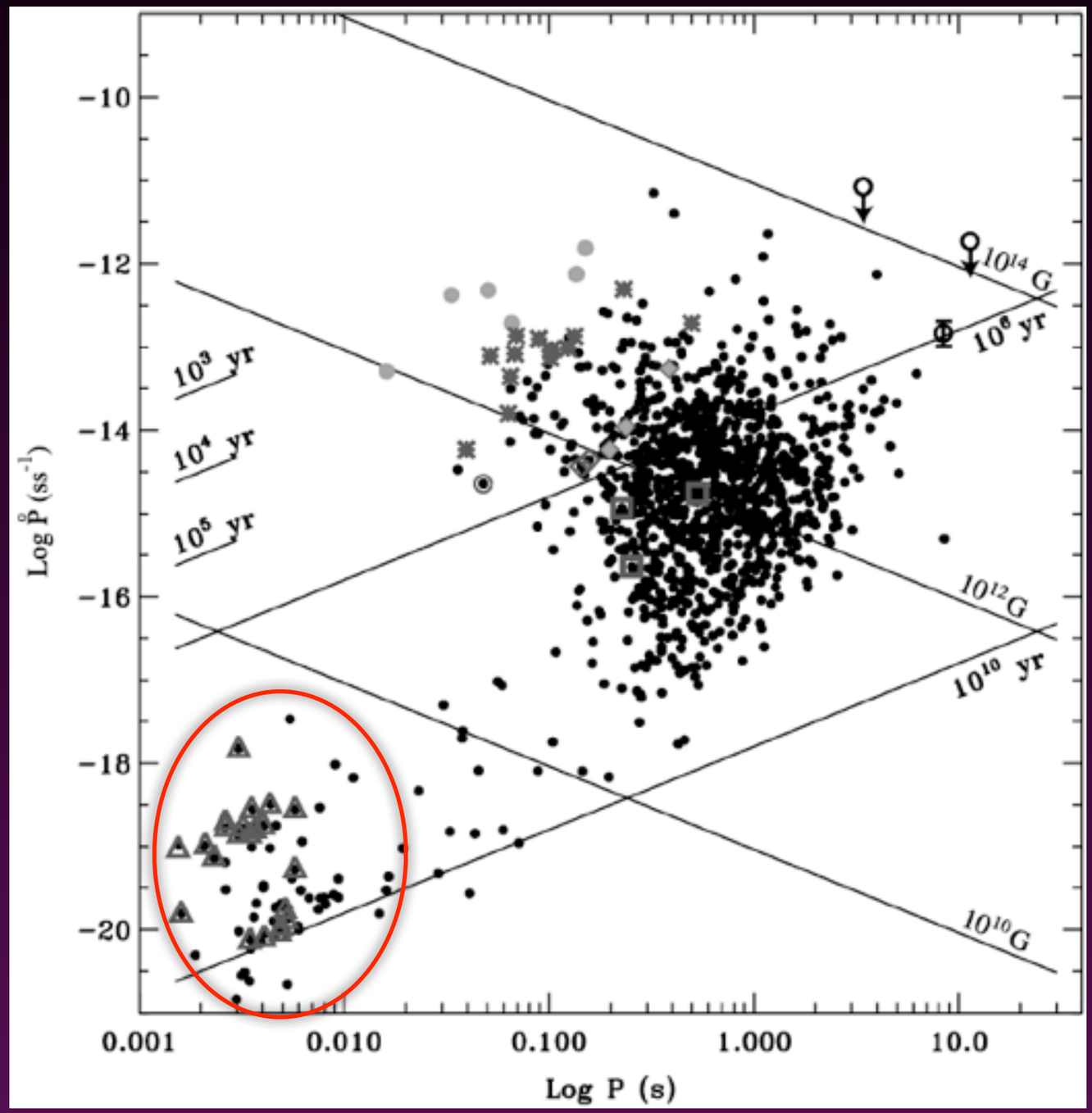
X-ray observations "radio-quiet" black widow-type millisecond pulsars

Albert Kong
Institute of Astronomy
National Tsing Hua University, Taiwan

Phyllis Yen
On behalf of the Fermi Asian Network (FAN)

Millisecond Pulsars (MSPs)

- Very rapid rotating neutron star
- Majority are in binaries
- MSP begins its life as a normal pulsar and is spun up via accretion from its companion
- MSPs are detected in the radio, X-ray, gamma-ray, and OIR



