The Latest Constraints on Polarised Dust Emission from Planck and PILOT

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On behalf of the Planck Collaboration and the PILOT team

Keck Institute for Space Study, Designing Future CMB Experiments

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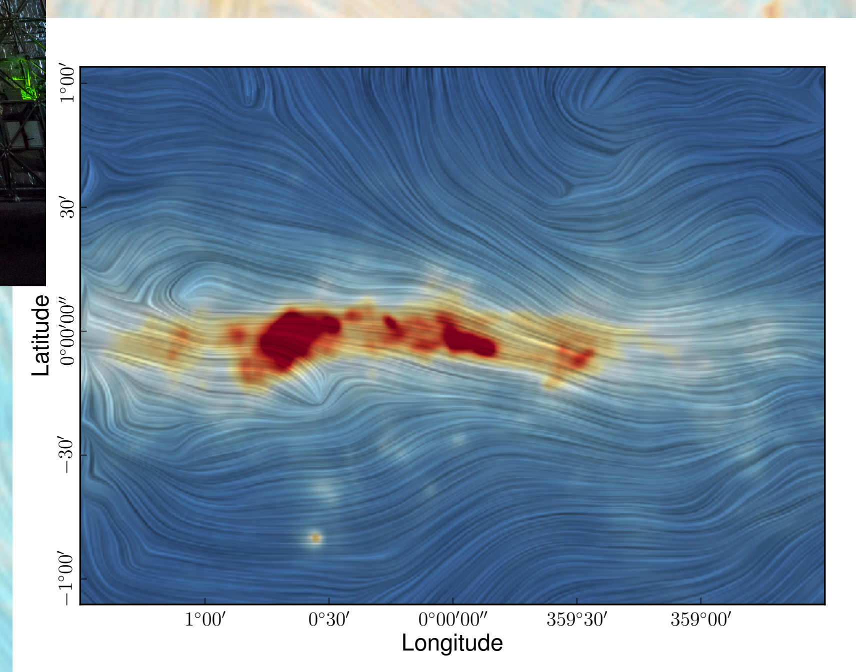
OUTLINE

- Polarised dust foregrounds from Planck
- The PILOT experiment & preliminary polarization results
- Conclusions



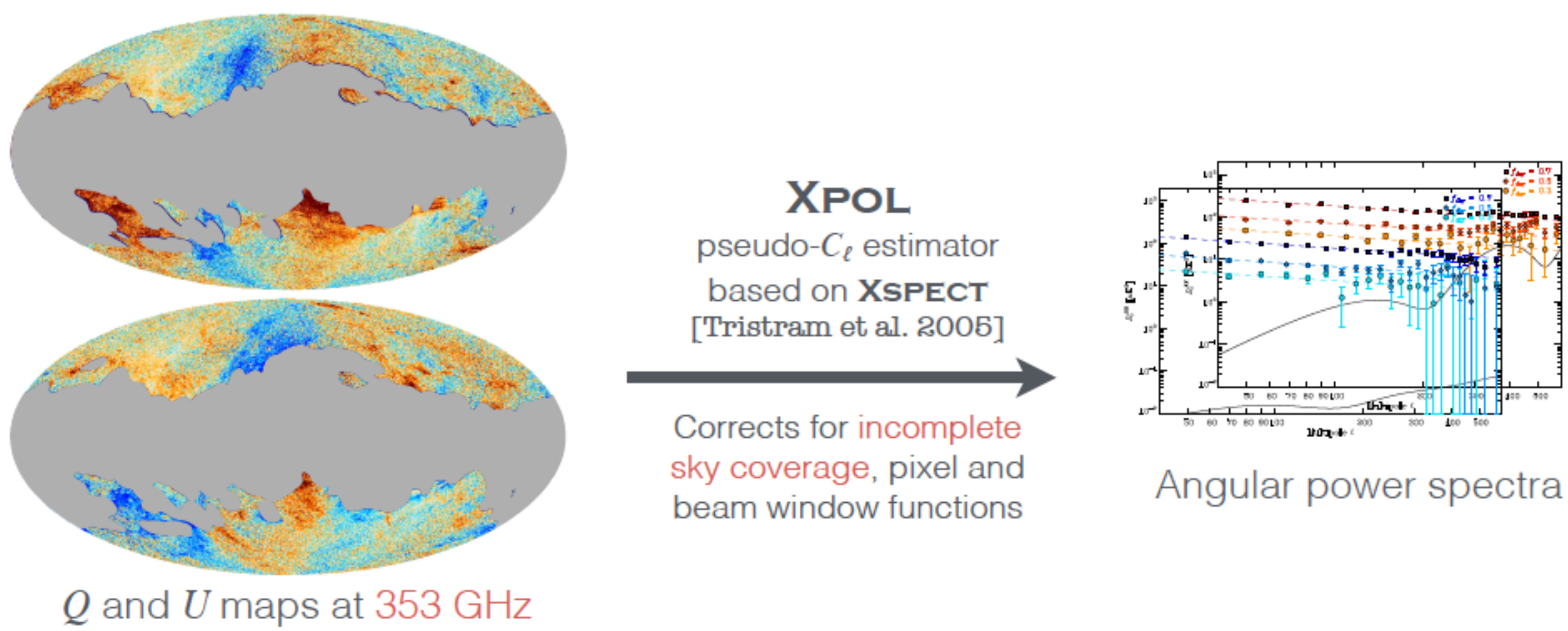
Polarised dust foregrounds from Planck

planck

Planck Coll., Planck Intermediate Results (PIR) LIV, sub. to A&A 2018:

Latest (PR3-2017) Planck maps (not public yet), follow up of PIR XXX , PIR L

* dust angular power spectra
* Spectral energy distribution
* frequency correlation of dust polarisation maps



- Planck (HFI 100-353 & 30 GHz LFI) , WMAP polarisation cross-spectra
- 6 sky regions: from fsky 24% to 72% (LR24 to LR71)
- CMB subtracted using Planck-2015 LCDM model
- Uncertainties from end-to-end E2E simulations (noise and residuals systematics)
- Multipole range extended to lowest multipoles

