Leaked GeV CRs from a Broken Shell:

Explaining 9 Years of Fermi-LAT Data of SNR W28

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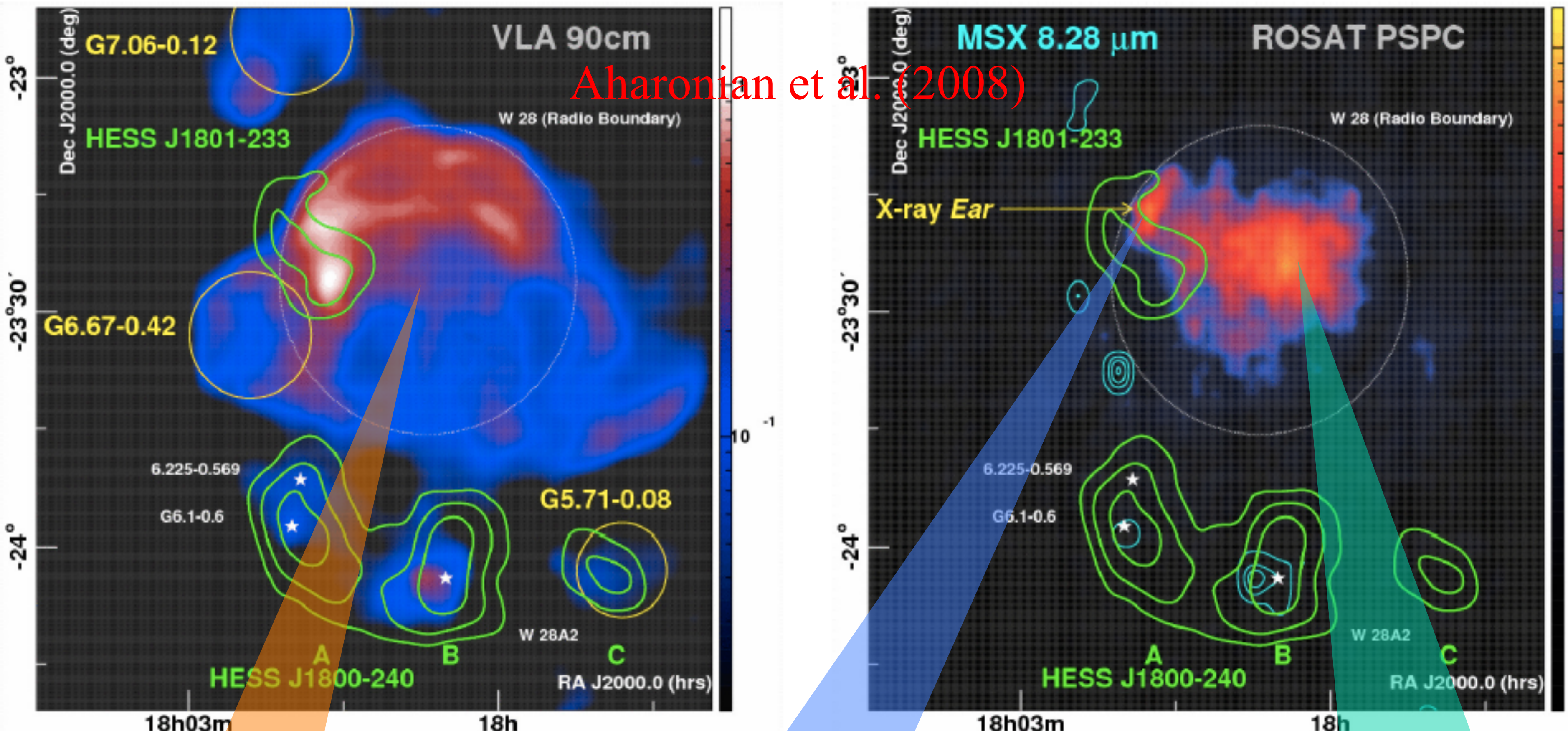
SNR W28 Radio & X-ray



Aharonian et al. (2008)

D~ 2kpc, with a radius of 13pc

~1keV 1Msun hot gas, ionization age ~>10 kyr, Zhou et. Al. 2016

~0.5keV 25Msun hot gas, ~ 30 kry, low elemental abundance. Zhou et al 2016

SNR W28 Masers

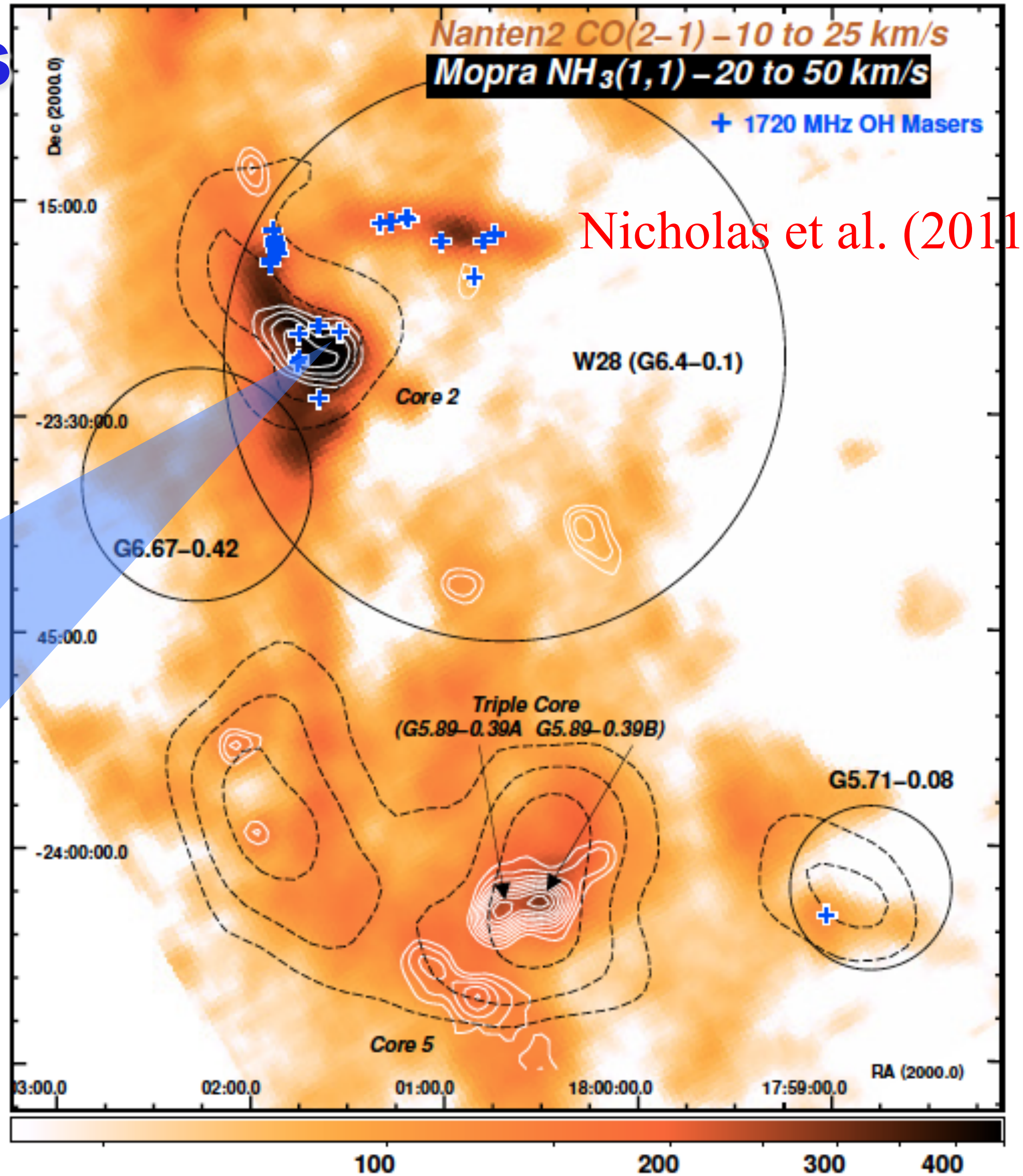
Clumps ~ $10^{3\text{-}5}$ cm^{-3}
Interclump medium ~ $5cm^{-3}$

Masers as The shock-MC encounter evidence

& evidence of ionized MC by leaked <1GeV CRs

DCO^+/HCO^+ abundance ratios, with IRAM 30m telescope, by Vaupre2014, A&A,568, A50;

