

The Pulsar Wind Nebulae of Three Radio Quiet Gamma- Ray Pulsars



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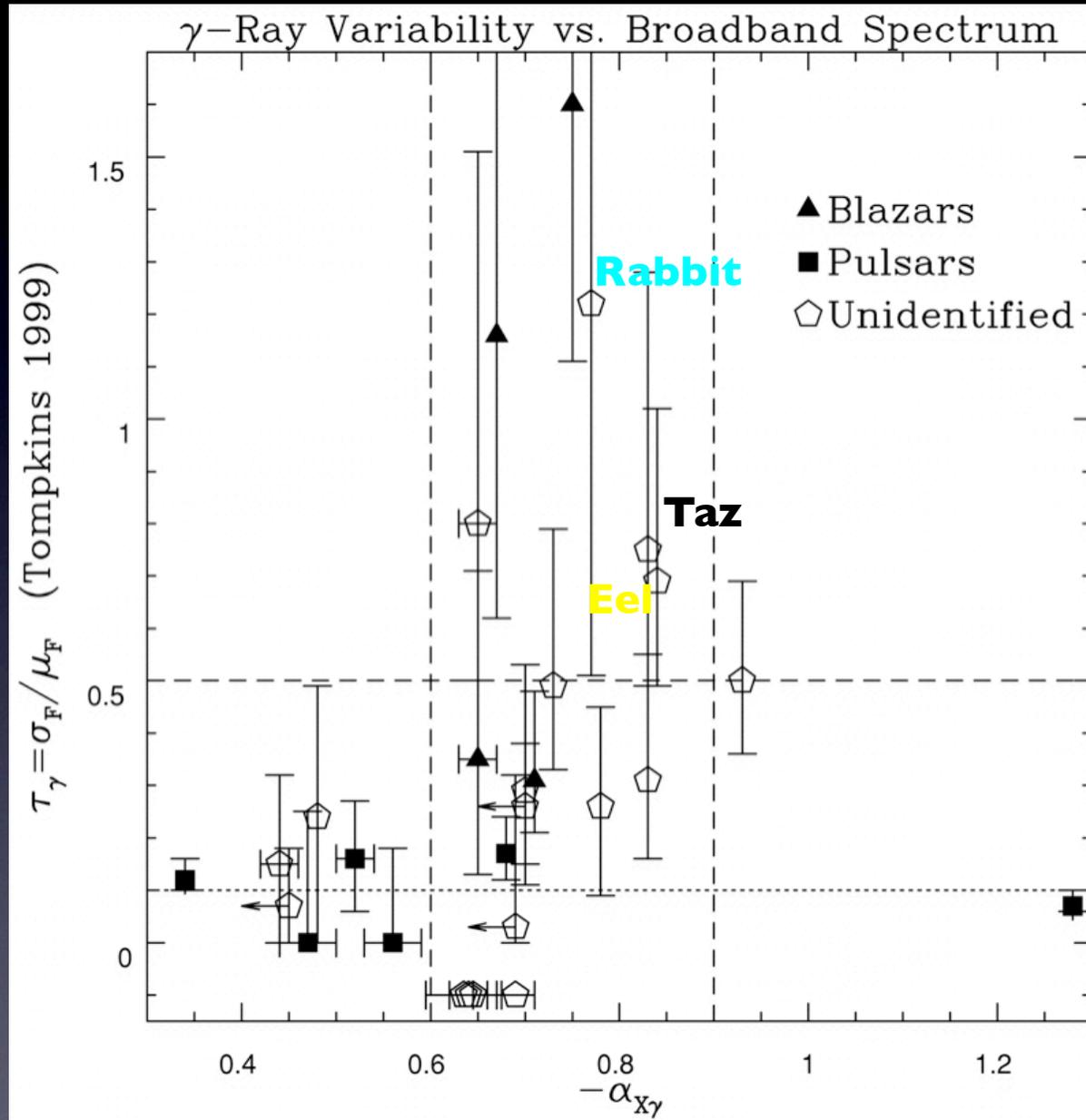
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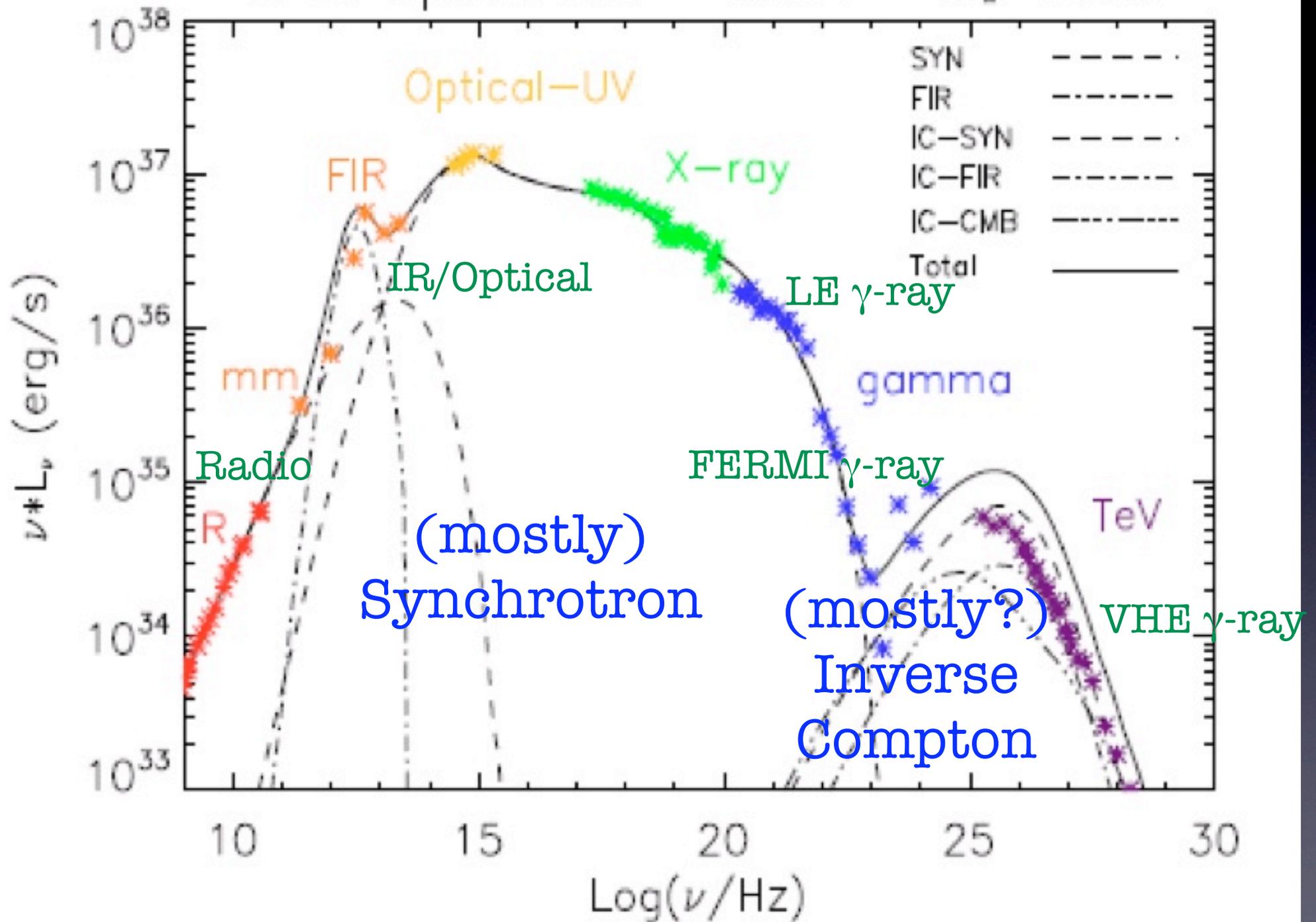
Regis Terrier

Variability of Potential ASCA X-ray Counterparts above 100 meV



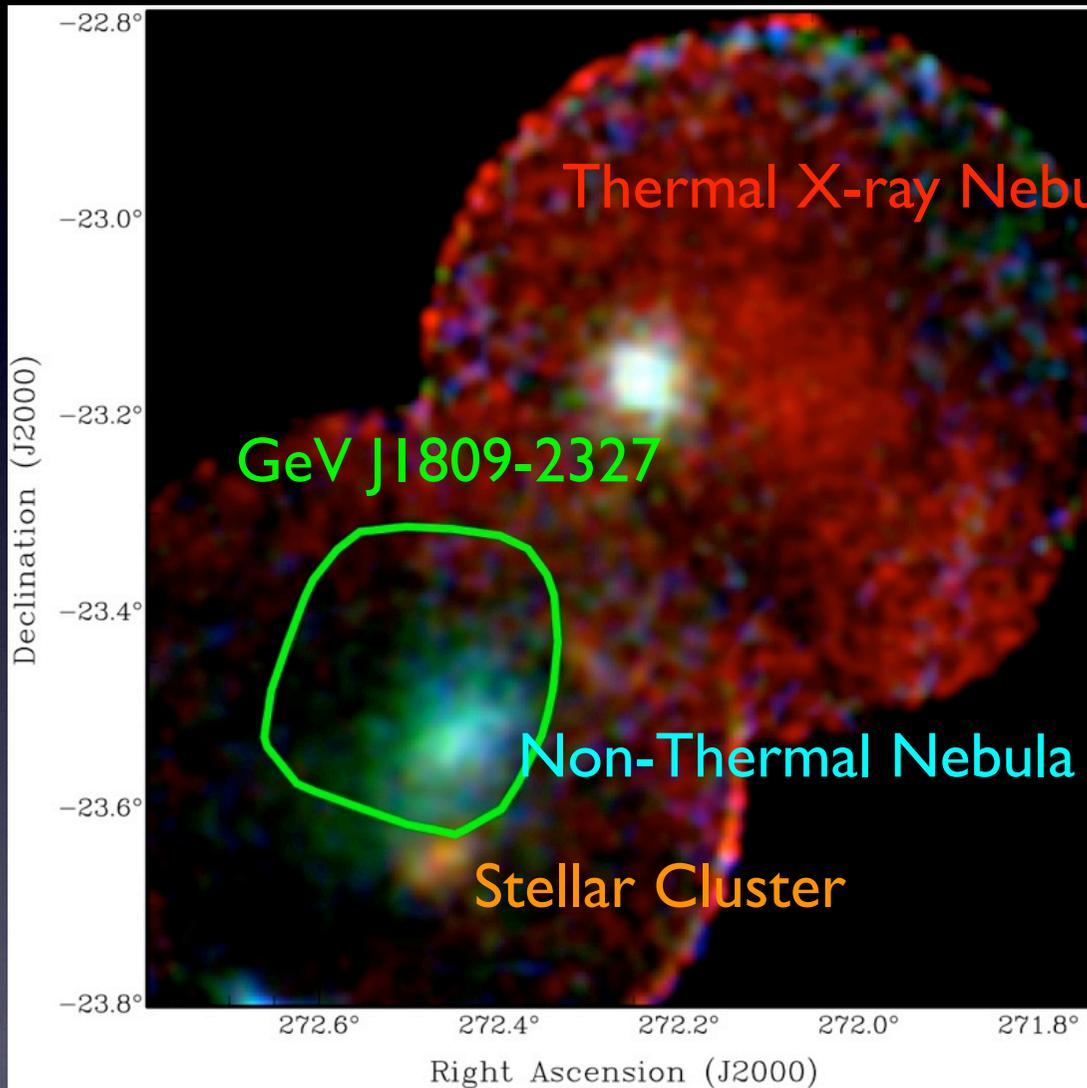
Roberts, Romani & Kawai 2001

CRAB PWN Spectrum



GeV J1809-2327: A GeV Emitting PWN?

ASCA Imaging



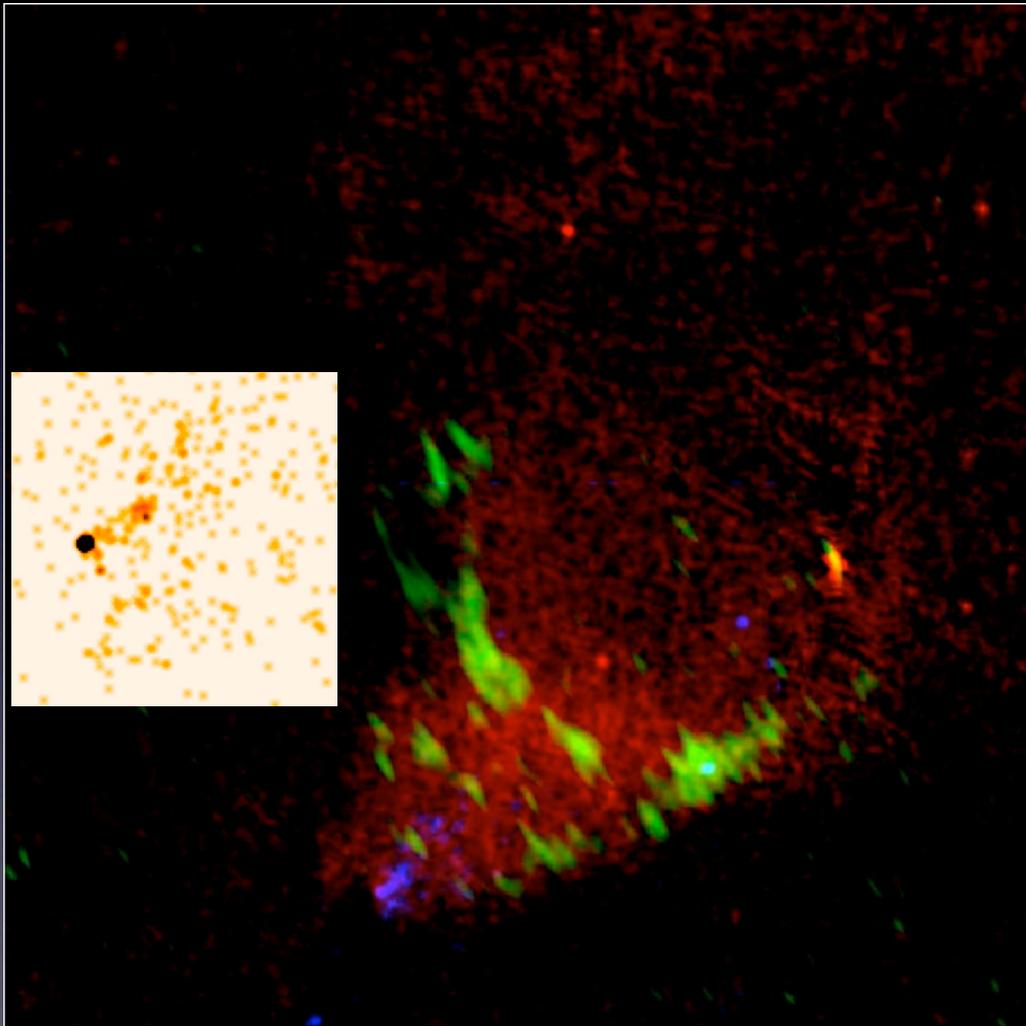
- Most prominent source in “small” GeV error box
- Most significant variability ($V_{12} = 3.93$, Nolan et al. 2003) of any low-latitude, non-AGN EGRET source

0.7-2 keV 2-10 keV 4-10 keV

Roberts et al. 2001, Roberts & Brogan 2008



Taz: A GeV Emitting RPWN?



