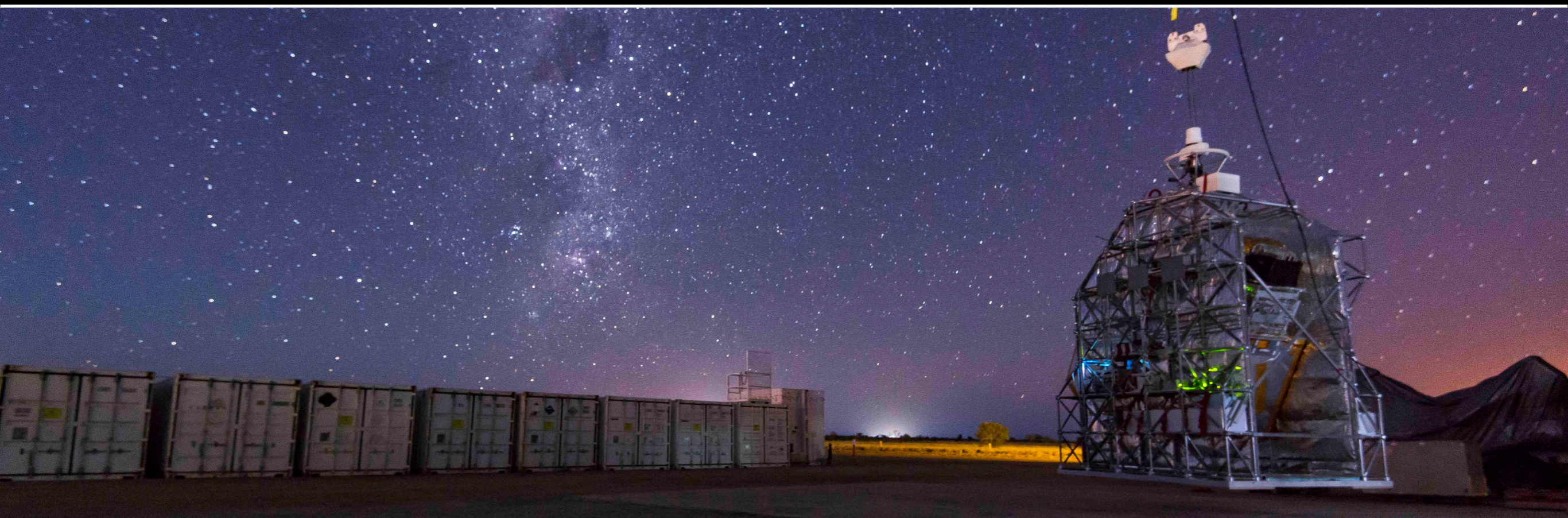


PILOT

A far-infrared balloon-borne polarization experiment



Jonathan Aumont

IRAP — Toulouse, France

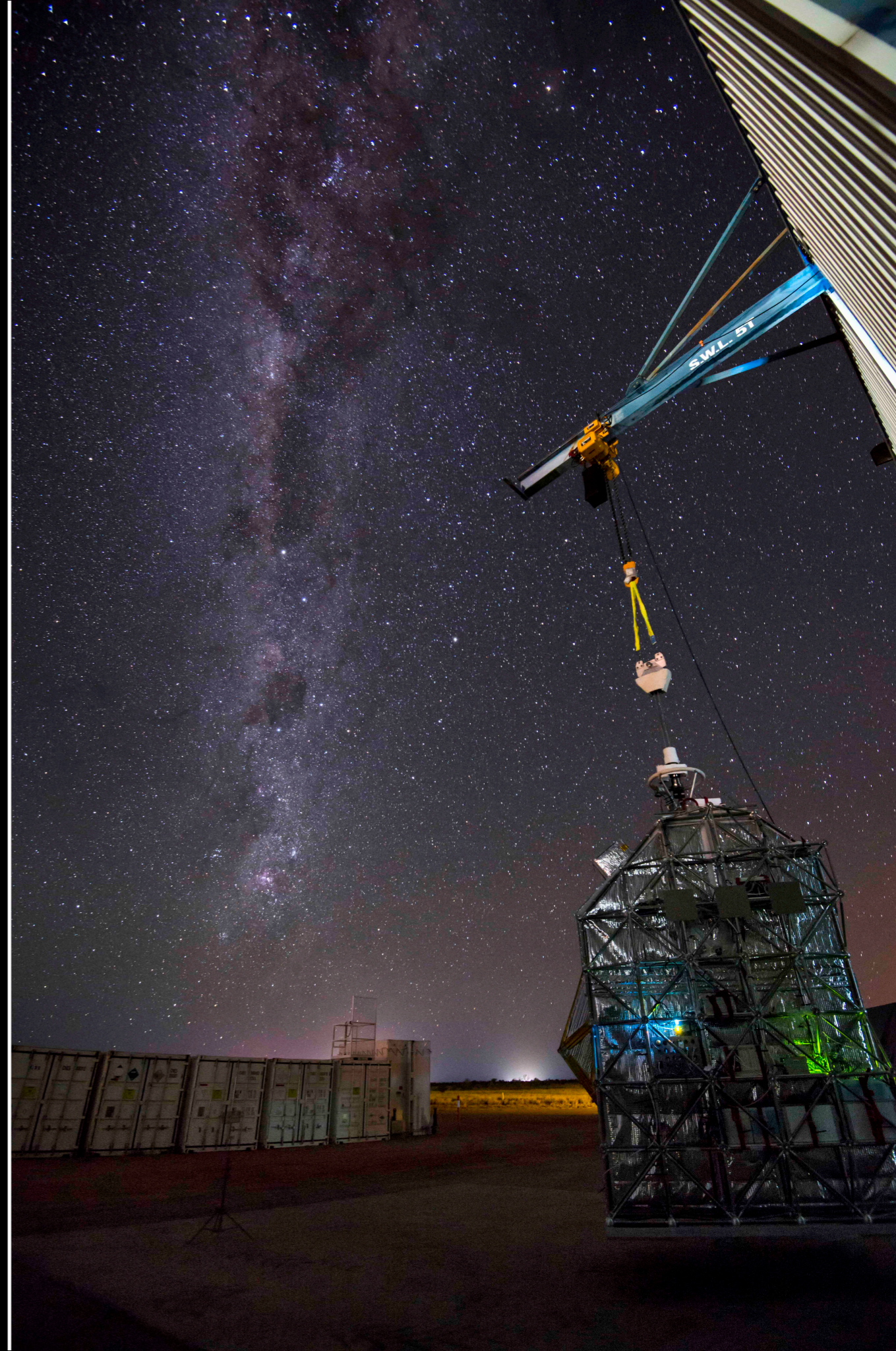
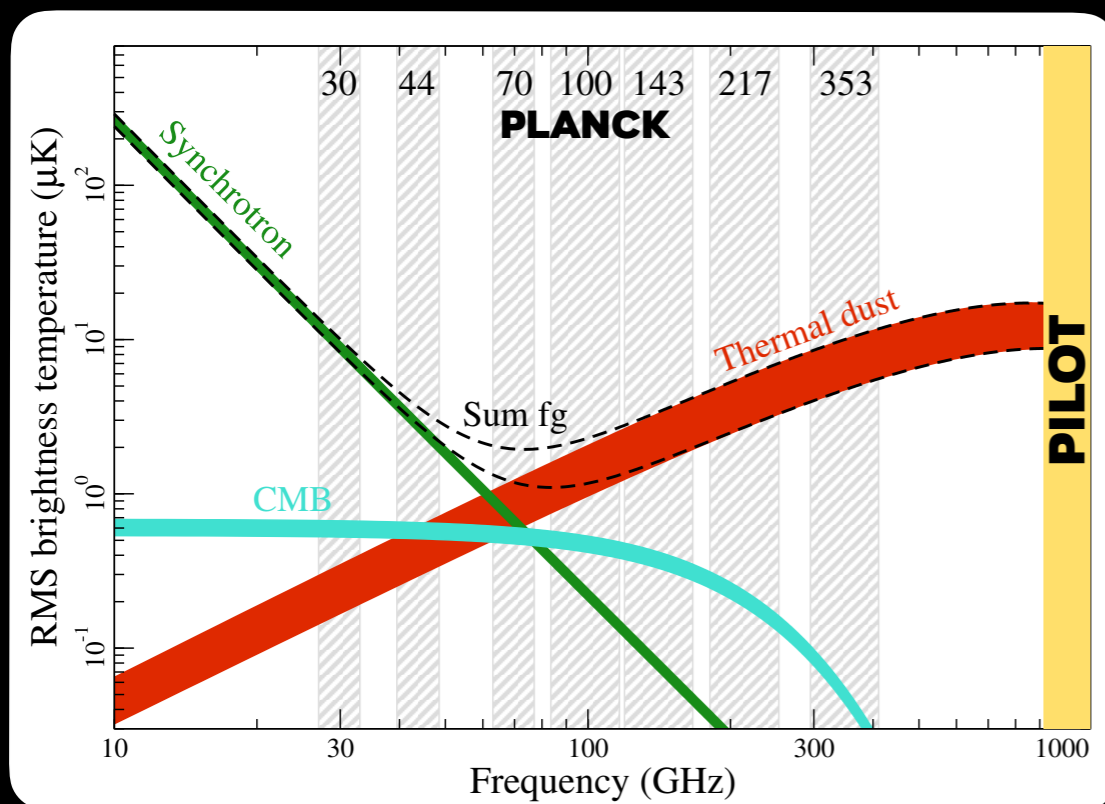
J.-Ph. Bernard (PI), A. Mangilli, A. Hughes, G. Foënard, I. Ristorcelli, G. De Gasperis, H. Roussel,
on behalf of the PILOT Collaboration

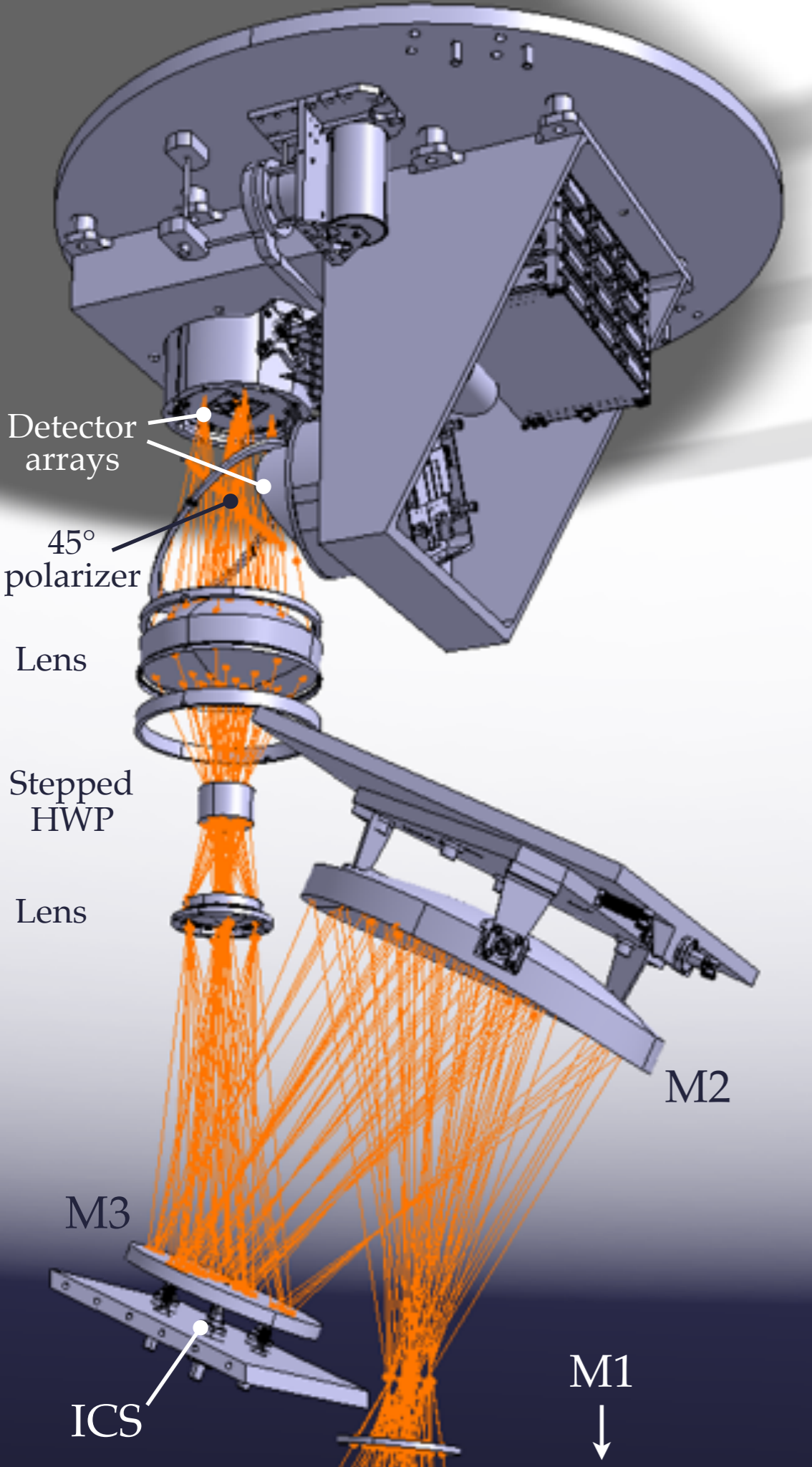
CMB Foregrounds - Tenerife - October 16th 2018