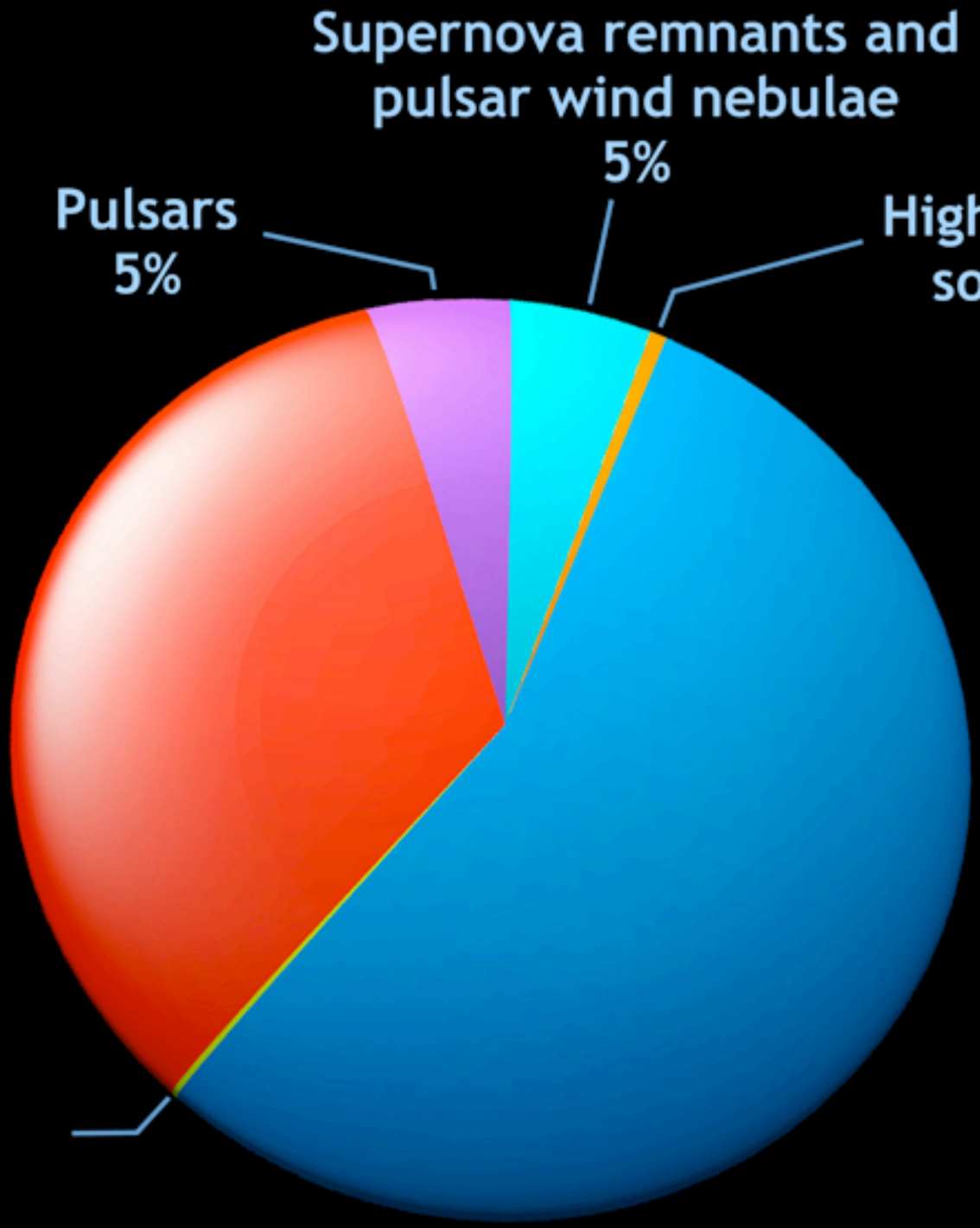
Black Widow-type MSPs

- Some MSP binaries have an orbital period of < 1day
- Pulsar radiation can ablate the companion, leaving an isolated MSPs (black-widow/redback systems)
- Companion can either be a late-type star (redback) or a degenerate object (black-widow)
- BW/RB MSPs are the missing link between LMXBs and isolated MSPs
- Because of the pulsar heating effect on the companion, the optical emission from the companion can be changed by more than 2 magnitudes in an orbital cycle

How can we search for BW/RB MSPs?

- Traditionally, MSPs are discovered via radio timing
- Radio timing at the Fermi positions
- Blind search of gamma-ray pulsation is now possible with Fermi; it is however very hard for MSPs (Pletsch+ 2012, Science) and optical data are required
- MSPs can be ``radio-quiet'' that have not been seen yet
- No radio => Need X-ray/gamma-ray data
- Too many X-ray sources and many different classes of sources
- Gamma-ray data are more ``simple''

