PILOT

A far-infrared balloon-borne polarization experiment

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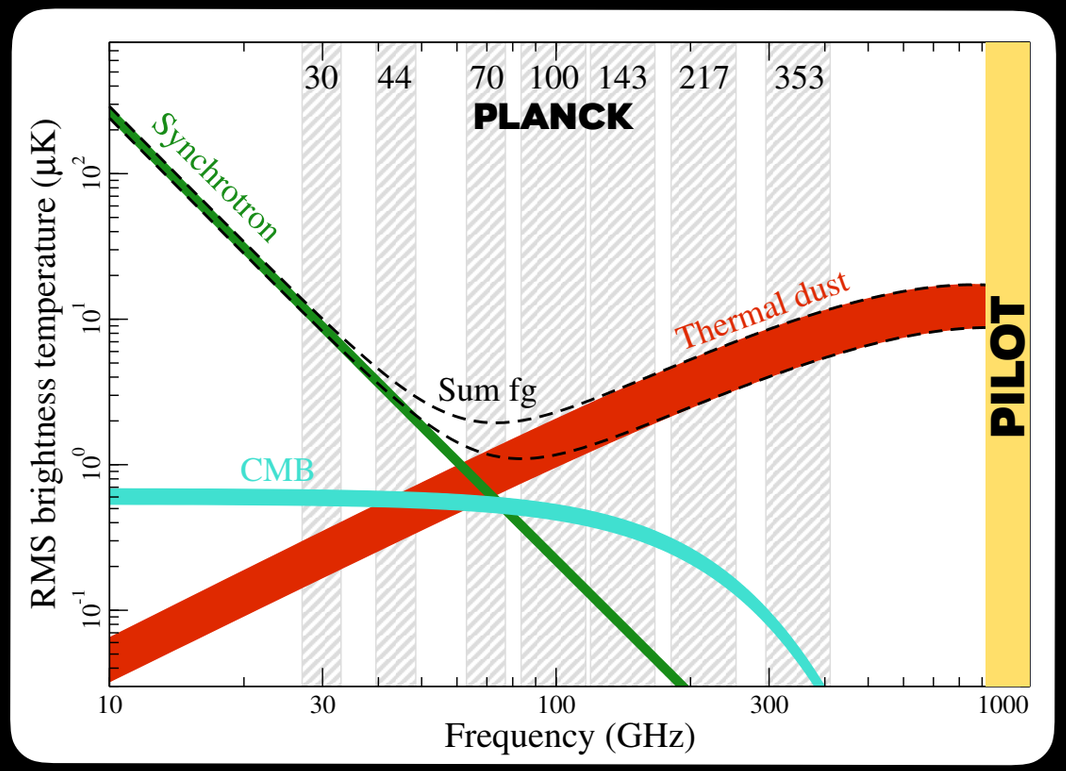
on behalf of the PILOT Collaboration

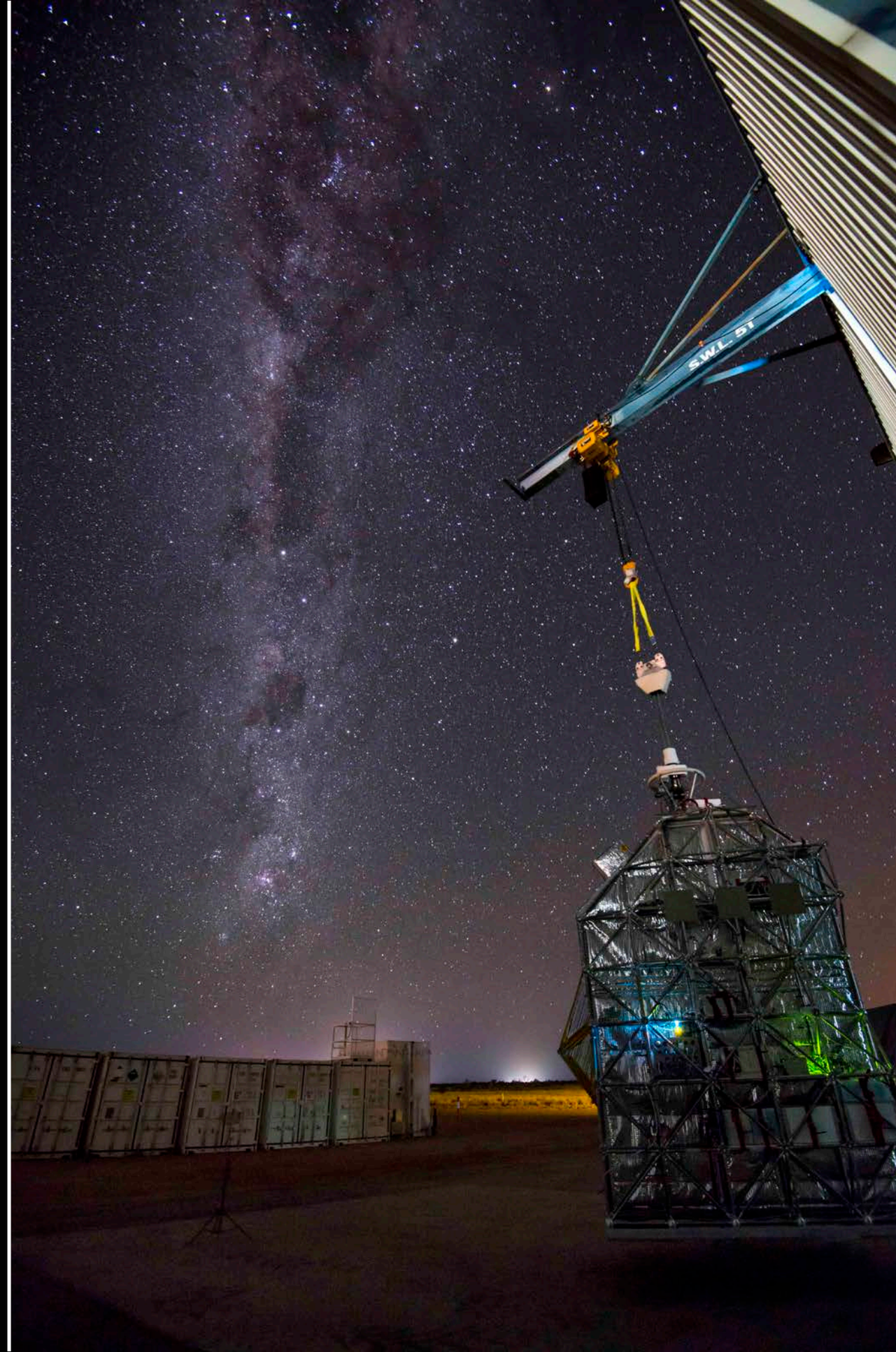
COSPAR-18 - Pasadena - July 20th 2018

PILOT

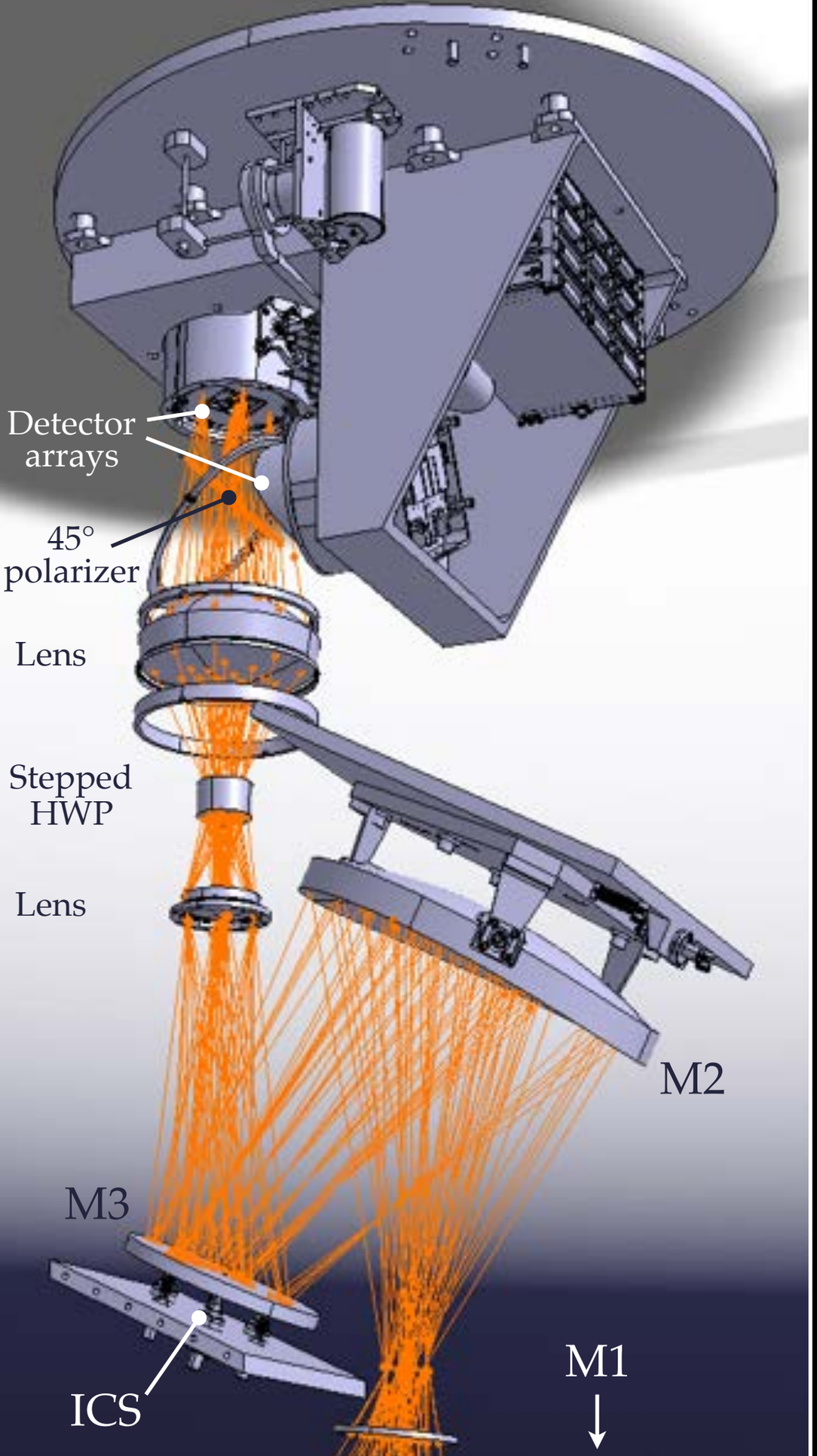
1.2 THz far-infrared polarization experiment

