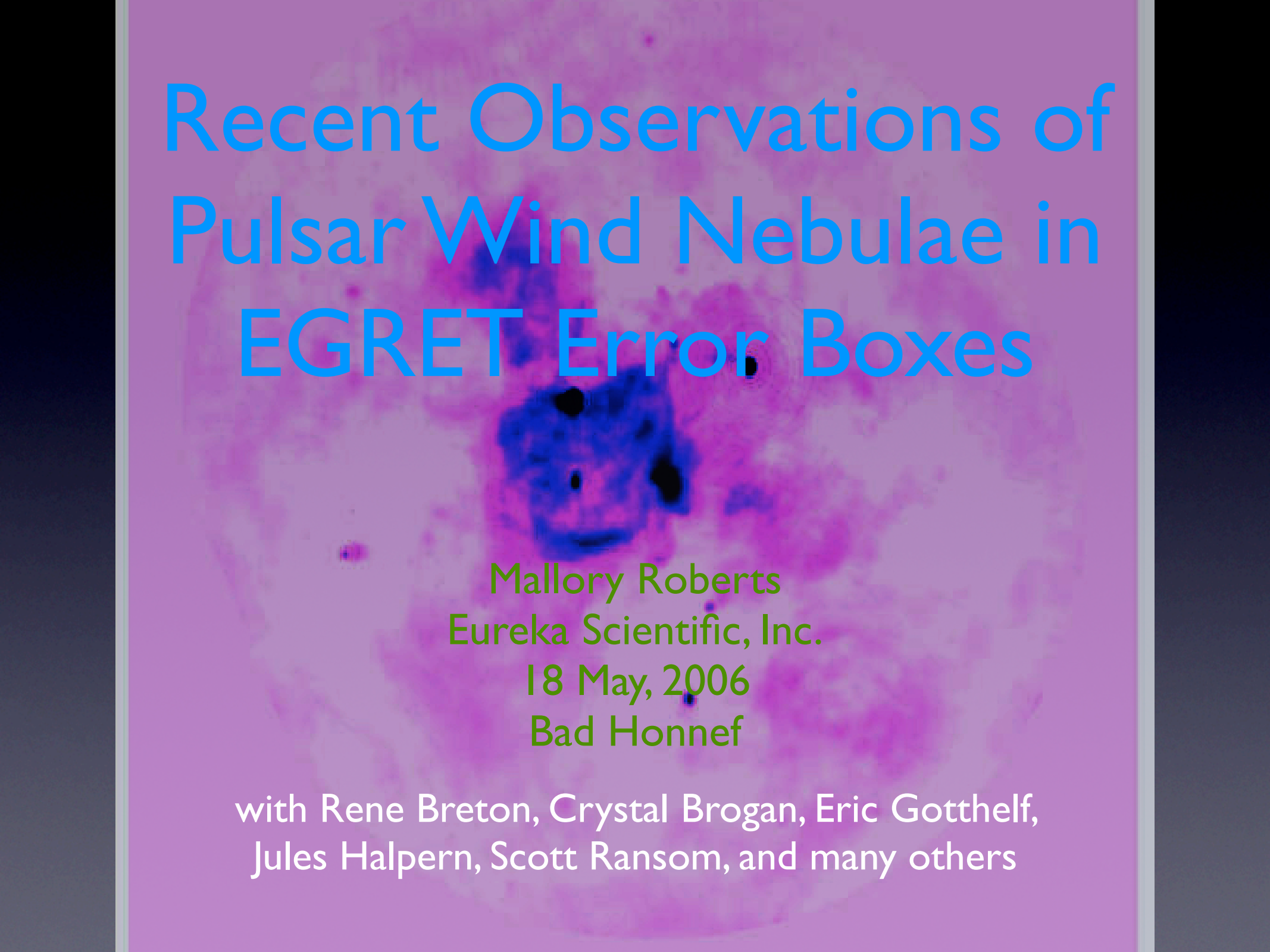
Recent Observations of Pulsar Wind Nebulae in EGRET Error Boxes

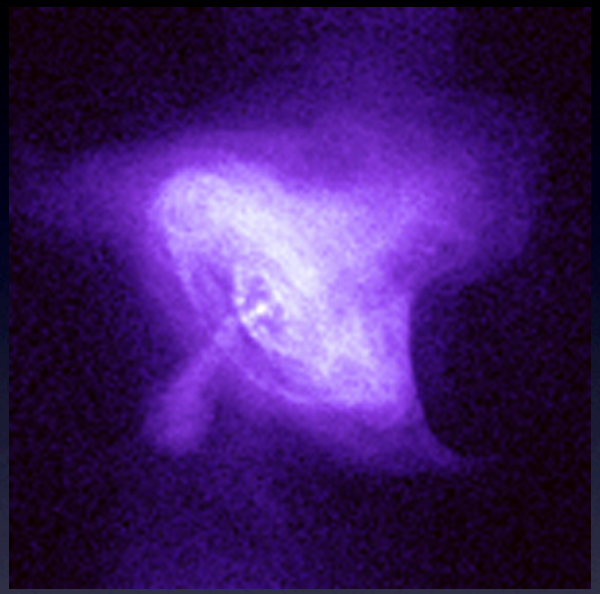


Mallory Roberts
Eureka Scientific, Inc.
18 May, 2006
Bad Honnef

with Rene Breton, Crystal Brogan, Eric Gotthelf,
Jules Halpern, Scott Ransom, and many others

