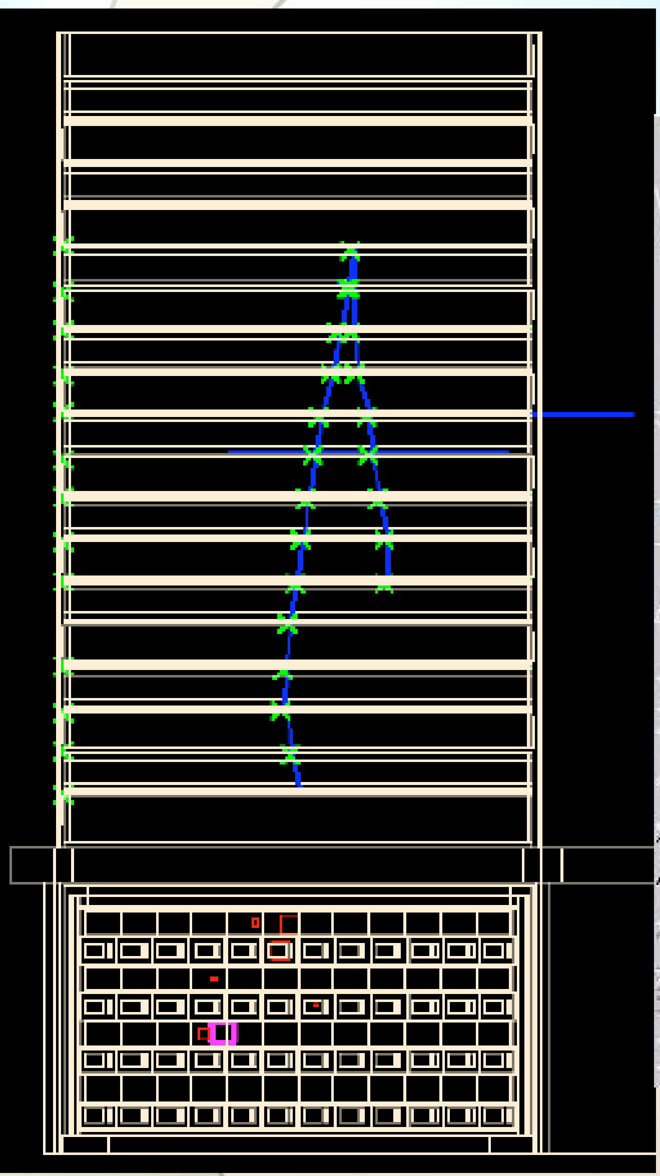
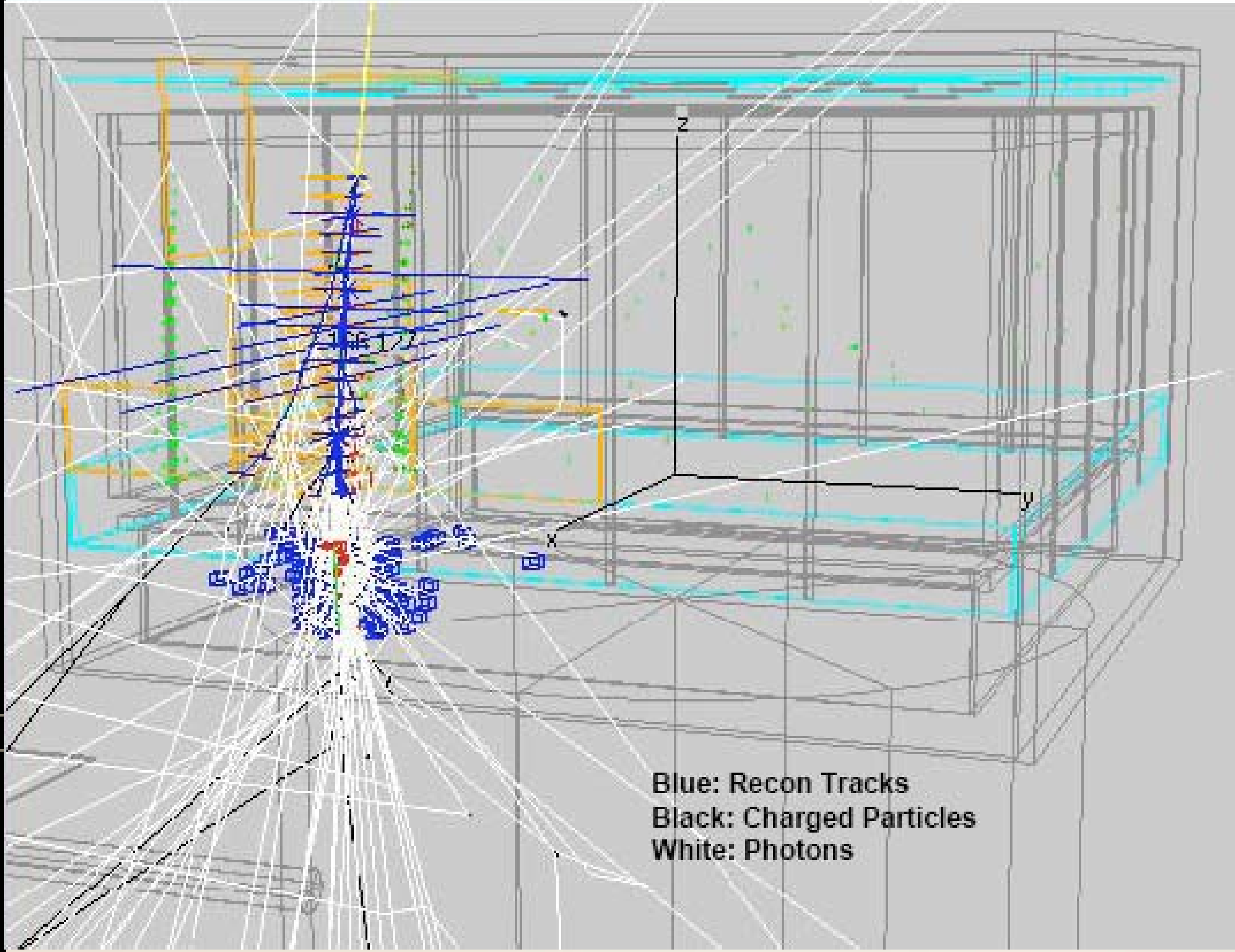

The future world
according to GLAST

GLAST mission

- **Large Area Telescope**
  - LAT: 20 MeV – 300 GeV
- **Gamma-ray burst monitor**
  - GBM: 10 keV – 20 MeV
- **launch 31/1/2008**
  - on Delta 2 H
- **lifetime**
  - 5 + 5 years

LAT telescope





LAT performance

20 MeV → 300 GeV

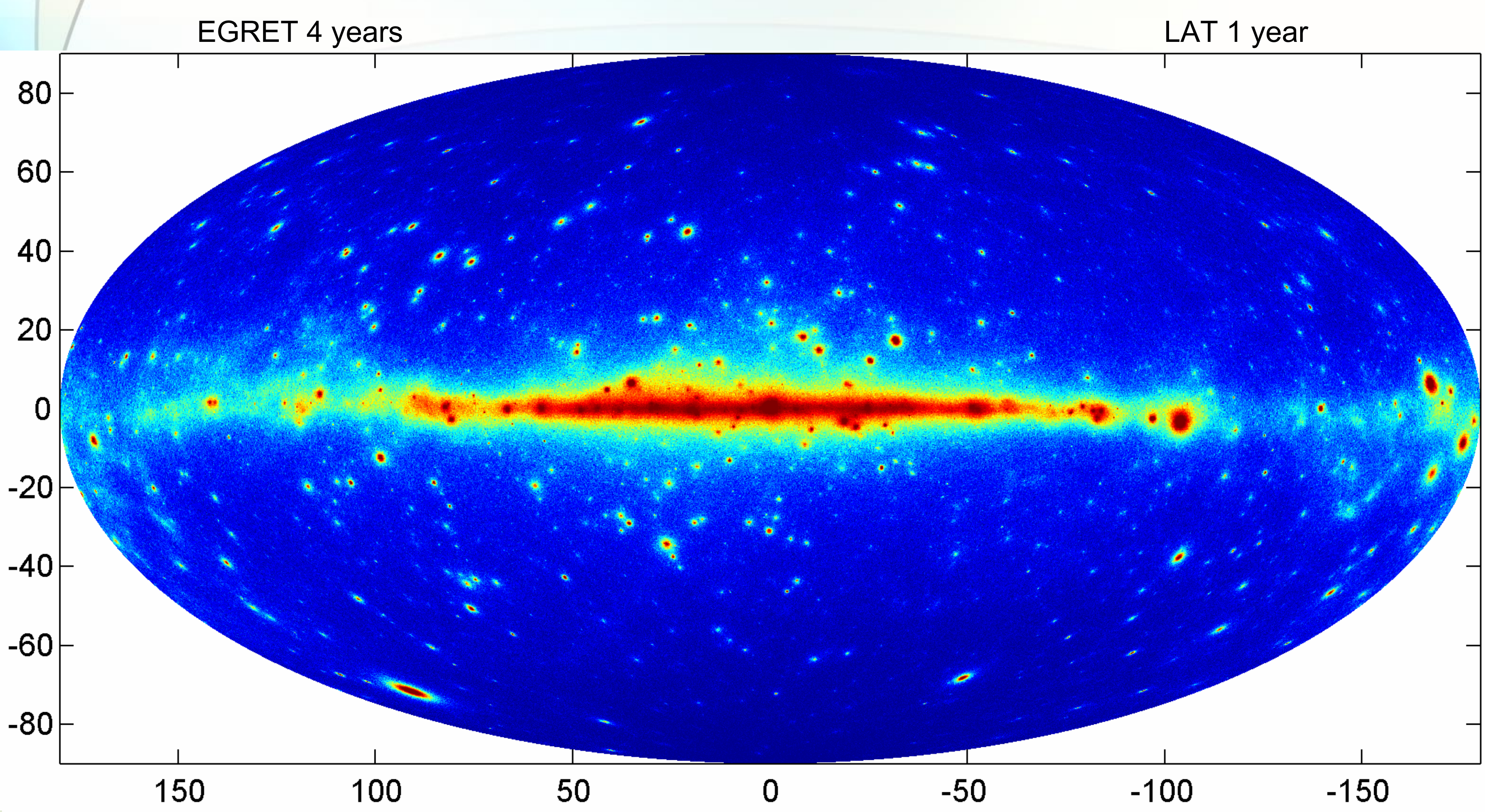
3.2° → 6' resolution

5 ≤ ΔE/E ≤ 10%

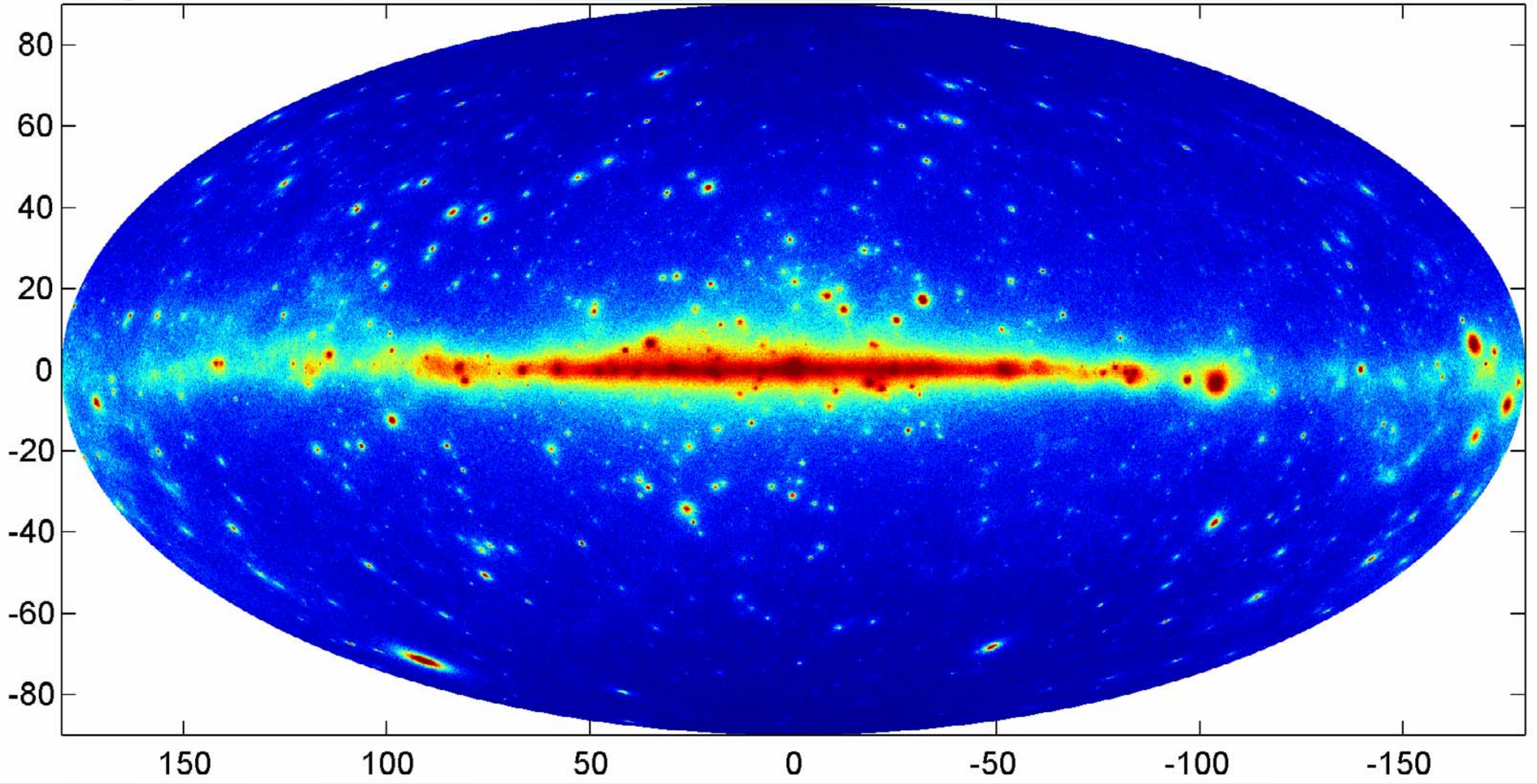
sensitivity > 25 x EGRET

>2 sr, ¾ sky per orbit

sky slewing survey



GLAST data



to be delivered to the community

readily:

γ-ray bursts, bright transients
lightcurves of useful variable sources
processed data after 1 year

after 1 year:

calibrated data, skymaps
source catalogue (1+2+5 year)
interstellar model
analysis software suite

the LAT sky

10^3 supermassive black holes

blazars and radiogal = f(θ,z)

evolution z ≤ 5

Sag A*

> 100 MeV, 1 yr
sensitivity x25
localization x10
field x4

> 40 pulsars

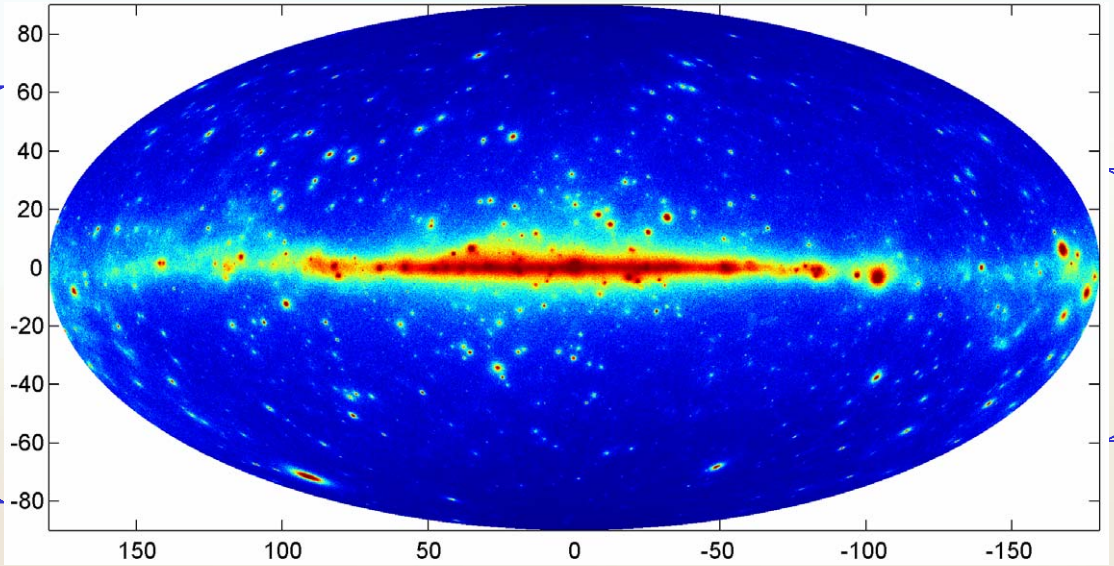
magnetosphere physics

pulsar wind nebulae

γ-ray binaries

pulsar winds

μ-qso jets



dark matter

neutralino lines

dark gas

10^2 GRB /year

GeV afterglow

hopes

starburst galaxies

galaxy clusters

unIDs

Cosmic rays

acceleration in supernova remnants

OB associations, SNOBs

propagation (MWay, M31, LMC, SMC)

interstellar mass tracers in galaxies

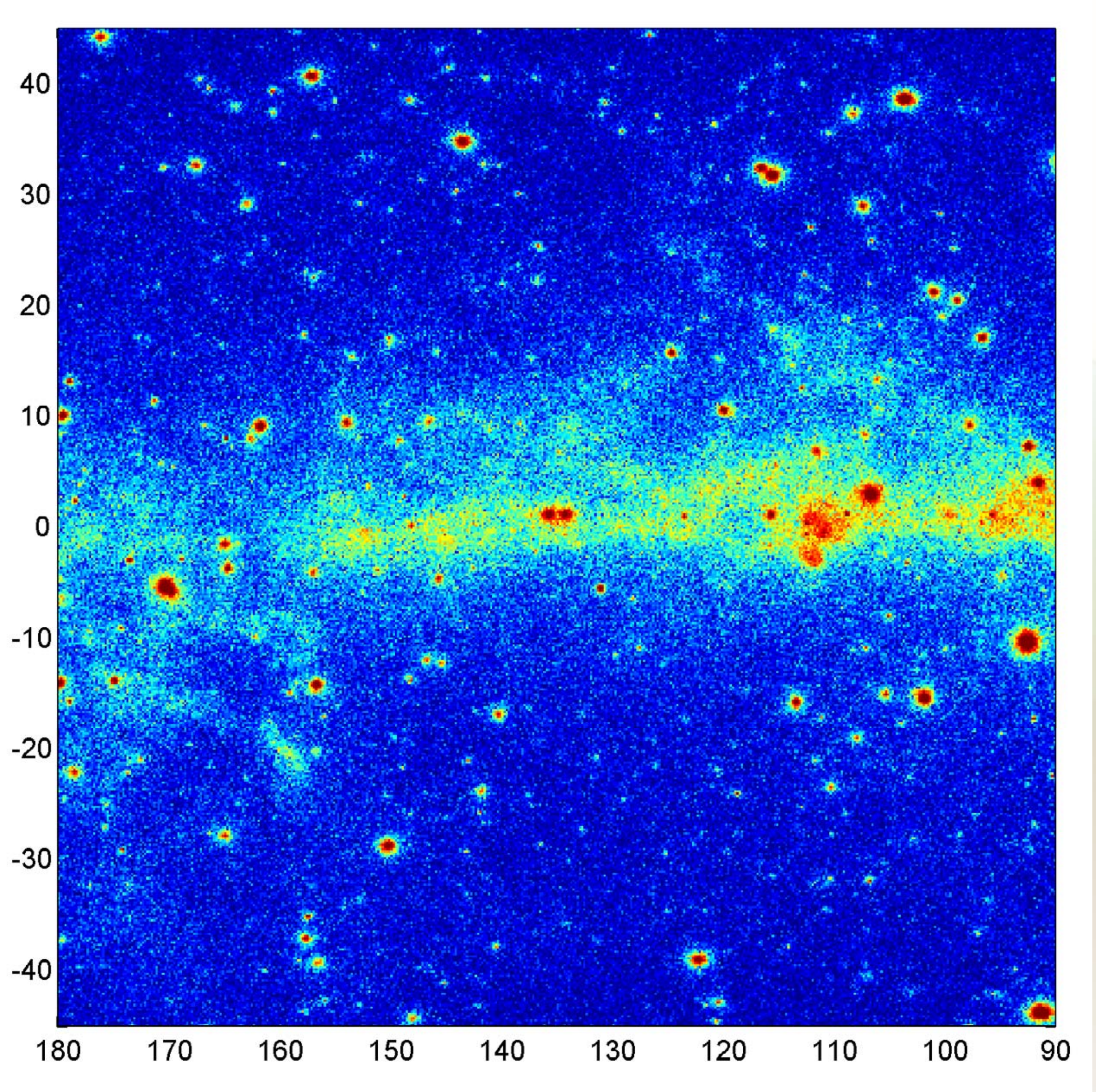
source detection

the interstellar model

> 1500 sources

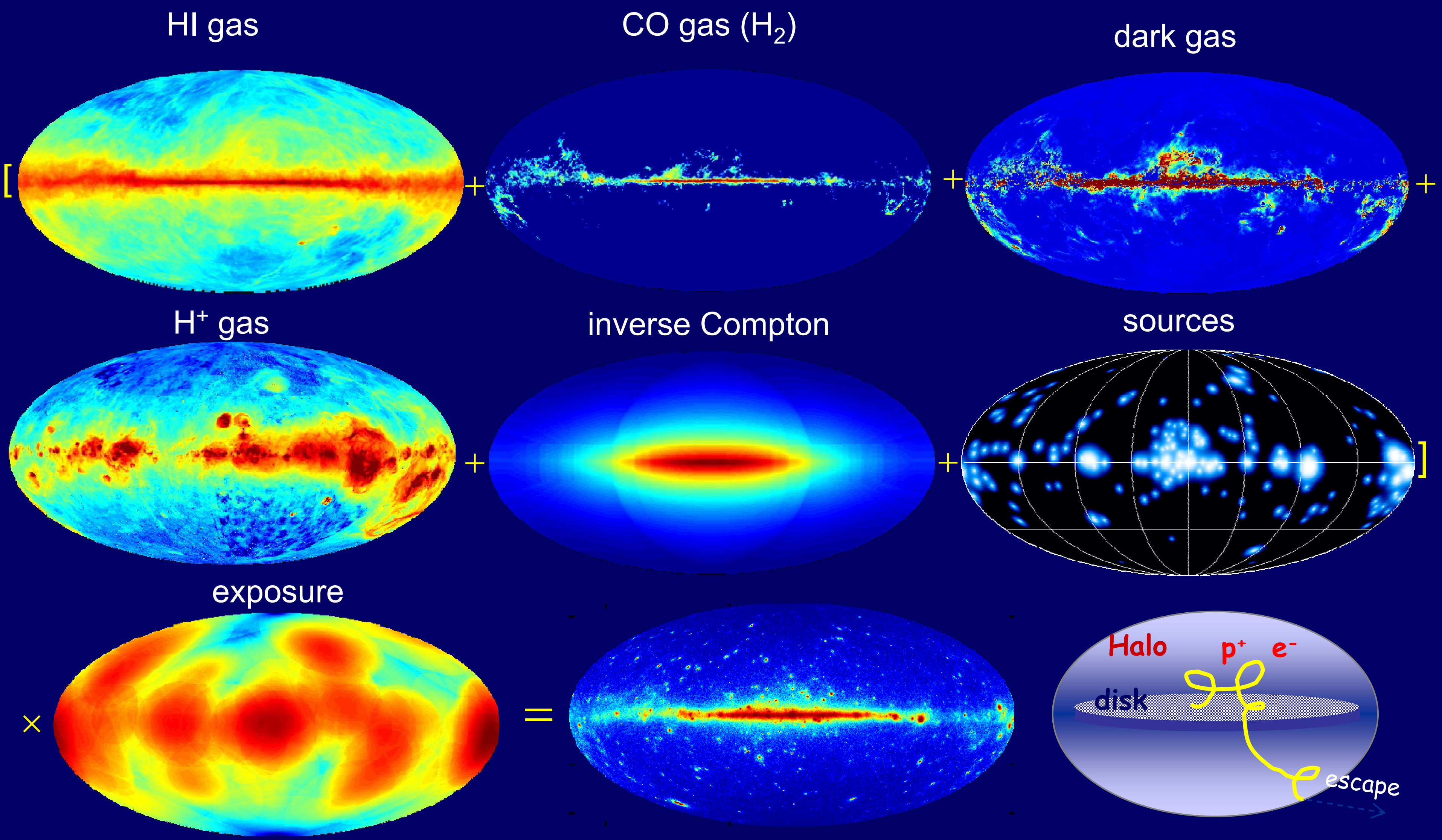
- **challenge**
  - structured ISM background
  - PSF varies with energy
  - low statistics
  - numerous sources

    => confusion
- **strategy**
  - wavelet detector
  - in several energy bands & time slots
  - likelihood validation and characterization



1 an, E > 500 MeV

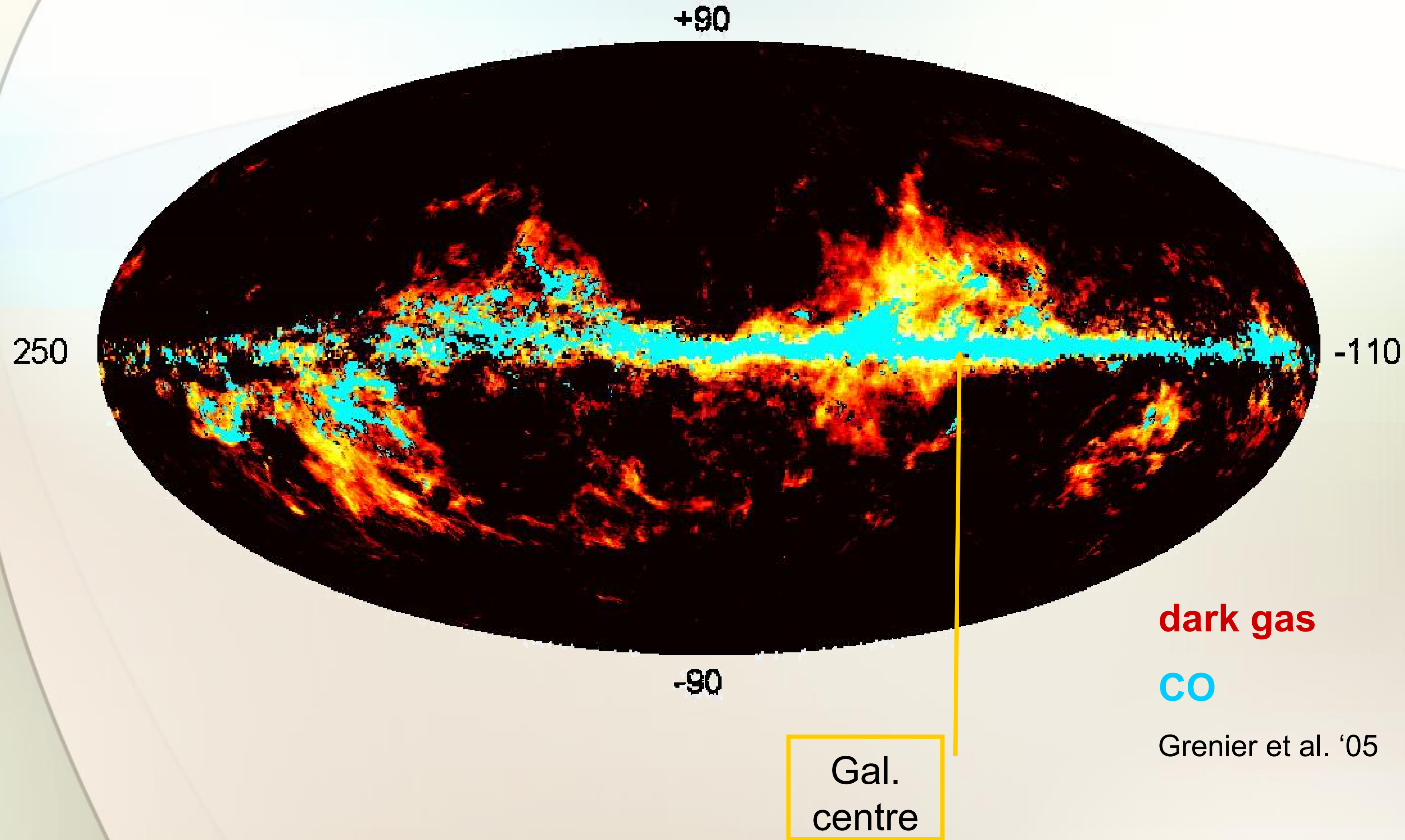
interstellar model



axisymmetric Galaxy → spiral arms and local anomalies

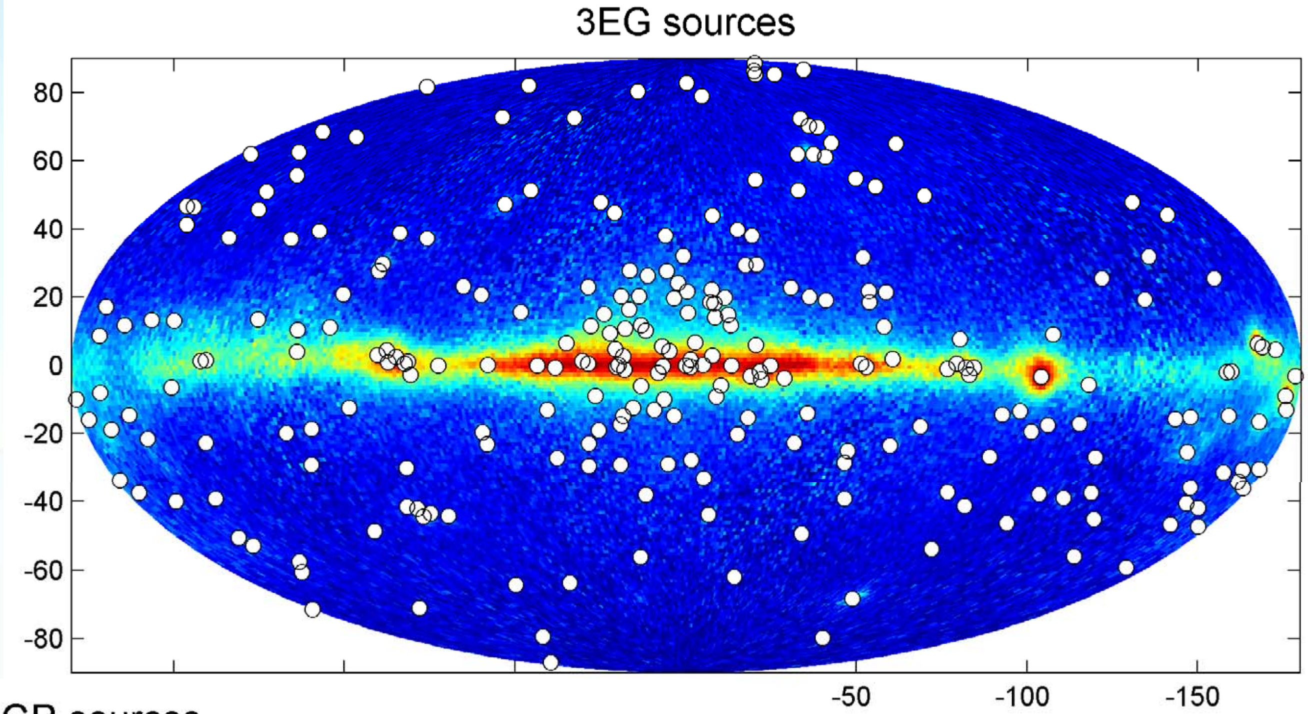
cloudy sources

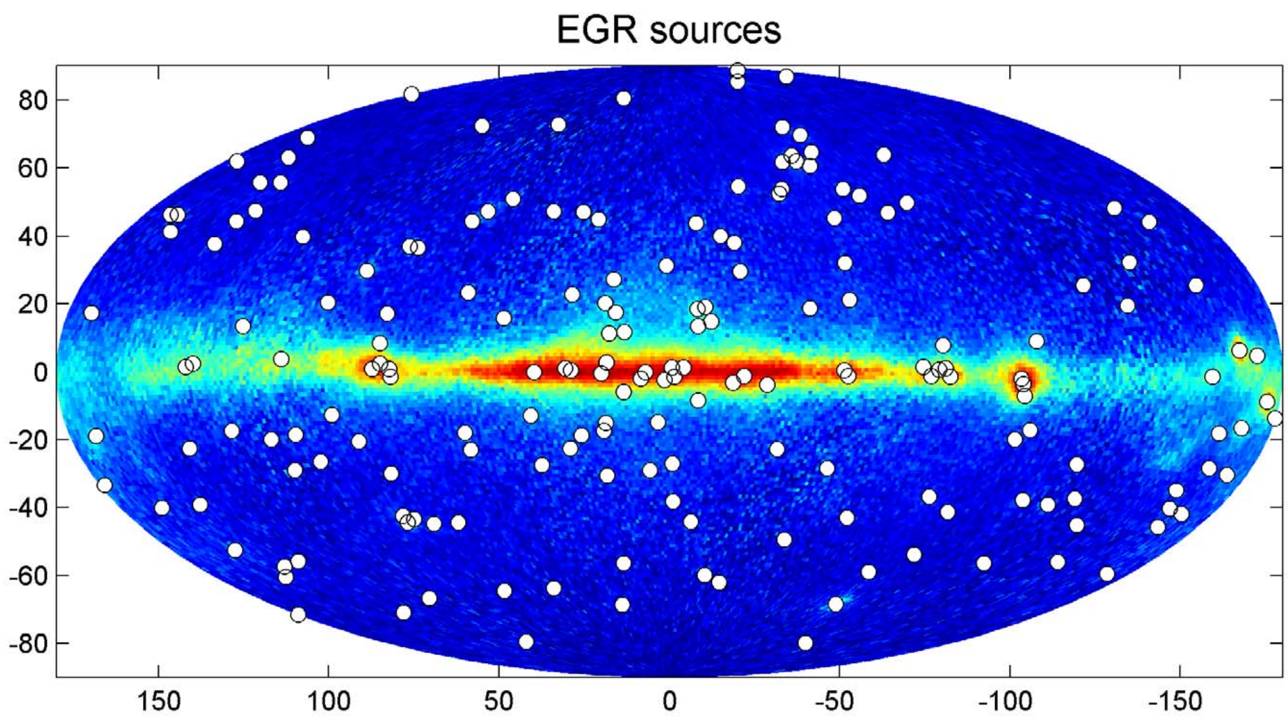
- **normal gas, but total mass is poorly traced**
  - ex: dark gas, optically thick HI or CO



