Morphology of the E and B mode foregrounds

For the "CMB foregrounds for B-mode studies" in Tenerife, Spain, 2018

Based on: Hao Liu et al., 2018, JCAP, 05, 059 & Hao 2018, A&A, 617, 90

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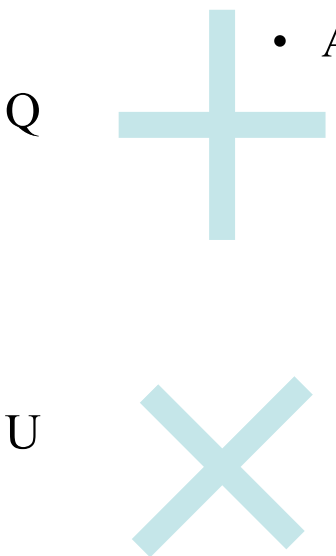
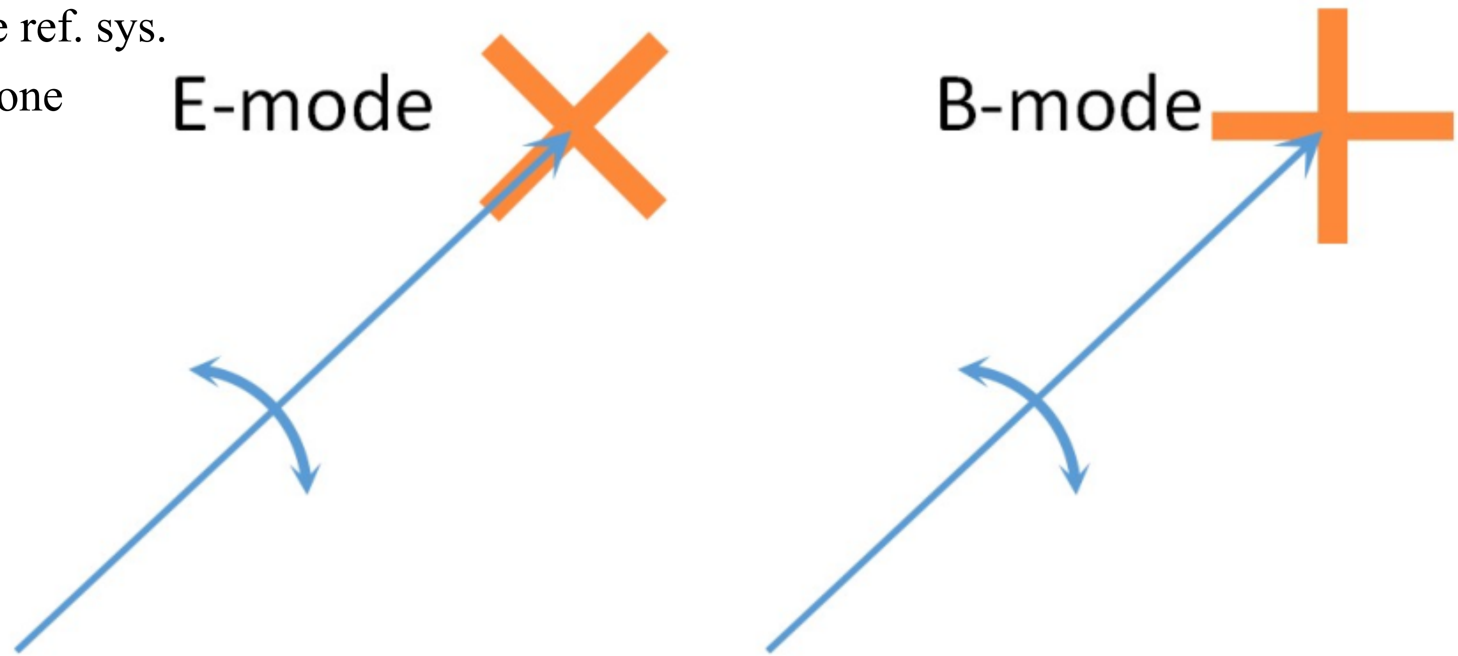
Outline

- One way to understand the E & B modes.
- Introduction of two types of real space EB decompositions.
  - Scalar-like ---- E/B maps ---- E(n), B(n)
  - Vector-like ---- E/B families ---- (Q_E, U_E), (Q_B, U_B)
- Polarized emissions from SNe:
  - Full sky.
  - All frequency bands.
  - Dominated by E-mode
  - A “source”, can contain any “components”
    - components: sync, dust, AME...
    - source: Galactic, point source, NPS...

