The Interstellar Medium Towards the Unidentified γ–ray Source HESS J1804–216

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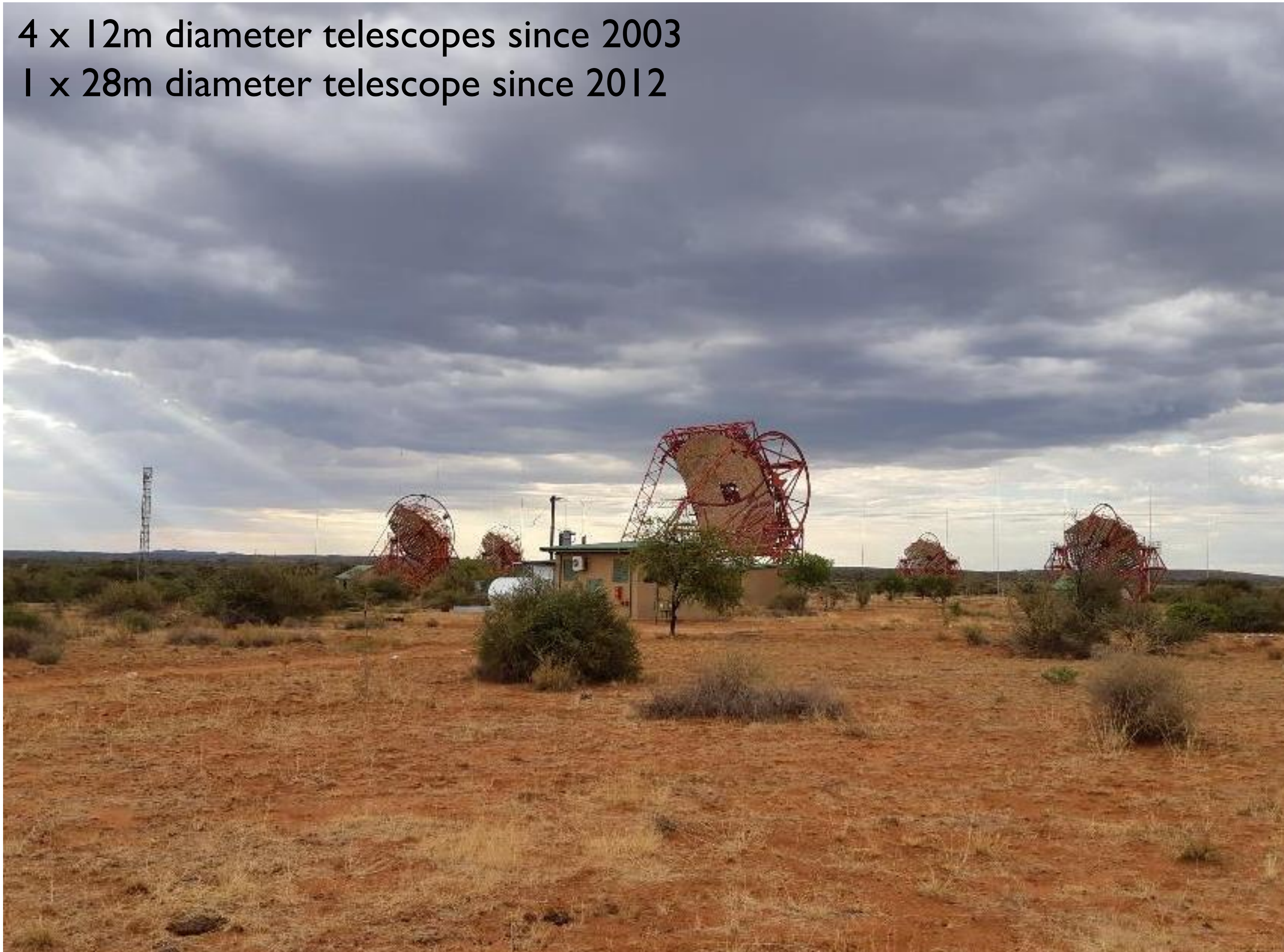
THE UNIVERSITY *of* ADELAIDE

