

Truths universally acknowledged? reflections on CRBSM

Andy Strong
MPE Garching

Cosmic Rays Beyond the Standard Model
San Vito di Cadore 18-24 Sept 2016

It is a truth universally acknowledged ...

It is a truth universally acknowledged, that a single man in possession of a good fortune, must be in want of a wife.

(Jane Austen, *Pride and Prejudice*)



Common notions, folklore?

It is a truth universally acknowledged, that

- 1 The Pion Bump has been detected in SNR by Fermi-LAT
- 2 CR are extragalactic only $>10^{15}$ eV or so
- 3 CR cannot come from the Galactic Centre only
- 4 The CR gradient in the Galaxy can be determined accurately
- 5 The spectrum of CR in the Galaxy has the same shape as the local spectrum
- 6 Reacceleration is a viable explanation of the B/C peak
- 7 Secondary production in sources is negligible
- 8 ^{60}Fe tells about CR age, delay
- 9 Positron/pbar ratio agrees with standard model
- 10 Diffuse Galactic emission is mainly interstellar not unresolved sources
- 11 CR are not important for galaxy evolution

Aim: be a bit provocative, stimulate discussion in the spirit of CRBSM

11 things which are taken as established but are not and deserve further investigation

- 1 The Pion Bump has been detected in SNR
- 2 CR are extragalactic only $>10^{15}$ eV or so
- 3 CR cannot come from the Galactic Centre only
- 4 The CR gradient in the Galaxy can be determined accurately
- 5 The spectrum of CR in the Galaxy has the same shape as the local spectrum
- 6 Reacceleration is a viable explanation of the B/C peak
- 7 Secondary production in sources is negligible
- 8 ^{60}Fe tells about CR age, delay
- 9 Positron/pbar ratio agrees with standard model
- 10 Diffuse Galactic emission is mainly interstellar not unresolved sources
- 11 CR are not important for galaxy evolution

11 things which are taken as established but are not and deserve further investigation

- 1 The Pion Bump has been detected in SNR **REALLY?**
- 2 CR are extragalactic only $>10^{15}$ eV or so **REALLY?**
- 3 CR cannot come from the Galactic Centre only **REALLY?**
- 4 The CR gradient in the Galaxy can be determined accurately **REALLY?**
- 5 The spectrum of CR in the Galaxy has the same shape as the local spectrum **REALLY?**
- 6 Reacceleration is a viable explanation of the B/C peak (Luke's talk) **REALLY?**
- 7 Secondary production in sources is negligible (including B, positrons) **REALLY?**
- 8 ^{60}Fe tells about CR age, delay (from gammas ^{60}Fe is everywhere in ISM) **REALLY?**
- 9 Positron/pbar ratio agrees with standard model (no: Lipari paper) **REALLY?**
- 10 Diffuse Galactic emission is mainly interstellar not unresolved sources **REALLY?**
- 11 CR are not important for galaxy evolution **REALLY?**

11 things which are taken as established but are not and deserve further investigation

1 The Pion Bump has been detected in SNR

- 2 CR are extragalactic only $>10^{15}$ eV or so
- 3 CR cannot come from the Galactic Centre only
- 4 The CR gradient in the Galaxy can be determined accurately
- 5 The spectrum of CR in the Galaxy has the same shape as the local spectrum
- 6 Reacceleration is a viable explanation of the B/C peak (Luke's talk)
- 7 Secondary production in sources is negligible (including B, positrons)
- 8 ^{60}Fe tells about CR age, delay (from gammas ^{60}Fe is everywhere in ISM)
- 9 Positron/pbar ratio agrees with standard model (no: Lipari paper)
- 10 Diffuse Galactic emission is mainly interstellar not unresolved sources
- 11 CR are not important for galaxy evolution

*See talk on SNR by
Leonardo Di Venere
(much more detail)*

The origin of Cosmic-Rays from SNRs: confirmations and challenges after the first direct proof.

M.Cardillo^{a,*}, M.Tavani^{b,c,d}, A.Giuliani^e

^a*INAF-Osservatorio Astrofisico di Arcetri, Largo E.Fermi 5, 50125, Florence (Italy)*

^b*INAF/IAPS, I-00133 Roma, Italy*

^c*Dip. di Fisica, Univ. Tor Vergata, I-00133 Roma, Italy*

^d*CIFS-Torino, I-10133 Torino, Italy*

^e*INAF/IASF-Milano, I-20133 Milano, Italy*

Abstract

Until now, providing an experimental unambiguous proof of Cosmic Ray (CR) origin has been elusive. The SuperNova Remnant (SNR) study showed an increasingly complex scenario with a continuous elaboration of theoretical models. The middle-aged supernova remnant (SNR) W44 has recently attracted attention because of its relevance regarding the origin of Galactic cosmic-rays. The gamma-ray missions AGILE and Fermi have established, for the first time for a SNR, the spectral continuum below 200 MeV which can be attributed to neutral pion emission. Our work is focused on a global re-assessment of all available data and models of particle acceleration in W44 and our analysis strengthens previous studies and observations of the W44 complex environment, providing new information for a more detailed modeling. However, having determined the hadronic nature of the gamma-ray emission on firm ground, a number of theoretical challenges remains to be addressed in the context of CR acceleration in SNRs.

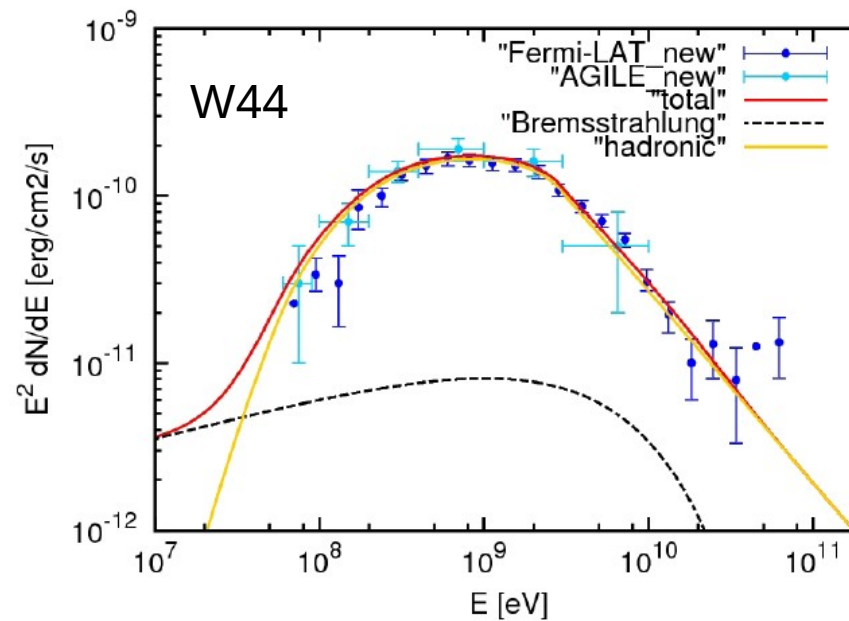
SNRs : several with claimed 'pion-peak'

But beware, this is at $m(\pi^0)/2 = 67.5$ MeV, so Fermi hardly covers it.

NB multiplying by E^2 is good but shifts the peak to higher energies, do not see the 'bump'

May be instead an indication for break in proton spectrum.

Sample spectrum: W44, Cardillo etal 2014. Model proton spectrum has break at 20 GeV.

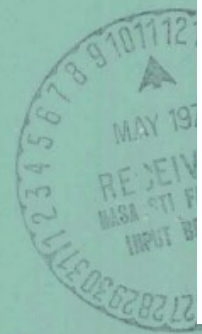


N71-24764/79

NASA SP-249

COSMIC
GAMMA
RAYS

CASE FILE
COPY



NASA SP-249

COSMIC
GAMMA
RAYS

FLOYD WILLIAM STECKER
Goddard Space Flight Center

We have thus proved an important kinematic property regarding the energy range of secondary γ -rays that are the product of two-body decays; viz,

(1-225)

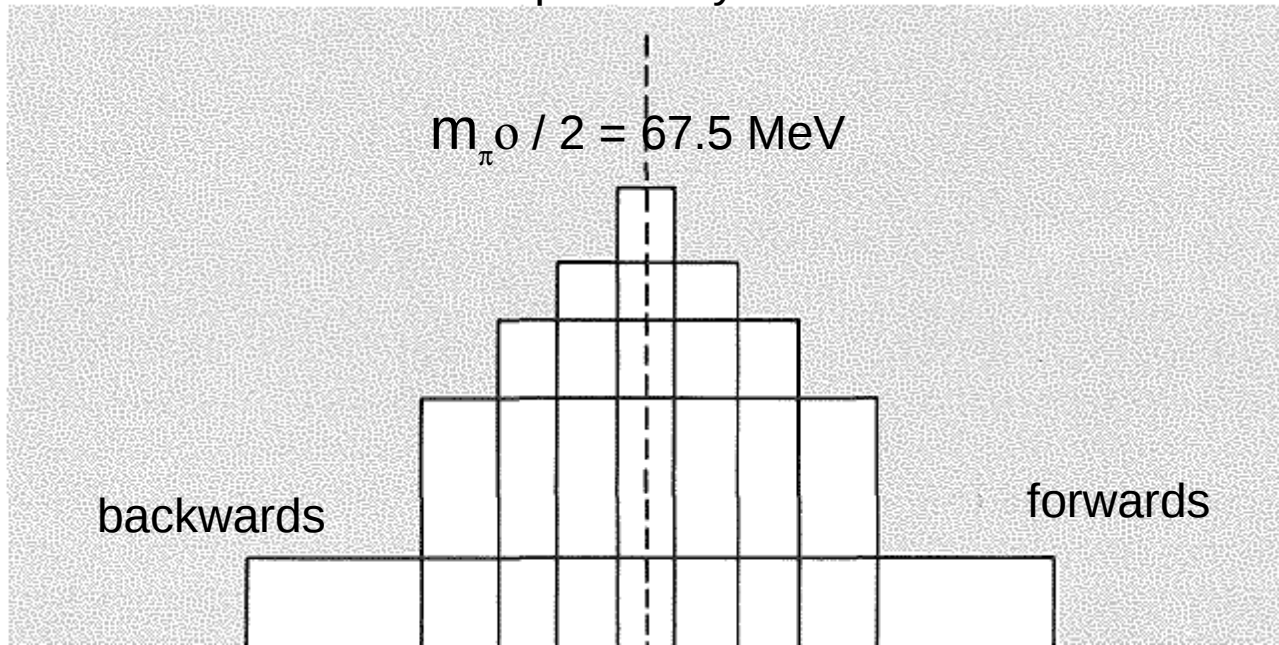
The geometric mean of the energy range of secondary γ -rays which are produced in all two-body decays is equal to the energy of the γ -rays in the rest system of the decaying primary μ and is independent of the energy of the primary particle.

these γ -rays, sum energies.

spectrum. We therefore deduce a second important kinematic property, which holds for two-body decays that produce γ -rays isotropically in the rest system of the decaying primary; viz,

The energy spectra of γ -rays produced isotropically in the rest system of the decaying primary will be symmetric on a logarithmic plot with respect to $E_\gamma = \mu$ and will peak at $E_\gamma = \mu$.

Isotropic decay in CM



This result, combined with equations (5-26) and (5-27), yields the conclusion that ϵ increases monotonically with δ . Since $F[\epsilon]$ is a monotonically decreasing functional of ϵ , it follows that $F[\delta]$ is a monotonically decreasing functional of δ . Thus, $F[\delta]$ is a maximum at $\delta=0$ and decreases more and more with increasing δ . It follows that $F(E_\gamma)$ is a maximum at $\ln E_\gamma = \nu$; i.e., at $E_\gamma = \frac{1}{2}m_\pi$ and that this is, in fact, the only maximum. Note that these results were reached by less rigorous arguments in our general discussion in section 1-6.

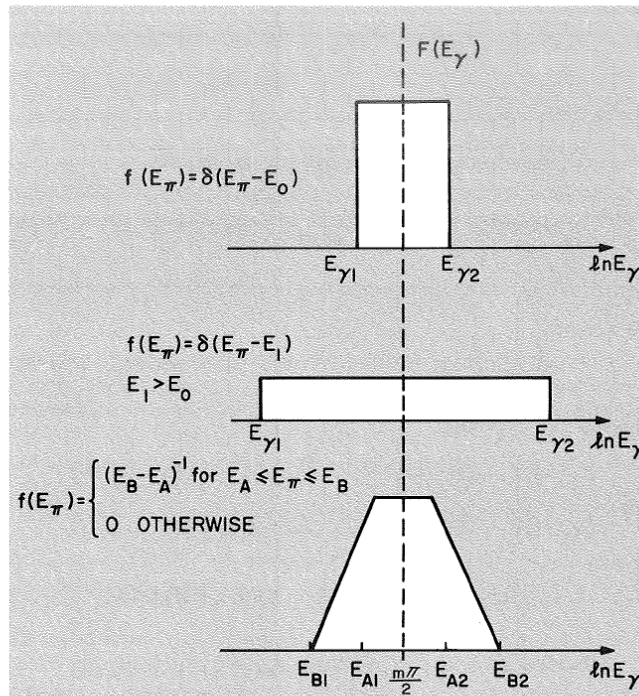


FIGURE 5-3.—Some ideal γ -ray spectra resulting from the decay of some ideal spectra of neutral pions.

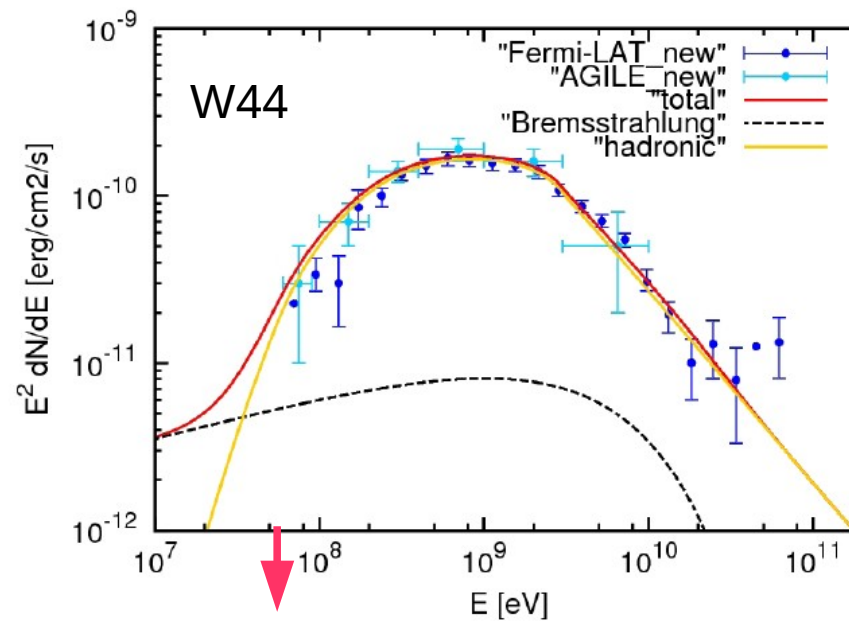
SNRs : several with claimed 'pion-peak'

But beware, this is at $m(\pi^0)/2 = 67.5$ MeV, so Fermi hardly covers it.

NB multiplying by E^2 is good but shifts the peak to higher energies, do not see the 'bump'

May be instead an indication for break in proton spectrum.

Sample spectrum: W44, Cardillo et al 2014. .



$$m_{\pi^0} / 2 = 67.5 \text{ MeV}$$

SNRs : several with claimed 'pion-peak'

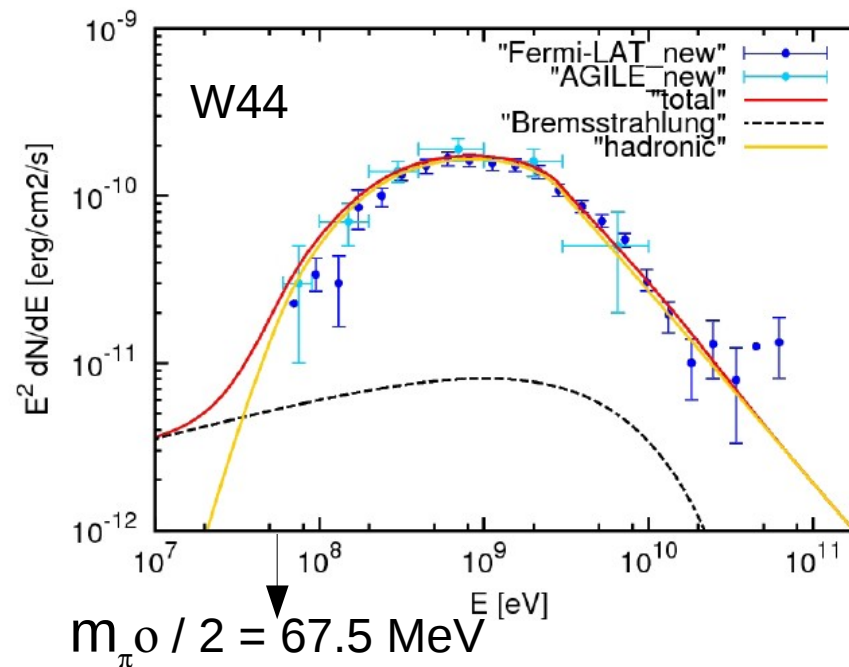
But beware, this is at $m(\pi^0)/2 = 67.5$ MeV, so Fermi hardly covers it.

NB multiplying by E^2 is good but shifts the peak to higher energies, do not see the 'bump'

May be instead an indication for break in proton spectrum.

Need Fermi extension to lower energies, coming with Pass 8.

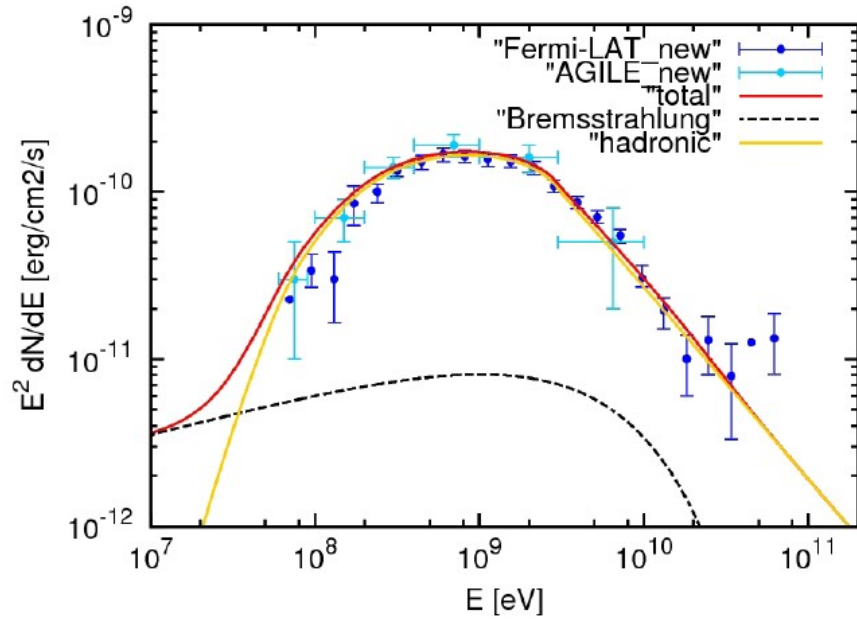
Sample spectrum: W44, Cardillo etal 2014. Model proton spectrum has break at 20 GeV.



Spectrum $\times E^2$

Shifts the peak to higher energy but Fermi cannot see a peak which is below it's range!

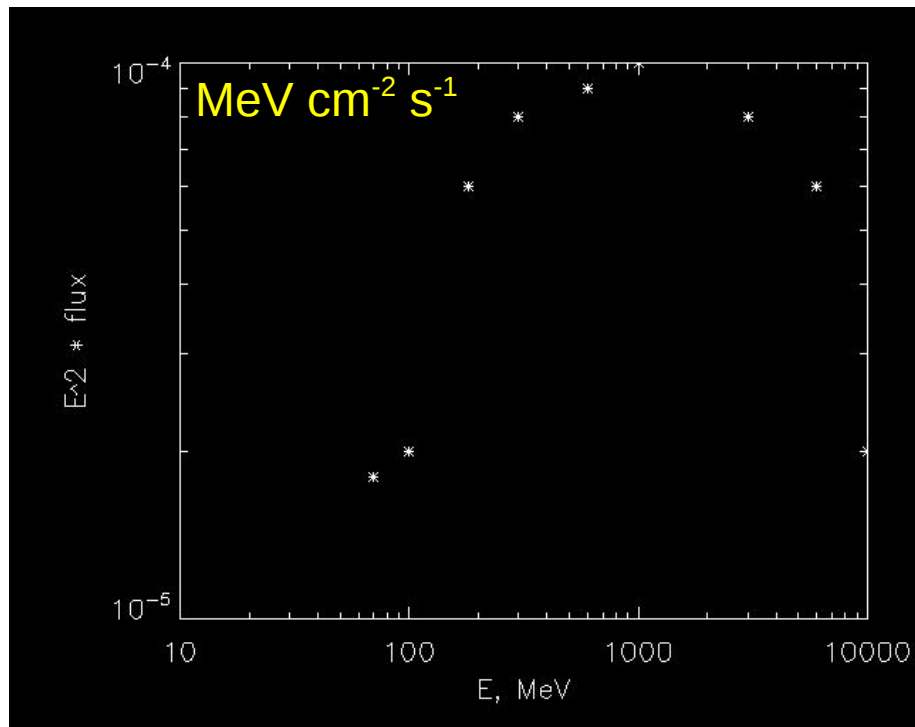
Sample spectrum: W44, Cardillo etal 2014. Model proton spectrum has break at 20 GeV.



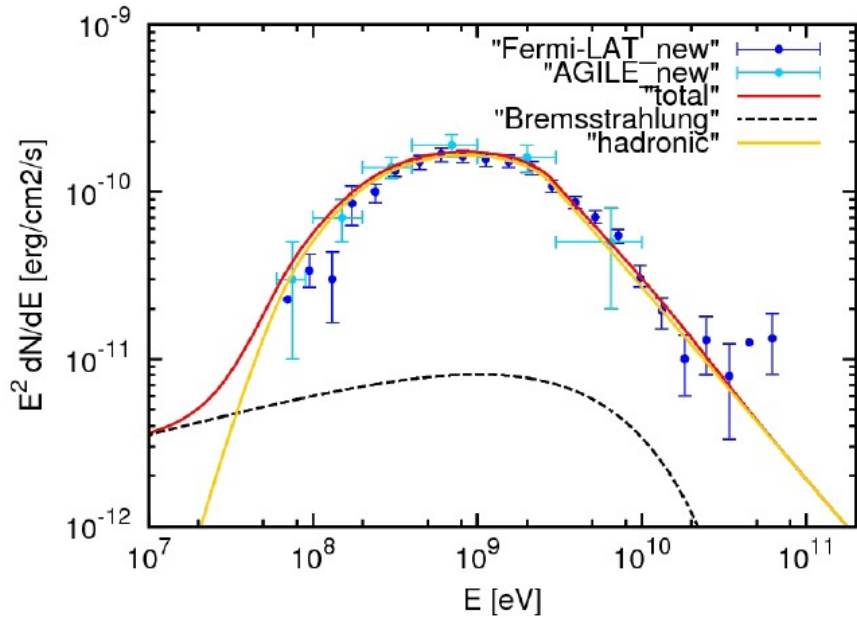
Spectrum X E^2

Shifts the peak to higher energy but Fermi cannot see a peak which is below it's range!

Spectrum times E^2



Sample spectrum: W44, Cardillo etal 2014. Model proton spectrum has break at 20 GeV.

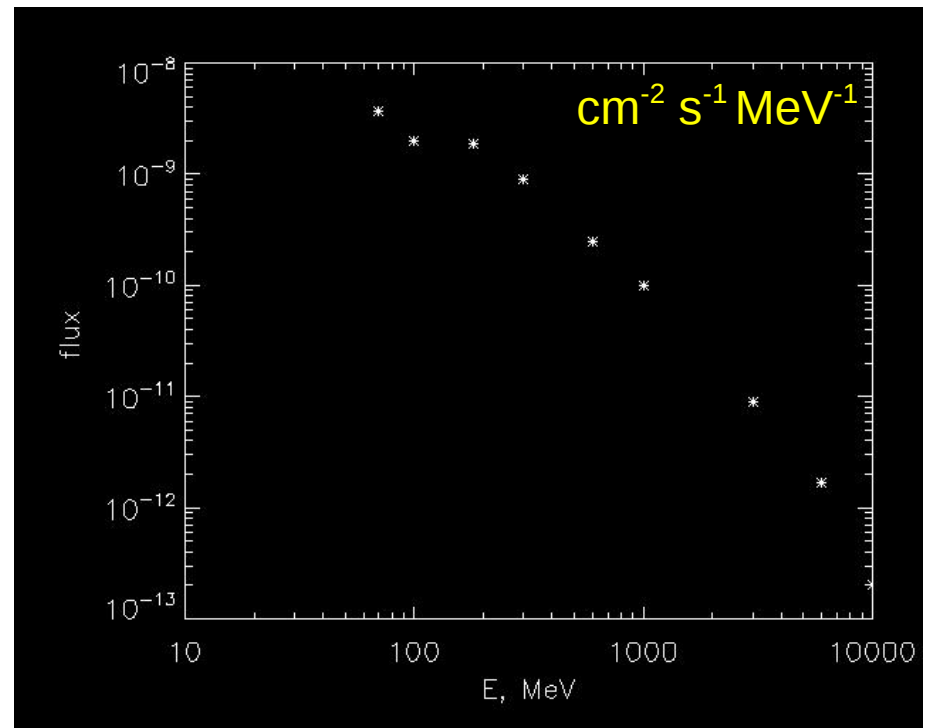
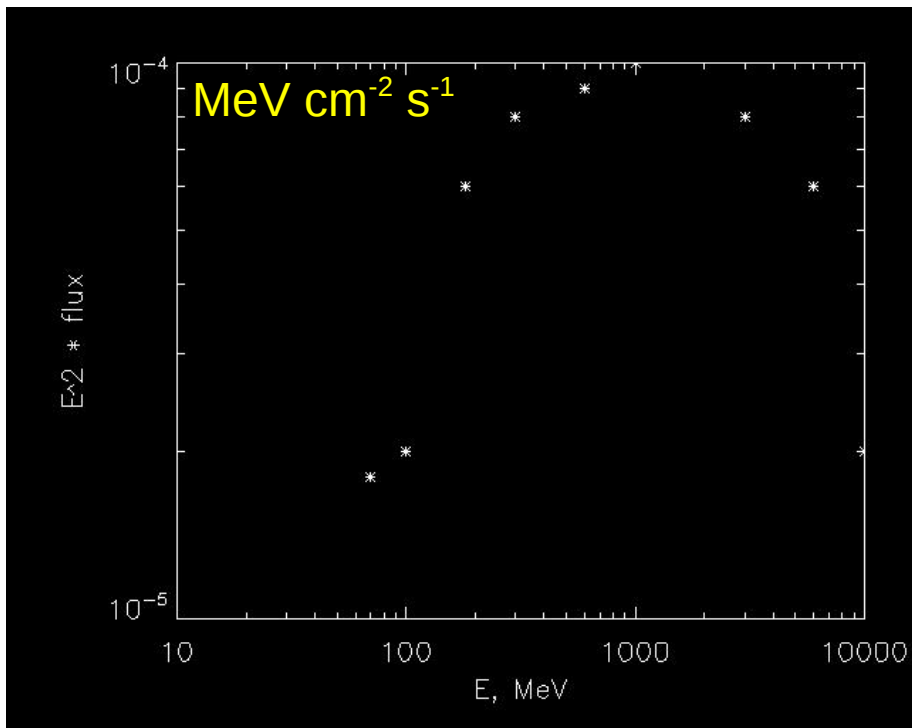


Spectrum times E^2

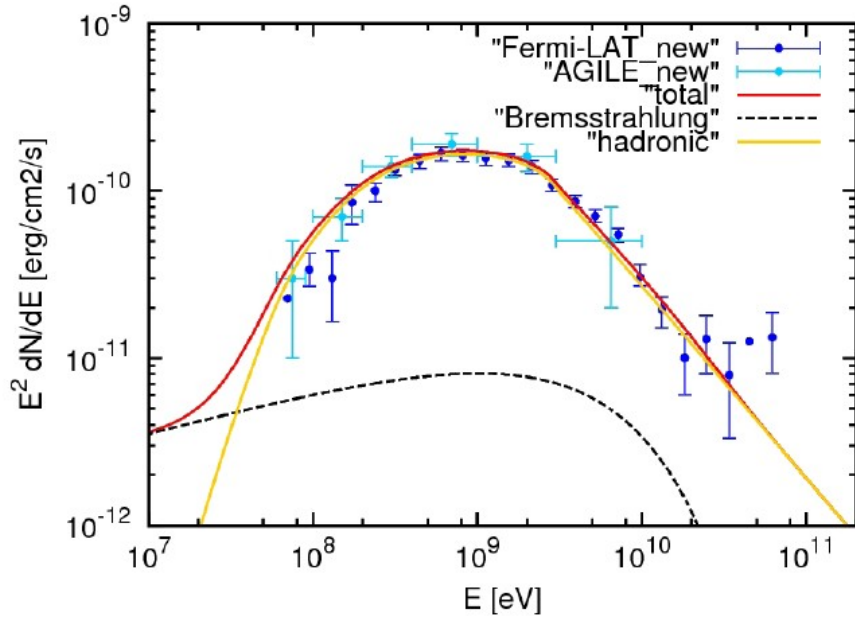
Spectrum $\times E^2$

Shifts the peak to higher energy but Fermi cannot see a peak which is below it's range!

Spectrum **without** E^2



Sample spectrum: W44, Cardillo etal 2014. Model proton spectrum has break at 20 GeV.

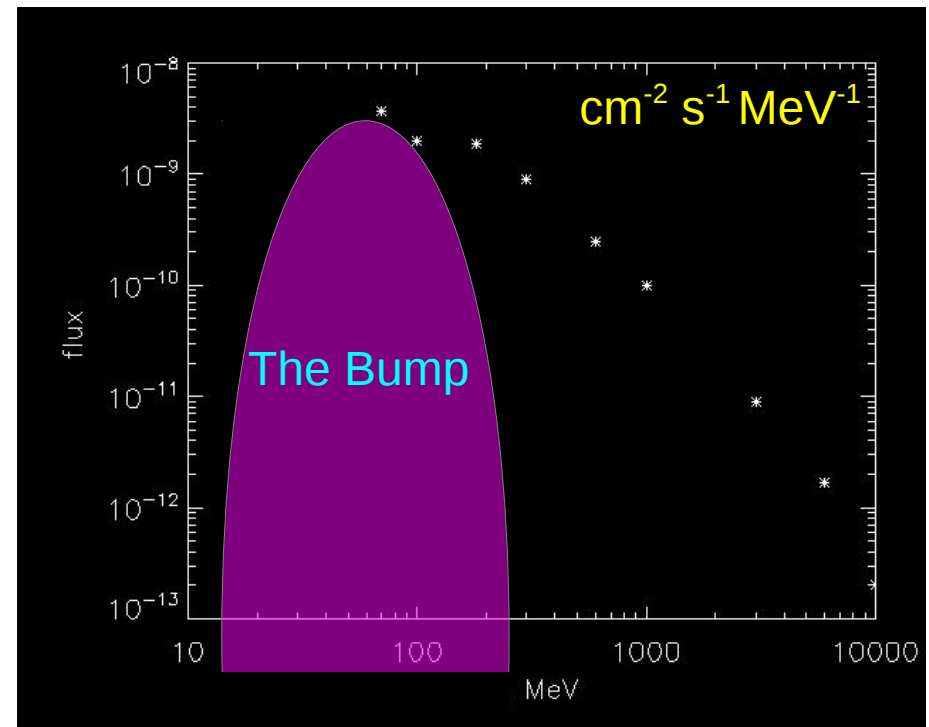
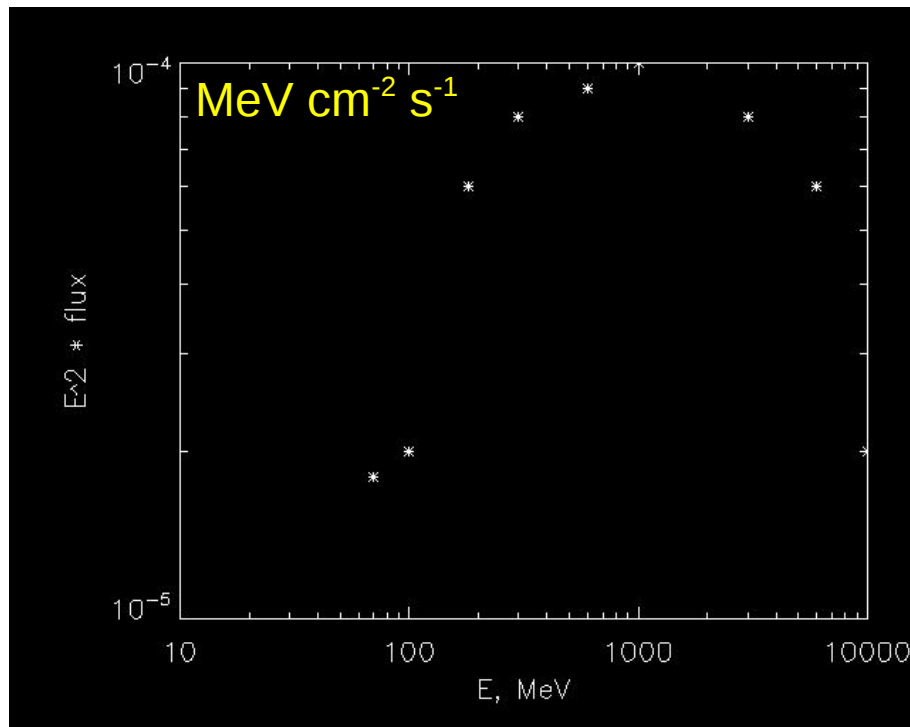


Spectrum times E^2

Spectrum $\times E^2$

Shifts the peak to higher energy but Fermi cannot see a peak which is below it's range!

Spectrum **without** E^2



The supernova remnant W44: a case of Cosmic-Ray reacceleration.

M. Cardillo¹, E. Amato¹, and P. Blasi^{1,2}

¹ INAF/Osservatorio Astrofisico di Arcetri, Largo E. Fermi, 5 - 50125 Firenze, Italy
e-mail:martina@arcetri.astro.it

² Gran Sasso Science Institute (INFN), viale F. Crispi 7, 67100 L' Aquila, Italy.

Received / Accepted

ABSTRACT

Supernova remnants (SNRs) are thought to be the primary sources of Galactic Cosmic Rays (CRs). In the last few years, the wealth of γ -ray data collected by GeV and TeV instruments has provided important information about particle energisation in these astrophysical sources, allowing us to make progress in assessing their role as CR accelerators. In particular, the spectrum of the γ -ray emission detected by AGILE and Fermi-LAT from the two middle aged Supernova Remnants (SNRs) W44 and IC443, has been proposed as a proof of CR acceleration in SNRs. Here we discuss the possibility that the radio and γ -ray spectra from W44 may be explained in terms of re-acceleration and compression of Galactic CRs. The recent measurement of the interstellar CR flux by Voyager I has been instrumental for our work, in that the result of the reprocessing of CRs by the shock in W44 depends on the CR spectrum at energies that are precluded to terrestrial measurement due to solar modulation. We introduce both CR protons and helium nuclei in our calculations, and secondary electrons produced *in situ* are compared with the flux of Galactic CR electrons reprocessed by the slow shock of this SNR. We find that the multi-wavelength spectrum of W44 can be explained by reaccelerated particles with no need of imposing any break on their distribution, but just a high energy cut-off at the maximum energy the accelerator can provide. We also find that a model including both re-acceleration and a very small fraction of freshly accelerated particles may be more satisfactory on physical grounds.

h.HEJ 22 Jul 2016

ArXiv:1604.02321 July 2016

The supernova remnant W44: a case of Cosmic-Ray reacceleration.

