

Leaked GeV CRs from a Broken Shell: Explaining 9 Years of Fermi-LAT Data of SNR W28

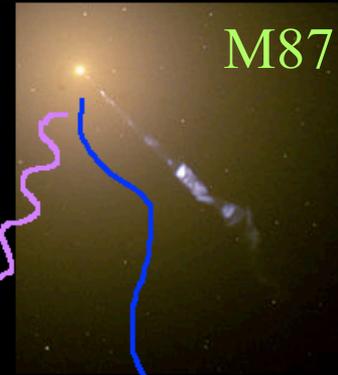
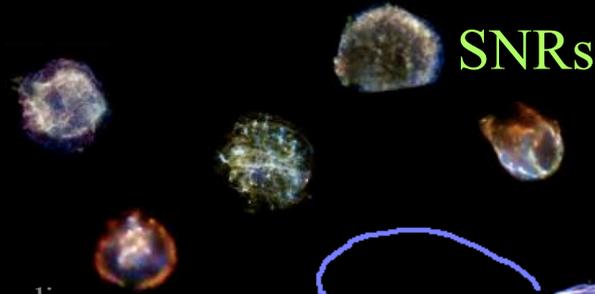
Very High Energy Phenomena in the Universe - 2018
Rencontres du Vietnam

崔昱东(Yudong Cui)

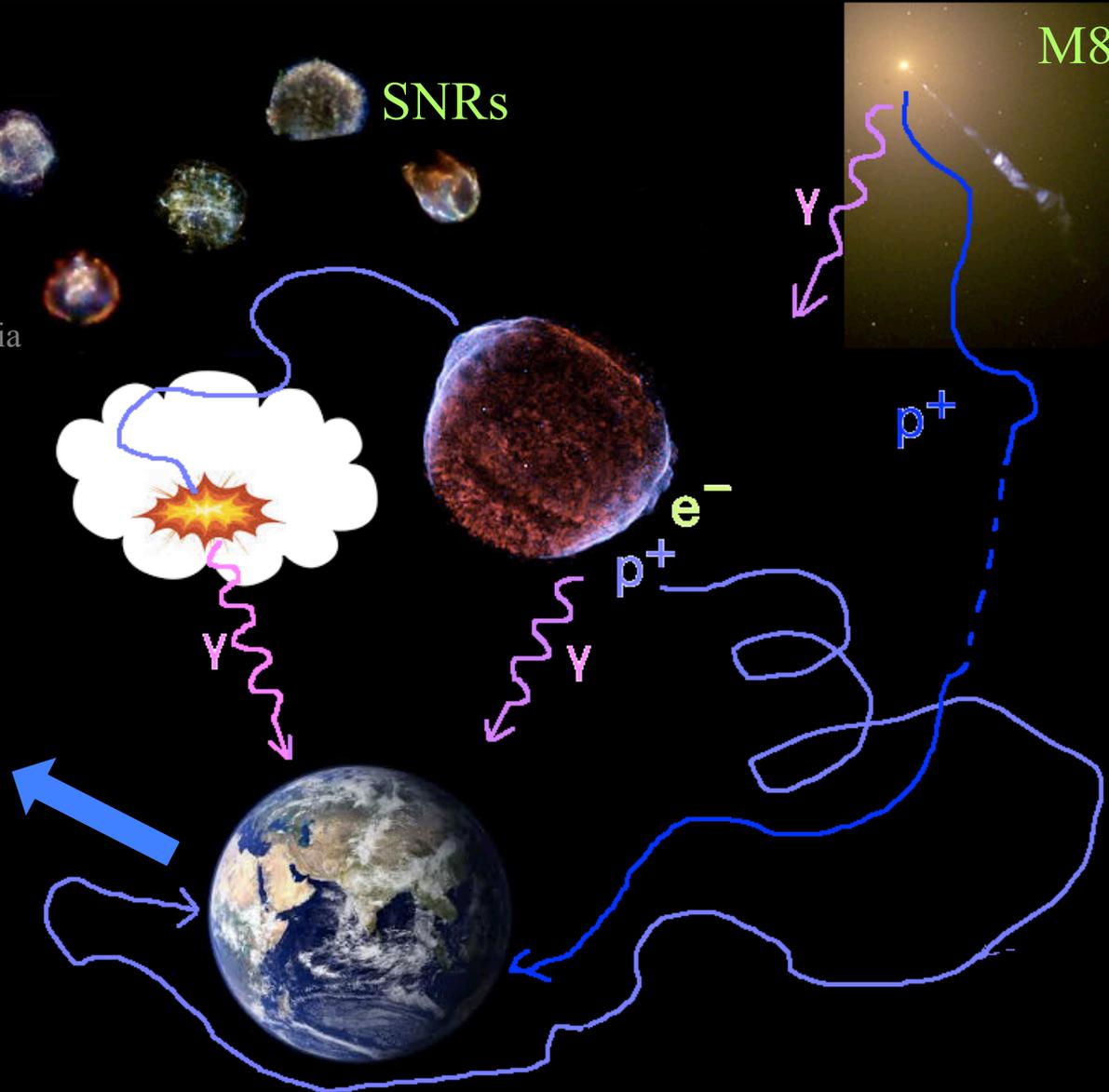
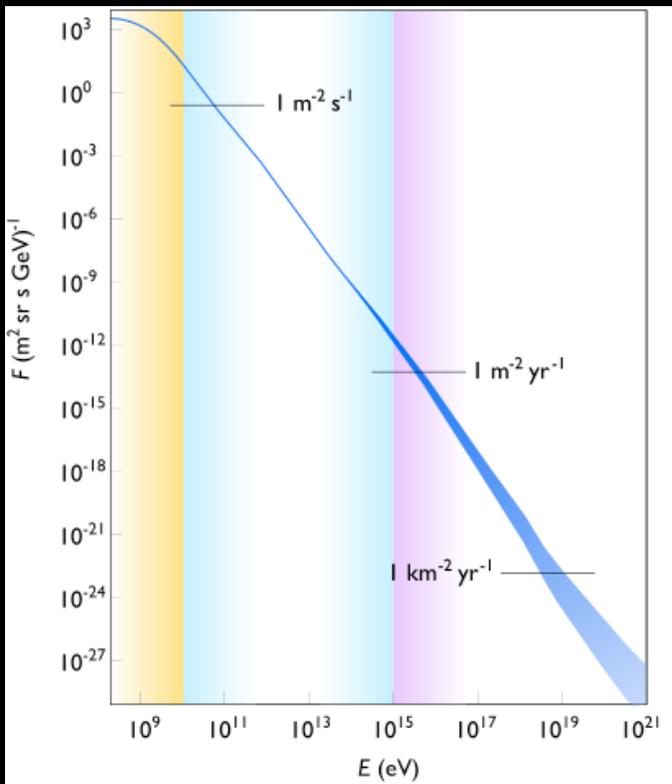
Paul Yeung, 谭柏轩(Thomas Tam), Gerd Pühlhofer

中山大学(Sun Yat-sen U)

