SNRs colliding with Molecular clouds

The story of the CRs

LHAASO 会议 2019

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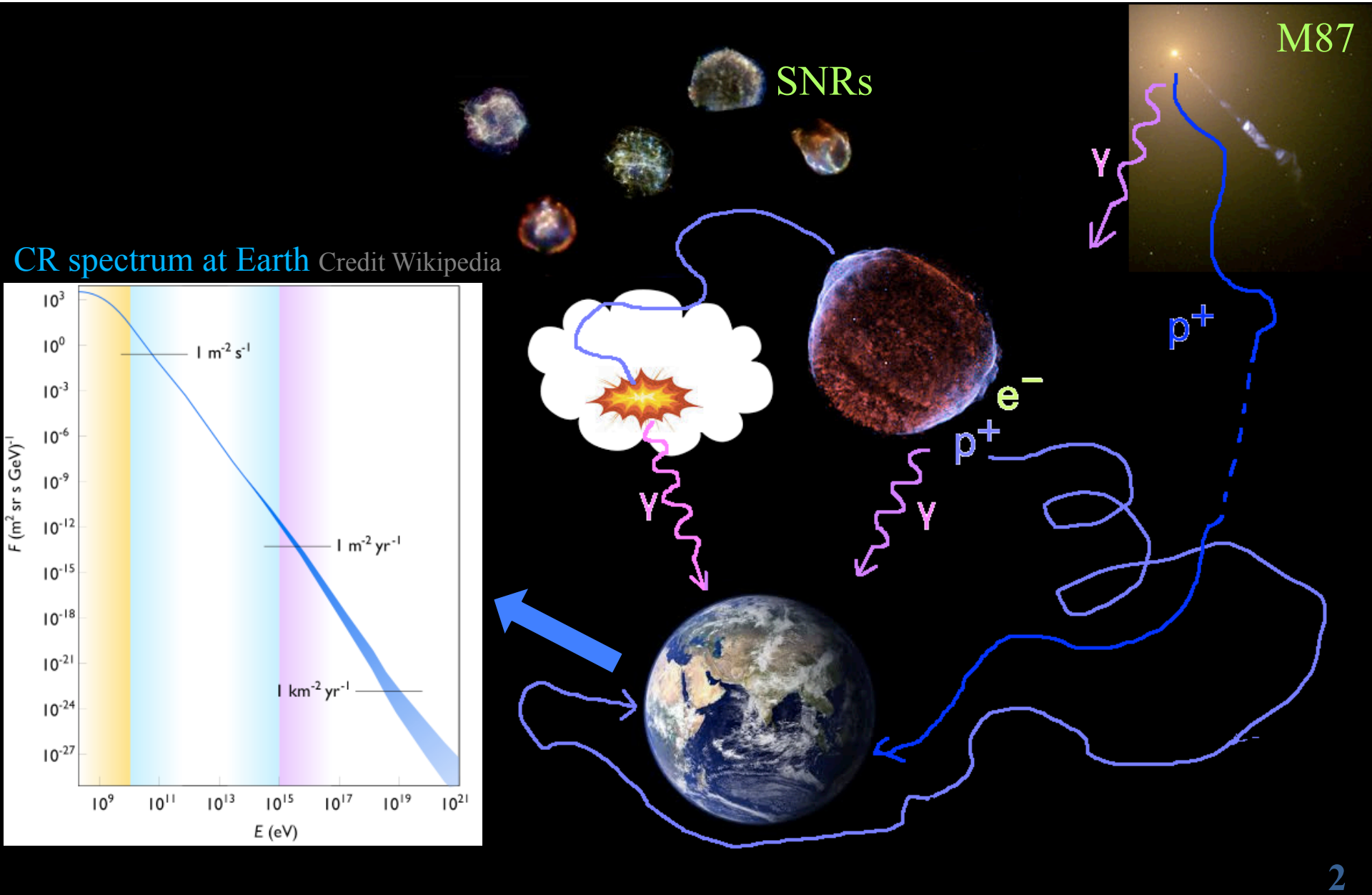
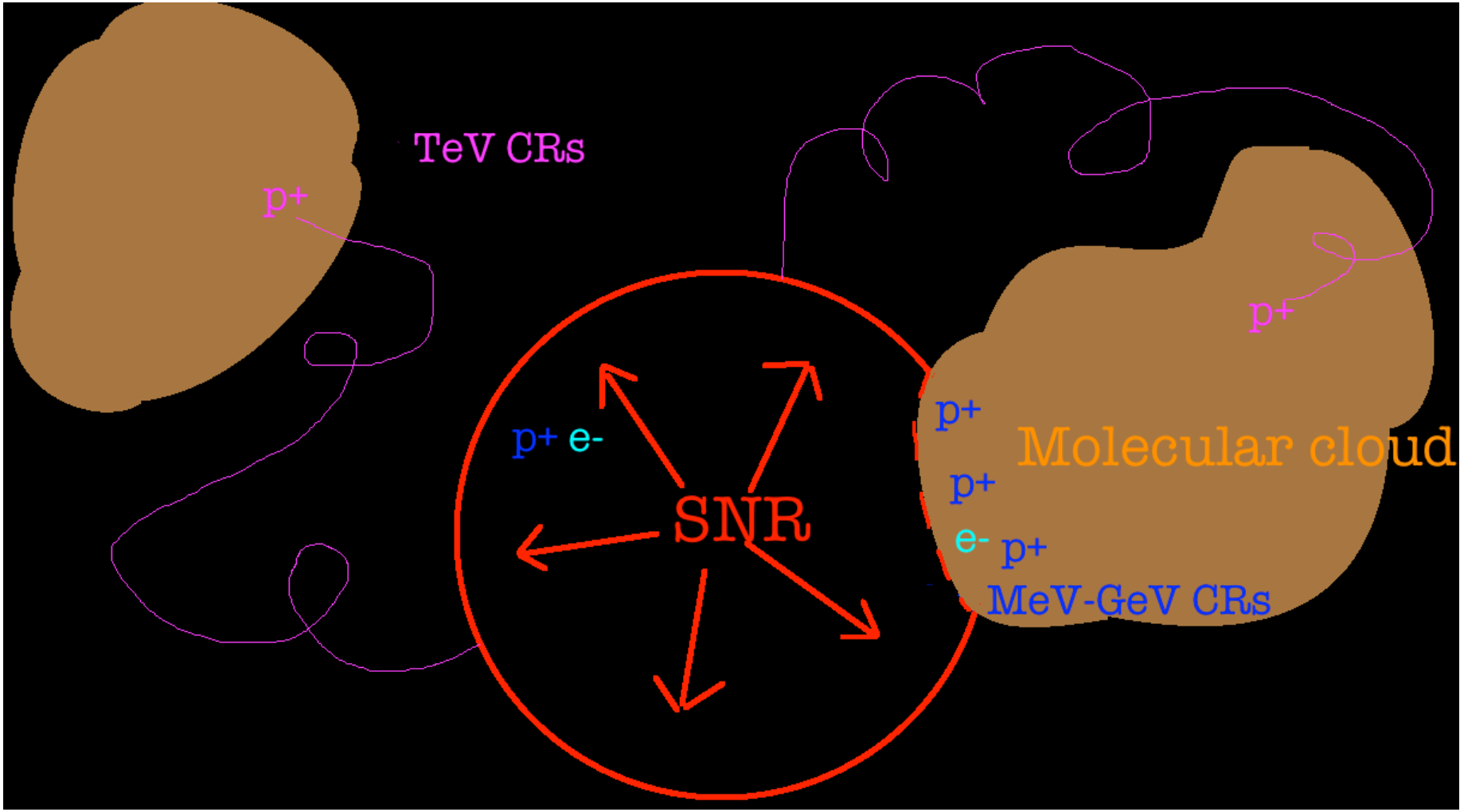
Cosmic ray (CR) sources