The E, B modes

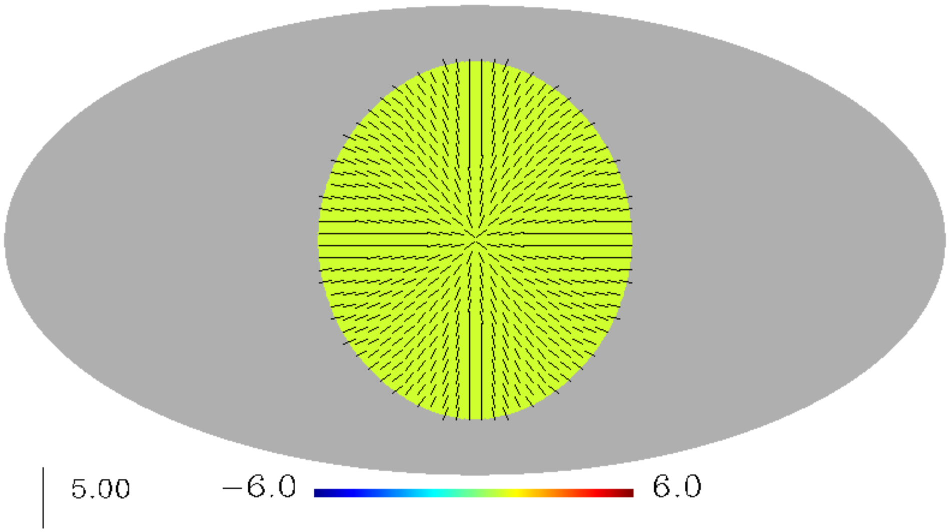
- There are many different ways to understand the E and B modes.
- Here we provide one way based on rotation sets
  - Direct relationship to the Q and U stokes parameters.
  - Rotational invariant
  - Three keywords:
    - normal vector
    - relative ref. sys.
    - All-in-one



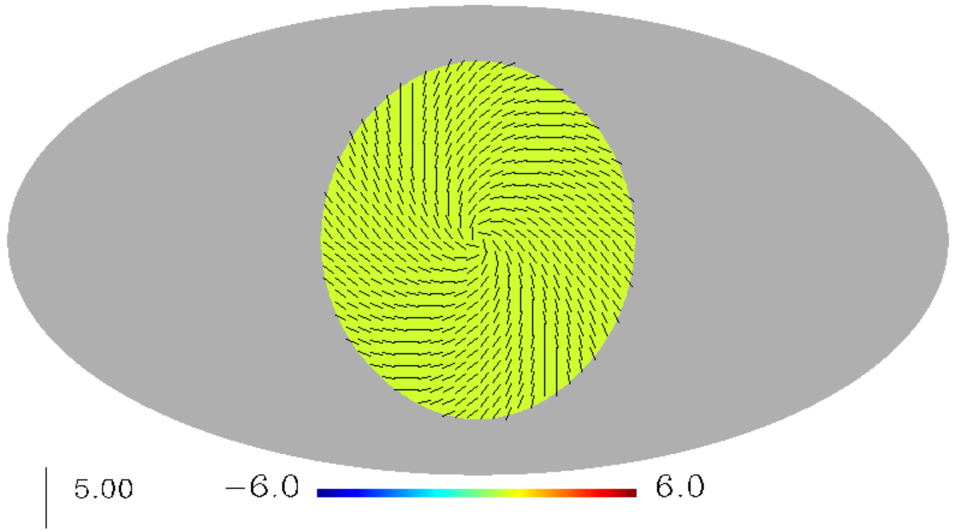


Examples of polarized sky signals in E and B modes

E



B



For a good real-space decomposition, we want to have some simple but very useful features:

**) Possibility to get pol-ang & pol-int for E and B*

**) Total signal = E + B*

**) Possibility to decompose E + B back to E and B*

What kind of decomposition can satisfy them?

Scalar-like and vector-like decompositions

- Common basis

$$a_{\pm 2,lm} = \int \left(Q(\hat{\mathbf{n}}) \pm iU(\hat{\mathbf{n}})\right)\, {}_{\pm 2}Y^*_{lm}(\hat{\mathbf{n}})\, \mathrm{d}\hat{\mathbf{n}}.$$

$$a_{E,lm} = -(a_{2,lm} + a_{-2,lm})/2,$$

$$a_{B,lm} = i(a_{2,lm} - a_{-2,lm})/2,$$

- Scalar-like decomposition (E/B maps)

Zaldarriaga et al., 1997, 1998, Kamionkowski 1997...

$$E(\hat{\mathbf{n}}) = \sum \sqrt{\frac{(l+2)!}{(l-2)!}} a_{E,lm} Y_{lm}(\hat{\mathbf{n}}),$$

$$B(\hat{\mathbf{n}}) = \sum \sqrt{\frac{(l+2)!}{(l-2)!}} a_{B,lm} Y_{lm}(\hat{\mathbf{n}}).$$

- Vector-like decomposition (E/B families)

$$F_{+,lm} = -\frac{1}{2}\left({}_2Y_{lm} + {}_{-2}Y_{lm}\right), \quad F_{-,lm} = -\frac{1}{2i}\left({}_2Y_{lm} - {}_{-2}Y_{lm}\right).$$

$$Q_E = \sum_{l,m} a_{E,lm} F_{+,lm}, \quad U_E = \sum_{l,m} a_{E,lm} F_{-,lm}.$$

