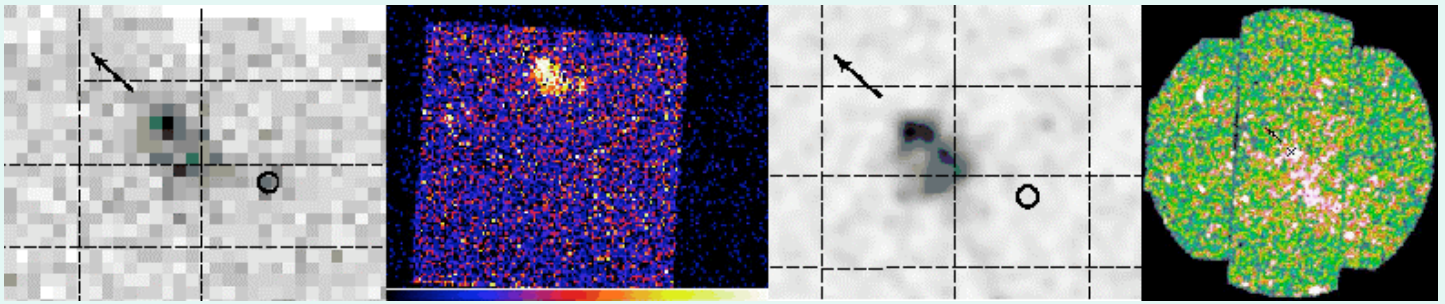
X-ray Observations of PSR B0355+54 and Its Pulsar Wind Nebula



Katie McGowan

Tom Vestrand (LANL), Jamie Kennea (PSU),
Silvia Zane (MSSL), Mark Cropper (MSSL),
France Cordova (UC Riverside)

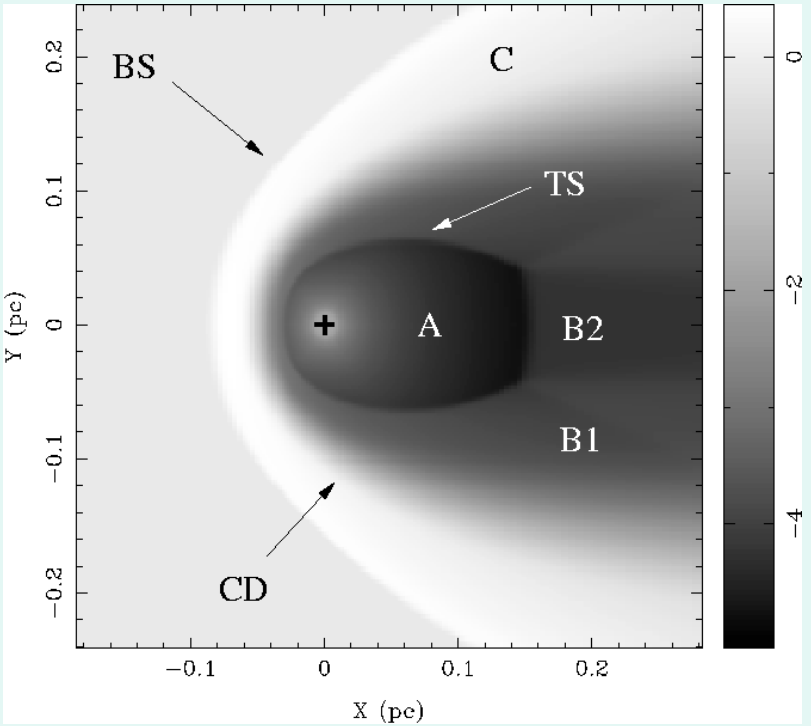
University of Southampton

Pulsar Wind Nebulae

- large fraction of energy from pulsar converted to relativistic wind
- wind interacts with ambient medium and produces a shock
- acceleration of relativistic particles at shock generates synchrotron emission -> PWN
- presence of PWN related to spin-down energy
  - PWN emission efficiency significantly reduced for sources with log $\dot{E} \leq 36$

