Astrosat and Neutron Stars

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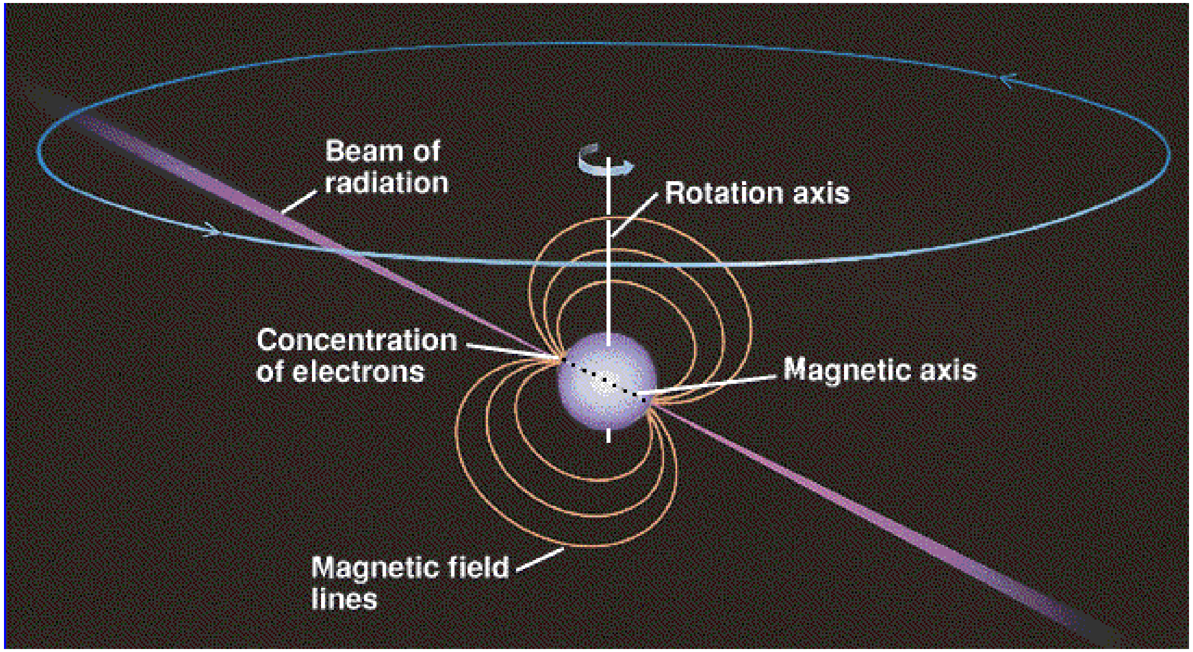
Neutron Stars as Physics Laboratories

- **superb clock-like properties** → superb laboratories for studying General Relativity
  - 1993 Nobel Prize in Physics to Hulse & Taylor
- **density at centre higher than in nucleus** → superb laboratory for studying nature of matter at high density
- **highest magnetic fields known in Universe** → superb laboratories for studying Feynman's QED: "magnetars"
- **Combination of properties** → amazing, deceptively simple electrodynamics puzzle

Astrosat Neutron Star Targets will be **Pulsars**

- rapidly rotating,highly magnetized neutron stars



Pulses because of misalignment of rotation and dipole axes.

Main Interesting Pulsar Questions Astrosat can Tackle

- **3 Main Categories:**
  - **ROTATION-POWERED PULSARS**
  - **MAGNETISM-POWERED PULSARS aka “*MAGNETARS*”**
  - X **ACCRETION-POWERED PULSARS**
- Another possible category:
  - “Isolated Neutron Stars” but unclear these are not one of the first 2 above…