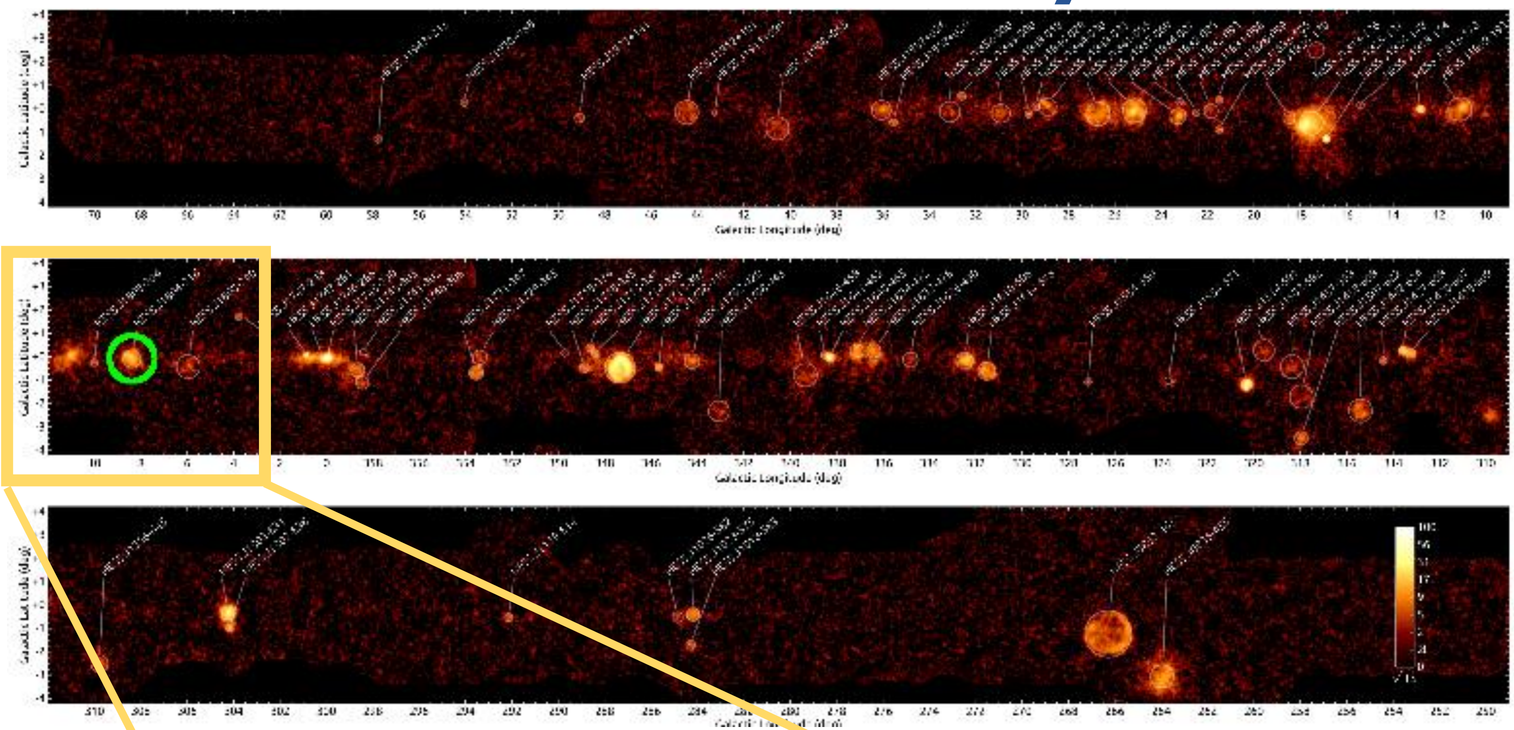
High Energy Stereoscopic System

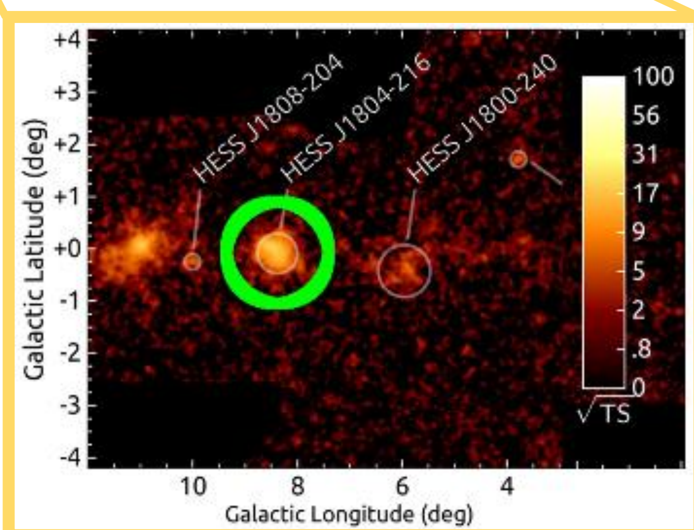
4 x 12m diameter telescopes since 2003

1 x 28m diameter telescope since 2012



HESS Galactic Plane Survey - 2018

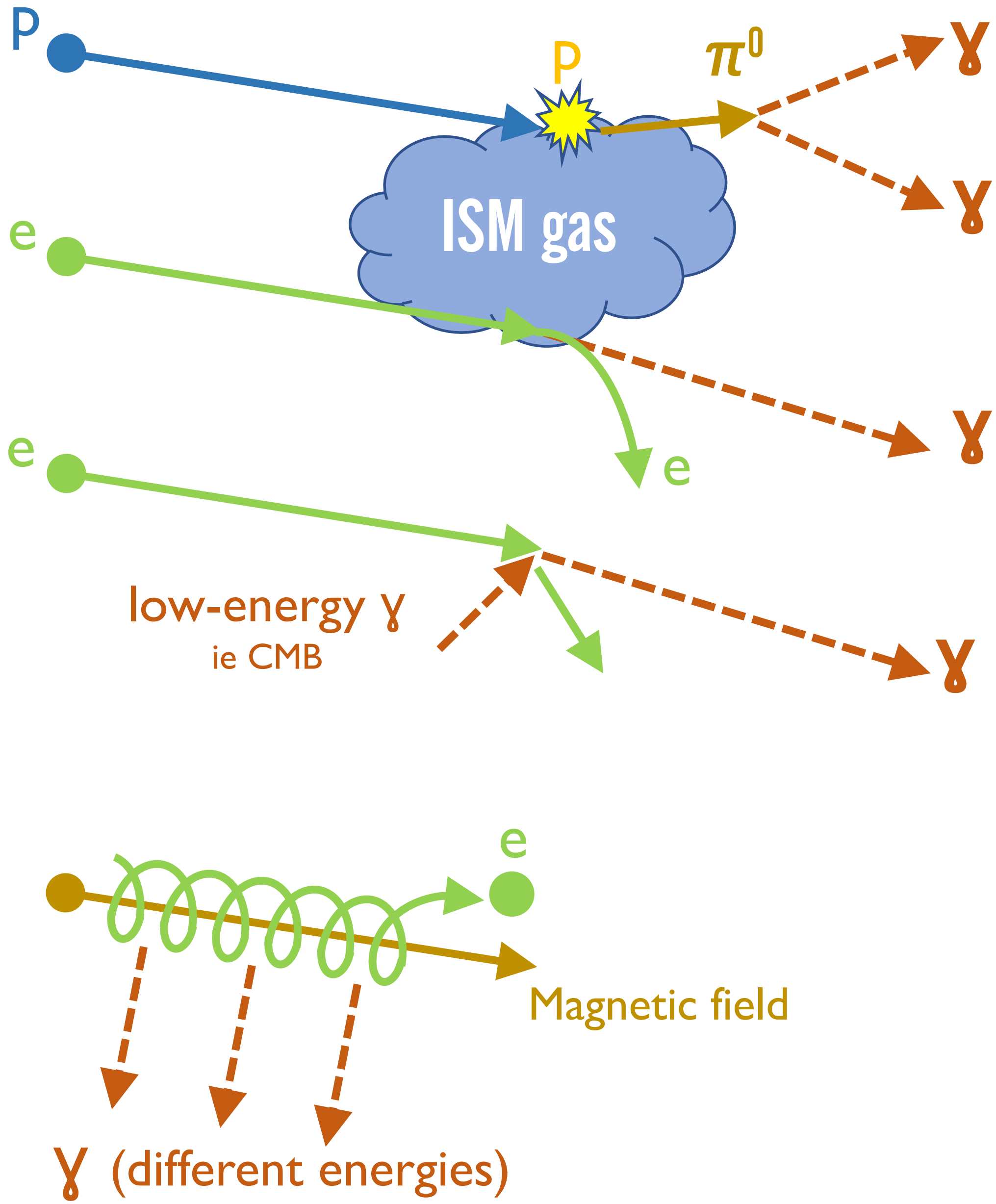




- 3 Binary
- 8 Composite
- 8 SNR
- 12 PWN
- **36 Unidentified**

HGPS map: HESS Collaboration at https://arxiv.org/pdf/1804.02432.pdf

Production of γ-rays



HADRONIC

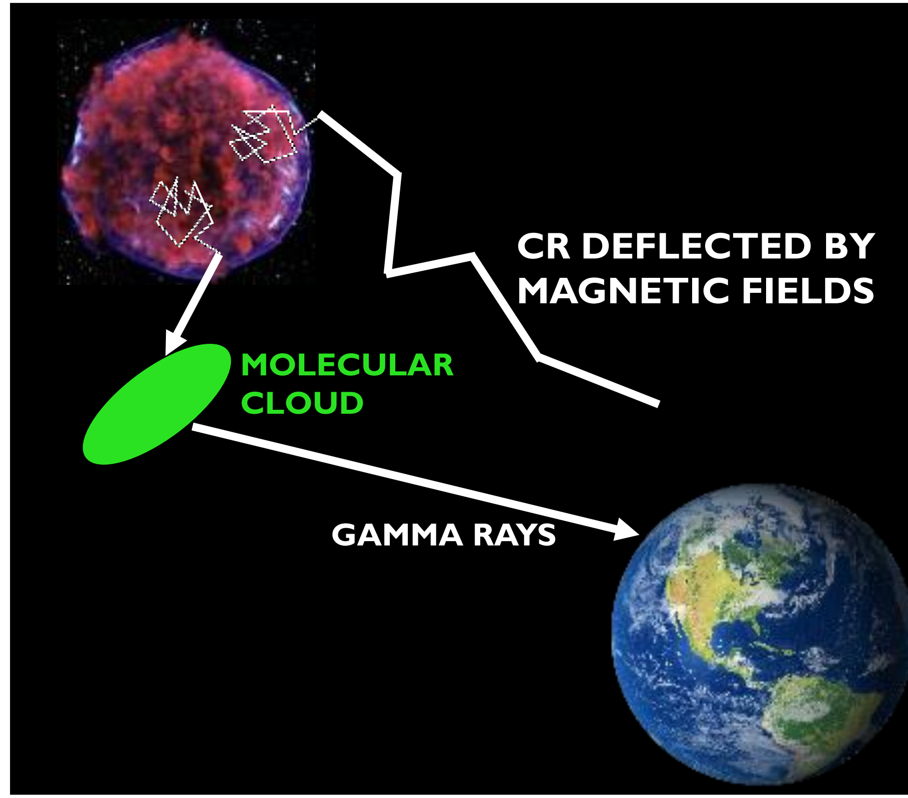
- π_0 decay

LEPTONIC

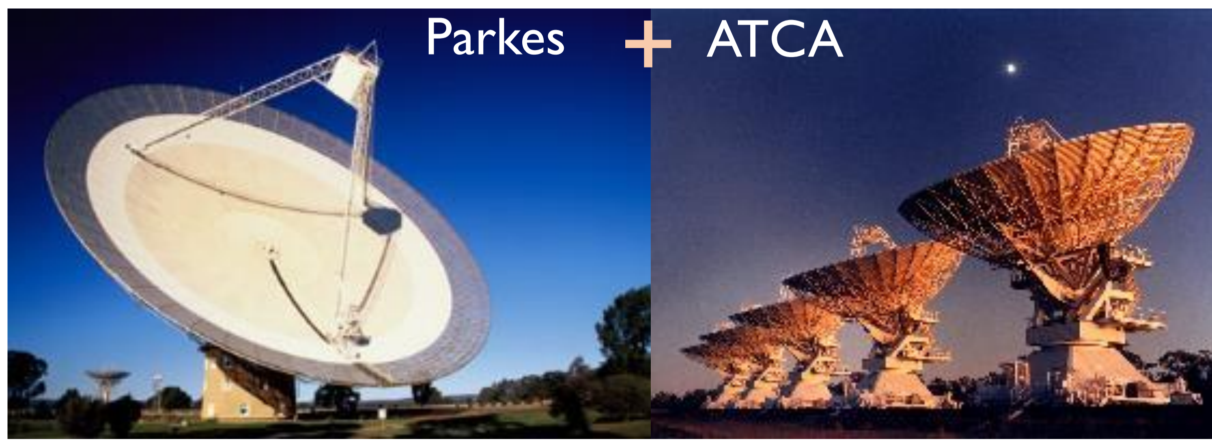
- Bremsstrahlung
- Inverse Compton
- Synchrotron Radiation

Molecular Clouds

- Clouds serve as a target for CR collisions
  - Dense regions of gas give information about γ–ray sources
- Important to understand the interstellar gas surrounding a source
- Different gas tracers include:
  - Carbon monoxide (CO)
  - Atomic hydrogen (HI)

