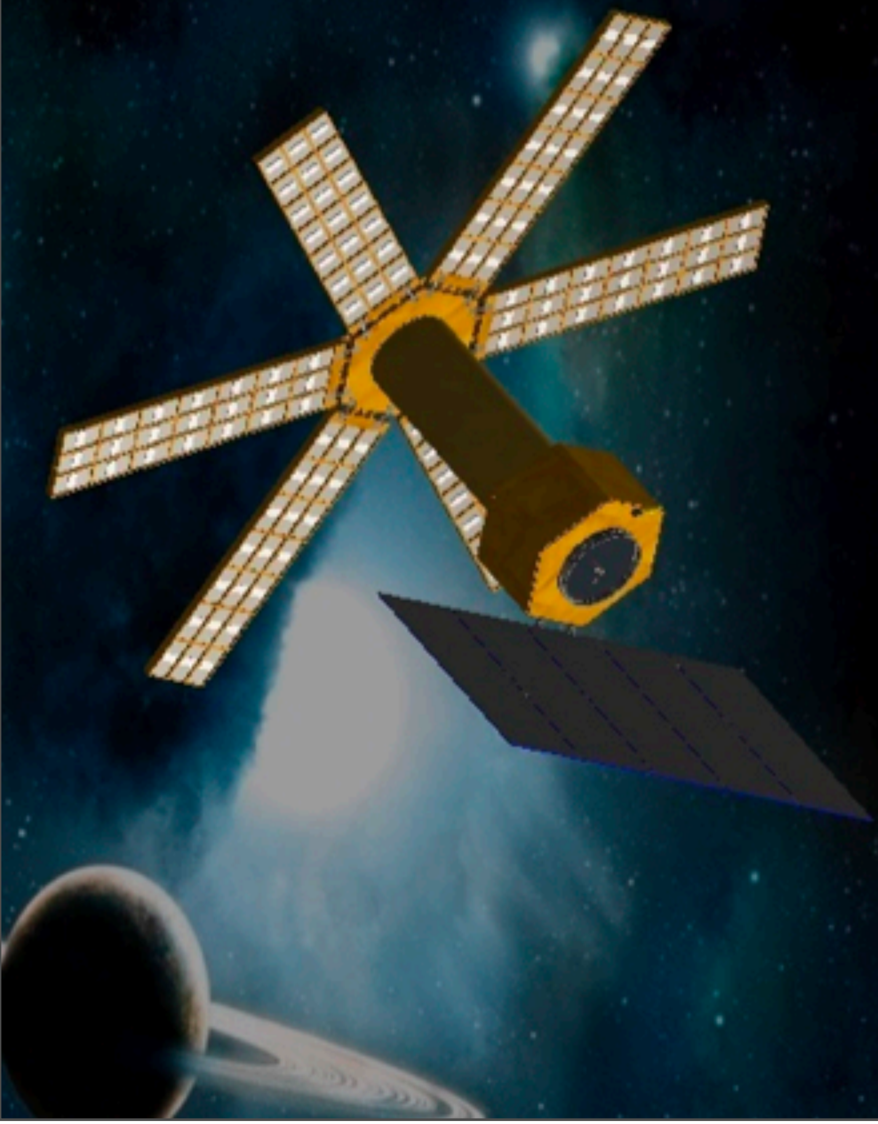
LOFT
Large Observatory For x-ray Timing



LOFT is mission proposal selected by ESA
as a candidate Cosmic Vision M3 mission

LOFT is mainly devoted to X-ray timing
and designed to investigate
space-time around collapsed objects
and the properties of matter at
supernuclear densities

Luigi Stella (INAF-OAR)
on behalf of the LOFT Consortium

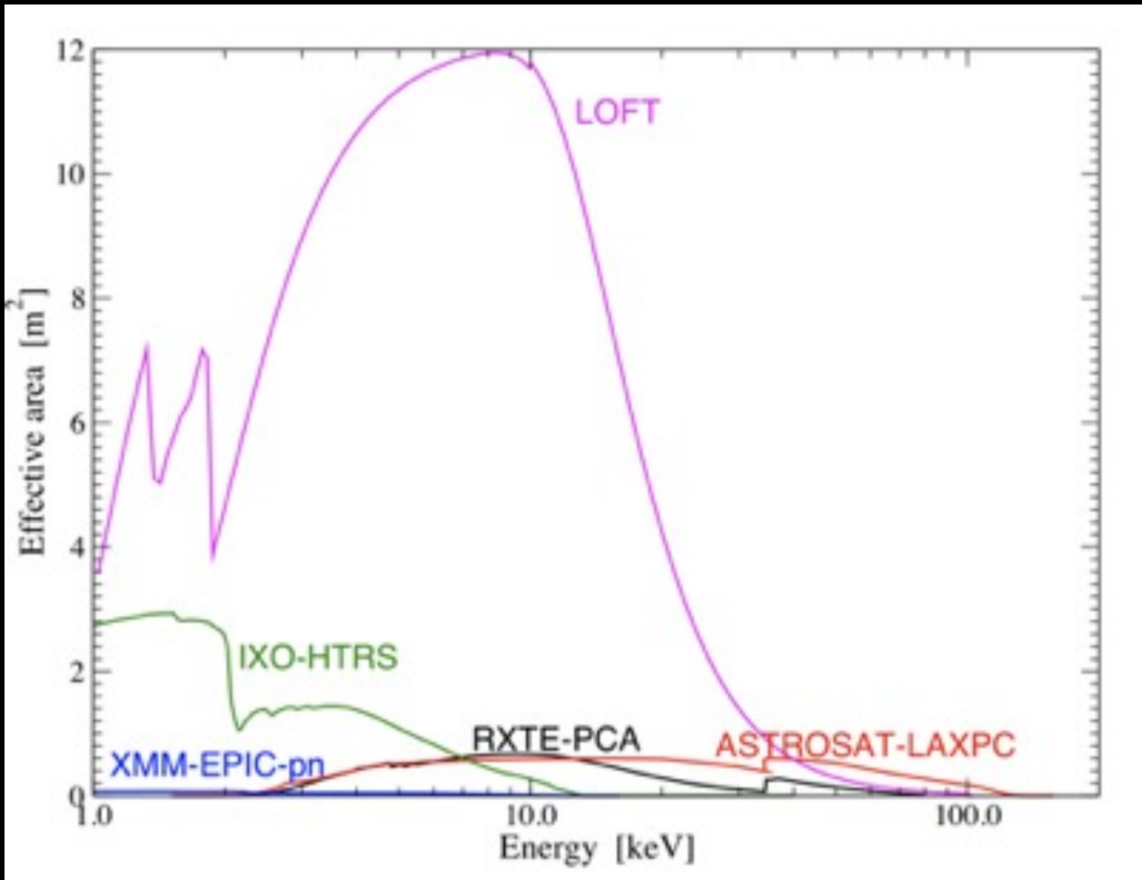
The LOFT Consortium

Jan-Willem den Herder	SRON, the Netherlands
Marco Feroci	INAF/IASF-Rome, Italy
Luigi Stella	INAF/OAR-Rome, Italy
Michiel van der Klis	Univ. Amsterdam, the Netherlands
Thierry Courvousier	ISDC, Switzerland
Silvia Zane	MSSL, United Kingdom
Margarita Hernanz	IEEC-CSIC, Spain
Søren Brandt	DTU, Copenhagen, Denmark
Andrea Santangelo	Univ. Tuebingen, Germany
Didier Barret	IRAP, Toulouse, France
Renè Hudec	CTU, Czech Republic
Andrzej Zdziarski	N. Copernicus Astronomical Center, Poland
Juhani Huovelin	Univ. of Helsinki, Finland
Paul Ray	Naval Research Lab, USA
Joao Braga	INPE, Brazil

on behalf of more than 250 scientists from:

Brazil, Canada, Czech Republic, Denmark, Finland, France, Germany, Greece, Ireland, Israel, Italy, Japan, the Netherlands, Poland, Spain, Switzerland, Turkey, United Kingdom, USA

LOFT - Large Observatory For x-ray Timing



~ 10 m^2 effective area

~ 200 eV energy resolution

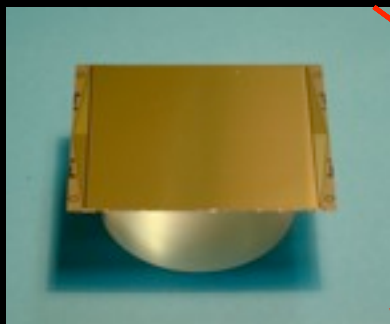
- Wide field monitor

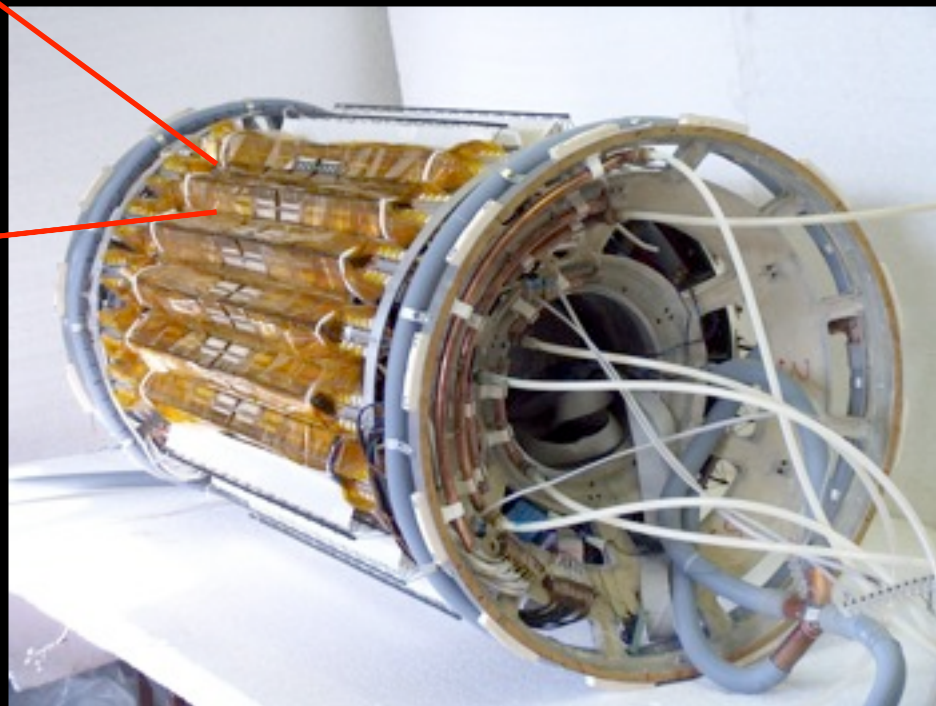
(Feroci et al 2010 http://arxiv.org/abs/1008.1009)

Silicon Drift Detectors (SDD)

A heritage of the Inner Tracking System of the ALICE experiment at the Large Hadron Collider (CERN)

INFN Trieste, in collaboration with Canberra Inc., designed, built, tested and calibrated 1.5 m^2 of SDD detectors (approximately 300 units), now operating since ~2 years. High Technical Readiness Level (TRL). Proven mass production.