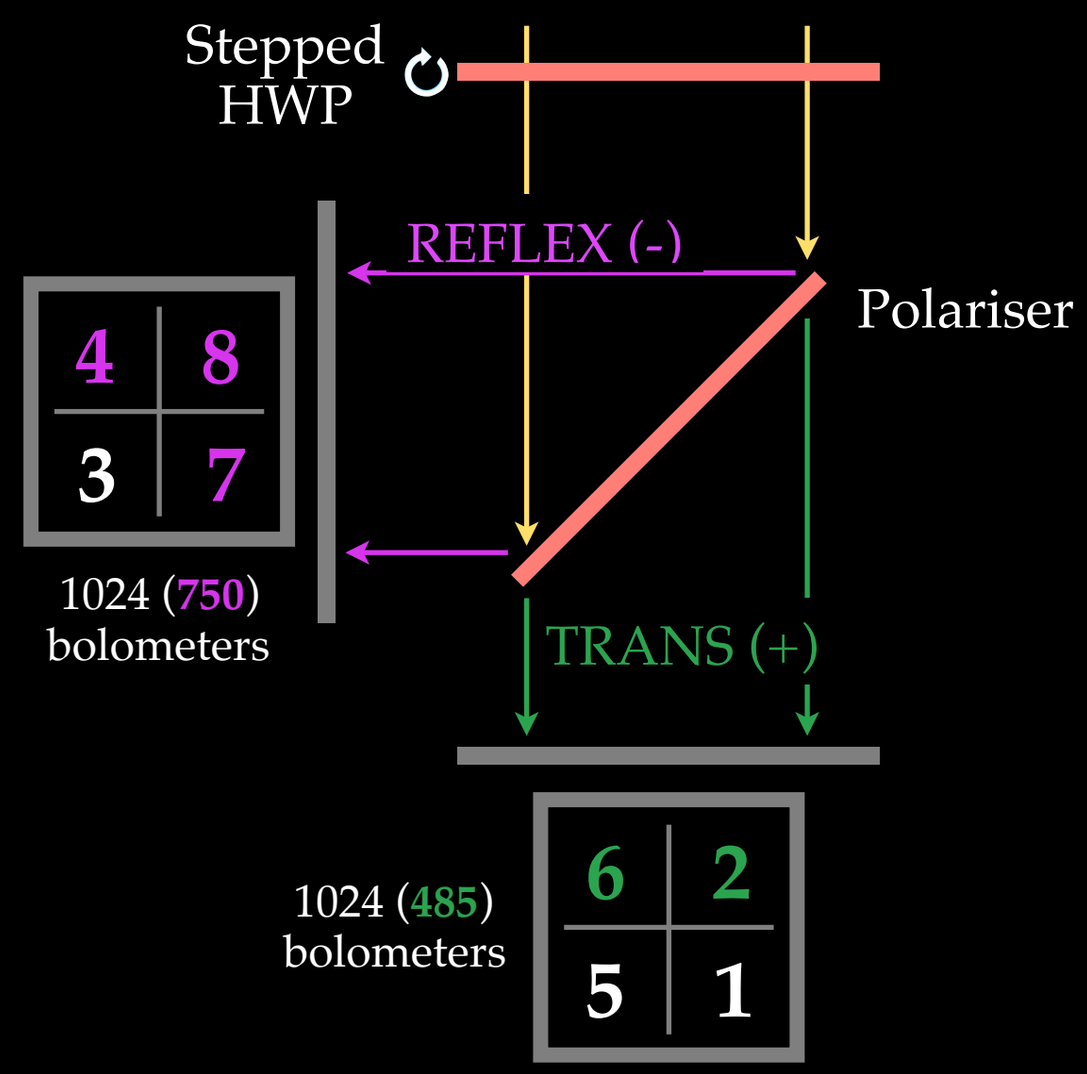
- ★ Reveal the structure of the magnetic field in our Galaxy and nearby galaxies
- ★ Characterize the geometric and magnetic properties of the dust grains
- ★ Understand polarized foregrounds
- ★ Complete the Planck observations at a higher frequency where the dust polarization has never been observed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





PILOT – Instrument

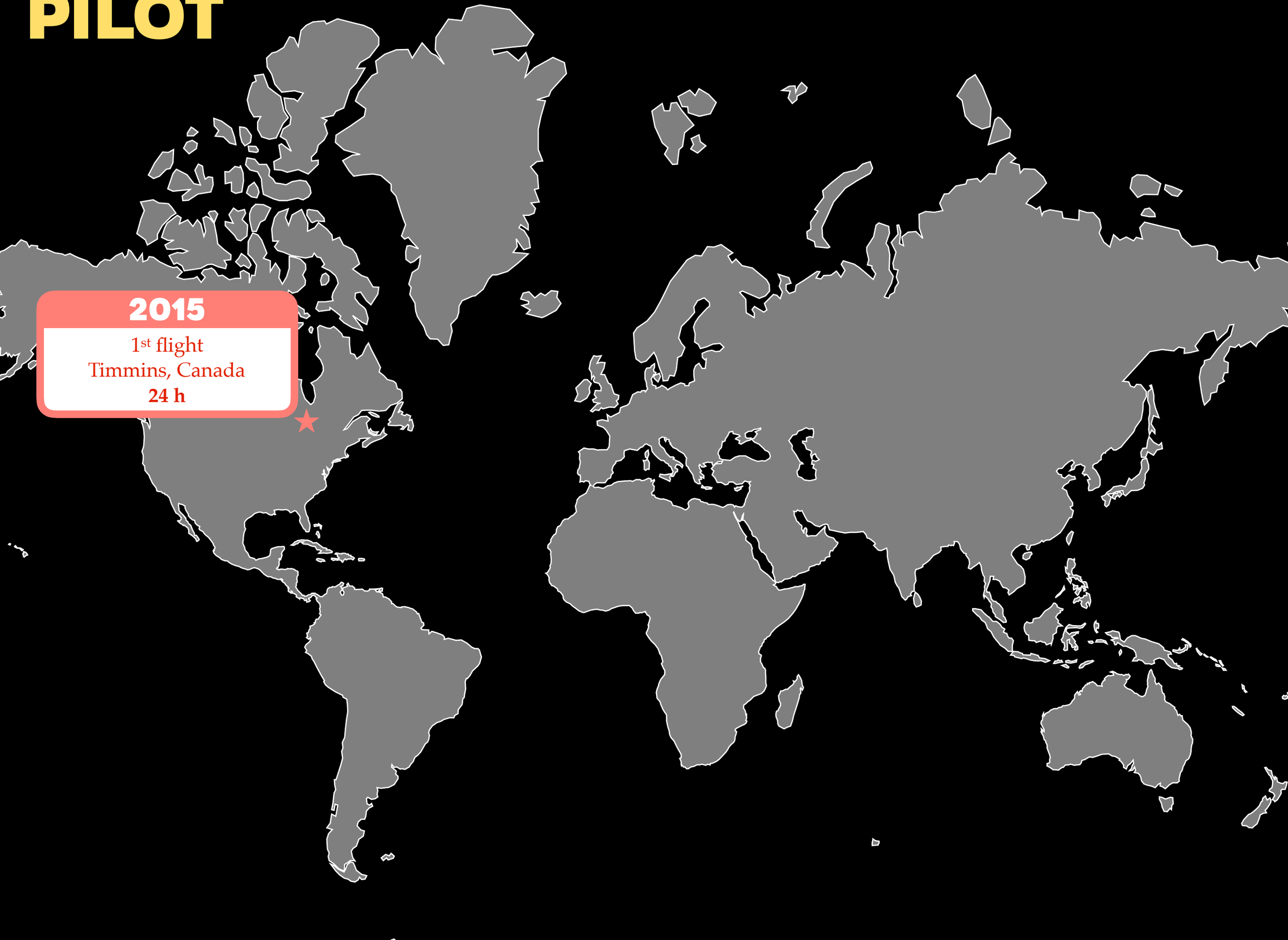




- ★ Multiplexed bolometer arrays with a total of 2048 detectors at 240 μm (1249 GHz), 2′ resolution
- ★ Observations at more than 2 HWP angles to reconstruct the Stokes parameters *I*, *Q*, *U*
- ★ Detectors cooled down to 0.3 K through closed-cycle ^{3}He fridge
- ★ NEP $\sim 4 \times 10^{-16}$ W/Hz$^{1/2}$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

[The PILOT Collaboration, Bernard et al. 2016]

PILOT



PILOT

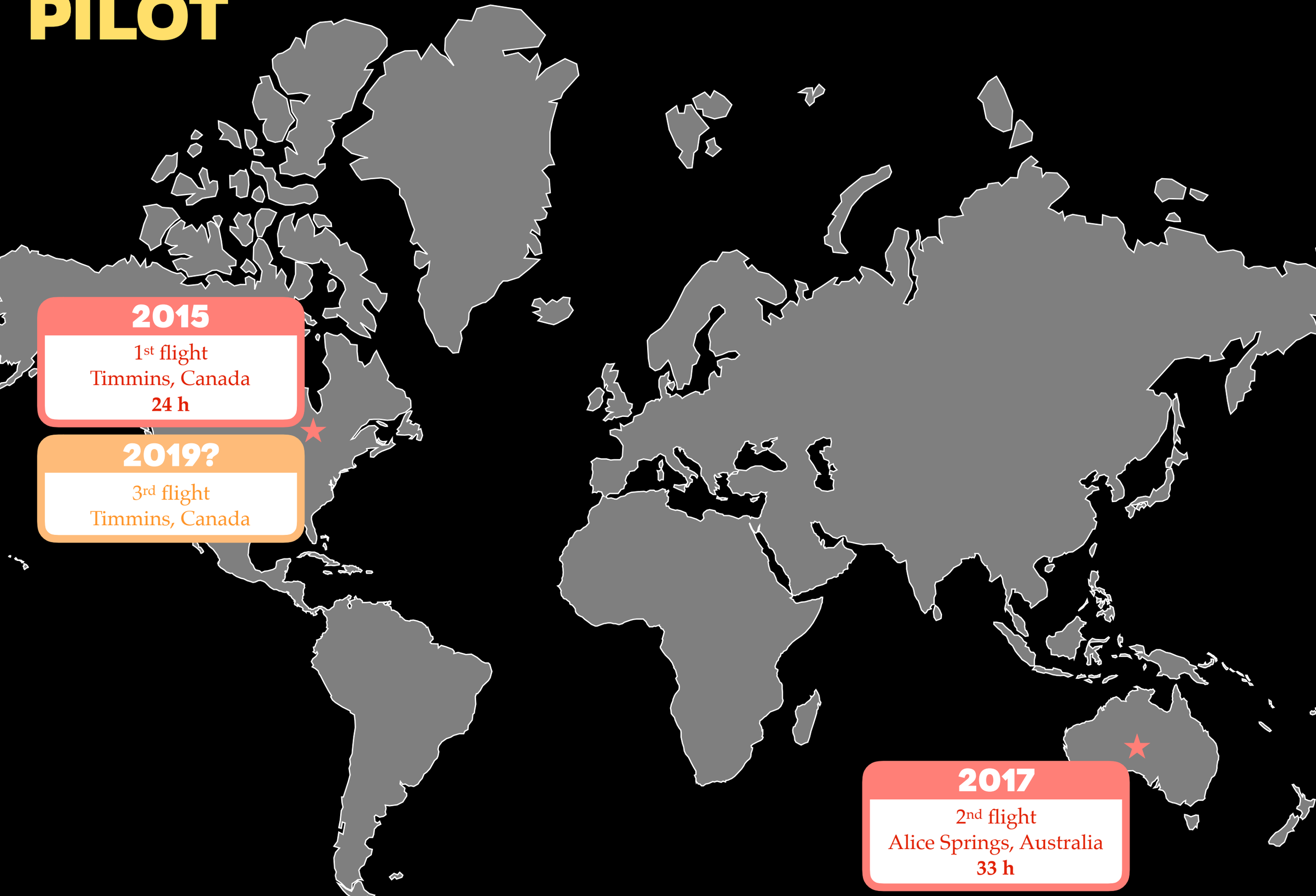
2015

1st flight
Timmins, Canada
24 h

2017

2nd flight
Alice Springs, Australia
33 h

PILOT



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2019?