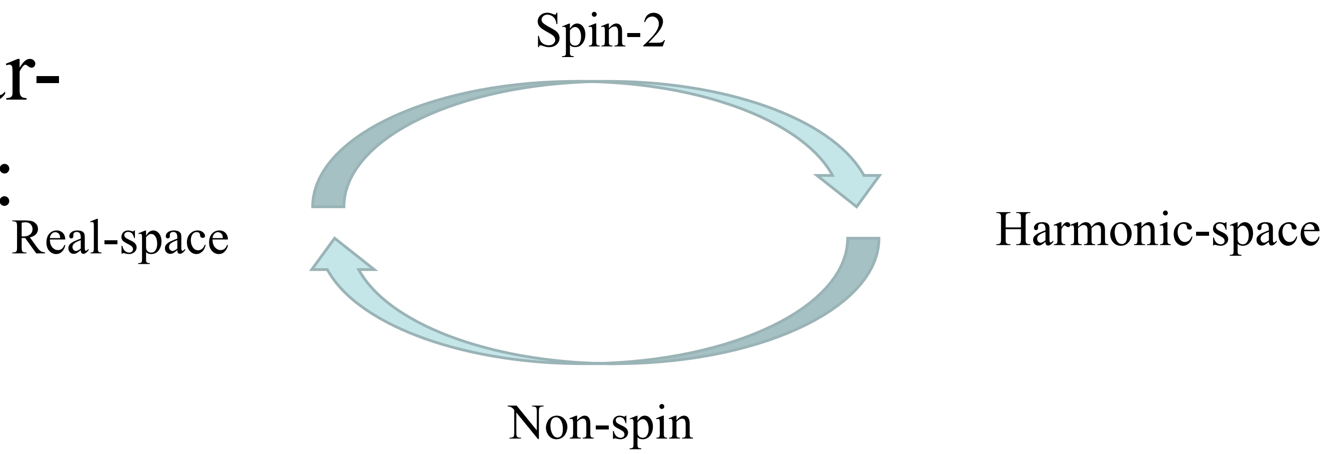
$$-Q_B = \sum_{l,m} a_{B,lm} F_{-,lm}, \quad U_B = \sum_{l,m} a_{B,lm} F_{+,lm}.$$

$$(Q, U) \equiv (Q_E, U_E) + (Q_B, U_B)$$

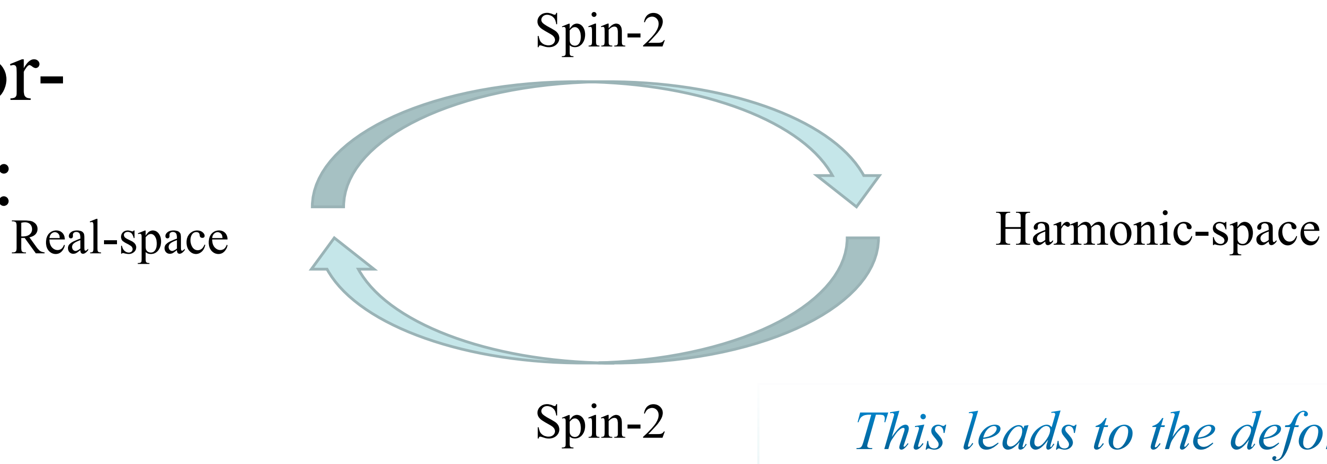
Proposed by us in Liu et al., 2018, JCAP 05..059L

Main difference of scalar-like and vector-like decompositions

Scalar-like:



Vector-like:



This leads to the deformation problem

For a good real-space decomposition, we want to have some simple but very useful features:

*) *Possibility to get pol-ang & pol-int for E and B*

*) *Total signal = E + B*

*) *Possibility to decompose E + B back to E and B*

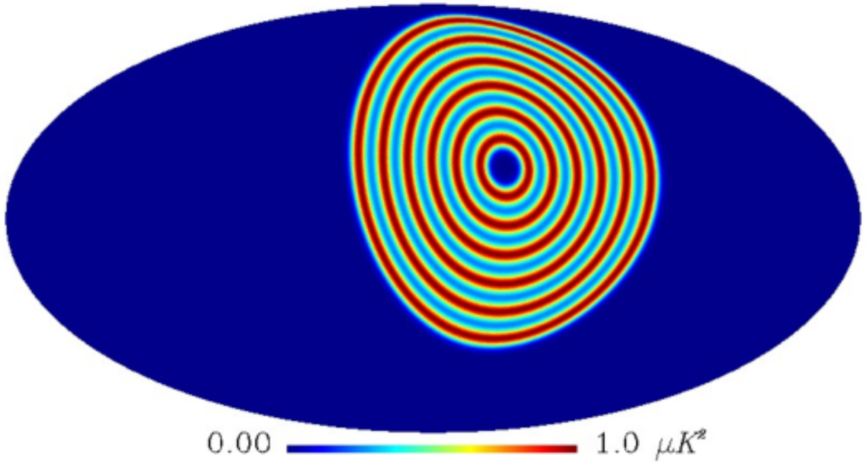
What kind of decomposition can satisfy them?