Pulsar Wind Nebulae

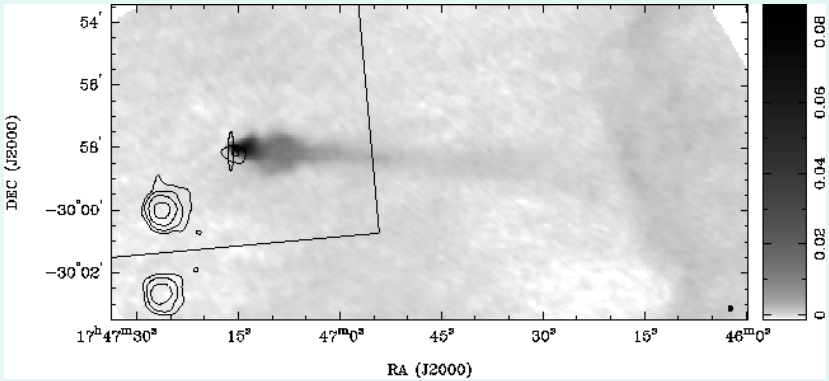
- synchrotron bubble blown at the center of expanding SNR - outer edge expands supersonically
- and/or if pulsar has supersonic space velocity
  - bow shock is formed in front
  - reverse shock formed behind
    - terminates pulsar wind



Gaensler et al. 2004

Pulsar Wind Nebulae

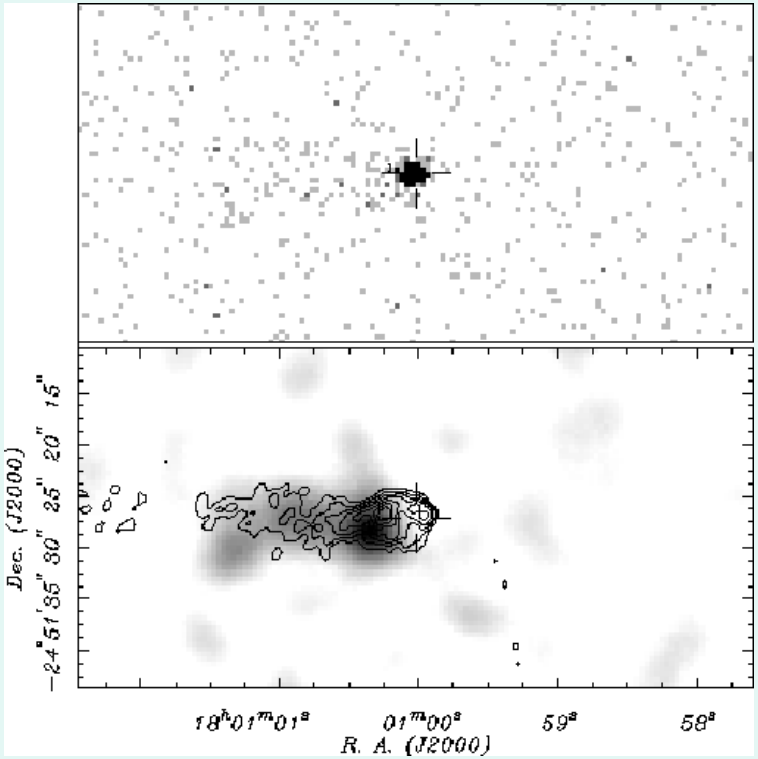
'Mouse'



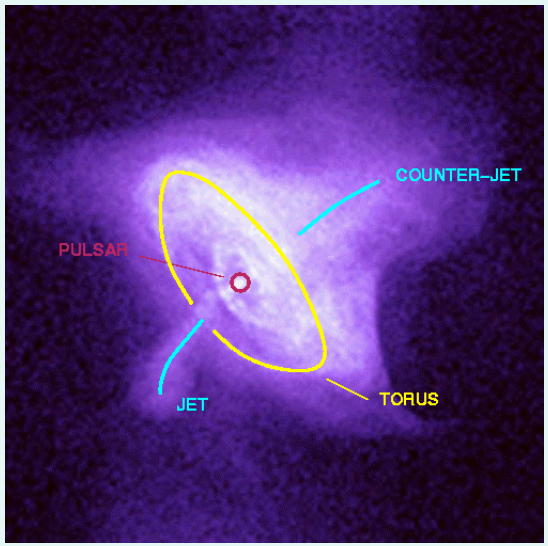
Gaensler et al. 2004

morphology related to spin-down energy

'Duck'