Young EGRET Pulsars with Torii+Jets

Crab



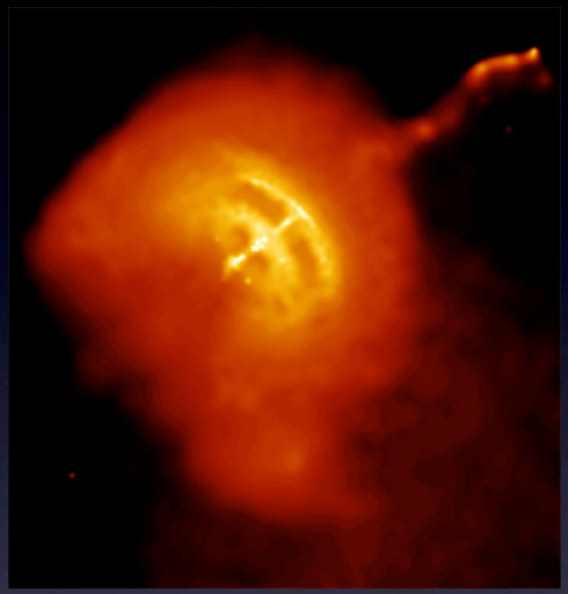
NASA/CXC/SAO

$\dot{E}=4.6\times10^{38}$erg/s

D~2 kpc

Age=952 yr

Vela



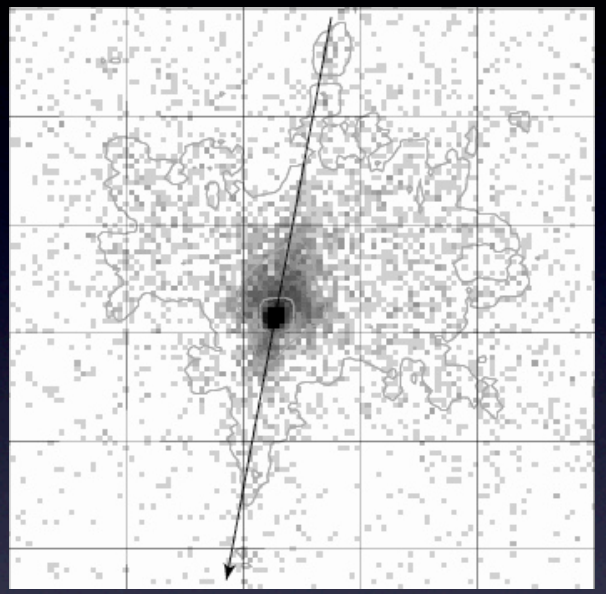
Pavlov et al. 2003

$\dot{E}=6.9\times10^{36}$erg/s

D~0.3 kpc

Age~11,000 yr

PSR B1706-44



Romani 2004

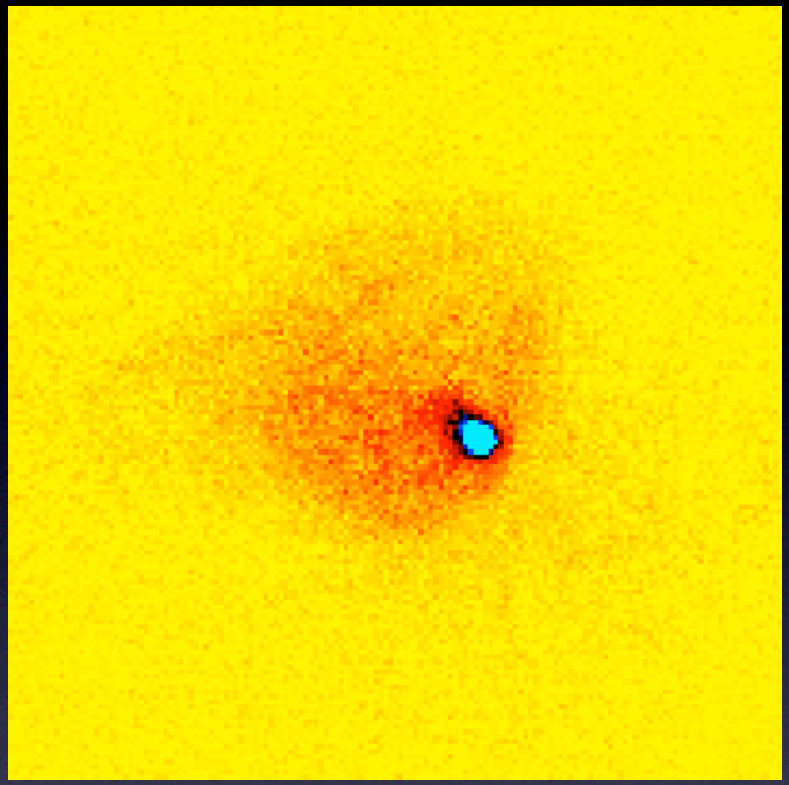
$\dot{E}=3.4\times10^{36}$erg/s

D~2 kpc

Age~17,000 yr

Youngish EGRET Pulsars with PWN

PSR B1951+32

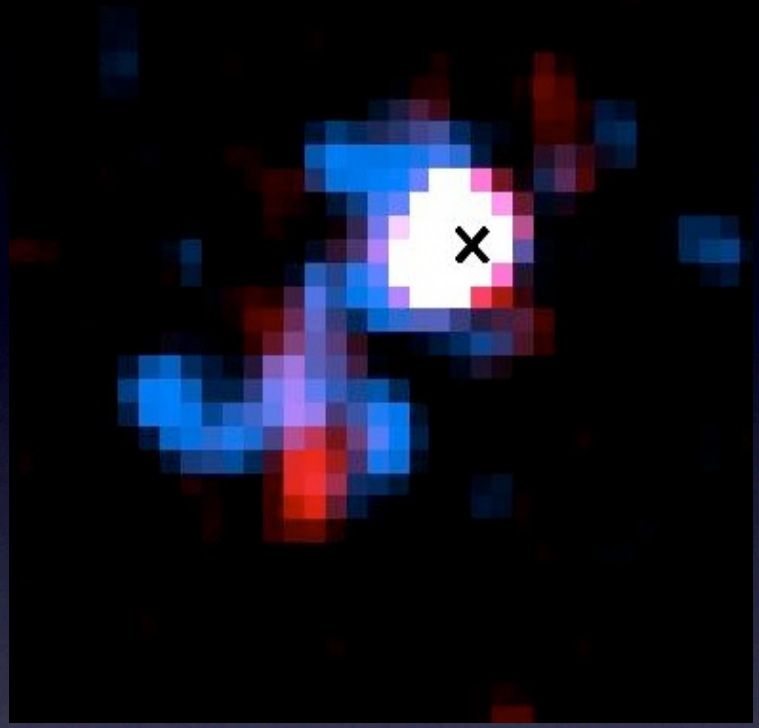


$\dot{E}=3.7\times10^{36}$erg/s

D~3 kpc

Age~100,000 yr

PSR B1046-58



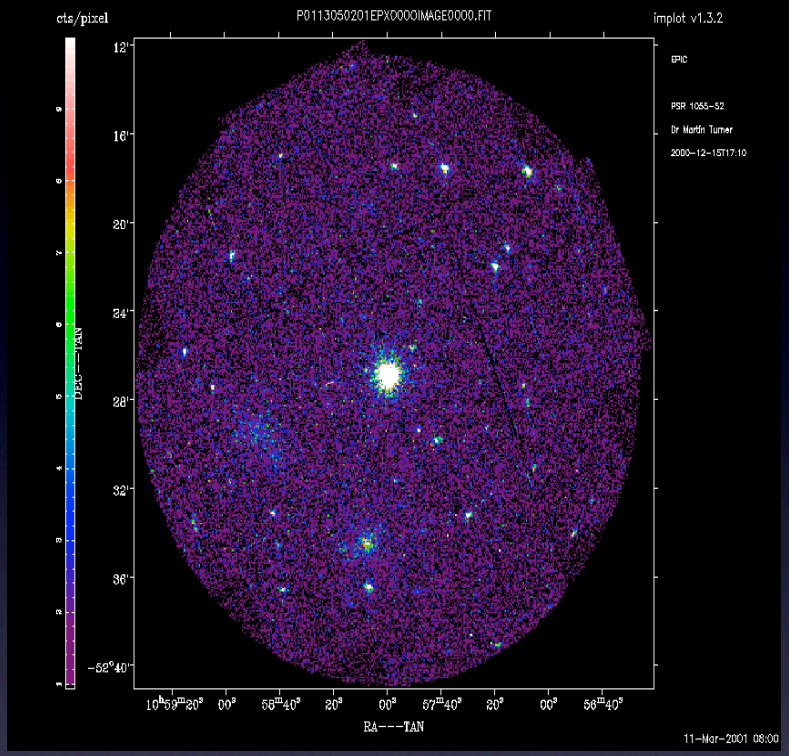
$\dot{E}=2.0\times10^{36}$erg/s

D~3 kpc

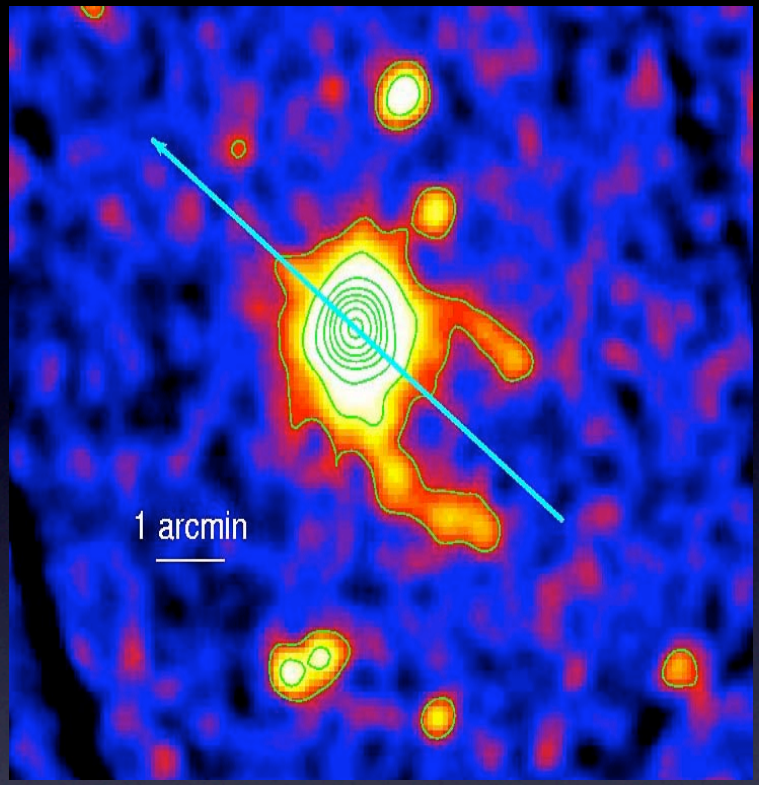
Age~20,000 yr

Old EGRET Pulsars

PSR B1055-52



Geminga



ESA

$\dot{E}=3.0 \times 10^{34}$ erg/s

D~0.7 kpc

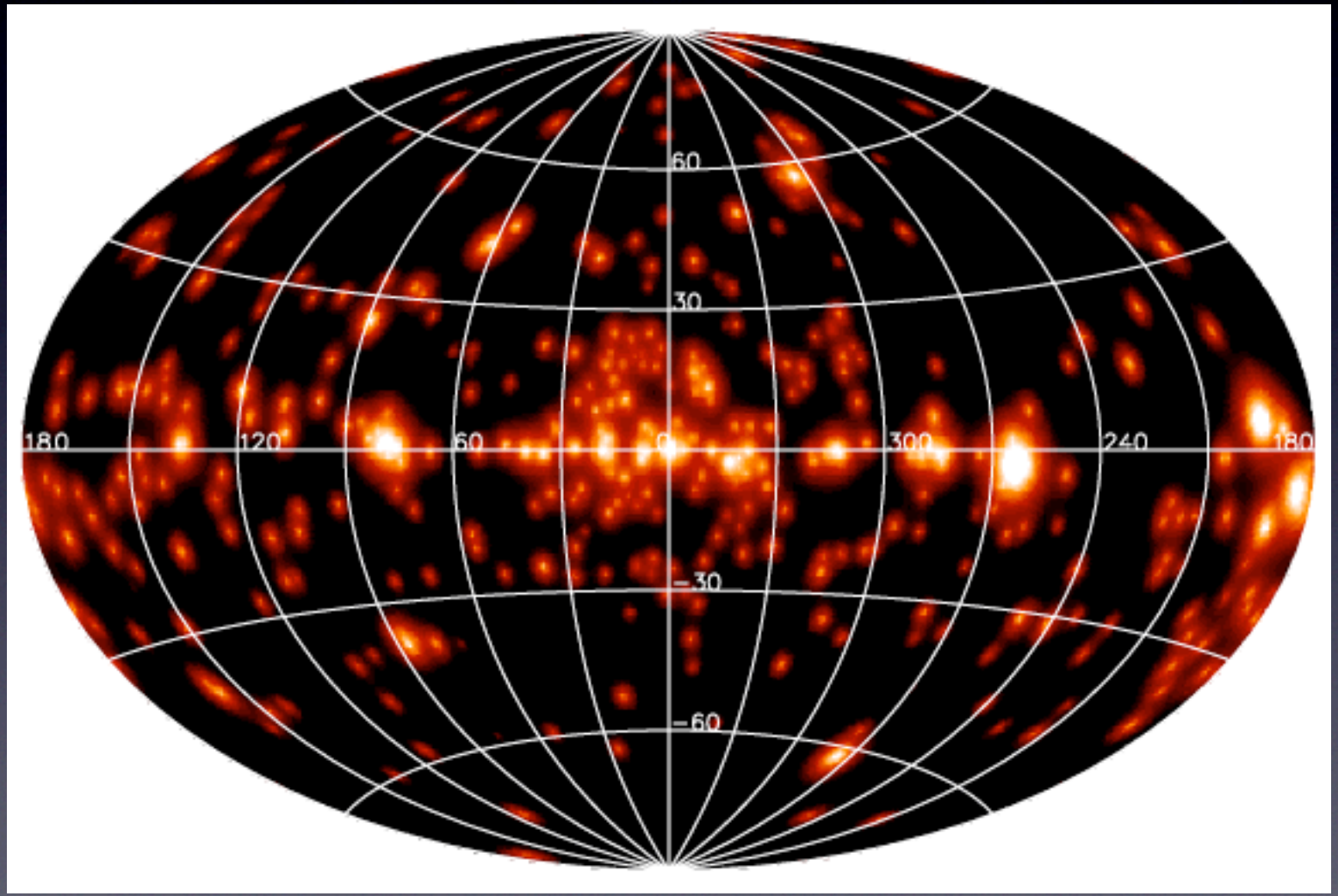
Age~500,000 yr

$\dot{E}=3.2 \times 10^{34}$ erg/s

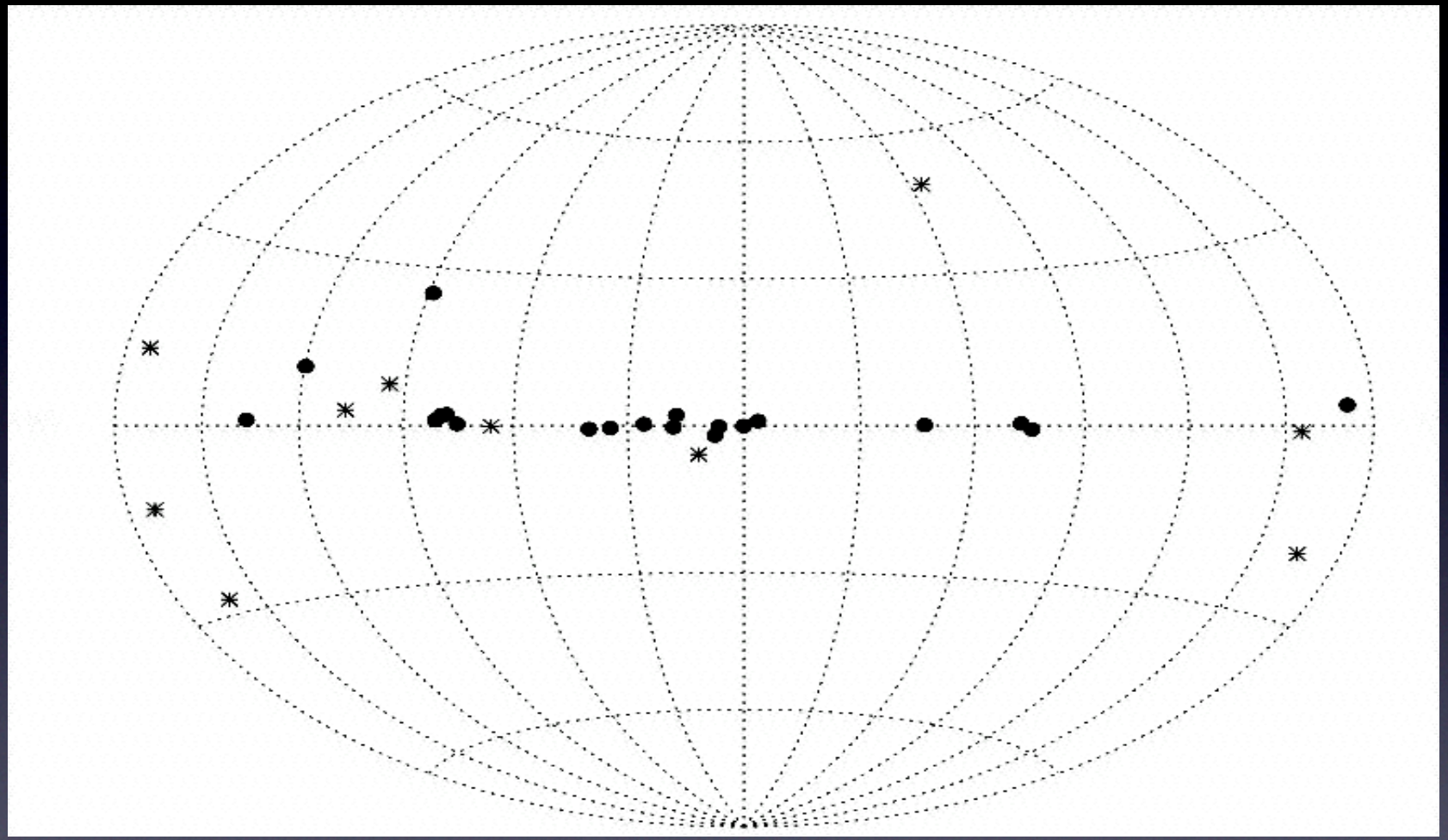
D~0.4 kpc

Age~350,000 yr

Discrete EGRET Sources

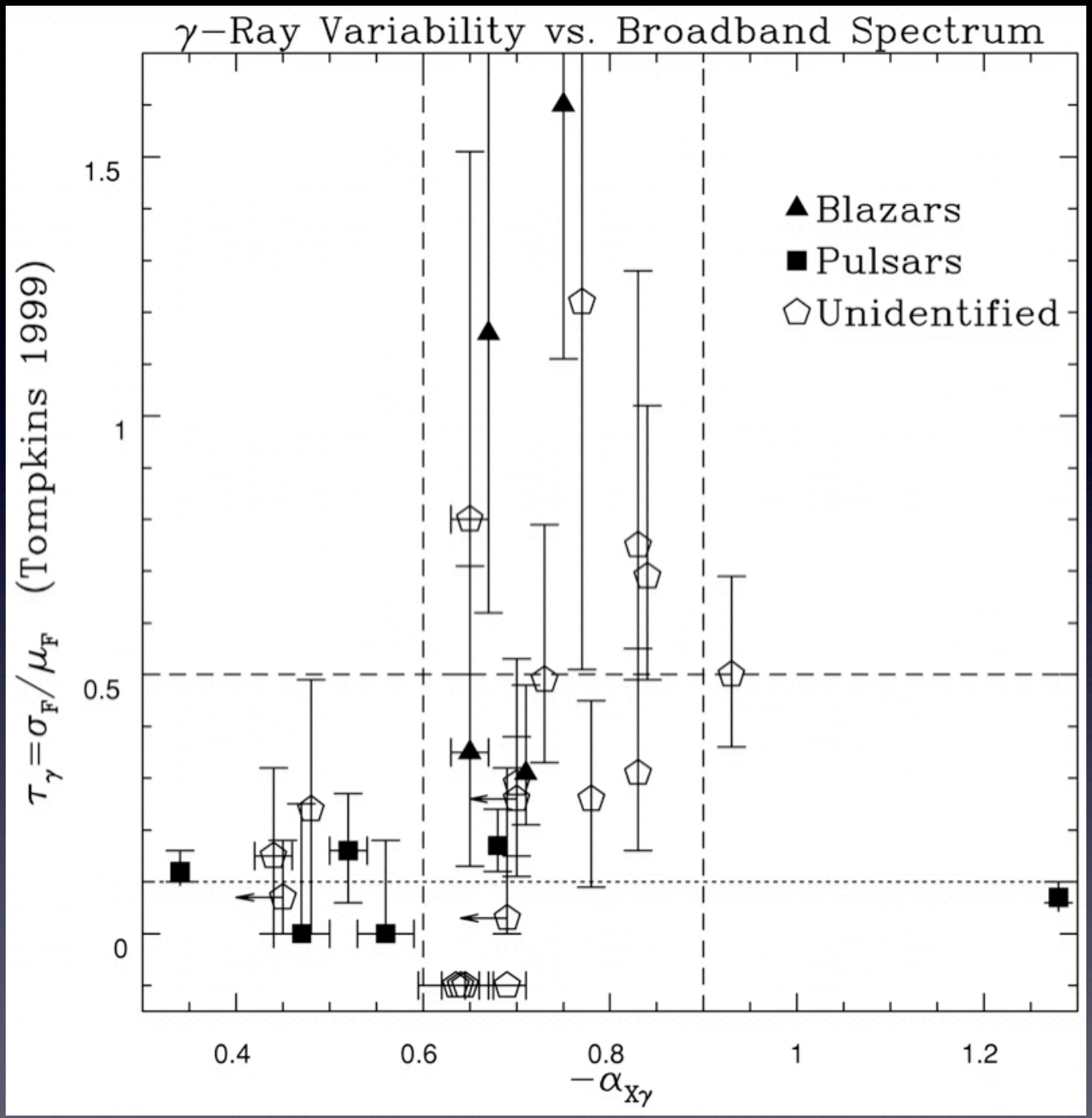


Unidentified Sources E > 1GeV



Lamb & Macomb 1997

Variability of Potential ASCA X-ray Counterparts



Roberts, Romani & Kawai 2001

Pulsars as Variable Low-Latitude Sources?

- Magnetospheric emission (i.e. Pulsations) is steady on timescales >> pulse period

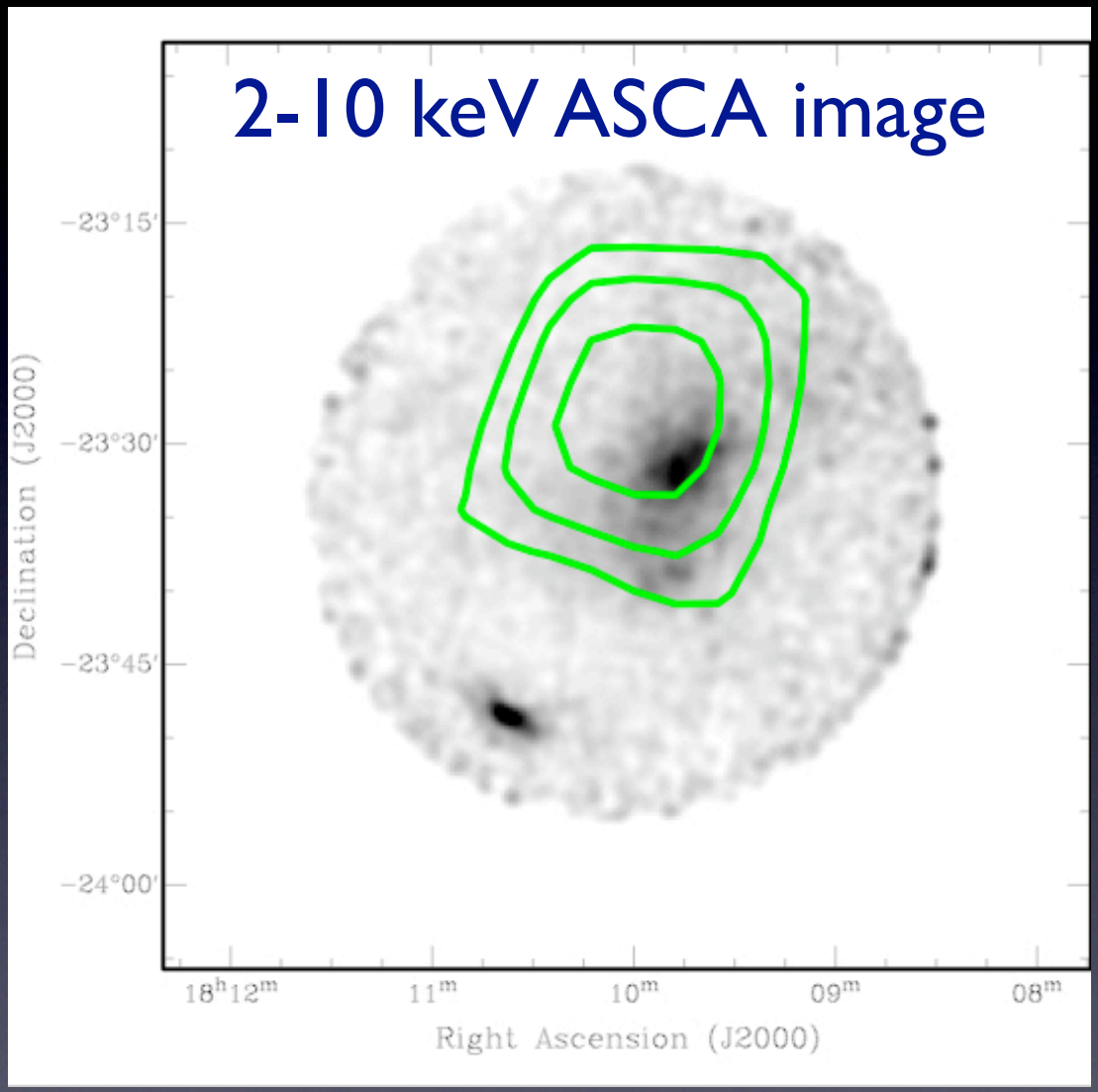
- Population of variable (timescale of months) low-latitude EGRET sources in inner Galaxy (Maclaughlin et al. 1996, Torres et al. 2001, Nolan et al. 2003)

- Log N-log S of plane sources differs from pulsars (Bhattacharya et al. 2004), but similar to molecular clouds

- BUT: Majority of energy goes into relativistic wind, and pulsar wind nebulae do vary

What about nebular emission from pulsars moving through molecular clouds?

