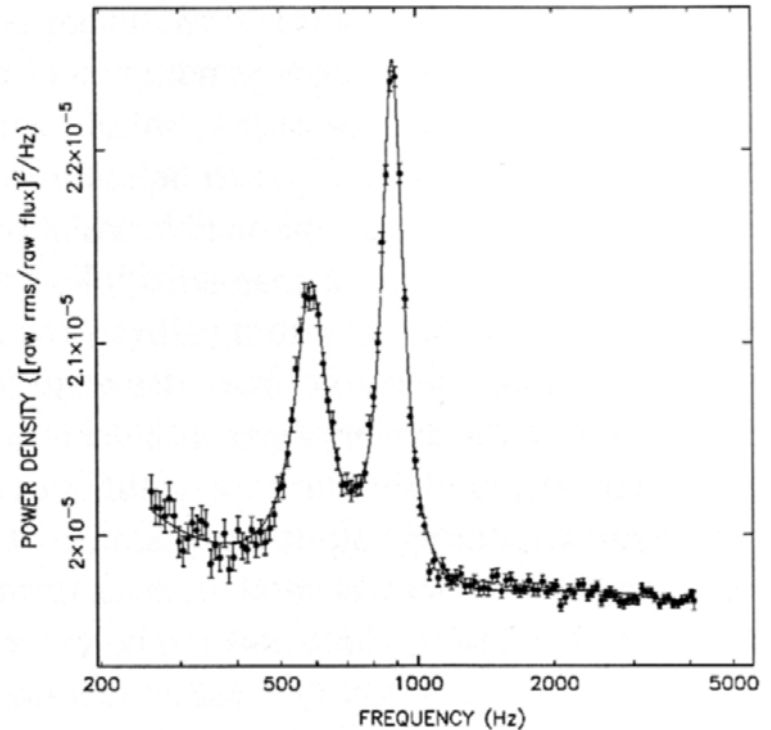
# Normal (Low Frequency) QPOs

- Frequencies of up to 100Hz



# High Frequency QPOs

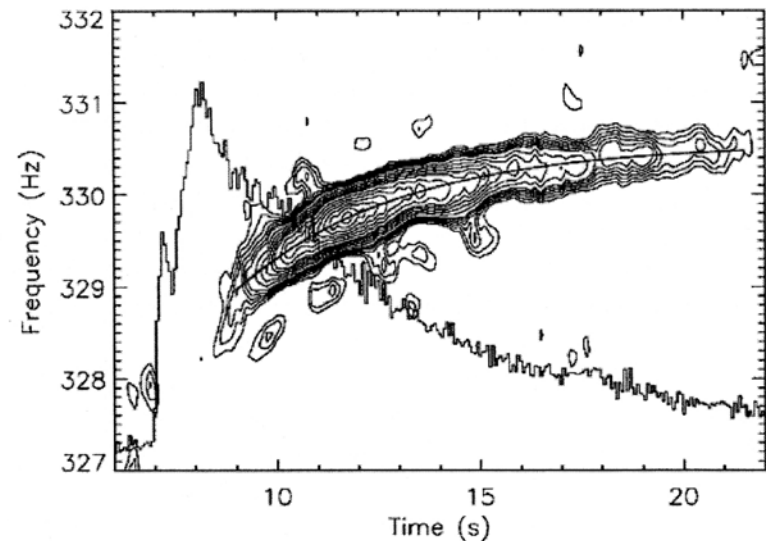
- Also known as kHz QPOs
- Often twin peaks



Van der Klis, 2000

# Burst Oscillations

- Do not occur in every burst
- Result from anisotropic burning on the surface and rotation of neutron star
- Close to neutron star rotation frequency



