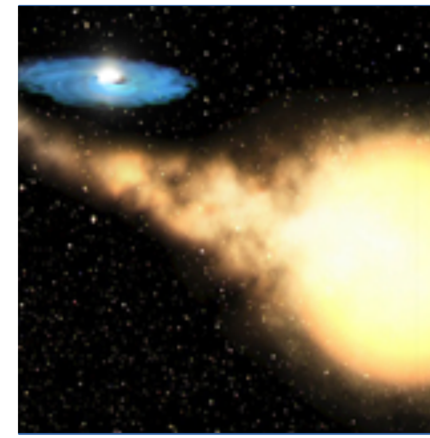
ATHENA

Athena's Constraints on the Dense Matter Equation of State from Quiescent Low-Mass X-ray Binaries



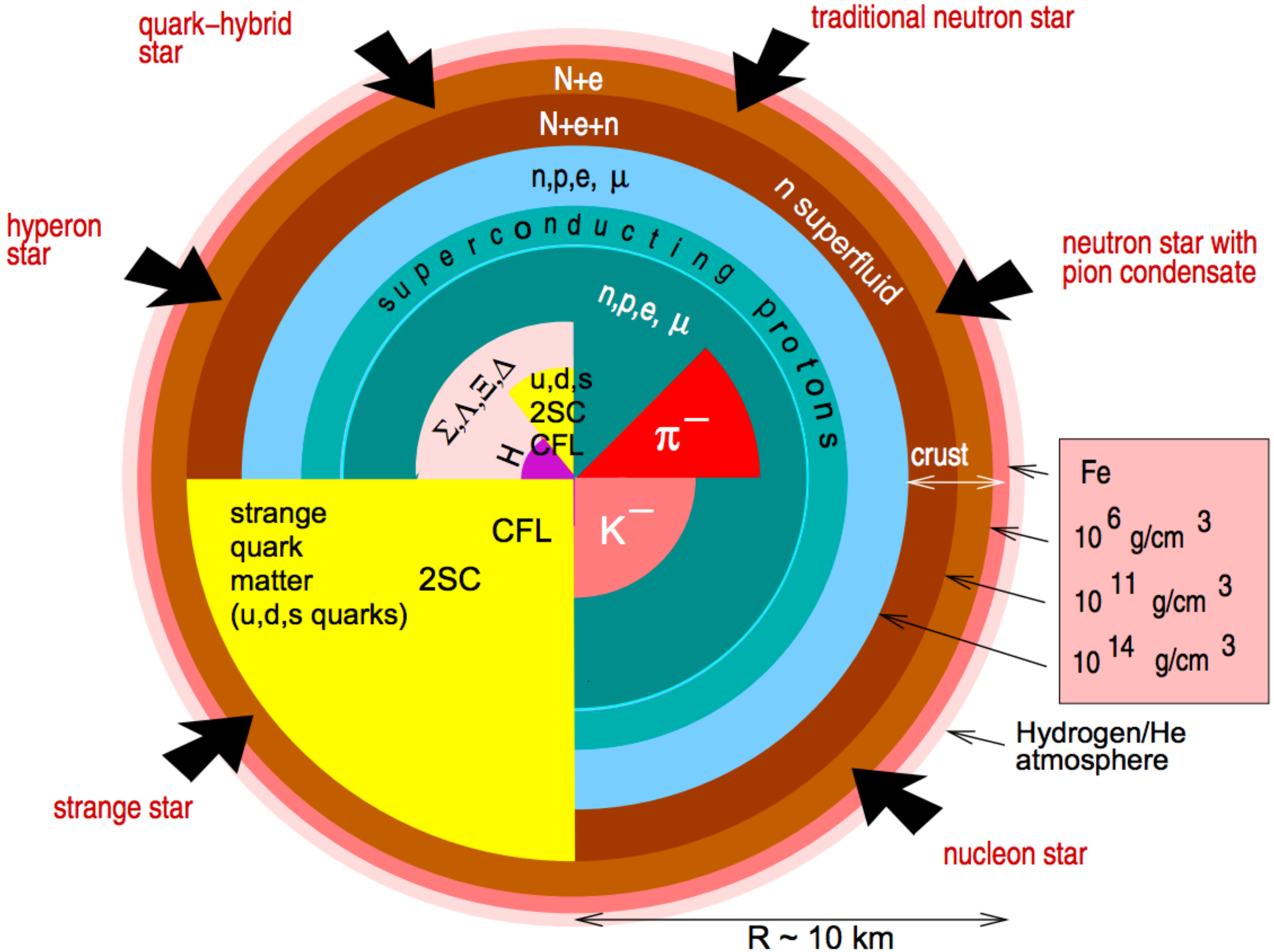
Sebastien Guillot

Pontificia Universidad Católica de Chile

Observatory Science: R-SCIOBJ-331

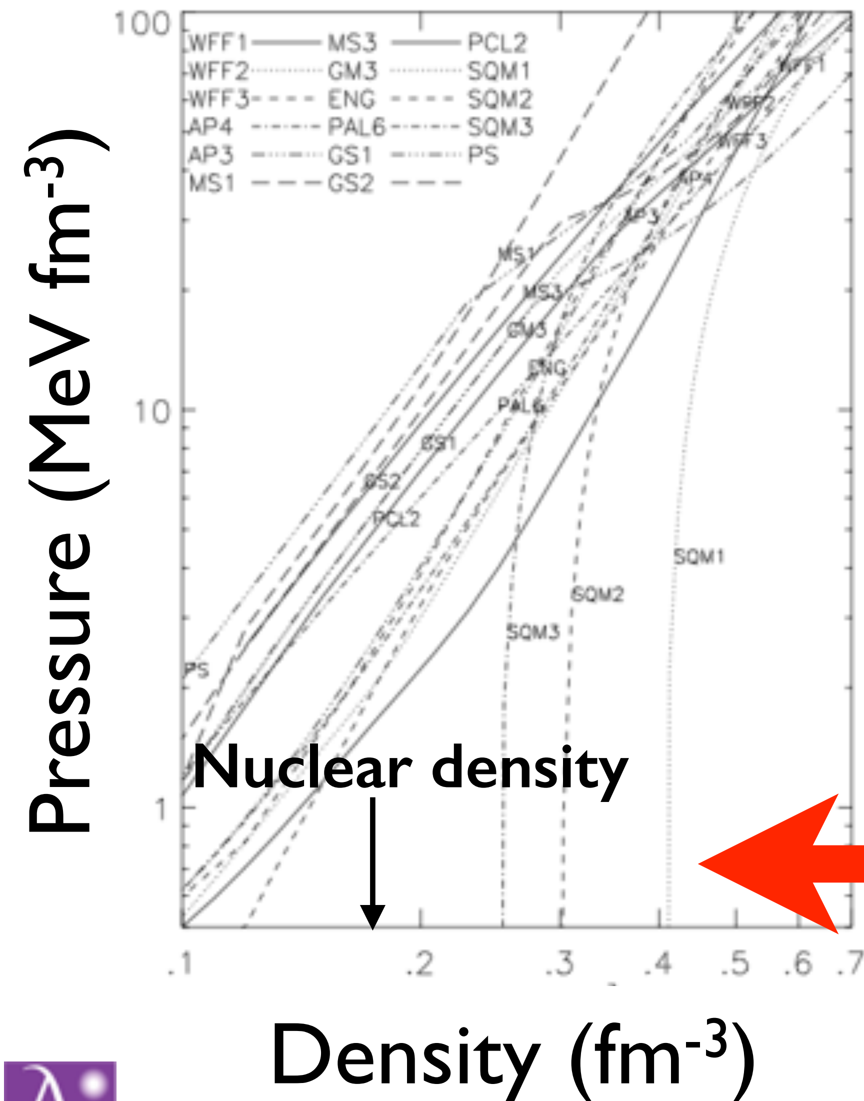
Athena shall constrain the equation of state of neutron stars by obtaining X-ray spectra of quiescent low-mass X-ray binaries with a good distance estimate

The internal structure of neutron stars is still unknown and many theories are proposed.