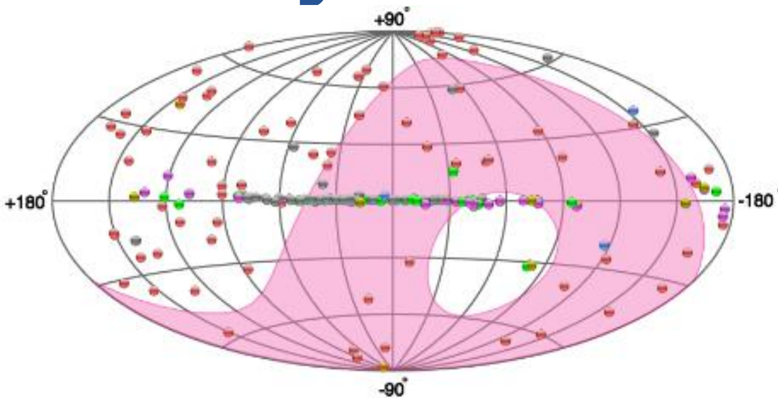


3mm: ^{12}**CO**, ^{13}**CO**, $C^{18}O$, $C^{17}O$
7mm: CS, SiO,
12mm: NH_3

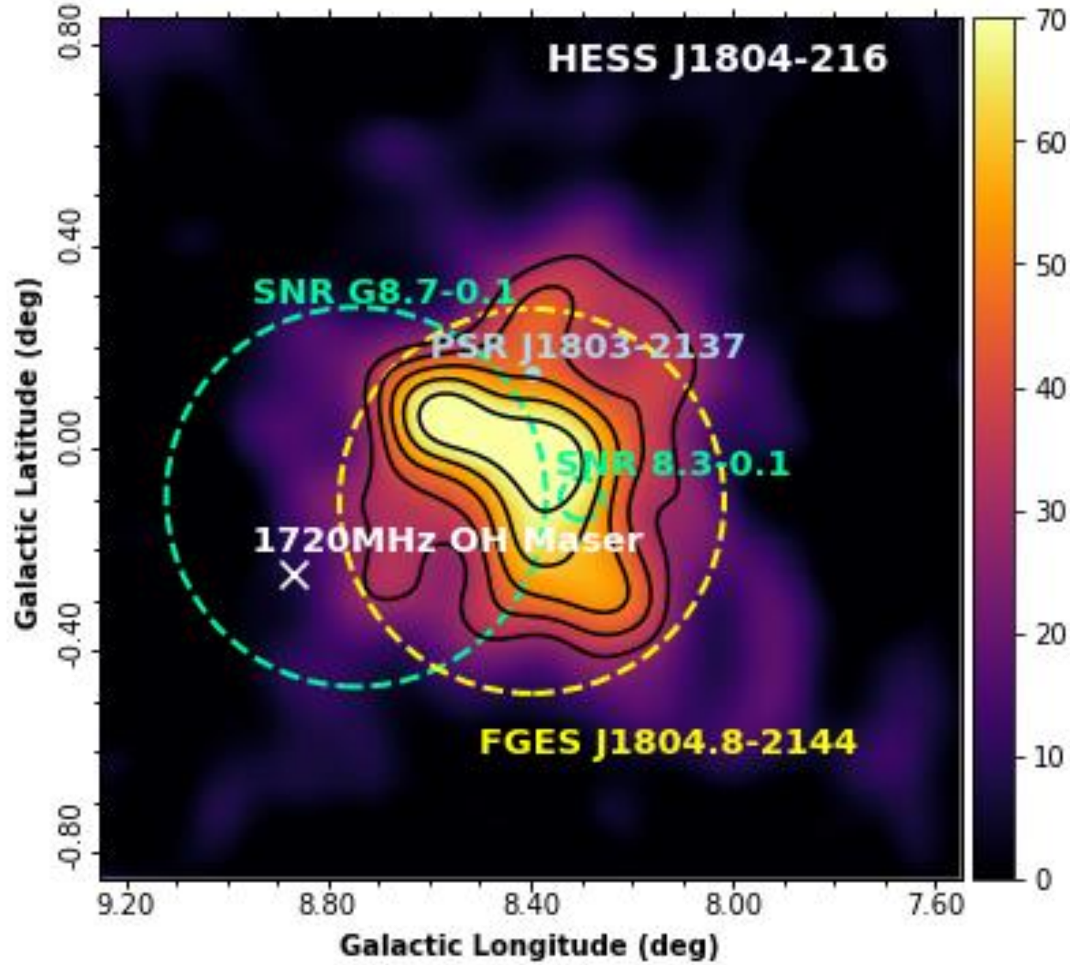


Parkes + ATCA = Southern Galactic Plane Survey (SGPS) of HI

HESS J1804-216



Top: TeVCat image of sources
Right: Excess counts map from the HGPS 2005 scan in the region of HESS J1804-216



- The origin of high-energy CRs is a mystery
- γ–rays provide information on high energy astrophysical environments
- Studying various γ–ray sources helps us understand the extreme universe

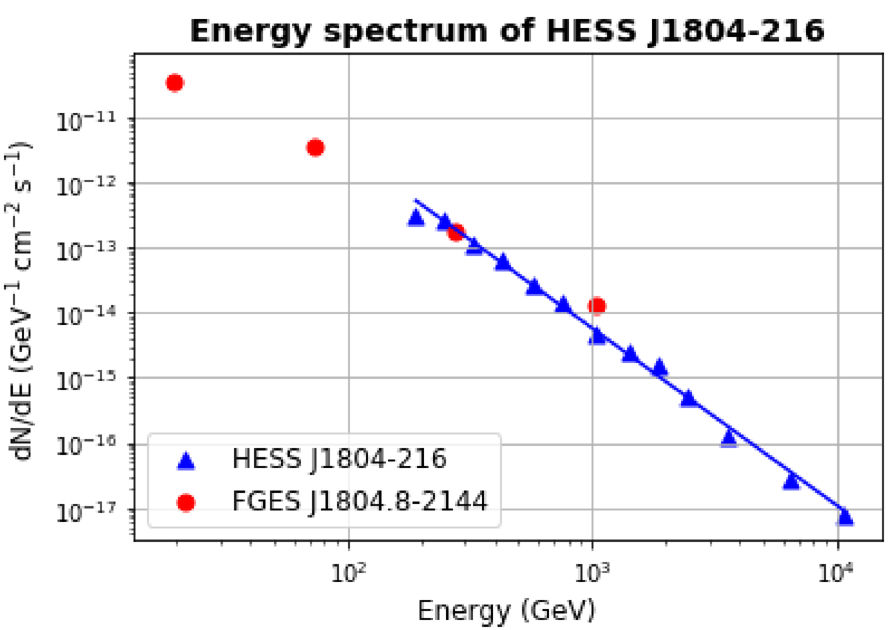
- HESS J1804-216 is the focus of this talk
- FGES = Fermi Galactic Extended Sources

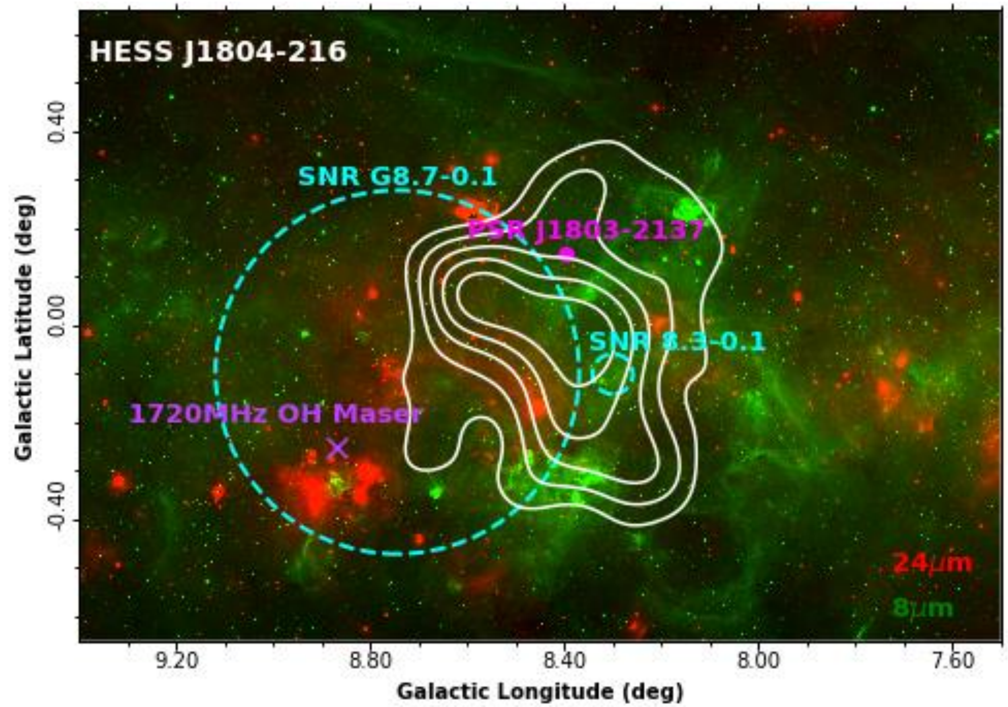
  → one of the Fermi catalogs

TeVCat Image: http://tevcat.uchicago.edu/

HESS J1804-216

- HESS J1804-216 is one of the most mysterious and brightest TeV γ–ray sources discovered
  - Flux of 25% of the Crab Nebula
  - γ–ray luminosity of $L_\gamma = 1.8 \times 10^{35}$ erg s^{-1}
- One of the softest galactic sources due to its photon index of 2.69, with an unusually steep γ–ray spectrum

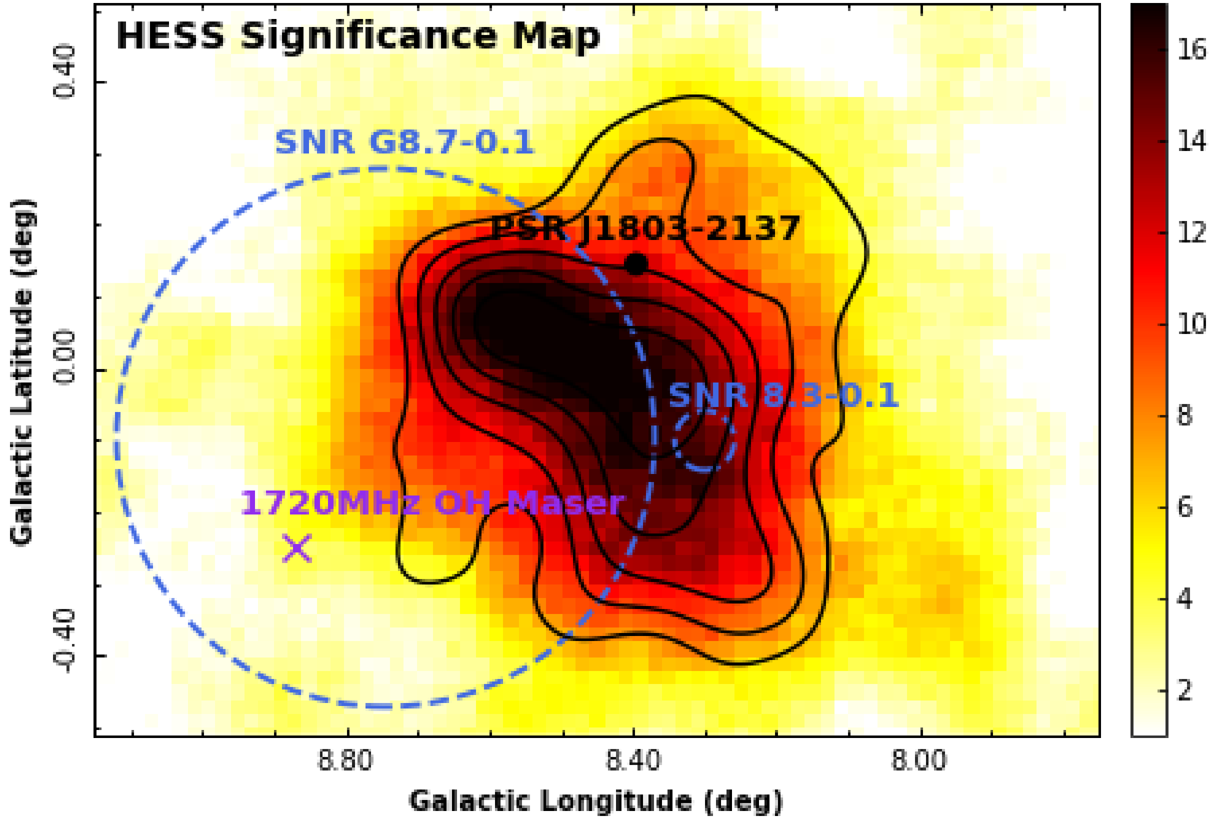




Top: Spitzer red-green image
Left: Energy spectrum for HESS J1804-216, from the HESS array and Fermi telescope

Local Region

- No objects coincide exactly with HESS J1804-216
- **SNR 8.3-0.1**
  - Size: 5’ x 4’
  - Distance: 16.3kpc
- **SNR G8.7-0.1**
  - Age: 15 kyr
  - Radius: 26′
  - Distance 4.5 kpc
- **1720MHZ OH Maser**
  - Distance: 4.6 kpc
- **PSR J1803-2137**
  - Spin down power: 2.2×10^{36}erg s^{-1}
  - Age: 16 kyr
  - Distance: 3.8 kpc