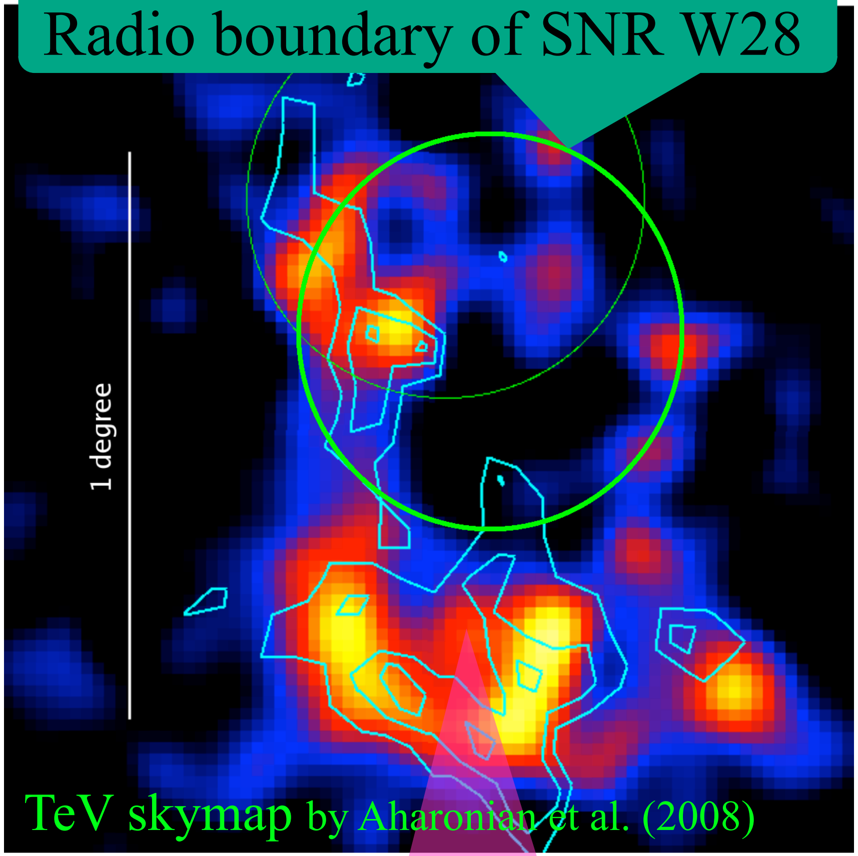
NH_3 lines, with Mopra radio telescope, by Maxted2016MNRAS462..532M;

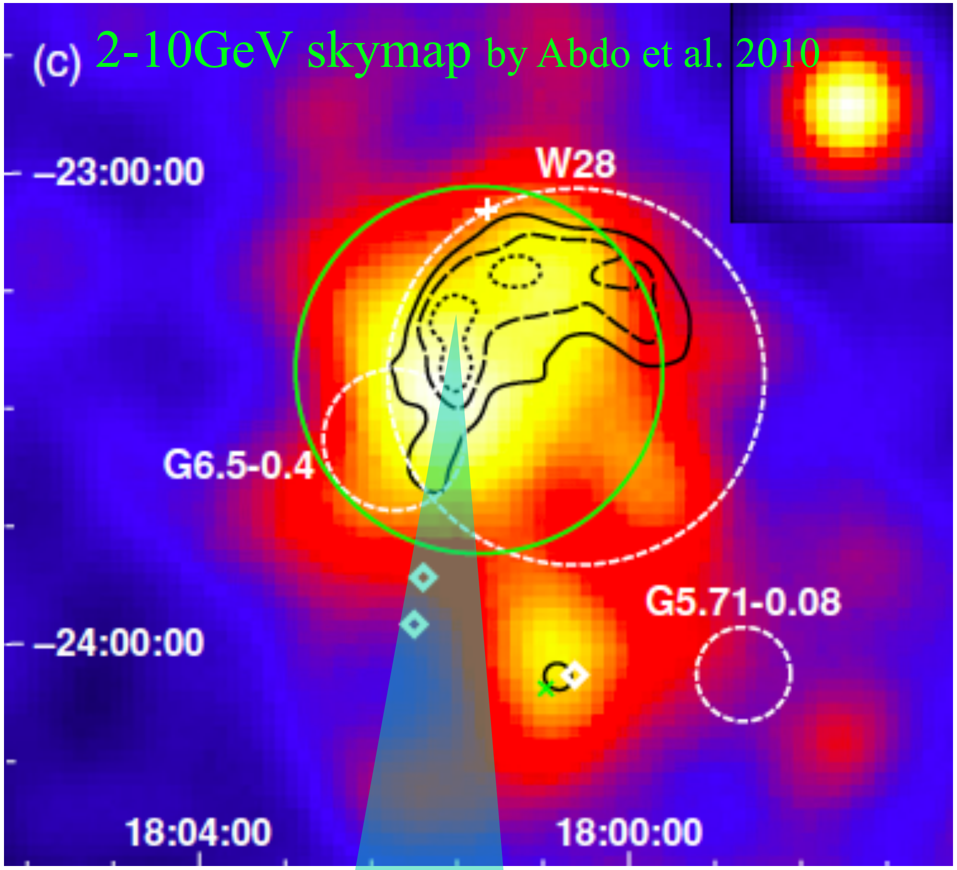


Nicholas et al. (2011)