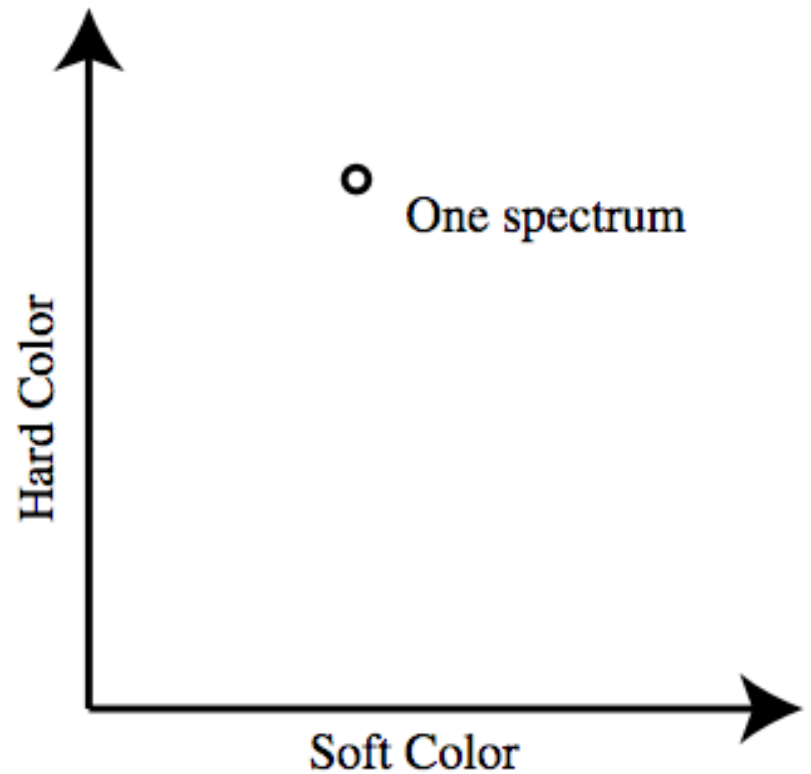
Van der Klis, 2000

# Color Index

- Difference of magnitudes in two filters
- Magnitudes are a logarithmic scale!
- “Minimal Spectrum”

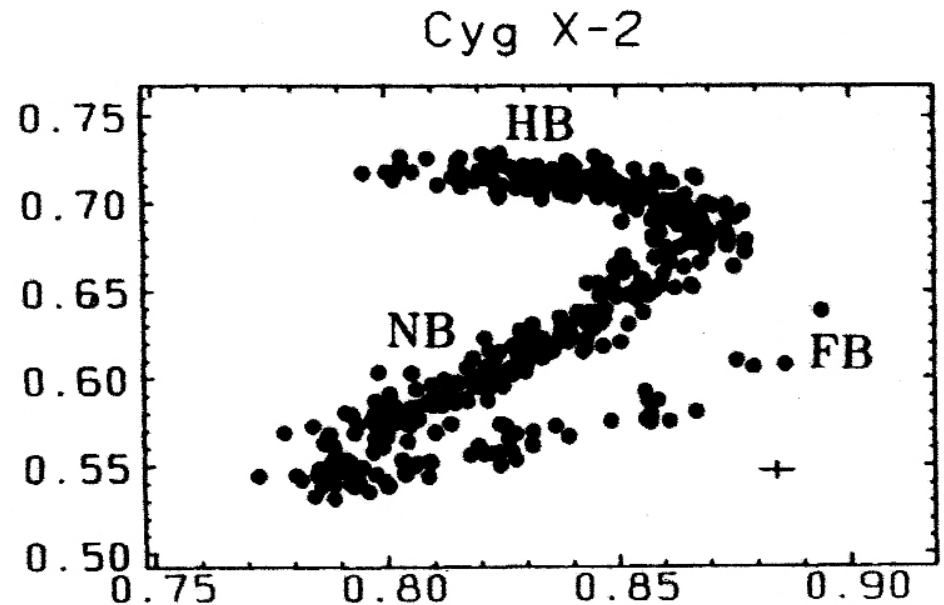
# Color Color Diagrams

- Determine the hardness ratio (“color index”) in a hard and a soft X-Ray band
- Plot the hard versus the soft color
- Every X-Ray spectrum produces 1 point in the Color-Color Diagram



# Shapes: Z-Shape

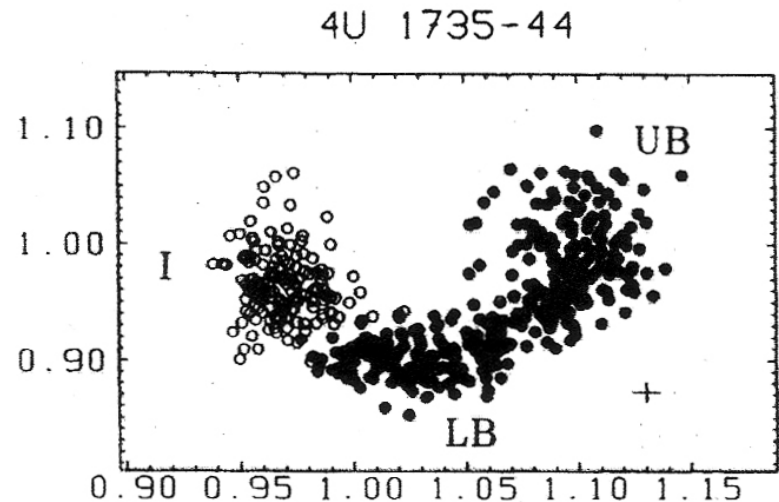
- Branches:
  - Horizontal Branch
  - Normal Branch
  - Flare Branch
- Very little scattering



