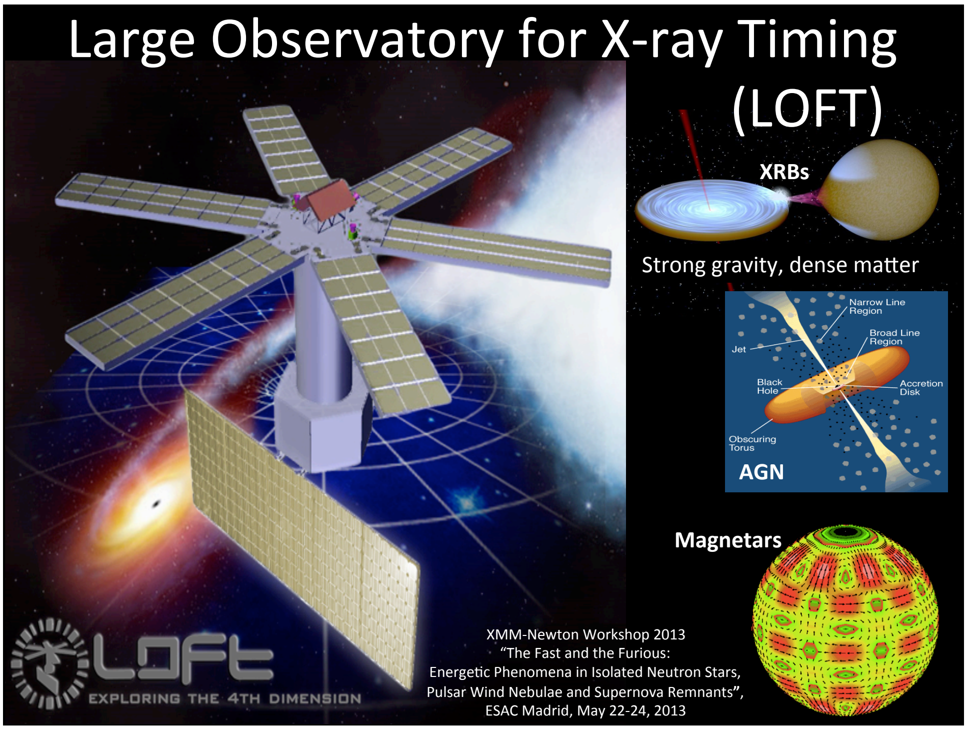
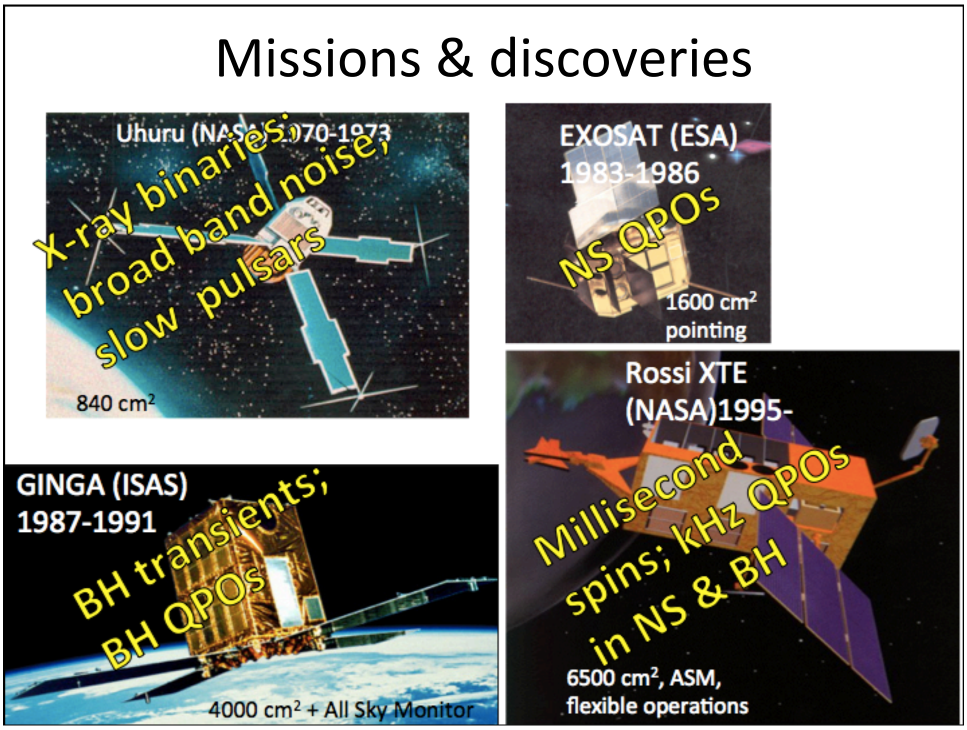
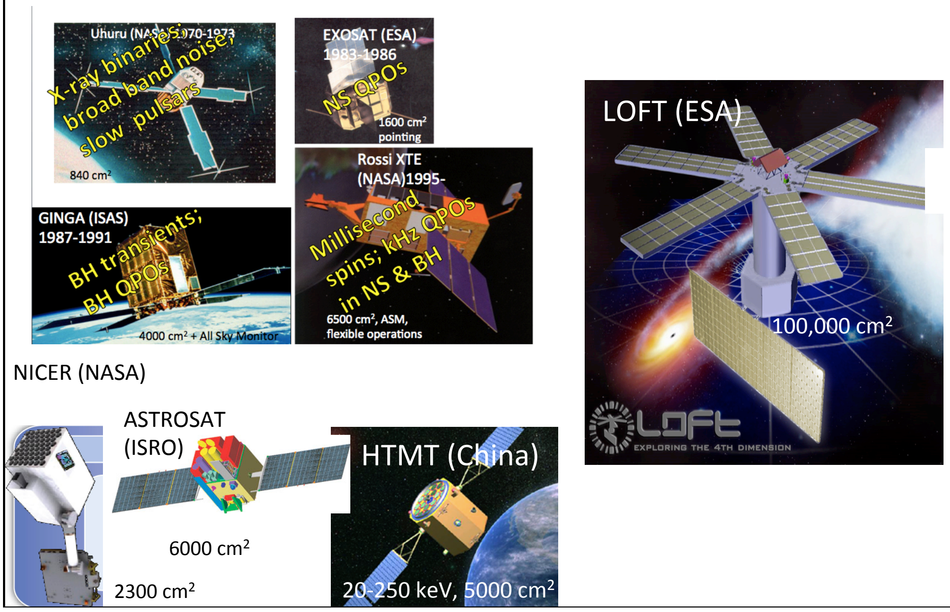

