TeV γ-ray observations of OH maser-emitting SNRs

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CRISM2011
Cosmic rays & their interstellar medium environment
26 June – 1 July 2011
Montpellier, France

OH masers, TeV γ-rays, CRs, & the ISM

Where are the sites of CR acceleration?

Supernova remnants?
(Talk by Y. Gallant.)

How do we know which SNRs are interacting with molecular clouds?

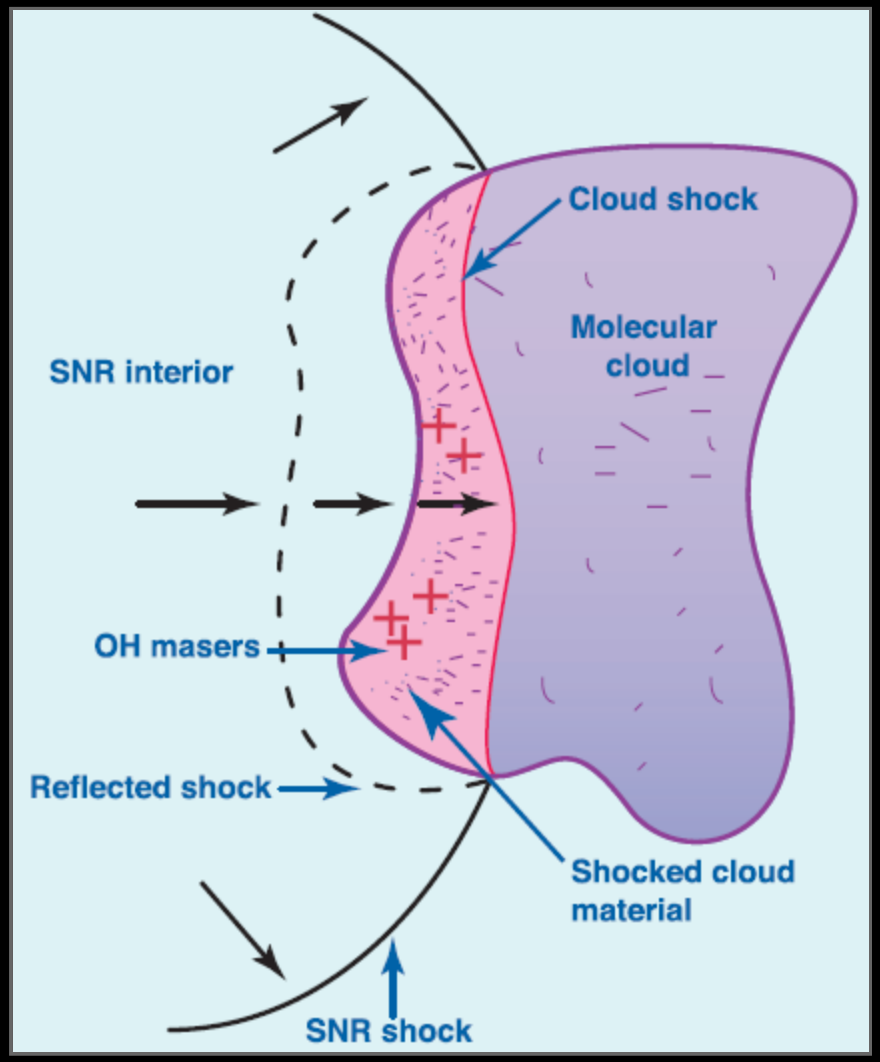
e.g. OH(1720 MHz) masers
(Talk by D. Frail.)

TeV γ-rays can identify sites of potential hadronic interactions.

$$p + p \rightarrow \pi^0 \rightarrow 2\,\gamma$$

ME SNRs are excellent candidates for TeV γ-ray emission.

OH masers, TeV γ-rays, CRs, & the ISM



Wardle & Yusef-Zadeh 2002

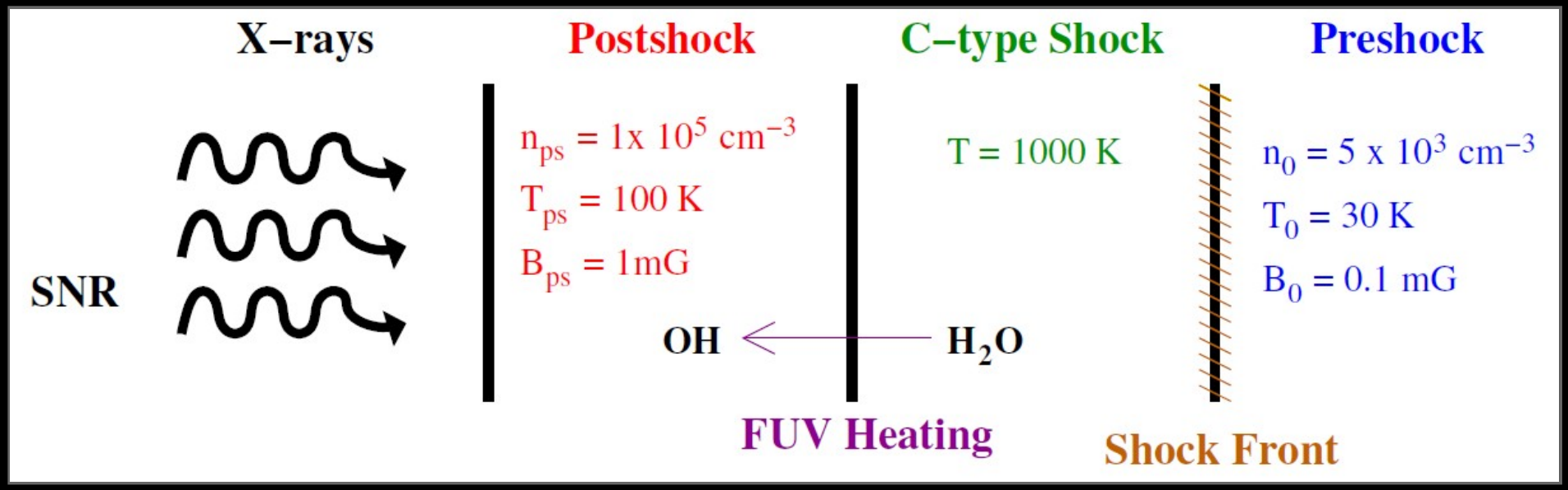
Where?
Maser emission from just behind the shock front, i.e. edge or rim of SNR shell

Required shocks are perpendicular to line-of-sight

OH masers link SNRs with density enhancements in the ISM, i.e. molecular clouds

OH masers → shocked cloud!
No OH maser → could still be shocked

OH maser environment



de Witt 2005

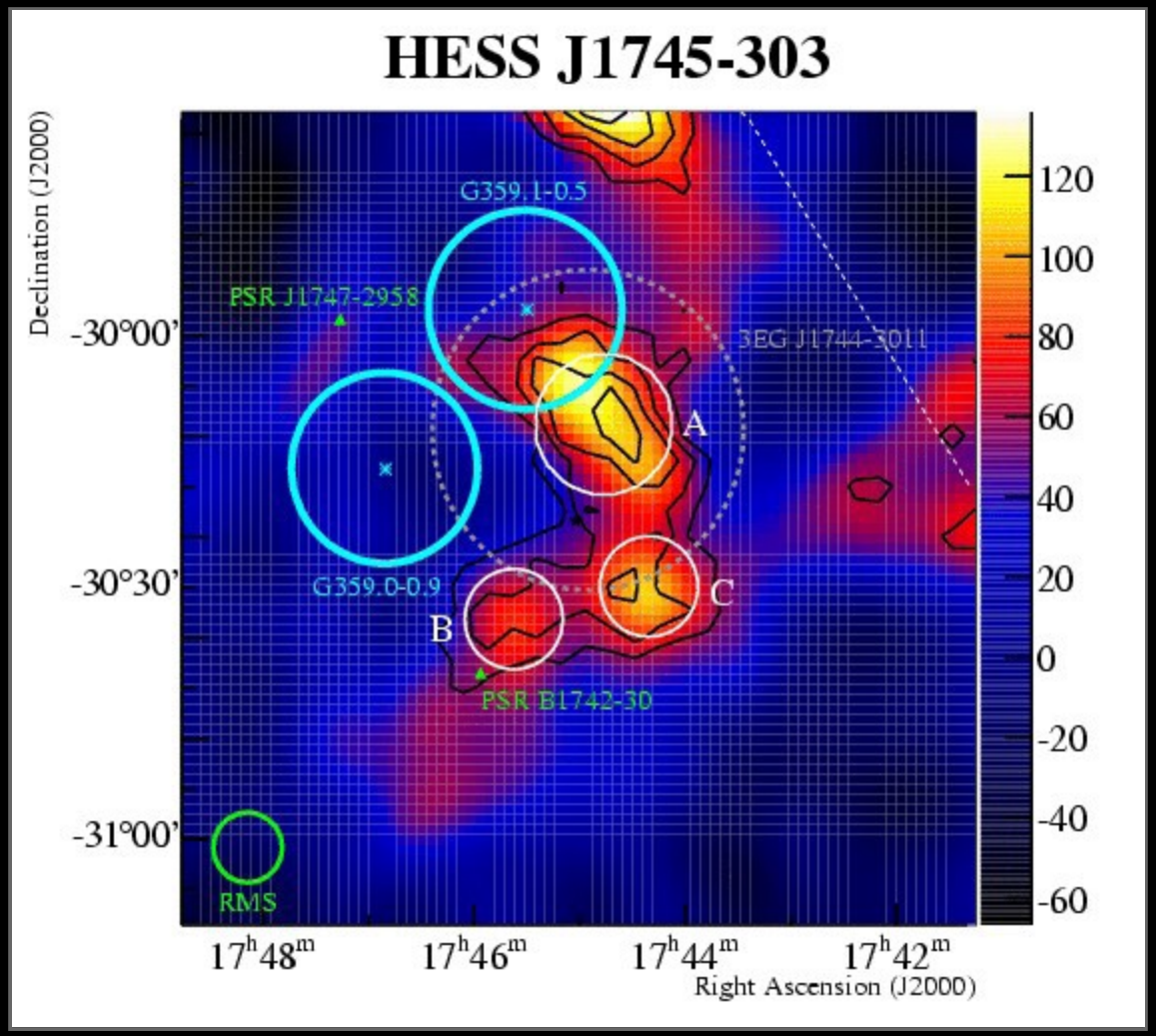
Specific physical constraints needed to produce OH maser

OH column density ~ 10^{16} – 10^{17} cm^{-2}
MC density ~ 10^3 – 10^5 cm^{-3}
T ~ 25 – 200 K