The shock-cloud collision model

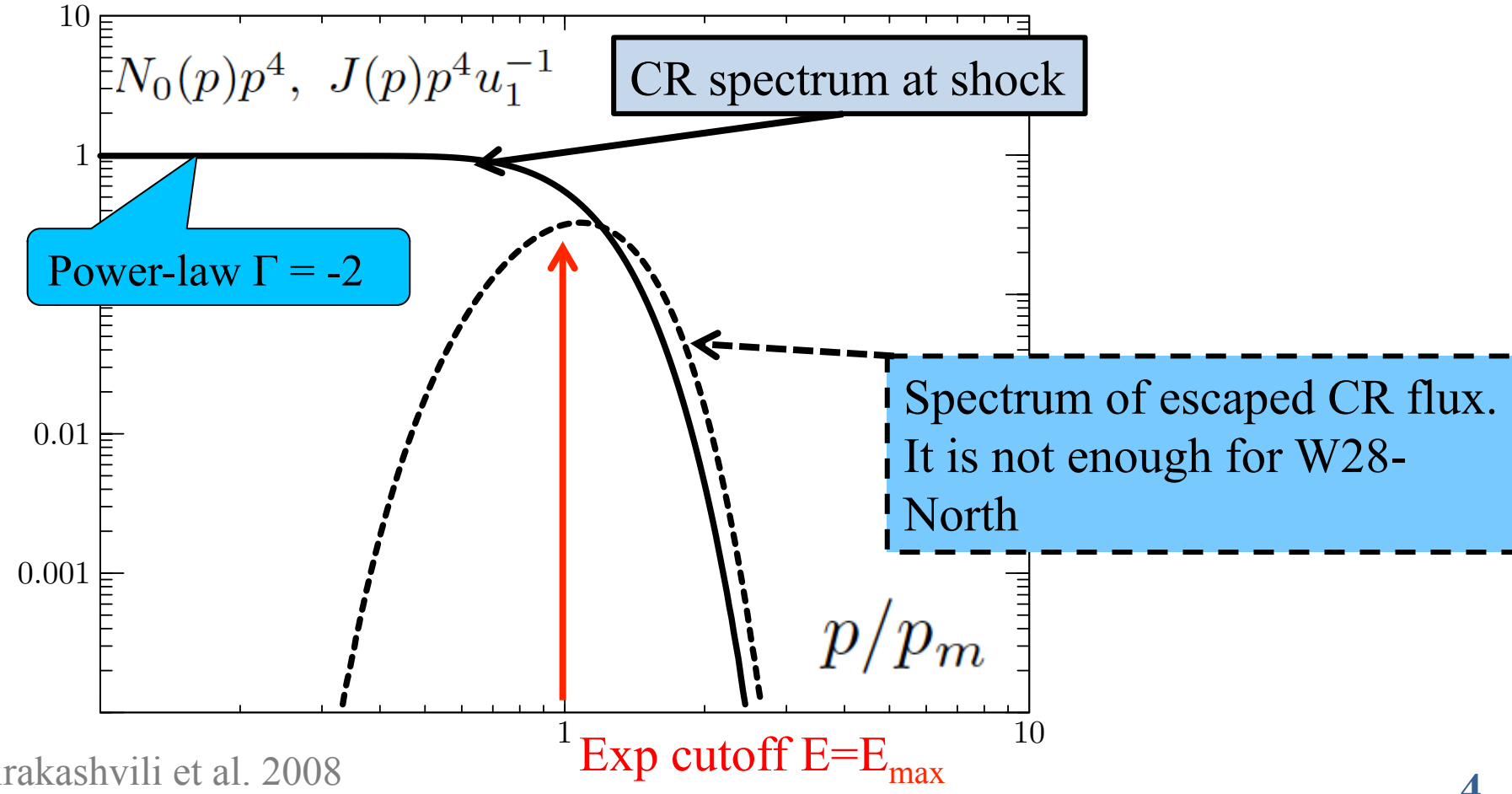


Good platform to Observe hadronic emission

shock acceleration and release

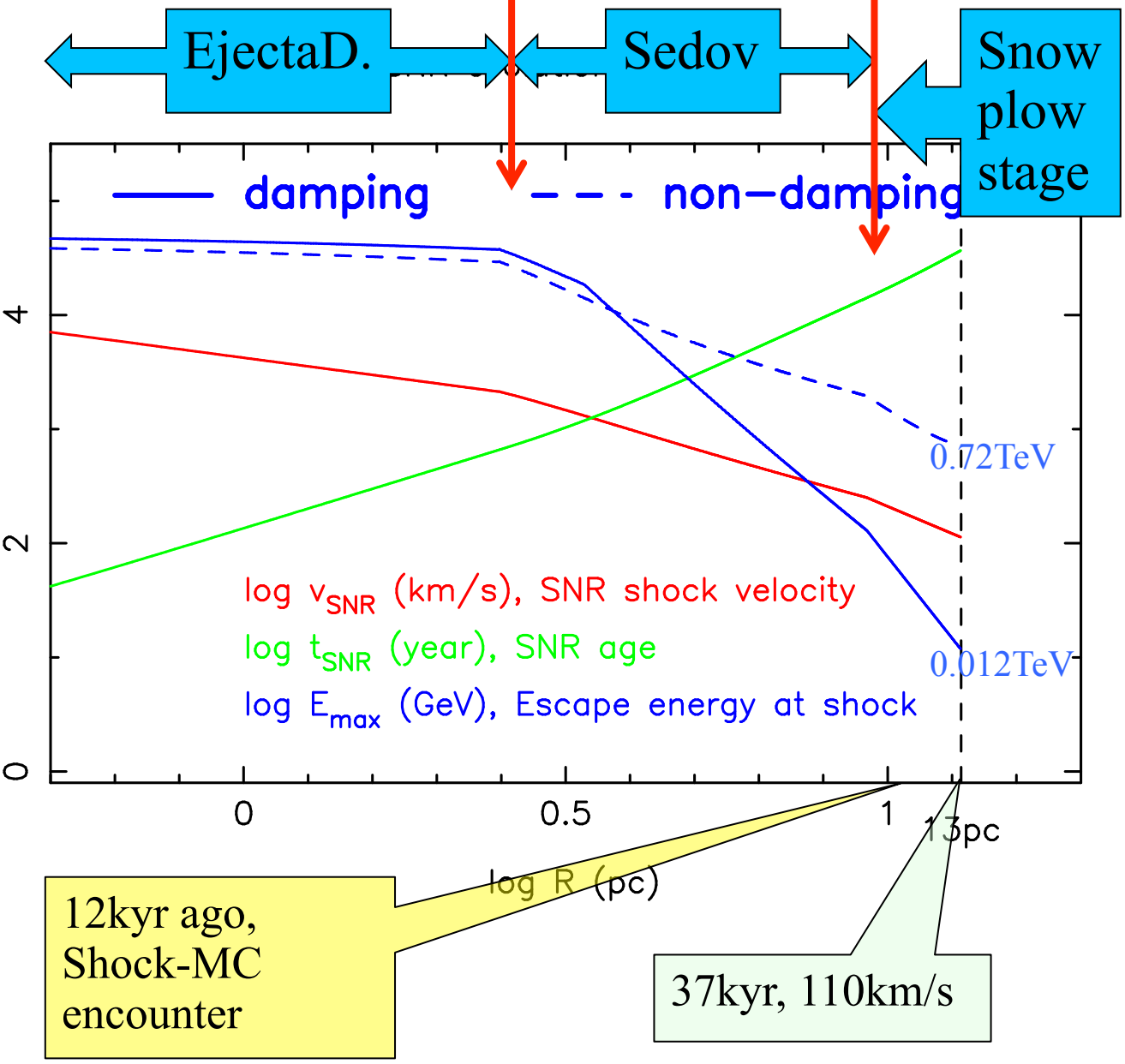
- Non-resonant instability ➔ quickly amplify the magnetic turbulence in upstream
- This theory is well established in both numerical simulation and analytical approximation.

(Bell 2004; Zirakashvili & Ptuskin 2008) 939)



Zirakashvili et al. 2008

SNR evolution W28

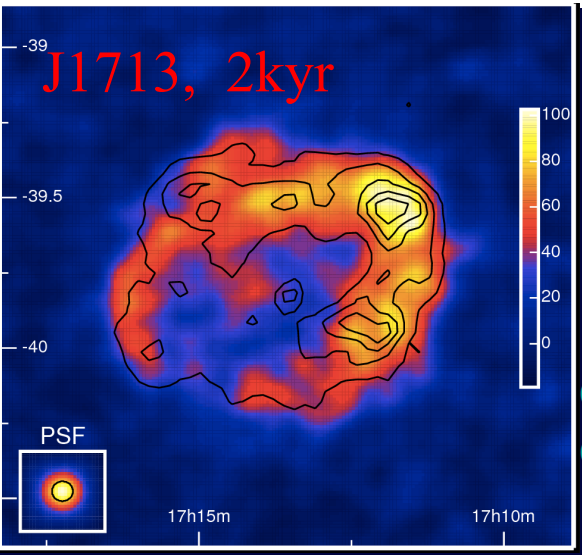


Assuming a typeIIP SN
8Msun scenario
6Msun ejecta mass

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.