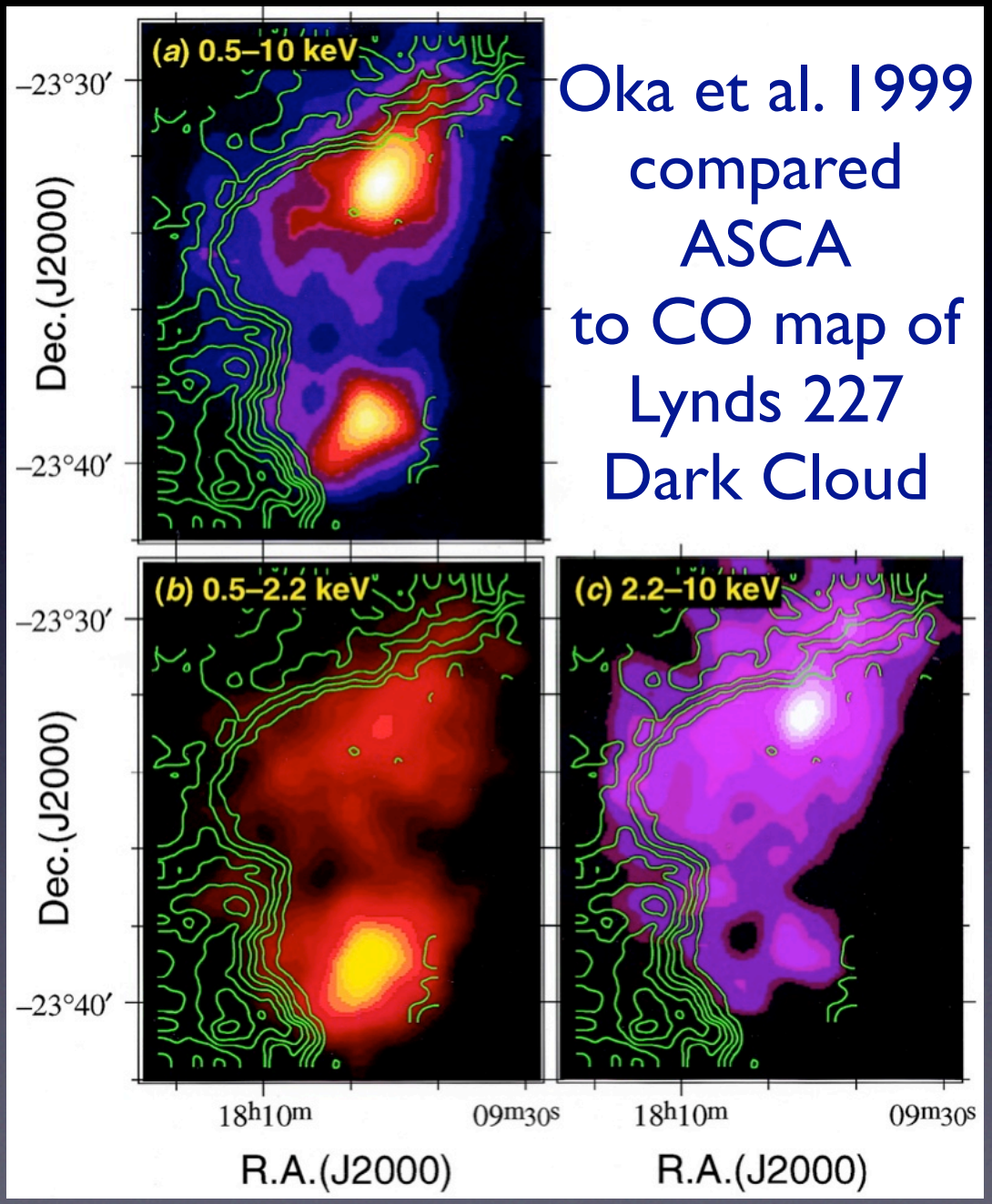
GeV J1809-2327: A GeV Emitting PWN?



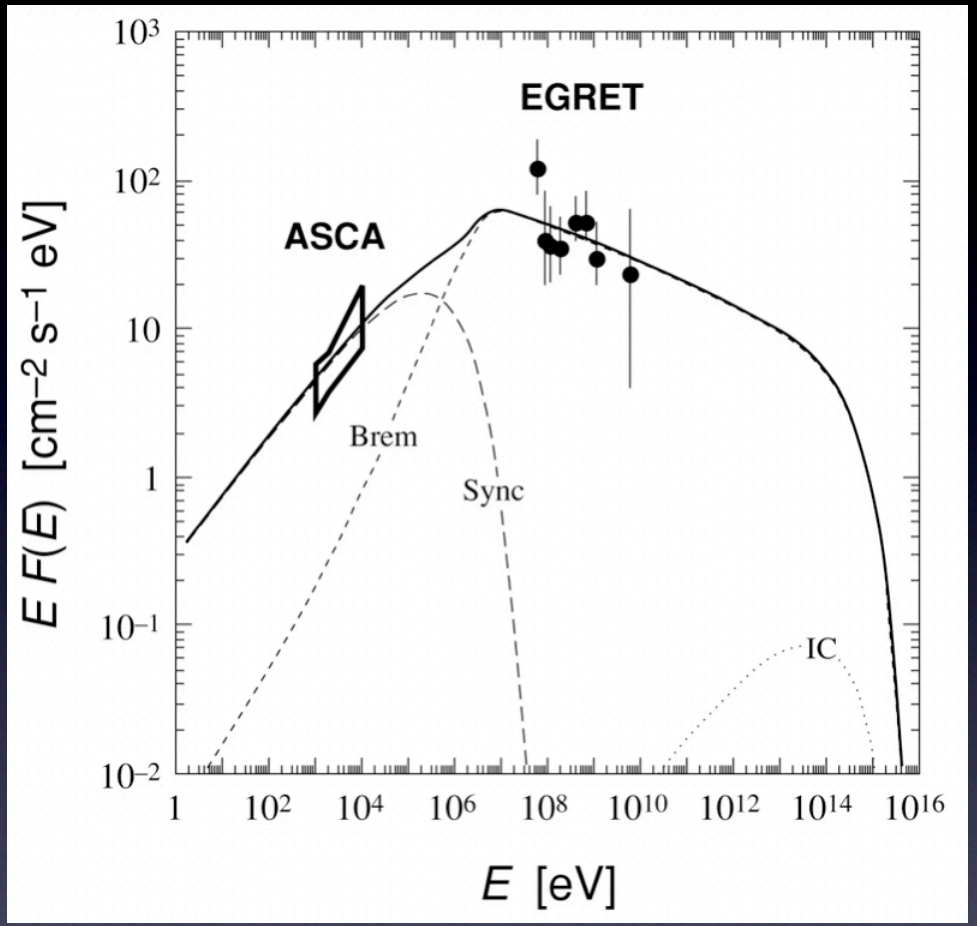
Roberts, Romani & Kawai 2001

- 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

A PWN Interacting with a Molecular Cloud?

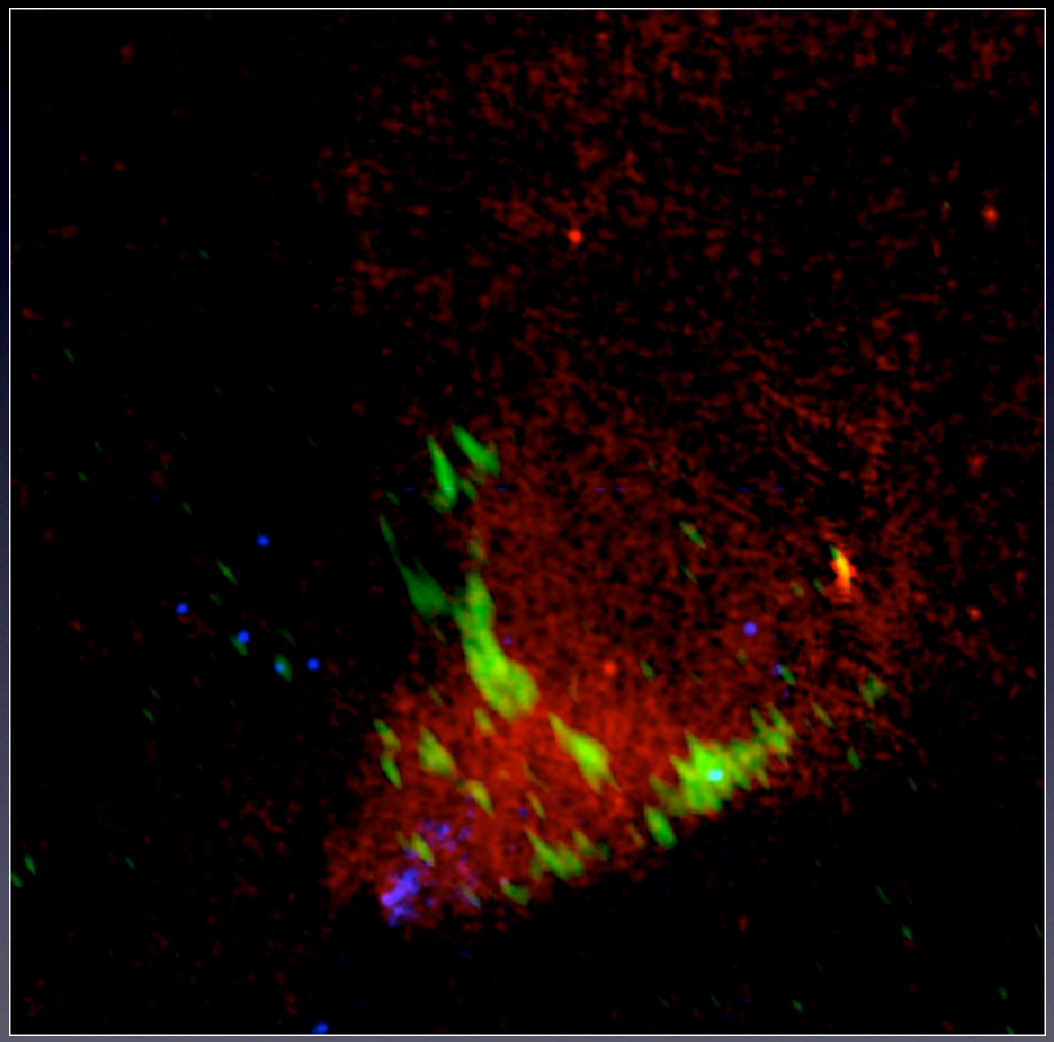


Oka et al. 1999 compared ASCA to CO map of Lynds 227 Dark Cloud



Suggested electrons accelerated in wind nebula emitting bremmstrahlung radiation from entire cloud

Taz: A GeV Emitting RPWN?

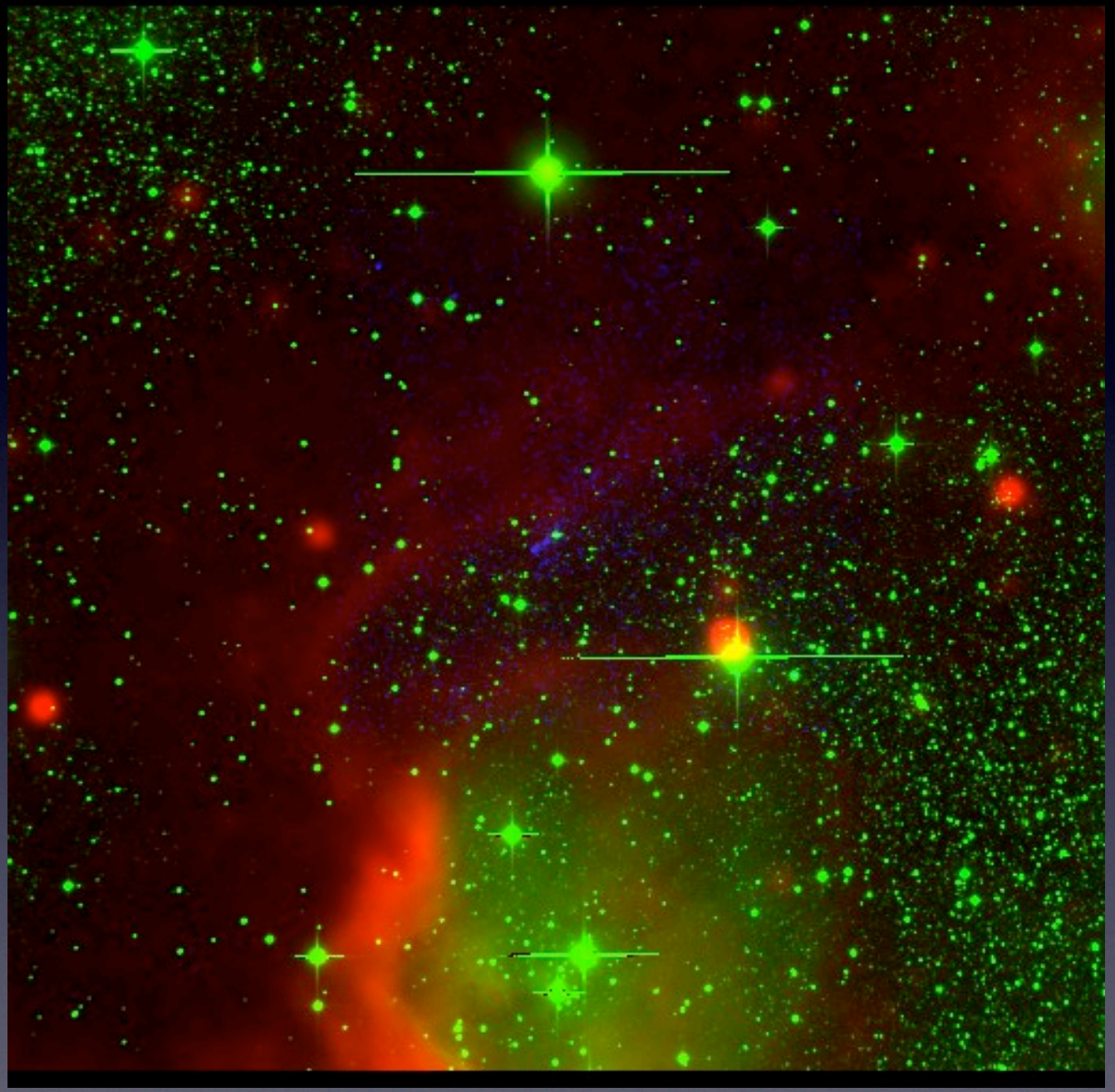


Braje et al. 2002, Roberts et al. in prep

- Radio Nebula with spectrum and polarization of PWN
- Short Chandra image resolved point source with trail
- Southern part of ASCA "nebula" resolved into stellar cluster

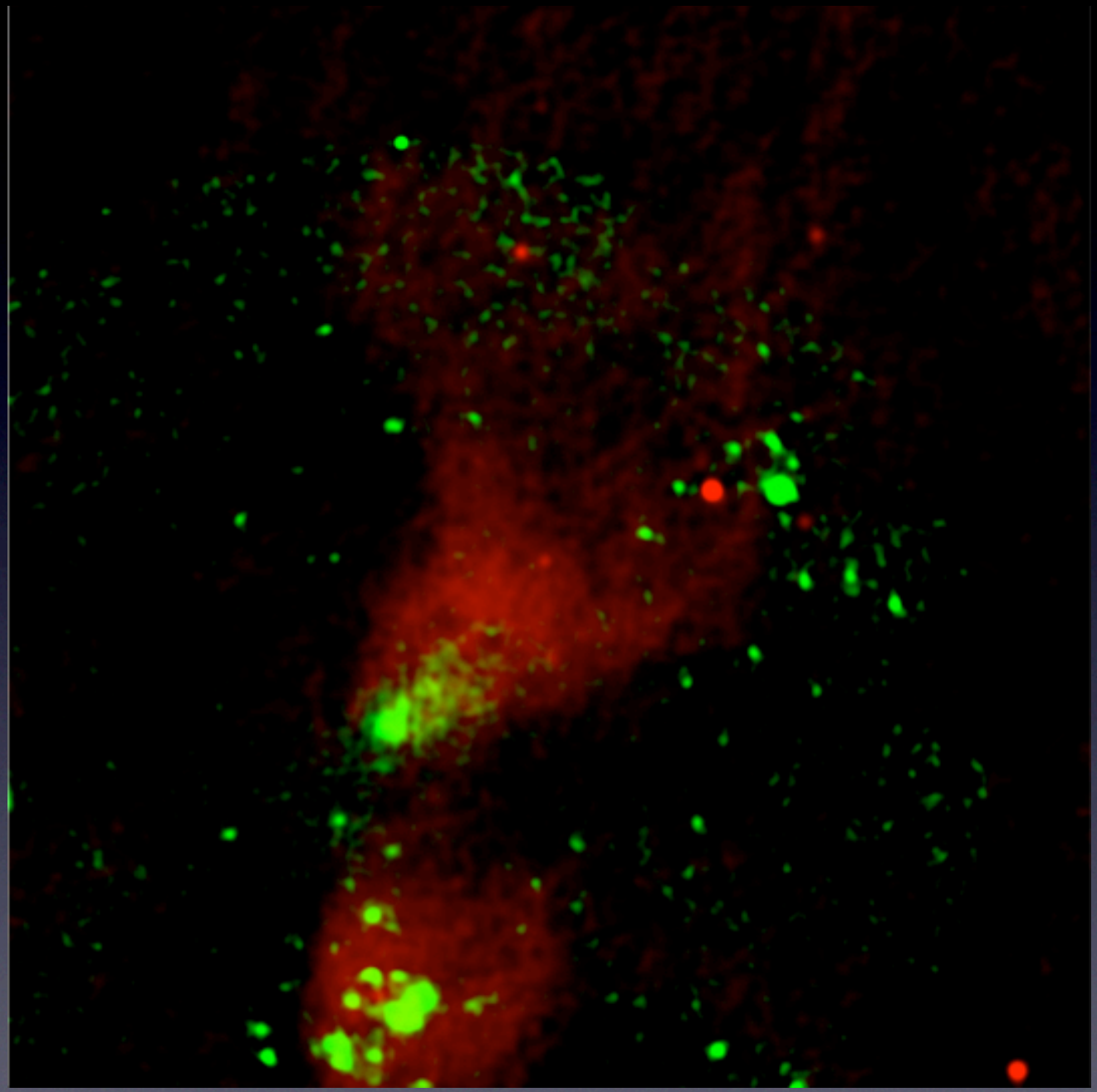
Radio Continuum Polarized Radio Non-Thermal X-Ray

GeV J1809-2328 from Cloud Interaction?