Strong suppression of population inversion otherwise

Elitzur 1976; Lockett et al. 1999

G359.1-0.5 & HESS J1745-303



Aharonian et al. (H.E.S.S.) 2008

unidentified TeV source

complex morphology
possibly multiple sources

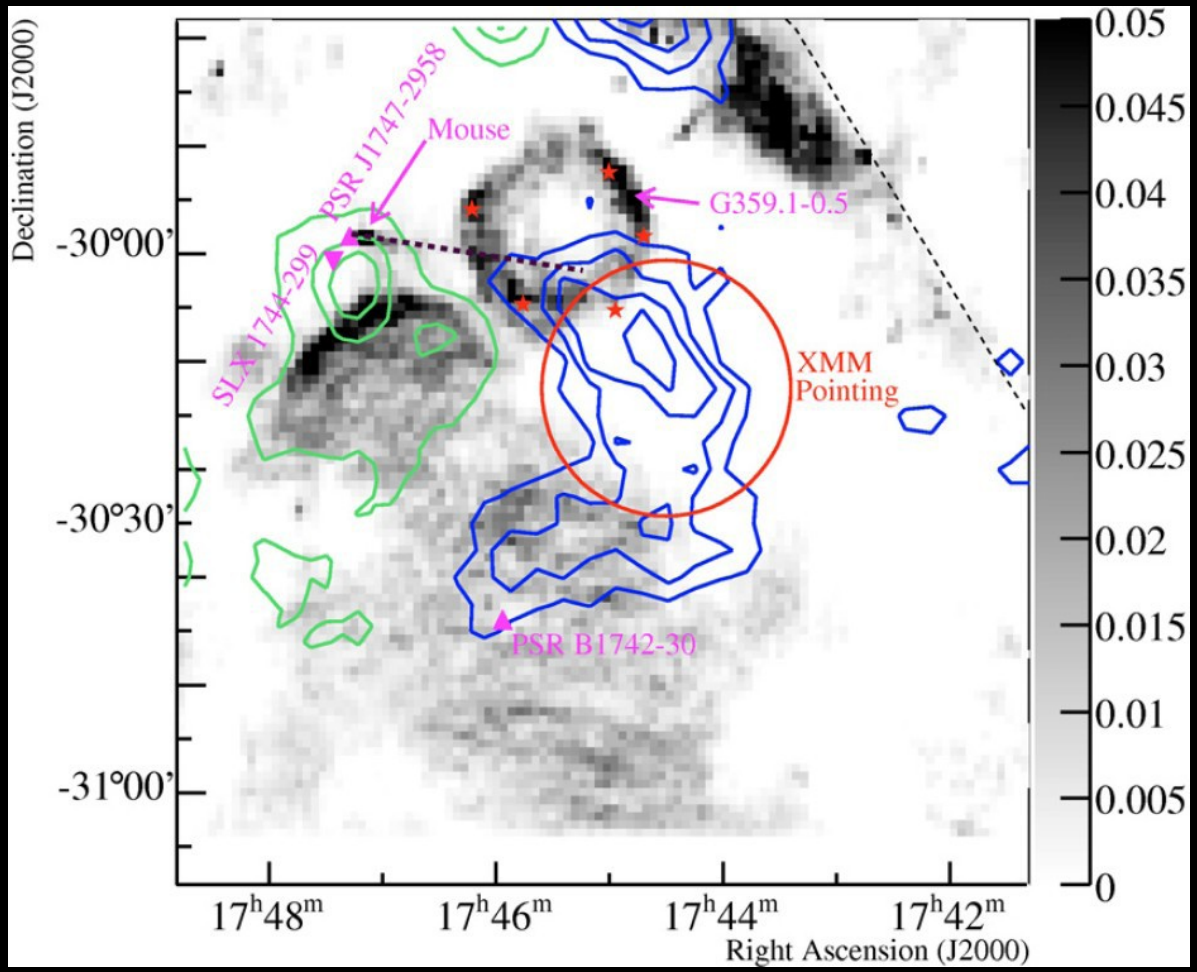
photon index $\Gamma = 2.71 \pm 0.11$

G359.1-0.5 & HESS J1745-303

unidentified TeV source

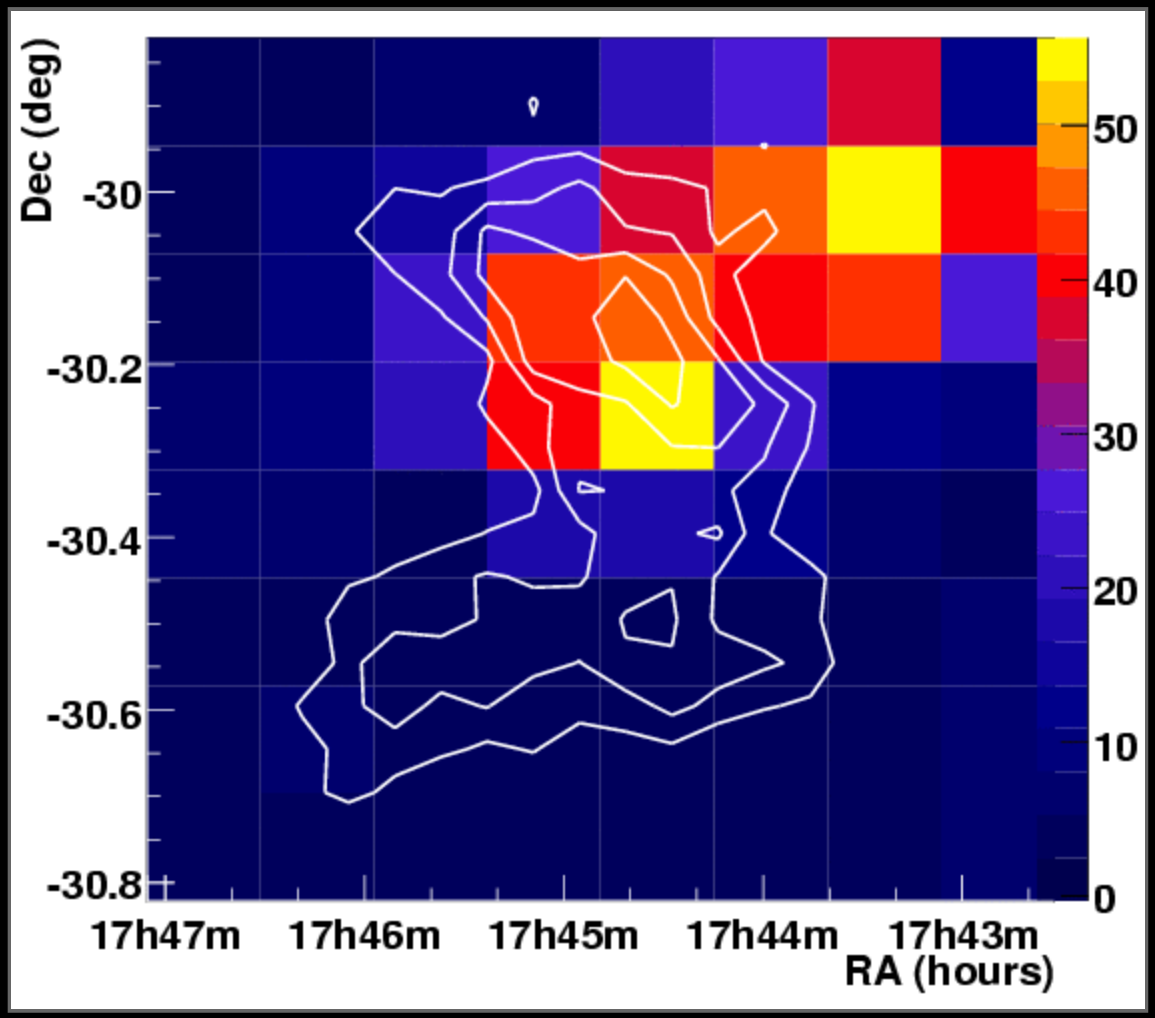
a MWL view

six OH masers!



Aharonian et al. (H.E.S.S.) 2008

G359.1-0.5 & HESS J1745-303



Aharonian et al. (H.E.S.S.) 2008

unidentified TeV source
and 12CO

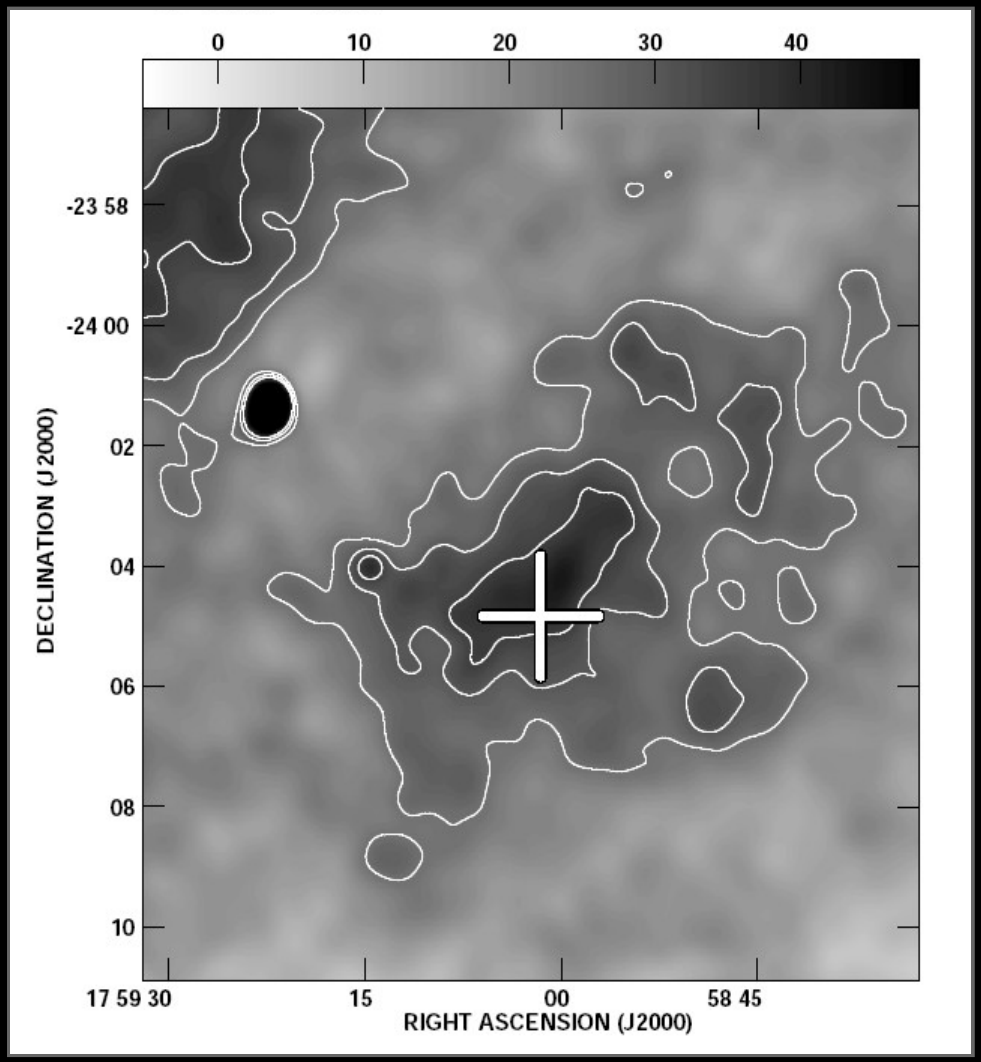
Interaction of SNR G359.1-0.5
blast wave w/ MC

OH masers at 1720 MHz
towards the
boundary of the SNR

CO coincidence w/ TeV emission

hadronic scenario within this
cloud?
Energetics compatible with CRs
from SNR interacting with MC
~30% of SN explosion energy
into CRs