These can only be satisfied by a vector-like (E/B family) decomposition.

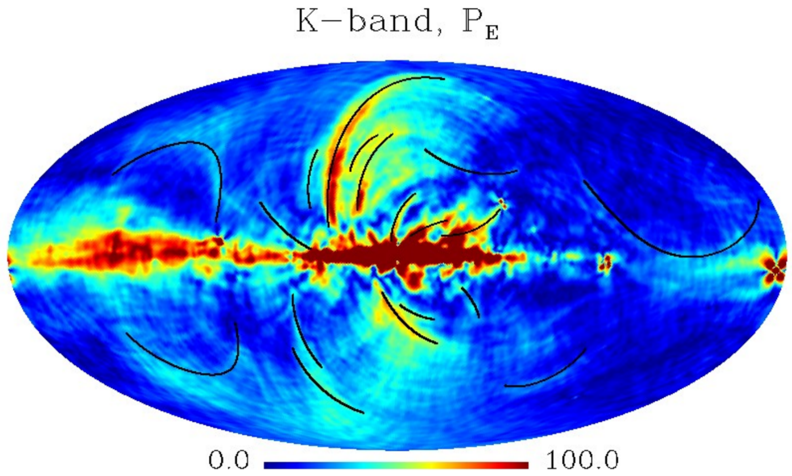
$$(Q, U) \equiv (Q_E, U_E) + (Q_B, U_B)$$

