Particle Acceleration in Supernova Remnants (SNR)

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Outline

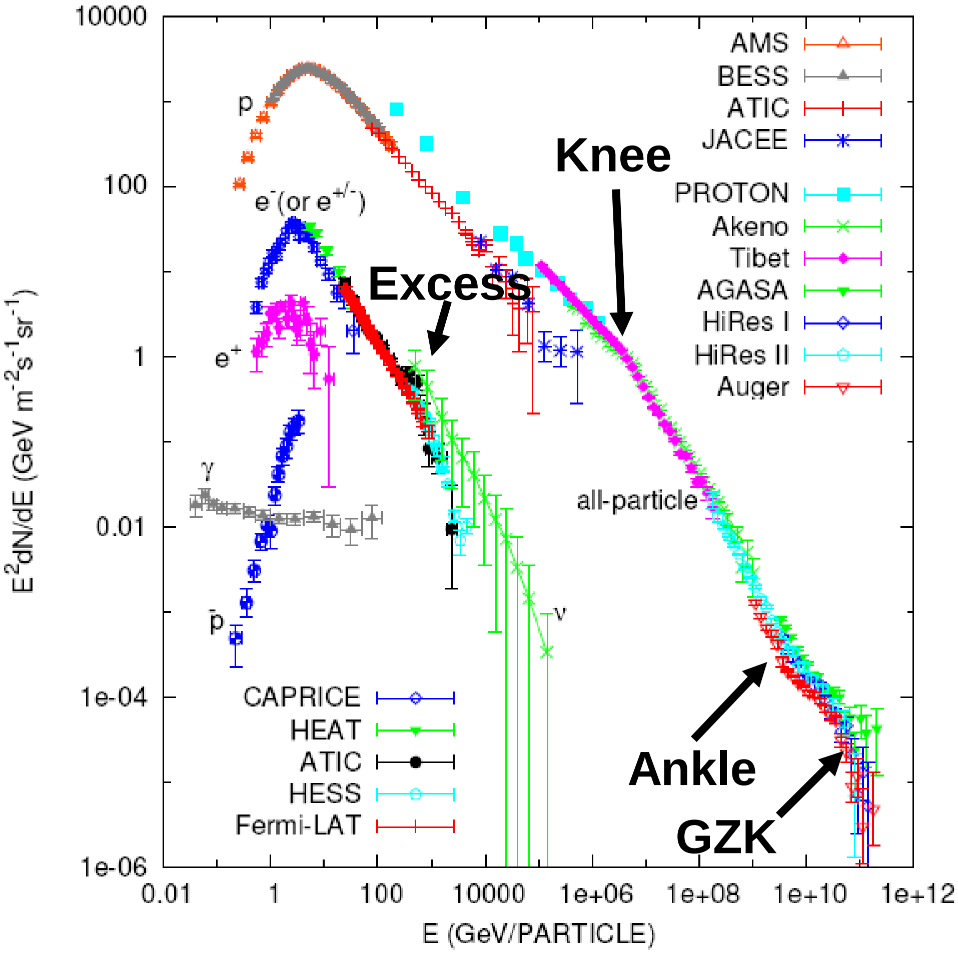
1: The SNR origin of Galactic Cosmic rays

2: A Unified Model for γ-ray emission in SNRs

3:Time-dependent Particle Acceleration in 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

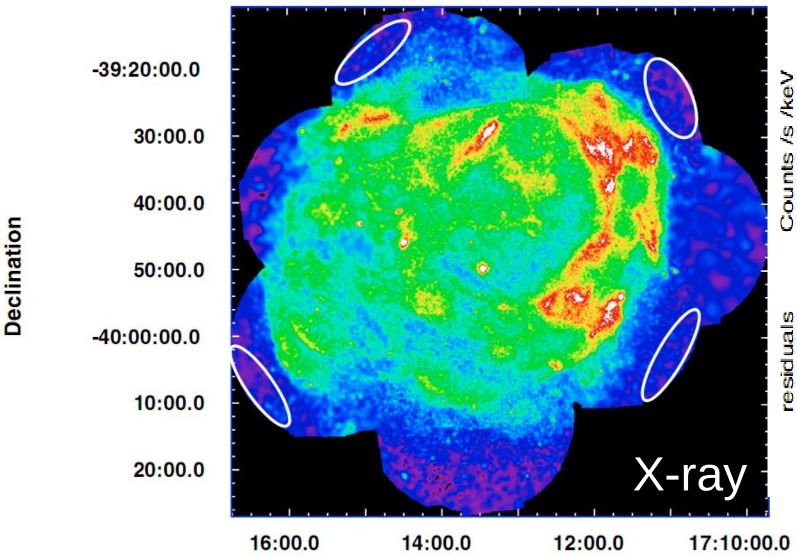
GZK Cutoff at ~ 1e20 eV

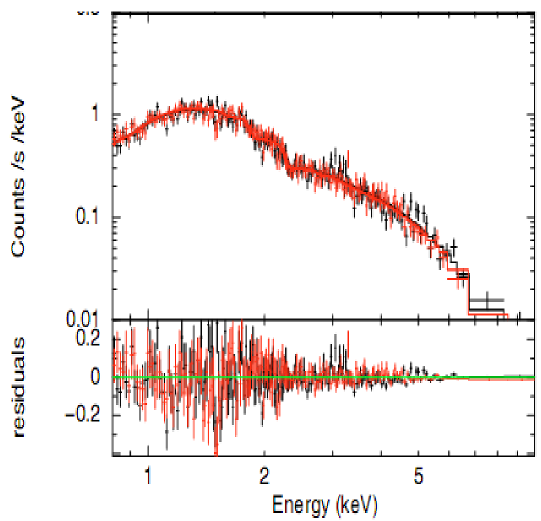
Discovered in 1912 by Victor Hess (1936 Nobel prize)

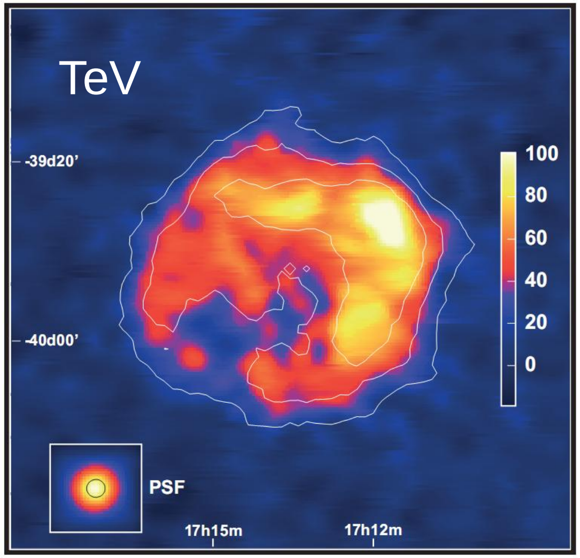
1: Shell Type TeV SNRs

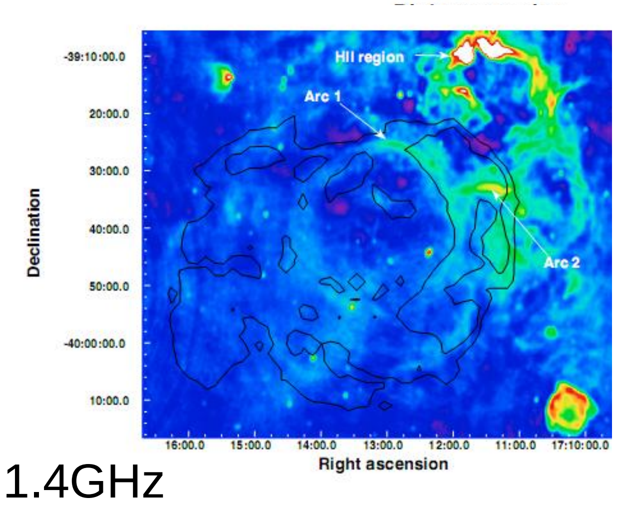
A joint spectro-imaging analysis of the *XMM-Newton* and HESS observations of the supernova remnant RX J1713.7-3946

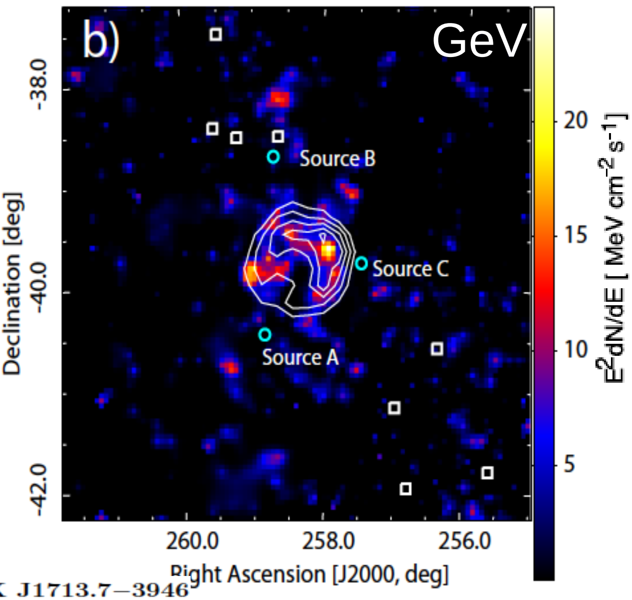
F. Acero[1], J. Ballet[1], A. Decourchelle[1], M. Lemoine-Goumard[2,3], M. Ortega[4], E. Giacani[4], G. Dubner[4], and G. Cassam-Chenaï[5]

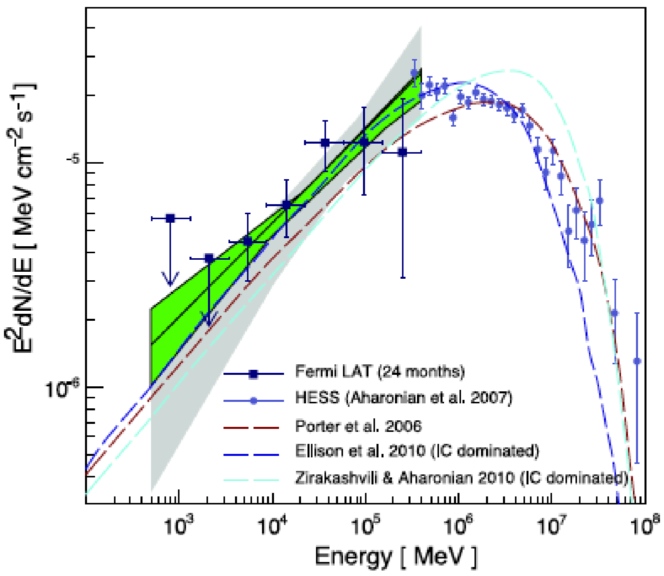












Observations of the young Supernova remnant RX J1713.7−3946 with the *Fermi* Large Area Telescope

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

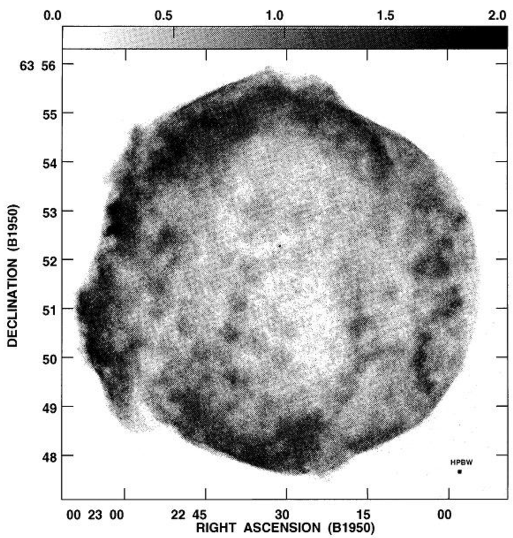
1:Most Supernova Remnants Were Observed in Radio-Evidence for GeV Electrons

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



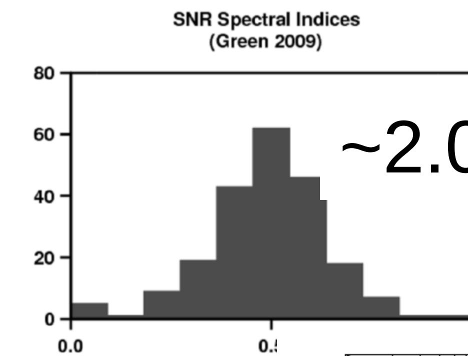
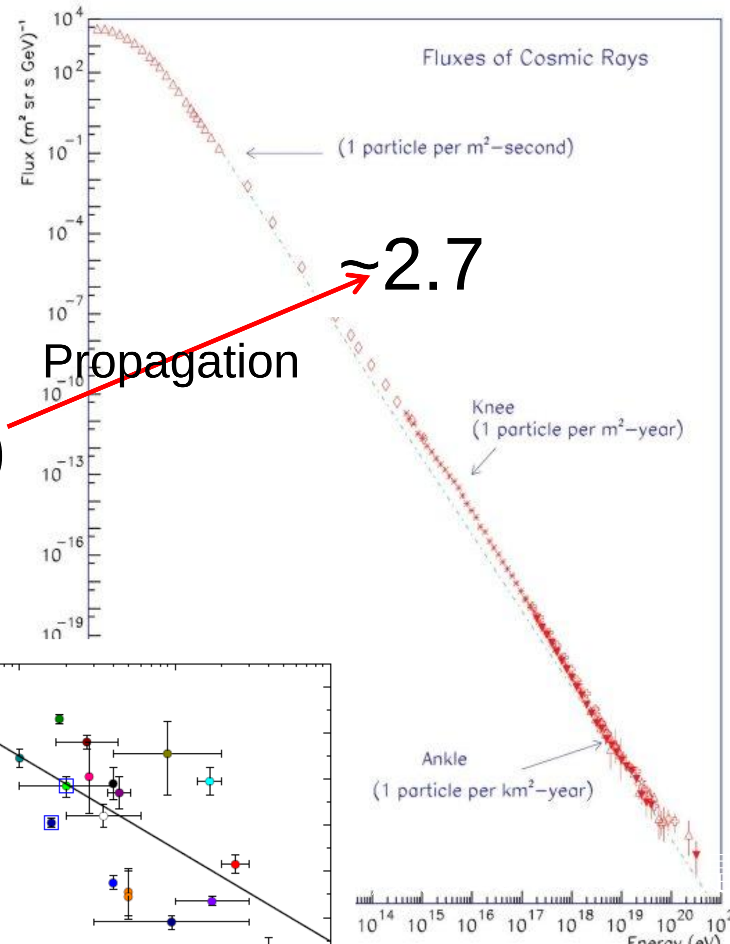
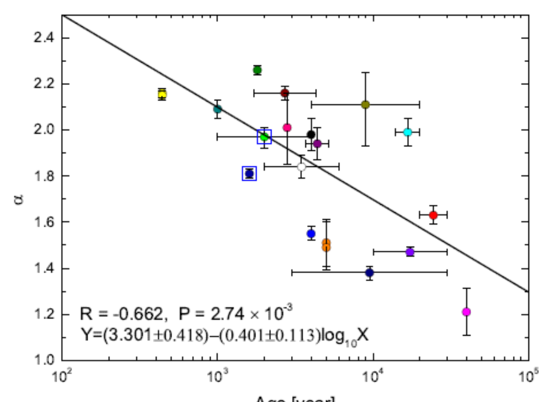


Fig. 1 Histogram of shell SNRs wit
spectral indices, from Green 2009. F



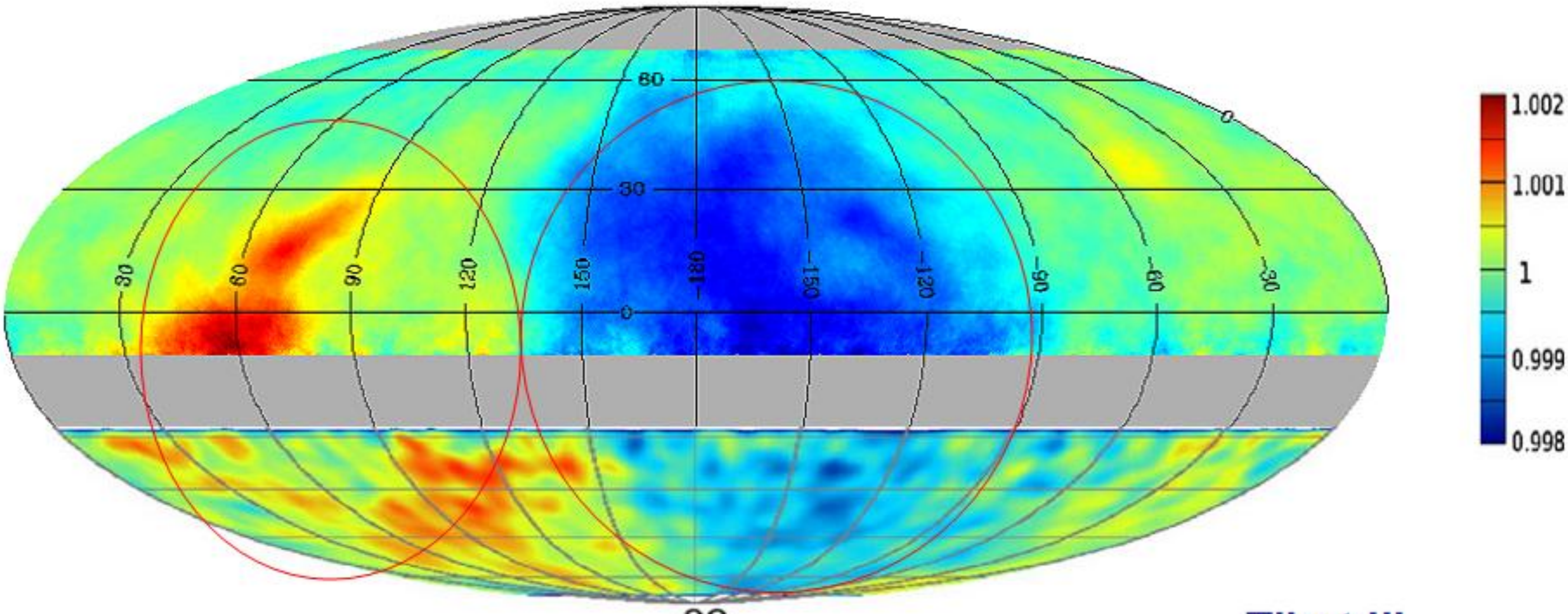


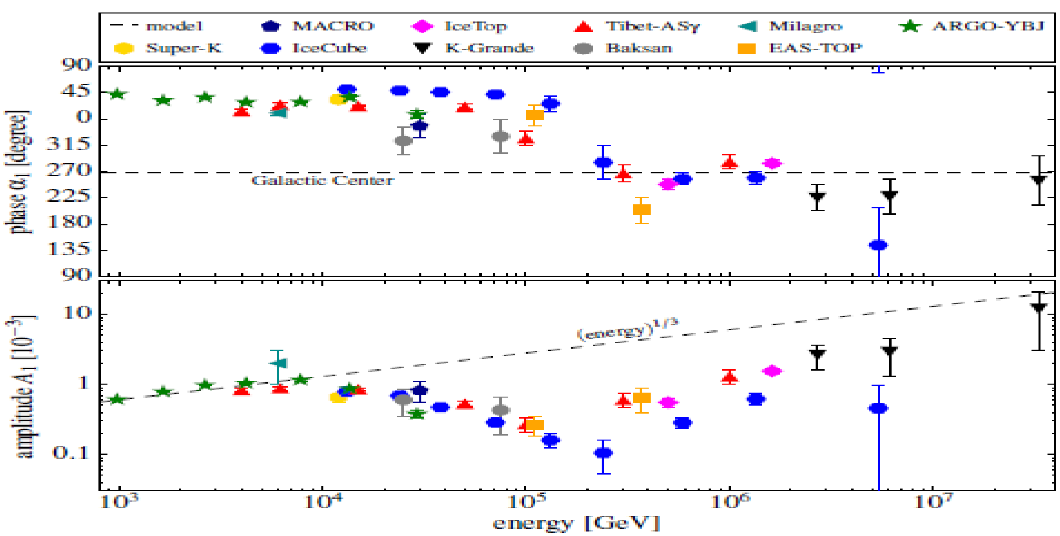
Magnetic fields in supernova remnants and puls
nebulae

