Pulsars and Pulsar-Wind Nebulae: TeV to X-Ray Connection

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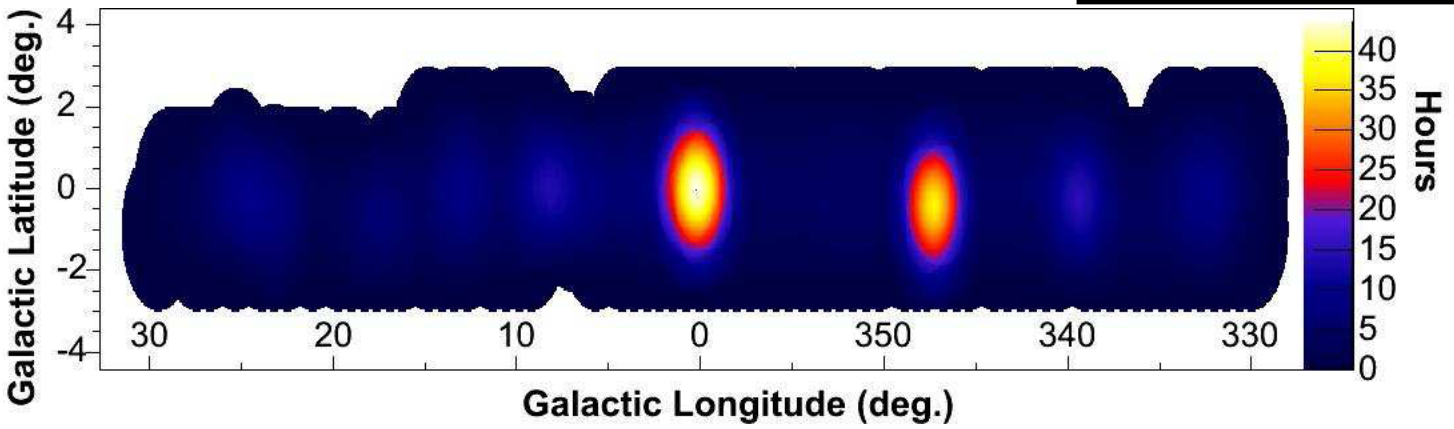
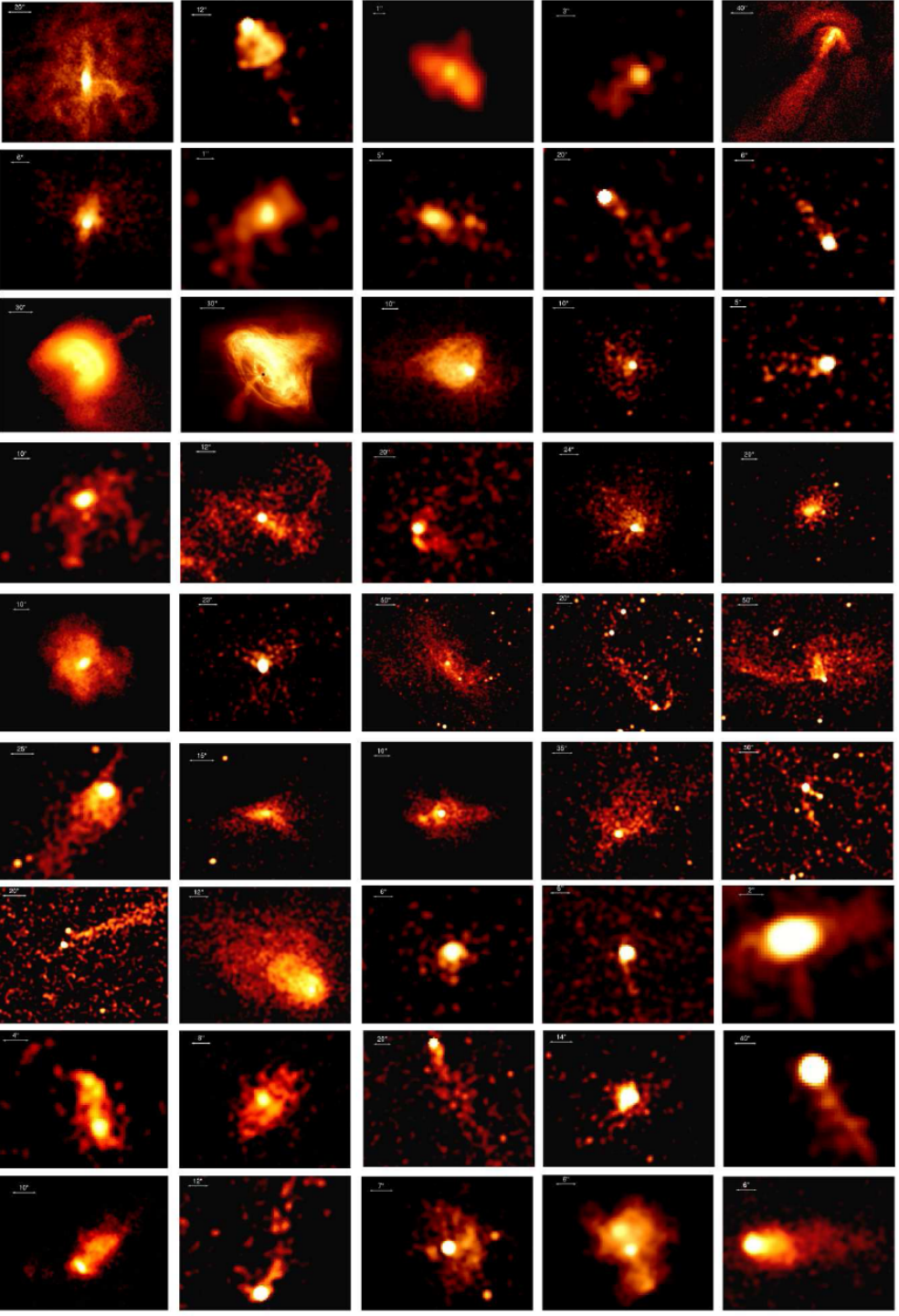
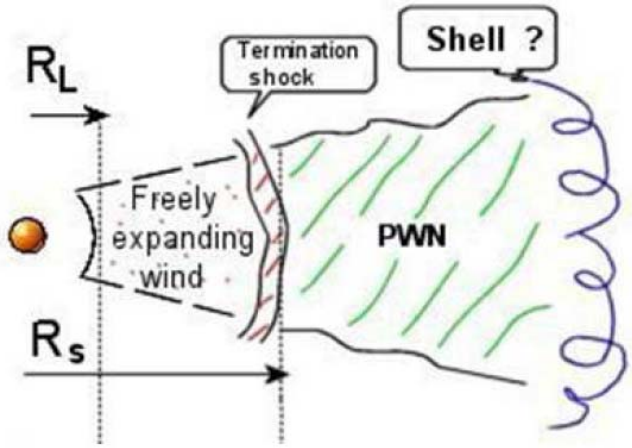


The effective exposure of the H.E.S.S. Galactic Plane survey

Pulsar Wind Nebulae.

