Synchrotron Constraints on the Cosmic Ray Electron Spectrum

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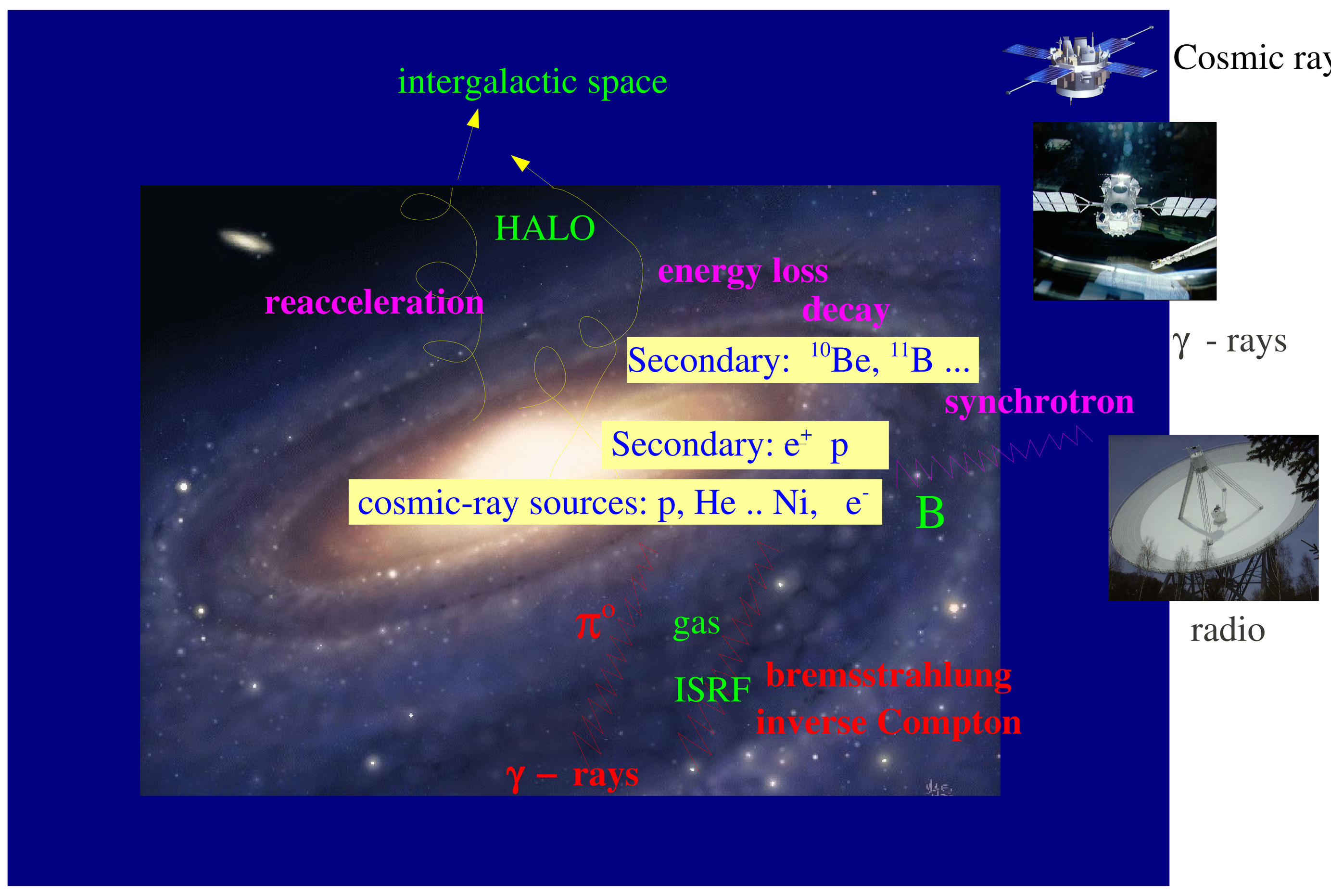
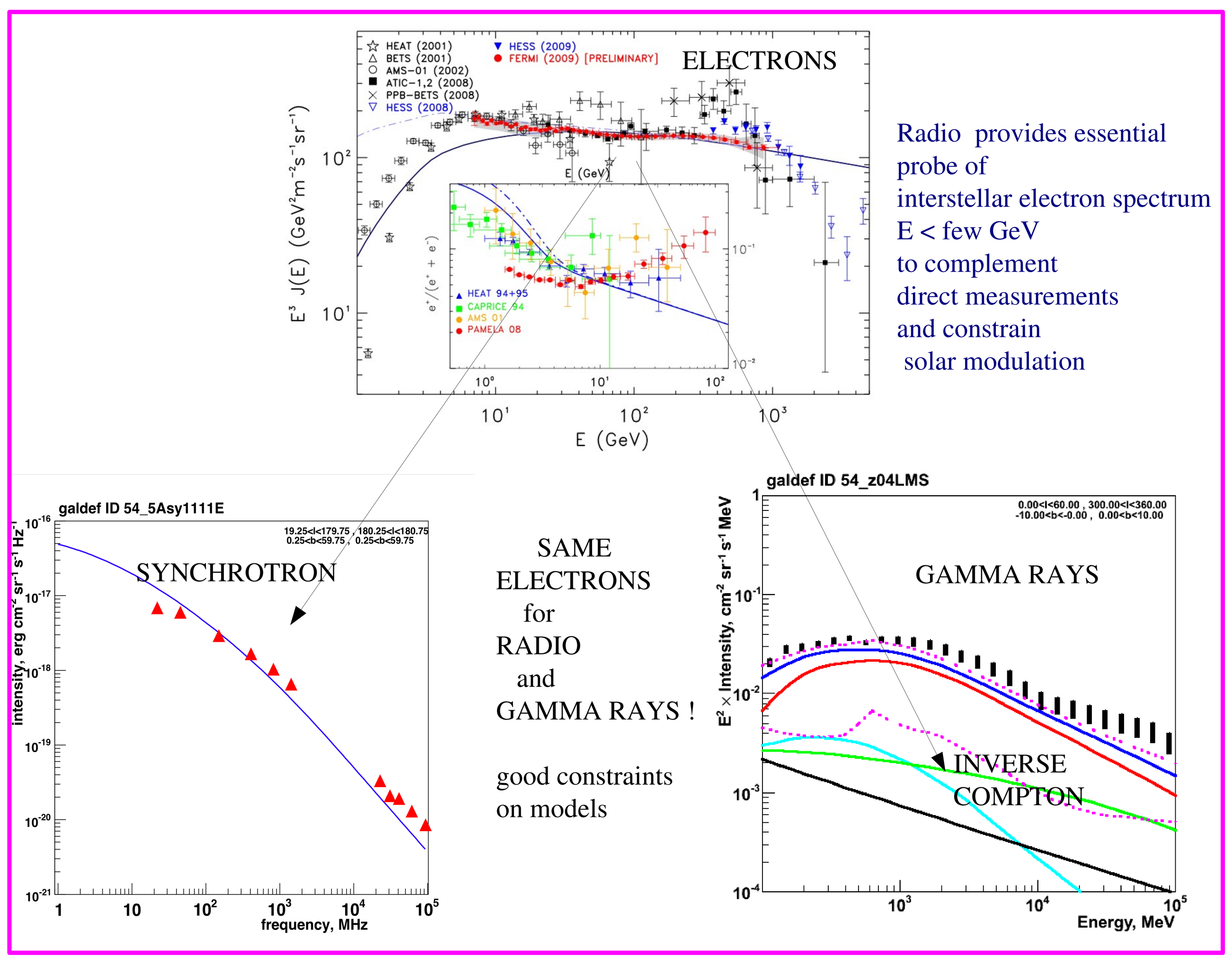
SUMMARY The interstellar electron (and positron) spectra are difficult to determine at low energies due to solar modulation. Synchrotron emission provides constraints which are independent of modulation, and which sample the Galaxy on the large scale. We use synchrotron surveys from 22 MHz to 94 GHz combined with direct measurements of electrons to obtain the ambient interstellar spectrum, and compare with models which relate this to the injection spectrum and cosmic-ray propagation.