M. Cardillo¹, E. Amato¹, and P. Blasi^{1,2}

arXiv: 1604.02321

interactions with ambient matter. Indeed the γ -ray spectrum of W44 showed the pion bump that can be unequivocally linked to CR hadronic interactions, as later confirmed by the Fermi-LAT

A&A proofs: manuscript no. Accepted

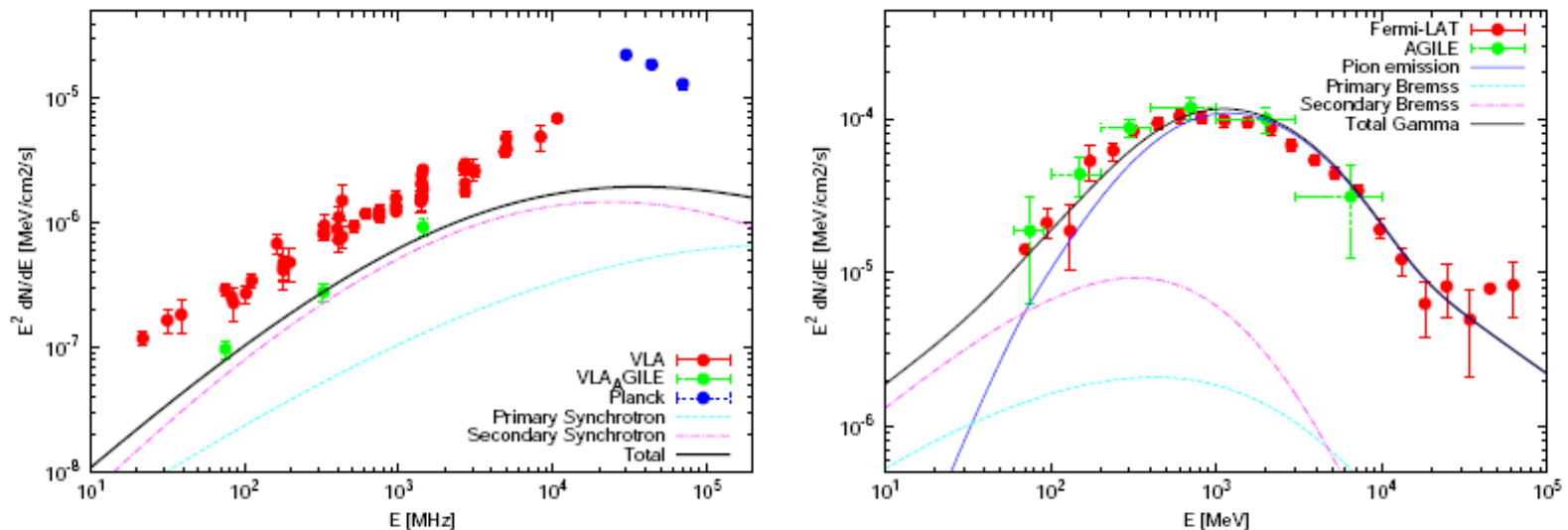


Fig. 3. **Left:** VLA (red) and Planck (blue) radio data from the whole remnant (Castelletti et al. 2007; Planck collaboration 2014) and VLA radio data from the high-energy emitting region (green), plotted together with primary (cyan dashed line), secondary (magenta dot-dashed line) and total (black line) synchrotron radio emission obtained in our best fit reacceleration model. **Right:** AGILE (green) and Fermi-LAT (red) γ -ray points (Cardillo et al. 2014; Ackermann et al. 2013) plotted with γ -ray emission from pion decay (blue dotted line), emission due to bremsstrahlung of primary (cyan dashed line) and secondary (magenta dot-dashed line) electrons, and total emission (black line).

The supernova remnant W44: a case of Cosmic-Ray reacceleration.

M. Cardillo¹, E. Amato¹, and P. Blasi^{1,2}

arXiv: 1604.02321

'bump' is result of break in proton spectrum

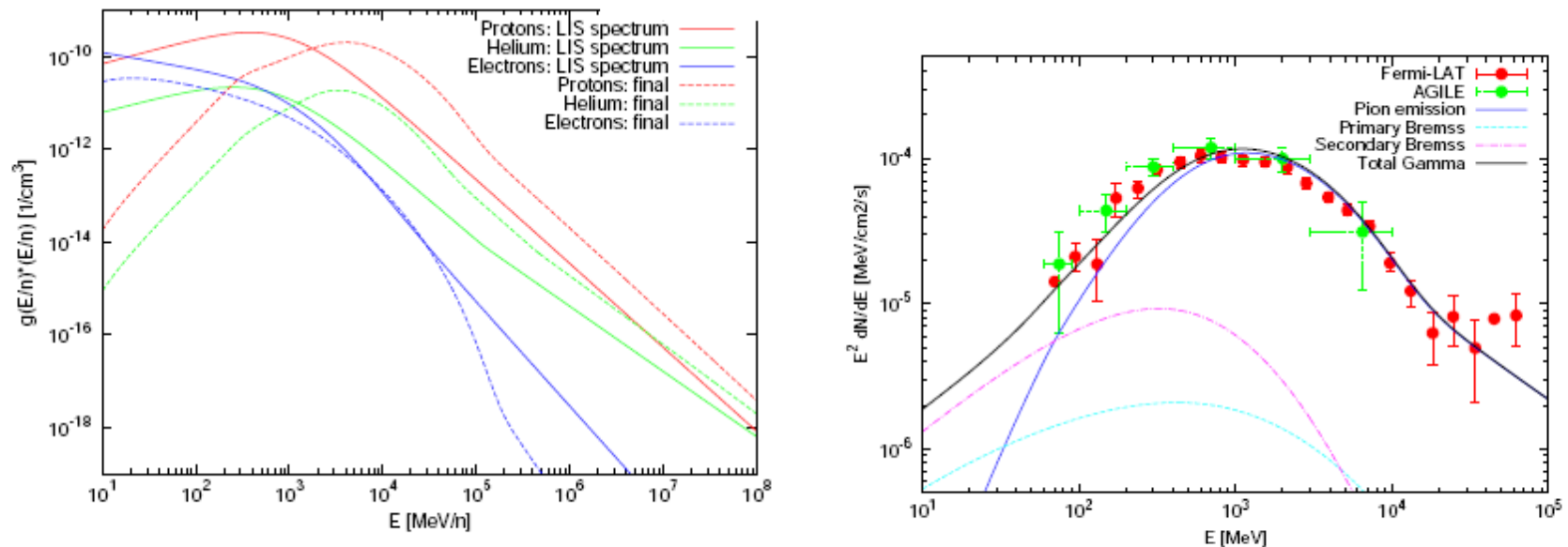


Fig. 2. Spectra of protons, He nuclei and electrons in the local ISM (solid lines) and after shock reacceleration and compression in the remnant (Castelletti et al. 2007; Planck collaboration 2014) and VLA radio primary (cyan dashed line), secondary (magenta dot-dashed line) and total reacceleration model. **Right:** AGILE (green) and Fermi-LAT (red) γ -ray points on from pion decay (blue dotted line), emission due to bremsstrahlung of electrons, and total emission (black line).

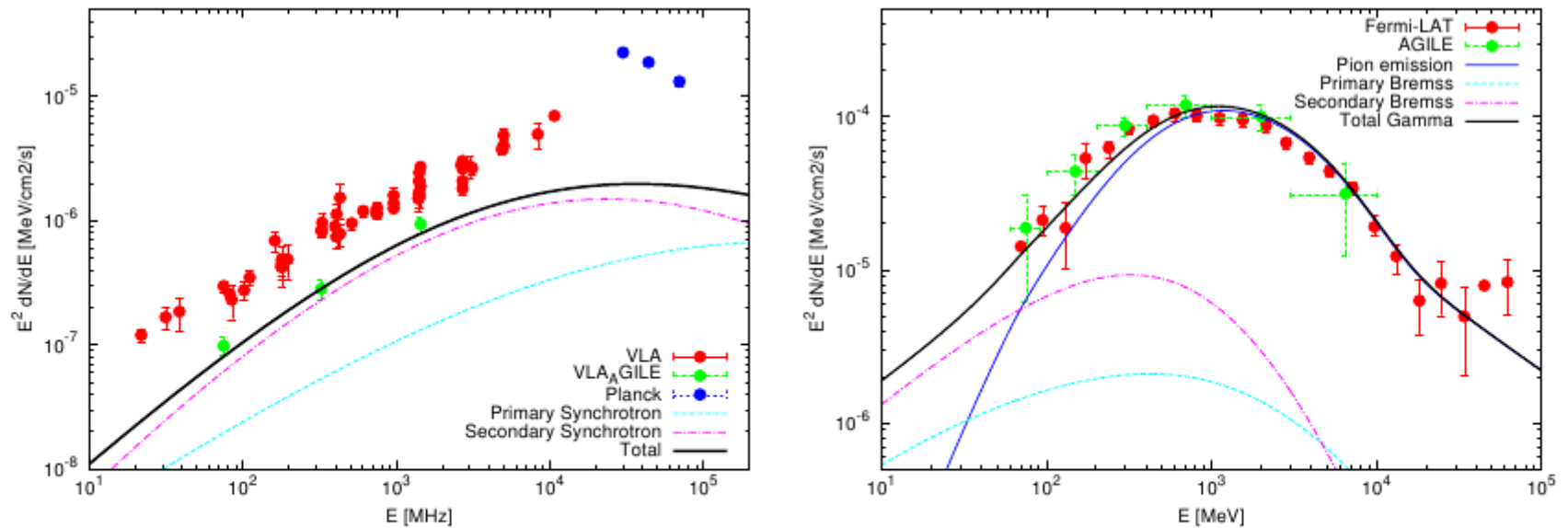
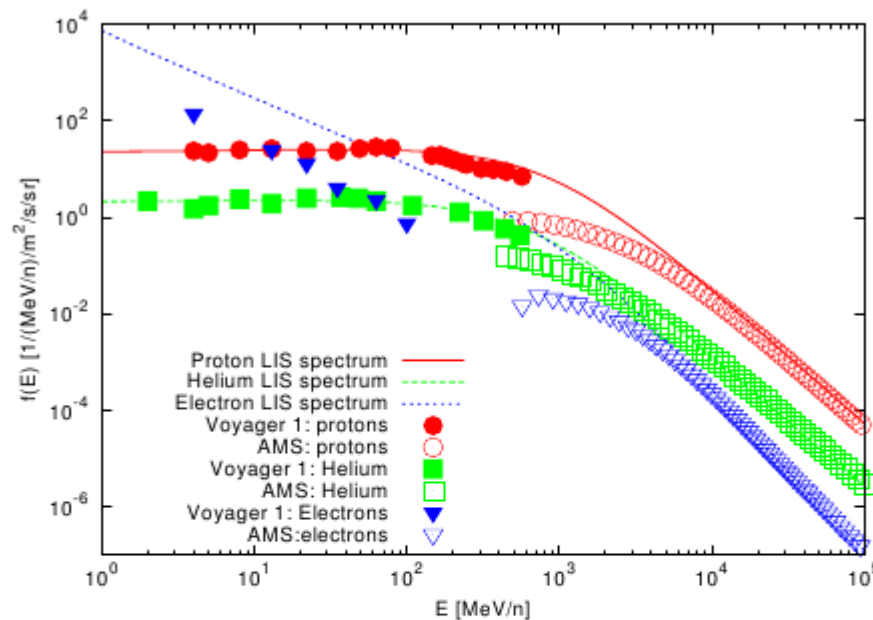


Fig. 3. **Left:** VLA (red) and Planck (blue) radio data from the whole remnant (Castelletti et al. 2007; Planck collaboration 2014) and VLA radio data from the high-energy emitting region (green), plotted together with primary (cyan dashed line), secondary (magenta dot-dashed line) and total (black line) synchrotron radio emission obtained in our best fit reacceleration model. **Right:** AGILE (green) and Fermi-LAT (red) γ -ray points (Cardillo et al. 2014; Ackermann et al. 2013) plotted with γ -ray emission from pion decay (blue dotted line), emission due to bremsstrahlung of primary (cyan dashed line) and secondary (magenta dot-dashed line) electrons, and total emission (black line).



Cardillo etal 2016

Fig. 1. Protons (red), Helium (green) and electrons (blue) spectra. Cir-

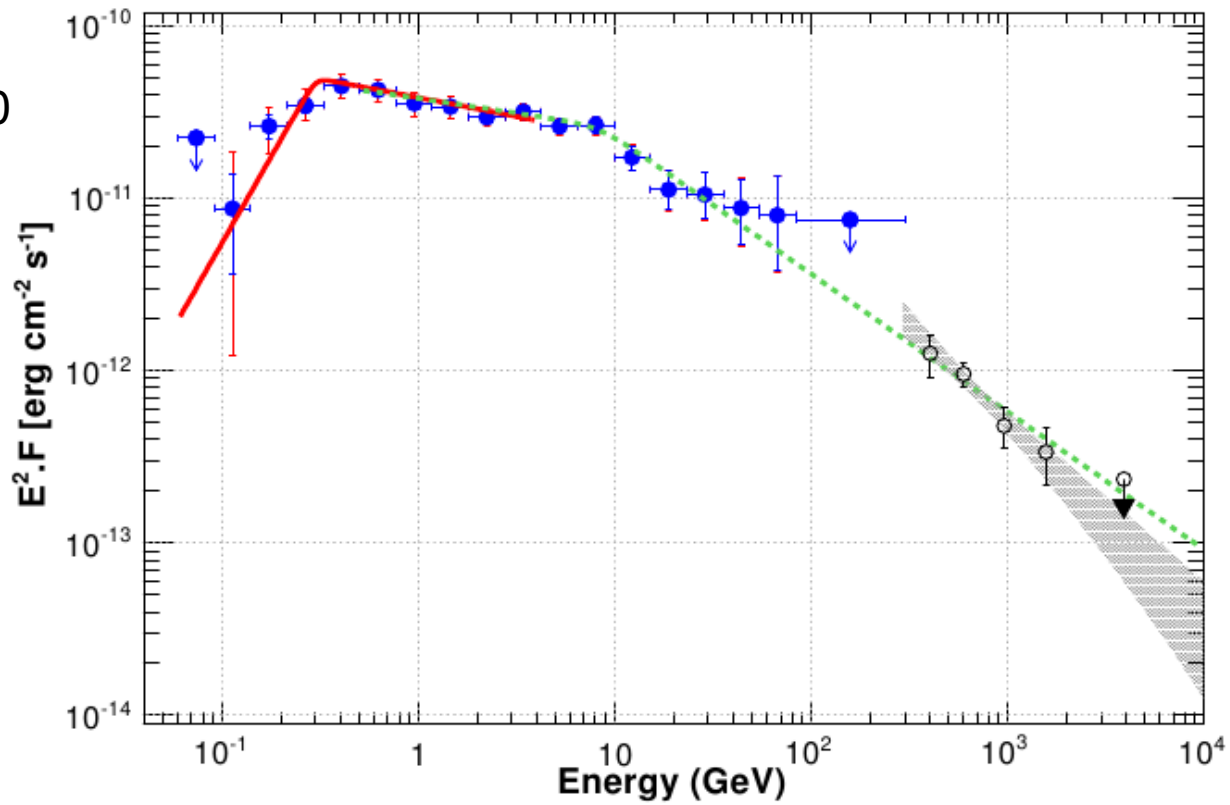
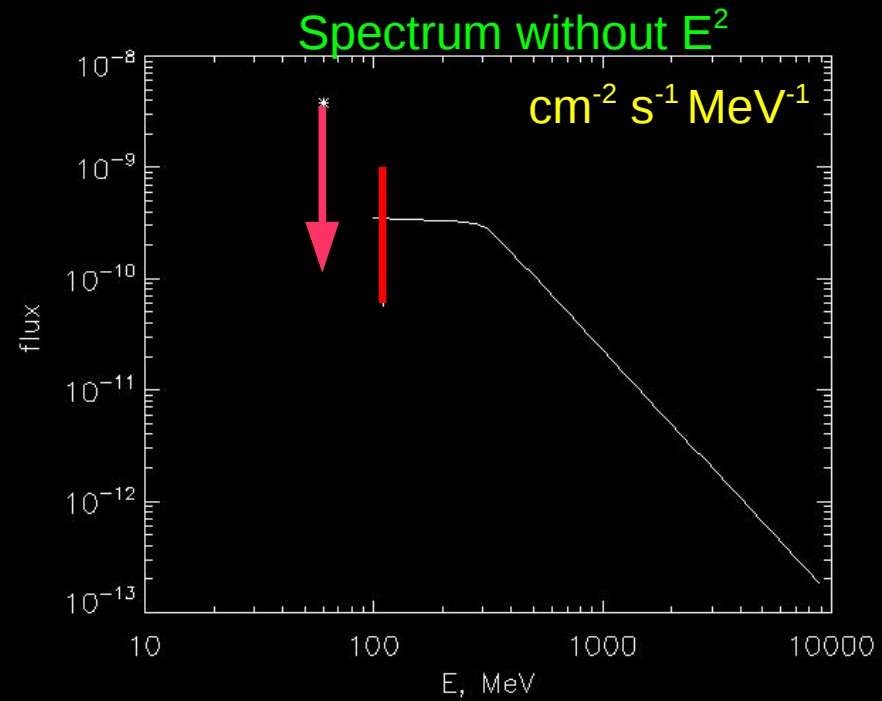
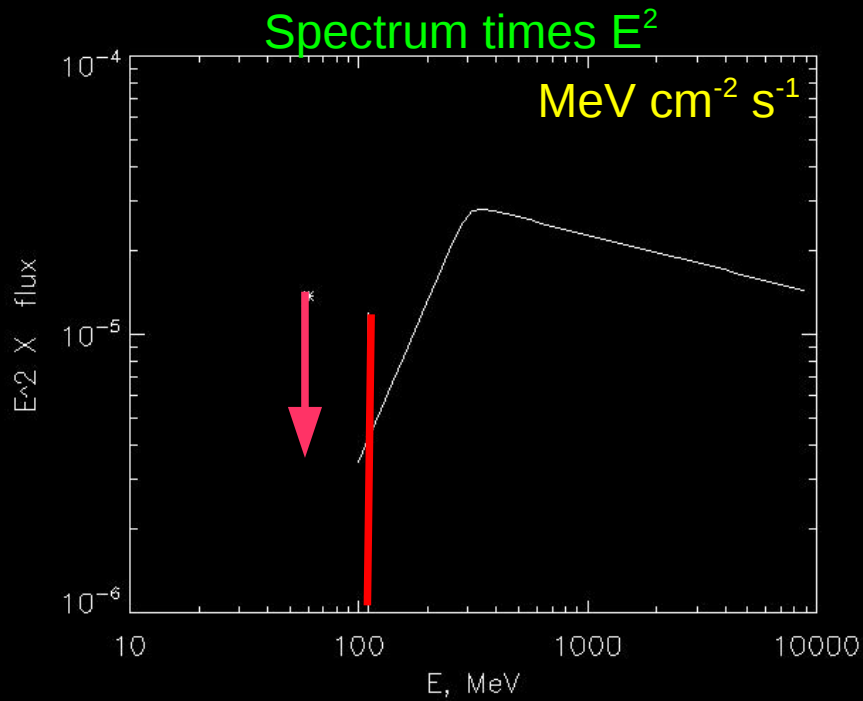
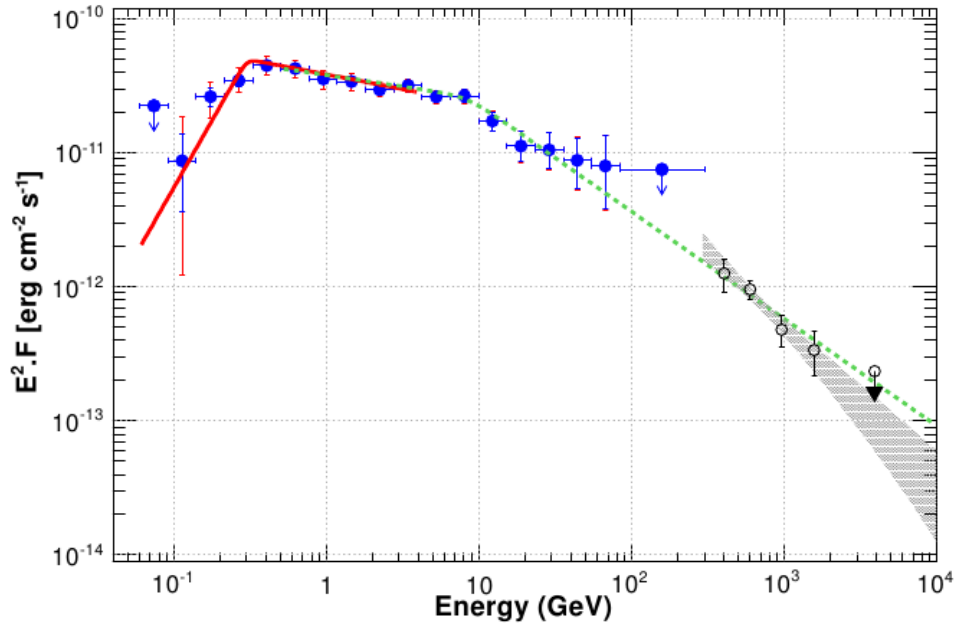
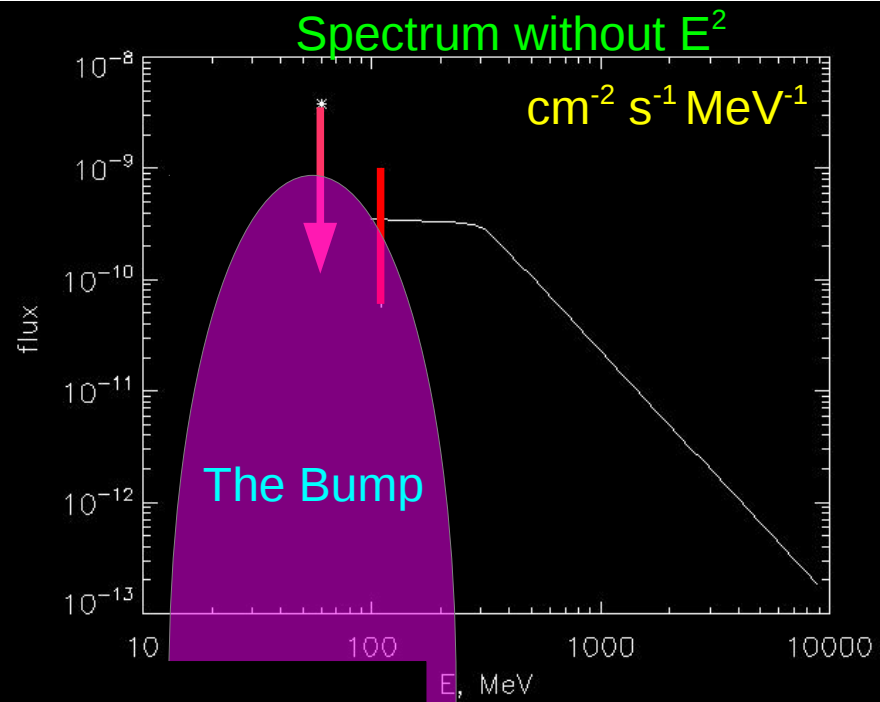
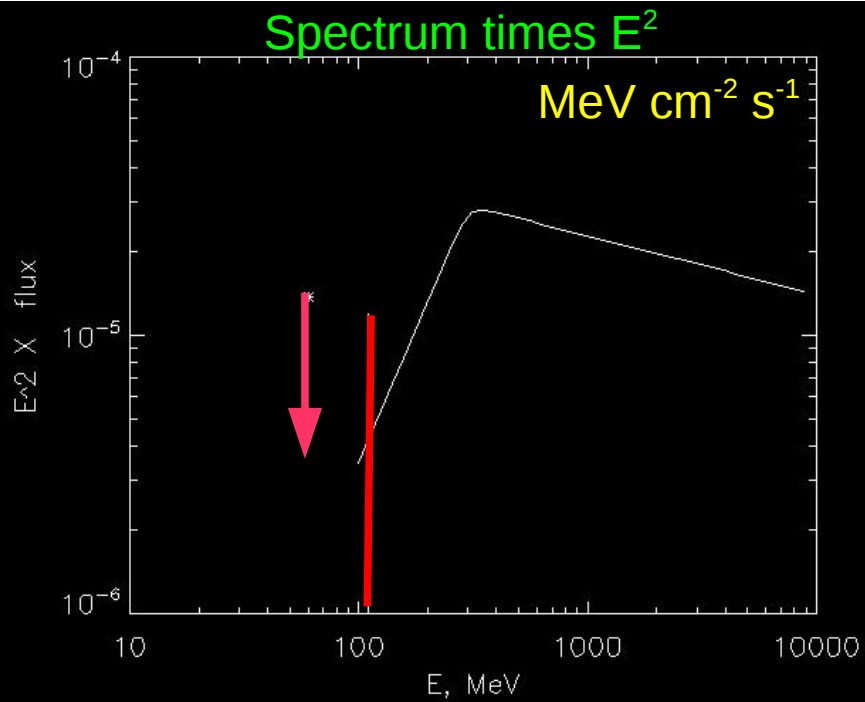
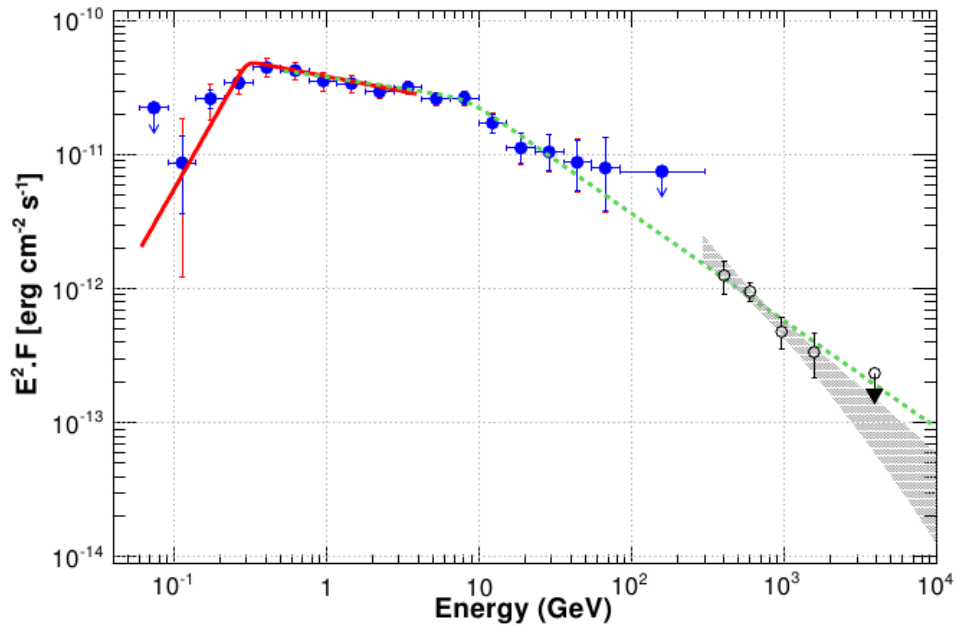


Fig. 3. *Fermi*-LAT and H.E.S.S. spectrum of W49B. The red line shows the best fit of a smoothly broken power-law derived between 60 MeV and 4 GeV and the blue data points indicate the fluxes measured in each energy bin with the *Fermi*-LAT. The statistical errors are shown in blue, while the red lines take into account both the statistical and systematic errors as discussed in Sect. 2.2.2. The gray band shows the 68% confidence level (CL) uncertainty of the best-fit power-law model with H.E.S.S. The open black circles are the spectral points computed from the forward-folding fit with their statistical errors shown in black. For both instruments, a 95% CL upper limit is computed when the statistical significance is lower than 2σ . The dotted green line shows the best smoothly broken power-law model obtained from the joint fit of the *Fermi*-LAT and H.E.S.S. data between 500 MeV and 10 TeV, as described in Sect. 2.3.





W49B

Fermi + H.E.S.S.

arXiv: 1609.00900

2 Sept 2016

A&A in press

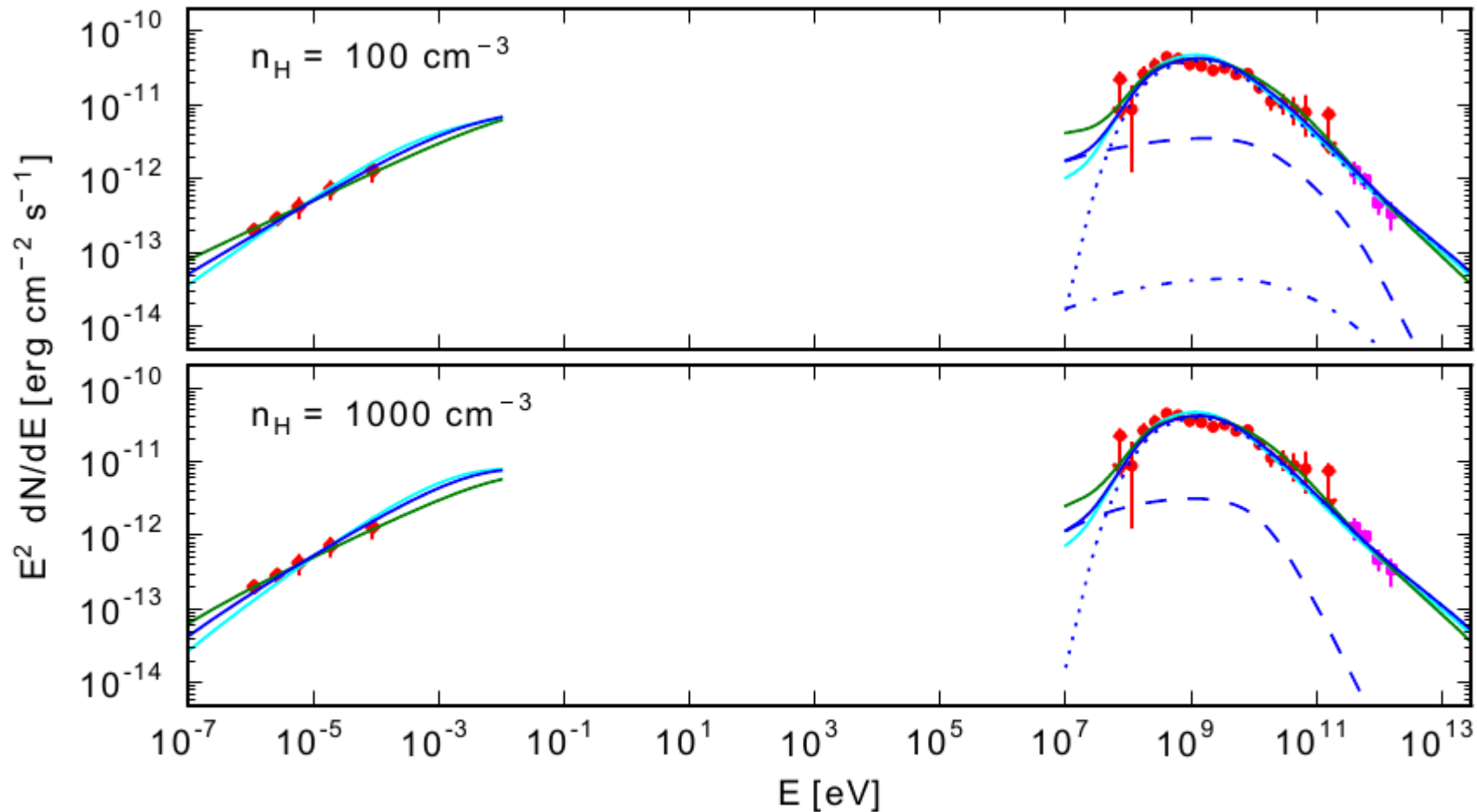


Fig. 5. SEDs of W49B with model curves for the hadronic-dominant scenario. The upper and the lower panels show (a1–3) and (a4–6) respectively (see Table 2). The red diamonds, red circles, and magenta squares represent observed data in the radio (Moffett & Reynolds 1994), LAT, and H.E.S.S. bands respectively. The radio emission is explained by the synchrotron radiation from the relativistic electrons. The γ -ray emission can be decomposed into π^0 -decay (dotted line), bremsstrahlung (dashed line), and IC scattering (dot-dashed line). The solid line represents the total flux of the components. The cases (a1)/(a4), (a2)/(a5), and (a3)/(a6) are represented by cyan, blue, and green lines respectively in the upper/lower panel. The decomposed emissions are shown for the cases (a2) and (a5) in the upper and the lower panels respectively.

