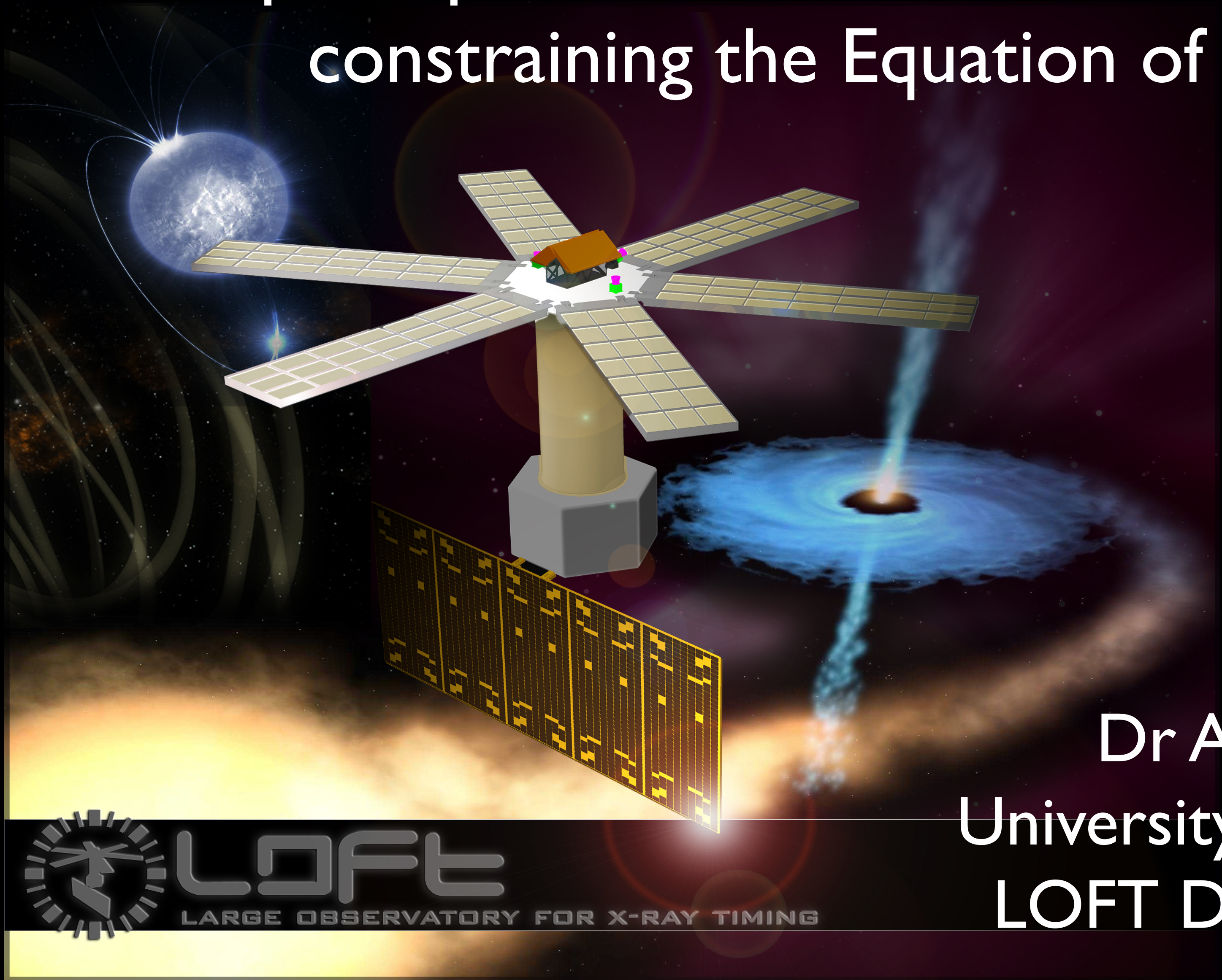
NS pulse profile measurements with LOFT: constraining the Equation of State



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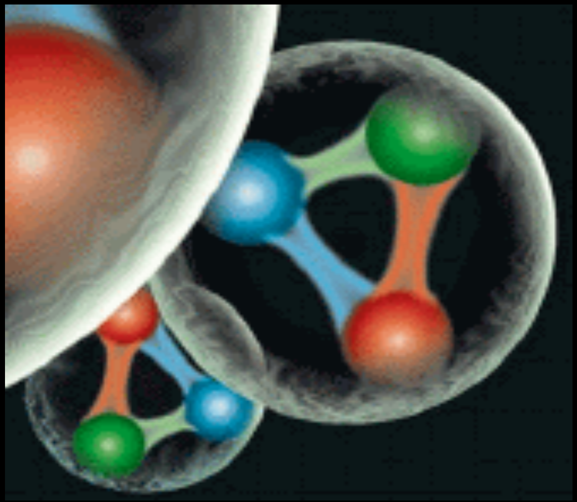
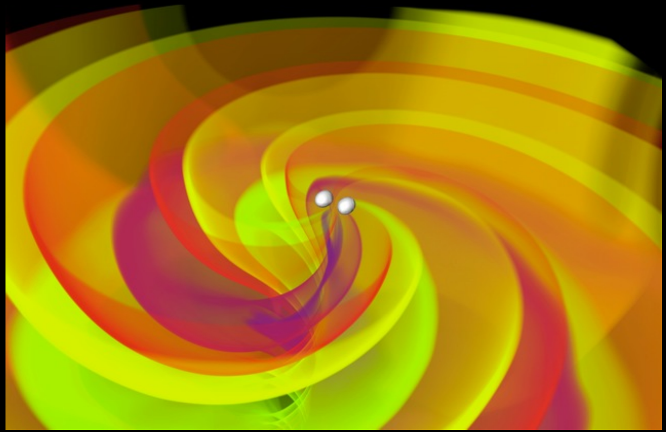
Motivation