G5.7-0.0 & HESS J1800-240C



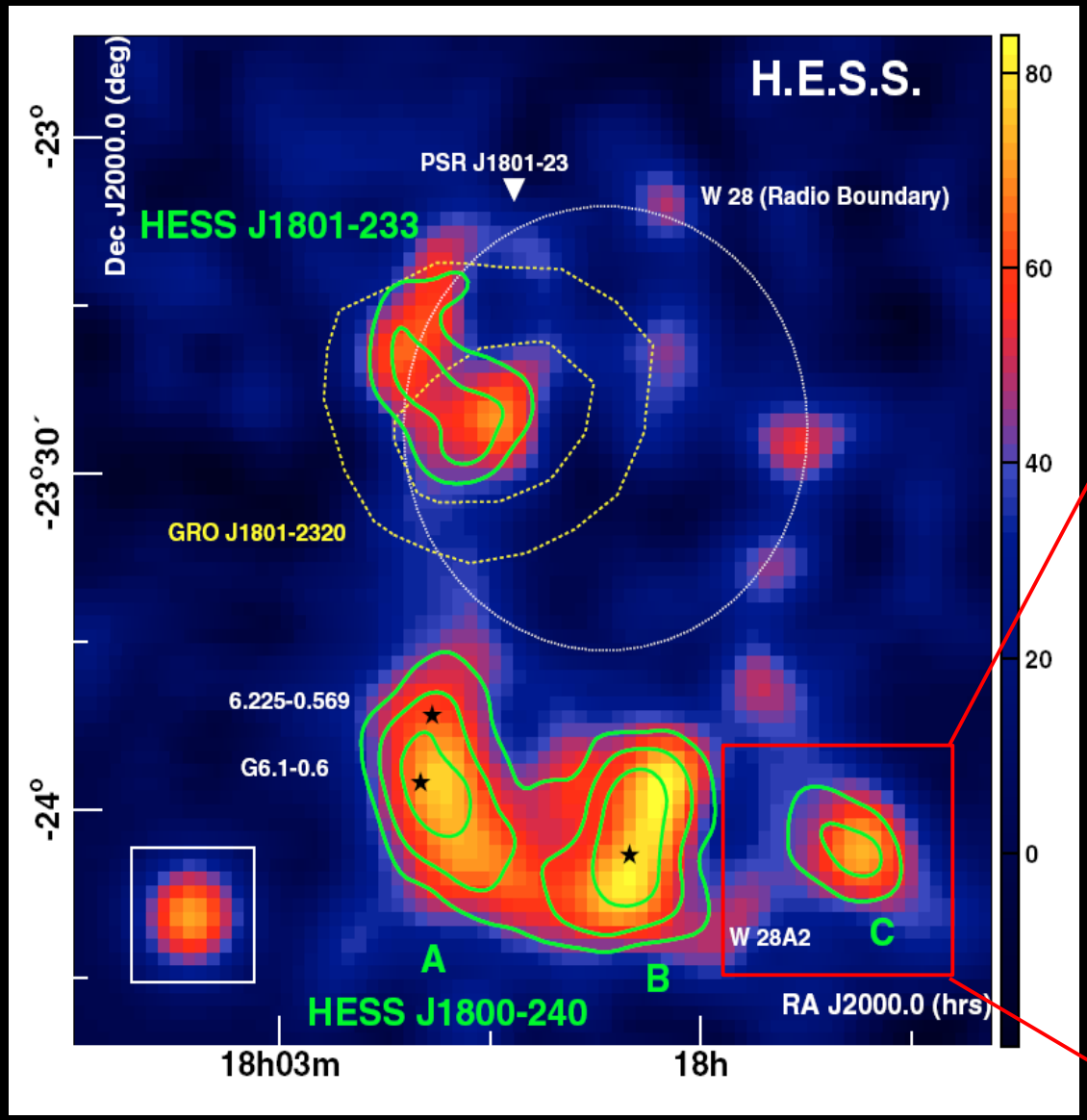
Brogan et al. 2006

SNR candidate G5.7-0.0
a partial 12′ shell
$\alpha = -0.5$

not well studied,
even in radio

Brogan et al. 2006

G5.7-0.0 & HESS J1800-240C



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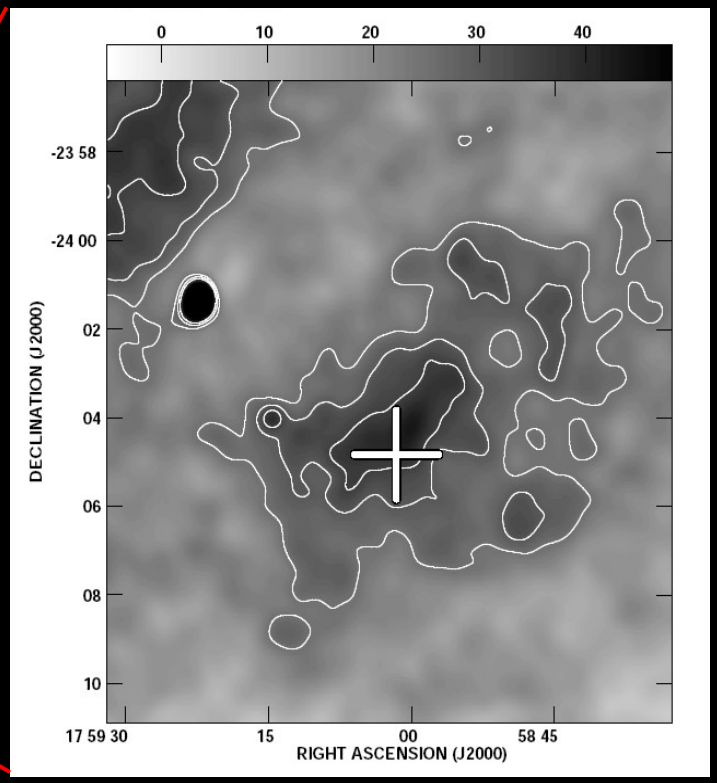
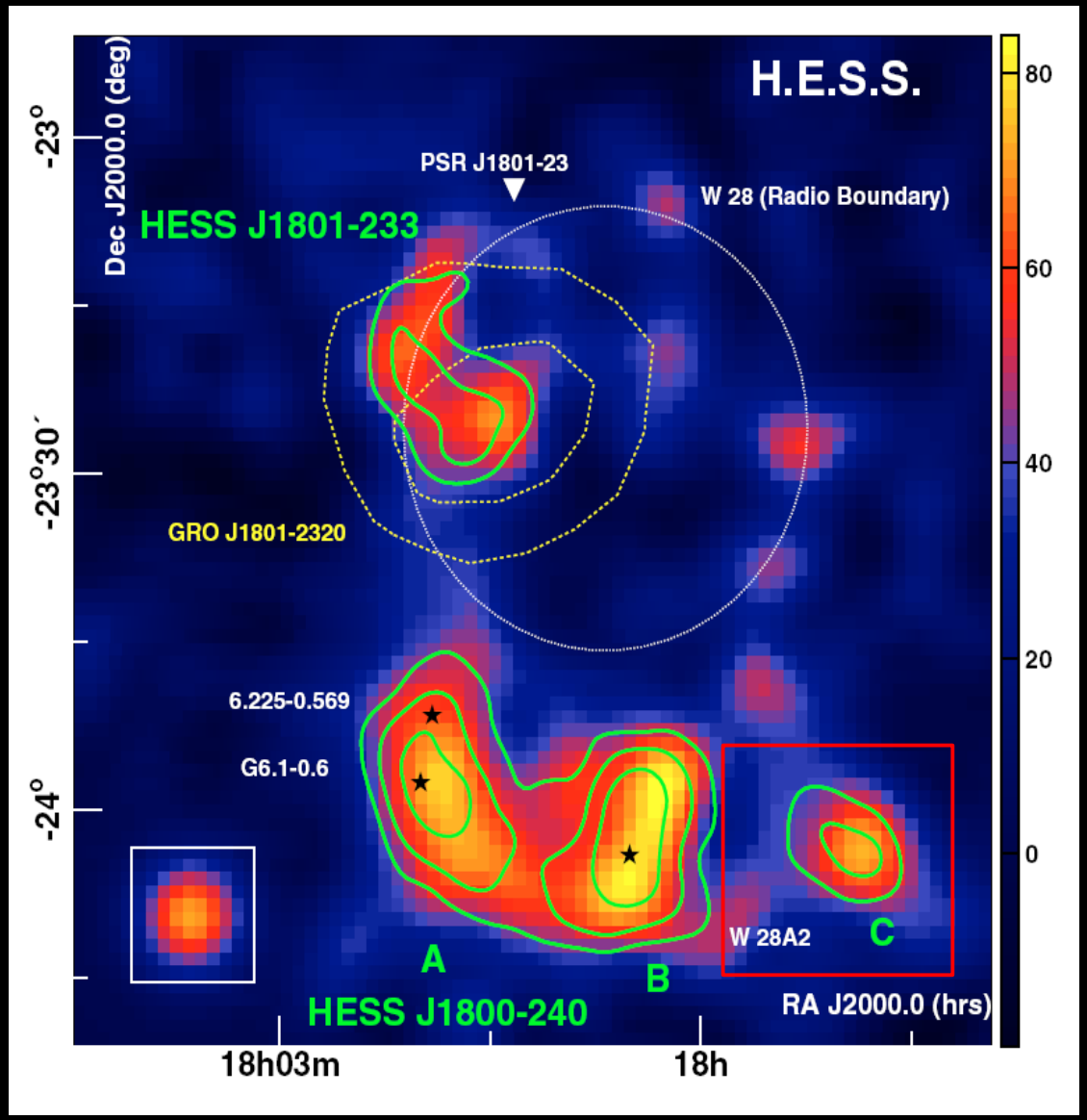


Aharonian et al. (H.E.S.S.) 2008

G5.7-0.0 & HESS J1800-240C



Aharonian et al. (H.E.S.S.) 2008

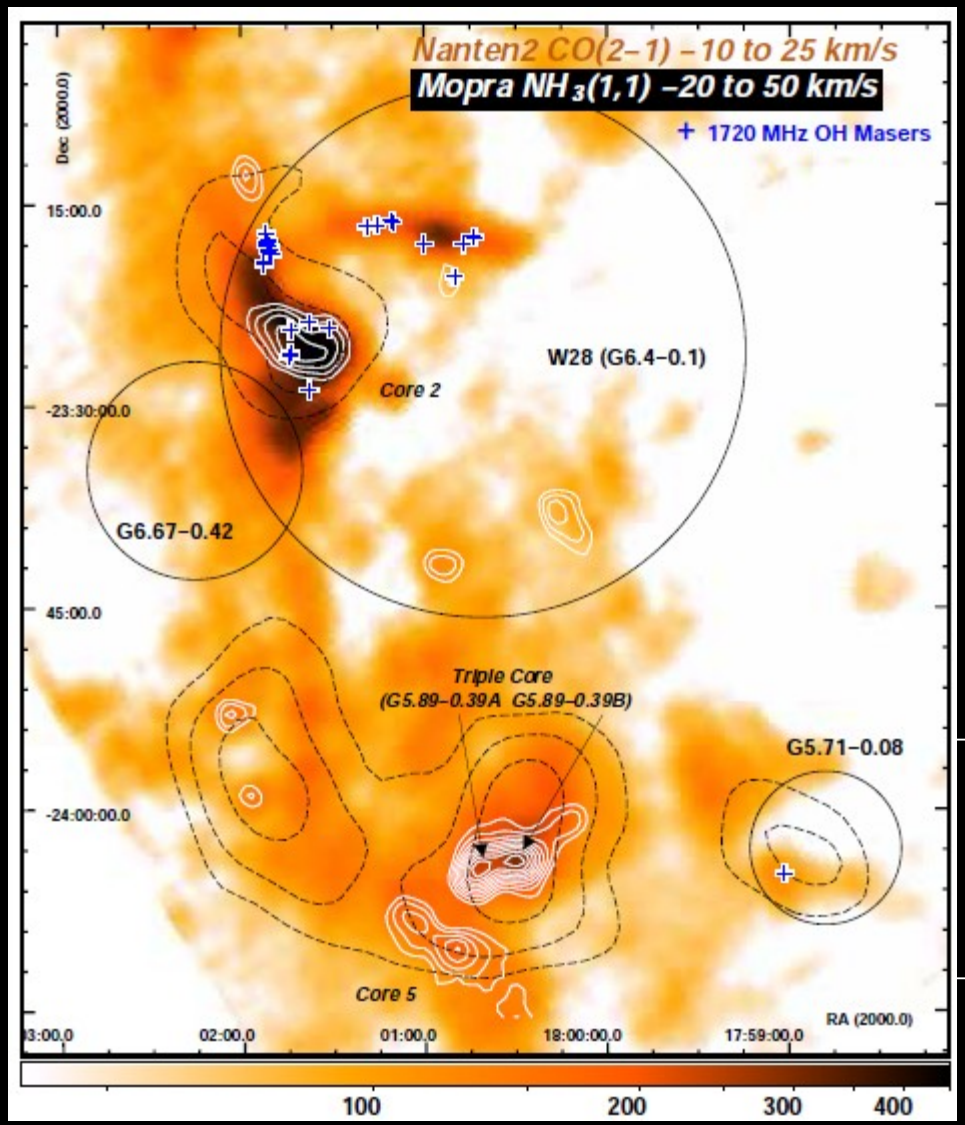
SNR candidate G5.7-0.0
in TeV γ-rays

detection significance ~5 σ
(weakest in W28 FoV)

