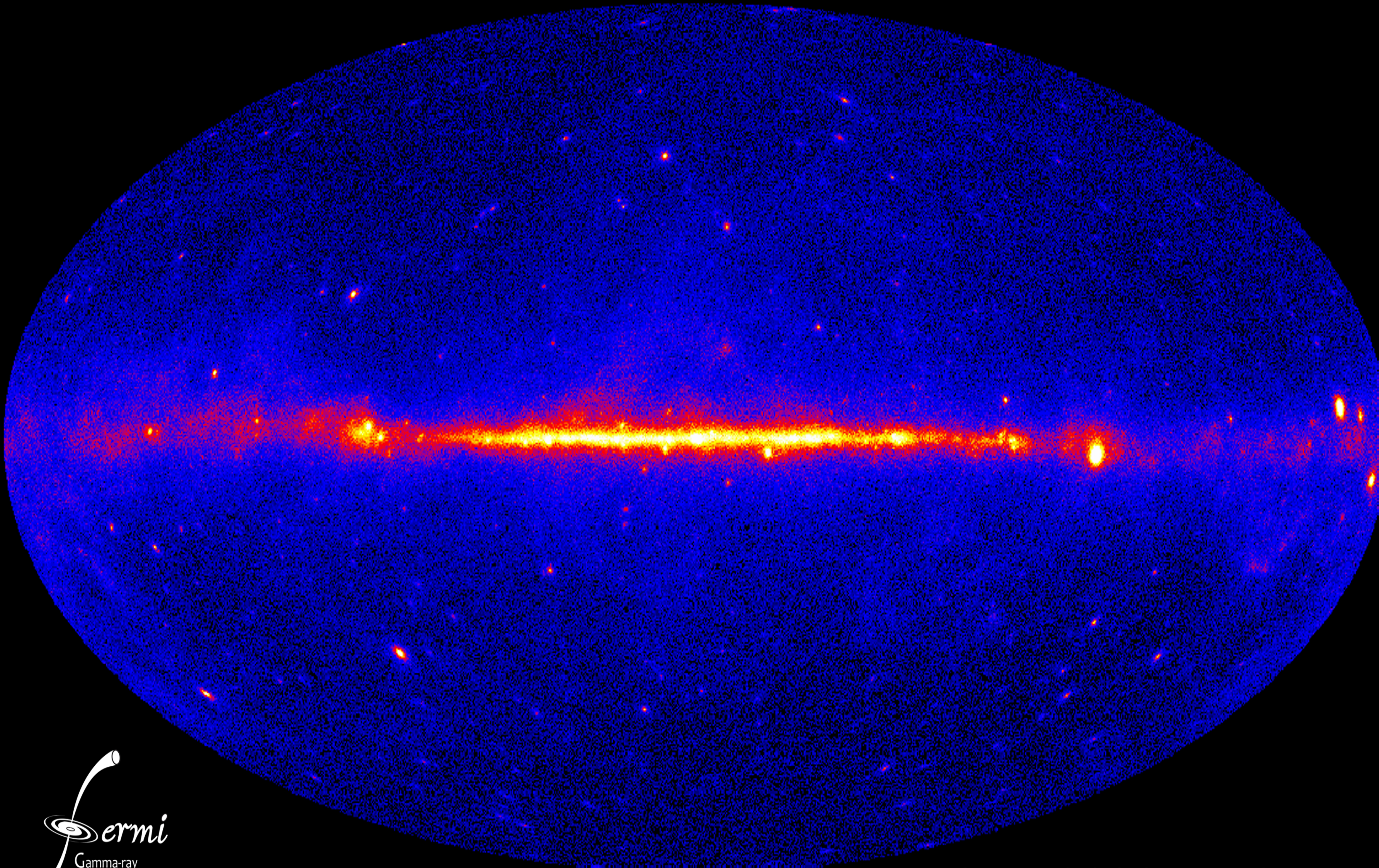
Binaries and pulsars

Atelier *diffuse MeV to TeV gamma-rays*

Guillaume Dubus

Laboratoire d'Astrophysique de Grenoble UMR 5571 UJF / CNRS

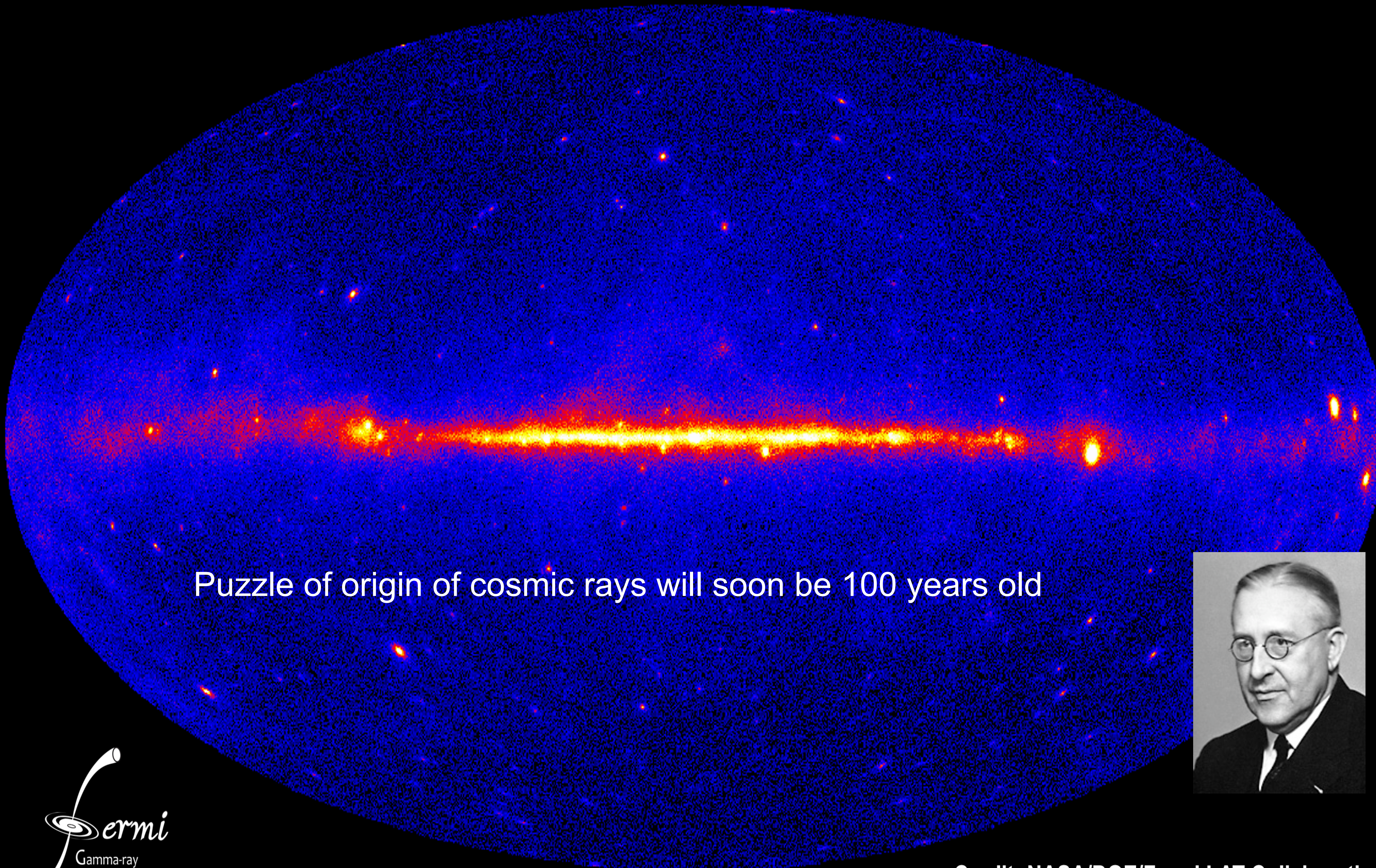
Diffuse emission: cosmic rays



Credit: NASA/DOE/Fermi LAT Collaboration

Fermi Gamma-ray Space Telescope

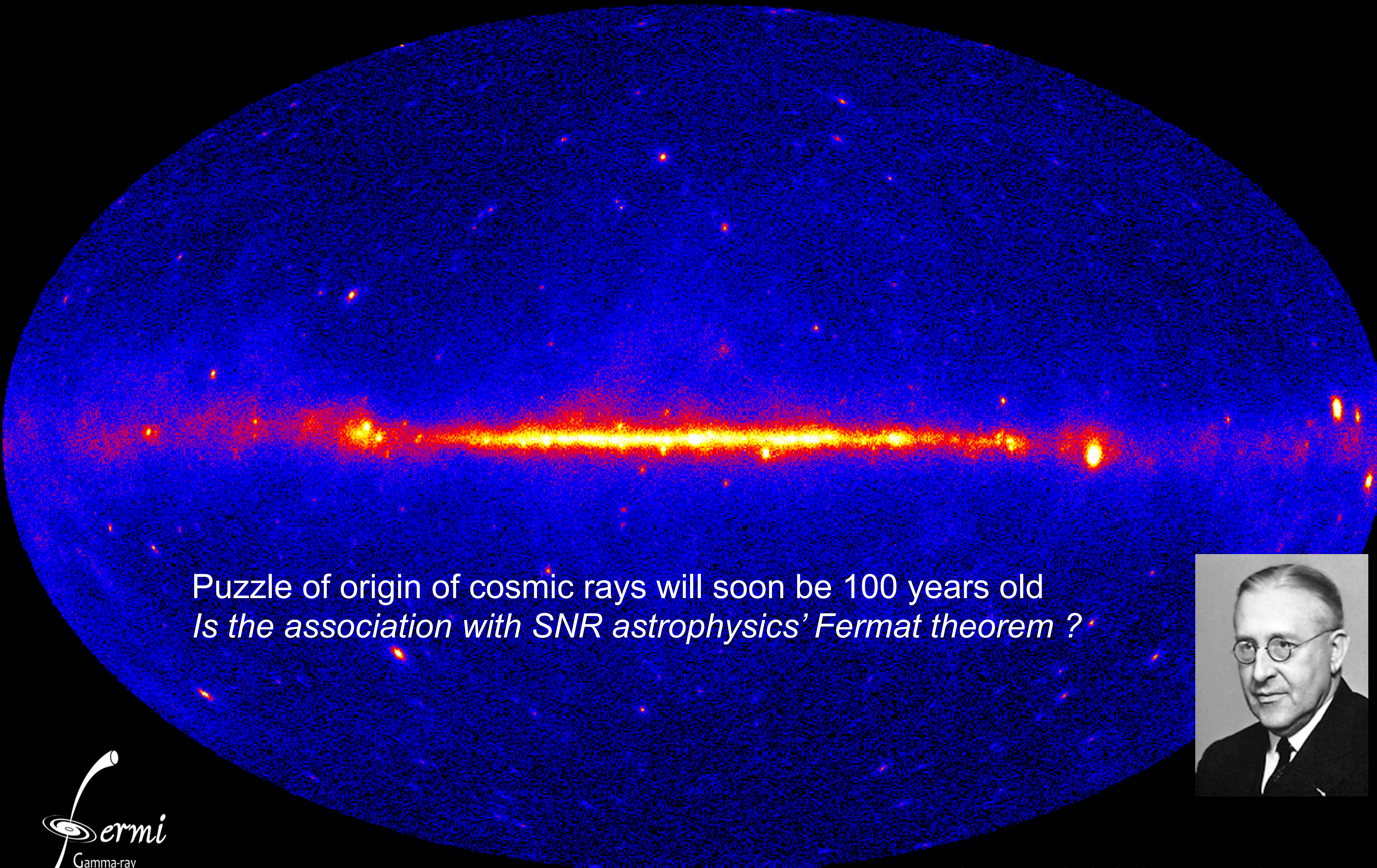
Diffuse emission: cosmic rays



Fermi
Gamma-ray
Space Telescope

Credit: NASA/DOE/Fermi LAT Collaboration

Diffuse emission: cosmic rays



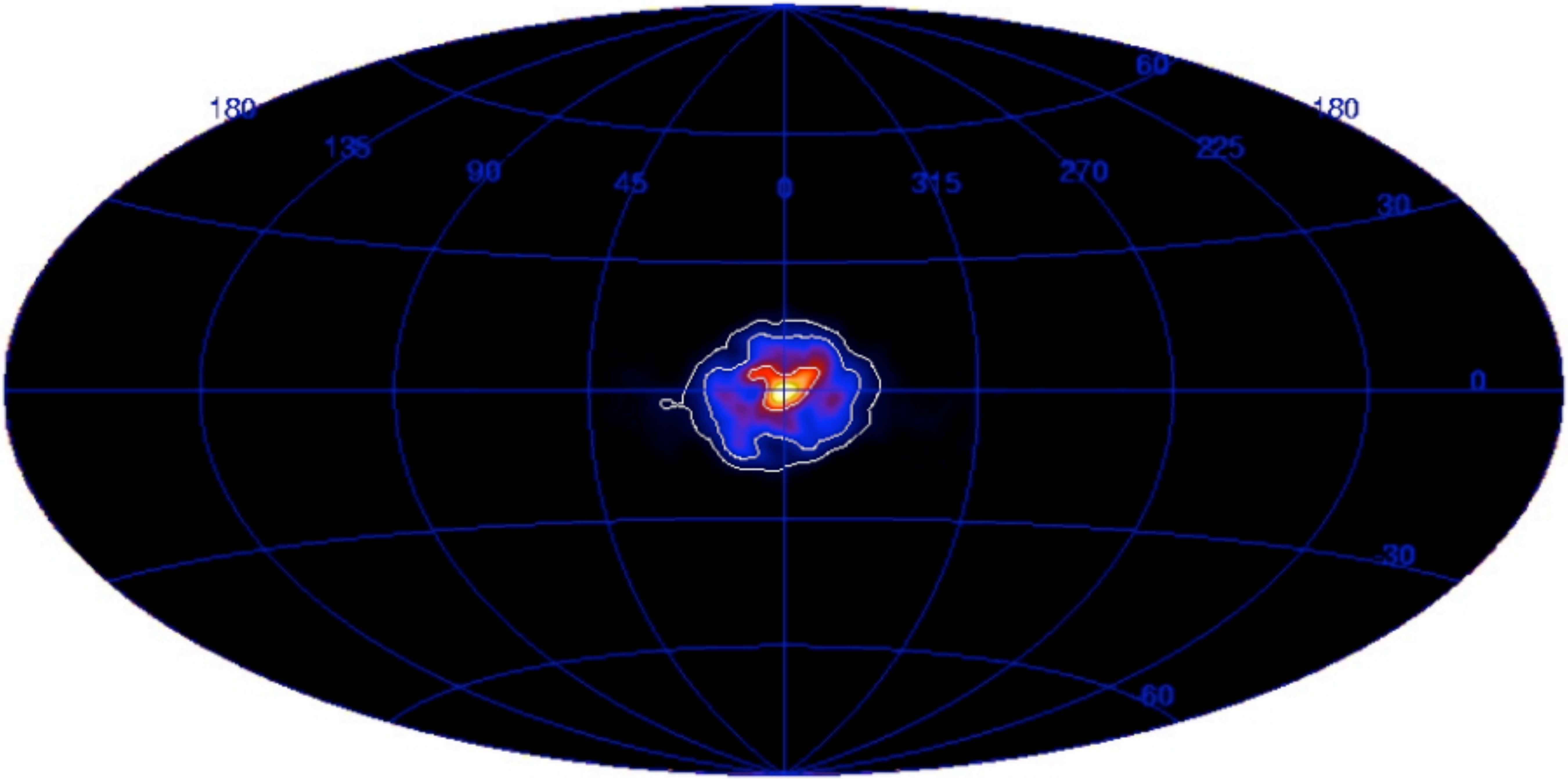
Puzzle of origin of cosmic rays will soon be 100 years old

Is the association with SNR astrophysics' Fermat theorem ?

Fermi Gamma-ray Space Telescope

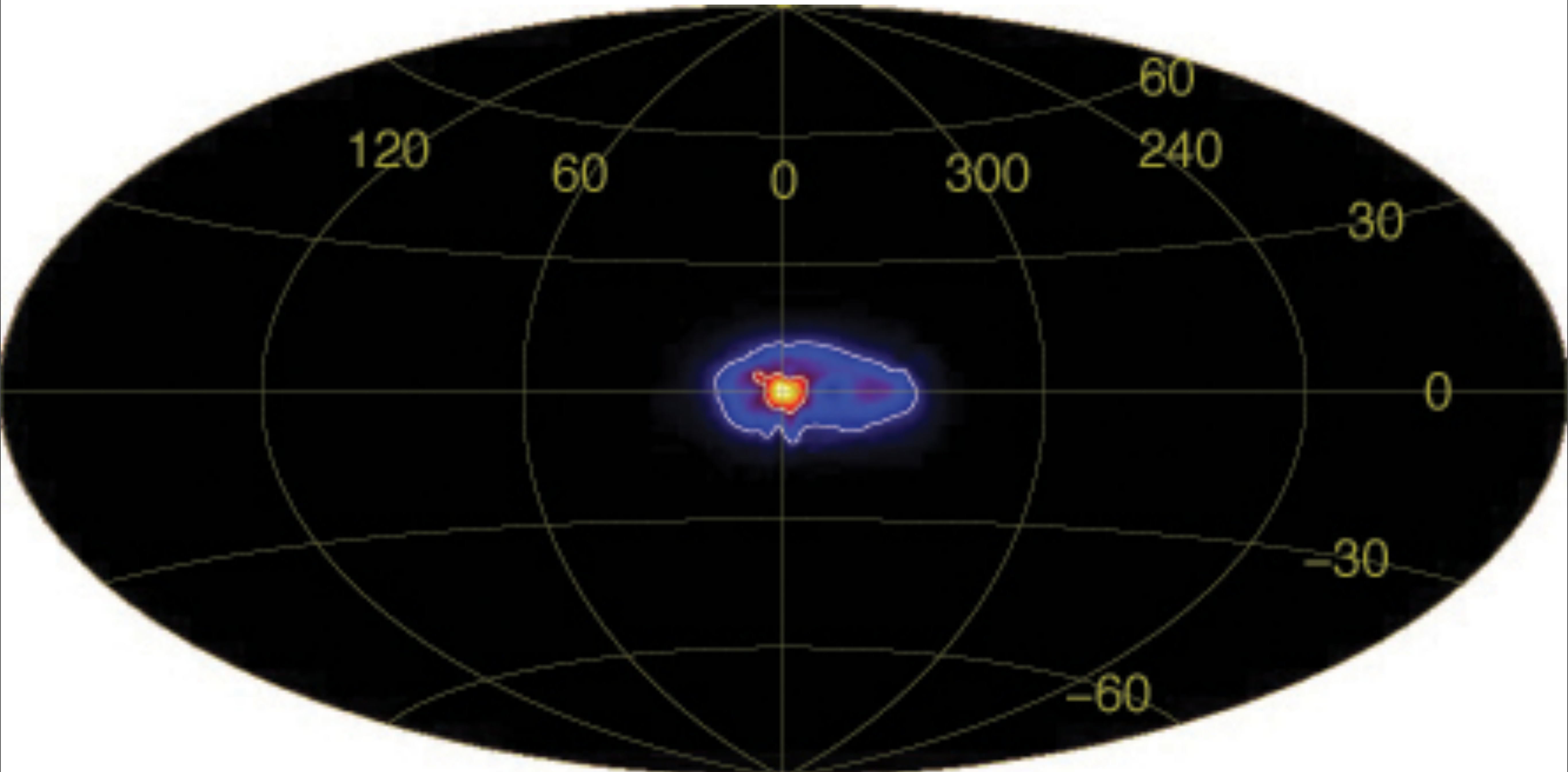
Credit: NASA/DOE/Fermi LAT Collaboration

Diffuse emission: e^+e^- annihilation



Knödlseder et al. 2005

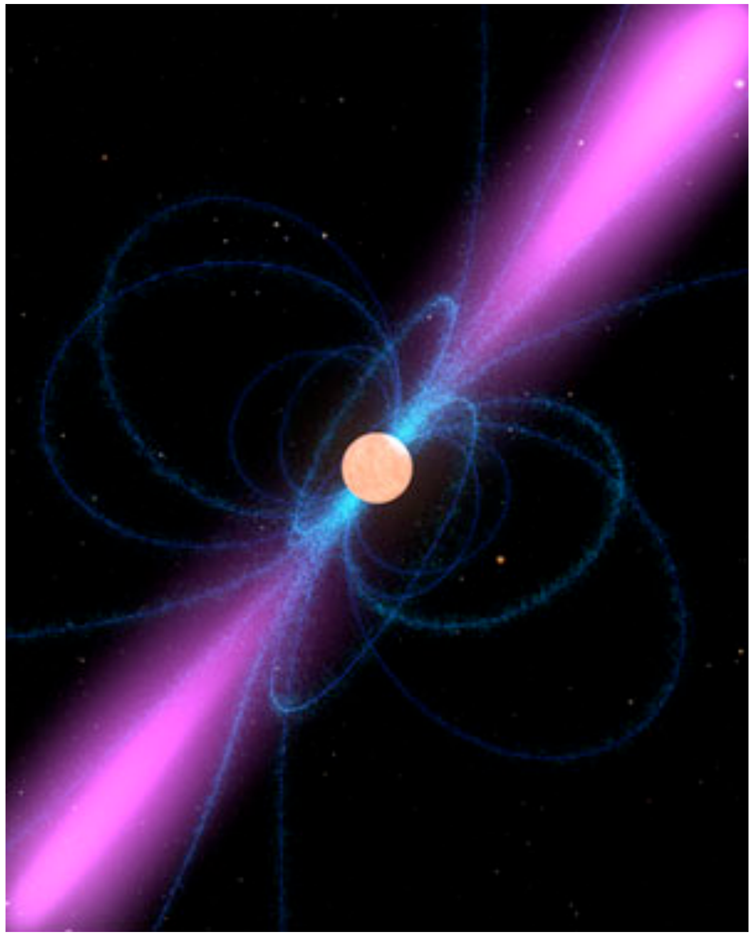
Diffuse emission: e^+e^- annihilation

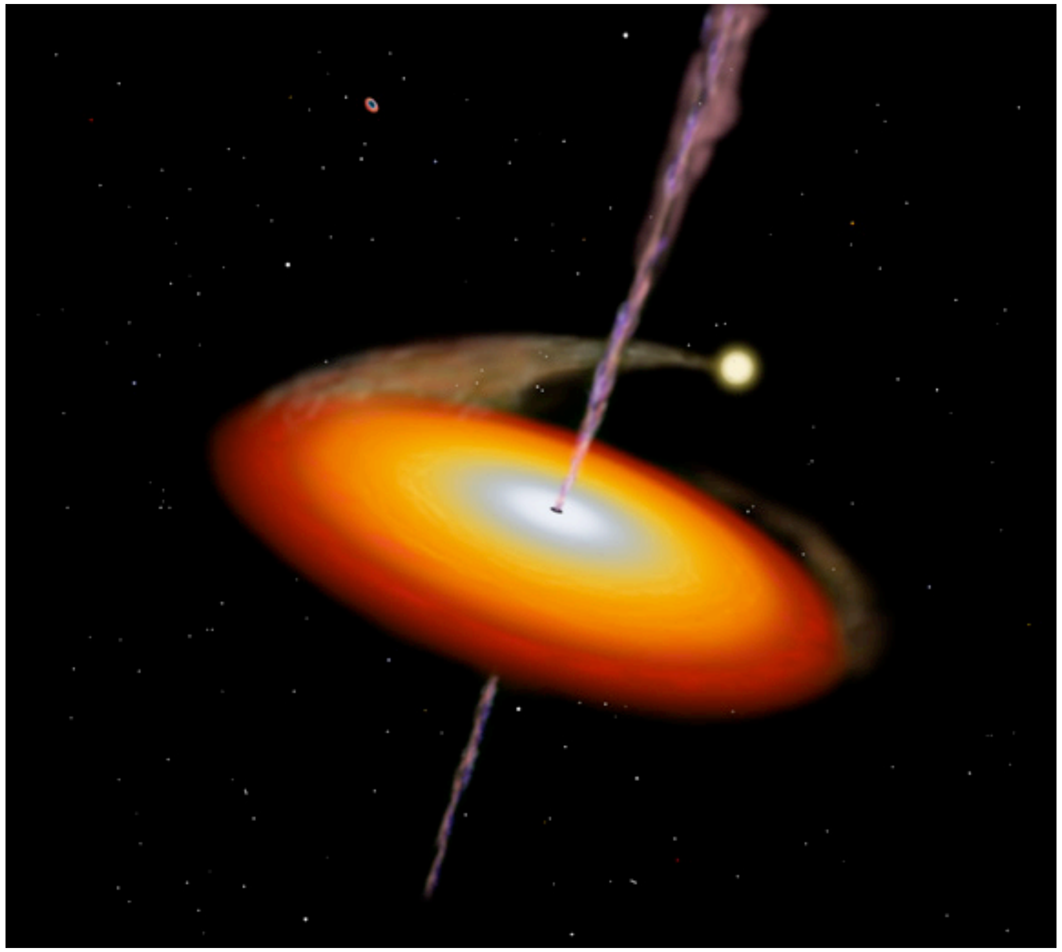


Weidenspointner et al. 2008

Pulsars and binaries

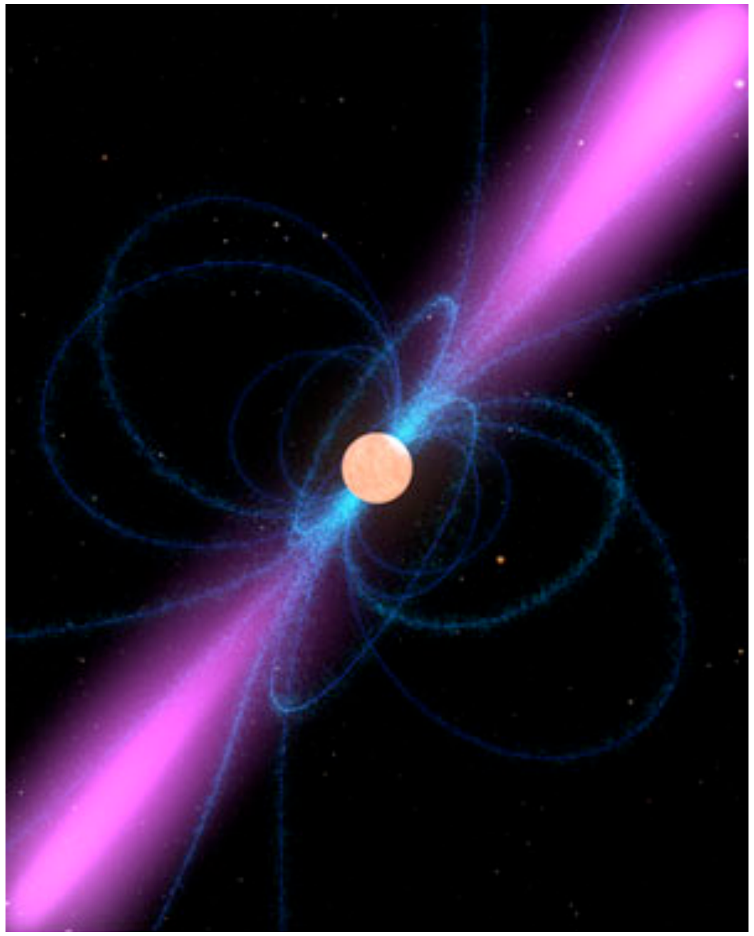
sources of cosmic rays and positrons ?



