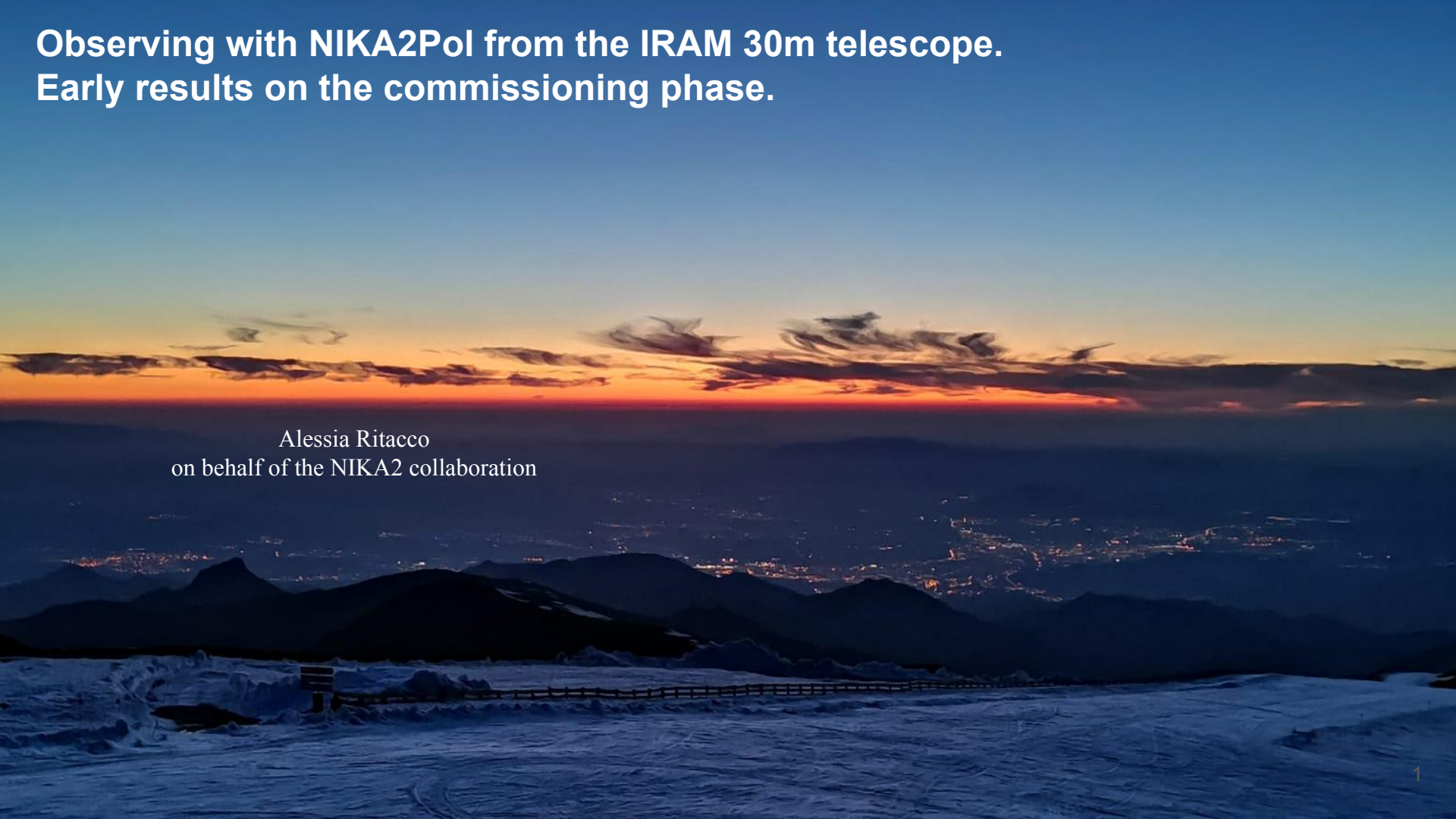
# Observing with NIKA2Pol from the IRAM 30m telescope. Early results on the commissioning phase.