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# Shapes: Atoll Shapes

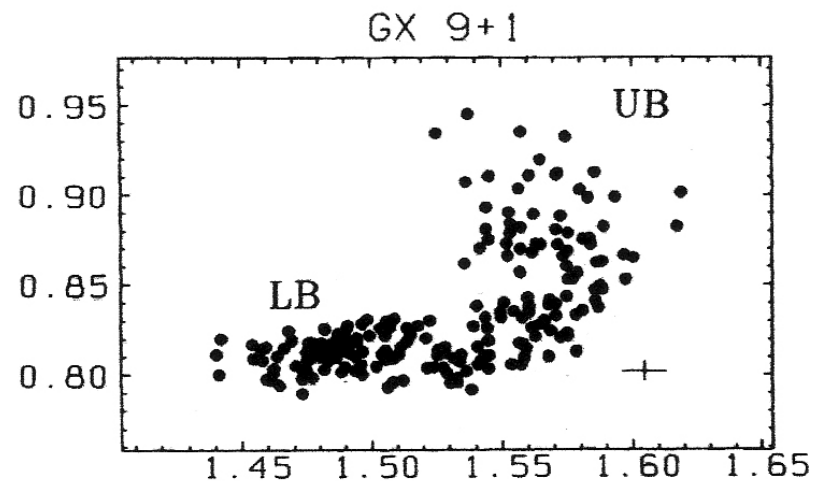
- No Z
- Two states:
  - Banana State
  - Island State
- Island Branch do not occur in fixed position



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# Shapes: Banana Shapes

- Larger scattering near top
- "Banana"-shaped branches
- Banana Branch  
recurses in the same place