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

1912

Sidereal time anisotropy in two hemisphere





Tibet III

data from 1997 to 2005

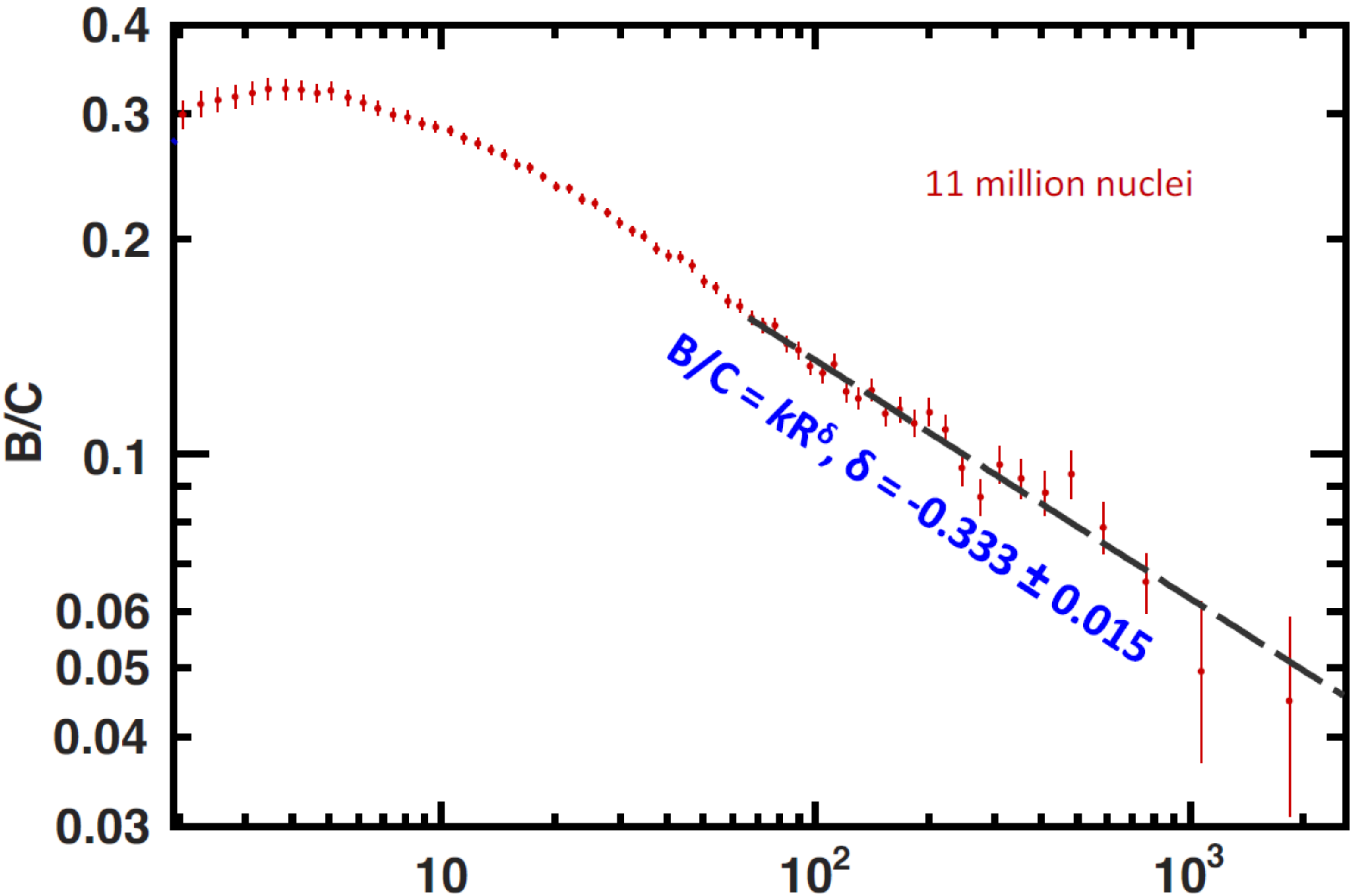
1874 days livetime

$3.7 \cdot 10^{10}$ events

angular resolution ~ 0.9°

modal CR energy ~ 3 TeV

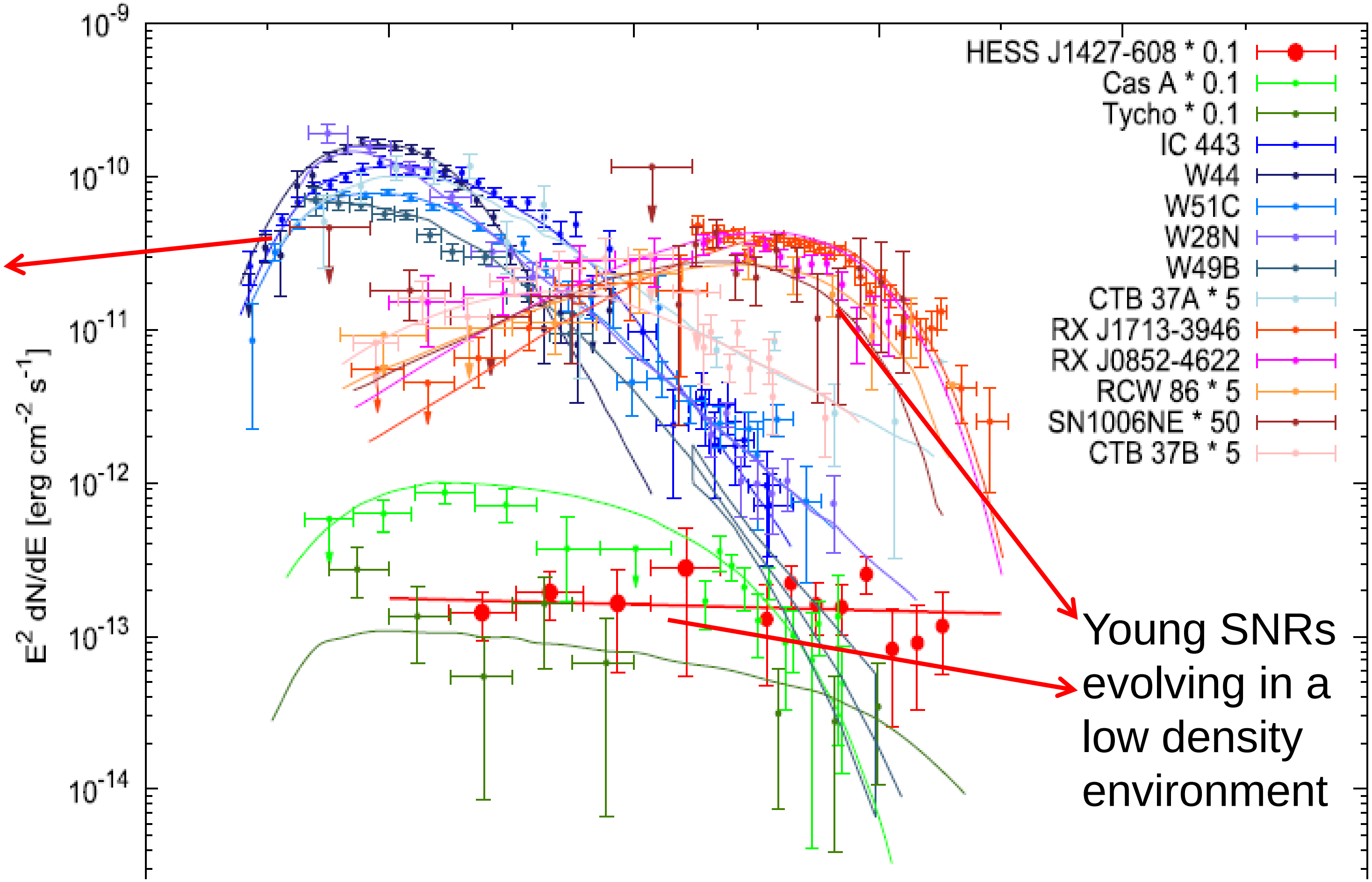
1:AMS Observations of Cosmic Rays: Propagation



M. Aguilar *et al.*, Phys. Rev. Lett. **117,** 231101 (2016)

1: Varieties of γ–ray Spectra

Old SNRs interacting with dense molecular clouds



The Astrophysical Journal, 835:42 (7pp), 2017 January 20 doi:10.3847/1538-4357/835/1/42

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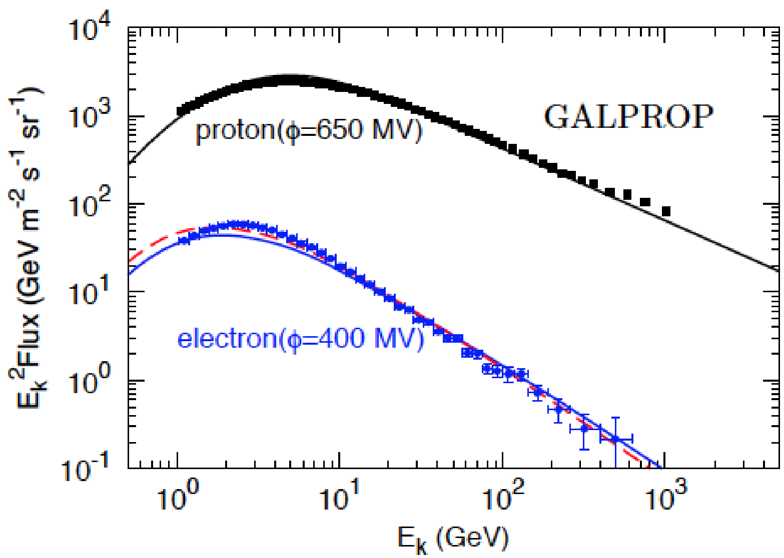
HESS J1427−608: AN UNUSUAL HARD, UNBROKEN γ-RAY SPECTRUM IN A VERY WIDE ENERGY RANGE

Xiao-Lei Guo[1,2], Yu-Liang Xin[2,3], Neng-Hui Liao[2], Qiang Yuan[2], Wei-Hong Gao[1],
Hao-Ning He[2], Yi-Zhong Fan[2], and Si-Ming Liu[2]

2: A Unified Model for γ–ray emission in SNRs

Modeling of Cosmic Ray Spectra

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



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

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

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

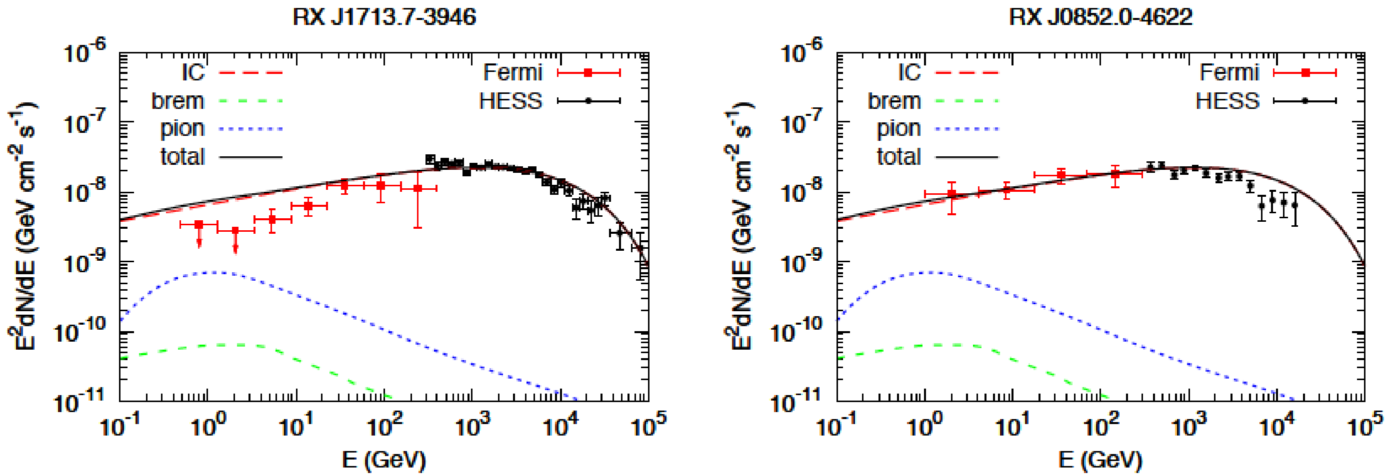
The Astrophysical Journal, 761:133 (7pp), 2012 December 20 doi:10.1088/0004-637X/761/2/133

AN ATTEMPT AT A UNIFIED MODEL FOR THE GAMMA-RAY EMISSION OF SUPERNOVA REMNANTS

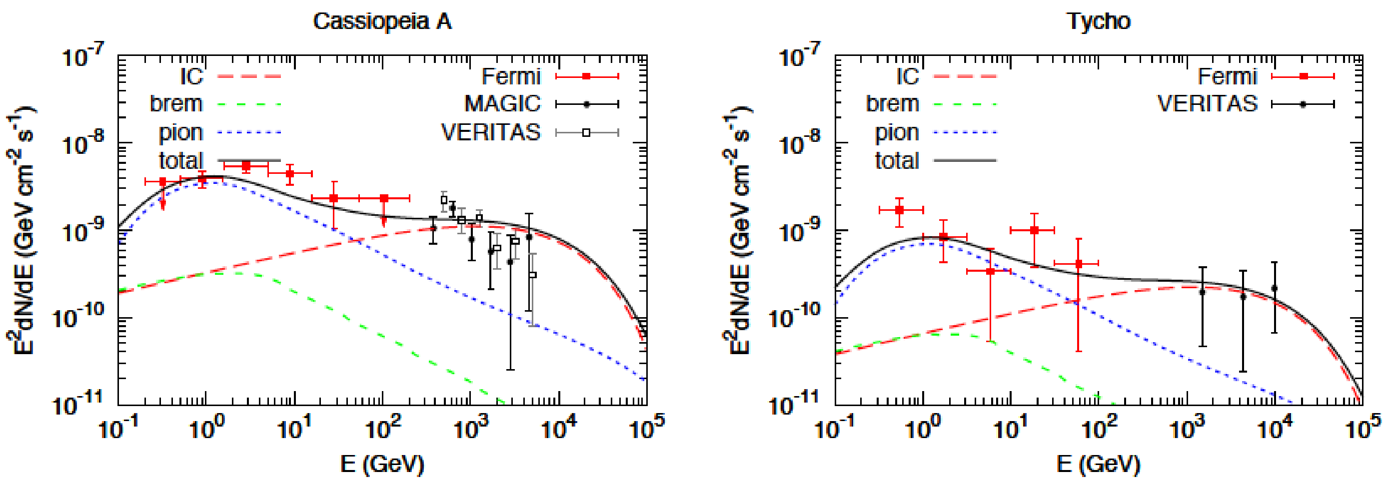
Qiang Yuan[1], Siming Liu[2], and Xiaojun Bi[1]