TeV emission region
compatible w/ point source
0.02° ± 0.15°

PL spectrum
$\Gamma = 2.31 \pm 0.05_{stat} \pm 0.20_{syst}$
< 1% Crab

G5.7-0.0 & HESS J1800-240C



NANTEN2

SNR candidate G5.7-0.0
in ^{12}CO

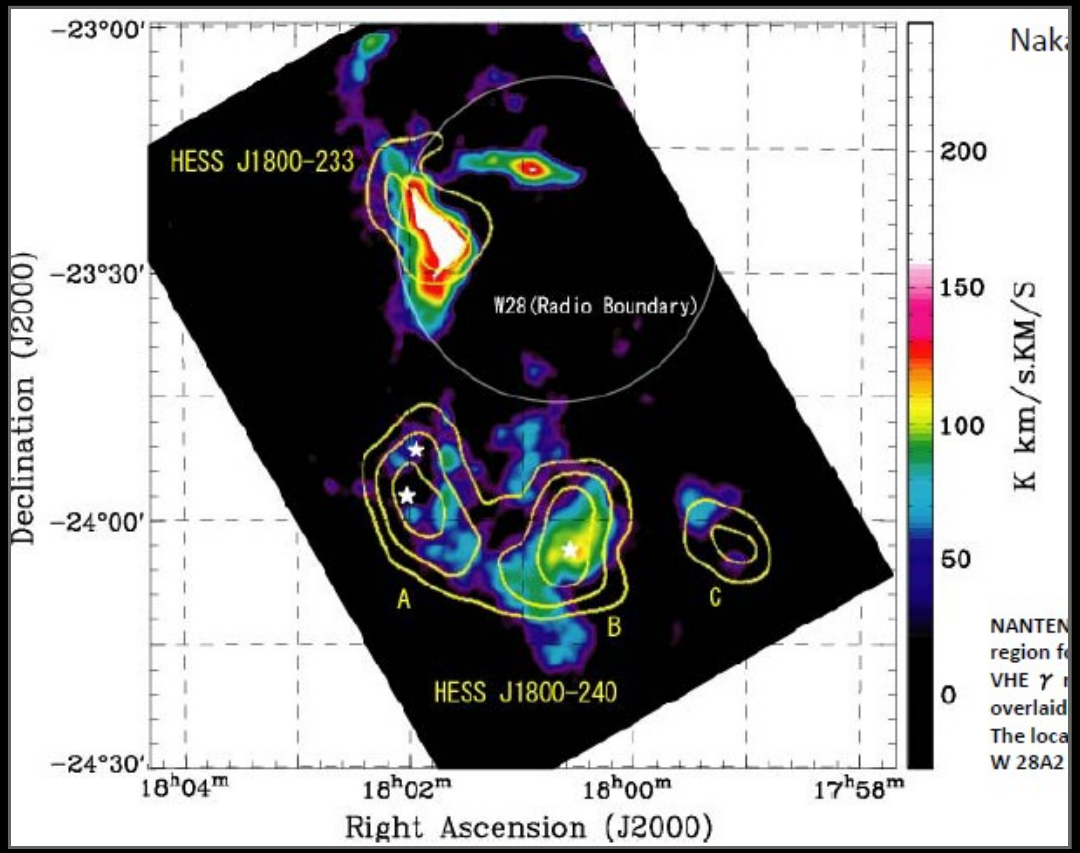
faint CO clumps
near HESS J1800-240C

G5.7-0.0 & HESS J1800-240C

SNR candidate G5.7-0.0
in ^{12}CO

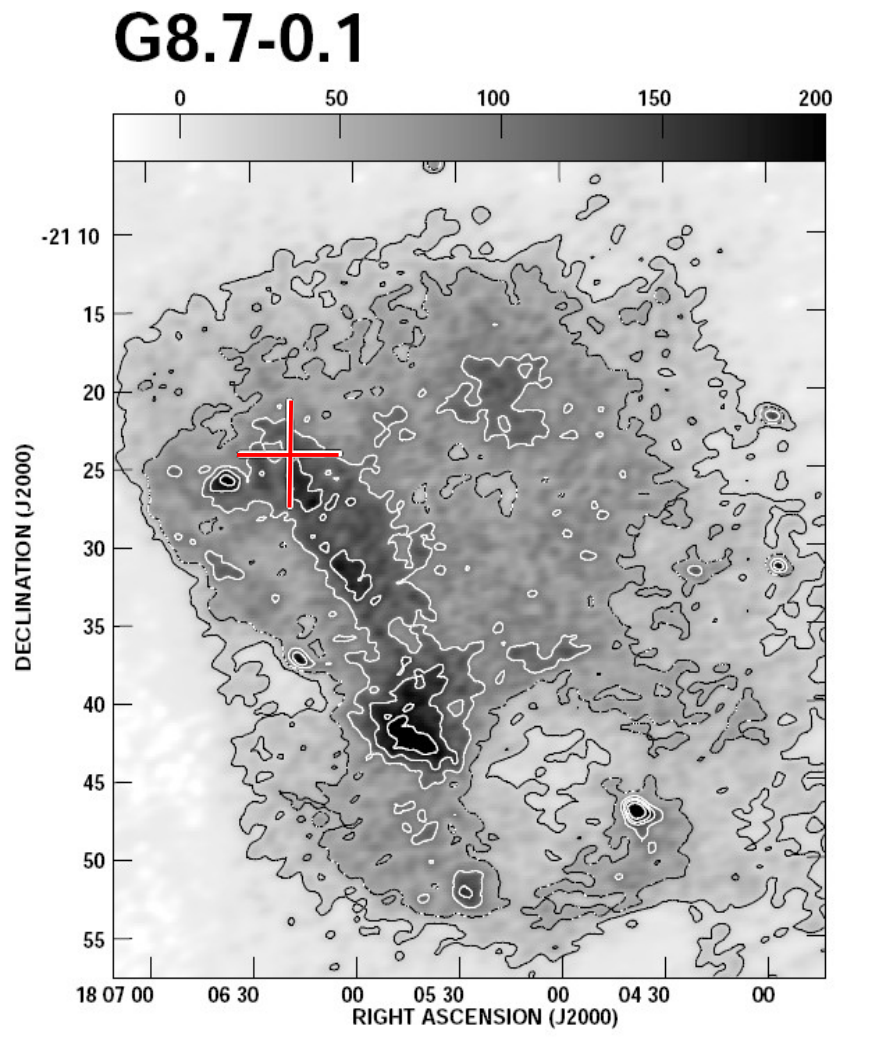
faint CO clumps
near HESS J1800-240C

Need deeper MWL exposures



NANTEN2: Nakashima et al. 2008

SNR G8.7-0.1 & HESS J1804-216



SNR G8.7-0.1
large 45′ MM SNR
interior filled w/ thermal X-rays
9 H II regions
W30 complex

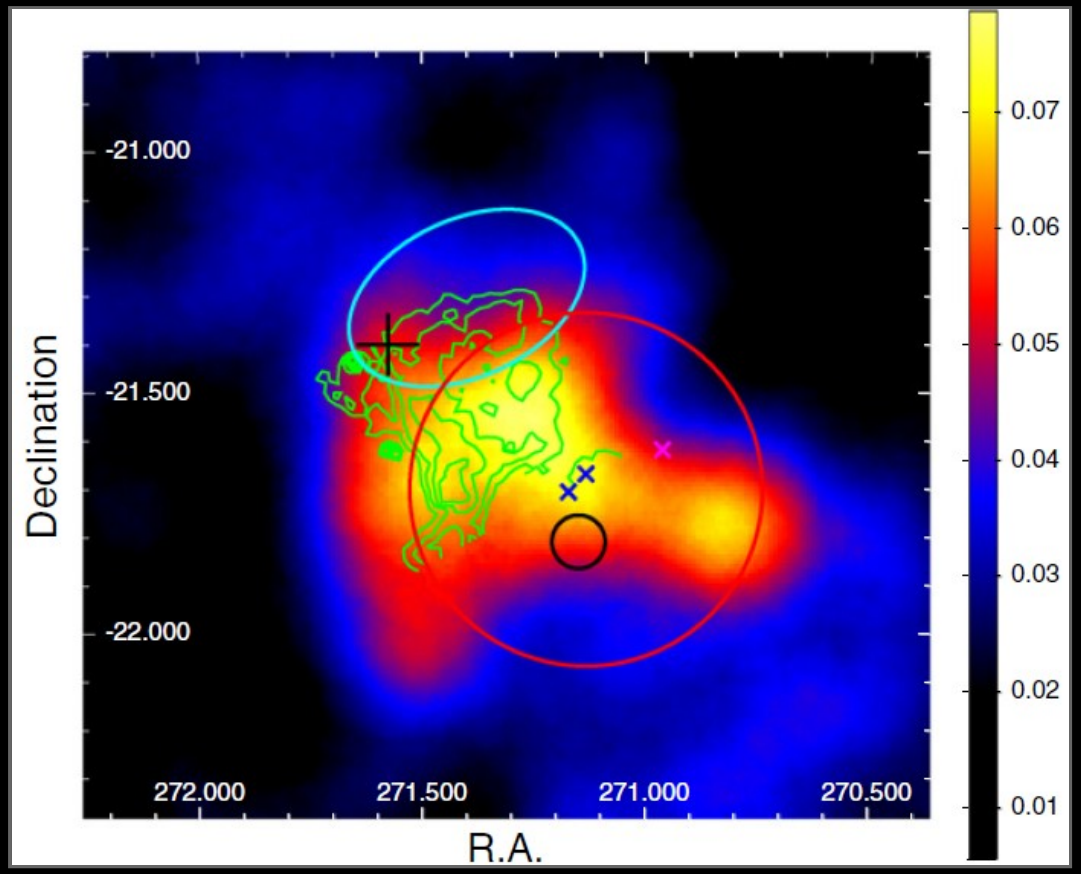
bright OH maser
on eastern edge

V_{LSR} & absorption features
& low N_H →
d = 4.5 kpc (near)