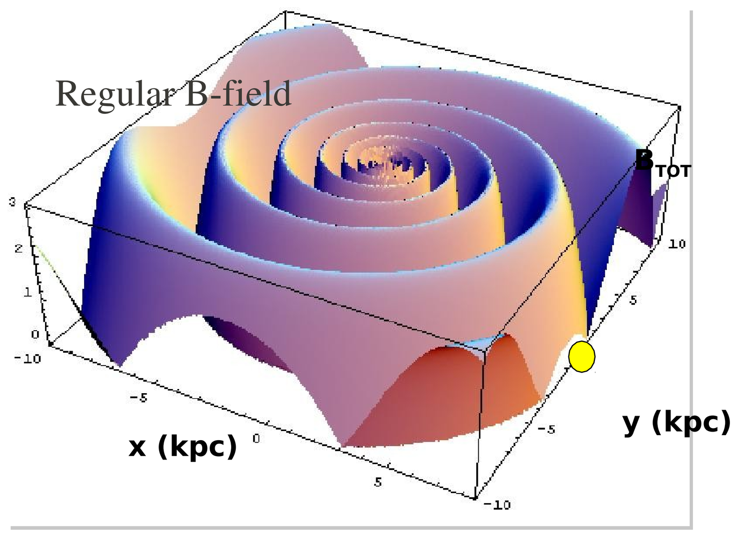


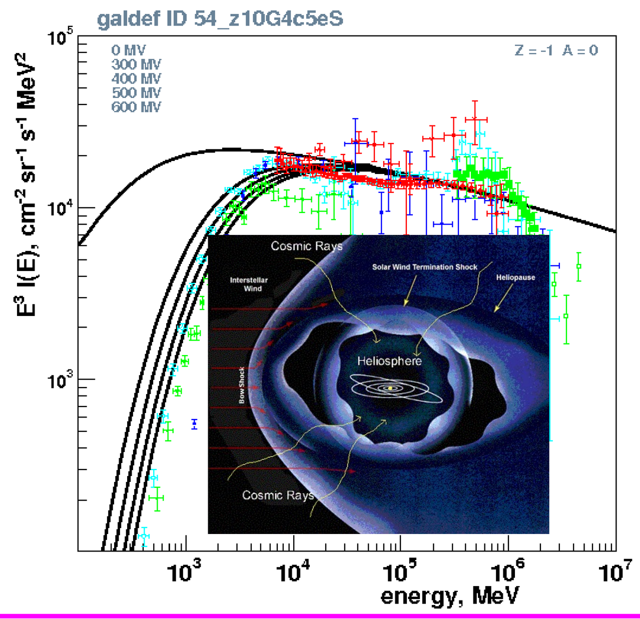


Radio provides essential probe of interstellar electron spectrum E < few GeV to complement direct measurements and constrain solar modulation

SAME ELECTRONS for RADIO and GAMMA RAYS !

good constraints on models





Cosmic-ray propagation

$\partial\psi(\vec{r},p)/\partial t = q(\vec{r},p)$

cosmic-ray sources (primary and secondary)

$+ \nabla\cdot(D_{xx}\nabla\psi - V\psi)$

diffusion convection

$+ \partial/\partial p\, [p^2 D_{pp}\, \partial/\partial p\, \psi / p^2]$

diffusive reacceleration (diffusion in p)