2: Modeling of Gamma-ray Spectra

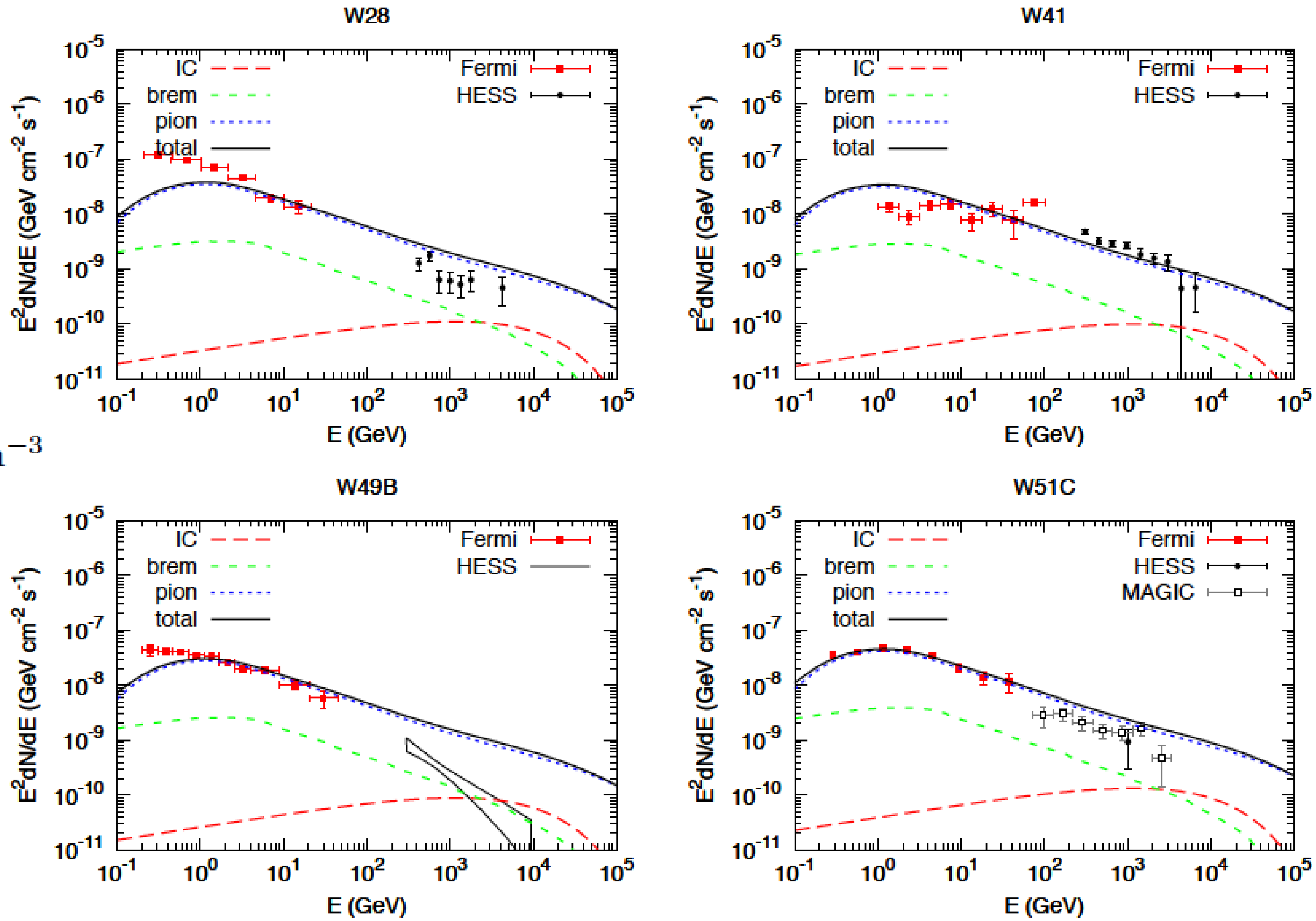
$n = 0.01\ \mathrm{cm}^{-3}$



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

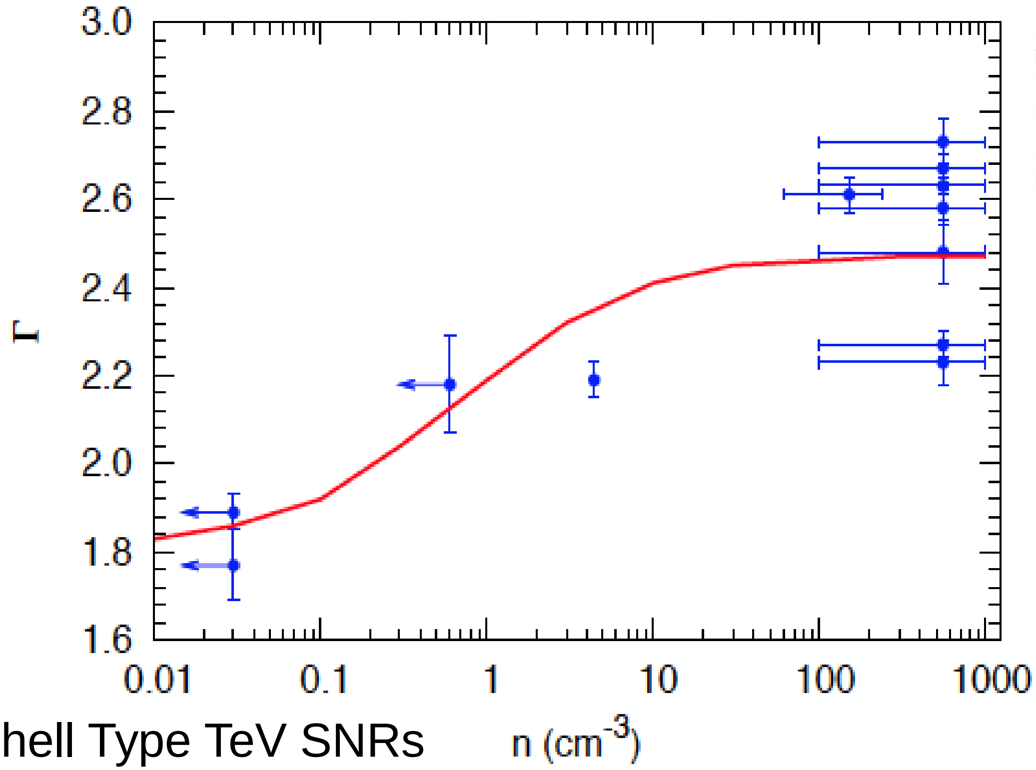


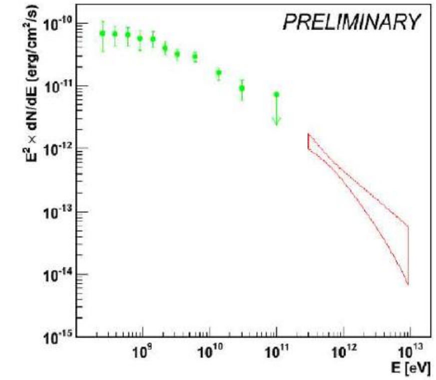
2: Modeling of Gamma-ray Spectra



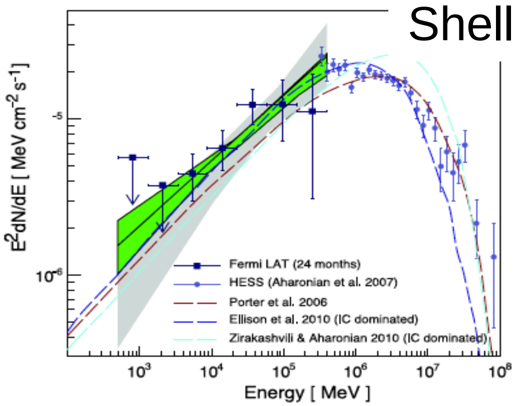
$\bar{n} = 100\ \mathrm{cm}^{-3}$

2: Summary

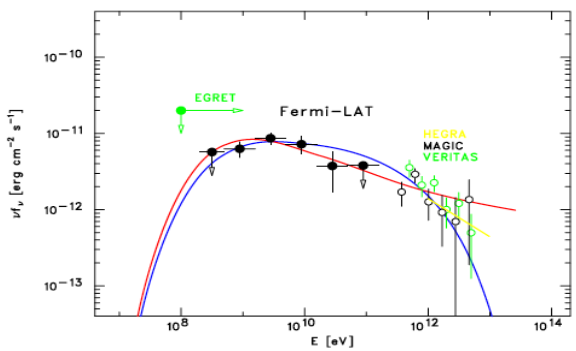




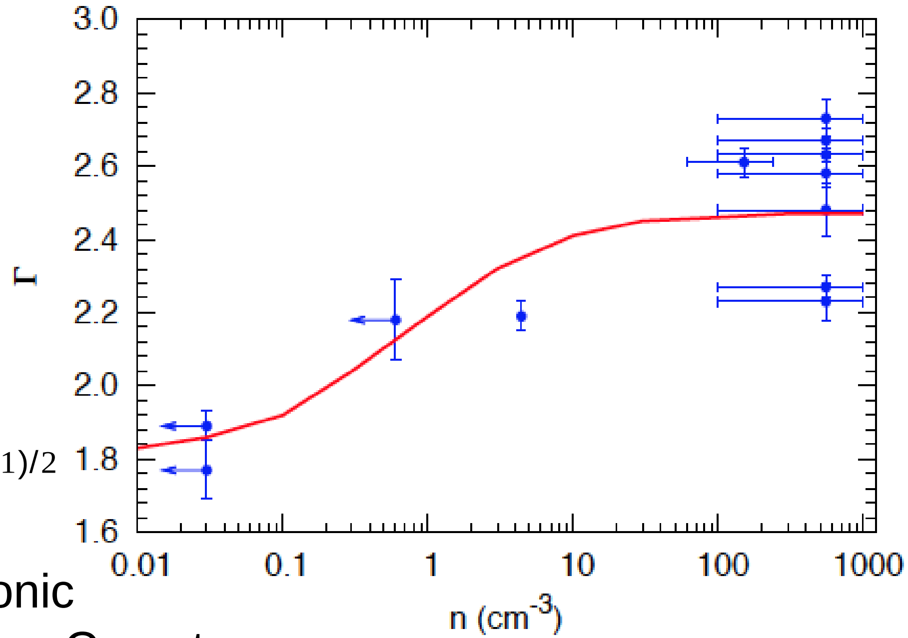
Older remnants interacting with molecular clouds



Shell Type TeV SNRs



2: Modeling of Gamma-ray Spectra

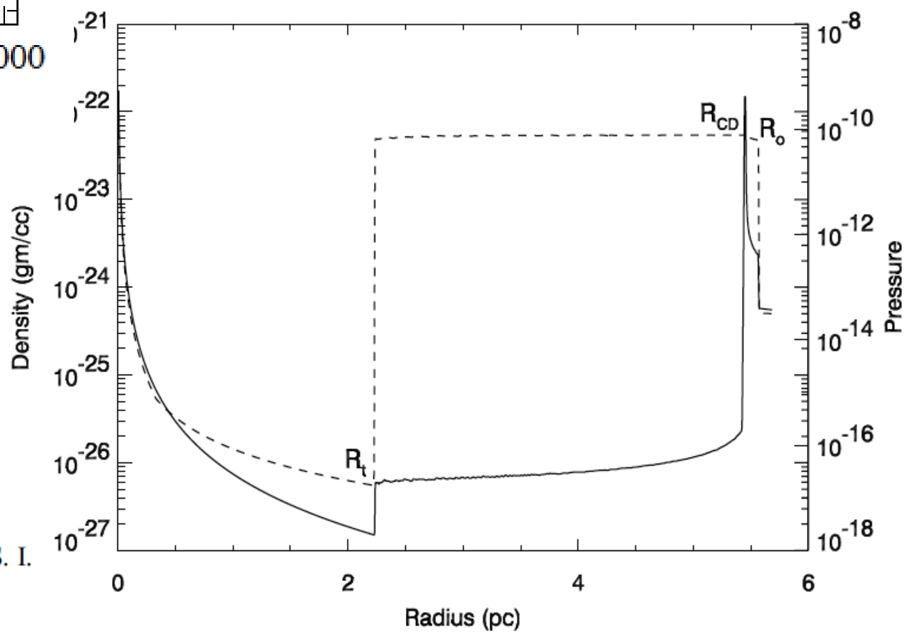


$(alpha + 1)/2$

$alpha = 2.52$

Hadrnic
pp scattering

Leptonic
Inverse Compton



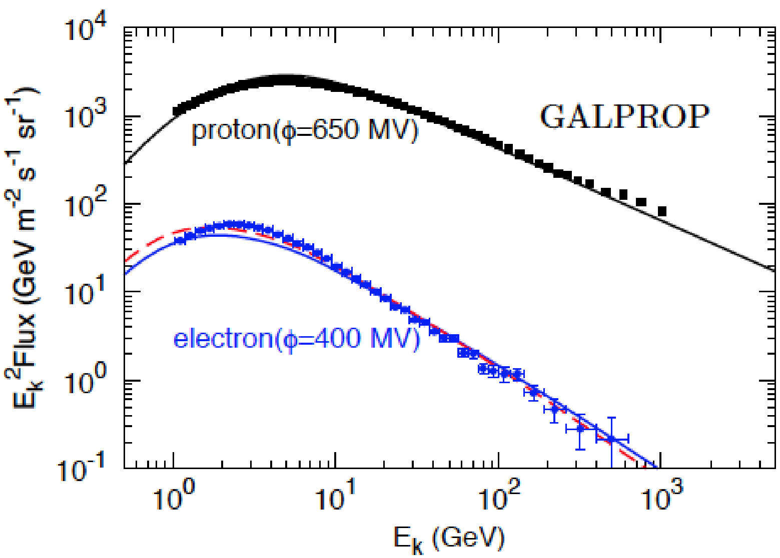
THE EVOLUTION OF SUPERNOVAE IN CIRCUMSTELLAR WIND-BLOWN BUBBLES. I. INTRODUCTION AND ONE-DIMENSIONAL CALCULATIONS

VIKRAM V. DWARKADAS

2: A Unified Model for γ–ray emission in SNRs

Modeling of Cosmic Ray Spectra

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



Consistent with γ–ray

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

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

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

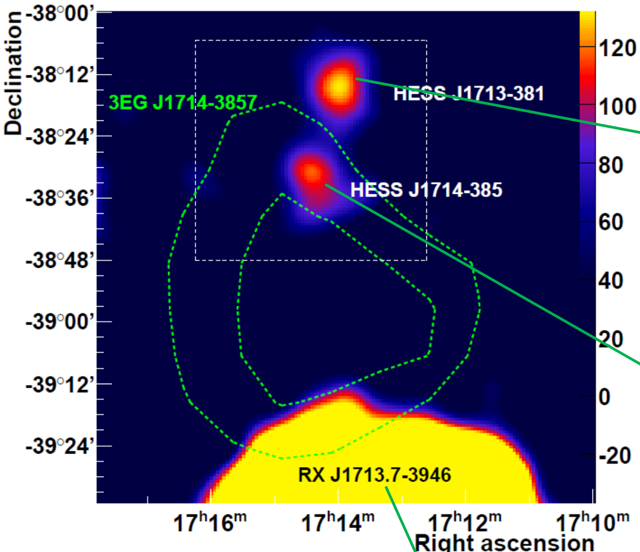
Consistent with Radio

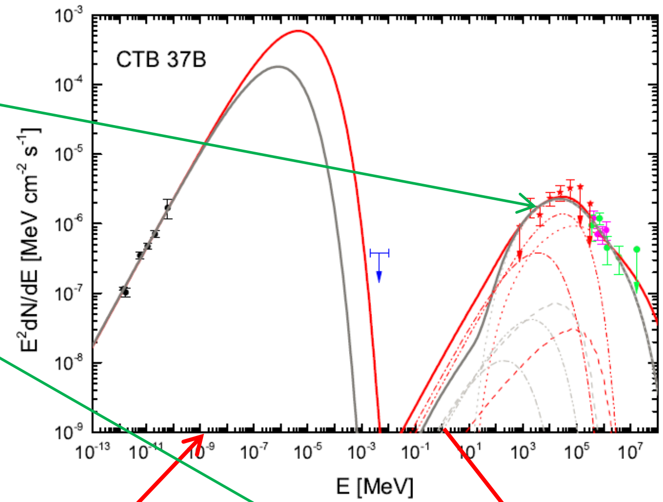
The Astrophysical Journal, 761:133 (7pp), 2012 December 20
doi:10.1088/0004-637X/761/2/133

AN ATTEMPT AT A UNIFIED MODEL FOR THE GAMMA-RAY EMISSION OF SUPERNOVA REMNANTS

Qiang Yuan[1], Siming Liu[2], and Xiaojun Bi[1]

3:Evolution of Particle Distribution in SNRs

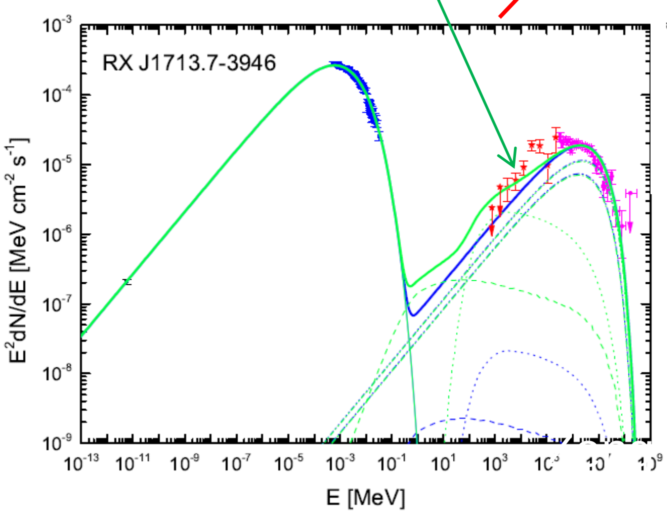


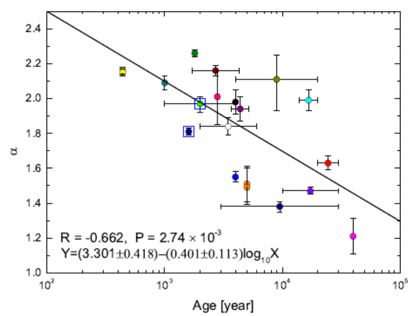


CTB 37B:
~5000 Years
Ebr~400GeV
Both IC and pp
contribute to γ-rays

CTB 37A:
>10000 Years
Ebr~2GeV

RX J1713.7-3946
1600 Years Ebr~1TeV
IC dominates γ-rays





ICAL JOURNAL, 834:153 (9pp), 2017

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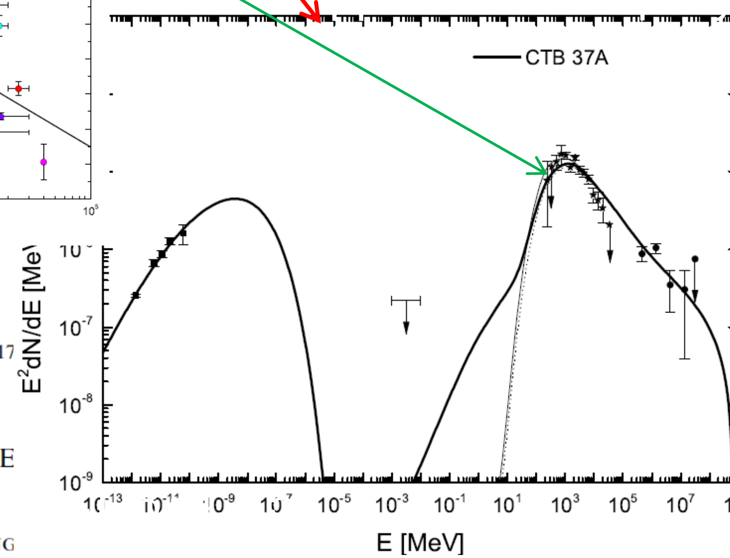
EVOLUTION OF HIGH-E

HOUDUN ZENG[1,2], YULIANG



357/834/2

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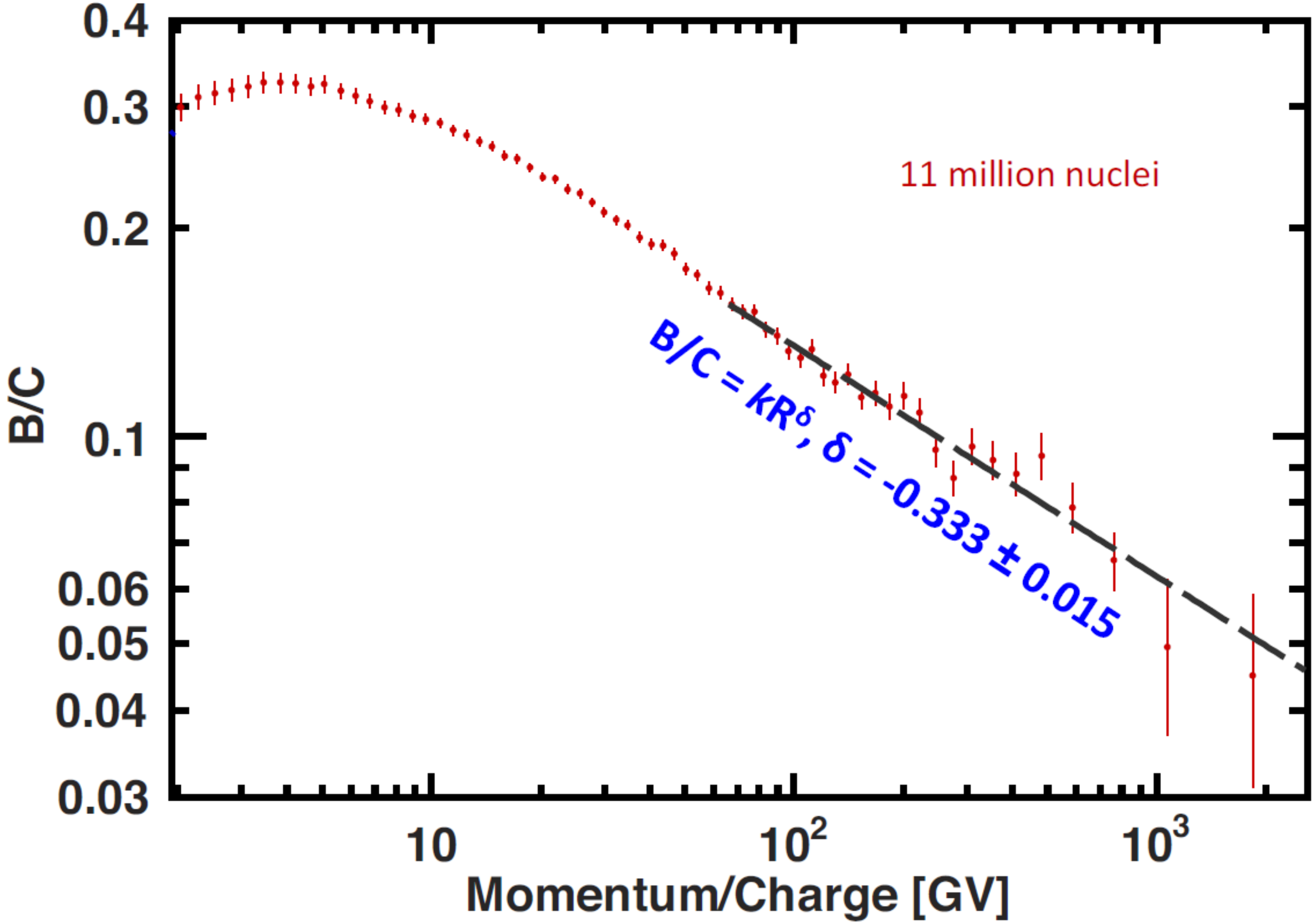
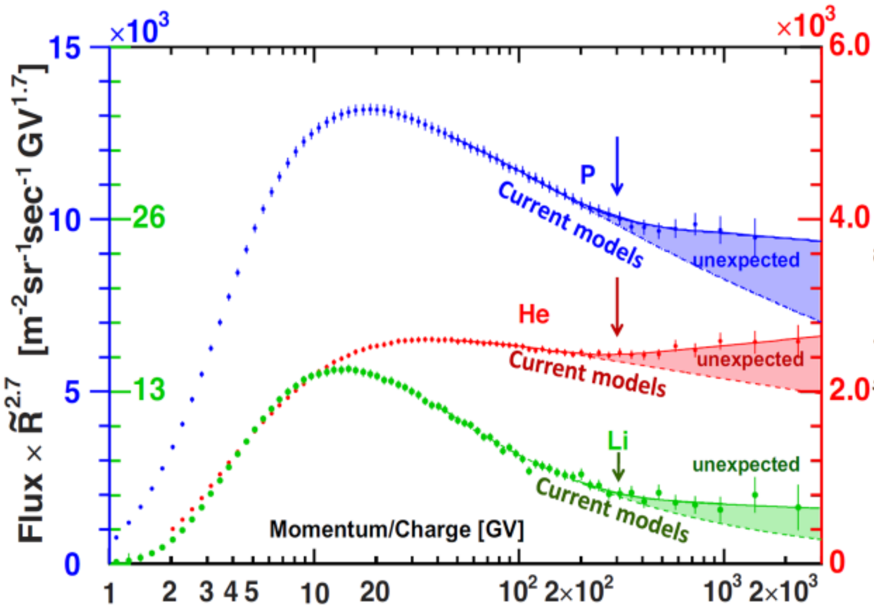
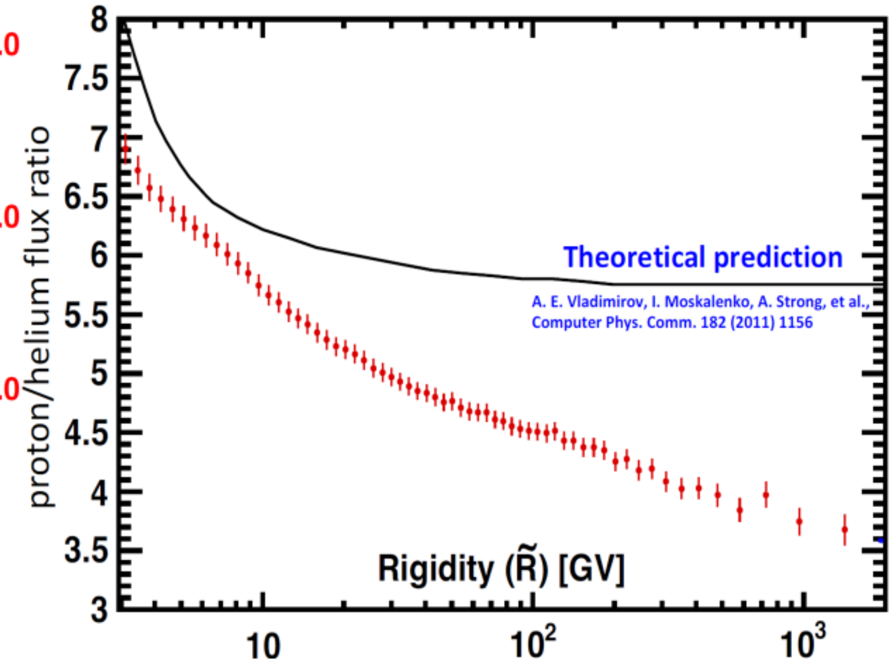
3:AMS Observations of Cosmic Rays: Propagation



