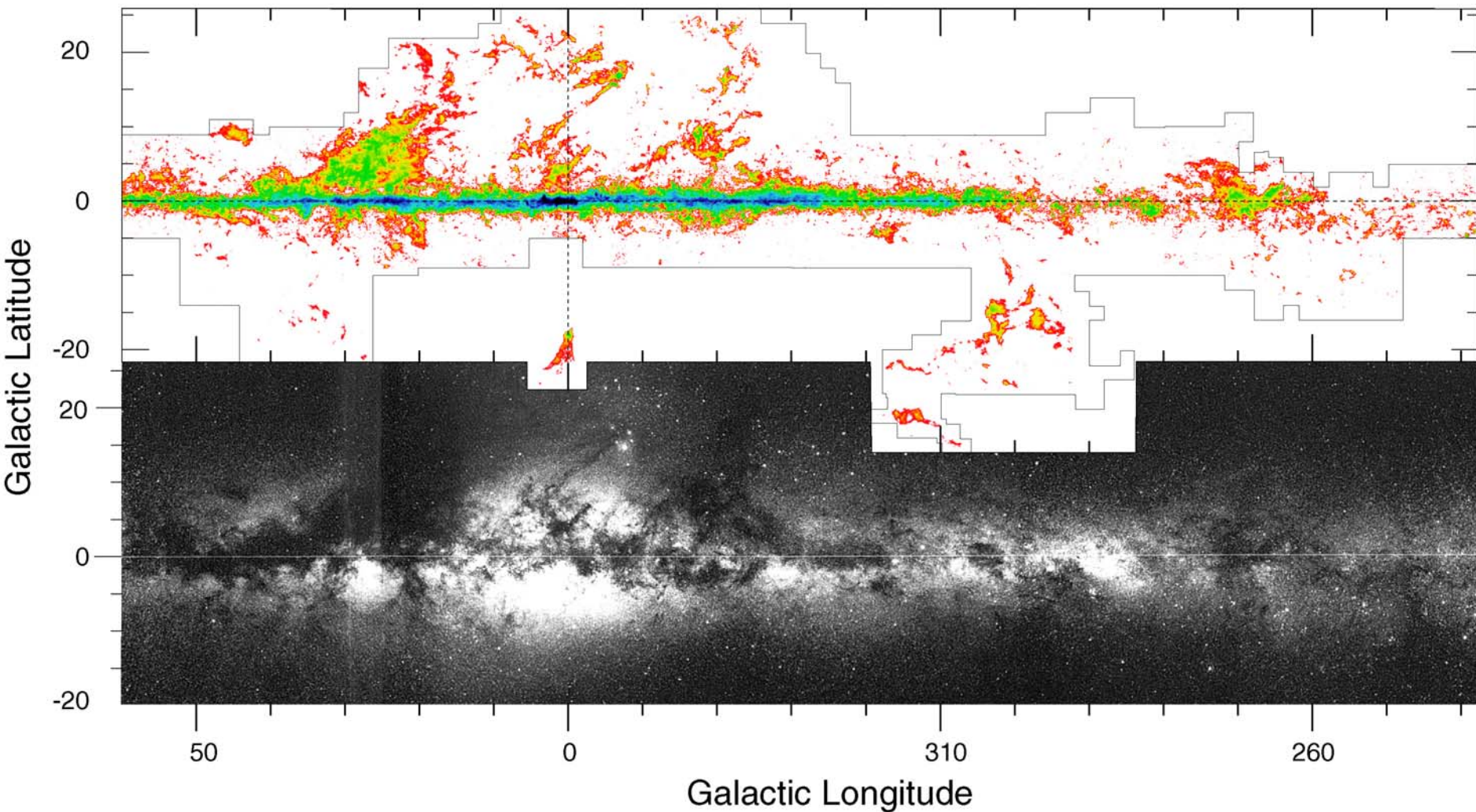


CO Observations of the Galactic Disk

Toshikazu Onishi (Nagoya University)



NANTEN
Submillimeter Observatory



Study of Molecular Observations of SNRs

- Samples of SNR-dense cloud interaction → still poor
- Observations of γ -rays from CR accelerated in SNRs
→ angular resolution becoming higher
- Distances of many Galactic SNRs → still unknown

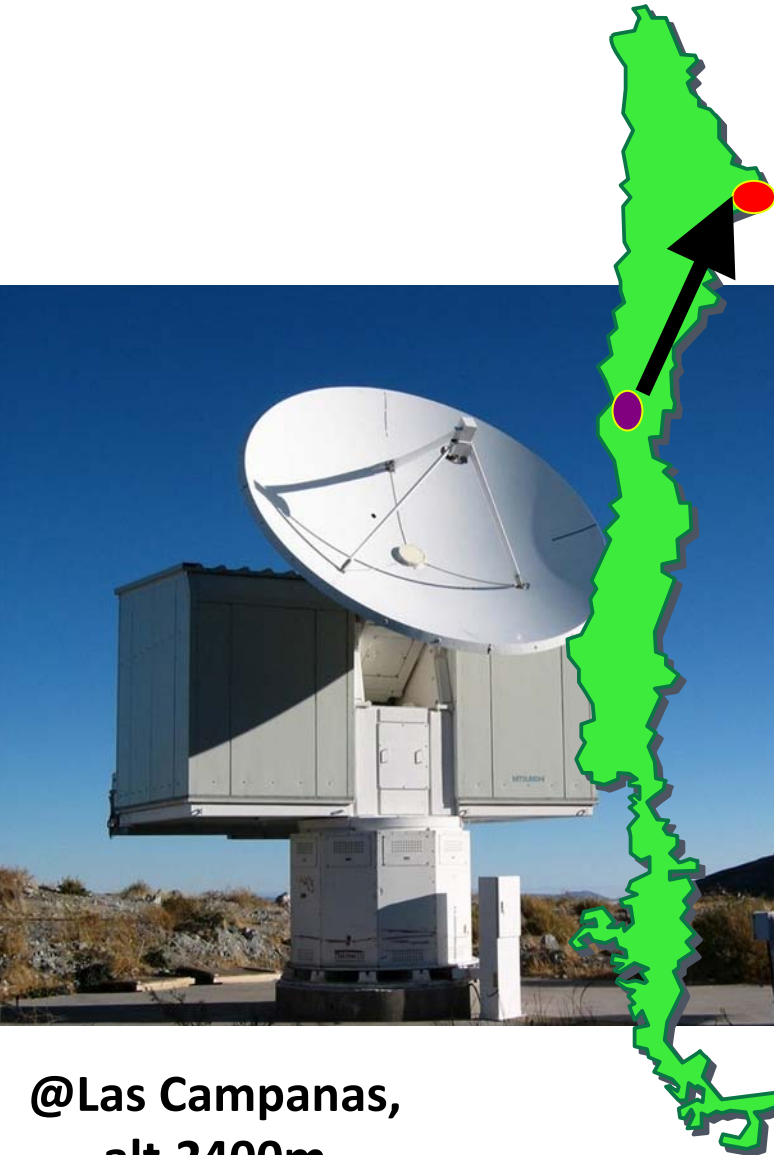
Molecular lines...

- spatial / velocity distribution of dense clouds
- kinematic distance
- column density toward SNRs (\Leftrightarrow X-ray)
- search for shocked dense gas

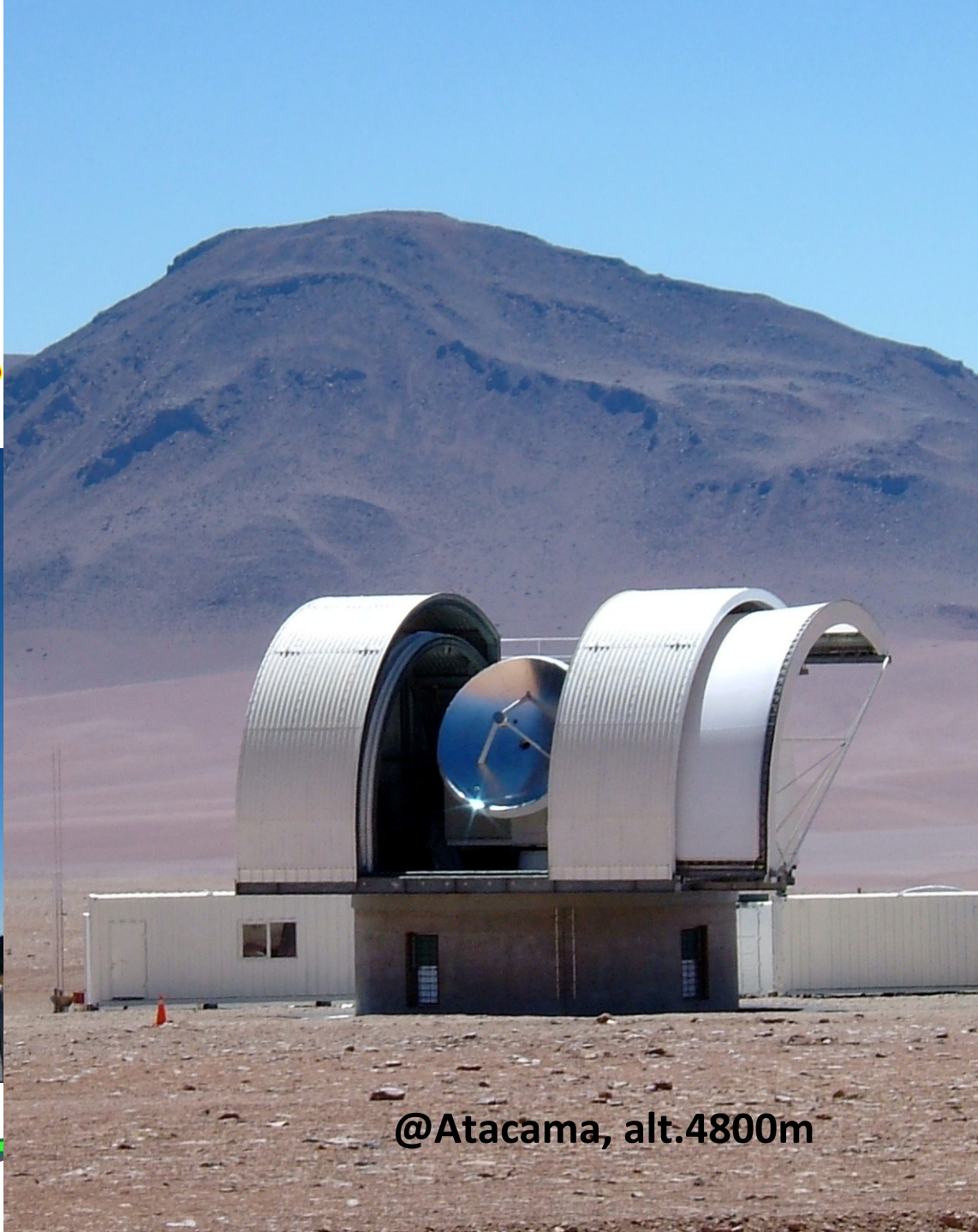
OUTLINE

- **NANTEN(2) CO molecular dataset**
 - **distribution of interstellar protons**
- **Detailed CO studies with X-ray and TeV;**
 - **Interaction of SNRs and molecular gas**
- **Future**

