Turbulence and Stochastic Particle Acceleration in High-beta Plasmas of SNRs

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Energetic Particles

	IPM	ISM	ICM
Observations	**Very Rich** From large to Small scales in both space and time From remote sensing to in situ measurement	**Multi-wavelength** remote sensing and in situ **cosmic ray** measurement	**Mostly Radio** For energetic electrons and **X-rays** for background plasma
Consequence	**Too rich to deal with.** Confusions?	Details on the physics of particle acceleration, radiation, and transport	Physics of DSA or SA?

Outline

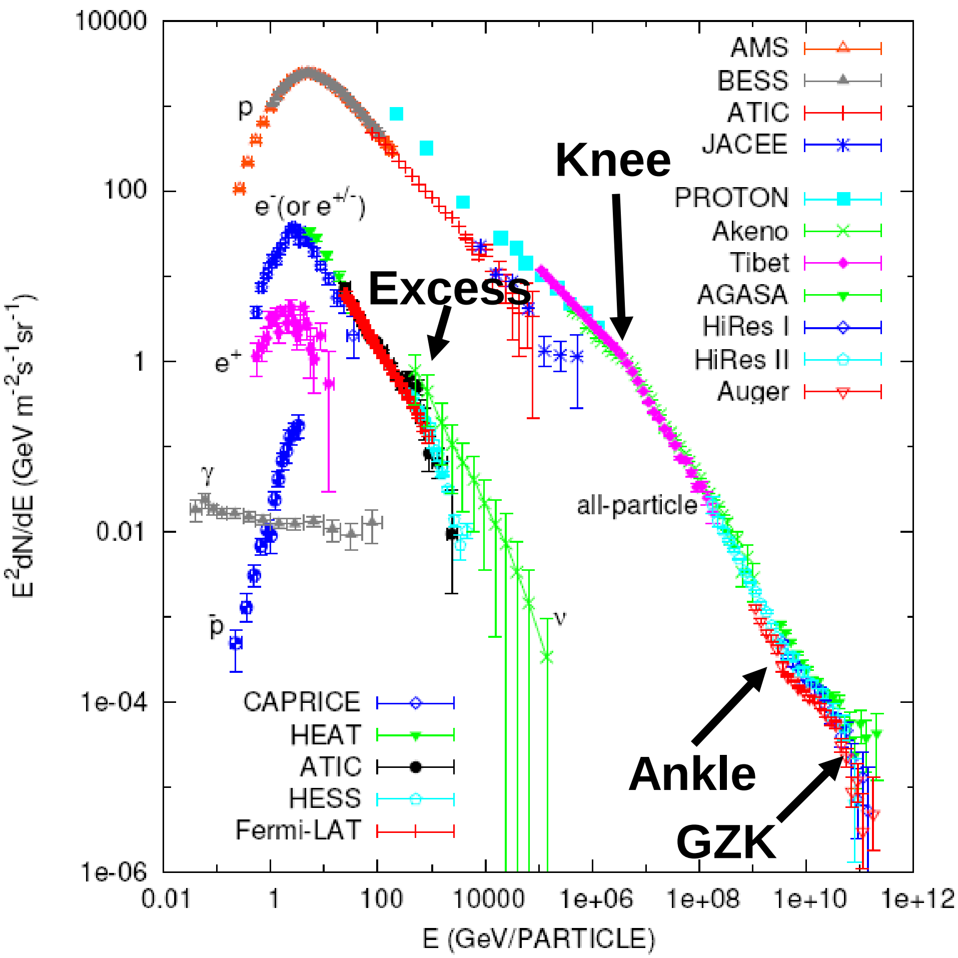
1: Observational Review of Particle Acceleration in SNRs

2: A Unified Model for Particle Acceleration in SNRs

3:Turbulence and Stochastic Particle Acceleration in High-beta Plasmas of SNRs

4: Conclusions

1: Cosmic Rays



Dominated by Nuclei, there are also electrons, positrons and antiprotons

Age: ~10^7 Year

Energy density: 1eV/cm^3

Power: ~ 10^{41} erg/s

Maximum Energy: 3×10^{20}eV ~ 50 Joule

Spectral Knee at ~ 1e15eV and Ankle at ~ 1e18eV

GZK Cutoff at ~ 1e20 eV

Discovered in 1912 by Victor Hess (1936 Nobel prize)

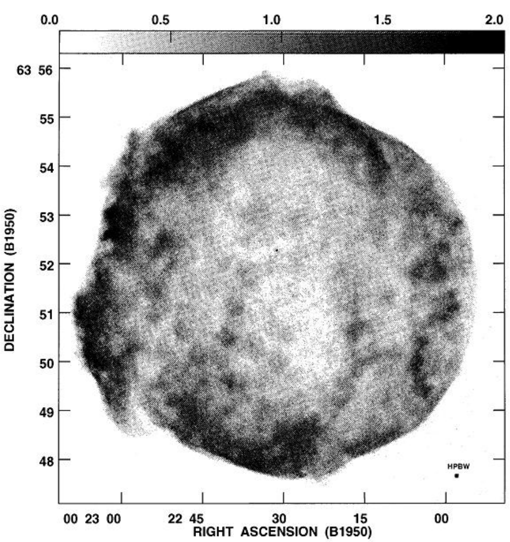
1:Radio Observations of Supernova Remnants-Evidence for GeV Electrons

COSMIC RAYS FROM SUPER-NOVAE

By W. Baade and F. Zwicky

Mount Wilson Observatory, Carnegie Institution of Washington and California Institute of Technology, Pasadena

Communicated March 19, 1934



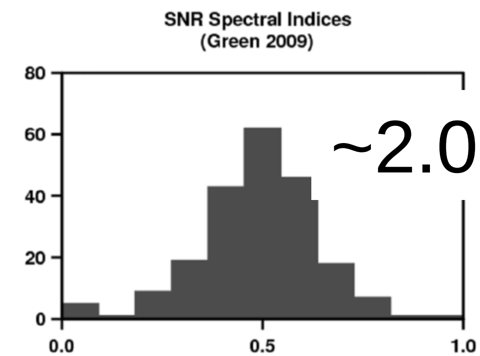
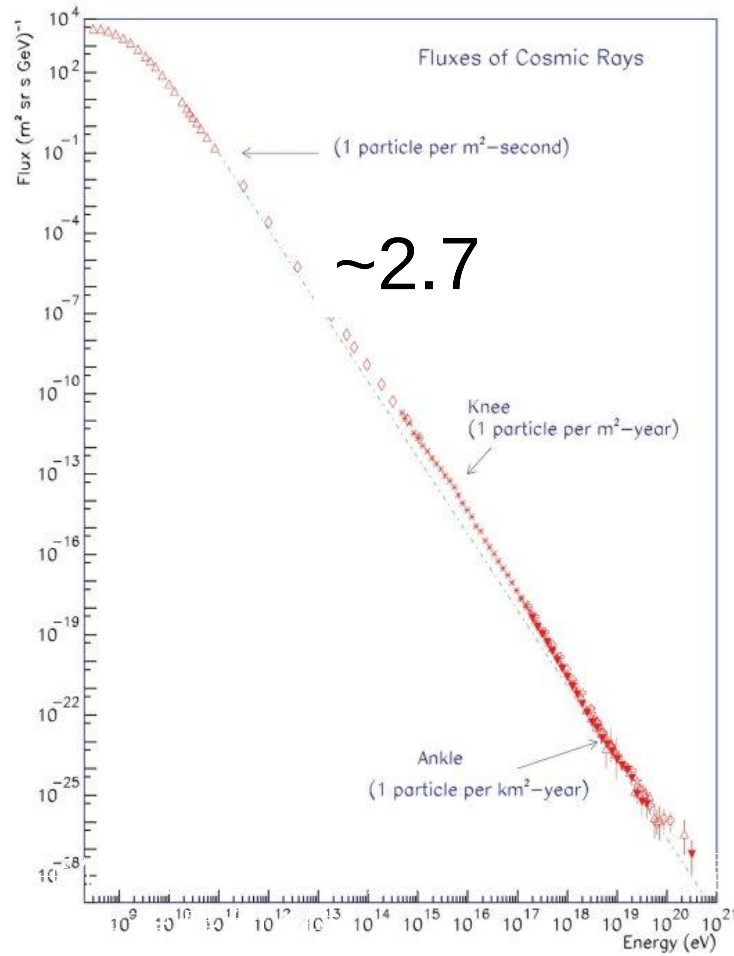


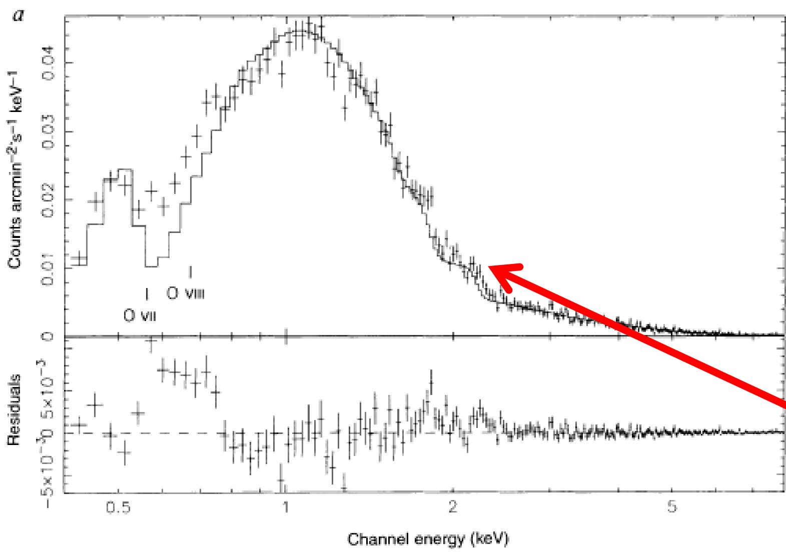
Fig. 1 Histogram of shell SNRs with fairly well-measured radio spectral indices, from Green 2009. PWNe are excluded.

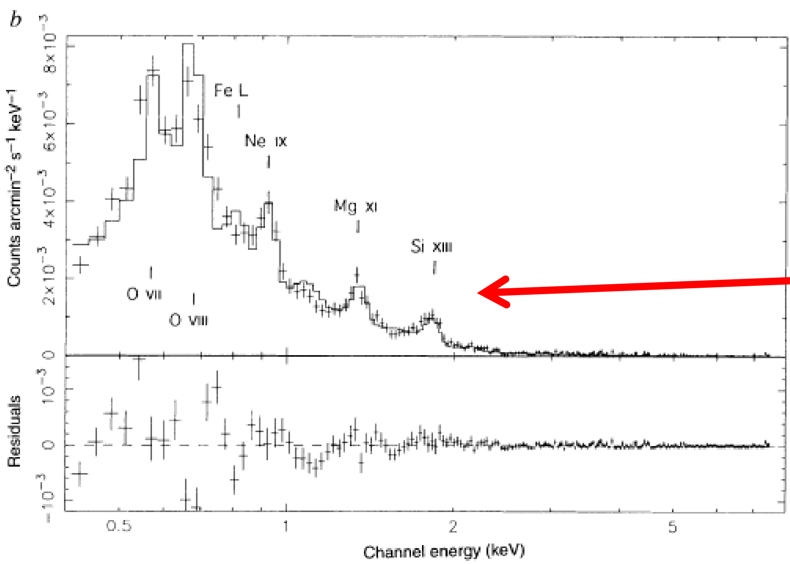


Magnetic fields in supernova remnants and pulsar-wind nebulae

Stephen P. Reynolds · B. M. Gaensler · Fabrizio Bocchino

1:X-ray Observations of TeV Electron Acceleration in Supernova Remnants

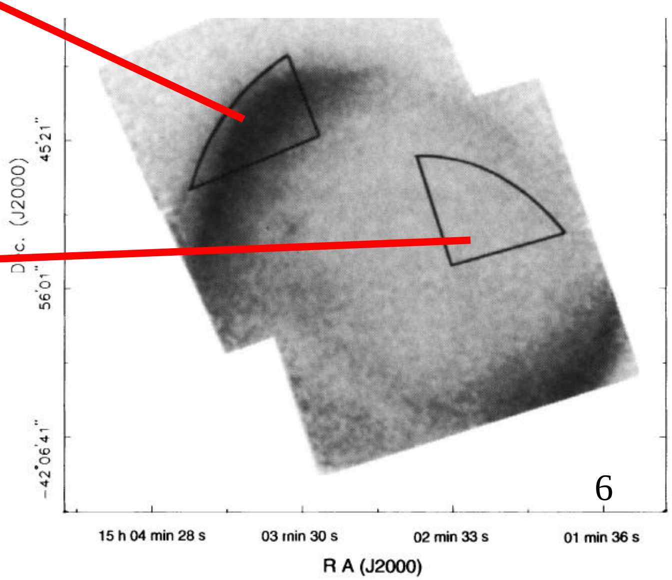




Evidence for shock acceleration of high-energy electrons in the supernova remnant SN1006

K. Koyama[*], R. Petre[†], E. V. Gotthelf[†‡], U. Hwang[†], M. Matsuura[§], M. Ozaki[*] & S. S. Holt[†]

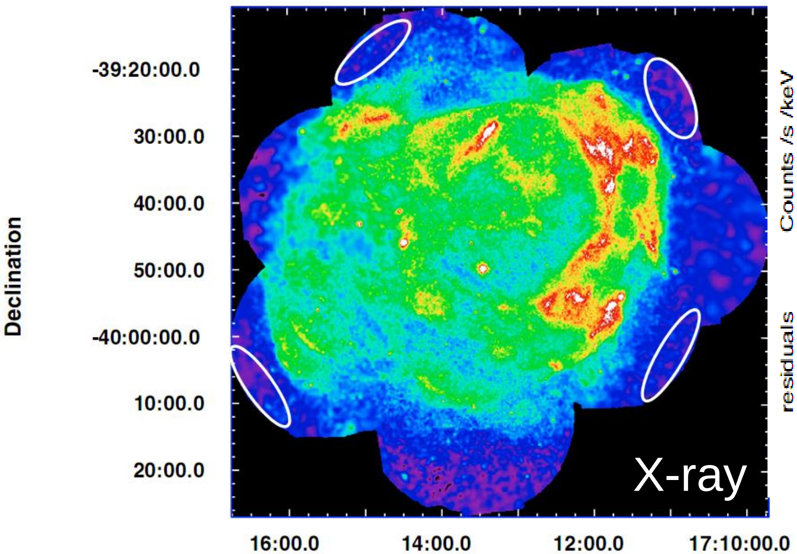
NATURE · VOL 378 · 16 NOVEMBER 1995

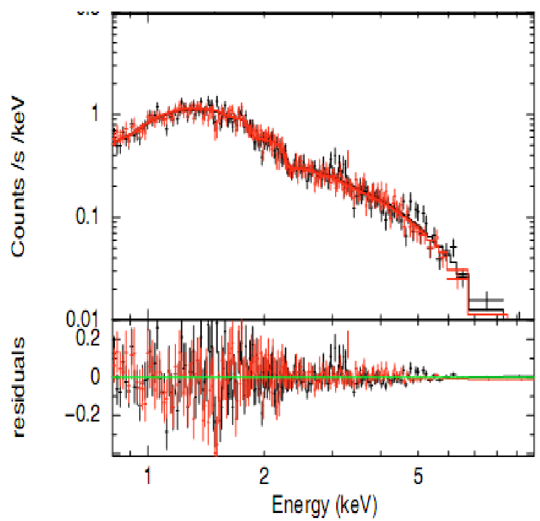


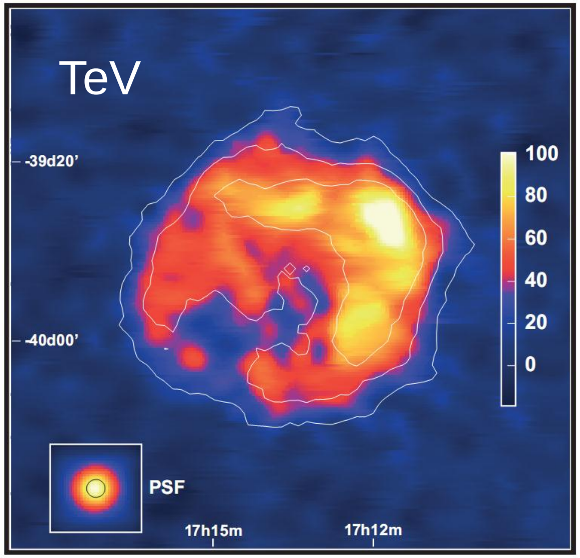
1: Shell Type TeV SNRs

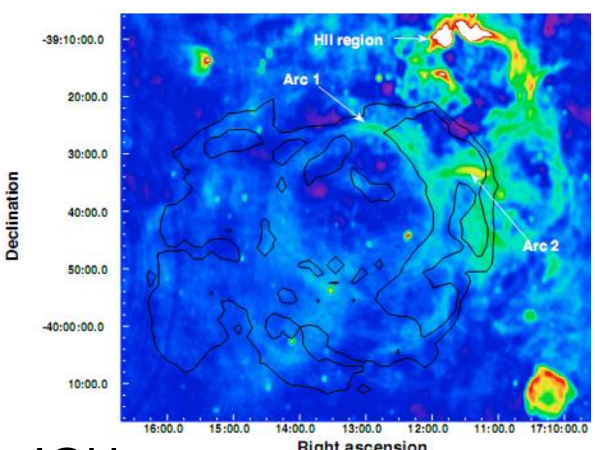
A joint spectro-imaging analysis of the *XMM-Newton* and HESS observations of the supernova remnant RX J1713.7-3946

F. Acero[1], J. Ballet[1], A. Decourchelle[1], M. Lemoine-Goumard[2,3], M. Ortega[4], E. Giacani[4], G. Dubner[4], and G. Cassam-Chenaï[5]

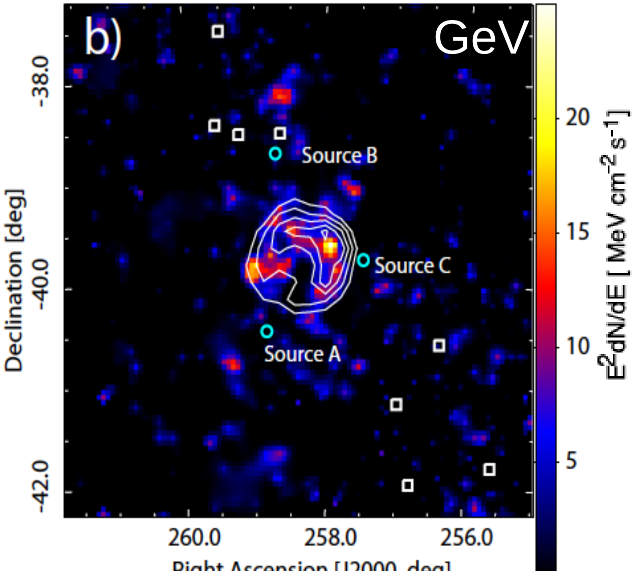


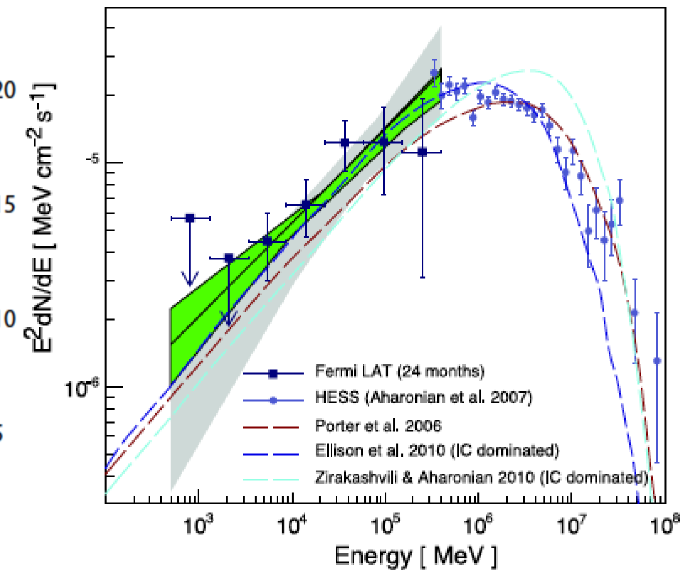






1.4GHz



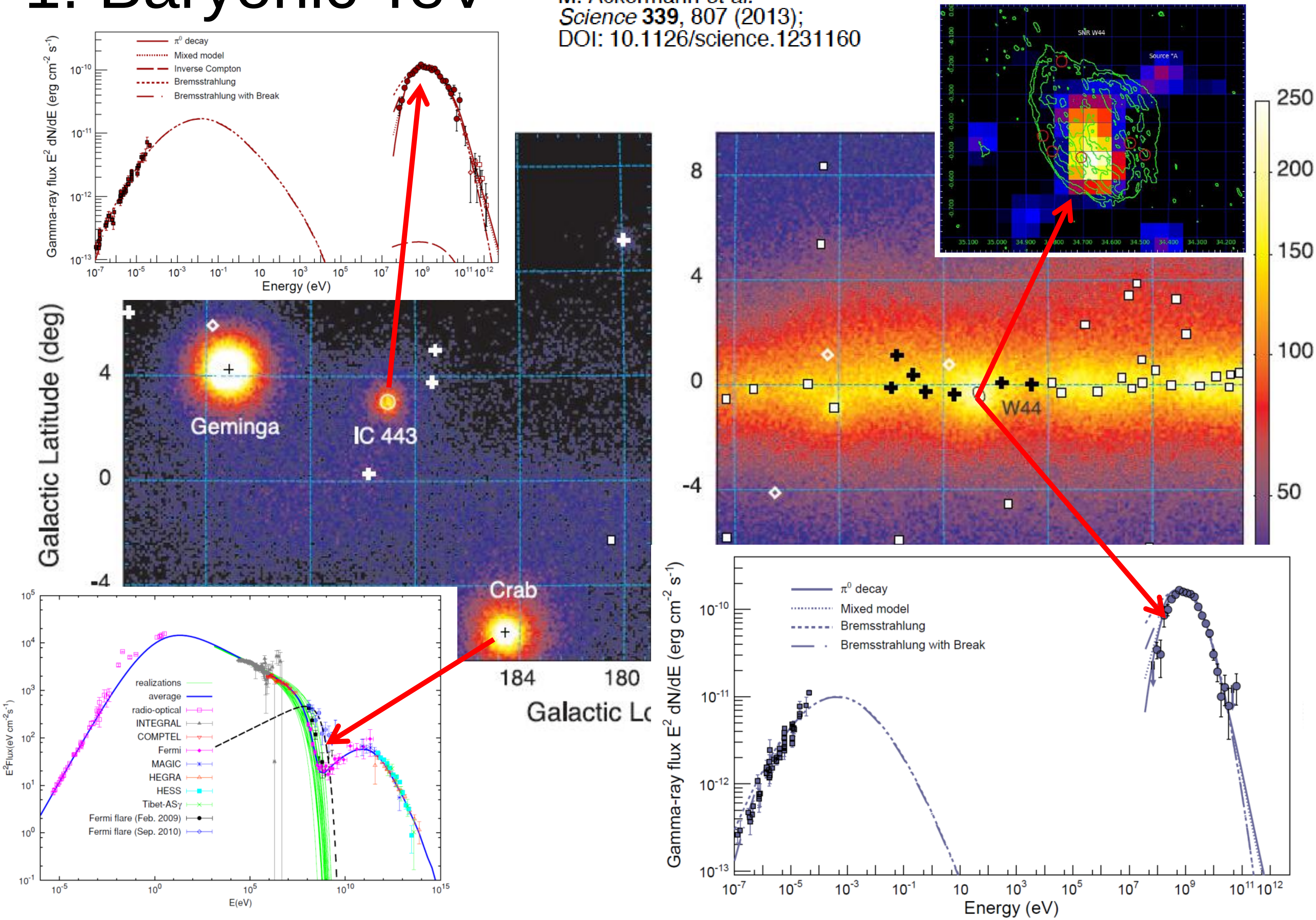


Observations of the young Supernova remnant RX J1713.7−3946 with the *Fermi* Large Area Telescope

A. A. Abdo[2], M. Ackermann[3,1], M. Ajello[3], A. Allafort[3], L. Baldini[4], J. Ballet[5],

1: Baryonic TeV

Detection of the Characteristic Pion-Decay Signature in Supernova Remnants
M. Ackermann *et al.*
Science **339**, 807 (2013);
DOI: 10.1126/science.1231160



1: Baryonic TeV

Detection of the Characteristic Pion-Decay Signature in Supernova Remnants
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Science **339**, 807 (2013);
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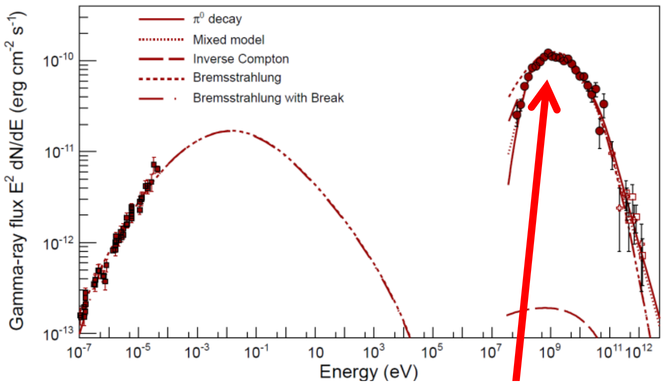
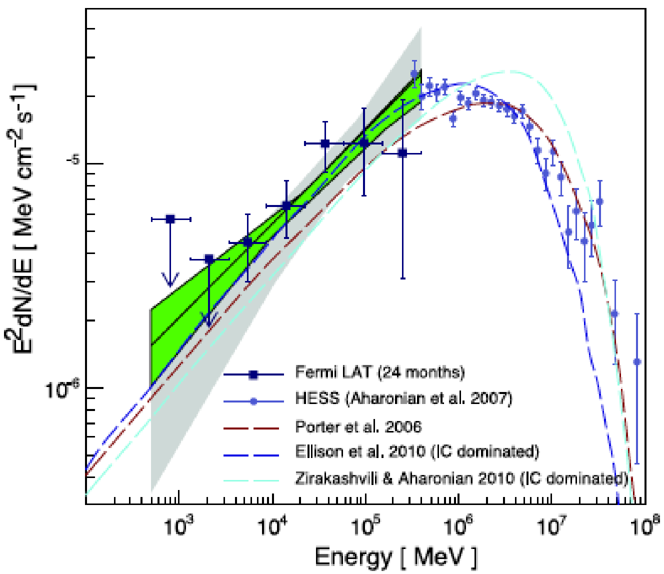
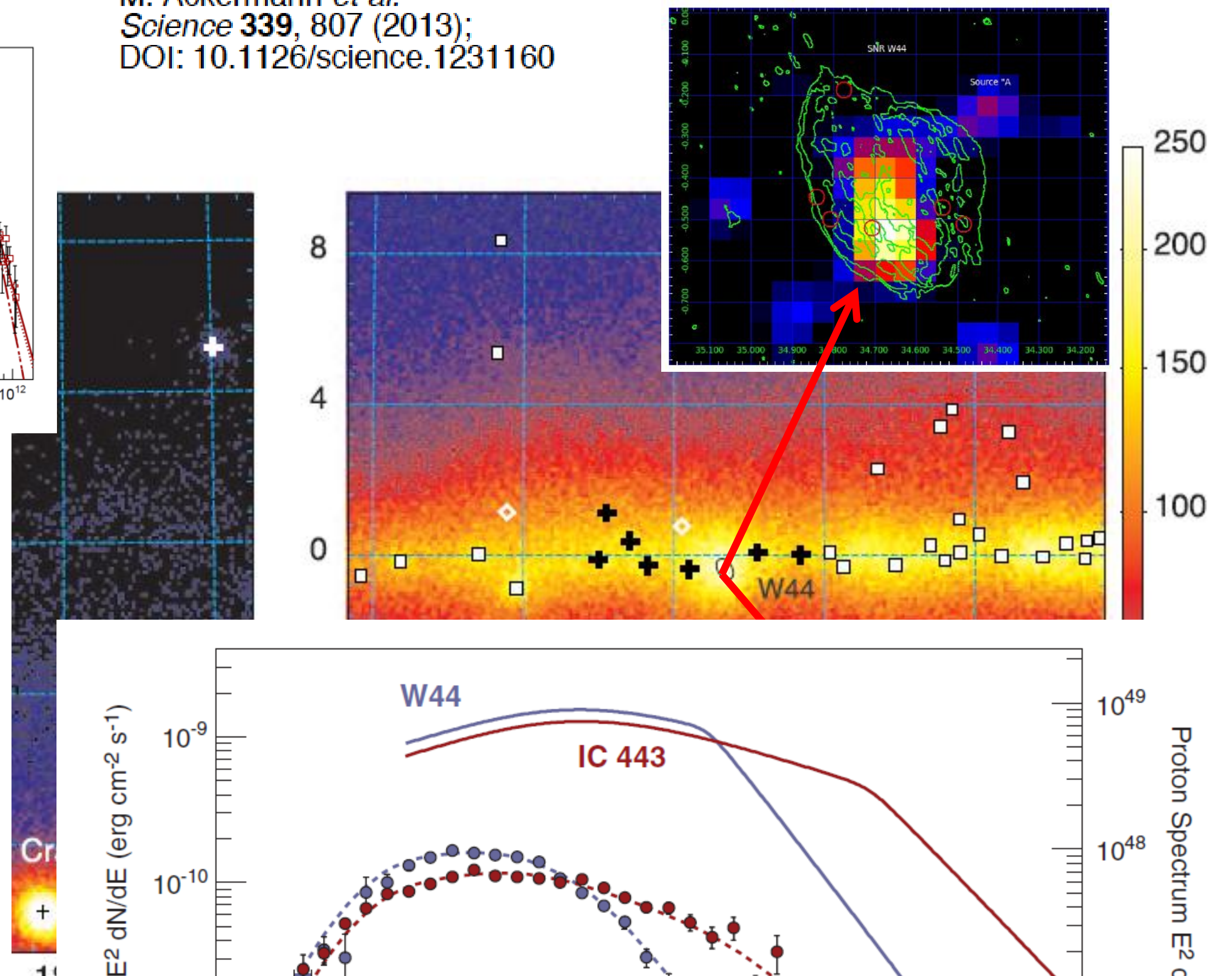
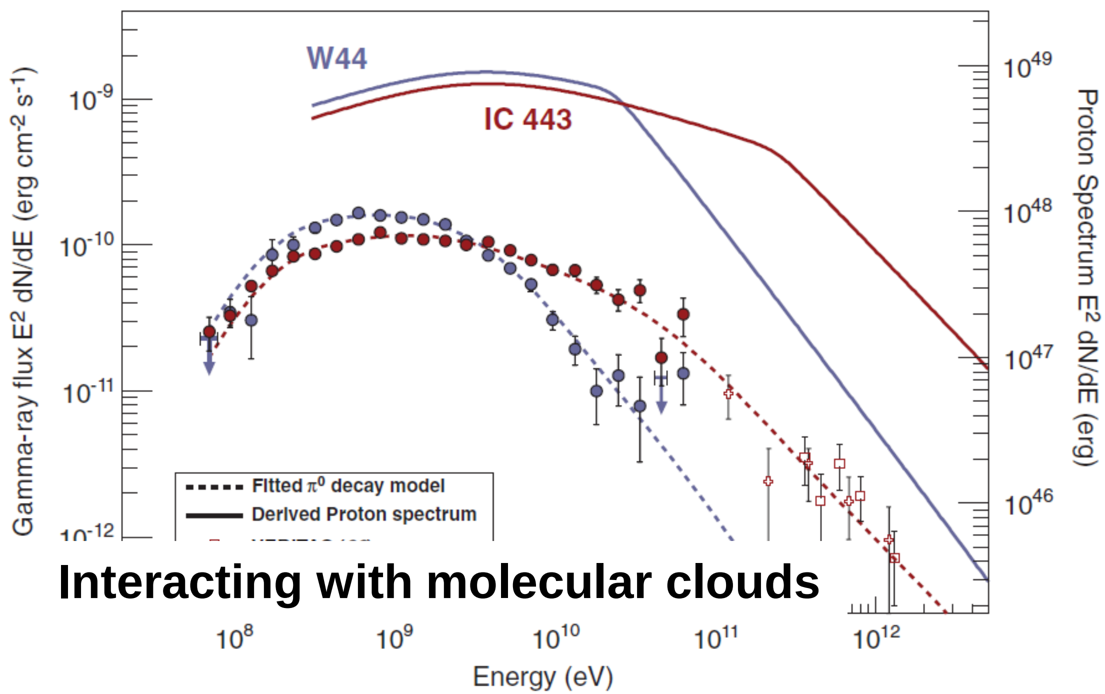




