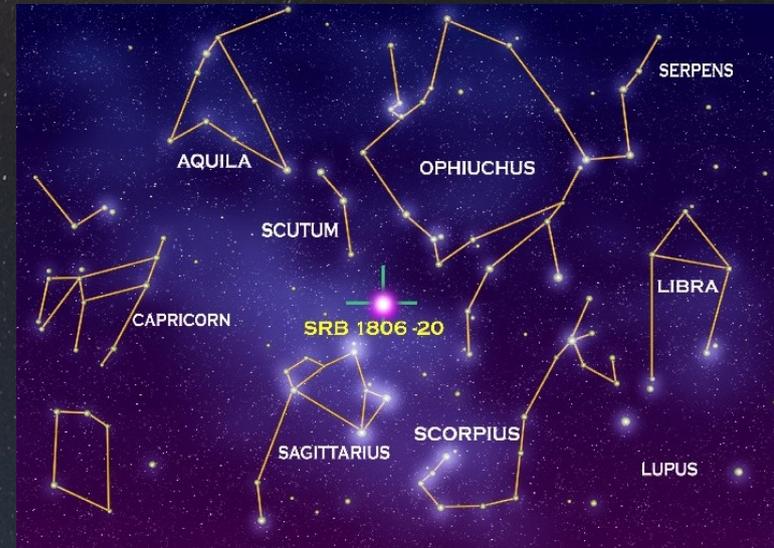


Discovery of extended TeV gamma-ray emission towards SGR1806-20 and C1-1806-20

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and HESS Collab.



"Intl. Symposium on High Energy Gamma-Ray Astronomy" Heidelberg. 9-13 July 2012

SGR1806-20

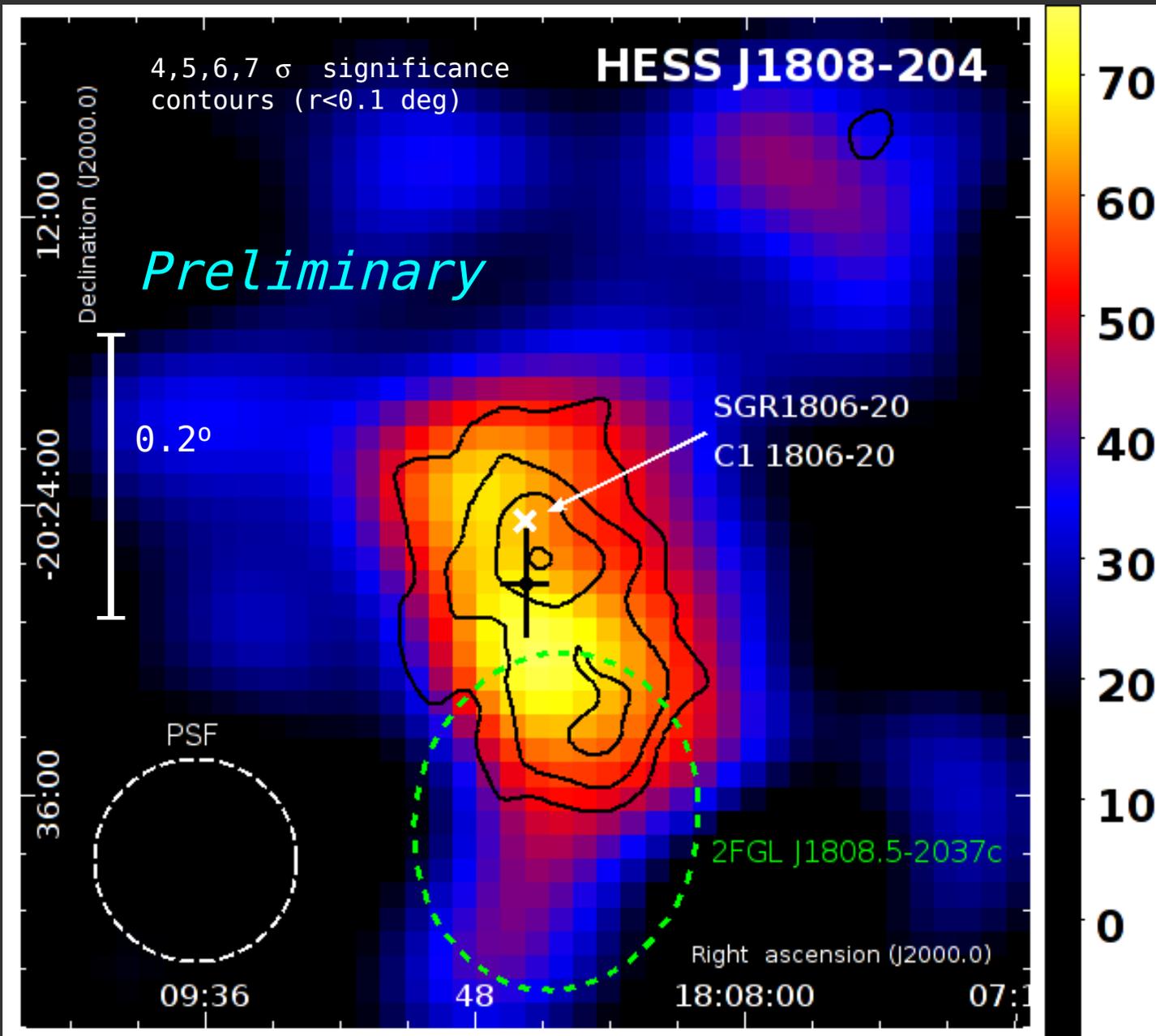
<http://www.physics.mcgill/pulsar/magnetar/main.html>

- magnetar with $B_{\text{surface}} \sim 10^{14-15}$ G
- Period $P \sim 7.6$ s;
P-dot $\sim 7.5 \times 10^{-10}$ s/s (varies x8); (e.g. Nakagawa etal 2009, Mereghetti 2011)
- Age $\tau \sim$ kyr (e.g. Kouveliotou etal 1998)
- Dist. $\sim 6-19$ kpc (e.g. McClure-Griffiths & Gaensler 2005; Bibby etal 2008; Svirski etal 2011)
- > spin-down power $L_{\text{sd}} \sim \text{few} \times 10^{34}$ erg/s
- magnetic dissipation energy $\sim 10^{35-36}$ erg/s
- many short/intermediate flares 10^{40-43} erg/s
- giant flare $\sim 10^{47}$ erg/s 27 Dec 2004

C1 1806-20

- massive stellar cluster (parent cluster of SGR1806-20?)
- 4 x WR stars + luminous blue variable LBV 1806-20
--> combined stellar wind KE $> 10^{38}$ erg/s
-
- > Potential site for multi-TeV particle acceleration
(giant flare models eg. Halzen etal 2005, Ioka etal 2005; Liu etal 2010)
- > TeV gamma-ray obs: search for transient & steady emission

H.E.S.S. TeV Image (>0.4 TeV) smoothed excess counts



H.E.S.S. Galactic plane scan + dedicated obs. (~82 hrs; 2004 – 2010)

Fermi-LAT GeV (Abdo et al 2011)

Energetics 0.5-5 TeV ($r < 0.2$ deg)

$F \sim 1.3 \times 10^{-12}$ erg/cm²/s

$L_{\text{TeV}} \sim 1.2 \times 10^{34} (d/8.7 \text{ kpc})^2$ erg/s

$dN/dE = N E^{-\Gamma}$ ph/cm²/s/TeV

$N = 4.2 (\pm 0.5) \times 10^{-13}$

$\Gamma = 2.5 (\pm 0.2 \pm 0.2)$

stat & sys. errors

Flux is steady (30min & nightly timescales)

- $\sim 6\sigma$ (pre-trial) at radio position ($r < 0.1$ deg)
- $> 7\sigma$ (pre-trial) fitted pos. ($r < 0.2$ deg)

SGR1806-20 : Spitzer IR (rb=24/8 μm)

HESS TeV
Contours

W31 HII Region

HESS J1808-204

SGR1806-20
C1 1806-20

VLA 1.4GHz
contours
(Jy/beam)
Kulkarni et al
1994

G10.0-0.3
Radio nebula

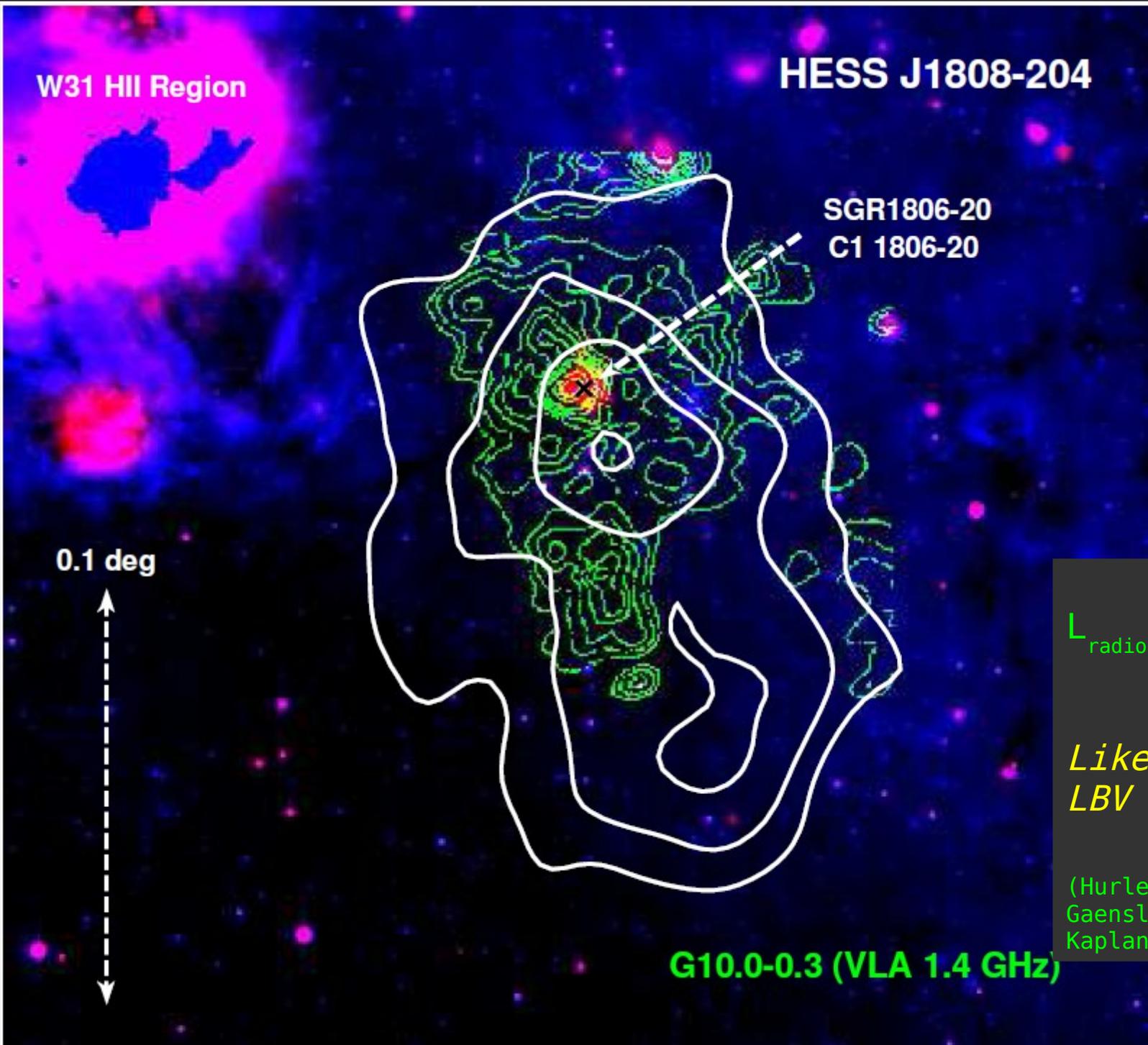
0.1 deg

$L_{\text{radio}} \sim \text{few} \times 10^{32} \text{ erg/s}$
($d=8.7 \text{ kpc}$)