- Radio Nebula with spectrum and polarization of PWN
- Short Chandra image resolved point source with trail
- Deep radio searches with Parkes and GBT did not detect pulsations to < 0.05 mJy @ 1400MHz

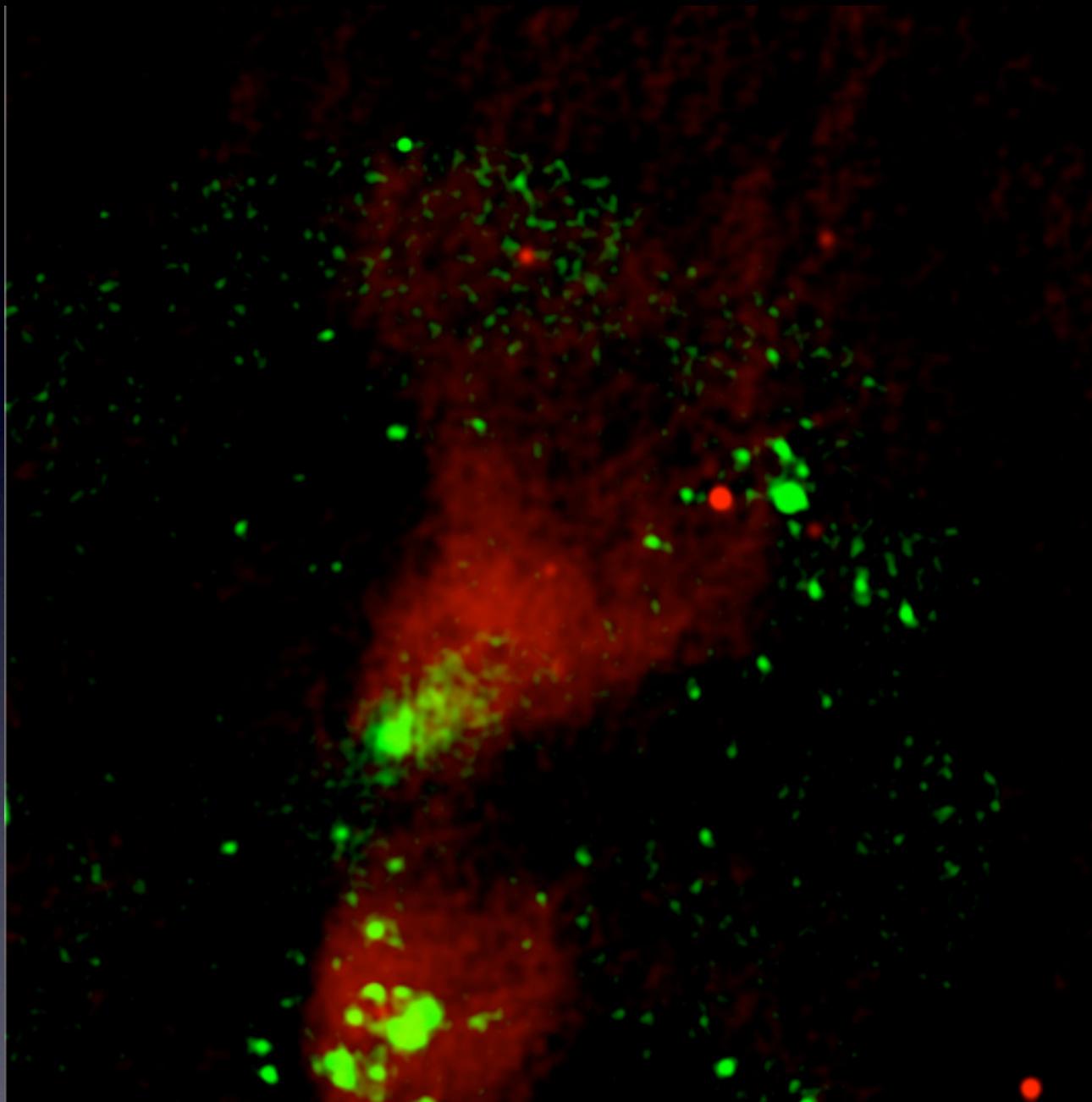
Braje et al. 2002, Roberts et al. in prep

Radio Continuum

Polarized Radio

Non-Thermal X-Ray

Taz: A GeV Emitting RPWN?



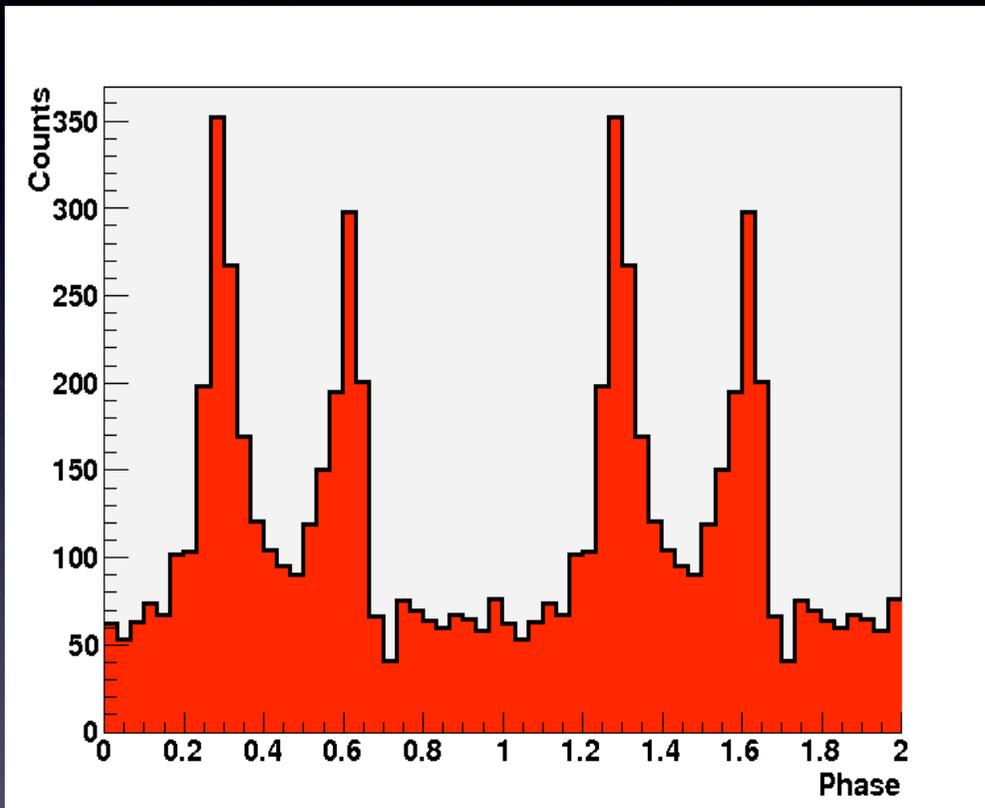
20cm radio

0.5-10 keV X-rays



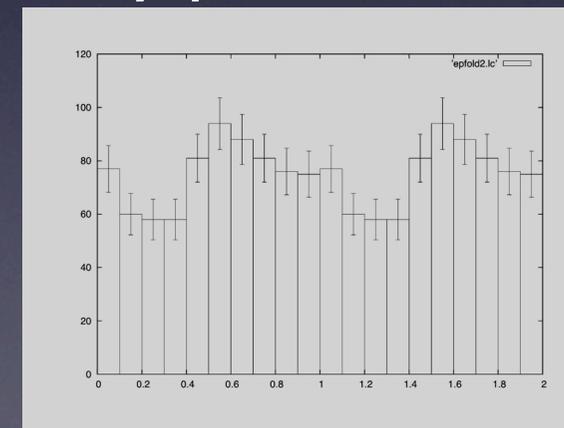
Taz Pulsar Discovered in Blind Search of Fermi data

- Moderate $\dot{E} \sim 4 \times 10^{35}$
- $\tau = 68$ kyr
- No radio means no DM distance, no radio phase, no polarization sweep
- Trail morphology means no geometrical constraint
- X-Ray pulsations helpful?



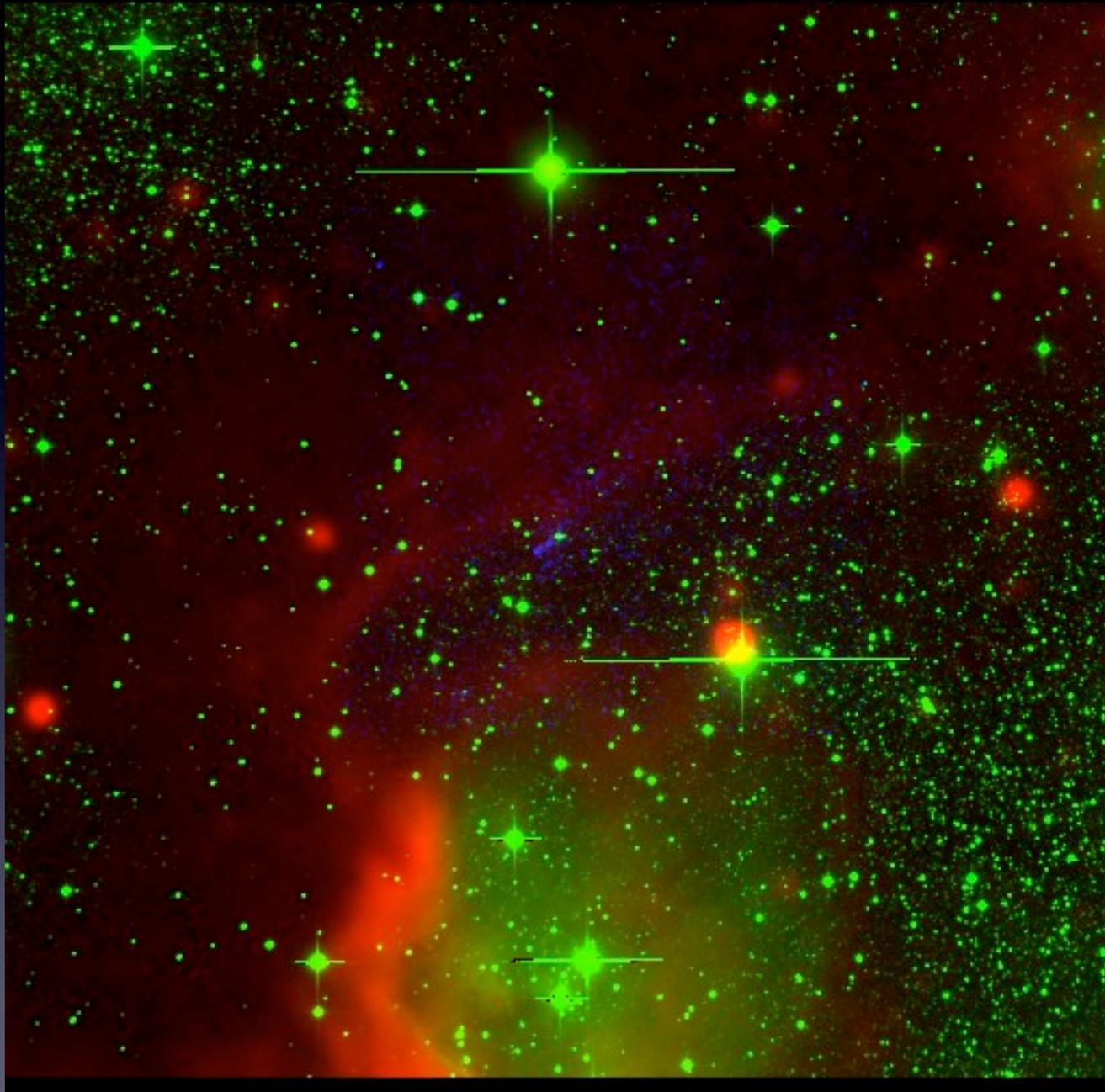
Fermi Light Curve

Abdo et al. 2009



2σ 'detection' of thermal X-ray pulsations with 70ks XMM PN

Distance from Cloud Interaction?



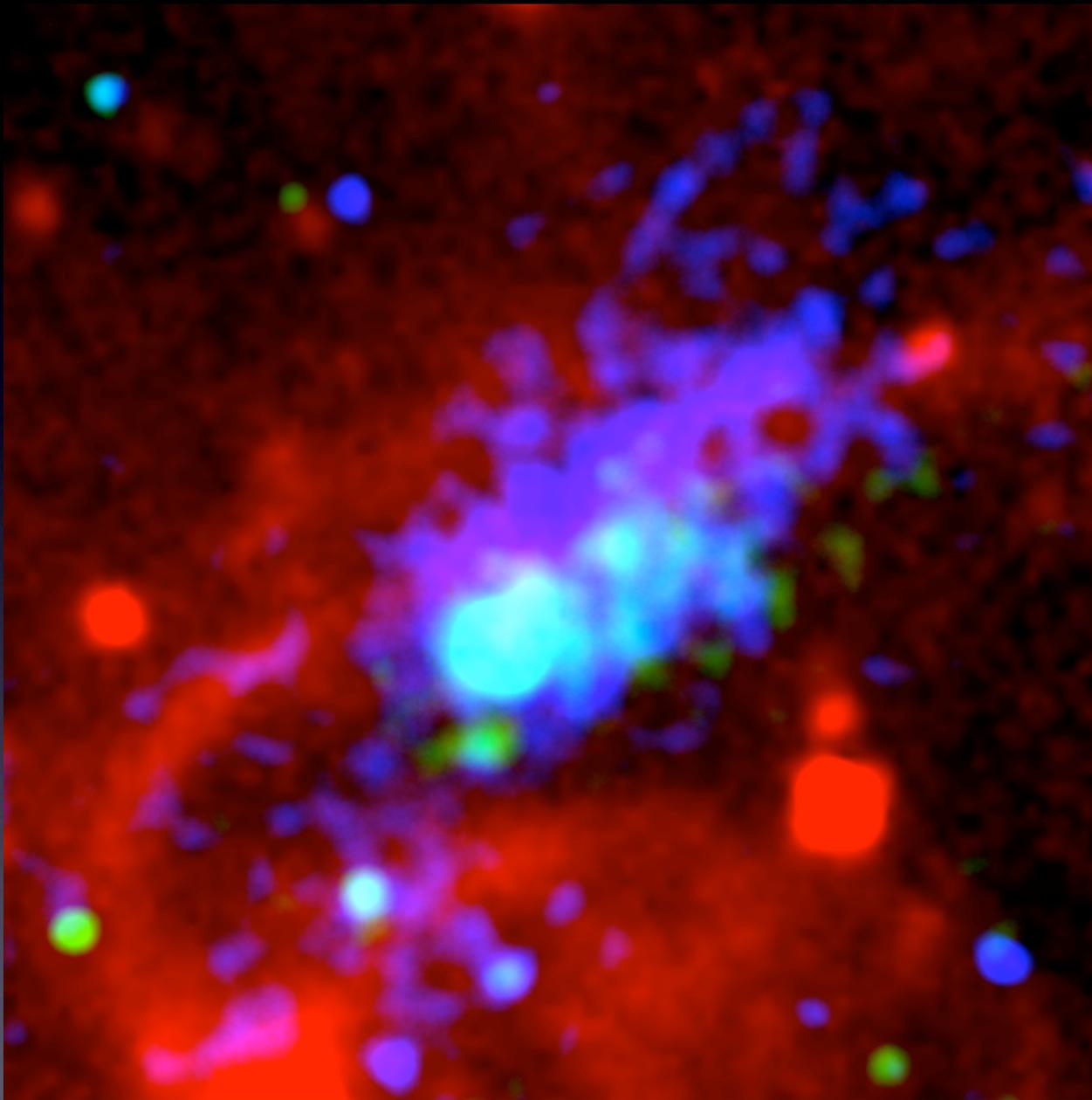
Lynds
227
Dark
Cloud
at
 $D=1.7\text{kpc}$

Mid-Infrared 8.3μ

Optical

Non-Thermal X-rays

Taz Cloud Interaction?