Large Observatory for X-ray Timing
(LOFT)
XRBs
Strong gravity, dense matter
Narrow Line Region
Broad Line Region
Jet
Black Hole
Accretion Disk
Obscuring Torus
AGN
Magnetars
LOFT
EXPLORING THE 4TH DIMENSION
XMM-Newton Workshop 2013
"The Fast and the Furious:
Energetic Phenomena in Isolated Neutron Stars,
Pulsar Wind Nebulae and Supernova Remnants",
ESAC Madrid, May 22-24, 2013

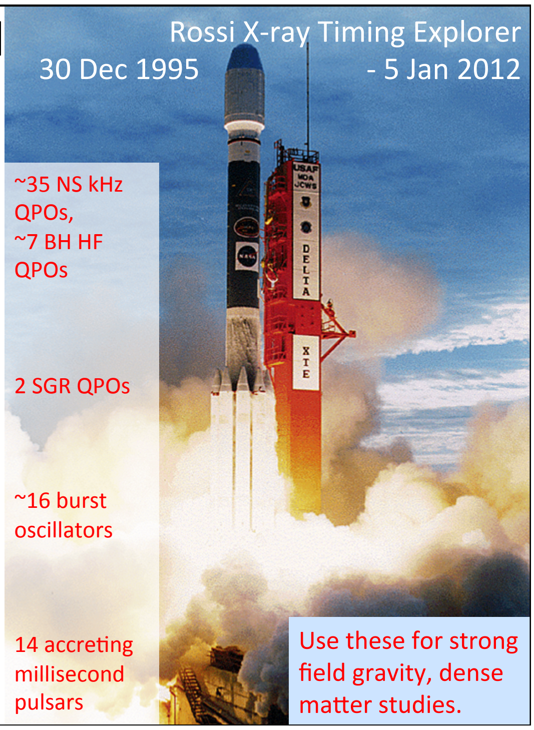

Missions & discoveries
Uhuru (NASA) 1970-1973
X-ray binaries;
broad band noise;
slow pulsars
840 cm²
EXOSAT (ESA)
1983-1986
NS QPOs
1600 cm²
pointing
GINGA (ISAS)
1987-1991
BH transients;
BH QPOs
4000 cm² + All Sky Monitor
Rossi XTE
(NASA)1995-
Millisecond
spins; kHz QPOs
in NS & BH
6500 cm², ASM,
flexible operations

Missions & discoveries

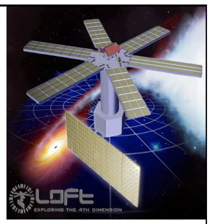


RXTE: the dynamical time scale

- Dynamical time scale (10^{-2}-10^{-5} s) flow variability (Svartzman 1971)
- Millisecond wavetrains due to clumps orbiting near ISCO (Sunyaev 1973)
- Neutron star vibrations (seismology) (Hoyle ea 1964 …)
- NS spin by anisotropic emission during X-ray bursts (Livio & Bath 1982)
- Millisecond accreting pulsars (magnetic channeling) (Alpar et al. 1982, Radhakrishnan & Srinivasan 1982)



LOFT objectives



1. Dense matter – supranuclear EOS
   - Pulse profiles
   - Spin measurements
   - Seismology

msec pulsations, seismics in XRB, SGR

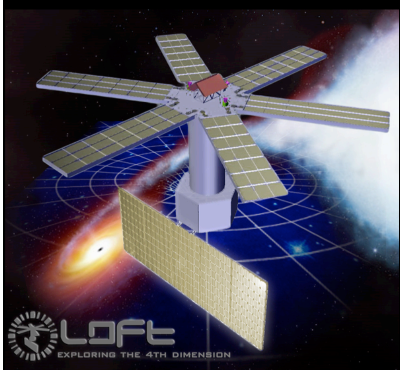
2. Strong field gravity – GR in action
   - Broad Fe line variability
   - Epicyclic motion
   - QPO waveforms

QPOs & Fe lines in XRB & AGN

3. Observatory science
   - Broad-ranging programme using LOFT unique capabilities

- All three areas mainly open-time & proposal-driven

The LOFT consortium



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

LOFT Science Team composed of scientists from:

Australia, Brazil, Canada, CzechRepublic, Denmark, Finland, France, Germany, Greece, Ireland, Israel, Italy, Japan, theNetherlands, Poland, Spain, Sweden, Switzerland, Turkey, United Kingdom, USA

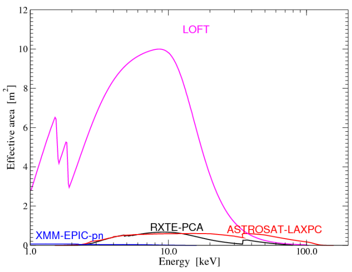
…

LOFT Consortium: national representatives:

Jan-Willem den Herder	SRON, the Netherlands
Marco Feroci	INAF/IAPS-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 Astron. Center, Poland
Juhani Huovelin	Univ. of Helsinki, Finland
Paul Ray	Naval Research Lab, USA
Joao Braga	INPE, Brazil
Tad Takahashi	ISAS, Japan
…	…

LOFT Large Area Detector

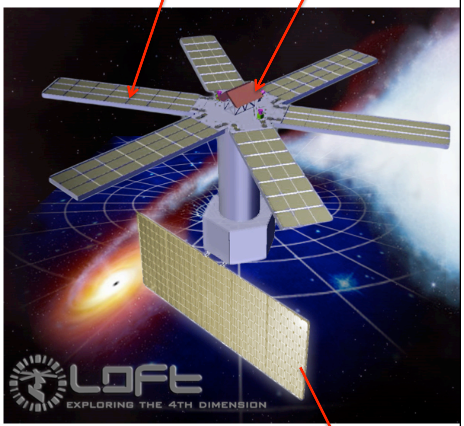
- Effective area 10 m^2 @ 8 keV
  - 0.25 10^6 c/s/Crab



  - 1σ timing feature becomes 20σ
    → detect QPOs coherently !