*Likely powered by
LBV rather than SGR!*

(Hurley et al 1999;
Gaensler et al 2001;
Kaplan et al 2002)

G10.0-0.3 (VLA 1.4 GHz)



SGR1806-20 Steady/Extended X-ray Emission

Radius < few arcsec
(unpulsed ~90-95%)

2-10 keV

Power law or thermal

kT~10 keV

(B-SAX Mereghetti et al 2000)

(XMM Mereghetti et al 2007)

20-60 keV

Power law

(INTEGRAL Esposito et al 2007)

$L_x \sim \text{few} \times 10^{35} \text{ erg/s}$

$> \sim L_{\text{spin down}}$

No evidence for X-ray PWN.

Radius < ~0.2pc

Extreme B-field --> PWN

short-lived (few yrs) and

small. Other magnetar PWN:

1E1547.0-5408?

(Yes - Vink et al 2009,

No - Olausen et al 2011)

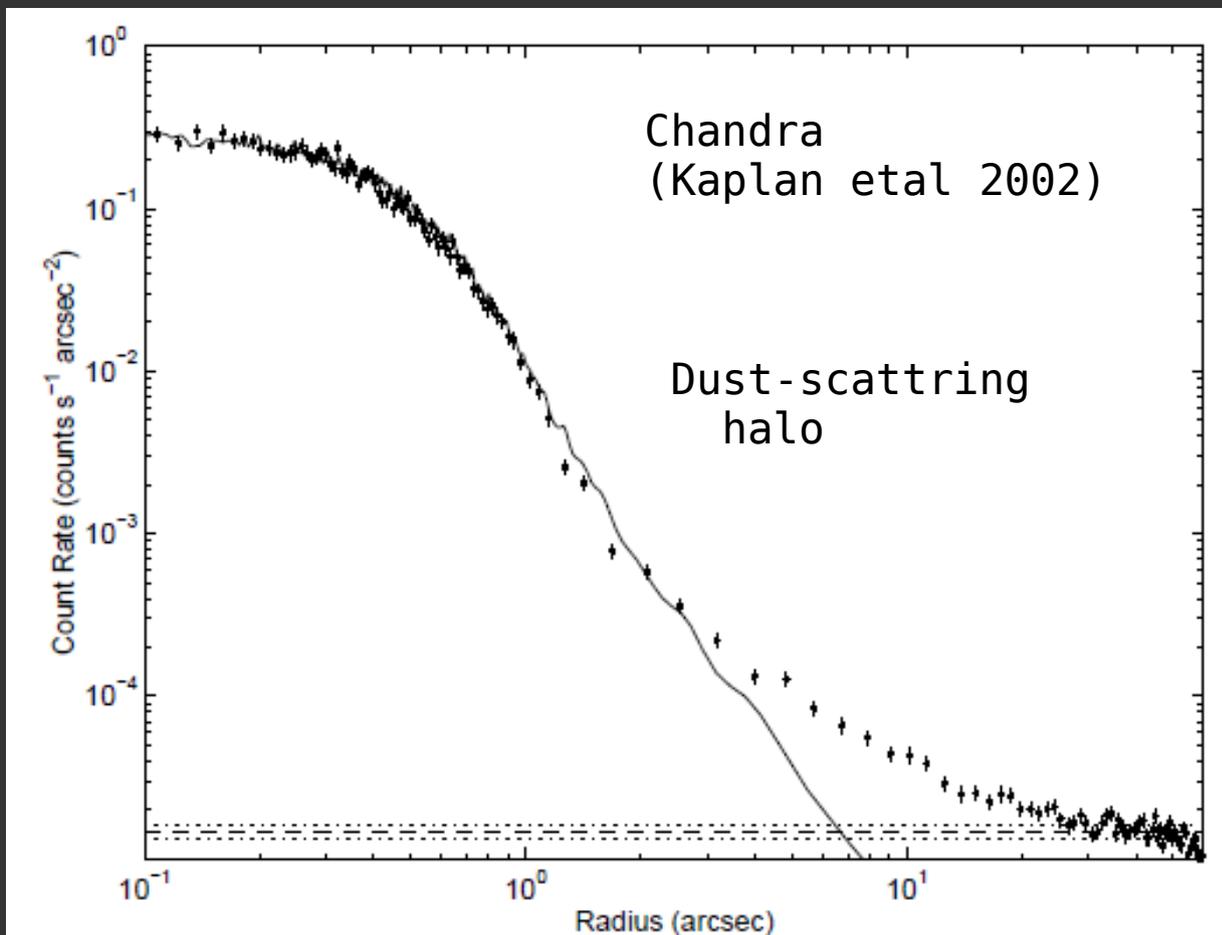


FIG. 3.—Radial profile of SGR 1806–20 from the 31 ks observation (points), along with that of a MARX model of the *Chandra* PSF (solid line), scaled to the same normalization for $r \lesssim 1''$. The mean background level (corrected for vignetting) is shown by the dashed line, with $\pm 1 \sigma$ levels indicated by the dotted lines.

Pulsar-powered? Magnetically-powered? Energetics

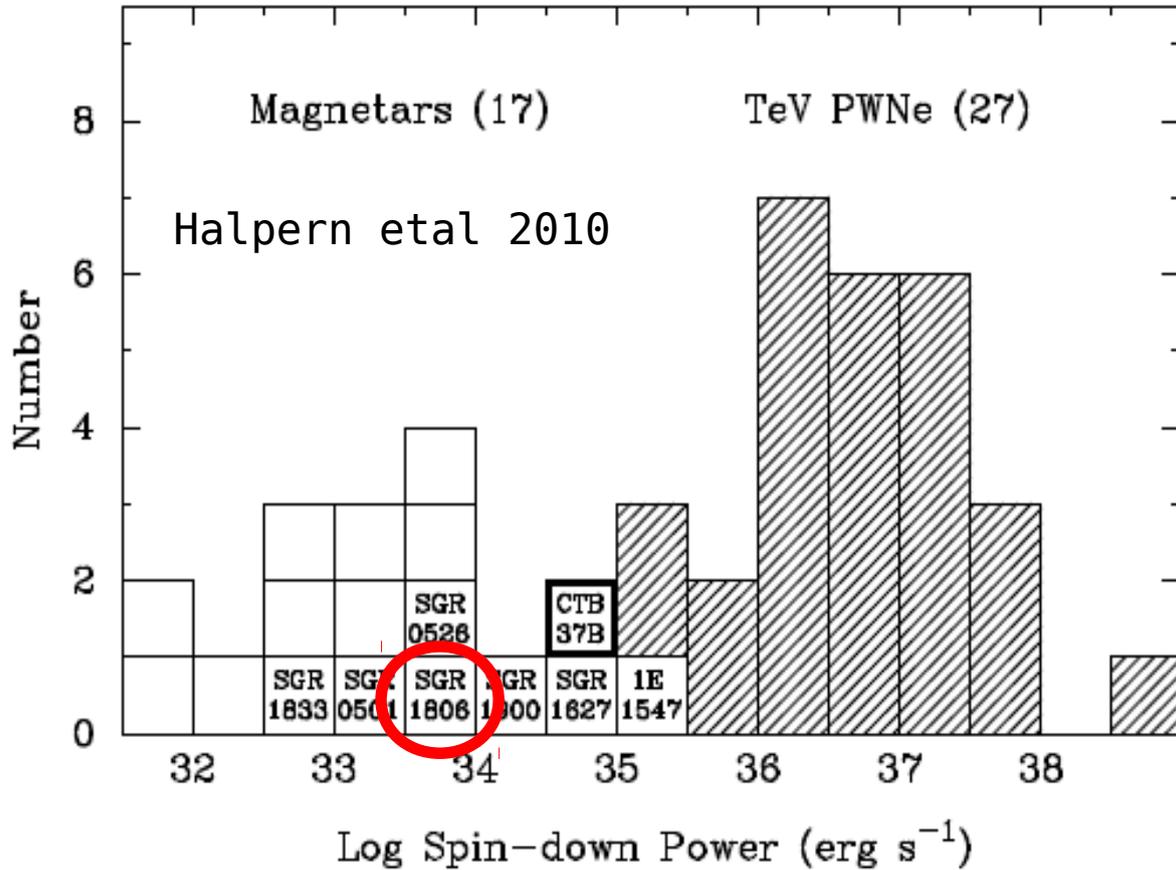


FIG. 1.— Spin-down power of 27 pulsars (hatched) whose PWNe are identified as TeV sources by HEGRA, HESS, VERITAS, MAGIC, and Milagro, in comparison with spin-down power of 17 magnetars (open squares) with measured period derivatives. The TeV PWNe are drawn from the reviews referenced in Section 1, and magnetars from references in Footnote 2. Magnetars that have had SGR outbursts, including 1E 1547.0–5408, are labeled individually; the unlabeled squares are AXPs. The spin-down power of CXOU J171405.7–381031 in CTB 37B is among the largest of magnetars, and falls in the range occupied exclusively by SGRs, although it is not known to be an SGR.