PILOT

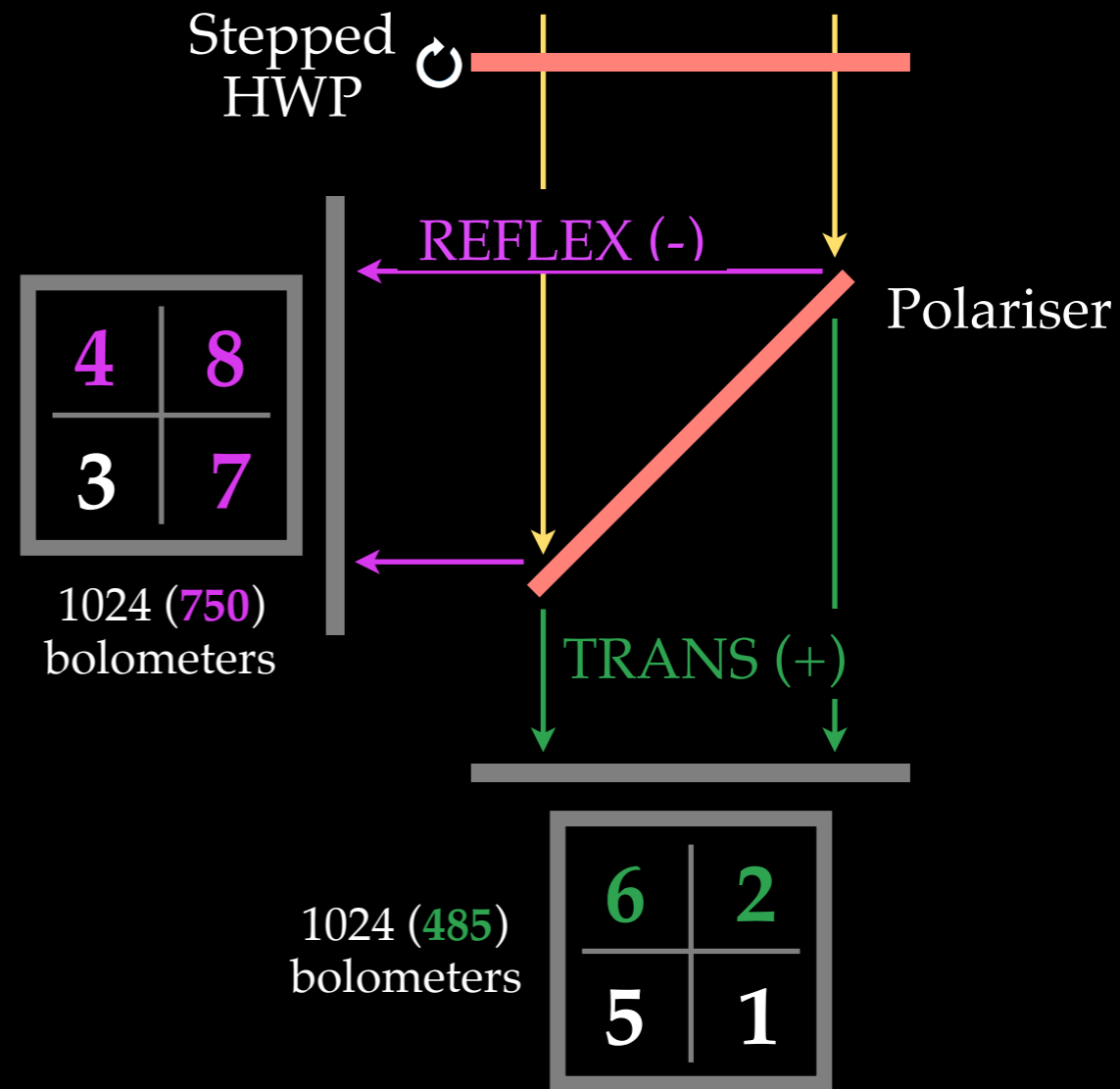
1.2 THz far-infrared polarization experiment

- ★ 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





PILOT – Instrument



- ★ Multiplexed bolometer arrays with a total of 2048 detectors at 240 μm (1249 GHz), 2' resolution
- ★ Observations at more than 2 HWP angles to reconstruct the Stokes parameters I, Q, U
- ★ Detectors cooled down to 0.3 K through closed-cycle ^3He fridge
- ★ NEP $\sim 4 \times 10^{-16} \text{ W/Hz}^{1/2}$
- ★ Control of systematics and detector response at 1% level

