Gamma-Ray Astronomy

David Berge | DESY & HU Berlin | Obertrubach

Tour de table

Goals

Why and how γ's?

Overview 15 years

Ask!

Plan

Why bother?

γ-ray sources

Detection techniques

Galactic & extra-galactic scene

Lecture 1

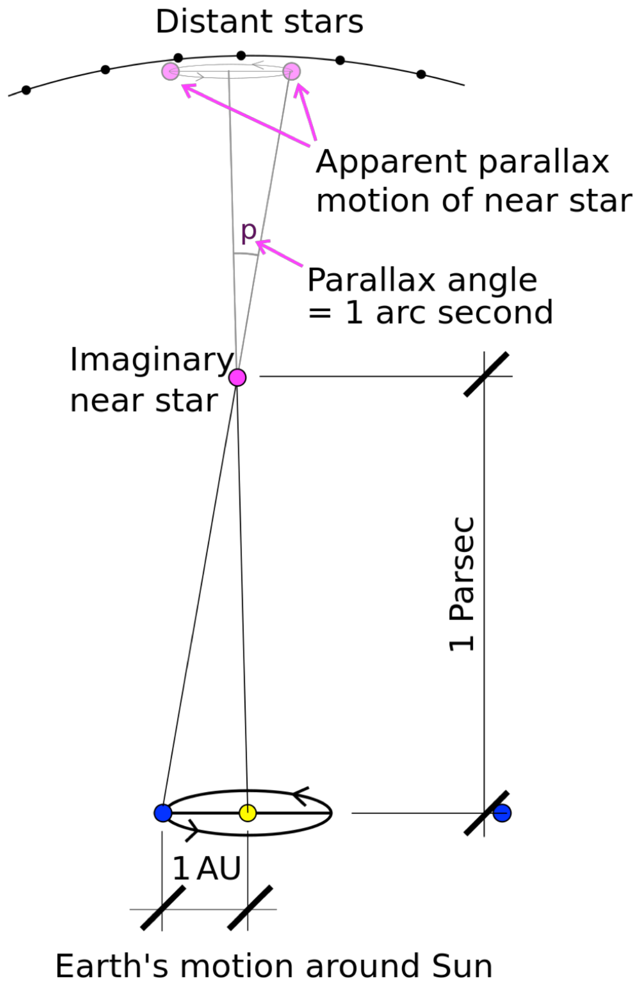
Units

$$1 \text{ parsec} \equiv 3.086 \cdot 10^{18} \text{ cm}$$

$$1 \text{ eV} = 1.6 \cdot 10^{-19} \text{ J}$$

$$1 \text{ AU} = 1.5 \cdot 10^{8} \text{ km}$$

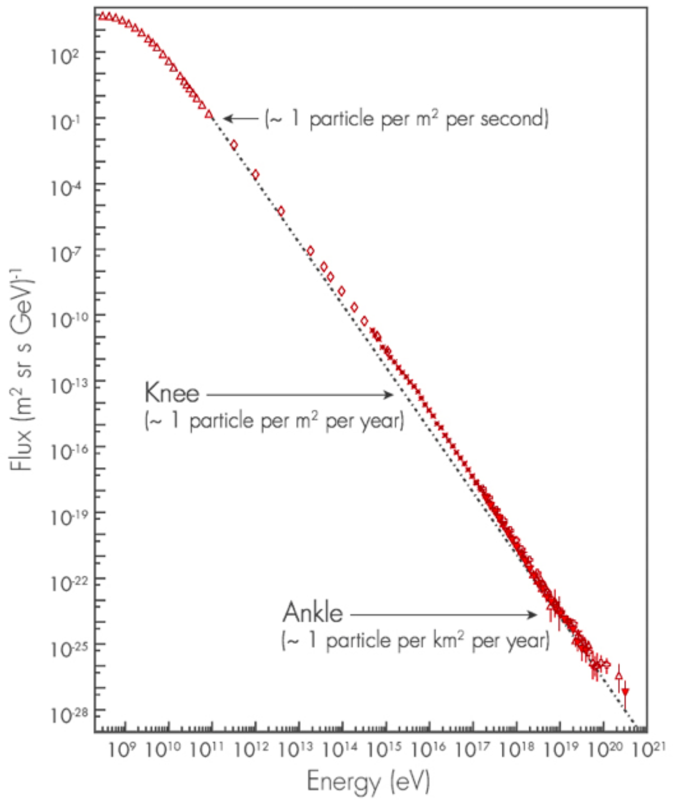
$$1 \text{ erg} = 10^{-7} \text{ J}$$



wikipedia

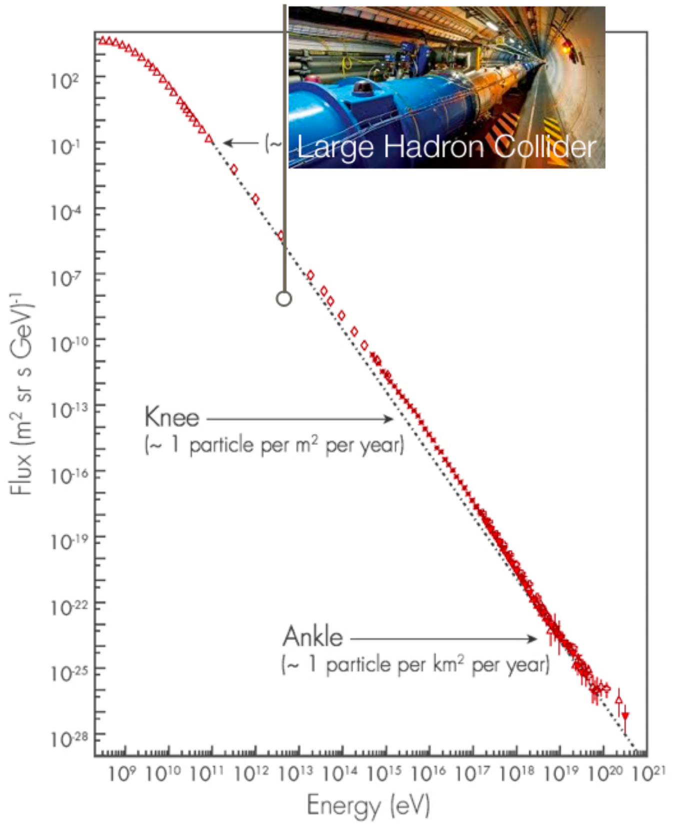
Why bother?

Why Bother?



Flux (m² sr s GeV)⁻¹
(~ 1 particle per m² per second)
Knee
(~ 1 particle per m² per year)
Ankle
(~ 1 particle per km² per year)
Energy (eV)

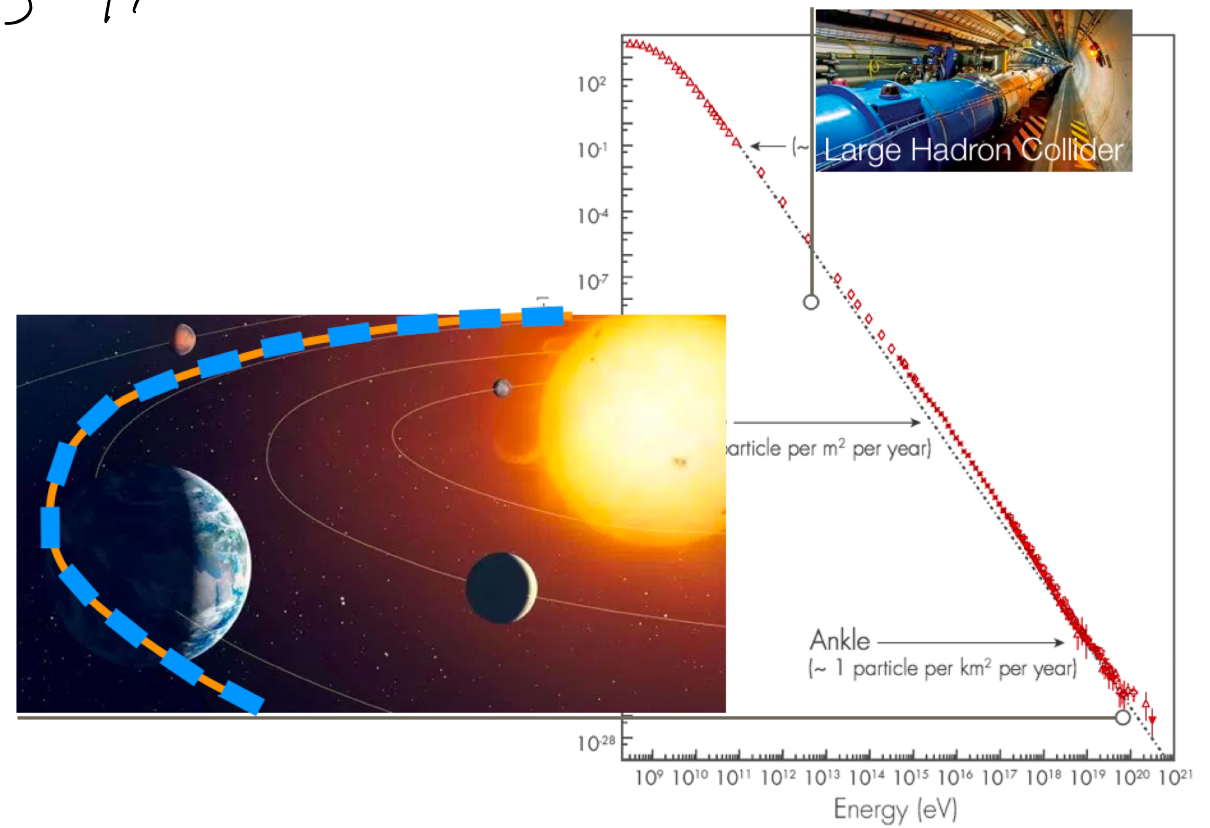
Why Bother?



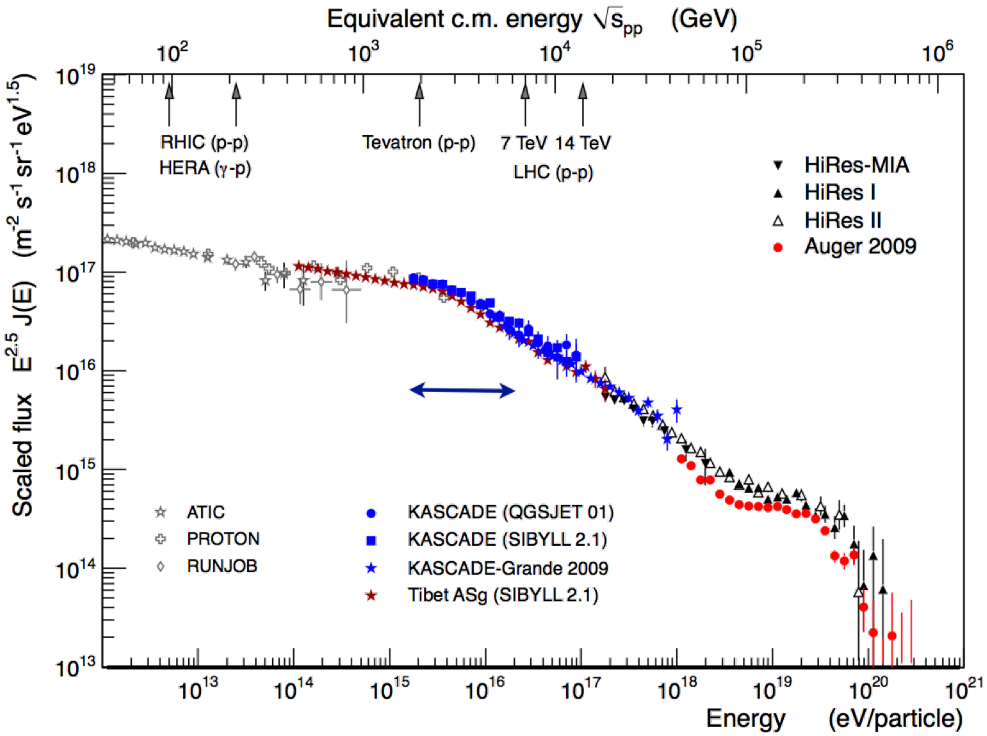
Large Hadron Collider
Knee
(~ 1 particle per m² per year)
Ankle
(~ 1 particle per km² per year)
Flux (m² sr s GeV)⁻¹
Energy (eV)

Why Bother?