TeV SNRs - Young and middle-aged

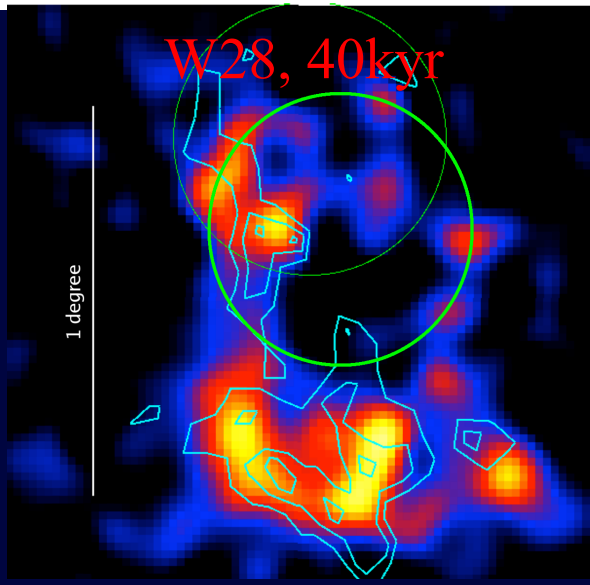


2006A&A...449..223A

Active shock
X-ray & γ-ray

Only highest energy
CRs released

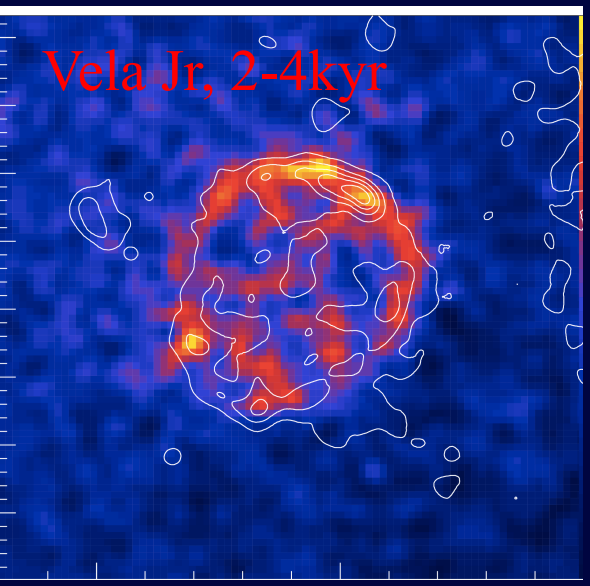
VS



No clear shock
X-ray & γ-ray

Most
CRs released

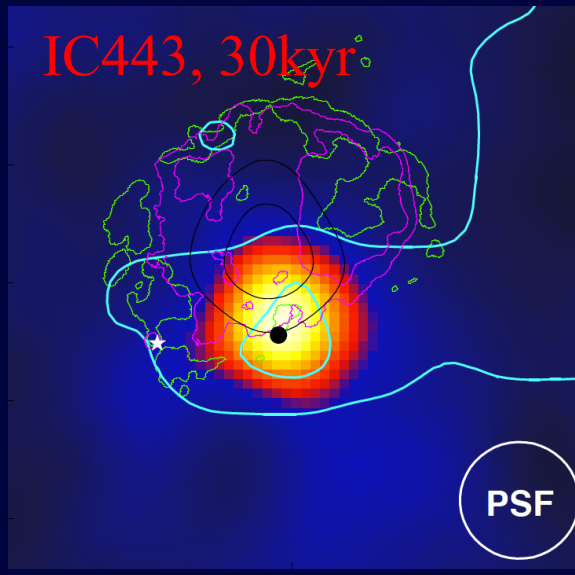
2008A&A...481..401A



2007ApJ...661..236A

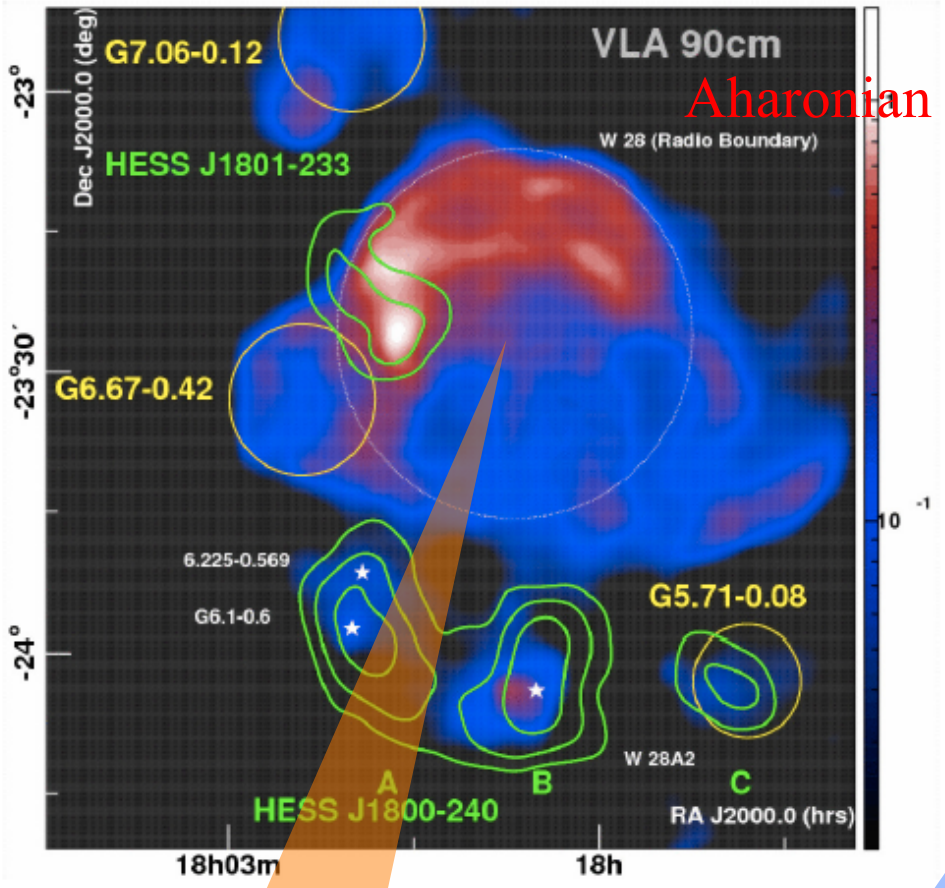
X-ray & TeV
Matching

Cold gas & TeV
Matching

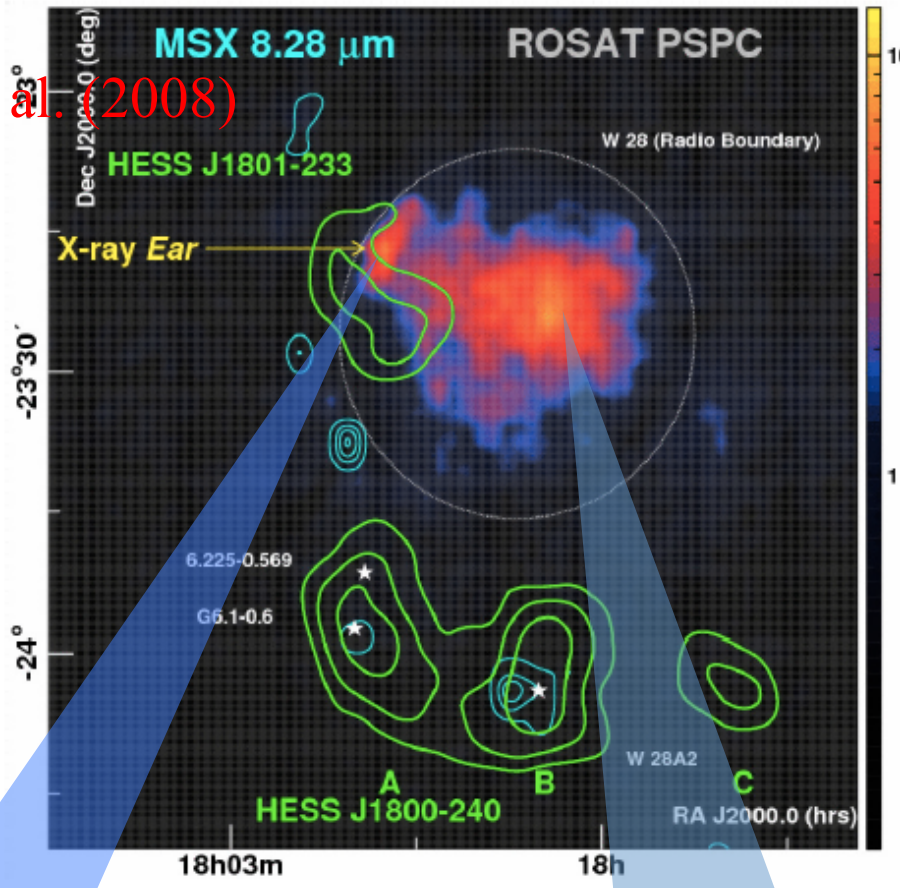


2007ApJ, 664, L87

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

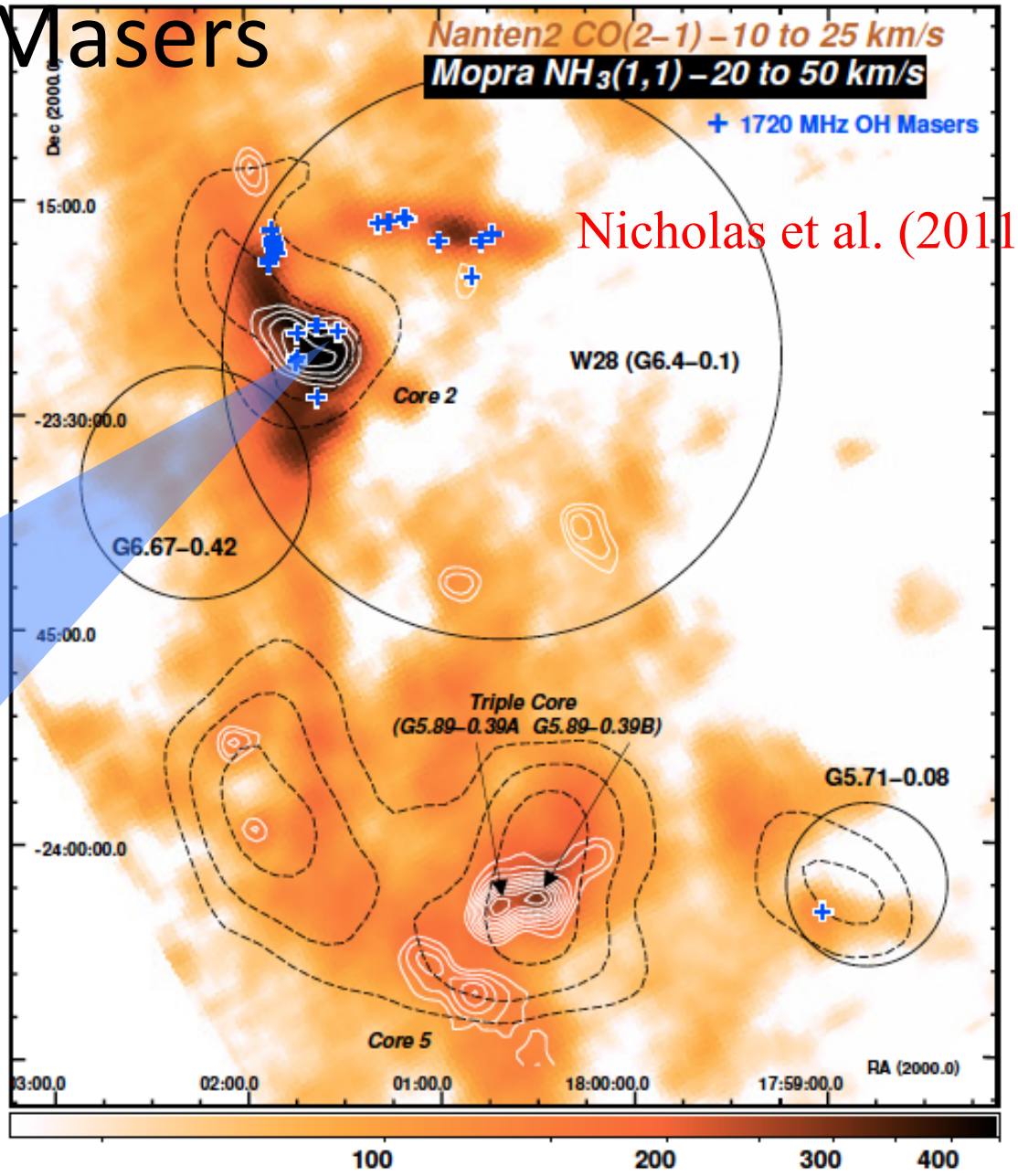
Clumps ~ $10^{3\text{-}5}$ cm^{-3}
Interclump medium ~ $5cm^{-3}$

Masers as The shock-MC encounter evidence

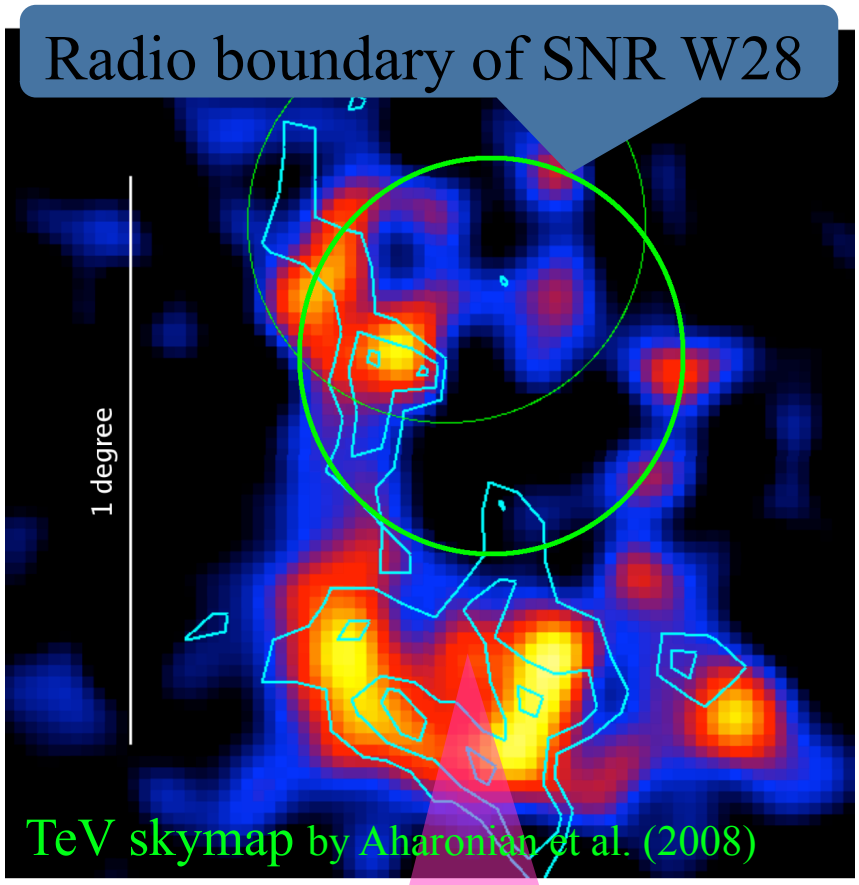
& evidence of ionized MC by leaked <1GeV CRs

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

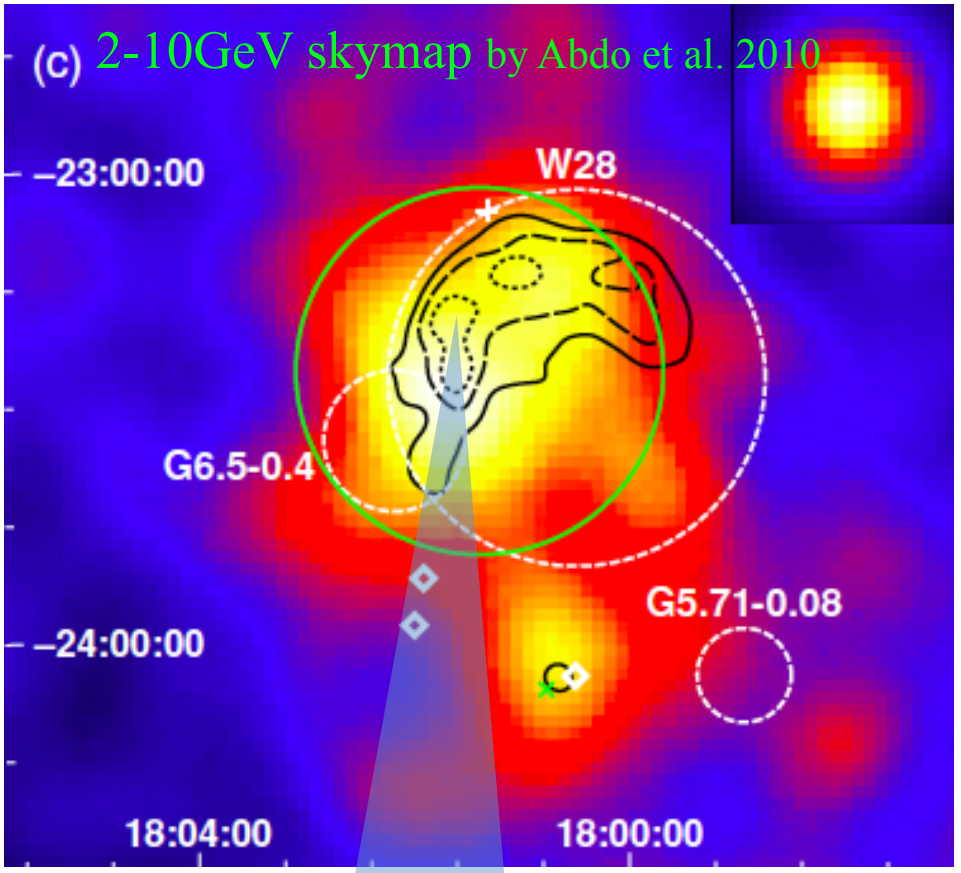
NH_3 lines, with Mopra radio telescope, by Maxted2016MNRAS462..532M;



SNR W28 TeV & GeV

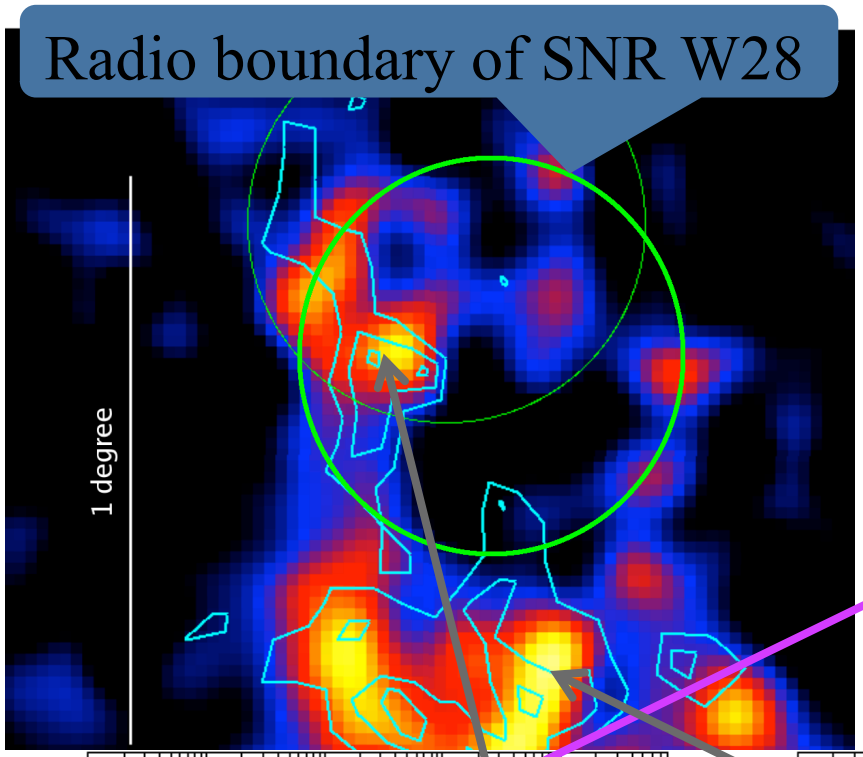


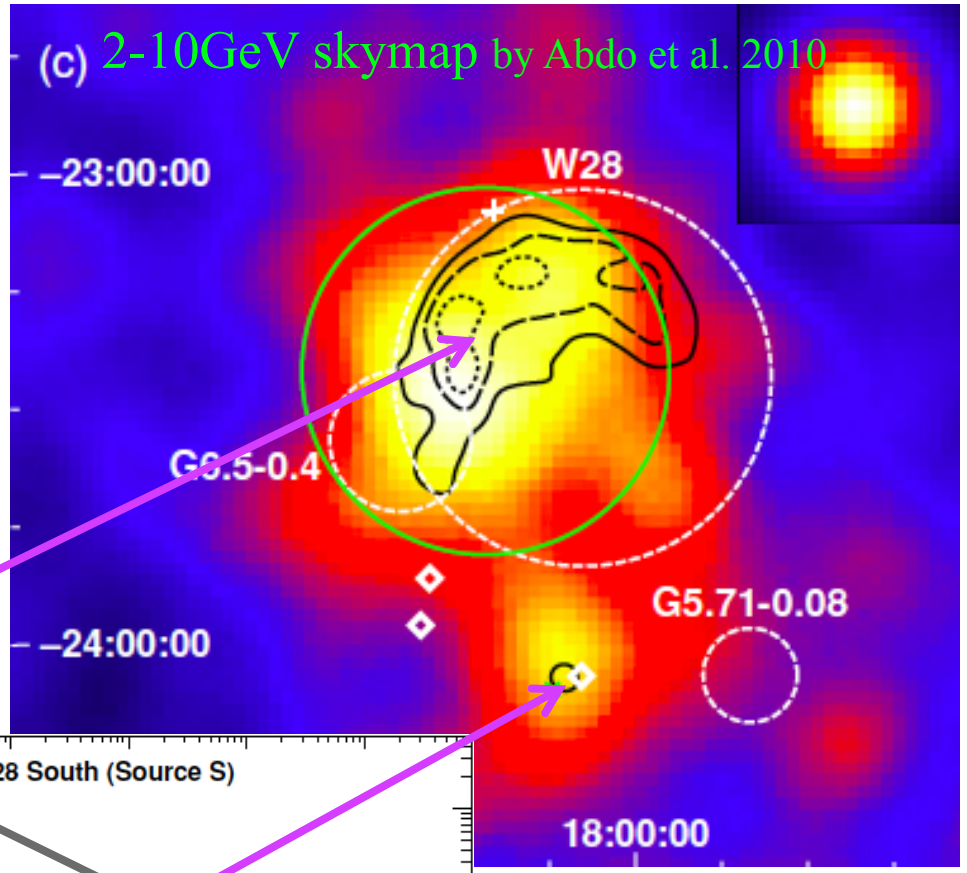
TeV CRs released in early stage diffuse Everywhere.