PILOT

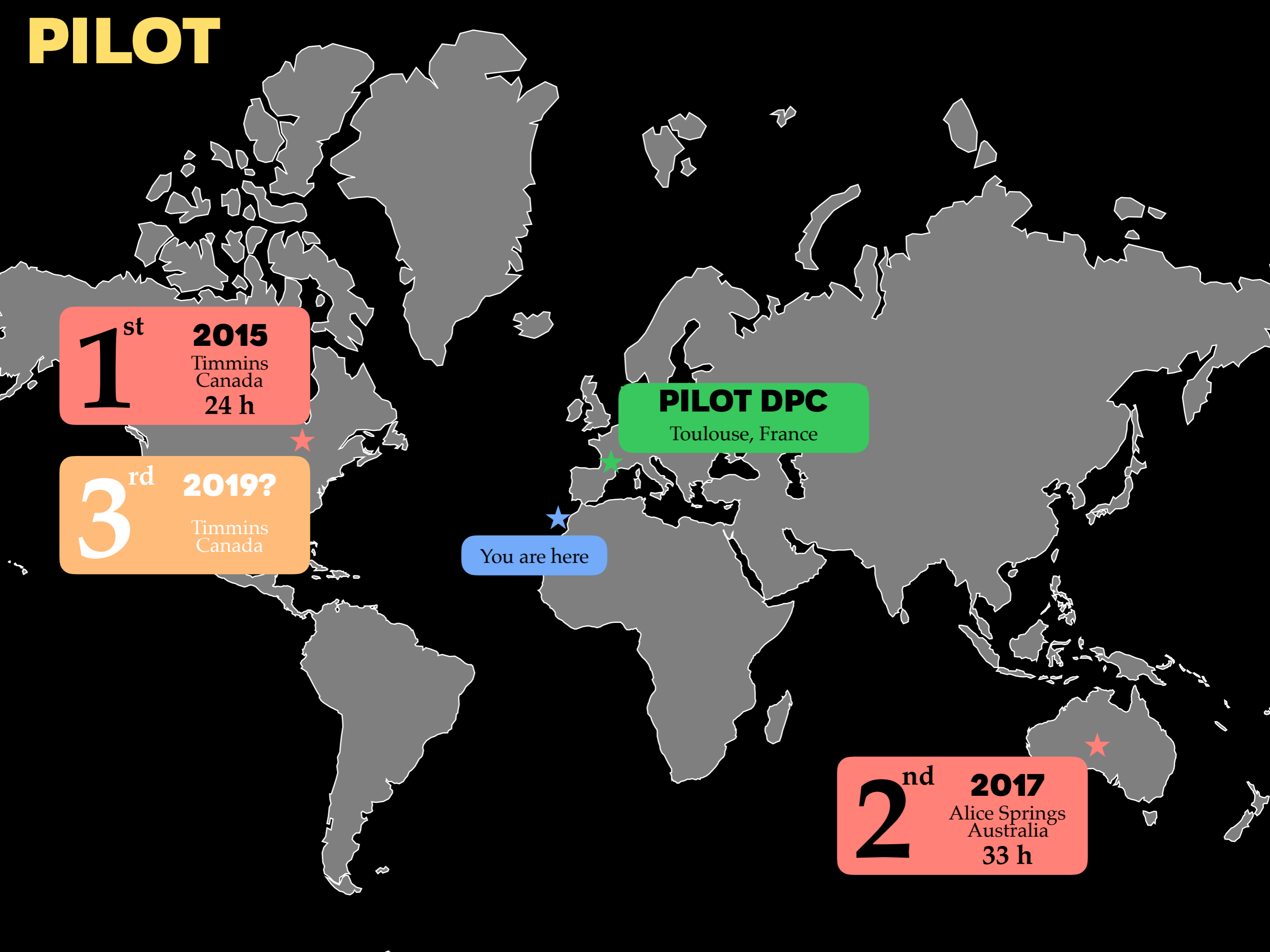
1st **2015**
Timmins
Canada
24 h

3rd **2019?**
Timmins
Canada

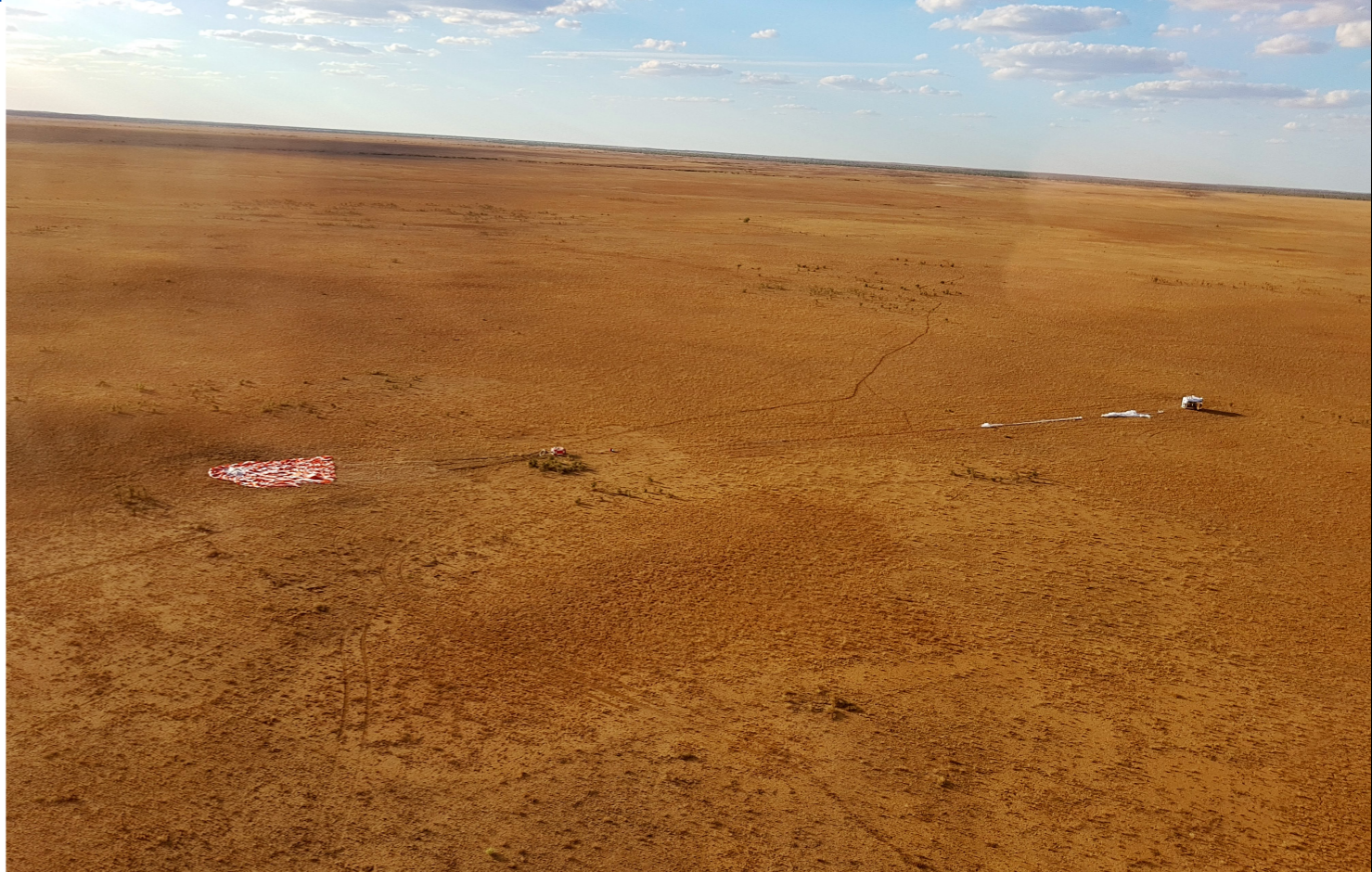
PILOT DPC
Toulouse, France

You are here

2nd **2017**
Alice Springs
Australia
33 h



PILOT — 2nd flight

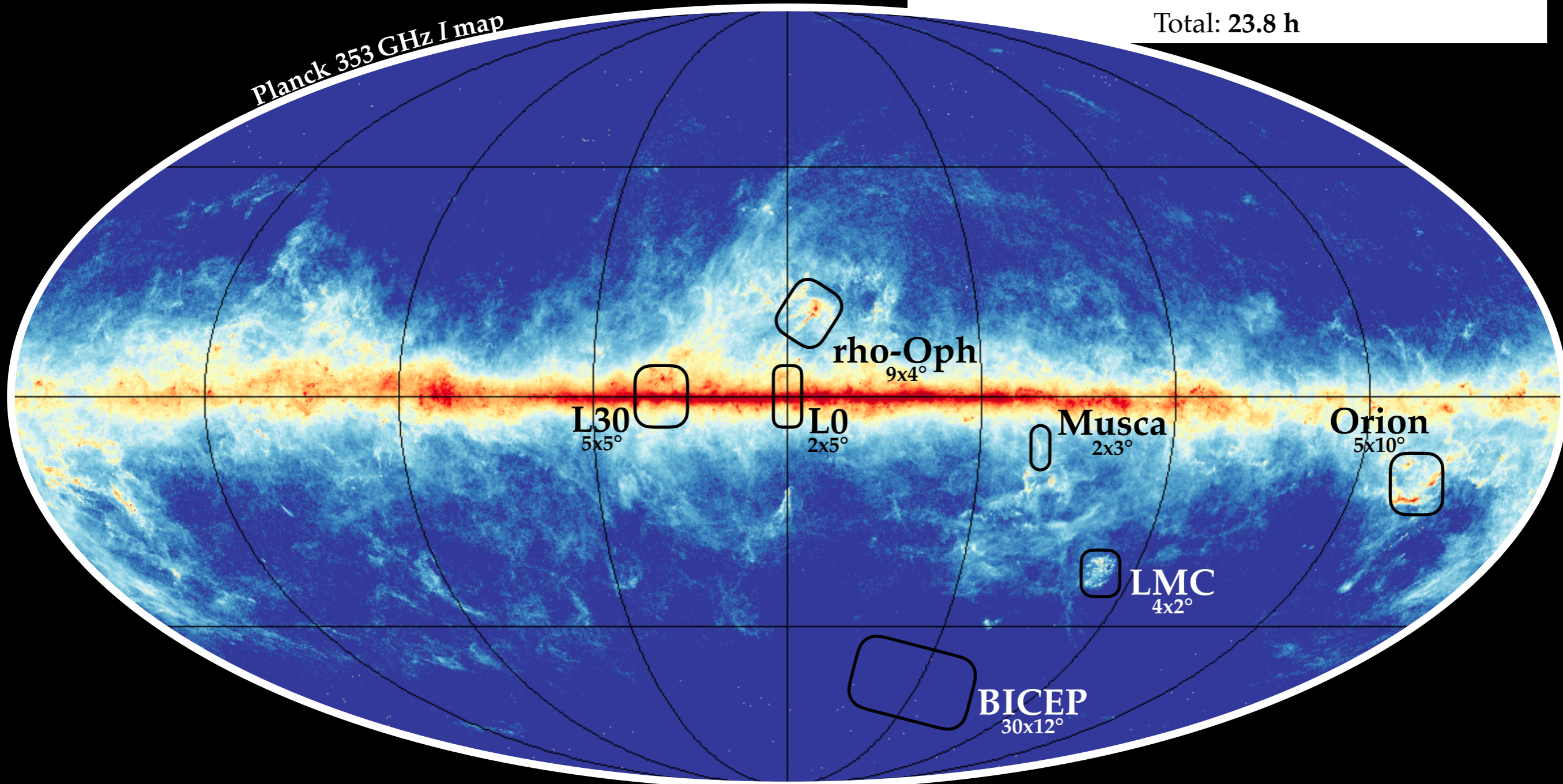


PILOT – 2nd flight

April 16th, 2017 from Alice Springs, Australia

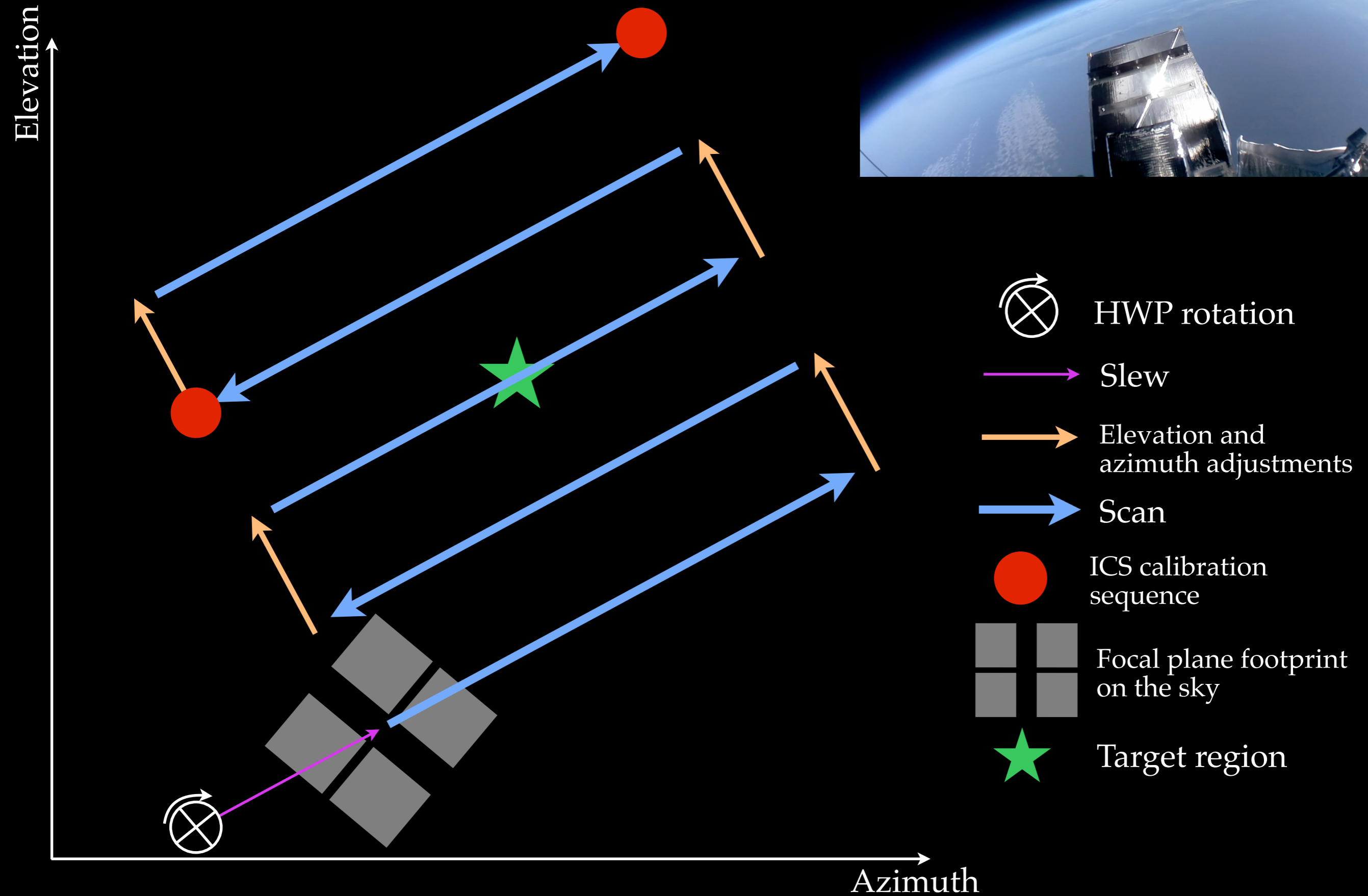
- ★ Total flight time: 33.5 h
- ★ Scientific data: **23.8 h**
- ★ Ceiling altitude: 32-40 Km

Galactic plane, 1.7 h, 7.1 %
Star forming regions, 9.9 h, 41.6 %
Galaxies, 6.1 h, 25.6 %
Diffuse field, 4.8 h, 20.2 %
Planets, 0.8 h, 3.5 %
Calibrations in all these scenes, 1.2 h, 5%
Total: 23.8 h



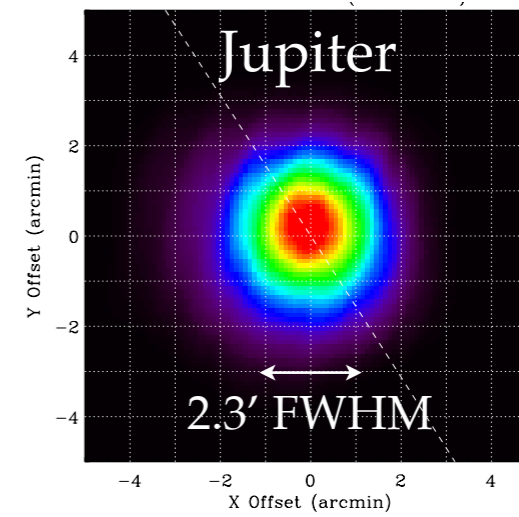
Note: most of these sources are not observable in balloon from South Pole (e.g. BLASTPol, SPIDER)

PILOT – Scanning strategy



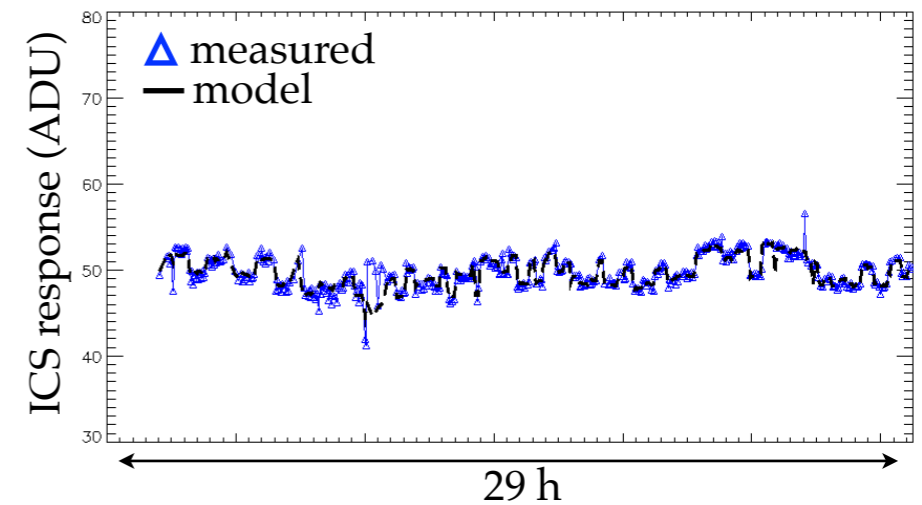
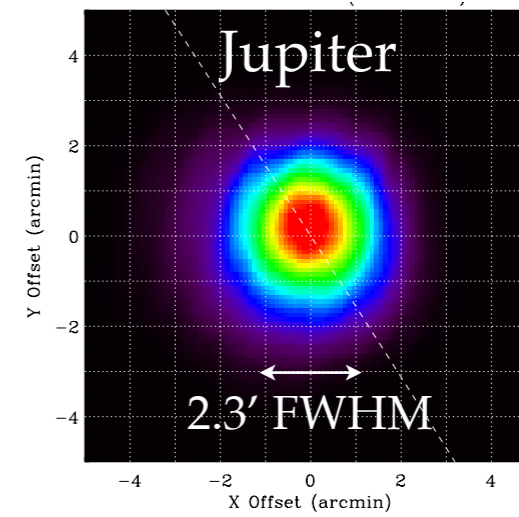
PILOT – In-flight performances