Large Area Detector (6 panels)

Wide Field Monitor



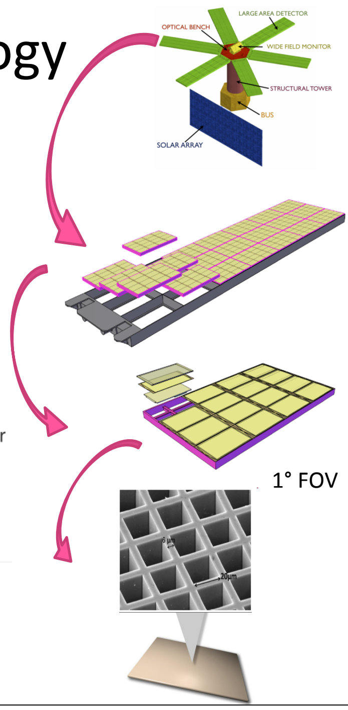
Solar panel

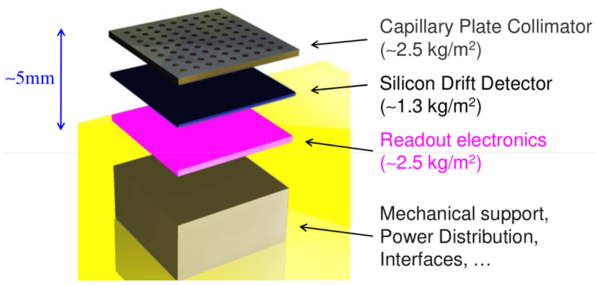
- 200-260 eV resolution
  - resolve relativistic Fe lines at huge S/N
    → see line profile fluctuate at GR timescales !
  - See all [sub]msec spins
  - Routine neutron star seismology
  - Measure pulse profiles at enormous precision

LAD technology

- Silicon Drift detectors + microchannel collimators:
  - Large collecting area per kg, per Watt
  - Good spectral resolution (200-260 eV)
- Modular and redundant:
  - 6 detector panels
  - 2016 Silicon drift detectors
  - 28224 ASICs
  - 451,584 anodes

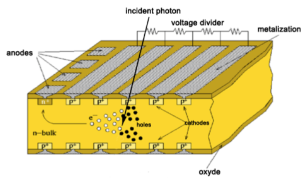
→ Massively parallel, so very low deadtime (<1% at 1 Crab)

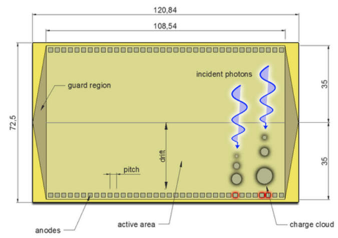




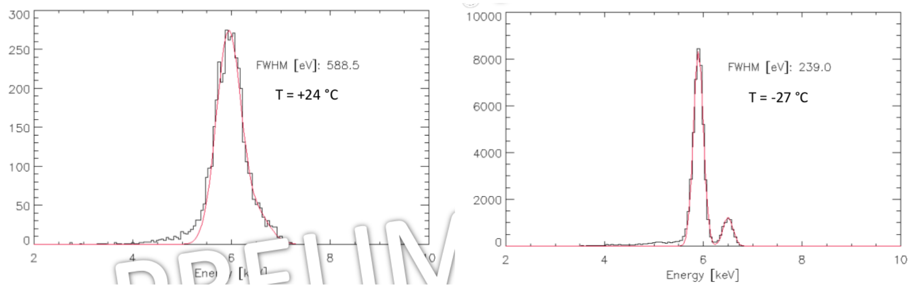
LOFT Payload: the Large Area Detector

The Silicon Drift Detectors:



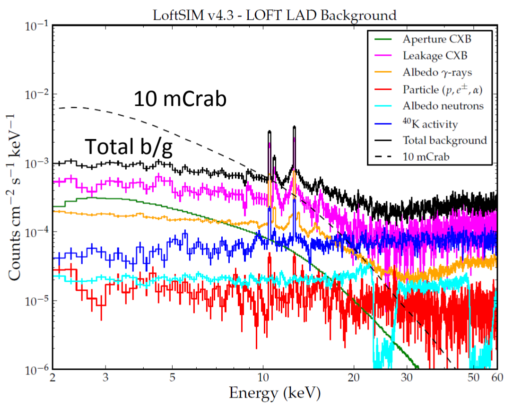


Preliminary Measured Spectroscopy Performance:



Still with non-optimal sensors and non optimal read-out electronics..

LAD background: <10 mCrab & stable



LAD Background components (2-30 keV):

1.Aperture CXB:	13%	all these components are steady/ predictable
2.CXB leak:	51%	
3.Earth albedo leak:	19%	
4.Coll. Radioactivity	14%	
5.Particles:	6%	

RXTE/PCA: gas sensors
→ particle background dominates
→ 250% orbital variation

LOFT/LAD: thin Si sensors
→ particle background is only 6%

RXTE: particle background prediction systematics ~0.5%
(Shaposhnikov et al. 2012).
So, LOFT will do much better.

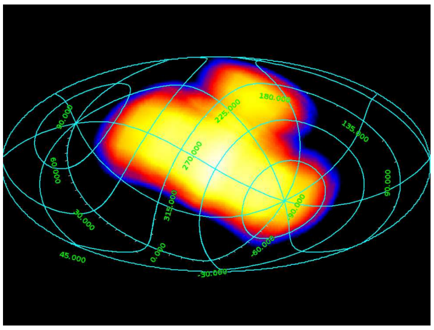
Additionally, LOFT monitors b/g with 'blocked collimator detectors', further pushing back systematics.