Cosmic accelerators >> LHC



Features in the CR spectrum



Exercise: CR gyroradius

Equation?

Exercise: CR gyroradius

Lorentz force

Centripetal force

$E_p = 5 \cdot 10^{19}$ eV

$B \approx 3\,\mu G$

Exercise: CR gyroradius

Lorentz force $q \cdot v \cdot B$

Centripetal force $\frac{m v^2}{r}$

$E_p = 5 \cdot 10^{19}$ eV

$B \approx 3 \mu G$

Exercise: CR gyroradius

Lorentz force $q \cdot v \cdot B$

Centripetal force $\frac{m v^2}{r}$

$E_p = 5 \cdot 10^{19}$ eV

$B \approx 3\,\mu G$

$q v B = \frac{m v^2}{r}$

$\Rightarrow \quad r = \gamma \frac{m v}{q B} = \frac{p}{q B}$

Exercise: CR gyroradius

SI units magic:

$$T = \frac{kg}{C\,s}$$

$$q = 1.6 \cdot 10^{-19}\,C$$

$$E/c = 5 \cdot 10^{19}\,eV$$

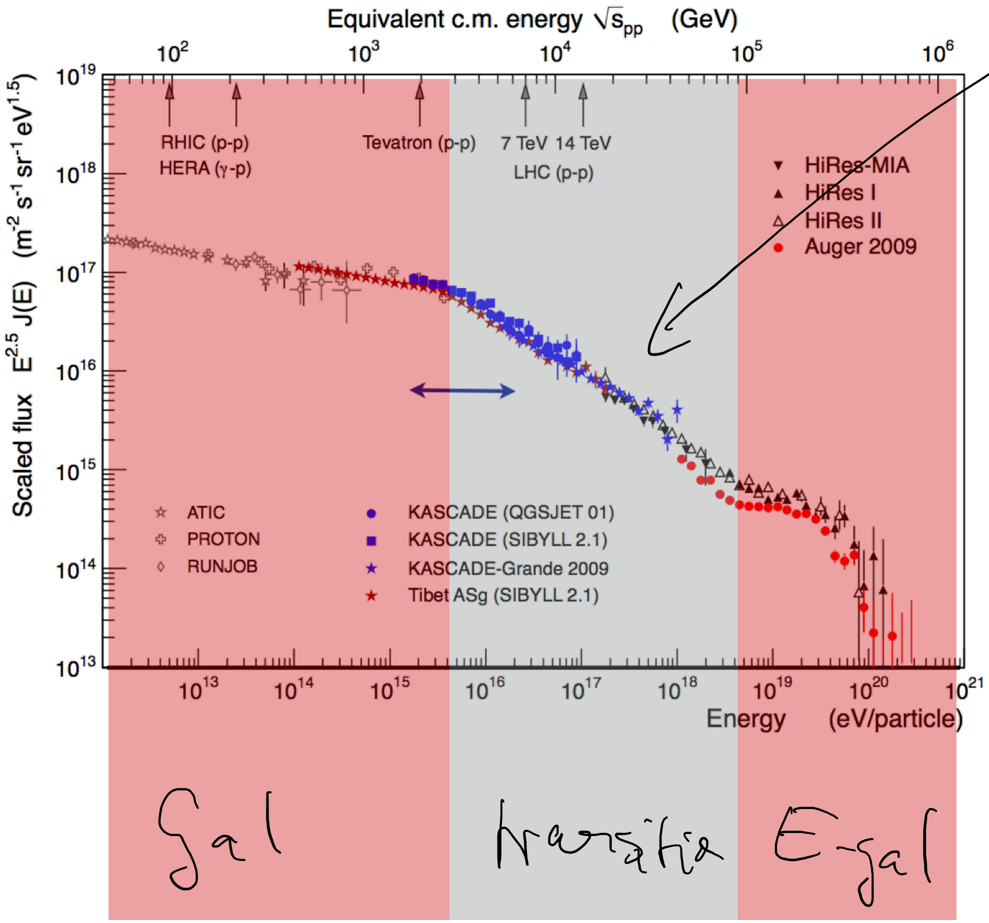
$$c = 3 \cdot 10^{8}\,m$$

$$1\,pc = 3.086\,e18\,cm$$

$$r = \frac{E/c}{q \cdot B} = \ldots = \frac{5}{9} \cdot 10^{21}\,m$$

$$\approx 18\,kpc$$

Features in the CR spectrum



gyroradius of CR p
> size of MW

- there are PeV sources
- there are 10^{20} eV sources

Why interesting?

1 eV/cm³

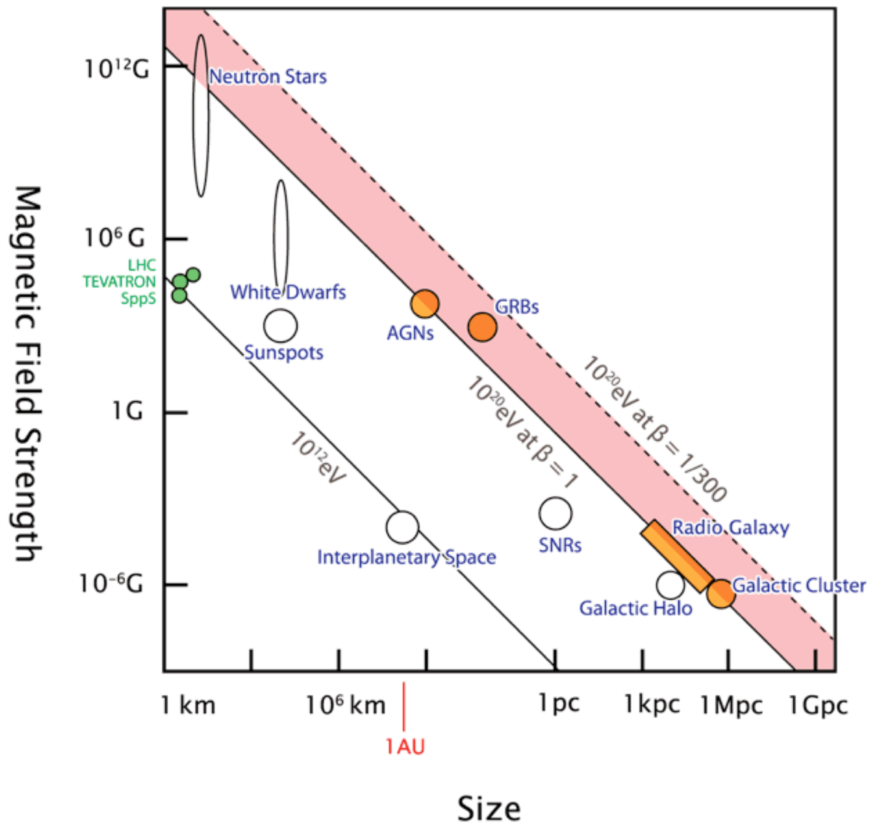
CRs

gas

B fields

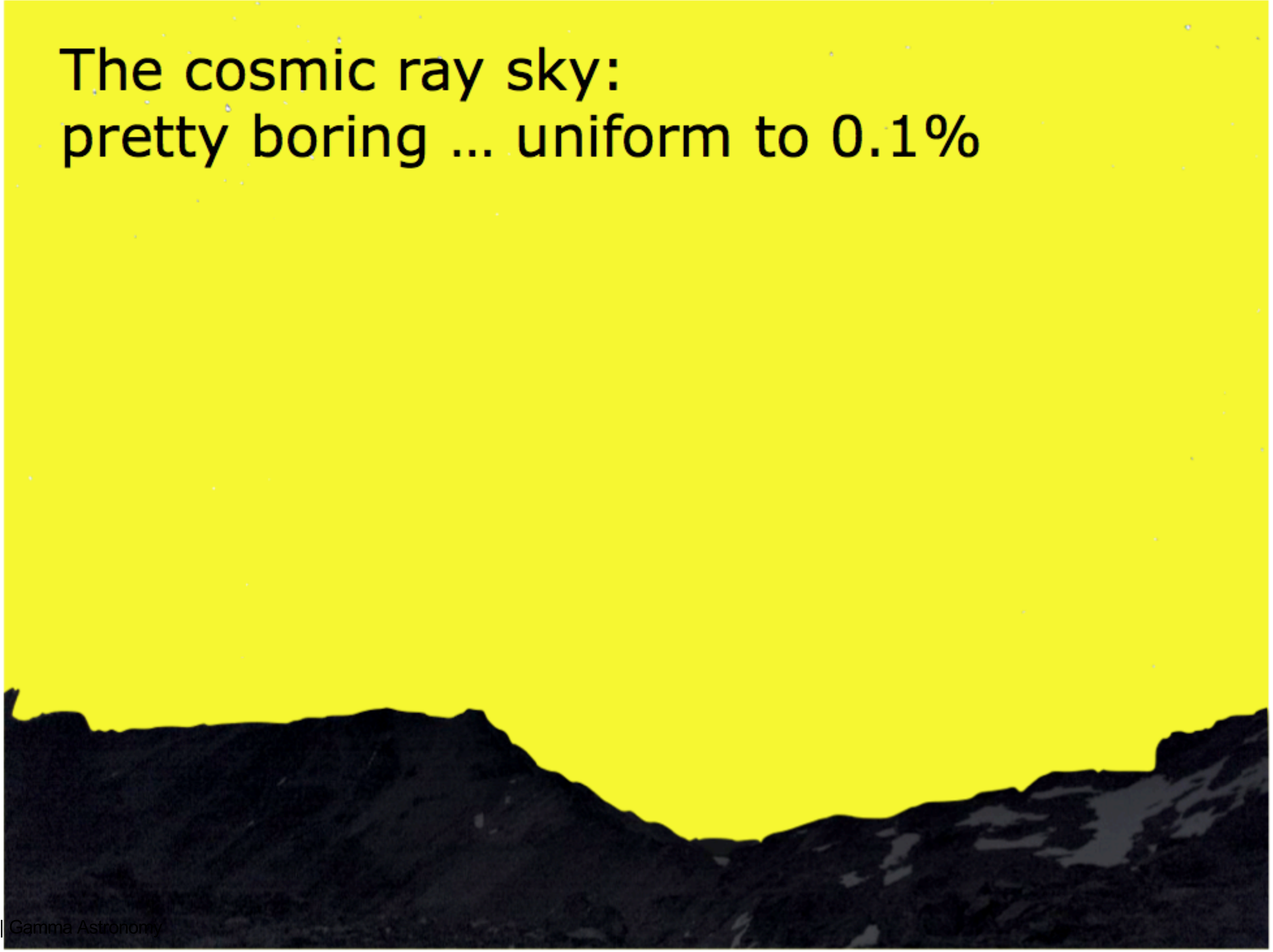
Why interesting?