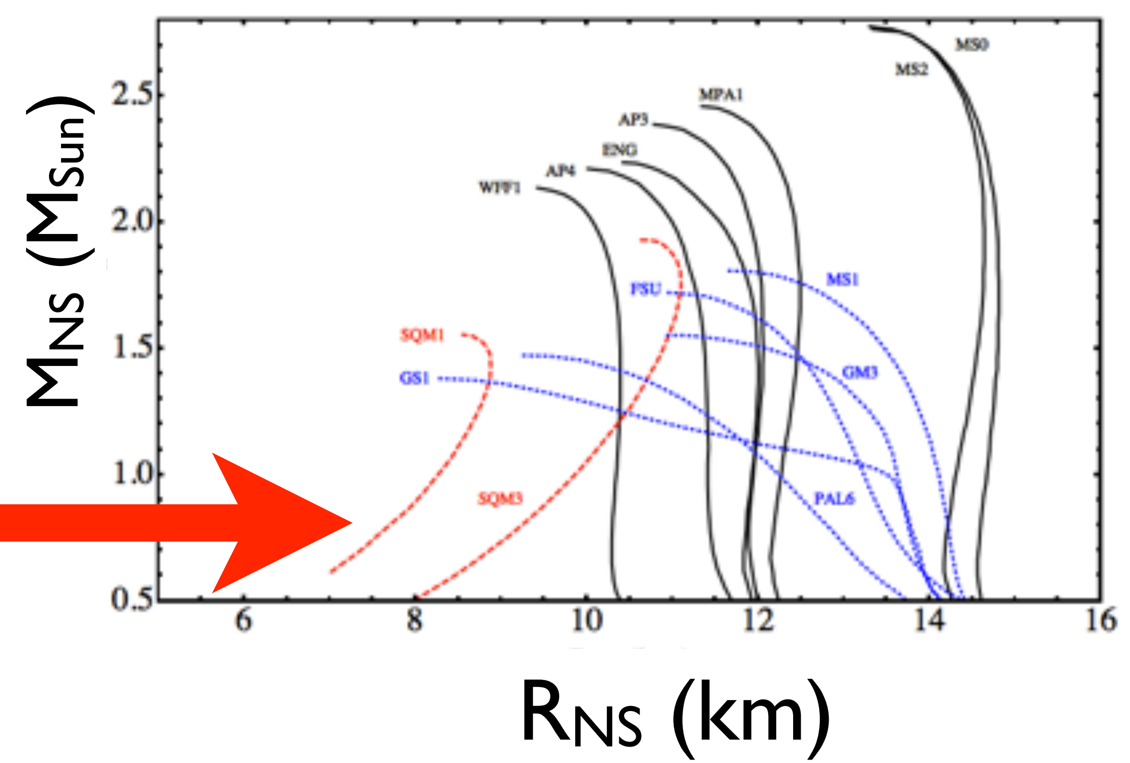


Weber et al. 2007

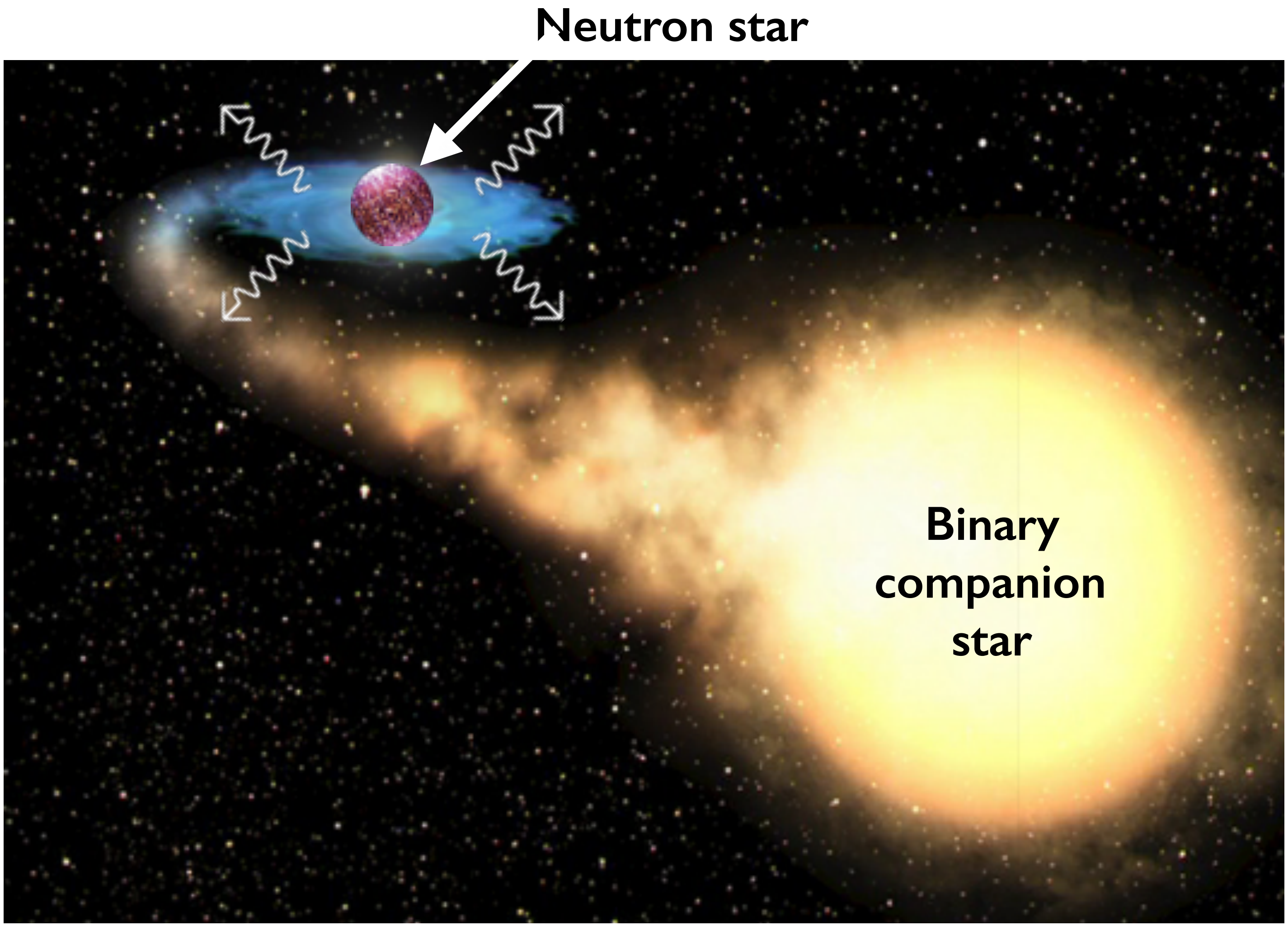
The internal structure of neutron stars is still unknown and many theories are proposed.



