TeV Gamma-Ray Astronomy and mm Surveys

Probing Galactic Cosmic-Rays and their accelerators

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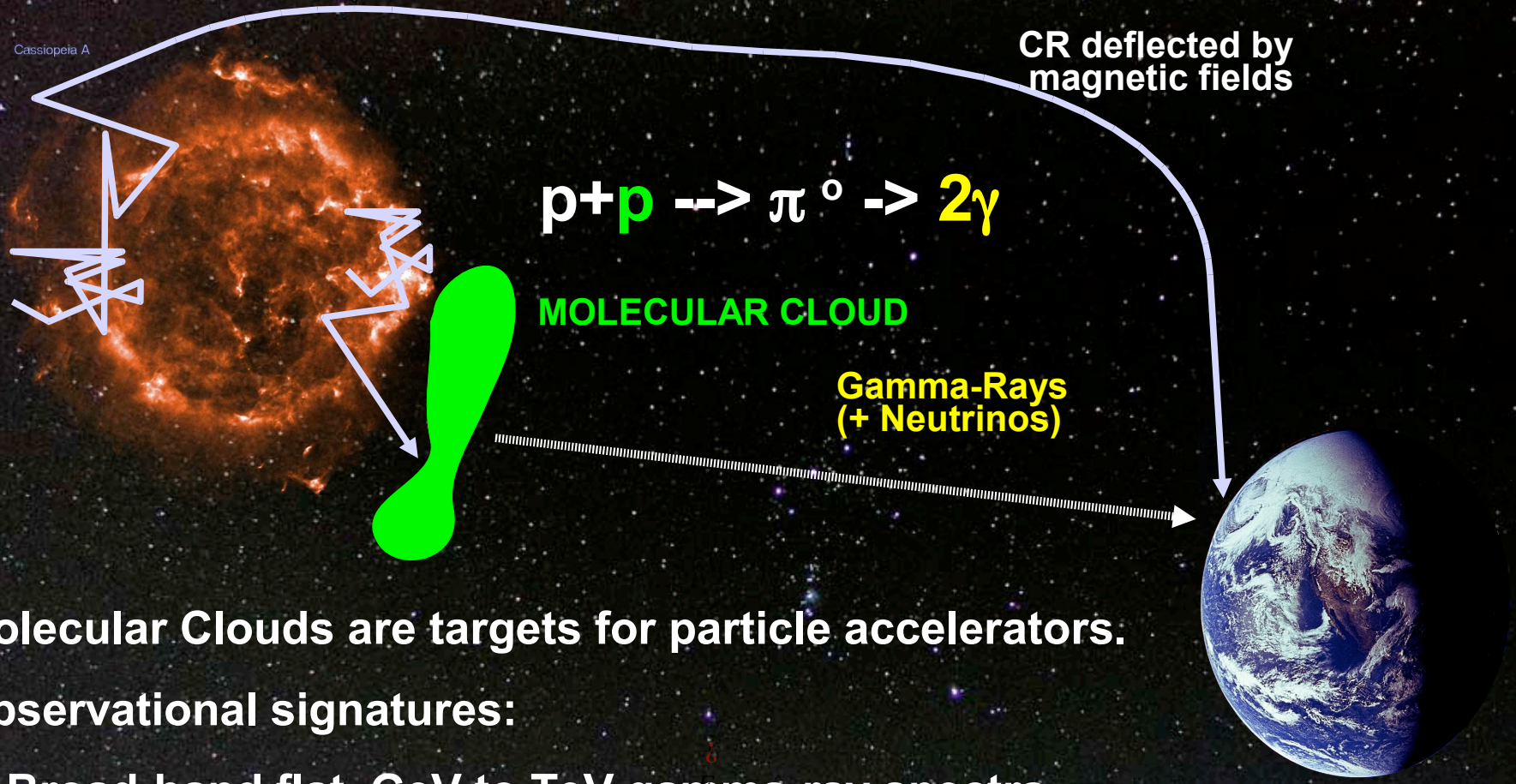
(+ colleagues Michael Burton, Yasuo Fukui & NANTEN team)

- TeV Gamma-Ray Astronomy & mm connections
- Some Key examples
- Future mm-survey requirements

MOPRA Survey Meeting, ATNF Sydney, 3 Nov 2008

Gamma Rays from multi-TeV hadrons
(p, He nuclei etc.. known as cosmic rays CRs)



Molecular Clouds are targets for particle accelerators.

Observational signatures:

- Broad-band flat GeV to TeV gamma-ray spectra

- TeV + Mol Cloud spatial correlation
  --> *TeV gamma and arc-min mm-wave observations*

CR accelerator + Molecular Cloud (passive target)

further discussion see also Drury etal 1984, Naito et al 1984, Aharonian etal 1986

TeV Gamma integral Flux from p+p --> π° --> $\gamma\,\gamma$

$$F(\geq E) \sim 3\times10^{-13}\left(\frac{E}{\mathrm{TeV}}\right)^{-1.6} k(E)\,\frac{M_5}{d^2_{\mathrm{kpc}}}\ \mathrm{ph\,cm^{-2}\,s^{-1}}$$

Aharonian (1991) Ap & SS. 180, 305

d_{kpc} – distance (kpc)

k(E) – CR density scaling factor:
For 'Earth-like' CRs k(E) = 1

M_5 – Mol. cloud mass (units: 10^5 M_{sun})
from line tracers CO, CS etc.....

If F & M_5 known --> can determine CR spectrum
at or near source

Objectives (a growing list) of TeV Gamma-ray Astronomy

Oldest question in modern astrophysics!

Origin of (Galactic) Cosmic Rays (CRs)

Shell-SNRs and other SNRs

TeV emission – rim morphology & nearby molecular clouds

In recent years : Stellar Clusters, Early Stars, Stellar Clusters (via wind/wind/ISM interactions)

Protostars – v.young stellar winds/natal mol. clouds

Other topics

Pulsar wind nebulae - Particle acceleration/interaction & Photon production/transport.....

Relativistic flows – Galactic & Extragalactic jets

Observational Gamma Ray Cosmology – TeV gamma absorption

Exotic – Dark matter....

H.E.S.S. Array: 4 x Cherenkov Imaging Telescopes (22° S 1800m a.s.l. Namibia)

120 m

H.E.S.S. >25 Institutions (Europe,Africa,Australia)

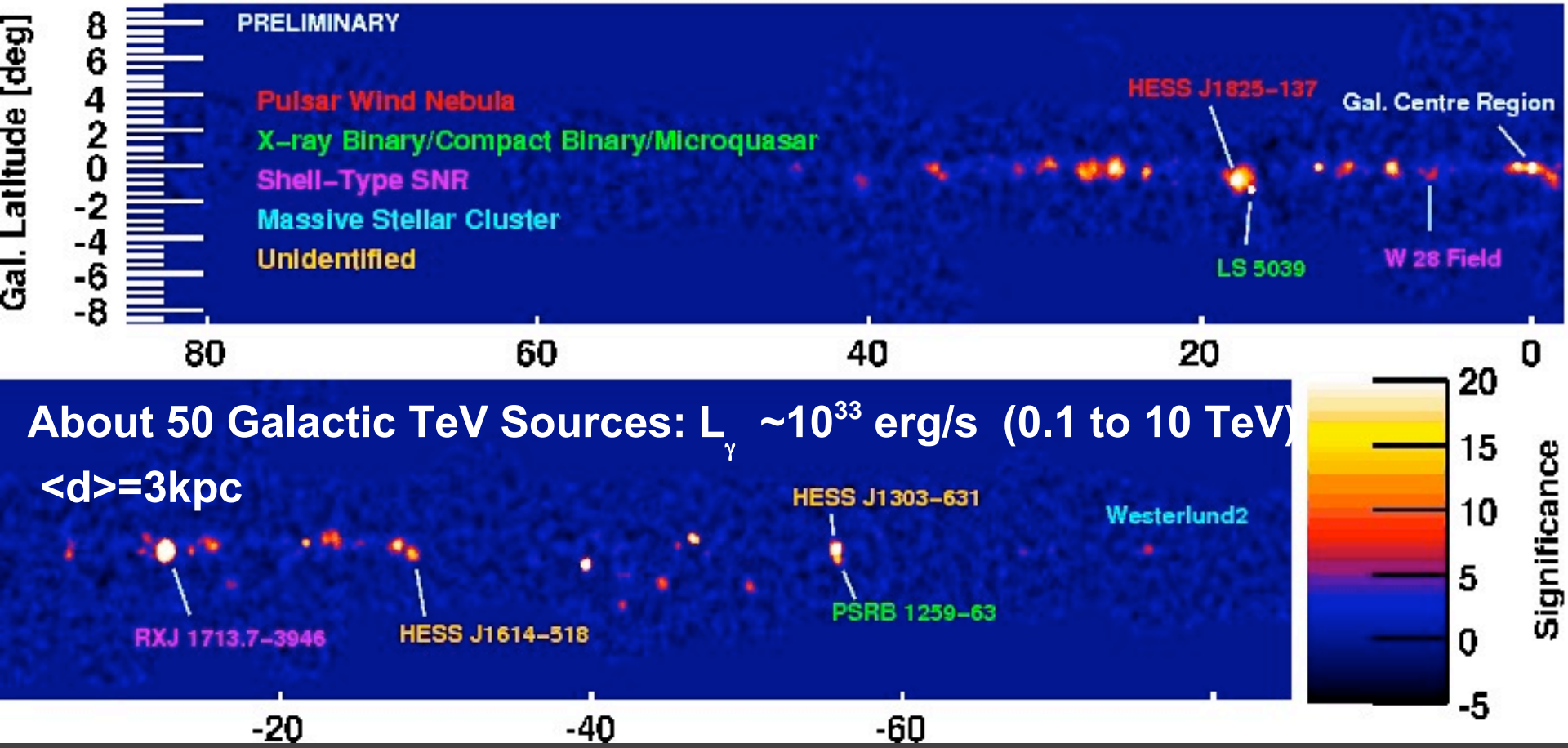
http://www.mpi-hd.mpg.de/hfm/HESS/HESS.htm

http://www.mpi-hd.mpg.de/hfm/HESS/public/som/current.htm

"Source of the Month"