Hillas Plot



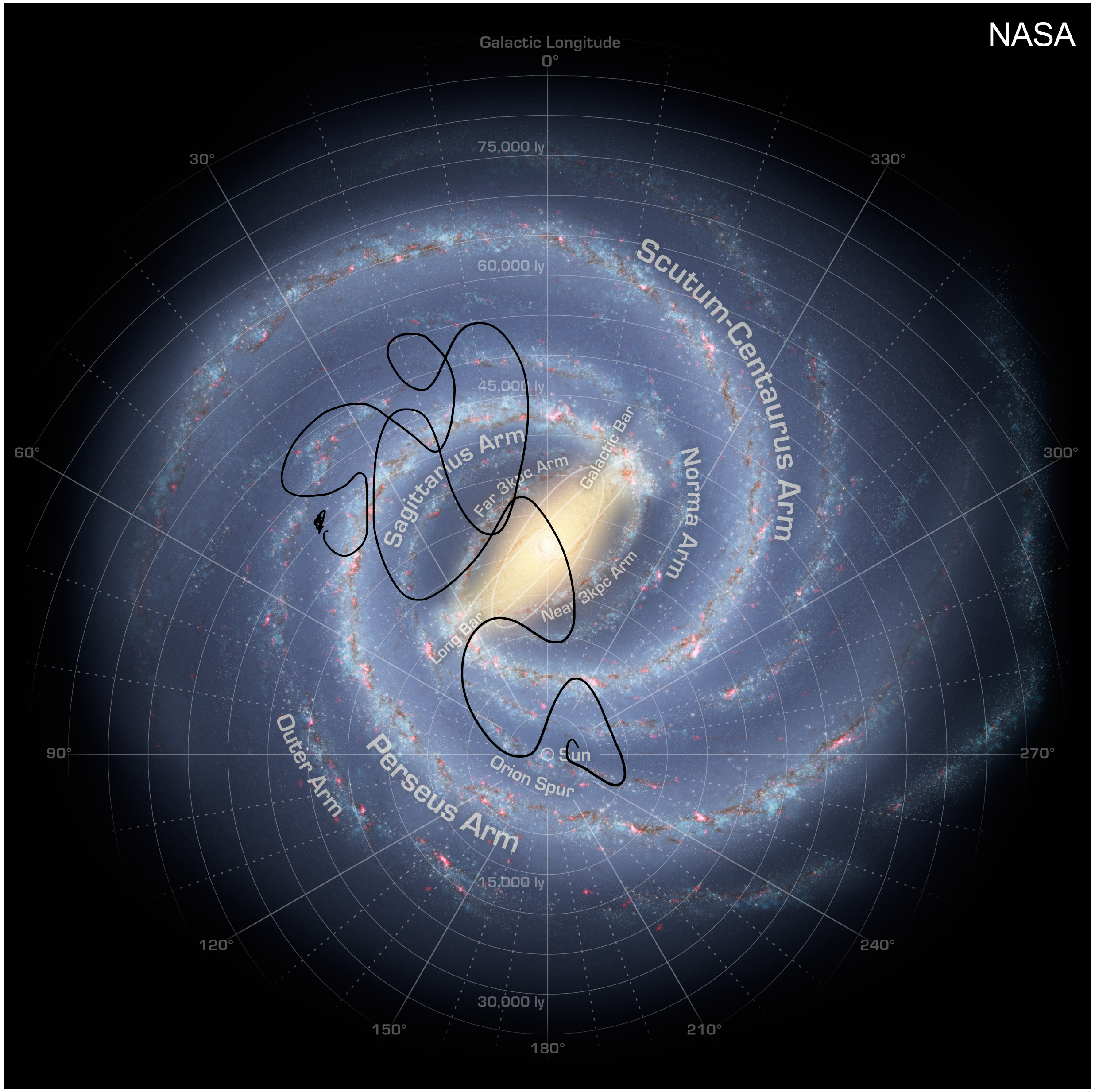
From http://jemeuso.riken.jp/en/about2.html


The cosmic sky:
fascinating


The cosmic ray sky:
pretty boring … uniform to 0.1%

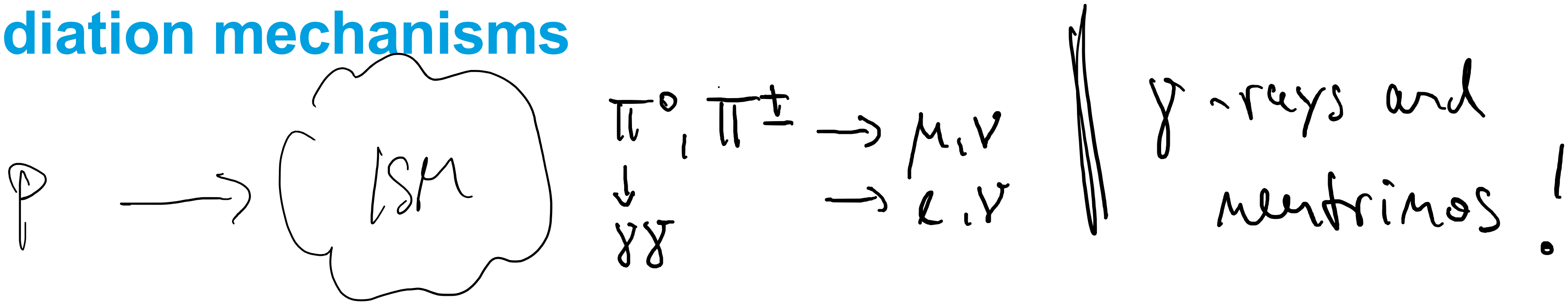
CRs do random walks in the B field of our galaxy

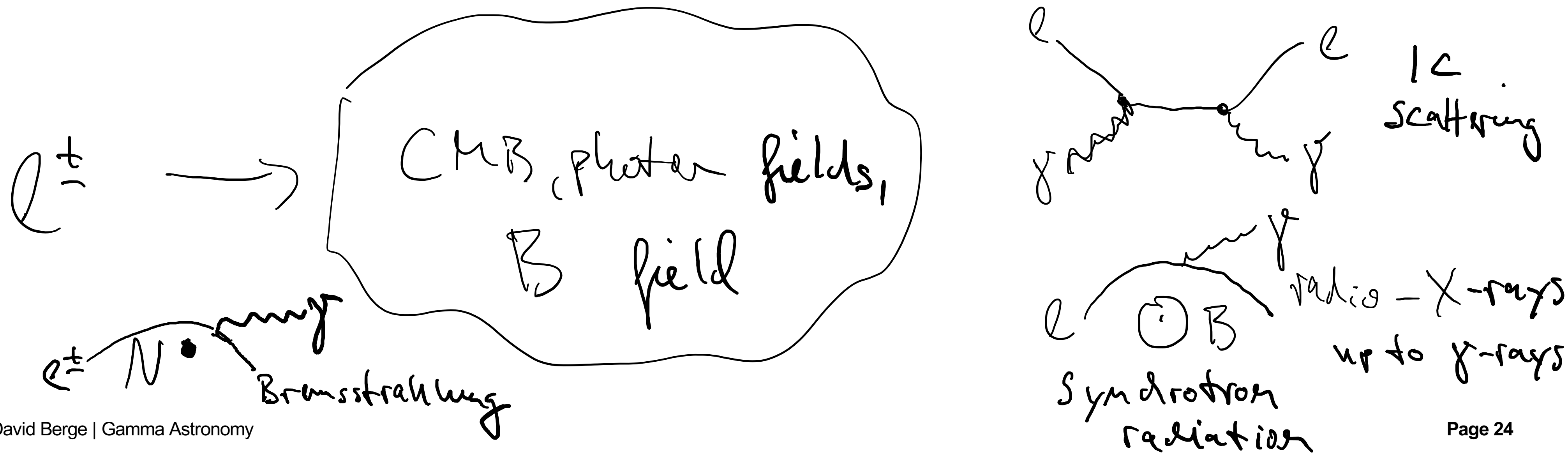
→ need neutral messengers!