M. Aguilar *et al.*, Phys. Rev. Lett. **117,** 231101 (2016)

3:AMS observations of cosmic rays: anomalies
1) spectral hardening above 200GV
2) helium spectrum harder than proton spectrum





3:Time-Dependent Particle Acceleration:

Injection makes proton softer than He

$$\frac{\partial f}{\partial t} - \frac{\partial u}{\partial x}\frac{p}{3}\frac{\partial f}{\partial p} + u\frac{\partial f}{\partial x} = \frac{\partial}{\partial x}\left(\kappa\frac{\partial f}{\partial x}\right) + Q,$$

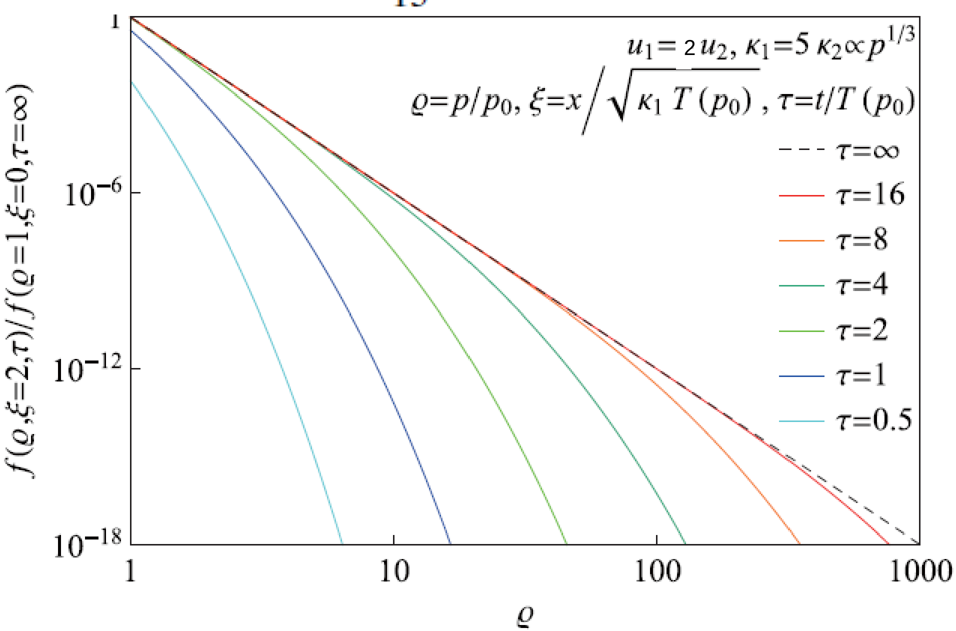
$$u(x,t) = u_1 + (u_2 - u_1)H(x),$$

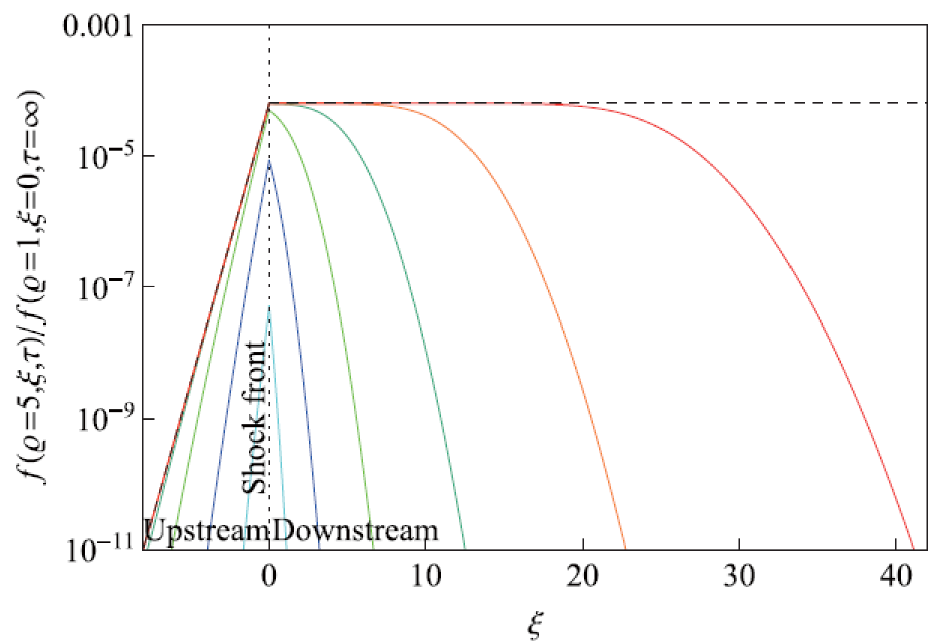
$$\kappa(p,x,t) = \kappa_1(p) + [\kappa_2(p) - \kappa_1(p)]H(x),$$

$$p^2 Q(p,x,t) = Q_0\delta(p-p_0)\delta(x)H(t).$$

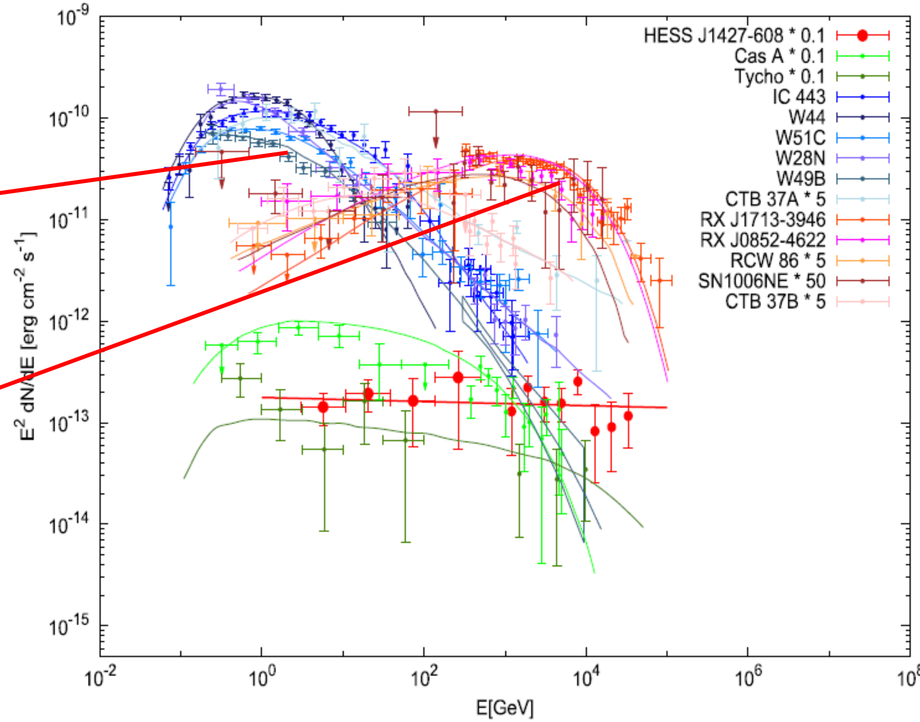
$$T(p) = \frac{4}{u_1 - u_2}\left[\frac{\kappa_1(p)}{u_1} + \frac{\kappa_2(p)}{u_2}\right].$$

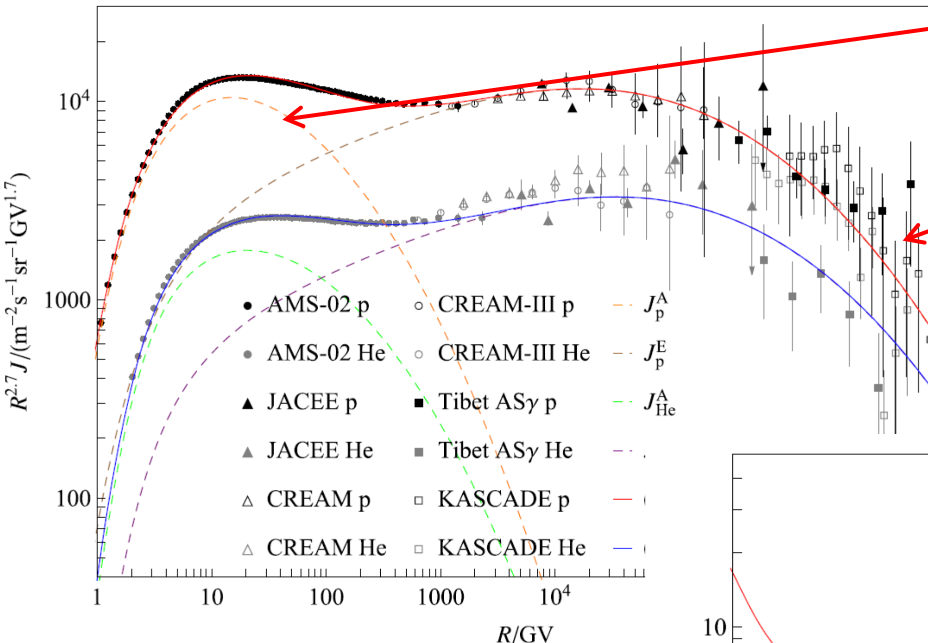
$$(R_0)^{\mathrm{E}}_{\mathrm{He}} = 2(R_0)^{\mathrm{E}}_{\mathrm{p}} \approx \frac{0.938}{15}\ \mathrm{GV}.$$

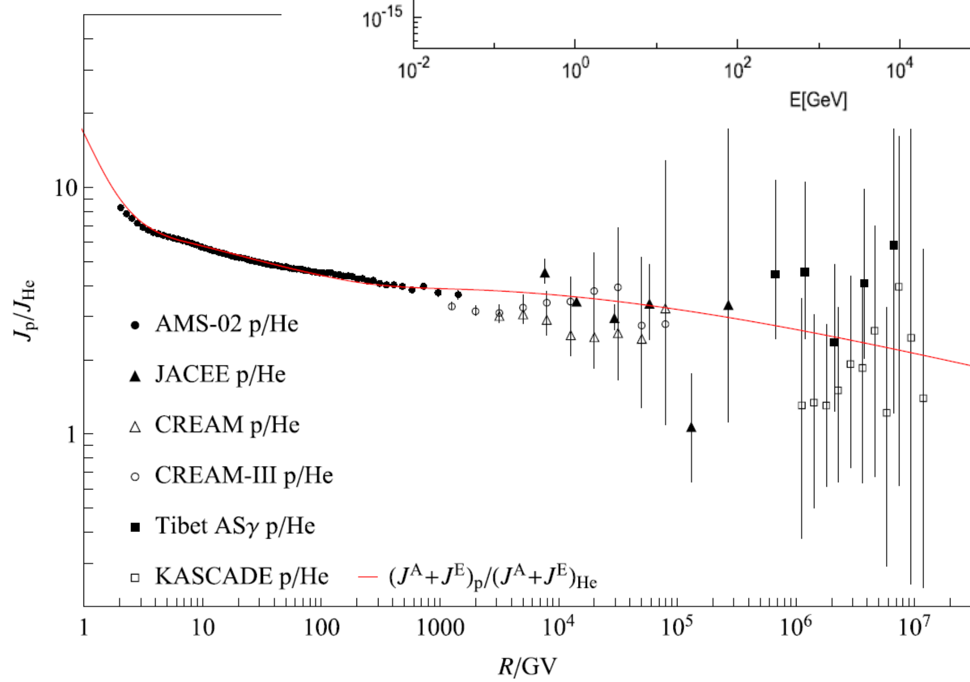




3:Time-Dependent Particle Acceleration in SNRs







3:Two Stages of Time-Dependent Particle Distribution in SNRs

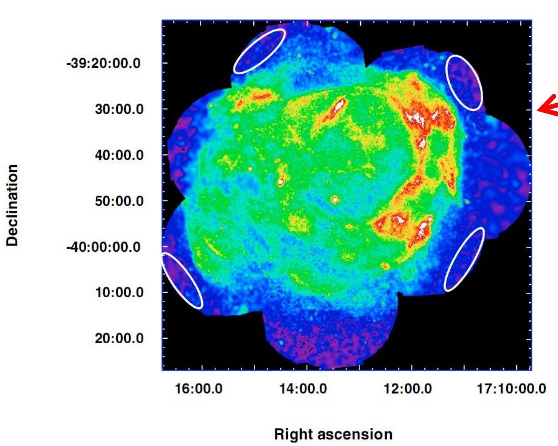
Early $$T_S^E \sim \text{kyr}, \;\; L_S^E = (T_S u_1)^E \sim 5\left(\frac{u_1^{\,E}}{5 \times 10^8 \text{ cm s}^{-1}}\right) \text{pc},$$

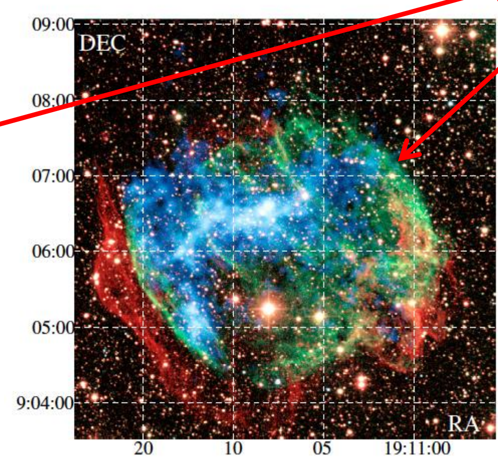
Advanced $$T_S^A \sim 100 \text{ kyr}, \;\; L_S^A = (T_S u_1)^A \sim 50\left(\frac{u_1^{\,A}}{5 \times 10^7 \text{ cm s}^{-1}}\right) \text{pc},$$

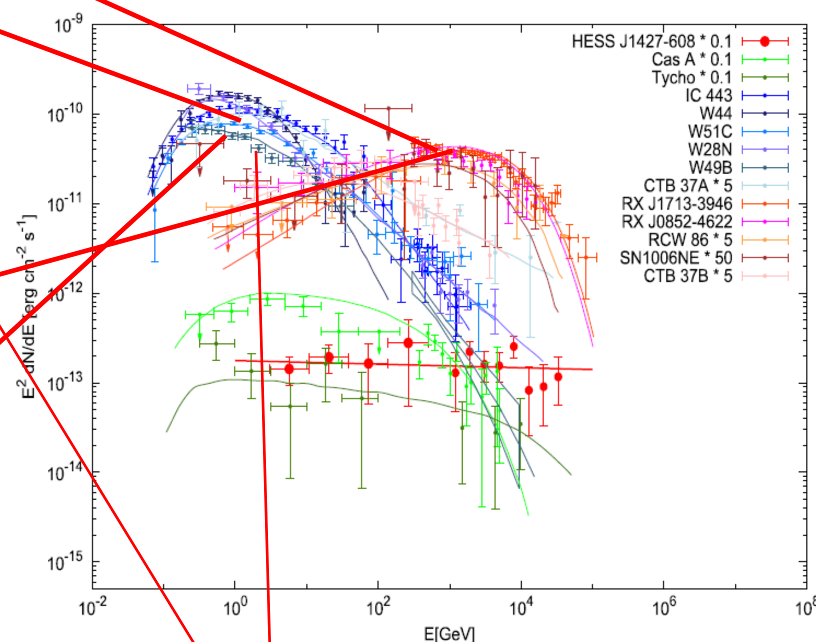
Injection in Early Stage: $(R_0)^E_{He} = 2(R_0)^E_p \approx \frac{0.938}{15}$ GV.

Table 1
Fitting Parameters

$\frac{\kappa_1}{\kappa_2}$	τ_S^E	τ_S^A	$\frac{(Q_0)_p^E}{(Q_0)_{He}^E}$	$\frac{(Q_0)_p^A}{(Q_0)_{He}^A}$	$\frac{(Q_0)_p^E}{(Q_0)_p^A}\left(\frac{10u_1^A}{u_1^E}\right)^2$
1	9.0	4.7	9.1	18.5	0.2
16	10.7	6.3	9.0	17.7	0.3







Dominant CR production

Conclusions

单幂律:

最简单的模型

不能解释伽玛能谱和宇宙线各向异性、 能谱反常

双幂律:

定性解释伽玛能谱和宇宙线各项异性

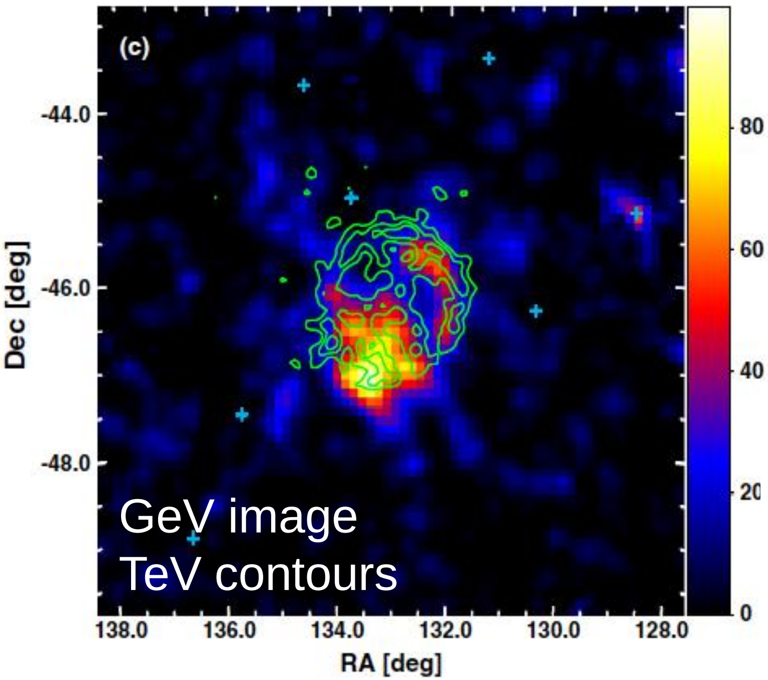
不能解释能谱反常

两个阶段的含时解(双幂律):