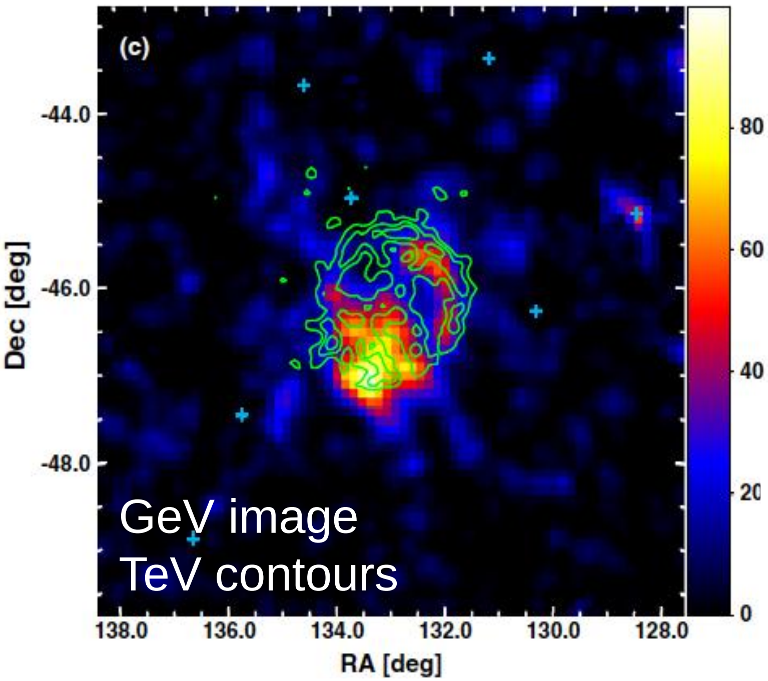




Shell Type TeV SNRs:
Younger, no-thermal emission,
Strong synchrotron X-rays

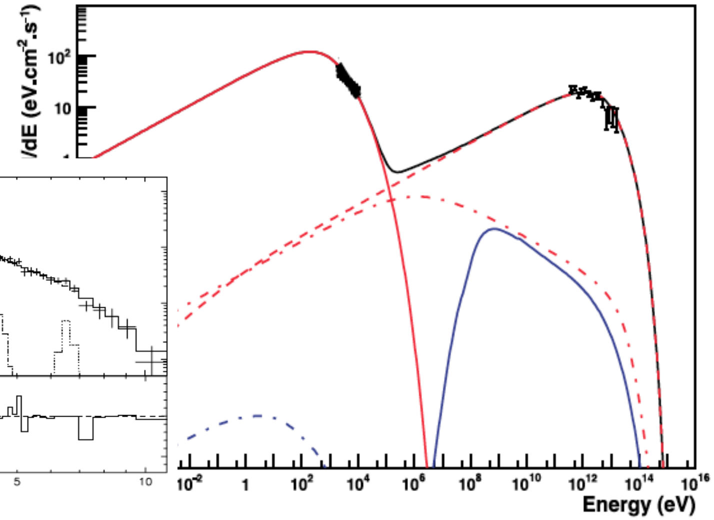
Interacting with molecular clouds

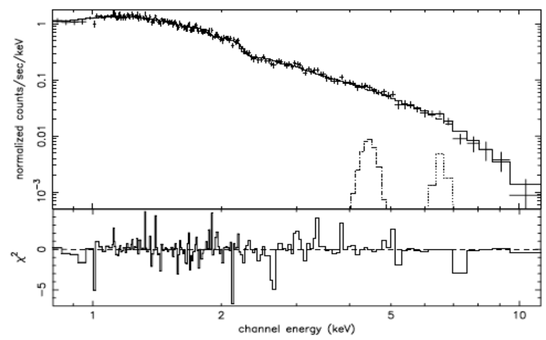
The Astrophysical Journal Letters, 740:L51 (5pp), 2011 October 20
doi:10.1088/2041-8205/74



GAMMA-RAY OBSERVATIONS OF THE SUPERNOVA REMNANT RX J0852.0−4622 WITH THE *FERMI* LARGE AREA TELESCOPE

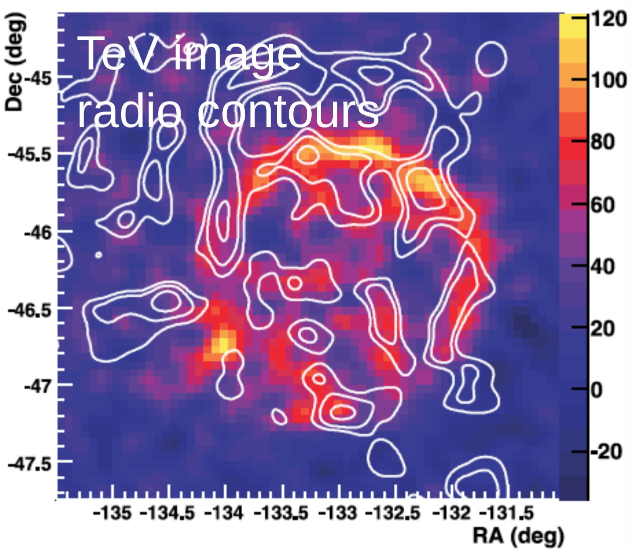
T. Tanaka[1], A. Allafort[1], J. Ballet[2], S. Funk[1], F. Giordano[3,4], J. Hewitt[5], M. Lemoine-Goumard[6,9], H. Tajima[1,7], O. Tibolla[8], and Y. Uchiyama[1]

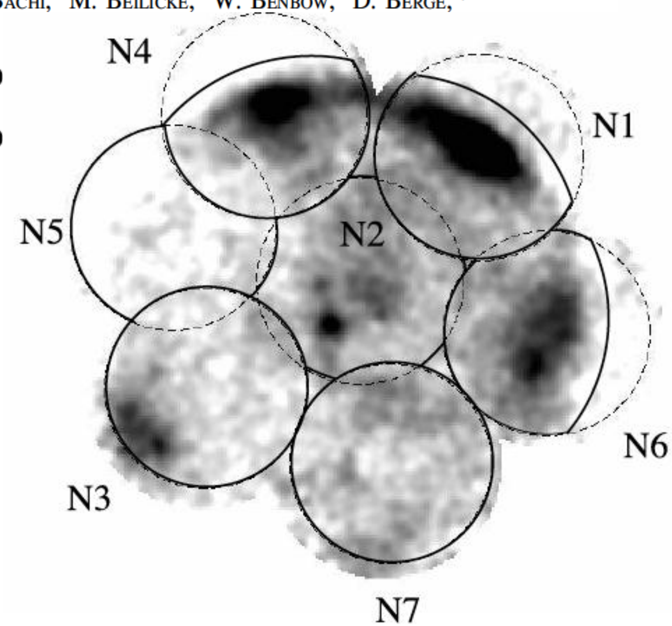


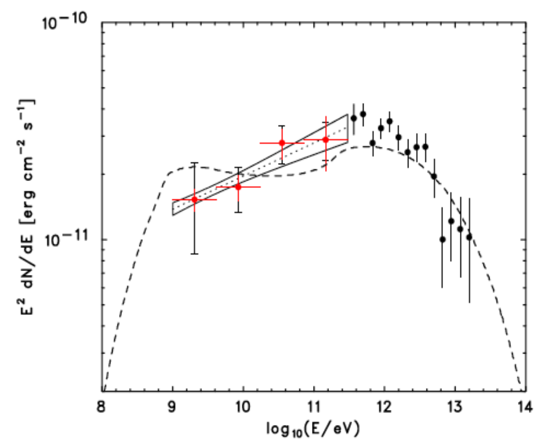


H.E.S.S. OBSERVATIONS OF THE SUPERNOVA REMNANT RX J085 AND SPECTRUM OF A WIDELY EXTENDED VERY HIGH E

F. Aharonian,[1] A. G. Akhperjanian,[2] A. R. Bazer-Bachi,[3] M. Beilicke,[4] W. Benbow,[1] D. Berge,[1,5]

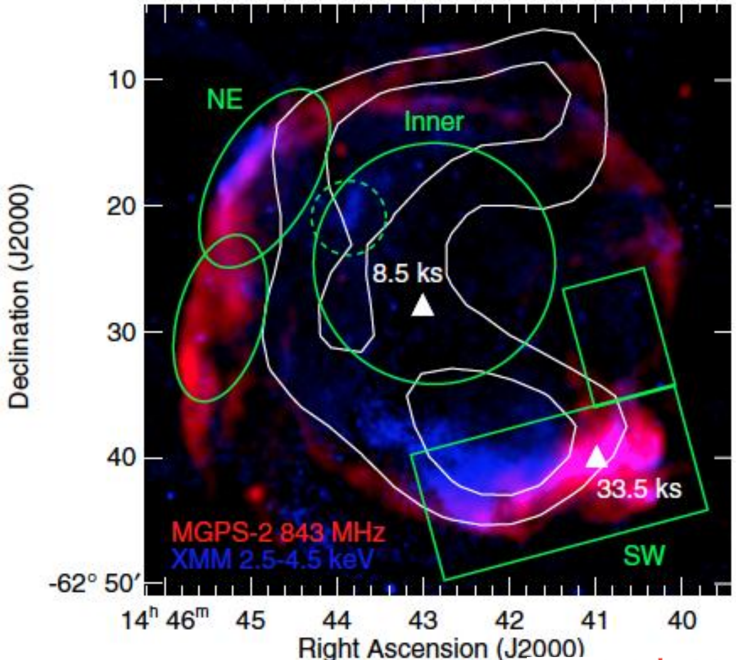






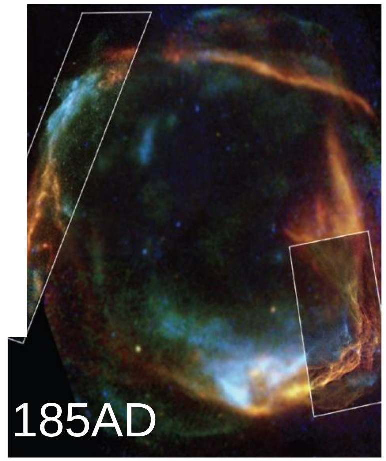
A&A 545, A28 (2012)
DOI: 10.1051/0004-6361/201219896

Astronomy & Astrophysics



Constraints on cosmic-ray efficiency in the supernova remnant RCW 86 using multi-wavelength observations

M. Lemoine-Goumard[1,2], M. Renaud[3], J. Vink[4], G. E. Allen[5], A. Bamba[6], F. Giordano[7,8], and Y. Uchiyama[9]

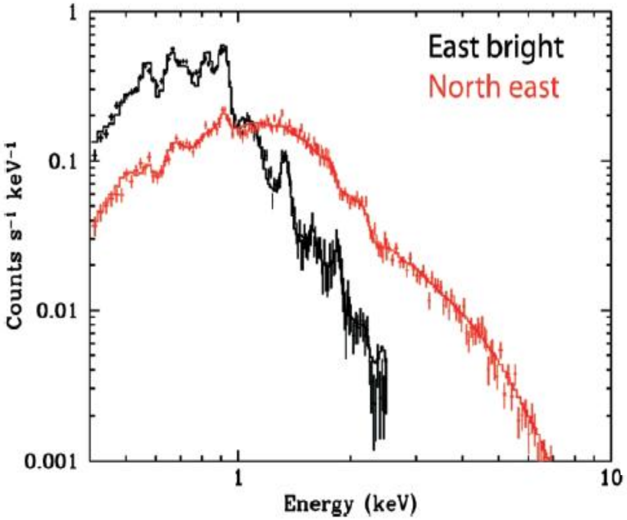


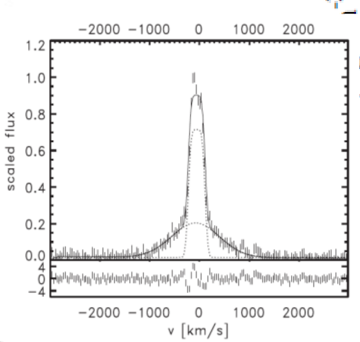
$$n_H = 2.4\,(2.1, 2.75)\ \mathrm{cm}^{-3}$$

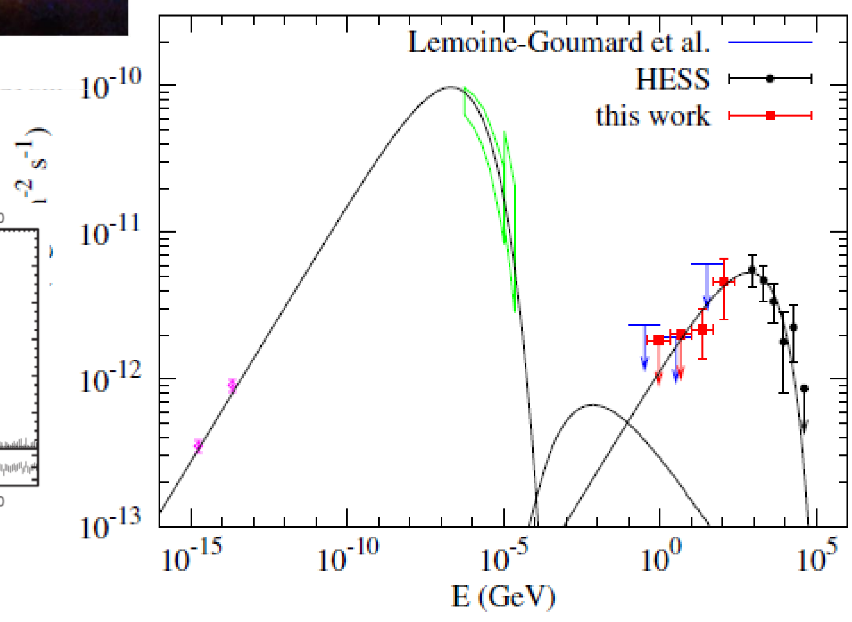
The Astrophysical Journal Letters, 785:L22 (5pp), 2014 April 20
doi:10.1088/2041-8205/785/2/L22

FERMI LARGE AREA TELESCOPE DETECTION OF SUPERNOVA REMNANT RCW 86

Qiang Yuan[1,2], Xiaoyuan Huang[3], Siming Liu[3], and Bing Zhang[2]







The X-ray emission of the supernova remnant W49B observed with *XMM-Newton*

M. Miceli[1,2,3], A. Decourchelle[1], J. Ballet[1], F. Bocchino[3], J. P. Hughes[4], U. Hwang[5,6], and R. Petre[6]

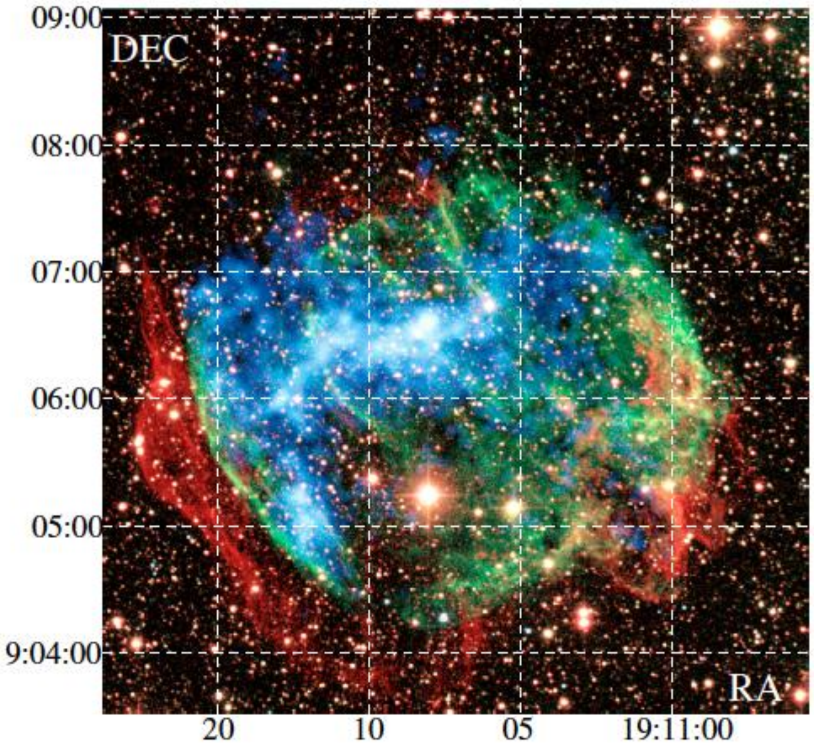
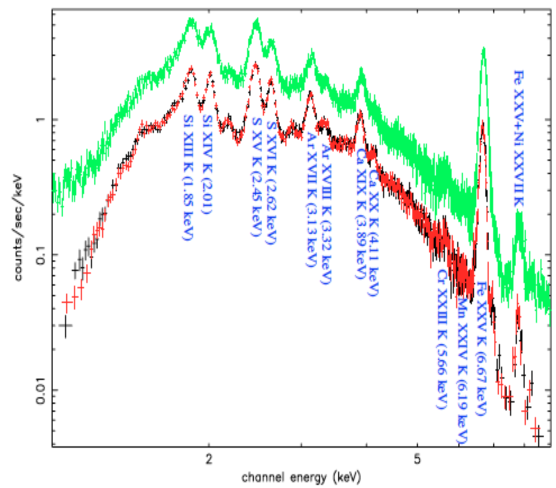
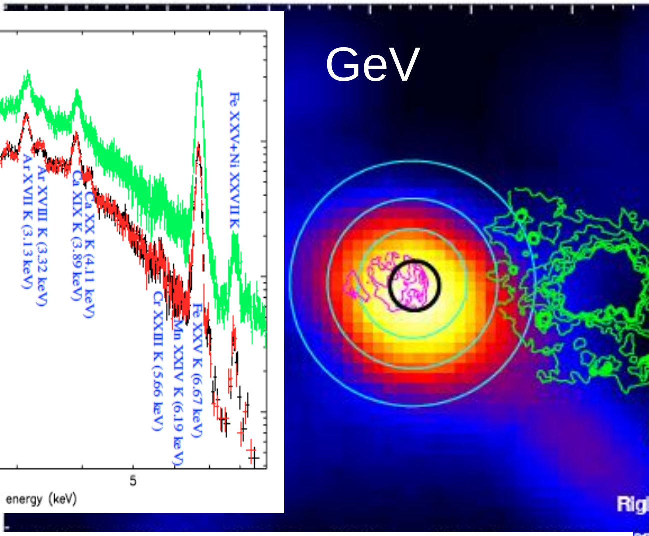
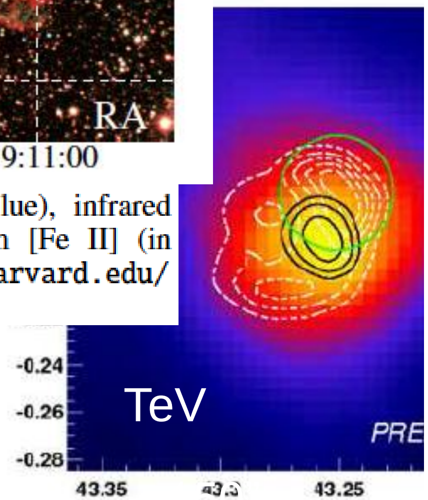
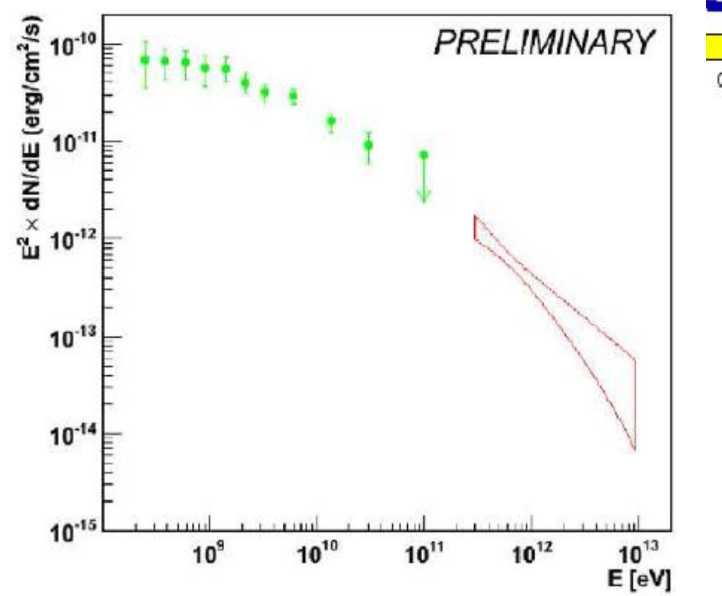


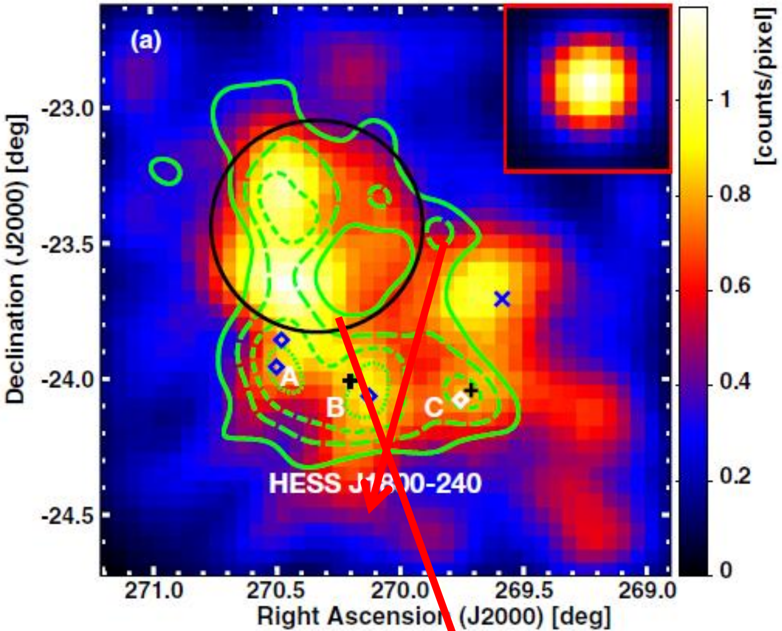
Fig. 2. Color composite *Chandra* X-ray image (in blue), infrared 2.12 μm molecular hydrogen (in red), and 1.64 μm [Fe II] (in green) images of W49B (from http://chandra.harvard.edu/press/04_releases/press_060204.html).

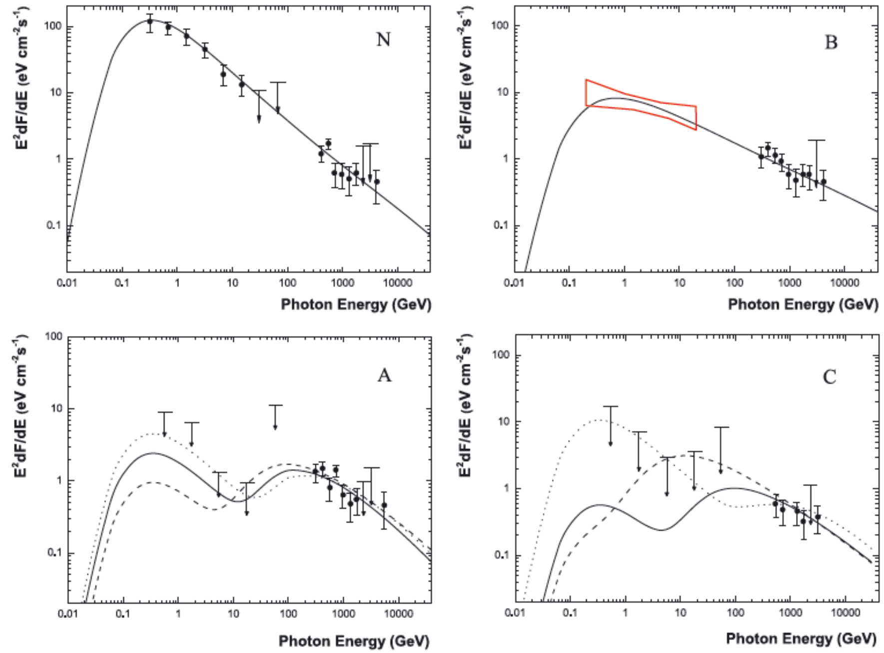






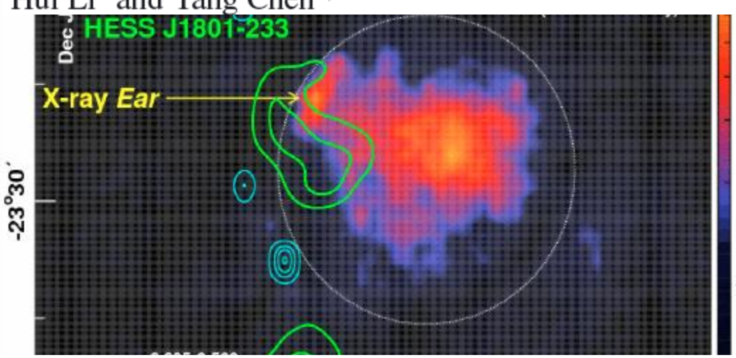


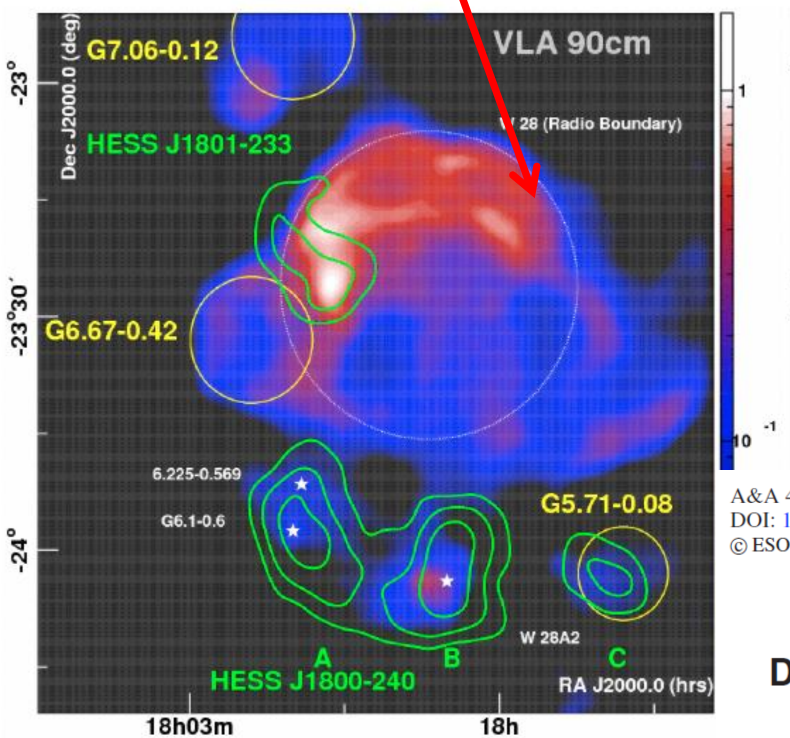




γ-rays from molecular clouds illuminated by accumulated diffusive protons from supernova remnant W28

