The interstellar medium towards three Supernova Remnants

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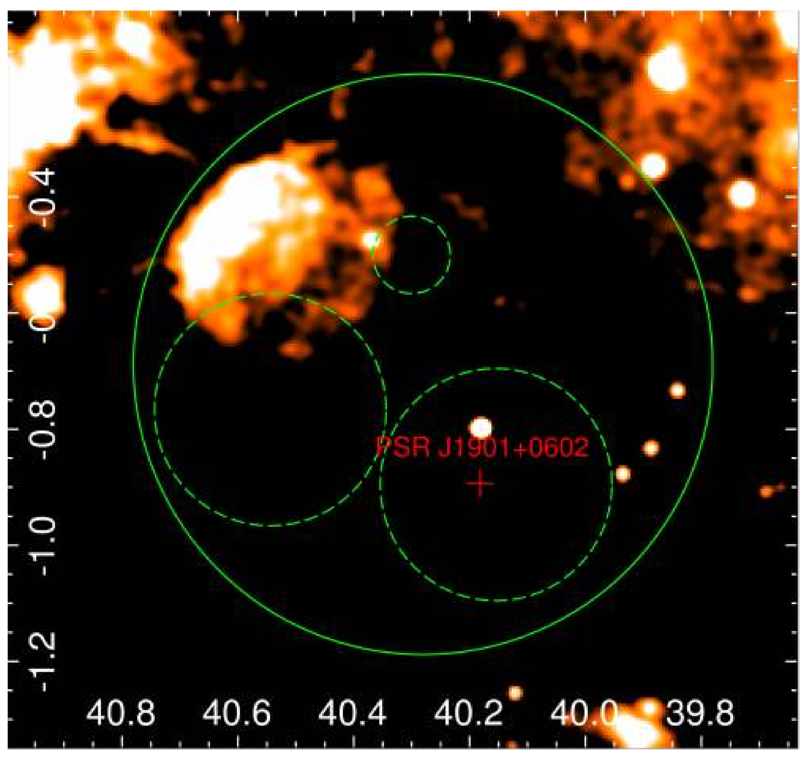
Introduction

In the last years, with the increasing number of discovered gamma-ray sources, important efforts have been dedicated to establish the origin of this high-energy emission using observations in other spectral bands. Supernova remnants (SNRs) have been proposed as possible generators of gamma rays in our Galaxy, among other astrophysical sources. SNR's shocks are expected to be sites of cosmic-ray acceleration and clouds of dense material can provide an effective target for proton proton collisions and subsequent production of gamma rays.

Aims: analyze the environmental conditions towards the SNRs G40.5-0.5 and G45.7-0.4 (located in the vicinity of high-energy sources) and the TeV SNR candidate G44.5-0.2, to establish the origin of the gamma-ray emission.

The SNR G40.5-0.5

G40.5-0.5 is a Galactic remnant with a shell-like type morphology of about 22', brighter towards the NE. Its distance has been estimated to be in the range 5.5–8.5 kpc (Downes et al. 1980 A&A ,92,47). This SNR is seen in projection over the NE border of the extended (~0.3° in radius) TeV gamma-ray source MGRO J1908+0.6, also detected by H.E.S.S. (HESS J1908+063) and VERITAS (VER J1907+062). PSR J1907+0602, a radio-faint 107 ms gamma-ray pulsar, is located well inside the extended TeV source, although 14' southwest of its centroid, but in coincidence with the strongest gamma emission. From the point of view of positional coincidence and energetic it has been proposed that MGRO J1908+06 is a pulsar wind nebula (PWN) powered by PSR J1907+0602 (Abdo et al. 2010, ApJ 711, 64). However, the extension of the very high energy (VHE) source, larger than other TeV PWNe, and the fact that the TeV spectrum does not present spatial variations, requires an additional source of TeV emission, as suggested by Aliu et al (2014, ApJ 787,166). These authors do not discard that MGRO J19080+0.6 may be composed of two TeV sources, either interacting or superimposed along the line of sight.