Mid-Infrared 8.3μ 0.5-2.5 keV X-rays 2.5-8 keV X-rays



G7.4-1.4: Mixed-Morphology SNR

Thermal X-rays

SNR radio shell

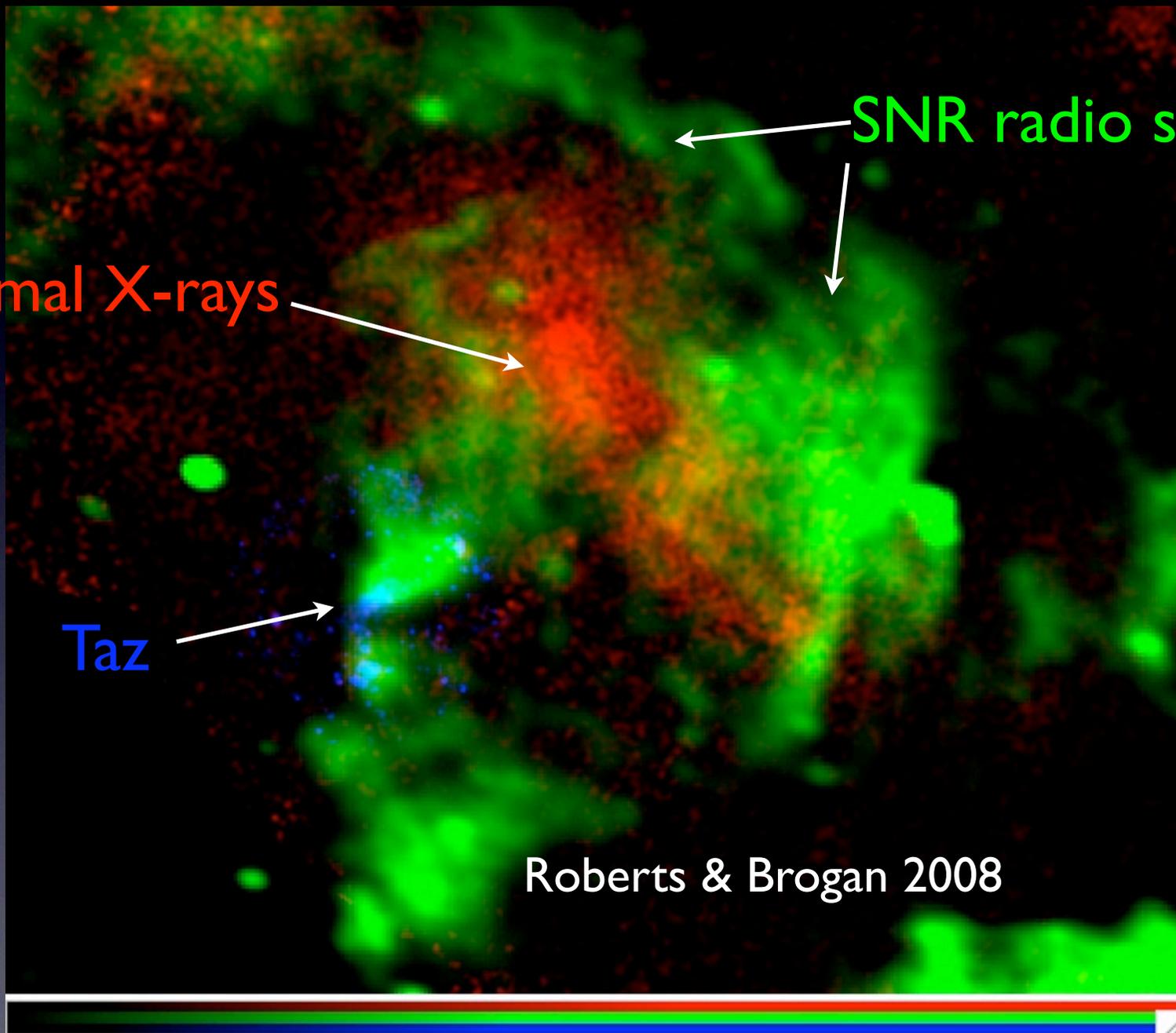
Taz

Roberts & Brogan 2008

ROSAT 0.1-2.4 keV

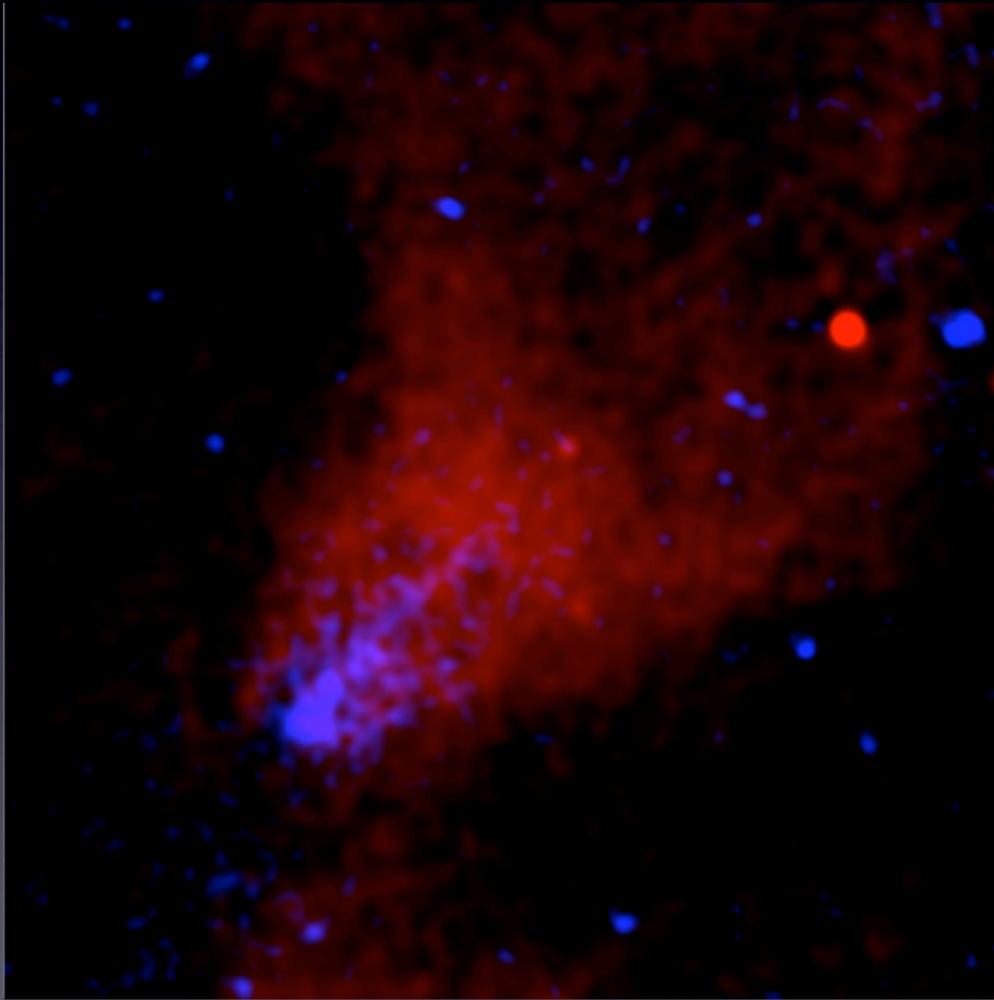
90cm Radio

2.5-8 keV X-rays





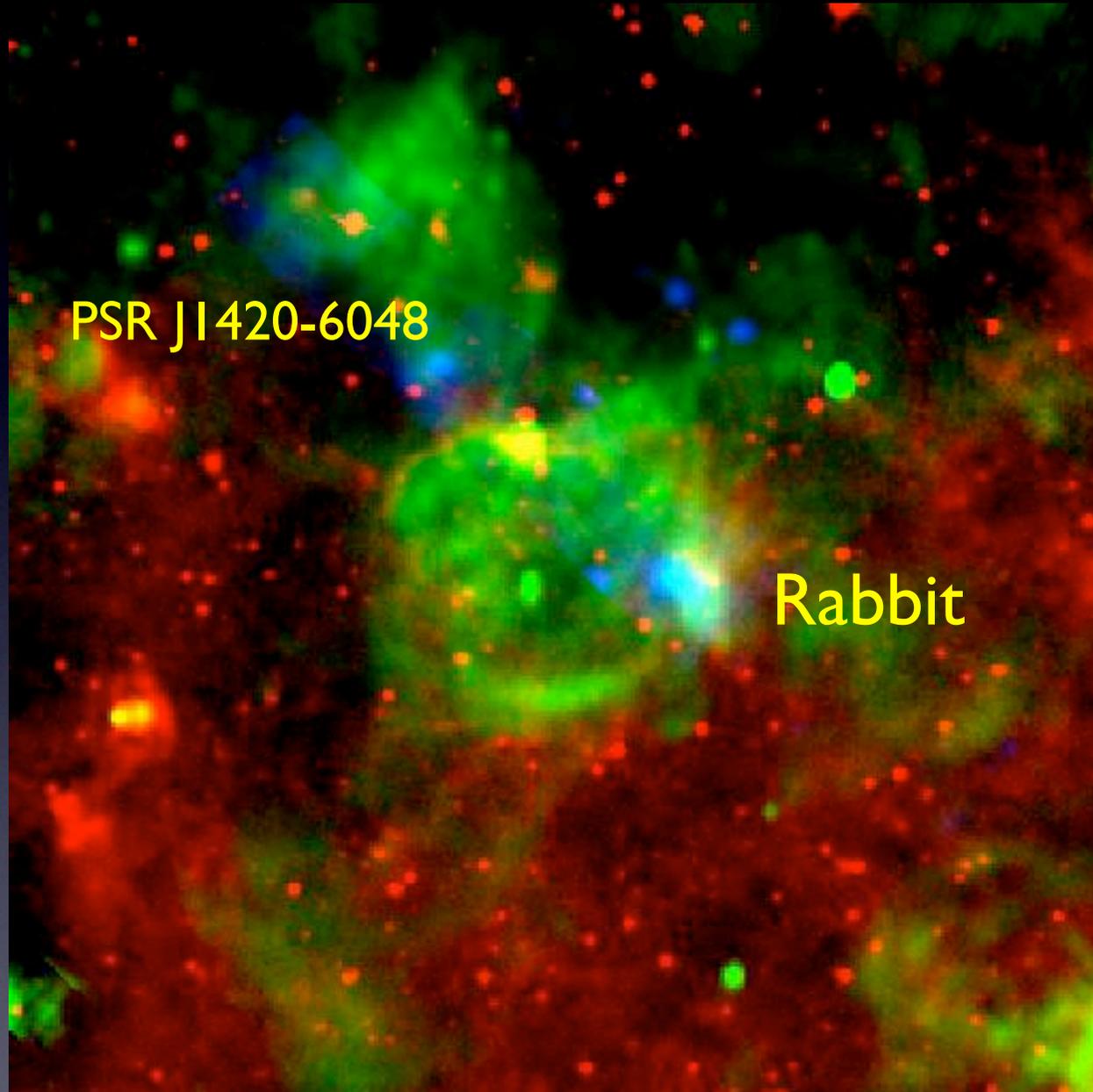
Taz -- A Very Efficient Pulsar in a Mixed-Morphology SNR



- γ -ray efficiency $\gtrsim 25\%$ (assuming isotropic emission)
- PWN $L_{2-10\text{keV}} > 2.5 \times 10^{33}$ erg/s (0.6% efficiency)
- Age ~ 50 ks consistent with MMSNR and moderate $V_T \sim 200$ km/s
- 5 of the 30 brightest GeV EGRET sources are within MMSNR, 4 have PWN, 2 have radio quiet Fermi pulsars

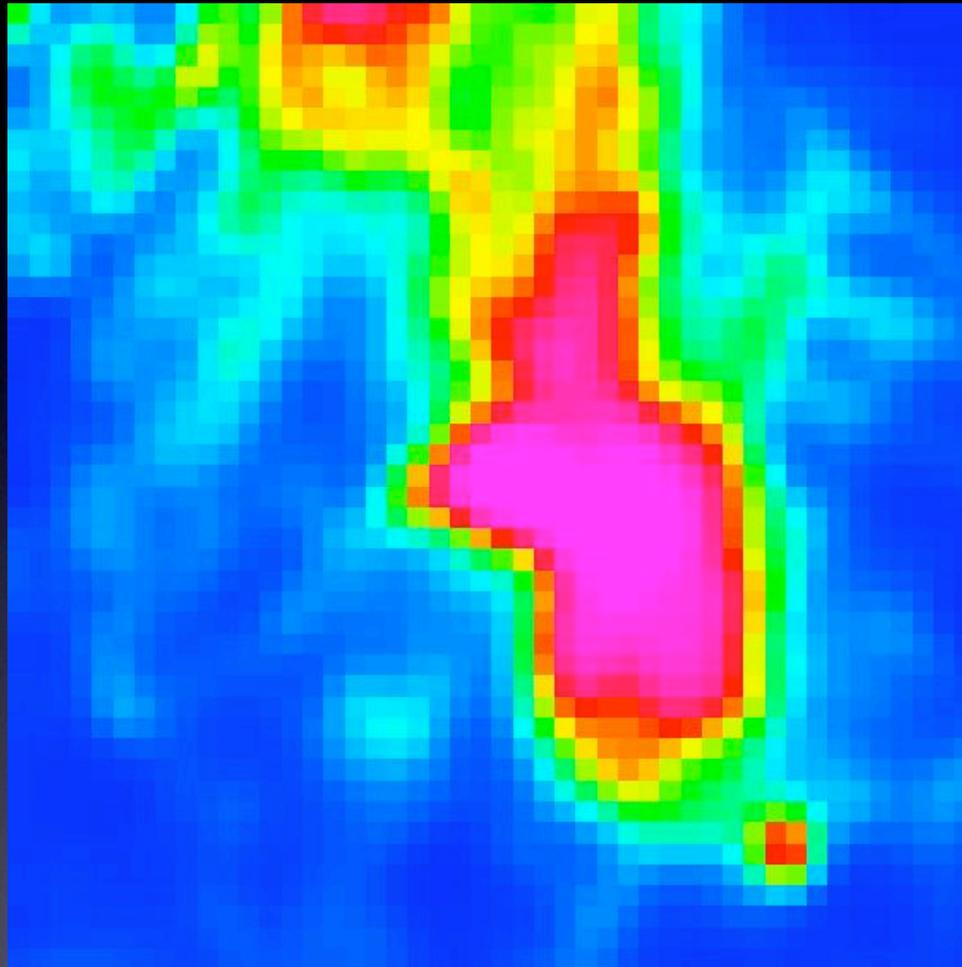
20cm radio 2.5-8 keV X-rays

The Kookaburra



Mid-Infrared 8.3μ Radio Continuum Non-Thermal X-rays

The Rabbit!



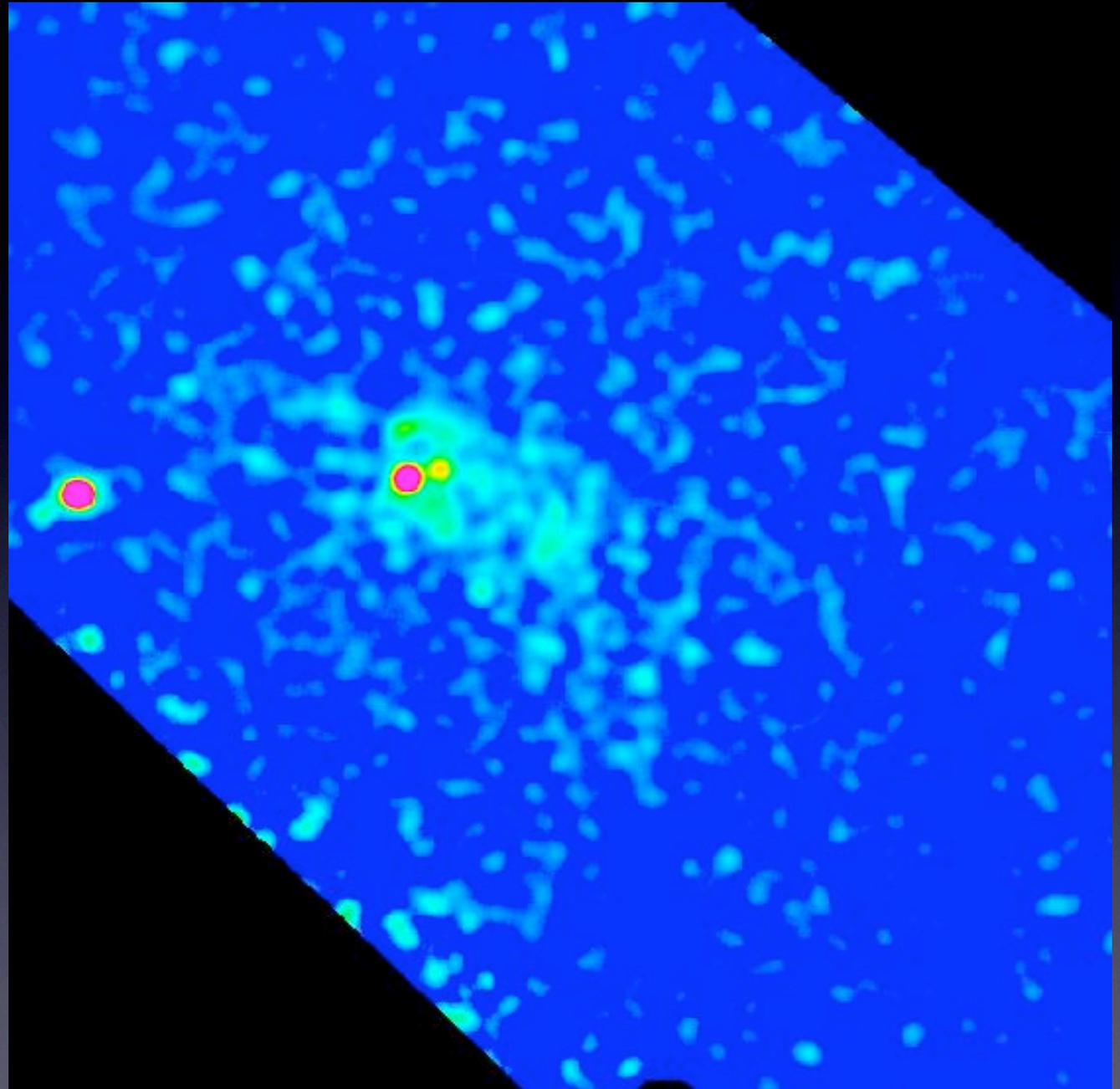
13 cm radio (Roberts et al. 1999)

Chandra 1-7 keV X-Ray Rabbit RPWN?



