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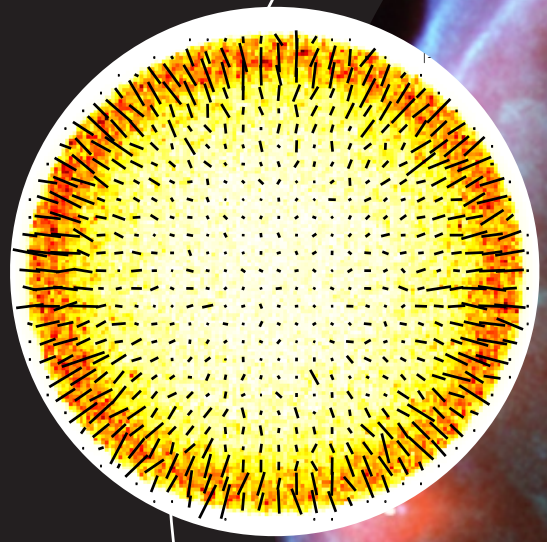

A new model to explain radial magnetic fields in young supernova remnants

Magnetic Fields in the Universe

October 17, 2017

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Brandon U.

Tom Landecker
DRAO

Roland Kothes
DRAO

Outline

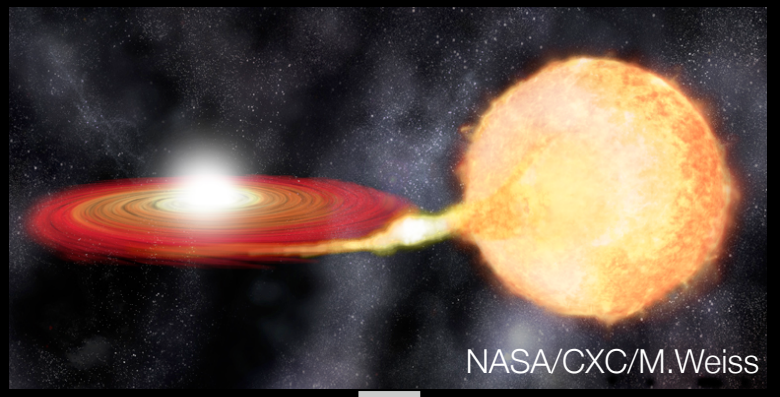
1. Brief background on supernova remnants
2. Summary of previous work: supernova remnants and the Galactic magnetic field
3. Radial magnetic fields in young supernova remnants

SUPERNOVA EXPLOSION

DIFFERENTIATED BY THEIR SPECTRA

Core collapse

Type Ia



COMPACT OBJECT

NO COMPACT OBJECT

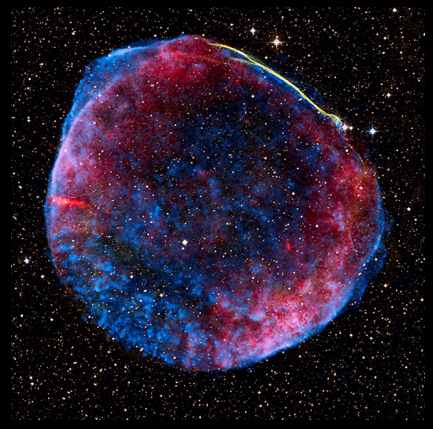
SUPERNOVA REMNANT

PULSAR WIND NEBULA

eg. Crab (SN1054)
(Credit: Chandra, Hubble, VLA)

COMPOSITE

eg. G21.5-0.9
(Credit: Matheson/Safi-Harb/ CHANDRA)



SHELL

eg. SN1006
(Credit: Chandra, Hubble, VLA)

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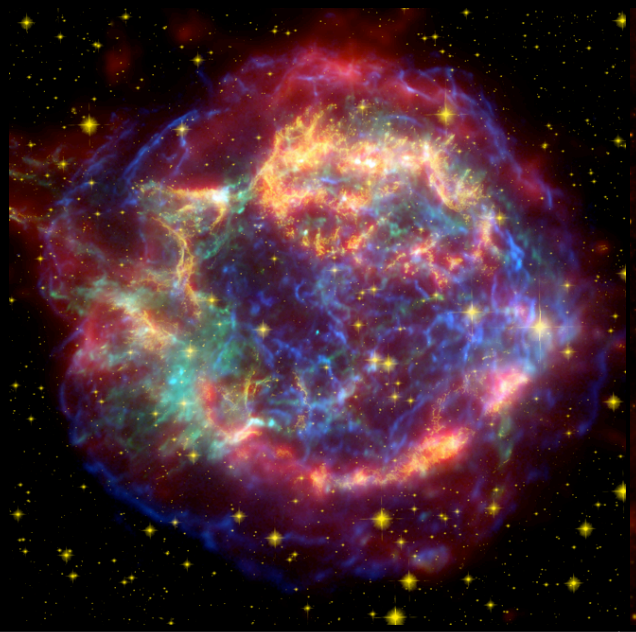
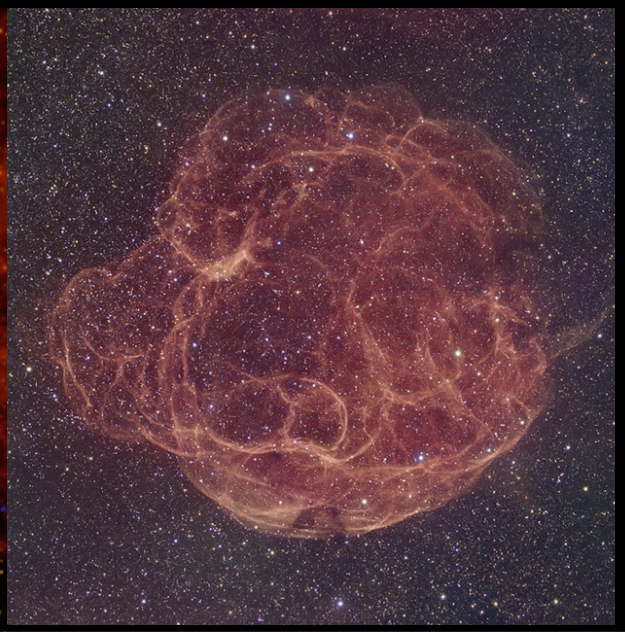
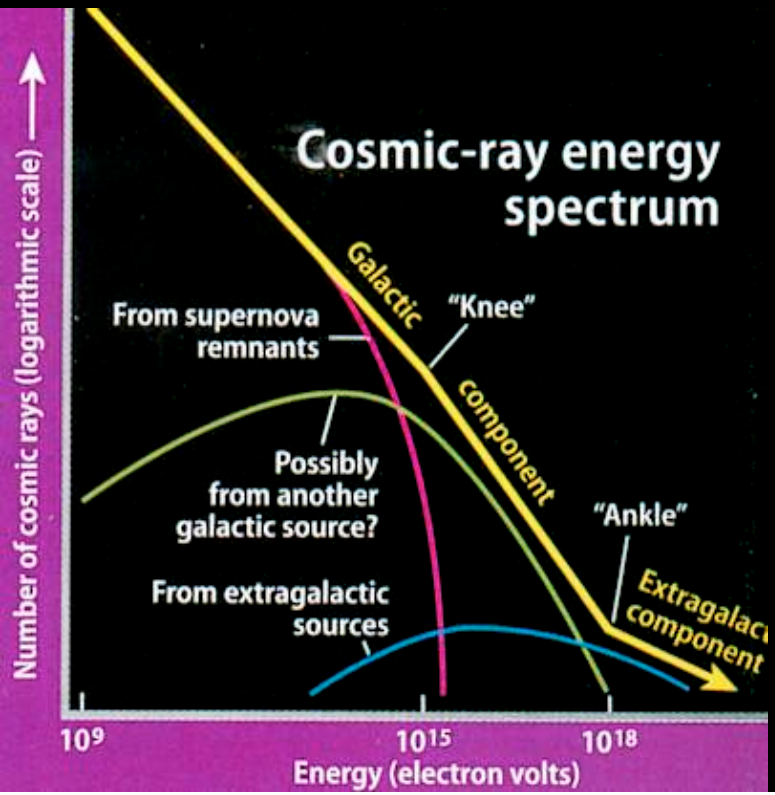
Evolutionary Phases of Supernova Remnant Shells





FREE EXPANSION PHASE	SEDOV PHASE	RADIATIVE PHASE
First ~1000 years	1000-30,000 years	30,000 years+
Radius ~7 pc (20 ly)	Radius ~35 pc (100 ly)	Radius ~65 pc (200 ly)
eg. Cas A (Credit: NASA/CXC/SAO)	eg. RCW86 (Credit: MOST, Chandra, WISE)	eg. S147 (Credit: Stefan Binnewies, Rainer Sparenberg)

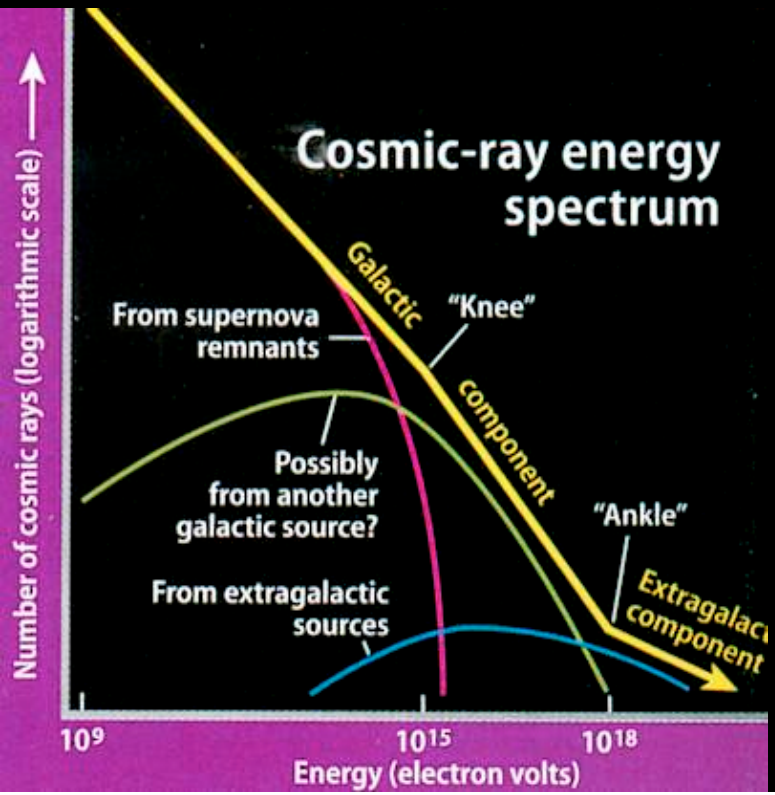
What do magnetic fields tell us about cosmic ray acceleration?



Soft X-Rays
Hard X-Rays

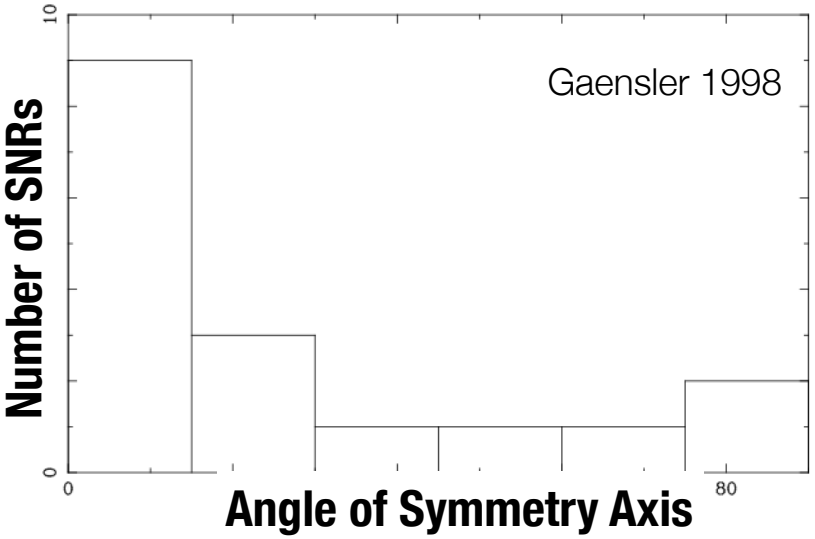
Credit: NASA/CXC/Middlebury College/F.Winkler

What do magnetic fields tell us about cosmic ray acceleration?



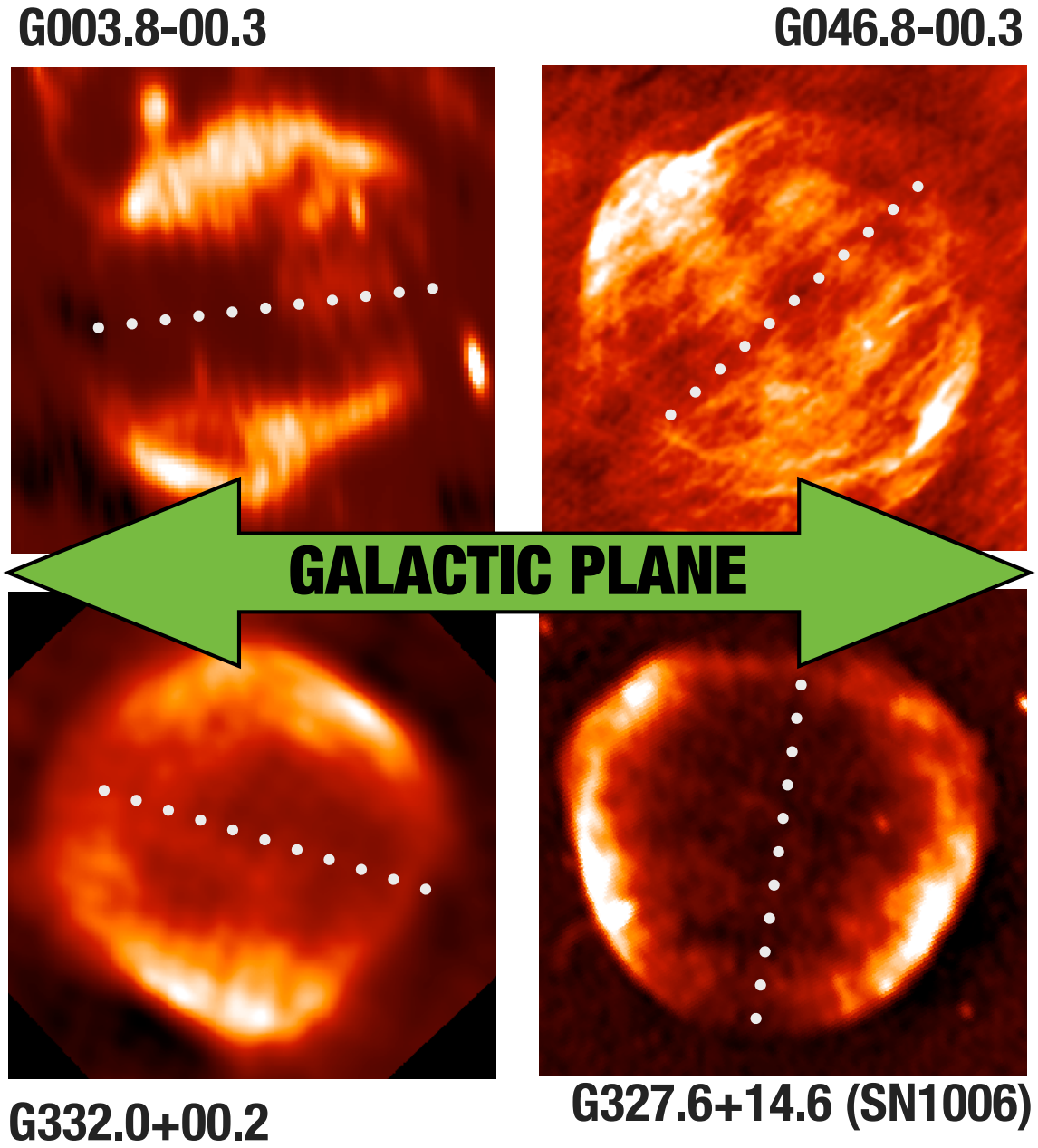
Credit: NASA/CXC/Middlebury College/F.Winkler