Spin-down power

$$L_{sd} \sim 3 \text{ to } 6 \times 10^{34} \text{ erg/s}$$

$$L_{TeV}/L_{sd} \sim 0.2 \text{ to } 0.3$$

Magnetic dissipation (reconnection) power (e.g. Zhang 2009)

$$L_B \sim 10^{35} \text{ to } 36 \text{ erg/s}$$

$$L_{TeV}/L_B \sim 0.01$$

--> TeV luminosity from spin-down possible but magnetic dissipation power clearly available.

Pulsar Wind Nebulae Trends

$$L_x, L_{\text{TeV}}, \text{Age}, L_{\text{sd}}$$

(Mattana et al 2009)

Typically

$$L_{\text{TeV}} \sim < 0.1 L_{\text{sd}}$$

SGR1806-20

$$L_{\text{TeV}} / L_{\text{sd}} \sim 0.2 \text{ to } 0.3$$

$$L_{\text{TeV}} / L_x \sim 0.1$$

--> outlier on F_{TeV}/F_x vs. spin-down trend

--> ok with F_{TeV}/F_x vs. age trend

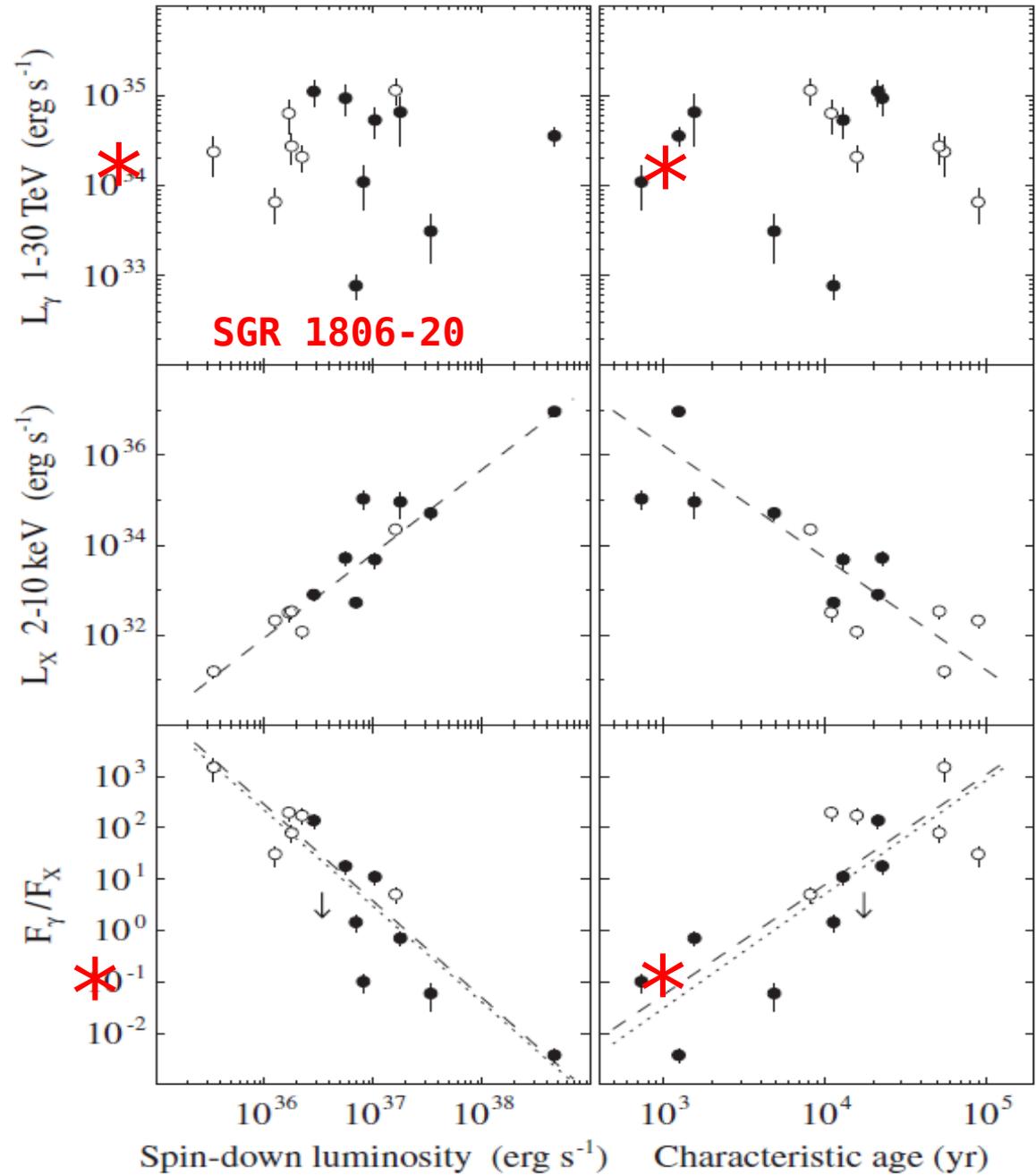


Figure 1. γ -ray luminosity, X-ray luminosity, and γ - to X-ray flux ratio vs. pulsar spin-down luminosity, \dot{E} (left column), and characteristic age, τ_c (right column). Filled and open circles stand for identified and candidate PWNe, respectively. The upper limit for the flux ratio of PSR B1706-44 (Aharonian et al. 2005a; Romani et al. 2005) is reported with an arrow. Also shown are the best-fit curves for identified PWNe (dotted lines) and for the whole sample (dashed lines).

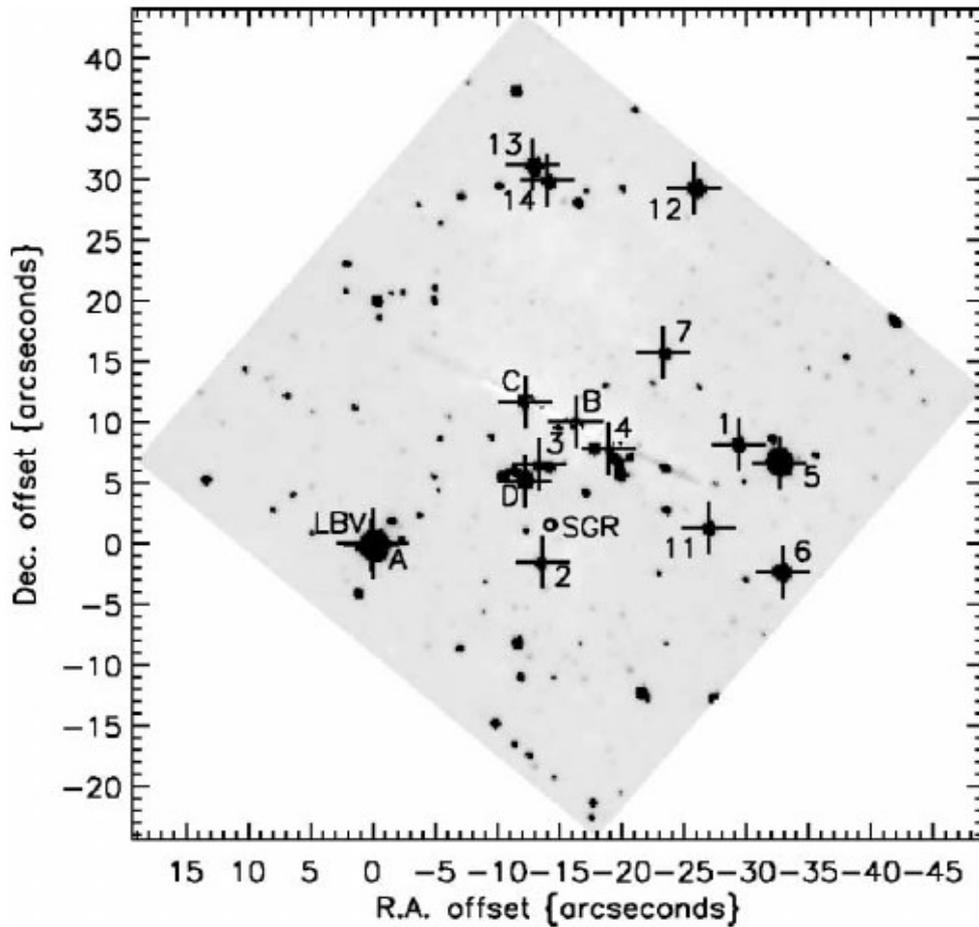


FIG. 1.—NIRSPEC/SCAM image of stars in the 1806–20 cluster with coordinates offset from LBV 1806–20 at $18^{\text{h}}08^{\text{m}}40^{\text{s}}.312$, $-20^{\circ}24'41''.14$ (J2000.0). Number designations are from this Letter. Letter designations are from Eikenberry et al. (2004). Stars 8, 9, and 10 are to the west of the field. The slit can be seen as a linear artifact superpositioned on images of stars C and B. A circle marks the location of SGR 1806–20 (Kaplan et al. 2002).