Kaspi et al. 2001



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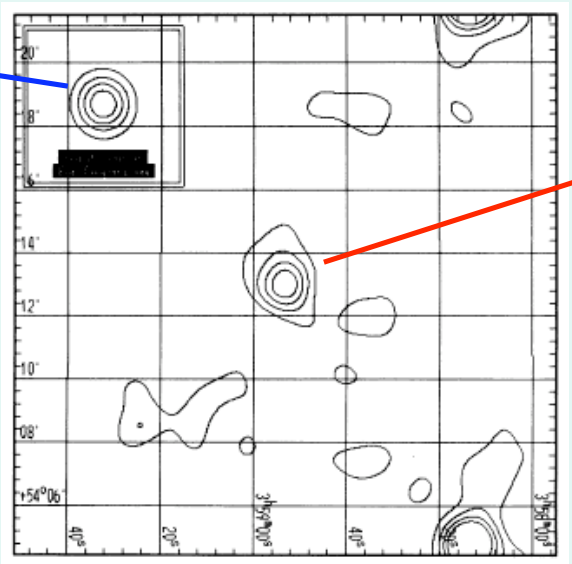
PSR B0355+54

- middle aged pulsar (5.6 x 10^5 yr), log $\dot{E}$ = 34.6
- emission extending 5′ (*Einstein*; Helfand 1983)
- emission extending 1.7′ (*Einstein*; Seward & Wang 1988)
- emission extending 1.6′ (*ROSAT*; Slane 1994)

