Molecular clouds and gamma ray sources in W28

Comparison between NANTEN2 CO(J=2-1) molecular clouds and H.E.S.S. TeV gamma-ray sources in whole area of W28 region.

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- Abstract -

We compared the new NANTEN2 molecular data of the CO J=2-1 emission line with HESS TeV gamma-ray distribution in W28. This comparison yields better correlation between CO and gamma-ray in W28 north than in CO 1-0 (Aharonian et al. 2008 [1]), providing a further support for the hadronic origin of the gamma-ray emission. We also examined the relationship of molecular clouds in W28 north and south and identified a molecular bridge between them. This suggests a physical linkage between the two regions and that the W28 SNR may be a possible candidate for the origin of cosmic ray protons that interact with the molecular clouds in W28 south. These results support the recent Fermi results (Katagiri et al. 2009, in preparation).

SNR W28

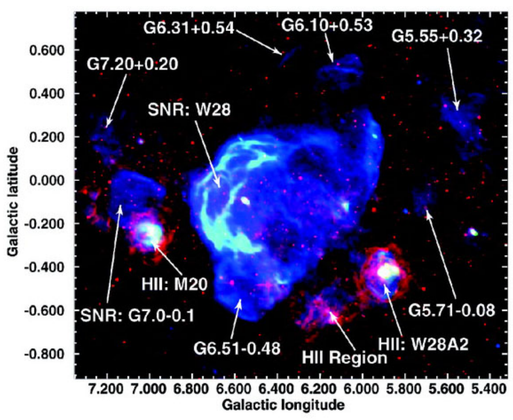


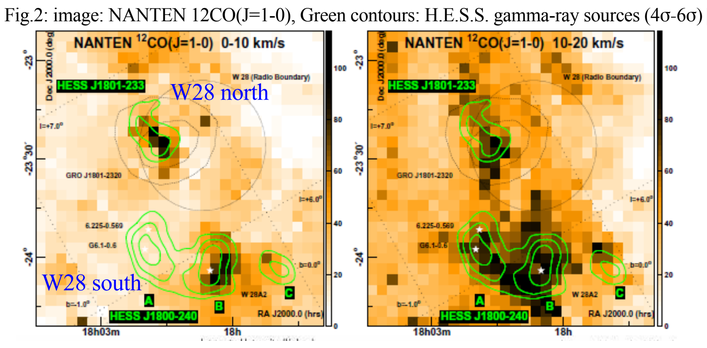
Fig.1: VLA 90cm (blue), MSX 8μm (red) and SGPS+VLA 20cm (green) [2].

- SNR complex
- D ~ 1.8-3.6 kpc [3,4]
- old age: <150 kyrs [5]
- Interactions between SNR and molecular gas [6-8].

Previous Study

- Aharonian et al. (2008) [1] -

Fig.2: image: NANTEN 12CO(J=1-0), Green contours: H.E.S.S. gamma-ray sources (4σ-6σ) [1].



- Gamma-ray sources are clearly associated with molecular gas.
- It is difficult to explain the gamma-ray energy with collisions between background CR and molecular gas.
- Accelerated proton origin?
- W28 north <-- possibly accelerated by the W28 SNR.
- W28 south <-- SNR? High mass star formign region?
- There are no previous study for physical conditions of molecular gas with uniform data set which covers throughout the W28 region.

NANTEN2 observations

- NANTEN2 4m mm/sub-mm telescope -

Fig.3: NANTEN2 telescope, Atacama, Chile.

- Atacama, Chile (4,800m)
- 12CO(J=2-1): 230GHz
  13CO(J=2-1): 230GHz
- Angular resolution: ~90”
- System noise temperature: ~120 K (DSB)
- Observation period: 2008/01-02, 2008/10-12

High resolution CO(J=2-1) observations thourghout the W28 region revel ...

- detailed structure of the molecular gas, which enable us to compare with the radio sources.
- SNR interactions by comparing with lower energy level NANTEN CO(J=1-0) data set.
- temperature and density of the gas with LVG analysis.