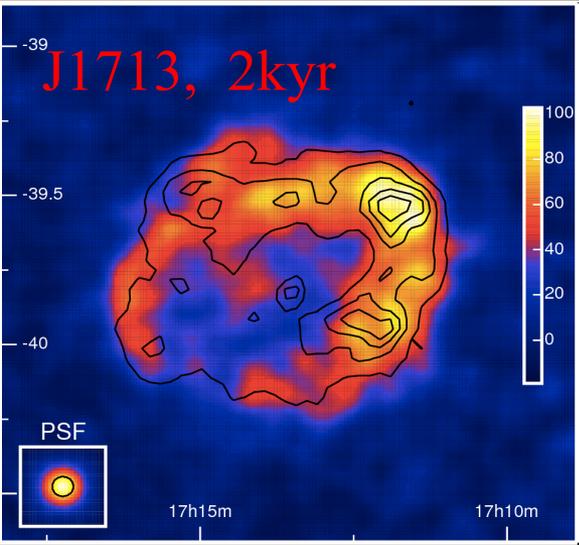
Cosmic ray (CR) sources



CR spectrum at Earth Credit Wikipedia



TeV SNRs - Young and middle-aged



J1713, 2kyr

2006A&A...449..223A

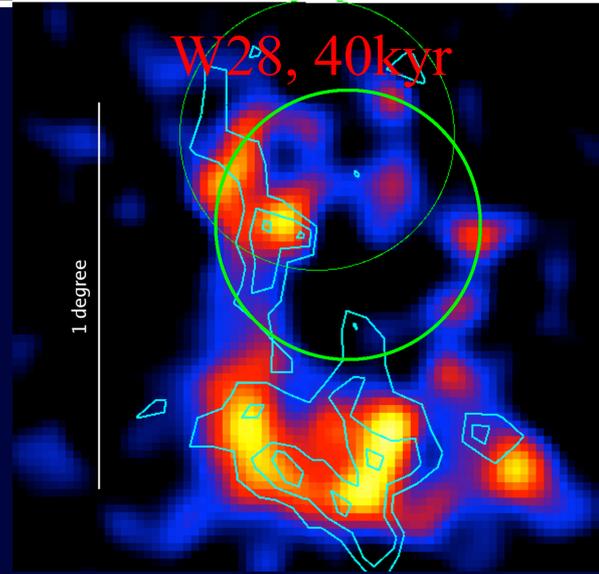
Active shock
X-ray & γ -ray

Only highest energy
CRs released

No clear shock
X-ray & γ -ray

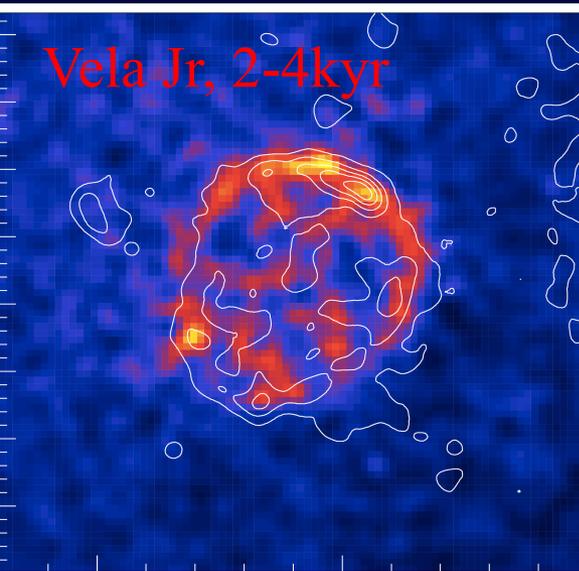
Most
CRs released

VS



W28, 40kyr

2008A&A...481..401A

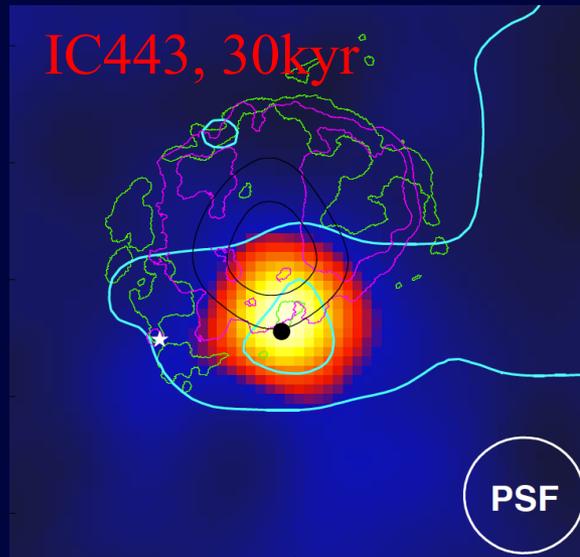


Vela Jr, 2-4kyr

2007ApJ...661..236A

X-ray & TeV
Matching

Cold gas & TeV
Matching



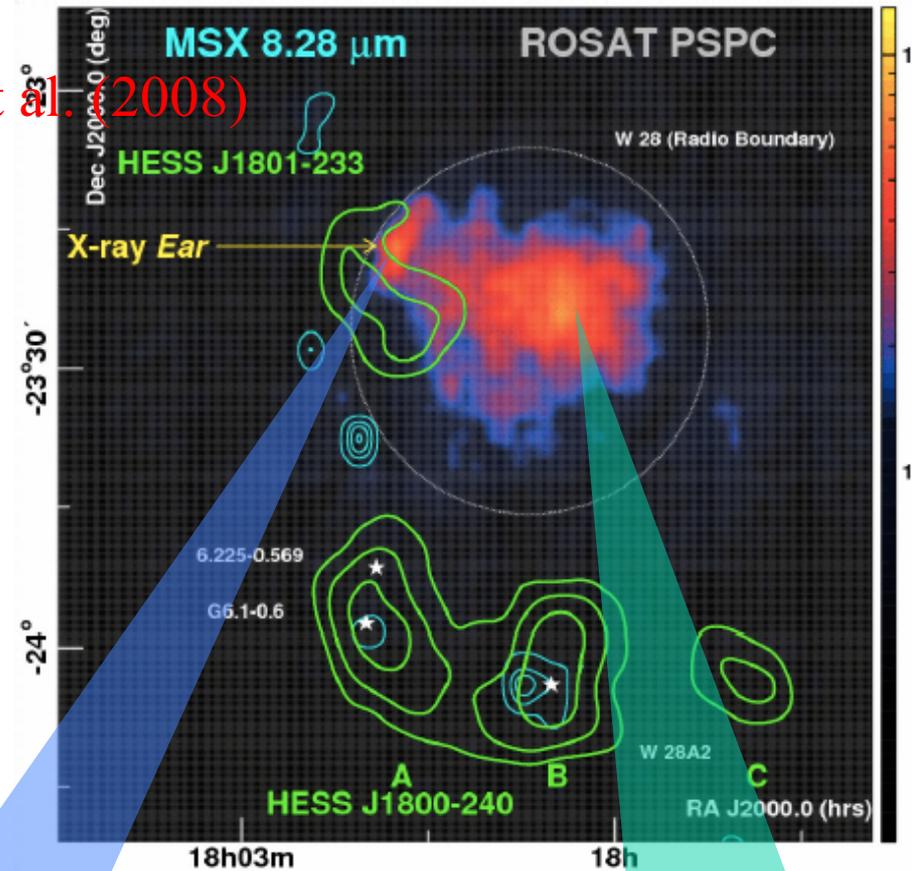
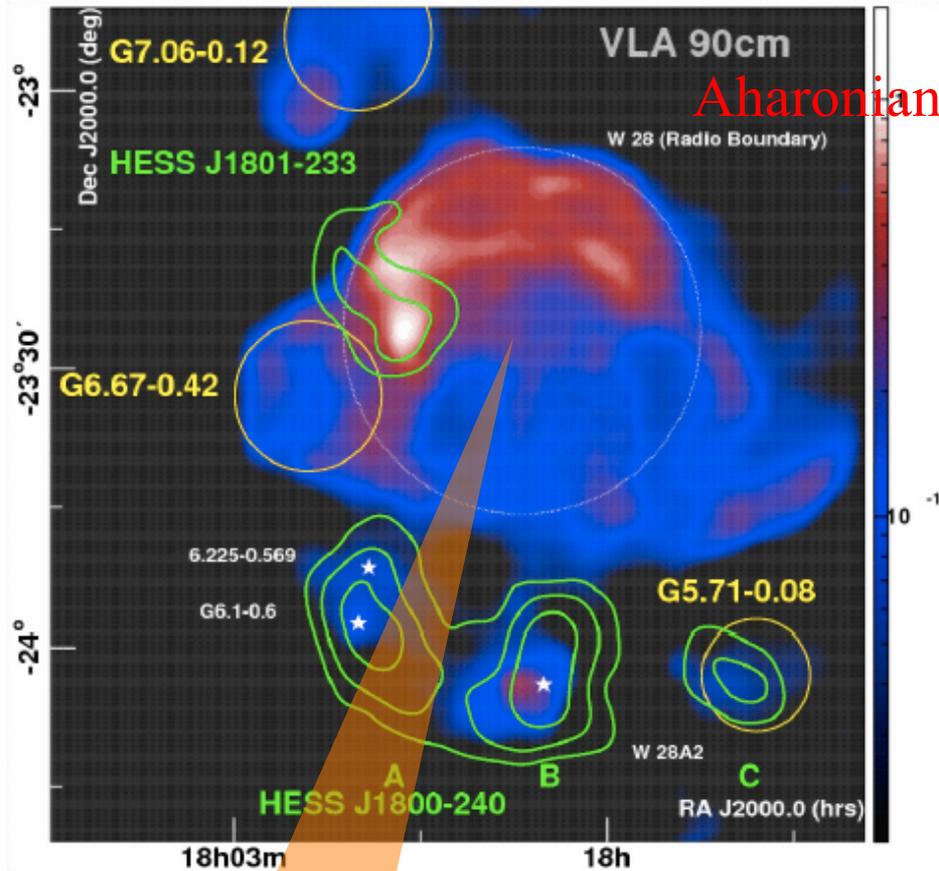
IC443, 30kyr

2007ApJ, 664, L87

PSF

SNR W28

Radio & X-ray



$D \sim 2 \text{ kpc}$, with a radius of 13 pc

$\sim 1 \text{ keV}$ $1 M_{\text{sun}}$ hot gas, ionization age $\sim > 10 \text{ kyr}$, Zhou et al. 2016

$\sim 0.5 \text{ keV}$ $25 M_{\text{sun}}$ hot gas, $\sim 30 \text{ kyr}$, low elemental abundance. Zhou et al 2016

SNR W28 Masers

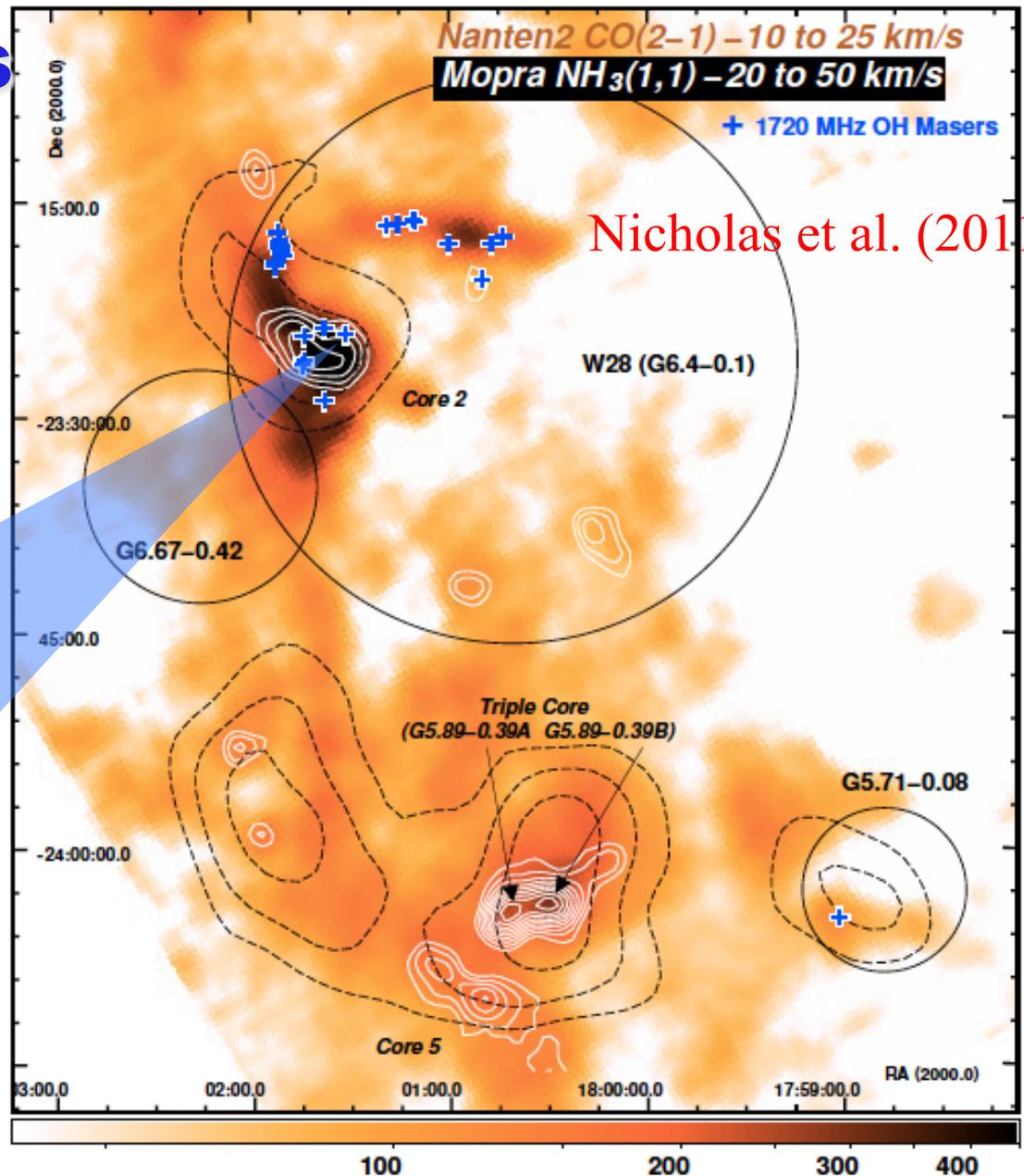
Clumps $\sim 10^{3-5} \text{ cm}^{-3}$
Interclump medium $\sim 5 \text{ cm}^{-3}$

Masers as The shock-MC
encounter evidence

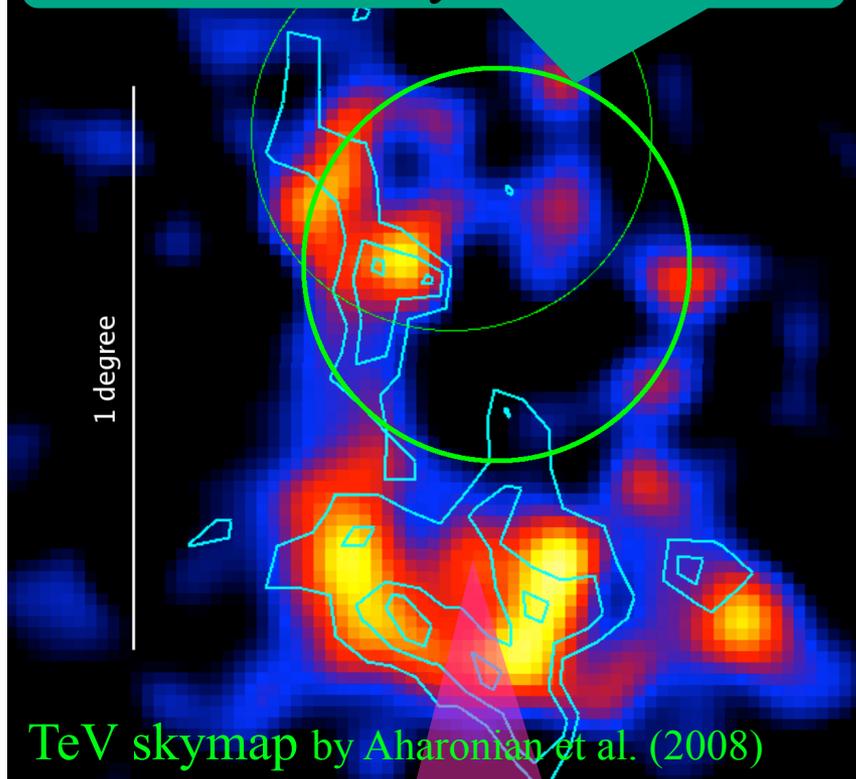
**& evidence of ionized MC by
leaked $<1 \text{ GeV}$ CRs**