DEEP MORPHOLOGICAL AND SPECTRAL STUDY OF THE SNR RCW 86 WITH *FERMI*-LAT

M. AJELLO², L. BALDINI^{3,4}, G. BARBIELLINI^{5,6}, D. BASTIERI^{7,8}, R. BELLAZZINI⁹, E. BISSALDI¹⁰, E. D. BLOOM⁴, R. BONINO^{11,12}, E. BOTTACINI⁴, T. J. BRANDT¹³, J. BREGEON¹⁴, P. BRUEL¹⁵, R. BUEHLER¹⁶, G. A. CALIANDRO^{4,17}, R. A. CAMERON⁴, M. CARAGIULO^{18,10,1}, E. CAVAZZUTI¹⁹, E. CHARLES⁴, A. CHEKHTMAN²⁰, S. CIPRINI^{19,21}, J. COHEN-TANUGI¹⁴, B. CONDON^{22,1}, F. COSTANZA¹⁰, S. CUTINI^{19,23,21}, F. D'AMMANDO^{24,25}, F. DE PALMA^{10,26}, R. DESIANTE^{27,11}, N. DI LALLA⁹, M. DI MAURO⁴, L. DI VENERE^{18,10}, P. S. DRELL⁴, G. DUBNER²⁸, D. DUMORA²², L. DUVIDOVICH²⁸, C. FAVUZZI^{18,10}, W. B. FOCKE⁴, P. FUSCO^{18,10}, F. GARGANO¹⁰, D. GASPARRINI^{19,21}, E. GIACANI²⁸, N. GIGLIETTO^{18,10}, T. GLANZMAN⁴, D. A. GREEN²⁹, I. A. GRENIER³⁰, S. GUIRIEC^{13,31}, E. HAYS¹³, J.W. HEWITT³², A. B. HILL^{33,4}, D. HORAN¹⁵, T. JOGLER⁴, G. JÓHANNESSEN³⁴, I. JUNG-RICHARDT³⁵, S. KENSEI³⁶, M. KUSS⁹, S. LARSSON^{37,38}, L. LATRONICO¹¹, M. LEMOINE-GOUMARD^{22,1}, J. LI³⁹, L. LI^{37,38}, F. LONGO^{5,6}, F. LOPARCO^{18,10}, M. N. LOVELLETTE⁴⁰, P. LUBRANO²¹, J. MAGILL⁴¹, S. MALDERA¹¹, A. MANFREDA⁹, M. MAYER¹⁶, M. N. MAZZIOTTA¹⁰, J. E. MCENERY^{13,41}, P. F. MICHELSON⁴, W. MITTHUMSIRI⁴², T. MIZUNO⁴³, M. E. MONZANI⁴, A. MORSELLI⁴⁴, I. V. MOSKALENKO⁴, M. NEGRO^{11,12}, E. NUSS¹⁴, M. ORIENTI²⁴, E. ORLANDO⁴, J. F. ORMES⁴⁵, D. PANEQUE^{46,4}, J. S. PERKINS¹³, M. PESCE-ROLLINS^{9,4}, F. PIRON¹⁴, G. PIVATO⁹, T. A. PORTER⁴, S. RAINÒ^{18,10}, R. RANDO^{7,8}, M. RAZZANO^{9,47}, A. REIMER^{48,4}, O. REIMER^{48,4}, T. REPOSEUR²², J. SCHMID³⁰, A. SCHULZ¹⁶, C. SGRÒ⁹, D. SIMONE¹⁰, E. J. SISKIND⁴⁹, F. SPADA⁹, G. SPANDRE⁹, P. SPINELLI^{18,10}, J. B. THAYER⁴, L. TIBALDO⁵⁰, D. F. TORRES^{39,51}, G. TOSTI^{21,52}, E. TROJA^{13,41}, Y. UCHIYAMA⁵³, G. VIANELLO⁴, J. VINK⁵⁴, K. S. WOOD⁴⁰, M. YASSINE¹⁴

Draft version January 26, 2016

ABSTRACT

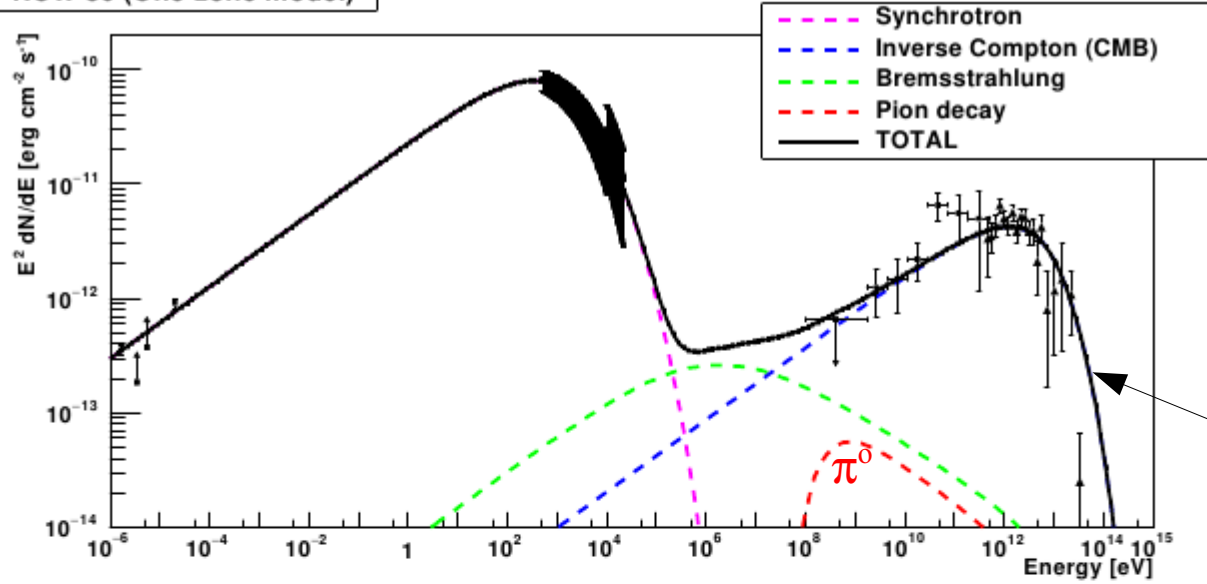
RCW 86 is a young supernova remnant (SNR) showing a shell-type structure at several wavelengths and is thought to be an efficient cosmic-ray (CR) accelerator. Earlier *Fermi* Large Area Telescope results reported the detection of γ -ray emission coincident with the position of RCW 86 but its origin (leptonic or hadronic) remained unclear due to the poor statistics. Thanks to 6.5 years of data acquired by the *Fermi*-LAT and the new event reconstruction Pass 8, we report the significant detection of spatially extended emission coming from RCW 86. The spectrum is described by a power-law function with a very hard photon index ($\Gamma = 1.42 \pm 0.1_{\text{stat}} \pm 0.06_{\text{syst}}$) in the 0.1–500 GeV range and an energy flux above 100 MeV of $(2.91 \pm 0.8_{\text{stat}} \pm 0.12_{\text{syst}}) \times 10^{-11}$ erg cm⁻² s⁻¹. Gathering all the available multiwavelength (MWL) data, we perform a broadband modeling of the nonthermal emission of RCW 86 to constrain parameters of the nearby medium and bring new hints about the origin of the γ -ray emission. For the whole SNR, the modeling favors a leptonic scenario in the framework of a two-zone model with an average magnetic field of 10.2 ± 0.7 μ G and a limit on the maximum energy injected into protons of 2×10^{49} erg for a density of 1 cm⁻³. In addition, parameter values are derived for the North-East (NE) and South-West (SW) regions of RCW 86, providing the first indication of a higher magnetic field in the SW region.

RCW 86

7.2. Modeling of the whole SNR

Here we present the results of two leptonic scenario models. Since a pure hadronic scenario requires unlikely parameter values such as a very hard spectral index for protons (as it was already suggested in Lemoine-Goumard et al. 2012) and a high magnetic field ($B > 100 \mu\text{G}$), we did not consider this case. The presence of a high magnetic field is not excluded in very thin regions, near the shock, but it is very unlikely to have such high values for the whole remnant. Moreover, a spectral index softer than 1.7 is excluded with more than 3σ , as described in Section 3.2. The hadronic model re-

RCW 86 (One-zone model)



Inverse Compton dominates

RCW 86 (Two-zone model)

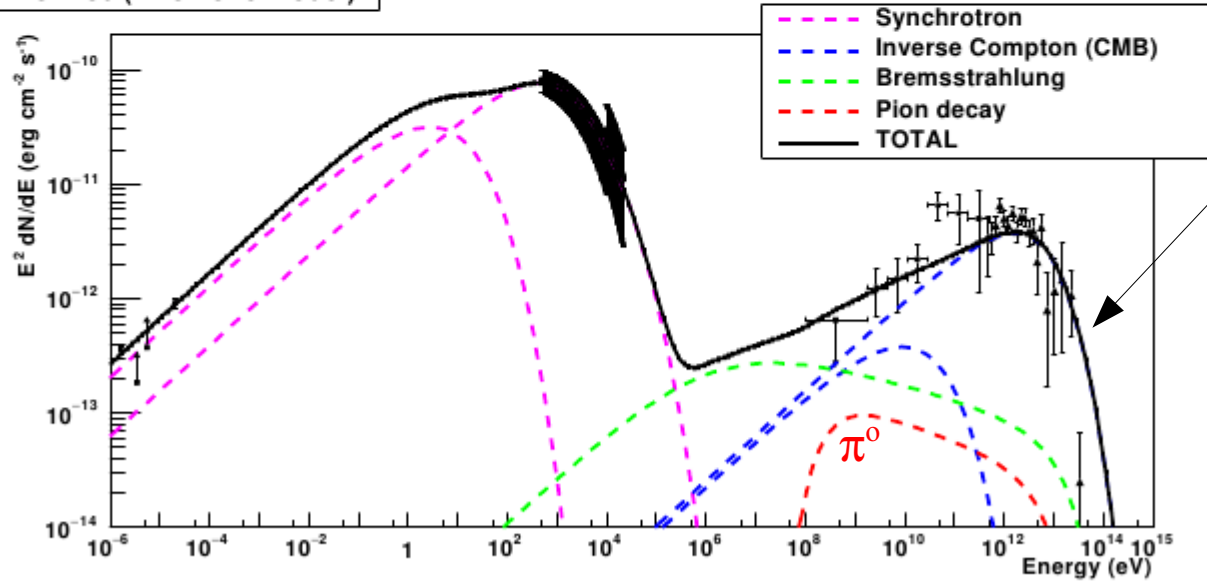


FIG. 9.— Spectral Energy Distribution of RCW 86 with the best-fit leptonic one-zone (top) and two-zone (bottom) models. The radio points are from Molonglo at 408 MHz and Parkes at 5 GHz (Caswell et al. 1975; Lemoine-Goumard et al. 2012) and lower limits from MOST at 843 MHz and ATCA at 1.43 GHz (Whiteoak & Green 1996; Dickel et al. 2001). X-ray spectra from ASCA and RXTE are from Lemoine-Goumard et al. (2012). The *Fermi*-LAT spectral points and upper limits (95% C.L.) derived in Section 3.2 and the H.E.S.S. data points in the VHE γ -ray domain from Abramowski et al. (2015) are also shown.

Moral:

Fit to hadronic models but don't call it the Pion Bump or even Pion Rise!

Need multiwavelength models to show hadronic origin, and this is of course done.

See Leonardo di Venere and other talks for SNR details.

11 things which are taken as proven but are not and deserve further investigation
“It is well known that”:

- 1 The Pion Bump has been detected in SNR
- 2 CR are extragalactic only $>10^{15}$ eV or so**
- 3 CR cannot come from the Galactic Centre only
- 4 The CR gradient in the Galaxy can be determined accurately
- 5 The spectrum of CR in the Galaxy has the same shape as the local spectrum
- 6 Reacceleration is a viable explanation of the B/C peak (Luke's talk)
- 7 Secondary production in sources is negligible (including B, positrons)
- 8 ^{60}Fe tells about CR age, delay (from gammas ^{60}Fe is everywhere in ISM)
- 9 Positron/pbar ratio agrees with standard model (no: Lipari paper)
- 10 Diffuse Galactic emission is mainly interstellar not unresolved sources
- 11 CR are not important for galaxy evolution

THE ASTROPHYSICAL JOURNAL, 174:253-291, 1972 June 1

© 1972. The American Astronomical Society. All rights reserved. Printed in U.S.A.

1972

EXTRAGALACTIC COSMIC RAYS

K. BRECHER AND G. R. BURBIDGE

Department of Physics, University of California, San Diego

Received 1971 September 27; revised 1971 December 28

ABSTRACT

A detailed analysis is given of the possibility that a large part of the primary cosmic-ray flux is of extragalactic origin. Following the introduction, § II contains a critical discussion of problems en-

Thus the limits of the background γ -ray flux only rule out extragalactic cosmic-ray schemes in cosmological models in which mass at a number density of 10^{-5} cm^{-3} exists in the form of diffuse gas in contact with the cosmic rays, or in models in which it is supposed that there was rapid evolution of sources in the past. There is certainly no evidence that gas at a density 10^{-5} cm^{-3} is present (Burbidge 1971), and the evidence for rapid

THE ASTROPHYSICAL JOURNAL, 174:253-291, 1972 June 1

© 1972. The American Astronomical Society. All rights reserved. Printed in U.S.A.

1972

EXTRAGALACTIC COSMIC RAYS

K. BRECHER AND G. R. BURBIDGE

Department of Physics, University of California, San Diego

Received 1971 September 27; revised 1971 December 28

ABSTRACT

A detailed analysis is given of the possibility that a large part of the primary cosmic-ray flux is of extragalactic origin. Following the introduction, § II contains a critical discussion of problems en-

Both gamma-ray and cosmological information have improved! 44 years on ...

Thus the limits of the background γ -ray flux only rule out extragalactic cosmic-ray schemes in cosmological models in which mass at a number density of 10^{-5} cm^{-3} exists in the form of diffuse gas in contact with the cosmic rays, or in models in which it is supposed that there was rapid evolution of sources in the past. There is certainly no evidence that gas at a density 10^{-5} cm^{-3} is present (Burbidge 1971), and the evidence for rapid

The gamma-ray background: a consequence of metagalactic cosmic ray origin?

J. Phys. A, 7, 120 (1974)



A W Strong, J Wdowczyk† and A W Wolfendale

Physics Department, University of Durham, South Road, Durham City, UK

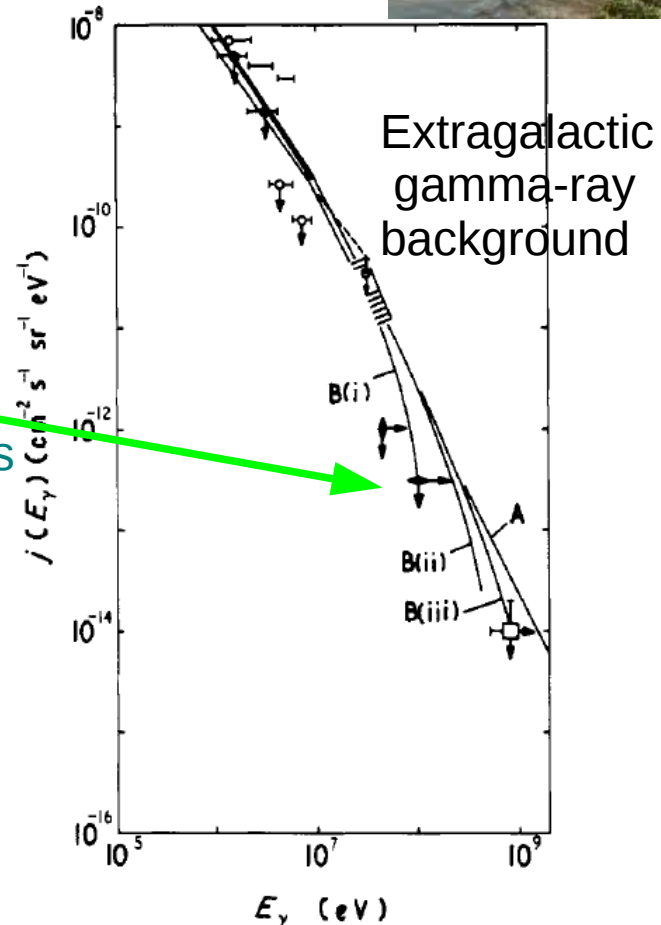
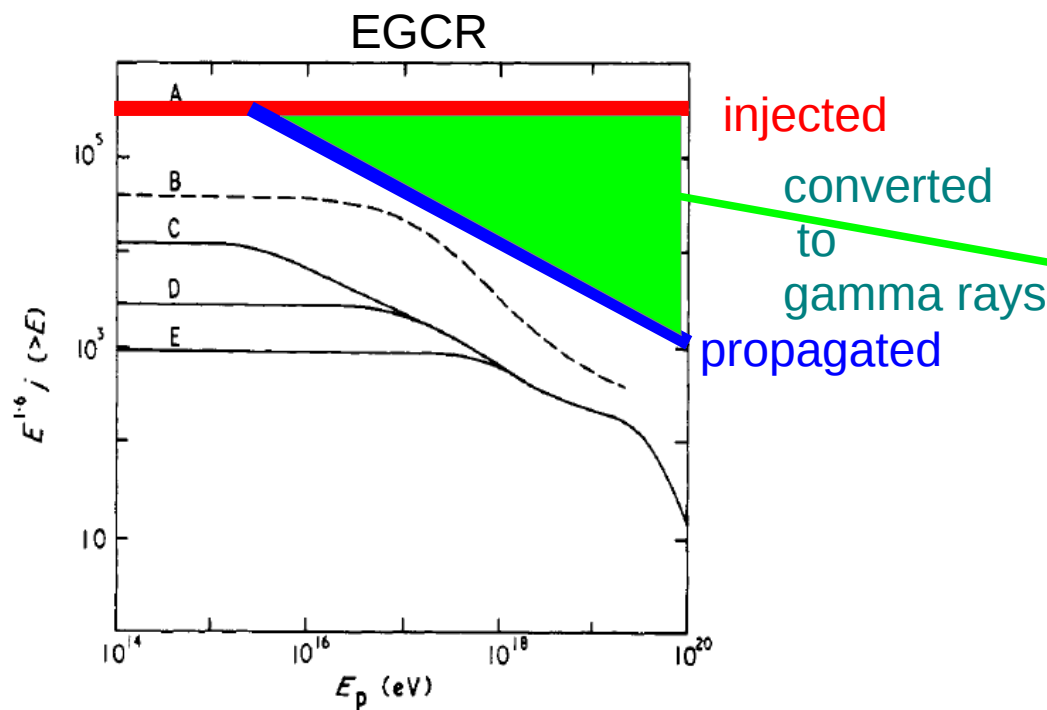


Figure 1. Primary spectra on Hillas' theory for various parameters, compared with (normalized) experimental summary. Curve A, experimental; B, $z_D = 10$; C, $z_m = 3$ and E, $z_m = 1$. Power law evolution: $\beta = 4.5$, exponential evolution: $(1 + z_D)z(1 + z)^{-1}$.

Figure 3. Gamma-ray spectrum expected from Hillas' model

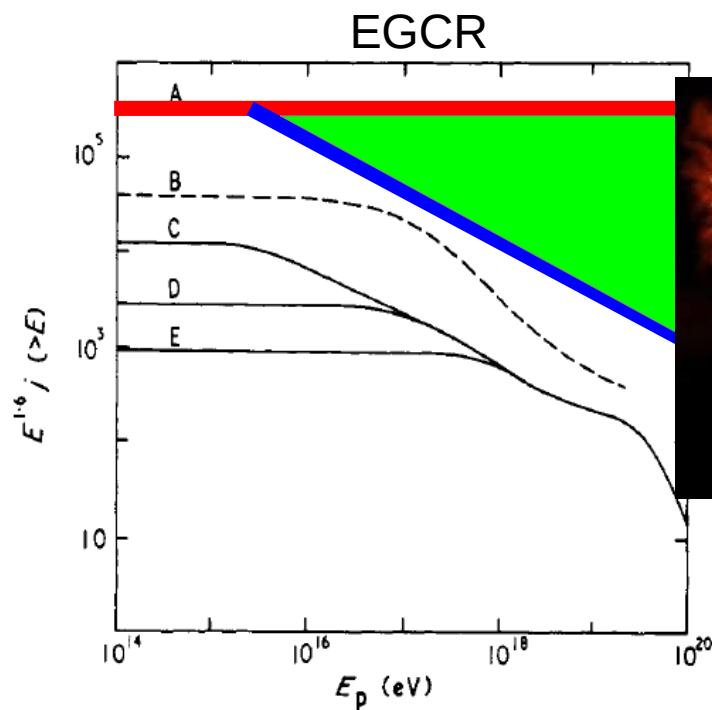
Universal EGCR, $z_{max}=15$, protons $> 10^{15}$ eV, EM cascades, source evolution
 Produces CR spectral break, energy \rightarrow gamma rays, provides the normalization!

The gamma-ray background: a consequence of metagalactic cosmic ray origin?

J. Phys. A, 7, 120 (1974)

A W Strong, J Wdowczyk† and A W Wolfendale

Physics Department, University of Durham, South Road, Durham City, UK



See later

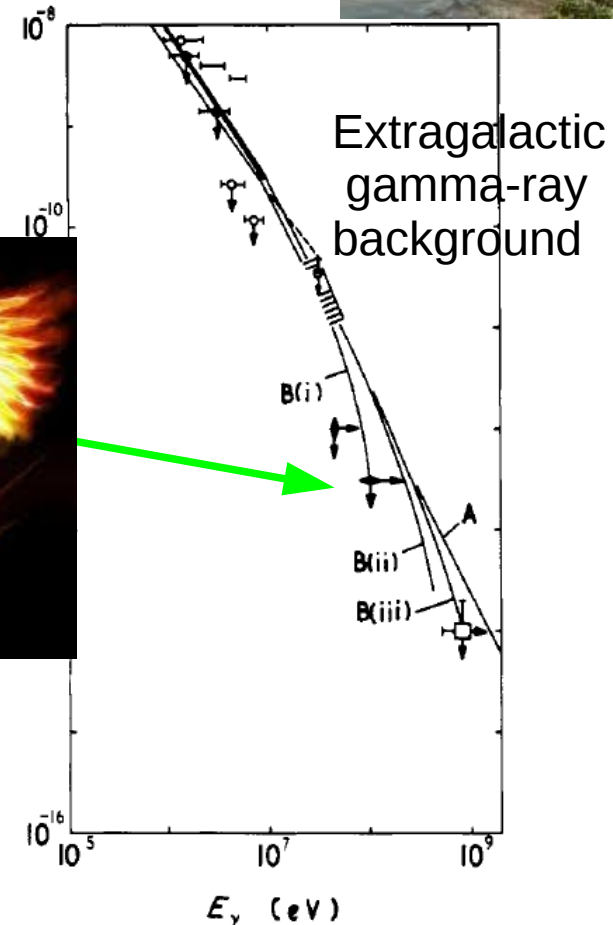


Figure 1. Primary spectra on Hillas' theory for various parameters, compared with (normalized) experimental summary. Curve A, experimental; B, $z_D = 10$; C, $z_m = 3$ and D, $z_m = 3$ and E, $z_m = 1$. Power law evolution: $\beta = 4.5$, exponential evolution: $(1 + z_D)z(1 + z)^{-1}$.

Figure 3. Gamma-ray spectrum expected from Hillas' model

Universal EGCR, $z_{max}=15$, protons $> 10^{15}$ eV, EM cascades, source evolution
 Produces CR spectral break, energy \rightarrow gamma rays, provides the normalization!

CR are extragalactic only $>10^{15}$ eV or so **REALLY?**

Heresy:

Universal CR theory Brecher&Burbidge 1972

Classical proof: pion-decay gammas would violate observations of EGB !

Back-of-envelope calculation:

Galactic gamma-ray emissivity for π^0 : $q(>100 \text{ MeV}) \sim 10^{-25} \text{ atom}^{-1} \text{ s}^{-1}$

IGM matter density $n \sim 10^{-7} \text{ atoms cm}^{-3}$ (see next slide)

Hubble distance $L \sim 10^{28} \text{ cm}$

Flux($>100 \text{ MeV}$) = $(q/4\pi) n L \sim 10^{-5} \text{ cm}^{-2} \text{ sr}^{-1} \text{ s}^{-1}$

Close to IGRB observed! But known to be mainly AGN.

Need to look at those numbers more closely!

But what is IGM matter density? Lower limit from normal galaxies,
But they certainly contribute at percent level to EGB even though
CR probably similar to MW.

Also CR gradients in Galaxy: but how solid are they

Small gradient has stimulated models, EGCR would solve the problem

Problem with CR secondaries?

They are Galactic certainly, but that does not exclude that primaries are extragalactic.

IGM gas from QSO UV absorption lines

Neeleman et al ApJ 818, 113 (2016)

$z < 0.6$

$$0.25^{+0.2}_{-.12} 10^8 M_{\text{sun}} \text{ Mpc}^{-3}$$

$$\rightarrow 10^{-9} \text{ atoms cm}^{-3}$$

Typical column densities 10^{20} cm^{-2}

cf Galactic halo so similar to EGB, Galactic high-latitudes

But from CMB, BBN: 10^{-7} cm^{-3} NB not directly observed but theory solid

'Missing baryons problem': WHIM too hot to observe easily

but at least 50% seen in clusters, etc so not critical to IGRB calculation

At any rate for $E > 10^{12} \text{ eV}$ CR can be EG



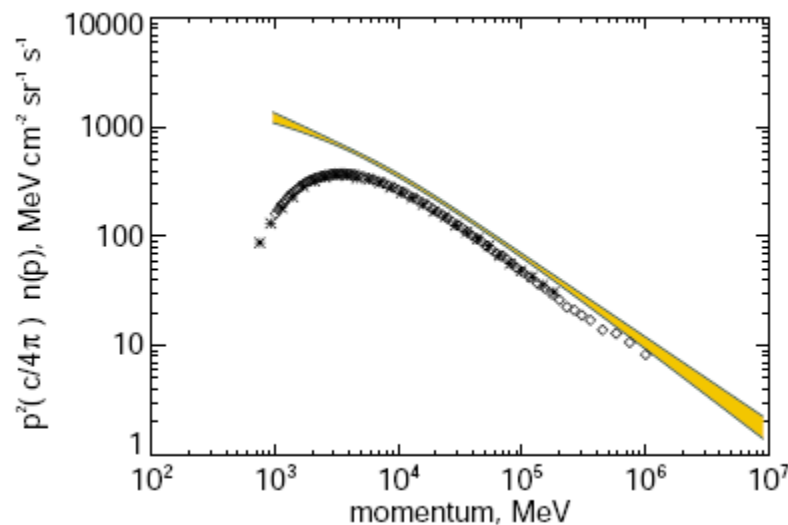
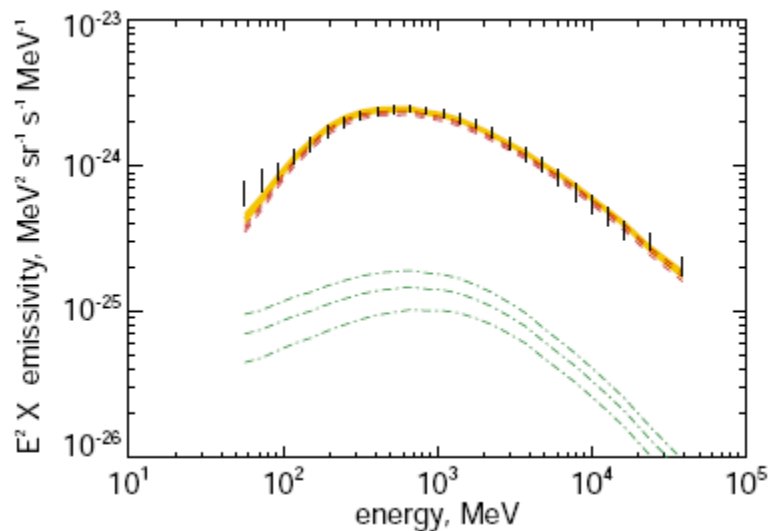
Interstellar Cosmic ray spectra derived from gamma rays

Method : Bayesian analysis (Strong et al. arXiv:1507.05006)

Gamma-ray gas emissivity

used to derive

Cosmic-ray protons via pion-decay



Below 10 GeV affected by solar modulation, but gamma rays probe the **interstellar** spectrum.

Emissivity of local interstellar gas – Jean-Marc Casandjian (Fermi-LAT Collab).

Power-law in momentum overall, but low-energy break

e.g. from power-law injection and interstellar propagation (diffusion = $f(E)$)

Extragalactic gamma-ray background from Fermi-LAT

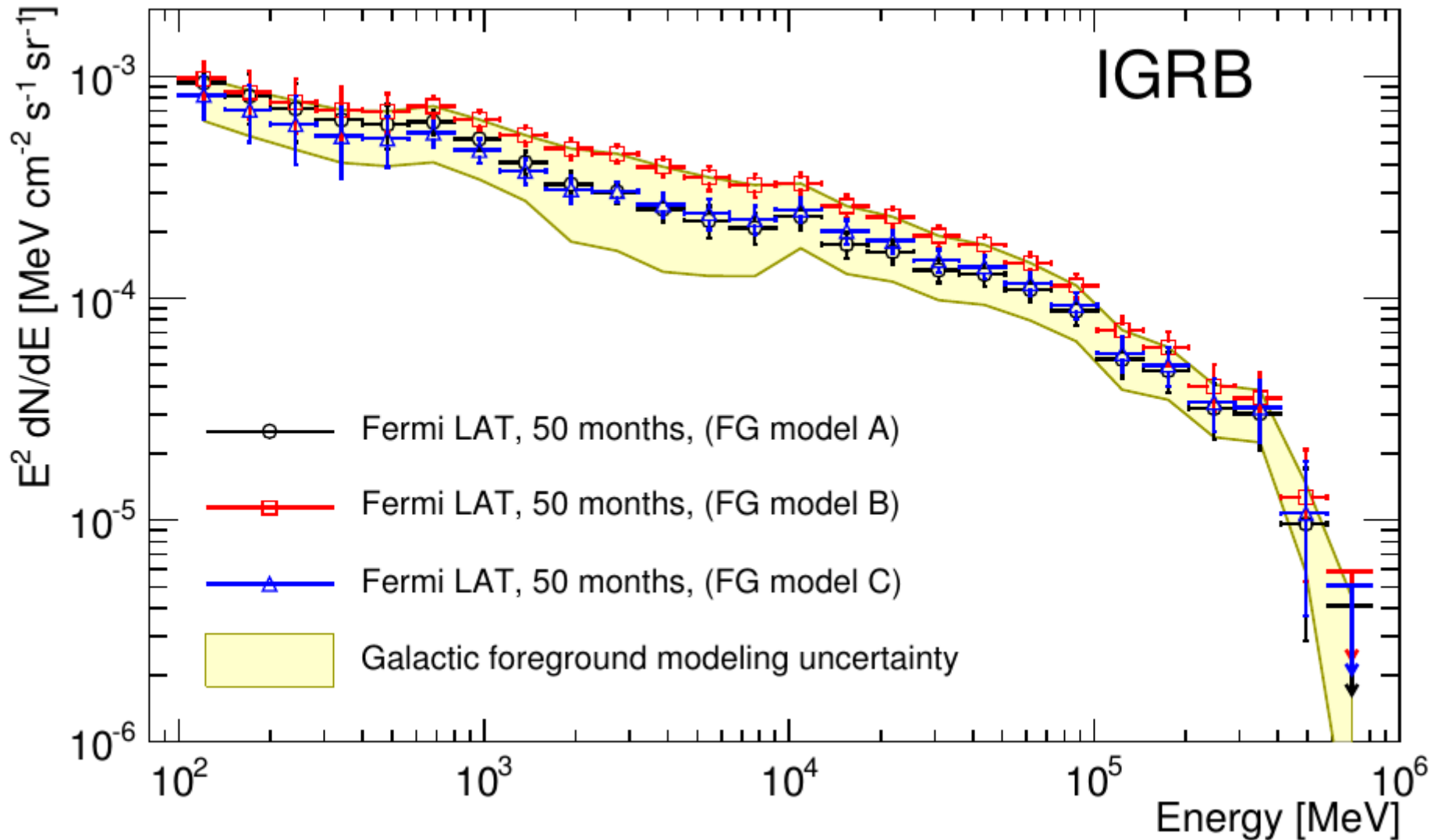
Ackermann et al 2015

IGRB = radiation not from (yet) detected sources

Time-dependent, decreases as detections go deeper

Appropriate for comparison with non-source components

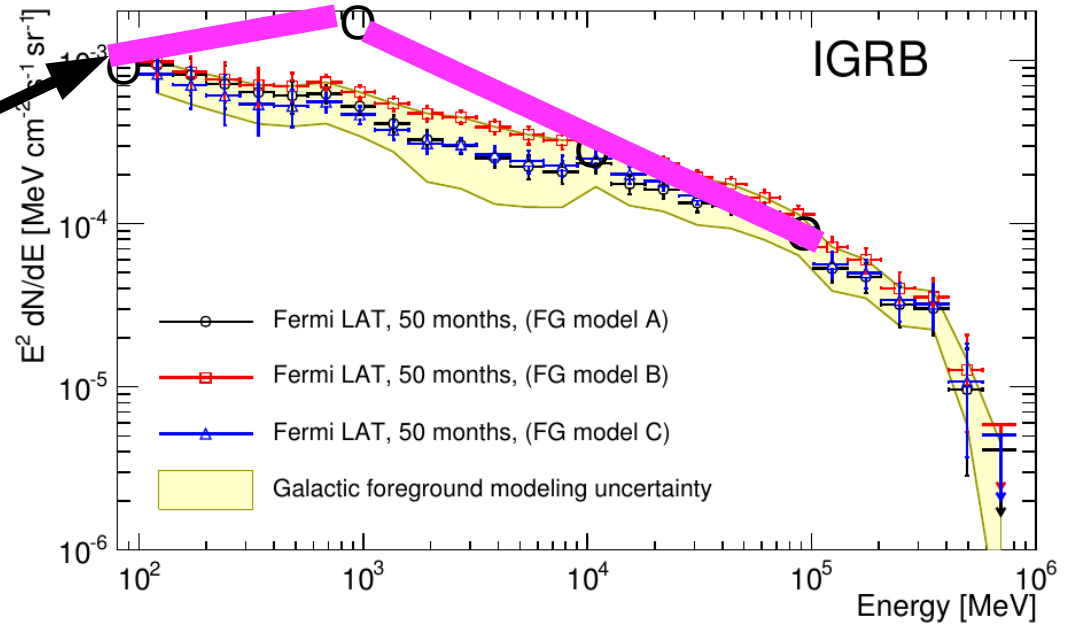
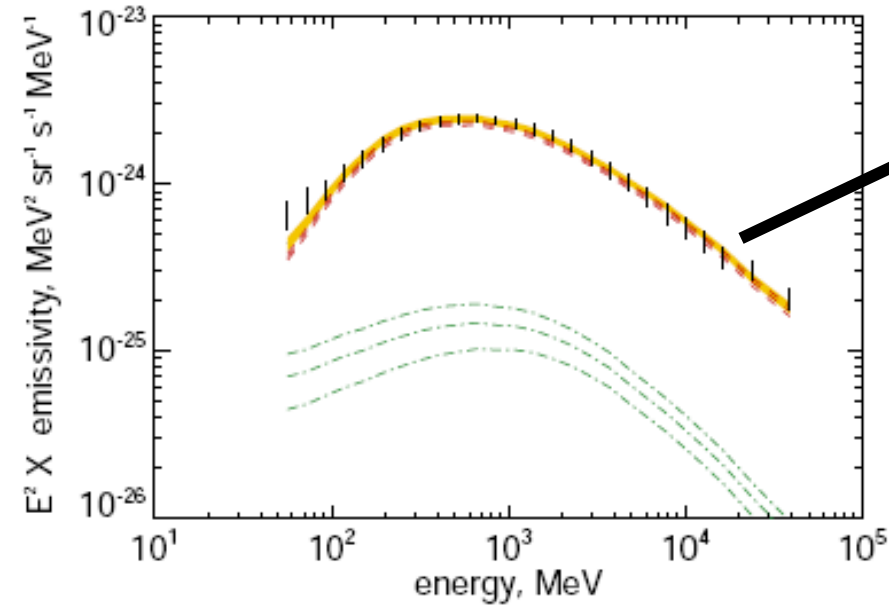
IGRB < EGB (total intergalactic photon field)



What if CR were universal?