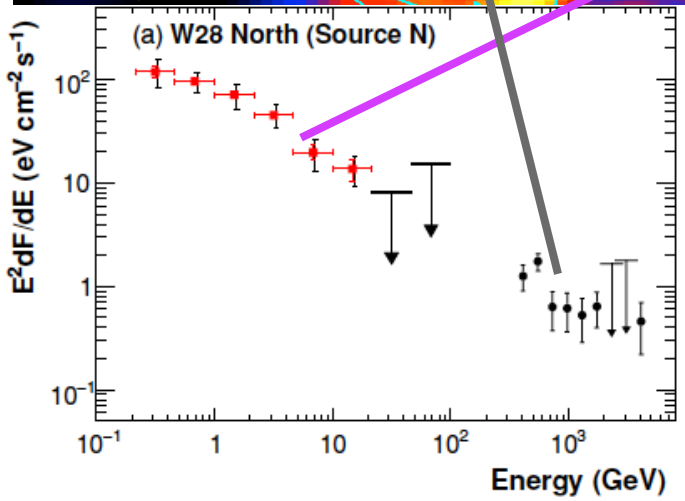


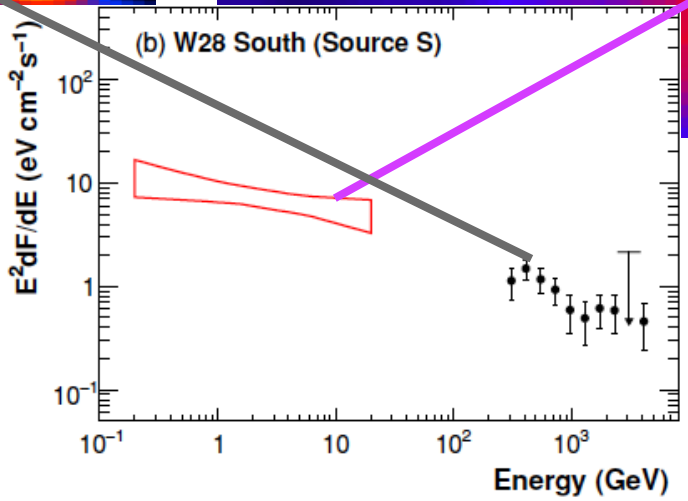
Part of the shock is stalled and the GeV CRs are leaking out.