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

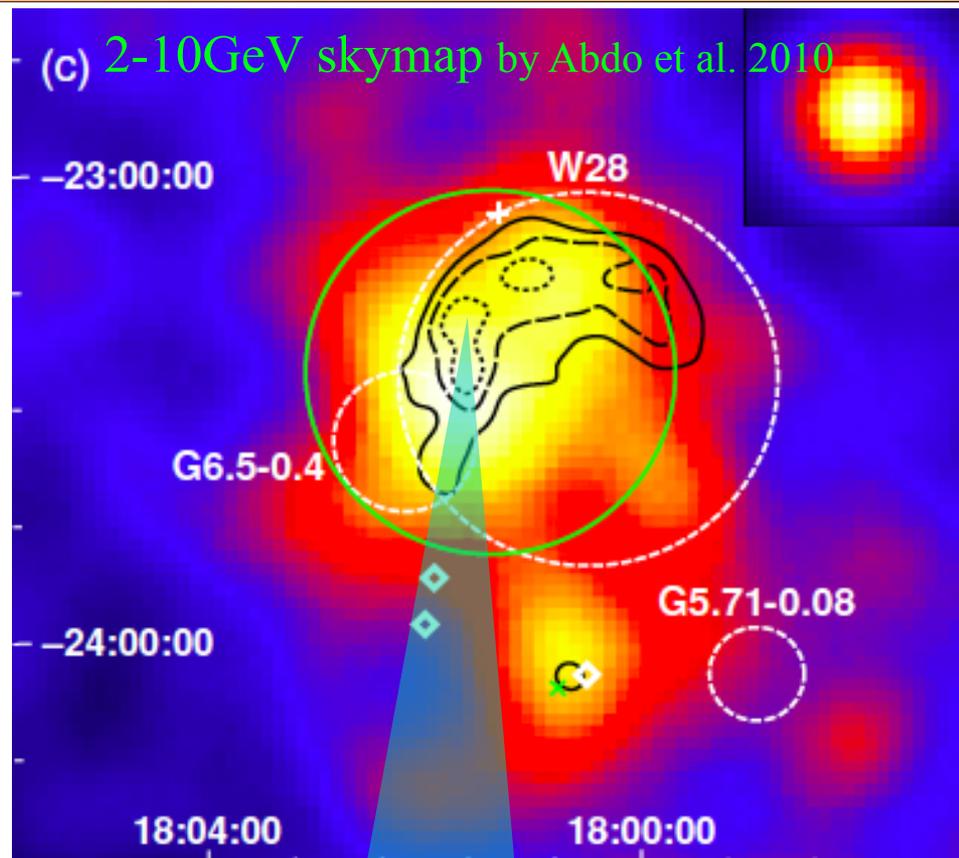
NH₃ lines, with Mopra radio
telescope, by
Maxted2016MNRAS462..532M;



Radio boundary of SNR W28



TeV CRs released in early stage diffuse Everywhere.

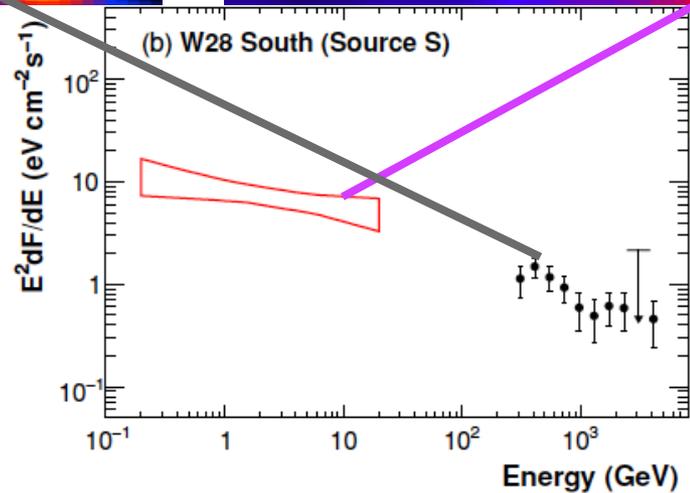
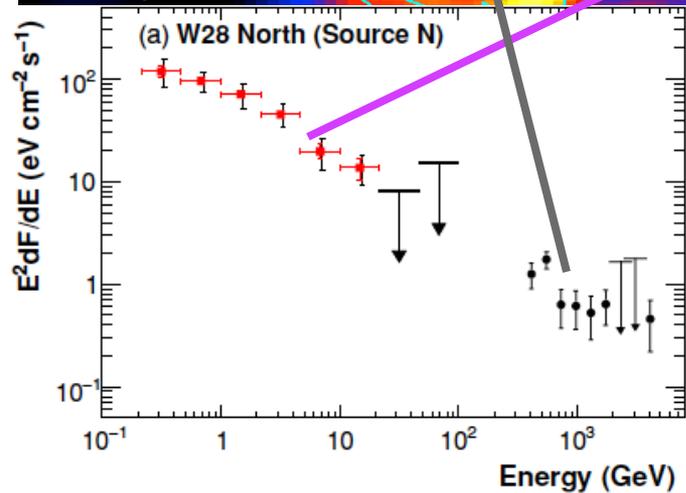
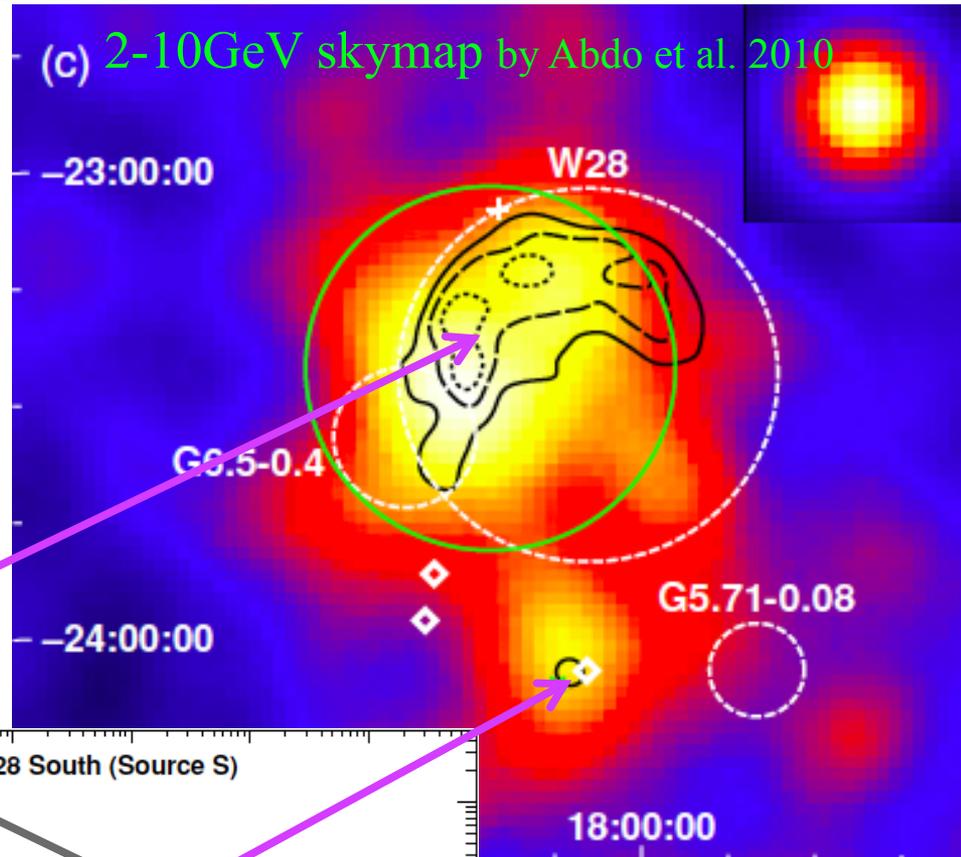
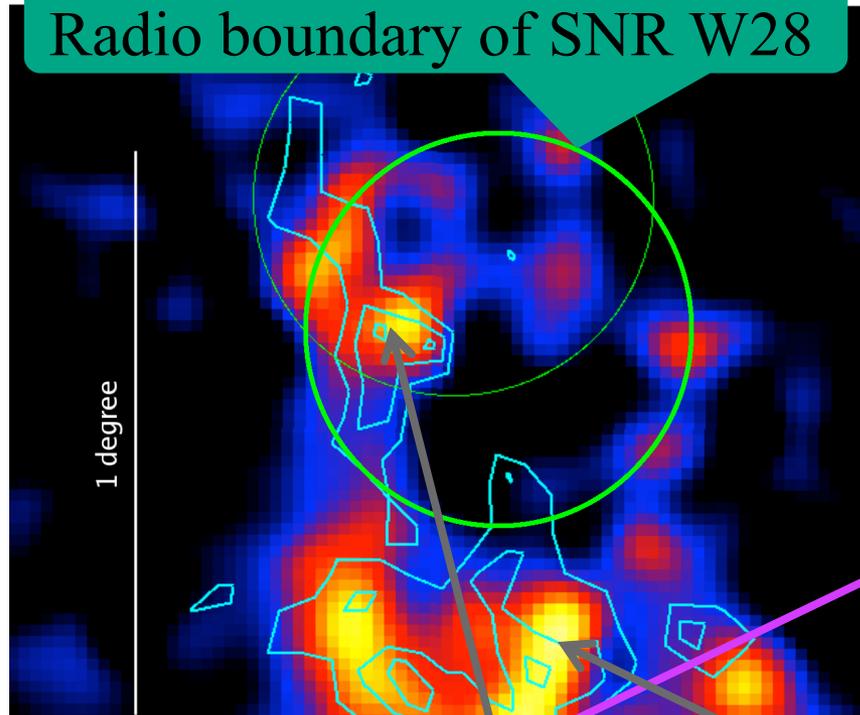


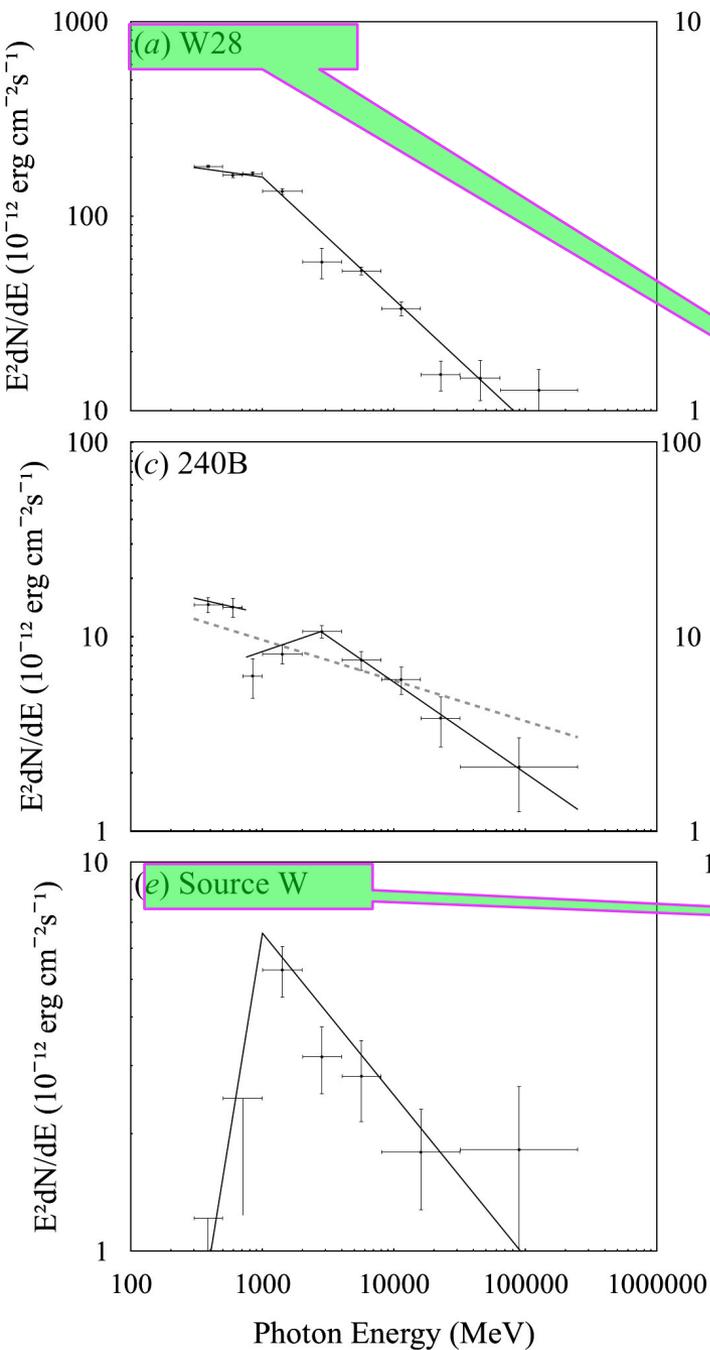
Part of the shock is stalled and the GeV CRs are leaking out.