Is there a connection between the Galactic magnetic field and the morphology of 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



Model Synchrotron Intensity

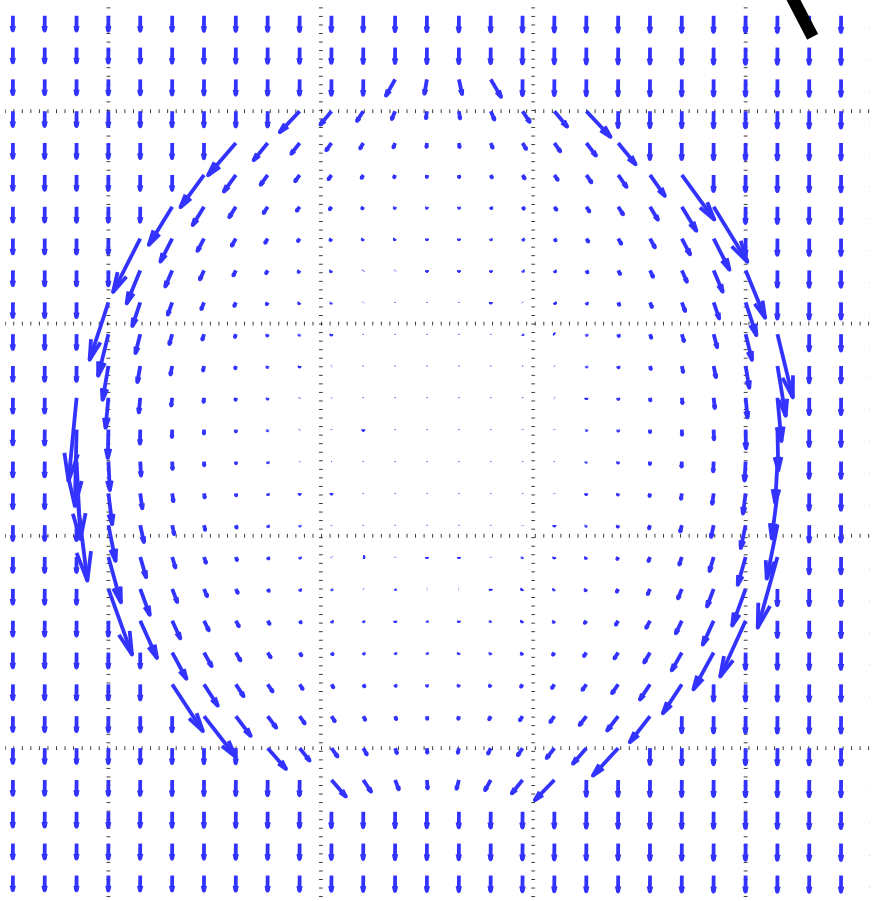
(CRE distribution)

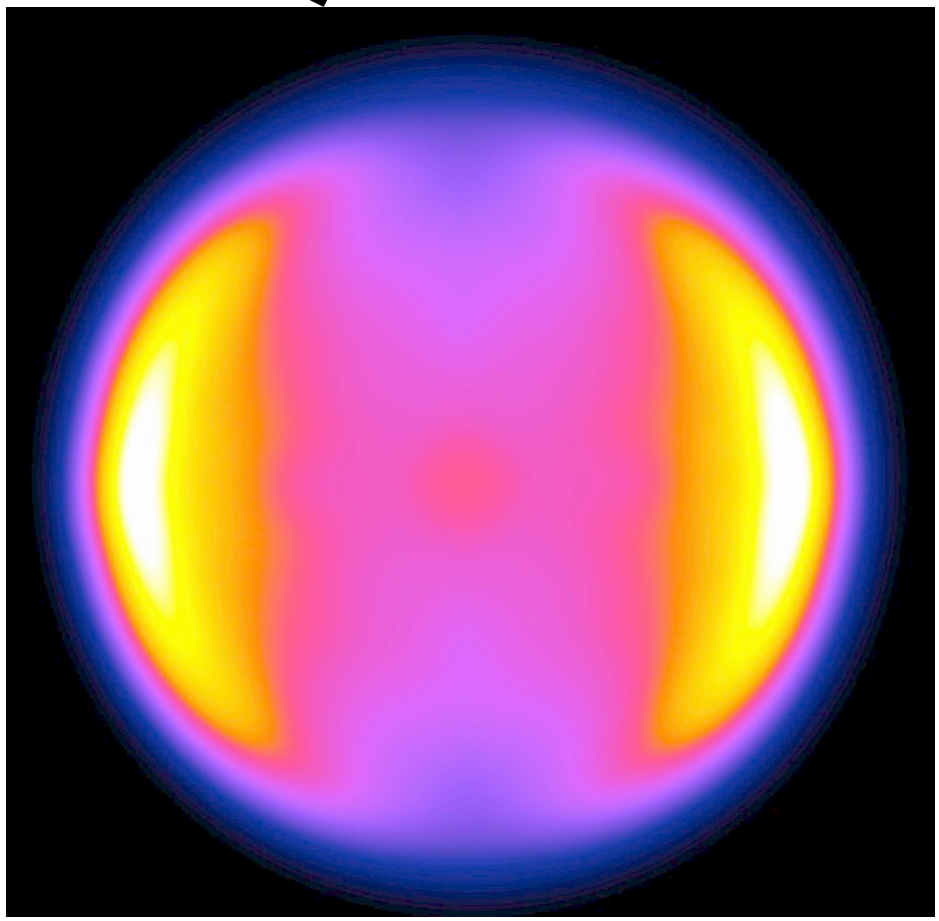
$$K(\alpha) B_{\perp}^{\alpha+1} \nu^{-\alpha} = j_{\nu}$$