- 4 x 12m diam dishes
- Focal-plane cameras 5° FoV
- Angular resolution ~3 to 6 arcmin

HESS Galactic Plane Survey: Mid 2008 (Chaves etal 2008)

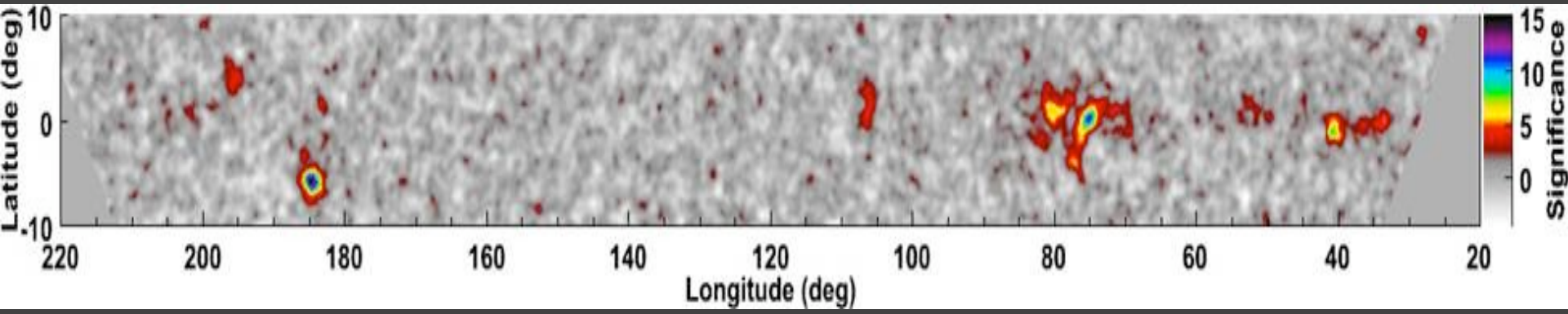


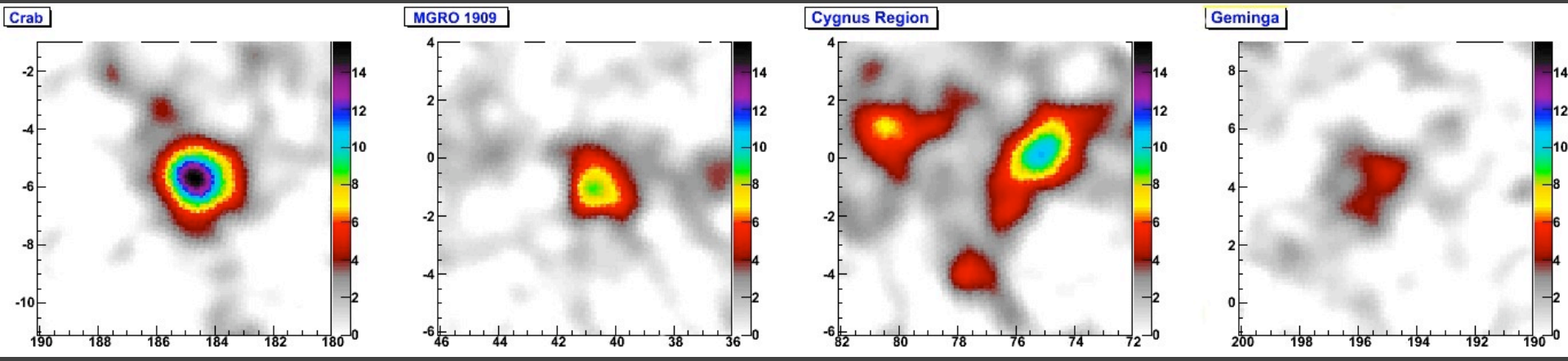
SNRs	~ 15%
Pulsar Wind Nebulae	~ 35%
Unidentified	~ 35%
Binary (XRBs etc.)	~10%
Diffuse	~ 5%

QUESTIONS

- Parent particles hadrons and/or leptons?
- Particle acceleration – how and where?
- Particle & photon transport/diffusion?
- Mystery of unidentified sources!

MILAGRO TeV survey - North. Gal. Plane (Abdo etal 2007)





MILAGRO was a water Cherenkov detector with ~2π sr FoV;
0.5° angular resolution

Watch out for its replacement HAWC (Mexico site +12° N)
It will see the Galactic Centre ! `http://umdgrb.umd.edu/hawc/`

Examples of TeV Gamma-Ray and Molecular Cloud Overlap

Not so common! Only 5 examples from ~35 Galactic TeV srcs

- Galactic Ridge (CMZ)
- W28 & field (SNR & unidentified)
- CTB 37A (SNR?)
- HESS J1745-303 (unidentified)
- IC 443 (SNR)

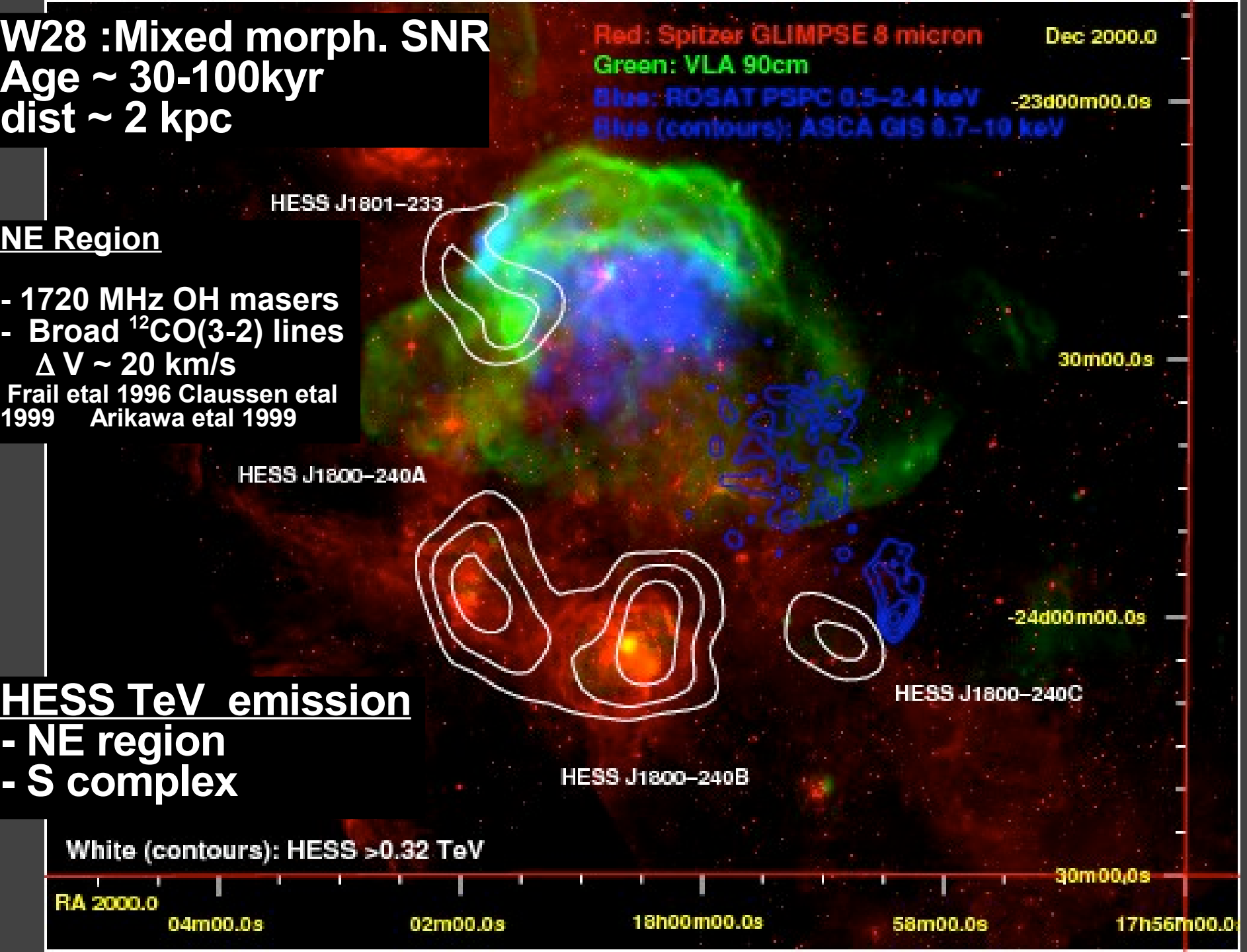
- 1720 MHz OH masers: SNR shock/M.cloud interaction.
  Zeeman splitting --> mag field B > 100 μG
- Old age >few x 10^3 yr ; Shock speed <100 km/s
  --> need cold to warm ISM tracers

