VHE observation of CTA 1 with VERITAS

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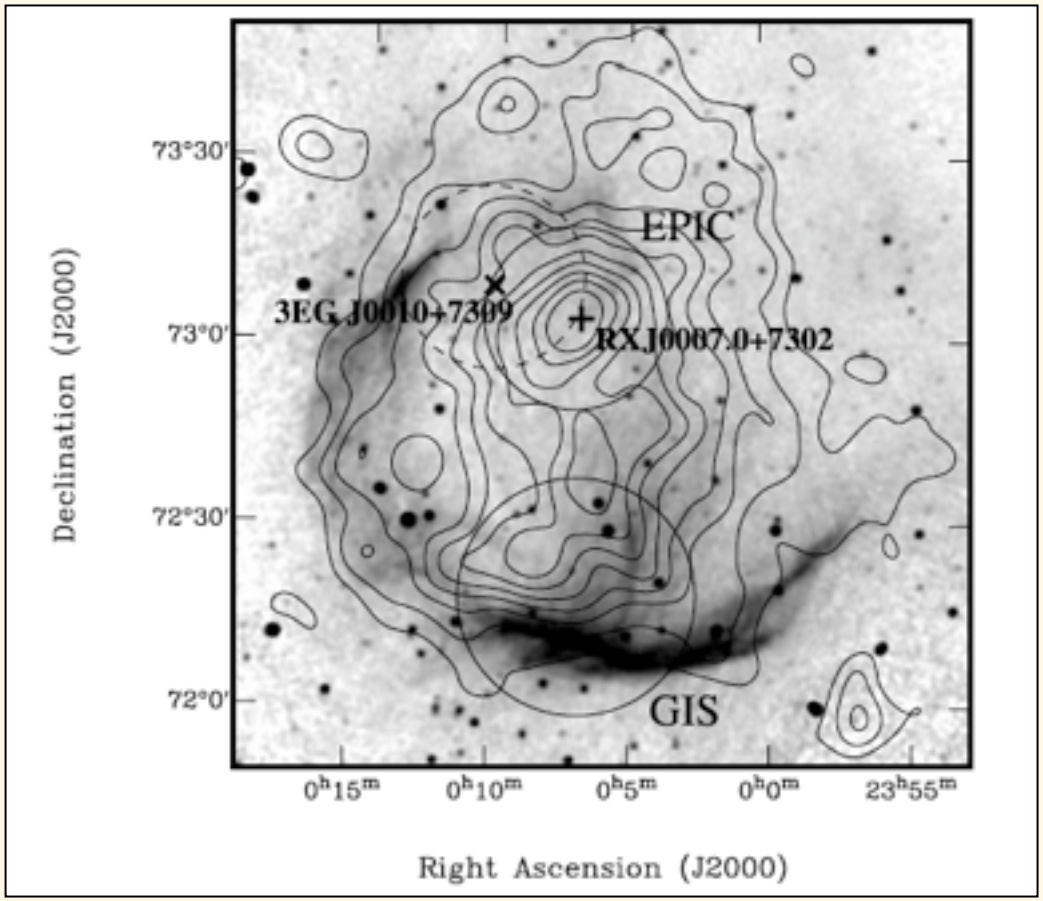
The Supernova Remnant CTA 1

- Composite SNR - radio shell; center-filled X-ray
- 00 07 01.56 +73 03 08.1 (J2000.0)
- distance: 1.4 ± 0.3 kpc