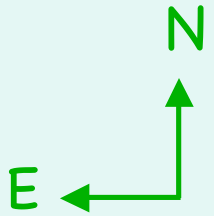
comparison, 3C 273

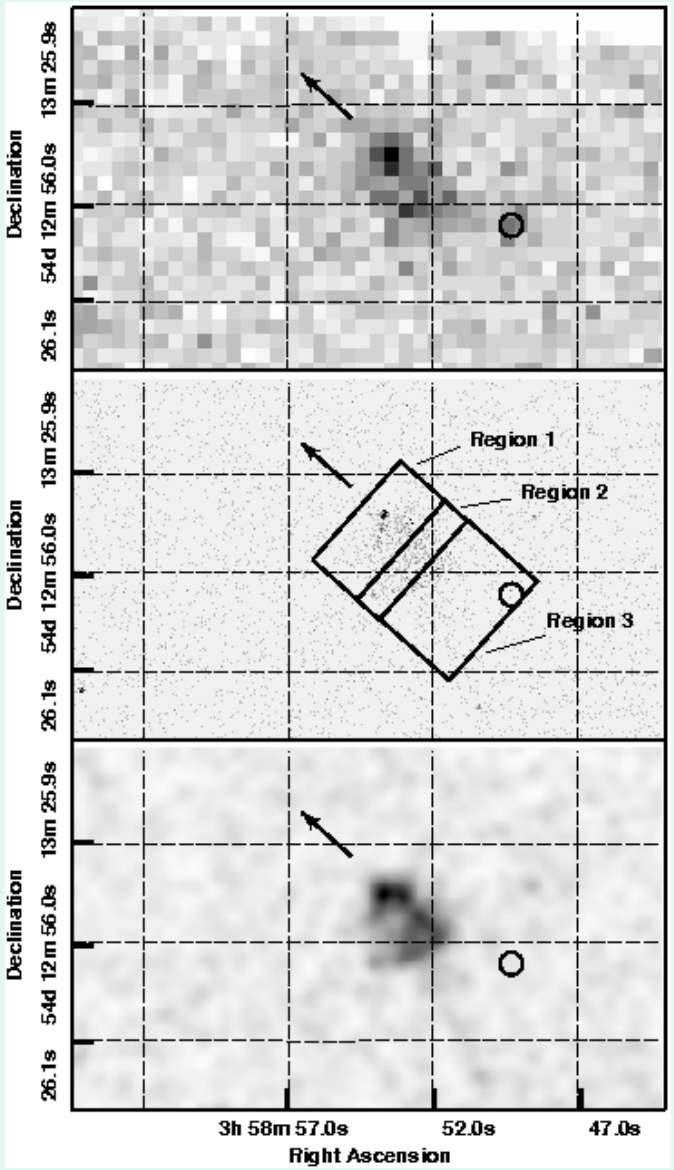


PSR B0355+54

Slane 1994

X-ray Images





XMM pn

Chandra ACIS

smoothed Chandra ACIS

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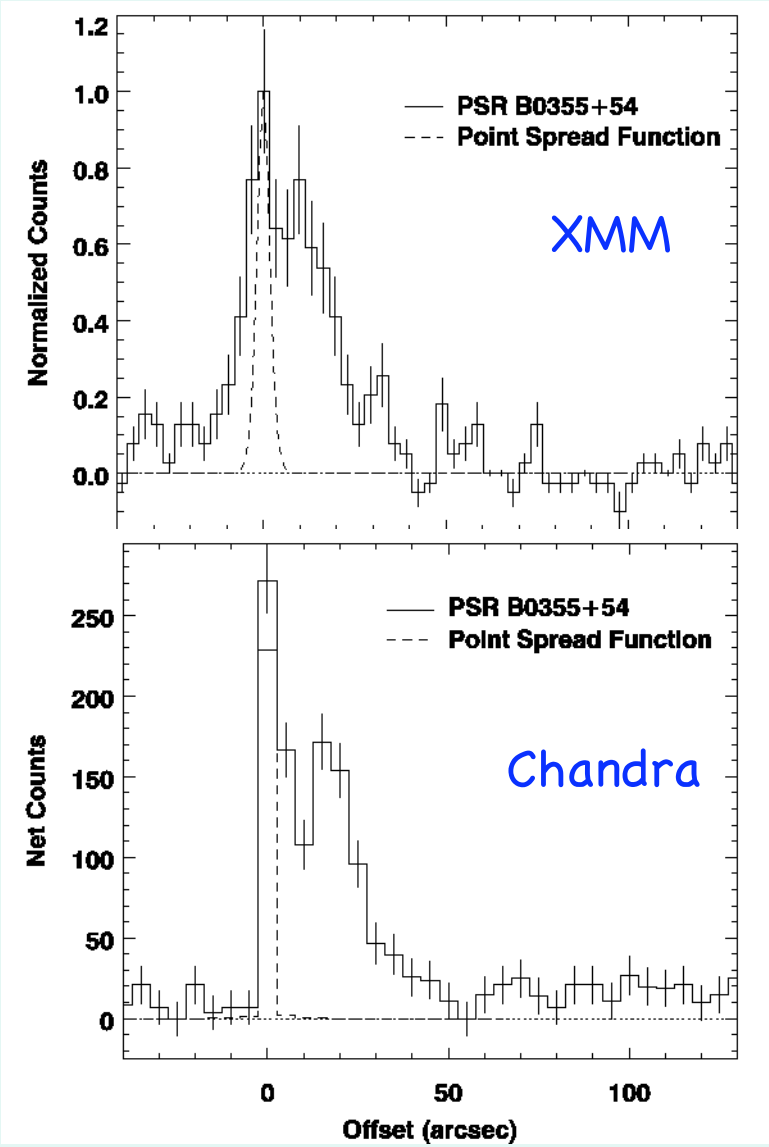
Compact Diffuse Emission

Compact diffuse emission extends ~ 50″

Possible dip at ~ 10″
- termination shock ?



