Image composed by Jörg P. Rachen for ISSI International Team 323, Bern 2014/15, http://www.issibern.ch/teams/bayesianmodel/

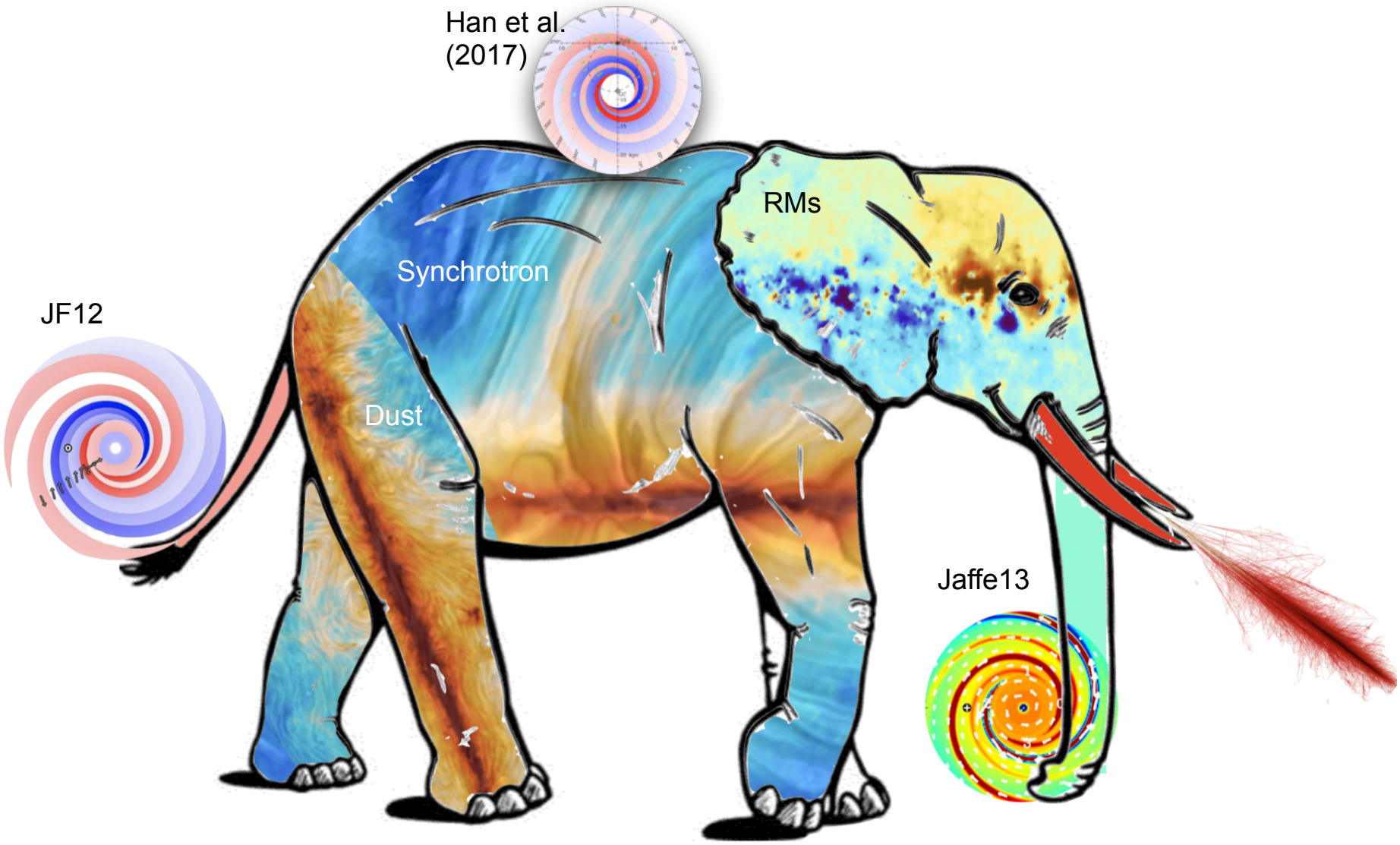
IMAGINE:
the Interstellar MAGnetic field INference Engine

https://arxiv.org/abs/1805.02496

Co-PIs:	François Boulanger	(IAS, Paris)	*Planck*, polarized dust
	Torsten Enßlin	(MPA, Munich)	Information Theory, CR and B-field theory
	Marije Haverkorn	(Radboud U., Nijmegen)	Radio astronomy, B-fields, turbulence
	Jörg Hörandel	(Radboud U., Nijmegen)	CR observations, radio emission
	Tess Jaffe	(NASA/GSFC)	*Planck*, B-field modeling, numerical simulation
	Jens Jasche	(TUM, Munich)	IFT, Bayesian methods, theory
	Jörg Rachen	(Radboud U., Nijmegen)	UHECRs, Bayesian methods
	Anvar Shukurov	(Newcastle U)	Theory of CRs, B-fields, turbulence.

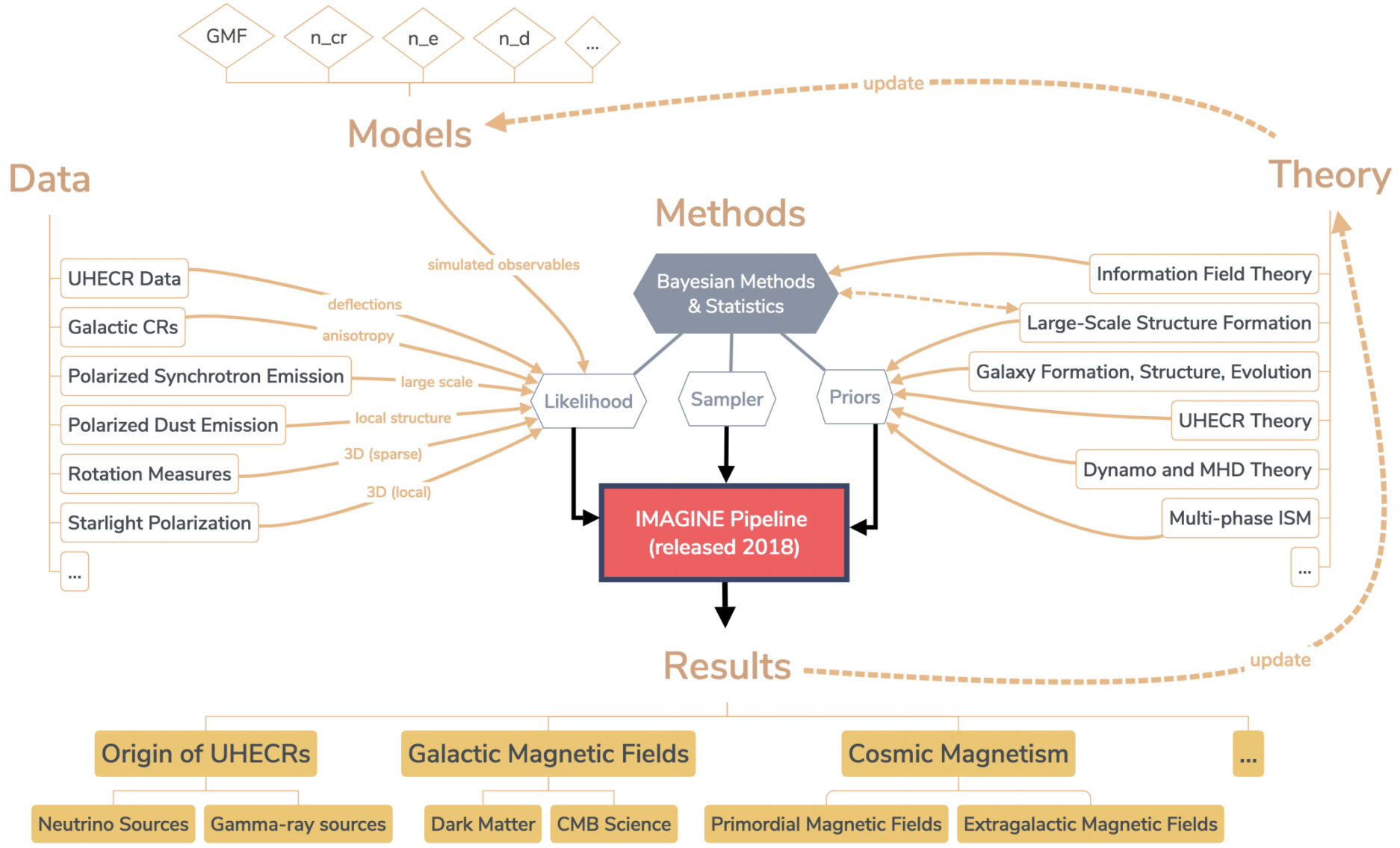
Members: Andrew Fletcher , Philipp Girichides, Michael Kachelreiß, Christoph Pfrommer, Luis Rodrigues, Beatrice Ruiz Granados, Günter Sigl, Theo Steininger, Ajen van Vliet, Jiaxin Wang….