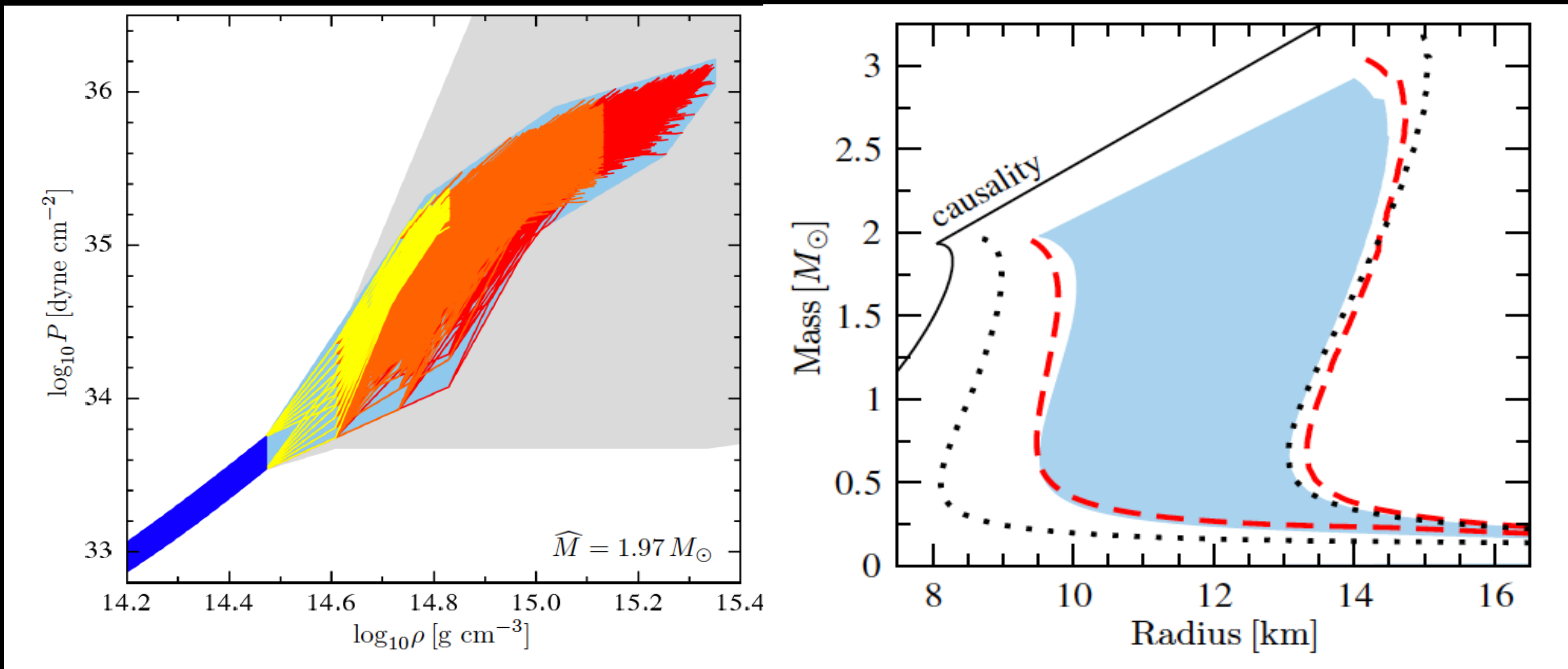
- Basic physics: the nature of matter
  - Nucleon-nucleon interactions poorly understood, especially for neutron-rich matter and at high density.
  - More exotic states of matter also possible at high density.