Fermi reveals the universe above 10 GeV

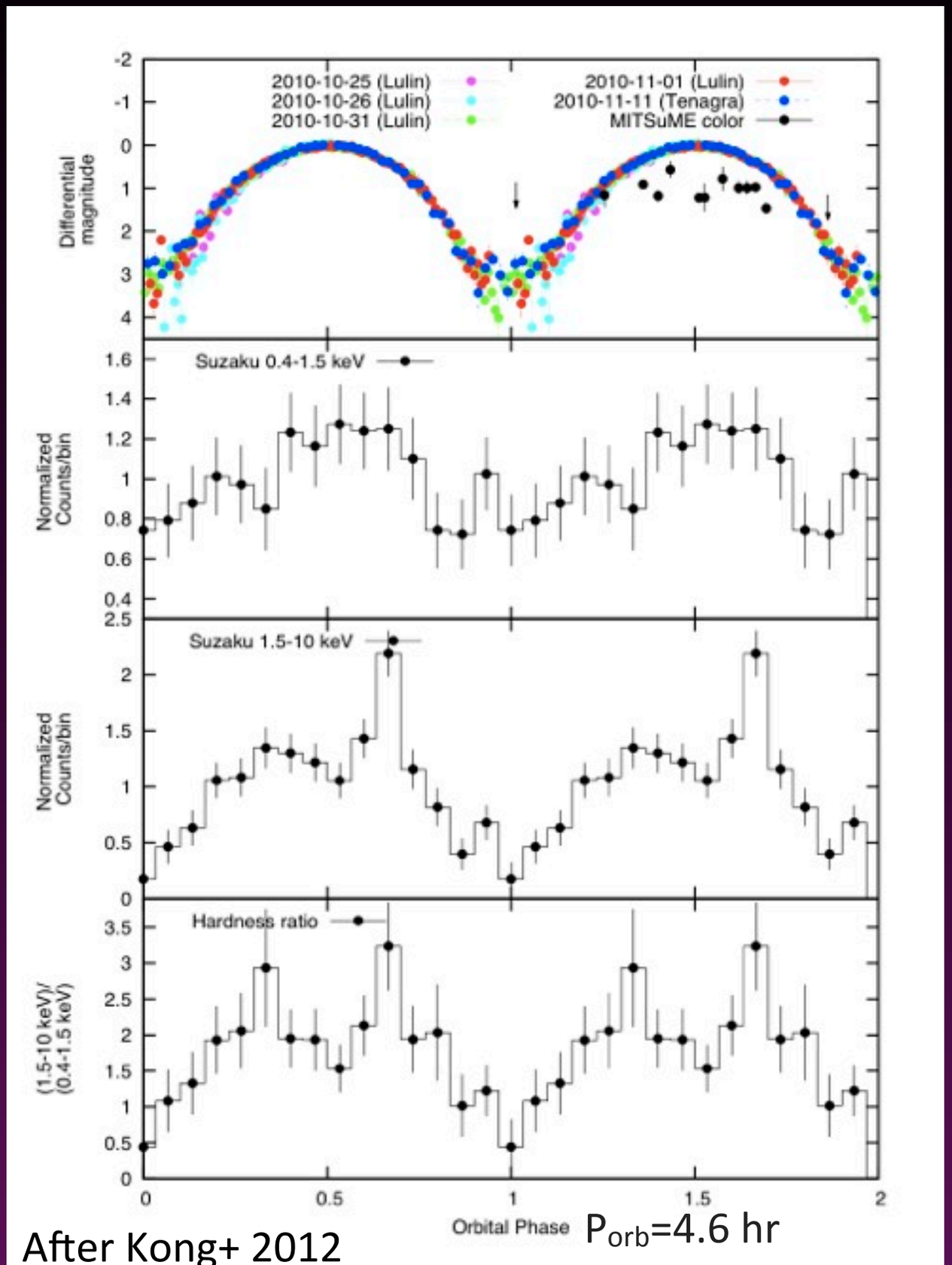


Credit: NASA/Goddard Space Flight Center

Multi-wavelength campaign for searching “radio-quiet” MSPs

- Select suitable unidentified Fermi objects (UFOs) for follow-up X-ray and optical observations
- Swift/Chandra/XMM observations can identify possible counterparts; no radio counterparts
- Identify the optical counterpart and look for optical variability due to the orbital modulation
- In principle, a blind search in optical data is also possible (but can be very time consuming), and data are contaminated by other variable stars.

Optical/X-ray Observations



After Kong+ 2012

Optical observations

100ks Suzaku observation

- Hard X-rays show obvious modulation on the orbital period
- Soft X-rays remain stable
- Spectral variability (phase resolved spectroscopy)
- A double-peak structure is evident