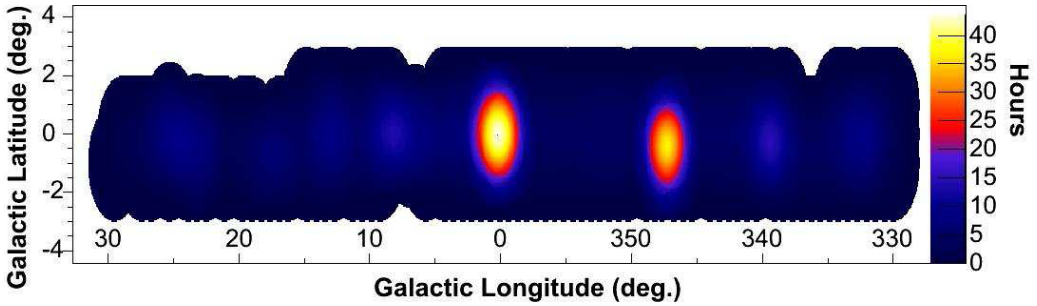




- All active pulsars emit relativistic winds
- $c > c_s$ → shock forms
- Shocked matter: subrelativistic flow of relativistic particles in magnetic field and radiation field (e.g. CMBR) → synchrotron (**radio** through **X-rays**) and IC radiation (GeV and **TeV**) → **PWN**

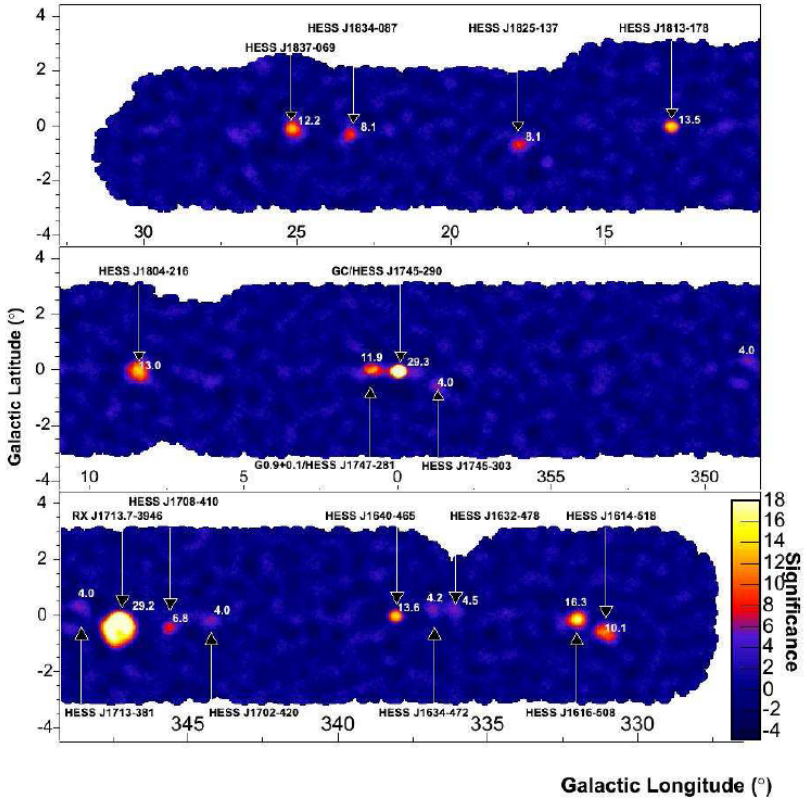
The above cartoon assumes symmetric wind expansion which may not be the case if the SNR shock becomes asymmetric (due to the interaction with the environment). In this case the propagating back reverse shock will also be **asymmetric** and can ``**crush"** a PWN pushing it to the side from the pulsar.

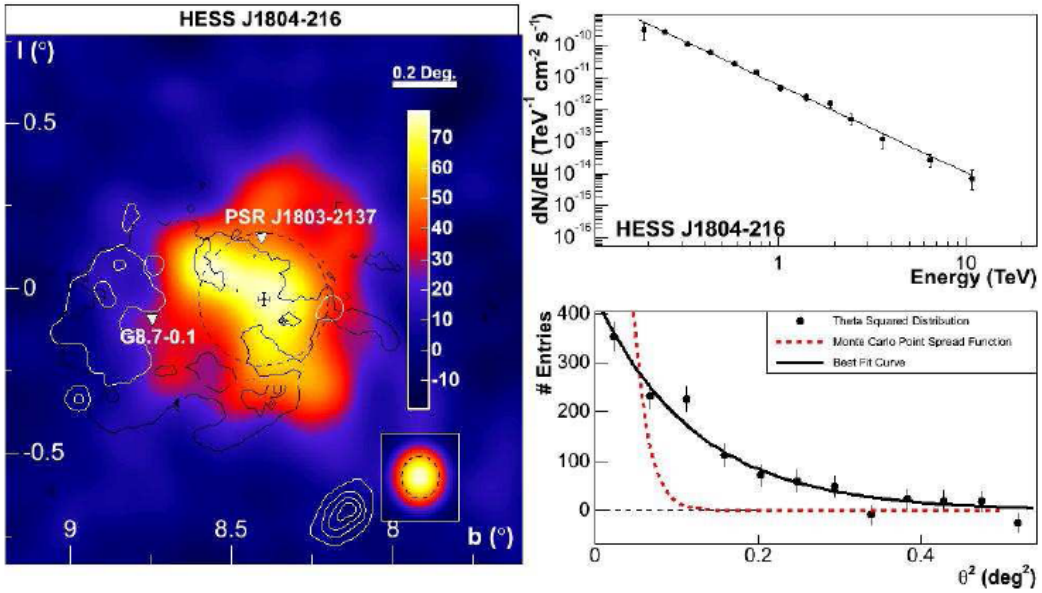
Galactic Plane Survey with H.E.S.S.



The effective exposure of the H.E.S.S. Galactic Plane survey

Extended TeV sources resolved:





Aharonian et al. (2006)

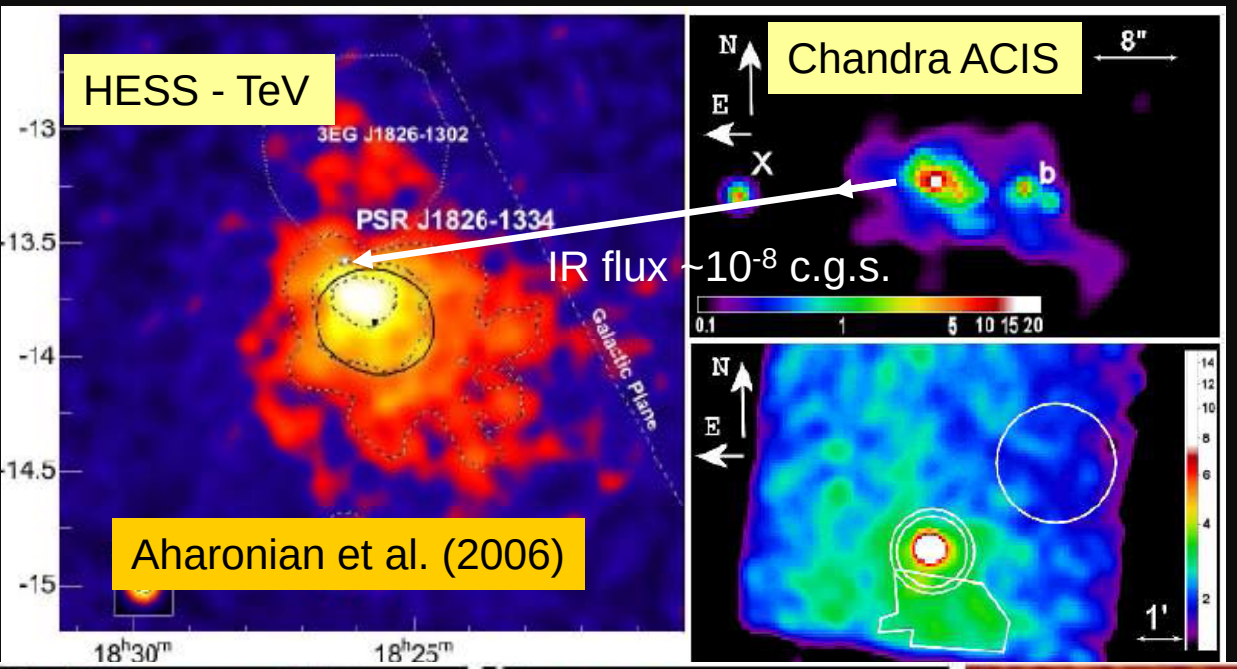
Many of these TeV sources are found in the vicinity of young, energetic pulsars!