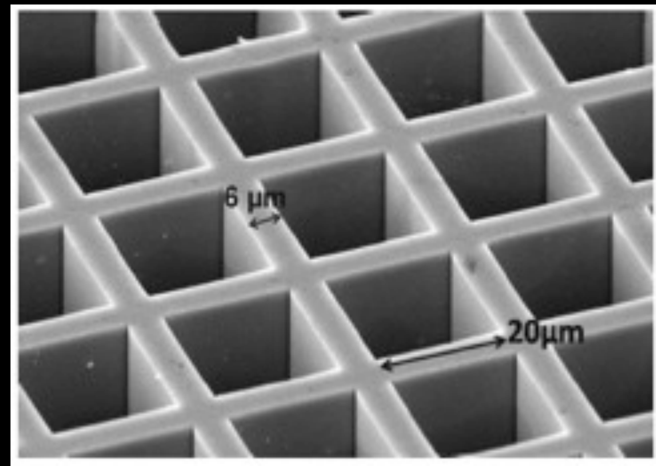


LOFT Baseline

Thickness	450 μm
Monolithic Active Area	76 cm^2
Drift time	<5 μs
Single-channel area	0.3 cm^2

LAD: collimators and panels

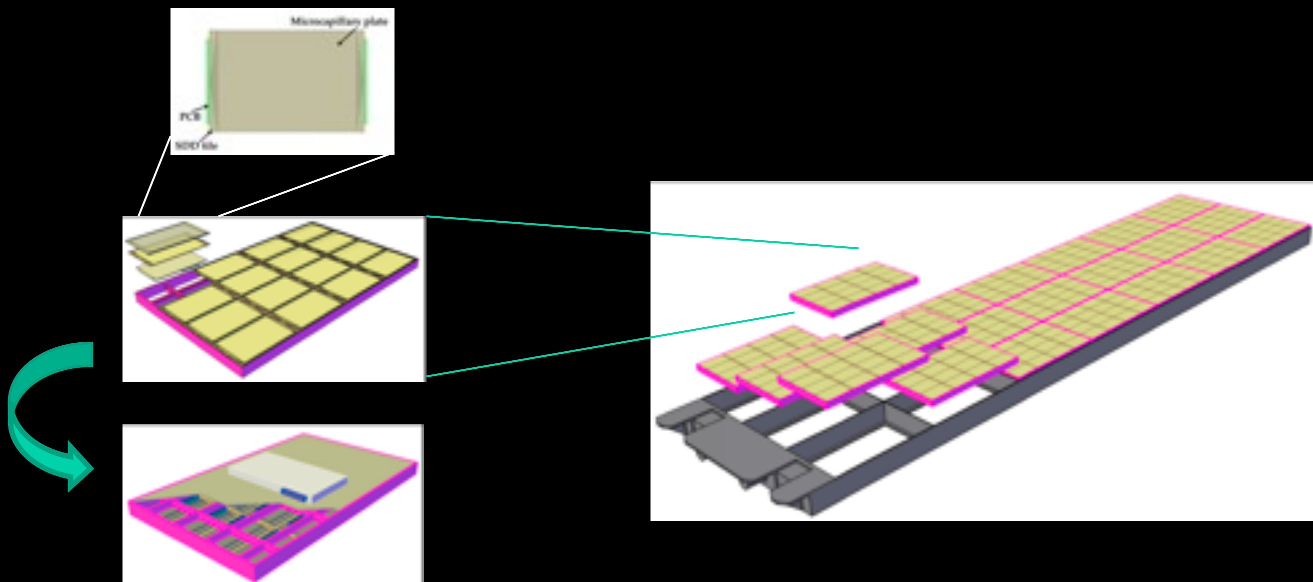
- Capillary plate
- High Pb content glass
- FoV ~40′



126 modules,

6 panels

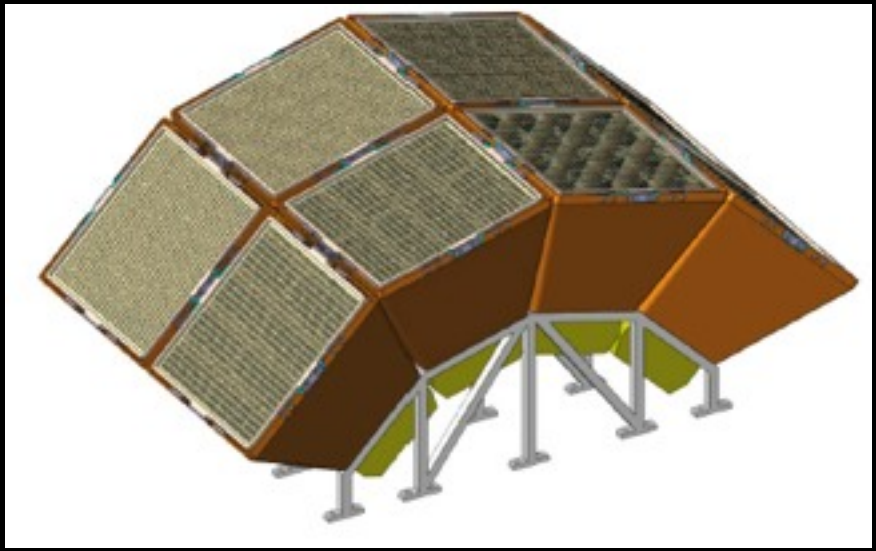
Total panel surface 21 m^2

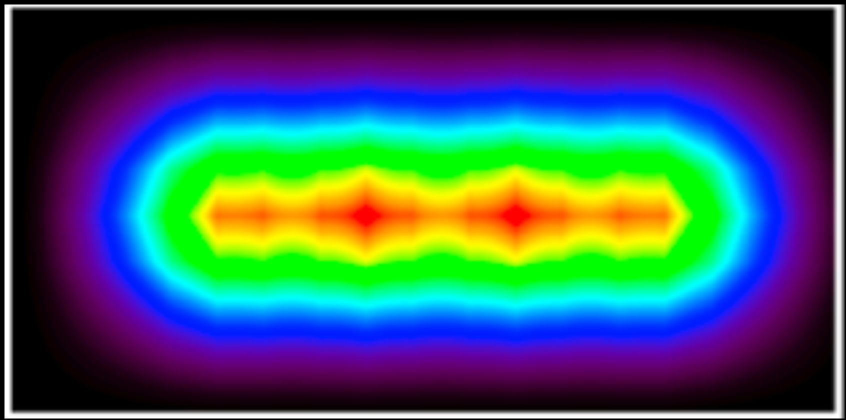


Silicon Drift Detectors 1D

Imaging:

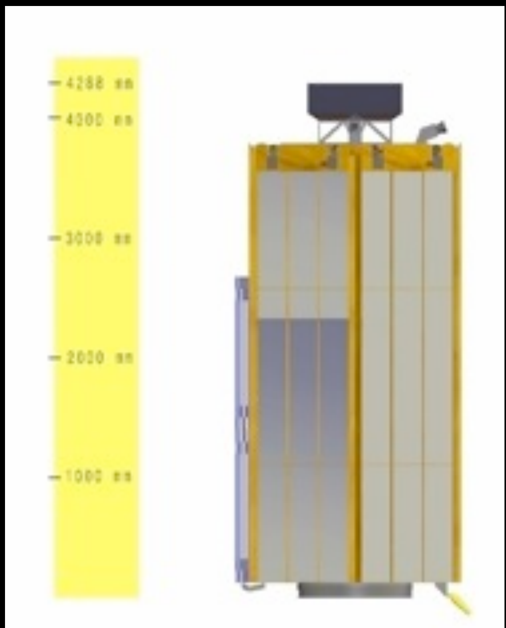
- coded mask
- Elements are 250μmx16mm
- 2 orthogonal projections
- FoV 90° x 90° (zero response)
- Resolution of 1 camera: 5′ x 5°
- Combination of 2 orthogonally oriented cameras gives 5′x 5′
- 2 cameras form 1 Unit
- Mask also integrates thermal shield/light filter (Kapton/Al/ Si_2O)



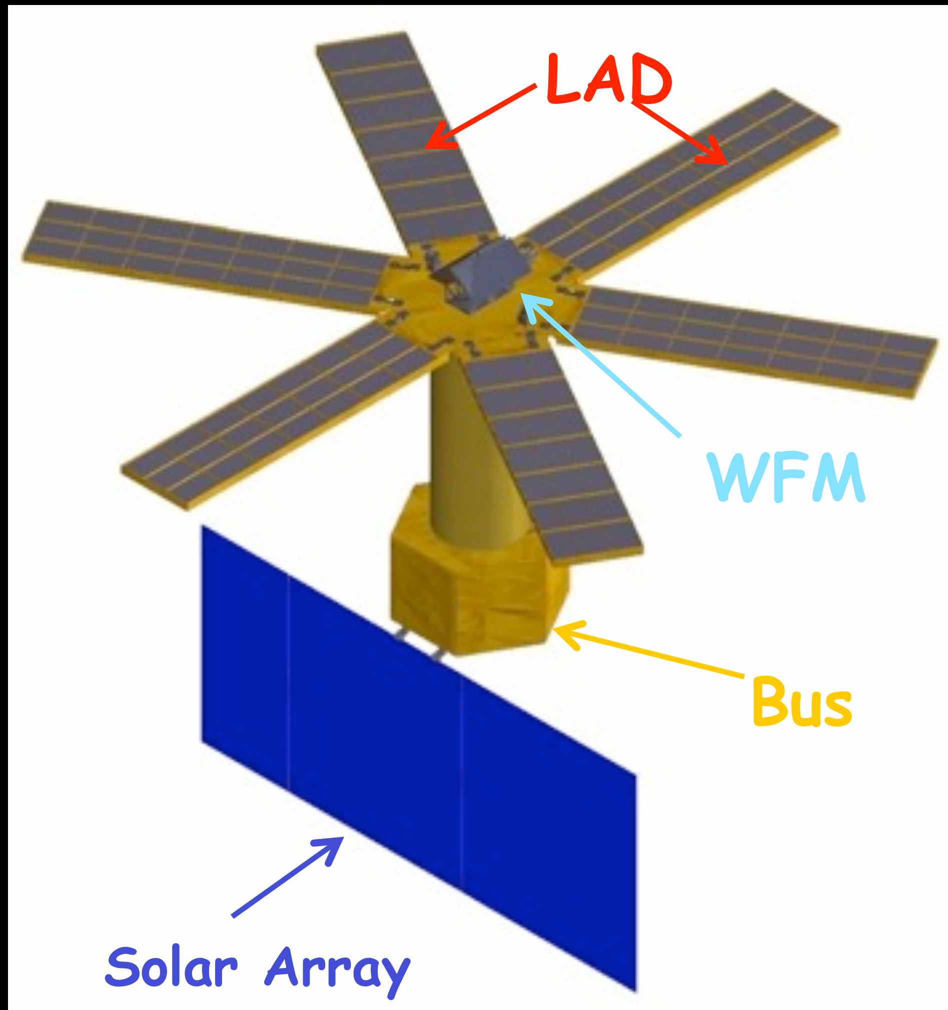


The LOFT satellite

Industrial study by Thales Alenia Space - Italia



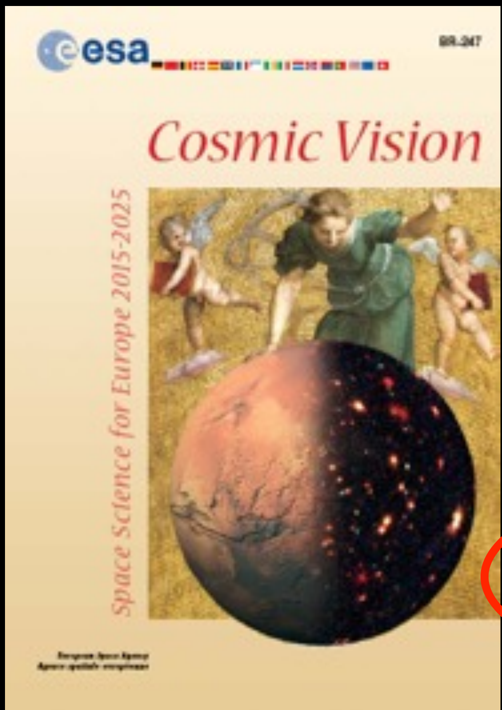
folded



The LOFT Mission: summary

Detector	450 μm thick SDD
Energy Range	2-30 keV (2-50 keV extended range)
Field of View	43 arcmin
Effective area(@8 keV)	10 m^2 (17x RXTE/PCA)
Energy Resolution	<260 eV (<200 eV for 40%)
Time Resolution	5 μs
Crab Count Rate	3×10^5 cts/s
Deadtime	<1% for 1 Crab
Sensitivity LAD	1 mCrab/1s
Supporting Experiment:	Wide Field Monitor (4 sr)
Satellite Mass	~1800 kg
Telemetry	<1 Mbps
Orbit	Low-Earth, equatorial