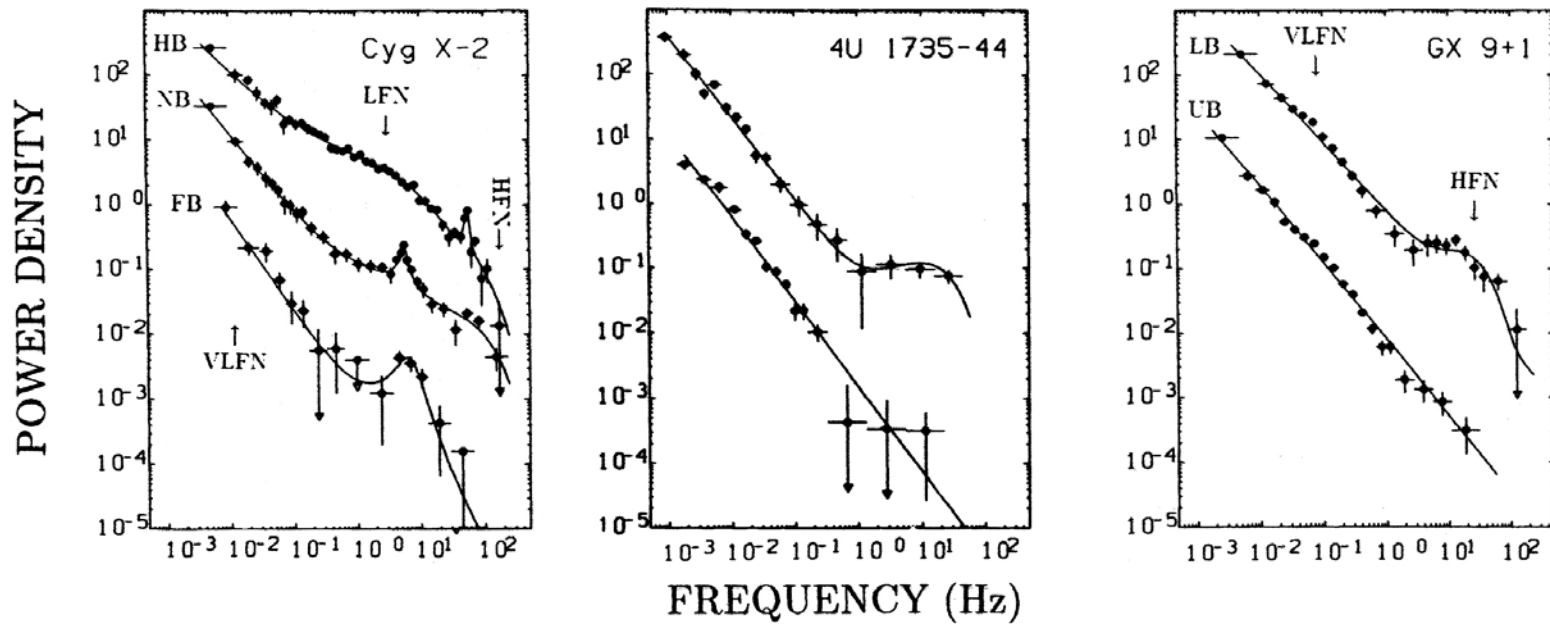


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# Sources where QPOs were observed

- Low Mass X-Ray Binaries
  - Neutron Stars
  - X-Ray Bursters
  - Black Hole Candidates

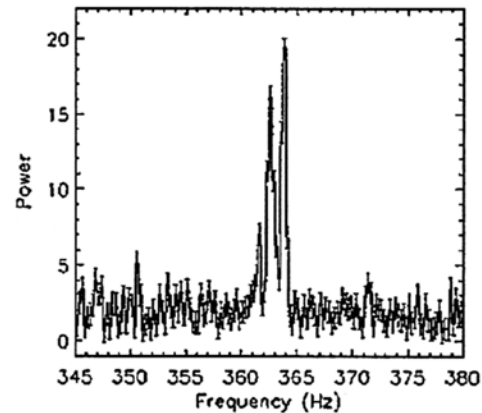
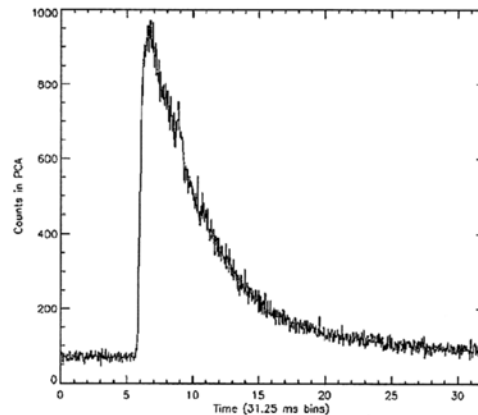
# QPO Spectra



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# Detection of QPOs

- Data with high time resolution
- Discrete Fourier Transformation
- Subtract noise



# Theoretical Explanations

- Beat-Frequency Model
- Relativistic Precession Model
- Photon Bubble Model
- Disk Mode Models

# Beat-Frequency Model

- Accretion Disk and the Magnetosphere of the Compact Object rotate at different frequencies
- Inhomogeneities in the Accretion Disk interact with Anisotropies of the Magnetosphere
- A beat frequency occurs

# Relativistic Precession Model

- Inclined eccentric orbits show
  - Nodal precession (wobble of the orbital plane)
  - Relativistic periastron precession
- Model identifies frequencies with orbit and precession frequencies

# Photon Bubble Model

- Proposed to explain kHz QPOs in Sco-X1
- Photon bubbles form while the accretion takes place
- The bubbles rise up by buoyancy and burst on top in a quasi-periodic sequence
- The Model does not require rotation

# Disk Mode Models

- The QPO frequency is interpreted as an oscillation mode of the accretion disk
- Some of the models can be interpreted as implementations of beat-frequency or precession models

# Literature

- Hasinger, van der Klis: Two Patterns of Correlated X-ray Timing and Spectral Behaviour in Low-Mass X-ray Binaries, *Astron. Astrophys.* 225, 79-96 (1989)
- van der Klis: Millisecond Oscillations in X-Ray Binaries, *Annu. Rev. Astron. Astrophys.* 2000. 38: 717-60
- Shibazaki, Lamb: Power Spectra of Quasi-Periodic Oscillations in Luminous X-Ray Stars, *The Astrophysical Journal*, 318:767-785, 1987
- Lamb, Miller: Changing Frequency Separation of KiloHertz Quasi-Periodic Oscillations in the Sonic-Point Beat-Frequency Model, *The Astrophysical Journal*, 553:1210-1215, 2001
- van der Klis: Rossi X-ray timing Explorer observations of kiloHertz QPO, *Nuclear Physics B (Proc. Suppl)* 69/1-3(1998) 103-112
- <http://spiff.rit.edu/classes/phys440/lectures/color/color.html>