SNR W28

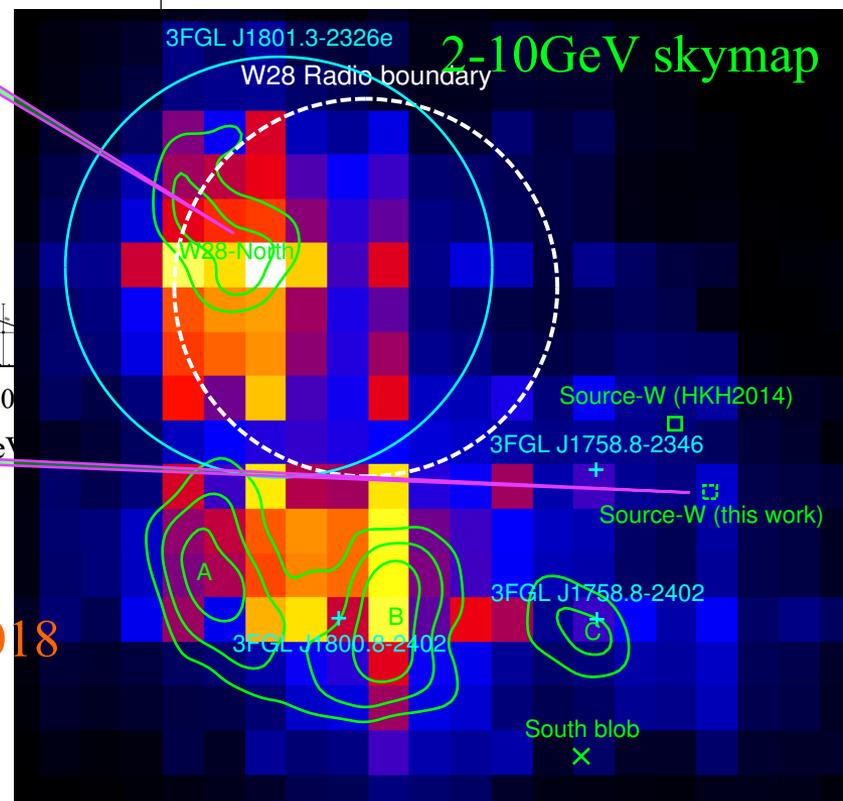
TeV & GeV

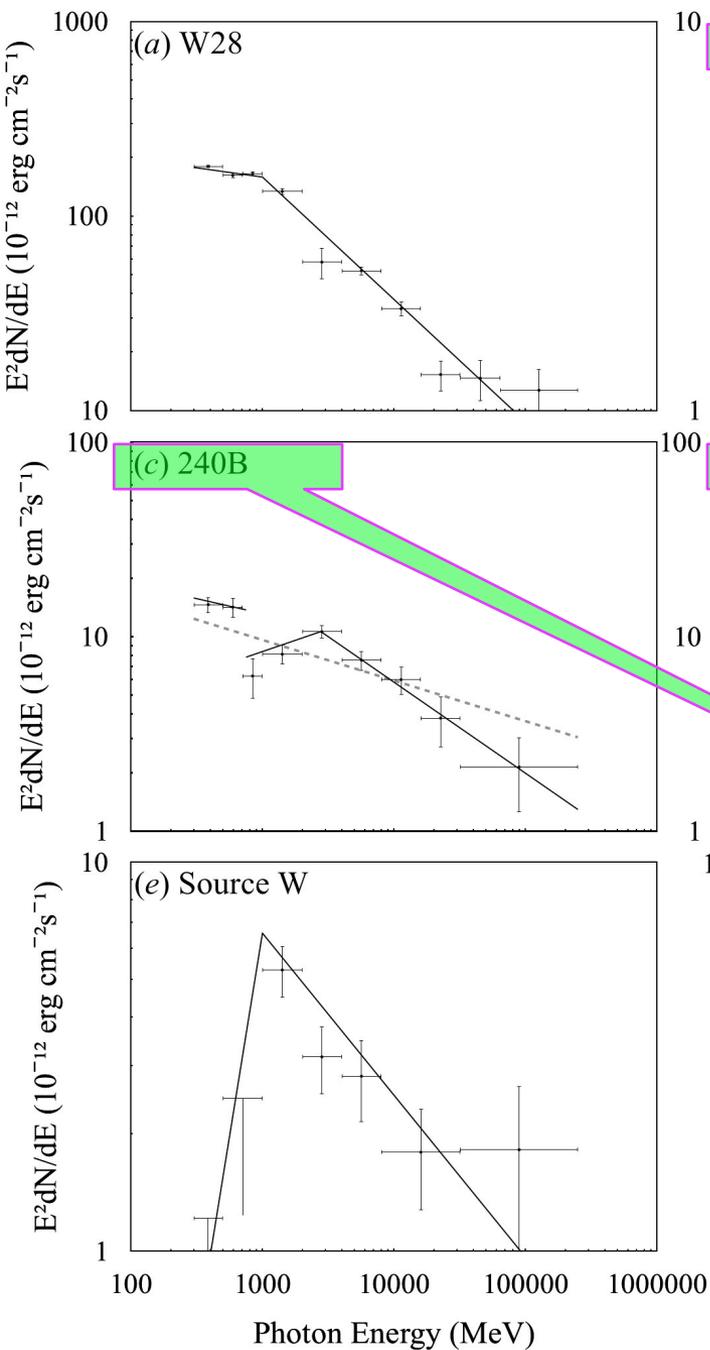
Radio boundary of SNR W28



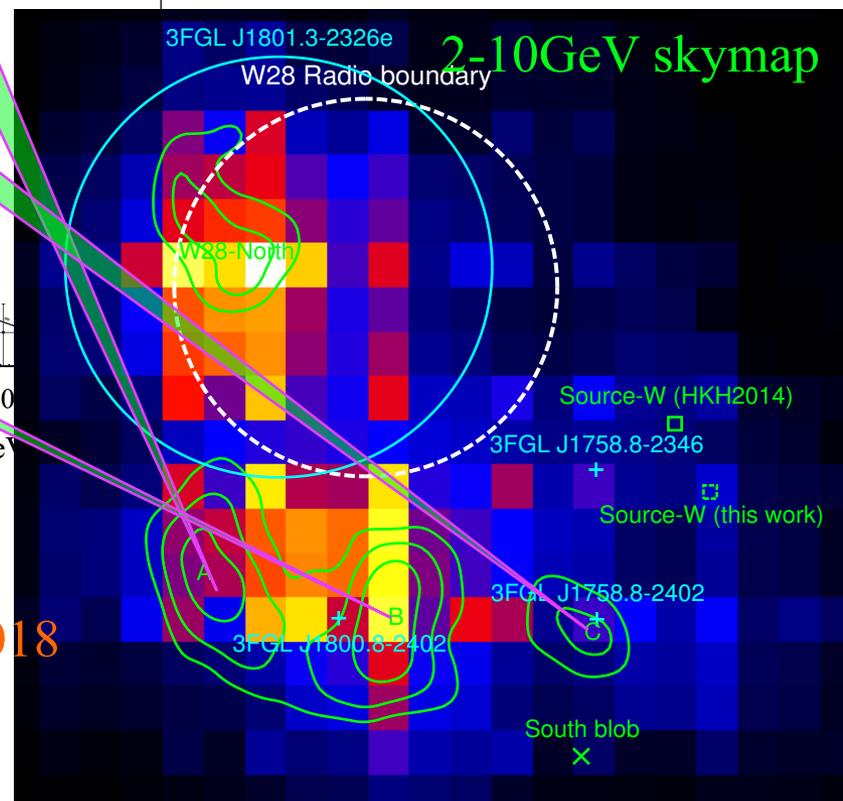


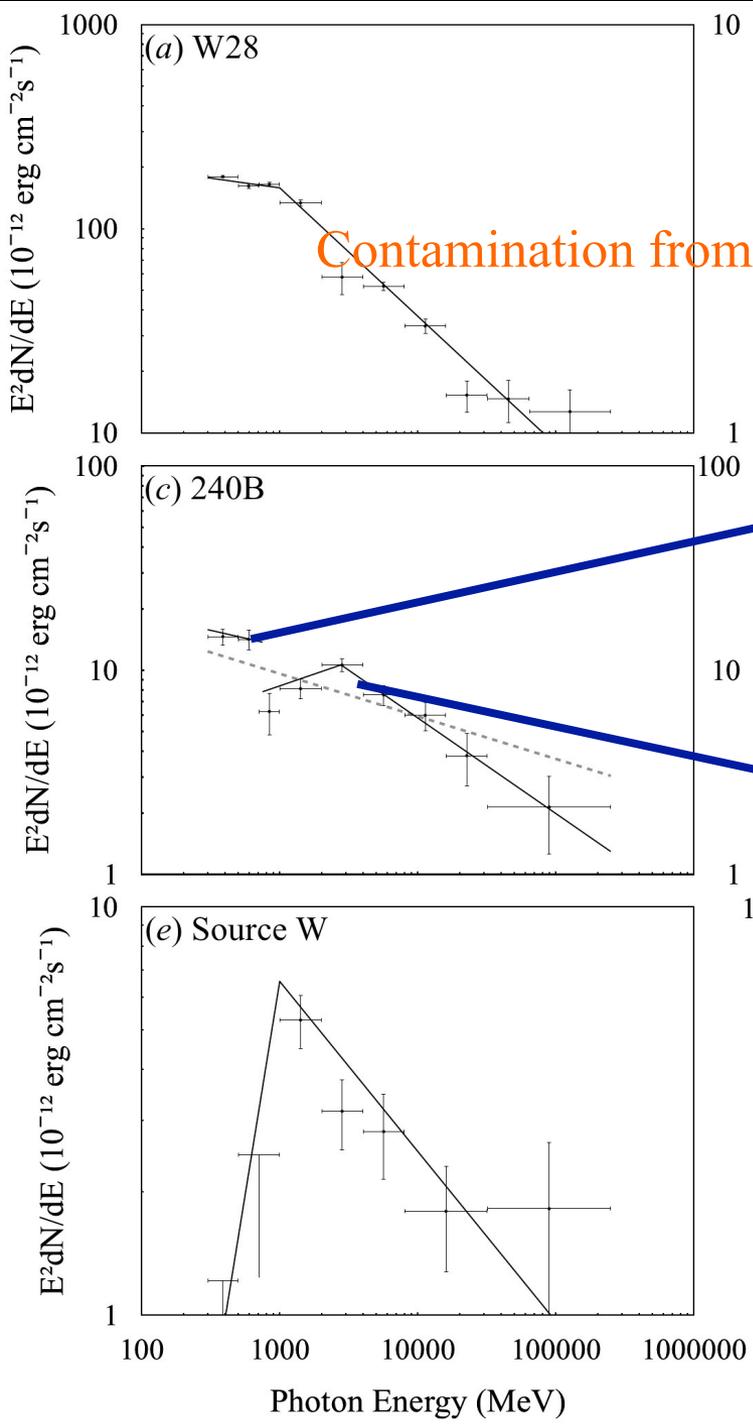
Cui et al. 2018



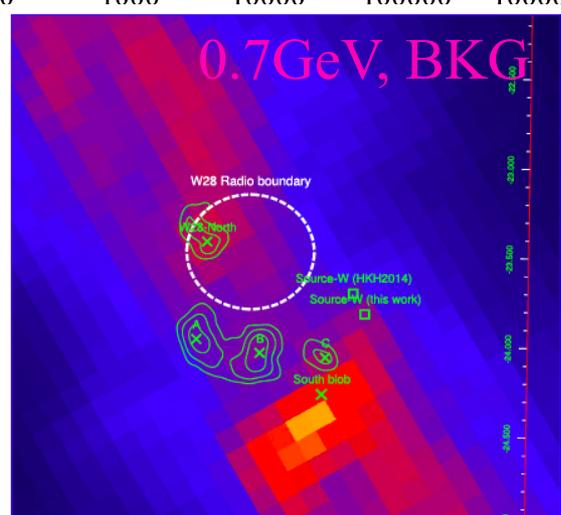
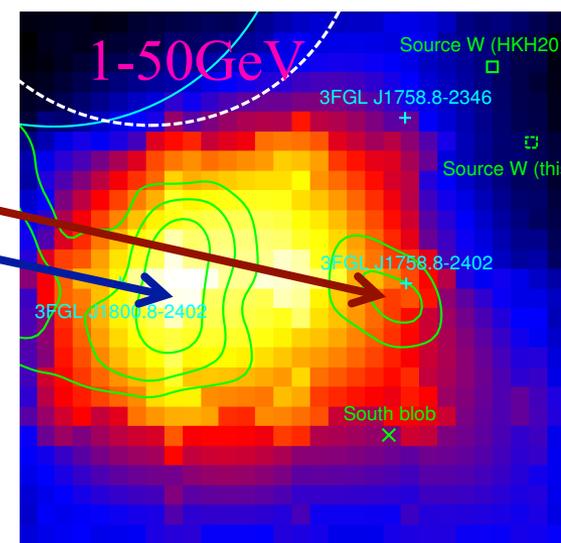
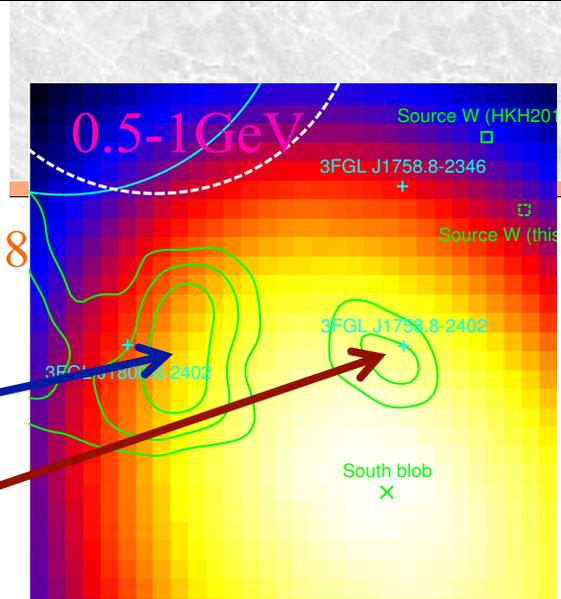


Cui et al. 2018

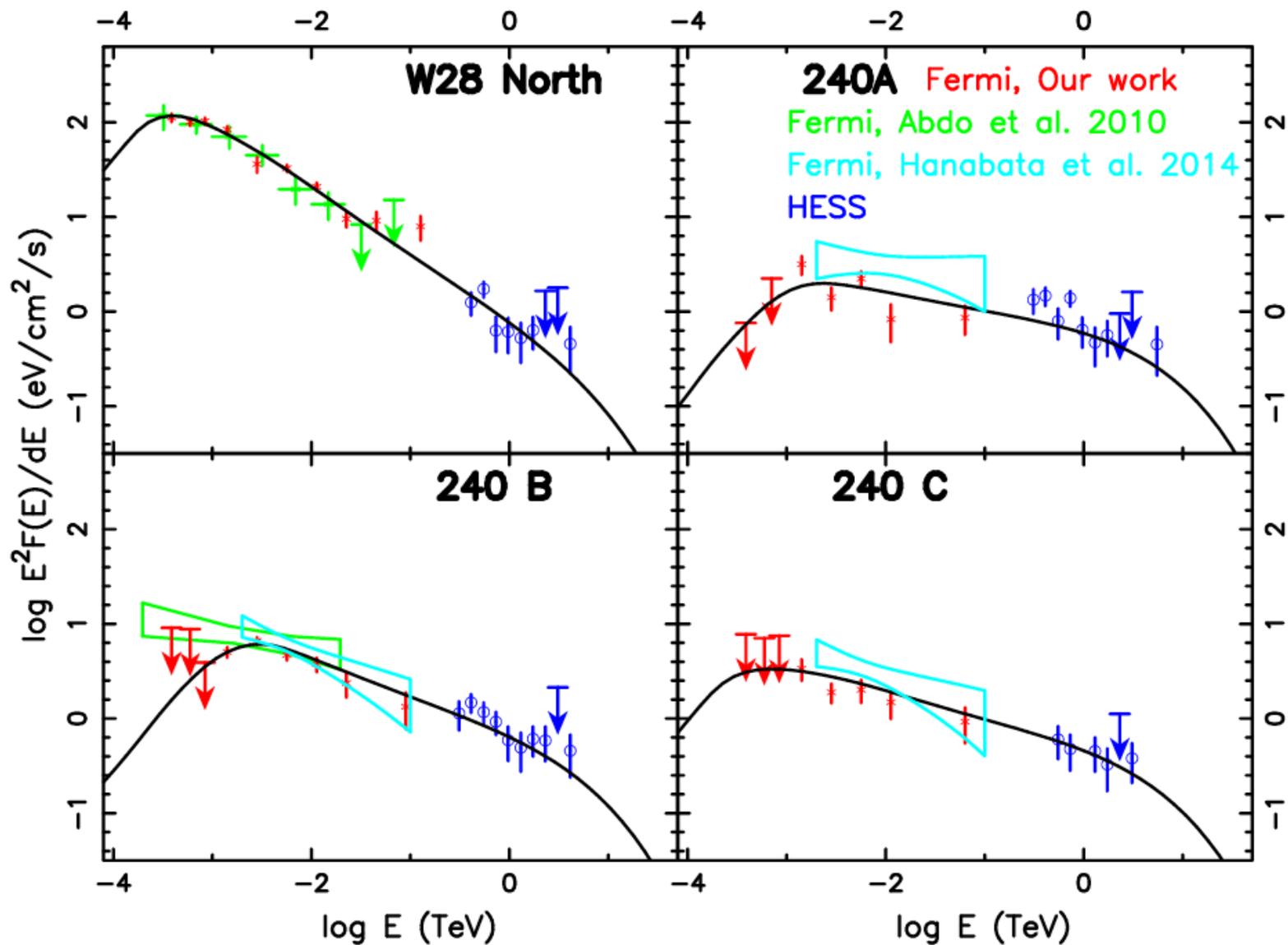




Contamination from south blob, by Cui et al. 2018



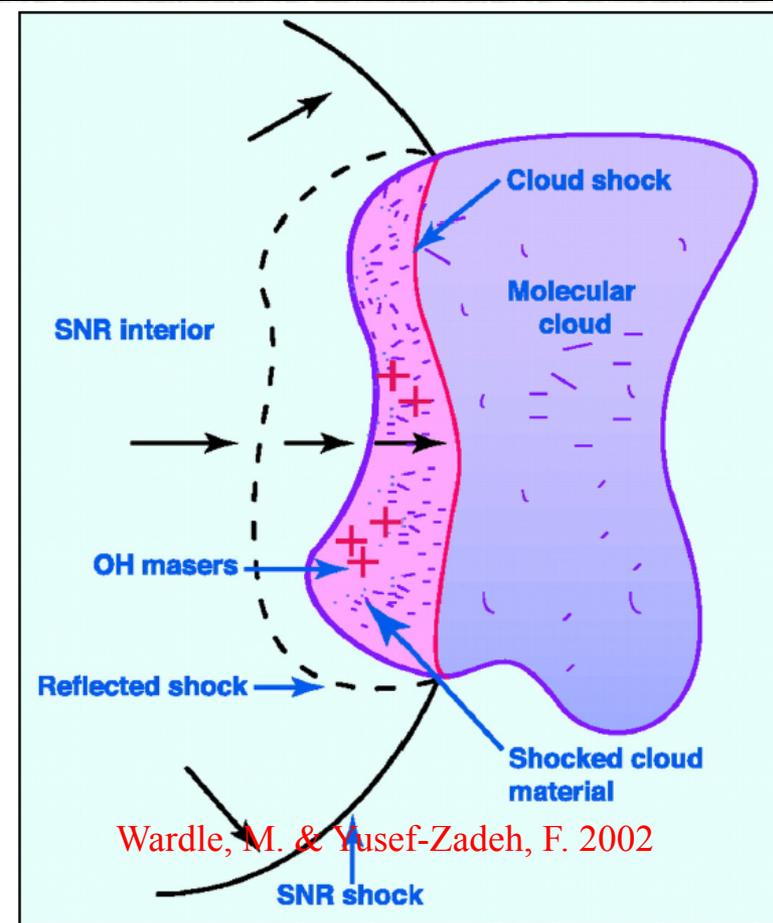