Hui Li[1] and Yang Chen[1,2]★



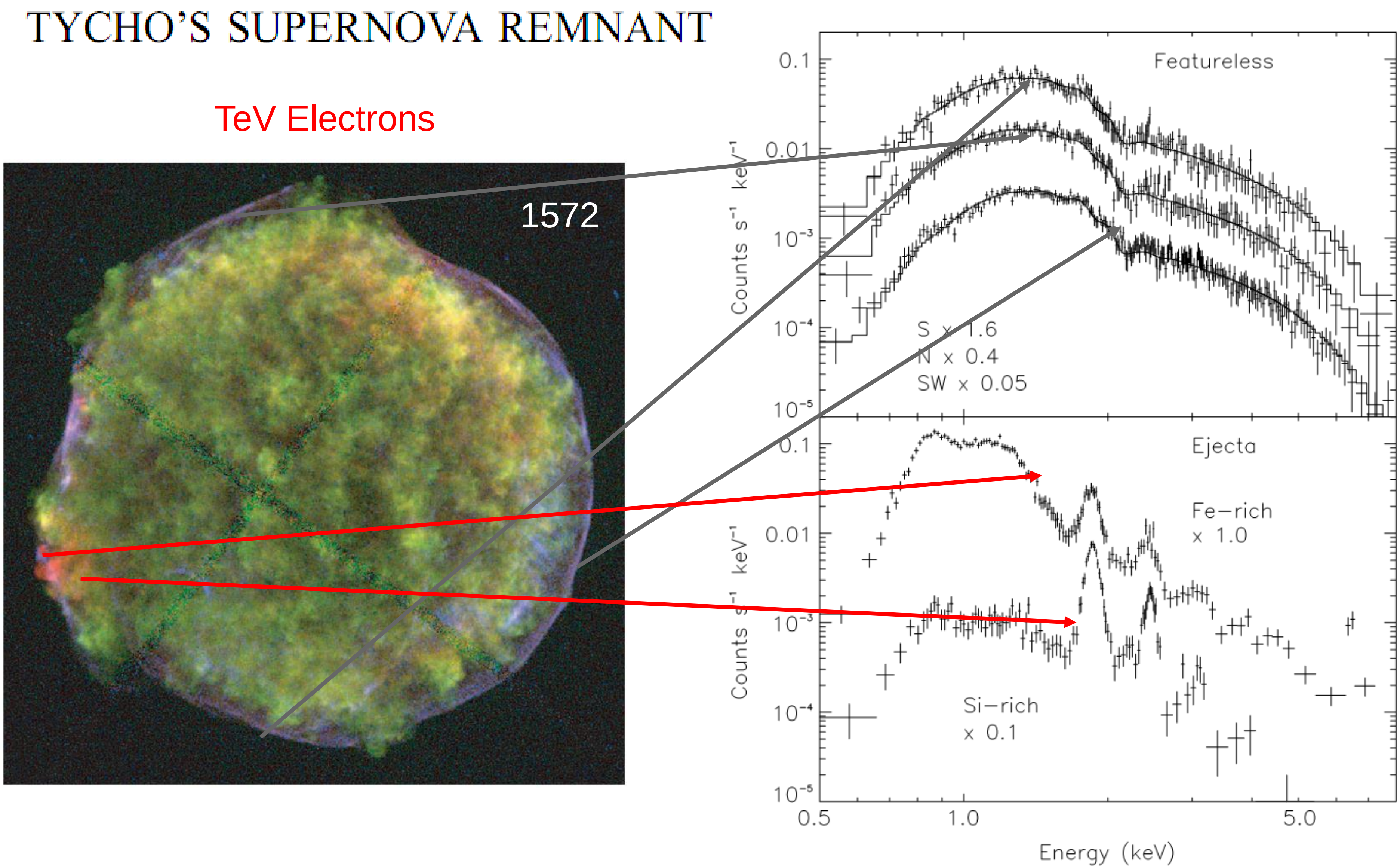


A&A 481, 401–410 (2008)
DOI: 10.1051/0004-6361:20077765

Astronomy & Astrophysics

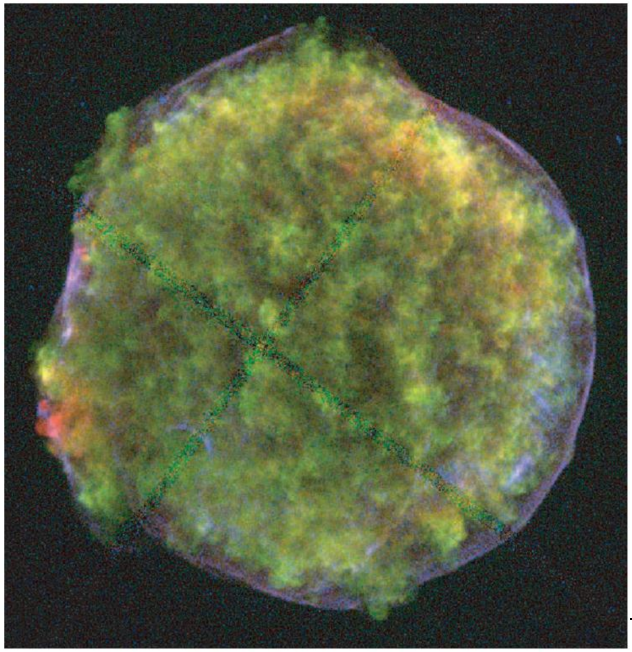
Discovery of very high energy gamma-ray emission coincident with molecular clouds in the W 28 (G6.4–0.1) field★

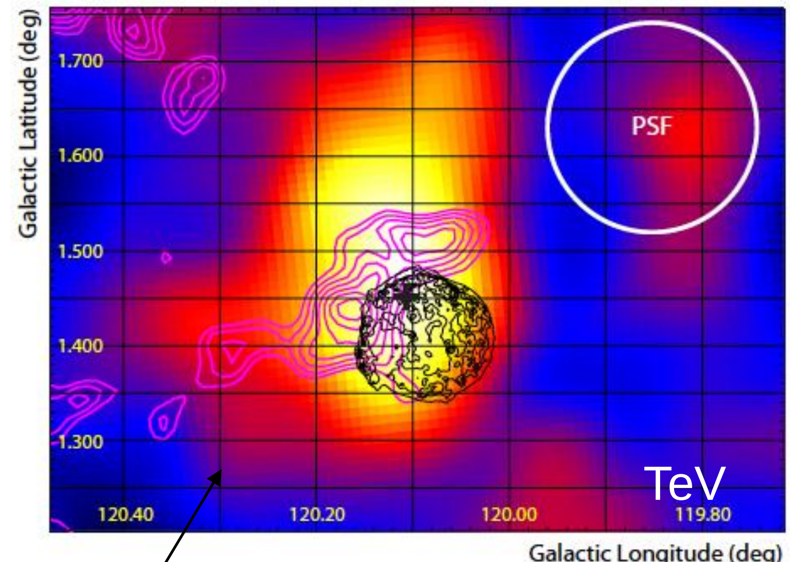
1:Synchrotron X-rays

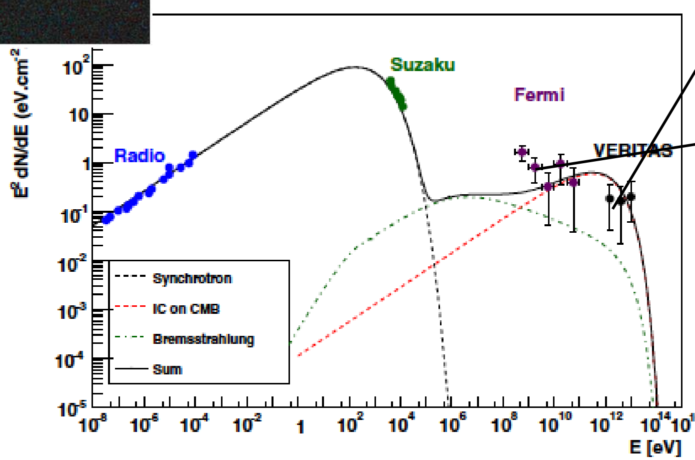


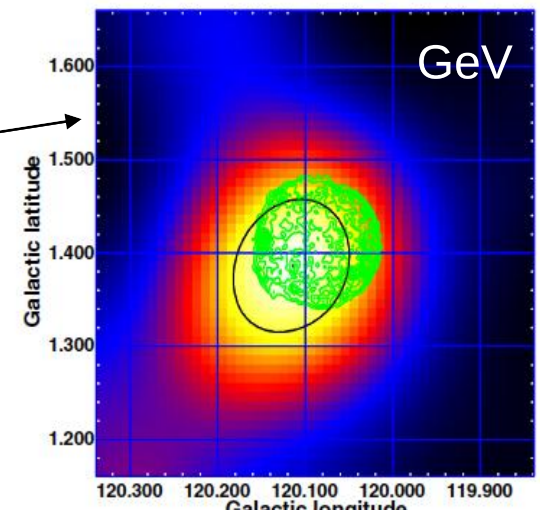
DISCOVERY OF TEV GAMMA RAY EMISSION FROM TYCHO'S SUPERNOVA REMNANT

V. A. Acciari[1], E. Aliu[2], T. Arlen[3], T. Aune[4], M. Beilicke[5], W. Benbow[1], S. M. Bradbury[6], J. H. Buckley[5],







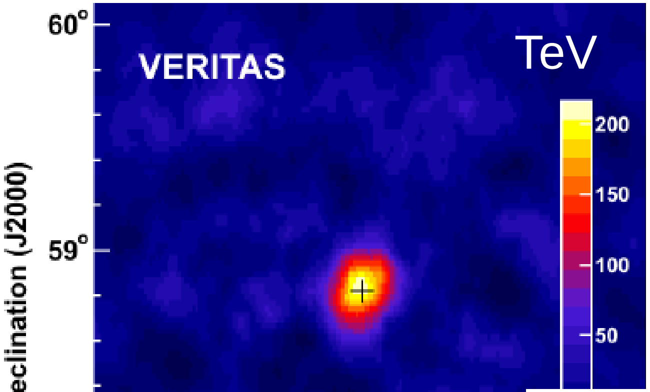


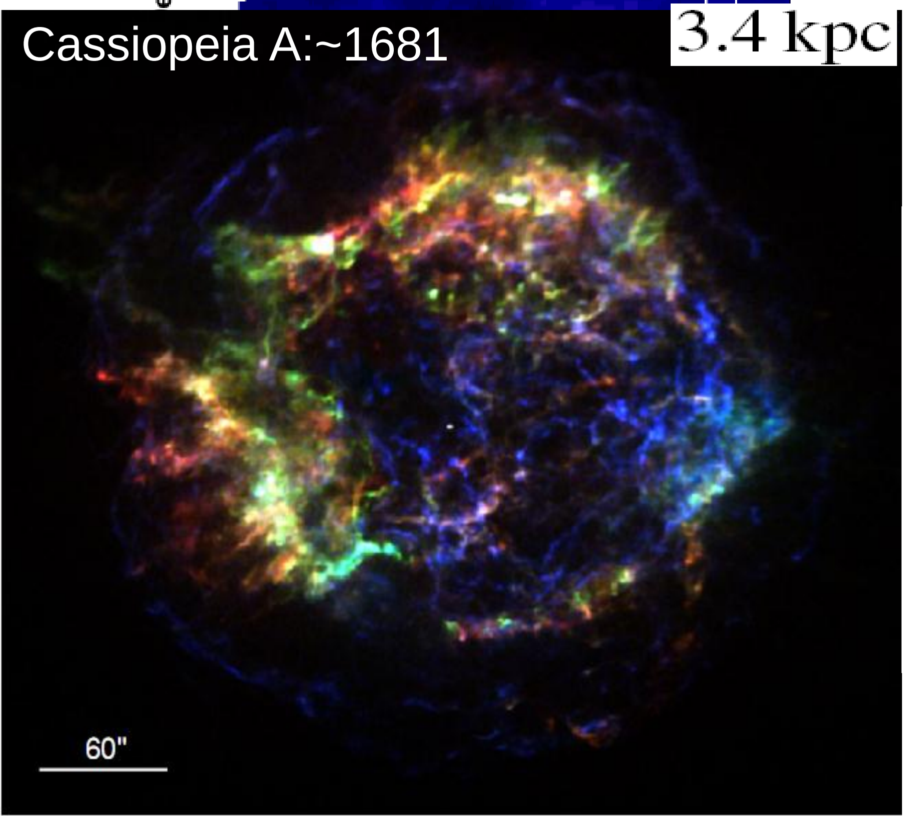
FERMI LARGE AREA TELESCOPE DETECTION OF THE YOUNG SUPERNOVA REMNANT TYCHO

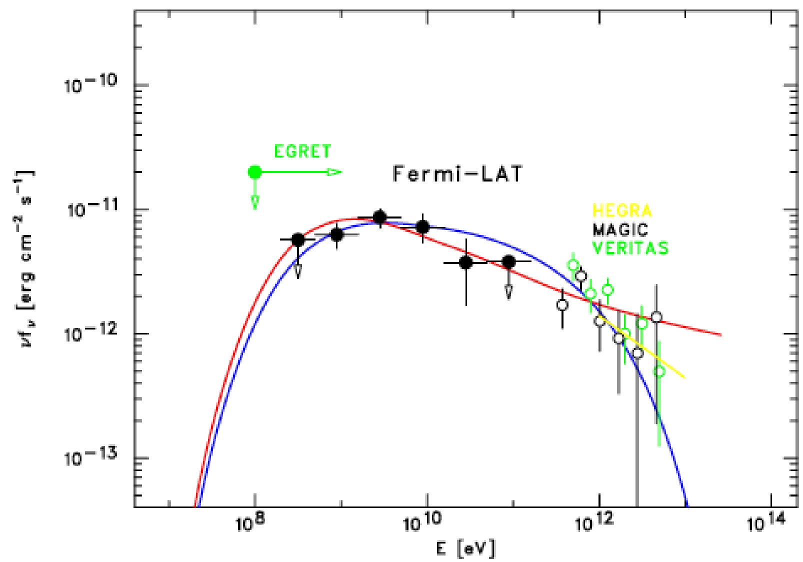
F. Giordano[1,2], M. Naumann-Godo[3], J. Ballet[3], K. Bechtol[4], S. Funk[4], J. Lande[4], M. N. Mazziotta[2], S. Rainò[2],

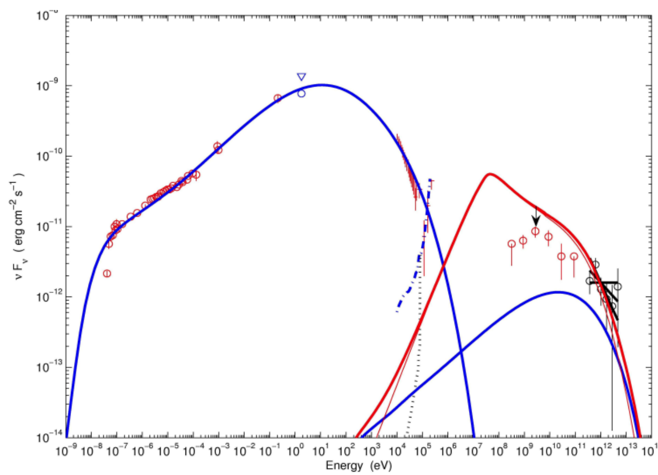
FERMI-LAT DISCOVERY OF GeV GAMMA-RAY EMISSION FROM THE YOUNG SUPERNOVA REMNANT CASSIOPEIA A

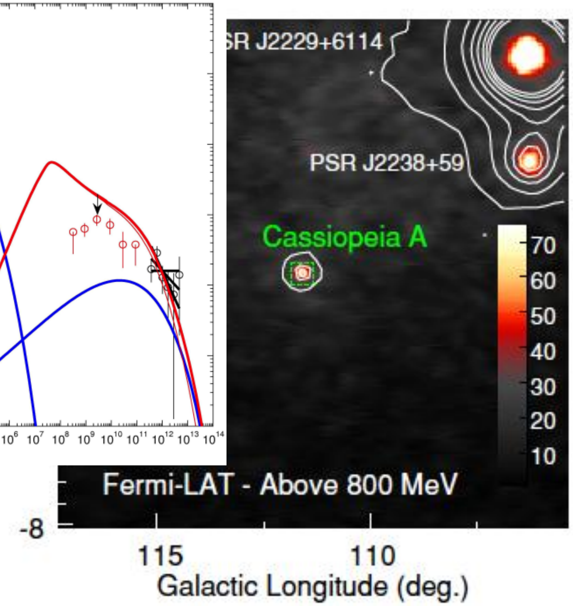
A. A. Abdo[1,2], M. Ackermann[3], M. Ajello[3], A. Allafort[3], L. Baldini[4], J. Ballet[5], G. Barbiellini[6,7], M. G. Baring[8],



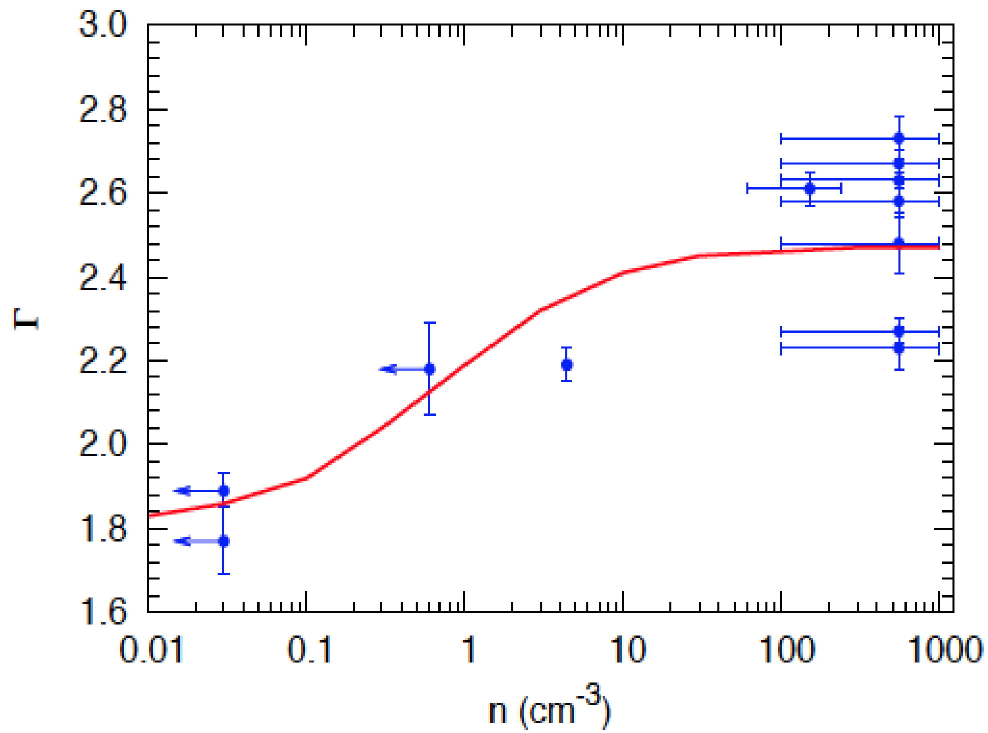


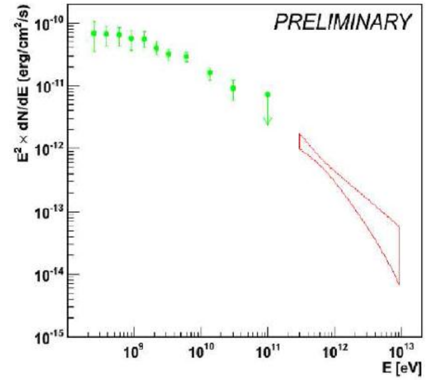






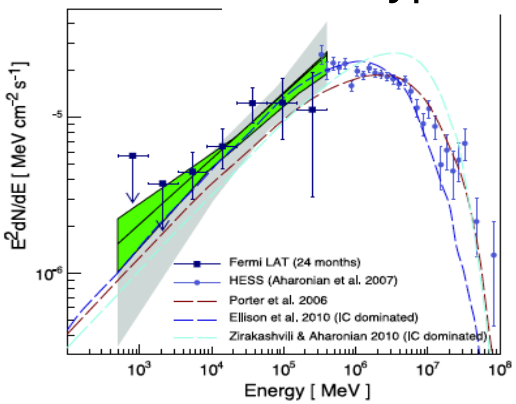
1: Summary

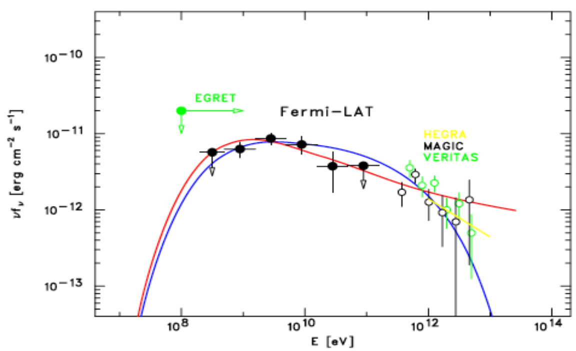




Older remnants interacting with molecular clouds, complex source structure

Shell Type TeV SNRs, relative simple





2: A Unified Model for Particle Acceleration in SNRs

Modeling of Cosmic Ray Spectra

$$f(R,z) \propto \left(\frac{R}{R_\odot}\right)^\alpha \exp\left[-\frac{\beta(R-R_\odot)}{R_\odot}\right] \exp\left(-\frac{|z|}{z_s}\right),$$

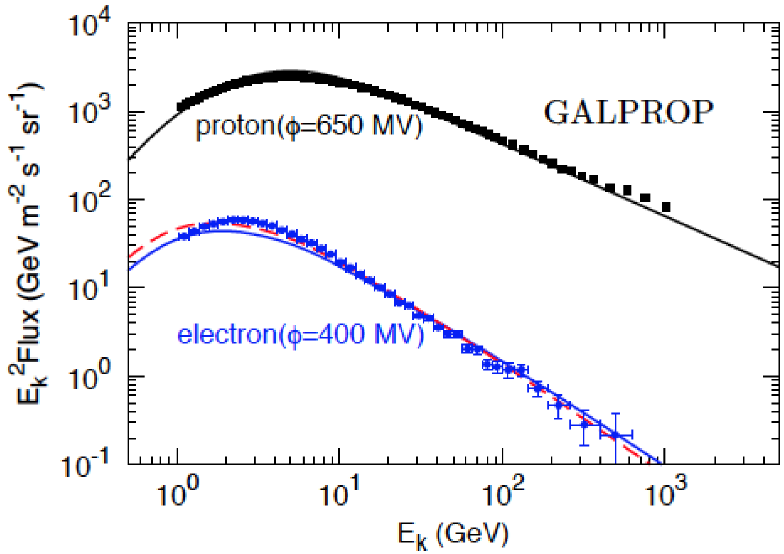


FIG. 1.— The expected fluxes of CR protons and electrons at the Earth, for the same spectral shape of the injected particles, compared with the PAMELA observational data (Adriani et al. 2011a,b). We adopt two parameter settings to calculate the electron spectrum: for solid line the magnetic field is the canonical one adopted in GALPROP and $K_{ep} \approx 1.3\%$; for dashed line the magnetic field is two times larger and $K_{ep} \approx 1.9\%$.

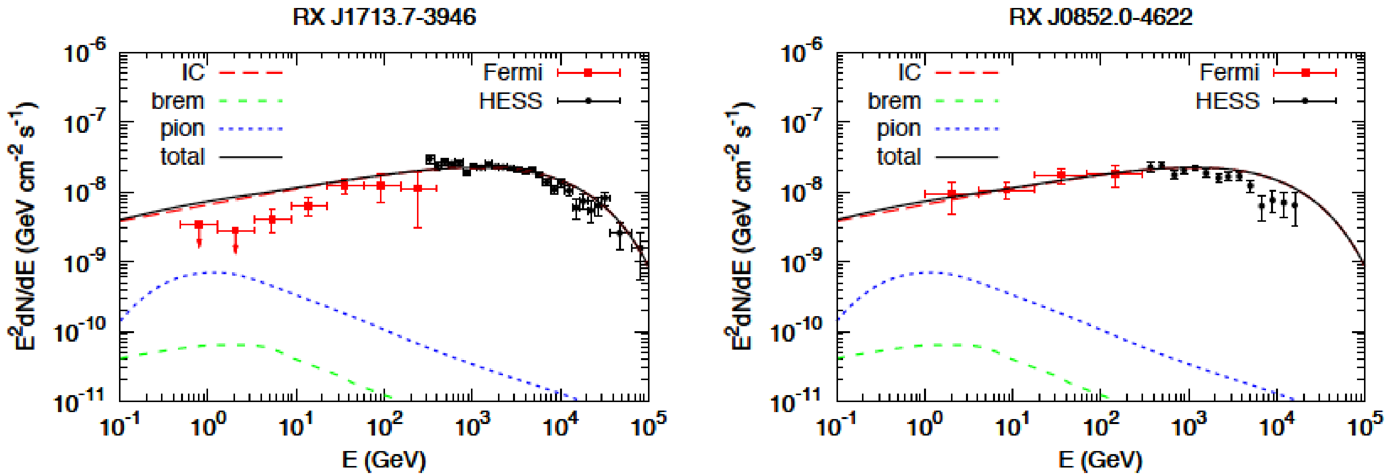
$$q(p) \propto \begin{cases} p^{-\alpha_1}, & p < p_{\rm br}, \\ p^{-\alpha_2}, & p \geq p_{\rm br}, \end{cases}$$

