l'expérience PILOT

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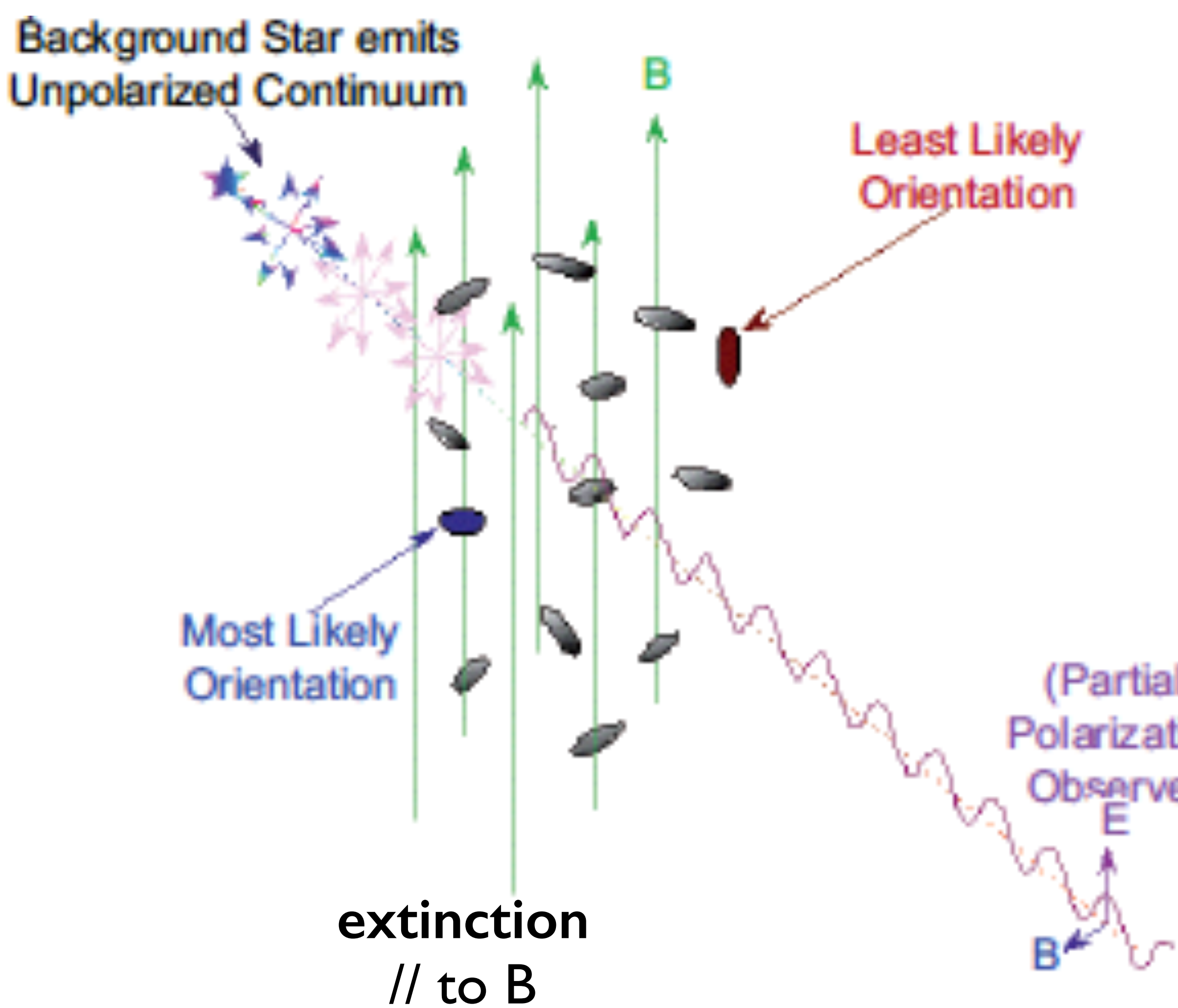
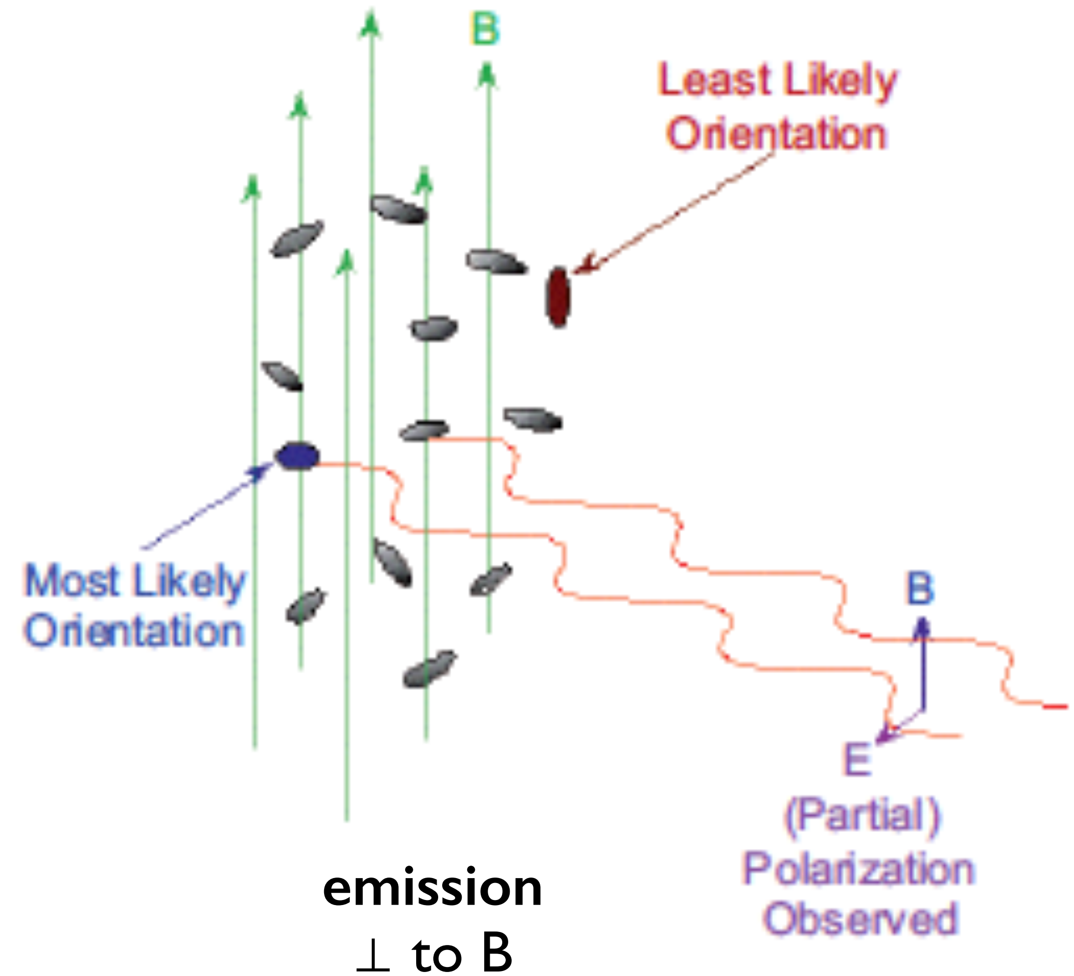
pour l'ensemble de la collaboration PILOT

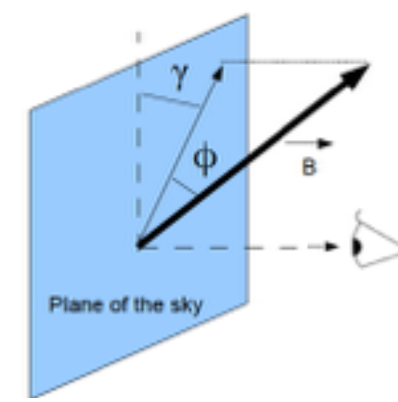
Contexte Scientifique
L'expérience PILOT
Les vols
Perfomances en vol
Traitement des données
Premiers résultats
Futur

Dust Polarization





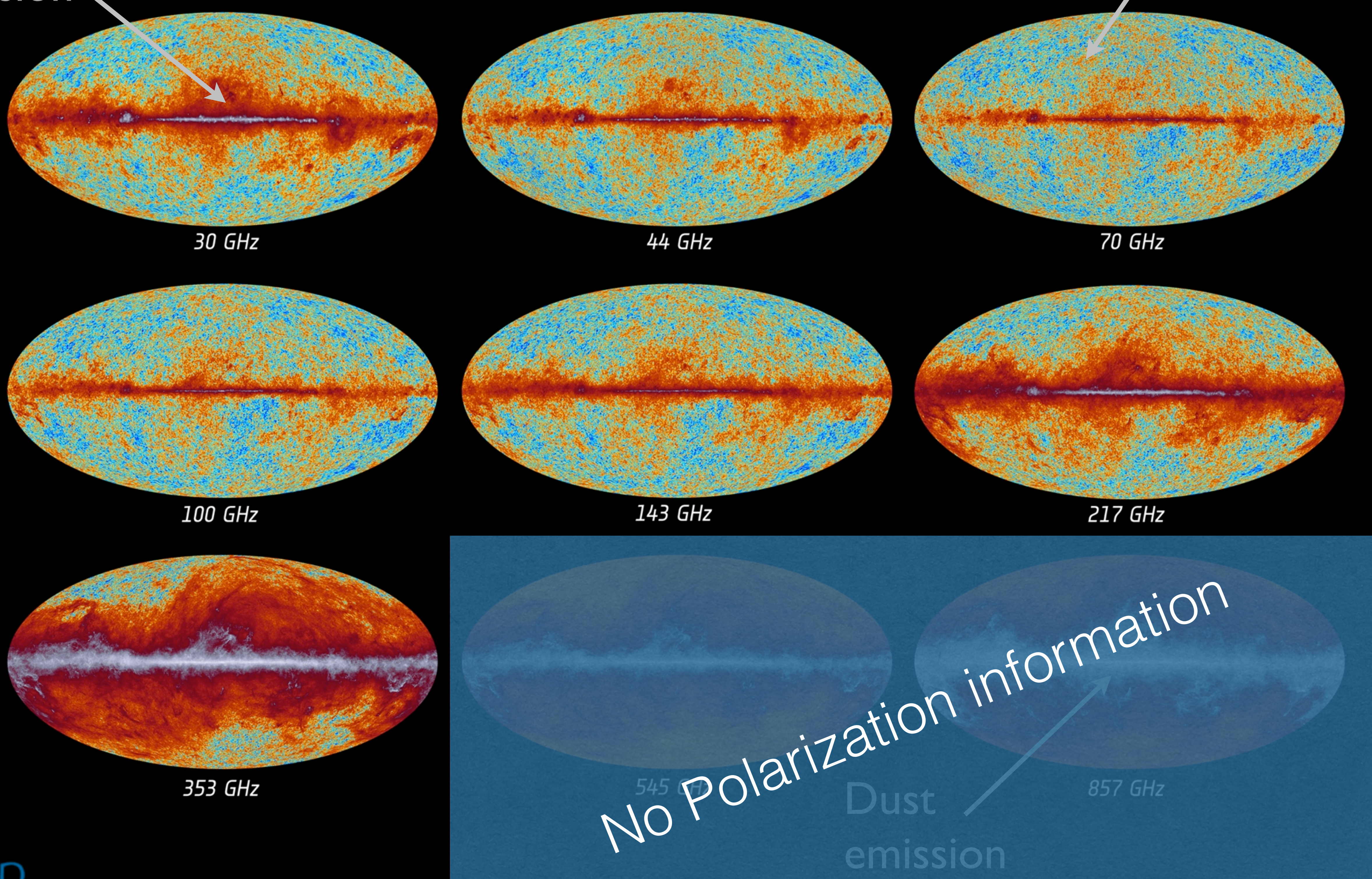
- Grains are rotating, elongated
- Grains align partially on B
- Cross sections α grains size,
  so polarization in extinction and emission
- Trace magnetic field direction projected on the sky
- Unlike Synchrotron emission, traces B field in star forming regions



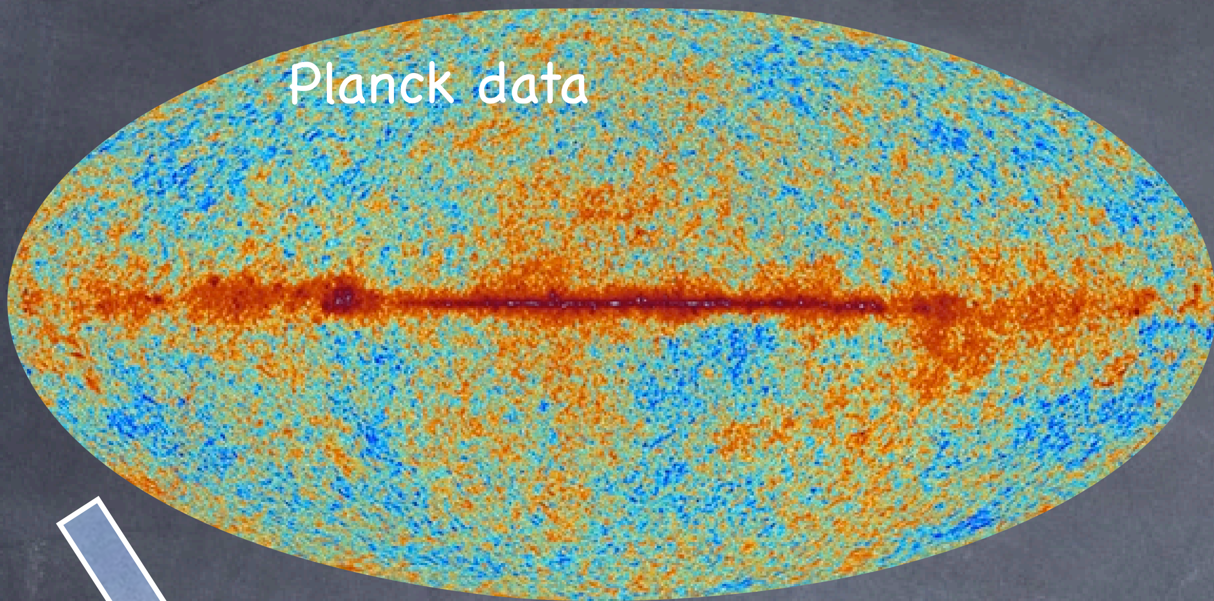
$$P = \sqrt{(Q^2+U^2)} \propto \cos^2\phi$$

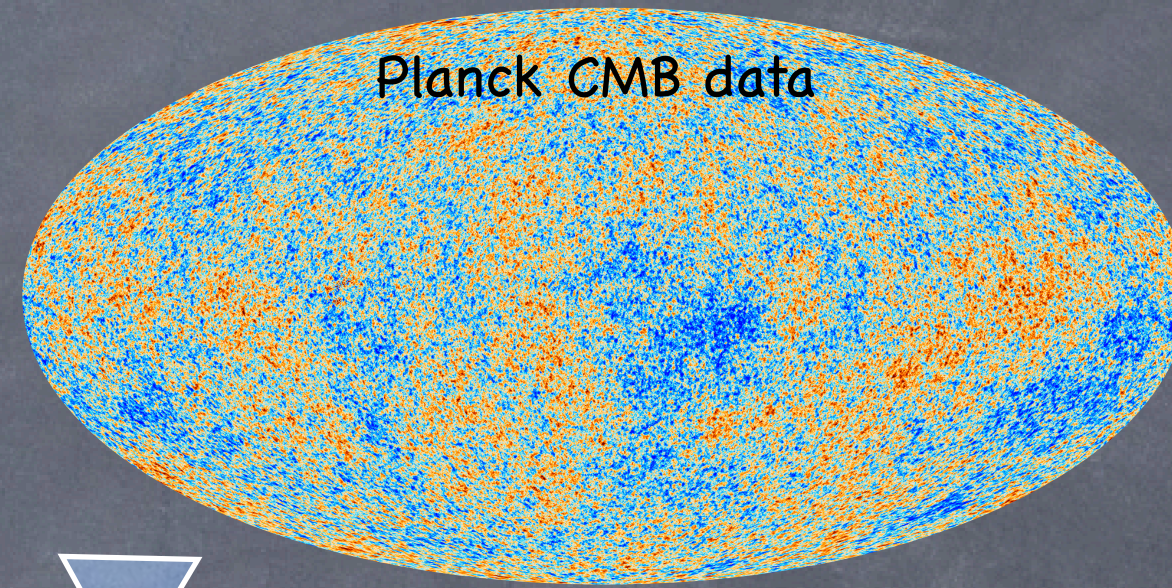
Stein 1966, Andersson 2012, Draine & Fraisse 2009, Hoang & Lazarian 2008, Martin 1975, 2007

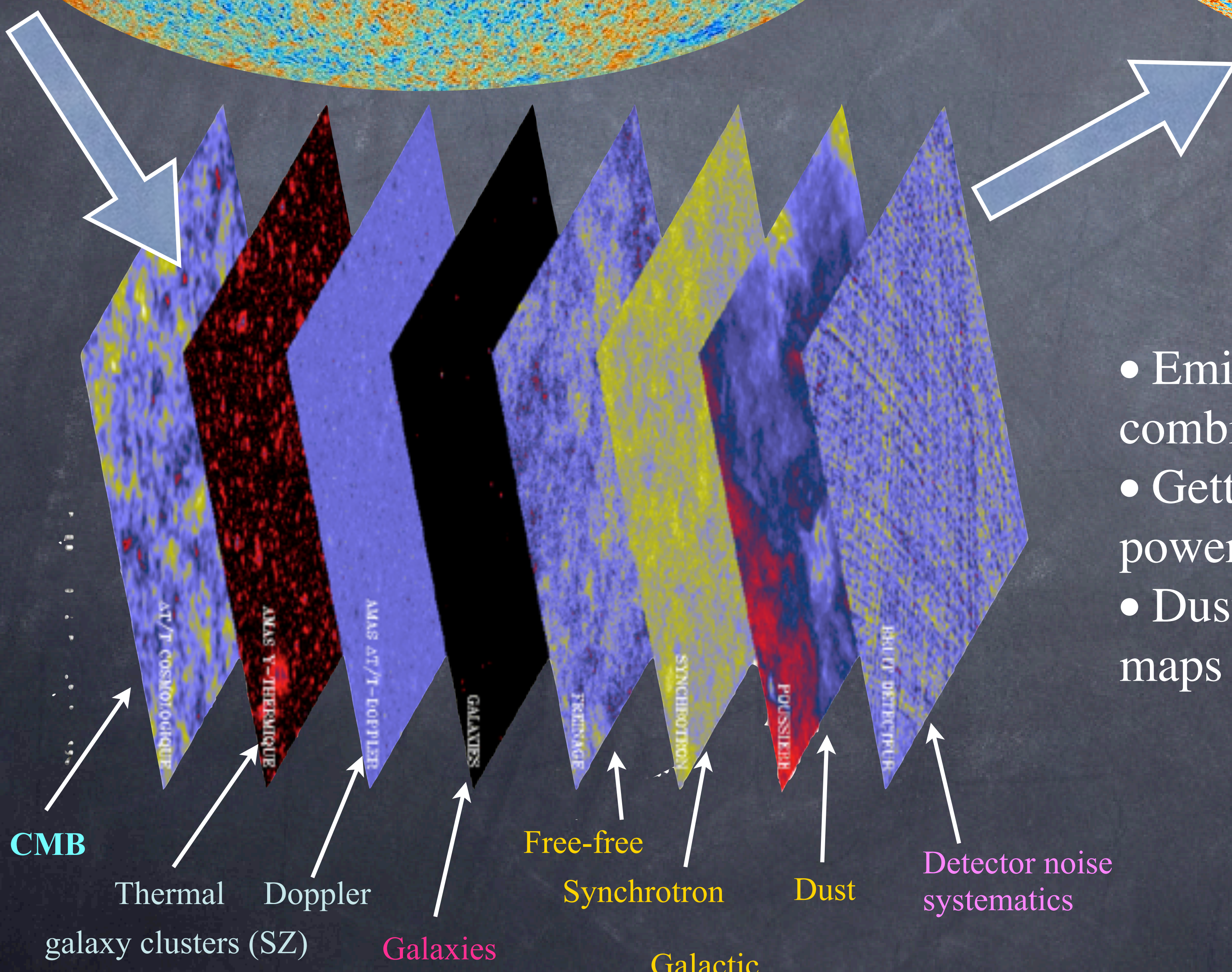
The Planck sky



Component separation







- Emission in the Planck bands is a linear combination of many components
- Getting to the CMB without affecting its power spectrum is a challenge
- Dust is a major contamination in CMB maps

Planck and CMB polarized Foreground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News & Comment > News > 2014 > May > Article

NATURE | NEWS

Gravitational wave discovery faces scrutiny

Cosmologist casts doubt on BICEP2's analysis of cosmic microwaves, but the team stands by its conclusions.

Erik Verlinde @erikverlinde Suivre

News from Princeton: BICEP2 polarization data are due to dust foreground and not caused by primordial gravity waves

Doubts Shroud Big Bang Discovery

By Adrian Cho | Monday, May 19, 2014 - 6:30pm

Staff Writer

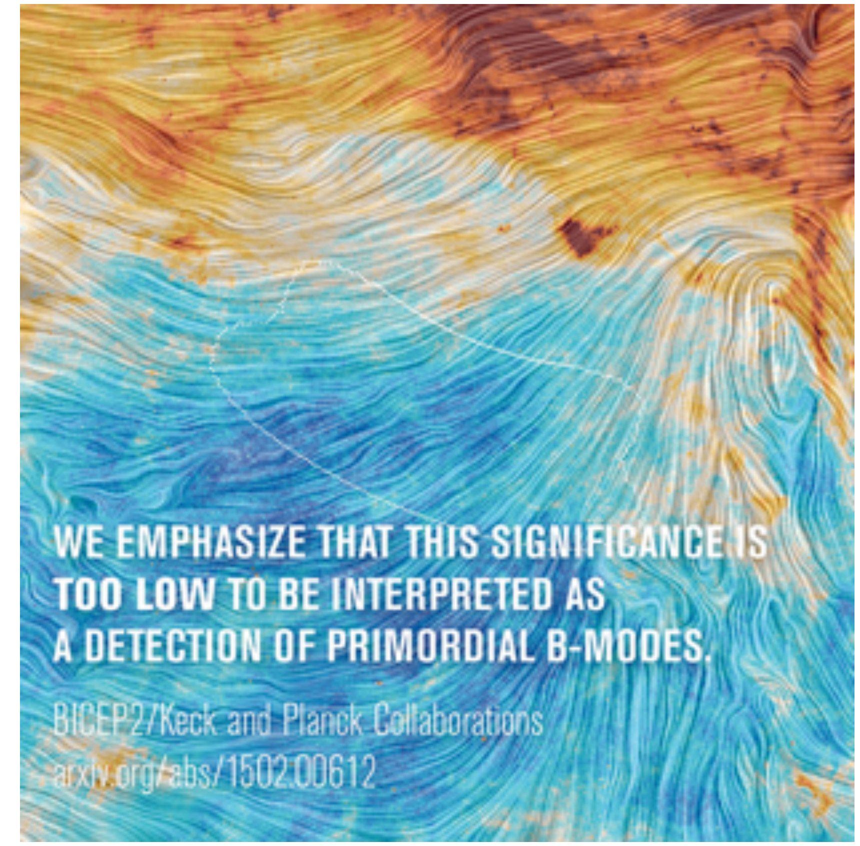
Email Adrian

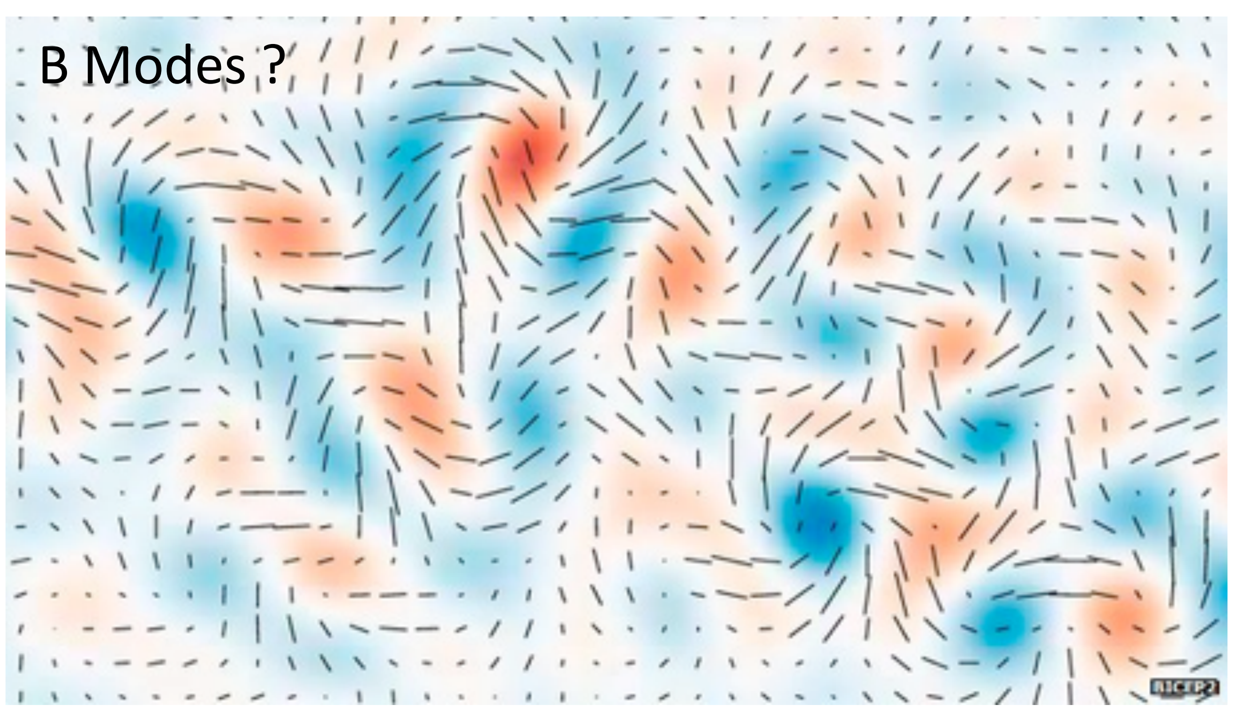
Two months ago, a team of cosmologists reported that it had spotted the first direct evidence that the newborn universe underwent a mind-boggling exponential growth spurt known as inflation. But a new analysis suggests the signal, a subtle pattern in the afterglow of the big bang, or cosmic microwave background, could be an artifact produced by dust within our own galaxy.