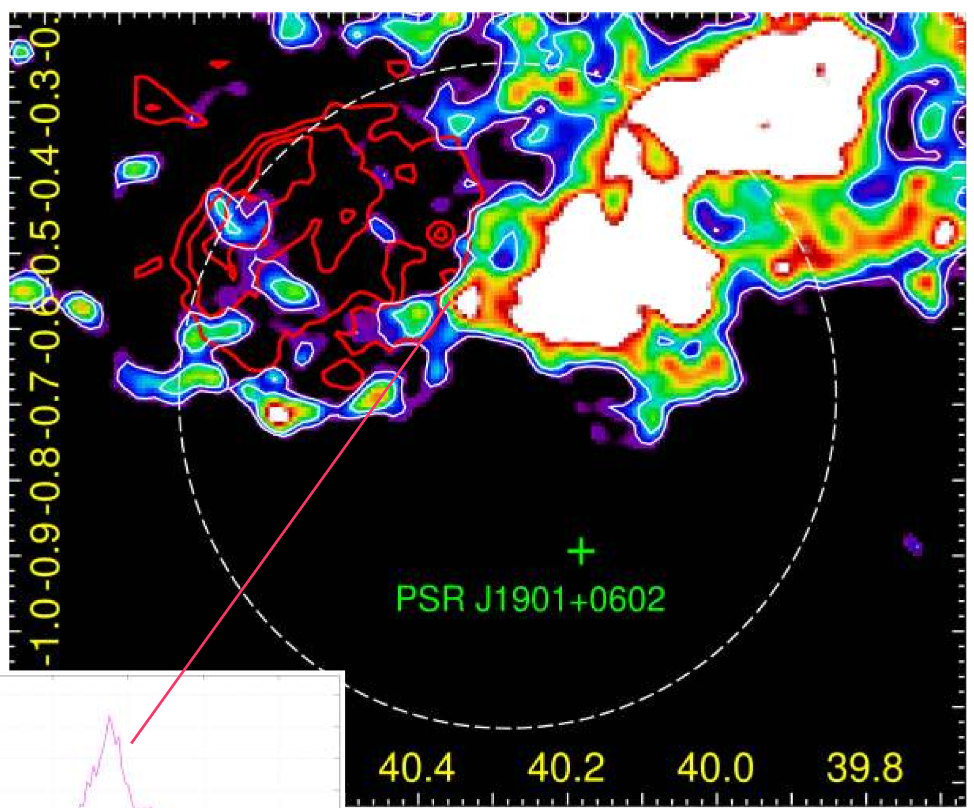


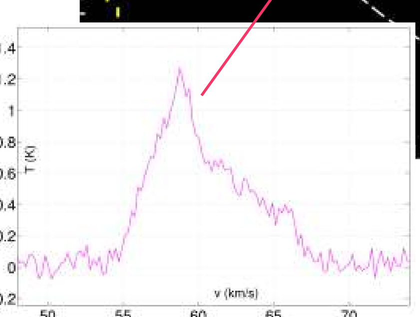
Radio emission at 20 cm toward the SNR G40.5-0.5, extracted from the VGPS. The filled green circle marks the best-fit extension of VER J1907+062. The green dotted circles indicate the most intense emission detected by VERITAS in the vicinity of G40.5-0.5 (the regions are taken from Aliu et al. 2014).

The molecular material

We found a molecular cloud in the 53–69 km/s velocity range, delineating mainly the N, SW and S borders of G40.5-0.5, and partially overlapping with the VHE emission. This molecular emission is associated with the molecular cloud G040.09-00.51 located at ~9 kpc (Roman-Duval et al. 2009, ApJ, 699, 1153). Such distance is compatible, within the errors, with that of 8.5 kpc to SNR G40.5-0.5.