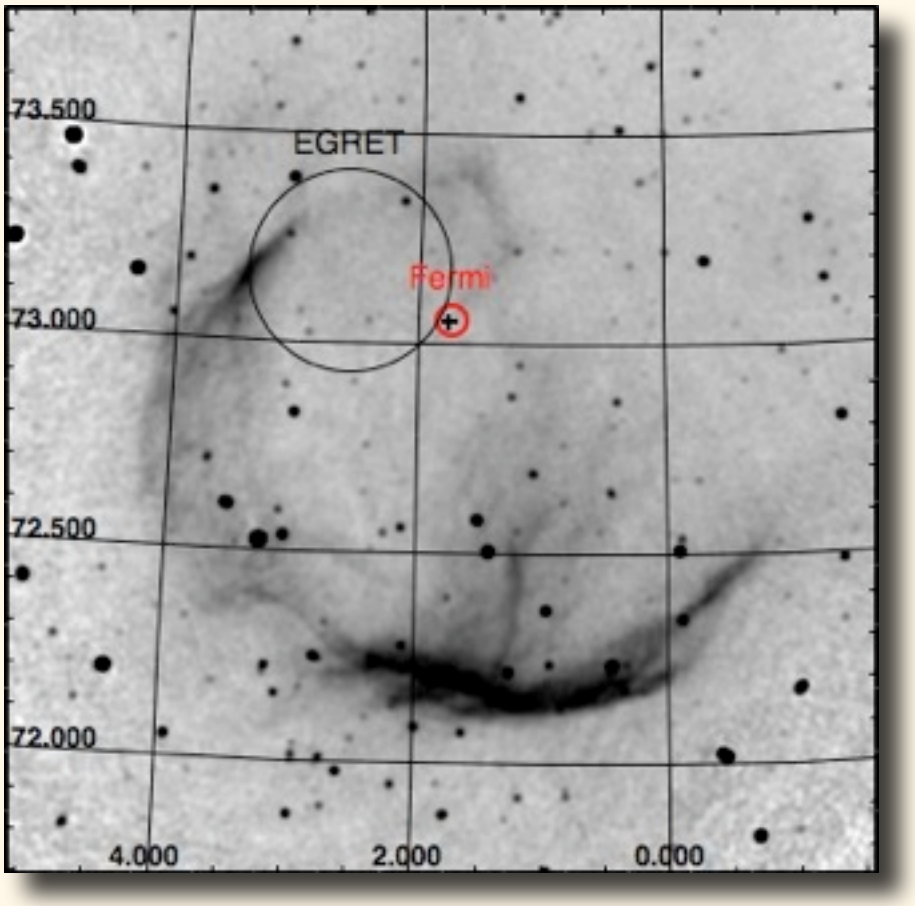
  estimated age ~1.3×10^4 yr

  radio shell diameter ~1.8°



Radio image of CTA 1 with ROSAT PSPC contours (Fig. from Slane et al. 2004).
The figure also shows the ASCA GIS FoV, the XMM-Newton pointing, and the error circle of 3EG J0010+7309.

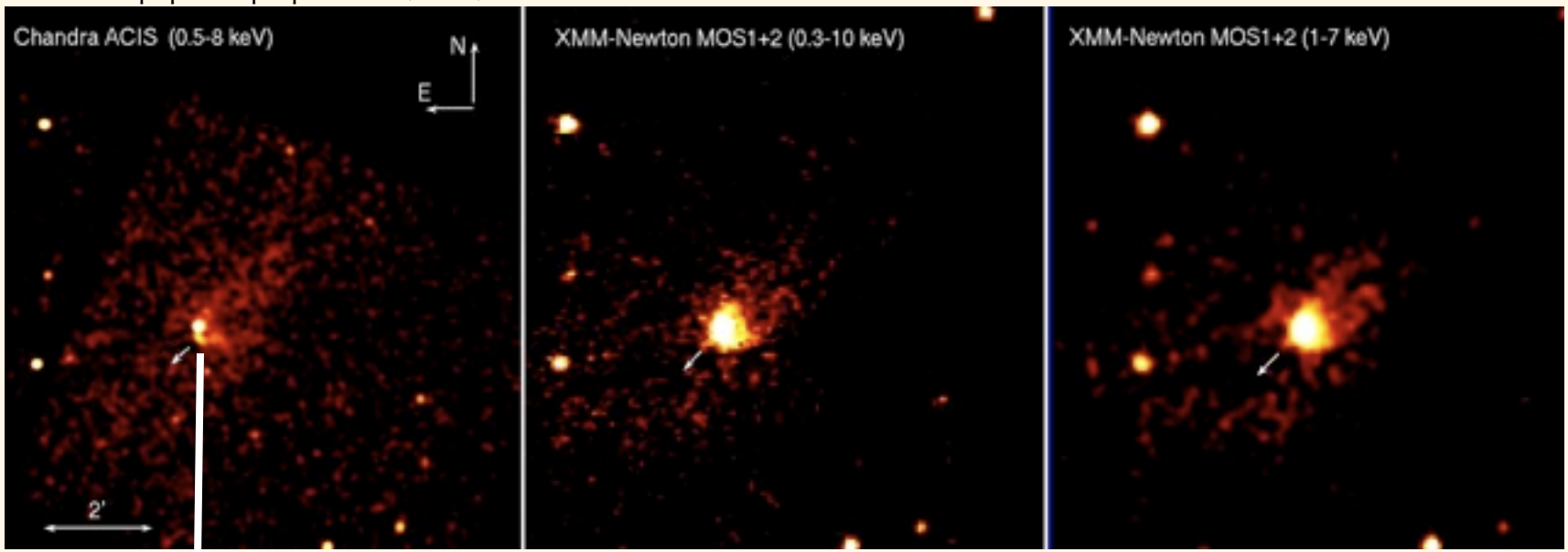
Fermi Pulsar

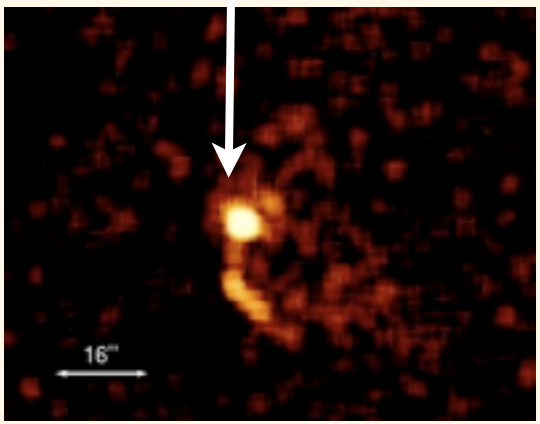


- Pulsed emission first detected within the first few months of Fermi operation (Abdo et al. 2008)
  - $\dot{E} = 4.5 \times 10^{35}$ erg s^{-1}
  - P = 315 ms
  - char. age = 1.39×10^{4} yrs
  - $\Gamma = 1.38 \pm 0.05$
  - $E_{cutoff} = 4.6 \pm 0.4$ GeV
- No radio or optical counterpart, X-ray pulsation now reported with XMM-Newton (Caraveo et al. 2010)