SNR W28 TeV & GeV

Radio boundary of SNR W28

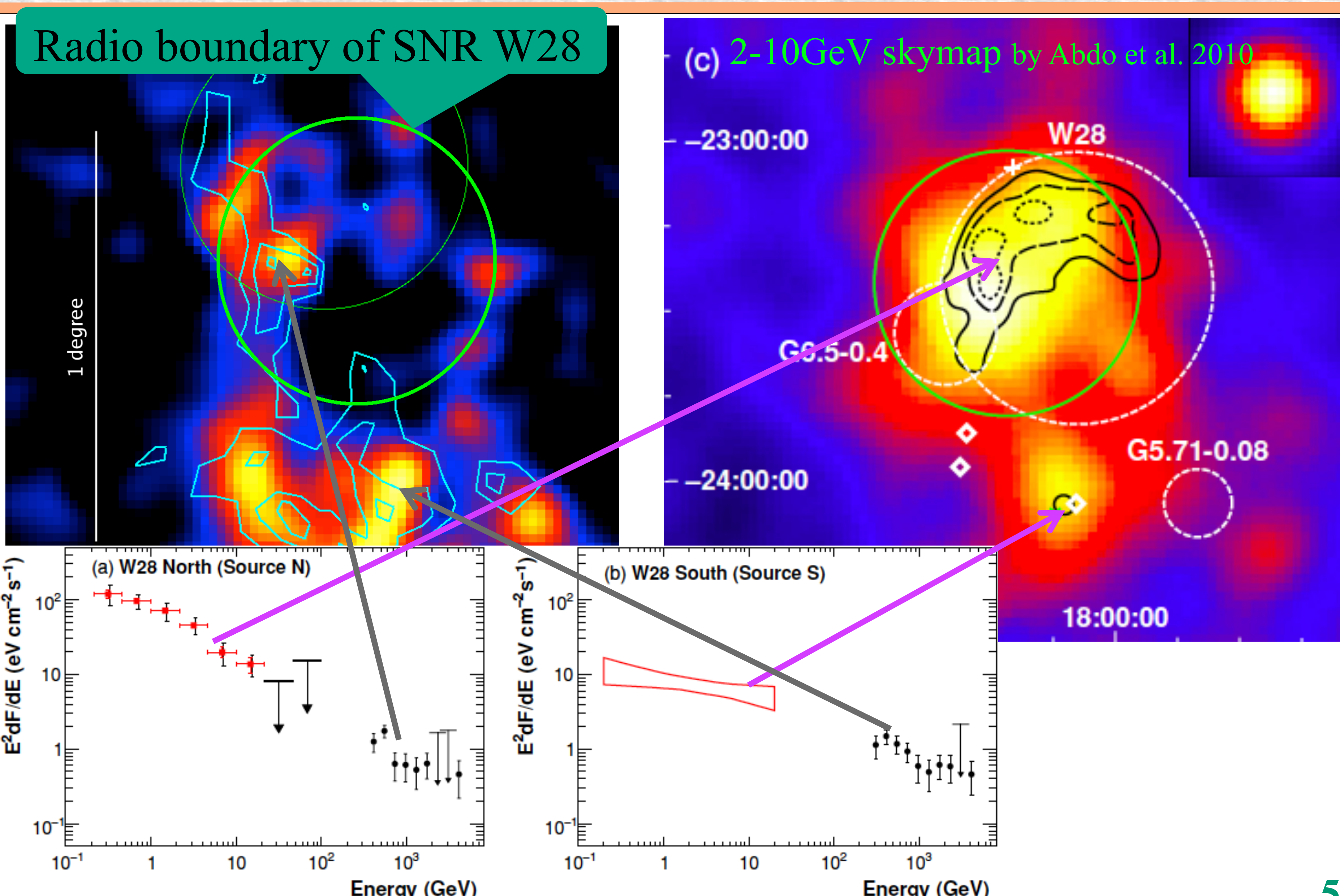


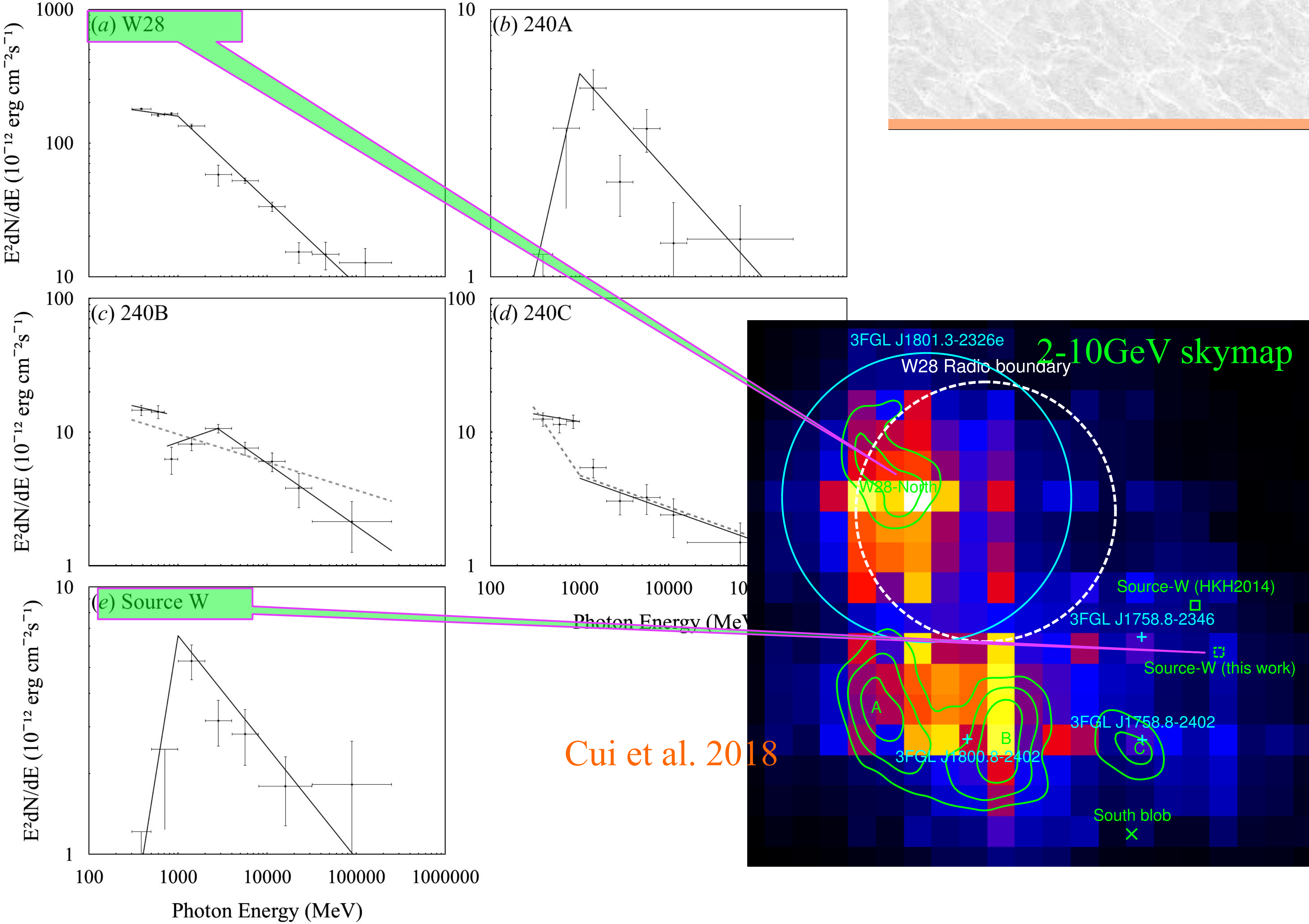


TeV CRs released in early stage diffuse Everywhere.

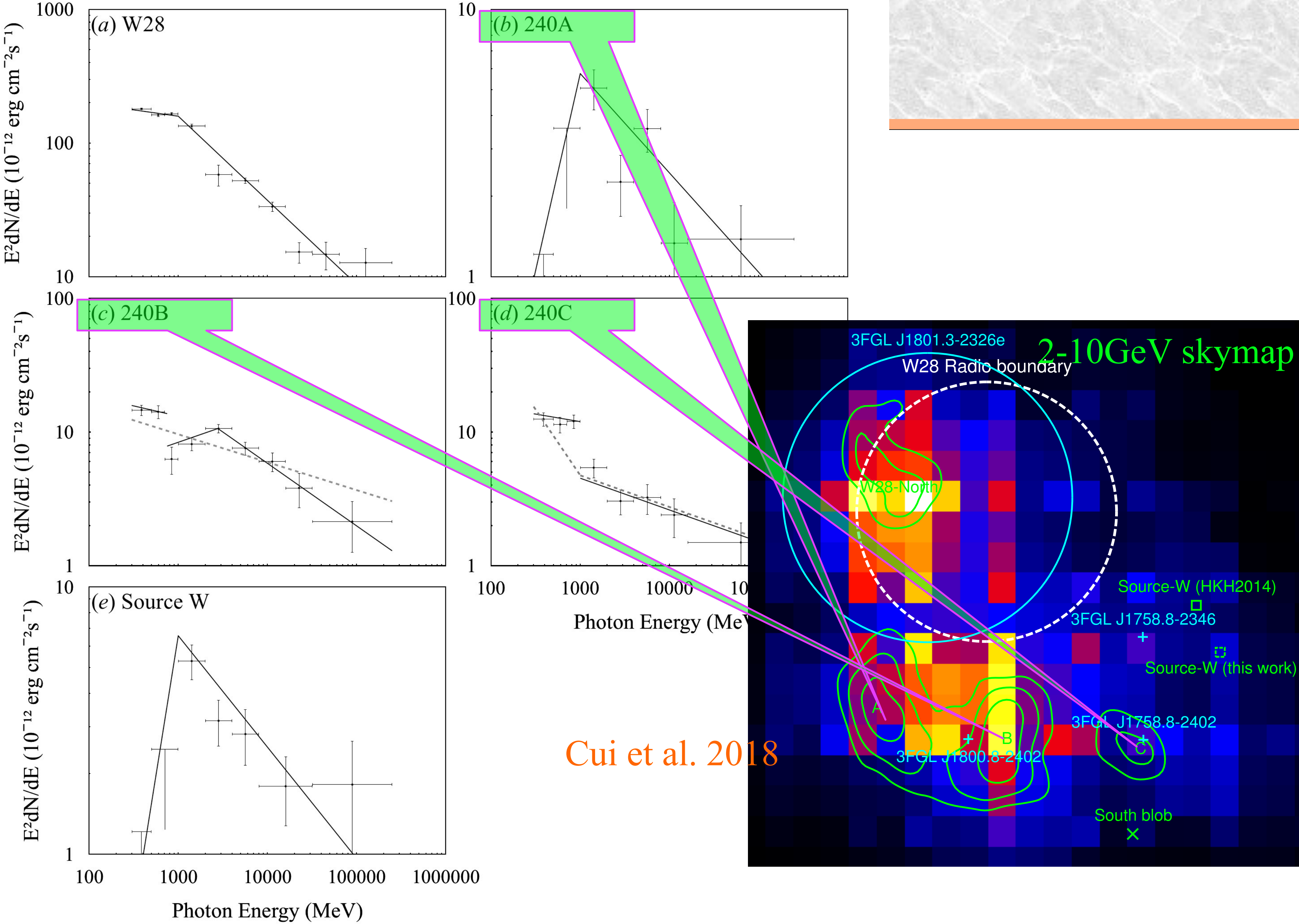
Part of the shock is stalled and the GeV CRs are leaking out.