^{13}CO J=1-0 (extracted from the GRS) integrated over the 53–69 km/s velocity range. The red contours indicate the radio continuum emission at 20 cm from the SNR G40.5-0.5.



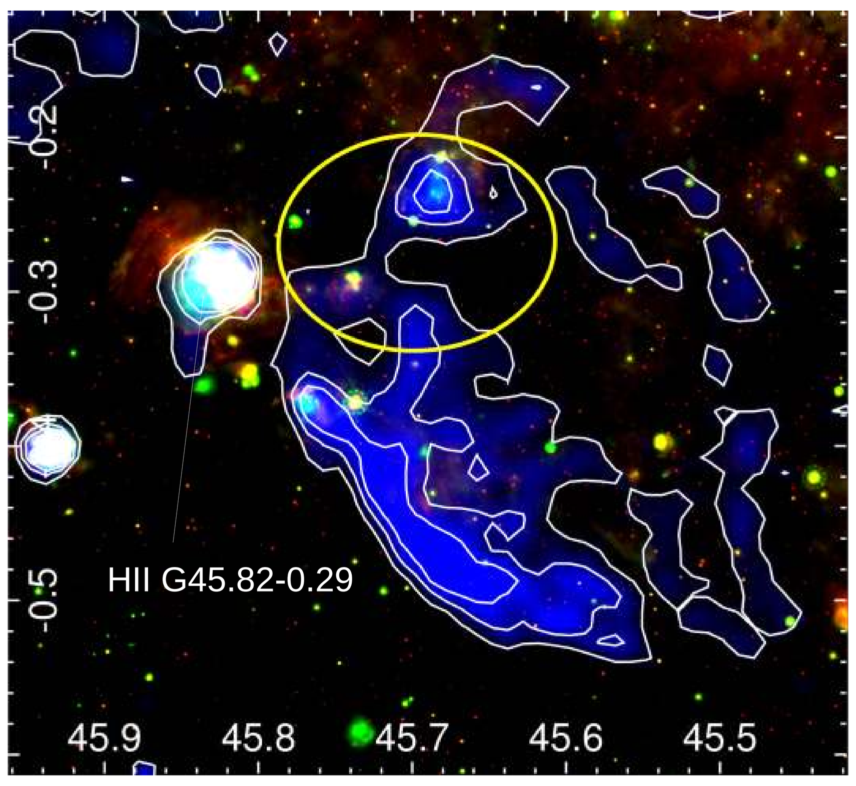


The CO spectrum presents spectral wings that can be interpreted as evidence of gas shocked by the shock front of the SNR.

The nature of VER J1907+062: We propose a scenario in which the emission from the TeV source could be produced by two superimposed sources along the line of sight. In one of them, the gamma emission is due to a PWN associated with PSR J1907+0602 located at about 3 kpc, while the VHE emission from the other source comes from hadronic emission produced by the interaction between dense molecular matter and the shock front of SNR G40.5-0.5.