3rd flight
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PILOT DPC

Toulouse, France

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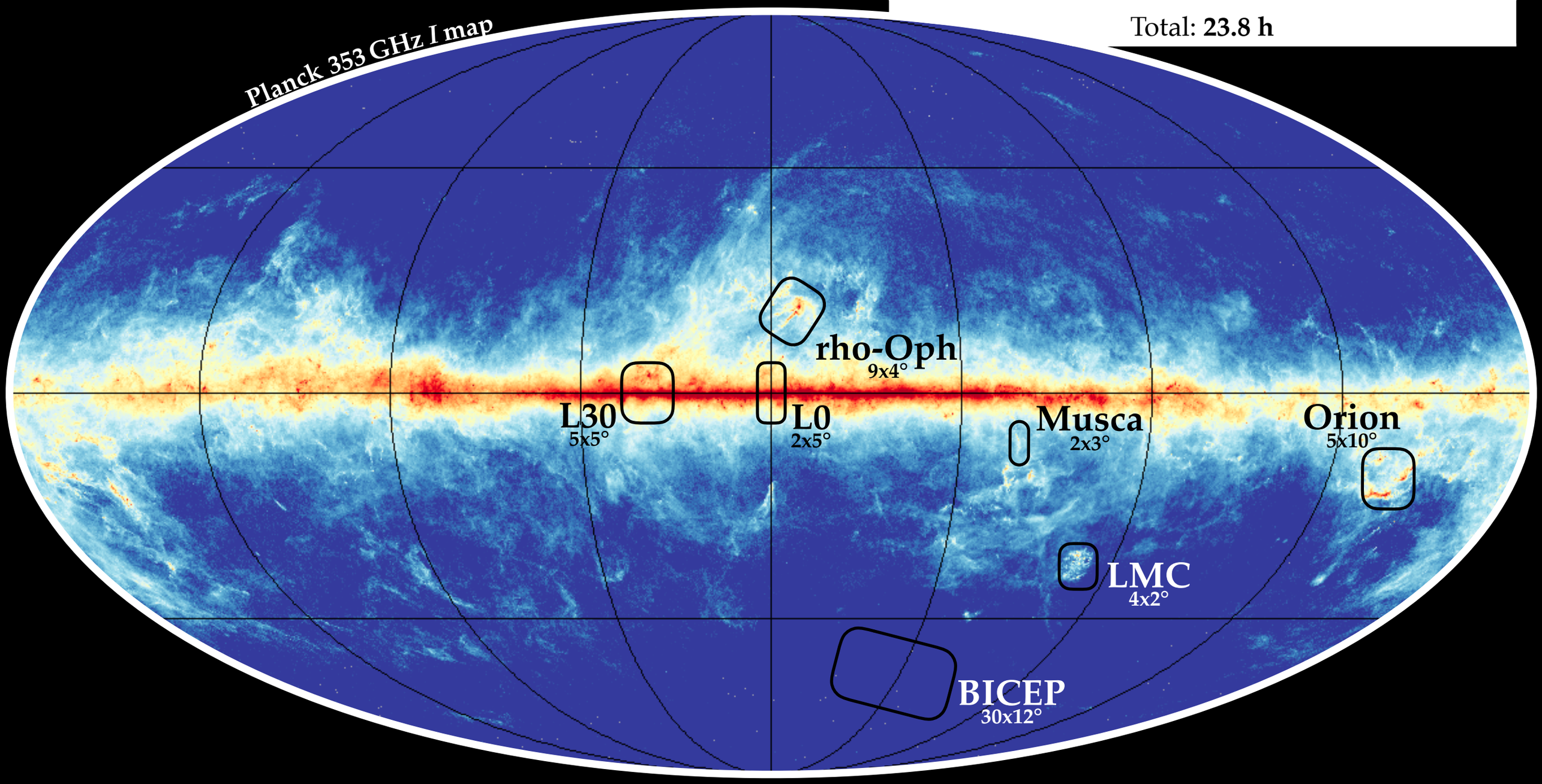
PILOT — 2nd flight

PILOT — 2nd flight

April 16th, 2017 from Alice Springs, Australia

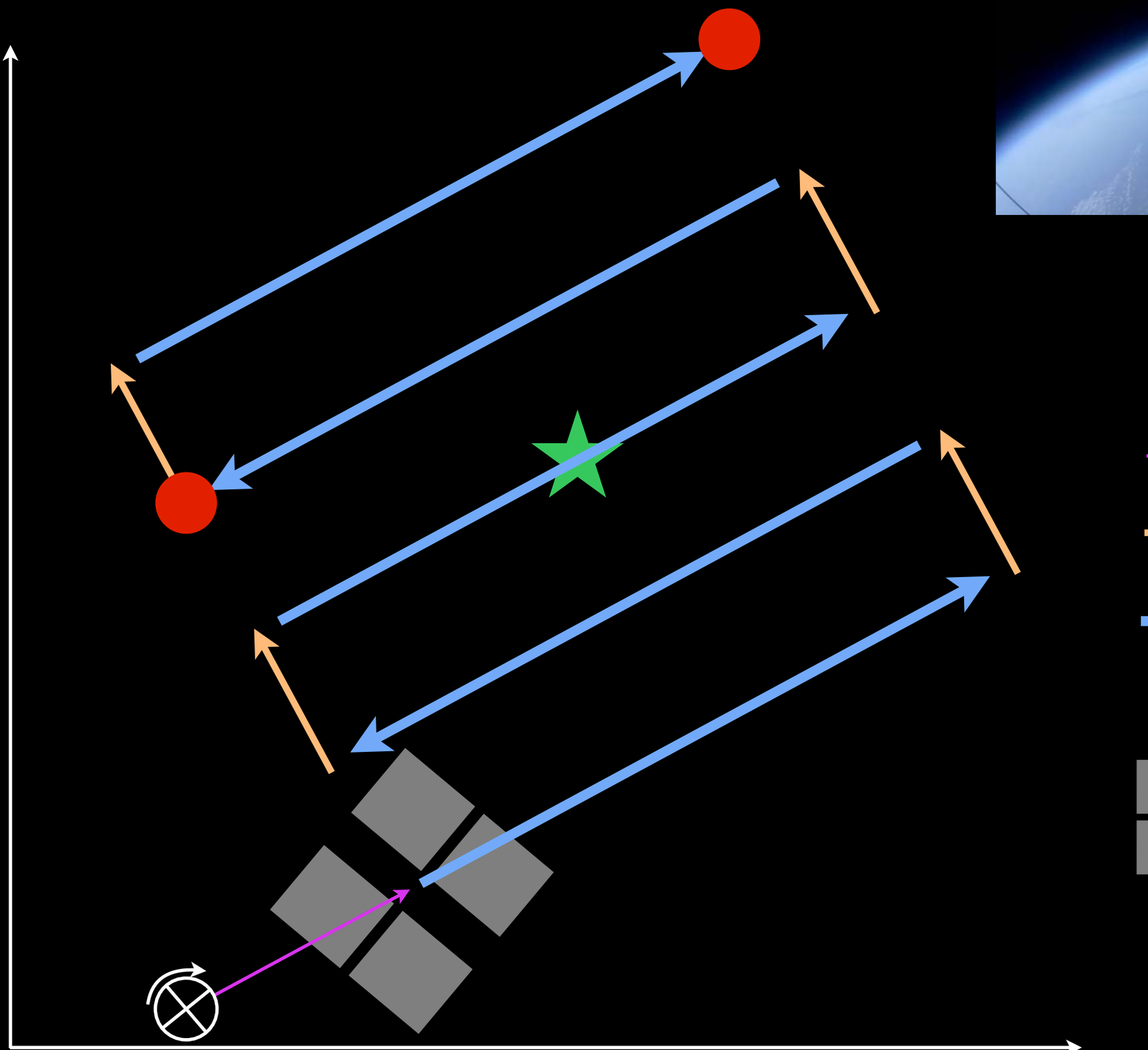
- ⋆ Total flight time: 33.5 h
- ⋆ Scientific data: **23.8 h**
- ⋆ Ceiling altitude: 32-40 Km

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



HWP rotation

Slew

Elevation and azimuth adjustments

Scan

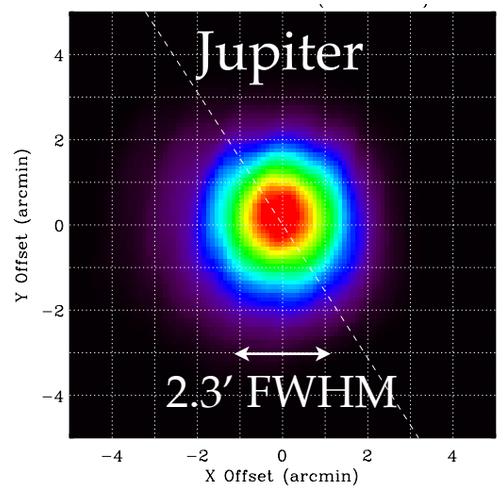
ICS calibration sequence

Focal plane footprint on the sky

Target region

PILOT — In-flight performances

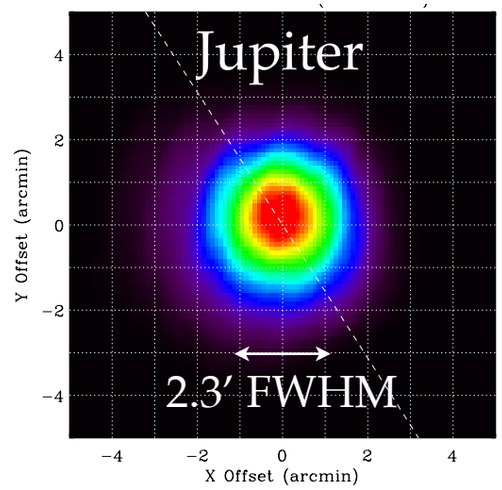
★ In-flight good optical quality and nominal resolution

