The Star-forming extra-Galactic Gamma-ray Background

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Motivation

- Origin of diffuse, extra-Galactic Gamma-ray background unknown
- Guaranteed unresolved counterparts of resolved sources like AGNs, star-forming galaxies
- Truly diffuse like dark matter annihilations, structure formation, unresolved pulsars, etc

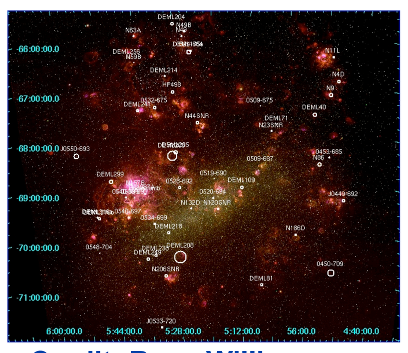
Which of the guaranteed sources form a major contribution to the diffuse EGB ?

Order of Magnitude

- AGNs very bright ($L \sim 10^{49}$ photons sec^{-1}) but fewer ($n \sim 10^{-9}$ Mpc^{-3})
- SFGs - Individually faint ($L \sim 10^{43}$ photons sec^{-1}) but numerous ($n \sim 10^{-3}$ Mpc^{-3})
- Luminosity density, $\langle n\, L \rangle$ comparable

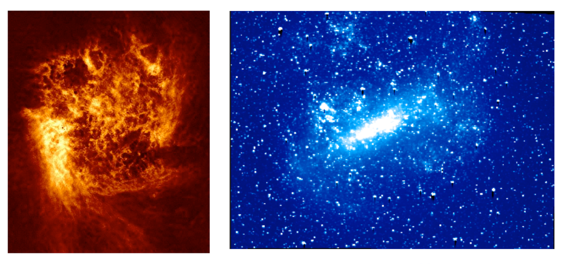
Cosmic ray-ISM interactions in star-forming galaxies

ϕ_{CR} in SNR



Credit: Rosa Williams and the MCSNR Team

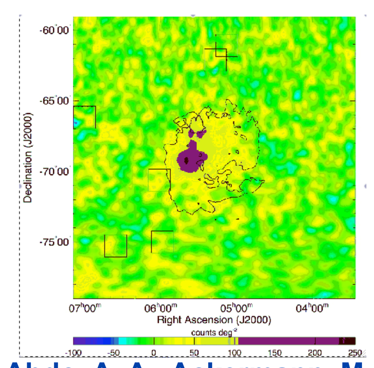
$\times$ n_{gas} and n_{ph} in ISM



ATCA plus Parkes image in HI by S. Kim, et al.