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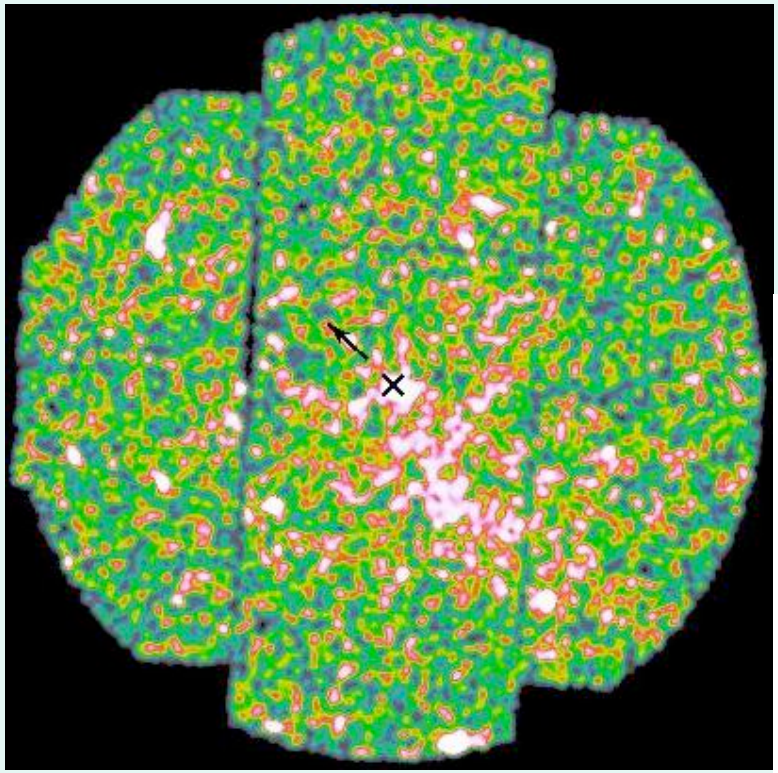
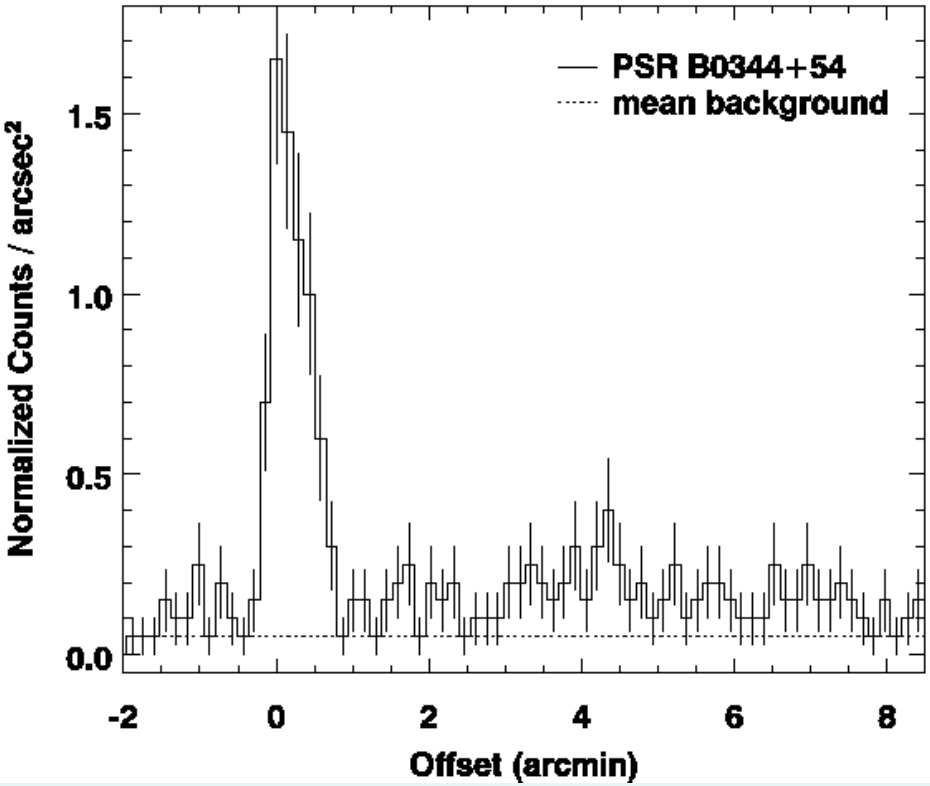
Extended Diffuse Emission



XMM MOS1

Very extended emission out to ~ 5′



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Ram-pressure Confined PWN

- pulsar space velocity v_{sp} = 61 km s^{-1}
  - time for pulsar to cross diffuse emission > 4000 yr (> 24,000 yr)
- synchrotron lifetime t_{sync} = 3000 yr
  - diffuse emission not due to particles left by pulsar
  - constant supply of particles with velocities > v_{sp}
- ram-pressure confined PWN