MAGPIS: Kassim & Weiler 1990

Finley & Oegelman 1994

SNR G8.7-0.1 & HESS J1804-216



Castro & Slane 2010

SNR G8.7-0.1
in GeV γ-rays

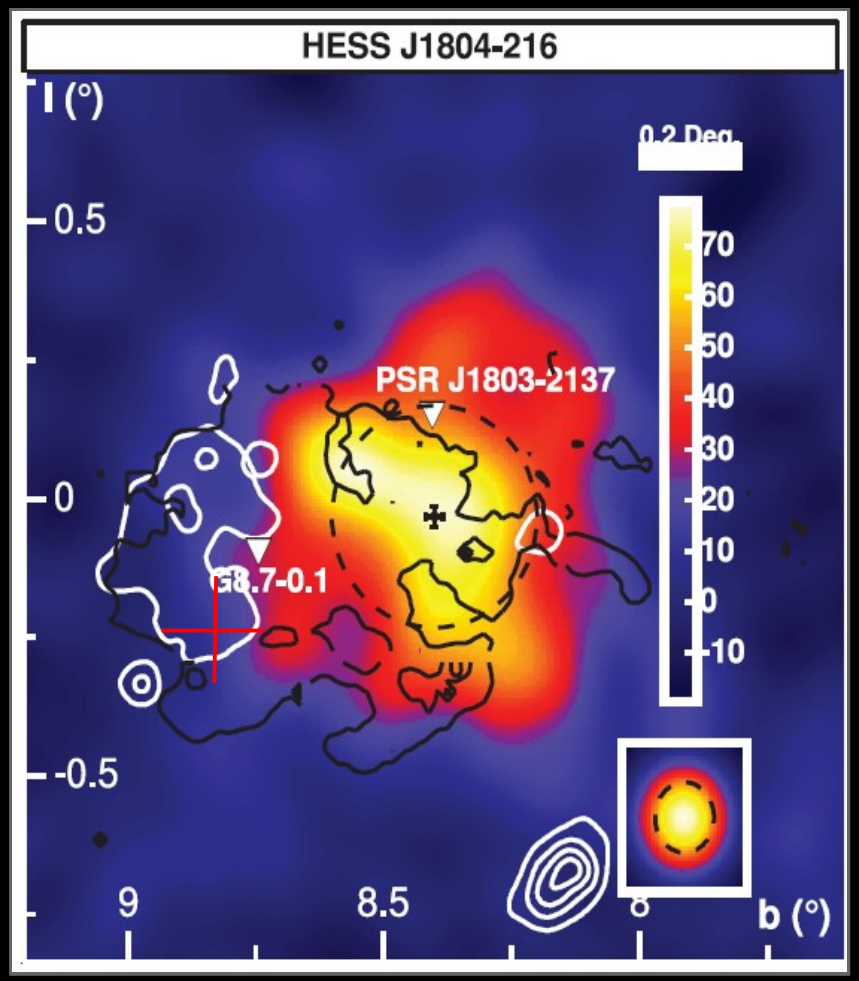
1FGL J1805.2-2137c

detection significance ~22 σ

possibly extended

Castro & Slane 2010

SNR G8.7-0.1 & HESS J1804-216



Aharonian et al. (H.E.S.S.) 2006

SNR G8.7-0.1
in TeV g-rays

~16 h of effective exposure w/ the H.E.S.S. telescope array

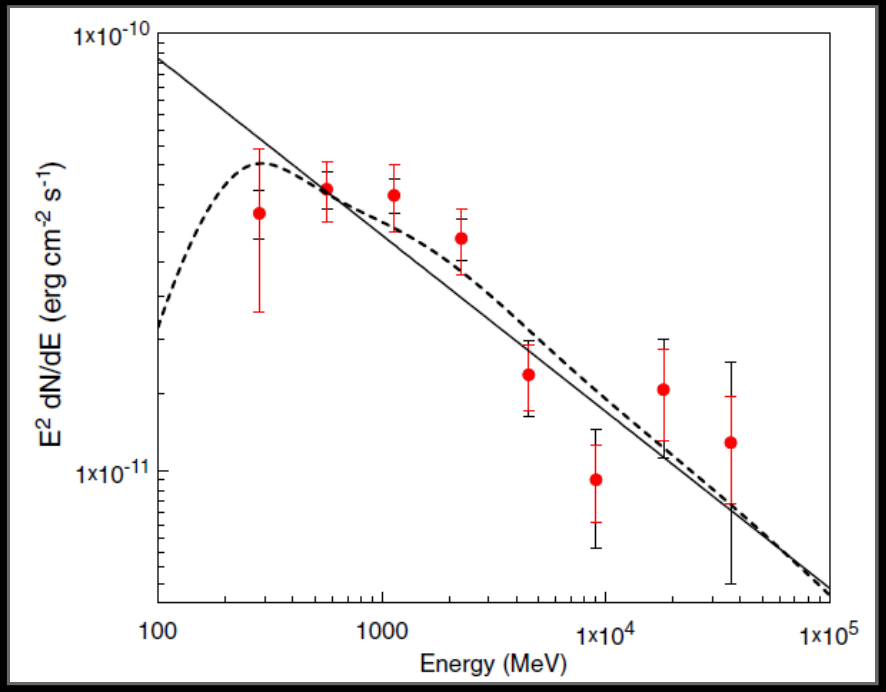
detection significance ~14 σ

TeV emission region extended
0.20° ± 0.01°

Aharonian et al. (H.E.S.S.) 2006

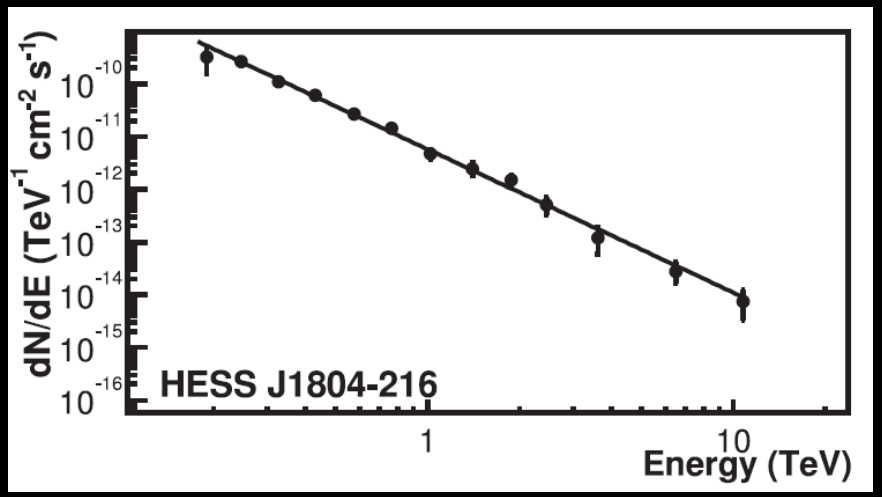
SNR G8.7-0.1 & HESS J1804-216

0.1 – 100 GeV
$\Gamma = 2.40 \pm 0.07$
(single PL)



Castro & Slane 2010

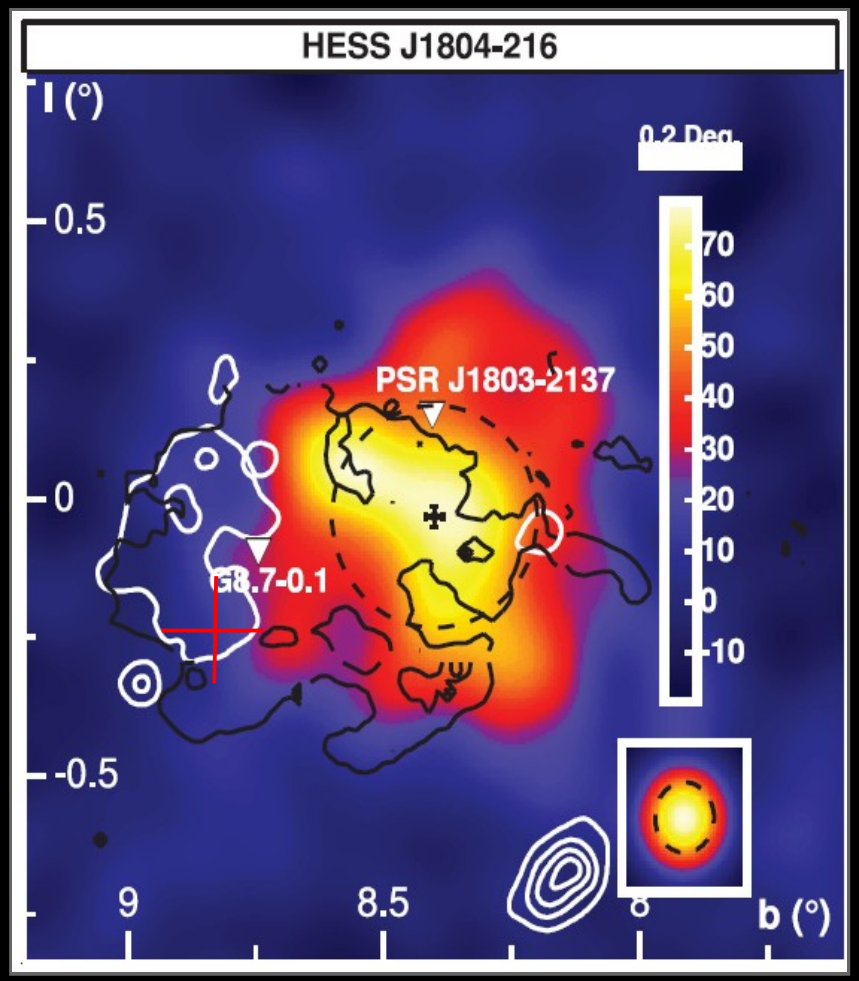
200 GeV – 10 TeV
relatively soft spectrum
$\Gamma = 2.72 \pm 0.06_{stat} \pm 0.20_{syst}$
very bright
~25% Crab Nebula flux



Aharonian et al. (H.E.S.S.) 2006

Marginally compatible spectrum?
Single PL 100 MeV – 10 TeV → Hadronic?

SNR G8.7-0.1 & HESS J1804-216



Aharonian et al. (H.E.S.S.) 2006

SNR G8.7-0.1
in TeV γ-rays

Effective exposure more than doubled in this region since 2006

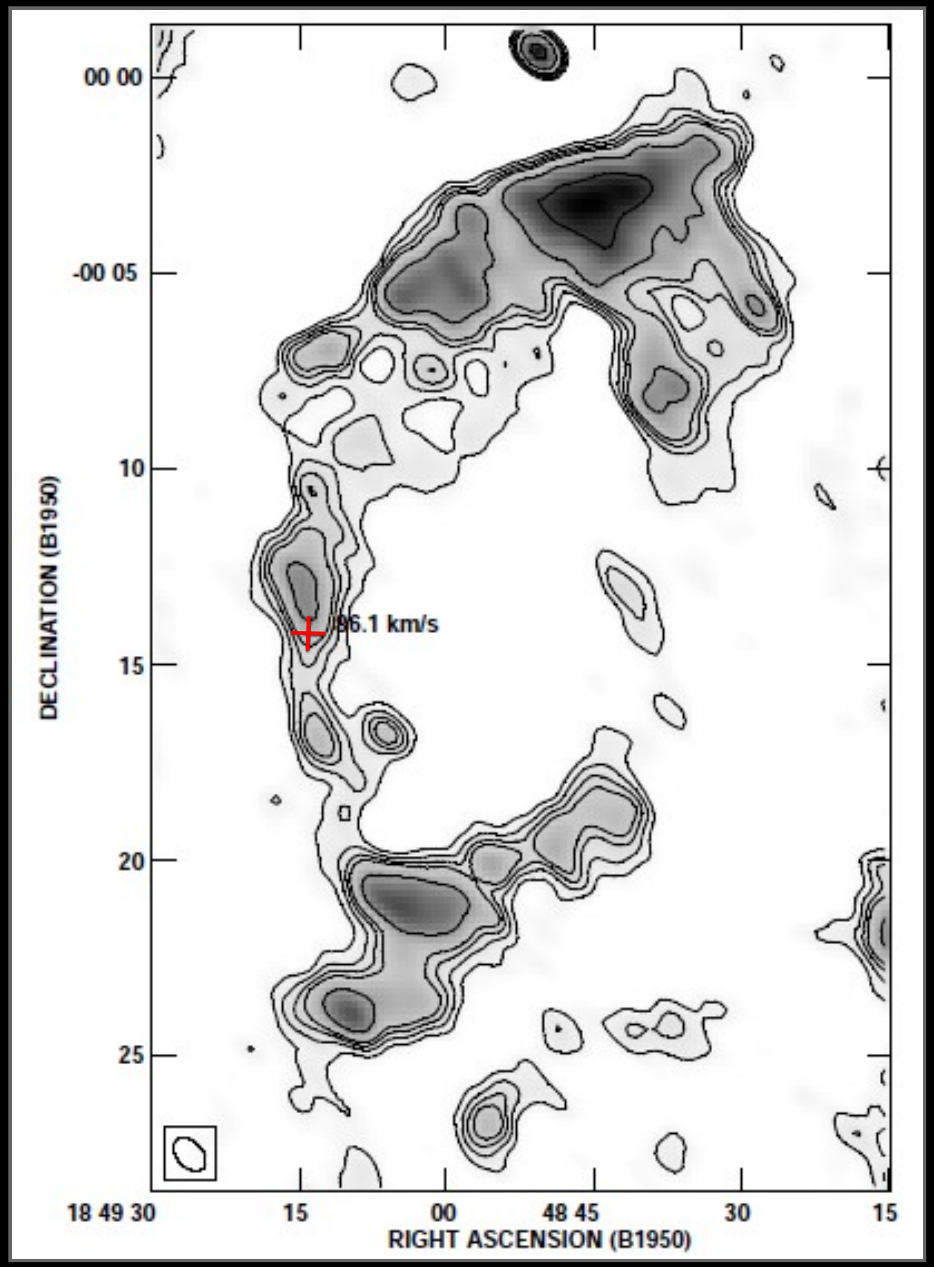
Follow-up TeV & MC studies in progress
What is CR overdensity?
$k_{CR} \sim F_\gamma (d^2 / M_5)$

Coincident GeV γ-ray emission

An unidentified TeV source:
SNR/MC shock interaction?
or
pulsar wind nebula?

Aharonian et al. 1991; Chaves (H.E.S.S.) 2010

G32.8-0.1 & HESS J1852-000



Koralesky et al. 1998

SNR Kes 78
an elongated shell
20′ (N-S) x 10′ (E-W)

OH maser spot
on eastern edge

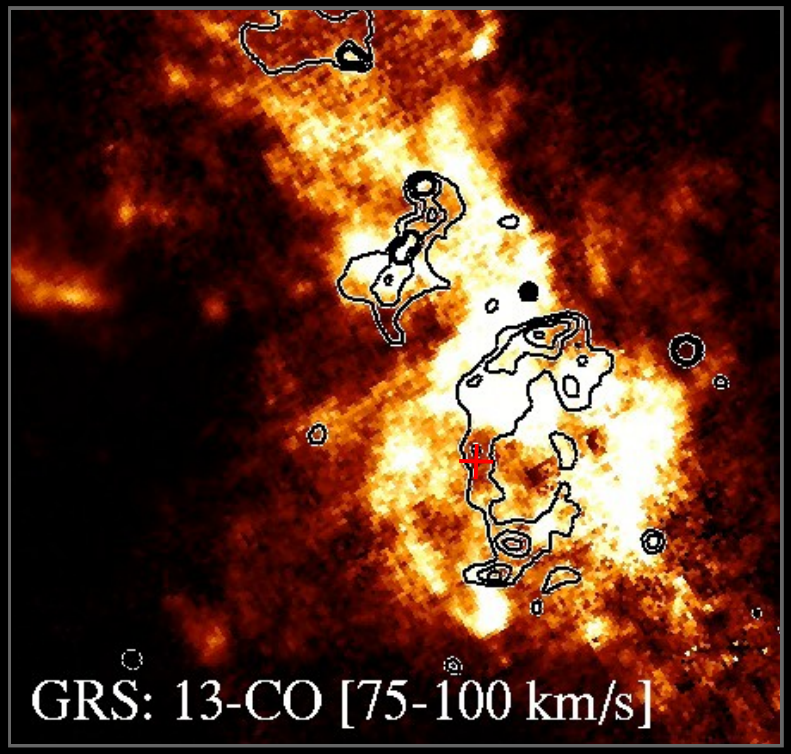
V_{LSR} →
d = 5.5 / 8.8 kpc (near / far)