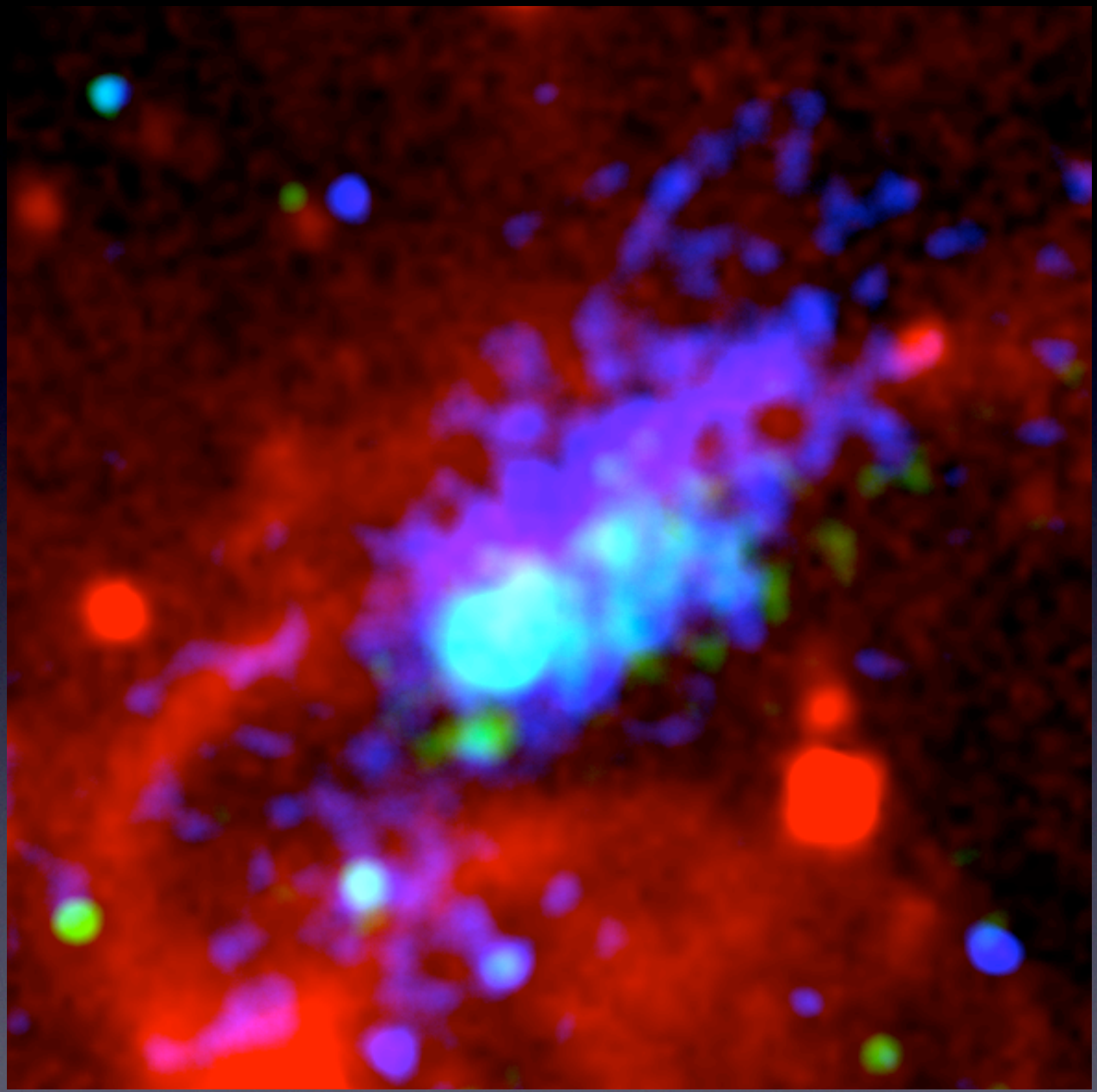
Mid-Infrared 8.3μ Optical Non-Thermal X-rays

Newton-XMM Observation of Taz



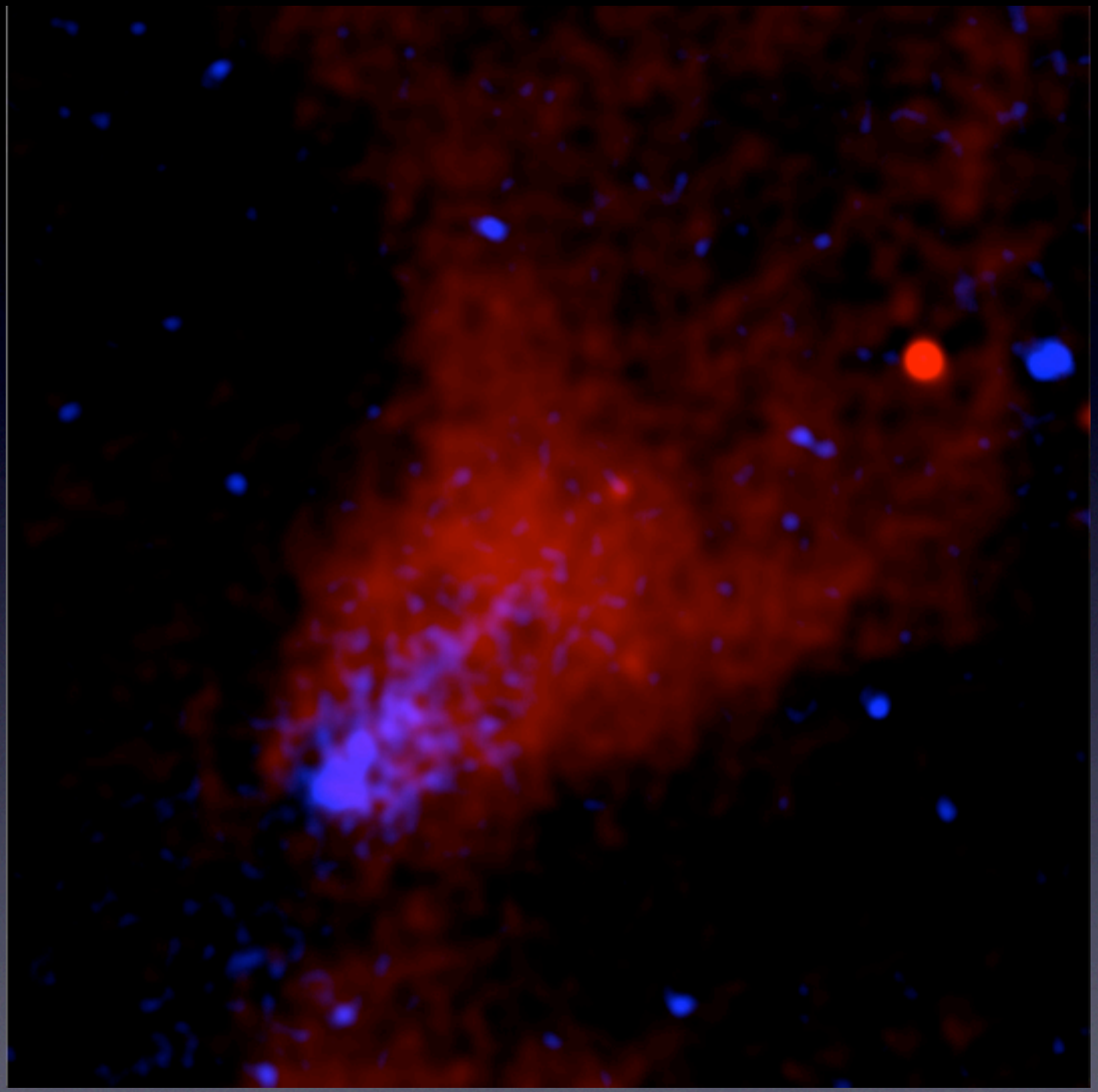
20cm radio 0.5-10 keV X-rays

Taz Cloud Interaction?

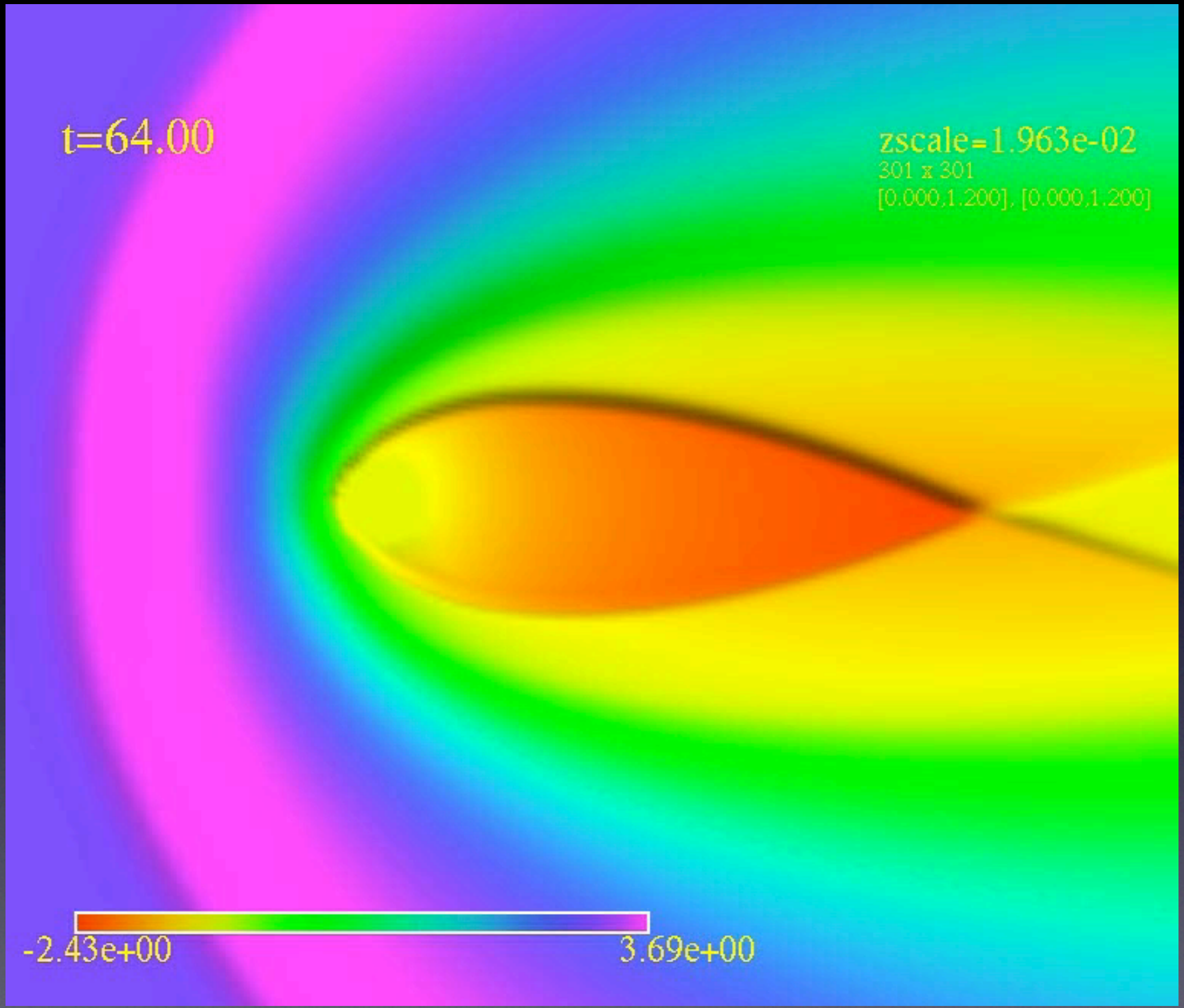


Mid-Infrared 8.3μ 0.5-2.5 keV X-rays 2.5-8 keV X-rays

Taz is classic RPWN!