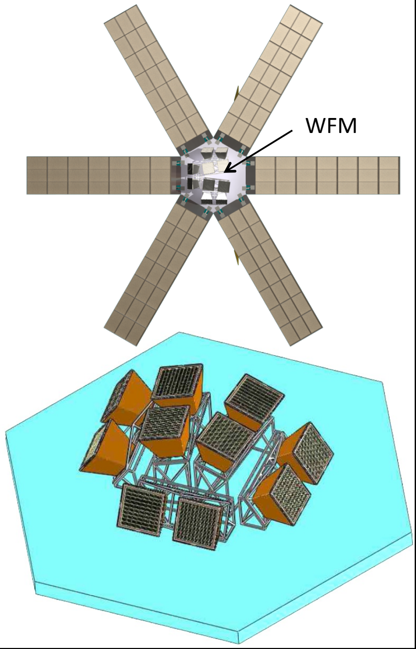
10^3 s sensitivity: <0.1 mCrab (5σ)

Campana et al. 2012, arXiv1209.1661C

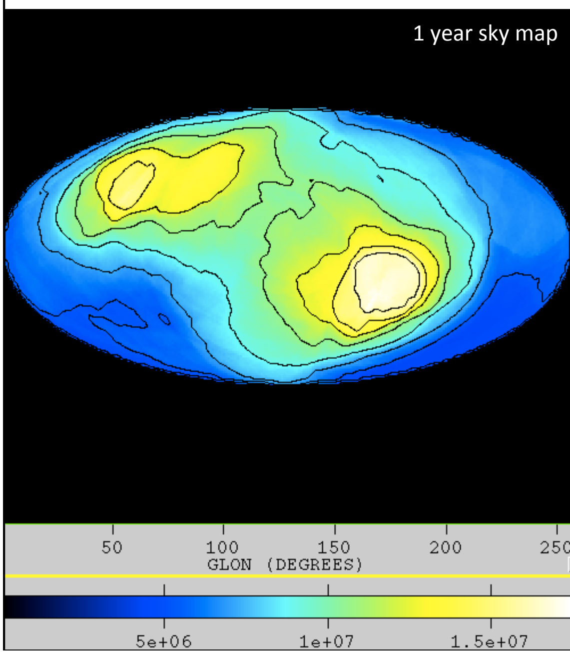
LOFT Wide Field Monitor

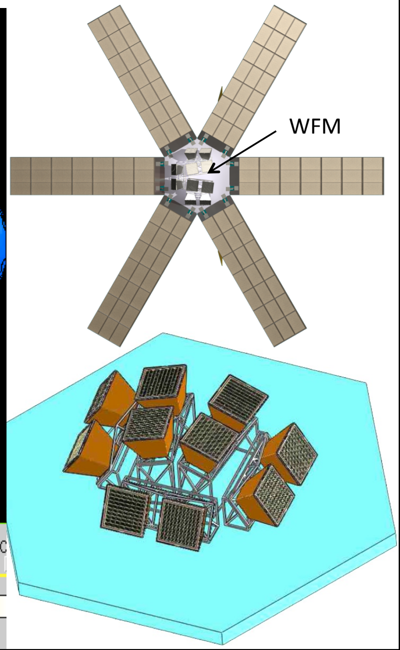
- 1820 cm² Si drift detectors
- 2-50 keV (-80 for b/g)
- 0.25 Crab in 3 sec, 2 mCrab in 60 ks
    - (5σ, galactic center;60 ks = 1 day elapsed)
- 1 arcmin positions (5 arcmin res)
- 300-500 eV energy resolution
- 10 µs time resolution, 1 µs absolute timing
- 30 s triggers through VHF system





LOFT Wide Field Monitor

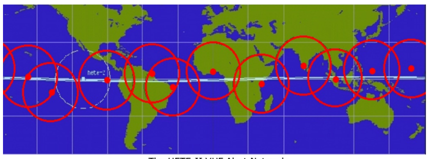




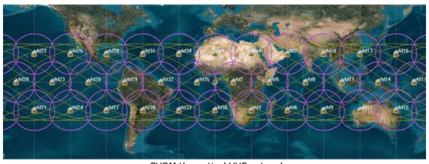
LOFT burst alert system

Automatic triggers for bright events on-board:

- Few to few 10 triggers/ day:
  ~1 arcmin location via VHF network within 30 s (onboard to end user)
- All triggers:
  - Full spectral and timing resolution
  - Pre-trigger data
  - Triggered data available within 1.5-3 hr



The HETE-II VHF Alert Network.



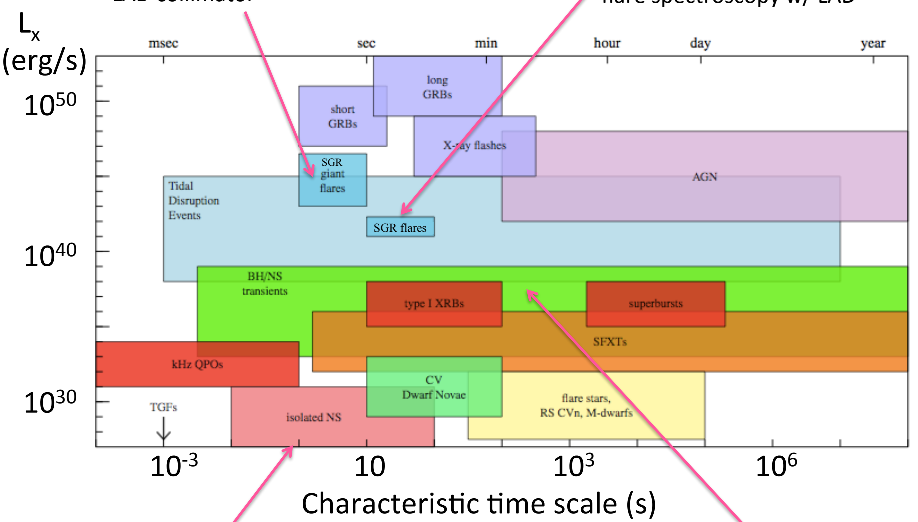
SVOM theoretical VHF network.