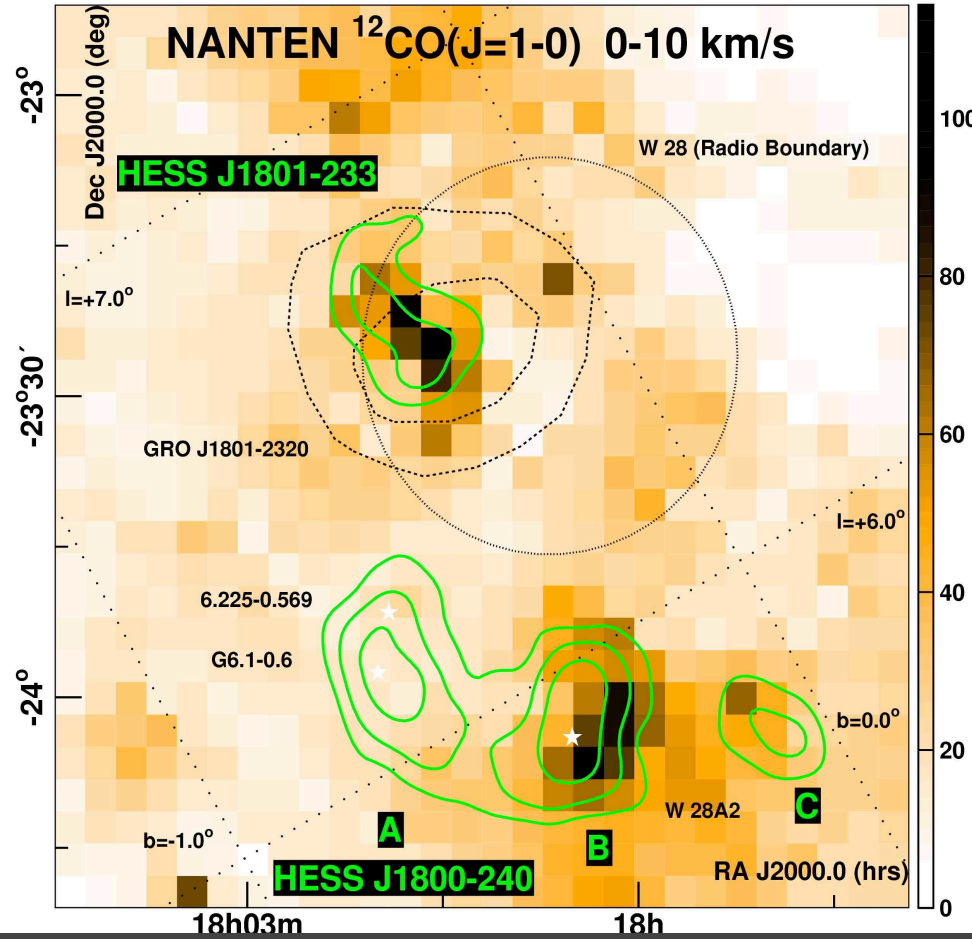
Bright TeV Shell SNRs

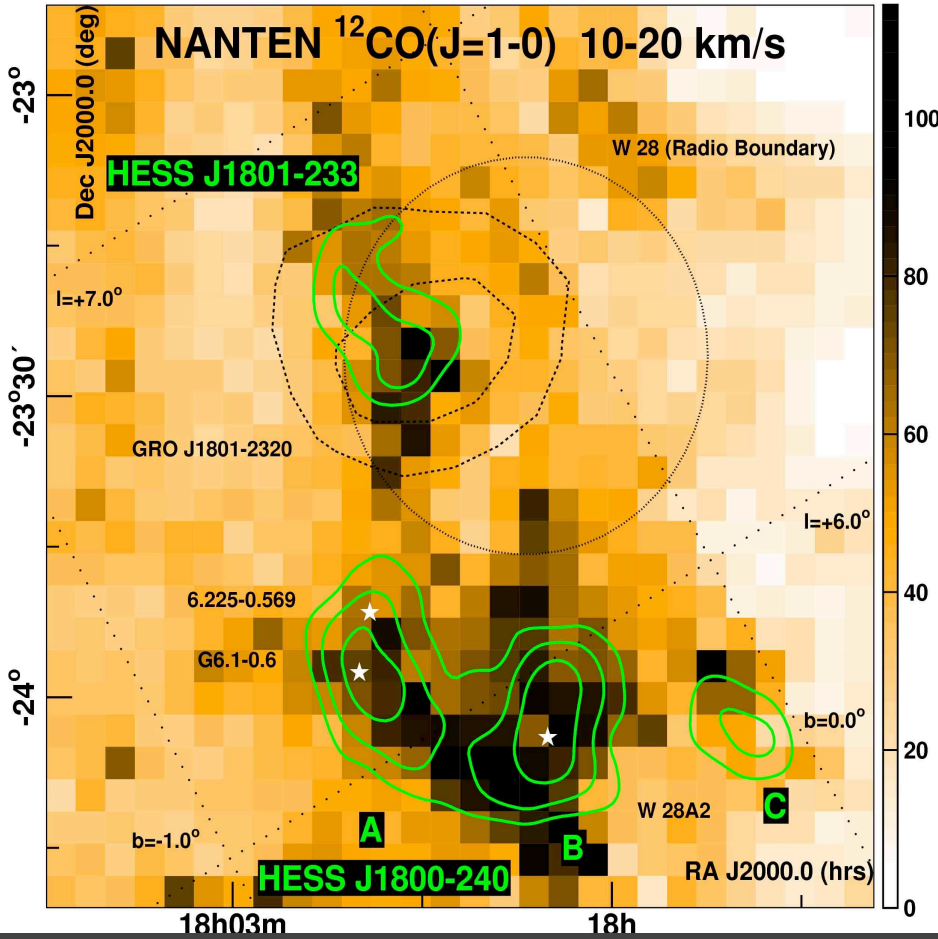
RXJ1713.7, Vela Junior, RCW 86 (age < 10^4 yr; synch. X-rays);
shock speeds > 1000 km/s
^{12}CO(1-0) not well correlated with TeV --> need warm/hot ISM tracers

Unidentified TeV Sources ~35% of Galactic TeV srcs!

--> new obs. X-rays, radio .... --> need ANY ISM tracers!


W28 :Mixed morph. SNR
Age ~ 30-100kyr
dist ~ 2 kpc
Red: Spitzer GLIMPSE 8 micron
Green: VLA 90cm
Blue: ROSAT PSPC 0.5–2.4 keV
Blue (contours): ASCA GIS 0.7–10 keV
Dec 2000.0
-23d00m00.0s
HESS J1801–233
NE Region
- 1720 MHz OH masers
- Broad ^{12}CO(3-2) lines
Δ V ~ 20 km/s
Frail etal 1996 Claussen etal 1999 Arikawa etal 1999
30m00.0s
HESS J1800–240A
-24d00m00.0s
HESS J1800–240C
HESS TeV emission
- NE region
- S complex
HESS J1800–240B
White (contours): HESS >0.32 TeV
30m00.0s
RA 2000.0
04m00.0s
02m00.0s
18h00m00.0s
58m00.0s
17h56m00.0s





d ~ 0 to 2.5 kpc

d~2.5 to 4 kpc

Excellent TeV & Molecular Cloud spatial association

--> indication for hadronic origin

TeV flux + Cloud masses --> k(E) ~7 to 30 x local value

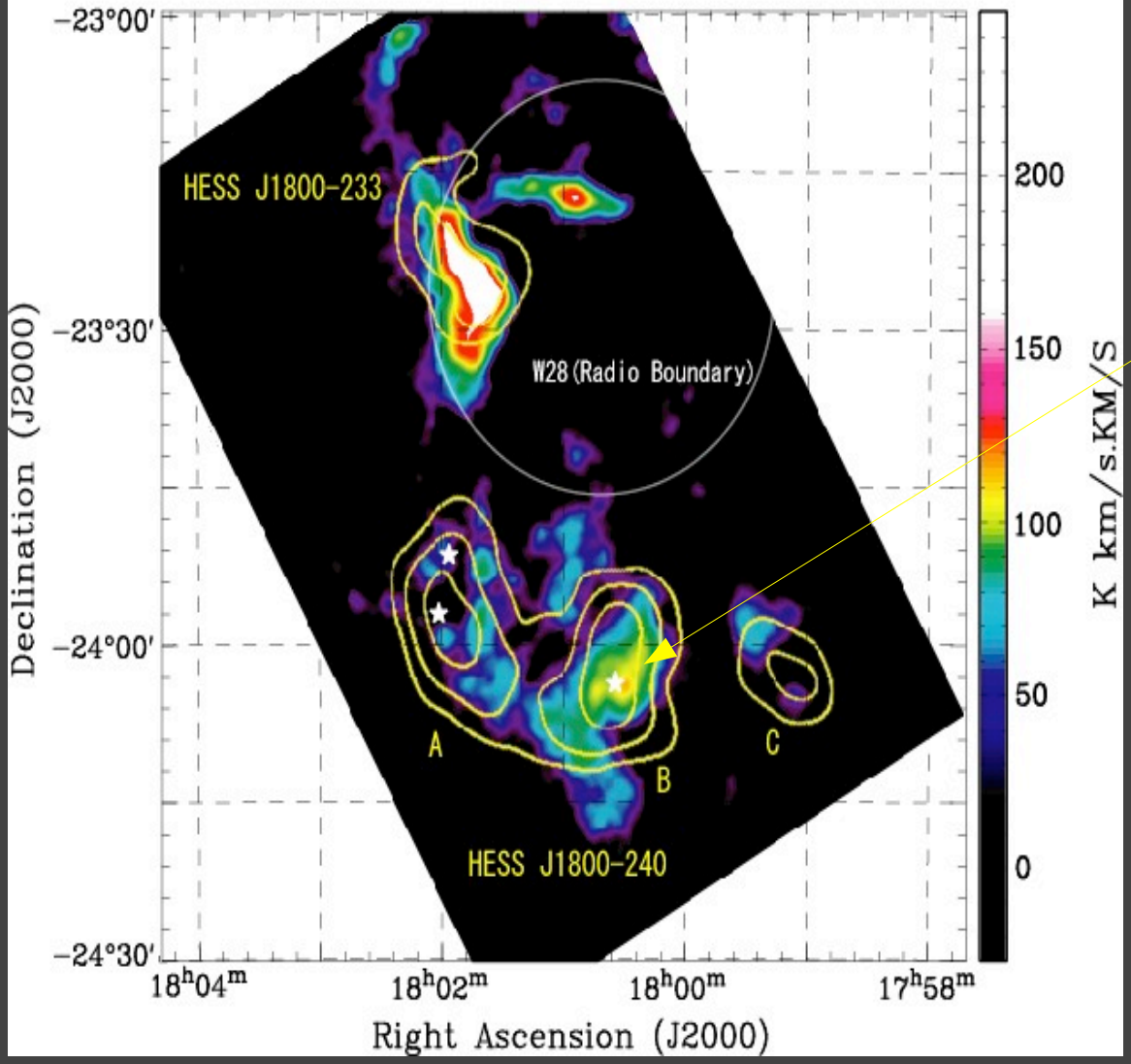
HESSJ1801-233 probably SNR shock/mol cloud interaction

HESSJ1800-240 more mysterious – CRs from W28 or HII regions??

are all clouds (5 to 20 km/s) connected?