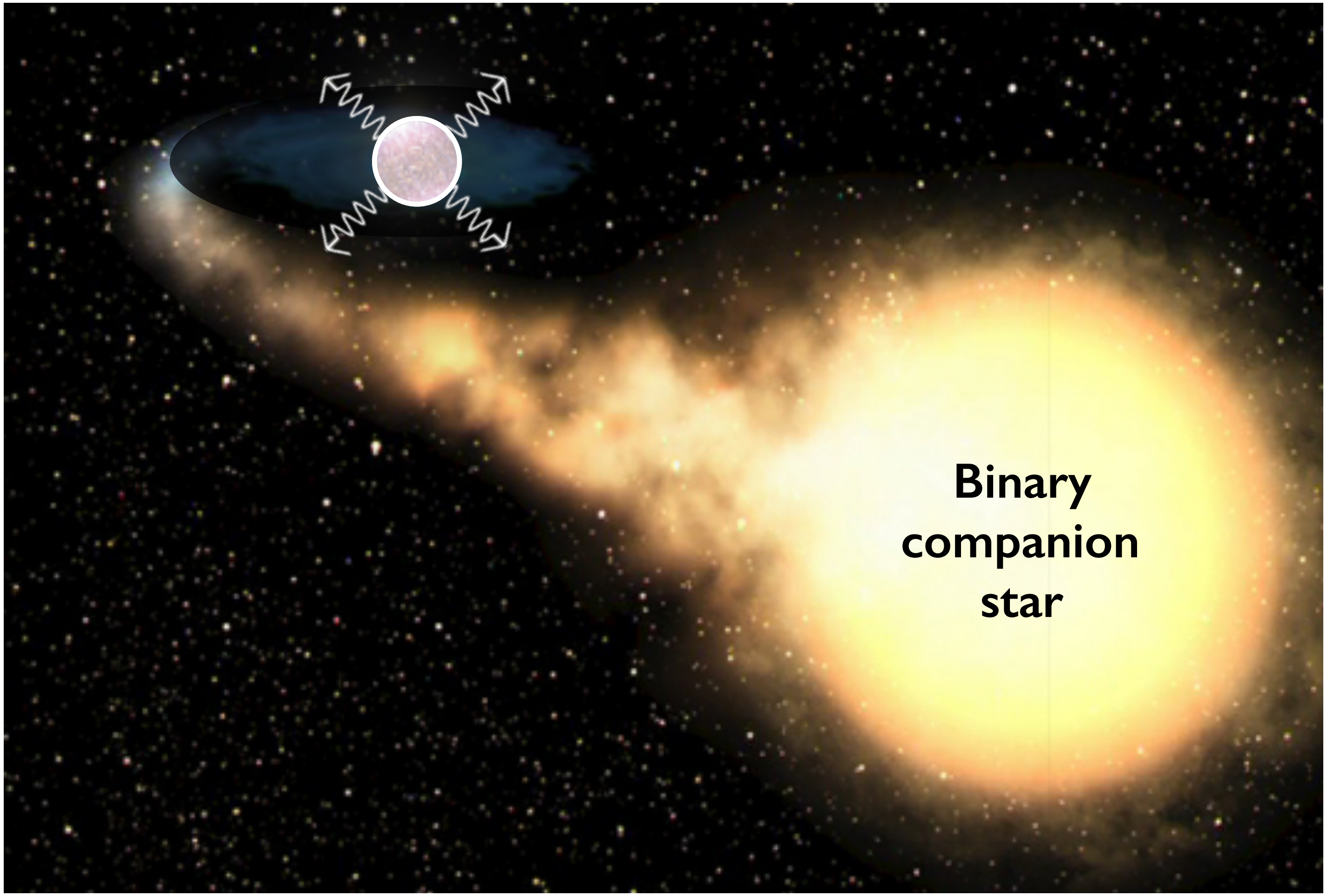
Lattimer and Prakash 2001



Low-mass X-ray binaries experience high- and low- accretion states.