EGRET

- before
- after

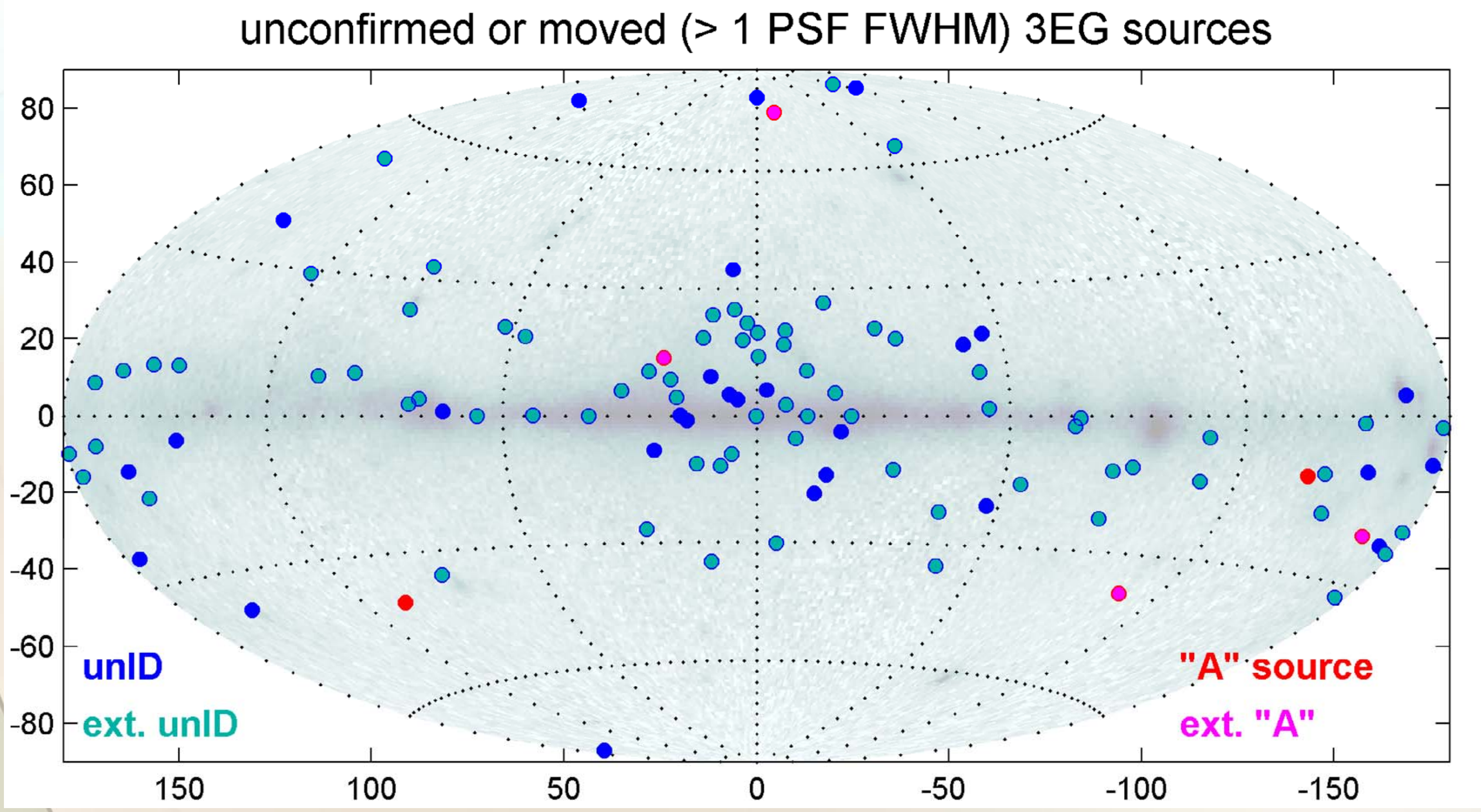




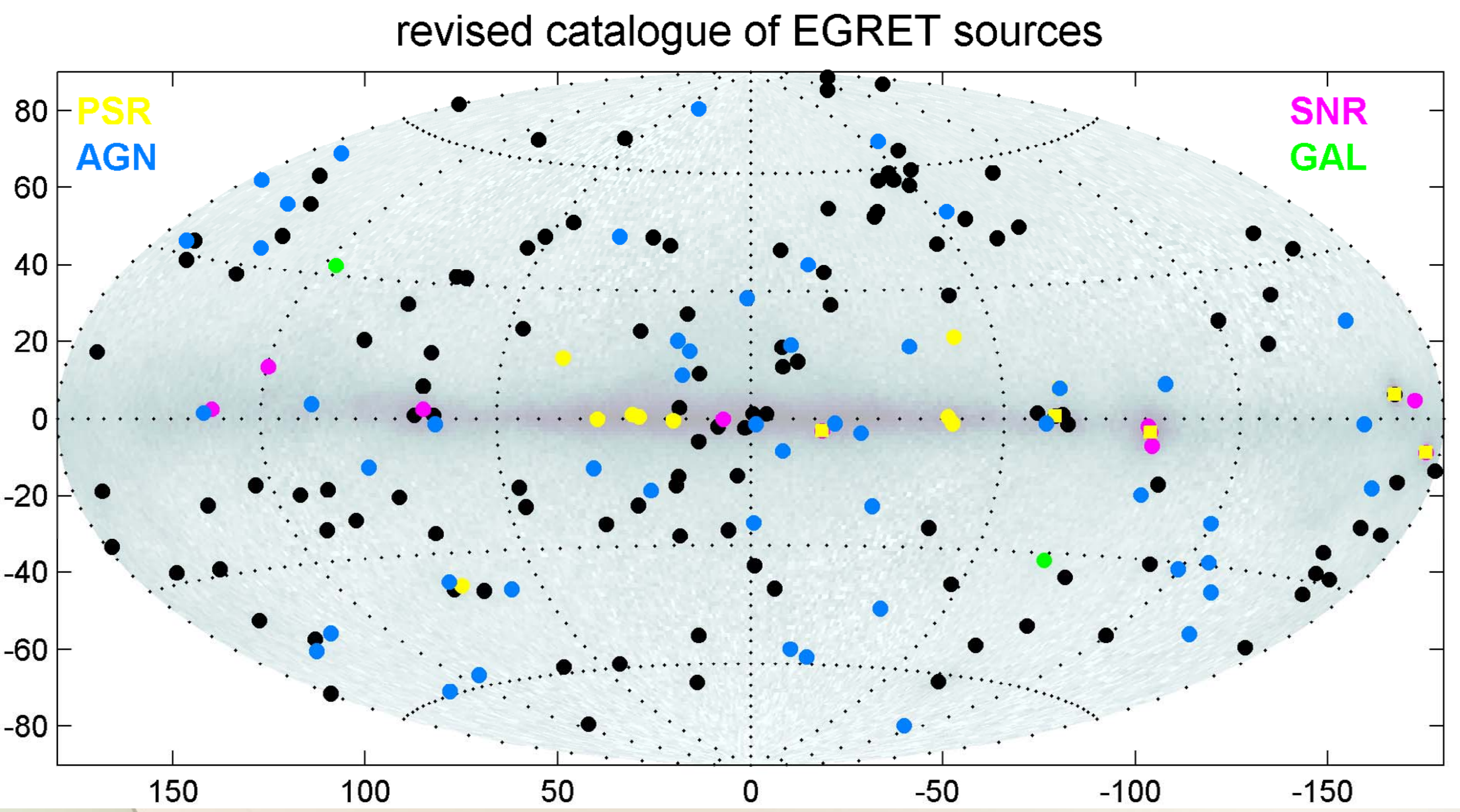
Casandjian & Grenier '07

cloudy sources

- 107 3EG sources not confirmed
  - nearly all the unidentified Gould Belt sources
- 32 new sources from 9-year data



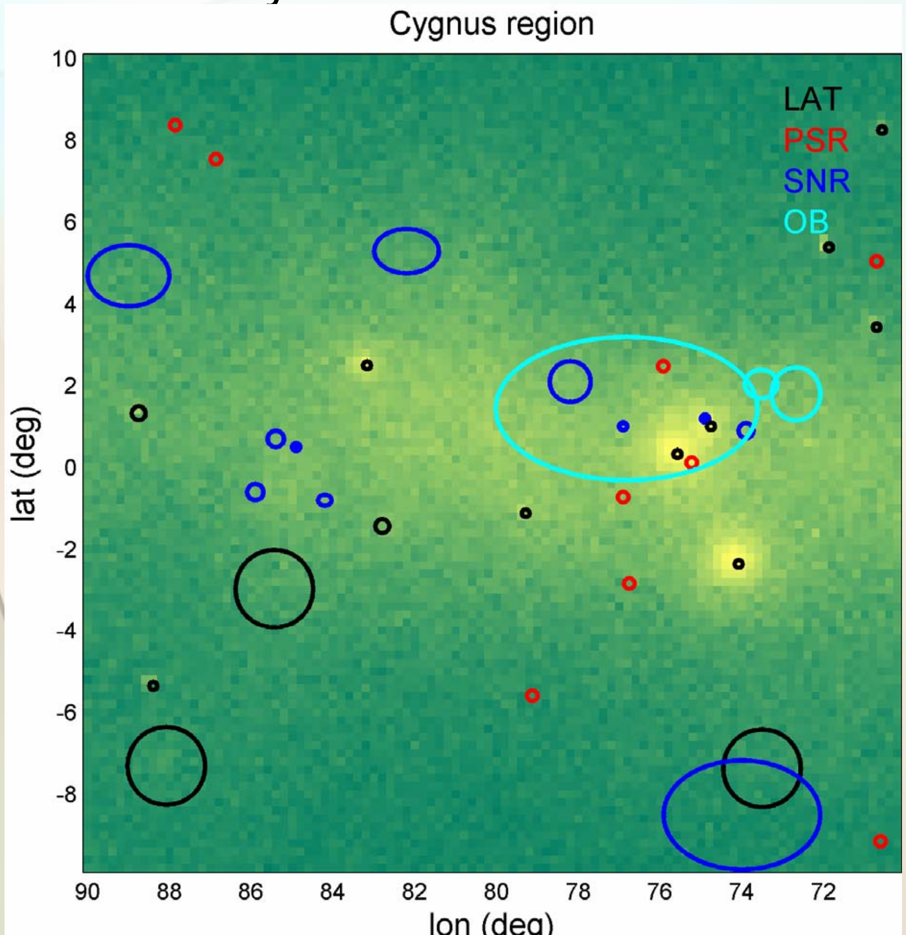
EGRET source classes

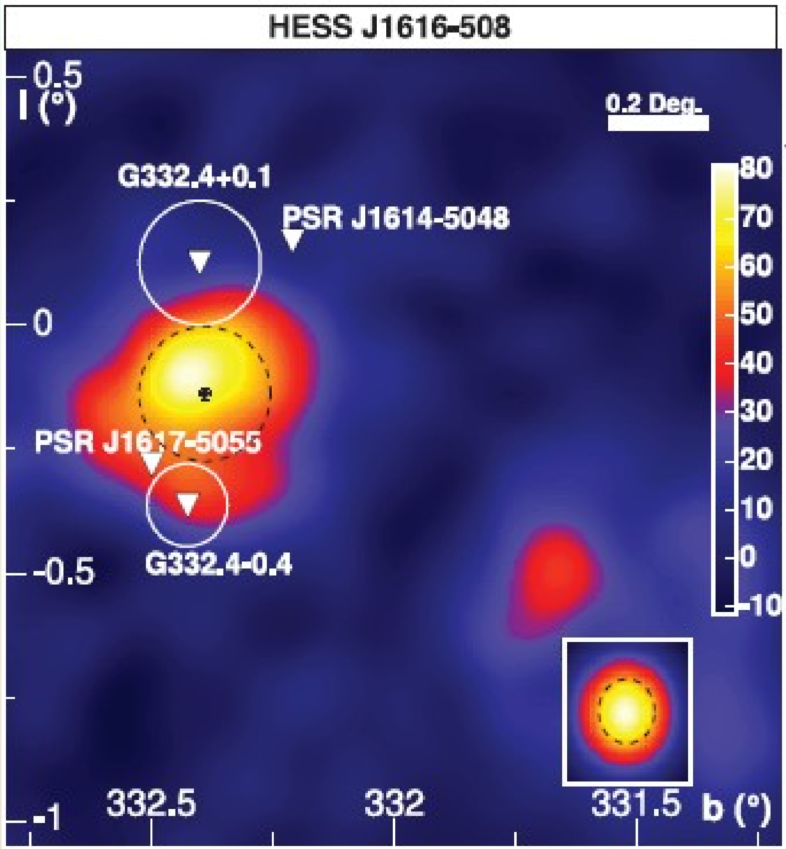


source identification

counterparts

- challenge
  - quantify the chance coincidence (incomplete, biased multi-λ surveys, incomplete/absorbed at high z)
  - extract SEDs (automatisation, CDS data + data mining)
  - variability





confused unIDs

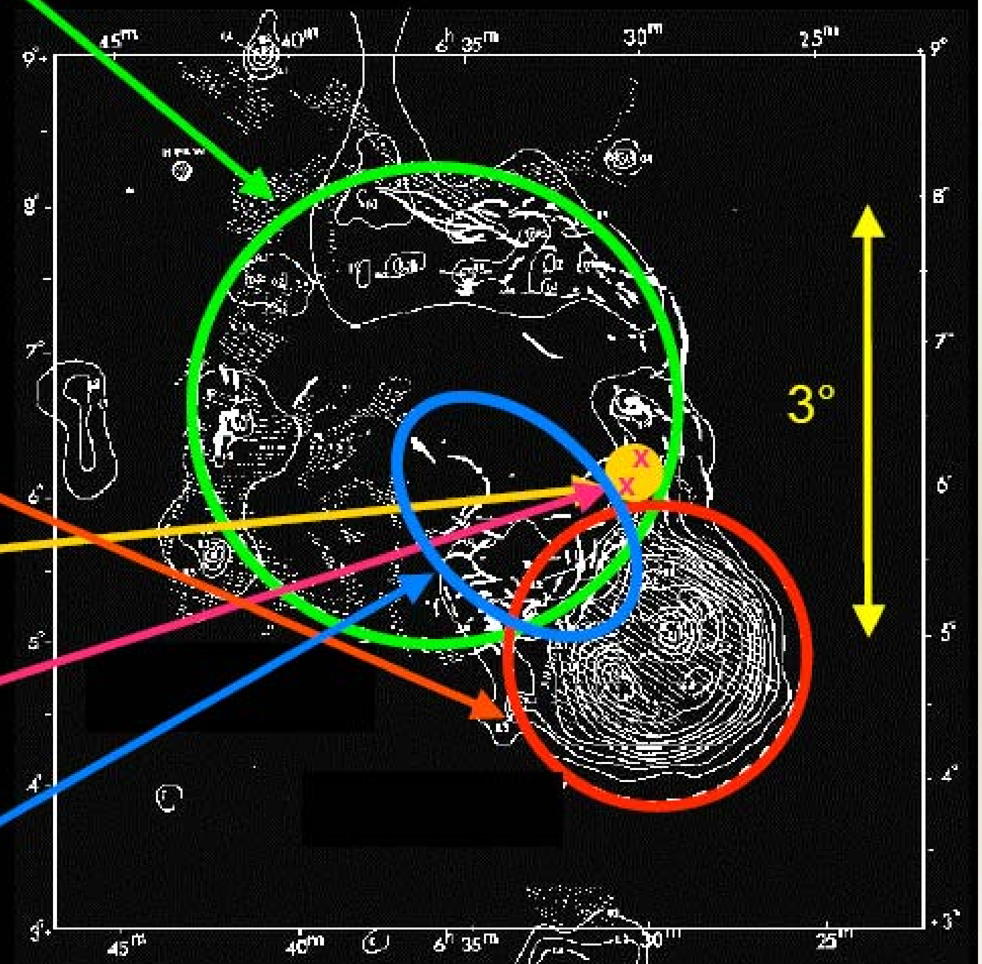
The Monoceros Loop SNR

- 3° diameter ring seen in Hα
- 30-150 kyrs old
- Distance ~1.5 kpc
- Interaction with the Rosette nebula?

- HESS J0632+058

- weak RX source
- Be Star

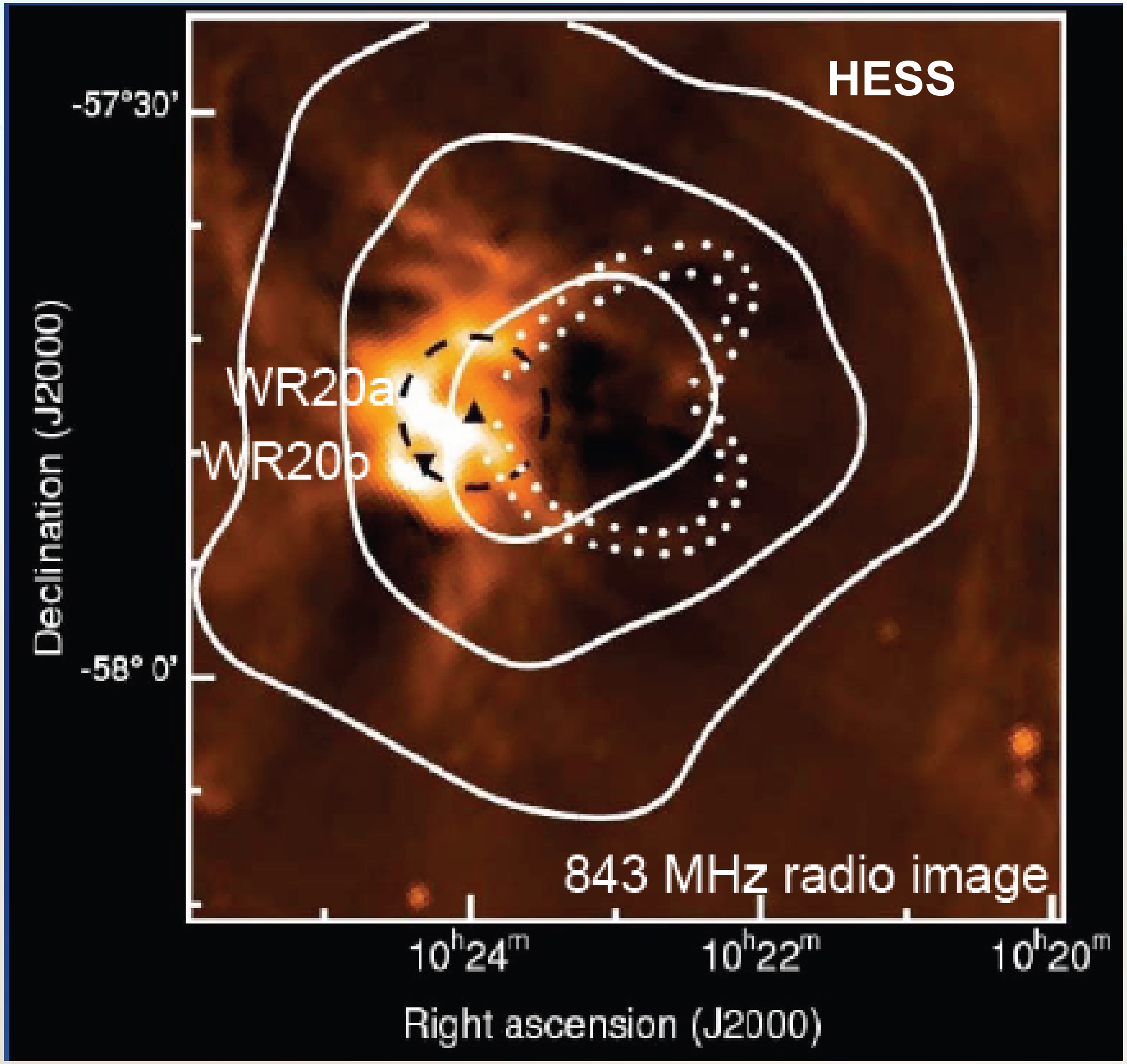
- 3EG J0634+057



extended unIDs

- **OB associations**
- **ex: Westerlund 2: 12 O + 2 WR stars**
  - unresolved sources?
  - hidden SNR(s)?
  - massive stellar winds?
  - blister wind?
- **colliding stellar winds**
  - expected for GLAST

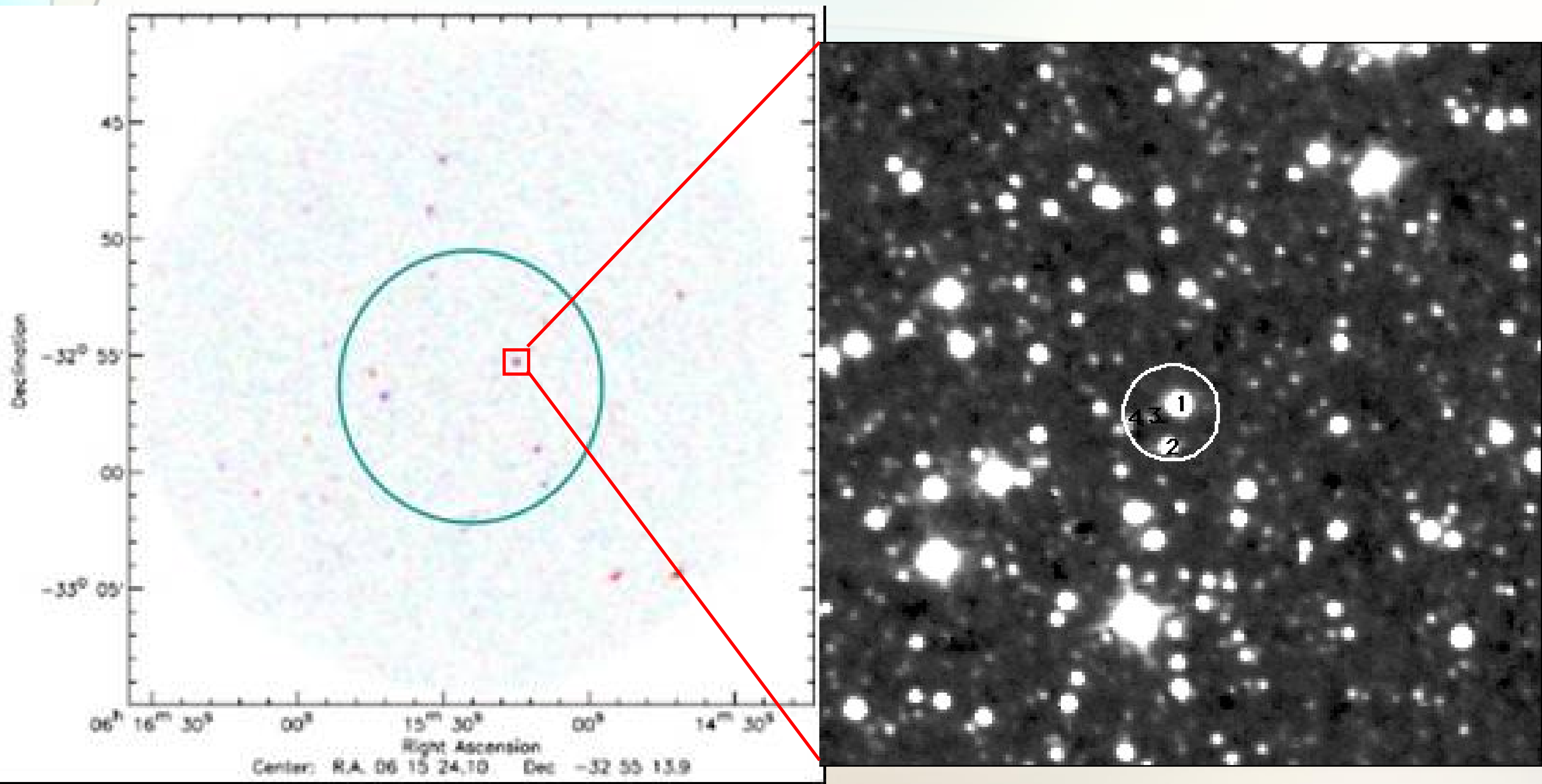
    Reimer et al. ‘06



Aharonian et al. ‘07

multi-λ identification

- 5 X-ray sources per LAT error box
- 1000 sources at 2.2 μm per 1’x1’
- => spectral modelling