LOFT will address Fundamental Question 3.3 "Matter under extreme conditions" in ESA's Cosmic Vision program



3. What are the fundamental physical laws of the Universe?

3.1 Explore the limits of contemporary physics

Use stable and weightless environment of space to search for tiny deviations from the standard model of fundamental interactions

3.2 The gravitational wave Universe

Make a key step toward detecting the gravitational radiation background generated at the Big Bang

3.3 Matter under extreme conditions

Probe gravity theory in the very strong field environment of black holes and other compact objects, and the state of matter at supra-nuclear energies in neutron stars

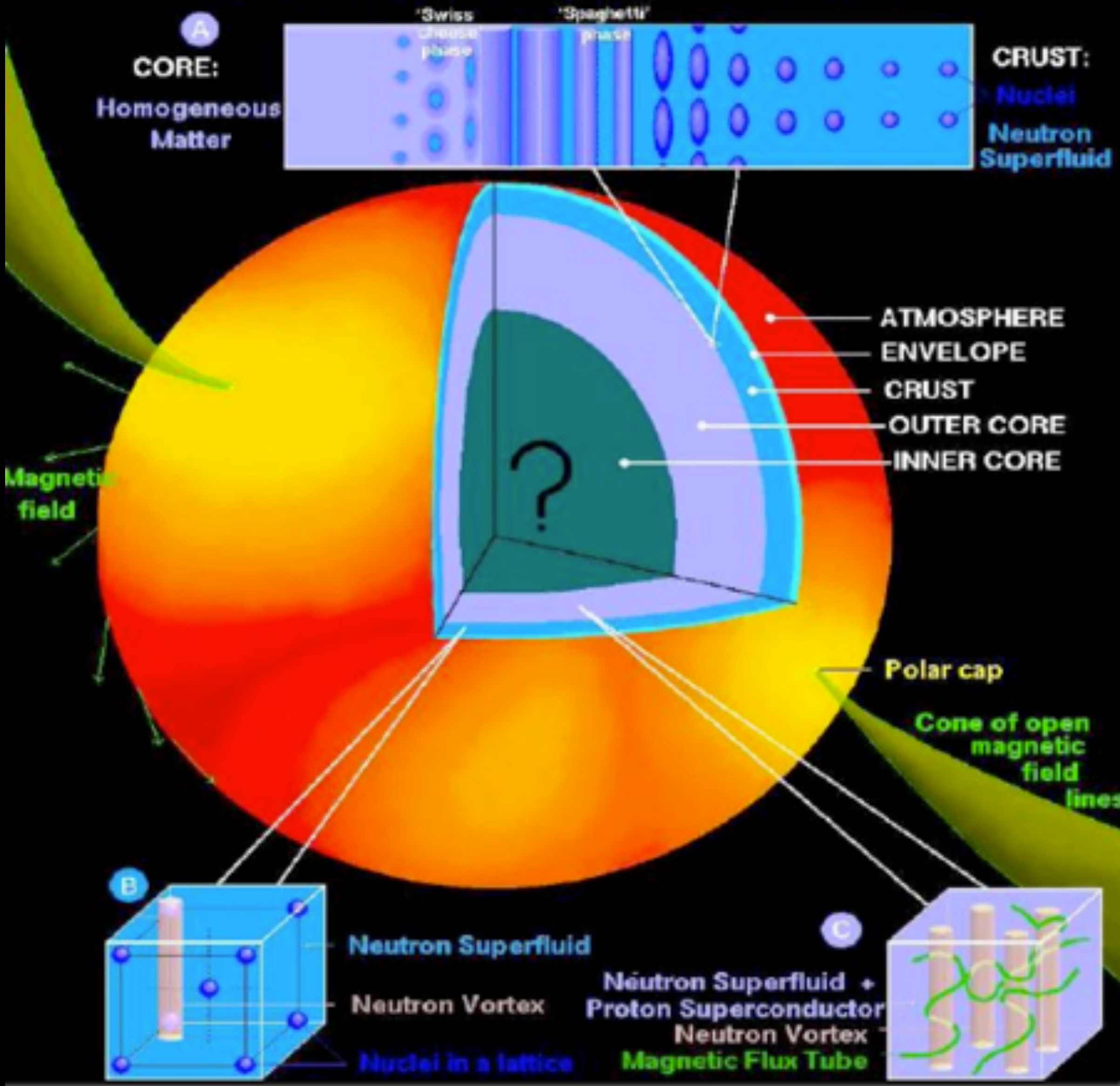
ESA Cosmic Vision Theme: Matter under extreme conditions

Strong Gravity

Dense Matter

- Does matter orbiting close to a Black Hole event horizon follow the predictions of General Relativity?
- What is the Equation of State of matter in Neutron Stars?

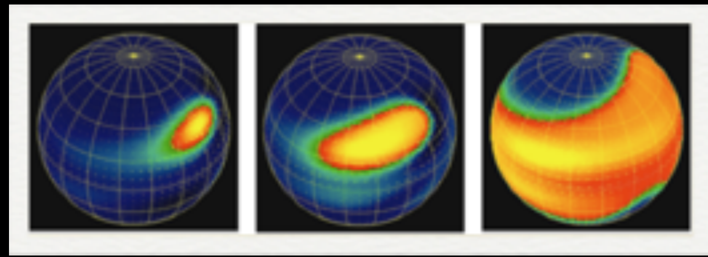
Dense Matter Diagnostic:
Neutron star structure and equation of state (EOS)



Neutron star masses and radii with a very large area X-ray instrument

- Coherent pulsations
- Pulsations during type I bursts (rise and decay)
- Seismic oscillations during magnetar flares
- Neutron star spin frequency
- Iron lines Fe-lines from accretion disk
- Eddington luminosity at the end of radius expansion bursts
- Absorption lines during type I bursts

Pulse Shape Modelling and Fitting in Fast Spinning Accreting Neutron Stars



- X-ray signal produced by hot spots on the surface of fast rotating neutron stars (magnetic pole or propagating burning front).

- Modeling of the pulses (shape, energy dependence) taking into account Doppler boosting, time dilation, gravitational light bending and frame dragging

-> M and R of the NS.

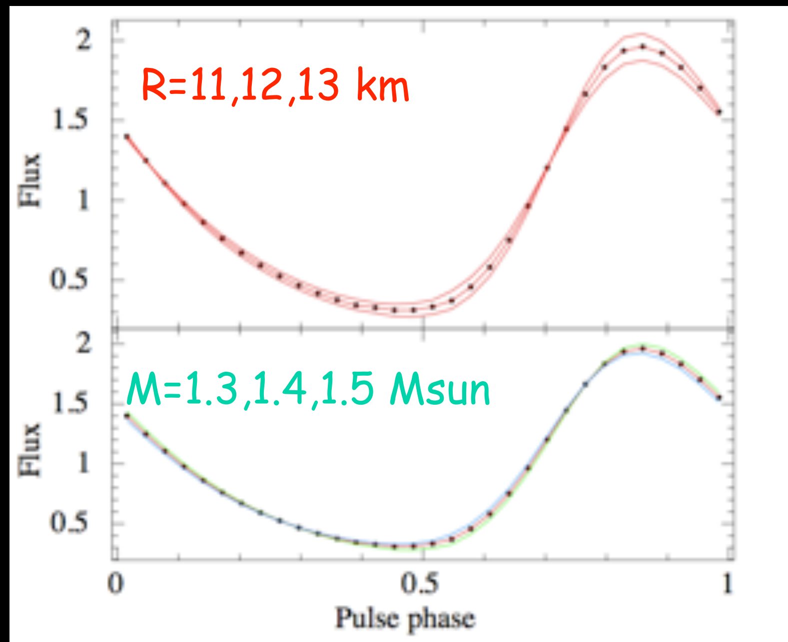
<u>LOFT simulation: SAX J1808.4-3658</u>