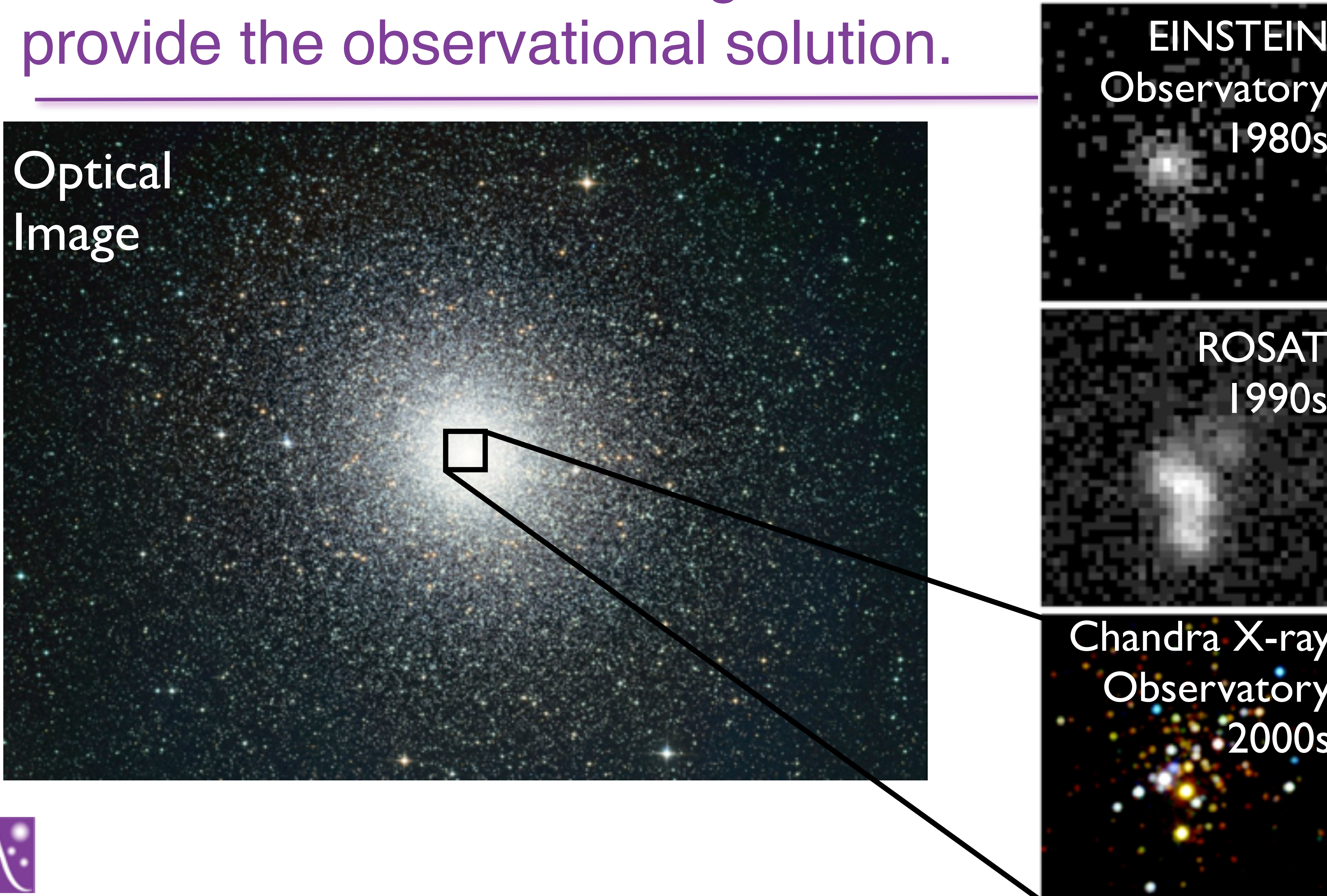


Low-mass X-ray binaries experience high- and low- accretion states.

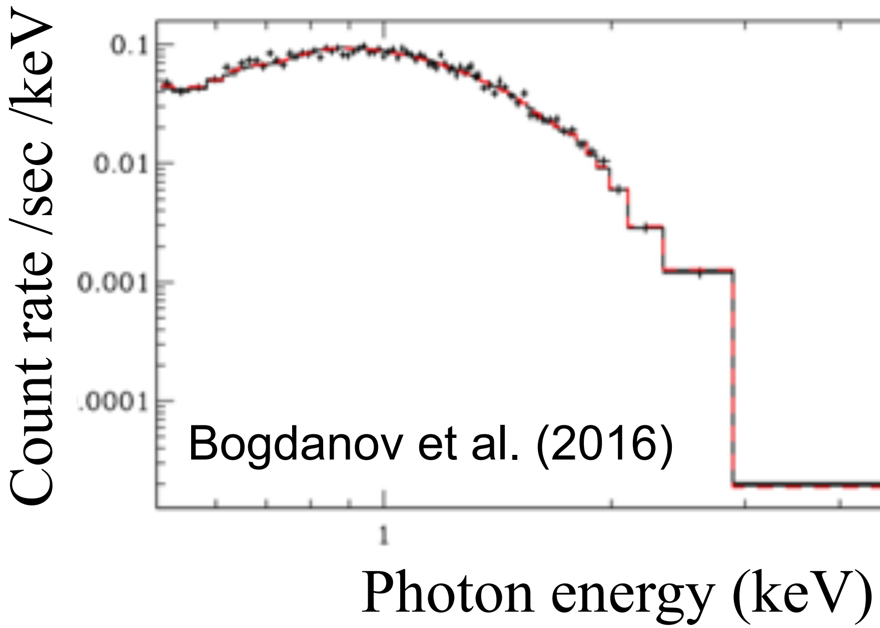


$F_X \sim 10^{-13}$ erg/sec/cm^2

Quiescent LMXBs inside globular clusters provide the observational solution.

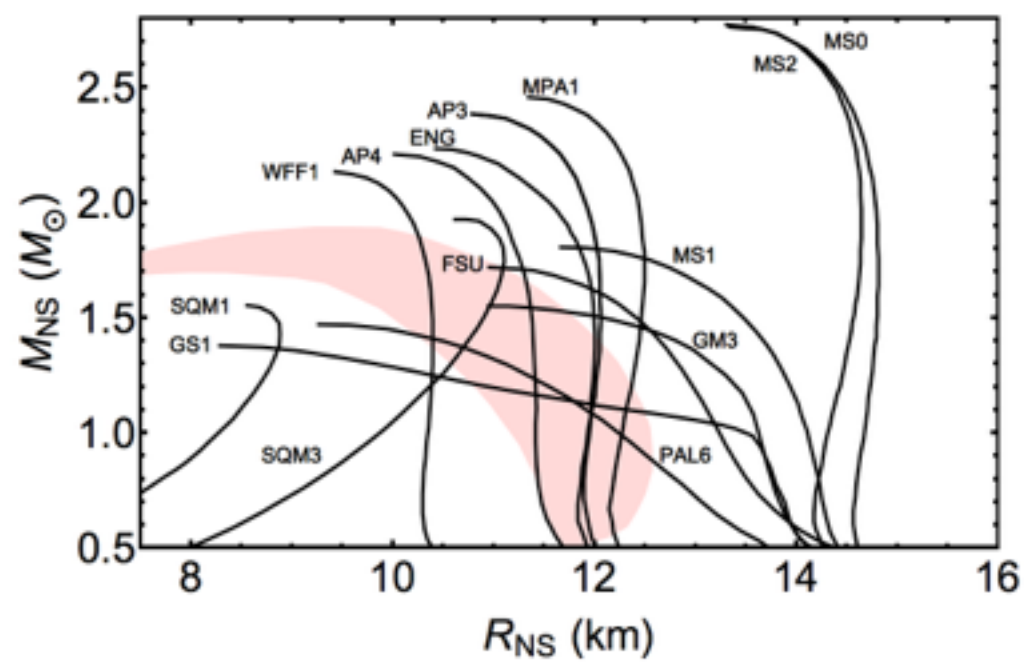


Fitting the X-ray spectra of qLMXBs provides measurement of R_{NS} and M_{NS}.



Assuming <u>non-magnetic Hydrogen</u> atmosphere NS with <u>uniform</u> surface emission

$$\boxed{R_\infty = R_{\rm NS}\,(1+z) = R_{\rm NS}\left(1 - \frac{2GM_{\rm NS}}{R_{\rm NS}\;c^2}\right)^{-1/2}}$$