定性解释伽玛能谱、定量解释p/He谱、能谱上翘、膝

随时间演化的粒子加速？

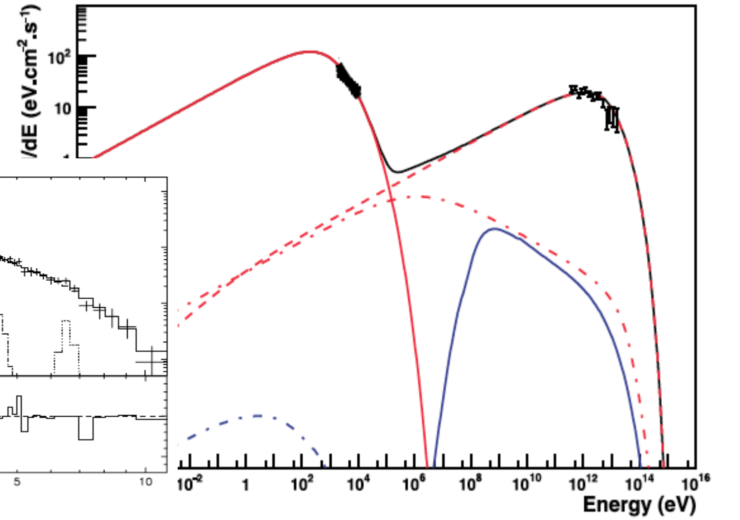
定量解释多波段观测？

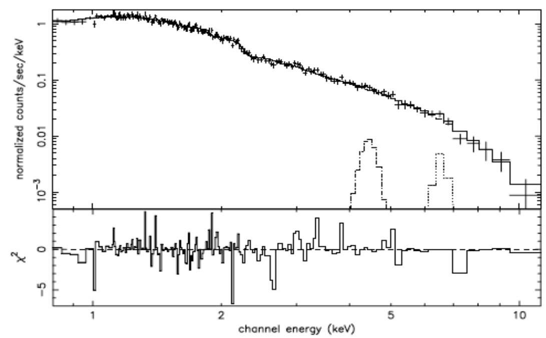


The Astrophysical Journal Letters, 740:L51 (5pp), 2011 October 20
doi:10.1088/2041-8205/7

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

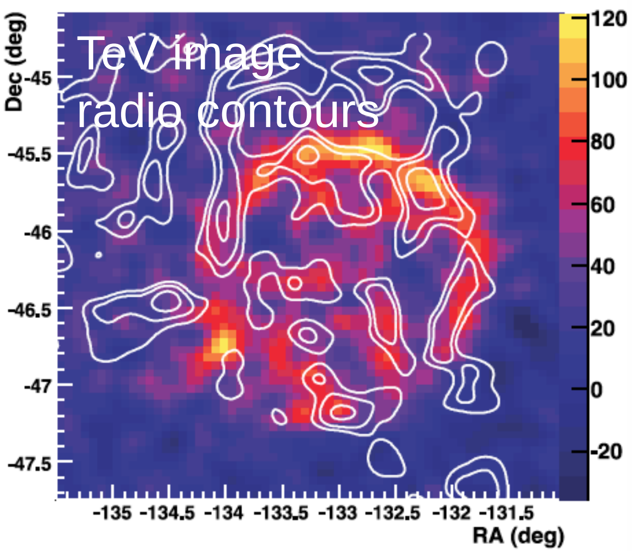
T. Tanaka[1], A. Allafort[1], J. Ballet[2], S. Funk[1], F. Giordano[3,4], J. Hewitt[5], M. Lemoine-Goumard[6,9], H. Tajima[1,7], O. Tibolla[8], and Y. Uchiyama[1]

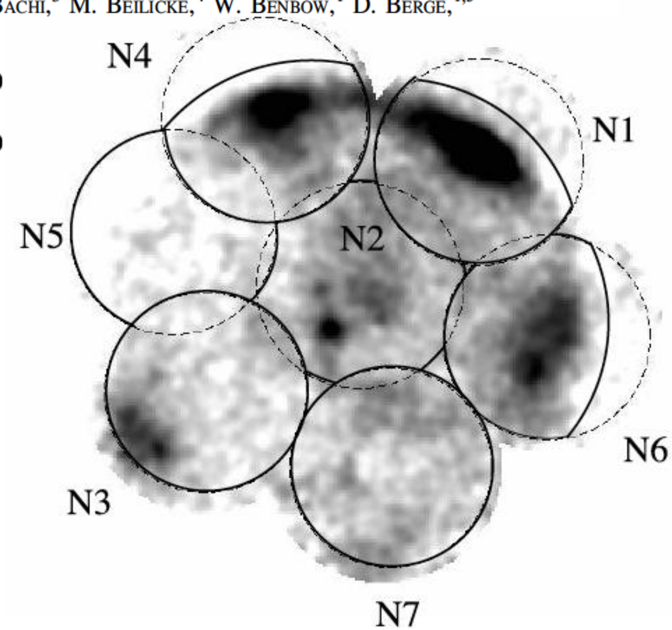


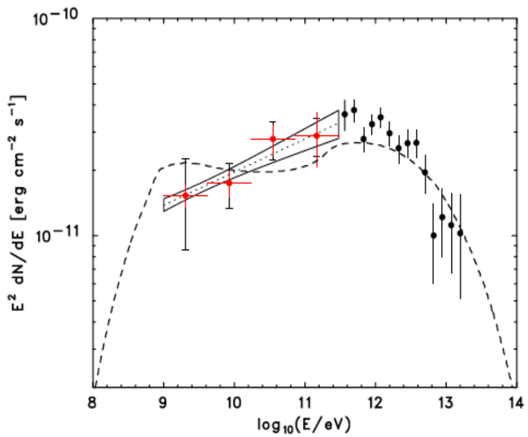


H.E.S.S. OBSERVATIONS OF THE SUPERNOVA REMNANT RX J085
AND SPECTRUM OF A WIDELY EXTENDED VERY HIGH E

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

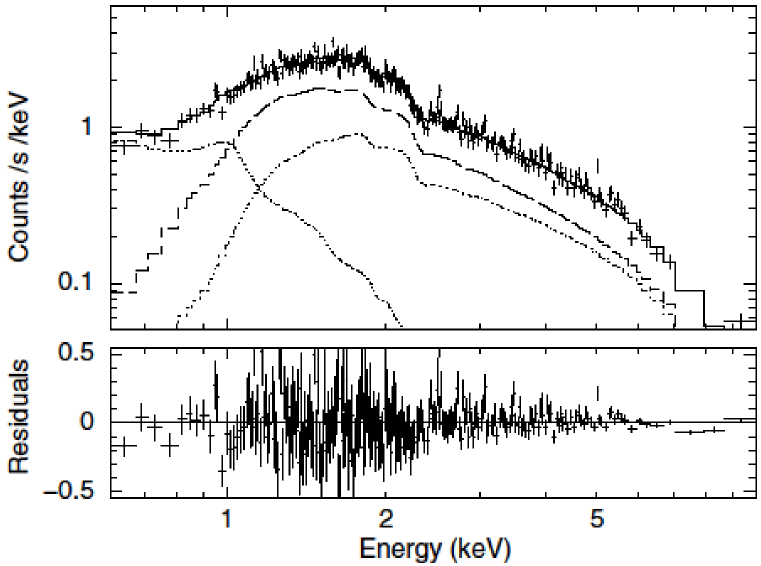


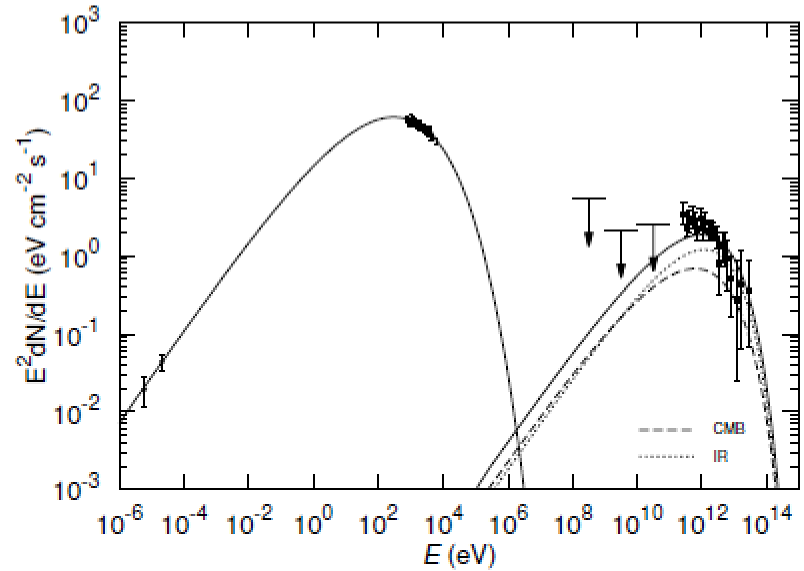


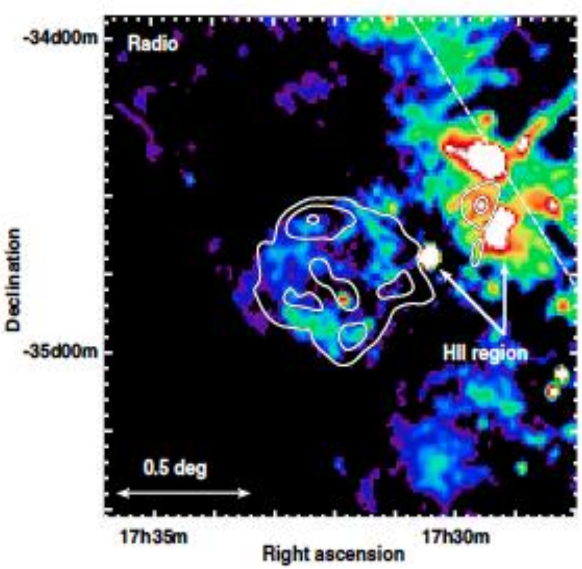


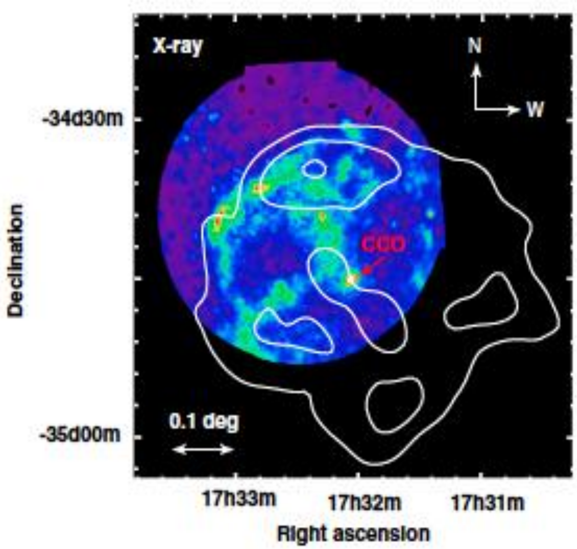
A new SNR with TeV shell-type morphology: HESS J1731-347

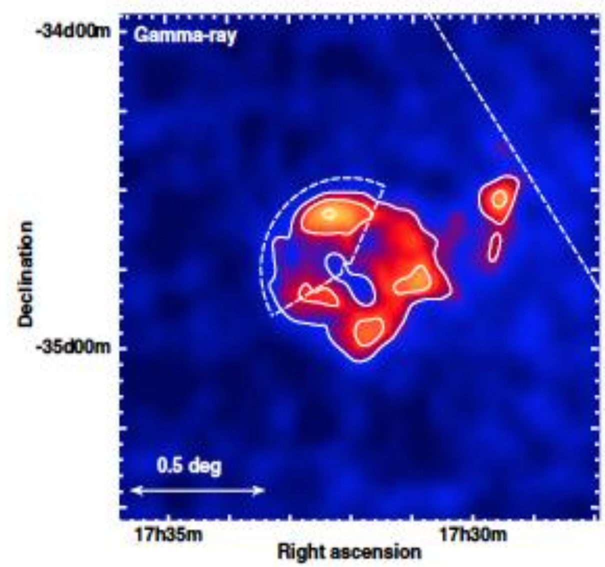
HESS Collaboration, A. Abramowski[1], F. Acero[2], F. Aharonian[3,4,5], A. G. Akhperjanian[6,5], G. Anton[7], A. Balzer[7],



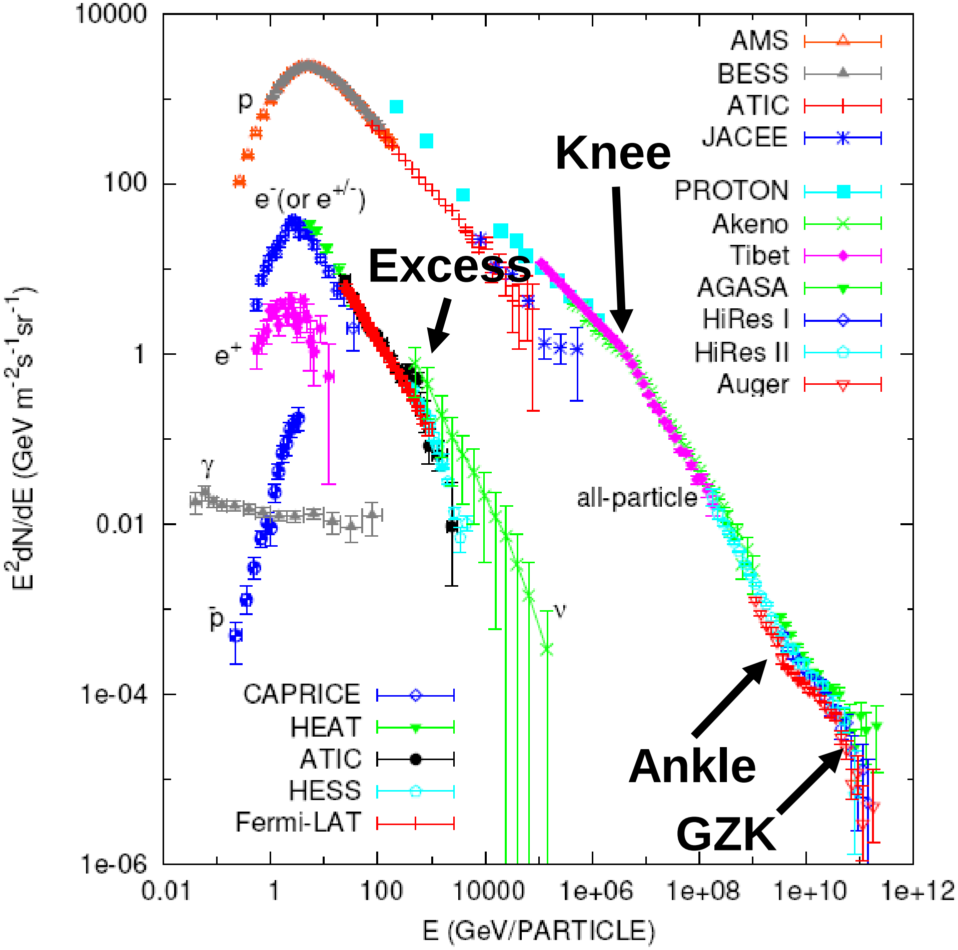


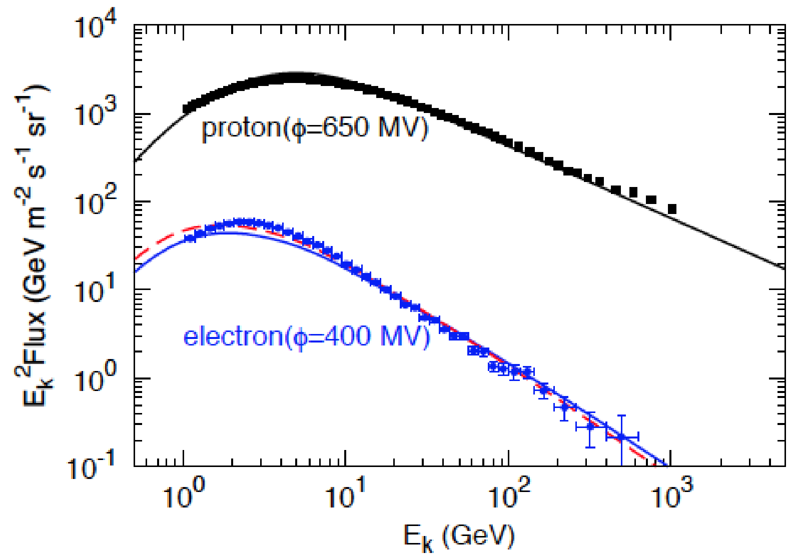






2: Cosmic Rays





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

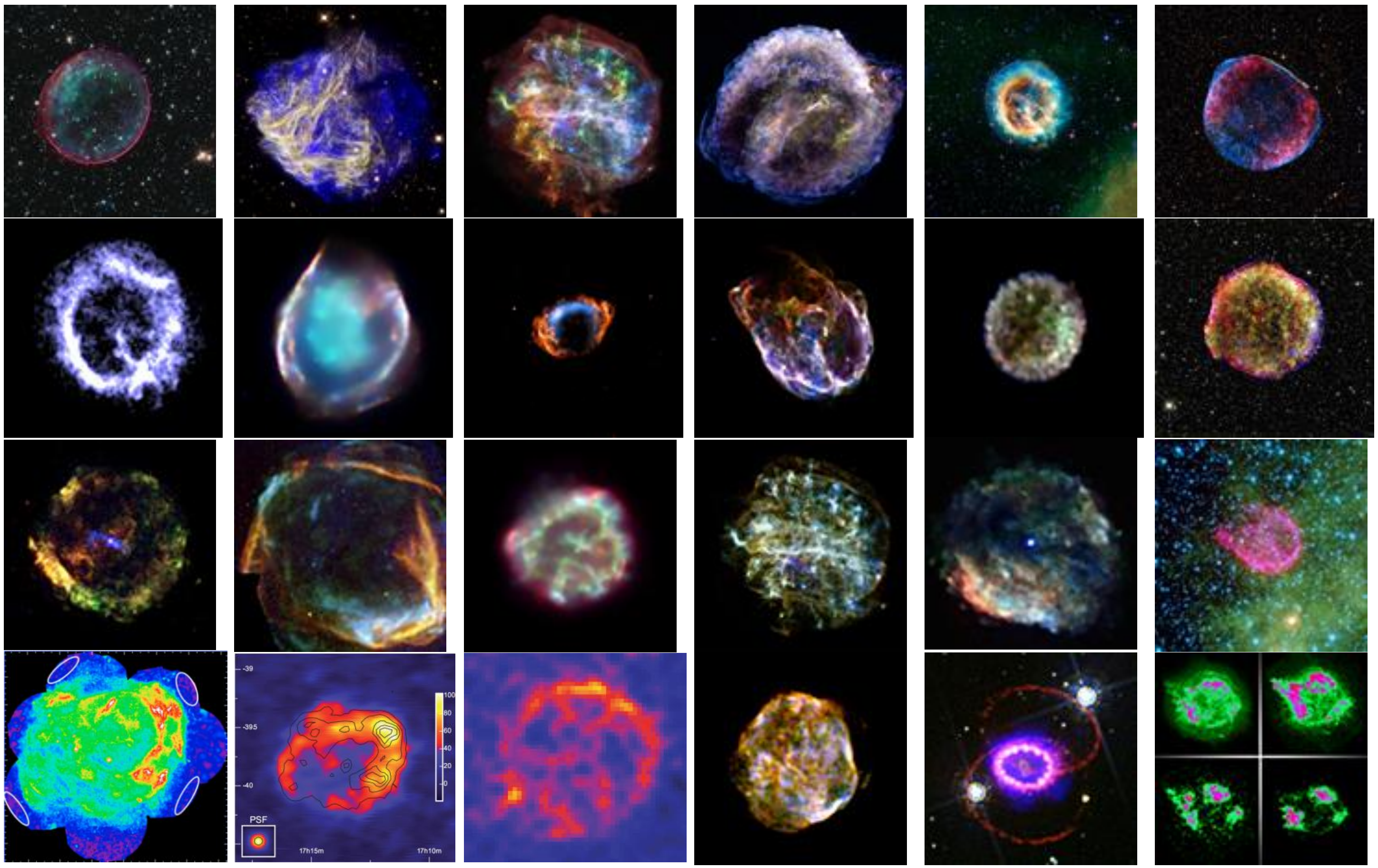
1: 3D MHD Simulations to Study Source structure