MASSIVE STARS IN THE 1806–20 CLUSTER

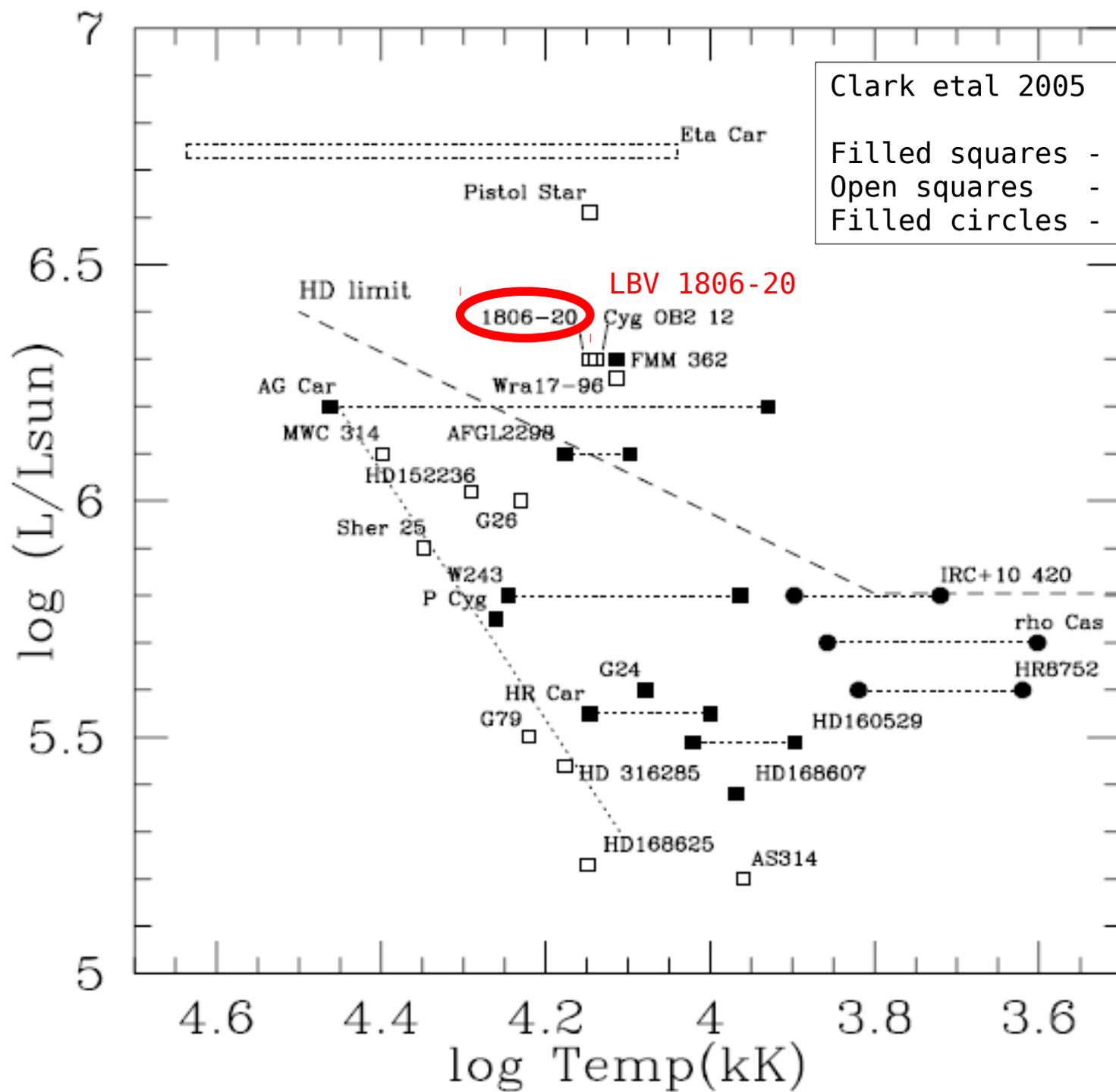
| Identification | R.A. (arcsec) | Decl. (arcsec) | $H - K$ | K | Type | Date Observed |
|----------------|---------------|----------------|---------|-------|-------|---------------|
| 1 | 38.32 | 33.5 | ... | 11.76 | WC8 | 2004 Jun 7 |
| 2 | 39.42 | 42.57 | 1.87 | 12.16 | WN6 | 2004 Jun 8 |
| 3 | 39.50 | 35.88 | ... | 12.87 | WN7? | 2004 Jun 8 |
| 4 | 39.16 | 32.88 | ... | 12.45 | OB I | 2003 Jun 22 |
| 5 | 38.13 | 34.77 | 1.68 | 9.25 | RG | 2004 Jun 7 |
| 6 | 38.12 | 43.35 | 1.42 | 10.96 | RG | 2004 Jun 7 |
| 7 | 38.75 | 26.48 | 1.49 | 11.90 | OB I? | 2004 Jun 7 |
| 8 | 36.72 | 54.27 | 1.40 | 8.70 | RG | 2004 Jun 8 |
| 9 | 36.72 | 27.80 | 1.45 | 8.89 | RG | 2004 Jun 8 |
| 10 | 37.96 | 16.47 | 2.95 | 10.09 | RG | 2004 Jun 8 |
| 11 | 38.52 | 39.95 | 1.66 | 11.92 | OB I? | 2004 Jun 8 |
| 12 | 38.57 | 13.55 | 1.42 | 10.81 | RG | 2004 Jun 8 |
| 13 | 39.49 | 11.77 | ... | 11.16 | | 2004 Jun 8 |
| 14 | 39.40 | 13.02 | ... | 12.00 | RG | 2004 Jun 8 |
| A | 40.31 | 41.14 | ... | 9.26 | LBV | 2003 Jun 22 |
| B | 39.24 | 31.86 | 2.94 | 10.50 | WC9 | 2003 Jun 22 |
| C | 39.51 | 30.02 | 1.85 | 10.96 | OB I | 2003 Jun 22 |
| D | 39.51 | 35.91 | 1.73 | 11.11 | OB I | 2003 Jun 22 |

- 4 x WR stars; 4 x O stars
 - Lum. Blue Variable (LBV)
LBV 1806-20
(similar to Pistol star, η -Car)
 - Cluster wind KE $L_{\text{KE}} > 10^{38}$ erg/s
- $$L_{\text{TeV}}/L_{\text{KE}} < 10^{-4}$$

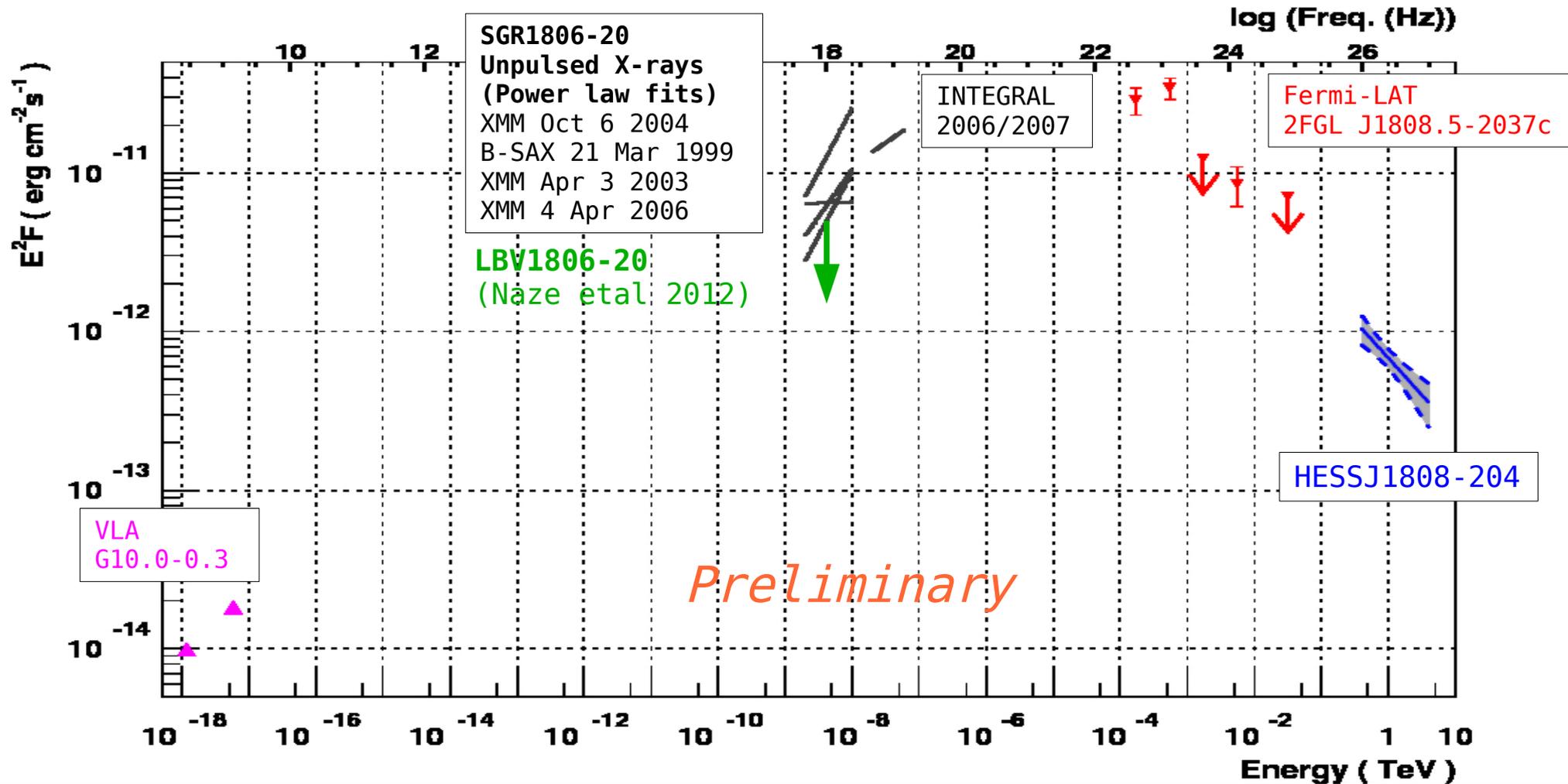
- stellar cluster origin possible (wind-wind/ISM interactions)
- dominated by LBV and/or WRs?
- other TeV WR/O/B clusters – Cyg-OB2, Wd1, Wd2 (part of)

LBV Population

(see Vink et al 2009; Clark et al 2005)



MWL Spectral Energy Distribution



Assume unpulsed X-ray flux ($\sim 10^{-11}$ erg/cm²/s) is synchrotron, and \sim TeV is inverse-Compton (CMB seed) \rightarrow estimate approx. B-field over region common to both (see Aharonian et al 1997):