Alessia Ritacco
on behalf of the NIKA2 collaboration

# Outline

- NIKA2Pol hardware and detection strategy;
- polarization commissioning timeline;
- a dedicated data analysis software: from NIKA(1) to NIKA2;
- point sources characterization: quasars;
- polarization calibration at large angular scales: diffuse sources observations;
- open questions.

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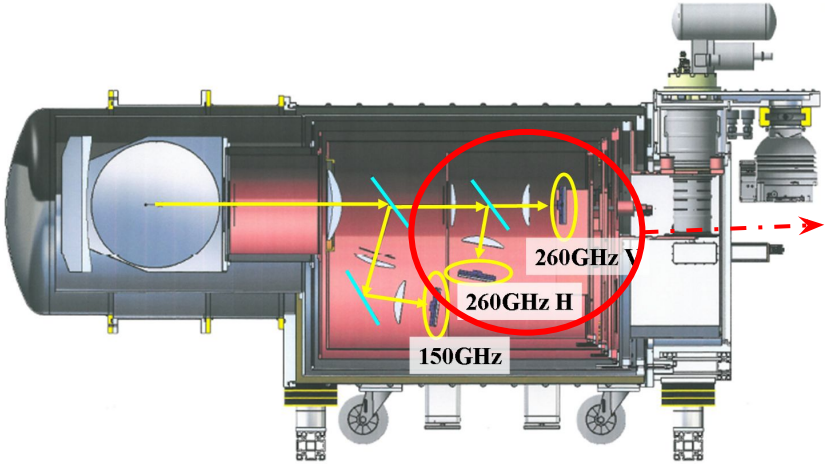
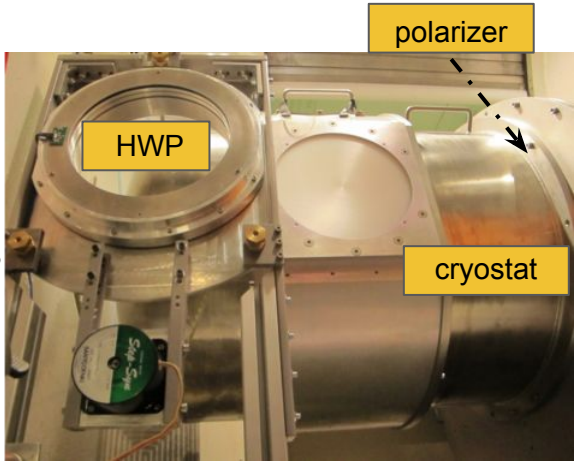
# NIKA2Pol hardware and detection strategy




Two 260 GHz arrays to measure the two linear polarization components




The continuous rotation of the **HWP + polarizer + KIDs** allows us to get a quasi-simultaneous measurement of the Stokes parameters I, Q, and U.

**Detection strategy**: polarization shifted at 4 x mechanical rotation frequency of the HWP, far from low frequency noise.

# Observing in polarization mode

The **AoD and/or the operator** are in charge of:

1. placing the half-wave-plate in front of the cryostat window (to be done in the cabin);
2. switching-on the motor that runs the HWP (remotely, from the control room);
3. checking that the HWP phase is stable;
4. check that the HWP is running, i.e. modulation of the signal (see later) and noise from the control room 

**What the astronomer should know**:

1. we work with a sampling frequency of ~47 Hz to run the HWP at ~3Hz → **a lot of data!!**
2. mapping speed is limited to ~40 arcsec/sec (TBC at the end of the commissioning)

# Observing in polarization mode

**Important to know**:

in polarization mode NIKA2 will (also) provide dual band images.
At 150 GHz (2mm) the total intensity map and at 260 GHz (1mm) the Stokes I, Q, and U maps will be provided.