$- \partial/\partial p\, [dp/dt\, \psi] \quad - p/3\, (\nabla\cdot V)\, \psi$

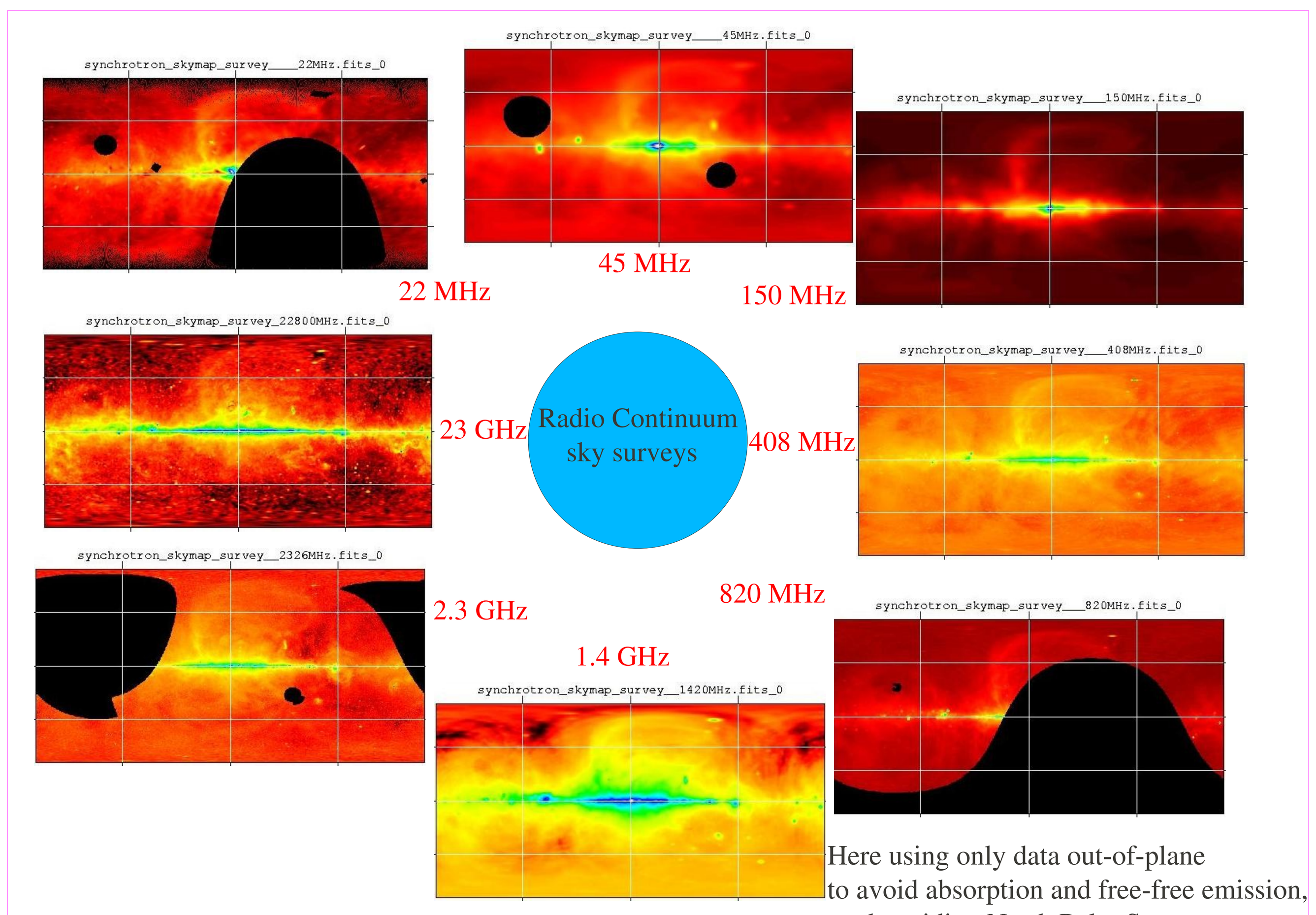
momentum loss ionization, bremsstrahlung — adiabatic momentum loss