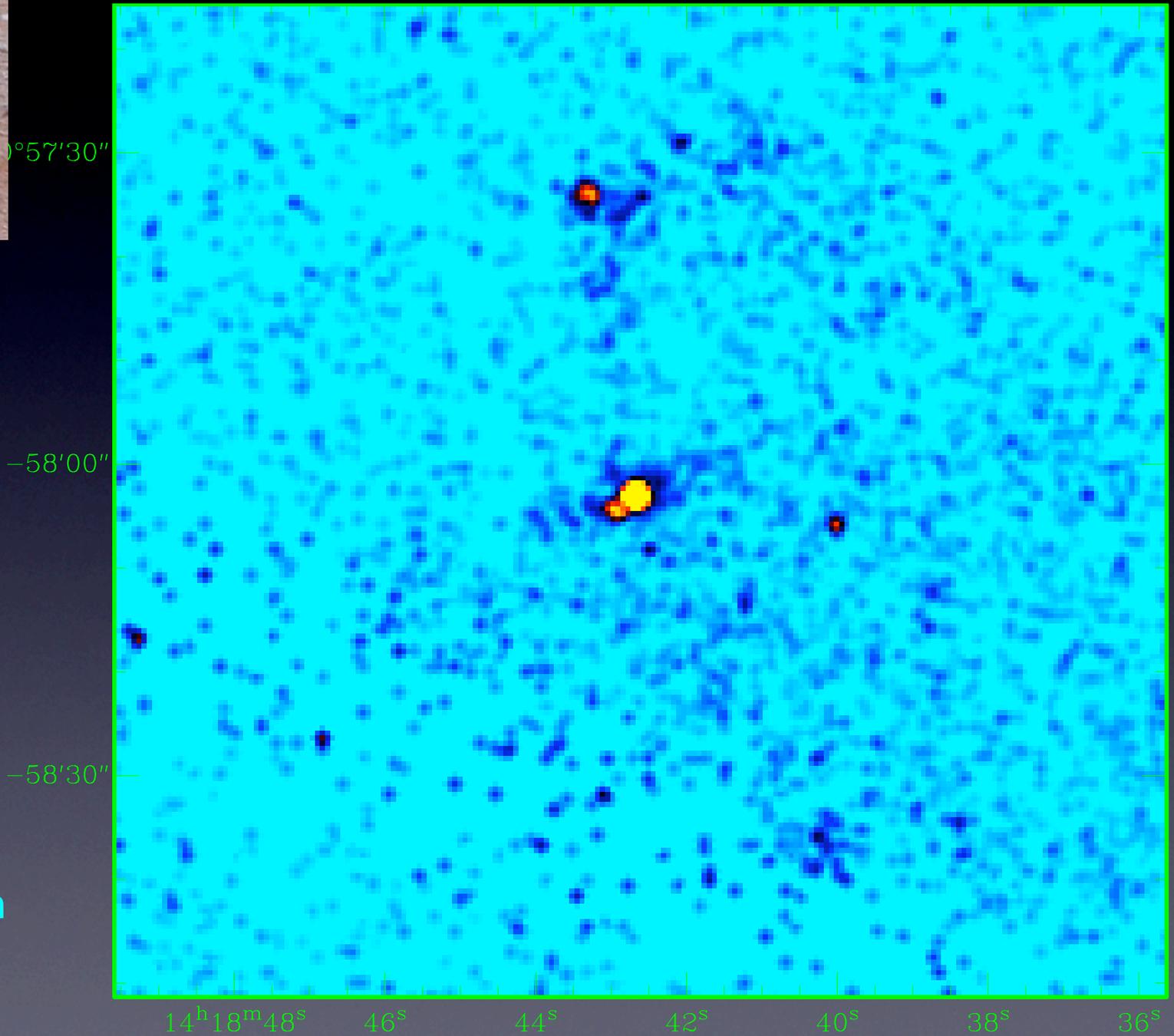
~20 ks

(10 ks on
source with
high resolution)



Ng, Roberts & Romani 2005

The Rabbit RPWN?



1-7 keV

$\sigma=1$

ACIS-I

75ks

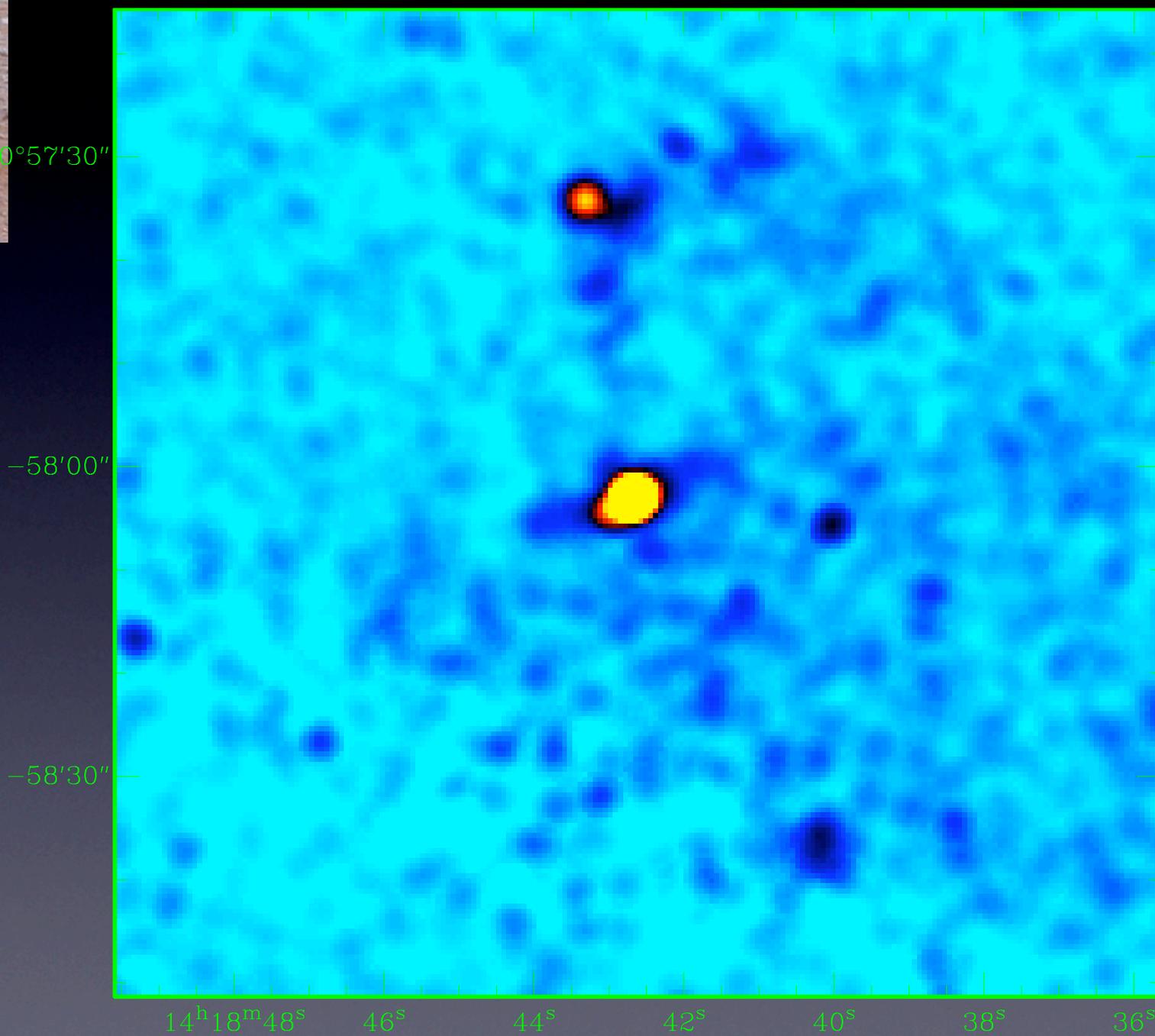
(Roberts et al. in
prep)

The Rabbit RPWN?

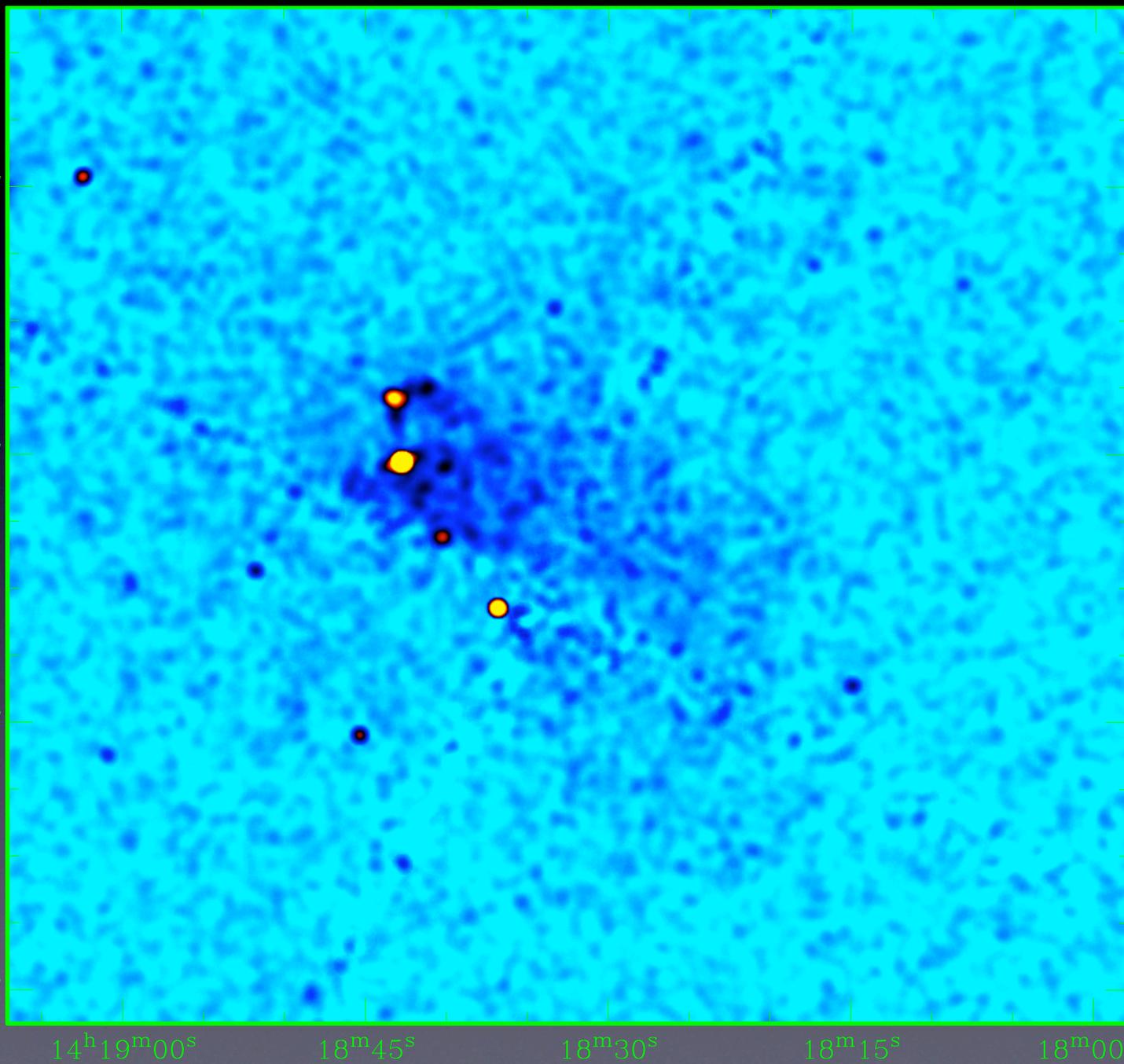


1-7 keV

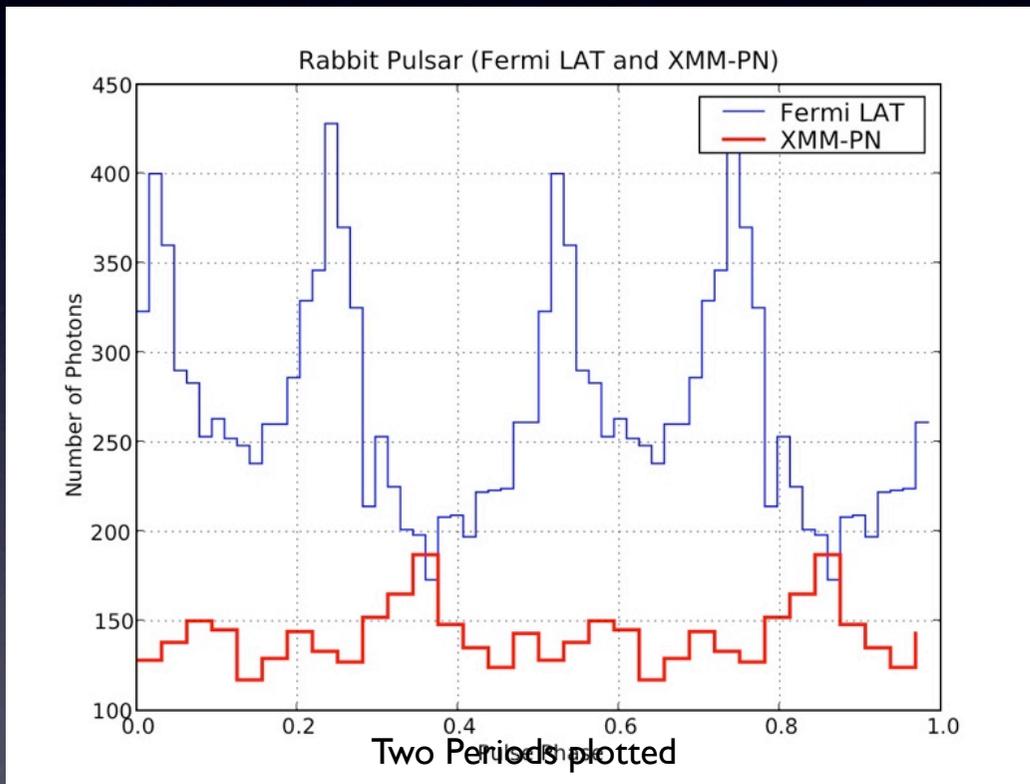
$\sigma=2.5$



The Rabbit RPWN?



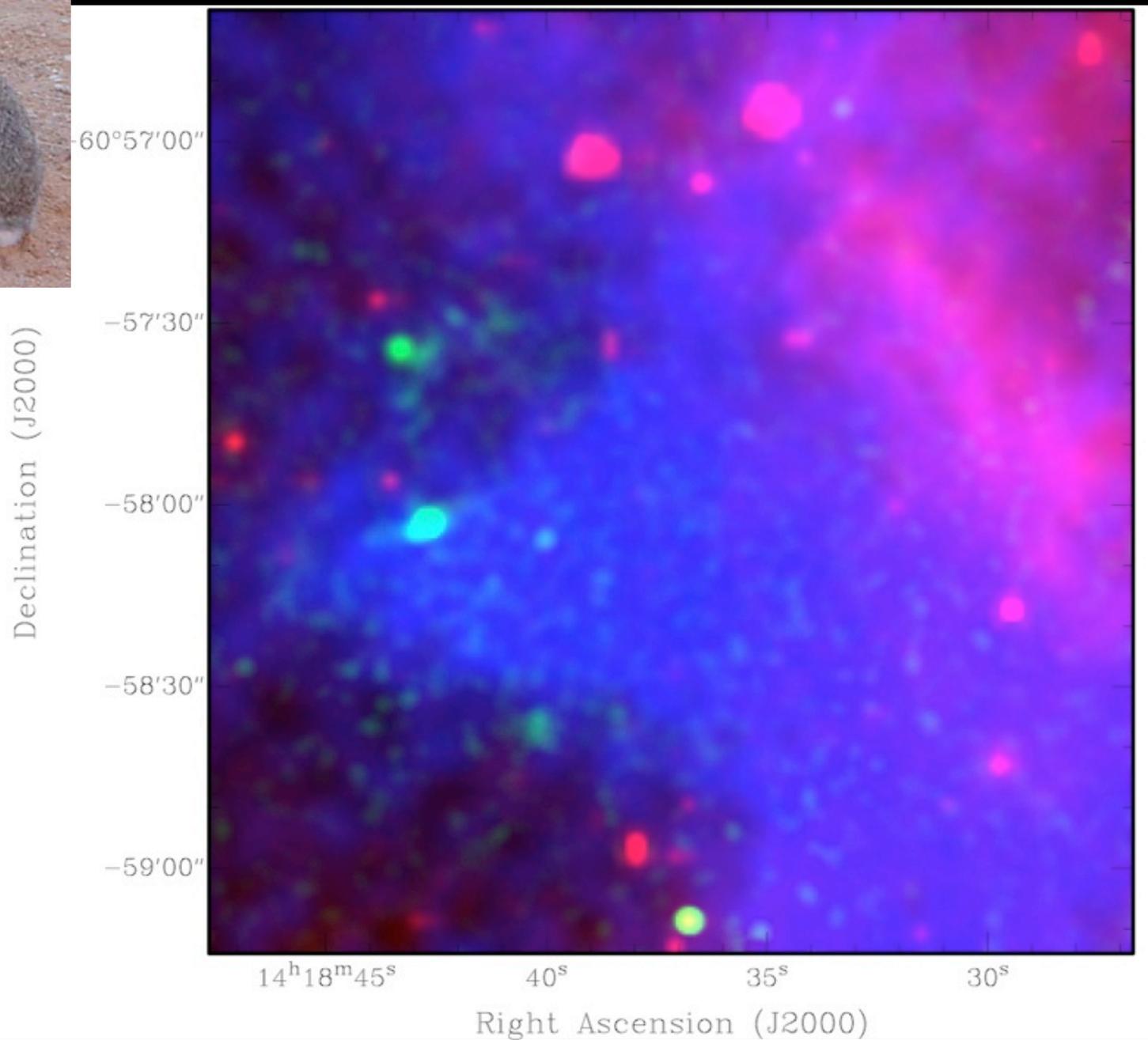
Rabbit Pulsar Discovered in Blind Search of Fermi data!