NANTEN2 ^{12}CO(J=2-1) vs. HESS TeV (Nakashima etal 2008)

V_{LSR} range -10 to 25 km/s



Also:

^{12}CO(4-3) from all TeV peaks

^{12}CO(7-6) from central S peak – towards the UC-HII region W28-A2

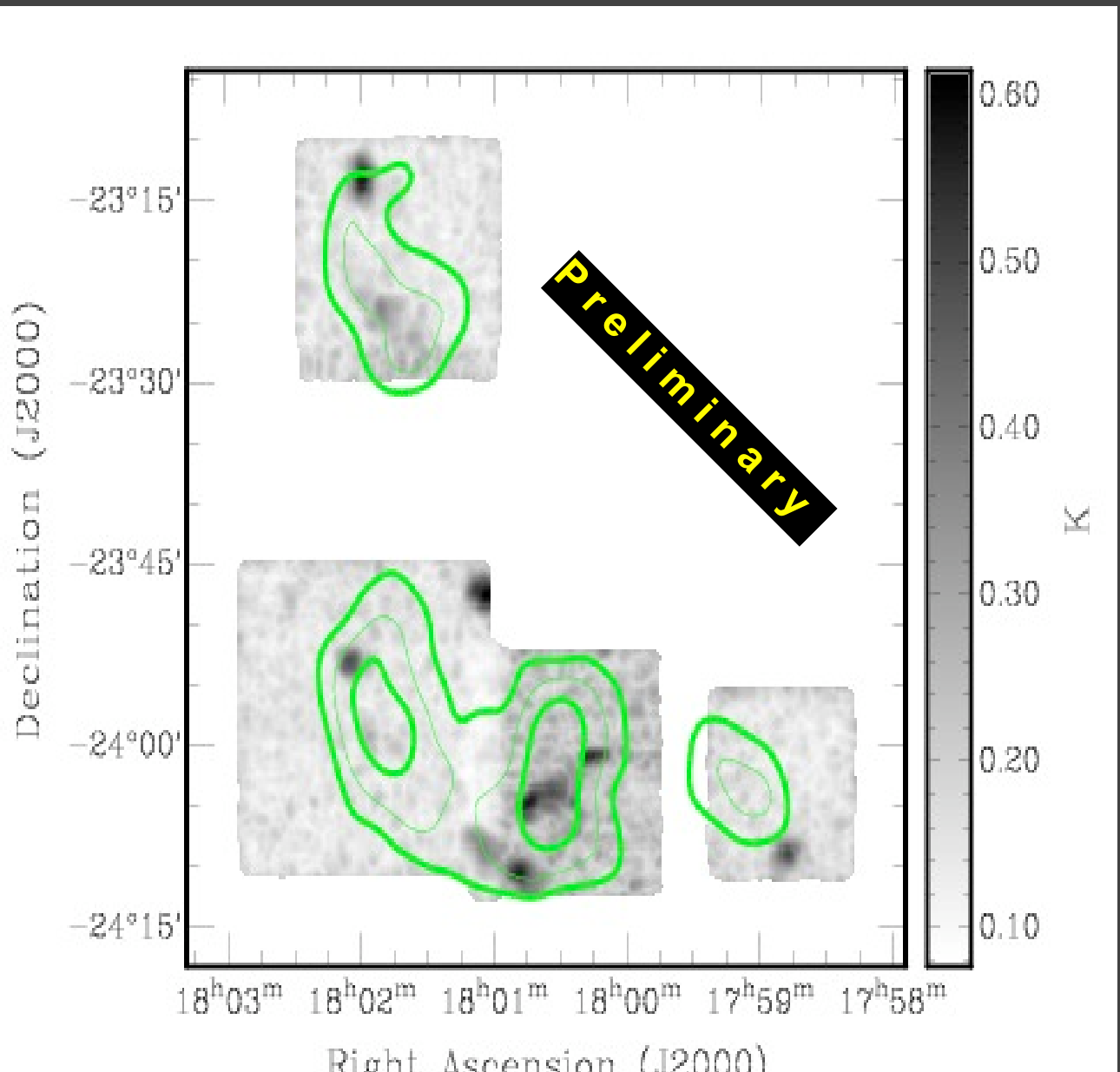
Ultra compact HII region W28-A2 (G5.89-0.39(

- Bipolar outflows in CO, SiO, HCO^+
- Radio & sub-mm shell
- few x 10^{46} erg in outflows (age < 10^4 yr)

see Hunter etal 2008 & therein for review

MOPRA NH_3 (~20 GHz) Observations (May/June 2008 vs. HESS TeV)

(Nicholas, Rowell (PI) , Burton, Fukui..)



OTF and deep obs at several cores.

Analysis ongoing.....

MIRIAD -2 moment map (peak pixel along z-axis)

Motivation

Use NH_3 to probe gas temperature and optical depth – complementary to NANTEN2 surveys

Several NH_3 cores assoc with TeV sources

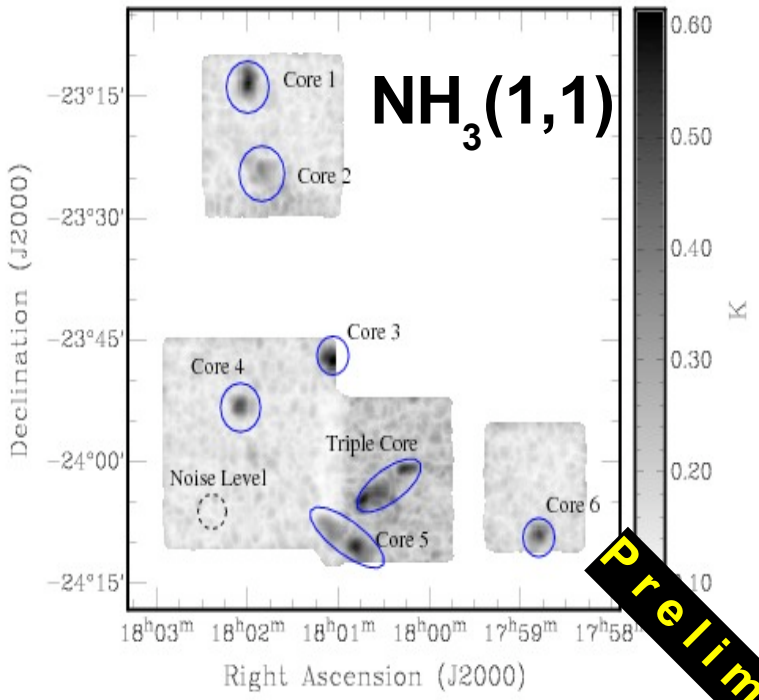
HOPS survey overlap

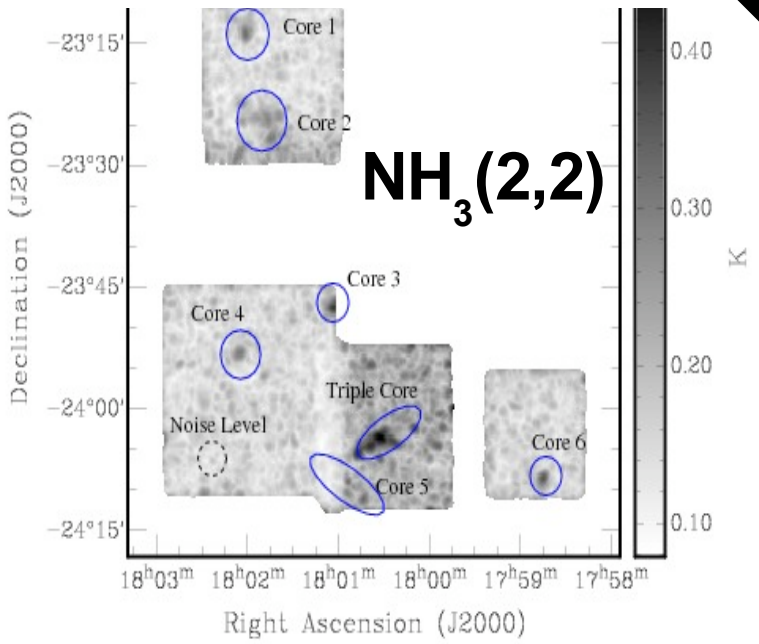
MOPRA NH_3 Detections: W28 SNR Field

MIRIAD -2 moment map (peak pixel along z-axis)