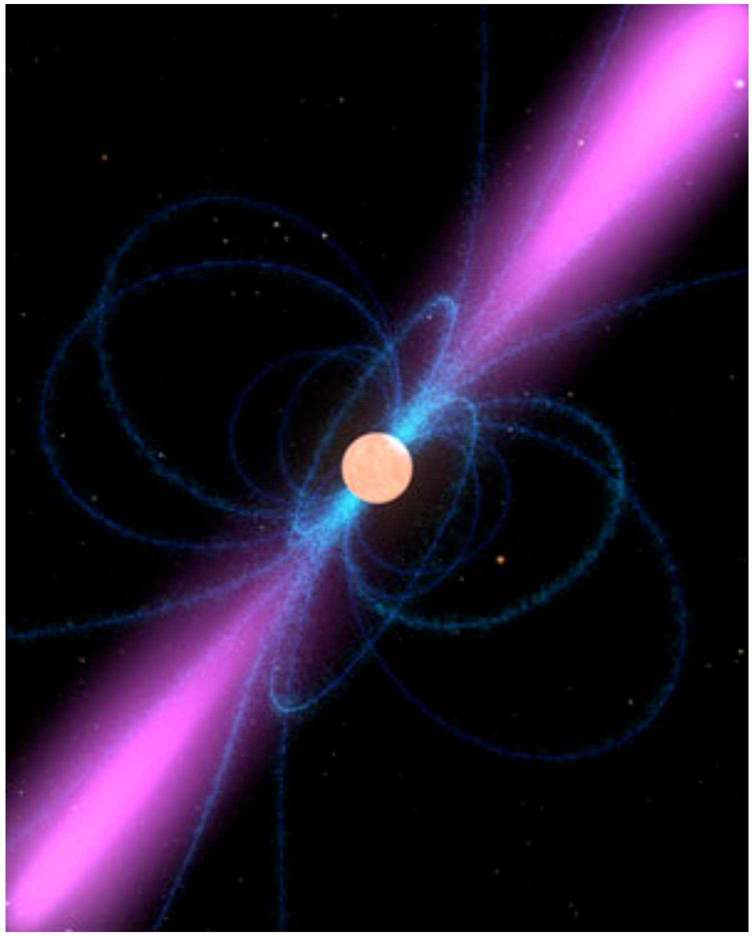


Pulsars

sources of cosmic rays and positrons ?



Pulsars
sources of cosmic rays and positrons ?



- pulse *P*

$$E = 0.5\ I\Omega^2 \approx 2\ 10^{46}\ I_{45} P_1^{-2}\ \mathrm{erg}$$

- spindown (spinup)

$$\dot{E} = I\Omega\dot{\Omega} \approx -4\ 10^{31}\ I_{45}\dot{P}_{-15}P_1^{-3}\ \mathrm{erg\ s^{-1}}$$

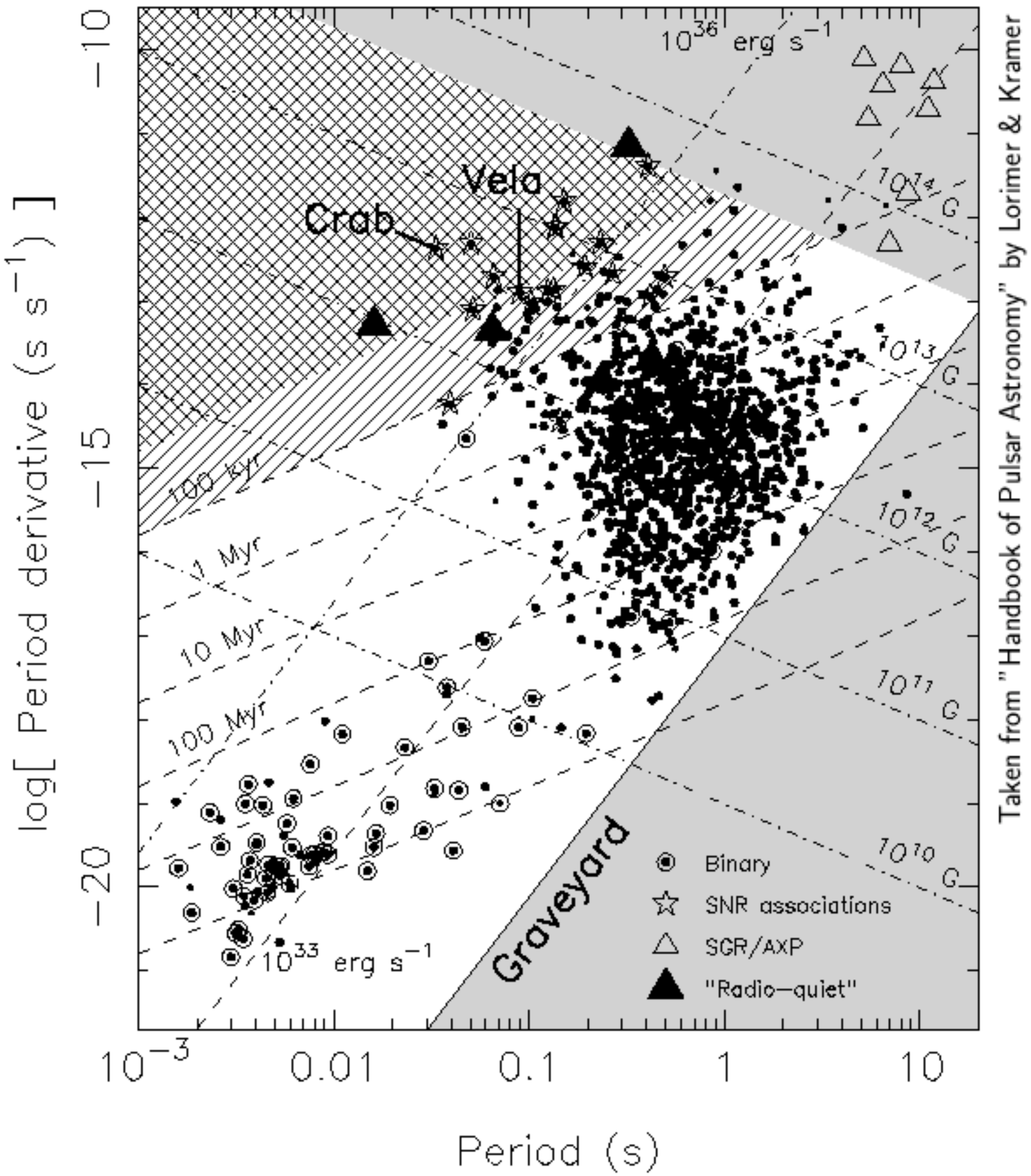
- age

$$\tau = 0.5 P\dot{P}^{-1}(1 - P_i^2 P^{-2}) \approx 15 P_1 \dot{P}_{-15}^{-1}\ \mathrm{Myr}$$

- magnetic dipole

$$L = \dot{E} \sim \frac{B^2 R^6 \Omega^4}{c^3} \quad \Rightarrow B \approx 10^{12}\ (P\dot{P}_{-15})^{1/2}\mathrm{G}$$

Pulsars come in many kinds



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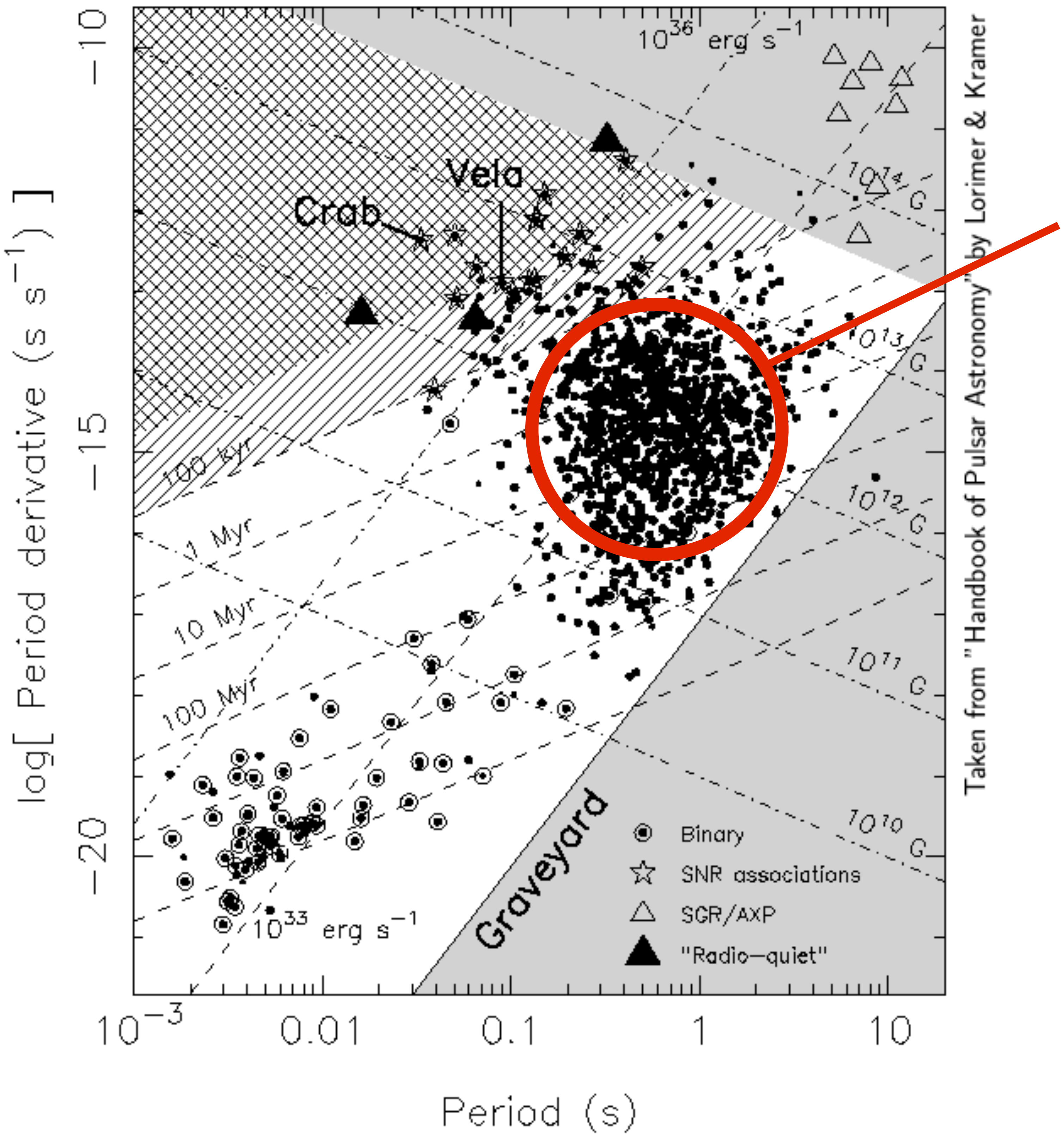
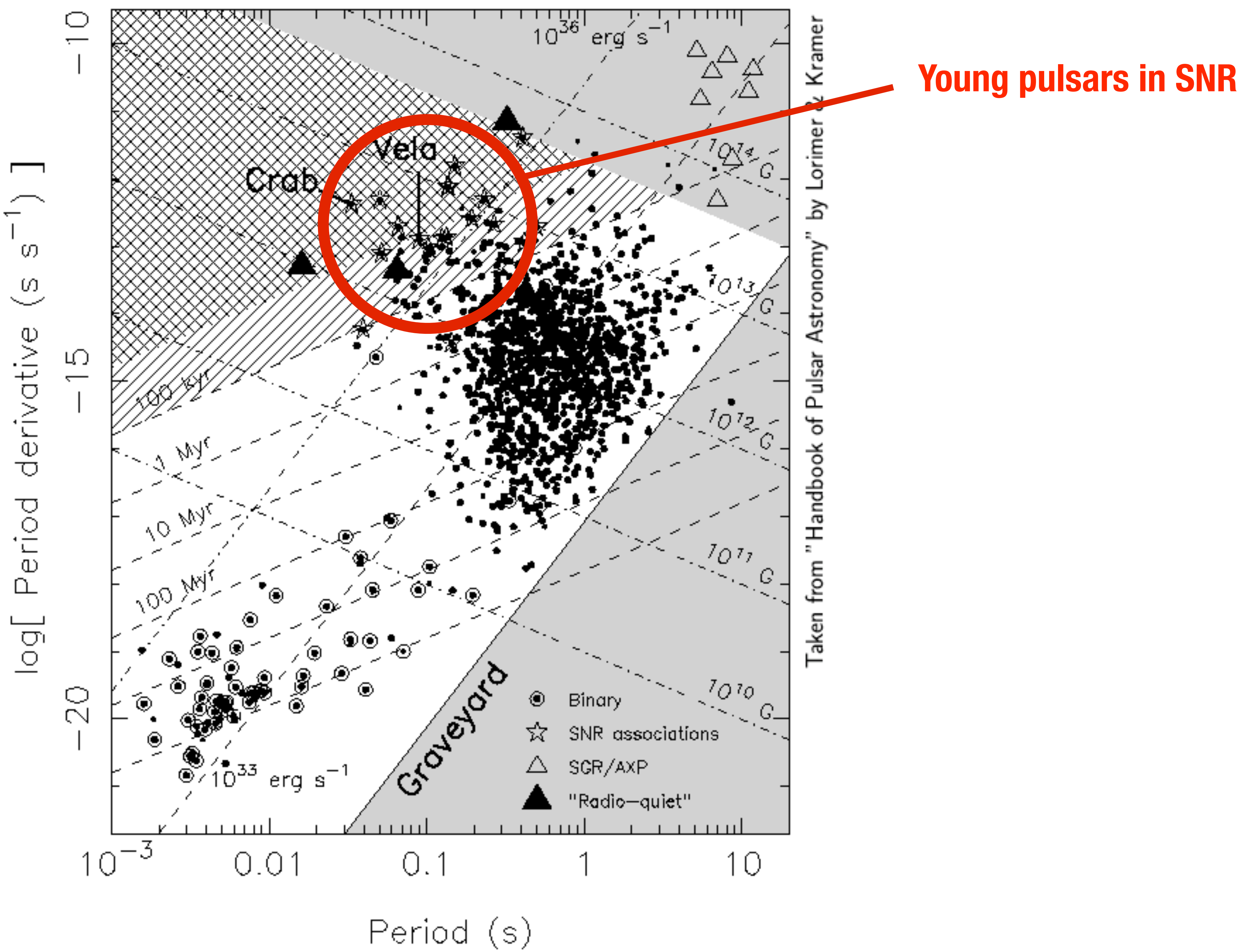


Typical radio pulsar

Pulsars come in many kinds



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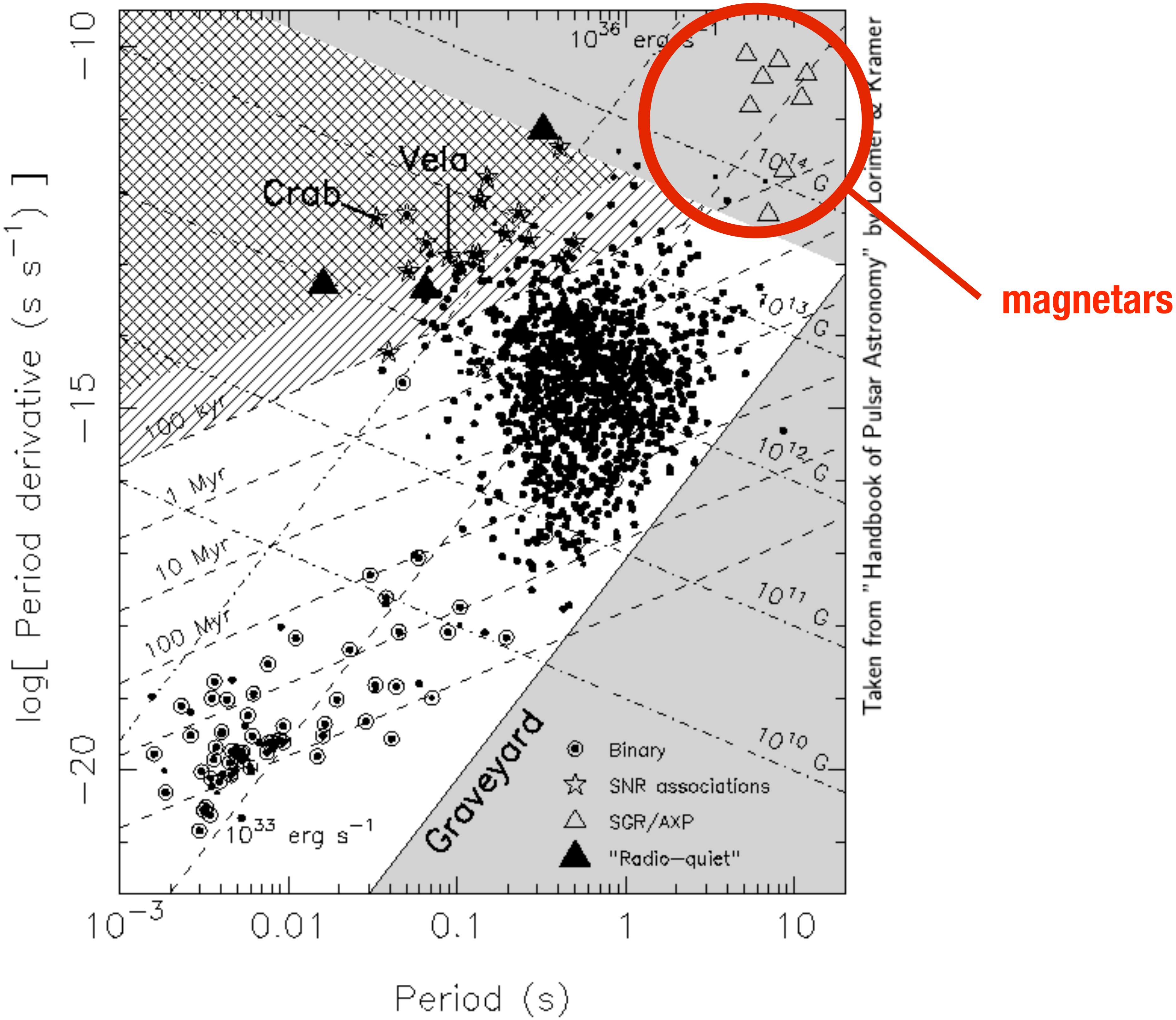