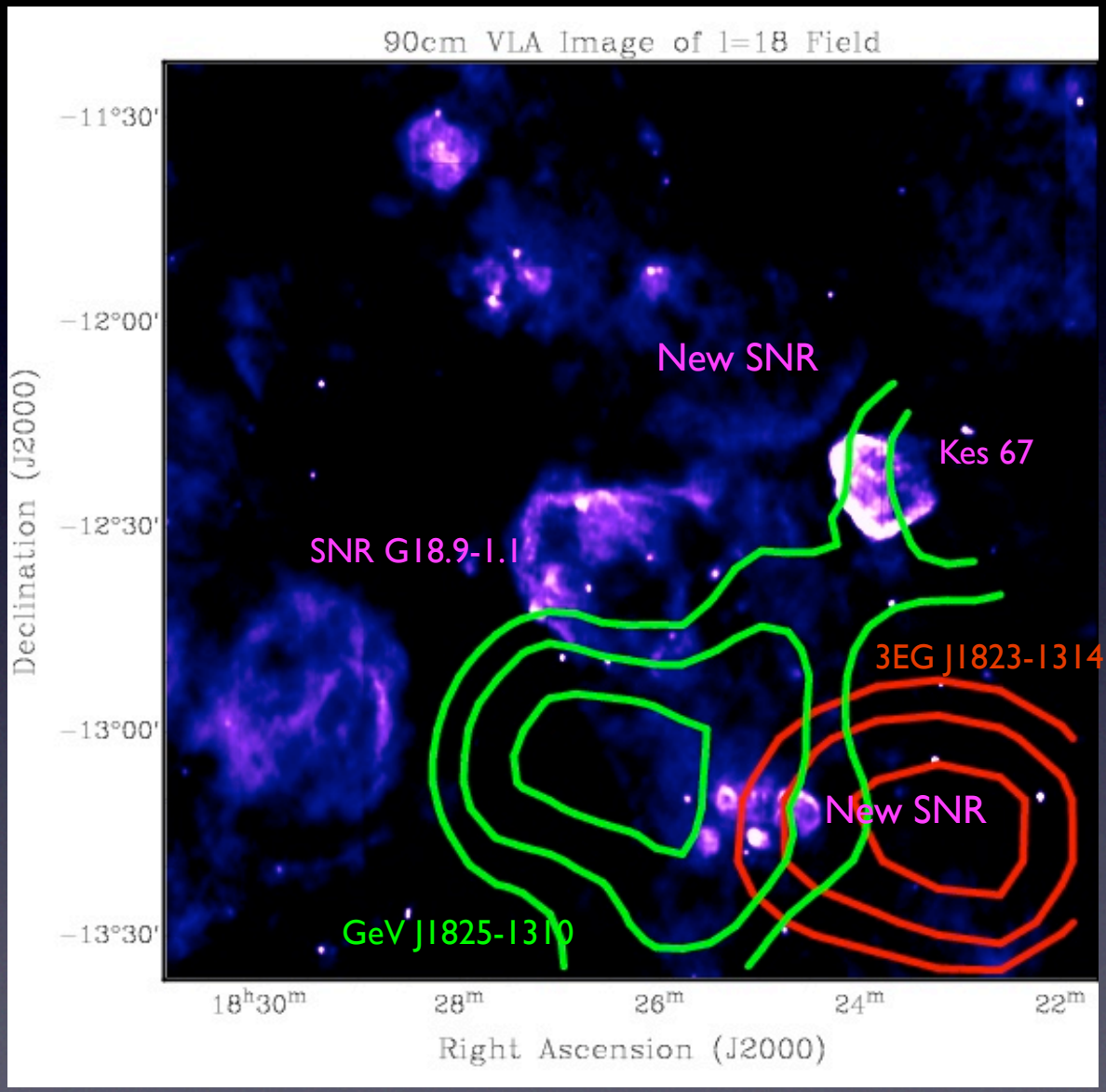


20cm radio 2.5-8 keV X-rays



Rahman et al. in prep

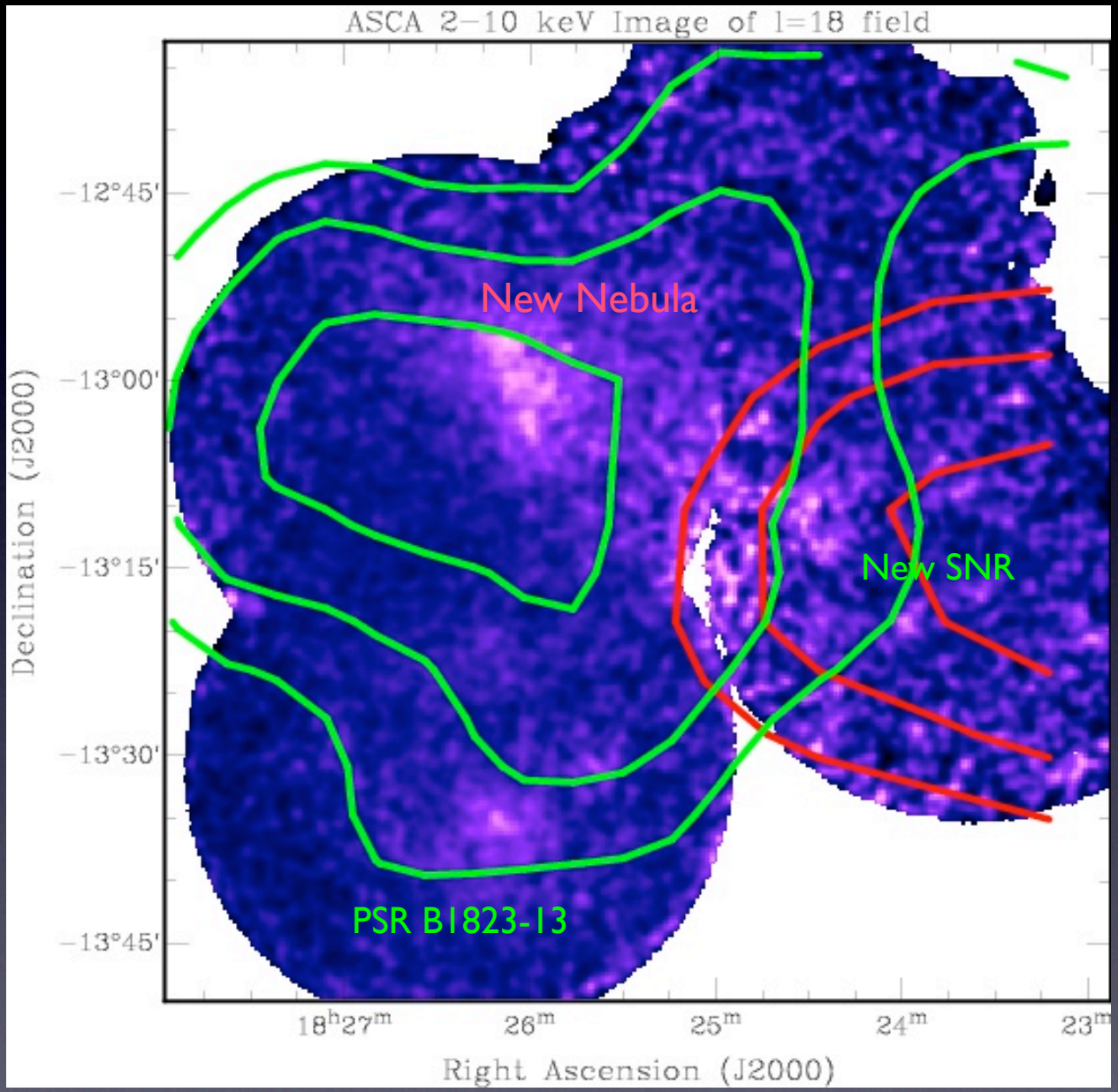
l=18° Sources



Brogan et al. in prep.

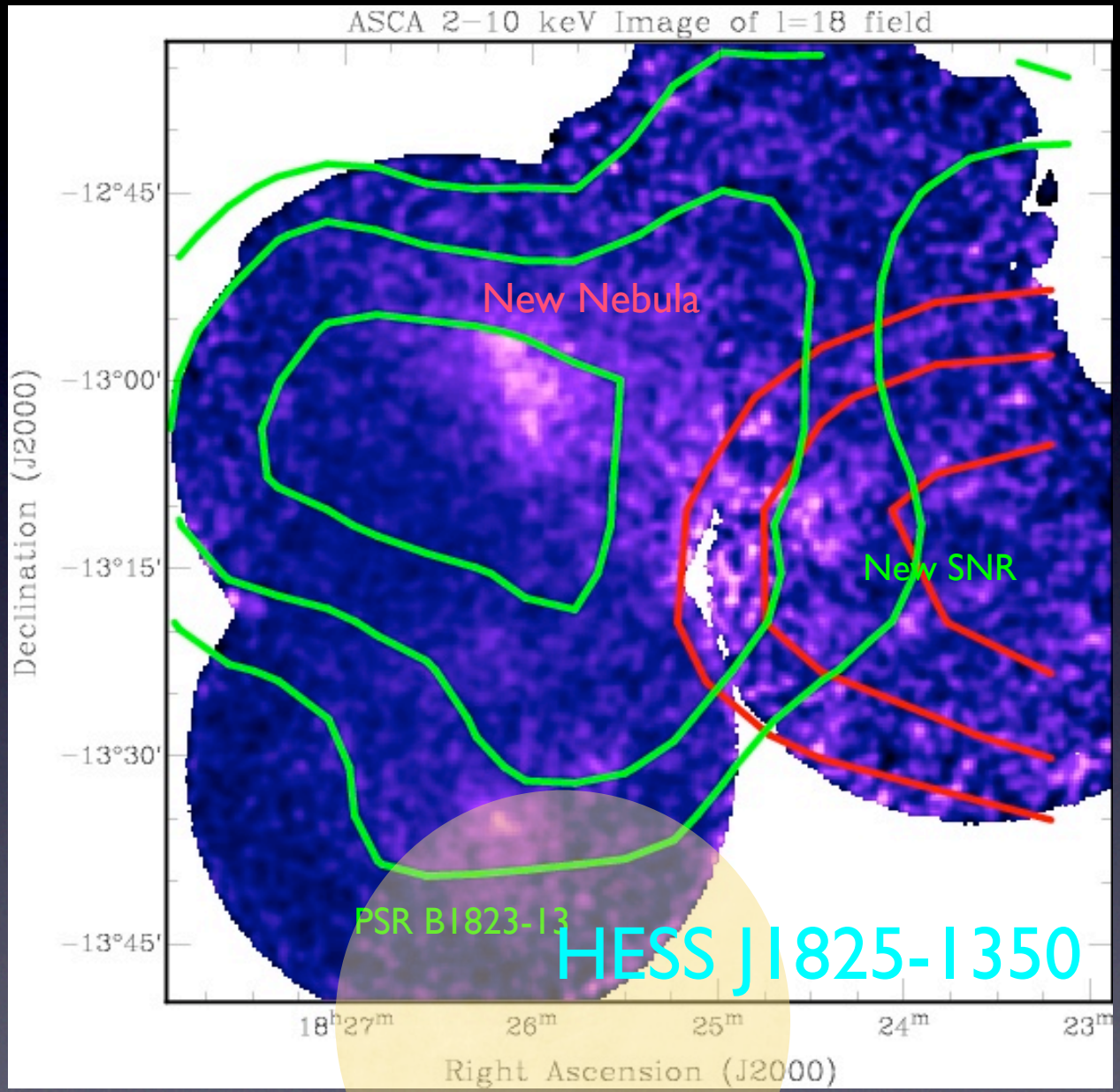
- Complex region with at least 2 EGRET sources
- Region of bright unidentified, variable Comptel source.
- GeV J1825-1310 (3EG J1826-1302) second highest V_{12}=3.22
- 20 and 90cm imaging resolve at least 4 SNR, 2 of them new, as well as many molecular clouds and some other structures