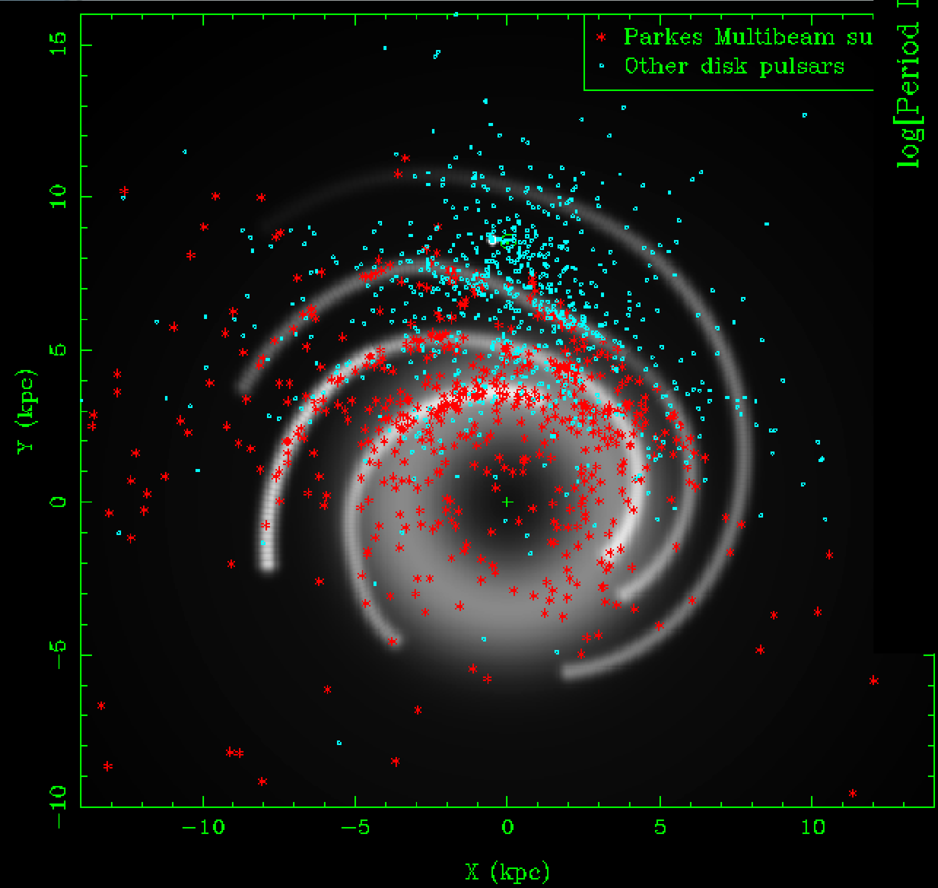
La Palombara et al. ’06

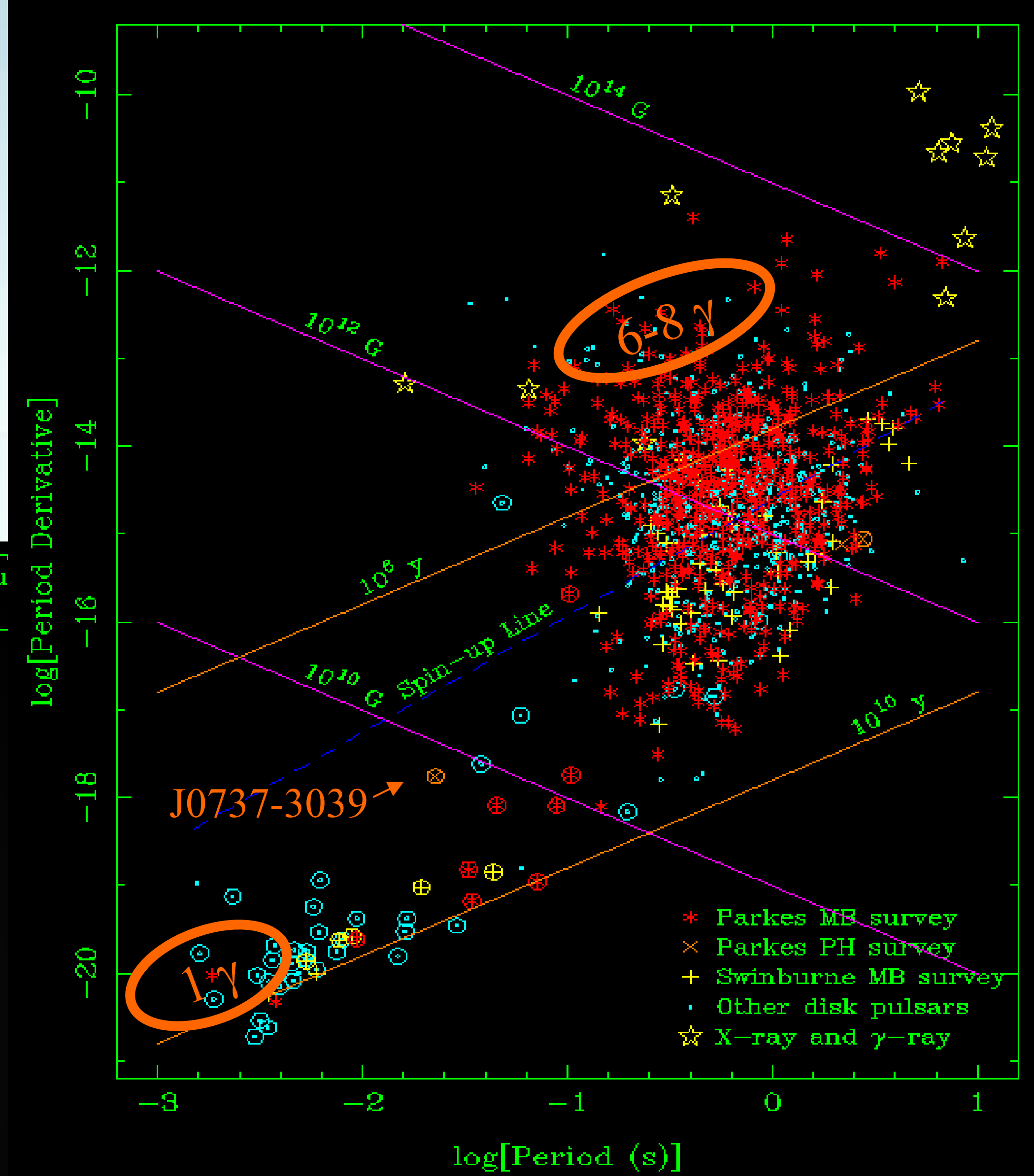
Chaty et al. ‘07

pulsars and their winds

radio & γ pulsars

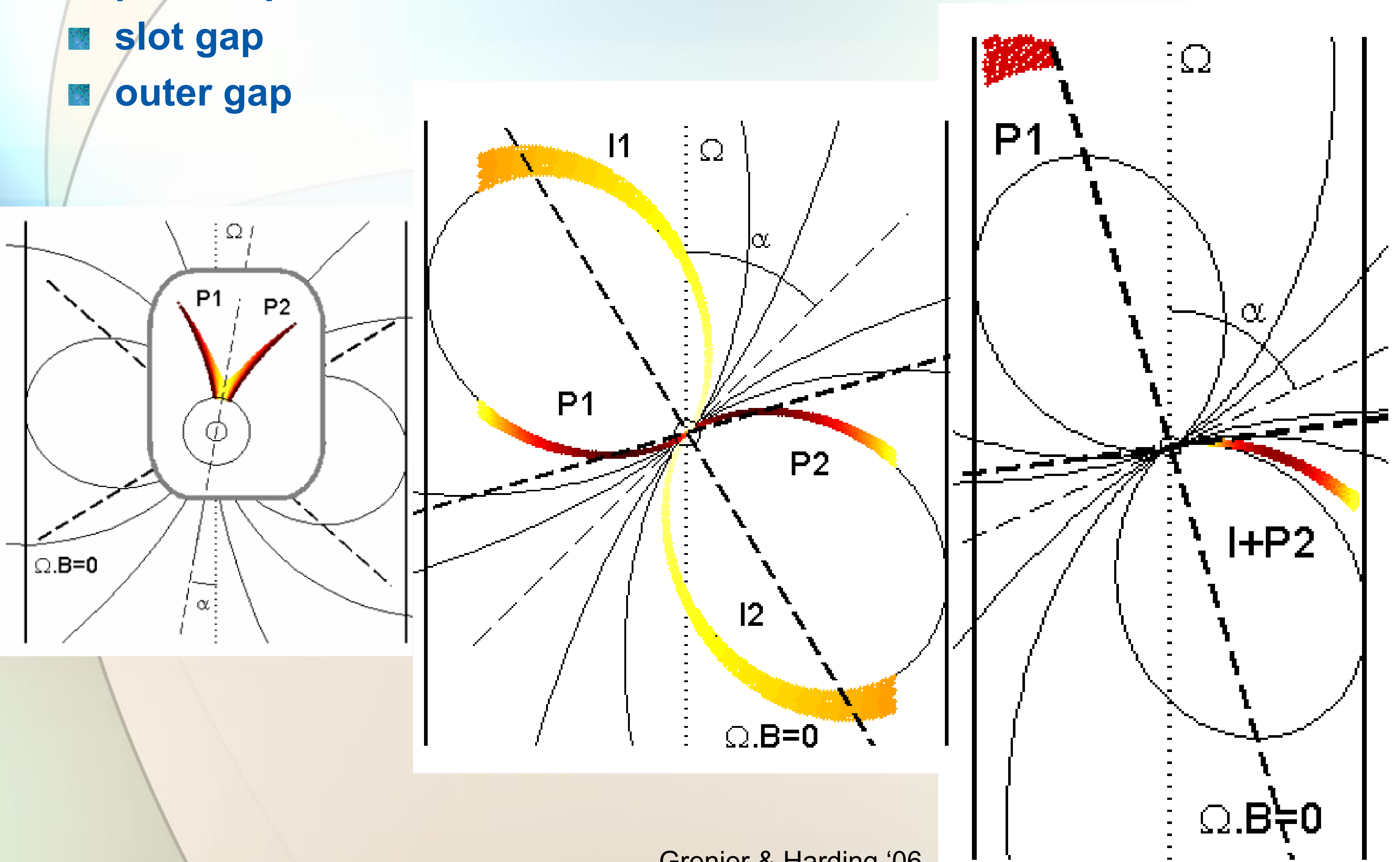
ATNF Pulsar Catalog





γ-ray pulsars

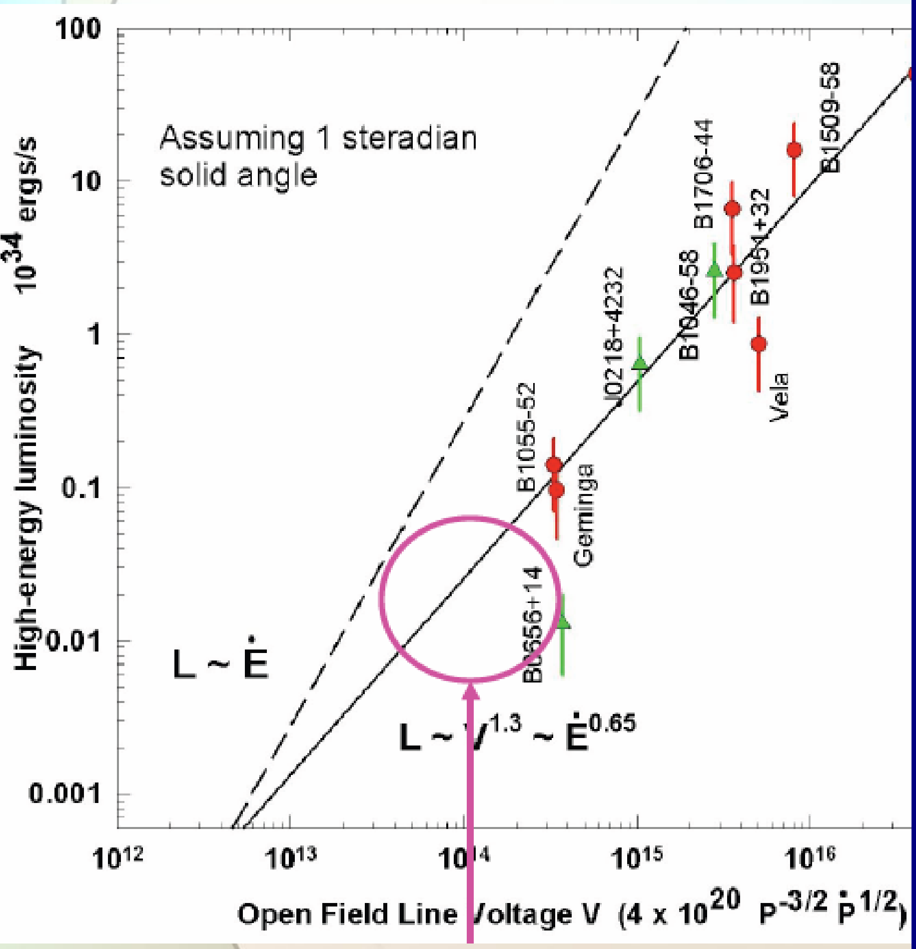
- polar cap
- slot gap
- outer gap

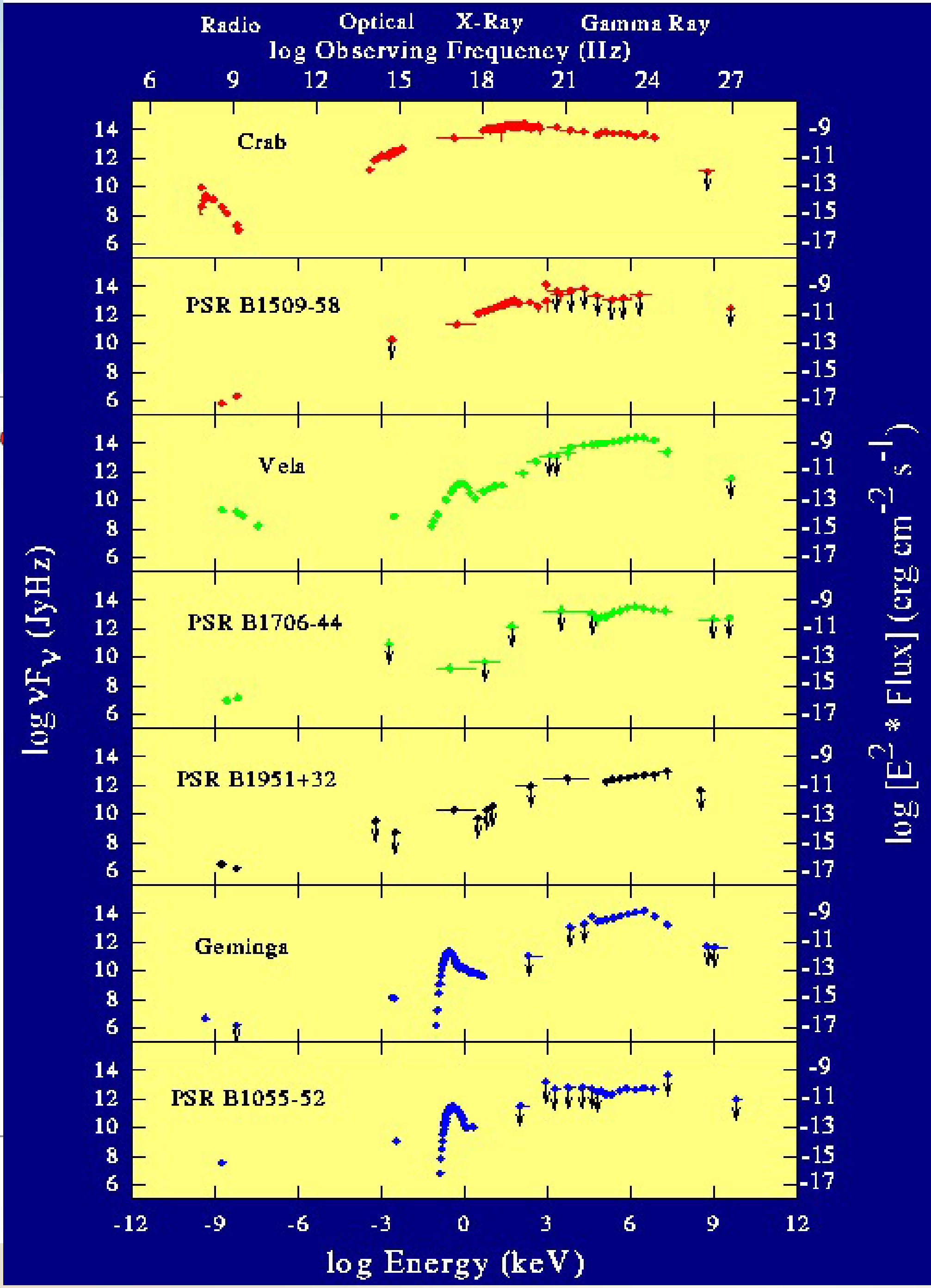


Grenier & Harding '06

γ-ray pulsars

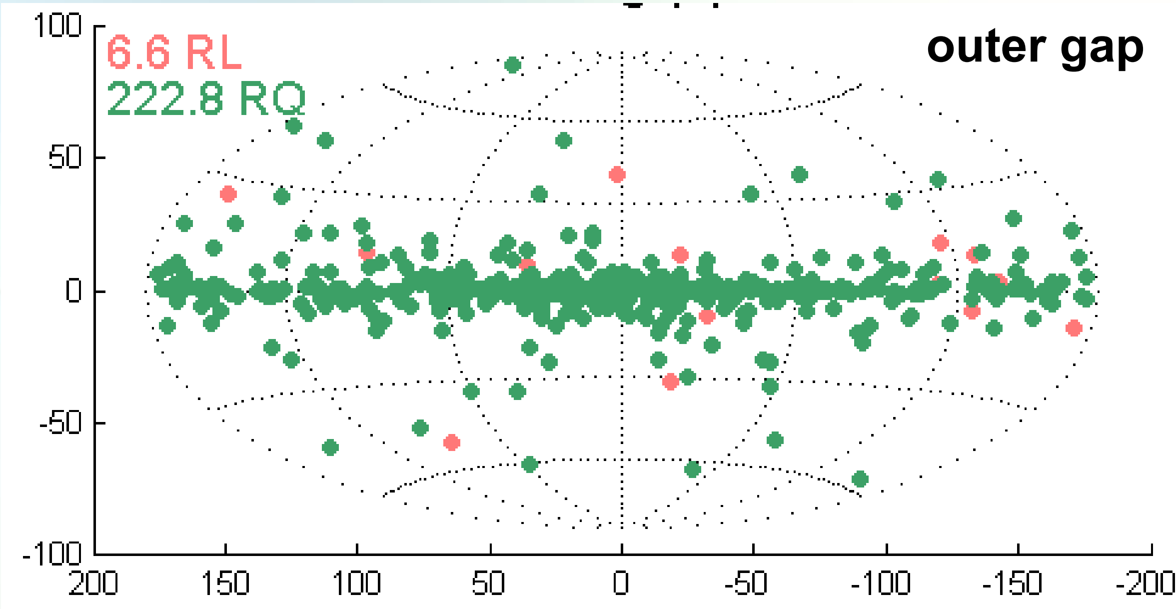
- magnetosphere evolution
- no pulsed emission at E > 10-50 GeV

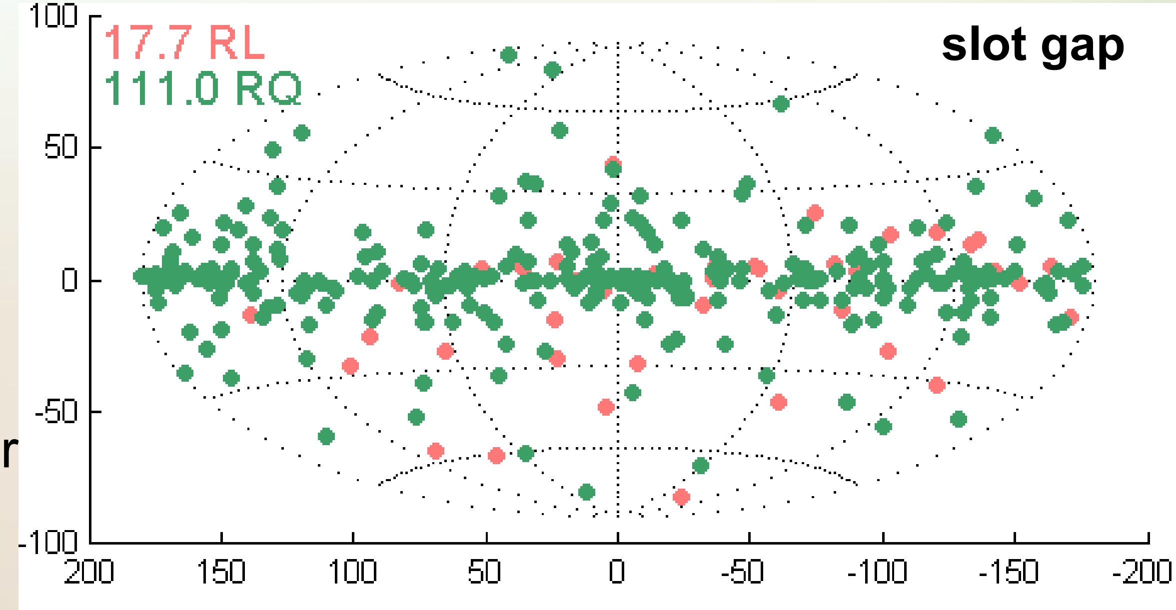




γ-ray pulsars

- > 40 LAT pulsars
  - flux distribution
  - spatial distribution
    (age)
  - spectral distribution
  - light curve shapes
- radio-γ objects
  - radio monitoring
    ($\dot{E}/D^2$ unreliable)
  - blind pulsation searches
  - γ+radio favoured in polar cap
  - many Gemingas from slot gap & outer gap
    identification?

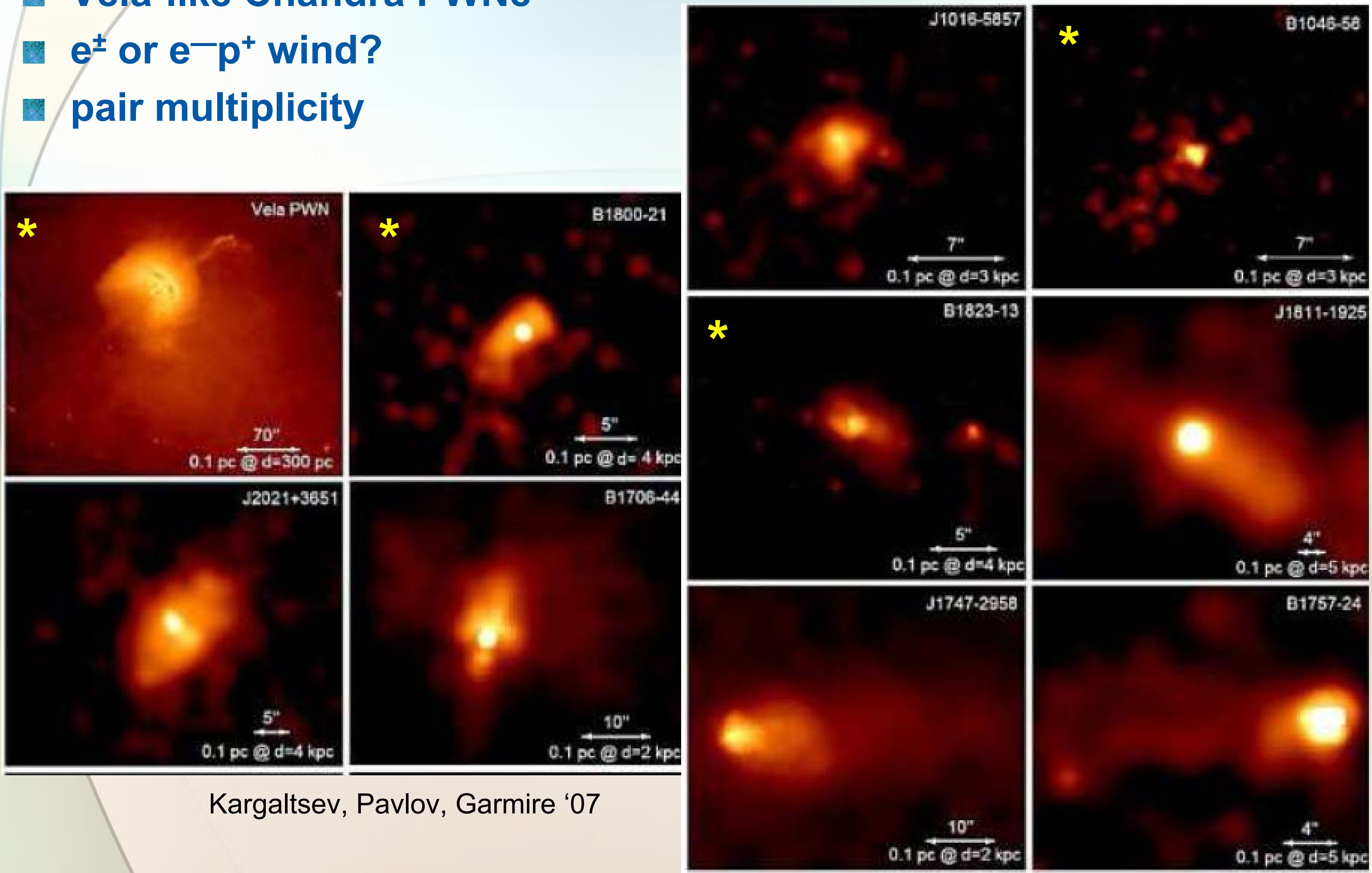




Harding, Grenier, Gonthier ‘07

pulsar wind nebulae

- Vela-like Chandra PWNe
- $e^{\pm}$ or $e^{-}p^{+}$ wind?
- pair multiplicity



Kargaltsev, Pavlov, Garmire '07

pulsar wind nebulae

- GeV emission: probable, GLAST to confirm identification
- TeV emission: several firm* and tentative cases from HESS
  - Crab*, Kes75*, G21.5-0.9*
  - G0.9+0.1* (torus)
  - B1509-58/MSH15-52* (jet)
  - VelaX* (jet+torus)
  - Rabbit
  - Kookaburra*
  - J1913+1011
  - B1823-13*
  - B1800-21 (torus)
  - J1809-1917
  - J1718-3825
  - HESSJ1640-465
  - HESS J1813-178*

why not

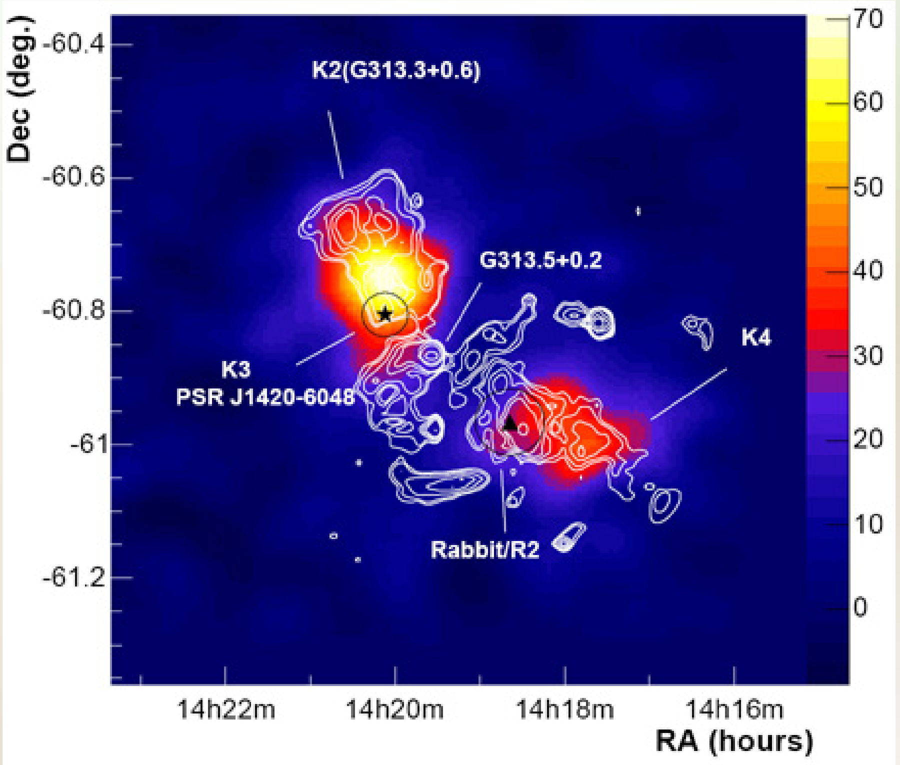
B1951+32, B1706-44

Duck, Mouse

IC 443, W44

J 2021+3651

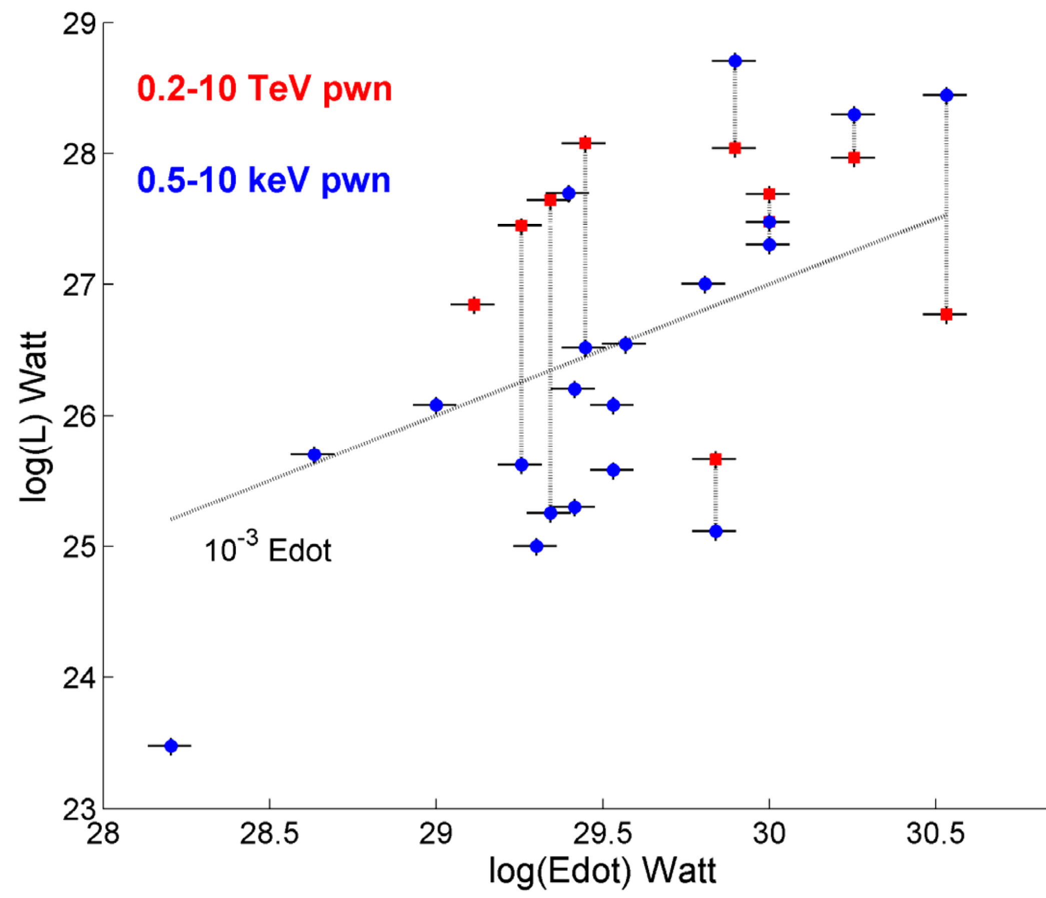
J 2229+61, Geminga, …

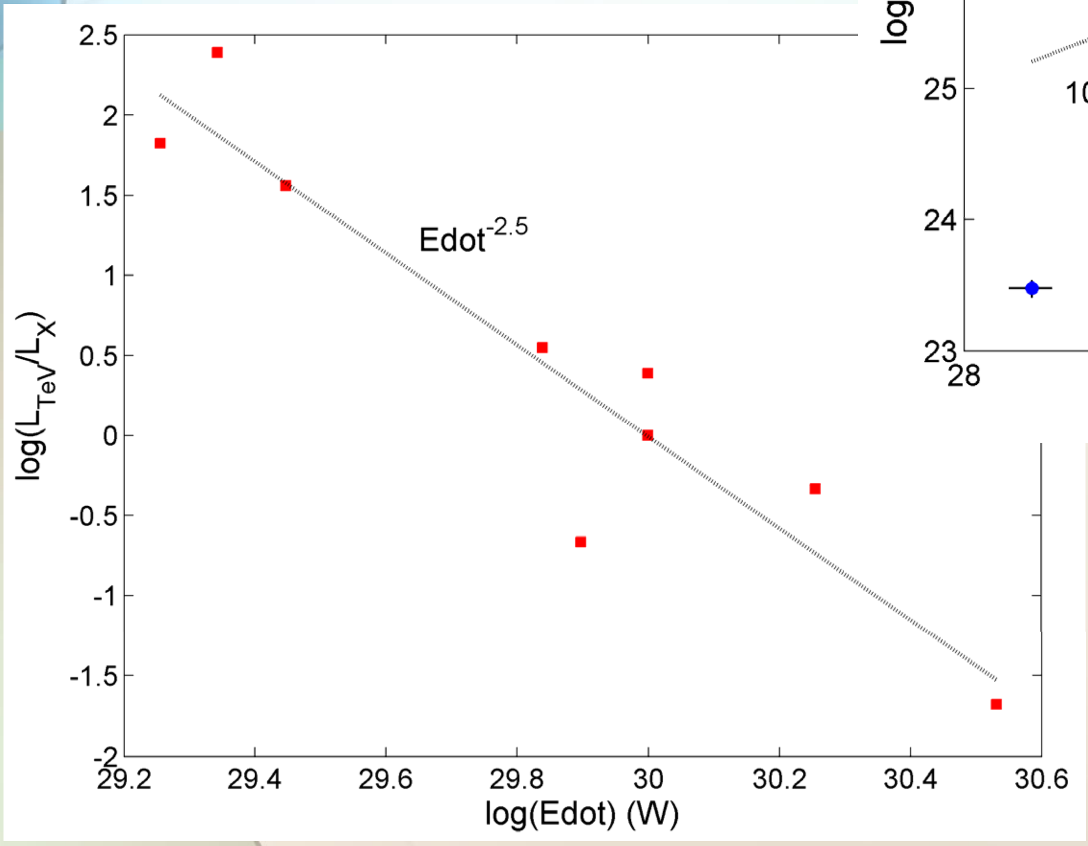


- $10^{29} < \dot{E}_{psr} < 10^{31}$ W, 1 – 90 kyr

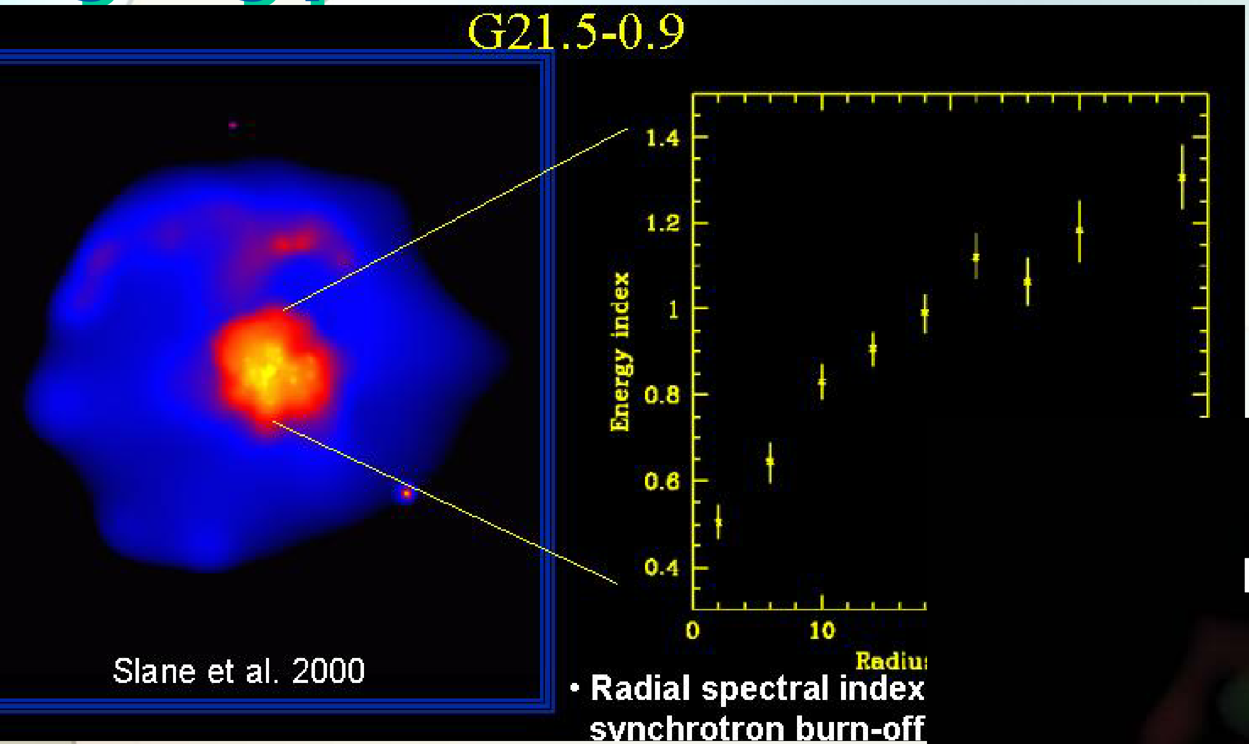
today's efficiencies

- $L_\gamma > L_X$
- $L_\gamma/\dot{E}_{psr} \sim 1\%$
- $10^{-3} < L_X/\dot{E}_{psr} < 10^{-2}$

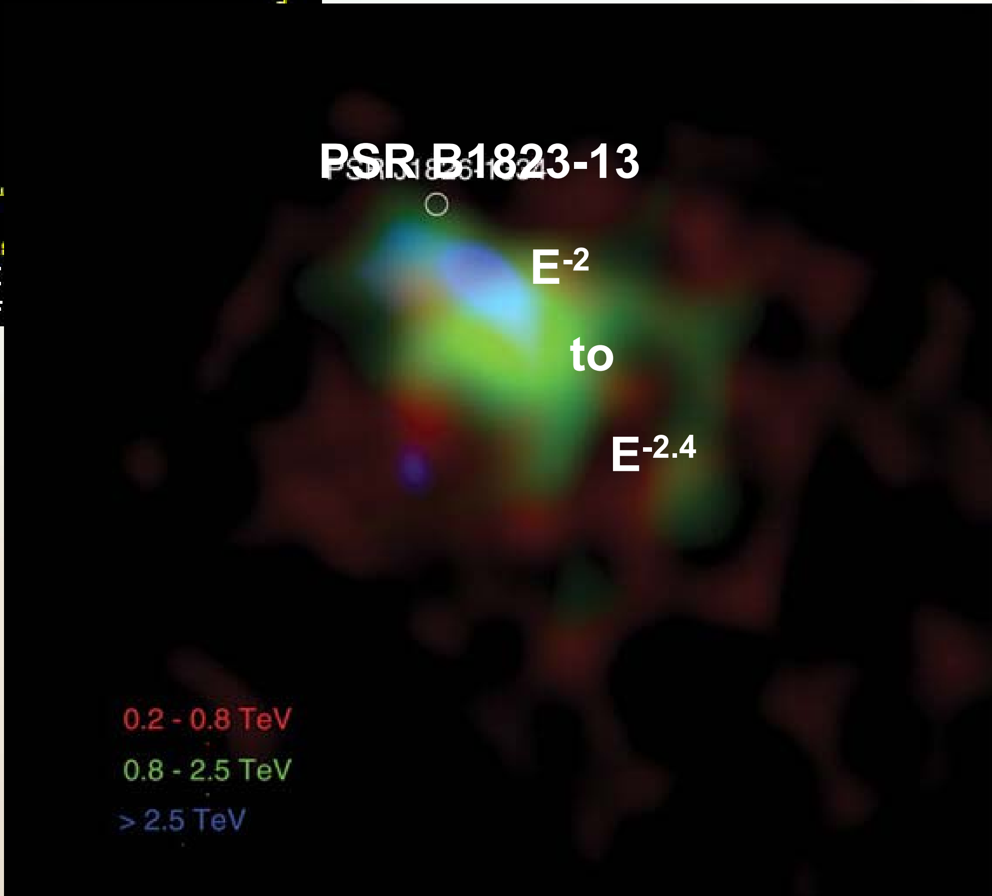




ageing pairs



- **young**
  - 1D spherical
  - $\dot{E}_{psr} \downarrow$ slowly
  - but expanding

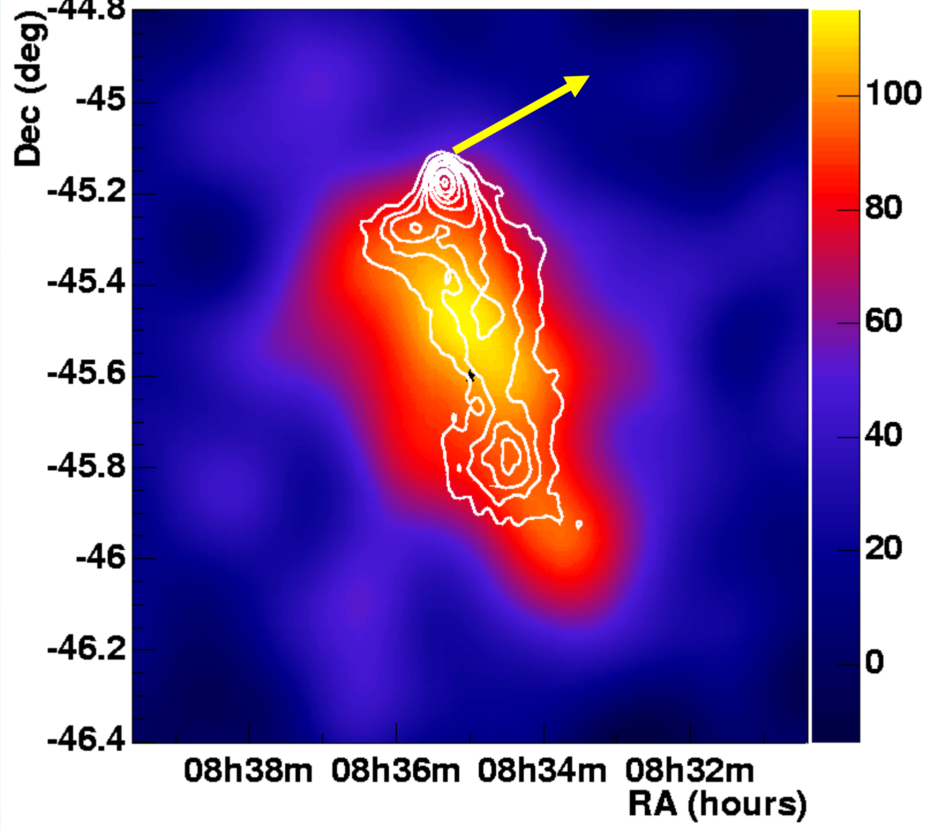


- **middle-aged:**
  - $\dot{E}_{psr} \propto e^{-t/\tau}$
  - subsonic motion
  - $n_e(r,\theta)$, $B(r,\theta)$???