SNR W28 TeV & GeV

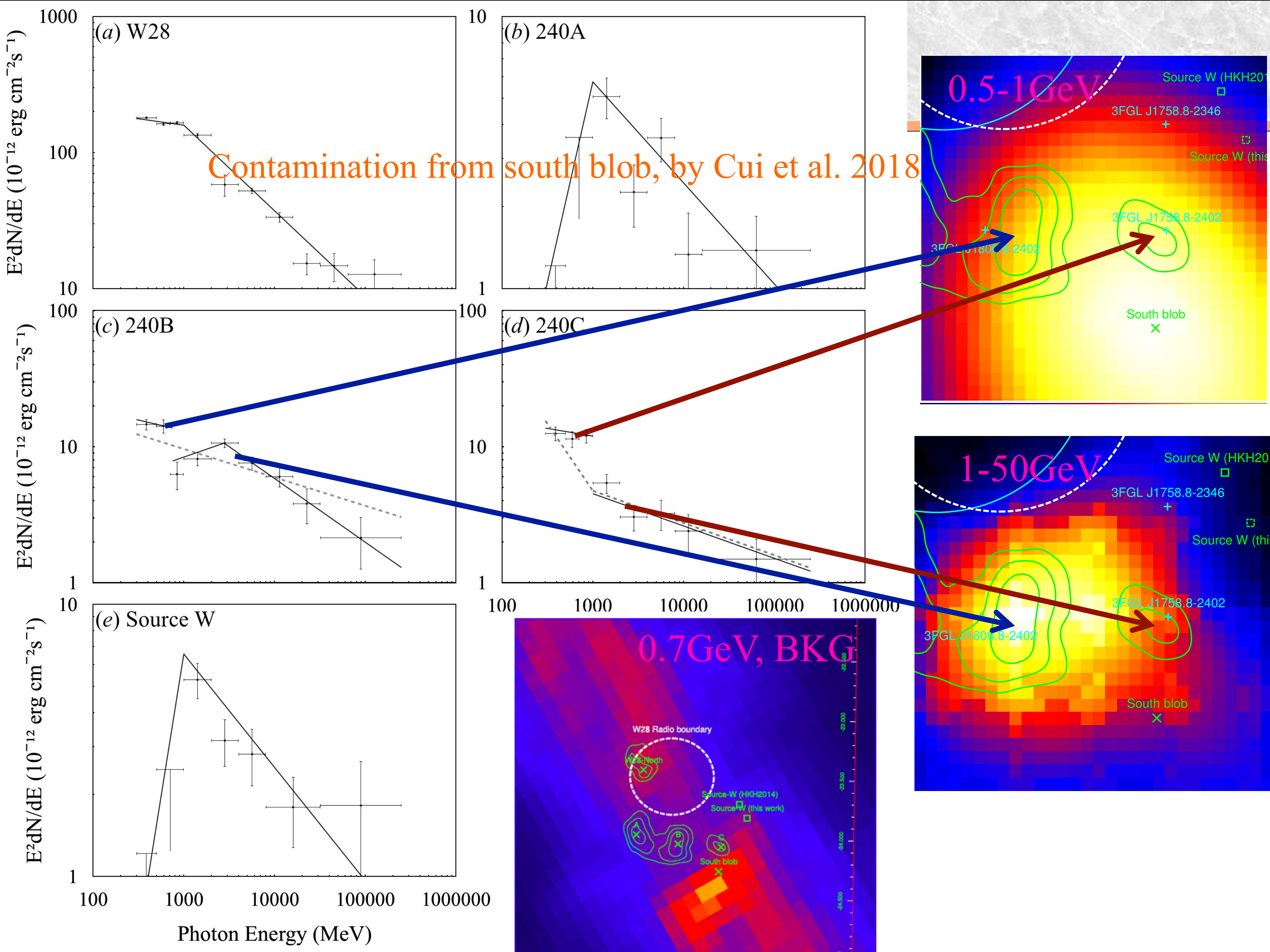




(a) W28
(b) 240A
(c) 240B
(d) 240C
(e) Source W
E²dN/dE (10⁻¹² erg cm⁻²s⁻¹)
Photon Energy (MeV)
2-10GeV skymap
3FGL J1801.3-2326e
W28 Radio boundary
W28-North
Source-W (HKH2014)
3FGL J1758.8-2346
Source-W (this work)
A
B
C
3FGL J1758.8-2402
3FGL J1800.8-2402
South blob
Cui et al. 2018

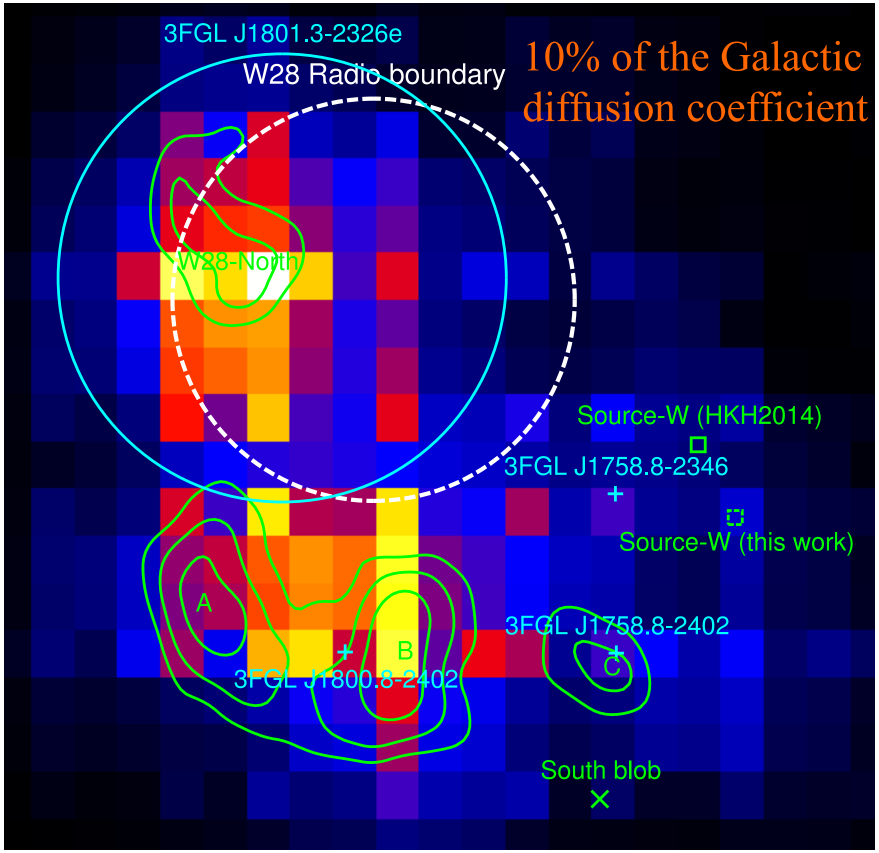


Cui et al. 2018


Contamination from south blob, by Cui et al. 2018
(a) W28
(b) 240A
(c) 240B
(d) 240C
(e) Source W
E²dN/dE (10⁻¹² erg cm⁻²s⁻¹)
Photon Energy (MeV)
1000
100
10
1
100
1000
10000
100000
1000000
0.5-1GeV
1-50GeV
0.7GeV, BKG
Source W (HKH201
3FGL J1758.8-2346
Source W (this
3FGL J1758.8-2402
South blob
W28 Radio boundary
Source-W (HKH2014)
Source-W (this work)

GeV-TeV CRs released from the SNR W28

	MC-N (5 M_4[a])	MC-A (4.3 M_4)	MC-B (6 M_4)	MC-C (2 M_4)
		Damping		
SNR center	13 pc	35 pc	31 pc	27 pc
W28-North	0~1 pc	37 pc	29 pc	28 pc
		Non-damping		
SNR center	13 pc	35 pc	28 pc	27 pc
W28-North	0~1 pc	33 pc	26 pc	25 pc

