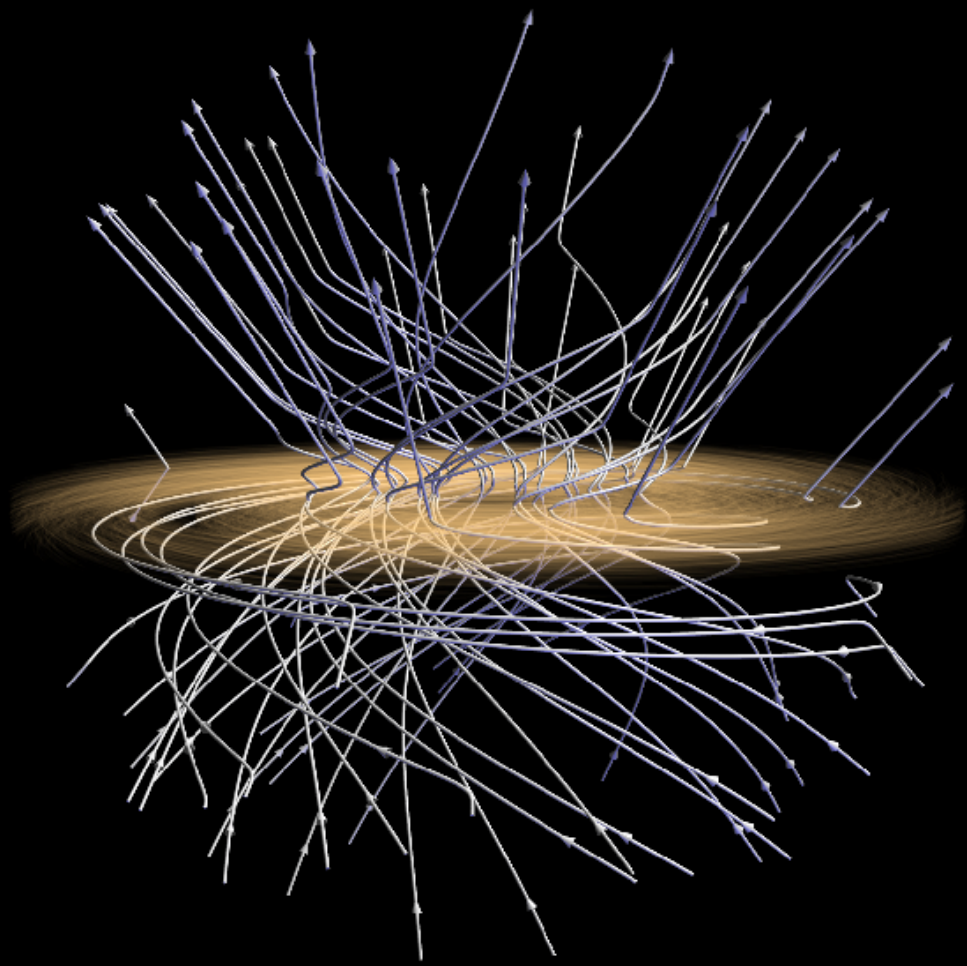
Global Modeling of the Galactic Magnetic Field and Thermal Electrons

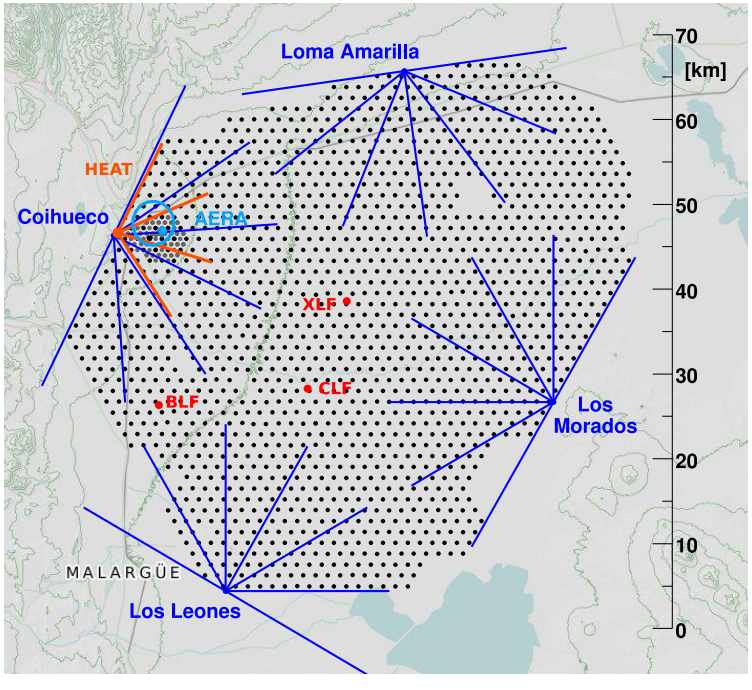
M. Unger[1,2] & G.R. Farrar[1]

[1]New York University, [2]Karlsruhe Institute of Technology



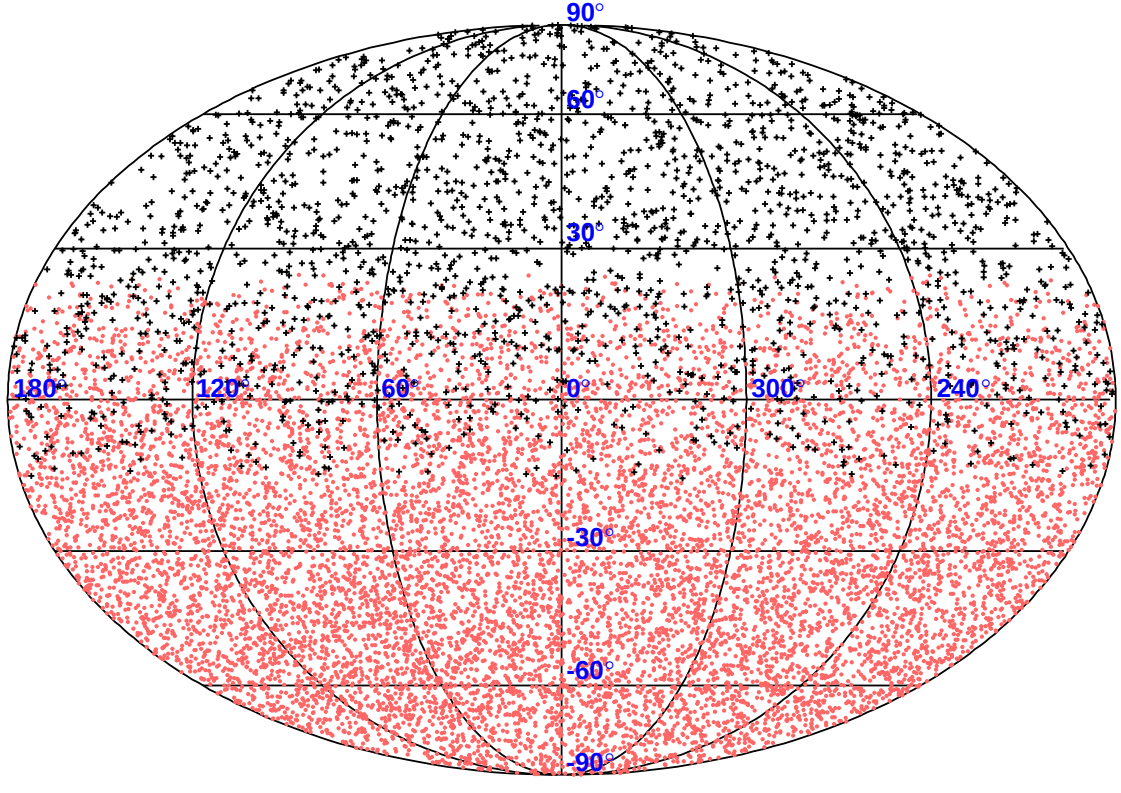
JF12 visualization by Farrar & Sandstrom

Global Modeling of the Galactic Magnetic Field: Arrival Directions of Ultrahigh Energy Cosmic Rays*



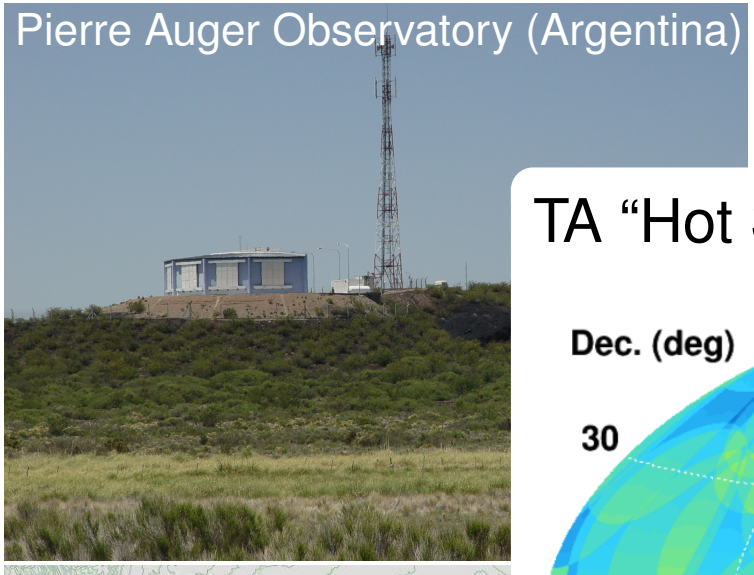
* one of many useful application of global GMF models!

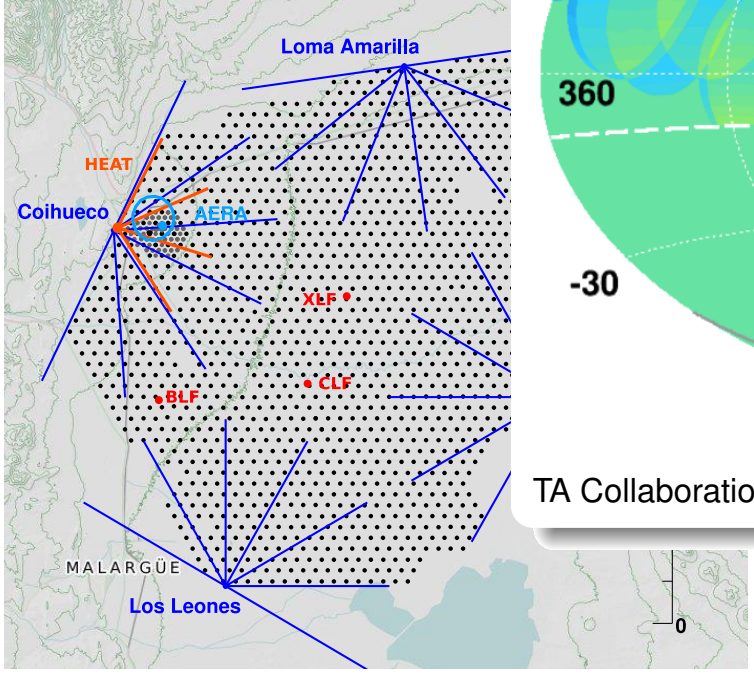
Cosmic-Ray Sky above 10^{19} eV:



Pierre Auger and TA Collaborations, ApJ **794** (2014) 2, 172

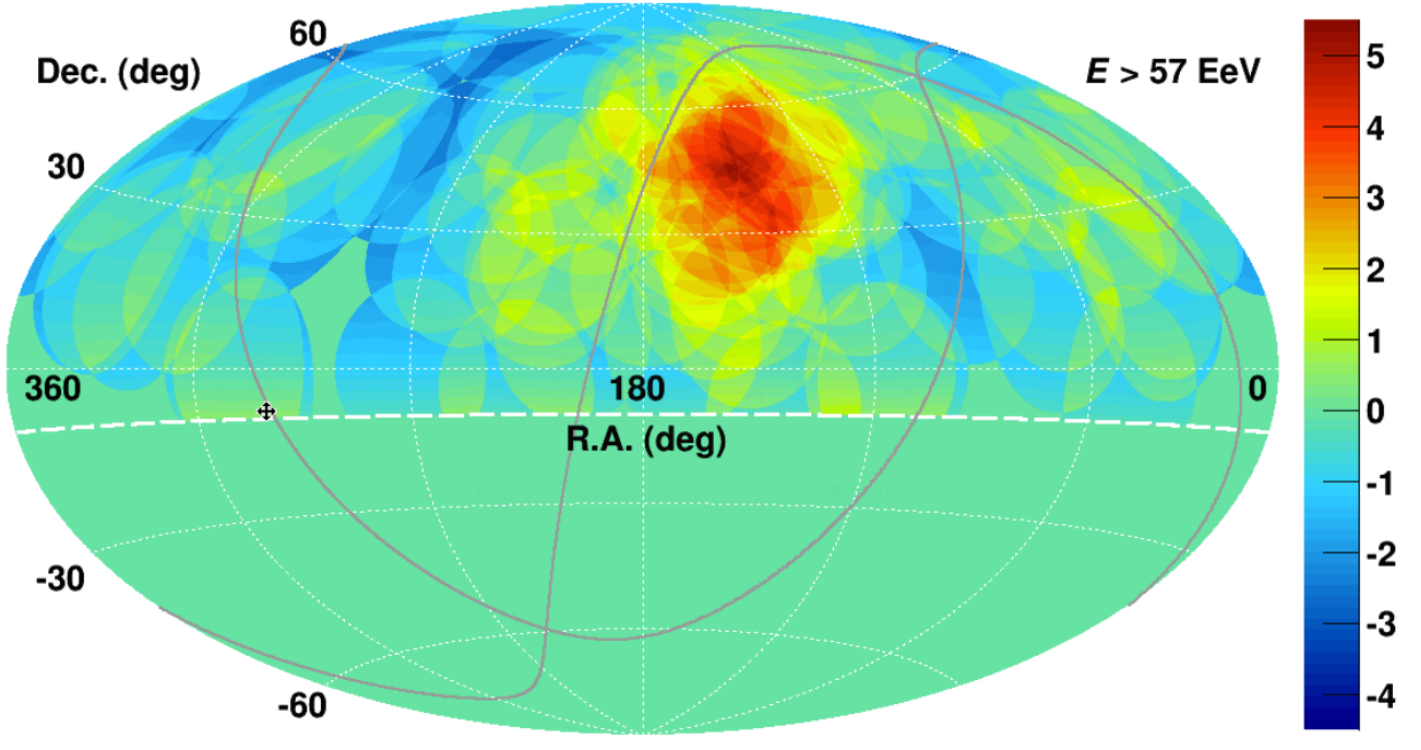
Global Modeling of the Galactic Magnetic Field: Arrival Directions of Ultrahigh Energy Cosmic Rays*





* one of many useful application of global GMF models!

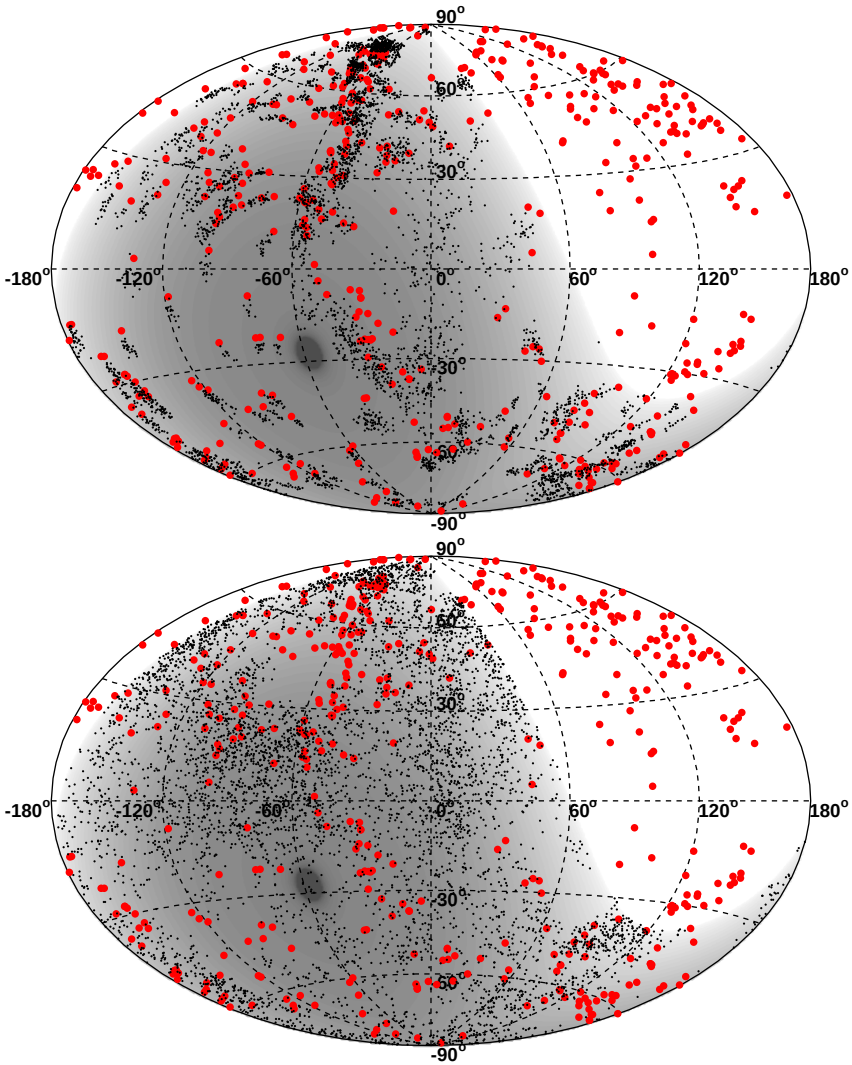
TA “Hot Spot”:

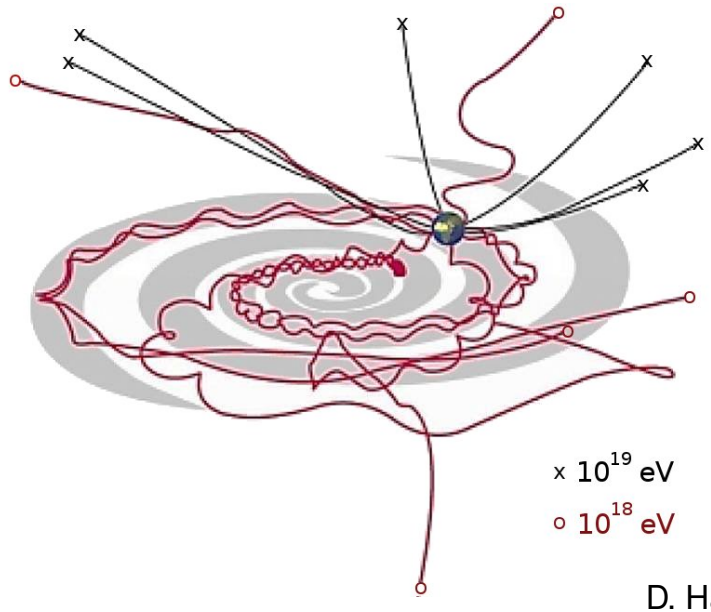


TA Collaboration ApJ **790** (2014) L21

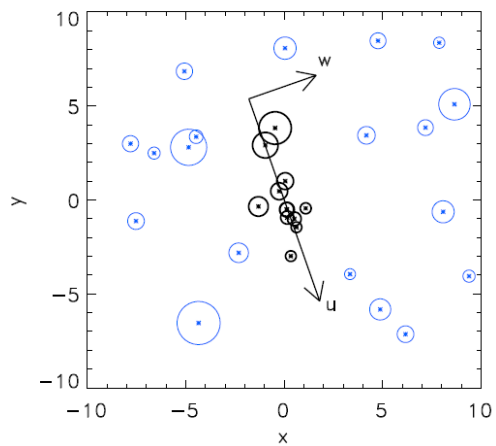
Global Modeling of the Galactic Magnetic Field: Arrival Directions of Ultrahigh Energy Cosmic Rays

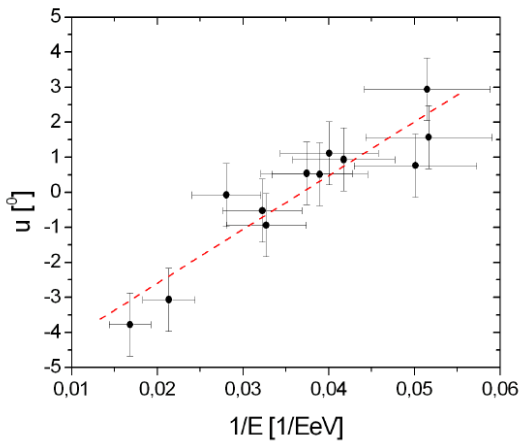
$E > 10^{19.7}$ eV, $Z = 1$ (top) and 6 (bottom)