Expected: ~ 150 GRBs yr^{-1}
~ 5000 thermonuclear X-ray bursts yr^{-1}
…

LOFT Observatory Science

SGR giant flare *through* LAD collimator

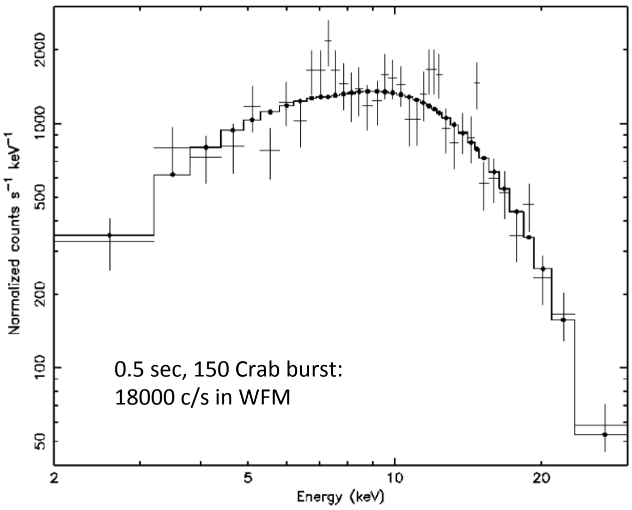
New magnetars w/ WFM, flare spectroscopy w/ LAD



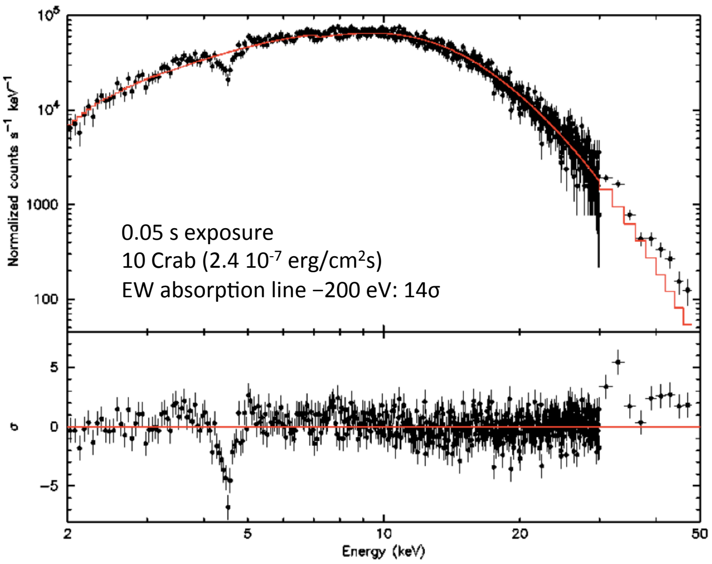
Find pulsars in distant PWN and SNR

BH/NS accretion/ejection physics

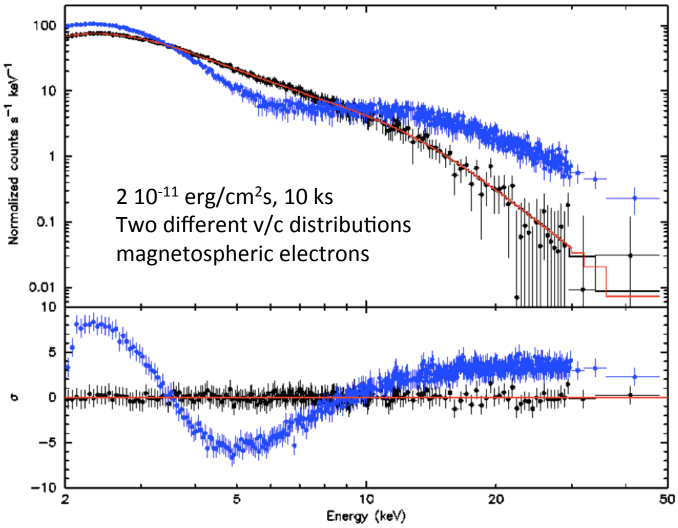
Discovering SGR with LOFT/WFM



SGR flare spectrum LOFT/LAD



SGR persistent emission in LOFT/LAD



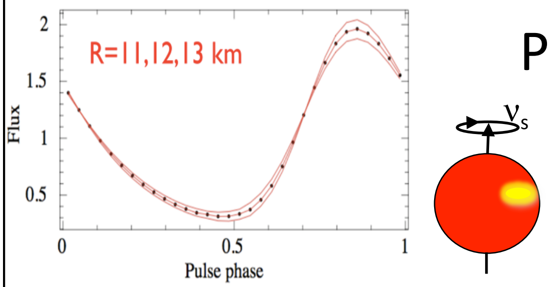
Dense matter

RXTE discovered the signals:

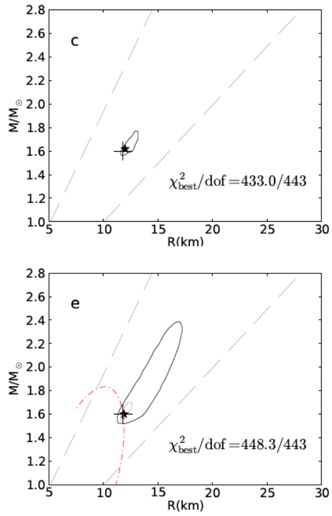
- accreting millisecond pulsars
- thermonuclear burst oscillations
- SGR seismic oscillations (in giant flares)

LOFT uses them to characterize neutron stars

- neutron star spin distribution
  [discover many more spins]
- pulse profile modeling
  [measure M and R]
- SGR seismic oscillations in *intermediate* flares
  [NS interior]



Pulse profiles



- Ray tracing from hot spot to Earth to constrain spacetime geometry
- Thermonuclear burst pulsars: 'simple' hot spots heated from below
- A few bursts sufficient to measure M,R to 4, 3 % (instrumental) if geometry is favourable (Lo et al. 2013).
- RXTE burst oscillation data checked for consistency (Artigue et al. 2013).