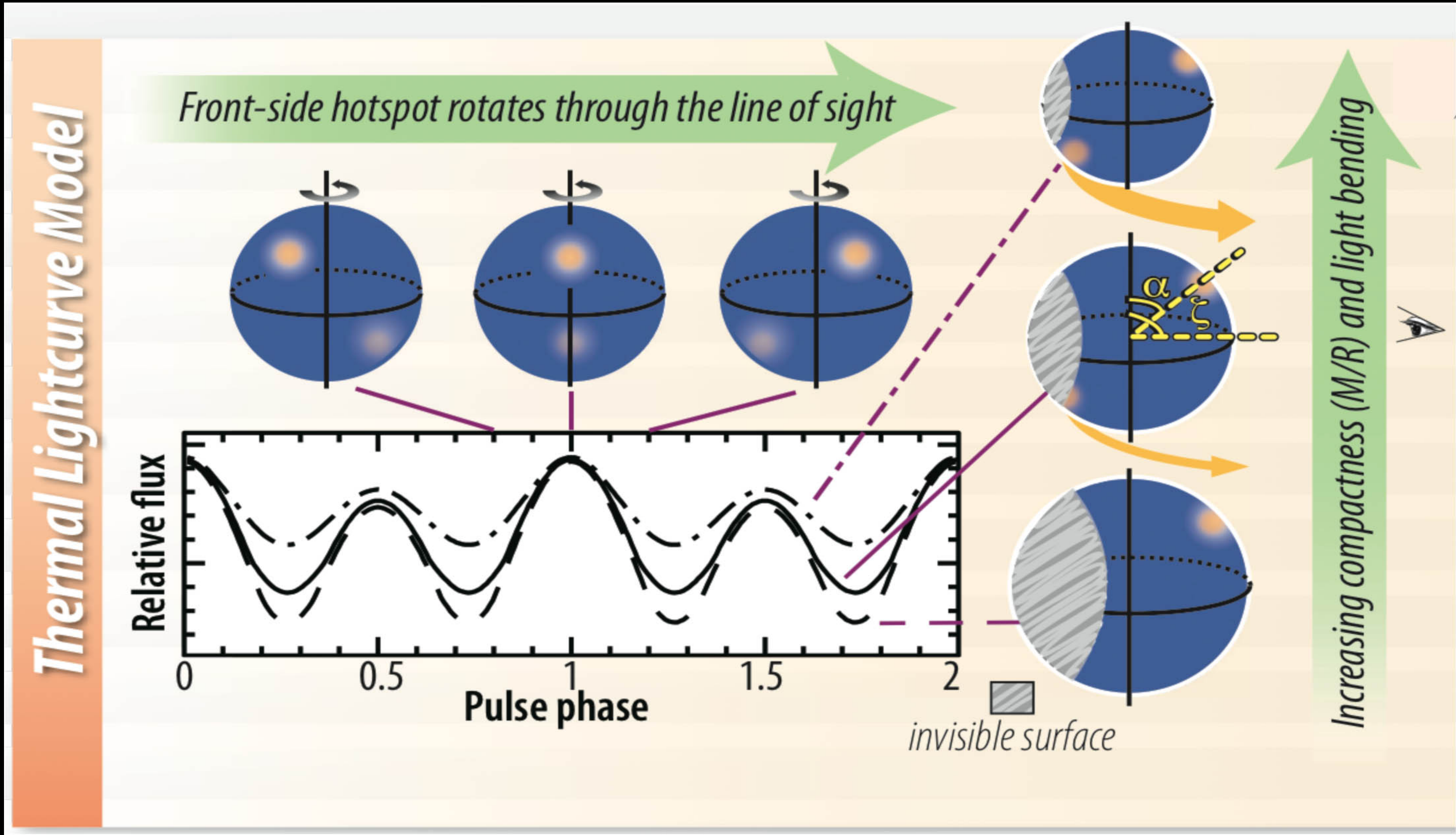
- Astrophysical phenomena
  - Supernova process
  - Black hole formation (NS maximum mass)
  - Gamma-ray bursts
  - NS binary mergers (prime GW sources)



Impact of uncertainty



- Current uncertainty in one nucleonic EoS (Hebeler et al. 2013)
- LOFT aims to measure M, R to accuracies of a few %.