  $\rho v_{sp}^2 = 1.4 \times 10^{-9}$ ergs cm^{-3}

Ram-pressure Confined PWN

- pulsar $L_X = 8.3 \times 10^{30}$ erg s^{-1}
  - conversion efficiency 2×10^{-4}
- compact nebula $L_X = 2.2 \times 10^{31}$ erg s^{-1}
  - conversion efficiency 5×10^{-4}
- energetic shocked particles are confined by the CD
  - $r_{CD} = 0.004$ pc
  - $r^F_{TS} \sim 0.003$ pc
- equate the pressure of the pulsar wind to that of the ambient medium (+ Mach number)
  - sound speed of medium indicates cold or mildly warm ambient gas

Pulsar Core Emission

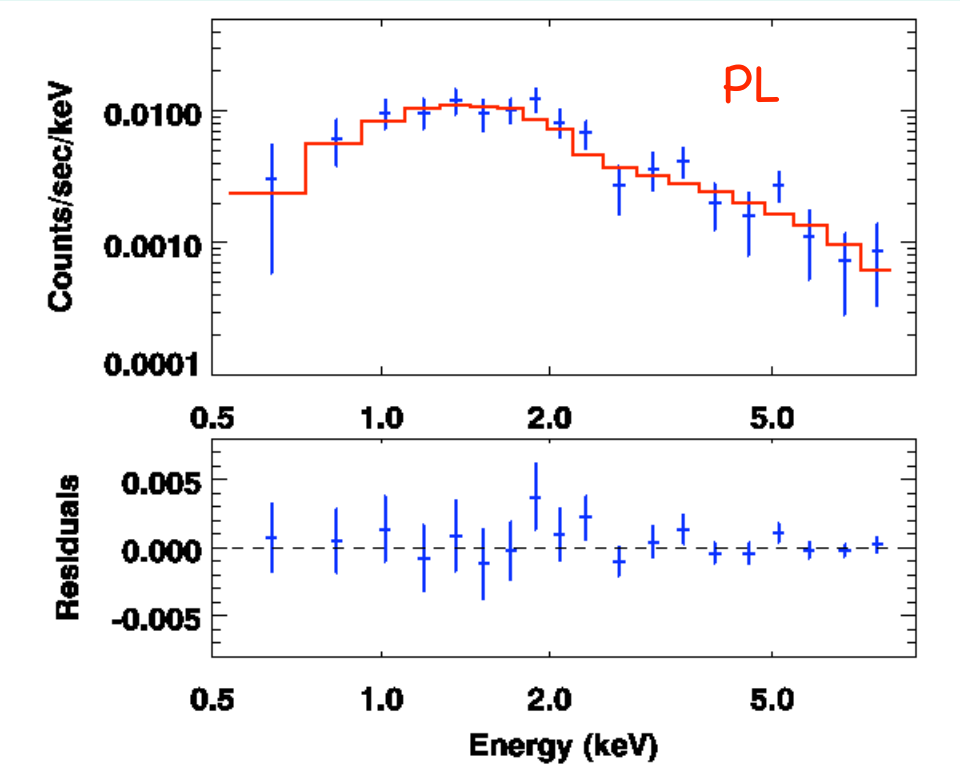
power-law

$\Gamma = 1.5$