- High resolution CO(J=2-1) survey -

Fig.4: Color and Contours: NANTEN2 12CO(J=2-1) integrated intensity

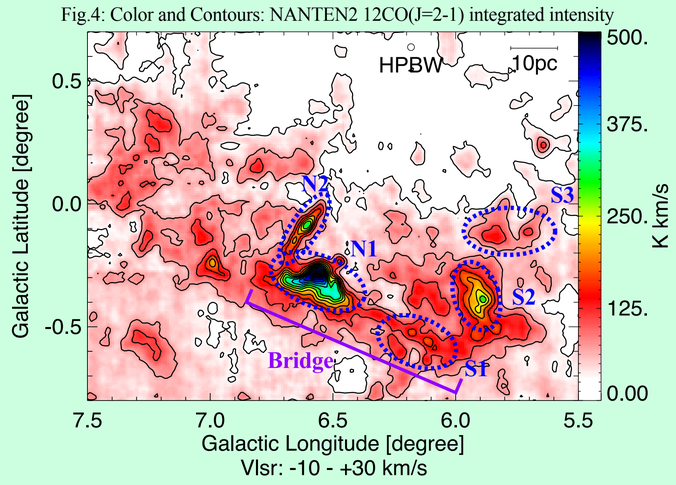


Fig.5: Red contours : same as Fig.4, Color: same as Fig.1

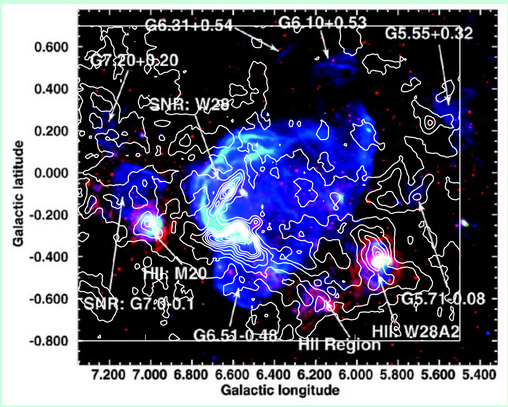
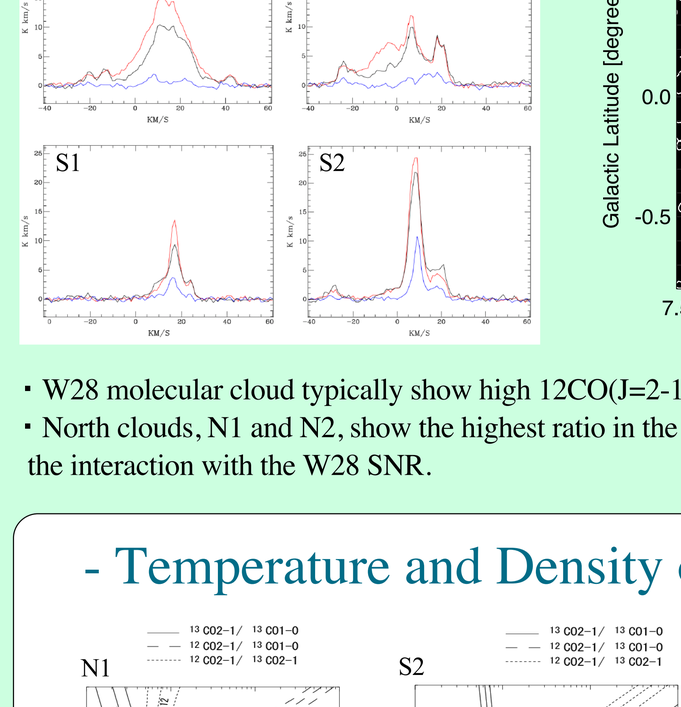


Fig.6: Contours: same as Fig.4, Color: H.E.S.S. TeV gamma-ray [1].



- Elongated cloud complex
- N1, S1 and S2 are clearly associated with TeV gamma-ray.
- N1 and N2 are reported as shocked gas by the W28 SNR [7].
  --> proton acceleration by the SNR.
- S2 corresponds to the W28A2 region.
- S1 and S3 correspond to radio sources.
- Bridge like feature connecting N1 and S1.
  --> Suggesting physical linkage between north clouds and south clouds at the same distance.
  --> Does W28 SNR also interact with the south clouds ?

- Observed spectra and intensity ratio -

By taking ratio between 12CO(J=1-0) and 12CO(J=1-0), we can investigate the excitation condition, because12CO(J=2-1) traces hihger excited gas than 12CO(J=1-0) traces.

Fig.7

Fig.8: Color: intensity ratio from 12CO(J=1-0) to 12CO(J=3-2), Contours: same as Fig.4.

- W28 molecular cloud typically show high 12CO(J=2-1)/12CO(J=1-0) > 1.0.
- North clouds, N1 and N2, show the highest ratio in the complex and broad velocity dispersion by the interaction with the W28 SNR.

- Temperature and Density of the gas -

- LVG (Large Velocity Gradient) model [9].
- Functions of intensity ratio in the temperature and velocity space.
- The N1 cloud shows lower density (~400 /cc) and higher temperature (~30 K), while the N2 cloud shows higher density (~1000 /cc) and lower temperature (~10-20 K).
- Study with higher transition lines is necessary to investigate hihger temperature and higher density gas.

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