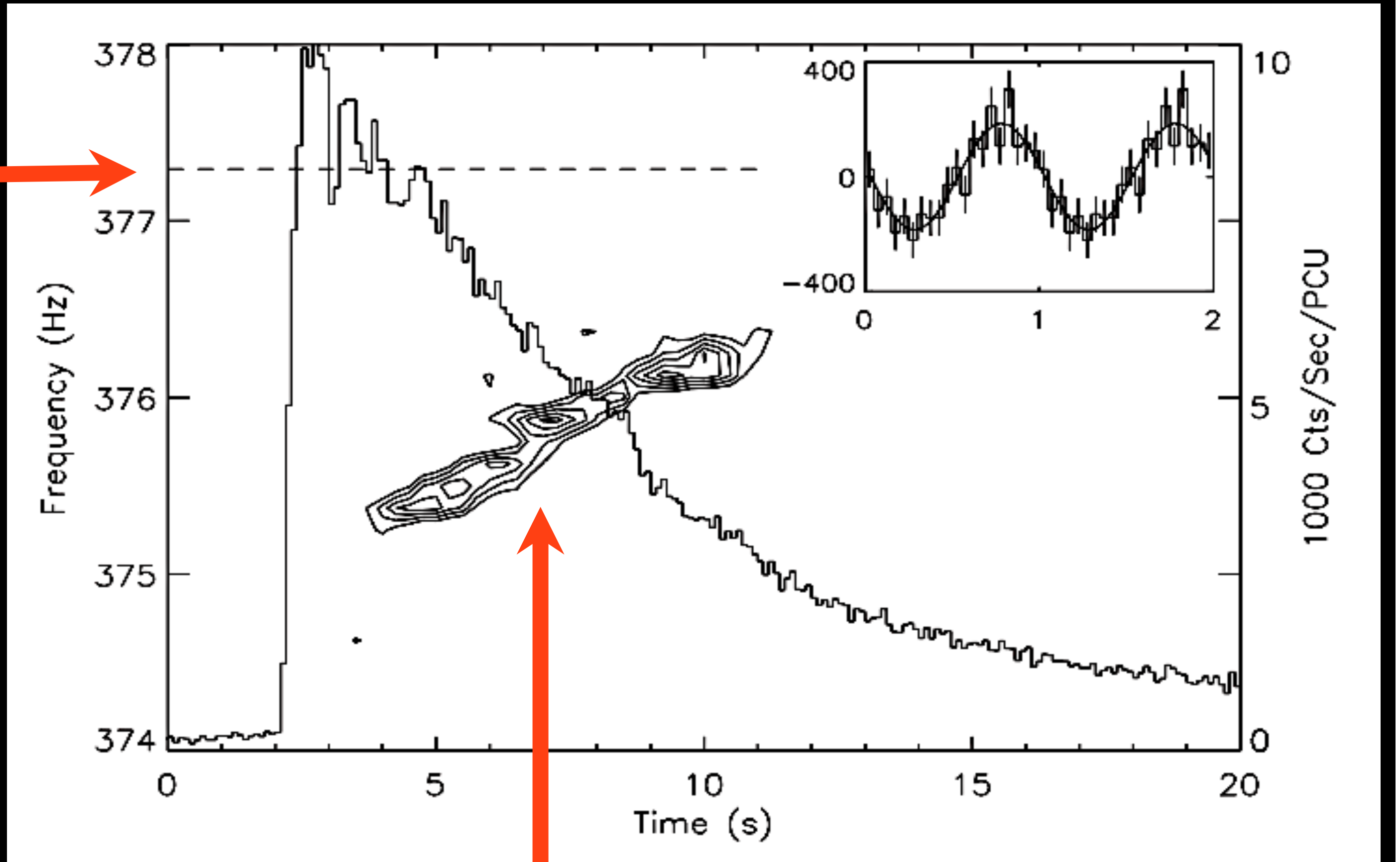


Thermal Lightcurve Model
Front-side hotspot rotates through the line of sight
Relative flux
0
0.5
1
1.5
2
Pulse phase
invisible surface
α
ζ
Increasing compactness (M/R) and light bending

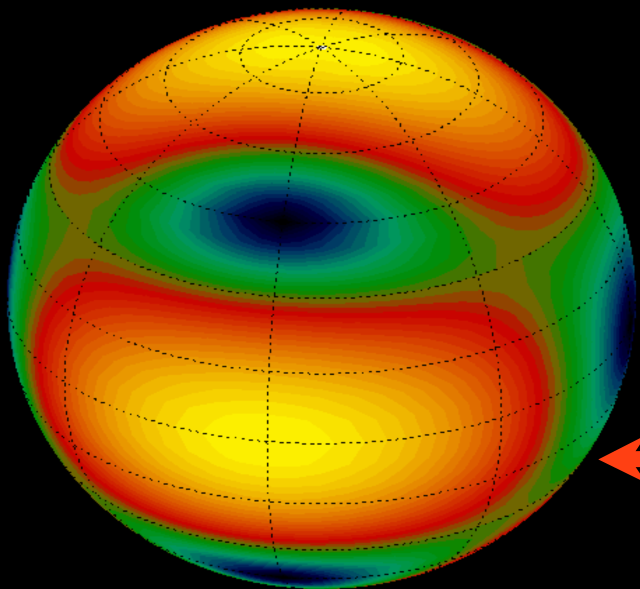
NASA

Thermonuclear burst oscillations

Spin frequency



Watts et al. 2009



Drifting hotspot

Analysis (Lo et al. 2013)

1. Generate synthetic burst waveform data for situations of interest.

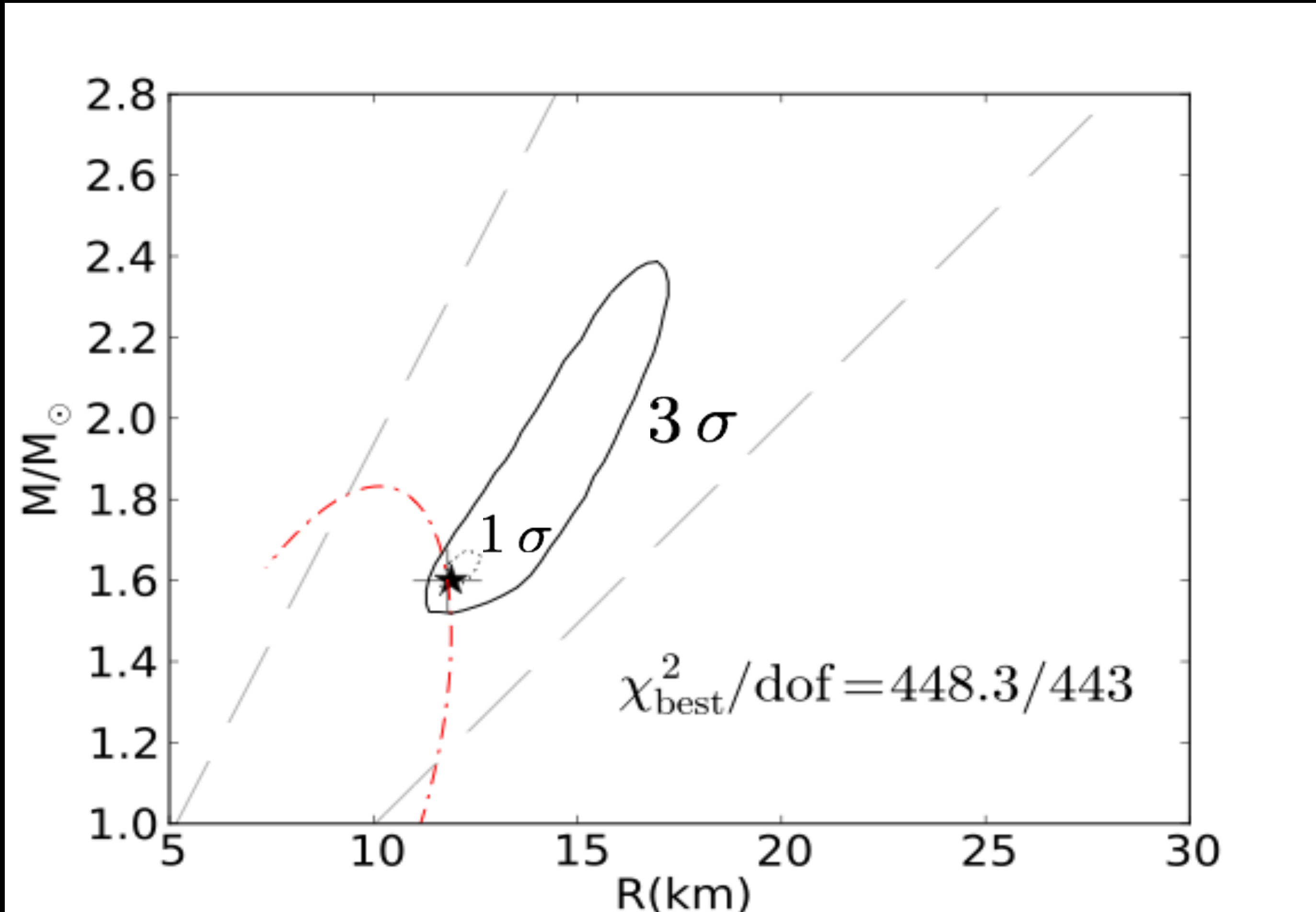
2. Compute the joint posterior distributions of all relevant parameters in the standard rotating hot spot model of burst oscillations, using MCMC sampling.