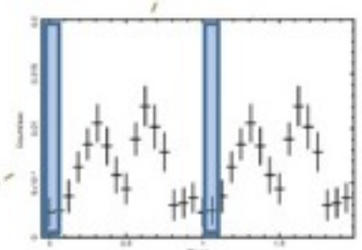
P_{orb}=4.6 hr

Hard X-rays from the shock

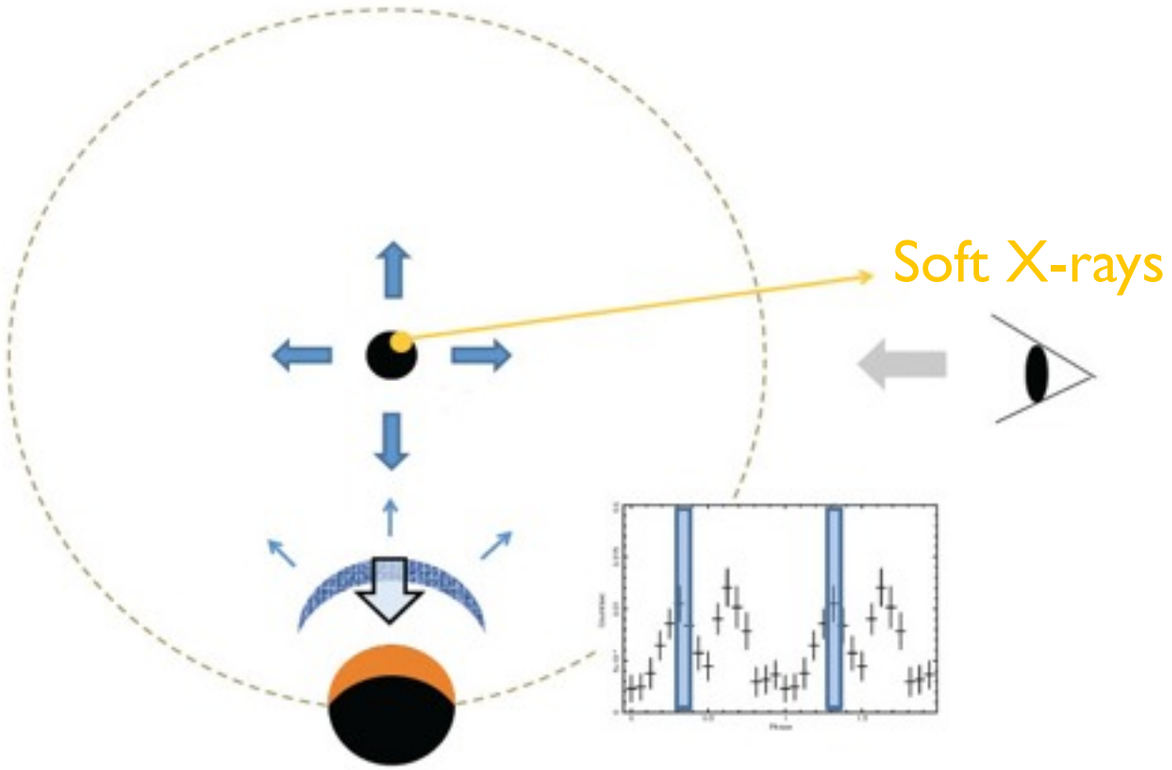
MSP