Note: vast majority of these objects are too absorbed/faint for UVIT…

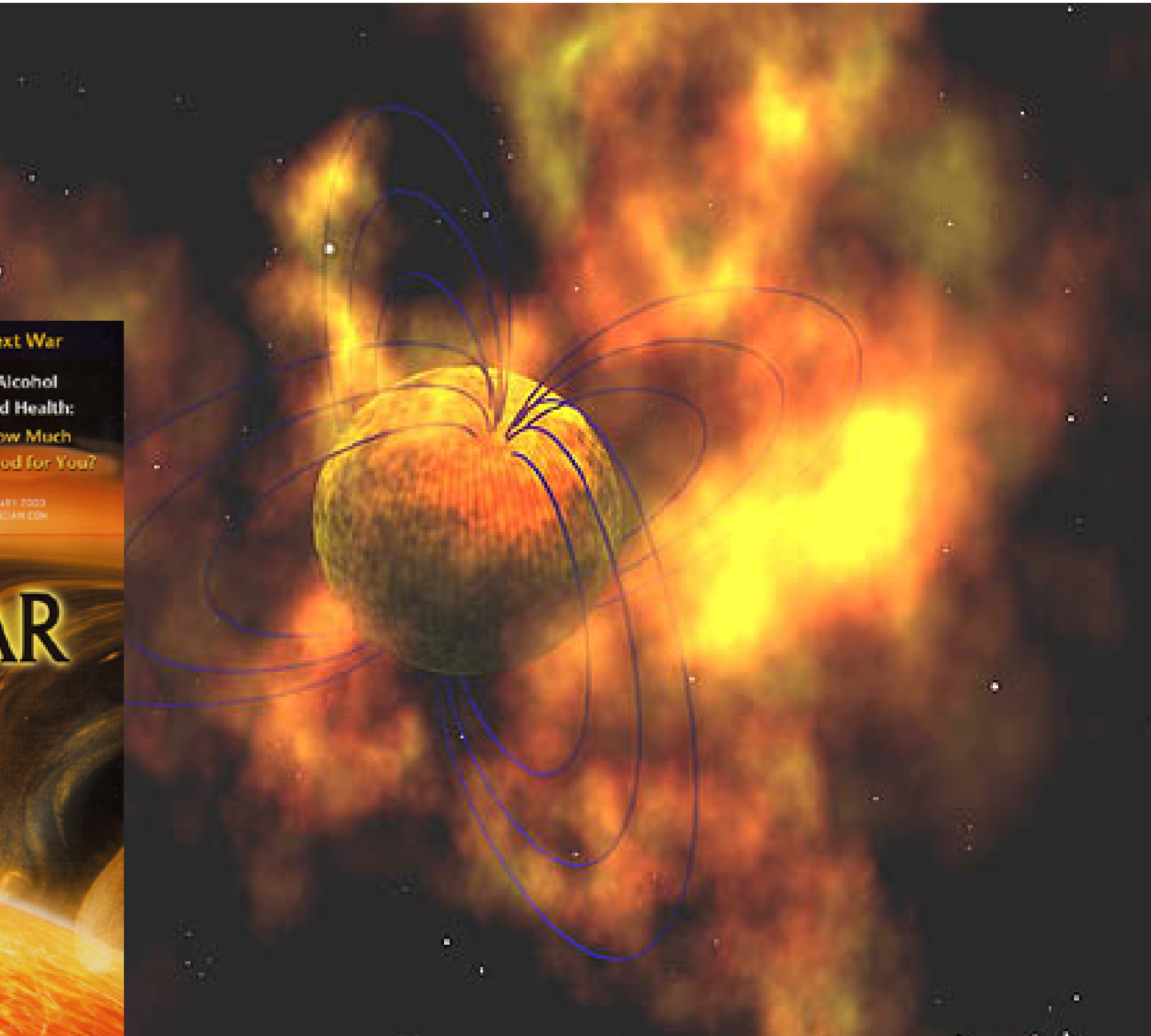
Rotation-Powered Pulsars

- **Basic electrodynamics problem: how and where does a rotating magnet produce pulsed radiation? Polar cap? Outer gap? Combo?**
  - Tackle via X-ray detections of radio pulsars
    - spectra, pulse morphologies, radio/X-ray pulse phases
    - much work done by ROSAT, ASCA, RXTE, CXO, XMM
    - But new sources being found: e.g. Arecibo “ALFA” survey, Green Bank Telescope surveys, GMRT surveys(?)
    - Astrosat could be well placed to do X-ray follow-up work on newly detected energetic radio pulsars
  - Tackle via Gamma-ray detections of radio pulsars w/GLAST
    - Astrosat could do contemporaneous X-ray timing of potential GLAST targets to provide pulse ephmerides, necessary to detect gamma-ray pulsations.

