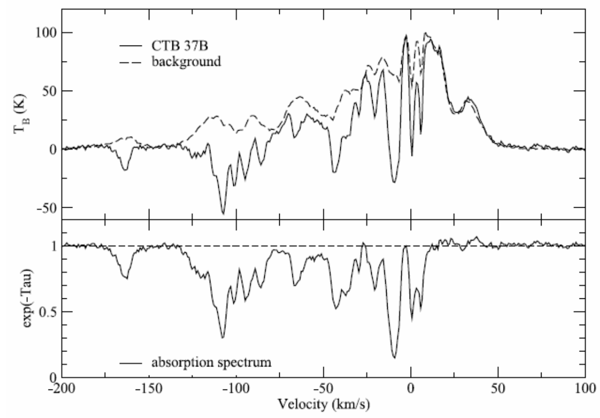
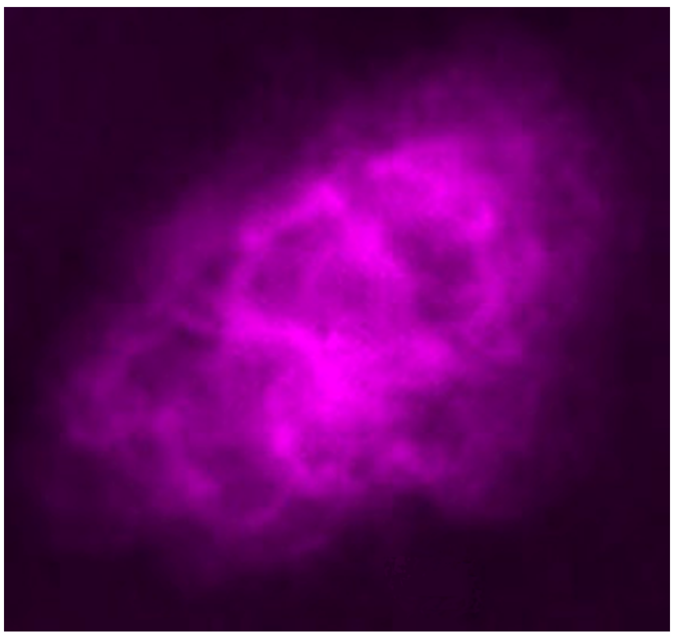
Radio Observations of TeV and GeV emitting Supernova Remnants





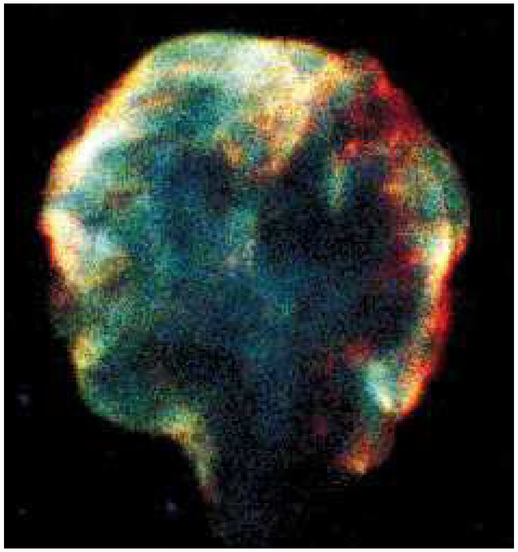
Denis Leahy

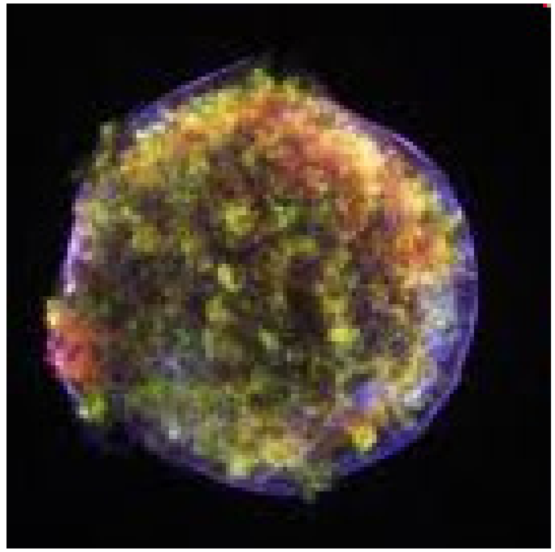
University of Calgary, Calgary, Alberta, Canada

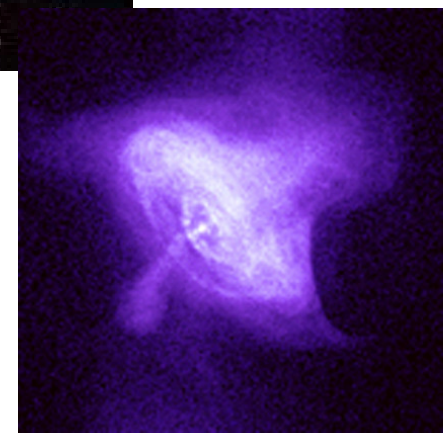
(collaborator Wenwu Tian, National Astronomical Observatories of China)

outline

- Overview of supernova remnants
- using HI absorption spectra to obtain distances
- HI spectra and images (radio, X-ray) of specific gamma-ray emitting SNR
- distance and derived properties
- summary

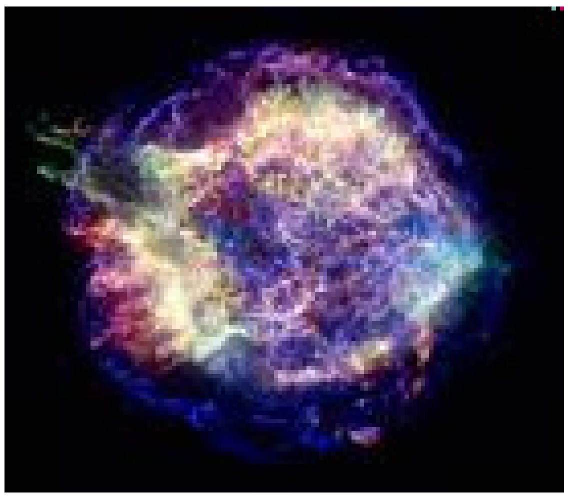






radius ~1-20 pc (1 pc~ 3×10^{16}m)