NANTEN & NANTEN2



@Las Campanas,
alt.2400m



@Atacama, alt.4800m

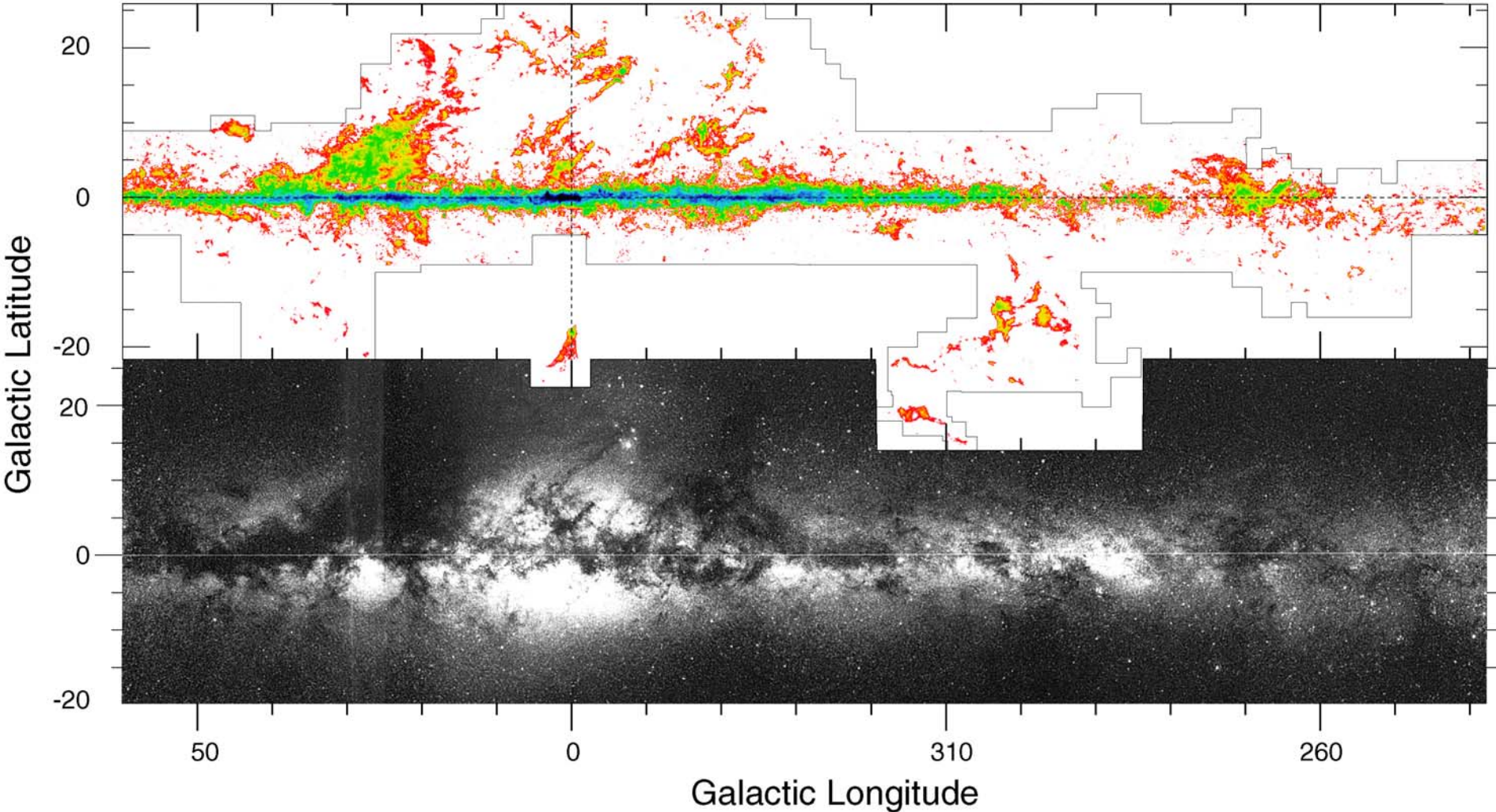
Target frequencies

CO(J=1-0)	115 GHz	2.'6 (HPBW)	Nagoya RX
CO(J=2-1)	230 GHz	1.'3 (HPBW)	
CO(J=3-2)	345 GHz	0.'9 (HPBW)	
CO(J=4-3)	460 GHz	39'' (HPBW)	Cologne SMART
CO(J=7-6)	806 GHz	22'' (HPBW)	
CI ($^3P_1 - ^3P_0$)	492 GHz	37'' (HPBW)	
CI ($^3P_2 - ^3P_1$)	809 GHz	22'' (HPBW)	

8 beams in 490GHz, 8 beams in 810GHz, simultaneously

Galactic Plane Survey

- $^{12}\text{CO}(J=1-0)$, Grid size $\sim 4'$ ($|b| < 5^\circ$), $8'$ ($5^\circ < |b| < 10^\circ$)
- Integ. time (typ) $\sim 5\text{sec/point}$, 1,100,000 observed points



Targets

- Galactic Plane Survey in Southern Sky
- Magellanic Clouds (LMC and SMC)
- High-mass star forming region (GMCs)
 - Carina, Centaurus, Orion, Bright-Rimmed Clouds,
- SNRs and Supershells
 - Vela SNR, Gum Nebula, Carina Flare
- Galactic Center
- Low-mass star forming region (Dense cores)
 - Ophiuchus, Lupus, Chamaeleon, Pipe Nebula
- Galactic High-Latitude Molecular Clouds
 - Aquila, Infrared-Excess Cloud, High-Latitude Survey

LMC

270 CO clouds
identified
($M > 10^4 M_{\text{sun}}$)

Total molecular
mass

$\sim 7 \times 10^7 M_{\text{sun}}$

+HI
+Spitzer
+Herschel

500pc

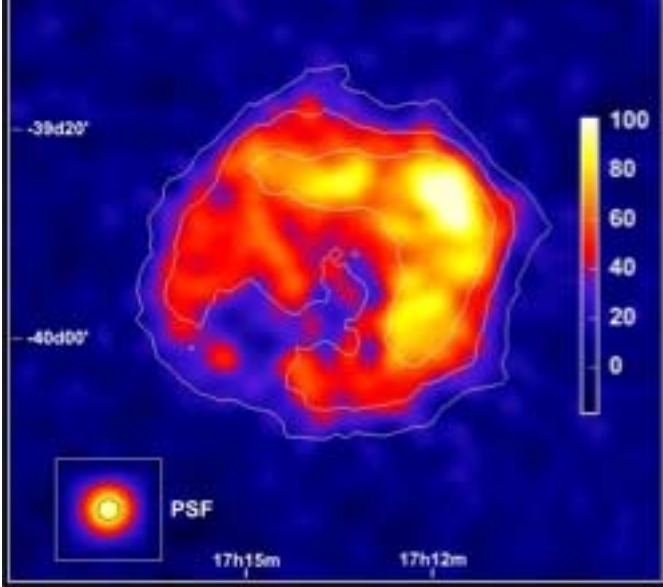
NANTEN → NANTEN2

- Large scale survey of interstellar gas
in the Galaxy and Magellanic Clouds
in Cl ($^3P_1 - ^3P_0$), Cl ($^3P_2 - ^3P_1$)
and CO (J= 2-1, 3-2, 4-3,)
- Move NANTEN telescope to Atacama, Chile
Alt. 4,800m starting from October 2003
- Replace the main-ref for higher-freq. operation
- Enclosed in a Dome