The SNR G45.7-0.4

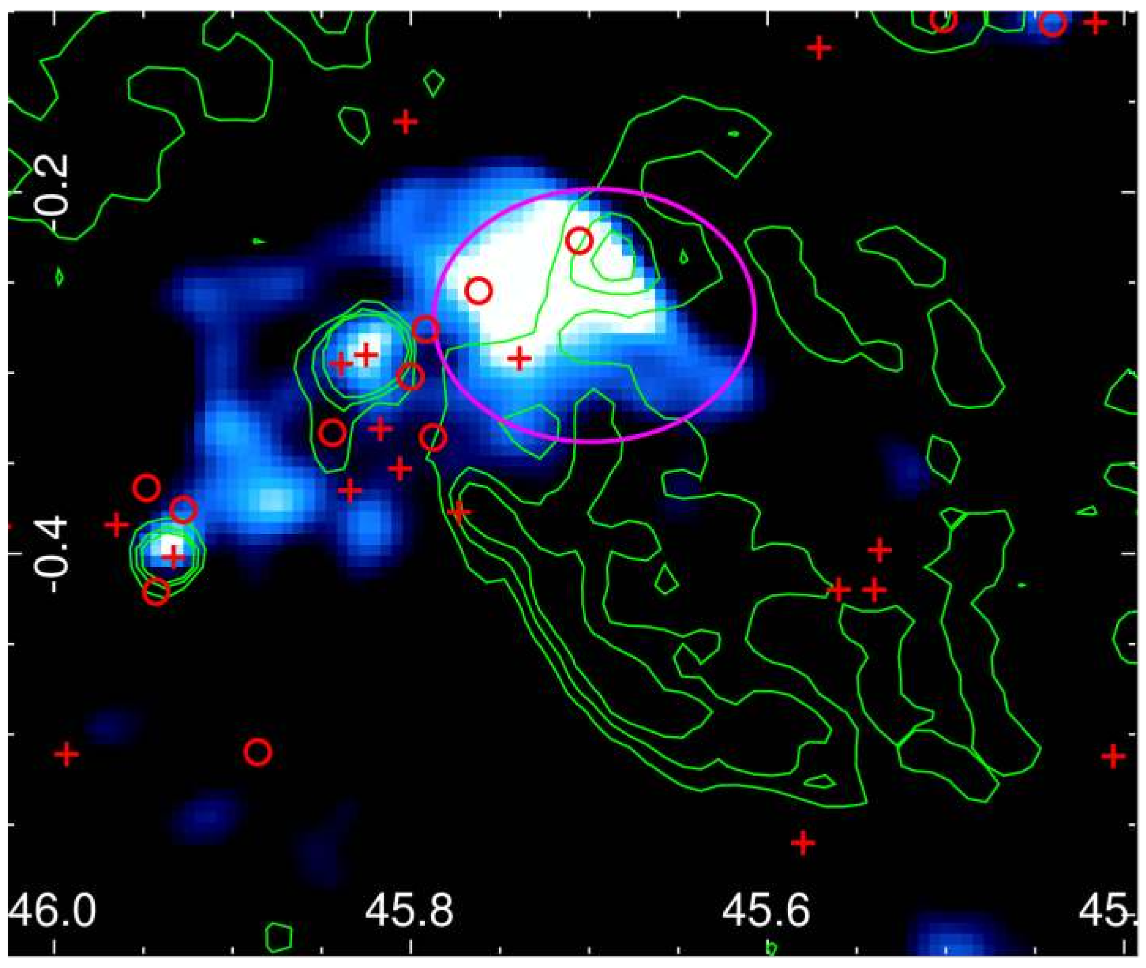
G45.7-0.4 is a large shell-type SNR of about 44' in size, without a counterpart in the X-ray band at present. Based on the spatial coincidence with the source 3FGL J1915.9+1112 detected at GeV energies by Fermi-LAT, Acero et al. (2016, ApJS, 224, 8) proposed an association between the high-energy source and G45.7-0.4. Evidence of interaction between the SNR G45.7-0.4 with a molecular cloud comes from the detection of 1720 MHz OH maser, although it has not been reported the velocity and localization (Hewitt et al. 2009, ApJ 694, L6). From the lack of any other known plausible counterparts, the Fermi source is a good candidate to investigate its origin by proton-induced processes.



Three color image toward G45.7-0.4: VGPS 20 cm (in blue with white contours), Spitzer-IRAC 8 μm (in red) and Spitzer-MIPS at 24 μm (in green). The yellow ellipse indicates the extension of the Fermi source.