The proverbial elephant

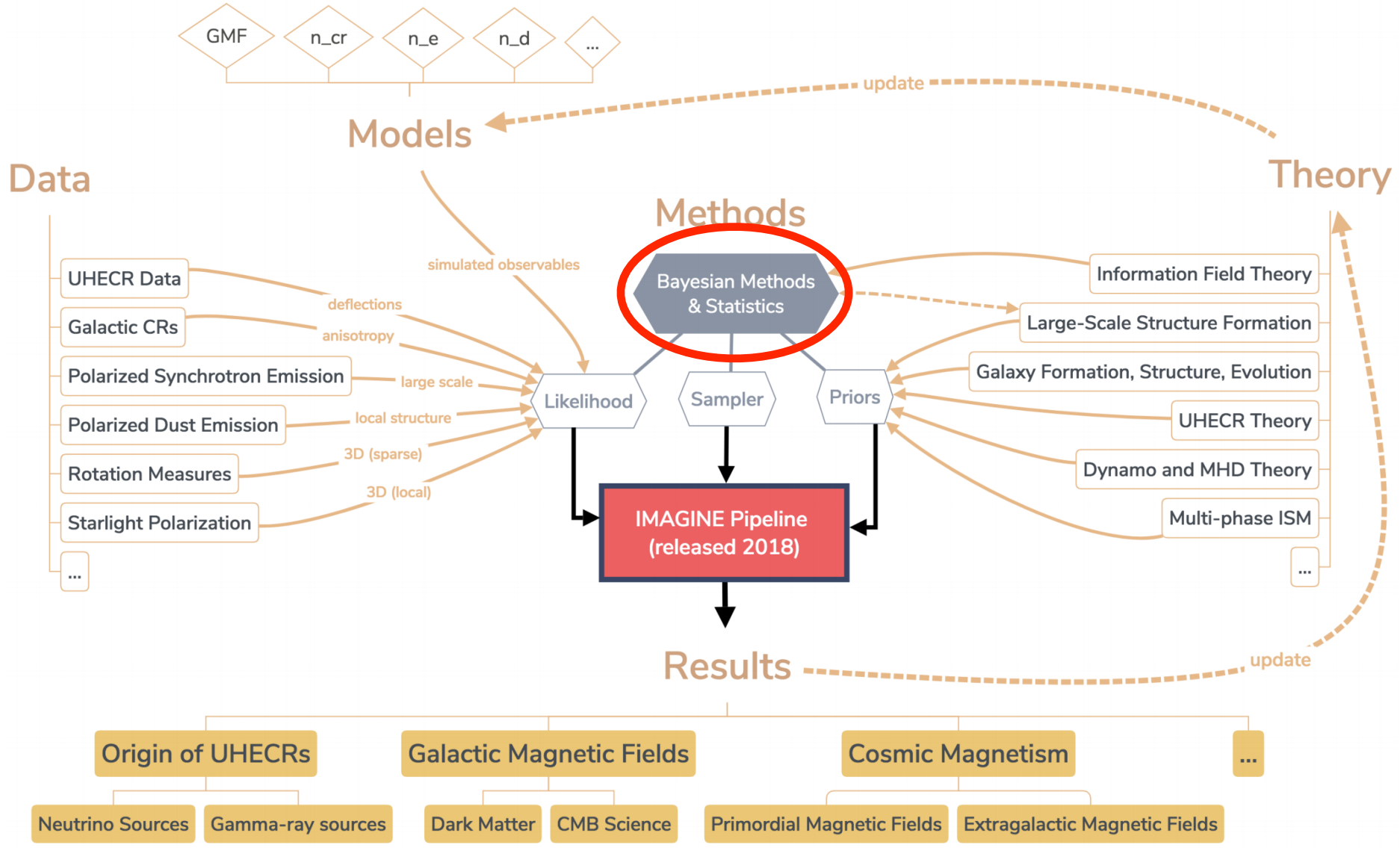


"If we knew the GMF, we could then use X to constrain Y.
Likewise, if we knew Y, we could use X to constrain the GMF."