$nH = 0.50 \times 10^{22}$ cm^{-2}

$F_X = 2.3 \times 10^{-13}$ ergs cm^{-2} s^{-1}

XMM pn



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Pulsar Core Emission

blackbody + power-law

$T^{\infty} = 2.32 \times 10^{6}$ K

$R^{\infty} = 0.12$ km

$\Gamma = 1.0$

$F_X = 6.4 \times 10^{-14}$ ergs cm^{-2} s^{-1}

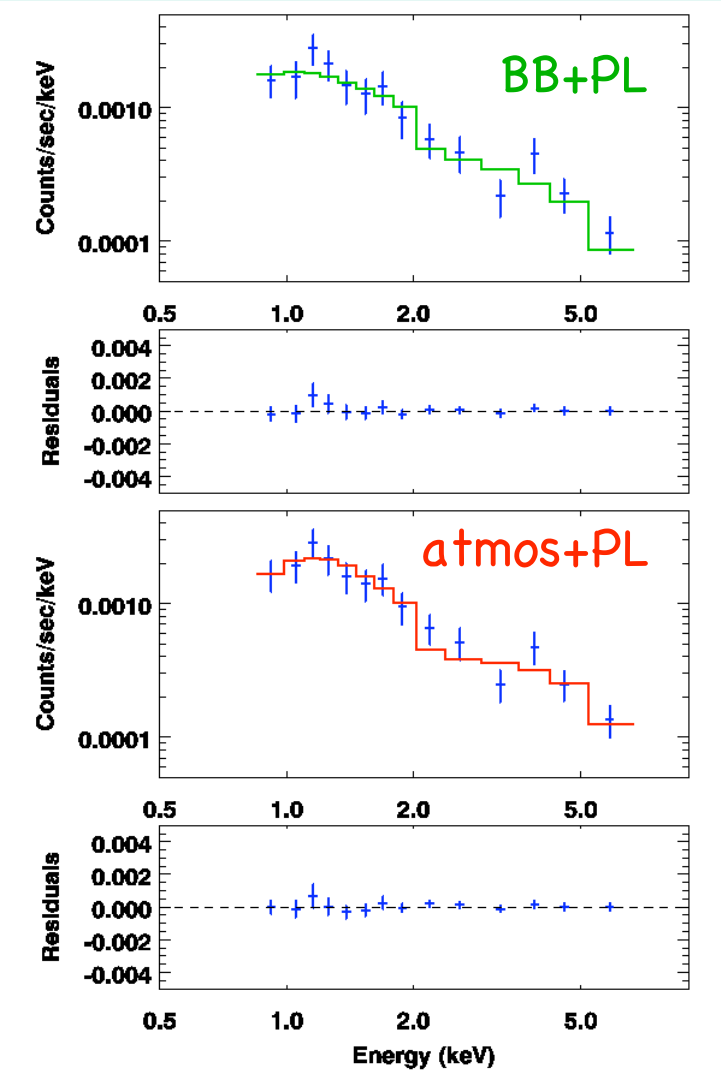
magnetic pure H atmosphere + power-law

$T^{\infty} = 0.45 \times 10^{6}$ K

$R_{NS} = 7.2$ km

$\Gamma = 1.5$

$F_X = 1.5 \times 10^{-13}$ ergs cm^{-2} s^{-1}



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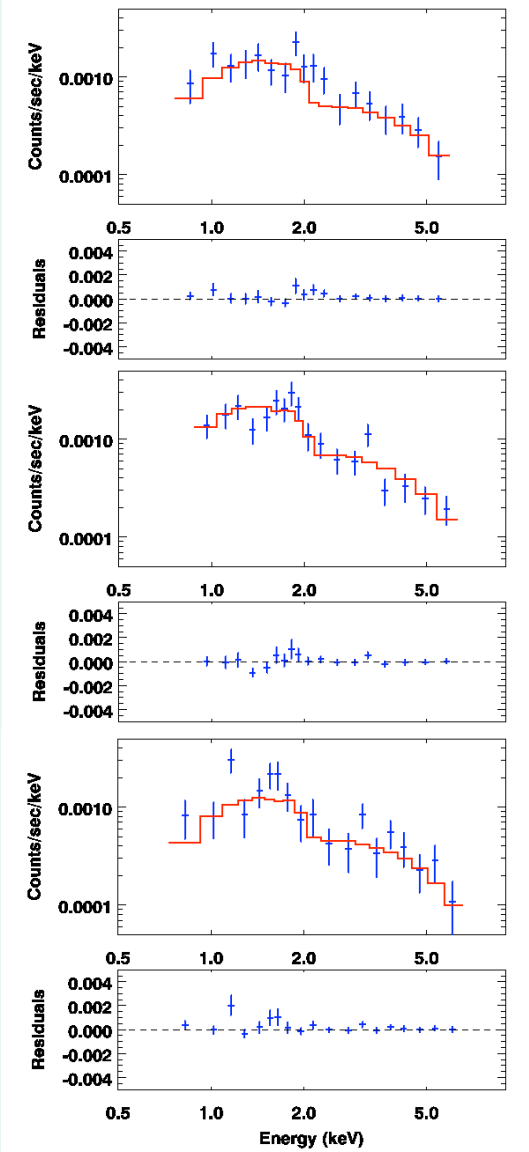
Diffuse Emission