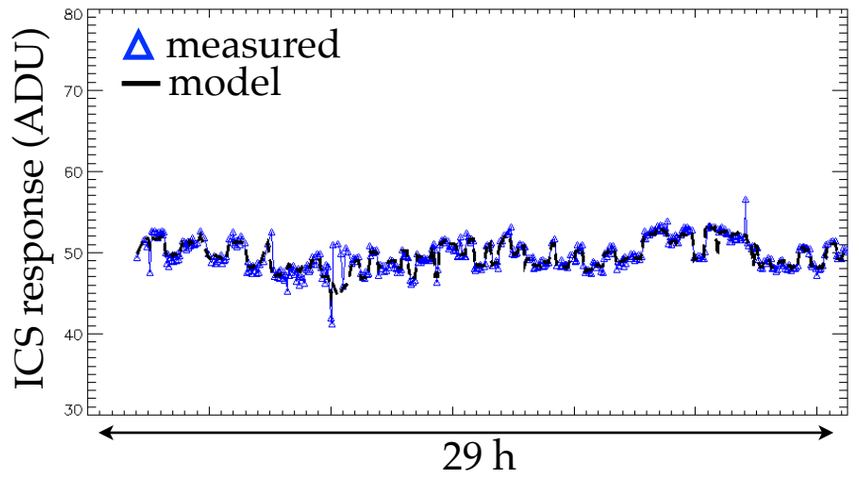


[The PILOT Collaboration, Foënard et al. 2018]

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 %





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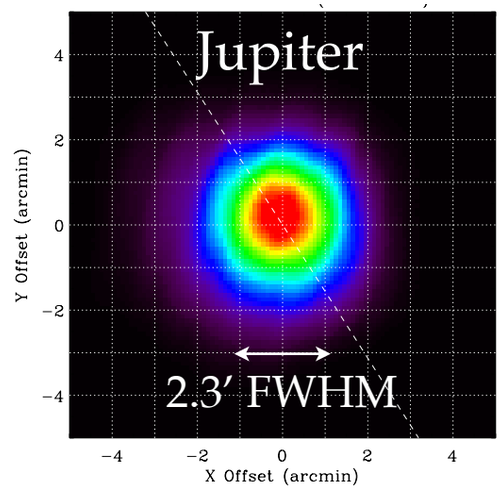
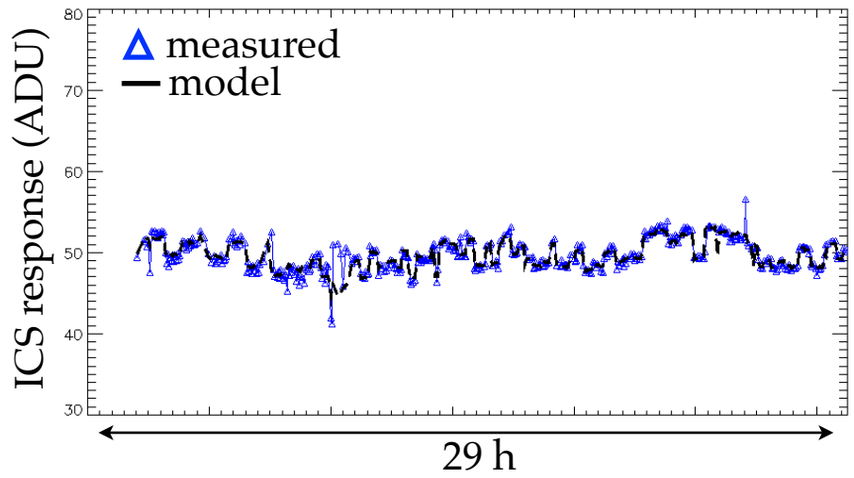
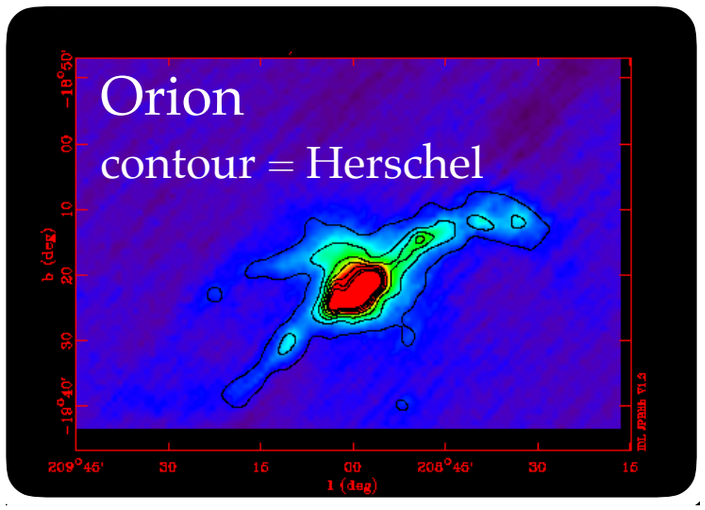
- ★ Variation of the detector responses due to polarized background & atmosphere variations. Modelled and corrected to better than 2 %
- ★ Pointing offset varies during flight. Pointing model constructed from elevation + temperatures and Herschel comparison, better than 1′
- ★ Spurious polarization measured on Jupiter of ~ 3 %







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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 %

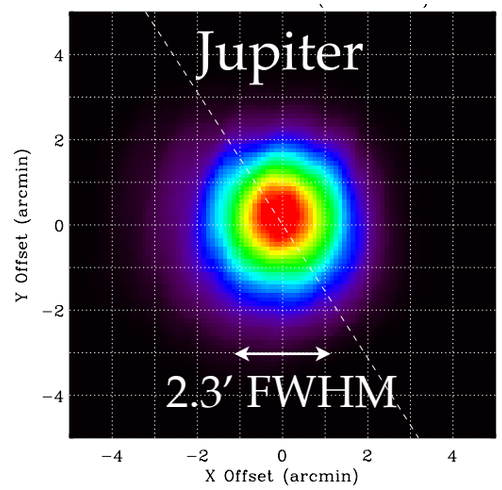
★ Pointing offset varies during flight. Pointing model constructed from elevation + temperatures and Herschel comparison, better than 1′

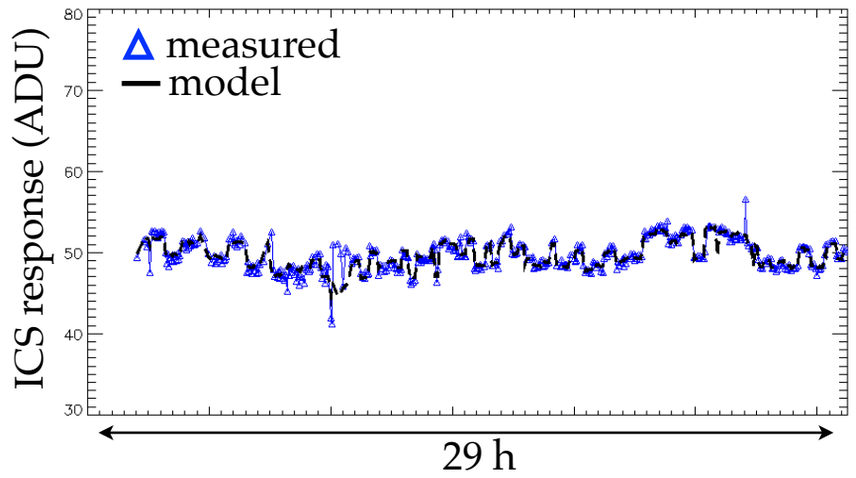
★ Spurious polarization measured on Jupiter of ~ 3 %

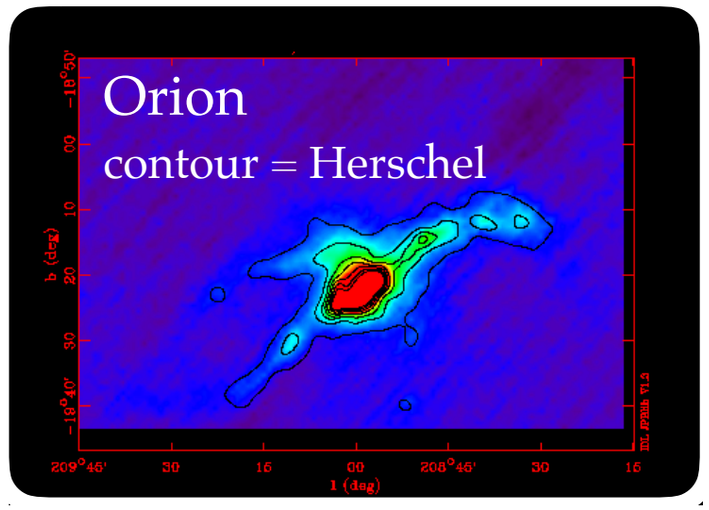
★ In-flight white noise levels as expected; noise stability over the whole flight

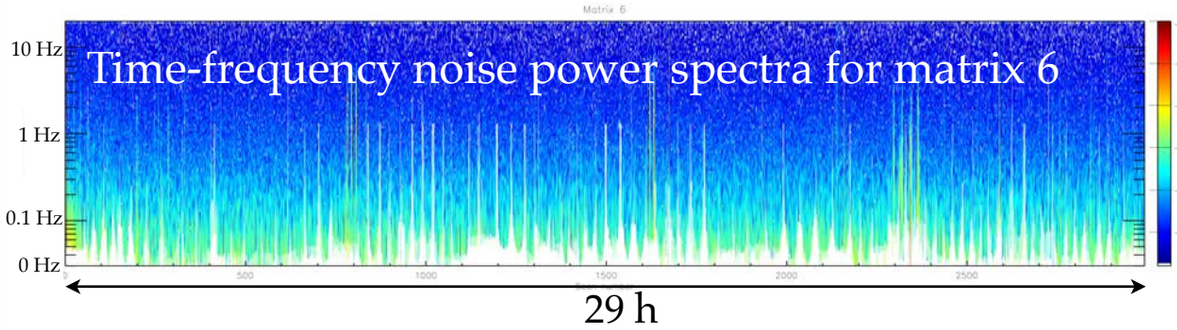
+ Significant improvements in ongoing analyses

[The PILOT Collaboration, Foënard et al. 2018]