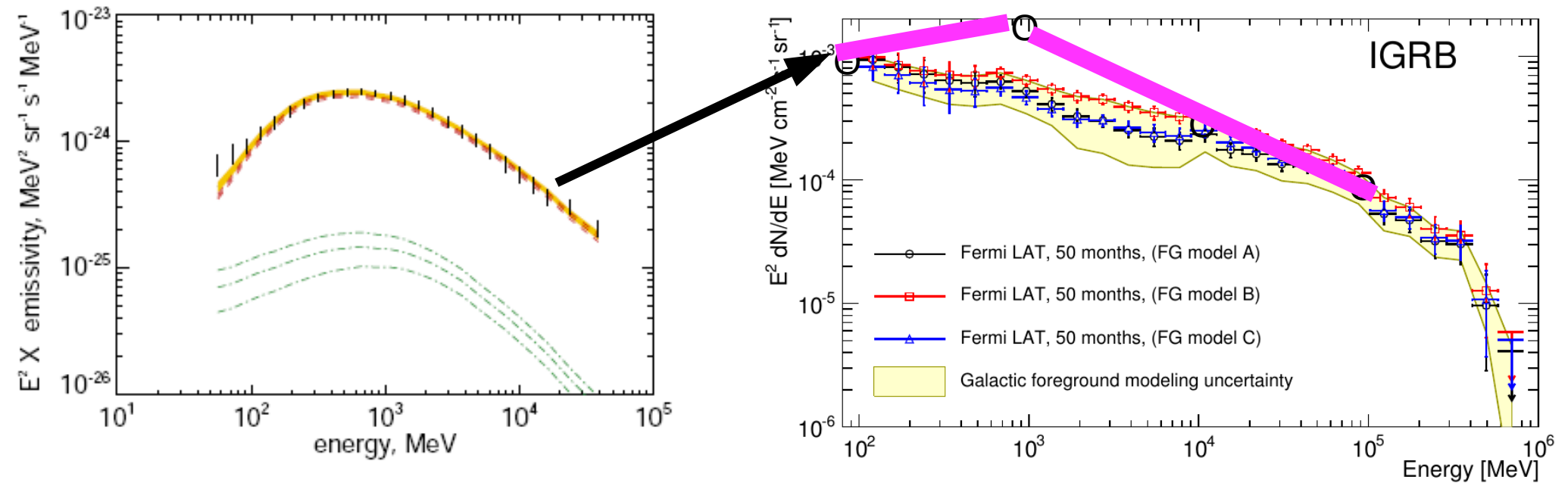
Local gamma-ray emissivity per atom

IGRB from Fermi-LAT



Extragalactic intensity \sim Hubble distance \times gas density \times emissivity
 $= 10^{28} \text{ cm} \times 10^{-7} \text{ cm}^{-3} \times \text{emissivity} = 10^{21} \times \text{emissivity}$

E MeV	$E^2 \times \text{emissivity}$	$E^2 \times \text{extragalactic intensity}$
10^2	1×10^{-24}	1×10^{-3}
10^3	2×10^{-24}	2×10^{-3}
10^4	4×10^{-25}	4×10^{-4}
10^5	1×10^{-25}	1×10^{-4}



But IGRB thought to be mainly AGN etc (>80%) so EGCR must be much less than GCR
 $\text{EGCR/GCR} = 5 - 10\%$ still allowed below 1 TeV

Beyond 1 TeV no IGRB measurements (now; any prospects?) so anything goes!!

THE ASTROPHYSICAL JOURNAL, 174:253-291, 1972 June 1

© 1972. The American Astronomical Society. All rights reserved. Printed in U.S.A.

EXTRAGALACTIC COSMIC RAYS

K. BRECHER AND G. R. BURBIDGE

Department of Physics, University of California, San Diego

Received 1971 September 27; revised 1971 December 28

ABSTRACT

A detailed analysis is given of the possibility that a large part of the primary cosmic-ray flux is of extragalactic origin. Following the introduction, § II contains a critical discussion of problems en-

Both gamma-ray and cosmological information have improved! 44 years on:
Intergalactic gas density and gamma-ray background much lower
Constraints on EGCR much stronger but still margin for speculation.

Thus the limits of the background γ -ray flux only rule out extragalactic cosmic-ray schemes in cosmological models in which mass at a number density of 10^{-5} cm^{-3} exists in the form of diffuse gas in contact with the cosmic rays, or in models in which it is supposed that there was rapid evolution of sources in the past. There is certainly no evidence that gas at a density 10^{-5} cm^{-3} is present (Burbidge 1971), and the evidence for rapid

CR Escape from normal galaxies,
luminosity times Hubble time

Using MW luminosity paper Strong et al. ApJL 722, L58 (2010) :

Cosmic-ray proton luminosity of MW Galaxy = 10^{41} erg s⁻¹

Space density of normal galaxies = 10^{-2} per Mpc⁻³

→ 10^{-5} eV cm⁻³

Guaranteed minimum EGCR density!

Energy-dependent escape steepens the Galactic spectrum
But the universe has no boundary so nucleon calorimeter and
reflects the injection spectrum! e.g. 2.3

Aublin & Parizot: A&A 452, 19 (2006)

Holistic model: all CR have same sources!
Escape from normal galaxies.

Global CR index 2.23

EGCR(10^{19} eV)/GCR(10^9 eV) = $2.4 \cdot 10^{27}$

→ GCR/EGCR(1 GeV) = 10^{-5}

Consistent with above estimate.

Cosmic-ray energy spectrum and composition up to the ankle — the case for a second Galactic component

S. Thoudam^{1,2,*}, J.P. Rachen¹, A. van Vliet¹, A. Achterberg¹, S. Buitink³, H. Falcke^{1,4,5}, J.R. Hörandel^{1,4}

arXiv:1605.03111

Cosmic-ray energy spectrum and composition up to the ankle – the case for a second Galactic component

S. Thoudam^{1,2,*}, J.P. Rachen¹, A. van Vliet¹, A. Achterberg¹, S. Buitink³, H. Falcke^{1,4,5}, J.R. Hörandel^{1,4}

arXiv:1605.03111

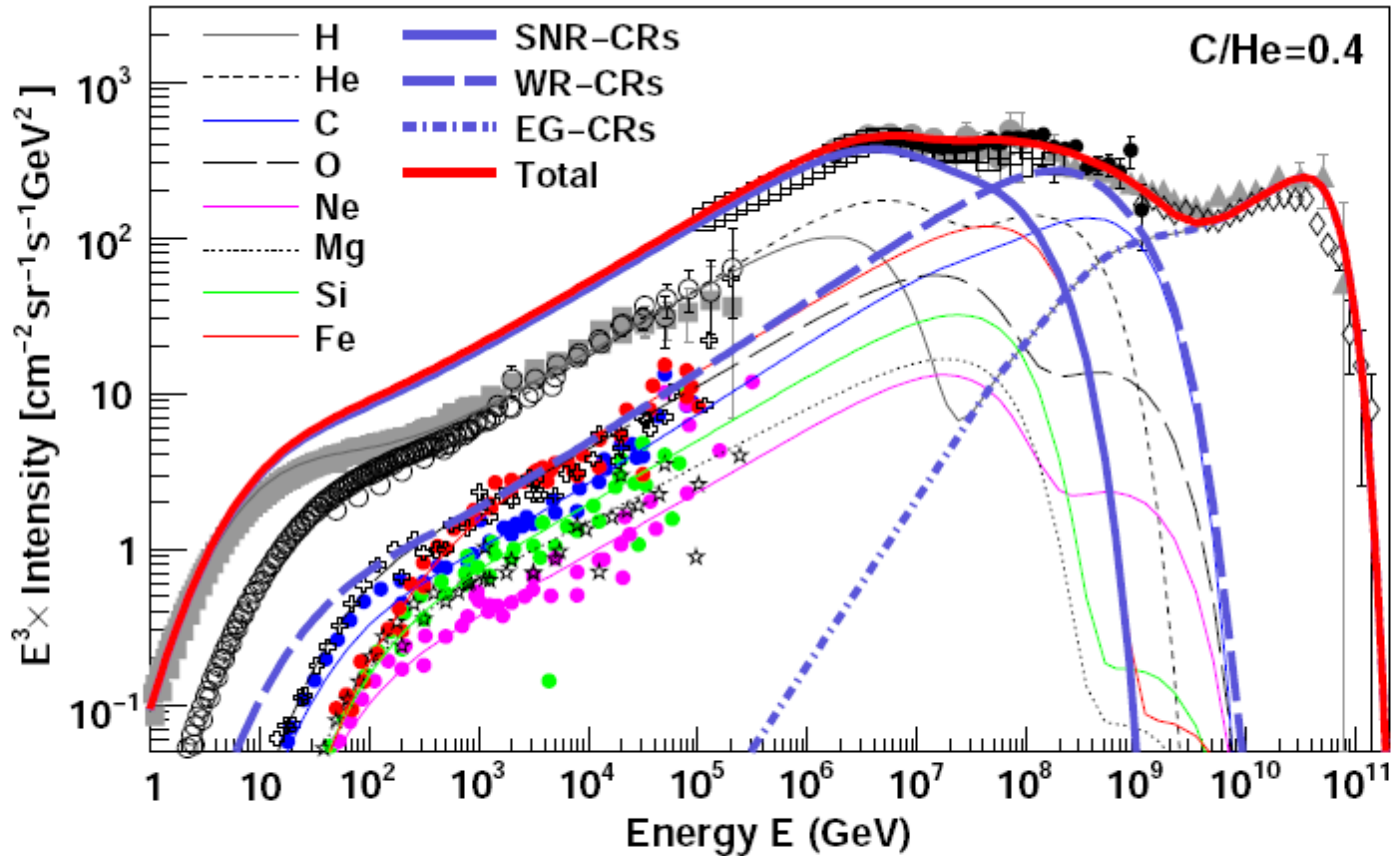


Fig. 6. Model prediction for the all-particle spectrum using the Wolf-Rayet stars model. *Top:* $C/He = 0.1$. *Bottom:* $C/He = 0.4$. The thick solid blue line represents the total SNR-CRs, the thick dashed line represents WR-CRs, the thick dotted-dashed line represents EG-CRs, and the thick solid red line represents the total all-particle spectrum. The thin lines represent total spectra for the individual elements. For the SNR-CRs, an exponential energy cut-off for protons at $E_c = 4.1 \times 10^6$ GeV is assumed. See

Cosmic-ray energy spectrum and composition up to the ankle – the case for a second Galactic component

S. Thoudam^{1,2,*}, J.P. Rachen¹, A. van Vliet¹, A. Achterberg¹, S. Buitink³, H. Falcke^{1,4,5}, J.R. Hörandel^{1,4}

arXiv:1605.03111

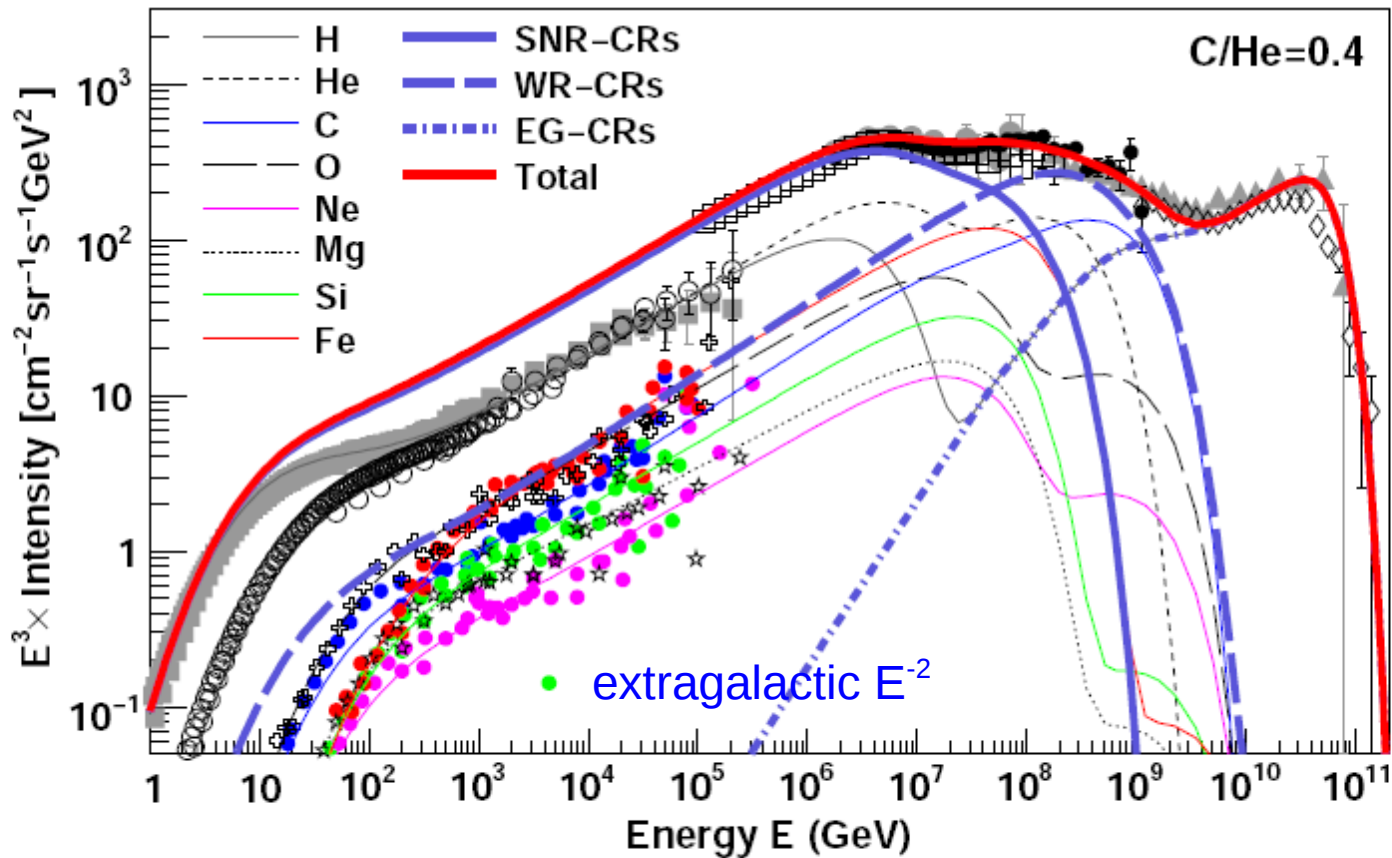


Fig. 6. Model prediction for the all-particle spectrum using the Wolf-Rayet stars model. *Top:* $C/He = 0.1$. *Bottom:* $C/He = 0.4$. The thick solid blue line represents the total SNR-CRs, the thick dashed line represents WR-CRs, the thick dotted-dashed line represents EG-CRs, and the thick solid red line represents the total all-particle spectrum. The thin lines represent total spectra for the individual elements. For the SNR-CRs, an exponential energy cut-off for protons at $E_c = 4.1 \times 10^6$ GeV is assumed. See

WHY extragalactic E^{-2} ?

Cosmic-ray energy spectrum and composition up to the ankle – the case for a second Galactic component

S. Thoudam^{1,2,*}, J.P. Rachen¹, A. van Vliet¹, A. Achterberg¹, S. Buitink³, H. Falcke^{1,4,5}, J.R. Hörandel^{1,4}

arXiv:1605.03111

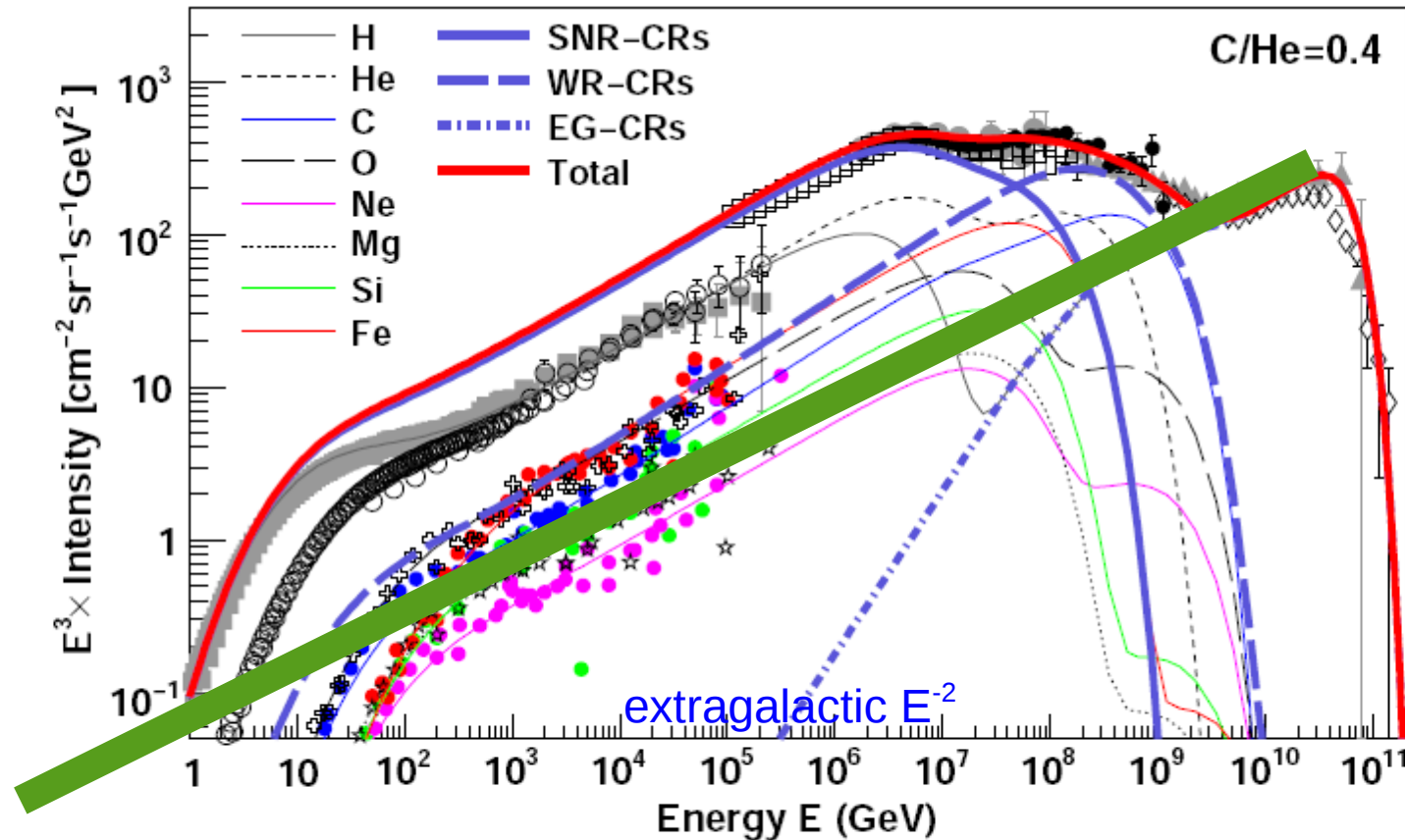


Fig. 6. Model prediction for the all-particle spectrum using the Wolf-Rayet stars model. *Top:* $C/He = 0.1$. *Bottom:* $C/He = 0.4$. The thick solid blue line represents the total SNR-CRs, the thick dashed line represents WR-CRs, the thick dotted-dashed line represents EG-CRs, and the thick solid red line represents the total all-particle spectrum. The thin lines represent total spectra for the individual elements. For the SNR-CRs, an exponential energy cut-off for protons at $E_c = 4.1 \times 10^6$ GeV is assumed. See

WHY not e.g. extragalactic $E^{-2.5}$? then significant EG component down to GeV
EGCR/GCR = 1% at 10 GeV is OK for pion-decay background

Cosmic-ray energy spectrum and composition up to the ankle – the case for a second Galactic component

S. Thoudam^{1,2,*}, J.P. Rachen¹, A. van Vliet¹, A. Achterberg¹, S. Buitink³, H. Falcke^{1,4,5}, J.R. Hörandel^{1,4}

arXiv:1605.03111

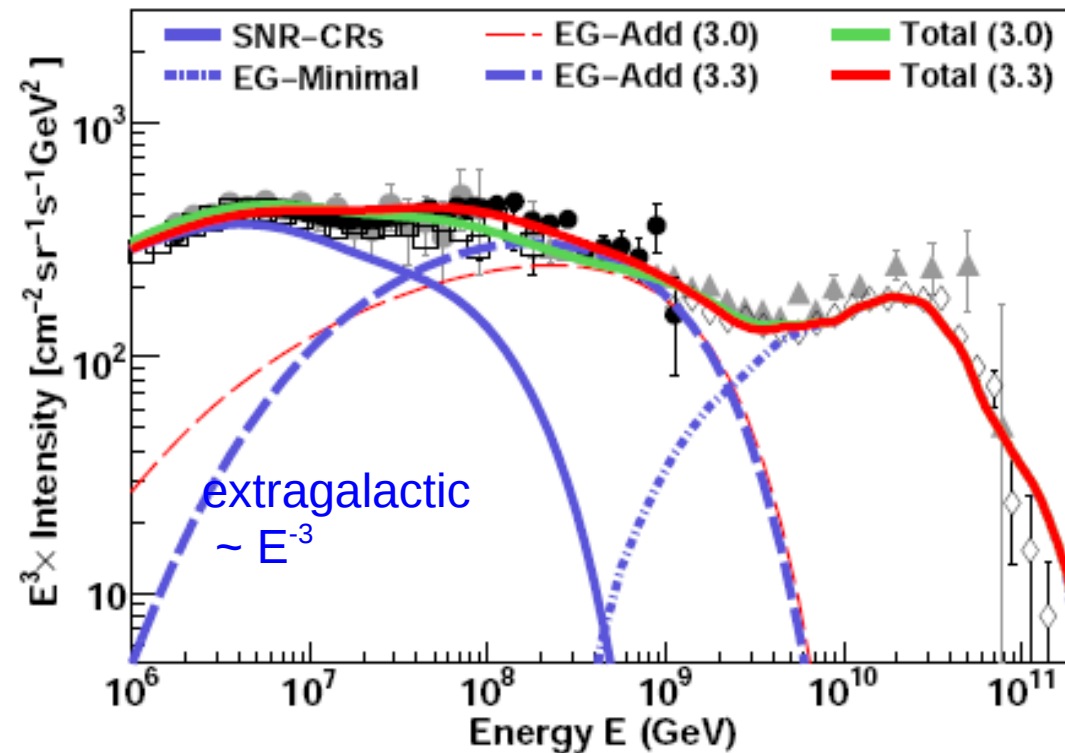


Fig. 13. All-particle energy spectrum for an additional component of EG-CR protons extended down to low energies and modulated by Galactic wind. The numbers within the parentheses denote the injection index for the additional extra-galactic component. For the SNR-CRs, an exponential cut-off energy for protons at 4.1×10^6 GeV is assumed. See text for other details.

Cosmic-ray energy spectrum and composition up to the ankle – the case for a second Galactic component

S. Thoudam^{1,2,*}, J.P. Rachen¹, A. van Vliet¹, A. Achterberg¹, S. Buitink³, H. Falcke^{1,4,5}, J.R. Hörandel^{1,4}

arXiv:1605.03111

An additional problem for EG-CRs with an overall spectrum steeper than $E^{-2.7}$ is that, if one assumes that they fill the extra-galactic space homogeneously with energies from ~ 1 GeV to 10^9 GeV, it contains more energy than the gravitational binding energy released in the universe during structure formation (Rachen 2016). Using realistically low efficiencies for this energy – which is, besides the lower overall nuclear binding energy released in fusion by all primordial baryonic matter going into stars, the only fundamental energy budget present in the late universe – to be converted into cosmic rays, one can conclude that spectral indices as discussed here for a dominant extra-galactic component below the second knee cannot easily be reconciled with this energy budget, no matter which kind of sources one proposes. Mainly on the basis of this argument, together with the difficulties of a sufficient spectral modification at low energies discussed above, we consider a dominantly extra-galactic explanation of cosmic rays below 10^8 GeV as implausible.

The jury is still out (or ought to be)

A complete model of the CR spectrum and composition across the Galactic to Extragalactic transition

Noemie Globus

School of Physics & Astronomy, Tel Aviv University, Tel Aviv 69978, Israel

Denis Allard and Etienne Parizot

*Laboratoire Astroparticule et Cosmologie, Université Paris Diderot/CNRS,
10 rue A. Domon et L. Duquet, 75205 Paris Cedex 13, France*

We present a complete phenomenological model accounting for the evolution of the cosmic-ray spectrum and composition with energy, based on the available data over the entire spectrum. We show that there is no need to postulate any additional component, other than one single Galactic component depending on rigidity alone, and one extragalactic component, whose characteristics

PRD 92, 021302, 2015 arXiv:1505.01377

4

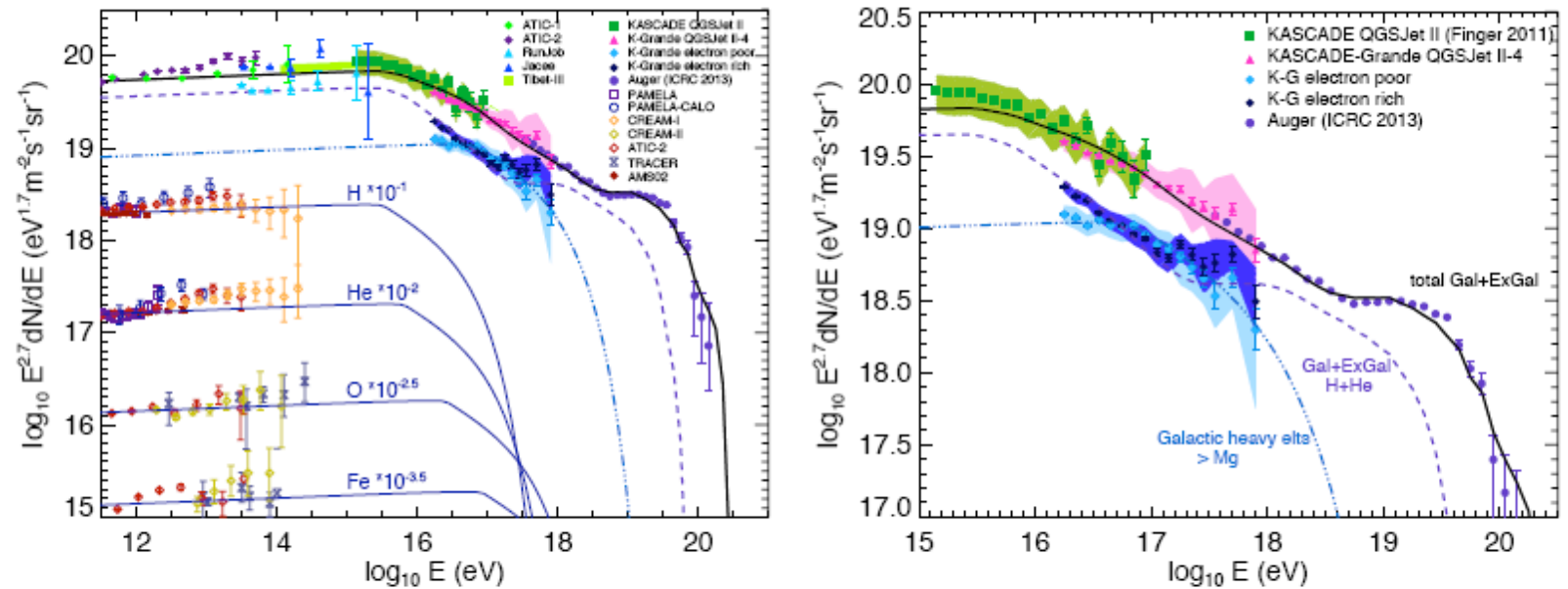


FIG. 2. Comparison between the spectrum of our global CR model and the available data, detailed in the upper right corners. The individual spectra of H, He, O and Fe are shown for the GCR component (left, with the indicated rescaling). In addition, the “heavy” and “light” components determined by KASCADE-Grande are shown with dashed and dotted-dashed line (see text). Right: close up view, showing the sum of the H and He fluxes (dashed) and the elements heavier than Mg (dotted-dashed).



Cascade photons as test of protons in UHECR

V. Berezhinsky,^{1,2} A. Gazizov,¹ and O. Kalashev³

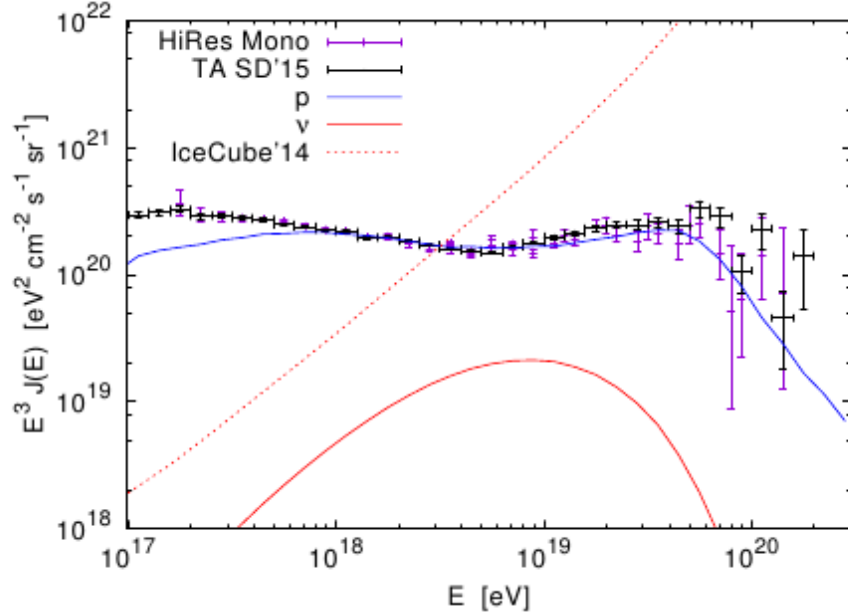
¹*INFN, Laboratori Nazionali del Gran Sasso, Assergi (AQ), 67010, Italy*

²*INFN, Gran Sasso Science Institute, viale F.Crispi 7, 67100 L'Aquila, Italy*

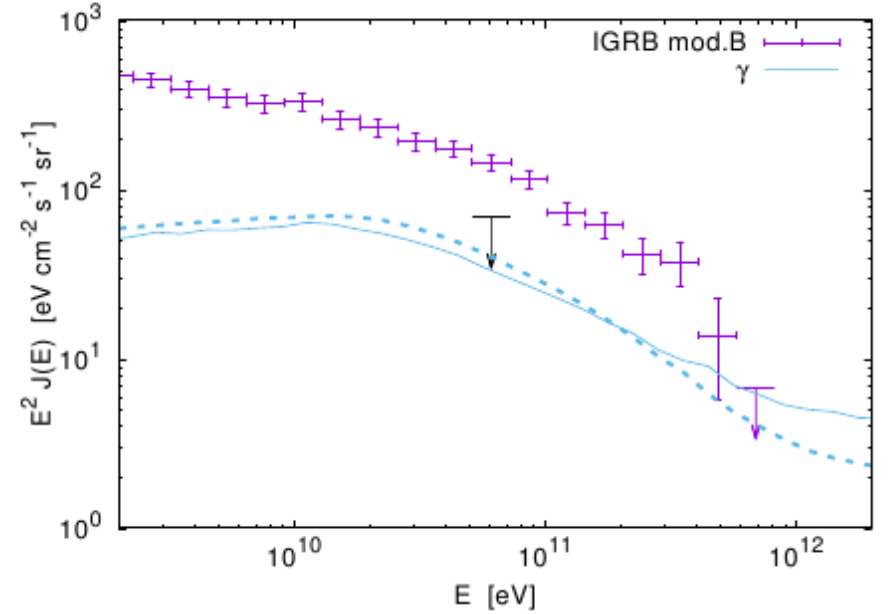
³*Institute for Nuclear Research of the Russian Academy of Sciences, Moscow 117312, Russia*

(Dated: August 30, 2016)

An isotropic component of high energy γ -ray spectrum measured by Fermi LAT constrains the proton component of UHECR. The strongest restriction comes from the highest, (580 – 820) GeV, energy bin. One more constraint on the proton component is provided by the IceCube upper bound on ultrahigh energy cosmogenic neutrino flux. We study the influence of these restrictions on the source properties, such as evolution and distribution of sources, their energy spectrum and admixture of nuclei. We also study the sensitivity of restrictions to various Fermi LAT galactic foreground models (model B being less restrictive), to the choice of extragalactic background light model and to overall normalization of the energy spectrum. We claim that the γ -ray-cascade constraints are stronger than the neutrino ones, and that however many proton models are viable. The basic parameters of such models are relatively large γ_g and not very large z_{\max} . The allowance for He⁴ admixture also relaxes the restrictions. However we foresee that future CTA measurements of γ -ray spectrum at $E_\gamma \simeq (600 - 800)$ GeV, as well as resolving of more individual γ -ray sources, may rule out the proton-dominated cosmic ray models.



(a) UHECR and secondary ν



(b) secondary γ

FIG. 1: Energy spectra of protons and neutrinos (left panel) and of cascade photons (right panel) from sources emitting protons with $\gamma_g = 2.6$, $m = 1$ and $z_{\max} = 5$ normalized on TA spectrum [41]. Also, the Fermi IGRB measurements are shown for galactic foreground model B, as well as secondary ν -spectrum along with IceCube neutrino 'differential flux' upper limit [18]. The Fermi LAT constraint of Eq. (13) is shown by the black arrow. EBL models of Ref. [36] (solid lines) and [35] (dashed line) were used in calculations. Only γ -ray spectrum is shown for EBL model [35] since p - and ν -spectra calculated using different EBL models are practically indistinguishable.

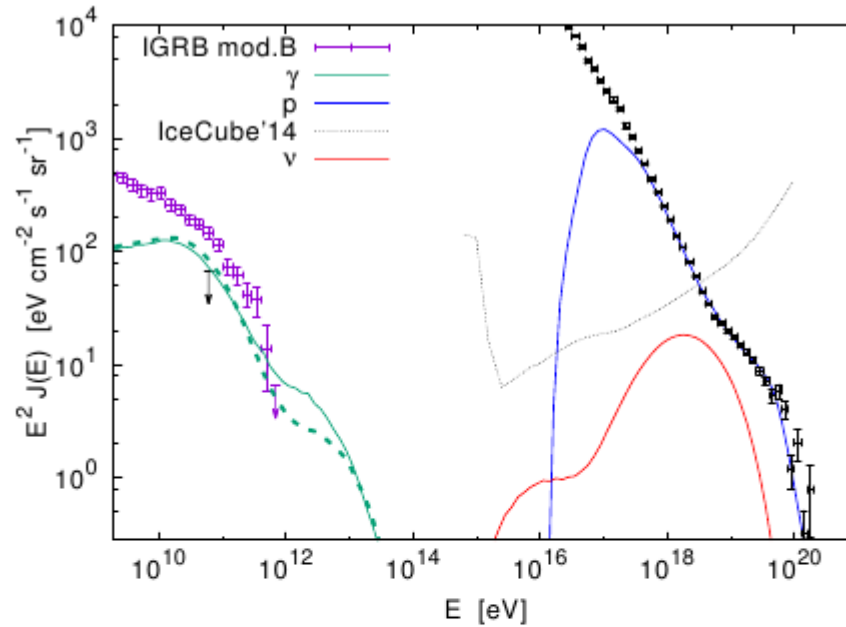


FIG. 2: Energy spectrum of cosmic rays and secondary ν 's and γ 's from sources emitting protons with $\gamma_g = 2.4$ and evolution corresponding to star formation rate (SFR) [37] normalized on TA spectrum [41]. The Fermi LAT constraint given by Eq. (13) is shown by the black arrow. The EBL models of Refs. [36] (solid lines) and [35] (dashed line) are used in calculations. The γ -ray spectrum is shown only for EBL of model Ref. [35] since p - and ν -spectra calculated using different EBL models are almost indistinguishable.