http://dirty.as.arizona.edu/~kgordon/research/mc/lmc_optical.html

$=$ $q_\gamma \sim \frac{L_\gamma}{V} \sim \phi_{CR}\, n_{targ}\, \sigma_{int}$



Abdo, A. A., Ackermann, M., —. 2010b, A&A, 512, A7+

Emission Mechanisms

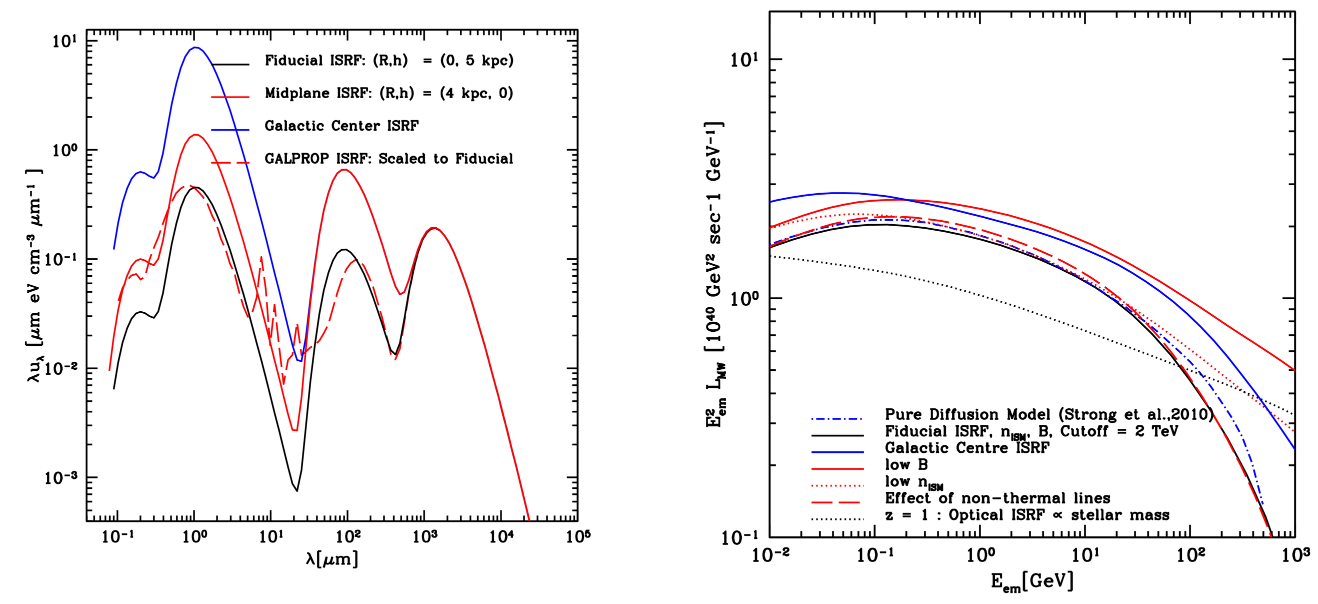
- High energy mechanisms : Cosmic ray interactions with interstellar gas and radiation (Strong et al., 1976 ; Sreekumar et al., 1998 ; Strong et al., 1996 ; Hunter et al., 1997)
  - Neutral pion decay (Stecker , 1970 ; Dermer 1986)
  - Inverse Compton scattering (Strong et al., 2000)
- Two most important mechanisms in the Galactic emission (Lacki et al., 2012 for bremsstrahlung)
- Pionic component dominant, next best is inverse-Compton

Luminosity Scaling for single galaxy

- Pionic component (Pavlidou and Fields, 2001 ; Fields, Pavlidou and Prodanovic, 2010)
  - Projectiles are cosmic ray protons
  - Targets are ISM gas HI, HII, H_2
  - Leaky box approximation results in escape dominated, steady-state solution