D. Harari





red: simulated sources, black: arrival direction at Earth

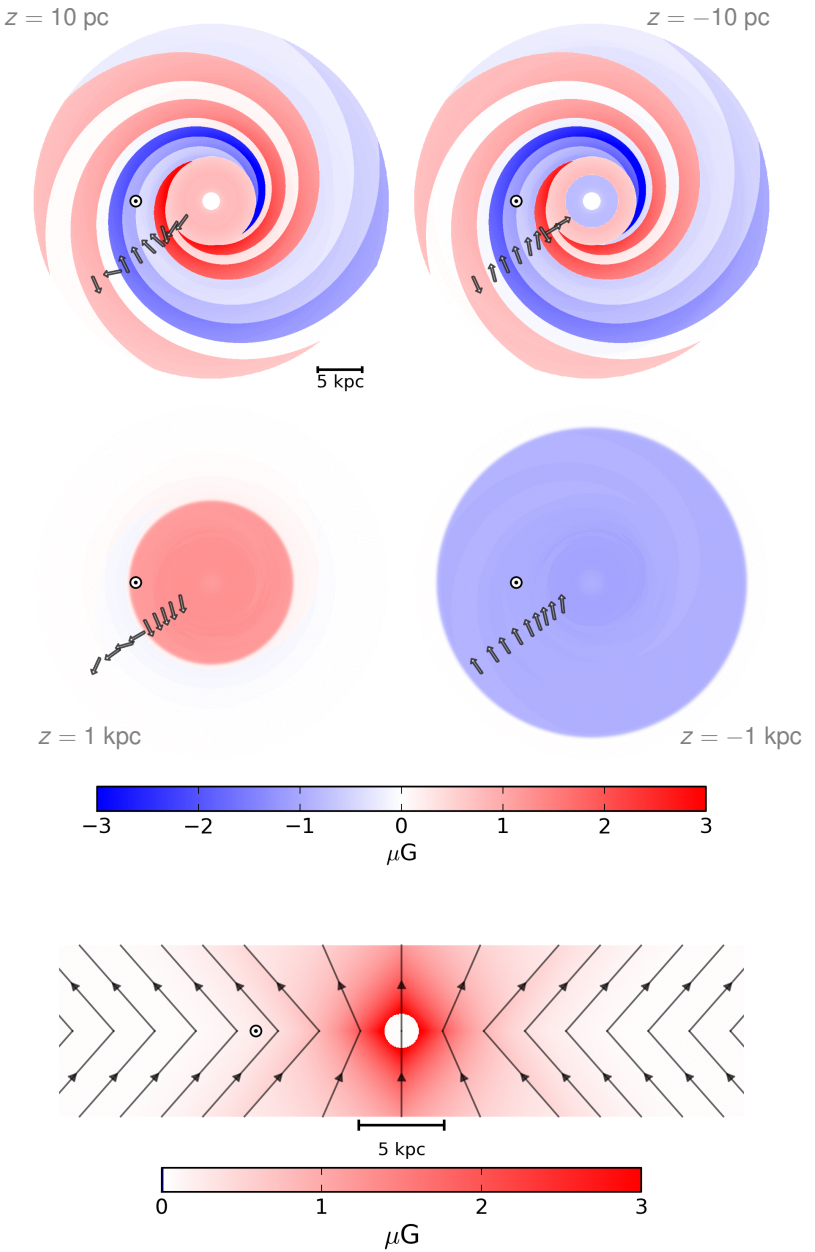
Pierre Auger Coll., APP **35** (2012) 354

Jansson&Farrar Global Magnetic Field Model (JF12)

three (divergenceless!) components:

- disk field, ($h \lesssim 0.4$ kpc)
- toroidal halo field ($h_{\rm scale} \sim 5.3$ kpc)
- "X-field" (halo) NEW

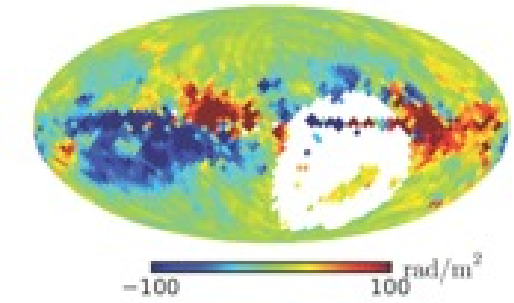
- regular field[a]: 21 parameters
- random field[b]: 13 parameters
- striation: 1 parameter
- CR electron norm.: 1 parameter



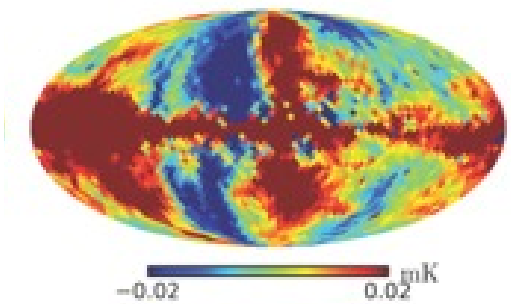
JF12 Model (Regular Field)

Data:

- extragalactic RMs

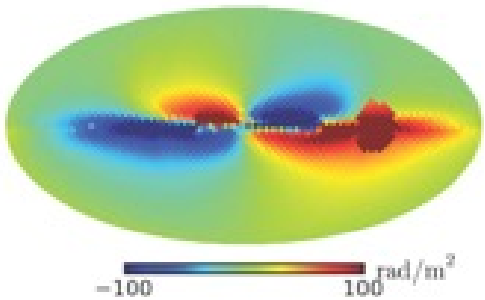


- WMAP Stokes Q and U

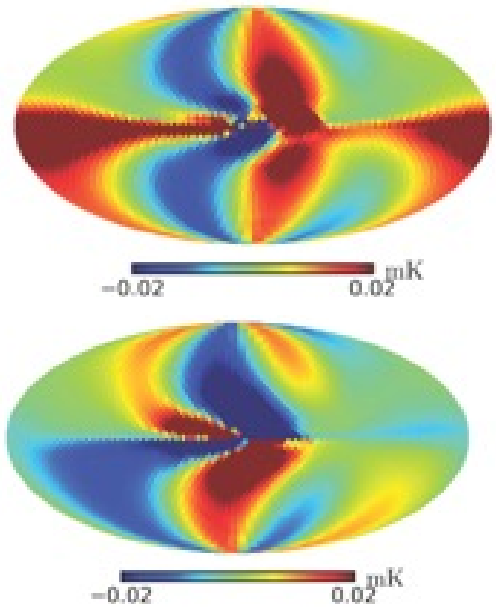


Model:

- $\mathrm{RM} \propto \int_{\infty}^{0} B_{\parallel}(l)\, n_e(l)\, \mathrm{d}l$



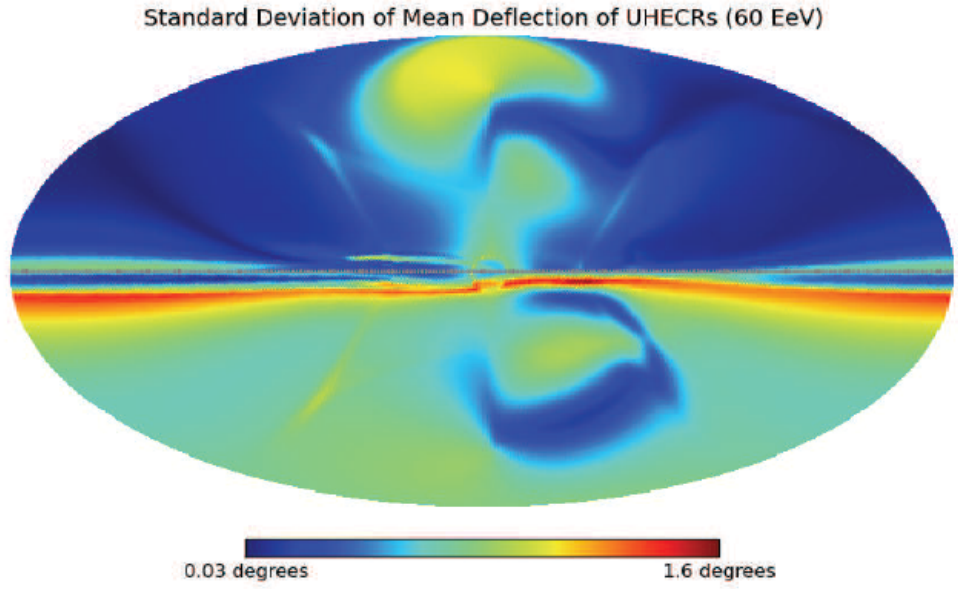
- $Q/U \propto \int_{\infty}^{0} B_{\perp}(l)^{\frac{p+1}{2}}\, n_{\mathrm{cre}}(l)\, \mathrm{d}l$



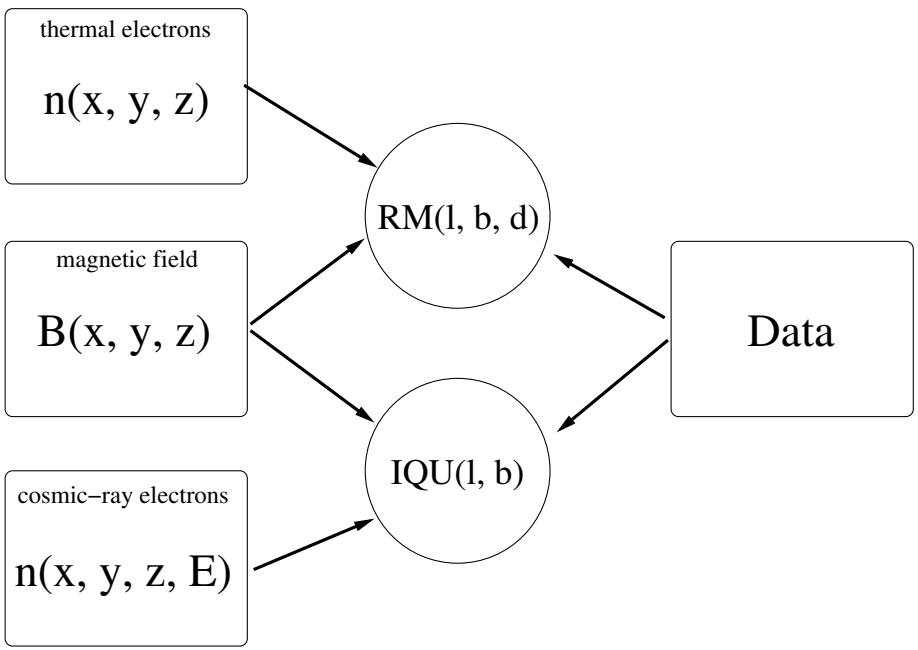
thermal electron density $n_e(l)$, CR electron density $n_{\mathrm{cre}}(l)$ and spectrum E^p

Model Uncertainties

Example:
Statistical (!) uncertainties cosmic-ray deflections in regular field:



G.R. Farrar, CRP **15** (2014) 339

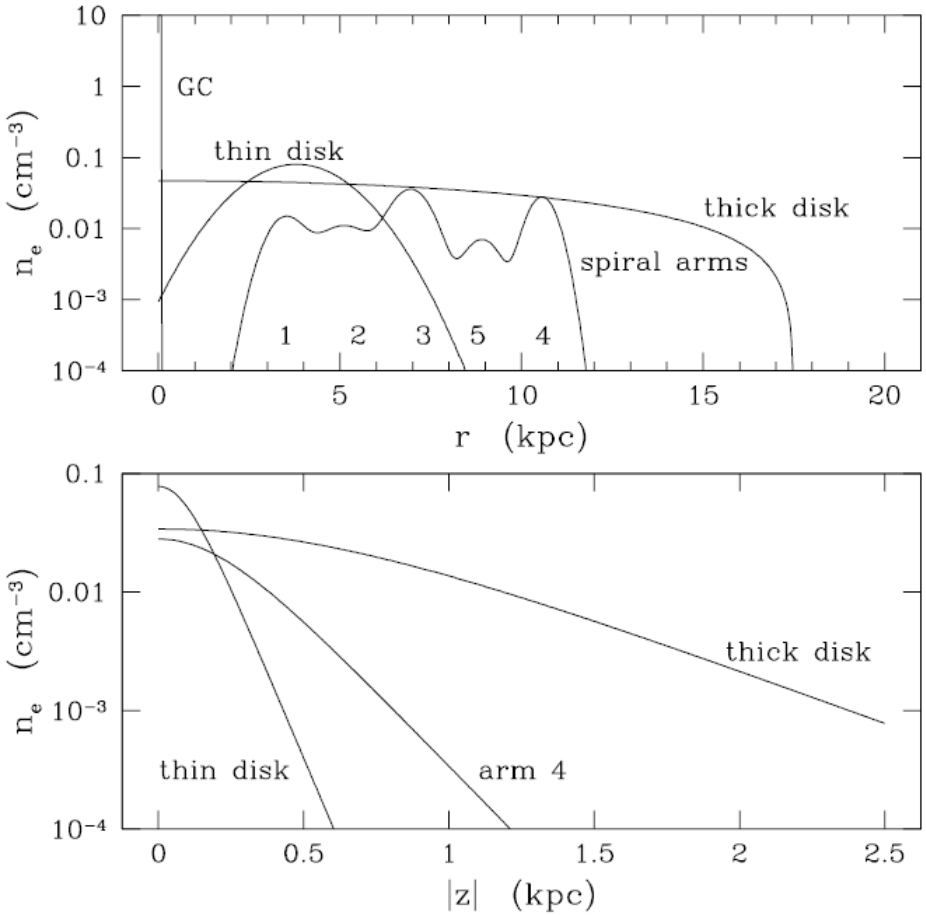


What about underlying model assumptions??