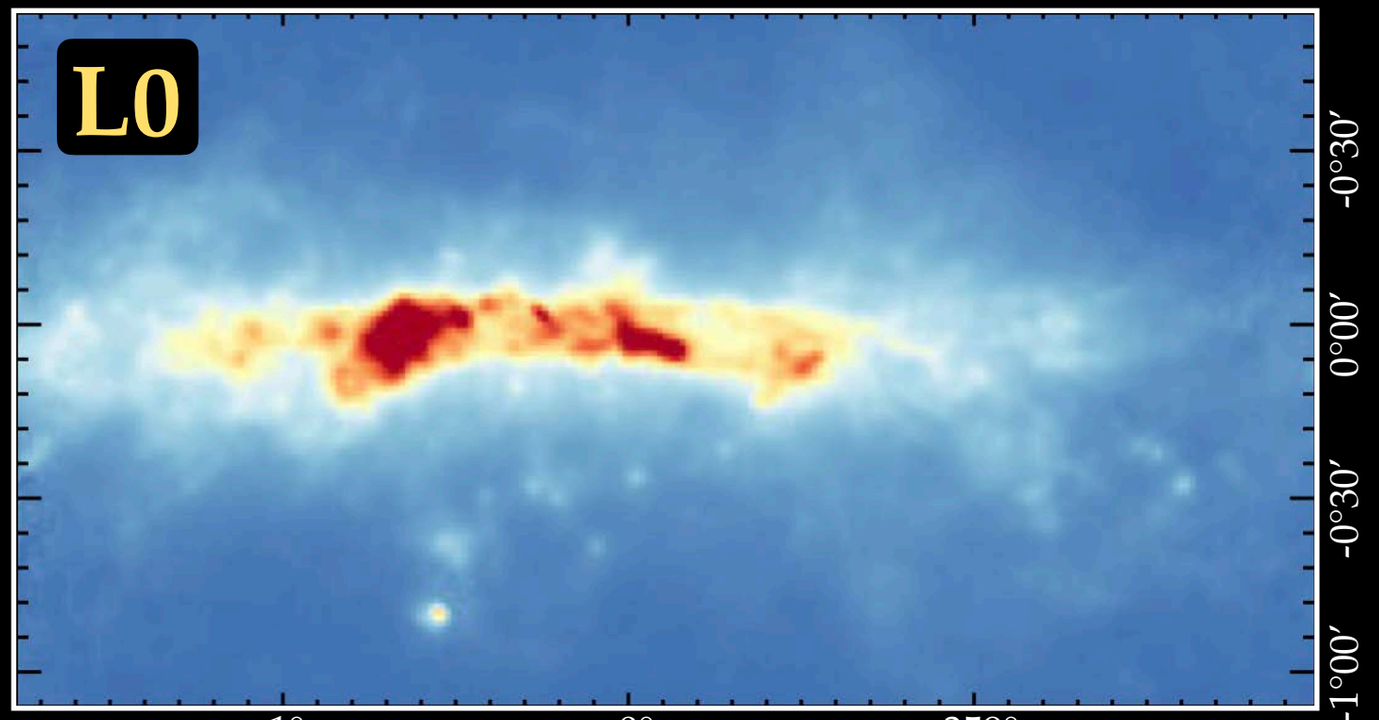


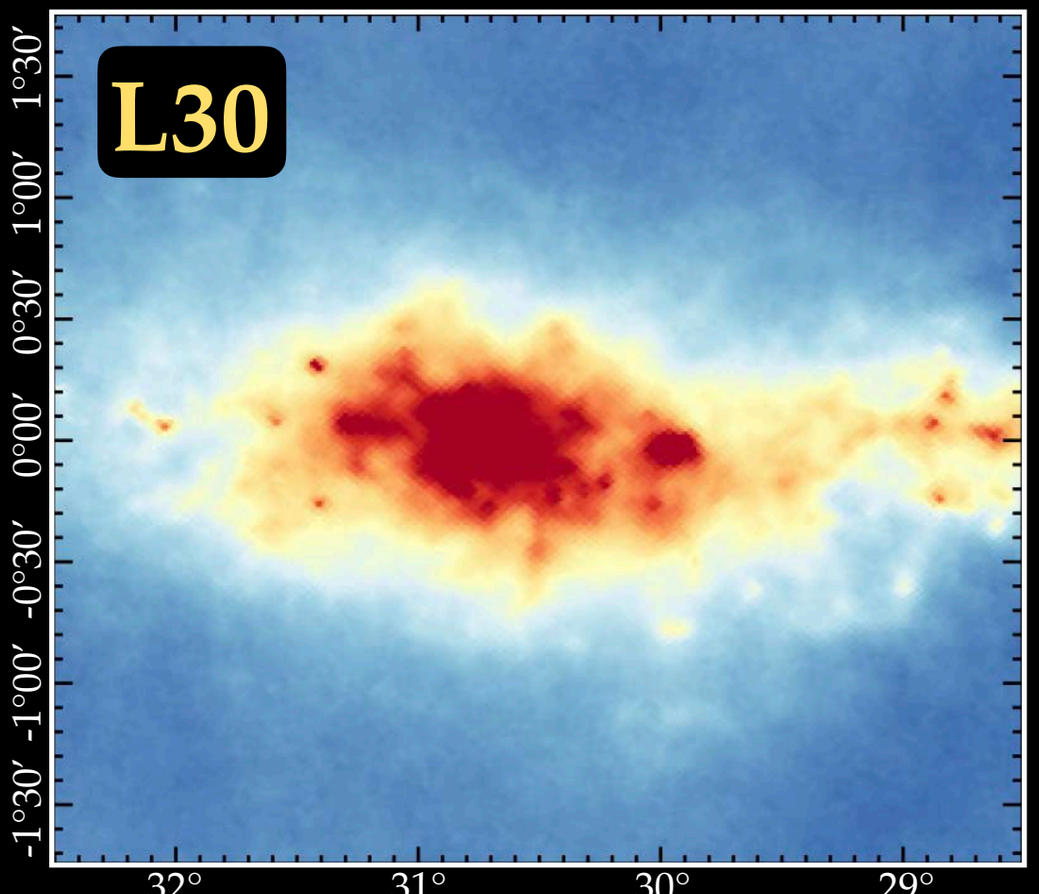


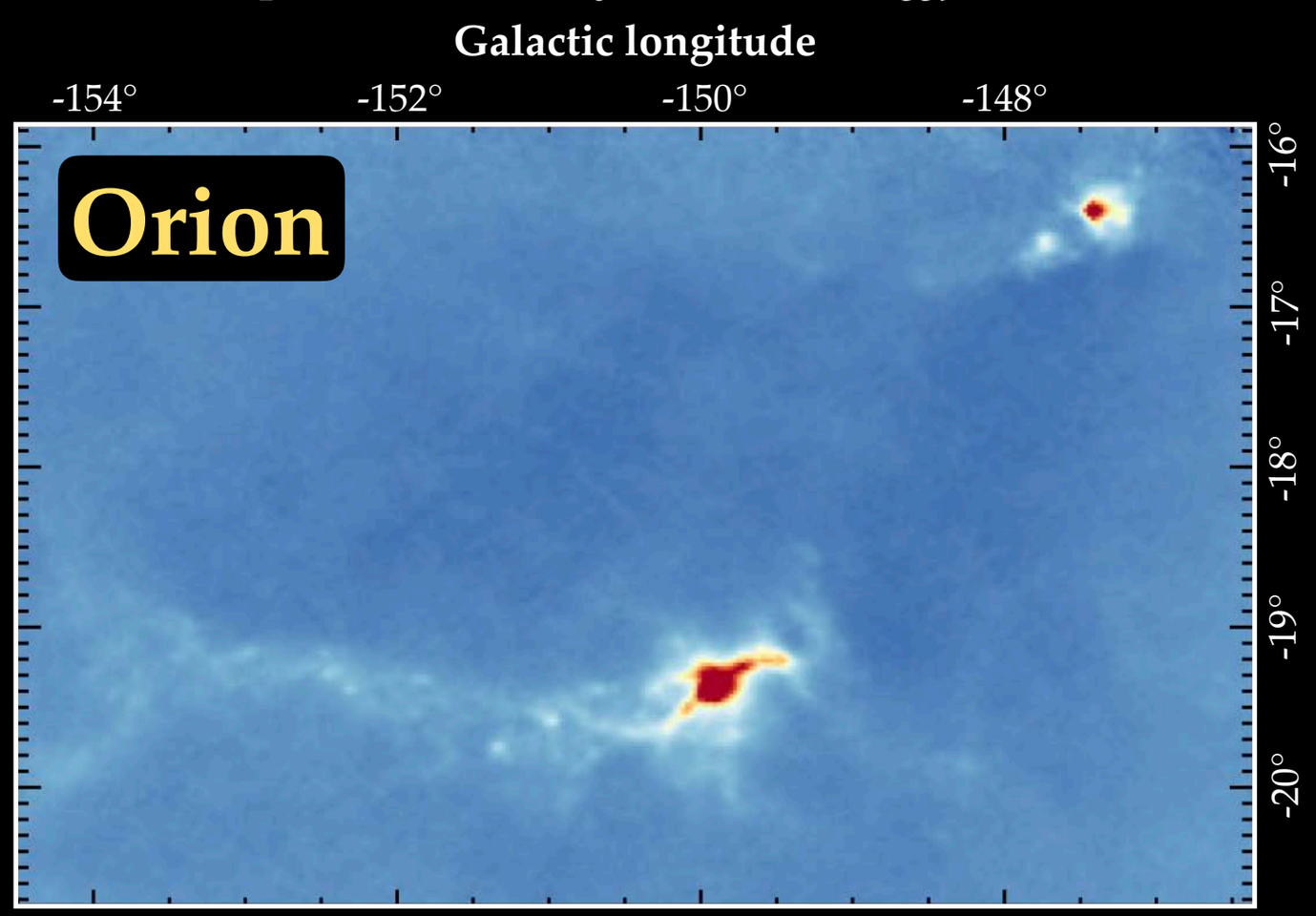


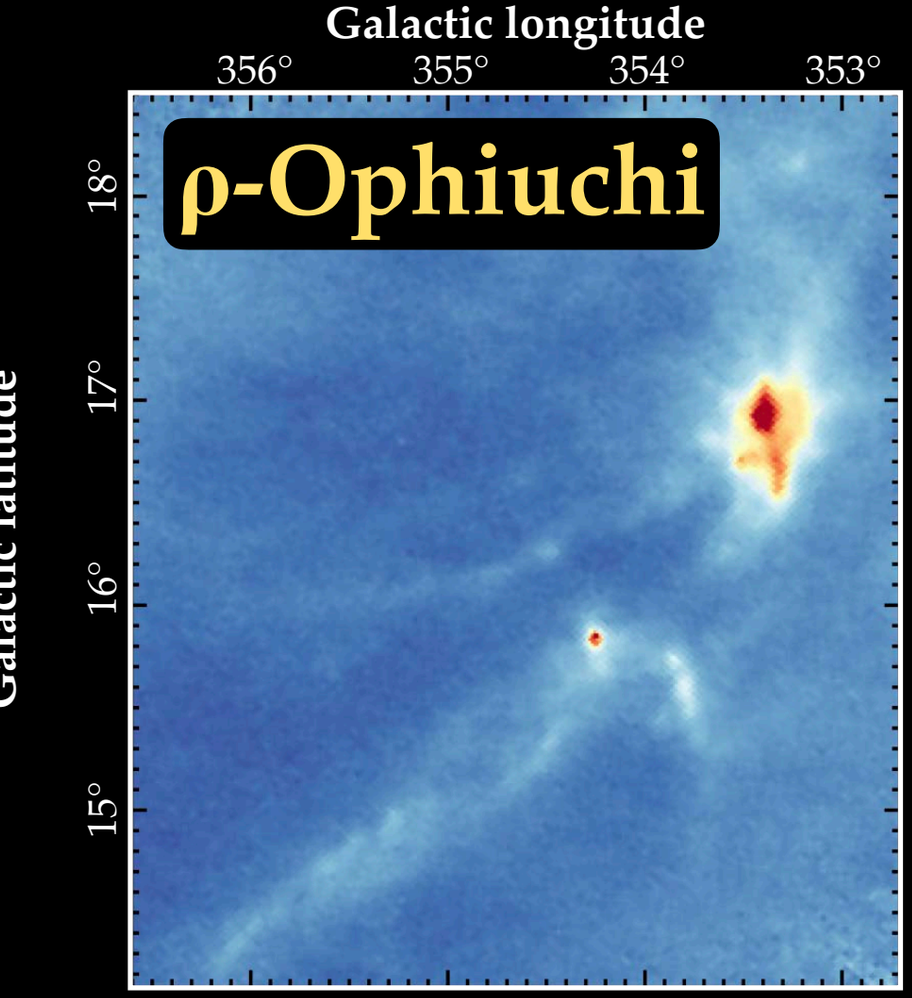


PILOT — Preliminary *I* maps

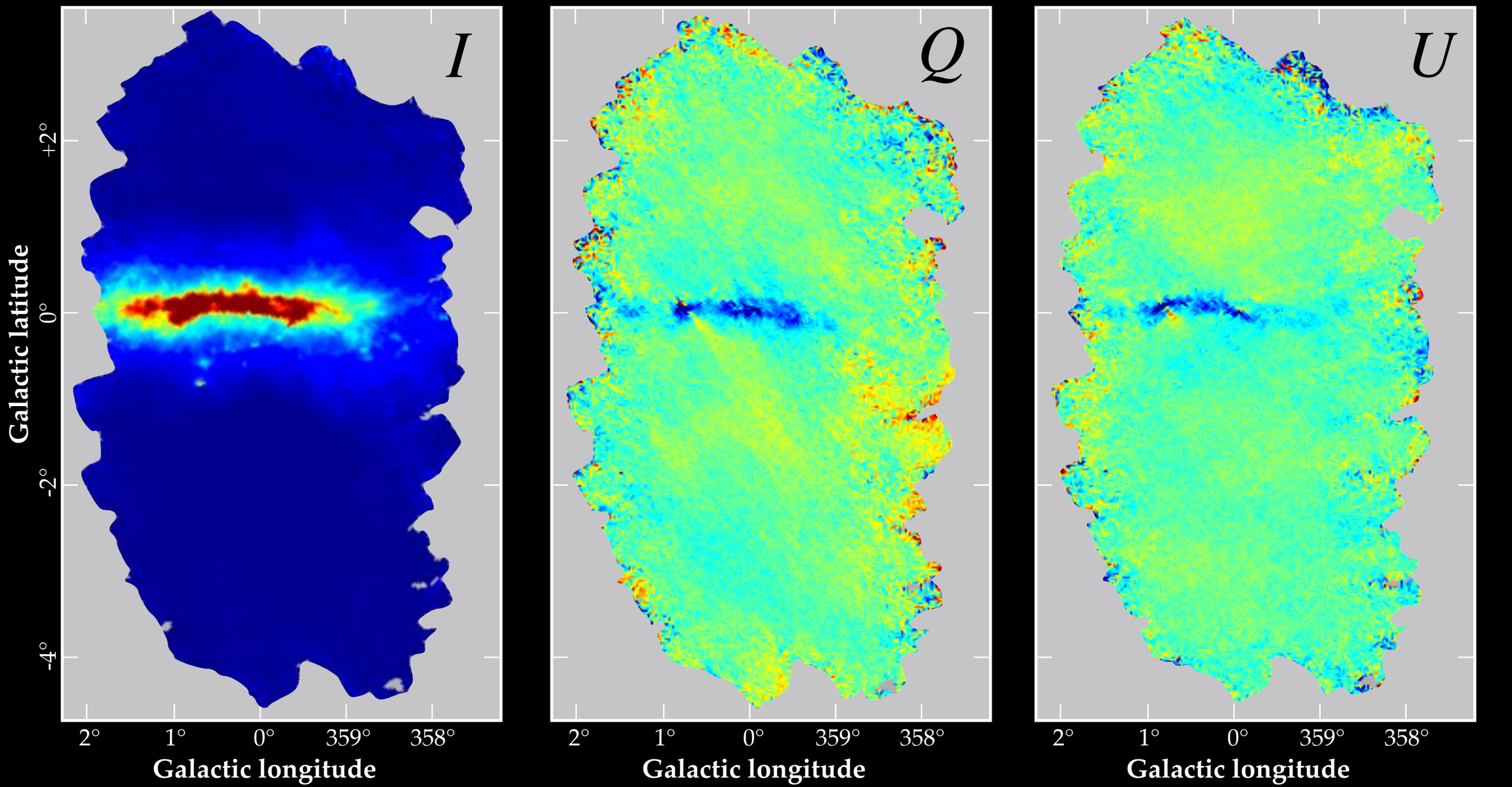