- ★ In-flight good optical quality and nominal resolution



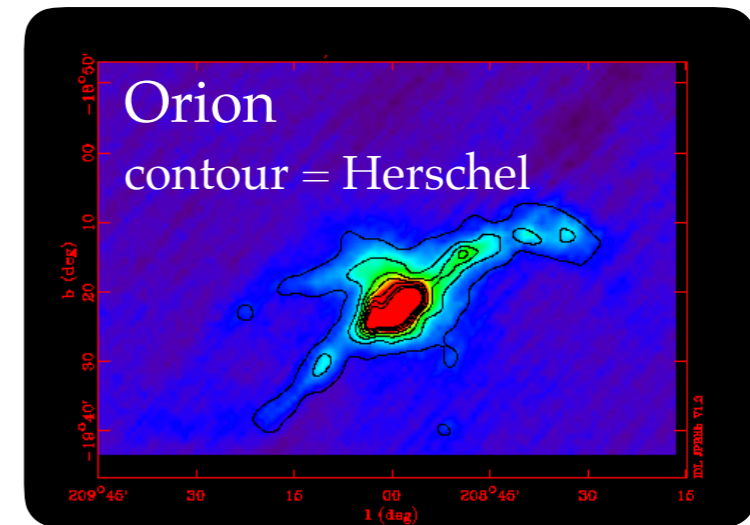
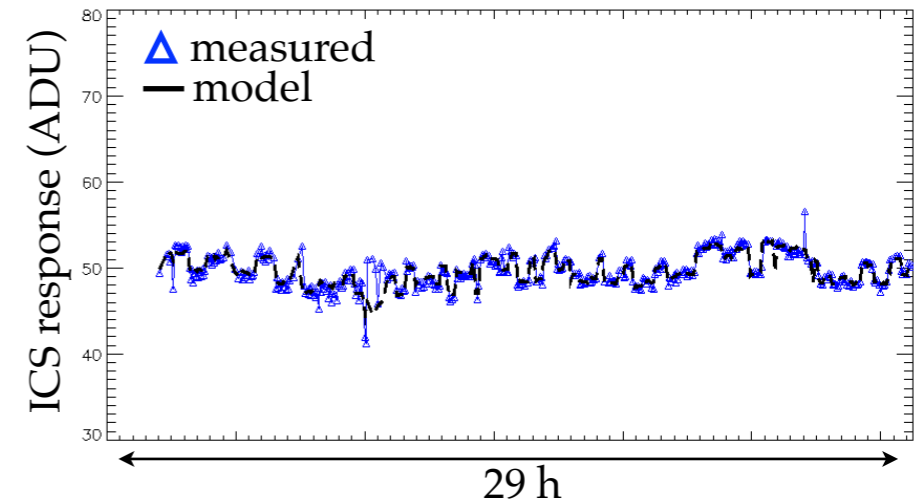
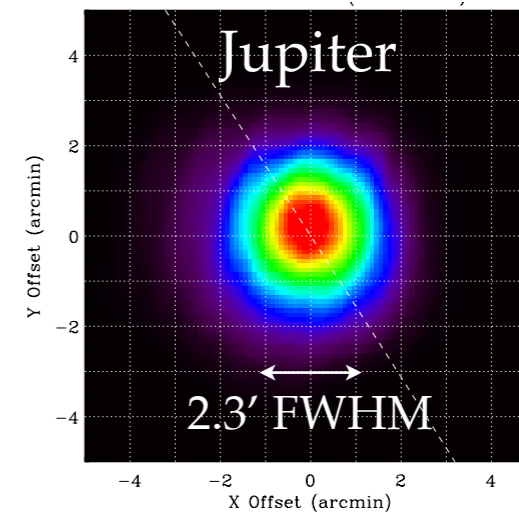
PILOT – In-flight performances

- ★ In-flight good optical quality and nominal resolution
- ★ In-flight background has a similar shape but is a factor ~ 2 stronger than ground measurements. Polarized at 4-10 % level
- ★ Variation of the detector responses due to polarized background & atmosphere variations. Modelled and corrected to better than 2 %



PILOT – In-flight performances

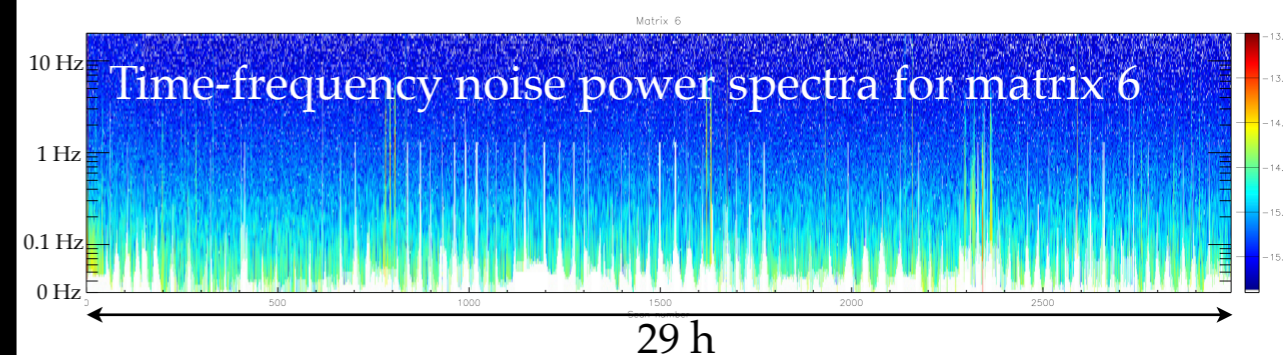
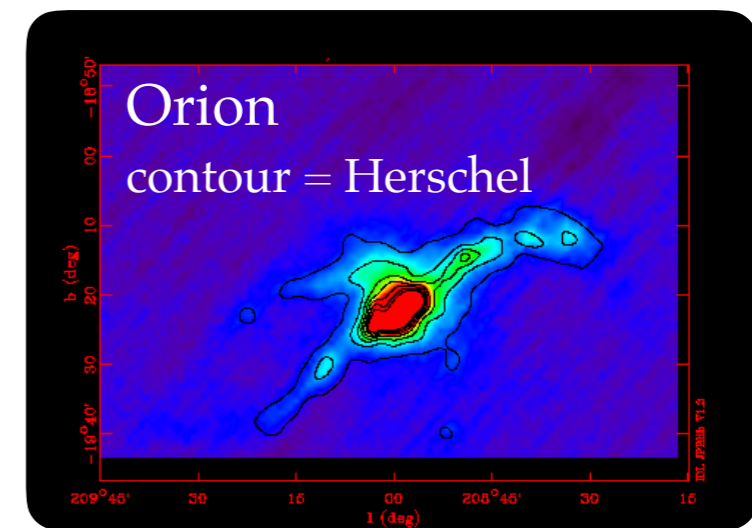
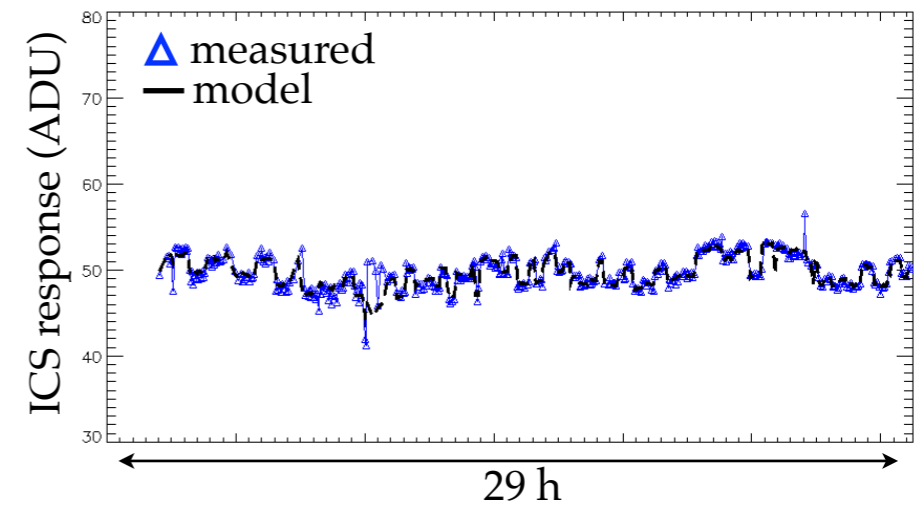
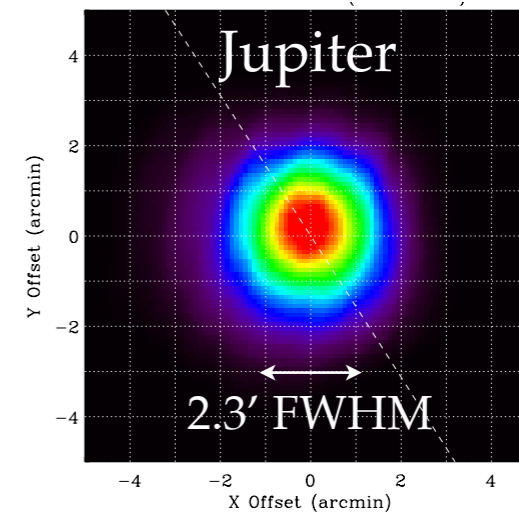
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- ★ Pointing offset varies during flight. Pointing model constructed from elevation + temperatures and Herschel comparison, better than 1'
- ★ Spurious polarization measured on Jupiter of $\sim 3\%$