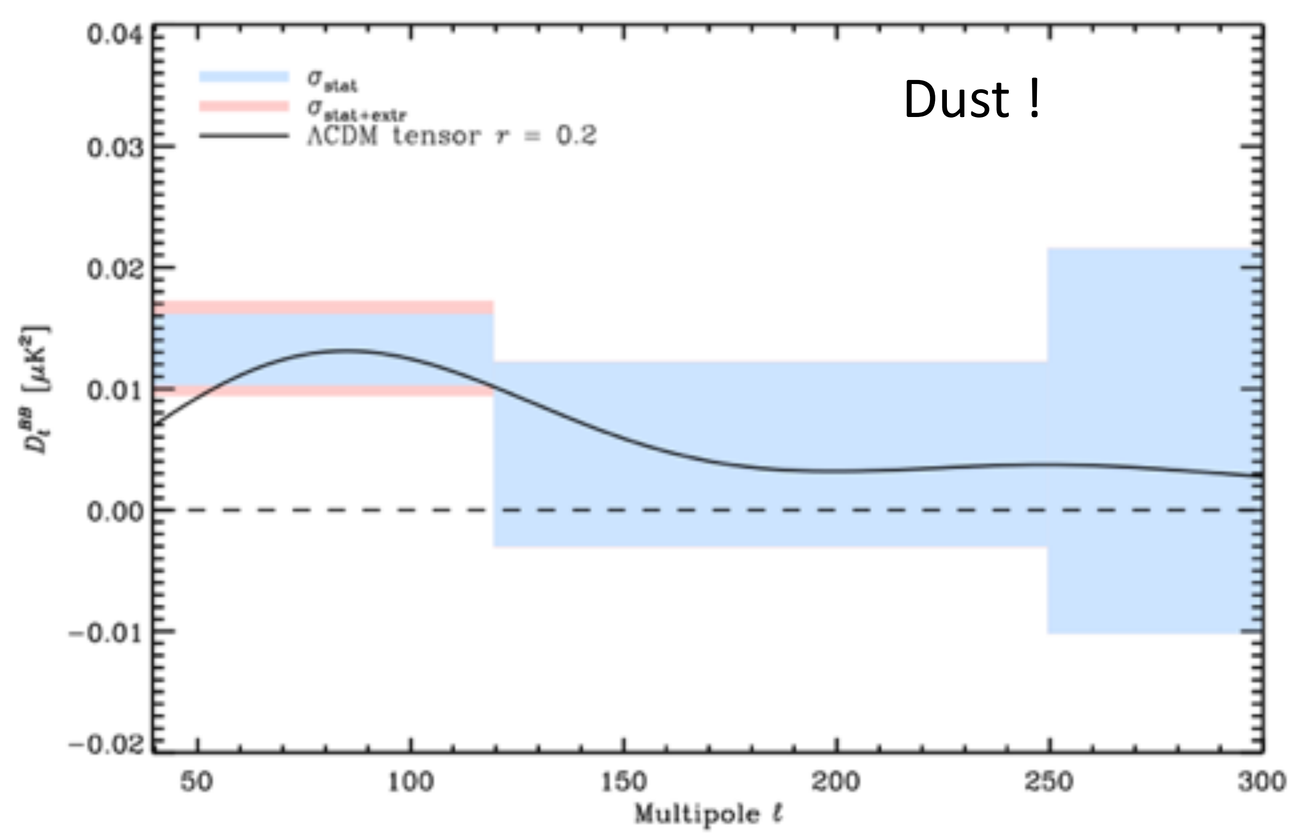
For the full story, see this week's issue of Science.

The Bicep2 episode !

The detection of B modes was in fact a detection of dust polarization





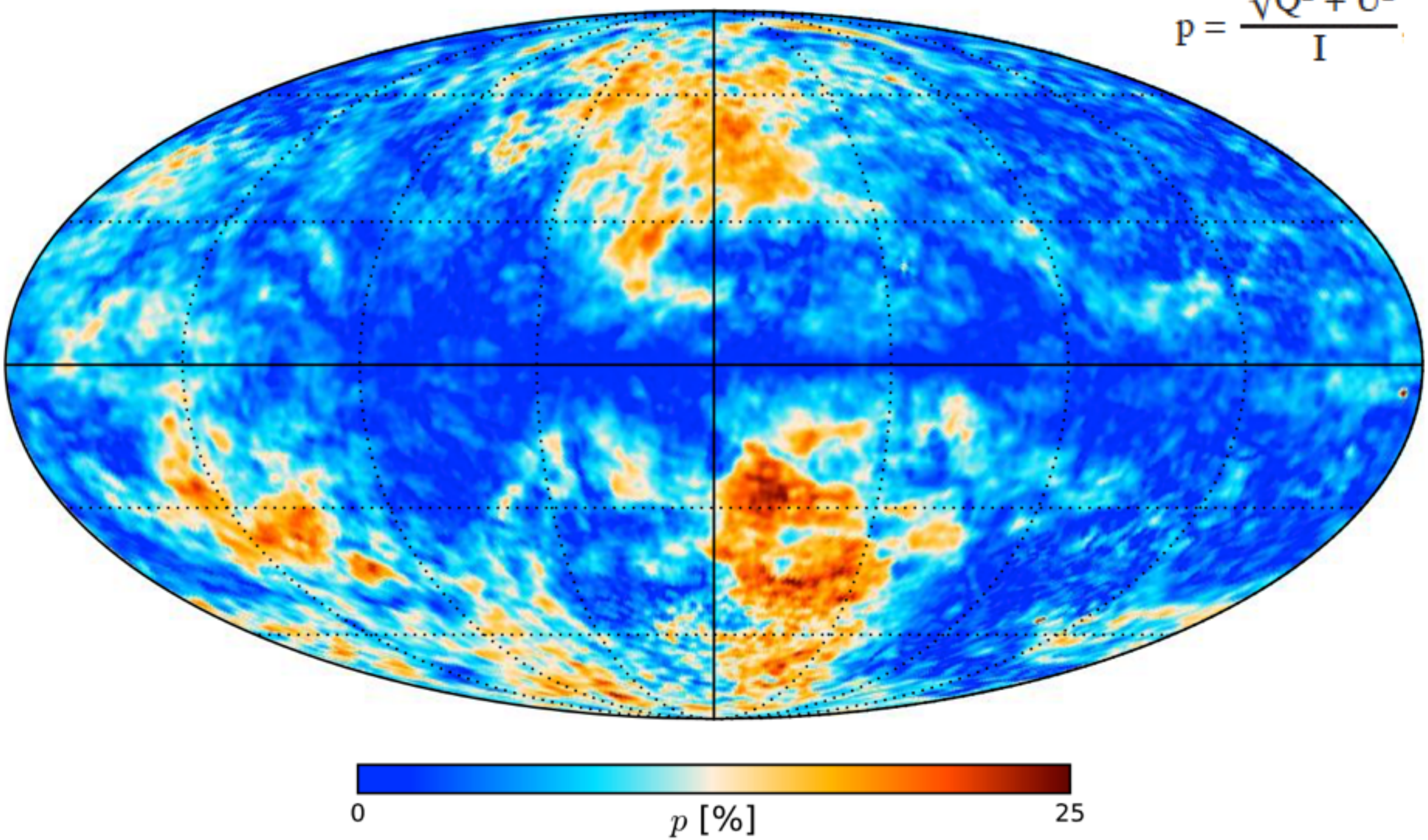


Planck intermediate results. XXX.

J.-Ph. Bernard, AsA, Oct 2nd 2018

fraction de polarization

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

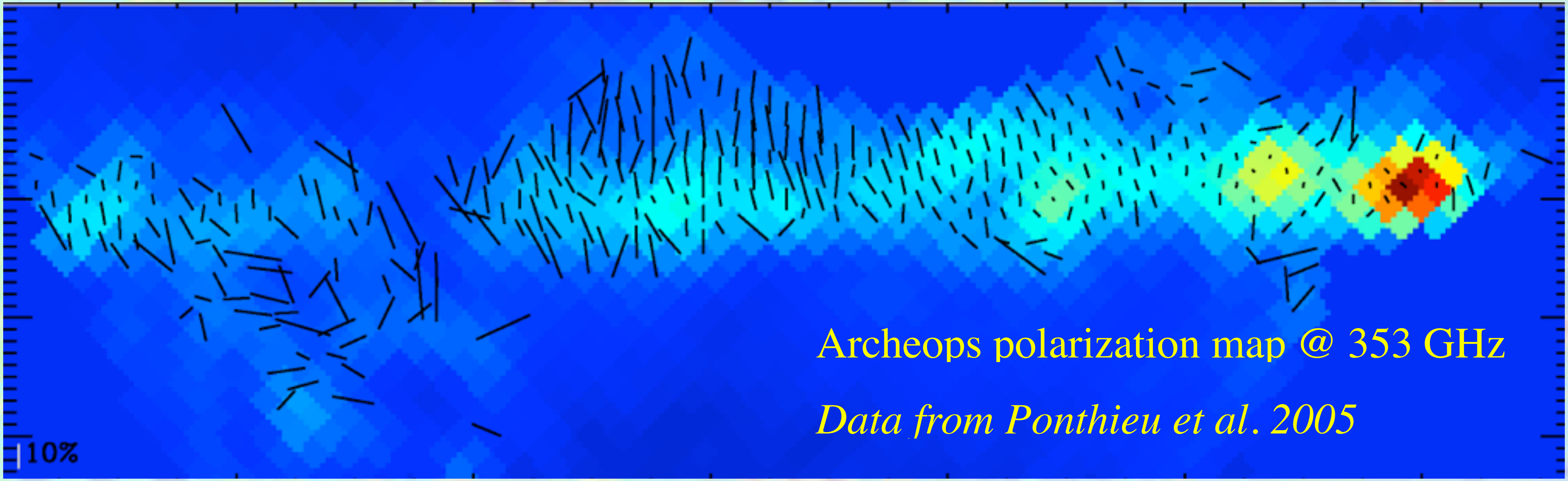


Dust polarization much higher than expected by most astronomers !

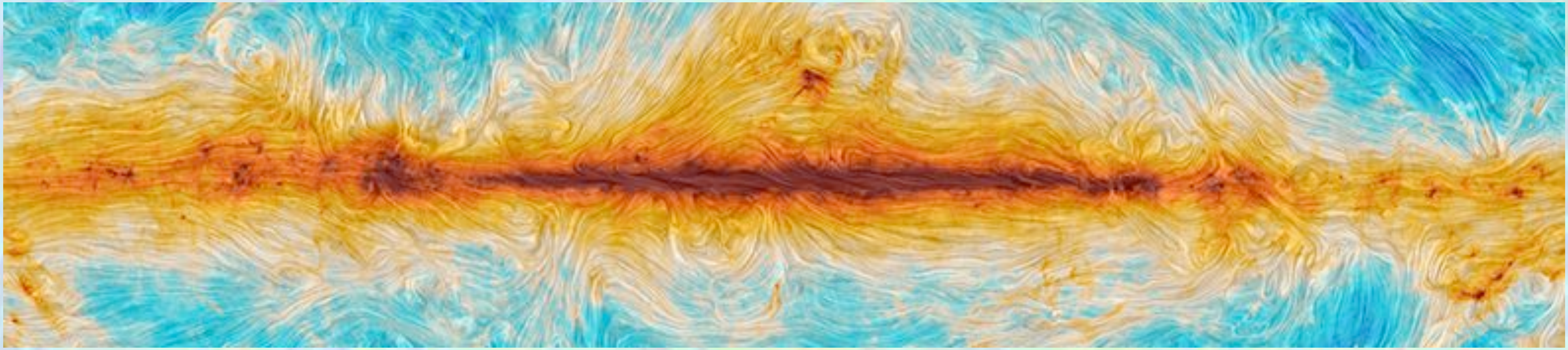
Planck intermediate results. XIX.

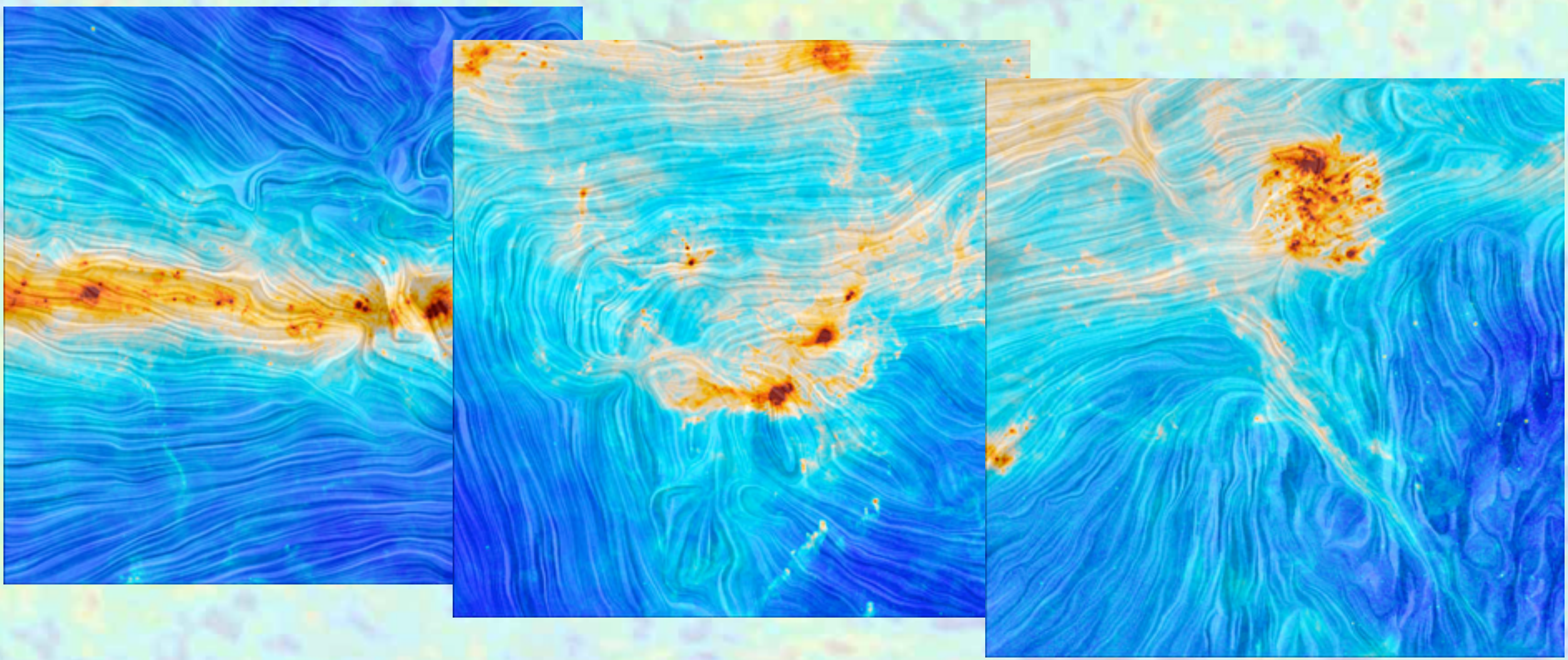
Foreground polarisation

- Archeops detected large scale dust polarization in emission for the first time
- Evidenced large polarization fractions (>10%) at high latitudes

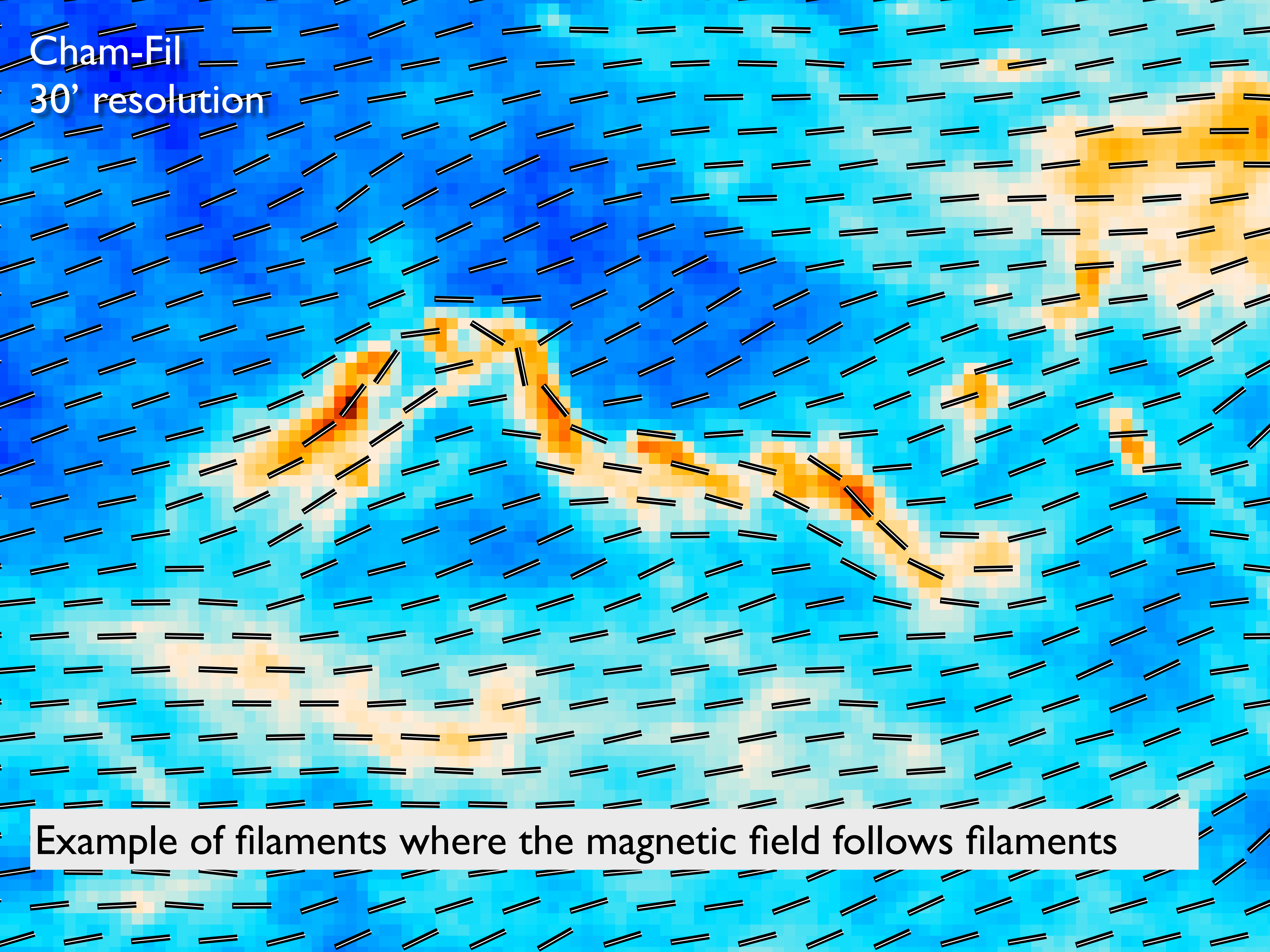


All sky polarization with Planck





Reveals the structure of the magnetic field



Example of filaments where the magnetic field follows filaments http://pilot.irap.omp.eu/

• **Science Objective:** measure linear polarization of dust emission in the Far-InfraRed
- Reveal the <u>structure of the magnetic field</u>
- Geometric and magnetic <u>properties of dust grains</u>
- Understand <u>Polarized foreground</u>
- Complement Planck observations at λ<850 µm with better accuracy and higher angular resolution

• **Observations:** Galactic plane (|b|<20°), star forming regions and diffuse Interstellar medium.

• **Characteristics:** λ=240 & 550 µm, resolution: 1.4'-3'. Bolometer array with 2048 detectors

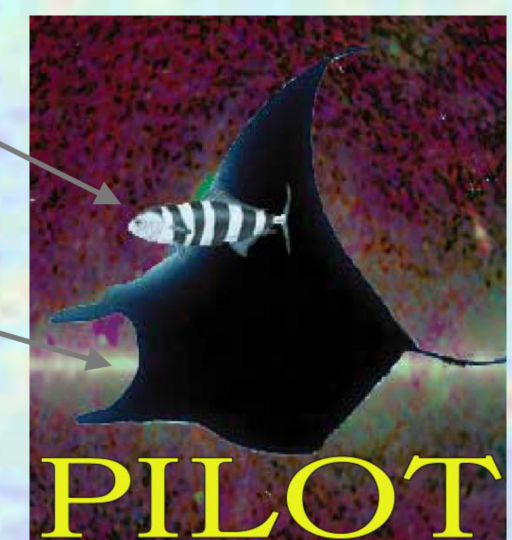
• **Weight, Altitude:** ~ 1 ton, 40 km

• **Status:**
1st flight Sept 2015 from Timmins, Canada.
2nd flight April 2017 from Alice Springs, Australia.

Participations: IRAP, IAS, CEA, CNES
Rome Univ., Cardif Univ.