(401 Hz) pulse profile measurement

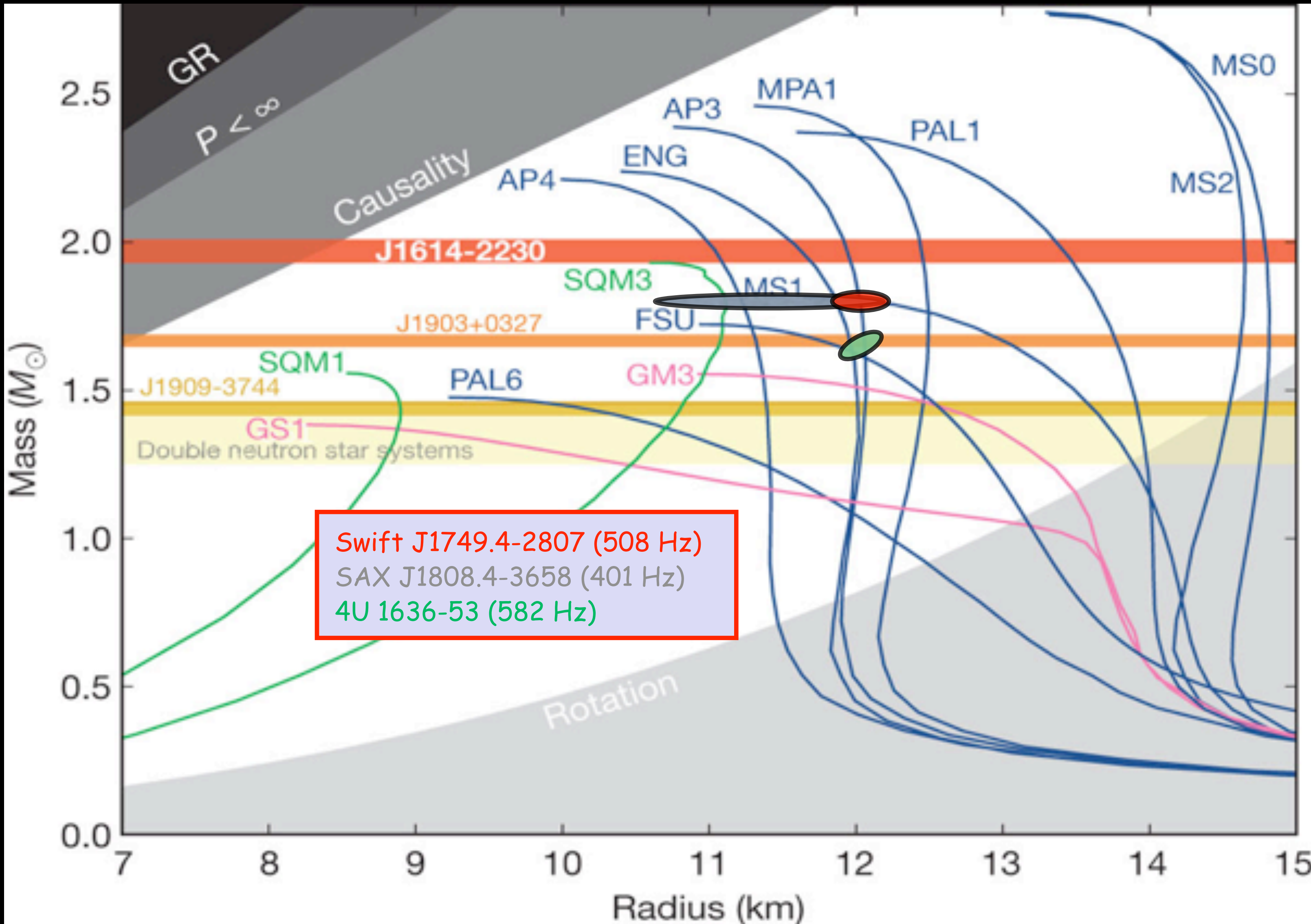
Determine NS

- NS mass: 4% uncertainty
- NS radius: 2-3 % uncertainty

Poutanen Gierlinski 2003 Morsink et al 2010



LOFT Constraints to NS EOS from M-R measurements



Strong Gravity

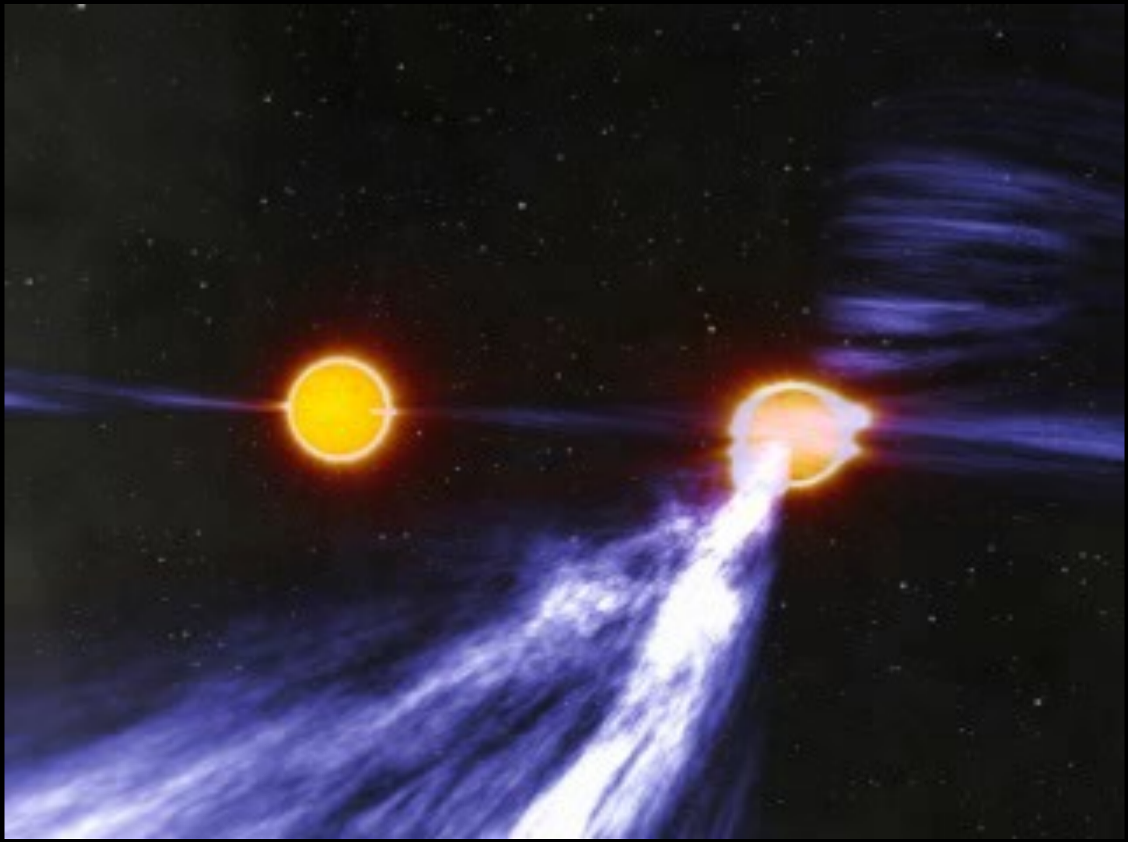
Relativistic binary radio pulsars

- Accurate test of gravity; several GR effects confirmed with very good accuracy
- BUT: direct measurements only at large radii ($R \sim 10^6 - 10^7$ Schwarzschild radii)

Strong Gravity

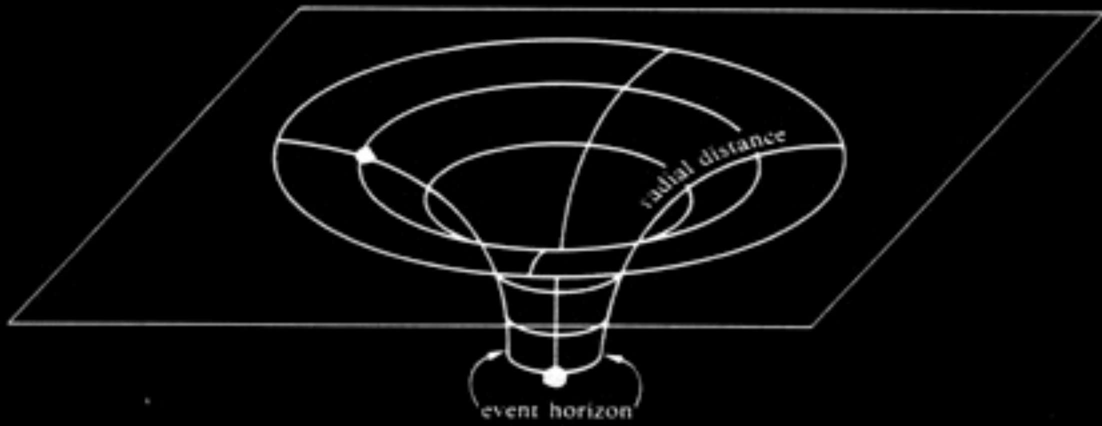
Relativistic binary radio pulsars

- Accurate test of gravity; several GR effects confirmed with very good accuracy
- BUT: direct measurements only at large radii ($R \sim 10^6 - 10^7$ Schwarzschild radii)

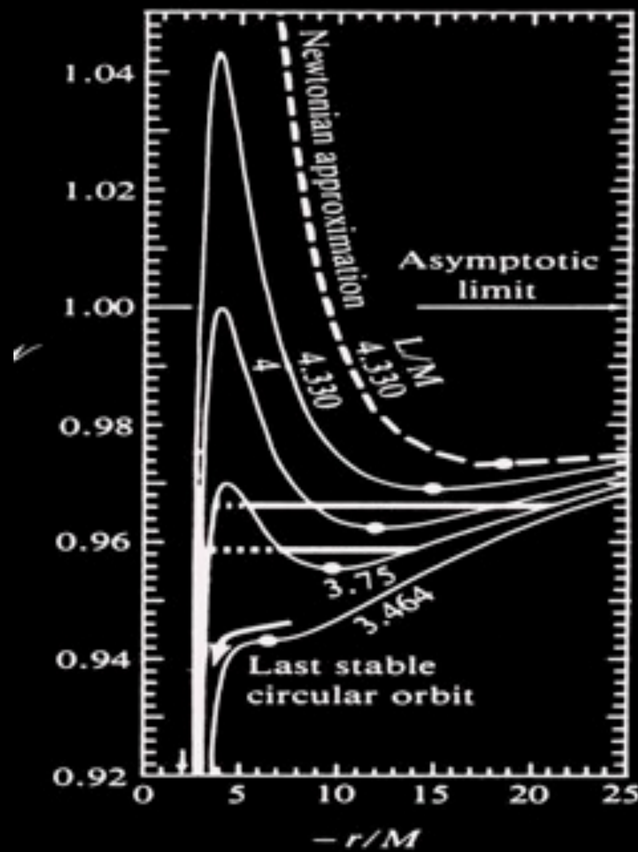


Strong Field Effects

Need to sample Radii close to the horizon ($R_g \sim GM/c^2$): matter accreti into black holes and neutron stars provi the best tool.



- Last Stable Circular orbit, aka ISCO (6 R_g -> 1 R_g)