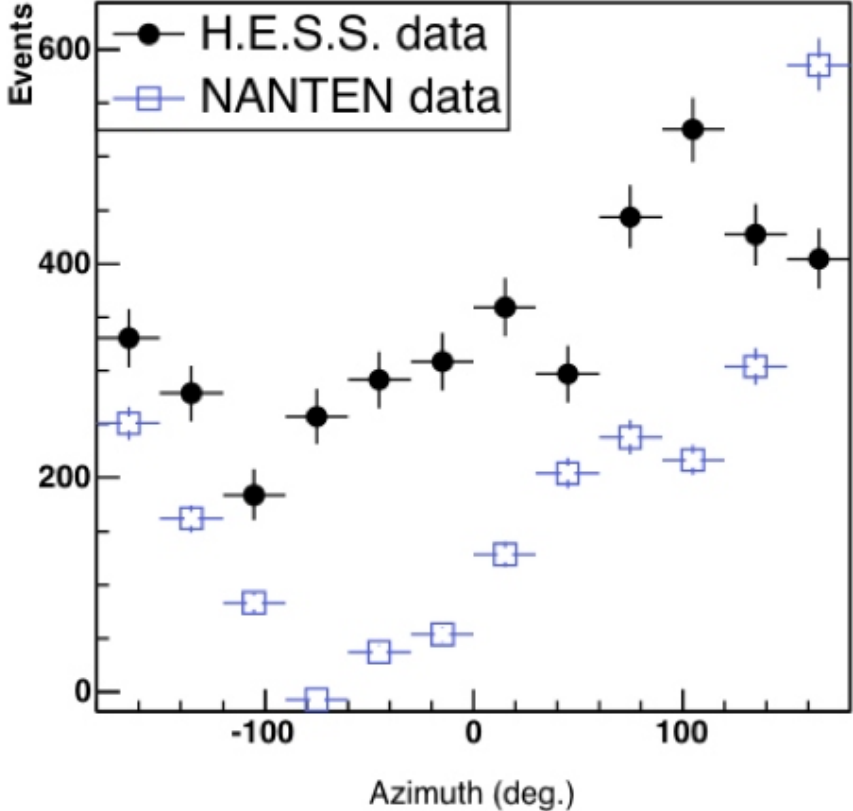
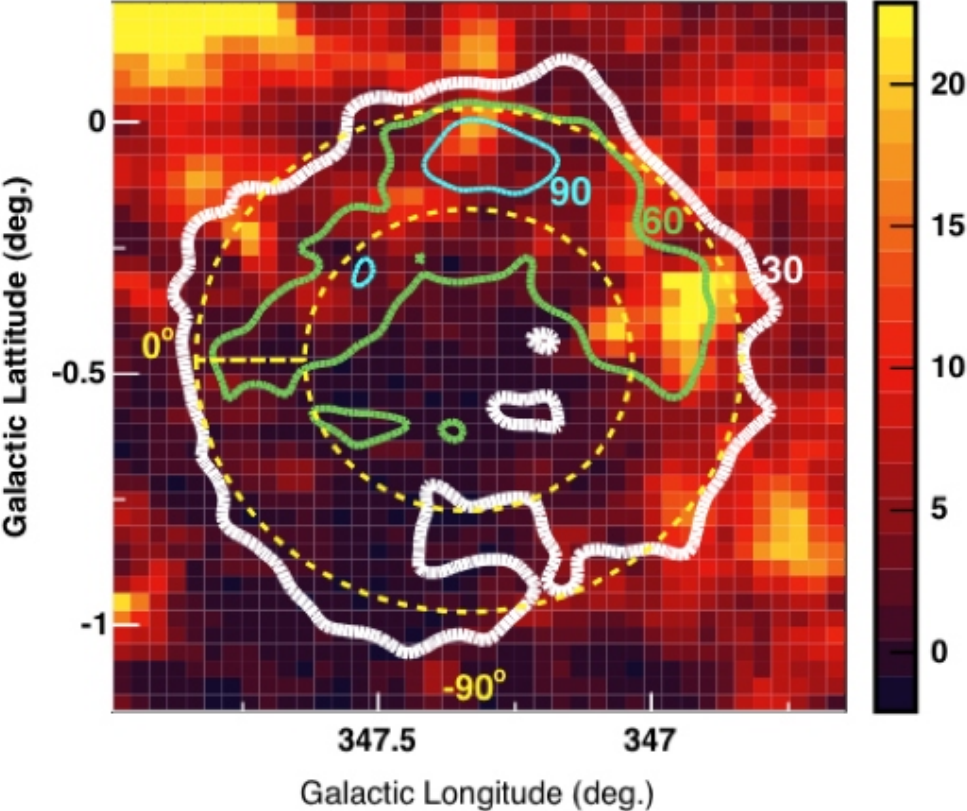
Molecular Cloud
and
TeV Gamma ray

SNR G347.3-0.5 (RXJ1713.7-3946)

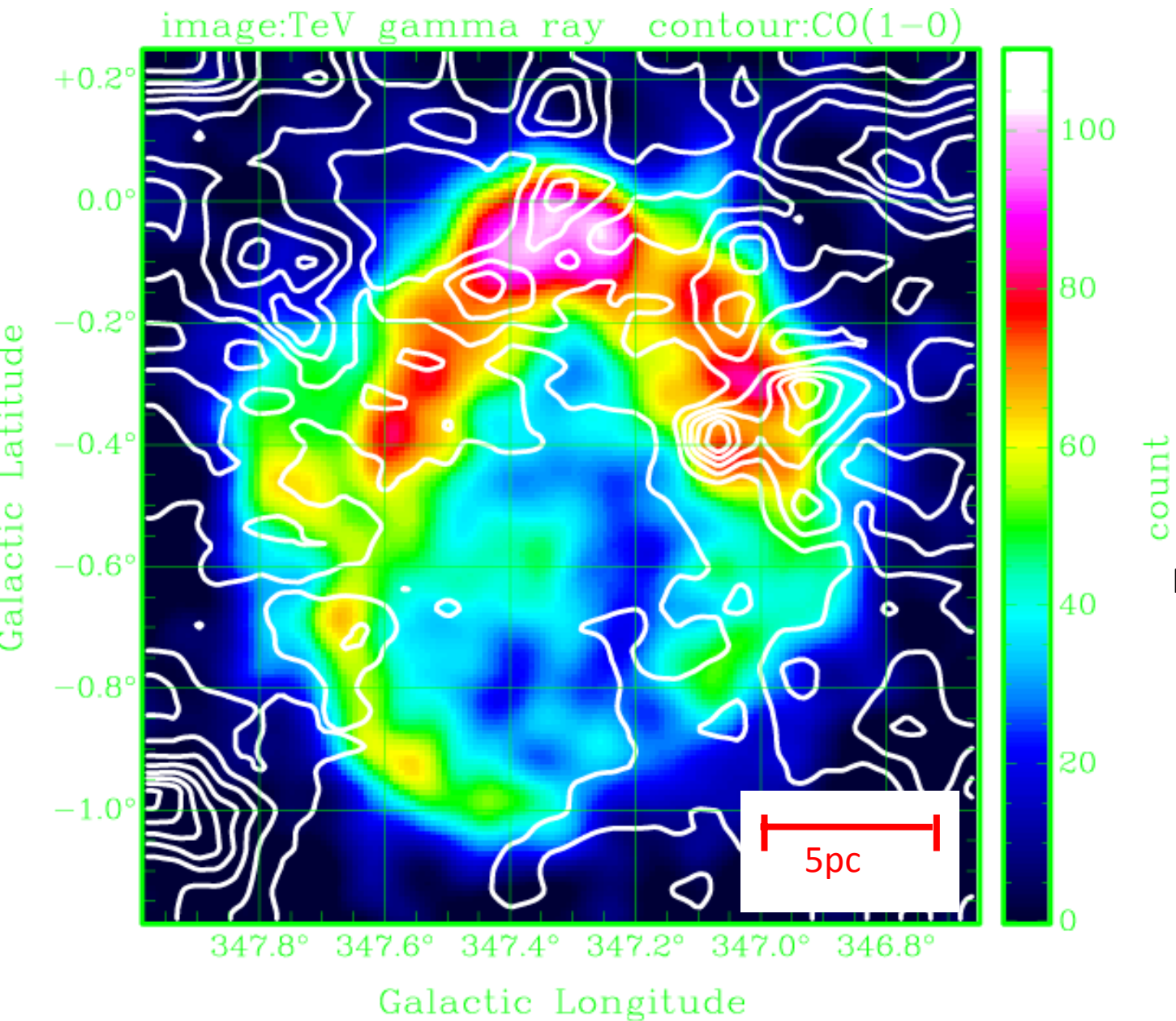
- Shell-like structure: similar with X-rays
- No significant variation of spectrum index across the regions
- spatial correlation with surrounding molecular gas



Aharonian et al. 2005



RXJ1713/ G347.3 : TeV Gamma vs 12CO(J=1-0)