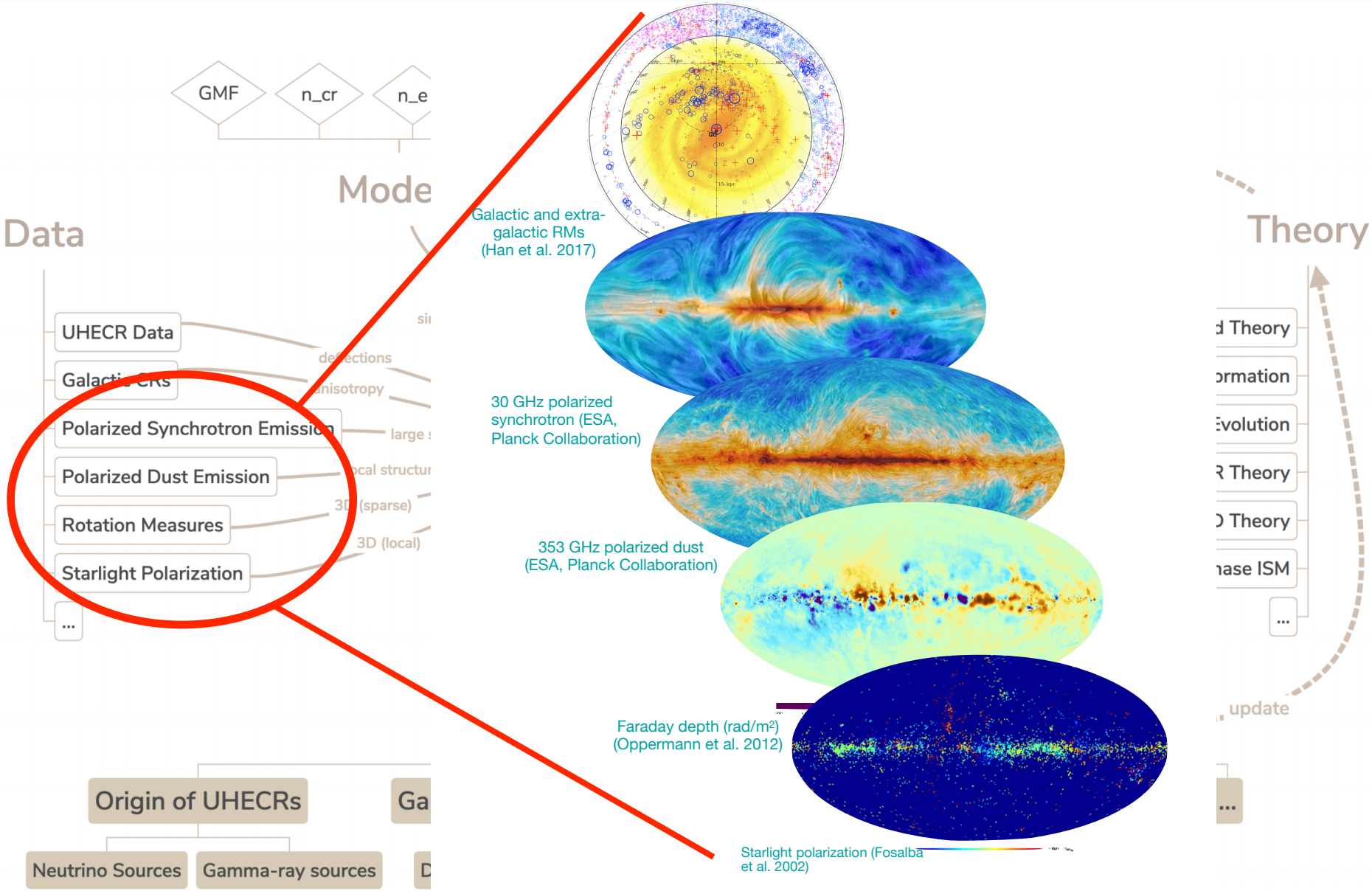
IMAGINE overview



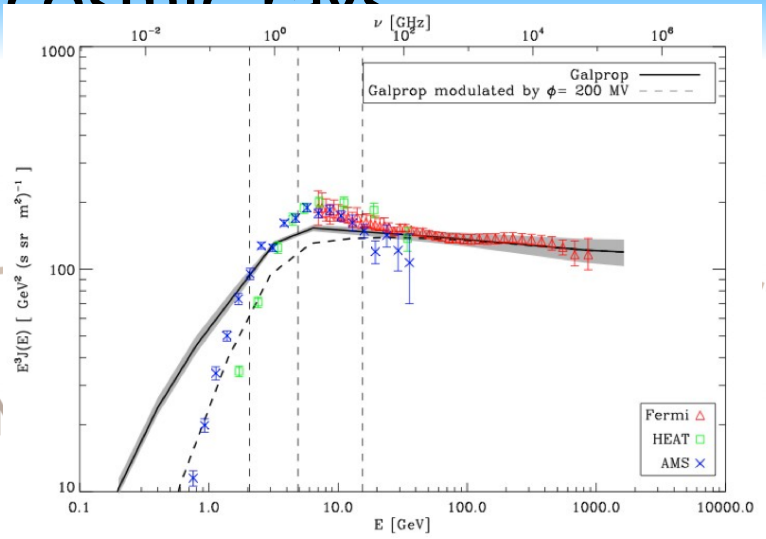
IMAGINE overview



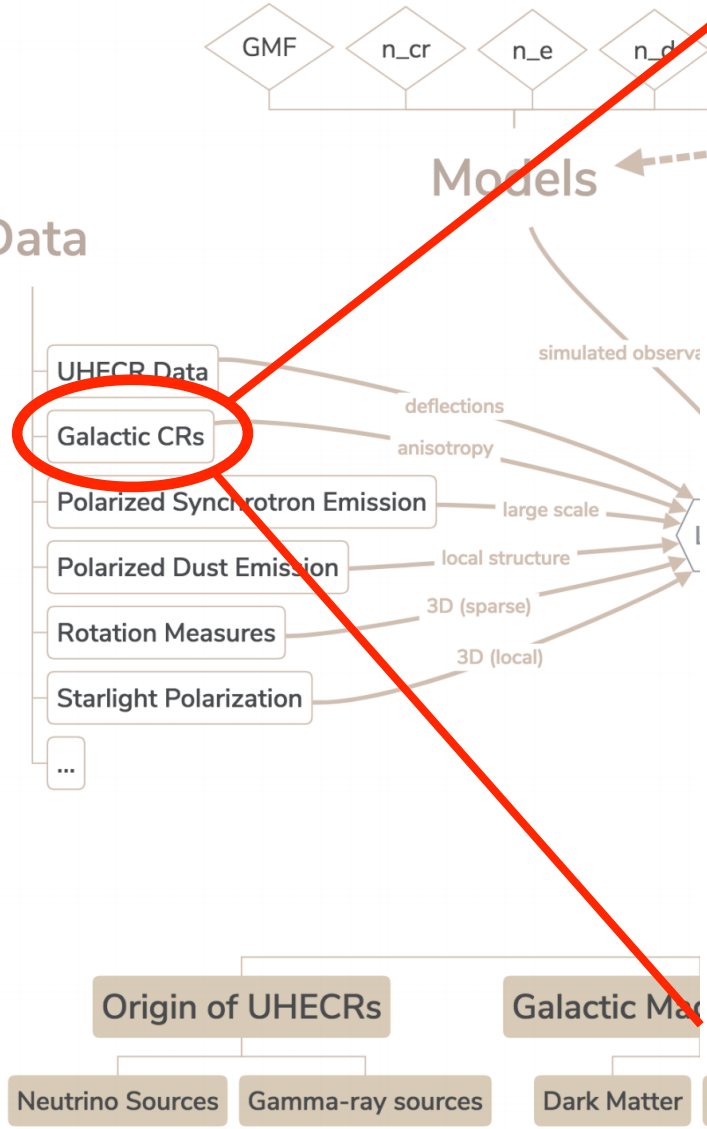
IMAGINE tracers



Galactic cosmic rays



Jaffe et al. (2011)



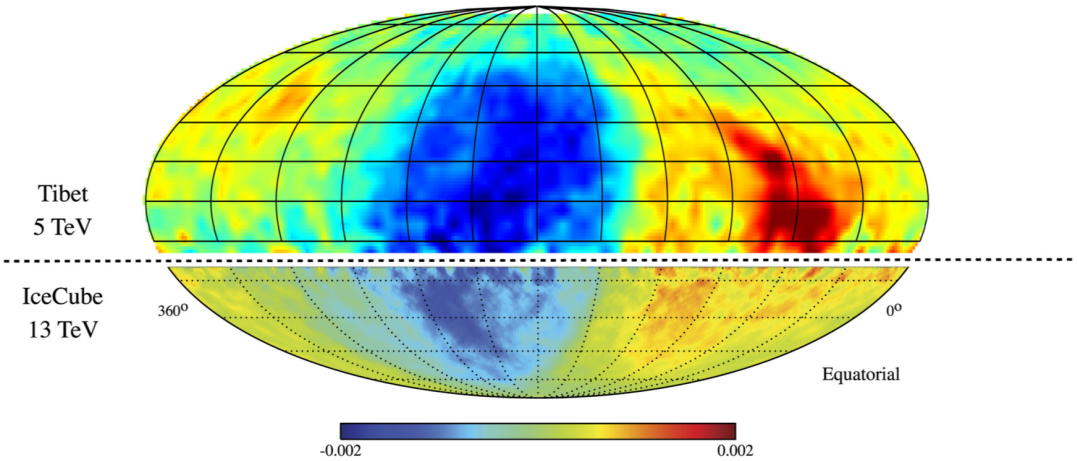


Figure 2. Combined cosmic ray anisotropy of the Tibet-AS and IceCube experiments in the equatorial coordinate system. Image credit and detailed information: M. Ahlers and P. Mertsch [30].

UHECRs

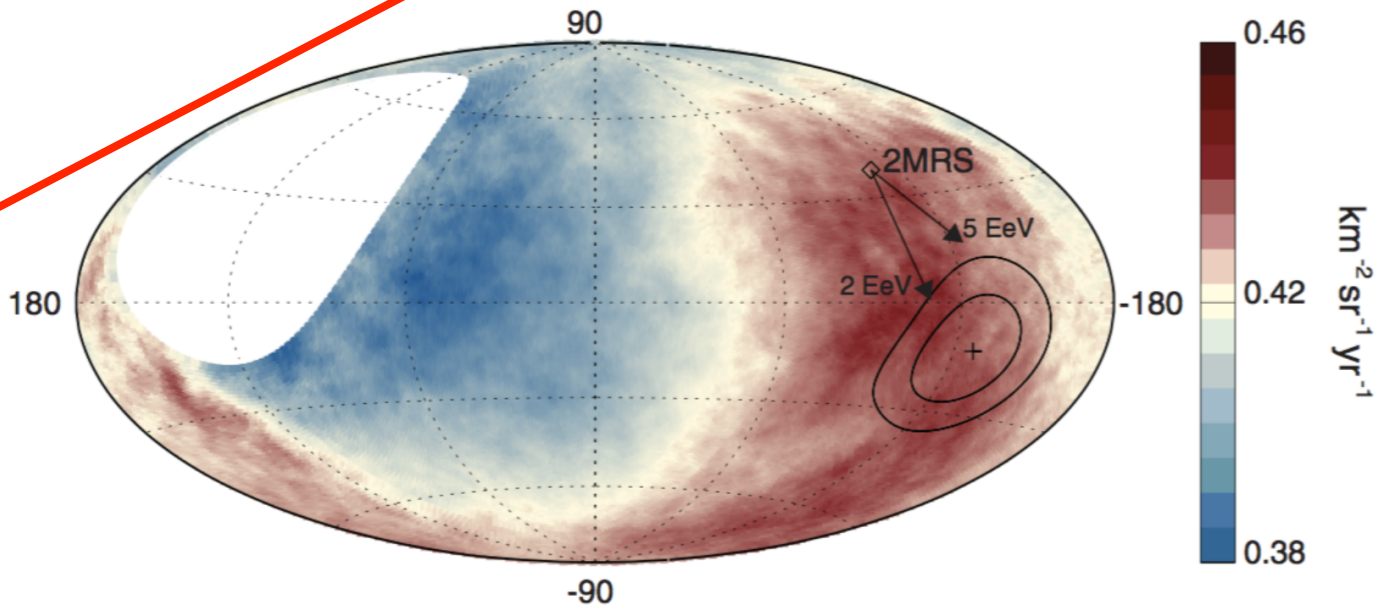


Figure 8. Sky map in galactic coordinates showing the cosmic ray flux as measured by the Pierre Auger Observatory for $E > 8$ EeV smoothed with a 45° top-hat function. The Galactic centre is at the origin. The cross indicates the measured dipole direction; the contours denote the 68% and 95% confidence level regions. The dipole in the 2MRS galaxy distribution is indicated. Arrows show the deflections expected for the JF12 GMF model on particles with $E/Z = 2$ or 5 EeV. Image credit: Pierre Auger Collaboration [149].

GMF

Data

UHECR Data

Galactic CRs

Polarized Synchrotro

Polarized Dust Emiss

Rotation Measures

Starlight Polarization

...