$$\alpha_1 = 1.80, \ \alpha_2 = 2.52$$

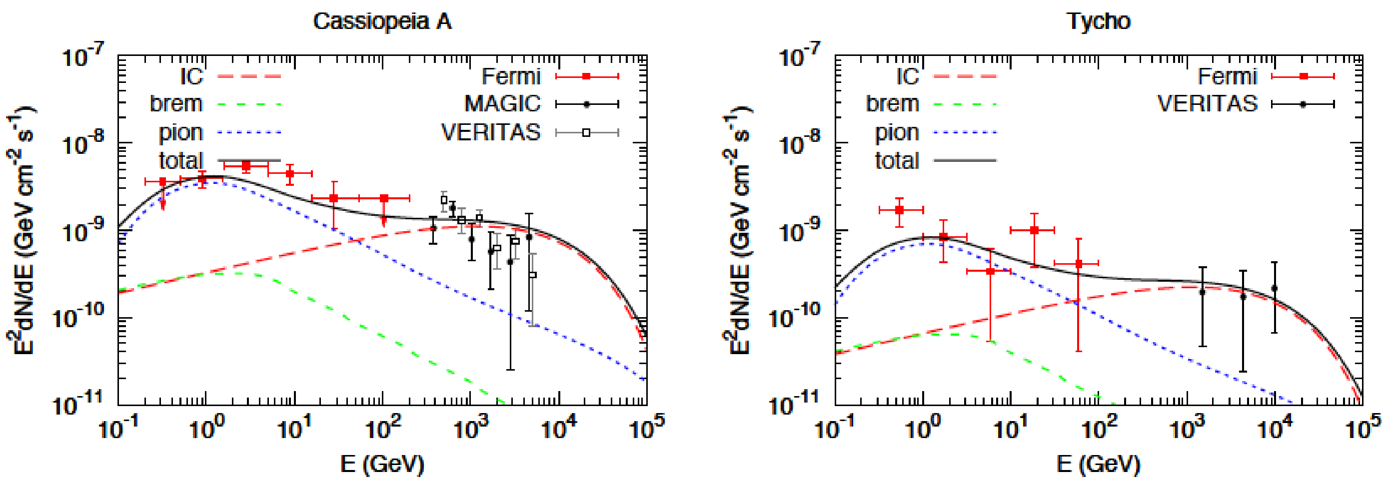
$$p_{\rm br}c = 6 \ \text{GeV}$$

2: Modeling of Gamma-ray Spectra

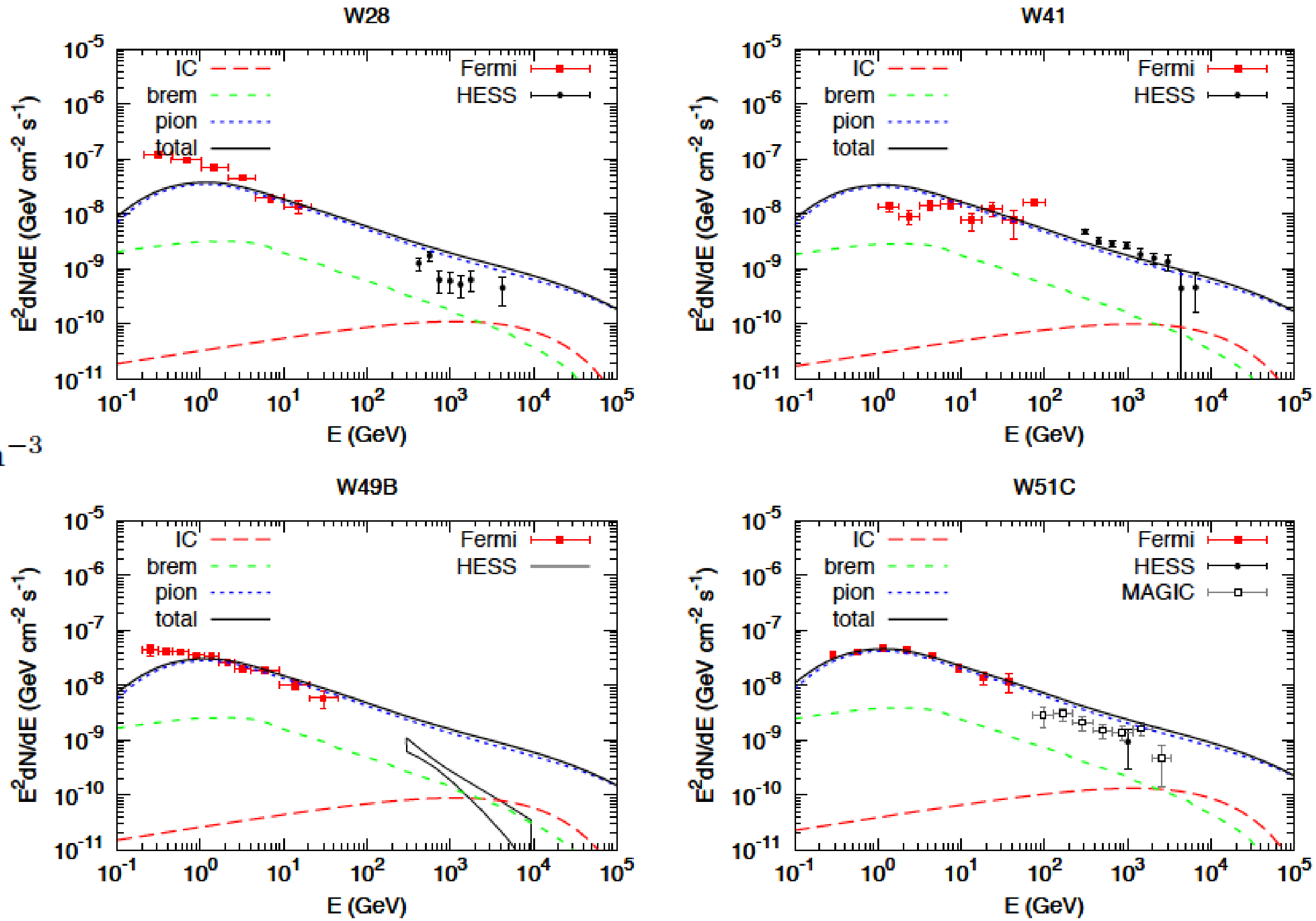
$n = 0.01\ \mathrm{cm}^{-3}$



$n = 1\ \mathrm{cm}^{-3}$

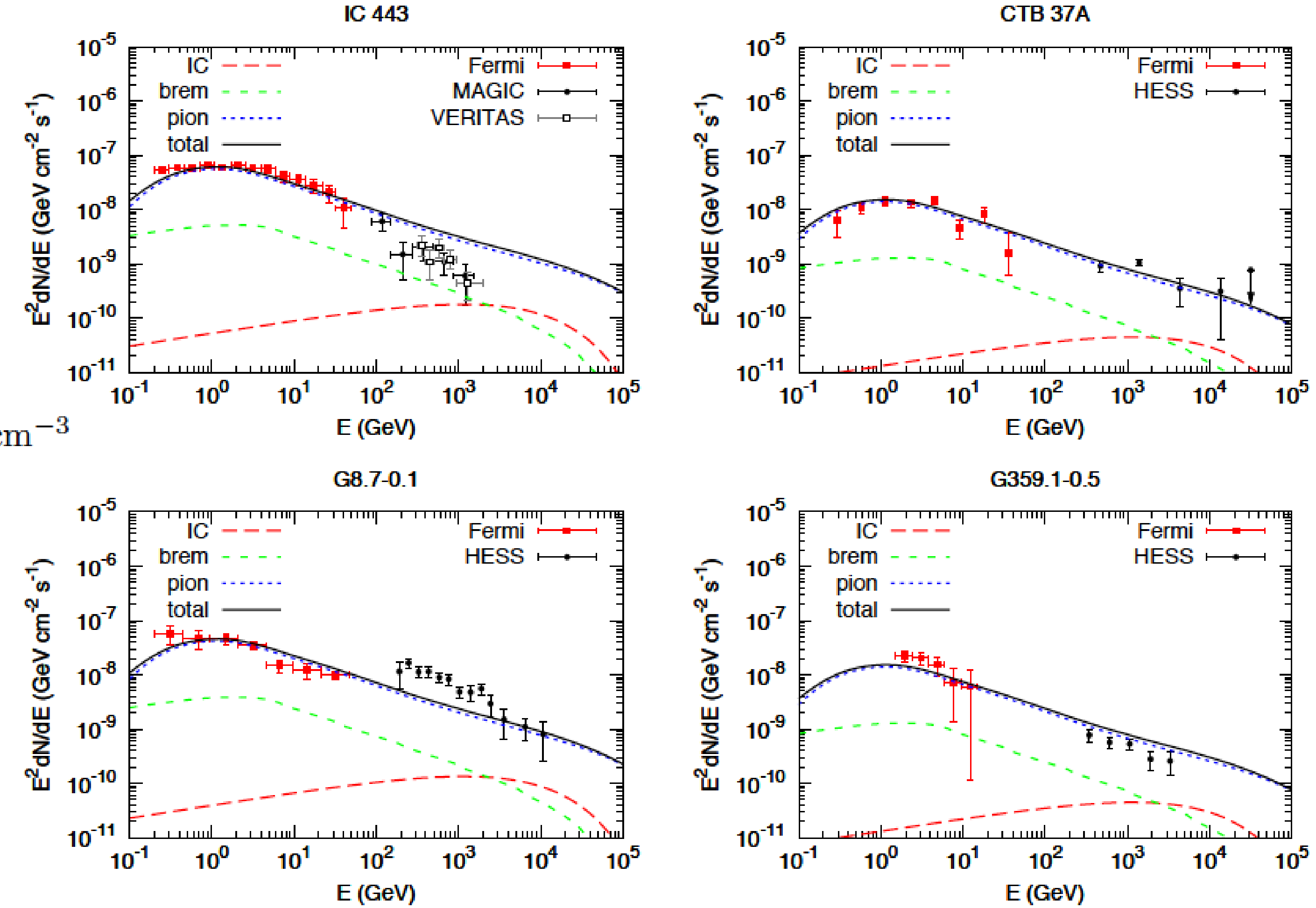


2: Modeling of Gamma-ray Spectra



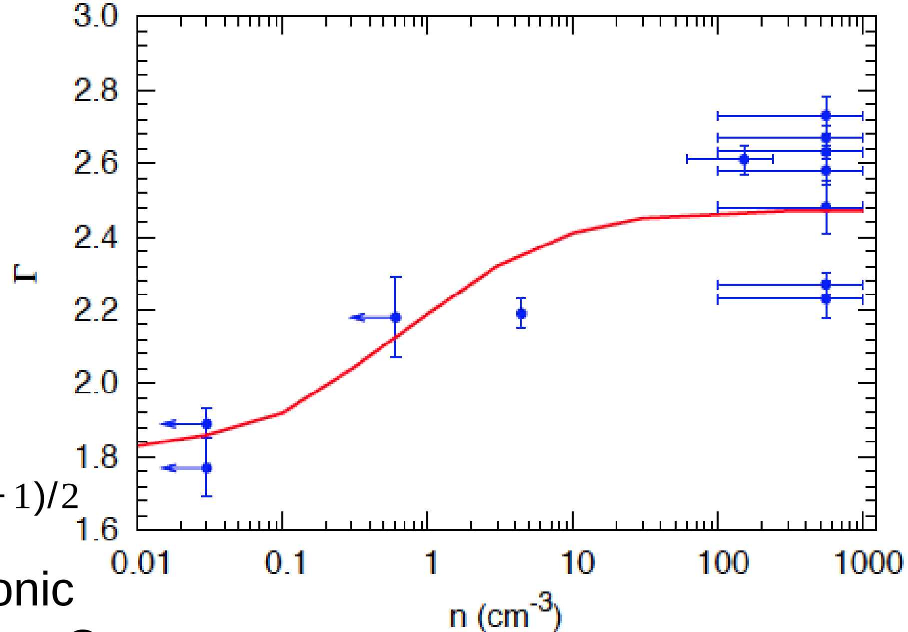
$\bar{n} = 100\ \mathrm{cm}^{-3}$

2: Modeling of Gamma-ray Spectra



$n = 100 \ \mathrm{cm}^{-3}$

2: Modeling of Gamma-ray Spectra

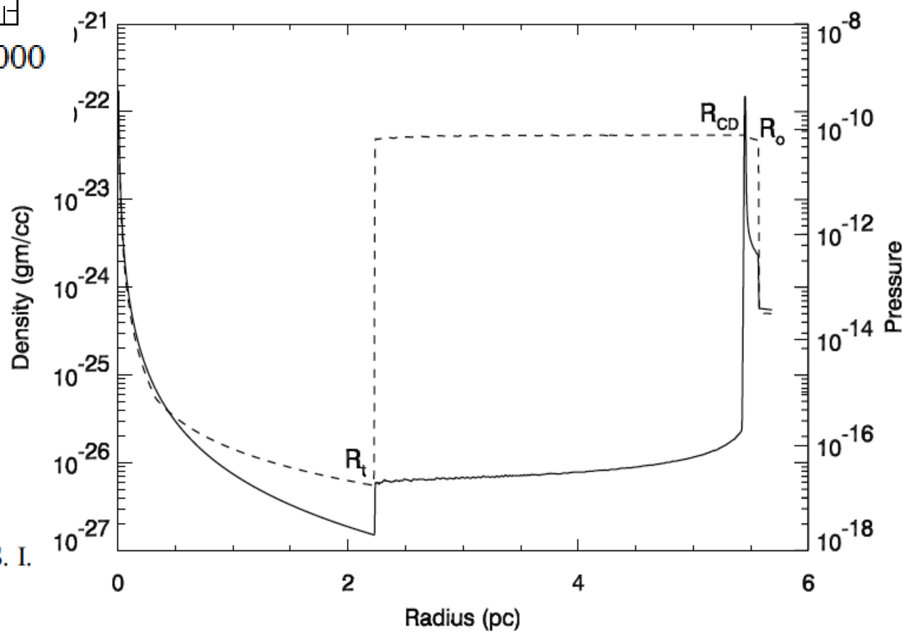


$alpha = 2.52$

Hadrnic
pp scattering

$(alpha + 1)/2$

Leptonic
Inverse Compton



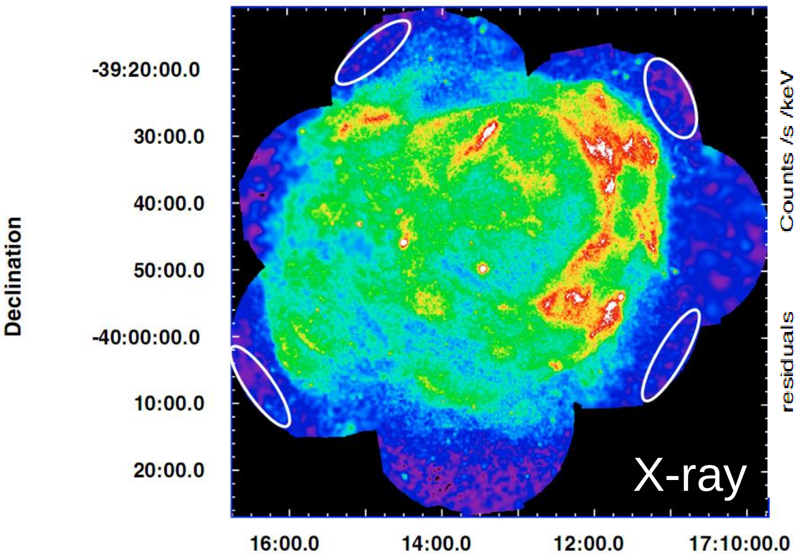
THE EVOLUTION OF SUPERNOVAE IN CIRCUMSTELLAR WIND-BLOWN BUBBLES. I. INTRODUCTION AND ONE-DIMENSIONAL CALCULATIONS

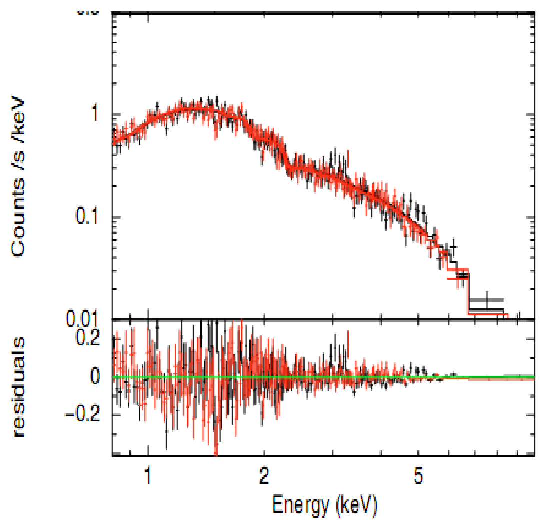
Vikram V. Dwarkadas

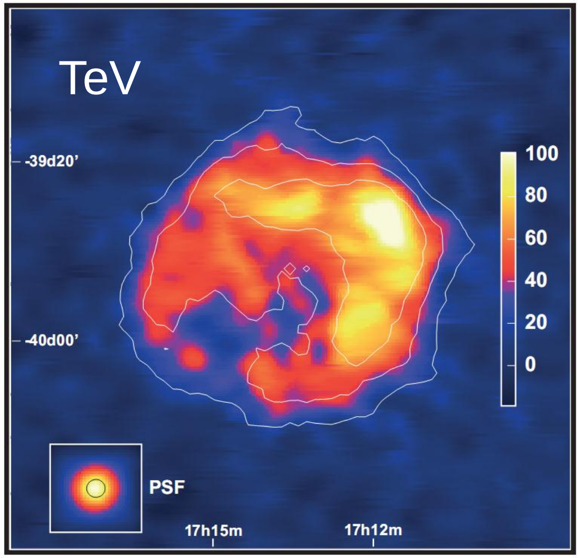
3: Shell Type TeV SNRs

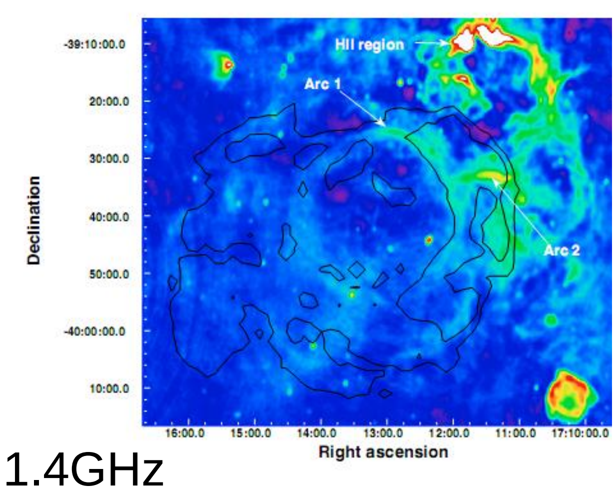
A joint spectro-imaging analysis of the *XMM-Newton* and HESS observations of the supernova remnant RX J1713.7-3946

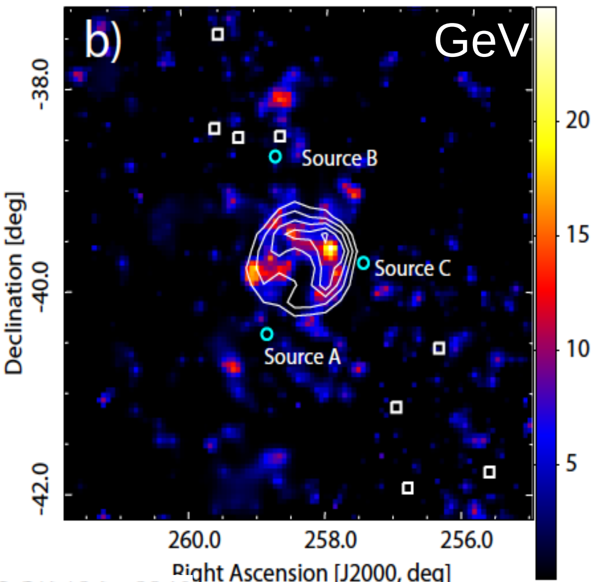
F. Acero[1], J. Ballet[1], A. Decourchelle[1], M. Lemoine-Goumard[2,3], M. Ortega[4], E. Giacani[4], G. Dubner[4], and G. Cassam-Chenaï[5]

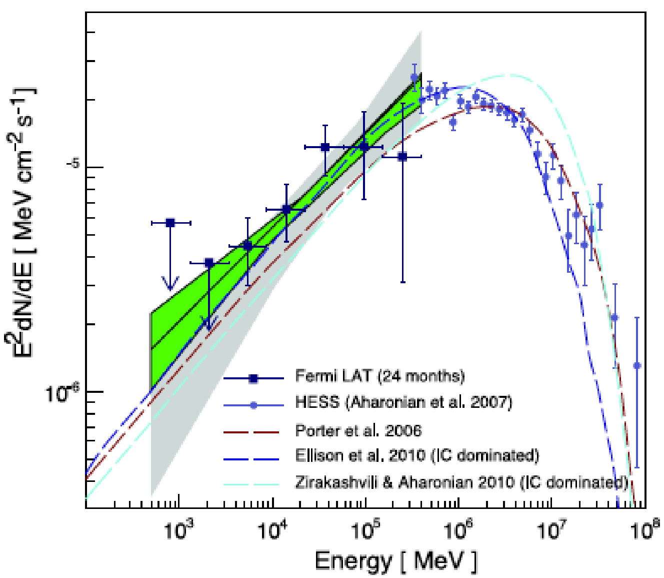












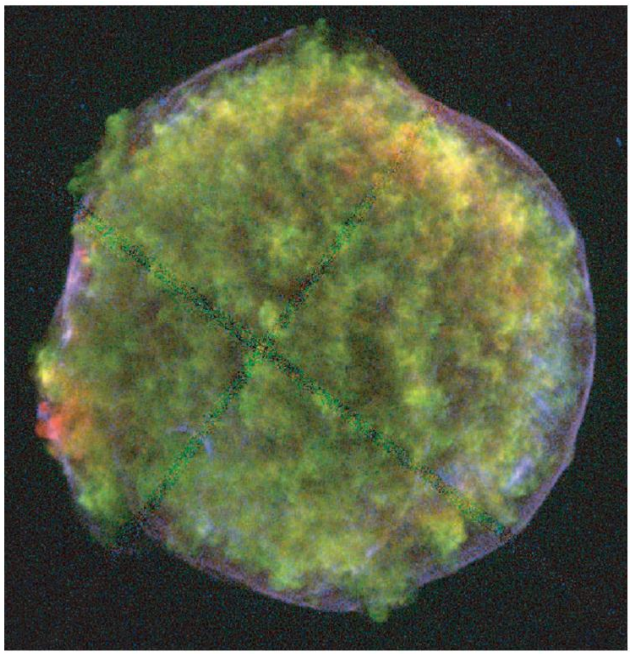
Observations of the young Supernova remnant RX J1713.7−3946 with the *Fermi* Large Area Telescope

A. A. Abdo[2], M. Ackermann[3,1], M. Ajello[3], A. Allafort[3], L. Baldini[4], J. Ballet[5],

3 Source Structure:

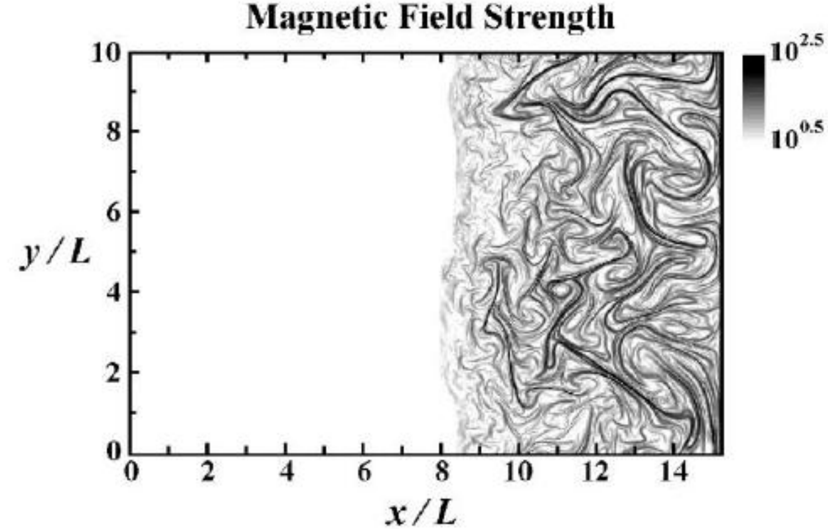
Magnetic Field

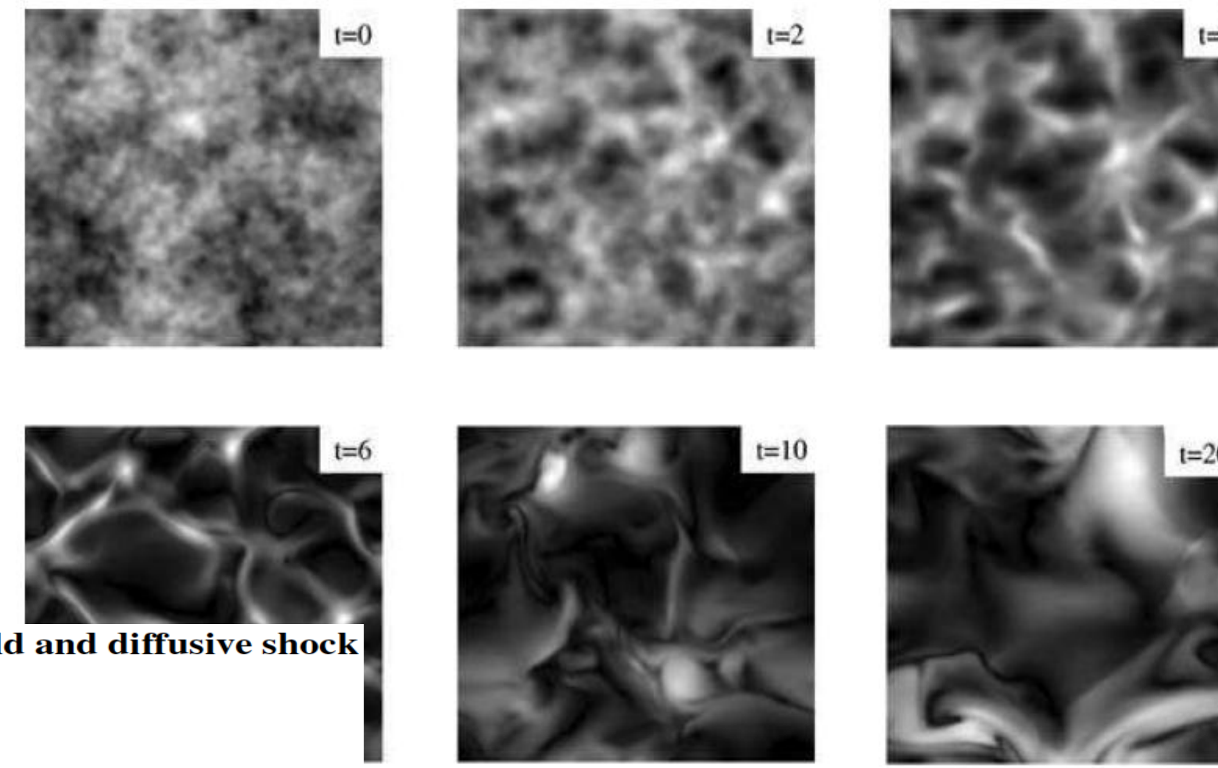
Amplification



MAGNETIC FIELD AMPLIFICATION BY SHOCKS IN TURBULENT FLUIDS

J. Giacalone and J. R. Jokipii



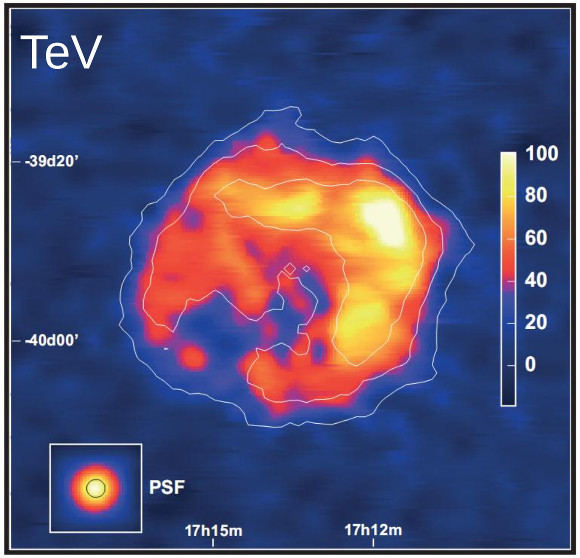


Turbulent amplification of magnetic field and diffusive shock acceleration of cosmic rays

A. R. Bell★

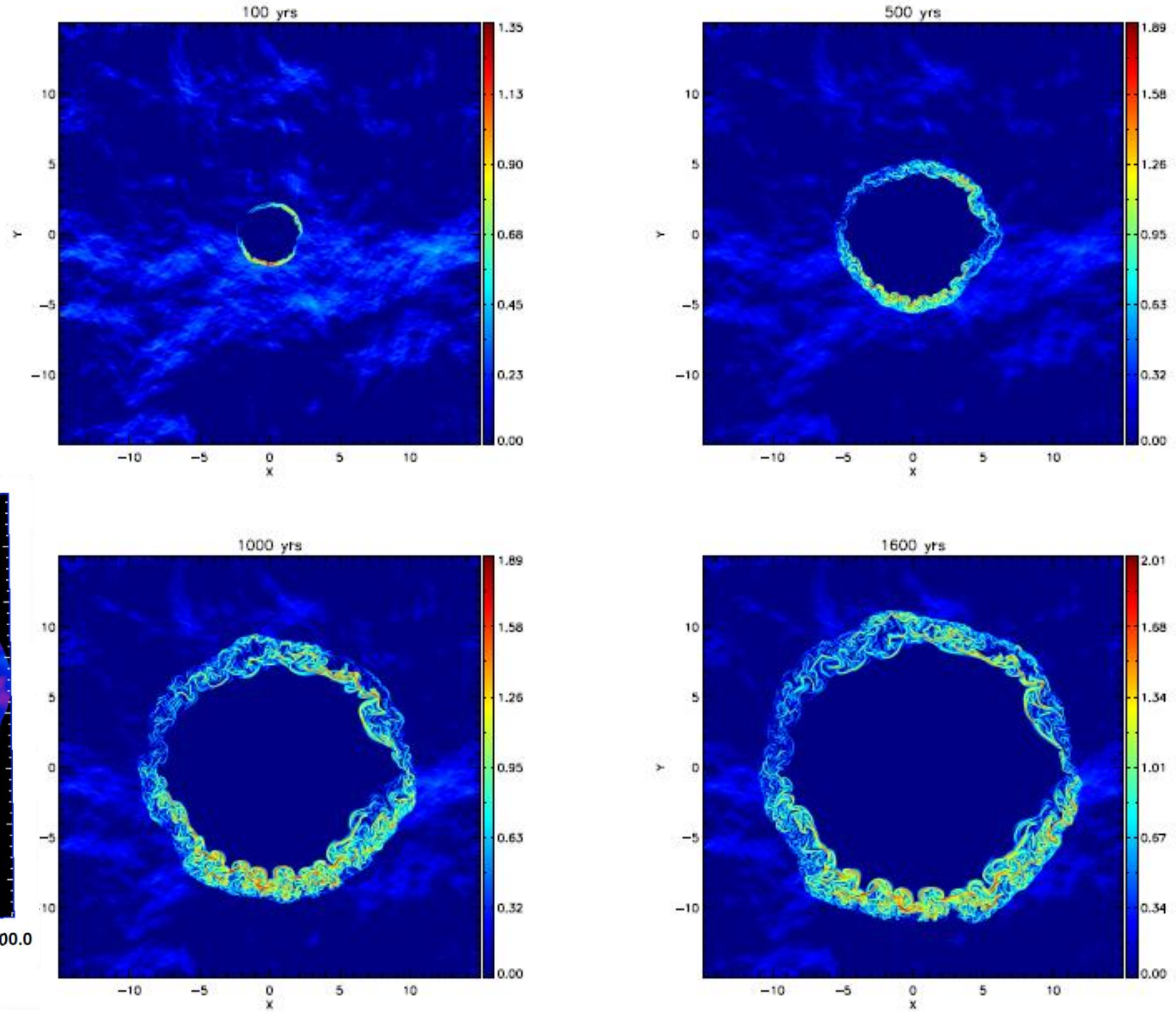
3: MHD Turbulence and Stochastic Electron Acceleration

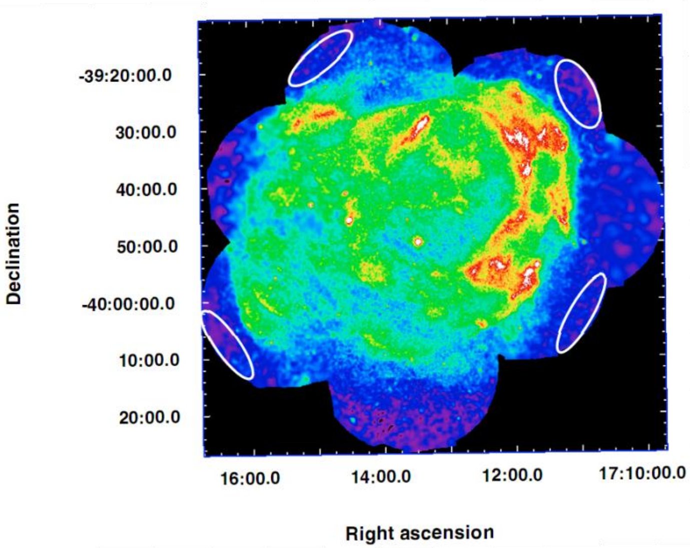
The Astrophysical Journal, 773:138 (6pp), 2013 August 20
doi:10.1088/0004-637X



ENERGY PARTITION BETWEEN ENERGETIC ELECTRONS AND TURBULENT MAGNETIC FIELD IN SUPERNOVA REMNANT RX J1713.7-3946

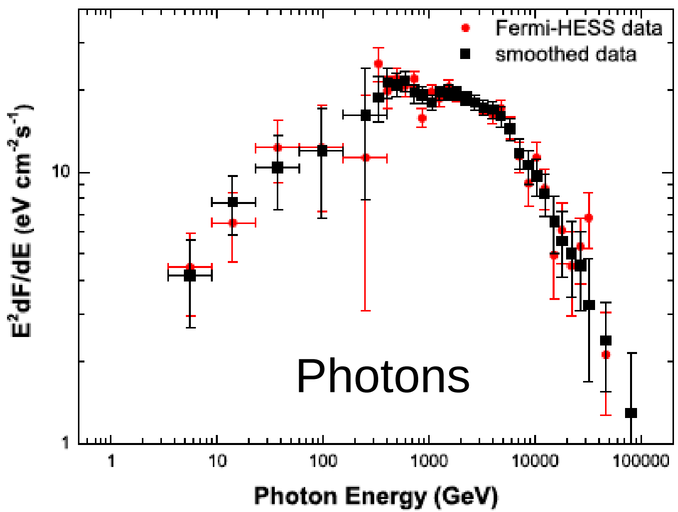
Chuyuan Yang[1,2,3] and Siming Liu[1]