Chandra (0.5-8 keV)

VERITAS paper in preparation (2011)





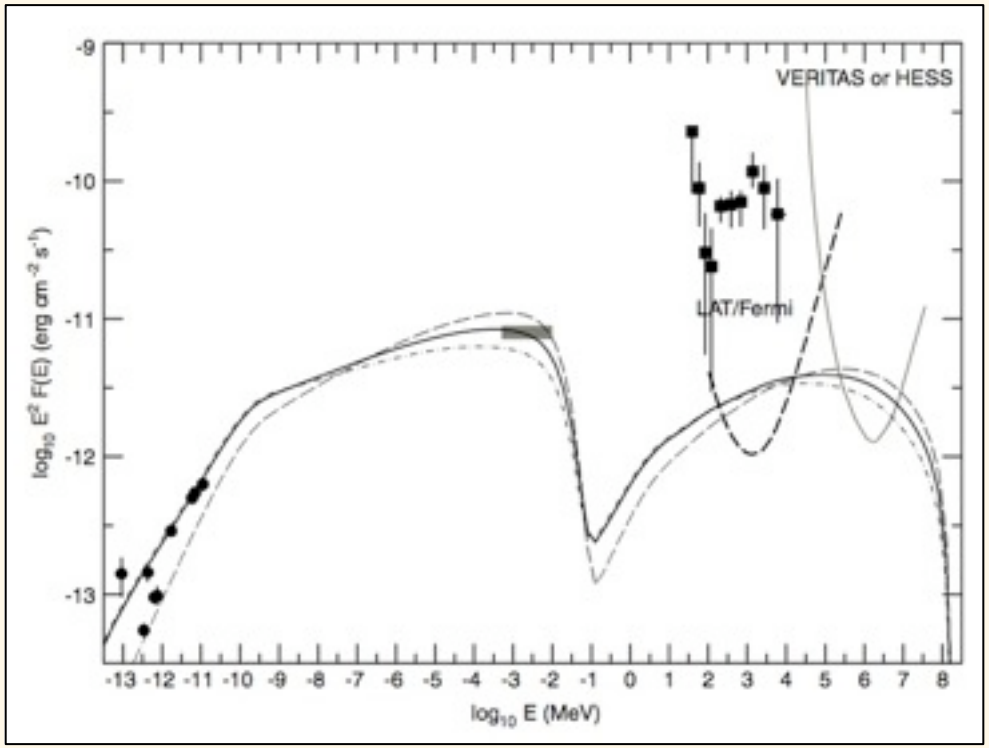
Halpern et al. (2004)

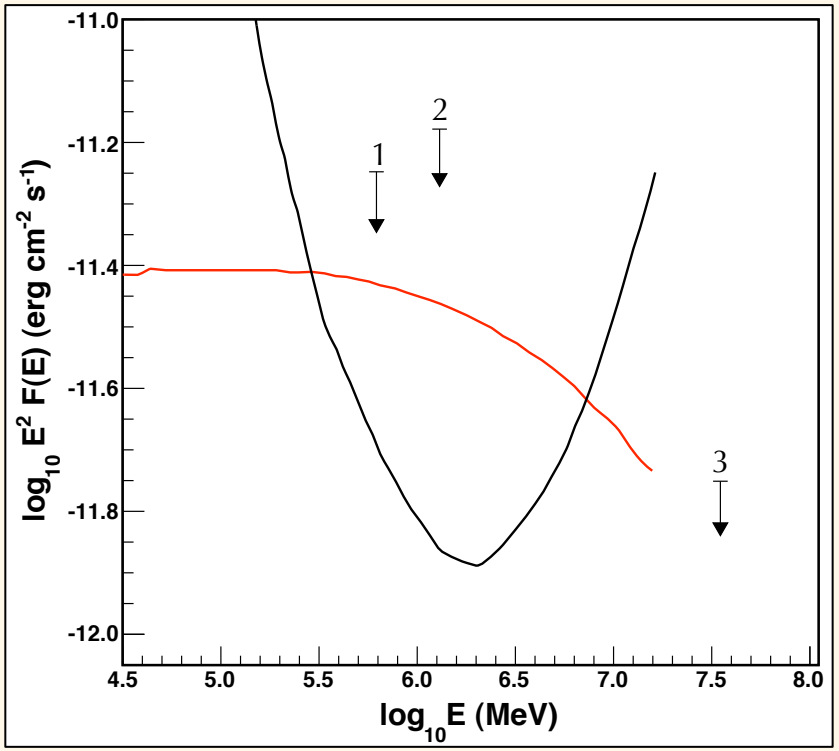
Chandra image of RX J0007.0+7303 reveals a point source, a cometary-shaped compact nebula, and a bent jet. These are all characteristic of energetic, rotation-powered pulsars.
X-ray image & PWN have very low X-ray surface brightness.