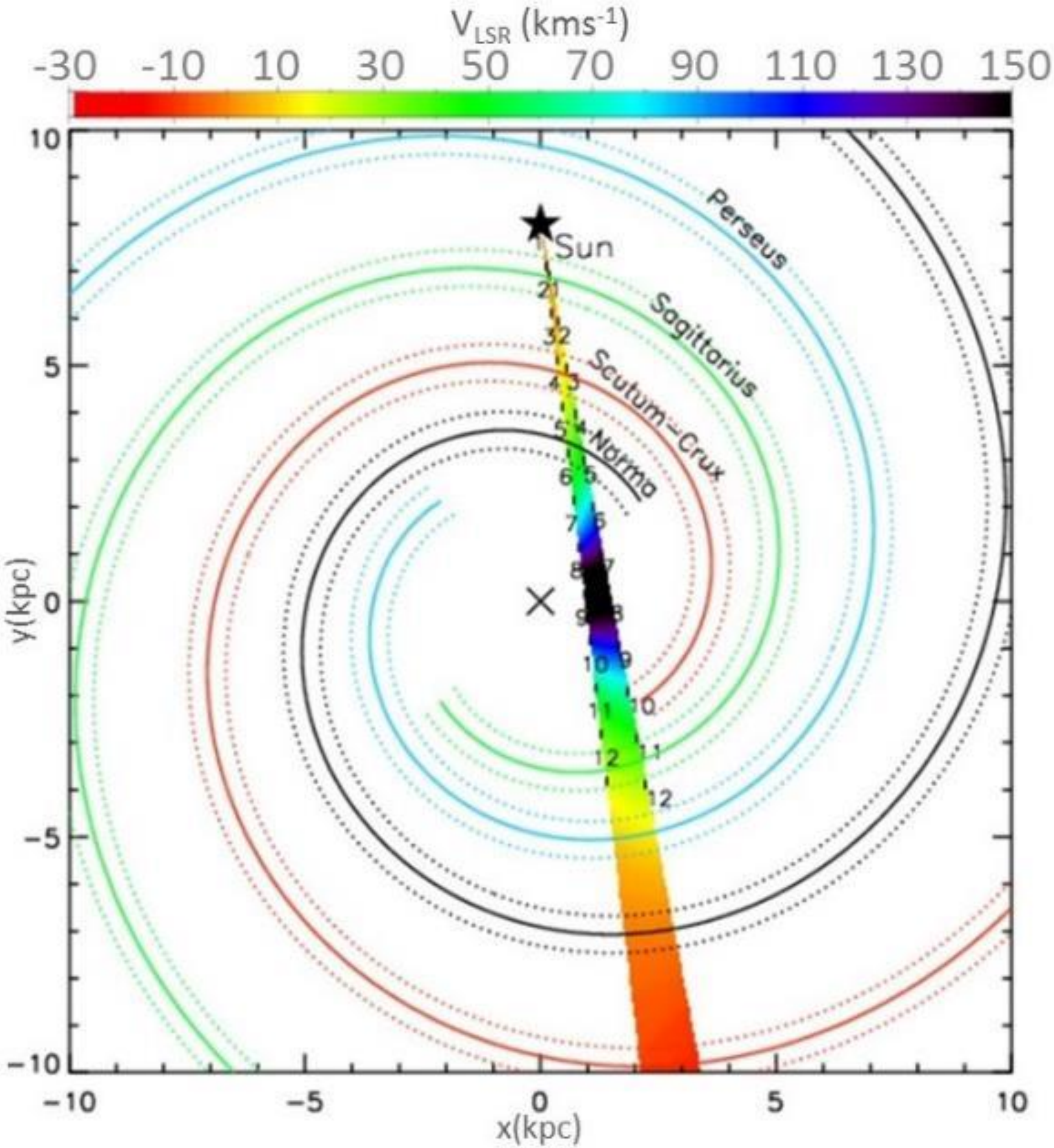


Top: Significance map from the 2018 HGPS

- PSR J1803-2137 born outside SNR G8.7-0.1, requires huge transverse velocity
  → Likely moving towards the SNR rather than away from it
  → Concluding that there is no connection between the two

Significance map: HESS Collaboration at https://arxiv.org/pdf/1804.02432.pdf

Galactic Rotation Curve

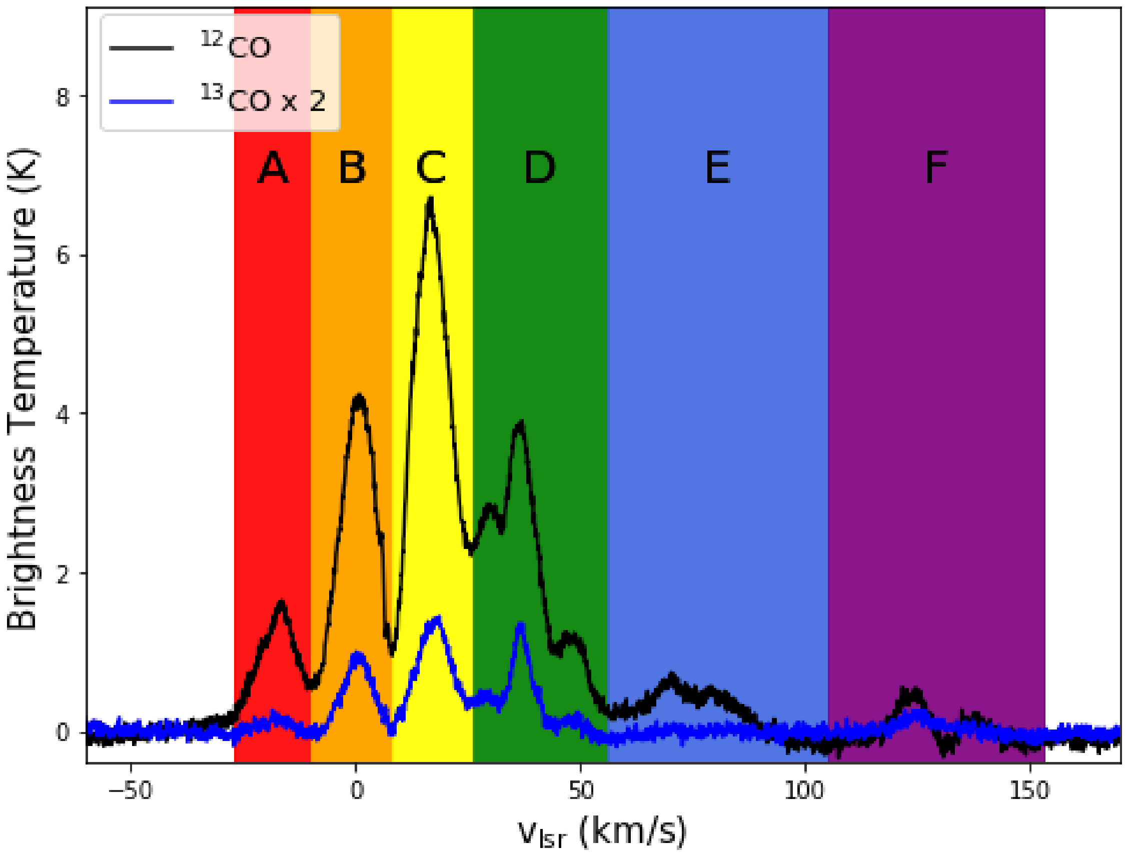


- Distances to sources not easily resolved
- Doppler shifting of spectral lines allows us to estimate these distances
- The Galactic Rotation curve is used to find the various distances related to objects in the local region of HESS J1804-216

Left: Galactic Rotation Curve model for HESS J1804-216

Spectra

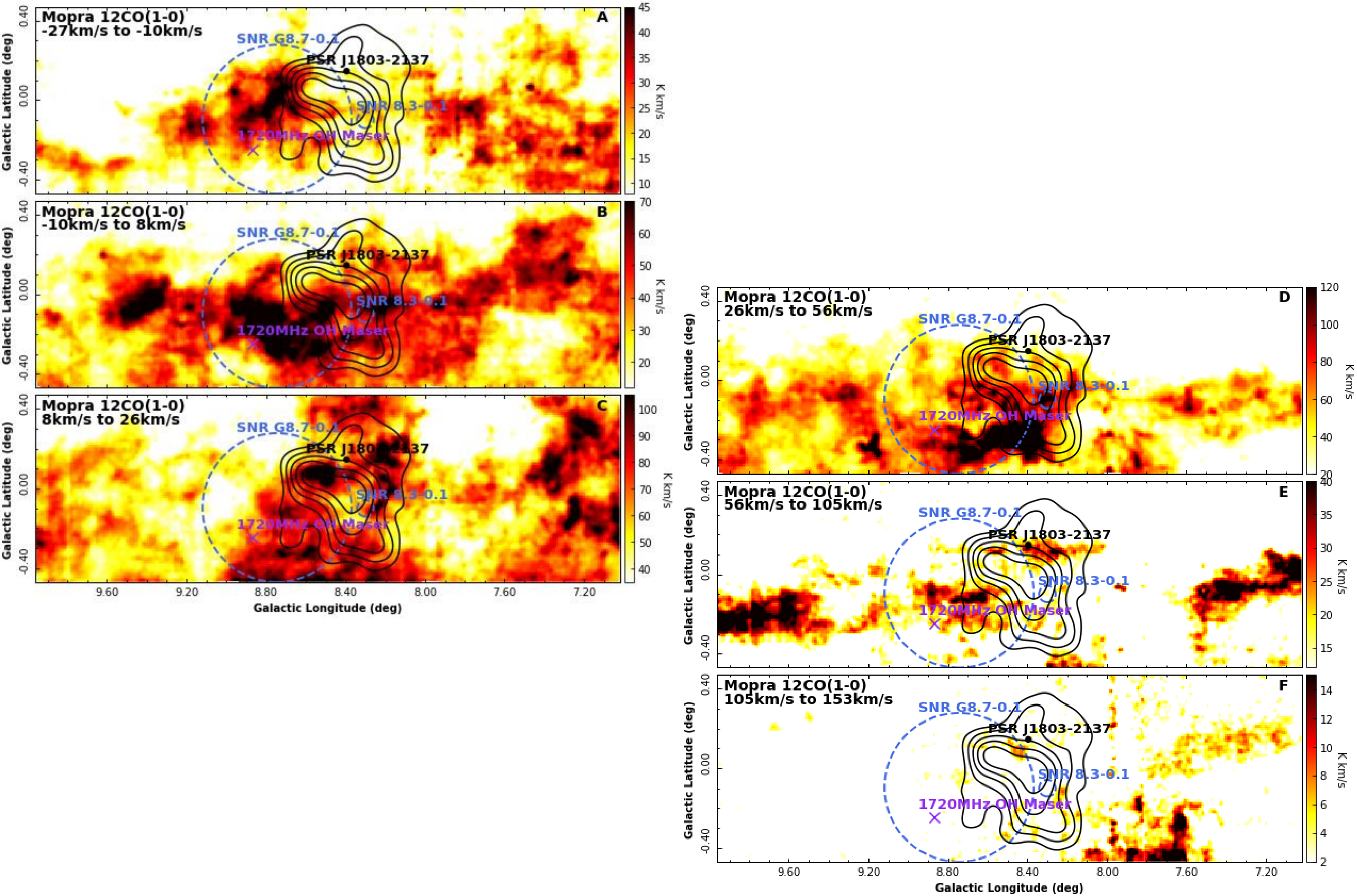
- Region taken to encompass the 5σ level of HESS J1804-216 on the Mopra ^{12}CO cube
  - Cube is Doppler-shifted velocity along the z-axis
  - This is used to create a spectrum
- The Mopra Galactic Plane CO survey data: ^{12}CO and ^{13}CO