PILOT – Preliminary polarization maps

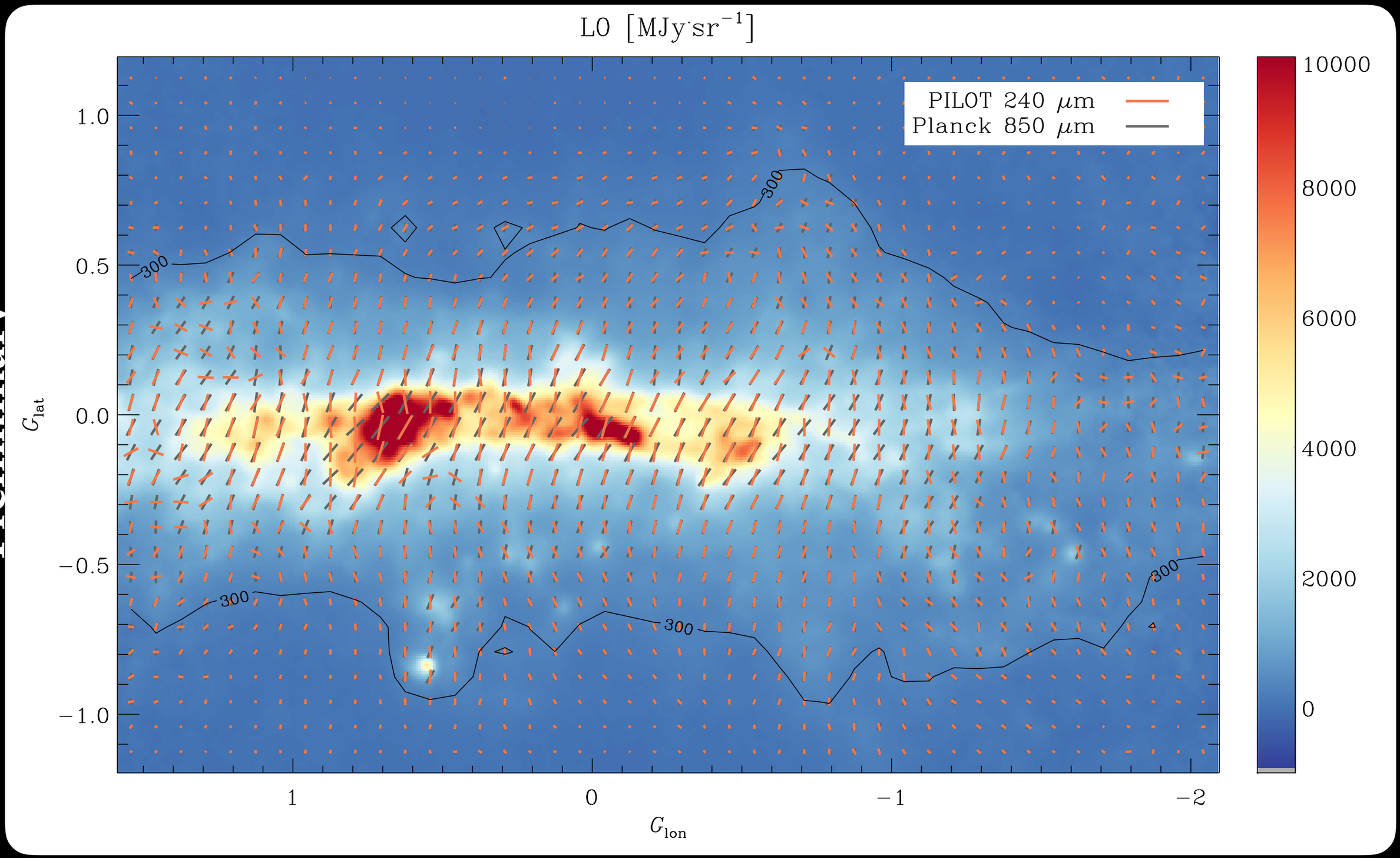


★Stokes parameters *I*, *Q* and *U* in the L0 Galactic plane region

★Strong signal but low polarization fraction

[The PILOT Collaboration, Mangilli et al. 2018 in prep.]