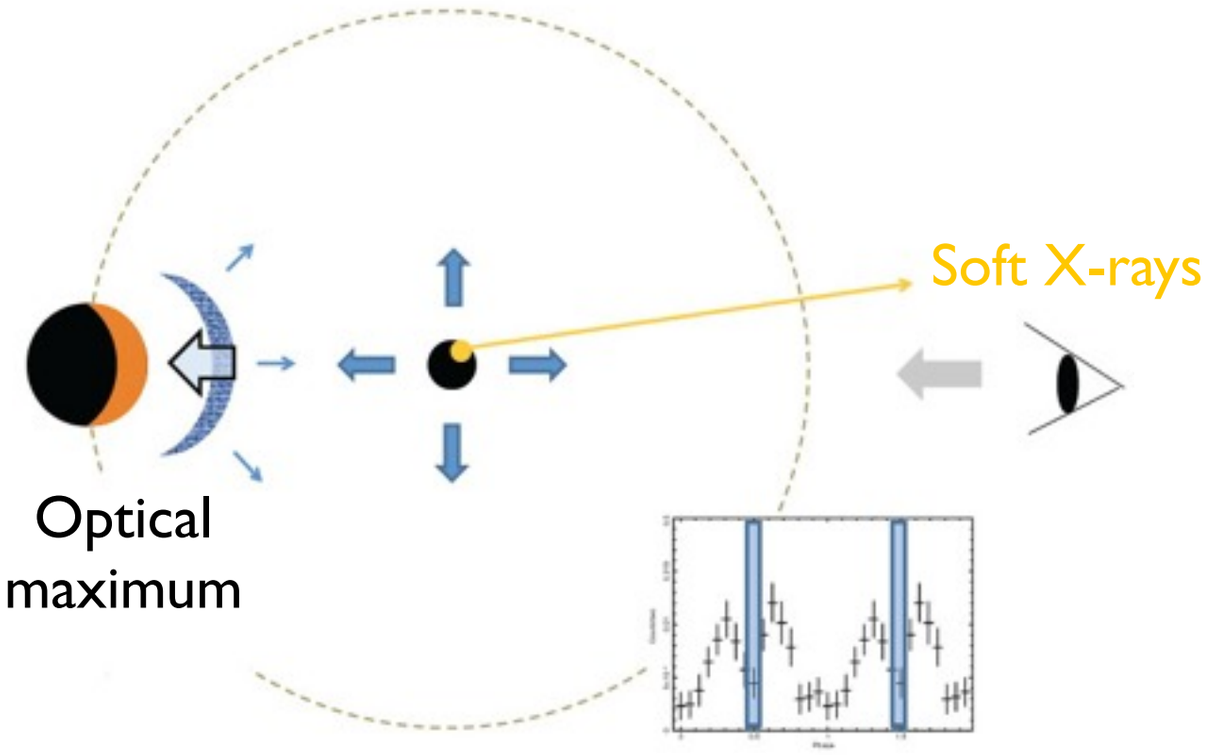
Soft X-rays

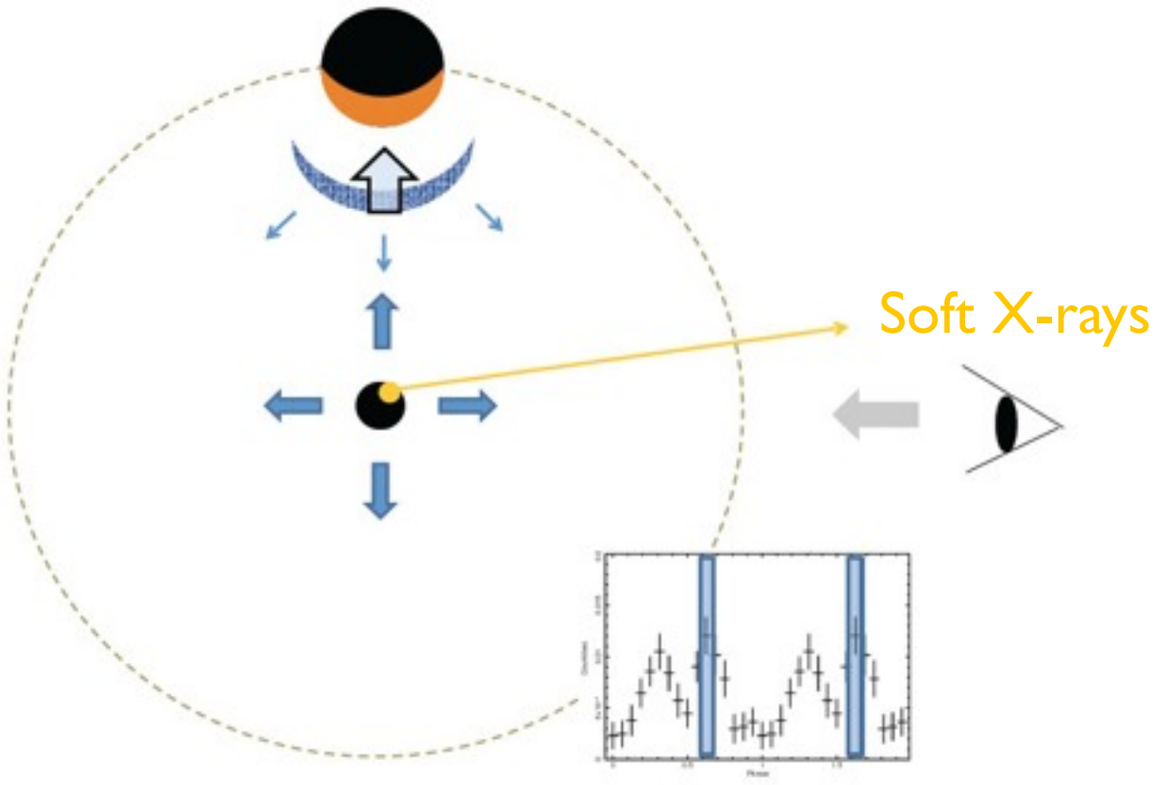
Pulsar wind



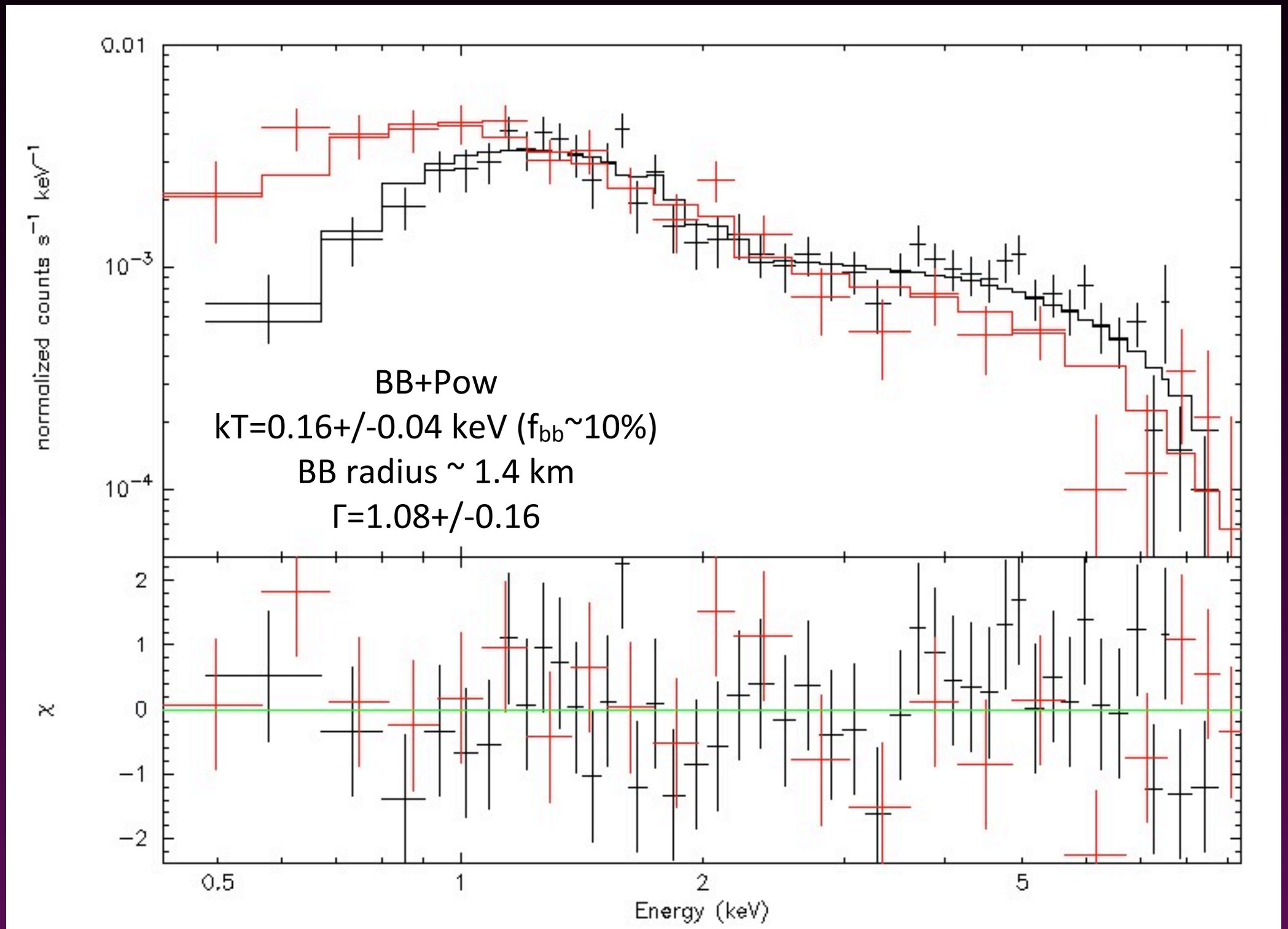
Suzaku 2-4 keV lightcurve