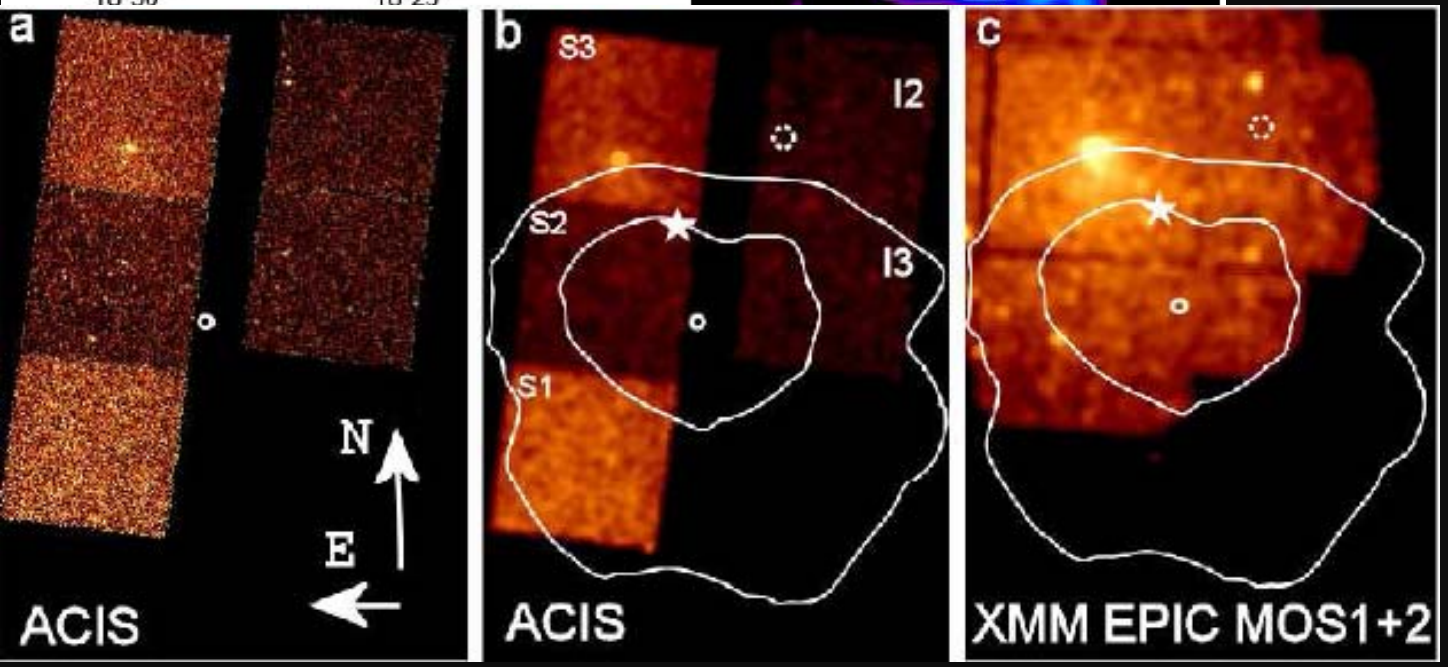
TeV PWN candidates.

HESS	Counterpart	d	$\log \tau$	$\dot{E}$	D	$\log f_\gamma$
		kpc	kyrs	10^{36} erg s^{-1}	arcmin	C.U.
J0534+220	B0531+21/Crab	2	1.24	461	0	1.0
J0835-455	**B0833-45/Vela-X**	0.3	11.3	6.92	60	0.75
J1514-591	B1509-58/MSH 15-52	5	1.55	17.7	12	0.15
J1825-137	**B1823-13**	4	21.4	2.84	60	0.17
J1420-607	J1420-6048/Kookaburra	6	13.0	10.4	7	0.07
J1837-069	J1838-0655	6	22.7	5.55	14	0.13
J1809-193	**J1809-1917**	3.5	51.3	1.78	60	0.14
J1804-216	**B1800-21?**	4	15.8	2.22	24	0.25
J1616-508	**J1617-5055?**	6	8.13	16.0	16	0.19
...						
J1747-281	G0.9+0.1	10	–	–	0	0.02
J1418-609	G313.3+0.1/Rabbit	5	–	–	8	0.06
J1640-465	G338.3-0.0	8	–	–	5	0.09
J1813-178	G12.82-0.02	4.5	–	–	4	0.06
...						

Up to 25 TeV PWN candidates as of June 2008 …

Vela-like PWNe - TeV PWNe: B1823-13



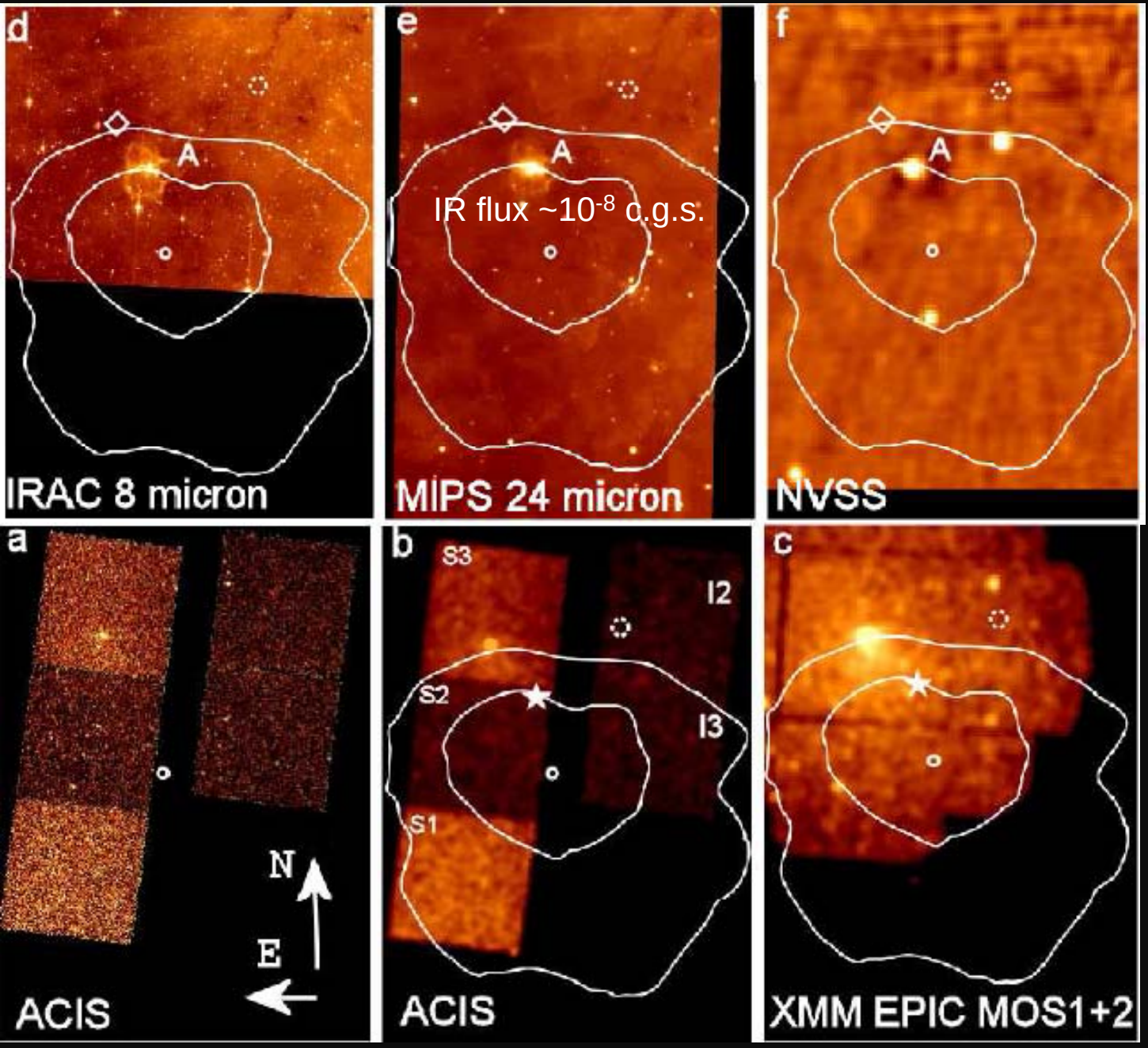


Pavlov, Kargaltsev & Brisken (2007)

HESS J1825-137

- Extremely large size, diameter exceeds 1°
- The pulsar is moving at 440 km/s but its proper motion does not correlate with the asymmetry of the TeV emission wrt to the PSR
- Correlation between TeV and extended X-ray emission, both Show softenning with the distance from the pulsar
- Bright IR/Radio sources within the extent of the TeV source
- No clear sign of the host SNR (at any wavelength)
- No evidence for highly non-uniform ISM, e.g. of a “wall” that could have reflected the SNR shock making it asymmetric wrt. to the explosion center (but see Lemiere et al. 2005).