Compare & Pre-model fitting



Leaking model

Two main ways (models) for a CR to leave the SNR,
1. Escape from a strong shock as a high energy CR.
2. Set free when the strong shock is no more.

Gabici et al. (2010) , Li & Chen (2010) ,
Ohira et al. (2011) , and Tang (2017) :
Model 1 + spherical symmetric →
explain North & 240B (Abdo et al. 2010)
Ohira et al. (2011) :
Model 2 + spherical symmetric →
explain North & 240B



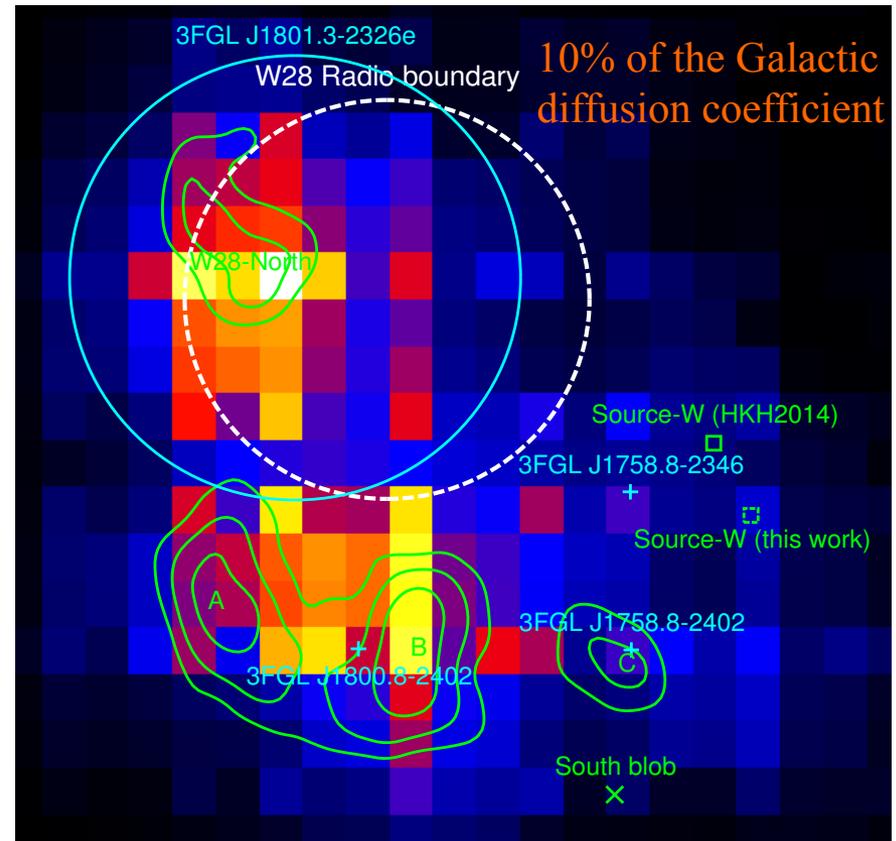
Hanabata et al. (2014) : the Fermi-LAT results at 240 A, C and Source W.