Shock speeds 100km/s-5000km/s



Supernova Remnants (left to right, top to bottom):
Cygnus Loop (~10000yr old) ROSAT X-ray, Tycho's SN (AD1572) Chandra X-ray, Crab nebula (AD1054) HST /Chandra, Cas A (AD1681+-19) Chandra X-ray, Kepler's SN (AD1604) Chandra X-ray

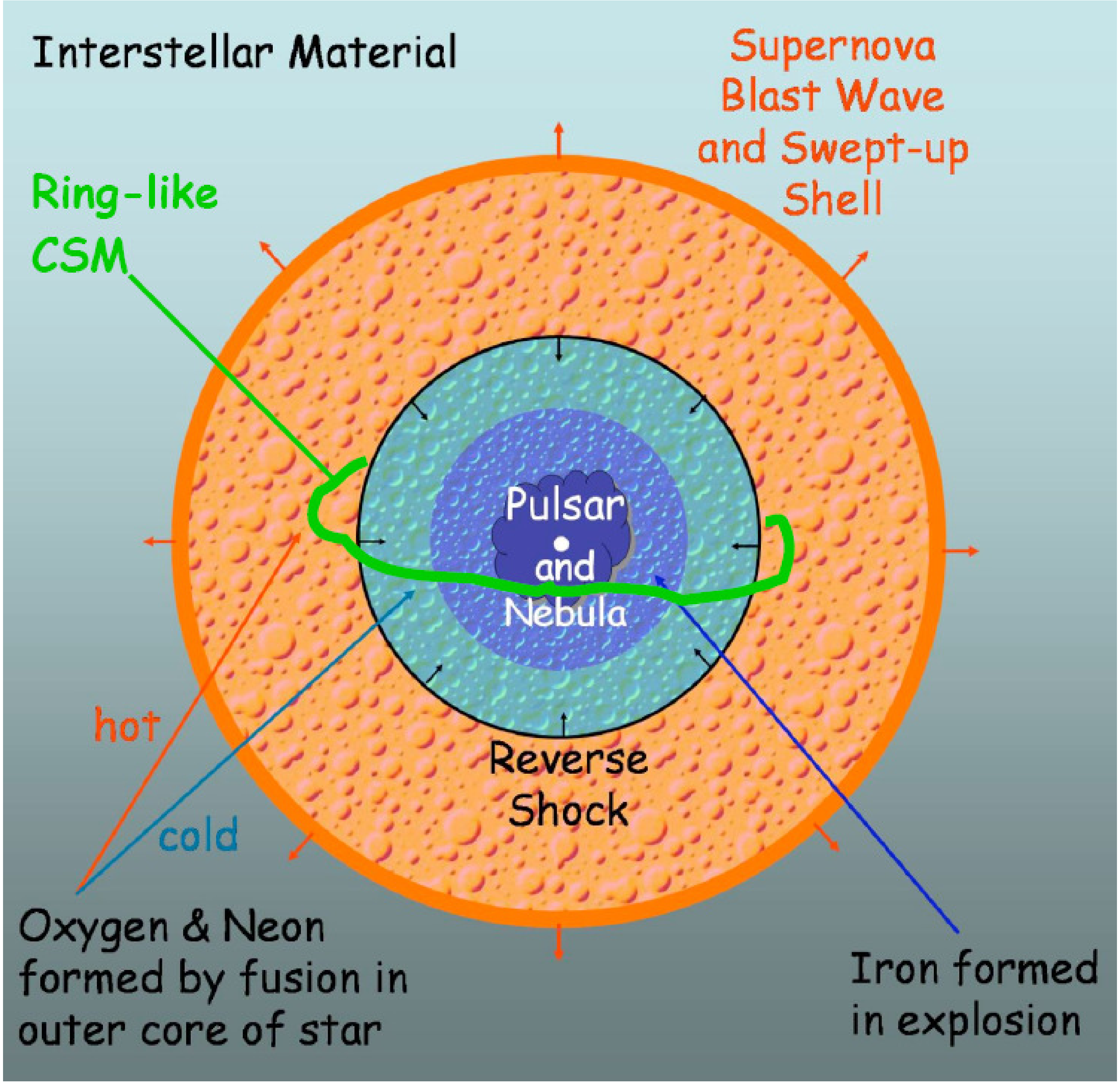
Supernova remnants

- 2 physical types of supernova (SN):
- Core collapse of a massive star (gravitational energy) ~10^{53} erg mostly in neutrinos, ~10^{51} erg in kinetic energy
- Thermonuclear explosion of a white dwarf: ~10^{51} erg in total / kinetic energy

- 2 observational types of SN:
- Type I: no H lines in SN spectrum
- Type II: with strong H lines in SN spectrum

- Supernova remnants (SNR): remains of SN explosion
- Number of known SNR in our Galaxy: approximately 280
- Large volume of the interstellar medium (~1 to 20pc in radius), filled with hot (10^6 K) plasma, heated by the shock wave of the explosion
- The shock wave via Fermi acceleration, produces high energy protons and electrons, up to ~10^{15} eV
- SNR emit X-rays (from the hot plasma), radio (from the relativistic electrons), infrared (from heated dust) and optical radiation (from recombining dense gas).
- Shock accelerated particles also emit X-rays and GeV & TeV gamma-rays.