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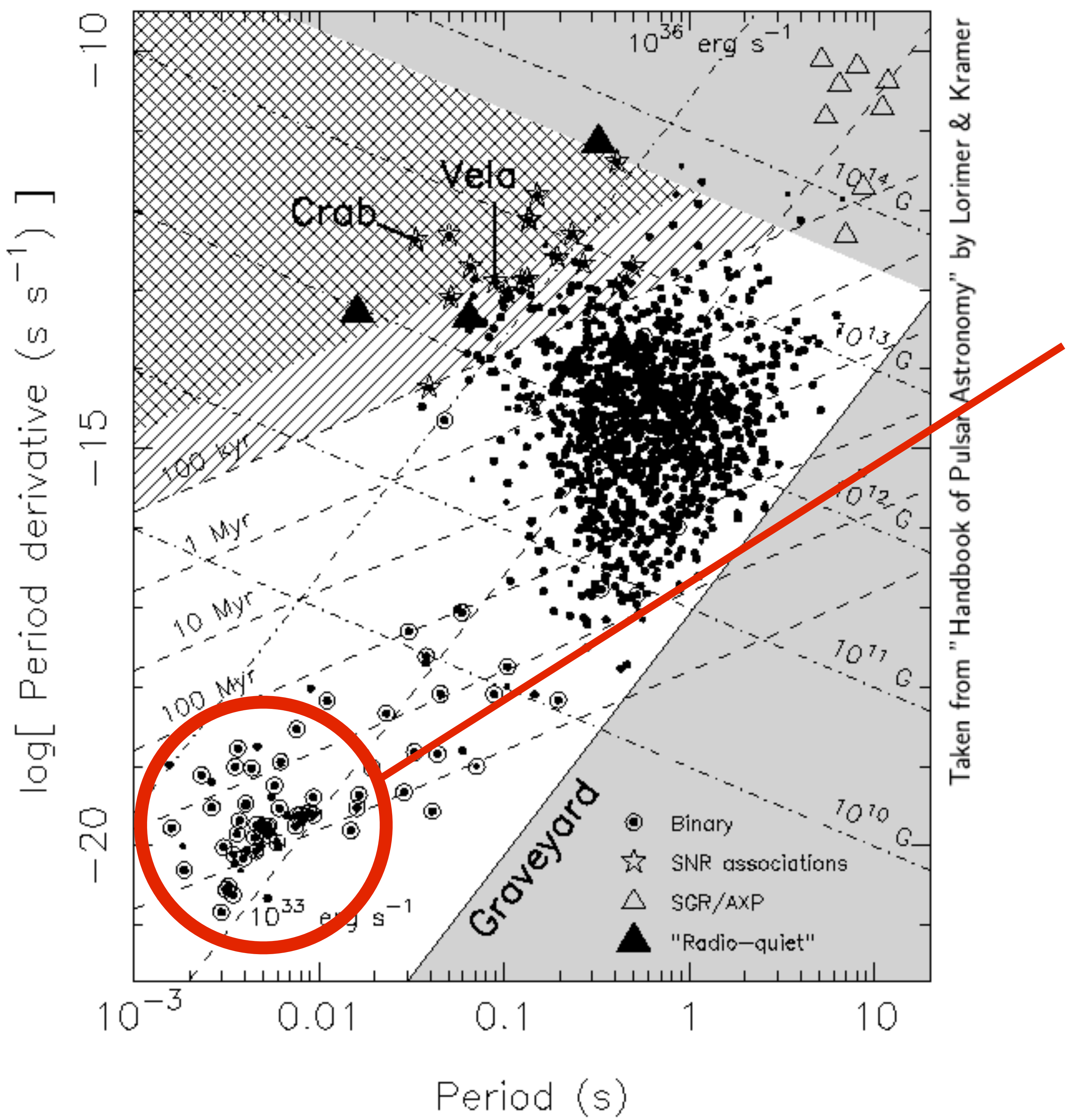
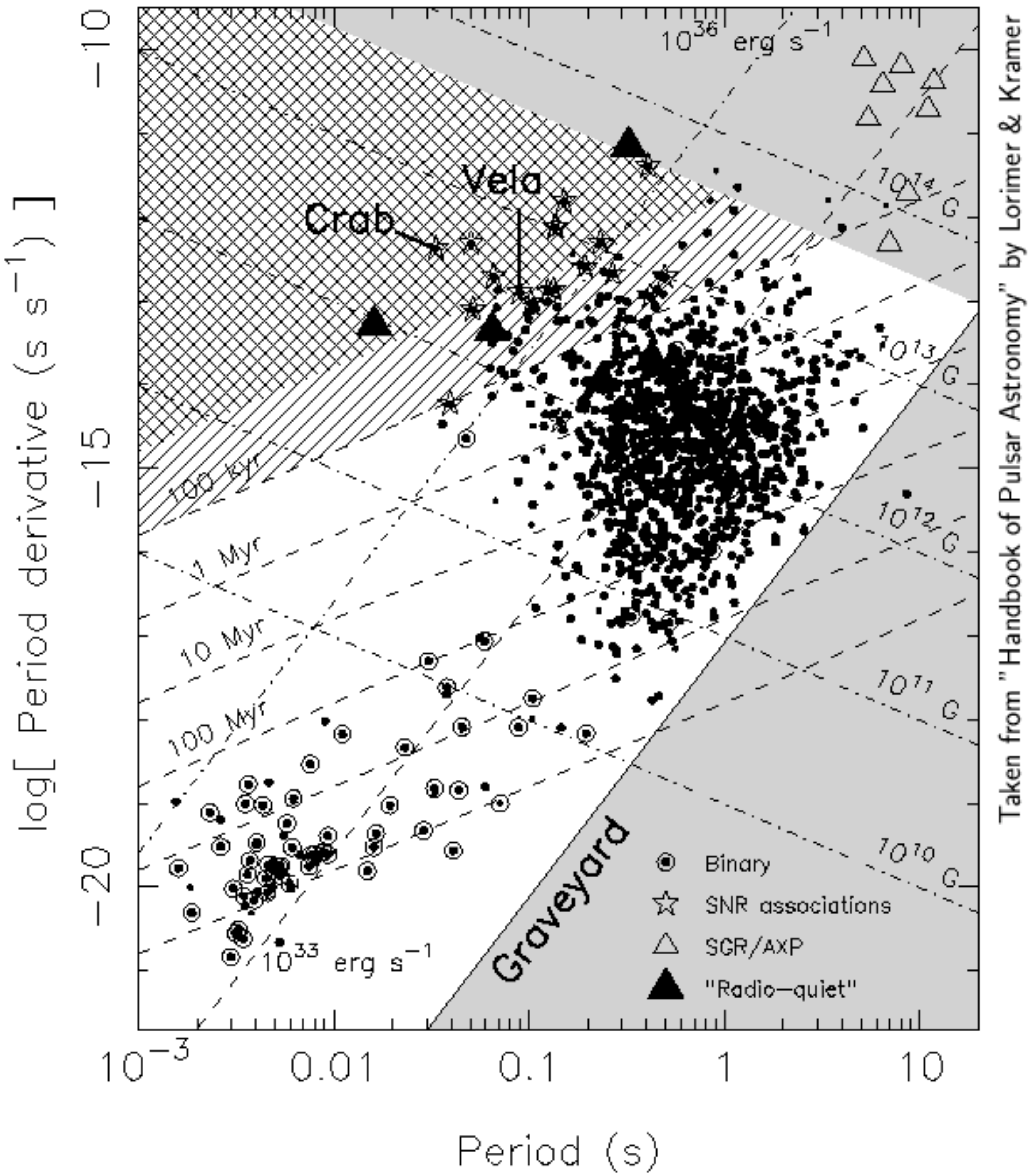


millisecond 'recycled' pulsars

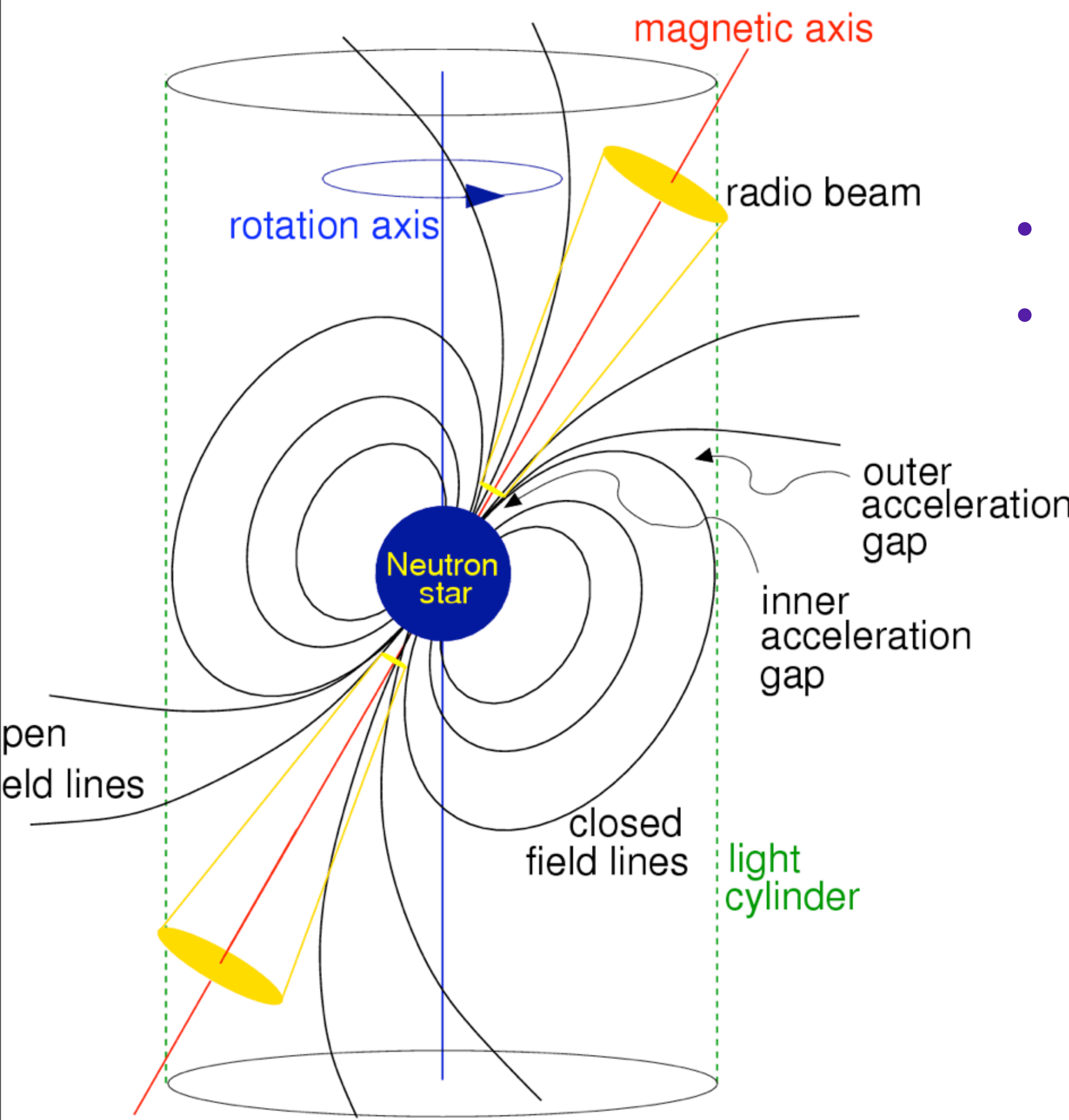
Pulsars come in many kinds



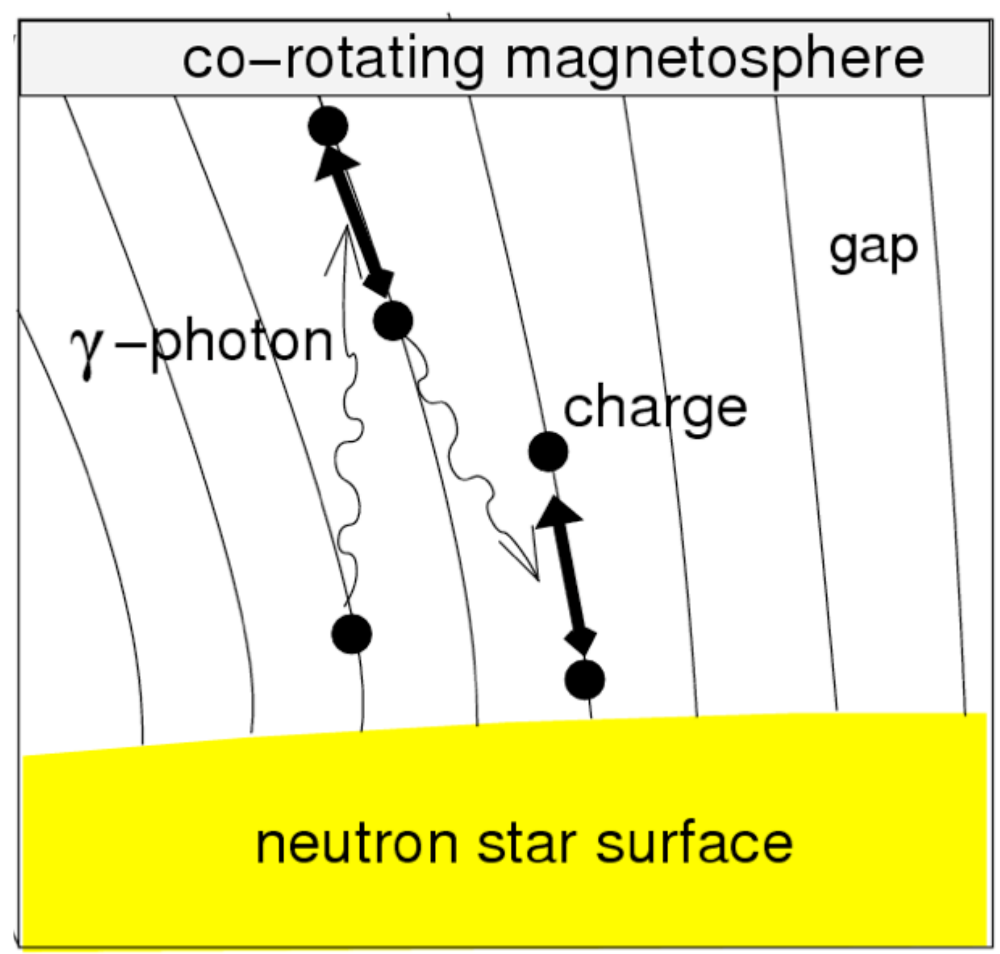
X-ray pulsars

accreting neutron stars
p~few ms to 1000 s

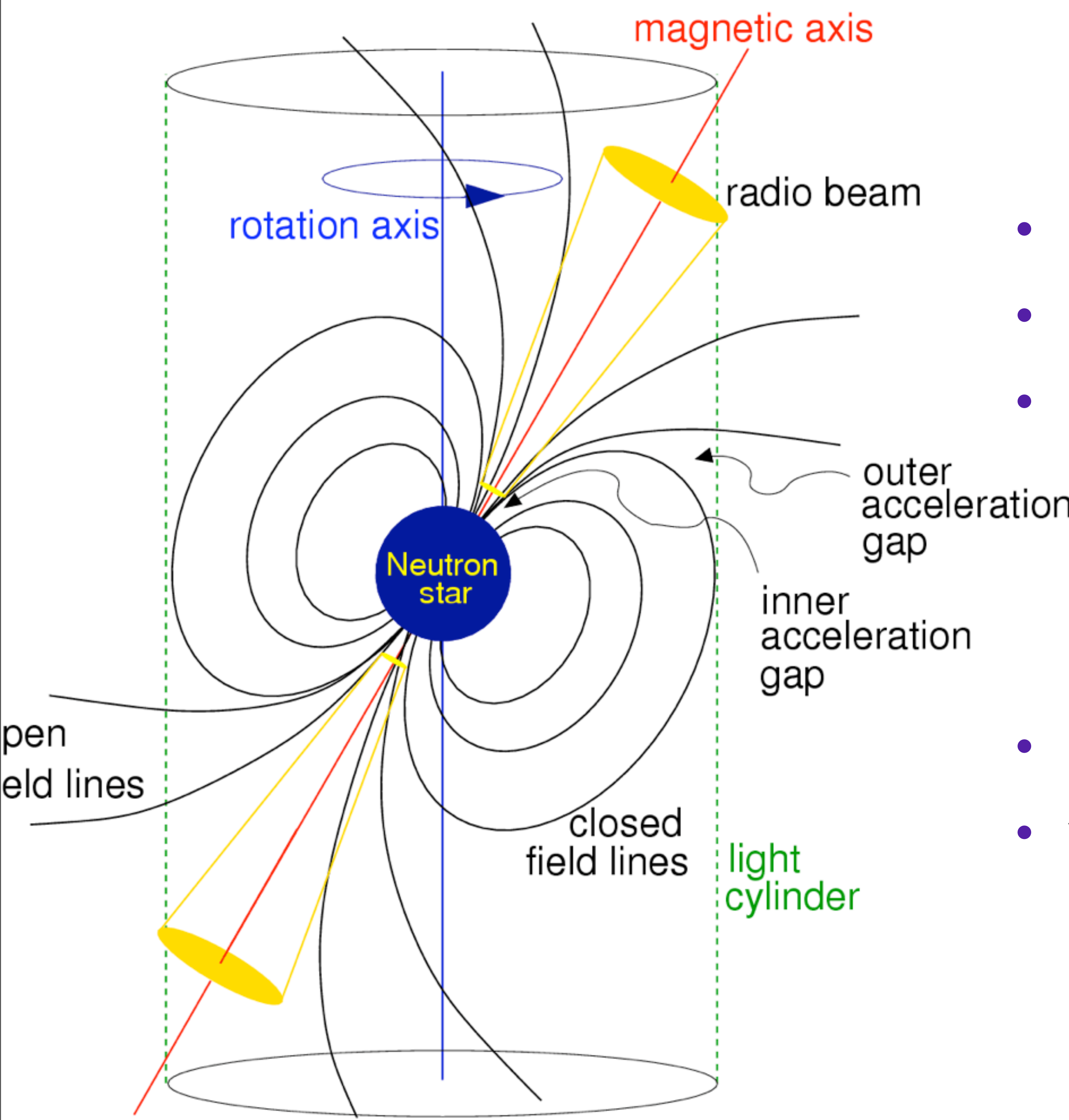
Magnetosphere



- electric field
- e^-e^+ pair production



Magnetosphere



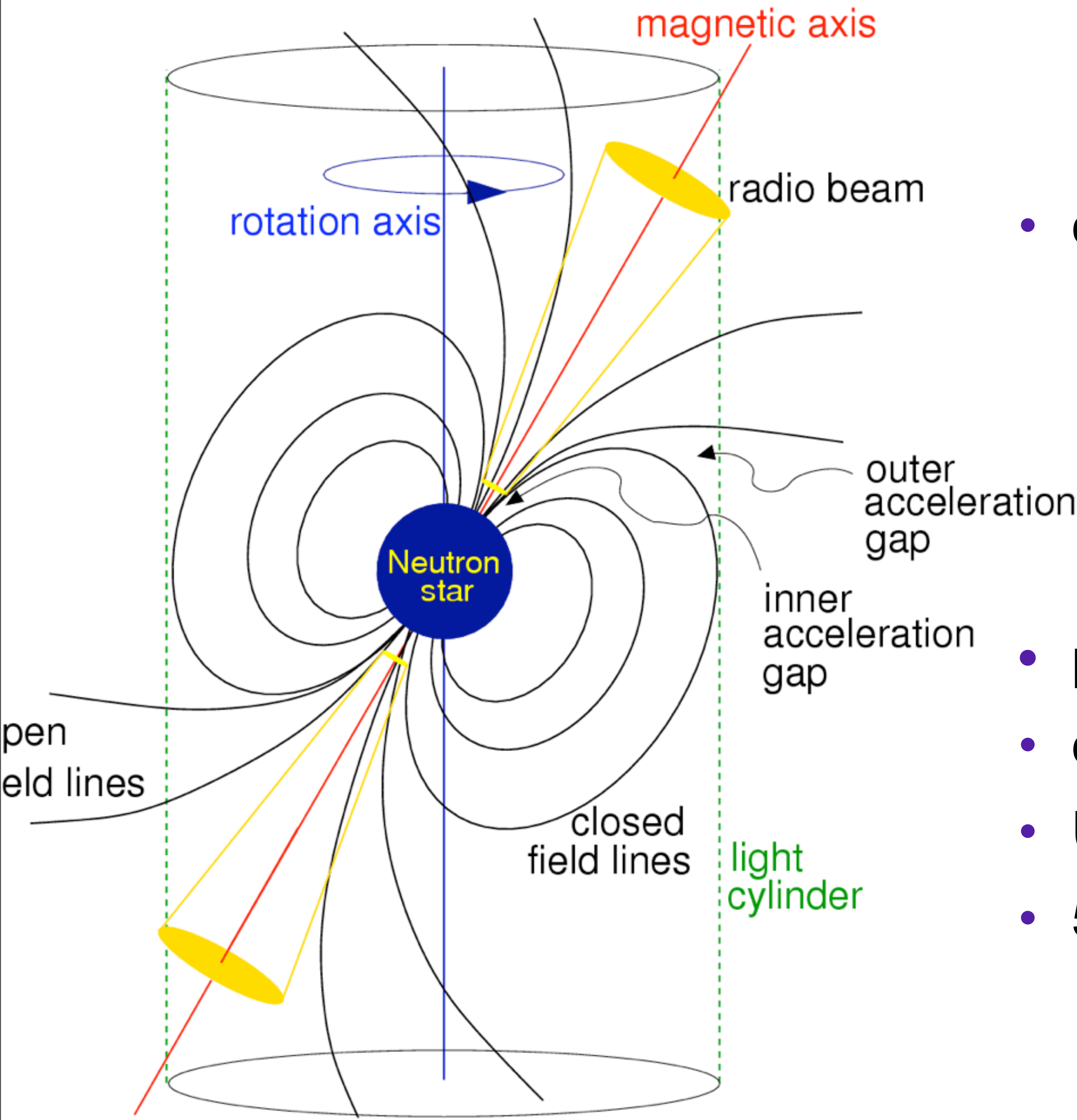
- electric field
- $e^- e^+$ pair production
- pairs fill magnetosphere

$$\mathbf{E} = -\frac{\mathbf{v}}{c} \wedge \mathbf{B} \qquad \rho = \frac{\nabla . \mathbf{E}}{4\pi} \approx -\frac{\mathbf{\Omega} \cdot \mathbf{B}}{2\pi c}$$

- **E** screened in co-rotating plasma
- voltage drop pole - last open field line

$$\Delta V = 7 \; 10^{12} \; B_{12} P^{-2} \; \mathrm{V}$$

Cosmic rays & pairs



- cosmic ray & pair energy and rate

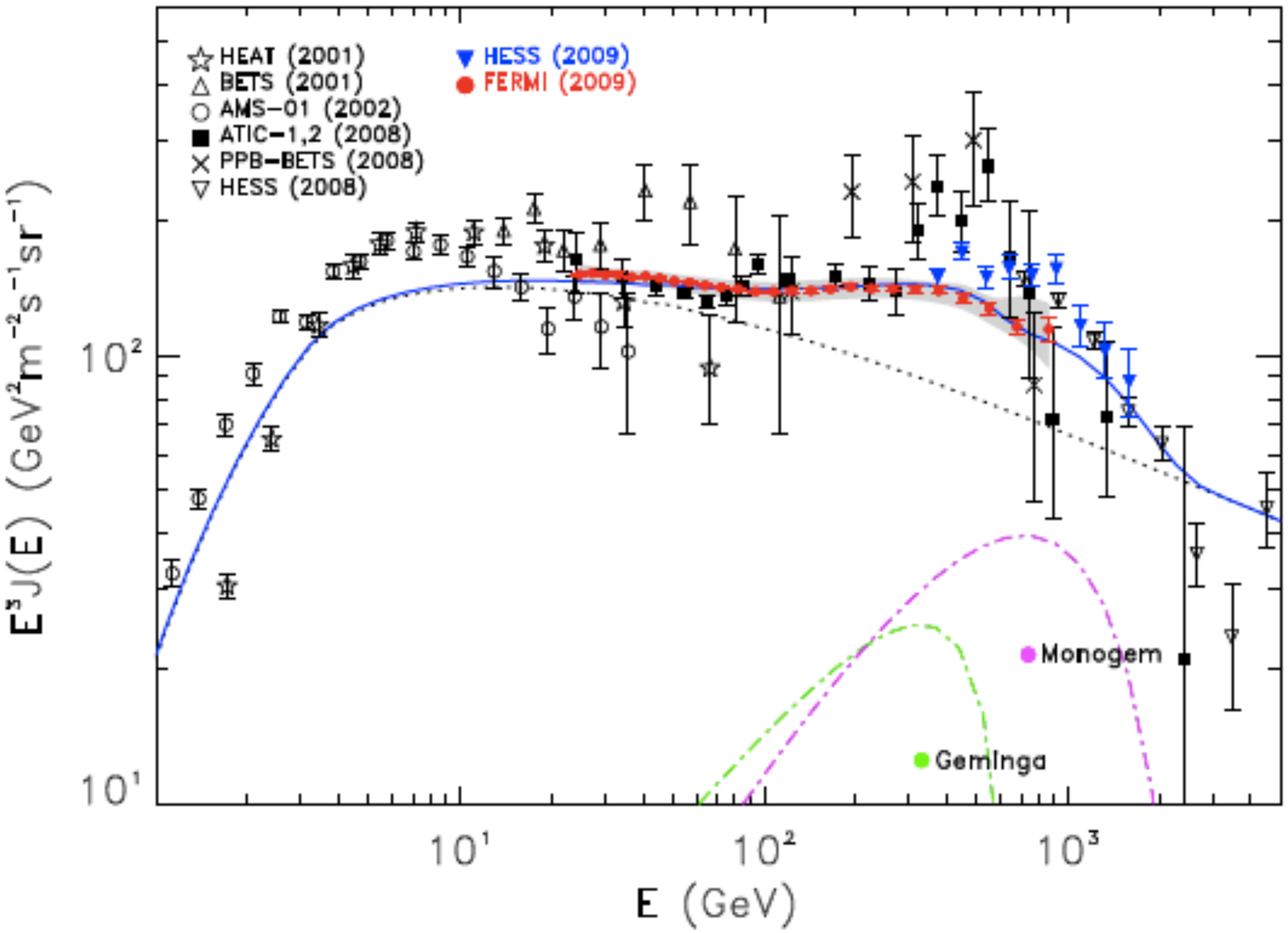
$$E_{\rm max} \approx 7\ 10^{12} Z B_{12} P^{-2}\ {\rm eV}$$

$$\dot{N} \approx 10^{30} \kappa B_{12} P_1^{-2} (Z^{-1})\ {\rm s}^{-1}$$

- **pulsars generate energetic e^-e^+**
- cosmic rays accelerated too ?
- UHECR from magnetars ?
- 511 keV contribution of ms pulsars ?

Blasi, Epstein & Olinto 2000
Giller & Lipsi 2002
Bednarek & Bartosik 2004
Wang, Pun, Cheng 2005

Pairs from nearby pulsar ?