$$(B/10 \mu\text{G}) \sim \sqrt{\xi F_x / (10 F_{\text{TeV}})}$$

$$\xi \sim (R_{\text{TeV}}/R_x)^2 \quad \text{size factor}$$

$$B \sim 1 \text{ mG}$$

$$\sim (19\text{pc}/0.2\text{pc})^2$$

\rightarrow TeV IC region with much lower B field

Summary & Outlook

New TeV source towards SGR1806-20 / C1-1806-20

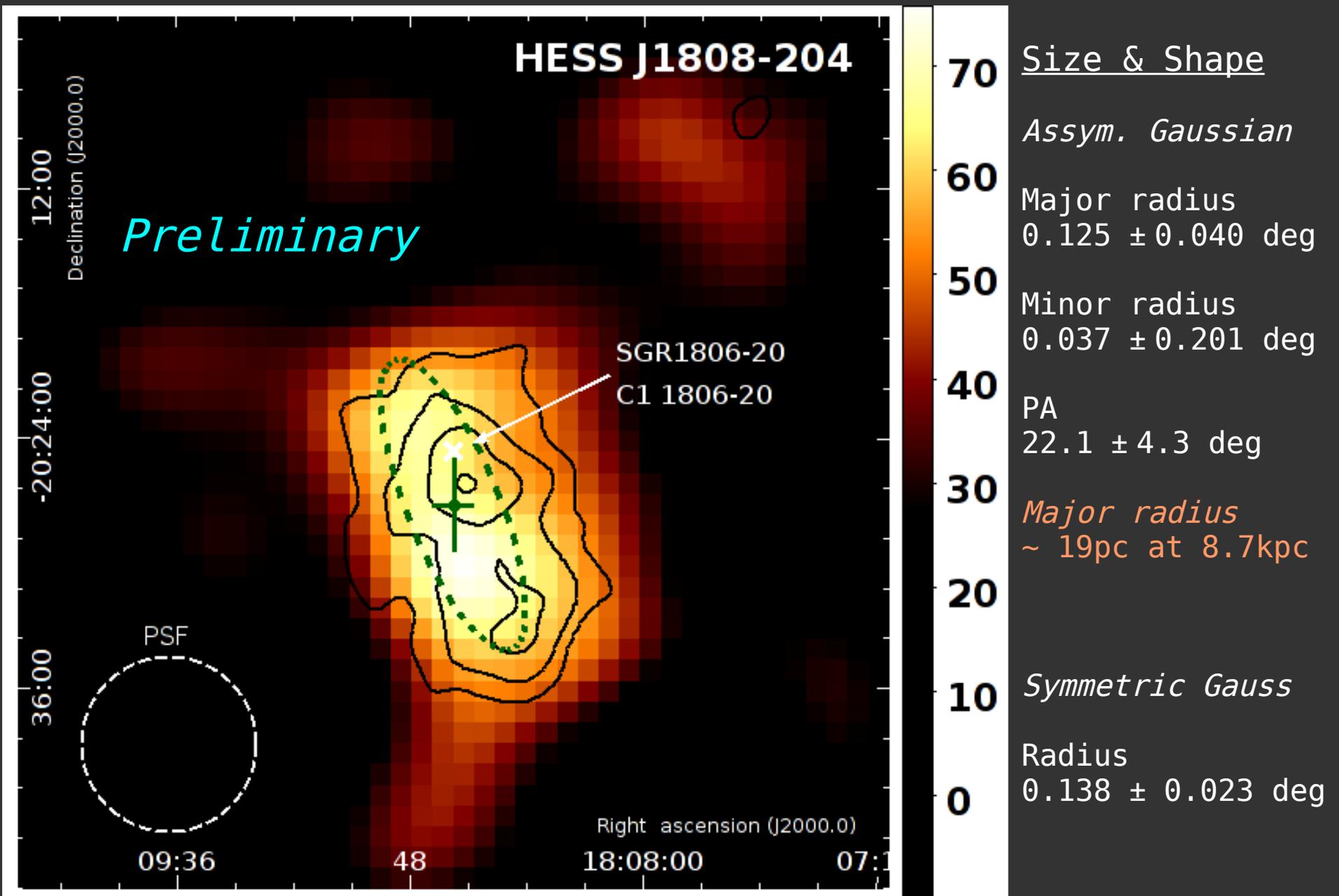
- first clear sign of multi-TeV particle acceleration towards these objects (electrons and/or cosmic-rays? – not clear)
- $L_{\text{TeV}} \sim 10^{34} (d/8.7\text{kpc})^2 \text{ erg/s}$
- Asymmetric (N-S) extension ~ 14 arcmin long (~ 38 pc at 8.7 kpc)
similar in scale to radio nebula
- Source of energy
 - magnetar/pulsar spindown?
 - B-field dissipation-powered?
 - stellar cluster winds (LBV, WRs..)
 - SNR? ISM target gas $A_V \sim 10$ ($N_H \sim 2 \times 10^{22} \text{ cm}^{-2}$)
(Kim&Koo 2002; Corbel et al 2004)
- *Possibly new type of multi-TeV particle accelerator (other AXPs/SGRs towards TeV sources: e.g. Westerlund 1; CTB37B Halpern et al 2010)*

SGR/AXP Transient ToOs with H.E.S.S.

- Ongoing ToO programme (trig. Swift BAT, GCN)
- H.E.S.S. II coming soon! $E_{\text{threshold}} \sim 30-50 \text{ GeV}$
collection area $\sim >10^4 \times \text{Fermi-LAT}$

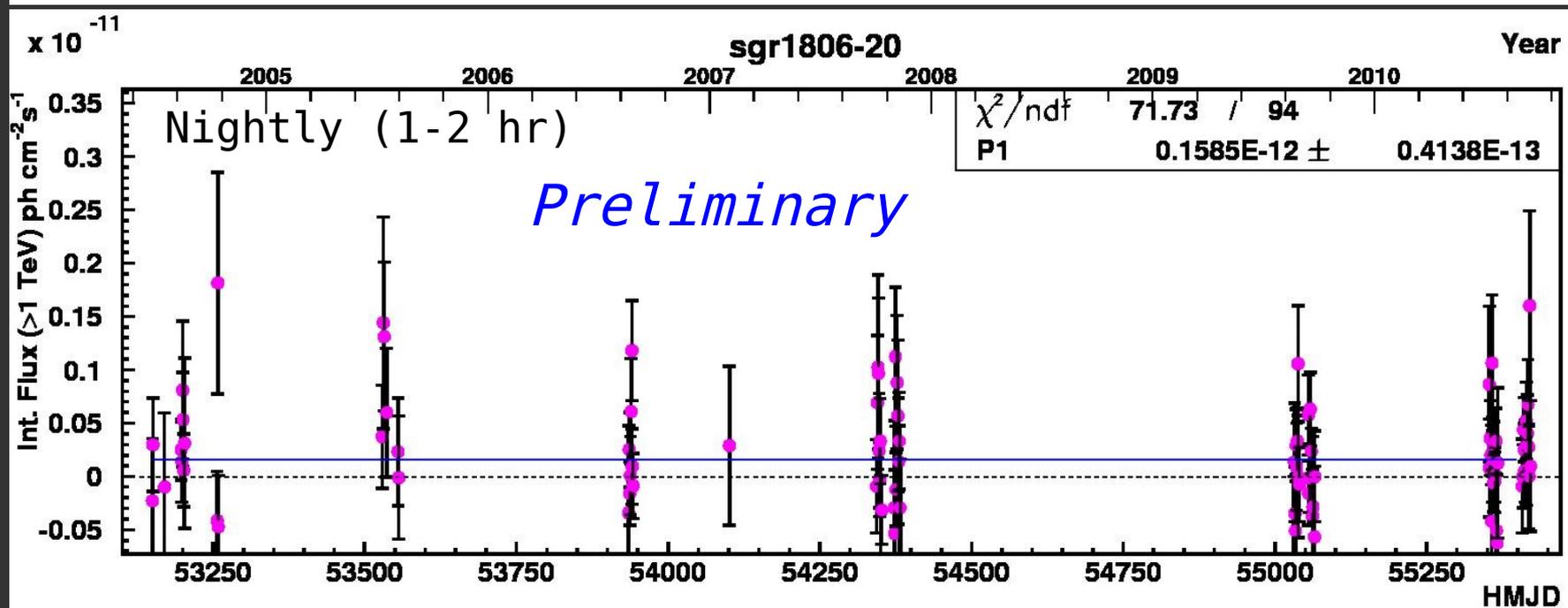
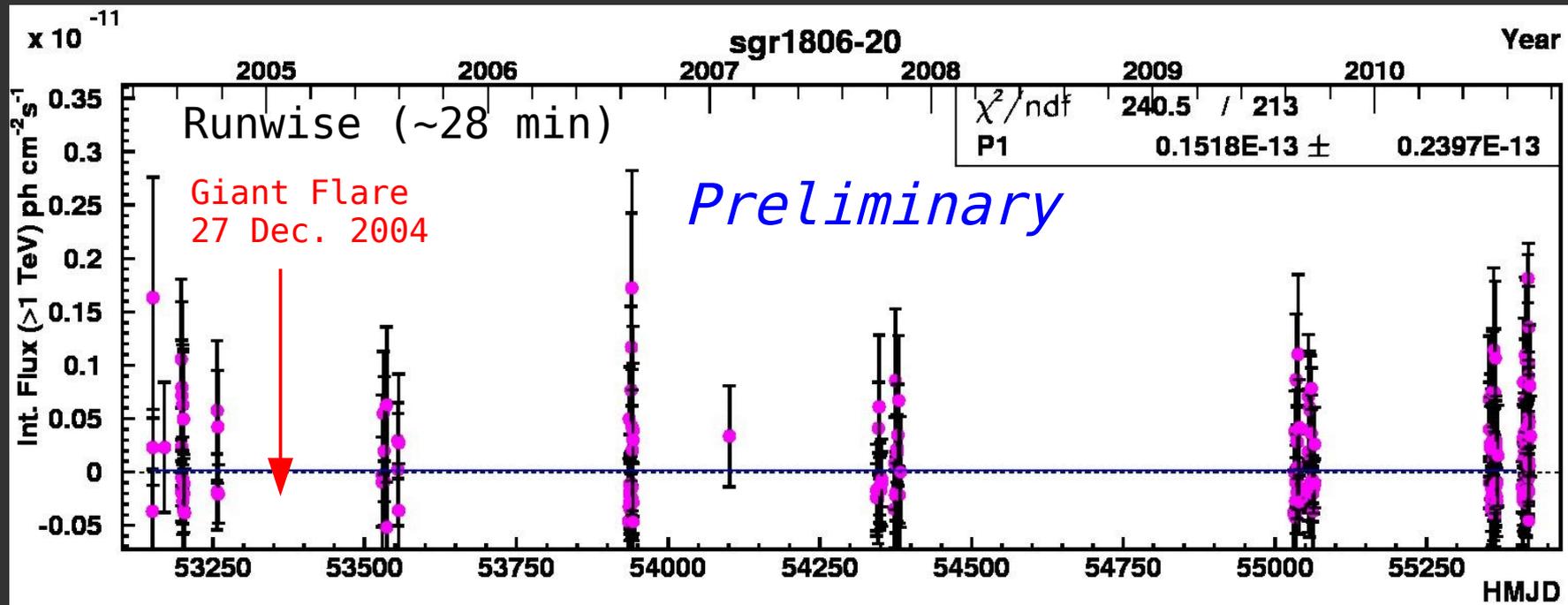
Backup slides....