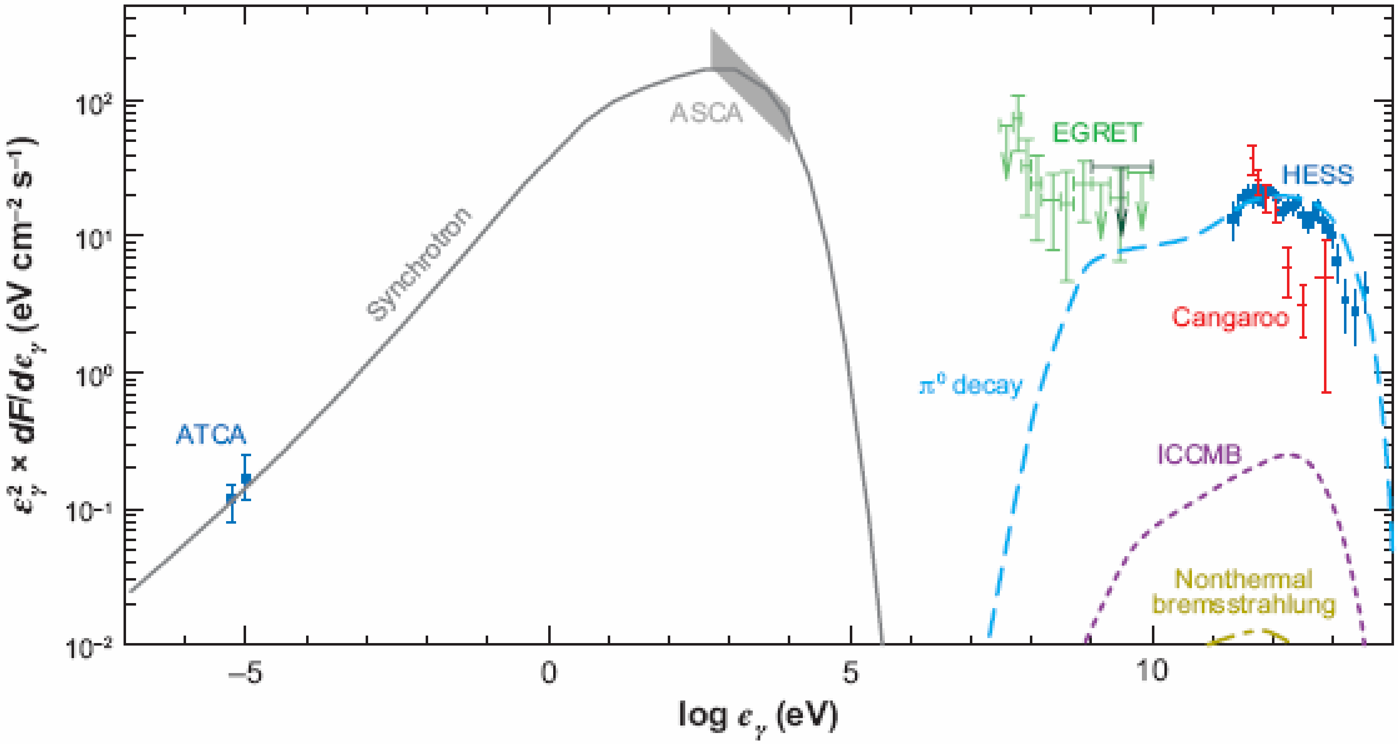
Diagram of a SNR from a massive star



Types of Supernova remnants:

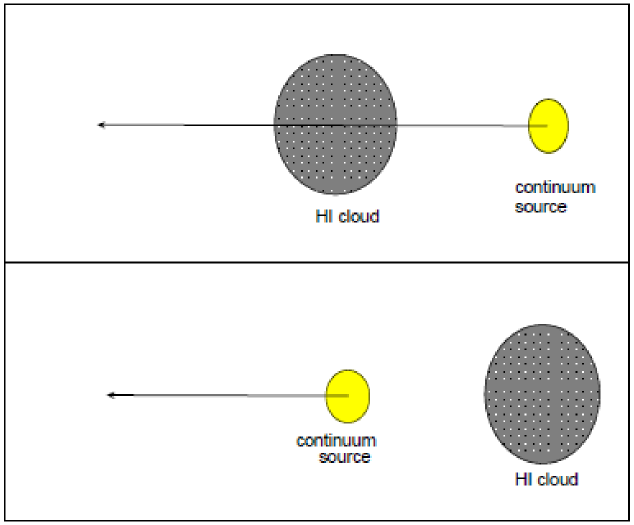
- i) Shell-like, such as Cygnus Loop, Tycho, Kepler
- ii) Composite, in which a shell contains a central pulsar wind nebula, such as G11.2-0.3 or G21.5-0.9. (Crab nebula is an exception)
- iii) Mixed-morphology SNR ("thermal composite"): central thermal X-ray emission enclosed by a radio shell. Thermal X-rays are from swept-up interstellar material, rather than SN ejecta; examples- SNRs W28 and W44.
- TeV and GeV emitting SNRs
- Young TeV SNRs Cas A, Tycho, SN 1006, RXJ1713.7-3946, RXJ0852-4622 (Vela Junior), RCW 86
- Old TeV SNRs G353.6-0.7(HESS J1731-347), W51C (HESS J1923+141), CTB 37A (HESS J1714–385), CTB 37B (HESS J1713–381)

Example: gamma-ray emitting SNR (G347.3 -0.5)



- Discovered with gamma-ray telescopes: Fermi, EGRET, HESS
- Demonstrates existence of high energy particles (electrons, protons)
- Particles were accelerated by the SNR shock wave
- Radio and X-ray emission from energetic electrons.
- Gamma-rays from high energy protons which collide to produce pions; the neutral pions decay to gamma-rays at 10^{10} to 10^{14} eV.

HI absorption spectra for Galactic distances (Leahy & Tian 2010 PASP, Dickey & Lockman 1990)



- Definition of brightness temperature

$$S_\nu = j_\nu/\kappa_\nu = B_\nu(T) = 2k_B T/\lambda^2$$

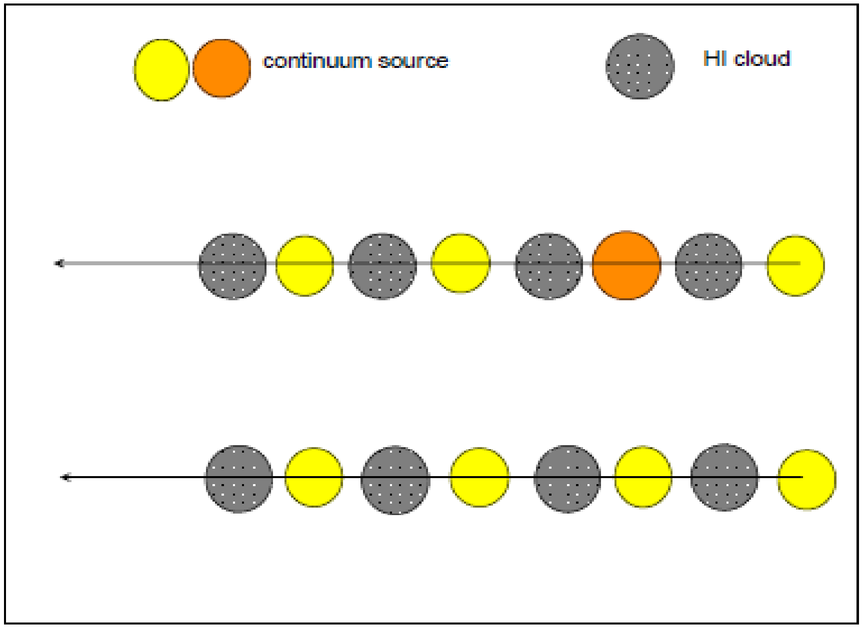
- Apply equation of radiative transfer

$$I_\nu(0) = I_\nu(\tau_0)e^{-\tau_0} + \int_0^{\tau_0} S_\nu(\tau)e^{-\tau}d\tau$$

