ISM studies of HESS TeV gamma-ray sources

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Introduction

HESS survey of the Galactic Plane



HESS Collaboration (2006)

Introduction

- TeV gamma-ray sources in the galaxy
- **Production channels:**
 - Leptonic: up-scattering of background photons by high energy electrons via the inverse Compton effect
 - Hadronic: Proton-proton interaction between cosmic-rays and ambient matter produce pions. Neutral pions decay into pairs of gamma-rays

$$p + p \to \pi^{\pm,0} \qquad \pi^0 \to \gamma + \gamma$$

• Possible sources:

- Pulsar wind nebulae, supernova remnants, star clusters, binary systems etc.
- 'Dark accelerators'
 - VHE gamma-ray sources with no clear counterparts in other wavelengths



Interstellar medium studies

- The interstellar medium and TeV gamma-ray sources
 - Use molecular lines to probe the interstellar medium towards TeV gamma-ray sources
 - What environment do theses sources exist in?
 - Morphological matches with TeV emission?
 - Constrain possible hadronic and leptonic models



Nanten

• Tracers

- Carbon monoxide (CO)
- Carbon monosulfide (CS)
- 21cm hydrogen line
- Ammonia (NH₃)
- Silicon Oxide (SiO)
- Hydroxyl (OH)
- And others



ATCA



Mopra



Parkes



HESS J1640-465 & HESS J1641-463

- **HESS J1640-465:** Discovered as part of HESS survey of the galactic plane (2006)
- **HESS J1641-463:** Observations towards HESS J1640-465 during 2004-2011 revealed a new TEV source, HESS J1641-463



Local environment



- HESS J1640-465 & HESS J1641-463 are seen towards supernova remnants
 - SNR G338.3-0.0 and SNRG338.5+0.1 respectively
 - Distance to the SNRs is ~ 10-11 kpc (via HI absorption) in the Norma II spiral arm (Kothes & Dougherty 2007)
 - Both the SNRs appear to be connected by a complex of HII regions

1640 & 1641 Mopra CO data



Mopra Galactic Plane CO survey data

Left: Integrated ¹²CO(1-0) between -53 and -23 km/s





Right: ¹²CO(1-0) and ¹³CO(1-0) spectra in regions towards HESS J1640-465 and HESS J1641-463

Lau et al. 2016

1640 & 1641 Mopra CO data



Lau et al. 2016

Integrated ¹²CO(1-0) slices

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Mopra 7mm data



Mopra 7mm data

0.1

0

CS(1-0) position velocity plot Contours indicate ¹³CO(1-0) emission



Black contours: HC₃N emission 0.16 Bridge core 2 -80 km/s core SiO -35 to -25 km/s SiO -85 to -75 km/s HC3N -35 to -25 km/s 0.14 HC3N -85 to -75 km/s 0.2 0.12 8 \mathbf{x} 0.0 0.08 Bridge core 1 SiO -45 to -35 km/s 0.06 HC3N -50 to -35 km/s 0.04 -0.2 0.02 338.2 338.8 338.6 338.4 338.0

Spitzer 8 micron image

Green contours: SiO emission

Lau et al. 2016

HESS J1640-465

- Hadronic
 - Significant overlap between TeV emission and SNR G338.3-0.0
 - Spectral shape similar to other VHE gamma-rays sources identified as SNRs interacting with molecular clouds
 - Hadronic production model assuming gas density of 150 cm⁻³ (dashed line)
 - Our observations/calculations:
 - densities > 150 cm-3
 - Required CR enhancement factor ~1000x that seen at Earth
- Leptonic
 - Pulsar suggests that PWN could be in part powering the TeV source.



HESS J1640-465

Red – Fermi data points Blue – HESS data points Dashed line - Hadronic production model

Lemoine-Goumard et al. (2014)

HESS J1641-463

- Connection between VHE gamma-ray spectra & HE gamma-ray spectrum is unclear
- VHE hadronic origin Galactic PeVatron?
 - If SNR G338.5+0.1 were young (<1000 years old), it could accelerate particles to required energies. Problem arises if SNR is not young
 - CRs from SNR G338.3-0.0 could have diffusively reached the gas towards 1641.
 - Higher energy CRs would reach the gas earlier, hardening the proton/gamma spectrum



HESS J1641-463 Red: Fermi data points, Blue: HESS data points Lemoine-Goumard et al. (2014)



Galactic Longitude

HESS J1614-518 & HESS J1616-508





- Both discovered as part of the HESS survey of the galactic plane (2006)
- Flux ~25% of Crab Nebula above 200 GeV
- Power-law spectrum
 - Spectral index 2.46 ± 0.21
- No immediately obvious counterparts in other wavelengths

- Flux ~19% of Crab Nebula above 200 GeV
- Power-law spectrum
 - Spectral index 2.35 ± 0.06
- Roughly circular, diameter 16 arcmin
- Flanked by 2 SNRs
 - PSR J1617-5055 nearby

(°) HESS Collaboration (2006)

10th April 2017

HESS J1614-518 Mopra CO data



¹²CO(1-0)

Lau et al. in prep.

10th April 2017

HESS J1614-518 CS(1-0) data



Lau et al. in prep.

James Lau

HESS J1616-508 Mopra CO data



Lau et al. in prep.