Gamma Ray Sources

Radiation mechanisms

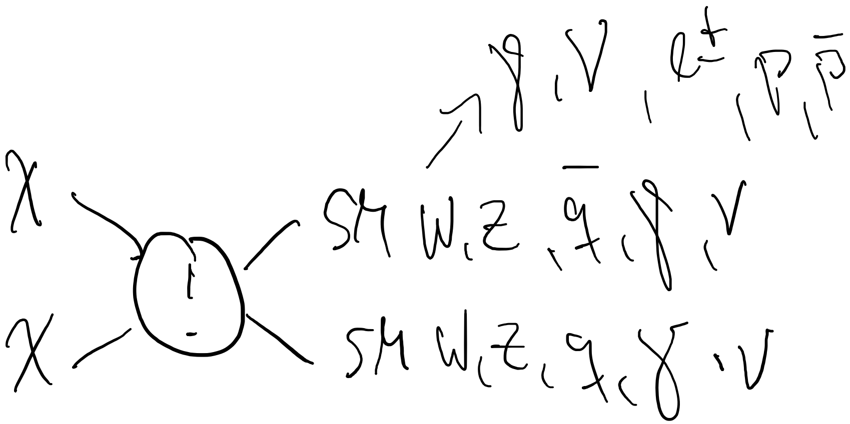




Gamma Rays from Dark Matter

1. DM is a particle

2. DM interacts with SM

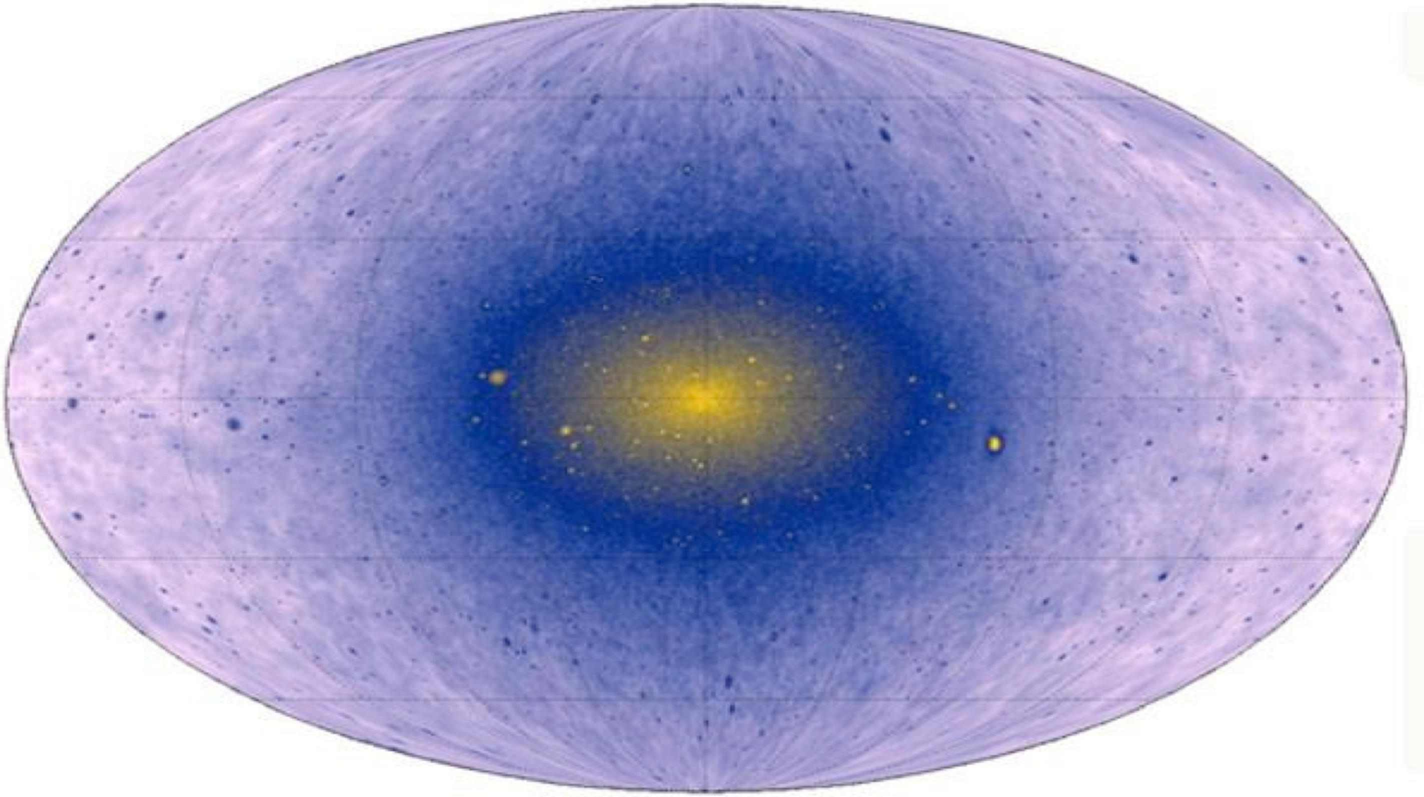


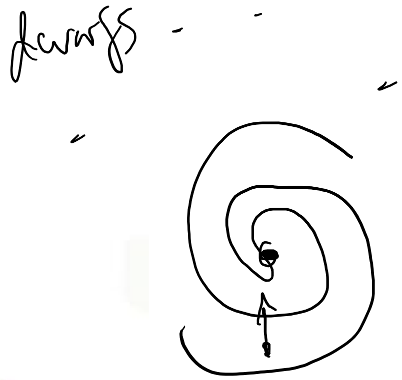
Gamma Rays from Dark Matter

$$\text{flux}_{DM} = \text{particle physics} \times \text{astrophysics}$$

$$= \frac{\langle \sigma v \rangle}{m_\chi^2} \times \sum \text{Bf} \cdot \text{processes} \rightarrow \gamma \times \int_{\text{los}} \rho^2 \, d\Omega$$

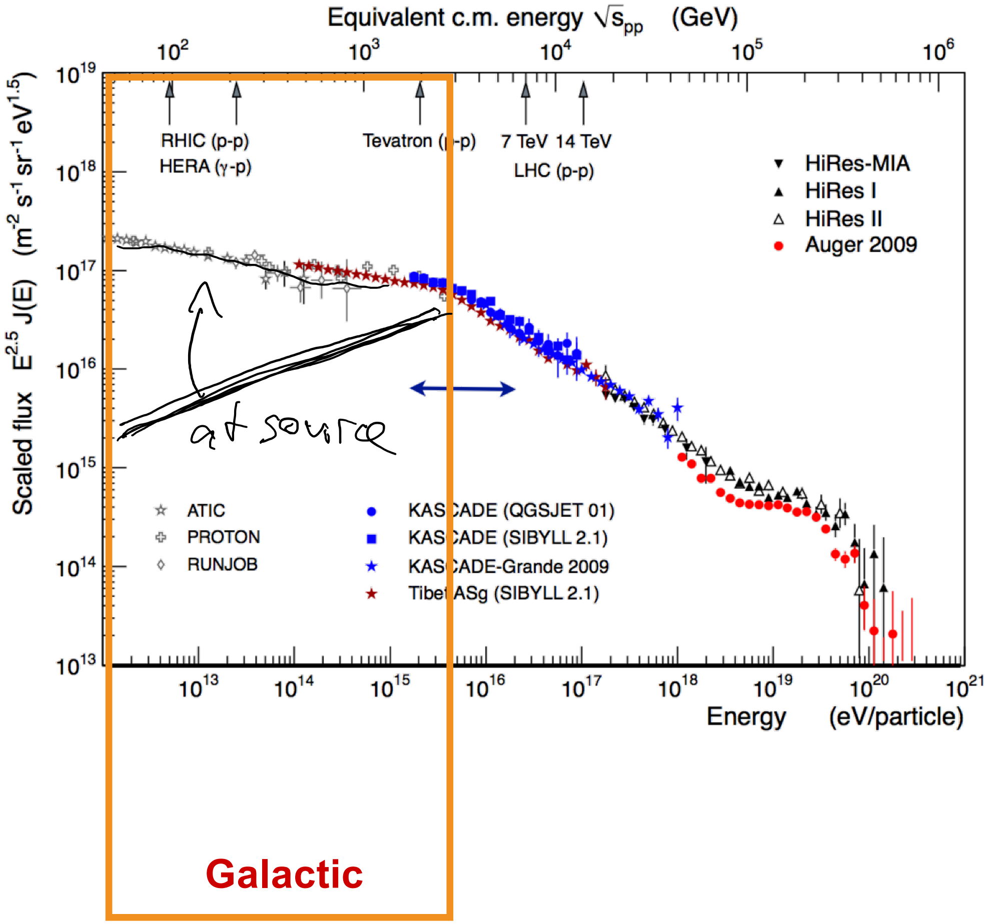
“How to search” turns into “Where to search”