- Energetic $\dot{E} \sim 5 \times 10^{36}$ erg/s
- $\tau = 10$ kyr
- No radio means no DM distance, no radio phase, no polarization sweep
- “Torus and Jet” morphology suggest spin axis in plane of sky?
- Hard X-Ray pulsations Found!

Fermi and XMM Light Curves
nb. phase alignment off by 0.04 (one leap second)

In the Paw of the Rabbit

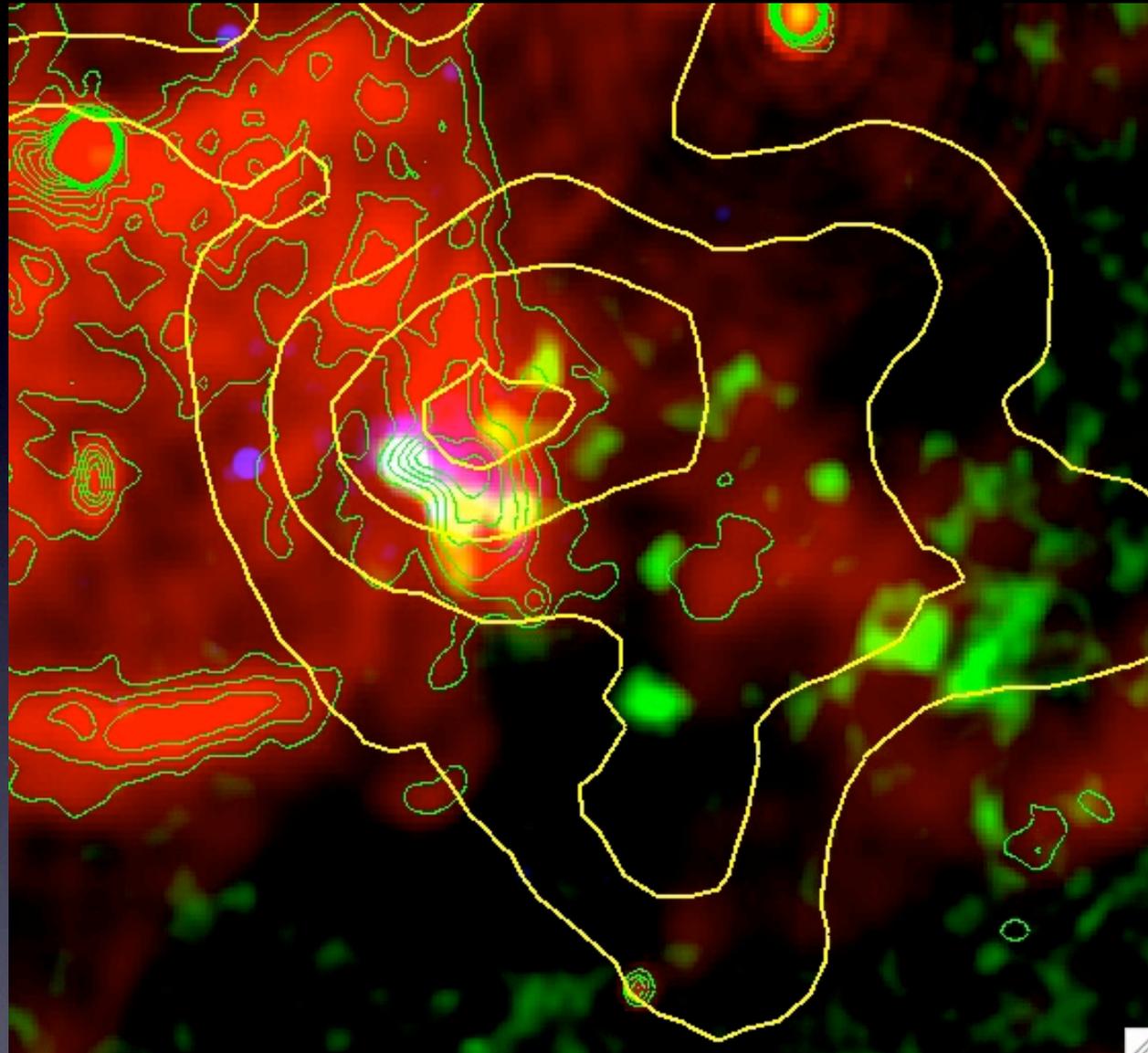


Spitzer 8 micron

Chandra 1-7 keV

ATCA 20cm radio

Lower Wing Containing Rabbit ALSO A TeV SOURCE!



HESS
J1418-609
peaks on
other side of
infrared
ridge

20cm Radio

Polarized Radio

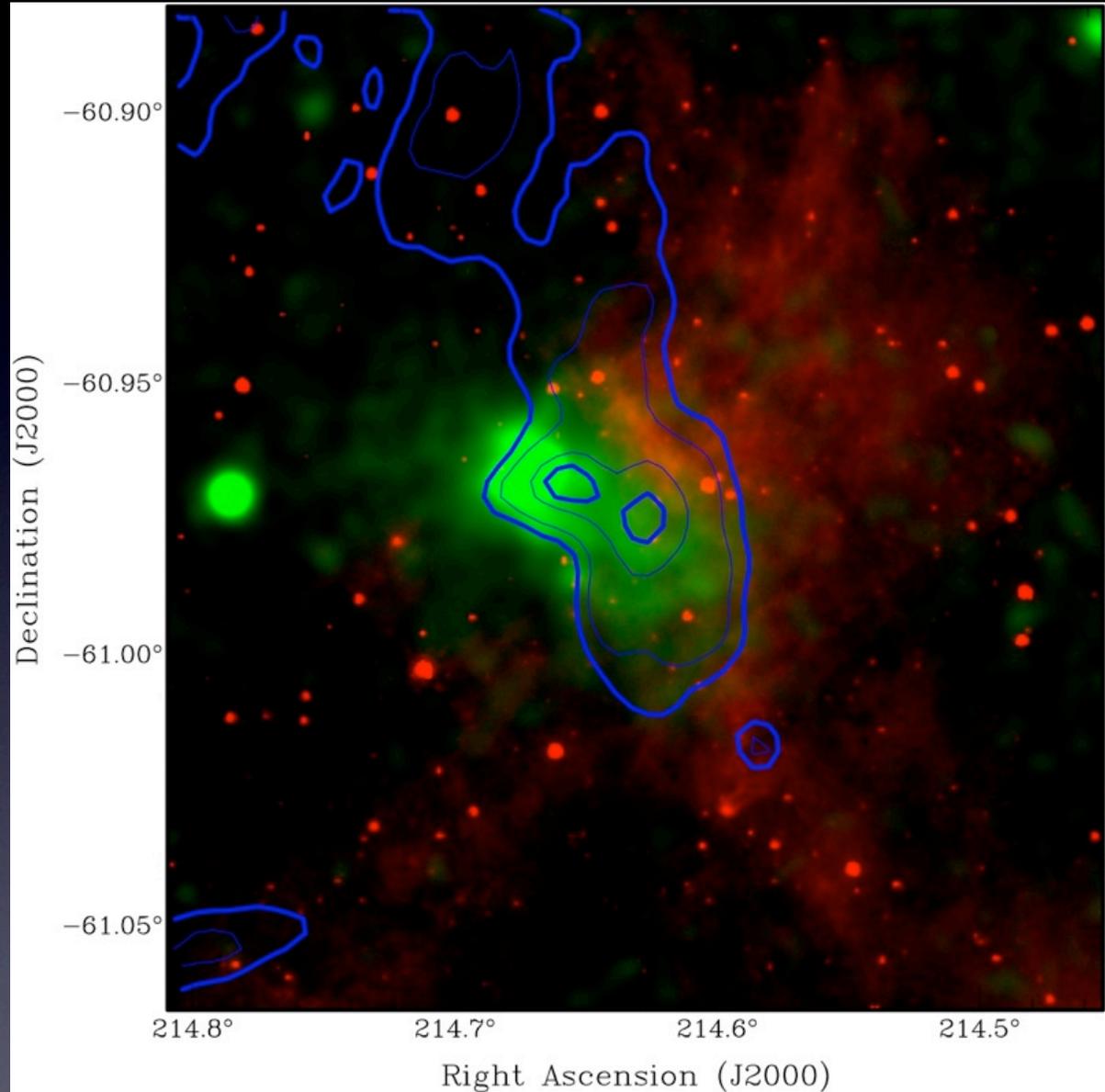
Hard X-ray

Off With His Head?



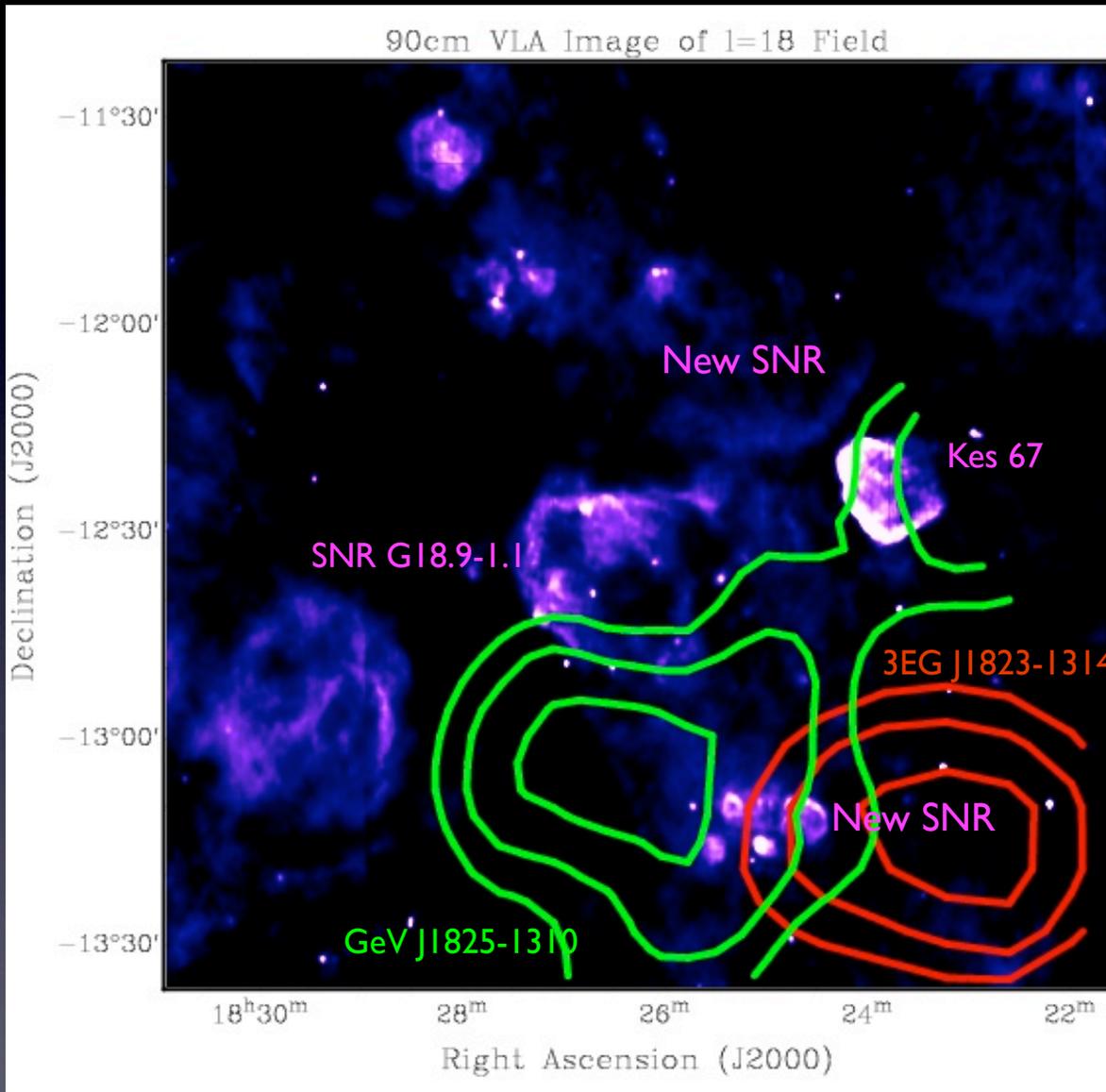
Mid-IR “wall”
bounds non-
thermal X-rays

Are the ears just
part of the
Kookaburra
shell?



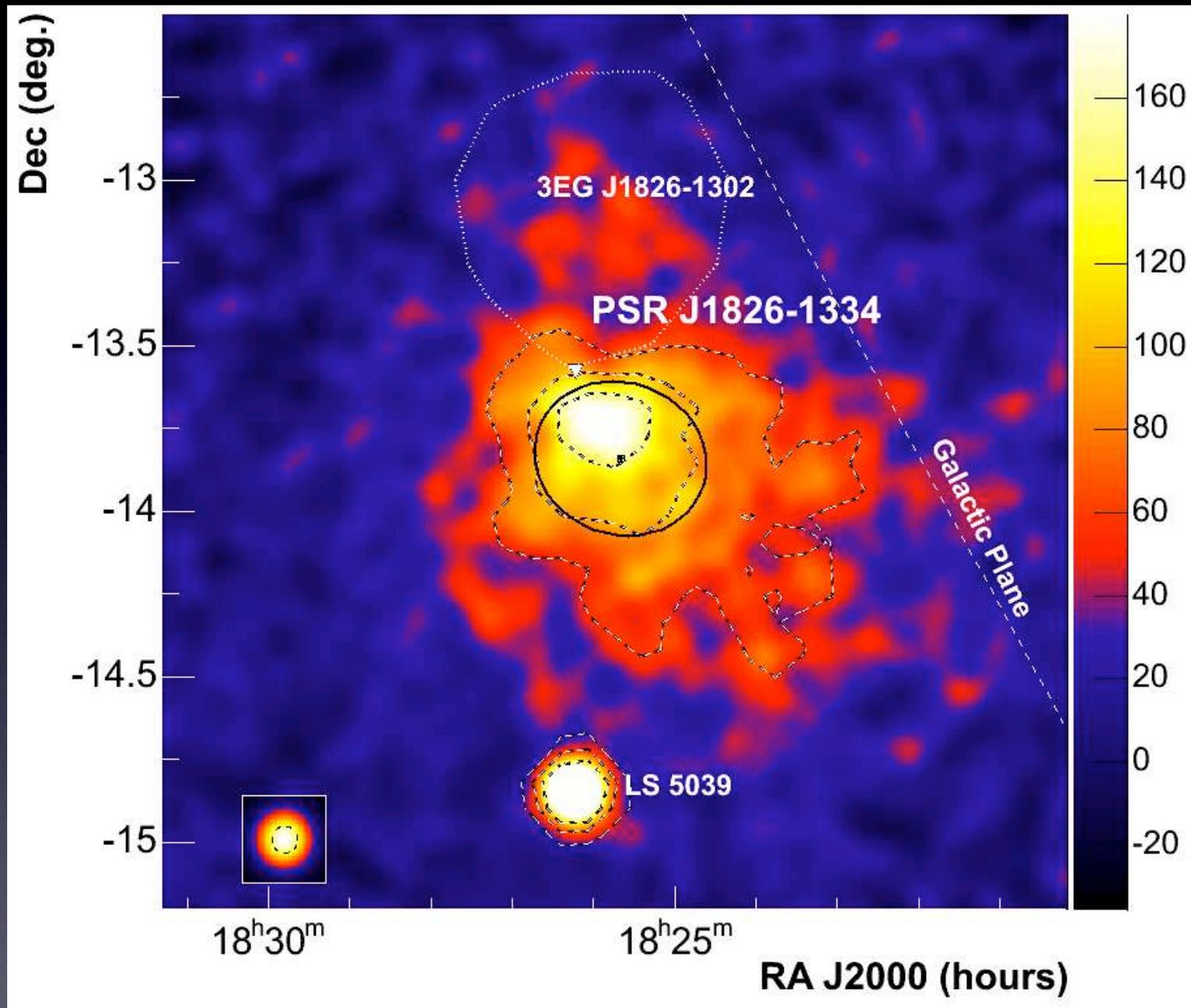
Spitzer 8μ XMM 0.8-8keV | 3cm radio

$l=18^\circ$ Sources



- Complex region with at least 2 EGRET (GeV) sources and a bright unidentified, variable Comptel (MeV) source.
- GeV J1825-1310 (3EG J1826-1302) probably variable (second highest $V_{12}=3.22$)
- 20 and 90cm imaging resolve at least 4 SNR, 2 of them new, as well as many molecular clouds and some other structures