Vela-like PWNe - TeV PWNe: B1823-13



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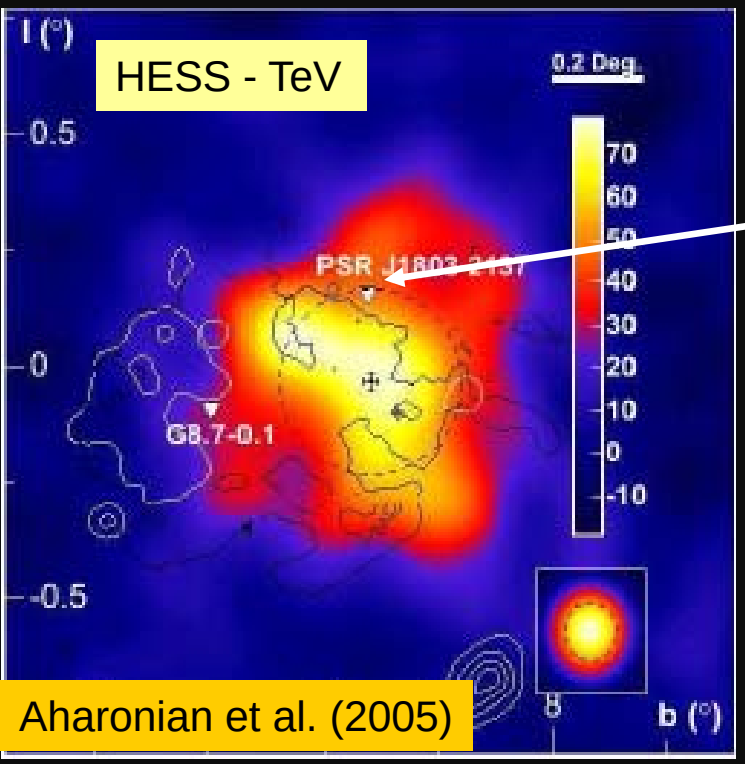
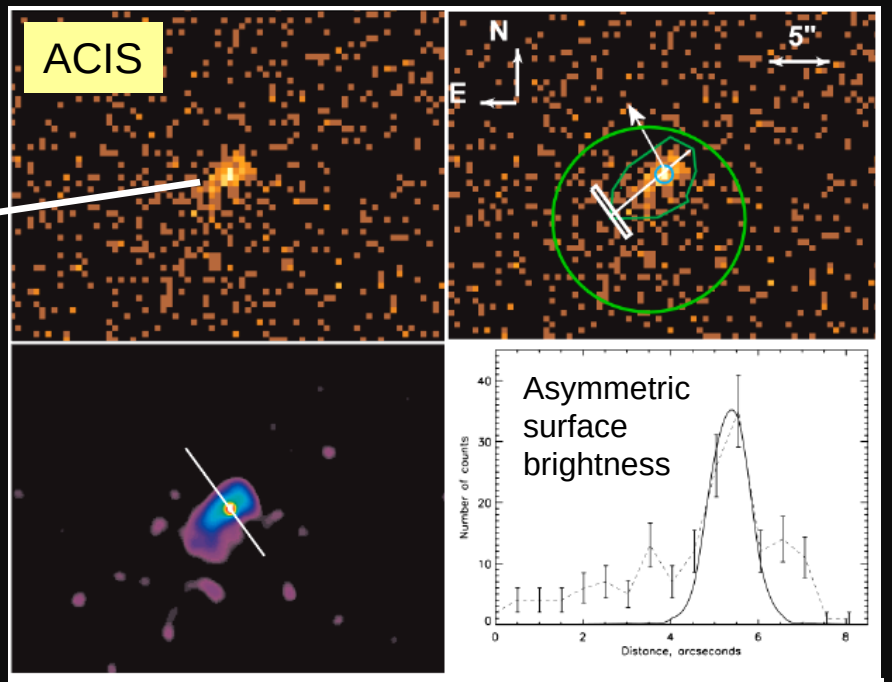
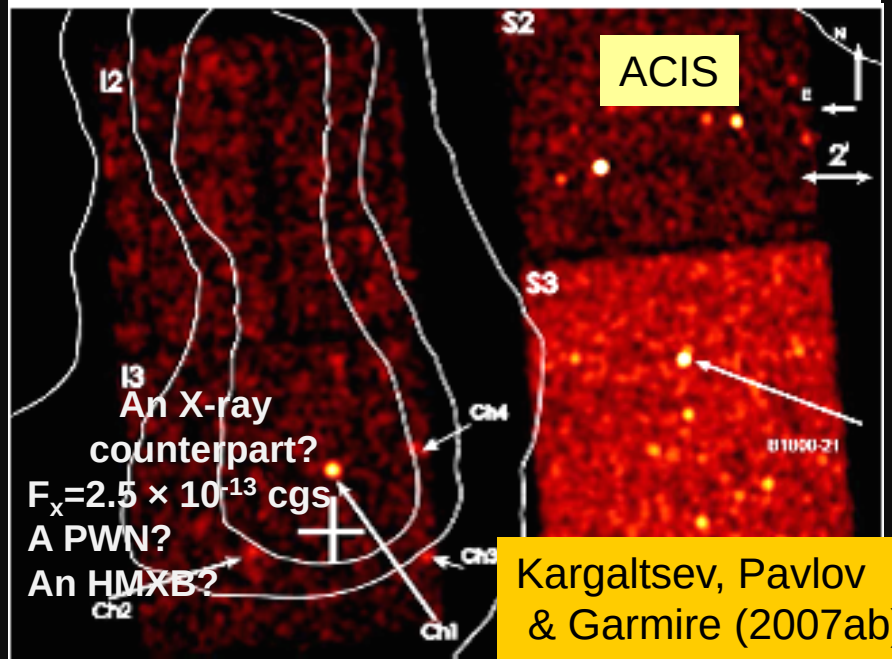
Vela-like PWNe -- TeV PWNe: B1800-21



Aharonian et al. (2005)