3. Compute the joint posterior distributions of M and R, by marginalizing the other parameters (observer inclination, hotspot inclination…)

4. Use the marginalized distributions to determine the most probable values of M and R and their 1-σ and 3-σ confidence regions.

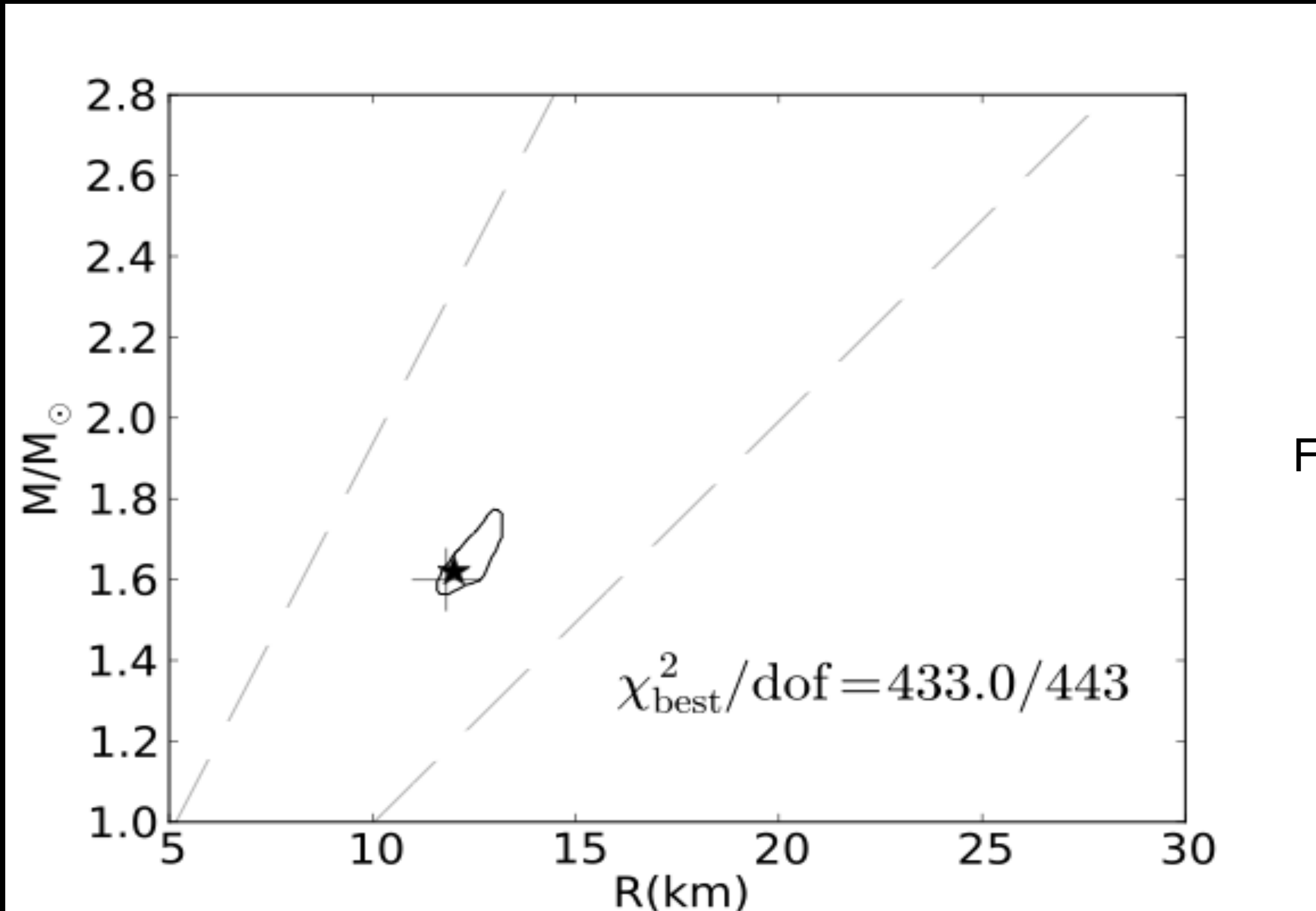
High inclinations allow tight constraints on M and R