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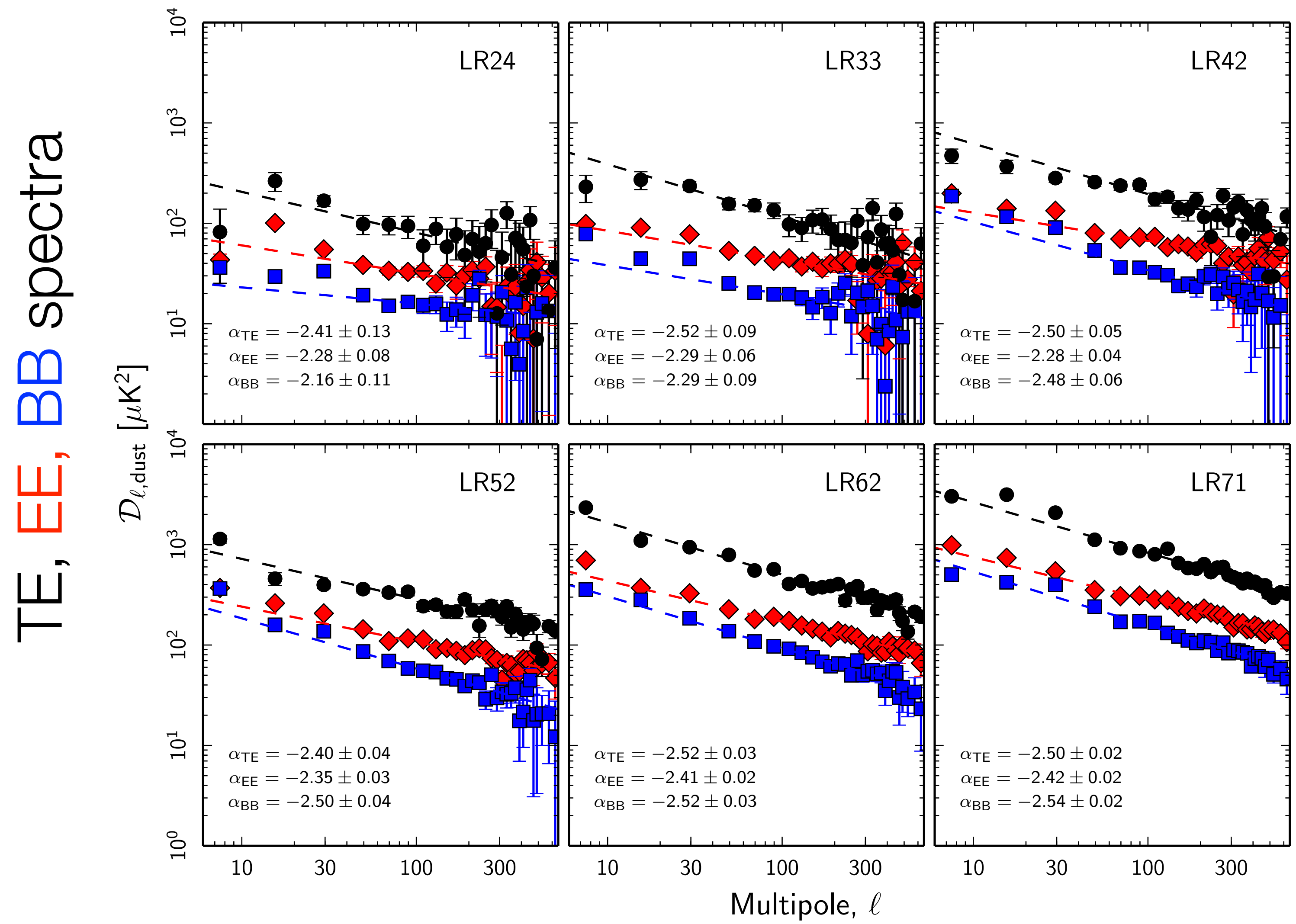
Power law fits & EE-BB asymmetry

$$\mathcal{D}_\ell^{XY} \equiv A^{XY} \, (\ell/80)^{\alpha_{XY}+2} \qquad 40 \leq \ell \leq 600$$



$$< A^{BB}/A^{EE} >= 0.52 \pm 0.01$$

$$< \alpha_{EE} >= -2.38 \pm 0.02$$

$$< \alpha_{BB} >= -2.51 \pm 0.02$$

$$< \alpha_{TE} >= -2.49 \pm 0.02$$

- slightly different exponent for EE and BB
- spectra are not well fitted by a single power law for the whole multipole range : model required to understand the results at lowest multiple
- EE/BB power asymmetry in agreement with PIPXXX, also at low multipoles (but with large variations over sky regions)

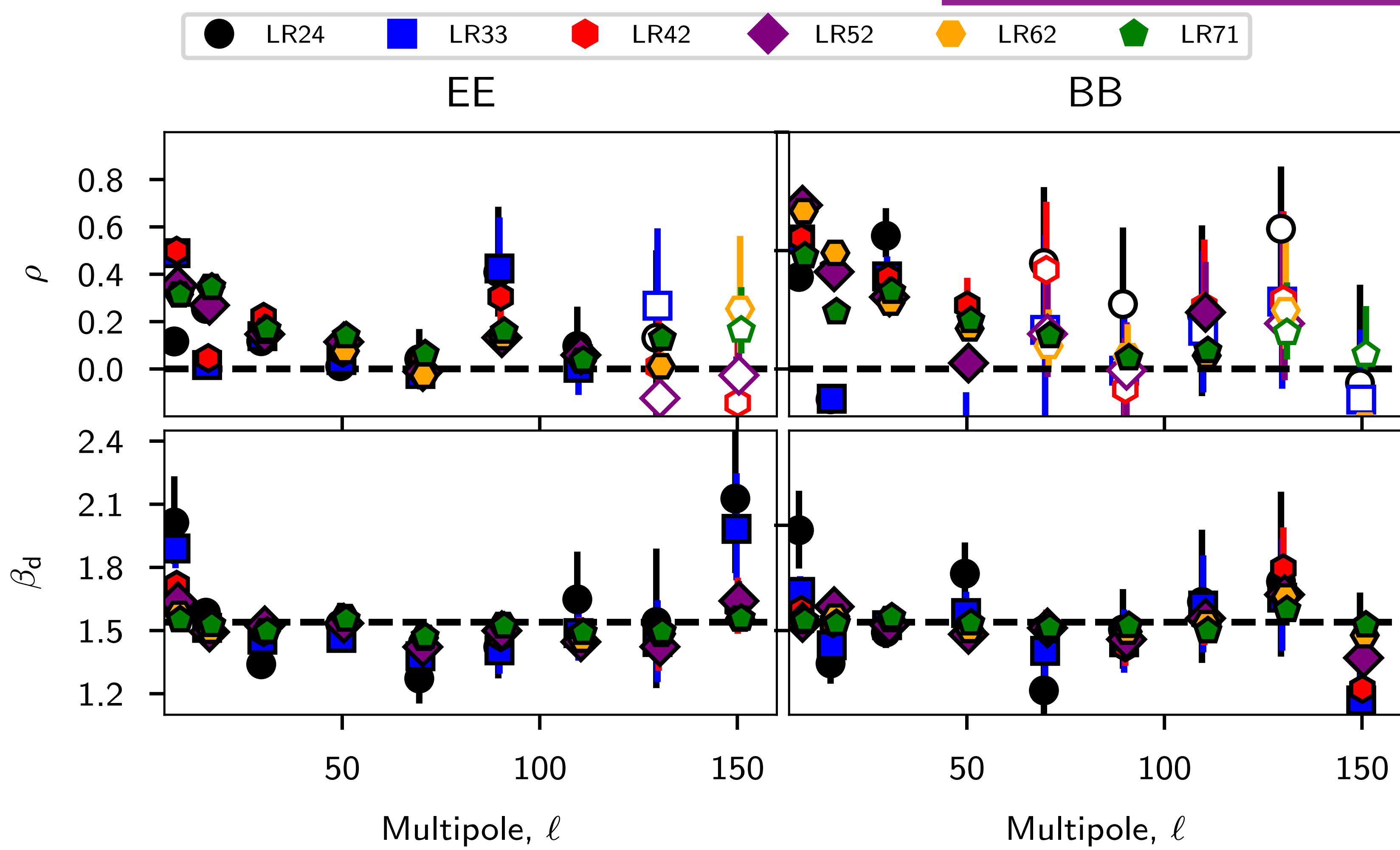
SED analysis

planck

- Multi-frequency analysis: spectral model for polarisation (Choi & Page 2015):

Synchrotron | Dust | Synchrotron x Dust

$$\mathcal{D}_\ell^{XX}(\nu_1 \times \nu_2) = A_s^{XX}\left(\frac{\nu_1\nu_2}{30^2}\right)^{\beta_s} + A_d^{XX}\left(\frac{\nu_1\nu_2}{353^2}\right)^{\beta_d-2}\frac{B_{\nu_1}(T_d)}{B_{353}(T_d)}\frac{B_{\nu_2}(T_d)}{B_{353}(T_d)} + \rho^{XX}(A_s^{XX}A_d^{XX})^{0.5}\left[\left(\frac{\nu_1}{30}\right)^{\beta_s}\left(\frac{\nu_2}{353}\right)^{\beta_d-2}\frac{B_{\nu_2}(T_d)}{B_{353}(T_d)} + \left(\frac{\nu_2}{30}\right)^{\beta_s}\left(\frac{\nu_1}{353}\right)^{\beta_d-2}\frac{B_{\nu_1}(T_d)}{B_{353}(T_d)}\right]$$



$\beta_d^P = 1.53 \pm 0.02$

- Dust-Synchrotron correlation: l-dependent, significant at low multipoles
- Dust spectral index: no dependence on l or sky region
- Small difference between polarisation and intensity spectral index 0.05 ± 0.03.