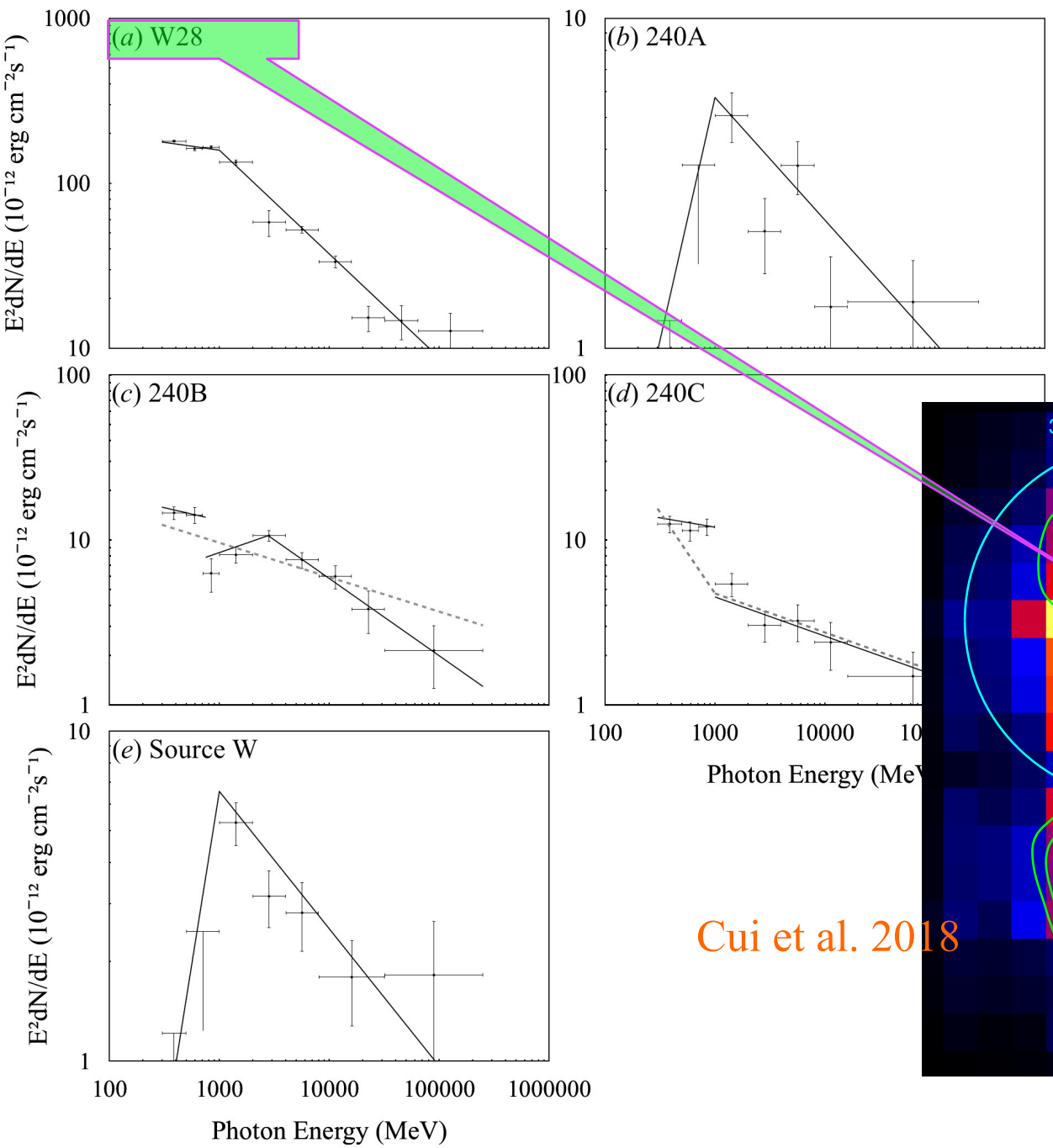
SNR W28 TeV & GeV



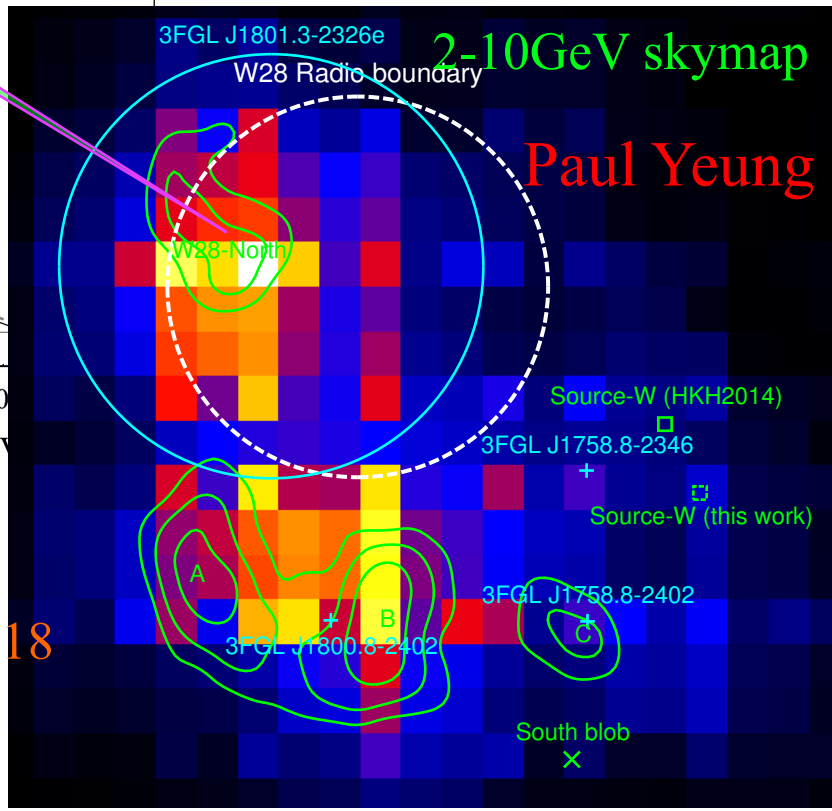








S

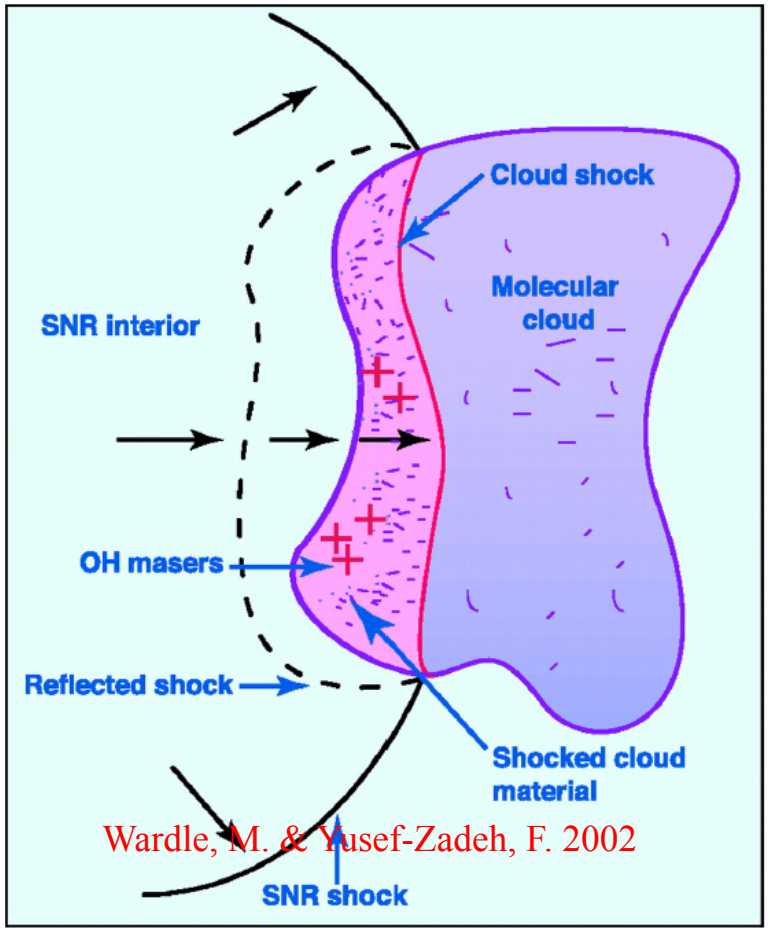


Cui et al. 2018

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

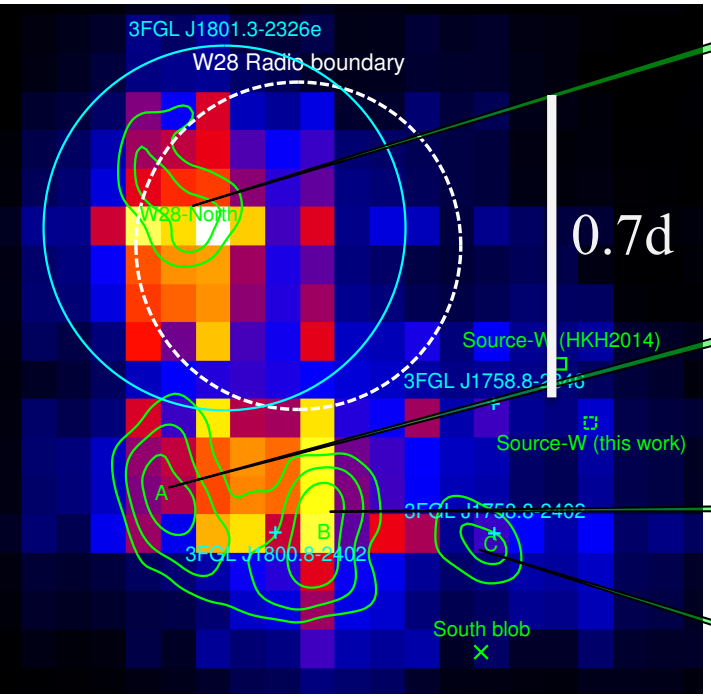


Wardle, M. & Yusef-Zadeh, F. 2002

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

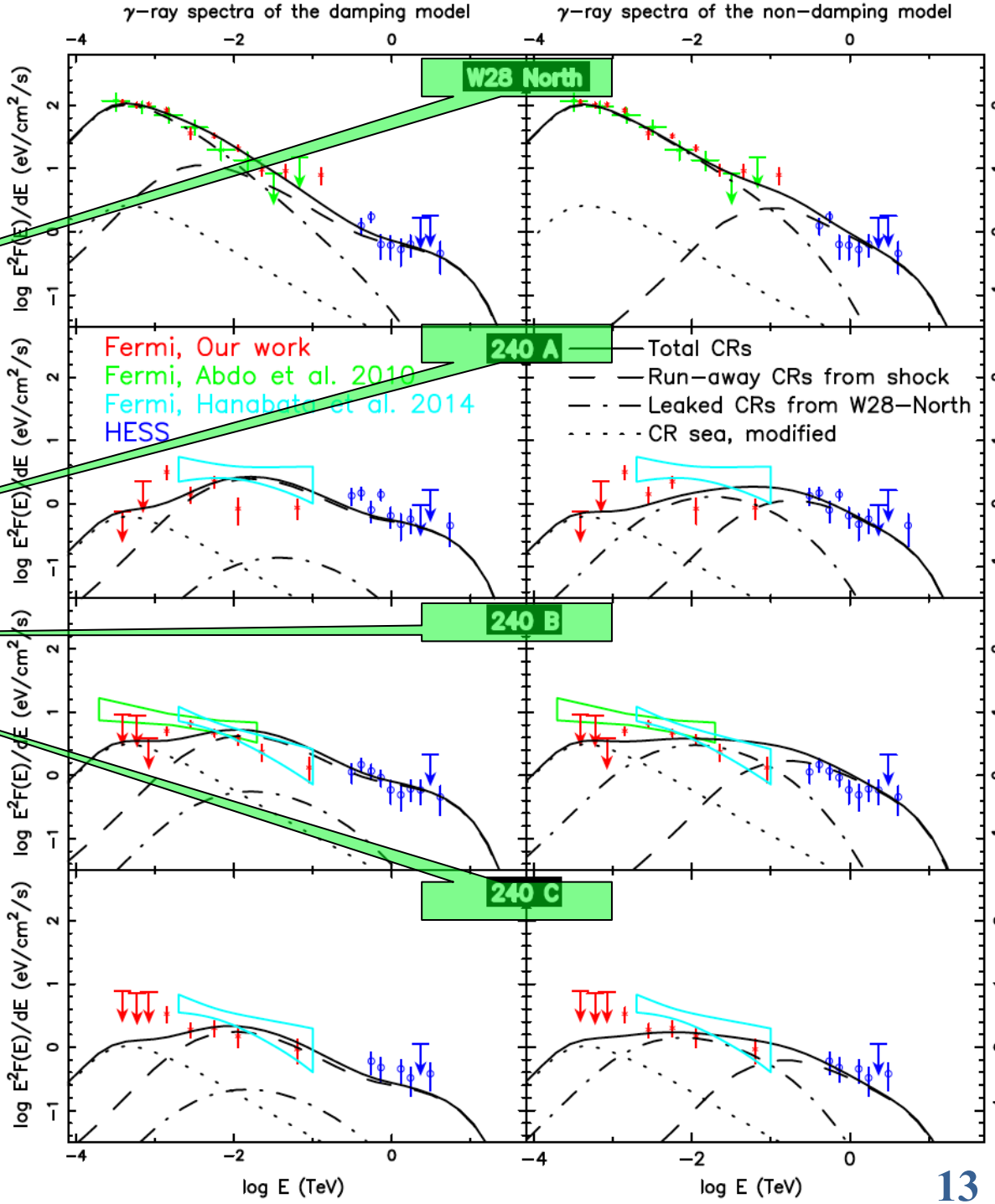
MC-N is partially colliding with SNR, and it is too big for the shock to swallow it unharmed.
When the shock at W28-North is stalled, the CRs down to <1GeV can be set free. X~10%

Averaged CR sea

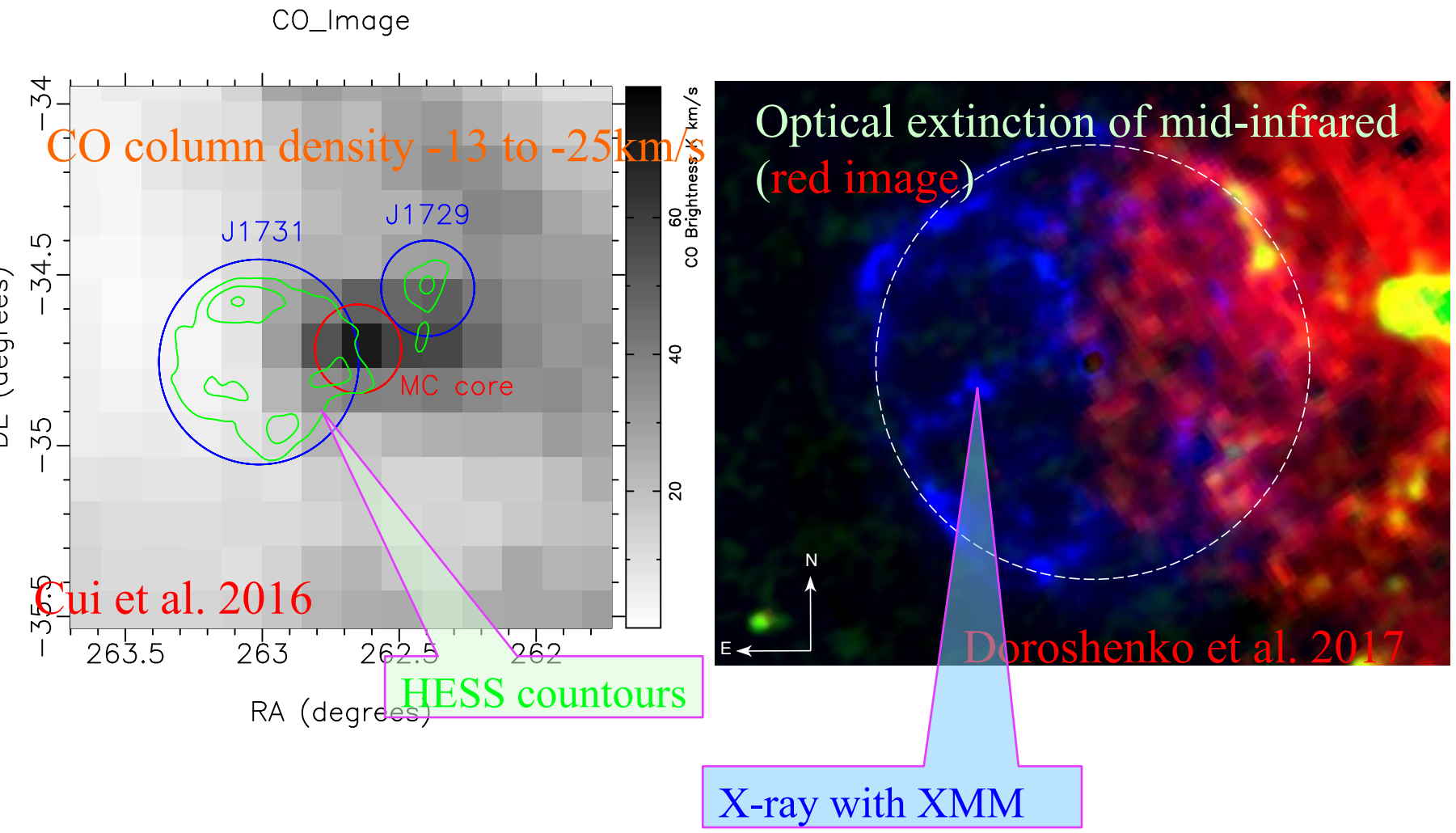


Homogeneous diffusion coefficient used here.

10% of the Galactic CR sea.

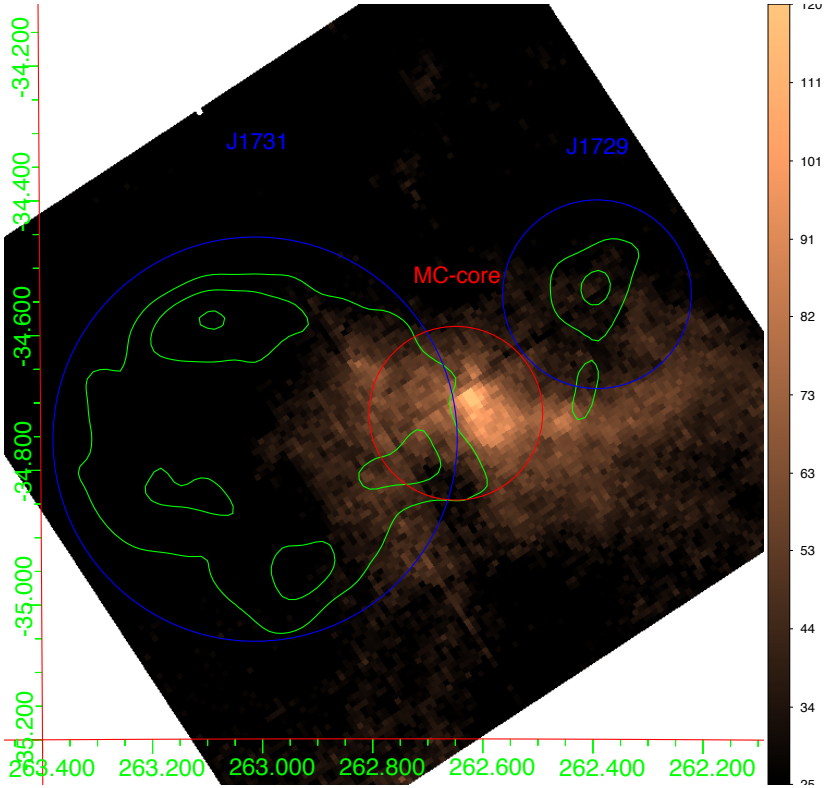


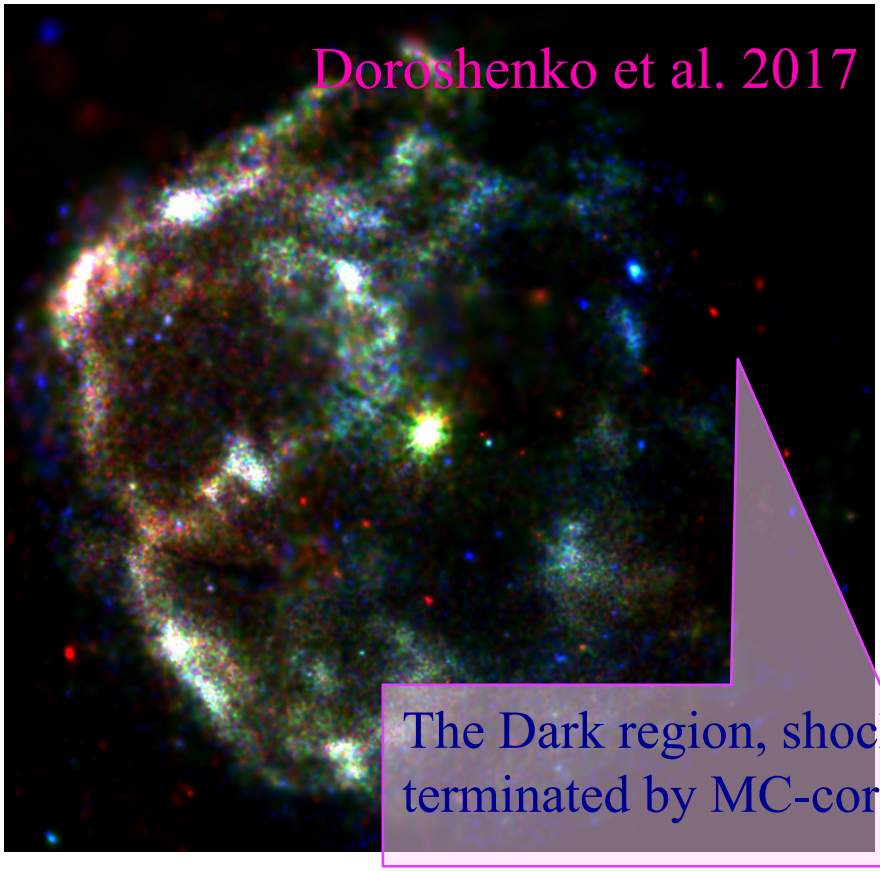
Giant Molecular cloud in front of the SNR



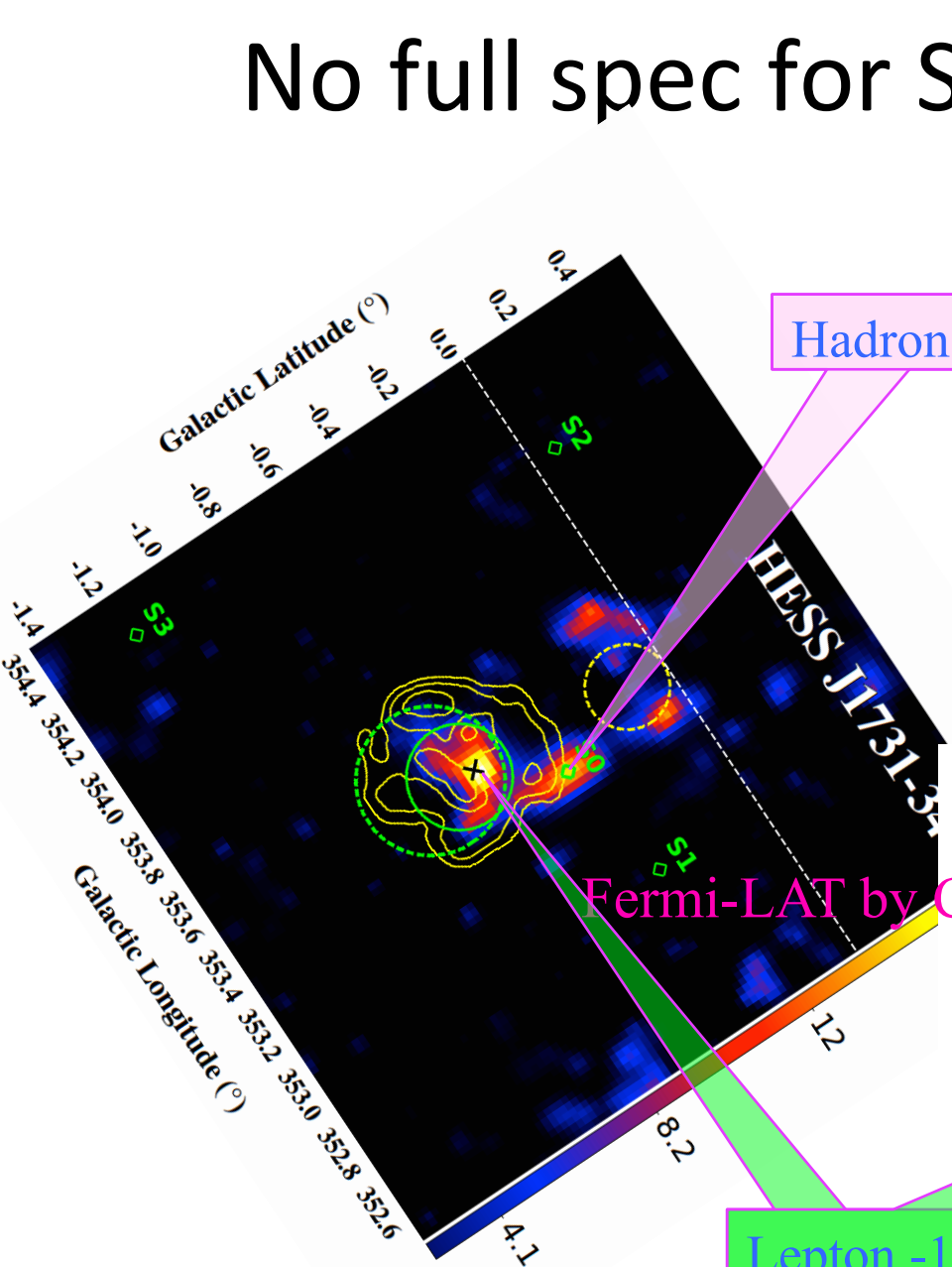
3.2kpc, 15pc radius, MC core was put 100pc away in Cui et al. 2016