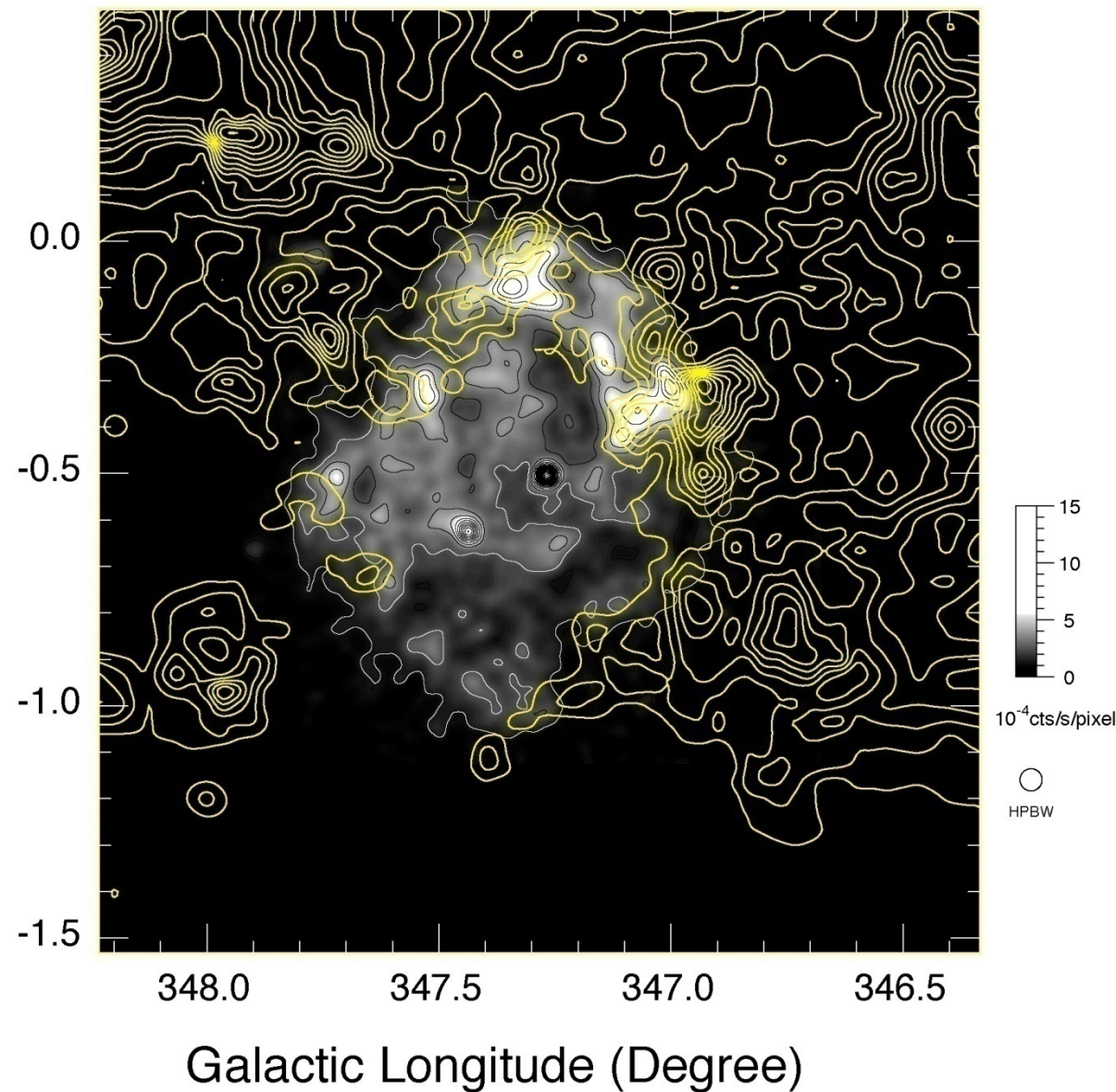


Map of J1713.7-3946

Image:
TeV gamma ray
by H.E.S.S.

Contour:
12CO(J=1-0)
by nanten
velocity range
-18 km/s – 0km/s
min. = 3K km/s
interval = 7K km/s

Comparison of $^{12}\text{CO}(J=1-0)$ with X-ray



molecular hole

surrounding boundary of
the SNR

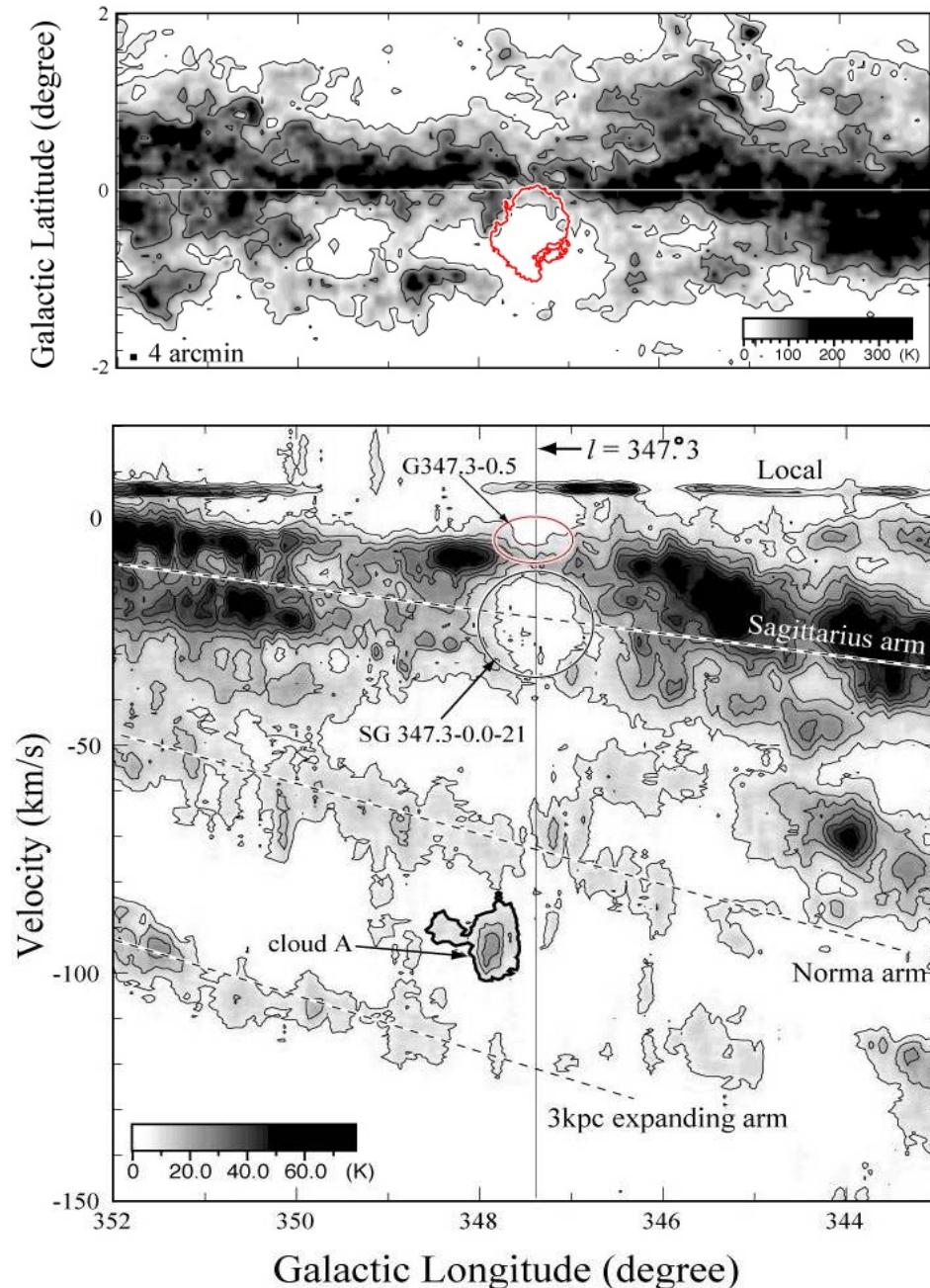
CO peaks \Leftrightarrow X-ray peaks
show good spatial
correlation
(northwestern bright rim)



indicates
interaction of the SNR
with molecular clouds.

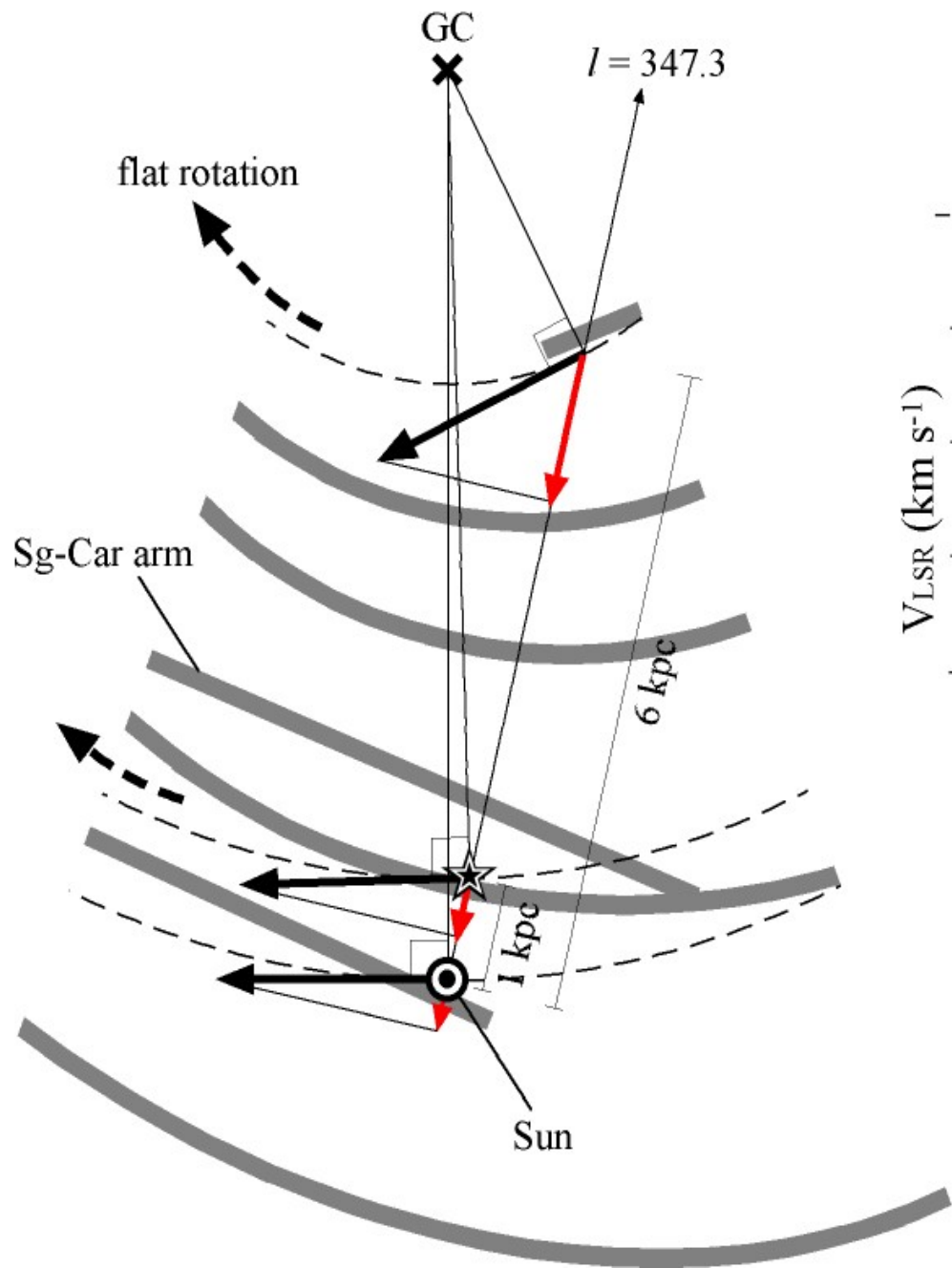
(Fukui et al. 2003)