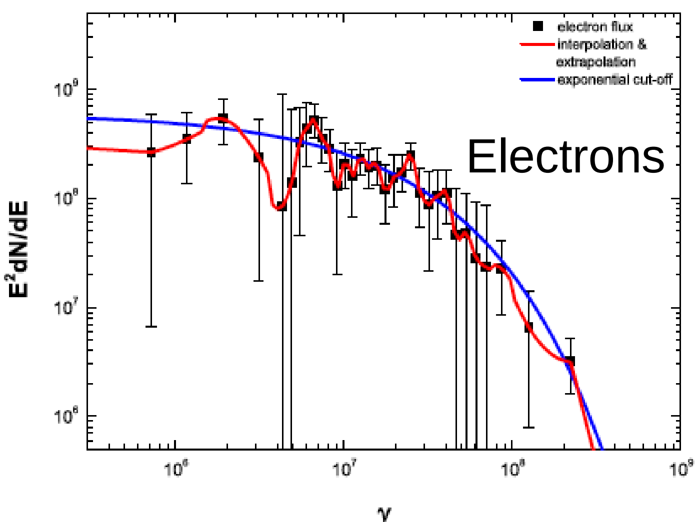




DERIVATION OF THE ELECTRON DISTRIBUTION IN SUPERNOVA REMNANT RX J1713.7−3946 VIA A SPECTRAL INVERSION METHOD

Hui Li[1], Siming Liu[2], and Yang Chen[1,3]
[1] Department of Astronomy, Nanjing University, Nanjing 210093, China
[2] Key Laboratory of Dark Matter and Space Astronomy, Purple Mountain Observatory, Chinese Academy of Sciences, Nanjing 210008, China





$$\gamma^{-2} \exp\left[-(\gamma/1.3 \times 10^{7})^{0.6}\right]$$

$$P(k) = ck \int d\gamma\, N(\gamma) \int d\epsilon\, n_{\rm ph}(\epsilon)\sigma_{\rm IC}(k, \epsilon; \gamma),$$

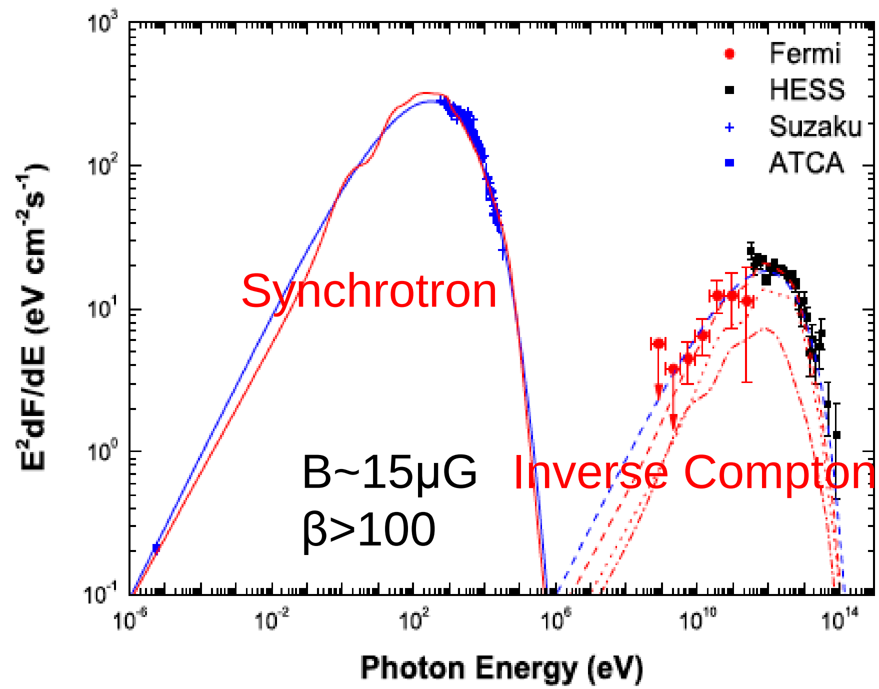
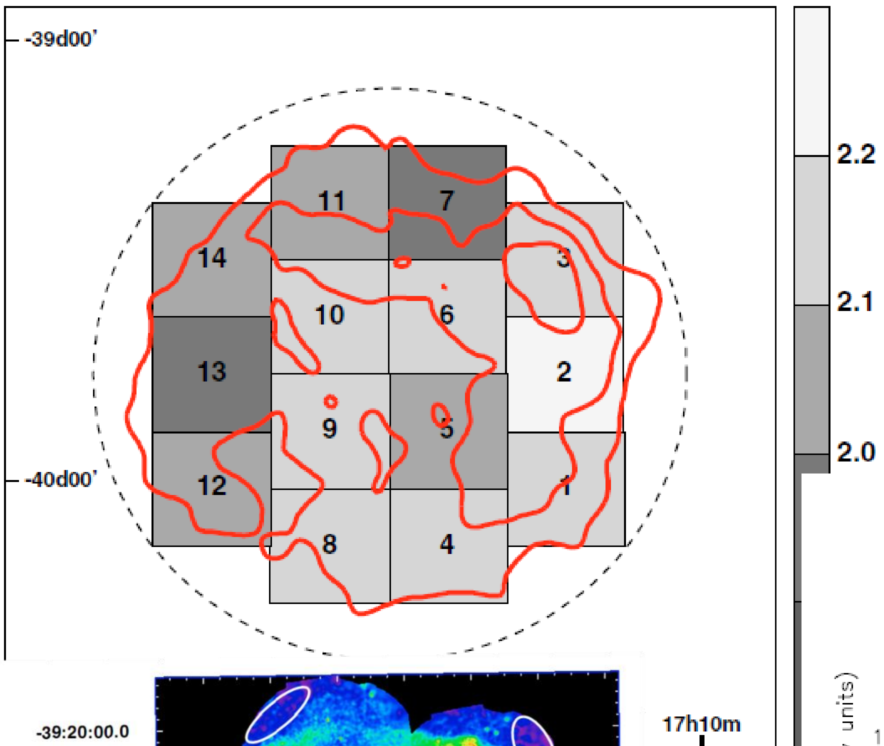
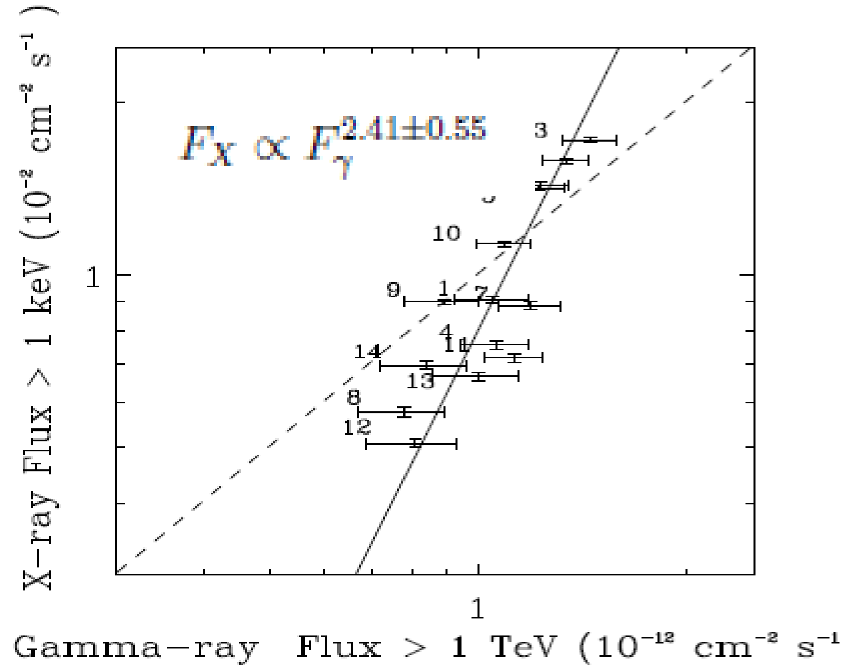


Figure 2. Comparison of the observed radio (Acero et al. 2009), X-ray (Tanaka et al. 2008), and γ-ray fluxes with the synchrotron (solid) and IC (dashed) spectra of the derived electron distributions using our inversion method. The blue lines are for the analytical distribution, whose parameters are described in Section 3. The red lines are the inter- and extrapolated electron distribution, where the dotted and dot-dashed lines are for the IC of IR and CMB photons, respectively.

3: Stochastic Electron Acceleration

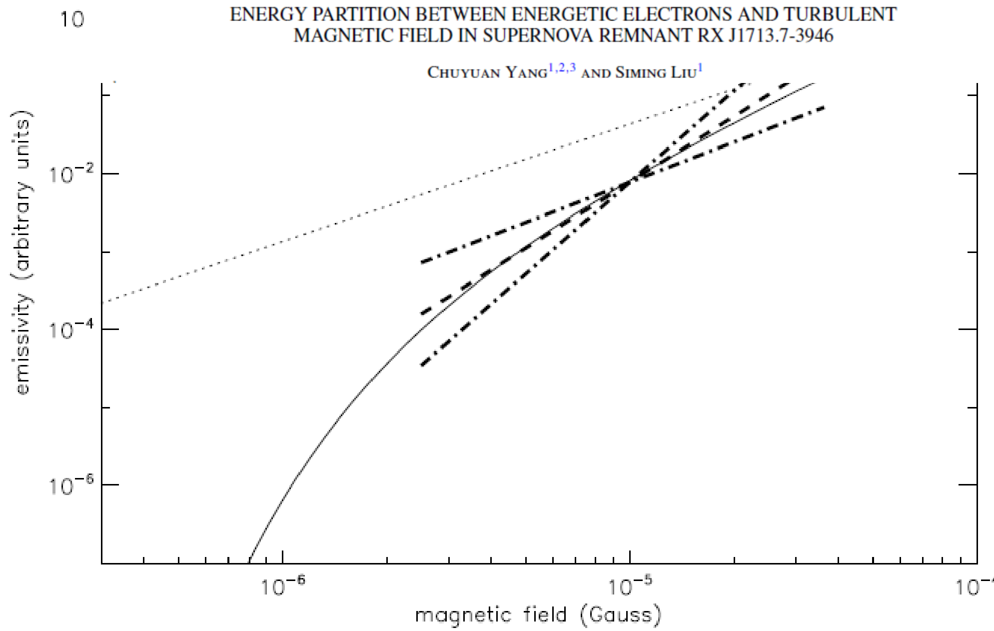


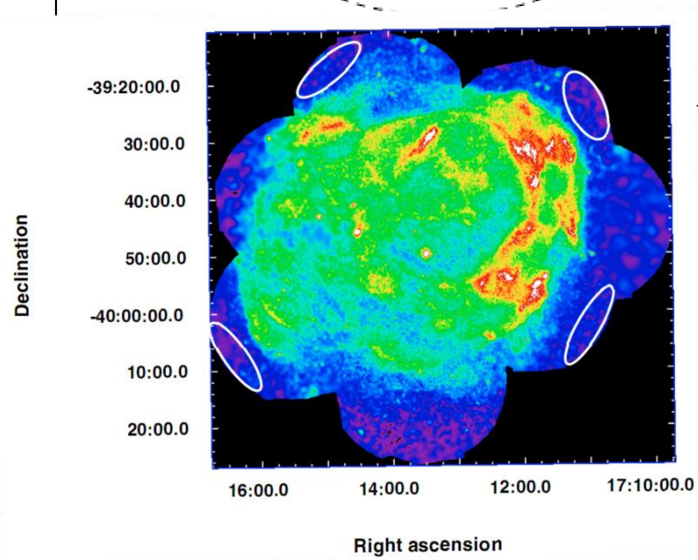


The Astrophysical Journal, 773:138 (6pp), 2013 August 20 doi:10.1088/0004-637X/773/2/138

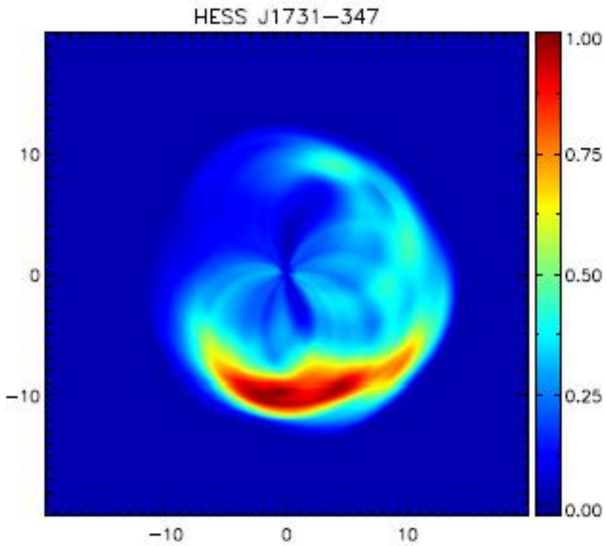
ENERGY PARTITION BETWEEN ENERGETIC ELECTRONS AND TURBULENT MAGNETIC FIELD IN SUPERNOVA REMNANT RX J1713.7-3946

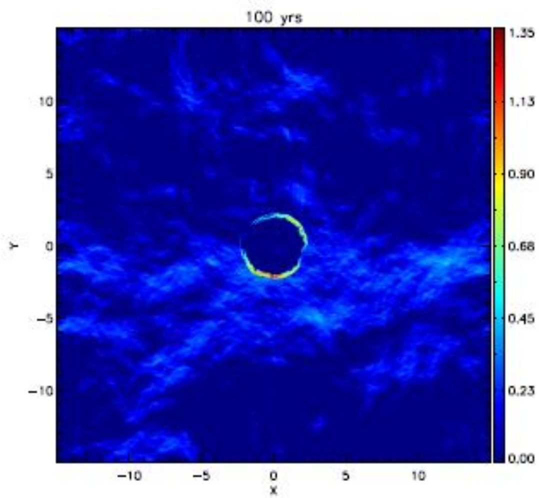
Chuyuan Yang[1,2,3] and Siming Liu[1]

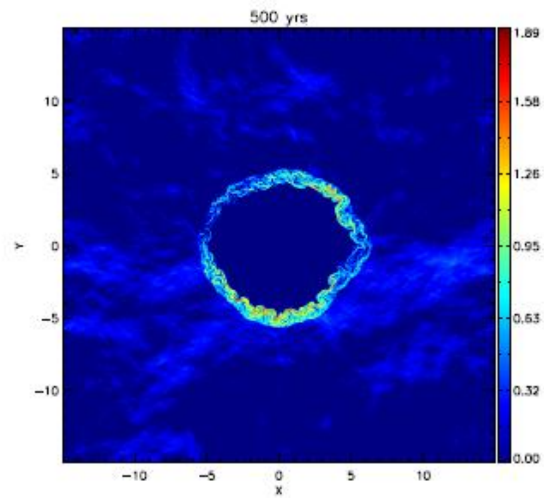


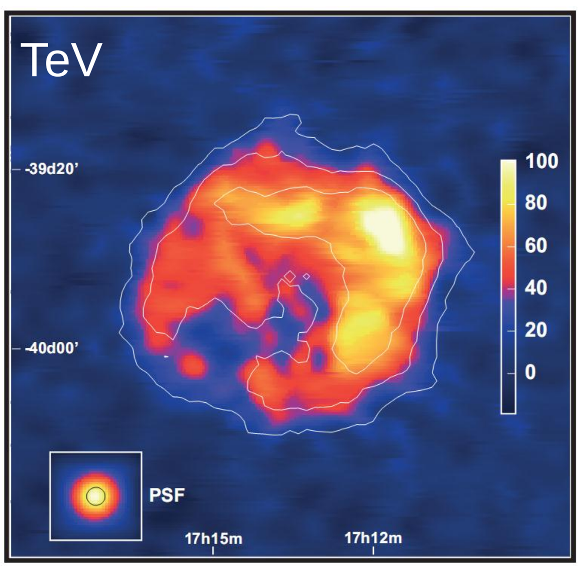


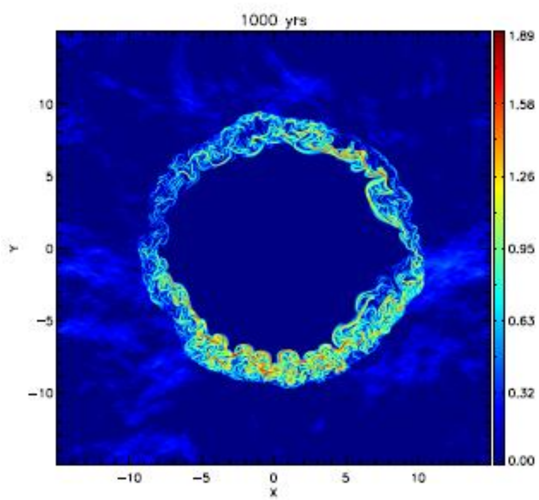
3: MHD Turbulence and Stochastic Electron Acceleration

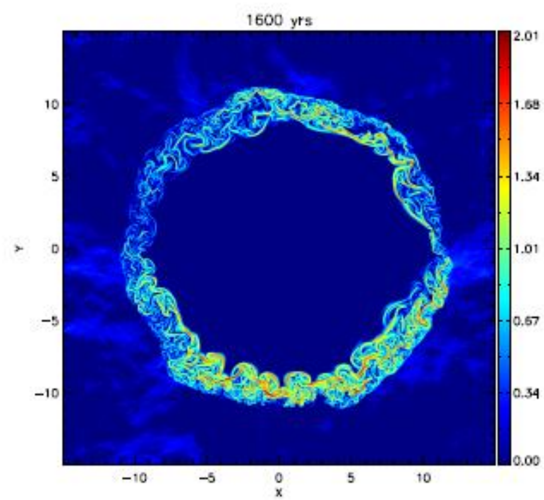




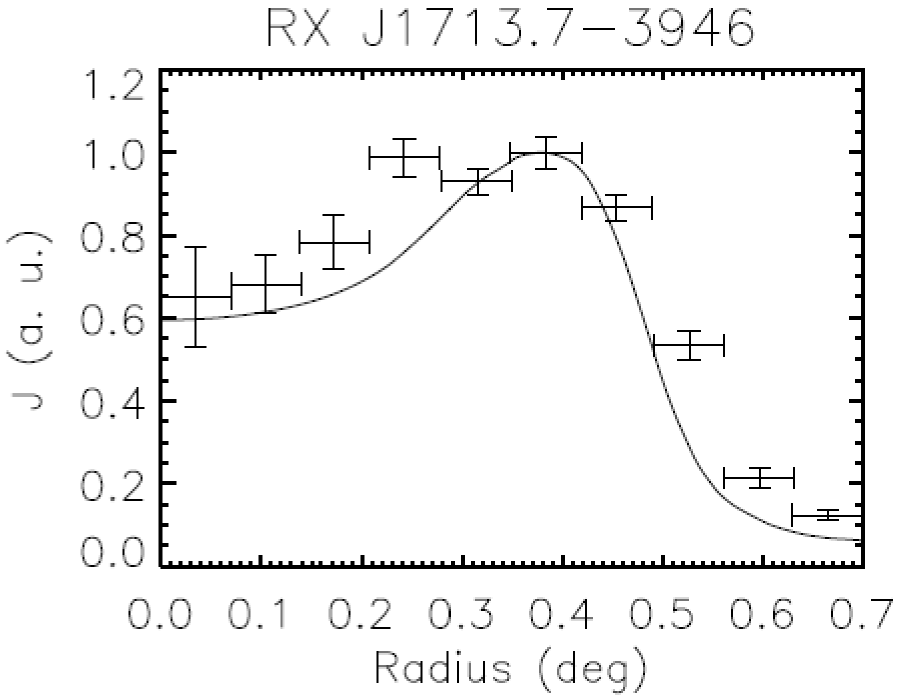




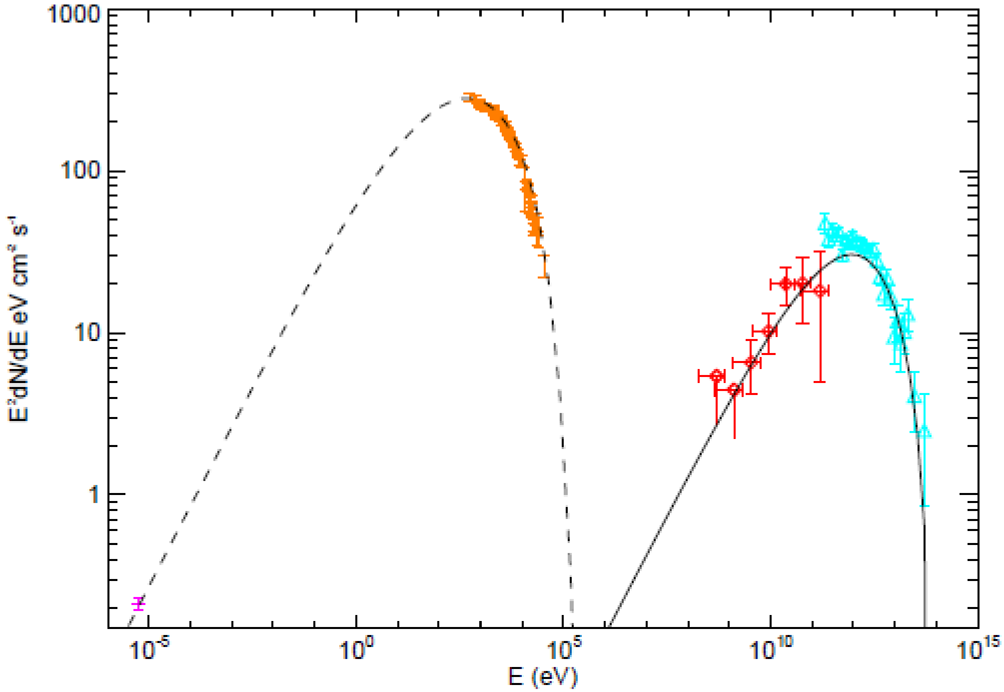




3 Radial Brightness Profiles



3 Multi-wavelength overall spectral fit



Name	$F_\gamma{}^a/F_X{}^b$ 10^{-10} erg s^{-1} cm^{-2}	Diameter^c pc	B^d μG	$W_e{}^d$ 10^{47} erg	W_B 10^{47} erg
RX J1713.7-3946	0.68/5.4	17.4(D/1.0)	12	3.9$(D/1.0)^2$	4.0$(D/1.0)^3(f/0.87)^e$
RX J0852.0-4622	0.66^{e,f} /0.83	34(D/1.0)	9.4	10$(D/1.0)^2$	10$(D/1.0)^3(f/0.49)^f$
HESS J1731-347	0.09/1.0^a	27(D/3.2)	28	2.3$(D/3.2)^2$	85$(D/3.2)^3(f/0.9)^a$
RCW 86	0.09/0.41^g	30(D/2.5)	25	9.3$(D/2.5)^{2*}$	91$(D/2.5)^3(f/0.88)^h$

A&A 567, A23 (2014)
DOI: 10.1051/0004-6361/201322737

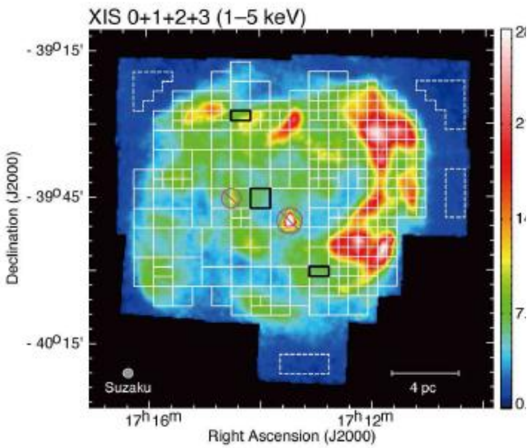
Astronomy & Astrophysics

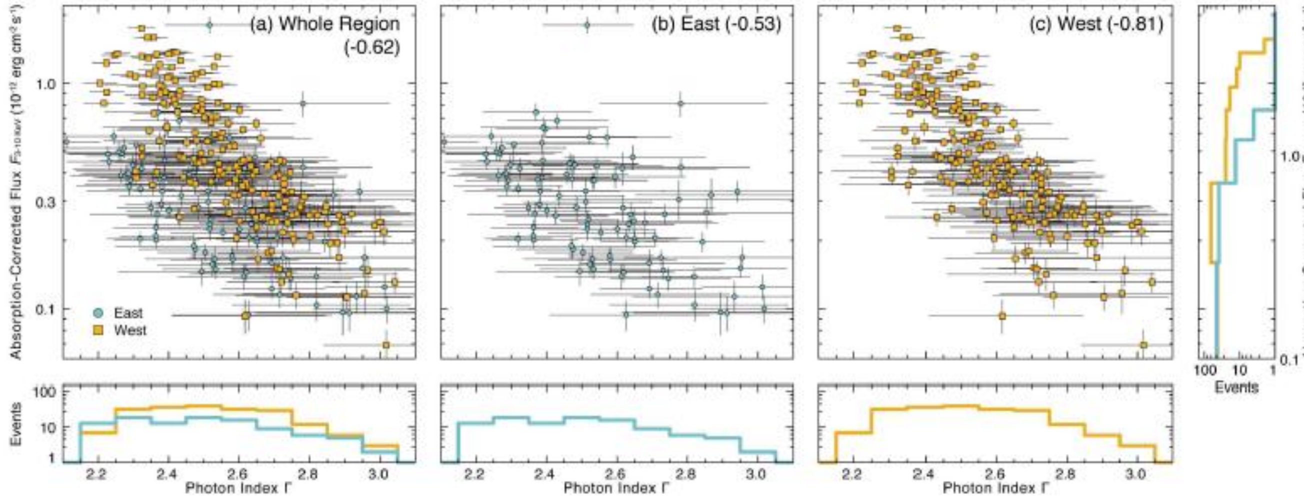
Fermi Large Area Telescope observations of the supernova remnant HESS J1731-347

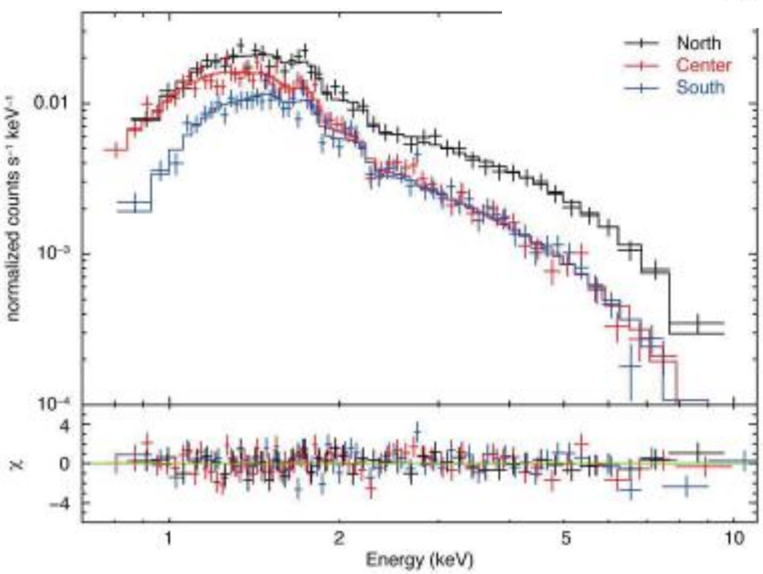
Rui-zhi Yang[1,4], Xiao Zhang[2], Qiang Yuan[3], and Siming Liu[1]

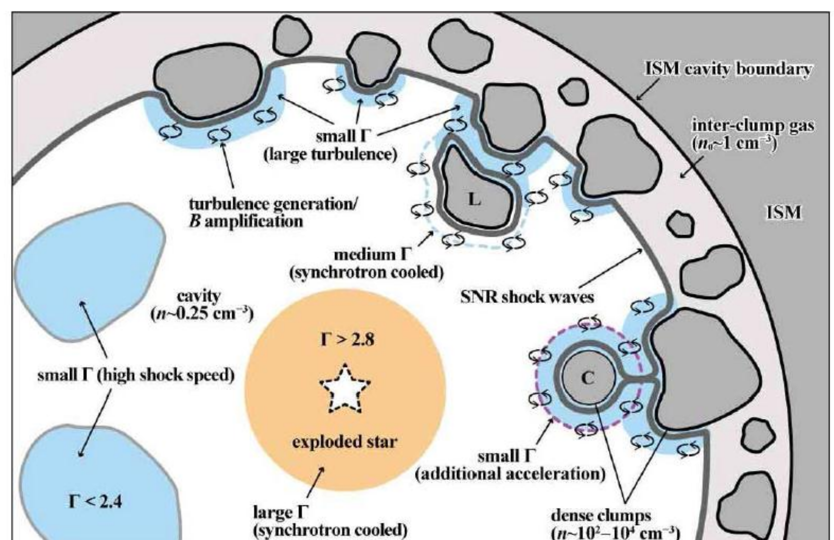
A DETAILED STUDY OF NON-THERMAL X-RAY PROPERTIES AND INTERSTELLAR GAS TOWARD THE γ-RAY SUPERNOVA REMNANT RX J1713.7−3946

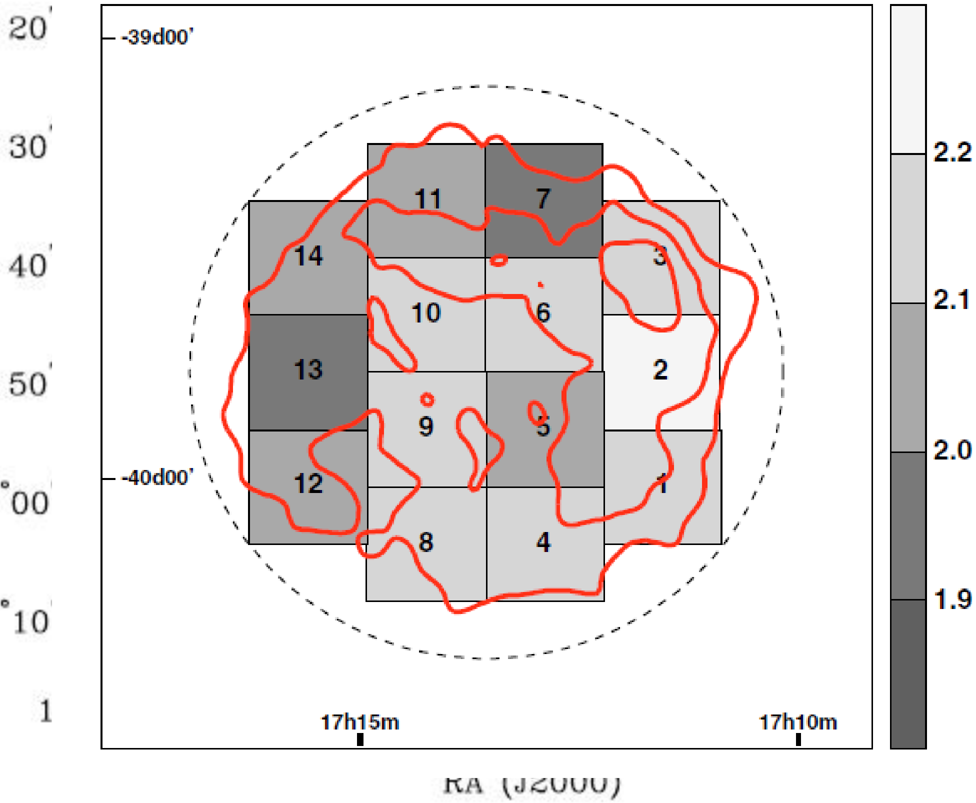
H. Sano[1], T. Fukuda[1], S. Yoshiike[1], J. Sato[1], H. Horachi[1], T. Kuwahara[1], K. Torii[1], T.