LOFT simulation

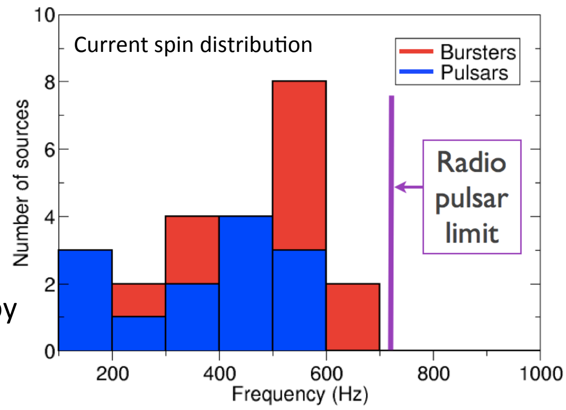
Lo et al. 2013

Spin frequencies

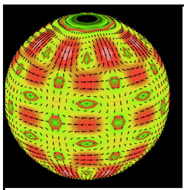
- Do spins pile up at ~700 Hz?
  - Faster spins directly constrain EOS
  - True pile up constrains torque mechanisms (cf. Gusakov this meeting)
    - grav. waves
    - magnetic

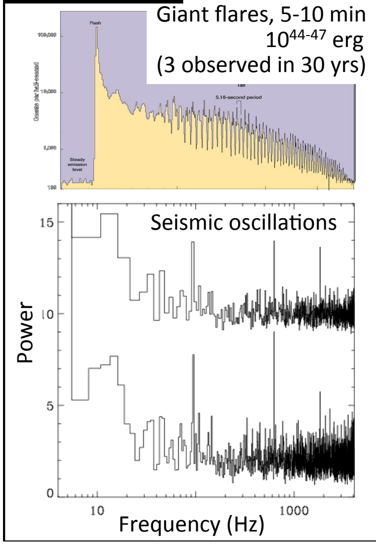
➔Discover spins to unprecedented sensitivity by three tested methods

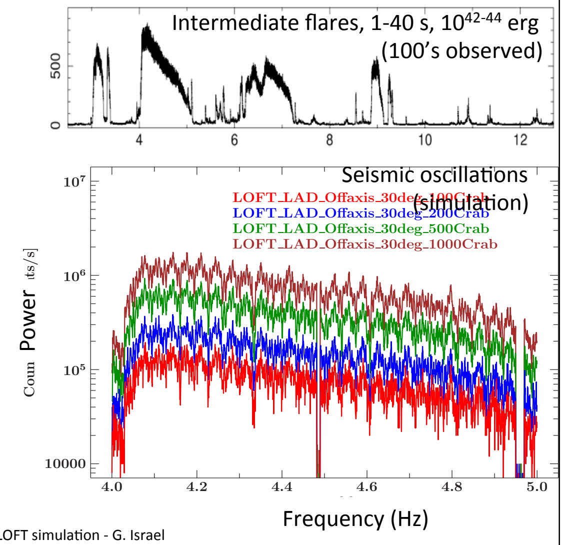
- Accreting pulsar
- Thermonuclear pulsar
  - Burst rise
  - Burst decay



Seismic oscillations

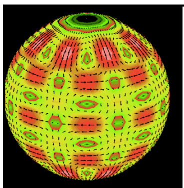


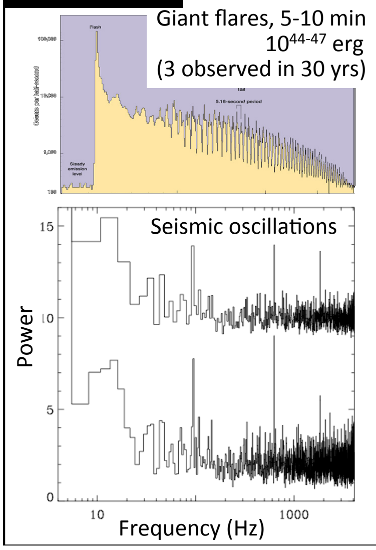


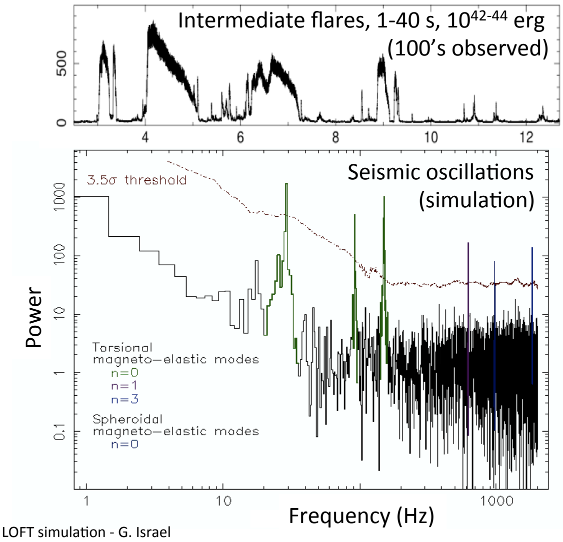


LOFT simulation - G. Israel
1-sec 500-Crab intermediate flare at 30° off-axis in LAD

Seismic oscillations







LOFT simulation - G. Israel
1-sec 500-Crab intermediate flare at 30° off-axis in LAD

Strong gravity

Previous missions discovered the signals:

- relativistic Fe lines (in binaries and AGN)
- dynamical and epicyclic timescale QPOs
    - black hole high-frequency QPOs (barely)
    - neutron star kiloHertz QPOs
    - BH&NS low-frequency QPOs

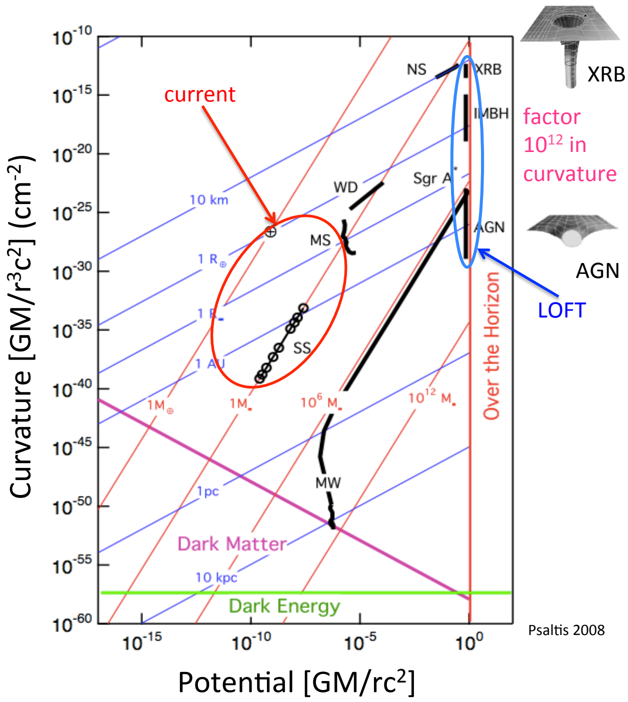
LOFT uses them to probe strong field gravity