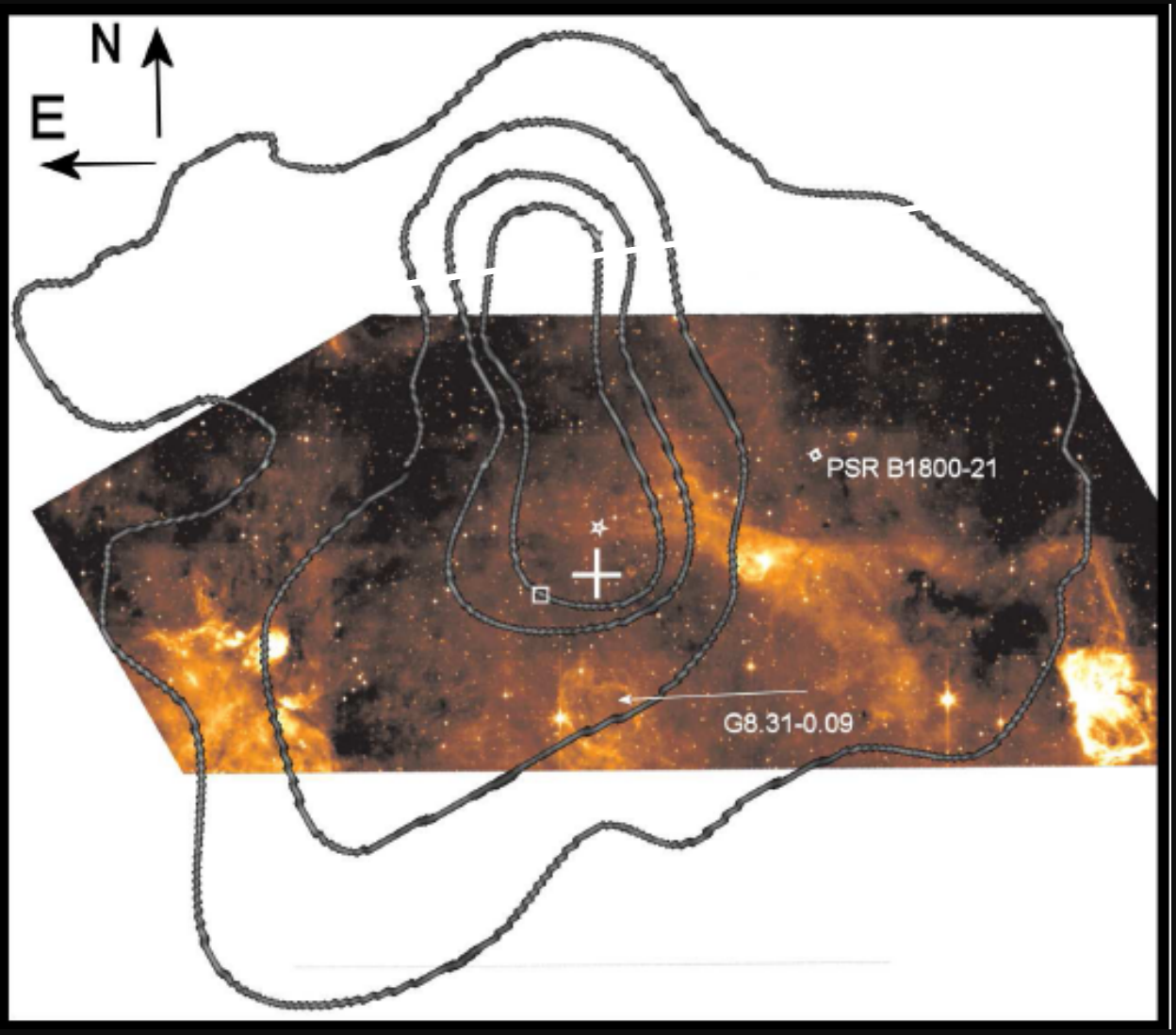


Kargaltsev, Pavlov & Garmire (2007ab)

HESS J1804-216

- **Diameter ~ 0.5°, complex surface brightness distribution**

Vela-like PWNe -- TeV PWNe: B1800-21



HESS J1804-216

- **Diameter ~ 0.5°, complex surface brightness distribution**

HESS J1804-216

- **Diameter ~ 0.5°, complex surface brightness distribution**

Diffuse IR/Radio emission within extent of the TeV source but correlation is poor

Asymmetric surface brightness

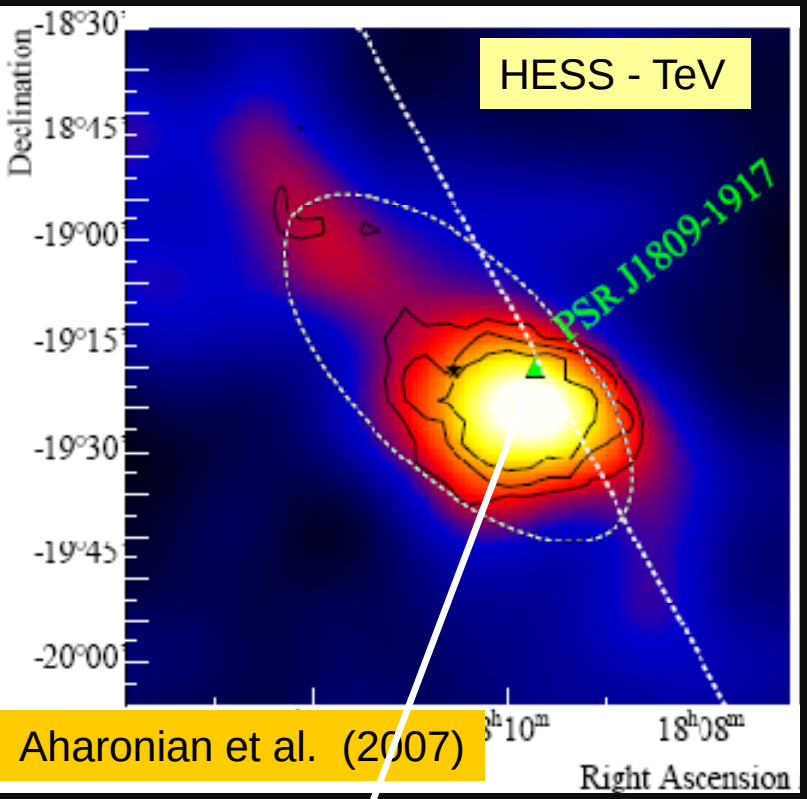
- **No sign of the host SNR** (at any wavelength)

- **No evidence for highly non-uniform ISM, e.g. of a "wall" that could have reflected the SNR shock making it asymmetric wrt. to the explosion center.**

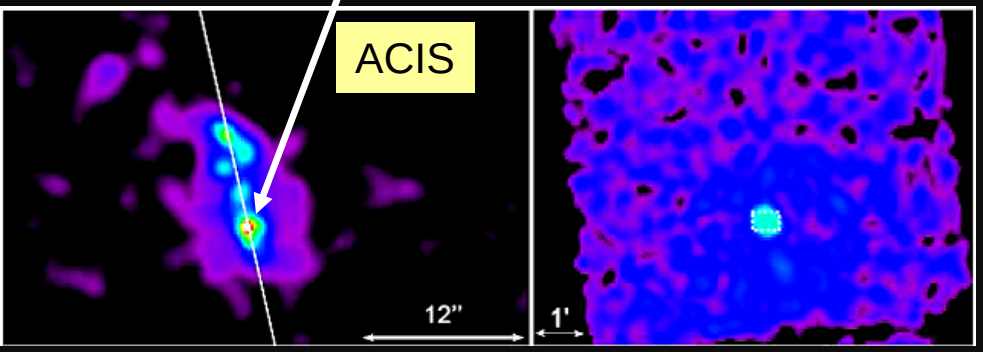
- **Possible correlation between TeV and extended X-ray emission but deeper X-ray observation is needed**

Kargaltsev, Pavlov & Garmire (2007ab)

Vela-like PWNe - TeV PWNe: J1809-1917



Aharonian et al. (2007)