TeV Emission: Location, Intrinsic Size & Shape



Fitted position RA 18.14340 hr ± 29.2 arcsec (stat) ± 20 arcsec (sys)
Dec -20.4458 deg ± 136.4 arcsec (stat) ± 20 arcsec (sys)

SGR1806-20 (radio position; pt src.): >1 TeV flux light curves



--> steady emission on ~0.5 to few hr timescales

Most luminous LBVs / LBV-candidates.....

| | Dist [kpc] | TeV | GeV | (l,b) | TeV counterpart |
|-------------------|---------------|-----------|-----------|--------------------|-----------------------------|
| η -Car | ~3 | N | Y | 287.60 -0.63 | |
| AG-Car | 9-10 | N | ? | 289.18 -0.70 | |
| Pistol Star | ~10 | Y? | Y? | 0.16 -0.07 | Gal. Cen. |
| FMM 362 | ~10 | Y? | Y? | 0.18 -0.07 | Gal. Cen. |
| LBV1806-20 | ~10 | Y? | Y? | 10.00 -0.02 | HESSJ1808-204 |
| Wray 17-96 | 5 | Y? | Y? | 358.54 +0.13 | HESSJ1741-302? (Gal. cen..) |
| Cyg OB2 #12 | 2 | Y | Y? | 80.10 +0.83 | TeVJ2032+4130/MGROJ2019+37? |

Table 1 The confirmed LBVs.

| Galaxy: | | | | |
|------------|-----------|-----------|-------------|----------|
| η Car | AG Car | HR Car | P Cygni | HD 16052 |
| HD 168607 | FMM 362 | AFGI 2298 | G24.73+0.69 | W243 |
| GCIRS 34W | | | | |
| LMC: | | | | |
| S Dor | R71 | R 110 | R 116 | R127 |
| R 143 | HD 269582 | HD 269929 | | |
| SMC: | | | | |
| R40 | HD 5980 | | | |
| M31: | | | | |
| AE And | AF And | Var A-1 | Var 15 | |
| M33: | | | | |
| Var B | Var C | Var 2 | Var 83 | GR.290 |
| M81: | | | | |
| I 1 | I 2 | I 3 | | |
| M101: | | | | |
| V 1 | V 2 | V 10 | | |
| NGC 2403: | | | | |
| V 12 | V 22 | V 35 | V 37 | V38 |
| NGC 1058: | | | | |
| SN 1961 V | | | | |

Table 2 The LBV candidates.

| Galaxy: | | | | |
|------------|-------------|---------------|-------------|------------|
| Cyg OB2#12 | Pistol star | HD 168625 | HD 326823 | HD 316285 |
| He3-519 | HD 80077 | ζ^1 Sco | MWC 314 | MWC 930 |
| AS 314 | G25.5+0.2 | G79.29+0.46 | G26.47+0.02 | Wra17-96 |
| Wra 751 | WR102ka | LBV1806-20 | Sher 25 | W51 LS1 |
| GCIRS 16NE | GCIRS 16C | GCIRS 16SW | GCIRS 16NW | GCIRS 33SE |
| LMC: | | | | |
| R 4 | R 66 | R 74 | R 78 | R 81 |
| R 84 | R 85 | R 99 | R 123 | R 128 |
| R 149 | S 18 | S 22 | S 61 | S 119 |
| S 134 | | | | |

Vink etal 2009

Steady/Extended Radio & X-ray Emission

Radio synch. nebula $\sim 9' \times 6'$ – core centred near LBV; spec. ind. = -0.6

$L_{\text{radio}} \sim \text{few} \times 10^{32} \text{ erg/s}$ (d=8.7 kpc)

Likely powered by LBV rather than SGR
(etal 2002)

(Hurley etal 1999; Gaensler etal 2001; Kaplan etal 2002)

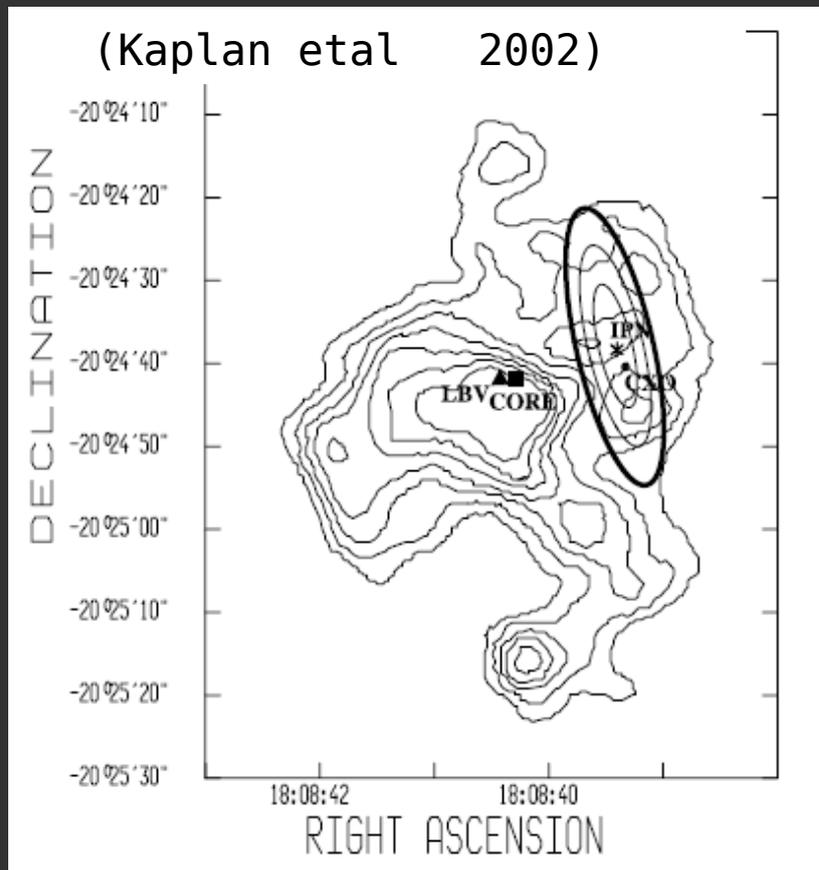
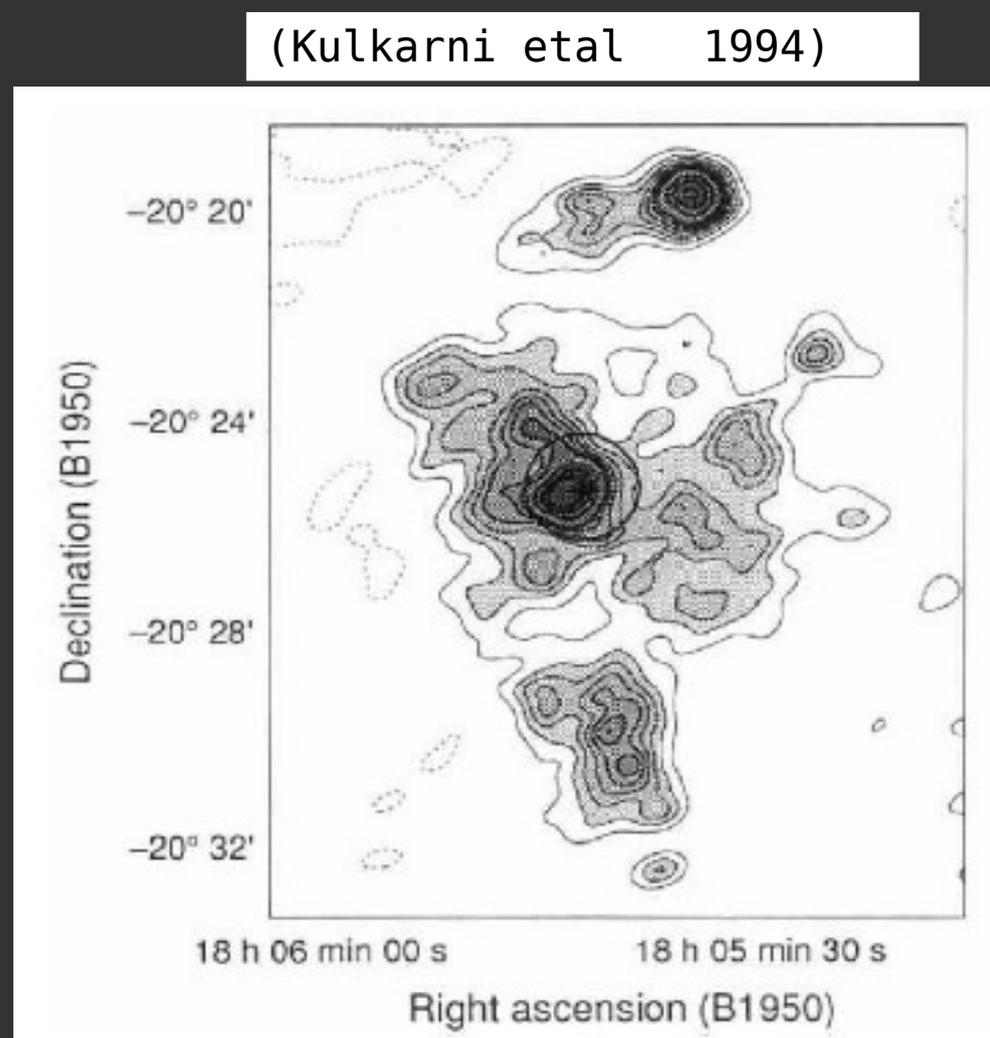


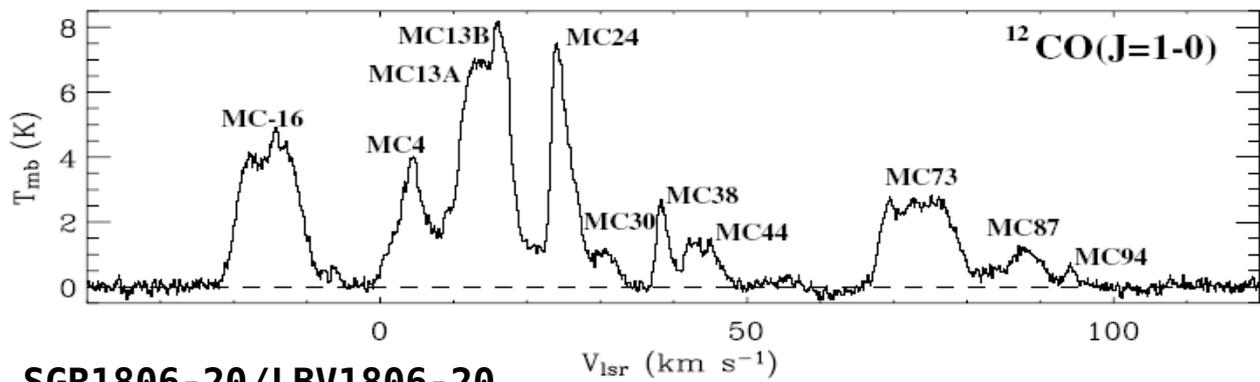
FIG. 2.—VLA image (3.6 cm) of central portion of G10.0-0.3 (Frail et al. 1997), with position of radio core at square labeled “CORE.” Superimposed are 1, 2, and 3 σ annuli around the best-fit IPN position (asterisk labeled “IPN”) from Hurley et al. (1999a), the corrected *Chandra* position (circle labeled “CXO”), and the position of the LBV star (triangle labeled “LBV”; Kulkarni et al. 1995). Note that the position of the core indicated in Hurley et al. (1999a) is slightly incorrect (K. Hurley 2001, private communication).