Zeeman splitting
B-field along line-of-sight
1.5 ± 0.3 mG

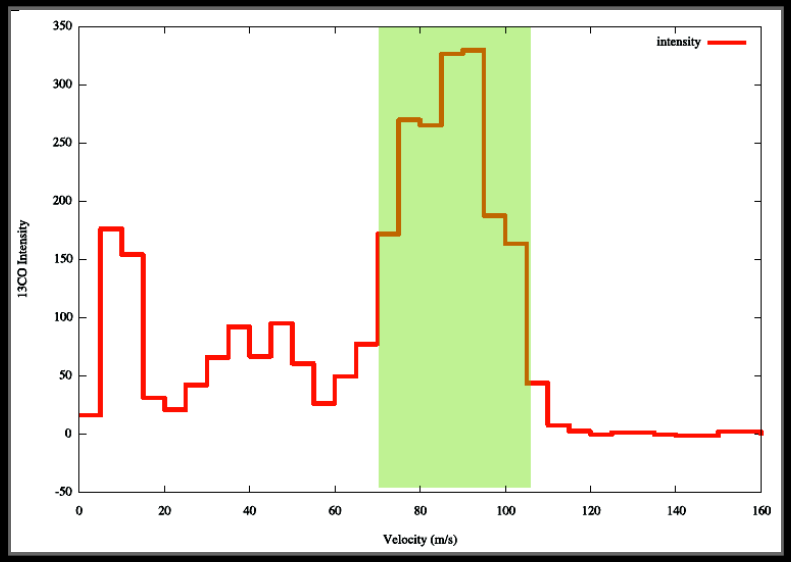
not well-studied in MWL

Koralesky et al. 1998

G32.8-0.1 & HESS J1852-000



GRS: Jackson et al. 2006

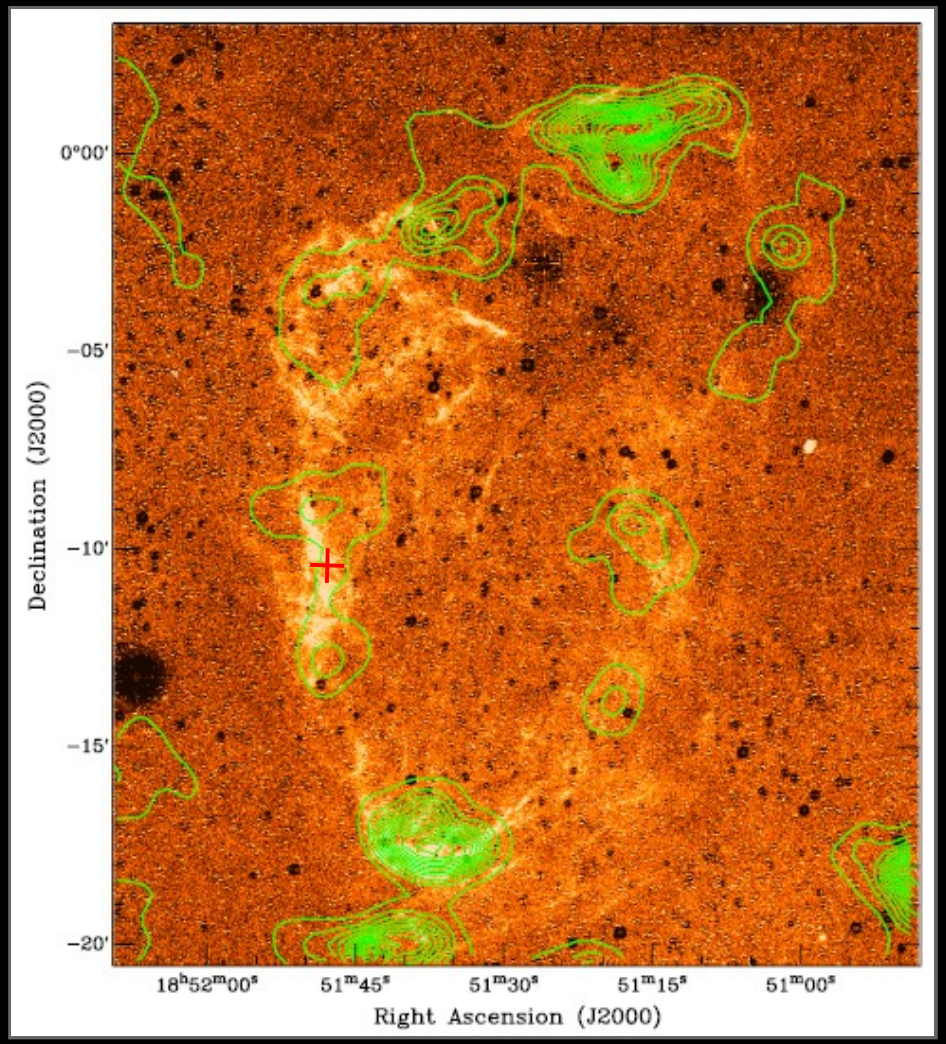


Kosack, Chaves, Acero, et al. (H.E.S.S.) 2010

SNR Kes 78
& its molecular environment

significant CO in the vicinity, but
morphological match unclear

G32.8-0.1 & HESS J1852-000



Stupar & Parker 2011

SNR Kes 78
in optical (Hα)

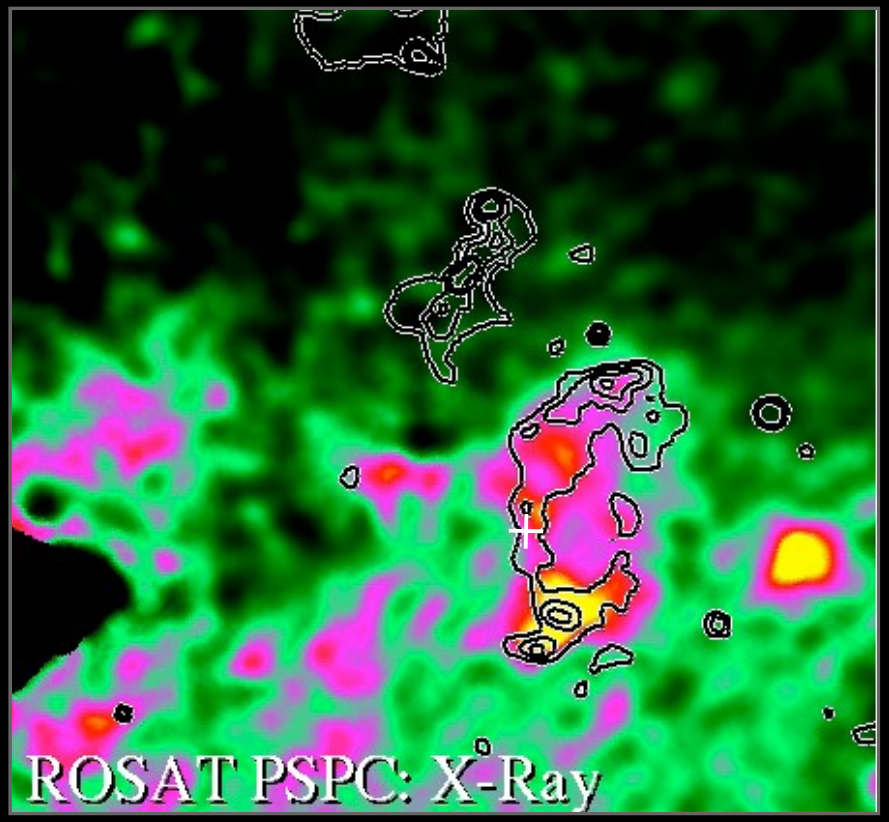
very clear optical shell
counterpart to radio emission

OH maser is co-located w/
group of bright optical filaments
(ionization)

Boumis et al. 2009; Stupar & Parker 2011

G32.8-0.1 & HESS J1852-000

Kosack, Chaves, Acero, et al. (H.E.S.S.) 2010



SNR Kes 78
in X-rays

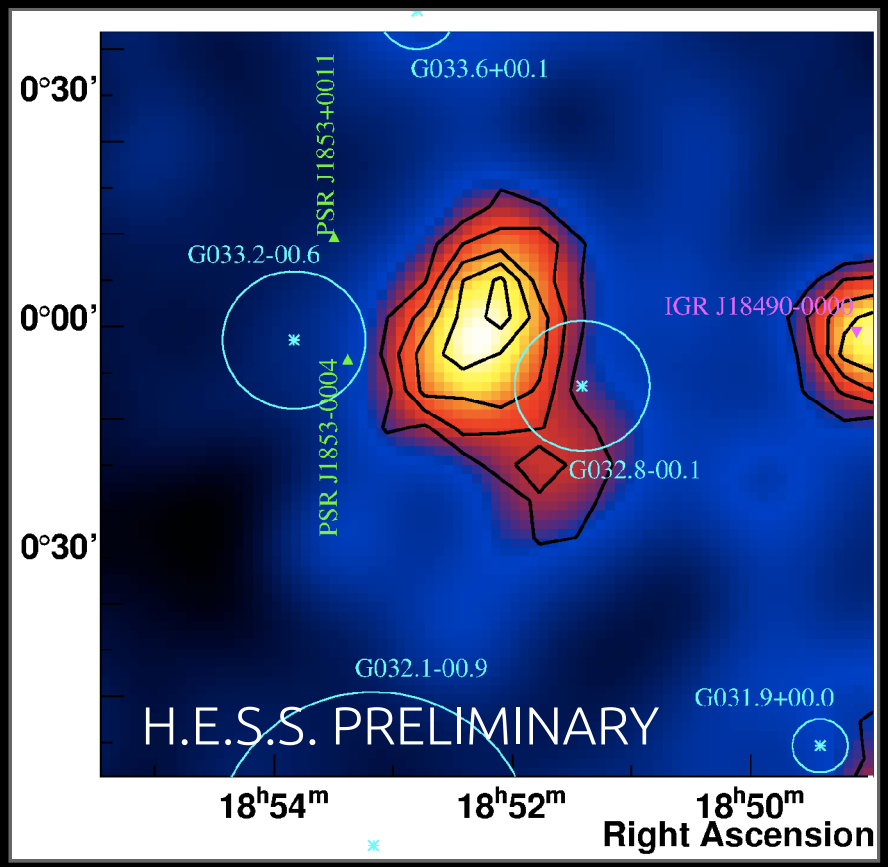
smoothed *ROSAT* count map
reveals weak X-ray emission
from shell

XMM-Newton observation (55 ks)
pending in AO12 to probe
thermal & non-thermal X-rays
in detail

Acero, Kosack, Chaves, et al. (H.E.S.S.) 2010

G32.8-0.1 & HESS J1852-000

Kosack, Chaves, Acero, et al. (H.E.S.S.) 2010



SNR Kes 78
in TeV γ-rays

~45 h of effective exposure w/ the H.E.S.S. telescope array

detection significance ~10 σ

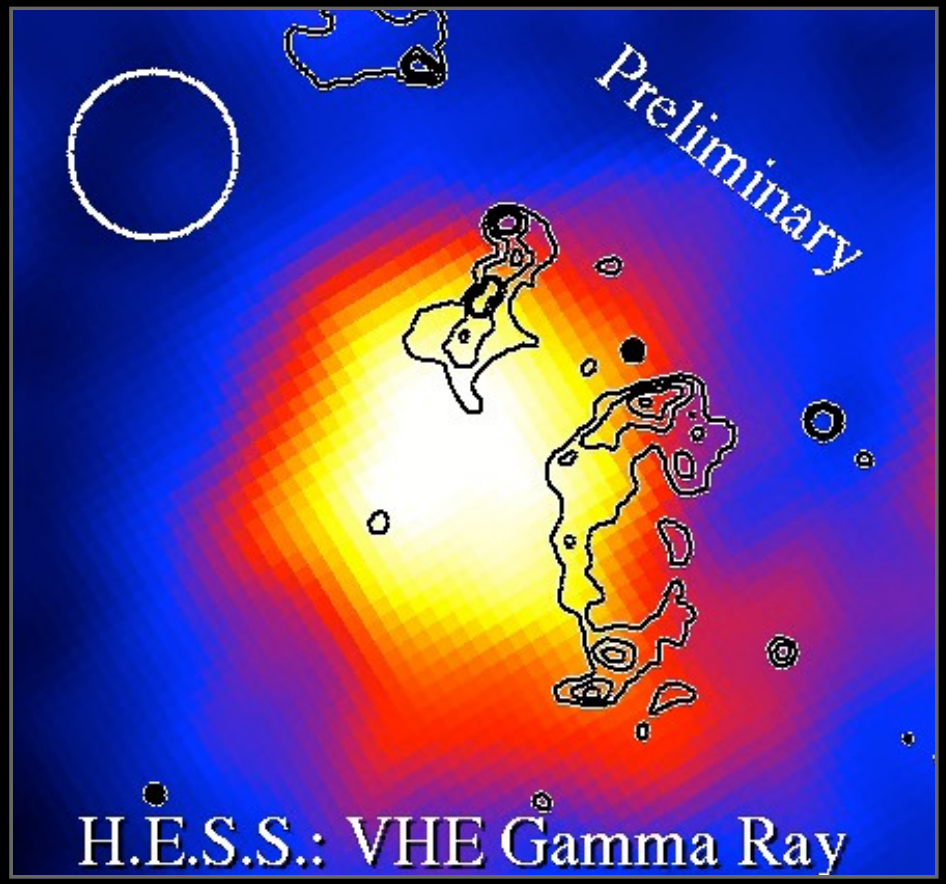
TeV emission region extended beyond PSF (0.1°)