The Chandra point source accounts for ~30% of the flux of RX J0007.0+7303. The compact nebula + jet comprise ~70%. The X-ray spectrum of the point source is power-law + BB, with $\Gamma = 1.6 +/- 0.6$

X-ray morphology strongly suggests that PSR is moving SE

Model Spectrum





[1]Whipple (Hall et al. 2001), [2]HEGRA (Rowell et al. 2003), [3]Milagro (Abdo et al, 2009)

- Zhang et al. (2009) modeled broadband emission for both pulsed and unpulsed emission
- Fermi detection is dominated by pulsed emission, but unpulsed should be detectable by VERITAS

VERITAS

Instrument design:

- Four 12-m telescopes
- 499-pixel cameras (3.5° FoV)
- Site in southern Arizona

Specifications:

- Angular resolution < 0.1° (1 TeV)
- Energy resolution 15-20 %
- Energy threshold ~ 100 GeV.
- 3-level trigger (250 Hz rate)

Sensitivity:

- 30% improvement after relocating 1 telescope in Summer 2009
- 1% Crab @ 5σ in <30hrs

photo by S. Criswell, Whipple Observatory

Observations & Trials

- "Wobble" pointing 0.7° around the center of SNR
- About 26.5 quality-selected hours, Oct. 2010 - early Jan. 2011
  Zenith angles between 40° & 45°

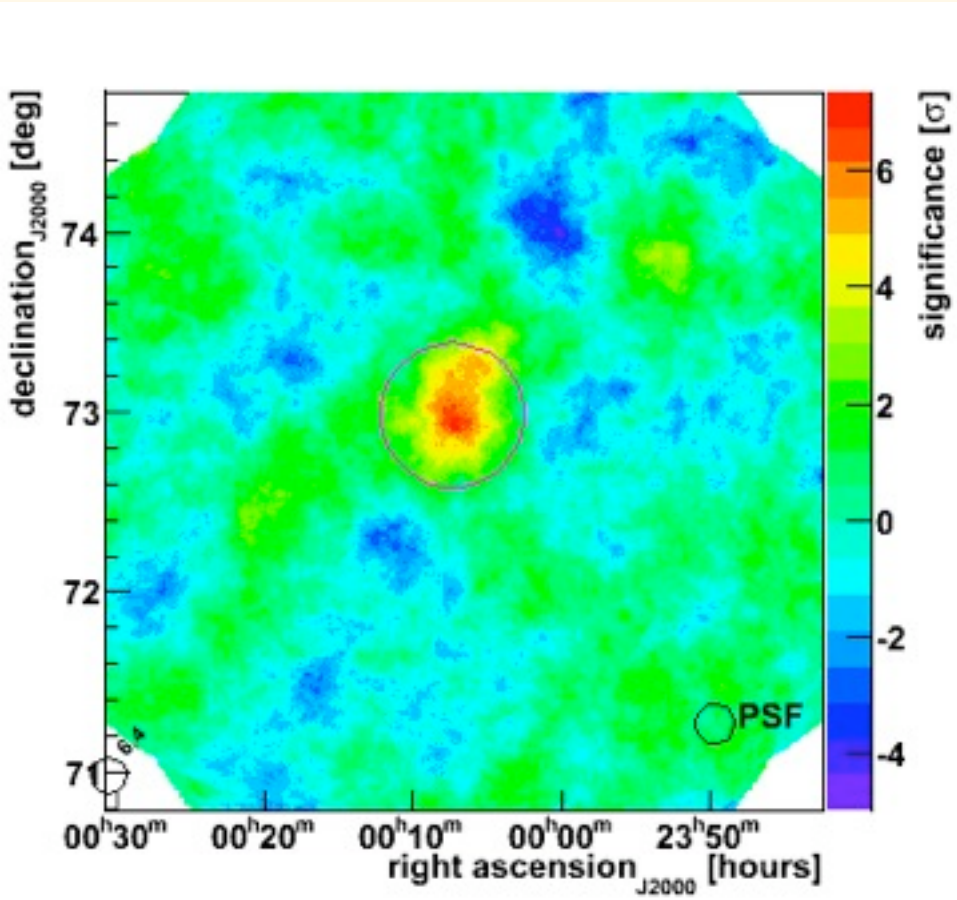
- Tile a region of 0.4° radius around the pulsar with 0.04° square sections
- 2 sets of gamma/hadron separation cuts (moderate/hard) for 2 integration sizes (0.1° pt-source, 0.3° extended)

Total trials factor of 1,257

Detection

- Maximum significance in correlated maps: 7.3σ pre-trials (~6.3σ post-trials) located within the search region