SED analysis

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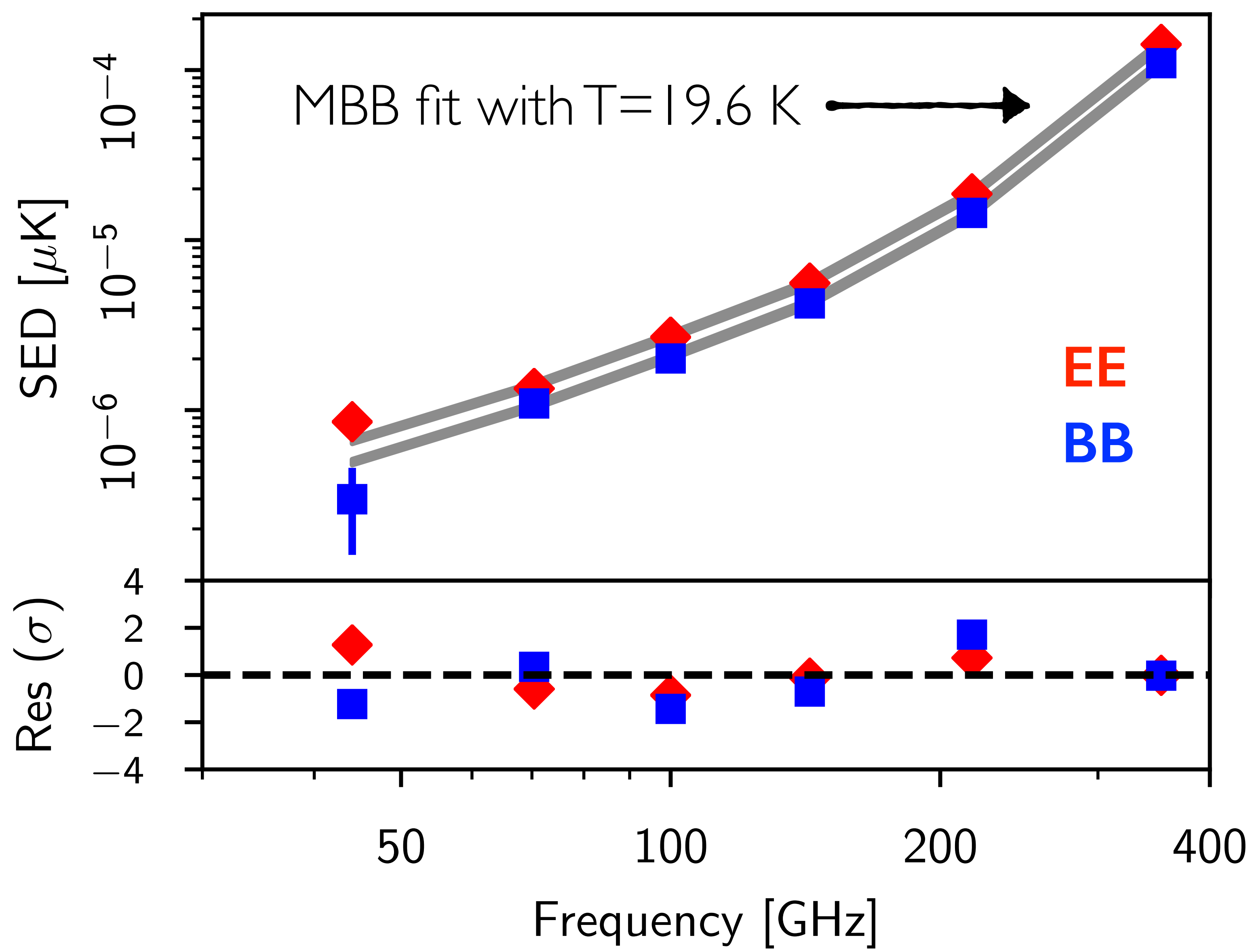
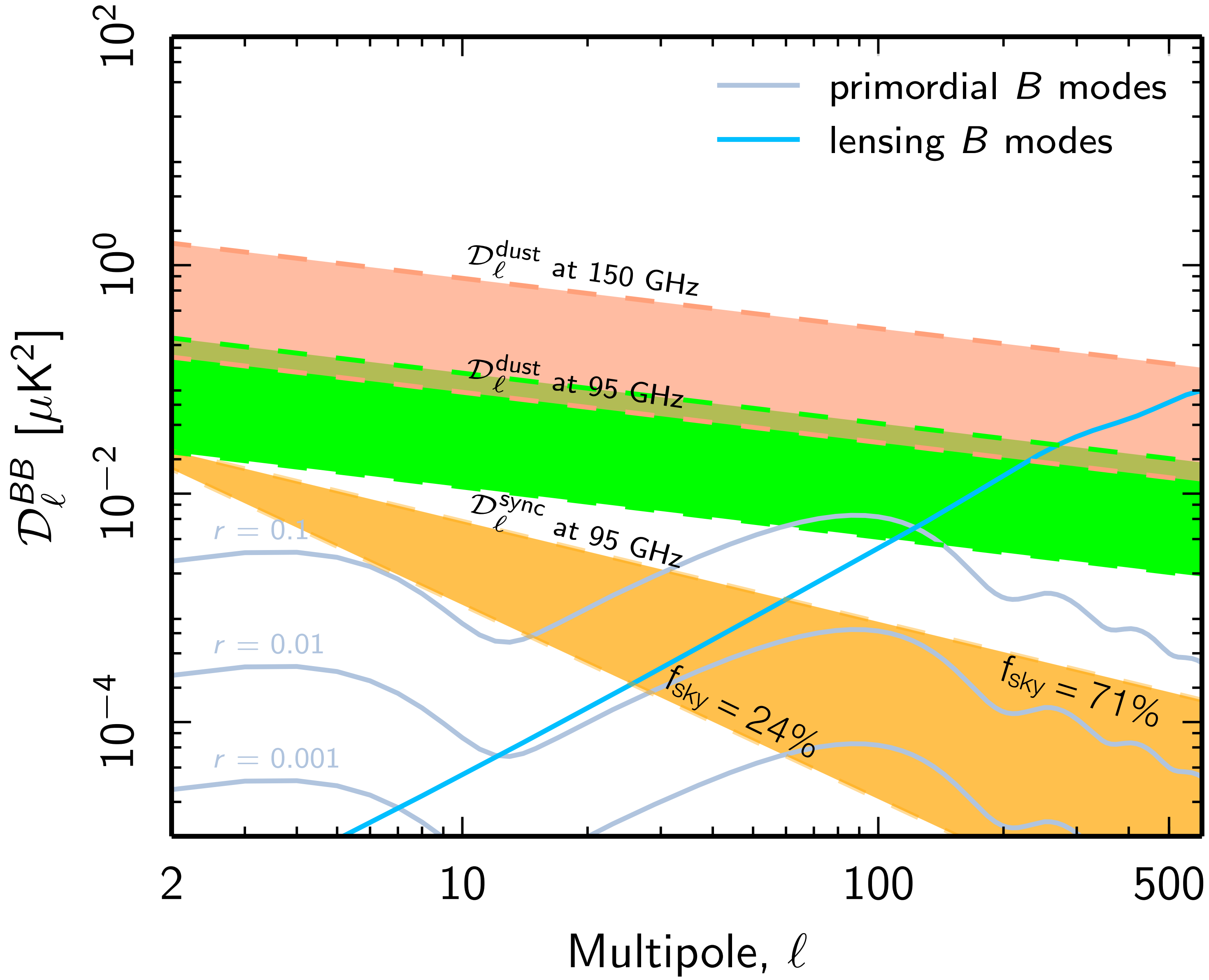
Dust SED from blind component separation: Spectral Matching Independent Component Analysis method (SMICA)