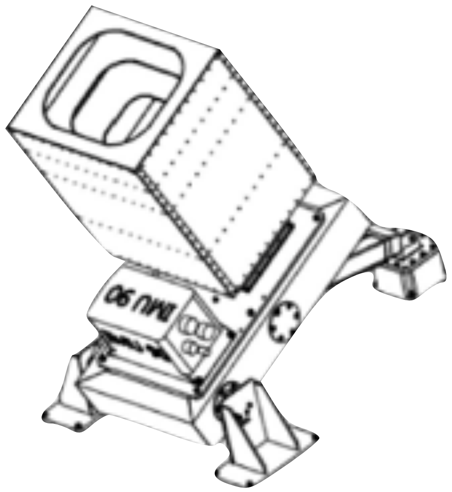
Pilot Fish

next CMB satellite

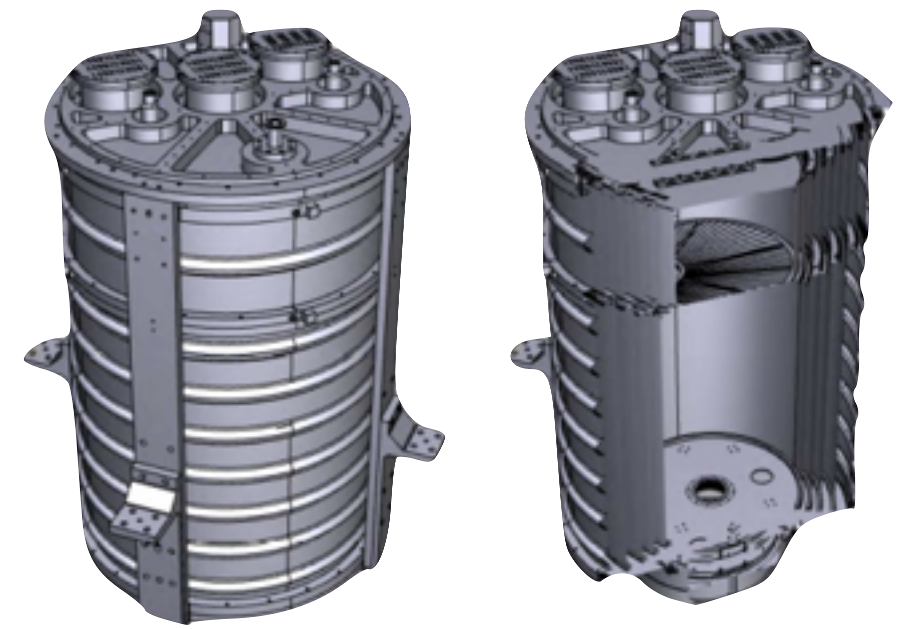


PILOT Subsystems

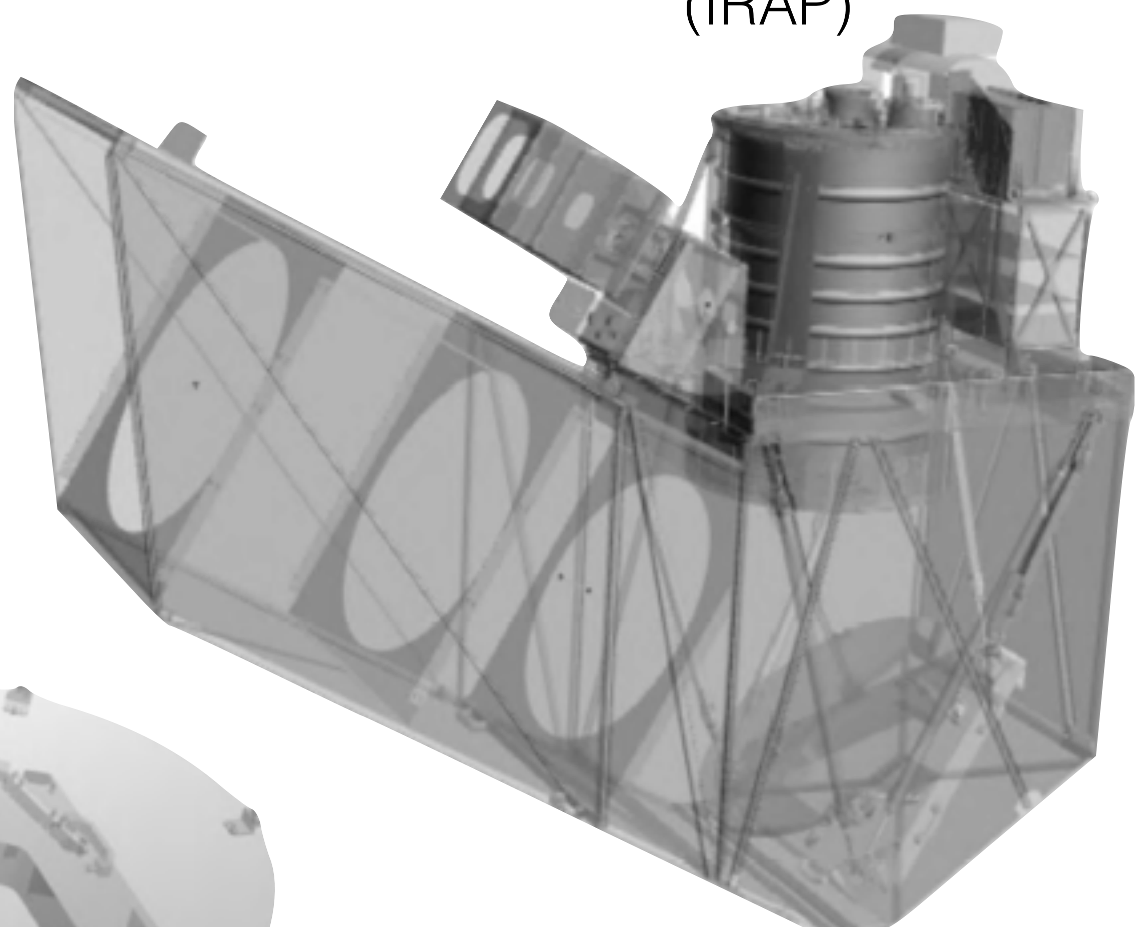
Senseur stellaire
(CNES)



Photometer (IAS, Rome Univ., Cardiff univ.)

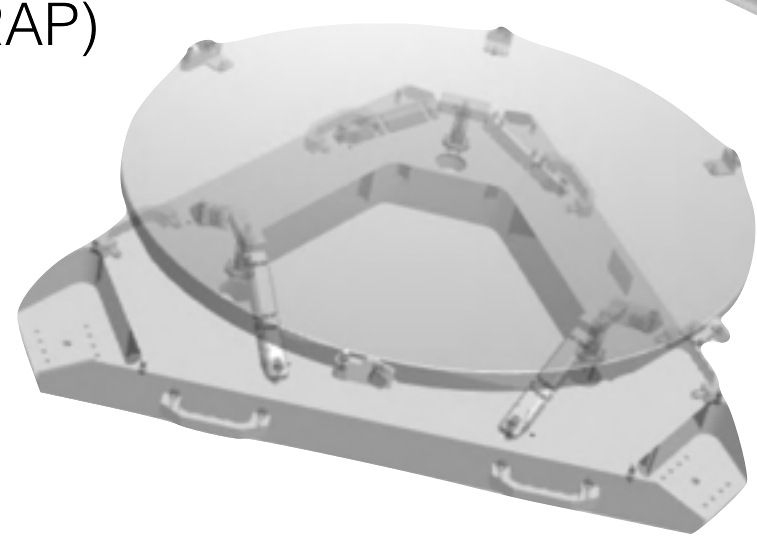


HK Electronics
(IRAP)

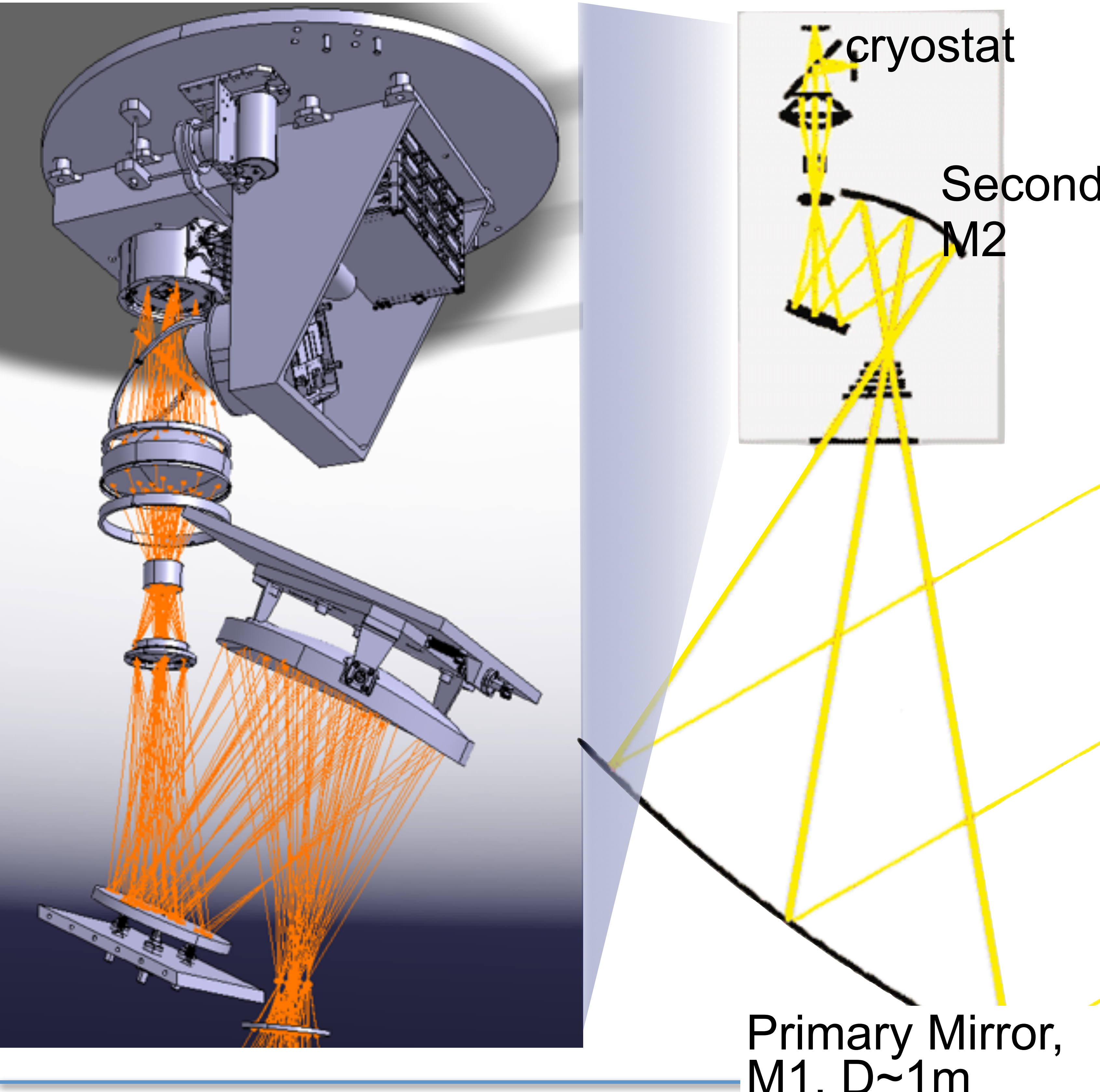


Pointed Load
(IRAP)

Miroir Primaire
(IRAP)

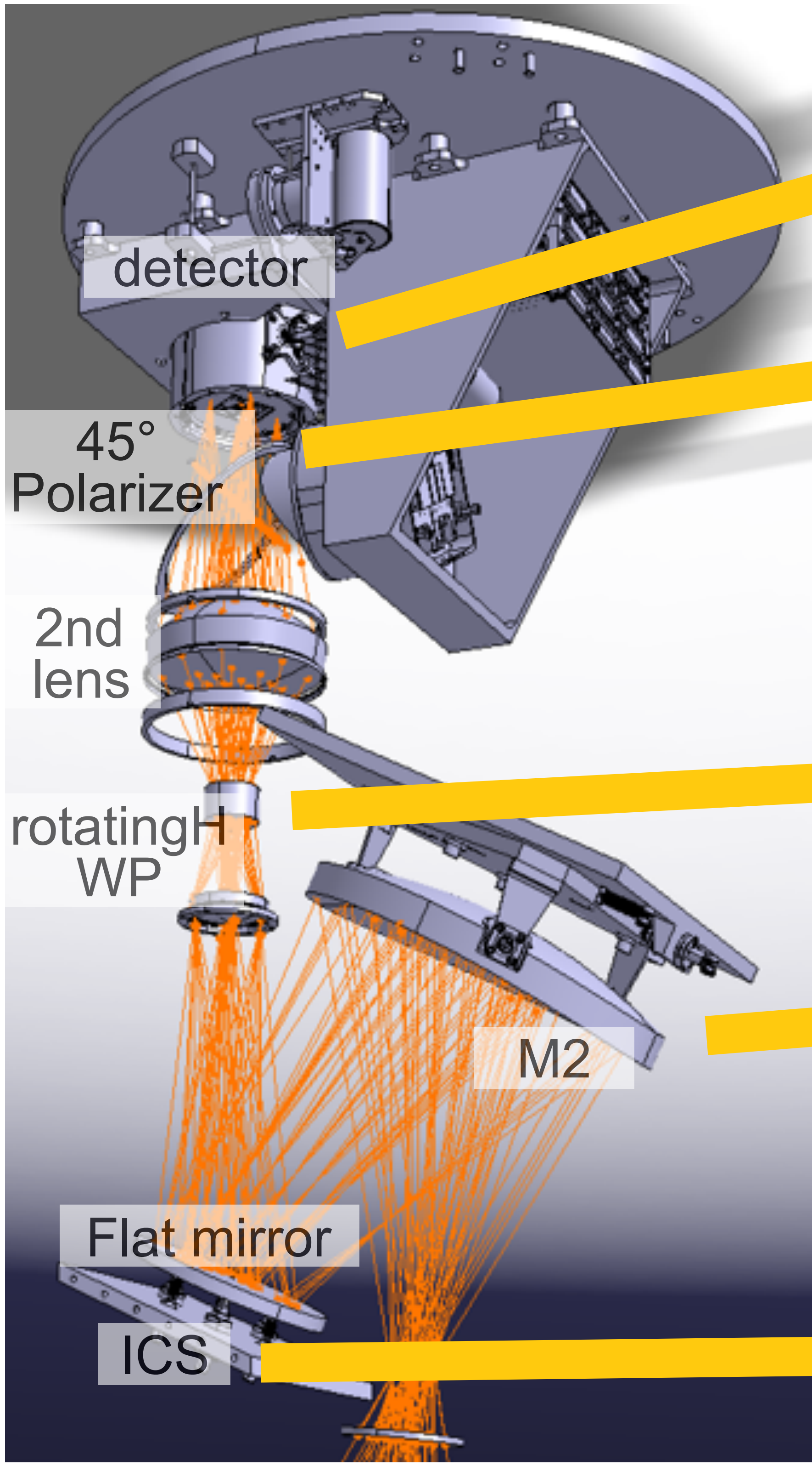


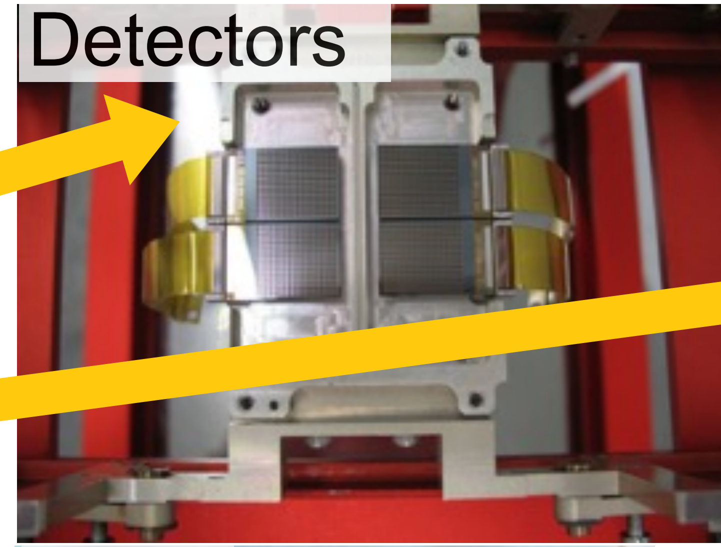
PILOT Concept



- Equivalent Focal length: <u>1800 mm</u>, F/2.5
- Image quality diffraction limited
- Distortion : < 5%
- Polarization rotation : < 5°
- Tolerance :
  translation M1 = ±0.3 mm
  rotation M1 = ±0.06°

PILOT Concept



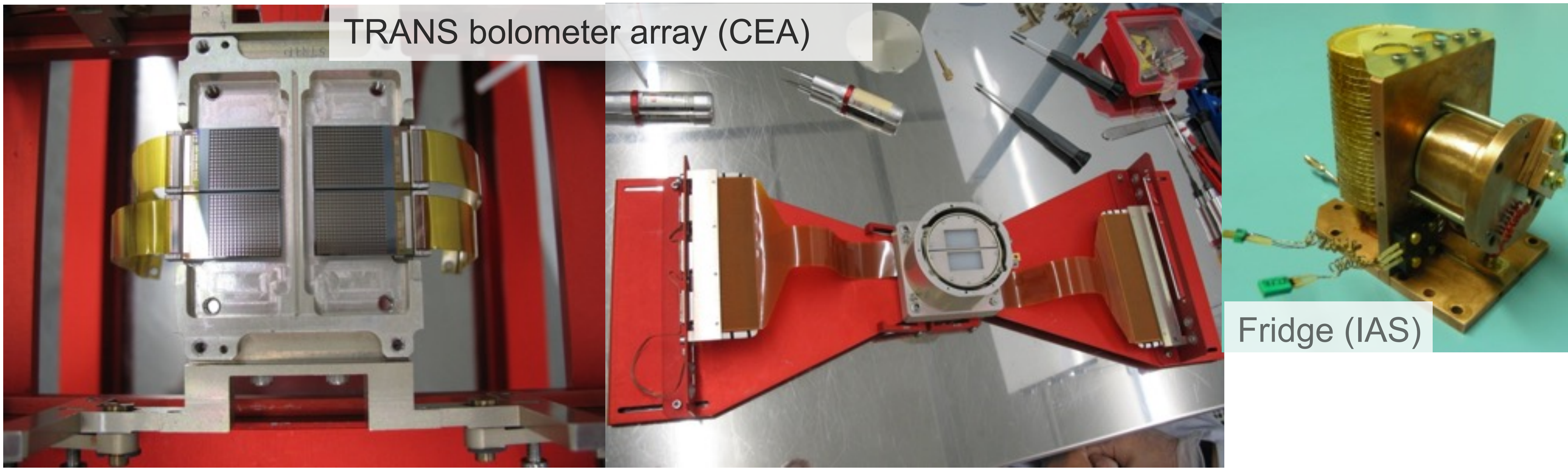


ICS

Internal Calibration Source

(calibrate the response of the detectors)

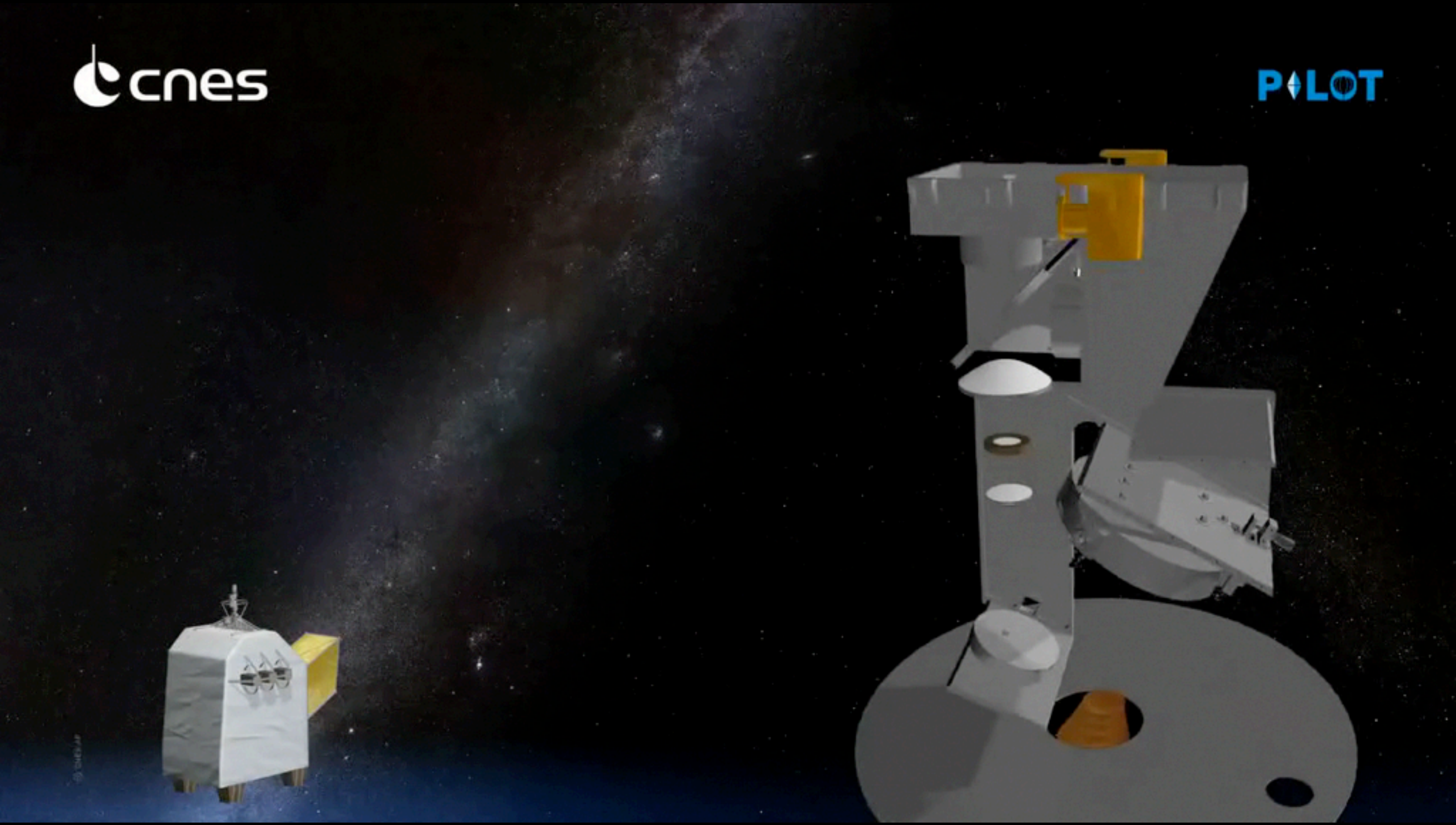
PILOT Concept



- Bolometer arrays developed by CEA/LETI
- Same technology as used on Herschel PACS
- Multiplexed bolometer arrays with a total of 2048 detectors
- Detectors cooled down to 0.3 K through closed-cycle He3 fridge
- NEP ~ 2×10^{-16} W/Hz$^{1/2}$

First flight : All detectors are at 240 µm

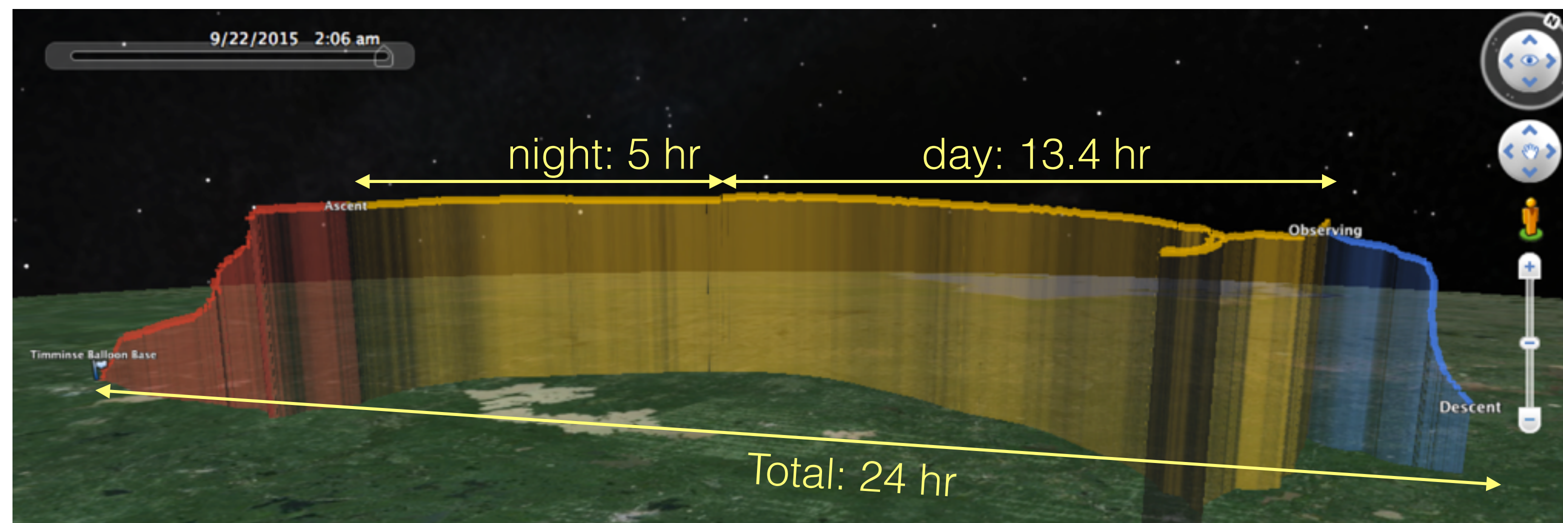
PILOT Scanning Strategy



PILOT Flights

<u>2 successful flights:</u>

- 21 September 2015 Timmins Ontario (Canada)
- 16 April 2017 Alice Springs (Australia)



<u>FLIGHT1:</u>

- Total flight time: 24 h
- Total time at ceiling: 18.4 h
- Ceiling altitude: 40 Km
- Scientific data: 14.8 h

Flight1 data accuracy affected by unexpected stray light due to baffle deterioration