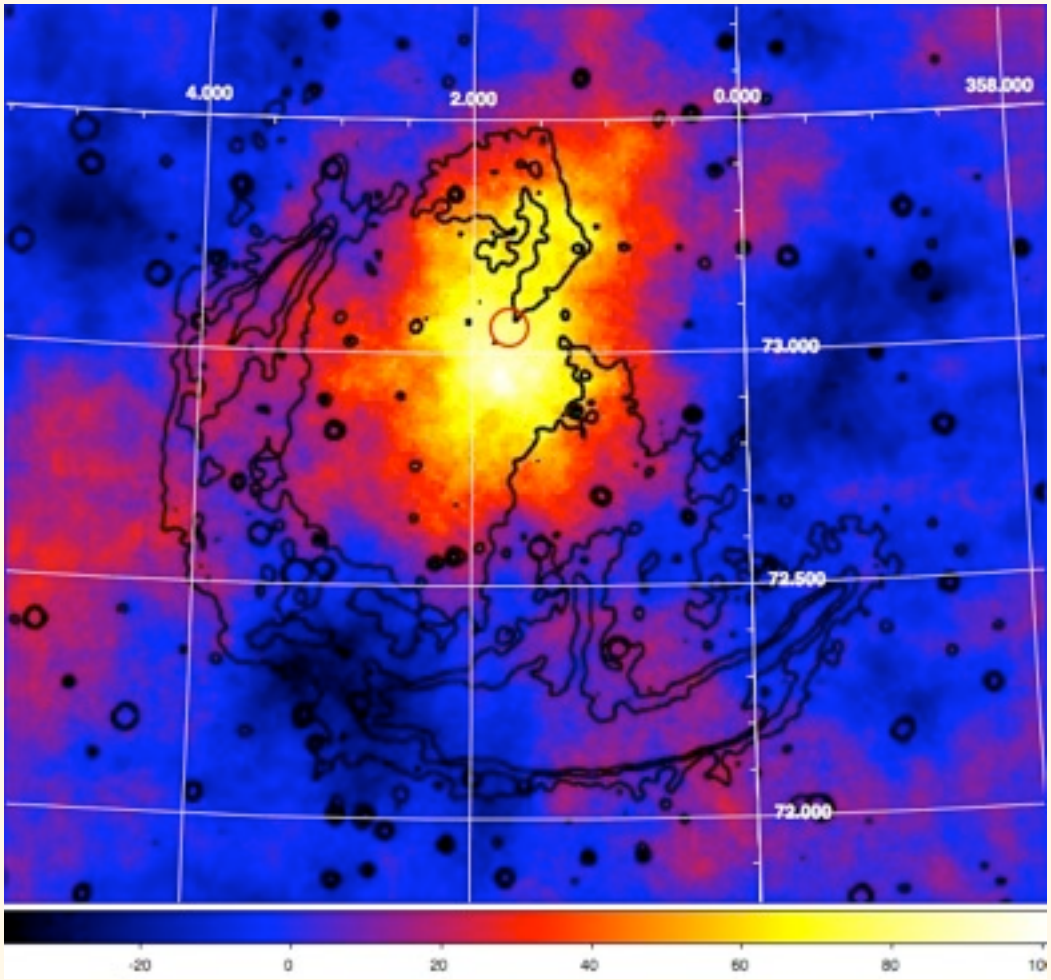
- F(>1 TeV) ~4% steady Crab flux (preliminary)



Multiwavelength Map

VERITAS correlated excess map with:

- Black contours: Radio 1420 MHz showing SNR shell
  (courtesy of T. Landecker)
- Red Circle: Fermi pulsar error circle

