# Discovery of Broad Molecular lines and of Shocked Molecular Hydrogen from the Supernova Remnant G357.7+0.3 (Square SNR): HHSMT, APEX, Spitzer and SOFIA Observations

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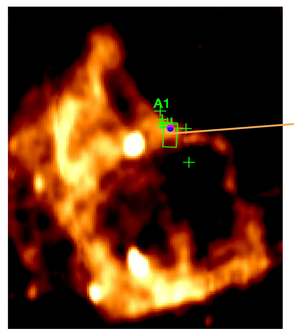
## The SNR G357.7+0.3 and Turbulence of Molecular Clouds (MC)

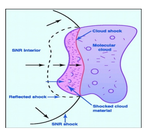
- G357.7+0.3: relatively unknown and under-studied SNR.
- OH masers detected (crosses): NW rim (Hewitt et al. 2008)
- Soft X-rays with T=5.4x10$^6$K and an age of 10,000 yr (Leahy 1989) and a shell like radio morphology (right).
- Phillips et al. (2009; 2010) suggests possible interaction with MC using Spitzer images and identification of protostars.
- SN shocks cause turbulences in molecular clouds which could enhance/initiate star formation.

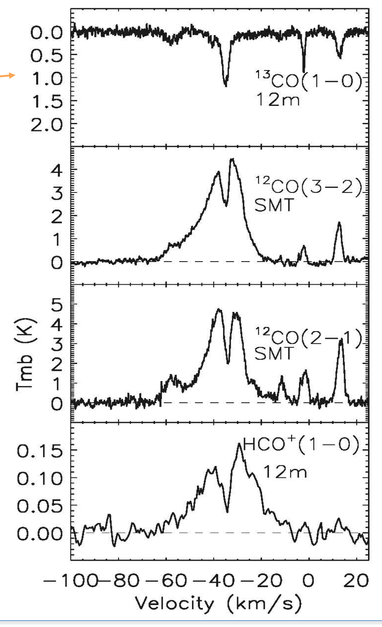



## Observations

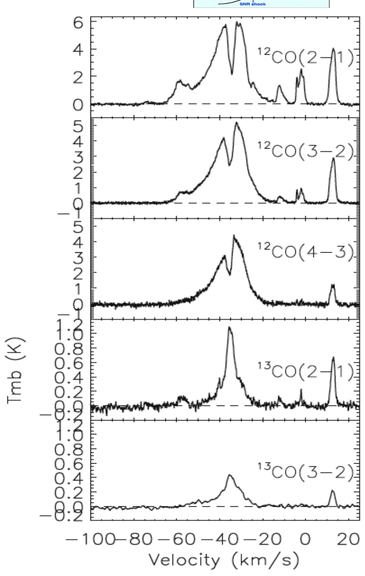
- ARO HH(Heinrich Hertz) SMT (2003, 2006): CO(2-1), CO(3-2)
- ARO 12-Meter: $^{13}$CO(1-0), HCO$^+$
- Spitzer IRS (2005): 8-40 μm including $H_2$ S(0)-S(7) lines
- SOFIA far-IR spectrometer GREAT (2013): [C II], CO(11-10)
- APEX in Chile (2015): CO(2-1), CO(3-2), CO(4-3), $^{13}$CO(3-2), $^{13}$CO(2-1)

## Discovery of Broad CO and HCO+ lines using HHSMT and APEX

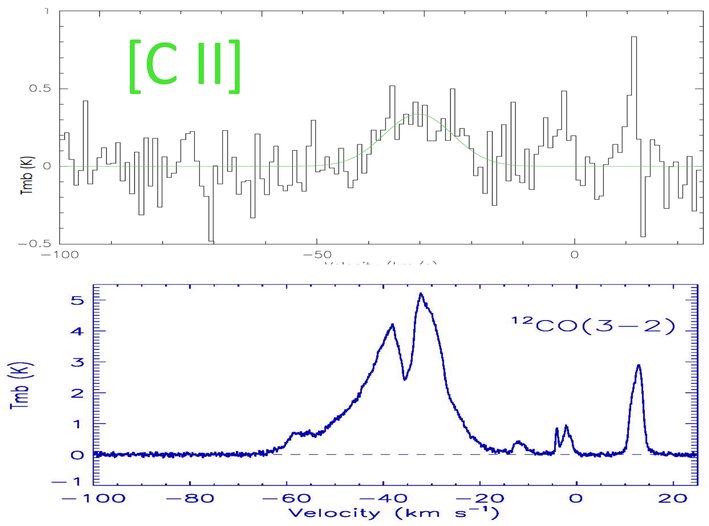





- Broad lines with widths of 15-30 km/s $^{12}$CO(4-3), $^{12}$CO(3-2), $^{12}$CO(2-1), HCO$^+$(1-0), $^{13}$CO(3-2), $^{13}$CO(2-1)
- Absorption dip is anti-correlated with $^{13}$CO(1-0) (from the parent cloud which is cold gas)
- Unrelated gas at -58, -13, -2, and 13 km/s



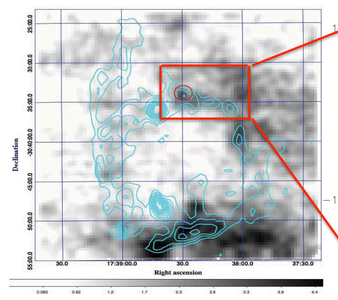

## SOFIA Observations of [CII] and CO(11-10)



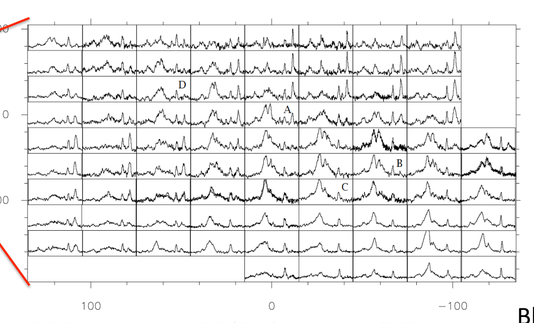

- [CII] at 157 μm has 3σ detection with ΔV~16 km/s and its profile is similar to those of CO lines, indicating C-shock origin.
- CO(11-10) is not detected.
- Each spectrum has only 5 min integration time.