PILOT Flights

FLIGHT2:
April 16 2017

Alice-Springs Australia

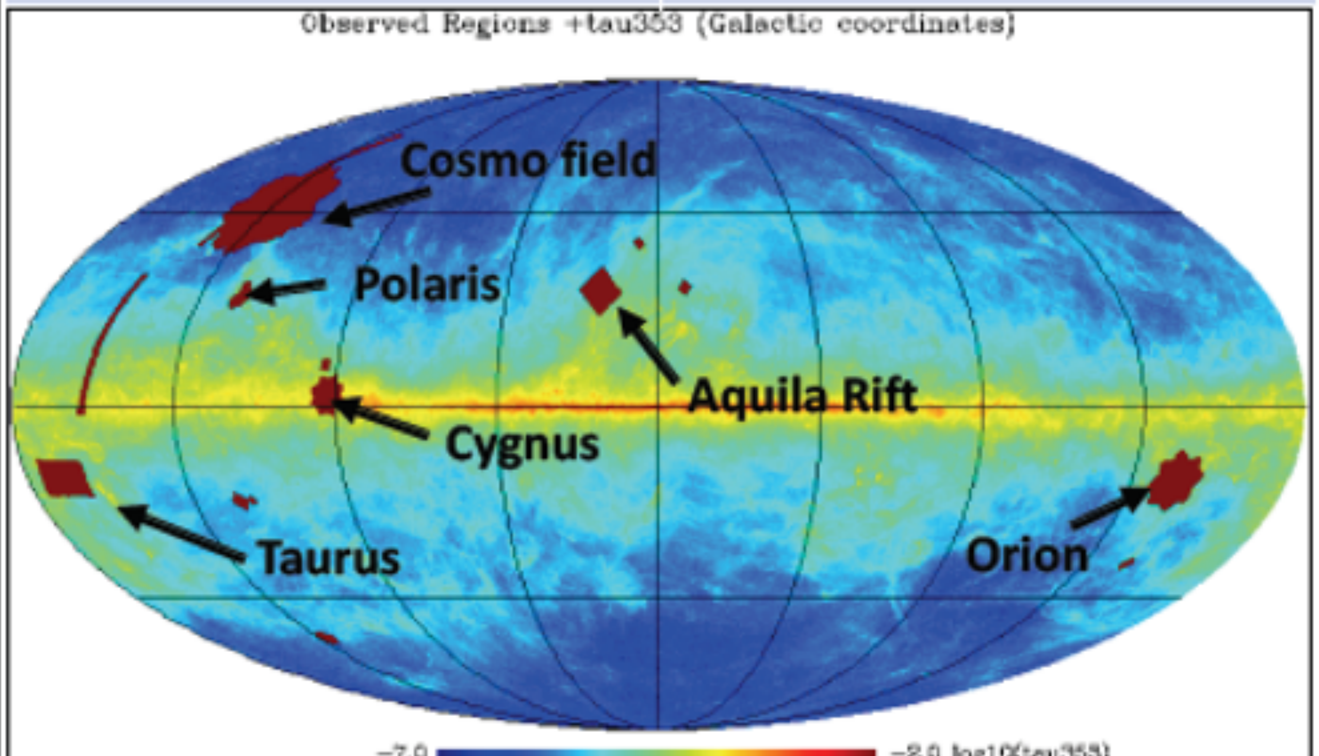
- Total flight time: 33.5 h
- Ceiling altitude: 32-40 Km
- Scientific data: 23.8 h

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

PILOT observations

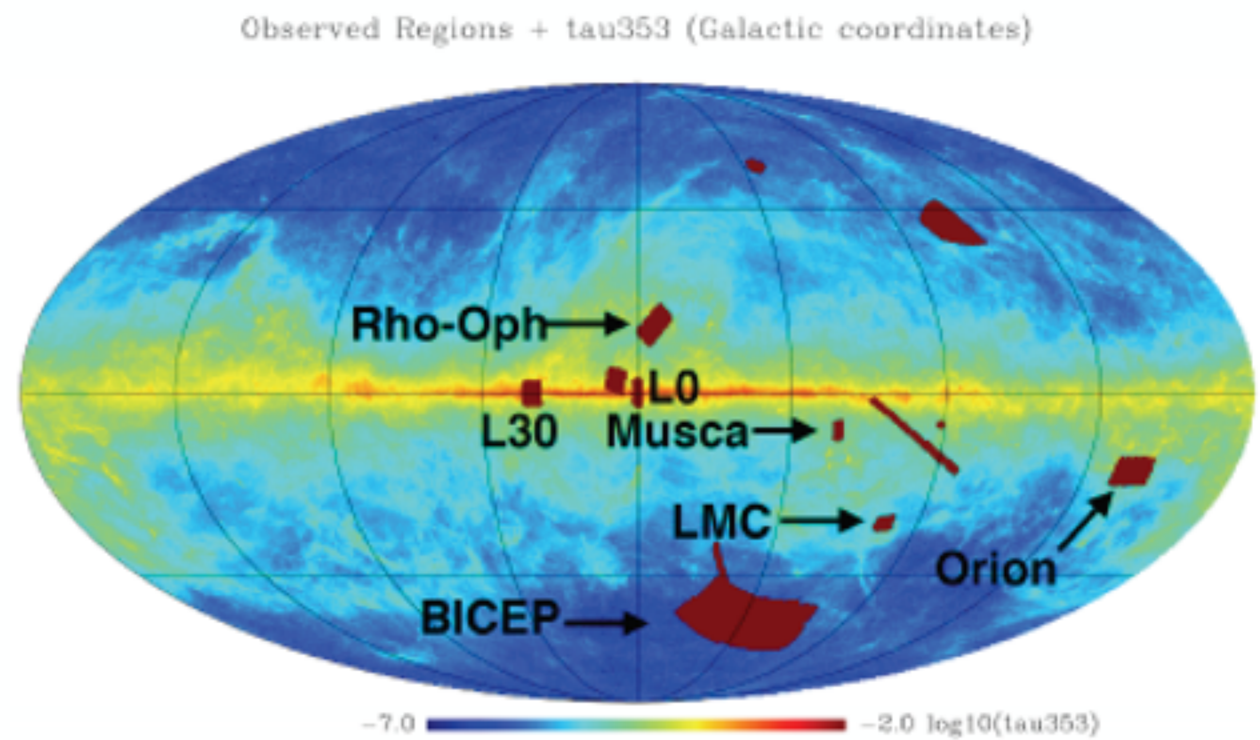
Flight 1

Observation	Time (hour)
Galaxies	1.4
Star forming regions	5.5
Cold cores	2.4
Deep fields	4.6
Calibrations	1



Flight 2

Observation	Time (hour)
Galaxies	6
Star forming regions	10
Galactic plane	1.5
Deep fields	5
Calibrations	1



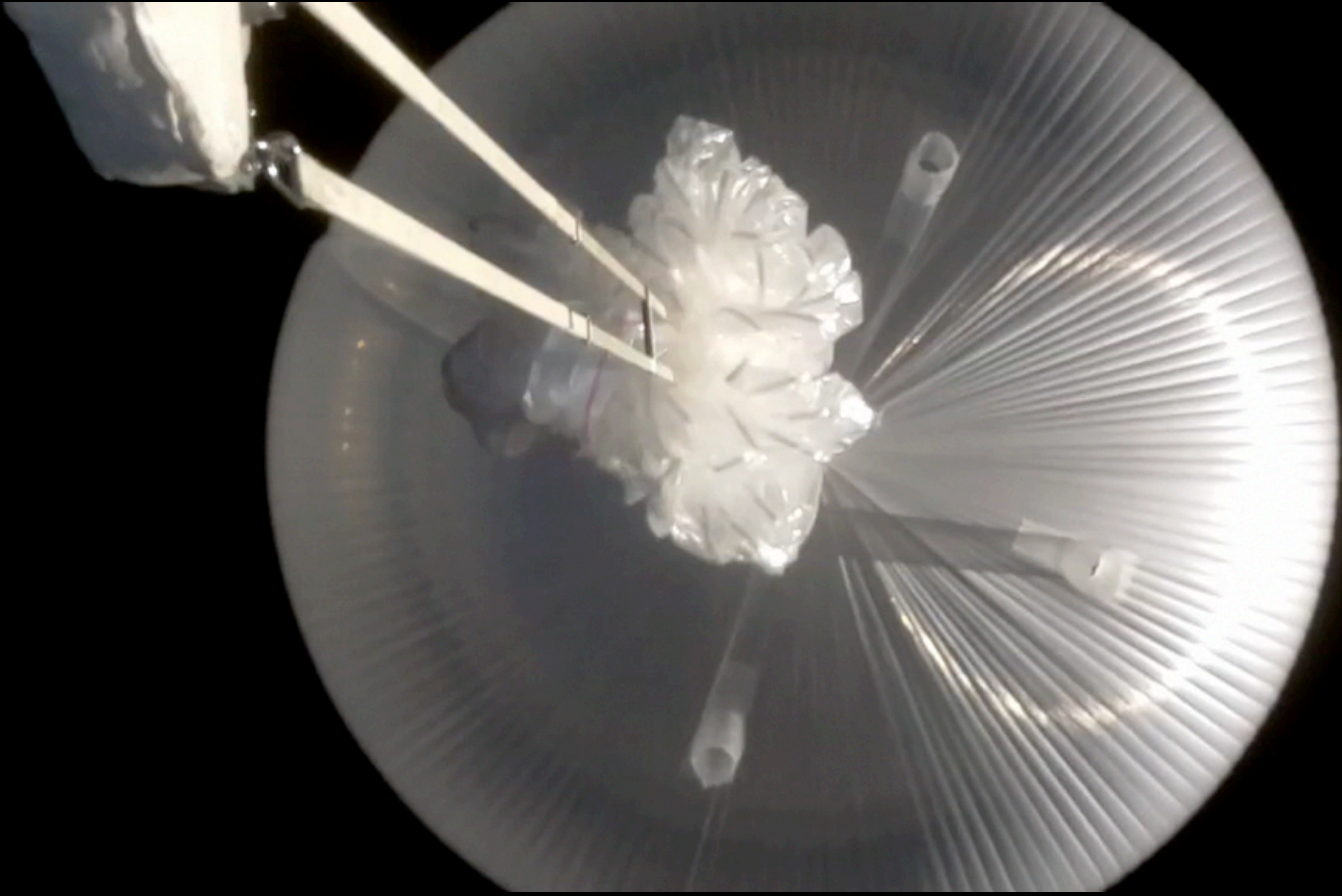
PILOT First Flight

Sept 21st 2015, Timmins, CA

Credit CNES/CNRS

PILOT Flight#1 ceiling

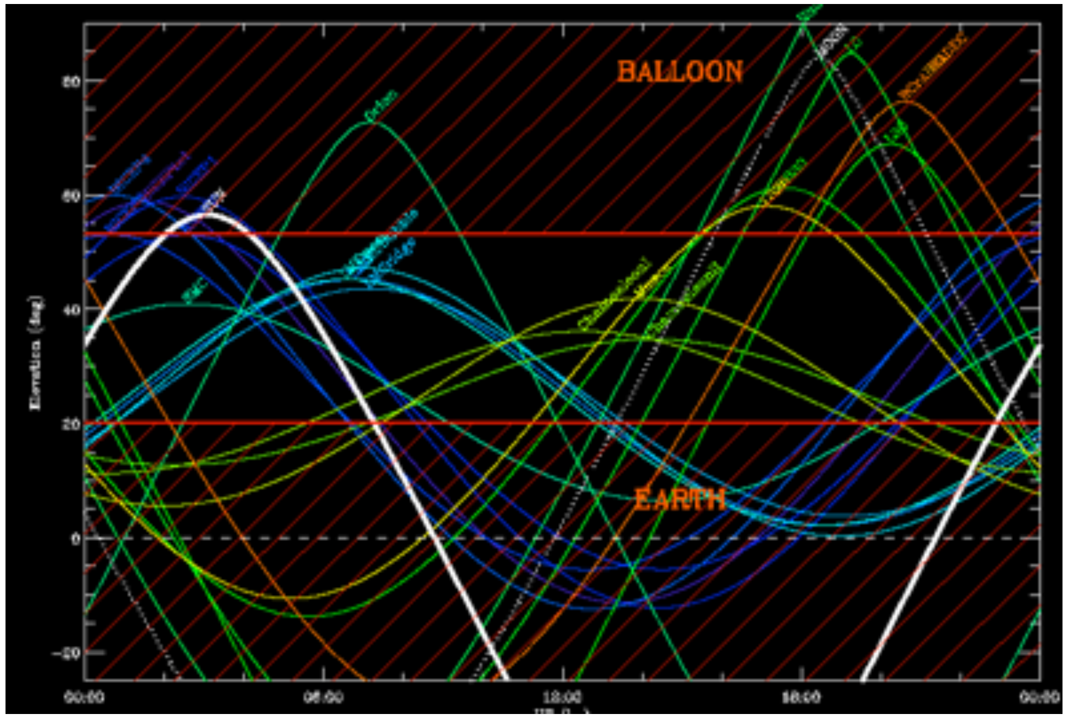
Credit CNES/CNRS



Credit CNES/CNRS

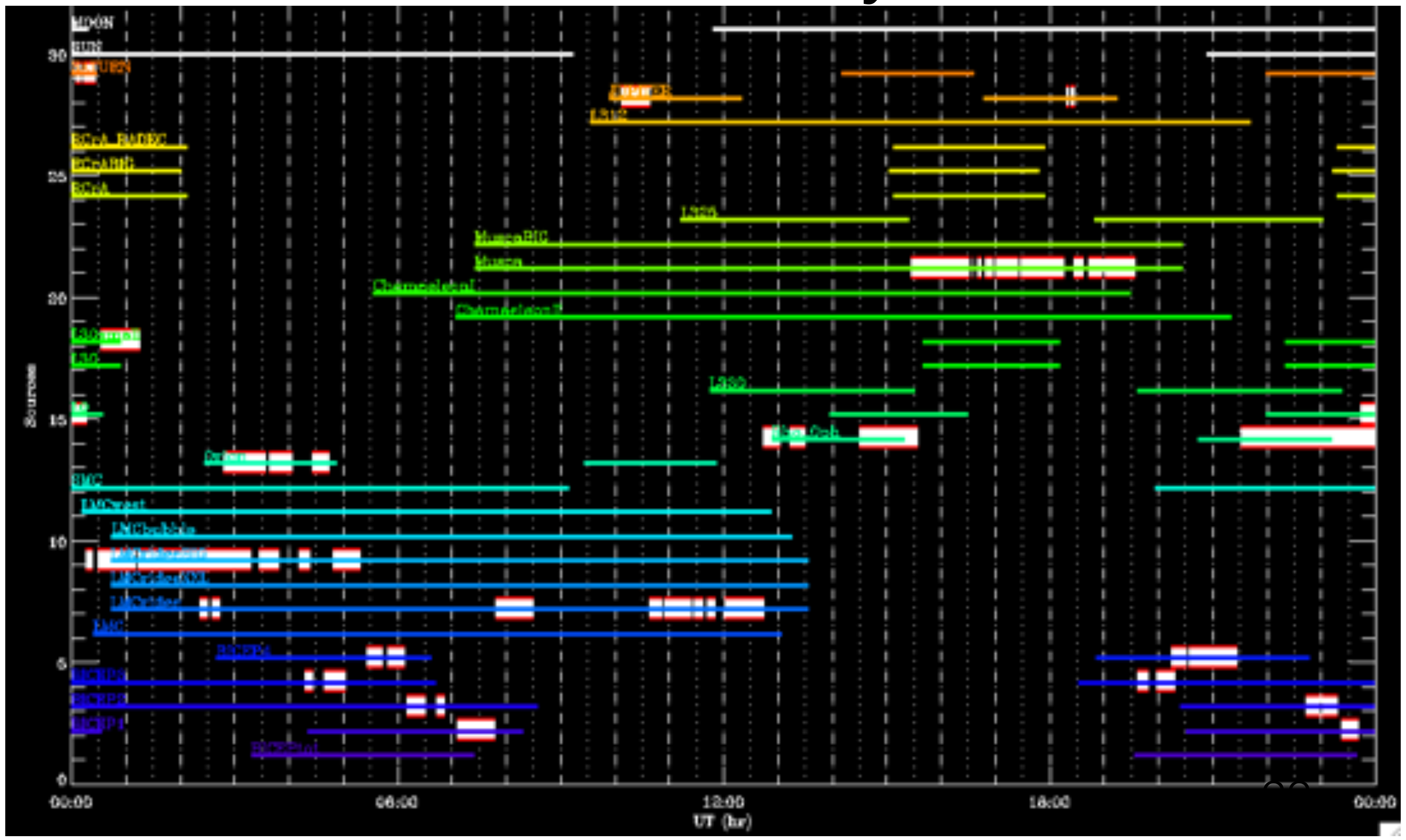
Flight plans elaboration

Sources transits



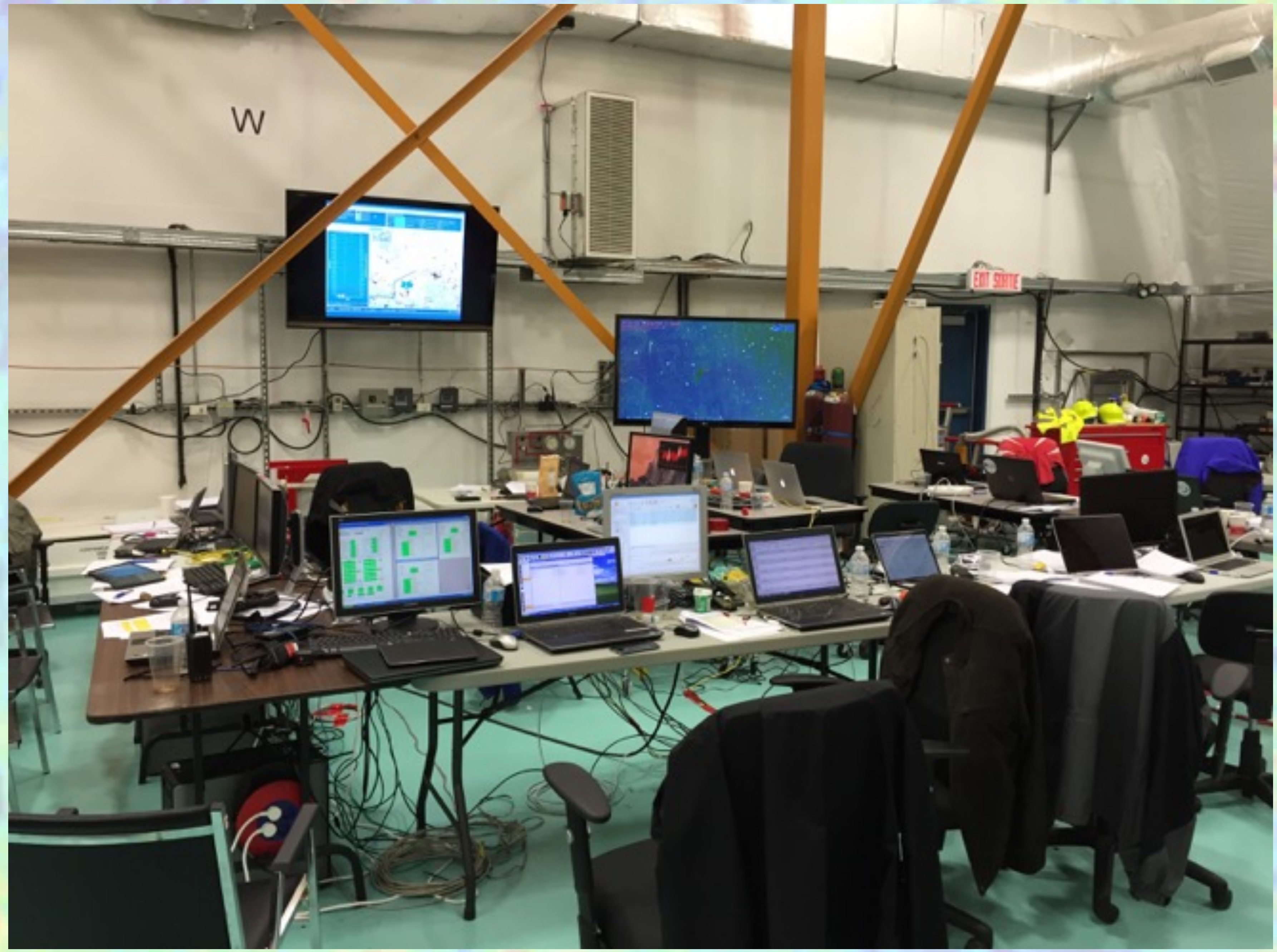
Flight Plan Editor

Sources observability



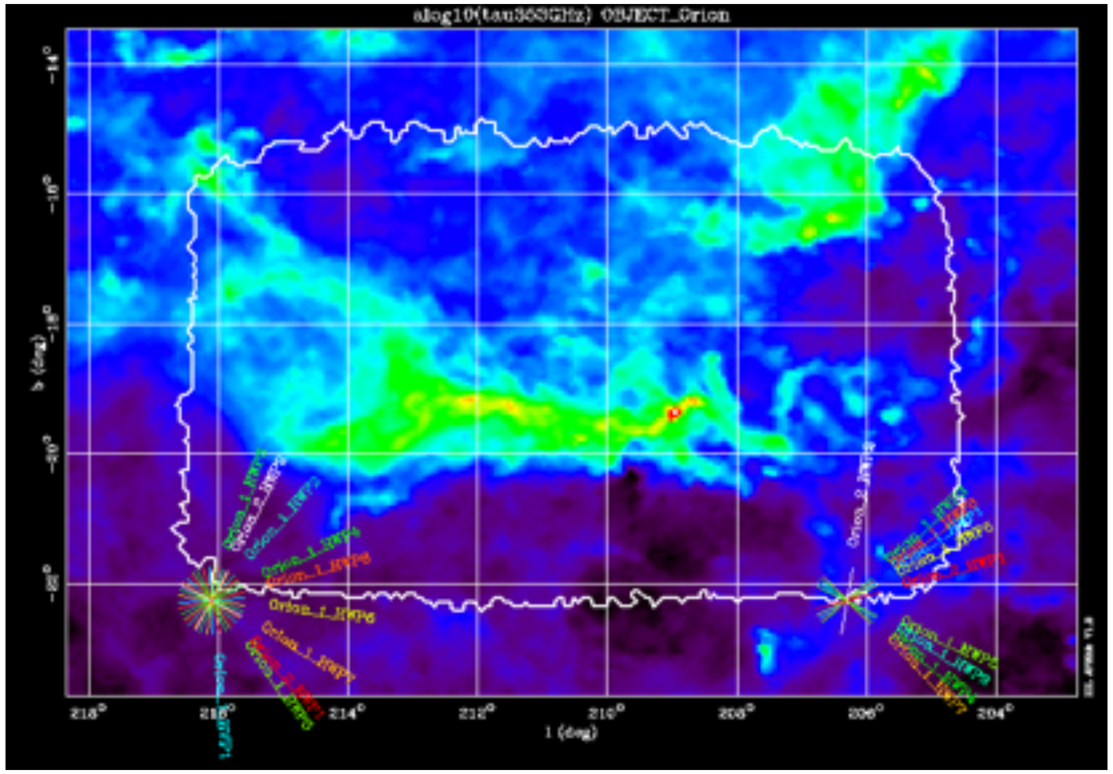
A scheduling tool allowing for a moving observatory in the stratosphere, and observational constraints

PILOT en mode auto-pilote



Improvements between flights

- Detector arrays repairs: -17%
- Operation at lower temperature: +26%
- Field stop size increased: (+10%)
- Front baffle fixed: no more straylight
- More efficient observing strategy
  - scans at varying elevation:
    scan directions allowing de-stripping
  - region of interest mapping (+20%)
- More strong sources:
  better pointing reconstruction