One more difference of the two decompositions: The deformation problem

Model: E-mode loops

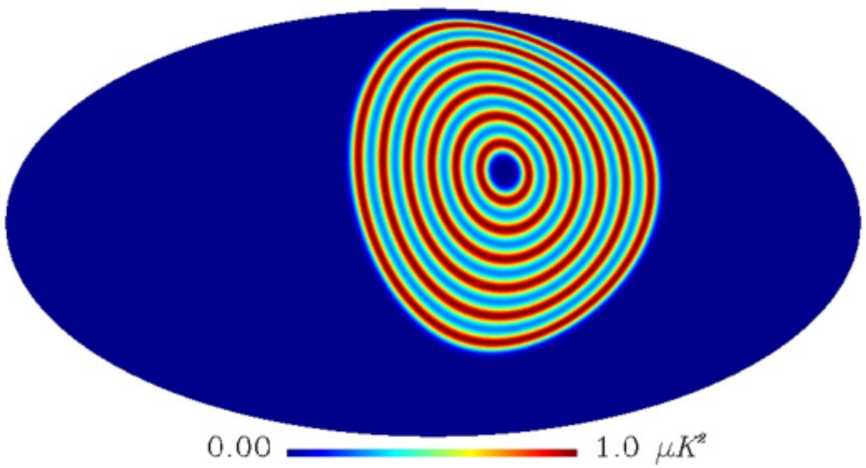


K-band, only E-family



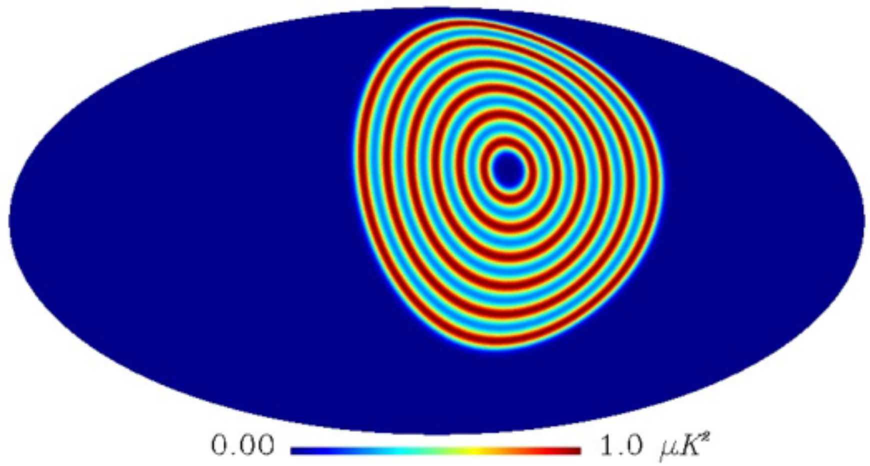
Deformation of the morphology

Model: E-mode loops



E-family

$$P_E^2 = Q_E^2 + U_E^2$$

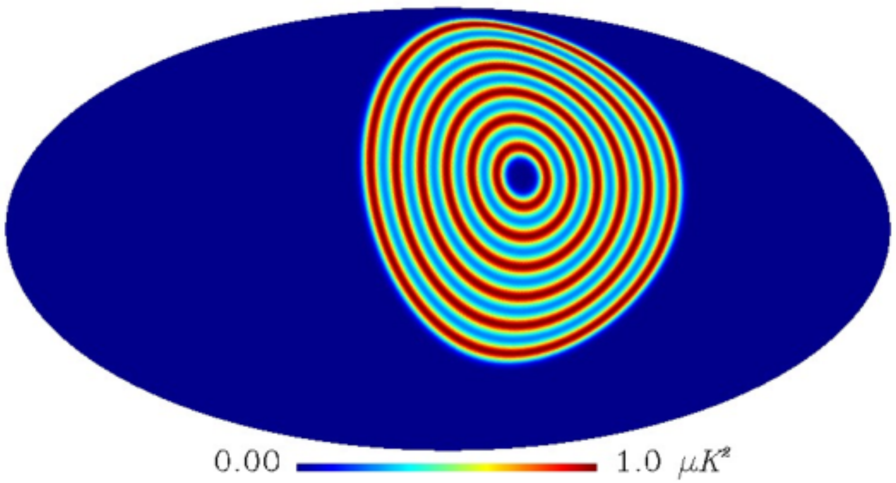


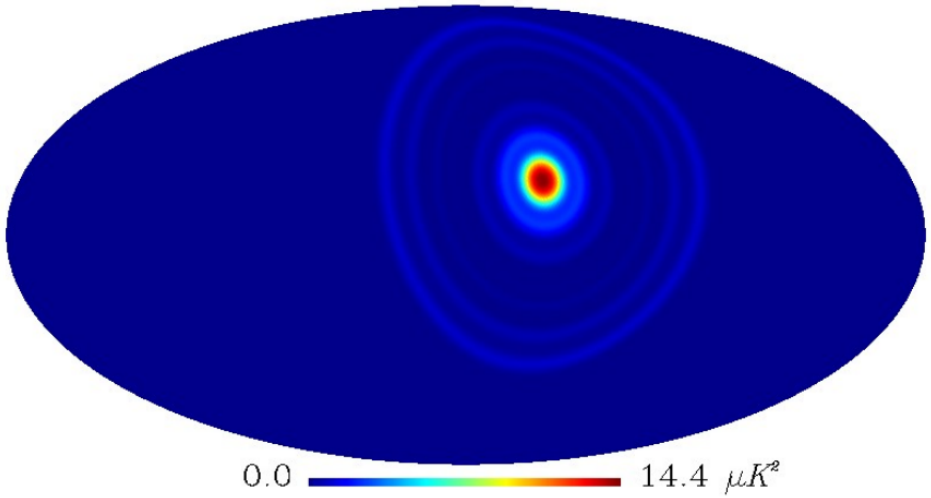
Deformation of the morphology

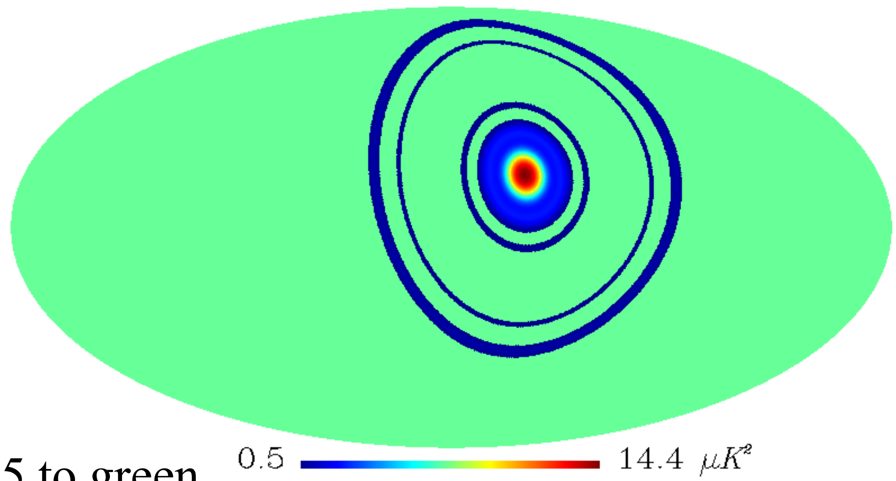
E-map output

$E^2(n)$

Model: E-family loops







For better visibility, set the region below 0.5 to green

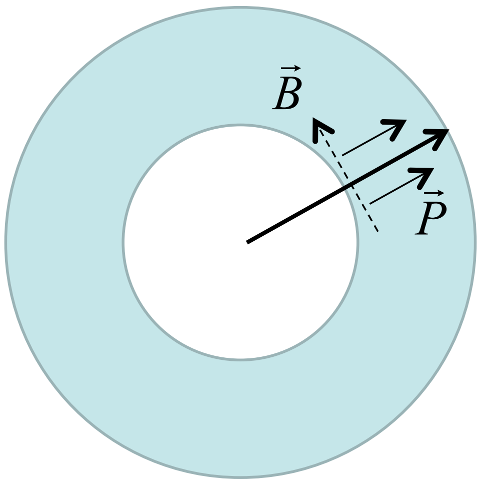
For foreground removal: do it directly on (Q,U), or on E/B families?