RXJ1713 CO Velocity distribution by NANTEN

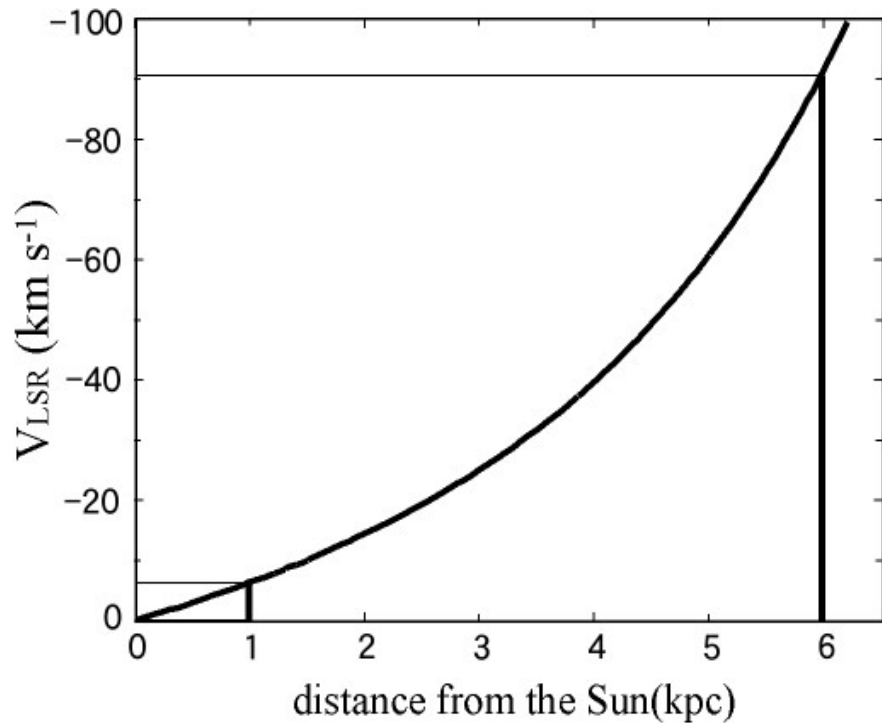


Moriguchi et al.
2005

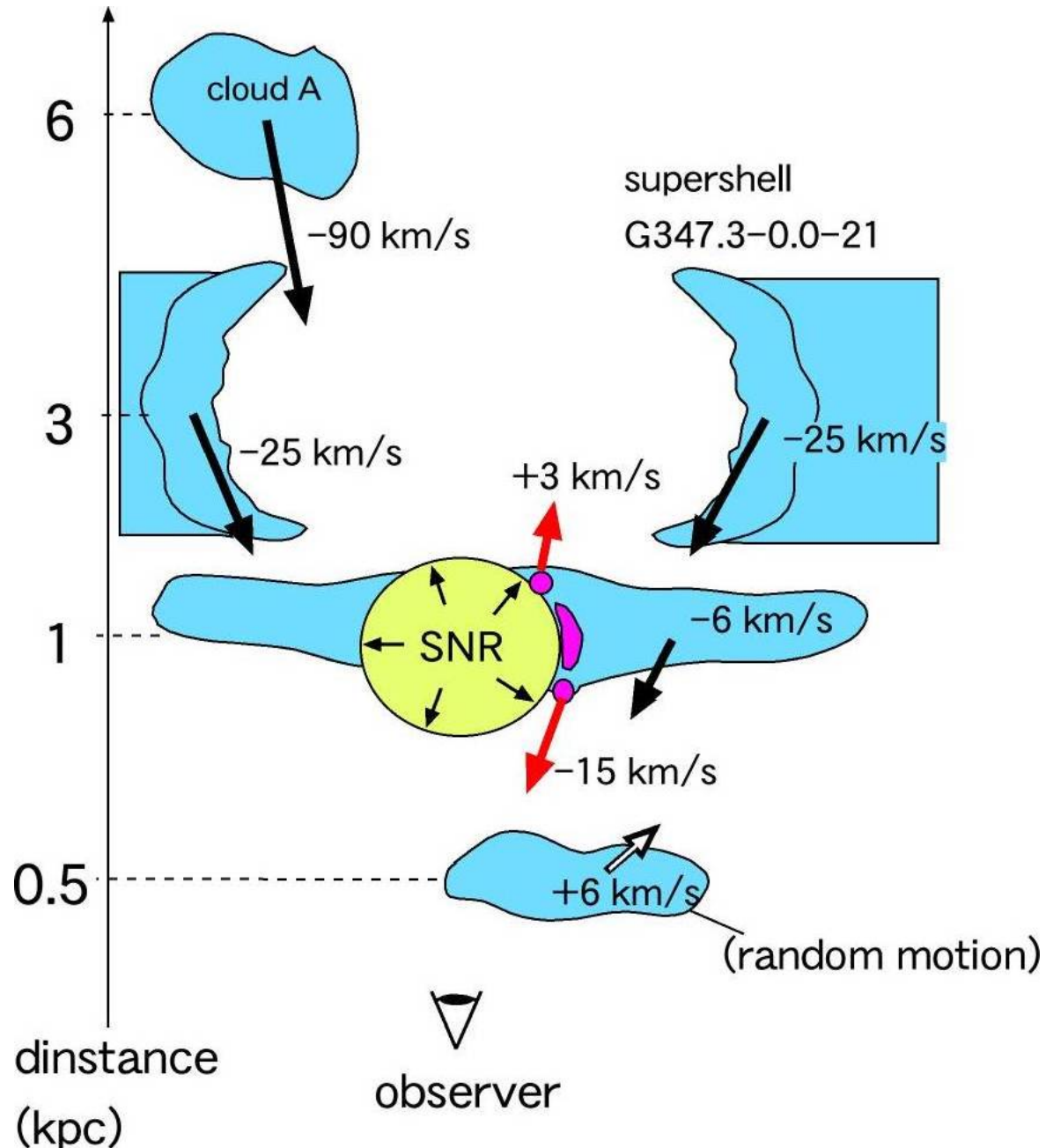
Face-On Map of our Galaxy



Kinematic Distance and V_{LSR} (toward $L = 347.3$ deg)

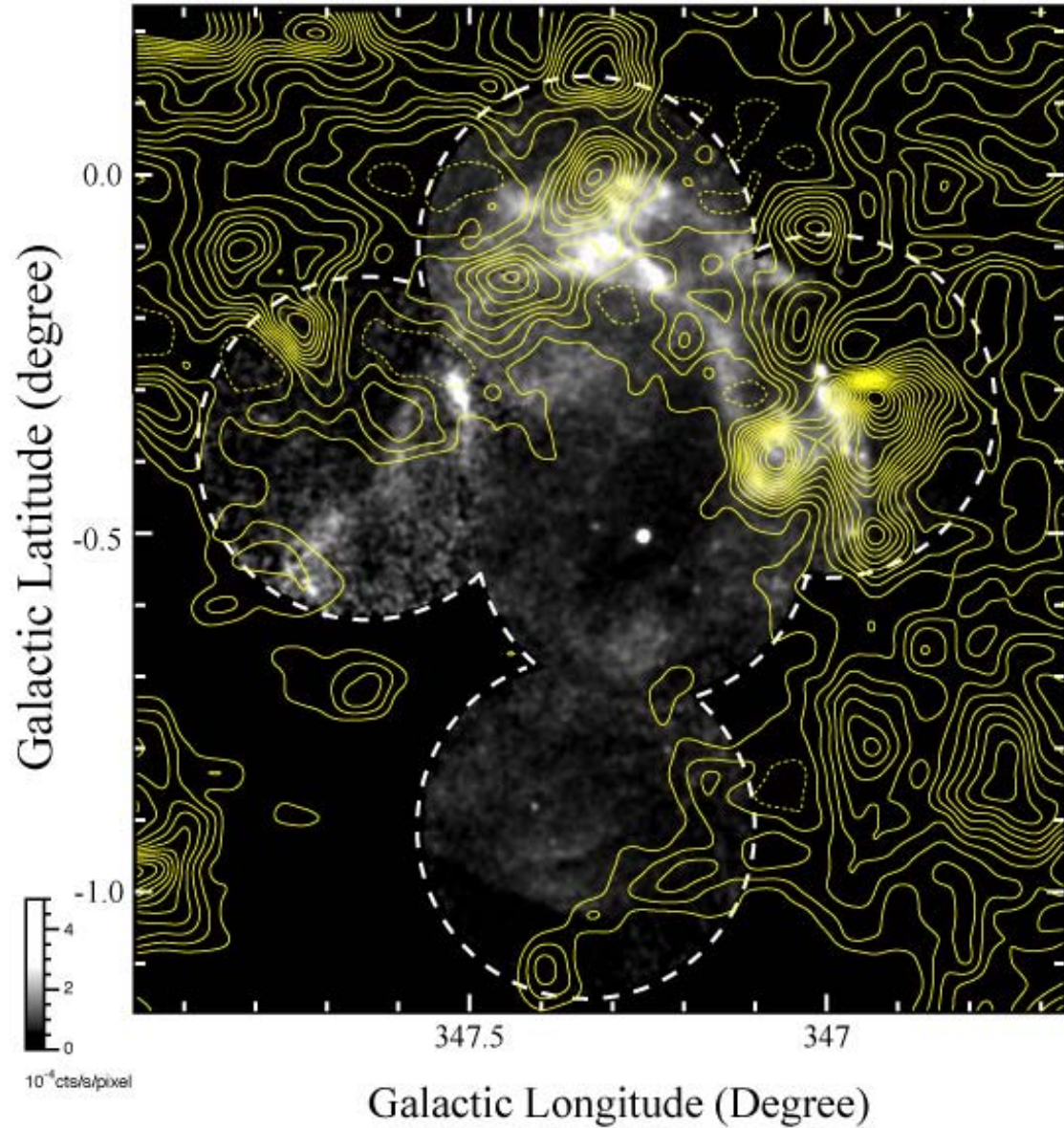


Schematic of positional relationship



Physical parameters of G347.3-0.5

Parameters	d = 1 kpc	d = 6 kpc
Radius (pc)	8.7	52
Age (yr)	1600	>10000
Evolutionary phase	Free-exp	Sedov
Ambient density (cm ⁻³)	< 0.01	0.003
Shock velocity (km/s)	5500	3200
E _{total} of accelerated particles (erg)	~ 10 ⁴⁸	~ 10 ⁵⁰