- Longer flight (flight#1: 14.8hr, flight#2: 23.8 hr): +60%

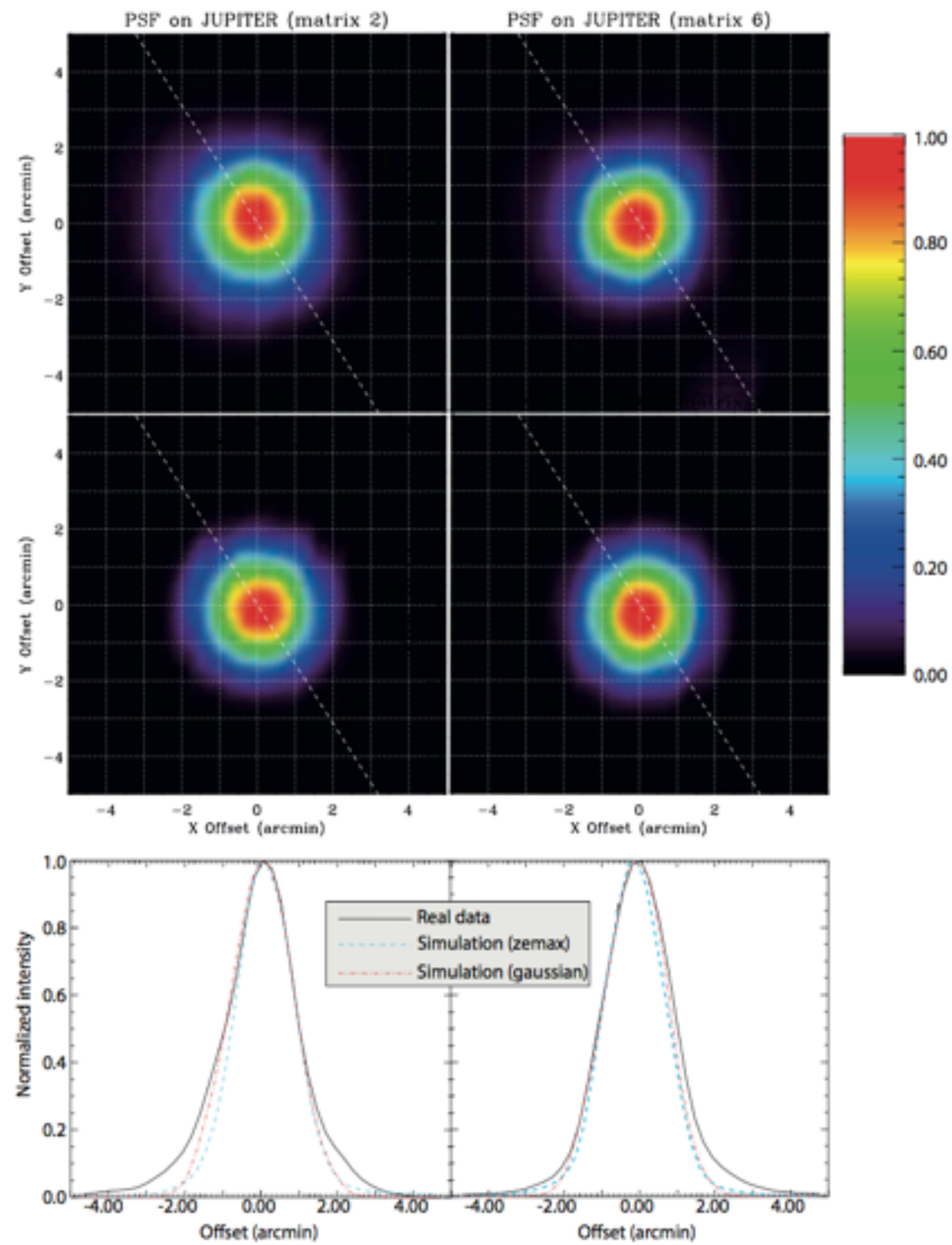
Total: +100%

+ data of much better quality allowing to overcome limitations of flight#1 …

In-flight performance: optics

In-flight Jupiter PSF

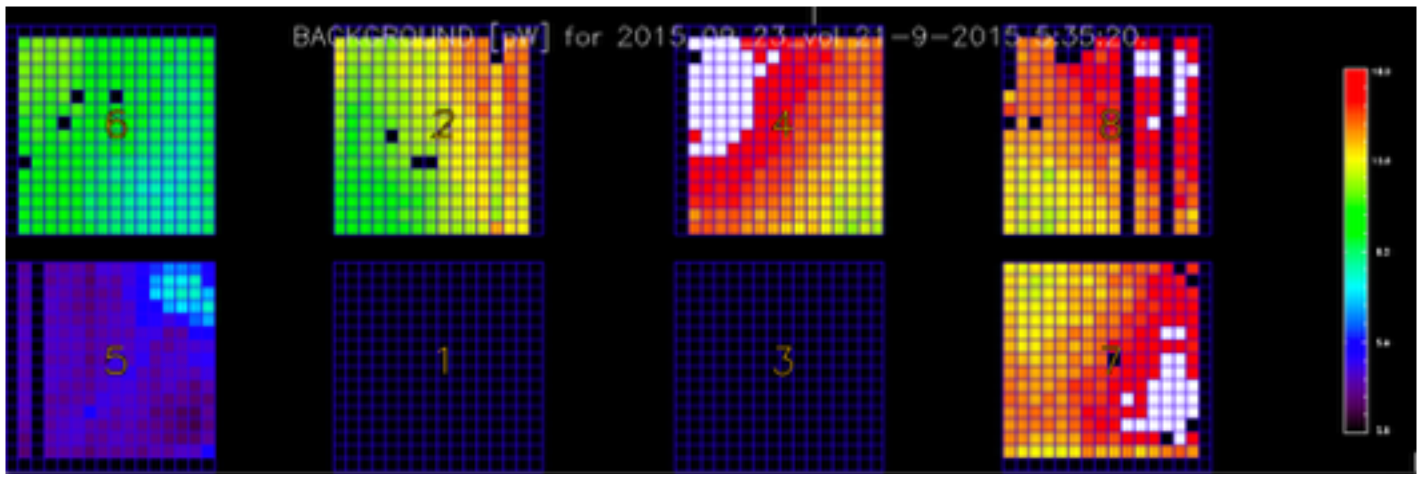
Simulations



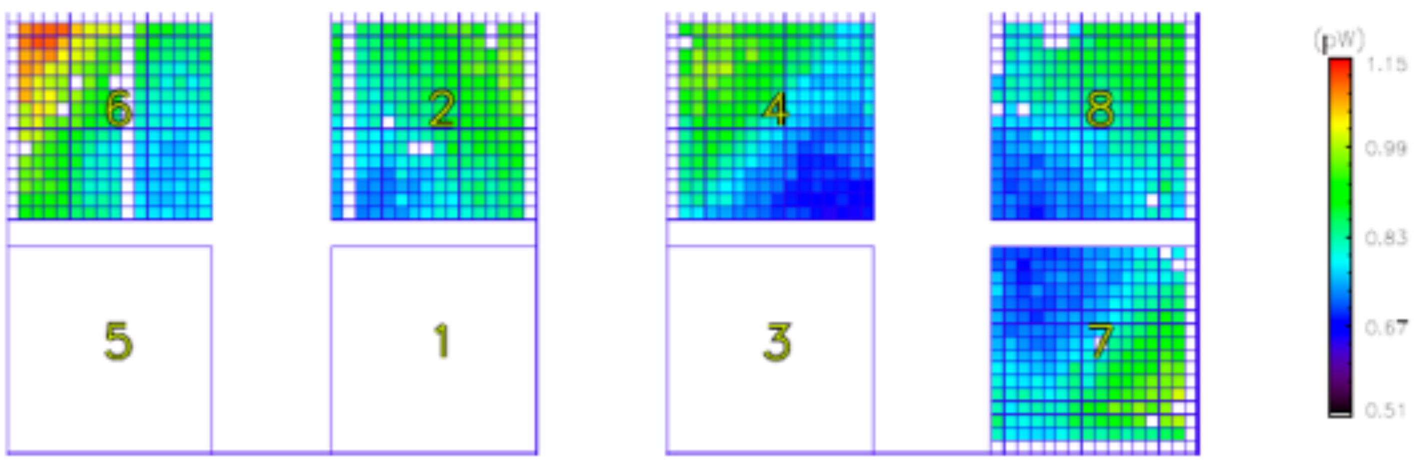
- In-flight measured PSF on Jupiter is 2.25’ ±0.15, sims 2.31’±0.07
- In-flight good optical quality and nominal resolution

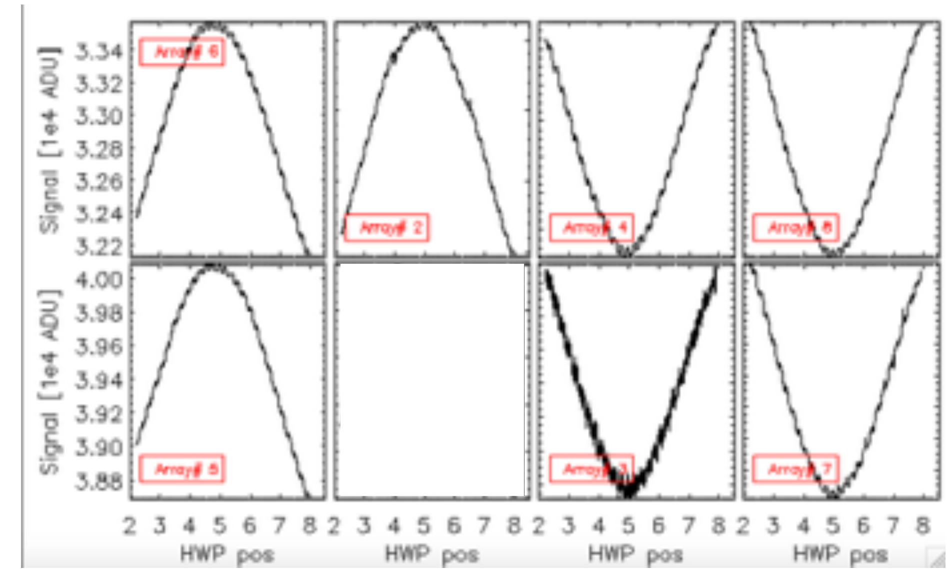
In-flight performances : instrumental Background

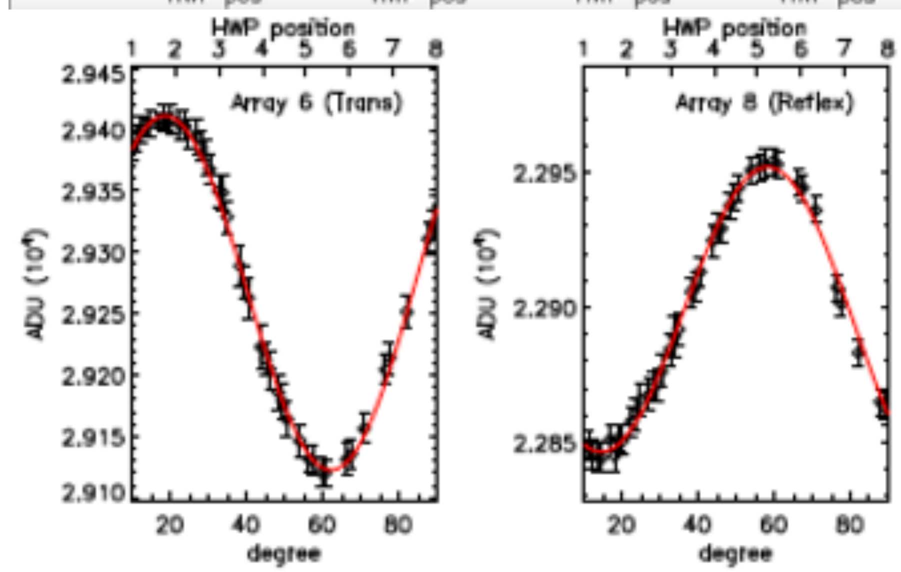
In-flight Background



Ground Background





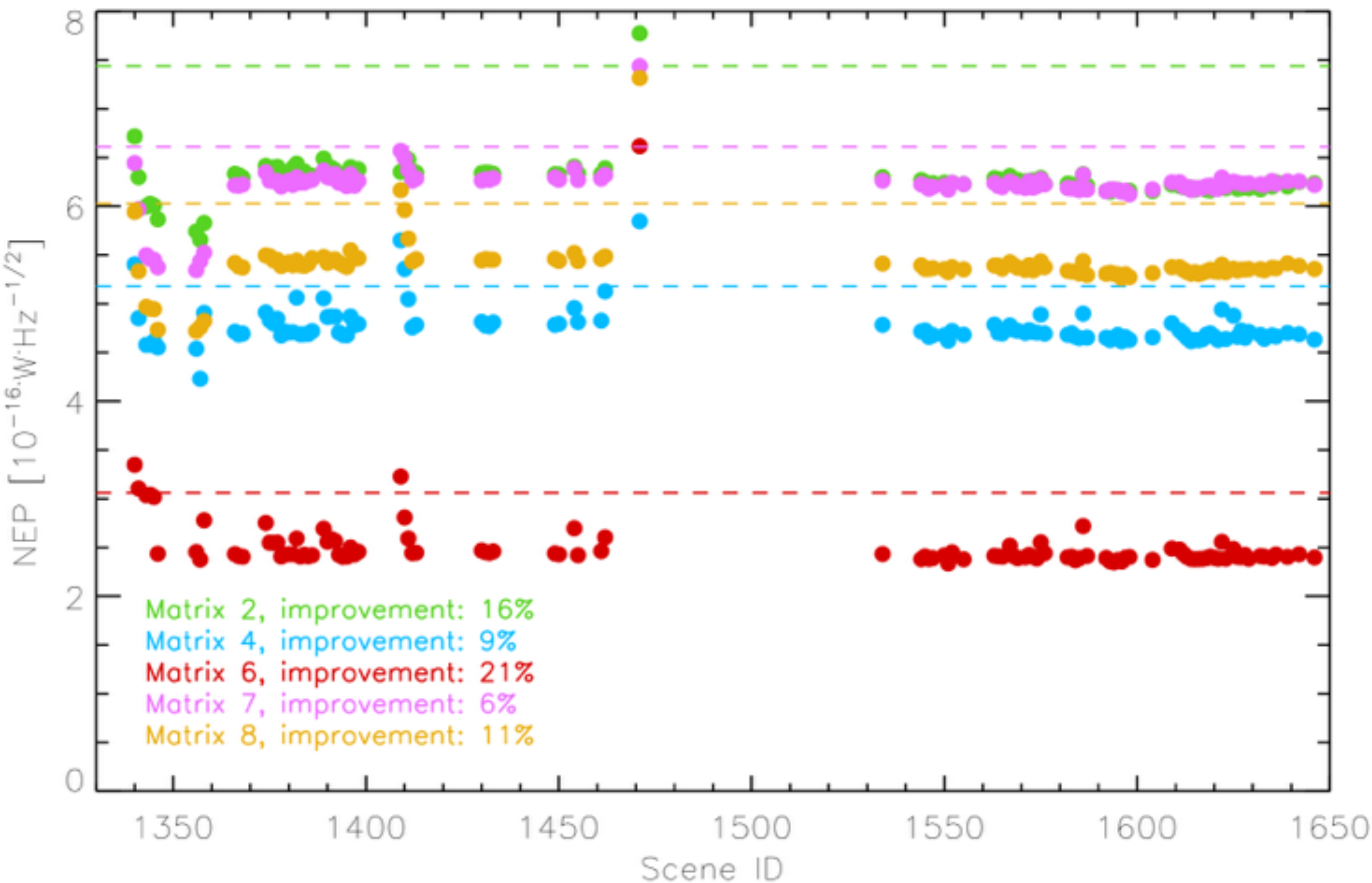


- In-flight background has a similar shape but is a factor ~2 stronger than expected
- The background is polarized at 4-10% level. Origin not understood. Unimportant for PILOT observations thanks to fixed HWP and Internal calibration but important for some future applications.
- A similar behavior has been observed in many polarization FIR/submm instruments

In-Flight Noise properties

Flight#1
(321-325 mK)

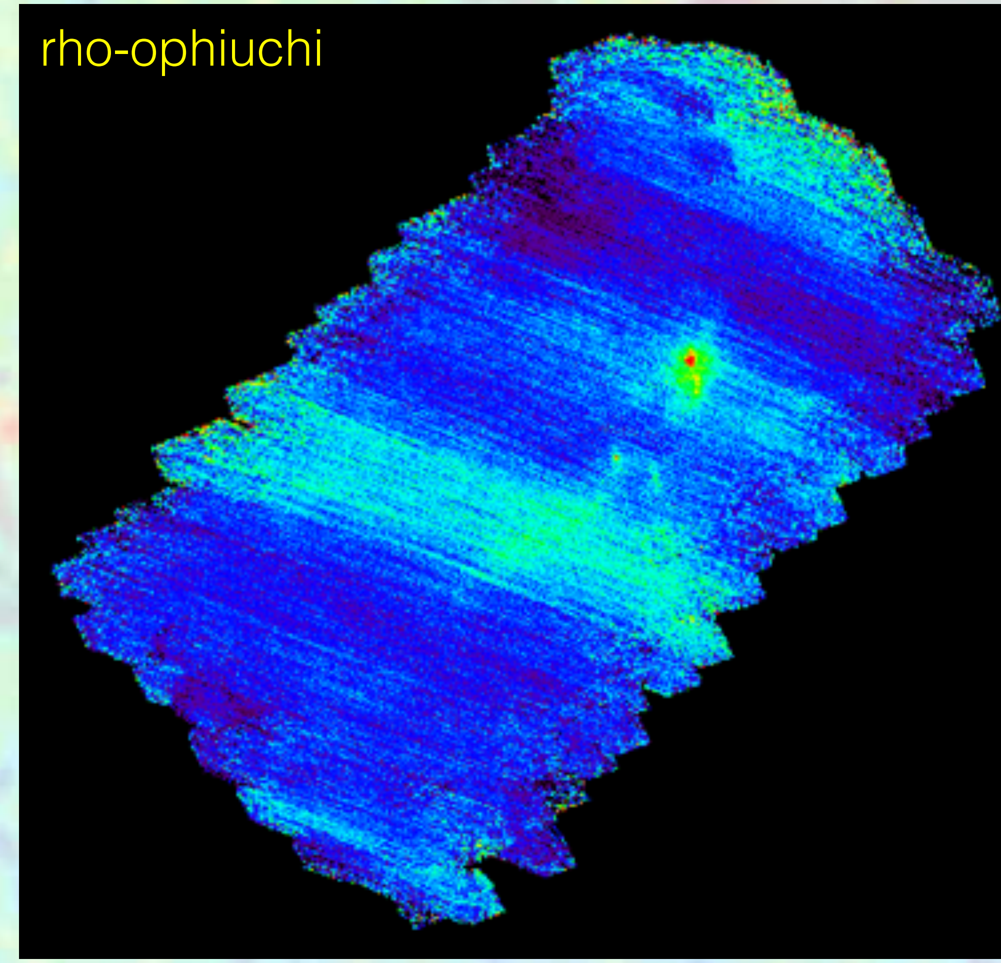
Flight#2
305 mK

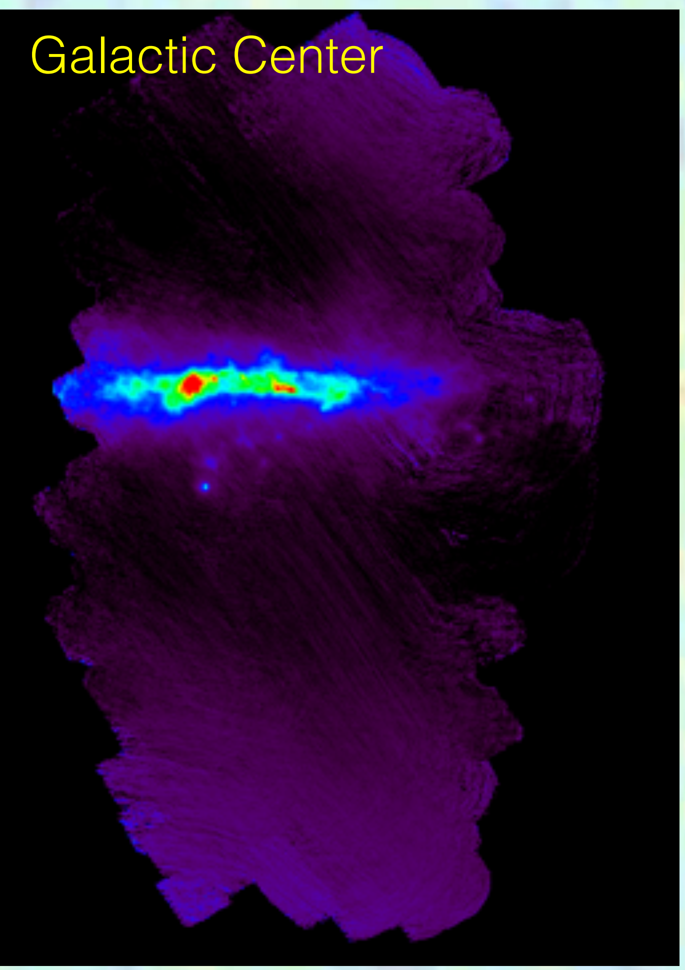


detectors were operated close to 300 mK
high frequency noise is 13% better than in flight #1
(equivalent to 26% more integration time)

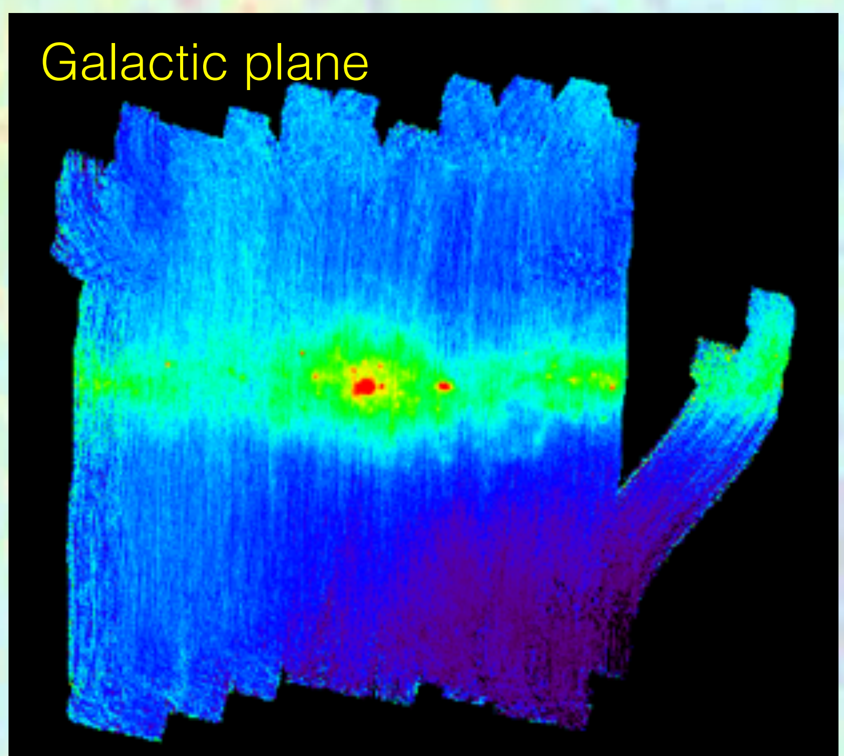
Real-Time data check

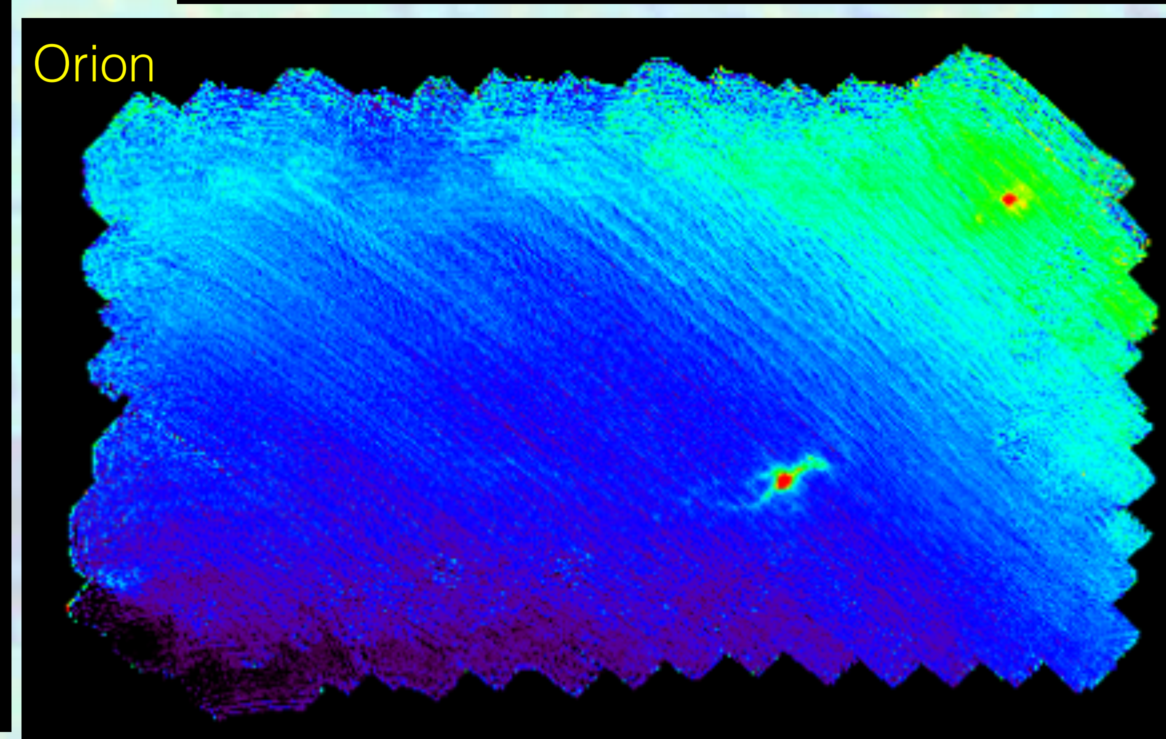
Example
raw maps:





The signal is already much better than for flight#1

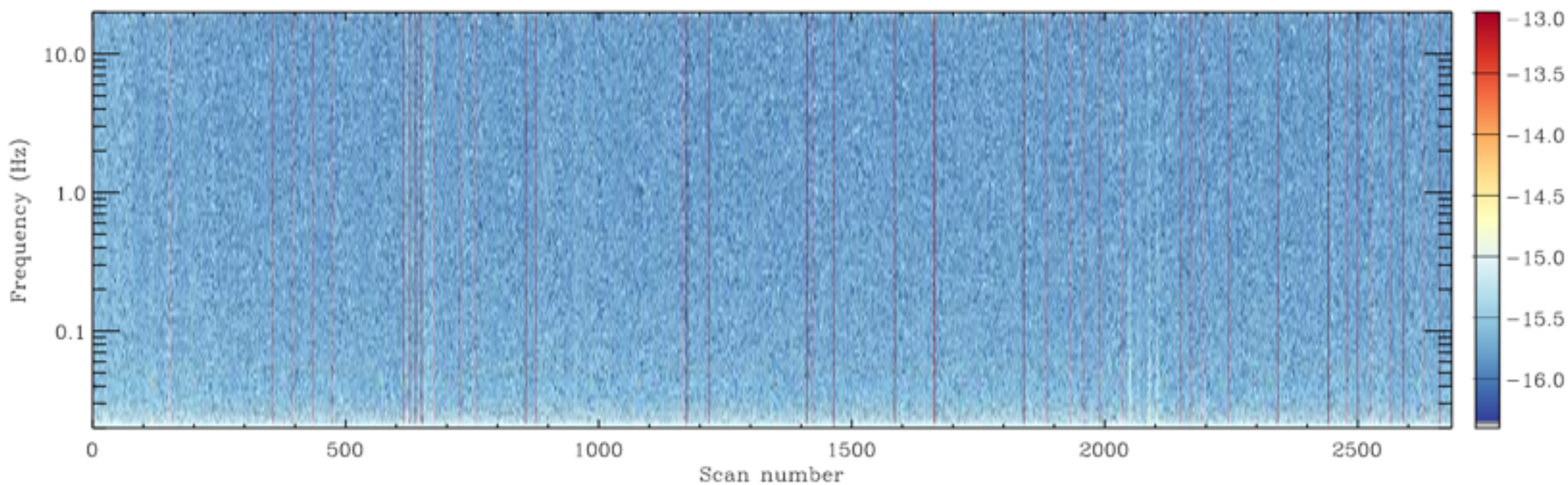


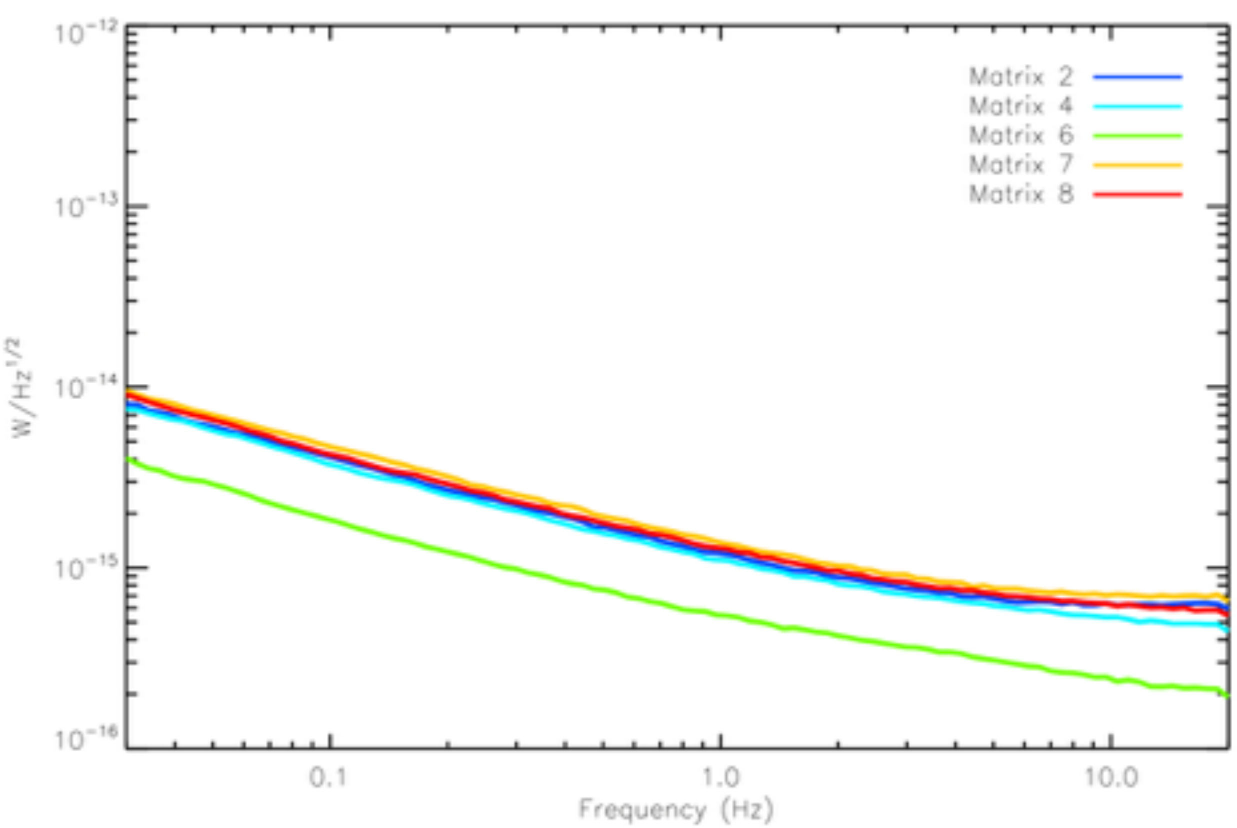


In-flight performance: noise

Foenard, PhD thesis 2018
Foenard et al. 2018, Exp Astr, submitted

Noise Time-frequency plot over the whole flight (array#6)





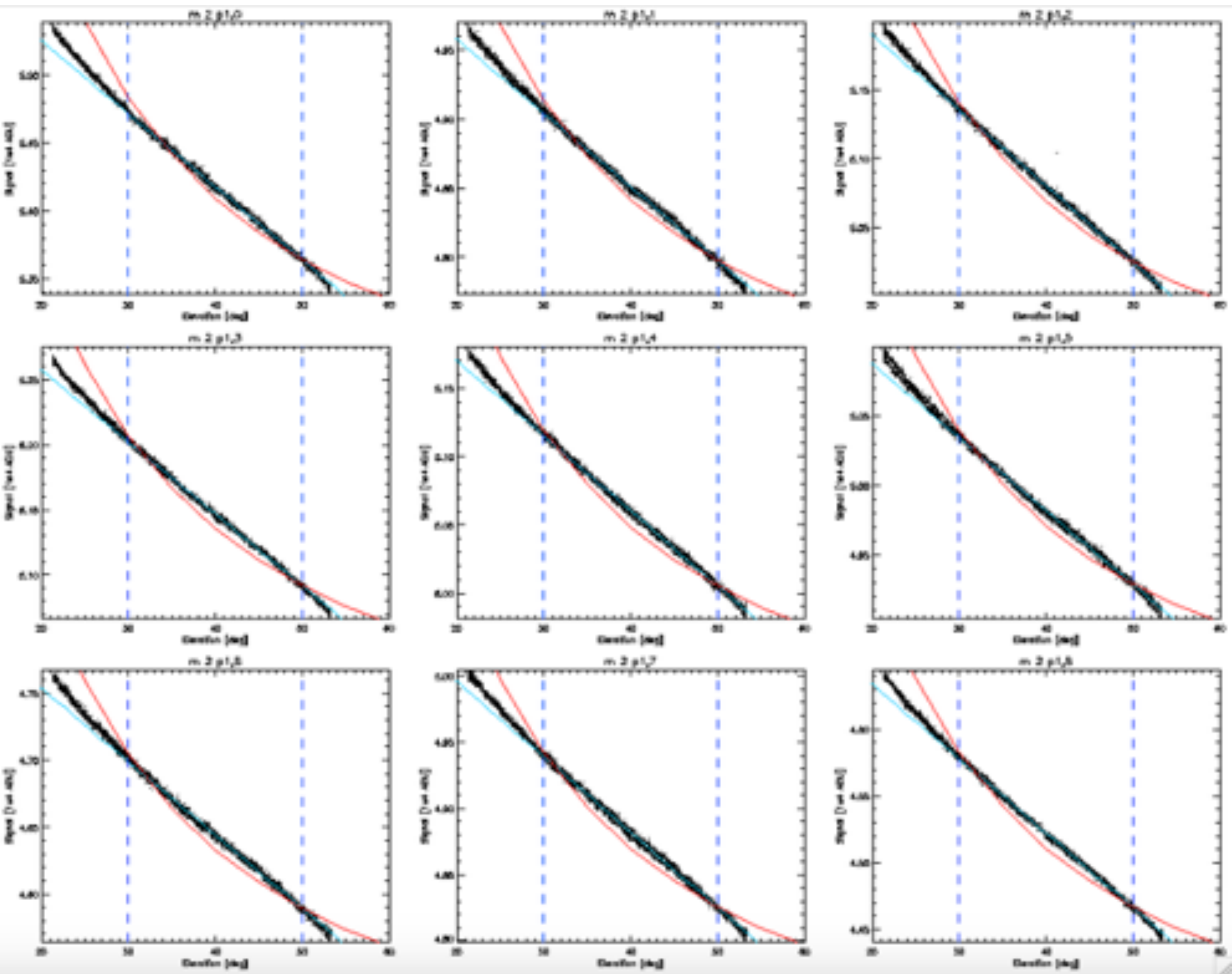
- Noise stability over the whole flight
- In-flight white noise levels as expected
- Slope: 1/f^0.6

In-Flight Response maps

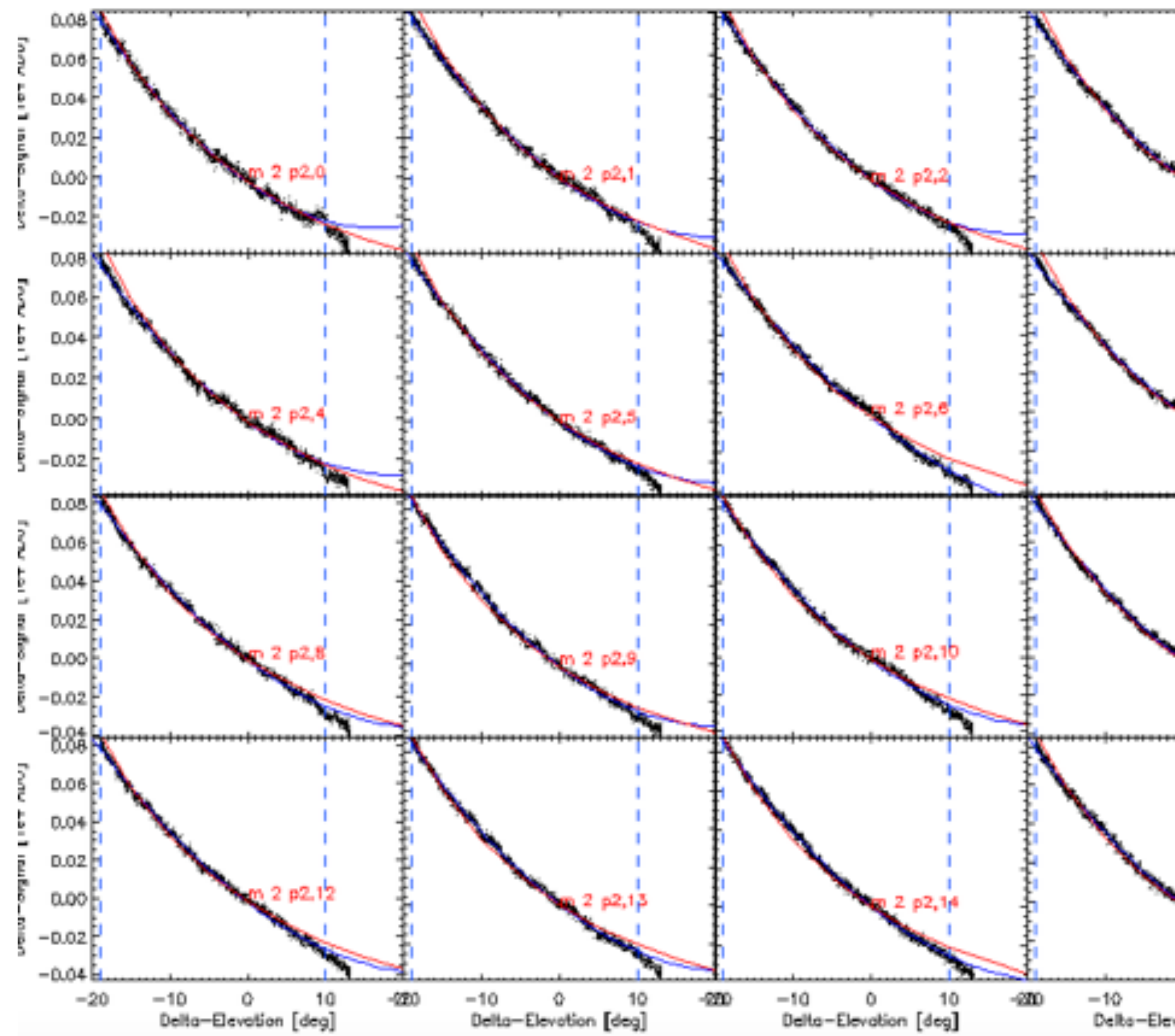
Measured on atmospheric signal (skydips)

Vol#1

Signal vs elevation



Vol#2



Non-linearity with elevation better detected

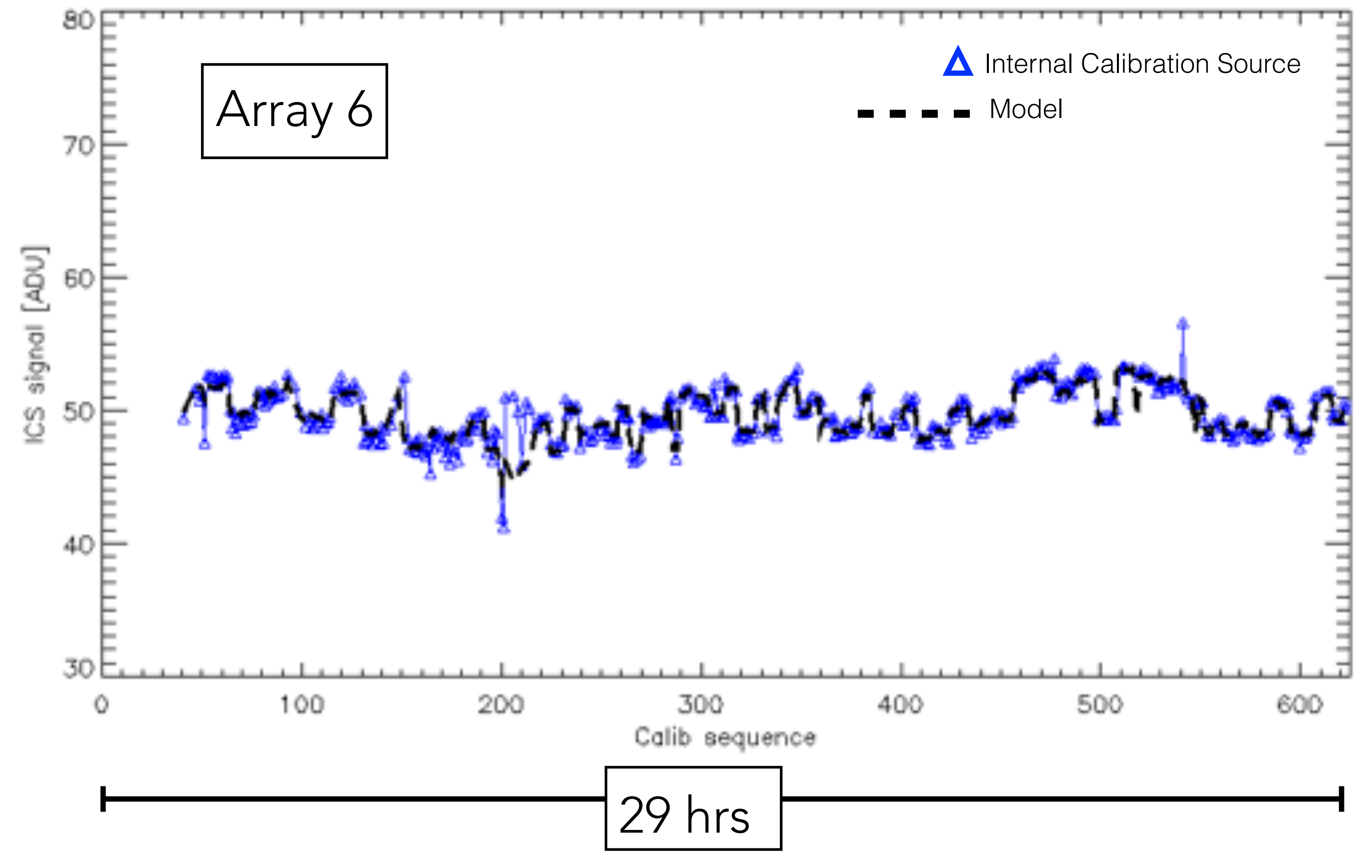
Analysis of sky-dips show Response maps accuracy of 0.7%

Data calibration

Foenard, PhD thesis 2018
Foenard et al. 2018, Exp Astr, submitted

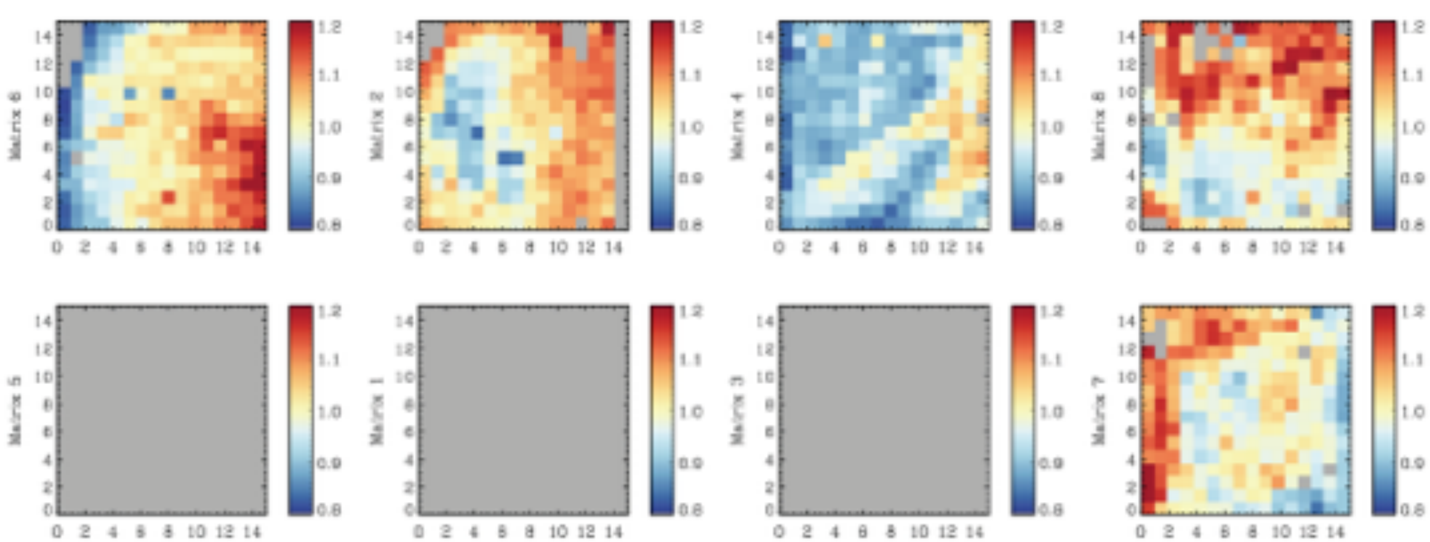
- **Temporal detector response variations: Internal Calibration Source (ICS)**

  - Step-like variations due to polarized background & atmosphere variations
  - Linear model parameters: HWP position, elevation, altitude, optics and structure temperatures



A simple model matches the variations with accuracy (2%) over the whole flight

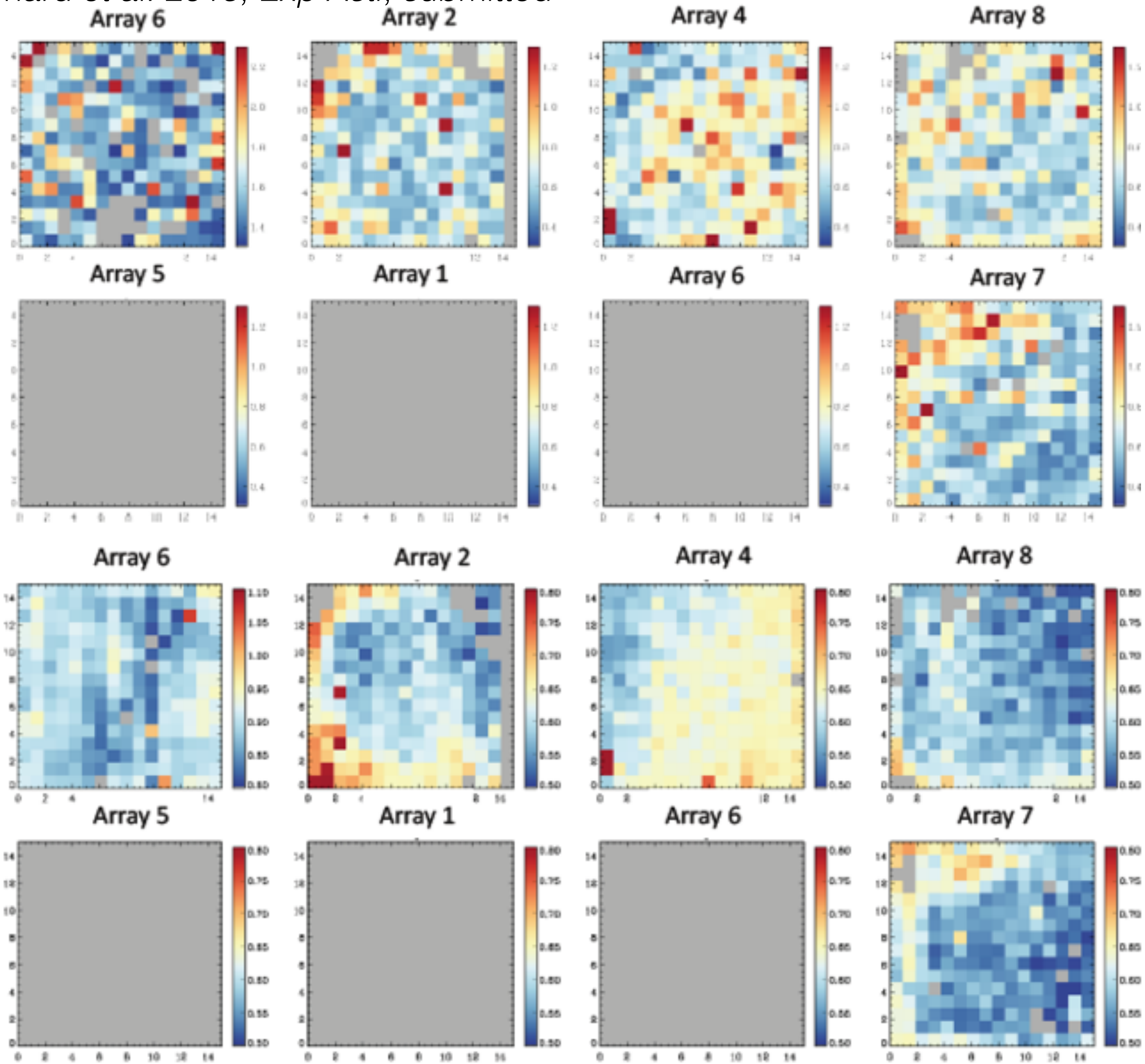
- **Detector response spatial variations:**



Atmosphere: extended and not polarized is used to determine the detector response flat-field.