The molecular gas

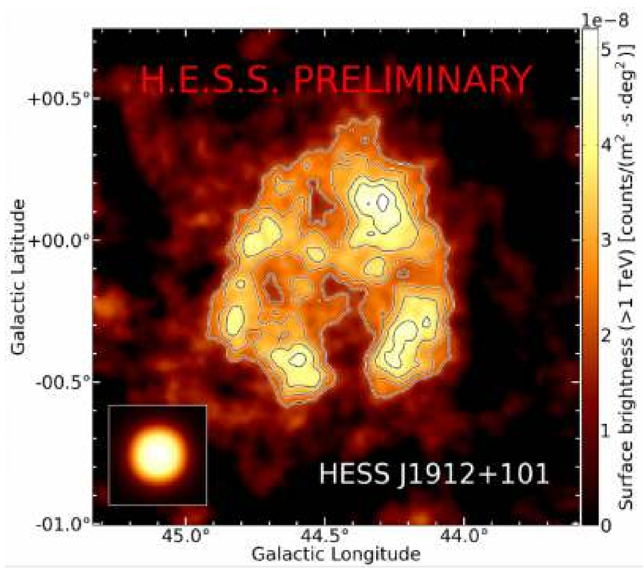
We found a molecular cloud in the 45–65 km/s velocity range with an excellent positional coincidence with the Fermi source. The systemic velocity of ~55 km/s places the cloud at nearly the tangent point, implying a distance of ~6 kpc. Assuming LTE, we obtain a mass and a number density of ~45000 $M_\odot$ and ~600 cm^{-3}, respectively. Interestingly, this molecular material surrounds the HII region G45.82-0.29. Besides, several compact HII regions and infrared dark clouds are embedded in the molecular cloud, suggesting massive star forming activity (Rathborne et al. 2007, ApJ, 662, 1082).



^{13}CO J=1-0 (extracted from the GRS) emission integrated in the 46–65 km/s velocity range. Green contours are the 20 cm continuum emission. The ellipse indicates the Fermi source. Red crosses are the HII regions from the The WISE Catalog of Galactic HII Regions (Anderson et al. 2014, ApJS, 212, 1) and red circles are the Spitzer dark clouds (Peretto & Fuller 2009, A&A, 505, 405).

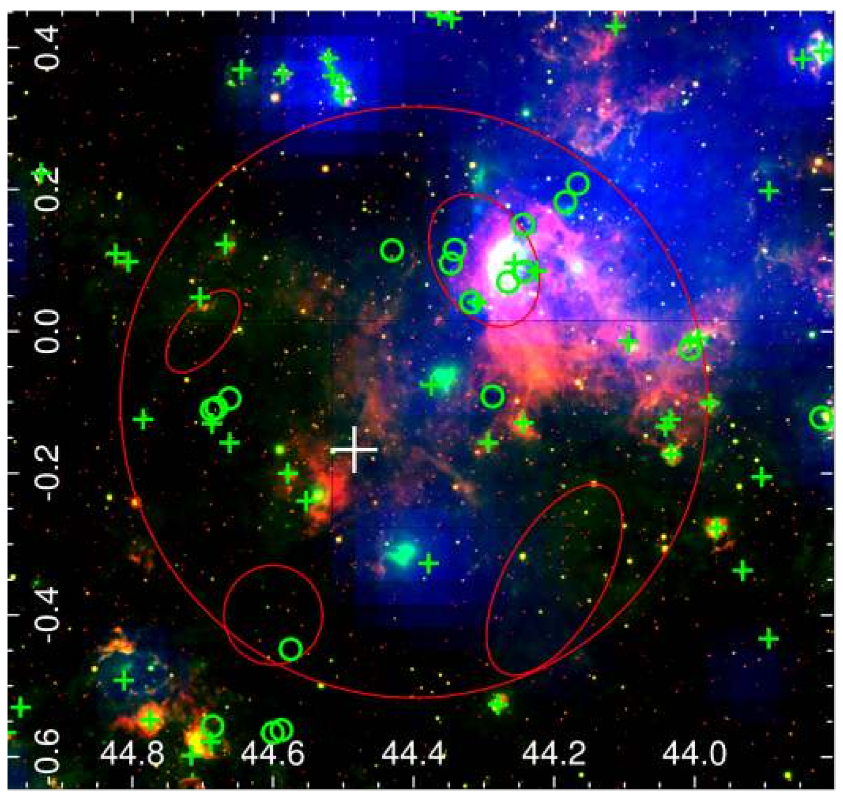
We found dense molecular gas in positional coincidence with 3FGL J1915.9+1112. An hadronic origin for the gamma ray emission requires an accelerating source for proton-proton collision. The SNR G45.7-0.4, whose radio shell appears in contact with the dense molecular material, is a plausible candidate. In fact, the detection of 1720 MHz OH maser emission is a strong evidence of SNR-cloud interaction. On the other hand, the presence of compact HII regions and infrared dark clouds embedded in the molecular material indicate star formation activity in the region. Thus, molecular jets from young stellar objects may also contribute to the production of gamma rays through an hadronic mechanism.