0.4-1.8KeV, 1.8-2.8KeV, 2.8-10KeV

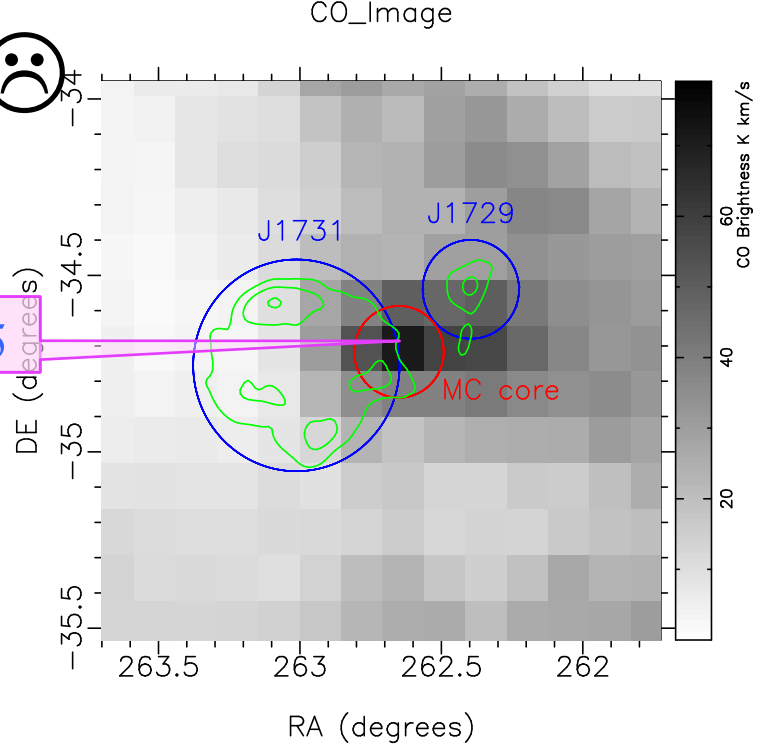




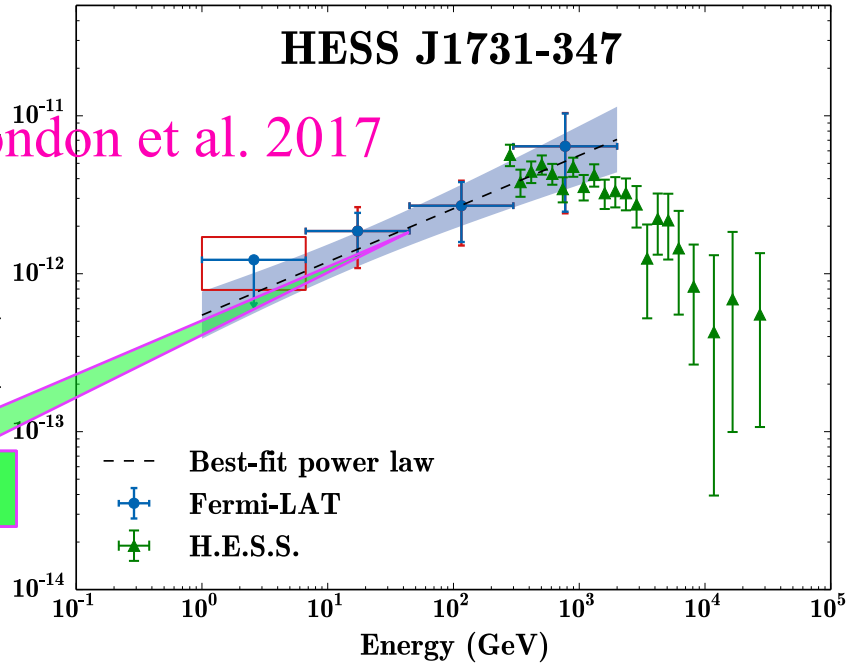
No full spec for S0 ☹



Hadron? -2.5

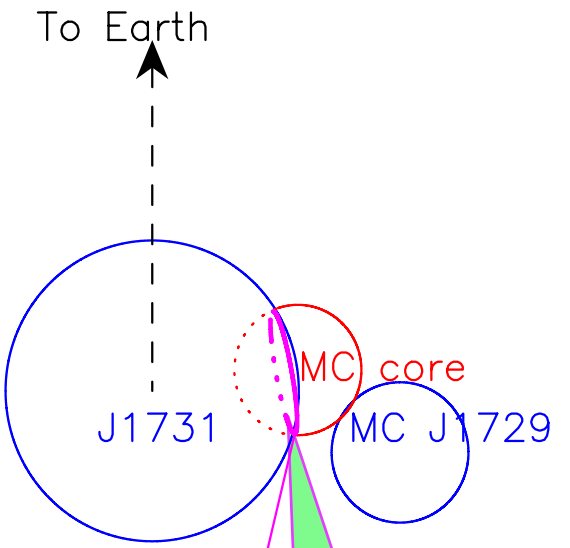


Fermi-LAT by Condon et al. 2017

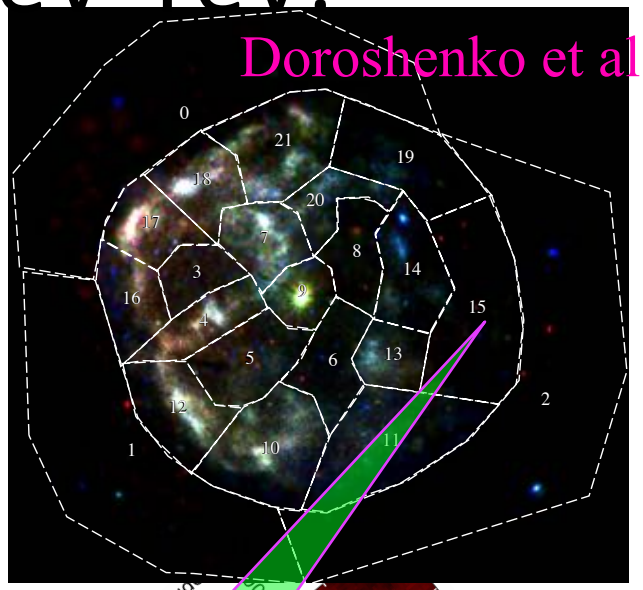


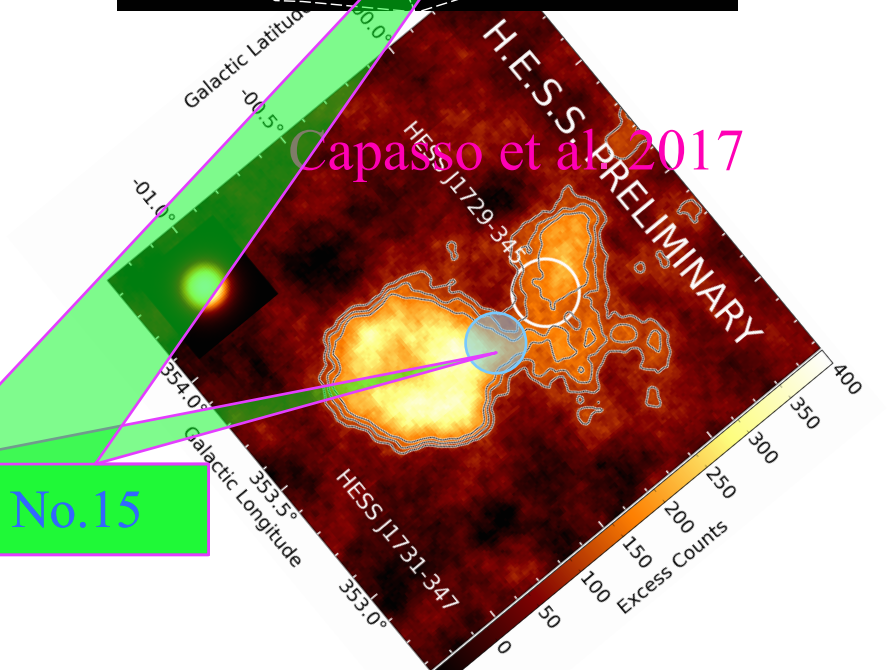
Lepton -1.7

The Dark Region - No.15, but Shine brightly in GeV-TeV.

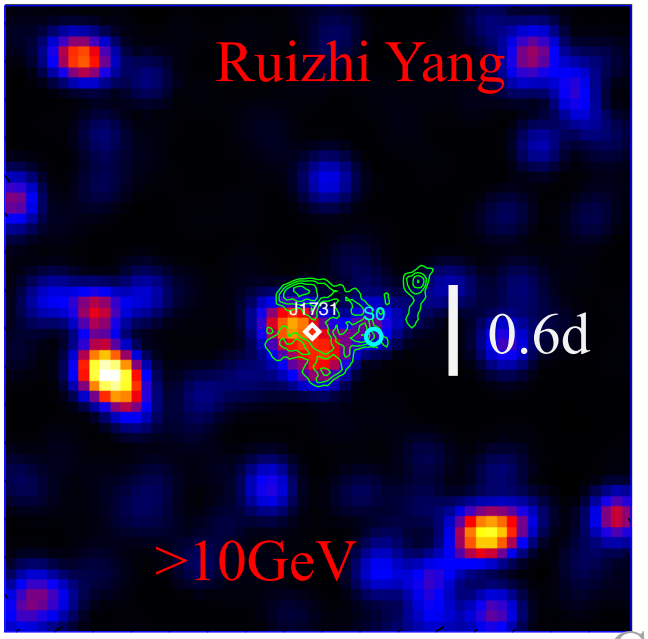


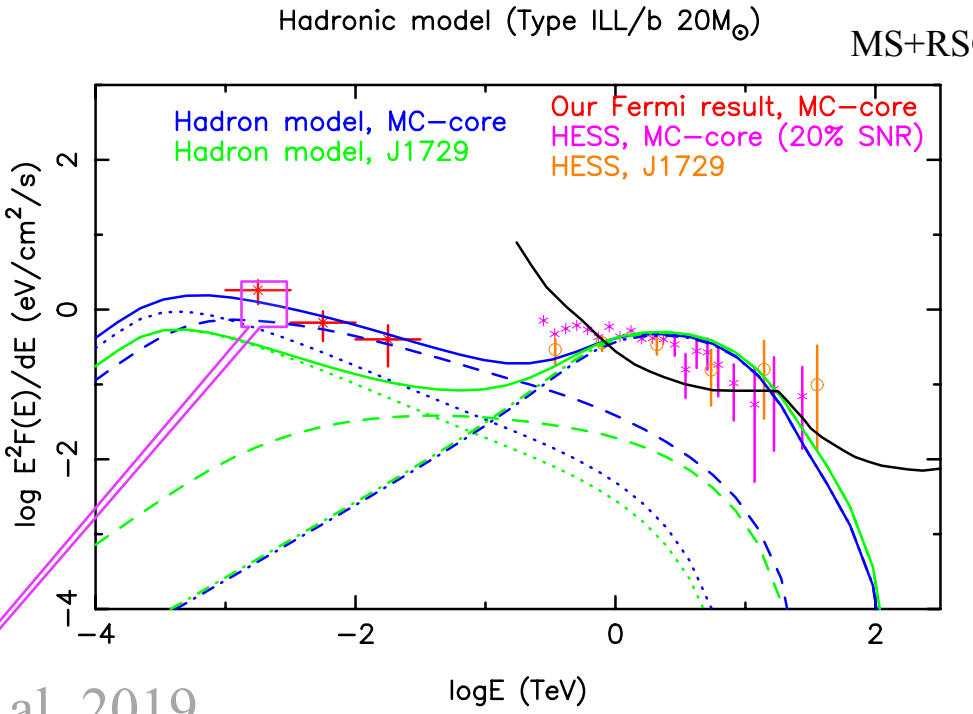
SNR J1731 is too young, <~5kyr,
shock−MC encounter should NOT be seen as an instantaneous event.