Rotation-Powered Pulsars Continued…

- **What is the origin of deviations from simple spin down, i.e. "glitches" and "timing noise" and how do these relate to neutron star structure?**
  - Tackle via long-term, regular (e.g. bi-monthly) phase-coherent X-ray timing of pulsars
    - Pulsar braking indexes: basic parameters of their spin-down, well predicted by theoretical models
    - Glitches: sudden spin-ups of the pulsar, indicative of internal superfluid properties
    - Timing noise: random deviations from spin down, unknown origin, common in younger pulsars (and reason GLAST requires contemporaneous ephemerides for gamma-ray pulsation detection)

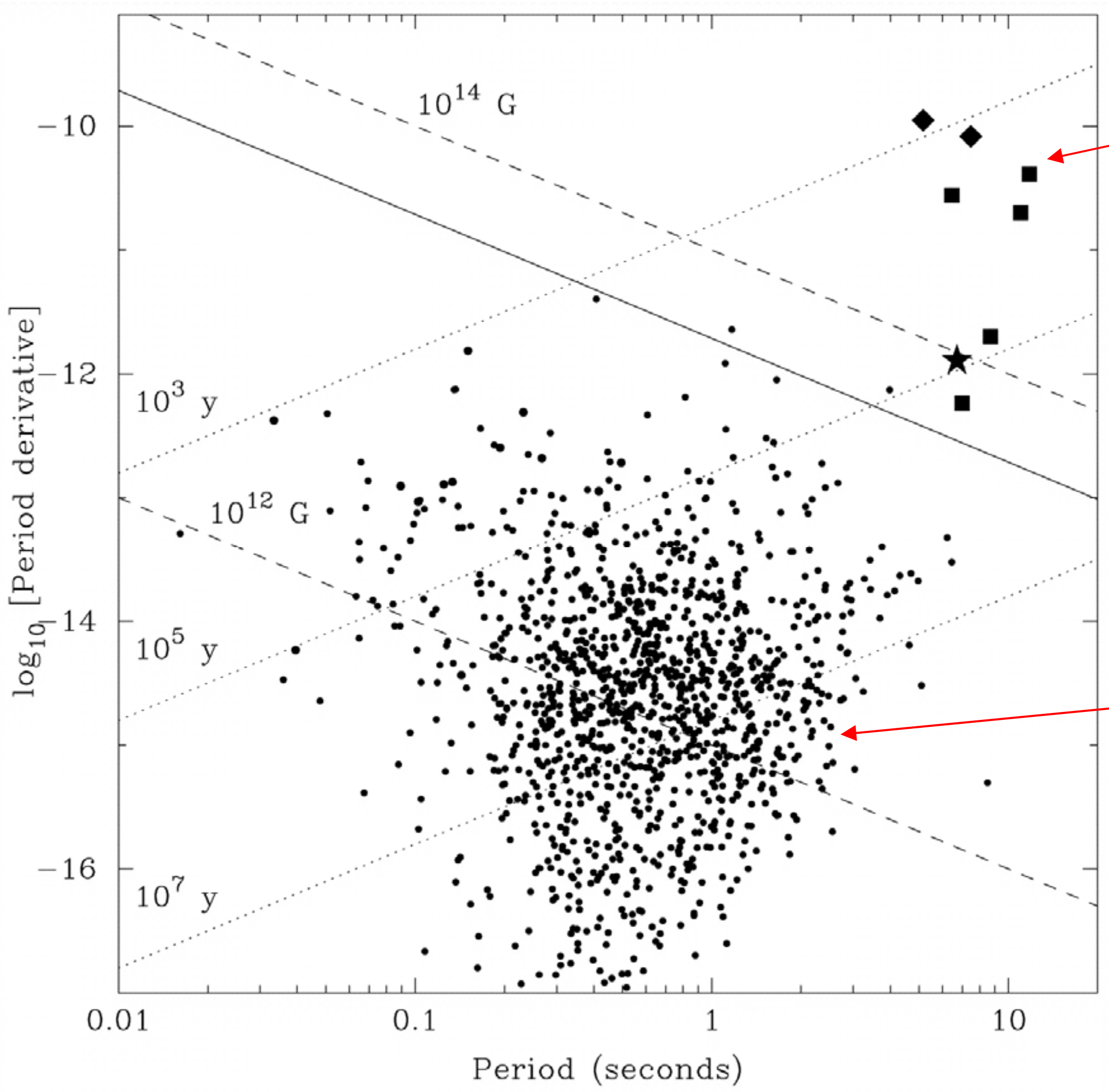
Magnetar: artist's depiction



Magnetars

- Isolated, young, ultrahighly magnetized neutron stars powered by the decay of their enormous internal magnetic field
- Only ~12 known, two “flavours”
  - Soft Gamma Repeaters
  - Anomalous X-ray Pulsars
- Just over ½ are persistent X-ray and hard X-ray sources
- Rest are transient w/recurrence times many years
  - Transient X-ray pulsations
  - X-ray/soft gamma ray bursts
- Thought to be large as yet unseen population in Galaxy; how large is unknown