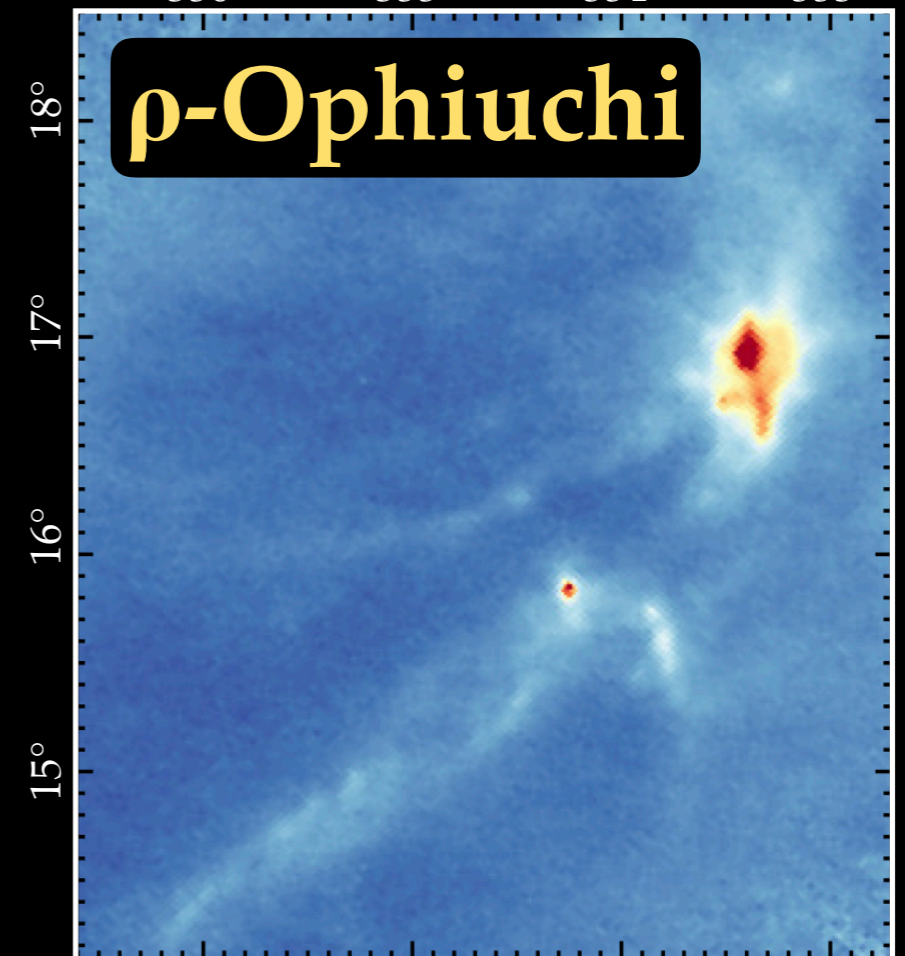
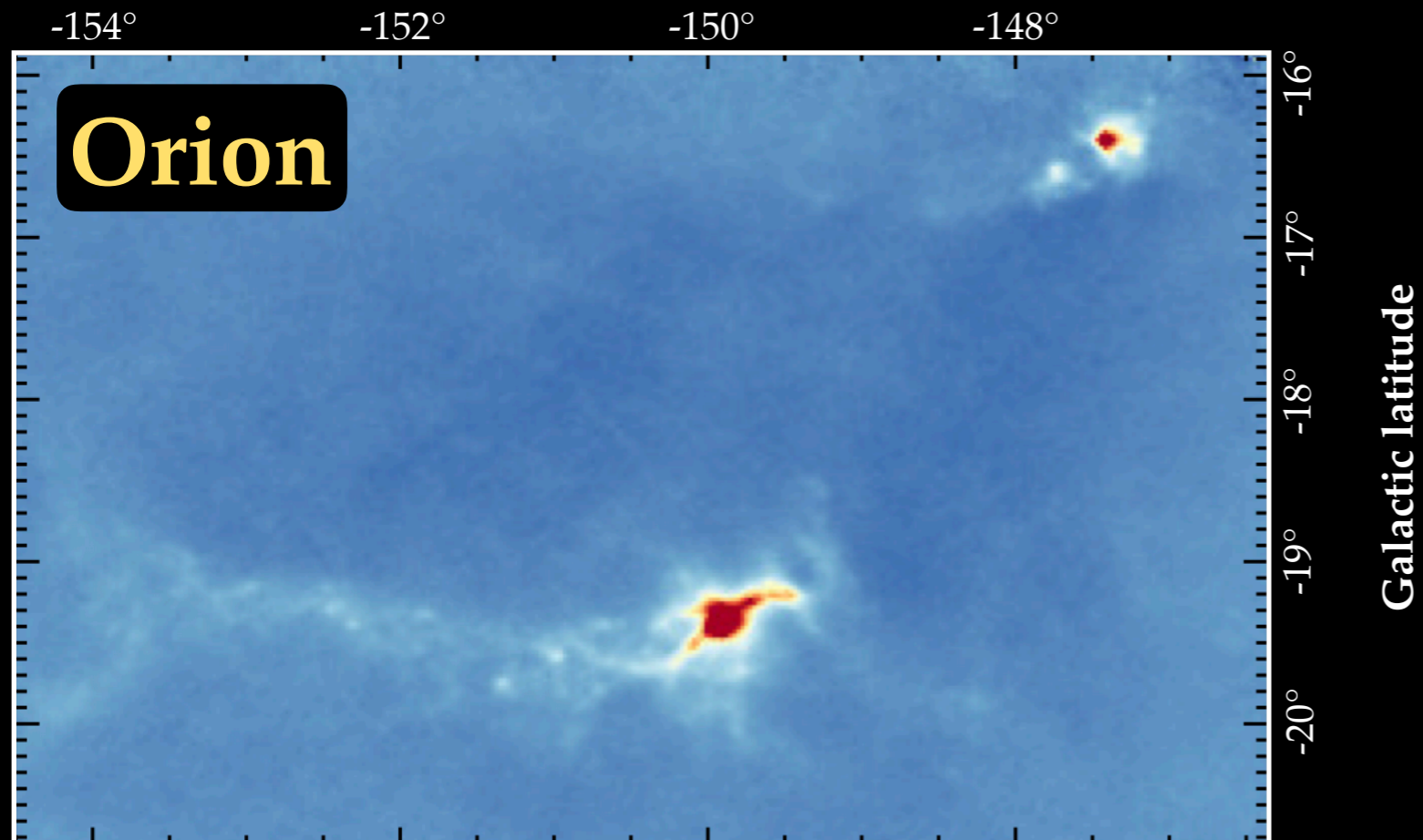
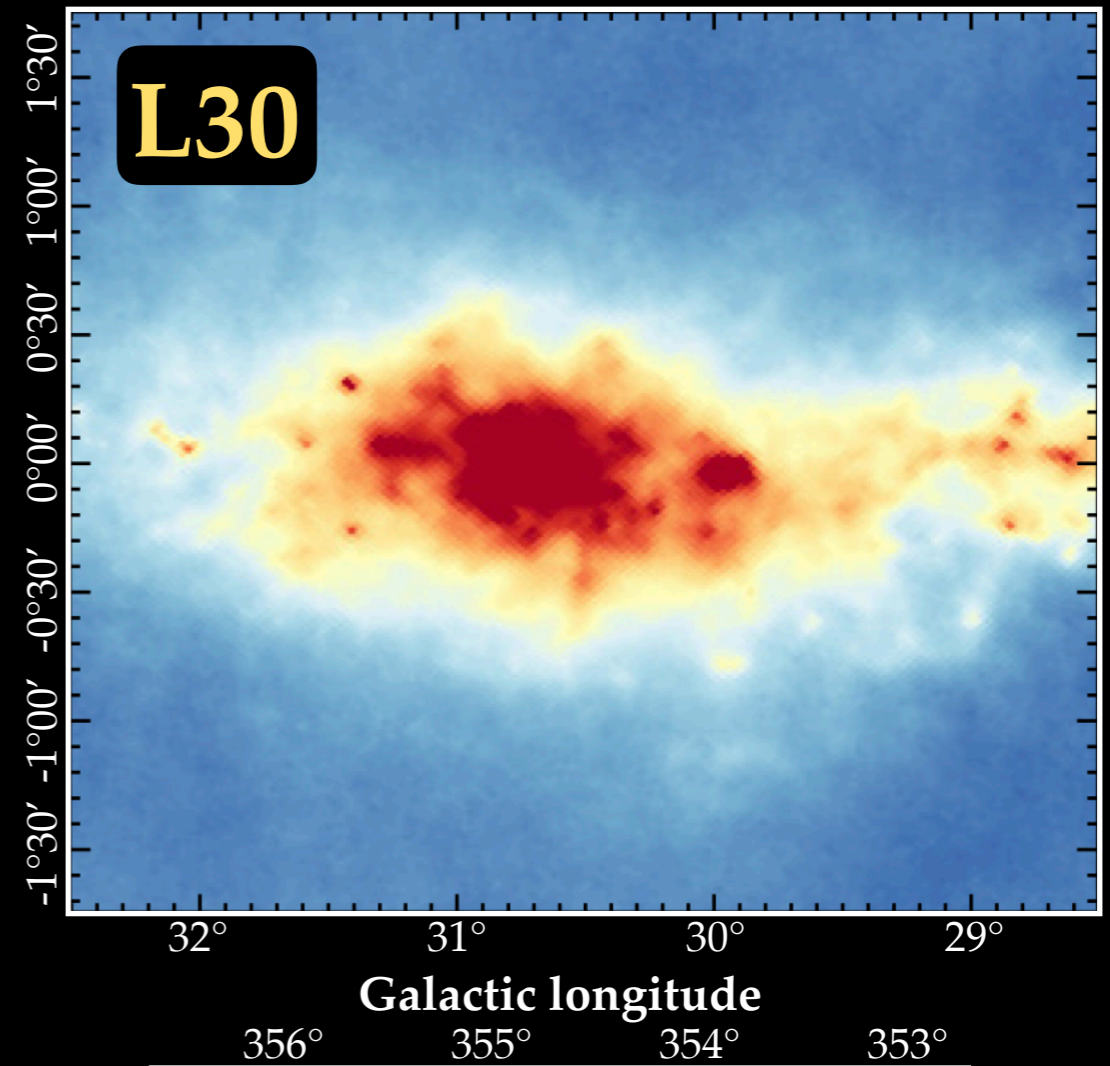
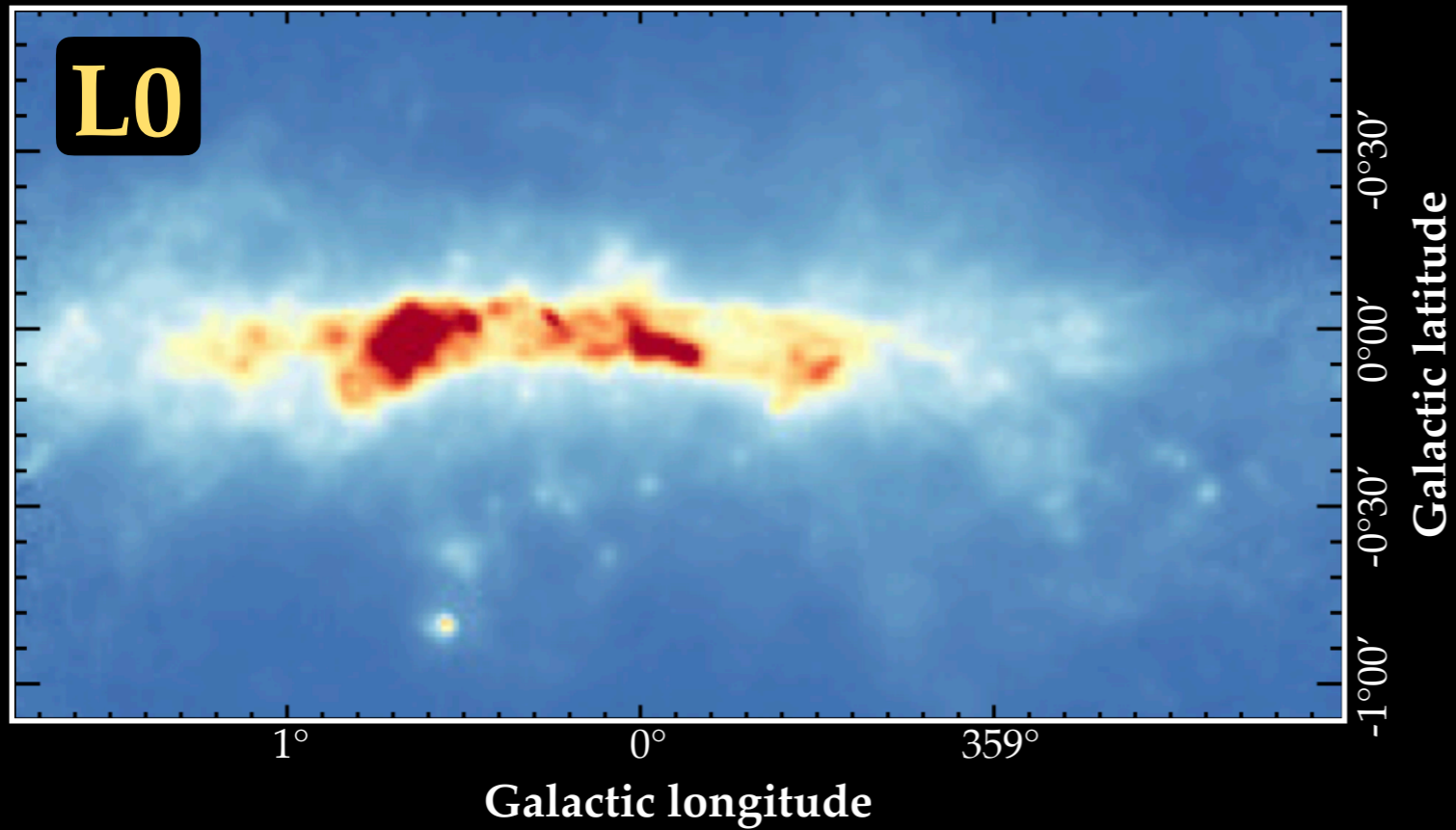
PILOT – In-flight performances

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- ★ Pointing offset varies during flight. Pointing model constructed from elevation + temperatures and Herschel comparison, better than 1'
- ★ Spurious polarization measured on Jupiter of $\sim 3\%$
- ★ In-flight white noise levels as expected; noise stability over the whole flight