- No prior spectral models of the SEDs are assumed,
- cross-spectra, 30 to 353 GHz,



Foregrounds vs CMB polarisation

- the synchrotron power decreases more steeply than the dust power & the difference is the strongest in the cleanest region (LR24)
- at 90 GHz the dust and synchrotron powers differ by two orders of magnitude, corresponding to the equivalent of $r = 0.1$ and $r = 10^{-3}$, respectively (LR24, $\ell_{\rm bin} = 69.5$)



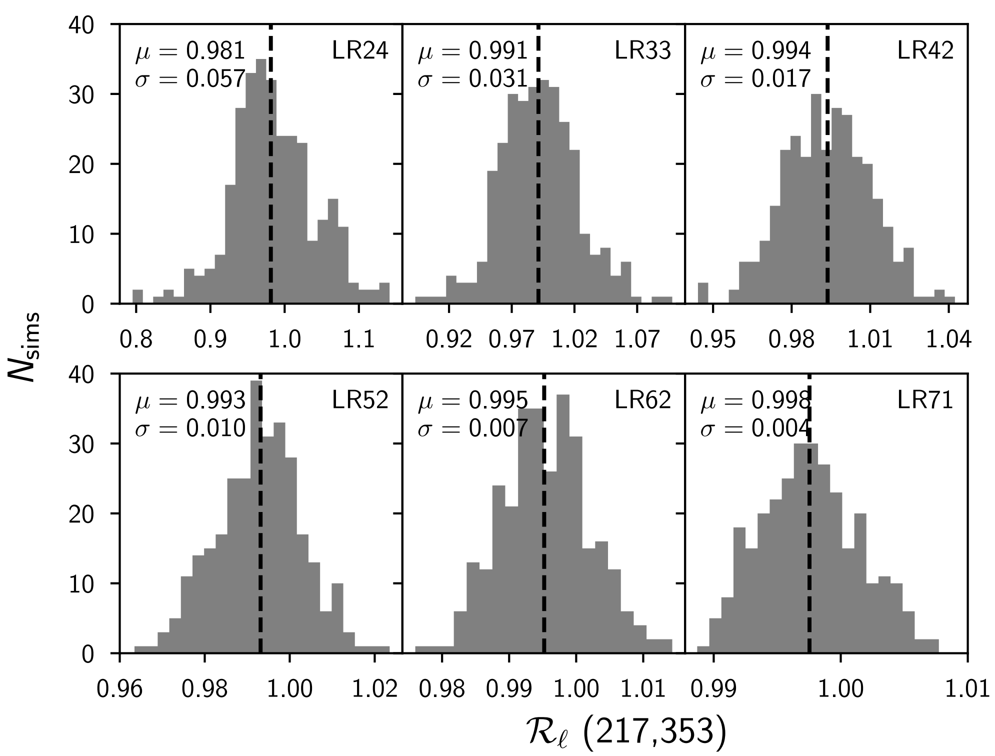
Bottom line: accuracy of dust-CMB B-modes separation to confidently search for primordial B-modes down to $r = 10^{-2}$. At this sensitivity synchrotron polarisation is not a significant foreground (95-150GHz, recombination bump)

Frequency decorrelation

Spatial variations of the spectral behavior of polarized dust emission are a critical issue for the analysis of the CMB: frequency decorrelation is expected at some level

- Revisited PIR-L (2017) analysis 217/353GHz: similar results: decorrelation increasing with smaller fsky, statistical significance revisited (overestimated in PIR-L (2017), see also Sheehy & Slosar (2017))
- Multi frequency analysis 100-353 GHz (caveat model -dependent) :

$$\mathcal{D}_\ell^{\mathrm{BB_d}}(\nu_1 \times \nu_2) = A_\mathrm{d} \left(\frac{\nu_1 \nu_2}{353^2}\right)^{\beta_\mathrm{d}-2} \times \frac{B_{\nu_1}(T_\mathrm{d})}{B_{353}(T_\mathrm{d})} \frac{B_{\nu_2}(T_\mathrm{d})}{B_{353}(T_\mathrm{d})} \quad \exp\left\{-\delta_\mathrm{d}\left[\ln(\nu_1/\nu_2)\right]^2\right\}$$



- Lower limits from E2E simulations

	LR24	LR33	LR42	LR52	LR62	LR71
HFI data	0.935 ± 0.054	0.932 ± 0.039	0.970 ± 0.021	0.983 ± 0.013	0.984 ± 0.008	0.989 ± 0.005
Mean E2E simulations[a]	0.976 ± 0.043	0.988 ± 0.026	0.993 ± 0.016	0.993 ± 0.011	0.995 ± 0.008	0.997 ± 0.005
E2E lower limits[b]	0.865	0.924	0.963	0.973	0.983	0.991
FFP10 dust model[c]	0.987	0.992	0.994	0.996	0.997	0.998
Two-frequency analysis of data[d]	0.822	0.886	0.932	0.954	0.976	0.989
Two-frequency E2E lower limits[e]	0.756	0.854	0.913	0.949	0.965	0.980

Bottom line: no evidence, but current limits still allow the presence of significant variations of the dust spectral index over the sky

Planck summary

- Spectral and frequency analysis of the latest Planck PR3 maps
- multicomponent analysis to measure polarized foregrounds SED as a function of sky regions and multipoles
- Uncertainties based on E2E simulations that includes systematics

★ no departure from one-parameter MBB emission law

★ Small difference between polarisation and intensity spectral index

★ non-zero TE and TB correlation

★The dust-synchrotron correlation dominates at low ells

★No evidence of frequency decorrelation

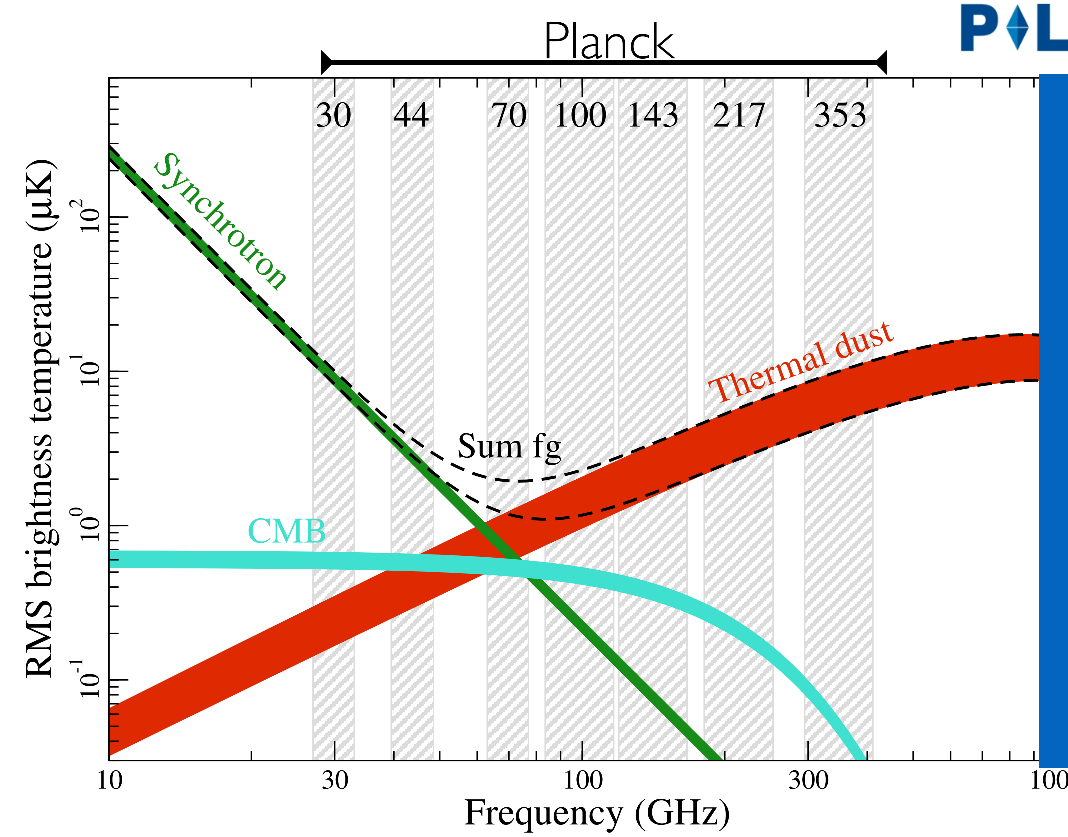
The PILOT balloon experiment

Stratospheric balloon. Measurement of the polarized emission of the dust in the inter galactic medium at 1.2 THz (far infra-red)