GeV J1825-1310



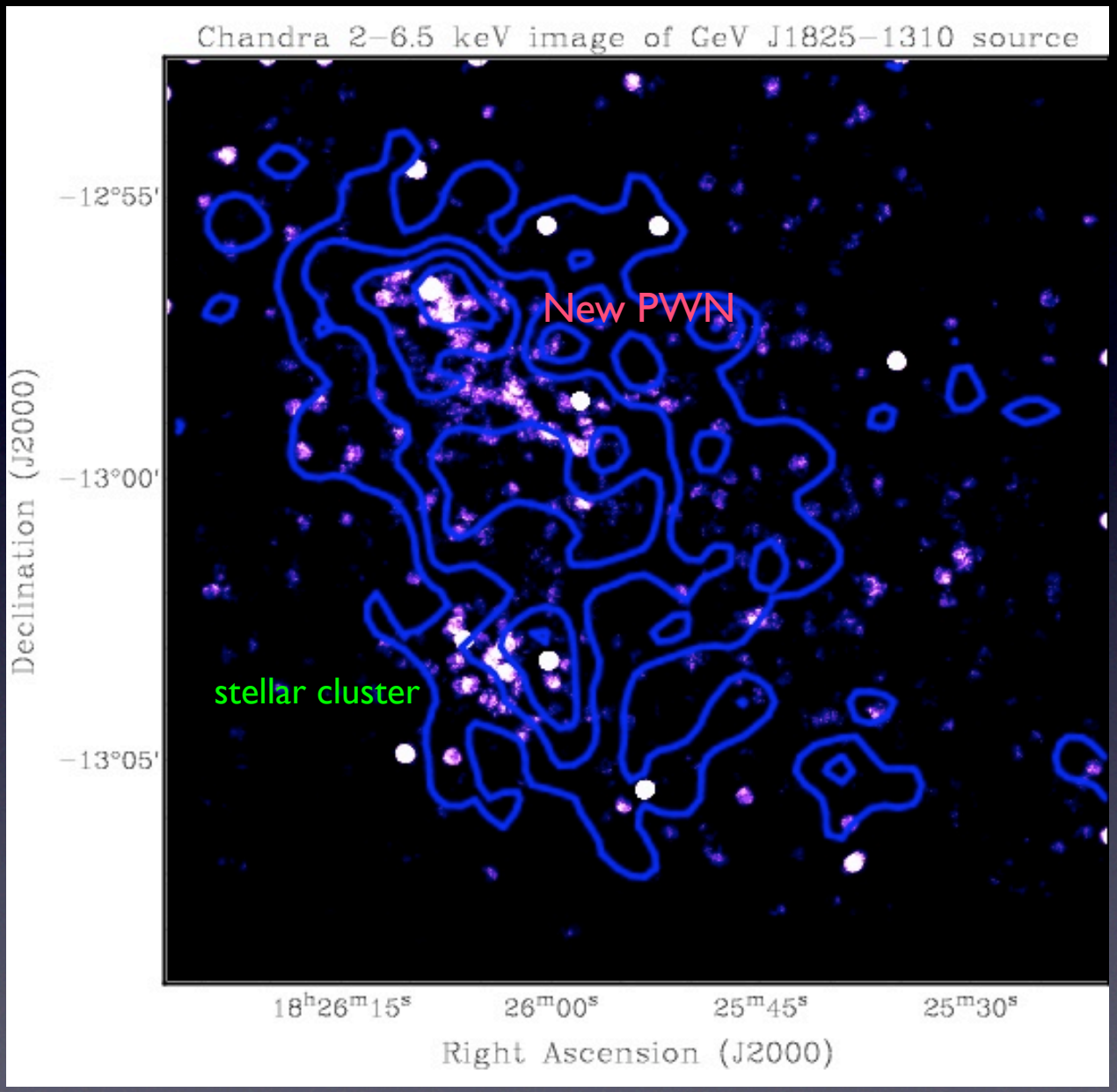
Roberts, Romani & Kawai 2001

GeV J1825-1310



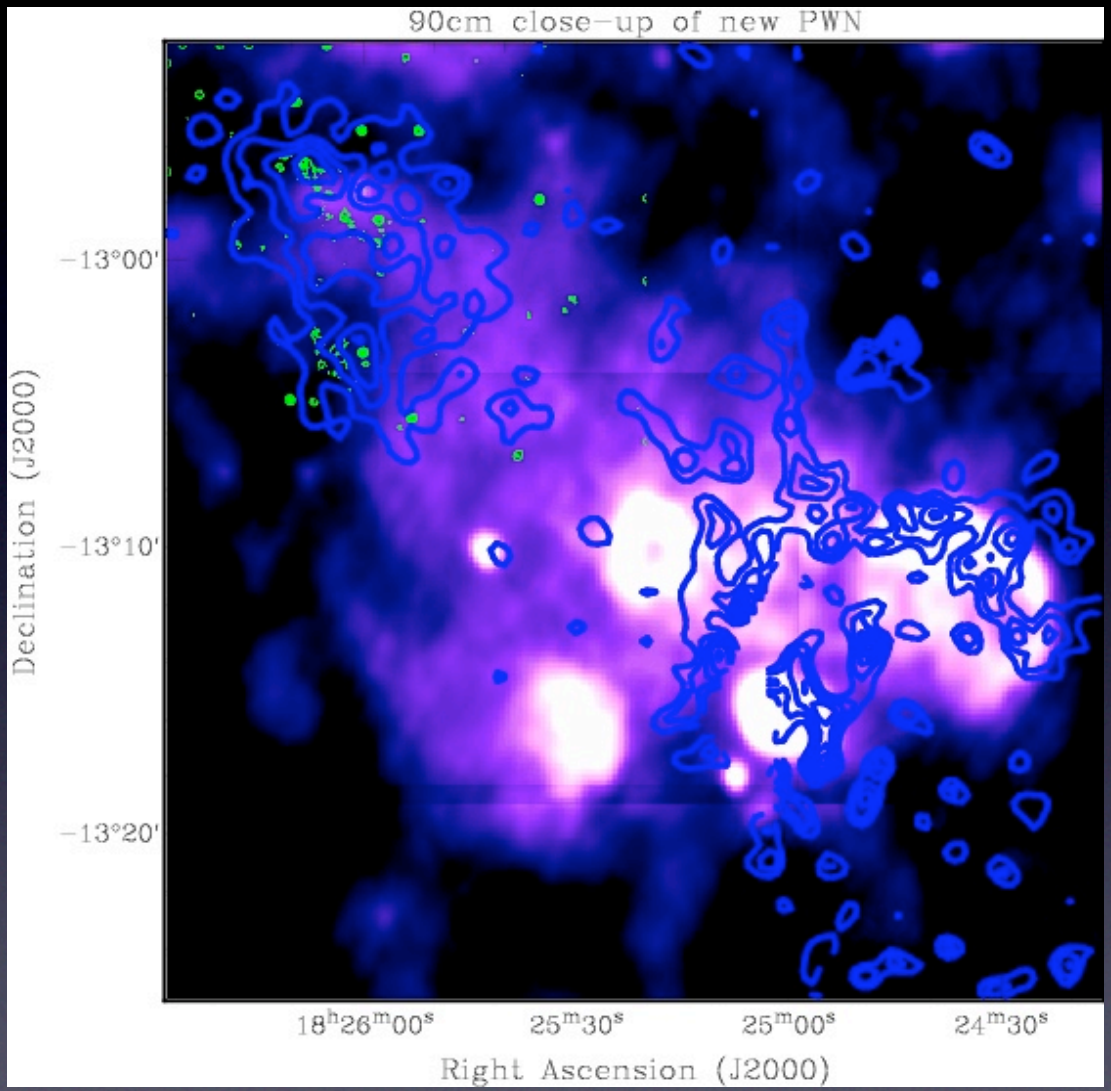
Roberts, Romani & Kawai 2001

The Eel X-ray RPWN in GeV J1825-1310

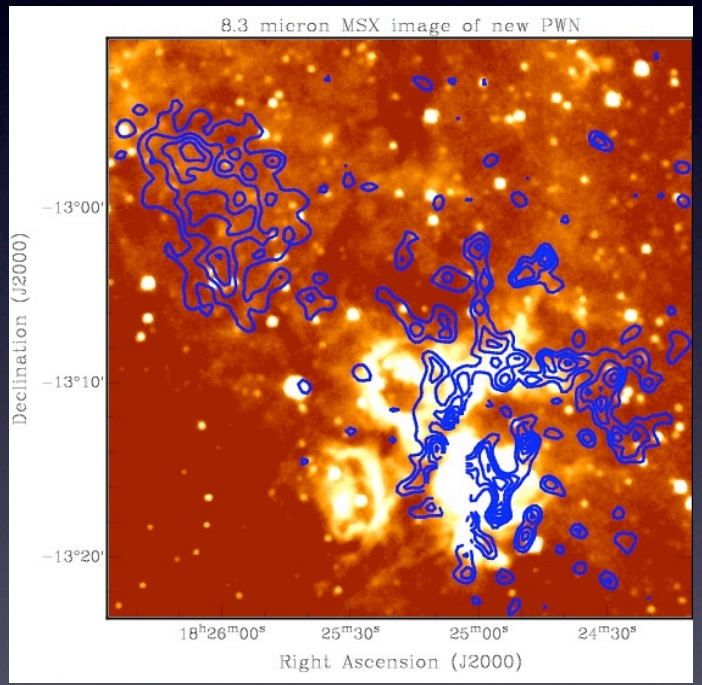


Roberts et al. in prep

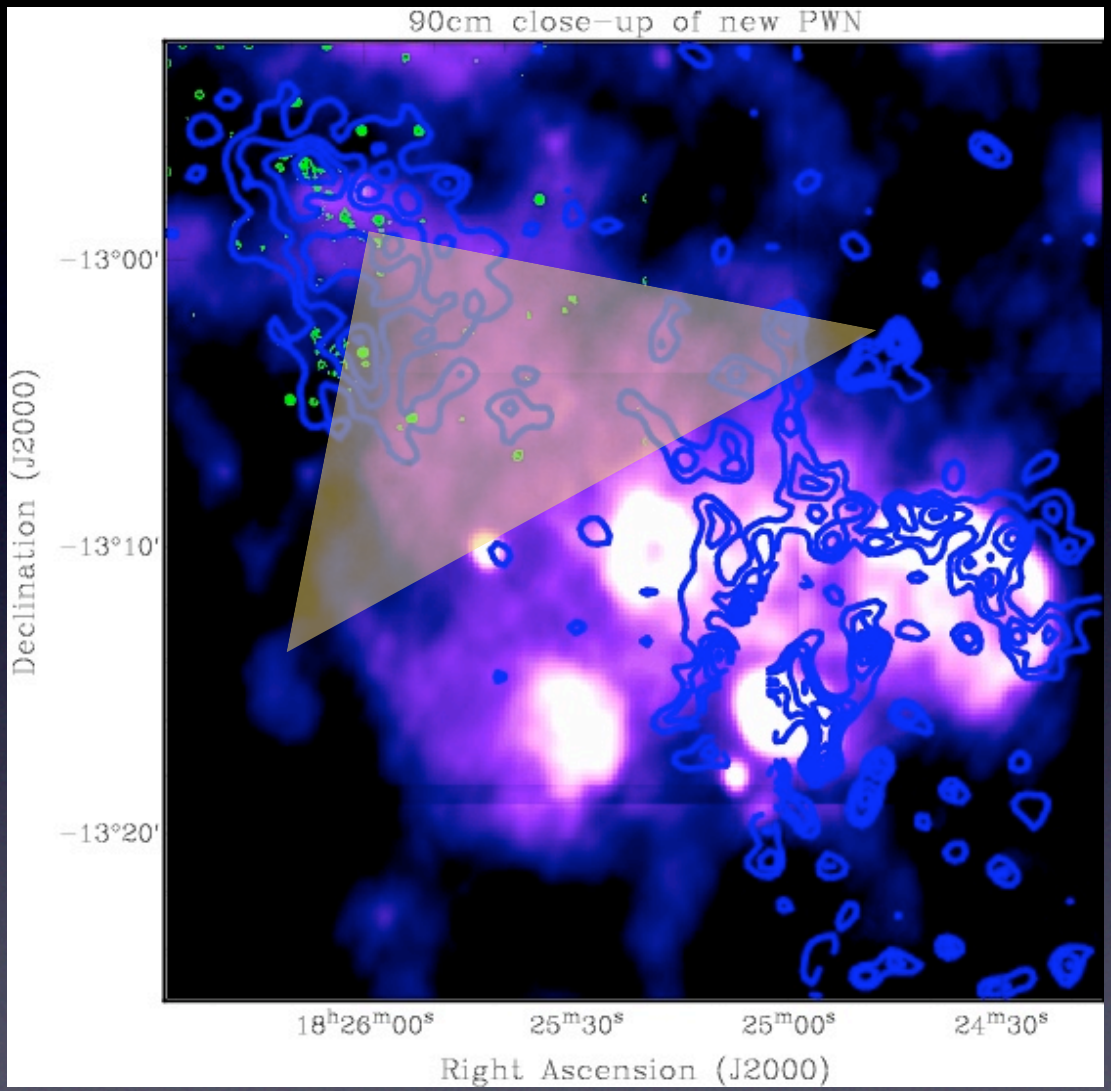
Eel radio RPWN?



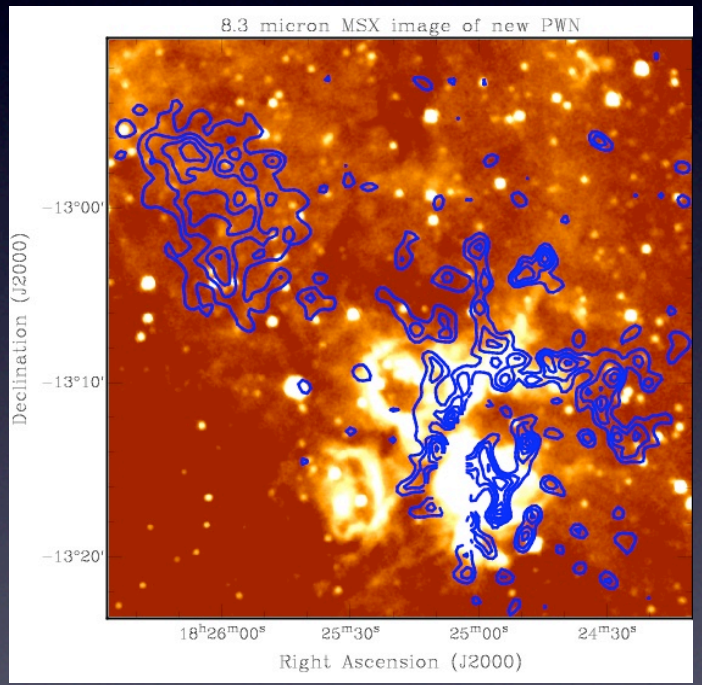
infrared counterpart



Eel radio RPWN?

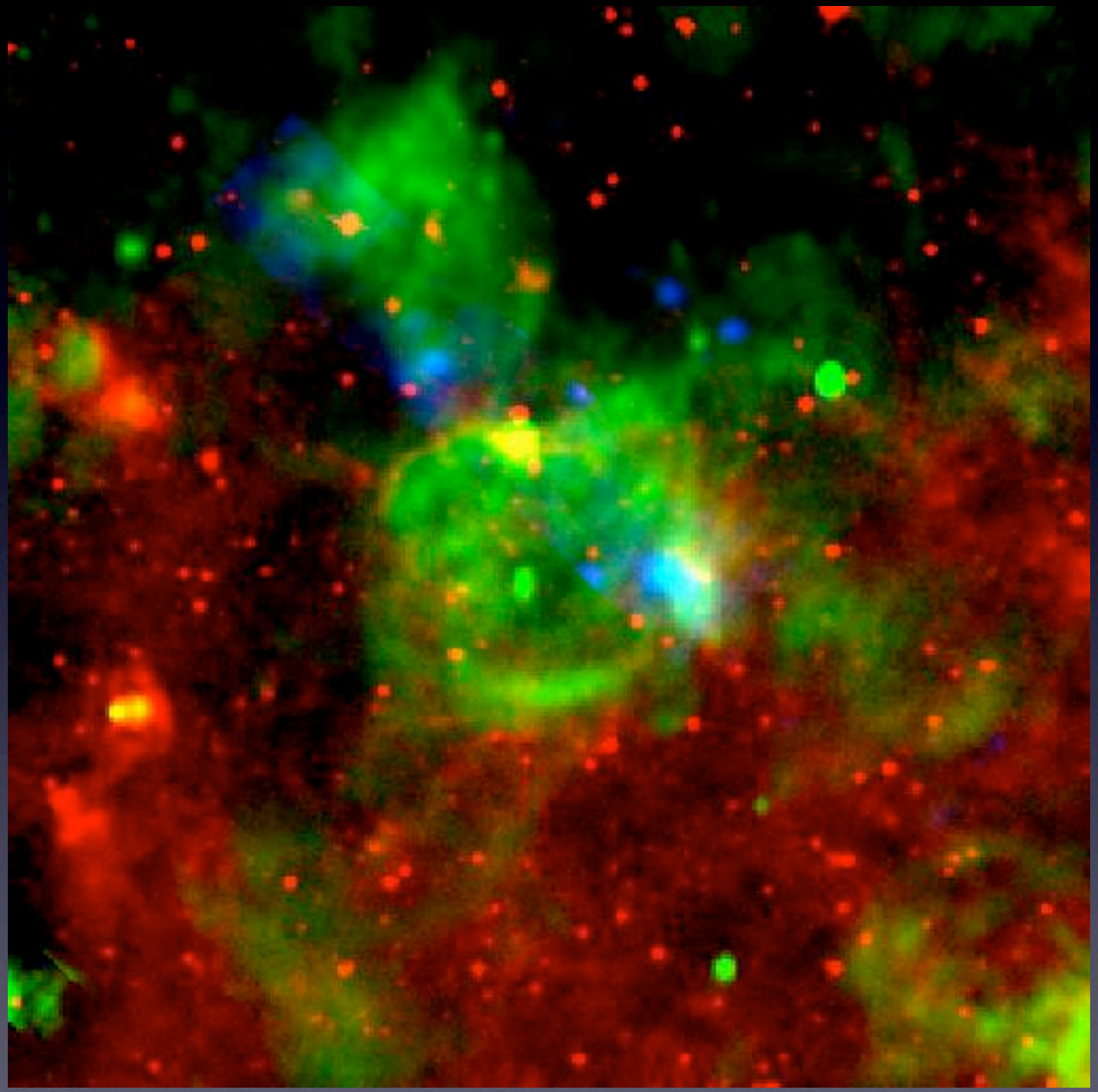


infrared counterpart



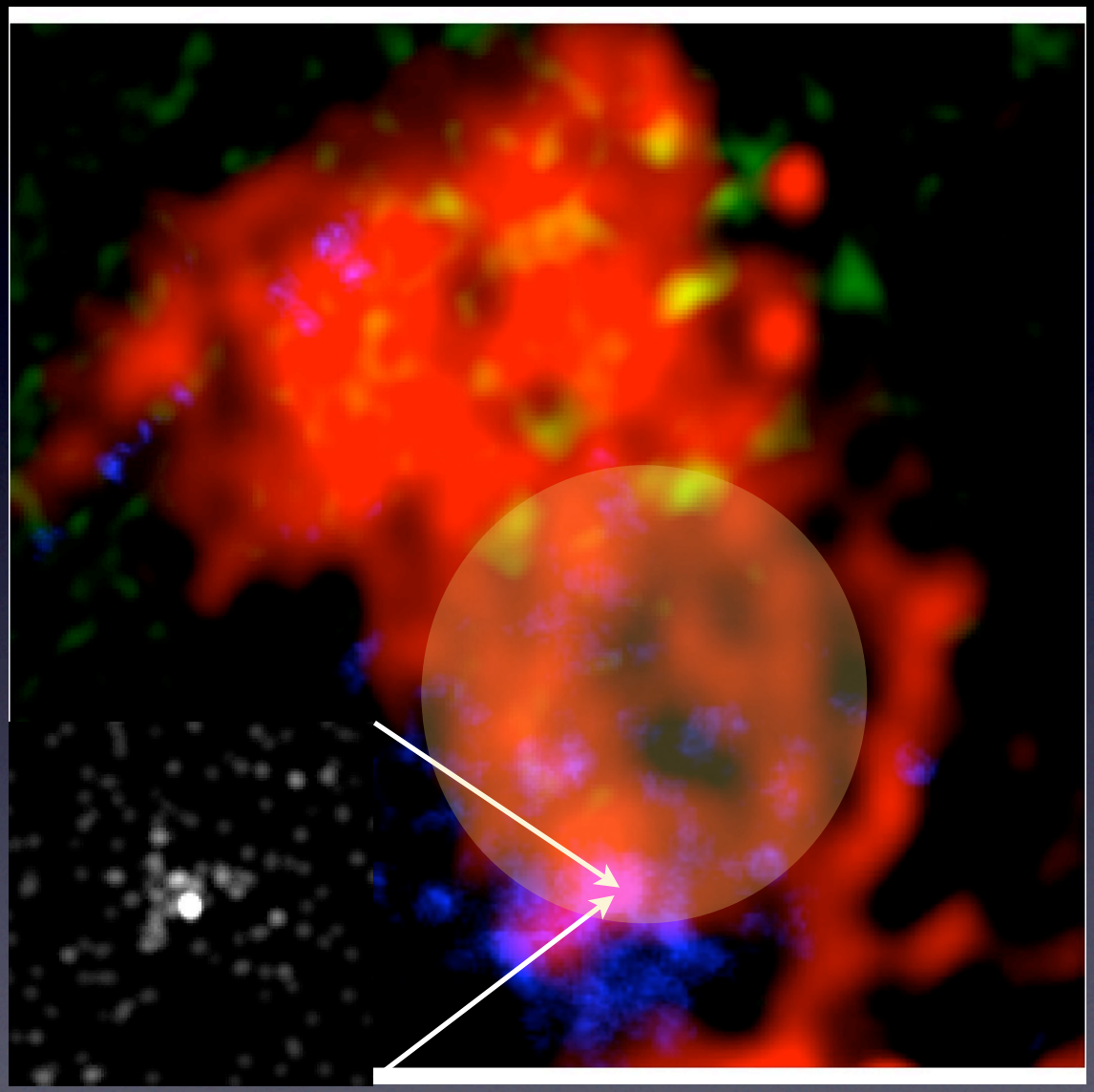
Unnamed HESS Source (see Poster by Lemiere et al.)?

And last but not least, the Kookaburra



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

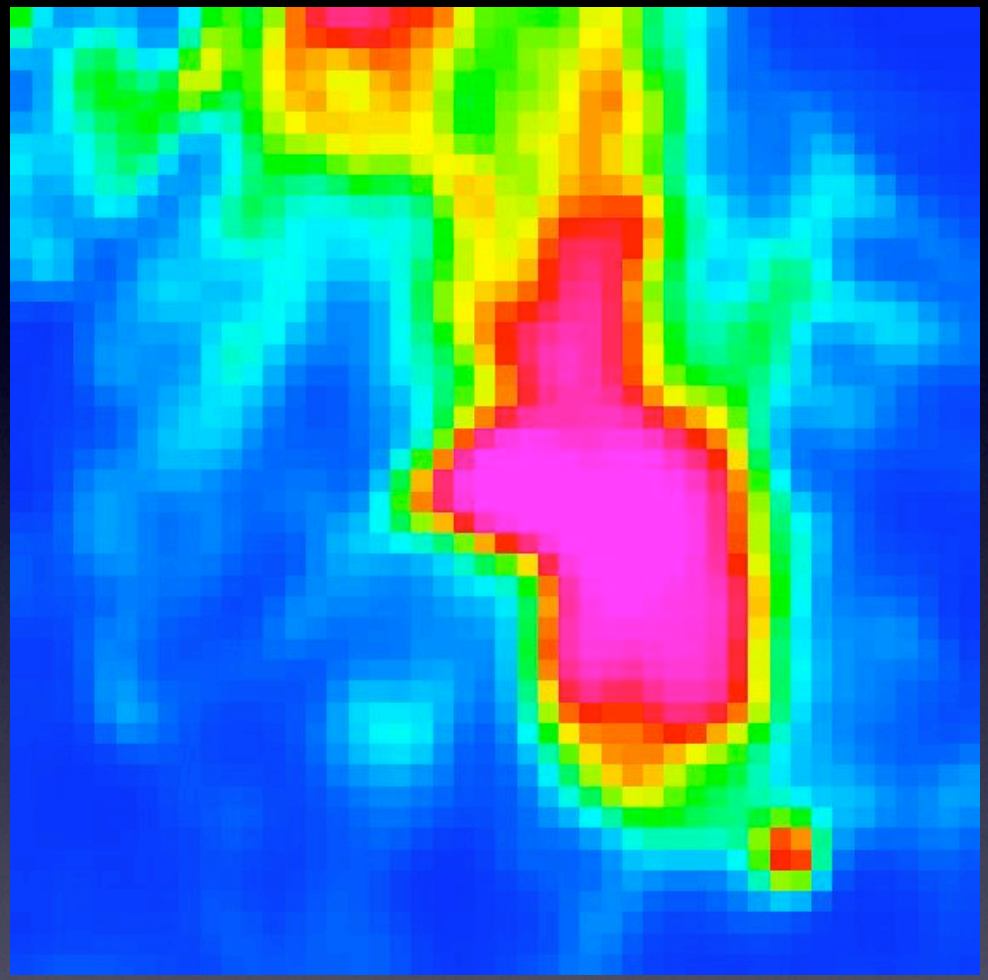
PSR J1420-6048



- Energetic pulsar in upper wing of Kookaburra
- Hint of X-ray Torus
- Is wing radio PWN?
  - Polarized emission
  - HESS SOURCE!