Indication of a Local “Fog” of Sub-Ankle UHECR

Ruo-Yu Liu¹, Andrew M. Taylor², Xiang-Yu Wang³ and Felix A. Aharonian^{1,2}

¹*Max-Planck-Institut für Kernphysik, Saupfercheckweg 1, 69117 Heidelberg, Germany*

²*Dublin Institute for Advanced Studies, 31 Fitzwilliam Place, Dublin 2, Ireland and*

³*School of Astronomy and Space Science, Nanjing University, Nanjing 210093, China*

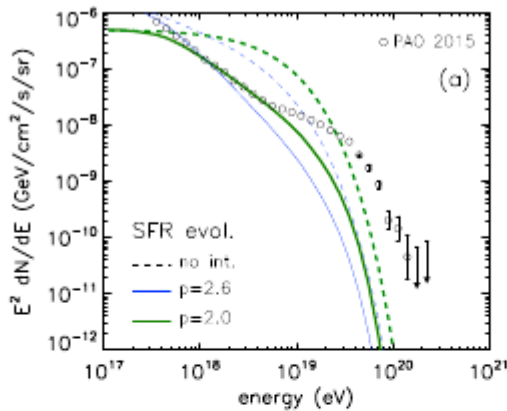
During their propagation through intergalactic space, ultrahigh energy cosmic rays (UHECRs) interact with the background radiation fields. These interactions give rise to energetic electron/positron pairs and photons which in turn feed electromagnetic cascades, contributing to the isotropic gamma-ray background (IGRB). The gamma-ray flux level generated in this way highly depends upon the UHECR propagation distance, as well as the evolution of their sources with redshift. Recently, the *Fermi*-LAT collaboration reported that the majority of the total extragalactic gamma-ray flux originates from extragalactic point sources. This posits a stringent upper limit on the IGRB generated via UHECR propagation, and subsequently constrains their abundance in the distant Universe. Focusing on the contribution of UHECR at energies below the ankle within a narrow energy band $((1 - 4) \times 10^{18}$ eV), we calculate the diffuse gamma-ray flux generated through UHECR propagation, normalizing the total cosmic ray energy budget in this band to that measured. We find that in order to not over-produce the new IGRB limit, a local “fog” of UHECR produced by nearby sources may exist, with a possible non-negligible contribution from our Galaxy. Following the assumption that a given fraction of the observed IGRB at 820 GeV originates from UHECR, we obtain a constraint on the maximum distance for the majority of their sources. With other unresolved source populations still contaminating the new IGRB limit, and UHECR above the ankle invariably contributing also to this background, the results presented here are rather conservative.



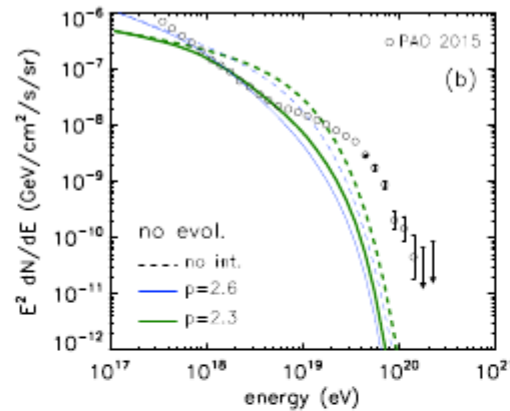
EM cascades from 10^{18} eV extragalactic CR protons

EGCR

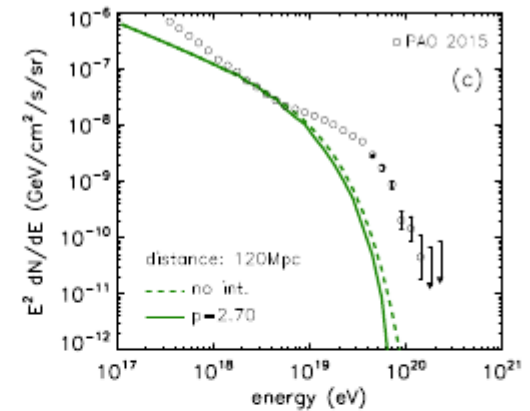
evolution



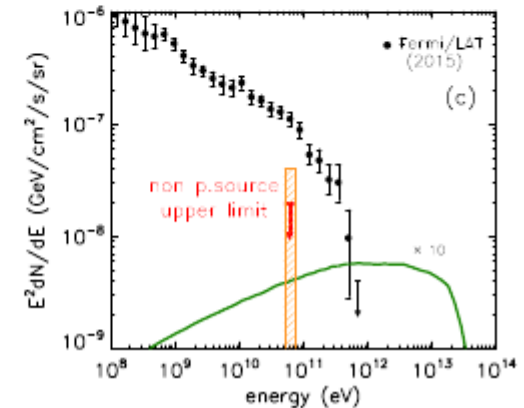
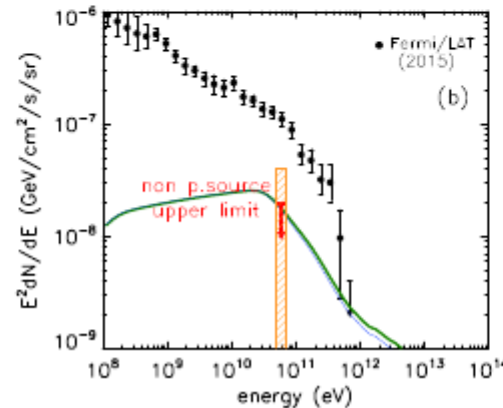
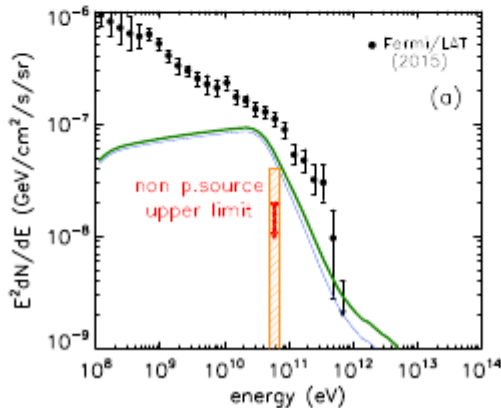
no evolution



local to 120 Mpc



Gamma ray background



Over Fermi limit

OK?

OK

Fermi IGRB limit considering unresolved source populations (sources~80%)
Severe limit on EGCR! those we see are local, not universal? Anisotropy?

FIG. 1. Fitting to UHECR spectrum below the ankle and the corresponding diffuse gamma-ray flux initiated by CR propagation with different source distributions (**left**: (a) SFR evolution; **middle**: (b) no evolution; **right**: (c) sources located at 120 Mpc). In the upper panels, the green solid lines represent the best-fit UHECR fluxes for each source distribution considered, while the dashed lines represent the unattenuated flux. The thin blue lines show the results for a soft injection spectrum of $p = 2.6$, normalized to the data at 1 EeV. Hollow circles show the PAO [5] data. The adopted values of the power-law index p and the local energy production rate are provided within the figure. The lower panels show the corresponding diffuse gamma-ray emission resulting from the cascade initiated by UHE protons, with thick lines and thin lines are respectively for best-fit case and $p = 2.6$ case. The black filled circles show the IGRB measured by Fermi/LAT [3]. The IGRB upper limit for the non-point-source component (or the truly diffuse component) are shown as a red bar with an arrow. The orange hatched region represents the uncertainty of the limit due to the uncertainties in the obtained source count distribution (i.e., dN/dS). The cascade flux in the right panel is multiplied by 10.

Cosmogenic photons strongly constrain UHECR source models

Arjen van Vliet^{1,★}

¹ *Department of Astrophysics/IMAPP, Radboud University, P.O. Box 9010, 6500 GL Nijmegen, The Netherlands.*

Abstract. With the newest version of our Monte Carlo code for ultra-high-energy cosmic ray (UHECR) propagation, CRPropa 3, the flux of neutrinos and photons due to interactions of UHECRs with extragalactic background light can be predicted. Together with the recently updated data for the isotropic diffuse gamma-ray background (IGRB) by Fermi LAT, it is now possible to severely constrain UHECR source models. The evolution of the UHECR sources especially plays an important role in the determination of the expected secondary photon spectrum. Pure proton UHECR models are already strongly constrained, primarily by the highest energy bins of Fermi LAT's IGRB, as long as their number density is not strongly peaked at recent times.

arXiv:1609.03336 12 Sept 2016

... and so it goes.... (Billy Joel)

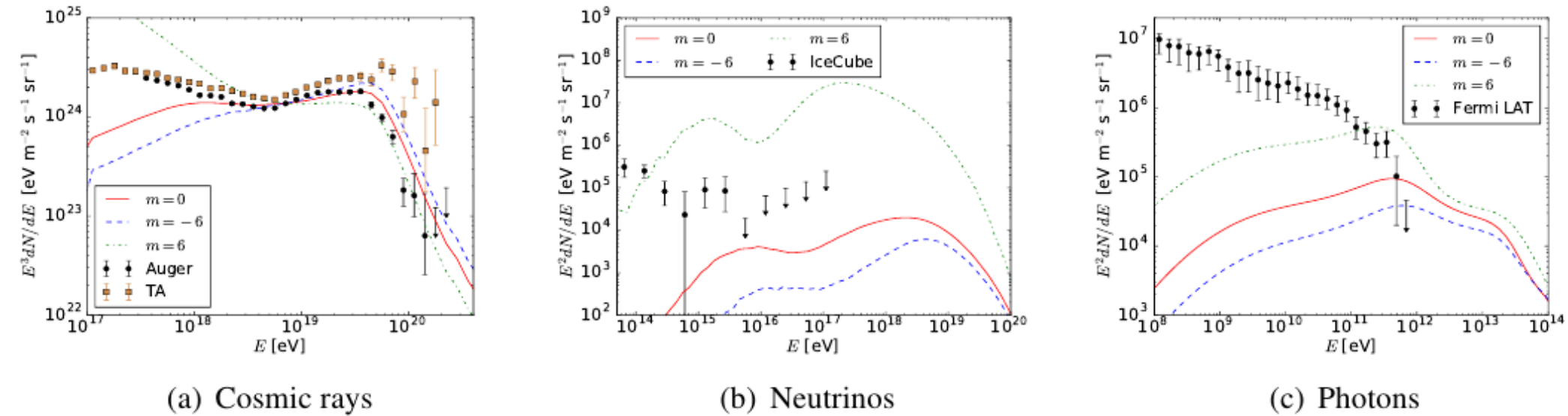


Figure 1. (a) Simulated cosmic ray spectra normalized to the Auger flux [3] (circles) at $E = 10^{18.85}$ eV. The spectrum measured by TA [5] (squares) is given as well. (b) Corresponding neutrino spectra compared with IceCube data [2] (circles). (c) Corresponding photon spectra compared with Fermi-LAT IGRB data [1] (circles) using Galactic foreground model A. The cosmic ray simulations were done starting a pure proton injection at $E_{\min} = 0.1$ EeV with an exponential cutoff at a cutoff energy of $E_{\text{cut}} = 200$ EeV and an injection spectral index of $\alpha = 2.5$ using the Gilmore 2012 EBL model [15]. The simulations were done up to a maximum redshift of $z_{\max} = 6$ with a comoving source evolution multiplied by $(1+z)^m$ with $m = 0$ (solid lines), $m = -6$ (dashed lines) and $m = 6$ (dashed-dotted lines). See text for further details.

Challenge: reduce IGRB with deep source detections
To actually detect the cascade diffuse gamma background!

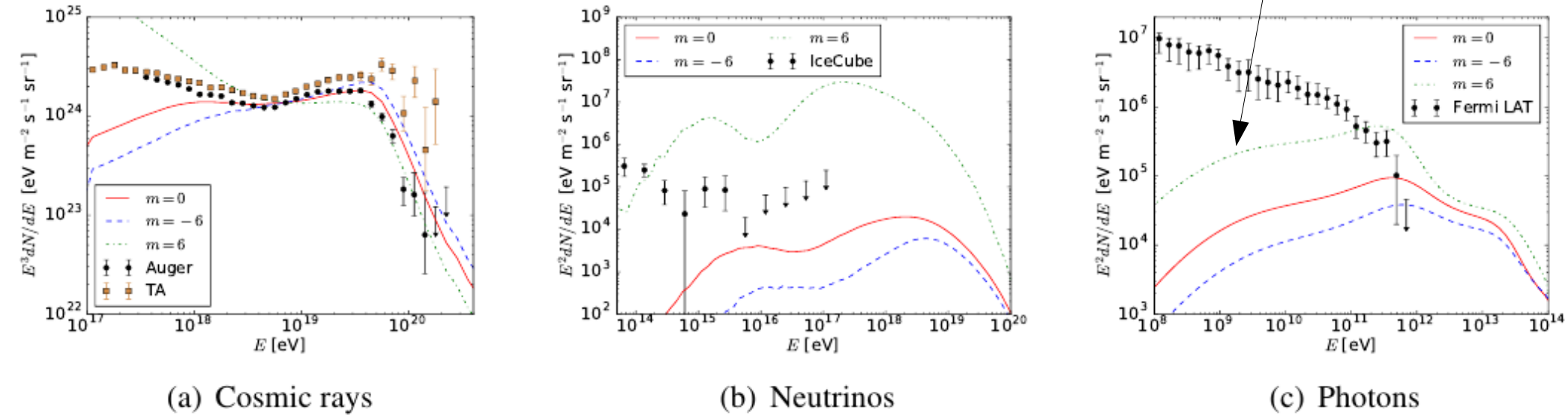


Figure 1. (a) Simulated cosmic ray spectra normalized to the Auger flux [3] (circles) at $E = 10^{18.85}$ eV. The spectrum measured by TA [5] (squares) is given as well. (b) Corresponding neutrino spectra compared with IceCube data [2] (circles). (c) Corresponding photon spectra compared with Fermi-LAT IGRB data [1] (circles) using Galactic foreground model A. The cosmic ray simulations were done starting a pure proton injection at $E_{\min} = 0.1$ EeV with an exponential cutoff at a cutoff energy of $E_{\text{cut}} = 200$ EeV and an injection spectral index of $\alpha = 2.5$ using the Gilmore 2012 EBL model [15]. The simulations were done up to a maximum redshift of $z_{\max} = 6$ with a comoving source evolution multiplied by $(1+z)^m$ with $m = 0$ (solid lines), $m = -6$ (dashed lines) and $m = 6$ (dashed-dotted lines). See text for further details.

11 things which are taken as established but are not and deserve further investigation

- 1 The Pion Bump has been detected in SNR by Fermi-LAT
- 2 CR are extragalactic only $>10^{15}$ eV or so
- 3 CR cannot come from the Galactic Centre only**
- 4 The CR gradient in the Galaxy can be determined accurately
- 5 The spectrum of CR in the Galaxy has the same shape as the local spectrum
- 6 Reacceleration is a viable explanation of the B/C peak (Luke's talk)
- 7 Secondary production in sources is negligible (including B, positrons)
- 8 ^{60}Fe tells about CR age, delay (from gammas ^{60}Fe is everywhere in ISM)
- 9 Positron/pbar ratio agrees with standard model (no: Lipari paper)
- 10 Diffuse Galactic emission is mainly interstellar not unresolved sources
- 11 CR are not important for galaxy evolution

GCR from Galactic Centre?

Inconsistent with Galactic gamma-ray gradient?
But large (10 kpc) halo smooths everything out
Gammas cannot decide

Consistent with B/C etc ?

^{10}Be OK since decays on way from GC (~ 1 Myr), hence $^{10}\text{Be}/^9\text{Be}$ low as observed

But need detailed calculations!

Fermi Bubbles are CR source in any case, but only electrons?

Crocker et al. arXiv:1607.03495 511 keV GC e^+ annihilation source
related to Fermi extended GC source? They look very similar in morphology!

11 things which are taken as established but are not and deserve further investigation

- 1 The Pion Bump has been detected in SNR
- 2 CR are extragalactic only $>10^{15}$ eV or so
- 3 CR cannot come from the Galactic Centre only
- 4 The CR gradient in the Galaxy can be determined accurately**
- 5 The spectrum of CR in the Galaxy has the same shape as the local spectrum
- 6 Reacceleration is a viable explanation of the B/C peak (Luke's talk)
- 7 Secondary production in sources is negligible (including B, positrons)
- 8 ^{60}Fe tells about CR age, delay (from gammas ^{60}Fe is everywhere in ISM)
- 9 Positron/pbar ratio agrees with standard model (no: Lipari paper)
- 10 Diffuse Galactic emission is mainly interstellar not unresolved sources
- 11 CR are not important for galaxy evolution

Gas content and distribution in the Galaxy is very uncertain,
CO is not good tracer of H_2 ,
Even HI has large uncertainty due to self-absorption.

Dark gas is omnipresent, in fact gammas are the best tracer of it but this is a circular argument since requires CR density.

FIR dust emission traces total gas but no distance information so use limited to local gas.

Hope from 3D dust models with stellar reddening ref....

Gaia!

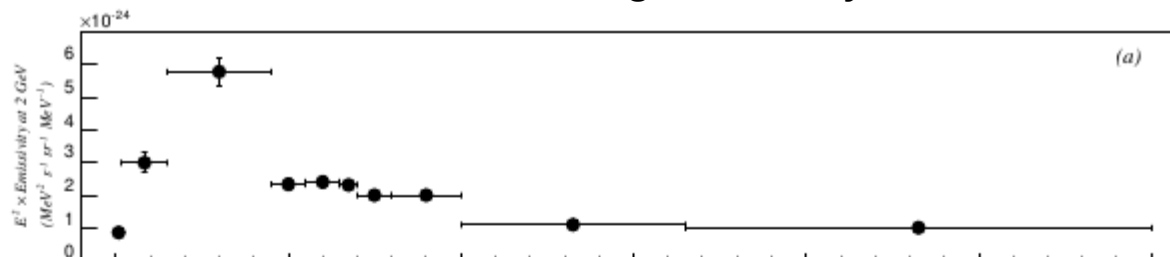
**Development of the Model of Galactic Interstellar Emission for Standard
Point-Source Analysis of *Fermi* Large Area Telescope Data**

F. Acero¹, M. Ackermann², M. Ajello³, A. Albert⁴, L. Baldini^{5,4}, J. Ballet¹, G. Barbiellini^{6,7},

ApJS 223, 26 (2016) arxiv:1602.07246

Fermi Galactic diffuse gamma-ray model

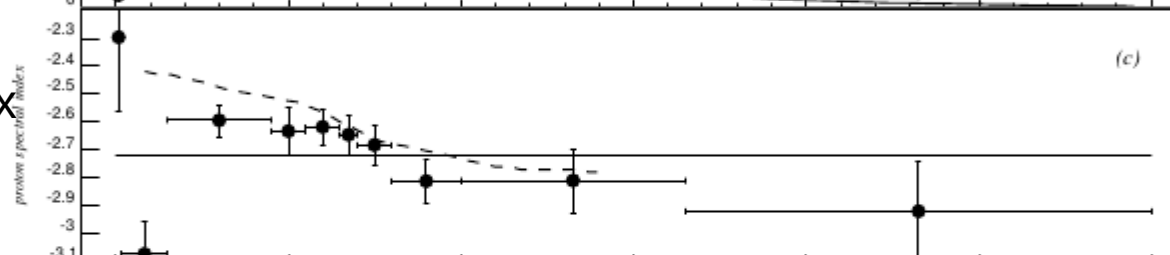
Gamma ray
emissivity



Proton flux



Proton spectral index



Proton flux,
SFR, SNR etc

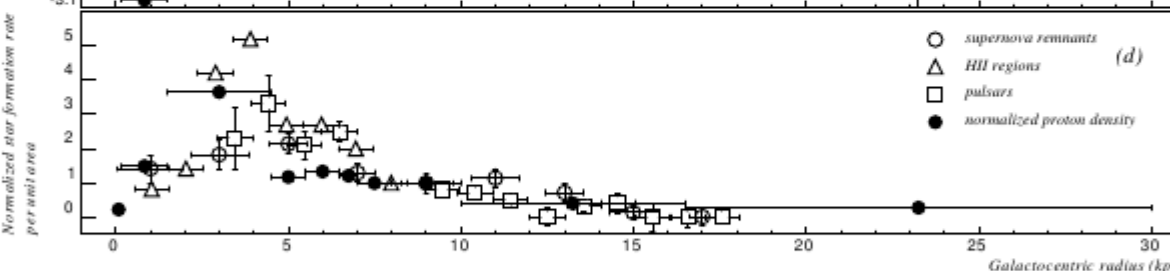


Fig. 8.— Radial distributions across the Galaxy of (a) the γ -ray emissivity per H atom measured at 2 GeV; (b) the proton flux integrated above 10 GV, with the prediction from the GALPROP model $S^Y Z^6 R^{30} T^{150} C^2$ (solid curve, Ackermann et al. 2012d); (c) the proton spectral index, P_2 , with statistical error bars and the prediction for proton rigidities above 1 TV from the same GALPROP model (solid line) and from Gaggero et al. (2015) (dashed line). In all plots, the horizontal bars span the radial widths of the gas annuli used for the measurements. The two data points with smallest Galactocentric radii have large systematic uncertainties (see text). Panel (d) shows the proton flux integrated above 10 GV, normalized to its value at the Sun Galactocentric radius, with the star formation rate traced by supernova remnants, H II regions, and pulsars (Stahler & Palla 2005).

Radial distribution of the diffuse gamma-ray emissivity in the galactic disk

Ruizhi Yang^{*,†}

*Max-Planck-Institut für Kernphysik,
P.O. Box 103980, 69029 Heidelberg, Germany*

Felix Aharonian[†]

*Max-Planck-Institut für Kernphysik, P.O. Box 103980, 69029 Heidelberg, Germany
Dublin Institute for Advanced Studies, 31 Fitzwilliam Place, Dublin 2, Ireland.*

Carmelo Evoli[‡]

*Gran Sasso Science Institute, 7 viale Francesco Crispi, 67100 LAquila (AQ), Italy
(Dated: Received: / Accepted:)*

arXiv:1602.04710

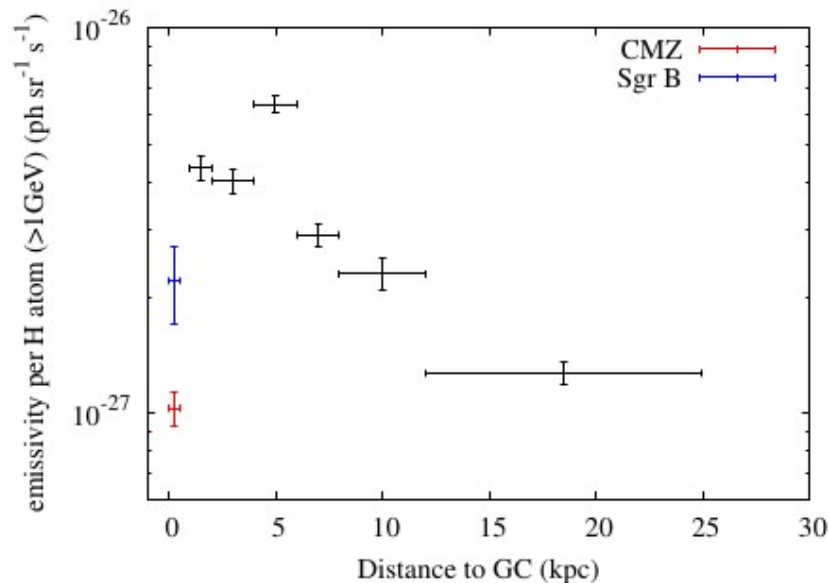
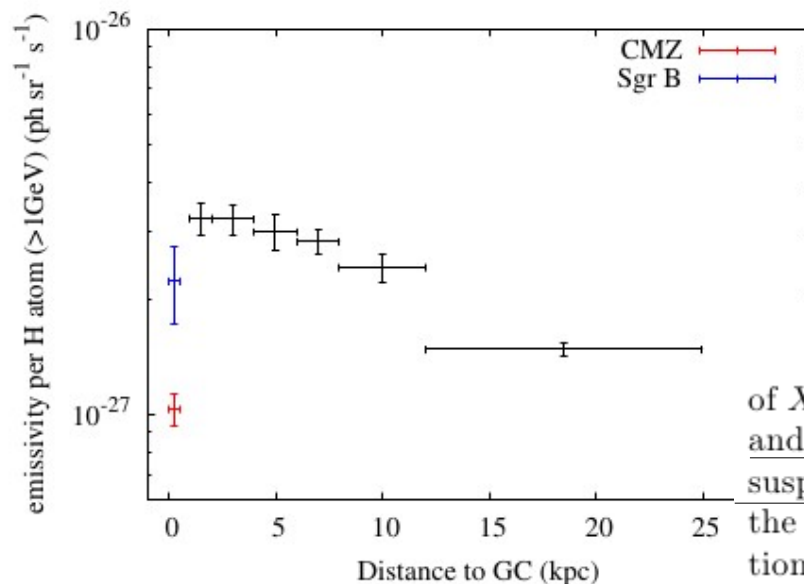


FIG. 7: Normalised per H-atom gamma ray emissivities above 1 GeV in different rings by using the best fit conversion factor X_{CO} as shown in Tab.1. The points close to the GC are taken from analysis of the γ -ray luminosity of the entire Central Molecular Zone [5] and from the analysis of the emissivity of the giant molecular complex Sgr B2 [15].

TABLE I: X_{CO} derived from the likelihood fit.

Ring	X_{CO}
1 kpc < r < 2 kpc	$1.5 \pm 0.2 \times 10^{20}$
2 kpc < r < 4 kpc	$1.4 \pm 0.2 \times 10^{20}$
4 kpc < r < 6 kpc	$0.5 \pm 0.2 \times 10^{20}$
6 kpc < r < 8 kpc	$1.4 \pm 0.2 \times 10^{20}$
8 kpc < r < 12 kpc	$2.0 \pm 0.2 \times 10^{20}$
12 kpc < r < 25 kpc	$3.7 \pm 0.4 \times 10^{20}$



Yang et al. arXiv:1602.04710

of X_{CO} . Yet, such a coincidence between the CR density and the conversion factor X_{CO} seems, to some extent, suspicious. Thus, one cannot exclude that the peak in the γ -ray emissivity could be caused by the underestimation of the gas density in this region. For comparison, in

FIG. 8: The same as in Fig. 7 but for the conversion factor X_{CO} fixed at the local value $2.0 \pm 0.2 \times 10^{20}$.

The Shape of Dark Matter Haloes

III. Kinematics and Structure of the HI disc

S. P. C. Peters¹, P. C. van der Kruit^{1*}, R. J. Allen² and K. C. Freeman³

¹*Kapteyn Astronomical Institute, University of Groningen, P.O.Box 800, 9700AV Groningen, the Netherlands*

²*Space Telescope Science Institute, 3700 San Martin Drive, Baltimore, MD 21218, USA*

³*Research School of Astronomy and Astrophysics The Australian National University, Cotter Road Weston Creek, ACT 2611, Australia*

Accepted 2015 month xx. Received 2015 Month xx; in original form 2015 Month xx

ABSTRACT

We present a new strategy for fitting the structure and kinematics of the HI in edge-on galaxies using a fit to the terminal-velocity channel maps of a HI data cube. The strategy can deal with self-absorbing HI gas and the presence of warps. The method is first tested on a series of models. We demonstrate that fitting optically thin models to real galaxies will lead to an overestimation of the thickness and velocity dispersion, and to a serious underestimation of the HI face-on column densities. We subsequently fit both self-absorption and optically thin models to the HI data of six edge-on galaxies. In three of these we have also measured the velocity dispersion. On average $27 \pm 6\%$ of the total HI mass of edge-on galaxies is hidden by self-absorption. This implies that the HI mass, thickness and velocity dispersion of galaxies is typically underestimated in the literature.

Name	Optically thin mass [M_{\odot}]	Self-absorbing mass [M_{\odot}]
IC 5052	$7.4 \pm 0.7 \times 10^8$	$9.5 \pm 0.9 \times 10^8$
IC 5249	$4.8 \pm 0.2 \times 10^9$	$7.8 \pm 0.8 \times 10^9$
ESO 115-G021	$5.6 \pm 0.2 \times 10^9$	$7.2 \pm 0.1 \times 10^9$
ESO 138-G014	$3.4 \pm 0.1 \times 10^9$	$4.6 \pm 0.2 \times 10^9$
ESO 274-G001	$3.1 \pm 0.02 \times 10^8$	$4.1 \pm 0.1 \times 10^8$
UGC 7321	$8.9 \pm 0.4 \times 10^8$	$1.17 \pm 0.02 \times 10^9$

Table 1. The total HI mass of each galaxy as measured with our outer envelope strategy assuming either an optically thin or a self-absorbing mass.

In Table 1 we show the list of all HI masses as measured using our outer envelope strategy. On average we find that $27 \pm 6\%$ of the HI mass is hidden by self-absorption. In Section 7 of Paper II, we predicted that self-absorption would hide 30% of the mass if galaxy NGC 2403 had been viewed edge-on. These results are thus compatible. However, we stress that our analysis is based on a couple of important assumptions. The first is the constant spin temperature of 100 K. While this appears to work well for the data, its value is chosen only for convenience. In reality, the spin temperature is not constant, but is dependent on location inside the galaxy and the state of the HI gas. Assuming a lower average spin temperature would have resulted in a much higher total HI mass.

11 things which are taken as established but are not and deserve further investigation

- 1 The Pion Bump has been detected in SNR by Fermi-LAT
- 2 CR are extragalactic only $>10^{15}$ eV or so
- 3 CR cannot come from the Galactic Centre only
- 4 The CR gradient in the Galaxy can be determined accurately
- 5 The spectrum of CR in the Galaxy has the same shape as the local spectrum**
- 6 Reacceleration is a viable explanation of the B/C peak (Luke's talk)
- 7 Secondary production in sources is negligible (including B, positrons)
- 8 ^{60}Fe tells about CR age, delay (from gammas ^{60}Fe is everywhere in ISM)
- 9 Positron/pbar ratio agrees with standard model (no: Lipari paper)
- 10 Diffuse Galactic emission is mainly interstellar not unresolved sources
- 11 CR are not important for galaxy evolution

Gamma-ray sky points to radial gradients in cosmic-ray transport

Daniele Gaggero,^{1,2,*} Alfredo Urbano,^{1,†} Mauro Valli,^{1,2,‡} and Piero Ullio^{1,2,§}

Phys. Rev. D 91, 083012 (2015)

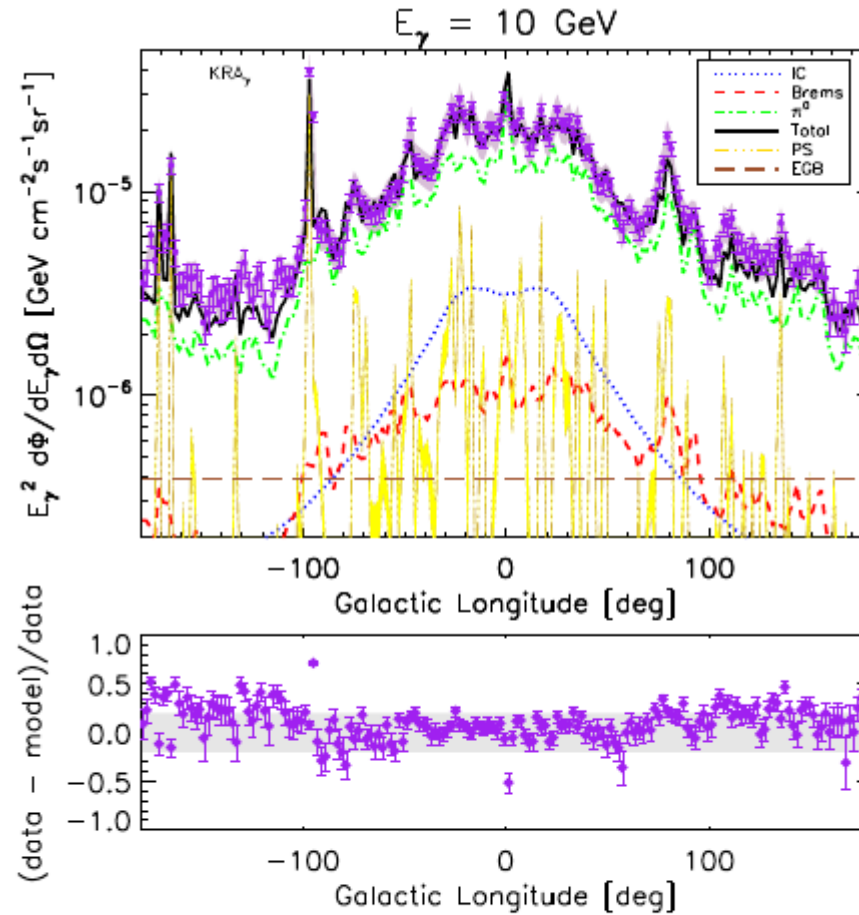


FIG. 8. Longitudinal profile at fixed energy $E_\gamma = 10 \text{ GeV}$. We average in latitude over the interval $|b| < 5^\circ$.

Gamma-ray sky points to radial gradients in cosmic-ray transport

Daniele Gaggero,^{1,2,*} Alfredo Urbano,^{1,†} Mauro Valli,^{1,2,‡} and Piero Ullio^{1,2,§}

Phys. Rev. D 91, 083012 (2015)

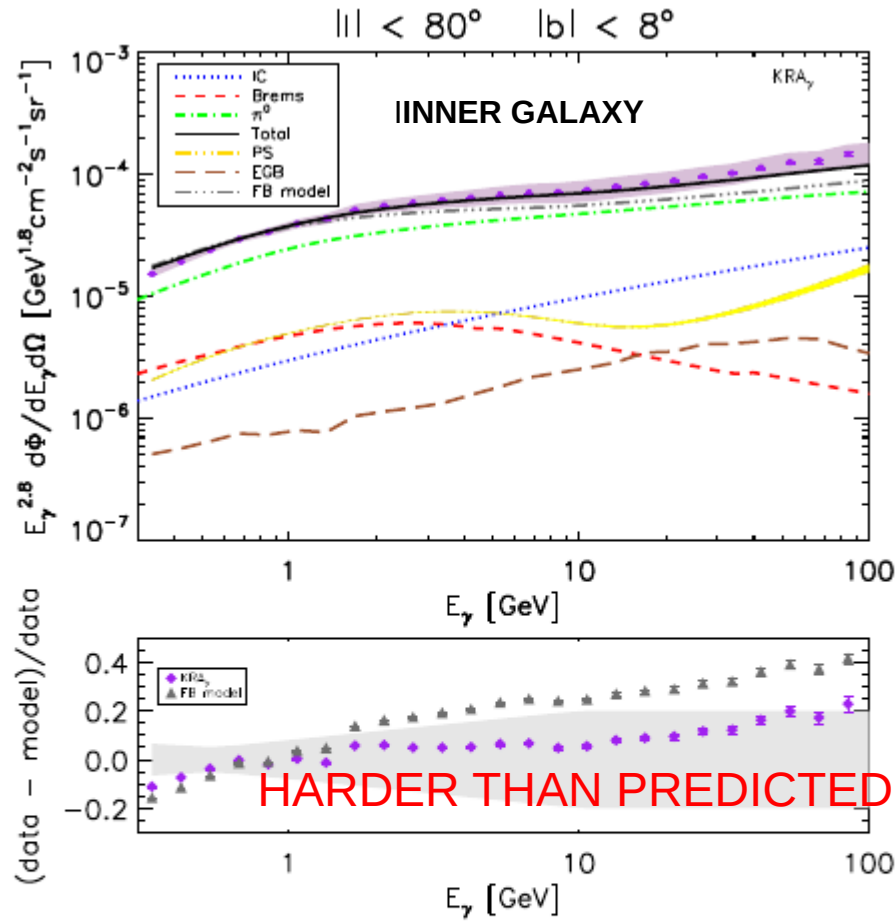


FIG. 1. Upper panel. Comparison between the γ -ray flux computed with the CR propagation model proposed in this Letter (KRA_γ total flux: solid black line; individual components shown) and the Fermi-LAT data (purple dots, including both statistic and systematic errors) in the Galactic disk. For comparison, we also show the total flux for the FB model defined in ref. [1] (double dot-dashed gray line). Lower panel. Residuals computed for the KRA_γ and FB models.