The interstellar medium in the Galaxy is filled with HI clouds

They absorb and emit 21cm line radiation at the frequency shifted by their line-of-sight velocity

Example configuration of multiple emitters and absorbers



$$T_B(\mathrm{v}) = \sum_{m=0}^{m_c} T^c_{B,m} e^{-\tau_m(\mathrm{v})} + \sum_{n=0}^{n_{HI}} \tau^{(n)}(\mathrm{v}) T_{B,n}(\mathrm{v}) e^{-\tau_n(\mathrm{v})}$$

For two adjacent lines-of-sight (1 and 2),

$$T_B(v,1) - T_B(v,2) = (T^c_{B,j,1} - T^c_{B,j,2}) e^{-\tau_j(\mathrm{v})}$$

For the data with a continuum image at a nearby frequency subtracted:

$$T_B(v,1) - T_B(v,2) = (T^c_{B,j,1} - T^c_{B,j,2})(e^{-\tau_j(\mathrm{v})} - 1)$$

Distance from velocity

- Galactic rotation from self-gravity
- Simplest model is circular motions V(R)
- For some directions (e.g. inner Galaxy, Cygnus X region) need more complex velocity model

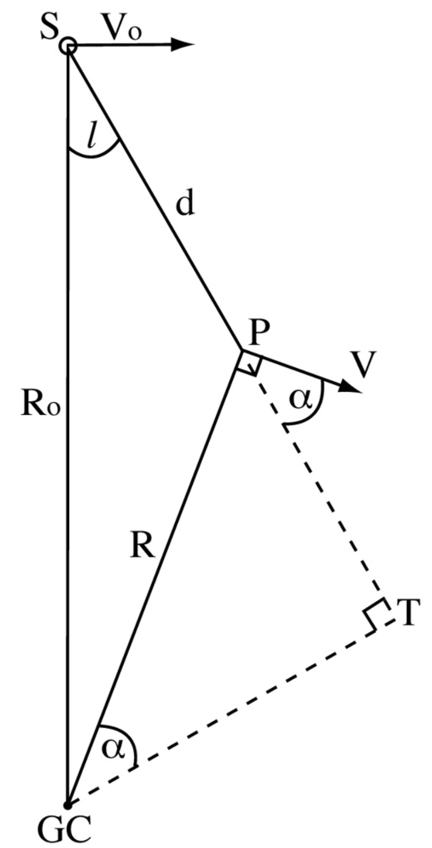


Fig 2.19 'Galaxies in the Universe' Sparke/Gallagher CUP 2007

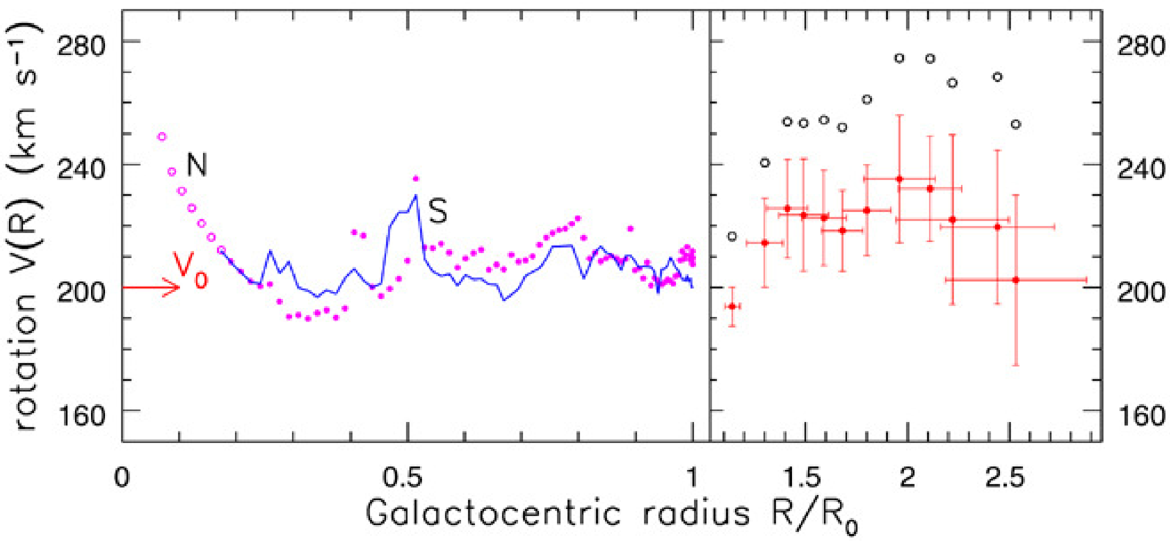


Fig 2.21 (Burton, Honma) 'Galaxies in the Universe' Sparke/Gallagher CUP 2007

DR4, gamma Cygni, G78.2+2.1

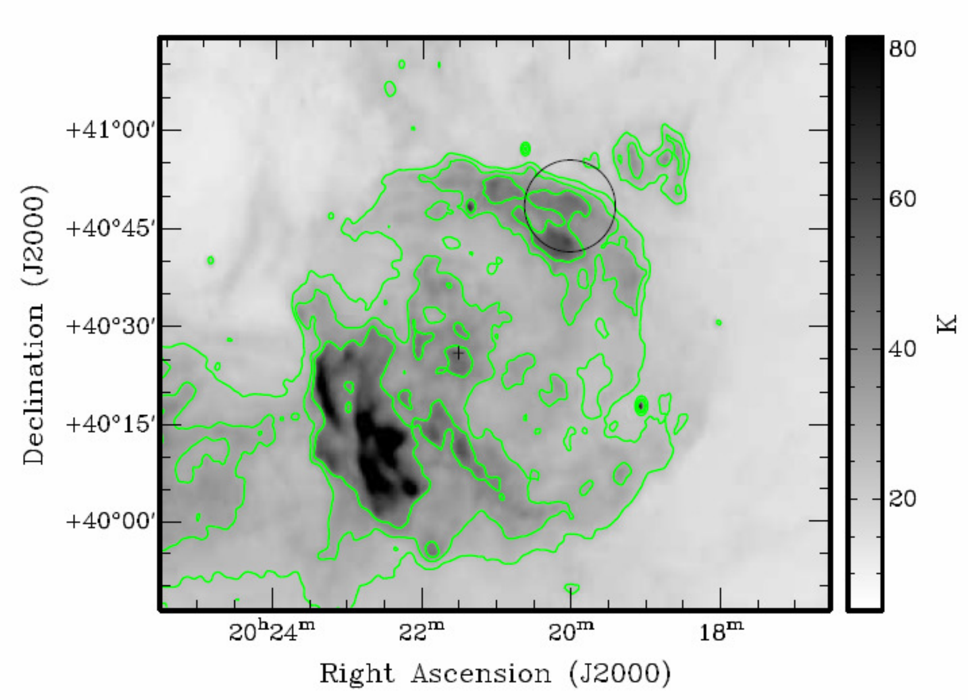
Extended TeV source VER J2019+407 (circle)

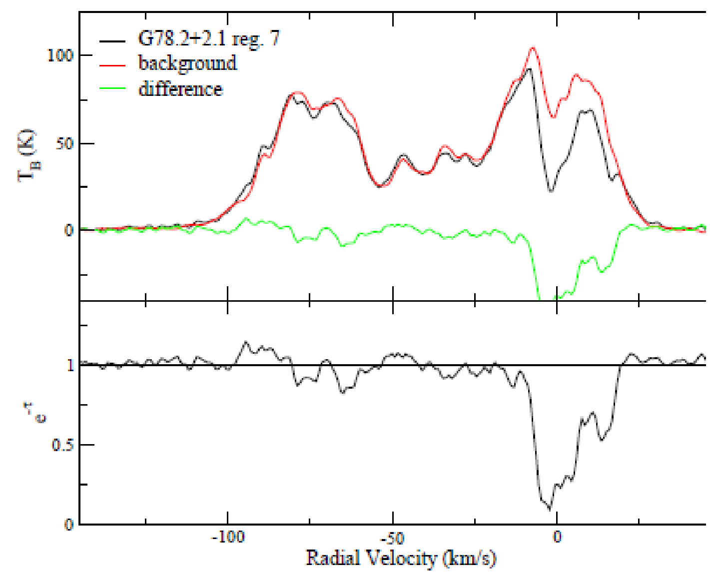
1420MHz radio continuum image CGPS

The HI absorption spectrum-same as gamma Cygni HII region

Distance of 1.7-2.6 kpc

Galactic circular rotation does not apply in this direction, near the Cygnus X star forming region





ROSAT image of G78.2+2.1

'+' marks position of an X-ray pulsar

Chandra 0.5-3 keV image of NW area of SNR:

i) Diffuse SNR emission

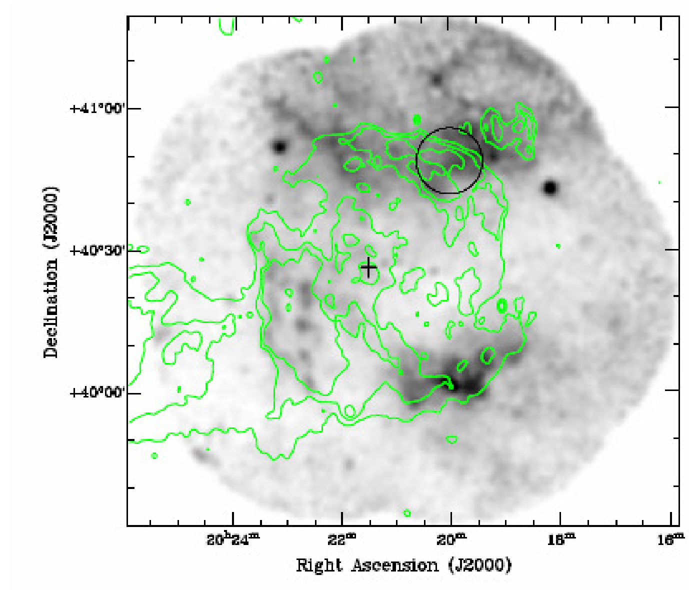
ii) Pulsar soft thermal X-rays

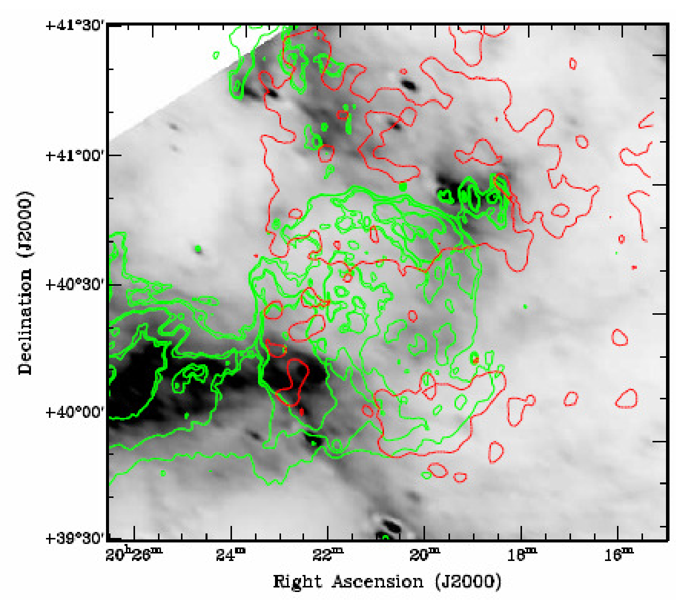
iii) New power-law spectrum point source