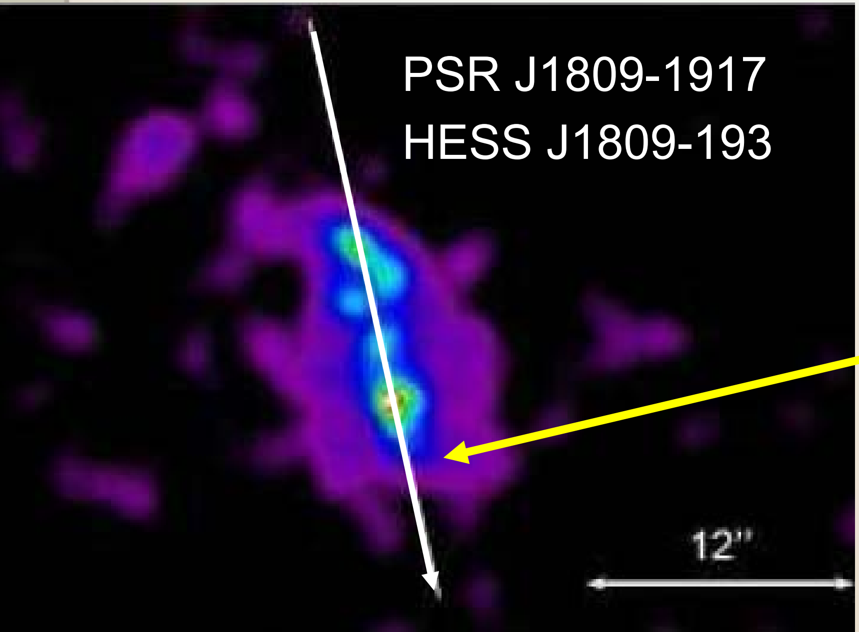
middle-aged difficulties

- crushed PWN:
- ex: Vela X
  - ~ 5 pc tail in X and γ rays
  - slightly larger γ-ray extent from ageing pairs

Aharonian et al. '06



Kargaltsev et al. '07



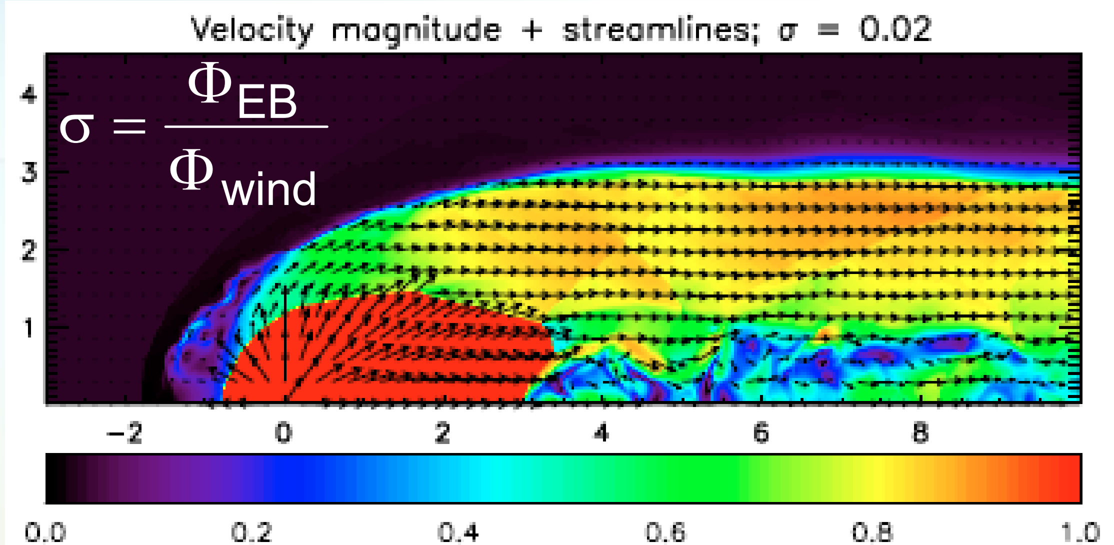
X-rays far in front of pulsar motion

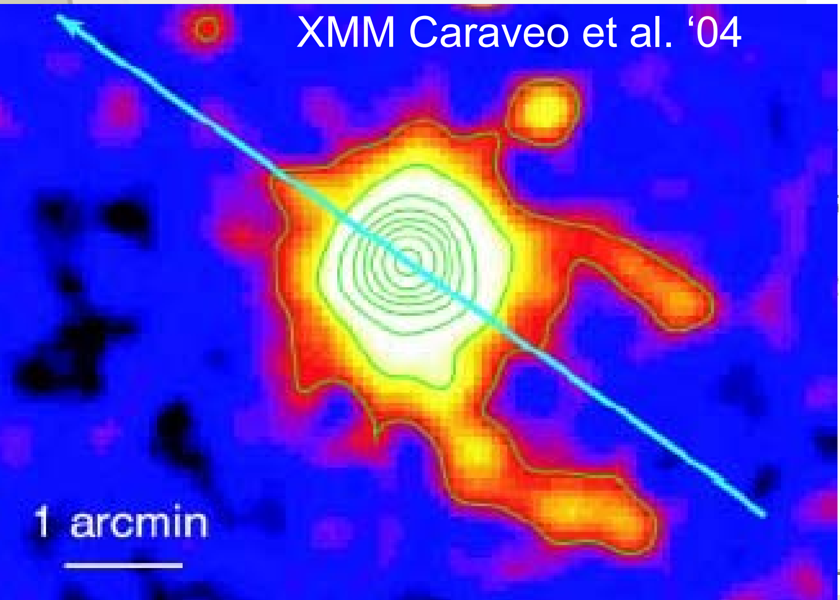
relic crushed PWN? but pulsar far from its birth place by the time it becomes supersonic

later-age difficulties

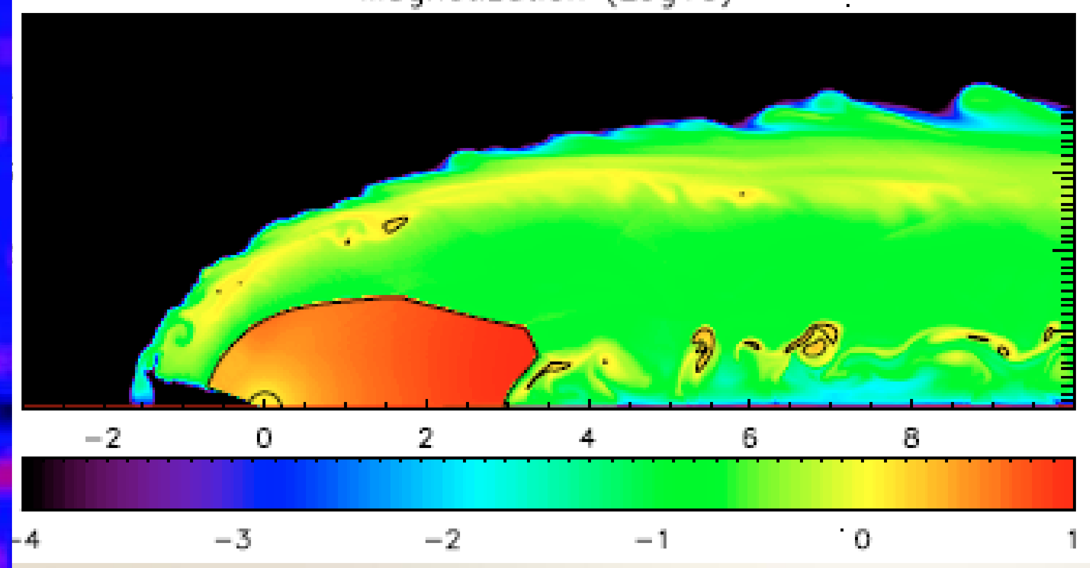
- supersonic motion by the time pulsar at 0.7 R_{SNR}, or outside SNR
  - ~ stationary bow shock
- ~ cylindrical symmetry
  - ex: Geminga
  - $E_{e\,max}$ = 200-300 TeV
  - $E_{e\,max}(R_{TS})$ = 35 TeV
  - $e\Phi_{open}$ = 400 TeV

Forot & Grenier '07





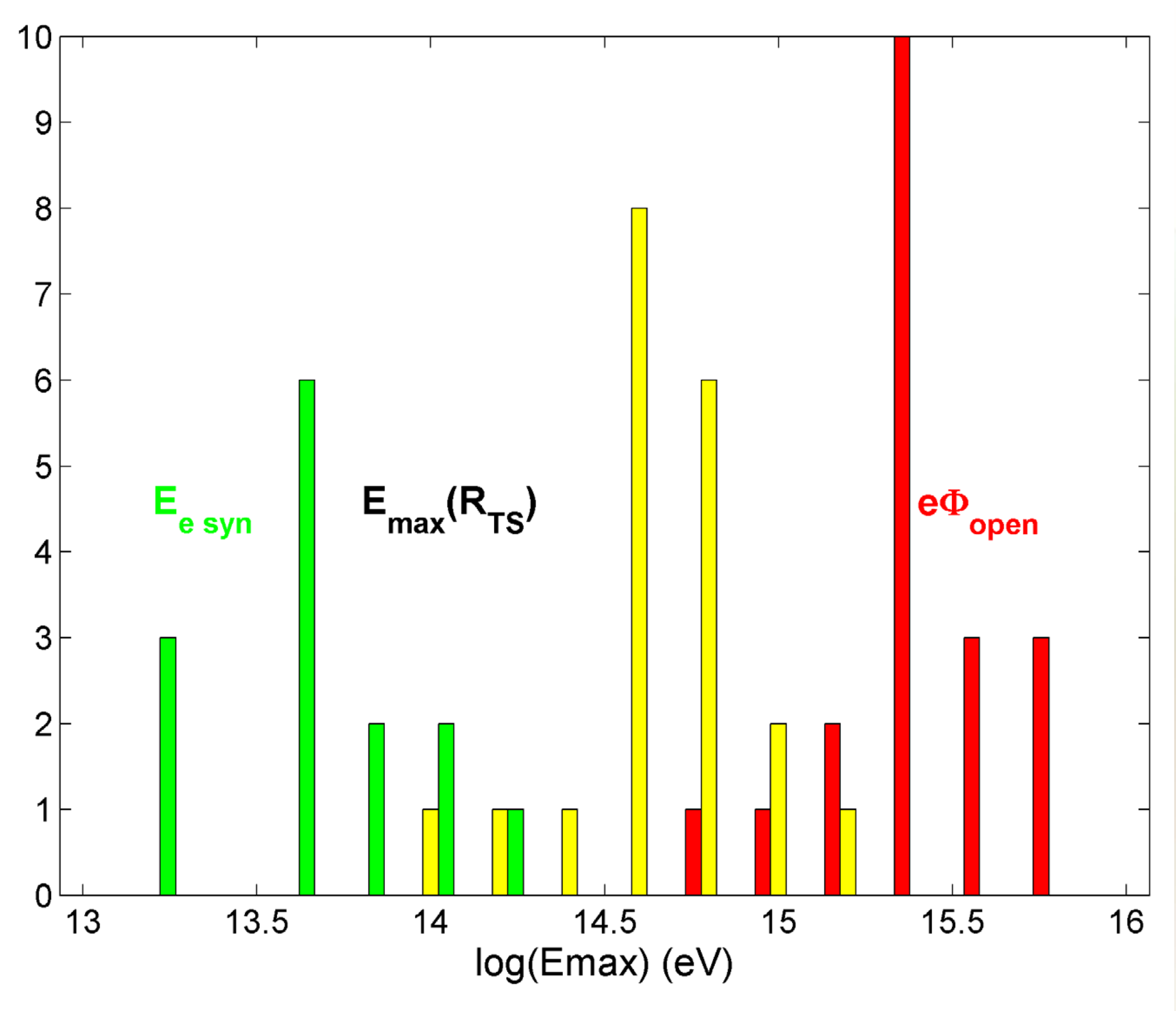
Magnetization (Log10) Bucciantini et al. '05



maximum energy

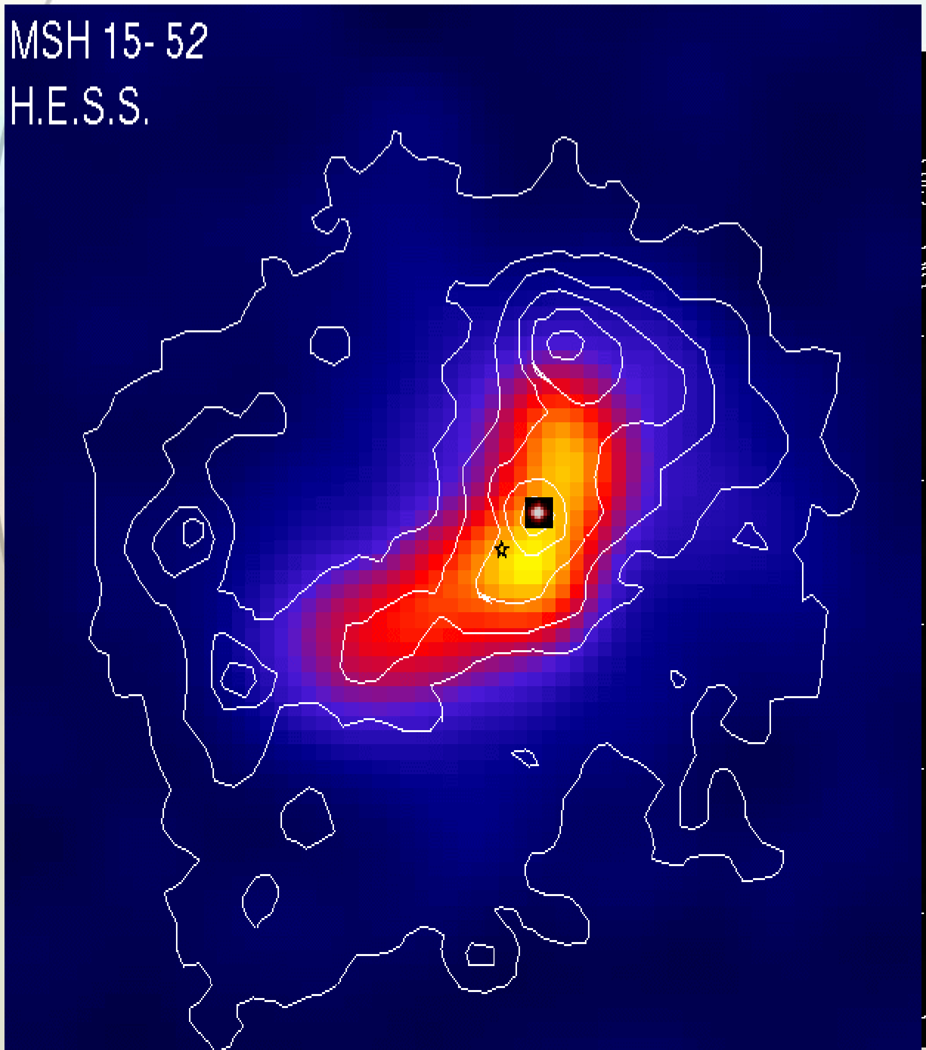
- **pair energy to explain 2 keV emission at the end of the X-ray tail**

  (equipartition B)

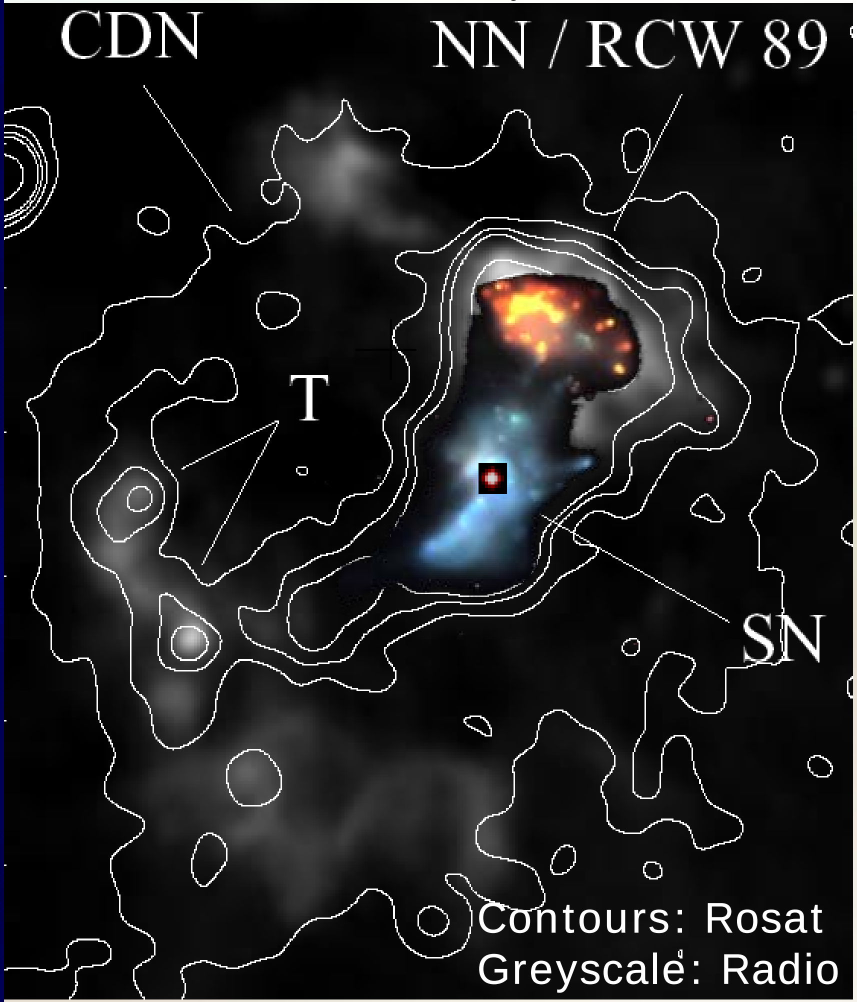


jet injection

- 1.7 kyr old pulsar at 5.2 ± 1.4 kpc, $\dot{E}_{psr}$ = 1.8 10^{30} W
- X-ray jets (12 pc, 0.5 c, long-term variability), variable knots (0.6c)
- 2 TeV arms ± 25 pc long, radiatively more efficient than the Crab

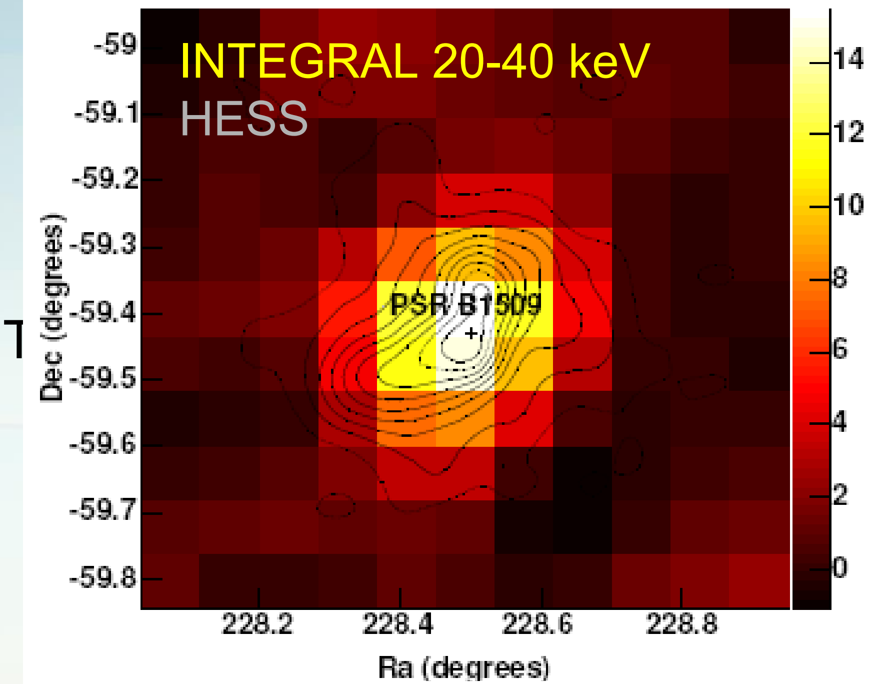


DeLaney ’06   Aharonian ‘05

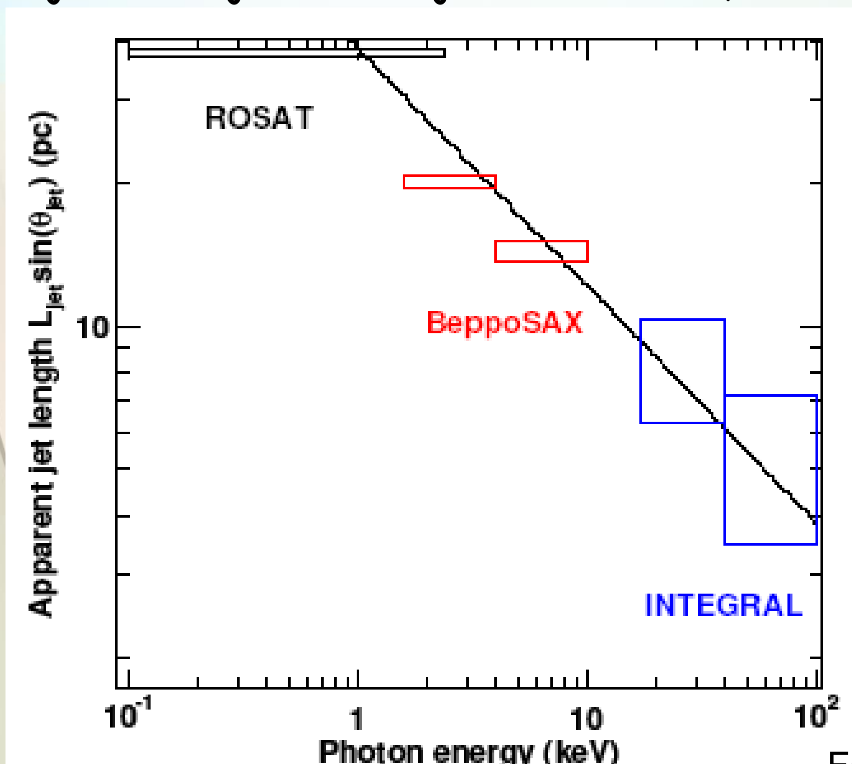


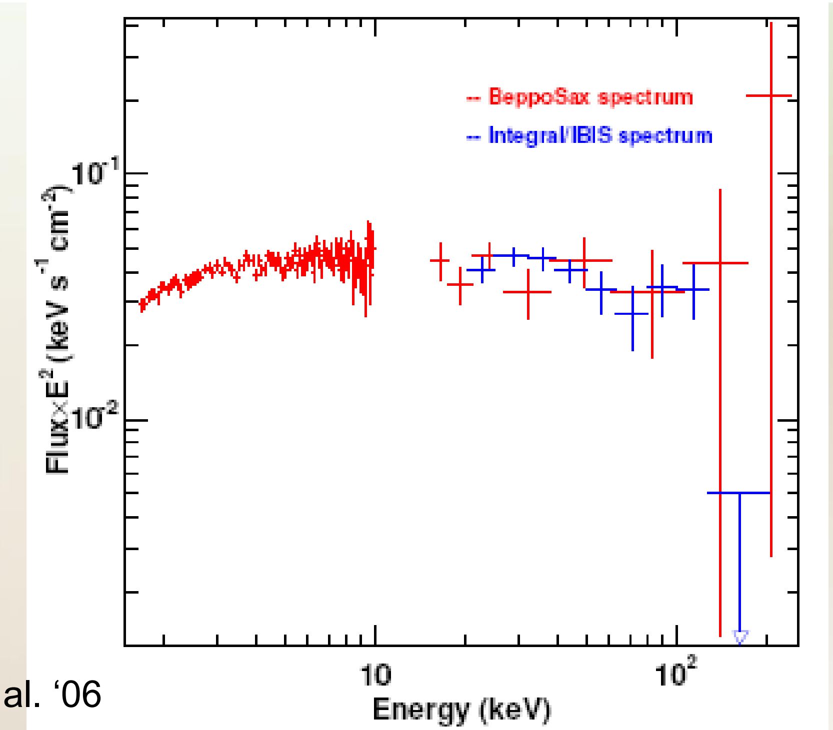
jet injection

- synchrotron up to > 160 keV
- pipe with uniform v and B
  - $0.3 < \beta_{jet} < 0.5 \Rightarrow 2.2 < B_{jet} < 3.3$ nT
  - $\Rightarrow E_{emax} > 400$ or 730 TeV



$$L_{jet} \propto \beta_{jet} \sin(\theta_{jet}) B^{-3/2} E_{\gamma}^{-1/2}$$



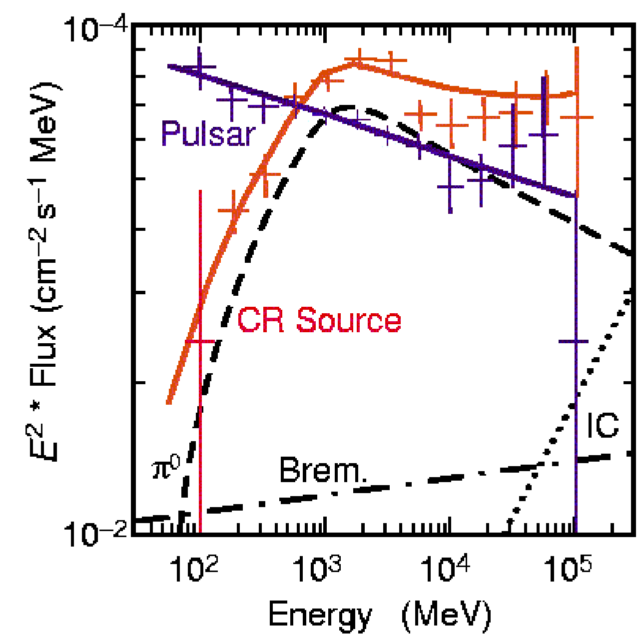


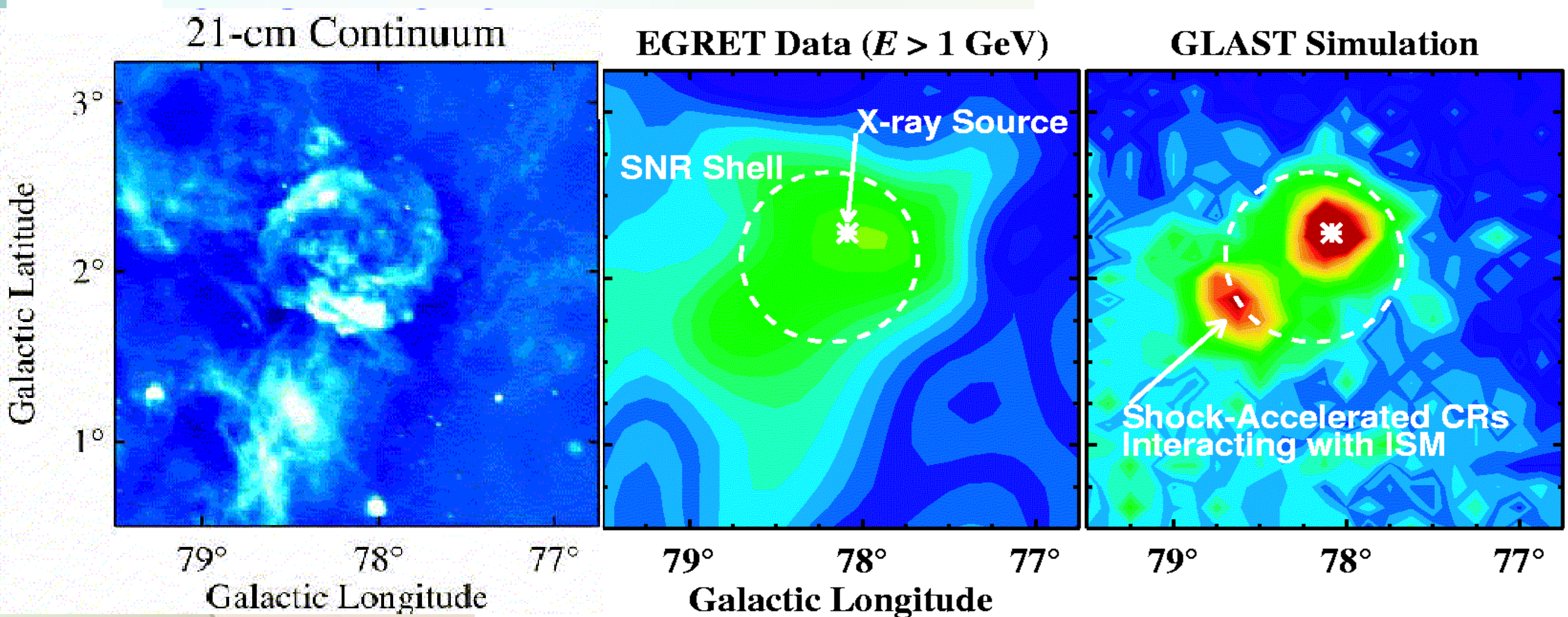
Forot et al. '06

supernova remnants

composite SNRs

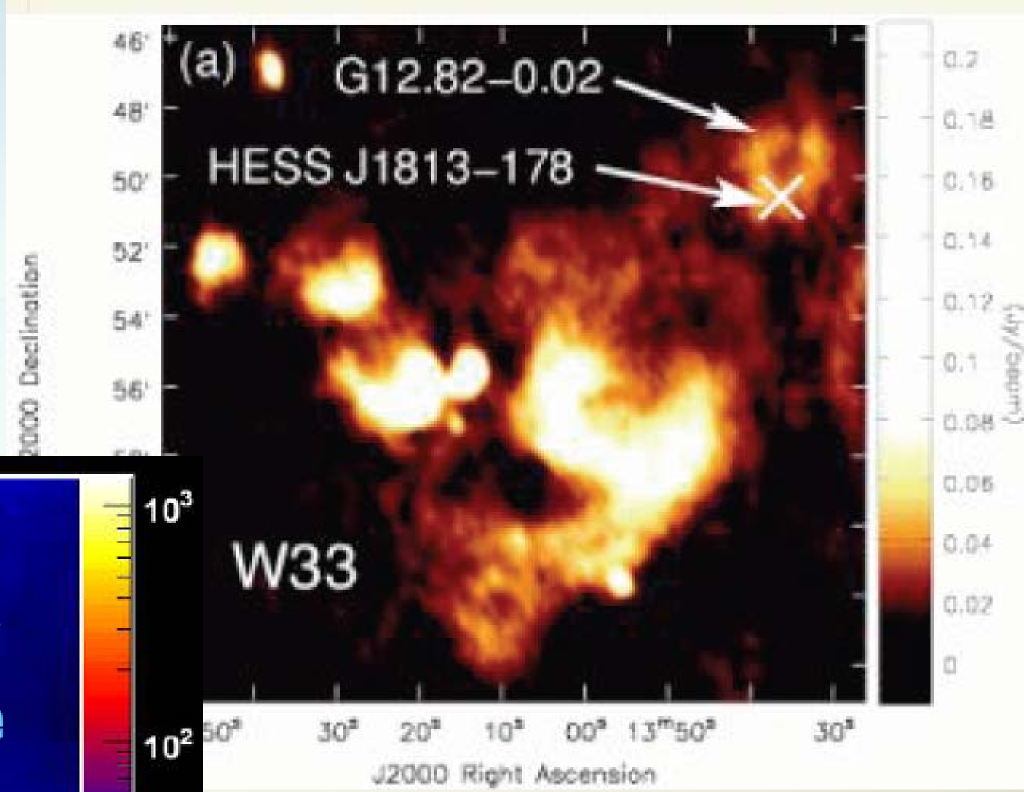
- **difficulty to resolve spatially and spectrally**
  - SNR
  - wind nebula
  - pulsar
- **ex: γ Cygni**