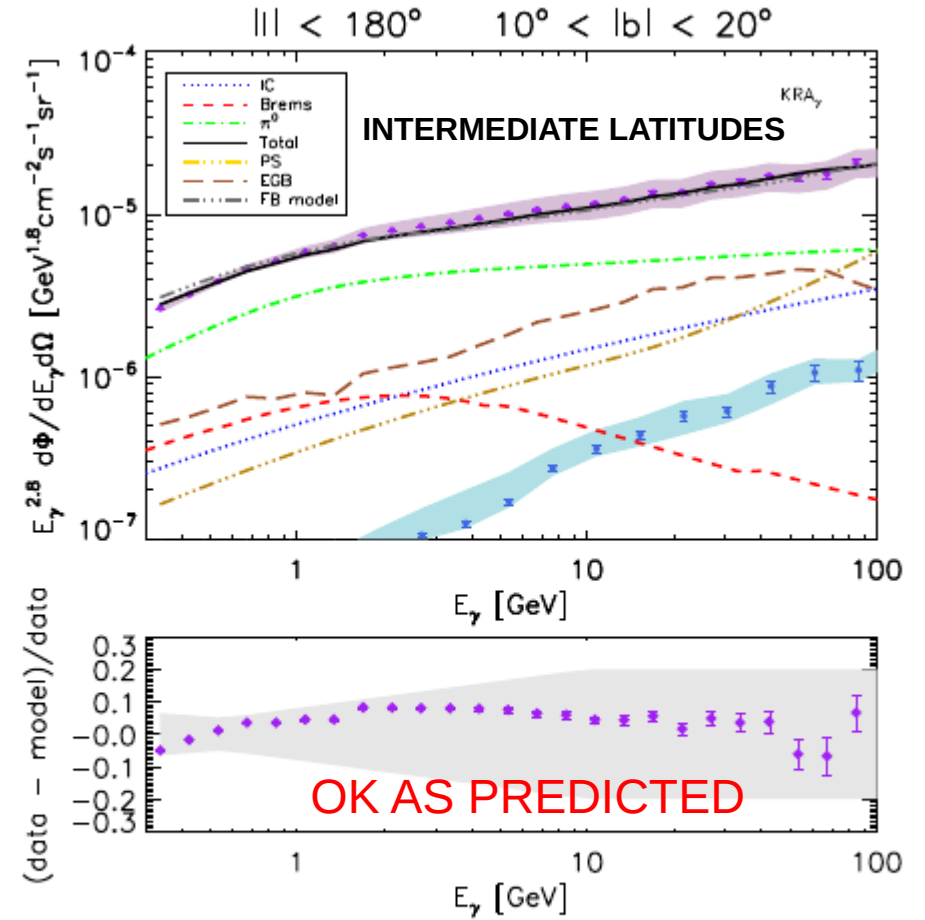


FIG. 7. The same as in fig. 1 but considering the strip $|l| < 180^\circ$, $10^\circ < |b| < 20^\circ$. The azure band represents the contribution of the Fermi bubbles according to ref. [37].

Interstellar gamma-ray spectrum

Harder gamma-ray spectrum in Galactic plane than expected from
local cosmic-ray proton spectrum via pion-decay

Gaggero et al. 2015 invoke spatially varying momentum-dependence of diffusion coefficient.

But since Galactic plane spectrum is harder than local, can be just a local CR source

Then spectral index in the plane is the “normal” one!

THIS IS A BIG EFFECT AND DESERVES MORE ATTENTION!

Normal proton spectrum is hard, local is special (local source?)

Affects everything in CR studies!

e.g. Boron/Carbon

B from harder C, compare with B, then B/C not meaningful
B comes from everywhere

C with index = 2.4 instead of 2.8

B normally index = $2.8 + 0.5 = 3.3$ to fit data

If C index = 2.4 then B 2.9 from D(p)

But if B index = 3.3 then $D(p) \sim p^{0.9}$!!

Should do GALPROP/DRAGON study

Hard spectrum of cosmic rays in the Disks of Milky Way and Large Magellanic Cloud.

A. Neronov¹, D. Malyshev¹

1. ISDC, Astronomy Department, University of Geneva, Ch. d'Ecogia 16, 1290, Versoix, Switzerland

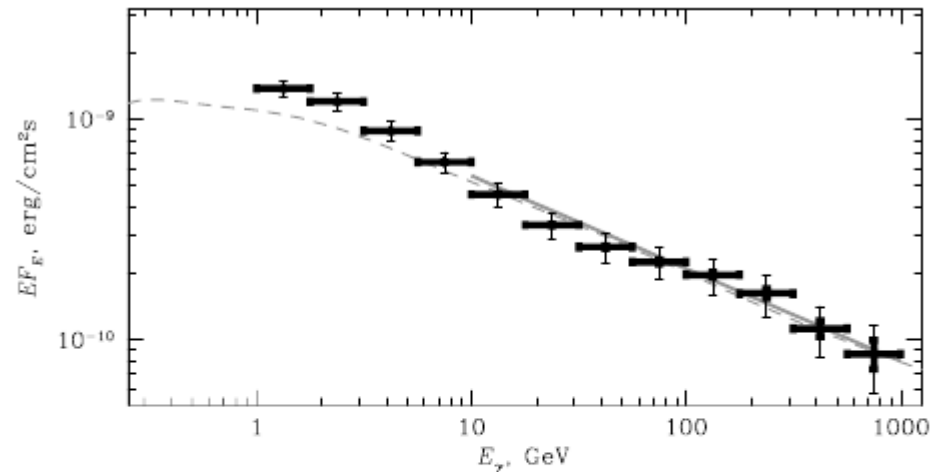


Fig. 2. Spectrum of emission from the $|l| < 90^\circ$, $|b| < 1.5^\circ$ part of the Galactic Plane. Thick / thin errorbars show the statistical / systematic error. Grey thick line shows the best-fit powerlaw with the slope $\Gamma_\gamma = 2.42$ in the energy range above 10 GeV. Dashed line shows the spectrum of the neutral pion decay emission produced a powerlaw proton spectrum with the slope $\Gamma_p = 2.45$.

Results. The spectrum of the pion decay γ -ray emission from the Galactic disk in the energy band 10 GeV – 1 TeV has the slope $\simeq 2.4$. There is no evidence for the variation of the slope with Galactic longitude / distance from the Galactic Centre. The slope of the spectrum of cosmic rays derived from the γ -ray data, $\simeq 2.45$, is harder than the slope of the locally observed cosmic ray proton spectrum. Pion decay emission from a powerlaw distribution of cosmic rays with the same hard slope also provides a fit to the γ -ray spectrum of the Large Magellanic Cloud.

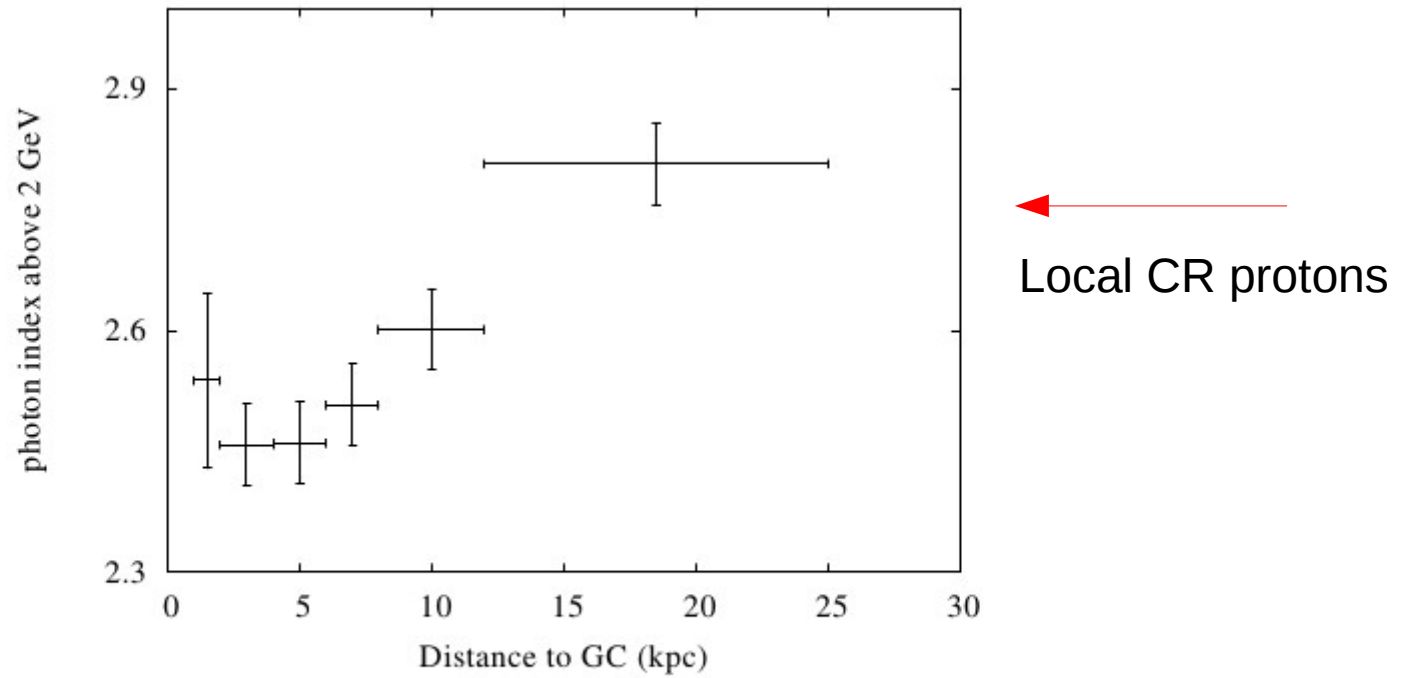


FIG. 6: The distribution of the photon index of the galactic diffuse gamma ray emission associated with the gas in different rings.

Yang etal arXiv:1602.04710

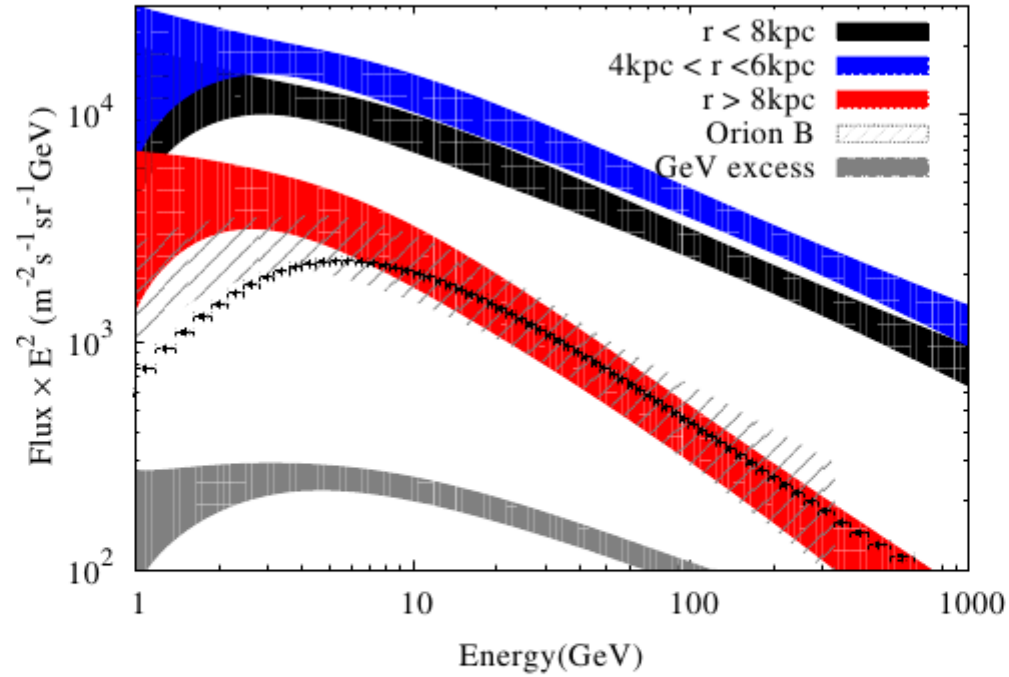


FIG. 9: The CR proton spectra in the inner ($r \leq 8$ kpc) and outer ($r \geq 8$ kpc) regions, as well as in the 4-6 kpc ring derived from γ -ray emissivities presented in Fig 7. Also are shown the proton spectra derived from the γ -ray measurements of the nearby molecular cloud Orion B [16], and from the low-energy γ -ray component called “GeV excess”. The direct measurements of the CR proton spectrum are from the AMS-02 collaboration report [17], which are shown as black squares.

Synchrotron harder spectrum in Galactic Plane
Planck XLIII (408 MHz/ 30 GHz)
WMAP Fusekland et al 2014 0.14 harder in plane
QUIET (microwave 45/90 GHz) $\beta=2.9$ in plane

Electron index
 $2(\beta - 2) + 1$

PLANCK Collab. Et al 2016 A&A in press, arXiv: 1601.00546
for review of observations.

2.0

$\beta=2.85 \rightarrow$ electron index 2.7

3.0 ←

Locally
measured
electrons

Low latitudes = large-scale Galactic spectrum. Harder than local electrons.
Similar to proton hardening seen in gamma rays.

11 things which are taken as proven but are not and deserve further investigation
“It is well known that”:

(Stated in contrary form)

- 1 The Pion Bump has been detected in SNR
- 2 CR are extragalactic only $>10^{15}$ eV or so
- 3 CR cannot come from the Galactic Centre only
- 4 The CR gradient in the Galaxy can be determined accurately
- 5 The spectrum of CR in the Galaxy has the same shape as the local spectrum
- 6 Reacceleration is a viable explanation of the B/C peak (Luke's talk)**
- 7 Secondary production in sources is negligible (including B, positrons)
- 8 ^{60}Fe tells about CR age, delay (from gammas ^{60}Fe is everywhere in ISM)
- 9 Positron/pbar ratio agrees with standard model (no: Lipari paper)
- 10 Diffuse Galactic emission is mainly interstellar not unresolved sources
- 11 CR are not important for galaxy evolution

Diffusive Reacceleration

See Luke Drury's talk, with simple derivation
Diffusion by on moving scatterers, momentum gain/loss.

Diffusion in momentum, $D_{pp} \sim v_A^2 / 9D_{xx}$

Popular explanation of GeV peak in B/C

Allows Kolmogorov $D(p)$ index 1/3, helps with anisotropy at high energies

But then large fraction of energy in GeV CR comes from reacceleration not SNR!

Analytical and GALPROP estimates agree.

Is that physically plausible?

NB B/C break already due to energy losses, example with and without

Energy losses are tricky, $\sim Z^2$ so C losses 36X proton losses

Modulation is uncertain anyway

Main evidence for peak is from ACE @ 100 MeV.

Should we trust all this?

11 things which are taken as proven but are not and deserve further investigation
“It is well known that”:

(Stated in contrary form)

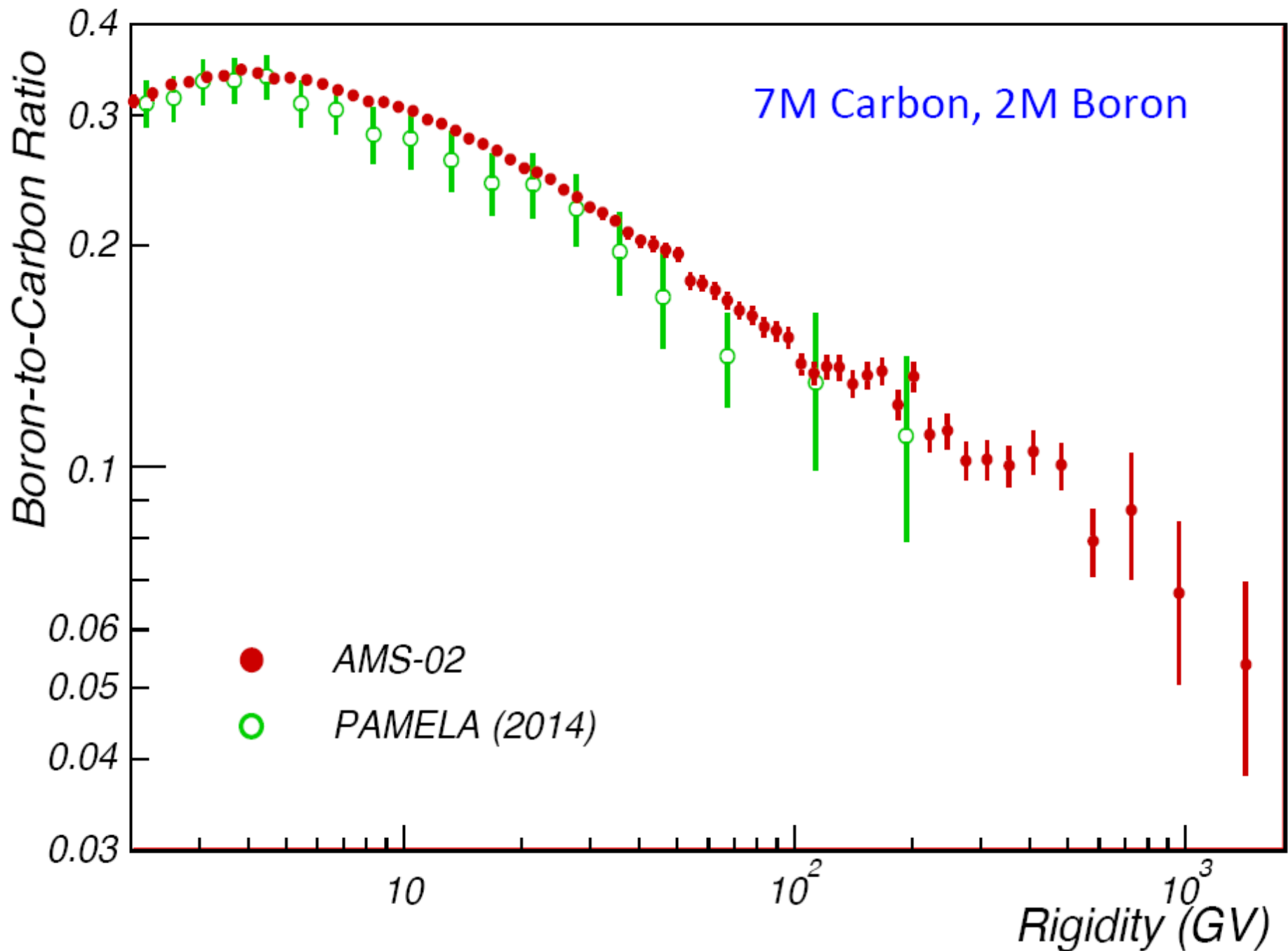
- 1 The Pion Bump has been detected in SNR
- 2 CR are extragalactic only $>10^{15}$ eV or so
- 3 CR cannot come from the Galactic Centre only
- 4 The CR gradient in the Galaxy can be determined accurately
- 5 The spectrum of CR in the Galaxy has the same shape as the local spectrum
- 6 Reacceleration is a viable explanation of the B/C peak (Luke's talk)
- 7 Secondary production in sources is negligible (including B, positrons)**
- 8 ^{60}Fe tells about CR age, delay (from gammas ^{60}Fe is everywhere in ISM)
- 9 Positron/pbar ratio agrees with standard model (no: Lipari paper)
- 10 Diffuse Galactic emission is mainly interstellar not unresolved sources
- 11 CR are not important for galaxy evolution

Secondaries in sources

Blasi paper and others

B/C Ratio

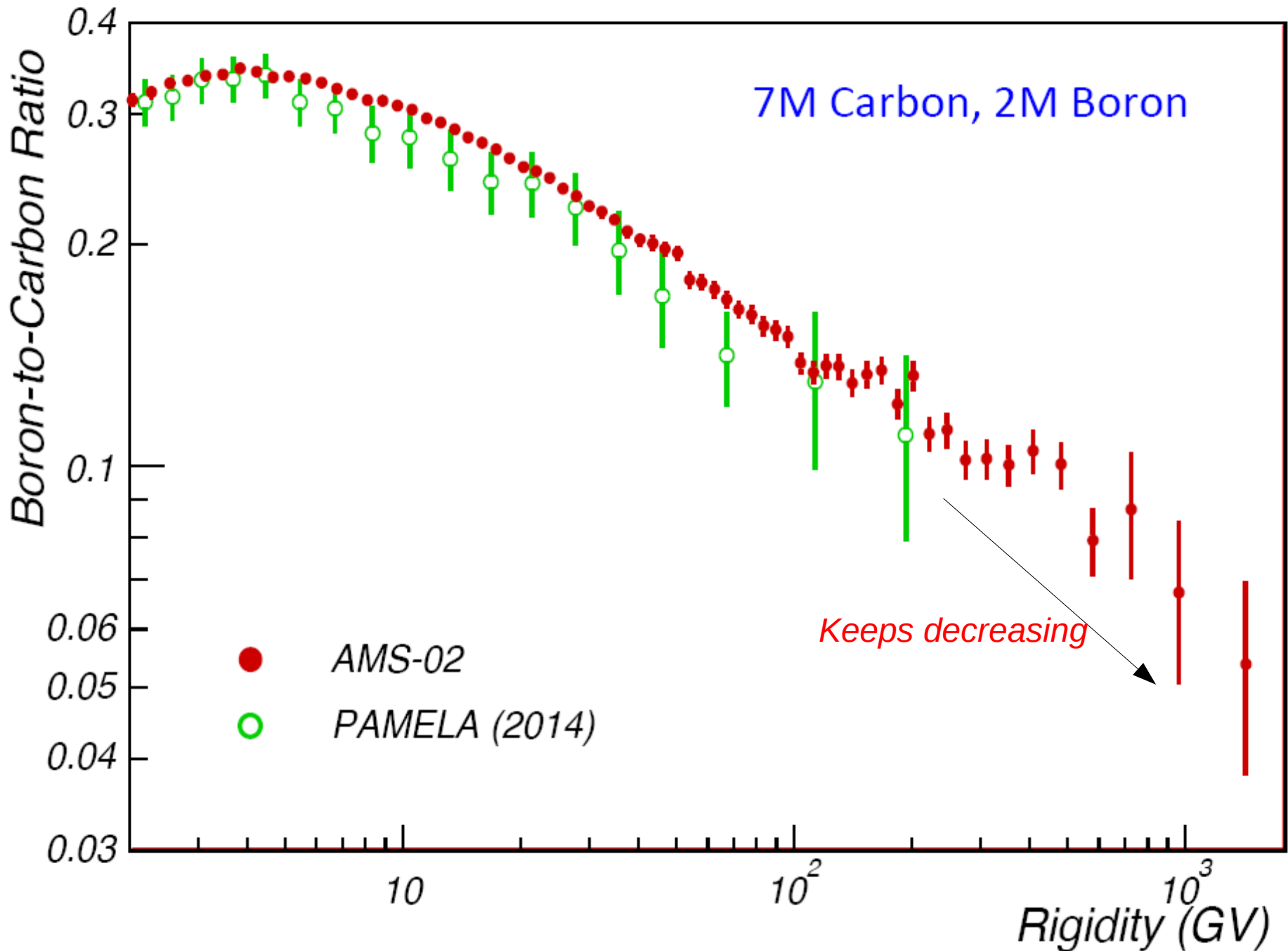
Stefan Schael
Gamma2016, Heidelberg



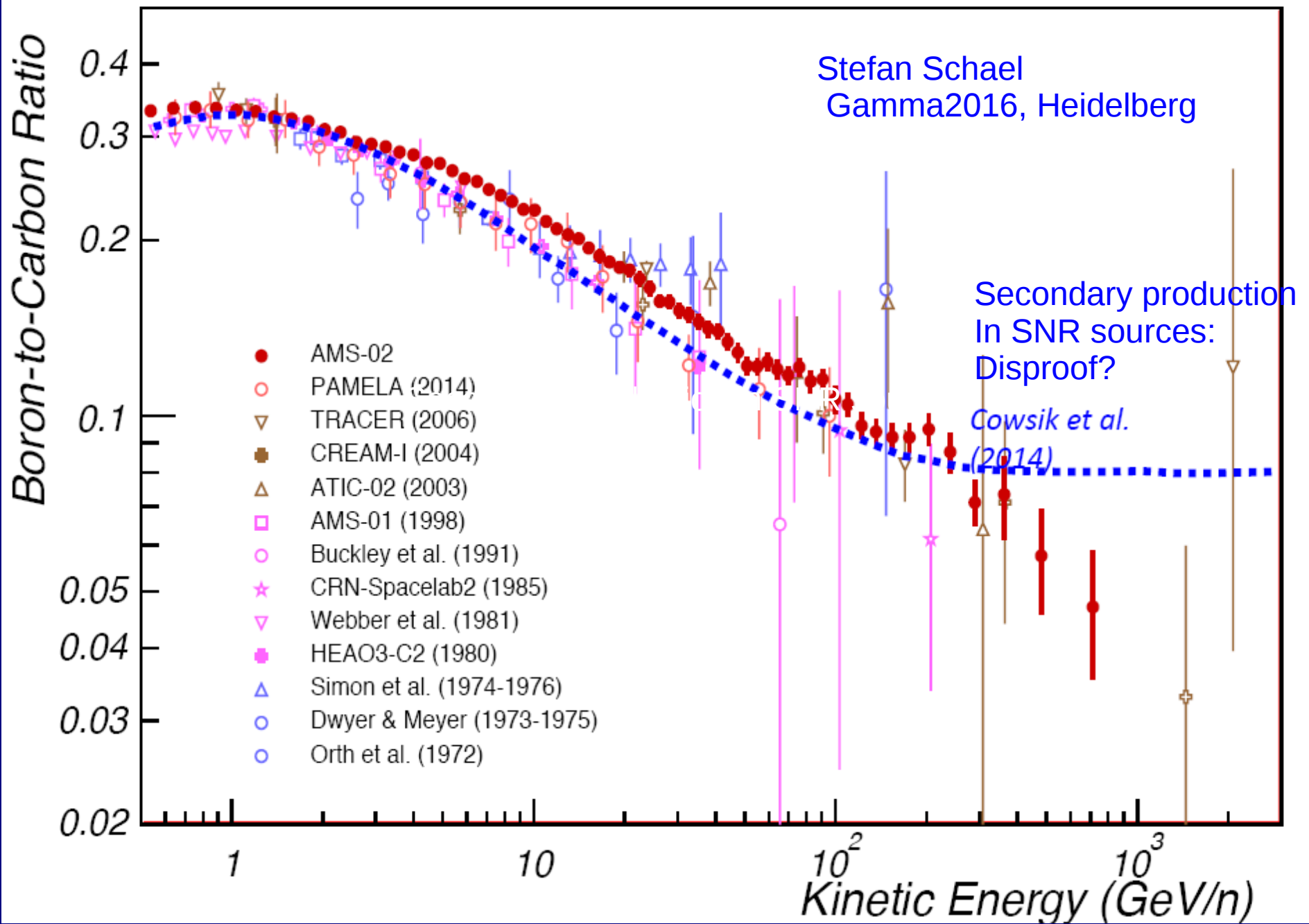
be

B/C Ratio

Stefan Schael
Gamma2016, Heidelberg



B/C Ratio converted in Kinetic Energy



11 things which are taken as established but are not and deserve further investigation

- 1 The Pion Bump has been detected in SNR
- 2 CR are extragalactic only $>10^{15}$ eV or so
- 3 CR cannot come from the Galactic Centre only
- 4 The CR gradient in the Galaxy can be determined accurately
- 5 The spectrum of CR in the Galaxy has the same shape as the local spectrum
- 6 Reacceleration is a viable explanation of the B/C peak (Luke's talk)
- 7 Secondary production in sources is negligible (including B, positrons)
- 8 ^{60}Fe tells about CR age, delay**
- 9 Positron/pbar ratio agrees with standard model (no: Lipari paper)
- 10 Diffuse Galactic emission is mainly interstellar not unresolved sources
- 11 CR are not important for galaxy evolution

Cite as: W. R. Binns et al., *Science*
10.1126/science.aad6004 (2016).

Observation of the ^{60}Fe nucleosynthesis-clock isotope in galactic cosmic rays

W. R. Binns,^{1*} M. H. Israel,^{1*} E. R. Christian,² A. C. Cummings,³ G. A. de Nolfo,² K. A. Lave,¹ R. A. Leske,³
R. A. Mewaldt,³ E. C. Stone,³ T. T. von Rosenvinge,² M. E. Wiedenbeck⁴

¹Washington University, St. Louis, MO 63130, USA, ²NASA/Goddard Space Flight Center, Greenbelt, MD 20771, USA, ³California Institute of Technology, Pasadena, CA 91125, USA, ⁴Jet Propulsion Laboratory, California Institute of Technology, Pasadena, CA 91109, USA

*Corresponding author. Email: wrb@wustl.edu (W.R.B.); mhi@wustl.edu (M.H.I.)

^{60}Fe is a radioactive isotope in cosmic rays that serves as a clock to infer an upper limit on the time between nucleosynthesis and acceleration. We have used the ACE-CRIS instrument to collect 3.55×10^5 iron nuclei, with energies ~ 195 to ~ 500 MeV/nucleon, of which we identify 15 ^{60}Fe nuclei. The $^{60}\text{Fe}/^{56}\text{Fe}$ source ratio is $(7.5 \pm 2.9) \times 10^{-5}$. The detection of supernova-produced ^{60}Fe in cosmic rays implies that the time required for acceleration and transport to Earth does not greatly exceed the ^{60}Fe half-life of 2.6 Myr and that the ^{60}Fe source distance does not greatly exceed the distance cosmic rays can diffuse over this time, $\lesssim 1$ kpc. A natural place for ^{60}Fe origin is in nearby clusters of massive stars.

Cite as: W. R. Binns et al., *Science*
10.1126/science.aad6004 (2016).

Observation of the ^{60}Fe nucleosynthesis-clock isotope in galactic cosmic rays

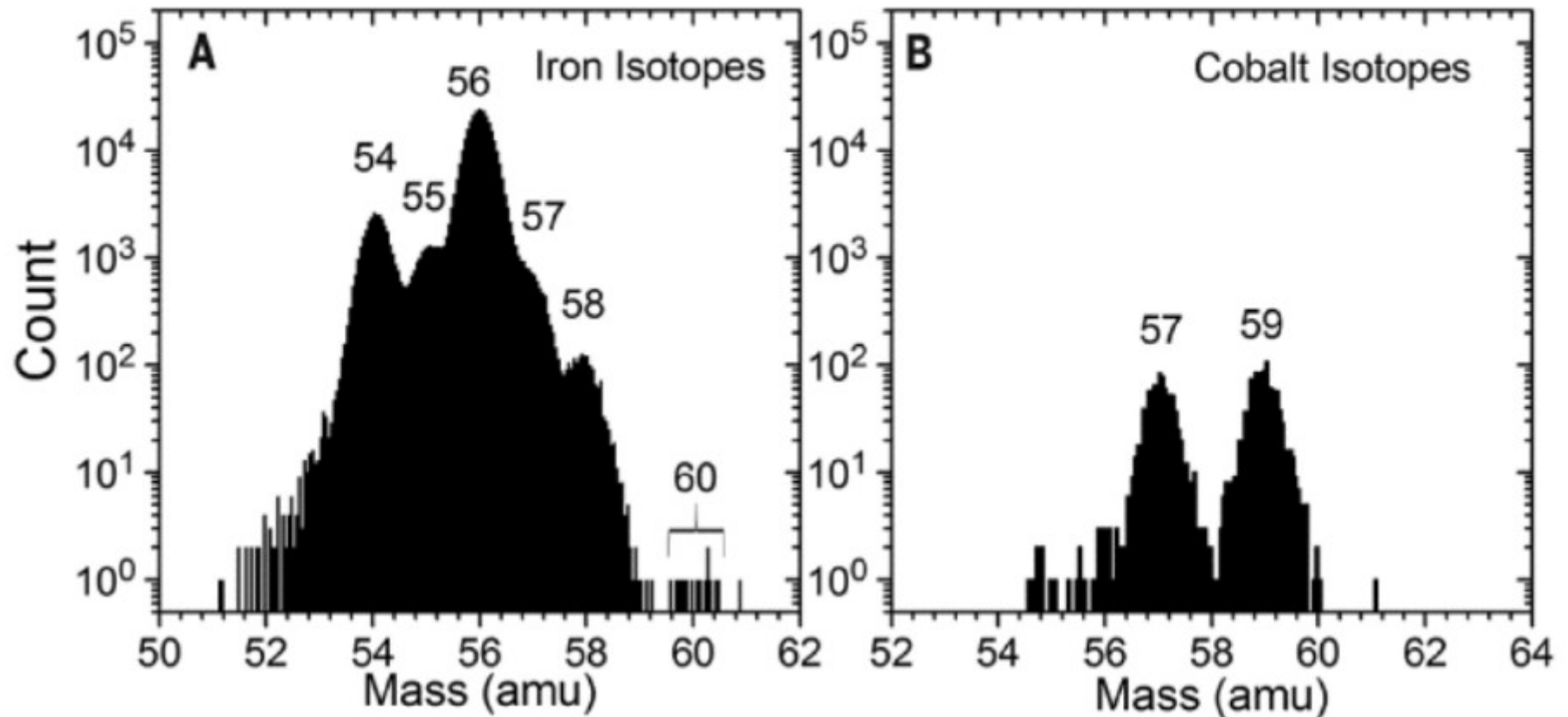


Fig. 2. Mass histograms of the observed iron and cobalt nuclei. (A) The mass histogram of iron nuclei detected during the first 17 years in orbit is plotted. Clear peaks are seen for masses 54, 55, 56, and 58 amu, with a shoulder at mass 57 amu. Centered at 60 amu are 15 events that we identify as the very rare radioactive ^{60}Fe nuclei. There are 2.95×10^5 events in the ^{56}Fe peak. From these data we obtain an $^{60}\text{Fe}/^{56}\text{Fe}$ ratio of $(4.6 \pm 17) \times 10^{-5}$ near Earth and $(7.5 \pm 2.9) \times 10^{-5}$ at the acceleration source. (B) The mass histogram of cobalt isotopes from the same data set are plotted. Note that ^{59}Co in panel B has roughly the same number of events as are in the ^{58}Fe peak in panel A. To the right of ^{59}Co there is only a single event spaced two mass units to the right of ^{59}Co , while there are 15 events in the location of ^{60}Fe , which is two mass units from ^{58}Fe . This is a strong argument that most of the 15 nuclei identified as ^{60}Fe are really ^{60}Fe , and not a tail of the ^{58}Fe distribution.

Using the mean lifetime of ^{60}Fe we can also estimate the distance to the associations contributing ^{60}Fe GCRs at Earth. Assuming a diffusive propagation model, cosmic rays originate within a volume with radius $L = (D\gamma\tau)^{1/2}$ surrounding the Solar System, where γ is the Lorentz factor and τ is the effective cosmic-ray lifetime. Assuming a diffusion coefficient of $D = 3.5 \times 10^{28} \text{ cm}^2/\text{s}$ (18), and using γ and τ calculated for ^{56}Fe and ^{60}Fe (supplementary material), we find $L_{56}=790 \text{ pc}$ and $L_{60}=620 \text{ pc}$. Since the volume goes as the cube of these diffusion lengths, the volume contributing to ^{60}Fe is only about half of that contributing to ^{56}Fe . There are >20 OB associations or major association subgroups that have been identified within 620 pc of the Sun including the very large and nearby (<150 pc) Sco-Cen association subgroups—Upper Scorpius (with 83 OB stars), Upper Centaurus Lupus (with 134 OB stars), and Lower Centaurus Crux (with 97 OB stars) (19), and the Orion OB1 association, modeled by (20) (with ~ 70 OB stars). These are very likely major contributors to the ^{60}Fe we have detected, owing to their size and proximity.