Bogdanov et al. 2016

Guillot et al. 2011, 2013

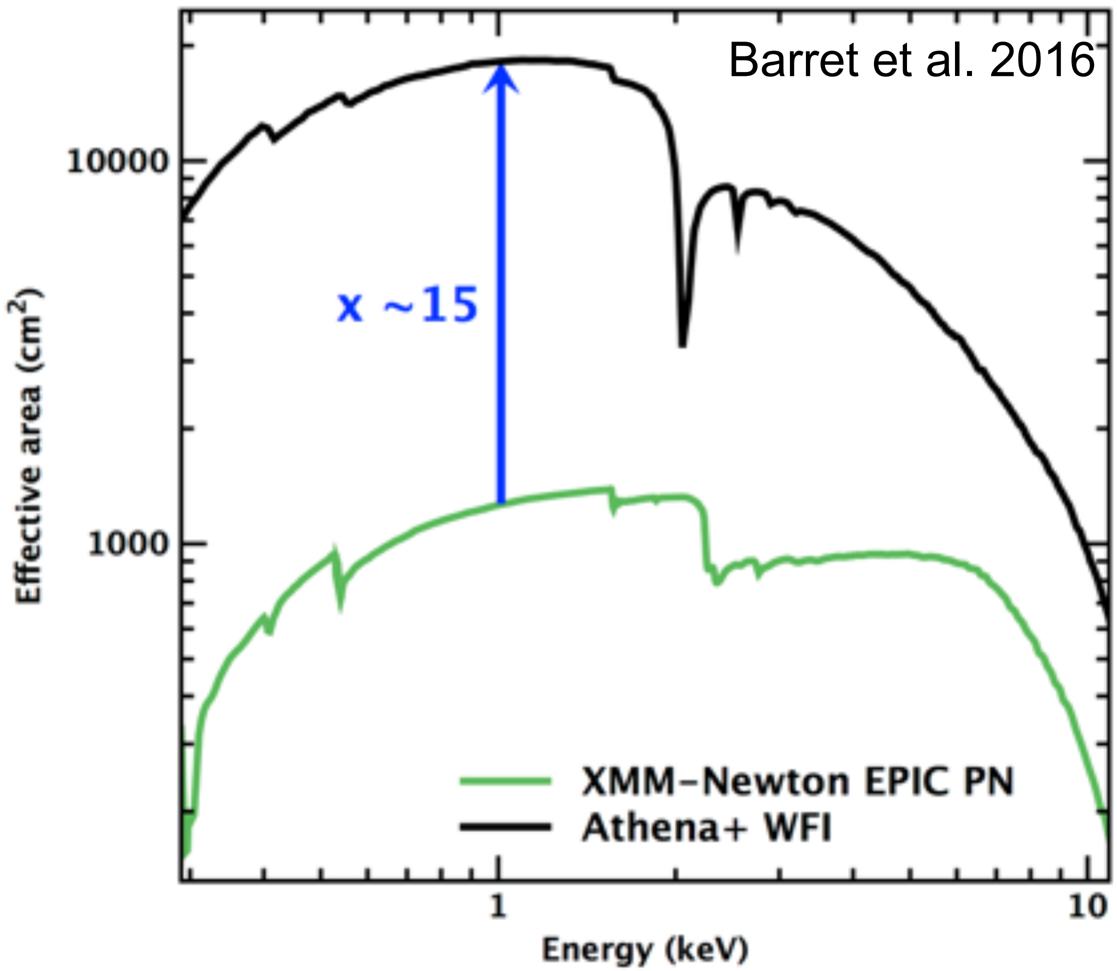
Heinke et al. 2006, 2014

Özel et al. 2016

Webb & Barret 2007

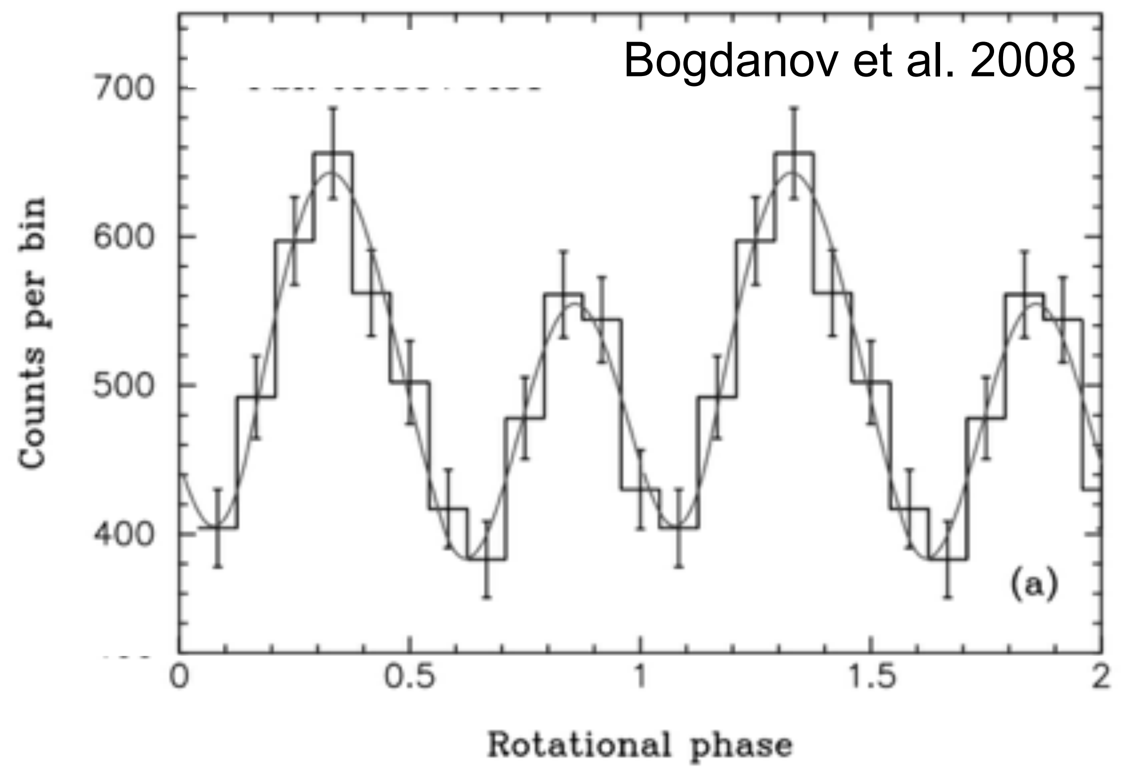
For observations of qLMXBs, ATHENA's capabilities will be critical.

- High throughput at soft X-ray energies
- High time resolutio
- Low background
- Good angular reso