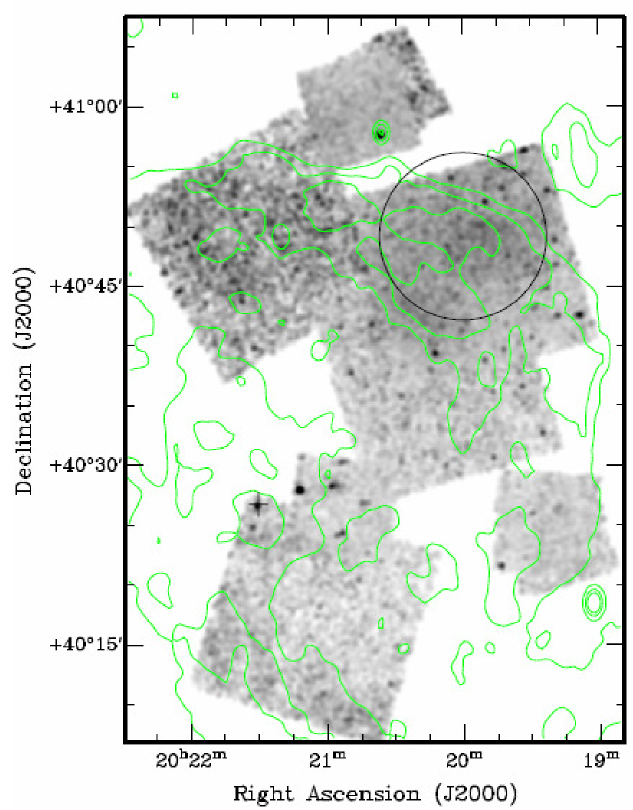
Chandra diffuse emission is consistent with VER J2019+407

IRAS 60micron (dust) map below

SNR: shock velocity 800 km/s, age ~8000yr, Esn=0.5-2x10^{51} erg (normal), ISM density~0.2cm^{-3}

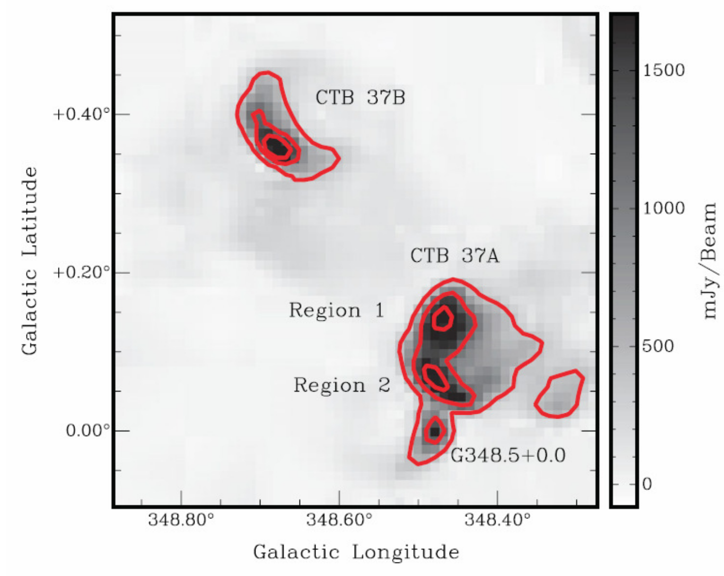






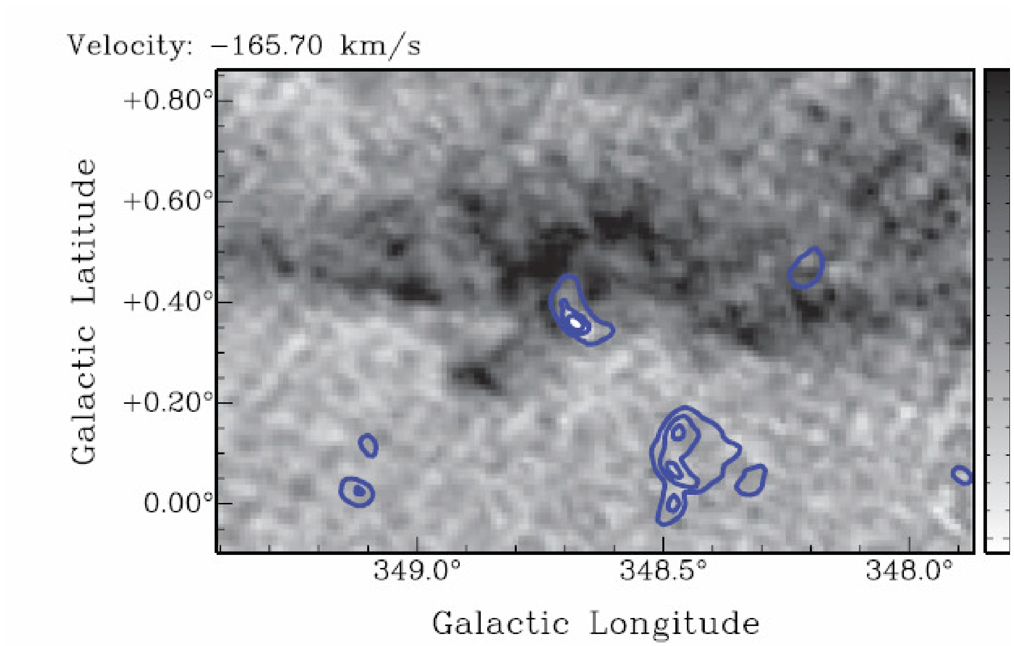
CTB 37A (G348.5+0.1), associated with the TeV *γ -ray source HESS J1714–385*