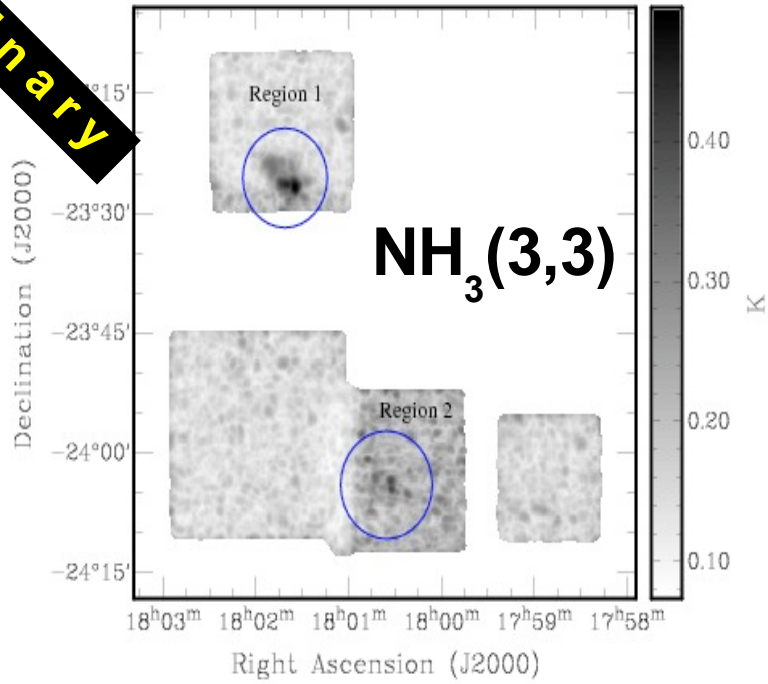
1,1 2,2 Cores seen towards all TeV peaks

3,3 Diffuse seen towards NE & S-middle



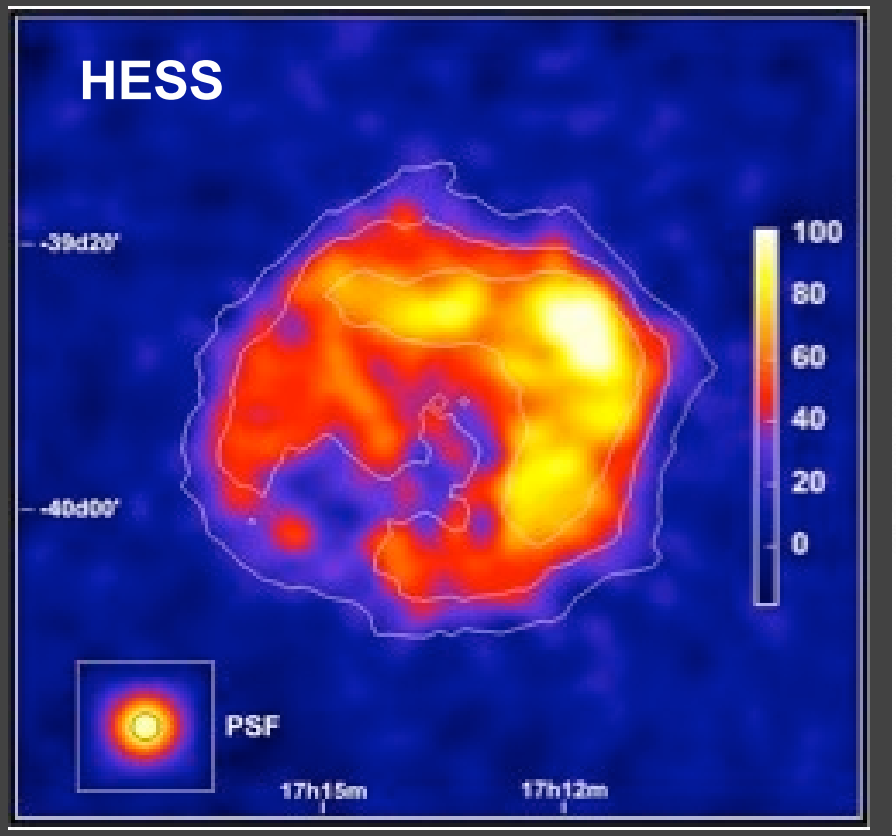


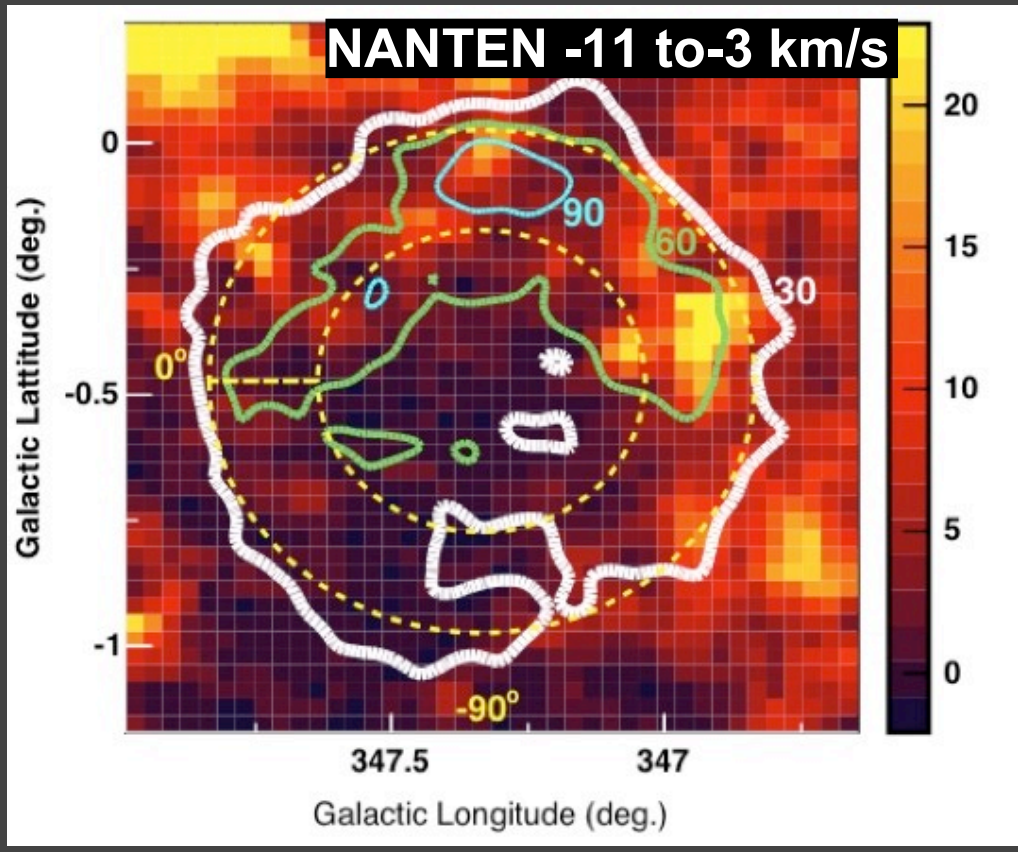
Preliminary



RX J1713.7-3946 HESS TeV & NANTEN ^{12}CO(J=1-0)

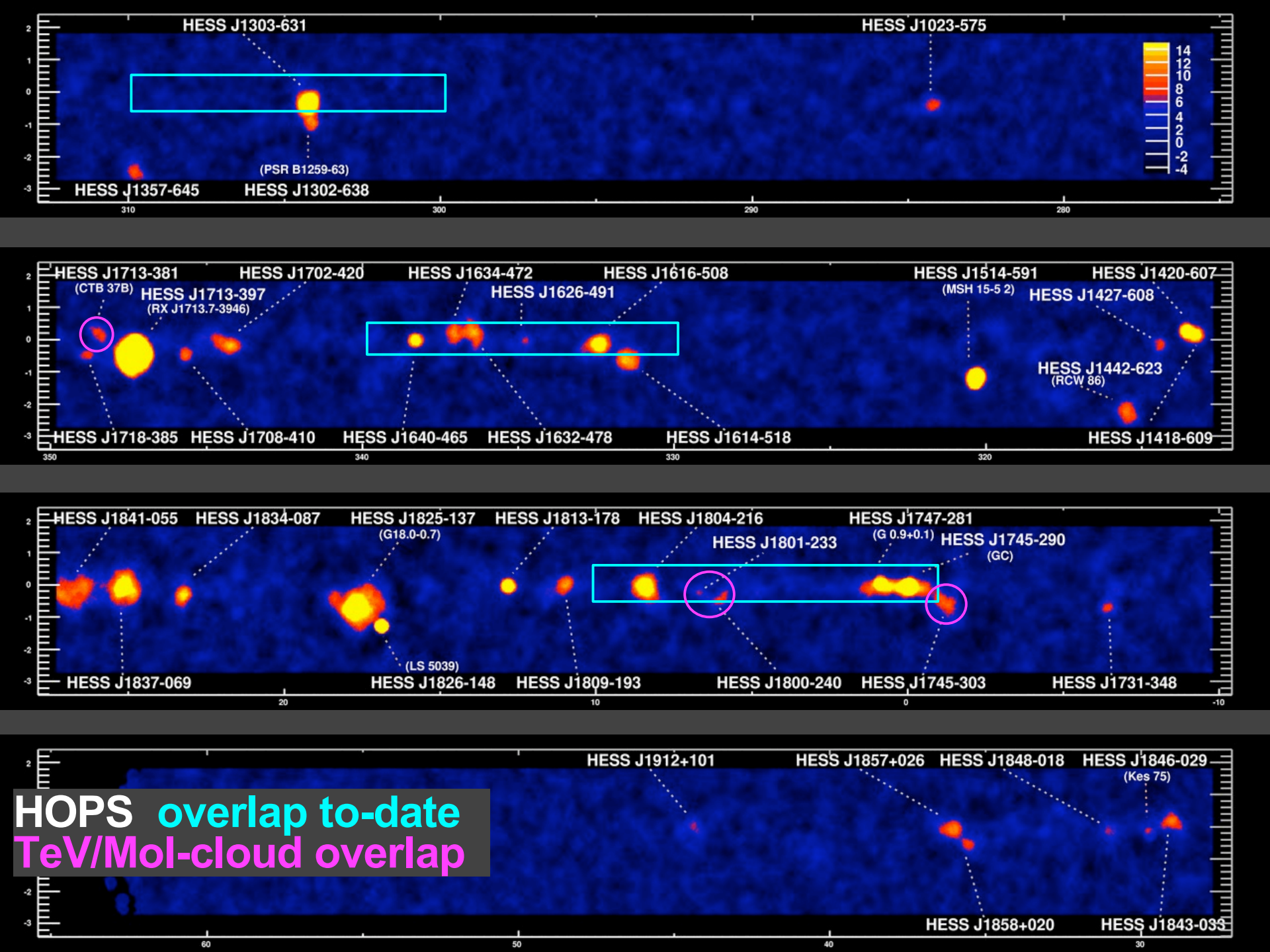
Aharonian etal 2007 , Moriguchi etal 2005