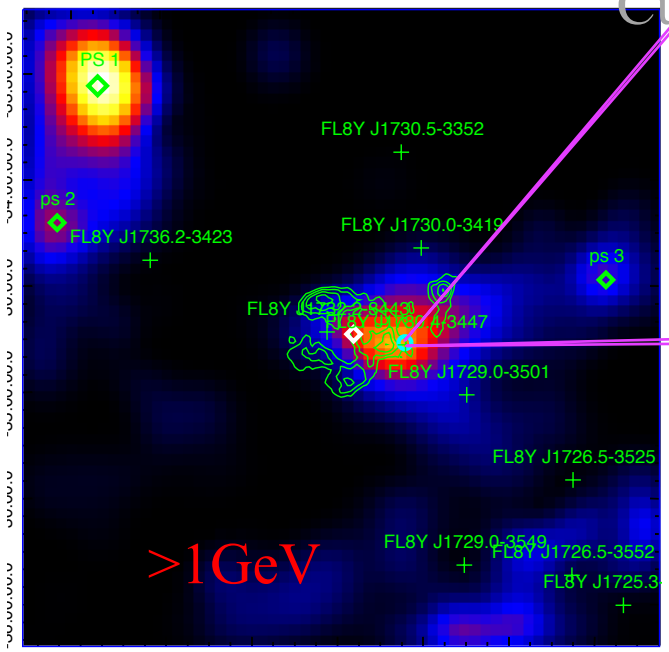


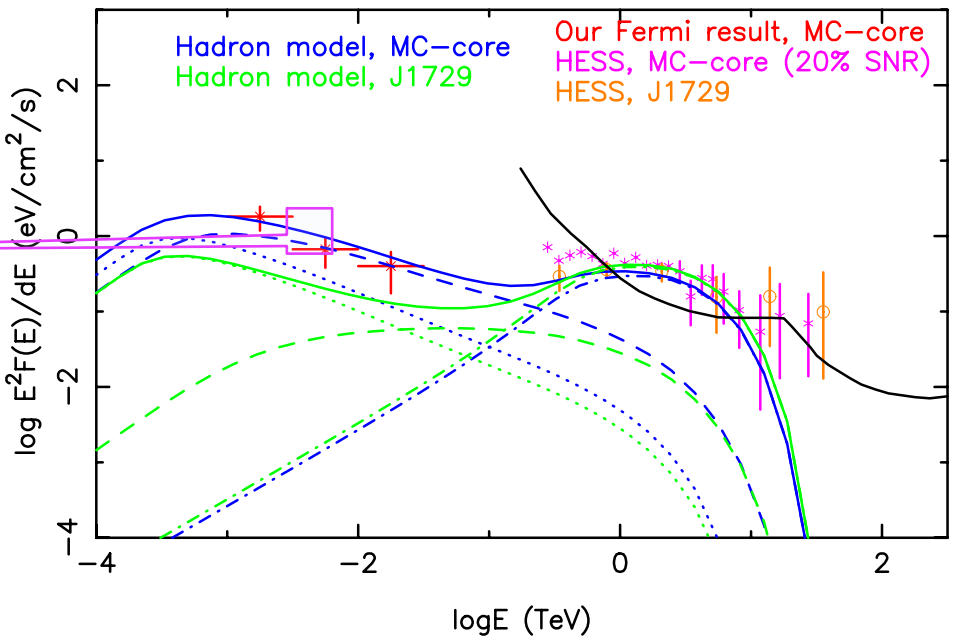
The hadronic Region No.15

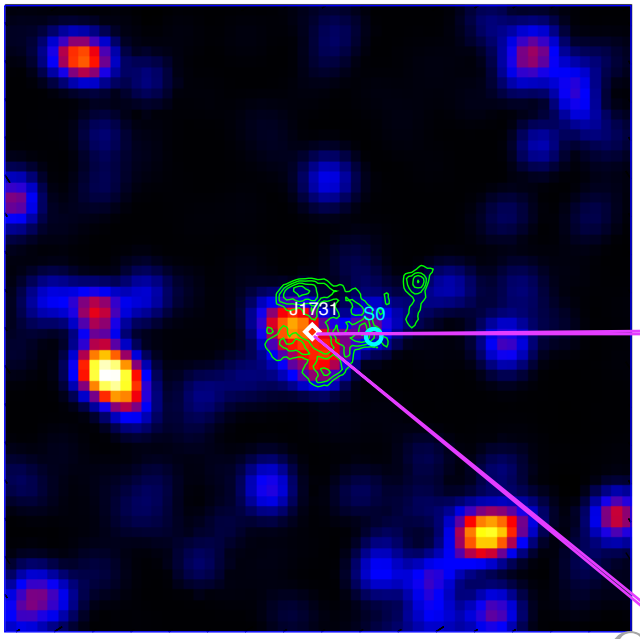


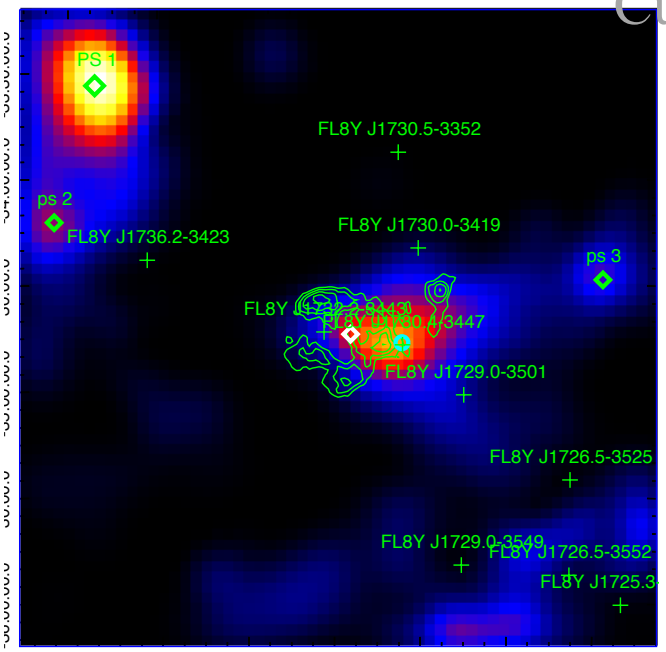


Cui et al. 2019

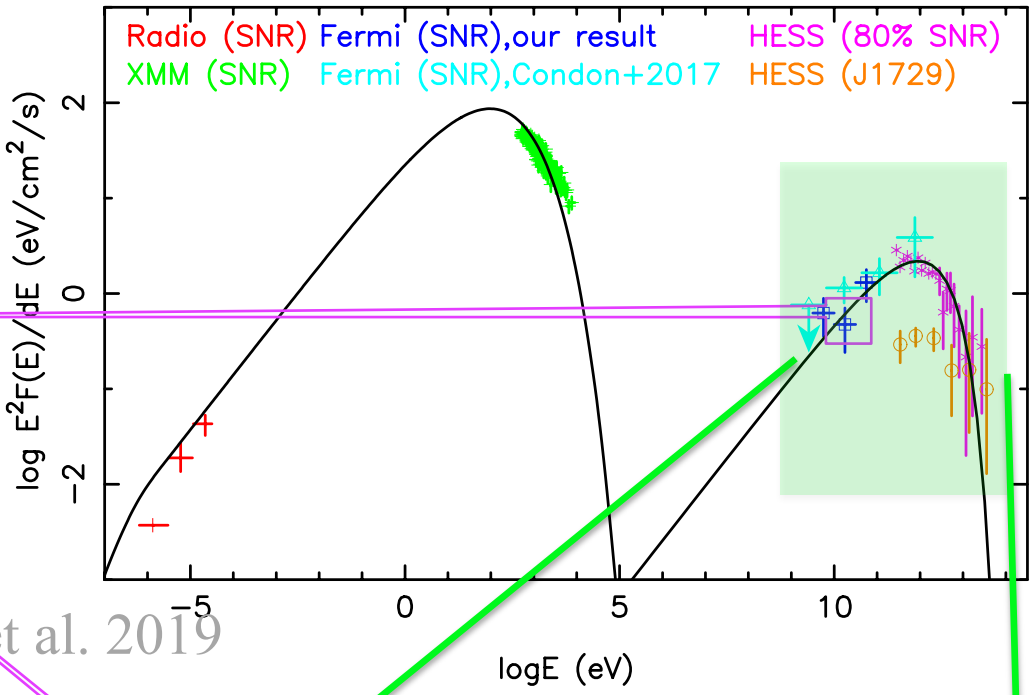




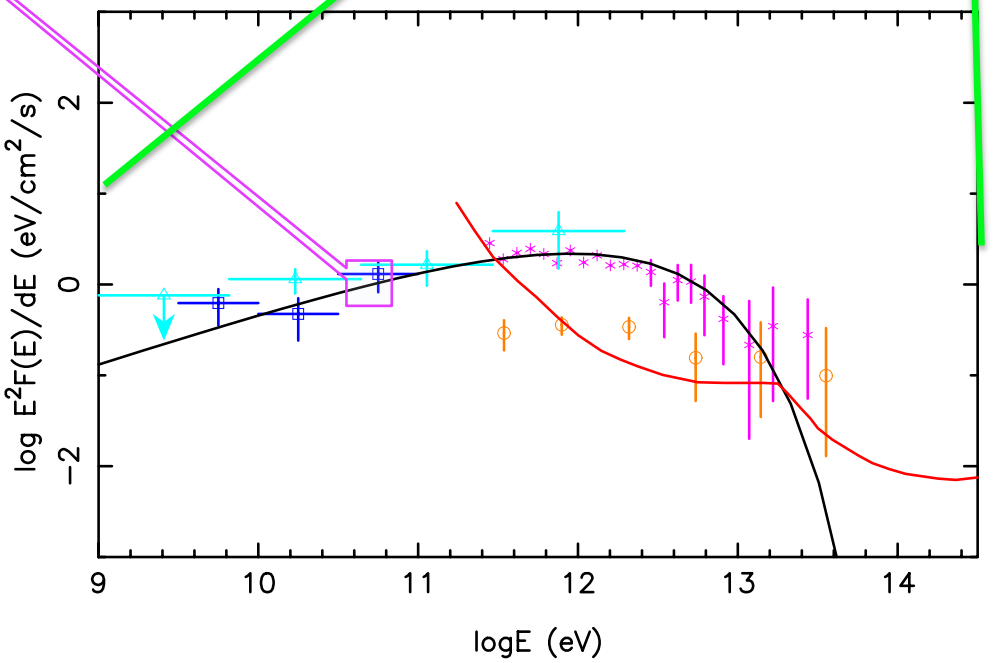




Leptonic model for the SNR



Cui et al. 2019



Any ionization proof in MC-core?

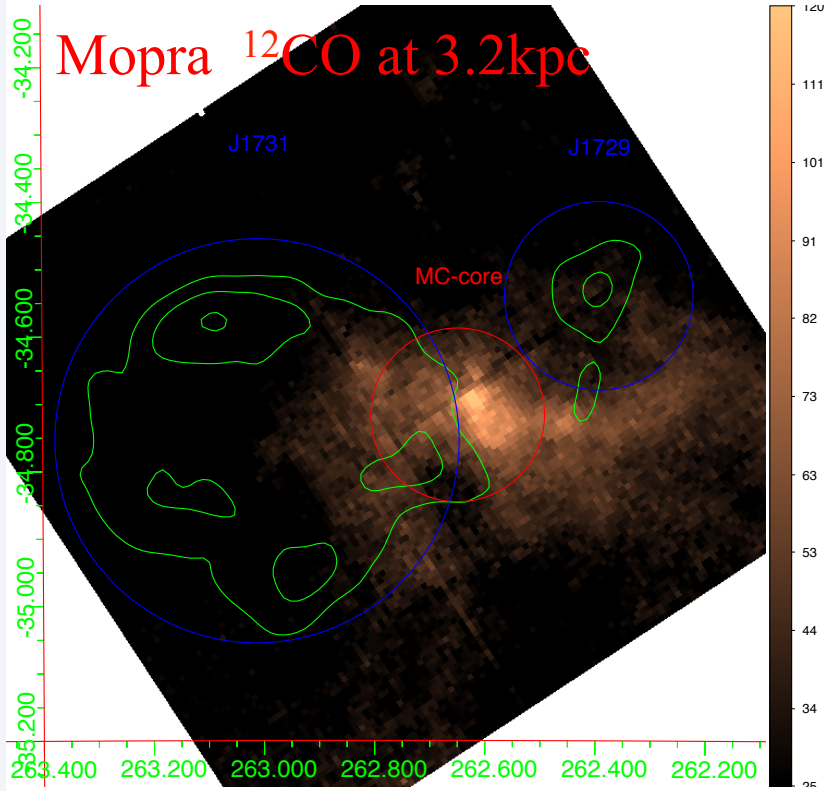
MeV - GeV Cosmic Rays could be injected into MC-core and ionize the molecular there. But for a young SNR?