P-Pdot Diagram



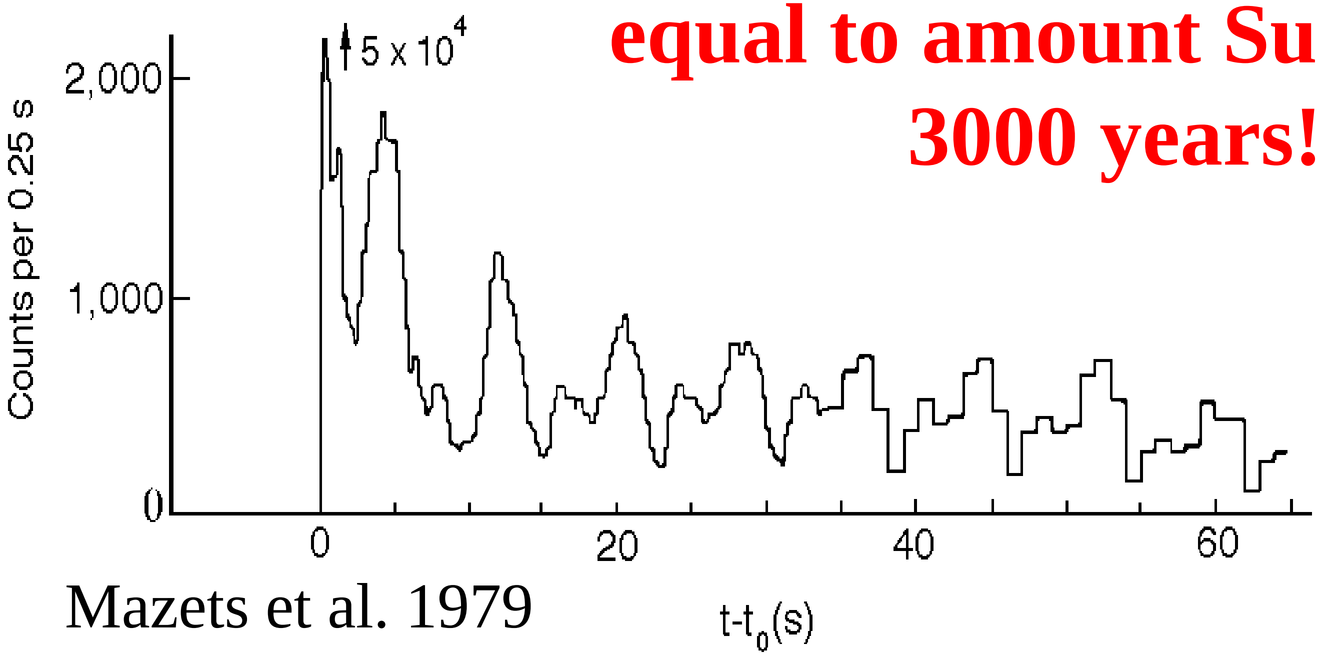
Magnetars

$$B = 3.2 \times 10^{19} \sqrt{\dot{P}P} G$$

main radio pulsar population

March 5, 1979: SGR 0526-66

total energy released in 1 minute equal to amount Sun releases in 3000 years!