+ Significant improvements in ongoing analyses

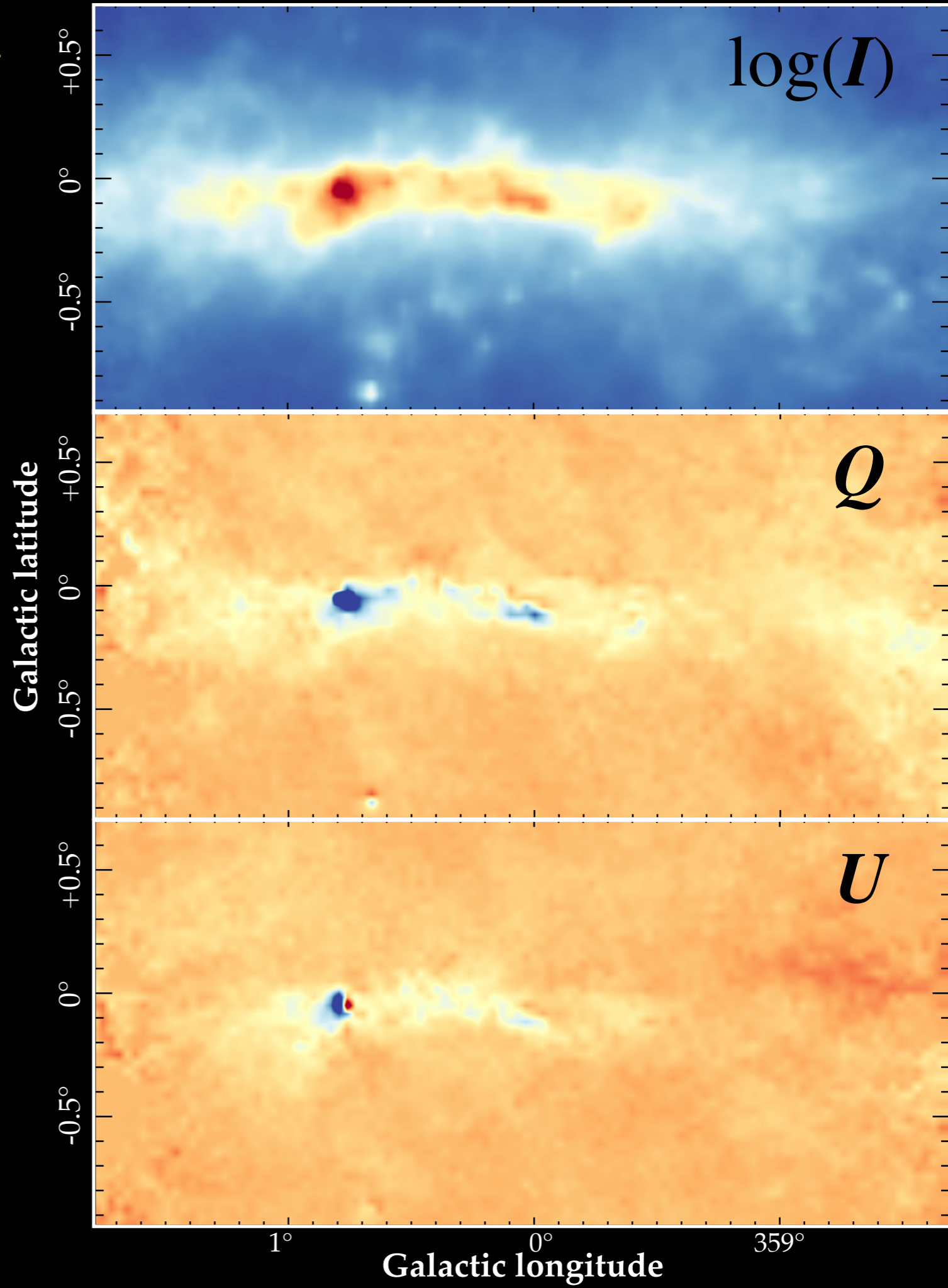


PILOT – Preliminary *I* maps



PILOT – Preliminary polarization maps

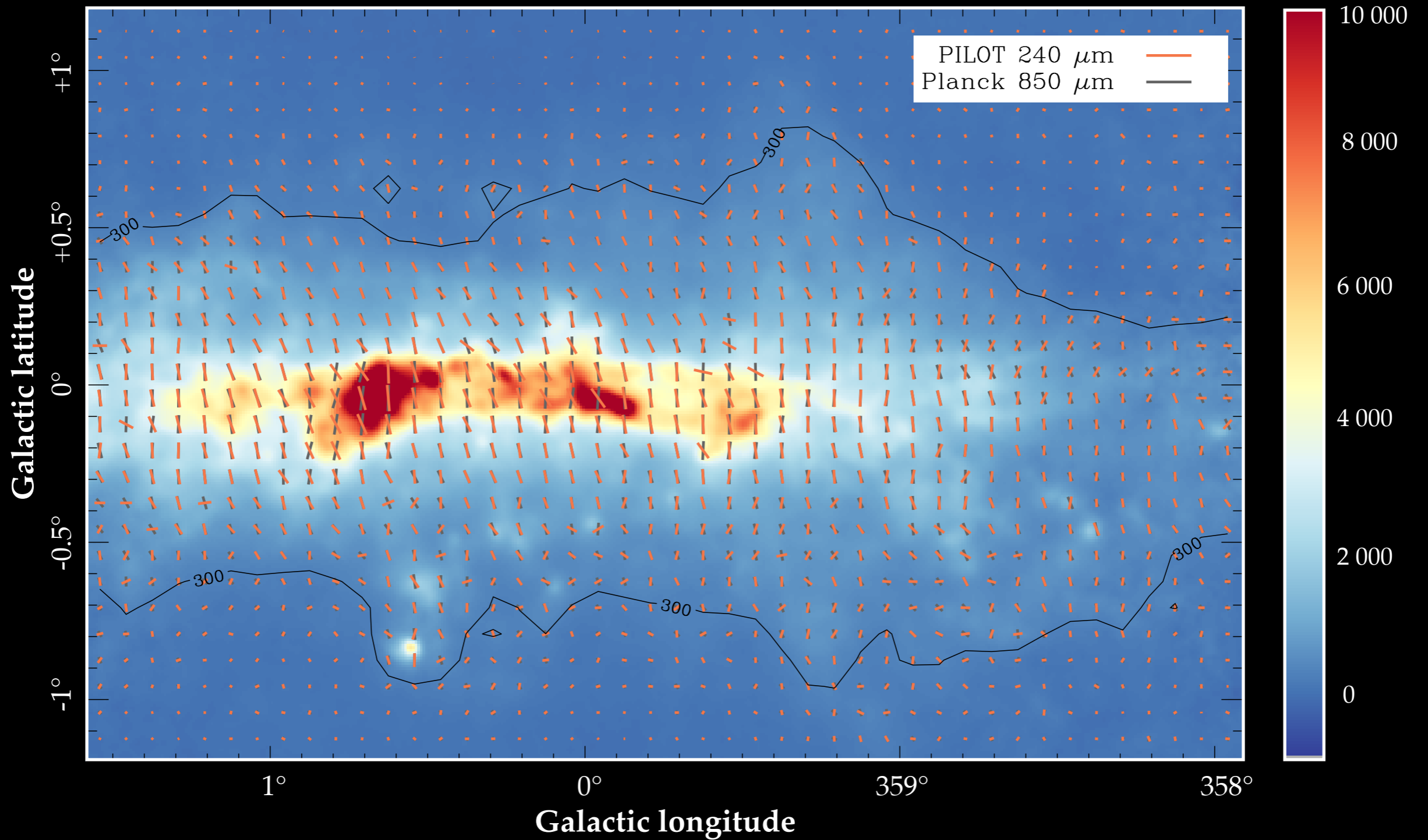
- ★ Stokes parameters I , Q and U in the L0 Galactic plane region
- ★ Strong signal but low polarization fraction



PILOT – Comparison to Planck

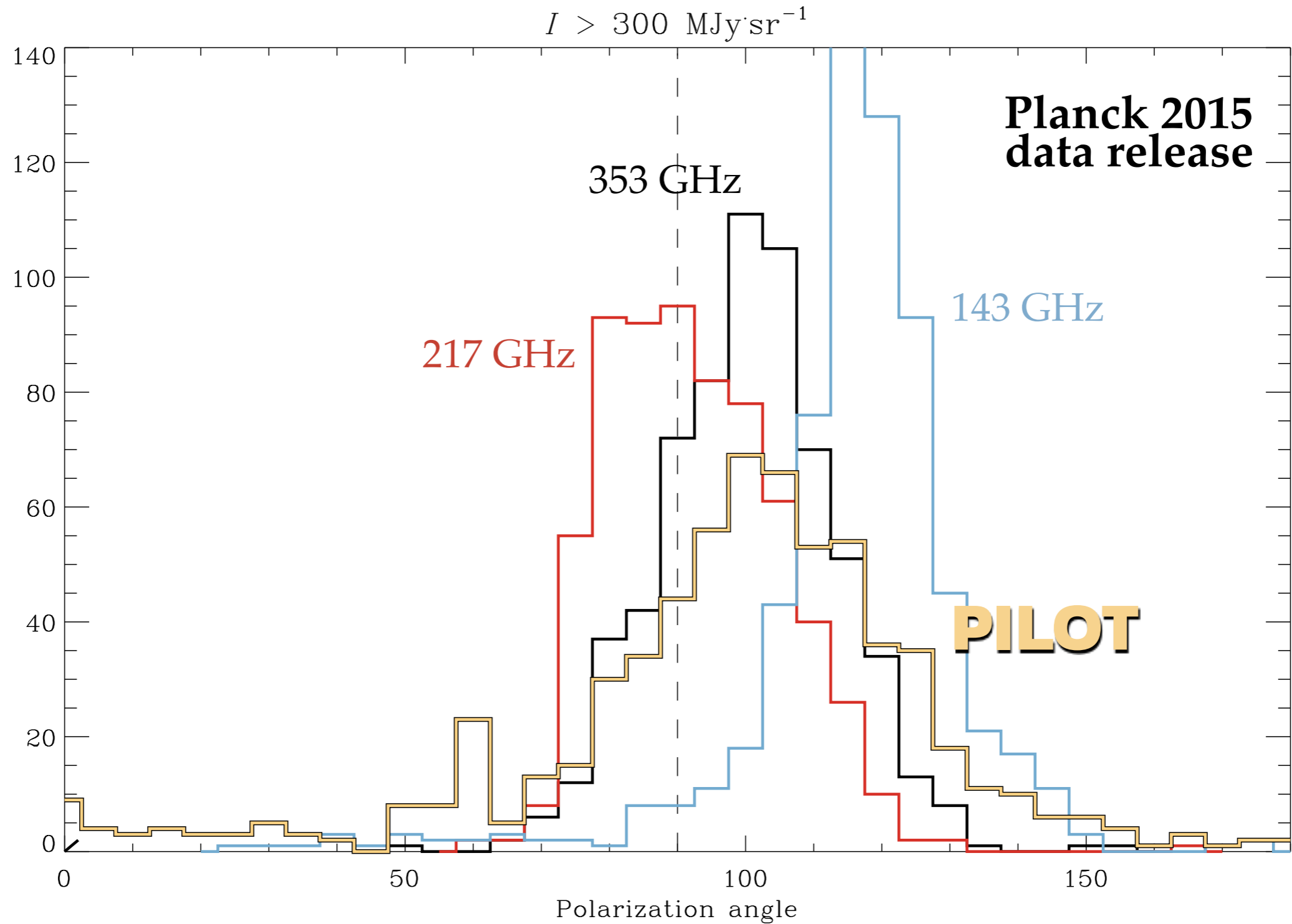
L0 [MJy·sr⁻¹]