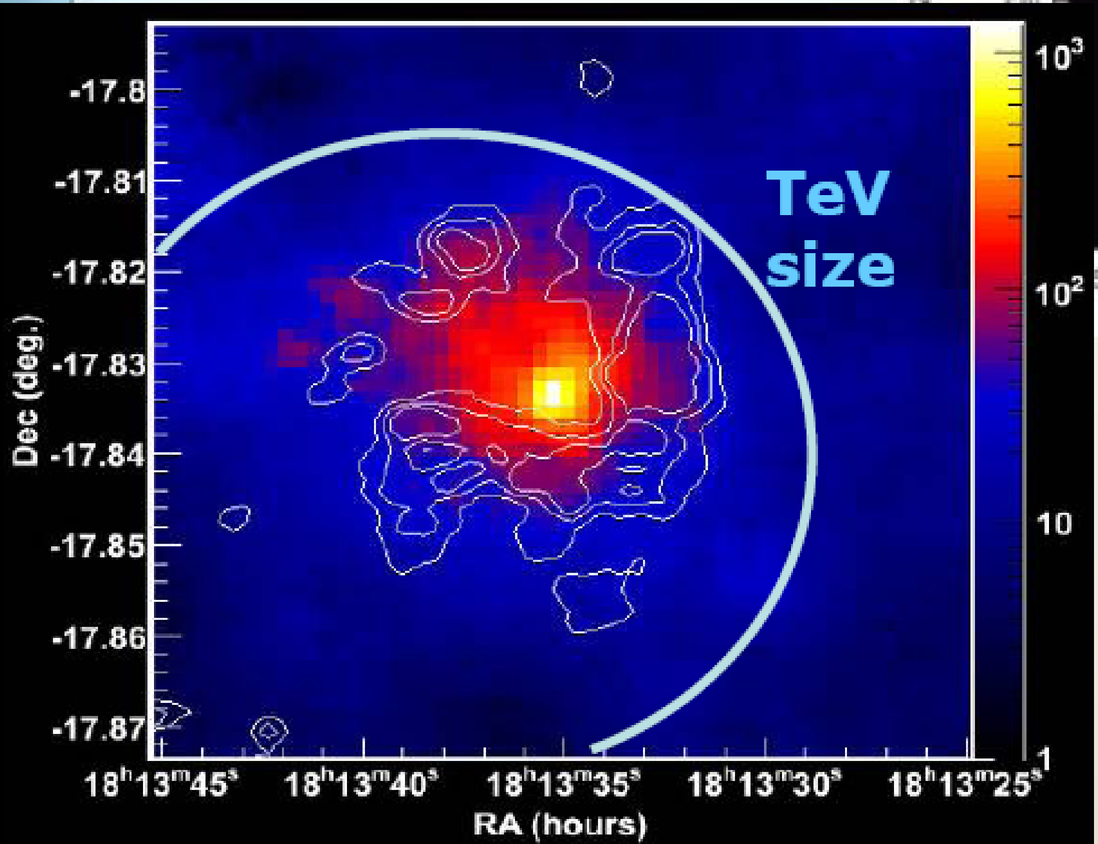




composite SNR

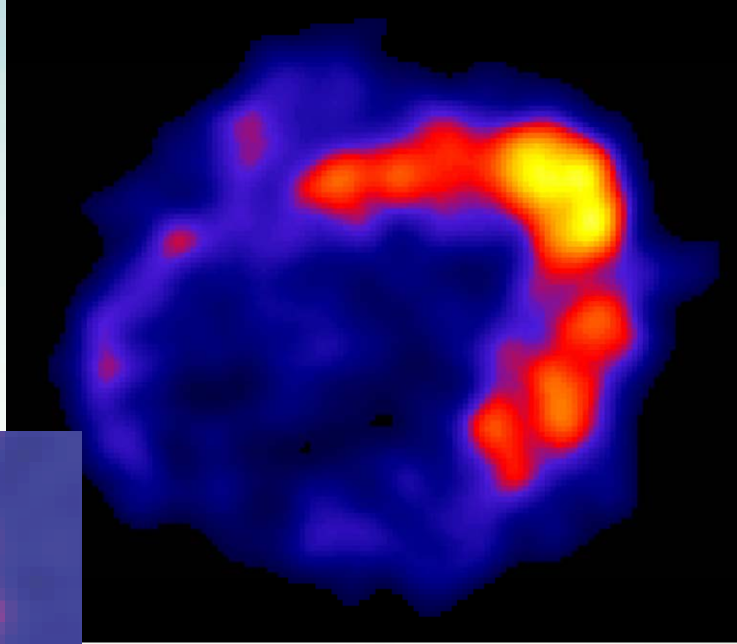
- ex: HESS J1813-178



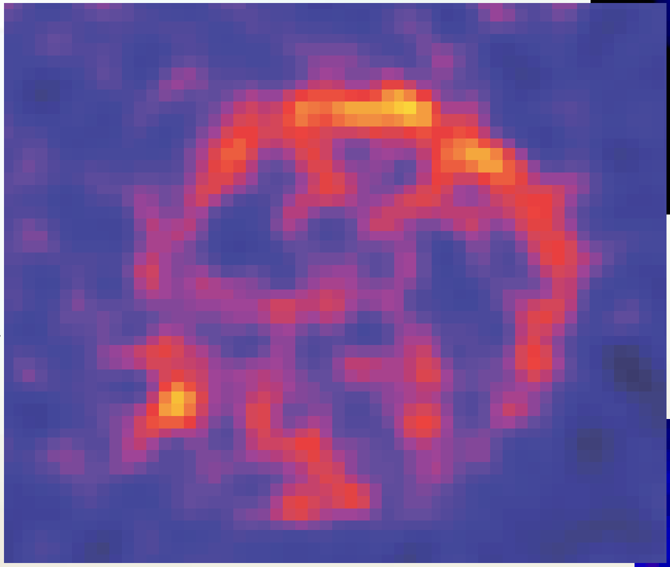


TeV SNRs

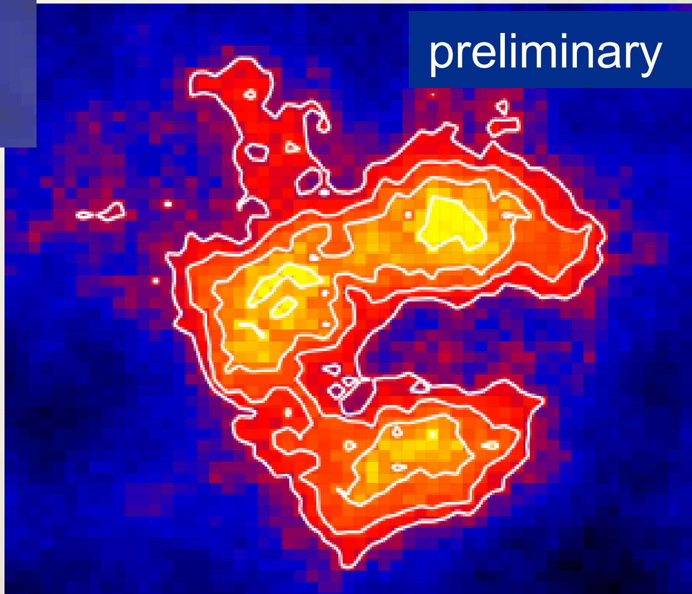
- G347.3-0.5
  - 10 pc radius
  - early Sedov stage in wind bubble
  - SN393?
  - western cloud



- Vela Jr
  - 15 pc at 1 kpc



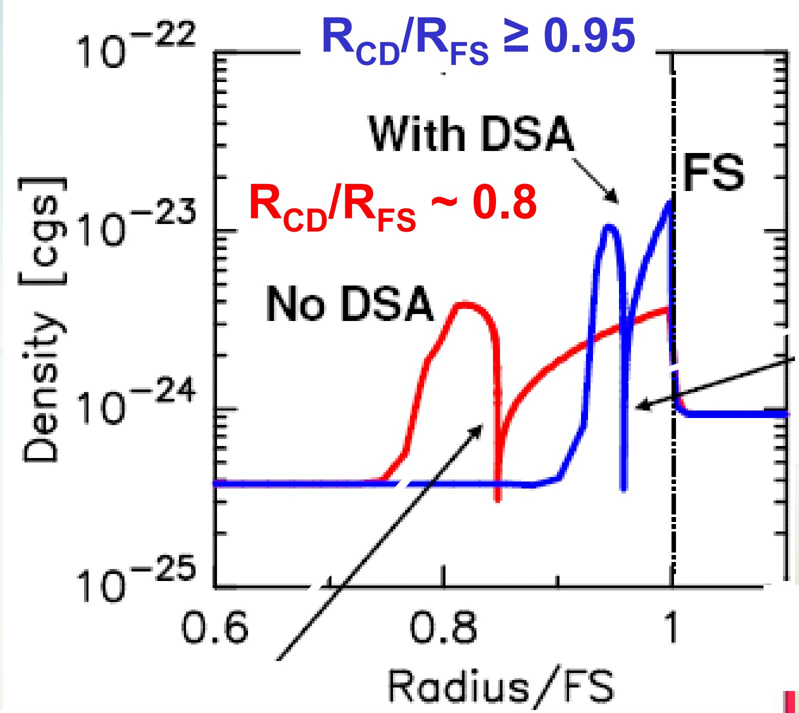
- RCW 86
  - 15 pc radius
  - 2 kyr (1 kpc) to 10 kyr (2.58 kpc) old
  - SN 185 ?
  - south-western cloud



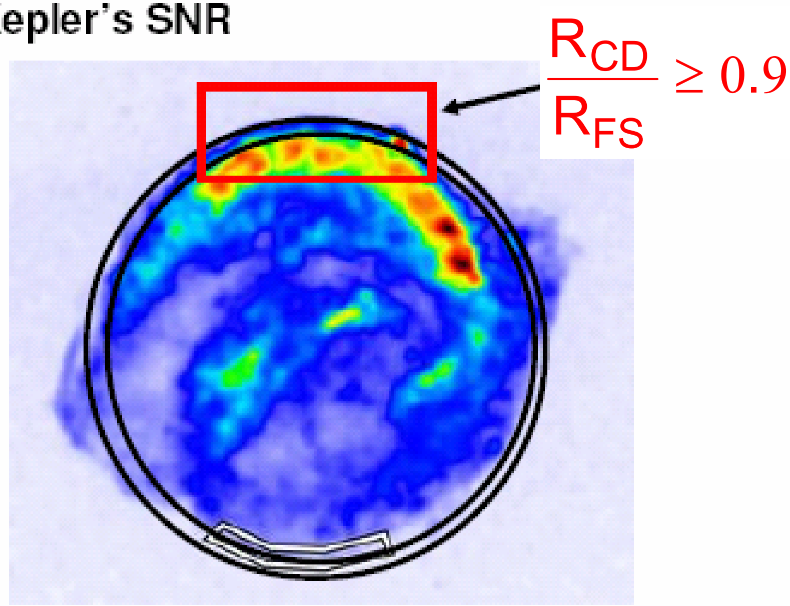
modified shocks

Ellison, Decourchelle, Ballet ‘04

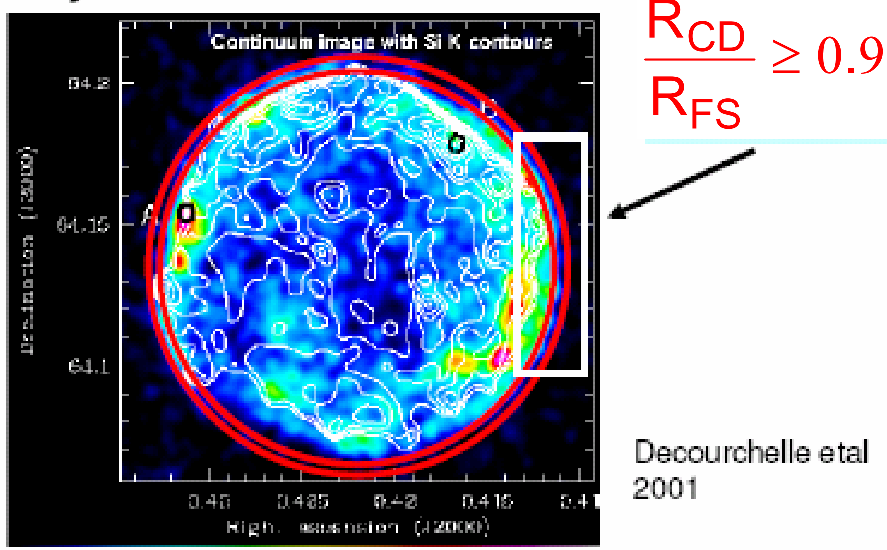
- required to reach E_p >> 100 TeV
- supported by observations
- ex: B amplification
  - few < B_{down} < 50 nT measured from sharp FS synchrotron profile
- ex: increased gas compressibility
  - CD closer to FS



Kepler's SNR



Tycho's SNR

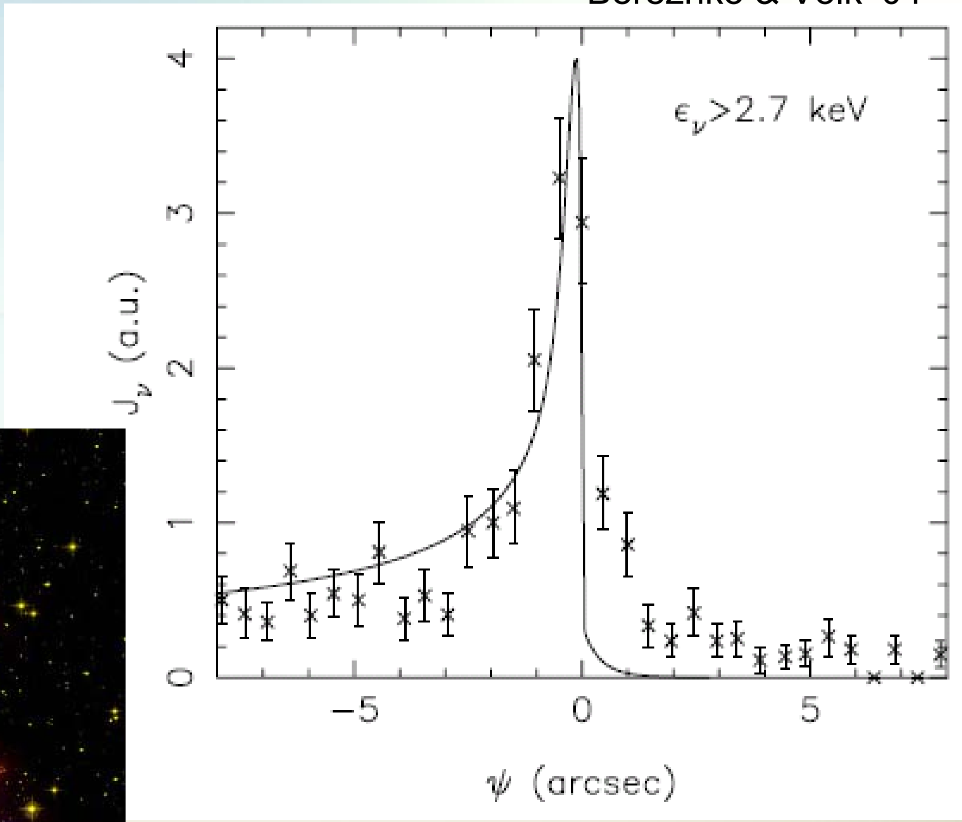


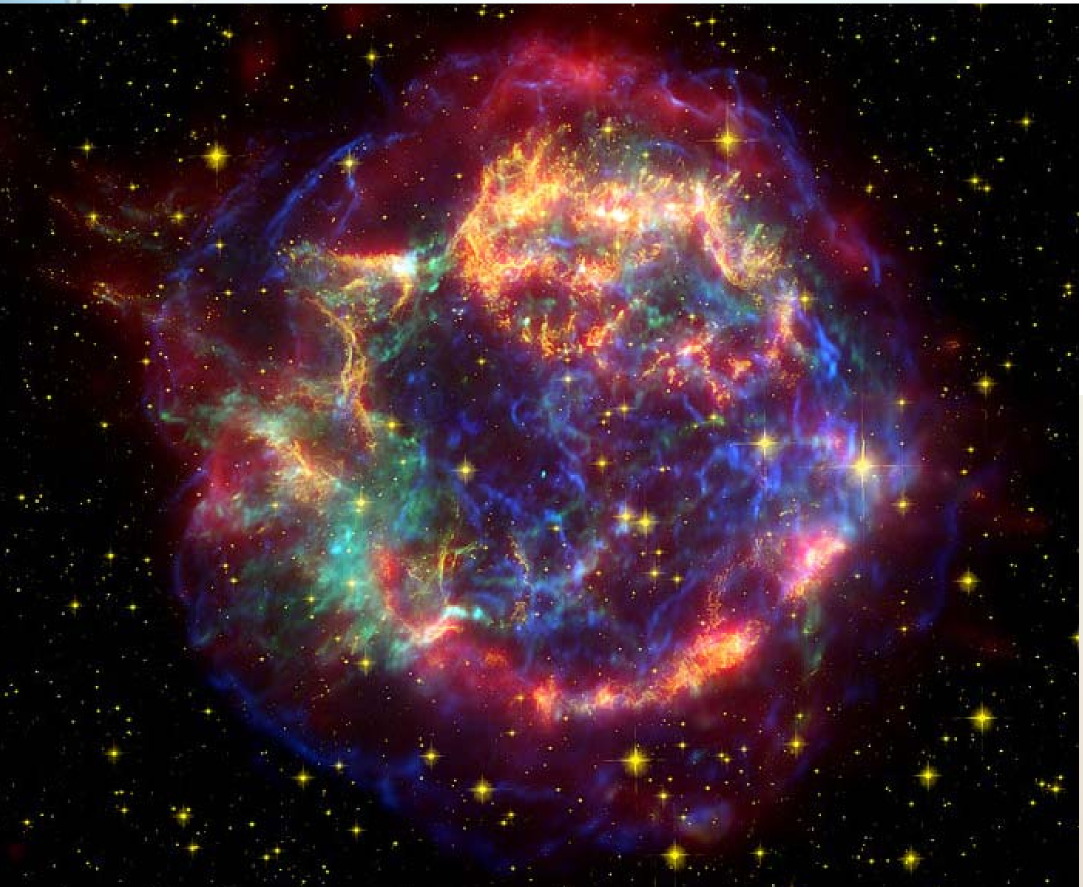
Decourchelle etal 2001

Cas A problem

- $B \sim 50$ nT $\gg r_{compression} \times B_{ISM}$
- but large R_{TS}/R_{CD}

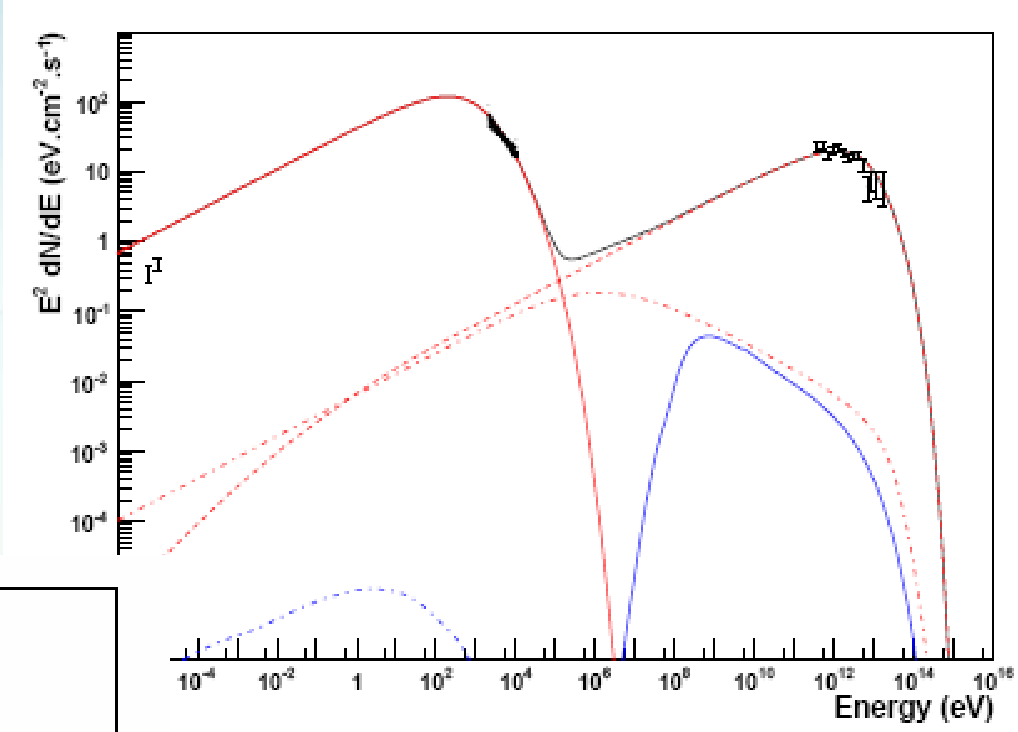
Berezhko & Völk '04



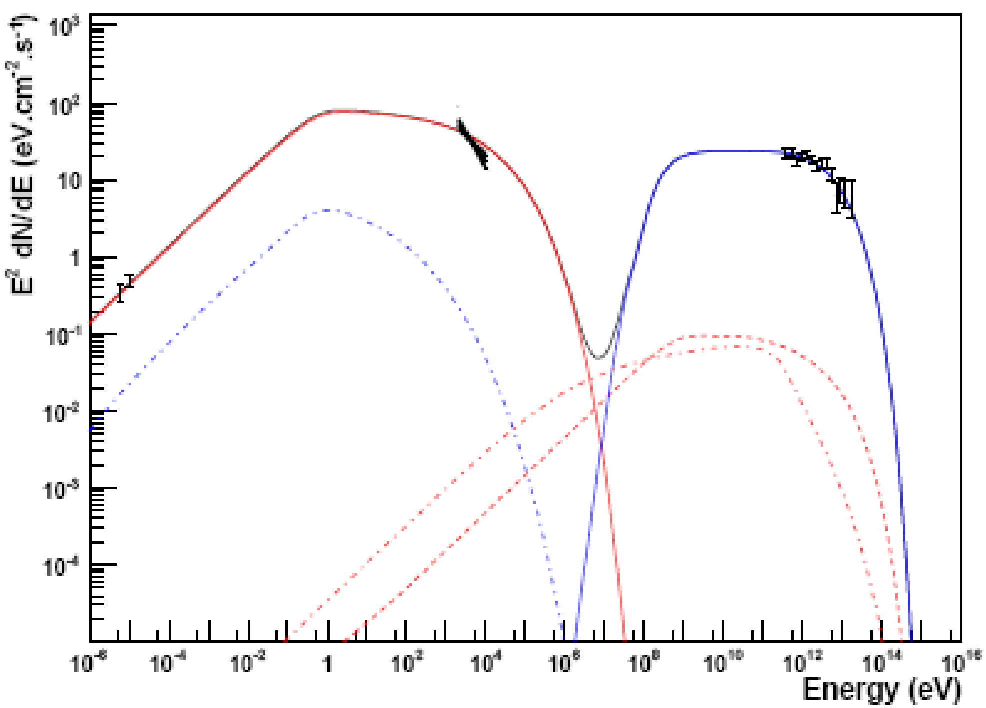


radiation ambiguity

- ex: Vela junior
  - electron IC emission



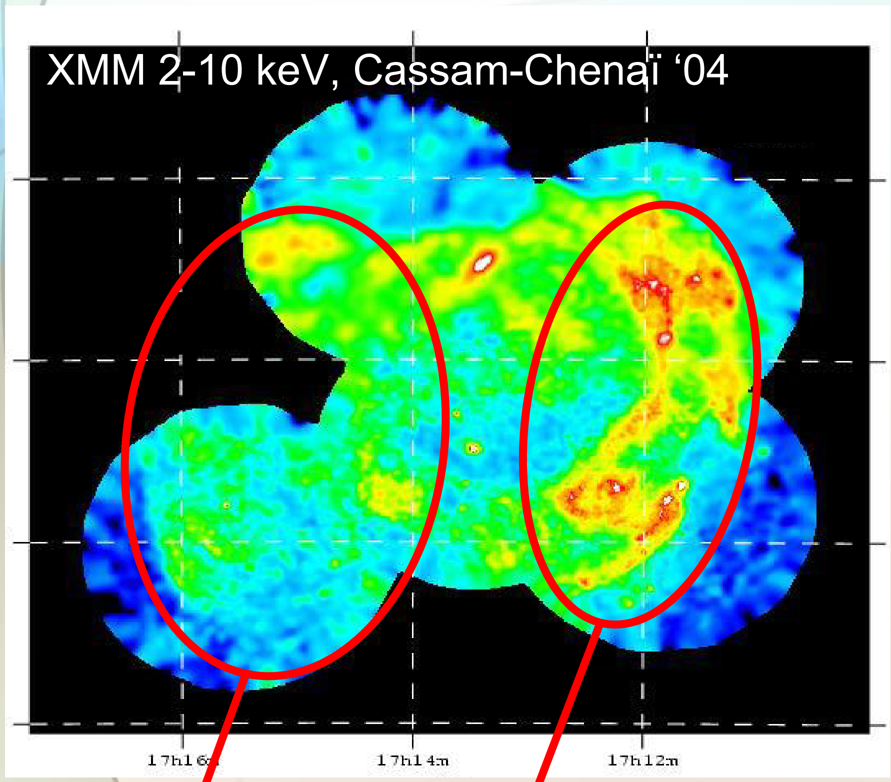
  - proton π^0 emission

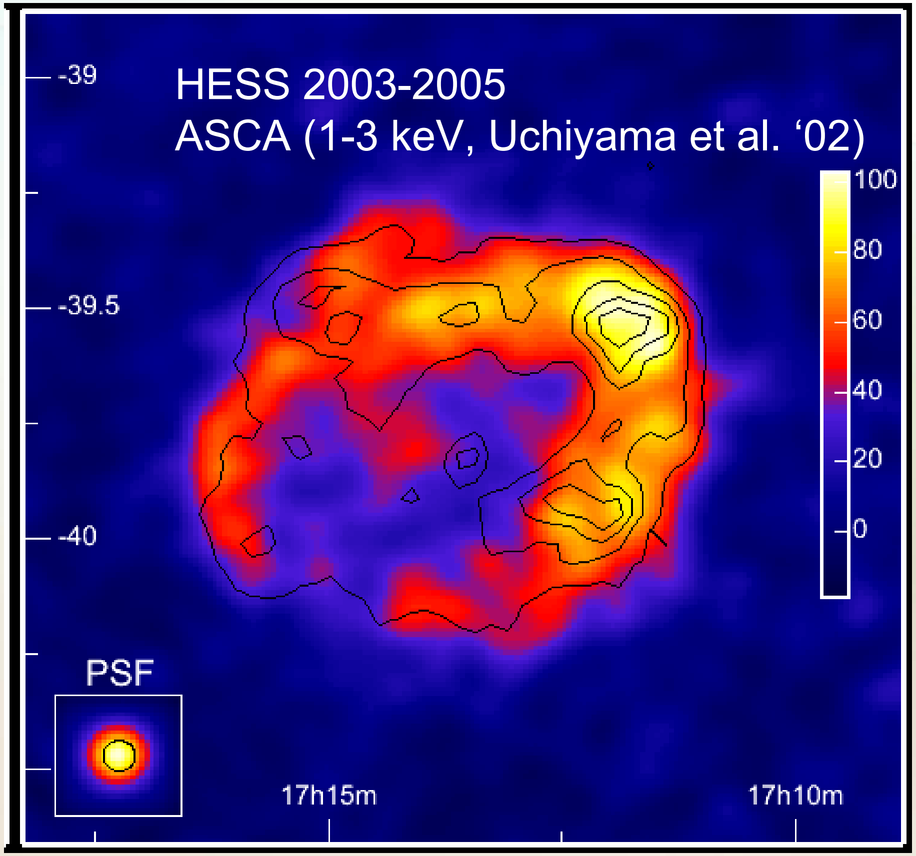


Aharonian et al. ‘07

IC problems

- **best IC emission fit => B_{G347} ~ 0.9 nT, B_{Vela} ~ 0.6 nT, B_{RCW} ~ 2.2 nT**
  - no or modest amplification
  - yet electrons acceleration to 60 – 150 TeV (also protons)
- **tight X-TeV flux correlation, but**



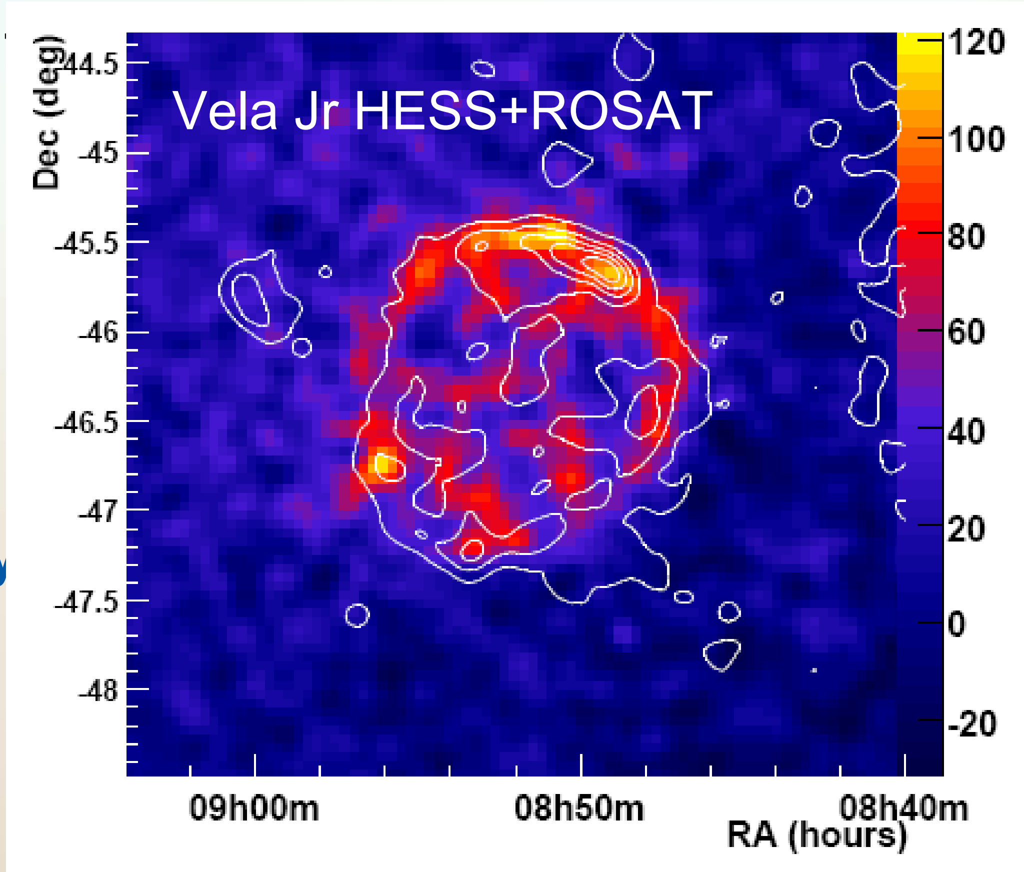


faint $E_x^{-2.0}$ synchrotron, low n_{ISM}
bright $E_x^{-2.5}$ synchrotron, large n_{ISM}

uniform $E_\gamma^{-2.04\pm0.04}$
E_{eX} ~ 200 TeV, E_{eIC} ~ 100 TeV

π^0 problems

- tight TeV-keV flux correlation in G347.3-0.5 and Vela Jr
- large densities needed to match the γ-ray flux
  - $n_{G347} \sim 1.5$ cm^{-3}, $n_{Vela} \sim 2.0$ cm^{-3}, $n_{RCW} \sim 1$ cm^{-3}
- yet lack of thermal X-rays $\Rightarrow$
  - $n_{G347} < 0.02$ cm^{-3} (without) or 0.1 cm^{-3} (with feedback)
  - $n_{Vela} < 0.03$ cm^{-3} (without) …
- low e/p ratios needed
- so, detailed modelling of the thermal X-ray contribution is crucial to constrain density