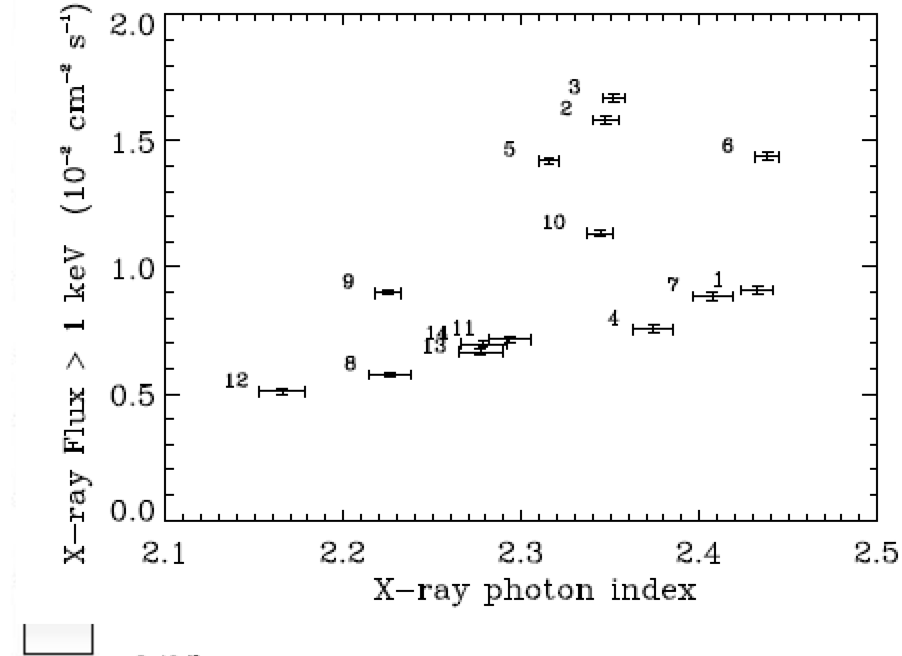


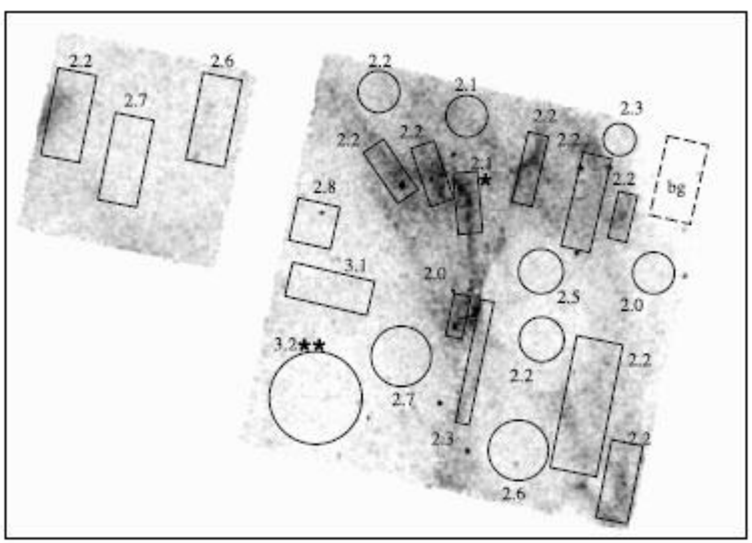


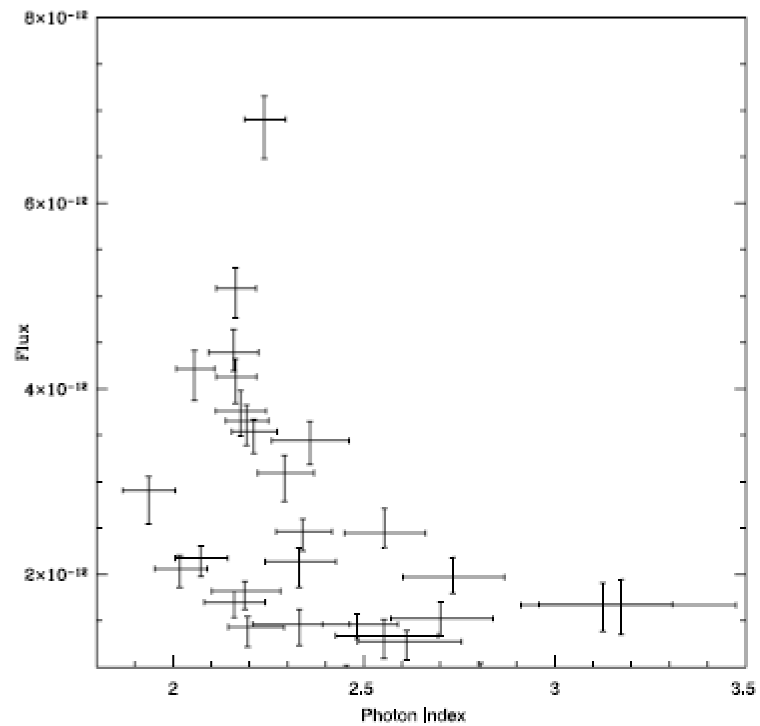





20'
30'
40'
50'
°00
°10
1
-39d00'
-40d00'
17h15m
17h10m
11
7
14
3
10
6
13
2
9
5
12
1
8
4
2.2
2.1
2.0
1.9
RA (J2000)


X−ray Flux > 1 keV (10⁻² cm⁻² s⁻¹)
X−ray photon index
2.0
1.5
1.0
0.5
0.0
2.1
2.2
2.3
2.4
2.5
3
2
5
6
10
9
7
1
14
11
13
4
8
12


2.2
2.6
2.7
2.2
2.1
2.2
2.3
2.2
2.2
2.2
2.1
2.2
2.2
bg
2.8
3.1
2.0
2.5
2.0
3.2
2.7
2.2
2.2
2.3
2.6
2.2


8×10⁻¹²
6×10⁻¹²
4×10⁻¹²
2×10⁻¹²
Flux
2
2.5
3
3.5
Photon Index

Conclusions

A century after the discovery of cosmic rays (1912), recent achievements in gamma-ray astronomy strengthen the cases that

SNRs are important sources of Galactic cosmic rays

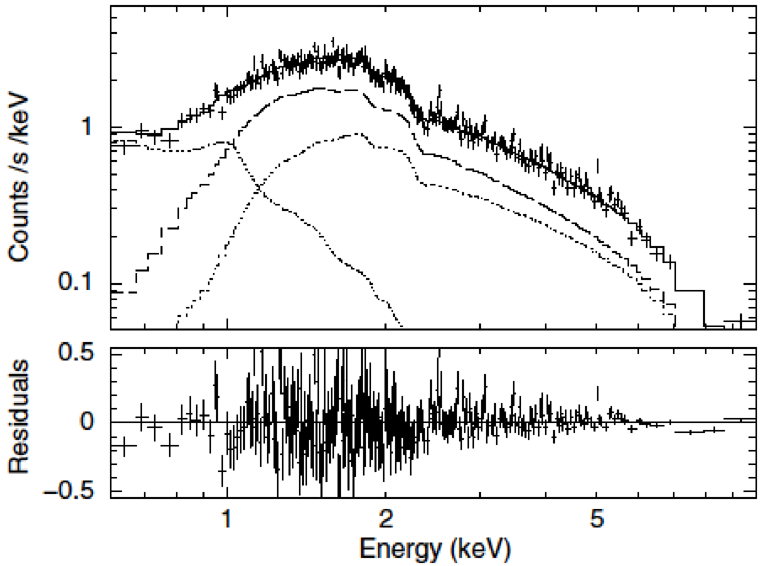
and

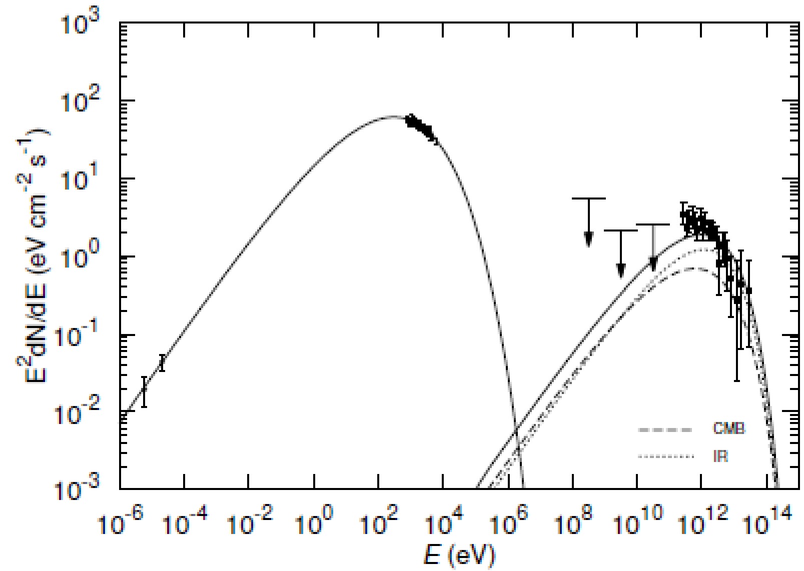
Astrophysical shocks are efficient particle accelerators and magnetic field generators

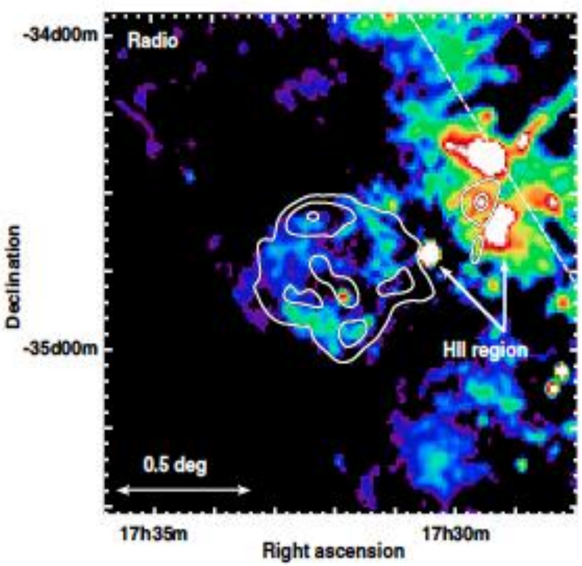
A unification model for particle acceleration in SNRs is emerging!!!

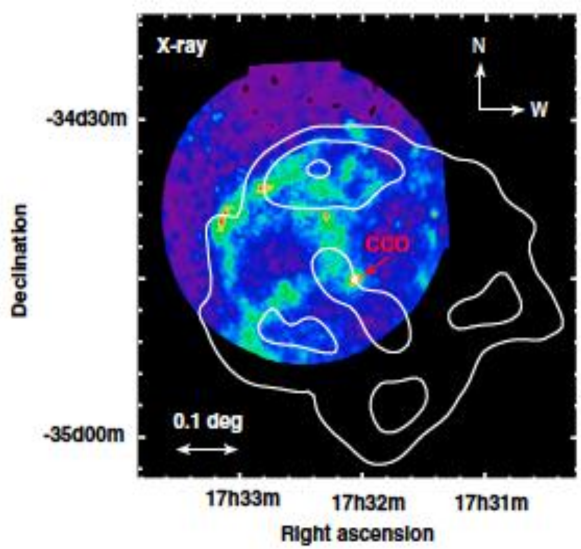
A new SNR with TeV shell-type morphology: HESS J1731-347

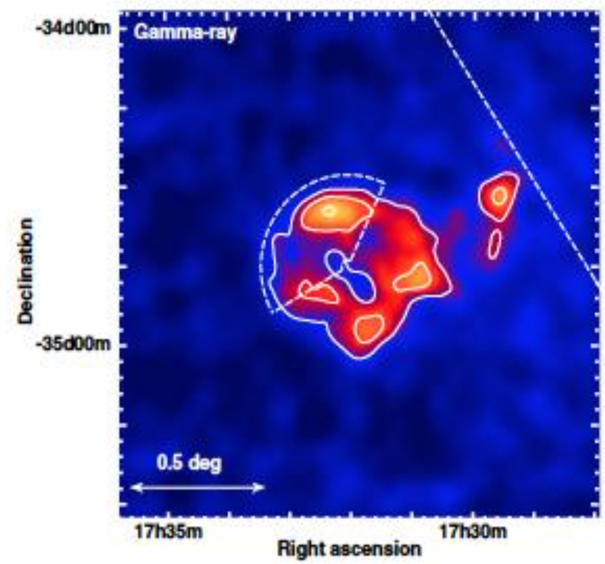
HESS Collaboration, A. Abramowski[1], F. Acero[2], F. Aharonian[3,4,5], A. G. Akhperjanian[6,5], G. Anton[7], A. Balzer[7],



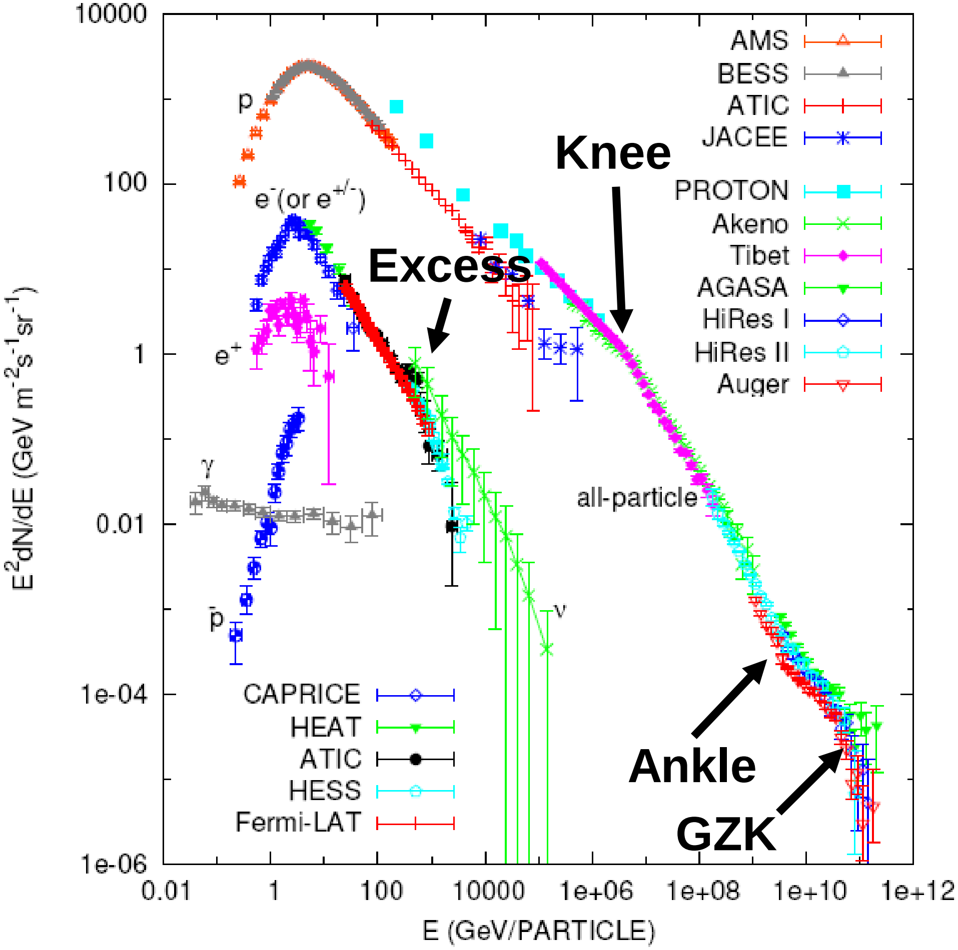


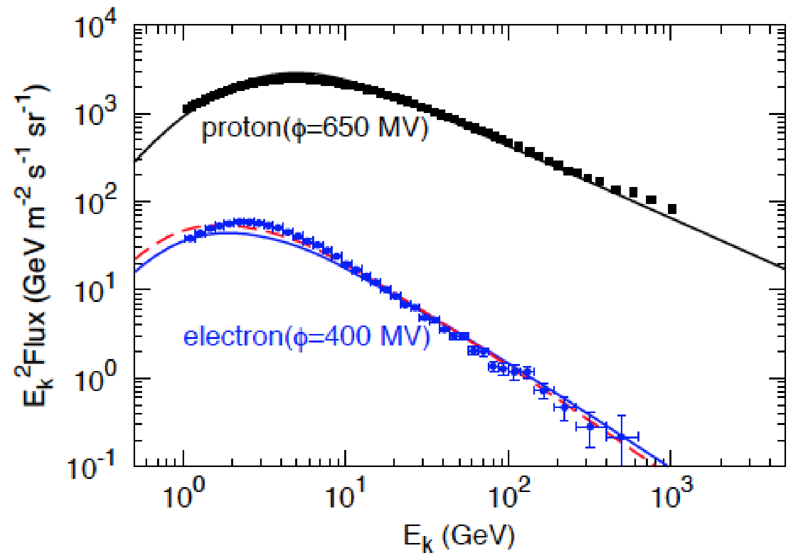






2: Cosmic Rays





G. 1.— The expected fluxes of CR protons and electrons at Earth, for the same spectral shape of the injected particles, pared with the PAMELA observational data (Adriani et al. a,b). We adopt two parameter settings to calculate the elec- spectrum: for solid line the magnetic field is the canonical adopted in GALPROP and $K_{ep} \approx 1.3\%$; for dashed line the netic field is two times larger and $K_{ep} \approx 1.9\%$.

3: Future Studies

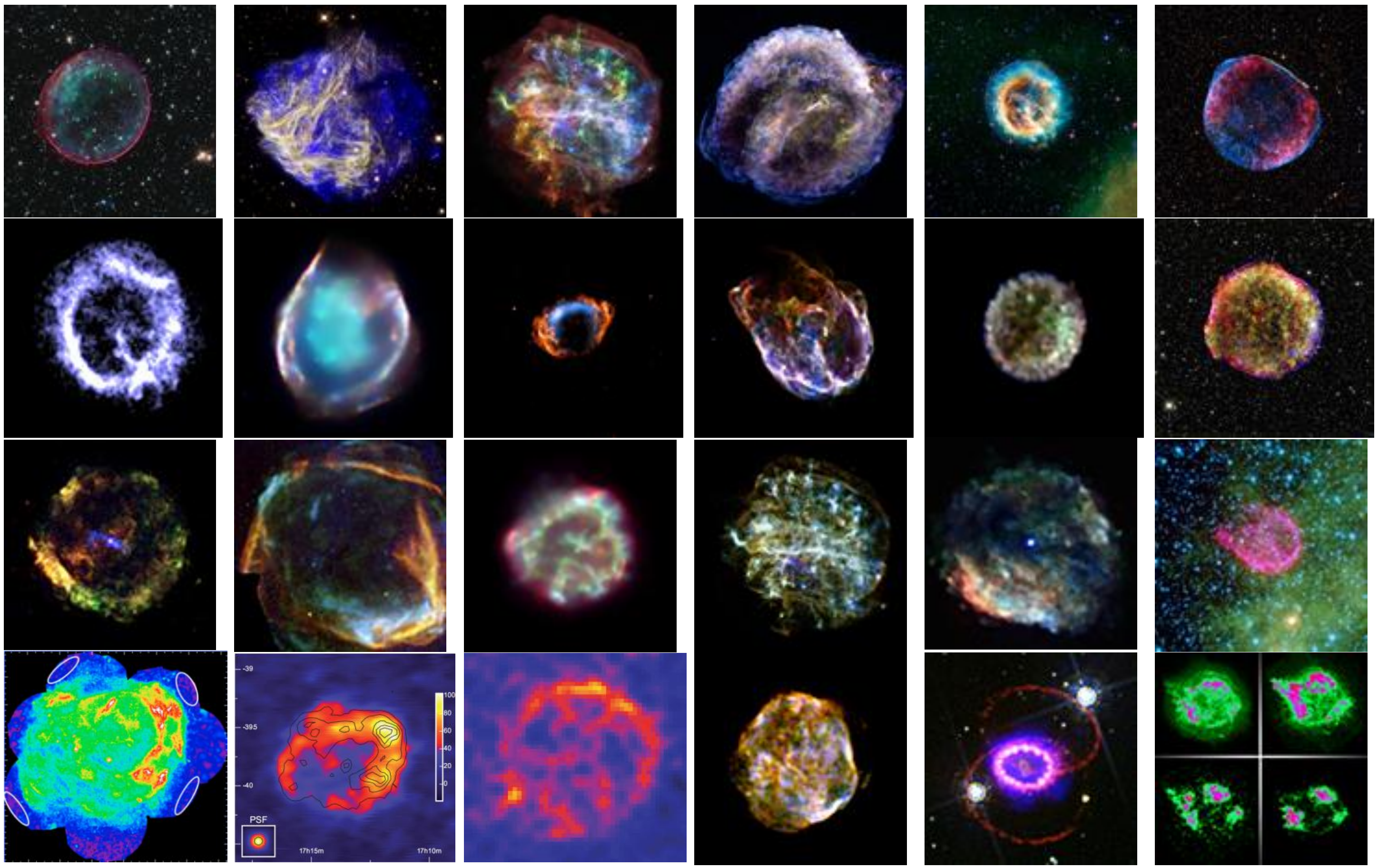
1: 3D MHD Simulations to Study Source structure