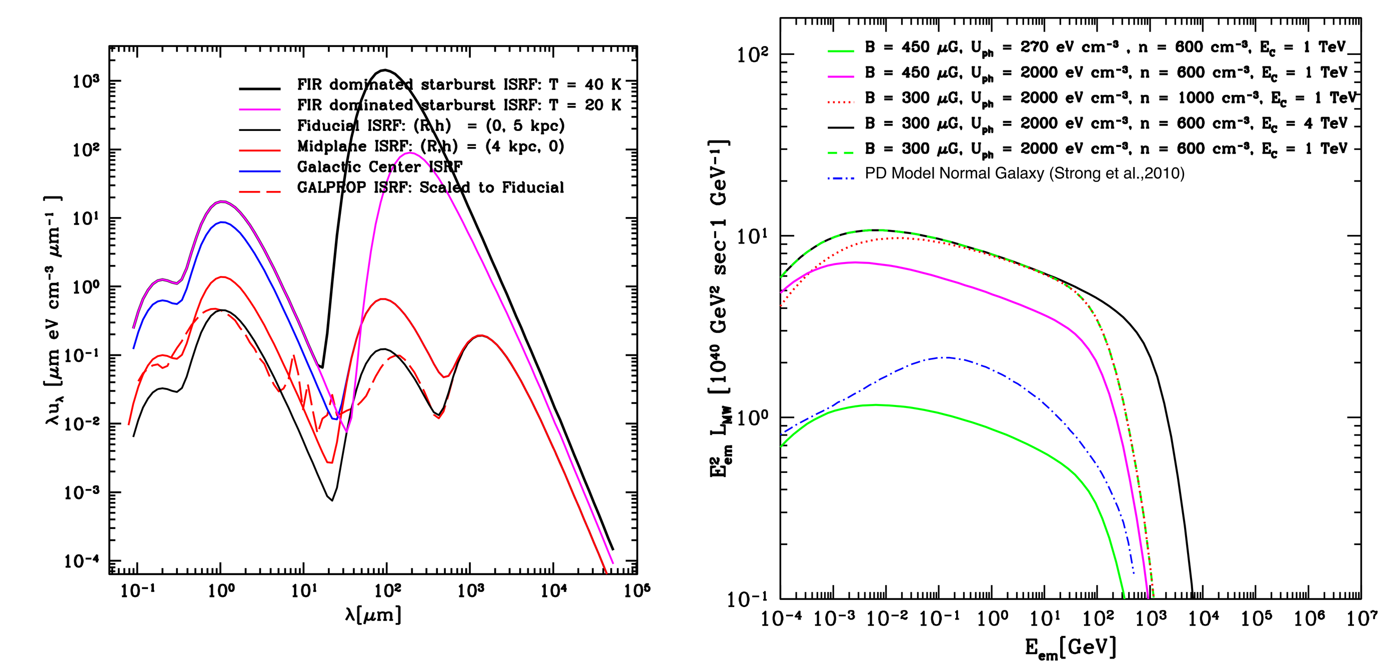
    $$\phi_p \propto q_{inj} \lambda_{esc}$$
  - Injected proton emissivity, are proportional to the supernova rate and hence the massive star-formation rate, $q_{inj} \propto \psi$
  - Target density is gas density, $\Sigma_{gas} \propto \dot{\Sigma}_\star^N$ given by composite Schmidt-Kennicutt
  - Pionic luminosity scales as, $L_{\pi^0} \propto \psi^\alpha$; $N = 1.4 => \alpha = 1.7$
- Inverse-Compton component (Chakraborty and Fields, 2012)
  - Projectiles are cosmic ray electrons
  - Targets are ISM photons comprising of ultra-violet, optical, infra-red and the cosmic microwave background
  - Using diffusion coefficient of 10^{28} cm^{-2} sec^{-1}, e's are confined to ≤ 1 Kpc
  - Radiative loss dominated, steady-state solution, $\phi_e = \frac{q_{inj}(> E_e)}{dE/dt} \propto \frac{\psi}{dE/dt}$
  - Target density is given as, $U_{ph} \propto \left(\frac{dE}{dt}\right)_{ic}$
  - IC luminosity scales as, $L_{ic} \propto \psi$

One zone model for single galaxy : Inverse Compton



- Amplitude set by ψ , controlled by fractional calorimetry, $\left(\frac{dE}{dt}\right)_{ic} / \left(\frac{dE}{dt}\right)_{tot}$
- Competition between synchrotron and Compton losses at GeV (Lacki et al., 2012 for bremsstrahlung)
- Fiducial values : B = 4 μG ; n_{gas} = 0.12 cm^{-3} ; U_{ph} = 1 eV cm^{-3} ; Cutoff at ~ 2 TeV