The similarity between [C II] and CO profile suggests that [C II] is also from low velocity C-shock.

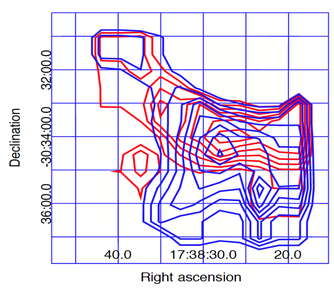
## Broad CO Molecular Line Map



$^{13}$CO(1-0) map of G357.7+0.3 showing the clouds at NW and S.



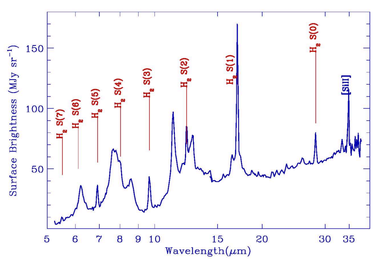

GRID spectra of CO(2-1) to cover 5x5 arcmin area.



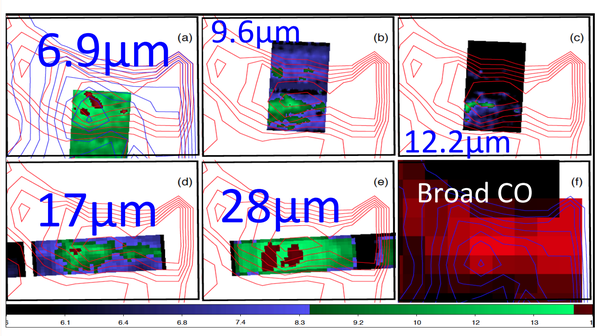

Blue (-53 to -38 km/s), middle (absorption dip: -38 to -31 km/s) and red (-31 to -27 km/s) velocity wings of CO(2-1) maps.

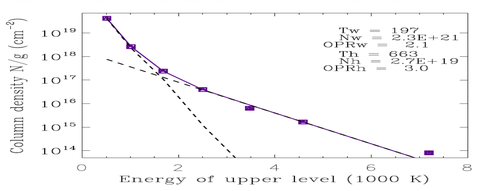
The broad CO lines appear from NE to SW, and the broad lines likely extend out side this map

## *Spitzer* Shocked $H_2$ Emission of G357.7+0.3

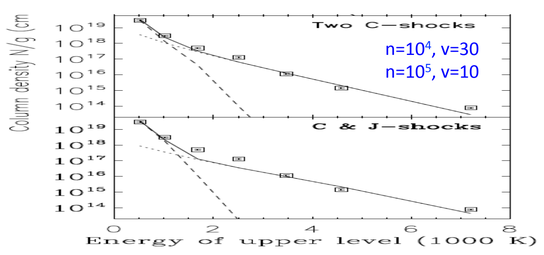



*Spitzer* IRS spectrum shows rotational $H_2$ lines. (left) . Each $H_2$ map shows different structures.

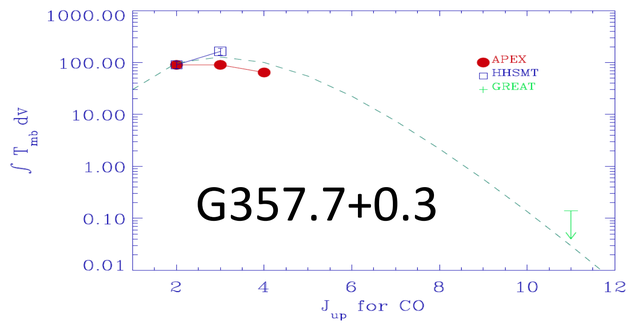


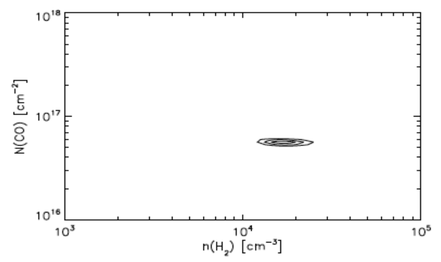




$H_2$ excitation diagram can be fit with two component LTE model with T=200 and 660 K (above)., and favors 2 C-shock model over a combination of C- and J-shock models (below).




## RADEX model of CO




G357.7+0.3 shows lack of high-J line; Non-LTE model yields a best-fit (right) of N(CO) = 6.8x10$^{16}$ cm$^{-2}$, size=0.01 pc, kinetic temperature of kT=60-200K, n($H_2$) = 6.3x10$^3$ cm$^{-3}$ (relatively low density). In contrast, G349.7+0.2 shows bright high-J line (below, Rho et al. 2015).