Participations: IRAP, (Toulouse, PI: J-P. Bernard), IAS, CEA, CNES, Rome Univ., Cardiff Univ

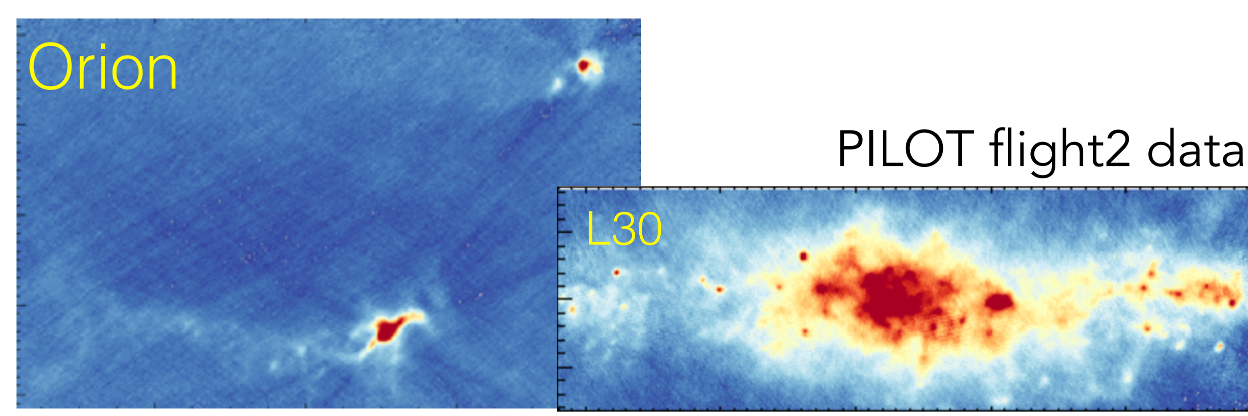
Main scientific goals:

- Reveal the structure of the magnetic field in our Galaxy and nearby galaxies
- Characterize the geometric and magnetic properties of the dust grains
- Understand polarized foregrounds
- Complete the Planck observations at a higher frequency where the dust polarization has never been observed over large sky regions



Observation targets:

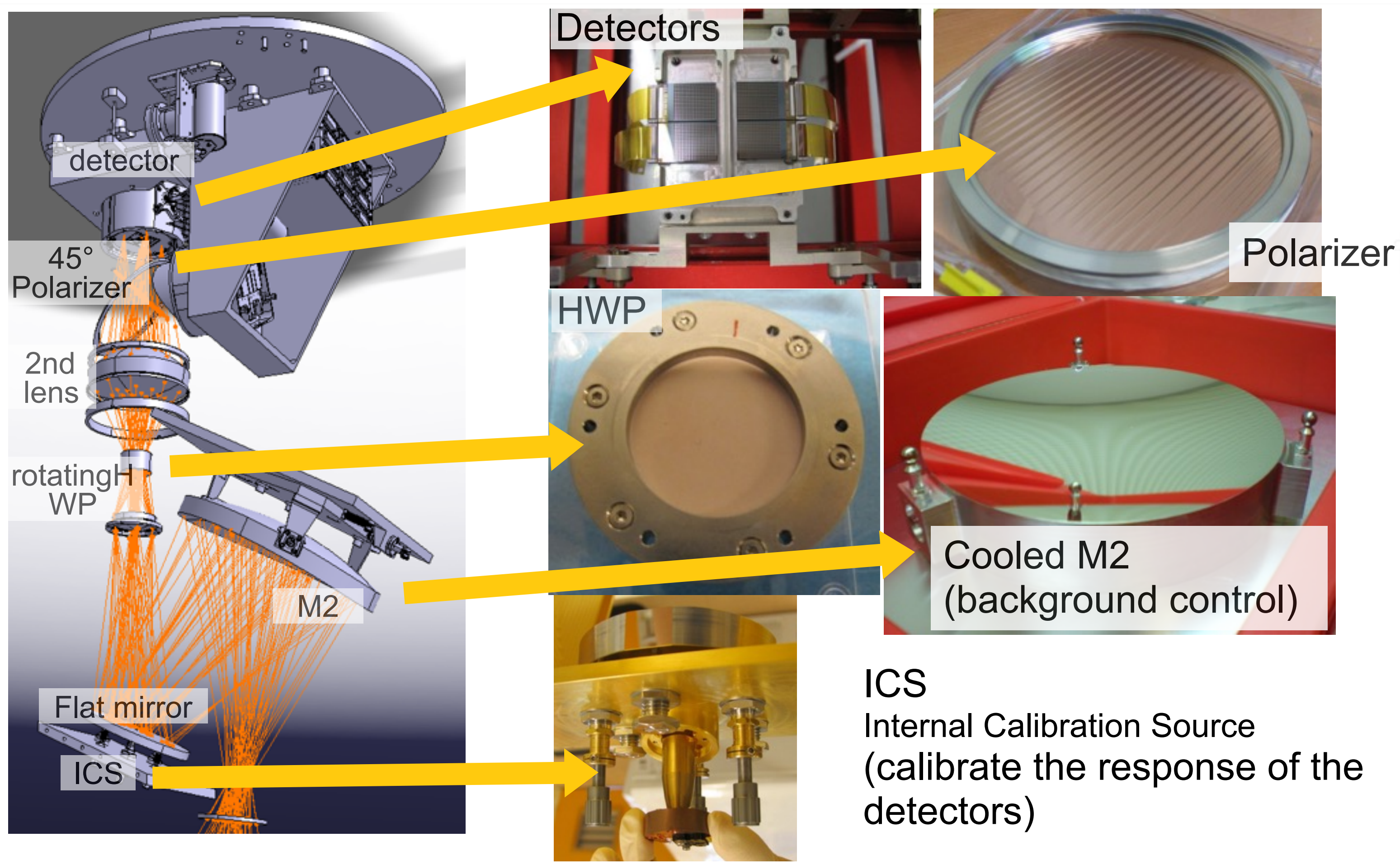
- Star forming regions
- Nearby galaxies
- Galactic plane
- Diffuse regions (e.g. the BICEP2 field)



PILOT flight2 data

The instrument

[The PILOT Collaboration, Bernard et al., Experimental Astronomy, 2016]



- Multiplexed bolometer arrays with a total of 2048 detectors at 240 µm
- Detectors cooled down to 300mK through closed-cycle He3 fridge
- NEP ~ 3×10^{-16} W/Hz$^{1/2}$