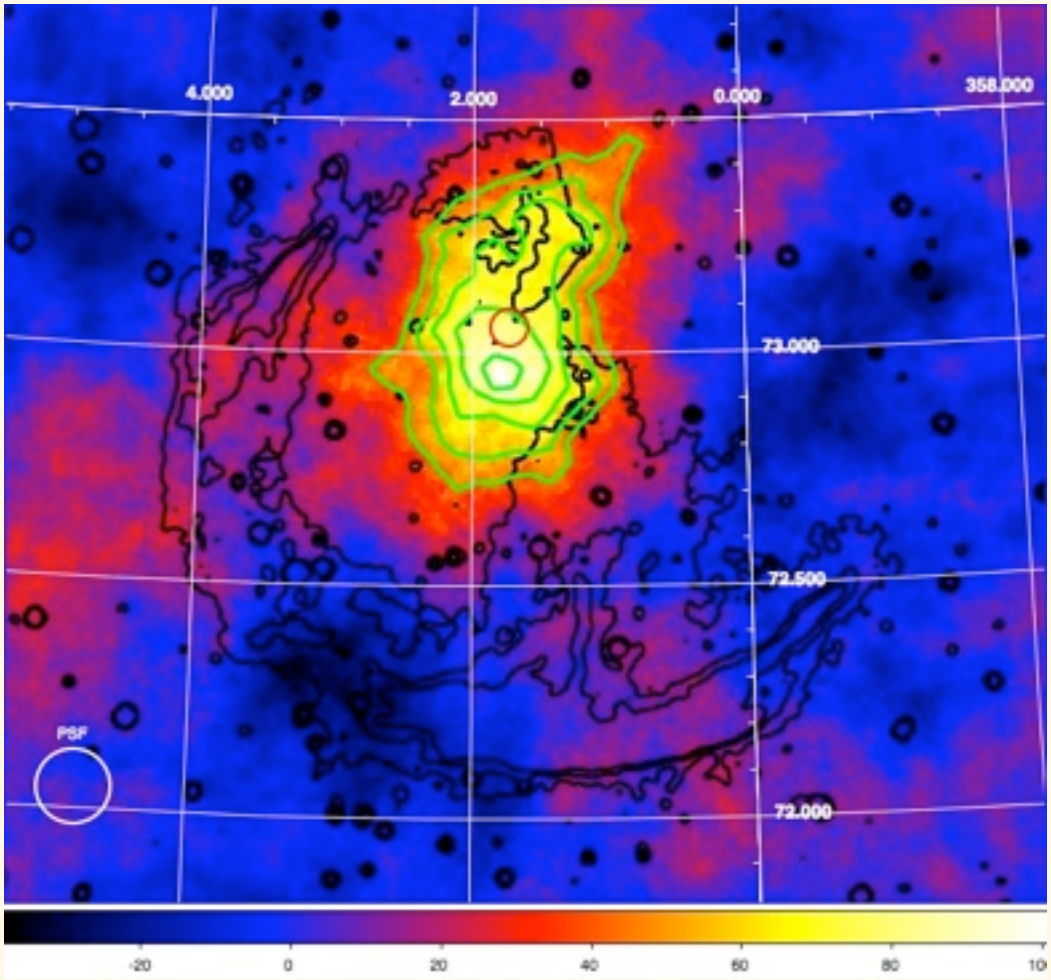


counts above background

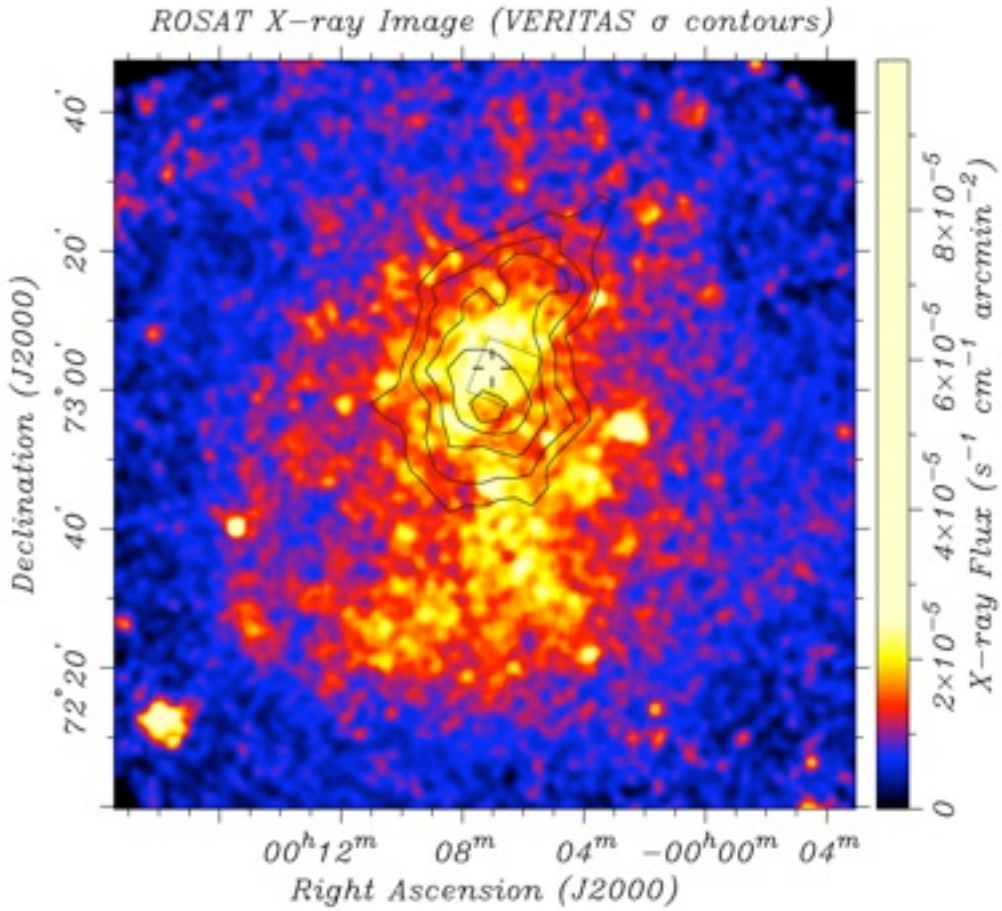
Multiwavelength Map

VERITAS correlated excess map with:

- Black contours: Radio 1420 MHz showing SNR shell
  (courtesy of T. Landecker)
- Red Circle: Fermi pulsar error circle
- White Circle: VERITAS Point-source PSF
- VERITAS 3-7σ contours in green



ROSAT PSPC (0.5-2.0 keV)