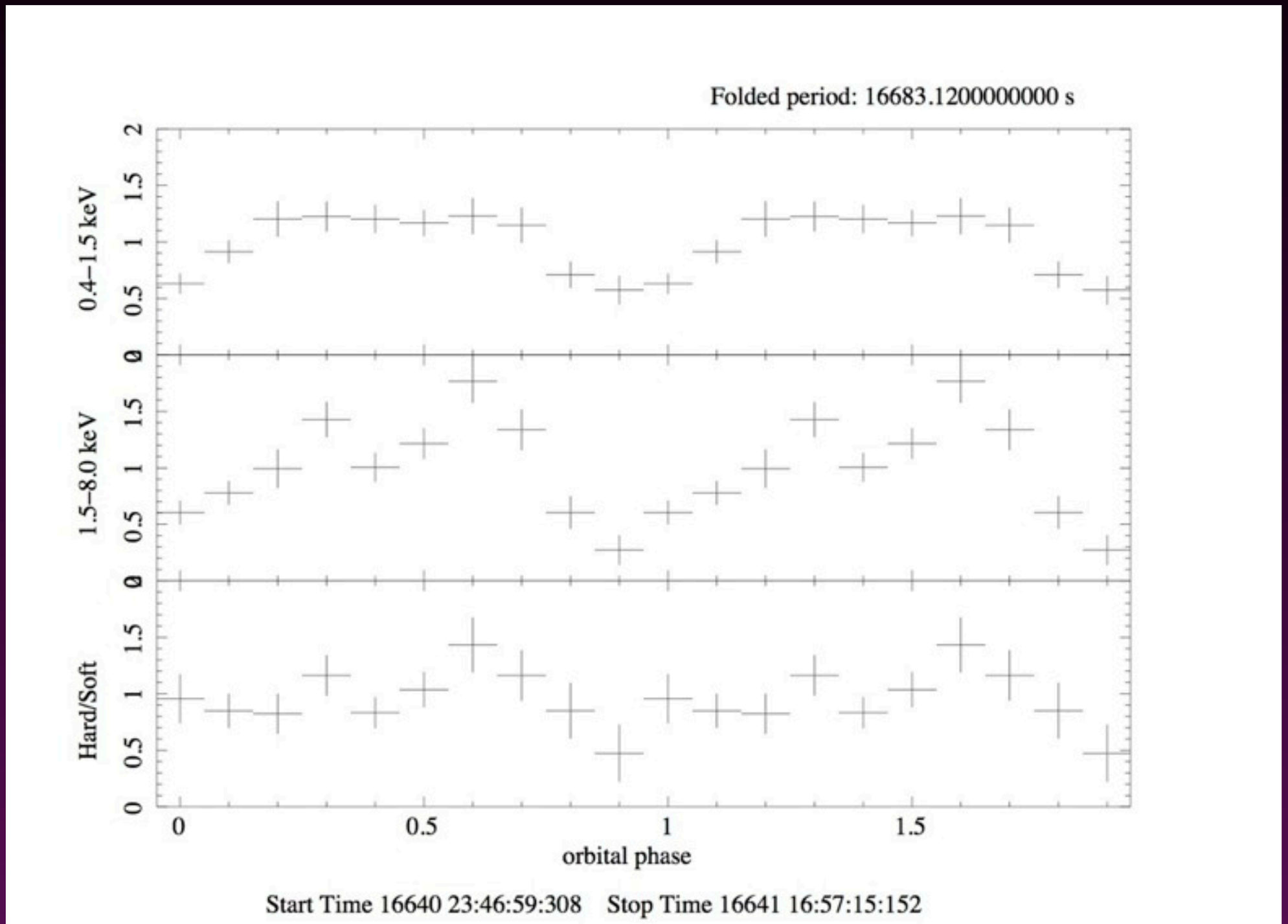




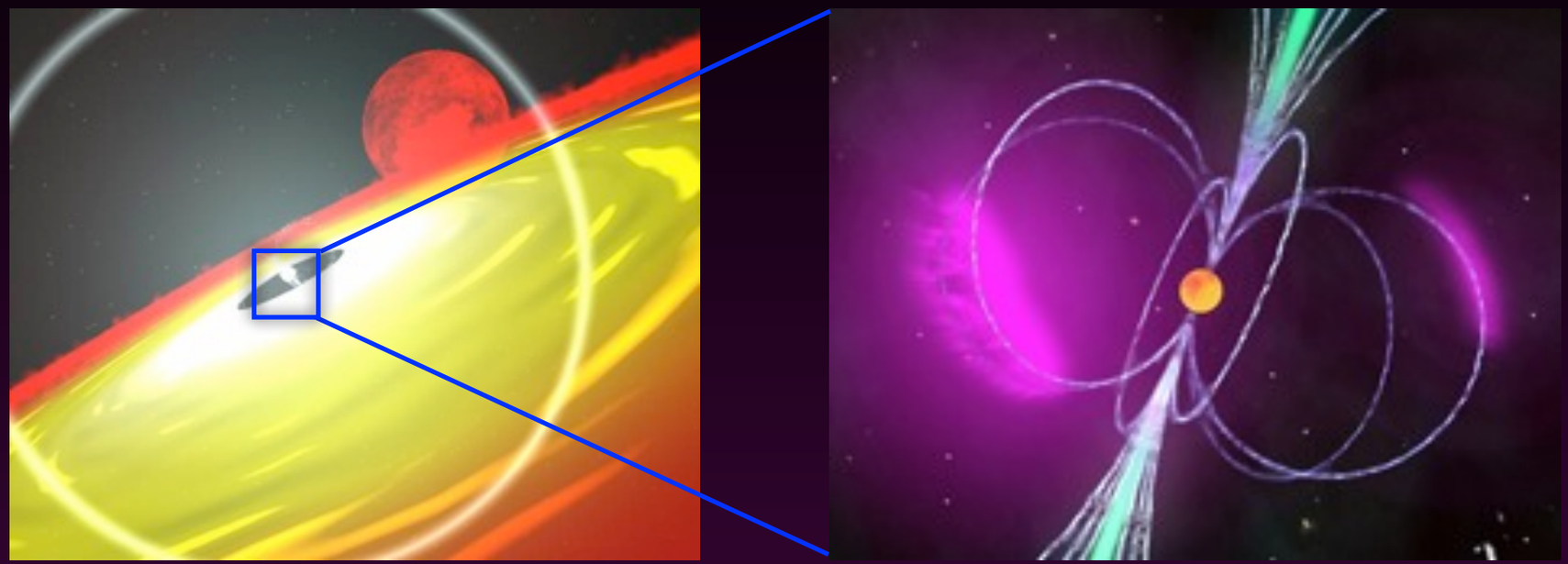
Energy Spectrum



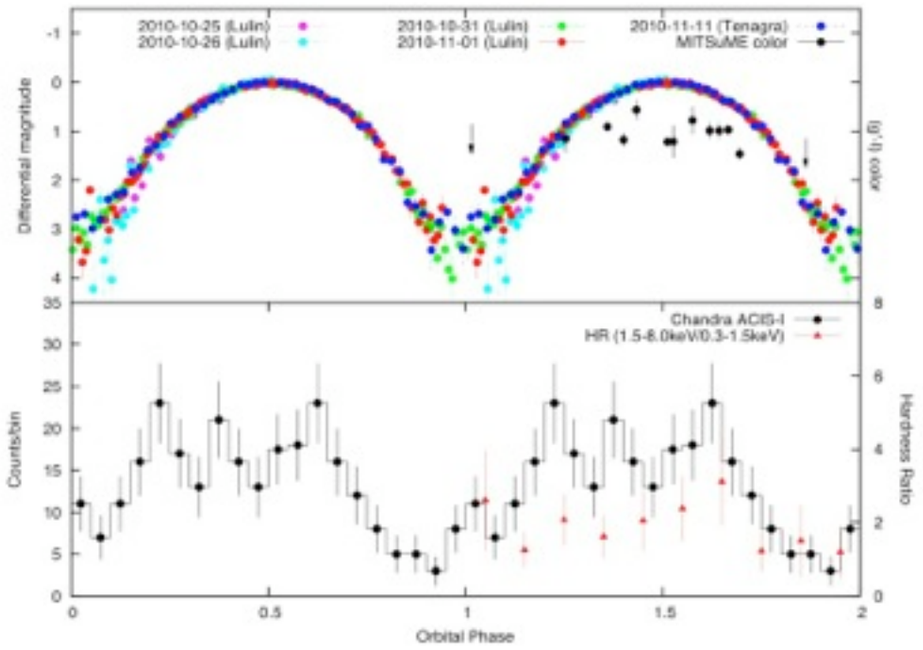