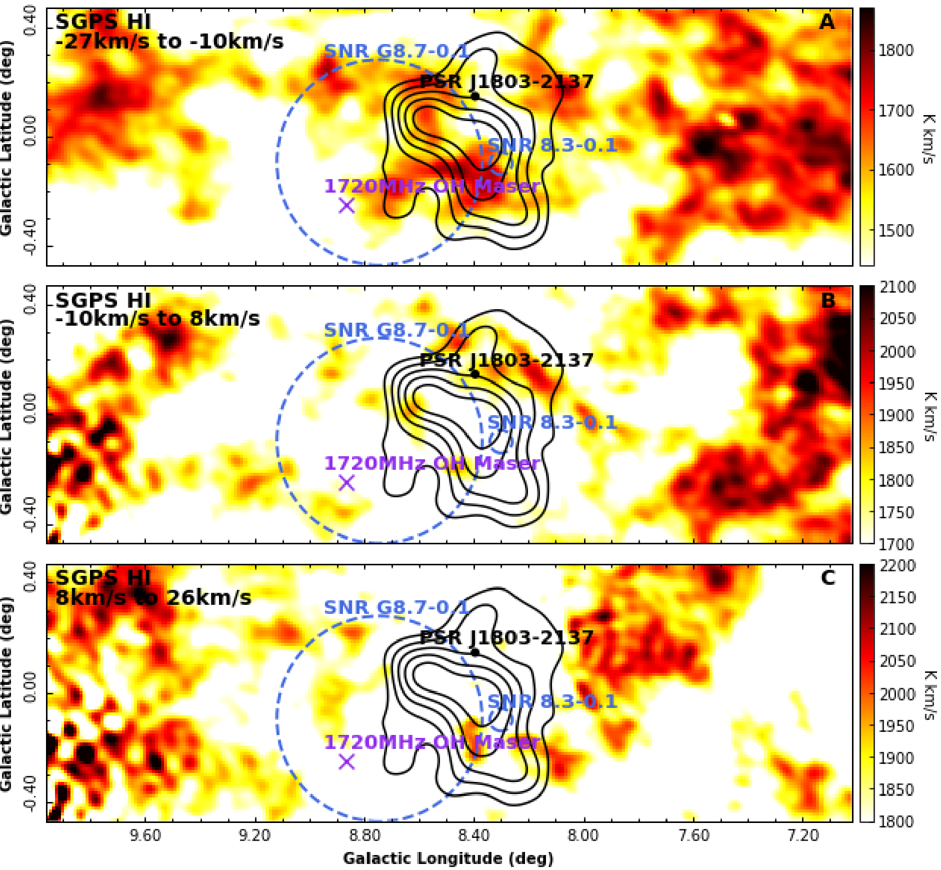
Left: Mopra ^{12}CO and ^{13}CO spectra towards HESS J1804-216
Bottom: Velocity components from left plot

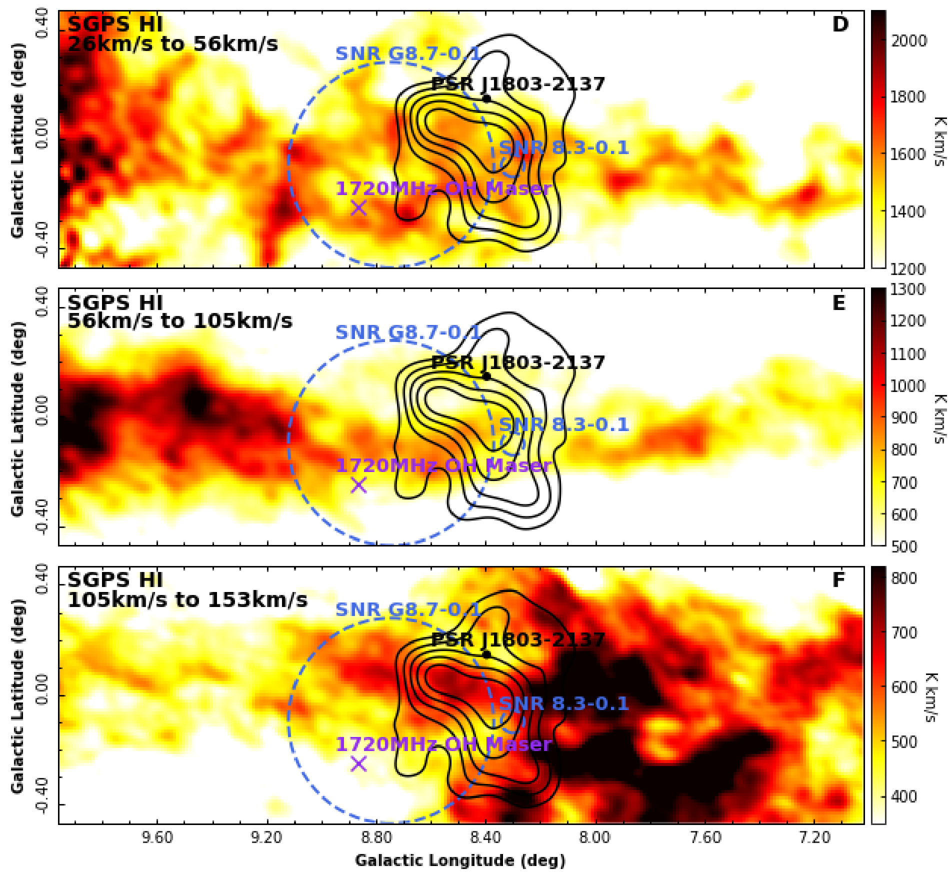
Velocity range (km/s)	Component
-27 to -10	A
-10 to 8	B
8 to 26	C
26 to 56	D
56 to 105	E
105 to 153	F

Mopra Data – $^{12}CO(1–0)$



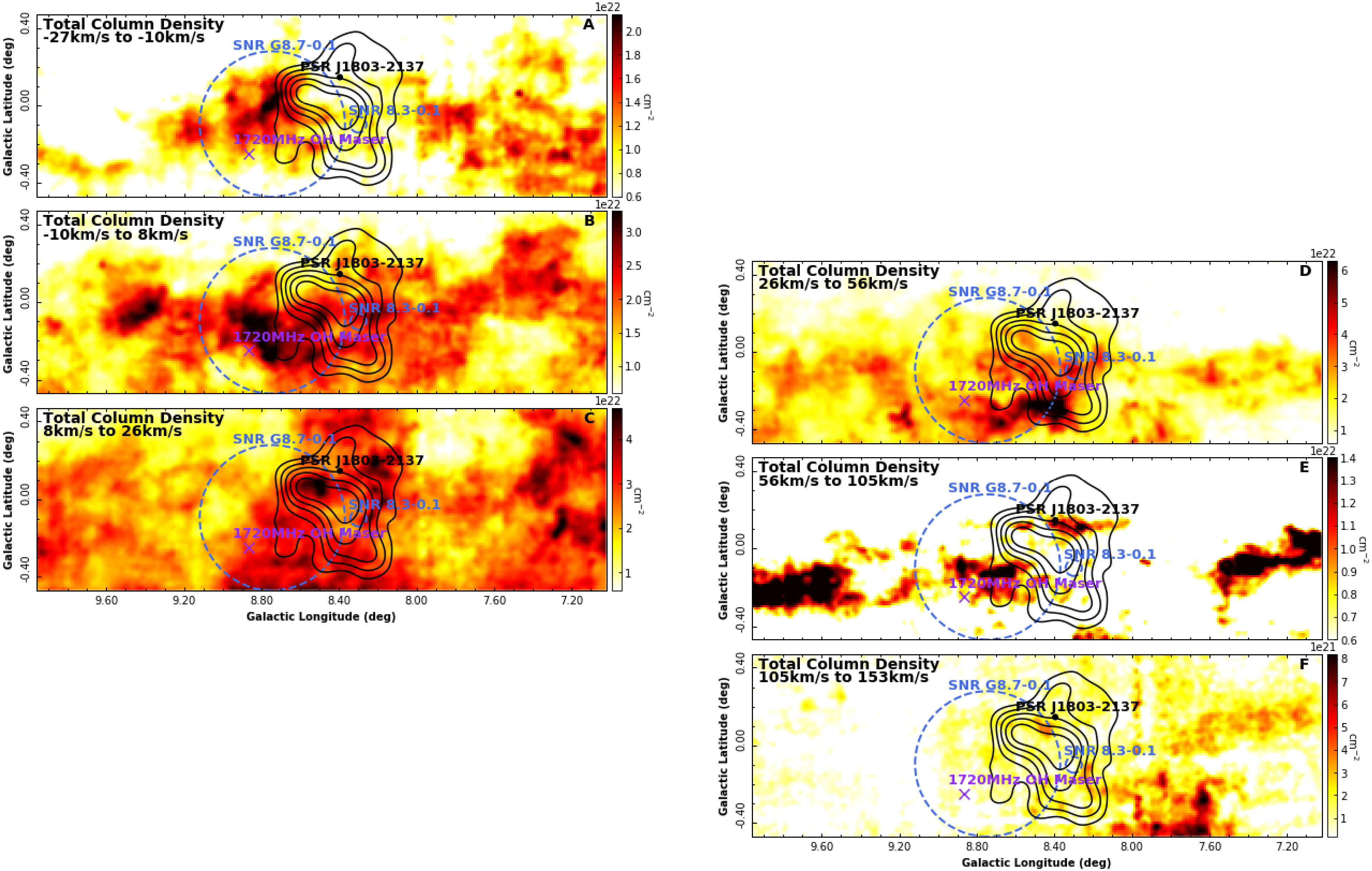
SGPS Data – HI


SGPS HI
-27km/s to -10km/s
A
SGPS HI
-10km/s to 8km/s
B
SGPS HI
8km/s to 26km/s
C
SNR G8.7-0.1
PSR J1803-2137
SNR 8.3-0.1
1720MHz OH Maser
Galactic Latitude (deg)
Galactic Longitude (deg)
K km/s
0.40
0.00
-0.40
9.60
9.20
8.80
8.40
8.00
7.60
7.20
1800
1700
1600
1500
2100
2050
2000
1950
1900
1850
1800
1750
1700
2200
2150
2100
2050
2000
1950
1900
1850
1800