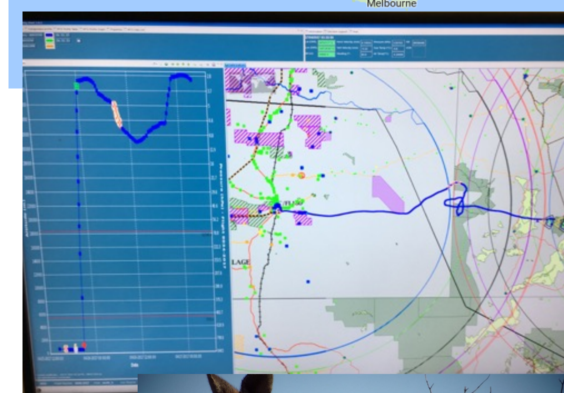
Observations at different HWP angles allow to reconstruct the Stokes parameters I, Q, U

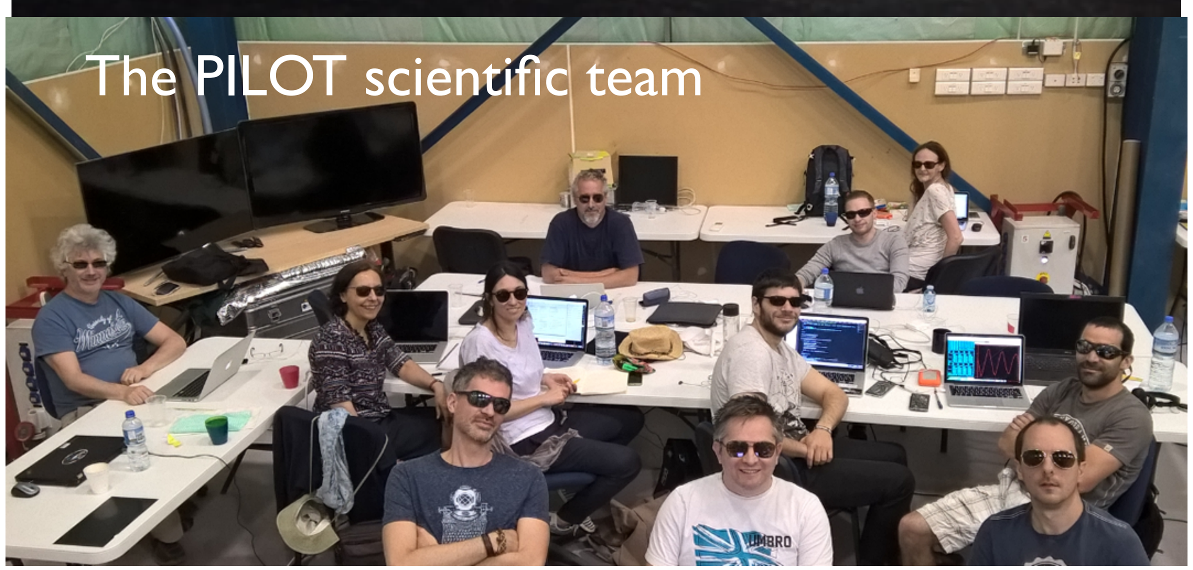
PILOT Flights

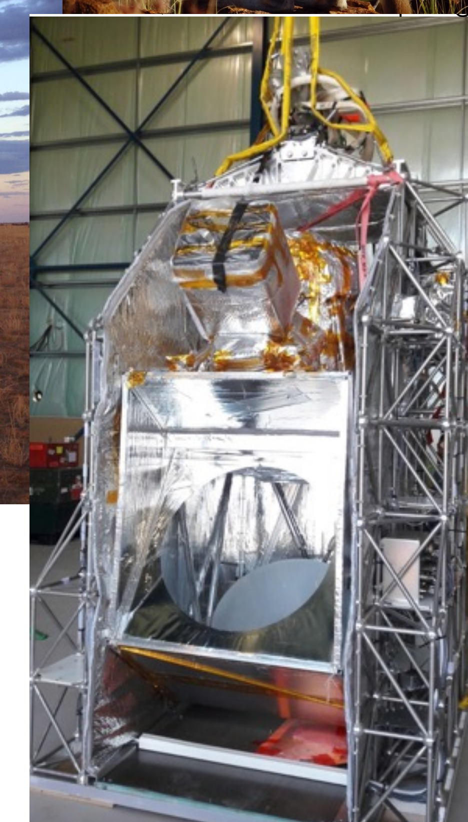
21/09/2015 Timmins Ontario (Canada); 16/04/2017 Alice Springs (Australia)

FLIGHT2:

- Total flight time: 33.5 h
- Total time at ceiling: 29 h
- Ceiling altitude: 32-40 Km
- Scientific data: 23.8 h







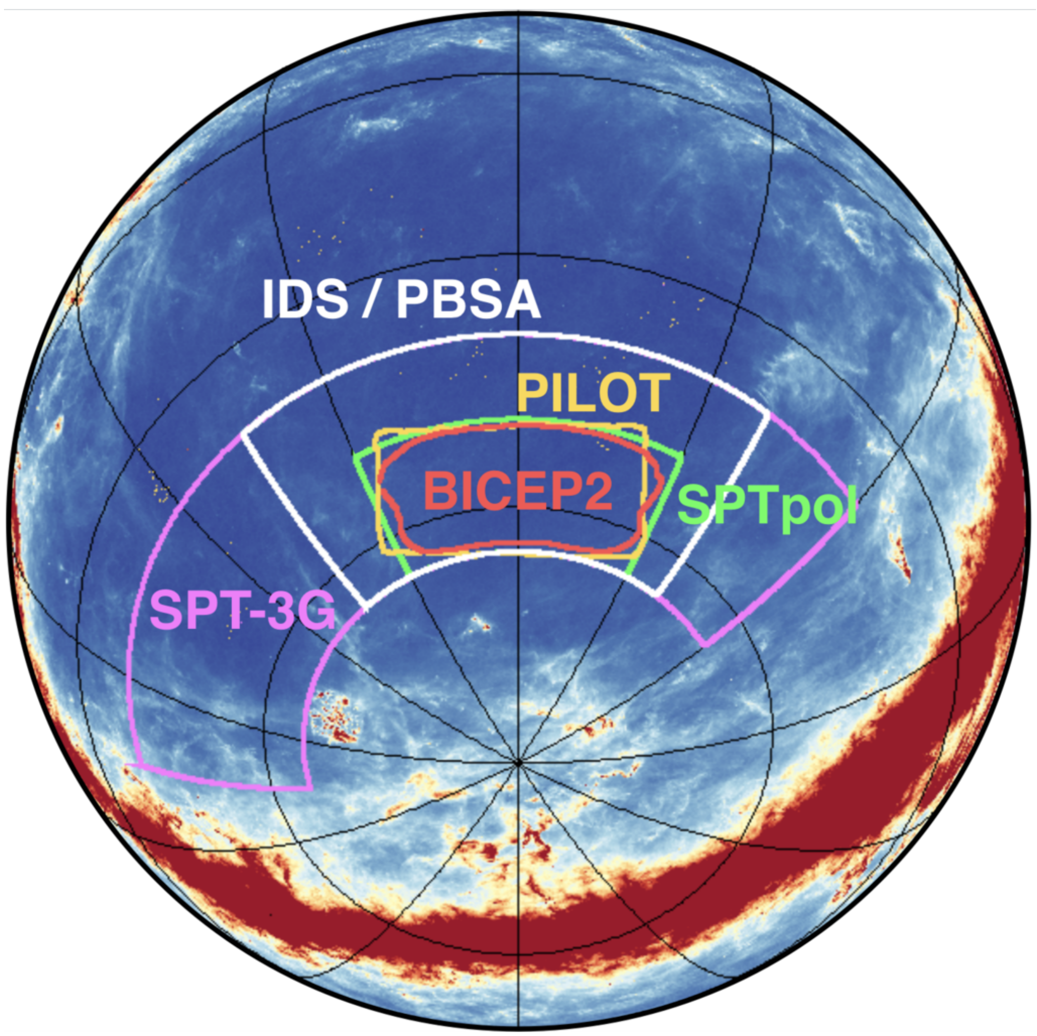
PILOT was recovered 836 Km east of Alice Spring in a desert area