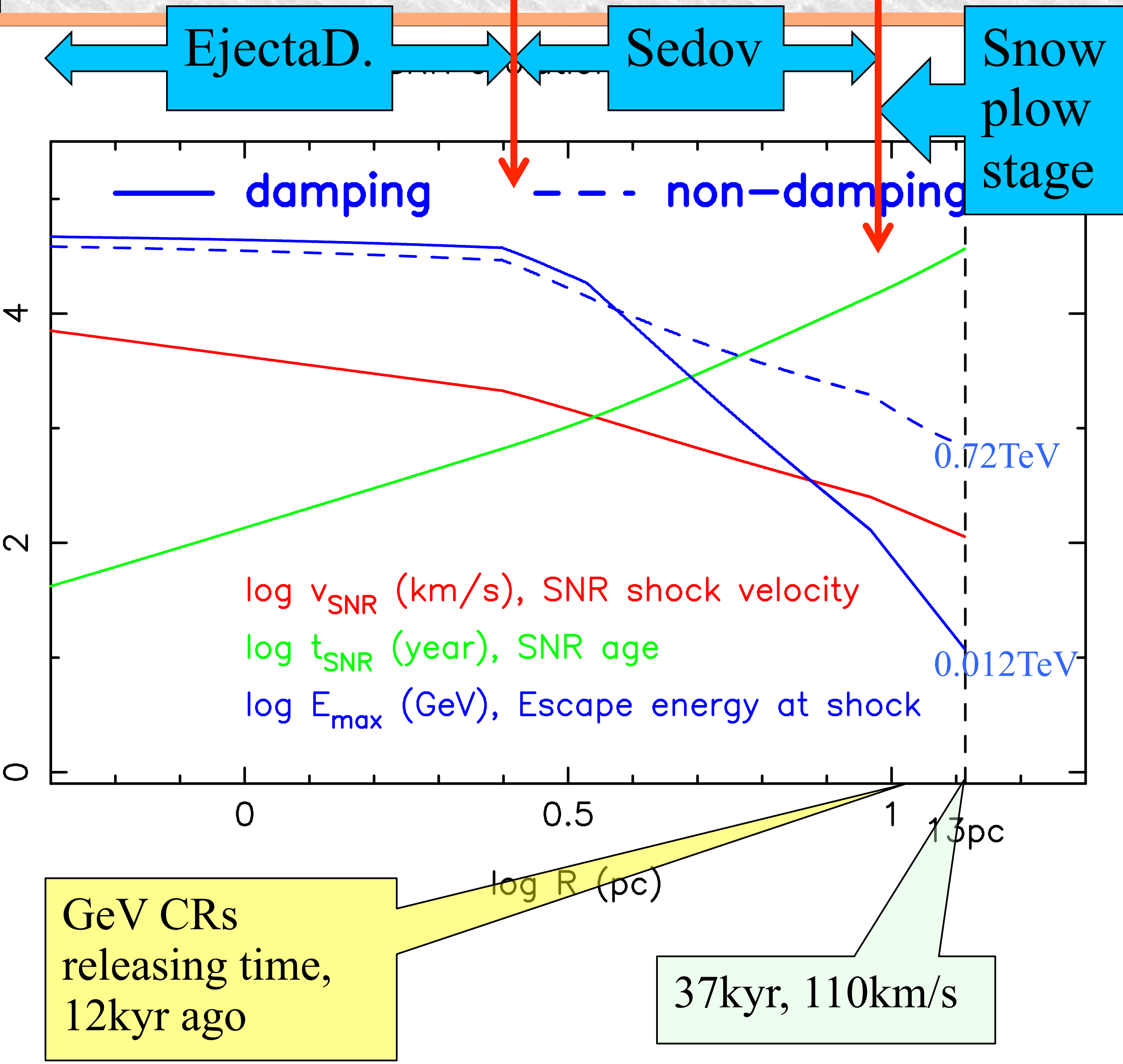


Run-away CRs from shock upstream ➔ dominating TeV band

Leaked CRs from W28-North 12kyr ago ➔ dominating GeV band

Galactic CR sea at 5kpc from GC ➔ dominating <10GeV band for 240ABC

SNR evolution

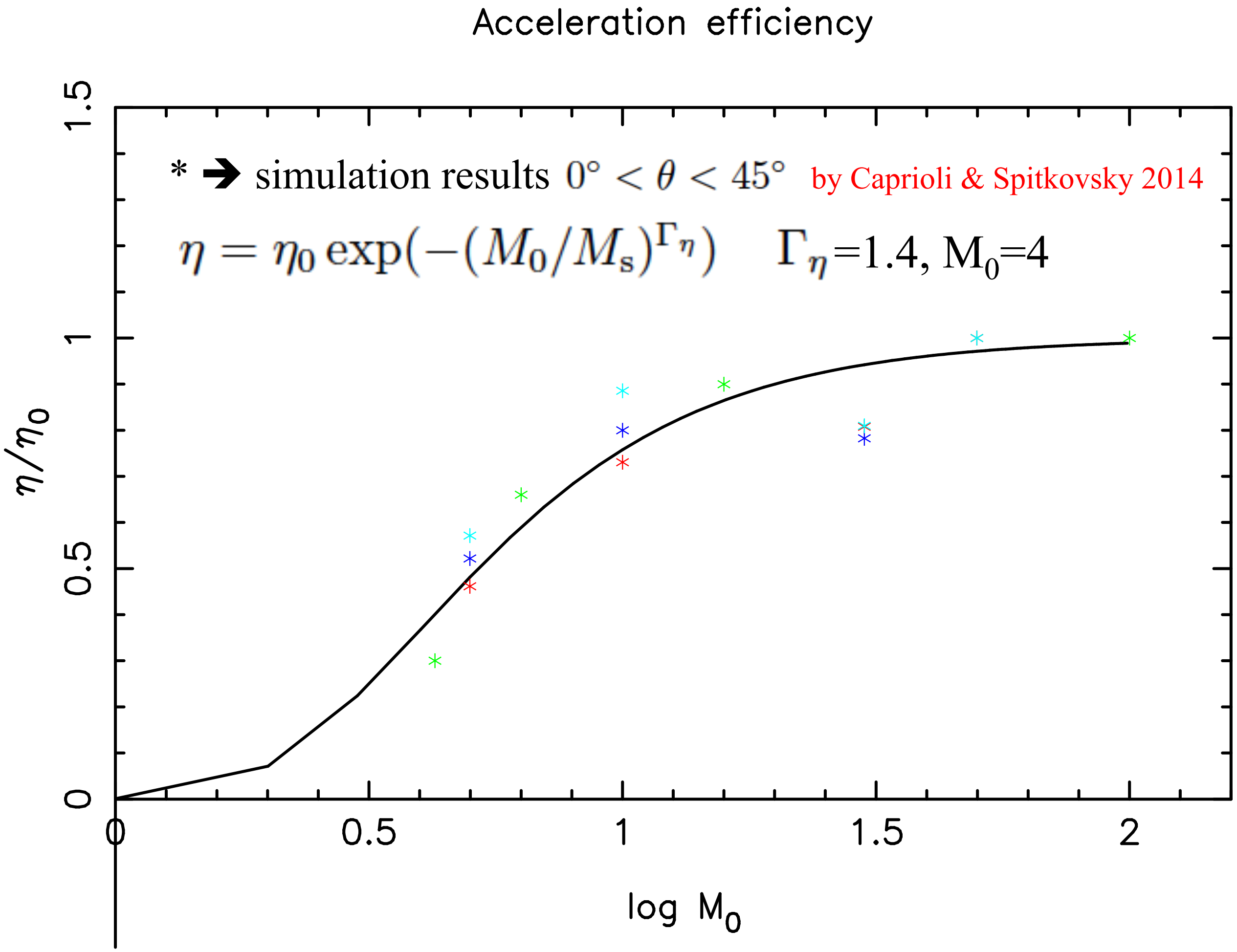


Assuming a typeIIP SN
8Msun scenario
6Msun ejecta mass

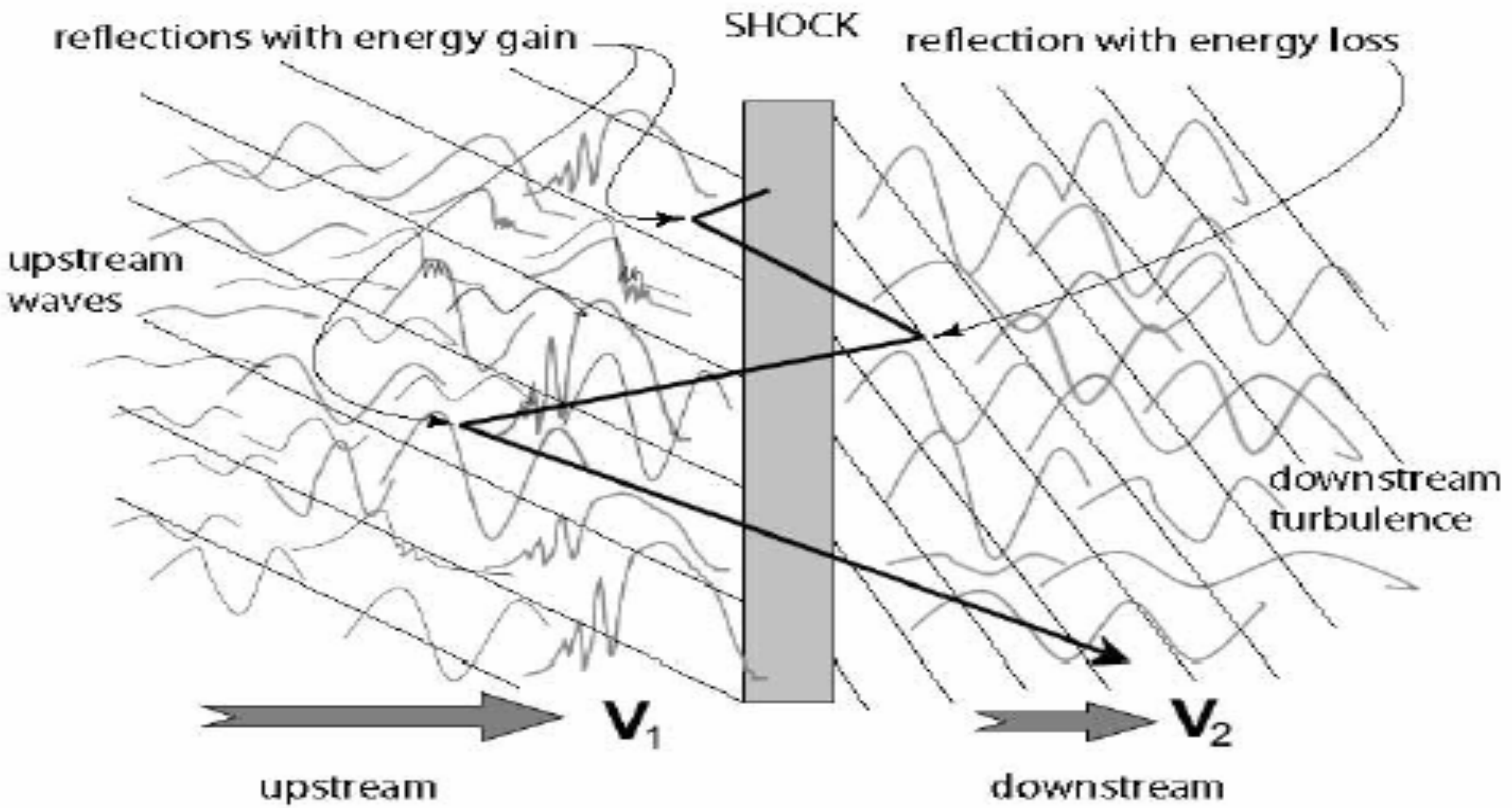
Expanding inside
Interclump medium
~5cm^{-3}

Old SNR➔
Damping of the magnetic waves by neutrals at upstream.
We use a Relationship from O'C Drury et al. 1996, Zirakashvili et al 2017.