Injection pairs

$E^{-1.6}\exp(-E/E_{cut})$

propagation

Monogem & Geminga pulsars

Hooper, Blasi, Serpico 2009
Grasso et al. 2009
...
Harding & Ramaty 1987

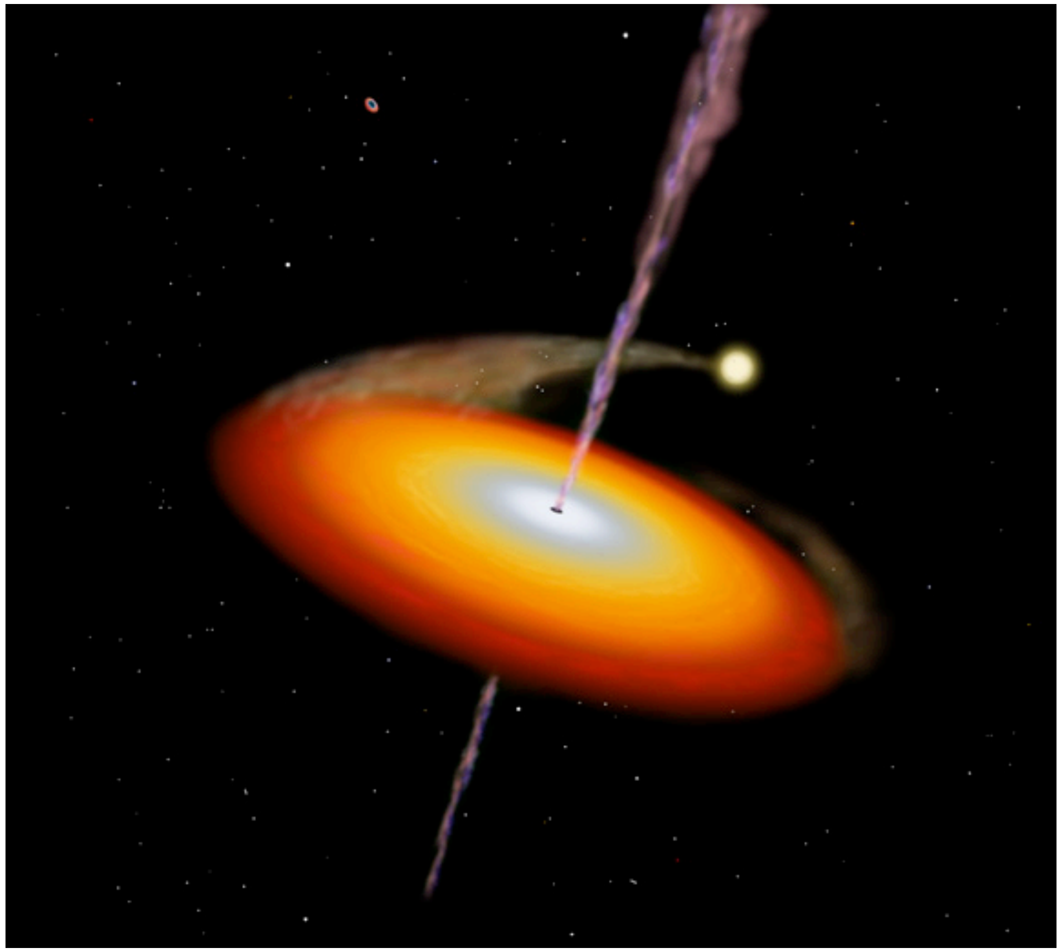
Binaries

sources of cosmic rays and positrons ?

- neutron star or black hole
- companion
- accretion

$$\dot{E} \sim \left(\frac{GM}{R}\right) \dot{M} \sim (0.05 - 0.4)\dot{M}c^2$$

- thermalized: X-ray emission
- what fraction can be tapped for non-thermal processes ?



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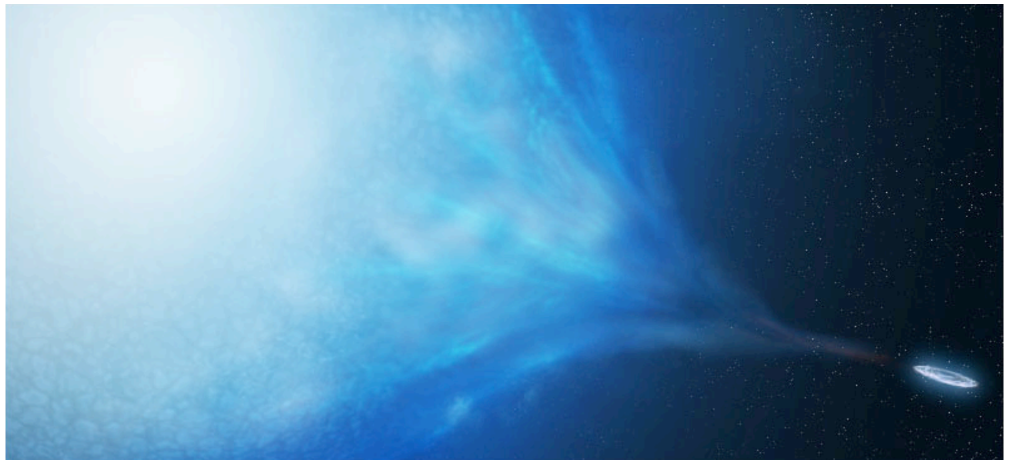
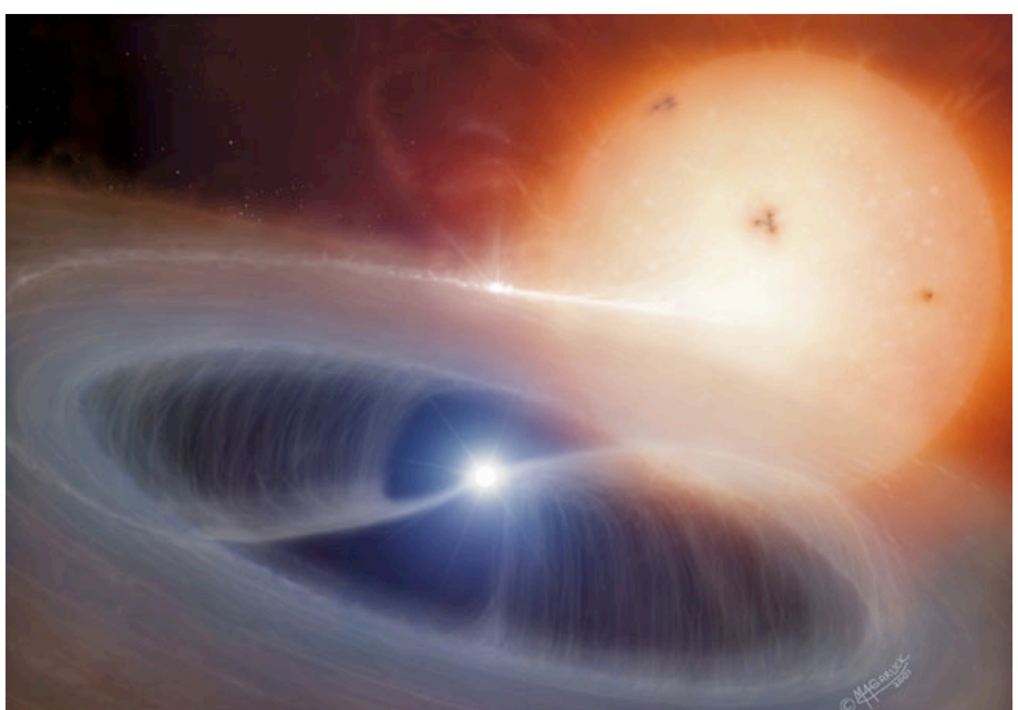
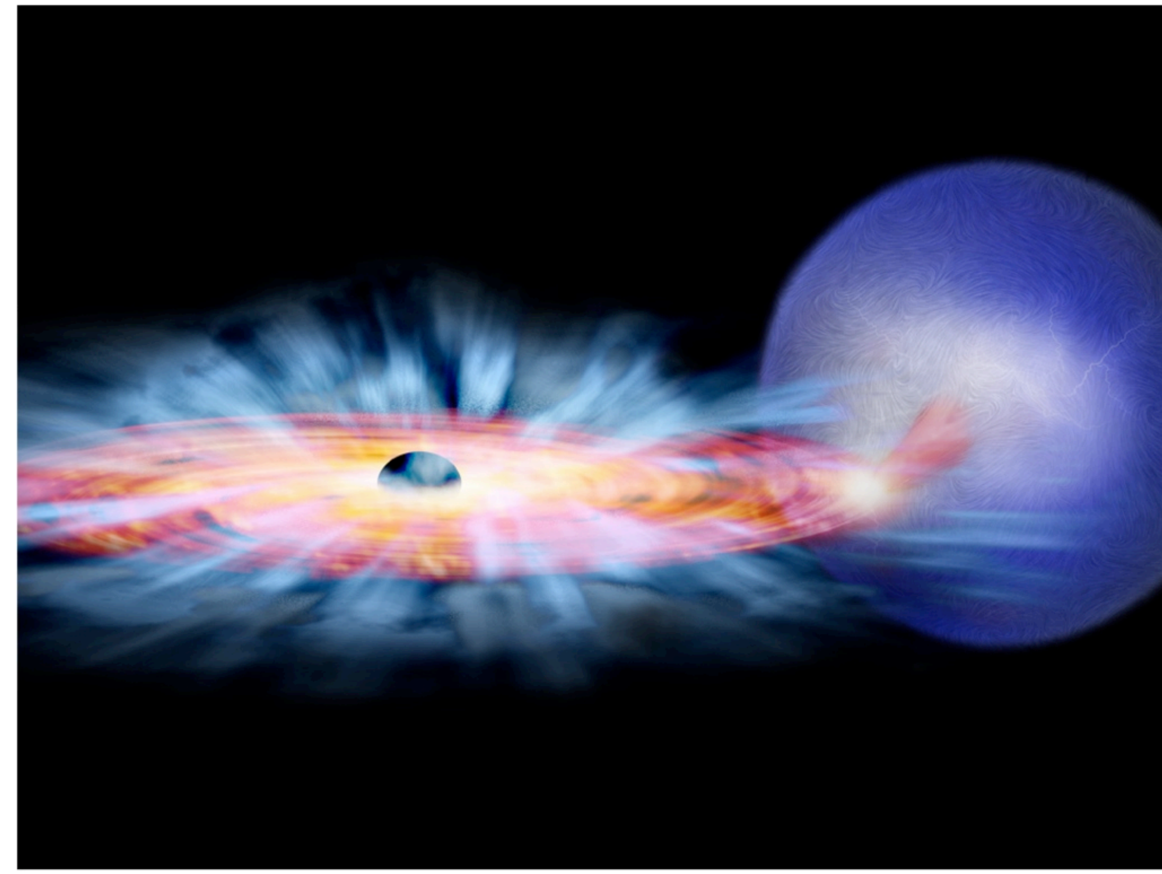


High-mass or low-mass companion
(wind or Roche lobe overflow)





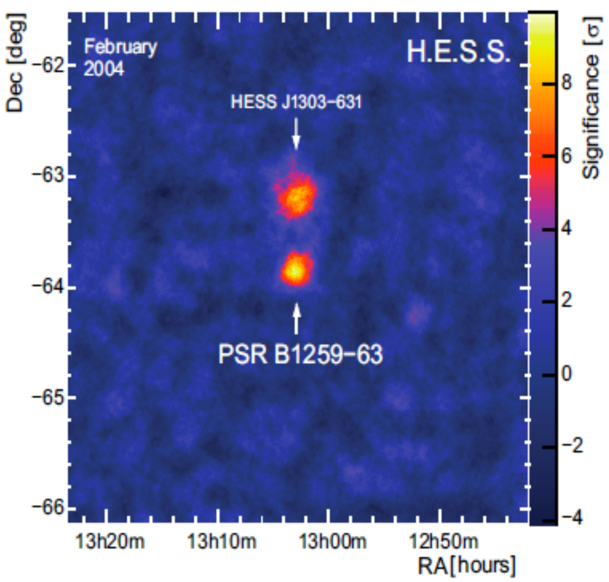
Black hole or neutron star

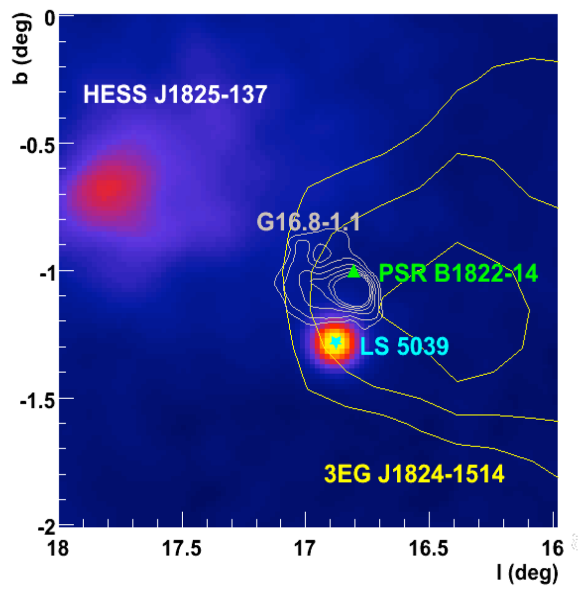
X-ray pulsars
relativistic jets: microquasars

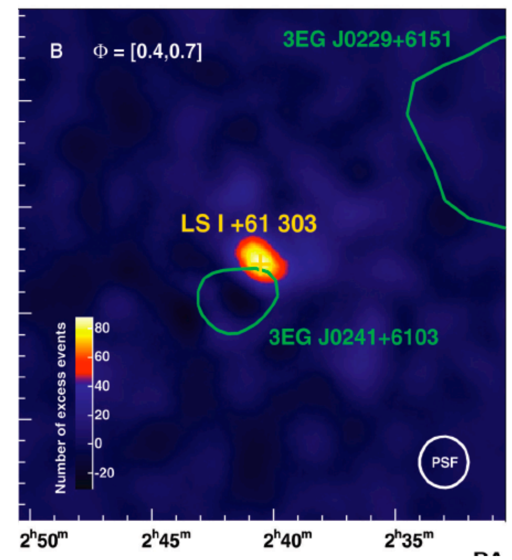
Gamma-ray binaries

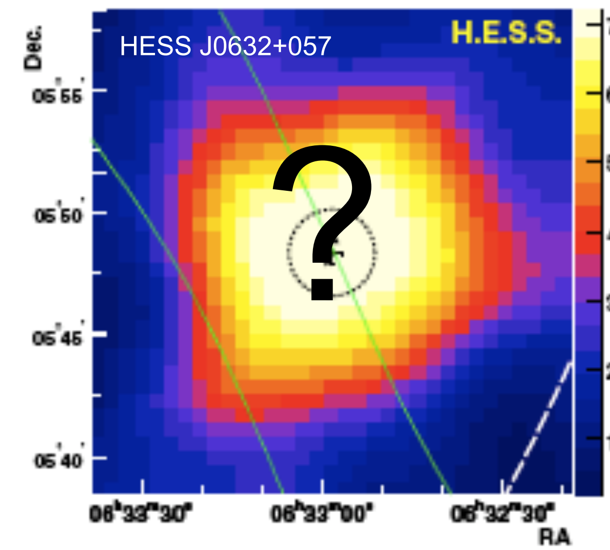
non-thermal radiation dominates

Gamma-ray binaries







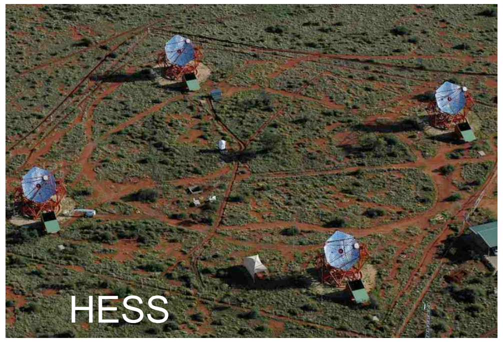


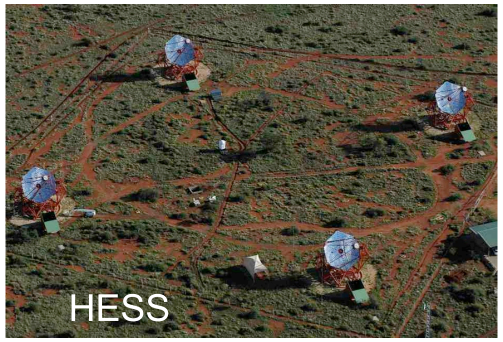
PSR B1259-63

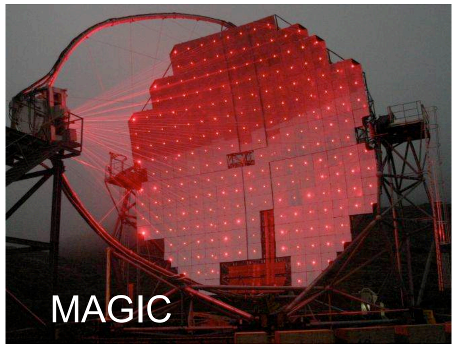
LS 5039

LS I+61 303

HESS J0632+057







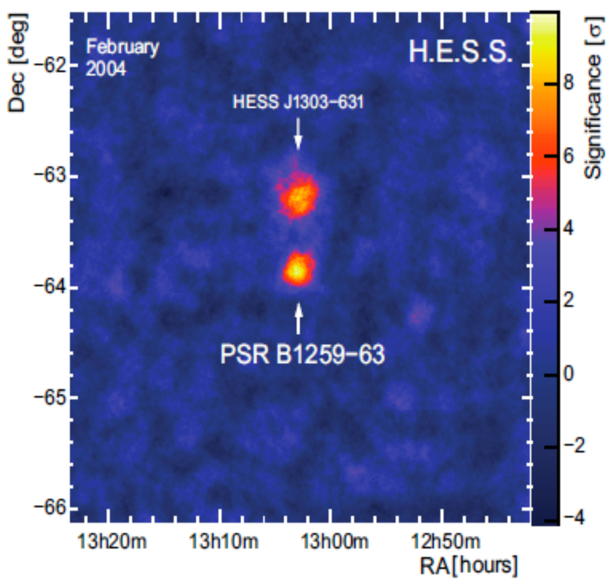
2004

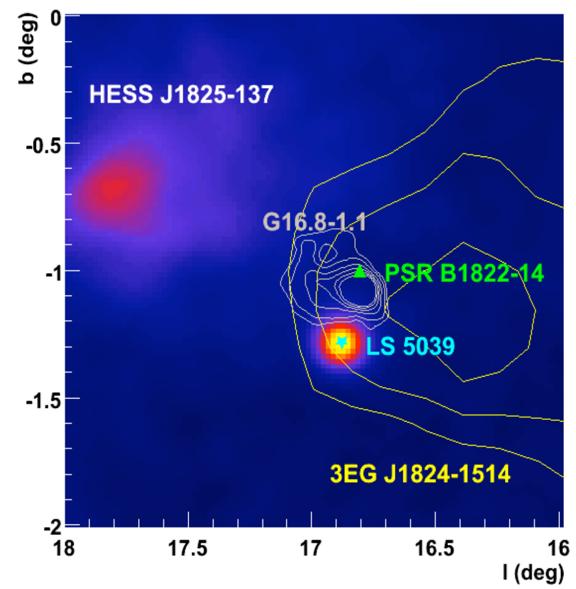
2005

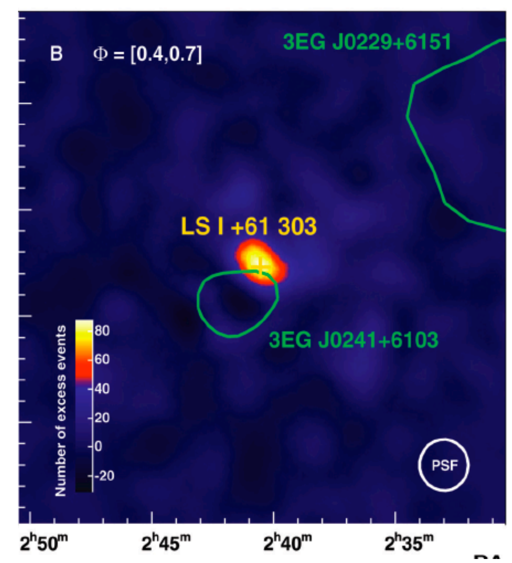
2008

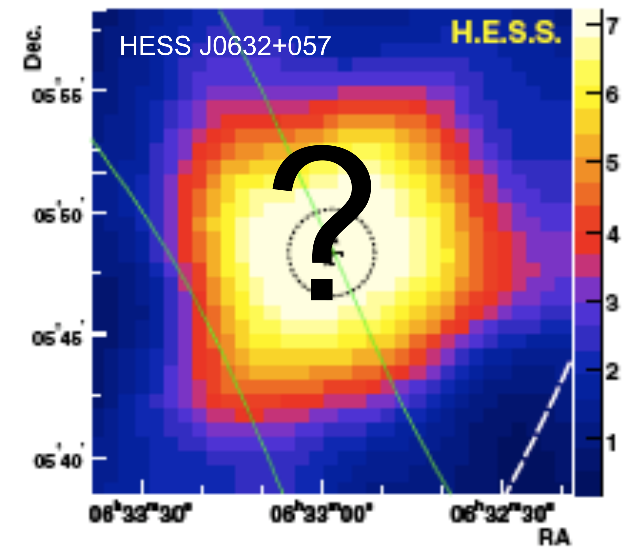
2006

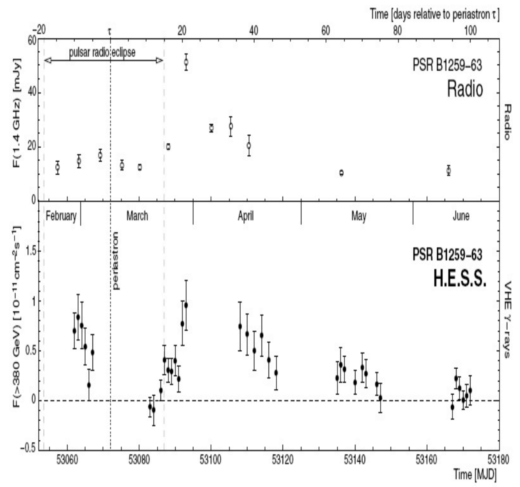
Gamma-ray binaries

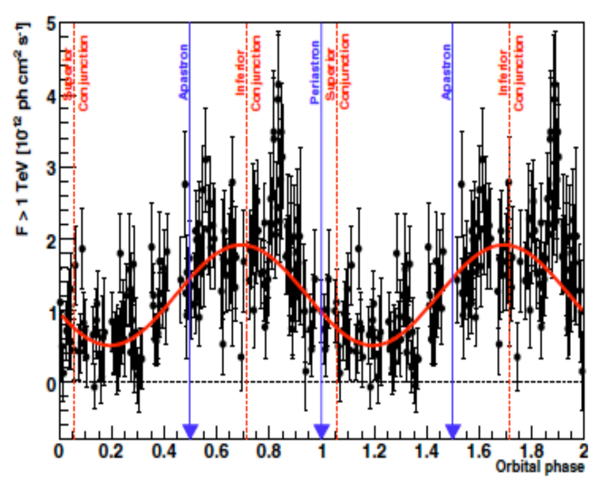


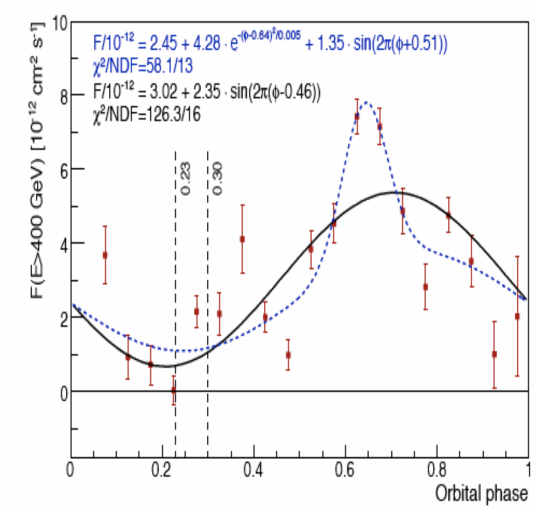








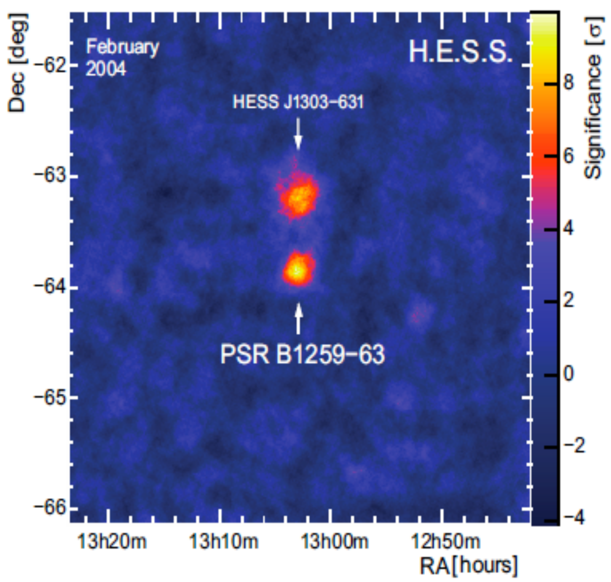


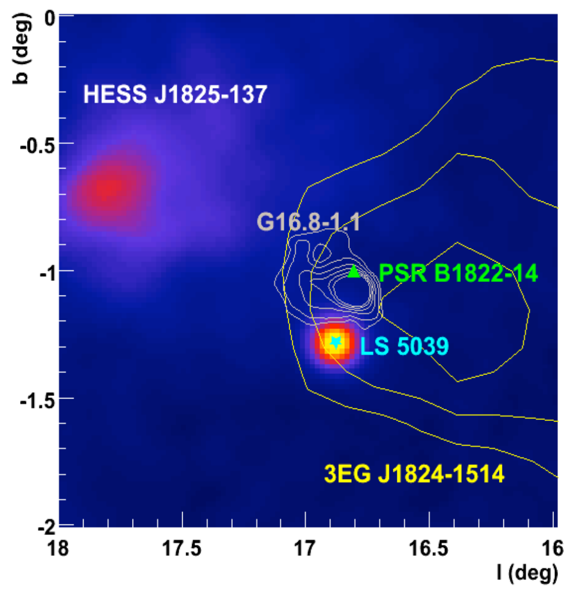


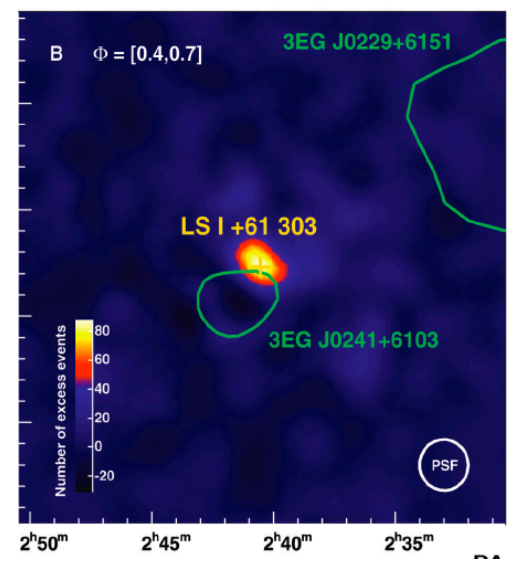
?