More detailed TeV analyses (morphological & spectral) at ICRC2011

Kosack, Chaves, Acero, et al. (H.E.S.S.) 2010

G32.8-0.1 & HESS J1852-000

Kosack, Chaves, Acero, et al. (H.E.S.S.) 2010



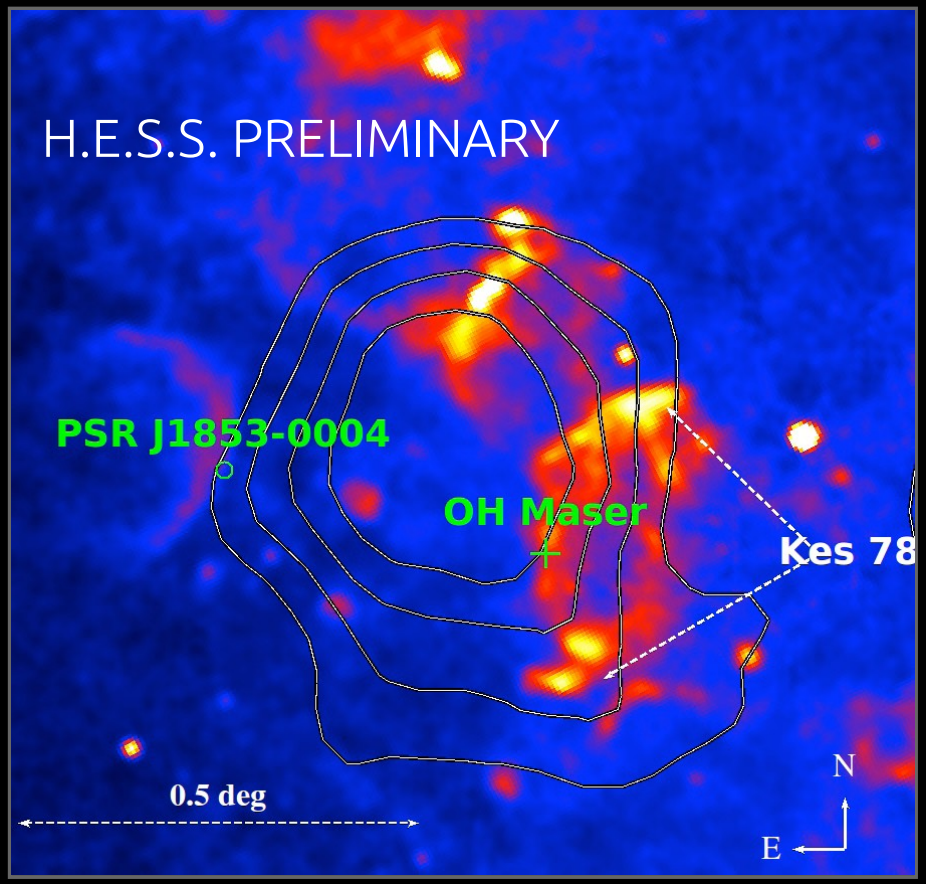
SNR Kes 78

in TeV γ-rays

TeV emission overlaps SNR,
but apparent centroid
offset from shell

G32.8-0.1 & HESS J1852-000

Kosack, Chaves, Acero, et al. (H.E.S.S.) 2010



SNR Kes 78

in TeV γ-rays

TeV emission overlaps SNR,
but apparent centroid
offset from shell

A new unidentified TeV source:
hadronic emission
from a SNR/MC interaction?
and/or
leptonic emission
related to an offset pulsar?
or
?

ME SNRs, MM SNRs, & TeV γ-rays

~10% of SNRs exhibit OH(1720 MHz) masers

Significant correlation with
bright, middle-aged, mixed-morphology SNRs.

→ Time for shock interaction with adjacent MCs.

→ Soft, thermal X-rays (& CRs?) enhance OH behind shock front.

Yusef-Zadeh et al. 2003; Hewitt & Yusef-Zadeh 2009

ME SNRs, MM SNRs, & TeV γ-rays

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Significant correlation with
bright, middle-aged, mixed-morphology SNRs.
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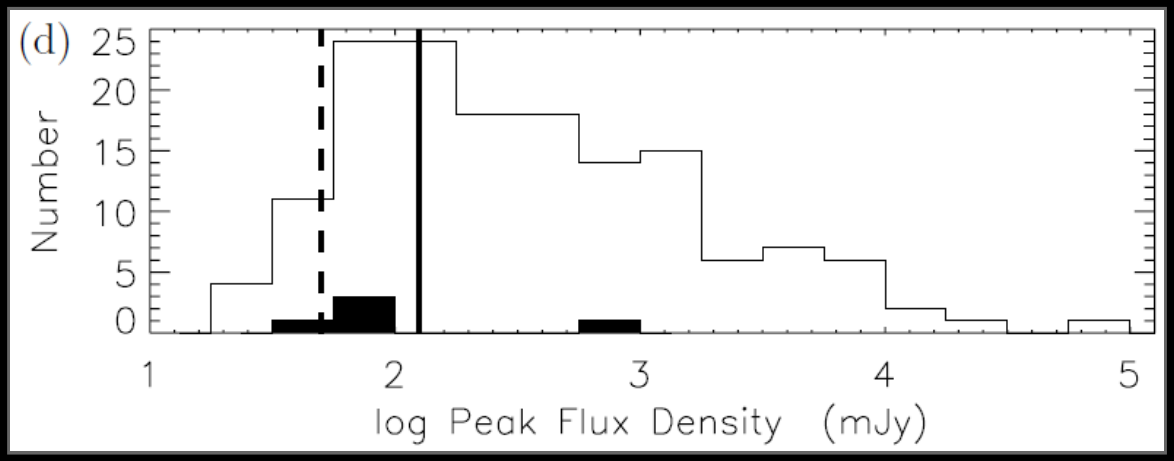
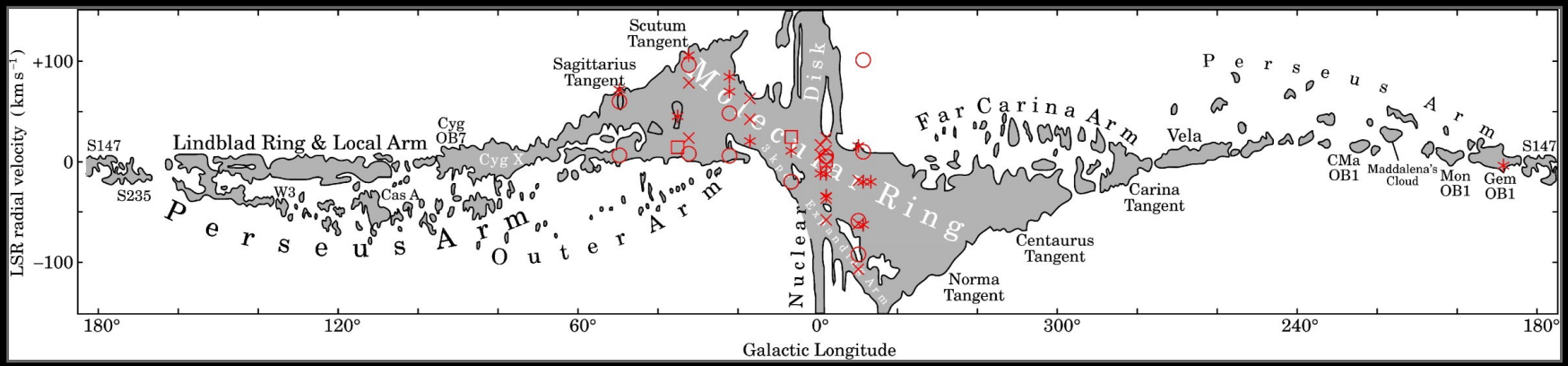
Are OH maser surveys complete?
Initially thought to be,
but new detections < 100 mJy challenge completeness.



Yusef-Zadeh et al. 2003; Hewitt & Yusef-Zadeh 2009

Distribution of ME SNRs

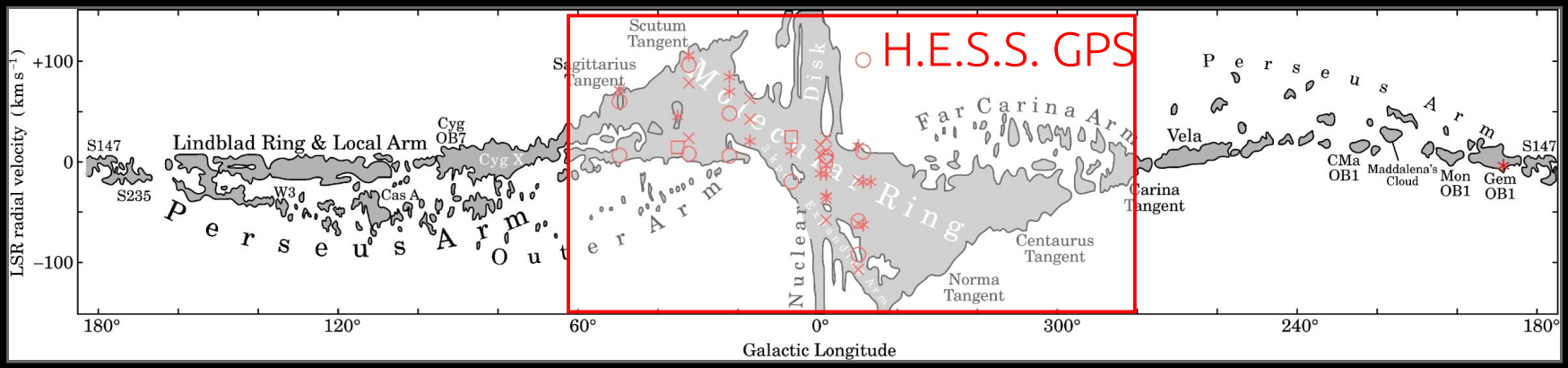


Dame et al. 2001
Hewitt et al. 2008

But only ~50% of ME SNRs appear to emit TeV γ-rays.