MC-N is partially colliding with SNR, and it is too big for the shock to swallow it unharmed.

When the shock at W28-North is stalled, the CRs down to $<1\text{GeV}$ can be set free $X \sim 10\%$

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

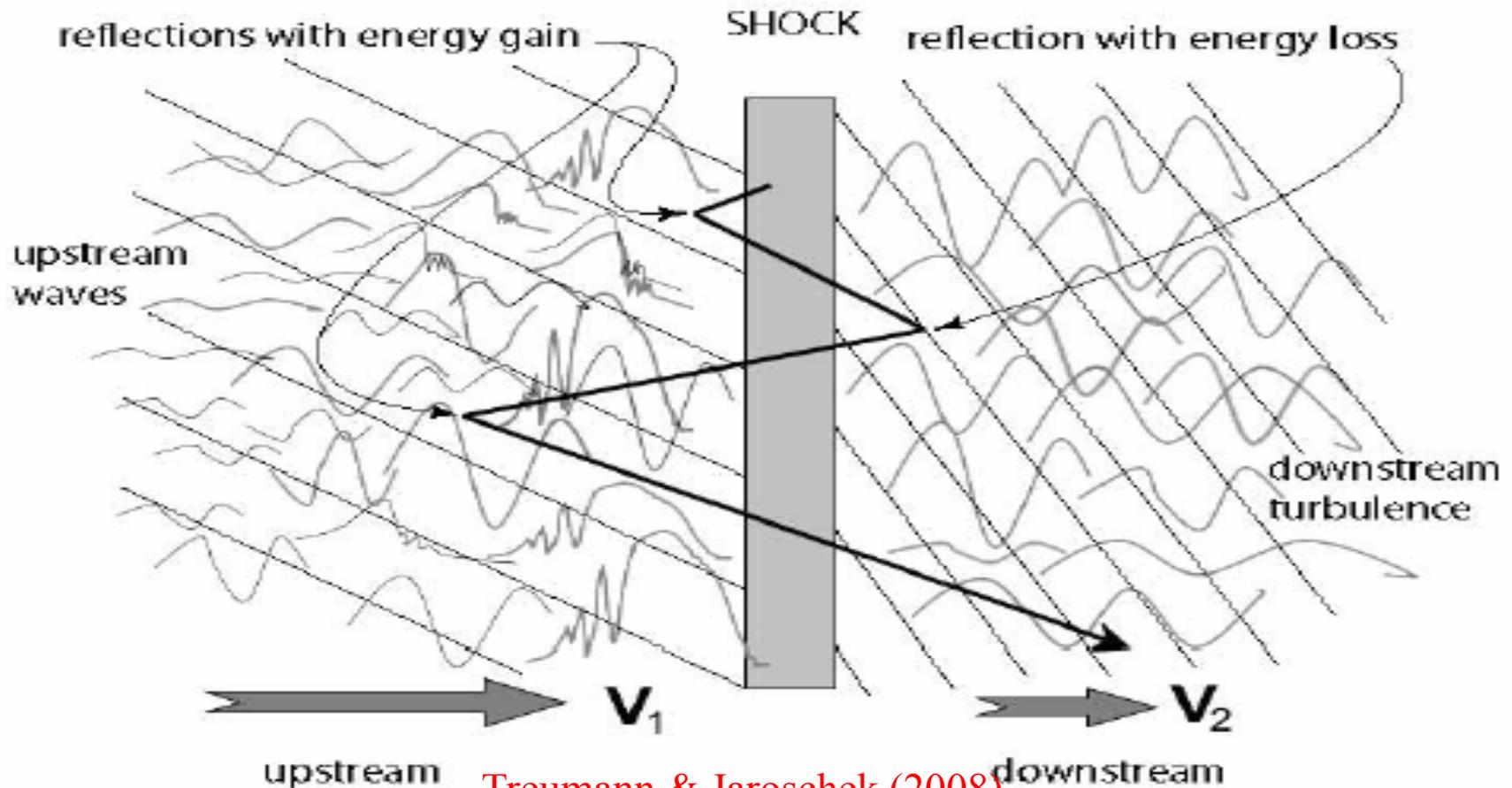


Run-away CRs from shock upstream → dominating TeV band

Leaked CRs from W28-North 12kyr ago → dominating GeV band (North)

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

CR acceleration at collisionless shock



Treumann & Jaroschek (2008)

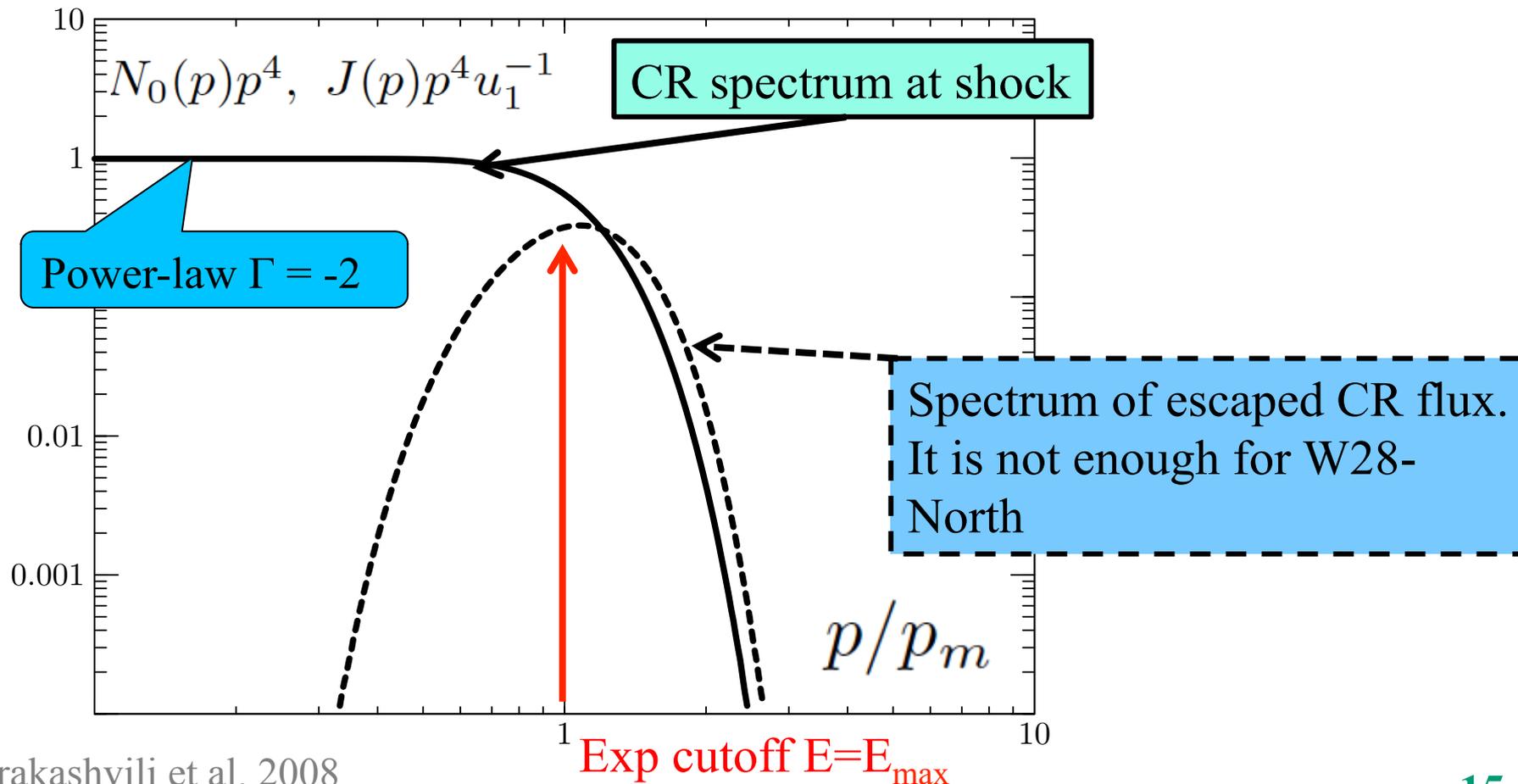
Particles swept away by the downstream flow \rightarrow power-law $\Gamma \sim -2$.

Particles escape from the upstream \rightarrow Exp cutoff E_{\max} .

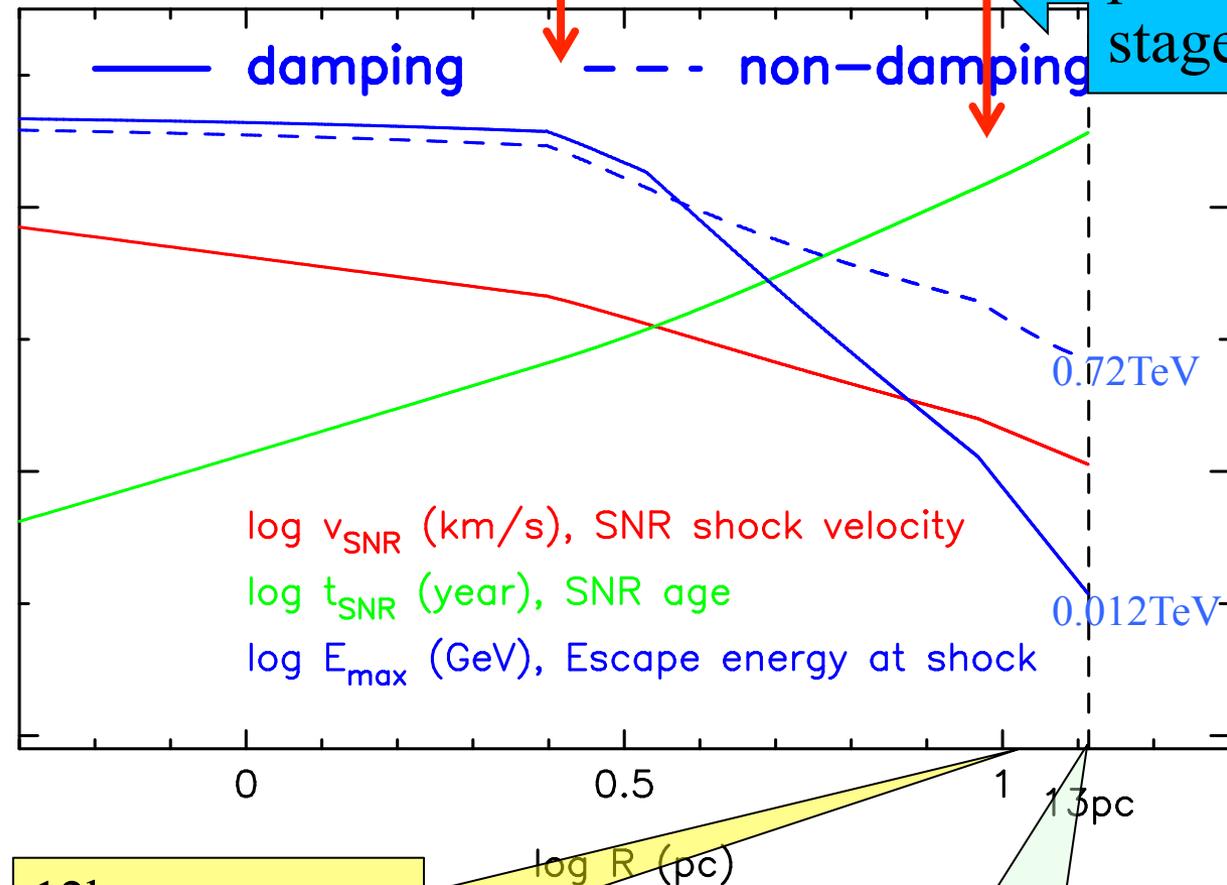
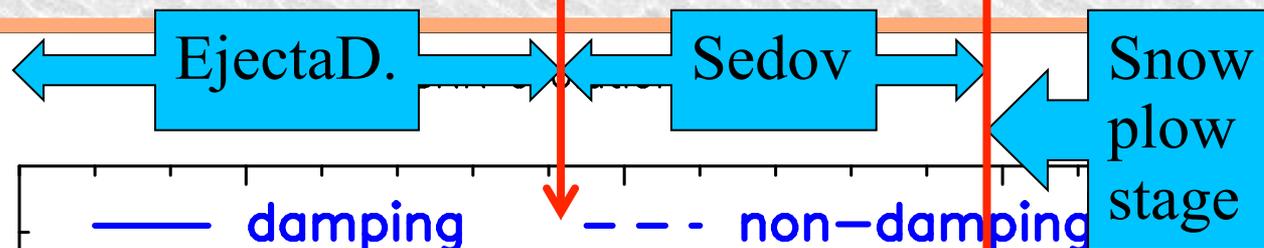
Big size + high velocity \rightarrow High E_{\max}