^{60}Fe rest-frame half-life 2.62 Myr (new measurement in Garching, old value 1.6 Myr)
At 523 MeV/nucleon $\gamma = 1.56 \rightarrow 4.1$ Myr

$$\tau = t_{1/2} / \ln 2 = 5.9 \text{ Myr}$$

15 events from ACE
Claim nearby SNR last 2.5 Myr

But ^{60}Fe everywhere in Galaxy, see decay gamma-ray line from INTEGRAL/SPI
 $^{60}\text{Fe} \rightarrow ^{60}\text{Co} \rightarrow ^{60}\text{Ni}$ 1.17, 1.33 MeV gamma-ray lines

SN rate 1/30 yr, 30 Myr residence time \rightarrow million SN made CR ^{60}Fe
so ^{60}Fe from everywhere in Galaxy
 $D \sim 3 \cdot 10^{28} \text{ cm}^2 \text{ s}^{-1}$
Limited by lifetime, $x \sim \sqrt{D\tau} = 0.76 \text{ kpc}$

But the huge source volume with longer residence time may win over decay
even if $e^{-(t/\tau)}$ reduces flux.

e.g. 10 Myr : $e^{-(t/\tau)} = 0.2$, 20 Myr : $e^{-(t/\tau)} = 0.03$

But need calculations with destruction of ^{60}Fe , energy losses etc
Which are also critical for all Fe and the ratio $\sim 5 \cdot 10^{-5}$ can still be viable.

Deep-sea sediments etc evidence for recent nearby SNR.

How to get ^{60}Fe ISM abundance from which CR accelerated?

$$\begin{array}{l} ^{60}\text{Fe}/^{56}\text{Fe} \text{ (measured at earth)} = 4.6 \pm 1.7 \cdot 10^{-5} \\ \text{('at source')} \qquad \qquad \qquad 7.5 \pm 2.9 \cdot 10^{-5} \text{ (model-dependent)} \end{array}$$

(for info $^{56}\text{Fe}/\text{Fe}$ (naturally occurring) = 0.92, $^{54}\text{Fe} \sim 5\%$)

Meteorites ^{60}Ni decay product of ^{60}Fe

Lower limit $5 \cdot 10^{-8}$, upper limit $2 \cdot 10^{-7}$ from chondrules (Tellus et al 2016)

Vasileidas et al 2013 ApJL 769, L8 : $\sim 10^{-8}$

But can fluctuate to 10^{-5} in clouds near SN, see also Kuffmeier et al 2016

But ^{60}Fe everywhere in Galaxy in equilibrium between production and decay
what do we expect from that?

$^{60}\text{Fe} \rightarrow ^{60}\text{Co} \rightarrow ^{60}\text{Ni}$ 1.17, 1.33 MeV gamma-ray lines

Measured by INTEGRAL / SPI

$$^{60}\text{Fe} / ^{56}\text{Fe} = 2.8 \cdot 10^{-7}$$

Also ^{26}Al mass from gammas, more robust, can use $^{27}\text{Al} / ^{56}\text{Fe} = 0.1$, $^{26}\text{Al} / ^{27}\text{Al} = 5 \cdot 10^{-5}$

SPI gamma-ray $^{60}\text{Fe} / ^{26}\text{Al} \sim 0.15$ (Wang et al 2007, A&A 469, 1005)

^{26}Al in CR radioactive (\sim Myr) also relevant but mainly secondary...

We assume but the ^{60}Fe results might affect that! Primary ^{26}Al ? Probably not since

$^{26}\text{Al}/^{27}\text{Al}$ still very small in SN.

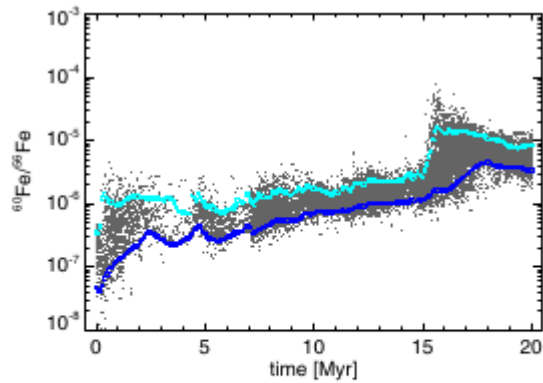


Figure 1. Supernova mass as a function of time (top), and values of the ratios $^{26}\text{Al}/^{27}\text{Al}$ (mid) and $^{60}\text{Fe}/^{56}\text{Fe}$ (bottom) in dense, star-forming gas of an evolving 40 pc, $10^5 M_{\odot}$ GMC with $\epsilon = 0.05$. The gray dots show values sampled in dense, star-forming clumps, with 10% and 90% percentiles marked in blue and cyan. The dashed line is the modeled bulk solar value of 2.8×10^{-5} (Larsen et al. 2011). Time is indicated in Myr after formation of the GMC (10 Myr offset from simulation start).

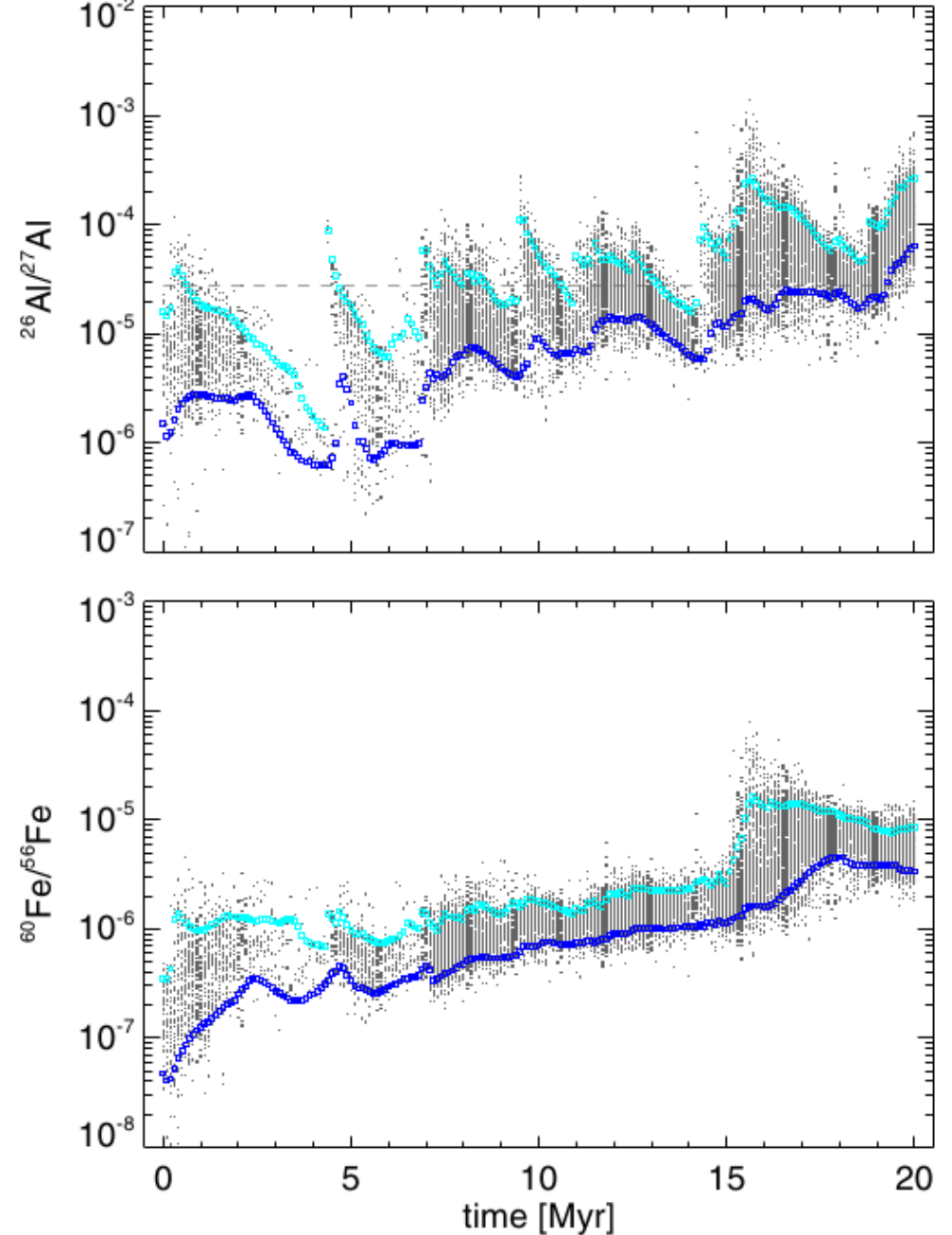


Figure 1. Supernova mass as a function of time (top), and values of the ratios $^{26}\text{Al}/^{27}\text{Al}$ (mid) and $^{60}\text{Fe}/^{56}\text{Fe}$ (bottom) in dense, star-forming gas of an evolving 40 pc, $10^5 M_{\odot}$ GMC with $\epsilon = 0.05$. The gray dots show values sampled in dense, star-forming clumps, with 10% and 90% percentiles marked in blue and cyan. The dashed line is the modeled bulk solar value of 2.8×10^{-5} (Larsen et al. 2011). Time is indicated in Myr after formation of the GMC (10 Myr offset from simulation start).

TRACKING THE DISTRIBUTION OF ^{26}Al AND ^{60}Fe DURING THE EARLY PHASES OF STAR AND DISK EVOLUTION

MICHAEL KUFFMEIER

Centre for Star and Planet Formation, Niels Bohr Institute and Natural History Museum of Denmark, University of Copenhagen, Øster Voldgade 5-7, DK-1350 Copenhagen K, Denmark

TROELS FROSTHOLM MOGENSEN

Centre for Star and Planet Formation, Niels Bohr Institute and Natural History Museum of Denmark, University of Copenhagen, Øster Voldgade 5-7, DK-1350 Copenhagen K, Denmark

TROELS HAUGBØLLE

Centre for Star and Planet Formation, Niels Bohr Institute and Natural History Museum of Denmark, University of Copenhagen, Øster Voldgade 5-7, DK-1350 Copenhagen K, Denmark

MARTIN BIZZARRO

Centre for Star and Planet Formation and Natural History Museum of Denmark, University of Copenhagen, Øster Voldgade 5-7, 1350 Copenhagen, Denmark

ÅKE NORDLUND

Centre for Star and Planet Formation, Niels Bohr Institute and Natural History Museum of Denmark, University of Copenhagen, Øster Voldgade 5-7, DK-1350 Copenhagen K, Denmark

Abstract

The short-lived ^{26}Al and ^{60}Fe radionuclides are synthesized and expelled in the interstellar medium by core-collapse supernova events. The solar system's first solids, calcium-aluminium refractory inclusions (CAIs), contain evidence for the former presence of the ^{26}Al nuclide defining the canonical $^{26}\text{Al}/^{27}\text{Al}$ ratio of $\sim 5 \times 10^{-5}$. A different class of objects temporally related to canonical CAIs are CAIs with fractionation and unidentified nuclear effects (FUN CAIs), which record a low initial $^{26}\text{Al}/^{27}\text{Al}$ of 10^{-6} . The contrasting level of ^{26}Al between these objects is often interpreted as reflecting the admixing of the ^{26}Al nuclide during the early formative phase of the Sun. We use giant molecular cloud (GMC) scale adaptive mesh-refinement numerical simulations to trace the abundance of ^{26}Al and ^{60}Fe in star-forming gas during the early stages of accretion of individual low mass protostars. We find that the $^{26}\text{Al}/^{27}\text{Al}$ and $^{60}\text{Fe}/^{56}\text{Fe}$ ratios of accreting gas within a vicinity of 1000 AU of the stars follow the predicted decay curves of the initial abundances at time of star formation without evidence of spatial or temporal heterogeneities for the first 100 kyr of star formation. Therefore, the observed differences in $^{26}\text{Al}/^{27}\text{Al}$ ratios between FUN and canonical CAIs are likely not caused by admixing of supernova material during the early evolution of the proto-Sun. Selective thermal processing of dust grains is a more viable scenario to account for the heterogeneity in $^{26}\text{Al}/^{27}\text{Al}$ ratios at the time of solar system formation.

1. INTRODUCTION

Giant molecular clouds (GMCs) are the primary reservoirs of cold, star-forming gas in the Galaxy. Astronomical observations and numerical simulations of star-forming regions suggest that GMCs have typical lifetimes of a few tens of Myr (Padoan et al. 2015; Dobbs et al. 2014; Kawamura et al.

clei, observable throughout the Milky Way due to the low opacity of γ -rays, have been used to determine the current average ISM abundance of ^{26}Al and ^{60}Fe and, hence, an estimate of the Galactic $^{60}\text{Fe}/^{26}\text{Al}$ ratio (Diehl et al. 2006; Wang et al. 2007).

Meteorites and their components provide insights into the

^{60}Fe facit: seems robust that an additional local CR source is required over global acceleration from the ISM

The whole approach to CR interpretation must change,
since primaries are dominated by local source,
while secondaries like B come from CR-gas interactions over whole Galaxy.

B/C, source abundances all affected.

Thanks to Roland Diehl for educating me on this unfamiliar topic!

See also talk by Elena Orlando on GALPROP analyses

11 things which are taken as established but are not and deserve further investigation

- 1 The Pion Bump has been detected in SNR by Fermi-LAT
- 2 CR are extragalactic only $>10^{15}$ eV or so
- 3 CR cannot come from the Galactic Centre only
- 4 The CR gradient in the Galaxy can be determined accurately
- 5 The spectrum of CR in the Galaxy has the same shape as the local spectrum
- 6 Reacceleration is a viable explanation of the B/C peak
- 7 Secondary production in sources is negligible
- 8 ^{60}Fe tells about CR age, delay
- 9 Positron/pbar ratio agrees with standard model**
- 10 Diffuse Galactic emission is mainly interstellar not unresolved sources
- 11 CR are not important for galaxy evolution

Positron and pbar spectra

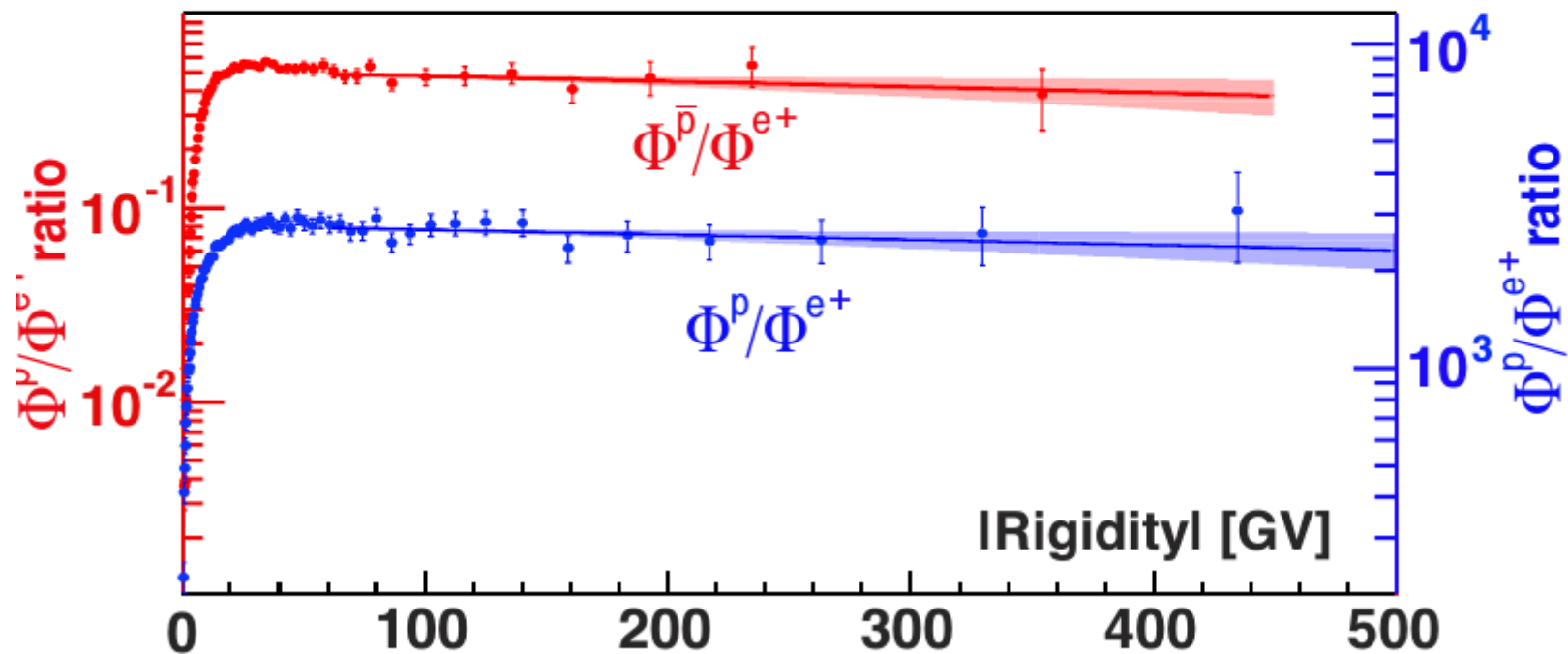
Positron and pbar spectra same shape

AMS Schael

and Lipari paper and Heidelberg Gamma 2016 talk

Flux Ratios \bar{p}/e^+ and p/e^+ are also energy independent in the interval 60–450 GV

Stefan Schael
Gamma2016, Heidelberg



pbar and e+ production have similar spectra since hadronic interactions
But e+ are supposed to lose energy and steepen !
A mean conspiracy – a coincidence? Or a challenge to standard models?

11 things which are taken as established but are not and deserve further investigation

- 1 The Pion Bump has been detected in SNR by Fermi-LAT
- 2 CR are extragalactic only $>10^{15}$ eV or so
- 3 CR cannot come from the Galactic Centre only
- 4 The CR gradient in the Galaxy can be determined accurately
- 5 The spectrum of CR in the Galaxy has the same shape as the local spectrum
- 6 Reacceleration is a viable explanation of the B/C peak (Luke's talk)
- 7 Secondary production in sources is negligible (including B, positrons)
- 8 ^{60}Fe tells about CR age, delay (from gammas ^{60}Fe is everywhere in ISM)
- 9 Positron/pbar ratio agrees with standard model (no: Lipari paper)
- 10 Diffuse Galactic emission is mainly interstellar not unresolved sources**
- 11 CR are not important for galaxy evolution

Diffuse emission has probably 5-10% source component
But could be more if many low-luminosity sources below threshold even locally
What would their luminosity and density be?
3FGL paper

Under construction

11 things which are taken as established but are not and deserve further investigation

- 1 The Pion Bump has been detected in SNR by Fermi-LAT
- 2 CR are extragalactic only $>10^{15}$ eV or so
- 3 CR cannot come from the Galactic Centre only
- 4 The CR gradient in the Galaxy can be determined accurately
- 5 The spectrum of CR in the Galaxy has the same shape as the local spectrum
- 6 Reacceleration is a viable explanation of the B/C peak (Luke's talk)
- 7 Secondary production in sources is negligible (including B, positrons)
- 8 ^{60}Fe tells about CR age, delay (from gammas ^{60}Fe is everywhere in ISM)
- 9 Positron/pbar ratio agrees with standard model (no: Lipari paper)
- 10 Diffuse Galactic emission is mainly interstellar not unresolved sources
- 11 CR are not important for galaxy evolution



LAUNCHING COSMIC-RAY-DRIVEN OUTFLOWS FROM THE MAGNETIZED INTERSTELLAR MEDIUM

PHILIPP GIRICHIDIS¹, THORSTEN NAAB¹, STEFANIE WALCH², MICHAŁ HANASZ³, MORDECAI-MARK MAC LOW^{4,5},
 JEREMIAH P. OSTRICKER⁶, ANDREA GATTO¹, THOMAS PETERS¹, RICHARD WÜNSCH⁷, SIMON C. O. GLOVER⁵,
 RALF S. KLESSEN⁵, PAUL C. CLARK⁸, AND CHRISTIAN BACZYNSKI⁵

¹Max-Planck-Institut für Astrophysik, Karl-Schwarzschild-Str. 1, D-85741 Garching, Germany

²Physikalisches Institut, Universität zu Köln, Zùlpicher Str. 77, D-50937 Köln, Germany

³Centre for Astronomy, Nicolaus Copernicus University, Faculty of Physics, Astronomy and Informatics, Grudziadzka 5, PL-87100 Toruń, Poland

⁴Department of Astrophysics, American Museum of Natural History, 79th Street at Central Park West, New York, NY 10024, USA

⁵Universität Heidelberg, Zentrum für Astronomie, Institut für Theoretische Astrophysik, Albert-Ueberle-Str. 2, D-69120 Heidelberg, Germany

⁶Department of Astronomy, Columbia University, 1328 Pupin Hall, 550 West 120th Street, New York, NY 10027, USA

⁷Astronomical Institute, Academy of Sciences of the Czech Republic, Bocni II 1401, 141 31 Prague, Czech Republic

⁸School of Physics & Astronomy, Cardiff University, 5 The Parade, Cardiff CF24 3AA, Wales, UK

$$\frac{\partial \rho}{\partial t} + \nabla \cdot (\rho \mathbf{v}) = 0$$

$$\frac{\partial \rho \mathbf{v}}{\partial t} + \nabla \cdot \left(\rho \mathbf{v} \mathbf{v}^T - \frac{\mathbf{B} \mathbf{B}^T}{4\pi} \right) + \nabla p_{\text{tot}} = \rho \mathbf{g}$$

$$\begin{aligned} \frac{\partial e}{\partial t} + \nabla \cdot \left[(e + p_{\text{tot}}) \mathbf{v} - \frac{\mathbf{B}(\mathbf{B} \cdot \mathbf{v})}{4\pi} \right] \\ = \rho \mathbf{v} \cdot \mathbf{g} + \nabla \cdot \mathbf{K} \nabla e_{\text{CR}} + \dot{u}_{\text{chem}} + \dot{u}_{\text{inj}} \end{aligned}$$

$$\frac{\partial \mathbf{B}}{\partial t} - \nabla \times (\mathbf{v} \times \mathbf{B}) = 0$$

$$\begin{aligned} \frac{\partial e_{\text{CR}}}{\partial t} + \nabla \cdot (e_{\text{CR}} \mathbf{v}) \\ = -p_{\text{CR}} \nabla \cdot \mathbf{v} + \nabla \cdot (\mathbf{K} \nabla e_{\text{CR}}) + Q_{\text{CR}} \end{aligned}$$



LAUNCHING COSMIC-RAY-DRIVEN OUTFLOWS FROM THE MAGNETIZED INTERSTELLAR MEDIUM

PHILIPP GIRICHIDIS¹, THORSTEN NAAB¹, STEFANIE WALCH², MICHAŁ HANASZ³, MORDECAI-MARK MAC LOW^{4,5},
 JEREMIAH P. OSTRICKER⁶, ANDREA GATTO¹, THOMAS PETERS¹, RICHARD WÜNSCH⁷, SIMON C. O. GLOVER⁵,
 RALF S. KLESSEN⁵, PAUL C. CLARK⁸, AND CHRISTIAN BACZYNSKI⁵

¹Max-Planck-Institut für Astrophysik, Karl-Schwarzschild-Str. 1, D-85741 Garching, Germany

²Physikalisches Institut, Universität zu Köln, Zùlpicher Str. 77, D-50937 Köln, Germany

³Centre for Astronomy, Nicolaus Copernicus University, Faculty of Physics, Astronomy and Informatics, Grudziadzka 5, PL-87100 Toruń, Poland

⁴Department of Astrophysics, American Museum of Natural History, 79th Street at Central Park West, New York, NY 10024, USA

⁵Universität Heidelberg, Zentrum für Astronomie, Institut für Theoretische Astrophysik, Albert-Ueberle-Str. 2, D-69120 Heidelberg, Germany

⁶Department of Astronomy, Columbia University, 1328 Pupin Hall, 550 West 120th Street, New York, NY 10027, USA

⁷Astronomical Institute, Academy of Sciences of the Czech Republic, Bocni II 1401, 141 31 Prague, Czech Republic

⁸School of Physics & Astronomy, Cardiff University, 5 The Parade, Cardiff CF24 3AA, Wales, UK

$$\frac{\partial \rho}{\partial t} + \nabla \cdot (\rho \mathbf{v}) = 0$$

Modified FLASH code

$$\frac{\partial \rho \mathbf{v}}{\partial t} + \nabla \cdot \left(\rho \mathbf{v} \mathbf{v}^T - \frac{\mathbf{B} \mathbf{B}^T}{4\pi} \right) + \nabla p_{\text{tot}} = \rho \mathbf{g} \quad p_{\text{tot}} = p_{\text{th}} + p_{\text{mag}}$$

$$\frac{\partial e}{\partial t} + \nabla \cdot \left[(e + p_{\text{tot}}) \mathbf{v} - \frac{\mathbf{B} (\mathbf{B} \cdot \mathbf{v})}{4\pi} \right] = \rho \mathbf{v} \cdot \mathbf{g} + \dot{u}_{\text{chem}} + \dot{u}_{\text{inj}} \quad e = \rho v^2 / 2 + e_{\text{th}} + B^2 / 8\pi$$

$$\frac{\partial \mathbf{B}}{\partial t} - \nabla \times (\mathbf{v} \times \mathbf{B}) = 0$$



LAUNCHING COSMIC-RAY-DRIVEN OUTFLOWS FROM THE MAGNETIZED INTERSTELLAR MEDIUM

PHILIPP GIRICHIDIS¹, THORSTEN NAAB¹, STEFANIE WALCH², MICHAŁ HANASZ³, MORDECAI-MARK MAC LOW^{4,5},
 JEREMIAH P. OSTRICKER⁶, ANDREA GATTO¹, THOMAS PETERS¹, RICHARD WÜNSCH⁷, SIMON C. O. GLOVER⁵,
 RALF S. KLESSEN⁵, PAUL C. CLARK⁸, AND CHRISTIAN BACZYNSKI⁵

¹Max-Planck-Institut für Astrophysik, Karl-Schwarzschild-Str. 1, D-85741 Garching, Germany

²Physikalisches Institut, Universität zu Köln, Zùlpicher Str. 77, D-50937 Köln, Germany

³Centre for Astronomy, Nicolaus Copernicus University, Faculty of Physics, Astronomy and Informatics, Grudziadzka 5, PL-87100 Toruń, Poland

⁴Department of Astrophysics, American Museum of Natural History, 79th Street at Central Park West, New York, NY 10024, USA

⁵Universität Heidelberg, Zentrum für Astronomie, Institut für Theoretische Astrophysik, Albert-Ueberle-Str. 2, D-69120 Heidelberg, Germany

⁶Department of Astronomy, Columbia University, 1328 Pupin Hall, 550 West 120th Street, New York, NY 10027, USA

⁷Astronomical Institute, Academy of Sciences of the Czech Republic, Bocni II 1401, 141 31 Prague, Czech Republic

⁸School of Physics & Astronomy, Cardiff University, 5 The Parade, Cardiff CF24 3AA, Wales, UK

$$\frac{\partial \rho}{\partial t} + \nabla \cdot (\rho \mathbf{v}) = 0$$

Modified FLASH code

$$\frac{\partial \rho \mathbf{v}}{\partial t} + \nabla \cdot \left(\rho \mathbf{v} \mathbf{v}^T - \frac{\mathbf{B} \mathbf{B}^T}{4\pi} \right) + \nabla p_{\text{tot}} = \rho \mathbf{g}$$

$$p_{\text{tot}} = p_{\text{th}} + p_{\text{CR}} + p_{\text{mag}}$$

$$\begin{aligned} \frac{\partial e}{\partial t} + \nabla \cdot \left[(e + p_{\text{tot}}) \mathbf{v} - \frac{\mathbf{B}(\mathbf{B} \cdot \mathbf{v})}{4\pi} \right] \\ = \rho \mathbf{v} \cdot \mathbf{g} + \nabla \cdot \mathbf{K} \nabla e_{\text{CR}} + \dot{u}_{\text{chem}} + \dot{u}_{\text{inj}} \end{aligned}$$

$$e = \rho v^2/2 + e_{\text{th}} + e_{\text{CR}} + B^2/8\pi$$

$$\frac{\partial \mathbf{B}}{\partial t} - \nabla \times (\mathbf{v} \times \mathbf{B}) = 0$$

$$\begin{aligned} \frac{\partial e_{\text{CR}}}{\partial t} + \nabla \cdot (e_{\text{CR}} \mathbf{v}) \\ = -p_{\text{CR}} \nabla \cdot \mathbf{v} + \nabla \cdot (\mathbf{K} \nabla e_{\text{CR}}) + Q_{\text{CR}} \end{aligned}$$

Supernovae energy input

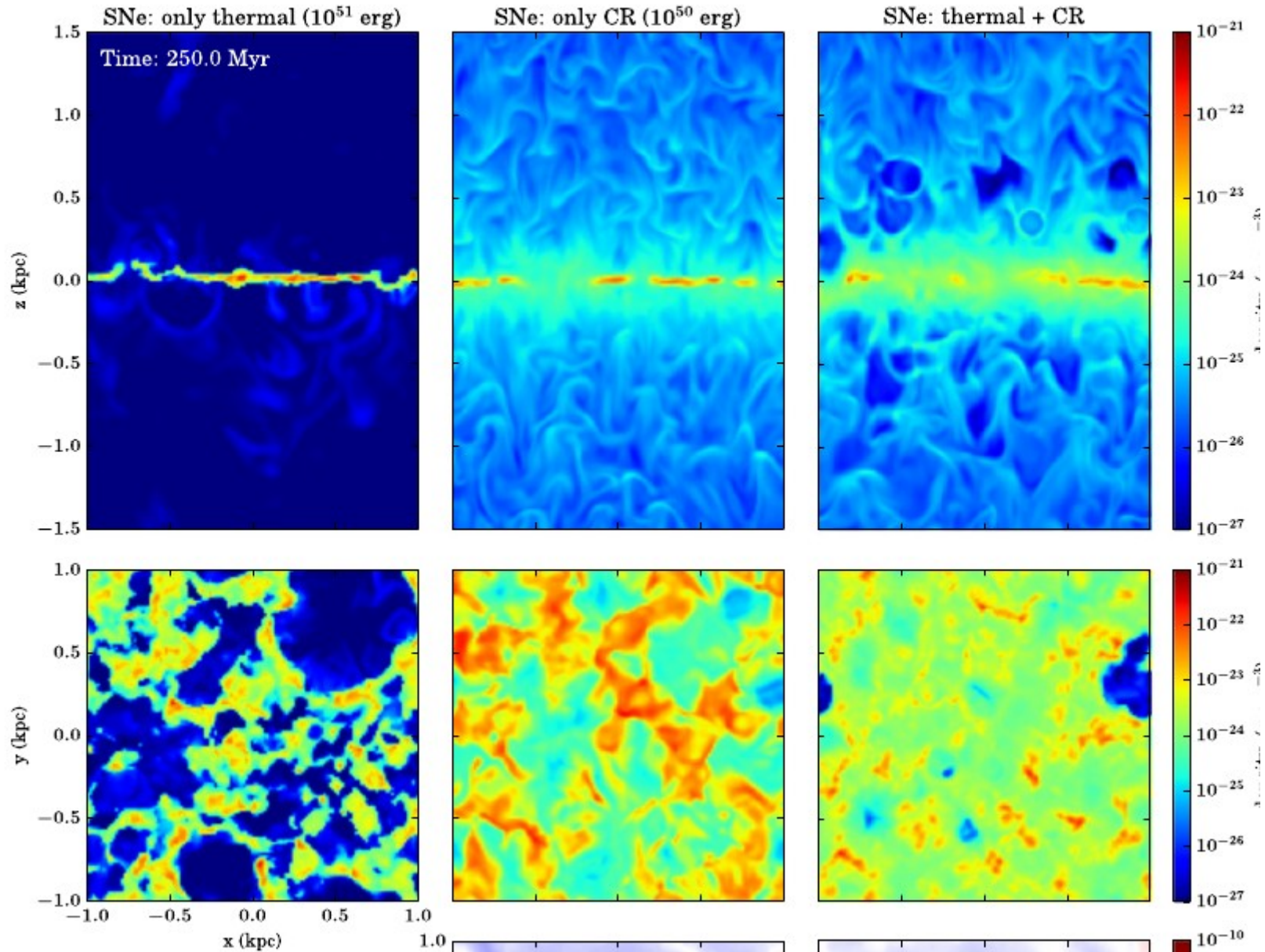
only thermal

only cosmic rays

both

THE ASTROPHYSICAL JOURNAL LETTERS, 816:L19 (6pp), 2016 January 10

GIRICHIDIS E



Time-dependent simulations available for download

Supernovae energy input

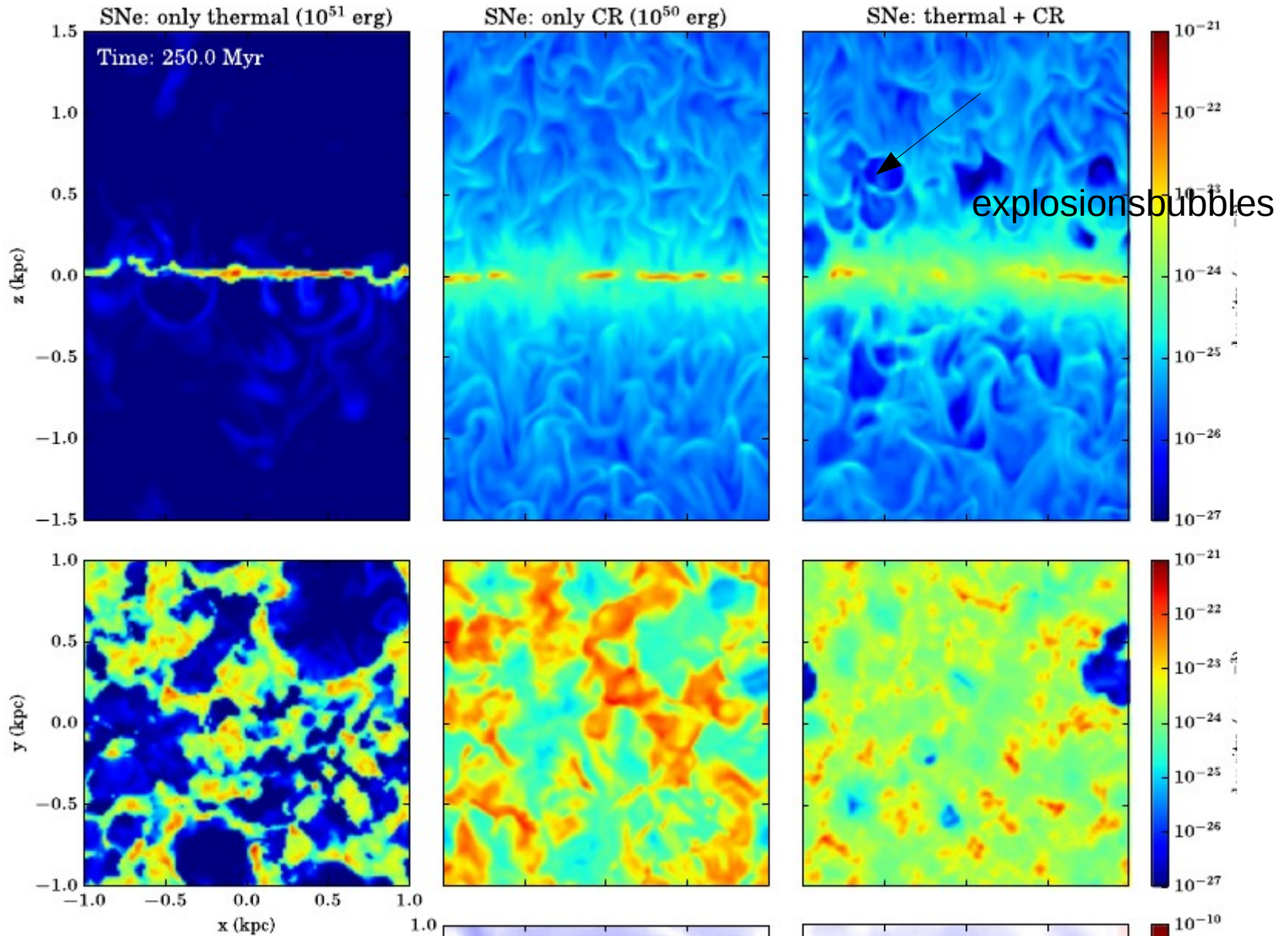
only thermal

only cosmic rays

both

THE ASTROPHYSICAL JOURNAL LETTERS, 816:L19 (6pp), 2016 January 10

GIRICHIDIS E



Time-dependent simulations available for download

Cosmic rays increase vertical gas scale

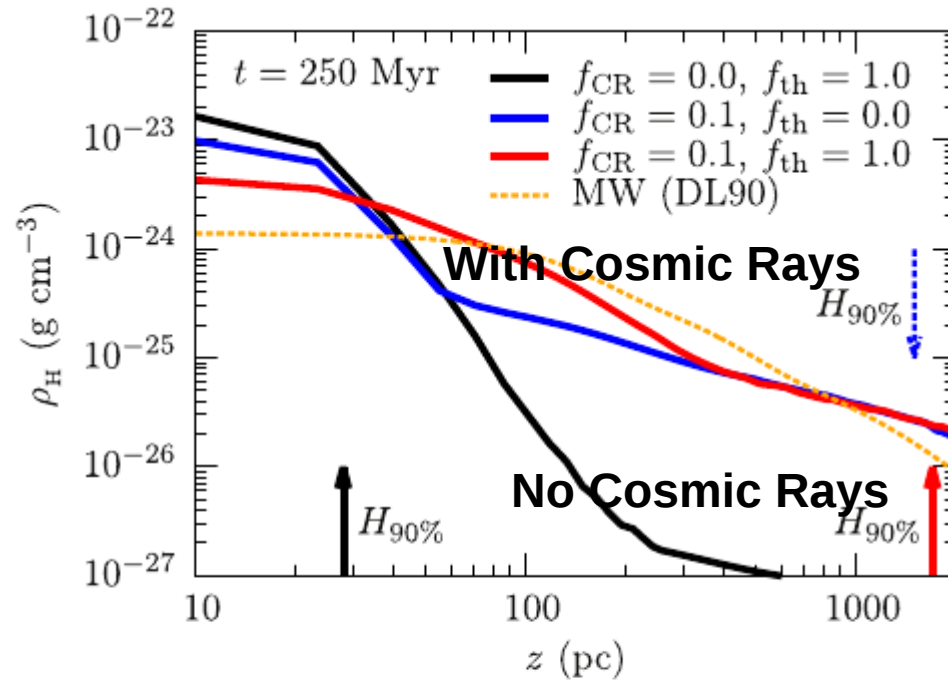


Figure 2. Vertical profiles of the total gas density for all simulations. The arrows indicate the height of 90% enclosed mass. A fit to the observed density profile of the solar neighborhood (Dickey & Lockman 1990) are shown in yellow. Thermal energy injection alone leads to a compact atomic gas distribution. Including CR feedback results in very extended distributions, which are much closer to the observed extent of the gas. The profiles indicate that CRs have their main impact at larger altitudes.