- Relativistic line profile variability
    - Merges spectral / timing diagnostics into one
    - Tomography & reverberation
- Relativistic epicyclic motions
- Relativistic distortions of QPO waveforms

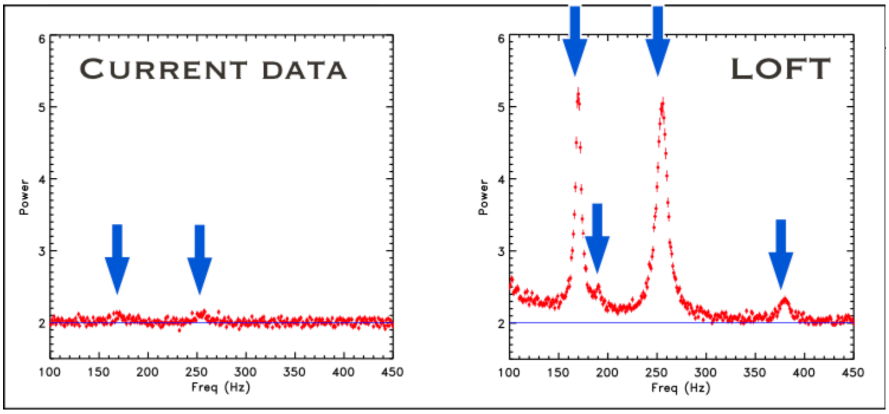
Probing gravity with LOFT

- Strong fields and *both*:
- weak curvatures
  &
- strong curvatures

- Complementary to gravitational wave experiments: LOFT probes *static* spacetimes



Signal to noise proportional to detector area



Incoherent variability detection:
S/N $\propto$ area instead of $\propto$ area$^{1/2}$

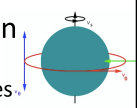
$$n_\sigma = \frac{1}{2} r^2 \sqrt{\frac{T}{\Delta\nu}} I_x$$

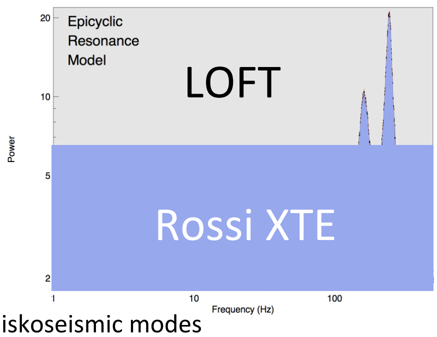
BH high-frequency QPO

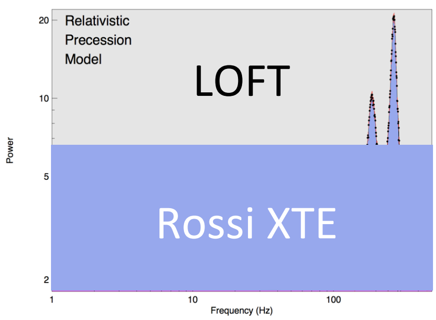
Different models predict different frequency behaviour:

Epicyclic Resonance
(Abramowicz & Kluzniak 2001)
Predicts fixed frequencies

Relativistic Precession
(Stella et al 1999)
Predicts variable frequencies







Diskoseismic modes
(e.g. Lai&Tsang 2009)
Alfven wave model
(Zhang et al. 2005)
Predict other dependencies on flux

LOFT:
- distinguish between the models
- clinch the interpretation of the QPOs in terms of GR
- measure mass and spin of the black hole

BH high-frequency QPO

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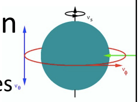

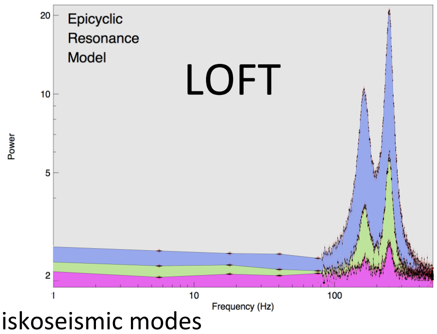

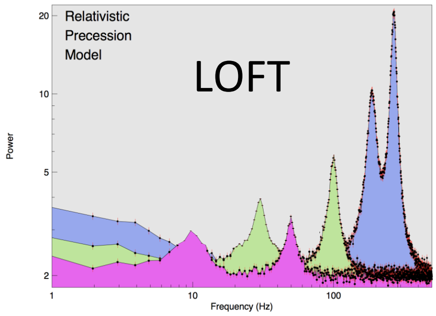

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LOFT spectral timing

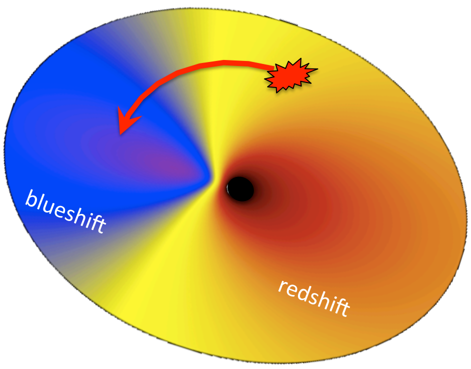
Two orthogonal diagnostics of strong field gravity:
- relativistic Fe lines
- dynamical time scale QPOs

LOFT will integrate them & clinch models.

Example: orbiting blob
- Fe line → orbital velocity & redshift
- QPO → orbital period in disk
- fix interpretation of both phenomena
- use to study motion of test fluid in strong field gravity

This is tomography: use disk surface map of gradients in temperature and redshift to reconstruct locations on the disk.