Origin of UHECRs

Neutrino Sources

Gamma-ray sources

Galactic Magnetic Fields

Dark Matter

CMB Science

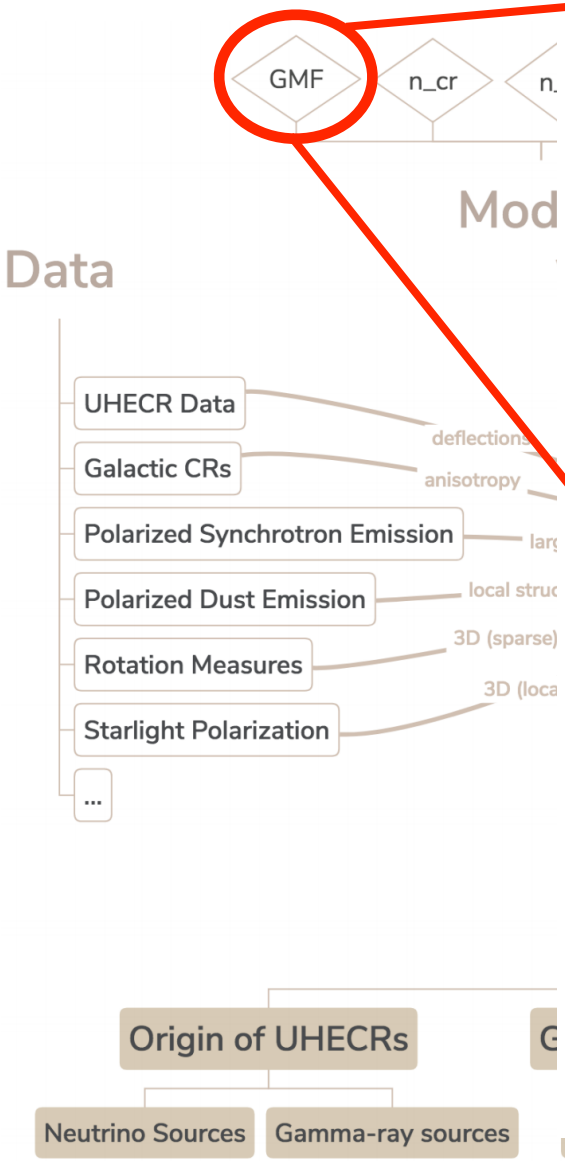
Cosmic Magnetism

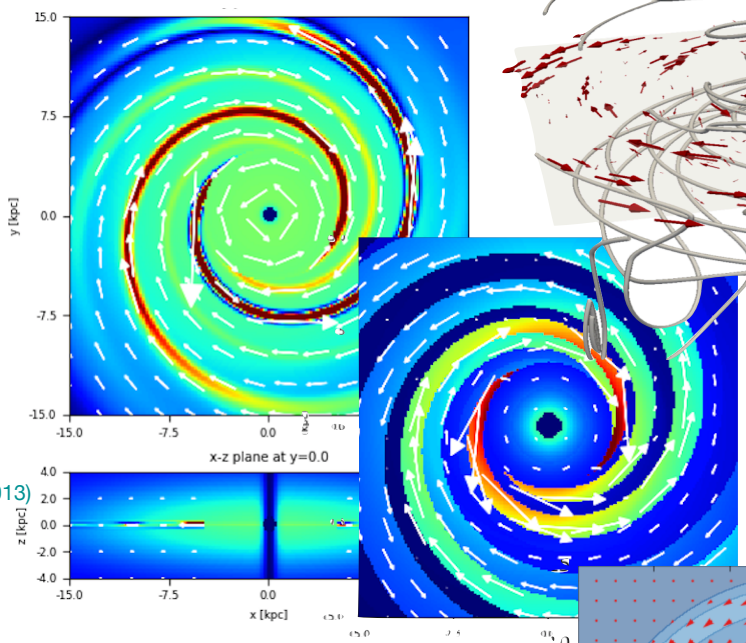
Primordial Magnetic Fields

Extragalactic Magnetic Fields

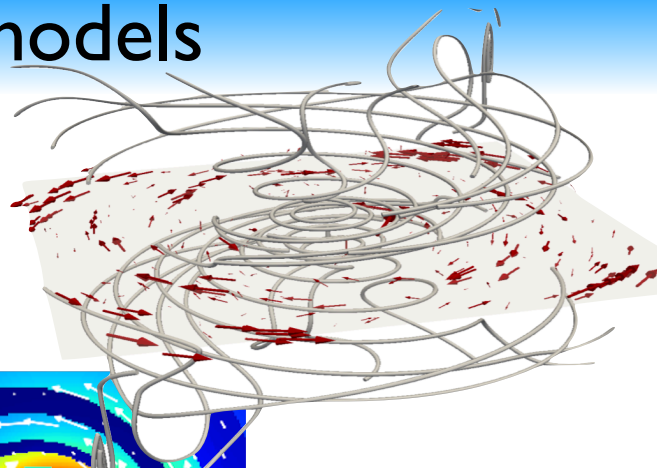
...

Galactic magnetic field models

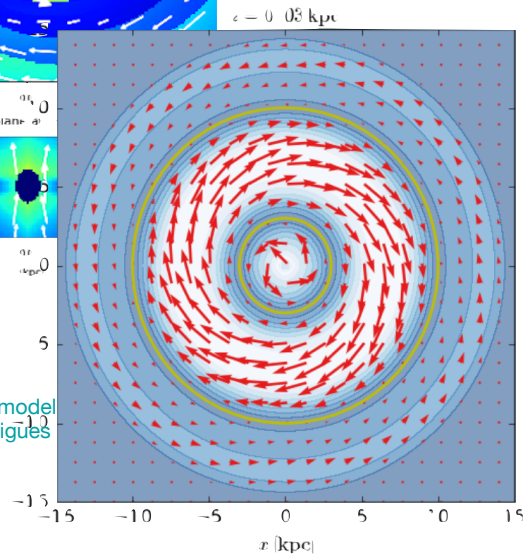




Jaffe et al. 2010,2011,2013)

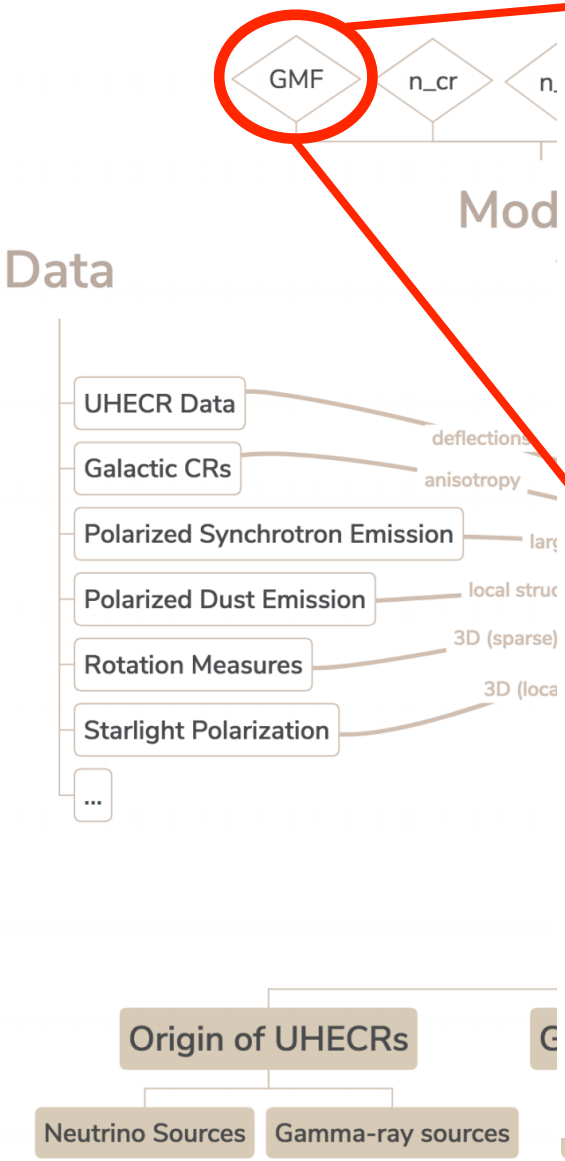


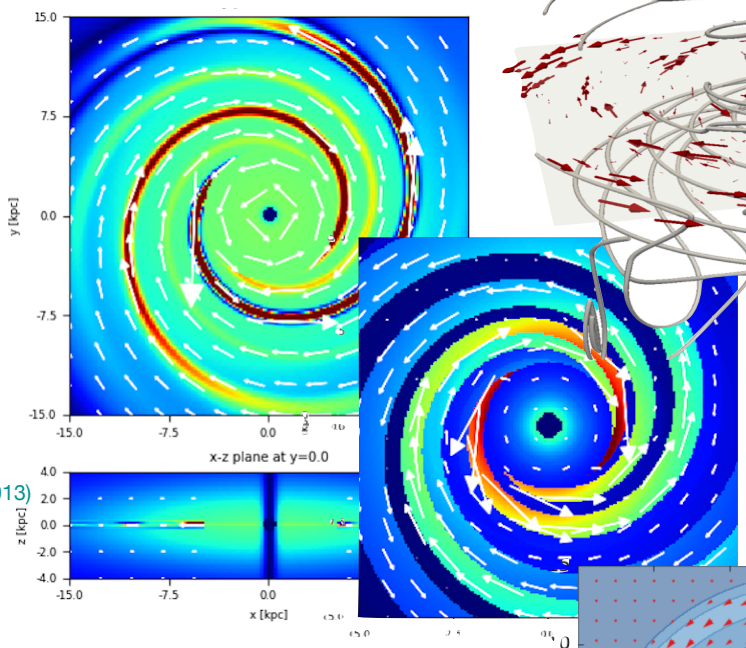
Jansson & Farrar (2012a,b)



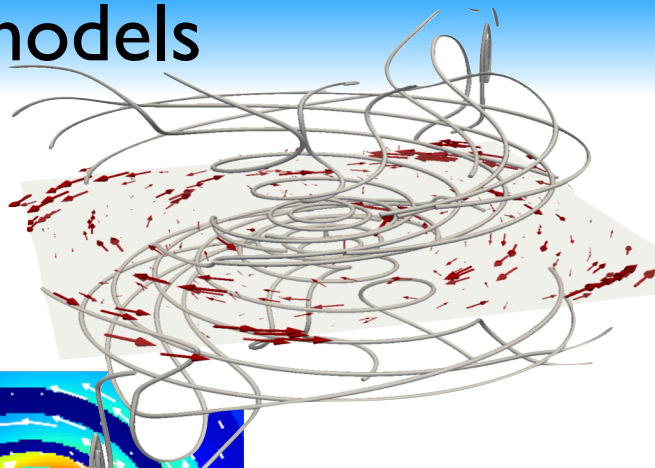
Theoretical GMF model (courtesy L. Rodrigues

Galactic magnetic field models

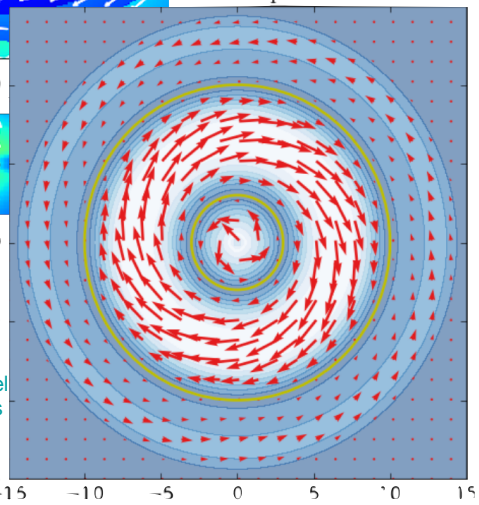




Jaffe et al. 2010,2011,2013)