Old SNR ➔ lower acceleration efficiency



CR acceleration at collisionless shock



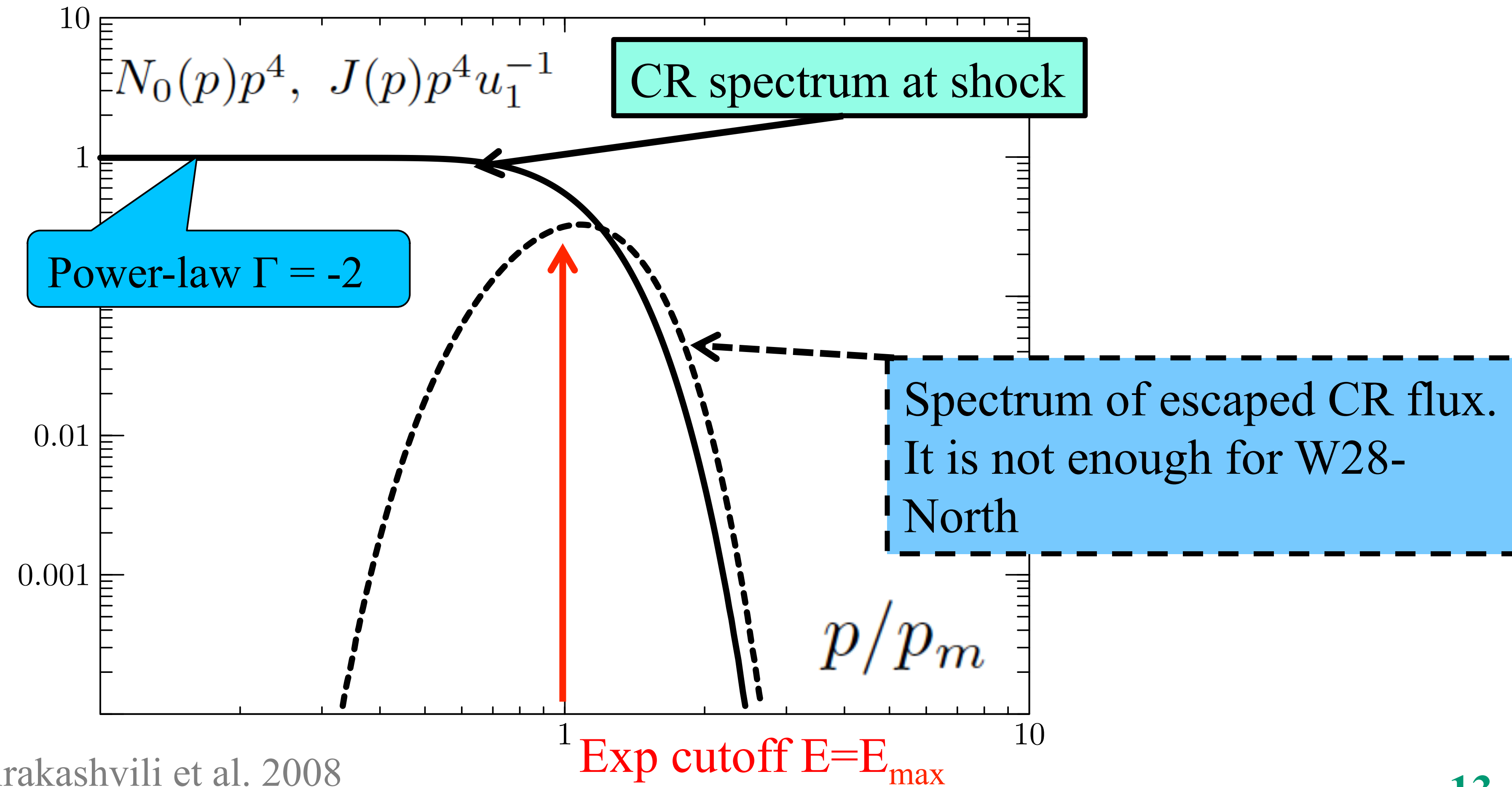
Treumann & Jaroschek (2008)

Particles swept away by the downstream flow ➔ power-law Γ ~ -2.
Particles escape from the upstream ➔ Exp cutoff E_{max} .

Trapping the CRs at the shock

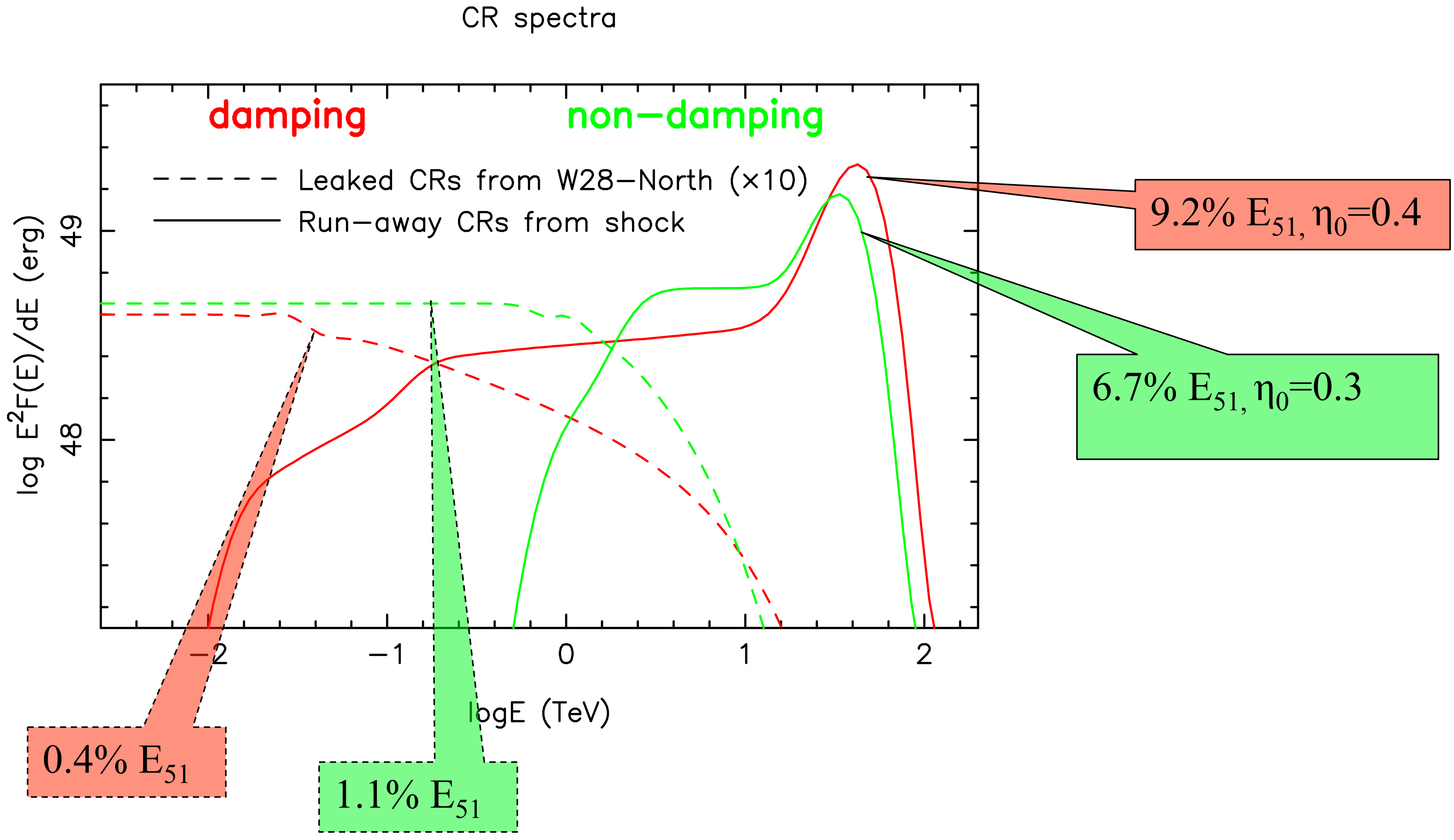
Non-resonant instability ➔ quickly amplify the magnetic turbulence in upstream

This theory is well established in both numerical simulation and analytical approximation. (Bell 2004; Zirakashvili & Ptuskin 2008)