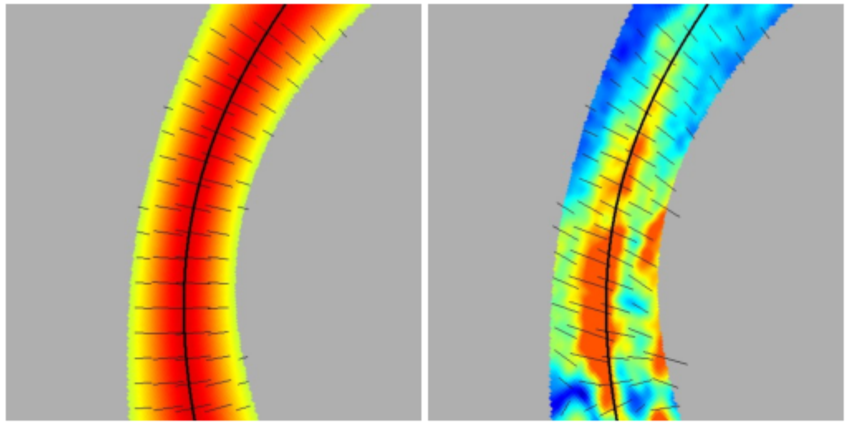
- We see from above that EB-family is better than EB-map in foreground removal.
- However, can we do foreground removal directly on (Q,U)?
- Simple criterion: Is there at least one source of foreground emission that is mainly in E- or B-family?
  - No: We can do foreground removal directly on (Q,U).
  - Yes: It's better to work on E/B families respectively.

E-mode emission from SNe & Galactic loops

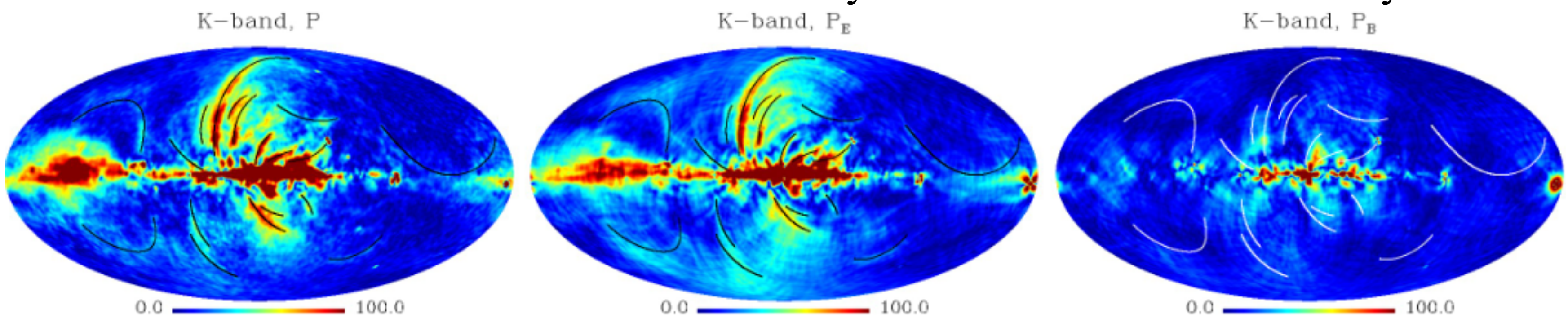
SNe suppress the magnetic field and makes it perpendicular to the normal vectors (which is well-known, like: Whiteoak & Gardner 1968; Milne 1987 Dubner & Giacani 2015; Petruk et al. 2016)