-Particle motion around ISCO and fundamental frequencies of motion

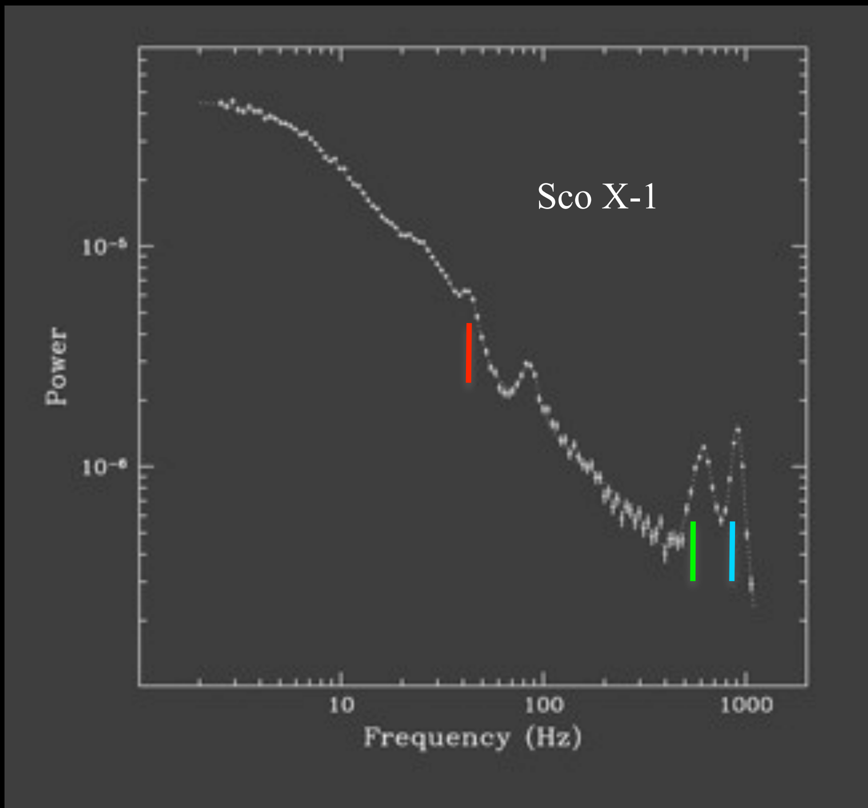
-Dragging of inertial frame

-Strong field light deflection

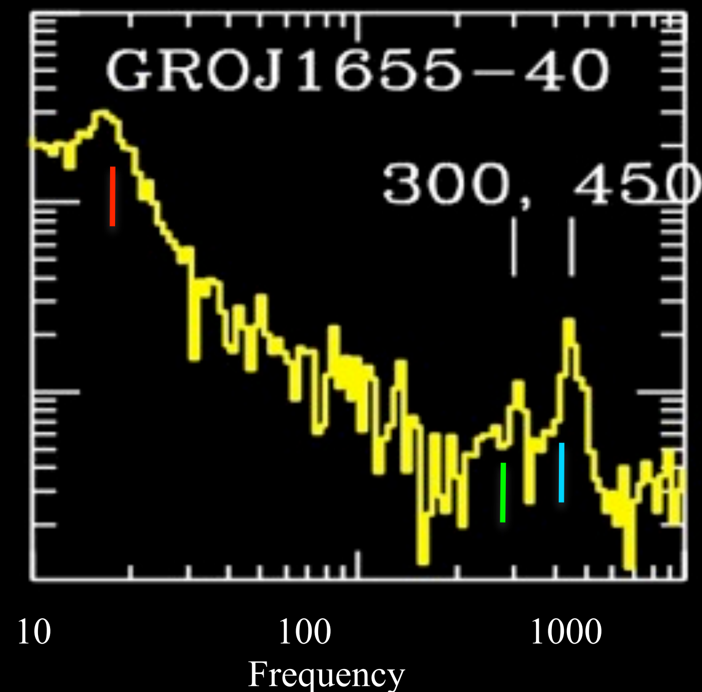
-Black hole mass and spin

Stong Field Diagnostic: Quasi Periodic Oscillations

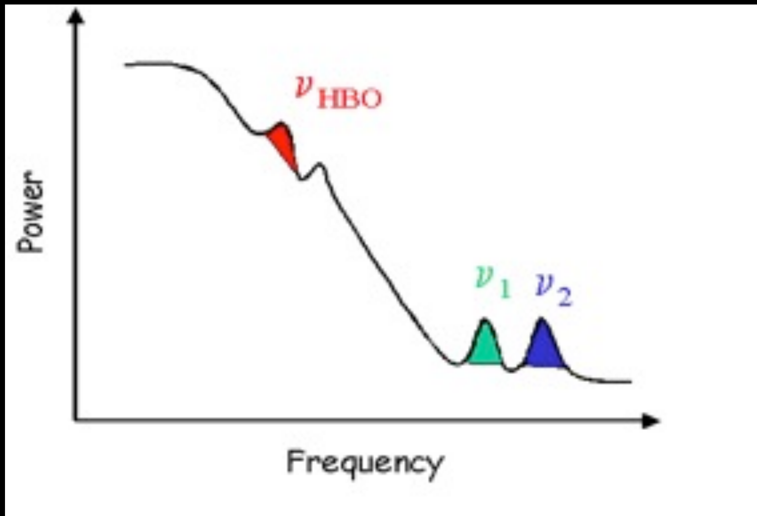
Accreting neutron stars



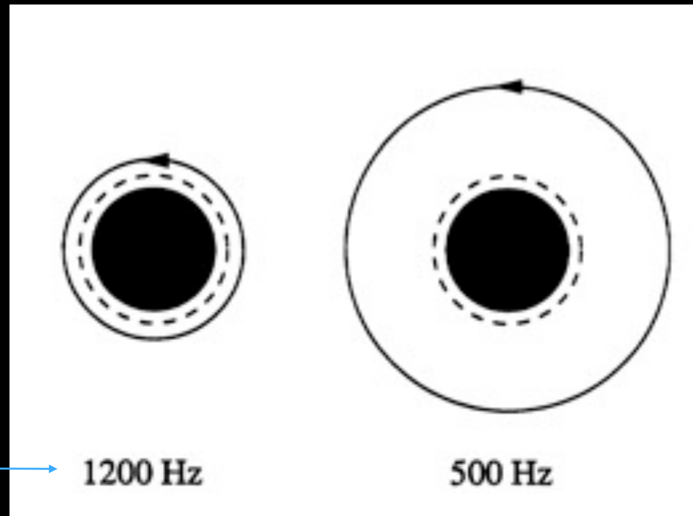
Accreting black hole candidates



Generic Model for higher frequency kHz QPOs



ν_2 →



A 10 km radius, 1.4 M ⊙ neutron star with the corrisponding innermost circular stable orbit (ISCO; dashed circle) and orbits (drawn circles) corresponding to orbital frequencies of 1200 and 500 Hz, drawn to scale.

$\nu_2 = \nu_{\varphi}(r_i)$ = Keplerian (φ) frequency at inner disk radius r_i

$$r_i \cong 15 \; (M/M_{\odot}) \; (\nu_2 / 1000 \text{ Hz})^{-2/3} \text{ km}$$

$$r_i = f(\dot{M})$$ to explain frequency variations

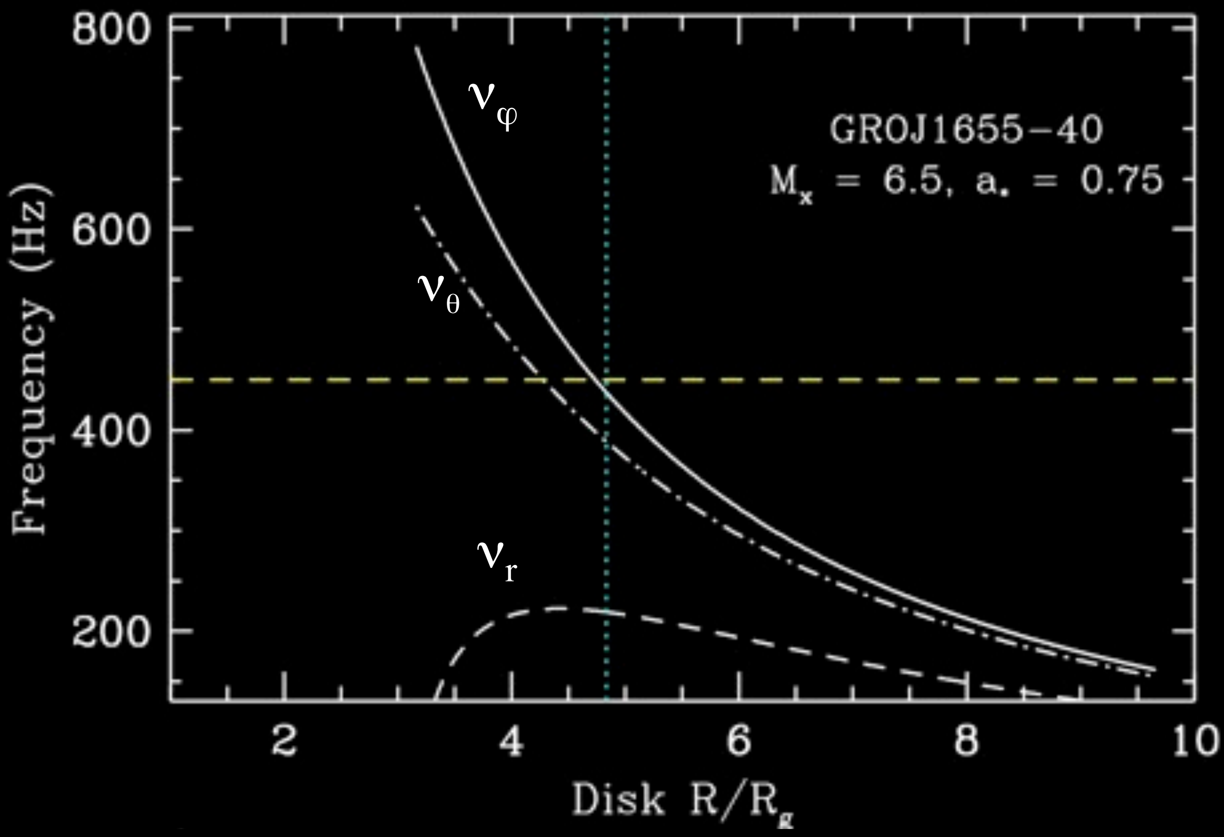
(Alpar, Shaham 1985; Strohmayer et al. 1996; Lamb et al. 1985; Miller et al. 1997)

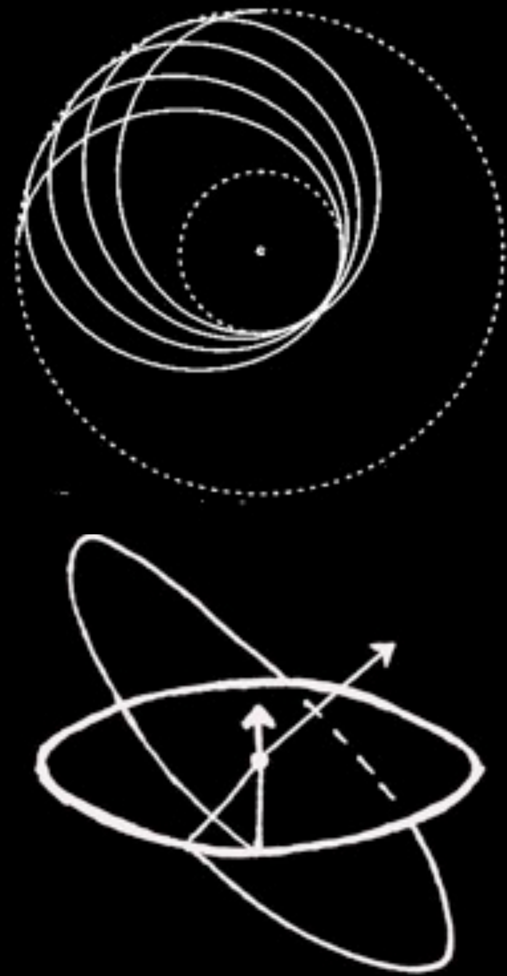
3 fundamental frequencies of motion which differ in GR