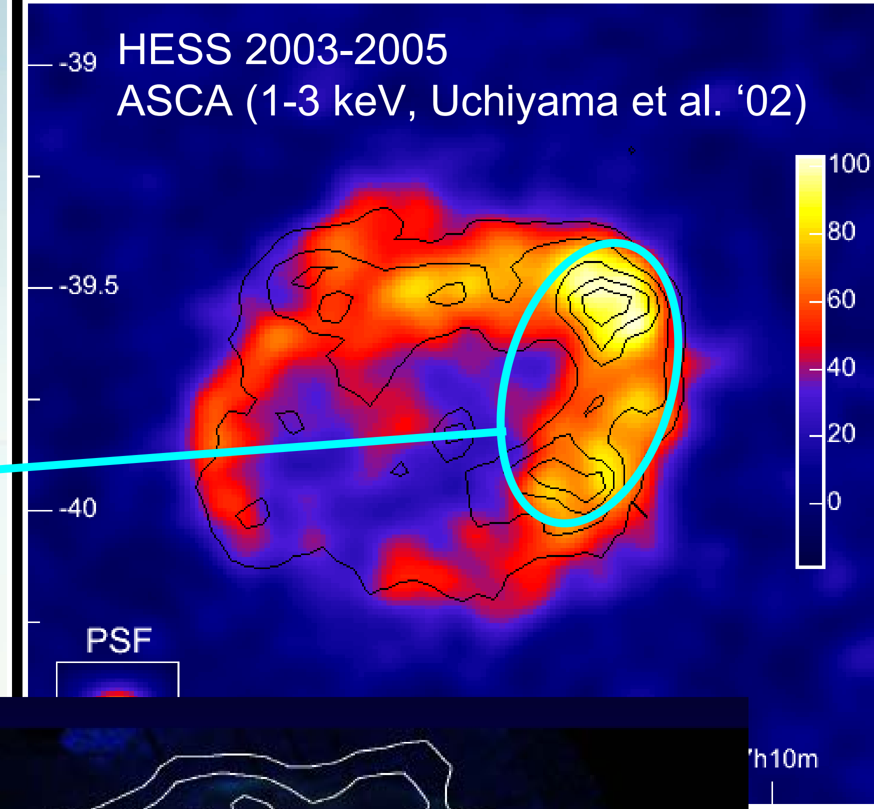


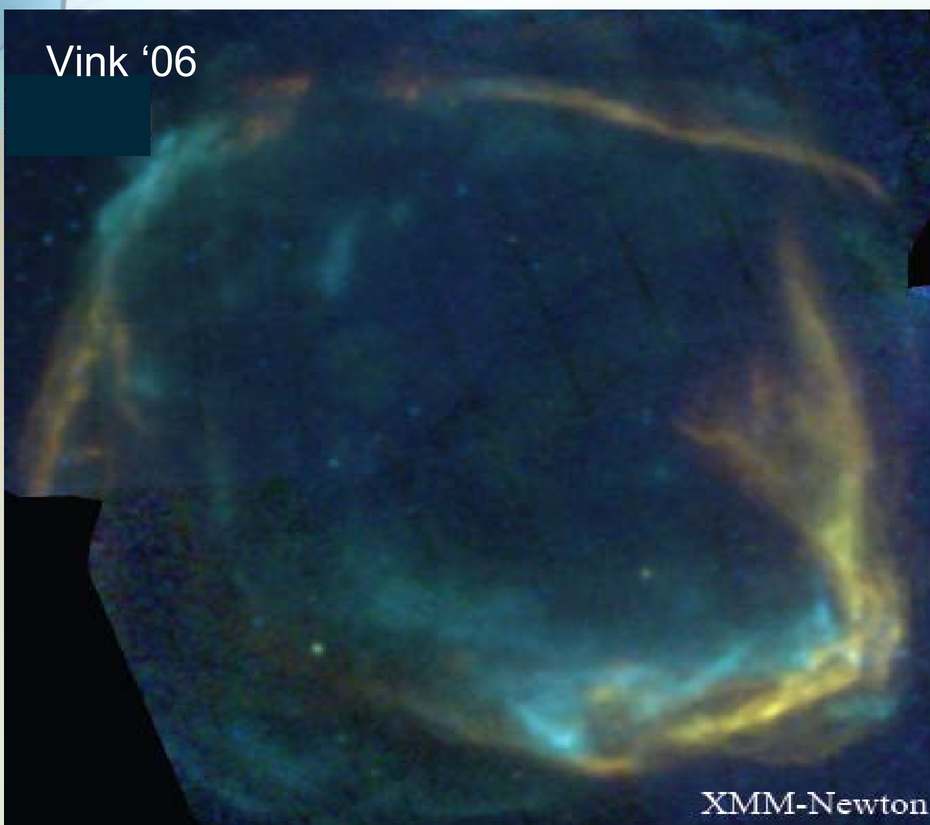
π^0 problems

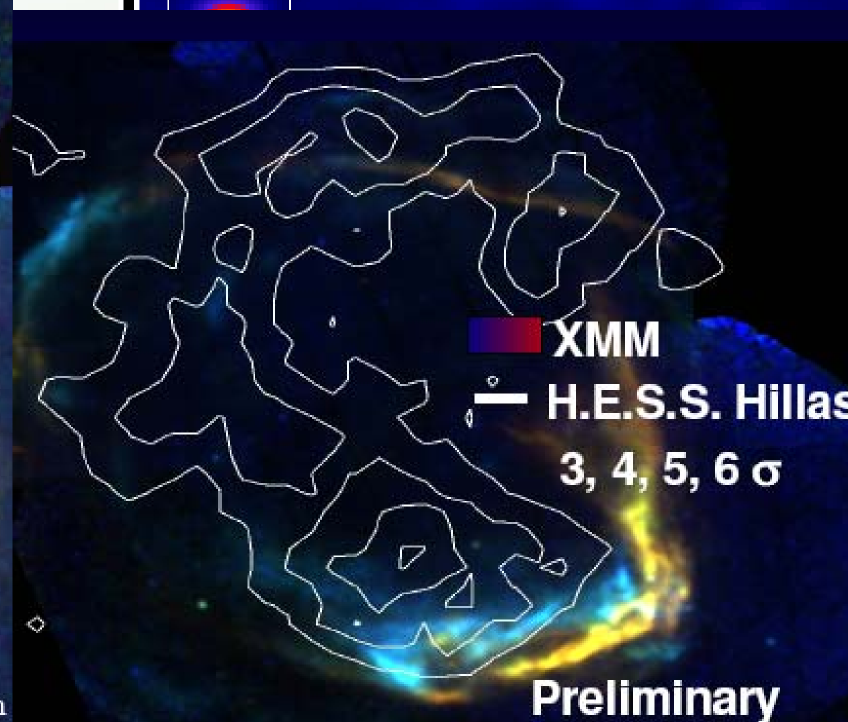
- **no γ-ray enhancement where highest target column-density**
  - test of shock efficiency $\propto v_s^2$

$$n_e \propto N_H$$

$$n_p \propto n_e \quad n_{target} \propto N_H$$

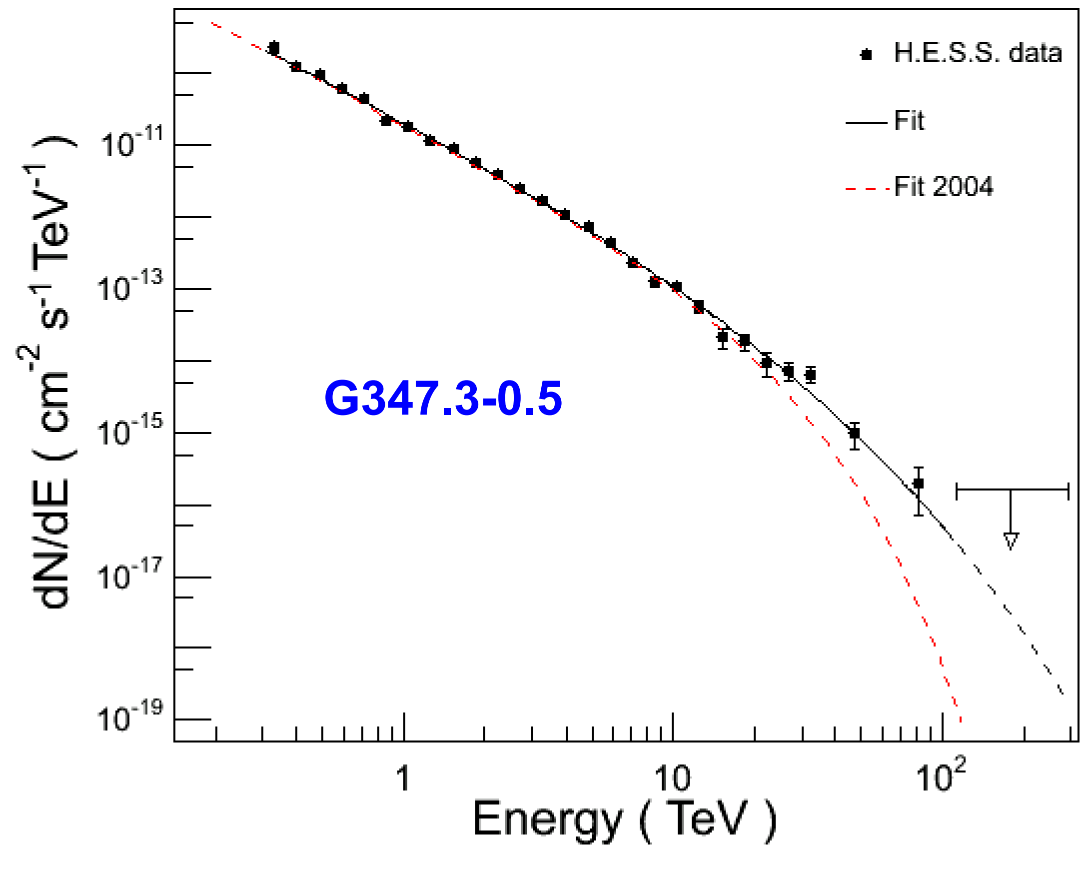






π^0 problems

- **low-energy slope ok with predicted proton spectrum**
  - -2.04±0.04 for G347.3-0.5
  - -2.24±0.05 for Vela Jr
  - < 2.5 for RCW 86
- **but dangerous TeV breaks wrt. $E_{p\ max}$ ~ 10^{15} eV from modified shock ?**
  - E_c(G347) ~ 18 TeV
    => E_p ~ 120 TeV
  - E_c(Vela) ~ 10 TeV
    => E_p ~ 70 TeV
  - RCW 86 like Vela Jr
- **so spectral maps and cut-off energies at E_γ > 10 TeV crucial**



γ-ray binaries

massive γ-ray binaries

- **jet**
  - $e_{jet} + UV_* \rightarrow \gamma$
  - $p_{jet} + p_{vent\,*} \rightarrow \pi^0 \rightarrow 2\gamma$

wind (cf. PSR B1259-63)

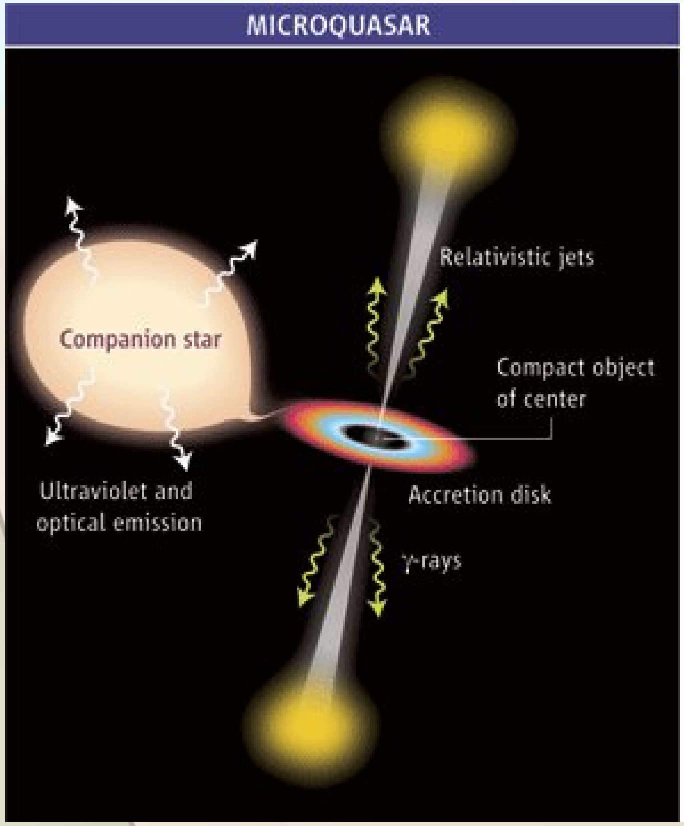
$e_{vent\ pulsar} + UV_* \rightarrow \gamma$

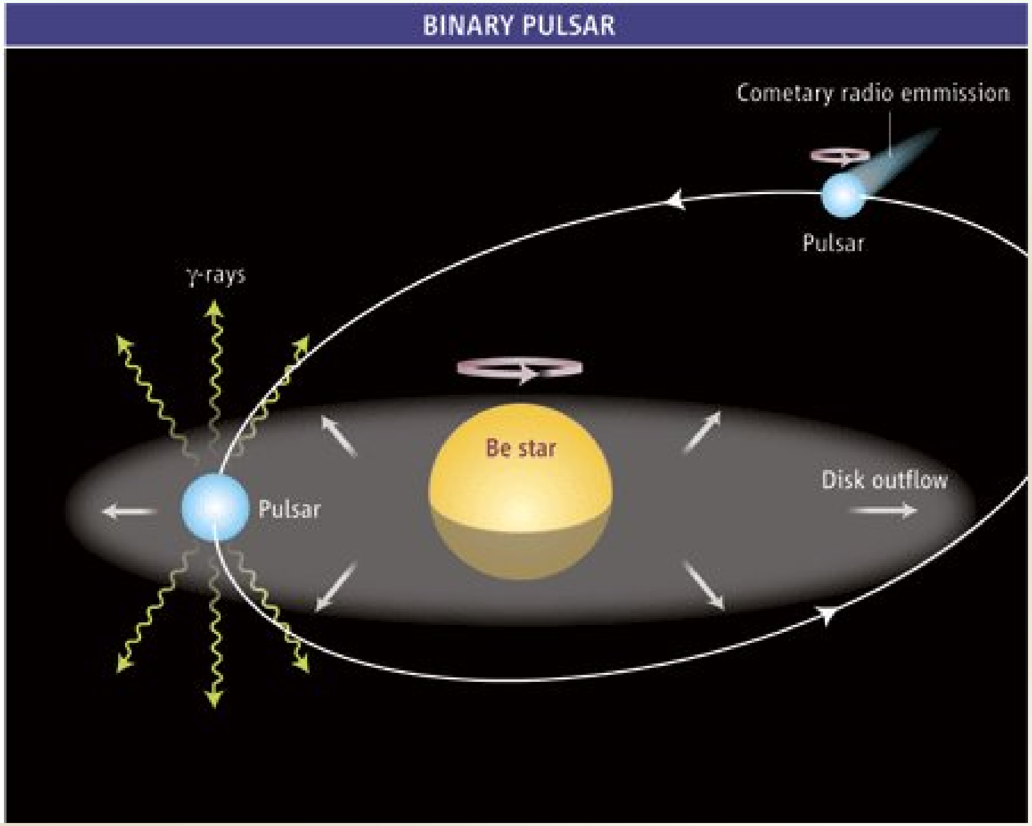
$p_{vent} + p_{vent\,*} \rightarrow \pi^0 \rightarrow 2\gamma$

- **when closer to star on eccentric orbit**
  - accretion rate ↑

wind more compressed

$\gamma + \gamma_* \rightarrow e^{\pm}$



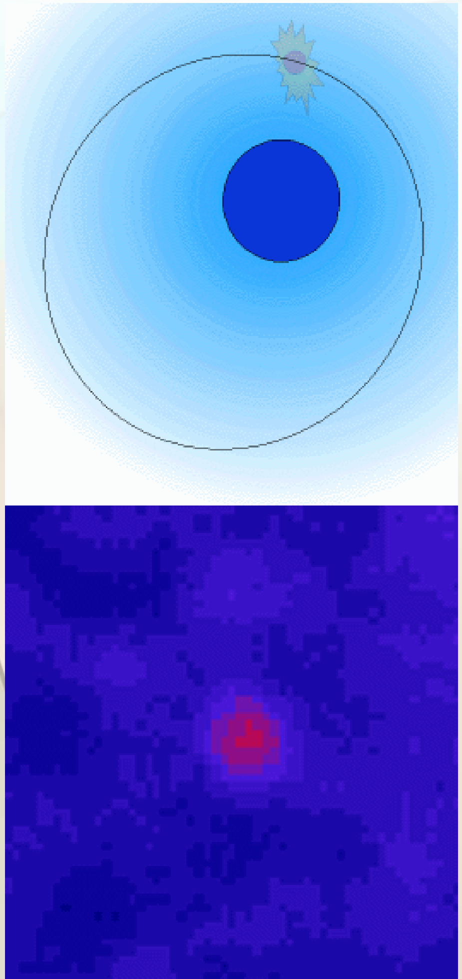


3 eccentric binaries

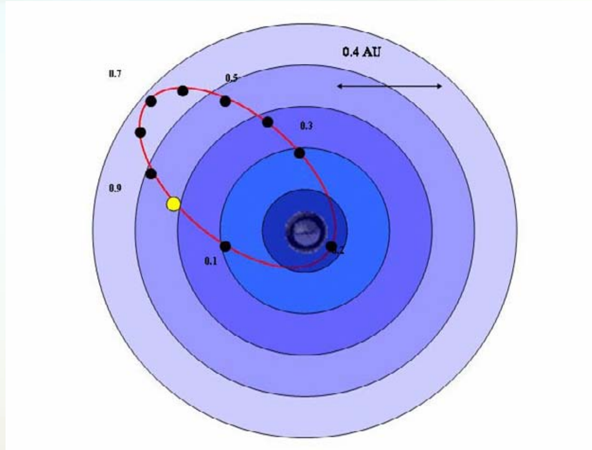
- $M_{BH} < 4\ M_\odot$ or NS
- age < 2-3 Myr

LS 5039 (HESS) LSI +61°303 (MAGIC)

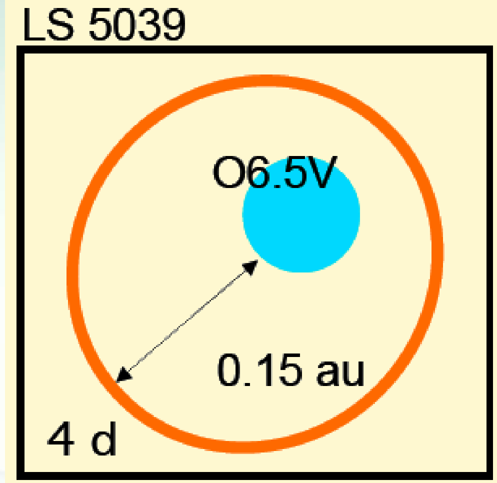
spectral brightening with flux

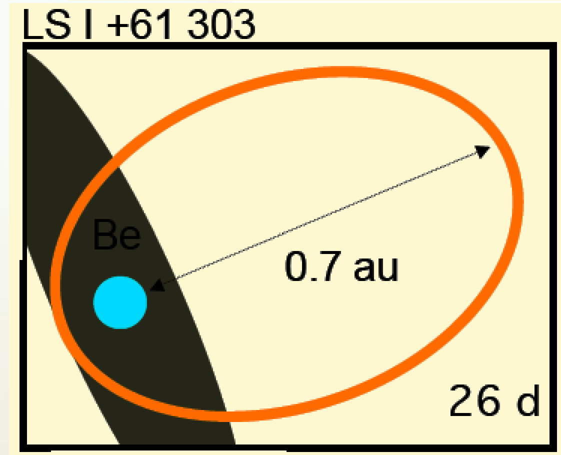


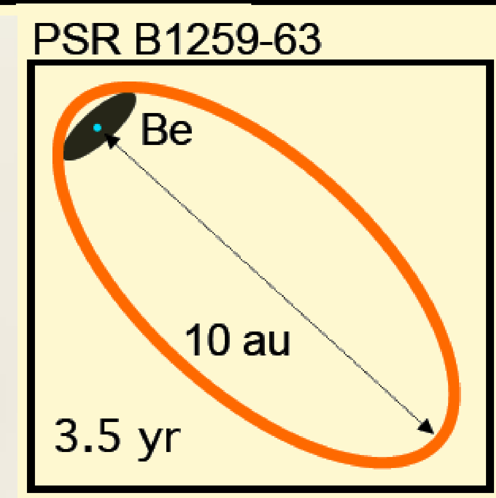
Aharonian et al. '05



Albert et al. '06

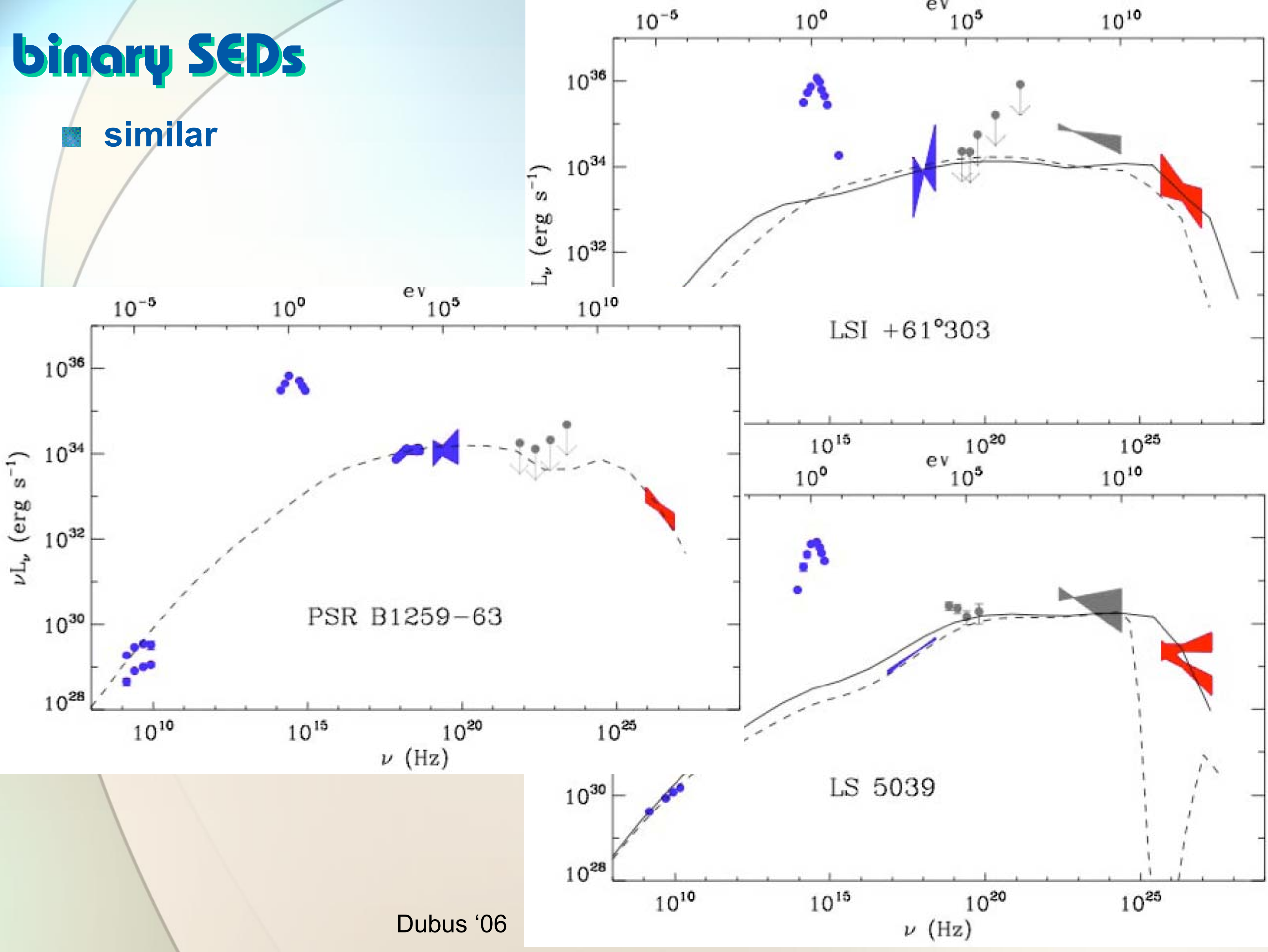






binary SEDs

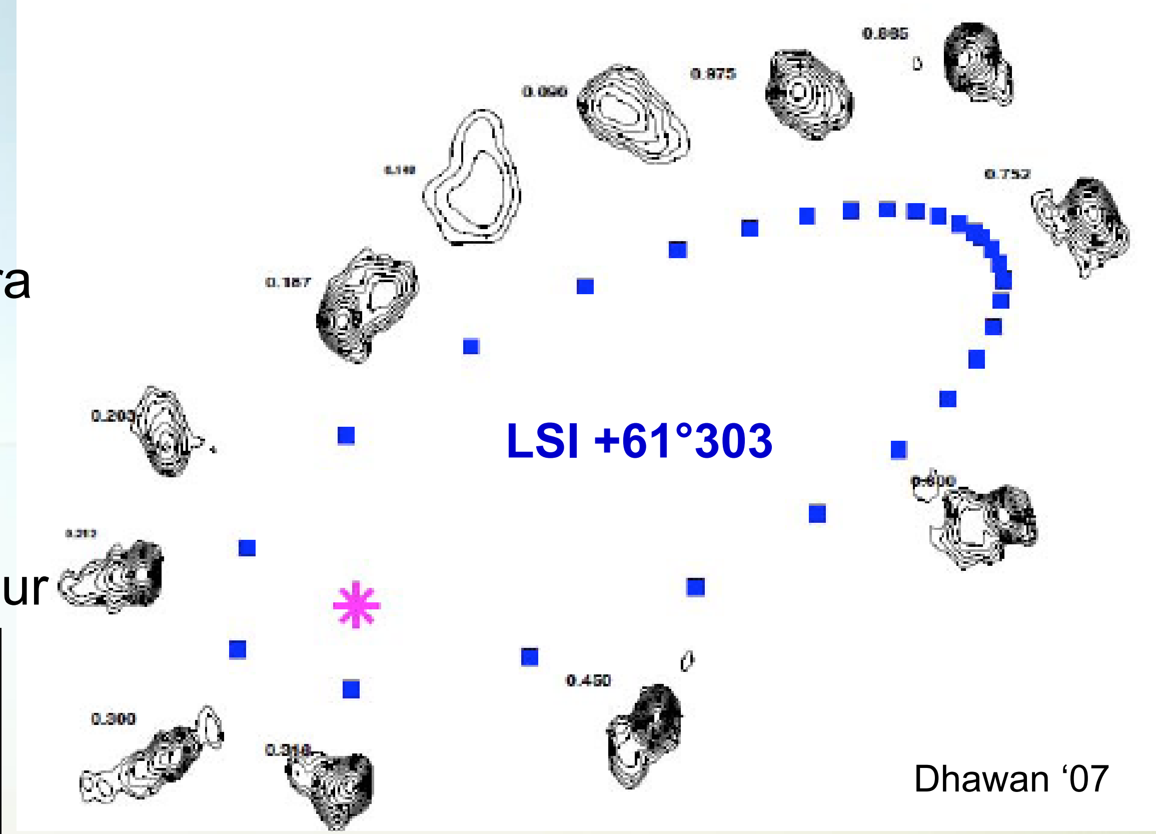
- similar

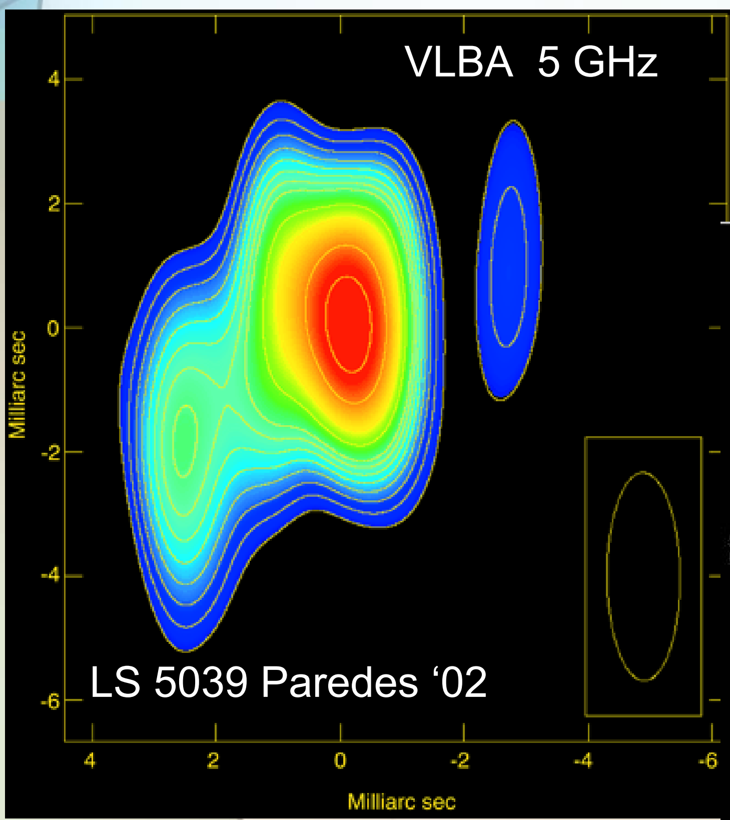


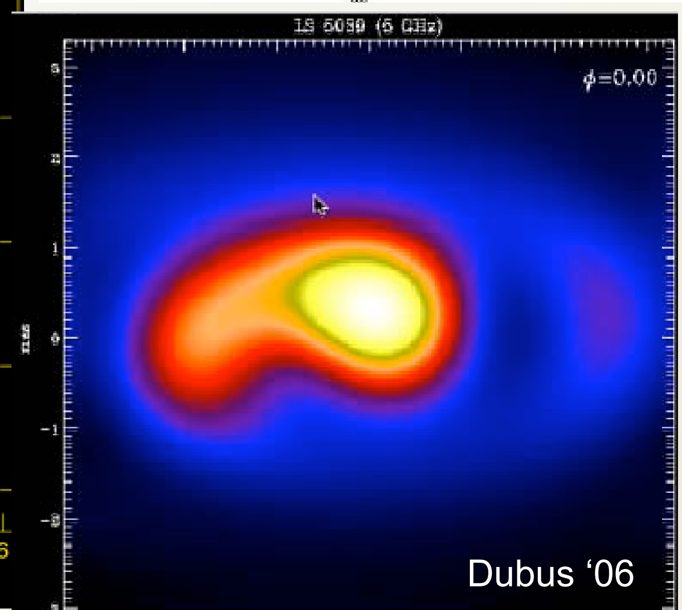
Dubus '06

jet or wind?

- **LSI +61°303 = PWN**
  - unresolved by Chandra
  - pwn like in VLBA
- **LS 5039**
  - jet-like in radio
  - µqso spectral behaviour



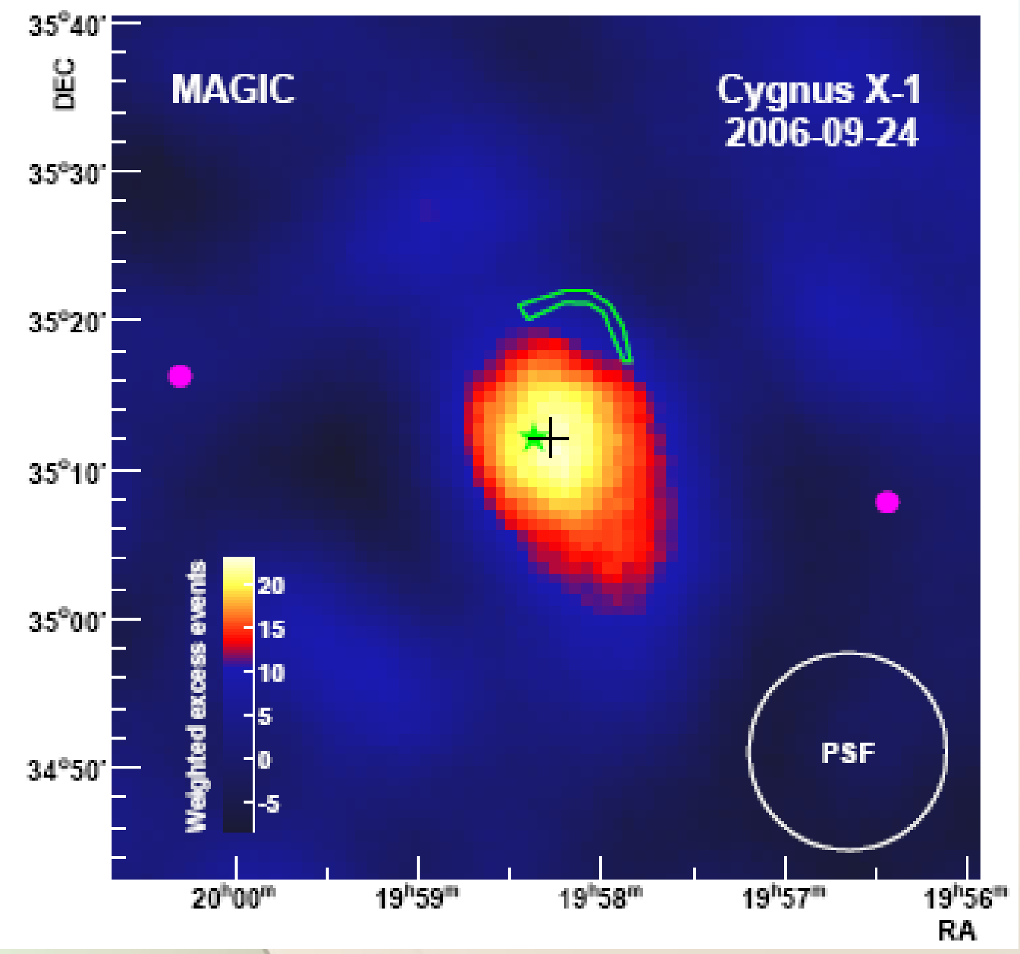




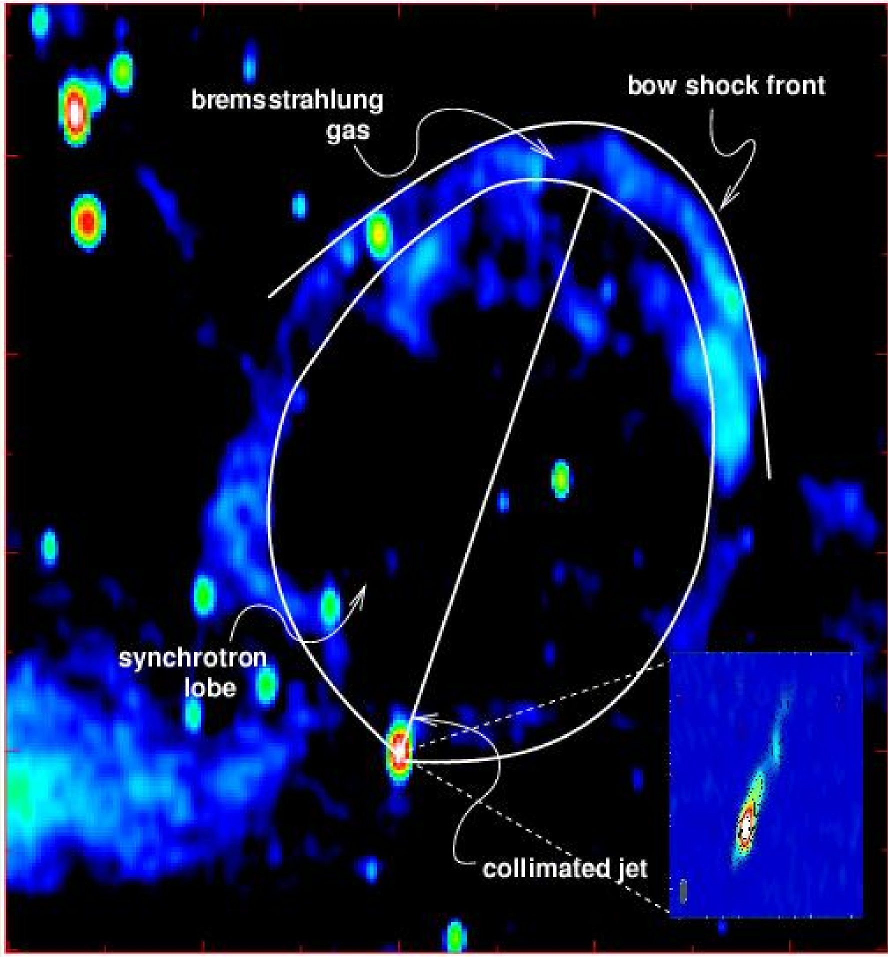
a γ-ray black hole !