TeV source(s) seen with HESS



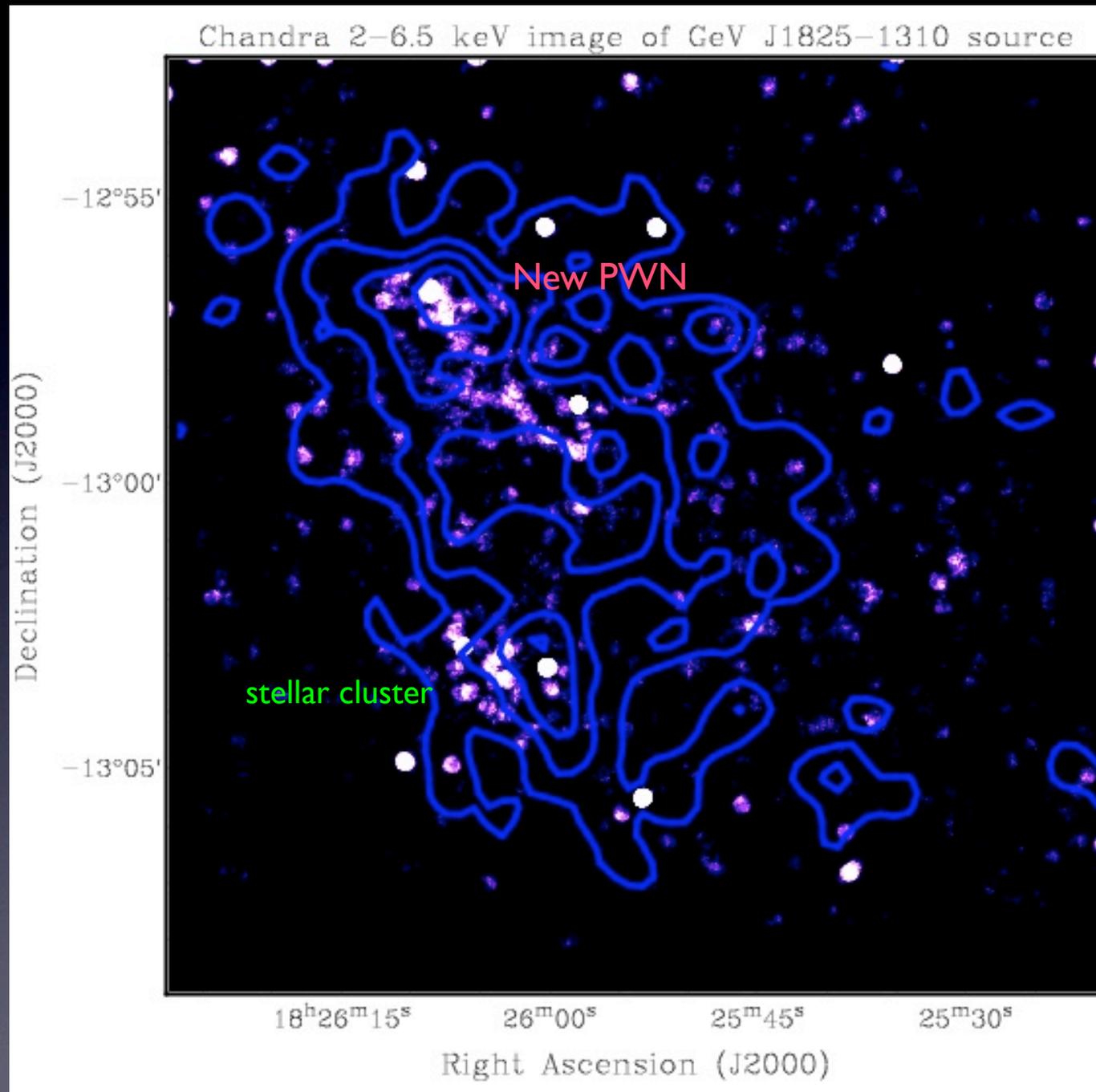
Aharonian et al. 2006

The Eel X-ray RPWN in GeV J1825-1310

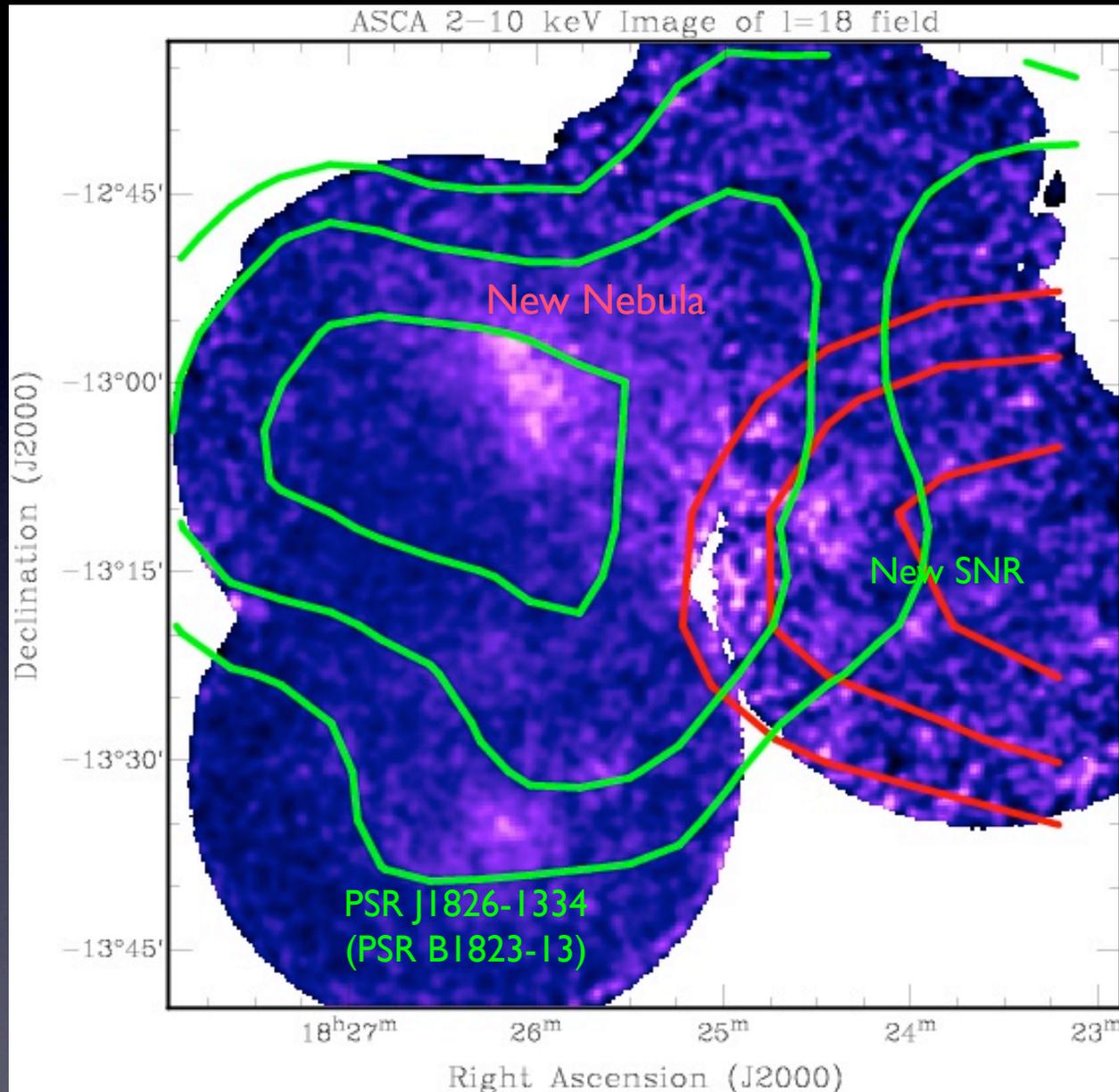


Chandra
15ks
2-6.5 keV

ASCA
Contours



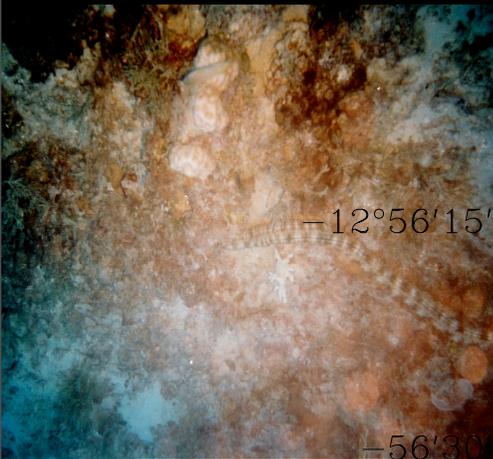
GeV J1825-1310



ASCA
2-10 keV

Roberts, Romani & Kawai 2001

The Eel torus+jet?



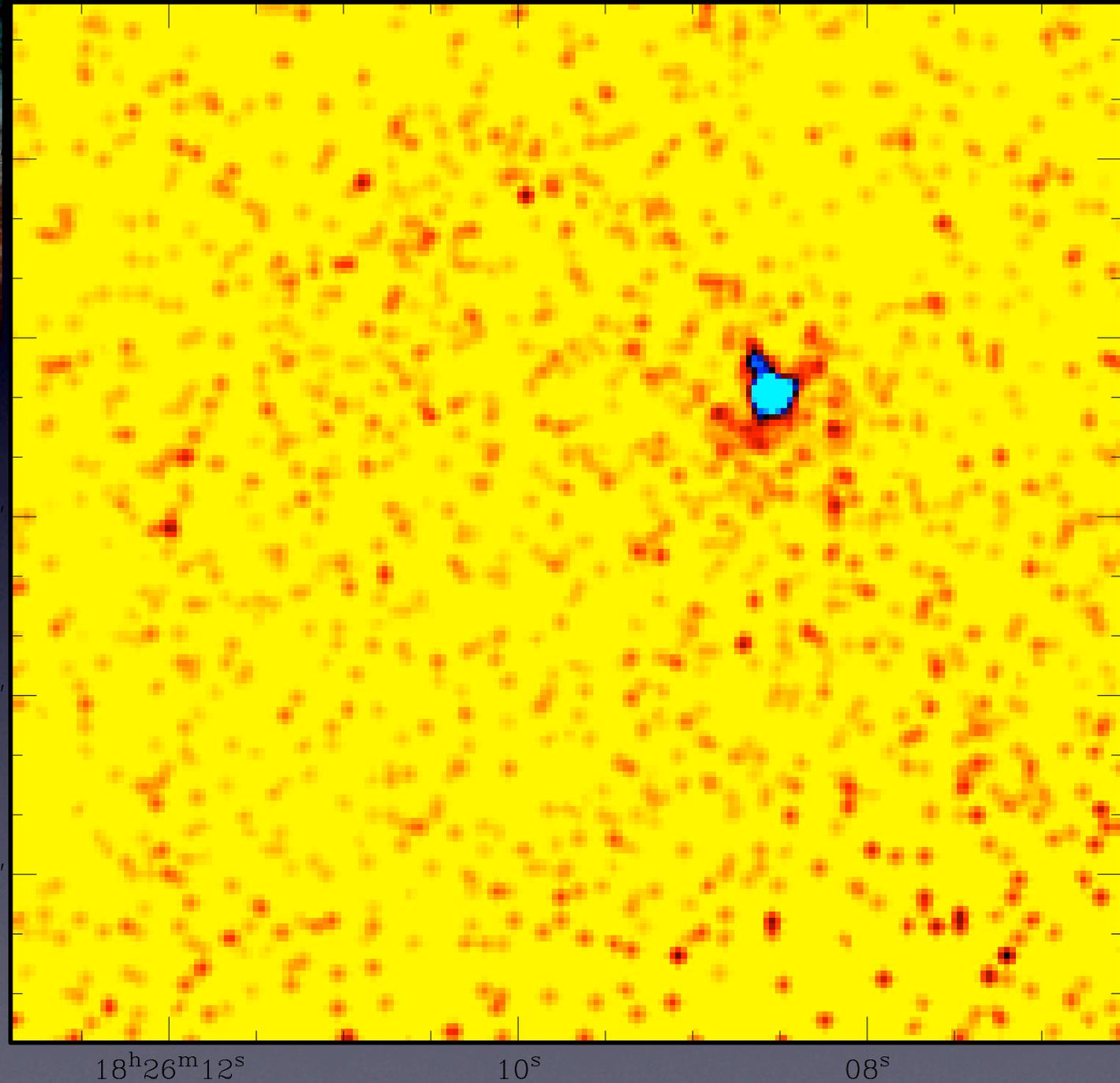
1-7 keV

$\sigma=1$

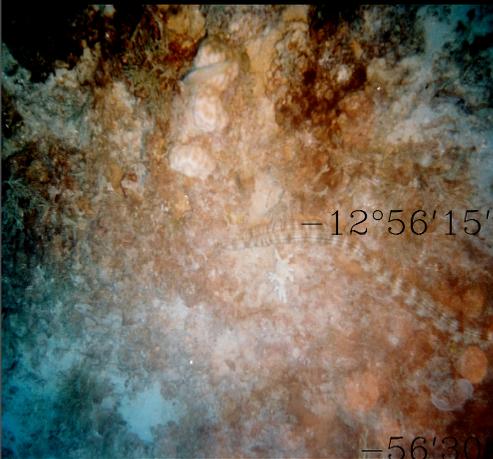
ACIS-I

75ks

(Roberts et al.
in prep)



The Eel torus+jet?



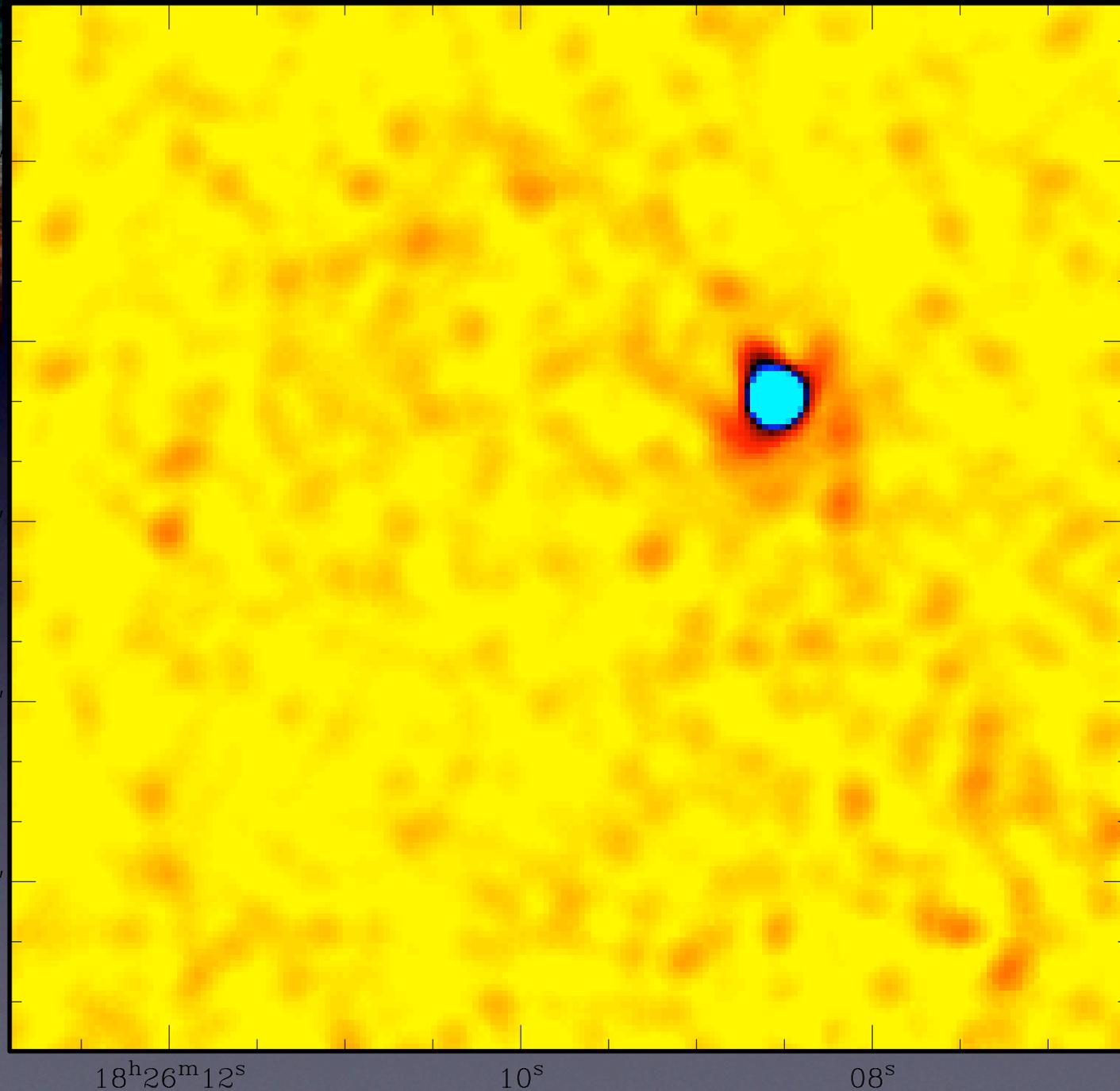
1-7 keV

$\sigma=2.5$

-56'45"

-57'00"

-57'15"



The Eel RPWN?