2: Multi-wavelength spectral fit

3: Evolution of SNRs

4: Incorporating the thermal component

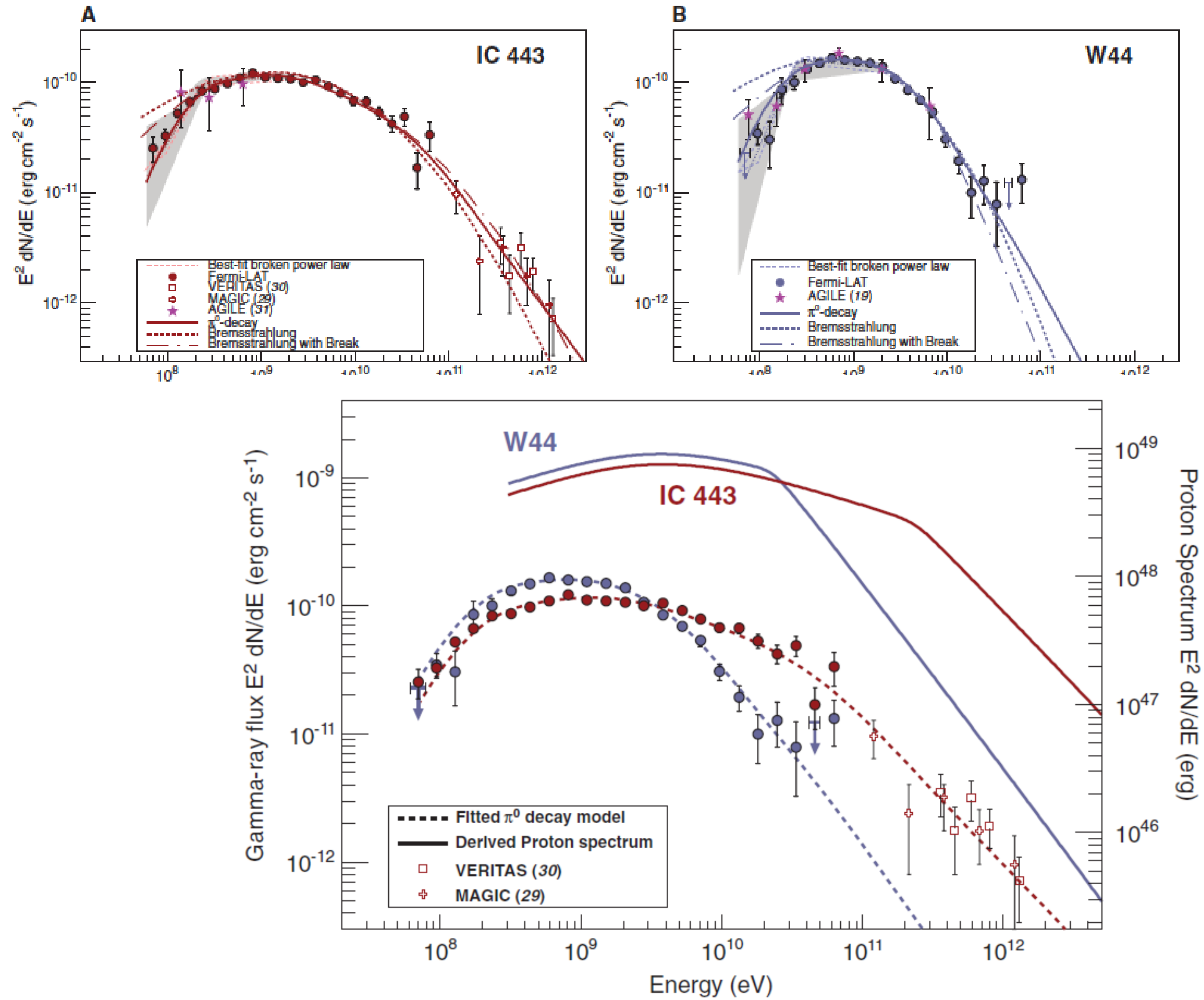
1:Supernova Remnants

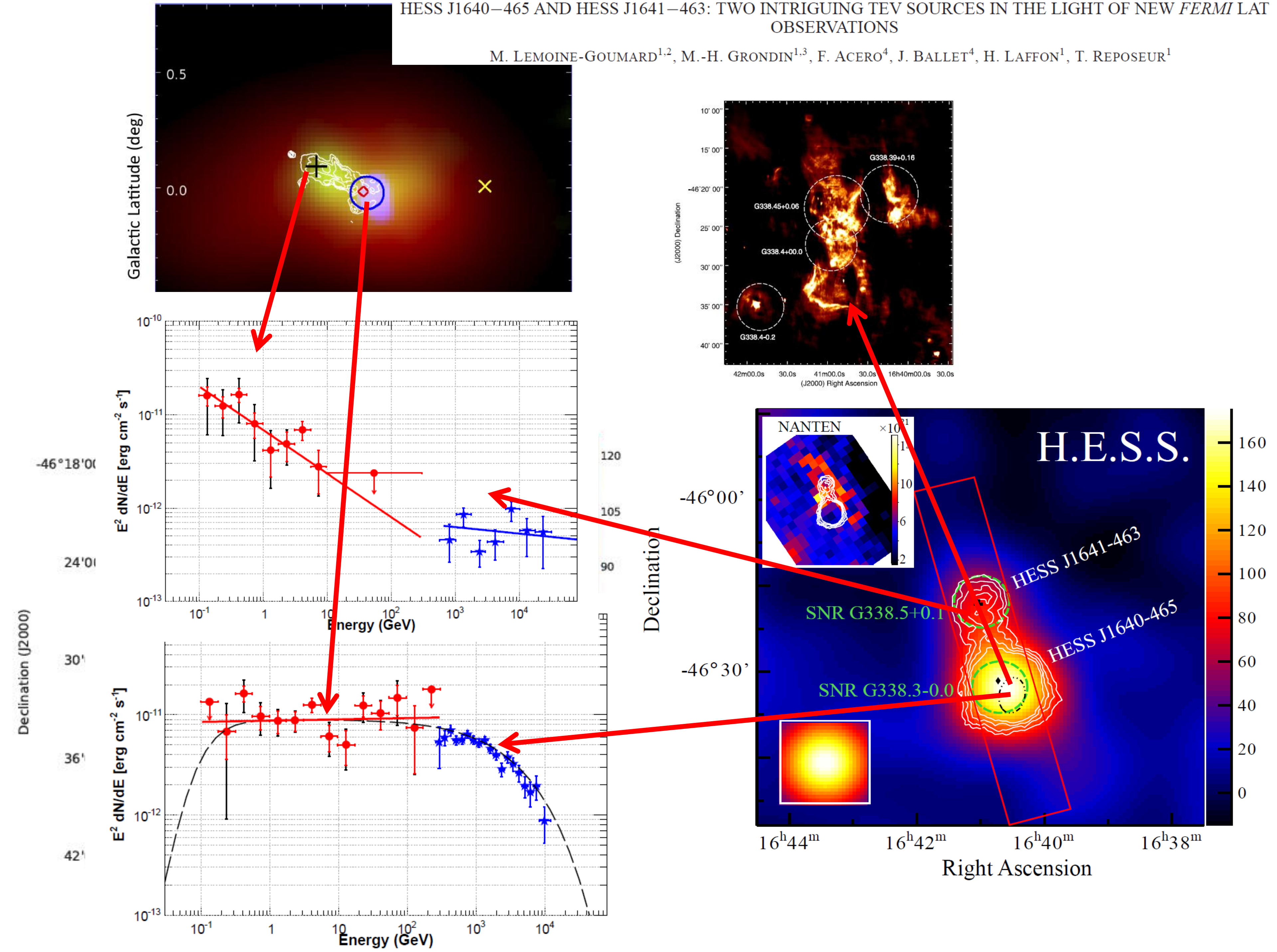


Detection of the Characteristic Pion-Decay Signature in Supernova Remnants

M. Ackermann *et al.*

Science **339**, 807 (2013);
DOI: 10.1126/science.1231160

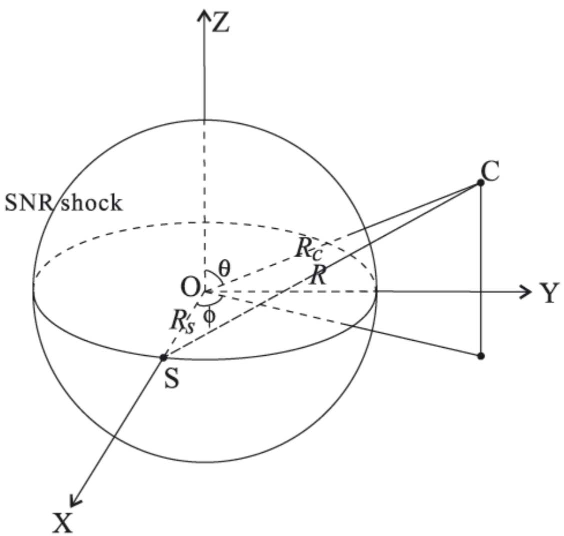


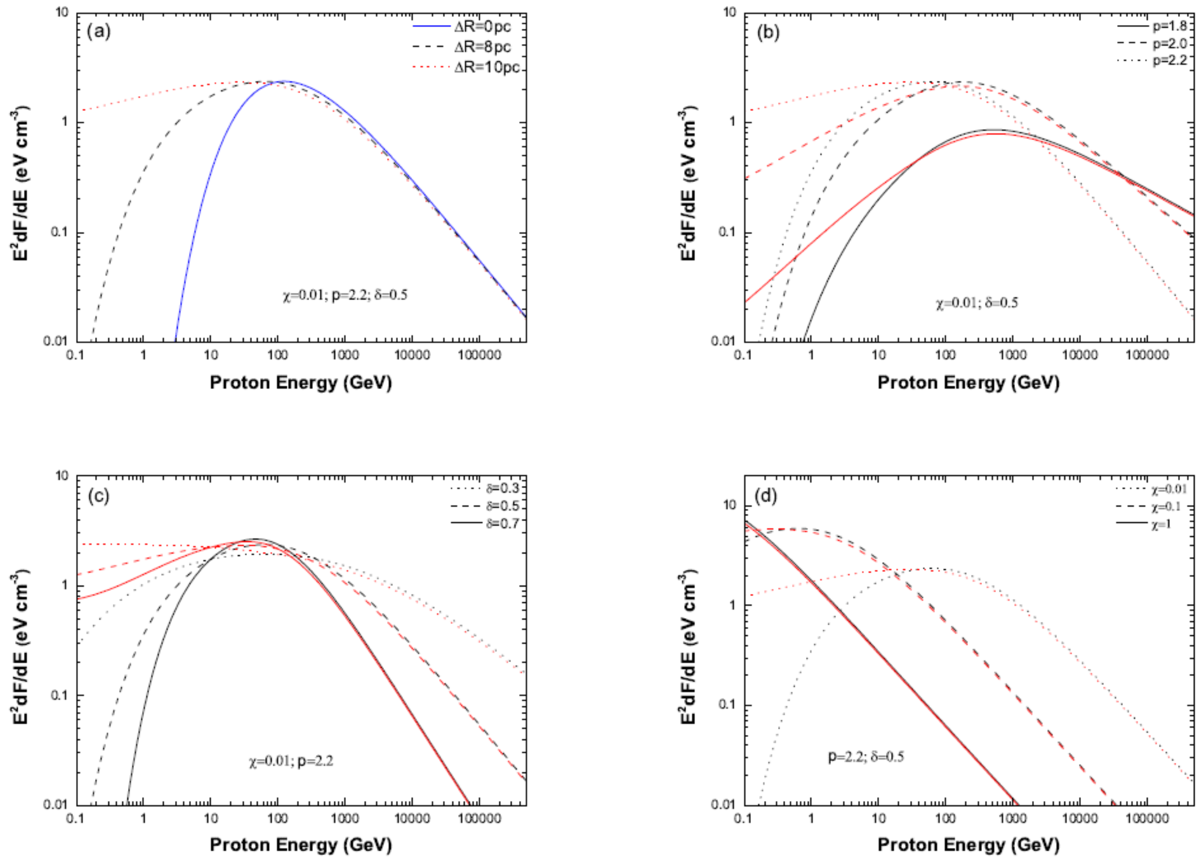


HESS J1640−465 AND HESS J1641−463: TWO INTRIGUING TEV SOURCES IN THE LIGHT OF NEW FERMI LAT OBSERVATIONS
M. LEMOINE-GOUMARD[1,2], M.-H. GRONDIN[1,3], F. ACERO[4], J. BALLET[4], H. LAFFON[1], T. REPOSEUR[1]
Galactic Latitude (deg)
0.5
0.0
E² dN/dE [erg cm⁻² s⁻¹]
Energy (GeV)
Declination (J2000)
-46°18'00
24'00
30'
36'
42'
120
105
90
G338.39+0.16
G338.45+0.06
G338.4+00.0
G338.4-0.2
(J2000) Declination
(J2000) Right Ascension
42m00.0s
30.0s
41m00.0s
16h40m00.0s
NANTEN
H.E.S.S.
HESS J1641-463
HESS J1640-465
SNR G338.5+0.1
SNR G338.3-0.0
-46°00'
-46°30'
Declination
Right Ascension
16h44m
16h42m
16h40m
16h38m

γ-rays from molecular clouds illuminated by accumulated diffusive protons. II: interacting supernova remnants

Hui Li[1] and Yang Chen[1,2]⋆
[1] Department of Astronomy, Nanjing University, Nanjing 210093, P. R. China
[2] Key Laboratory of Modern Astronomy and Astrophysics, Nanjing University, Ministry of Education, Nanjing 210093, China

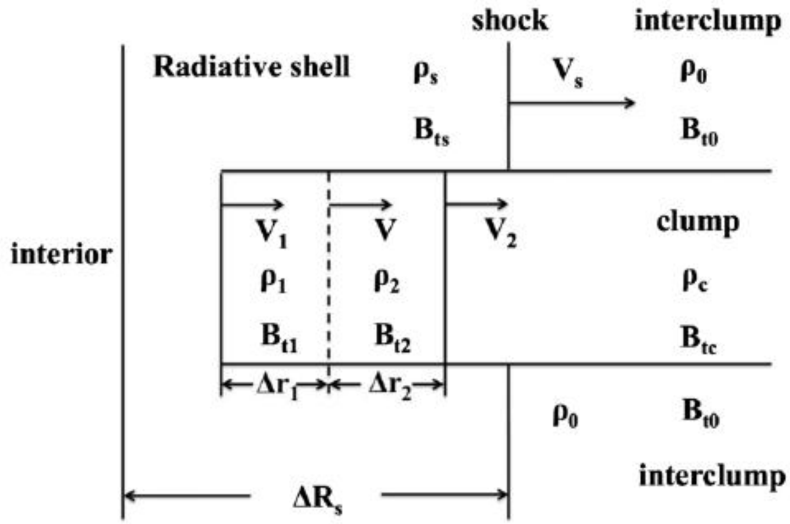


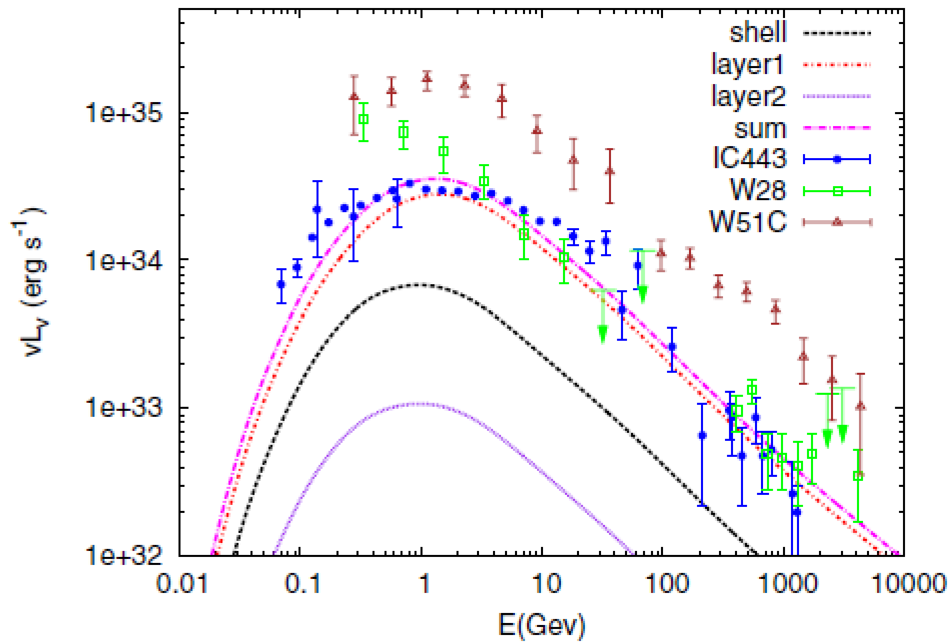


The Astrophysical Journal Letters, 784:L35 (5pp), 2014 April 1 doi:10.1088/2041-8205/784/2/L3

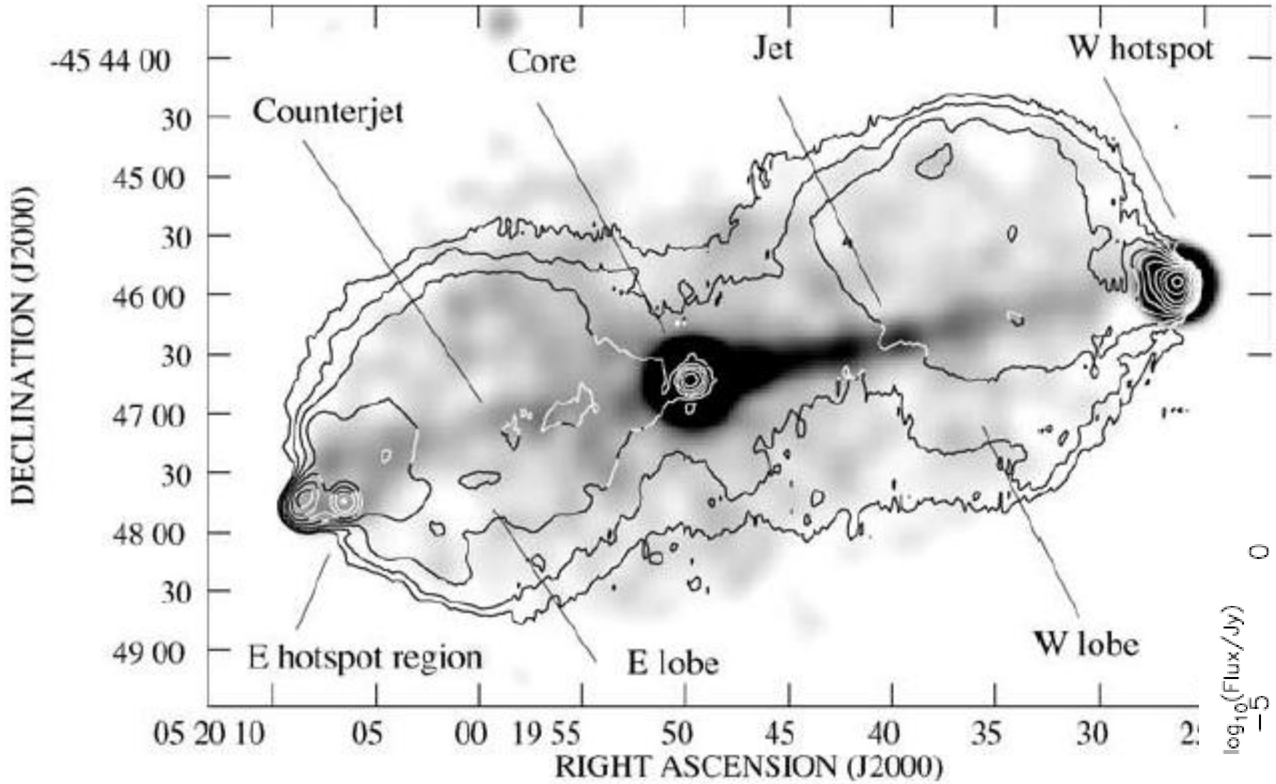
GAMMA-RAY EMISSION FROM SUPERNOVA REMNANT INTERACTIONS WITH MOLECULAR CLUMPS

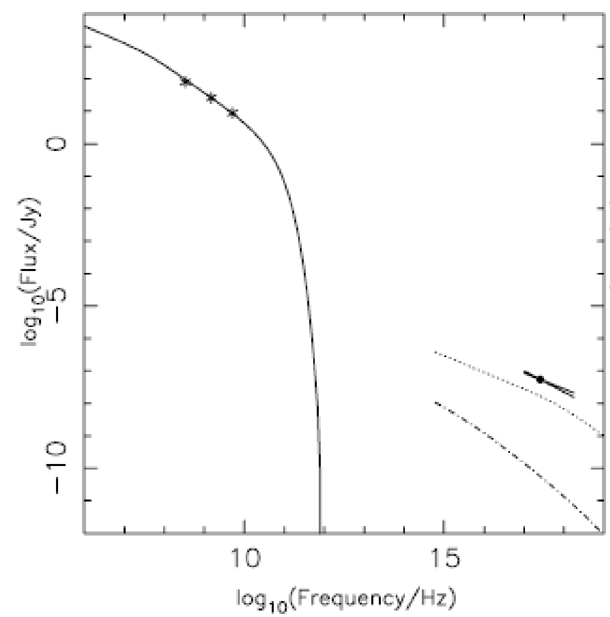
Xiaping Tang and Roger A. Chevalier



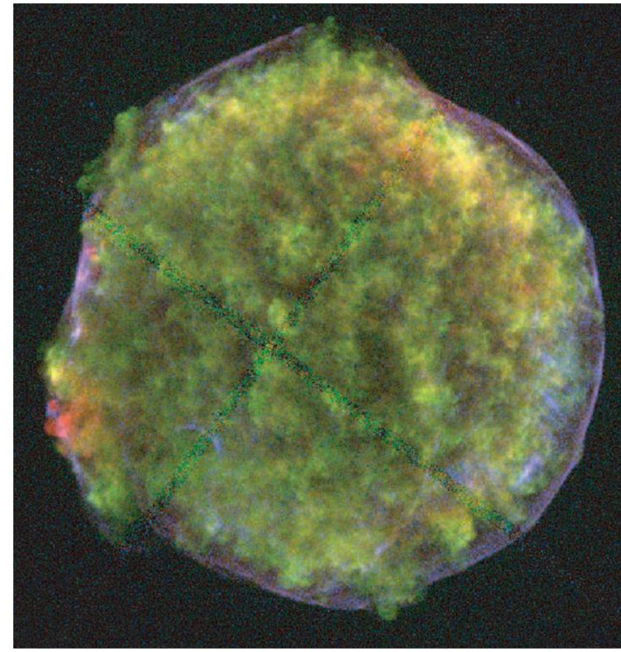


1 Energy Partition between Magnetic Field and Energetic Electrons





4.2 Multi-wavelength spectral fit



GAMMA RAYS FROM THE TYCHO SUPERNOVA REMNANT: MULTI-ZONE VERSUS SINGLE-ZONE MODELING

ARMEN ATOYAN[1] AND CHARLES D. DERMER[2]

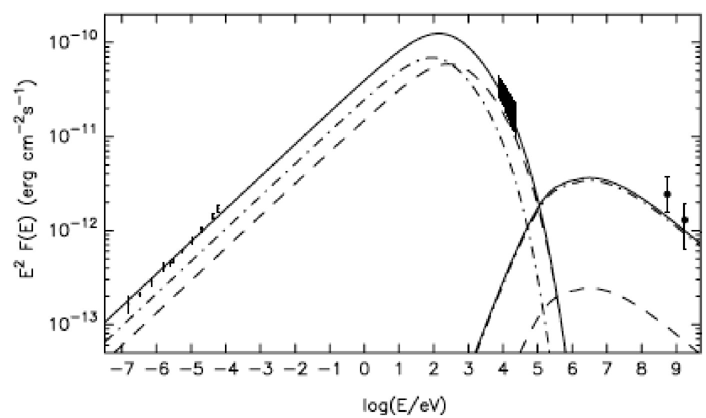


Figure 1. Synchrotron fluxes from radio through X-rays in the two-zone model. Dashed and dot-dashed lines show the fluxes from zone 1 and zone 2, respectively, and the total flux is shown by the solid line. Calculations assume density $n_2 \approx 3\,\mathrm{cm}^{-3}$ at $d_{\rm kpc} = 2.8$, $n_1 \approx n_2$, $B_1 = 100\,\mu$G and $B_2 = 34\,\mu$G, $\eta = 0.2$, $\alpha = 2.31$, and $E_{\rm cut} = 40$ TeV. Also shown are the lower-energy ($\lesssim$GeV) bremsstrahlung fluxes produced by relativistic electrons in zones 1 and 2.

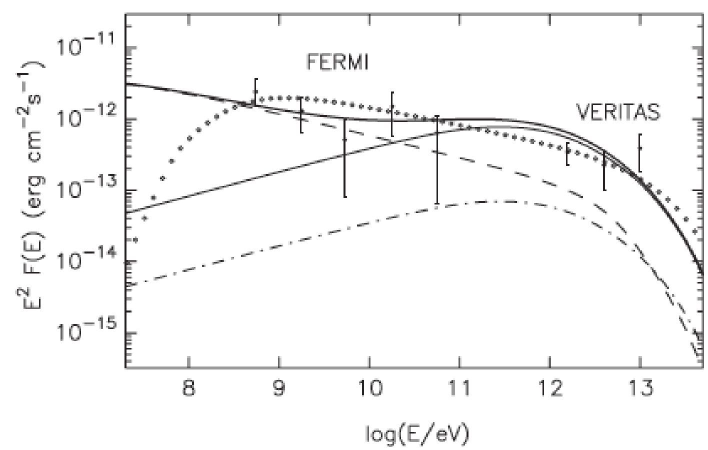


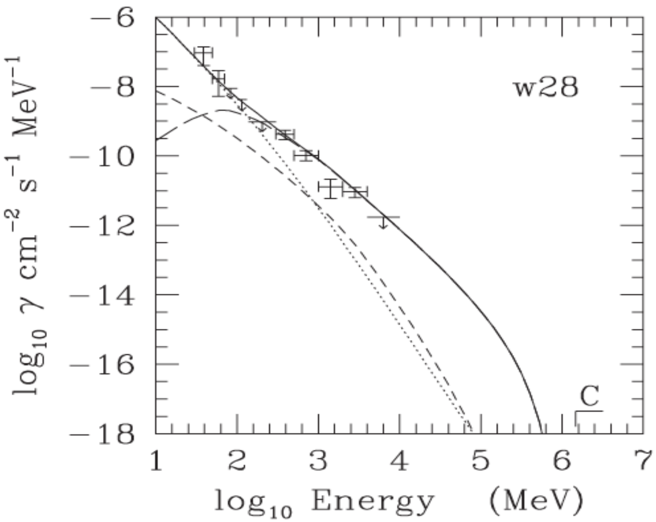
Figure 2. γ-ray fluxes in the two-zone model with parameters described in Figure 1. The heavy solid line shows the total flux of leptonic origin. The total bremsstrahlung and Compton radiation fluxes are shown by dashed and solid (thin) lines, respectively. For comparison, the Compton flux contribution from zone 1 is also shown (dot-dashed line). The open dotted curve shows the flux of hadronic origin calculated for protons with total energy $E_p = 3 \times 10^{49}$ erg.

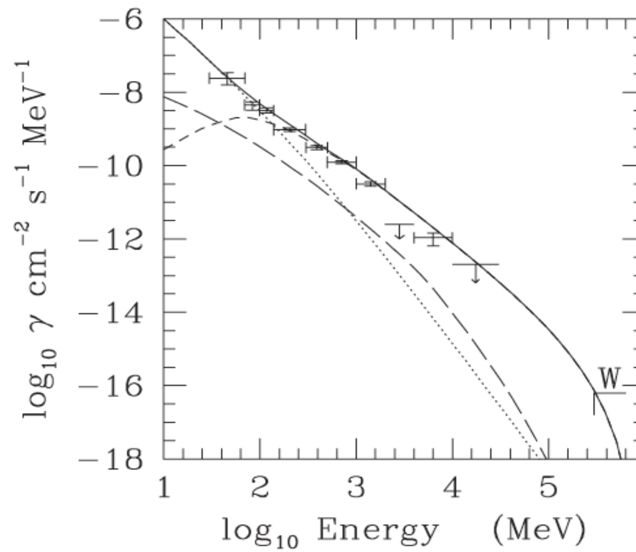
4.2 Multi-wavelength spectral fit

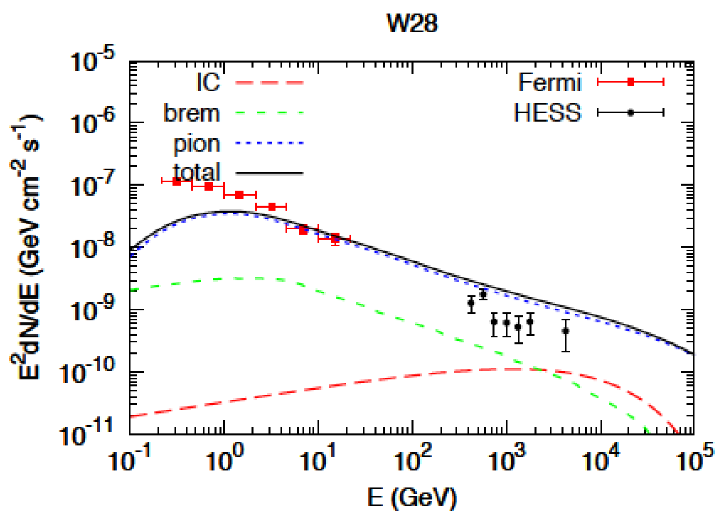
PRIMARY VERSUS SECONDARY LEPTONS IN THE EGRET SUPERNOVA REMNANTS

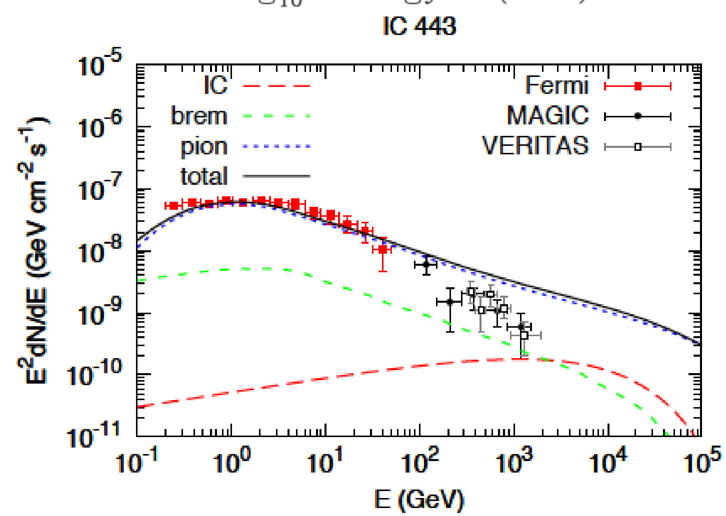
Marco Fatuzzo[1] and Fulvio Melia[2]

Received 2004 December 17; accepted 2005 May 6









RADIO TO GAMMA-RAY EMISSION FROM SHELL-TYPE SUPERNOVA REMNANTS: PREDICTIONS FROM NONLINEAR SHOCK ACCELERATION MODELS

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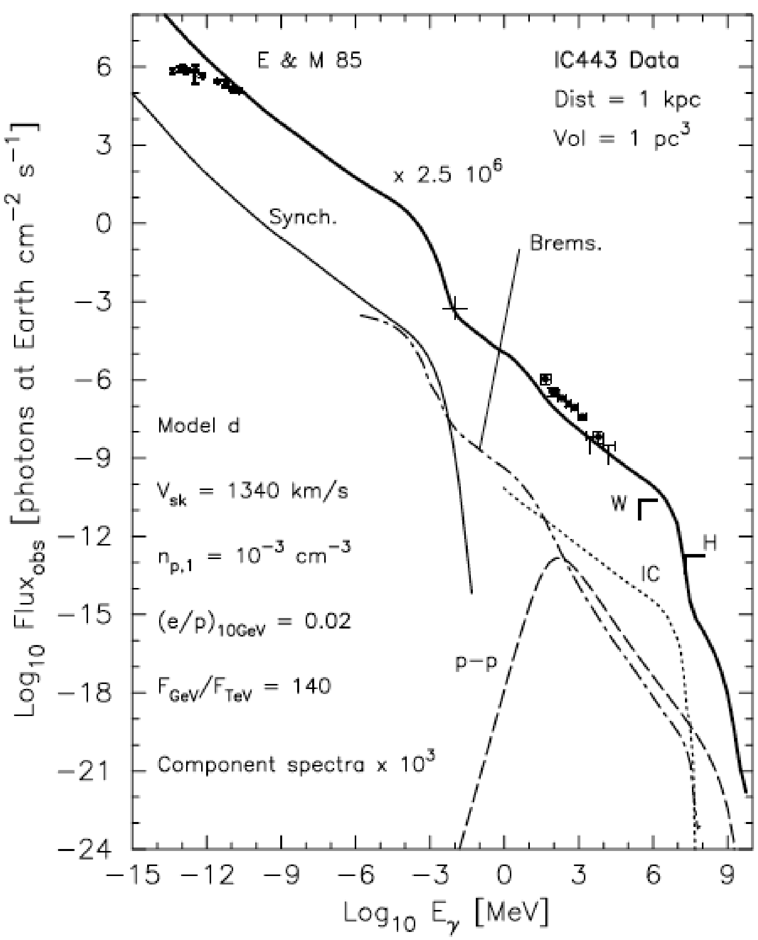
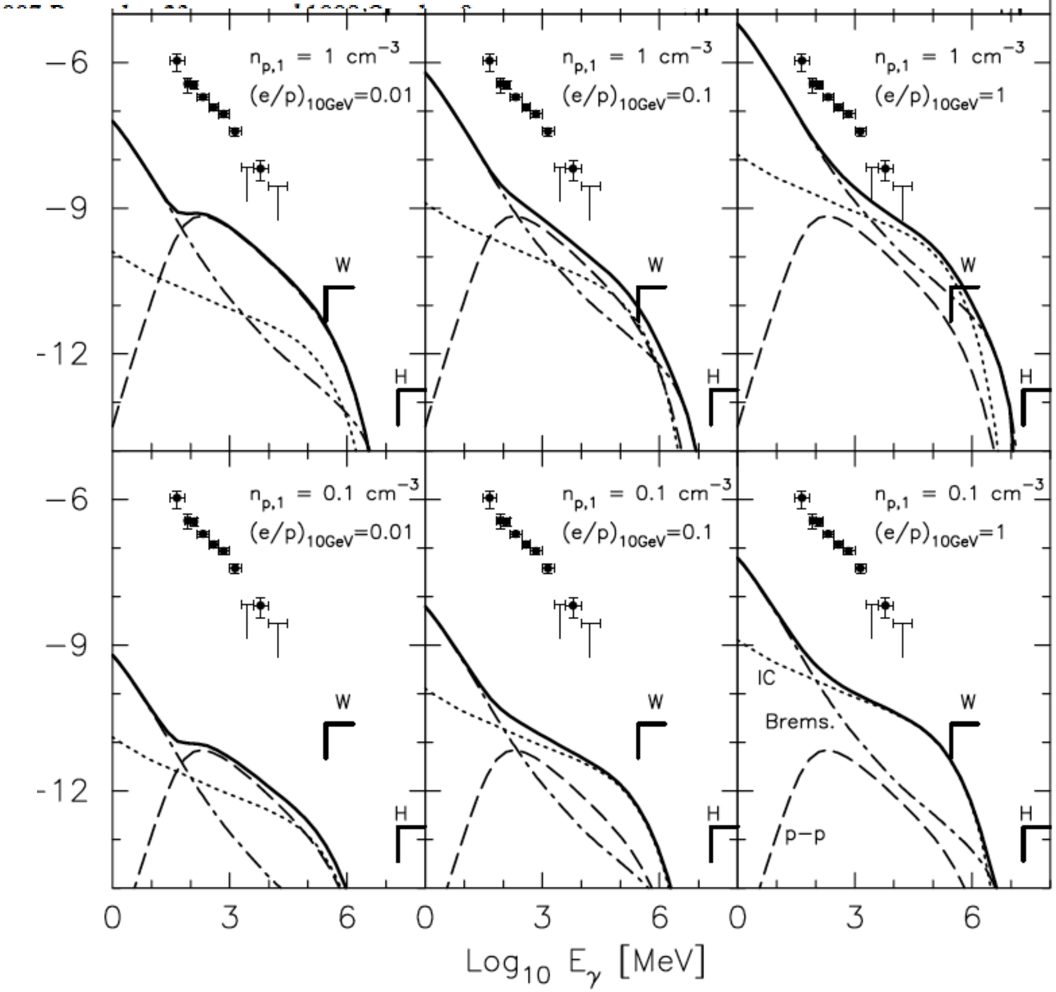




4.4 Thermal Emission

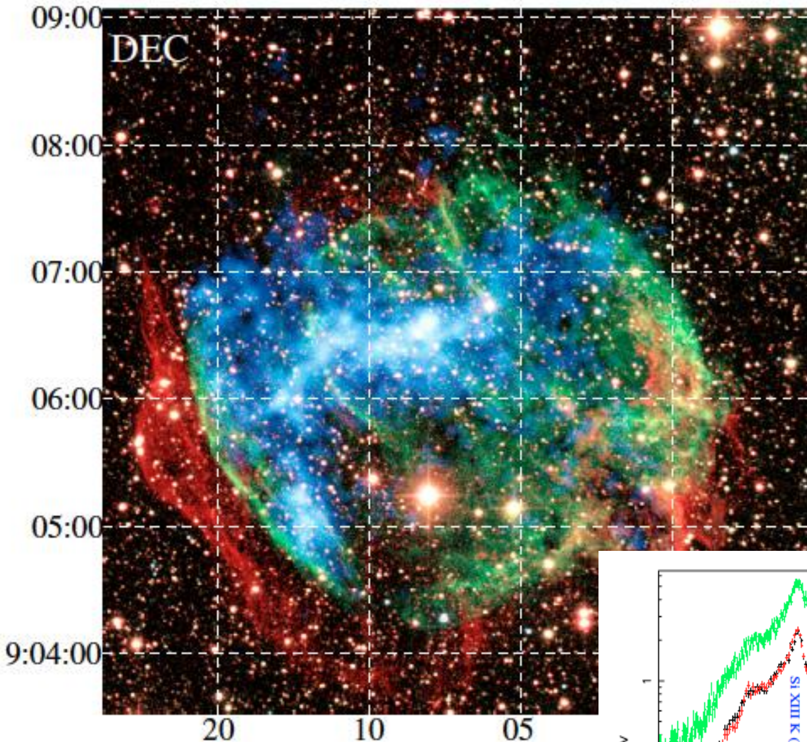
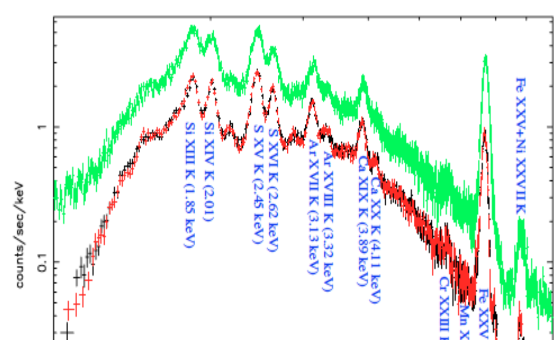
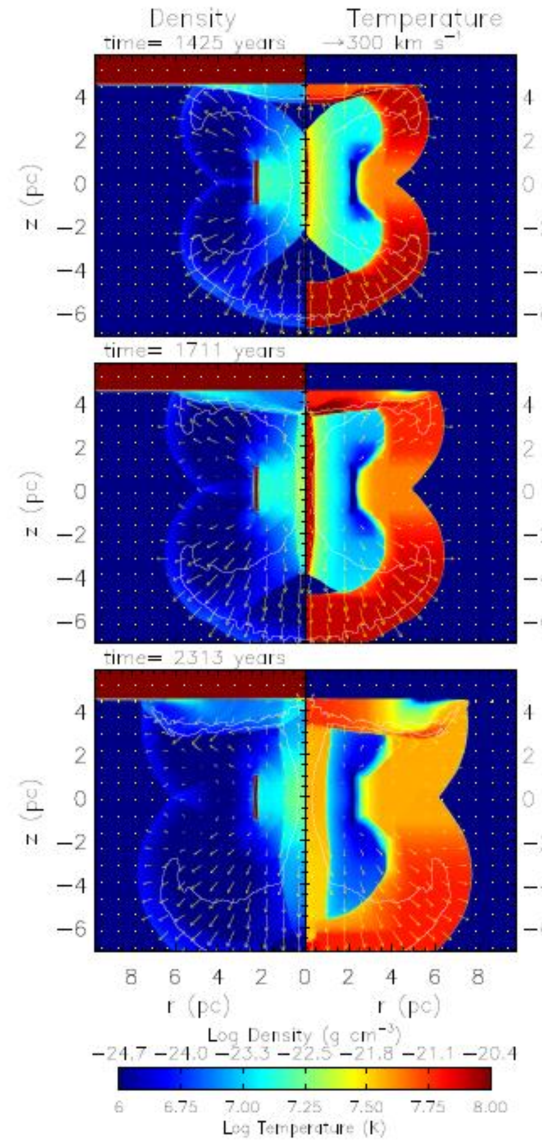


Fig. 2. Color composite *Chandra* X-ray image (in
2.12 μm molecular hydrogen (in red), and 1.64
green) images of W49B (from `http://chandra`
`press/04_releases/press_060204.html`).