No clear spatial overlap/correlation between TeV and Mol. Clouds. using CO(1-0) but – cool gas tracer and optically thick

NANTEN2: Possibly small-scale ^{12}CO(4-3) -- TeV – X-ray overlap
Fukui etal 2008


HESS J1303-631
HESS J1023-575
(PSR B1259-63)
HESS J1357-645
HESS J1302-638
HESS J1713-381
(CTB 37B)
HESS J1713-397
(RX J1713.7-3946)
HESS J1702-420
HESS J1634-472
HESS J1626-491
HESS J1616-508
HESS J1514-591
(MSH 15-5 2)
HESS J1420-607
HESS J1427-608
HESS J1442-623
(RCW 86)
HESS J1718-385
HESS J1708-410
HESS J1640-465
HESS J1632-478
HESS J1614-518
HESS J1418-609
HESS J1841-055
HESS J1834-087
HESS J1825-137
(G18.0-0.7)
HESS J1813-178
HESS J1804-216
HESS J1801-233
HESS J1747-281
(G 0.9+0.1)
HESS J1745-290
(GC)
(LS 5039)
HESS J1837-069
HESS J1826-148
HESS J1809-193
HESS J1800-240
HESS J1745-303
HESS J1731-348
HESS J1912+101
HESS J1857+026
HESS J1848-018
HESS J1846-029
(Kes 75)
HESS J1858+020
HESS J1843-033
HOPS overlap to-date
TeV/MoI-cloud overlap

Required - To better understand extreme astrophysical srcs

- Tracers of shocked/heated/disrupted gas up to degree scales.
  SNRs, stellar cluster shocks,
  protostellar winds, jets, and even pulsar winds are possible.

- Previous surveys NANTEN ^{12}CO(J=1-0) just the first look.
  Now NANTEN2 ^{12}CO(J=2-1) & higher transitions surveys underway

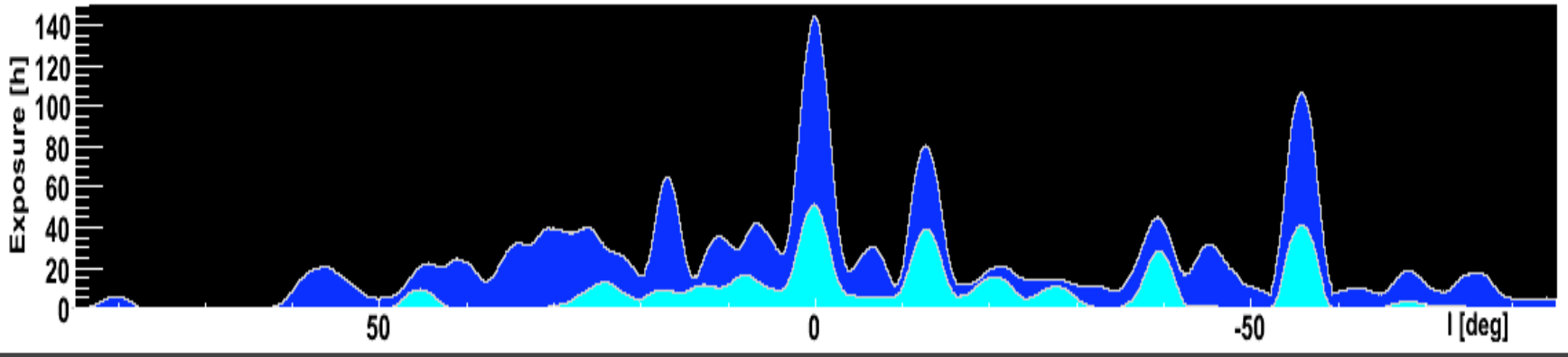
- Future TeV instruments (HAWC – large scale , CTA < 1 arcmin res.?)

New MOPRA Surveys/Ideas

- Extend HOPS/CHAMP surveys to cover key/bright TeV sources
  eg. CTB-37A, HESSJ17145, RXJ1713.7, Vela-Junior, RCW-86,
  (should be complementary to NANTEN2)

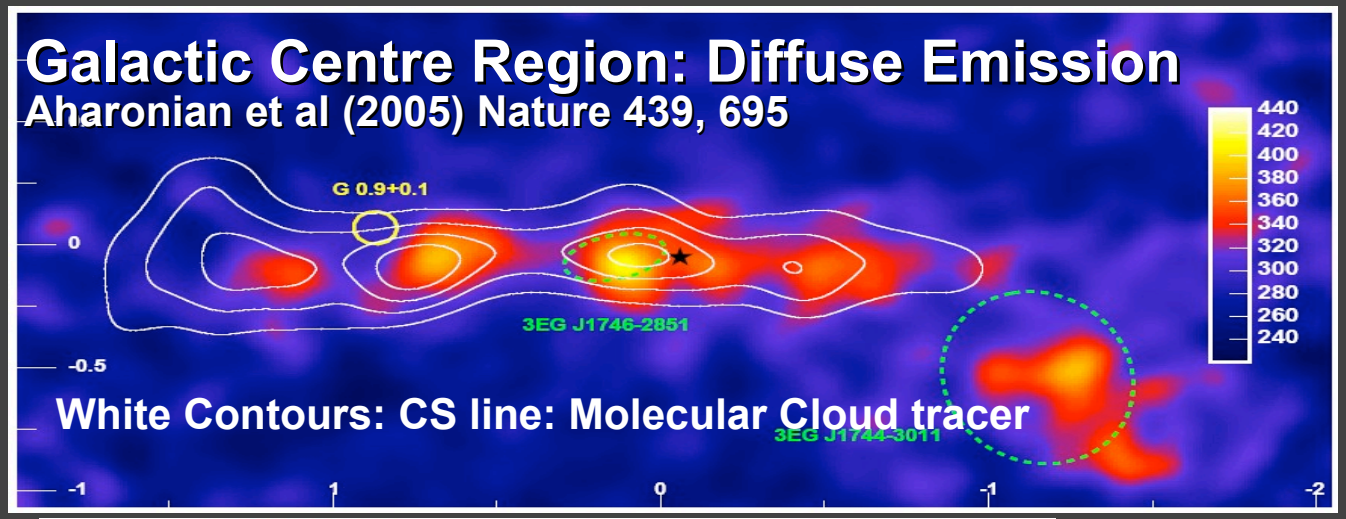
- Other tracers of shocked gas eg. SiO -- focus on bright TeV srcs
  initially; guided by HOPS/NANTEN2 results

- Other Ideas from ISM experts most welcome!

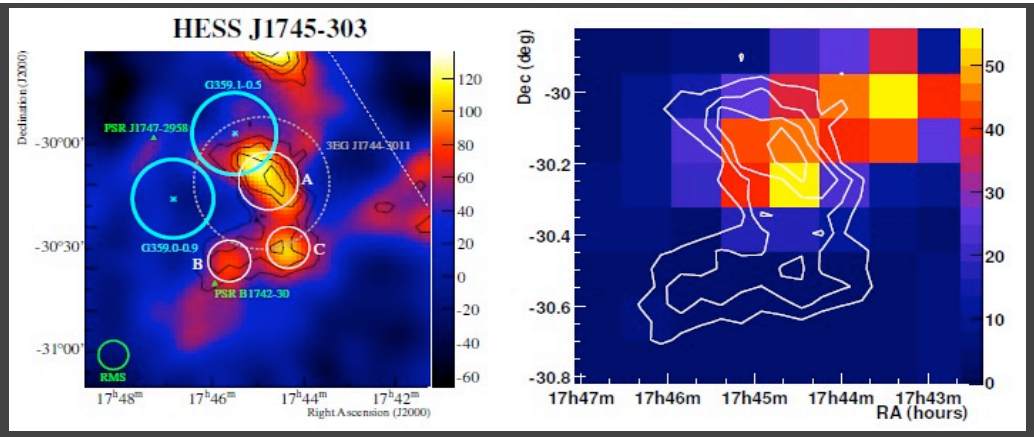

Exposure [h]
140
120
100
80
60
40
20
0
50
0
-50
l [deg]