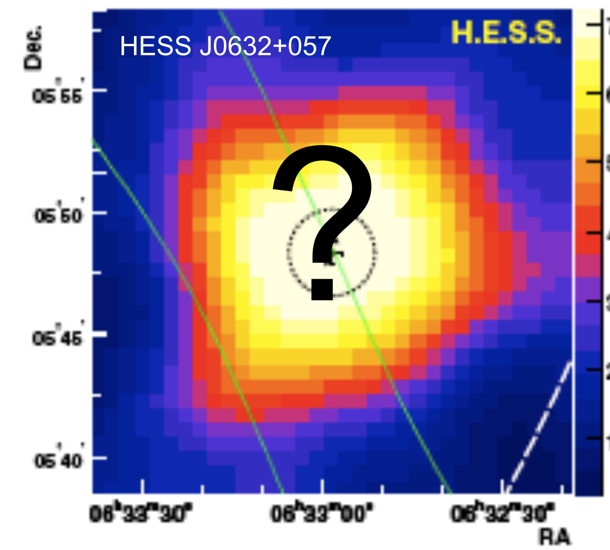
Variable VHE sources on orbital period

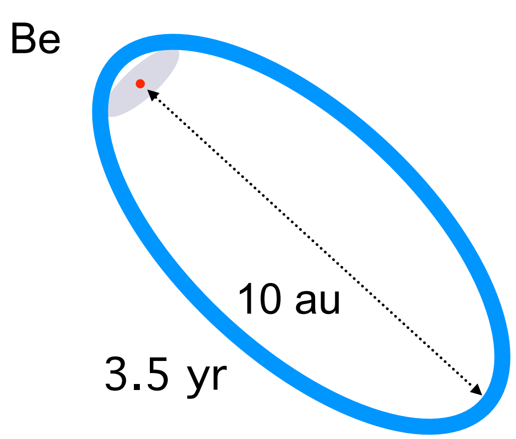
Gamma-ray binaries

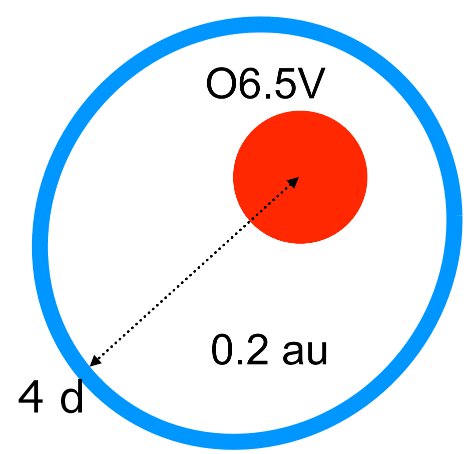


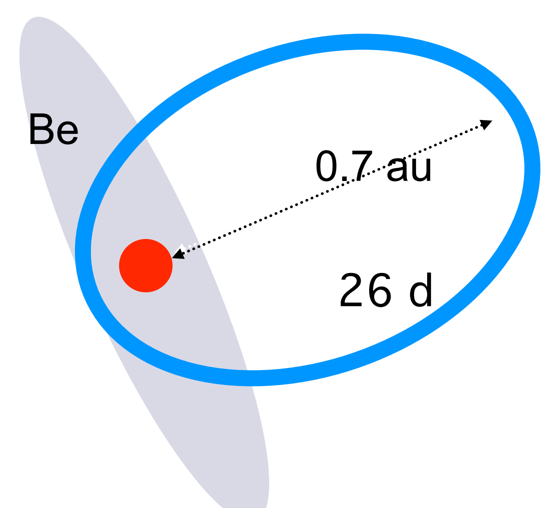


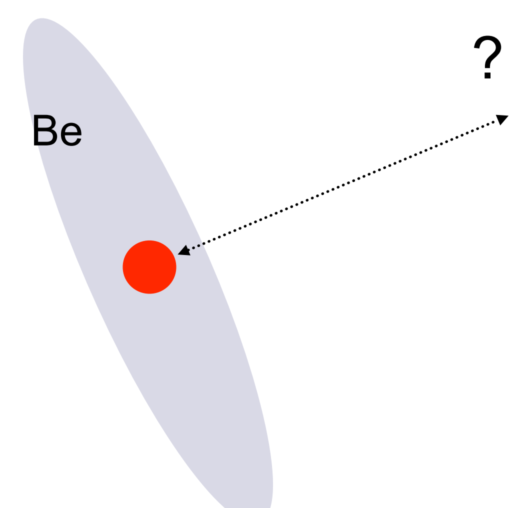






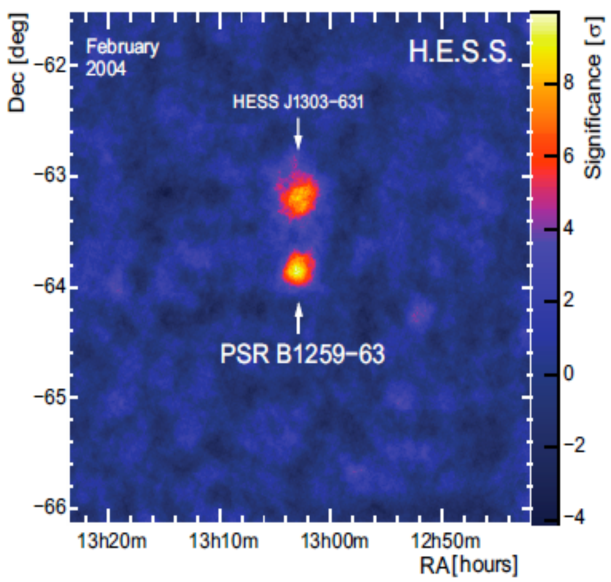


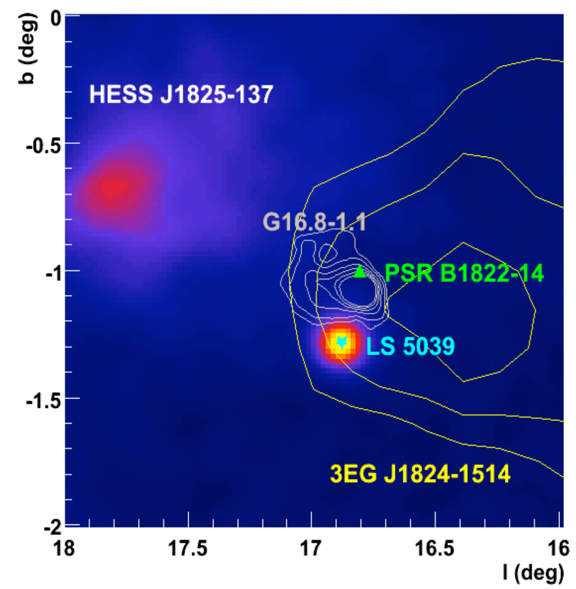


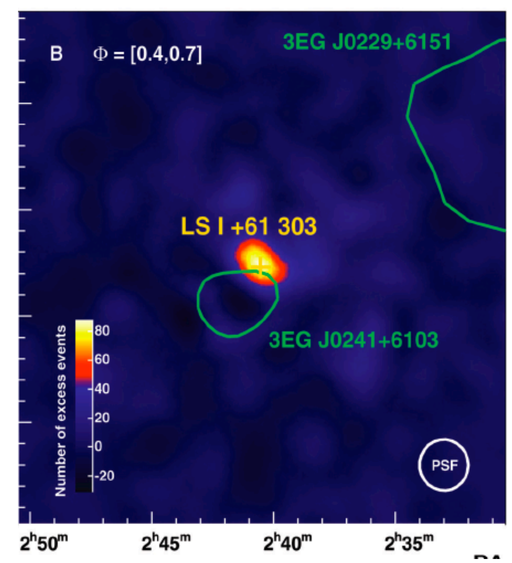


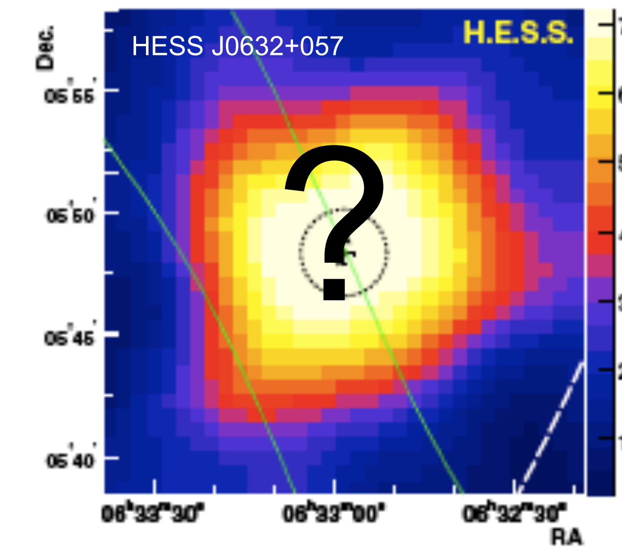
All have massive stars

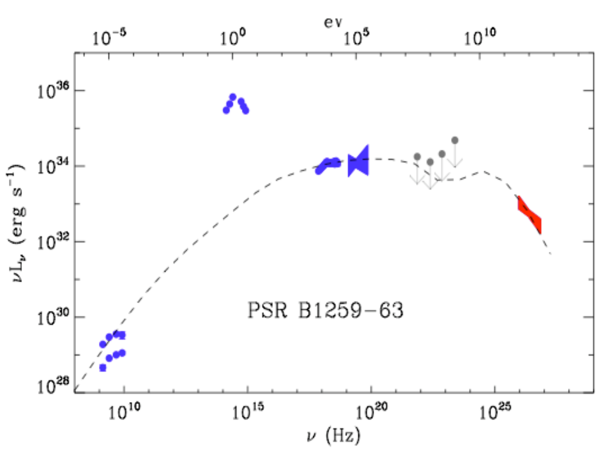
Gamma-ray binaries

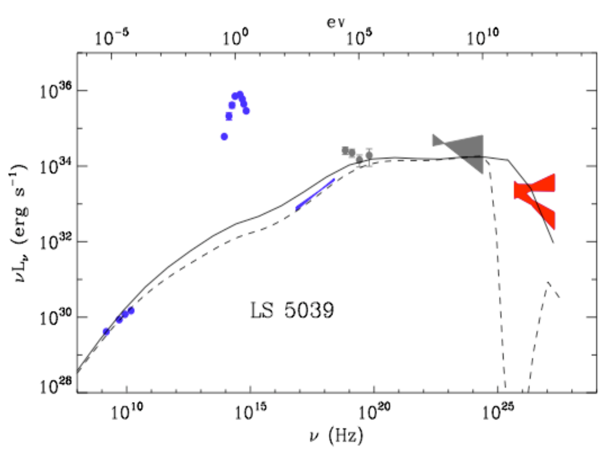


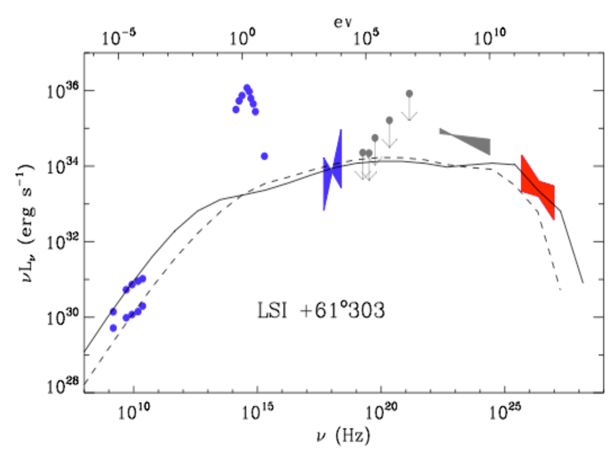


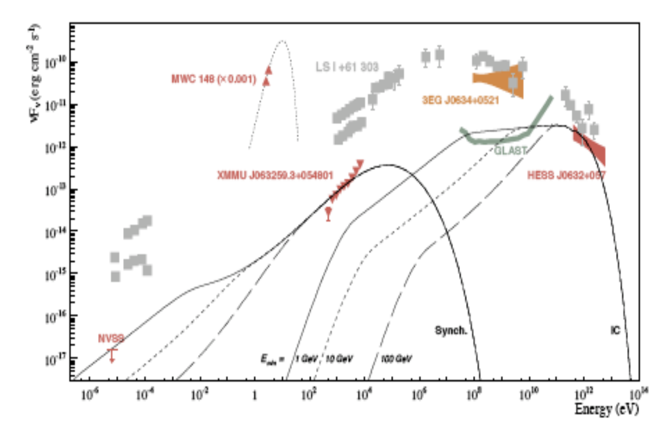








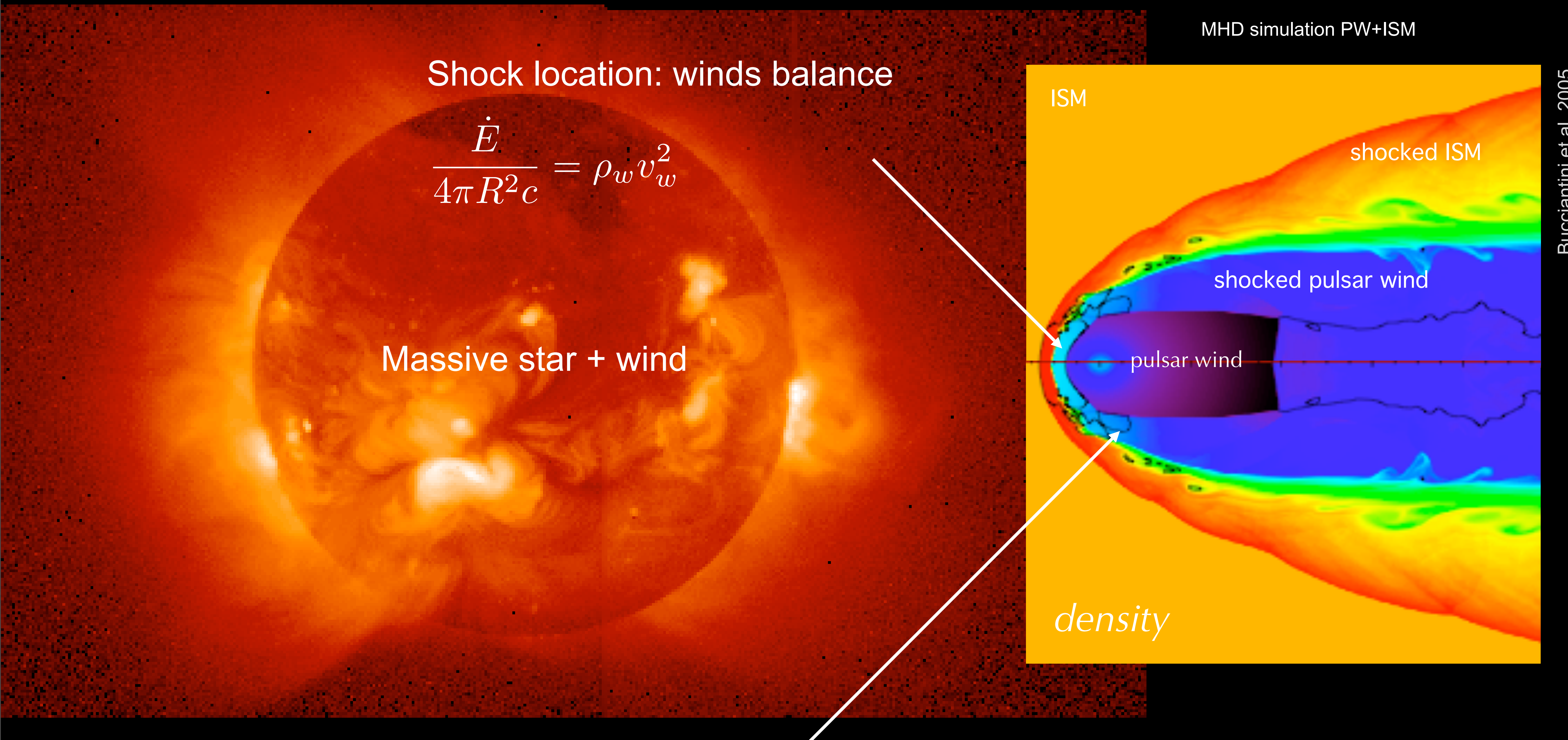




All are radio sources: rare in HMXBs
most have GeV counterparts, **HE gamma-ray dominates non-stellar output**

Compact Pulsar Wind Nebula

scaled to LS 5039



PSR B1259-63 is a 48 ms radio pulsar with spindown power 8 10^{35} erg/s
VHE emission ~ 0.1% of spindown power as in PWN

Rotation-powered, not accretion-powered

Gamma-gamma opacity

$$\epsilon_{\min} \approx 60 \frac{(10\ \mathrm{eV}/kT_\star)}{(1+\cos\psi)}\ \mathrm{GeV}$$