1. Including CRs thickens the galactic disk. The height of 90% enclosed total mass is found to be ~ 1.5 kpc in the case of 10% CR energy injection per SN after 250 Myr and to increase continuously. Comparison with the vertical density distribution in the MW indicates good agreement.
2. We find that CRs quickly lead to the formation of a warm and neutral galactic atmosphere providing a mass reservoir for galactic winds and outflows. Whereas the thermal contribution of the SNe mainly shapes the disk close to the midplane, the additional CR energy shows the strongest impact above the disk and in the halo.
3. All simulations drive gas out of the midplane with little variation over time. For purely thermal SN feedback, the outflows are hot and composed of mainly ionized hydrogen with rates below the star formation rate. They are fast (up to \sim a few 100 km s^{-1}) with low densities ($\rho \lesssim 10^{-27} \text{ g cm}^{-3}$). CRs alone can drive outflows with mass loading factors of order unity, which are warm (10^4 K) and mainly composed of atomic hydrogen. They are a factor of a few slower ($\sim 10\text{--}50 \text{ km s}^{-1}$) and 1–2 orders of magnitude denser ($\rho \sim 10^{-26}\text{--}10^{-25} \text{ g cm}^{-3}$) compare to their thermally driven counterparts.

Future work in context of cosmic-ray physics:

- * Test such cosmic-ray-driven wind models against cosmic-ray and gamma-ray data.
- * Extend models to include energy spectrum of cosmic rays (at present just a single fluid)
- * Use to make GALPROP-like approaches more physical for convection and halo structure instead of simple pre-defined forms.

B-field in Girichidis et al. Models

Dynamo-produced B-field (ab initio from seed field)
Small-scale, turbulent dynamo
Not large-scale dynamo.

Michal Hanasz models

CR-driven dynamo, no thermal input SNR etc

Large-scale Galactic dynamo

GALACTIC DISK MODEL – MILKY WAY TYPE GALAXY

(Hanasz et al 2009, ApJ 706L, 155)

- Galactic gravitational potential: halo+bulge+disk: analytical model (Allen & Santillan 1991), N-body model (Hernquist 1993)
- Interstellar gas: Global model of ISM for the Milky Way (Ferriere 1998)
- **Schmidt-Kennicutt law:** $\text{SFR} \propto (\text{gas density})^{1.4}$
- $\text{SNR} \propto \text{SFR}$
- 10% of SN energy output is converted to CR energy.
- **No magnetic field at $t = 0$**
- **weak ($10^{-4} \mu\text{G}$) dipolar, small scale ($r \sim 50\text{pc}$) randomly oriented magnetic field is supplied locally in 10% of SN remnants (Krab type)**

MHD EQUATIONS

$$\frac{\partial \mathbf{V}}{\partial t} + (\mathbf{V} \cdot \nabla) \mathbf{V} = -\frac{1}{\rho} \nabla(p + p_{CR}) + \mathbf{g} + \frac{1}{\rho} \nabla \left(\frac{B^2}{8\pi} \right) + \frac{\mathbf{B} \cdot \nabla \mathbf{B}}{4\pi\rho}$$

$$\frac{\partial \rho}{\partial t} + \nabla \cdot (\rho \mathbf{V}) = 0$$

$$p = c_s^2 \rho \quad (\text{isoth. approx})$$

$$\frac{\partial \mathbf{B}}{\partial t} = \nabla \times (\mathbf{V} \times \mathbf{B}) + \eta \nabla^2 \mathbf{B}$$

CR TRANSPORT EQUATION

Diffusion - advection approximation

(e.g. Schlickeiser & Lerche 1985, A&A, 151, 151)

$$\frac{\partial e_{\text{cr}}}{\partial t} + \nabla(e_{\text{cr}} \mathbf{V}) = -\rho_{\text{cr}} \nabla \mathbf{V} + \nabla(\hat{K} \nabla e_{\text{cr}}) \quad (1)$$

+ CR sources (SN remnants)

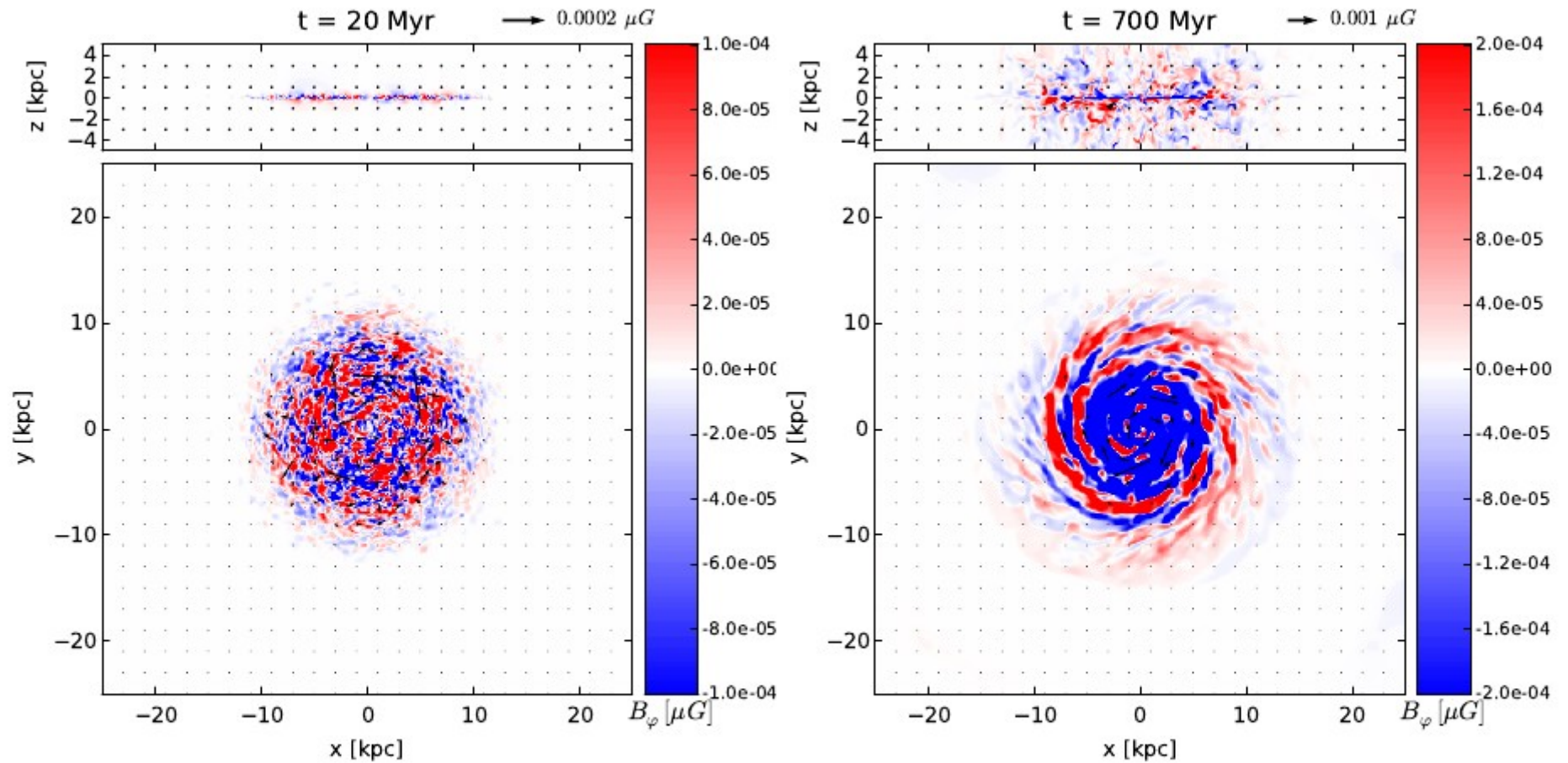
$$\rho_{\text{cr}} = (\gamma_{\text{cr}} - 1)e_{\text{cr}} \quad (2)$$

Anisotropic diffusion of CRs

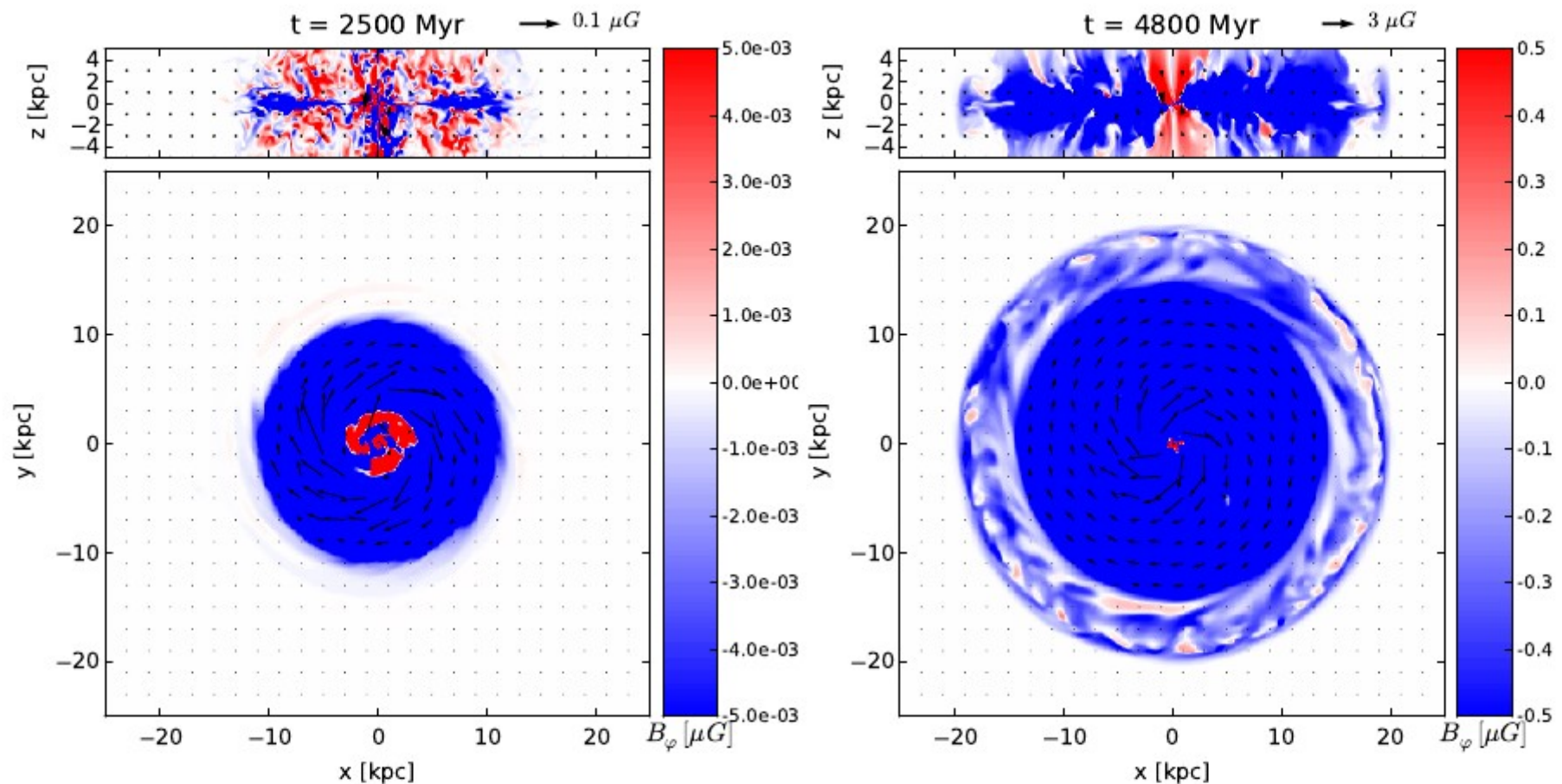
(Giaccalone & Jokipii 1998 , Jokipii 1999, Ryu et al. 2003)

$$K_{ij} = K_{\perp} \delta_{ij} + (K_{\parallel} - K_{\perp}) n_i n_j, \quad n_i = B_i / B, \quad (3)$$

$$K_{\parallel} = 3 \cdot 10^{28} \text{cm}^2 \text{s}^{-1}, \quad K_{\perp} = (1 - 10)\% (K_{\parallel})$$



Colours: – azimuthal (toroidal) magnetic field **blue: $B_\phi < 0$, red: $B_\phi > 0$**
 Exploding magnetised stars spread weak irregular magnetic fields in the ISM

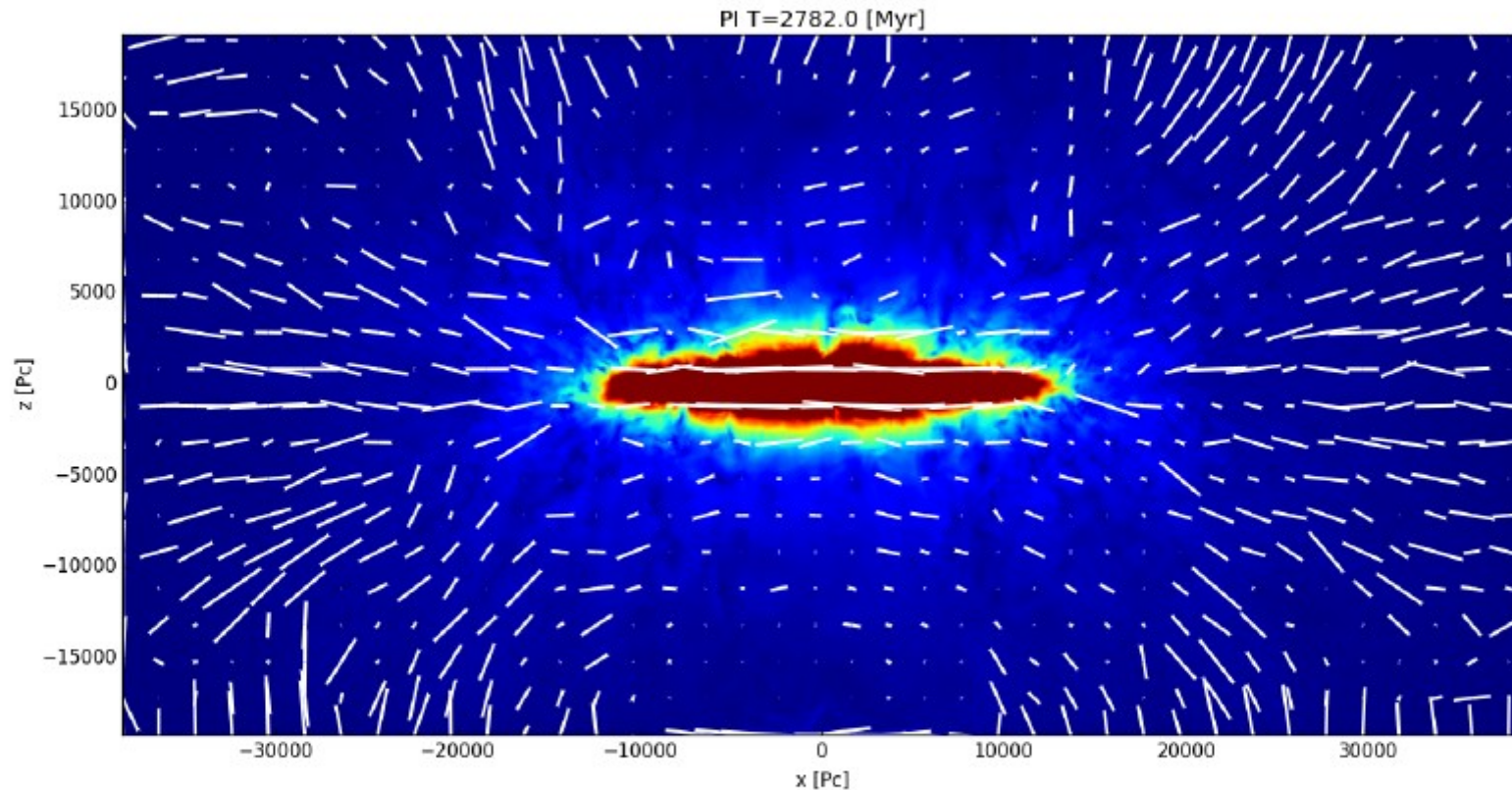


Colours: – azimuthal (toroidal) magnetic field **blue: $B_\phi < 0$** , **red: $B_\phi > 0$**

- Cosmic-ray driven **buoyancy**, **Coriolis force** and **disk differential rotation** lead to amplification (timescale $\sim T_{rot}$) of magnetic field – $\alpha\omega$ -type dynamo.
- **Galactic wind** evacuates selectively one of magnetic polarities \Rightarrow regularisation of magnetic field.

Credit: Michal Hanasz

MAGNETIC FIELD STRUCTURE RESULTING AS PROJECTION OF THE WIND-SHAPED HELICES



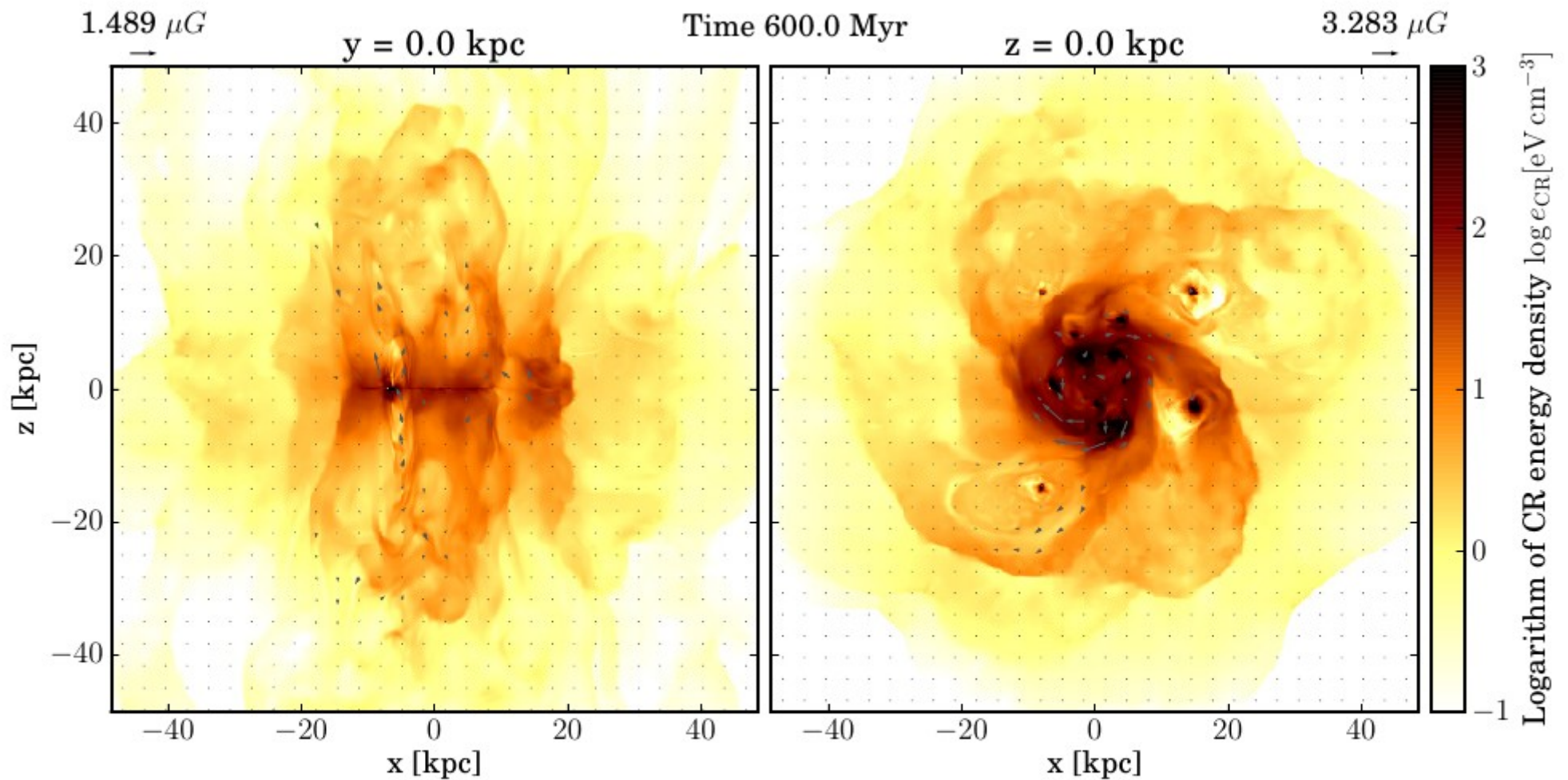
Colour: polarised synchrotron intensity integrated along the line of sight
Vectors: polarisation vectors of synchrotron emission
(direction $\parallel \vec{B}$, length \propto polarisation degree)

Credit: Michal Hanasz

Cosmic rays can drive strong outflows from gas-rich high-redshift disk galaxies.

**Hanasz, Lesch, Naab, Gawryszczak, Kowalik, Wóltański,
ApJL, 777, L38 2013**

- A galaxy similar to Milky Way (same masses of galactic halo, and stellar disk), but $\sim 10\times$ higher gas contents ($z = 2$).
- **Isothermal gas, no momentum feedback.**
- Fresh gas supplied at the fixed rate $\dot{M}_{in} = 100 M_{\odot}/\text{yr}$.
- Toroidal magnetic field, $B_0 = 3\mu\text{G}$ already present in the disk.
- Self-gravity forms dens gas blobs as soon as gaseous disk becomes gravitationally unstable.



Logarithm of CR energy density and magnetic vectors. The high concentration of CRs at the horizontal plane coincides with the star forming clouds.

Credit: Michal Hanasz

MeV gammas hold key to some topics

COMPTEL

SPI

...

eAstrogam

COMPTEL reloaded: new initiatives in heritage MeV gamma-ray astronomy

A. W. Strong¹, W. Collmar¹, T. A. Enßlin², M. Reinecke², D. Pompe², F. Guglielmetti²



1. MPE Garching 2. MPA Garching



ABSTRACT

The COMPTEL gamma-ray telescope on NASA's Compton Gamma Ray Observatory (CGRO) operated from 1991 to 2000. It was a double-scatter Compton instrument covering the energy range 0.75-30 MeV, both in continuum and lines. Full-sky maps and a source catalogue were the main outcome of the mission. While the Fermi-LAT instrument has now vastly enhanced our knowledge of the gamma-ray sky at higher energies, the MeV range remains devoid of new missions, so that the heritage COMPTEL data is an essential resource. Data analysis has continued at MPE Garching, with improved event processing and selections. The original skymapping method using Maximum Entropy has been adapted to current technology. A new initiative for skymapping using state-of-the-art Bayesian techniques has been started at MPA Garching; this involves Information Field Theory with the D²PO system.

INSTRUMENT

COMPTEL on CGRO
(1991 - 2000)

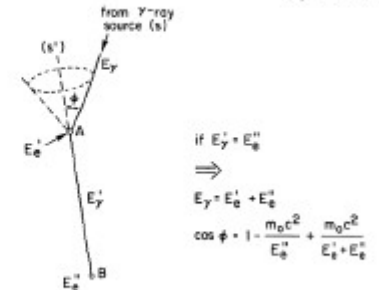


DETECTION TECHNIQUE

The double-Compton scattering detection technique means that each photon is associated with an annulus on the sky, with known centre, radius and shape; this makes deconvolution essential for imaging. One method is Maximum Entropy (Maxent), which has been used to make all-sky images. The large instrumental background is a further challenge for any COMPTEL analysis.

PRINCIPLE OF MEASUREMENT

(Ryan & Lockwood, 1989)



Original Maxent images (A)

In the original work (Strong et al. 1998) the MEMSYS5 Bayesian 'Classic' Maxent package was used (Skilling, 1989). It employed a template for the instrumental background taken from high Galactic latitudes where the celestial signal is small. In the original work 240 COMPTEL observations were used, and the data and instrumental response were treated in the instrumental coordinate system. Because of the large computing requirements the computation was performed on 240 CPUs of a Cray supercomputer which was state-of-the-art at the time.

Classic Maxent

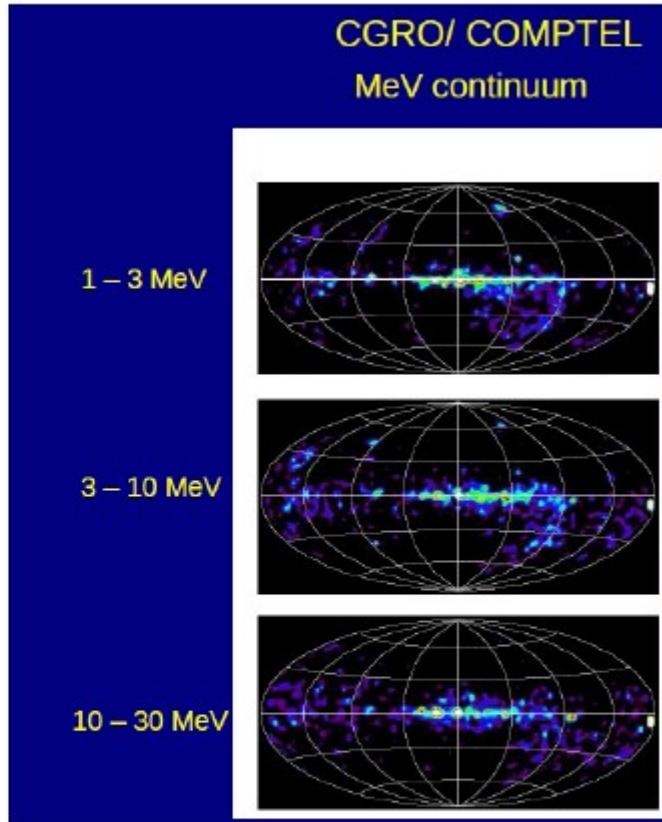
Entropic prior on image:

$$\Phi(S) \propto \exp(\alpha S)$$

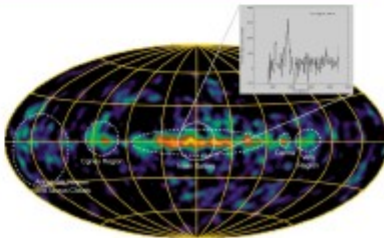
Posterior of image:

$$\begin{aligned} \Pr(h, \alpha, D) &= \Pr(\alpha) \Pr(h | \alpha) \Pr(D | h) \\ &= \Pr(\alpha) \frac{\exp(\alpha S(h) - \mathcal{L}(h))}{Z_S(\alpha) Z_{\mathcal{L}}} \end{aligned}$$

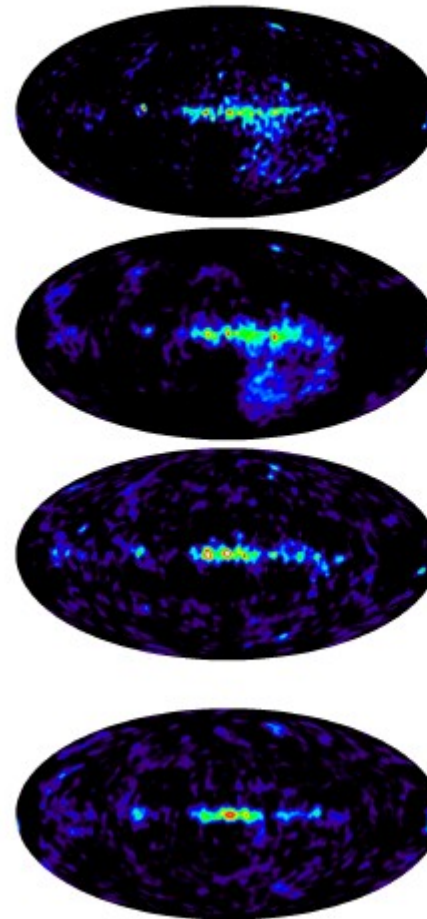
(A)



1.8 MeV – ²⁶Al



(B)



New Maxent images (B)

In view of the importance of the COMPTEL data, we have recently revisited imaging with current software and hardware technology. The original code was adapted to use the HEALPix sky representation for a uniform sky coverage both in data and image space instead of the original straight (l,b) system. This also allows fast convolution/correlation on the sphere, replacing the original "brute-force" method. This already gives an enormous speed gain, and running in on a multicore machine produces images in hours (compared to weeks on the original Cray implementation). A finer pixelization (0.5° instead of the original 1°) is hence possible. The HEALPix format enhances the value of the images and the speed allows investigation of more imaging parameters, data selection etc.

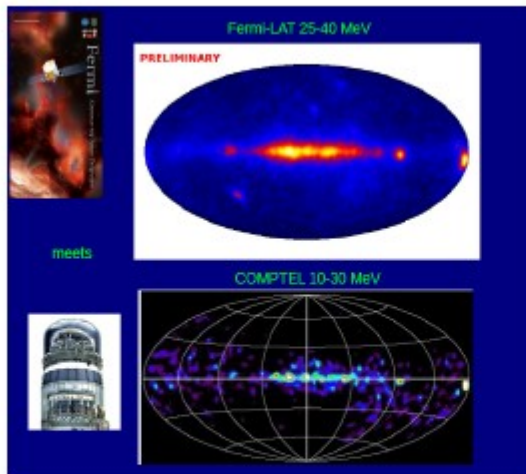
The new images are fully consistent with the original ones, with the Galactic plane clearly visible, and in addition the well-known sources including the Crab, Vela, Cyg X-1, LS5039, 3C273, 3C279, PKS0528+134 and the Galactic Centre. (Note: the excess at lower right is due to Earth atmospheric emission)

In addition we have produced a 1.8 MeV ²⁶Al line map which can be compared with the standard Maxent image (Plüschke et al. 2001).

Comparison with Fermi-LAT

Fermi-LAT energy range extends to lower energies with Pass 8, and this allows a comparison with COMPTEL.

(from A. Strong on behalf of Fermi-LAT Collaboration, talk at MeV Conference, APC Paris 2012)



OUTLOOK

New COMPTEL photon data processing

COMPTEL data analysis continues at MPE (Collmar & Zhang 2014). The event processing and selection is also under study at MPE with improved time-of-flight calculation and other enhancements to reduce the instrumental background. More observations are also now available than for the sky maps shown above. This new data will be used to generate updated images in the near future.

Future methods

While Maxent has been very successful for image COMPTEL data, further advances in data analysis have been made in the last decade. Information Field Theory (IFT) as implemented in the NIFTY and D'PO software has been applied to Fermi-LAT data (Selig et al. 2015), see talk 'Gamma-ray analysis with D'PO' at this symposium. Application of this method to COMPTEL is in progress.

References

- Collmar, W., Zhang S., 2014, A&A 565, A38
- Plüschke, S., Diehl, R., Schönfelder, V., et al. 2001, in Exploring the Gamma-Ray Universe, ESA SP, 459, 55
- Selig, M., et al., 2015, A&A 581, A126
- Skilling, J., 1989 in Maximum Entropy and Bayesian Methods, (Dordrecht: Kluwer), ISBN-0-7923-0224-9, 45
- Strong, A.W. et al. 1998, Proc. 3rd INTEGRAL Workshop, arXiv:astro-ph/9811211; Astrophys. Lett. Commun. 39, 209

INTEGRAL

Reminder of the great science it is doing (in 14th year!)
11th INTEGRAL Symposium 10-14 October 2016 in Amsterdam

SPI:

511 keV map and high-resolution spectroscopy
²⁶Al high-resolution spectroscopy

Galactic continuum 20 keV – 2 MeV, important for CR
No followup mission with this level of energy resolution!

Spare a thought for eAstrogam etc

It is a truth universally acknowledged, that
much of what we think we know about CR
is actually not necessarily so.

(apologies to Jane Austen, *Pride and Prejudice*)



And apologies to the audience for these random speculations.