Detector time constants

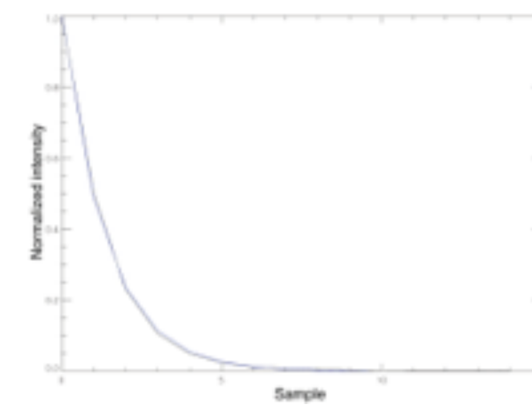
Foenard, PhD thesis 2018
Foenard et al. 2018, Exp Astr, submitted



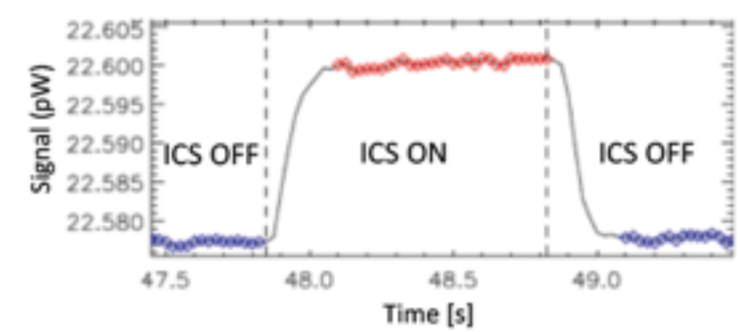
average τ = 0.7 sample

Time constants derived from combination of :

- Glitches measuring detectors τ with low SNR

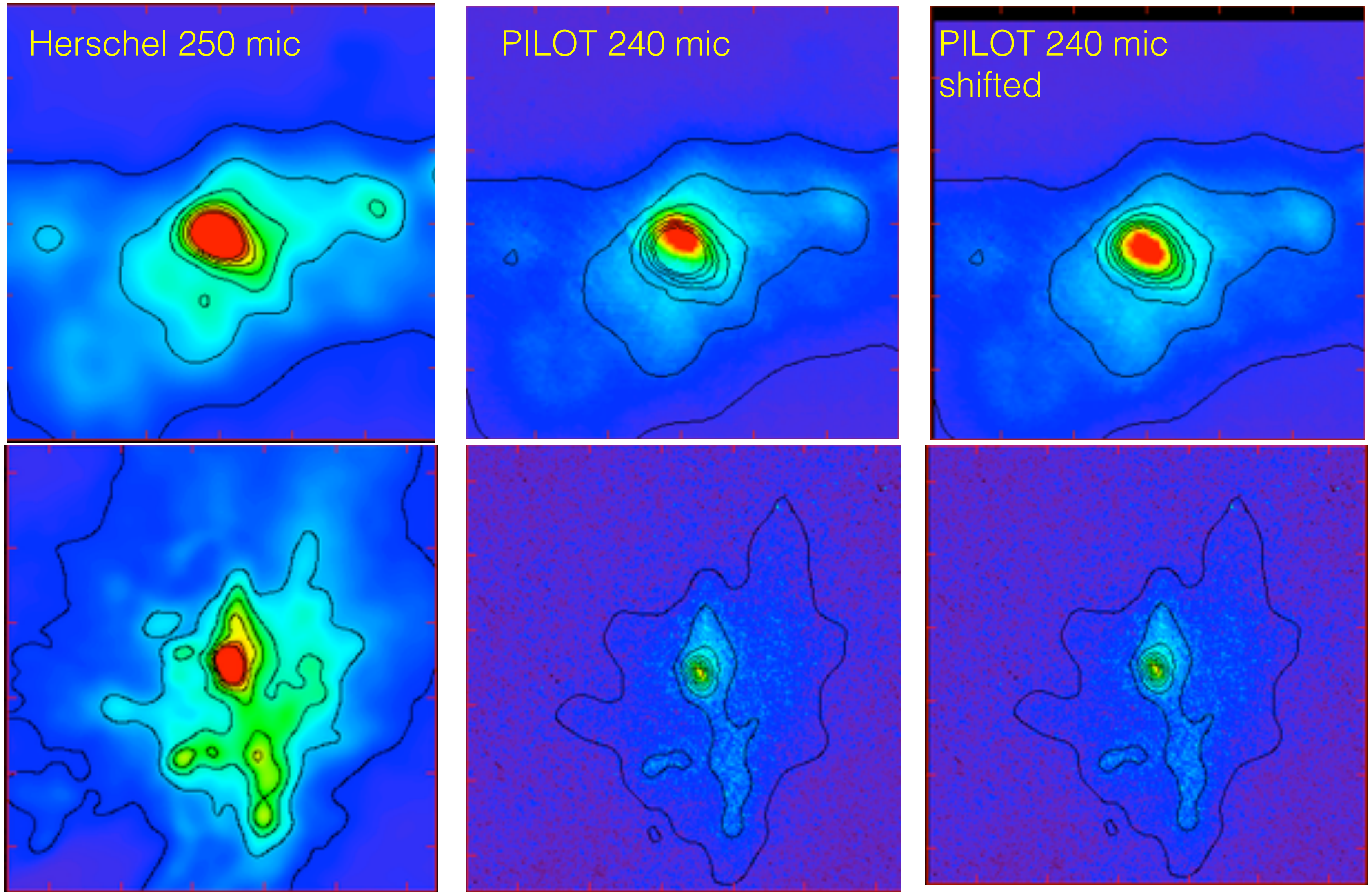


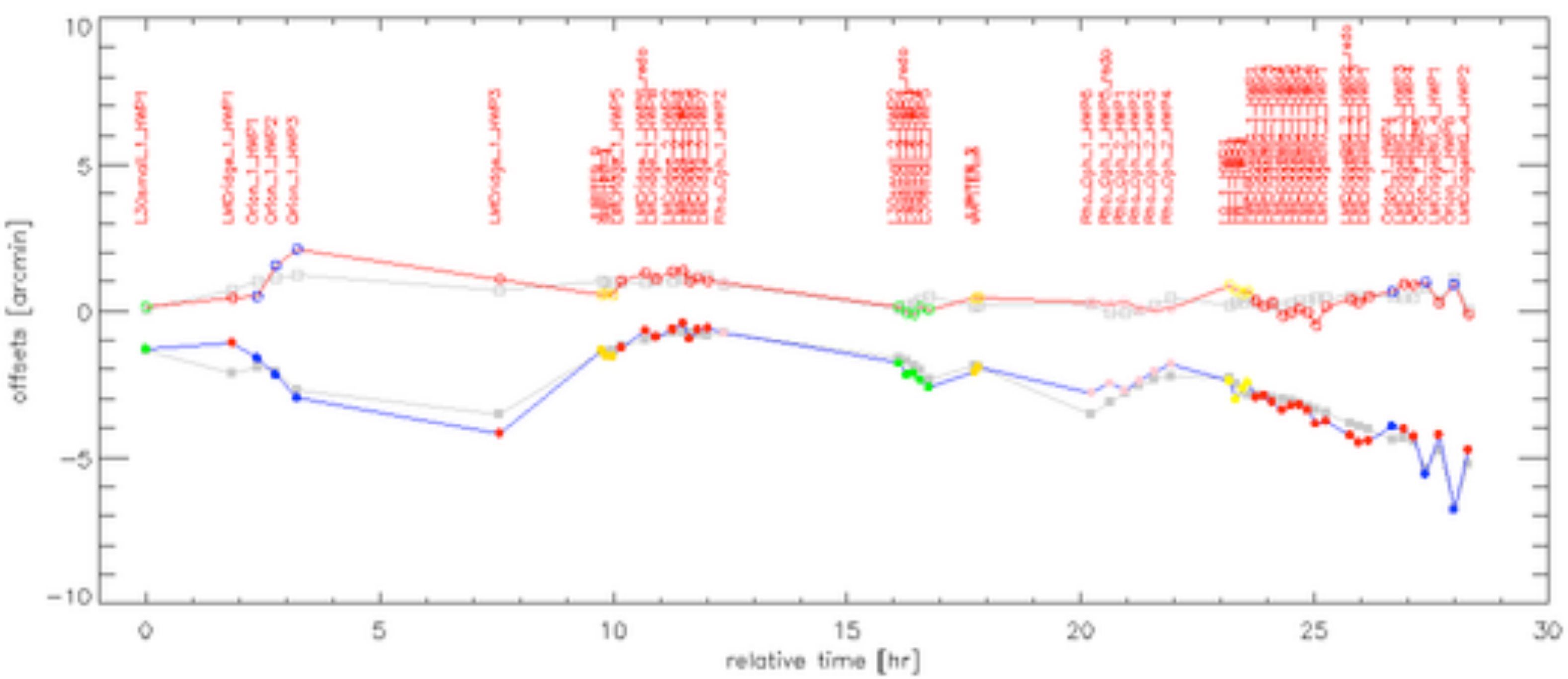
- ICS raising curves measuring detector + ICS τ with high SNR



$$e^{-\frac{t}{\tau_{\mathrm{cal}}}} = e^{-\frac{t}{\tau_{\mathrm{det}}}} \otimes e^{-\frac{t}{\tau_{\mathrm{ICS}}}}$$

pointing





- Estadius offset computed from correlation with 250 µm Herschel image of individual observations

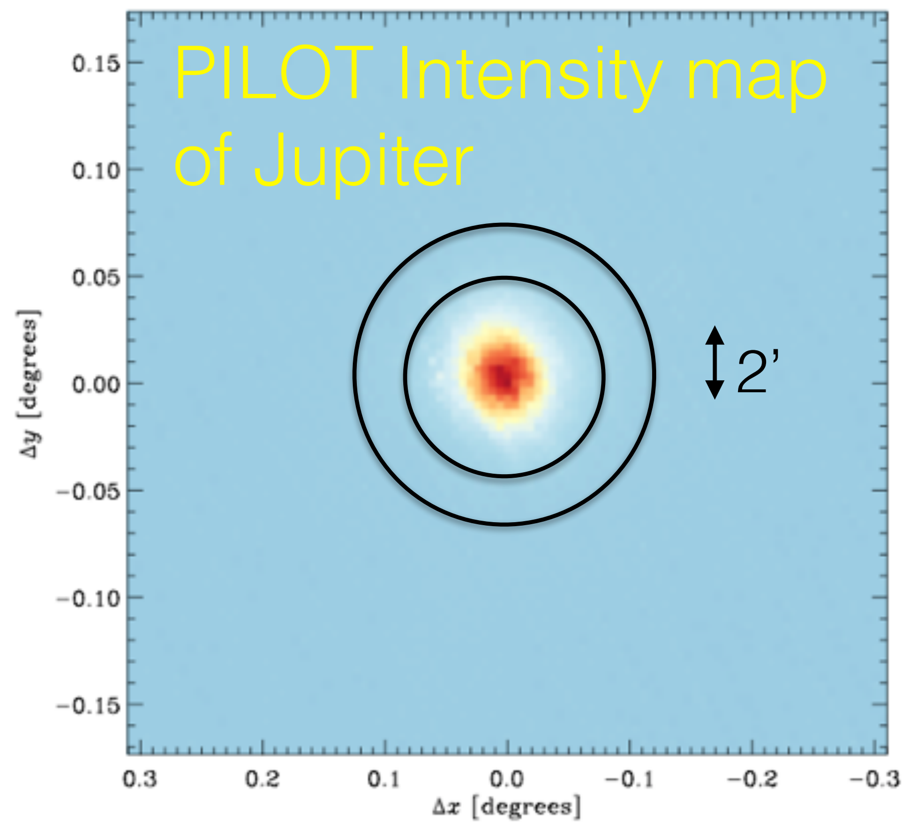
- Uses scanamorphos de-striped maps of the PILOT data.

- Variations related to thermal and mechanical deformations of the instrument

- Modeled using linear regression with temperature and elevation

Residual polarization

Residual polarization on an unpolarized planet mesures the data calibration accuracy



The residual polarization measured through aperture photometry on Jupiter is

$\Delta P/I \sim 3\%$

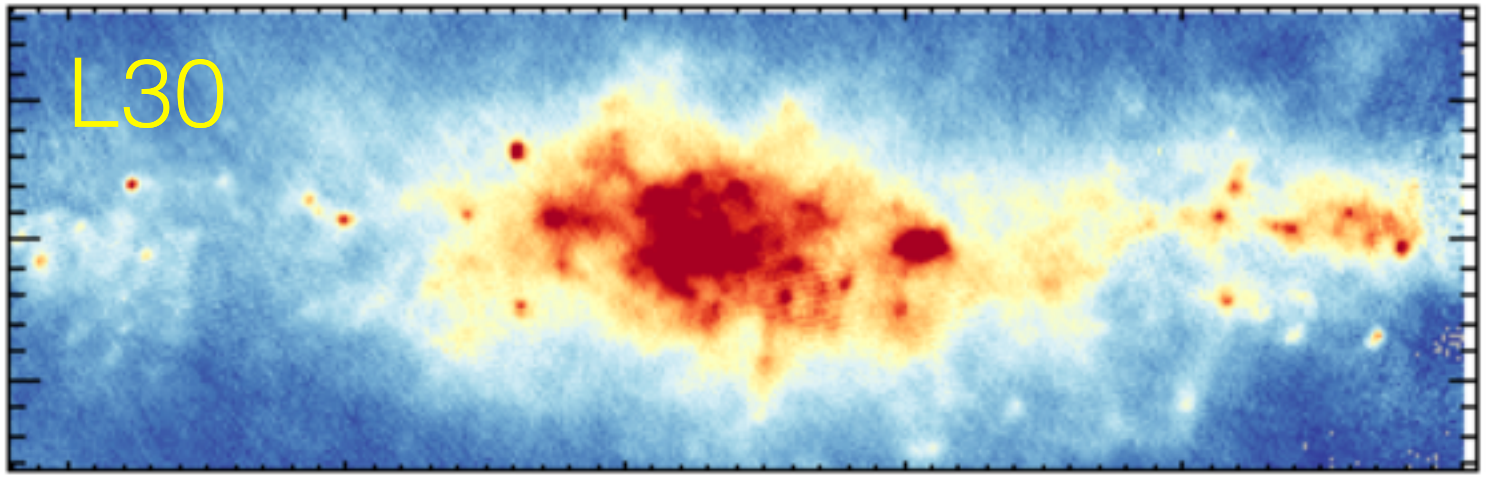
Significant improvement expected, more detailed calibration analysis on-going

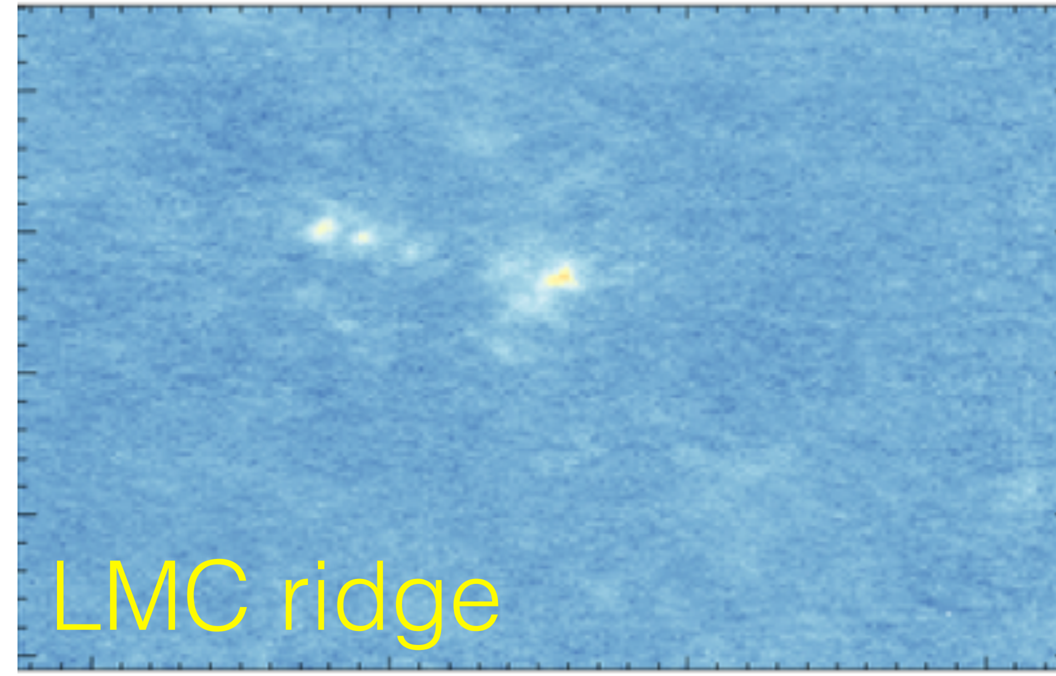

AUSTRALIA
INDIAN OCEAN
Darwin
Cairns
Townsville
NORTHERN TERRITORY
QUEENSLAND
Alice Springs
WESTERN AUSTRALIA
SOUTH AUSTRALIA
Brisbane
Perth
NEW SOUTH WALES
Sydney
Adelaide
CANBERRA
VICTORIA
Melbourne
TASMANIA
LEGEND