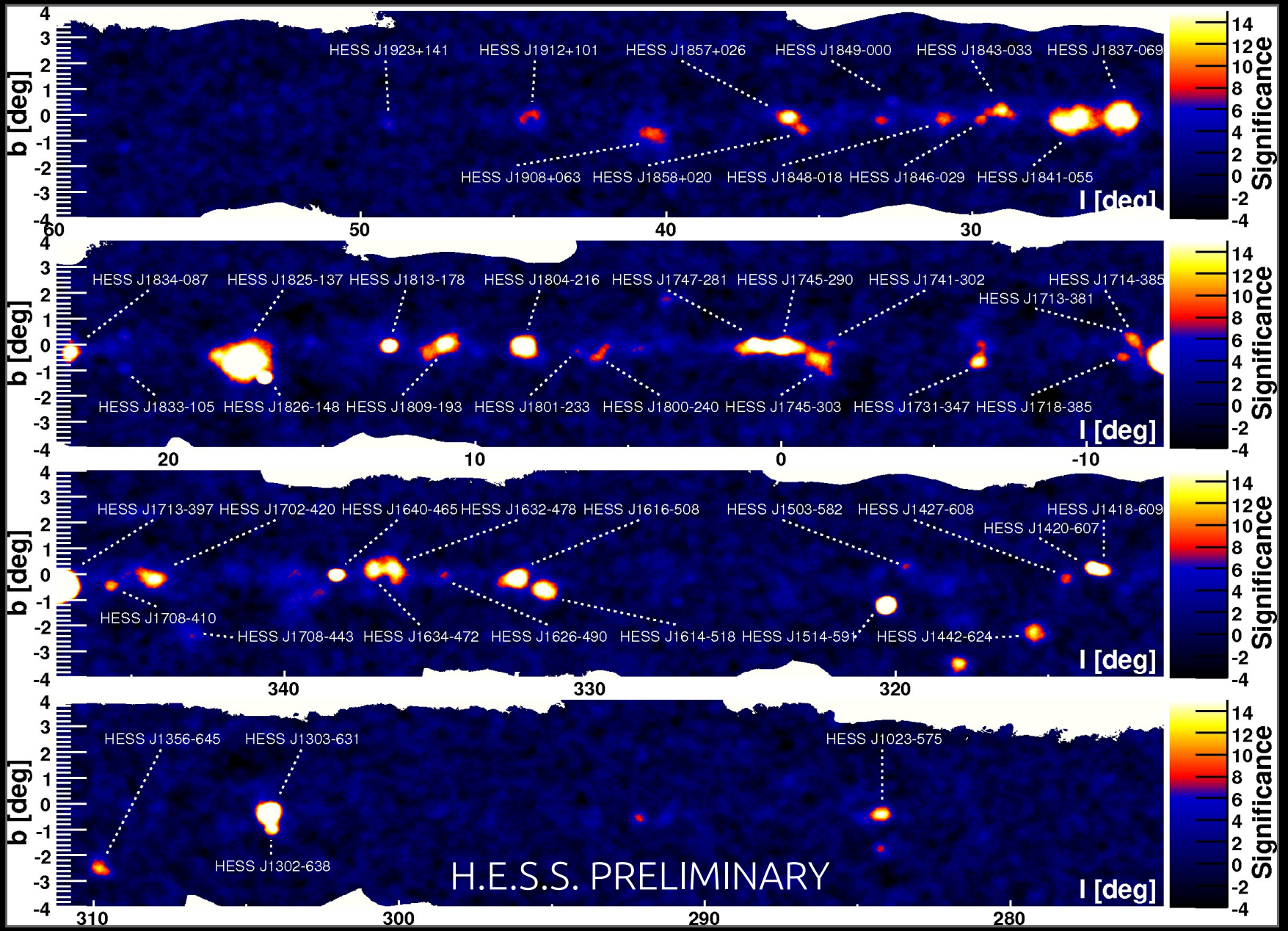
Are TeV surveys complete?

TeV coverage of ME SNRs



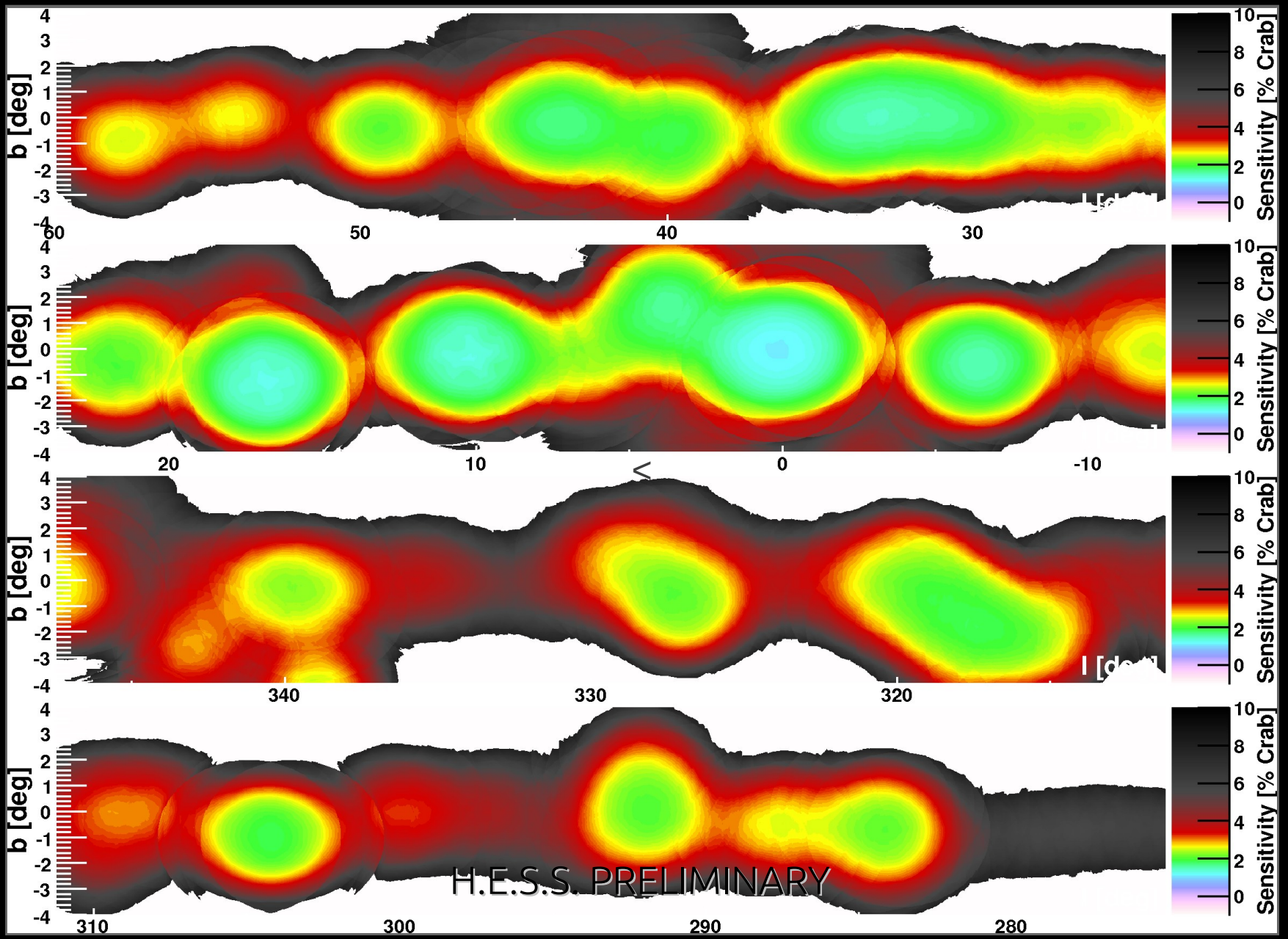
Chaves (H.E.S.S.) 2009

Inner Galaxy in TeV γ-rays

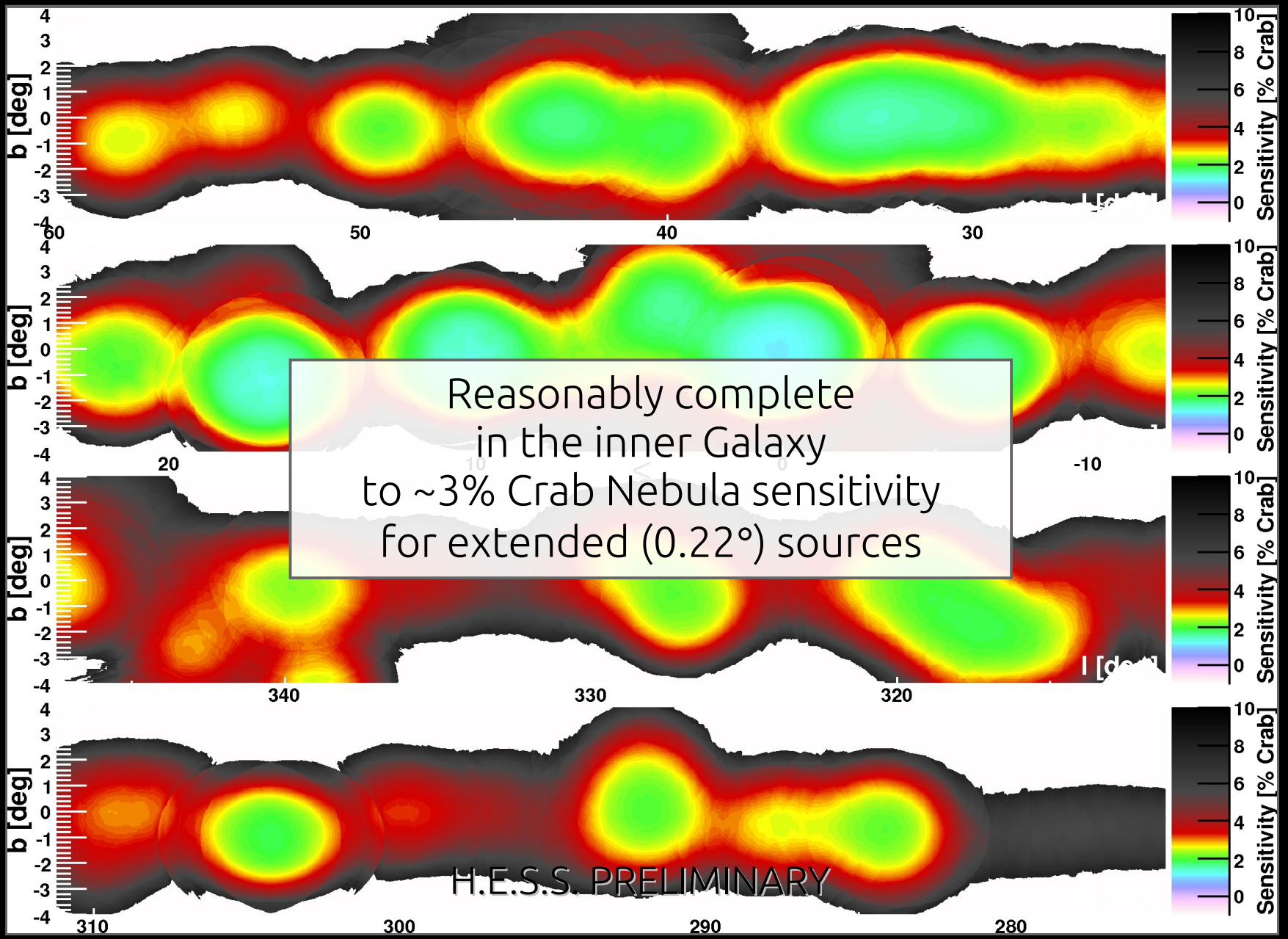


Chaves (H.E.S.S.) 2010

Completeness of TeV survey



Completeness of TeV survey



TeV-quiet ME SNRs

ME SNRs with no known TeV γ-ray counterpart:

G1.4-0.1
G5.4-1.2
G9.7-0.0
G16.7+0.1
G21.8-0.6 (Kes 69)
G31.9+0.0 (3C391)
G34.7-0.4 (W44)
G337.0-0.1 (CTB 33)
G337.8-0.1 (Kes 41)
G346.6-0.2
G349.7+0.2
G357.7+0.3 (Square)
G357.7-0.1 (Tornado)
G359.1-0.5

Faint (< ~3% Crab) in the TeV domain.

But H.E.S.S Galactic Plane Survey has good coverage of molecular ring at a nominal sensitivity ~3% Crab Nebula.

ME SNRs with no TeV γ-rays

Why?

Physical requirements to produce OH masers not satisfied
OH maser beamed out of line-of-sight

Only ~50% of these emit TeV γ-rays.
More thorough surveys?
or
OH masers an imperfect predictor of TeV emission?

CR escape from SNR → MC interaction (S. Gabici talk)
pursue other indicators, e.g. Class I methanol masers (c.f. D. Frail talk)
older MM SNRs cannot accelerate multi-TeV particles any longer?

Summary

OH masers reveal actual shocked SNR/MC interactions
TeV γ-rays can be produced in hadronic (p-p) SNR/MC interactions
→ Together can identify sources of CR interaction with the ISM

~50% of OH maser-emitting SNRs emit TeV γ-rays
Well-known: GC, W28, IC443, CTB 37A, W51C
Newer cases:
G359.1-0.5 & HESS J1745-303
G5.7-0.0 & HESS J1800-240C
G8.7-0.1 & HESS J1804-216
Kes 78 & HESS J1852-000

Future:
GeV-TeV morphology correlation
Broadband γ-ray spectra (*Fermi* + H.E.S.S.)
Detailed ^{13}CO studies (e.g. NANTEN2)