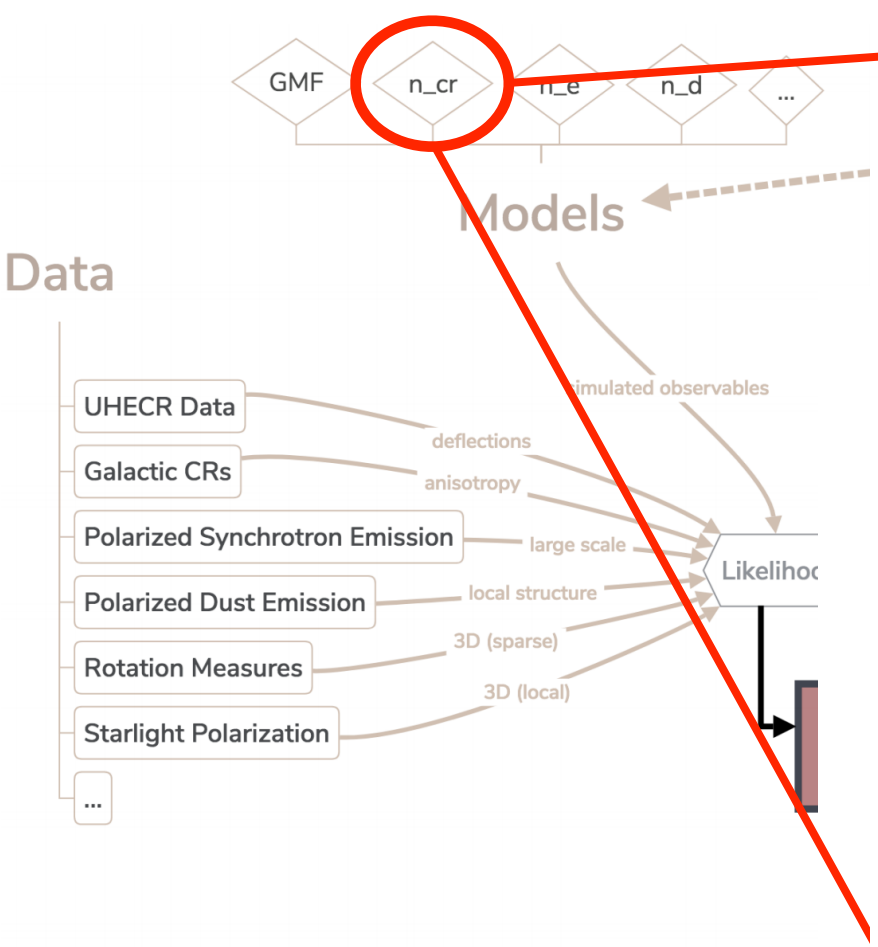
Jansson & Farrar (2012a,b)



Theoretical GMF model (courtesy L. Rodrigues

+ "Non-parametric" models!

Cosmic ray models



Orlando (2018)

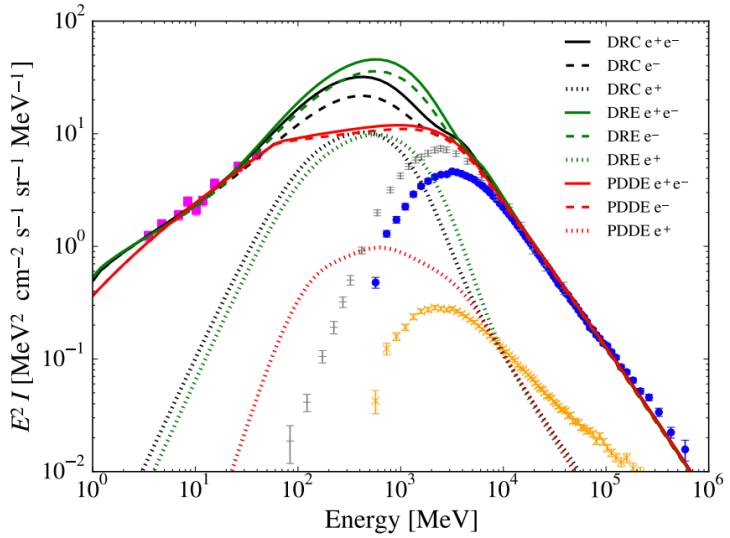
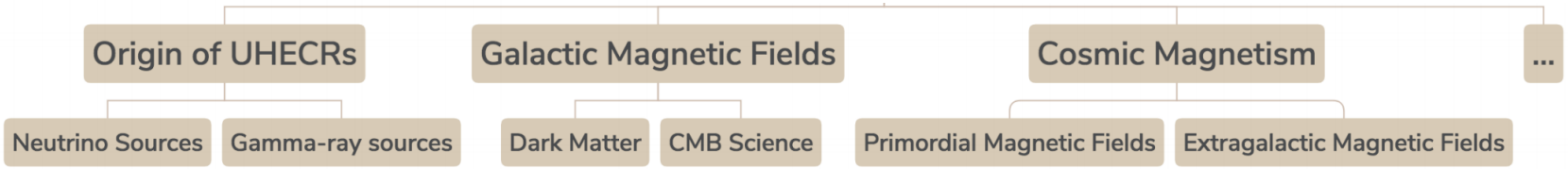
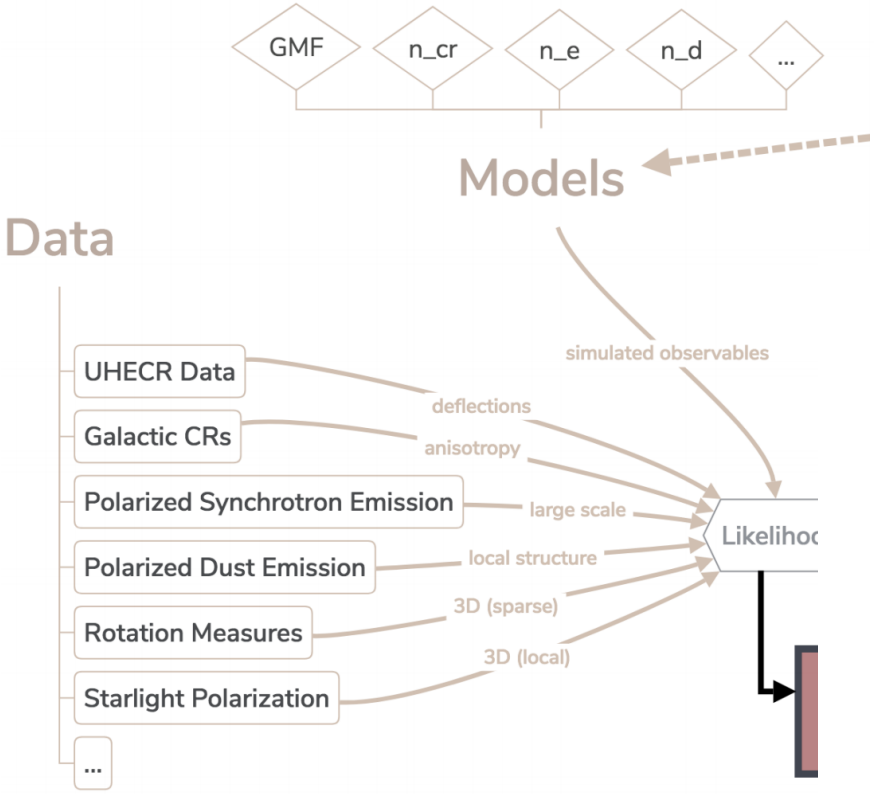


Figure 2. Propagated interstellar spectra of the three baseline models DRE (green line), DRC (black line), and PDDE (red line) for positrons (dotted lines), electrons only (dashed lines), and all-electrons (solid lines) compared with data: orange crosses: AMS-02 positrons (Aguilar et al. 2014); blue points: AMS-02 electrons (Aguilar et al. 2014); grey dashes: PAMELA electrons (Adriani et al. 2015); magenta squares: *Voyager 1* all-electrons (Cummings et al. 2016).



Cosmic ray models



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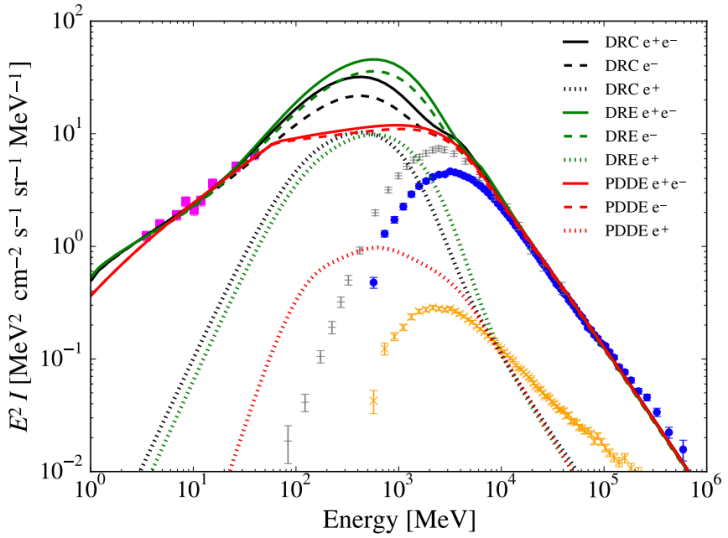