Orbital Period Folded Lightcurve by XMM



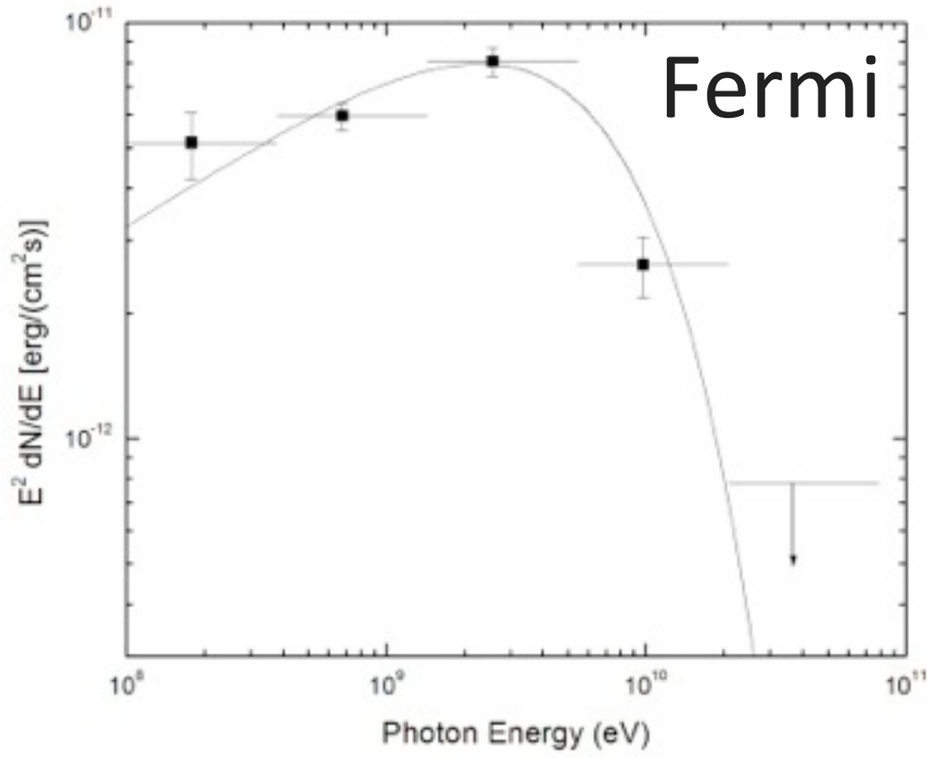
UFO as a ``radio-quiet'' gamma-ray emitting MSP in a binary?



