RXTE Observations of the Vela Pulsar: The Pulsar Rosetta Stone

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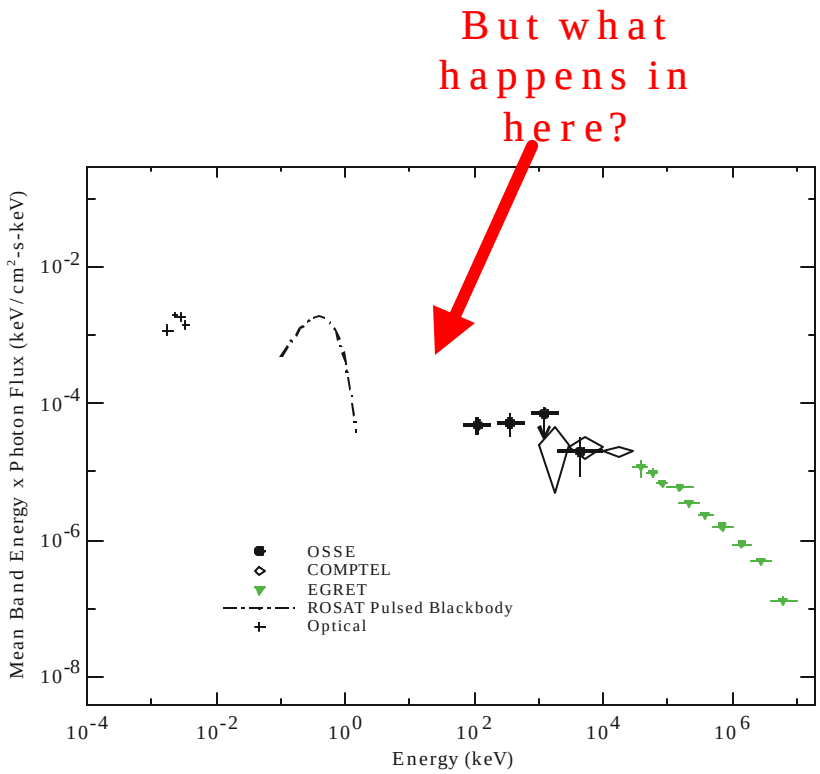
PSR B0833-45: The Vela Pulsar

- ***Brightest celestial g-ray source but difficult X-ray object***
  - Faint
  - Embedded in bright pulsar wind nebula
- ***First X-ray observation by ROSAT***
  - Pulsed spectrum described by black body
  - "Point source" spectrum described by black body or power law
  - Pulsed fraction ~11% (<1.2 keV)

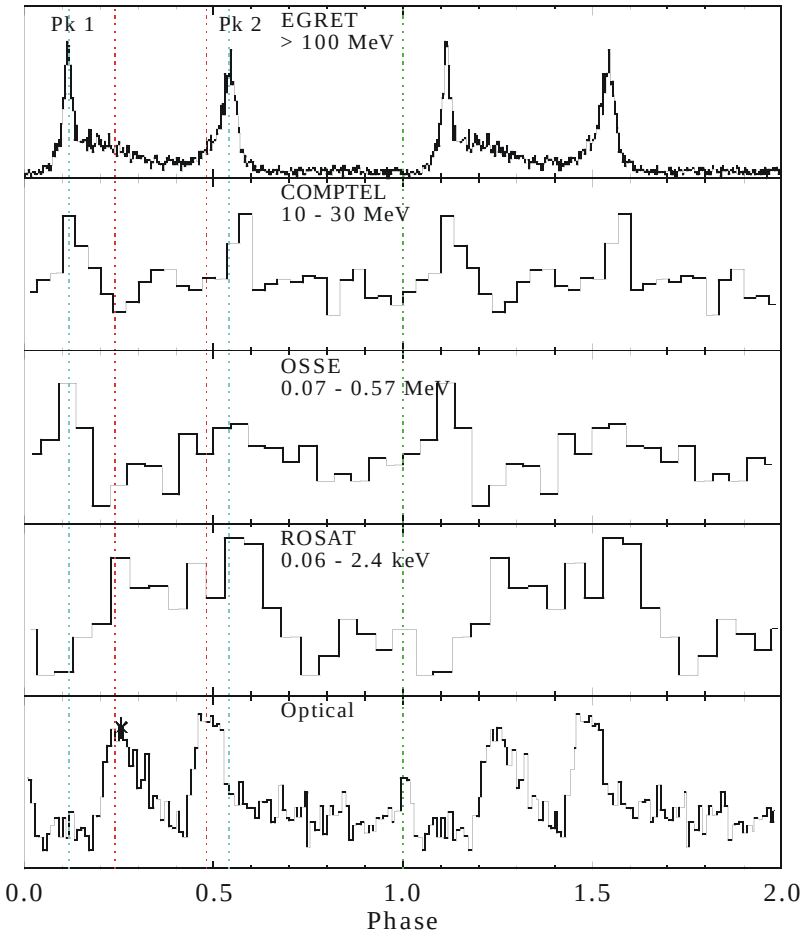
Vela Pulsar (cont'd)