Thermal Electrons: NE2001 Model

J. Cordes&T. Lazio, arXiv:0207156 and 0301598

- spiral arms
- thin and thick disk
- local ISM
- ad-hoc “clumps”
- ad-hoc “voids”

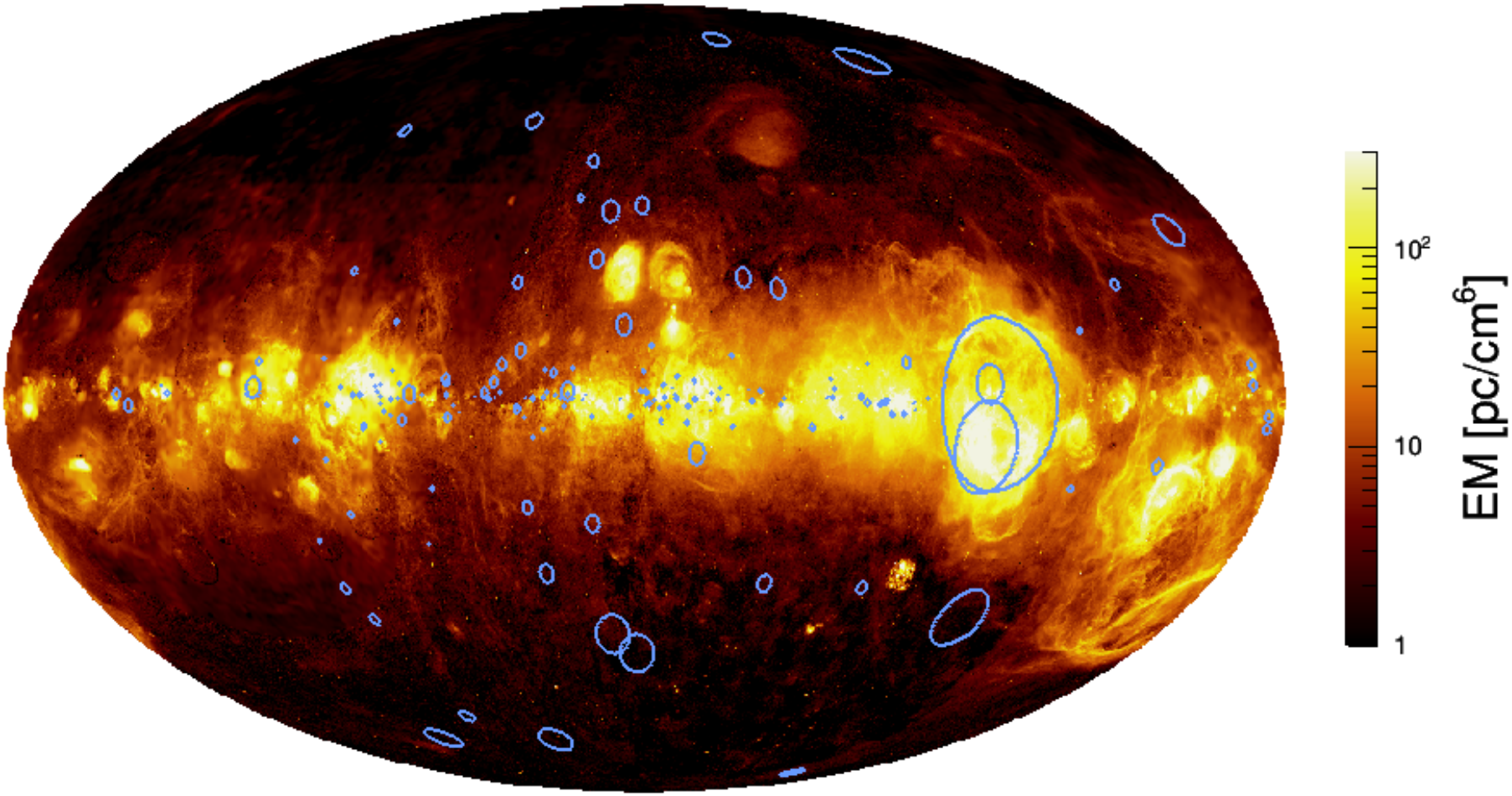


“Superposed with the large-scale and local-ISM components are clumps of excess electron density that we infer from the database of measurements as outliers from the smooth model.”

(C&L 2002, each pulsar line of sight is discussed in C&L (2003)).

NE2001 “clumps” vs. Hα Data

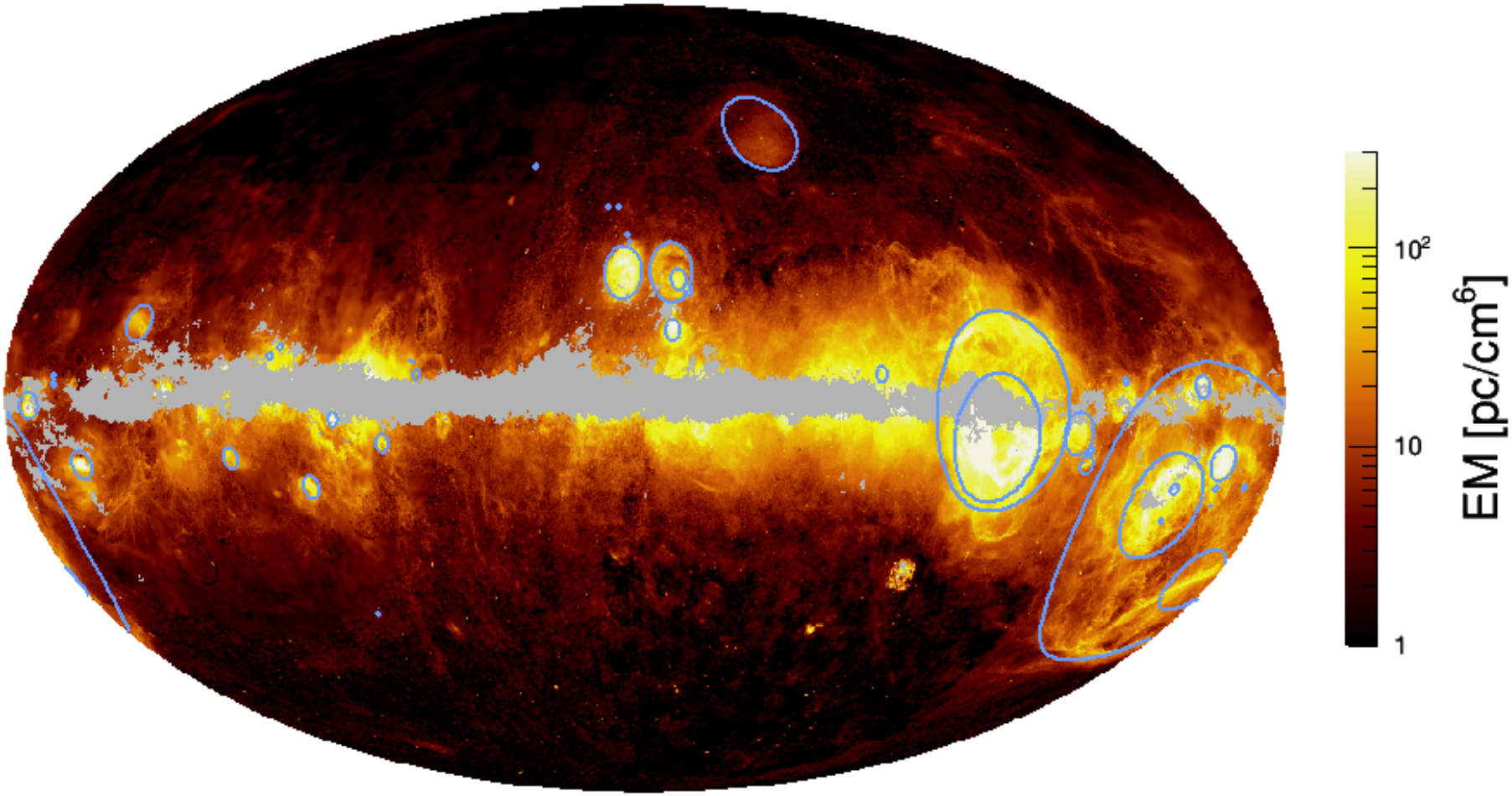
- emission measure $\mathrm{EM} \propto \int_0^\infty n_e^2(l)\mathrm{d}l$ from Hα map
- NE2001 “clumps” + Gum



VTSS, SHASSA, WHAM (D. Finkbeiner ApJS **146** (2003) 407)

NE2001 “clumps” vs. Hα Data

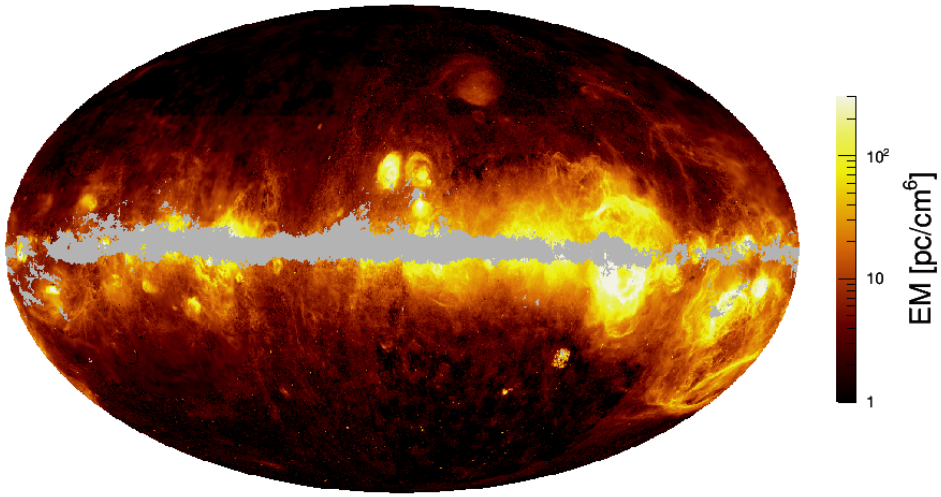
- emission measure $\mathrm{EM} \propto \int_0^\infty n_e^2(l)\mathrm{d}l$ from Hα map
- classical HII regions ($\tau(\mathrm{SFD}) < 2$)