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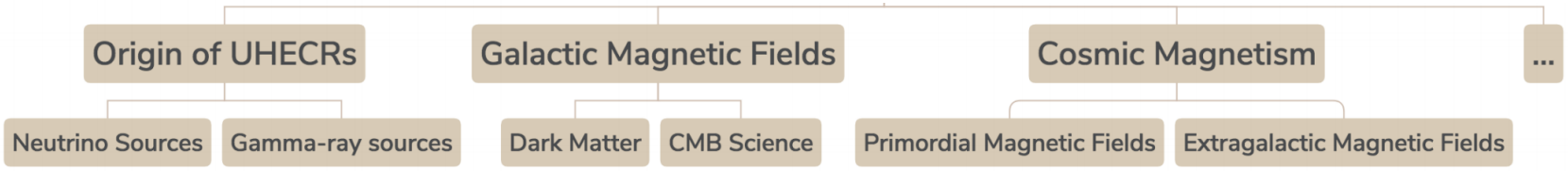
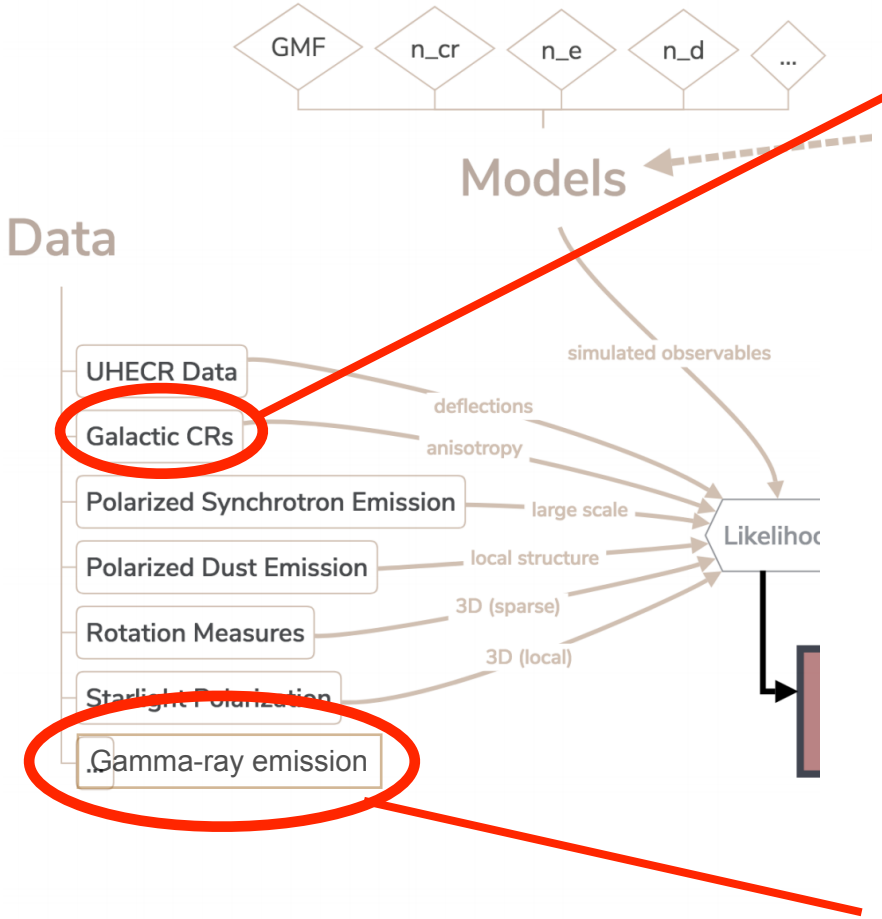
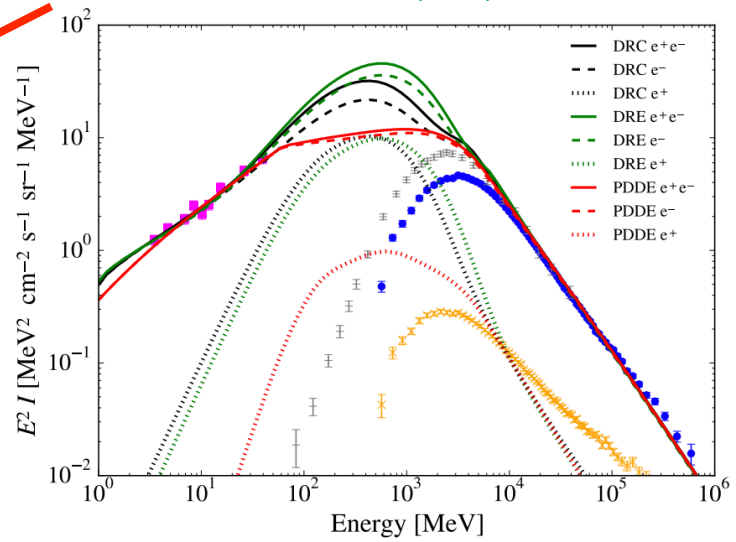


Cosmic ray models



Orlando (2018)



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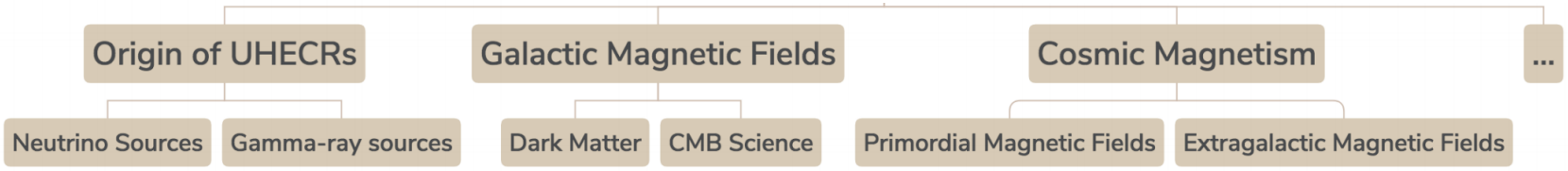
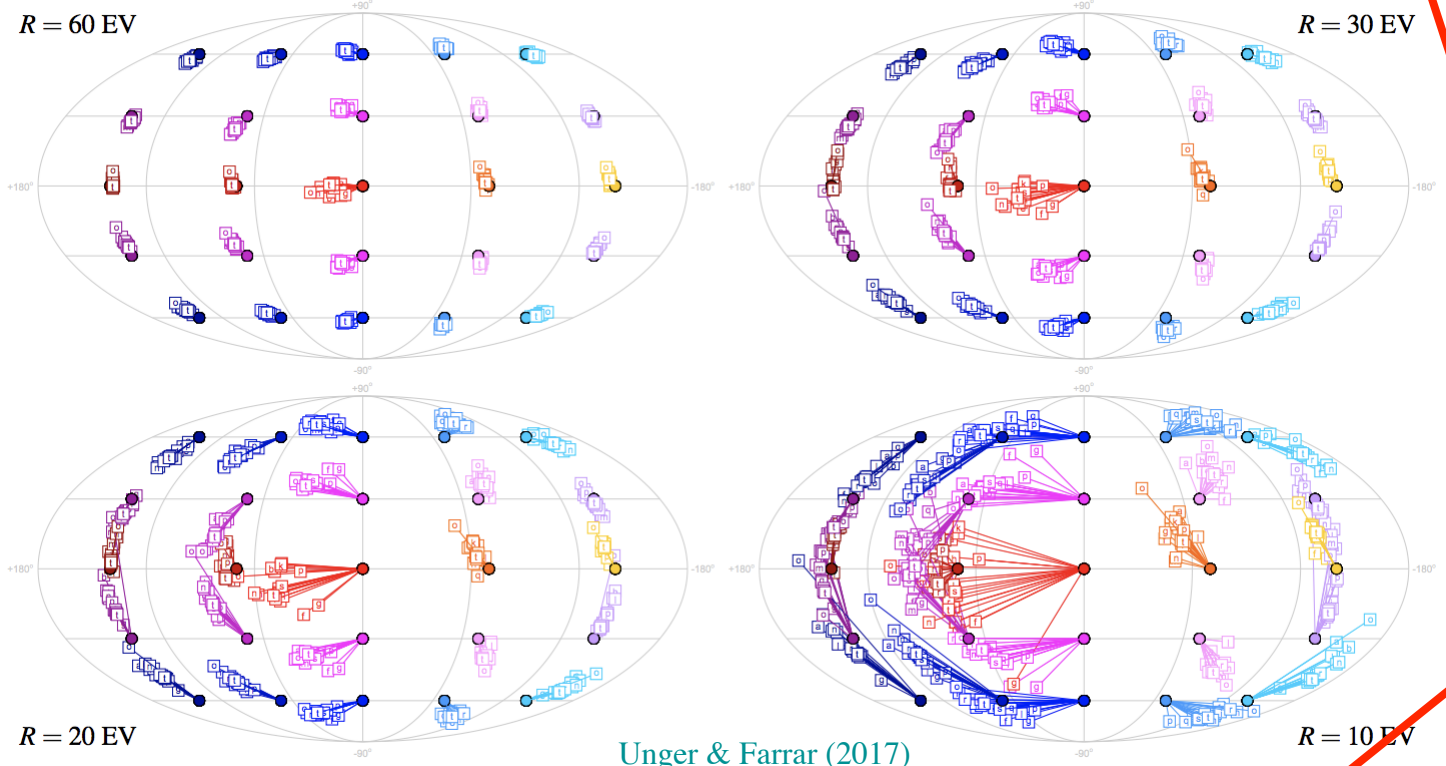


IMAGINE sources of UHECRs



Unger & Farrar (2017)

Theory

Information Field Theory

Large-Scale Structure Formation

Formation, Structure Evolution

UHECR Theory

Dynamo and MHD Theory

Multi-phase ISM

...