- ***First convincing hard X-ray/soft g-ray observations by OSSE and COMPTEL***
  - Pulsed spectrum only
  - Gradual rollover from very hard OSSE spectrum (Γ =1.3) to EGRET (Γ = 1.7)



Vela Pulsar (cont'd)

- ***Light curve behavior seems to have three "regimes"***
  - Radio: 1 peak
  - Optical: 2 peaks, small separation
  - γ-ray: 2 peaks, wider separation
- ***Where does the switch from "optical-like" to "γ-like" behavior occur?***
- ***Whither the radio pulse?***

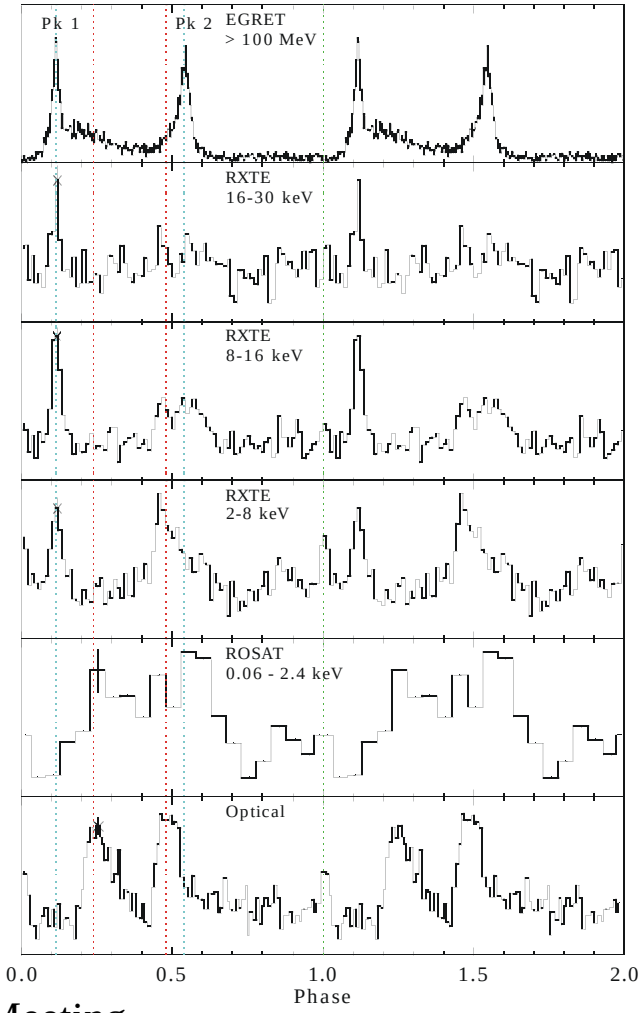


RXTE Arrives with Answers and Questions

- ***RXTE Observations***
  - Cycle 1: 93 ksec
  - Cycle 3: 274 ksec
- ***Analysis***
  - Ephemerides from Princeton pulsar database
  - Epoch folding analysis with standard RXTE ftools
  - "On-pulse minus off-pulse" or fitting sinusoid model plus off-pulse "background"
- ***Cycle 1 results appeared in 1999*** ***(Strickman, Harding & deJager, 1999, ApJ, 524, 373)***
- ***"X-ray gap" between ROSAT and OSSE is filled in!***
- ***Paper speculates that:***
  - "Peak 2" may have multiple components
  - Some components may be "γ-like", others "optical-like"
- ***Statistics insufficient to prove either claim***