2: Multi-wavelength spectral fit

3: Evolution of SNRs

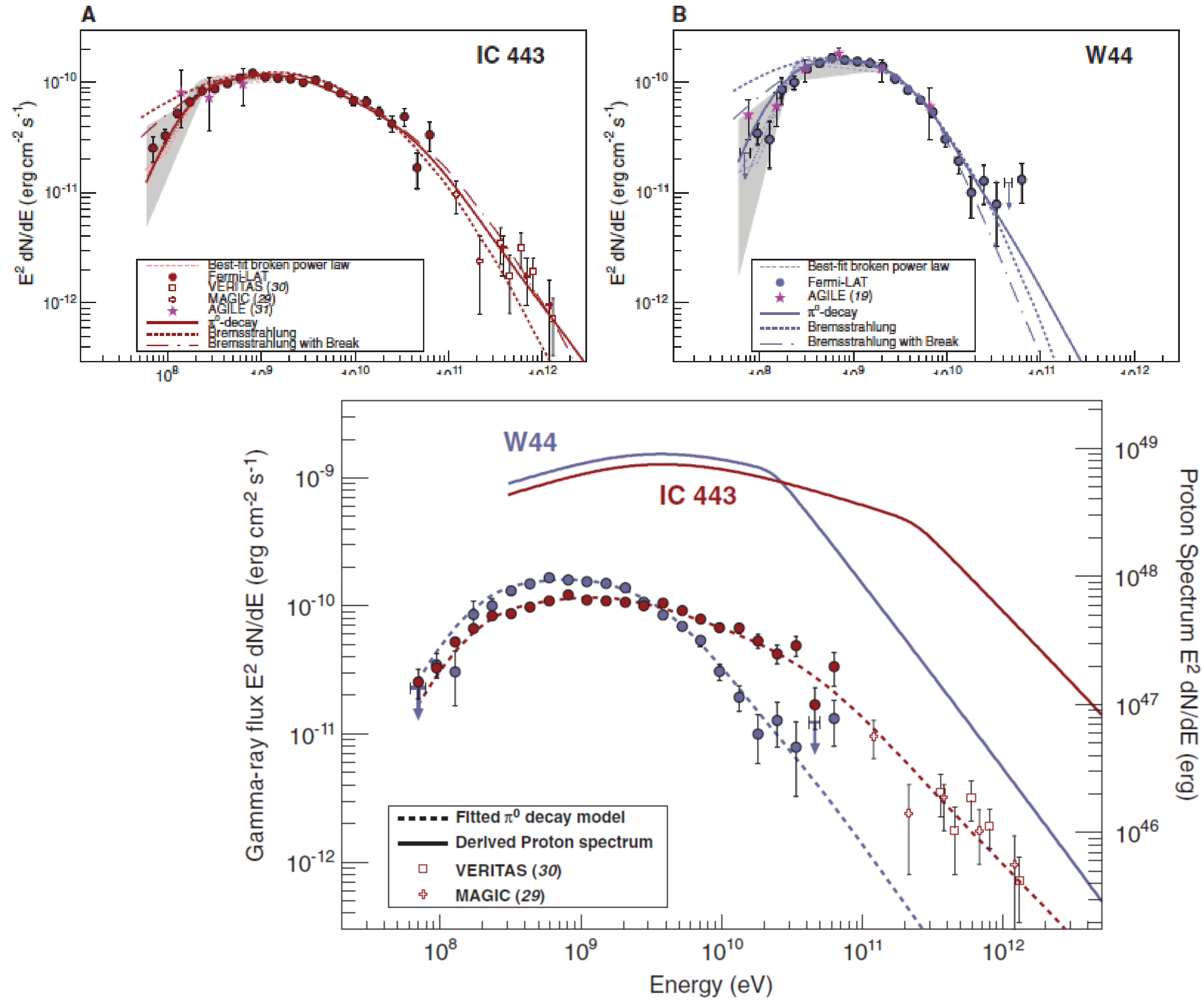
4: Incorporating the thermal component

1:Supernova Remnants



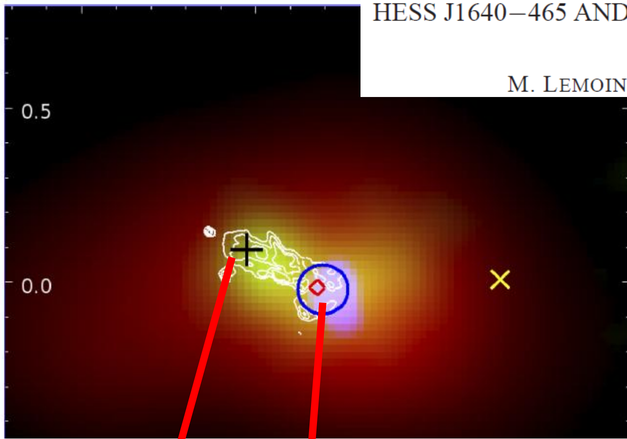
Science AAAS

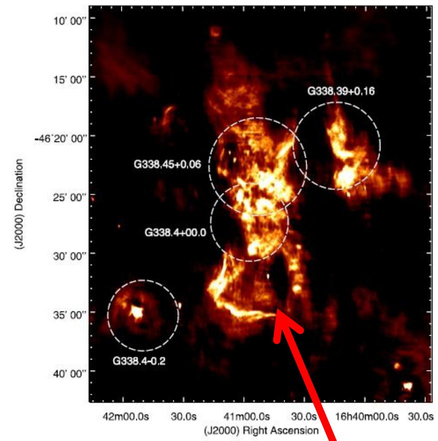
Detection of the Characteristic Pion-Decay Signature in Supernova Remnants
M. Ackermann *et al.*
Science **339**, 807 (2013);
DOI: 10.1126/science.1231160

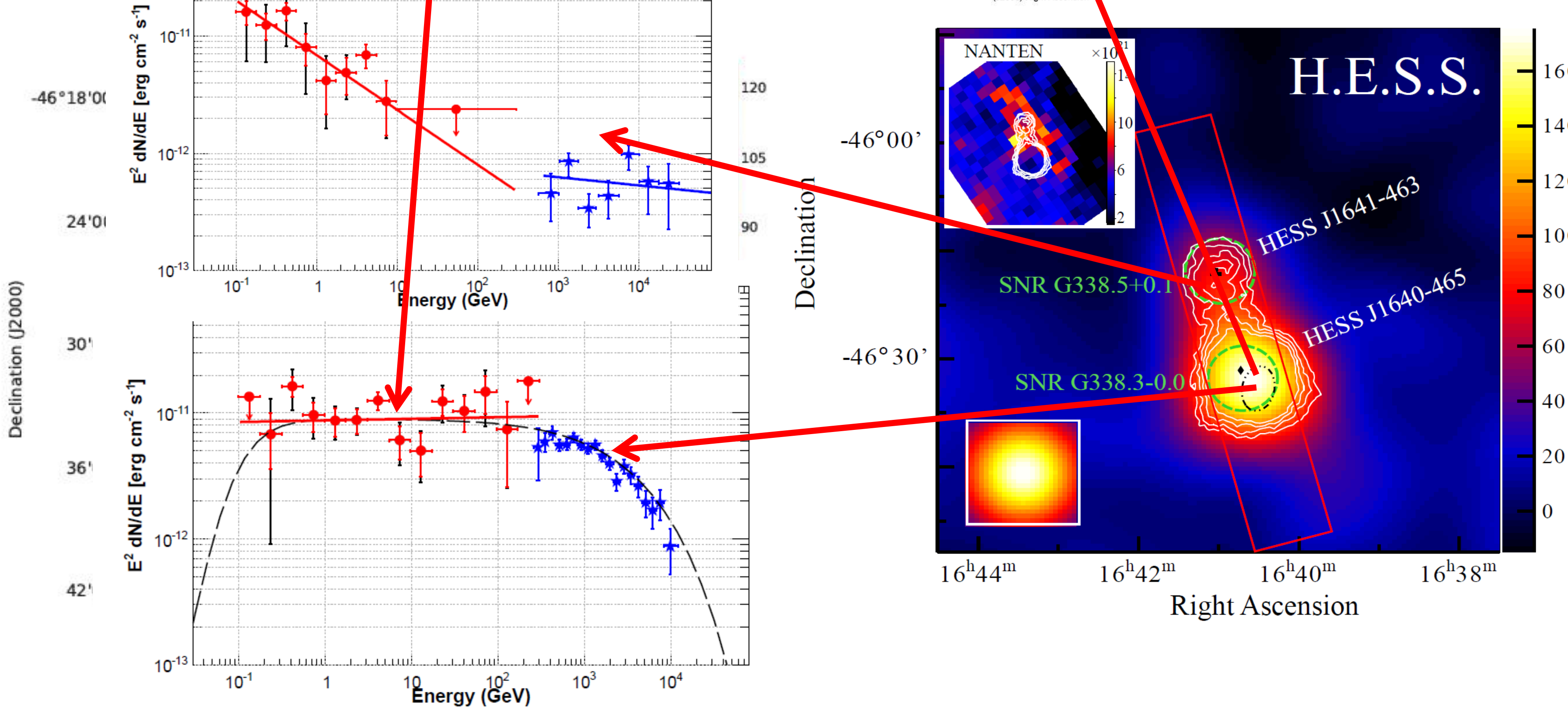


HESS J1640−465 AND HESS J1641−463: TWO INTRIGUING TEV SOURCES IN THE LIGHT OF NEW *FERMI* LAT OBSERVATIONS

M. Lemoine-Goumard[1,2], M.-H. Grondin[1,3], F. Acero[4], J. Ballet[4], H. Laffon[1], T. Reposeur[1]

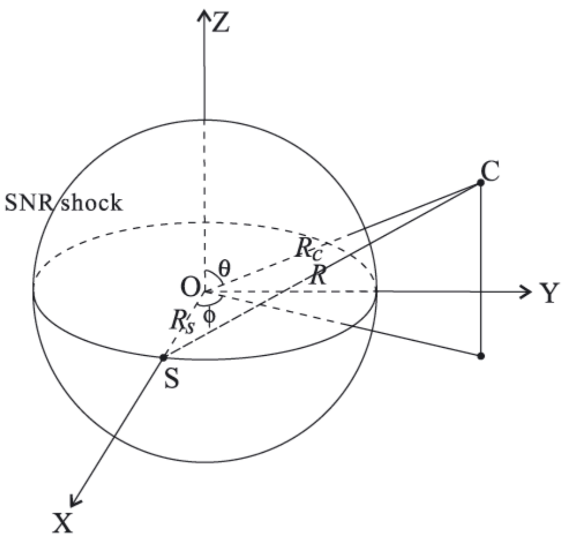


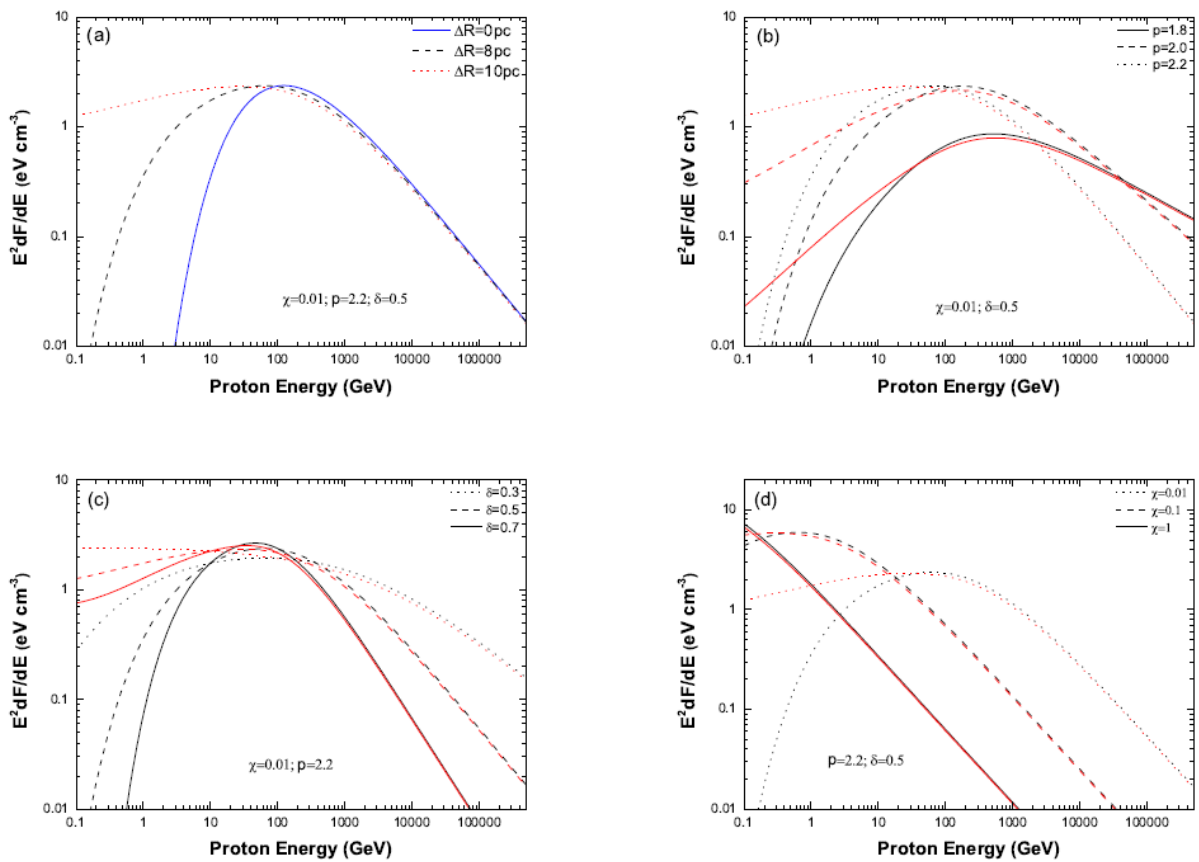




γ-rays from molecular clouds illuminated by accumulated diffusive protons. II: interacting supernova remnants

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

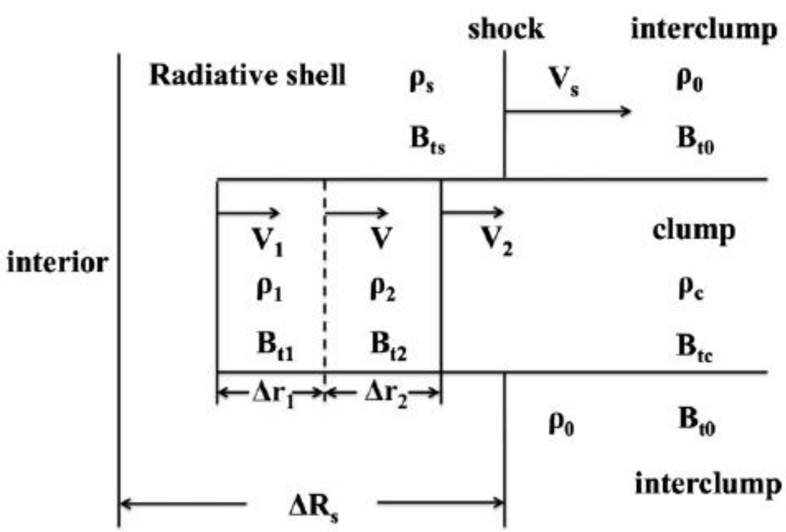


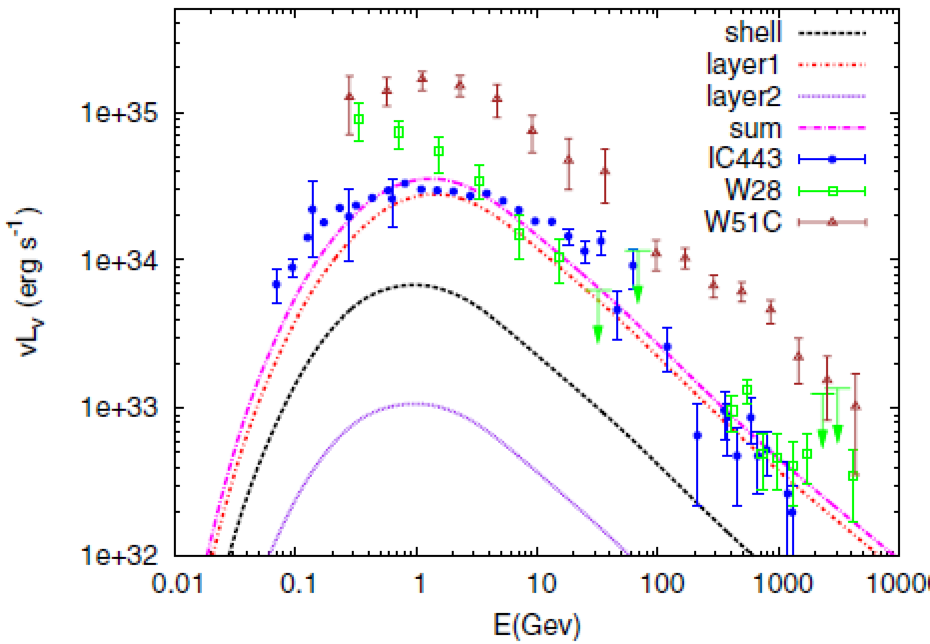


The Astrophysical Journal Letters, 784:L35 (5pp), 2014 April 1
doi:10.1088/2041-8205/784/2/L3

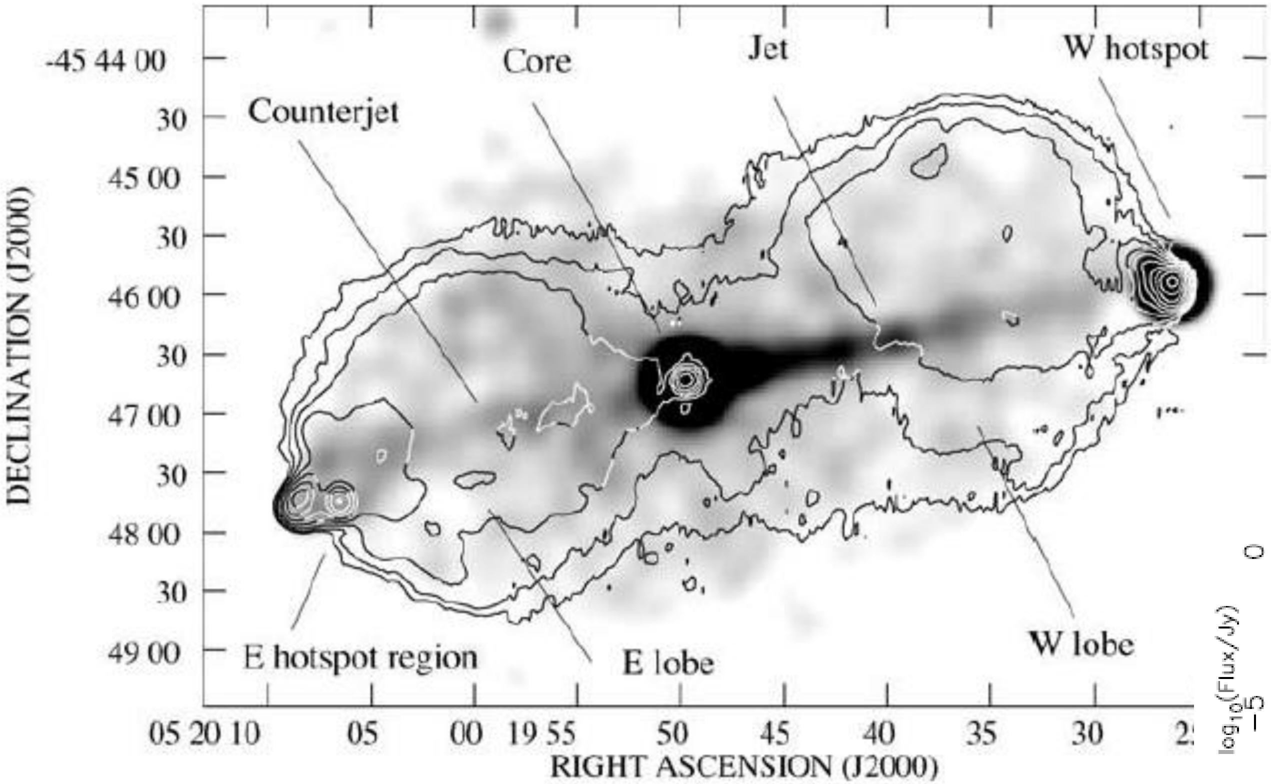
GAMMA-RAY EMISSION FROM SUPERNOVA REMNANT INTERACTIONS WITH MOLECULAR CLUMPS

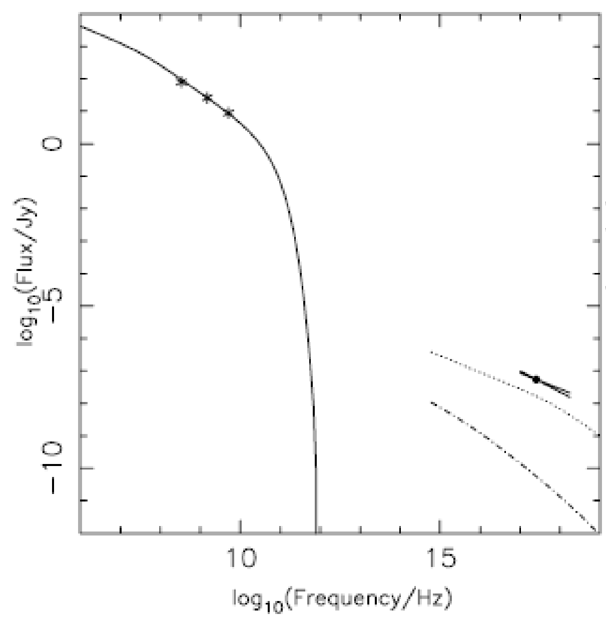
Xiaping Tang and Roger A. Chevalier



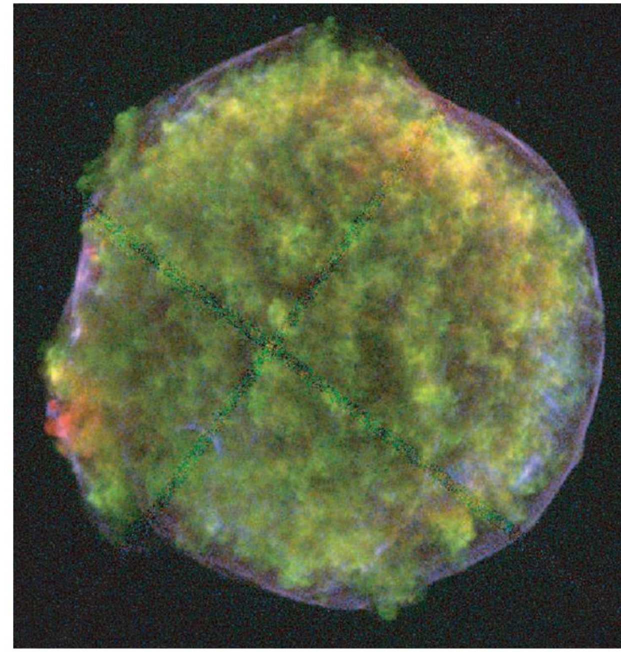


1 Energy Partition between Magnetic Field and Energetic Electrons





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]