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)



SNR evolution



12kyr ago,
Shock-MC
encounter

37kyr, 110km/s

Assuming a type IIP SN
8Msun scenario
6Msun ejecta mass

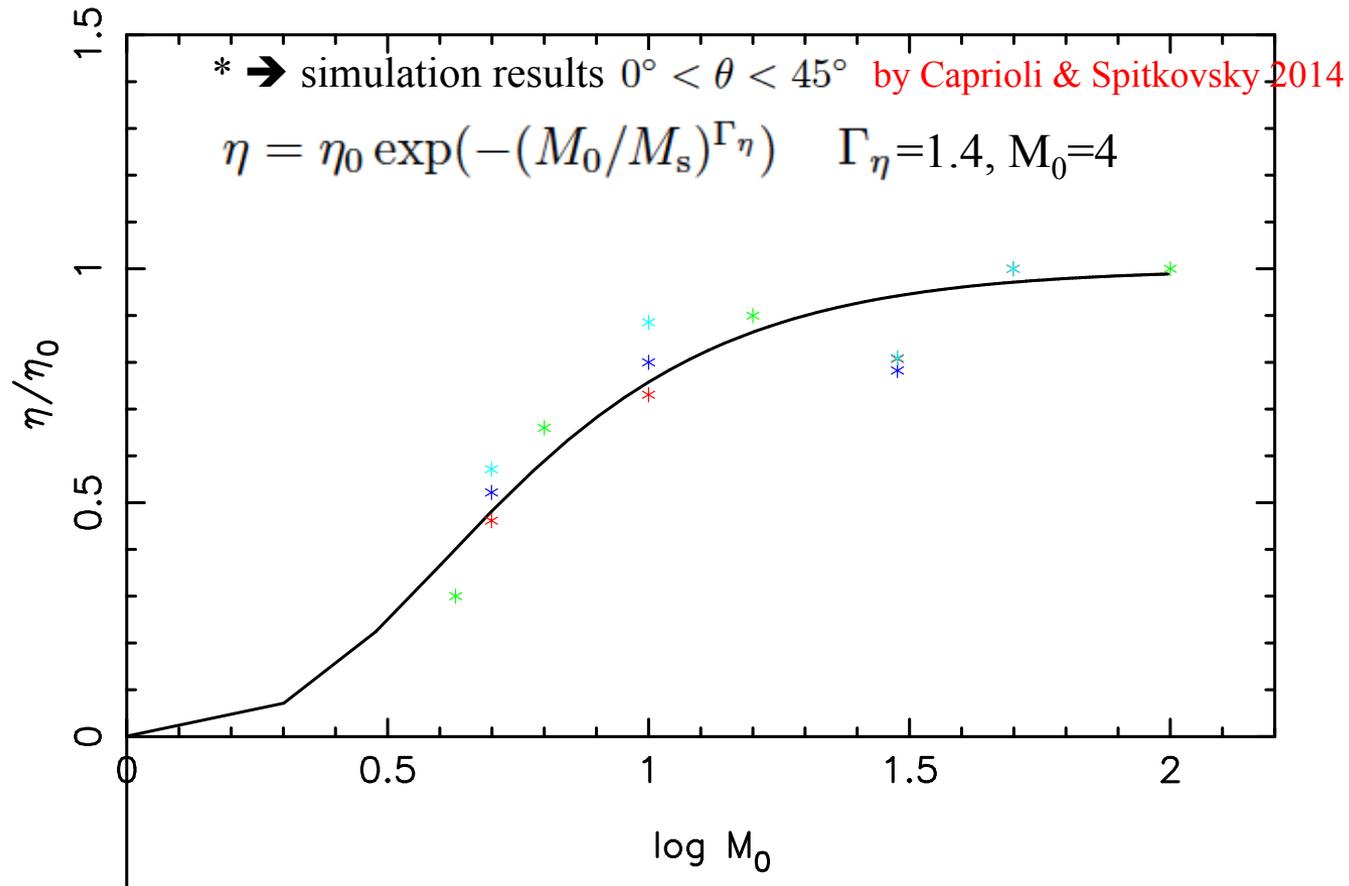
Expanding inside
Interclump medium
 $\sim 5\text{cm}^{-3}$

Old SNR →
Damping of the magnetic
waves by neutrals at
upstream.

We use a Relationship
from O'Connell et al. 1996,
Zirakashvili et al 2017.