One zone model for starburst galaxy : Inverse Compton

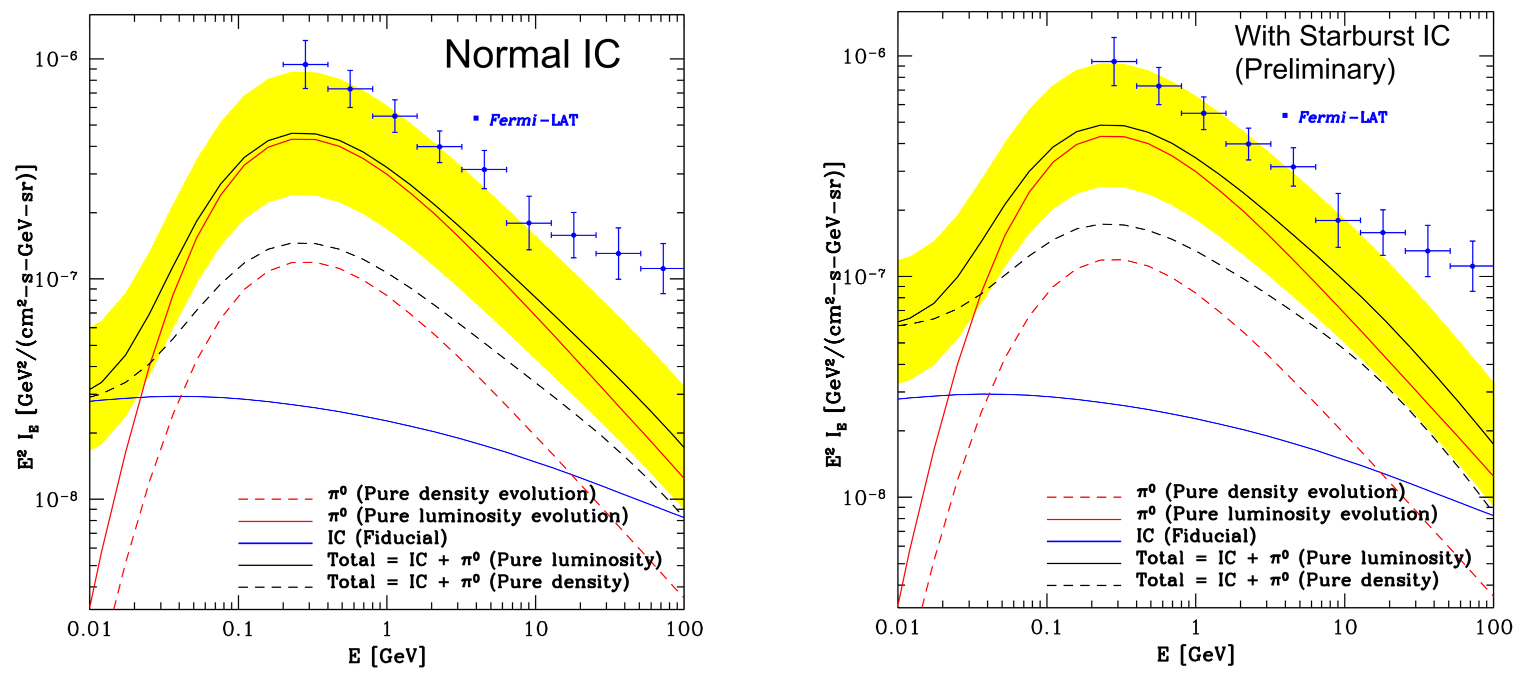


- Similar scaling to normals ; star-formation rate higher by factor of 8 for fiducial case
- Synchrotron more dominant at GeV energies
- Fiducial values : B = 300 μG ; n_{gas} = 600 cm^{-3} ; U_{ph} ~ 2000 eV cm^{-3} ; Cutoff at ~ 0.5 TeV

One zone model for single galaxy : Pionic

- For normal galaxies, Milky Way template (Fields, Pavlidou and Prodanovic, 2010)
- Gas density from Kennicutt-Schmidt
- Dispersion around $m_\pi/2$ peak - distinctive feature of pionic contribution
- Single galaxy : Steep decline with power law index 2.75

Results : Normal and Starburst Line-of-sight Intensity



- Pionic in red, IC in blue
- Pure luminosity evolution model for pionic ; for IC there's degeneracy
- Difference with Fermi-LAT team (Ackermann et al., 2012) - accounting of gas density - star formation correlation using Kennicutt-Schmidt & scaling of Milky Way as template
- Pure density evolution numbers comparable to Fermi-LAT model
- Star forming contribution still peaked at ~ 0.3 GeV
- IC subdominant by almost an order ; improves high energy slope for fiducial models
- Error budget dominated by error in ψ

Source Count Statistics - SFGs, Blazars & Dark Matter

- Need independent discriminators for between sources of EGB
- Source count statistics could be a tiebreaker (Baxter, Chakraborty, Dodelson, Fields - In Prep)
- Advance from Malyshev and Hogg, 2012
  - PD analysis with physical models ; differential source flux distribution derived from luminosity functions
  - Angular information of sources and non-uniform exposure of Fermi-LAT
  - Monte-Carlo simulated mock maps establishing consistency of results

Conclusions

- **Pionic emission dominates the star-forming EGB, followed by inverse-Compton**
- **IC may dominate in a narrow high energy window in galaxies with lower gas content than Milky Way**
- **Density evolution results for pionic comparable to Fermi-LAT team results**
- **Luminosity evolution suggests substantial star-forming contribution**
- **Future work on clarifying pionic scaling - linear vs non-linear**
- **Need independent discriminators in addition to intensity spectrum - stay tuned for results on source count statistics**

References

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