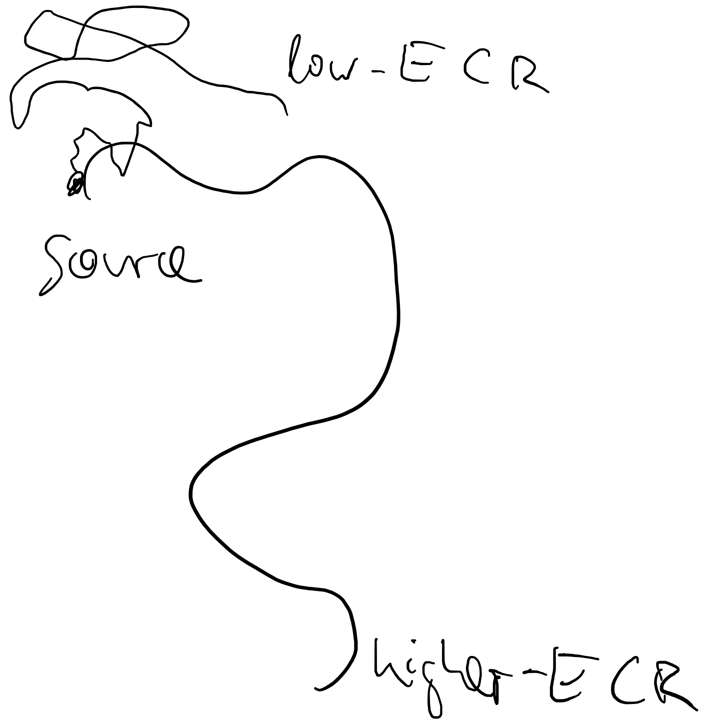




Particle acceleration mechanisms

What galactic cosmic rays teach us



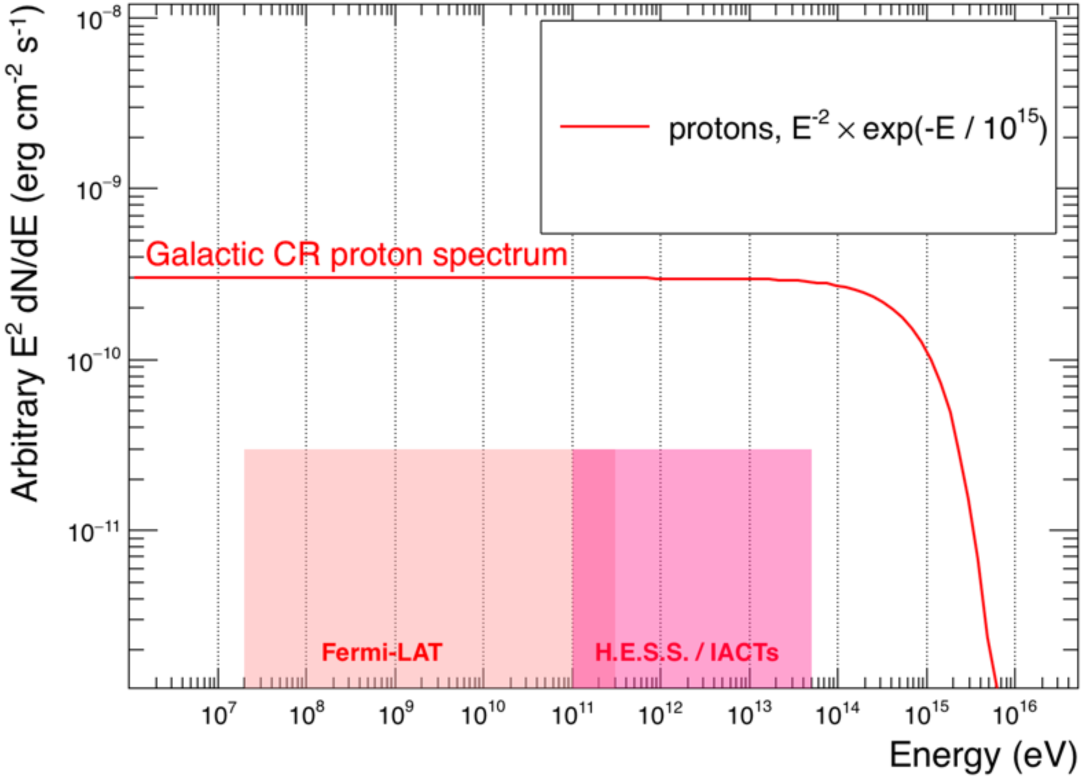


at source E^{-2}

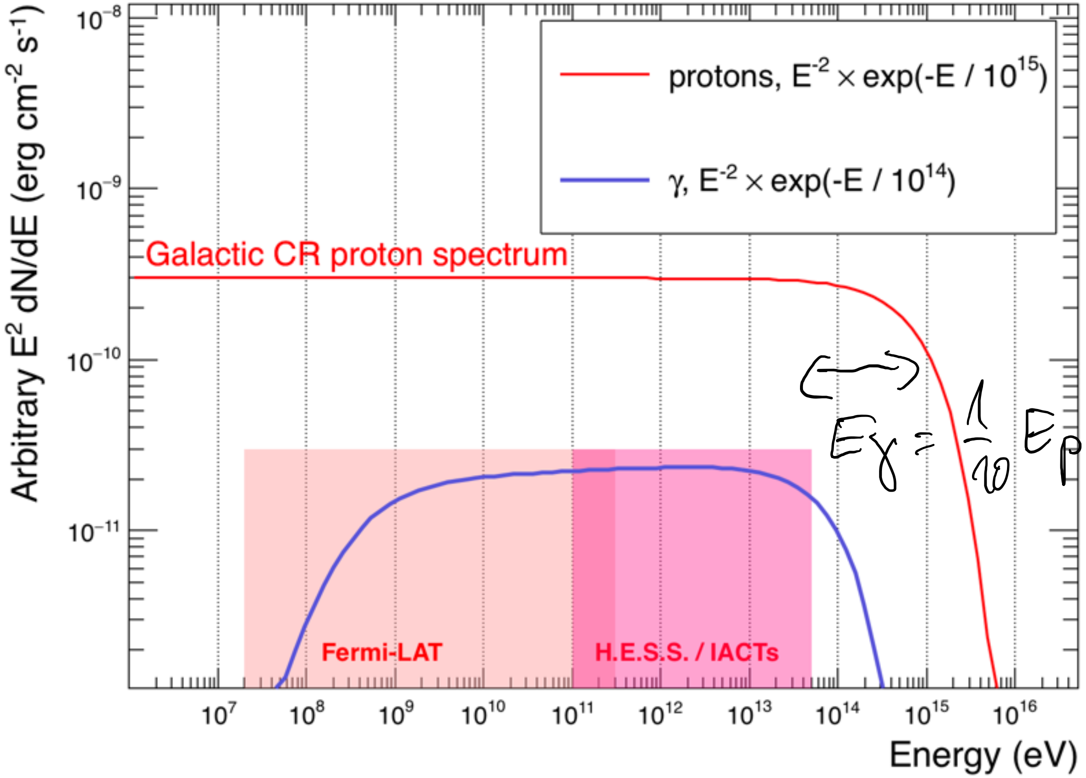
at Earth $E^{-2-\delta}$

$\delta \sim 0.3 - 0.7$

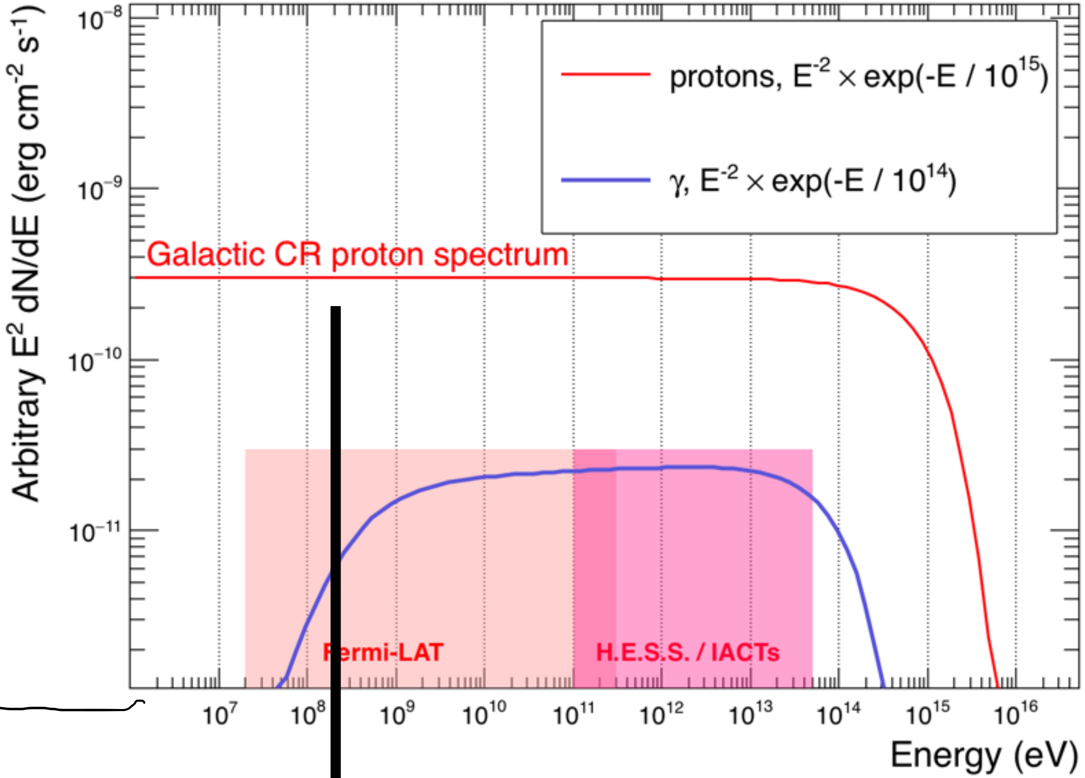
Expected energy flux distribution of Galactic CR accelerator



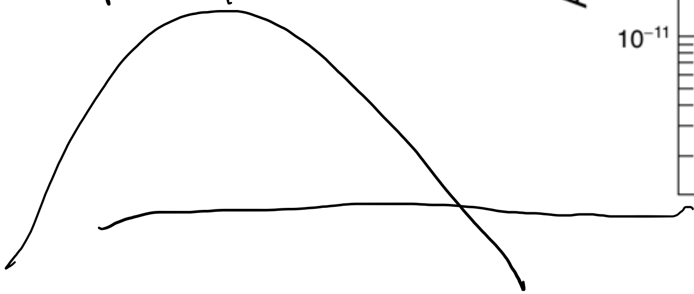
Expected energy flux distribution of Galactic CR accelerator



Expected energy flux distribution of Galactic CR accelerator

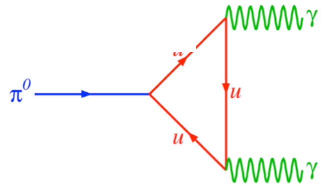


P symdr.



$$\frac{m_{\pi^0}}{2}$$

P_{CR} + P_{ISM} via π_0



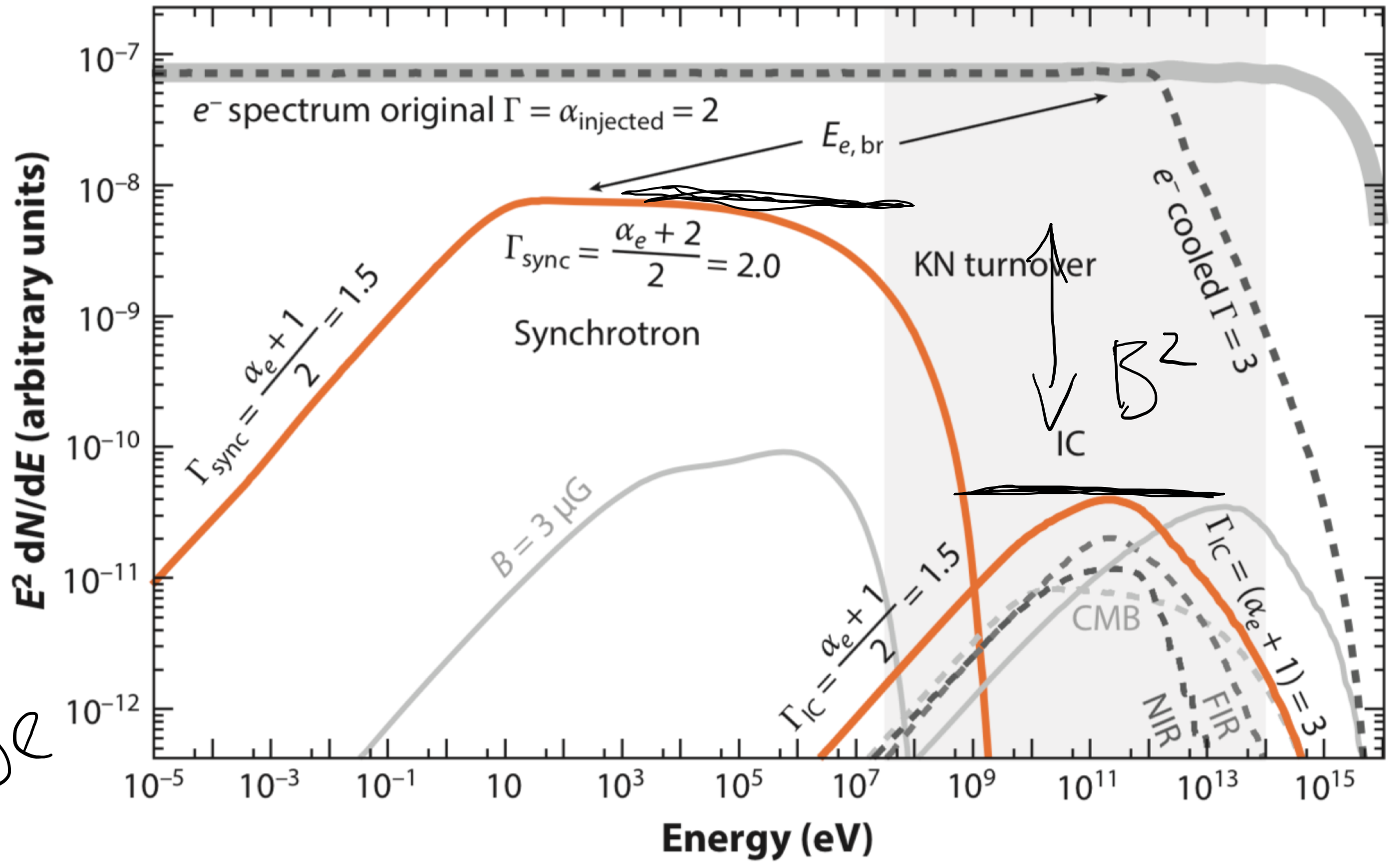
Expected energy flux distribution of Galactic electron accelerators