Liu Hao 2018, A&A, 617 A90





E-family B-family



Ratio of the E/B families

$$P_E = \sqrt{Q_E^2 + U_E^2}$$

$$P_B = \sqrt{Q_B^2 + U_B^2}$$

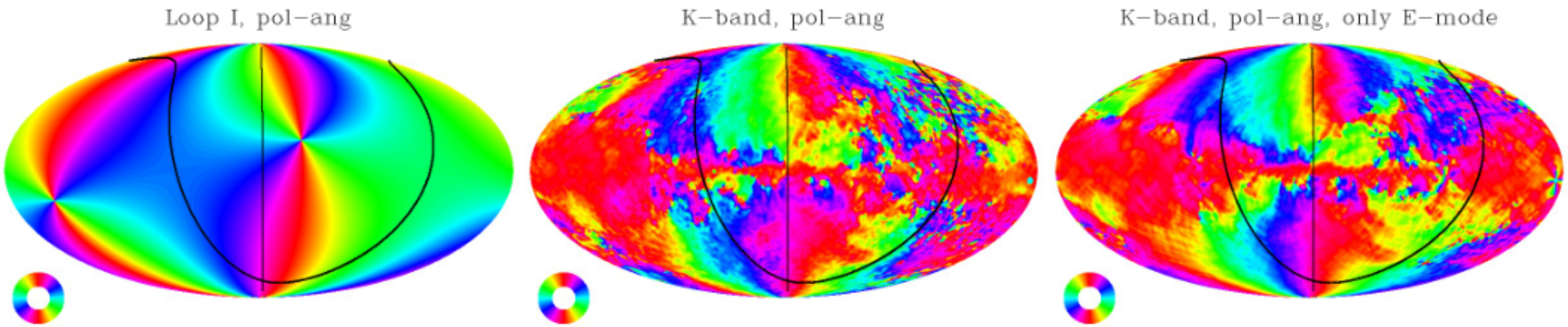
$$\rho = P_E / P_B$$

Value of rho for the loop and non-loop regions

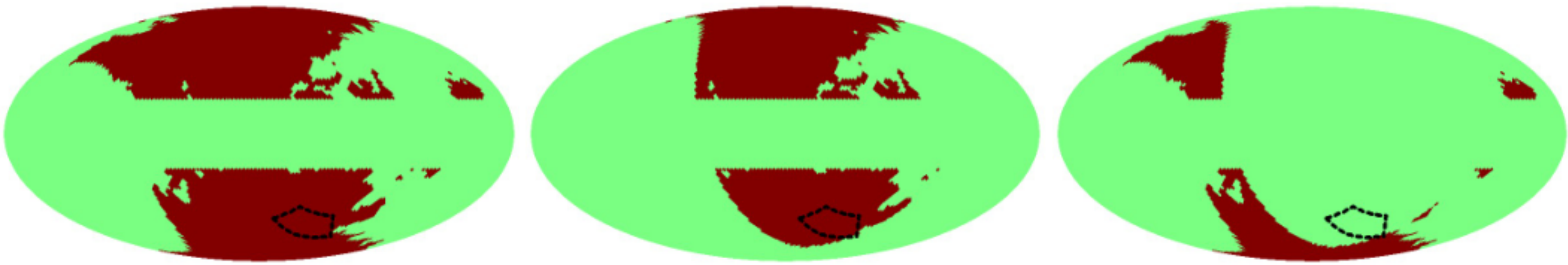
	Median inside (outside)	Mean inside (outside)
K-band	2.6 (1.9)	5.4 (2.8)
353 GHz	1.9 (1.3)	3.0 (2.1)

Pol-ang comparison

Model and data (Note: the model has **no** free parameter)

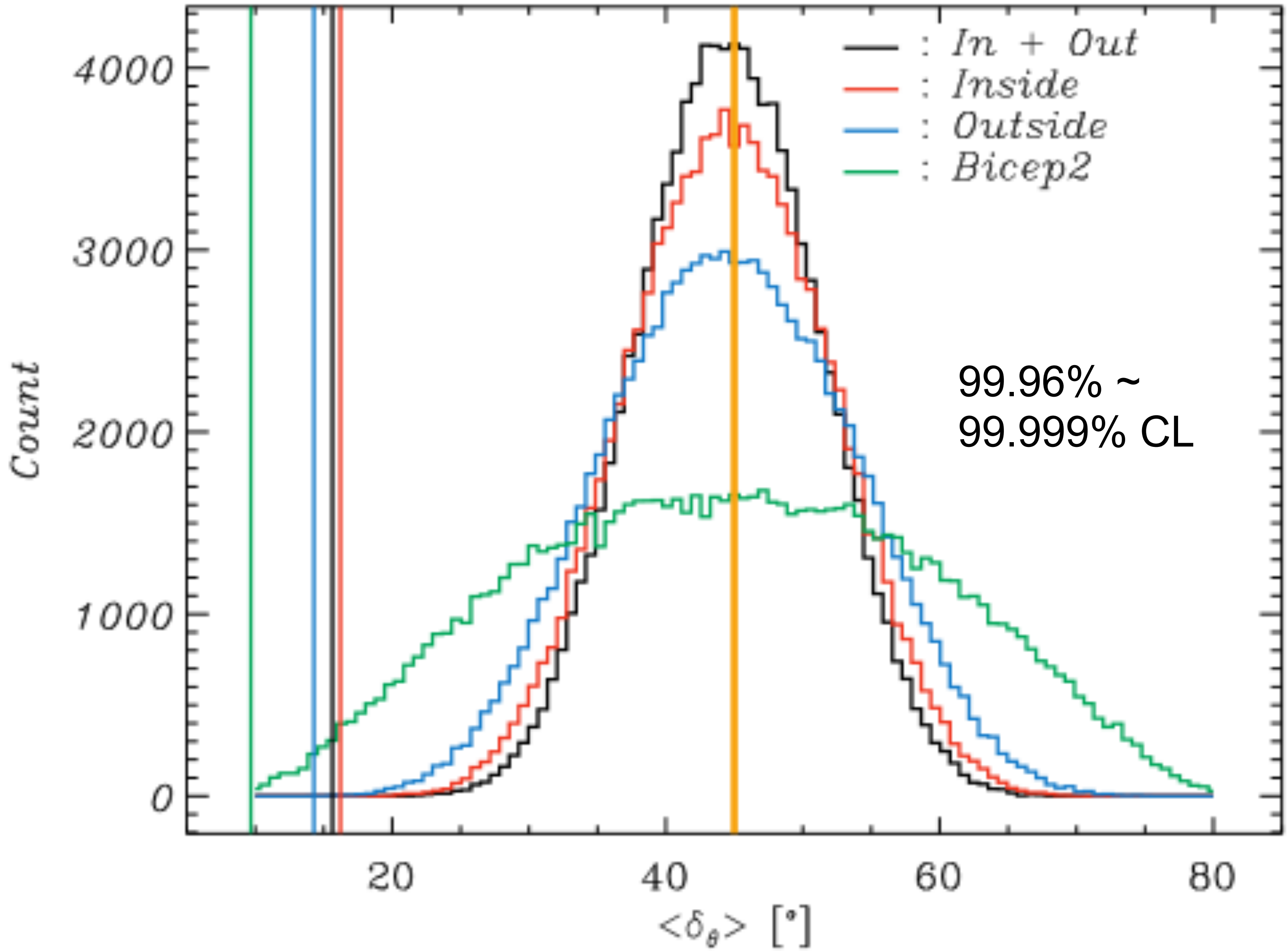


Regions for comparison



$$\delta_\theta = |\arcsin(\sin(\delta'_\theta))| \equiv 90^\circ - |90^\circ - \arccos[\cos(\delta'_\theta)]|,$$

$$\langle \delta_\theta \rangle = \mathrm{arctan2}\left(\sum \sin(\delta_\theta), \sum \cos(\delta_\theta)\right),$$



Important message 1:
polarized emissions from SNe exist everywhere.