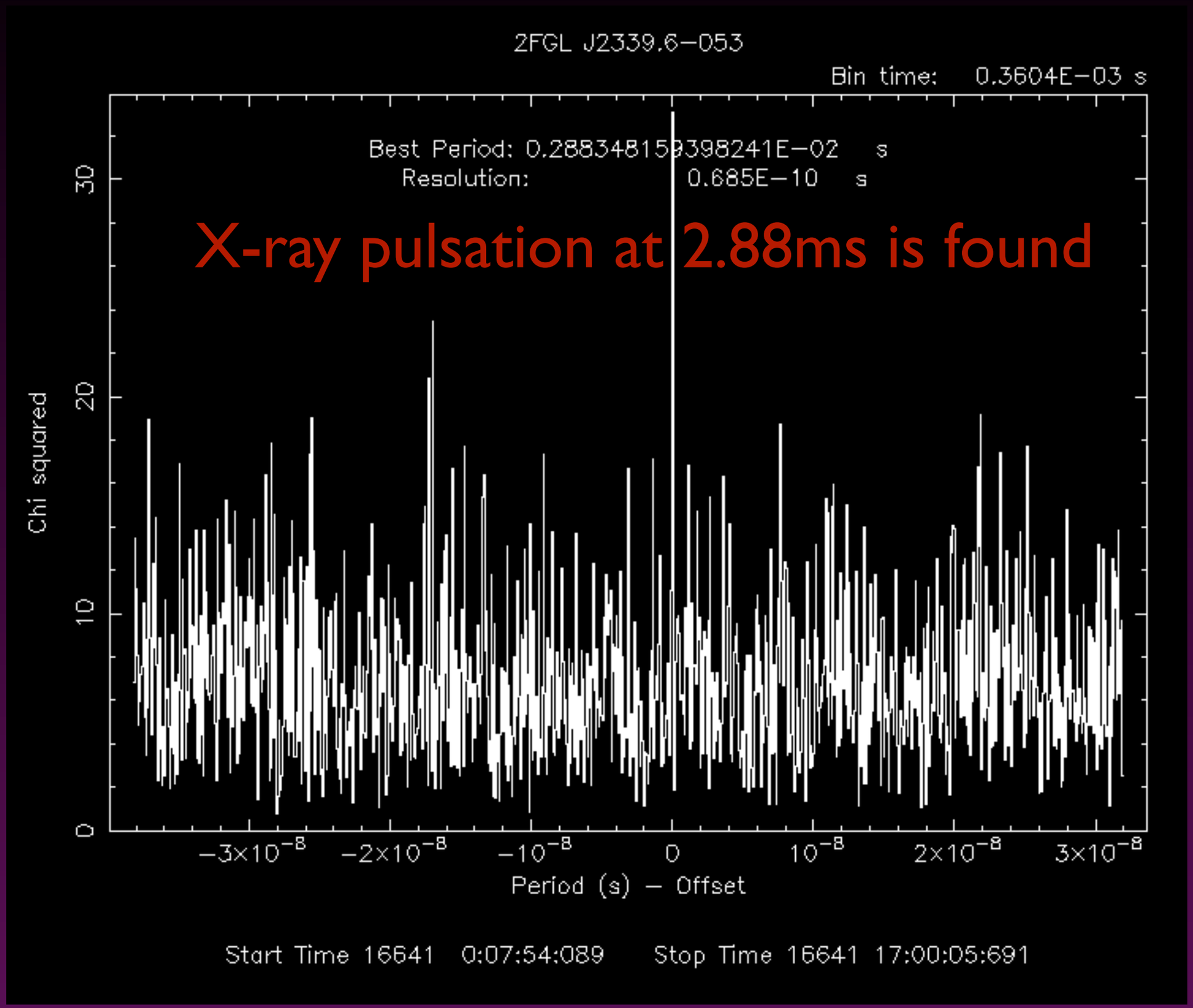
Optical/X-ray @4.6hr



Kong+ 2012



XMM 60ks Timing Observations



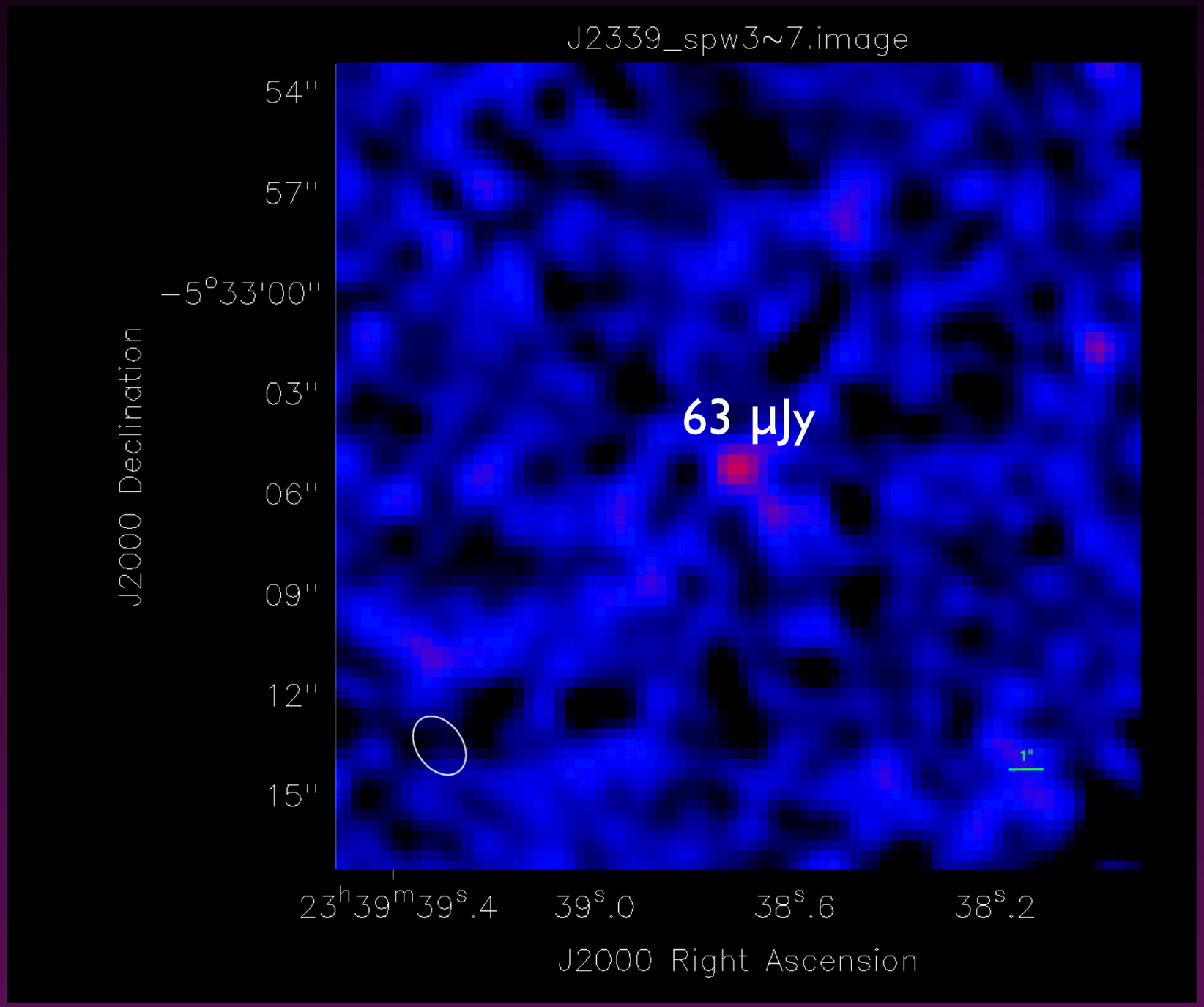
UFO as a ``radio-quiet'' gamma-ray emitting MSP in a binary?

Radio and gamma-ray pulsation at 2.88ms was finally found (Ray et al., in prep.)
About the same time, we confirm the radio source with JVLA at 2.6GHz

=> Still no ``radio-quiet'' MSP

Radio pulsation search can be tricky (Ray+ 2012) and continuum observation can help understanding the vicinity of BW/RB MSPs

JVLA Continuum Observation of the BW MSP 1FGL J2339.7-0531



Searching for ``radio-quiet'' MSPs are ongoing

- Follow-up optical observations are being carried out for a few other UFOs
  - 1FGL J0523.5-2529 (Strader+ 2014); a 16.5-hr orbital period
  - X-ray and optical modulations on timescales of 1-2 hours have been found for some sources within the error circles of UFOs. **Ultracompact MSPs?**
- Blind search in optical data is being studied via the Palomar Transient Factory (PTF)

Multi-wavelength Synergy

- Radio and gamma-ray timing are still the most efficient way to search for BW/RB MSPs
- Gamma-ray data with X-ray/optical identification will play a key role when radio pulsation search fails (Kong+ 2012 and Romani+ 2012). X-ray pulsation search is also feasible
- Orbital modulation from optical/X-ray data are critical for searching radio/gamma-ray pulsation (Pletsch+ 2012)
- Radio continuum observations will allow us to study the scattering/absorption effects of the systems