Preliminary



$$\psi = \frac{1}{2} \cdot \text{atan} \left(\frac{U}{Q} \right)$$

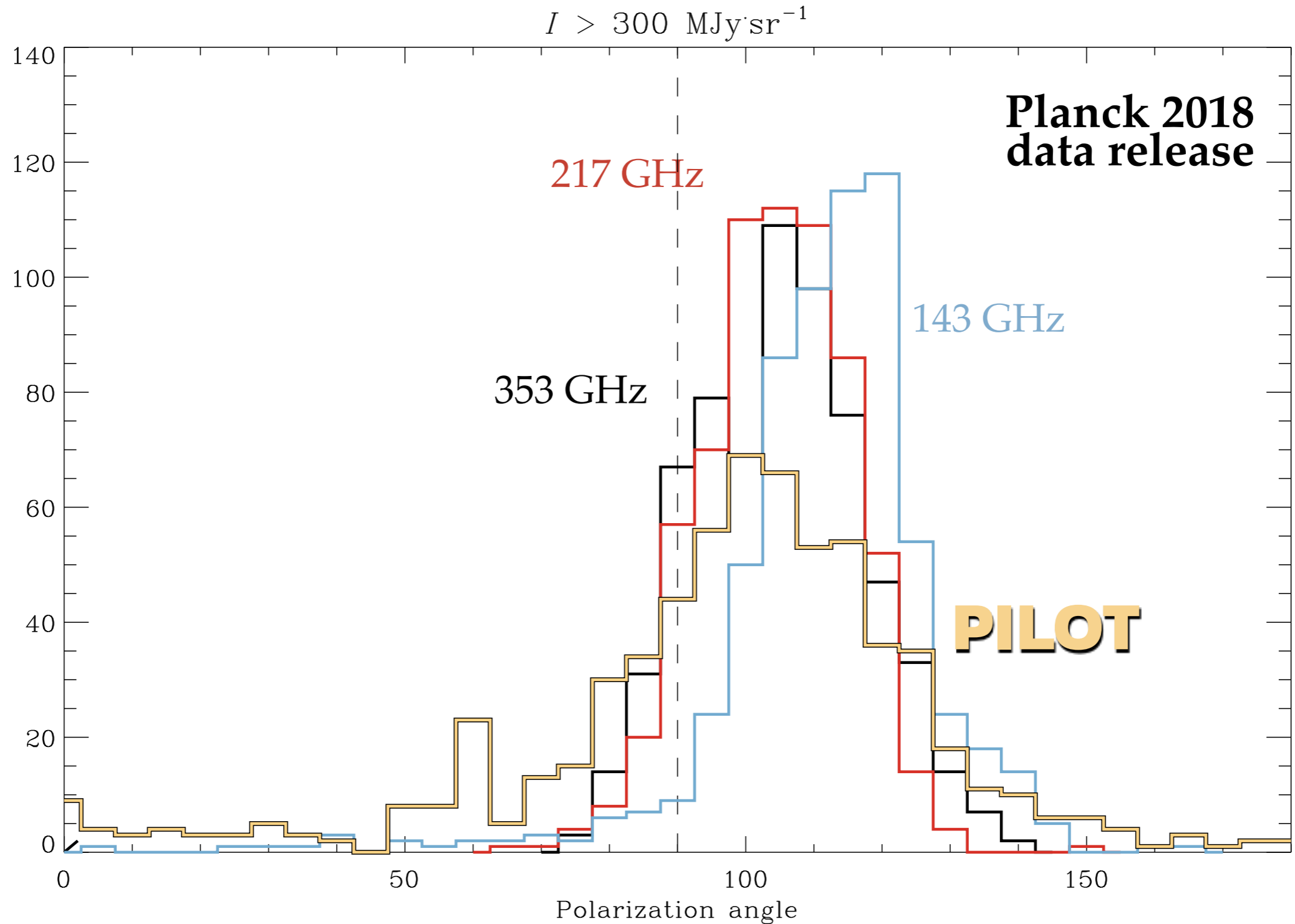
PILOT – Comparison to Planck



Preliminary

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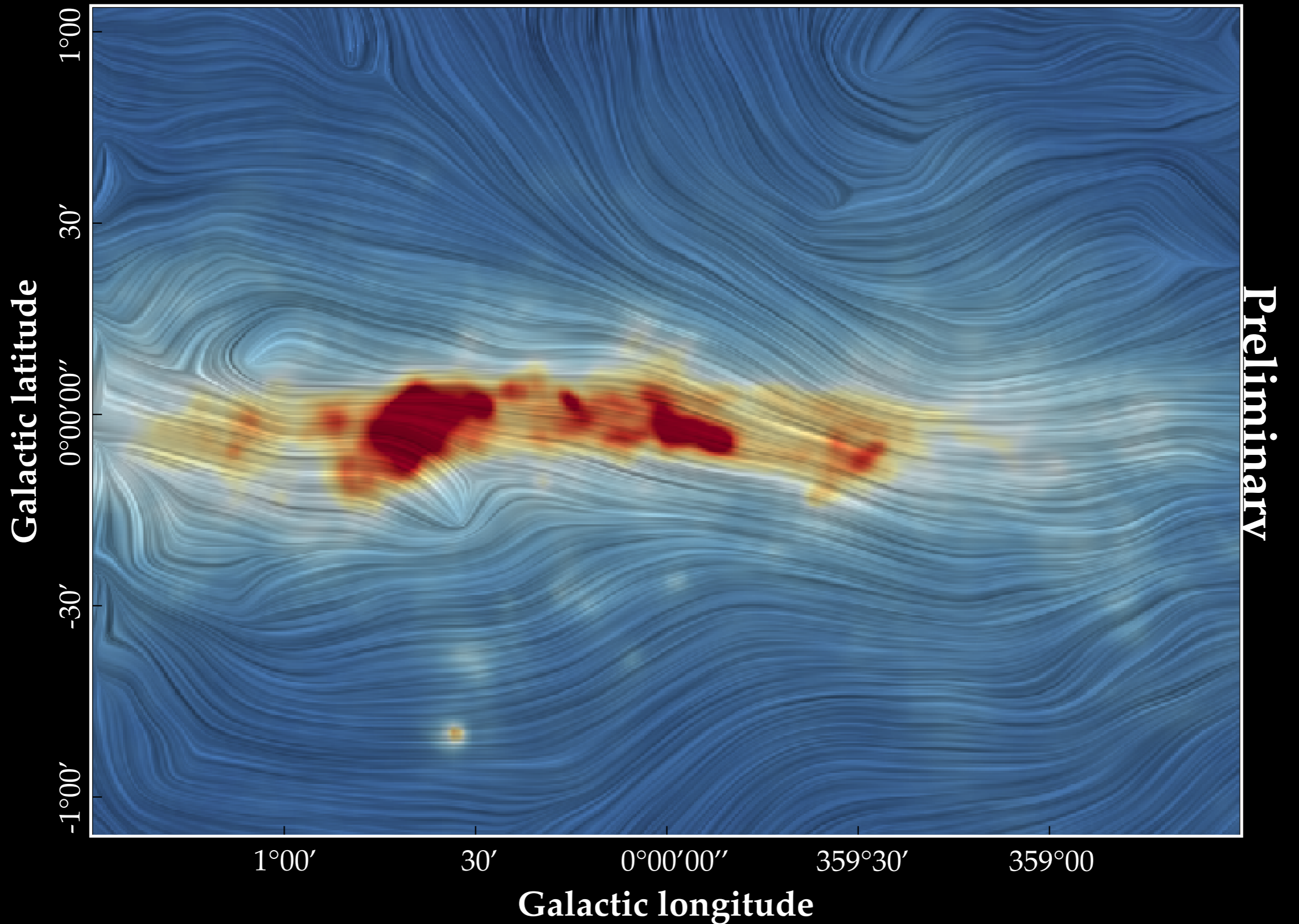
PILOT – Comparison to Planck