# NIKA2Pol commissioning timeline

- **June 2017**: First light, mechanical tests
- **November 2017**: technical issue on the HWP phase
- **March 2018**: Week completely lost due to snowstorm
- **June 2018**: Poor weather - testing the "new" acquisition software updated to solve the HWP phase issue
- **September 2018:** HWP phase stability checks after hardware changes
- **December 2018:** good weather, all data collected reliable
- January-May 2019: progress on data analysis and calibration

**Polarization commissioning team**: Nicolas Ponthieu, Aina Andrianasolo, Anaelle Maury, Philippe André, Hamza Ajeddig, Yoshito Shimajiri and Alessia Ritacco

# NIKA2Pol commissioning timeline

- **June 2017**: First light, mechanical tests
- **November 2017**: technical issue on the HWP phase → **Not reliable data**
- ~~**March 2018**~~: Week completely lost due to snowstorm
- **June 2018**: Poor weather - testing the "new" acquisition software updated to solve the HWP phase issue
- **September 2018:** HWP phase stability checks after hardware changes → **Ready to observe**
- **December 2018:** good weather, all data collected reliable
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# How to commission the NIKA2 polarimeter ?

- ☑ estimation of the **instrumental polarization**, a.k.a intensity to polarization leakage, on known unpolarized and bright sources;
- ☑ verification of the **hardware stability** from one observing session to another;
- ☑ verification of the stability of the **leakage for different elevations, sky conditions, focus change**, to be able to model it and subtract from the map; (*see Hamza's talk*)
- ☑ **parallel-session of point sources observations with XPOL** (EMIR polarimeter) and comparison;
- ☑ observation of known extended sources to verify the **good reconstruction of the polarization at large angular scales**;
- ☑ observation of a **weak and unpolarized source to estimate the NEFD**.

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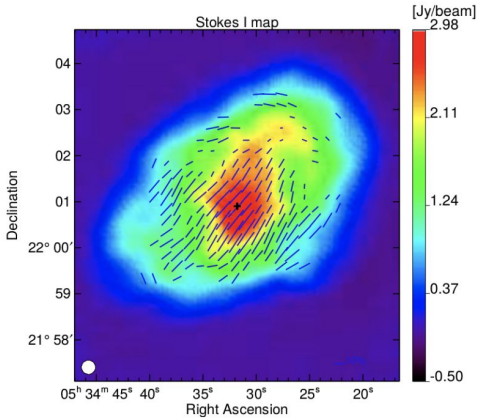
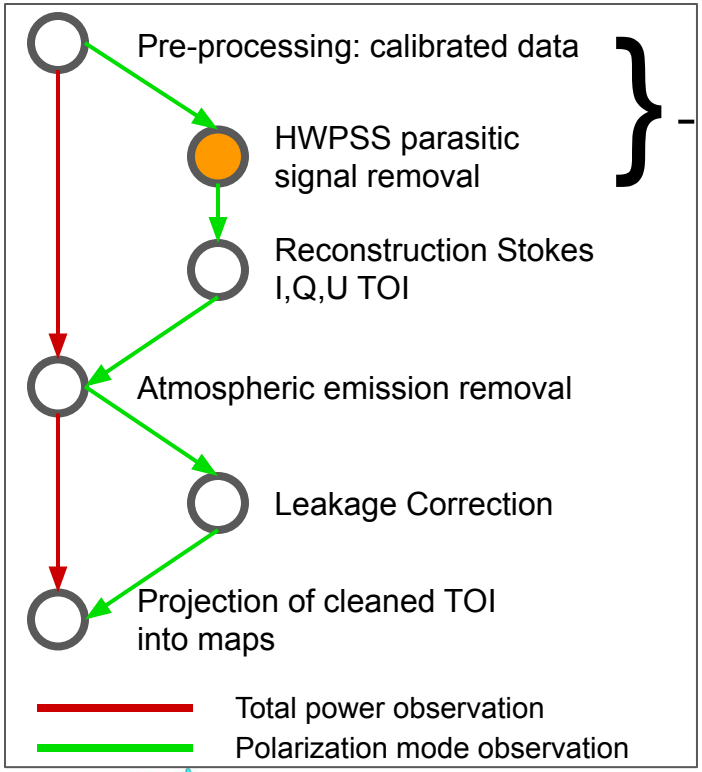
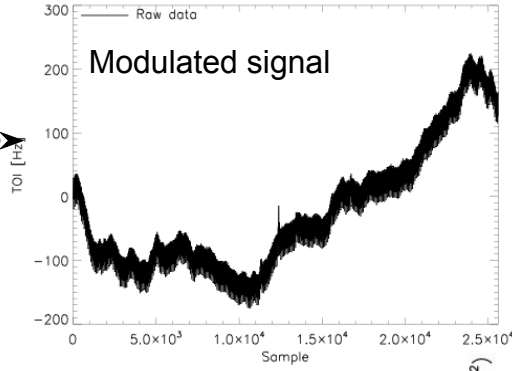
# The NIKA/NIKA2 collaboration pipeline