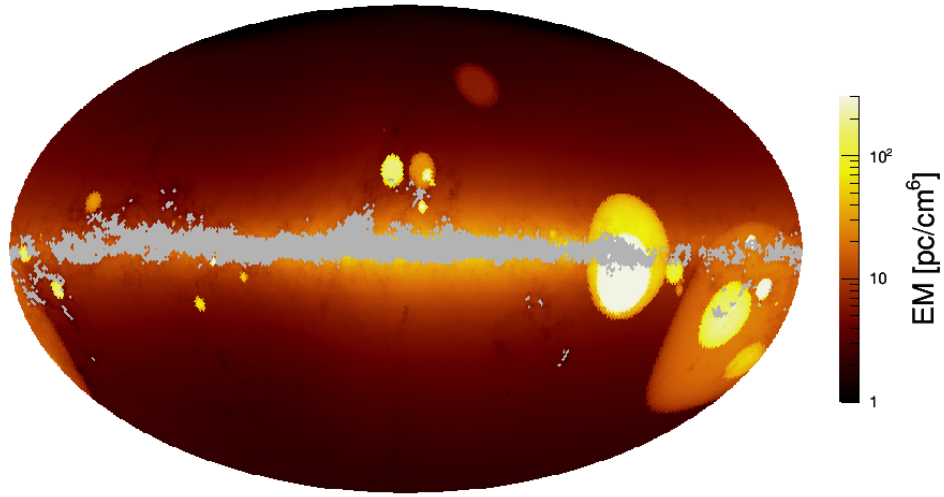
VTSS, SHASSA, WHAM (D. Finkbeiner ApJS **146** (2003) 407)

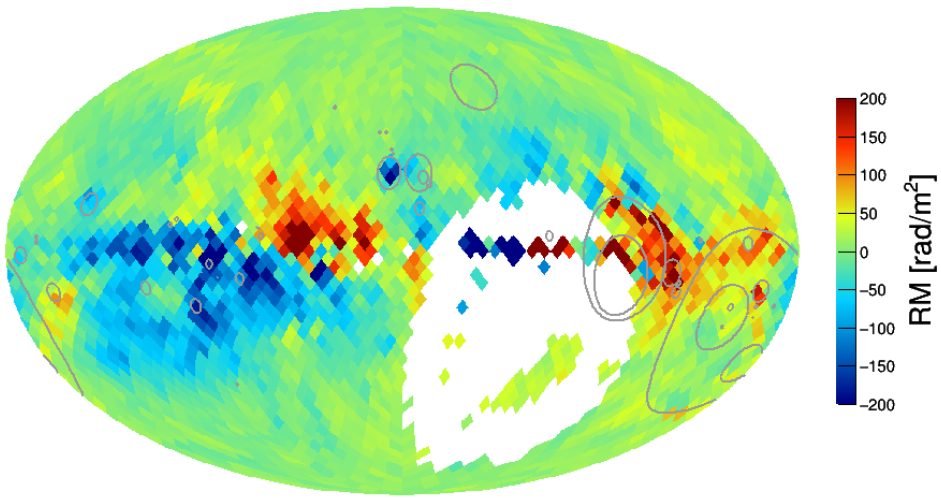
EM (top) and RM (bottom)

data

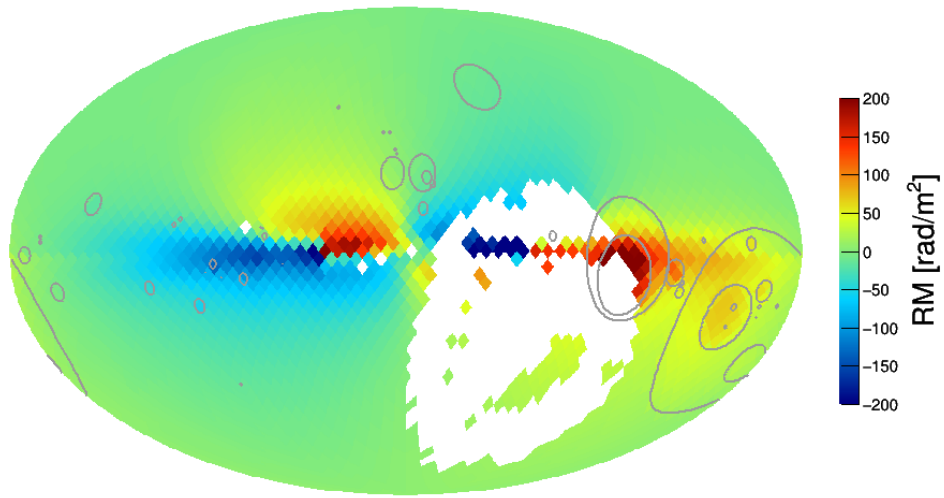


NE2001+HII+τ(SFD)



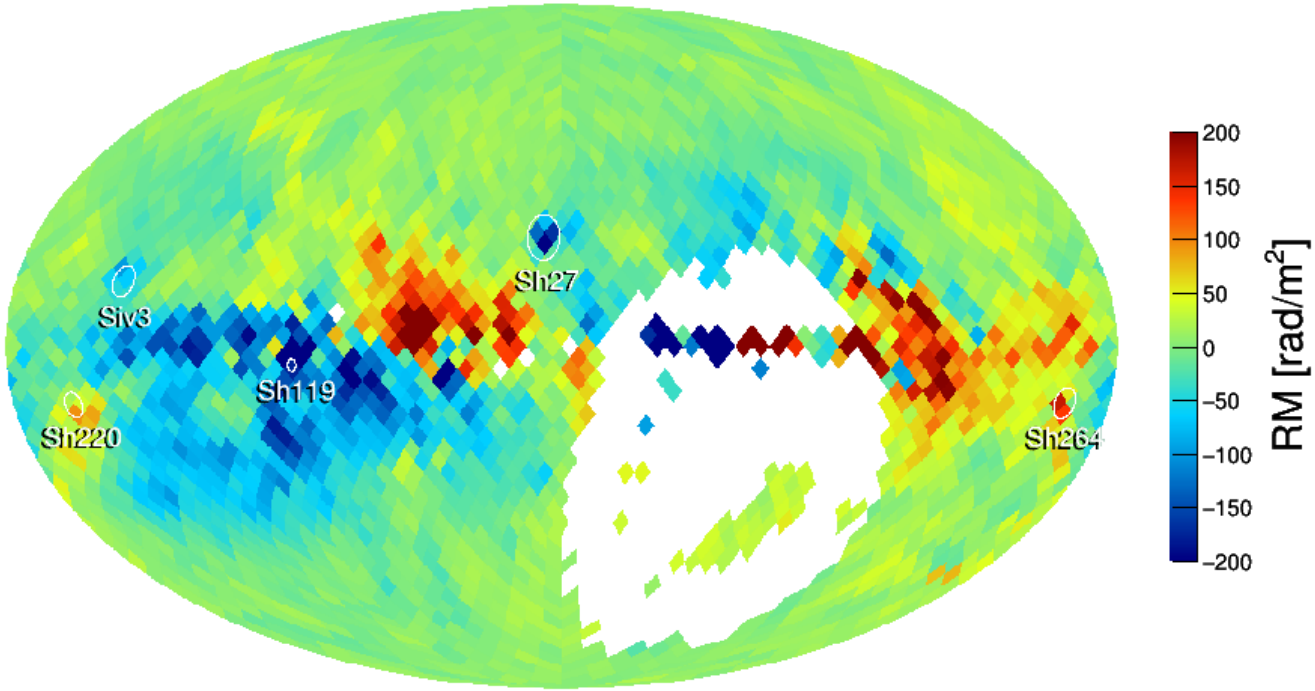


data



NE2001+HII+JF12

HII B-field Estimates vs. Regular (!) JF12

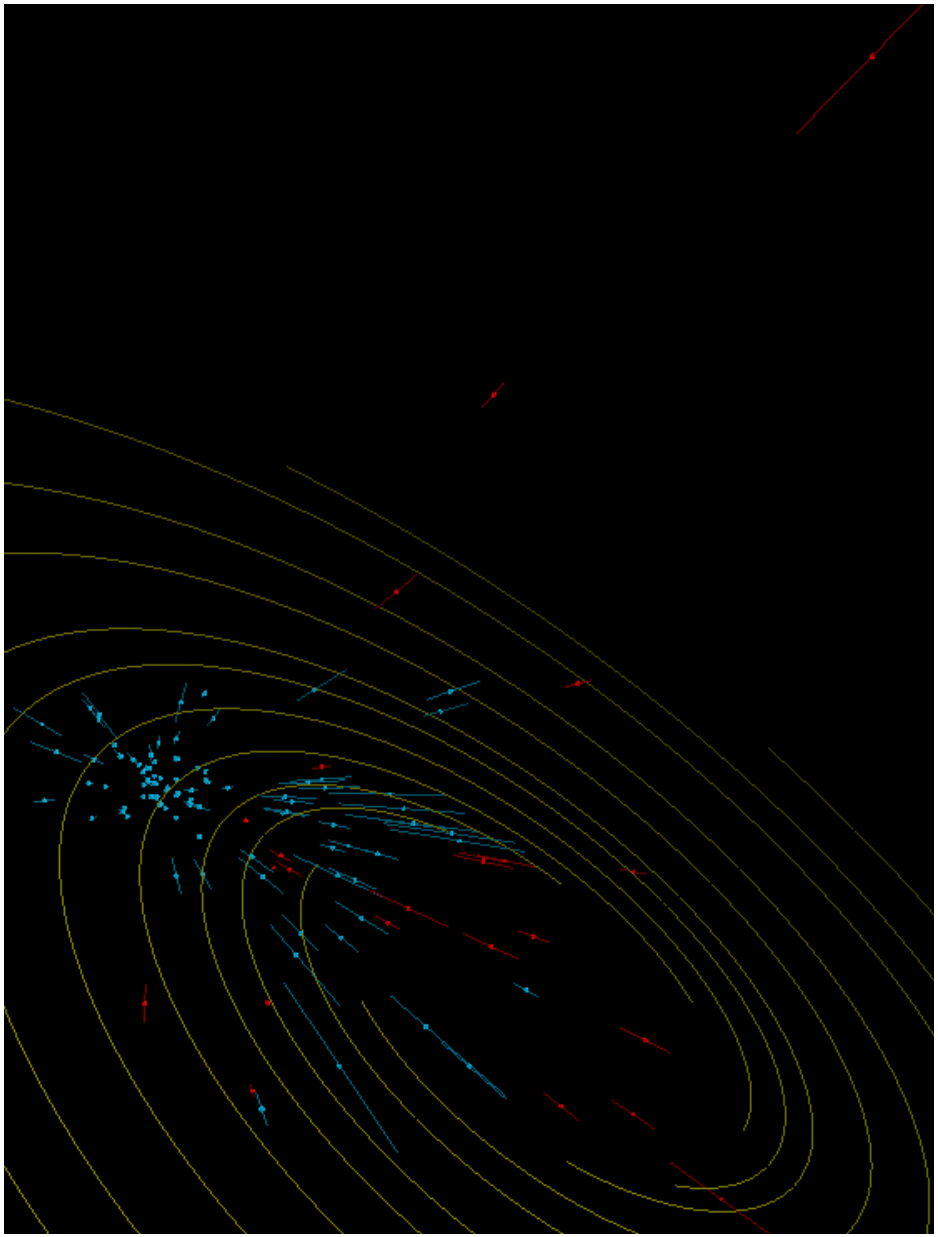


	JF12 $B_{\parallel}$ [μG]	estimated $B_{\parallel}$ [μG]
S27	-0.2	-6.1$\pm$2.8[b]
Sh119	-1.1	-19.9$\pm$5.3[a]
Sh220	+0.0	-6.3$\pm$2.4[b]
Sh264	+0.6	+1.3$\pm$1.3[a], +2.2$\pm$1.5[b],
Siv3	-0.4	-2.5$\pm$1.5[b]