region 1

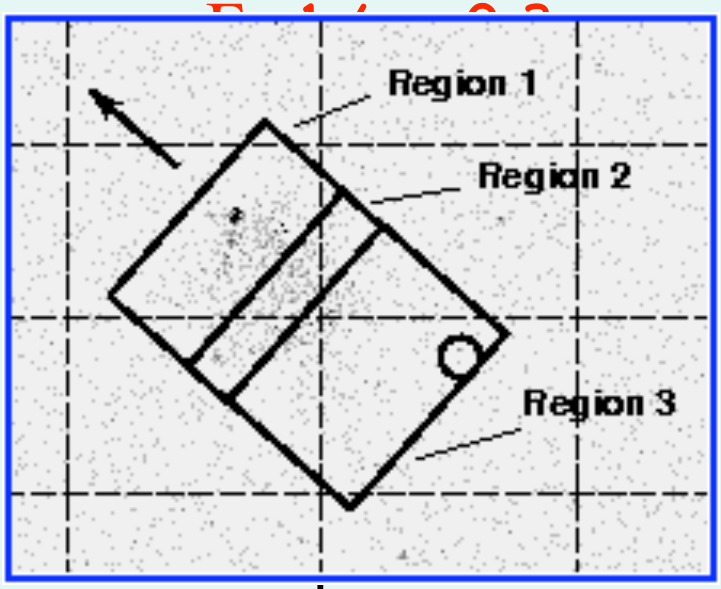
region 2

region 3



all regions

power-law



power-law

$\Gamma = 1.2 \pm 0.5$

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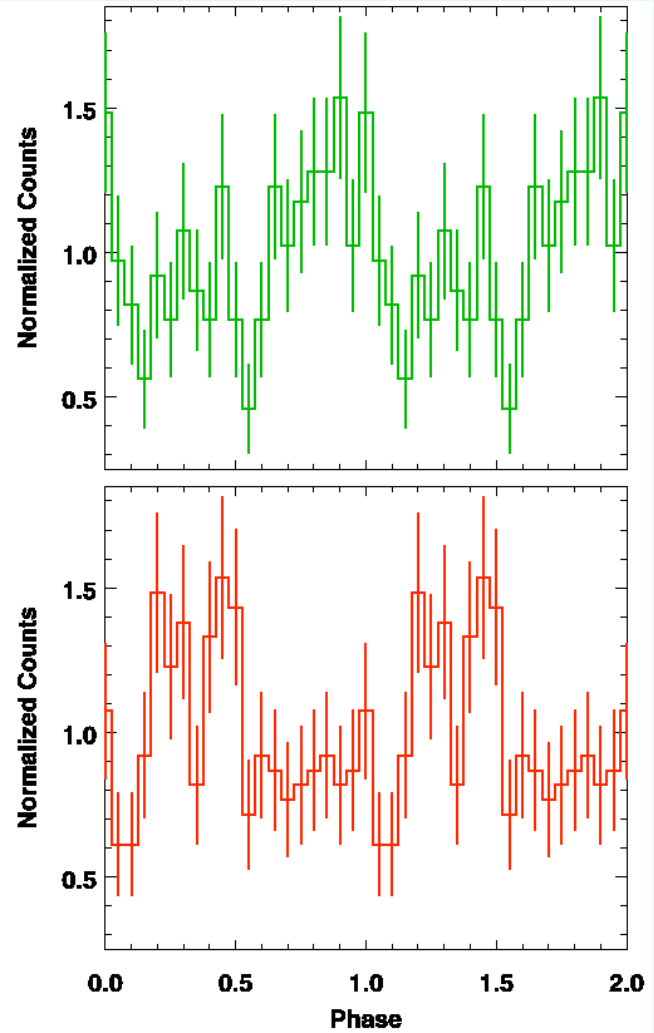
Pulse Profile

Detected period is consistent with predicted radio period

P = 156 ms



folded on predicted period

PF = 25 ± 7 %

folded on detected period

PF = 21 ± 8 %

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Summary

- detect X-rays from PSR B0355+54 and diffuse emission
  - lies in opposite direction to pulsar's proper motion
  - compact diffuse emission extends 50''
  - fainter diffuse emission extends out to 5'
  - interpreted as a ram-pressure confined PWN
- fit core emission with a thermal plus power-law model
  - hot polar cap
- detect pulsations consistent with radio period