How do we produce maps from raw data?

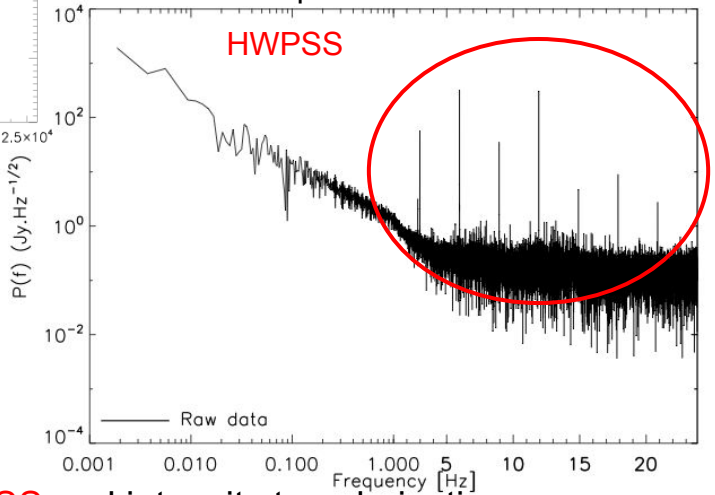


# NIKA/NIKA2 Data reduction software



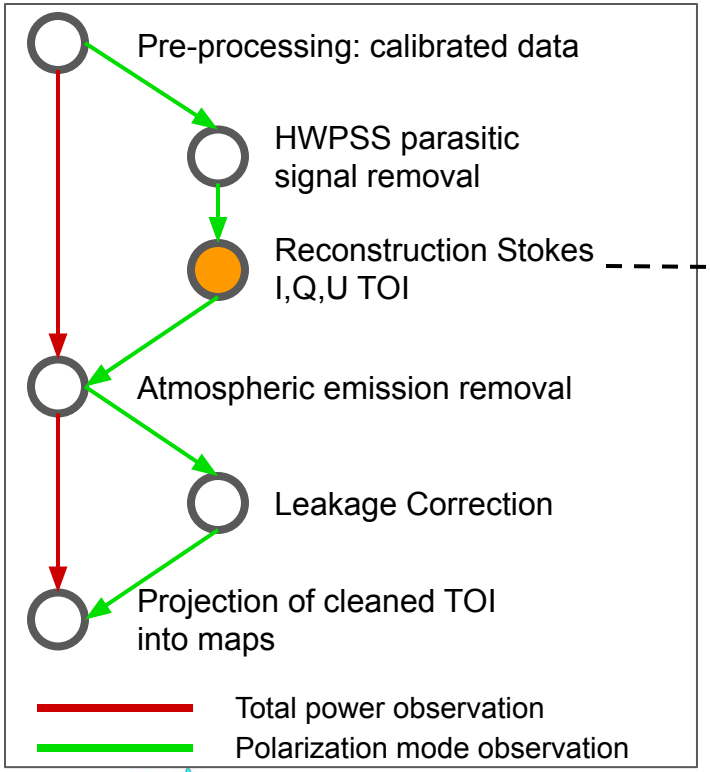




Power spectrum for one KID

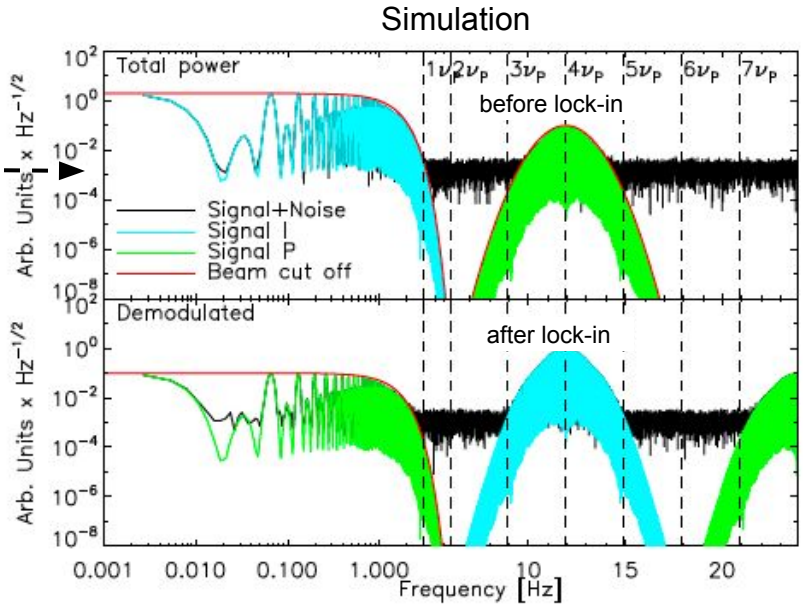



Major issues: HWPSS and intensity to polarization leakage correction (*see Hamza's talk*).