Supernova remnant (SNR) ,W28(G6.4-0.1)

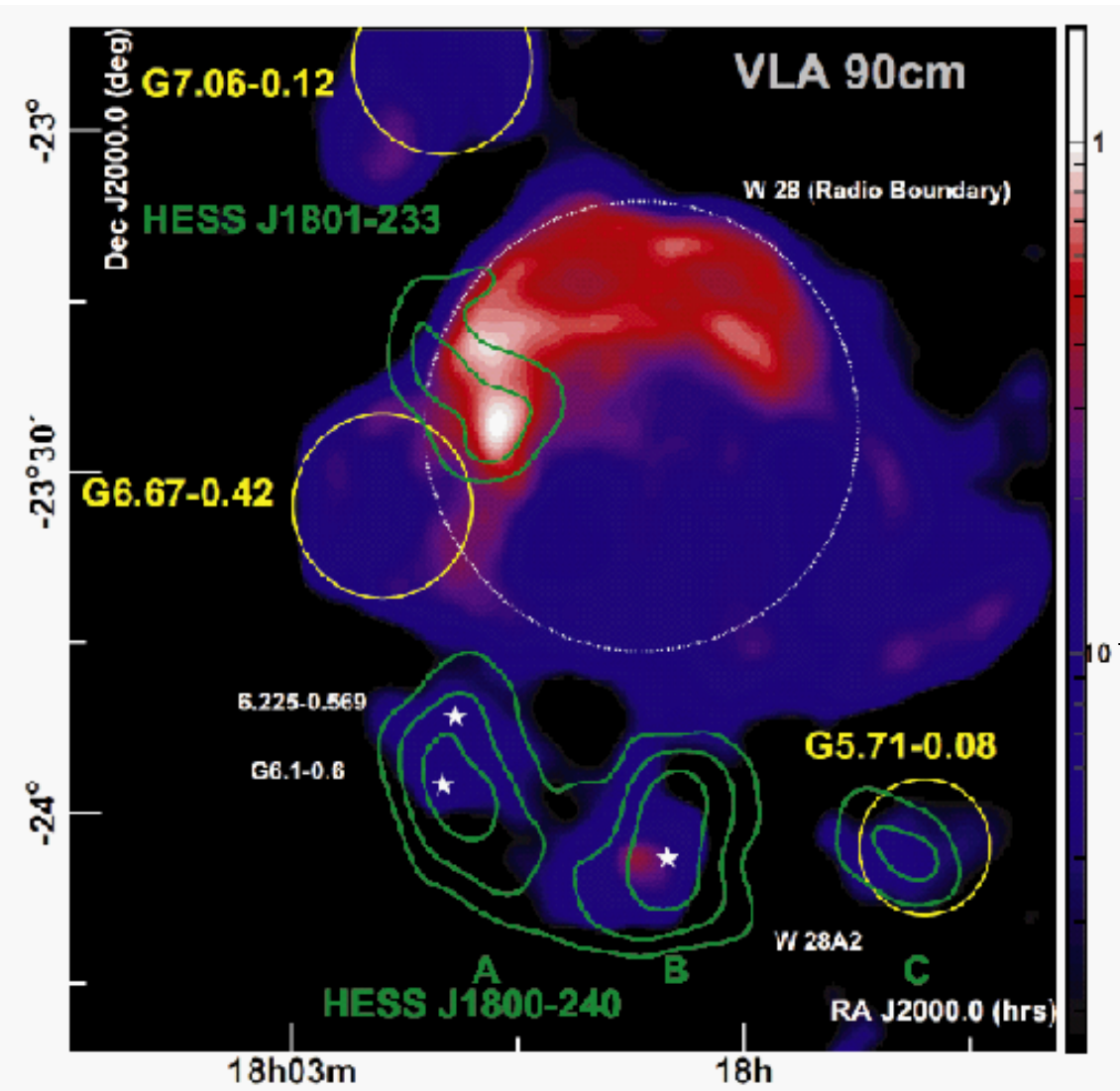
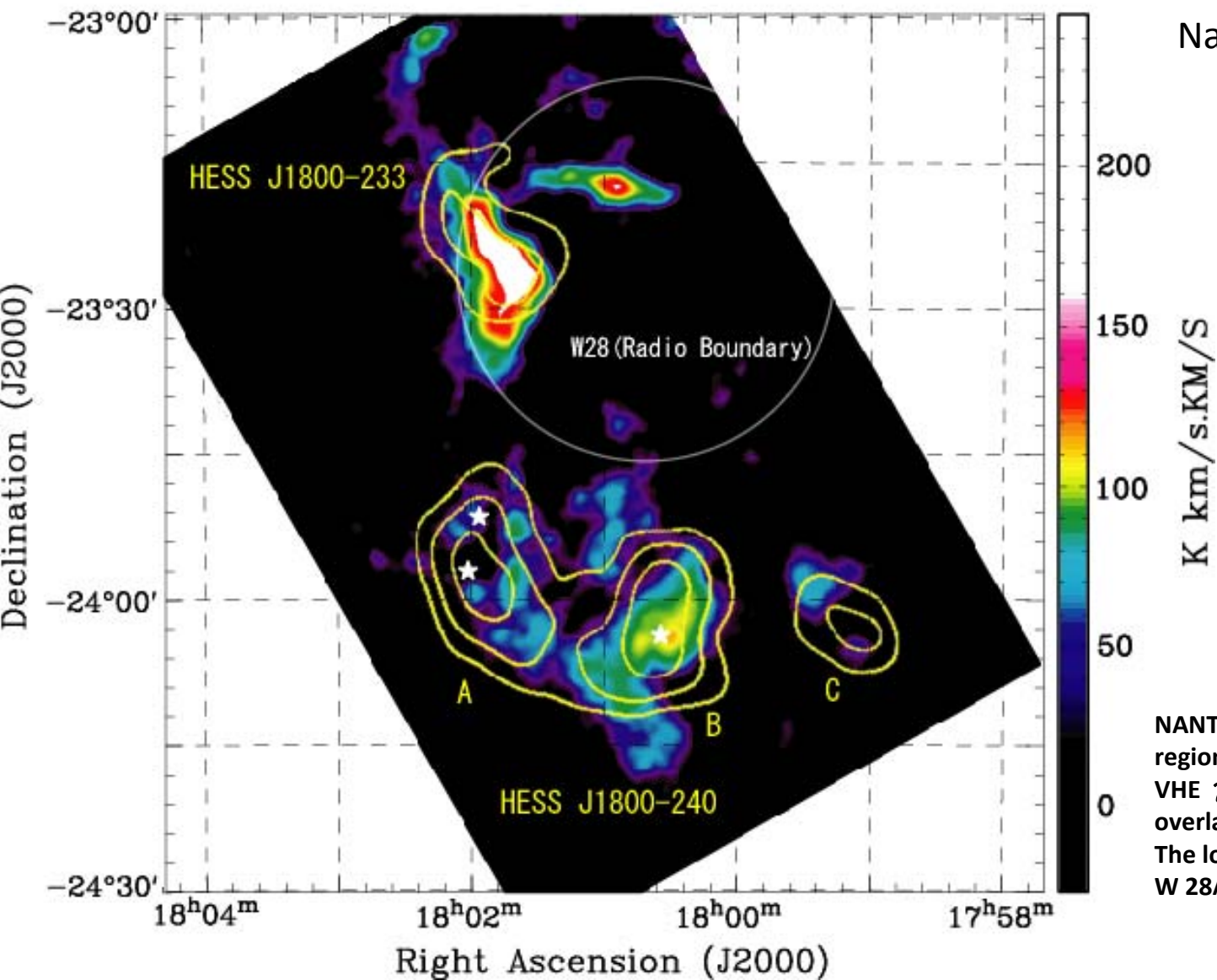


Fig: VLA 90cm radio image from Brogan et al.(2006). Overlaid are solid green contours of TeV gamma-ray significance levels of 4 ,5 and 6 σ . White stars indicate HII region.