SGPS HI
26km/s to 56km/s
D
SGPS HI
56km/s to 105km/s
E
SGPS HI
105km/s to 153km/s
F
SNR G8.7-0.1
PSR J1803-2137
SNR 8.3-0.1
1720MHz OH Maser
Galactic Latitude (deg)
Galactic Longitude (deg)
K km/s
0.40
0.00
-0.40
9.60
9.20
8.80
8.40
8.00
7.60
7.20
2000
1800
1600
1400
1200
1300
1200
1100
1000
900
800
700
600
500
800
700
600
500
400

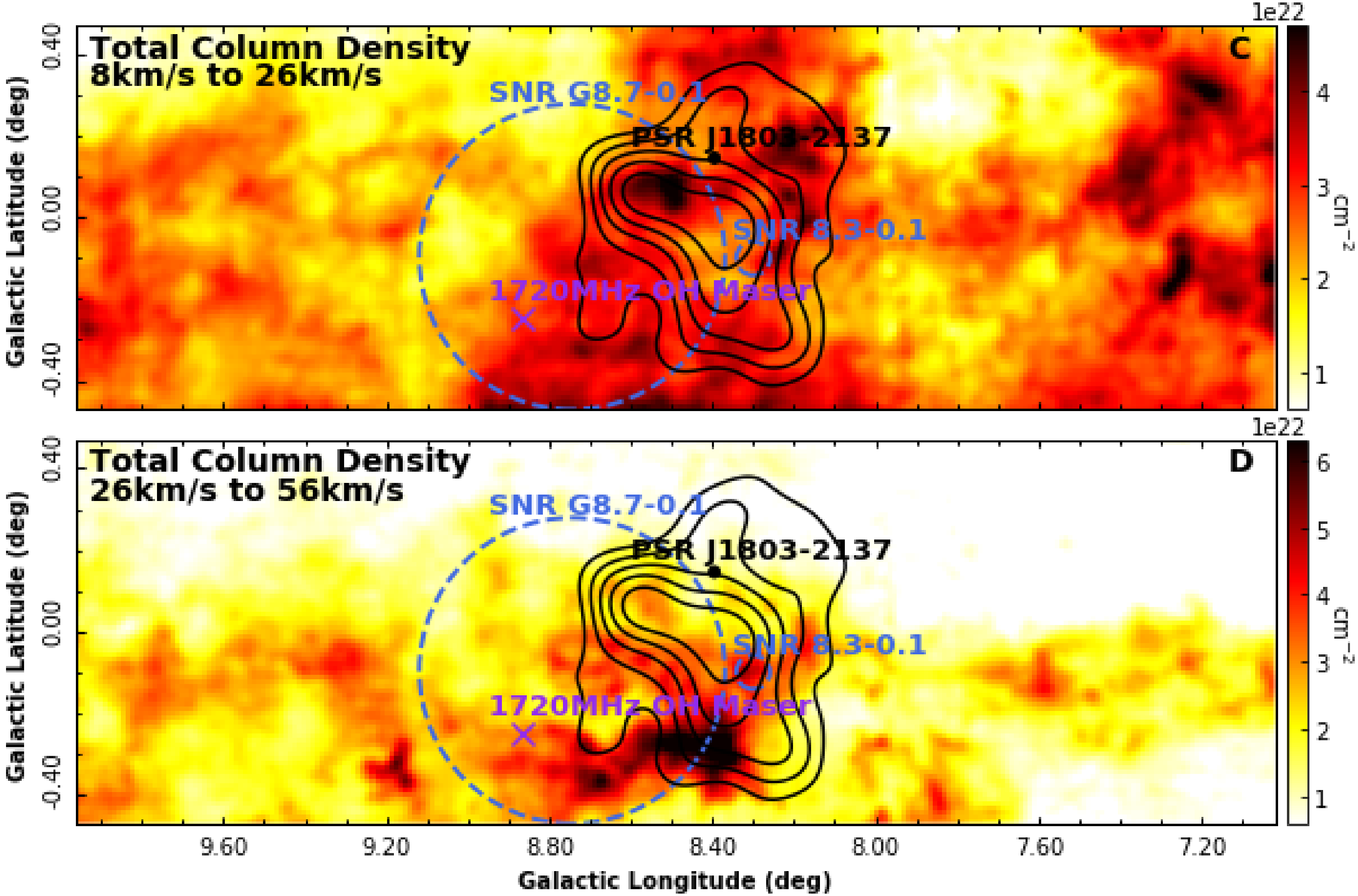
Total Column Density:

$$N(H) = N(HI) + 2N(H_2)$$

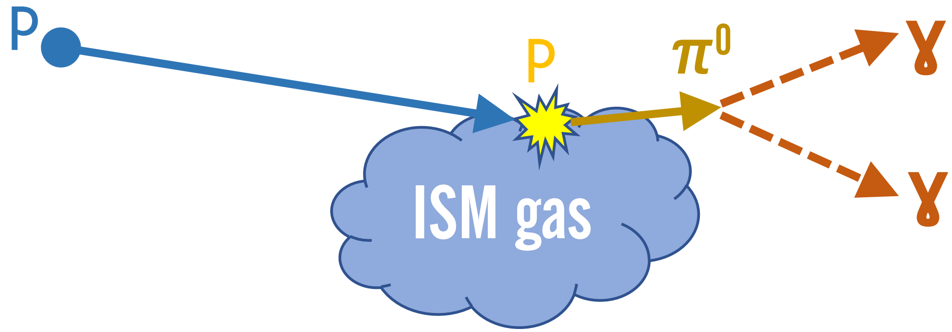


Components of Most Interest

- PSR J1803-2137 ~25km/s (component C)
- SNR G8.7-0.1 ~35km/s and 1720MHZ OH maser 36km/s (component D)

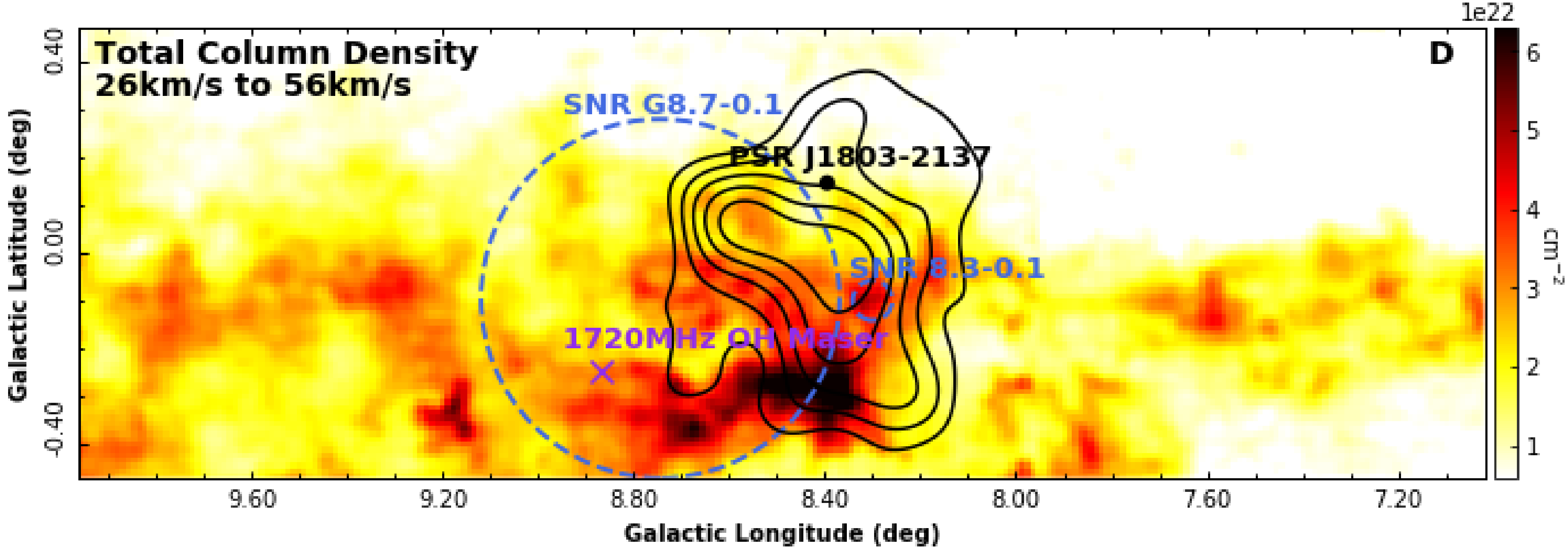


Hadronic Scenario



- Older SNRs are believed to have a large enough hadronic (proton-proton) contribution to account for TeV γ–ray emission
- SNR G8.7-0.1 is assumed to be the accelerator of CRs for this scenario
- Hadronic scenario is feasible as the total energy budget of CRs is on the order of 10^{48}erg
  - SNR canonical energy budget ejected into CRs is 10^{50}erg
- The cosmic ray enhancement factor (k) can be calculated through:
  - $F(\geq E_{\gamma}) = 2.85 \times 10^{-13} E_{TeV}^{-1.6} \left(\frac{M_5}{d_{kpc}^2}\right) k \quad [\mathrm{cm}^{-2}\mathrm{s}^{-1}]$
- Provided the γ–rays are produced via hadronic interactions between the SNR and surrounding dense gas:
  - SNR G8.7-0.1 (component D) requires a CR enhancement factor of 45 times that of the Earth-like CR density to produce the observed photon flux towards HESS J1804-216