The TeV SNR candidate G44.5-0.2



VHE emission from the SNR candidate G44.5-0.2. Credits: Pühlhofer et al. 2015.

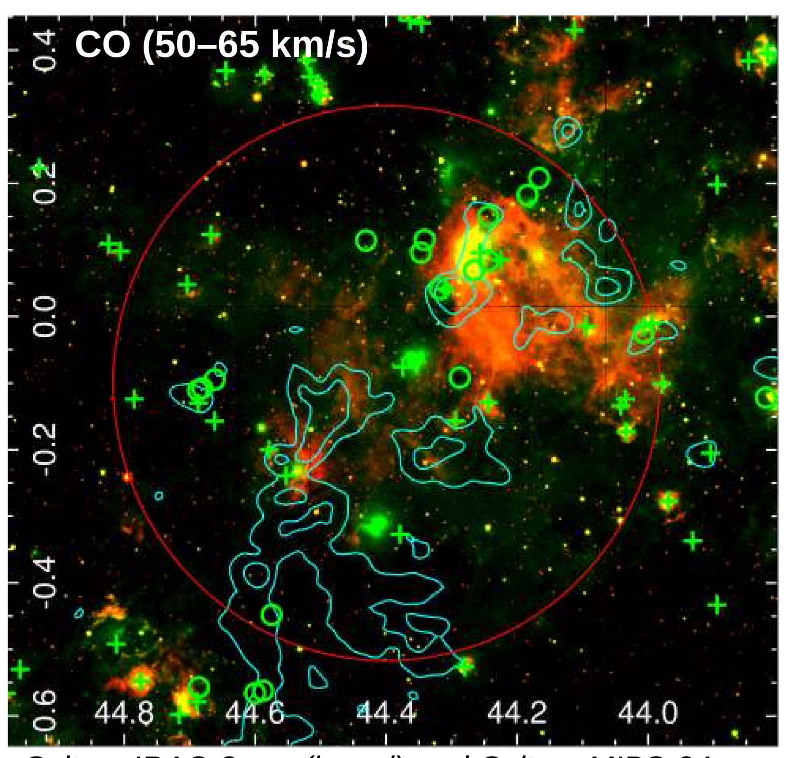
G44.5-0.2, also named **HESS J1912+101**, is a TeV SNR candidate with a shell-type morphology without a known counterpart that matches the shell (Pühlhofer et al. 2015, PoS, in press). Such morphology has been detected in only five SNRs at VHE. All of them have counterparts in other wavebands and in particular are bright X-ray synchrotron emitters. The origin of the gamma emission of this kind of sources is still debated. As Acero et al. (2015, A&A, 580, 74) pointed out, the gamma-ray emission in TeV shell SNRs is likely leptonic-dominated at the scale of the whole SNR, but this does not rule out efficient hadron acceleration.