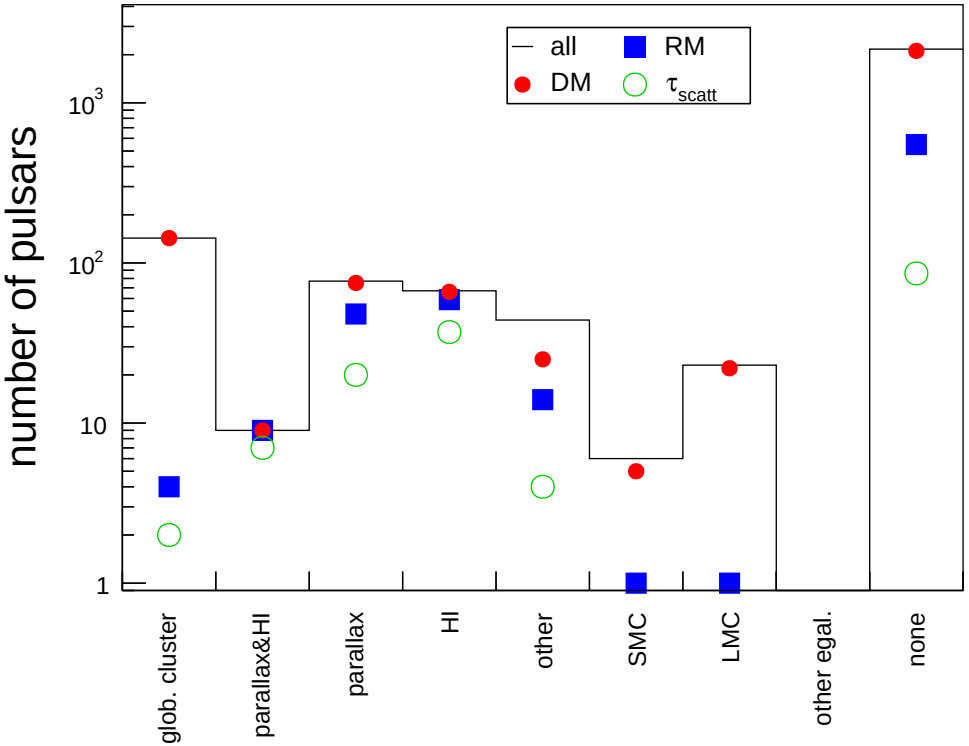
[a] C. Heiles, Y.H. Chu, T.H. Troland, ApJ **247** (1981) 77

[b] L. Harvey-Smith, G.J. Madsen, B.M. Gaensler, ApJ **736** (2011) 83

NE2001 vs. Pulsar DMs



red: globular clusters, blue: individual pulsars

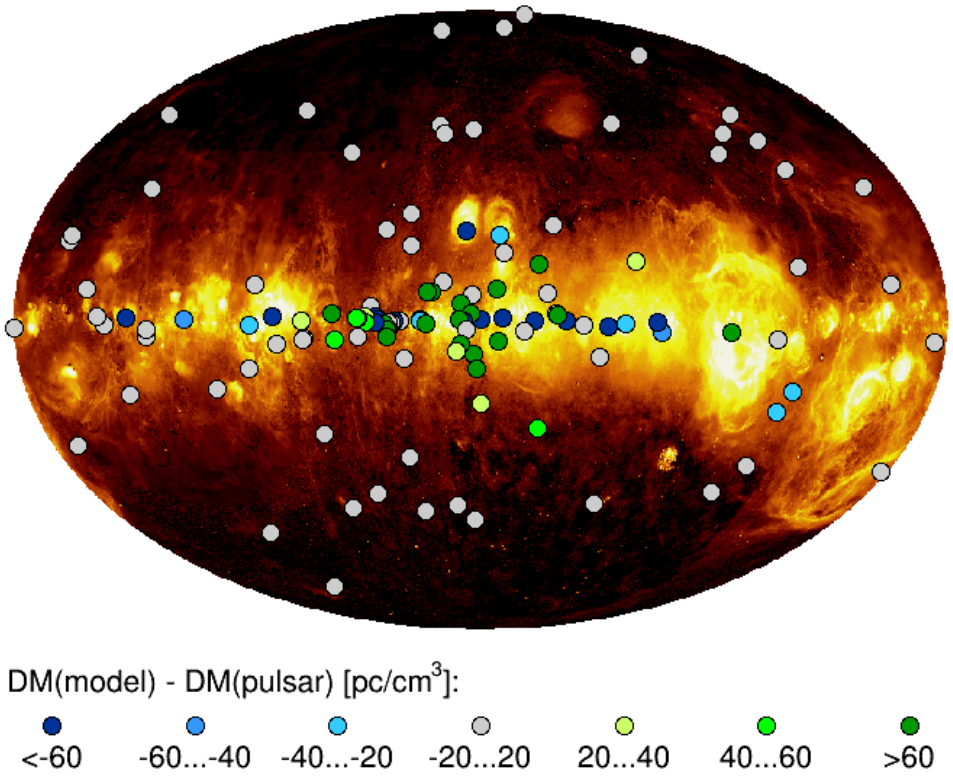


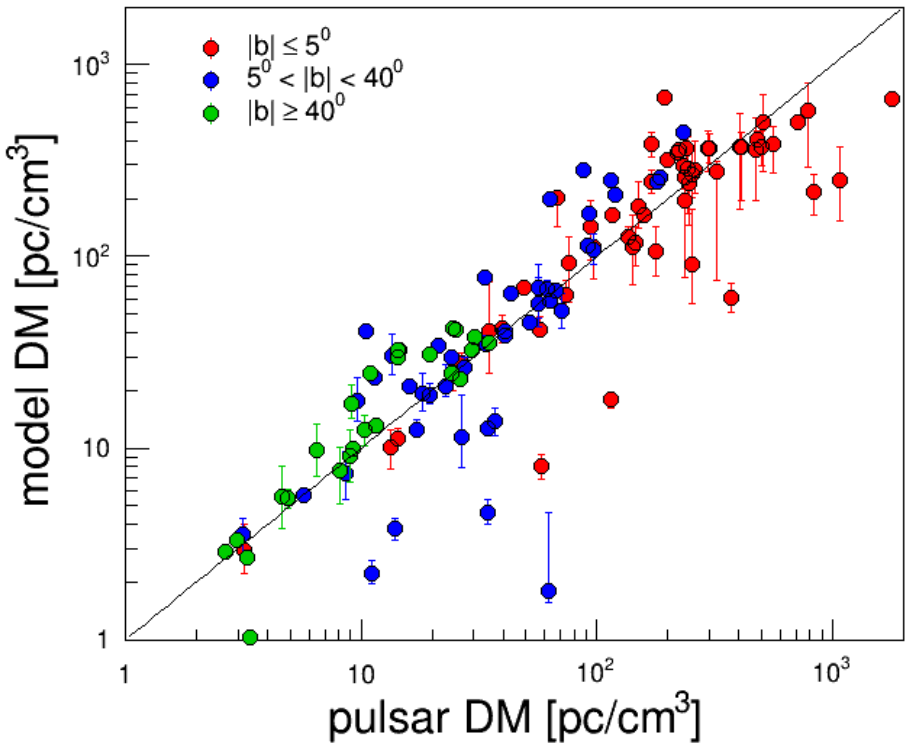
- 123 line of sights with dispersion measure $DM = \int_0^D n_e(l)\mathrm{d}l$ and $\sigma(D)/D < 1/3$ (LMC/SMC excluded).

ATNF pulsar database v1.54
G. Desvignes et al, MNRAS 458 (2016) 3341
`www.astro.cornell.edu/~shami/psrvlb/parallax.html`
`psrpop.phys.wvu.edu/LKbias/about.php`
`www.physics.mcmaster.ca/~harris/mwgc.dat`

NE2001 vs. Pulsar DMs

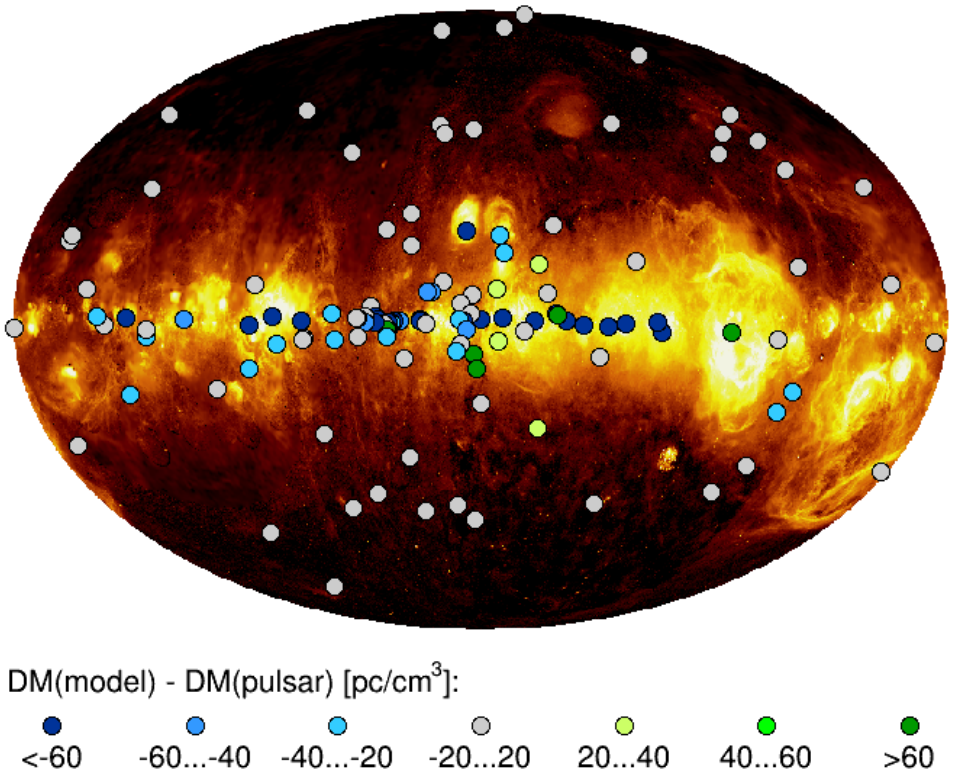
original NE2001 model:

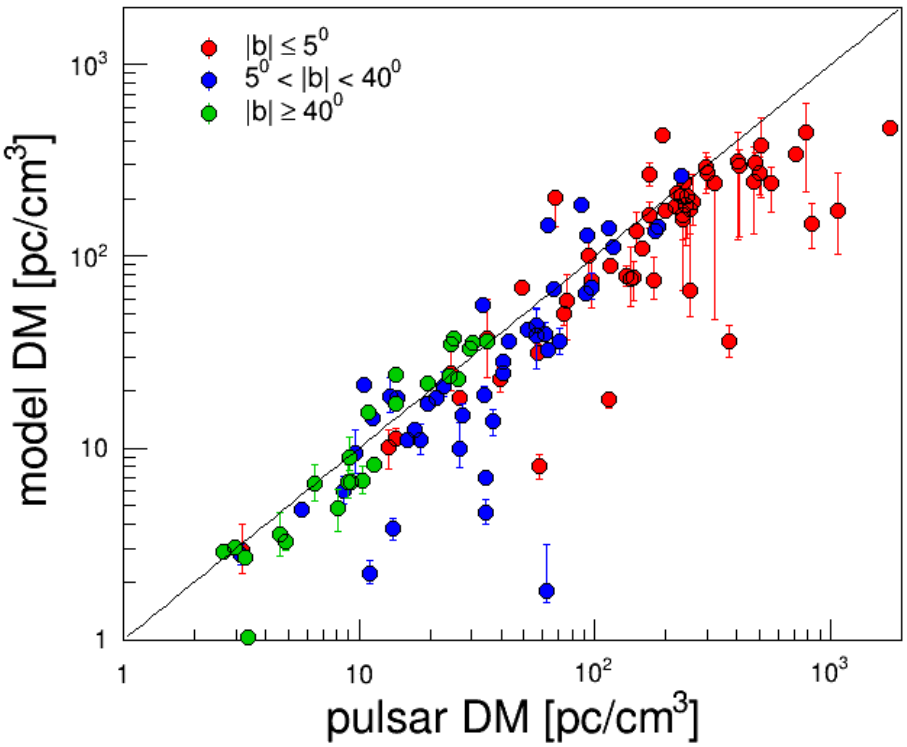




NE2001 vs. Pulsar DMs

re-tuned[a] thick-disk scale height (used for JF12): 0.97→1.83 kpc

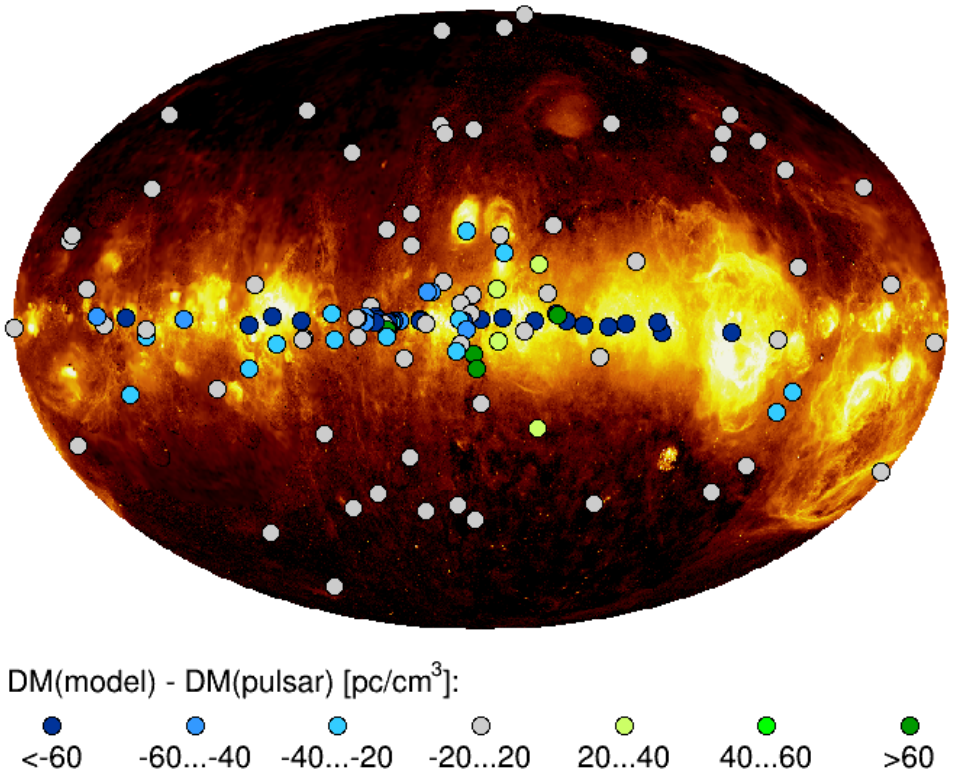


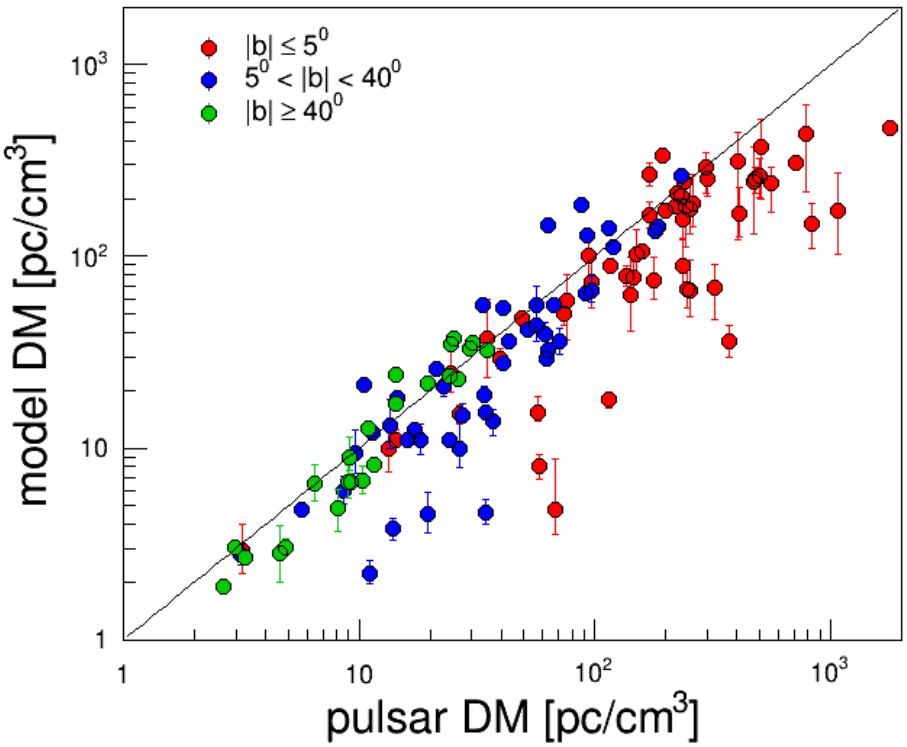


[a]B. Gaensler et al, PASA **25** (2008) 184, also D. Schnitzeler, MNRAS **427** (2012) 664.

NE2001 vs. Pulsar DMs

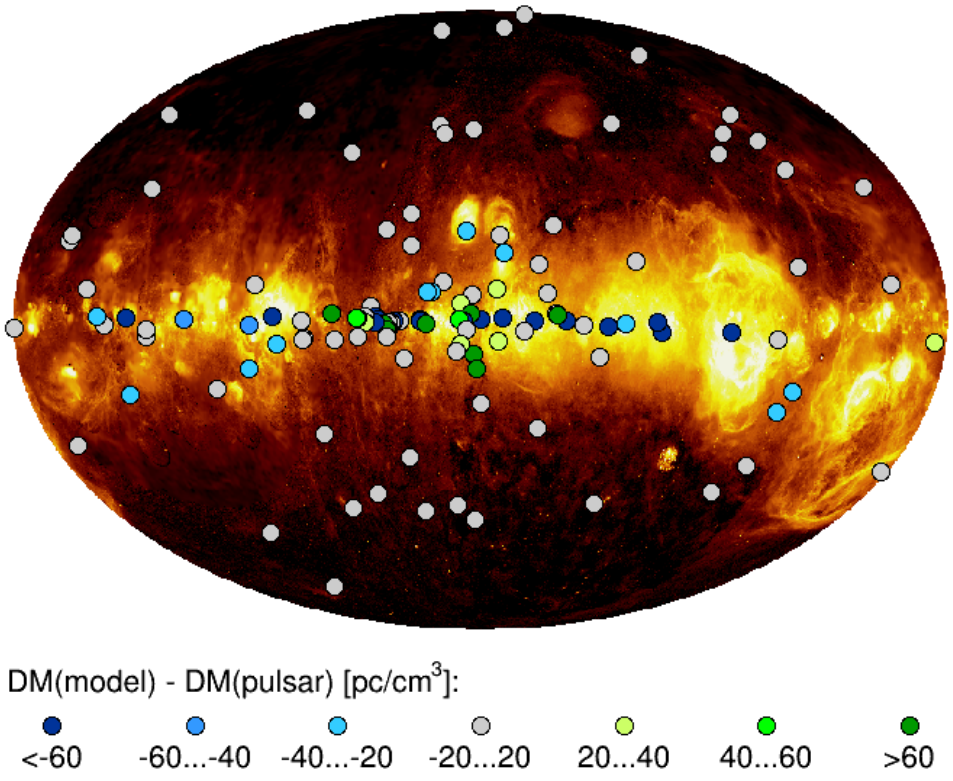
Removing ad-hoc NE2001 clumps, adding 47 nearby HII regions

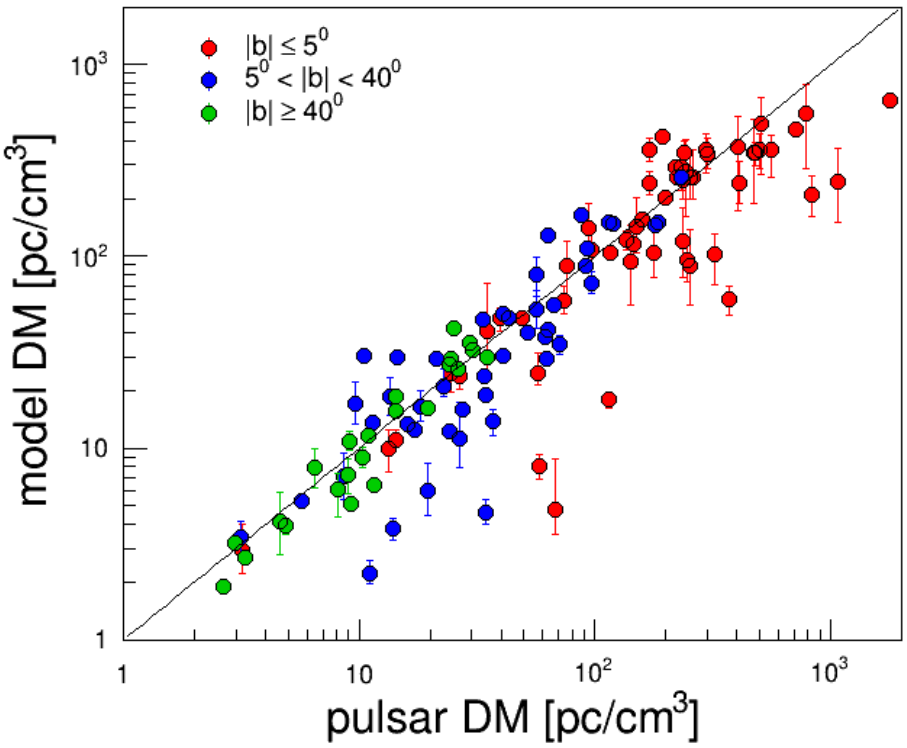




NE2001 vs. Pulsar DMs

Refit with double-exponential thick disk (for illustration)