update

Results

Origin of UHECRs

Neutrino Sources

Gamma-ray sources

Galactic Magnetic Fields

Dark Matter

CMB Science

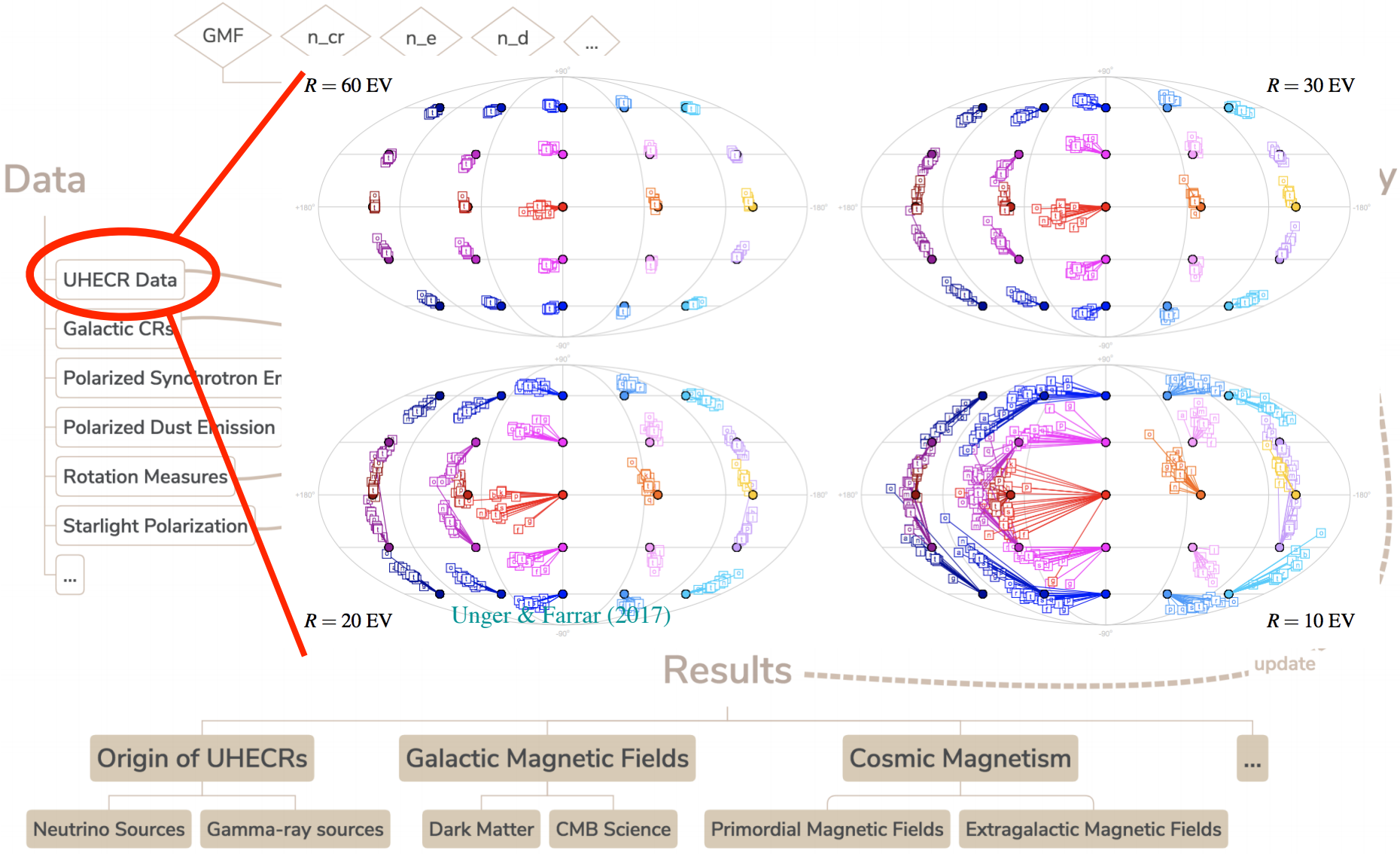
Cosmic Magnetism

Primordial Magnetic Fields

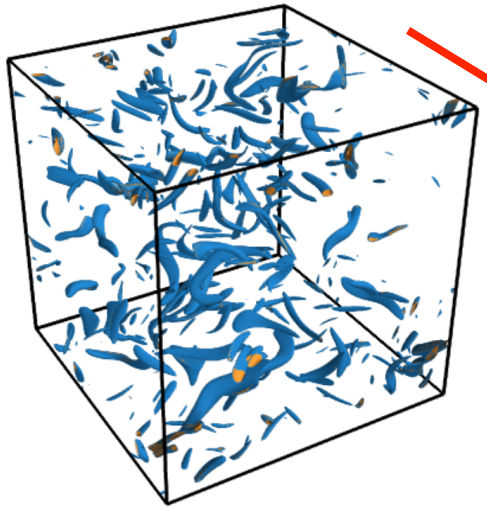
Extragalactic Magnetic Fields

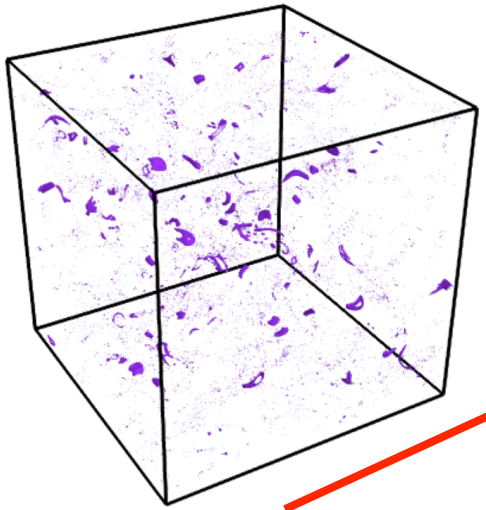
...

IMAGINE sources of UHECRs



Turbulent ISM

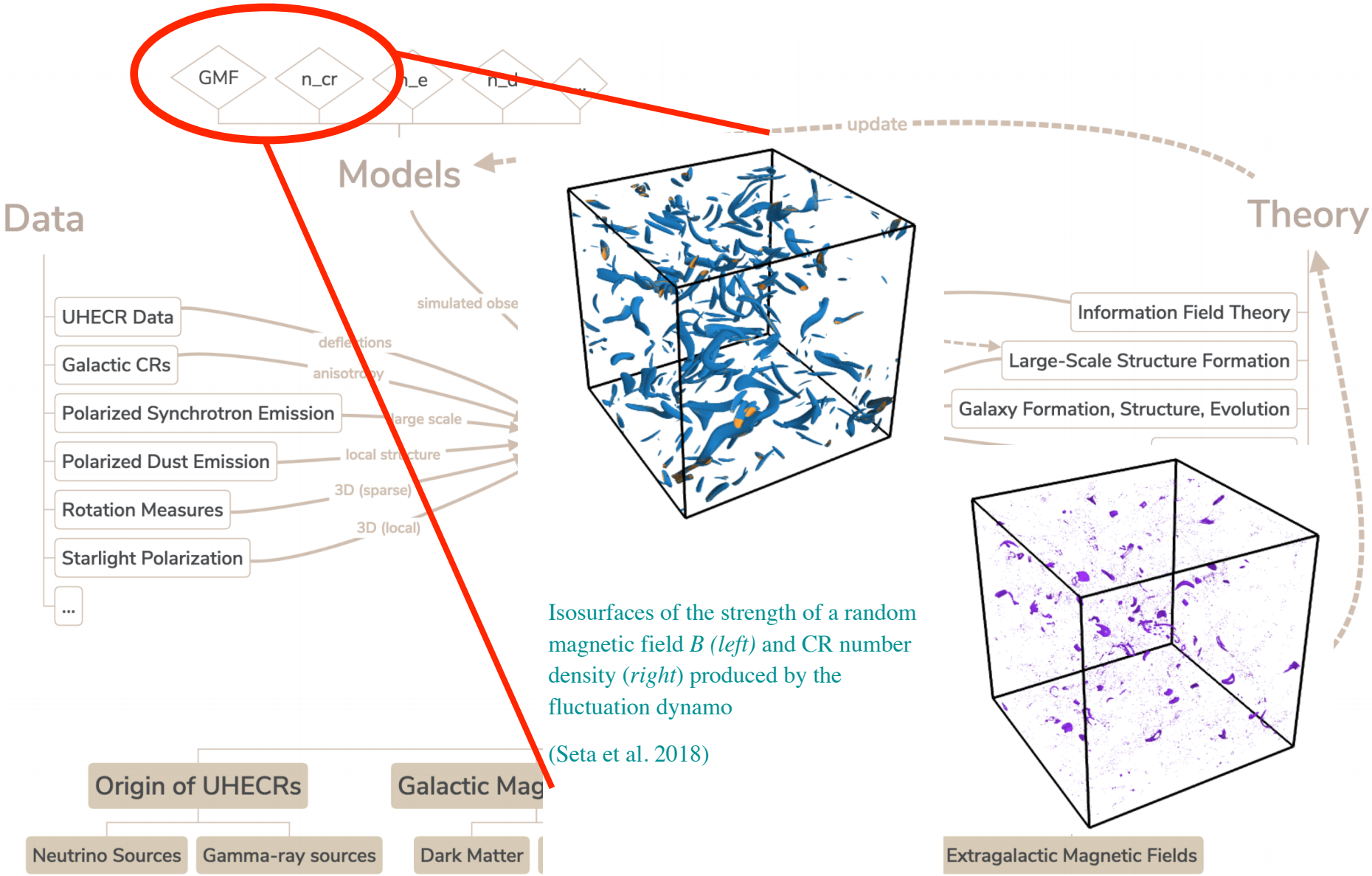




Isosurfaces of the strength of a random magnetic field *B (left)* and CR number density (*right*) produced by the fluctuation dynamo

(Seta et al. 2018)