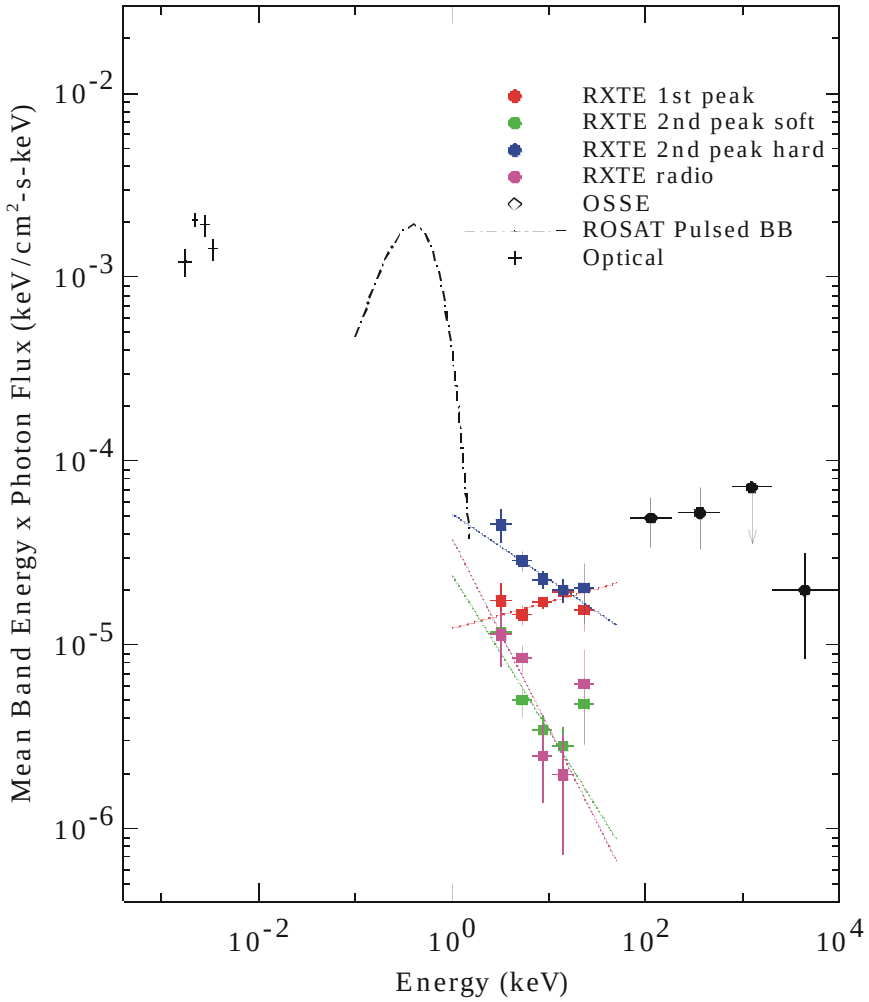
Cycle 3 Provides Some Answers

- ***Broadband light curves:***
  - First peak clearly aligns with EGRET first peak
  - "Second Peak" is clearly two peaks ($\Delta\varphi=0.09\pm0.01$)
    - Lower phase, softer component aligned with optical
    - Higher phase, harder component aligned with EGRET second peak
  - Soft spectrum peak present at radio peak phase
    - Note similar feature in optical lightcurve
    - No such feature at higher energies



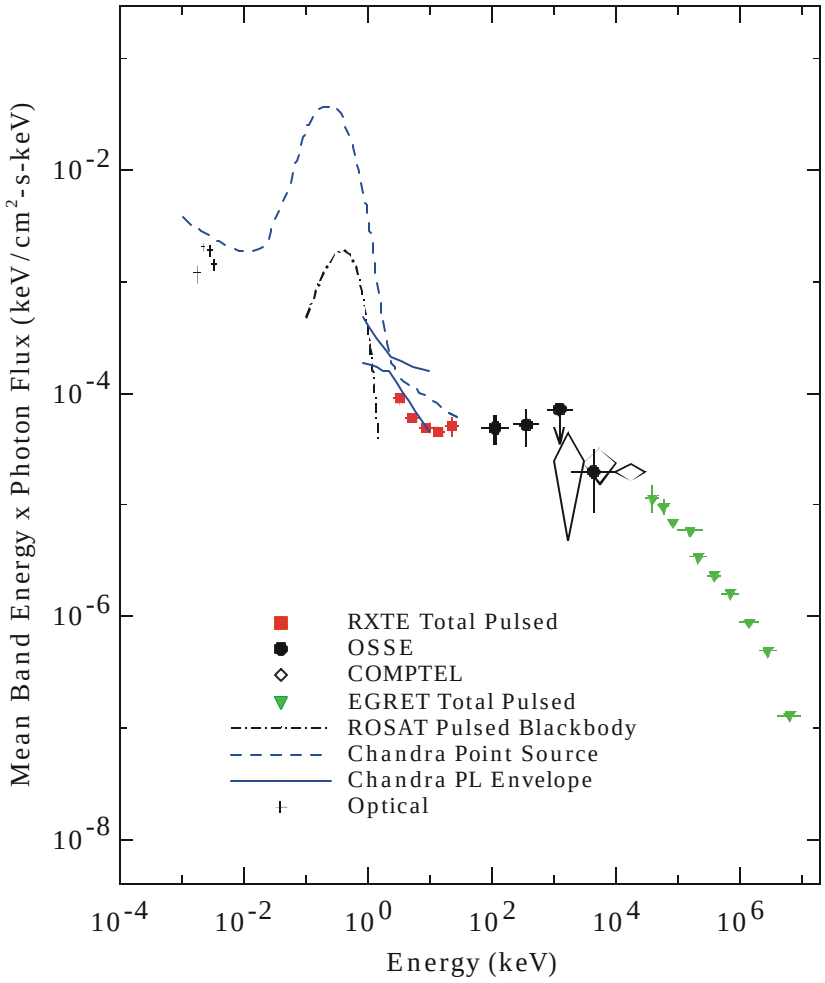
Cycle 3 Provides Some Answers (cont'd)