- Cyg X-1
  - 5 pc bow shock, 50 % unseen energy

Albert et al. '07



Gallo et al. '05



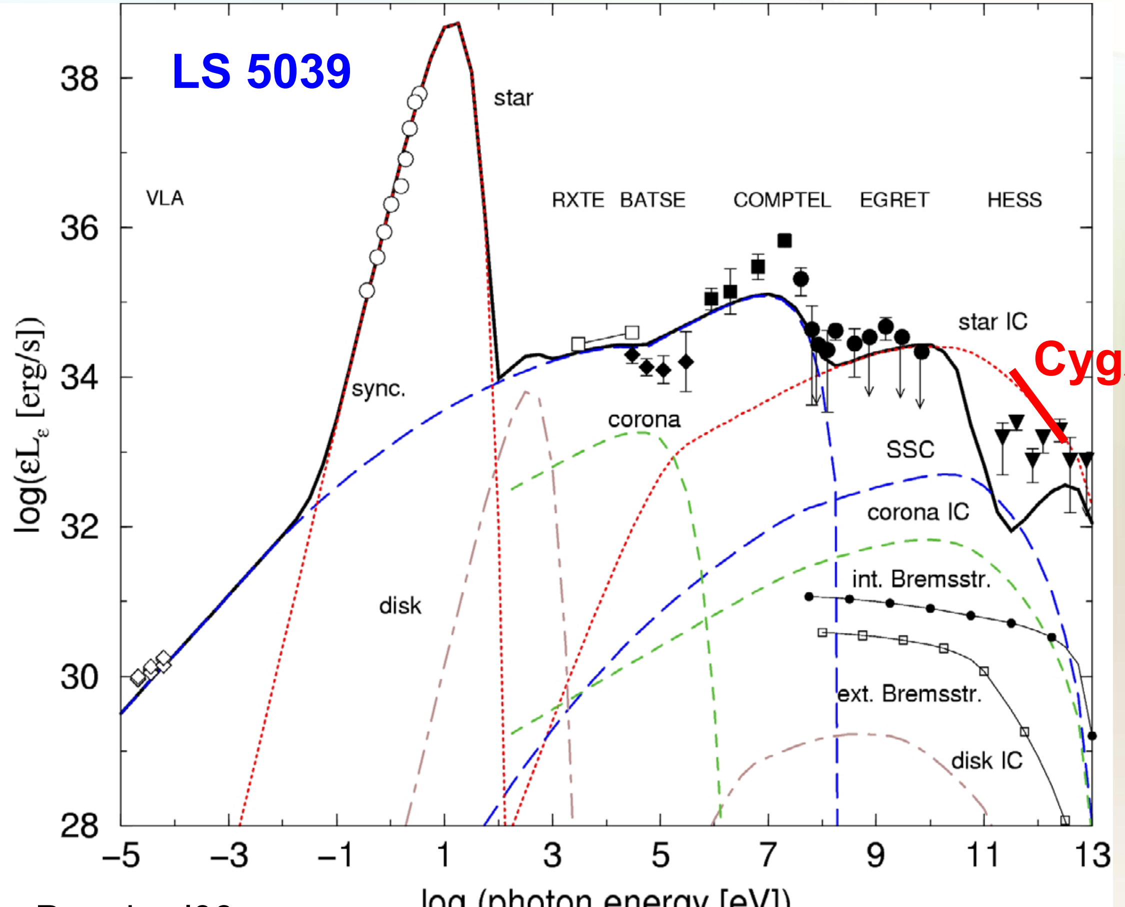
radiation components

- **LS 5039**
  Dermer & Böttcher ’06
  Paredes et al. ’06

Cygnus X-1
Romero et al. ’02 (too bright)

- **competition between absorbed star IC and SSC contributions**
  - nice since stellar radiation best known

- **low-mass binary systems**
  - much fainter
  - << visibility
  Grenier et al. ‘05

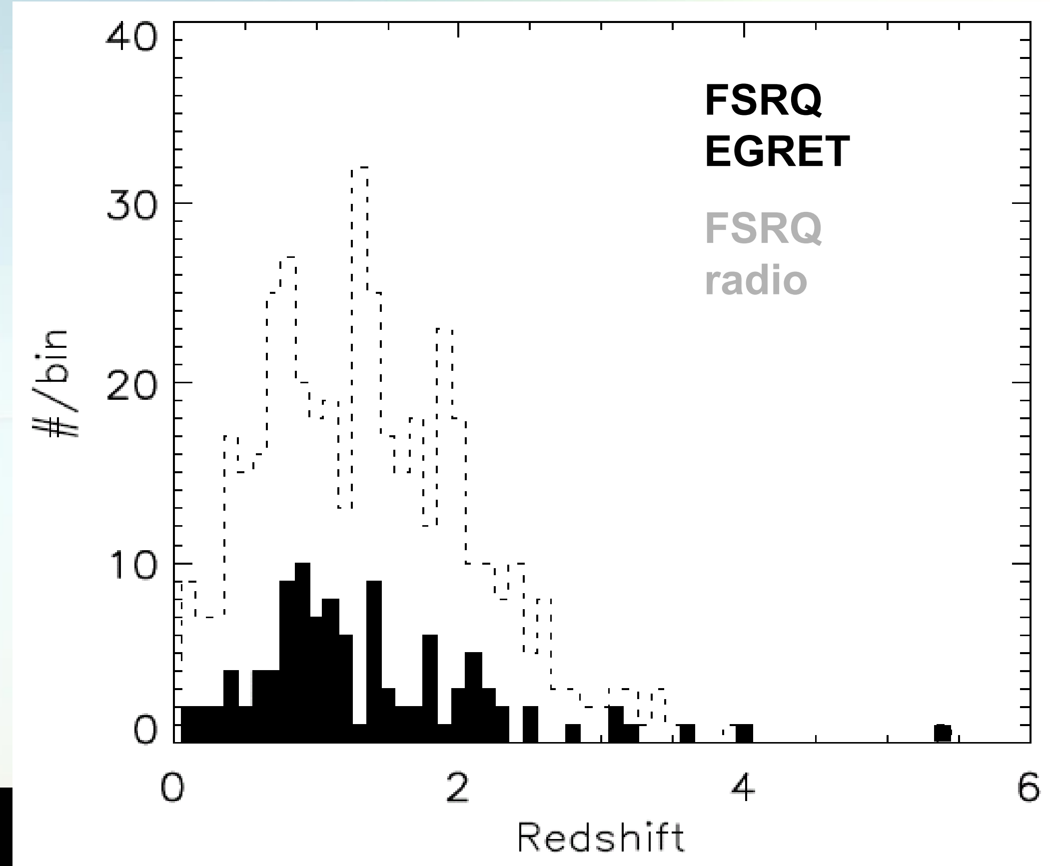


Paredes ’06

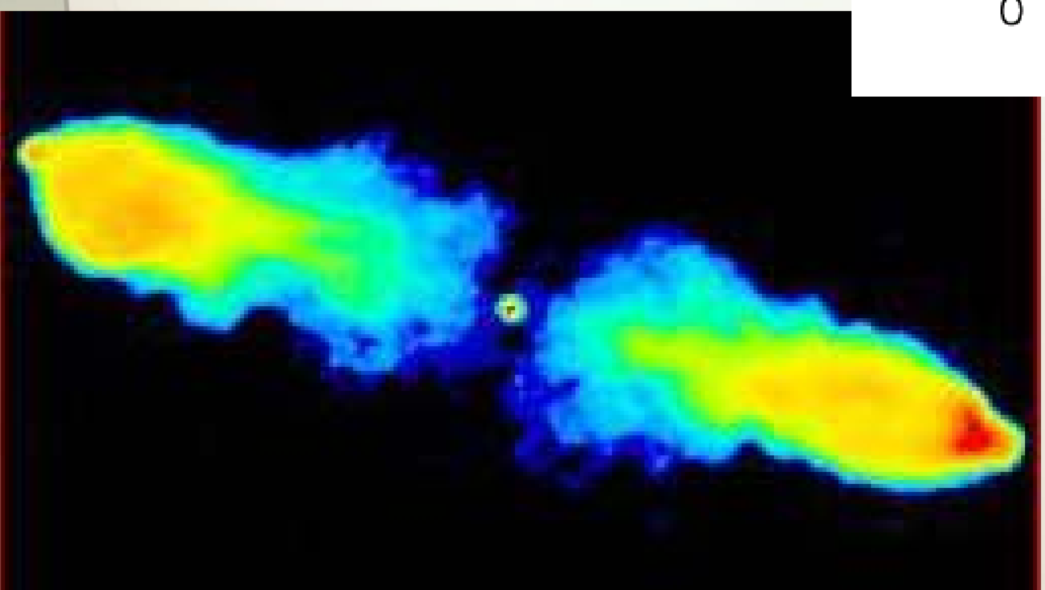
extragalactic sources

γ-ray blazars

- **EGRET**
  - 46 FSRQ + 14 Bl Lac
  - (to be revised)
  - to $z = 4.5$ and 5.5
- **TeV**
  - 18 sources, $z < 0.2$
  - to $E_\gamma > 30$ TeV

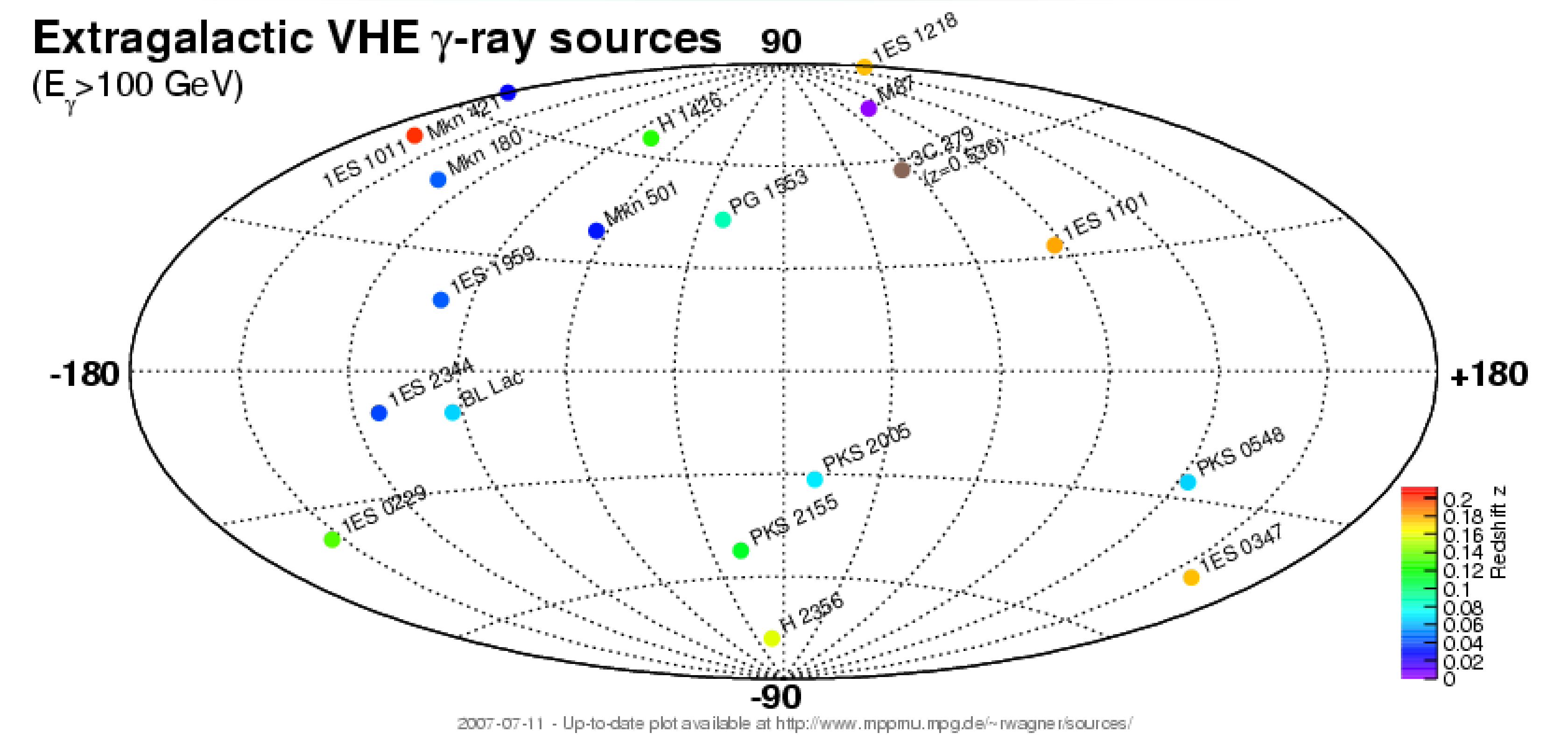


Sowards-Emmerd et al. ’04
Dermer ‘07



TeV Bl Lacs

- 18 Bl Lacs
- + 3C279 ?

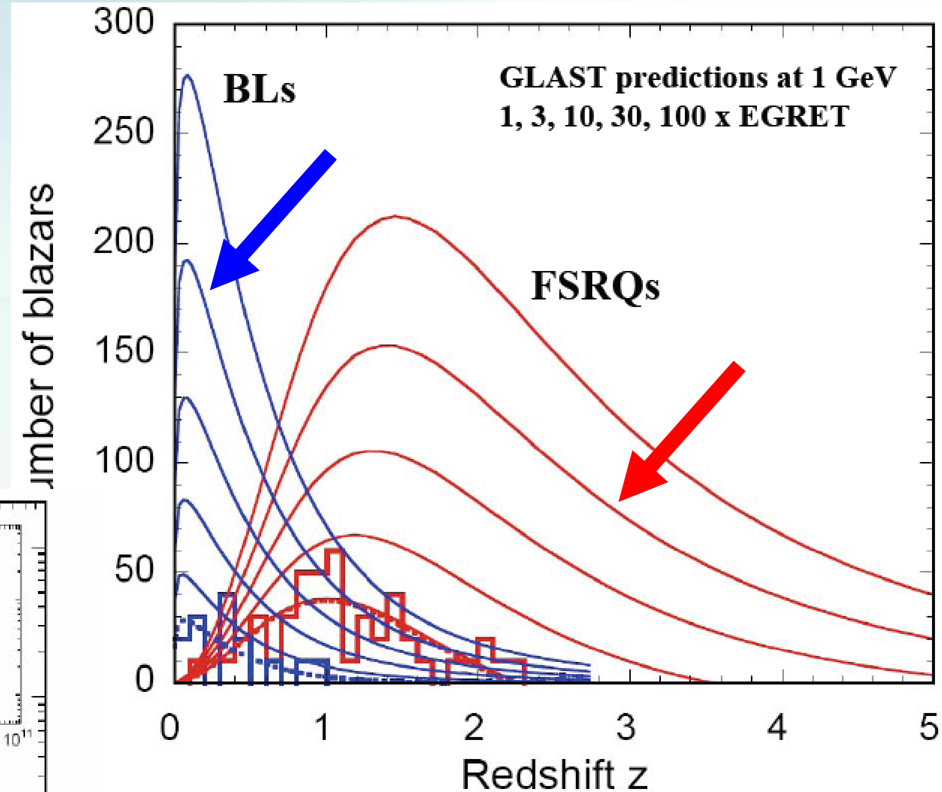


Wagner '07

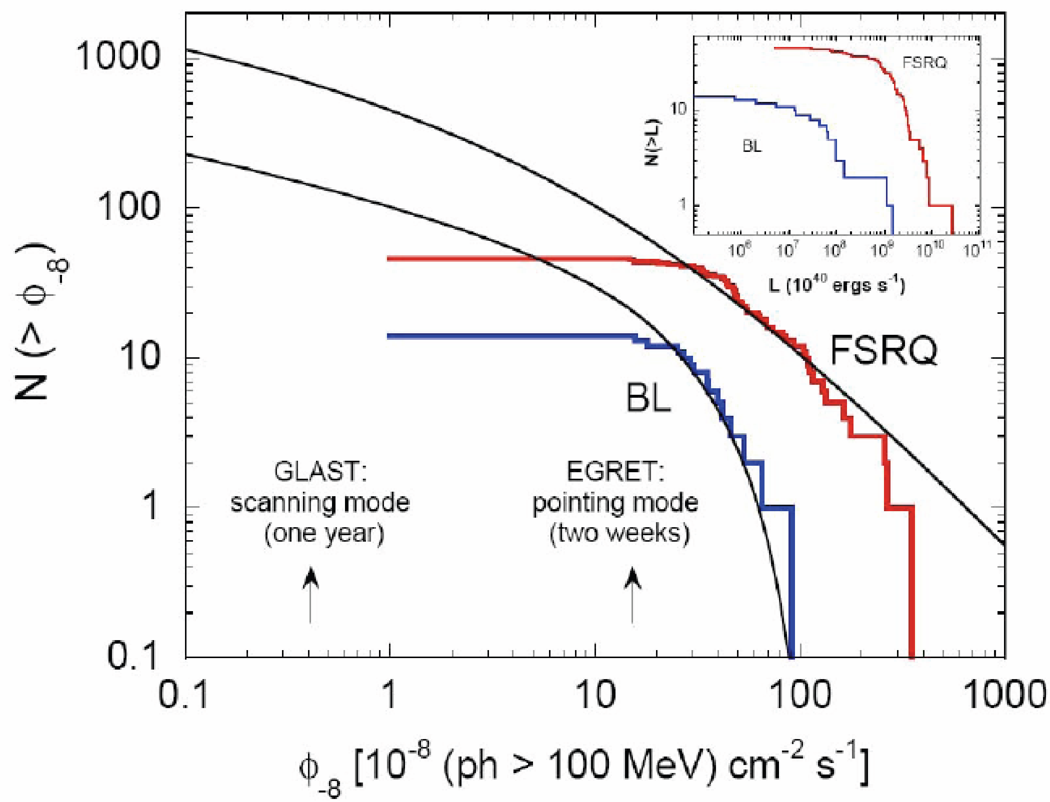
LAT simulated sky

γ-ray blazars

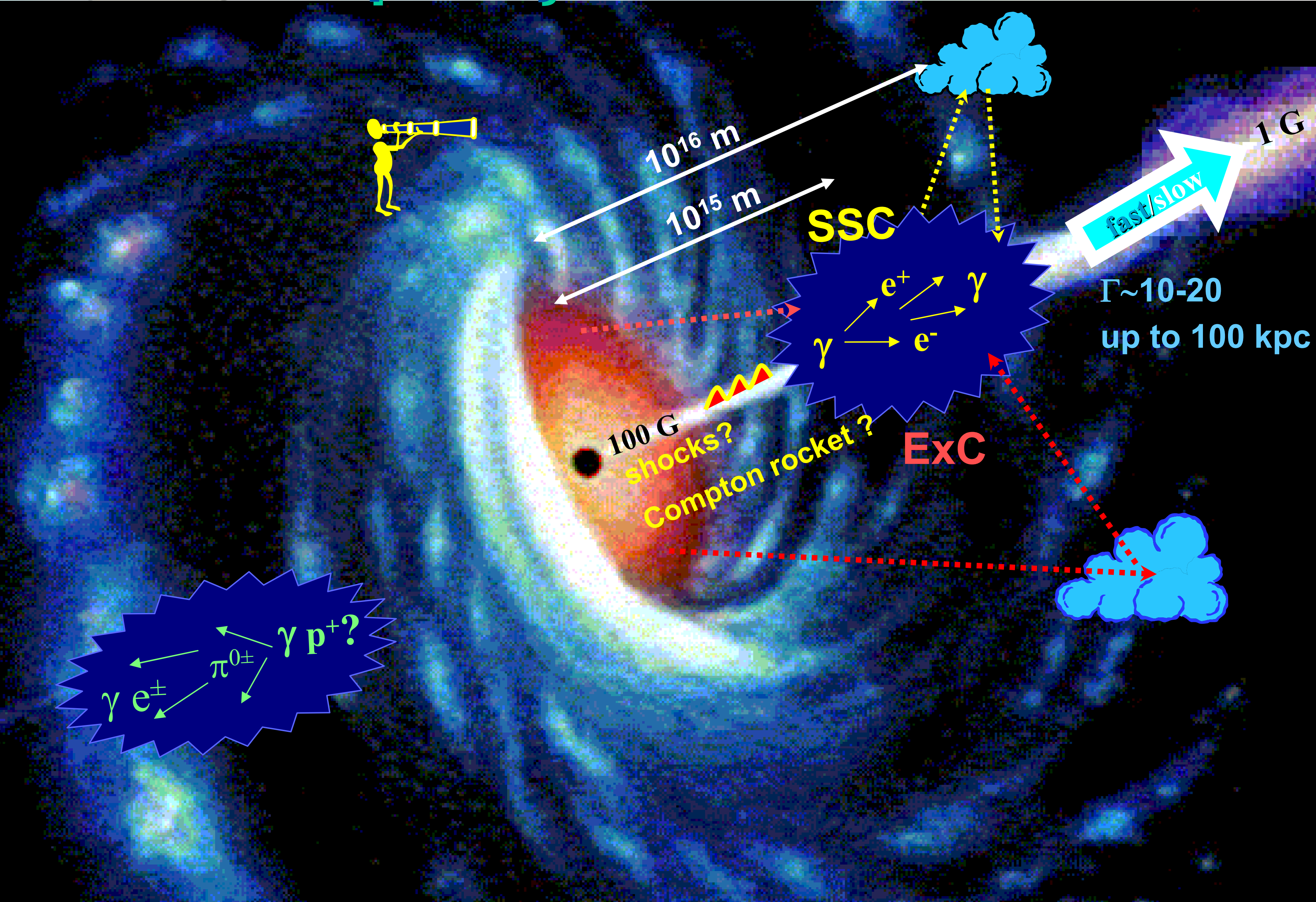
- **LAT**
  - ~ 2000 blazar detections
- **deep all-sky survey**
  - z ≤ 5 because of Doppler amplification



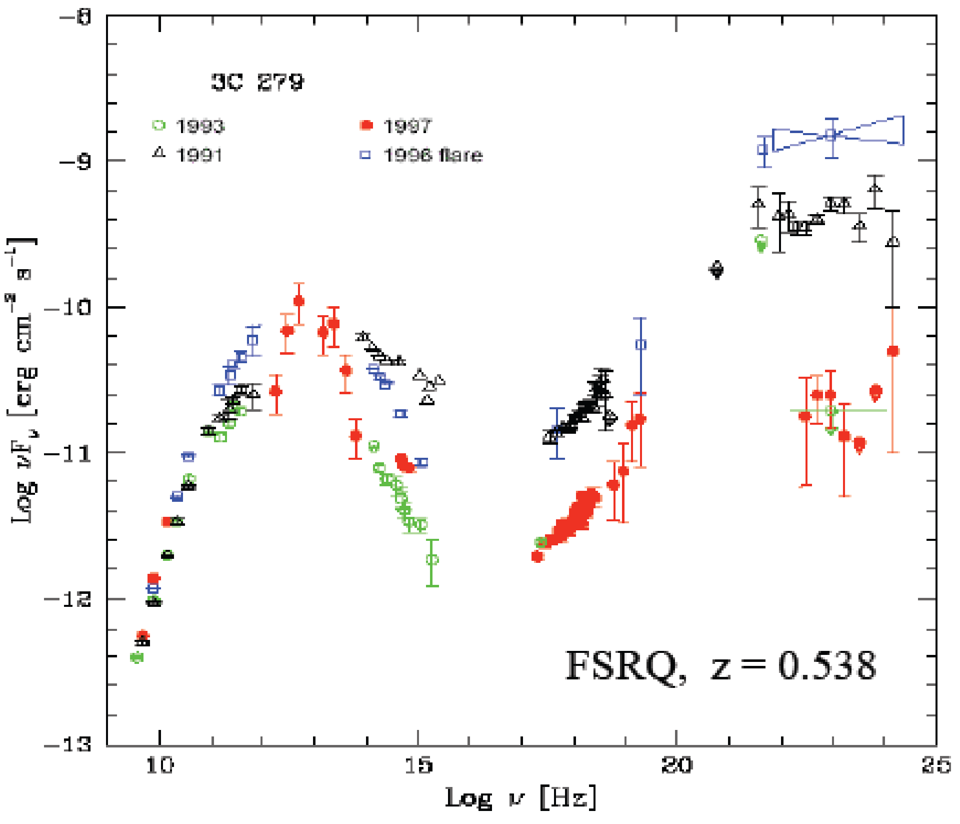
Dermer ’07



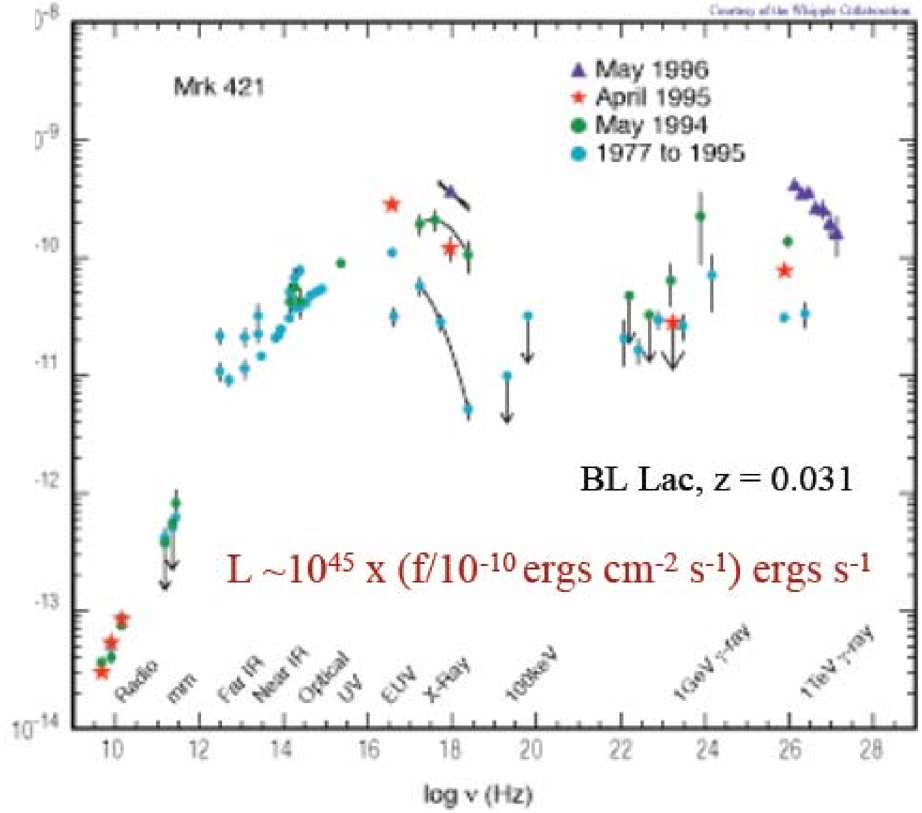
hadronic or leptonic jets



variability: multi-λ campaigns



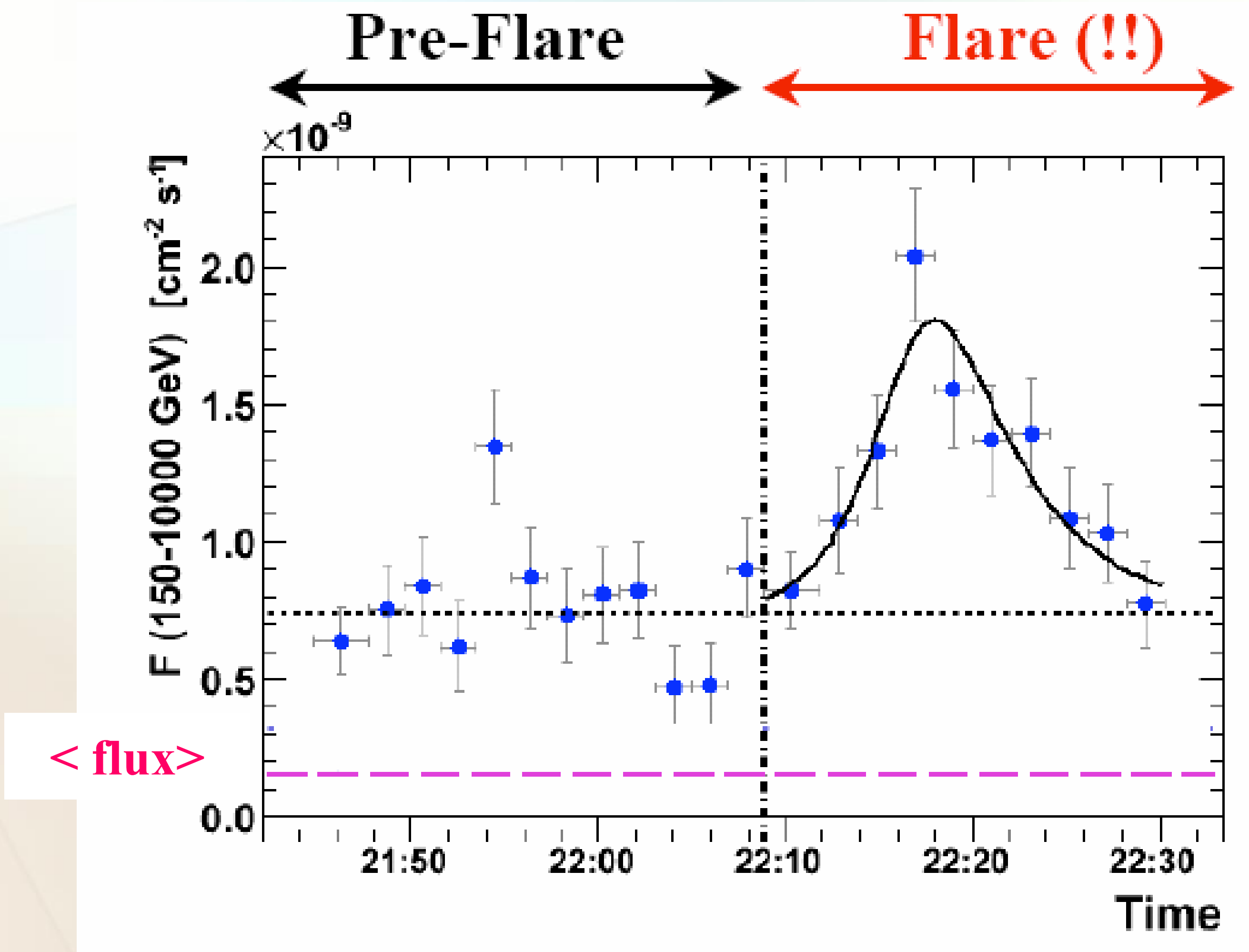
L ~5x10^48 x (f/10^-9 ergs cm^-2 s^-1) ergs s^-1