CTB 37B (G348.7+0.3), associated with HESS J1713–381

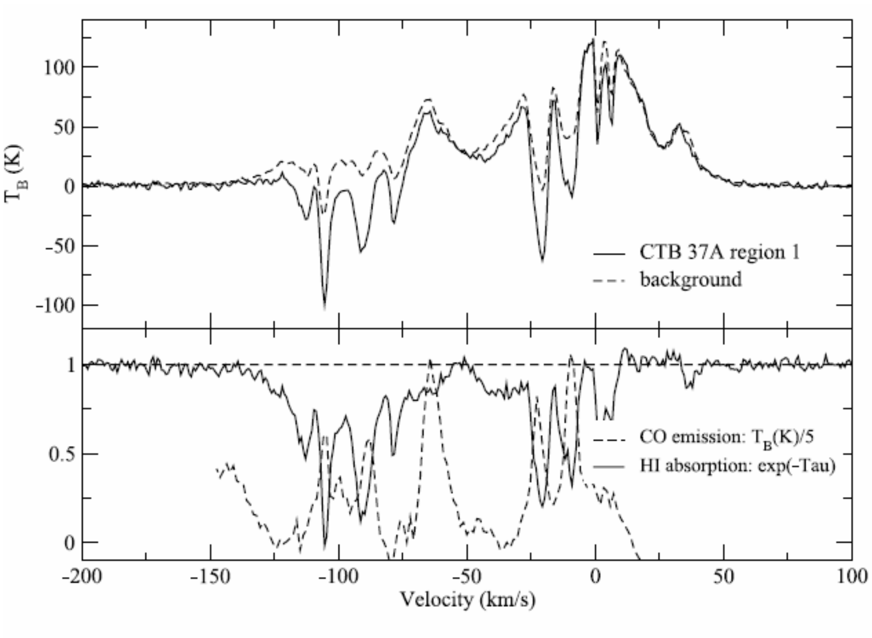


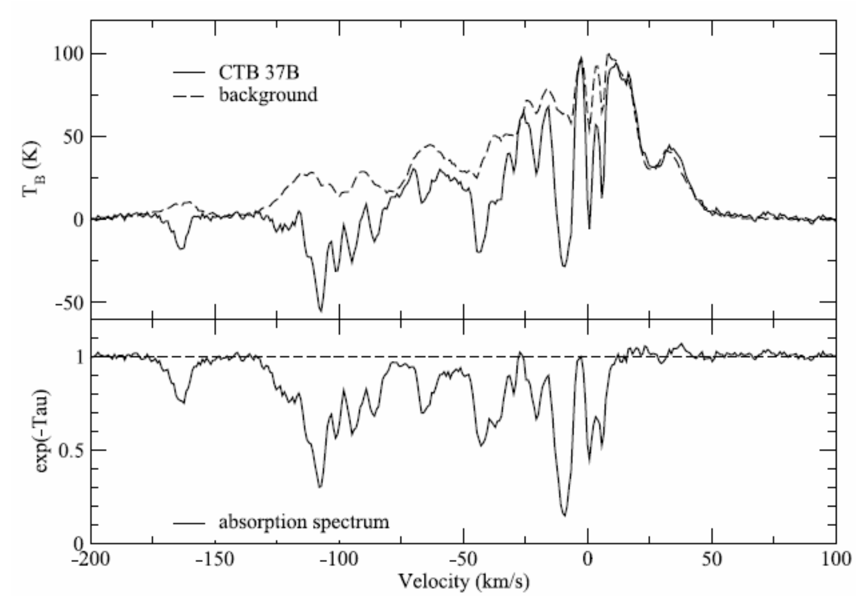
1420 MHz radio continuum image SGPS

The HI channel image at -166km/s with 1420 MHz contours, showing absorption for CTB37B only



CTB 37A and *CTB 37B*





The HI absorption spectra spectrum for CTB37A and CTB37B yield new distances

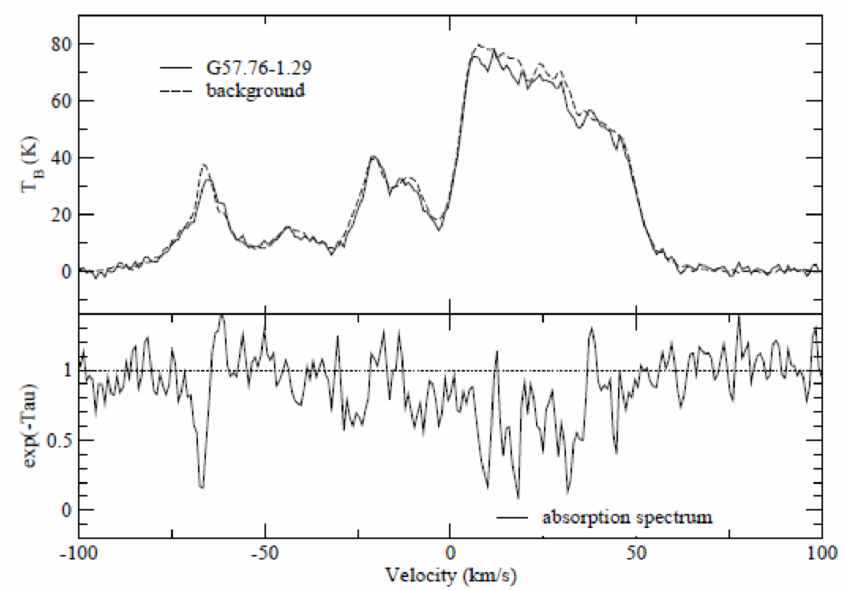
CTB 37A and 37B are not associated with the historical supernova AD 393.

Table 1. Comparison of distance estimates from the earlier studies and the present study for SNR complex CTB 37.

SNR name	37A	37B	G348.5−0.0
The past	∼11.3 kpc[a]	5–9 kpc[b]	∼14 kpc[c]
Ours	6.3–9.5 kpc	∼13.2 kpc	≤6.3 kpc

References: [a]Reynoso & Mangum (2000); [b]Aharonian et al. (2008), Caswell et al. (1975); [c]Reynoso & Mangum (2000).