-12°56'

-12°57'

1-7 keV

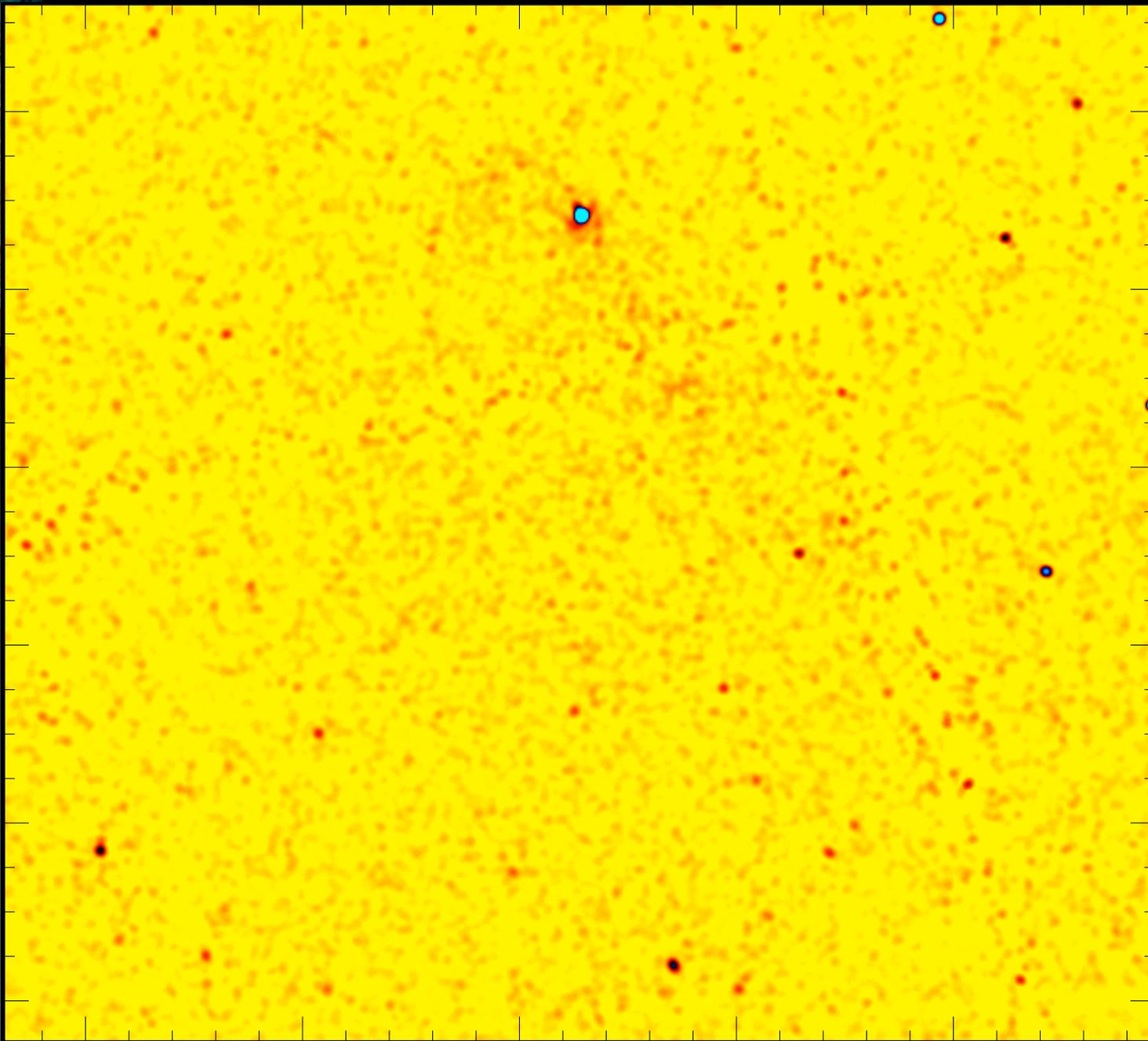
$\sigma=2.5$

-12°58'

-12°59'

-13°00'

-13°01'



18^h26^m20^s

26^m15^s

26^m10^s

26^m05^s

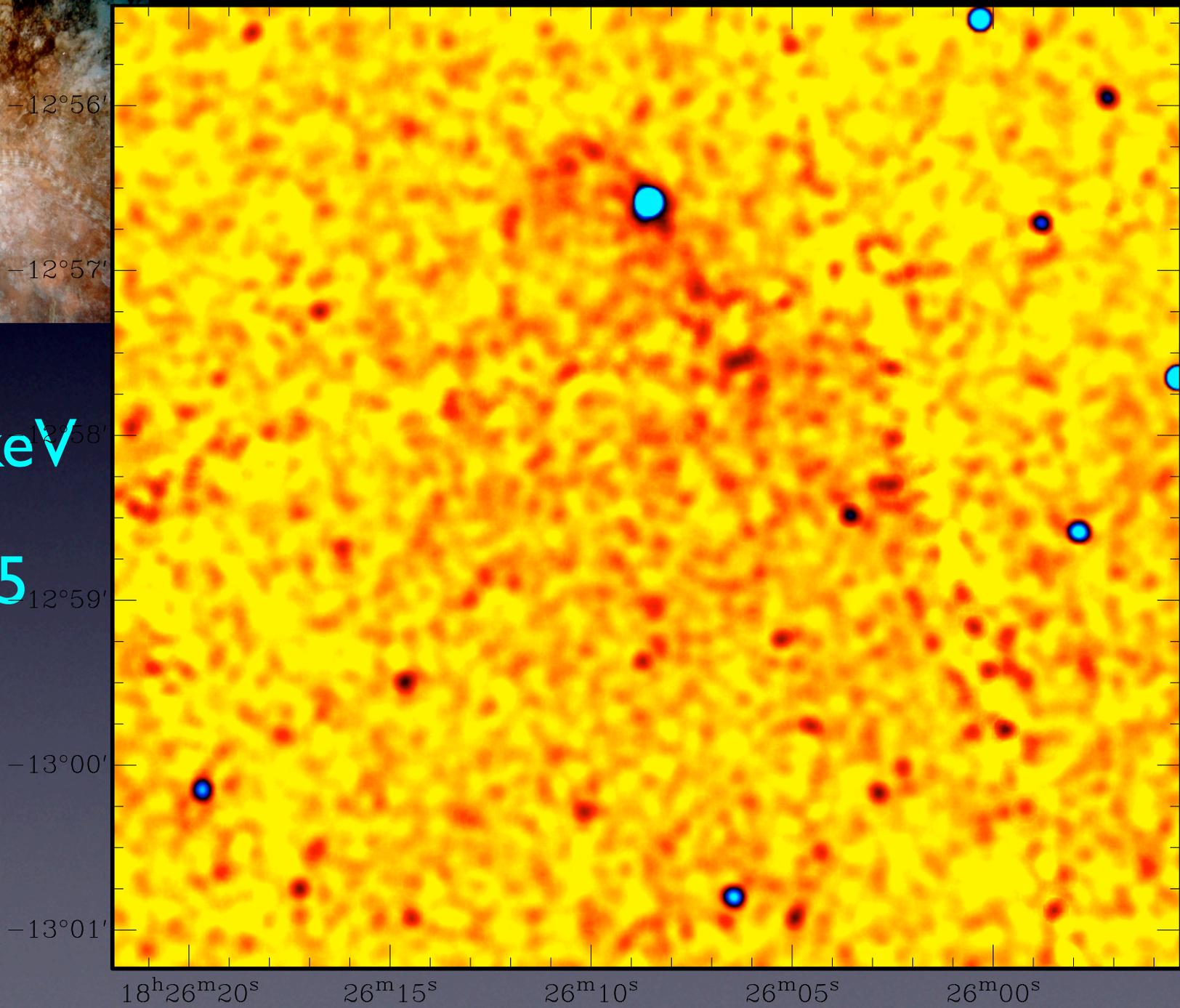
26^m00^s

The Eel RPWN?



1-7 keV

$\sigma=5$

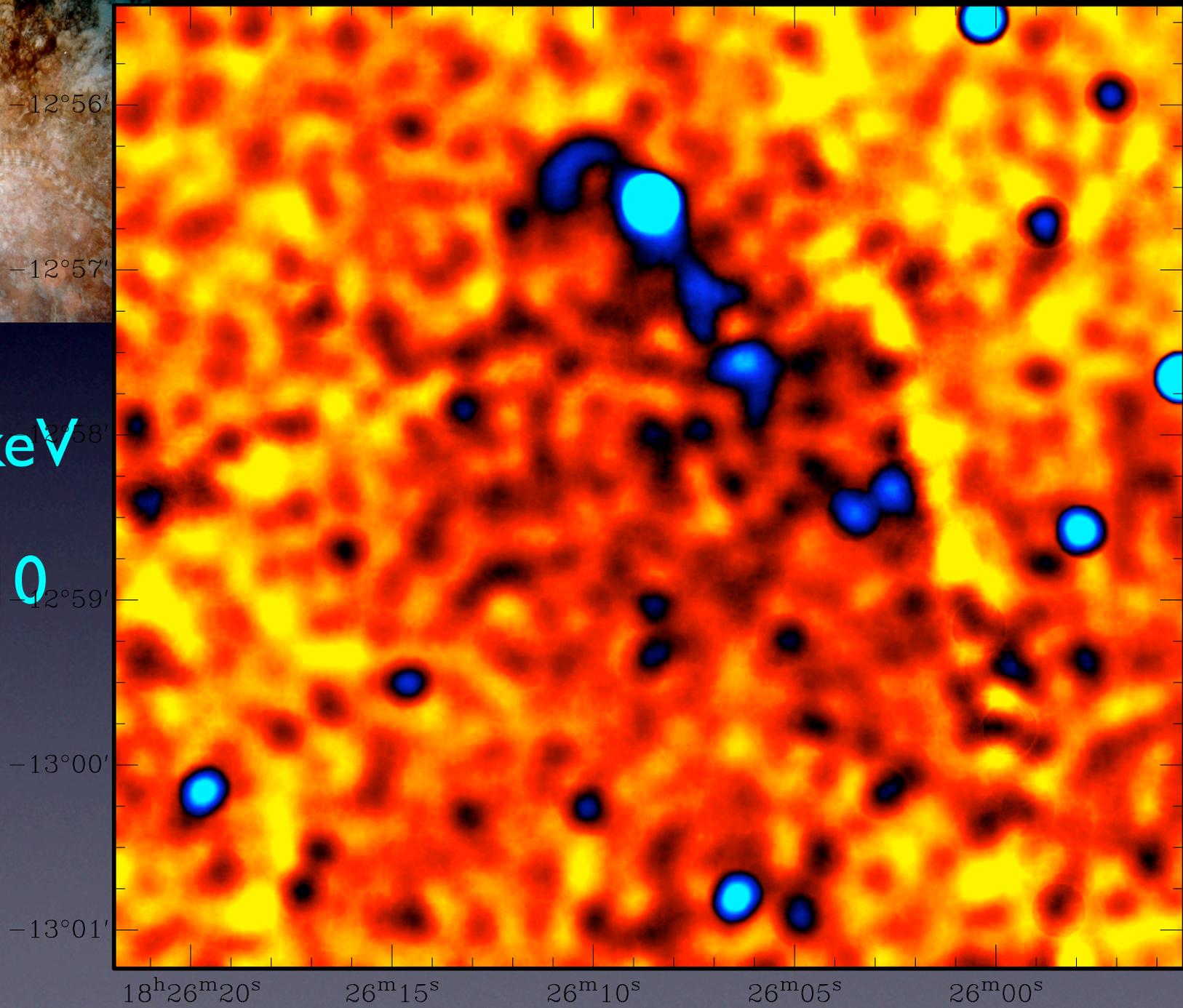


The Eel RPWN?



1-7 keV

$\sigma=10$

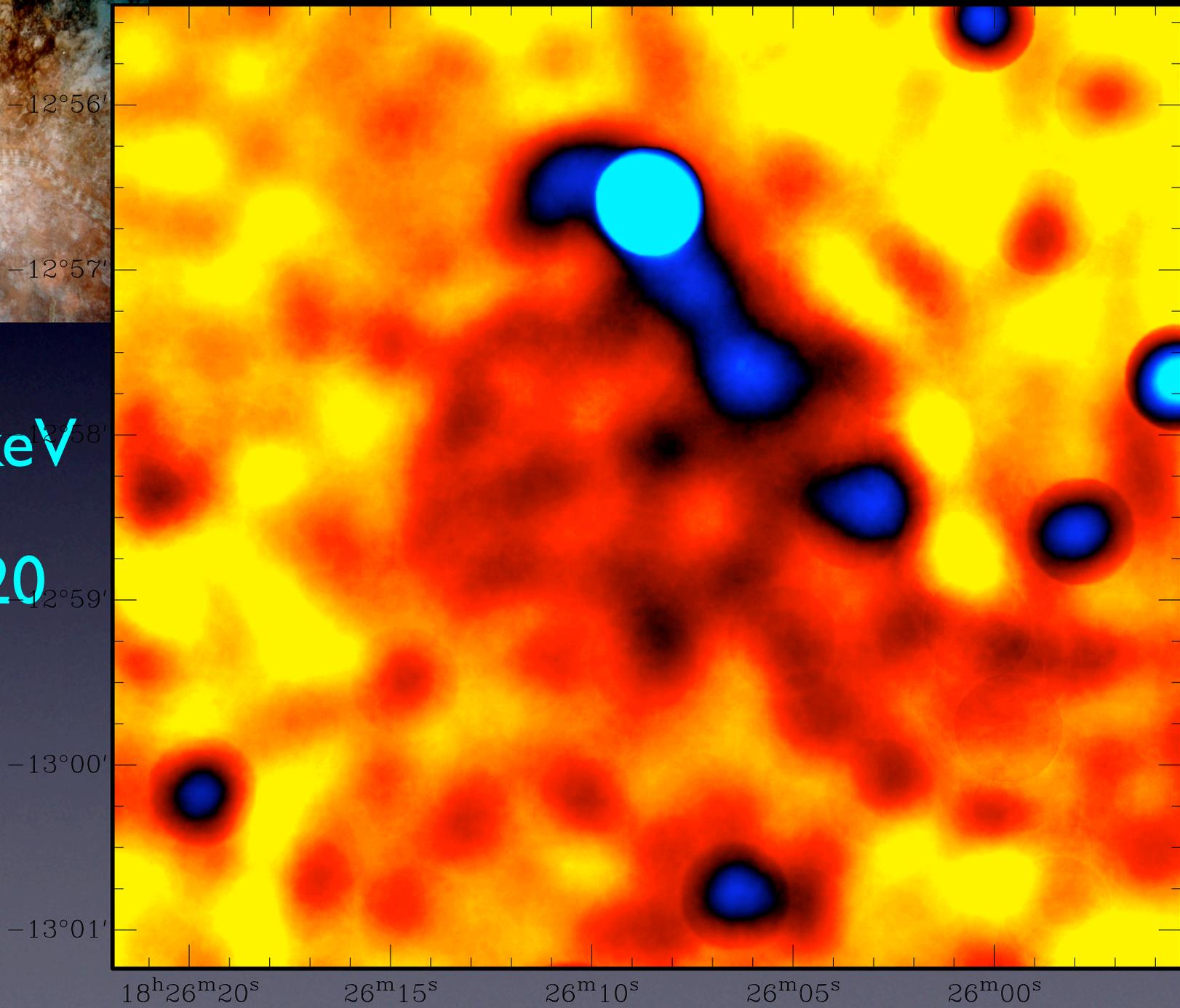


The Eel RPWN?