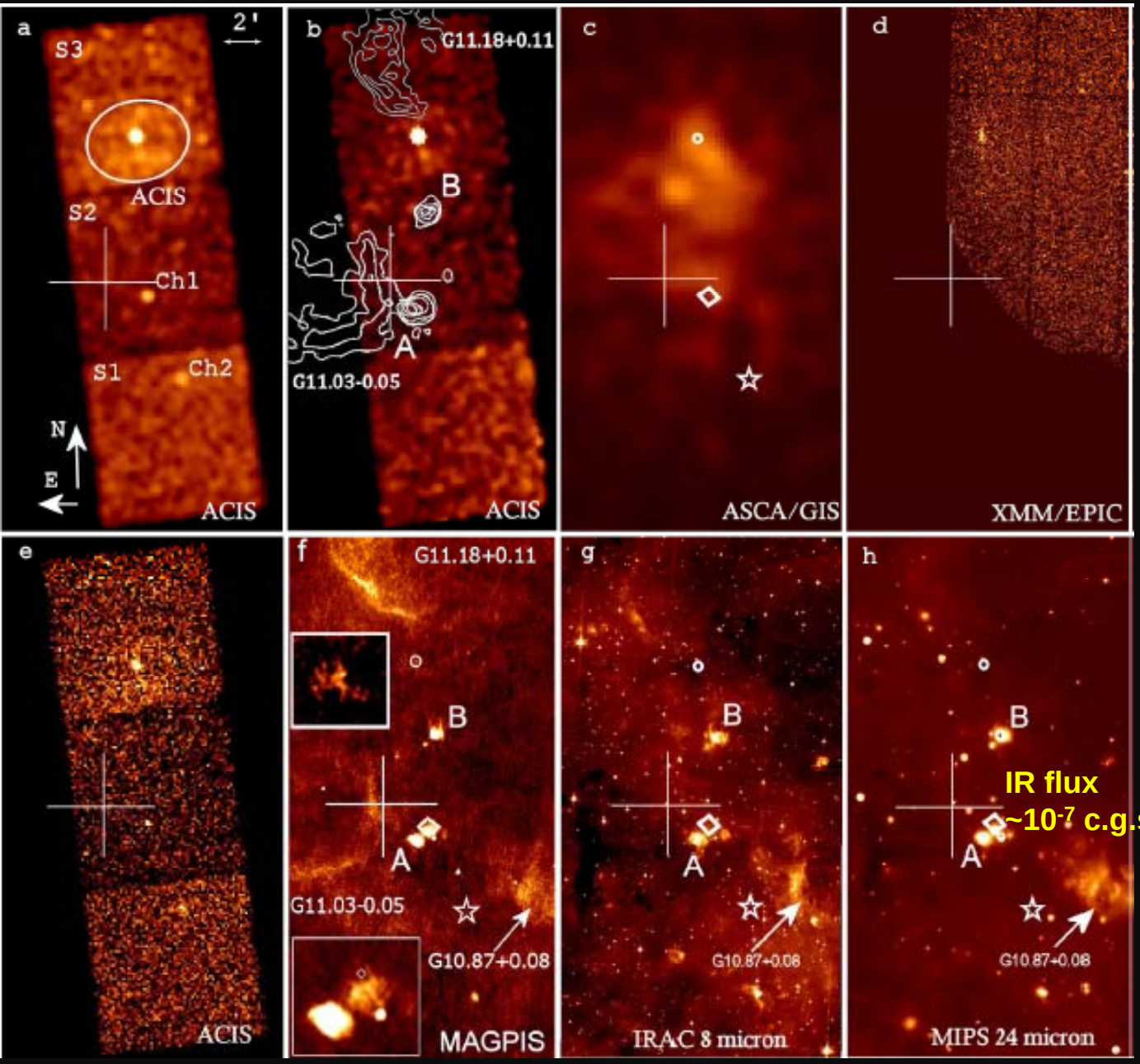


Kargaltsev & Pavlov (2007)

HESS J1809-193

- **Modest size, diameter~20' (excluding the faint tail)**
- **Pulsar proper motion does not correlate with the asymmetry of the TeV emission wrt to the pulsar**
- **Correlation between TeV and extended X-ray emission**
- **The region is very rich in sources emitting in Radio/IR, some correlate with the asymmetry wrt. to the pulsar**
- **No clear sign of the host SNR** (at any wavelength) . There are **some background SNRs**
- **No evidence for highly non-uniform ISM, e.g. of a "wall" that could have reflected the SNR shock making it asymmetric wrt. to the explosion center.**

Vela-like PWNe - TeV PWNe: J1809-1917



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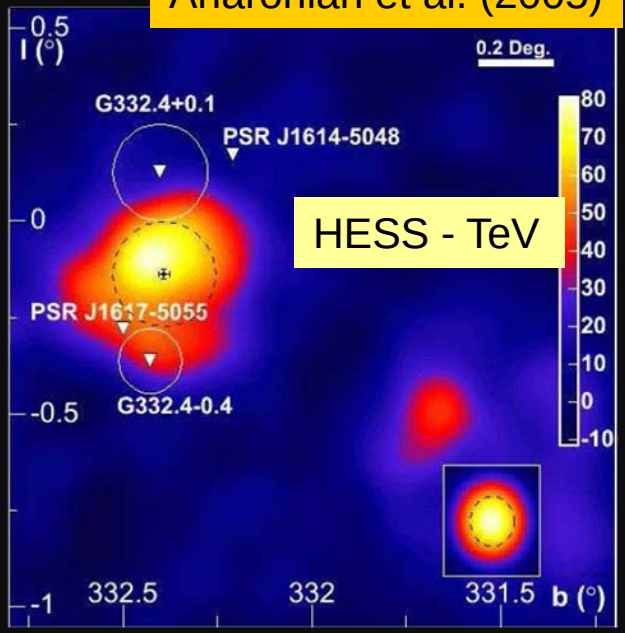
IR flux ~10^{-7} c.g.s.

- **No evidence for highly non-uniform ISM, e.g. of a "wall" that could have reflected the SNR shock making it asymmetric wrt. to the explosion center.**

Kargaltsev & Pavlov (2007)

Vela-like PWNe - TeV PWNe: J1617-5055

Aharonian et al. (2005)

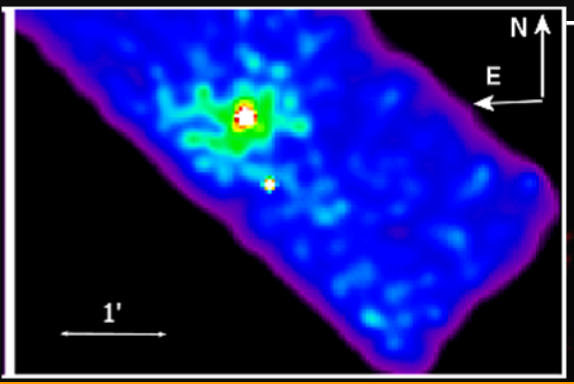


Kargaltsev, Pavlov & Wong 2007

HESS J1616-508

- **Large size, diameter~1°, rather symmetric**
- **NO correlation between TeV and extended X-ray emission from the J1617-5055 PWN**
- **The region is very rich in sources emitting in Radio/IR/X-rays, some correlation with the TeV is seen in the radio/IR**
- **Possibly a hint of an unidentified SNR** in radio . There also are **two background SNRs and a large number of compact diffuse sources in the Radio/IR.**