Other sources with successful ionization hunt

1. H_3^+ absorption features for SNR IC 443, with Near Infrared Echelle Spectrograph at the W. M. Keck Observatory, and the Infrared Camera and Spectrograph at the Subaru Telescope, by Indriolo 2010ApJ...724.1357I;

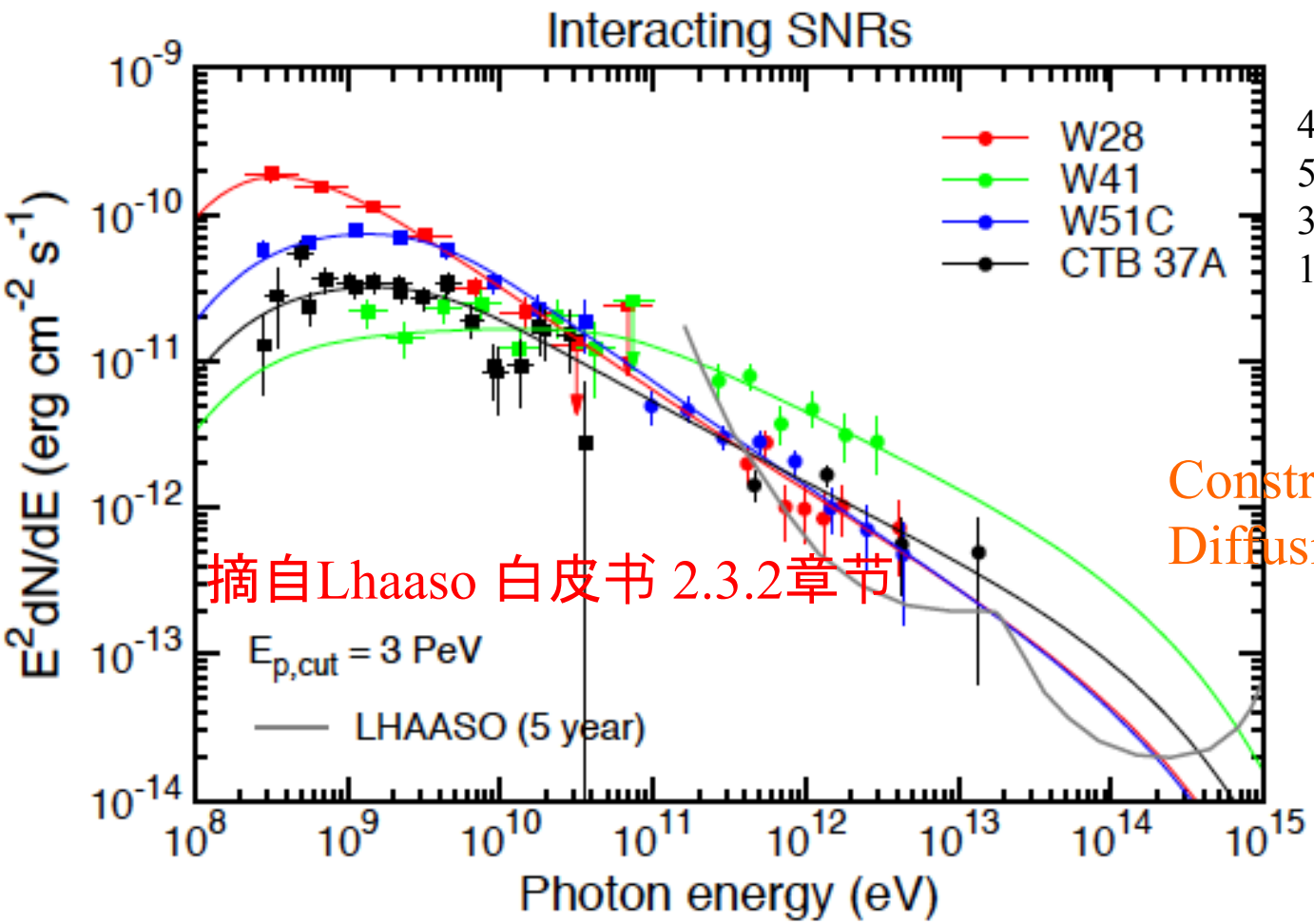
2. DCO^+/HCO^+ abundance ratios for SNR W28, with IRAM 30m telescope, by Vaupre2014, A&A,568, A50;

3. NH_3 lines for SNR W28, with Mopra radio telescope, by Maxted2016MNRAS.462..532M;



And HD simulation is needed for MeV-GeV CRs.

Shock-cloud cases via LHAASO

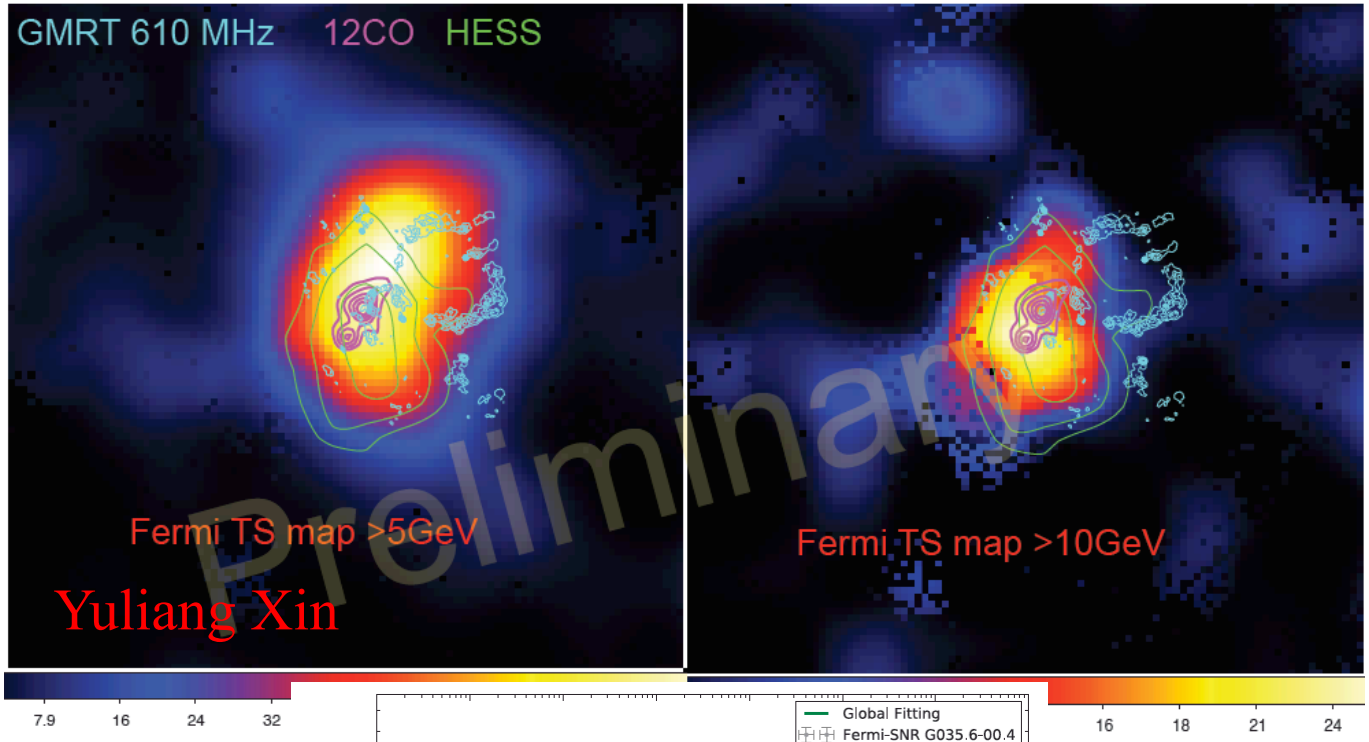


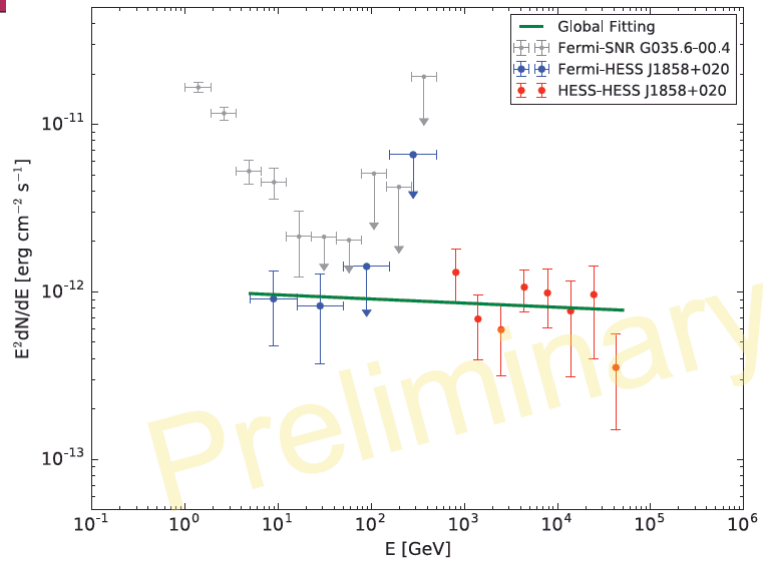
40kyr, HESS, 2kpc
5-100kyr, HESS, 4kpc
30kyr, Magic, 6kpc
10kyr, HESS, 10kpc

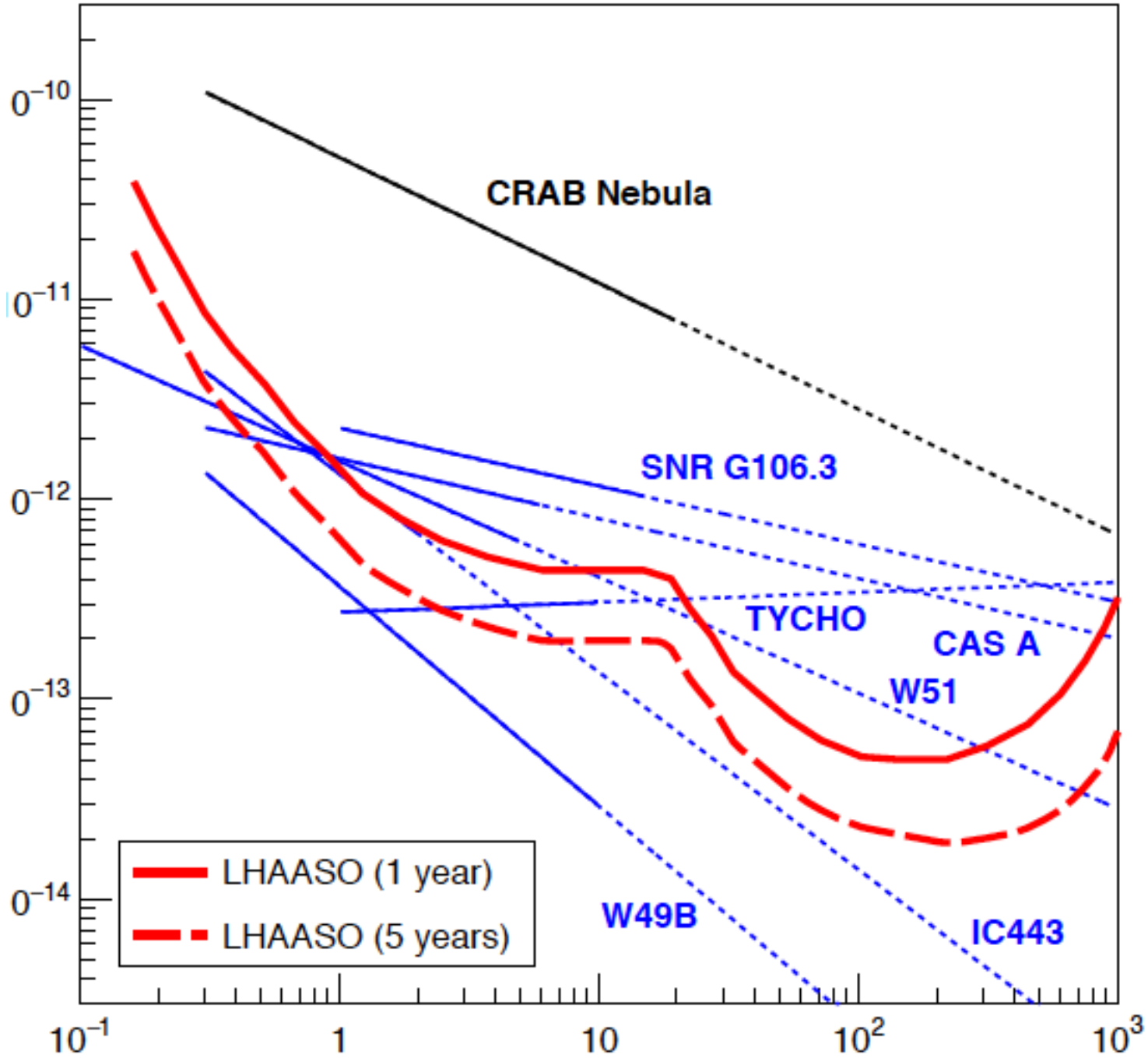
摘自Lhaaso 白皮书 2.3.2章节

Constrains on the SNR age & Diffusion coefficients

SNR G35.6-0.4, another W28 case?






CRAB Nebula
SNR G106.3
TYCHO
CAS A
W51
W49B
IC443
LHAASO (1 year)
LHAASO (5 years)
10^{-10}
10^{-11}
10^{-12}
10^{-13}
10^{-14}
10^{-1}
1
10
10^{2}
10^{3}