Funk 2015

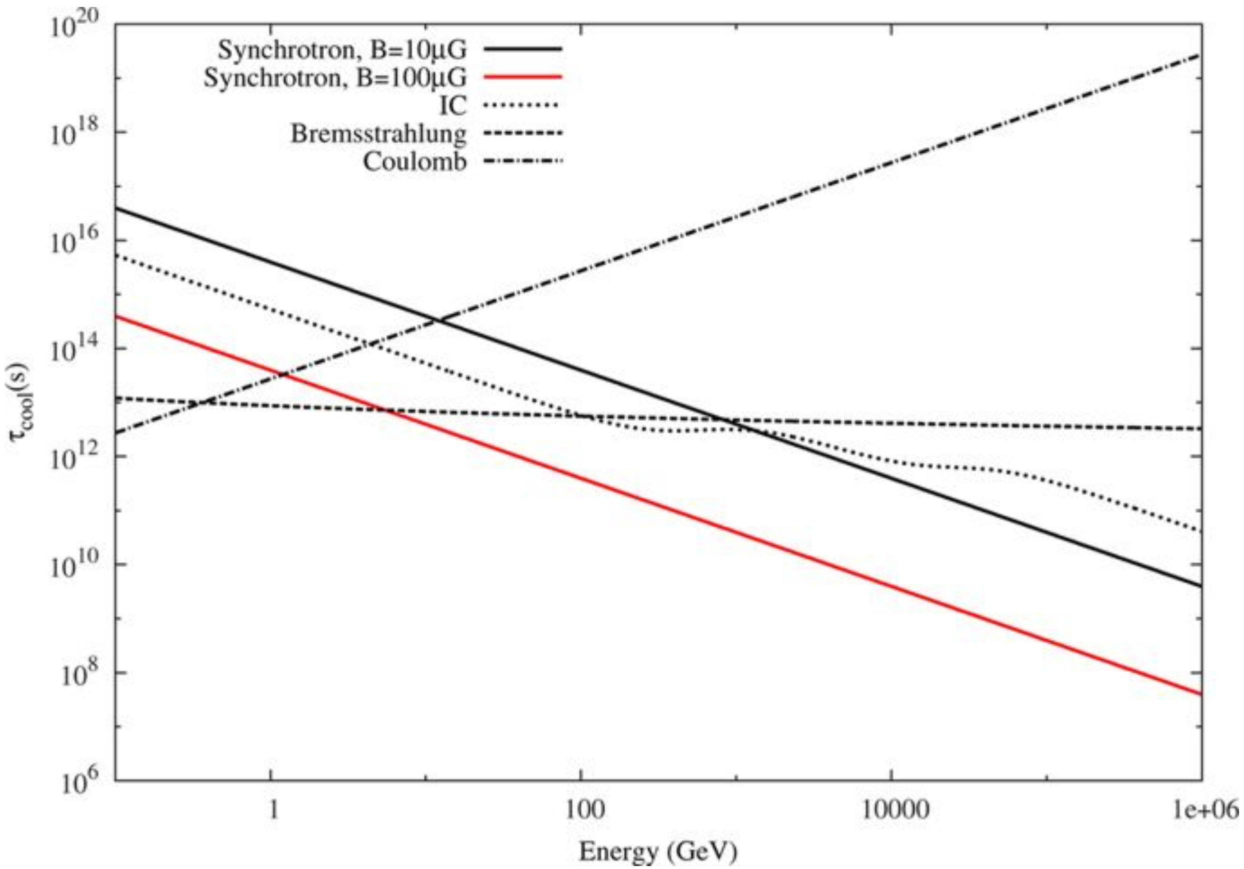
$E_e = \frac{1}{11}\sqrt{E_\gamma}$

$F_{synch} \propto B^2 \times g_e$

$F_{IC} \propto ph \times g_e$



Electron cooling, energy dependence

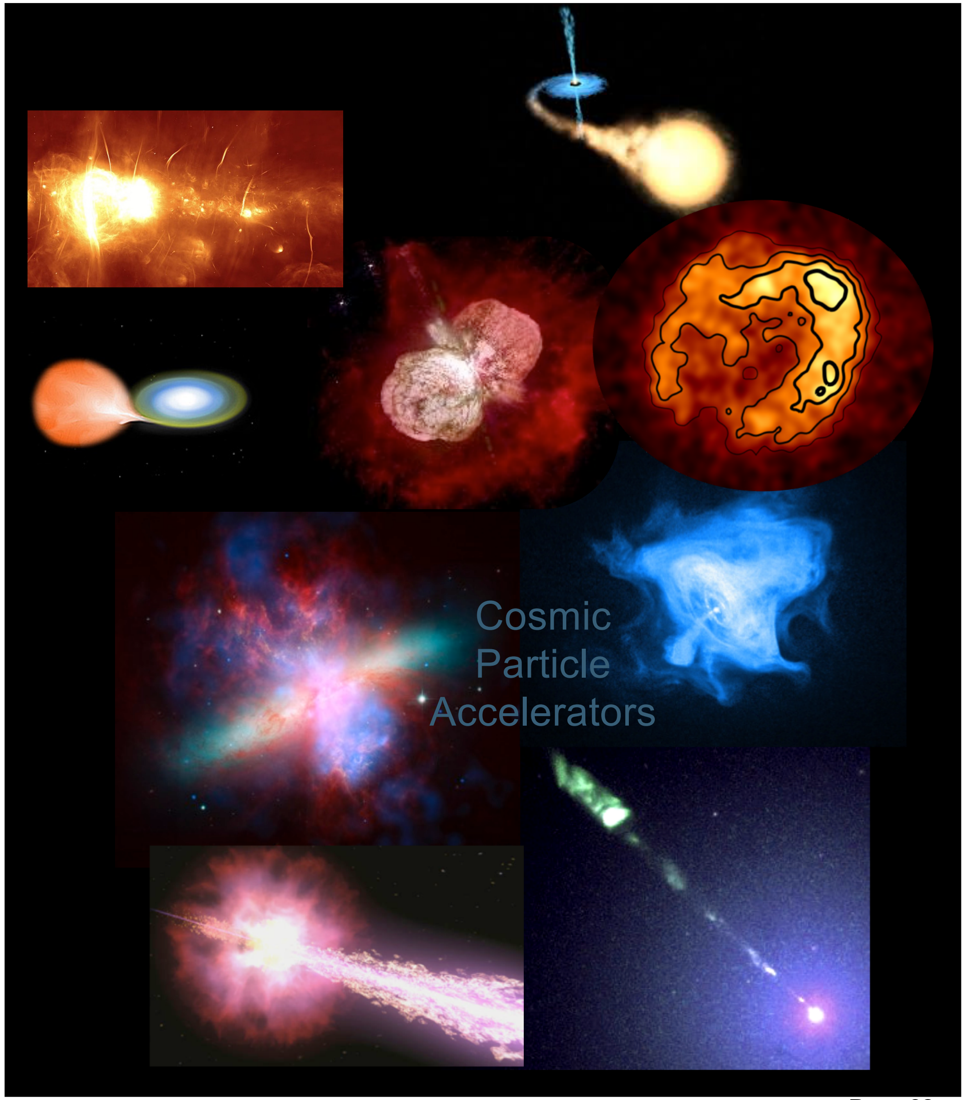


Galactic centre, HESS, Nature 2016

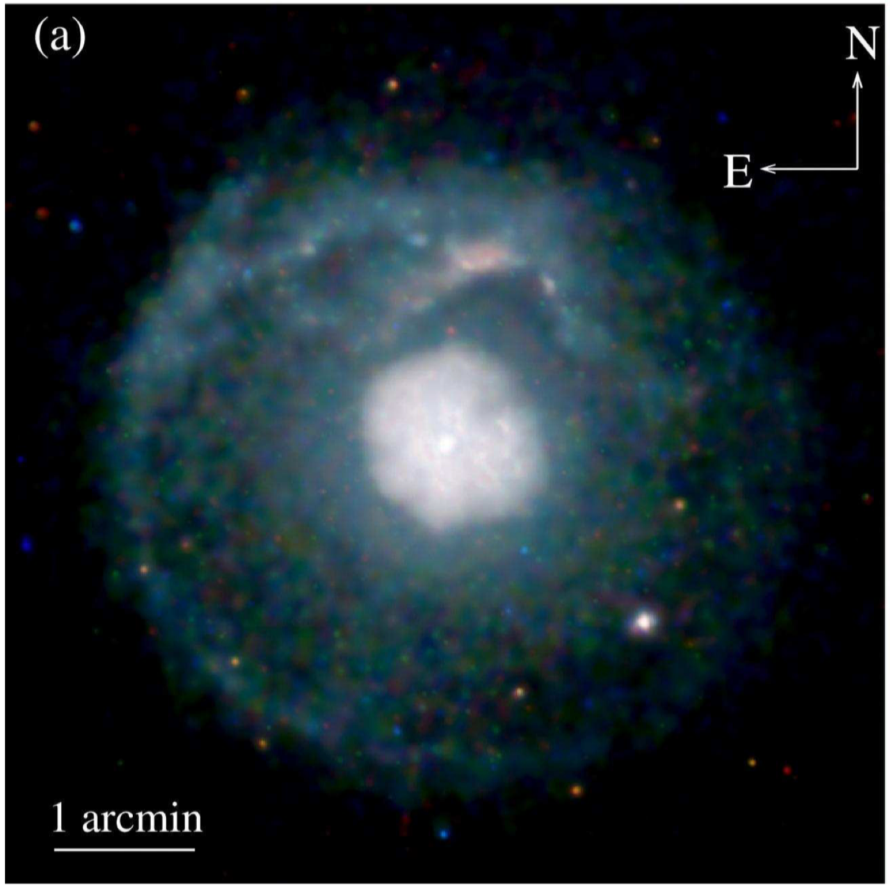
The GeV to TeV Sky (incomplete!)

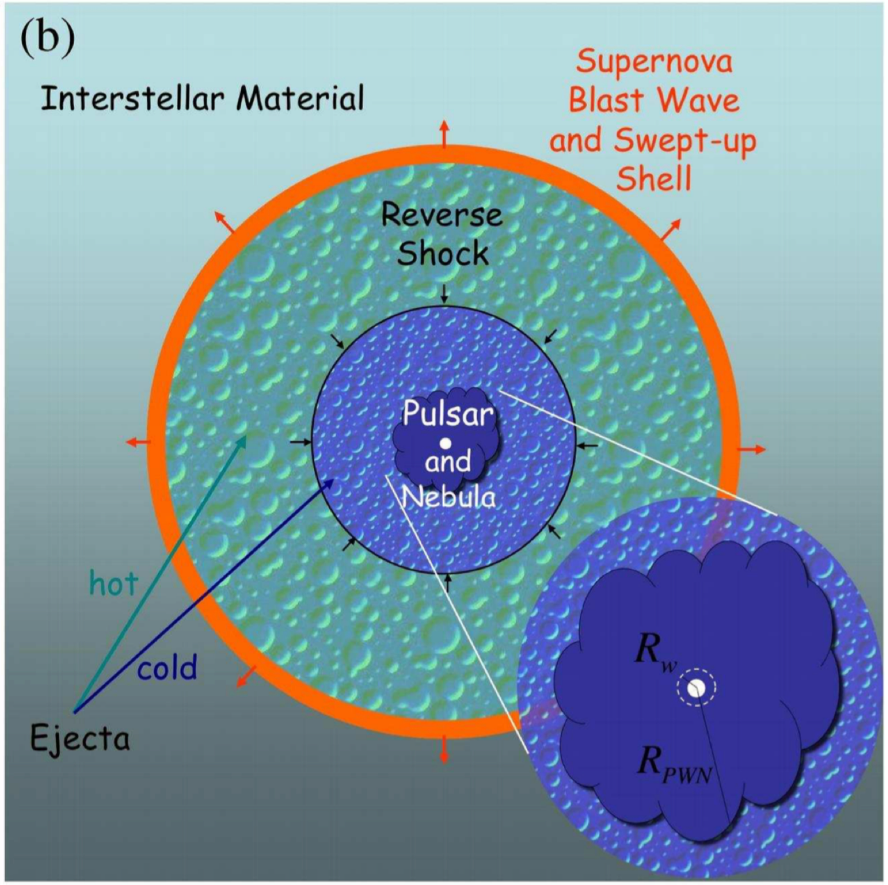
MW
- SNR
- MC
- binaries
- pulsars & PWN