Aharonian et al. (2008)

TeV γ vs. CO(J=2-1) in W28 by NANTEN2

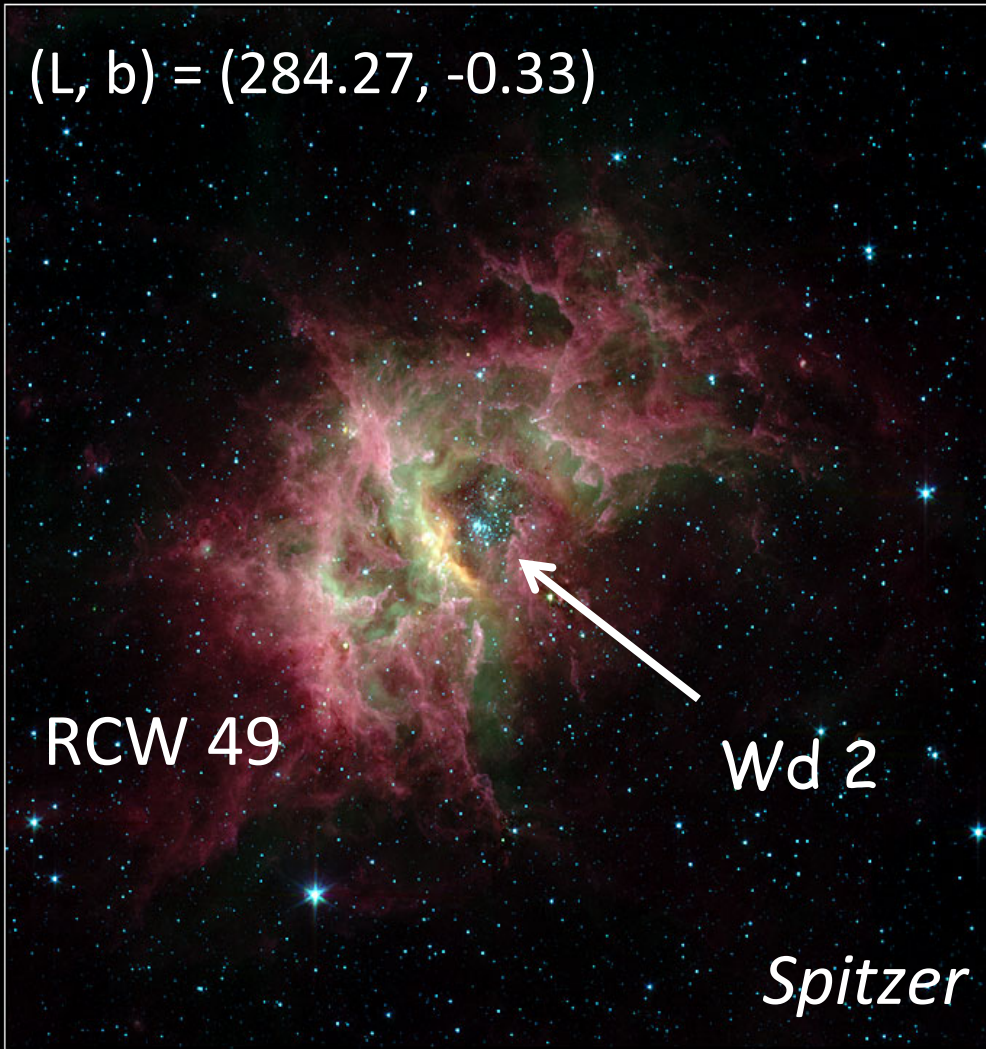


Nakashima et al.

NANTEN2 12CO(2-1) image of the W 28 region for VLSR=-10 to 25 km/s with VHE γ ray significance contours overlaid (yellow) levels 4,5,6 σ . The location of the HII region W 28A2 (white stars) are indicated. (Aharonian et al.)