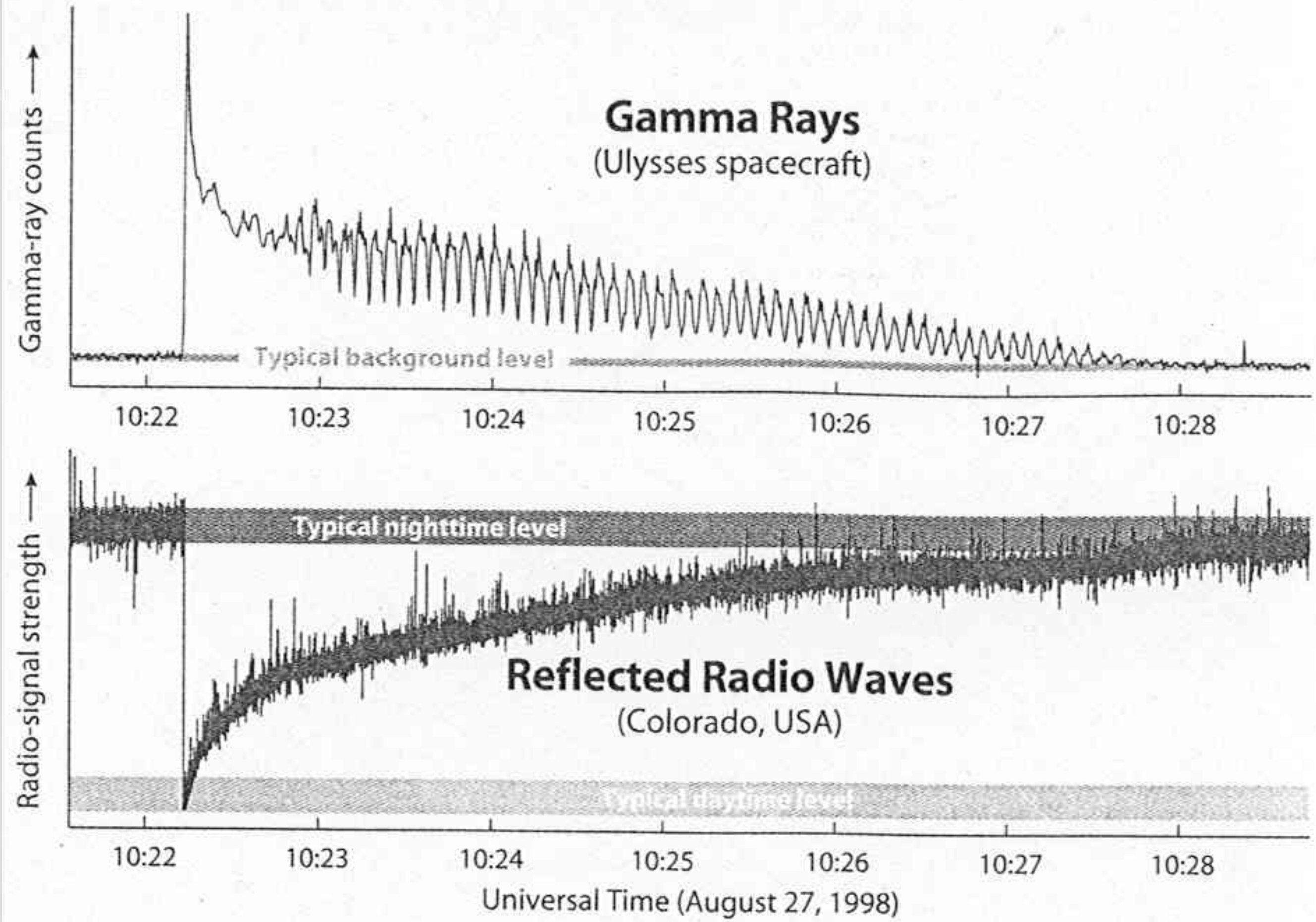


gamma rays

Mazets et al. 1979

From supernova remnant N49 in LMC

August 17, 1998: SGR 1900+14



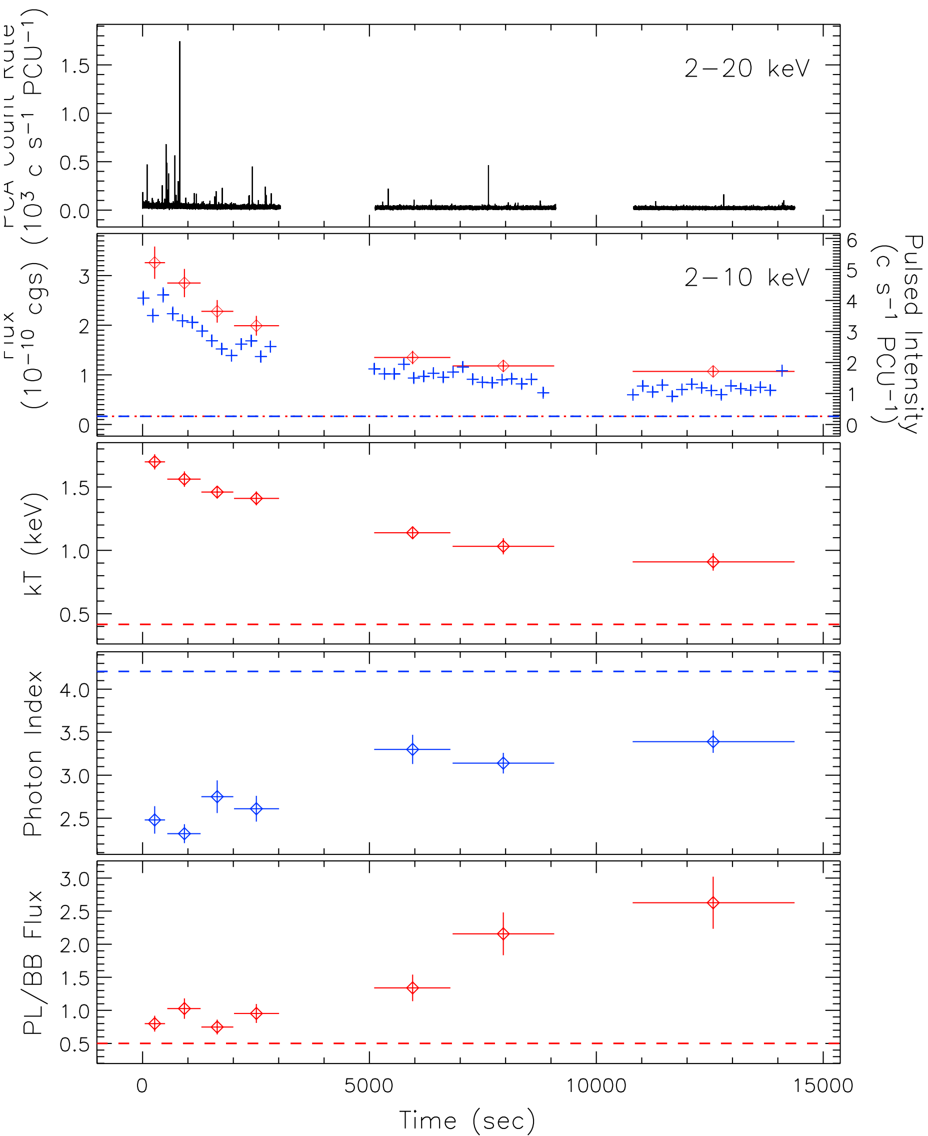
Blast from the past. High-energy photons erupted from a neutron star in Aquila roughly 20,000 years ago, only to smash into Earth last August. They then bloated our ionosphere, temporarily weakening radio transmissions that travel from Hawaii to Colorado and are reflected by the ionosphere en route. Courtesy Michael Johnson, Stanford University.

A Major Outburst from 1E 2259+586

- pulsed, persistent flux increased during outburst; decreased with the burst rate
- spectral evolution
- also rotation glitch
  - first pulsar “glitch” associated with any radiative event

