High and very-high energy gamma-ray observations of the Milky Way

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Interstellar gamma-ray emission

Source

Gamma ray

Cosmic ray

Apparent direction

Earth
Mostly interstellar diffuse emission
- Searching for faint sources depends on interstellar model and is challenging
- Mainly sources
- Searching for interstellar emission only after subtraction of sources in very bright regions and it is challenging

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Sources
Freshly accelerated nuclei

Hadronic emission from accelerated protons in the **SNR W44** expanding in a dense medium

**AGILE**


**FERMI-LAT**

Ackermann et al. 2013 Science 339 807

See talk by F. de Palma on Friday
SNRs

Figure from Funk. S., 2016, Ann. Rev. of Nuclear and Particle Science Vol. 65: 245-277
The first LAT SNR catalog

Candidate SNRs are within expectations if SNRs provide the majority of Galactic CRs

Acero et al. 2016 APJS Vol. 224, 1, 8

See talk by F. de Palma on Friday
The gamma-ray sky seen by Fermi LAT

Count map
Pass 8 data – 7 years
Adaptively smoothed

Credits: Fermi LAT collaboration
The interstellar emission
Major non-thermal emission mechanisms

- Pion decay
- Inverse Compton
- Bremsstrahlung
- Synchrotron
Interstellar emission
CR propagation models

CR propagation codes such as GALPROP solve transport equation (energy losses, diffusion, acceleration, convection, fragmentation, radioactive decay) for all CR species.

INPUTS (also sources of uncertainties):

CR source distribution
Gas distribution
ISRF
Magnetic field

CR propagation parameters:
- Injection spectral indexes
  - Halo size
- Solar modulation
- Diffusion coefficient
  - Convection
  - Reacceleration
The gamma-ray sky in the ‘70s

from Acero et al. 2016 and NASA HEASARC
In the ‘90s: Comptel

1 – 3 MeV

3 – 10 MeV

10 – 30 MeV

Strong et al. 1998
In the ‘90s: EGRET

Credits: EGRET coll.
SPI: the sky from 30 KeV to 0.6 MeV

Bouchet et al., ApJ. (2011) 739,29

Inverse Compton emission with 2x CRe or 10X ISRF in the ridge
The gamma-ray sky seen by Fermi LAT

Count map
Pass 8 data – 7 years
Adaptively smoothed

Credits: Fermi LAT collaboration

>1 GeV

Planck Coll. 2014 A&A 564, A45
353 GHz, dust map
Our Galaxy in gamma – 30÷80MeV

Fermi-LAT

Intensity map
Pass 8 data – 6 years
Adaptively smoothed

Credits: Fermi LAT collaboration

408 MHz (Haslam et al 1981)
Example of gamma-ray spectrum

Spectral components depend on the CR spectra!

Relative intensities depend on the region of the sky!

π° decay

bremsstrahlung

Inverse Compton

$E^2 \times \text{Intensity, } \text{cm}^2 \text{s}^{-1} \text{s}^{-1} \text{MeV}$

100 MeV 1 GeV 10 GeV

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CR propagation models


Data counts
Model counts

With CRs consistent with CR local measurements

Excess:
- Outer Galaxy
- Fermi Bubbles?
- Inner Galaxy

(model-data) model
CRs and the Fermi Bubbles

References: Dobler et al. 2010; Su et al 2010, 2012; ..; since then many studies including different wavelength (e.g. Carretti 2013, S-PASS; Dobler 2012, WMAP; Snowden 1997, Su 2012 ROSAT; Kataoka 2013, Tahara 2015, Suzaku, Planck coll 2013; ... )

Both leptonic and hadronic models represent Fermi spectral data well

(Ackermann et al., 2014 ApJ 793, 64)
Planck polarization and Fermi Bubbles

Planck 2015 results. XXV

Fermi-LAT $> 10$ GeV from Ackermann et al 2014 (dust subtracted)

Planck polarization map

Filament around the Fermi Bubble
CRs in the inner Galaxy


- CRs? - Unresolved sources? - Dark Matter?

Credit: R. Hurt/NASA/JPL-Caltech/ESO
CRs toward the Galactic center

- GeV excess with respect to usual interstellar models
- IC dominant and enhanced (ISRF or CR electrons?)

Galactic plane above 200 GeV

H.E.S.S.


Updated observations of the GC ridge: a fraction of emission is distributed like dense gas tracers (CR hadronic origin) -> info on CRs.

See talk by Dmitry Zaborov on Mon
Discovery of PeVatron protons

- Location of the CR source in the inner \( \sim 10 \) pc
- Radial profile of the emission is consistent with with CRs accelerated in BH diffusing away
- Diffuse emission possibly associated to Sgr A* activity in the last \( 10^6-10^7 \) yrs
Galactic Ridge above 2 TeV

VERITAS

VERITAS & HESS 3FGL

Archer et al. 2016

Residual emission after subtracting the sources overlaps the countour from H.E.S.S

*See talk by Qi Feng on Mon*
HAWC >10 TeV

Detections that are coincident with known TeV SNRs and PWN along the Galactic plane

Waiting for deeper observations of diffuse emission in different regions of the sky

See talk by Francisco Salesa Greus on Mon
Still long-standing open questions:

1. What are all the Galactic sources producing CRs?

2. How CRs accelerate and propagate in the interstellar medium?

n. ...
Present & future

With upcoming mission will have a full and deeper coverage of the gamma-ray sky

From Knödlseder, Jürgen Comptes Rendus Physique 17 (2016) 663-678
Today you have seen

- CR sources
- Diffuse Interstellar emission and its uncertainties
- Many questions still open

From X to TeV energies diffuse emission is a common feature (also radio should be included for a complete picture)

Multiwavelengh observations and especially the advent of CTA + possible missions at MeV will answer open questions