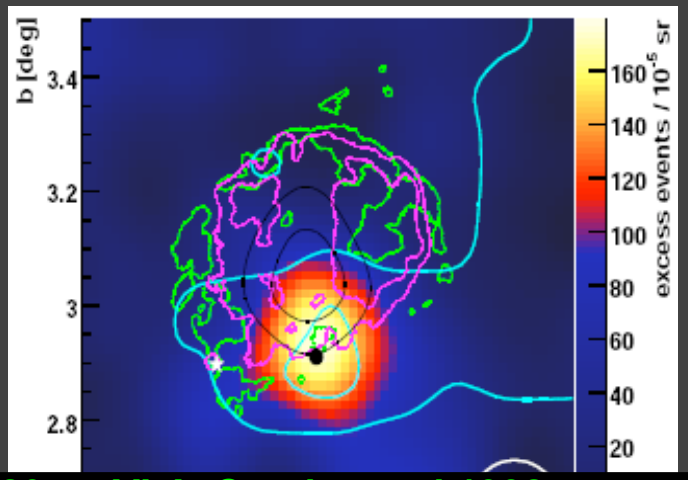
Galactic Centre Region: Diffuse Emission

Aharonian et al (2005) Nature 439, 695

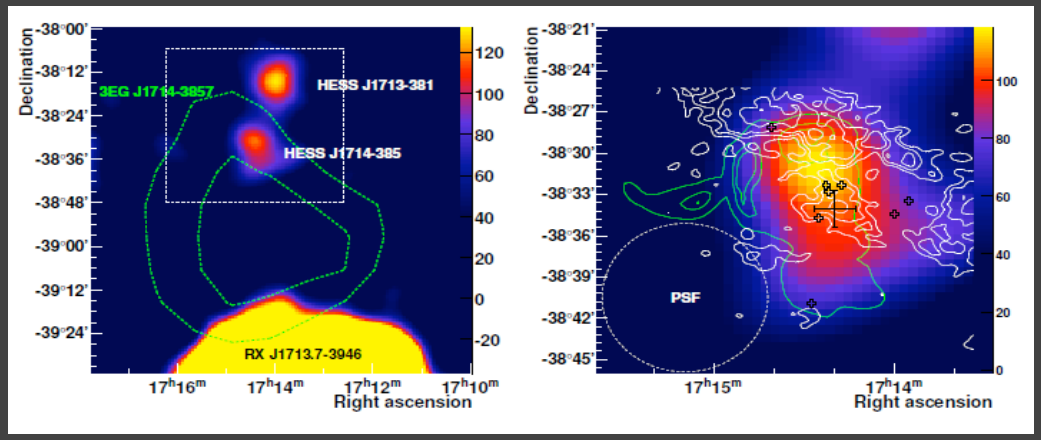


1st Smoking gun for hadronic origin of accel. particles.
- CR density 3-9x Earth-like values

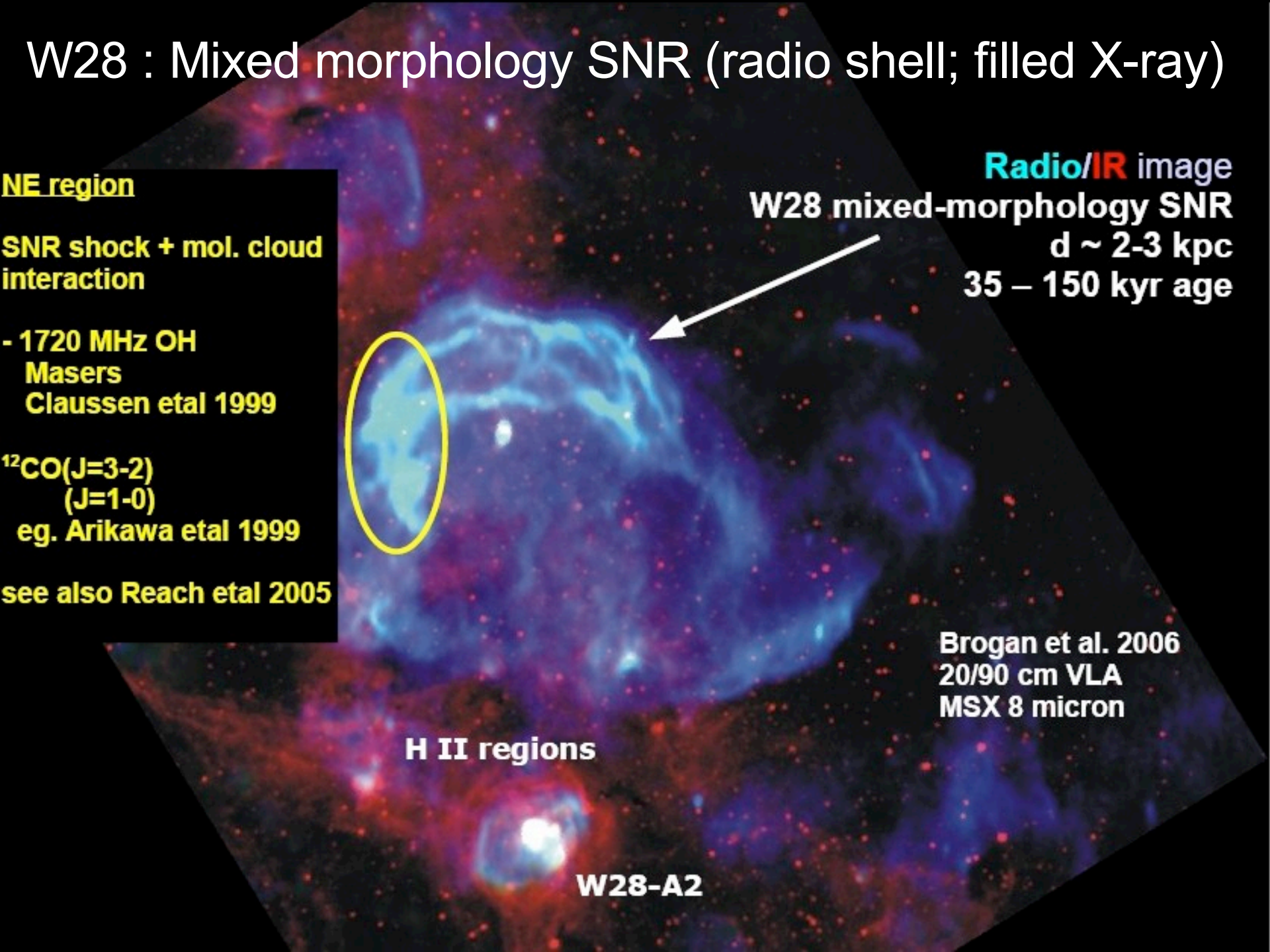




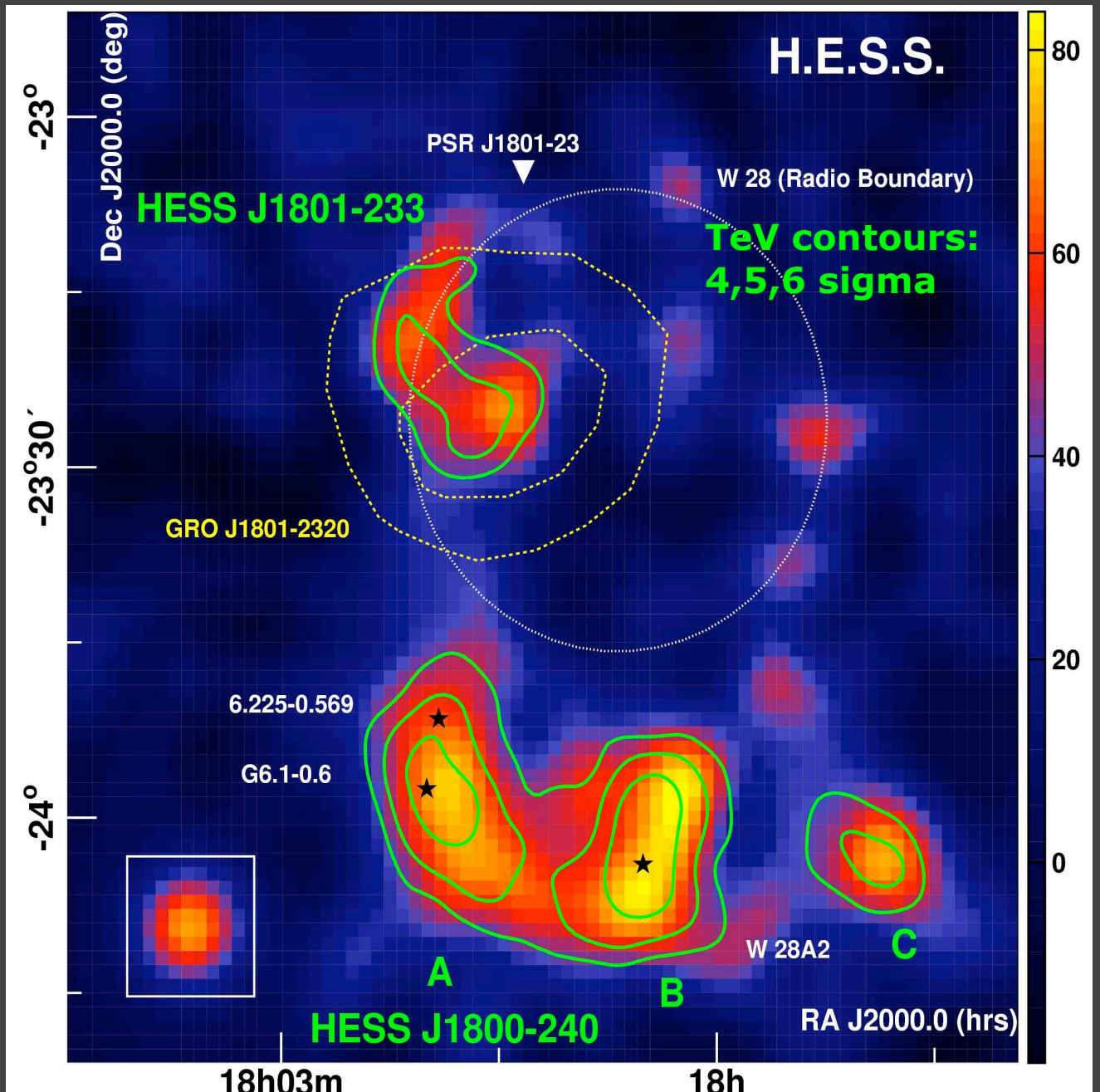
20cm VLA Condon etal 1998
EGRET MeV/GeV source
ROSAT X-ray Asaoka etal 1994
^{12}CO Dame etal 2001 (-20 to 20 km/s