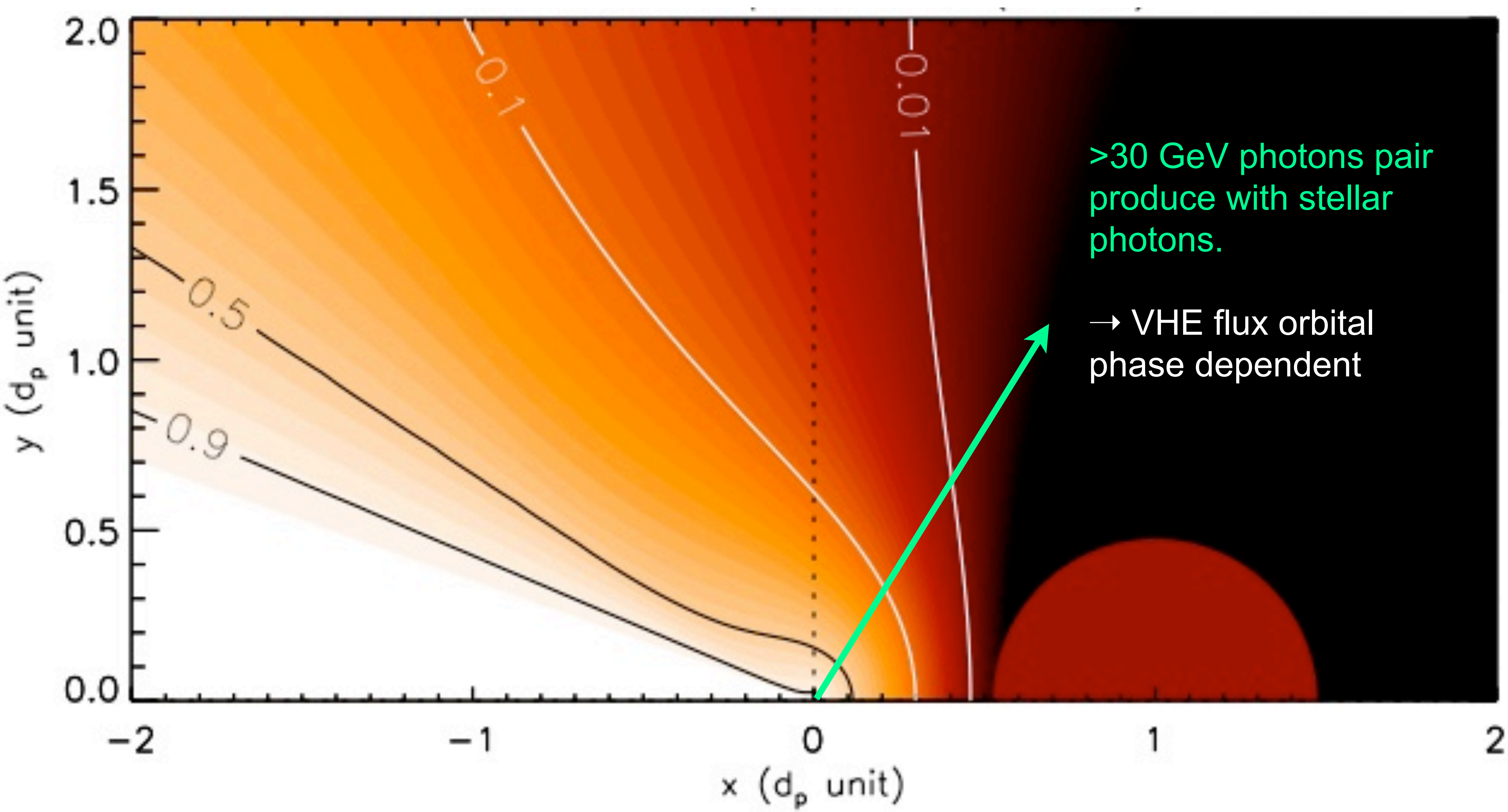


Figure: Benoît Cerutti

Pair production

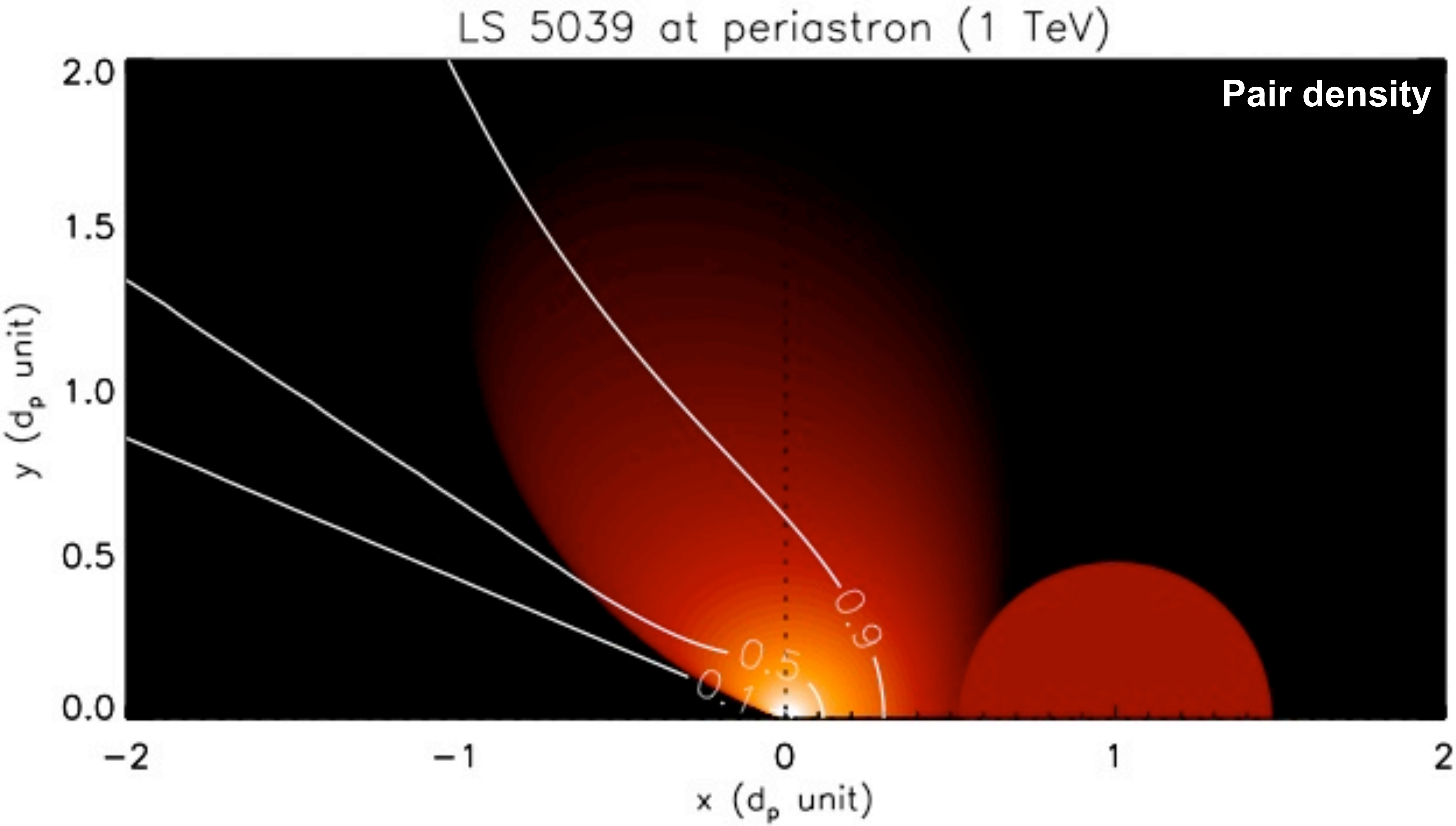
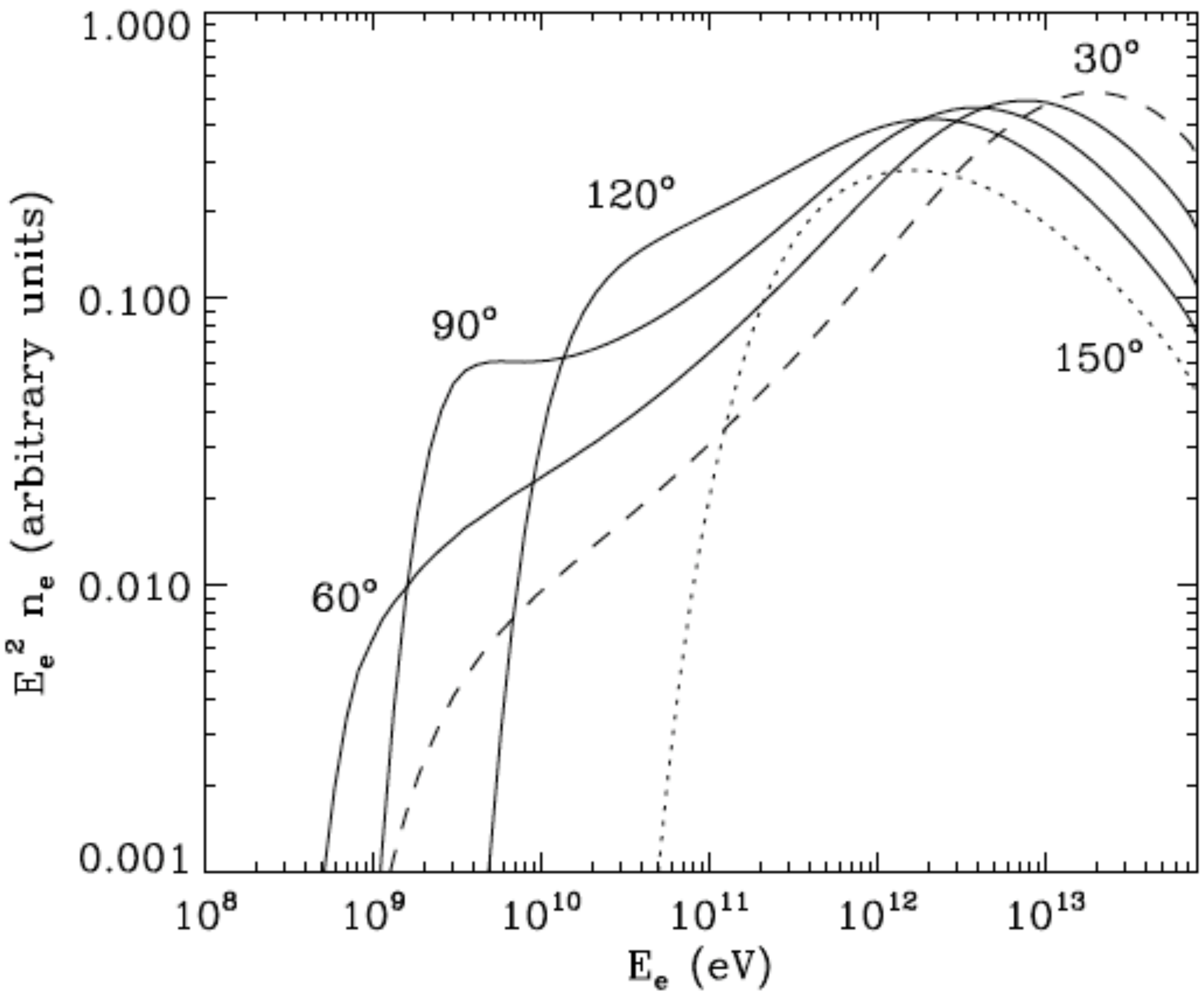


Figure: Benoît Cerutti

Pair production



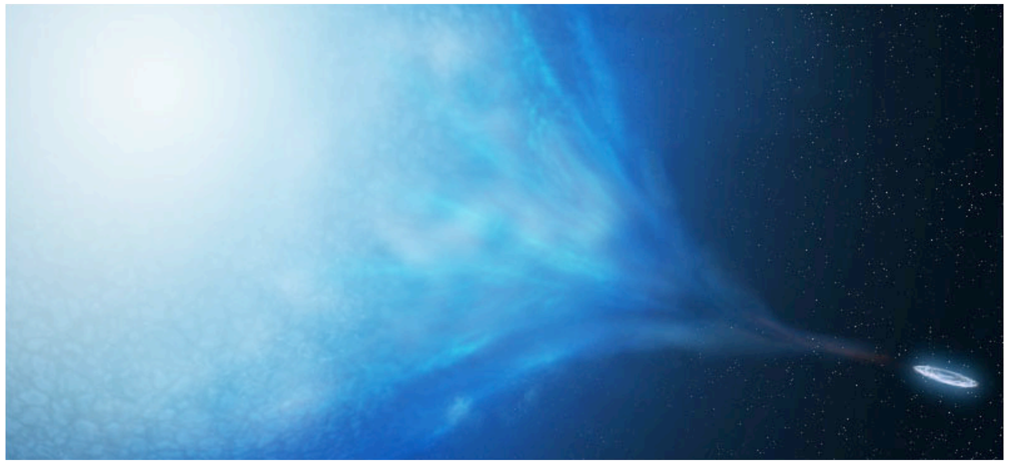
- average over angles

  $< \dot{N} > \sim 5 \cdot 10^{35}\ \mathrm{s}^{-1}$

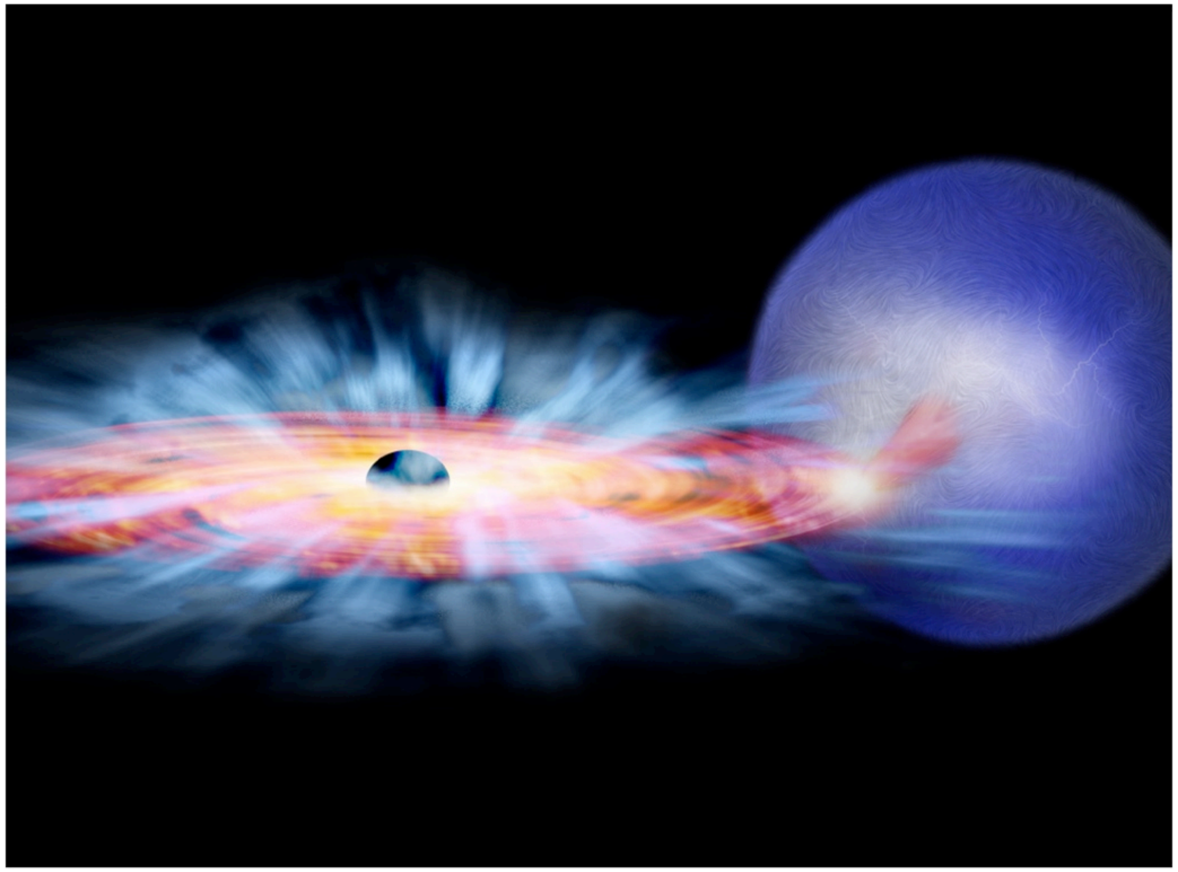
- high <E>: escape and annihilate in ISM
- young pulsars, short lifetime before X-ray pulsar turns on: ~ 100 systems in our Galaxy
- $\gamma\gamma$ **pairs unobservable.**

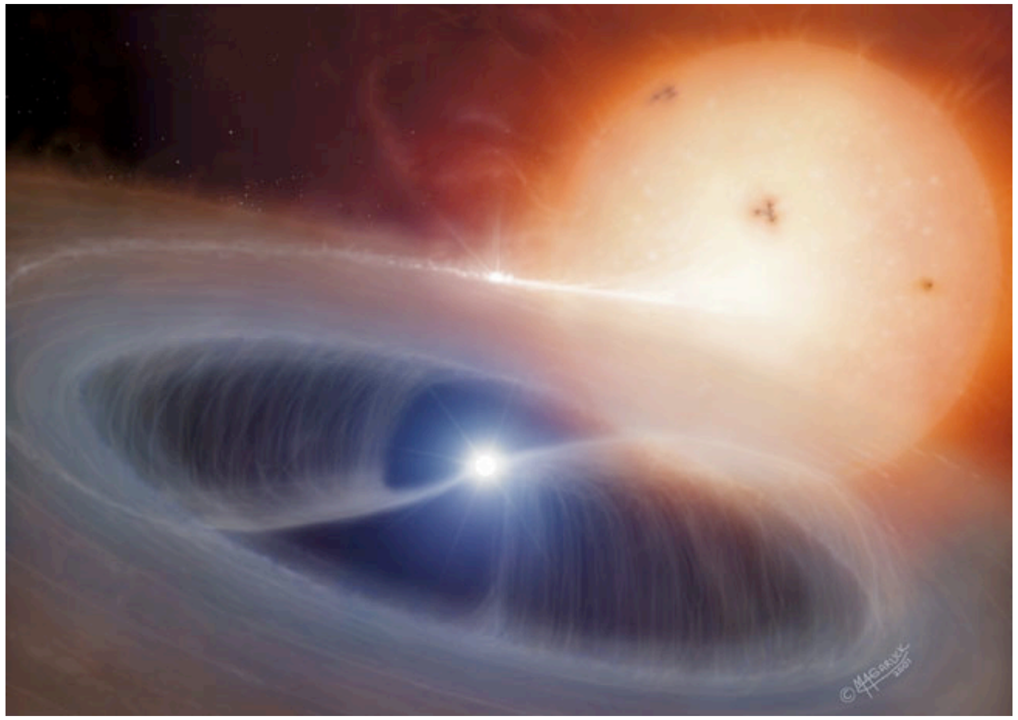
Cerutti et al. 2009, submitted

Binaries come in many kinds



High-mass or low-mass companion
(wind or Roche lobe overflow)





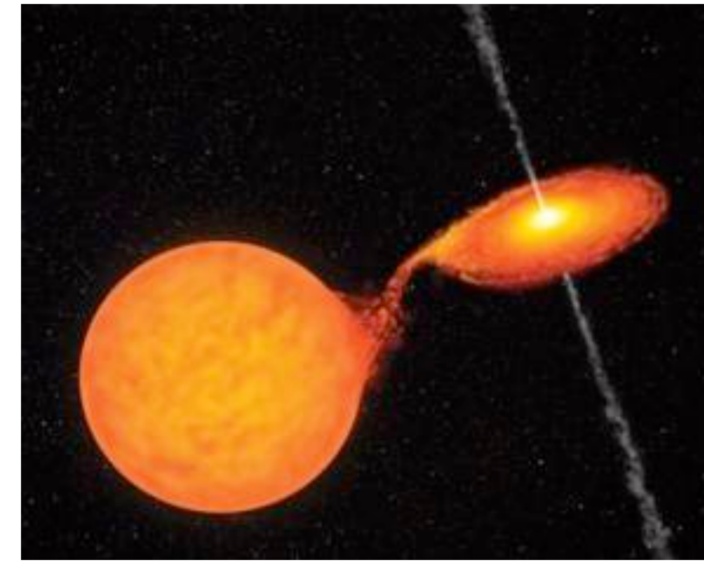
Black hole or neutron star

X-ray pulsars
relativistic jets: microquasars

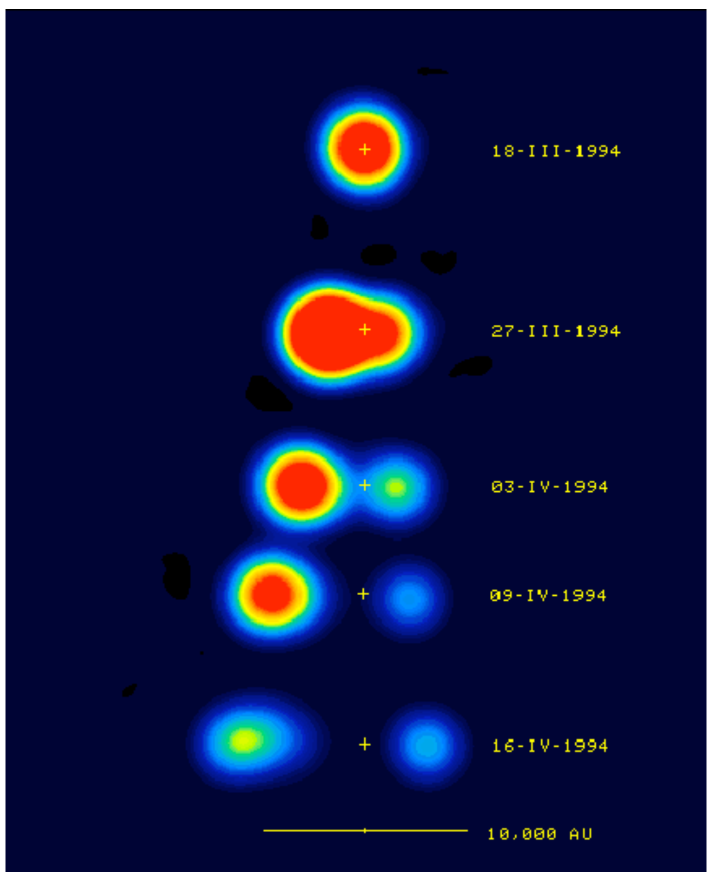
Gamma-ray binaries

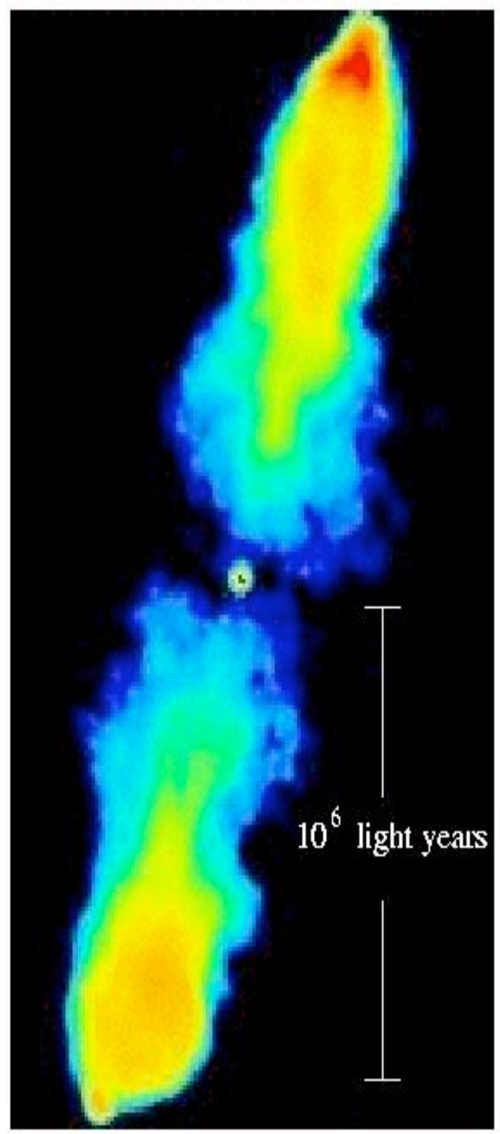
non-thermal radiation dominates

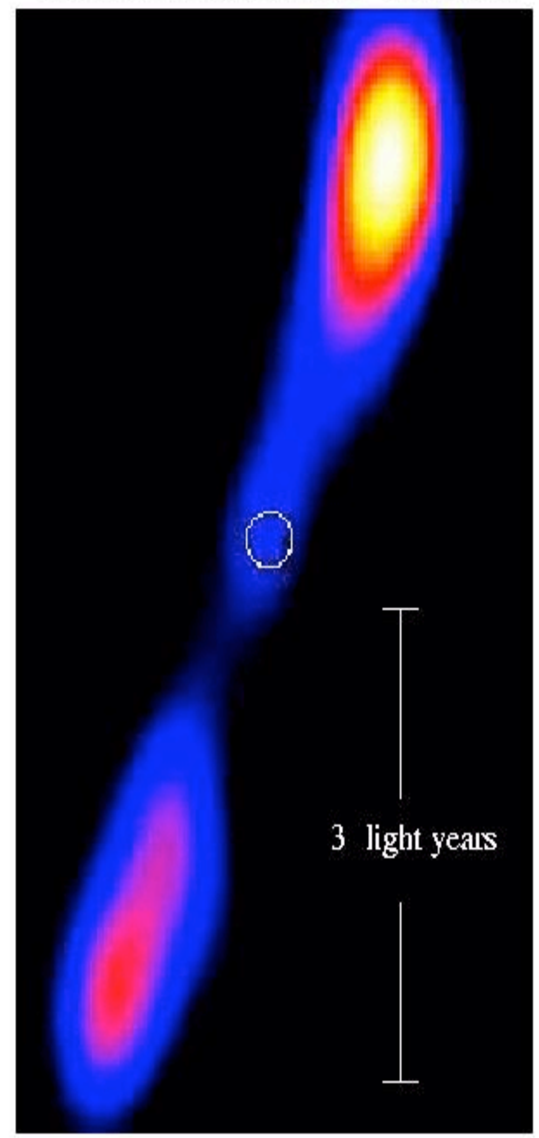
Microquasars

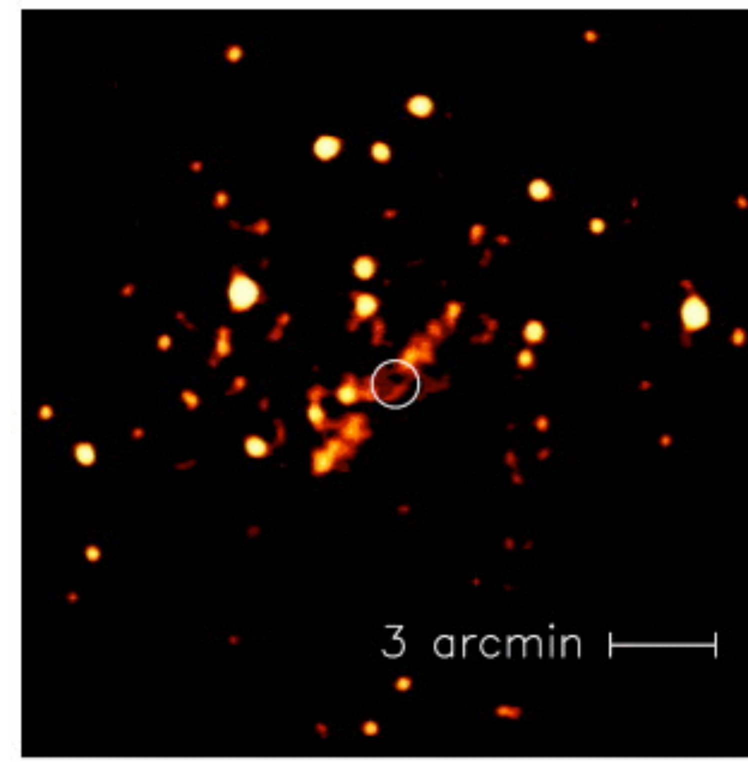


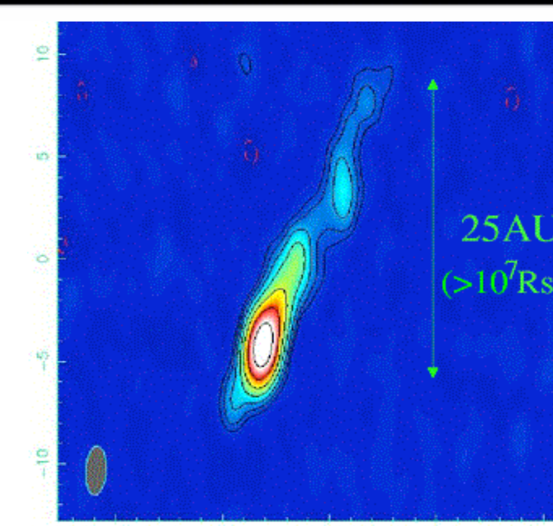
Microquasars have relativistic jets like AGNs