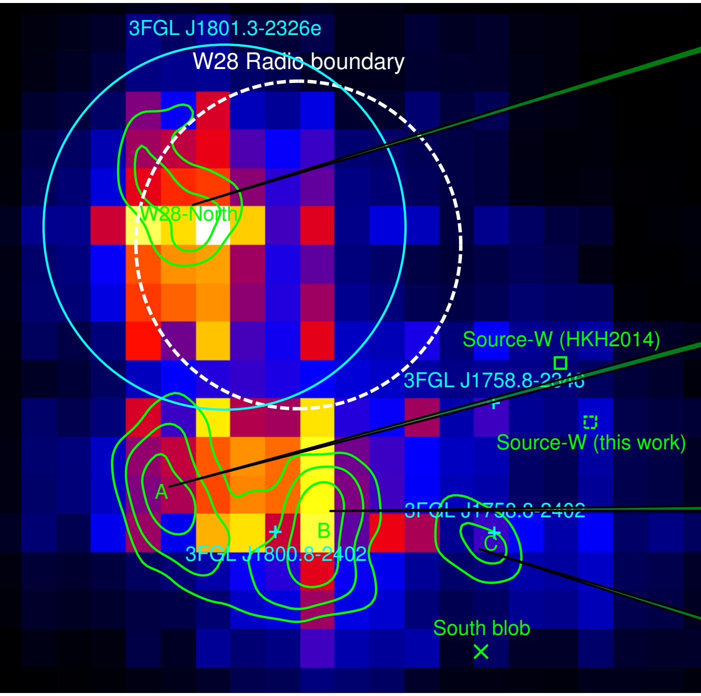


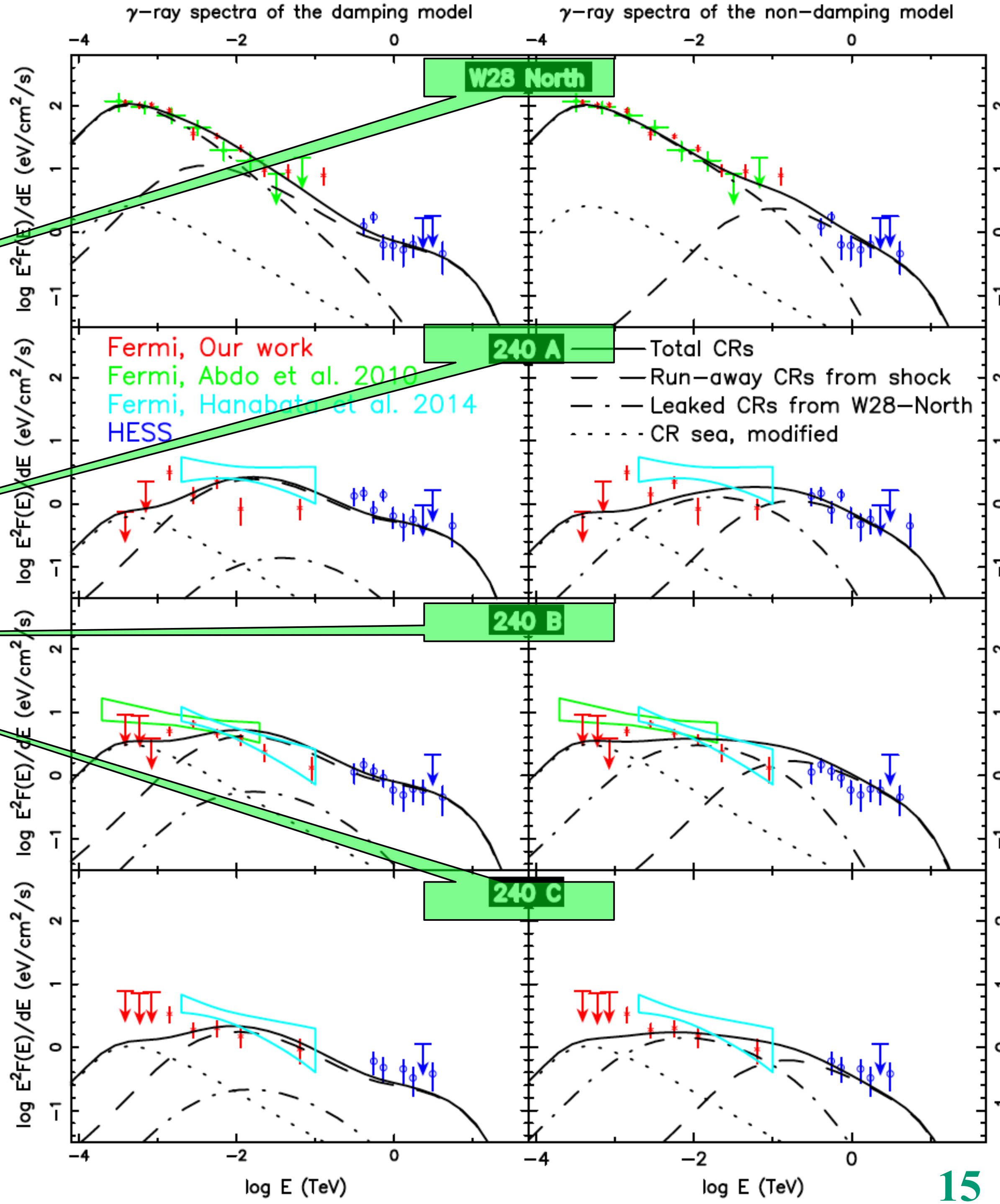
Zirakashvili et al. 2008

Run-away CRs VS Leaked CRs

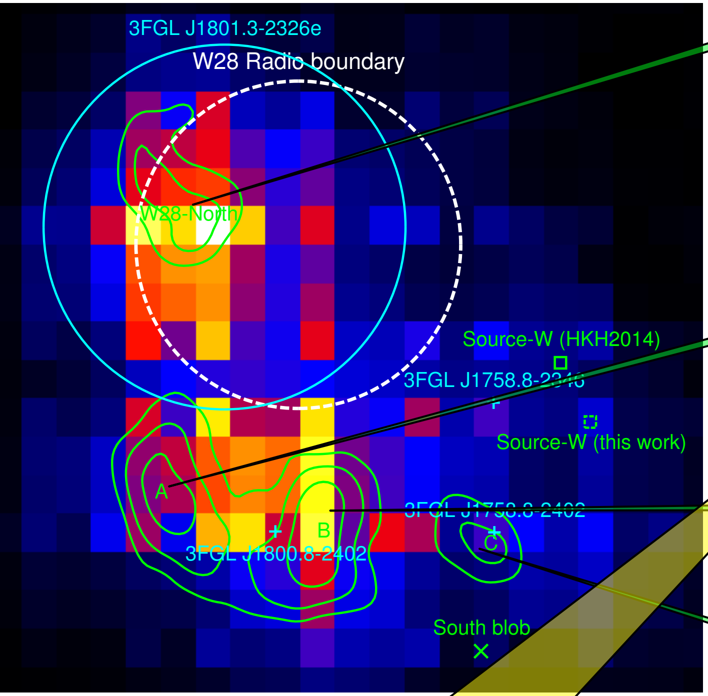


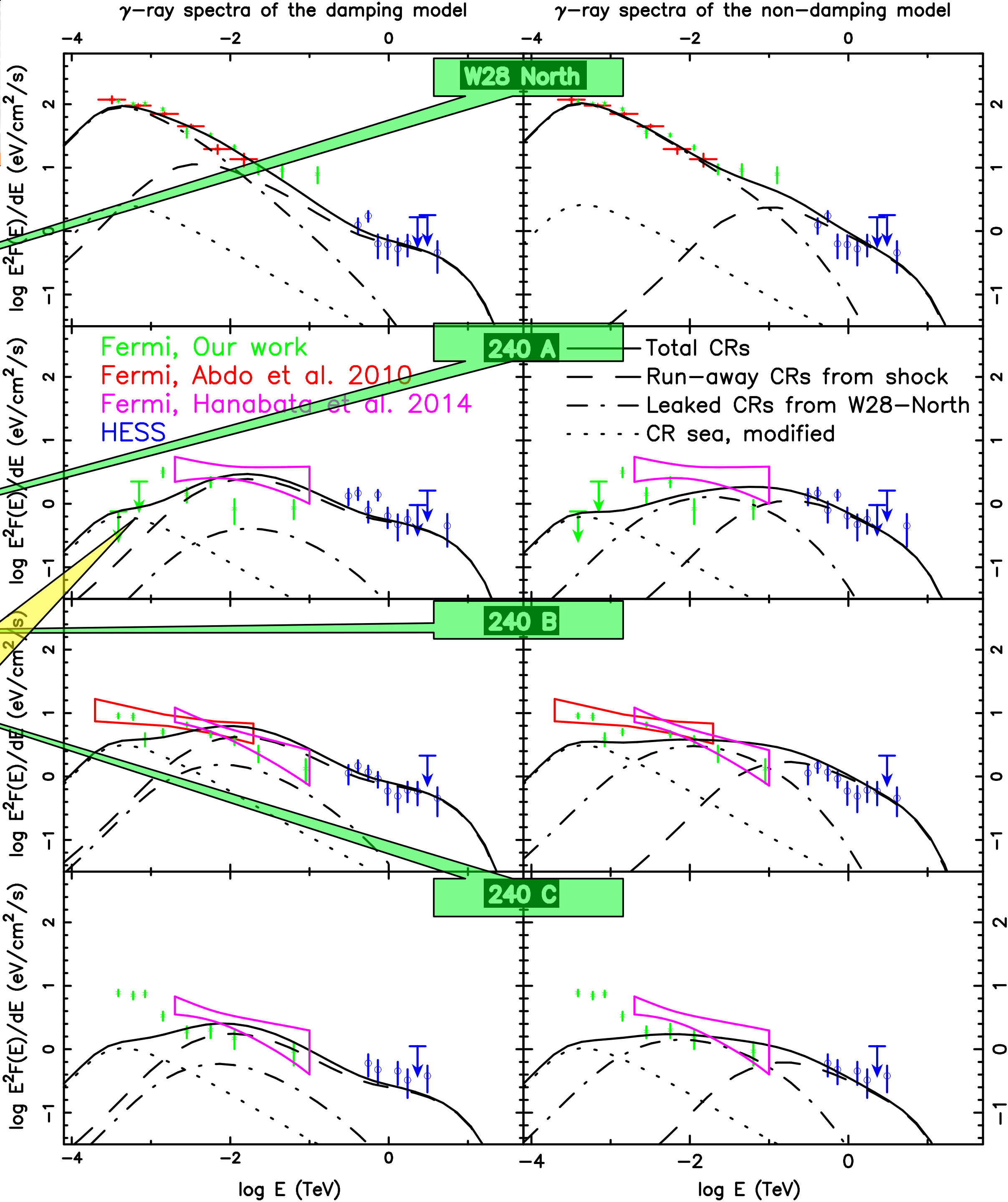
Averaged CR sea





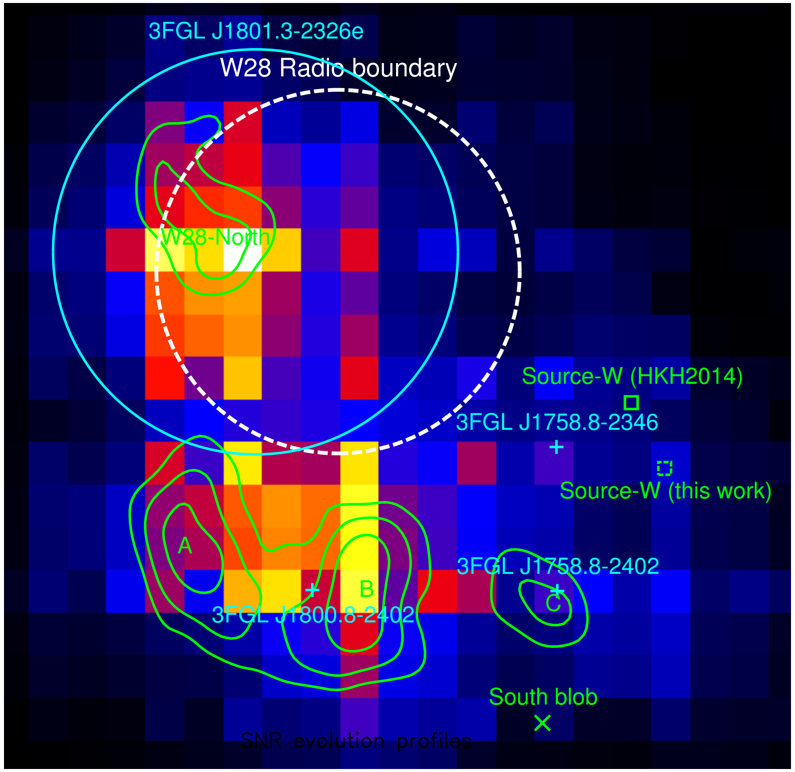
Clumpy CR sea