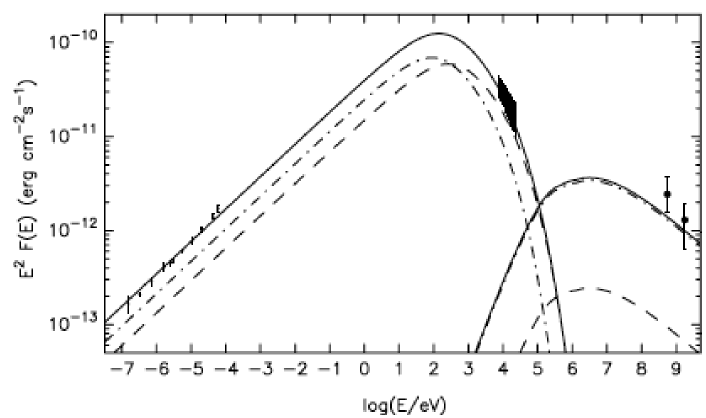


Figure 1. Synchrotron fluxes from radio through X-rays in the two-zone model. Dashed and dot-dashed lines show the fluxes from zone 1 and zone 2, respectively, and the total flux is shown by the solid line. Calculations assume density $n_2 \approx 3\,\mathrm{cm}^{-3}$ at $d_{\mathrm{kpc}} = 2.8$, $n_1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

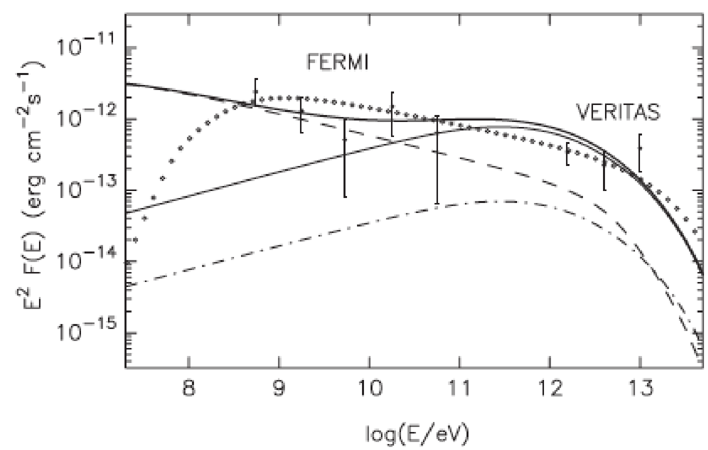


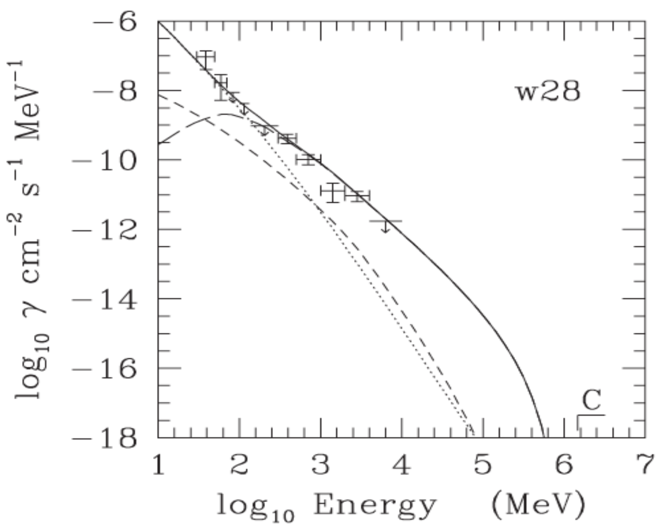
Figure 2. γ-ray fluxes in the two-zone model with parameters described in Figure 1. The heavy solid line shows the total flux of leptonic origin. The total bremsstrahlung and Compton radiation fluxes are shown by dashed and solid (thin) lines, respectively. For comparison, the Compton flux contribution 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 $E_{\mathrm{p}} = 3 \times 10^{49}$ erg.

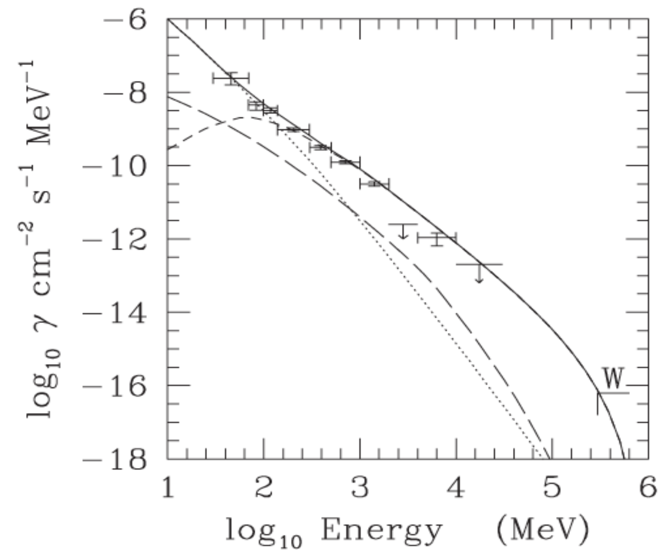
4.2 Multi-wavelength spectral fit

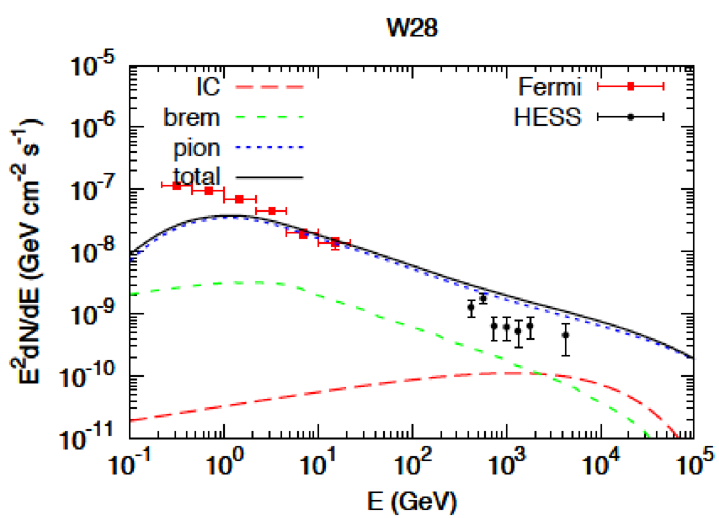
PRIMARY VERSUS SECONDARY LEPTONS IN THE EGRET SUPERNOVA REMNANTS

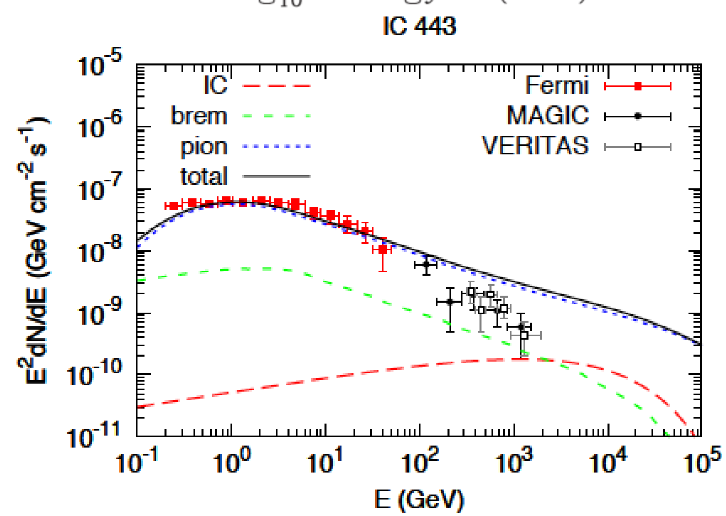
Marco Fatuzzo[1] and Fulvio Melia[2]

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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Laboratory for High-Energy Astrophysics, Code 661, NASA Goddard Space Flight Center, Greenbelt, MD 20771; baring@lheavx.gsfc.nasa.gov

DONALD C. ELLISON AND STEPHEN P. REYNOLDS
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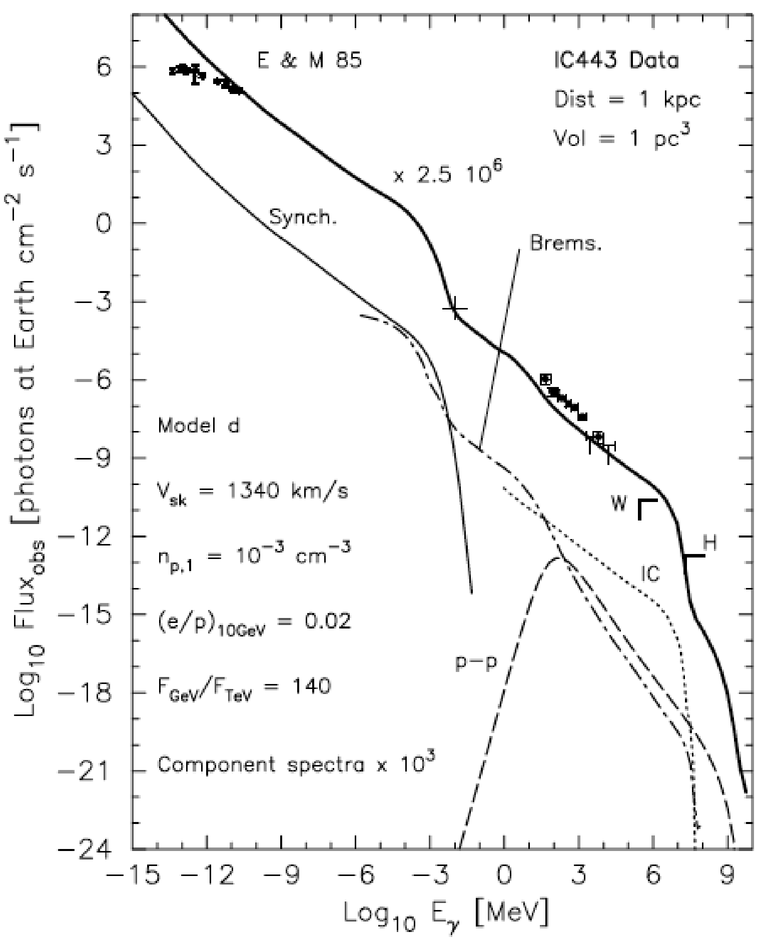
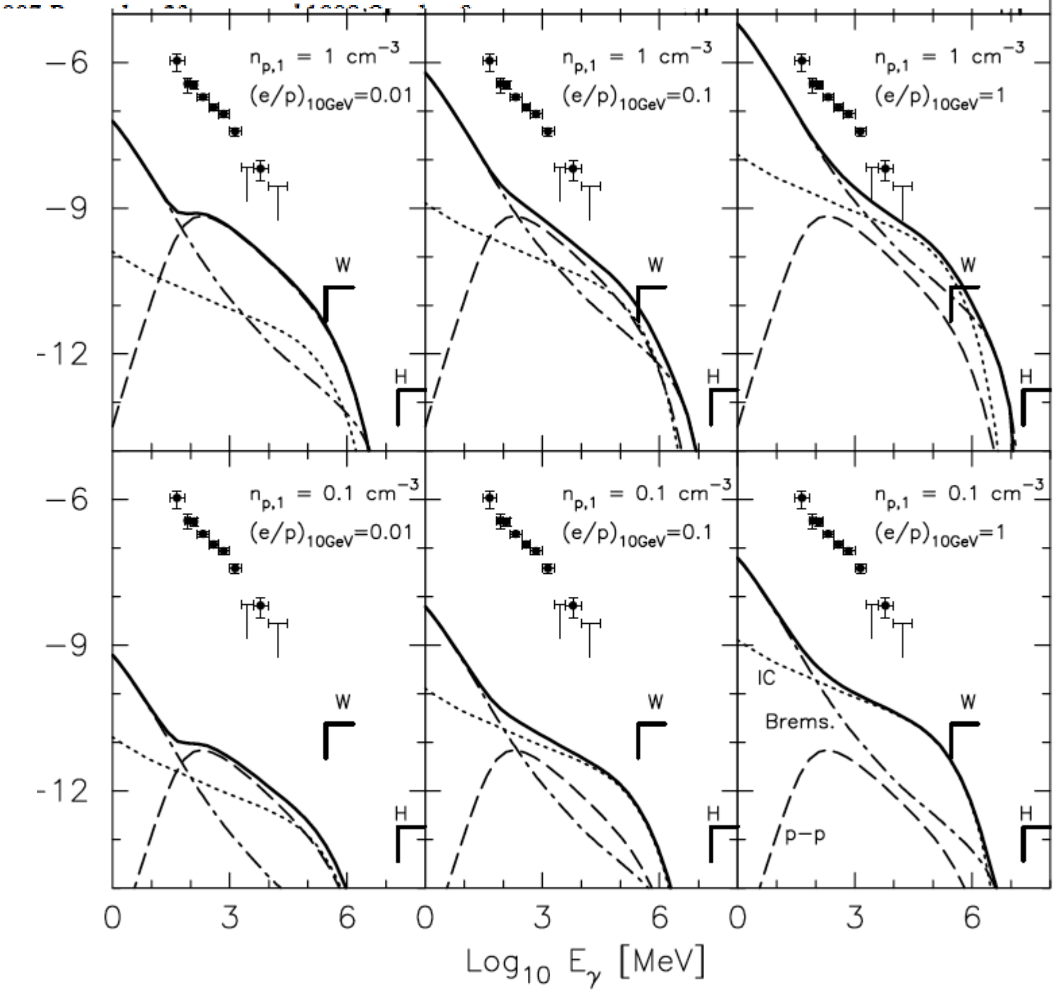
AND

ISABELLE A. GRENIER AND PHILIPPE GORET
Service d'Astrophysique, CEA, DSM, DAPNIA, Centre d'Etudes de Saclay, 91191 Gif-sur-Yvette, France; isabelle.grenier@cea.fr, goret@sapvxg.saclay.cea.fr





4.4 Thermal Emission

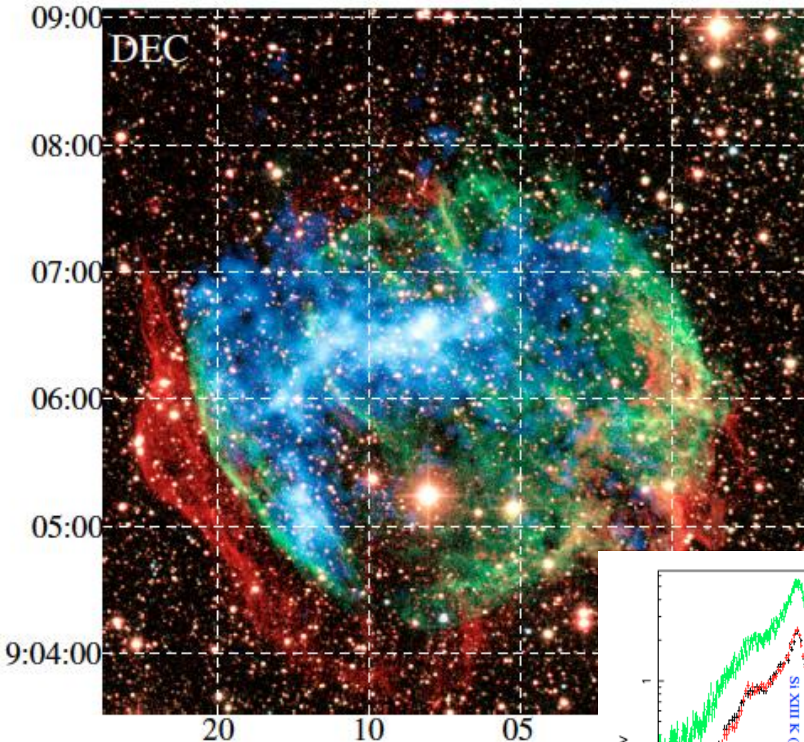
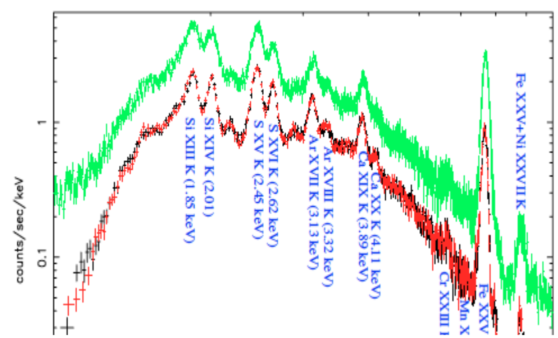
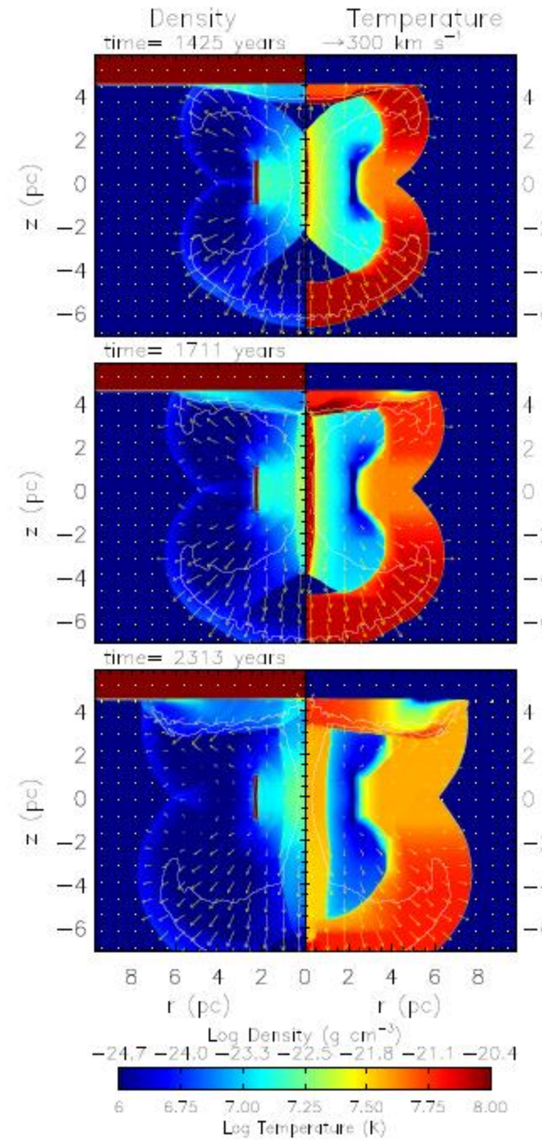


Fig. 2. Color composite *Chandra* X-ray image (in
2.12 μm molecular hydrogen (in red), and 1.64
green) images of W49B (from `http://chandra`
`press/04_releases/press_060204.html`).