α = spectral index

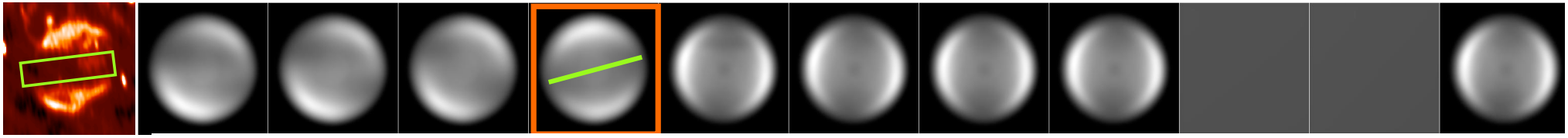
ν = observation frequency

j_{ν} = synchrotron intensity

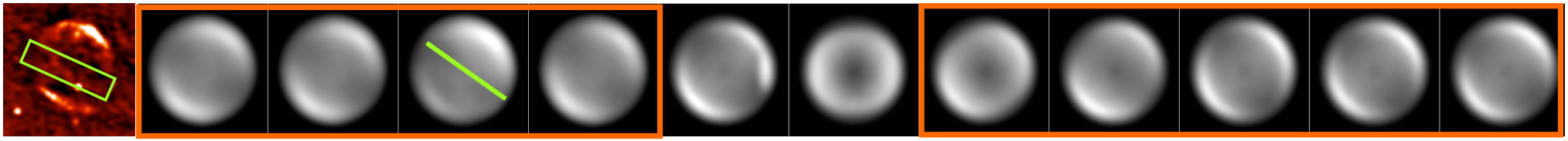




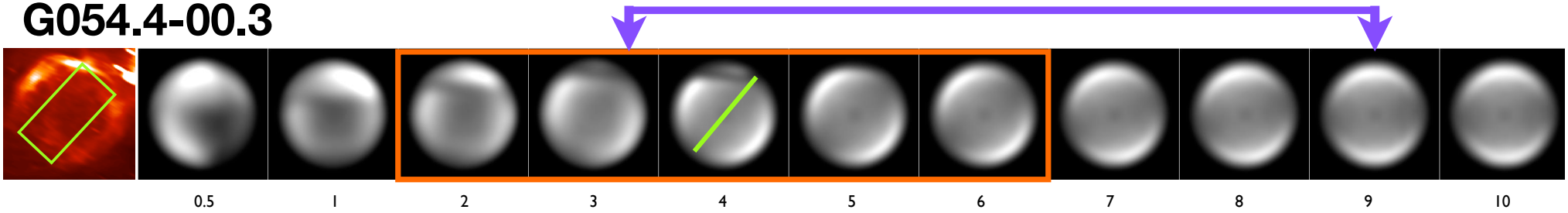
G003.7-00.2



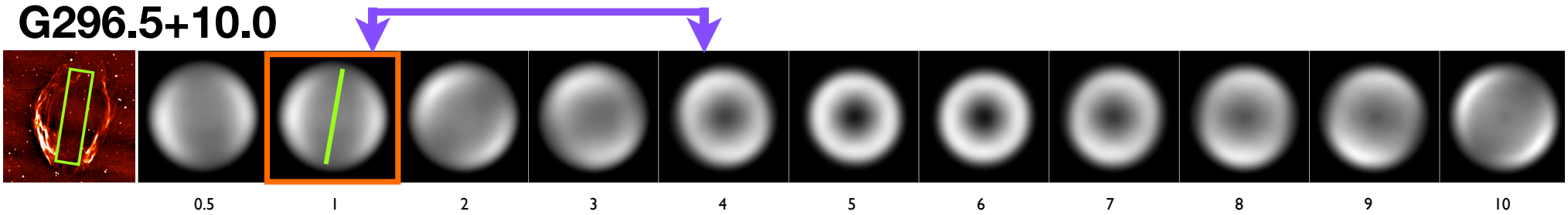
G036.6+02.6



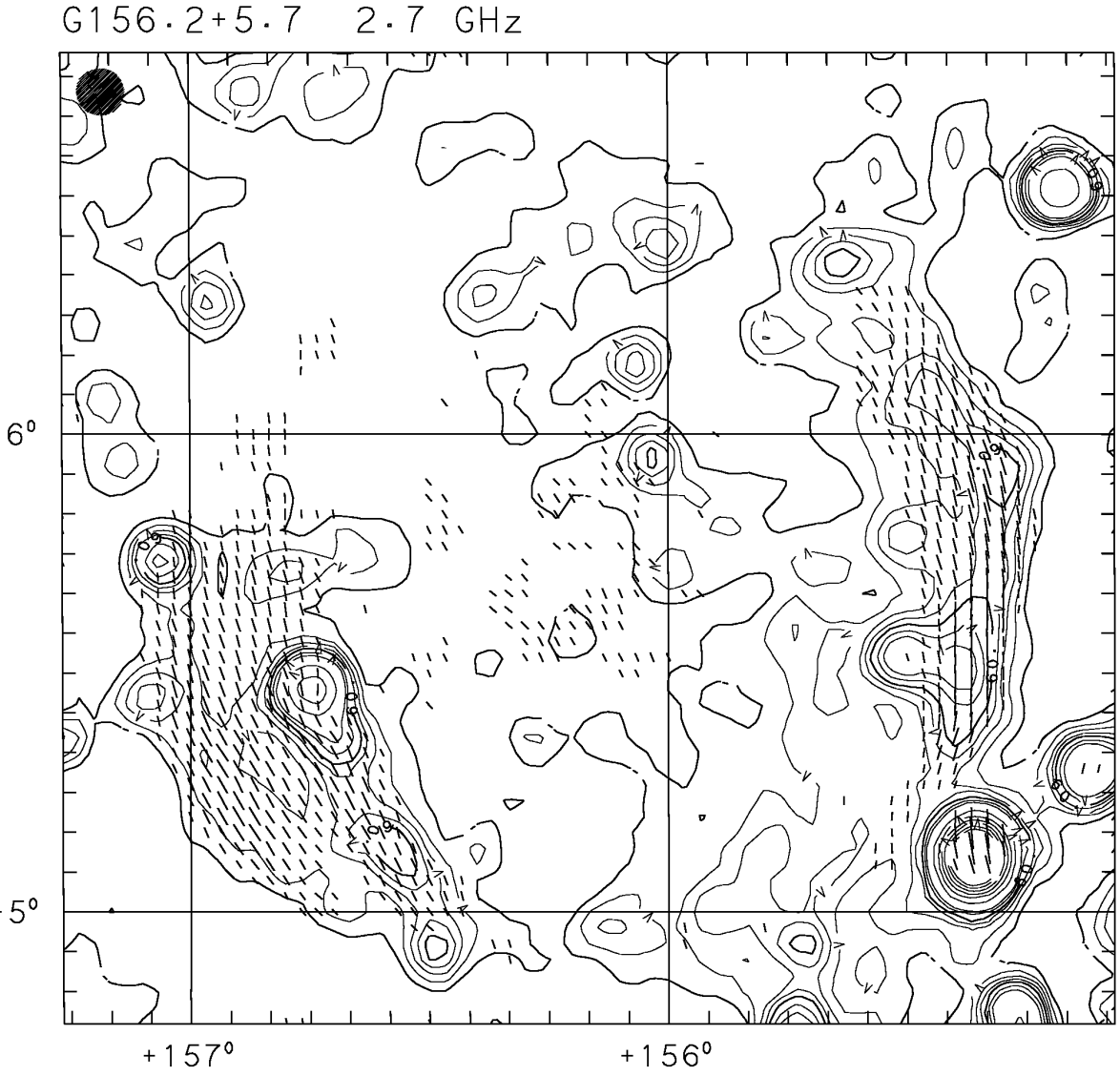
G054.4-00.3



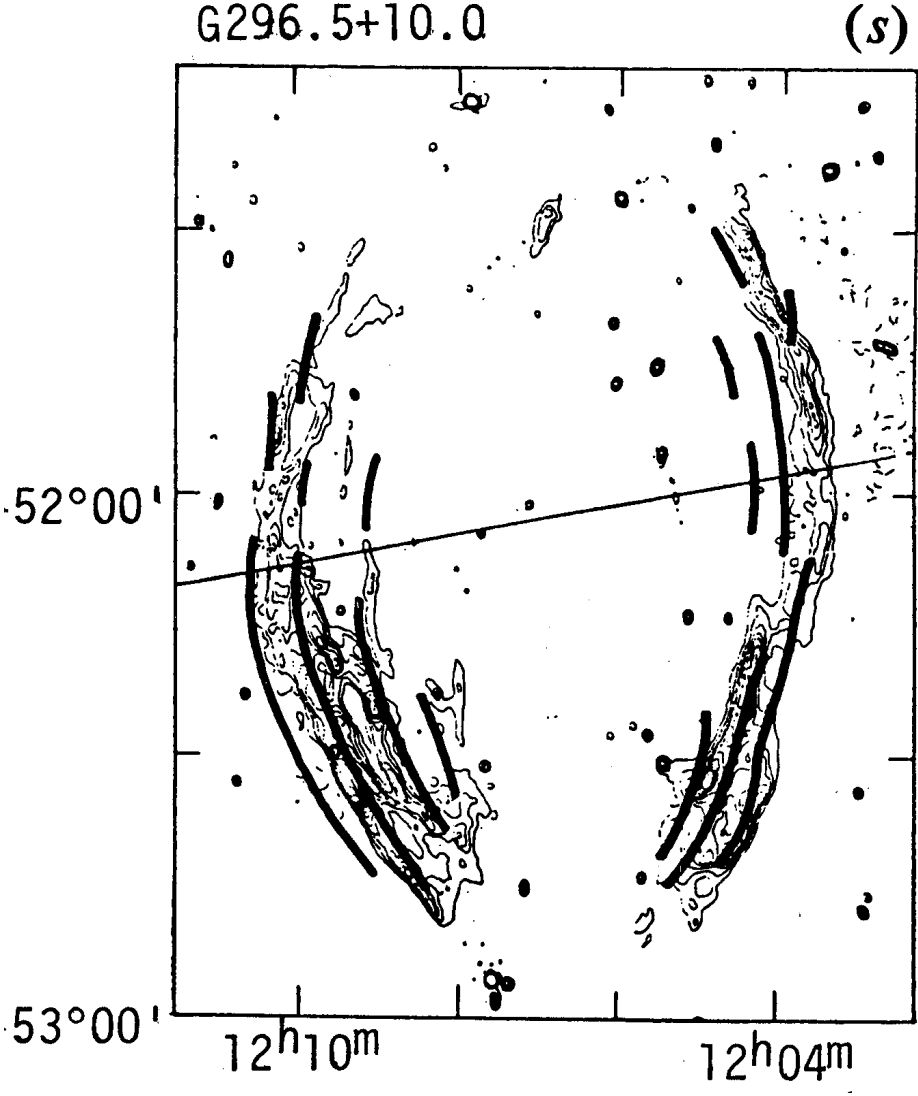
G296.5+10.0



West et. al 2016

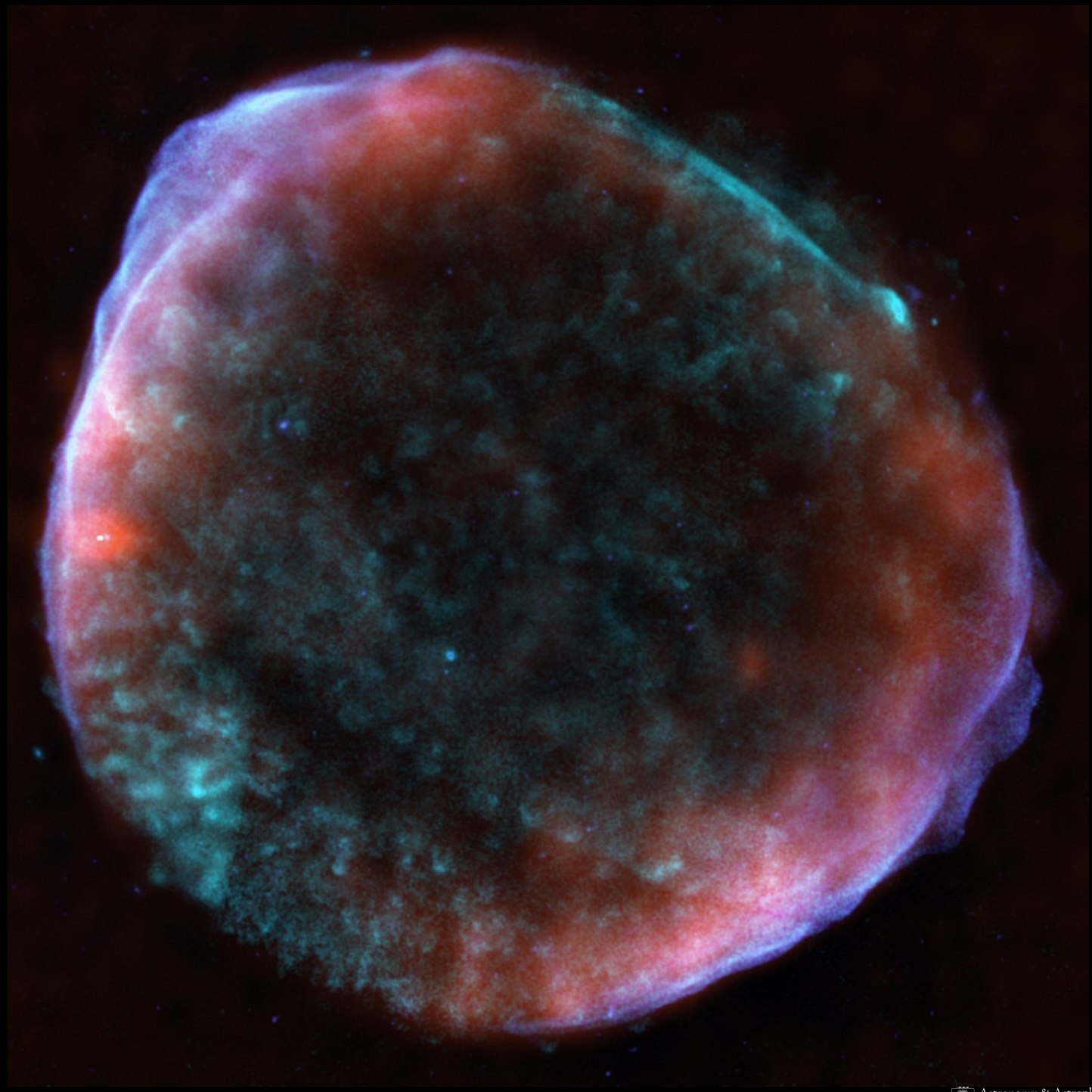


Reich 2002

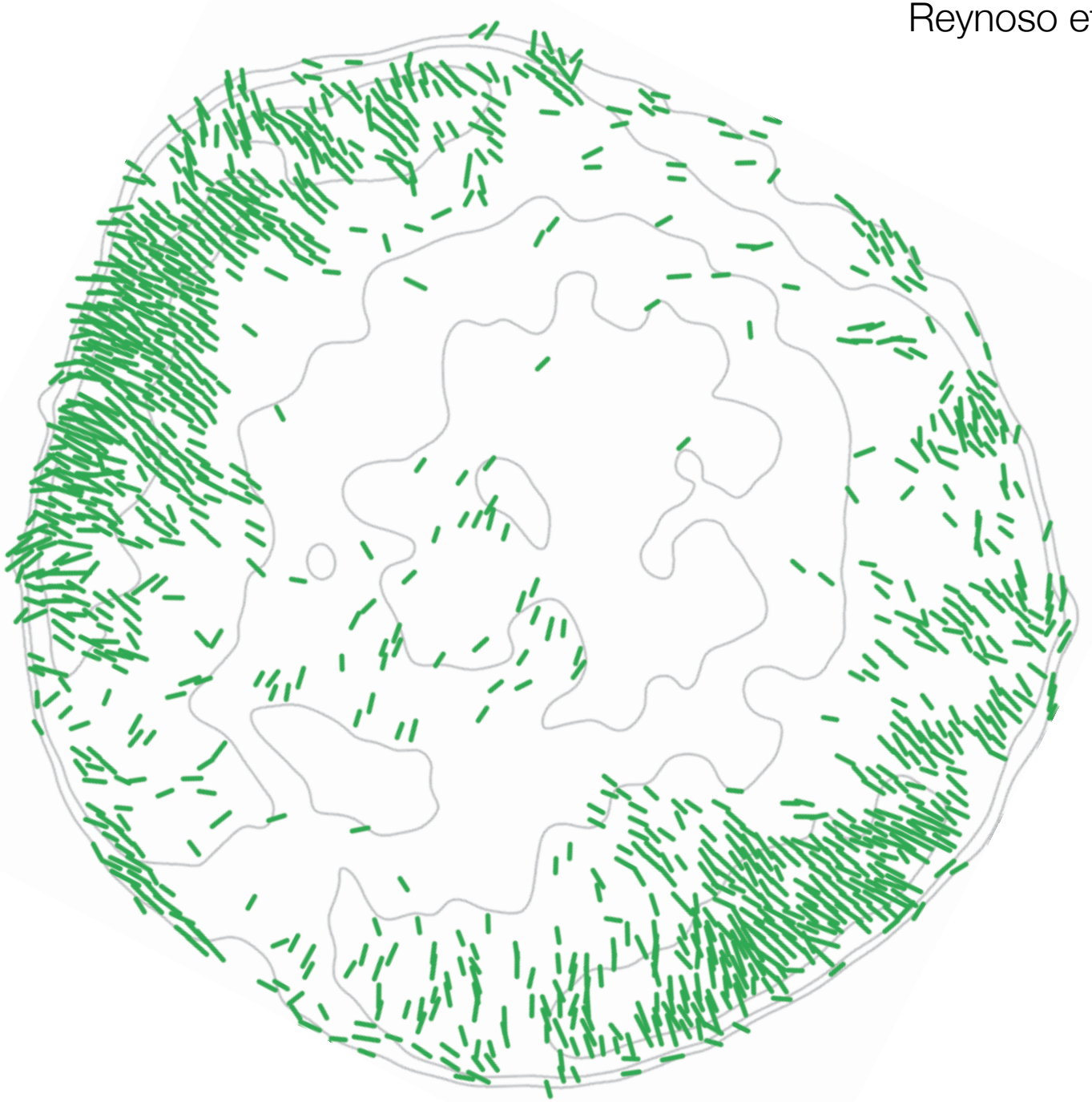


Milne 1987

SN1006



Reynoso et al. 2013



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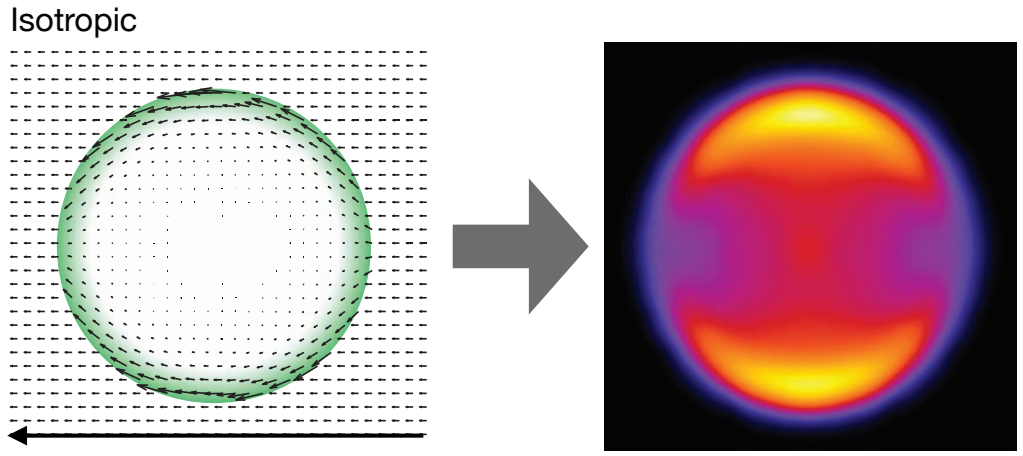
Cosmic Ray Electron Distribution

CRE distribution scaled by

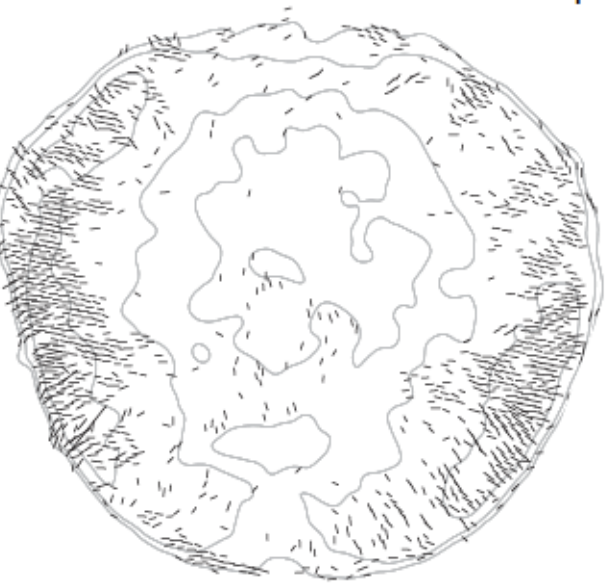
$$\sin^2 \phi_{Bn2}$$

CRE distribution scaled by

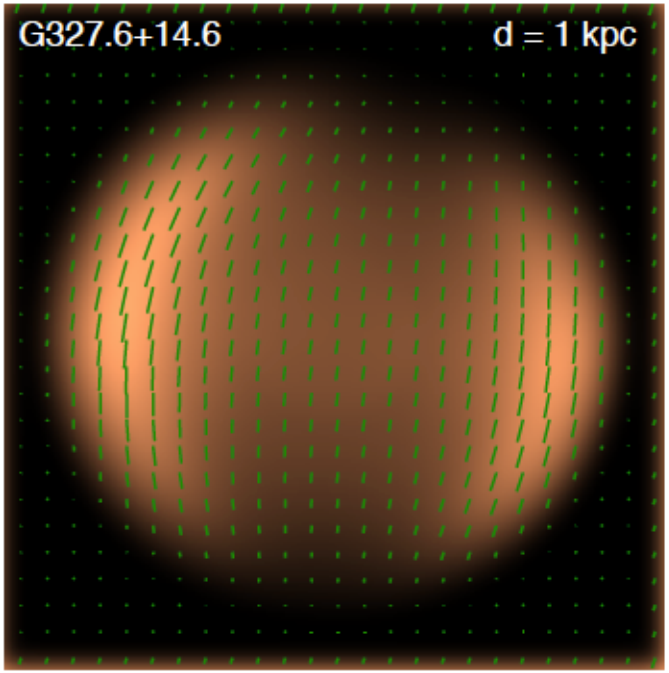
$$\cos^2 \phi_{Bn2}$$



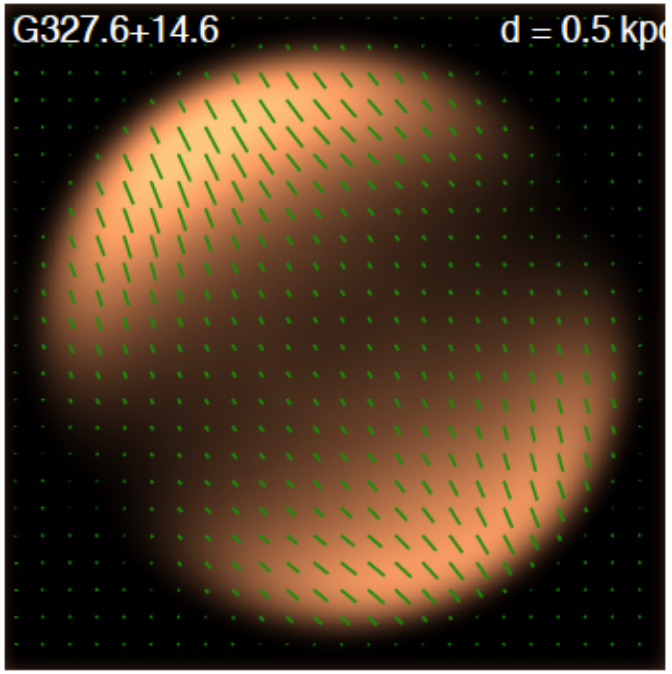
Where: ϕ_{Bn2} is the angle between the shock normal and the post-shock magnetic field