E-gal
- AGN
- Starburst galaxies
- GRBs



Stellar deaths and particle accelerators

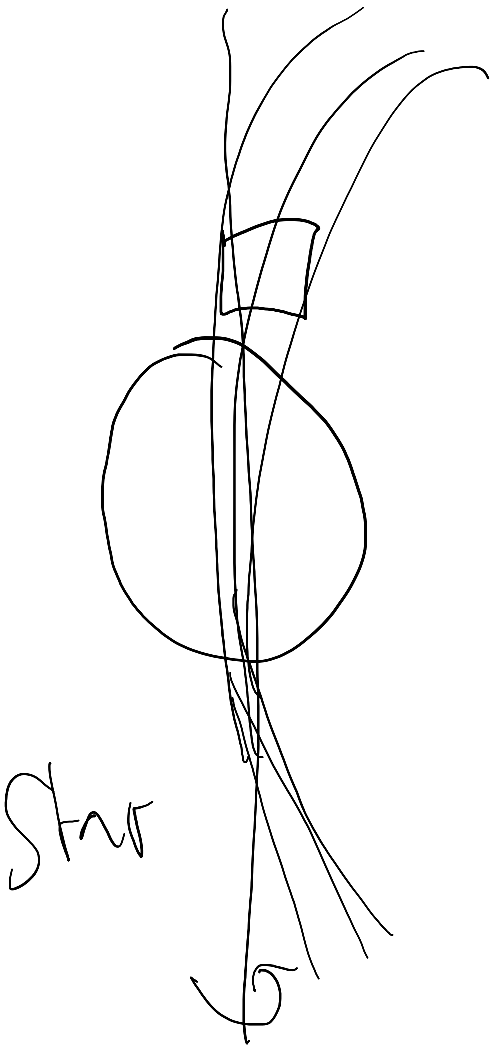


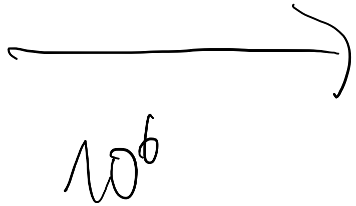


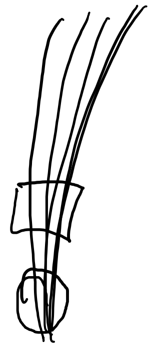
Gaensler & Slane 2006

Stellar deaths and particle accelerators

Pulsars







rotation $P_{NS} = P_{star} \frac{R^2_{NS}}{R^2_{star}}$

$P \sim 1 ms$

Pulsars

Exercise: Pulsars

$R_{star} = 0.5 \cdot 10^6$ km

$R_{pulsar} = 10$ km

$P_{star} = 30$ days

$P_{pulsar} = ?$

- Use angular momentum conservation
- Angular velocity $\omega = \frac{2\pi}{P}$
- Moment of inertia of sphere

$I = \frac{2}{5} m r^2$

Exercise: Pulsars

$$\Theta_{star} \cdot \omega_{star} = \Theta_{pulsar} \cdot \omega_{pulsar}$$

$$r^2_{star} \cdot \omega_{star} = r^2_{pulsar} \cdot \omega_{pulsar}$$

$$\frac{r^2_{star}}{r^2_{pulsar}} \cdot \omega_{star} = \omega_{pulsar}$$

$$P_{pulsar} = \frac{r^2_{pulsar}}{r^2_{star}} \cdot P_{star}$$

$$= \frac{100}{1e12} \cdot 4 \cdot 30 \cdot 24 \cdot 60 \cdot 60 \, s \approx 1 \, ms$$

Exercise: Pulsars

Similar for B field, assume B flux constant before/after contraction,

$$B_{pulsar} = B_{star} \frac{r_{star}^2}{r_{pulsar}^2}$$

$B_{star} = 0.1\,T$

$B_{pulsar} \simeq 10^8\,T$

LHC =

Earth =

Exercise: Pulsars

Stability :

Exercise: Pulsars

Stability: gravitational > centrifugal acceleration

$$\omega^2 R < \frac{GM}{R^2}$$

$$\frac{4\pi^2 R^3}{P^2} < GM$$

$$\rho = \frac{M}{4/3\,\pi R^3}$$

Exercise: Pulsars

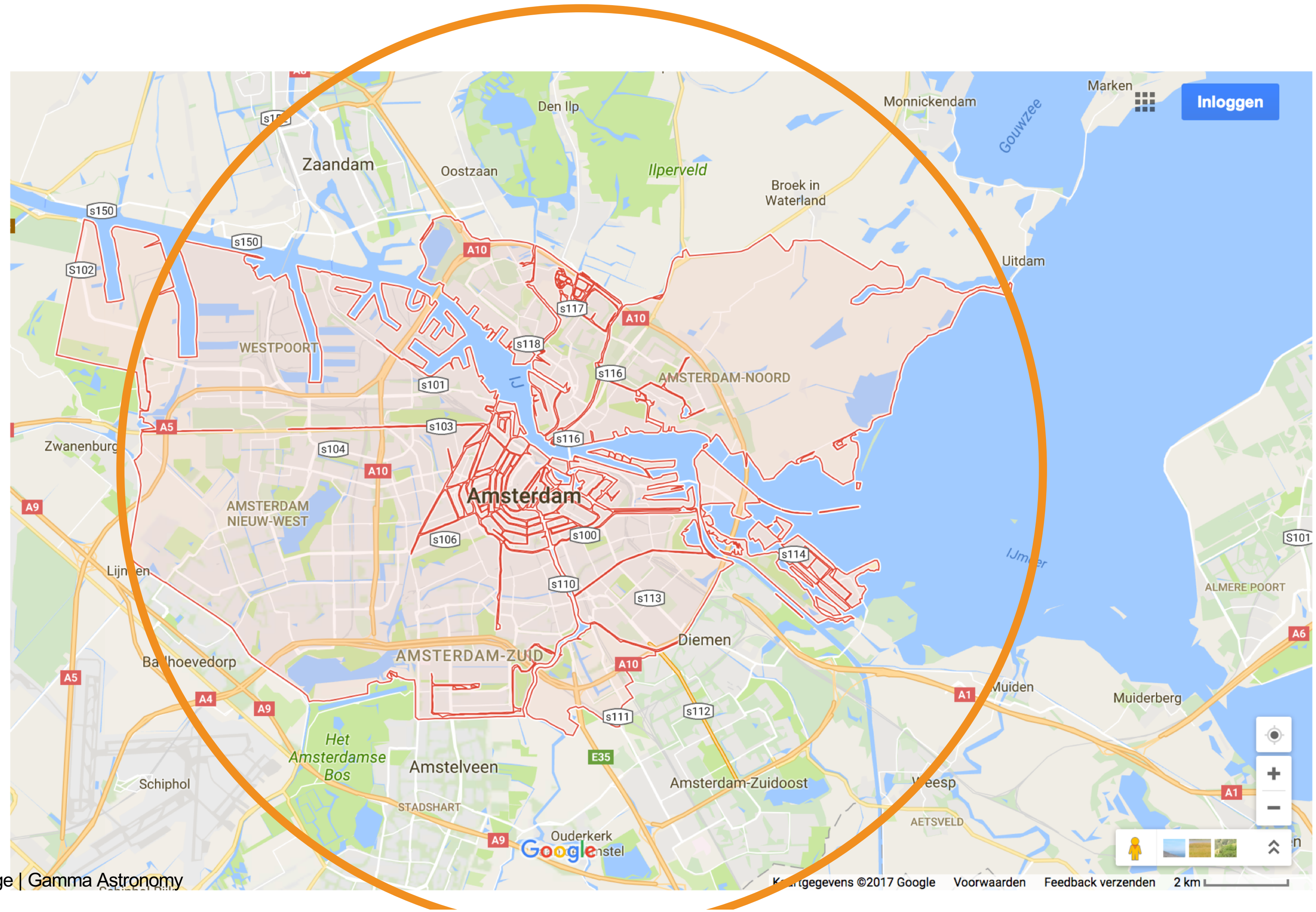
Stability: gravitational > centrifugal acceleration

$$\rho = \frac{M}{\frac{4}{3}\pi R^3} \qquad \frac{4\pi^2 R^3}{P^2} < GM$$

$$\rho > \frac{3\pi}{G P^2} \implies$$ radio pulsars must be neutron stars, not White Dwarfs!

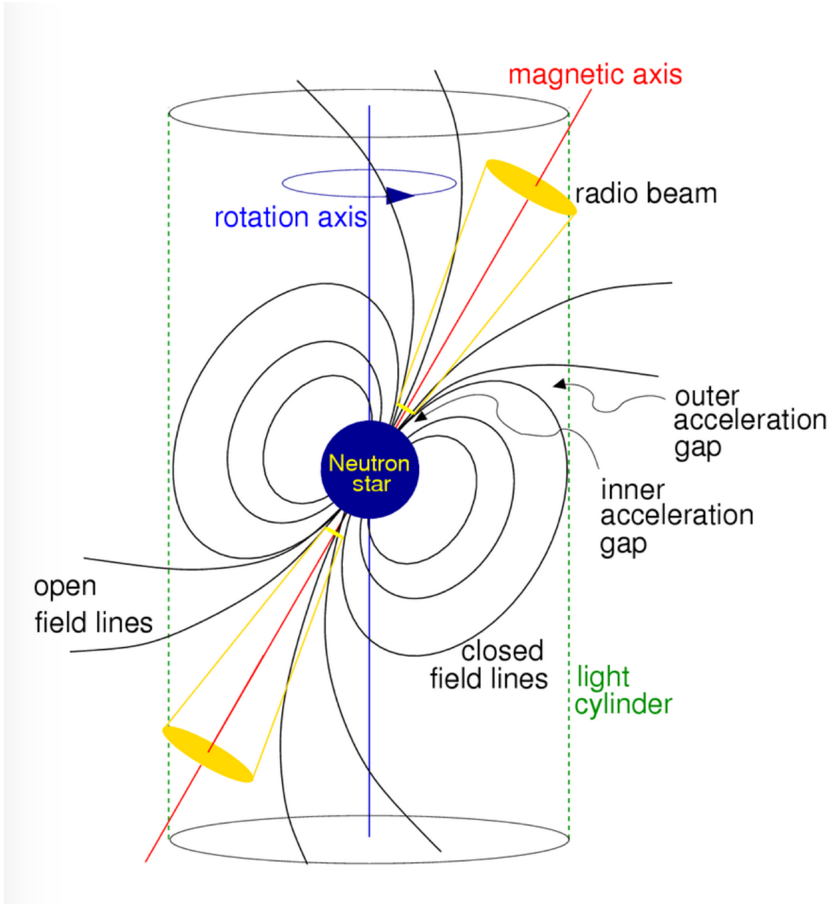
$$\rho > 1.3 \times 10^{11}\ g/cm^3$$

Like Amsterdam rotating at 100-1000 Hz!