$- \psi/\tau_f$ nuclear fragmentation

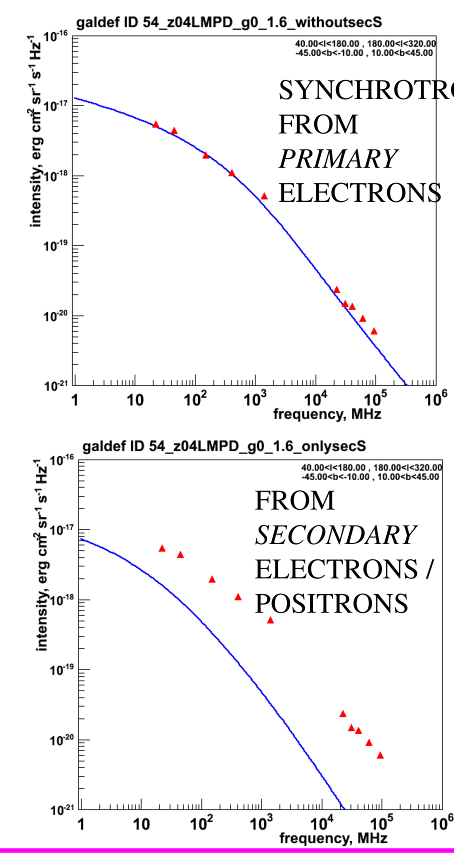
$- \psi/\tau_r$ radioactive decay

Numerical solution on a grid

This work uses the GALPROP code, http://galprop.stanford.edu



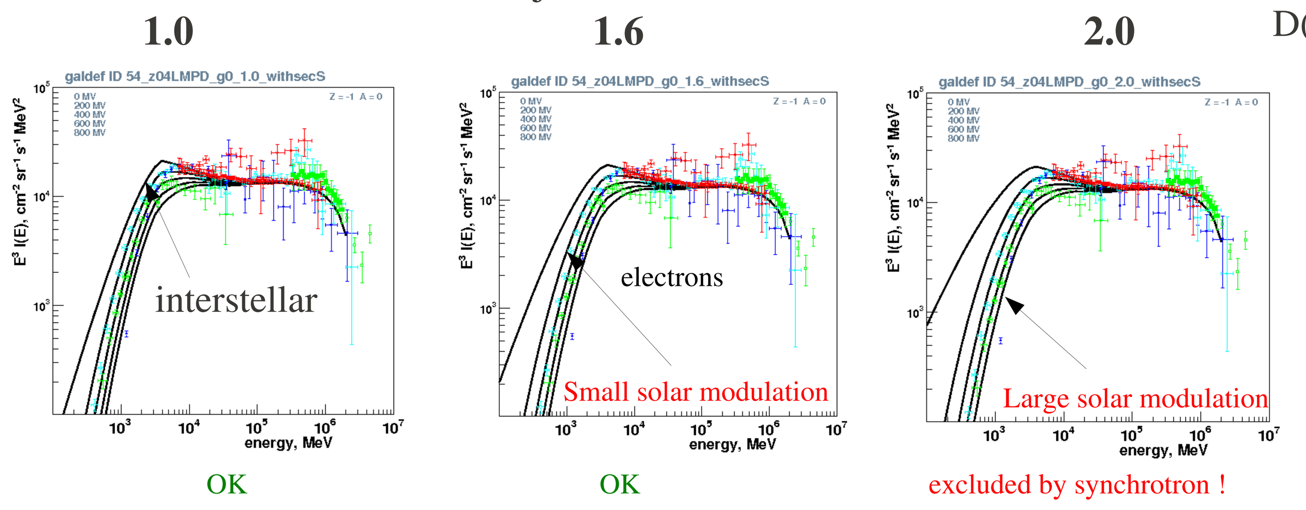
Here using only data out-of-plane to avoid absorption and free-free emission, and avoiding North Polar Spur



Secondary positrons & electrons are important for synchrotron !