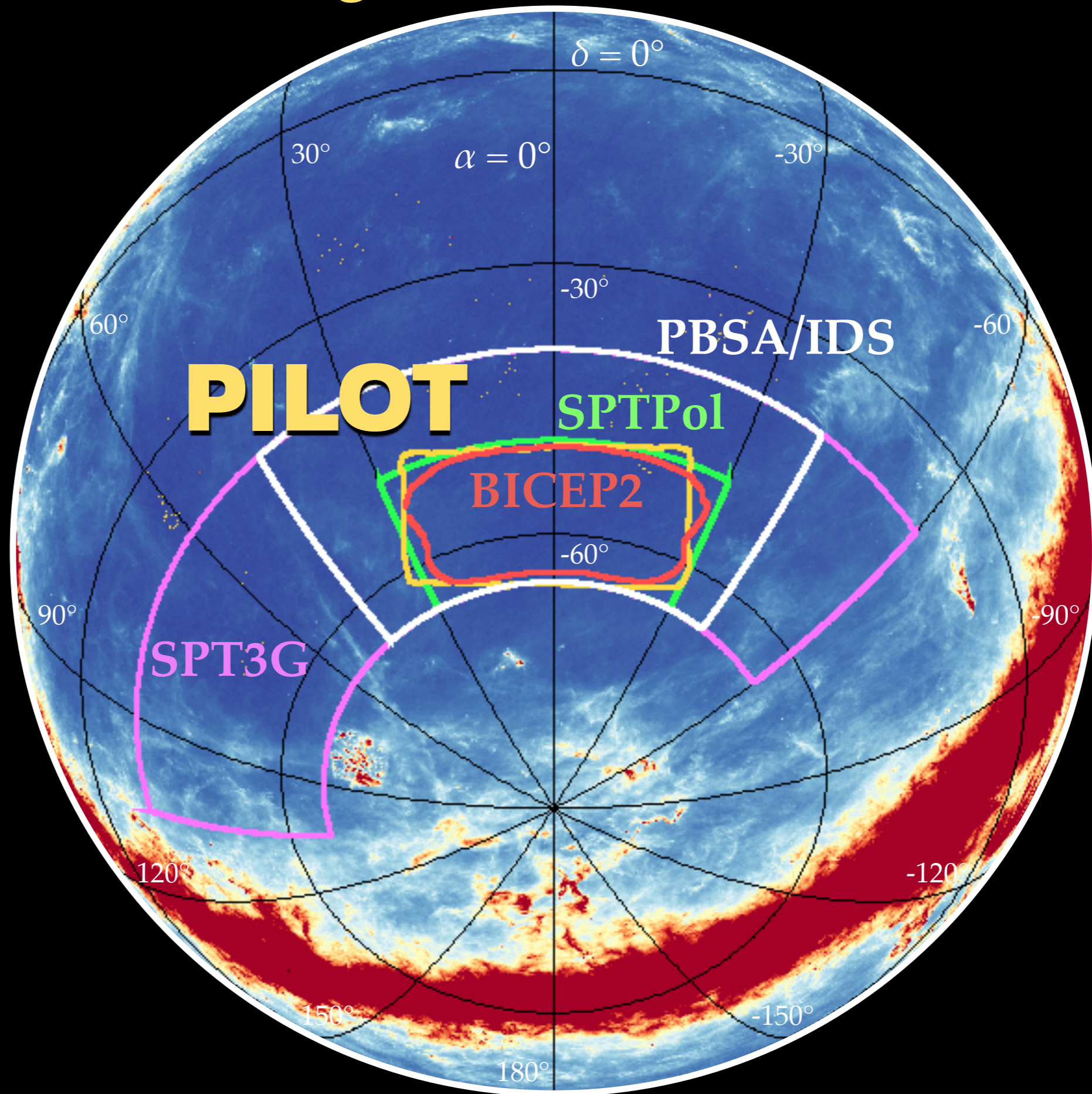
Preliminary

$$\psi = \frac{1}{2} \cdot \text{atan} \left(\frac{U}{Q} \right)$$

PILOT – Direction of the magnetic field

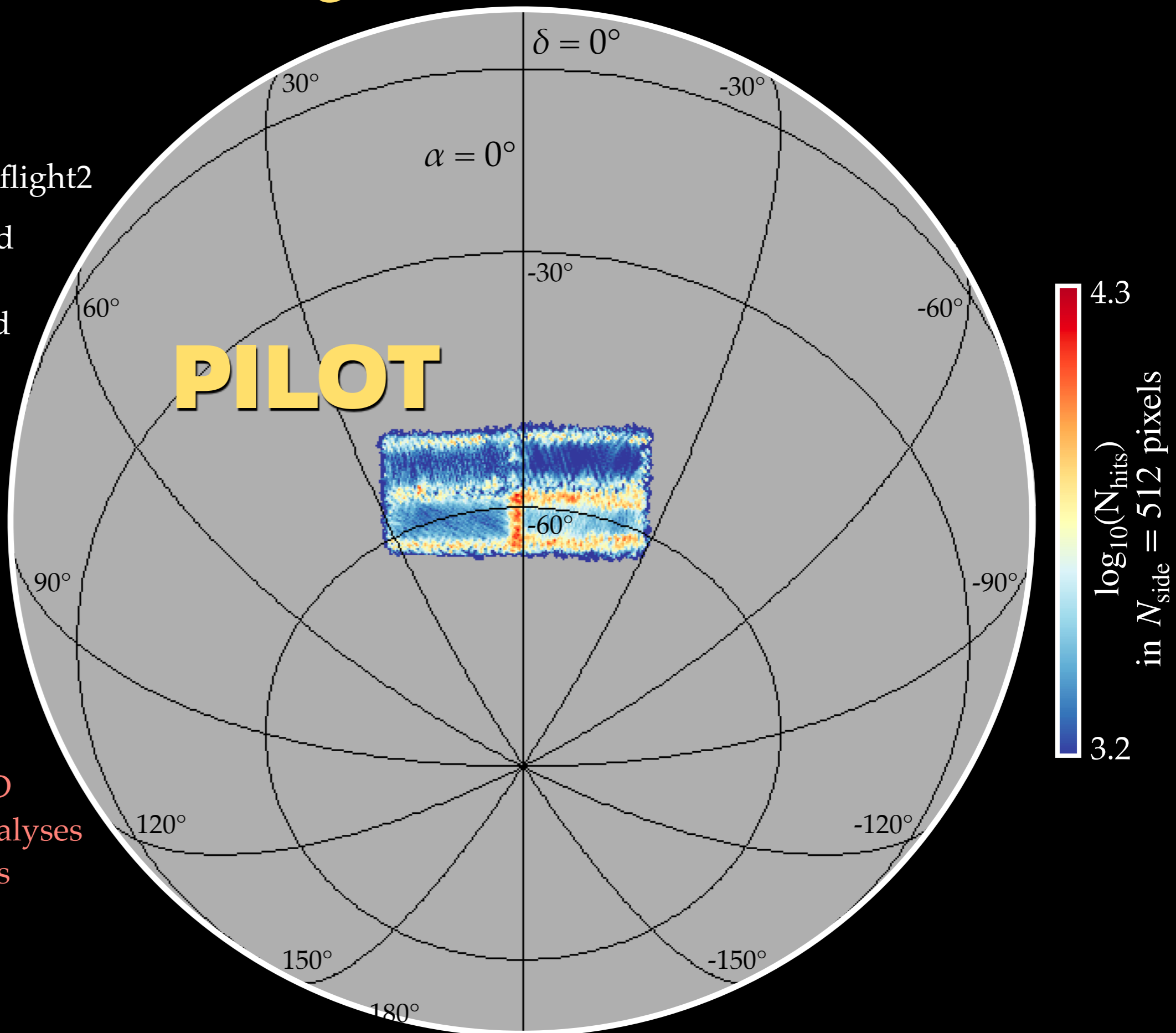


PILOT – “BICEP” region

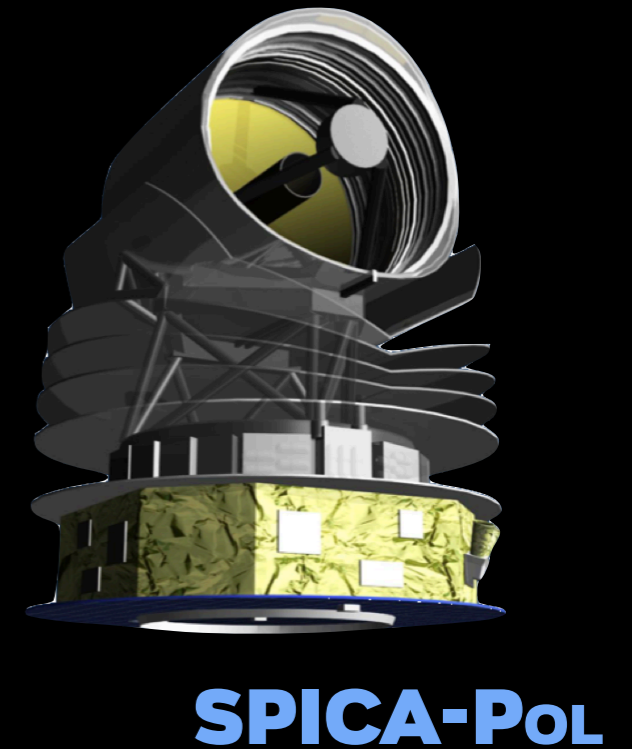
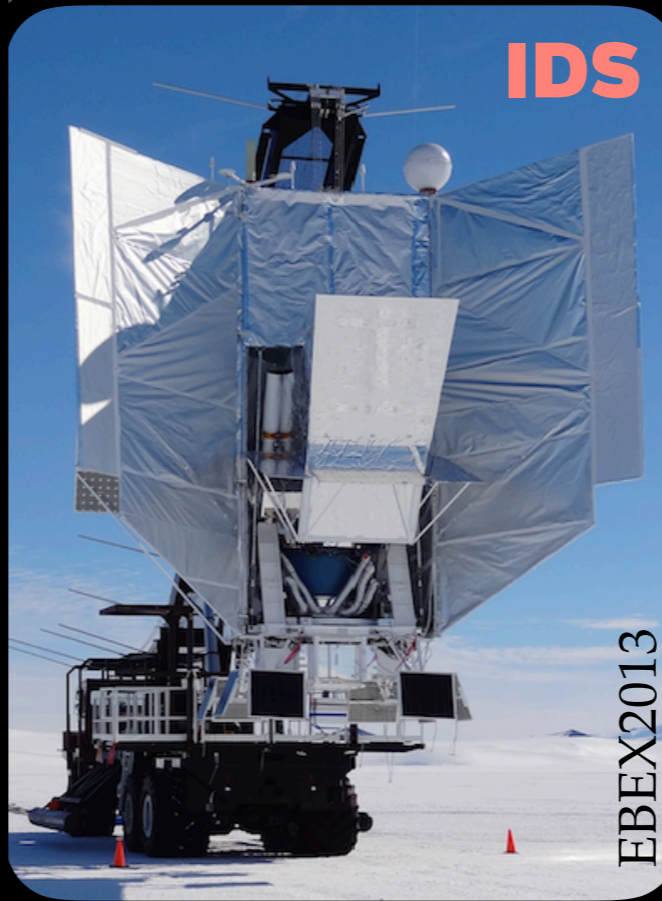
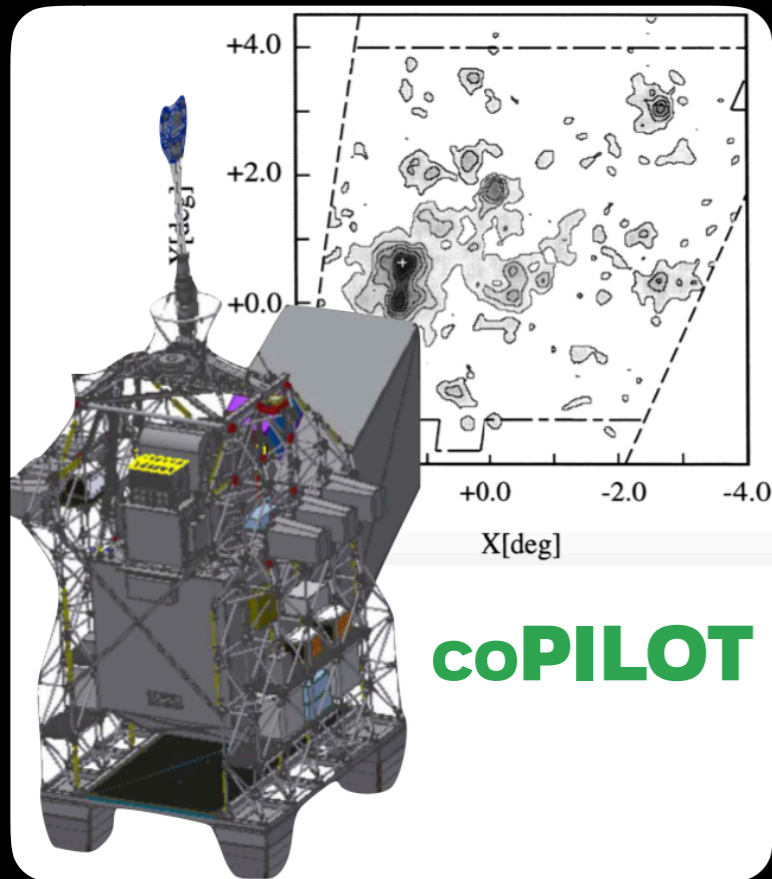


PILOT – “BICEP” region

- ★ 4.8 h of data during flight2
- ★ BICEP field observed with 4 tiles, each of them being observed at least twice with 2 different HWP positions
- ★ Goal signal to noise ratio of ~ 20 on the polarized intensity integrated over the whole field
- ★ Unique data for constraining the SED or for correlation analyses in CMB observations



PILOT – Legacy



- ★ **coPILOT**: modification of **PILOT** will allow very accurate measurements of C+ ($158 \mu\text{m}$) total intensity. Dark molecular gas distribution in solar neighborhood, nearby galaxies. CNES Phase A.
- ★ **IDS** (Inflation and Dust Surveyor): CMB *B*-modes + dust, to be submitted again to NASA. Contribution to provide **PILOT** attitude control + internal calibration source
- ★ **SPICA-POL**: polarized instrument on **SPICA**. Design and science case strongly inspired from **PILOT**. Accepted in pre-phaseA/0.
- ★ **BOOST** proposal (IRAP) to lower detector temperature to 150 mK. Increase in sensitivity by 2.7 for **PILOT**, up to 14 for **coPILOT**

PILOT – Summary

- ★ Operational and instrumental success of the PILOT two flights
- ★ Unique experiment: observation of the dust polarization at 1.2 THz over large regions of the sky relevant for cosmology
- ★ PILOT legacy for future instruments
- ★ Data analysis in progress. No showstopper for the moment but we are a small team!



– BACKUP –

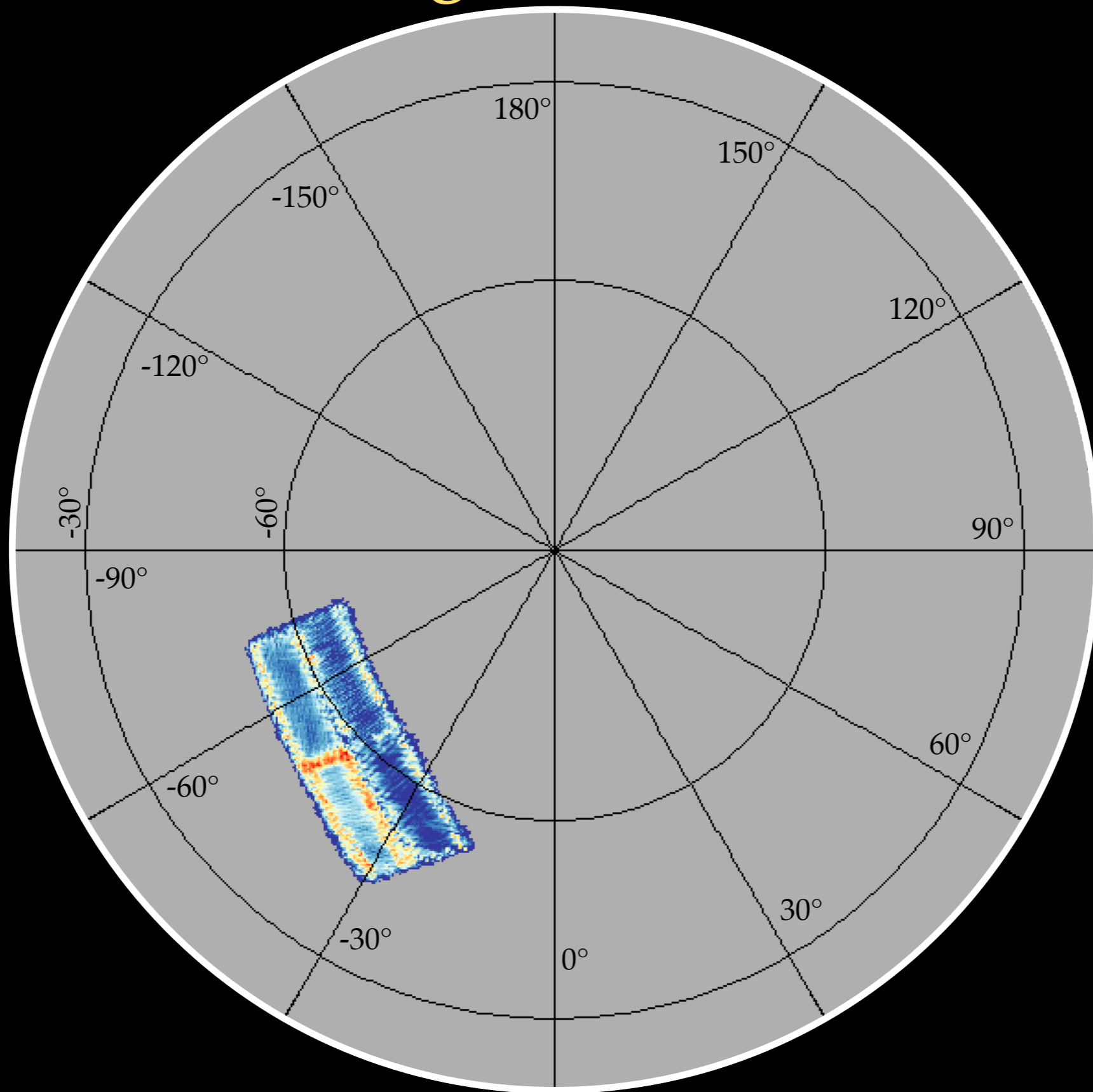
PILOT – Improvements after 1st flight


- + arrays #1 and #3 were repaired
 - ★ ground tests: array #3 ok, arrays #1 and #5 not working
 - in flight: arrays #1, #3 and #5 not working: **-17%**
- + autonomy tests at 300 mK accomplished
 - ★ detectors were operated 20 mK lower than flight#1 (305 mK): **+26%**
 - ★ in-flight autonomy was longer than the long flight (>33.5 hr)
- + Field stop size increased to avoid edge effects in polarization
 - ★ polarization now ok everywhere: gain of 0.6 arrays: **+10%**
- + Longer flight (flight#1: 14.8hr, flight#2: 23.8 hr): **+60%**
- + Front baffle thermal insulation was re-designed
 - ★ no deterioration observed in flight. **No sign of external straylight.**
- + More efficient observing strategy implemented
 - ★ scans at varying elevation (**better control of response variations** + de-stripping)
 - ★ region of interest mapping (saves **20%** of of target time)

= **Total: +100%**

- ★ important qualitative improvements: less straylight, more scan directions more HWP positions, more strong pointing sources

PILOT – “BICEP” region



2.0  3.2
 $\log_{10}(N_{\text{hits}})$