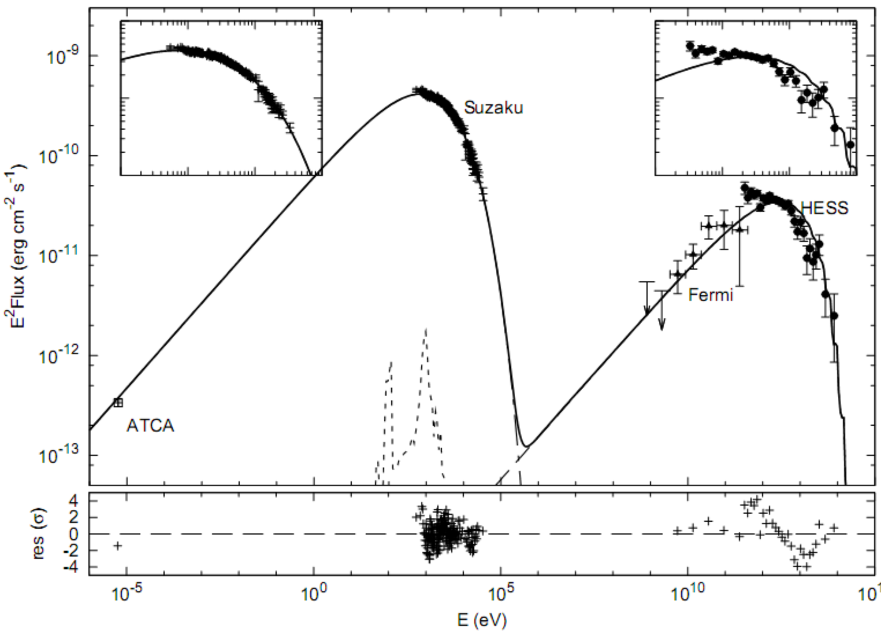


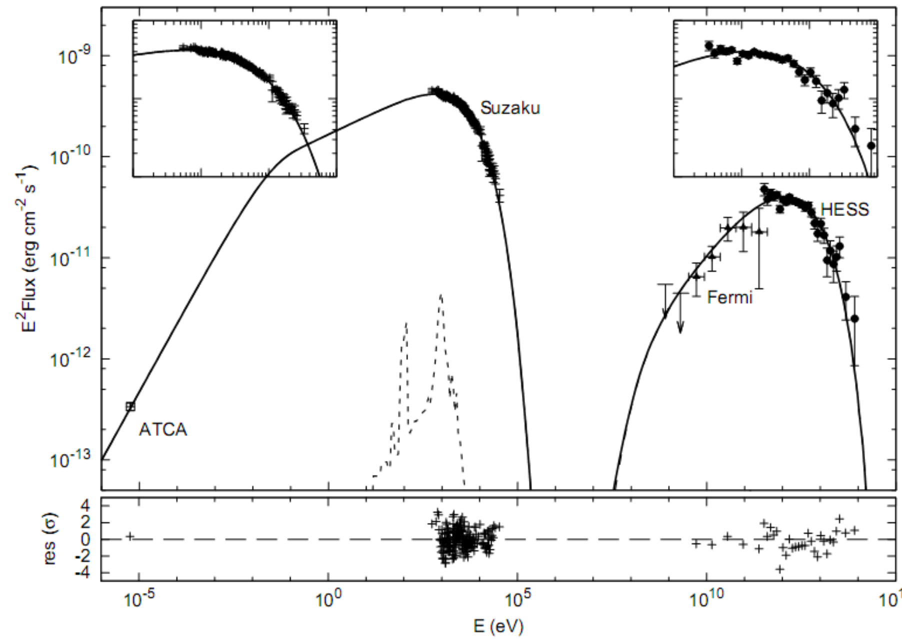
Unveiling the spatial structure of the overionized plasma in the supernova remnant W49B

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}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

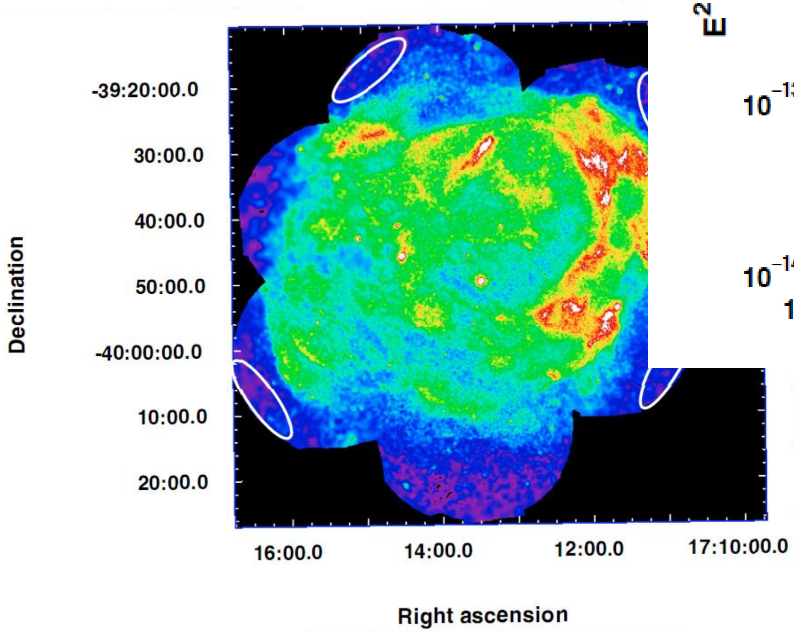
1: 3D MHD Simulations to Study Source structure

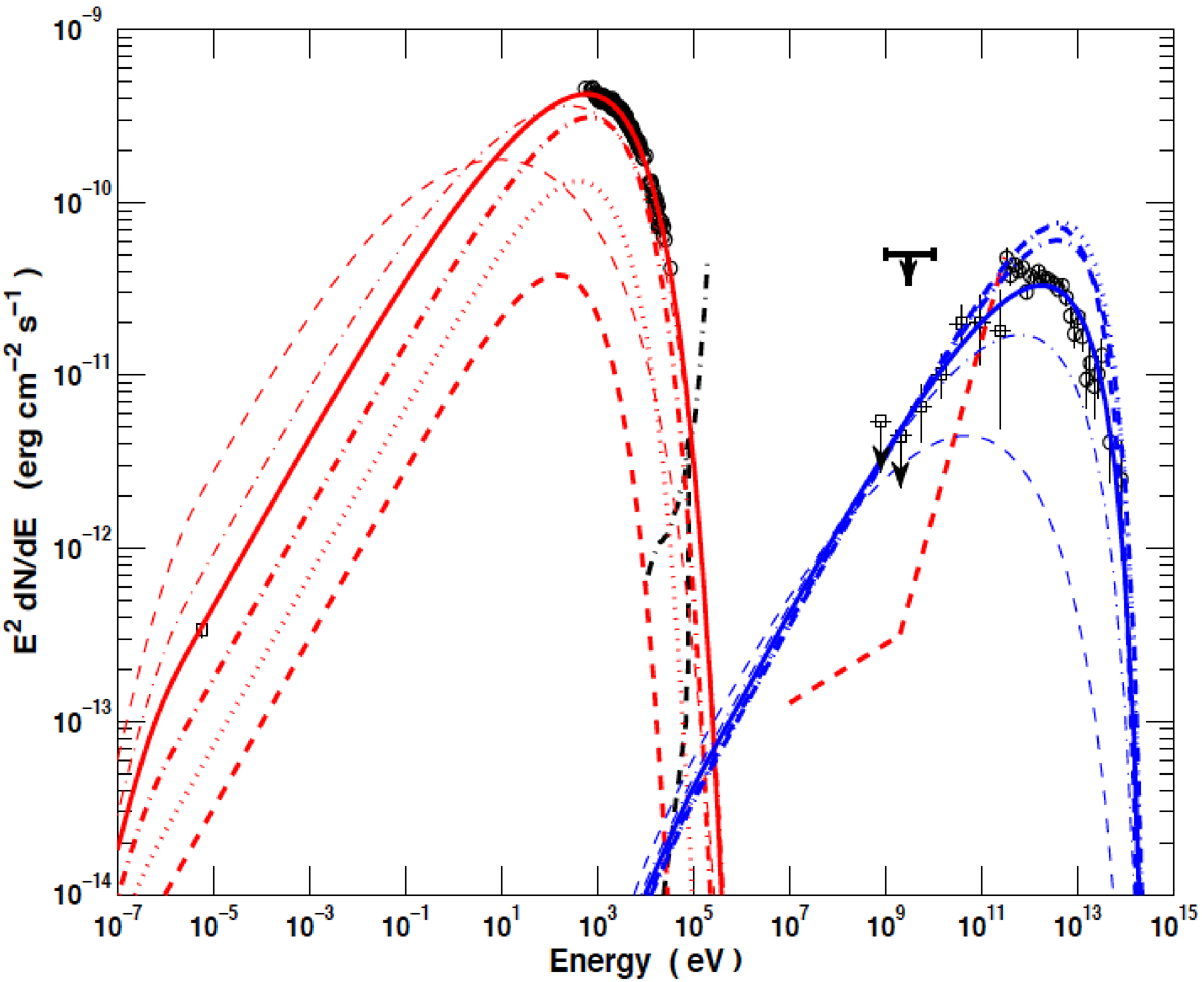
2: Multi-wavelength spectral fit

3: Evolution of SNRs

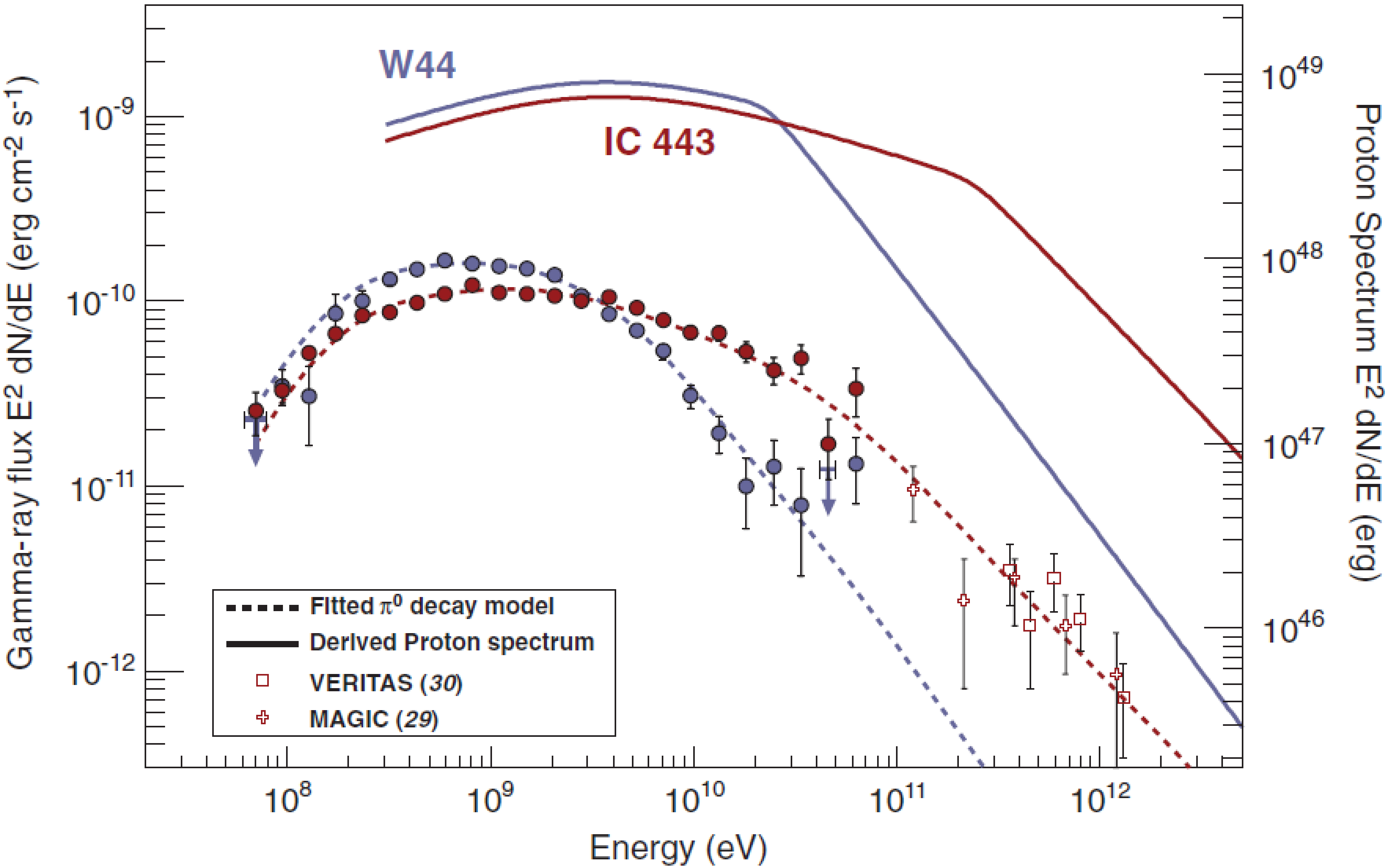
4: Incorporating the thermal component

4.3 Time Evolution





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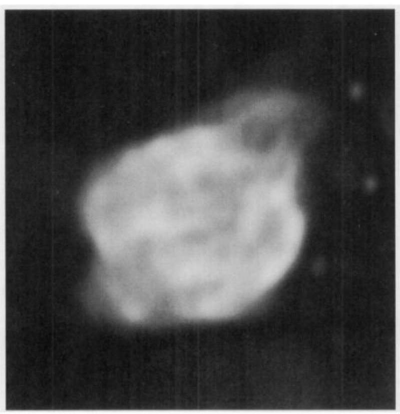
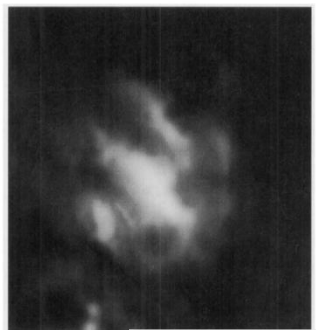
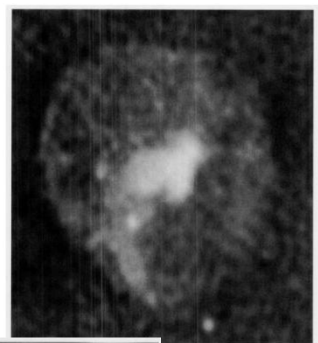
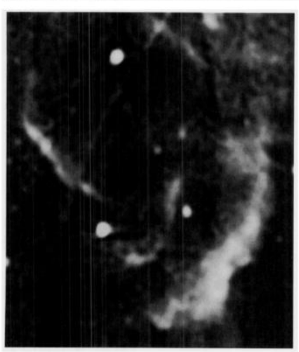
Manipulation: You can re-order the instrumental columns by dragging-and-dropping the header of one column (reload the page to reset the order). You can also sort all rows according to an instrument by clicking on the header

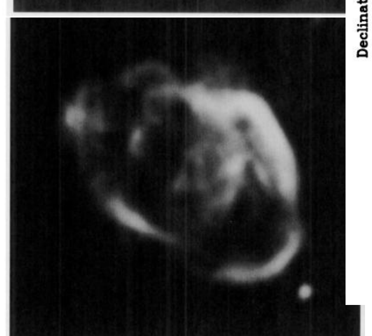
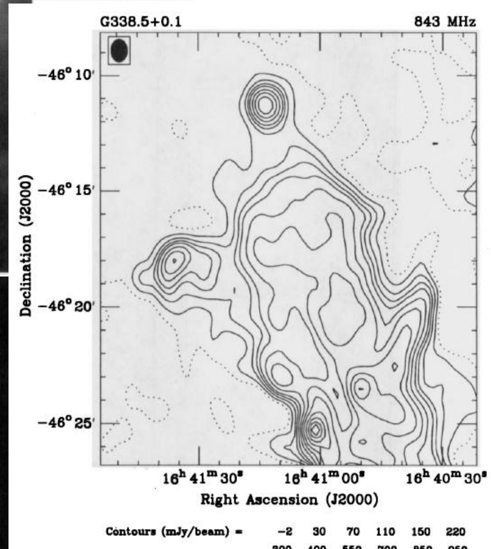
ID	names	context	SN	age	distance	type	CHANDRA	XMM	SUZAKU	ROSAT	ASCA	FERMI	AGILE	HESS	VERITAS	MAGIC	MILAGRO
							all	all	all	all	all	all	all	all	all	all	all
G000.0+00.0	Sgr A East, *1FGL J1745.6-2900c, 2FGL J1745.6-2858, 1FHL J1745.6-2900, HESS J1745-290*	contains CXOGC J174545.5-285829 = the cannonball = 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					

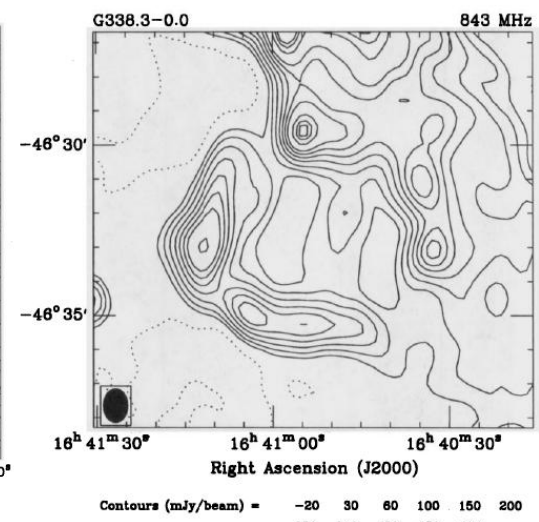
1:Radio Observations of Supernova Remnants-Evidence for GeV Electrons

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

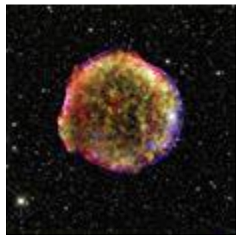
Astron. Astrophys. Suppl. Ser. **118**, 329-380 (1996)

The MOST supernova remnant catalogue (MSC)

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

1:Young Supernova Remnants

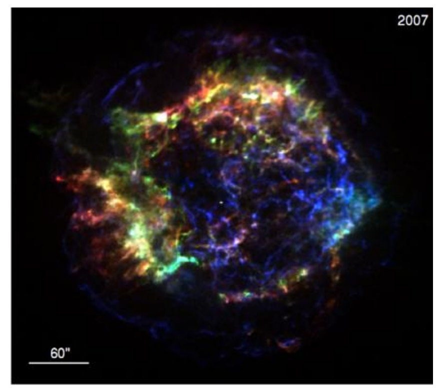
1054AD



1572AD

1604AD

1006AD



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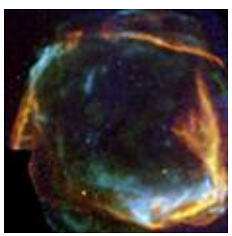
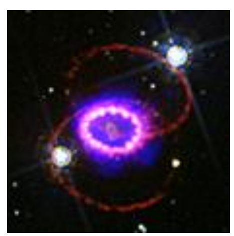


185AD



1987AD