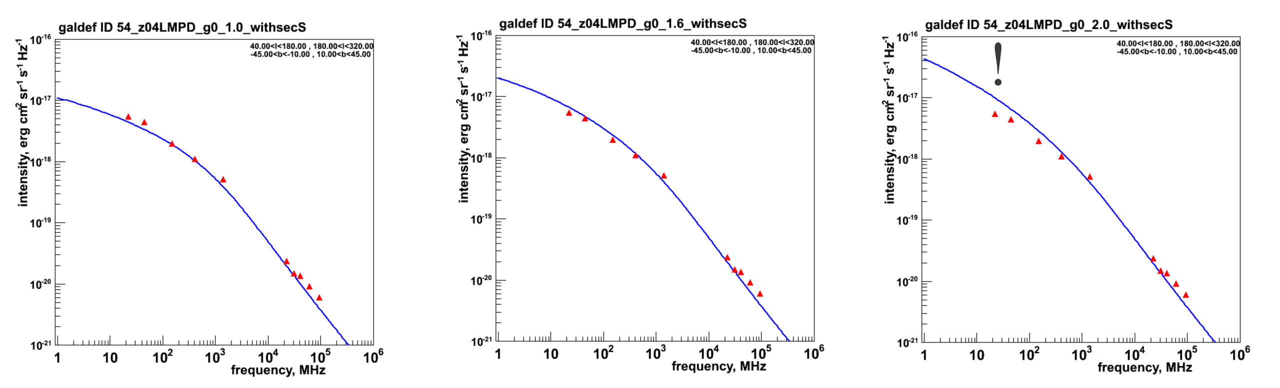
Electron injection index E < 4 GeV

Plain diffusion model
D(E) = const < 4 GeV
$E^{0.5}$ >4 GeV

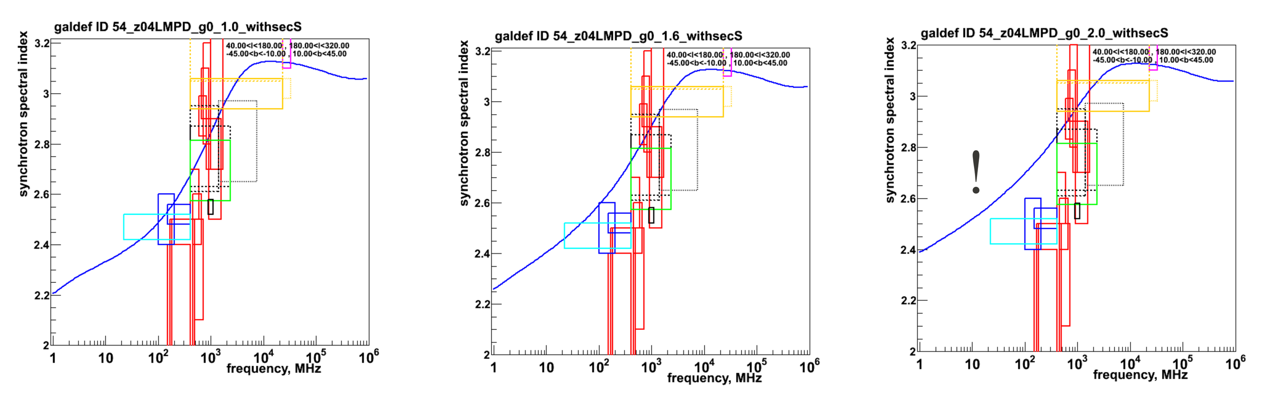


OK — OK — excluded by synchrotron !

ELECTRONS
Injection index
2.5 4 – 50 GeV
2.2 > 50 GeV



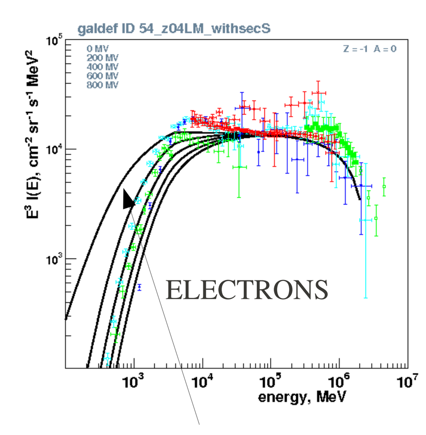
SYNCHROTRON



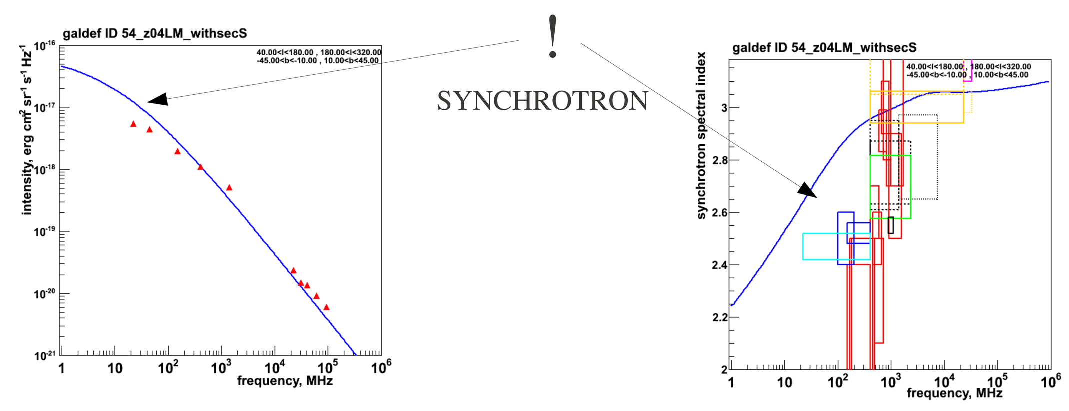
Synchrotron spectral index :