ACIS



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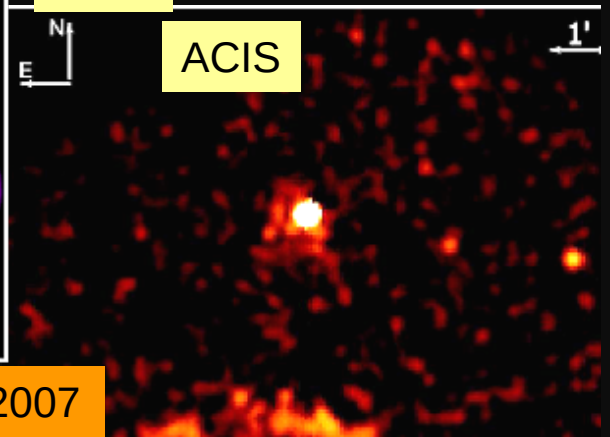
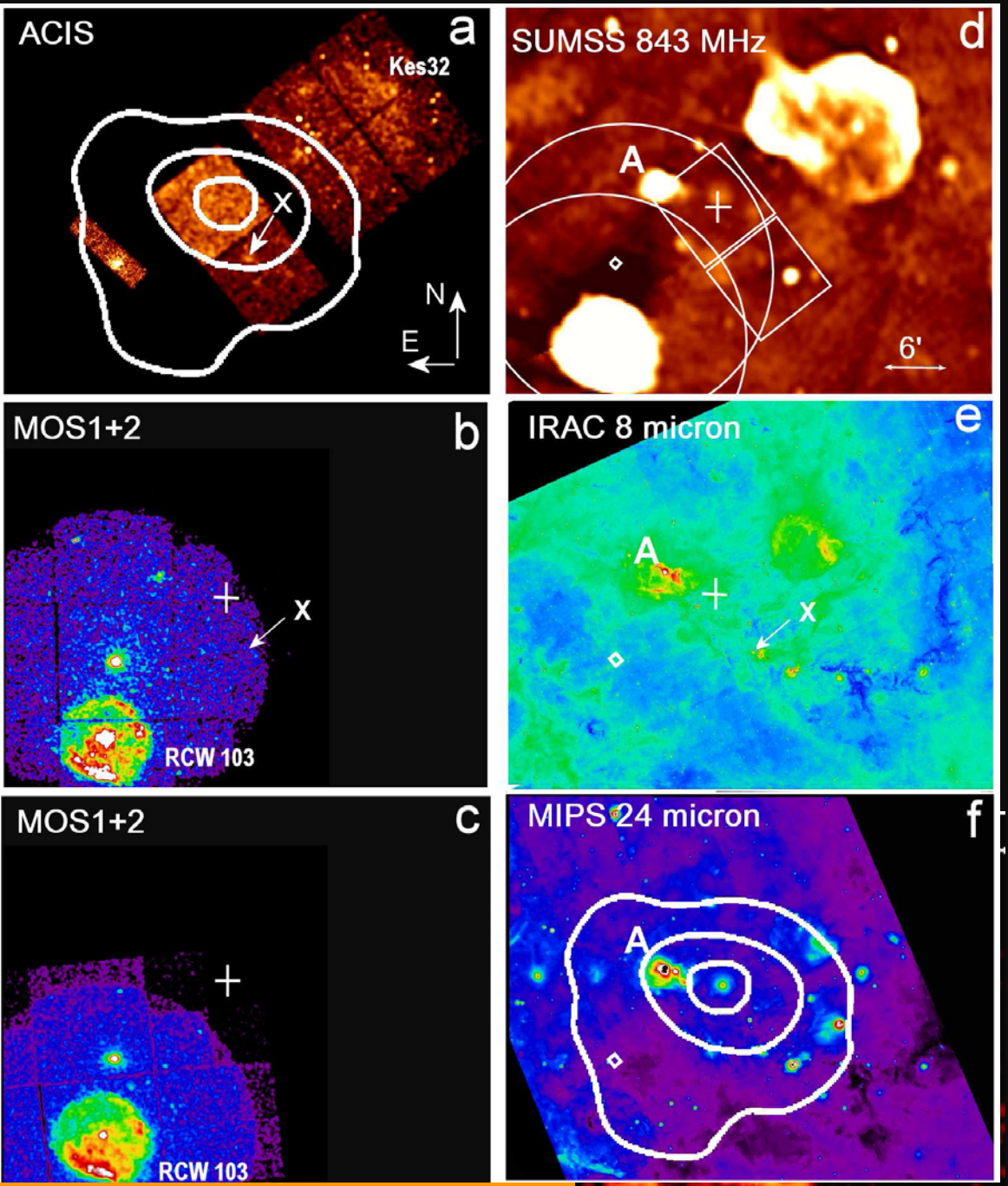


Kargaltsev, Pavlov & Wong 2007

Vela-like PWNe - TeV PWNe: J1617-5055



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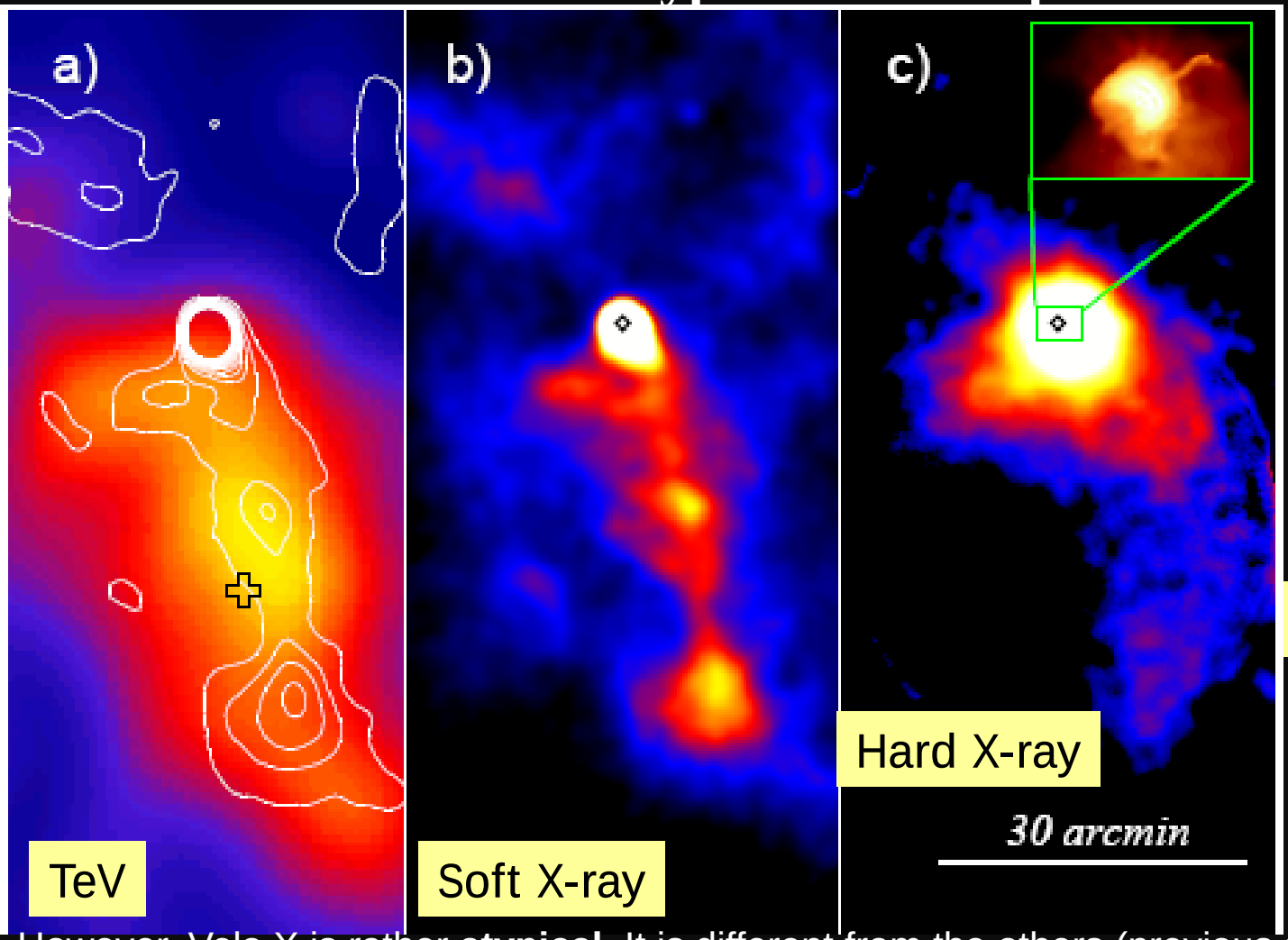
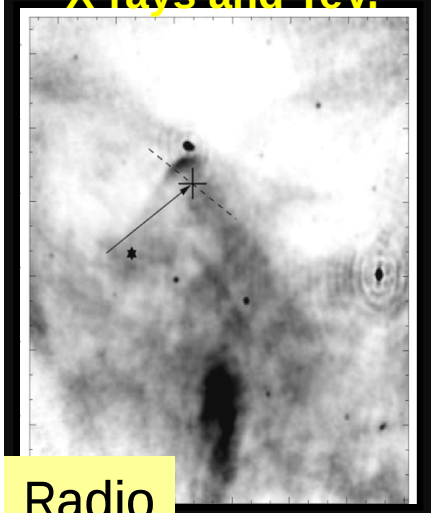
Vela-X region: Radio-X-ray-TeV PWN. A typical crashed plerion?