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 $^{12}CO(1-0)$

James Lau

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HESS J1616-508 Mopra CO data



Lau et al. in prep.

¹³CO(1-0)

HESS J1616-508 MALT-45 CS data



Lau et al. in prep.

HESS J1809-193

- \rightarrow 2 SNRs G011.0-00.0 and G011.1+00.1 (no info on age or distance)
- → 1 PWNe powered by PSR J1809-1917 (blue contours)

$$\begin{array}{l} \text{PSR J1809-1917} \\ \rightarrow \ \text{E}_{_{\text{SD}}} &= 1.8 \times 10^{36} \ \text{erg/s} \\ \rightarrow \ \text{d} &= 3.7 \ \text{kpc} \\ \rightarrow \ \tau &= 51 \ \text{kyr} \end{array}$$



Dense molecular clouds overlapping the TeV source at v_{lsr} = 25 to 38 km/s (d~3.7 kpc)

(Voisin et al, *in prep*)

Fabien Voisin

HESS J1809-193

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Dense molecular clouds overlapping the TeV source at v_{lsr} = 25 to 38 km/s (d~3.7 kpc)

(Voisin et al, in prep)

HESS J1809-193

SNR G011.0-00.0 at 3.7 kpc?



→ $HC_3N(5-4)$ detections (HC1 to HC3) at v_{lsr} =25-38 km/s coincident with IR dark clouds

→ SiO(1-0) detections (S1 and S2) towards dense molecular clouds with no IR counterparts

=> POSSIBLE SNR-MC INTERACTION ? => POSSIBLE HADRONIC CONTRIBUTION FROM SNR CRs REACHING THE MC.

=> Association between the SNR and the PWN powered by PSR J1809-1917 ?

→ DIFFICULT TO RECONCILE THE SMALL ANGULAR SIZE OF THE SNR AND THE AGE OF PSR J1809-1917 AT THIS DISTANCE

(Voisin et al, in prep)

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The HESS Galactic Centre

Rebecca Blackwell



HESS Collaboration (2016)

The Central Molecular Zone and Galactic Ridge



The Central Molecular Zone and Galactic Ridge



Blackwell et al. in prep.

Dense Gas at 12mm towards Galactic TeV sources

Phoebe de Wilt

- Southern Galactic Plane (l=290 to 30 deg, b=+-0.5 deg) is already completely covered at reasonable sensitivity (HOPS). First look at overlap with TeV emission also completed (de Wilt et al 2017)
- Can be used to resolve distance ambiguity of dense gas towards star-forming regions e.g. Infra-red dark clouds
- Can identify regions of previous shock activity (Ortho-to-para abundance ratio see Maxted et al. 2016 & de Wilt et al. 2017)
- Currently using 12 mm to help identify distances to ambiguous TeV sources (e.g. HESS J1745-303 see next slide)
- Satellite lines in NH3 emission help to isolate velocity components of gas where observations of other species are blended



HESS J1745-303

- ISM studies towards HESS J1745-303 have concentrated on broadline CMZ gas partly covering TeV emission : distance identified for SNR by CO void (Uchida et al 1992)
- 12 mm (HOPS) observations identified narrow line gas foreground to CMZ at same velocity of 1720 MHz OH masers (possible alternative SNR distance?)
- Two possible distances of SNR = two scenarios of hadronic TeV emission.
 - Both are being explored with ISM studies : HI, CO, CS, NH3 (plus other 7 and 12 mm lines) (de Wilt et al. in prep)



Galactic longititude (deg)

James Lau

HESS J1646-458

- Large gamma-ray source approx 2 degrees in diameter
- Overlaps a number of potential particle accelerators
 - LMXB 4U 1642-45
 - PSR J1648-4611
 - Stellar cluster Westerlund 1, with magnetar
 CXOU J164710.2-455216
- Single source scenario: Westerlund 1 is the favoured particle accelerator
 - Hadronic interaction between target ISM and CRs producing the gamma-rays
- Westerlund 1 is one of the most massive stellar clusters in the Milky Way
- 24 Wolf-Rayet Stars
- Approx. 150 OB super- & hyper-giants
- 80-150 stars of 50 solar masses have already gone supernova



5E-05 4.5E-0 4E-05 3.5E-0 00 1 (w/ Ma 3E-05 2.5E-0 2E-05 340.5 339.0 338.5

Cameron Snoswell

HESS J1646-458



- Shell-like feature seen in HI at -55 km/s surrounding Westerlund 1.
- ¹²CO emission at approximately -49 km/s (Region A) overlaps Eastern part of extended gamma-ray source.
- CS emission shows gas overlapping Northern peak at -34 km/s, potentially influenced by stellar winds from Wd1.
- Extending CO mapping with Mopra from +0.5 to -1.5 degrees latitude needed.



Summary

- Interstellar medium towards HESS TeV gamma-ray sources
- Investigation of galactic TeV sources
 - Analysis of the gas in the region and its properties essential in investigating the nature of TeV sources
- Linkages with other ISM projects:
 - MopraCO, MopraGam, SGPS, SPLASH, HEAT, HOPS, Nanten, MALT-45 etc.



• High resolution molecular line studies will be excellent counterparts to next generation ground-based gamma-ray observatories



Thanks for your attention