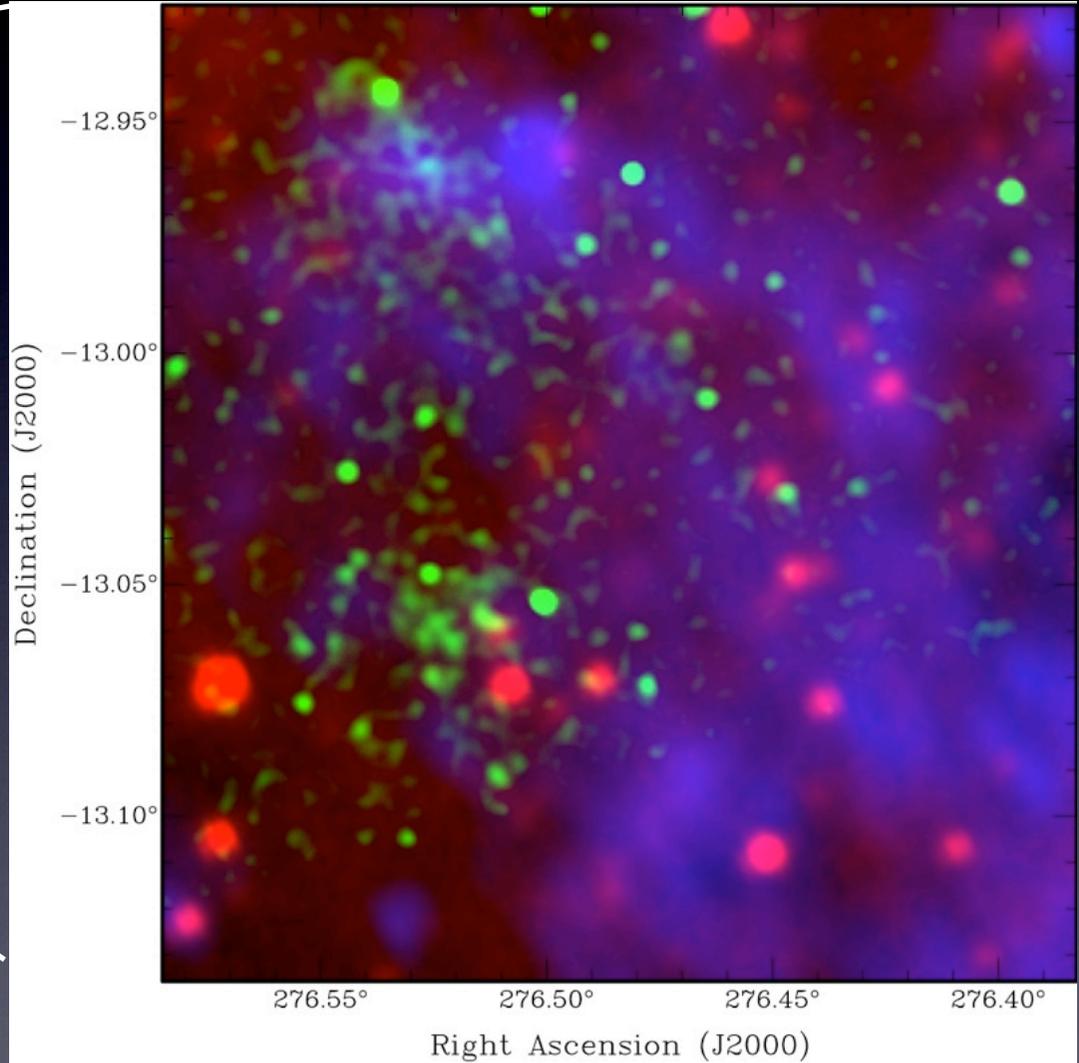
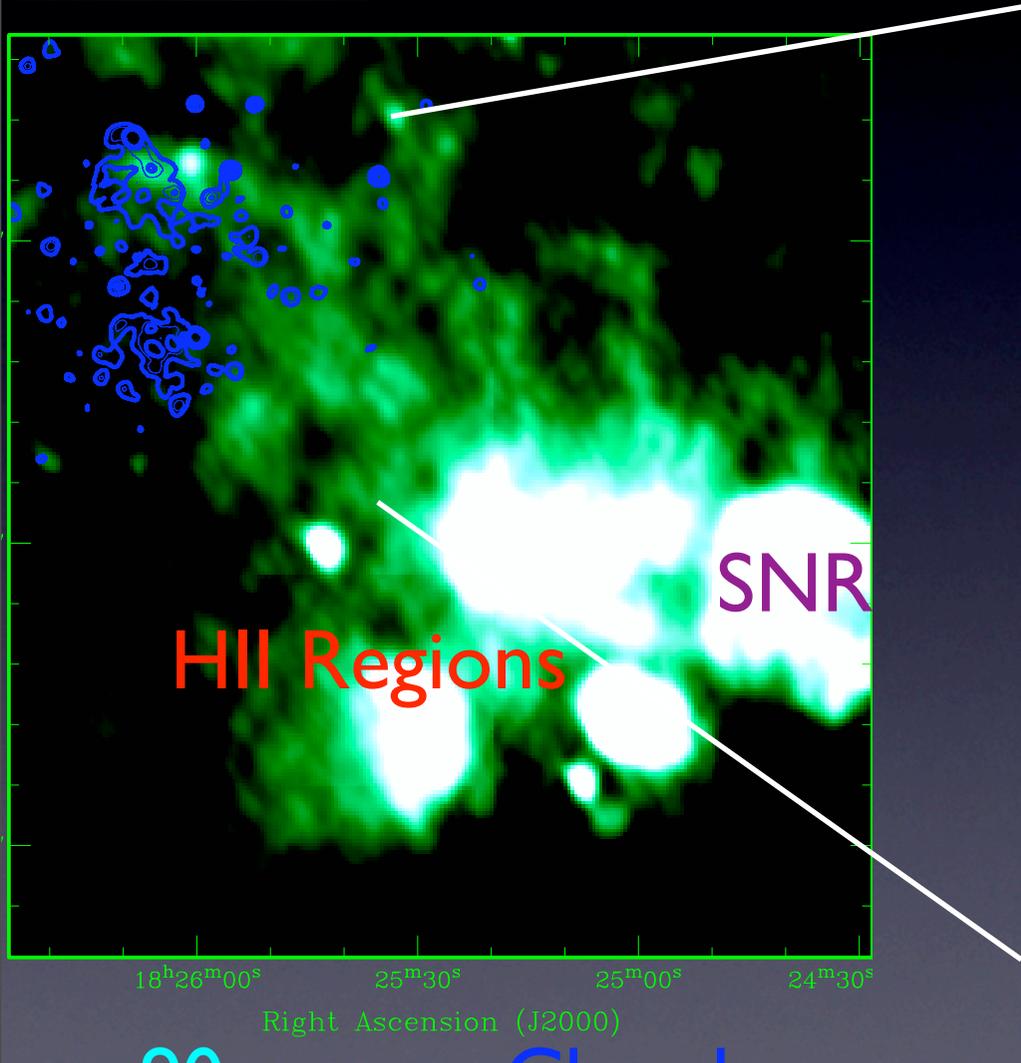
1-7 keV

$\sigma=20$



Eel radio RPWN?

Suggestively shaped radio nebula, no clear infrared counterpart

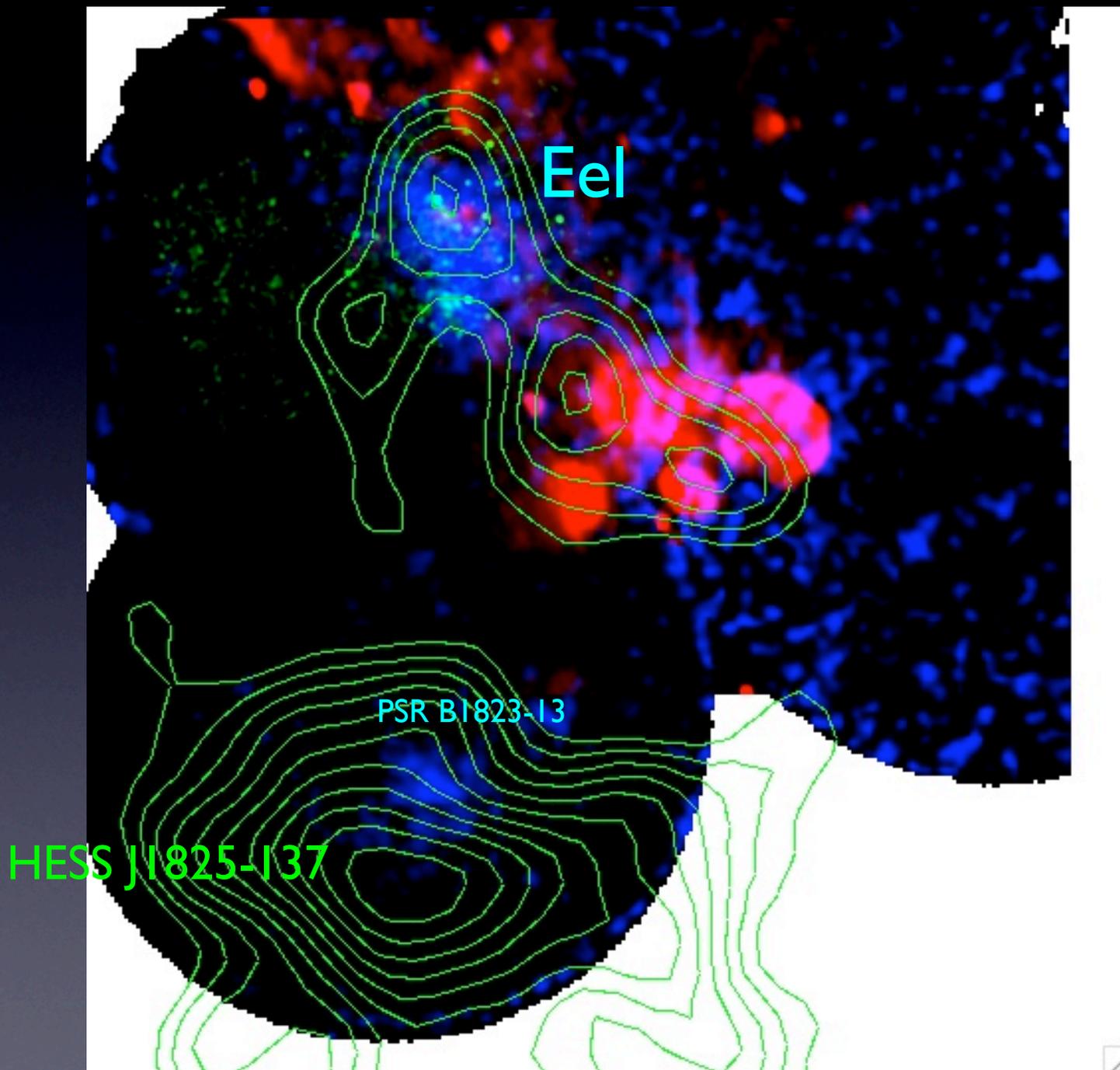


90cm
VLA

Chandra
contours

MSX 8.3 micron Chandra 90cmVLA

Eel TeV RPWN?



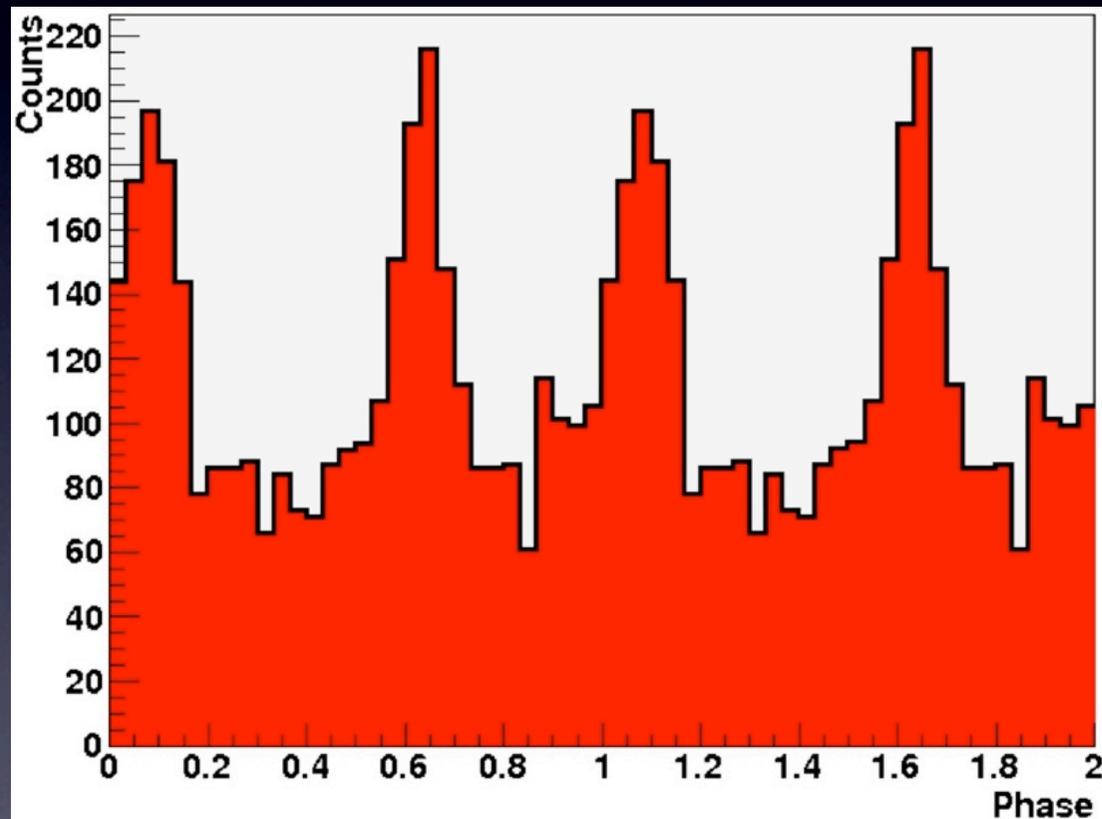
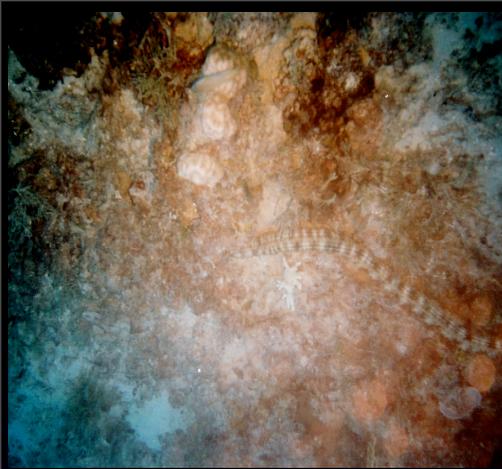
20cm VLA

Chandra

ASCA

HESS
Contours

Eel Pulsar Discovered in Blind Search of Fermi data!



Fermi Light Curve

- Energetic $E \sim 3.6 \times 10^{36}$ erg/s
- $\tau = 14$ kyr
- $F_r < 0.05$ mJy @ 1400 MHz (GBT & Parkes)
- “Torus and Jet” morphology suggest spin axis near plane of sky?
- No X-Ray pulse search yet!

The Rabbit and the Eel

- Have similar morphologies... small (10-20") "torus" in plane of sky, larger "jets", "forward" one bent $\sim 30^\circ$ away from pulsar, with most of the X-ray emission on side towards jet bend.
- Have similar spin periods (110ms), spin-down energies ($4-5 \times 10^{36}$), characteristic ages (10-15 kyr), and X-ray fluxes.
- $L_X - L_{\text{spin}}$ suggest distances of ~ 3 kpc (within a factor of 3 or so)
- Both have associated TeV nebulae, with sizes similar to larger, radio nebulae
- Forward X-ray "jet" in front of radio nebula.

Three “variable” EGRET sources containing PWN found to pulse at GeV energies with Fermi

- Variability not confirmed--- nor ruled out. Note that EGRET “variability” was on timescales of several months to several years.
- Unpulsed flux not yet well constrained, especially at low energies (< 300 MeV) where Fermi PSF is large and effective area small (sensitivity in survey mode similar to EGRET or AGILE pointings).
- PWN give some information about distance and geometry.
- radio detections unlikely... unless very steep spectra or highly scattered (see eg. recent discoveries by Camilo et al.)
- Further X-ray pulse detections desirable.