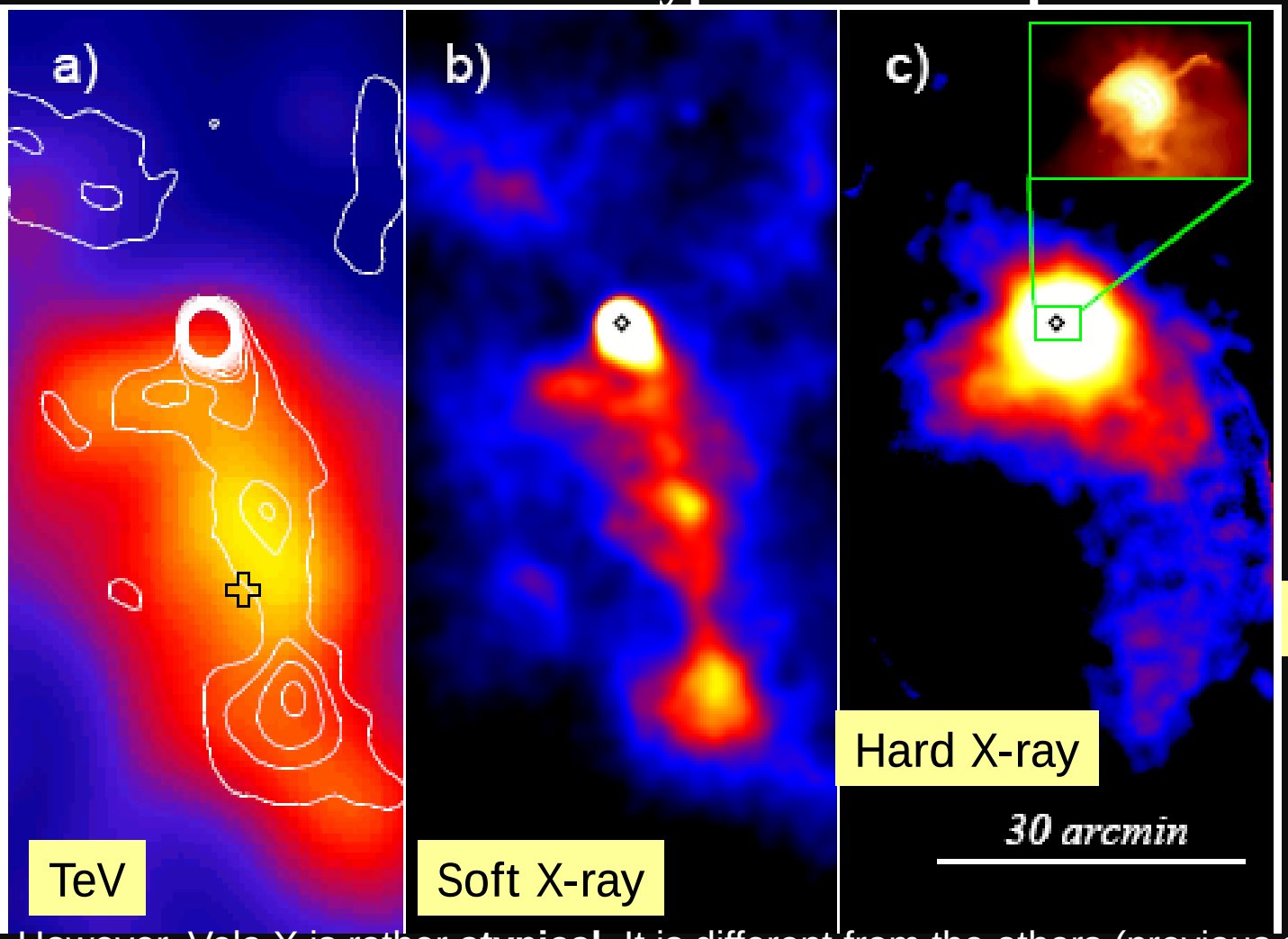
Often considered "canonical"example of crashed (relic) plerion seen both in X-rays and TeV.





However, Vela X is rather **atypical**. It is different from the others (previous slides) because in Vela X the TeV and X-rays come from approximately the same region and also radio emission from the same region is seen. If one looks deeper possibly similar correlations can be found in other TeV plerions. Multiwavelength spatially-resolved spectrum allows one to constrain wind composition and B field.

Vela-X region: Radio-X-ray-TeV PWN. A typical crashed plerion?



Often considered "canonical" example of crashed (relic) plerion seen both in X-rays and TeV.

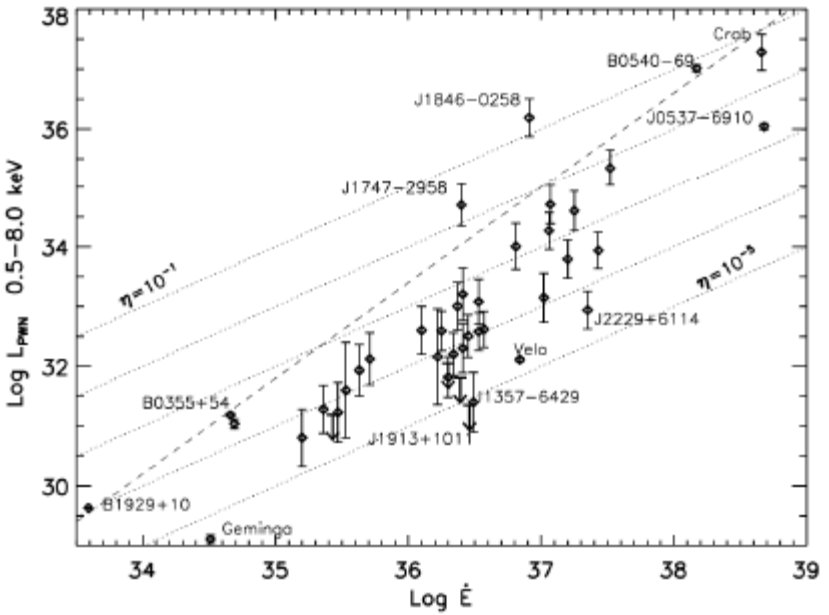
But…

- **Small size, angular size ~1°** but the distance is only 300 pc
- **Perfect correlation between TeV and extended X-ray and radio emission**
- **Pulsar proper motion does not correlate with the location of the TeV emission.**

However, Vela X is rather **atypical**. It is different from the others (previous slides) because in Vela X the TeV and X-rays come from approximately the same region and also radio emission from the same region is seen. If one looks deeper possibly similar correlations can be found in other TeV plerions. Multiwavelength spatially-resolved spectrum allows one to constrain wind composition and B field.

Do all TeV PWNe exhibit similar gamma-ray efficiencies?

We know that in the case of X-ray PWNe the efficiencies vary dramatically (Kargaltsev & Pavlov 2007).



Pulsars with X-ray PWNe (located within the HESS survey area) but no TeV counterparts have been reported so far.

#	PSR*	SNR	PWN	$\log \dot{E}$	P ms	$\log \tau$	$\log B_s$ †	$\log B_{LC}$ **	d ‡ kpc	Rad./H_α/TeV§
14	J1811–1925	G11.2–0.3	G11.18–0.35	36.81	65	4.37	12.8	4.02	5	Y/N/N
20	B1757–24	...	Duck	36.41	125	4.19	12.5	3.69	5	Y/N/N
22	J1747–2958	...	Mouse	36.40	99	4.41	12.0	4.35	5	Y/N/N
29	J1509–5850	...	G319.97–0.62	35.71	89	5.19	12.4	4.40	4	P/N/N

Possibly these are dimmer in TeV because wind expands into low-density medium or the local background photon density is lower?

Short Summary :

- Pulsar winds inject electrons/positrons with energies of up to 10-100 TeV

- Relativistic pulsar-winds fill much larger volumes than we can see in X-rays.
  Reasons: Weak magnetic field? Efficient cooling of X-ray emitting electrons? Possibly both…

- Sensitive TeV observations allow one to find new PWNe!

Question and problems:

• Why only some of the Vela-like pulsars have TeV plerions counterparts? Different environments?

• Why don’t we see SNRs associated with some TeV plerions? ISM absorption in X-rays? But the SNRs could be seen in the radio…

• What causes the displacement of the TeV emission wrt. to the pulsar? Is the “crushed PWM’’ scenario the only explanation? Alternatives: Intrinsically anisotropic winds,e.g. jets? Strongly non-uniform photon background, IR ``flashlights’’ ?

• Are the X-ray (synchrotron) and TeV (IC) emission produced by the same population of electrons (similar photon indices in X-rays and TeV, e.g. in the B1823 PWN)? If yes, why TeV brightness is lower near the pulsar (Klein-Nishina effect)? Are there hadrons in the wind?

• Can some of the extended TeV sources near PRSs be actually unrelated and powered by some other sources (SNRs, or superposition of several unresolved HMXBs?)