Observer inclination = 90°, high background



High inclinations allow tight constraints on M and R

Observer inclination = 90°, medium background



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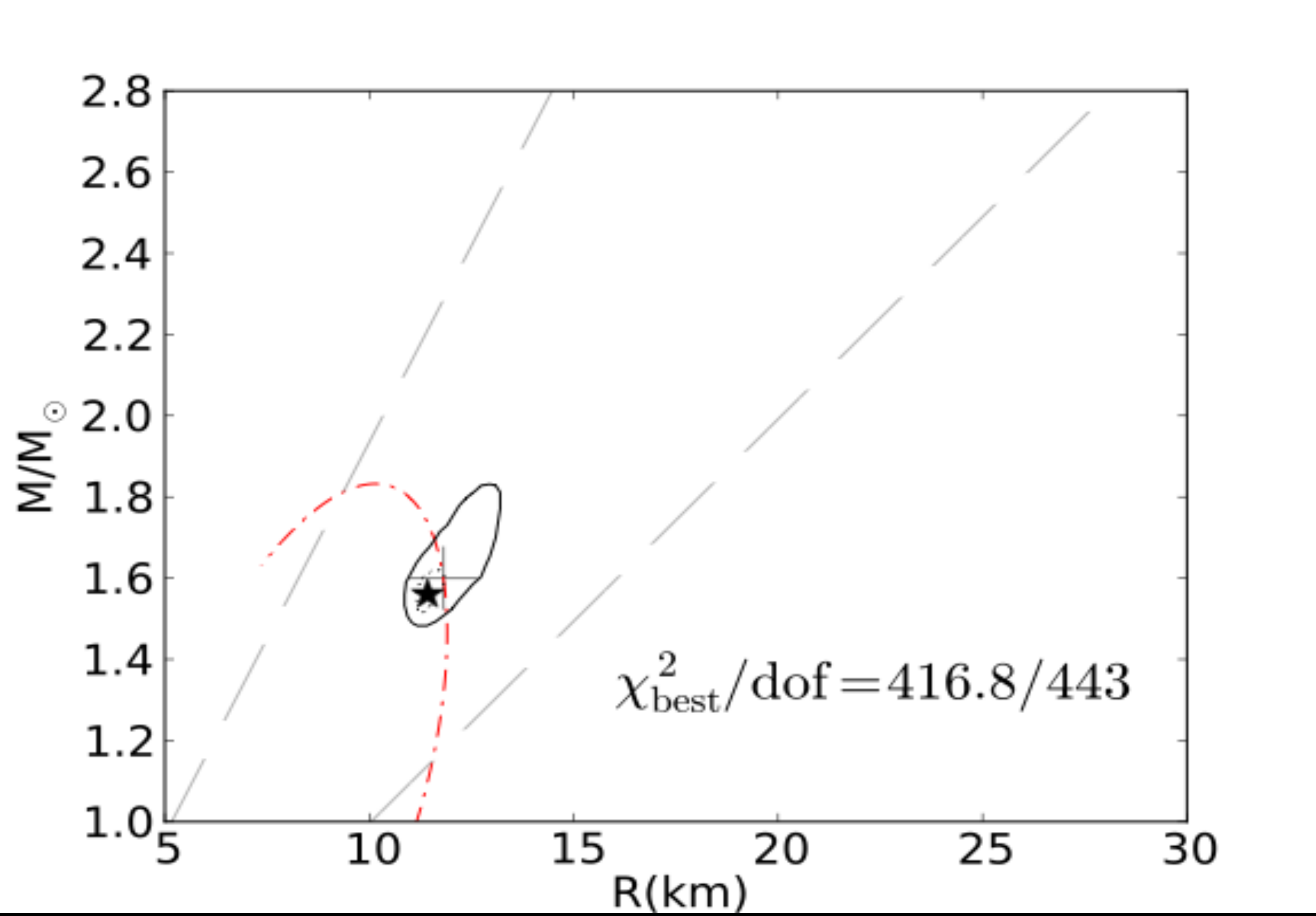
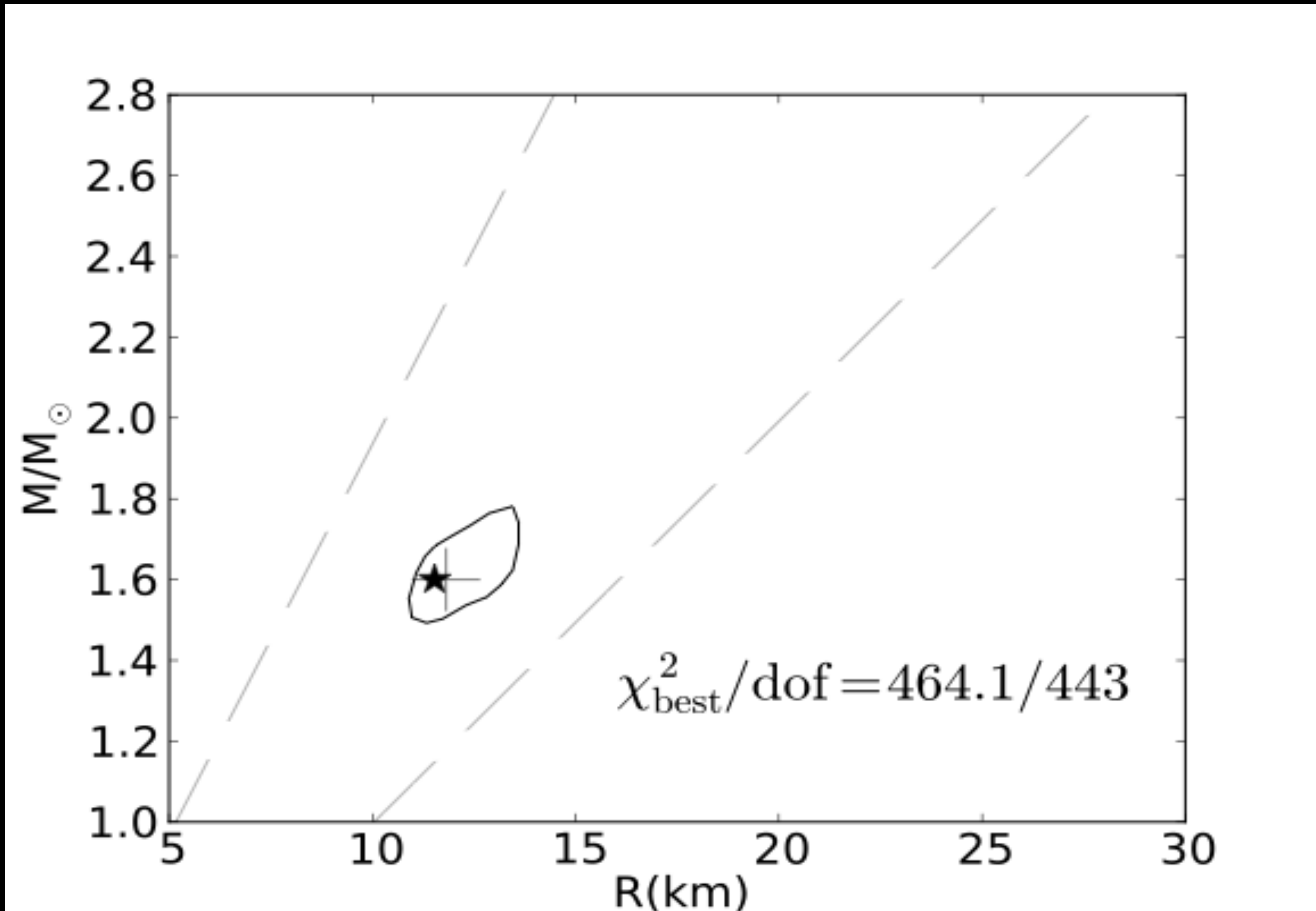
Confidence regions expand slowly with decreasing spot inclination for inclinations > 60°