Turbulent ISM

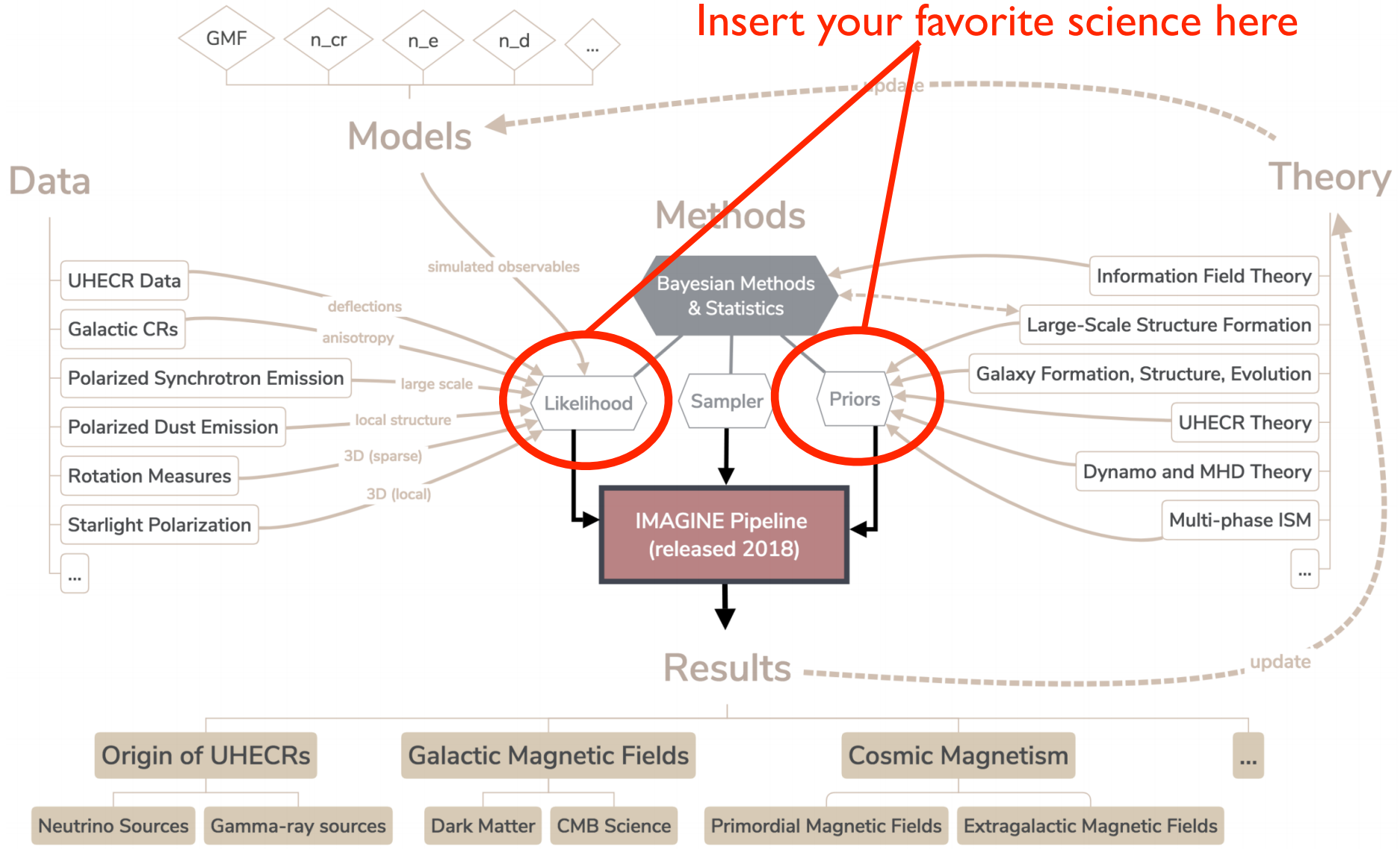


Isosurfaces of the strength of a random magnetic field *B (left)* and CR number density (*right*) produced by the fluctuation dynamo

(Seta et al. 2018)

IMAGINE a modular framework

https://arxiv.org/abs/1805.02496



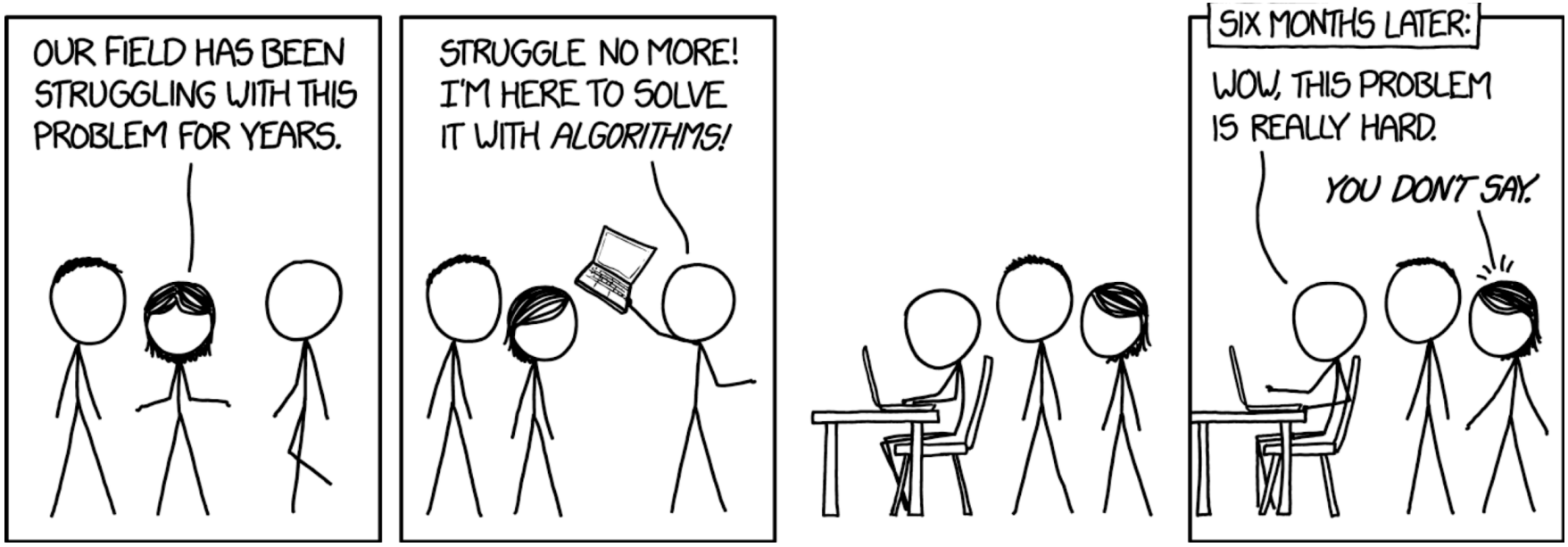
Technical details

- **Bayesian**: the idea is that each topic/dataset/theory/etc. is represented by a module calculating either a likelihood or a prior.
- **Open source**: https://gitlab.mpcdf.mpg.de/ift/IMAGINE
  - (and new hammurabiX at https://bitbucket.org/hammurabicode/hamx)
- **Bayesian open source**: IMAGINE will host any modules that can be mixed and matched quantitatively within our infrastructure.
- **Python** on top.
- **Modular** underneath: C++ integrator; Galprop, DRAGON, etc. to be integrated.

Demonstrated in Steininger et al. (2018, arxiv:1801.04341)

Caveat

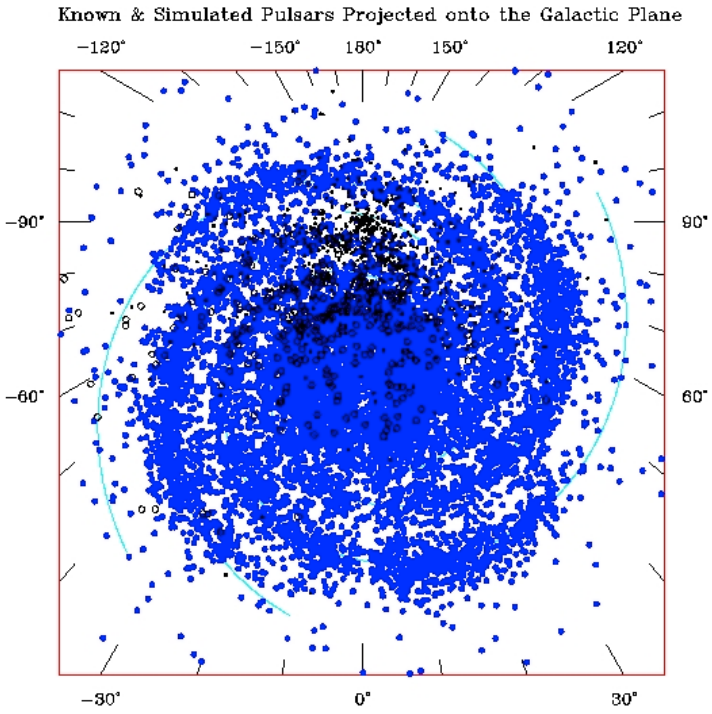
- IMAGINE isn't a silver bullet. This is still a complicated problem. But IMAGINE gives us a framework for putting the many different pieces together.



Randall Munroe, XKCD (https://xkcd.com/1831/)

Prospects for magnetic field modeling

- C-Band All Sky Survey (C-BASS) full sky, full Stokes, at 5 GHz. Important for CMB component separation, **synchrotron spectral studies**, and turbulent field modeling, etc.
- GALFACTS polarization survey at 1.4GHz from Arecibo. An order of magnitude more extragalactic RM sources as well as diffuse polarized emission for RM synthesis. Can use hammurabi to model turbulence, depolarization horizon, SNa remnants, RM synthesis testing, ...
- Low Frequency ARray (LOFAR) to model fields in Galactic halo, particularly where fields weak, ionized gas tenuous.
- Pilot, PIXIE, CORE++ (?) for post-Planck microwave and sub-millimeter polarization
- Gaia for dust distribution via extinction.
- ASKAP and SKA!



SKA simulation (J. Cordes)

What IMAGINE can do for you

- Polarized CMB foregrounds
- Primordial magnetic fields
- Structure formation
- UHECR sources
- CR propagation
- Supernovae
- MHD turbulence
- dynamo theory
- galaxy formation, feedback
- energy coupling, hydrostatic equilibrium

What you can do for IMAGINE ... ?

(Funding!)