Reynoso et al. 2013



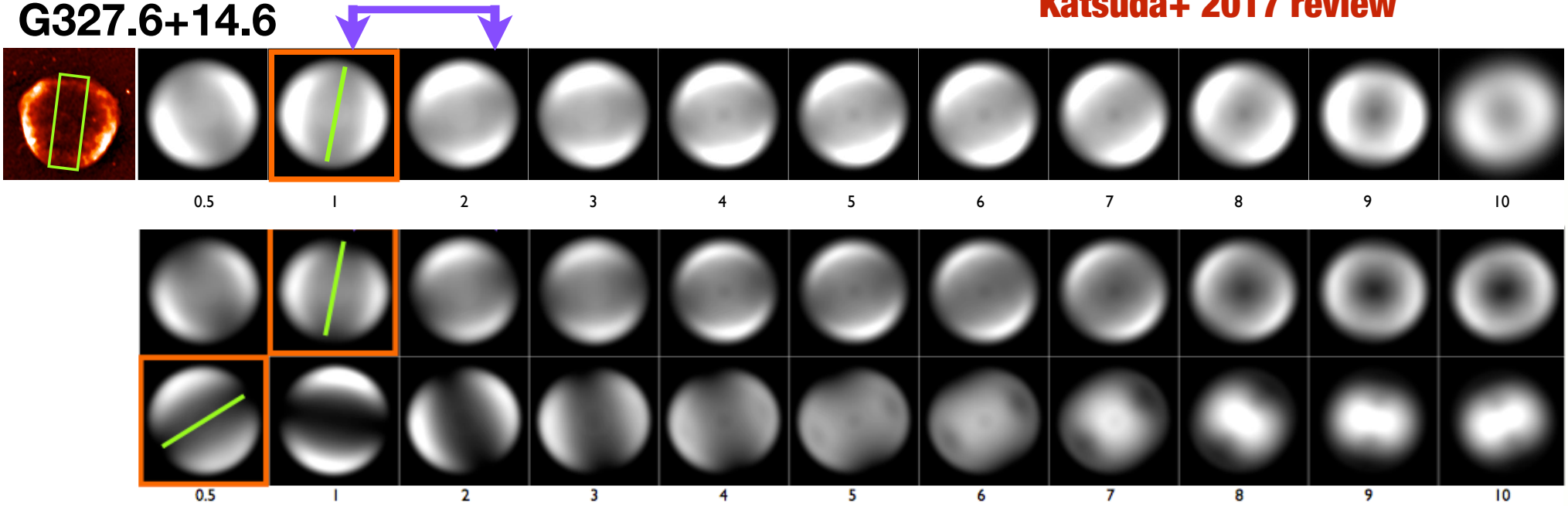
Quasi-perpendicular

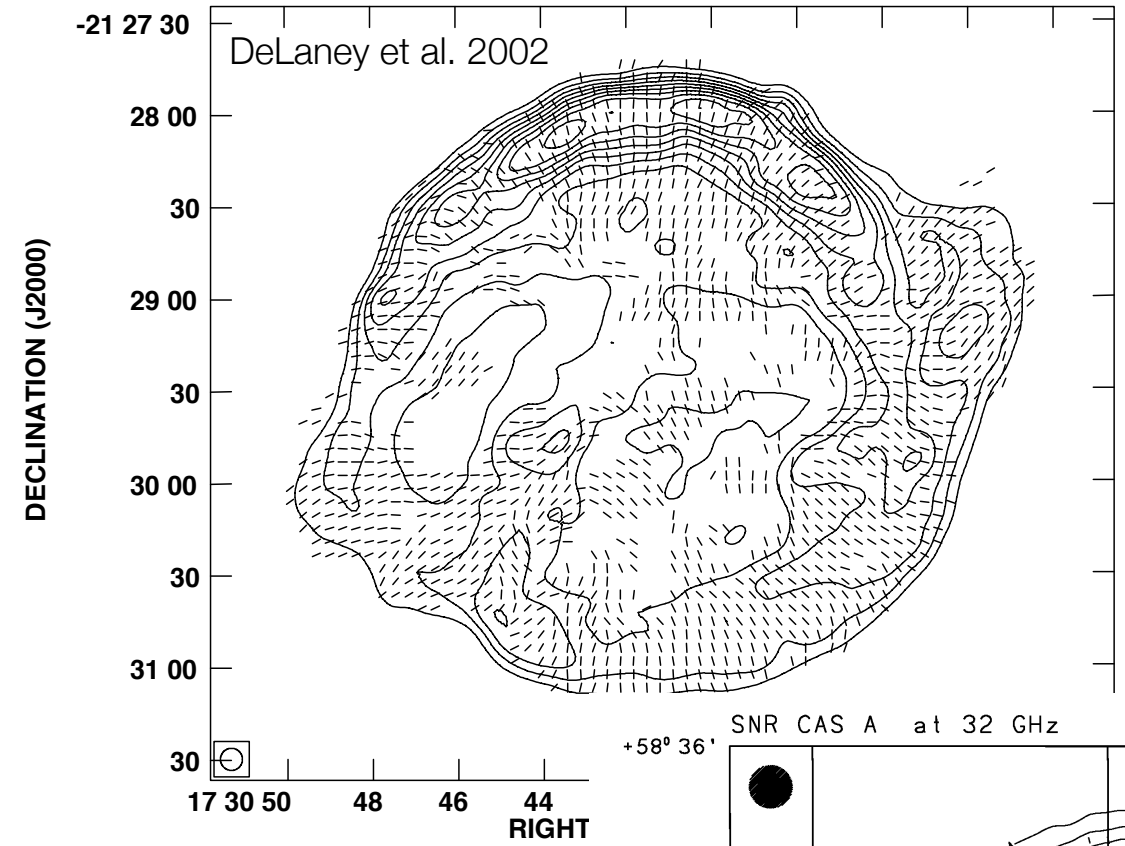


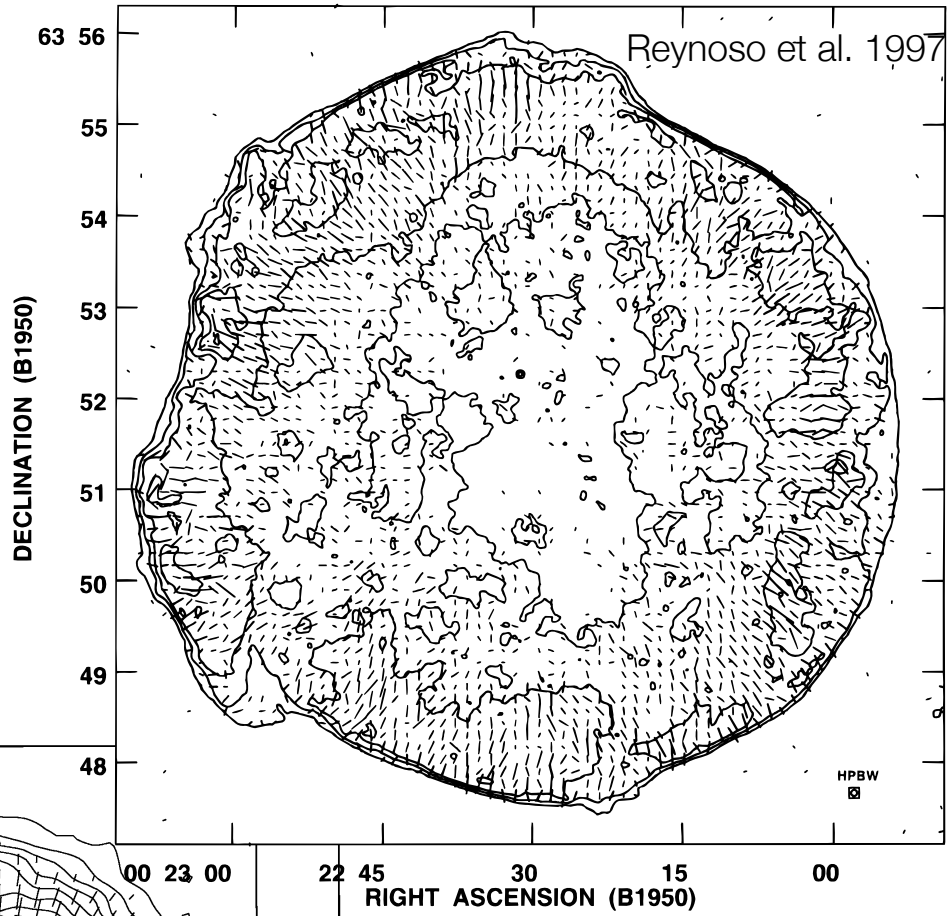
Quasi-parallel

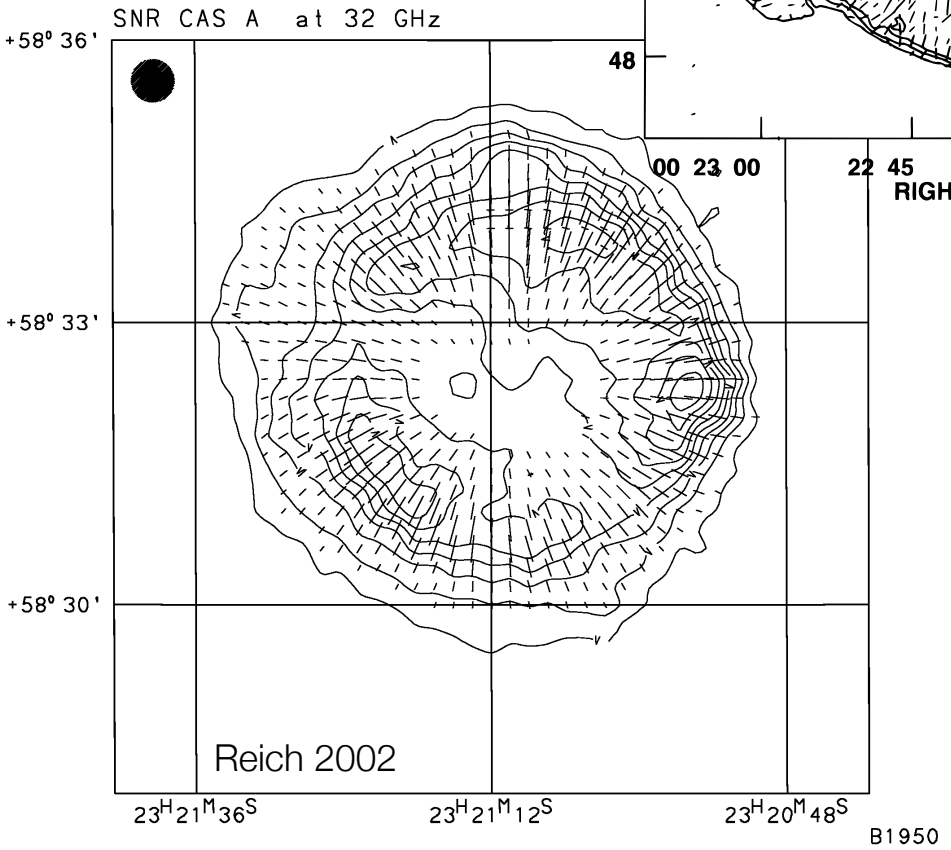
Current favoured model of SN1006
Katsuda+ 2017 review

G327.6+14.6









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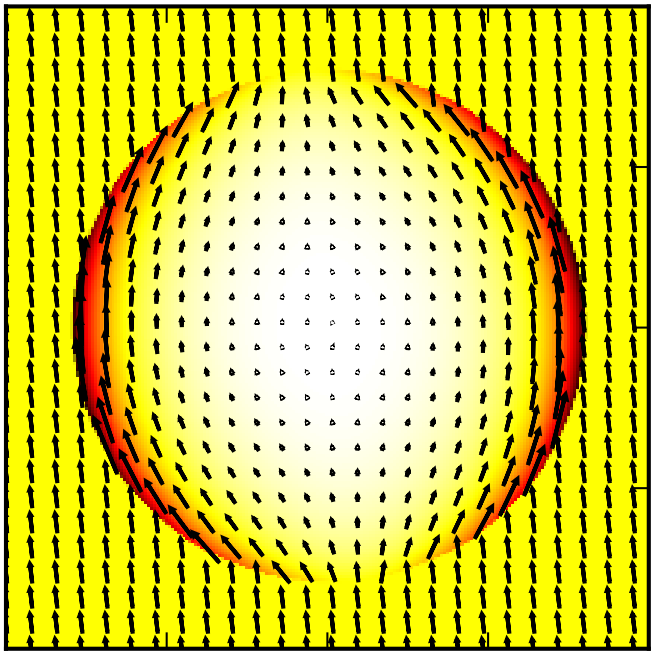
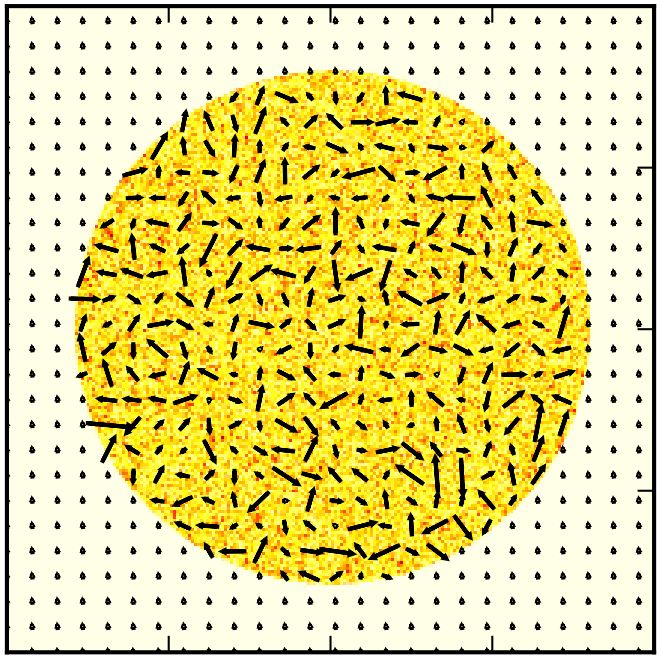
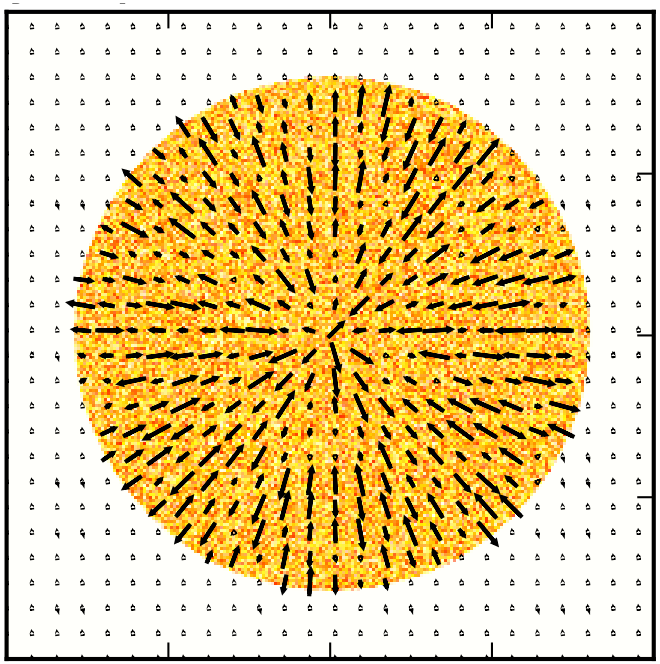