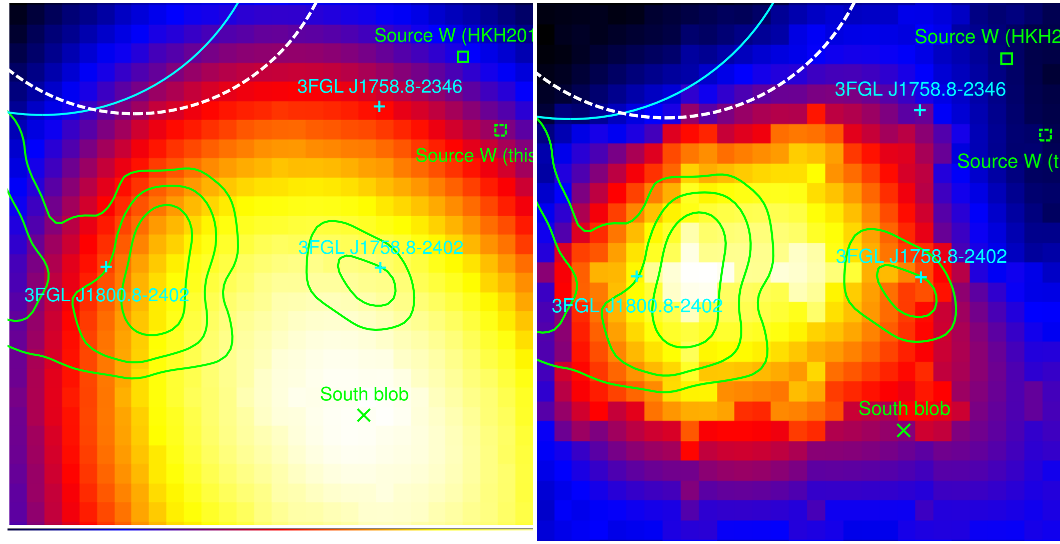




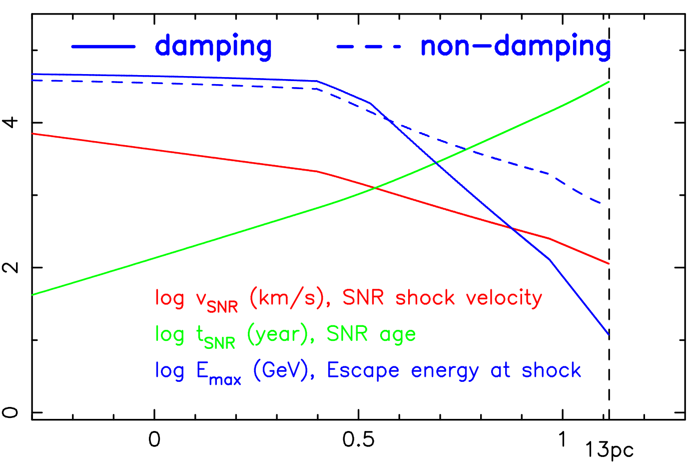
240A need 14% of the averaged CR sea.
If we put MC-A further from Earth ➔ closer to GC ☹

Summary

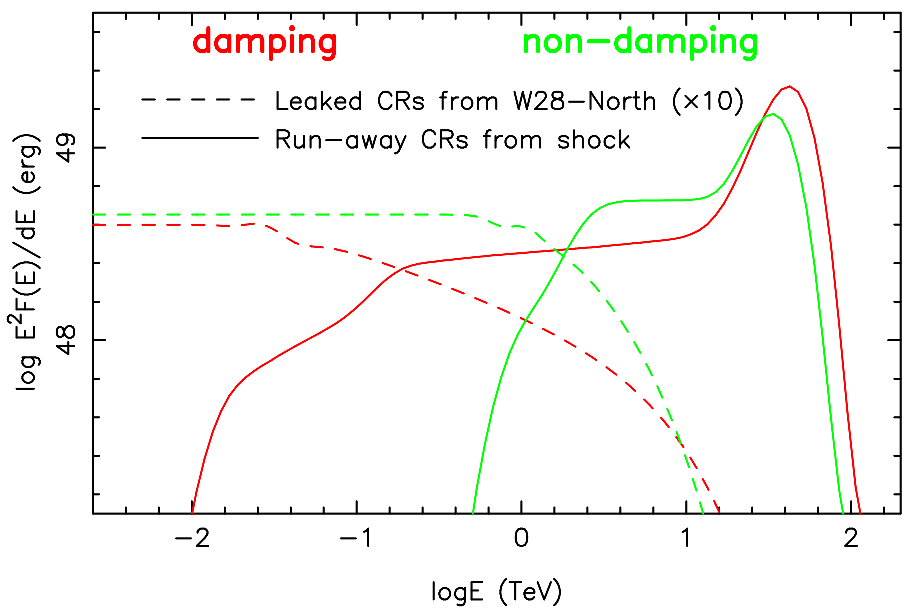




SNR evolution profiles



CR spectra



CR distribution inside the SNR