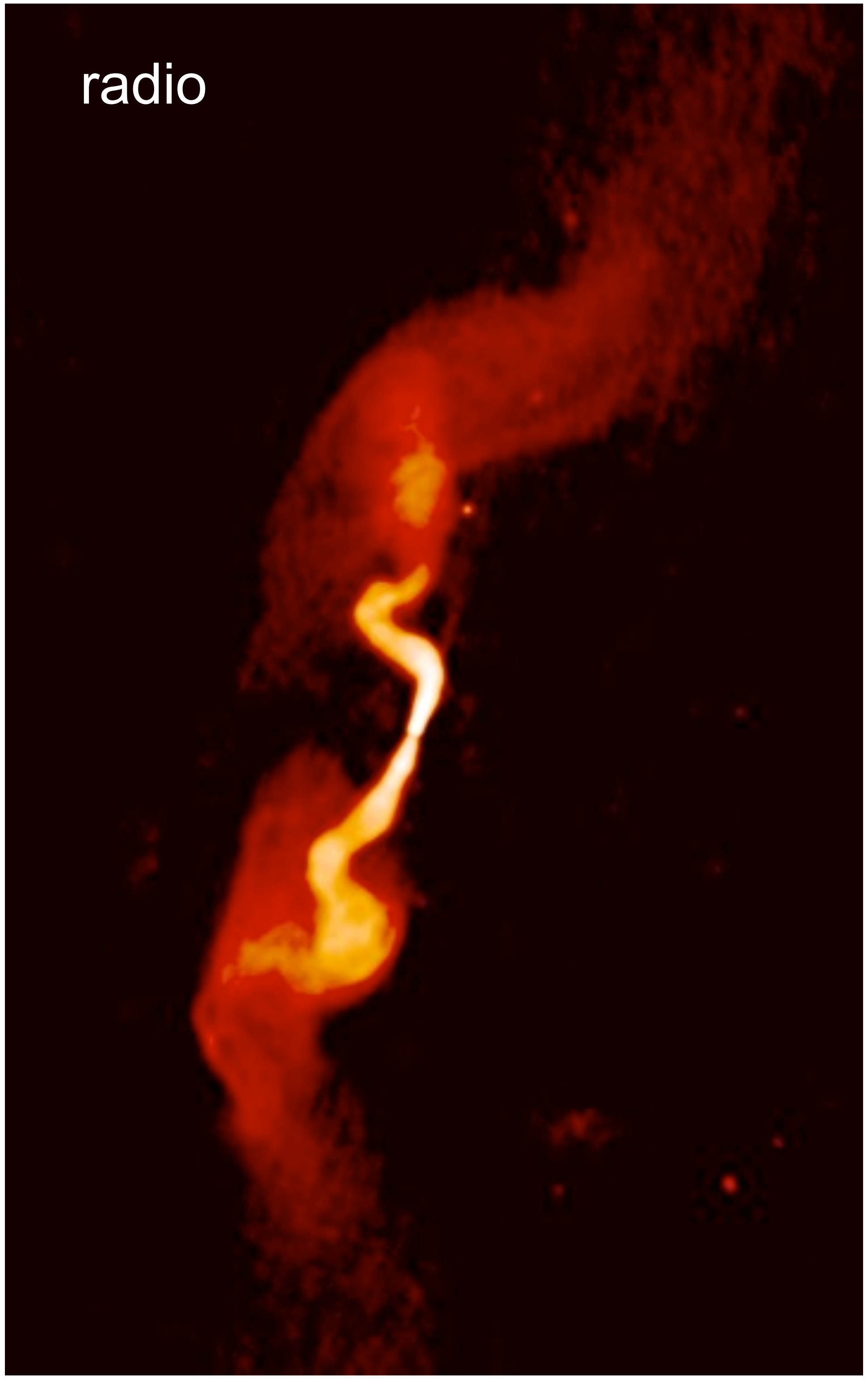


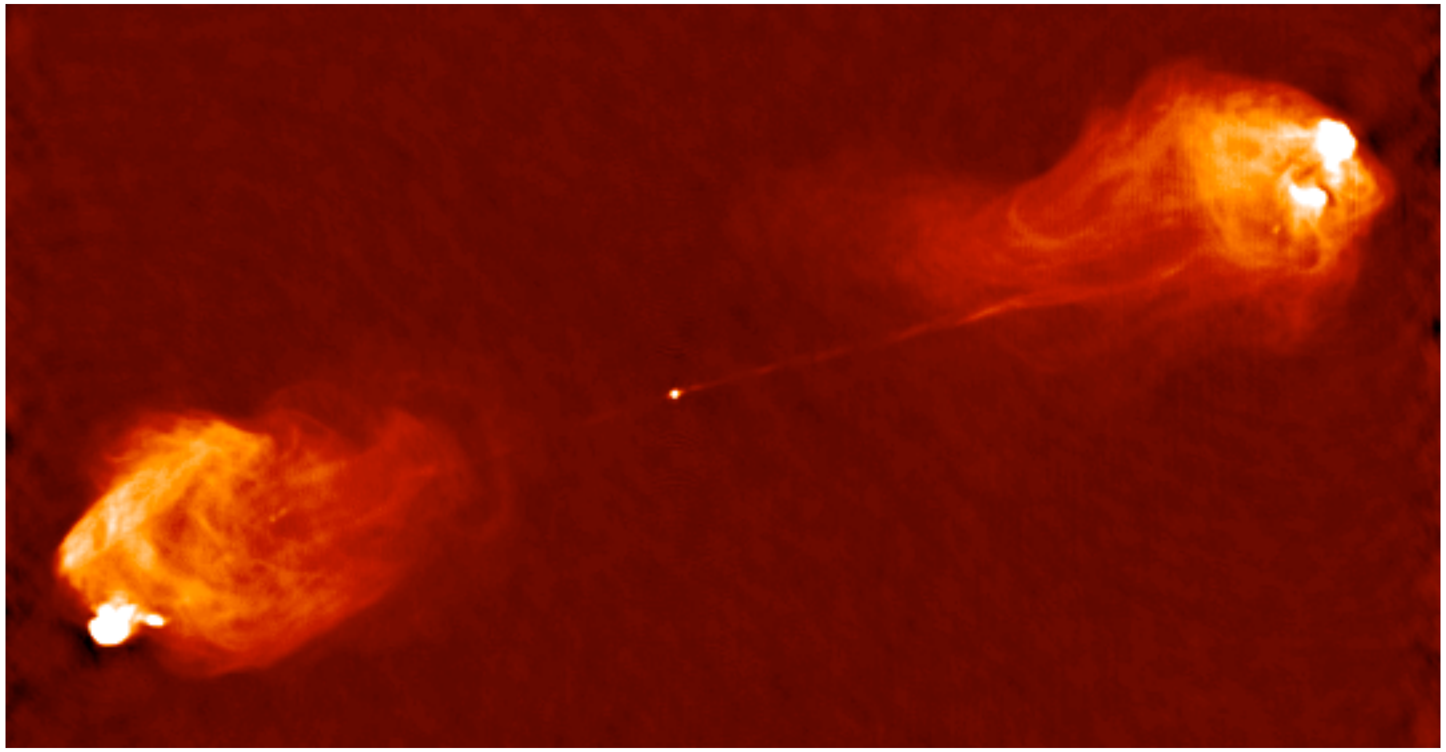






AGN jet dissipate in IGM





jet composition: e-e+ pairs ?

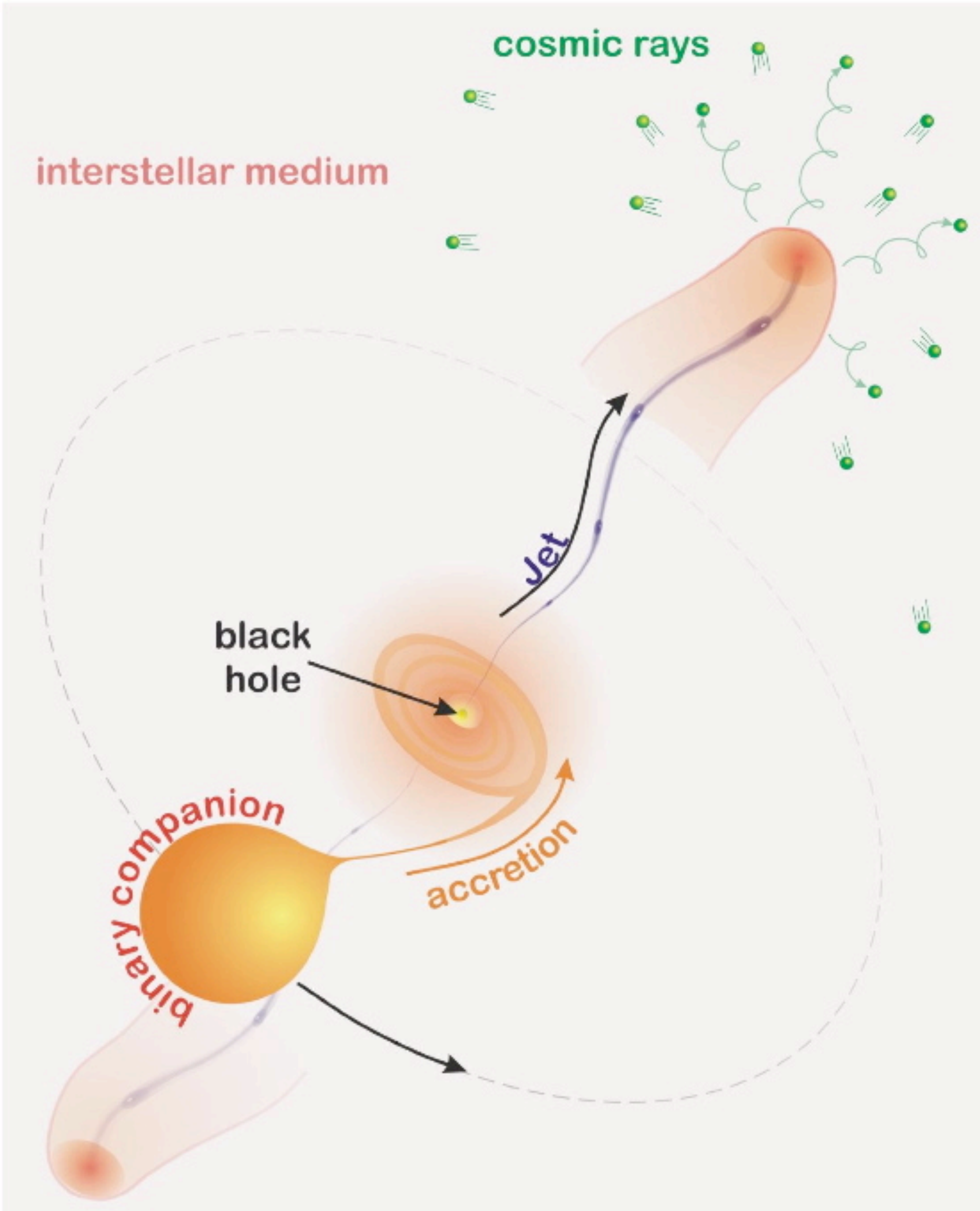
strong γ-ray emission in compact regions

easiest on energy budget to accelerate

jet termination: radio lobes imply huge energy

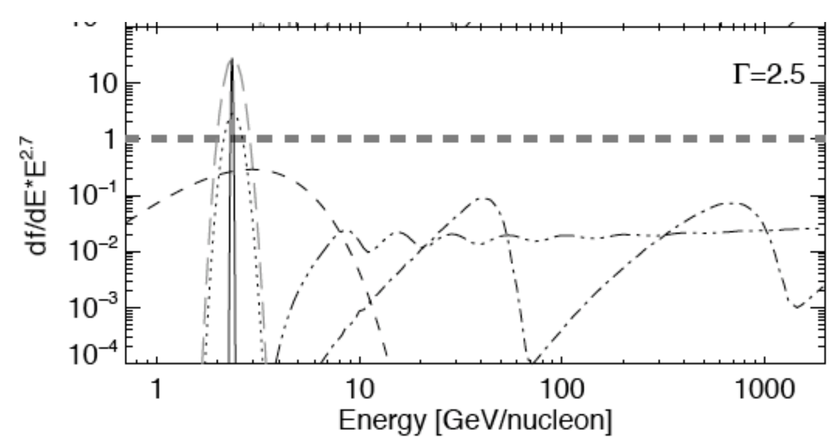
sites of CR acceleration ?

Microquasar jets and cosmic rays



- radio vs X-ray show $L_{\rm jet} \sim L_{\rm X}^{0.5}$
- general arguments give

  $L_{\rm jet}/L_{\rm CR} \sim 1 - 30\%$
- SS433: cold Balmer, iron lines in relativistic plasma
- Narrow peaks at $\Gamma_{\rm jet} m_p c^2 \approx 5\ \Gamma_5\ {\rm GeV}$

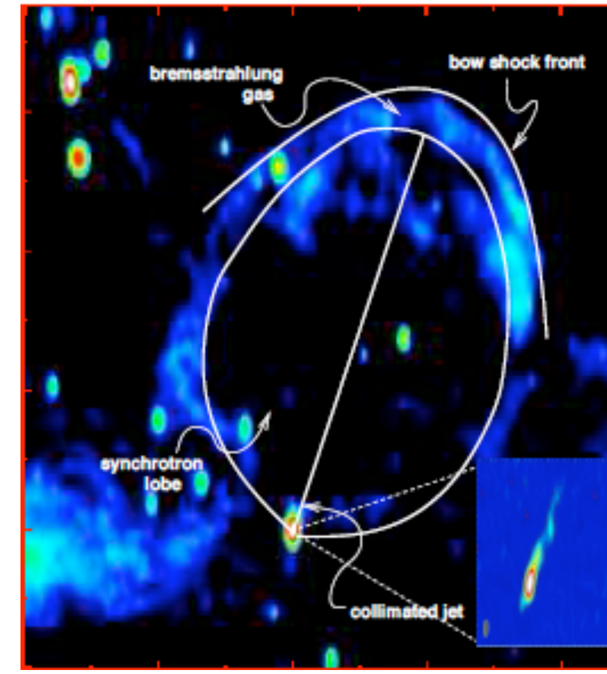


Heinz, Sunyaev 2002
Fender, Maccarone, van Kesteren 2005

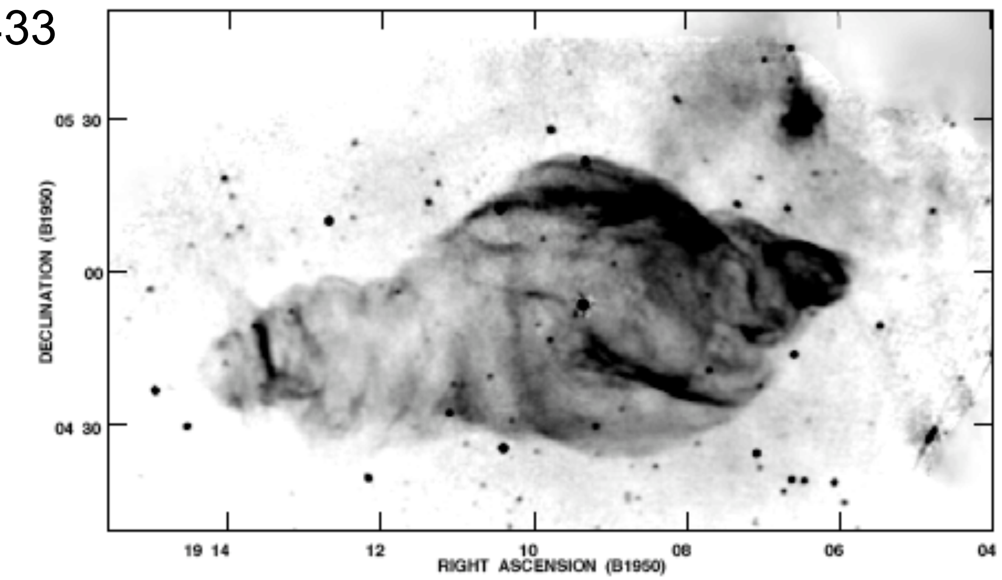
Microquasar jets and ISM

Typically ~ 1 pc. Comparatively far from black hole
[1000 x distance of AGN lobes to black hole in units of R_g]

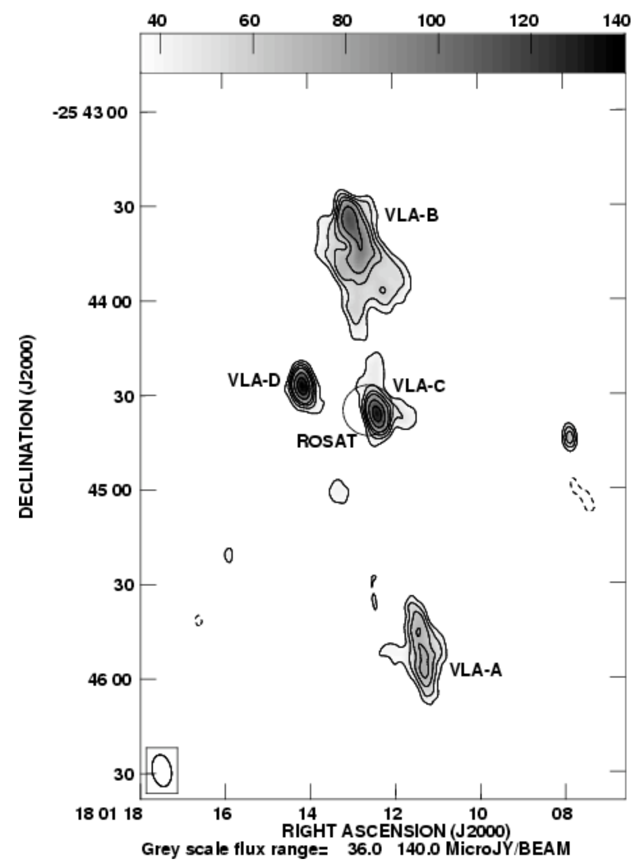
Cyg X-1



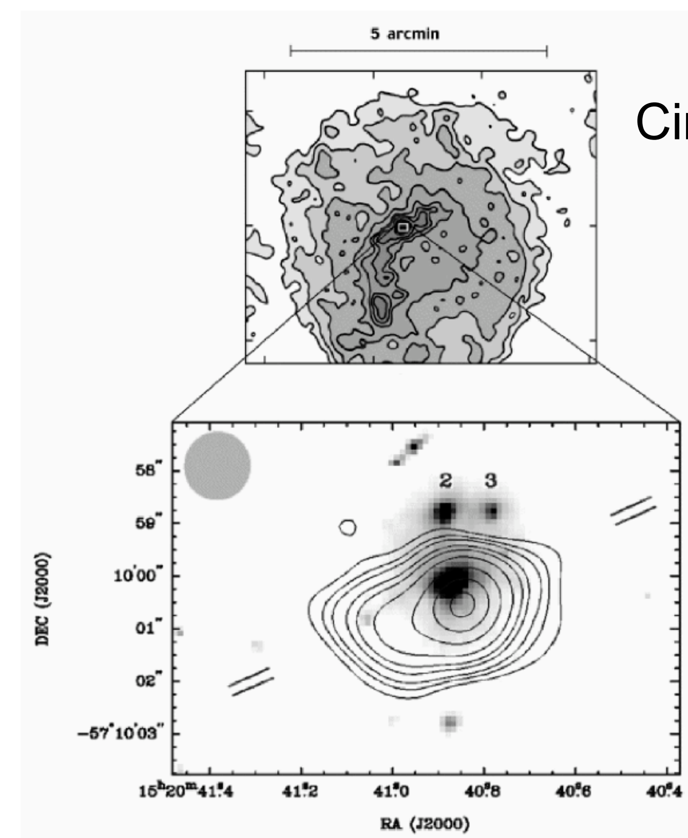
SS 433

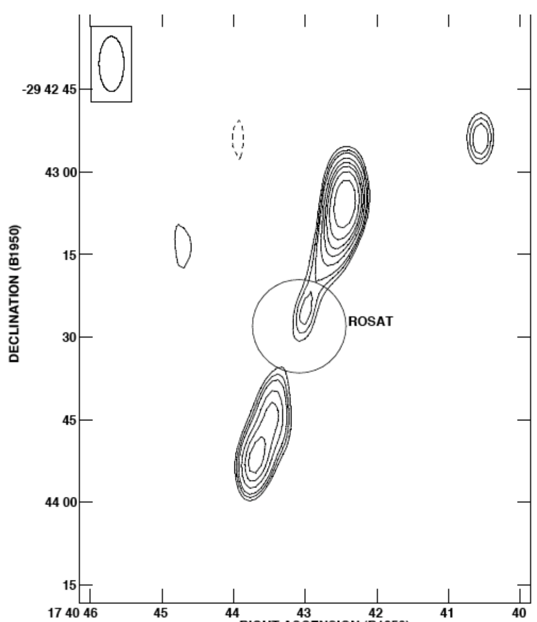


GRS 1758-258



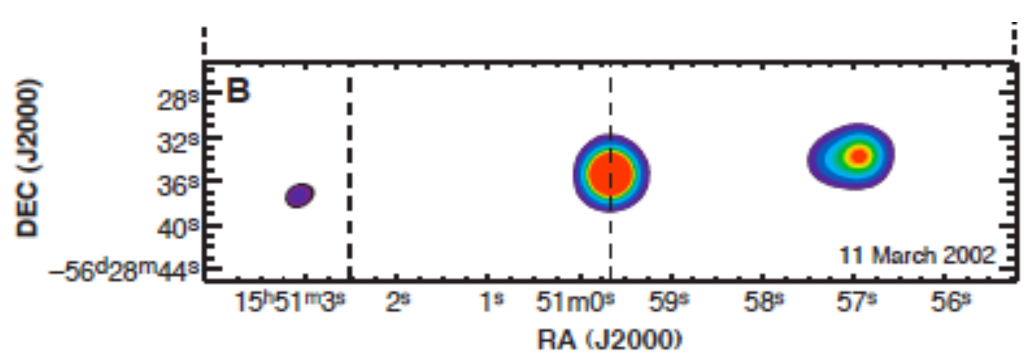
Cir X-1





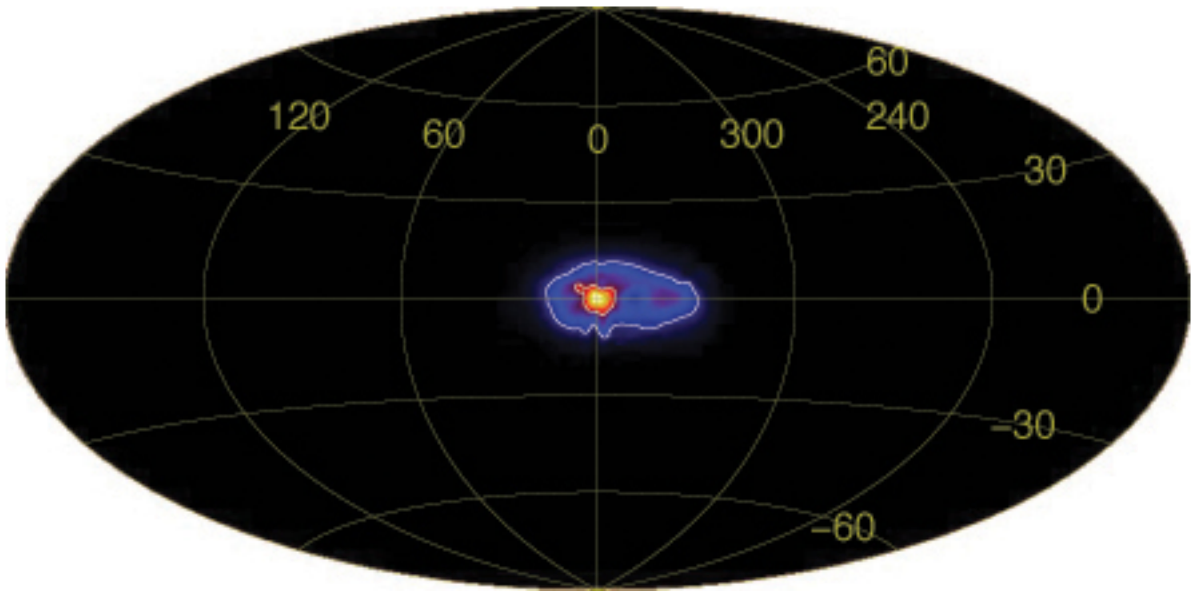
1ES1740.7-2942

XTE J1550-564

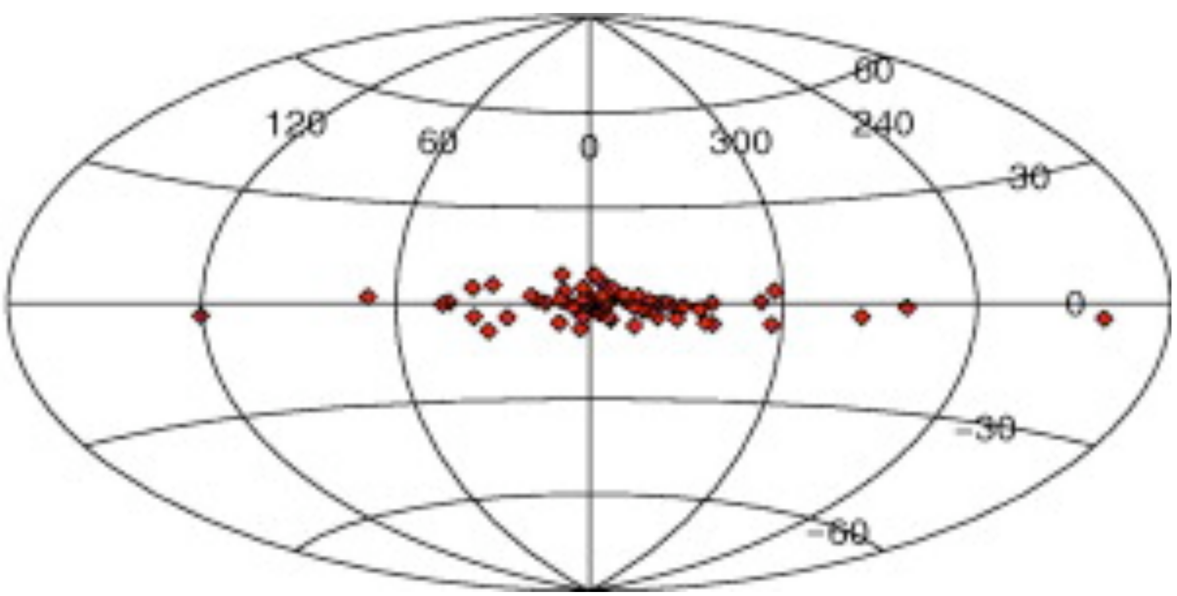


Oddballs?