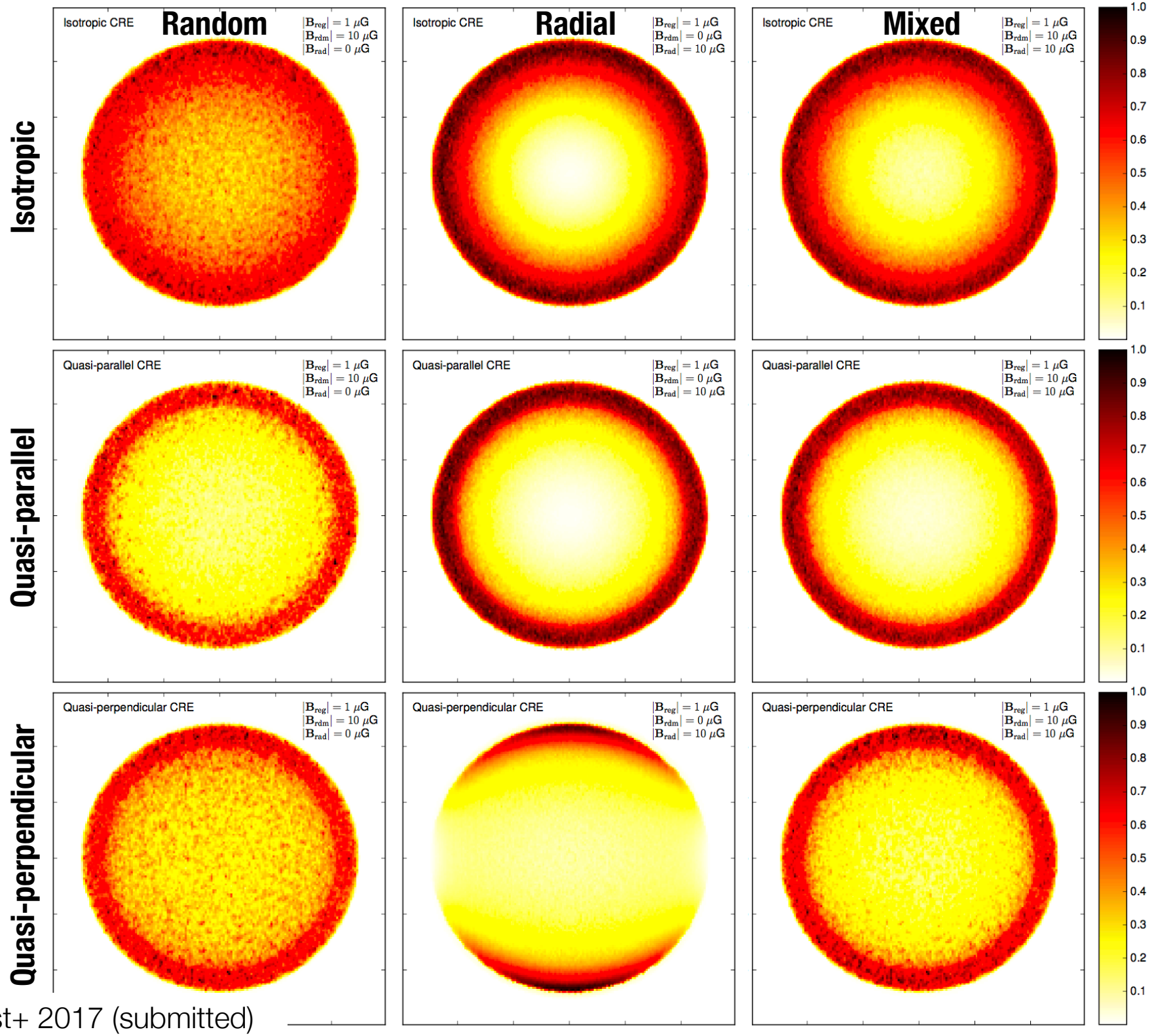
Regular component



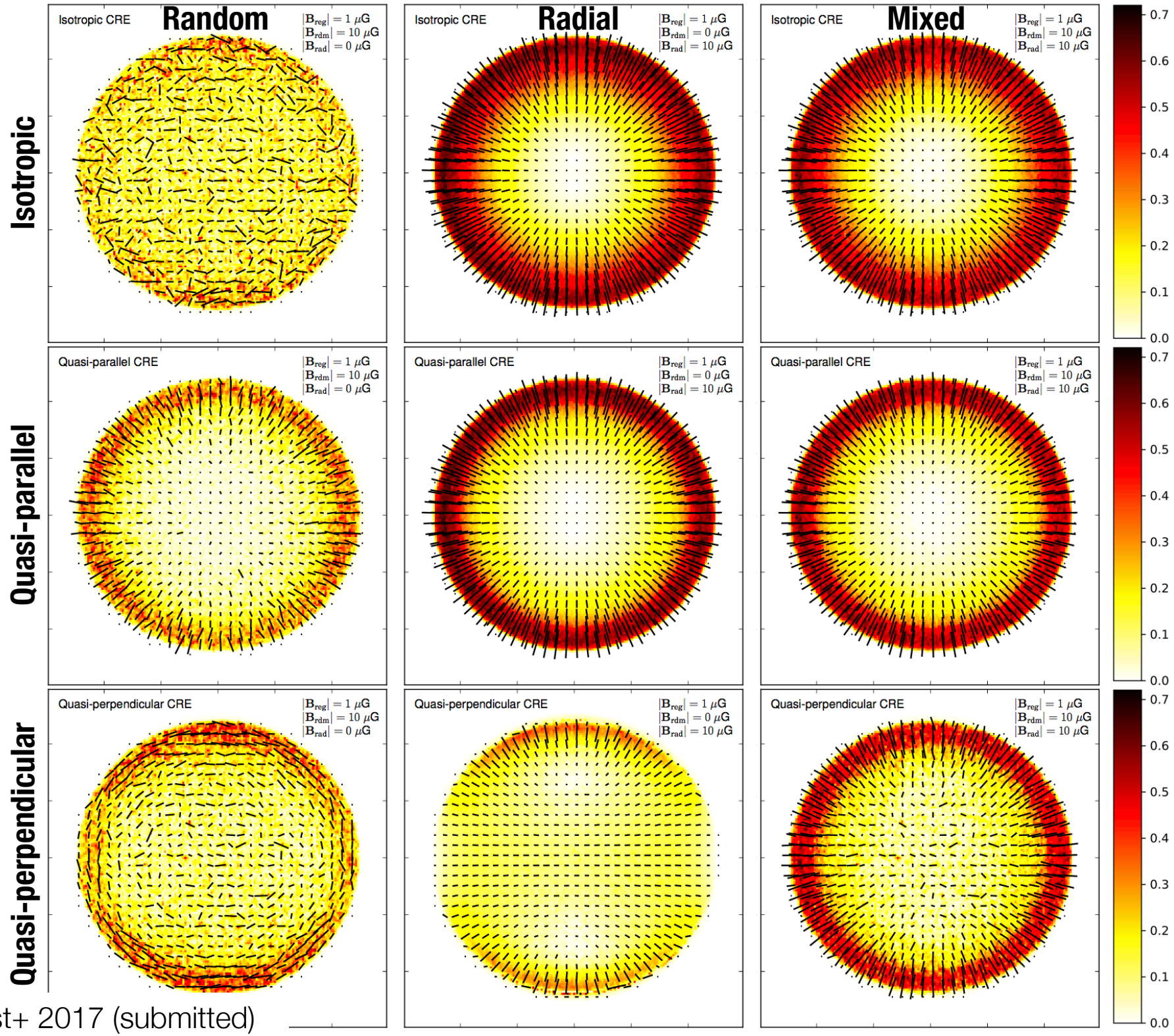
Random component



Radial component



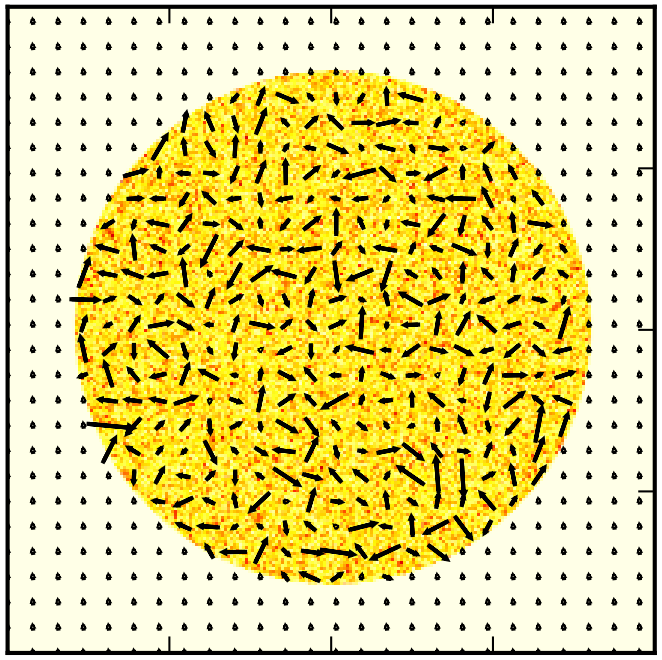
West+ 2017 (submitted)



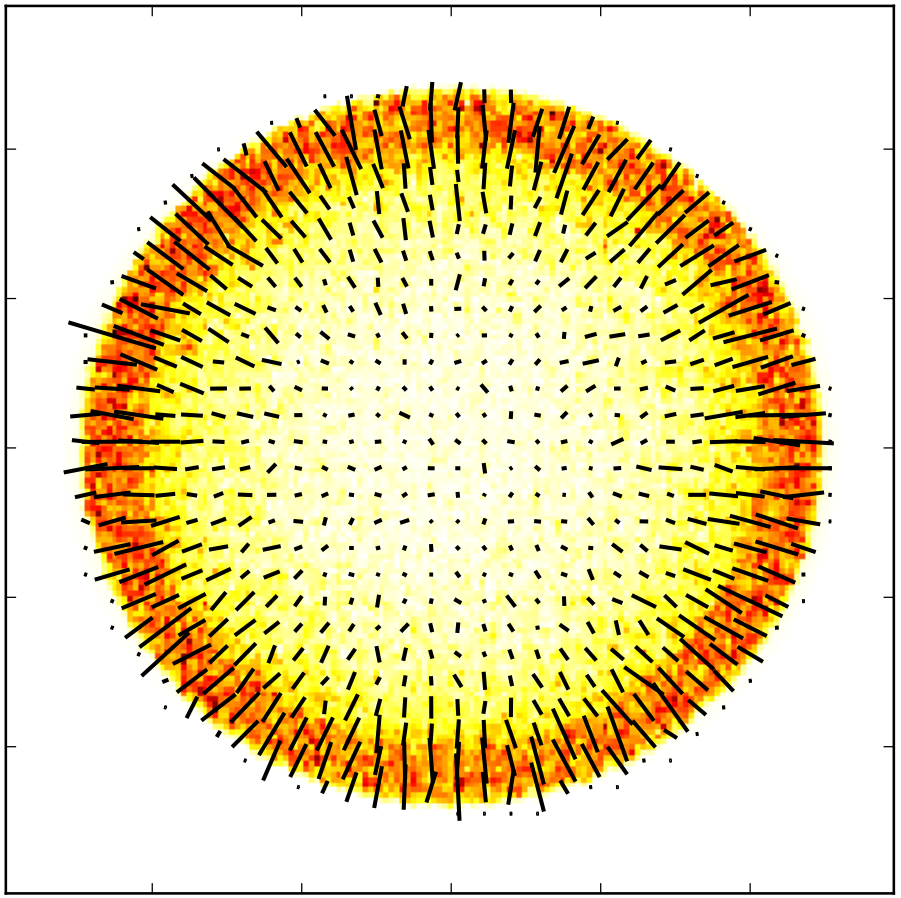
West+ 2017 (submitted)

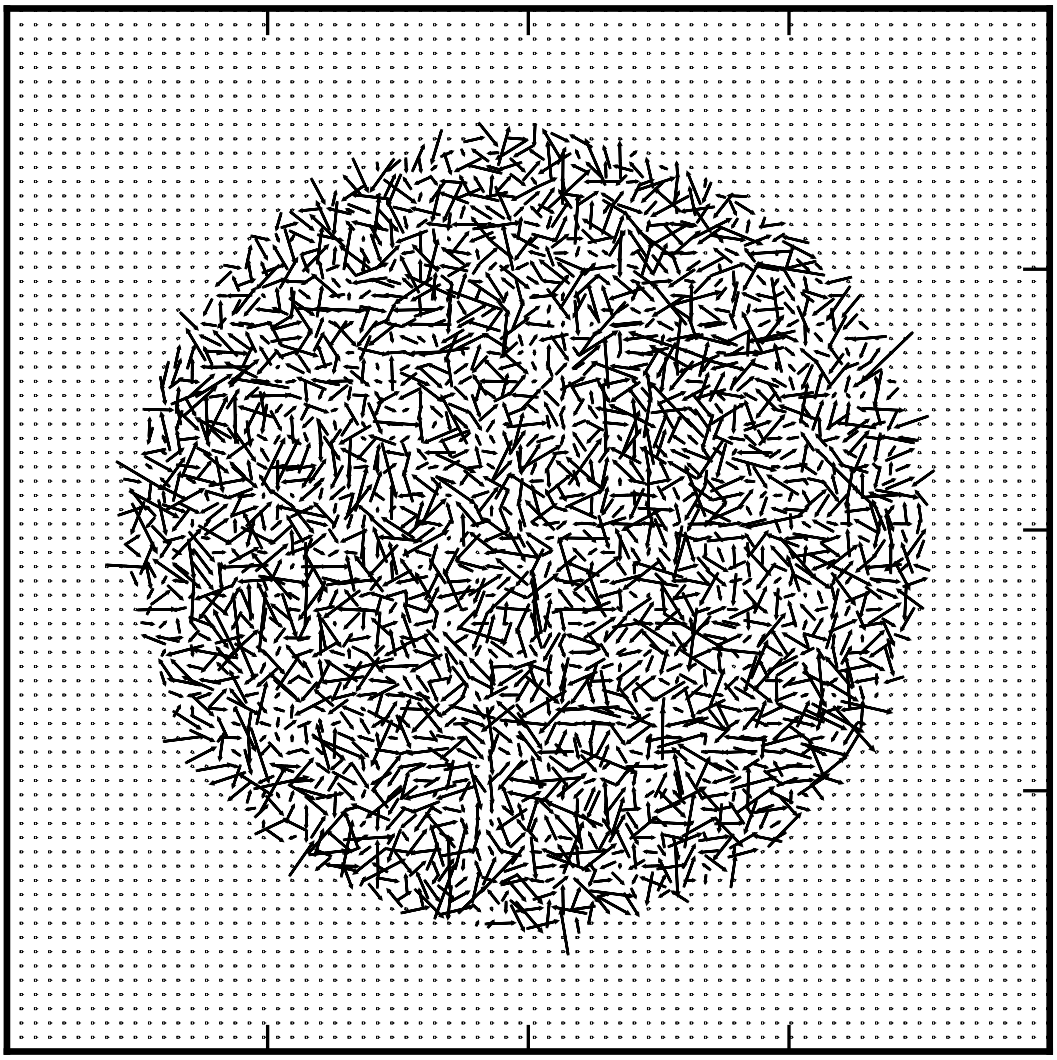
Random magnetic field with quasi-parallel acceleration