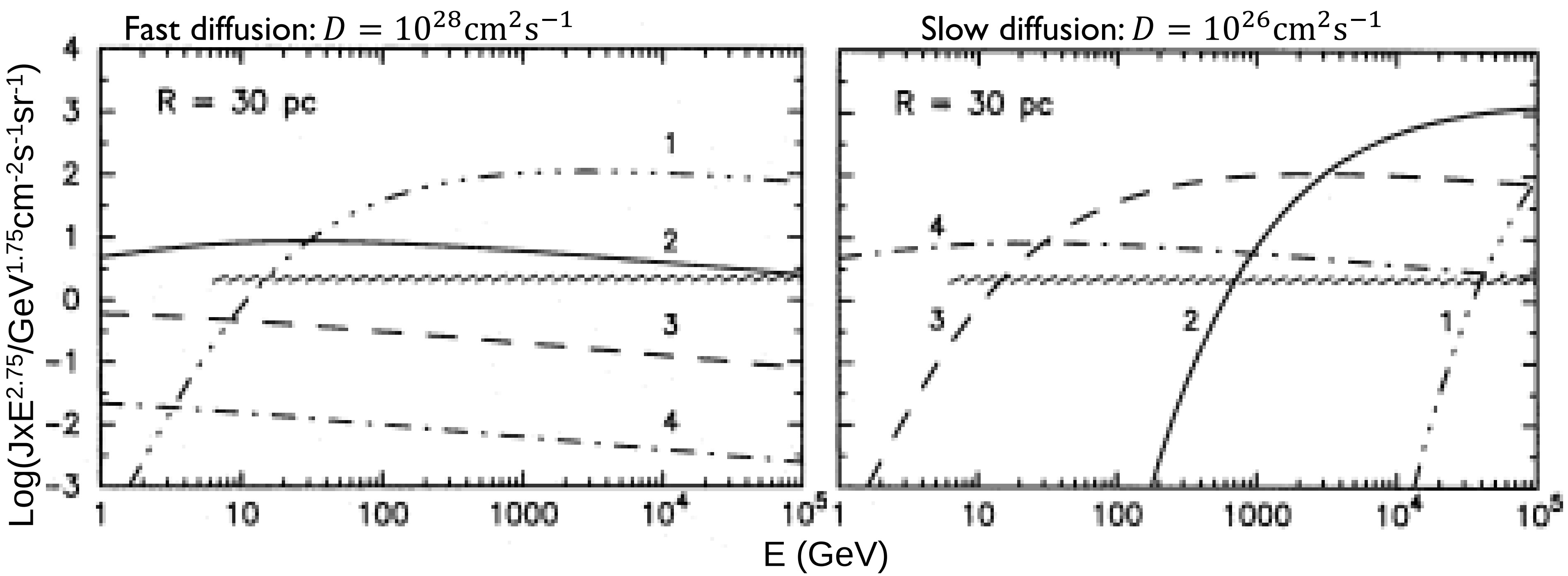
Hadronic Scenario



- Cloud partially overlapping HESS source component D
  - At the assumed distance to SNR G8.7-0.1 ($d = 4.5\text{kpc} \therefore v \sim 35\text{km/s}$)
- Assuming CRs have propagated a distance of 30pc from the accelerator to the cloud, the below diffusion coefficient is obtained:
  - $D = 9.06 \times 10^{27}\text{cm}^2\text{s}^{-1}$ given $R = \sqrt{2Dt}$ (t=15kyrs, age of the SNR)
- CRs accelerated by SNR G8.7-0.1 undergo moderate diffusion to reach HESS J1804-216
  - Fast diffusion: $D = 10^{28}\text{cm}^2\text{s}^{-1}$, slow diffusion: $D = 10^{26}\text{cm}^2\text{s}^{-1}$

Hadronic Scenario

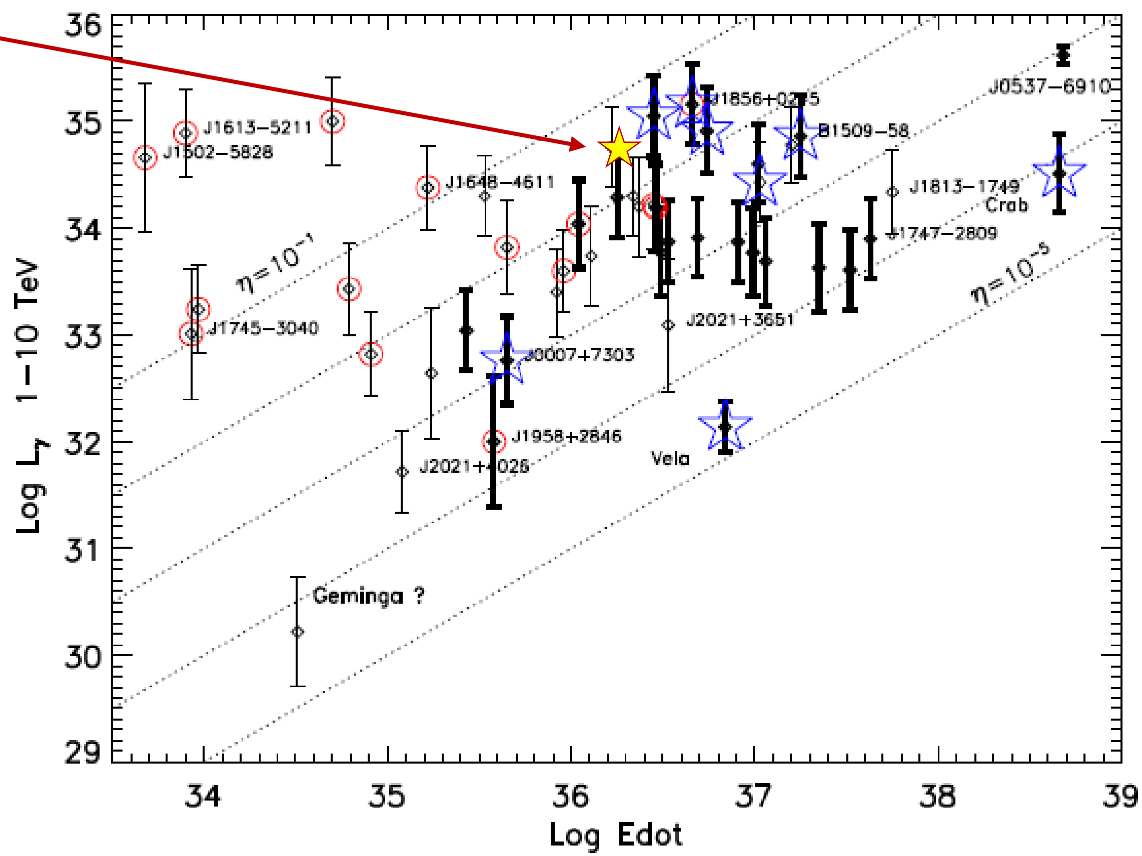
- CR enhancement factor of 45, distance to cloud is 30pc and moderate diffusion are all assumed for SNR G8.7-0.1
- Age of the source is between 10^3yrs (LHS: curve 1) and 10^5yrs (RHS: curve 3)
- Consistent with the lack of X-rays, as a young source is not expected
  - Lack of X-ray emission suggests that the age is greater than the cooling time
- Hadronic scenario is feasible
- Plot below is for an impulsive accelerator ie an SNR



Evolution of escaping CRs plot: http://adsabs.harvard.edu/abs/1996A%26A...309..917A

Leptonic Scenario

- PSR J1803-2137 is assumed as the accelerator of CRs for the leptonic scenario
  - Due to the high spin down power its plausible that emission is produced by high energy electrons as a pulsar wind nebula
- TeV γ–ray efficiency for PSR J1803-2137 is 3%:
  - Calculated from spin down power of the pulsar ($\dot{E} = 2.2 \times 10^{36} \mathrm{erg\ s^{-1}}$) and luminosity of HESS J1804-216 ($L_\gamma = 7.09 \times 10^{34} \mathrm{erg\ s^{-1}}$)
    - $\eta_\gamma = L_\gamma / \dot{E}$