W28 : Mixed morphology SNR (radio shell; filled X-ray)



TeV emission from W28 and surrounding field

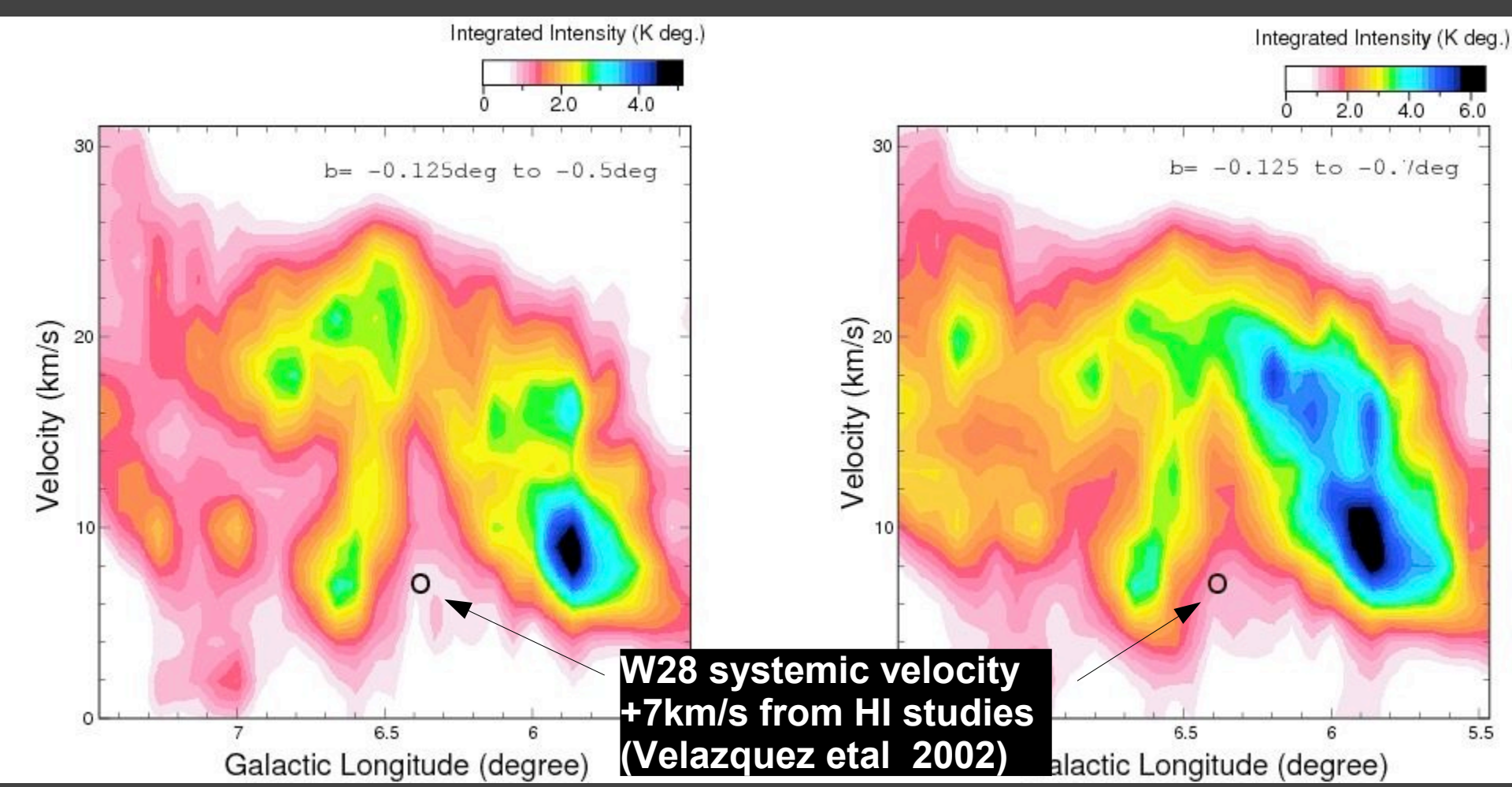


Aharonian et al 2008

TeV sources

HESSJ1801-233
NE SNR region
shocked gas
OH masers

HESSJ1800-240
Complex of 3 TeV peaks
UC HII & HII regions



Galactic l-v picture covering W28 Gal-b range:

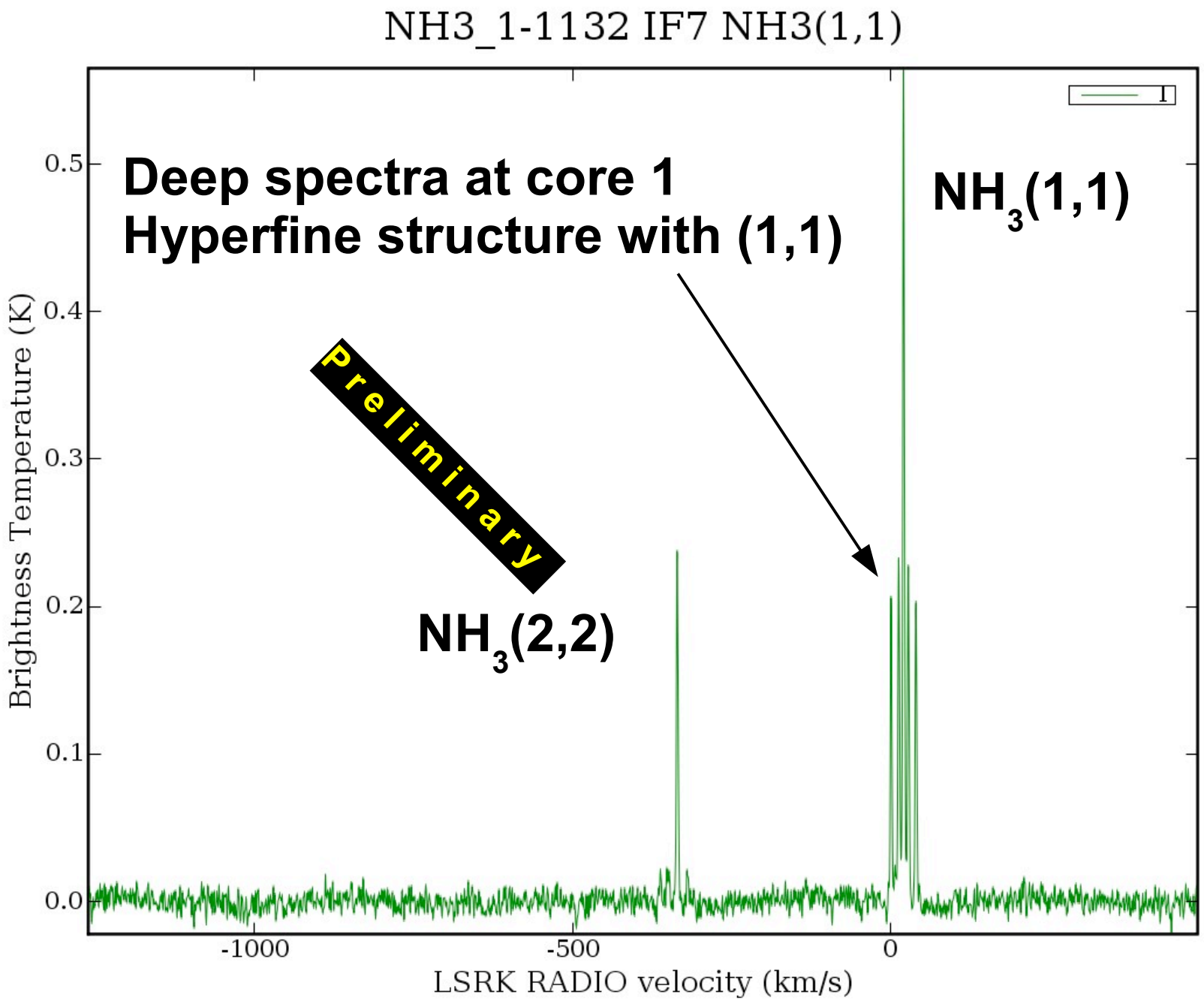
CO emission may 'surround' W28 extending to ~ +20 km/s

---> possible disruption by W28 SNe

---> Δ v ~ 10-15km/s consistent with W28 shock speed

but..cannot rule out components at d~4 kpc (Scutum-Crux arm)

Require understanding of cloud dyamics


NH3_1-1132 IF7 NH3(1,1)
1
Deep spectra at core 1
Hyperfine structure with (1,1)
NH3(1,1)
Preliminary
NH3(2,2)
Brightness Temperature (K)
0.5
0.4
0.3
0.2
0.1
0.0
-1000
-500
0
LSRK RADIO velocity (km/s)

TeV Shell SNRs...