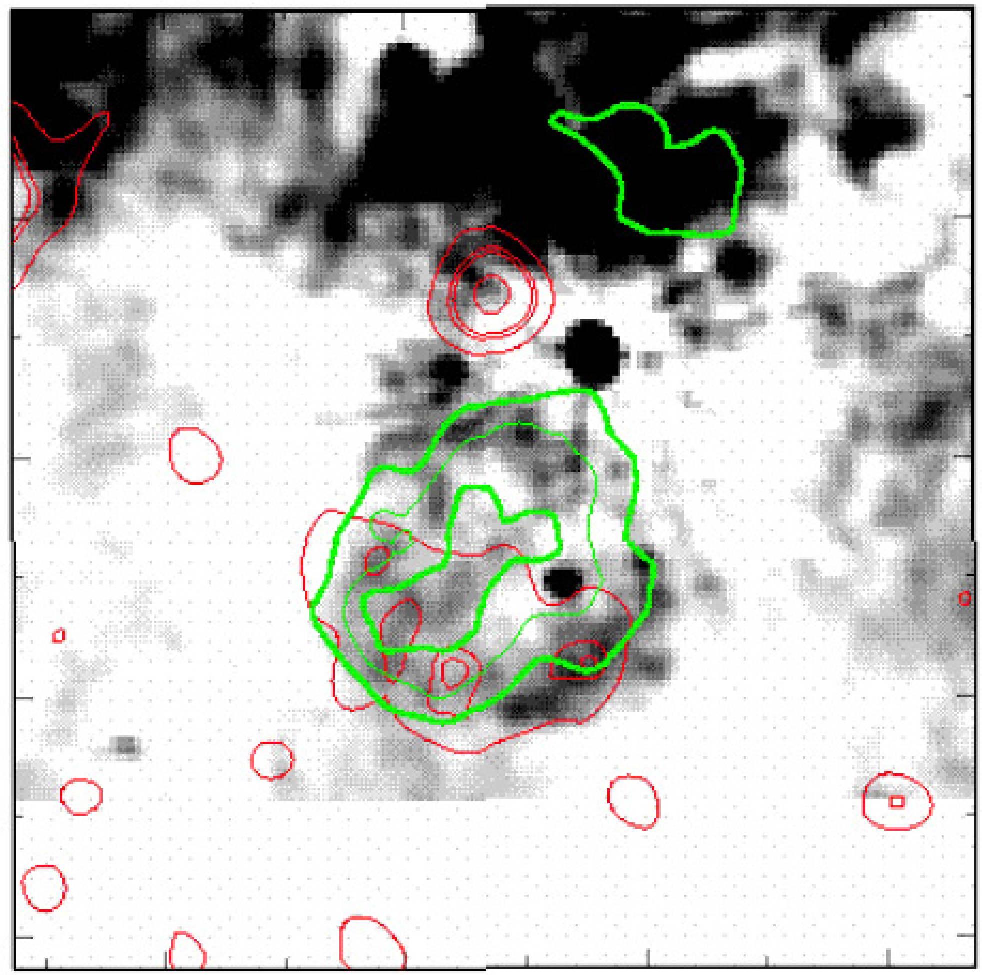
HI absorption distance of HESS J1943+213



- The H.E.S.S. collaboration (Abramowski et al. 2011) discovered a new TeV point-like source HESS J1943+213 in the Galactic plane
- three possible low-energy-band counterparts: a -ray binary, a pulsar wind nebula (PWN), or a BL Lac object.
- distance G57.76-1.29/HESS J1943+213 from HI absorption spectrum is ≥ 16 kpc.
- This strongly supports that HESS J1943+213 is an extragalactic source.

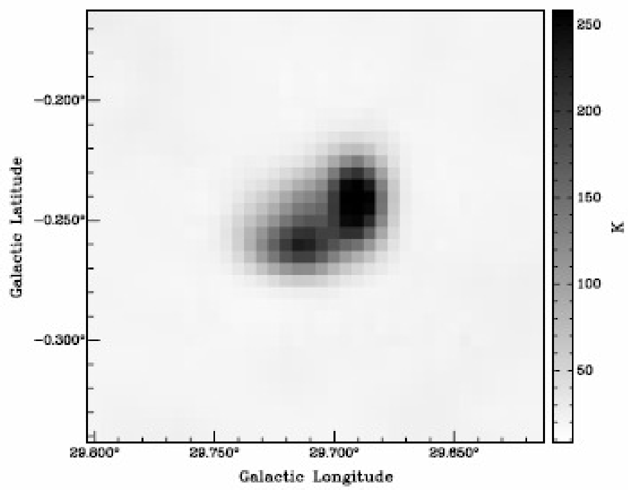
HESS J1731-347 / G353.6-0.7: a gamma-ray emitting SNR

- A faint SNR discovered in radio and X-ray (Tian, Leahy, Haverkorn, Jiang 2008)
- Distance ~3.2kpc, radius~14pc, age~25000yr.



TeV /GeV SNRs G54.1+0.3, Kes 75, H23.3-0.3 (W41), G21.5-0.9 and G353.6-0.7

- Kes75 is at 6kpc, previous estimate was 20kpc
- New distance gives normal explosion energy



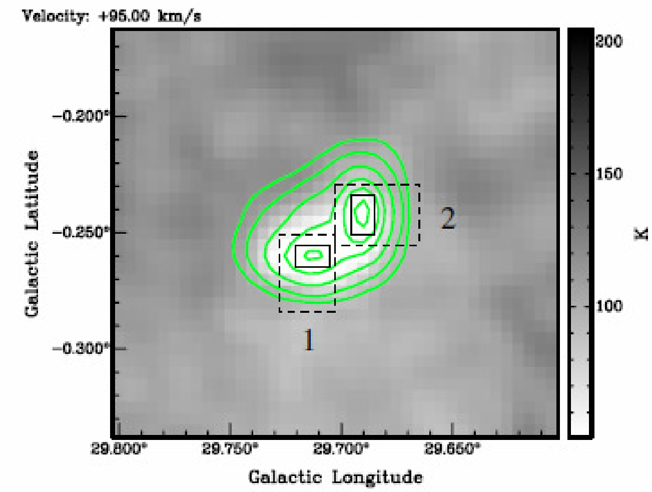


Table 1. Summary of Distances of Five SNRs

SNR names:	G353.6-0.7	G21.5-0.9	H23.3-0.3	Kes 75	G54.1+0.3
Highest absorption *v (km/s)*:	-20	67	78	95	65
Kinematic distance (kpc):	~ 3.2	~ 4.8	~ 4.2	~ 6.0	~ 6.5

Summary

- SNR: strong shock wave in ISM
- non-thermal emission from shock accelerated particles from radio to X-rays to gamma-rays
- Improved methods for HI absorption spectra
- Use maximum velocity of HI absorption, Galactic rotation model to infer distance or limits
- Main goal: obtain distances.
- Distance allows derivation of physical properties of SNR (e.g radius, explosion energy, density) from multi-wavelength data (radio, HI, CO, IR, X-ray, gamma-ray)