Pol-ang comparison

For other frequency bands, Planck 2015 data, lists the model-to-data mean-pol-angle-difference, lower than 45-deg means the data is correlated with Loop I model

Band	K	30	Ka	Q	44	V	70	W	100	143	217	353
ν (GHz)	22.8	28.4	33.0	40.7	44.1	60.8	70.4	93.5	100	143	217	353
In & Out	15.6	26.9	16.5	16.7	28.3	29.6	31.7	22.0	17.1	20.0	18.6	19.7
Inside	16.2	25.0	16.6	16.4	26.1	27.4	28.7	22.2	17.3	19.8	18.3	19.8
Outside	14.3	31.1	16.2	17.3	32.5	34.5	36.8	21.7	16.8	20.6	19.3	19.5
BICEP2	9.7	53.5	9.0	6.8	27.2	21.8	30.2	19.5	35.5	5.3	4.1	7.7

Same but with the Planck 2018 data (better systematics control). The suspicious value (in blue) becomes apparently lower.

Band	K	30	Ka	Q	44	V	70	W	100	143	217	353
ν (GHz)	*22.8*	*28.4*	*33.0*	*40.7*	*44.1*	*60.8*	*70.4*	*93.5*	*100.0*	*143.0*	*217.0*	*353.0*
In & Out	15.6	18.9	16.5	16.7	23.0	29.6	29.9	22.0	22.4	19.0	17.3	17.1
Inside	16.2	18.8	16.6	16.4	20.5	27.4	27.4	22.2	19.1	19.3	18.0	17.9
Outside	14.3	19.2	16.2	17.3	28.3	34.5	34.4	21.7	30.3	18.3	15.6	15.1
Bicep2	9.7	13.9	9.0	6.8	17.0	21.8	38.1	19.5	8.7	7.8	5.6	5.2

Important message 2:
polarized emissions from SNe exist for all frequencies

Properties of the polarized Loop I emission

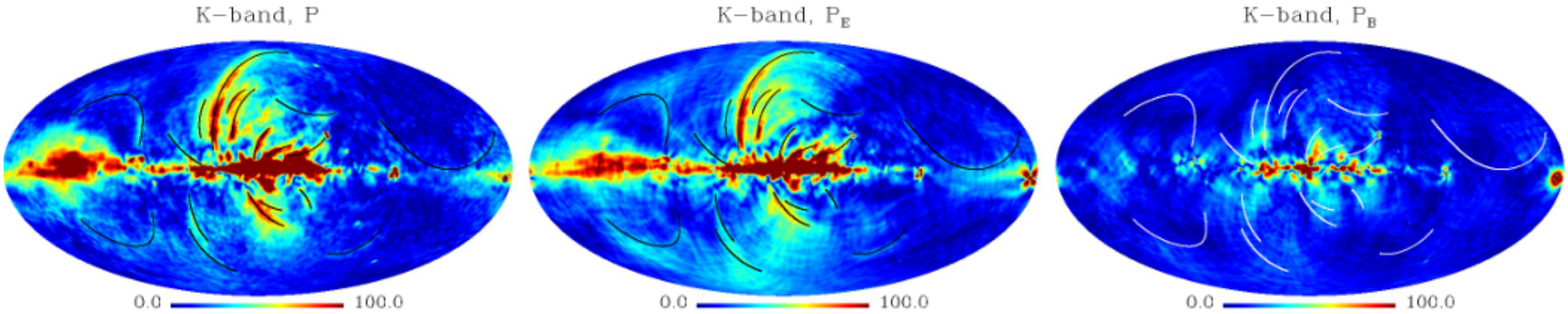
- At least part of the loop I (NPS) emission is from a local bubble.

- The size of Loop I is bigger than the distance to its center (we are inside the bubble).

- Polarized emissions from SNe provides a natural explanation to the E-mode excess problem reported by Planck (Planck, 2016, A&A, 586, A133), which means a huge contribution to the total polarized emission

- This also provides possible constraint on the interstellar magnetic field:
  - Turbulent background **B** + SNe + LOS integration ≡ regular appearance of **B**
  - Liu Hao A&A 2018, 617 A90, Appendix B

The morphologies of the E/B families are completely different



Conclusion

- All frequency bands and almost all-sky region contain significant polarized foreground from supernova explosion, which is mainly in E-mode.

- Polarized emissions from supernova come from different distances than Galactic emissions, so they can certainly have different frequency spectra.

- The input map should be separated in terms of E/B families before foreground removal, which certainly helps to reduce the complexity of foreground emissions.

- To the best of our expectation, pol-emission from SNe can be removed by EB-family separation, but small residual B-mode can exist when:
  - Asymmetric of the SNe (Very likely!)
  - Properties of the background magnetic field

Thanks!