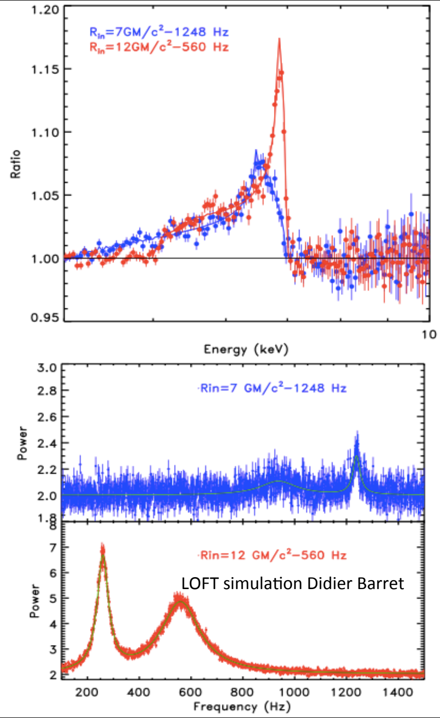
More realistic fluctuation patterns
→ spectrum of fluctuations
  → orbiting
  → propagating inwards



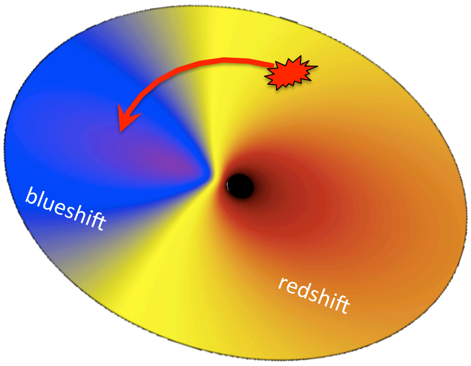
map fm. Dauser et al. 2010

With 10 m^2, can use Fourier techniques to measure this statistically in stellar mass holes: amplitude spectra and phase lag spectra

Also: reverberation (light echos on disk) in AGN and XRB.



:tral timing



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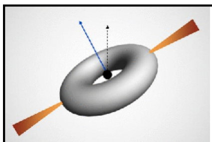
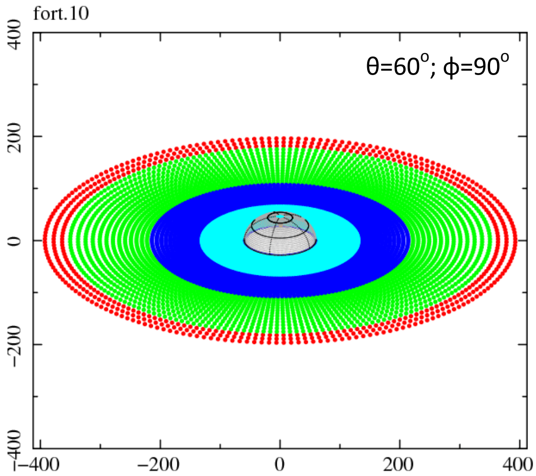
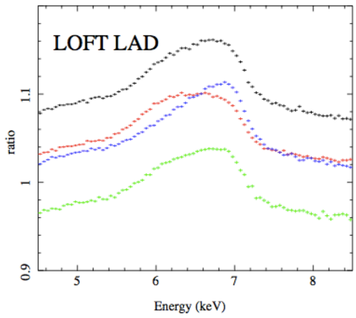


Precessing torus Fe line

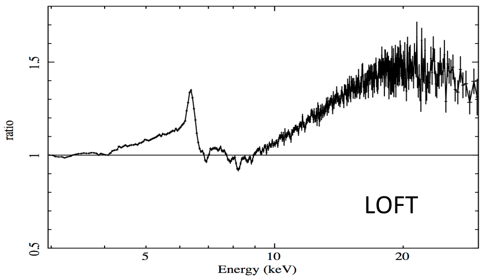
LOFT will see the reflection Fe line profile vary with phase of precessing torus



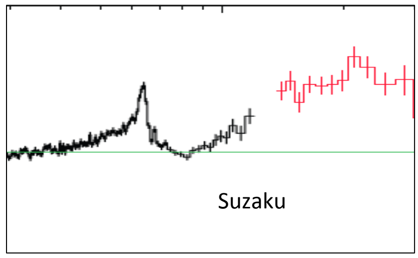


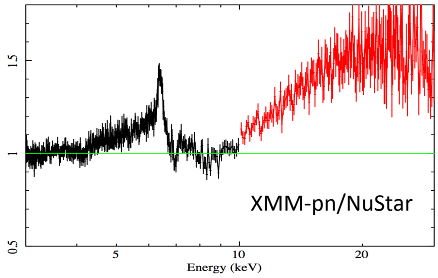
Ingram & Done 2012

Active Galactic Nuclei



LOFT simulation A. de Rosa
MCG-6-30-15, 2 mCrab, exposure 150 ks





BH spins to 10-20% for ~30 AGNs

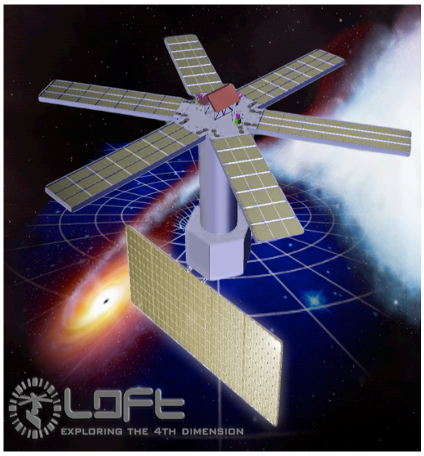
(Fero sample >1 mCrab)

BH masses to 30% for ~8 AGNs

(tomography)

Summary

- LOFT 'core science' aims:
  1. dense matter
  2. strong gravity
- Innovative main instrument with tremendous capabilities: 10 m^2, 200-260 eV
- Very good wide field monitor
- Useful for a broad range of additional studies:
  3. 'observatory science'
- Synergies with many other instruments projected for the 2020's



Thank you!

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