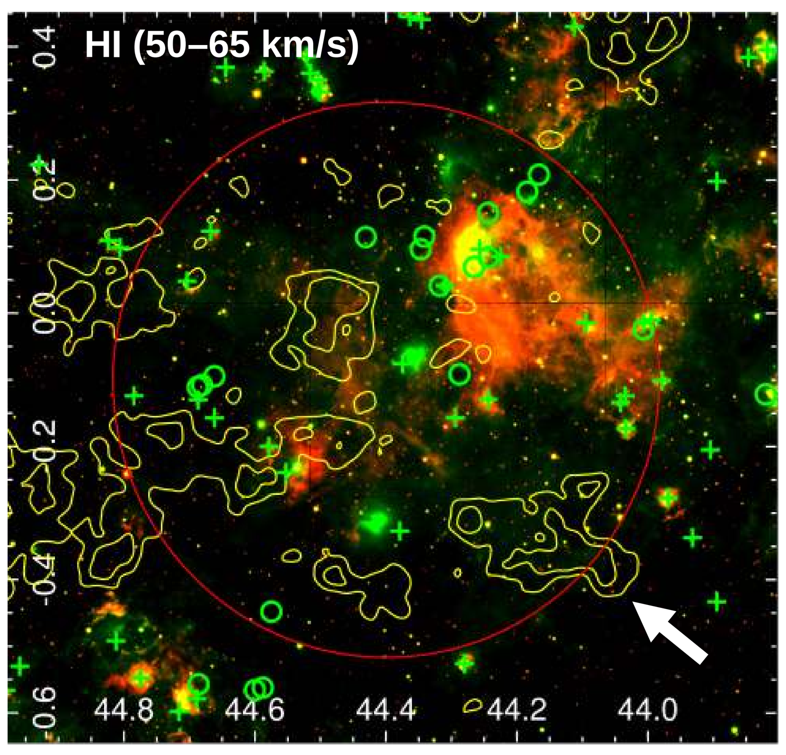
Three color image towards G44.5-0.2: Effelsberg 11 cm radio continuum (blue), Spitzer-IRAC 8 μm (red), Spitzer-MIPS 24 μm (green). The white cross is PSR J1913+1011. The red circle and red ellipses mark the extension and most intense VHE emission of HESS J1912+101, respectively. Green crosses are the HII regions (Anderson et al. 2014) and green circles are the Spitzer dark clouds (Peretto & Fuller 2009).

The ISM toward HESS J1912+101

We detect molecular gas toward HESS J1912+101 in the 50–65 km/s velocity range, which translates into near and far distances of ~5 and ~7 kpc, respectively. The molecular clumps are observed in the direction of several HII regions located at about 5 kpc, and toward infrared dark clouds. The near distance is compatible with the distance to PSR J1913+1011 (~4.5 kpc). Assuming that all these sources are associated, we adopt 5 kpc as the most probable.
The neutral gas distribution in the same velocity range is clumpy. The denser atomic cloud (n ~ 200 cm^{-3}) coincides with the most intense VHE emission toward the SW.



Spitzer-IRAC 8 μm (in red) and Spitzer-MIPS 24 μm (in green). The ^{13}CO distribution from the GRS is displayed in cyan contours.



Spitzer-IRAC 8 μm (in red) and Spitzer-MIPS 24 μm (in green). The HI distribution from the VGPS is displayed in yellow contours. The white arrow indicated the HI clump in the direction of the most intense VHE emission toward the SW.

While the lack of a counterpart in the X and radio bands is not conclusive, the presence of high density target favors the gamma-ray hadronic emission, at least in localized regions where molecular and/or atomic clouds show a good correspondence with HESS J1912+101. The existence of HII regions and infrared dark clouds, precursors of massive stars, within the boundary of the TeV source, indicates an active star forming region (Rathborne et al. 2007). Thus, outflows from massive protostars may be the source of accelerated protons colliding with the ambient gas. The contribution from relativistic leptons via inverse Compton process produced by PSR J1913+1011 working together with the hadronic process can not be discarded.