Molecular Gas

CO, NH₃

Corbel et al 2004
(see also Kim & Koo 2004)



SGR1806-20/LBV1806-20

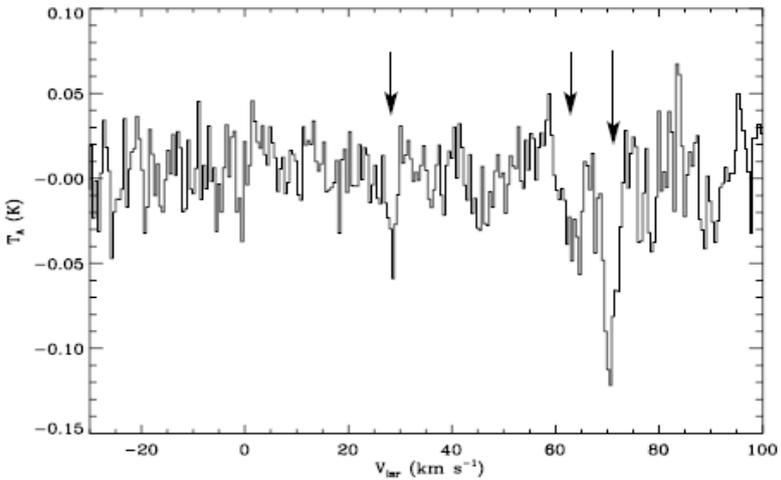
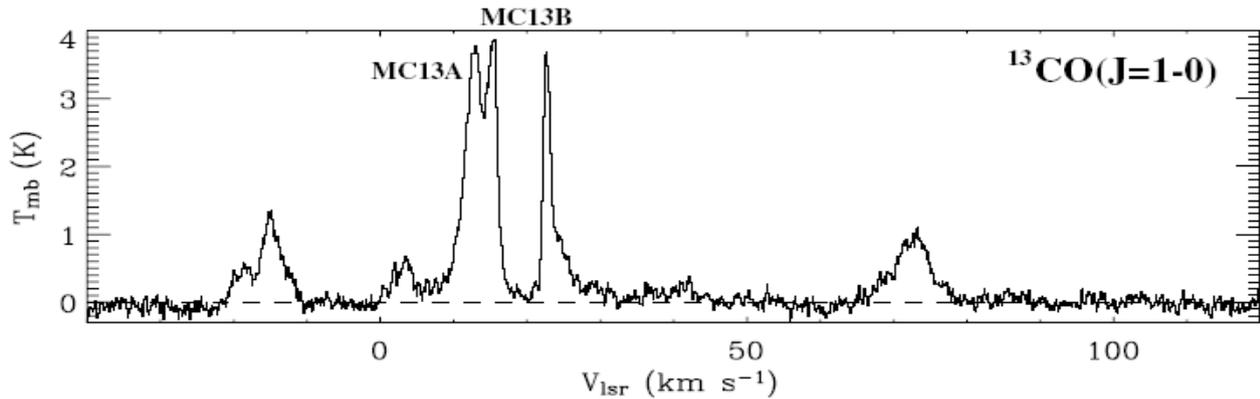
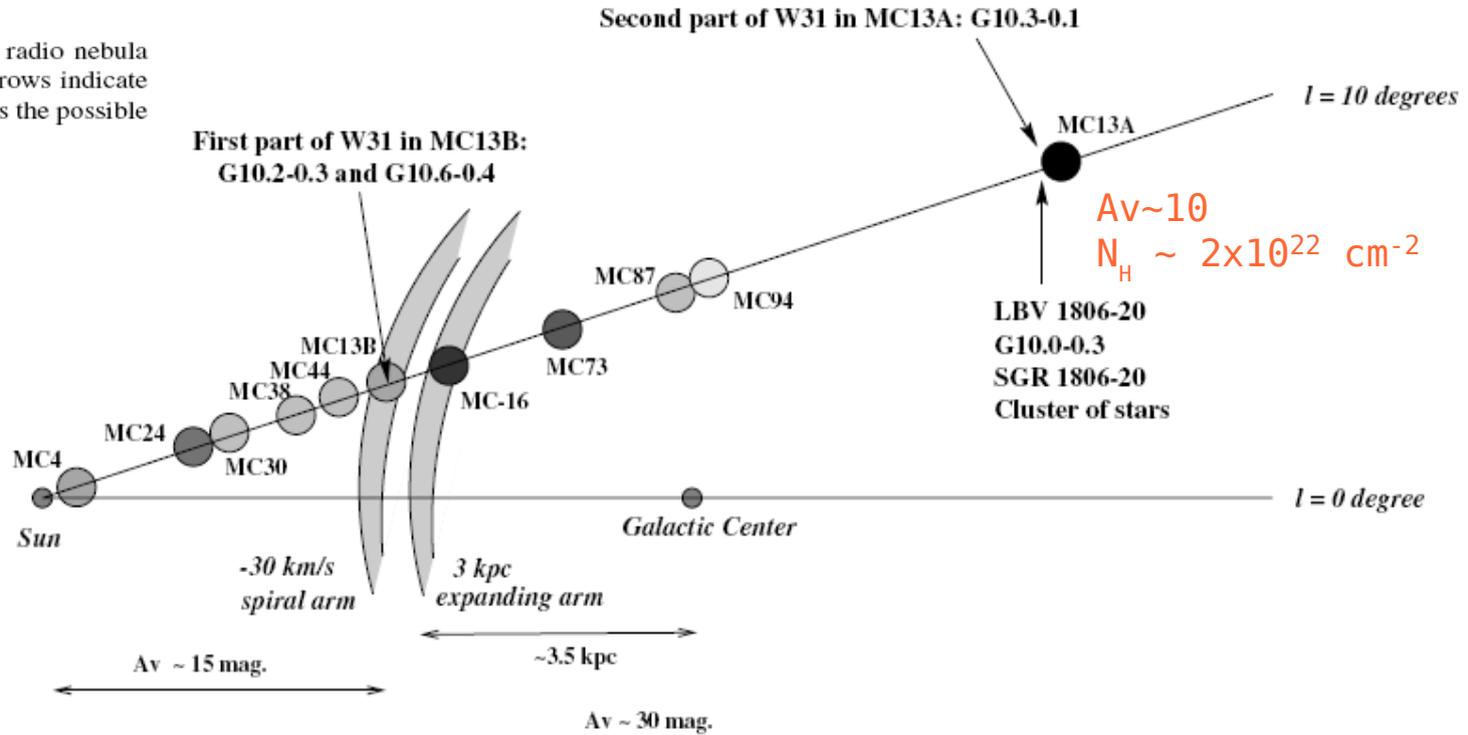


Fig. 3. NH₃ absorption spectrum measured against the radio nebula G10.0-0.3 produced by the wind of LBV 1806-20. Arrows indicate the main (~9σ) absorption feature at 71 km s⁻¹ as well as the possible features at 62 km s⁻¹ (~4σ) and 29 km s⁻¹ (~2σ).

- -> d~15 kpc
(V_{lsr} = +17 km/s)



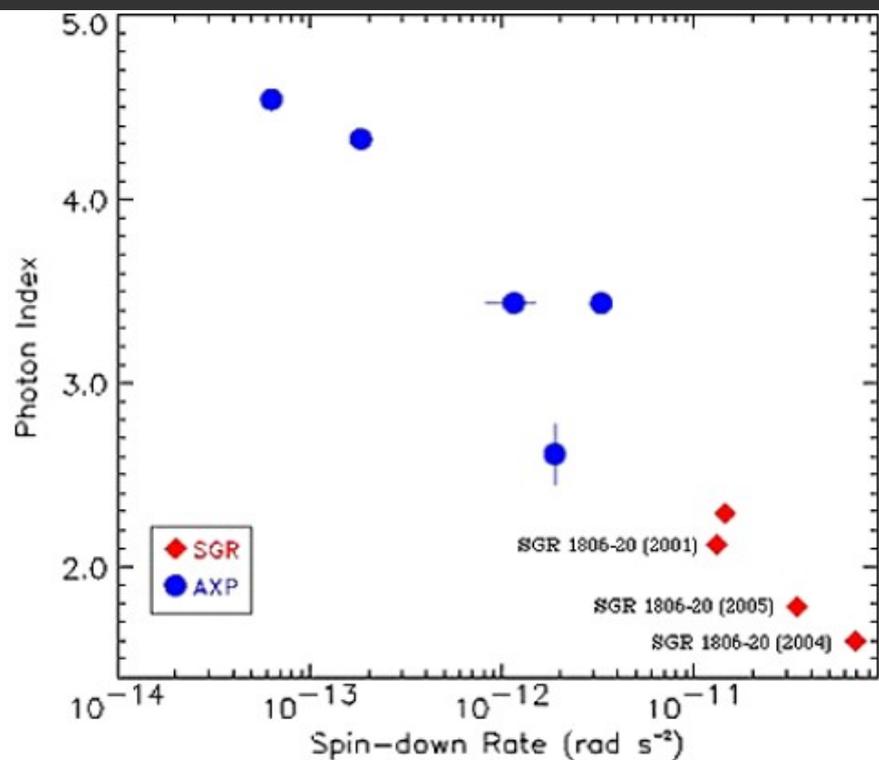


Fig. 3 Correlation between power law photon index and spin-down rate in Anomalous X-ray Pulsars and SGRs (adapted from Marsden and White 2001). Each point refers to a different source, except the three points for SGR 1806-20 in different time periods