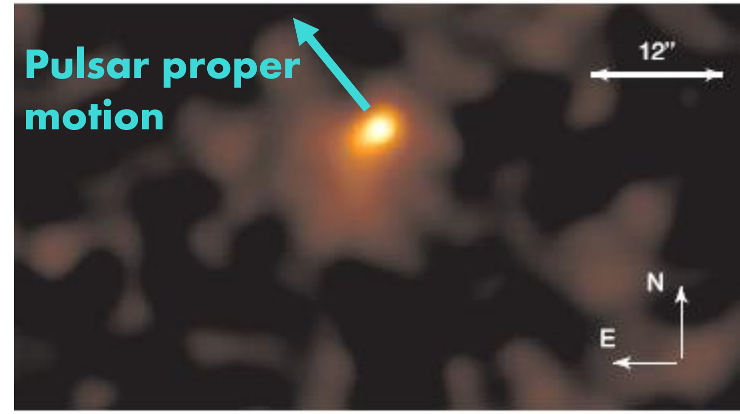


- Leptonic TeV γ–ray emission is supported from an energetics point of view

PWNe plot: https://arxiv.org/abs/1305.2552

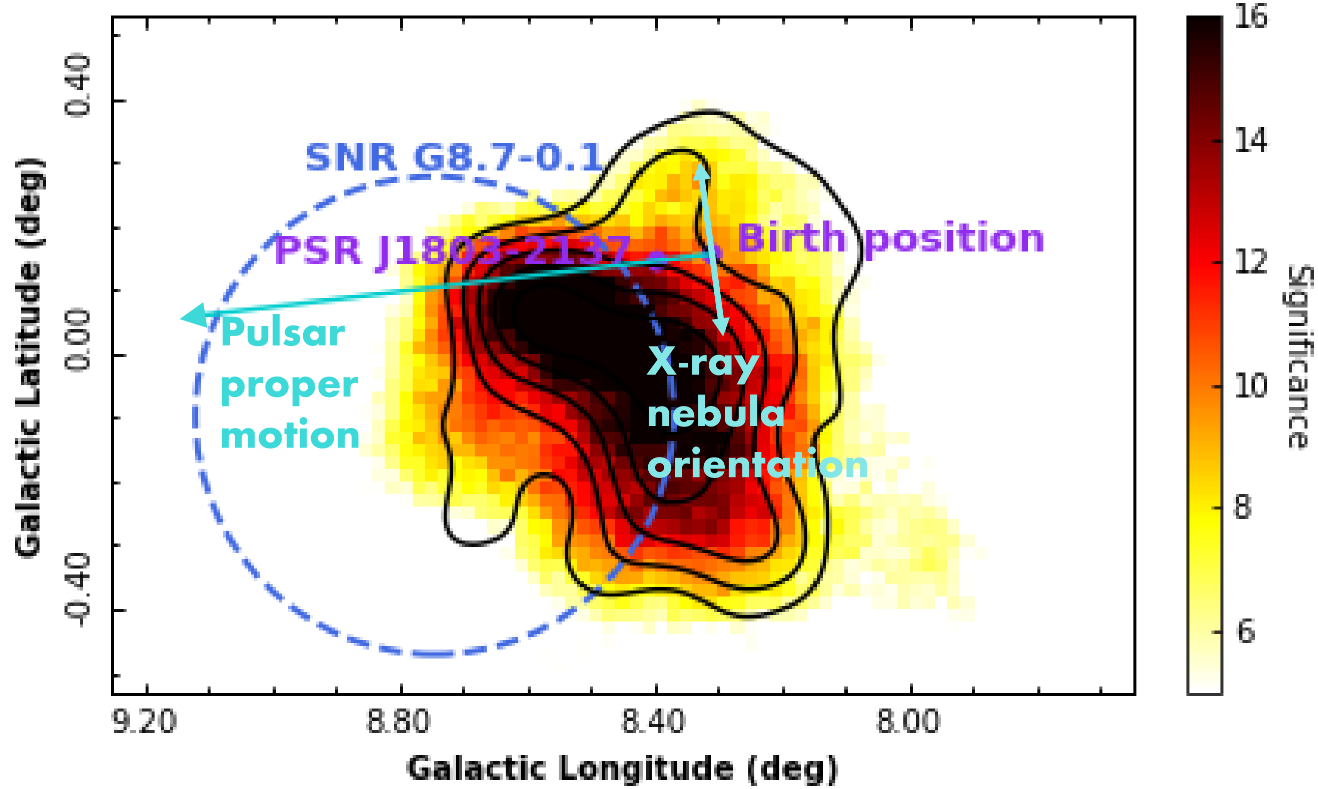
Leptonic Scenario

- The *Chandra X-ray Observatory* has detected a small, faint pulsar wind nebula (PWN) towards PSR J1803-2137
  - Size of 7”x4” (~0.02°x0.01°, for comparison to plot) for the inner PWN
- It is positioned perpendicular to the proper motion of PSR J1803-2137



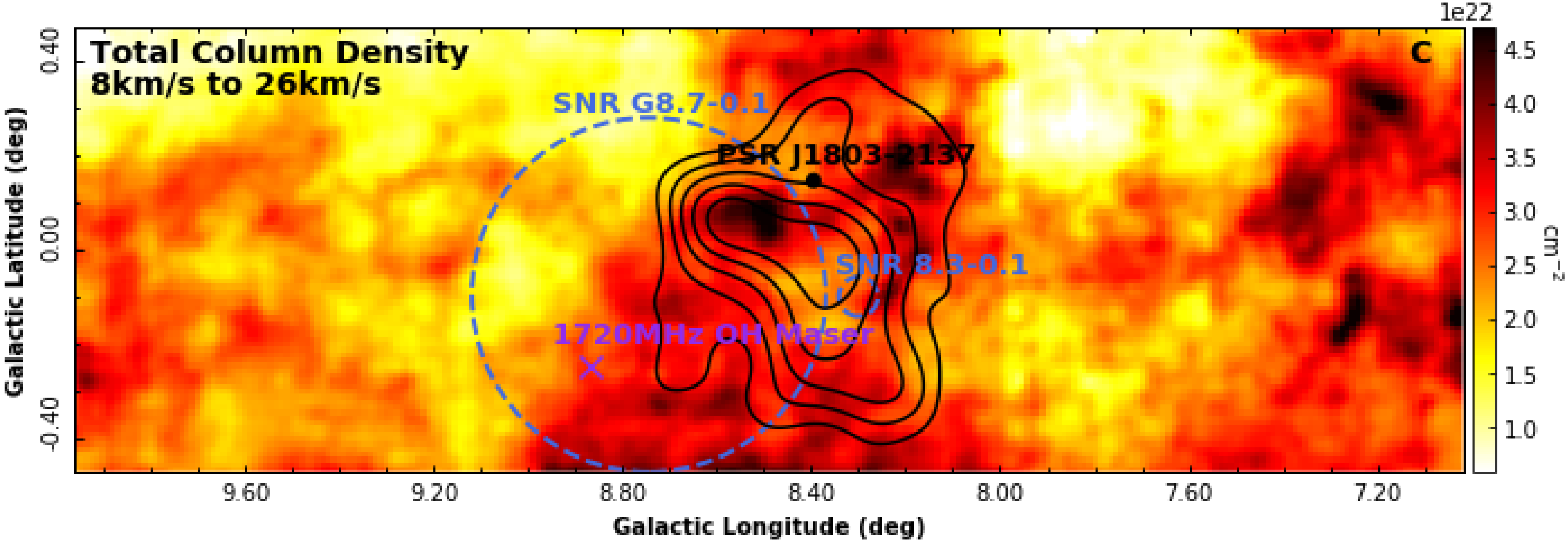
Top: Smooth X-ray map of PSR J1803-2137 and its PWN
Bottom: PSR J1803-2137 proper motion

- Small x-ray nebula and a large TeV nebula is consistent with a pulsar with a high-magnetic field



X-ray plot: https://arxiv.org/abs/astro-ph/0611599

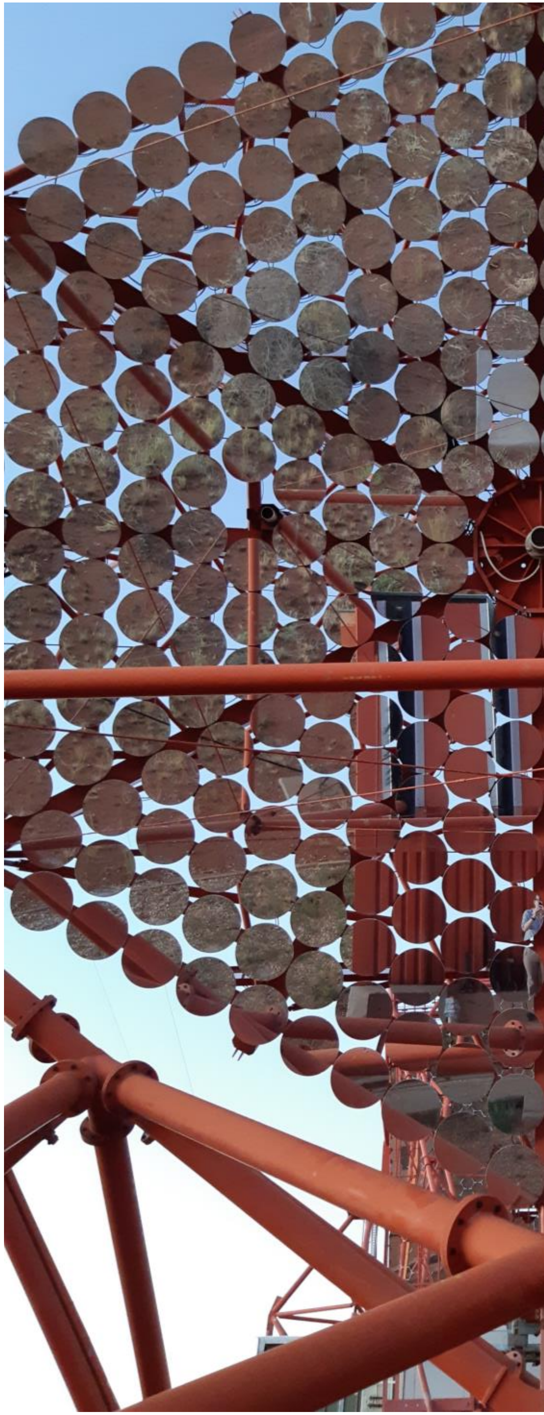
Leptonic Scenario



- Assuming that only electrons are being accelerated by PSR J1803-2137, the three leptonic cooling times are calculated:
- $t_{diff} = 12$ kyr, $t_{brem} = 120$ kyr, $t_{IC} = 2310$ kyr, $t_{sync} = 22$ kyr
  - At the assumed distance to PSR J1803-2137 ($d = 3.8\text{kpc} \therefore v \sim 25\text{km/s}$)
- Diffusion time (12 kyr) is similar to that of the pulsars age (16 kyr), hence electrons can diffuse the required distance of 30pc
- $age_{PSR} < t_{cool} \rightarrow$ energy losses from each effect are negligible

Summary

- Molecular clouds provide insight to the complex nature of γ–ray sources
  - Analysis of ^{12}CO and HI allows us to determine the morphology of the gas
- Comparisons between gas and the TeV γ–ray data allows us to, potentially, categorise the γ–ray source
- Two solutions for HESS J1804-216 are proposed:
  - A completely hadronic source
  - A completely leptonic source
- Both hadronic and leptonic scenarios are theoretically possible
  - HESS J1804-216 still remains unidentified in nature
- It is also possible to have a mixture of hadronic and leptonic, which will be investigated in time
- Next generation γ-ray telescopes (CTA) will be able to shed light on these unidentified sources



Mass calculations

- The column density is a useful parameter as it can help determine important gas parameters such as mass and density
- The mass is calculated through:
  - $M = \mu m_H N A$

Cross-sectional area

Column density of given region

Mass of hydrogen atom

where $\mu = 2$ for molecular hydrogen, $\mu = 1$ for atomic hydrogen

- The number density, n, can be calculated using the column density and volume of the gas column
  - $n = \frac{3N}{4D\tan(\theta)}$

Angular size of HESS source

Distance to source

- Characteristics can be analysed to provide a better look into the complex nature of the TeV emission
- This allows a limit to be placed on which scenario is powering the TeV source, HESS J1804-216