PILOT – Comparison to Planck



Preliminary

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

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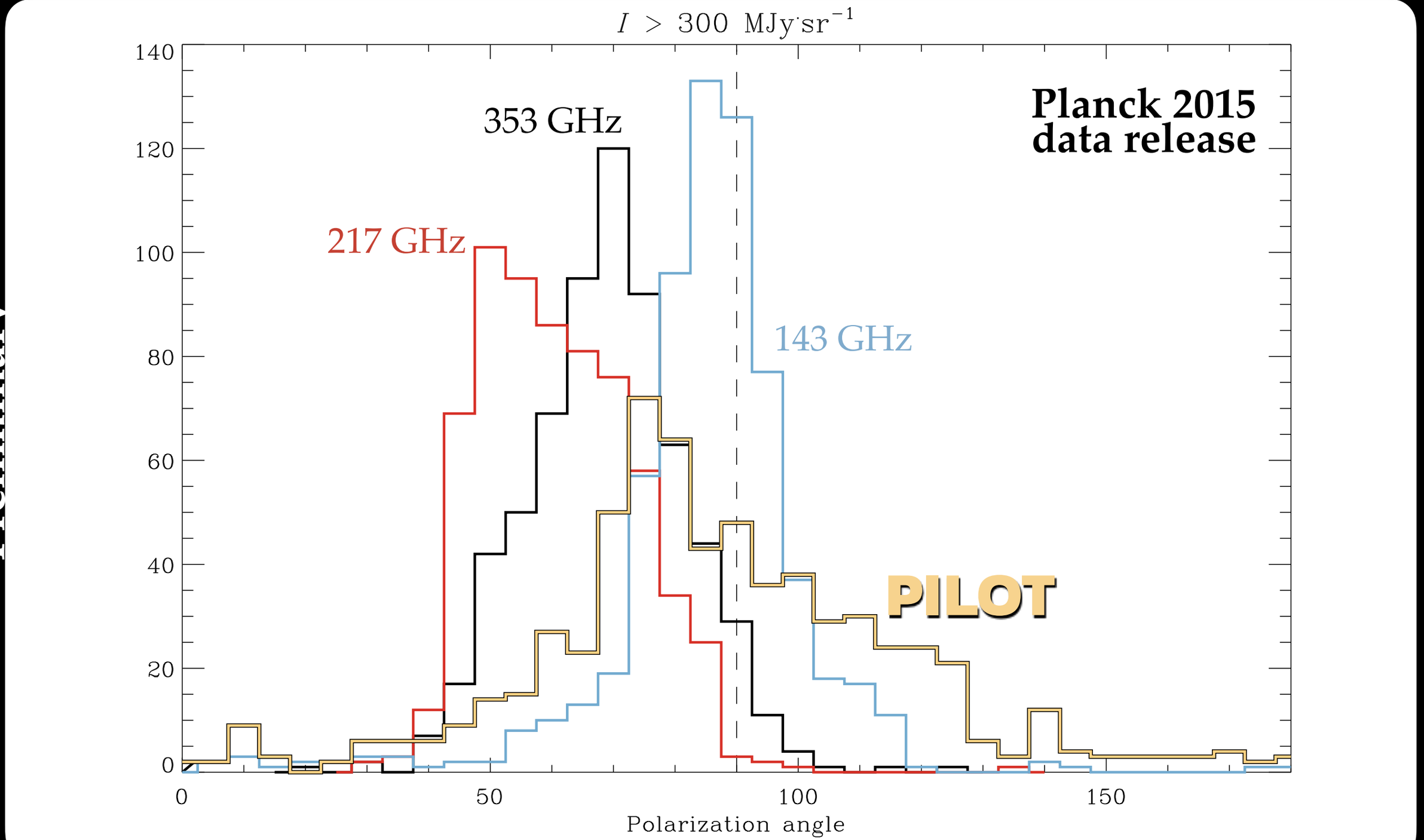

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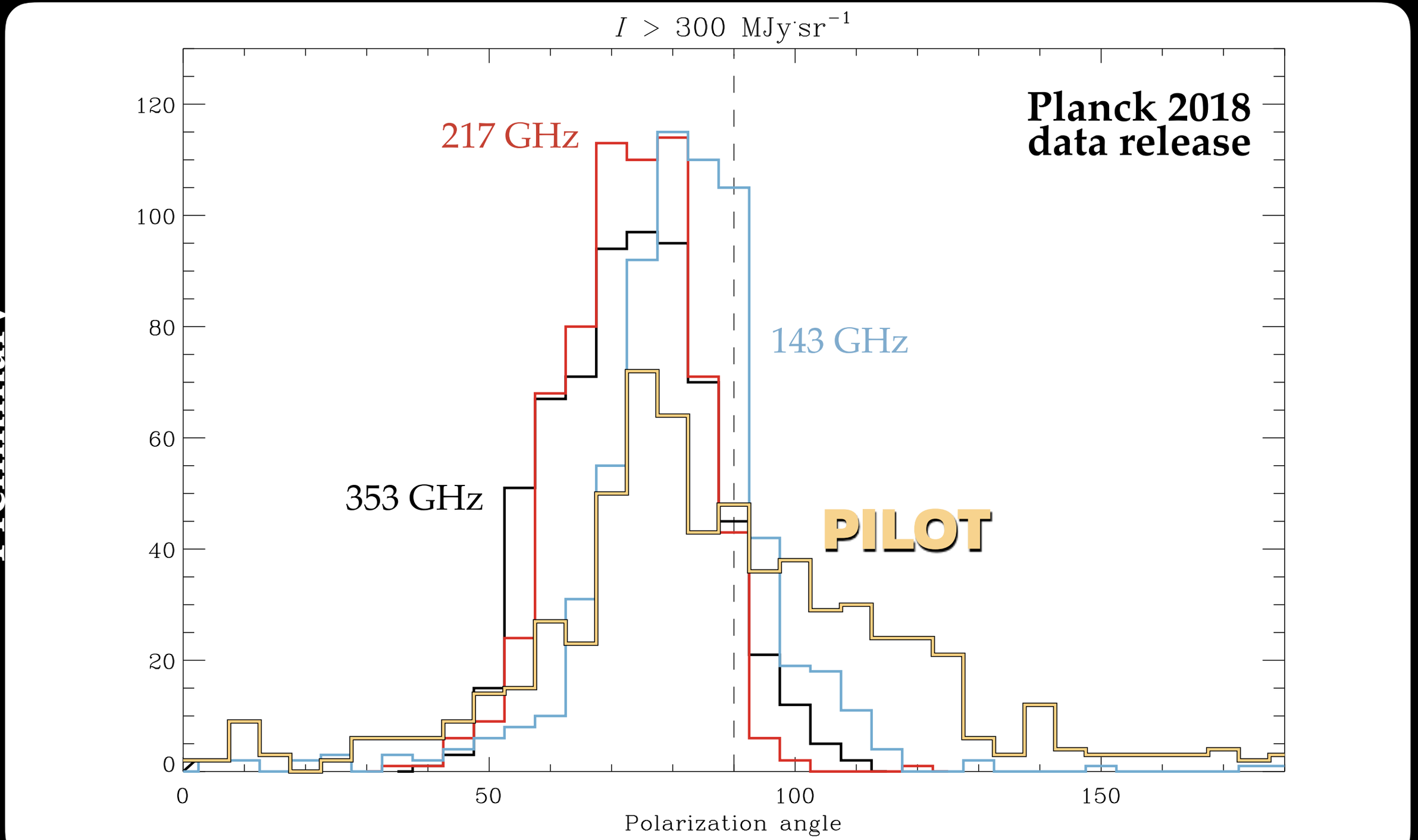

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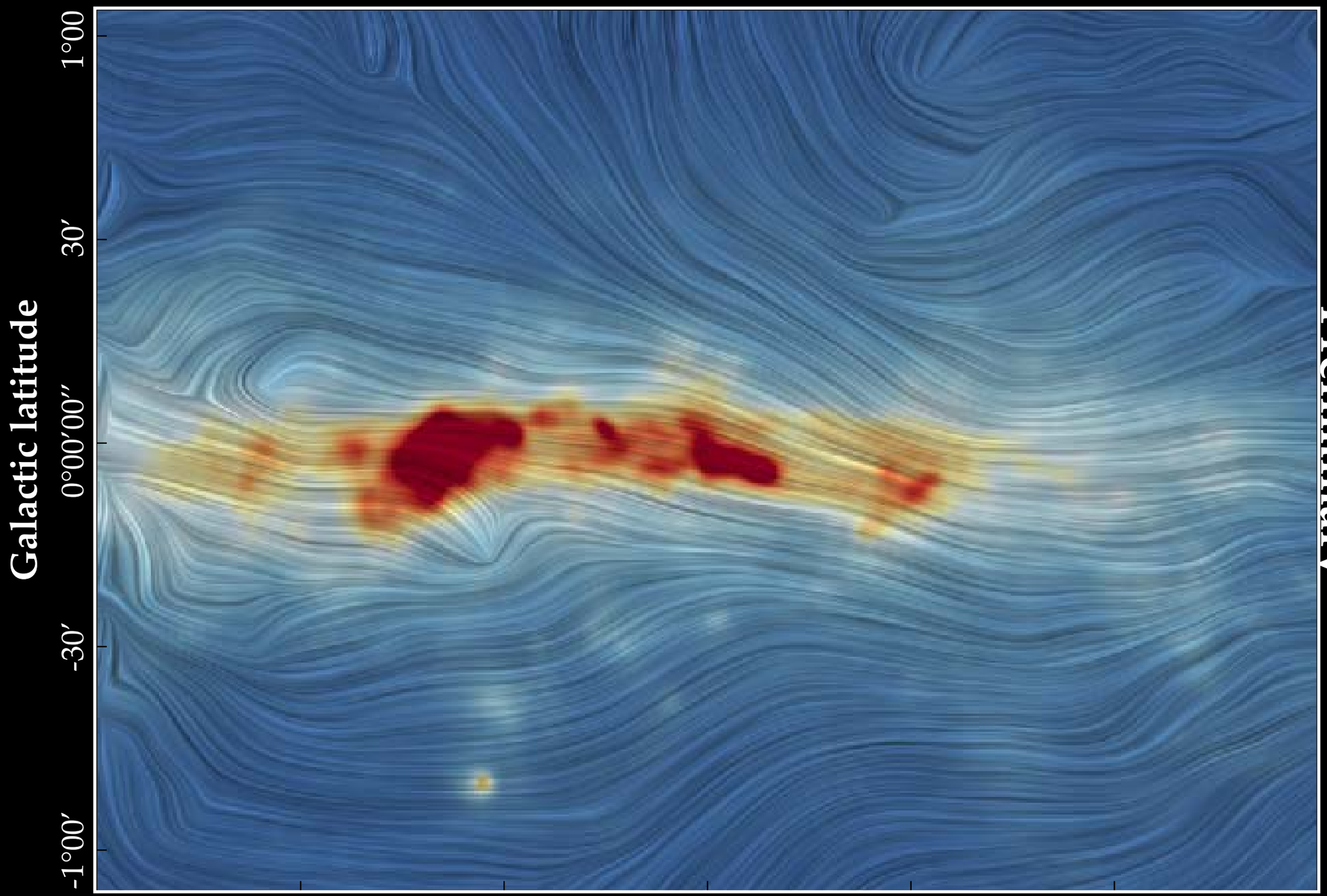
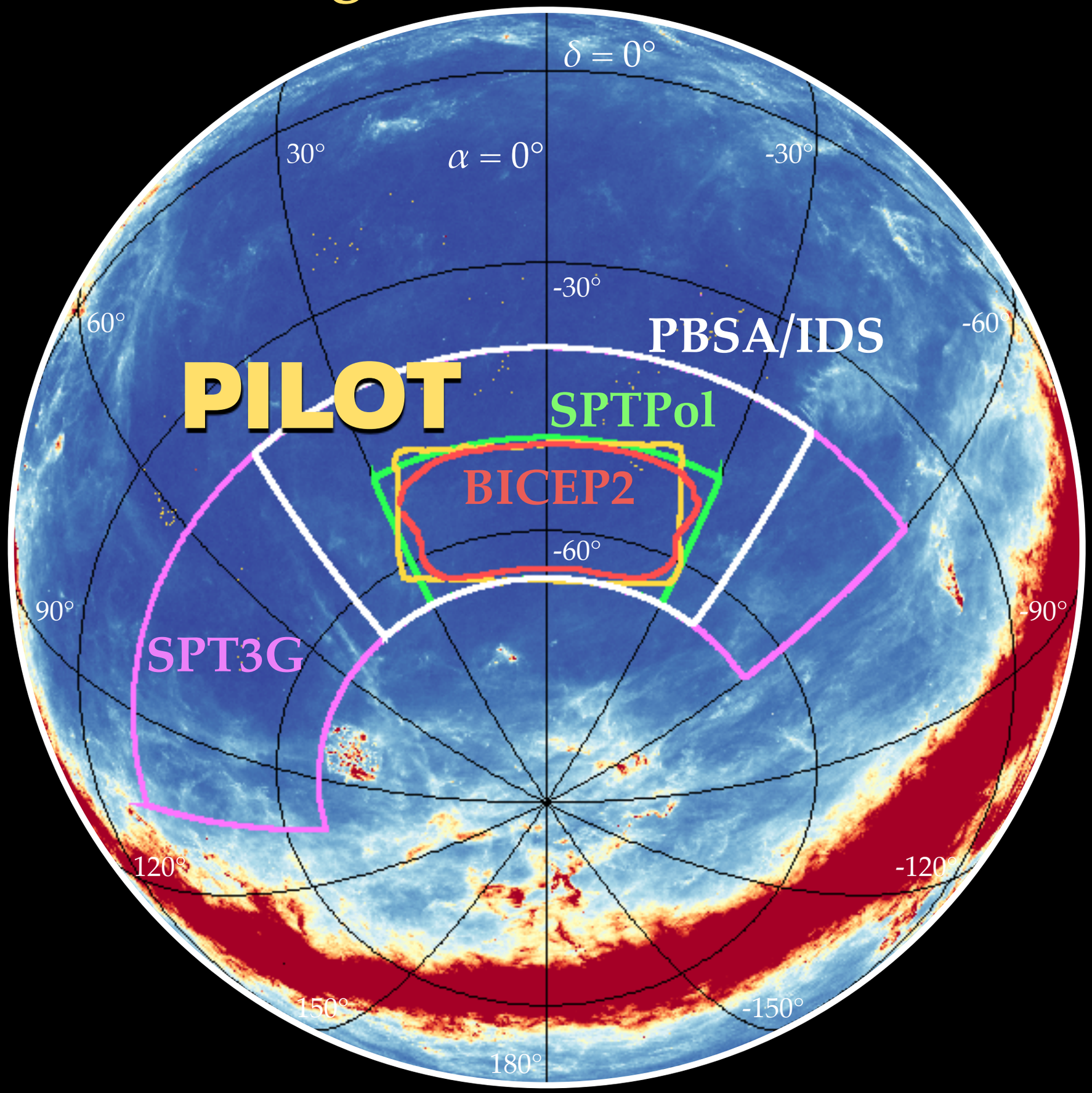
PILOT – Direction of the magnetic field