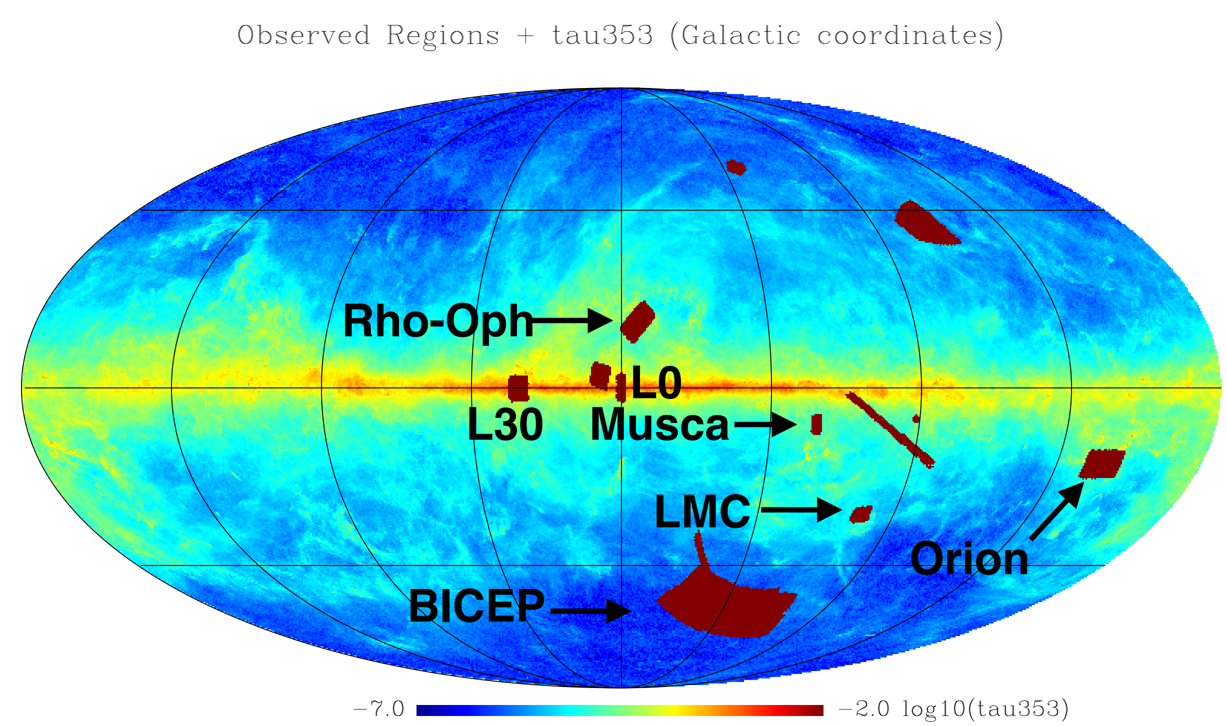
Gondola back to Alice Springs: looks ready to fly again!

Flight2 observations

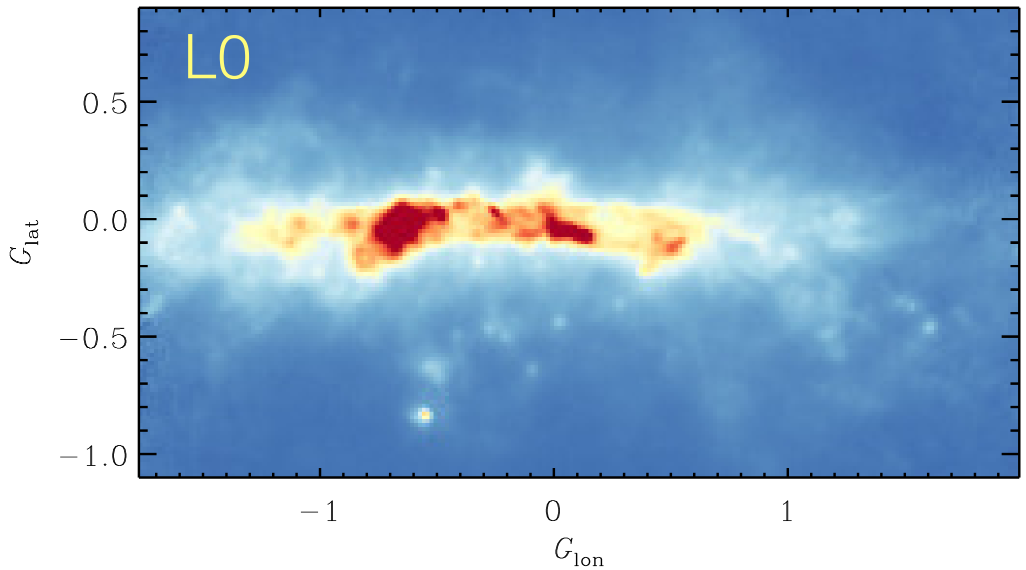
Sources	Nb scenes	t obs	Map size	scene depth	total depth
		[mn]	[deg x deg]	[Deg^2/h]	[Deg^2/h]
L30	8	72.	5 x 5	187	21
L0	4	32	2 x 5	75	18.8
LMCridge	16	134.4	3.5 x 1	15.7	1.6
LMCridgeBIG	19	232.5	4.0 x 2	39.2	2.0
Orion	6	140.8	5 x 10	127.8	21.3
BICEP	14	290.1	30 x 12	253.1	74.5
Rho-oph	11	268.8	9 x 4	88.4	8.0
Musca	14	185.6	2 x 3	27.0	1.9
JUPITER	5	27.7	3 x 2	65.0	13.0
SATURN	3	23.5	5 x 3.4	130.2	43.0
SkyDip	8	21.3	1 x 32.0		
Total:	104	1428.7 (23.8h)	--	--	--

- Galactic plane: L0, L30 (1h30)
- Star forming regions: Orion, Rho-Oph. , Musca (10h)
- Large Magellanic Cloud (6h)
- Diffuse region: BICEP field (5h)
- Planets: Saturn & Jupiter (1h)





Polarisation results on galactic center (L0)