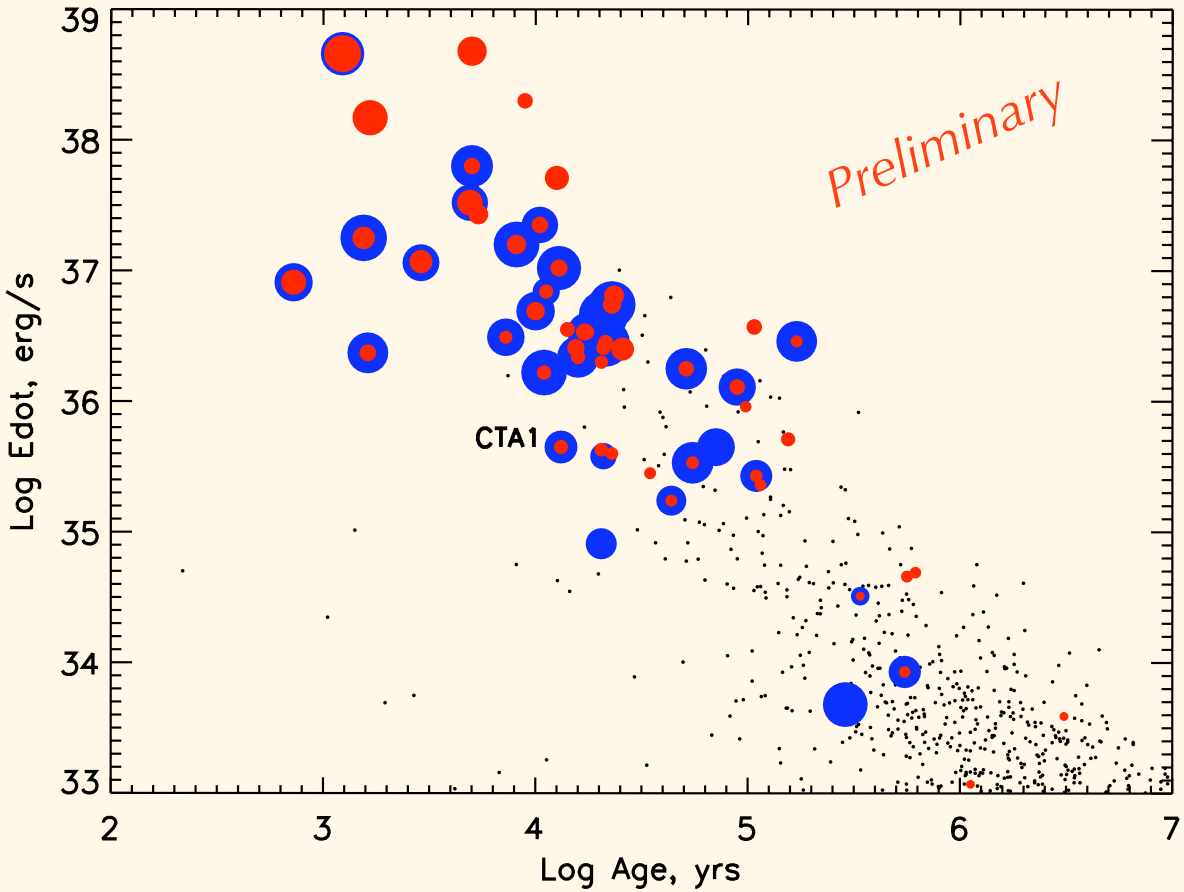
ROSAT images reveals a center-filled morphology and a faint compact source located at the peak of the central brightness distribution (Slane et al. 2004).

Cross shows location of X-ray point source RX J0007.0+7303 and Fermi pulsar: (J2000.0) 00 07 01.56 +73 03 08.1

Image: X-ray ROSAT PSPC
Contours: VERITAS significance
Square: Chandra FoV (S3 chip)

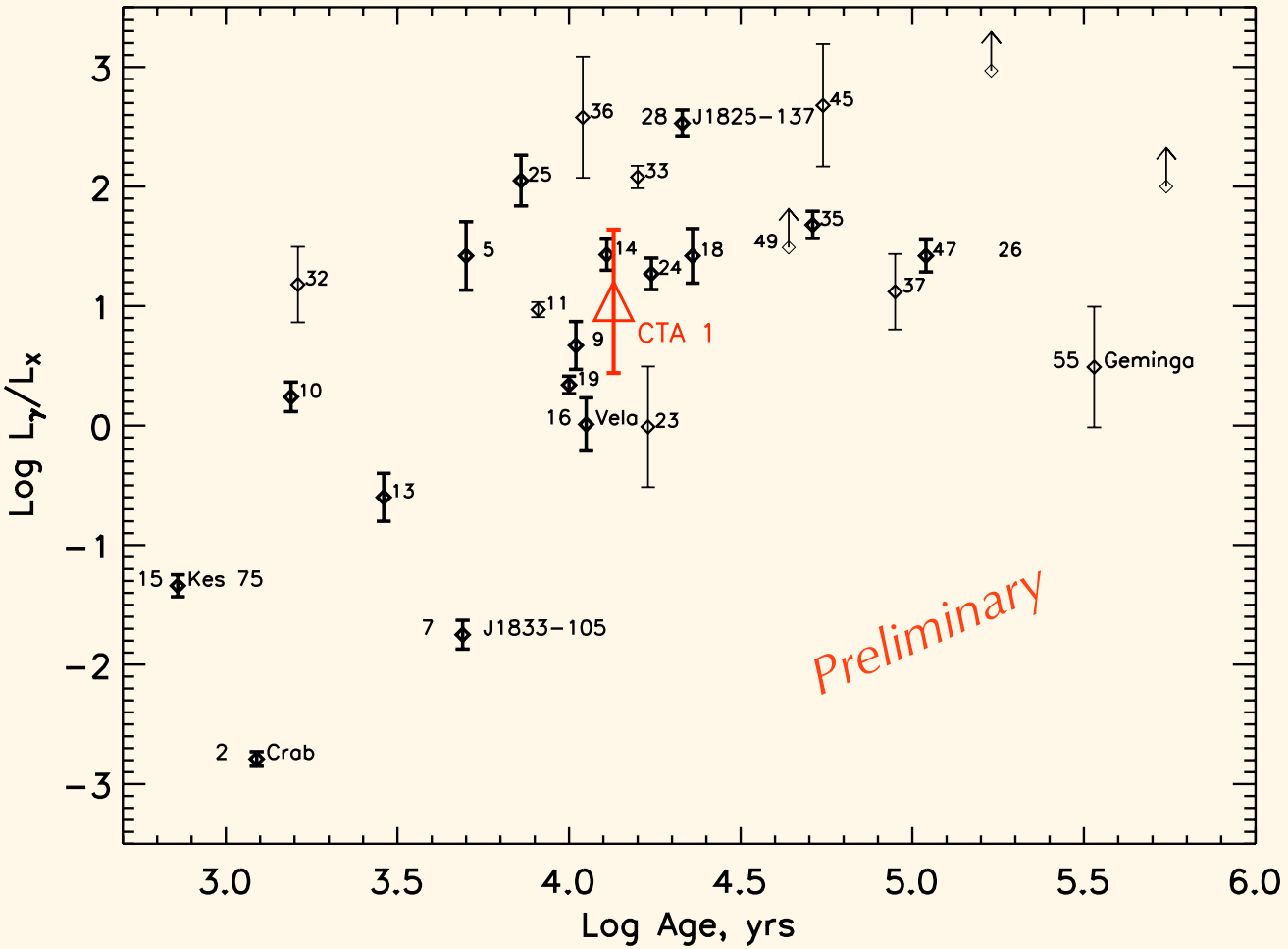
VERITAS excess lines up with location of pulsar.
Indicative of young PWN?