ν_φ : azimuthal

ν_θ : vertical epicyclic

ν_r : radial epicyclic

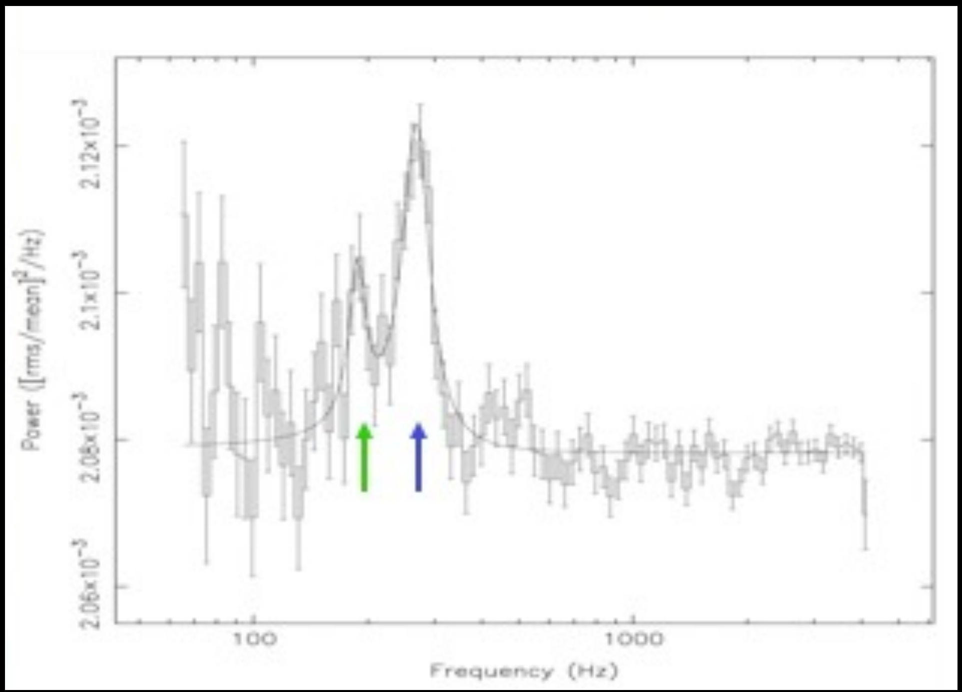




(Tomsick et al 2004)

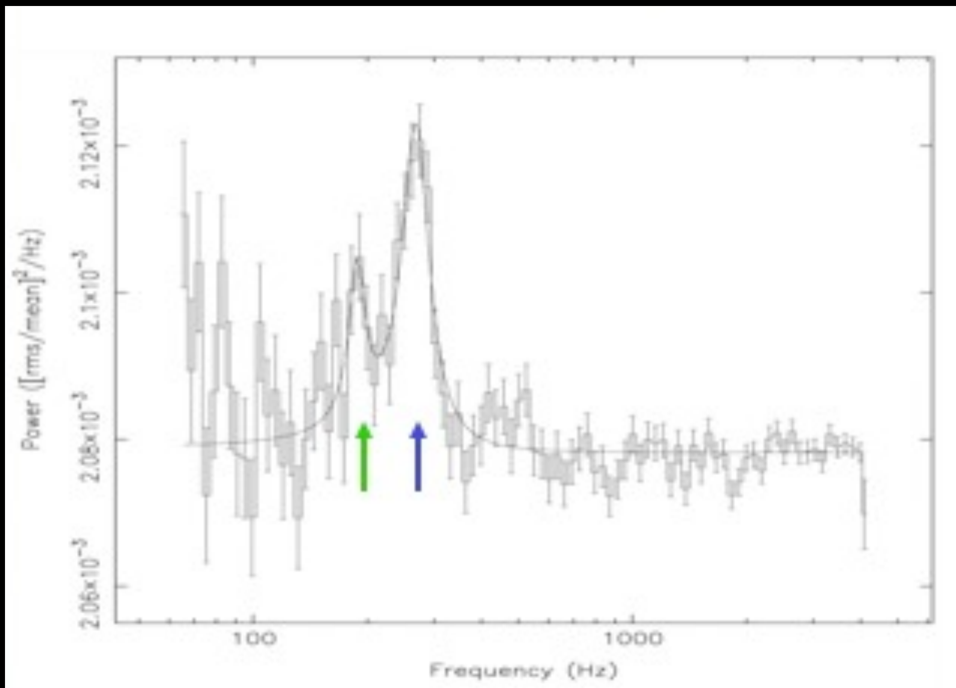
Example: high frequency QPOs in the BHC XTE J1550-564

v_1=188 Hz, v_2=268 Hz, frac rms v_1= 2.8%,
frac rms v_2=6.2% (Miller et al. 2001),
flux = 1 Crab, RXTE Exposure 54 ks,
significance ~3-4σ

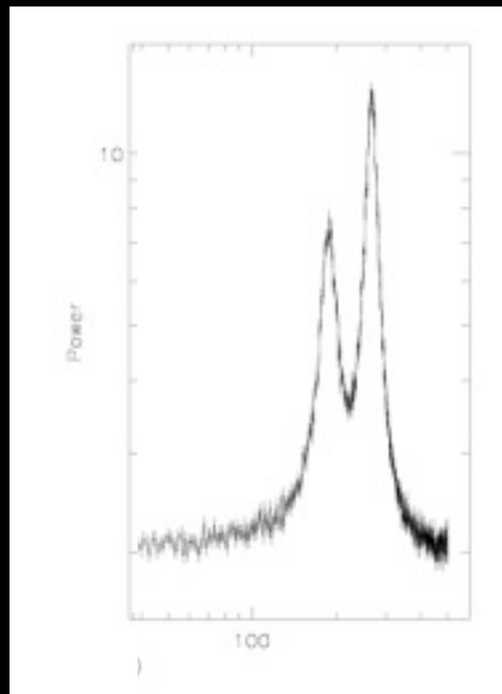


Example: high frequency QPOs in the BHC XTE J1550-564

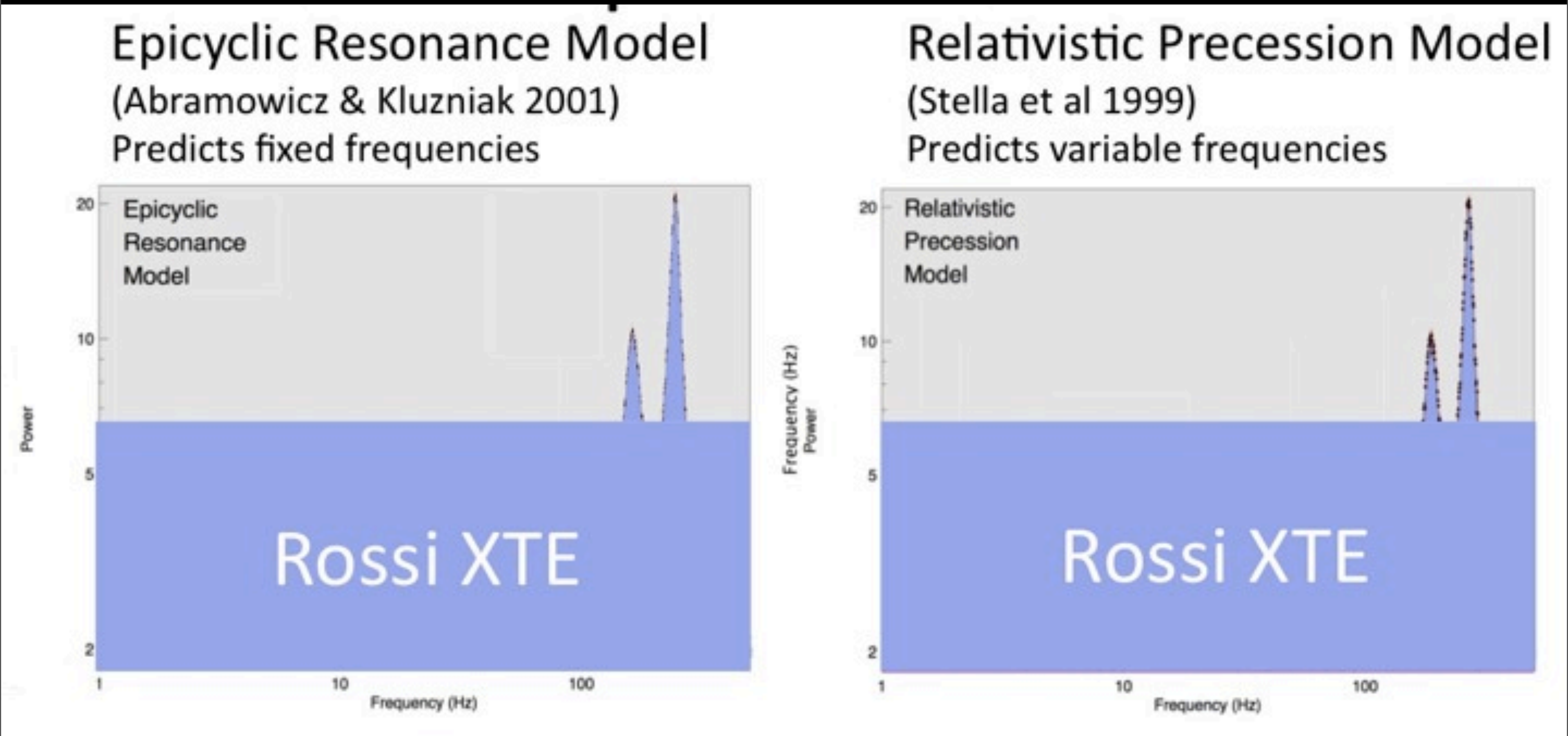
ν_1=188 Hz, ν_2=268 Hz, frac rms ν_1= 2.8%, frac rms ν_2=6.2% (Miller et al. 2001), flux = 1 Crab, RXTE Exposure 54 ks, significance ~3-4σ



LOFT simulation: Texp=1 ks



LOFT study of the QPO evolution with flux

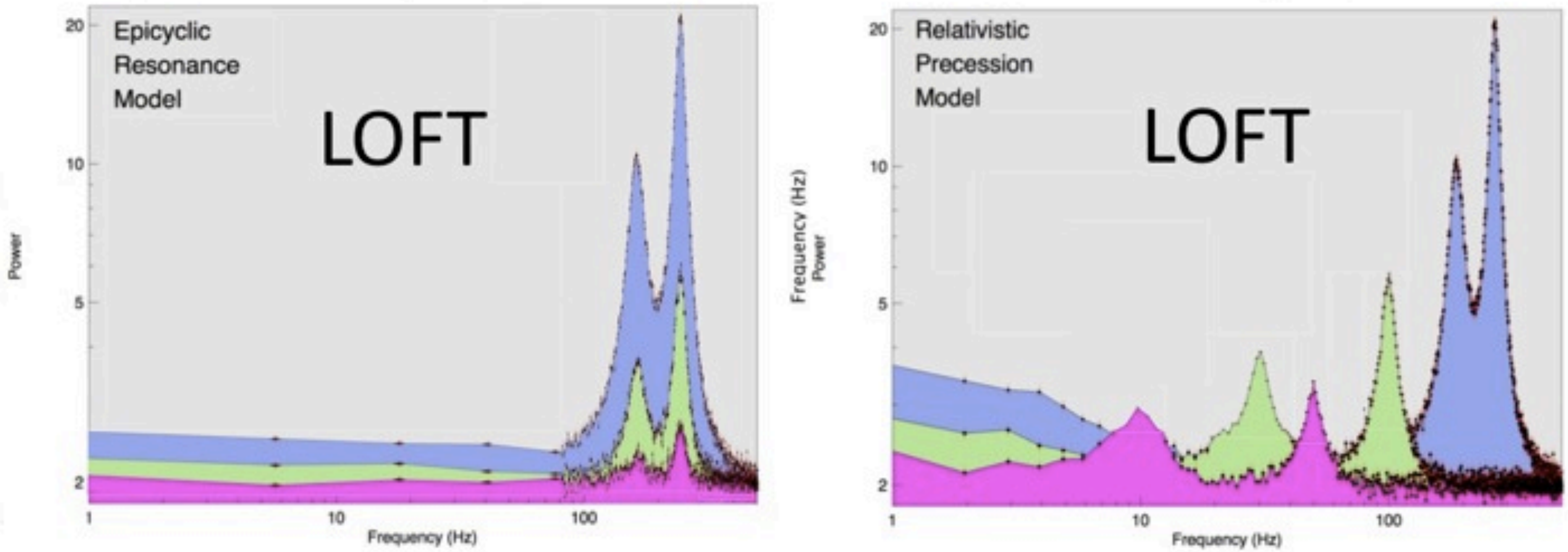


Different models still fit the available data.