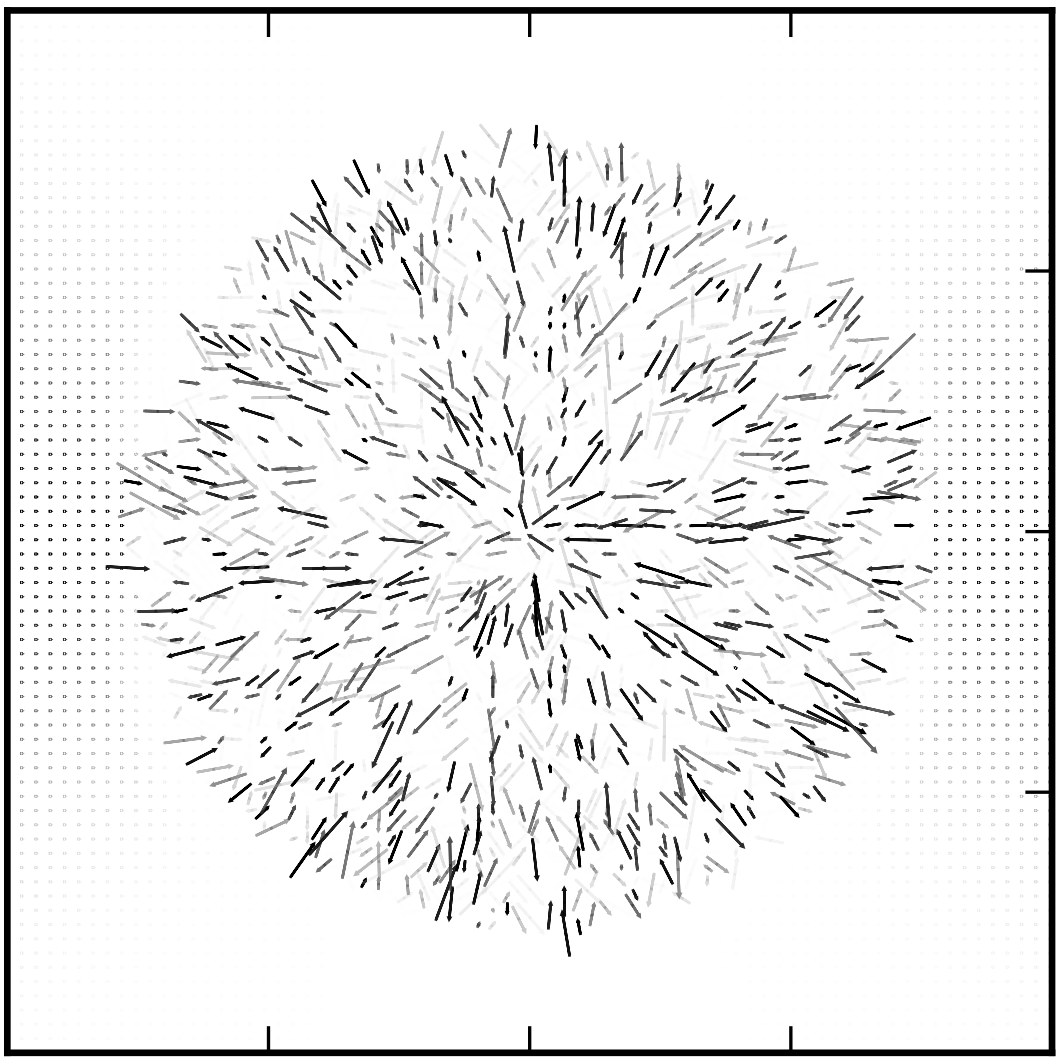
Input magnetic field



Simulated observation







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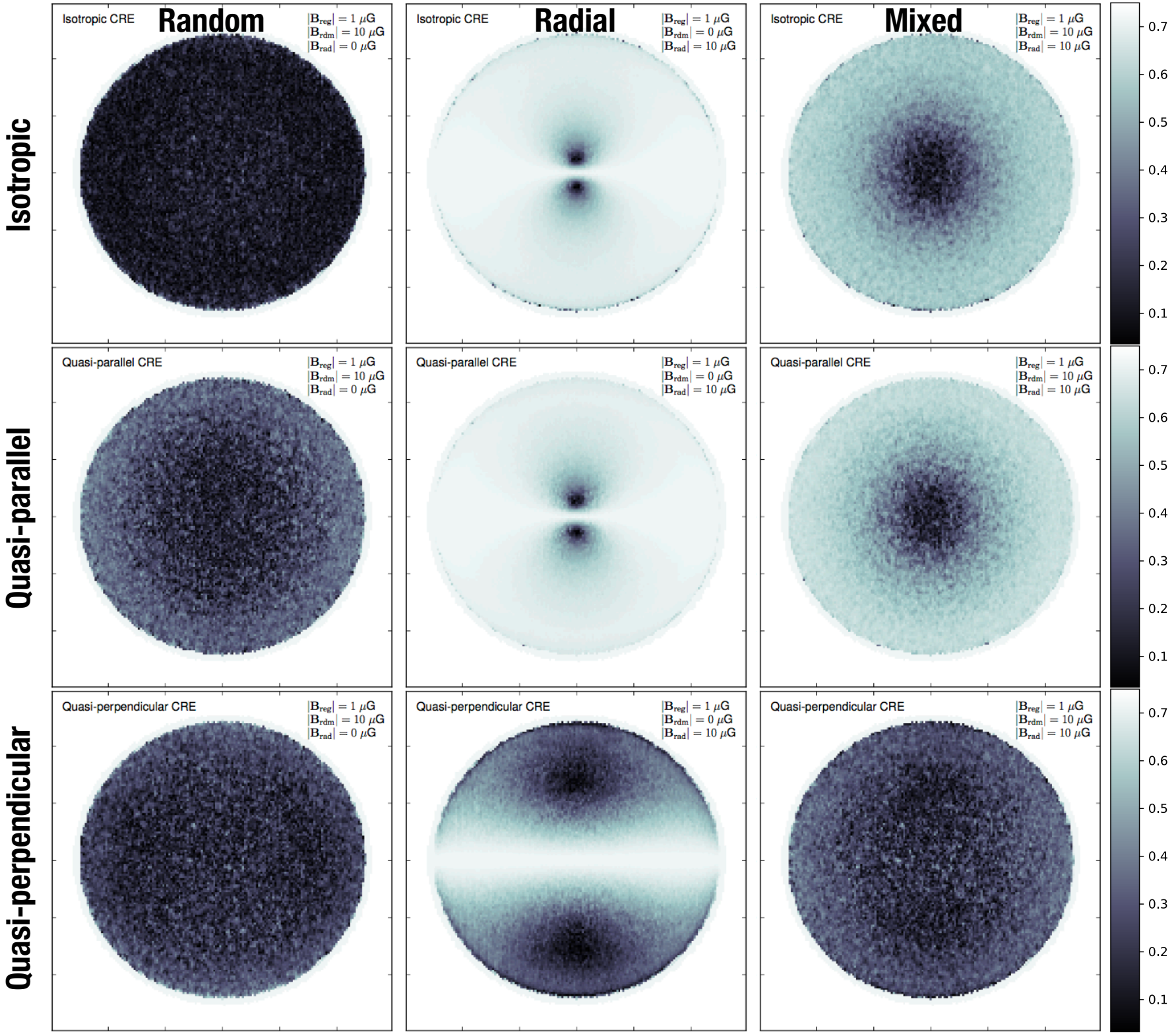
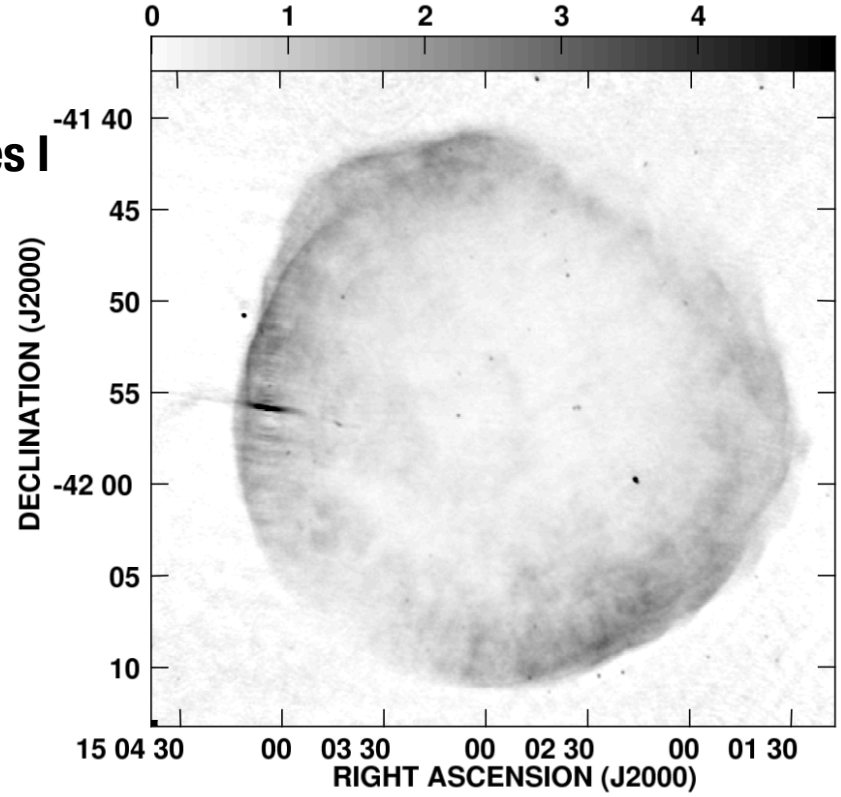
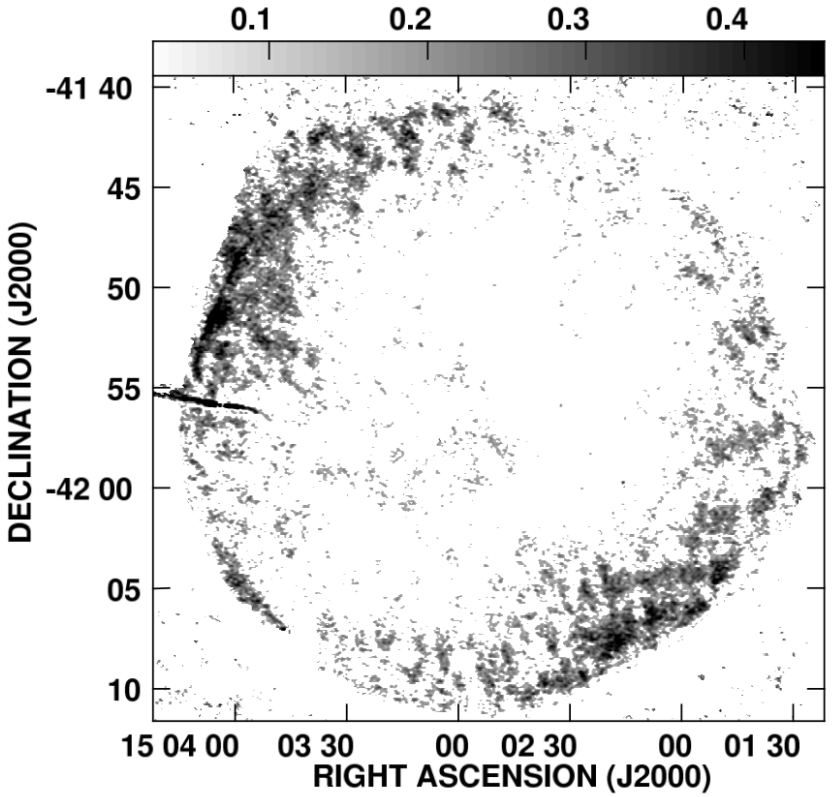

Random
Radial
Mixed
Isotropic
Quasi-parallel
Quasi-perpendicular
Isotropic CRE
Quasi-parallel CRE
Quasi-perpendicular CRE
$|\mathbf{B}_{\rm reg}| = 1\ \mu$G
$|\mathbf{B}_{\rm rdm}| = 10\ \mu$G
$|\mathbf{B}_{\rm rad}| = 0\ \mu$G
$|\mathbf{B}_{\rm rdm}| = 0\ \mu$G
$|\mathbf{B}_{\rm rad}| = 10\ \mu$G
0.7
0.6
0.5
0.4
0.3
0.2
0.1