Many careful measurements in the literature

Reacceleration model – in trouble with synchrotron ?

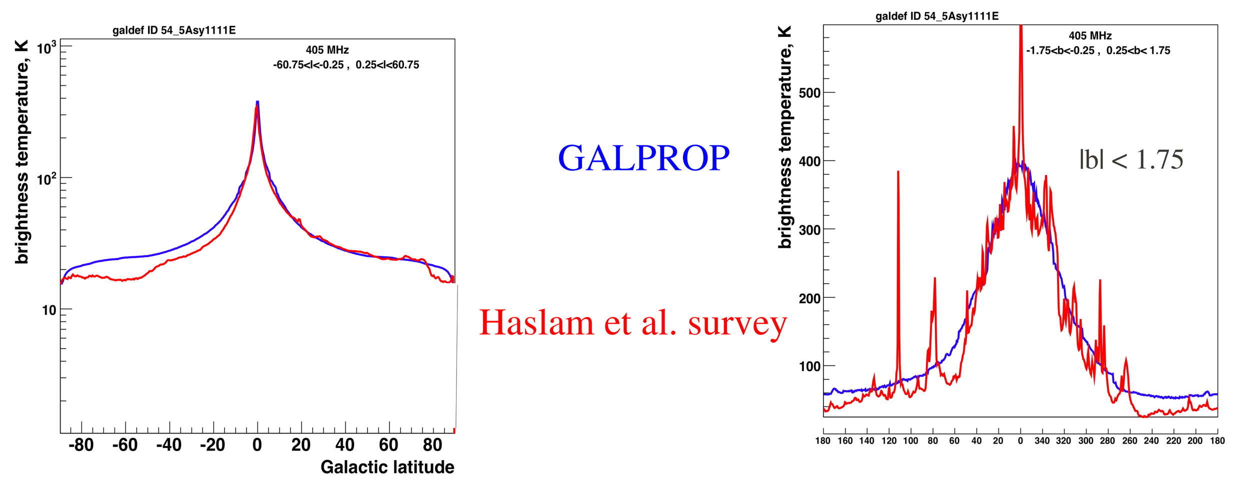


Reacceleration with V_A = 30 km s^{-1}
Injection index 1.6 / 2.3
Break at 4 GeV
(standard parameters)



SYNCHROTRON

408 MHz



Synchrotron spatial distribution is not the subject of this study (which is on spectra), but the models are in satisfactory agreement with surveys.

Synchrotron provides an essential constraint on interstellar electrons which has not been fully exploited. By combining surveys over a wide frequency range with direct electron measurements, we can :

1. Obtain the interstellar electron spectrum independent of solar modulation
2. Use this to test models of propagation and injection

Main results :

1. The *ambient* interstellar electron spectrum has a break from index ~2 to ~3 around a few GeV
2. This requires *less* solar modulation than usually adopted for direct measurements.
3. The injection spectrum below a few GeV is 1.3 - 1.6 in pure diffusion models with D(E) = constant
4. Standard reacceleration models are *hard to reconcile* with the interstellar spectrum.
5. Secondary $e^+ e^-$ important for - and constrained by - radio emission

REFERENCES

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Jaffe et al. 2011, Submitted to MNRAS. (Related study in the plane, using polarization and statistical analysis: consistent findings with this work.)
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Trotta et al. , 2011, ApJ 729, 106 (and references therein for GALPROP).
Vladimirov et al. , 2011, Computer Physics Communications, 182, 1156 (GALPROP Webrun)