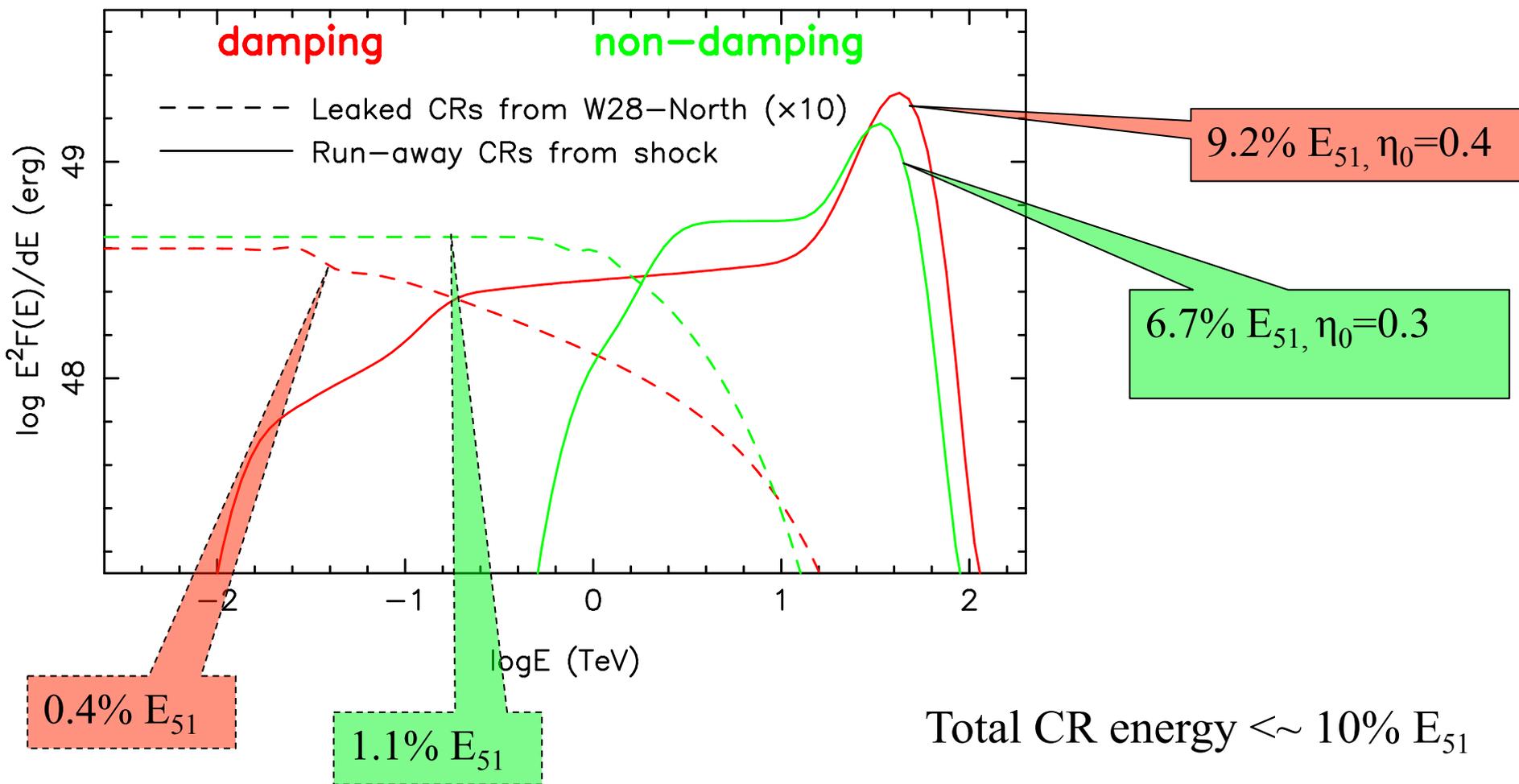
Old SNR → lower acceleration efficiency

Acceleration efficiency

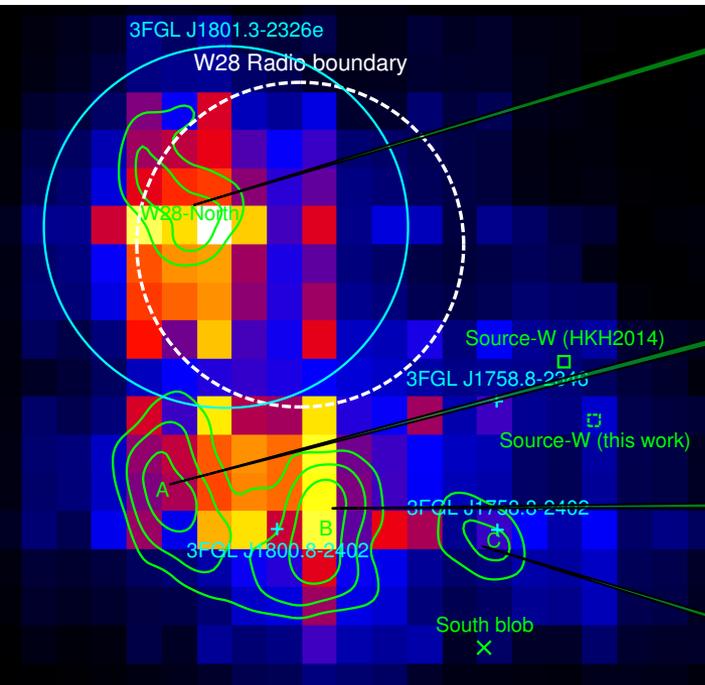


Run-away CRs VS Leaked CRs

CR spectra

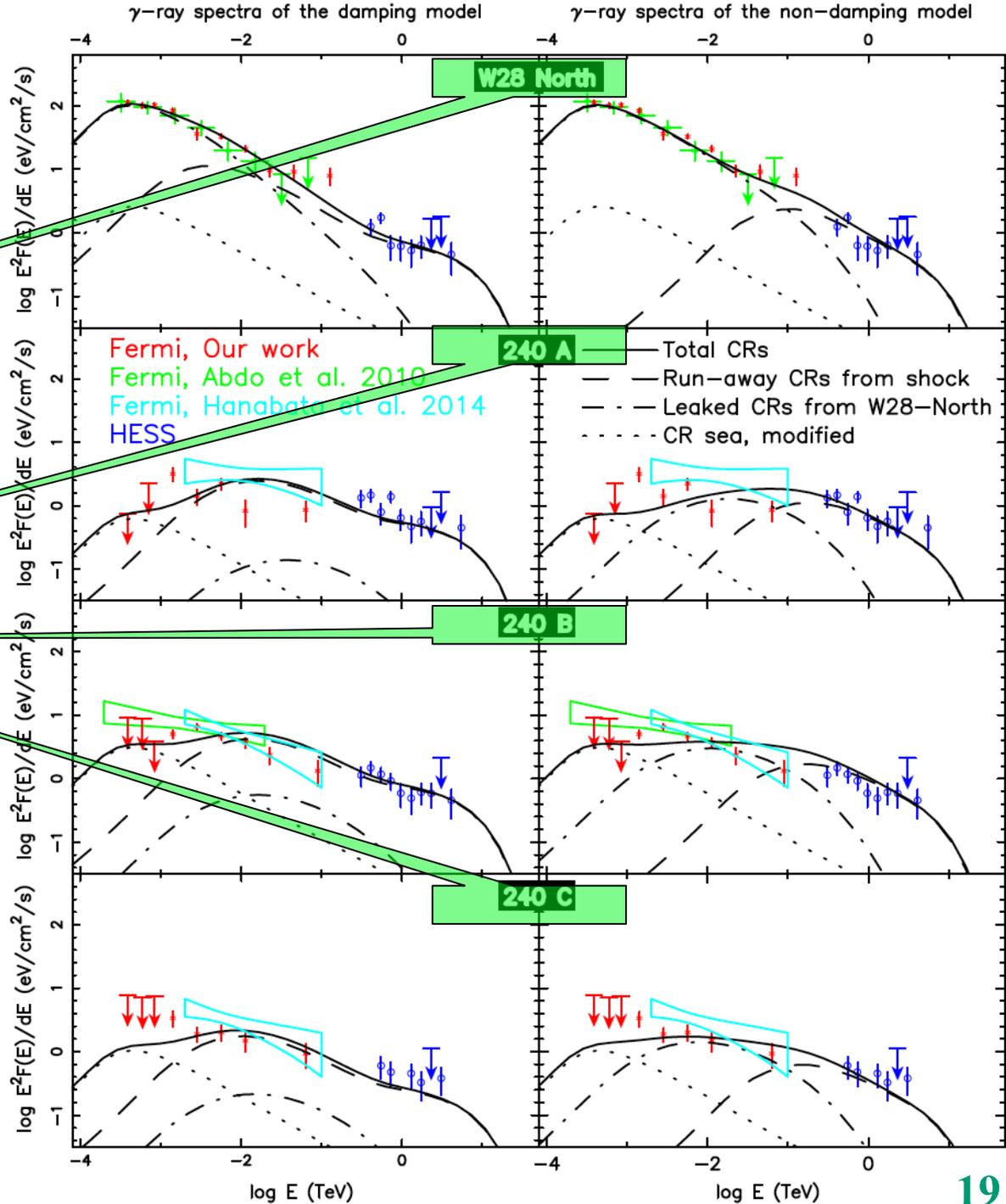


Averaged CR sea

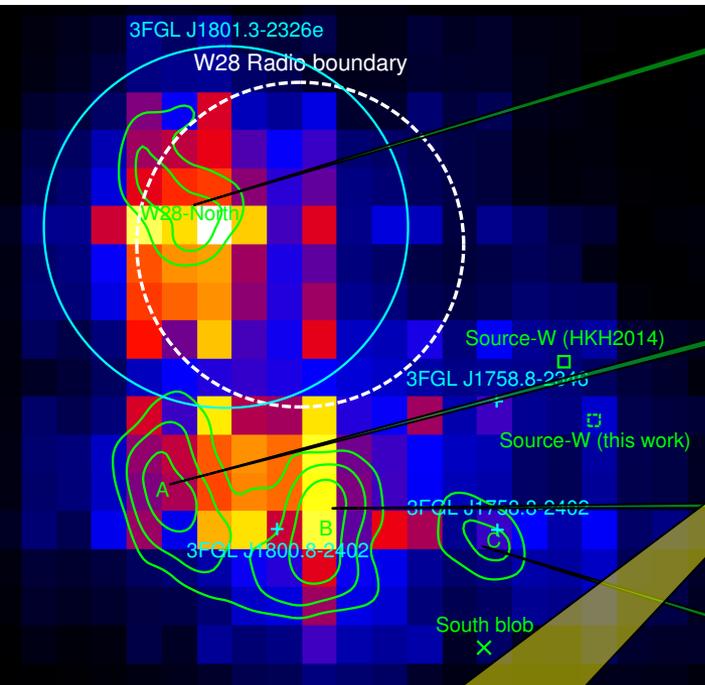


Homogeneous diffusion coefficient used here.

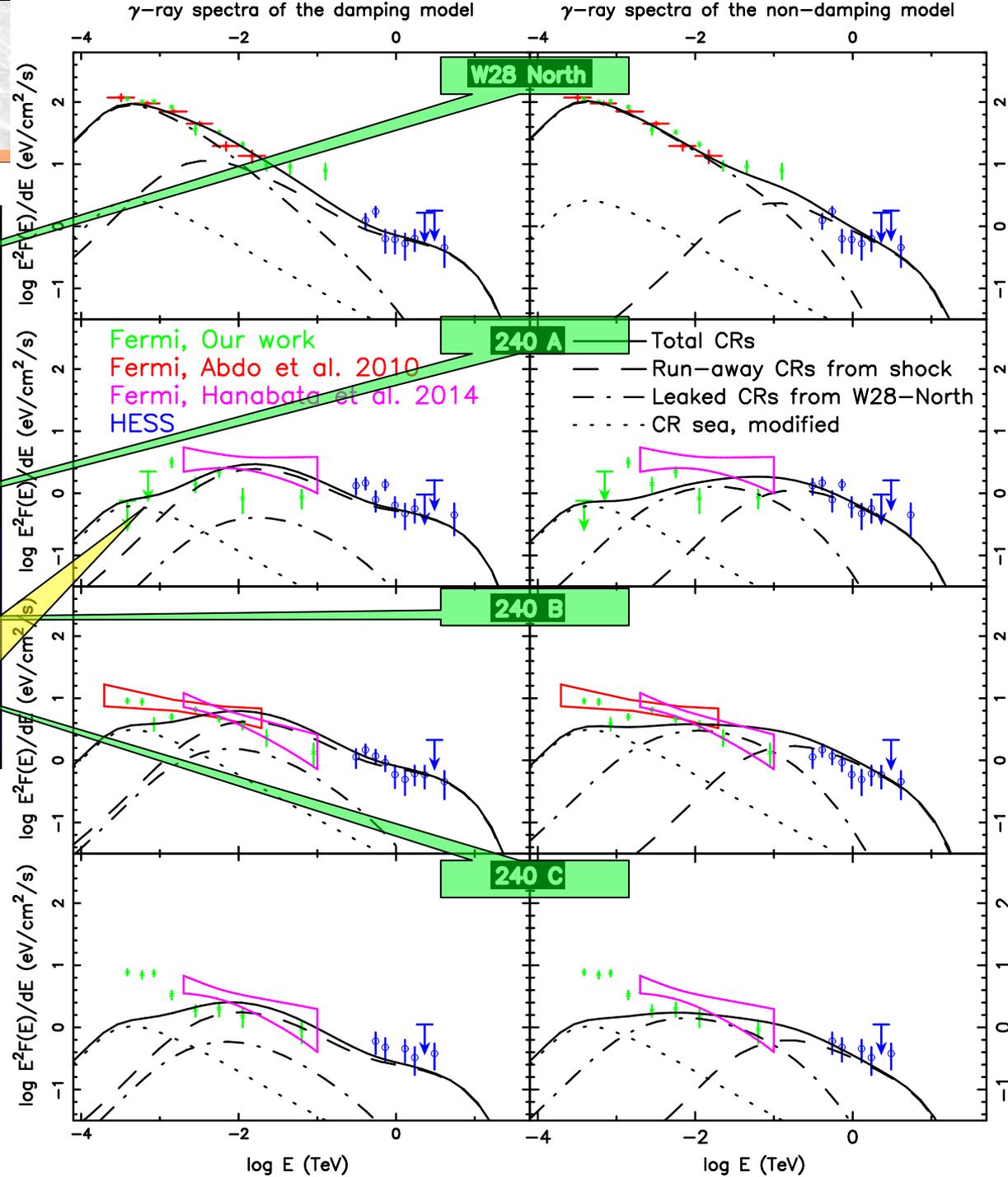
10% of the Galactic one.



Clumpy CR sea



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



Summary

1. $>2\text{GeV}$ Fermi skymap match well the TeV skymap & $<1\text{GeV}$ south blob found.

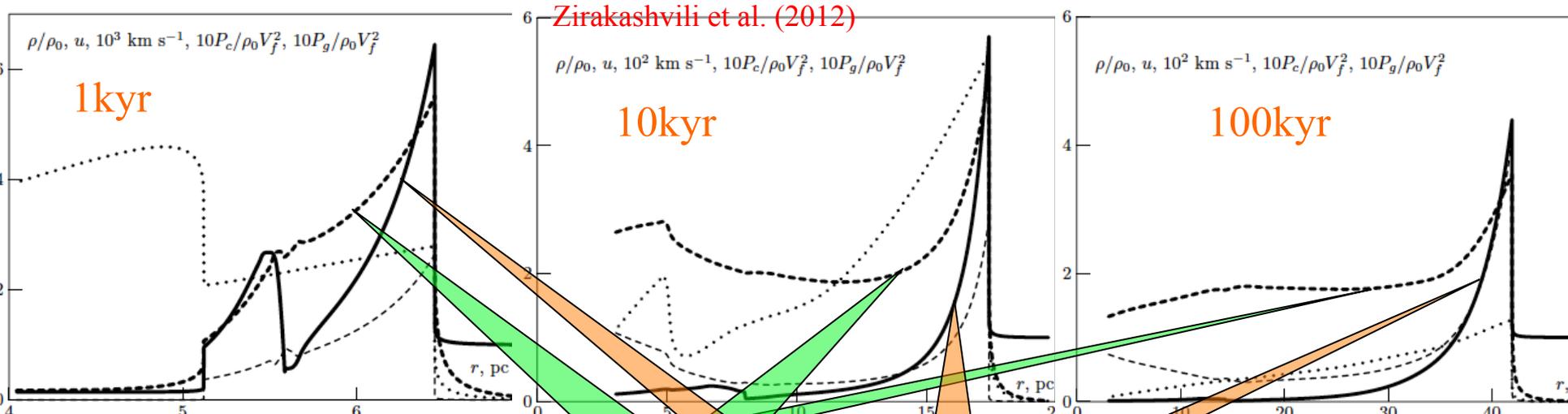
2. Under one SNR/environment model.

Leaked CRs from broken shell + escaped CRs from strong shock → can roughly explain the GeV-TeV observation.

3. Low detection at 240 A assumes an inhomogeneous CR background. Or the uncertainty of the diffuse background?

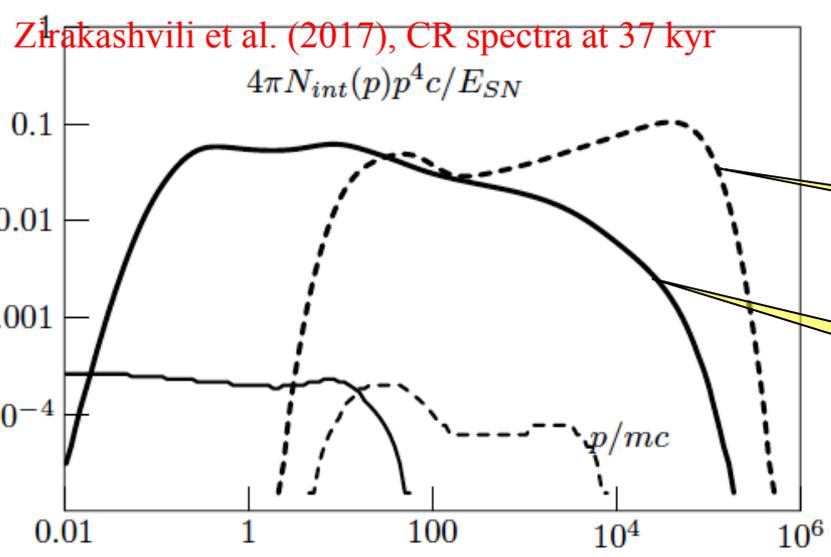
We are applying this test to Young SNRs (E_{max} is high) .

CR distribution inside the SNR



CR pressure

Gas density



Runaway CRs

CRs in SNR

Summary