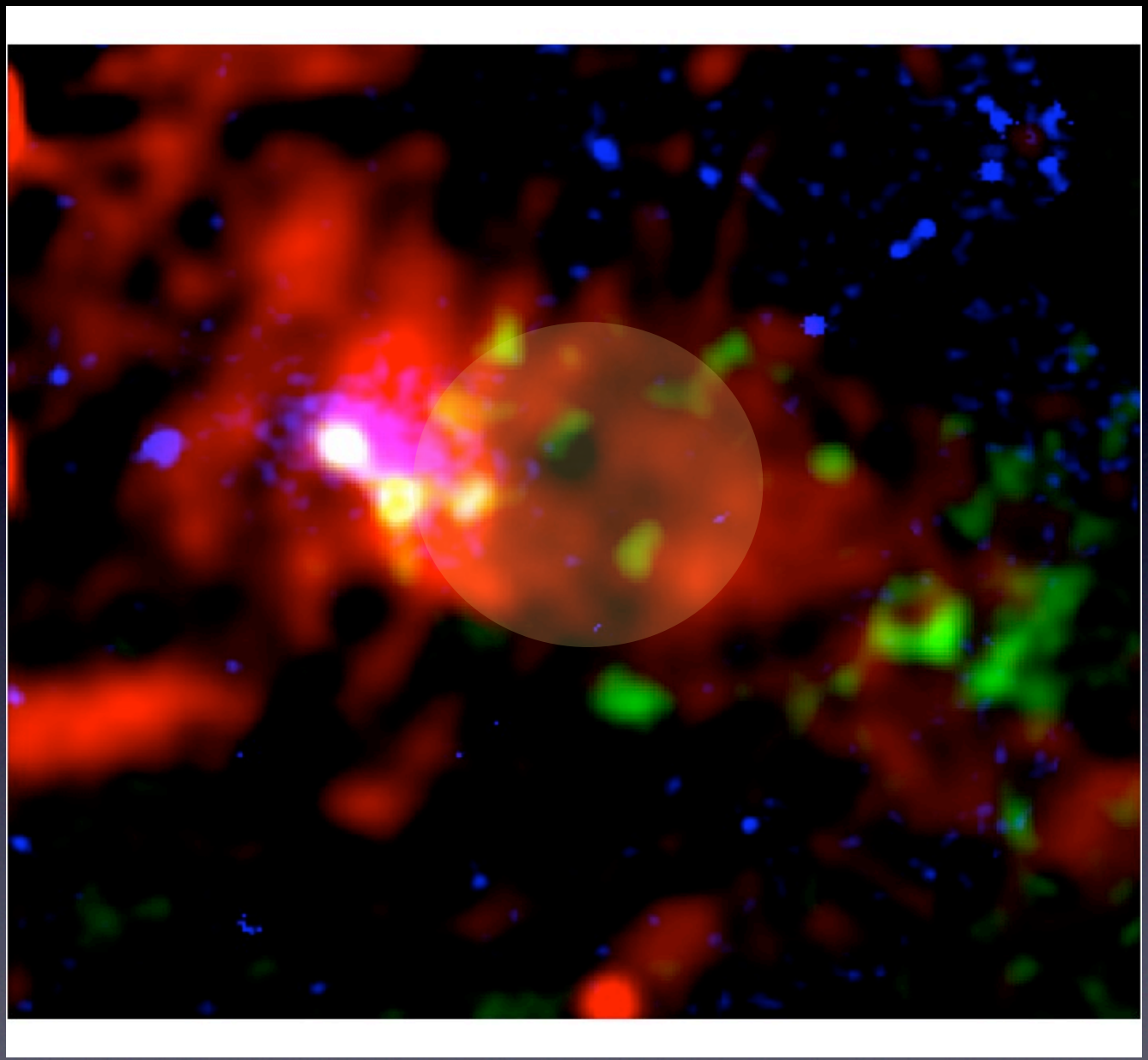
20cm Radio Polarized Radio Hard X-ray

But There is Also the Rabbit!



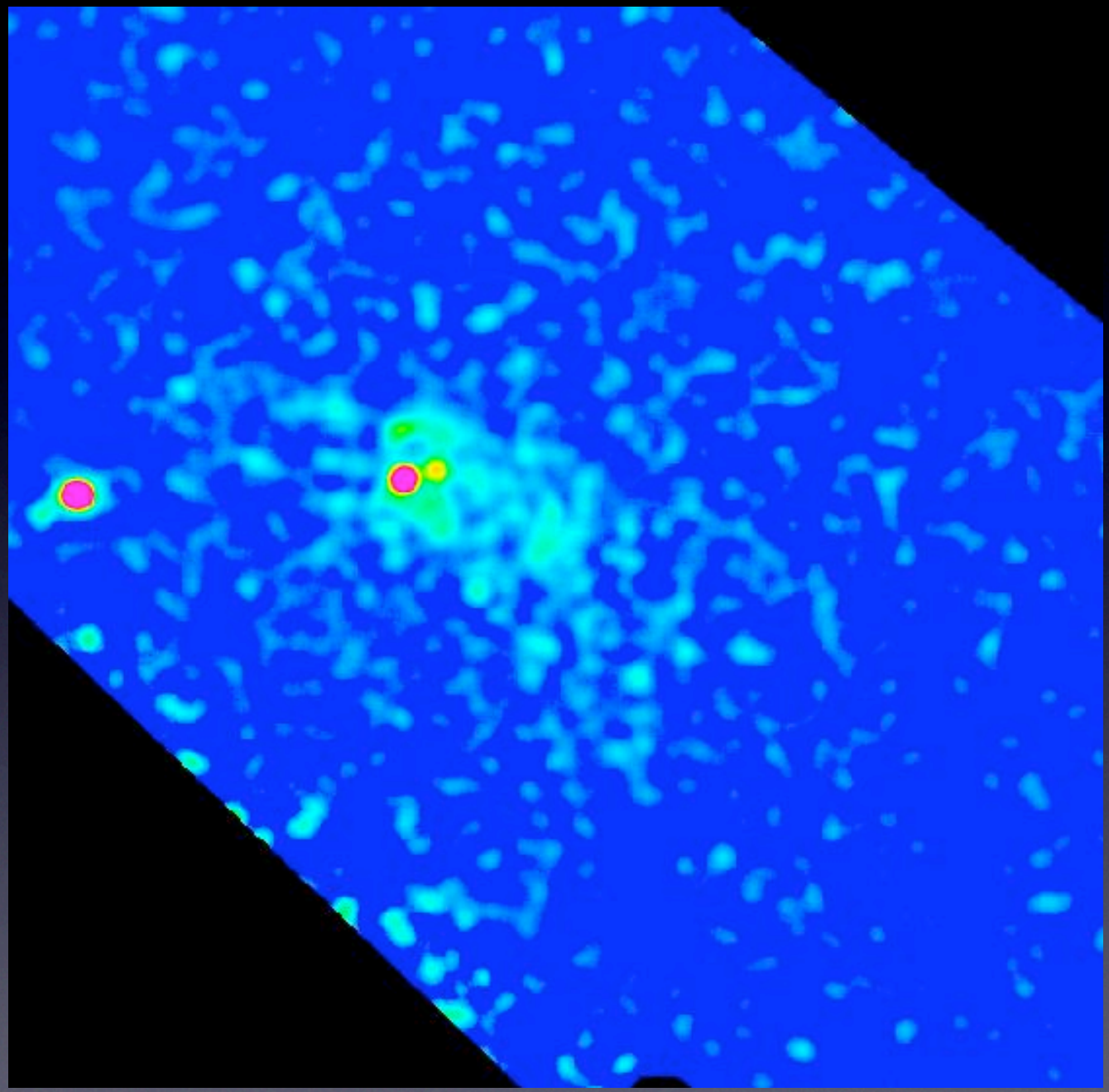
13 cm radio (Roberts et al. 1999)

Lower Wing Containing Rabbit ALSO A HESS SOURCE!



20cm Radio Polarized Radio Hard X-ray

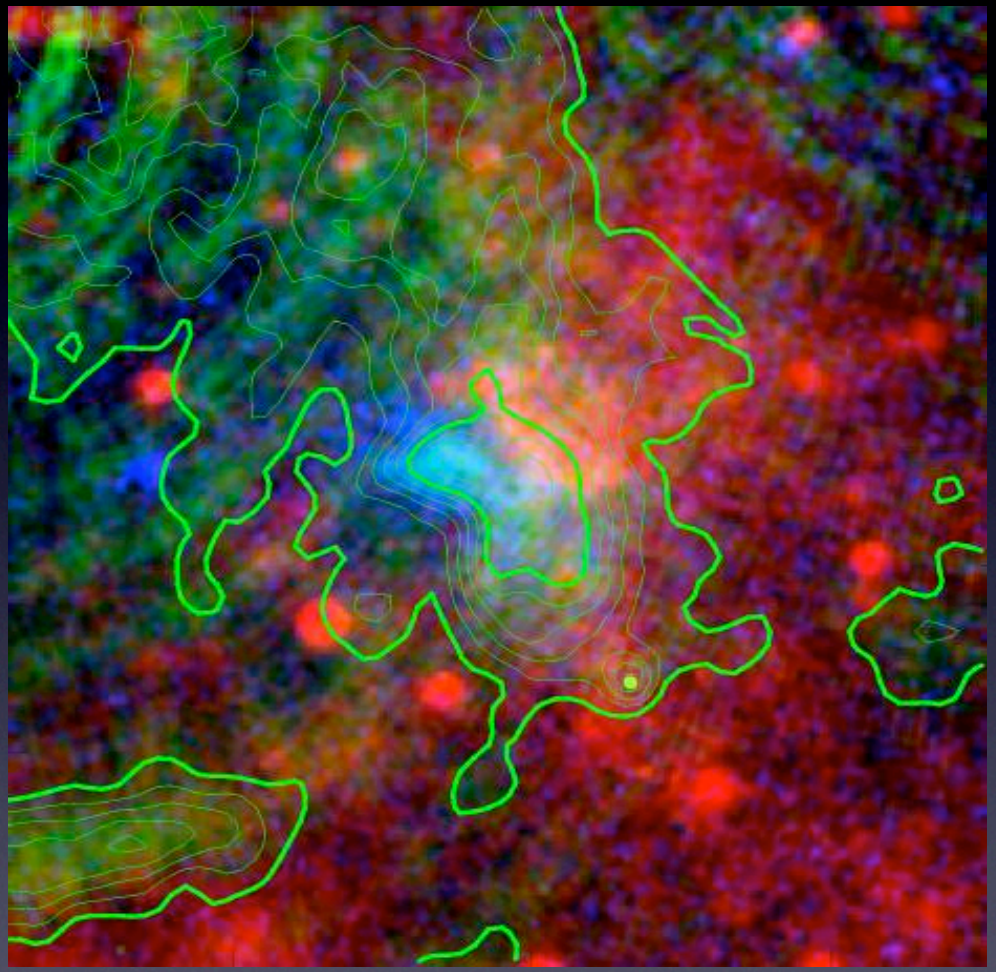
Chandra 1-7 keV Rabbit



Chopping off Head of Rabbit?

Mid-IR emission bounds non-thermal X-rays

Are the ears just part of the thermal shell?



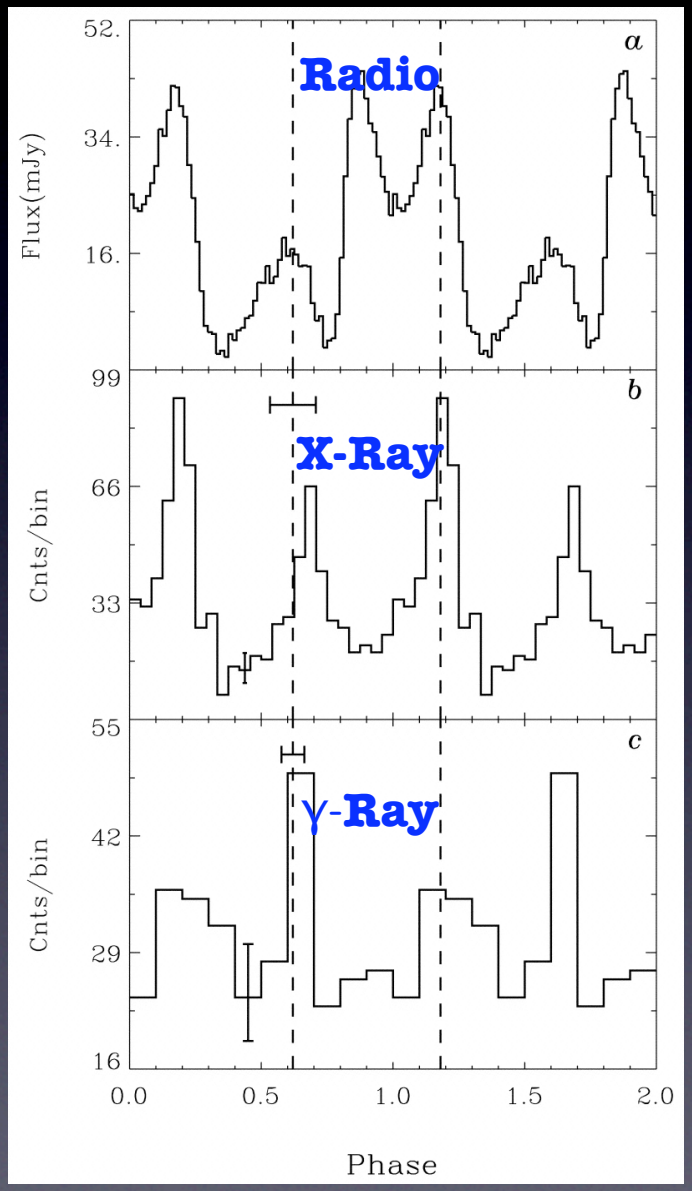
mid-Infrared 8.3 μ Radio non-thermal X-Ray

Searching for γ-ray pulsars out of the plane

- Nearby, middle-aged pulsars
- Millisecond pulsars in Galactic Halo?

Millisecond Pulsars?

PSR J0218+4232



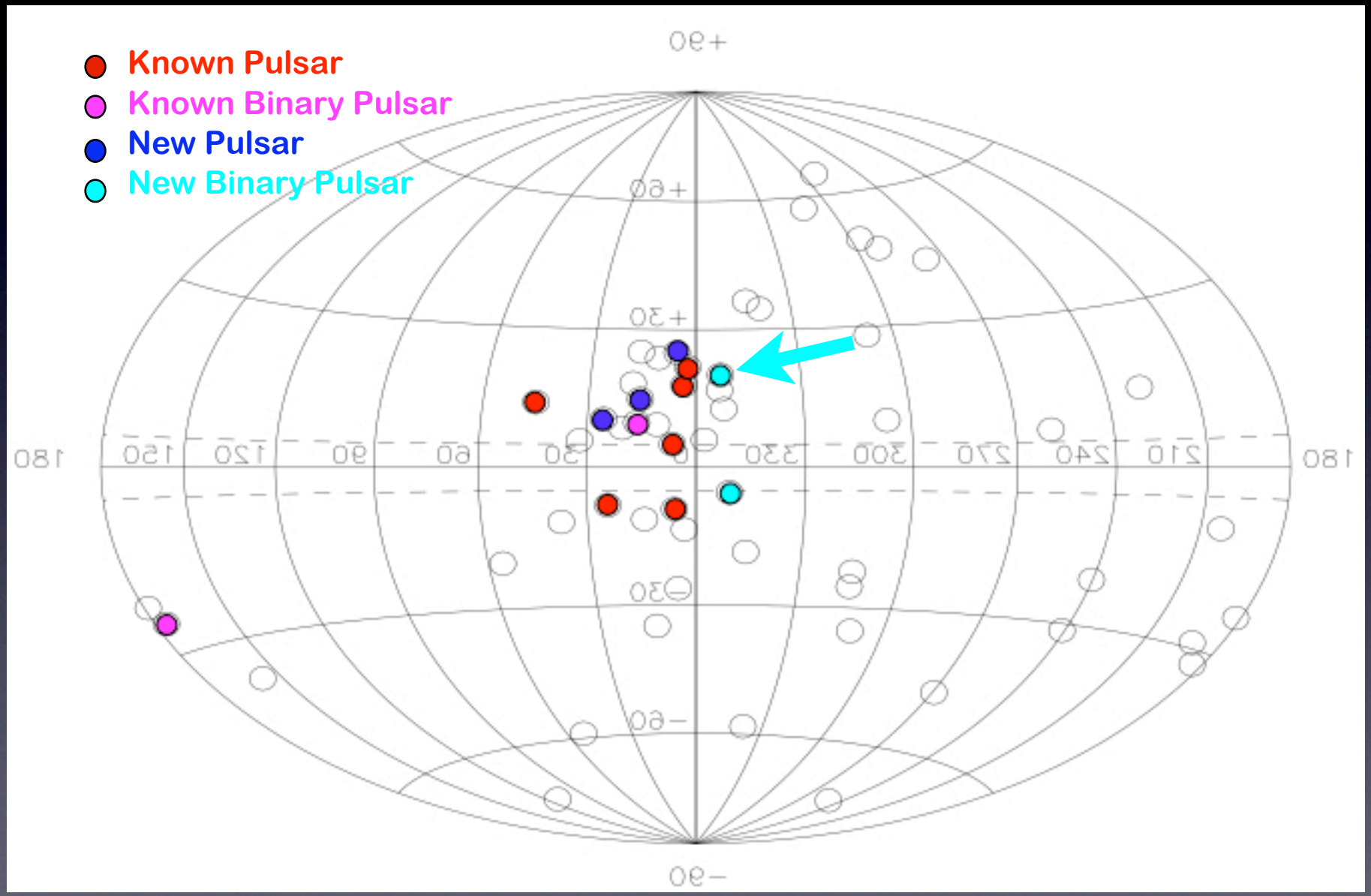
Kuiper et al. 2002

- **MSPs can have spin-down**
- **energies and magnetospheric potentials similar to young pulsars**