LOFT study of the QPO evolution with flux

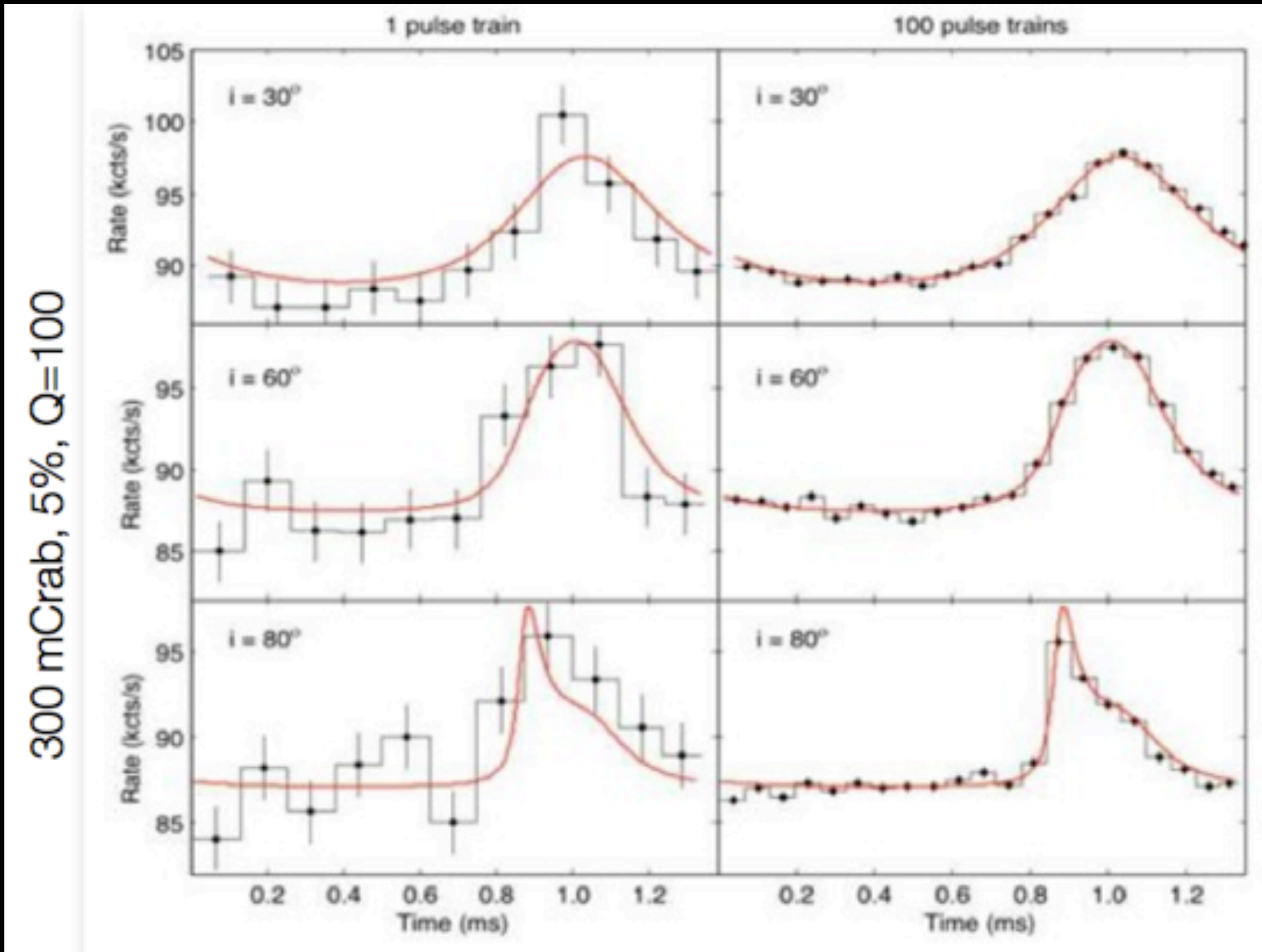
Epicyclic Resonance Model
(Abramowicz & Kluzniak 2001)
Predicts fixed frequencies

Relativistic Precession Model
(Stella et al 1999)
Predicts variable frequencies



Once the ambiguity of the interpretation of the QPO phenomena is resolved, the frequency of the QPOs will provide access to general relativistic effects (e.g, Lense-Thirring or strong-field periastron precession) and to the mass and spin of the black hole.

Studying kHz QPOs in Time Domain with LOFT

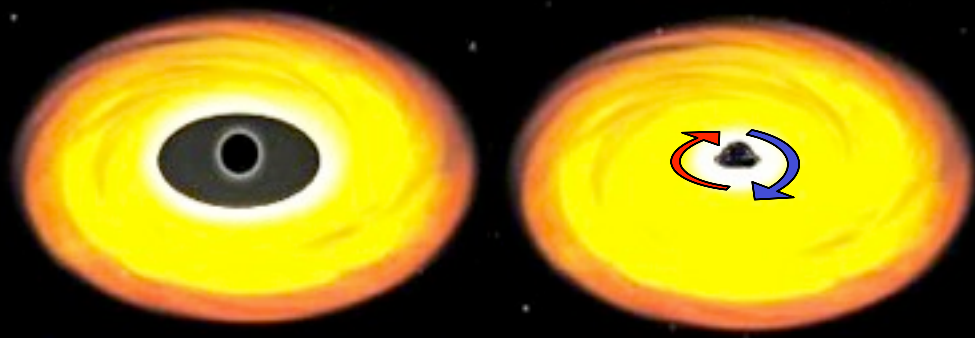


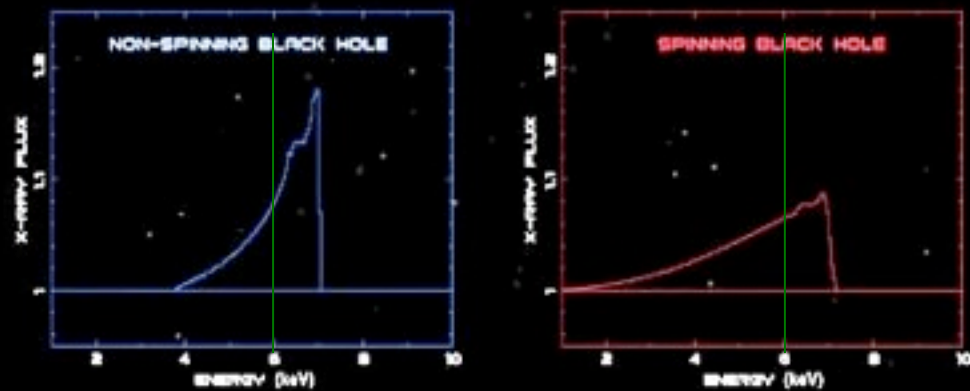
- Very powerful diagnostic of strong field regions !

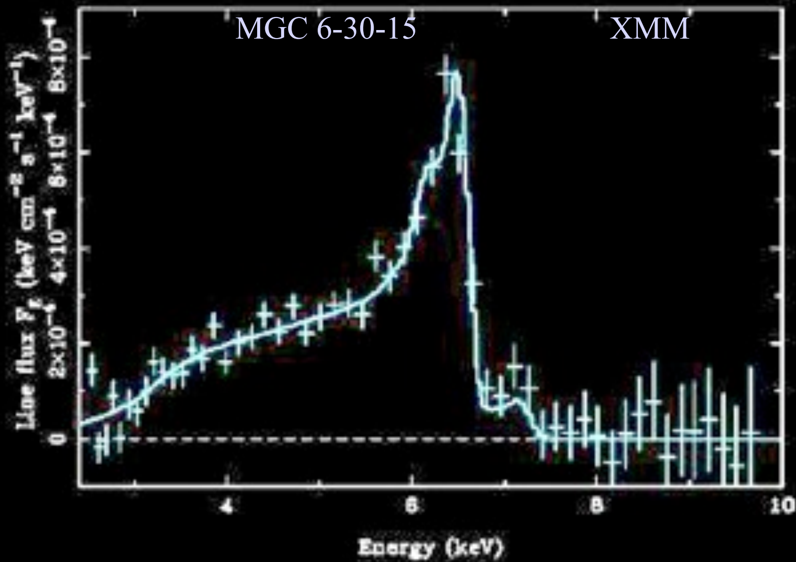
Strong field diagnostic
Fe-lines from accretion disks

- Strong field relativistic effect: Doppler shifts and boosting, gravitational redshift, strong field lensing

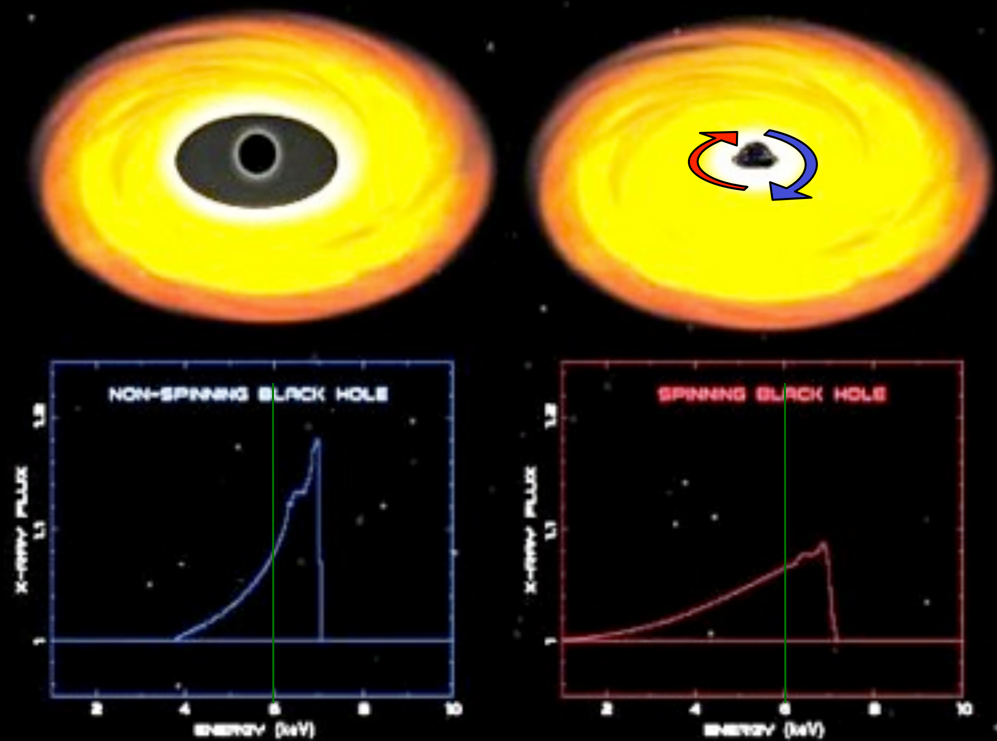
- Observed in many Active Galactic Nuclei and X-ray binaries