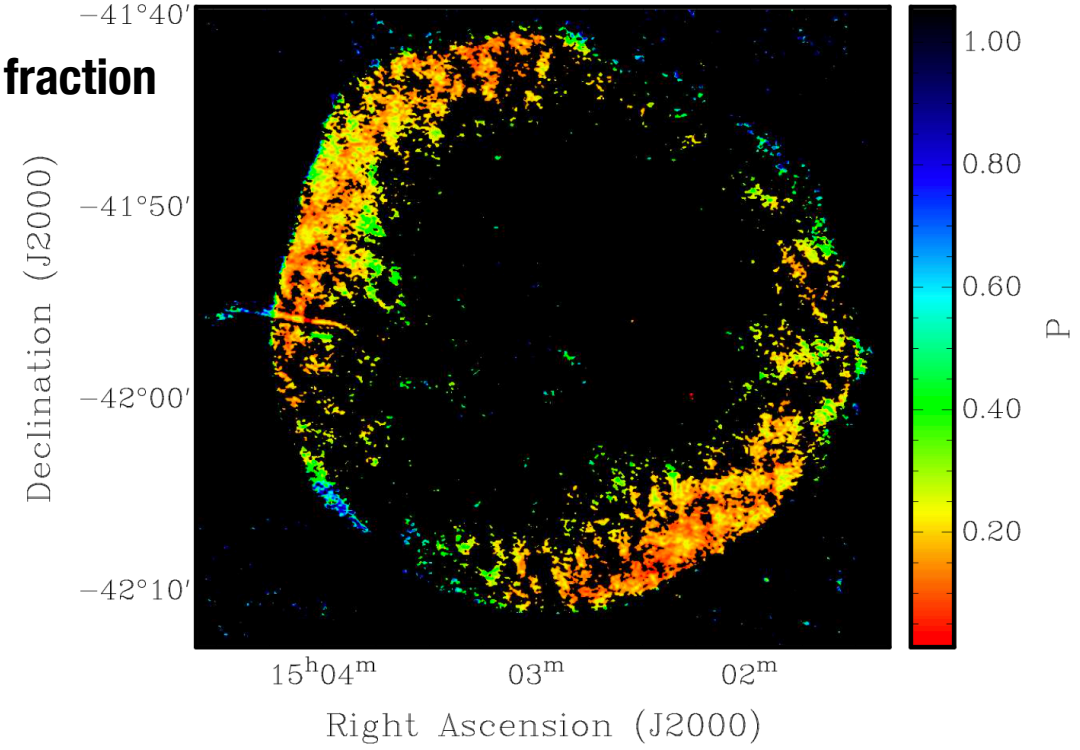
Stokes I



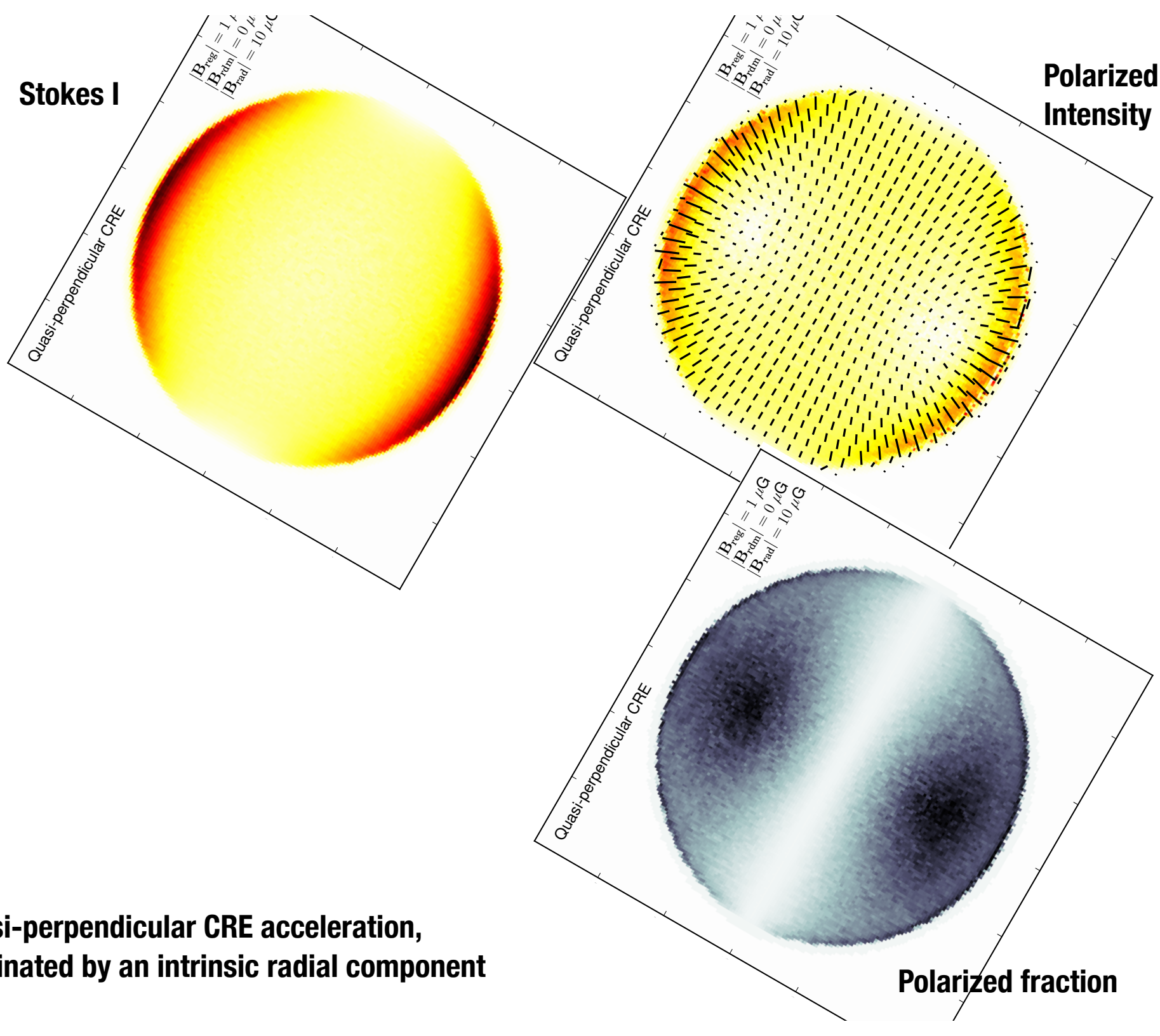
Polarized Intensity



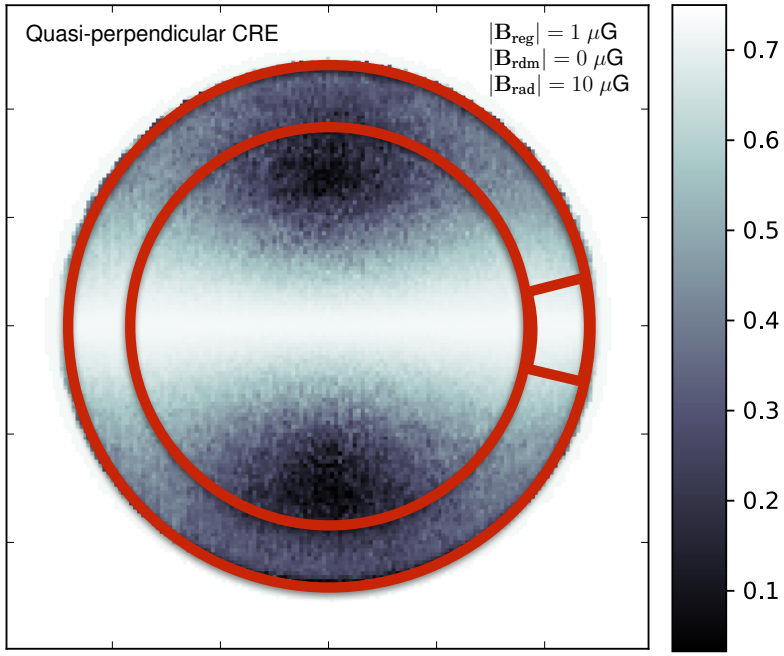
Polarized fraction

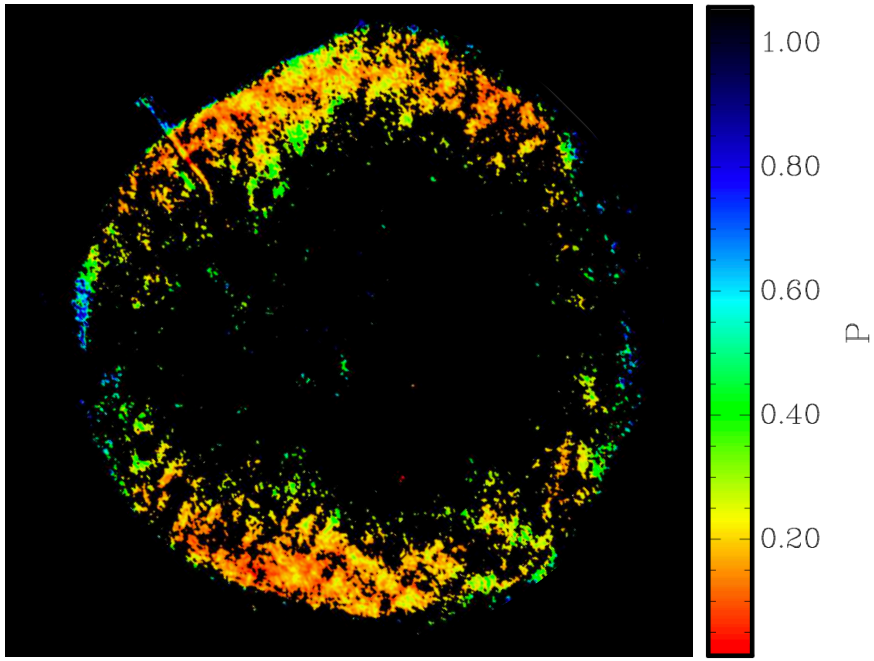


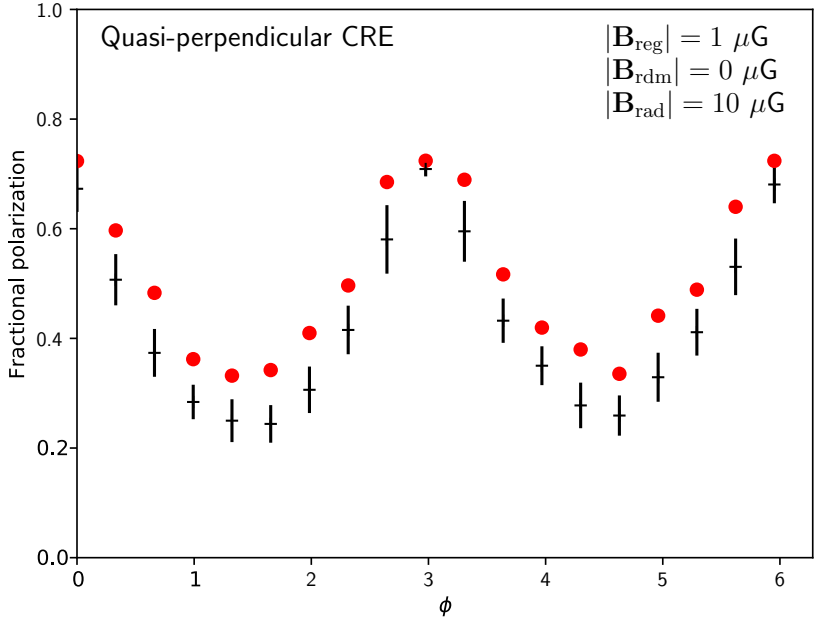
Reynoso+ 2013

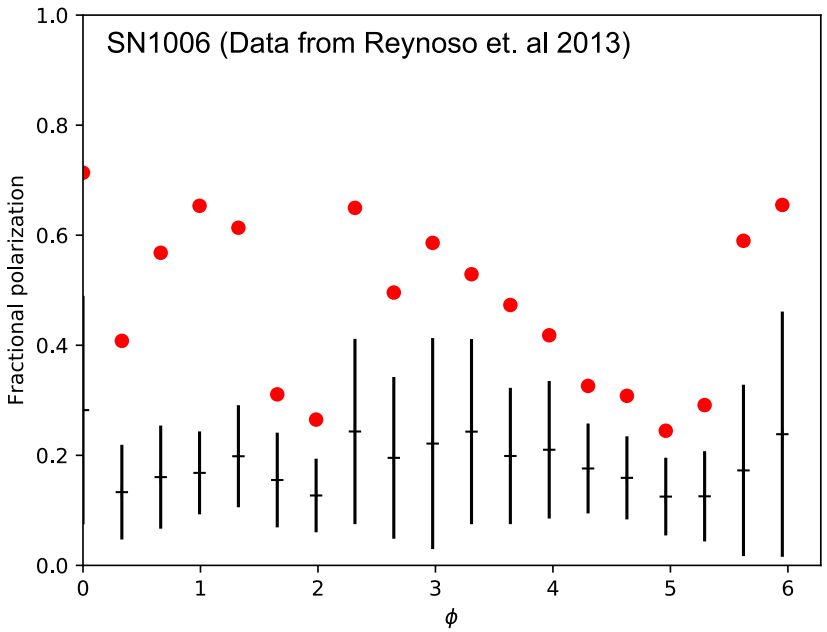


Quasi-perpendicular CRE acceleration, dominated by an intrinsic radial component

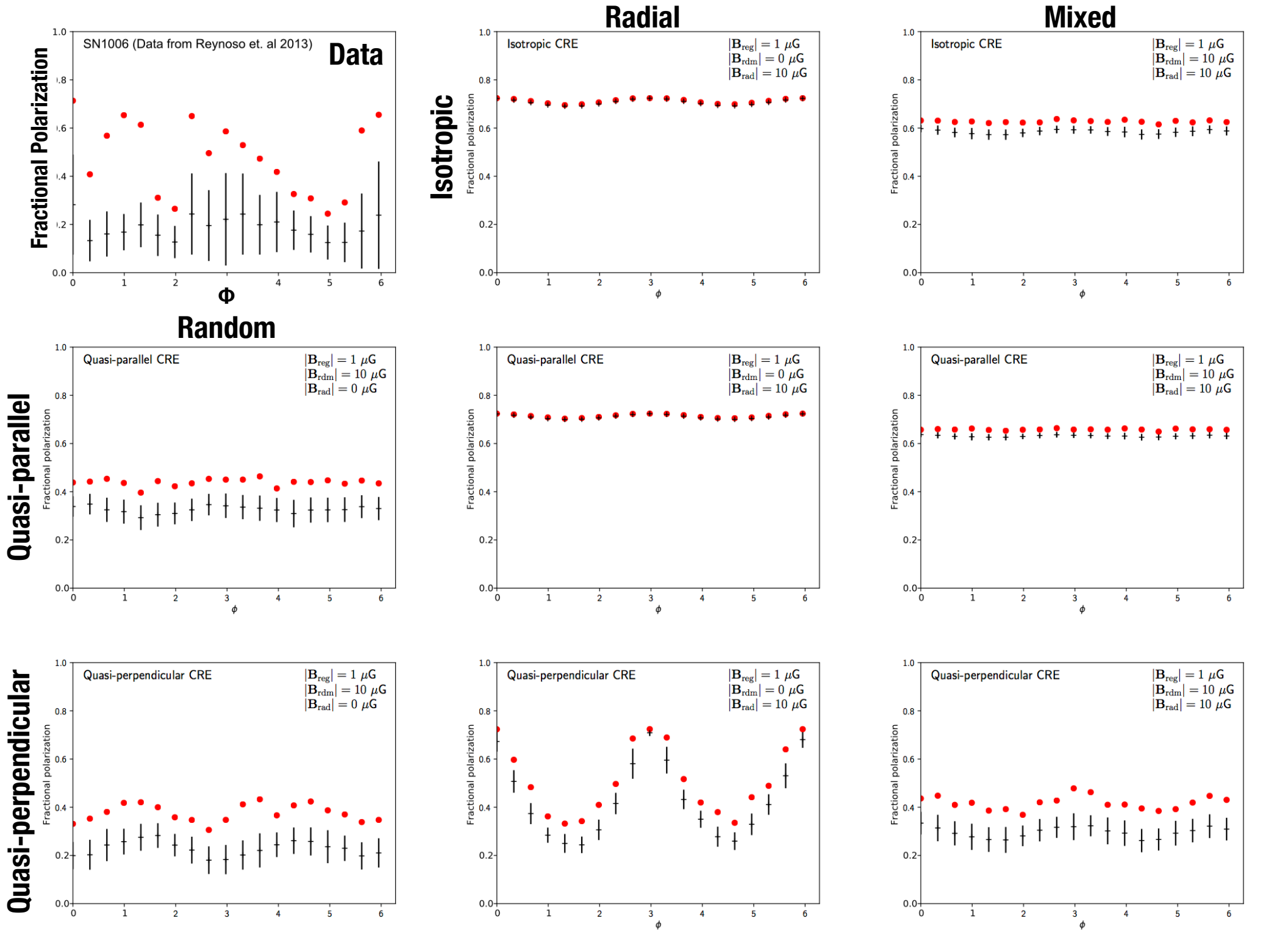








West+ 2017 (submitted)



West+ 2017 (submitted)

Conclusions

1. Supports a simple compressed magnetic field model in **evolved**, bilateral supernova remnants

2. Supports a connection between Galactic interstellar medium and supernova remnant morphology

3. Possible distance determination method: both for supernova remnants and possibly for some features in the Galactic magnetic field

4. Possible selection effect due to cosmic ray distribution: quasi-parallel acceleration can make a turbulent field look radial

5. Intrinsic radial component in young SNRs?

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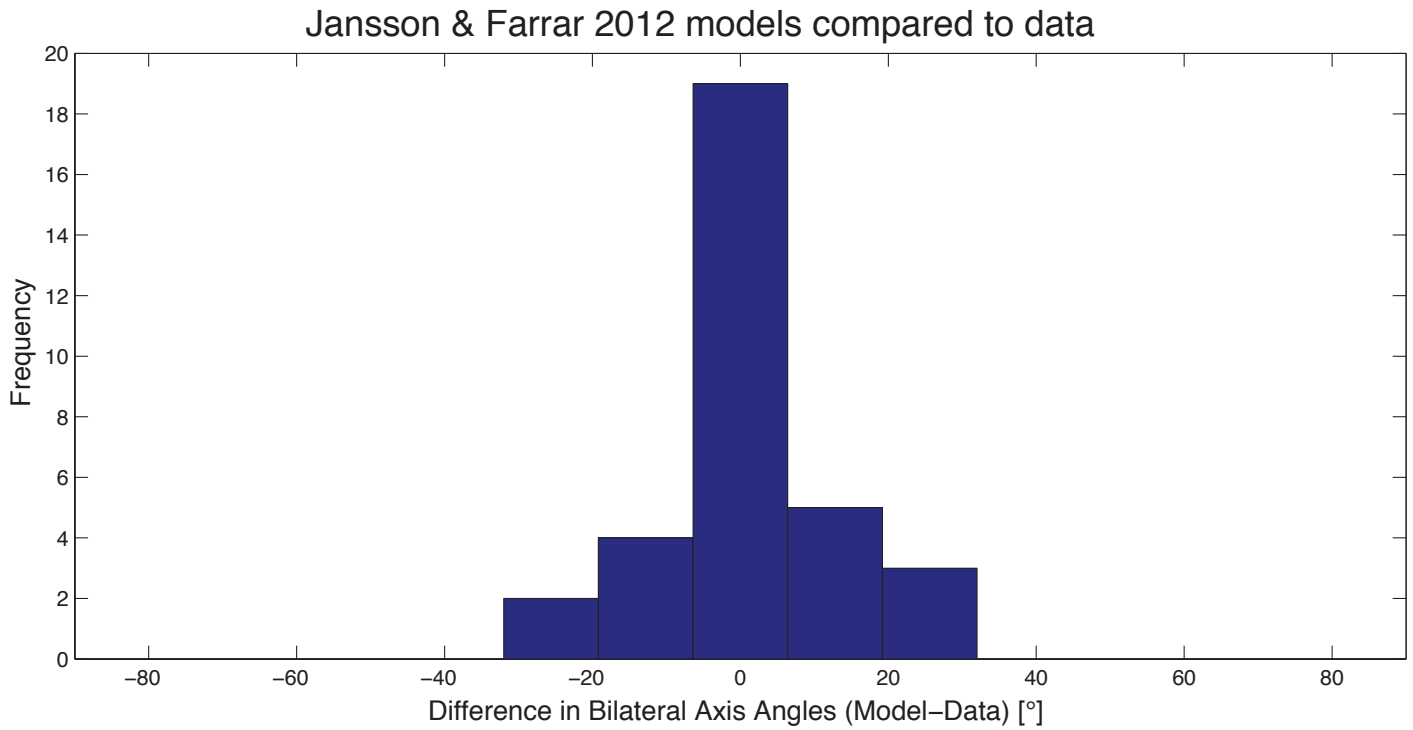
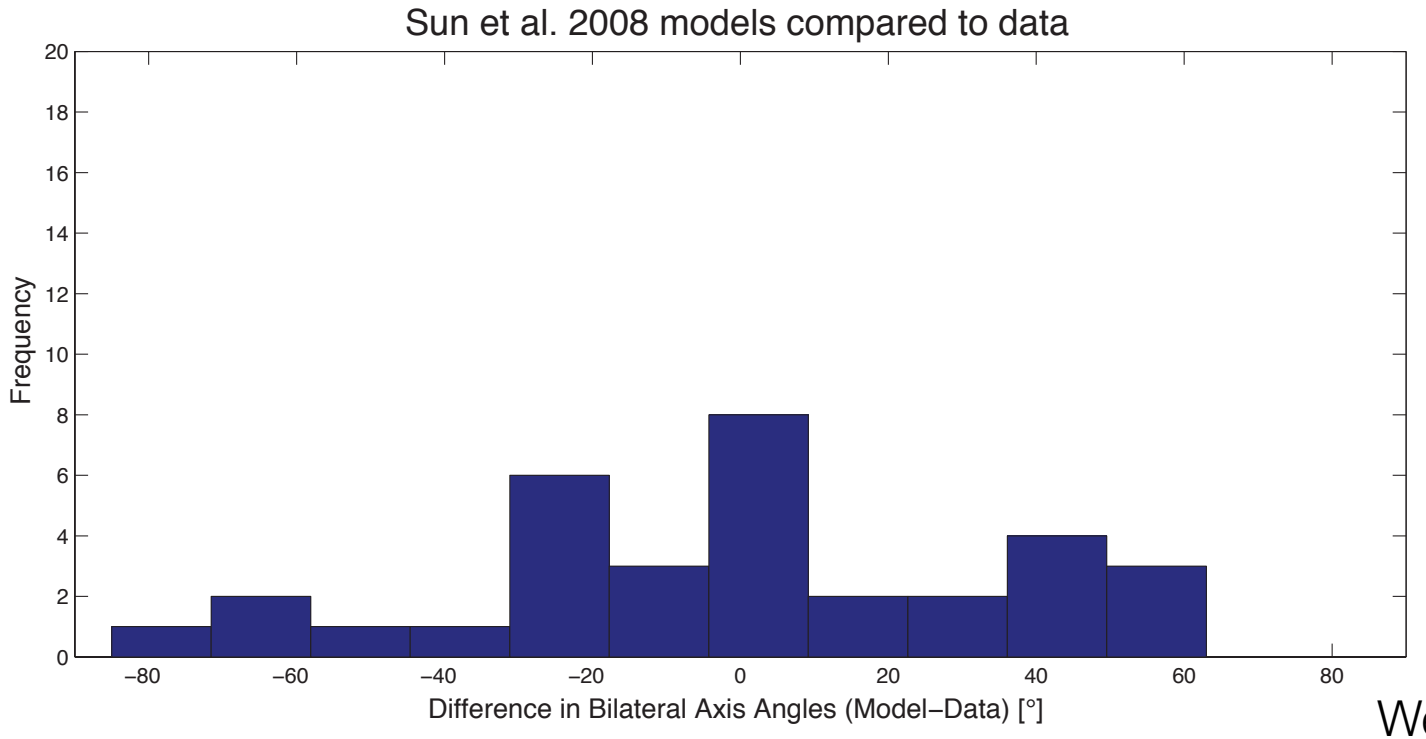