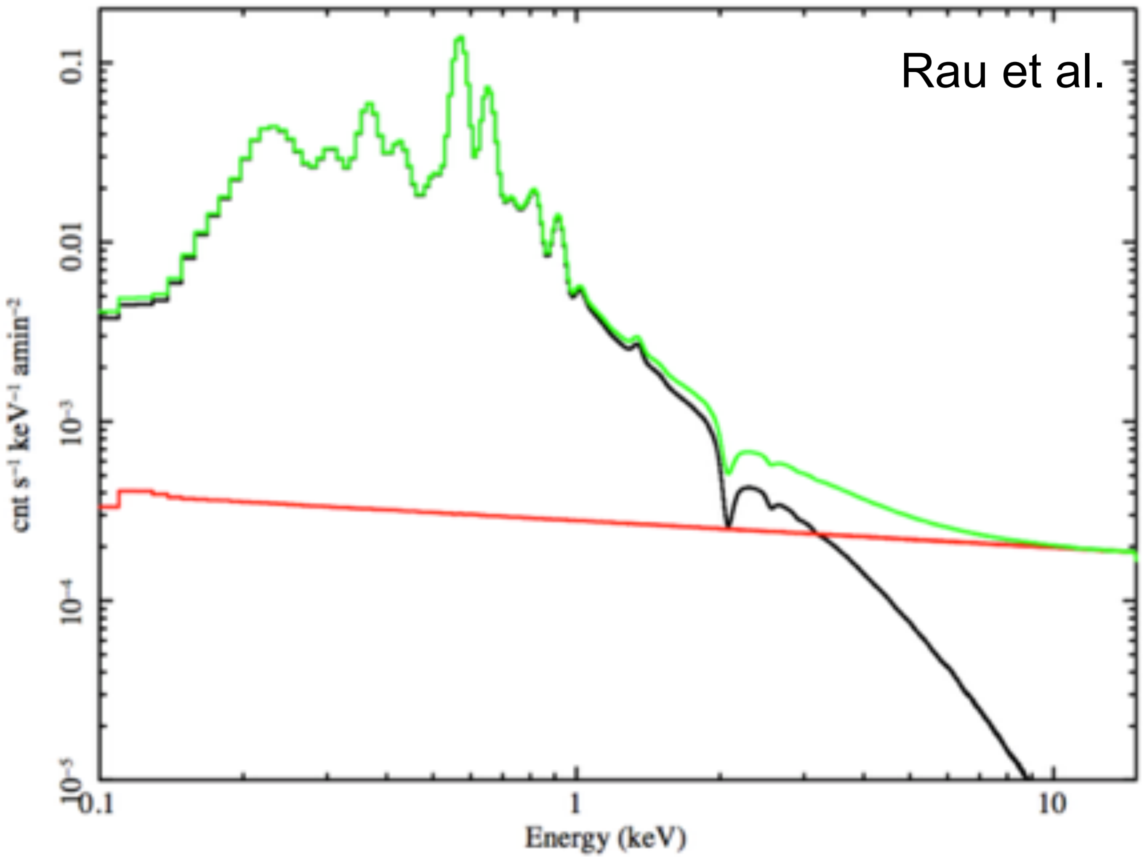
For observations of qLMXBs, ATHENA's capabilities will be critical.

- High throughput at soft X-ray energies
- High time resolution (X-IFU or WFI fast chip)
- Low background
- Good angular reso



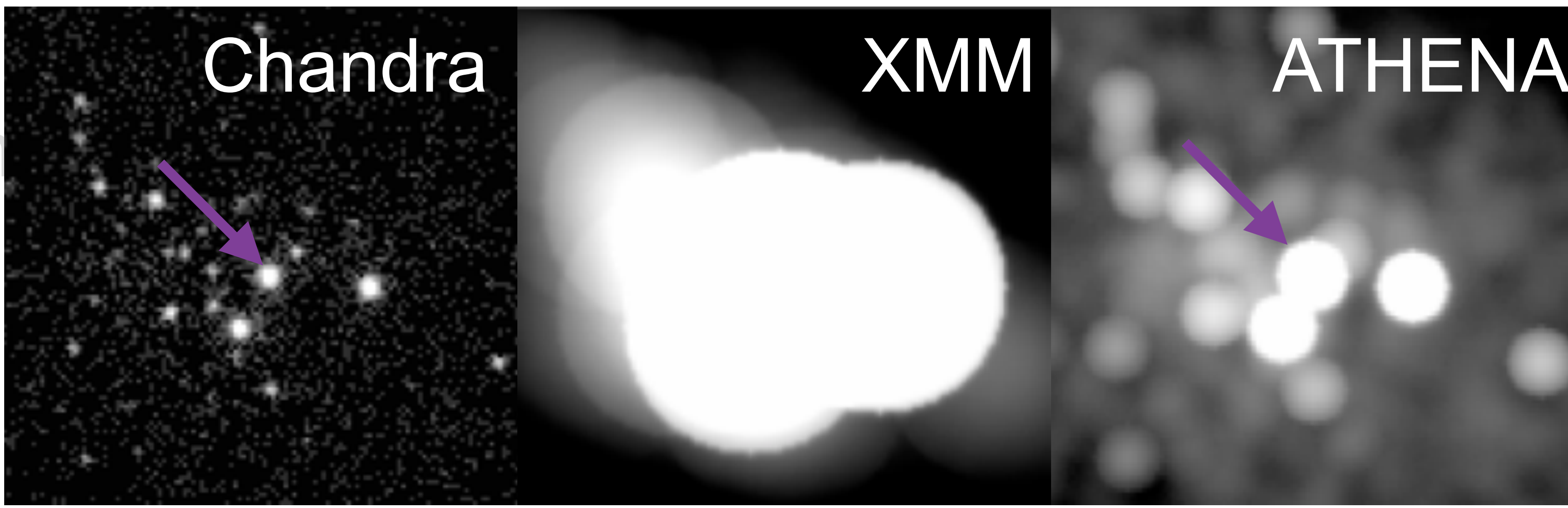
For observations of qLMXBs, ATHENA's capabilities will be critical.

- High throughput a
- High time resolutio
- **Low background**
- Good angular reso



For observations of qLMXBs, ATHENA's capabilities will be critical.

- High throughput at soft X-ray energies



- High
- Low
- Good angular resolution

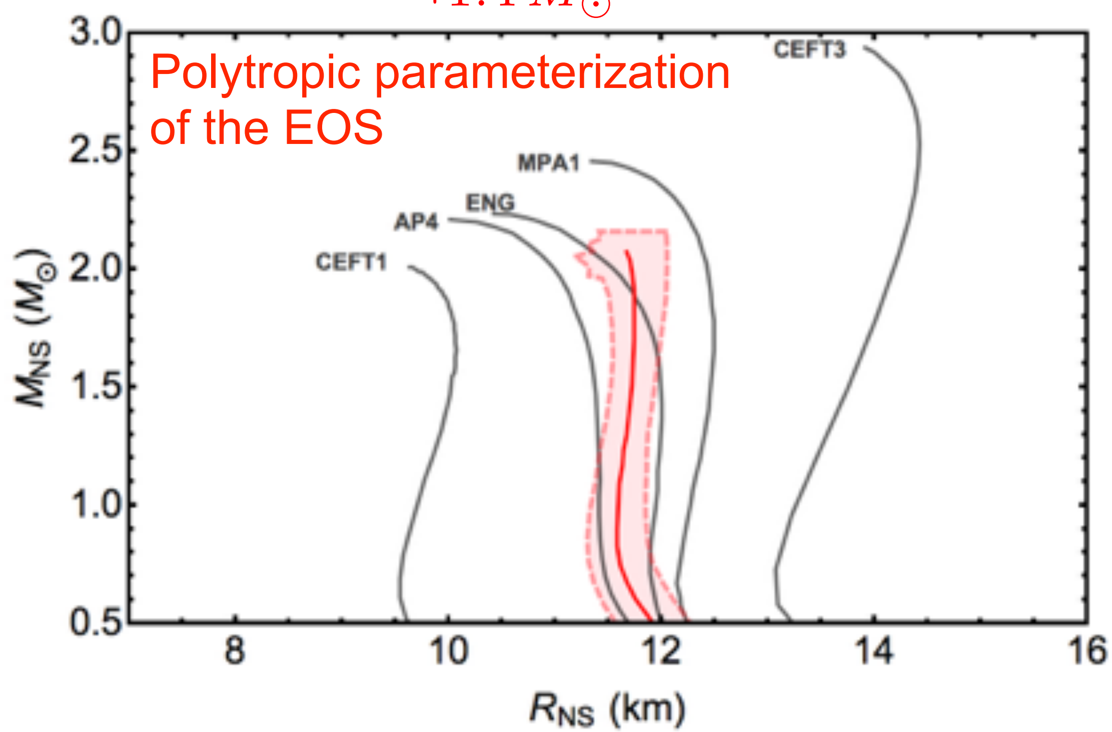
About 500 ks of qLMXBs observations with ATHENA will place constraints on the EoS.