Discussion



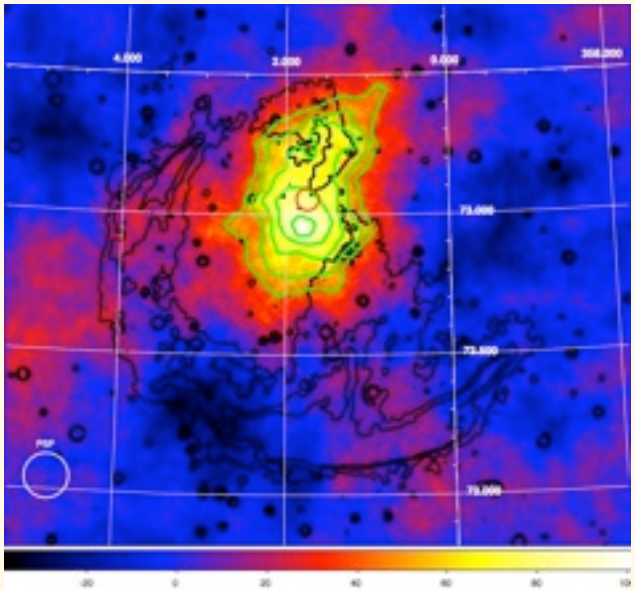
Plot of pulsar spin-down luminosity vs age, from Kargaltsev and Pavlov (2010), with CTA 1 point overlaid. Filled circles: X-ray (red) and TeV (blue) detected PWNe or PWN candidates. Circle size corresponds to luminosity. Small black dots denote ATNF catalog pulsars.

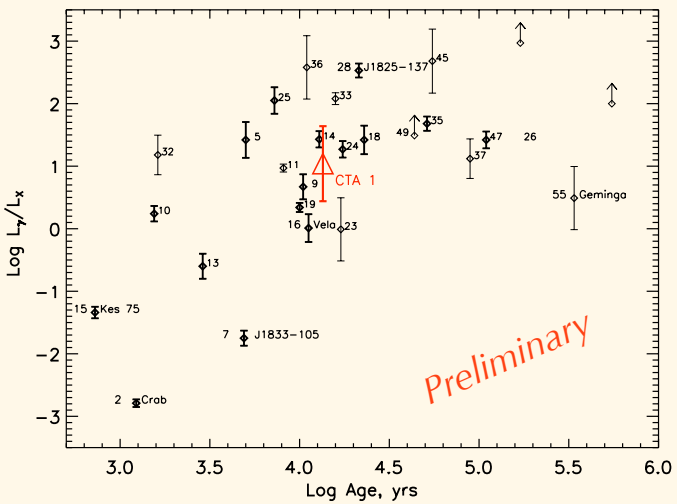
Discussion



Plot of the ratio of TeV to X-ray luminosity vs pulsar spin-down age, from Kargaltsev and Pavlov (2010), with CTA 1 point overlaid.

Summary





- Detection of non-point-source TeV emission in SNR CTA 1 at >6σ post-trials significance level in 26.5 hours of observation
- Preliminary spectral analysis shows integral flux above 1 TeV ~4% steady Crab flux
- Properties of CTA 1 fit nicely in the middle of those for the known TeV/X-ray PWN population

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