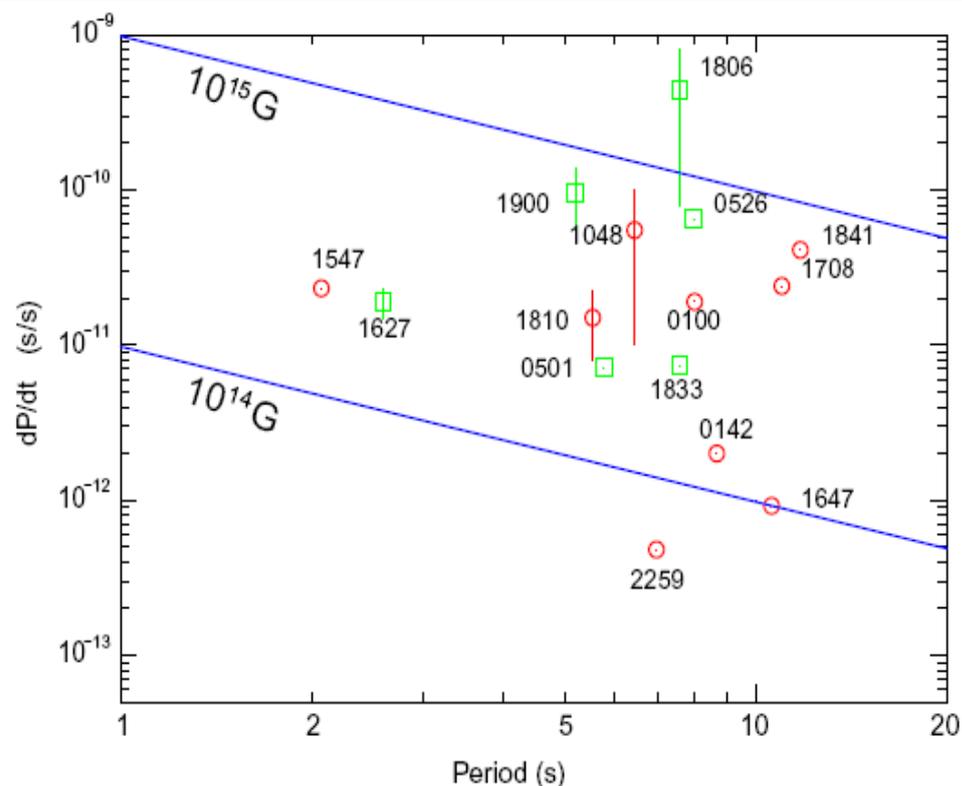


Fig. 1. $P - \dot{P}$ diagram for AXPs (red circles) and SGRs (green squares). The vertical lines associated to some sources indicate the observed range of variability in \dot{P} . The lines indicate the dipolar magnetic fields inferred assuming that the spin-down is entirely due to the emission of dipole radiation, $B = 3.2 \times 10^{19} (P\dot{P})^{1/2}$ G. (For interpretation of the references to colour in this figure legend, the reader is referred to the web version of this article.)

TeV PWN

Kargaltsev & Pavlov 2010

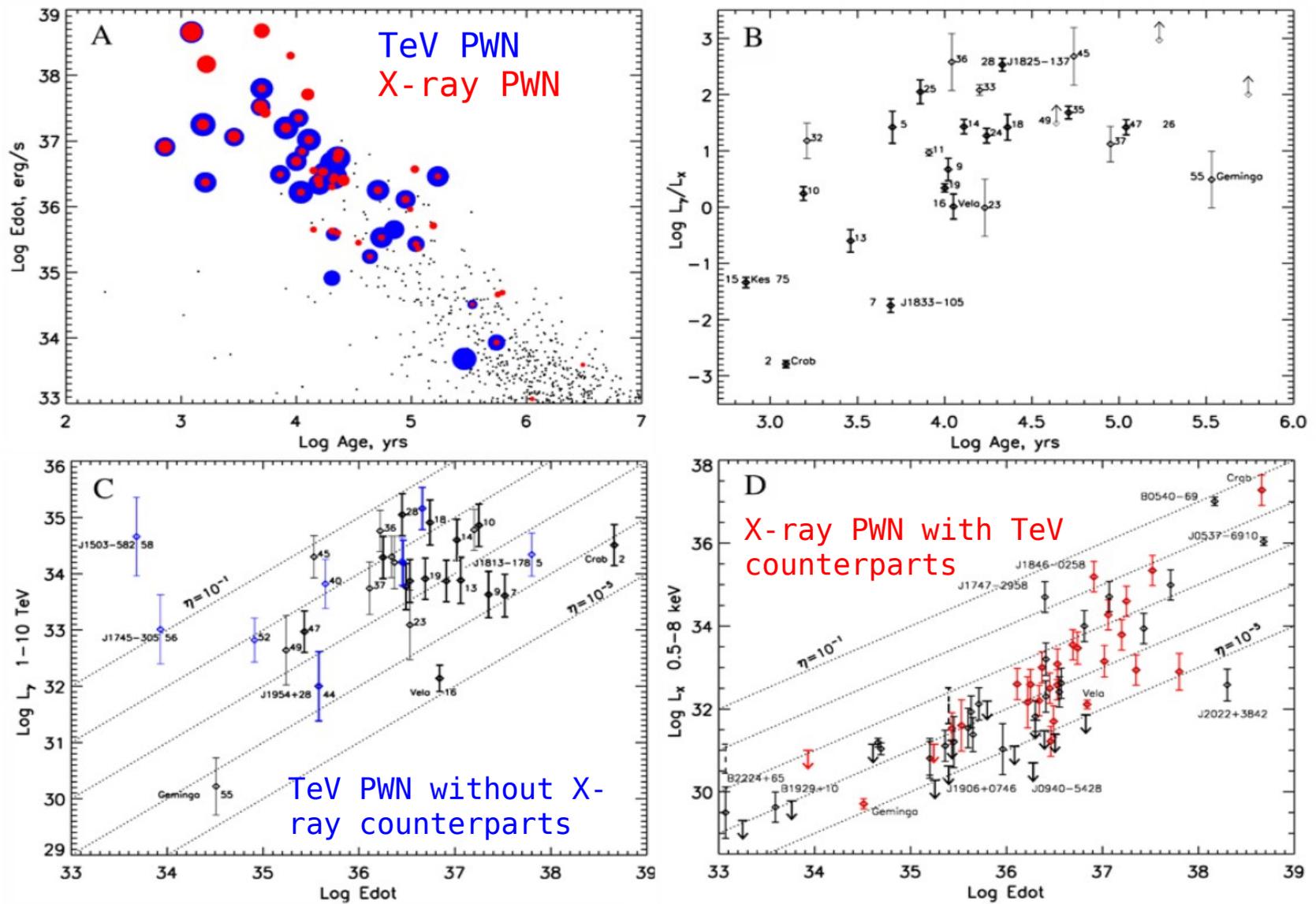


FIGURE 1. (A) Filled circles are X-ray (red) and TeV (blue) detected PWNe or PWN candidates. Larger circle sizes correspond to higher luminosities. The small black dots denote the pulsars from the ATNF catalog ([81]). (B) Ratio of the TeV to X-ray luminosities vs. pulsar's spin-down age. Here and in panel C the thin error bars mark questionable associations. (C) TeV luminosities of PWNe and PWN candidates vs. pulsar's \dot{E} . The blue error bars mark TeV objects without X-ray counterparts. Here and in panel D the luminosity uncertainties include 50% systematic uncertainty assigned to the distances unless the pulsar is in LMC or its parallax has been measured. (D) X-ray luminosities of PWNe vs. \dot{E} . The red error bars denote X-ray PWNe with TeV counterparts. The lines of constant radiative efficiency ($\eta \equiv L_{X,\gamma}/\dot{E}$) are plotted in panels C and D.

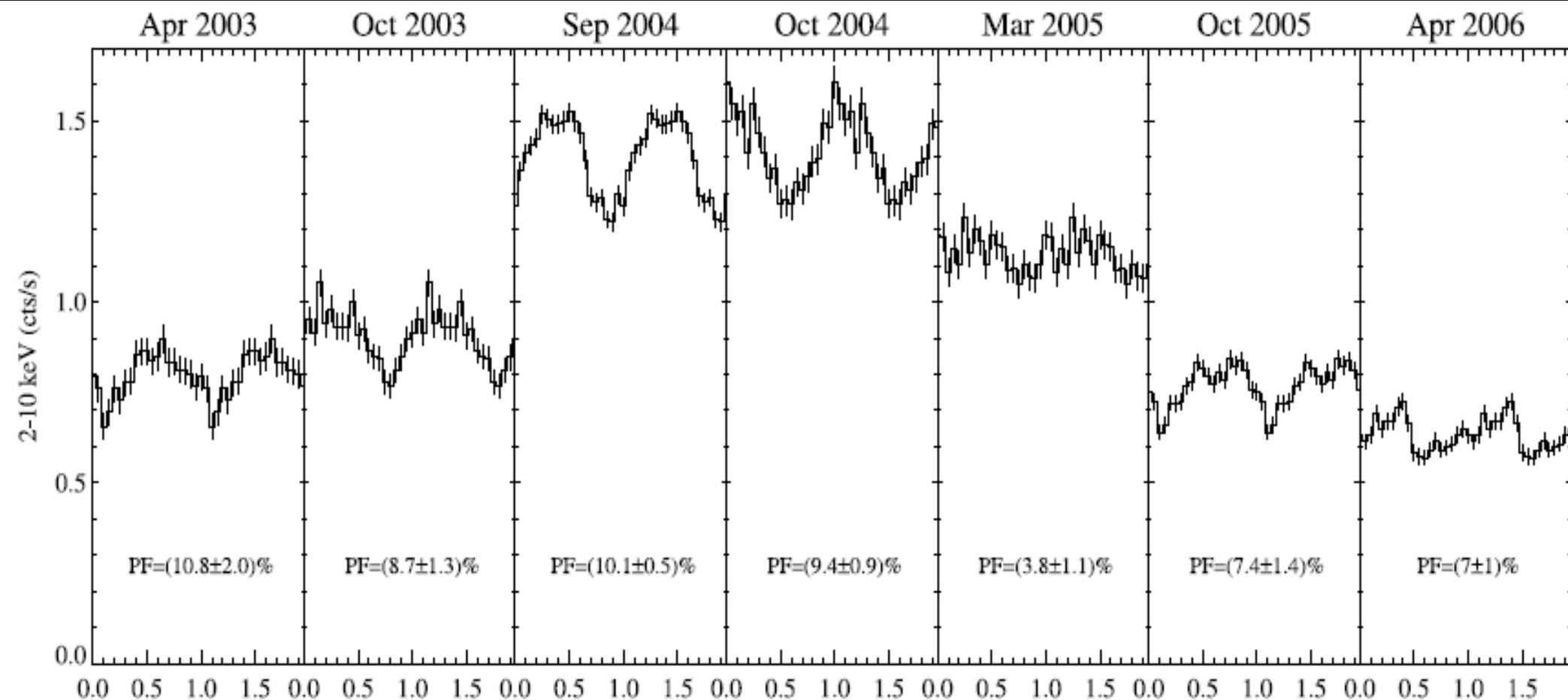


Fig. 1 *Folded light curves* of SGR 1806-20 obtained with the EPIC pn instrument in the seven XMM-Newton observations. Note the flux increase in the two observations before the December 2004 giant flare and the small pulsed fraction in the first 2005 observation