Host Globular Cluster	qLMXB Flux (erg/cm²/sec)	Dist. (kpc)	Exposure time (ksec)
47 Tuc	5×10^{-13}	4.6	10
NGC 6397	9×10^{-14}	2.2	35
NGC 362	8×10^{-14}	8.6	50
M13	5×10^{-14}	7.1	65
OmCen	5×10^{-14}	4.6	75
M80	3×10^{-14}	10.0	95
NGC 6304	5×10^{-14}	6.2	115

TOTAL: 450 ksec

Combined analysis of 7 qLMXBs with exposure times sufficient to get 50000 counts for each source

$$\left.\frac{\Delta R_{\rm NS}}{R_{\rm NS}}\right|_{1.4\,M_\odot} = \pm 1.7\%$$



Some current limitations will be resolved by X-ray and multi-wavelengths observations.

- <u>Neutron star atmosphere</u>

  Identifying the lightest element in the system

- <u>M_{NS} - R_{NS} degeneracy</u>

  Measuring M_{NS} independently

- <u>Distance precision</u>

  Be patient and wait for GAIA's results

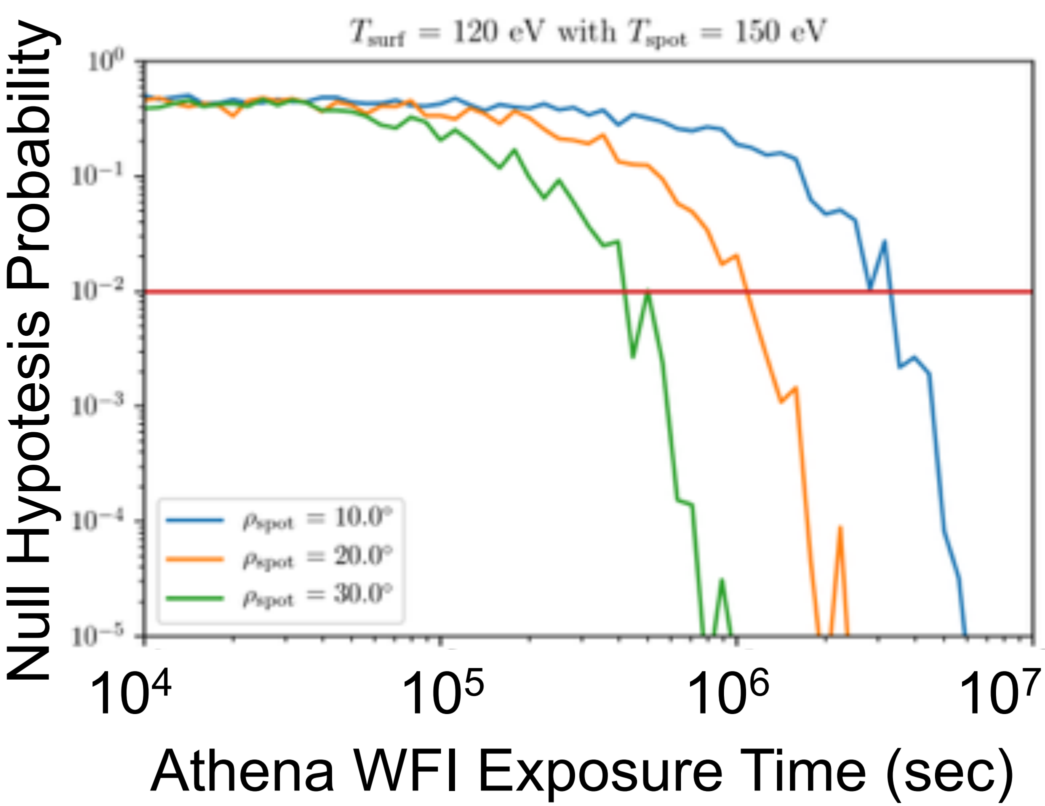
- <u>Presence of a hot-spot</u>

  Looking for pulsations, or evidence for two-Temperature spectrum

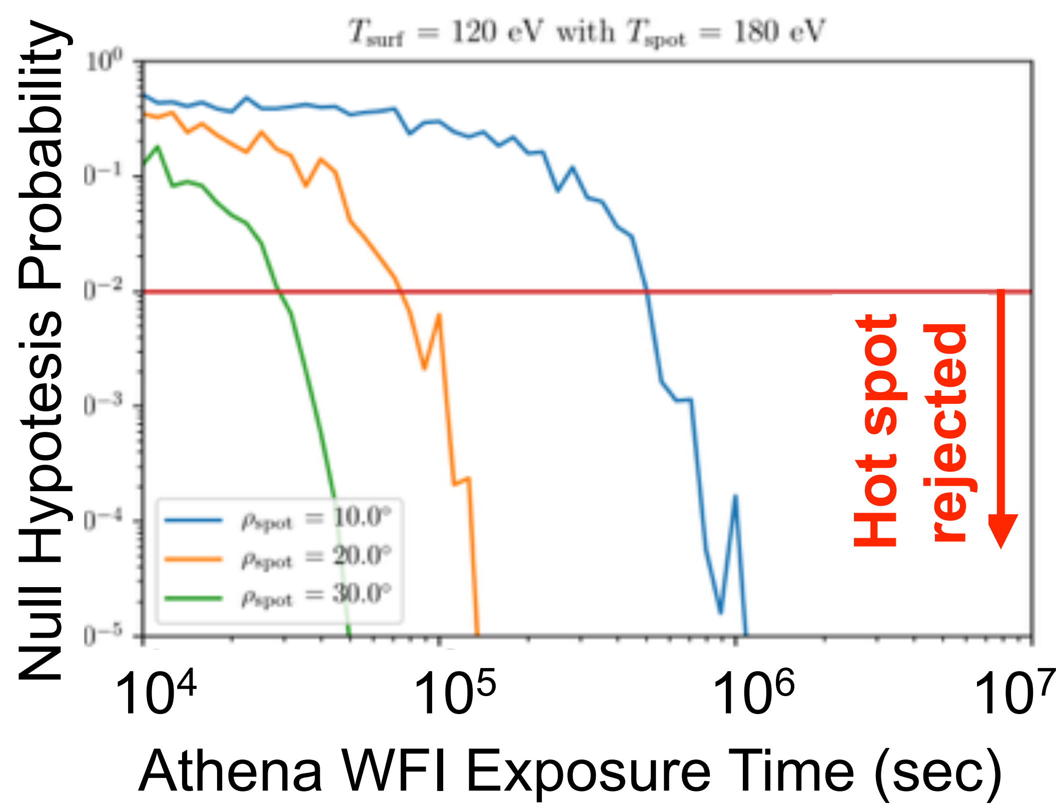
High Signal-to-Noise X-ray spectra can exclude the presence of a hot-spot.