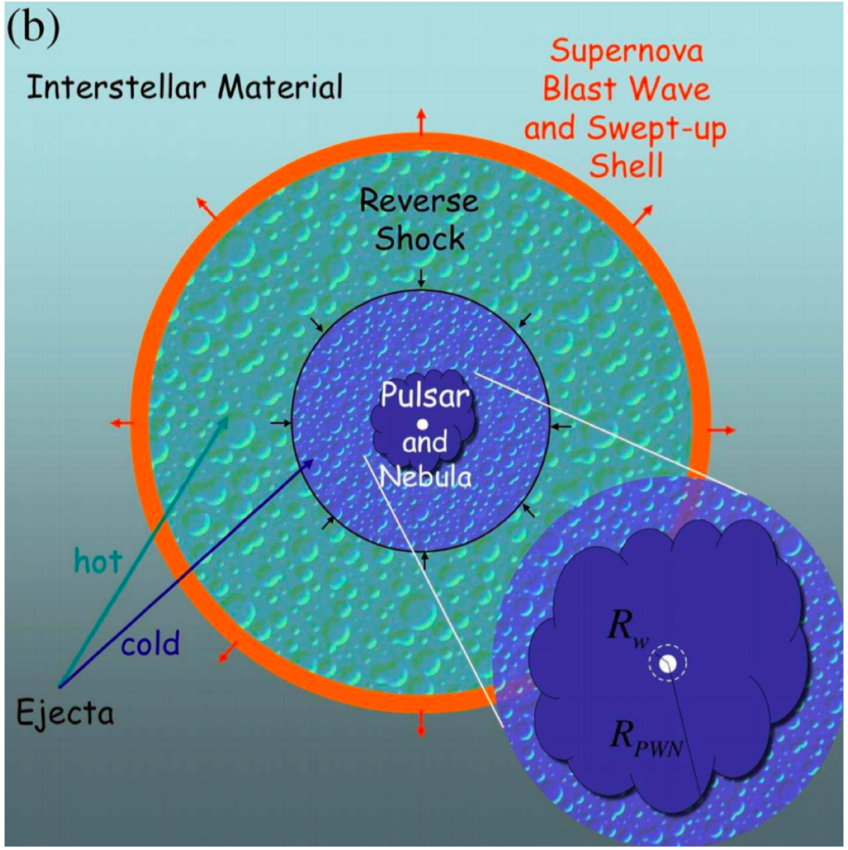
Pulsars

Pulsar particle acceleration

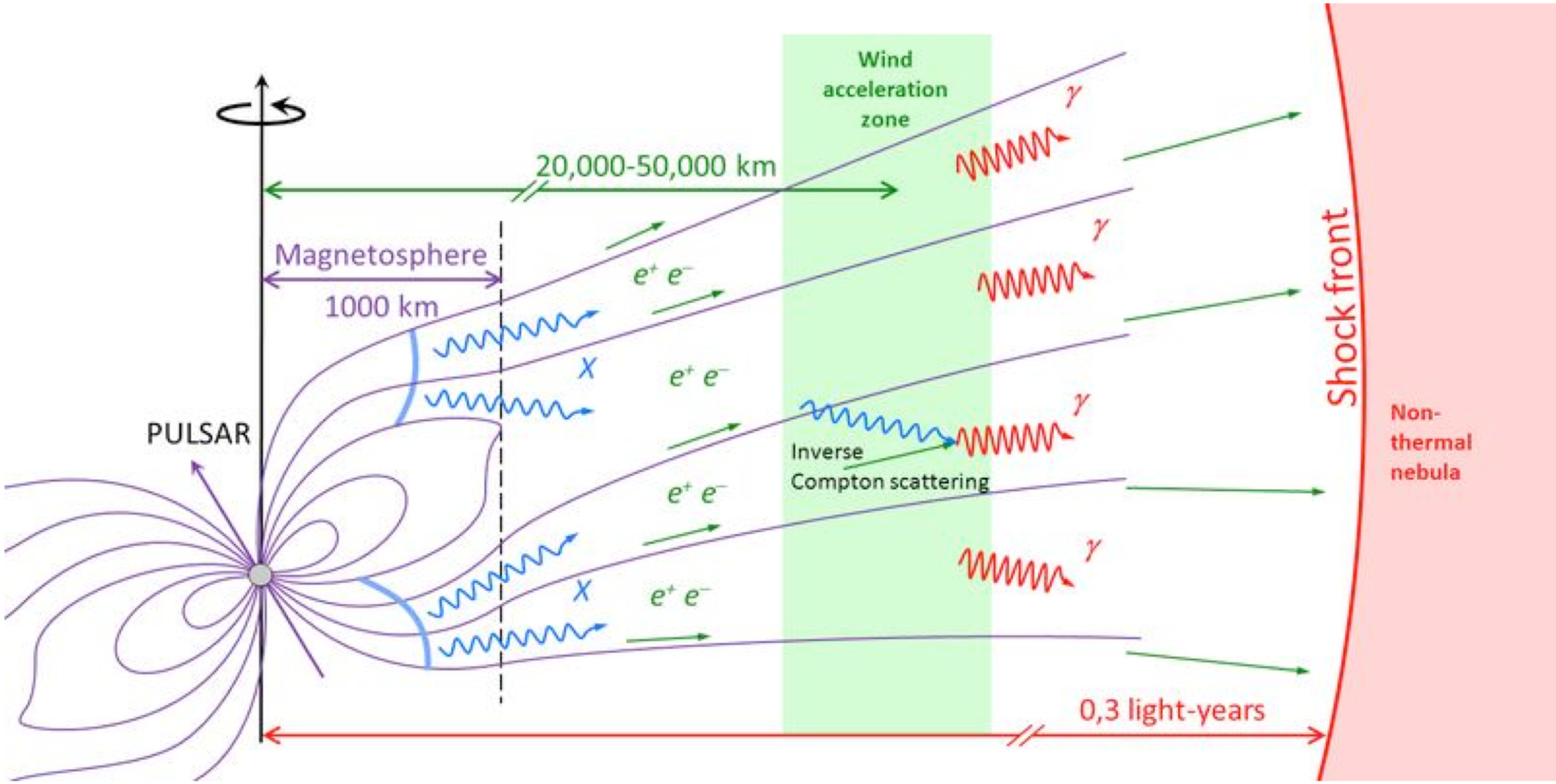


Pulsar symphony: https://www.youtube.com/watch?v=gb0P6x_xDEU

Pulsar Wind Nebulae



Pulsar Wind Nebulae



The Crab nebula

Name goes back to Lord Rosse (1844)

[321]

XII. *Observations on some of the Nebulæ. By the Earl of* Rosse, *F.R.S., &c.*

Received June 10,—Read June 13, 1844.

As every addition, however trifling, to the little we know with certainty respecting the nebulæ can scarcely be considered wholly uninteresting, I have ventured to communicate a few observations made with the speculum of three feet aperture described in the Philosophical Transactions for 1840.

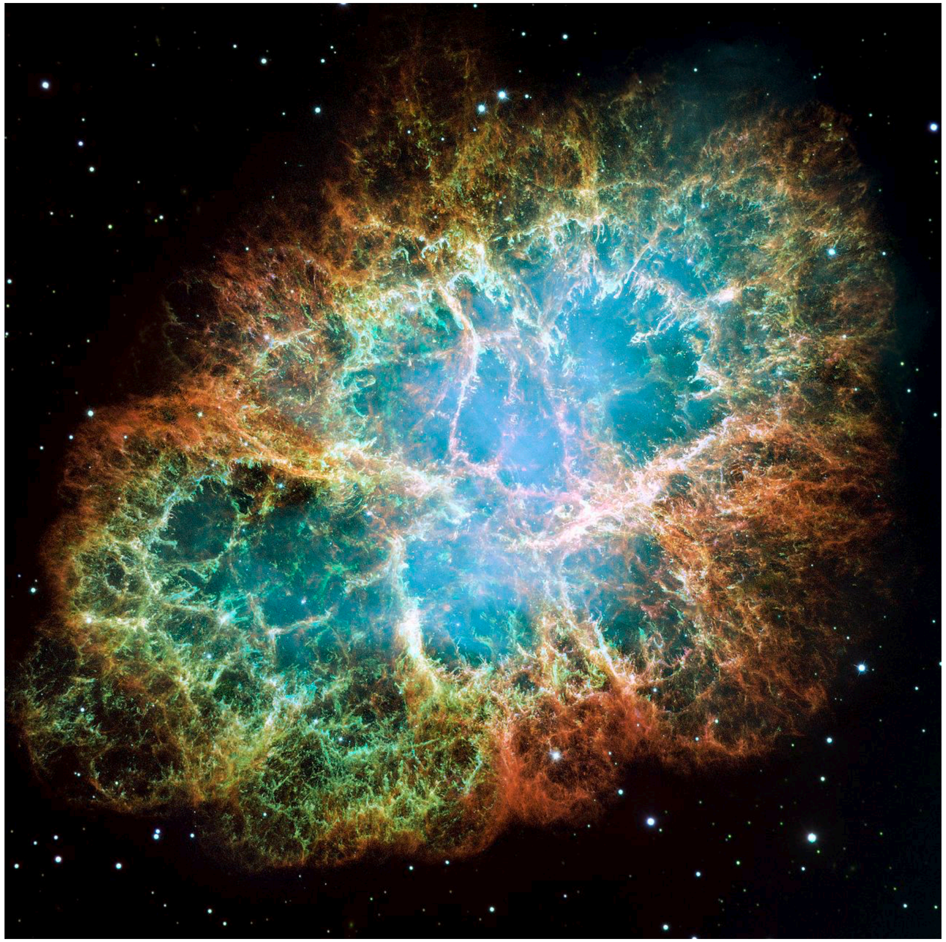
Fig. 81. *R.A. 5^h 24'. Dec. 21° 53' North.*

The Crab nebula

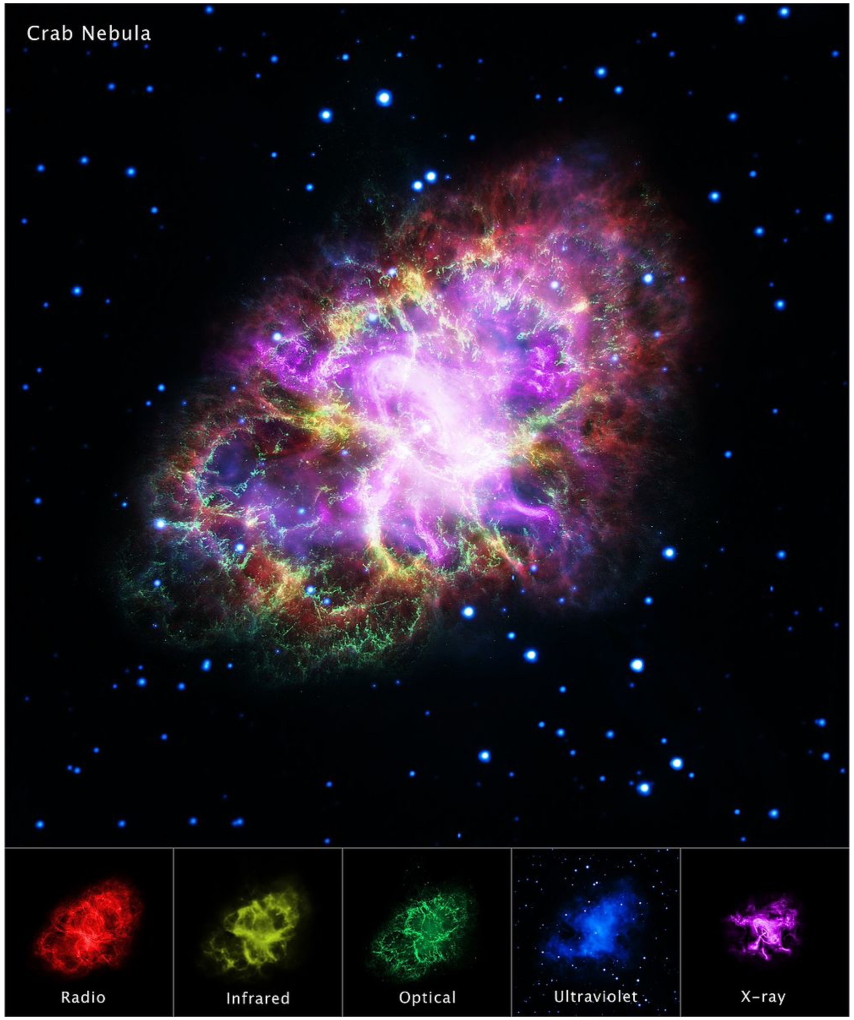
SN 1054 Chinese Astr.

nearby : 2 kpc

→ across the entire spectrum



The Crab nebula



Movie: https://www.youtube.com/watch?v=H9DN3ODUY-4

Galactic Cosmic Rays