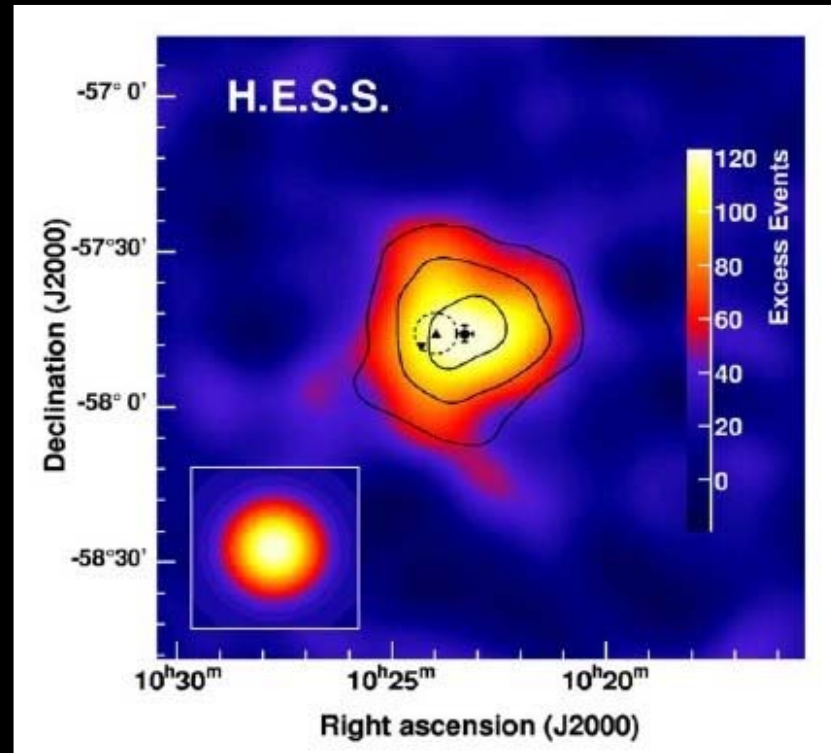
Westerlund 2

$(L, b) = (284.27, -0.33)$



TeV Gamma ray source

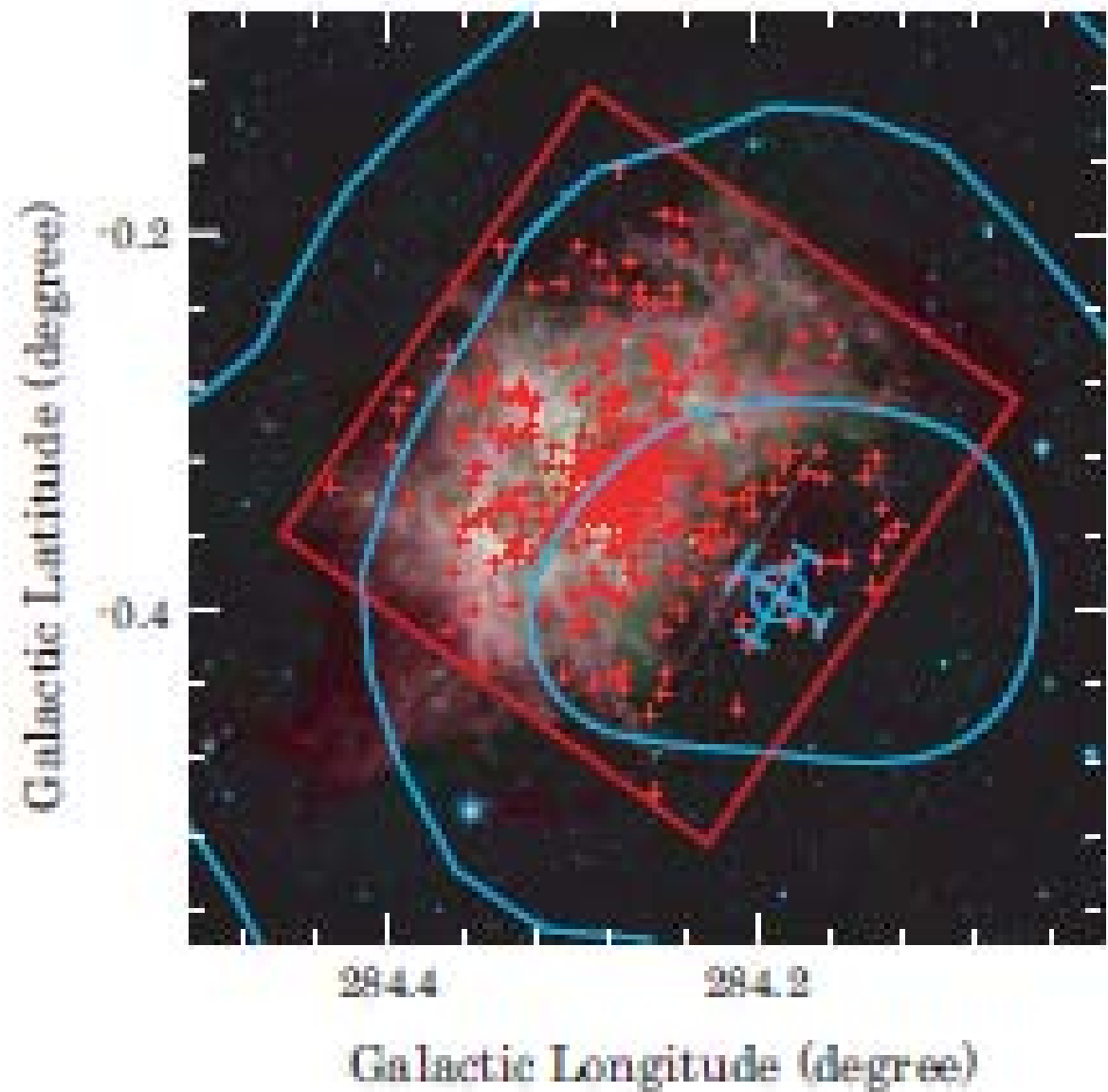
HESS J1023-575

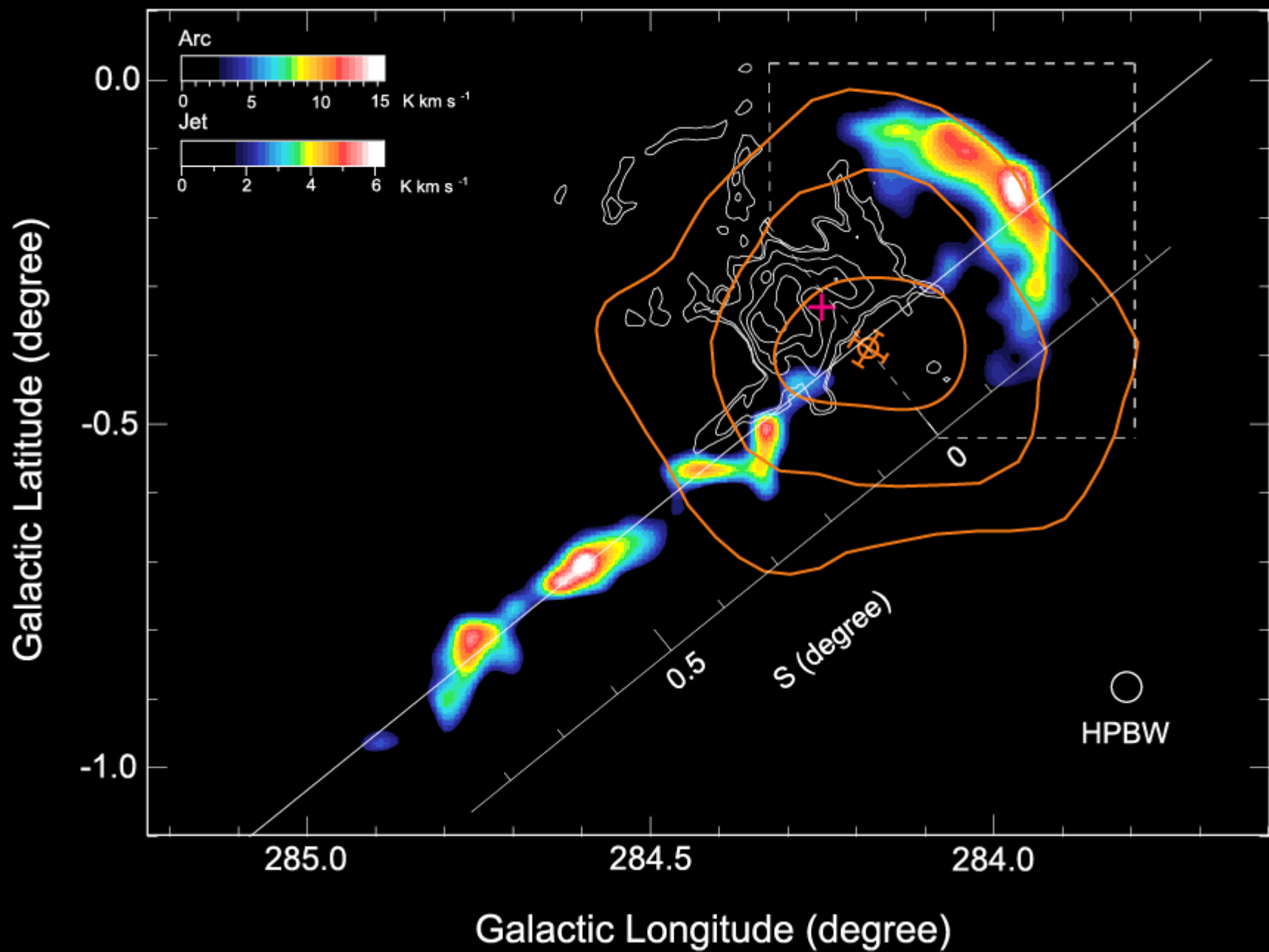


Star Formation in RCW49 Spitzer Space Telescope • IRAC

NASA / JPL-Caltech / E. Churchwell (Univ. of Wisconsin)

ssc2004-08a





Summary

- **NANTEN and NANTEN2**
 - ~ arcmin resolution
 - Shock region, Hot region with higher excitation lines.
- **SNRs: RXJ1713=G347.3-0.5 is a site of interaction between the SNR and the molecular clouds at 1 kpc.**
- **W28: active star forming clouds with TeV Gamma ray**
- **Westerlund2: massive young star cluster, molecular jet and arc, possibly collimated SN explosion.**
- **Comparisons of high resolution TeV- γ image with molecular data will provide an important clue for the distinction between proton and electron accelerations.**

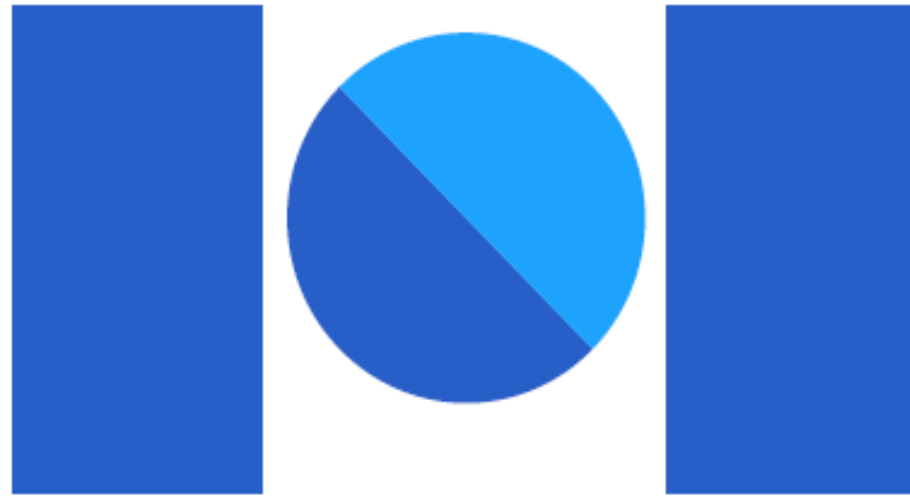
Future : NANTEN2

Entire southern galactic survey in 12CO(2-1)

~ 1.5 arcmin

Large scale survey in 12CO(4-3, 7-6)

24 ~ 38 arcsec



NANTEN
Submillimeter Observatory

Highly collimated SNe to create Jet and Arc

Search for X ray counterparts

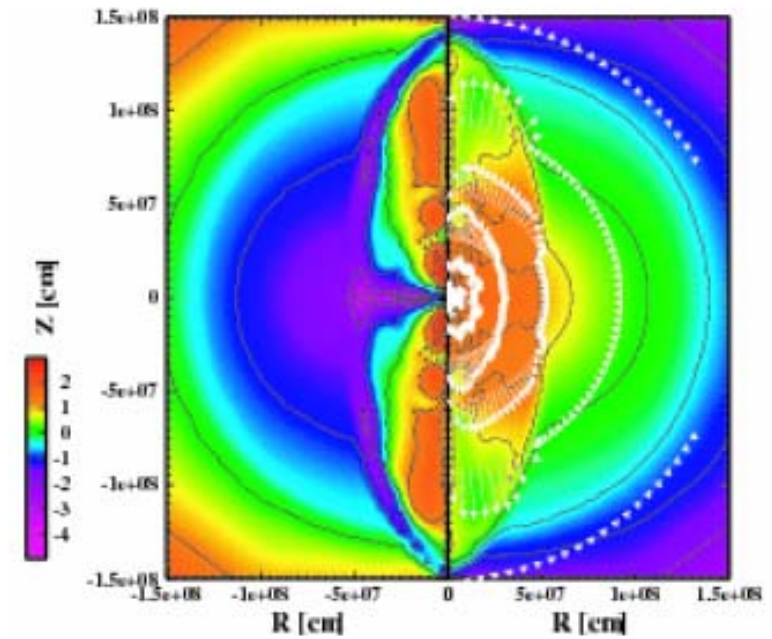
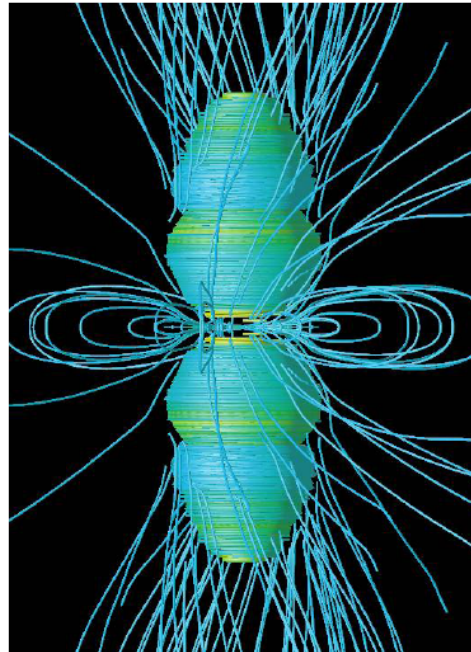
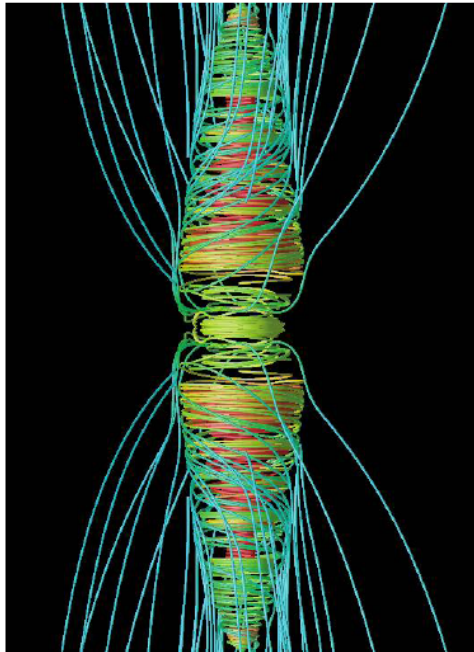


FIG. 4.—*Left*: Magnetic field lines for model M15B11UP2A1H at 264.5 ms after bounce. The size of the displayed region is $3000 \times 4000 \text{ km}^2$. “Footpoints” for the field lines are randomly distributed in the inner 500–1000 km, with a denser distribution along the polar axis to probe the region of larger magnetic energy where the explosion takes place in our simulations. Hence, the crowding of field lines does not correspond directly and accurately to regions of larger magnetic fields. *Right*: Same as the left panel, but for model M15B10DP2A1H at 855.5 ms after bounce and on a scale of $6000 \text{ km} \times 8000 \text{ km}$. Notice how much more tightly the B field is wound.

Burrows et al. 2007

Sawai et al. 2008