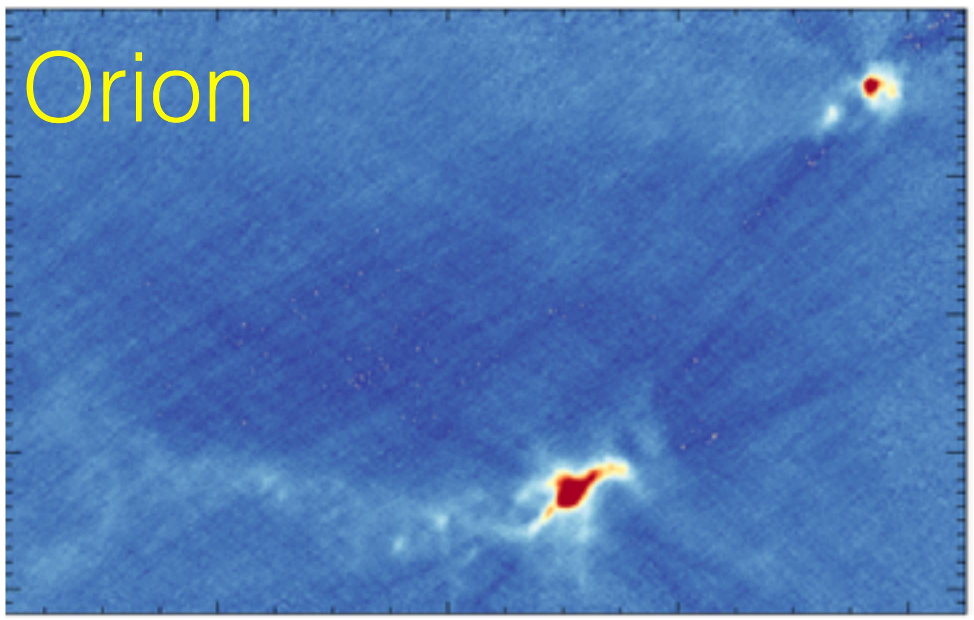
The End


NON MAGN
HELIUM
HELI
NON
1000kg

Flight#2 preliminary Intensity maps

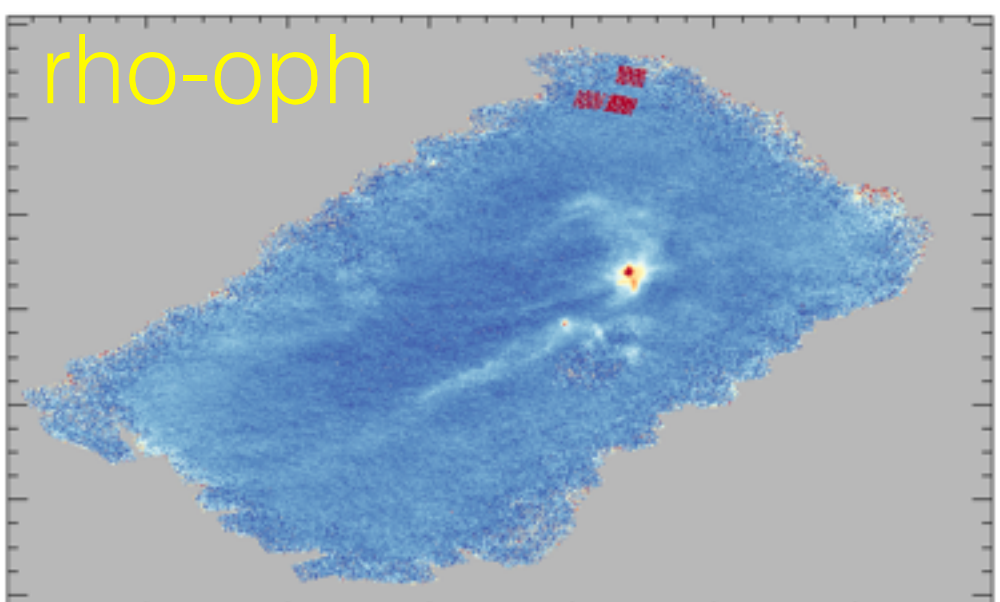


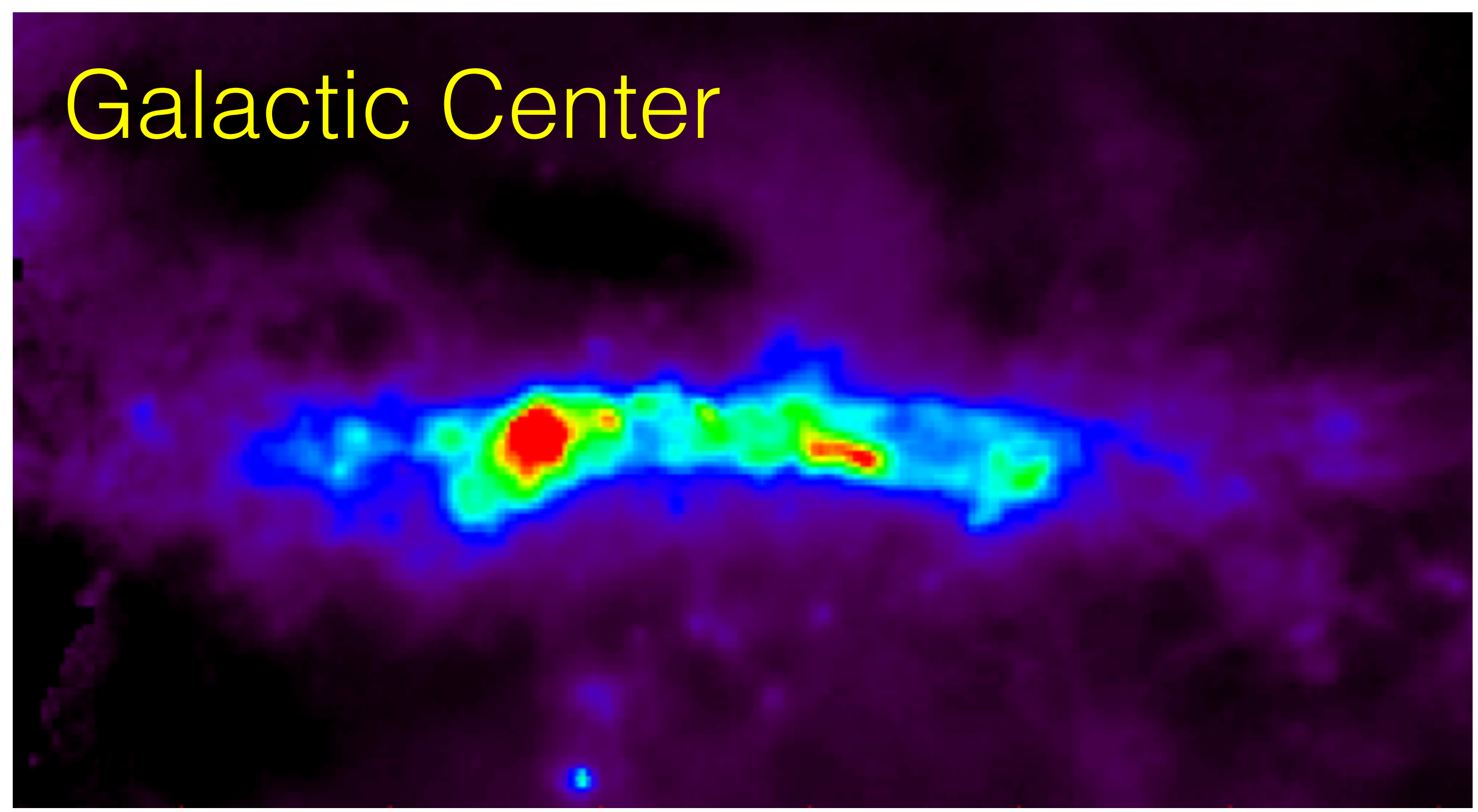




No destriping

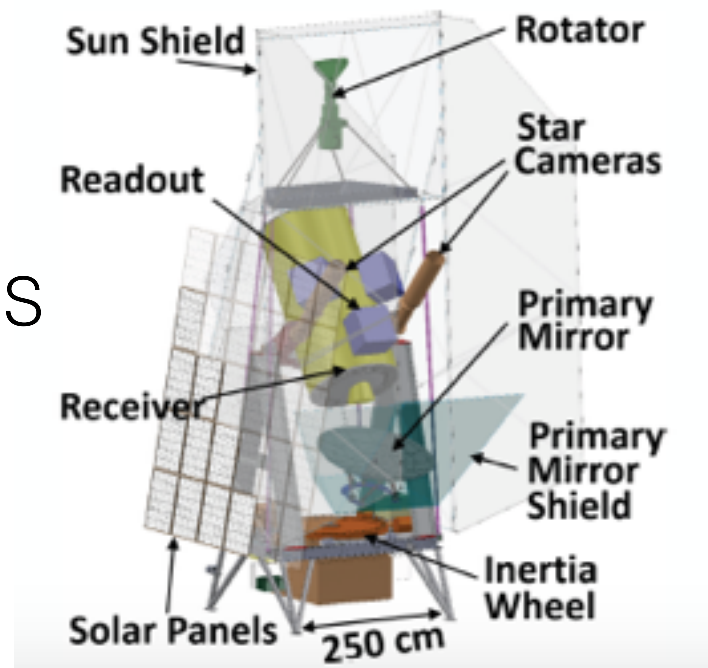
atmospheric subtraction

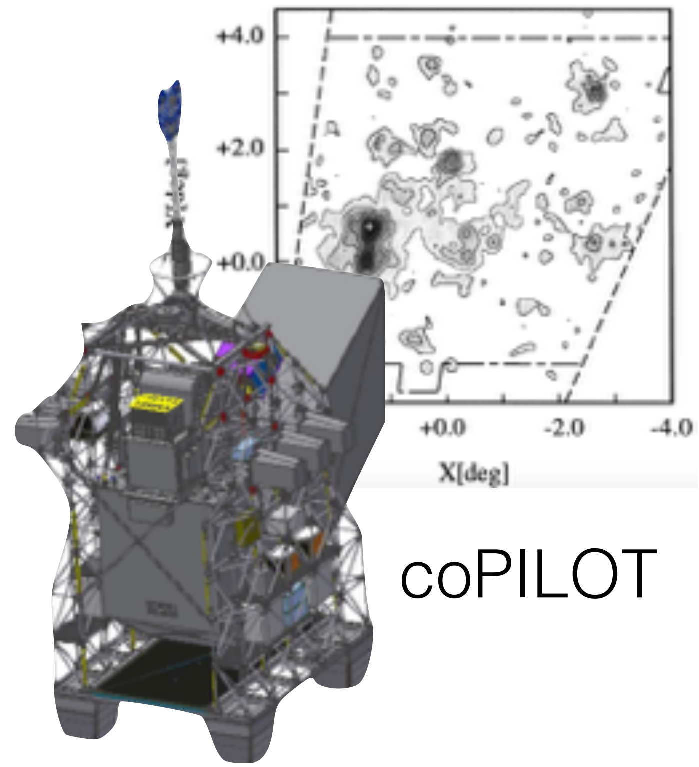




PILOT Spin offs

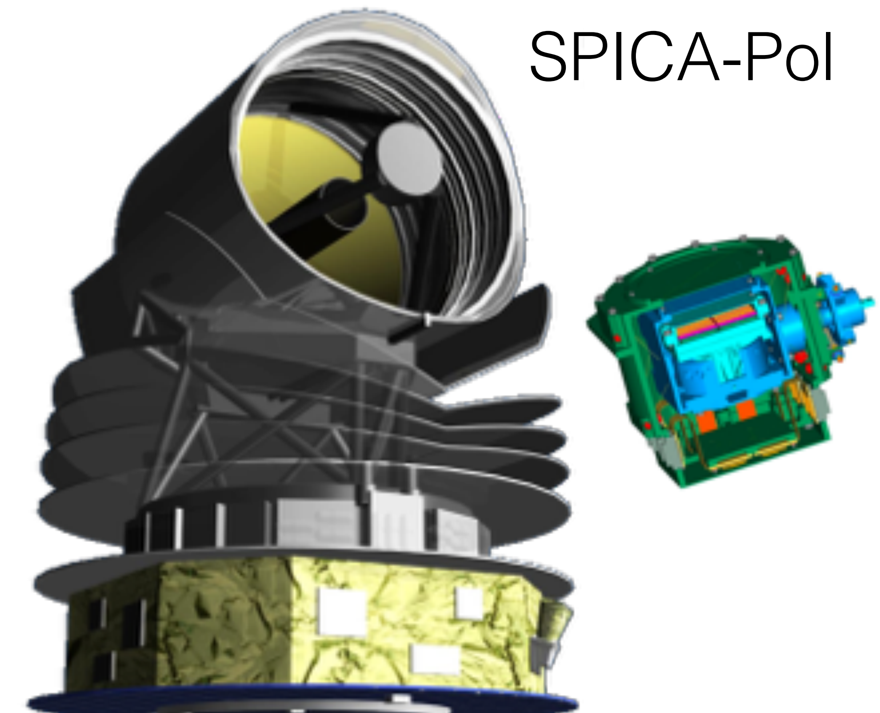
IDS





coPILOT

SPICA-Pol



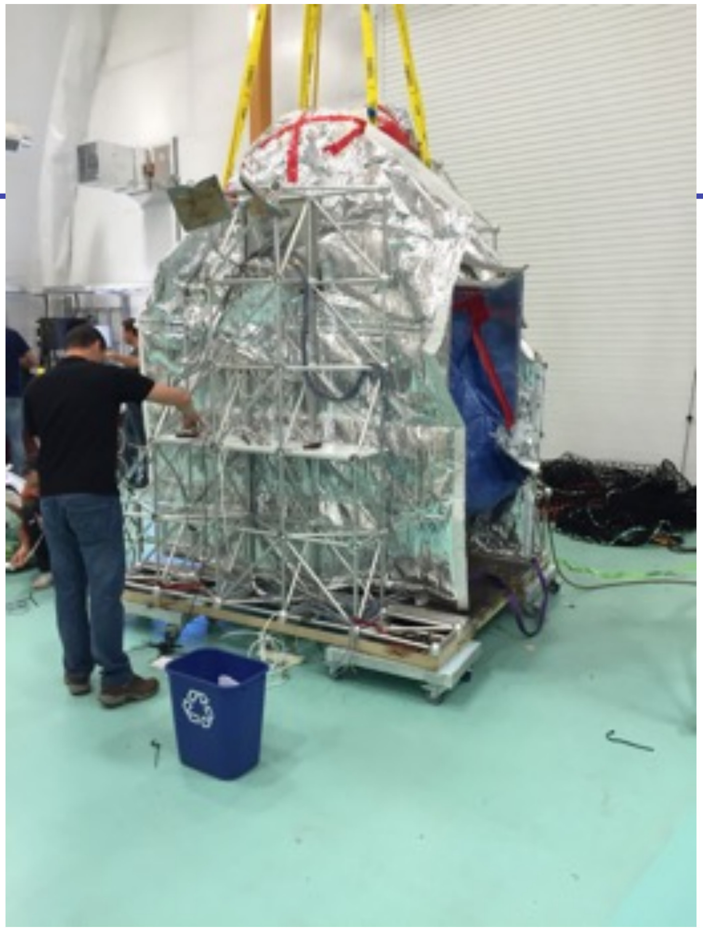
- IDS (Inflation and Dust Surveyor): CMB Bmodes + dust proposed to NASA 2018. Contribution to provide Pilot Estadius + ICS.

- CoPilot: modification of PILOT will allow very accurate measurements of C+ (158 mic) total intensity. Dark molecular gas distribution in solar neighborhood, nearby galaxies. Submitted to CNES in 2017, 2018.

- SPICA-pol: Polarized instrument on SPICA. Design and science case strongly inspired from PILOT. Accepted in pre-phaseA/0.

Gondola retrieval

Avoided lakes …



but not forest …

Science instrument ok but for a few repairs

Gondola retrieval

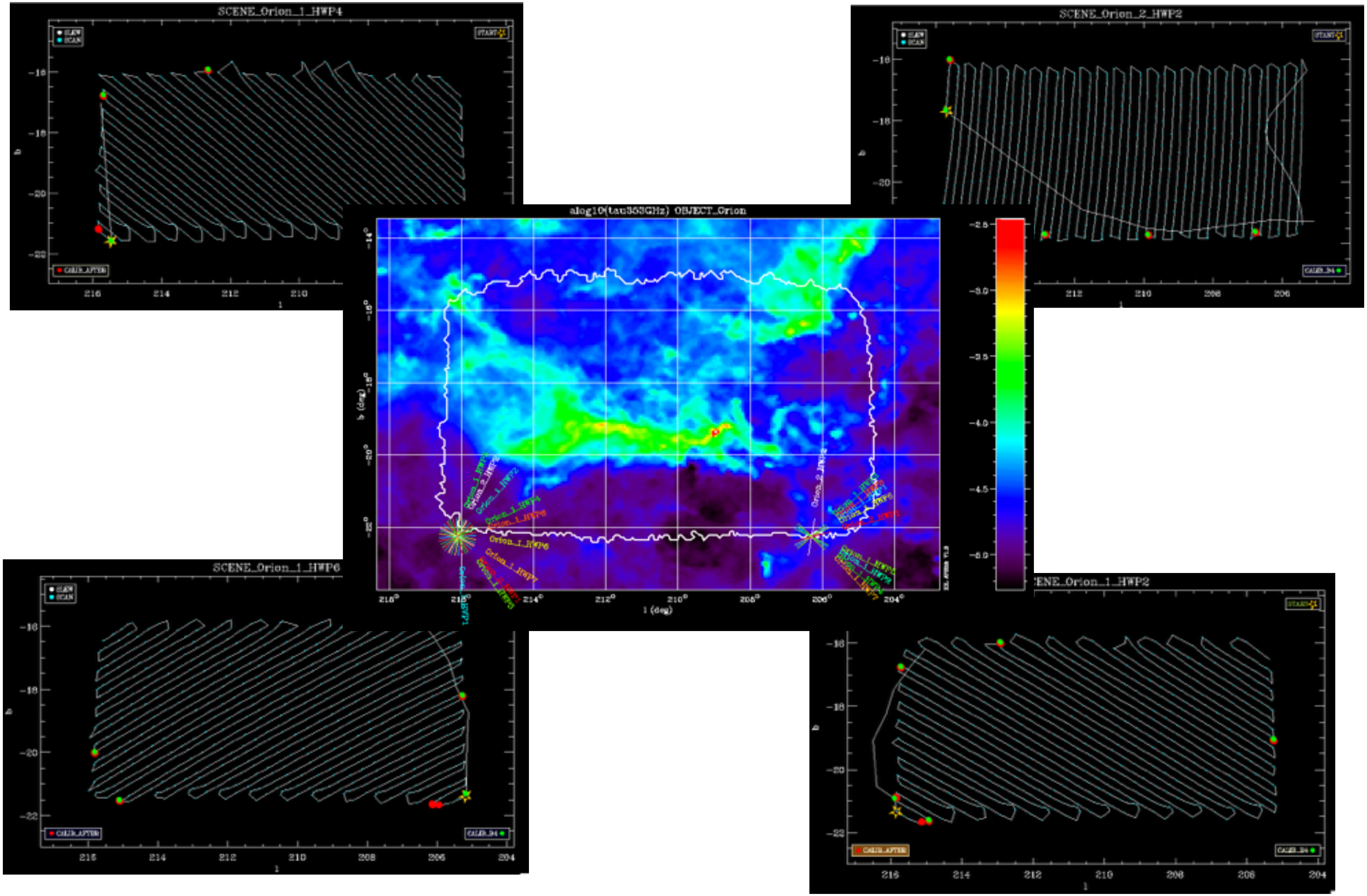
Instrument was recovered ~836 km East of Alice Springs
Desertic area.

Gondola, back to Alice Springs

landing area

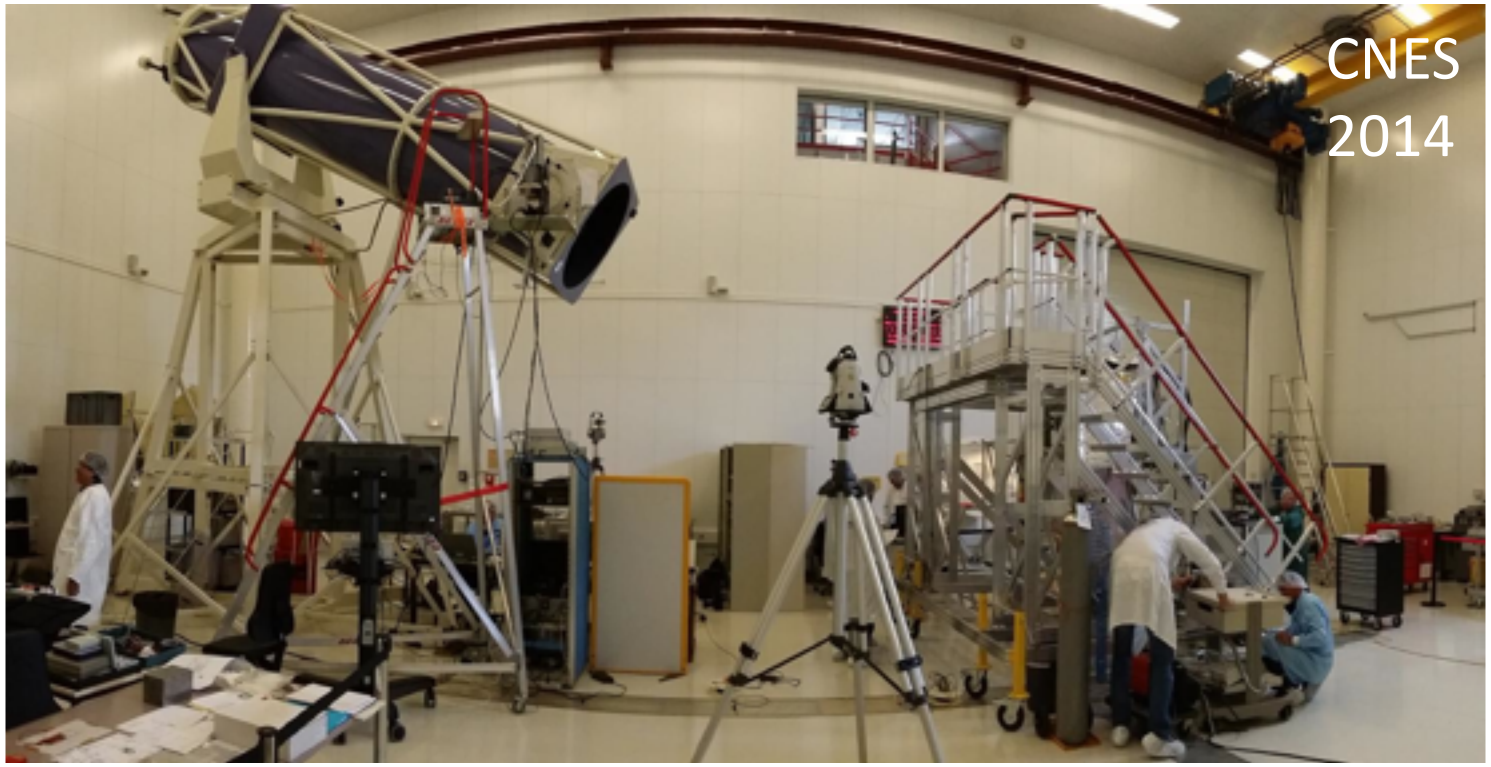
The instrument looks ready to fly again !

Orion mapped with 6 scenes at different scan angles



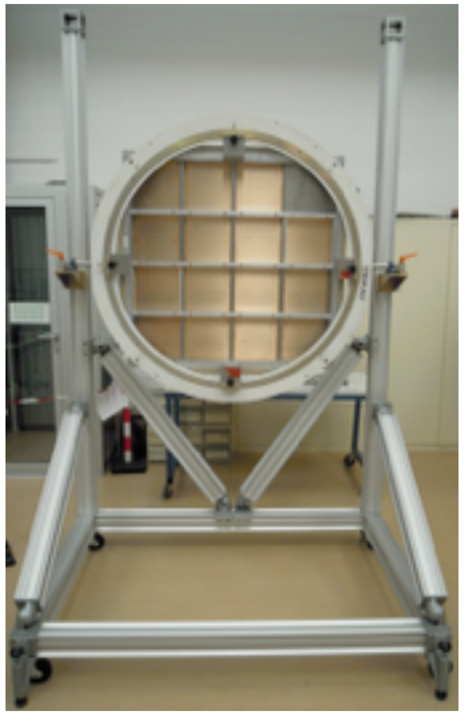
J.-Ph. Bernard, LLR, June 26 2017

Ground Tests



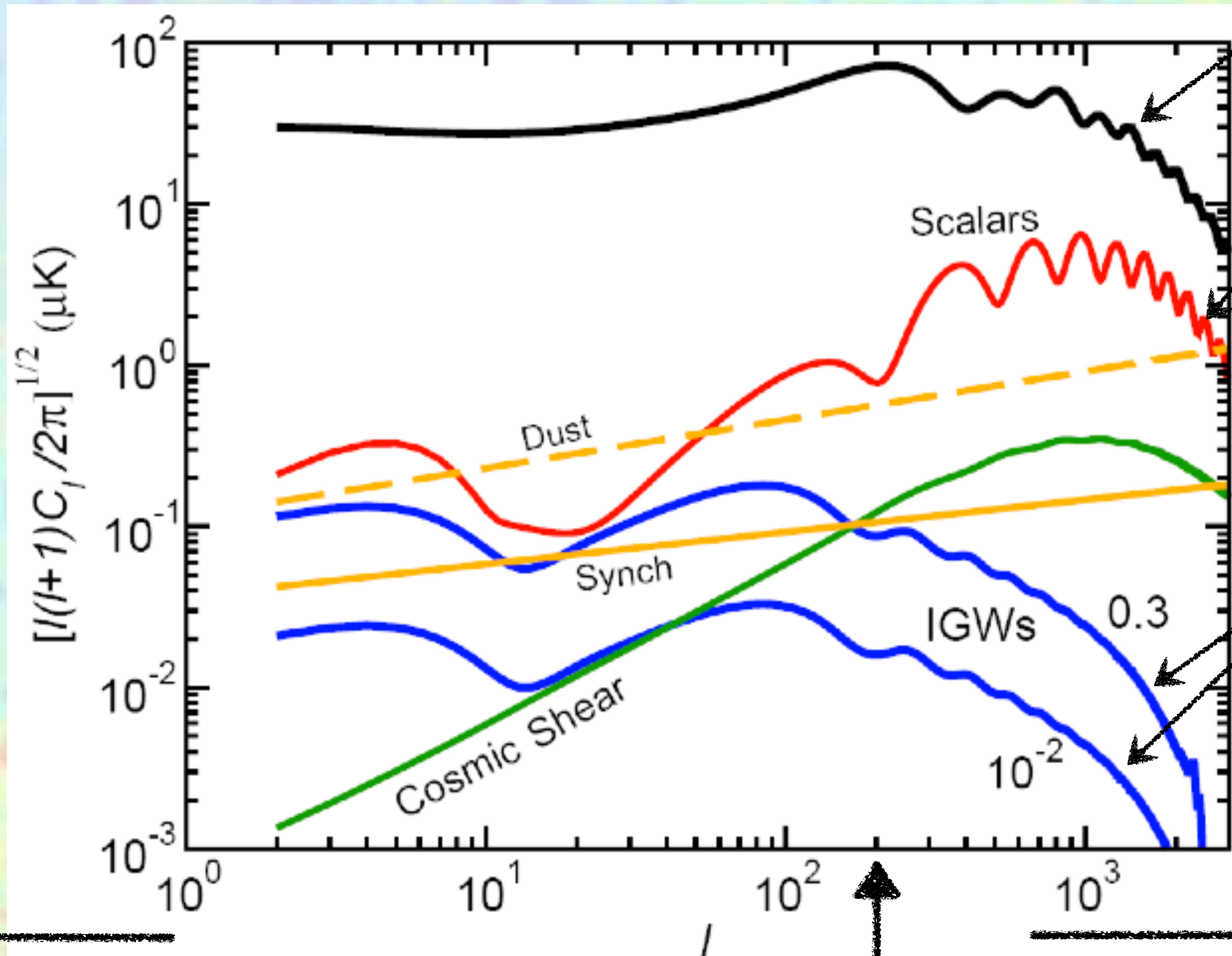
Detectors/Instrument:
- Detectors issues
- Detector optimization
- Noise
- Time constants
- Response (ICS)

Optics:
- Background
- Spectral Transmission
- PSF/Defocus
- Straylight
- Focal Plane Geometry
- PS Polarization



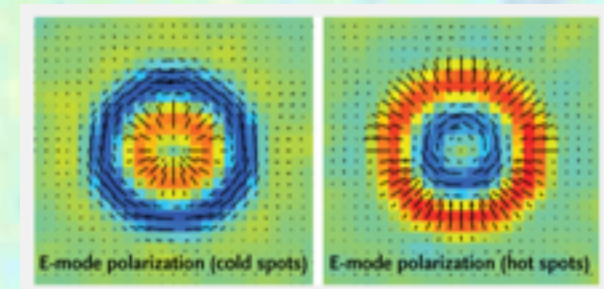
Polarized CMB

Spatial power spectrum of CMB fluctuations

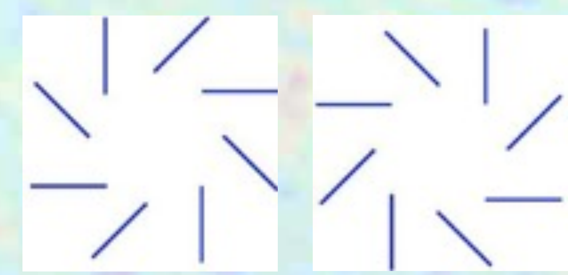


Intensity

Polarization
E-modes



Polarization
B-modes



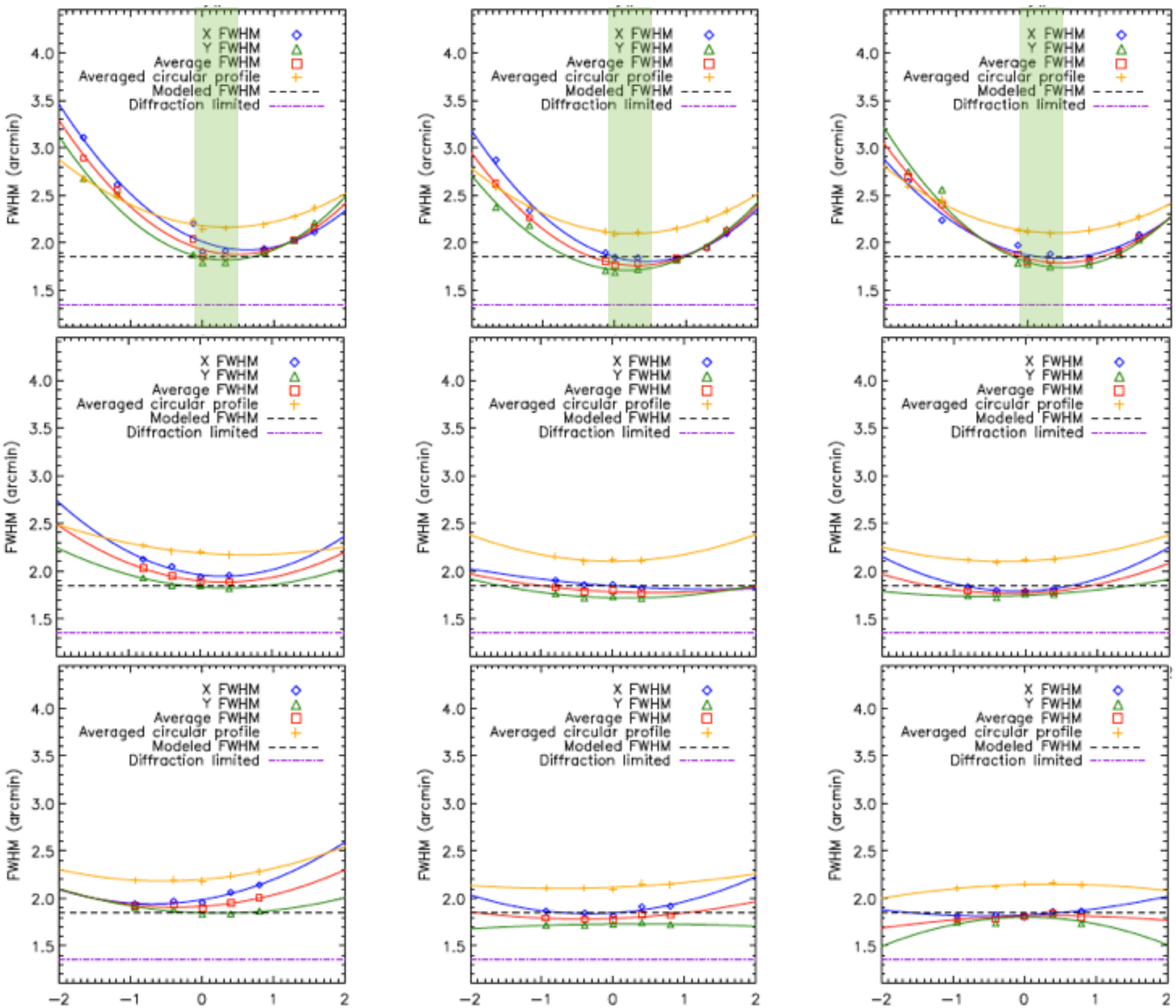
Small-scales

large-scales

1°

B-modes have not been detected yet !!

PSF quality/Defocus



Z defocus

X defocus

Y defocus