Observer inclination = 90°, medium background



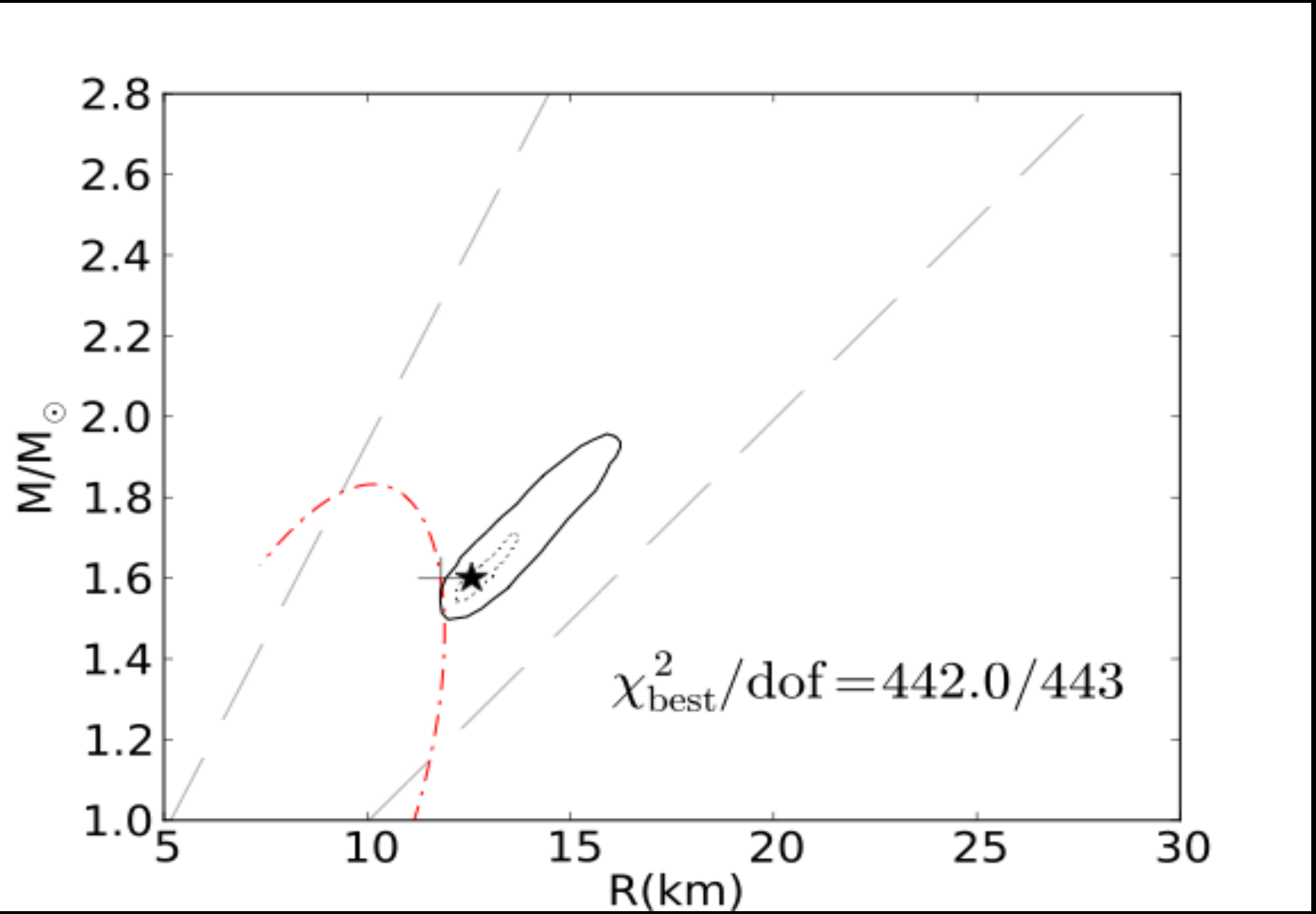
Independent knowledge of the observer's inclination can increase the precision

