Up-to-date pp-interaction model + galprop as a tool to study galactic diffuse gammas

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History of Changes:
September 14, 2005 written by T. Mizuno
Introduction: Cosmic Rays

- Since the discovery by HESS in 1912, origin and nature of Cosmic Rays (CRs) are one of the biggest topics in astrophysics.
- Proton is the major component of CRs (~90%).
- Spectral break around $10^{15}$ eV (“knee”)
  - $E < E_{\text{knee}}$: Galactic origin
  - $E > E_{\text{knee}}$: extragalactic

Question:
- Where were they accelerated to such a high energy?
- How do they distribute in our Galaxy?

- X-ray/Gamma-ray observation can tell!
CR Electrons

CR electrons emit photons via synchrotron radiation:

\[ \nu \approx 28 \gamma^2 \left( \frac{B}{1 \text{T}} \right) \text{GHz} \]

(High Energy Astrophysics, Longair 1992)

The spectrum of the Galactic radio emission

X-ray spectrum of a SNR, SN1006 (Koyama et al. 1995, Nature)

\[ E \approx 0.44 \times \left( \frac{E_{\text{electron}}}{100 \text{TeV}} \right)^2 \times \left( \frac{B}{1 \text{uG}} \right) \text{keV} \]

electrons of \geq 100 \text{TeV} ("knee")

What about protons?
CR Protons

CR protons emit photons via pi0 production: \( pp \rightarrow \pi^0 + X \)

Gamma-ray spectrum from the Galactic Center

So called “GeV excess” was found by EGRET (Hunter et al. 1997, ApJ)
More about GeV excess

- GeV excess is observed from the outer Galaxy as well as the inner Galaxy regardless of galactic latitude.

Possible Solutions:
- harder proton spectrum
- pp-interaction model
- contribution of electron radiation
- etc.

- We need tools to study GeV excess/diffuse emission
  - galprop + up-to-date pp-interaction model

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galprop

• galprop is a framework to predict CR propagation and gamma-ray emission in Galaxy, developed by I. Moskalenko and A. Strong (see Igor’s talks)

CR source model

Propagation of CRs
- Diffusion
- Diffusive reacceleration
- Energy loss
- Fragmentation

Emission of gamma-rays
- Synchrotron radiation (e-)
- Bremsstrahlung (e-)
- Inverse Compton (e-)
- Pi0 production (p)

source of CRs

ISRF model

B model

Cross section for pi0 generation

matter distrib.

H2

H I

H II

CMB

Dust

Stellar

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galprop (Contd.)

- Most of parameters (e.g., CR source model, inject spectrum, diffusion coefficient) can be specified by galdef file. 
  - user can play with them
- Not all, but most of the codes are written in C++.
  - user can replace (upgrade) galprop
- Output in FITS format. 
  - standard in astrophysics. Lots of tools to read/plot

1GeV gamma-ray intensity

proton energy spectra
**PP-interaction model**

- Based on up-to-date knowledge, pp-interaction model update was proposed by Kamae et al. (2005 ApJ). This model was intended to be used to calculate gamma-ray emission (galactic diffuse, AGN, SNR, GRB, etc.) without uncertainty. Hereafter we call this “TK model”
- The features; rising cross section, diffractive dissociation and scaling violation

**pp-interaction cross section**

- Rising cross section in high energy
- Add diffractive dissociation process

**Spectrum of generated gamma-rays**

- Scaling violation
Parameterization of pp-interaction

- Under development by N. Kerlsson and T. Kamae (see Niklas’s lunch talk) to replace time-consuming Monte Carlo simulations.
- One update; add the Delta resonance (1232) and the other resonance (1600) to reproduce pp-interaction cross section and inclusive π0 cross section in lower energies.
- Immediate application: incorporate into galprop!

Gamma Spectrum for diffractive dissociation

Gamma Spectrum for non-diffractive dissociation

Inclusive Pi0 cross section
Prediction of gammas by galprop with updated pp-interaction model

- Comparison of gamma spectra toward galactic center, predicted by conventional interaction model and updated one (TK model; parameterized)
- Work in progress; parameterization is yet to be tuned to reproduce the MC.

Predict higher flux above 1GeV
Summary

• Galactic diffuse gammas are strong tool to study CRs.
• Galprop is a flexible framework to study CR propagation and gamma-ray emission.
• Up-to-date of pp-interaction model leaves less (or no) uncertainty in π0 production calculation and can be used for variety of data (e.g., GLAST, EGRET, HESS and Suzaku).
• We incorporated a (preliminary) parameterization of up-to-date pp-interaction model in galprop.

Future Plan

• Complete the parameterization
• Comparison with EGRET data; energy and spatial distribution of diffuse gammas
• Prepare for GLAST; develop 3D-model calculation (need 3D model of matter distribution)
• Apply pp-interaction model to SNR/AGN/GRB/etc.