Simulated neutron star surface with hot spot, but fitted with single temperature model

120 eV surface with 150 eV hot-spot



120 eV surface with 180 eV hot-spot

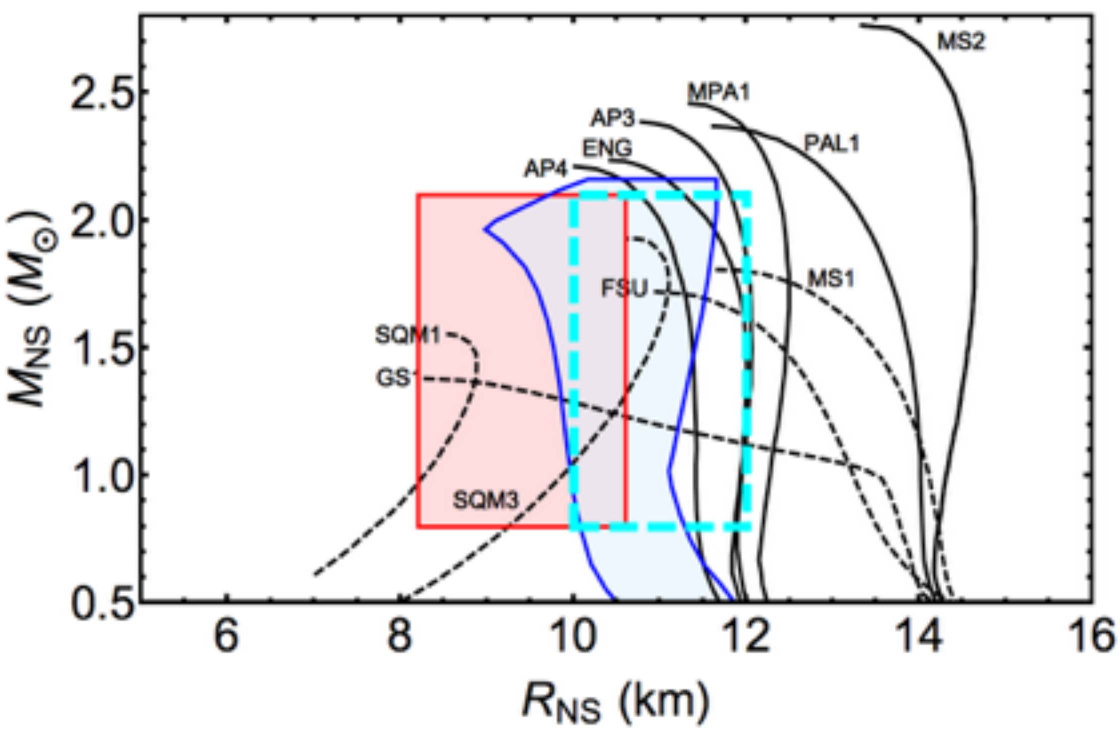


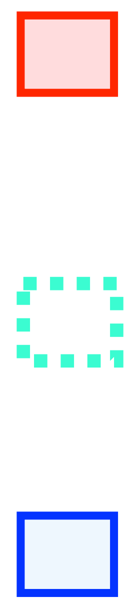
See Elshamouty et al. (2016) for bias on R_{NS} caused by hot spots

Summary

- Quiescent LMXBs offer one of the robust method to constrain the equation of state
- ATHENA can provide high S/N observations of qLMXBs to constrain the equation of state with high precision
- Synergy with other observatories will limit the effect of systematic uncertainties.
- We could probably use more than 500 ks

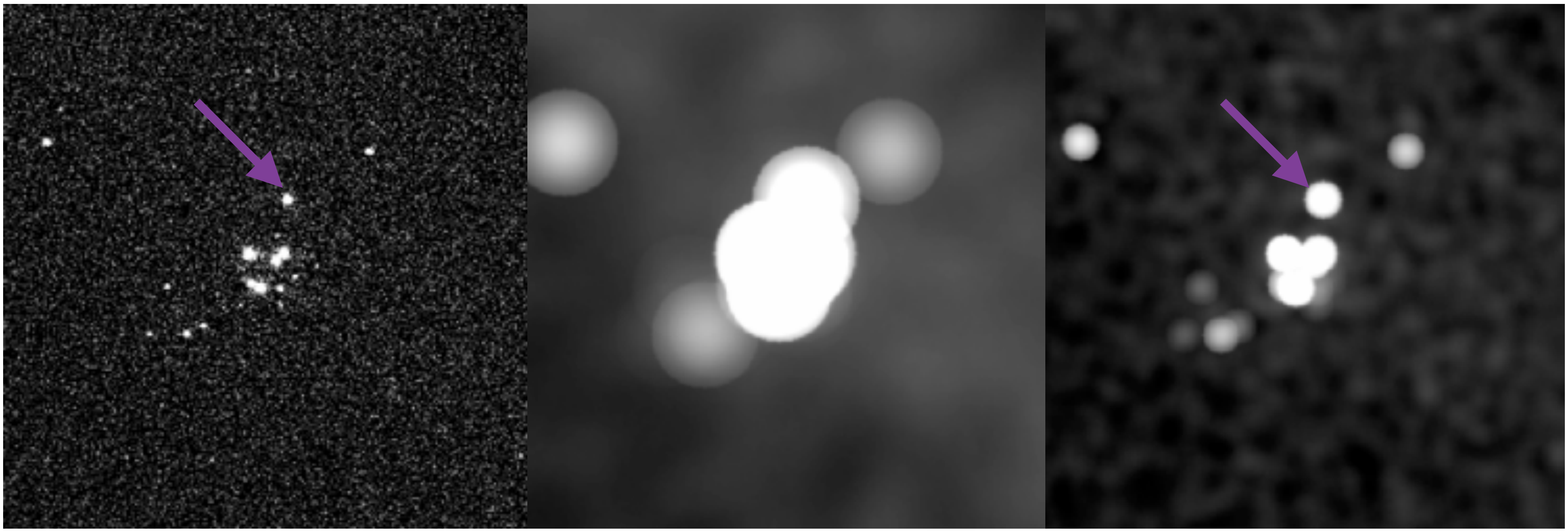
Combining observations into a statistical analysis provides more useful constraints.





See also the works of:

- Steiner et al. (2013)
- Lattimer & Steiner (2014)
- Baillot d'Etivaux et al. (in prep.)



Chandra XMM ATHENA