remaining “outliers” mainly in GP, including more HII may tighten scatter

Summary

Ongoing studies: Effect of thermal electron uncertainties on global GMF fit

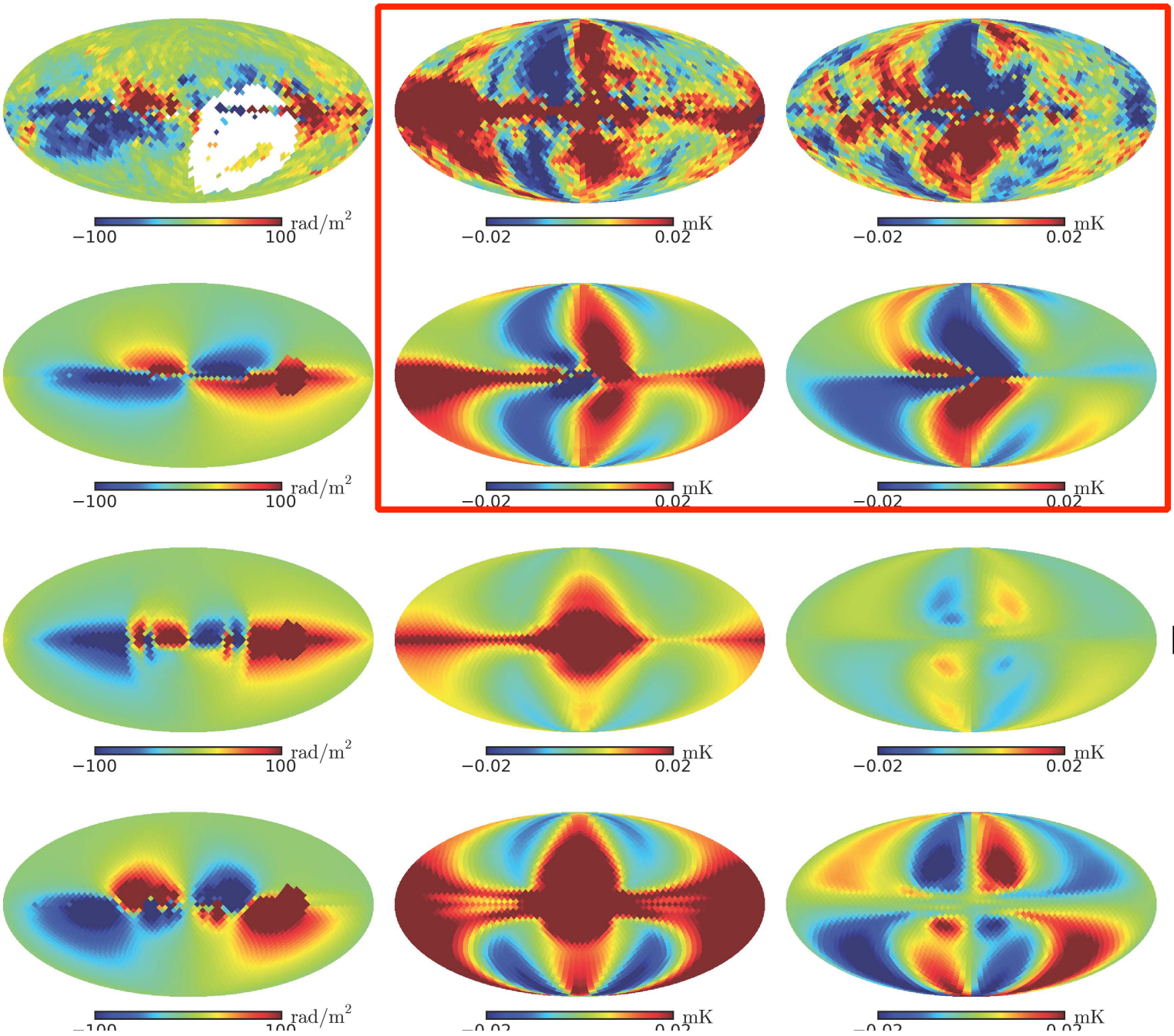
- better modeling of local distribution of n_e helpful to understand fluctuations and "locality" of extragalactic RMs
- in preparation: WHAM(v)+3D Dust.
- re-tune NE2001

Further improvements / studies for a successor to JF12 (and more realistic GMF uncertainties):

- cosmic ray electrons
- functional forms used in JF12
- functional forms used in NE2001
- correlation of n_e and B
- ...

backup

Spiraling X-field ↔ distinctive L-R, up-down pattern in Q, U



Observed data

Simulated data

JF 2012

χ^2 = 1.096 per d.o.f.

for 6605 observables

Pshirkov+ 2011

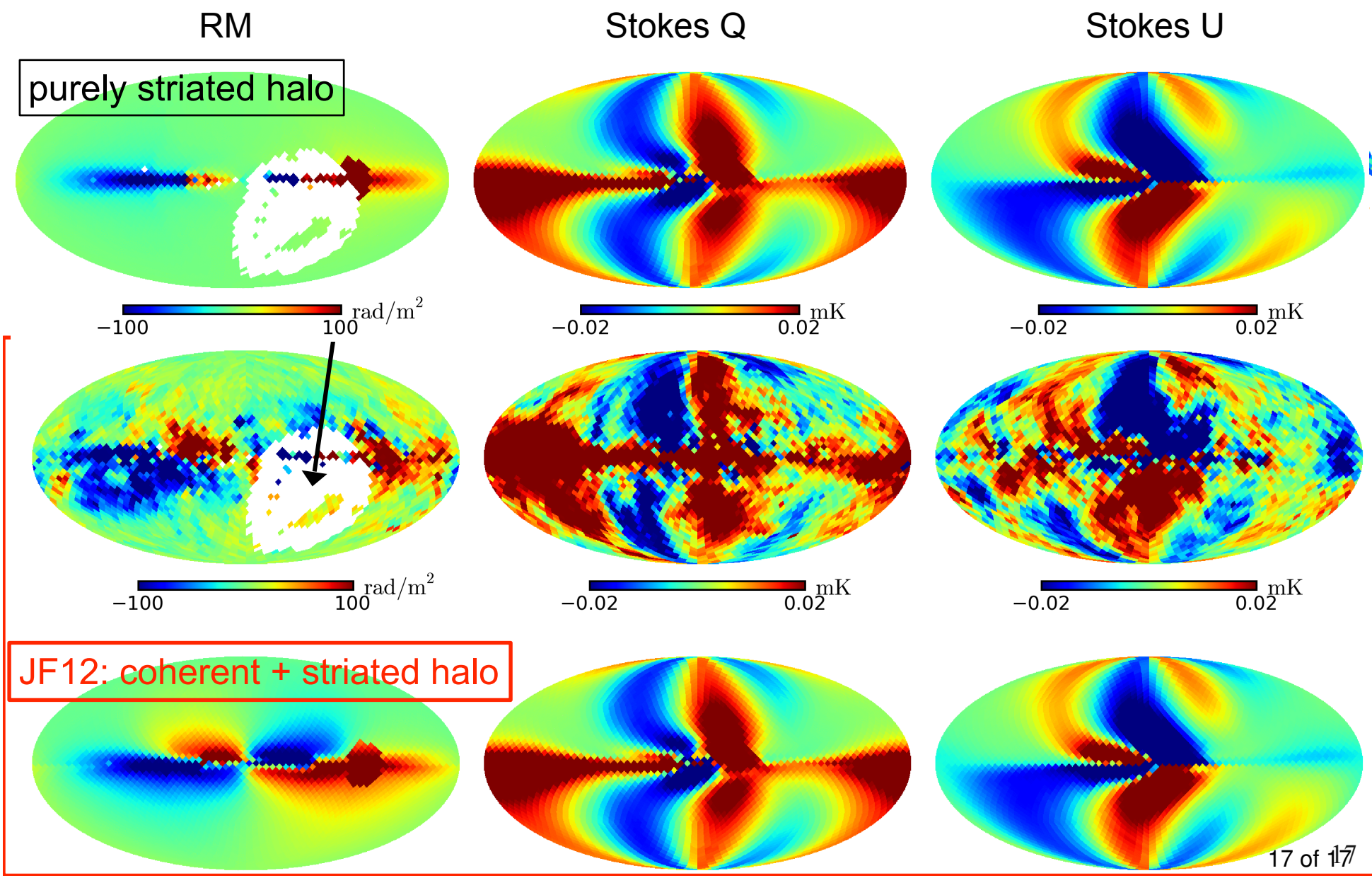
χ^2 = 2.66 per dof

No X-field

Sun et al.,2010

χ^2 = 1.67 per dof

The halo field is DIRECTED, not just striated



Independent evidence for JF12 X-field, from orientation of Supernova Remnants

Jennifer West, IAU DD.6.03

The Connection between Supernova Remnants and the Galactic Magnetic Field

(A&A, submitte

Jennifer West, PhD Candidate
University of Manitoba, Canada

Supervisor: Samar Safi-Harb (U. of Manitoba, Canada)
Collaborators: Tess Jaffe (IRAP, Toulouse, France), Roland Kothes (NRC Herzberg, Canada), Tom Landecker (NRC Herzberg, Canada), Tyler Foster (Brandon U., Canada)

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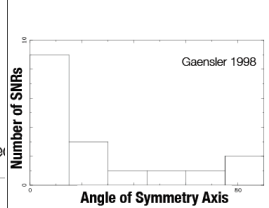
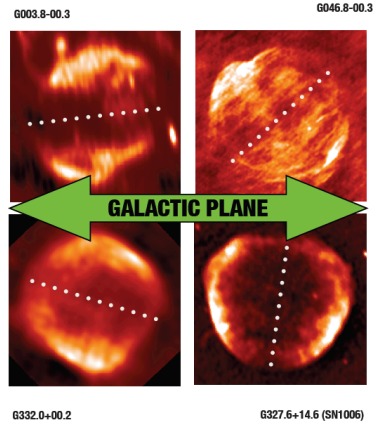
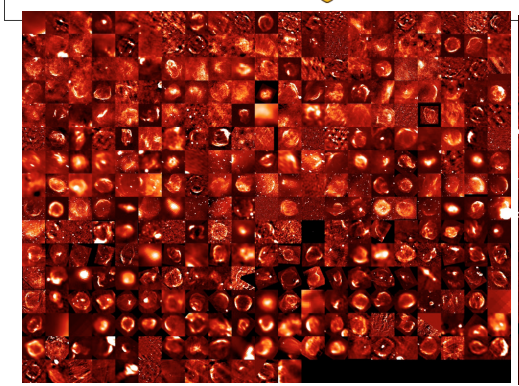
Is there a connection between the Galactic Magnetic Field and Supernova Remnants?

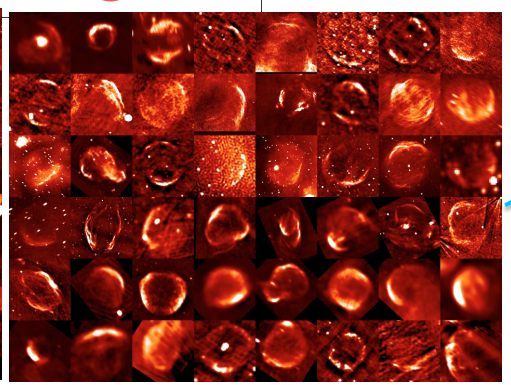


Gaensler (1998): a highly significant tendency for the axes of these SNRs to be aligned with the Galactic plane

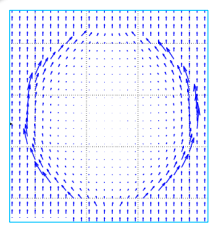
Leckband et al. (1989): no preferred orientation between the angle of symmetry and the Galactic plane







Orientation relative to model prediction



Predicted - observed