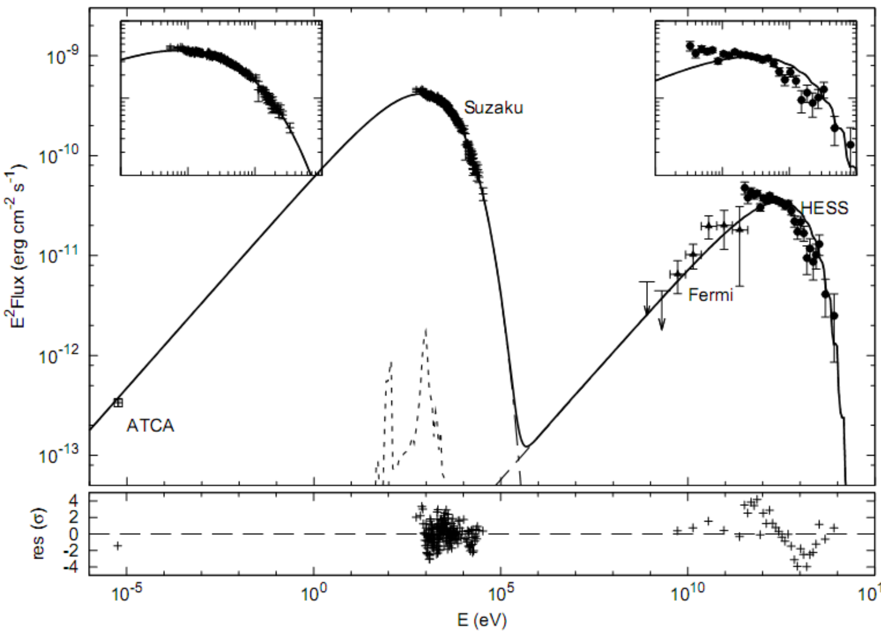


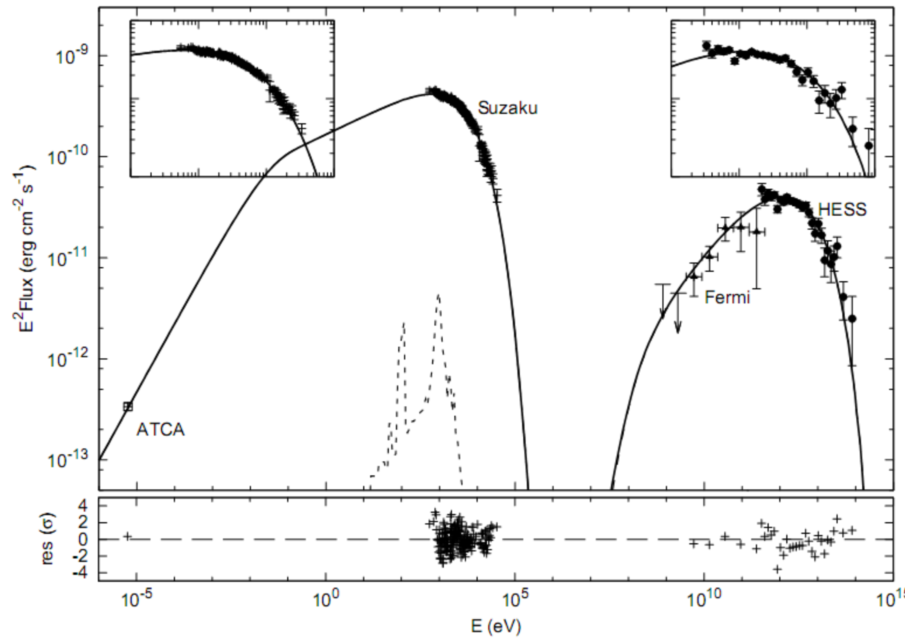
Unveiling the spatial structure of the overionized plasma in the supernova remnant W49B

Xin Zhou[1,2], Marco Miceli[3,2], Fabrizio Bocchino[2], Salvatore Orlando[2], and Yang Chen[1,4]

1: Two emission models for SNR RX J1713.7-3946

Leptonic $F_e(E) \propto E^{-\alpha_e} \exp\left[-(E/E_c^e)^{\delta_e}\right]$ Hadronic





	α_e	E_c^e (TeV)	W_e (10^{47}erg)	δ_e	B (μG)	$n_{\rm ISM}$ ($10^{-2}{\rm cm}^{-3}$)	α_p	E_c^p (TeV)	W_p (10^{52}erg)
leptonic	$2.15^{+0.01}_{-0.01}$	$51.3^{+2.3}_{-2.2}$	$5.5^{+0.3}_{-0.3}$	$1.21^{+0.04}_{-0.04}$	$11.6^{+0.1}_{-0.1}$	< 0.7	—	—	—
hadronic	$1.64^{+0.09}_{-0.08}$	$14.5^{+4.8}_{-3.9}$	$0.05^{+0.05}_{-0.02}$	$2.1^{+0.2}_{-0.2}$	$428.2^{+233.9}_{-159.6}$	< 1.1	$1.58^{+0.06}_{-0.06}$	$53.7^{+7.1}_{-6.2}$	> 1.6
hadronic*	$1.58^{+0.05}_{-0.05}$	$12.3^{+2.1}_{-1.8}$	$0.03^{+0.01}_{-0.01}$	$1.9^{+0.1}_{-0.1}$	$596.8^{+173.0}_{-129.0}$	< 1.2	—	$54.7^{+6.0}_{-5.7}$	> 1.4

The Astrophysical Journal, 735:120 (9pp), 2011 July 10 doi:10.1088/0004-637X/

MODELING THE MULTI-WAVELENGTH EMISSION OF THE SHELL-TYPE SUPERNOVA REMNANT RX J1713.7−3946

Qiang Yuan[1], Siming Liu[2,3], Zhonghui Fan[4], Xiaojun Bi[1,5], and Christopher L. Fryer[6,7]
[1] Key Laboratory of Particle Astrophysics, Institute of High Energy Physics, Chinese Academy of Sciences, Beijing 100049, China
[2] Department of Physics and Astronomy, University of Glasgow, Glasgow G12 8QQ, UK
[3] Key Laboratory of Dark Matter and Space Astronomy, Purple Mountain Observatory, Chinese Academy of Sciences, Nanjing 210008, China

3: Future Studies

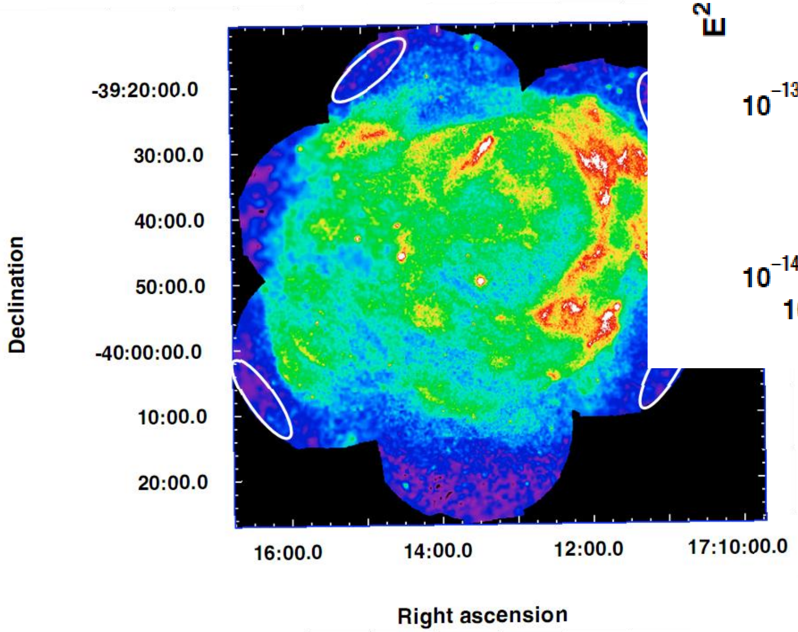
1: 3D MHD Simulations to Study Source structure

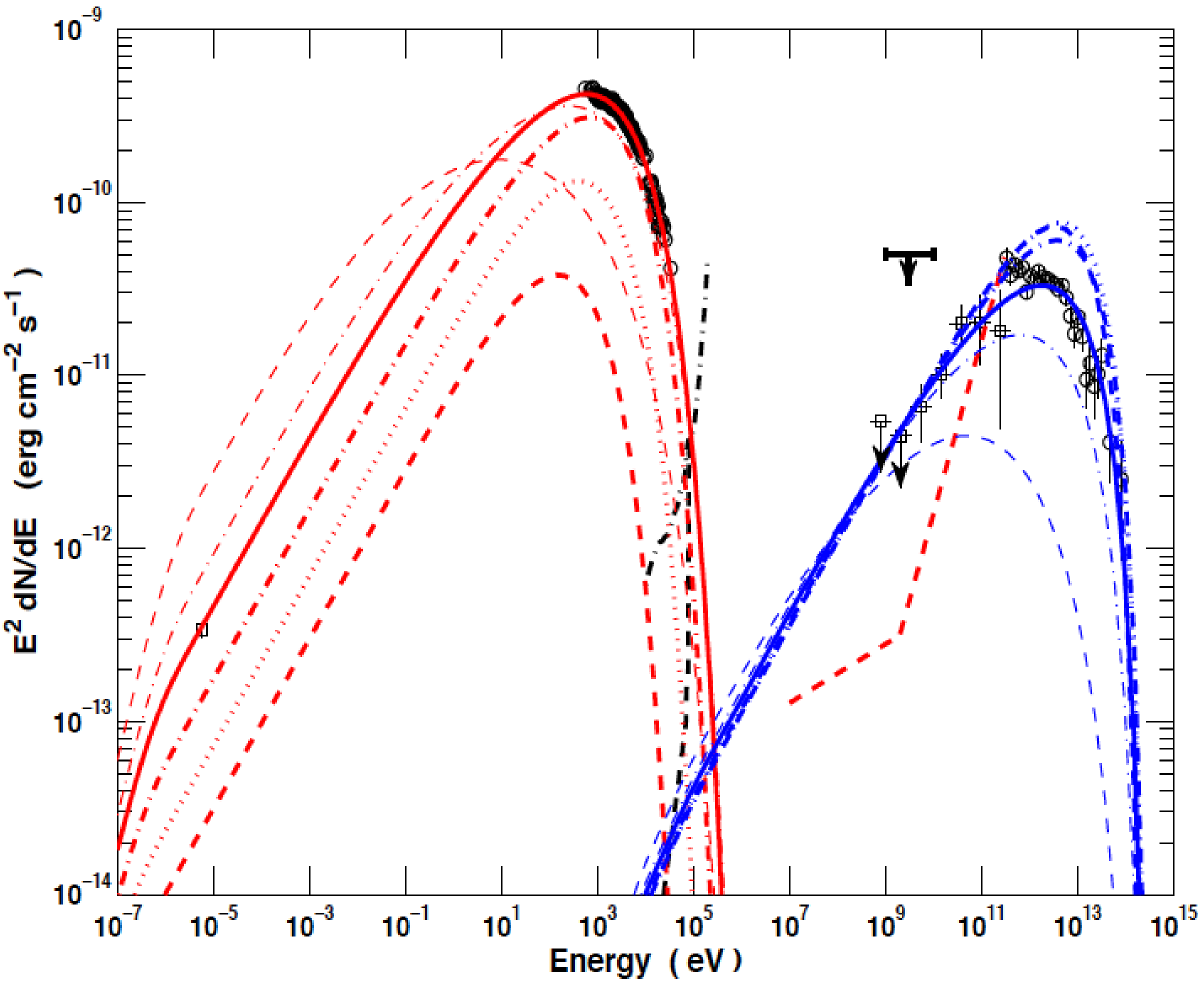
2: Multi-wavelength spectral fit

3: Evolution of SNRs

4: Incorporating the thermal component

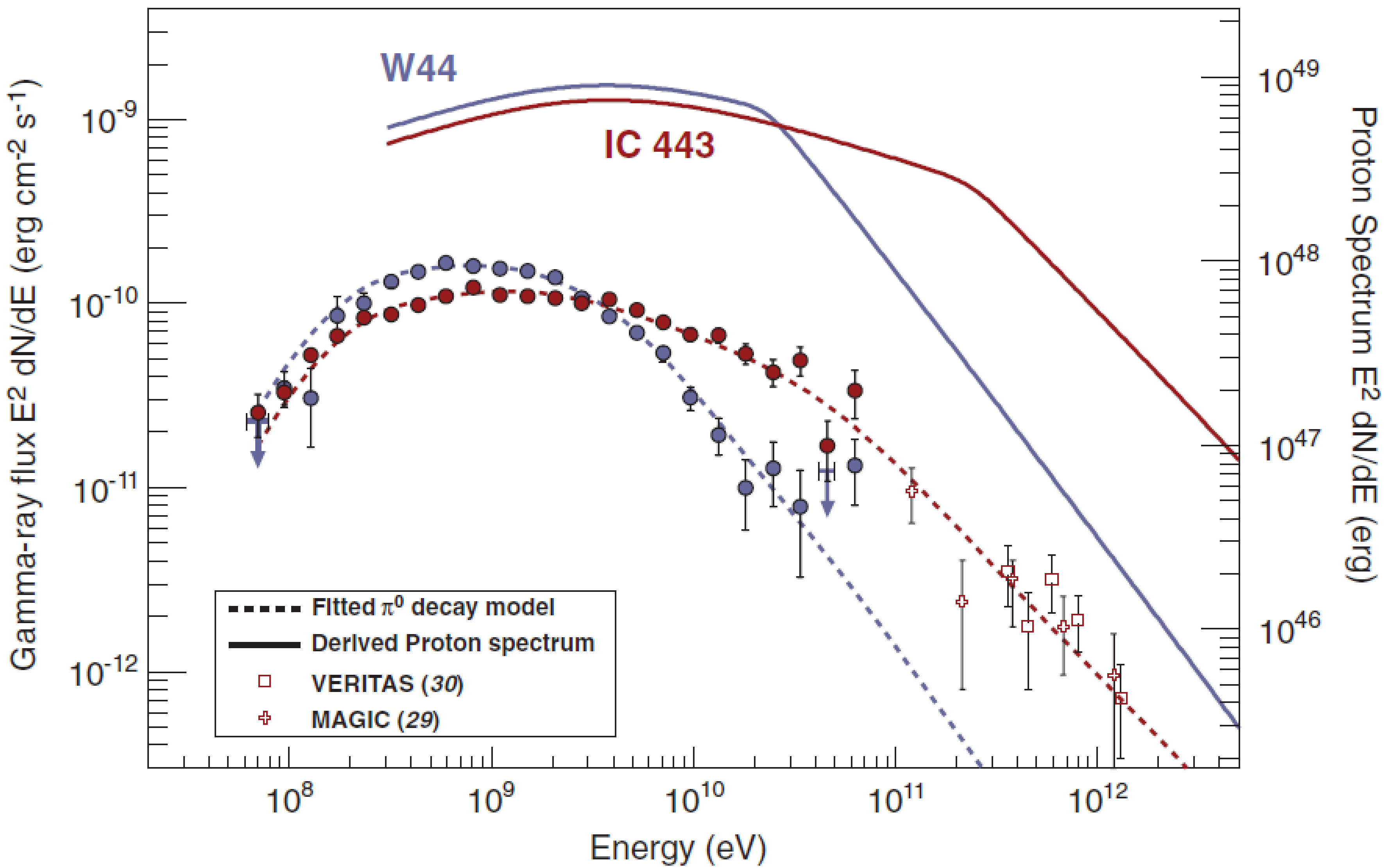
4.3 Time Evolution





Science AAAS

Detection of the Characteristic Pion-Decay Signature in Supernova Remnants
M. Ackermann *et al.*
Science **339**, 807 (2013);
DOI: 10.1126/science.1231160



2:Gamma-ray Observations of Particle Acceleration in Supernova Remnants

http://www.physics.umanitoba.ca/snr/SNRcat/

A census of high-energy observations of Galactic supernova remnants

Authors and credits: This database is maintained by Gilles Ferrand, under the supervision of Samar Safi-Harb, in the SNR group of the Department of Physics and Astronomy at the University of Manitoba.
The list of SNRs with their basic physical properties was based on the radio Catalogue of Galactic Supernova Remnants by Dave Green, including the 2014 update, and aims to be complete for Galactic SNRs (but it does not include any extragalactic object). This work also builds on the List of Galactic SNRs Interacting with Molecular Clouds maintained by Bing Jiang, and on the census of the youngest Galactic SNRs by Matthieu Renaud. Entries have also been cross-checked with the Pulsar Wind Nebula Catalog and the SGR/AXP Catalog from the McGill Pulsar Group.

More detailed information on this work (motivation, usage, statistics, future extensions) can be found in a companion paper: *Ferrand, G., Safi-Harb, S., A Census of High-Energy Observations of Galactic Supernova Remnants, AdSpR, 49, 9, 1313-1319* (get it on ScienceDirect, ADS, arXiv). When making use of this catalogue for your own research, we kindly ask you to cite this article and the URL of this page in all your related publications.

This catalogue is updated regularly, with typically weekly updates (see date at the bottom of any page). You can get recent statistics here (updated several times a year). You can send us feedback with this form (the link is also available on each page, pre-filled with the SNR name). You can use this form to suggest corrections to existing SNRs, or to let us know about new SNRs or candidates.

Description: The table on this page is the list of all the identified SNRs. Each row corresponds to a single object. Click anywhere on the row to open the full record in a new page, with more details and all references. The columns of this table summarize the properties a

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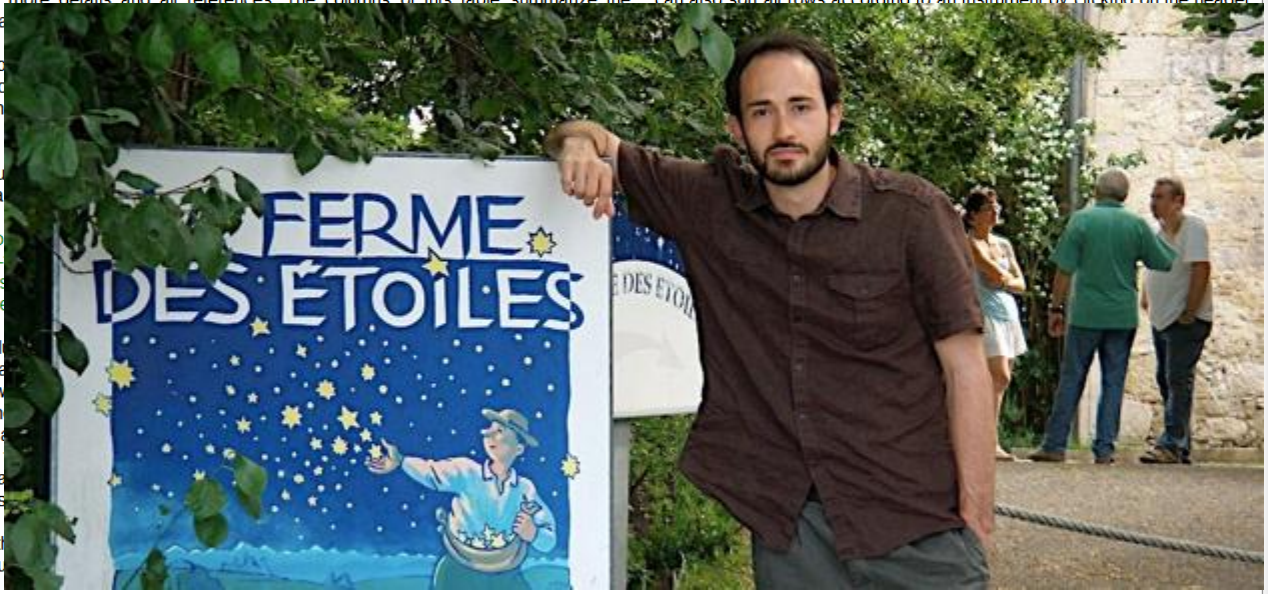
Manipulation: You can re-order the instrumental columns by dragging-and-dropping the header of one column (reload the page to reset the order). You can also sort all rows according to an instrument by clicking on the header

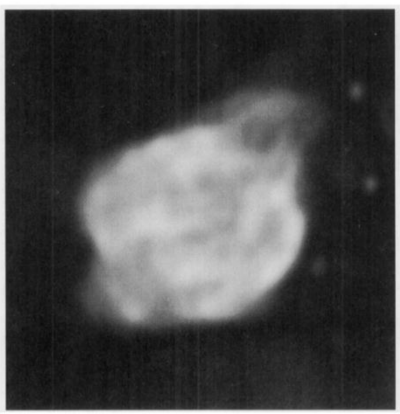


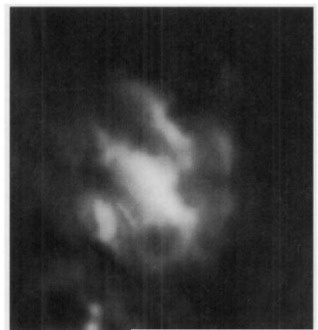
ID	names	context	SN	age	distance	type	CHANDRA	XMM	SUZAKU	ROSAT	ASCA	FERMI	AGILE	HESS	VERITAS	MAGIC	MILAGRO
							all	all	all	all	all	all	all	all	all	all	all
G000.0+00.0	Sgr A East, *1FGL J1745.6-2900c, 2FGL J1745.6-2858, 1FHL J1745.6-2900, HESS J1745-290*	contains CXOGC J174545.5-285829 = the cannonball = NS candidate and possibly PWN, close to BH Sgr A*, interacts with molecular cloud		1200 - 10000 yr	8 kpc	composite	CHANDRA	XMM	SUZAKU		ASCA	FERMI		HESS	VERITAS		
G000.1-00.1	*1FGL J1746.4-2849c, 1FHL J1746.3-2851*	contains PWN G0.13-0.11, interacts with molecular cloud??				composite?	CHANDRA	XMM				FERMI					

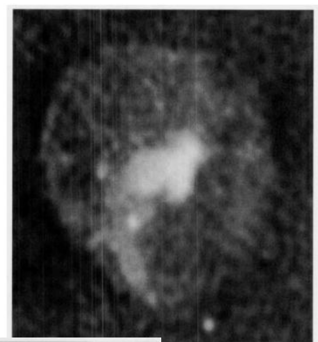
1:Radio Observations of Supernova Remnants-Evidence for GeV Electrons

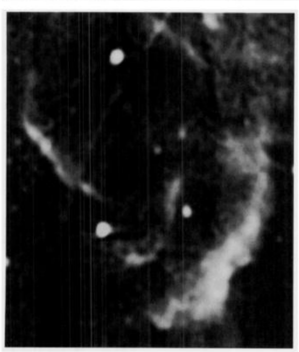
https://www.mrao.cam.ac.uk/surveys/snrs/

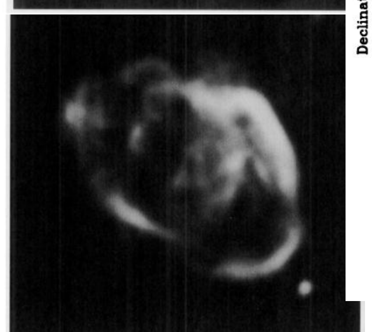
D. A. Green:"This, the 2014 May version of the catalogue, contains 294 SNRs (which is 20 more than in the previous version; 21 remnants have been added, and one object removed), with over fifteen hundred references in the detailed listings, plus notes on many possible or probable remnants. For each remnant in the catalogue the following parameters are given."

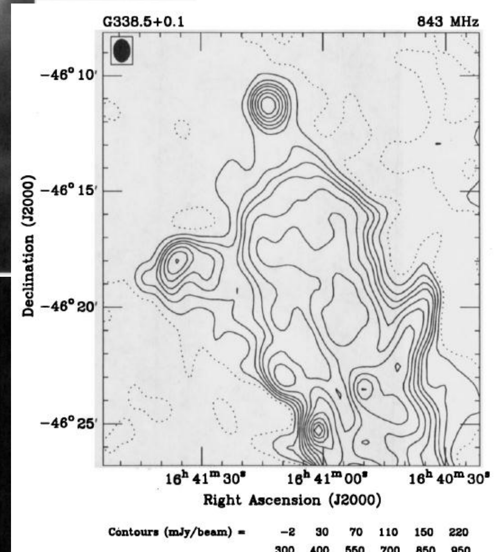


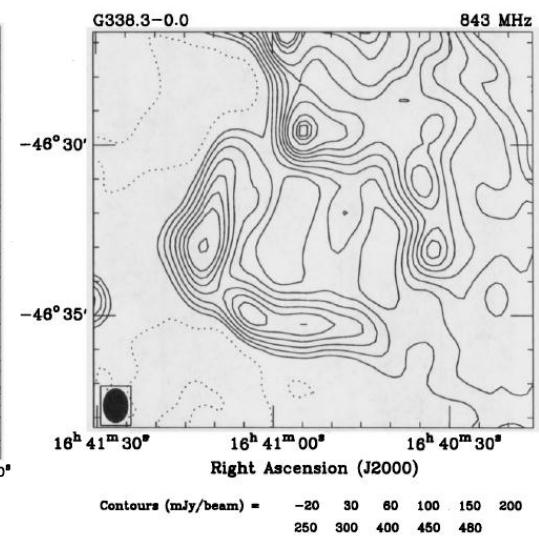












ASTRONOMY & ASTROPHYSICS SUPPLEMENT SERIES

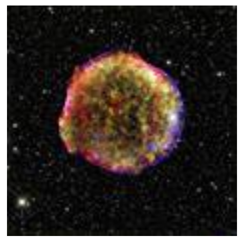
Astron. Astrophys. Suppl. Ser. **118**, 329-380 (1996)

The MOST supernova remnant catalogue (MSC)

J.B.Z. Whiteoak[1,2] and A.J. Green[2]

1:Young Supernova Remnants

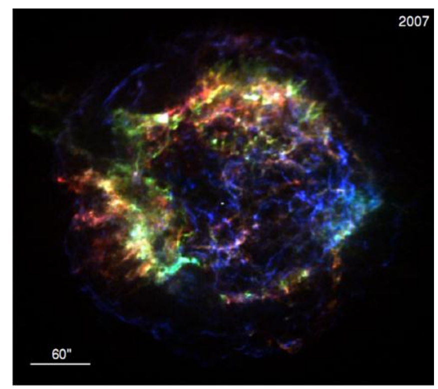
1054AD



1572AD

1604AD

1006AD



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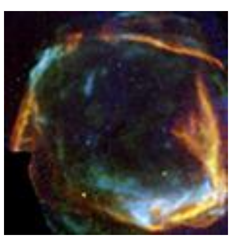

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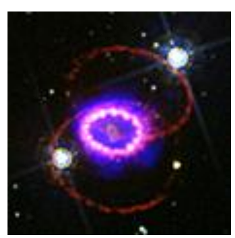

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