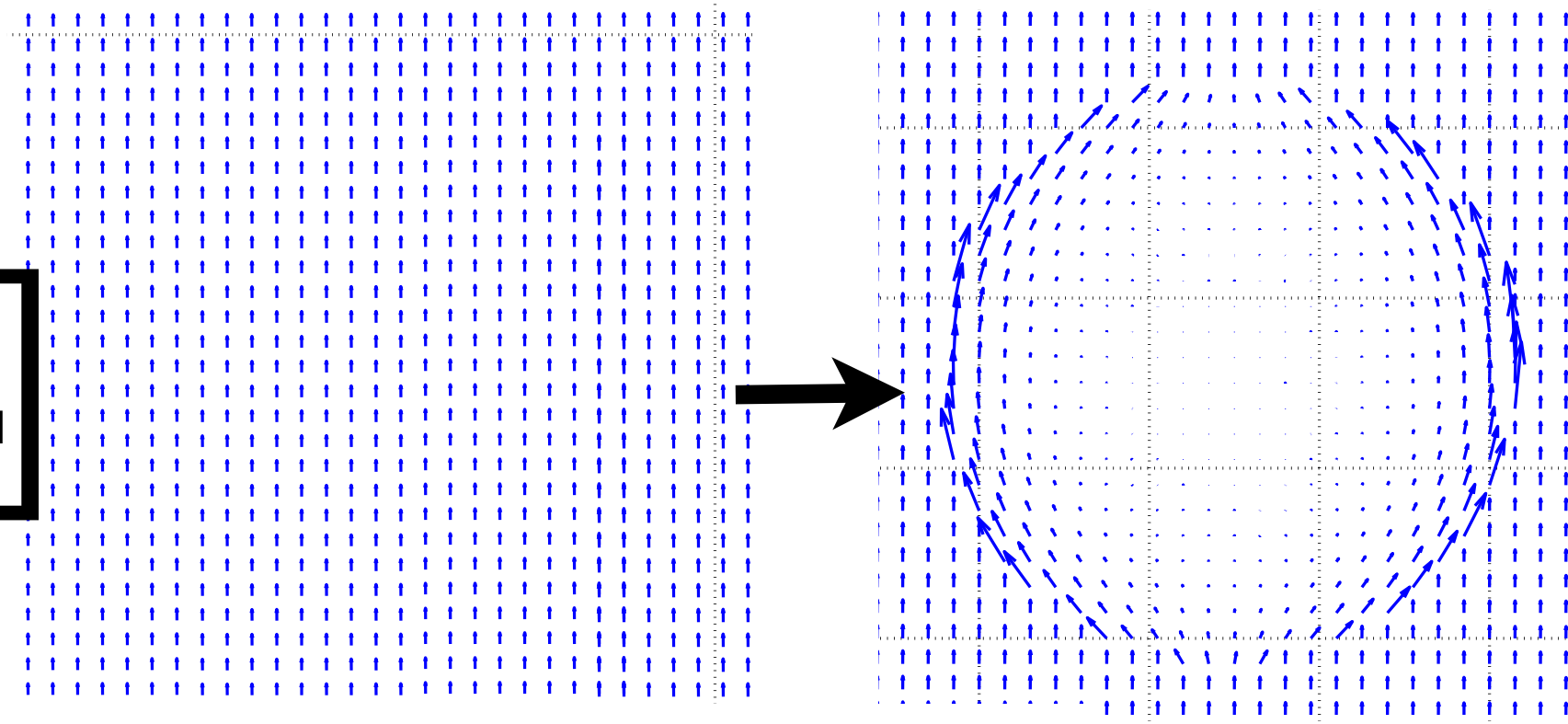
Galactic magnetic field model with an **X-shaped halo component**



Galactic Field model with **no vertical component** (toroidal halo component only)

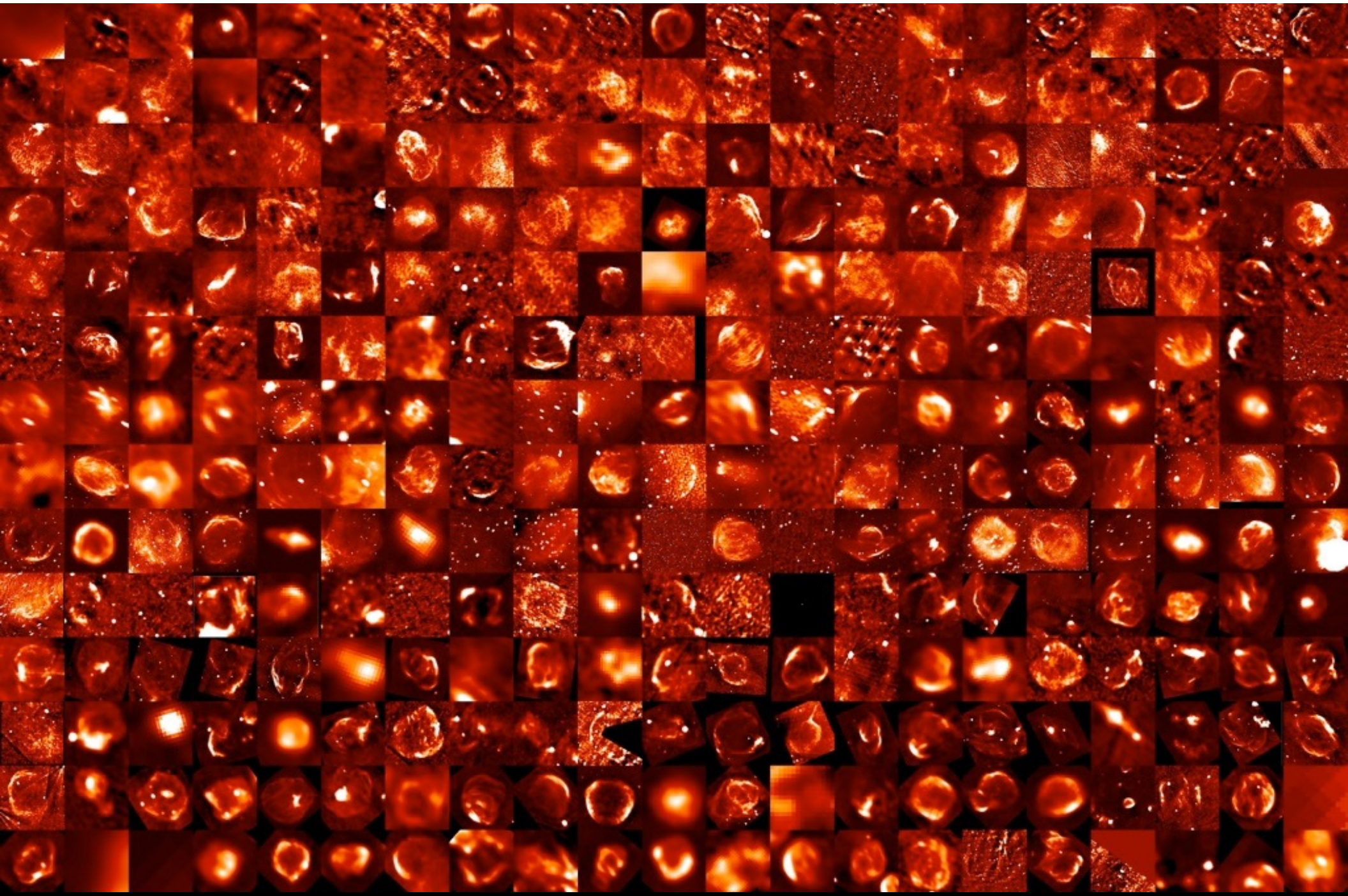
West et al. 2016

Use the Coordinate Transformation to Transform the Magnetic Field in 3D



$$\frac{1}{\det \mathbf{J}} \begin{bmatrix} \frac{\partial x'}{\partial x} & \frac{\partial x'}{\partial y} & \frac{\partial x'}{\partial z} \\ \frac{\partial y'}{\partial x} & \frac{\partial y'}{\partial y} & \frac{\partial y'}{\partial z} \\ \frac{\partial z'}{\partial x} & \frac{\partial z'}{\partial y} & \frac{\partial z'}{\partial z} \end{bmatrix} \begin{bmatrix} B_x \\ B_y \\ B_z \end{bmatrix} = \begin{bmatrix} B_x{}' \\ B_y{}' \\ B_z{}' \end{bmatrix}$$

Franzmann et. al 2014



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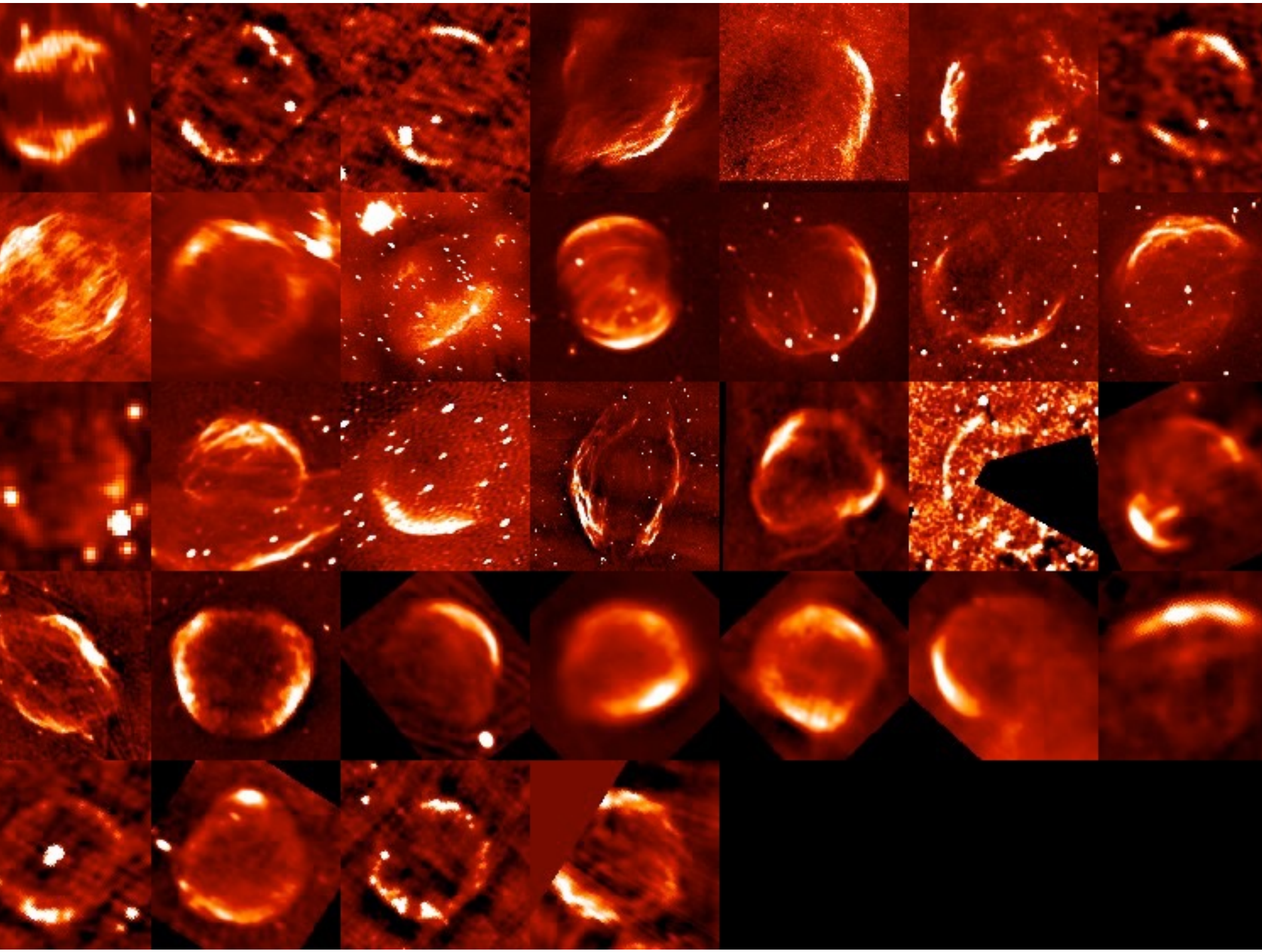
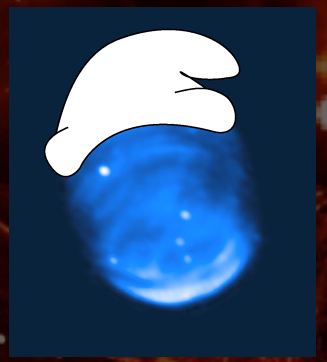


Supernova remnant Models & Images at Radio Frequencies (SMIRF)

http://www.physics.umanitoba.ca/snr/smirf/



West et al. 2016, A&A
West et al. 2017, A&A
West et al. 2017 in prep