- ***Phase-resolved spectra:***
  - Peaks that are phase-aligned with γ-ray peaks are hardest
  - Peaks phase-aligned with optical and/or radio peak are softest
  - Soft component of Peak 2 extrapolates to near optical fluxes



Cycle 3 Provides Some Answers (cont'd)

- ***Total pulsed spectrum***
  - Smoothly fills in gap between hard X-ray and thermal
  - Complex shape from superposition of phase-resolved spectra
  - Comparison to Chandra "point source" spectrum indicates higher pulsed fraction than in thermal component (similar to other nonthermal emission)



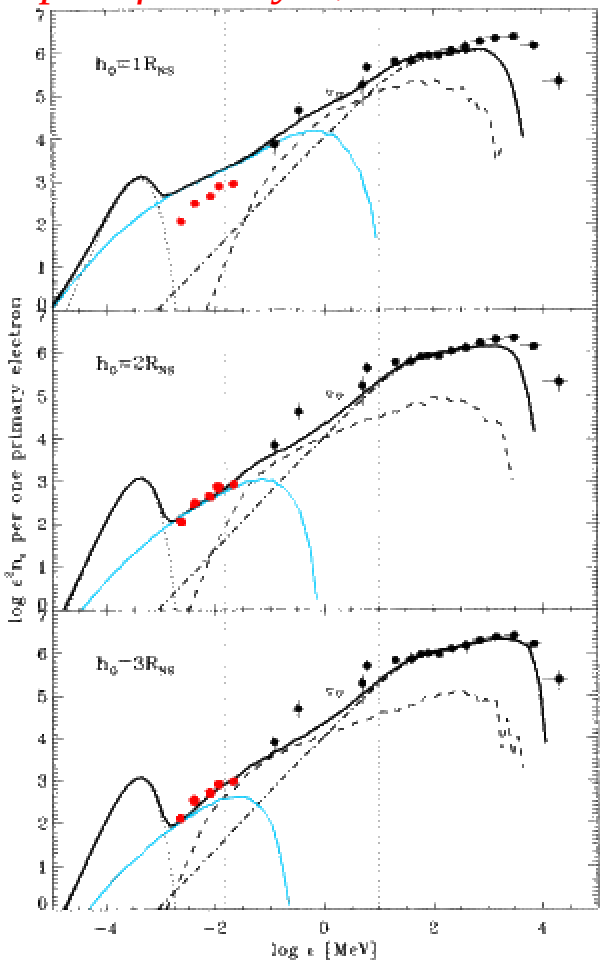
Conclusions and Future Directions

- ***Conclusions***
  - Cycle 3 RXTE observations confirm the multicomponent nature of the pulsed Vela emission
  - Features from radio through γ-ray present in the 2-30 keV spectrum (hence the Vela Pulsar Rosetta Stone)
  - Components behavior in spectrum and phase correlated
    - Soft components phase-aligned with lower energy features (radio and optical)
    - Hard components phase-aligned with higher energy features (γ-ray)

Conclusions and Future Directions (cont'd)

- Conclusions (cont'd)
  - Nonthermal X-ray measurements present new challenges to modeling the global spectrum
  - Attempts have been made to model these energies (e.g. ⇒)
  - Nothing yet predicts phase resolved spectra behavior

Adapted from Dyks, Rudak & Bulik (00)



Conclusions and Future Directions (cont'd)

- ***Future Directions***
  - More observations with RXTE (>1000ksec required; not currently approved)
    - Significantly improve statistics for characterization of peaks
    - Better high energy behavior
  - Chandra observations (Pavlov et al)
    - Imaging allows phase resolved spectra without subtracting "off-pulse"
    - Need better statistics
- ***Simultaneous Radio***
  - We have full pulse-by-pulse radio coverage during the cycle 3 observation
  - Epoch fold X-ray data for different ranges of radio pulse strength/arrival time
  - Study radio phase peak as a function of radio properties