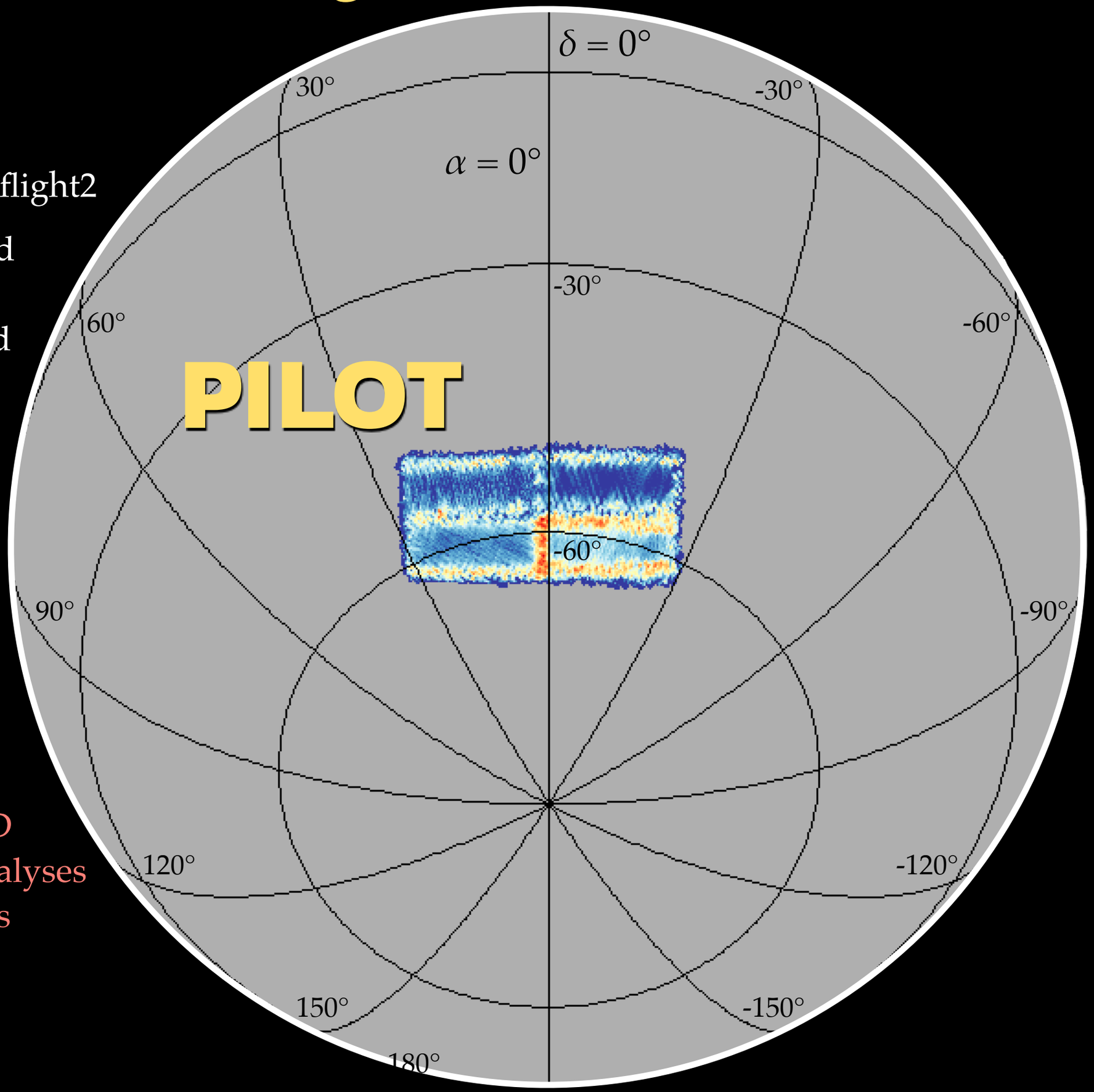
[The PILOT Collaboration, Mangilli et al. 2018 in prep.]

PILOT – "BICEP" region

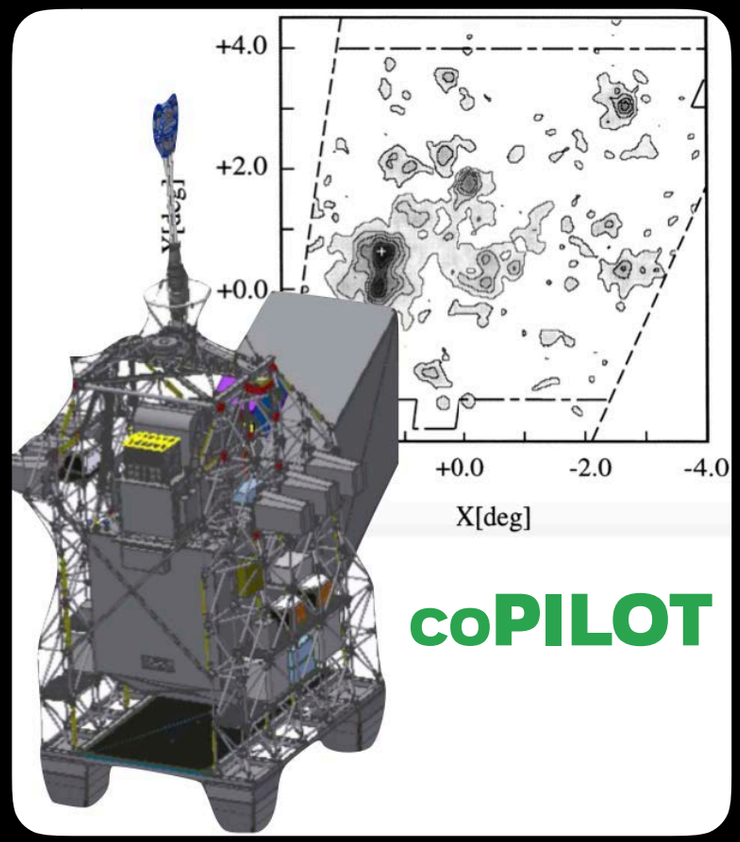


PILOT – "BICEP" region

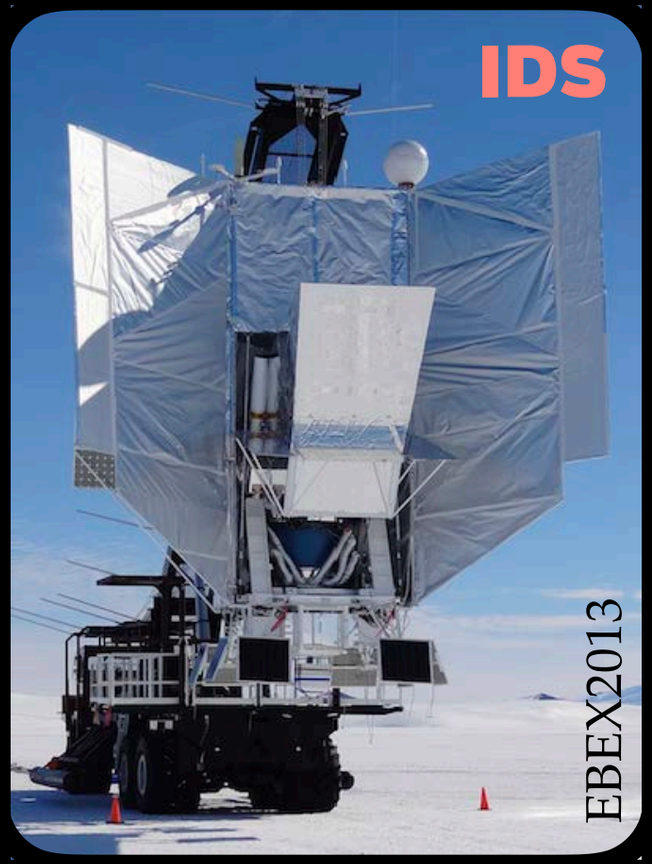
- ★ 4.8 h of data during flight2
- ★ BICEP field observed with 4 tiles, each of them being observed at least twice with 2 different HWP positions
- ★ Goal signal to noise ratio of ~20 on the polarized intensity integrated over the whole field
- ★ Unique data for constraining the SED or for correlation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



PILOT – Legacy



coPILOT



SPICA-PoL

★ **coPILOT**: modification of **PILOT** will allow very accurate measurements of C+ (158 μm) total intensity. Dark molecular gas distribution in solar neighborhood, nearby galaxies. Submitted to CNES

★ **IDS** (Inflation and Dust Surveyor): CMB *B*-modes + dust, proposed to NASA 2018. 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