L ~10^45 x (f/10^-10 ergs cm^-2 s^-1) ergs s^-1

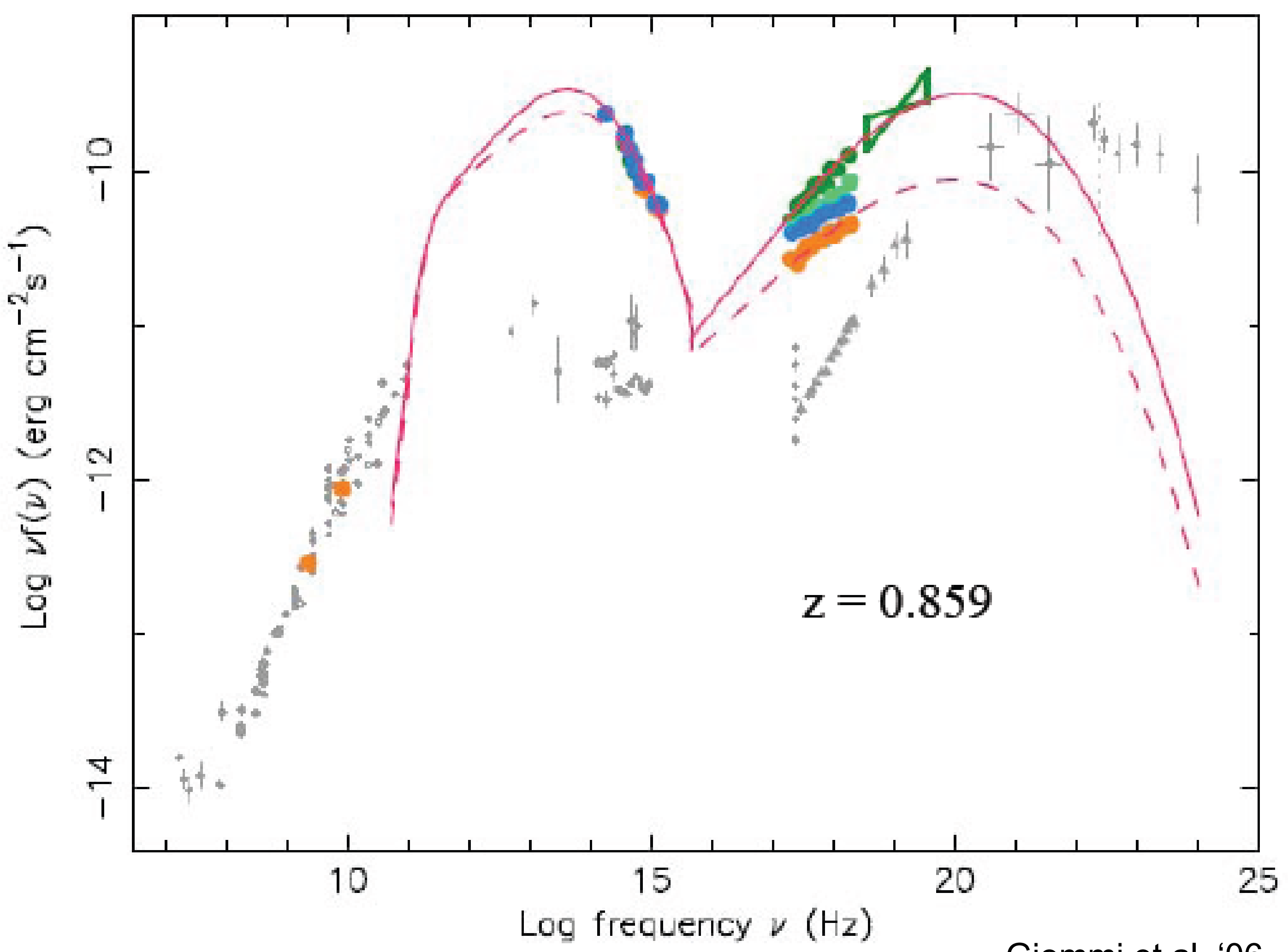
rapid variability

- Mrk 501: MAGIC E > 150 GeV   12 mn



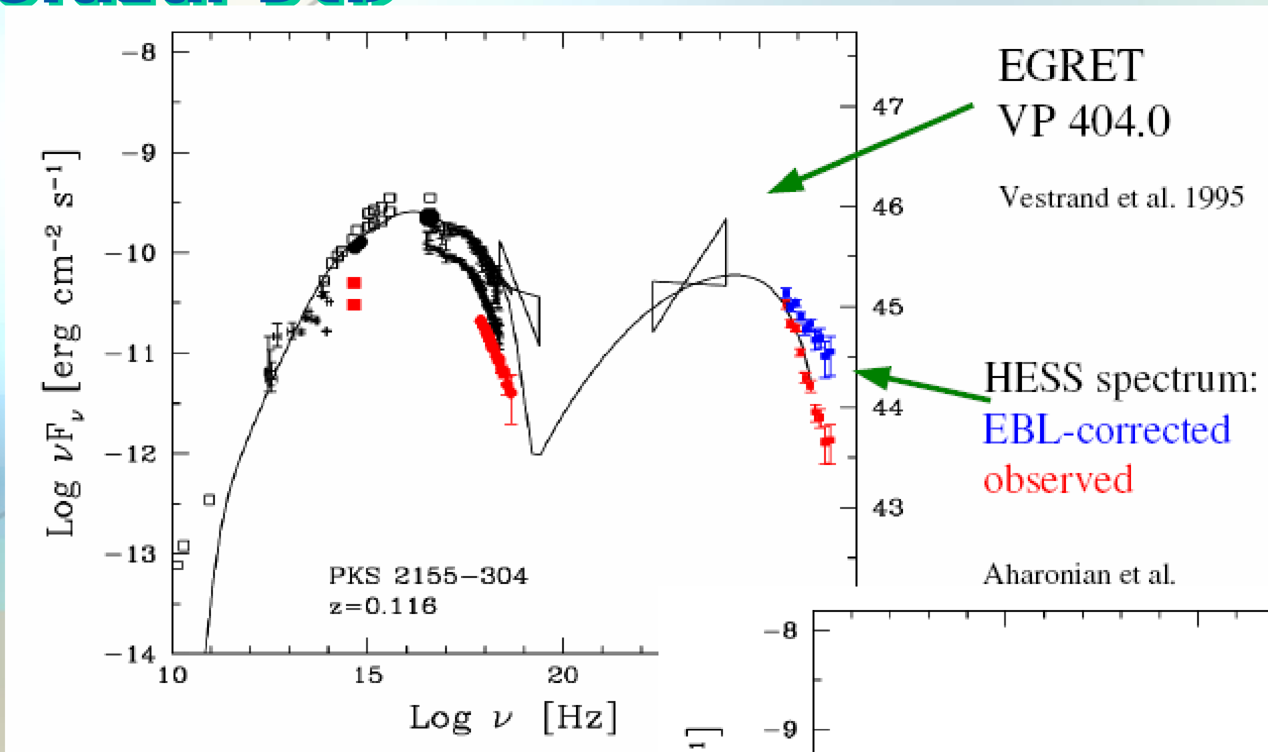
Paneque '07

blazar SED

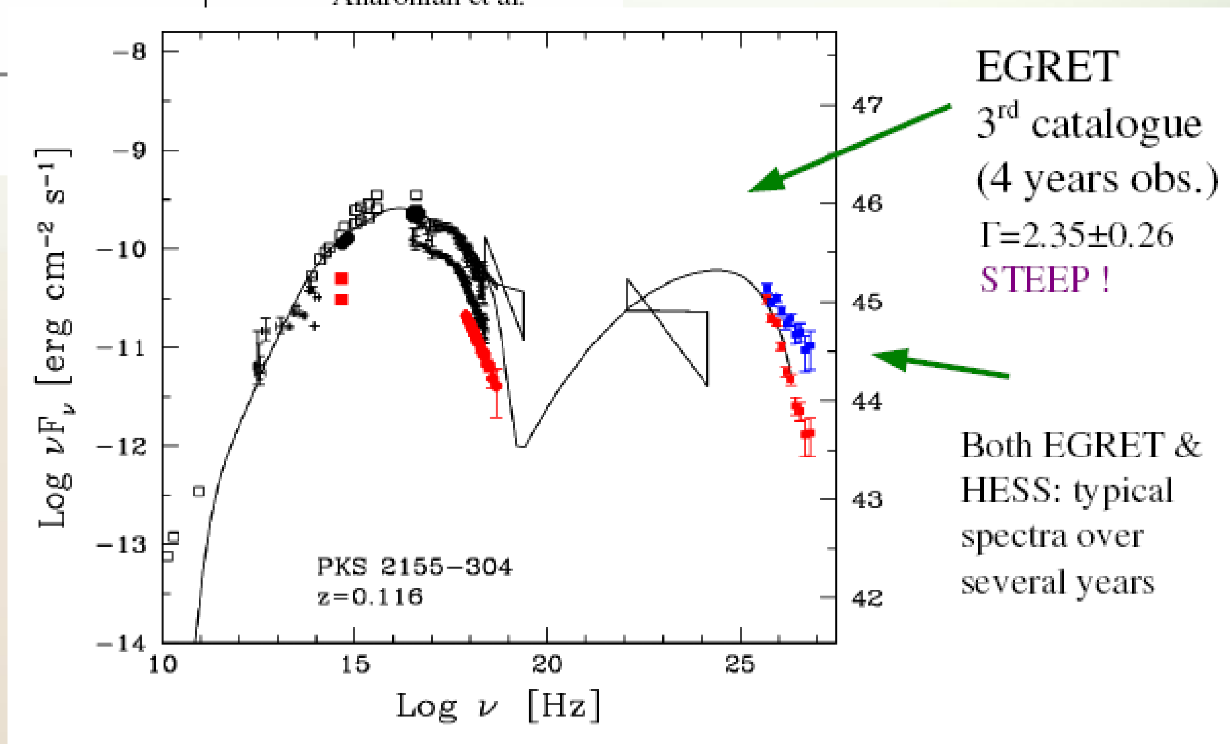


Giommi et al. ‘06

blazar SED



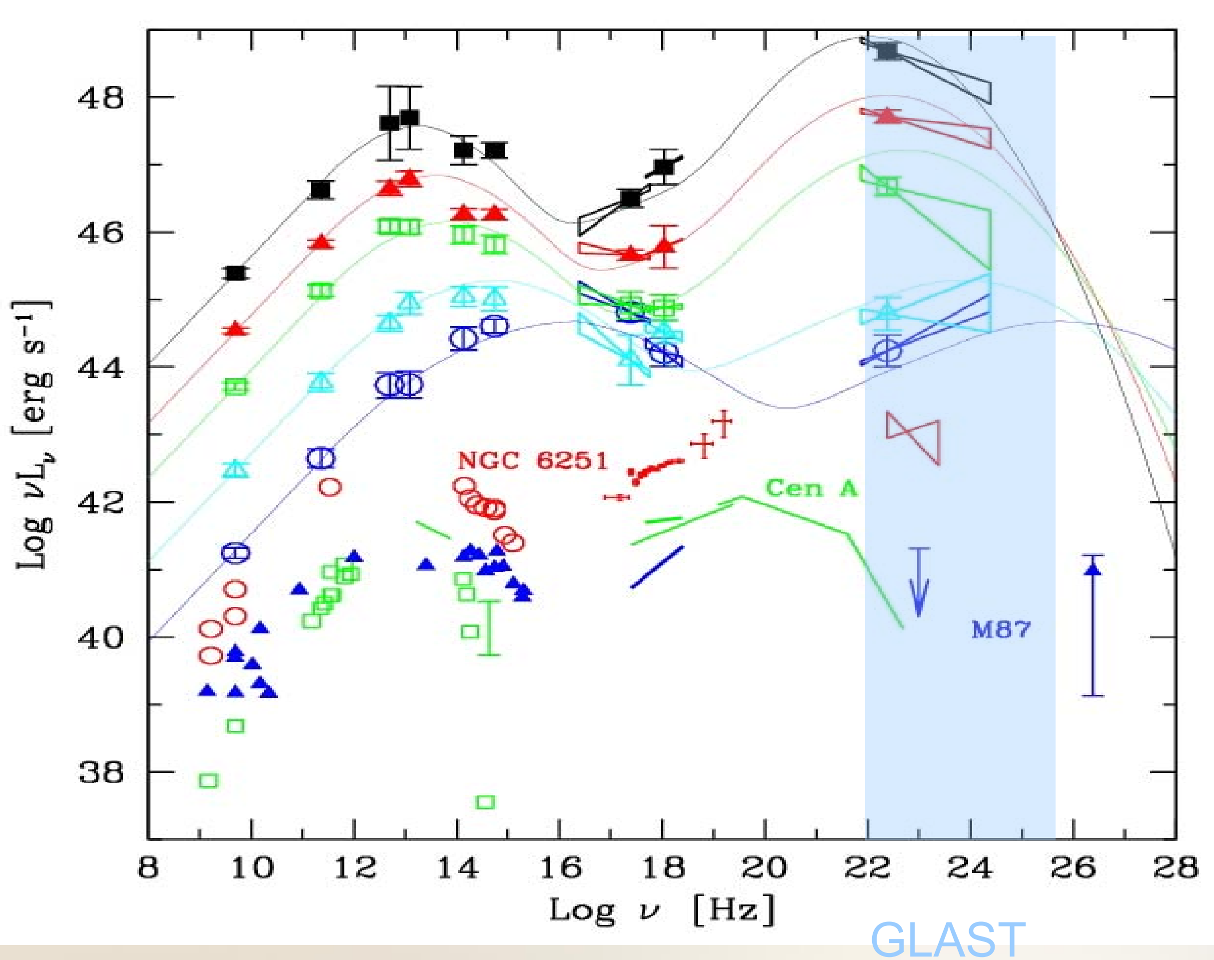
- double jet?
- double source?



Costamante '07

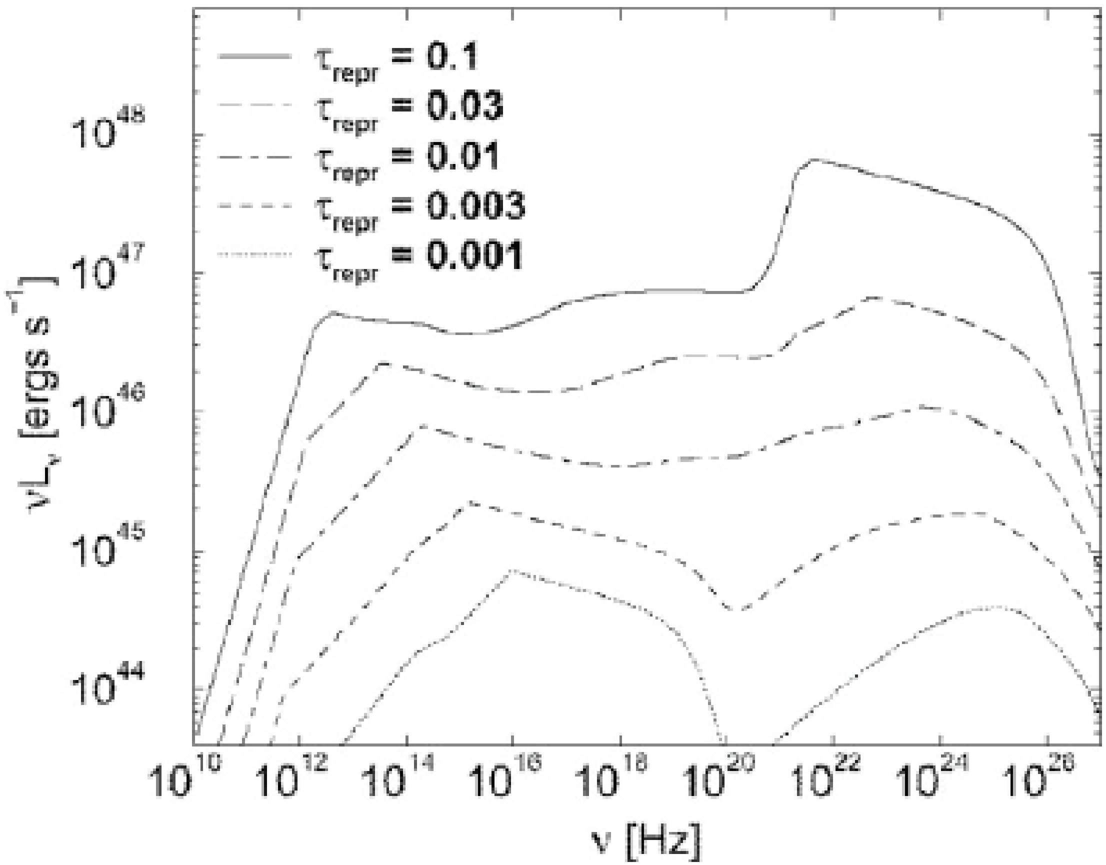
blazar main sequence

- **questions:**
  - complete sample??
  - duty cycle?
  - beaming factor ?
    $\Gamma \sim$ 10-20
- **feeding and mass evolution**
  - environmental effects
  - host galaxy history?



GLAST

blazar main sequence

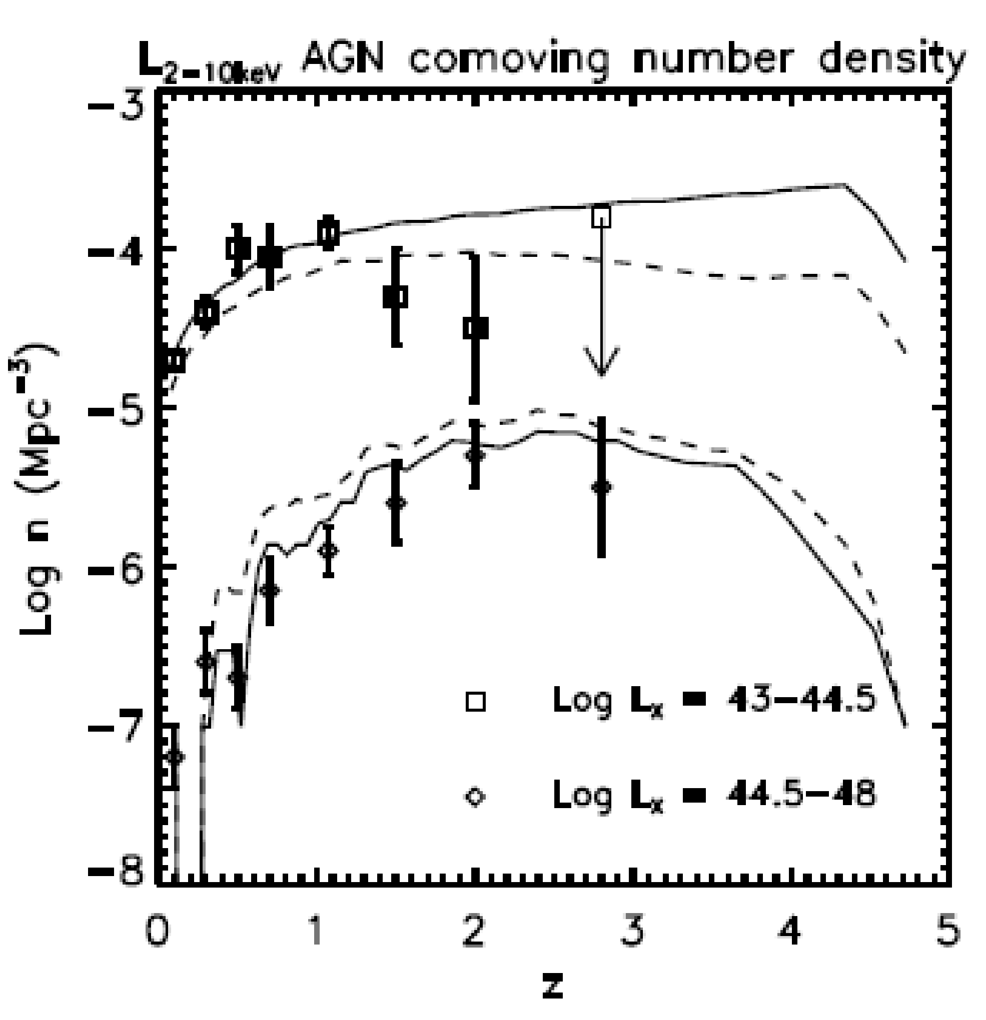


Evolution from FSRQ to BL Lac Objects in terms of a reduction of fuel from surrounding gas and dust

Böttcher and Dermer (2000)
Cavaliere and d'Elia (2000)

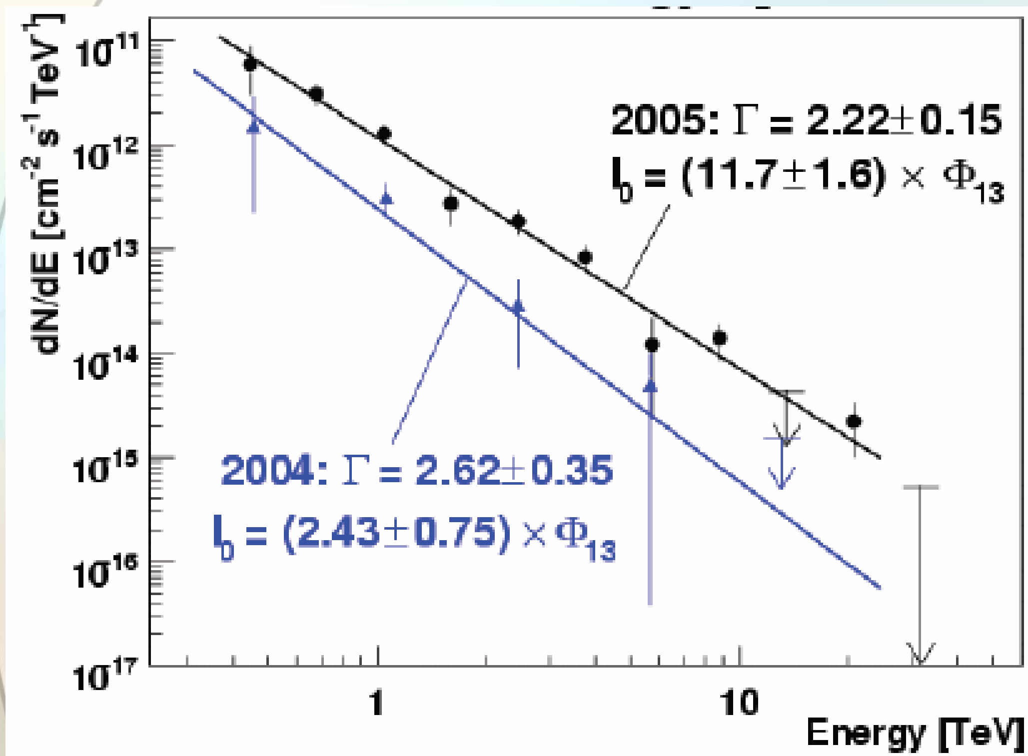
AGN evolution

- AGN/blazar evolution
  - formation rate BFR(z)
    $\rightarrow$ comobile density
  - growth by accretion? fusion?
    $M(z) \propto M_{bulb}$
  - feeding evolution ?
    - collisions => SFR(z)
  - accretion power vs. L_{Edd} ?
  - environmental effects
  - dichotomy epoch ?
    Bl Lac-FR I vs. FSRQ – FR II
- $\Rightarrow$ compare γ, radio, IR, X
  - many redshifts and SED measurements

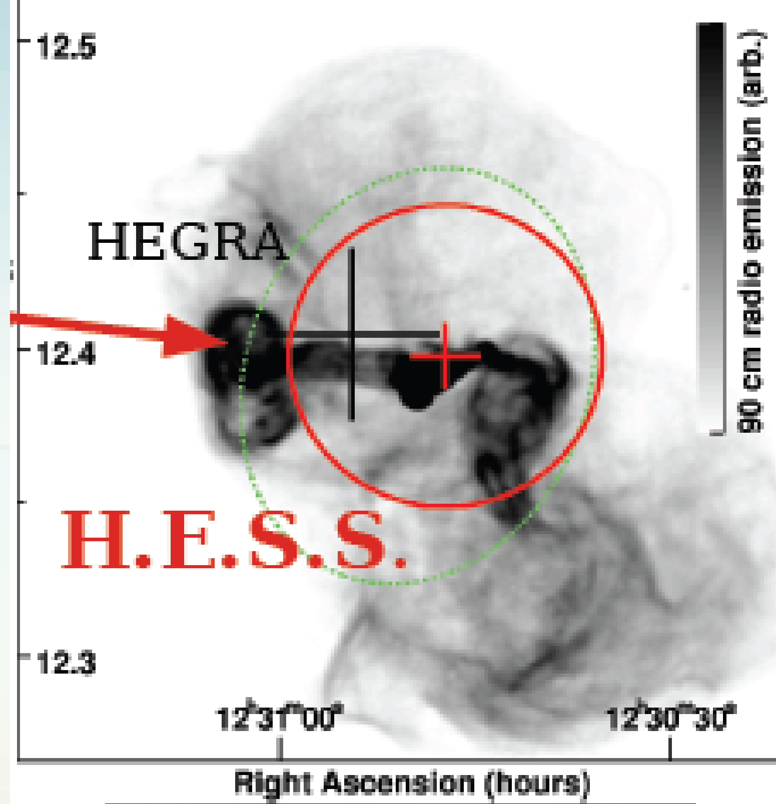


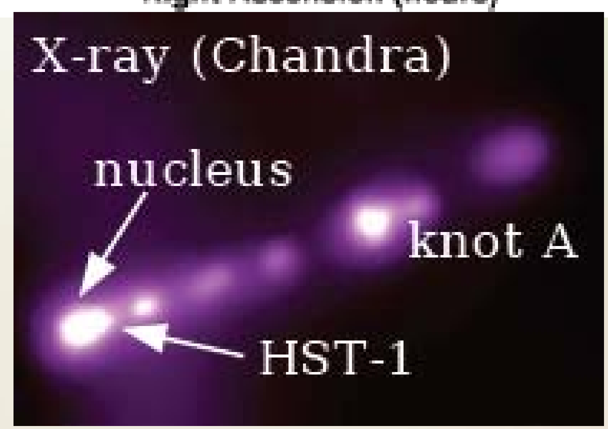
M 87

- FR I 16 Mpc, 3 GM⊙, jet at 30°



$\Phi_{13} = 10^{-13}$ cm^{-2} s^{-1} TeV^{-1}

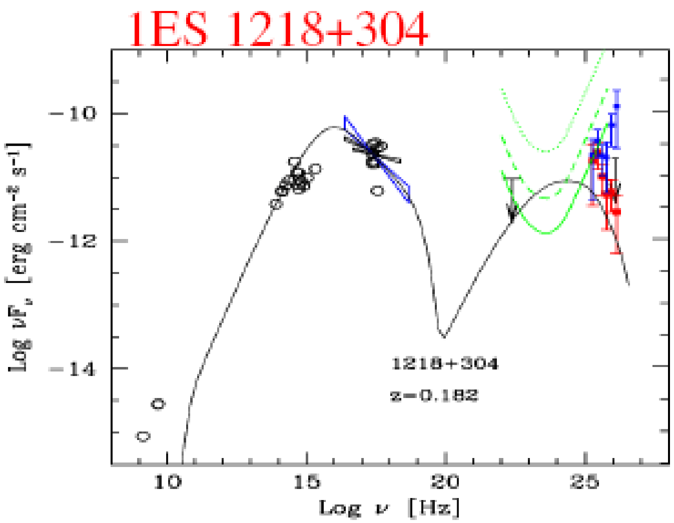


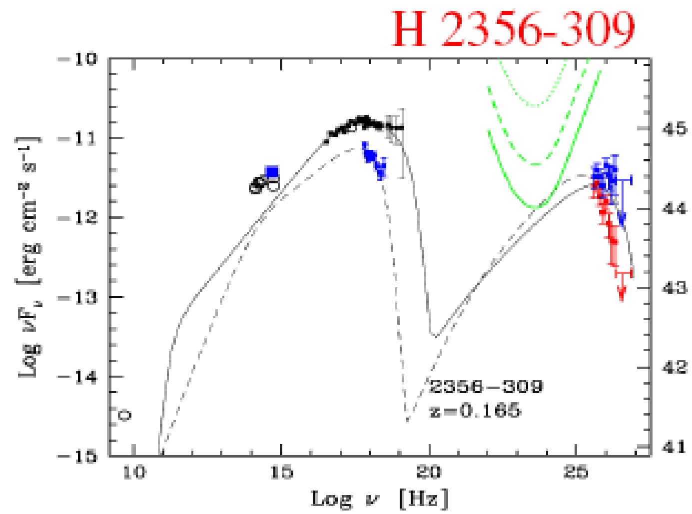


- statistical problem
  - TeV Bl Lac detection probability at z < 0.13, even with double jet (Γ ~ 3-5 and 25) P = 6.35 10^{-6} whereas 5-6 observed out of 29 known

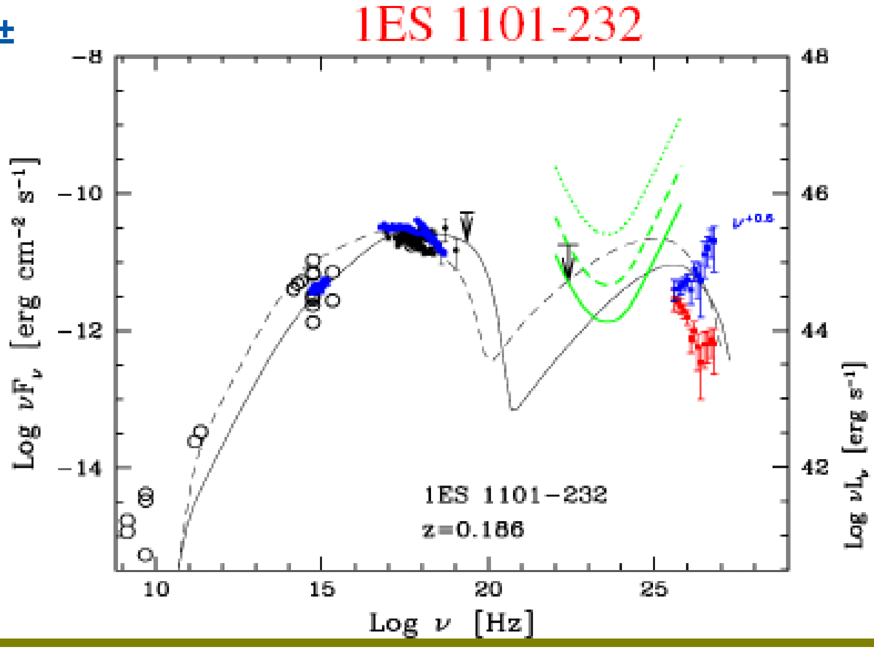
Saugé & Henri ’04

extragalactic $\gamma+\gamma \rightarrow e^{\pm}$ absorption



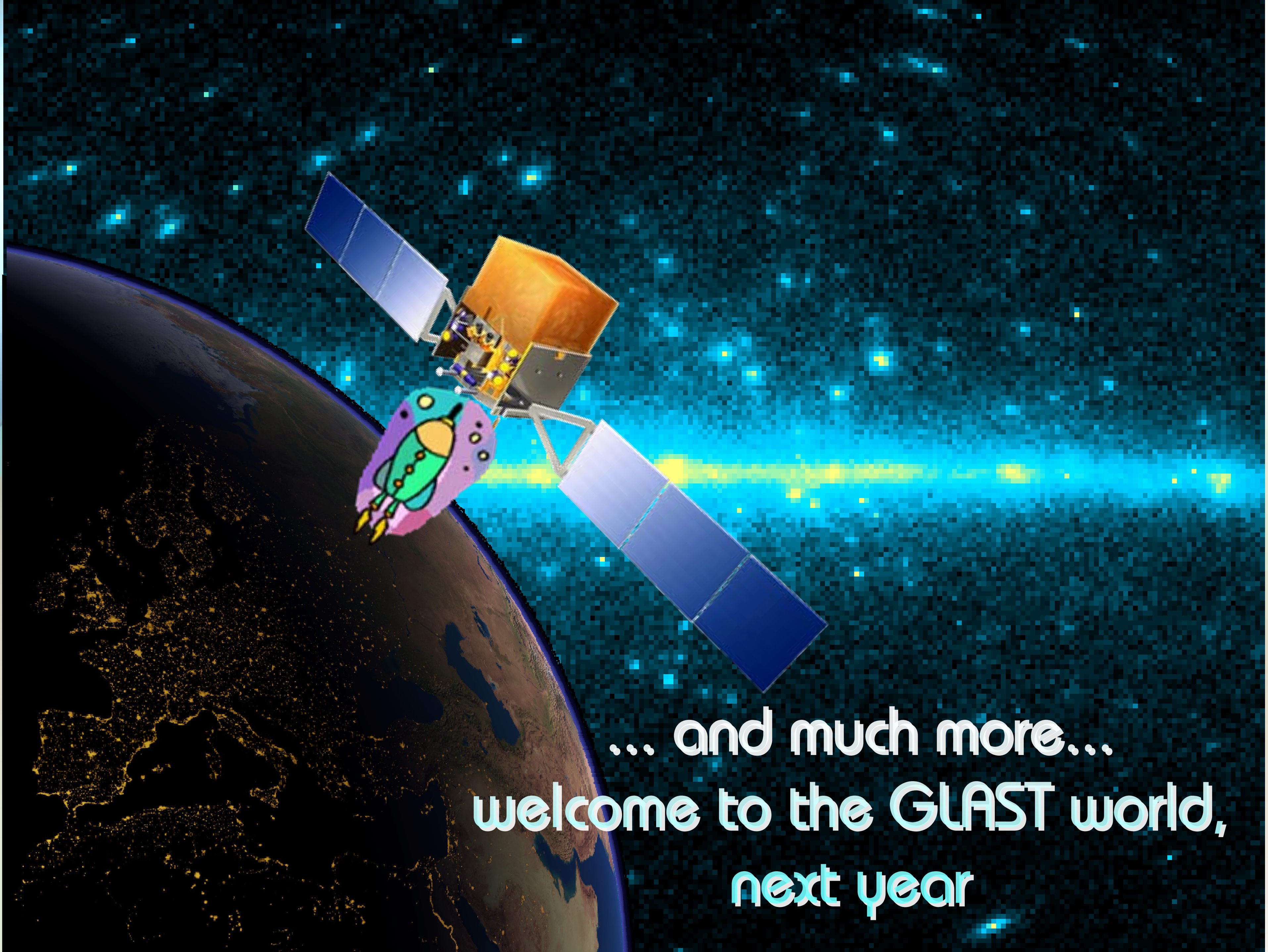


- TeV + CMB/IR $\rightarrow e^{\pm}$
- GeV + IR/opt $\rightarrow e^{\pm}$



HESS data

corrected for EBL


... and much more...
welcome to the GLAST world,
next year