Microquasar jets and pairs



Weidenspointner et al. 2008



- if only e⁻e⁺ in jet then total in ISM

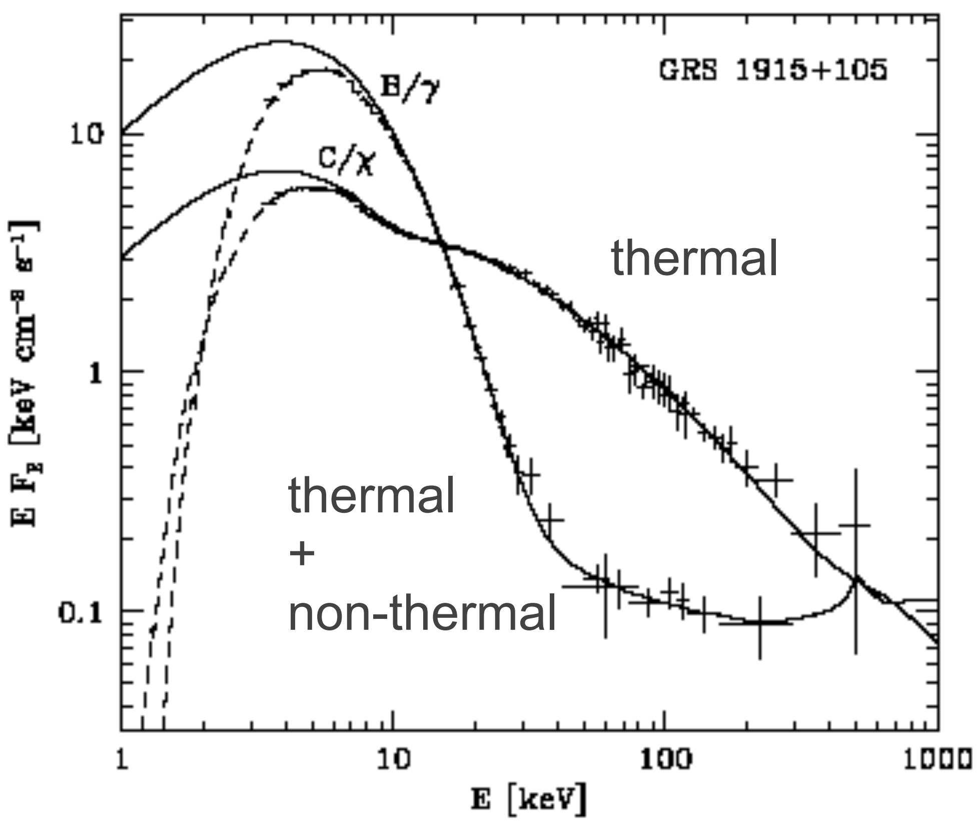
$$\dot{N} \sim \frac{L_{\rm jet}}{\Gamma_{\rm jet}\bar{\gamma} m_e c^2} \approx 10^{43}\ L_{38}\Gamma_5^{-1}\bar{\gamma}_1^{-1}\ {\rm s}^{-1}$$

- Disk distribution fits asymmetric distribution of LMXBs > 20 keV ??
- Do LMXBs produce pairs?

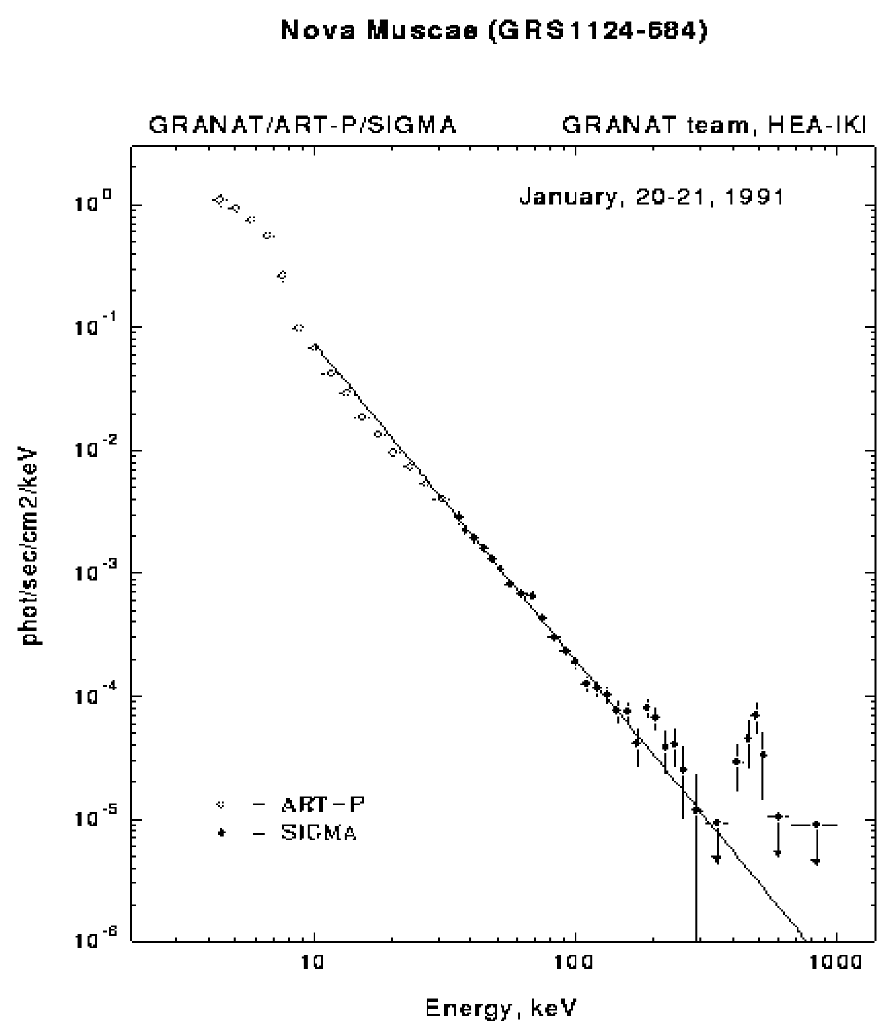
Heinz, Sunyaev 2002
Guessoum, Jean, Prantzos 2006
Bandyopadhyay et al. 2009

Microquasar jets and pairs

Zdziarski et al. 2001



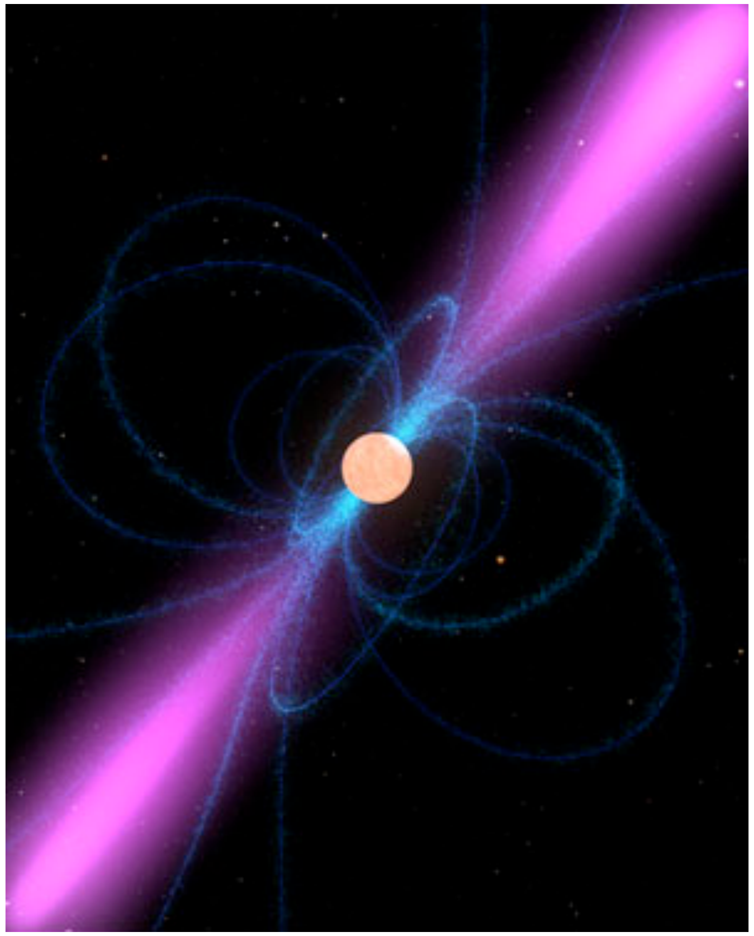
- 511 keV line from pairs produced in *hybrid* plasma (non-thermal heating)

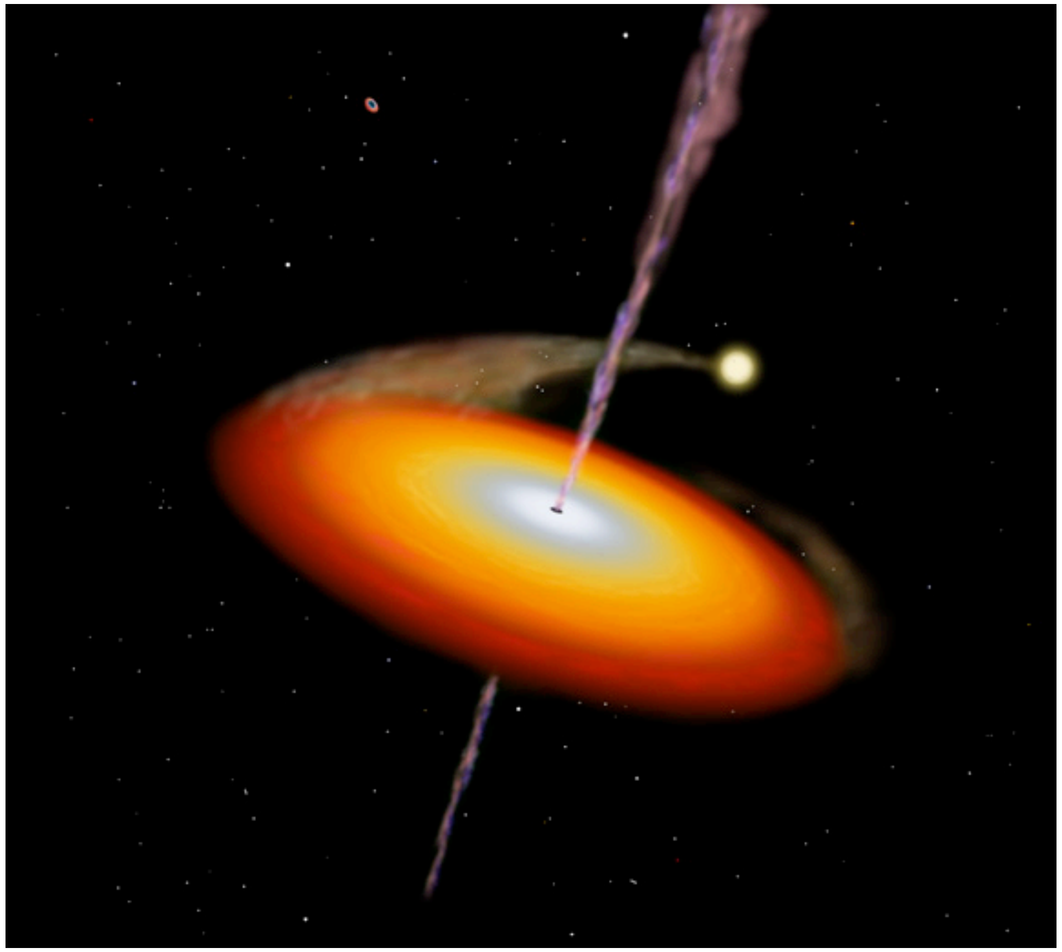


- **annihilation lines** in Nova Muscae and 1E1740-2942 flux >10^{-3} s^{-1} ??
- line at 480 keV: Li production or redshift ??

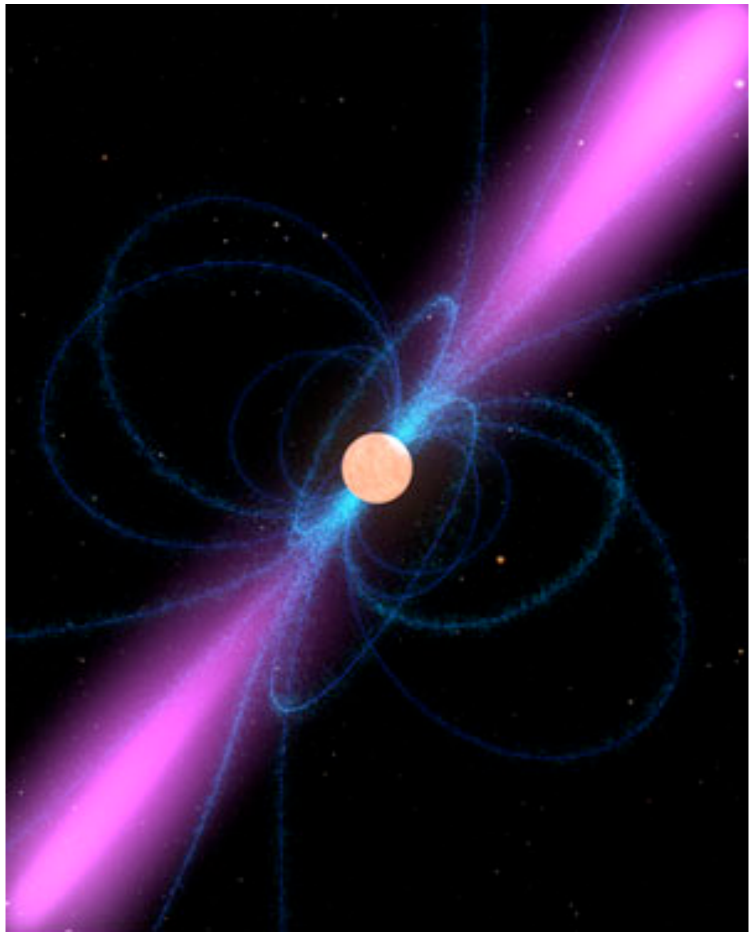
Conclusion: pulsars and binaries

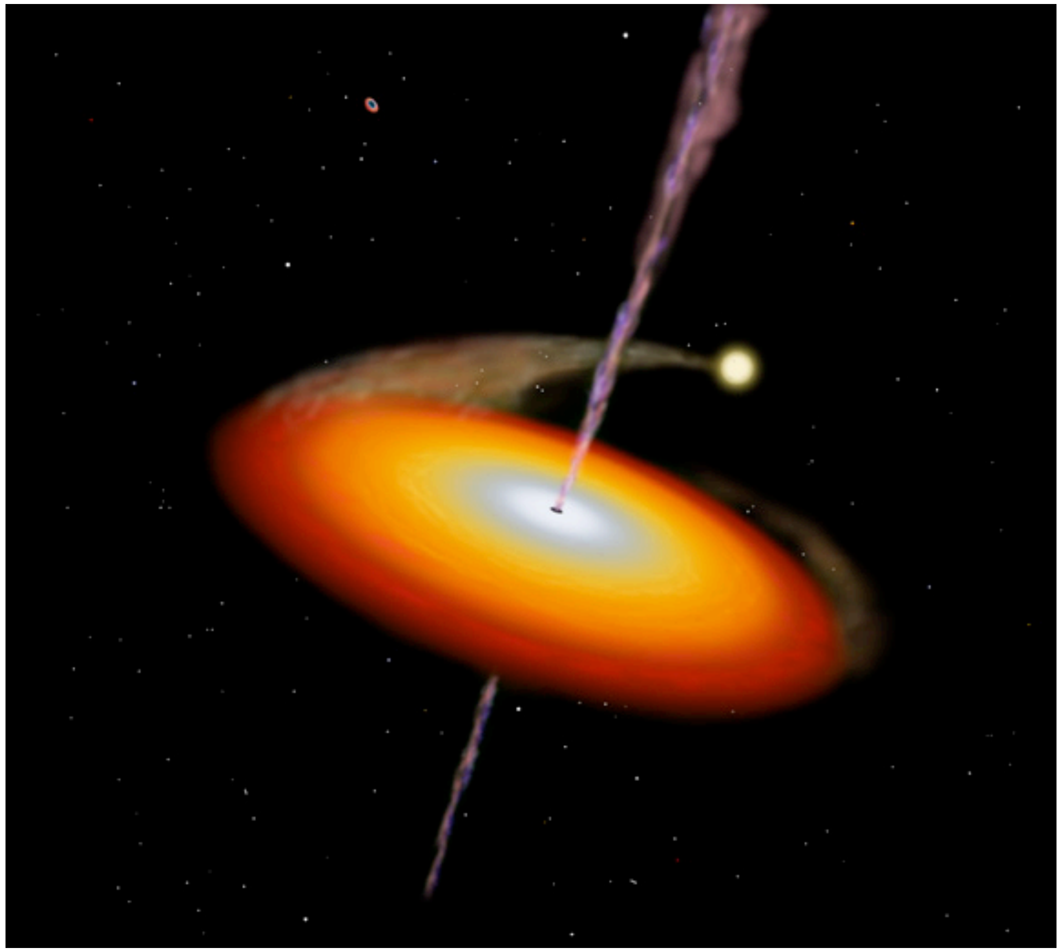
sources of cosmic rays and positrons ?





Conclusion: pulsars and binaries
sources of cosmic rays and positrons ?

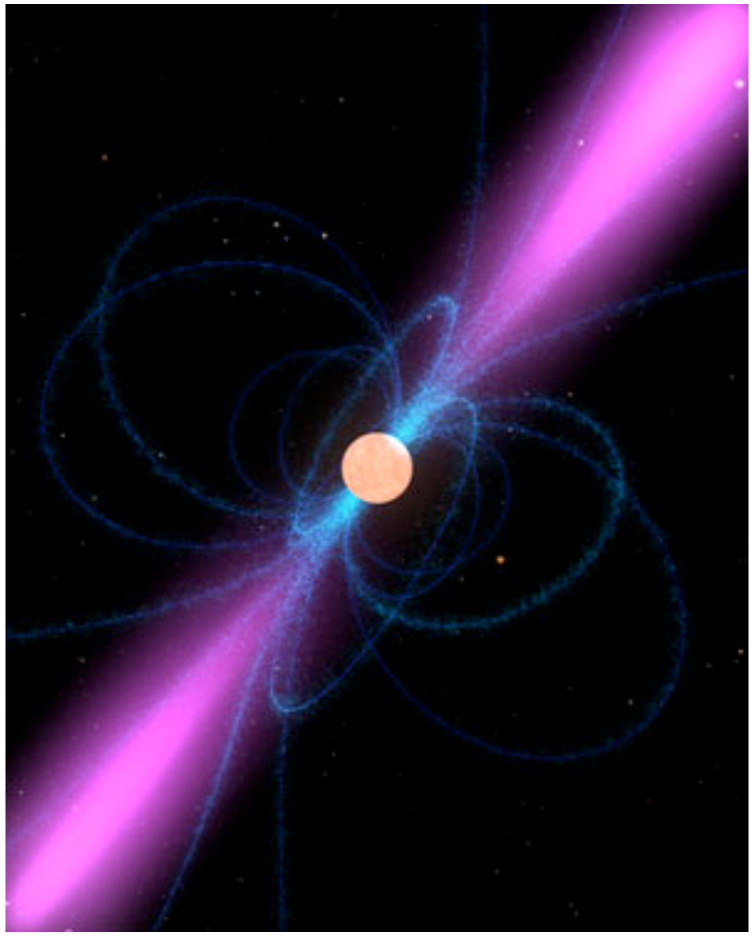


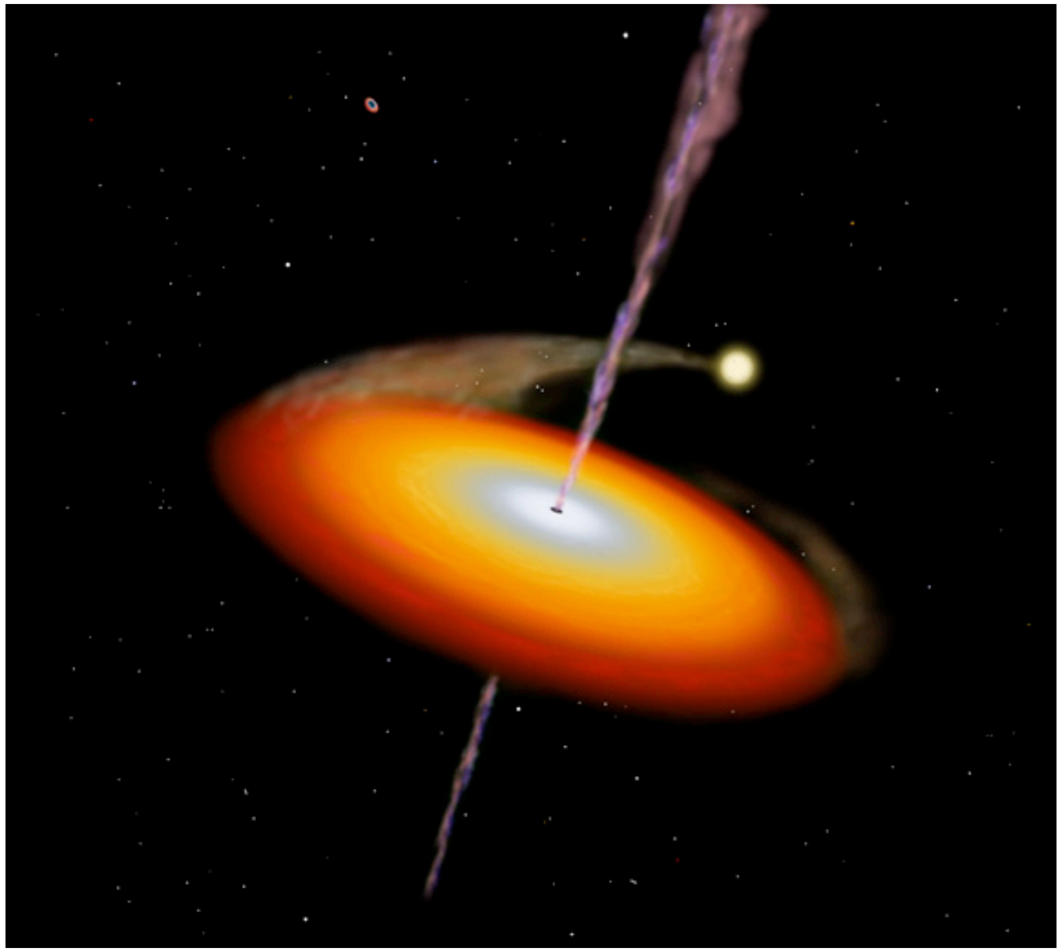


- produce high energy pairs
- nearby pulsar seen in e^+e^- ?
- ms pulsars for 511 keV line ??
- CR sources - in theory ???

Conclusion: pulsars and binaries

sources of cosmic rays and positrons ?





- produce high energy pairs
- nearby pulsar seen in e^+e^- ?
- ms pulsars contribution 511 keV ??
- CR sources - in theory ???

- produce high energy pairs ?
- γ-ray binaries don't contribute much
- microquasars contribution 511 keV ?
- CR sources - in theory ???