Spot and observer inclinations = 90°, high background



Incorrect modeling of the spot shape increases the uncertainties

Spot and observer inclinations = 90°, medium background



Summary of results

- If the hot spot is within ~ 10° of the equator, *M* and *R* can be determined with a 1 σ uncertainty ~ 10%, using only waveform data.

- Uncertainties increase slowly as the hot spot moves away from the rotation equator, becoming large if the spot is within ~ 30° of the pole

- Independent knowledge of inclination/distance reduces uncertainties.

- Spectra (continuum fitting or lines) provide complementary constraints.

- *Importantly, these constraints should be achievable even if the burst properties vary with time and we need to combine data from multiple bursts.*

Feasibility

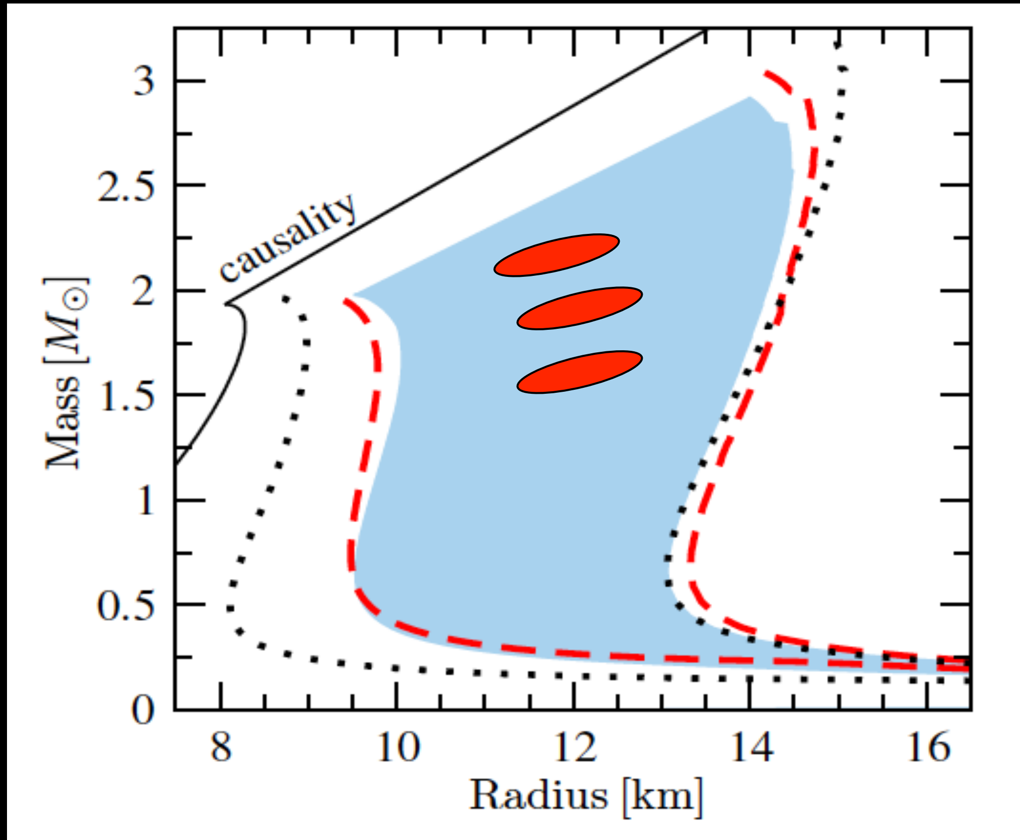
- Priority sources identified: need 10-100 bursts, ~1000 ks/source.
- Checks on model and geometry using RXTE data on harmonics and phase lags (Muno et al. 2002, Artigue et al. 2013).
- Complementary information
  - Spectra (continuum, lines)
  - Distances from GAIA
  - Inclination from optical

Source	Counts in 10s
EXO 0748-676	307800
4U 1608-52	876420
4U 1636-536	336420
4U 1702-429	444420
4U 1728-34	328320
KS 1731-260	238680
Aql X-1	575100

Expected pulsed counts per burst (Psaltis, Ozel, Chakrabarty)

Comparison to NICER

- Neutron star Interior Composition ExploreR
  - NASA Explorer Mission of Opportunity, operating on ISS from late 2016.
  - Same goal as LOFT DM, uses pulse profile modelling technique.
  - Different sources, hence different emission models.
  - Obtain mass from radio measurements.
  - Anticipate comparable results to LOFT for one source, PSR J0437-4715.



LOFT will, using burst oscillation pulse profile modelling of known sources, deliver 3-5 measurements of M and R accurate at the few % level. This will allow us to reconstruct the EoS.

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