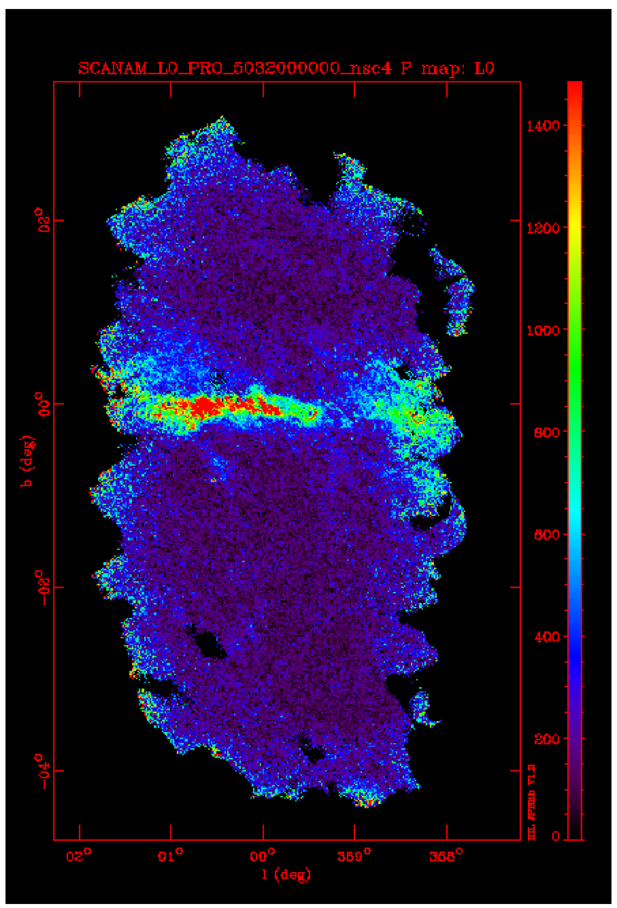


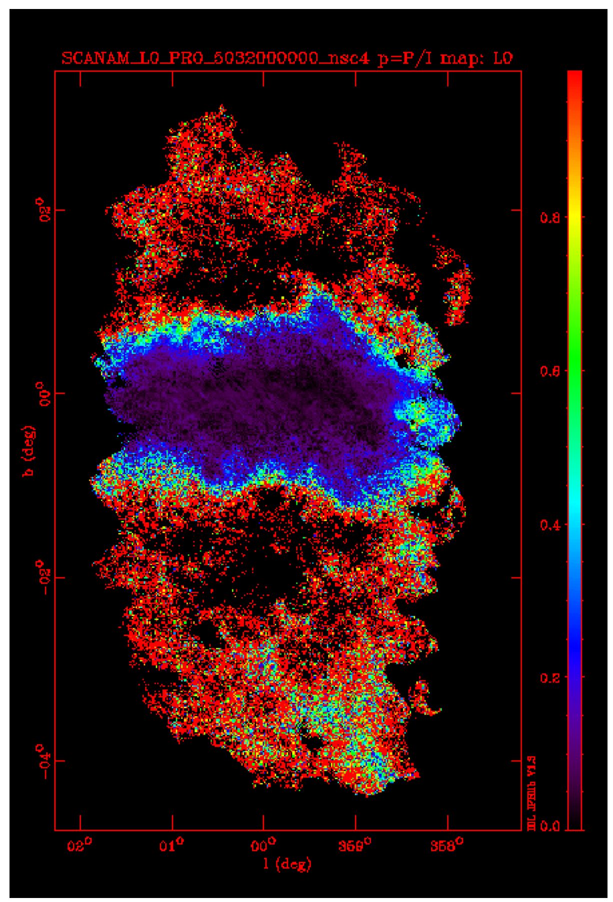
- 4 observations (~30min)
- Very bright (intensity): check data calibration, detector responses and inter-calibration
- Weakly polarized (~2%)

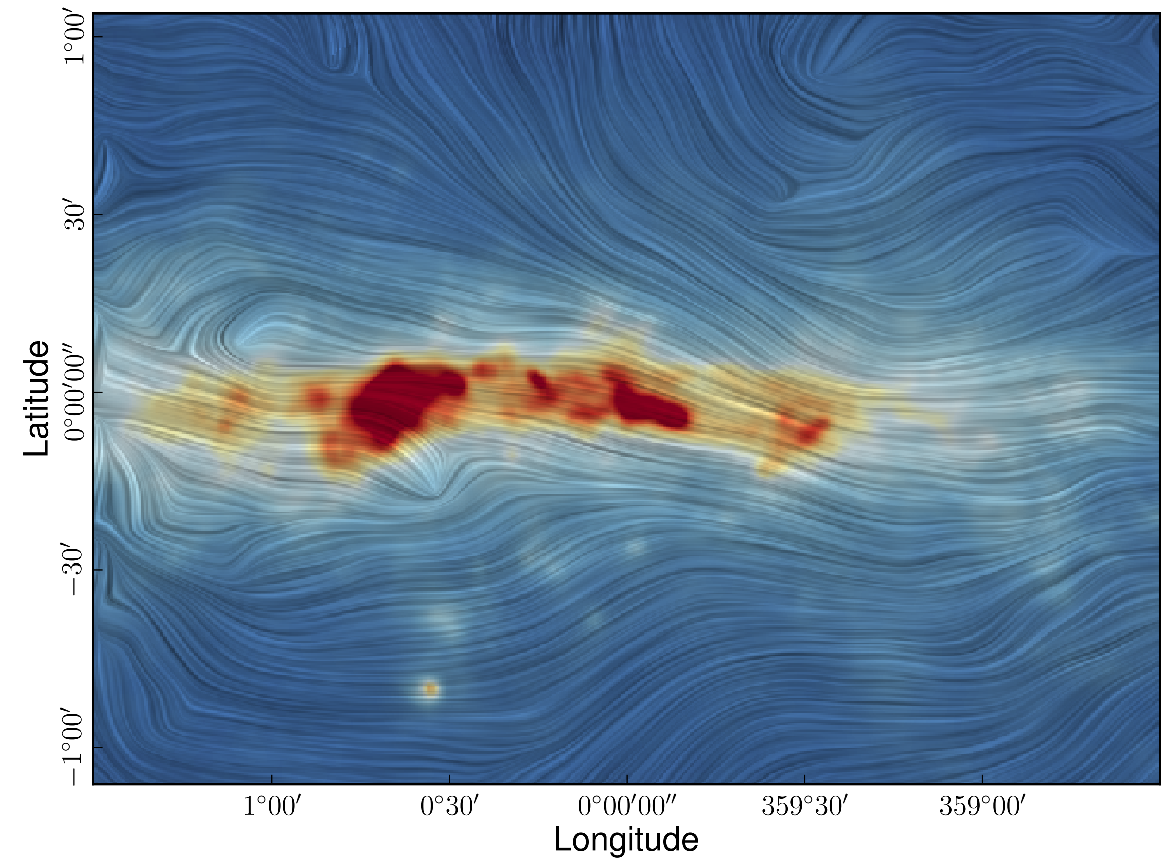
Preliminary!

$$P = \sqrt{Q^2 + U^2}$$

$$p = \frac{\sqrt{Q^2 + U^2}}{I}$$







- the orientation of the magnetic field along the galactic plane in agreement with expectations
- Pilot analysis on the galactic center confirms a good control of gain inter-calibration

PILOT

- 2 successful flights (2015, 2017). Flight 3 on the northern hemisphere foreseen for 2019
- first PILOT polarization maps on bright but weakly polarized source (L0)
- First and only high frequency (1.2 THz) observation of the BICEP field with expected SNR p of ~16

LESSON LEARNT SO FAR

- Instrumental background is polarized
  - Could be a problem for future experiments, if variable
  - Can change bolometer response
- Internal calibration source highly beneficial
- Detector inter-calibration possible on un-polarized residual atmospheric signal

[The PILOT Collaboration, Foenard, Mangilli et al., 'In-flight performances',sub. Exp. Astr. 01/2018]

PILOT & CNES LEGACY

- High success rate of balloon launching campaigns
- 1-2 days flights from mid-latitude, ~40 km altitude, 1 ton
- NOSYCA telemetry system (high rate, 500 km per portable antenna)
- Pointed gondolas
- Day/night pointing system (ESTADIUS), accuracy of a few arc-seconds while scanning at a few °/sec

PILOT team & CNES involved in the IDS proposal to NASA

CONCLUSIONS

Understanding the polarised galactic foregrounds is the main issue for current and future CMB B-modes measurements at the reionization and the recombination bumps

- Latest Planck analysis (PIR-LIV, 2018, PR3 polarised maps):
  - no departure from one-parameter MBB emission law
  - frequency decorrelation and synchrotron should not be an issue for r=0.01

HOWEVER

- A level of decorrelation is expected (and not excluded by Planck data) and can be a serious issue for lower r
- Decorrelation might not be homogeneous over the sky
- Synchrotron-dust correlation at low-l increase the complexity of the CMB B-modes measurement at the reionization bump

Develop increasingly realistic models for the polarized foregrounds is a critical and urgent issue

Work in progress

A. Mangilli, J. Aumont, L. Montier, F. Boulanger, T. Gosh in prep.

PILOT

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