Strong field diagnostic
Fe-lines from accretion disks



- Strong field relativistic effect: Doppler shifts and boosting, gravitational redshift, strong field lensing

- Observed in manyActive Galactic Nuclei and X-ray binaries

Line profile and time variability

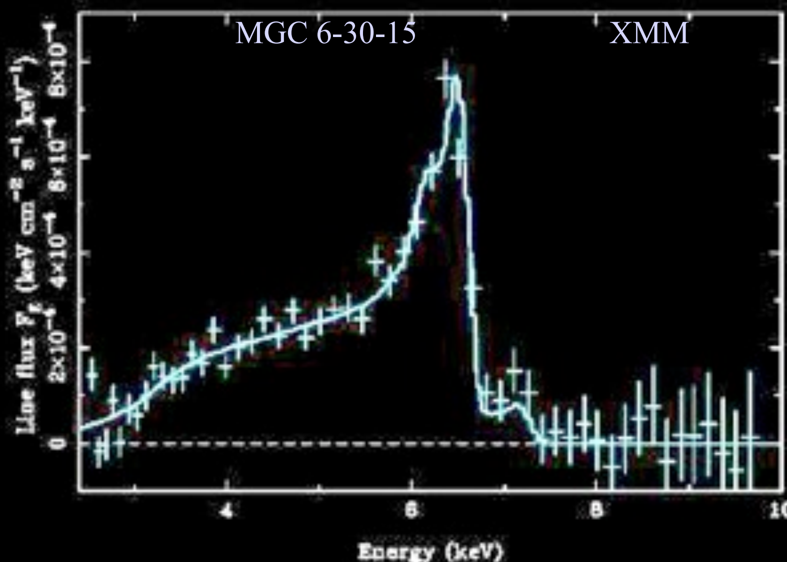
black hole mass and spin

In situ probing of strong field gravity

(~few Rs)

e.g. MCG 6-30-15:

- Kerr BH required to fit line profile

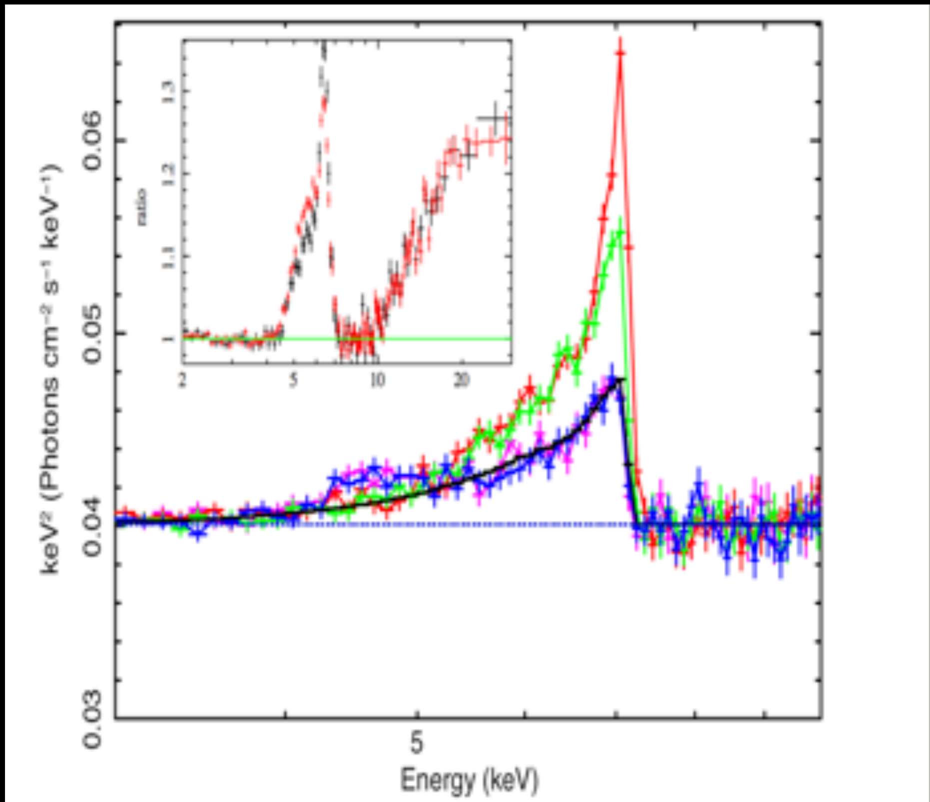


Fe K-line studies with LOFT

- Measure the Fe-line profile and carry out reverberation mapping of ~ 5 BHs in binaries to provide BH spins to an accuracy of 5% of the maximum spin (a/M=1), constraining fundamental properties of stellar mass black holes and of accretion flows in strong field gravity.

- Measure the Fe-line profile of ~30 AGNs, and carry out reverberation mapping of ~10 brightest AGNs, to provide BH spins to an accuracy of 20% of the maximum spin (10% for fast spins) and measure their masses with 30% accuracy, constraining fundamental properties of supermassive black holes and of accretion flows in strong field gravity.

Fe line reverberation studies in bright AGNs

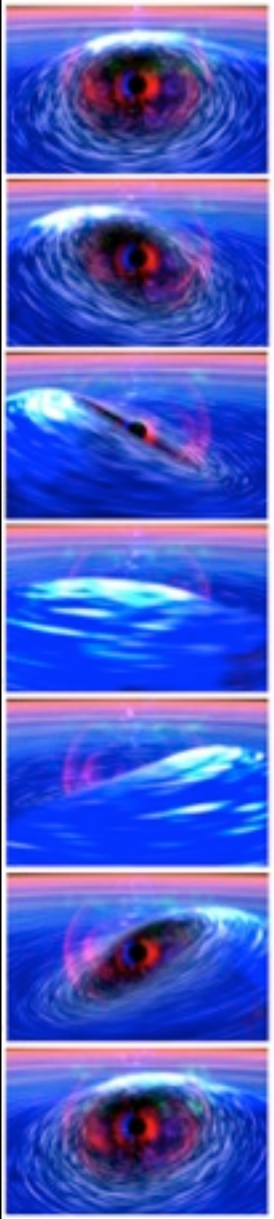


LOFT simulation of a steady and variable Fe line.

F=3mCrab, a=0.99, r_{in}=1r_g,
r_{out}=100$r_{g,}$ q=45°, e~r^{-3},
r_{sp}=10r_g, T_{orb}=4 ks
T_{exp}=16 ks → mapping 4 phases (1 ks each) in four cycles

M=3-4 x 10^6 M_{sun}
a=0.93-0.99

Inner disk nodal precession and Fe-Kα line

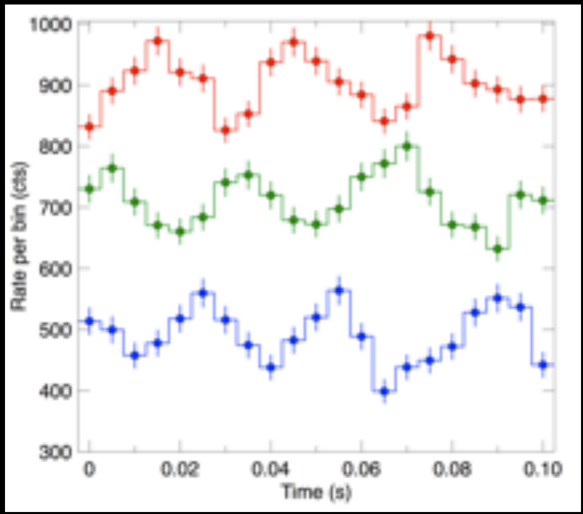


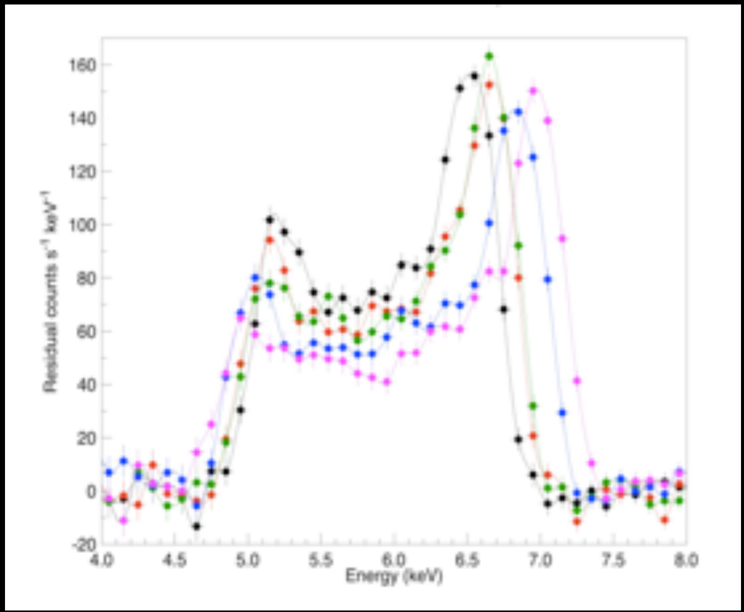
- Simulation of phase resolved spectroscopy of 30 Hz horizontal branch oscillation arising from Lense-Thirring precession of the inner disk (9-10 r_g) from a 300 mCrab source (i=26°, 5° precession angle)

- Line emission from 9 to 100 r_g
  10 ks exposure

- Continuum + steady line model gives unacceptable fit

- Addition of a line component from the precessing ring is required: varying ring inclination measured with 20% accuracy.





LOFT Core Science

Strong Gravity

Dense Matter

To match ESA Cosmic Vision Theme:
Matter under extreme conditions

- Does matter orbiting close to a Black Hole event horizon follow the predictions of General Relativity?
- What is the Equation of State of matter in Neutron Stars?

Observatory Science

Observatory Science

LOFT will also be an Observatory for virtually all classes of relatively bright sources

These include:

- X-ray bursters,
- High mass X-ray binaries
- X-ray transients (all classes)
- Cataclismic Variables
- Magnetars
- Gamma ray bursts (serendipitous)
- Nearby galaxies (SMC, LMC, M31, ...)
- Bright AGNs

Activities

- ESA is studying mission in house (Sept/Oct)
- 2 parallel industrial studies in 2012
- Instrument consortium is working on payload:
  - WFM: Hernanz (IEEC/CSIC) and Brandt (DTU)
  - LAD: Zane (MSSL)
- Science case
  - Coordinated by Stella (INAF), vd Klis (UvA) and Jonker (SRON)

    3 Working Groups:

    Dense Matter (A. Watts)

    Strong Gravity (D. Barret)

    Observatory Science (J. Wilms)
  - Science meeting in Amsterdam (26-28 October)

    http://www.isdc.unige.ch/loft/index.php/meetings/loft-science-meeting

-> Yellow book for ESA down selection end 2012

Down selection of M3 missions first half 2013

LOFT is a simple mission, relying on solid hardware heritage

It will provide crucial measurements in the physics of ultradense matter and strong gravitational fields.

It will also be a operated ~ 50% of the time like an observatory in order to address a variety of subjects in high energy astrophysics

http://www.isdc.unige.ch/loft

Thank you