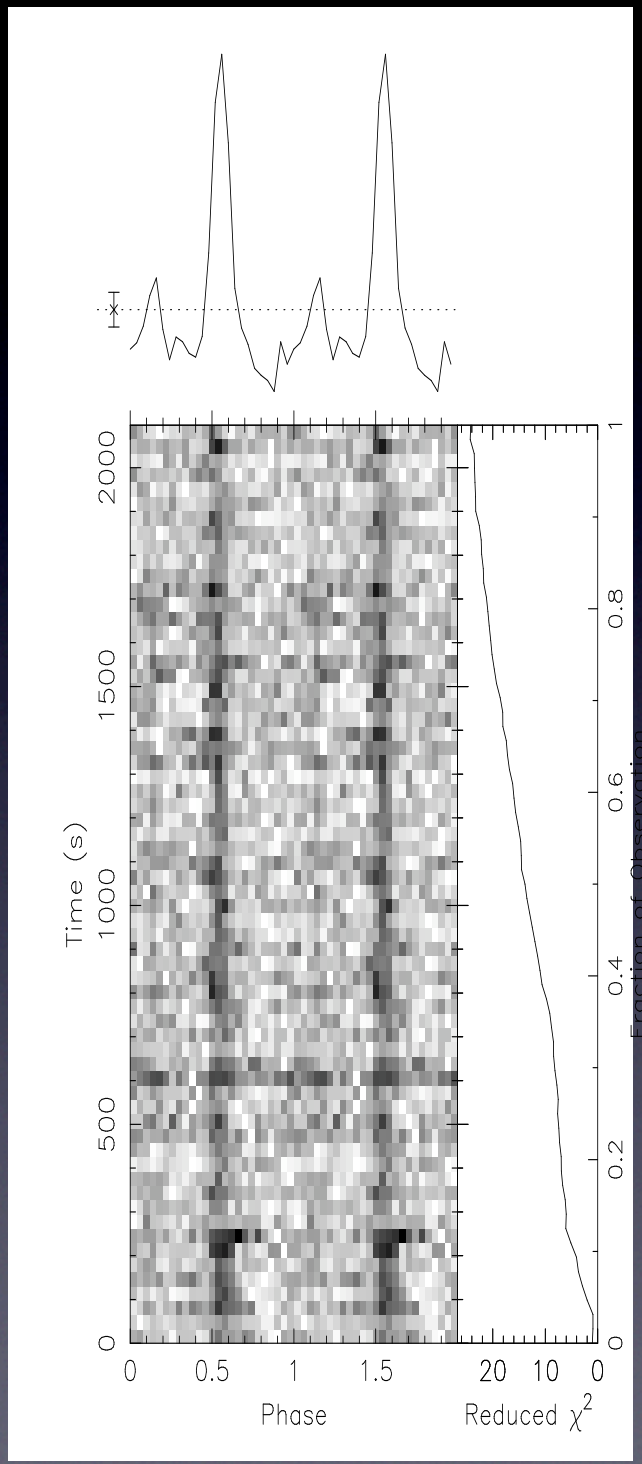
- **They have a mid-latitude distribution similar to the EGRET unidentified sources**

- **There was one possible detection with EGRET of an MSP.**

Survey Results
(Crawford et al. 2006)



PSR J1614-2230



Ransom et al. in prep

$P_s = 3.15$ ms

$\dot{E} = 1.2X10^{34}$ ergs/s ~ $L_\gamma(d/1.3kpc)^2$

$B = 1.8X10^8$ G

$\tau = 5.2X10^9$ yr

d ~ 1.3 kpc

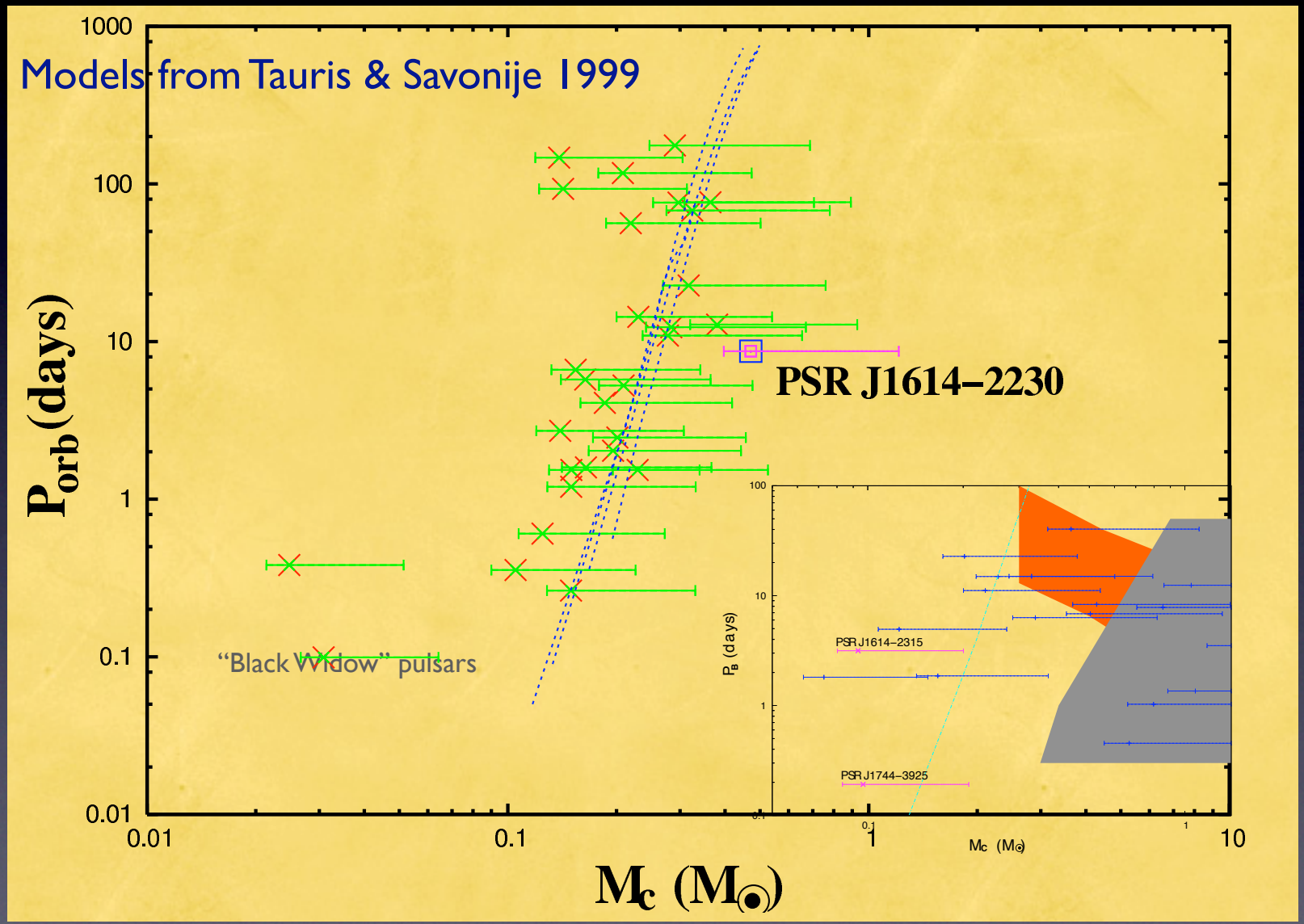
$P_{orb} = 8.7$ days

ecc = $1.4X10^{-6}$

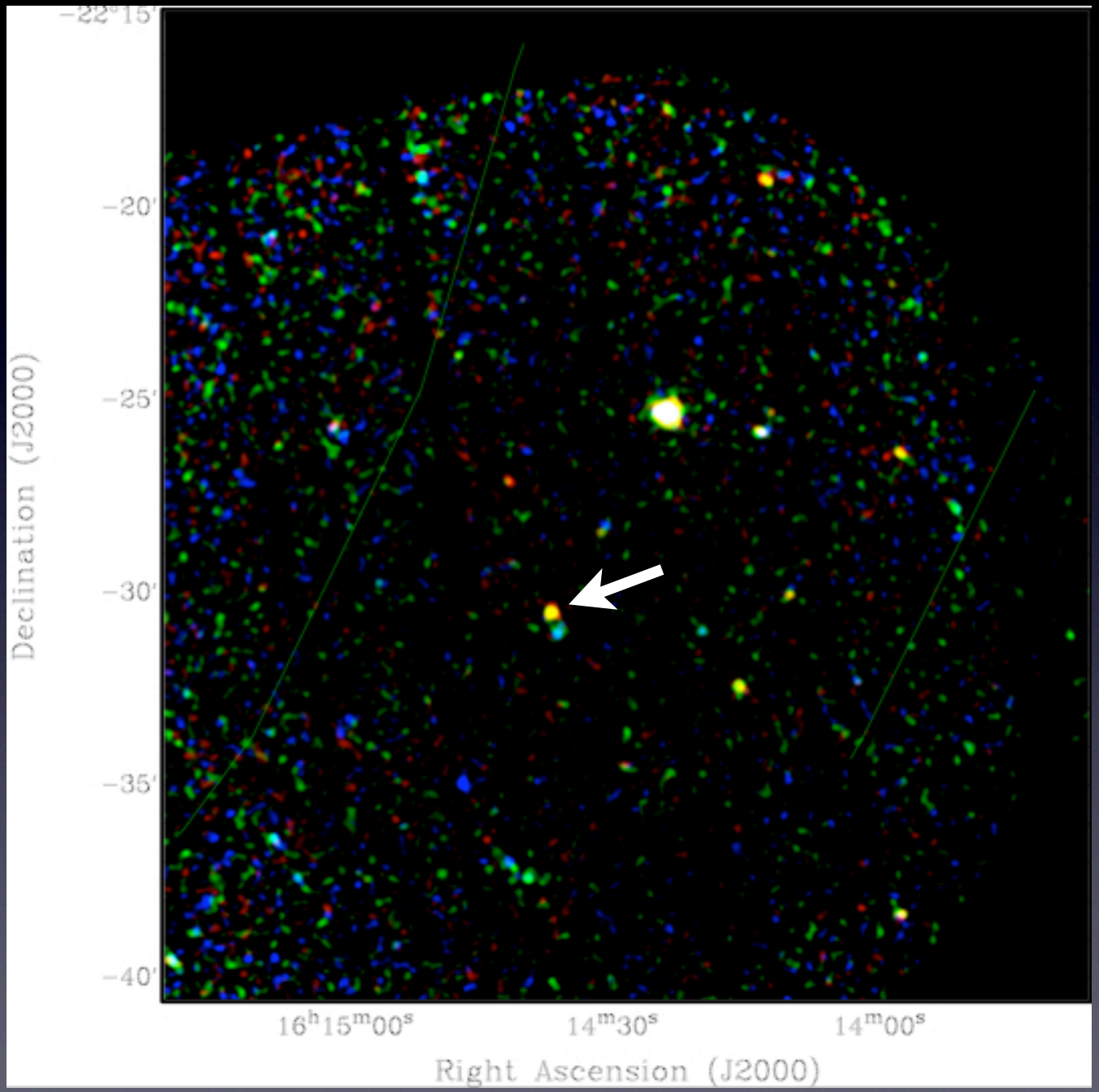
HEAVY WHITE DWARF COMPANION

$M_c > 0.4\ M_{sun}$

Orbital Period / Companion Mass relationship for P < 8ms pulsars in Galactic Field

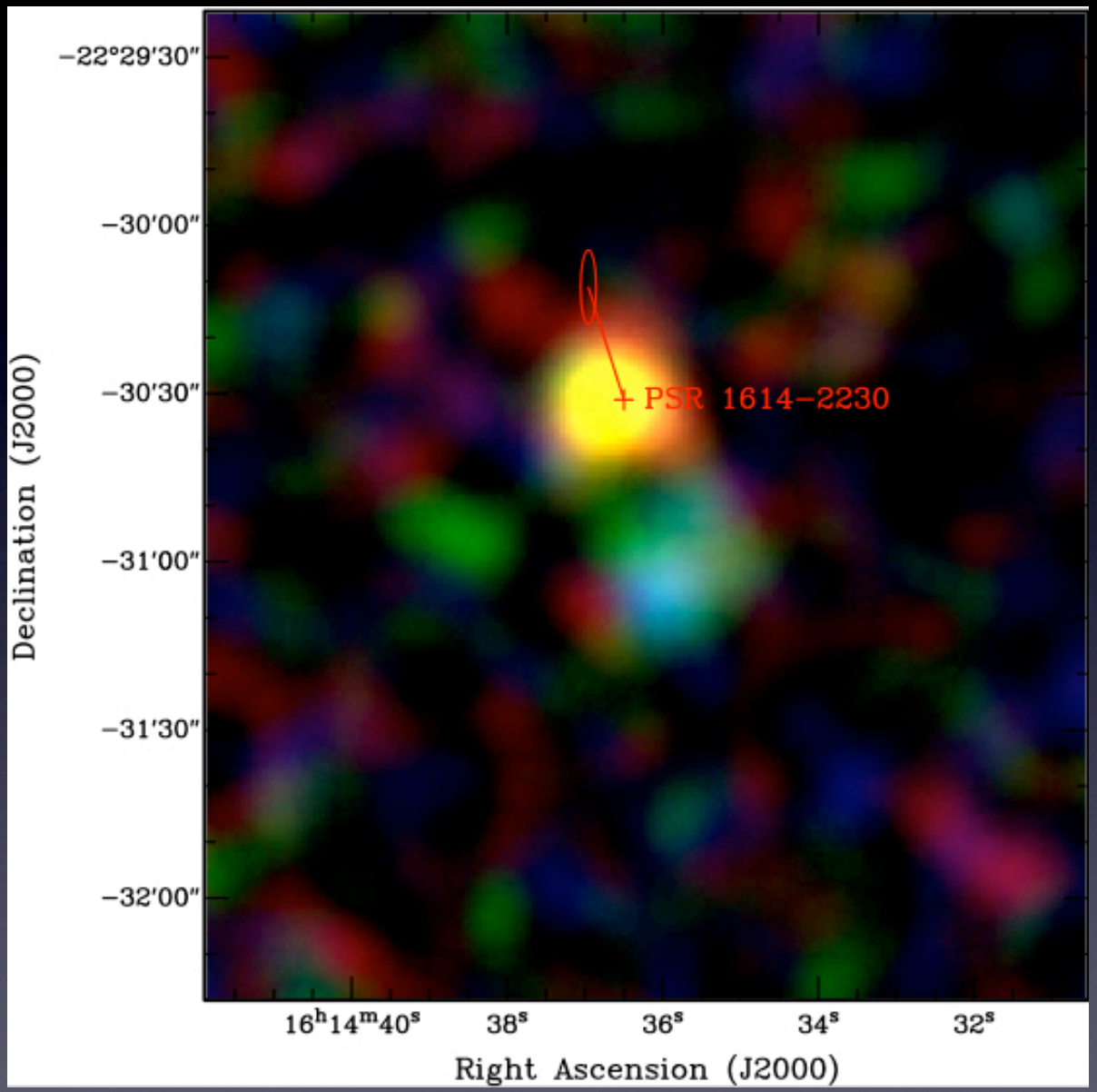


XMM-Newton Observation of PSR J1614-2230



PSR J1614-2230

Ransom et al. in prep



0.3–1 keV 1–2 keV 2–5 keV

- Soft X-ray point source with low absorption
- Harder, probably extended emission
- X-ray efficiency ~0.1%
- preliminary proper motion, assuming DM distance, $V_\perp$=780±350 km/s (twice tempo errors)

Summary

- Three probably variable EGRET sources are probably PWN
  - XMM-Newton observation confirms RPWN morphology of Taz but suggests it may be behind Lynds 227
  - Eel may be confirmed RPWN by HESS
  - HESS sources in Kookabura confirm PSR J1420-6048 and Rabbit are associated with wings. K3 probably PWN offset by SNR reverse shock, Rabbit less clear
- PSR J1614-2230 may be EGRET source. 3rd MSP RPWN? Evolution unclear.