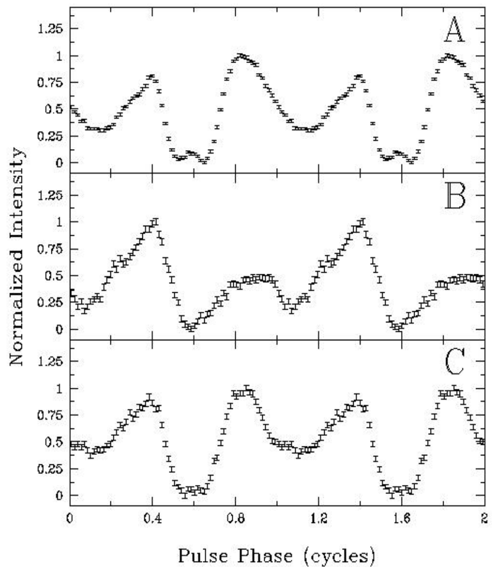
WORK DONE BY RXTE/PCA

Kaspi et al. 2003, Woods et al 2004

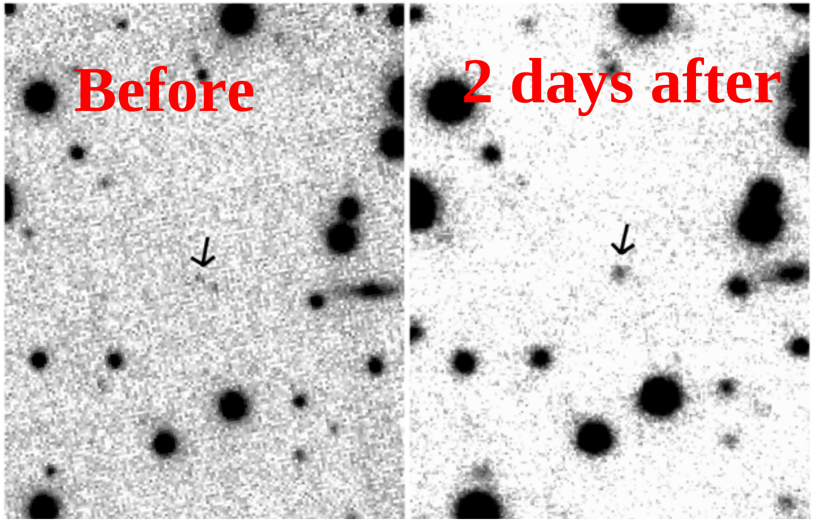


A Major Outburst from 1E 2259+586

- significant RXTE/PCA pulse profile change during the outburst, relaxed back in ~6 days



- brightening of its IR counterpart by factor of 2, two days after the burst, using Gemini North and NIRI



Magnetars

- **How many magnetars are there in the Galaxy and do they represent a significant fraction of the neutron star population?**
  - Tackle via Galactic Plane monitoring program with Astrosat, looking for magnetars in outburst
  - Tackle via careful long-term monitoring of transient magnetars to better constrain duty cycle, physical reasons for outburst

How Many Magnetars in Milky Way?

- past studies of SGR bursts suggested 10 active magnetars (Kouveliotou et al. 1993)
- AXPs double this
- **AXP transients suggest many more…**
- Cappellaro et al 1997: Galactic core-collapse SNe every 50-125 yr
- Lyne et al. 1998: radio pulsar born every 60-330 yr
- **if magnetar, radio pulsar birth rates comparable, and if magnetars “live” 10 kyr, could be >150 in Galaxy**
- Sources of some short-duration gamma ray bursts?

Magnetars

- **What is the origin of deviations from simple spin down, i.e. "glitches" and "timing noise" and how do these relate to magnetar external and internal structure?**
  - Tackle via long-term, regular phase-coherent X-ray timing of persistent magnetars (see Kaspi 2007 for review)
    - Glitches: 3 observed thus far in magnetars seem different from those in radio pulsars: large, slow glitch recoveries
    - Timing noise: generally but not universally larger than in radio pulsars, possible correlations with flux, spectrum, infrared brightness, bursting properties. (Reason why contemporaneous timing ephemeris needed for INTEGRAL detections…maybe GLAST too??)

Magnetars

- **What is the origin of the X-ray and surprising hard X-ray emission (e.g. Kuiper et al. 2006) seen in magnetars?**
  - Tackle via monitoring in softer and harder bands; Astrosat/LAXPC larger effective area in hard X-rays (>15 keV) compared w/PCA useful here!
    - Measure pulsed flux in both bands
    - Does hard band follow variations in soft band?

Isolated Neutron Stars

- Isolated, very nearby (< 1kpc) neutron stars, seen in X-rays and optically only thus far
- Only ~7 known
- 3-4 are pulsars; have few-second periods
- Could be “quiescent” magnetars
- Could be off-beam radio pulsars
- Could be UVIT targets, but tough: Mv >25 mag; needs investigation; spectral point in UV could help clarify origin of the optical and X-ray spectra
- See reviews by Kaspi, Roberts & Harding (2006),

Popov & Turolla (2003)

Conclusions

- For Astrosat, LAXPC (maybe SSM), not UVIT, will be the neutron-star workhorses
- Much interesting science to be tackled!
- Potential UVIT target: "isolated neutron stars" but would require very long integration times, and unclear whether useful outcome. TBI.