# NIKA/NIKA2 Data reduction software




## Reconstruction of the Stokes parameters I, Q, and U




**Lock-in procedure**

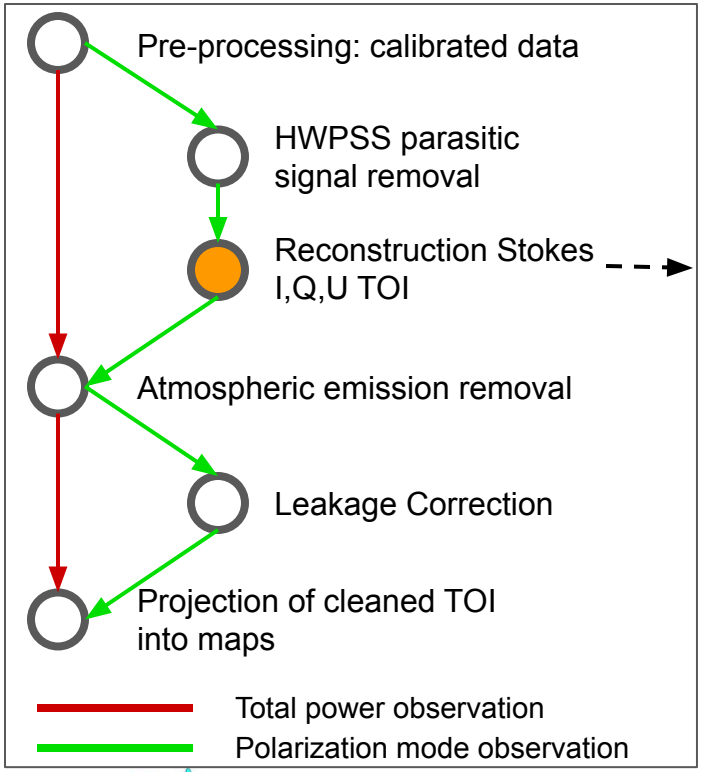
Modulated signal
x
$\cos(4\omega t + 2\psi_t)$
$\sin(4\omega t + 2\psi_t)$

High frequency filtering

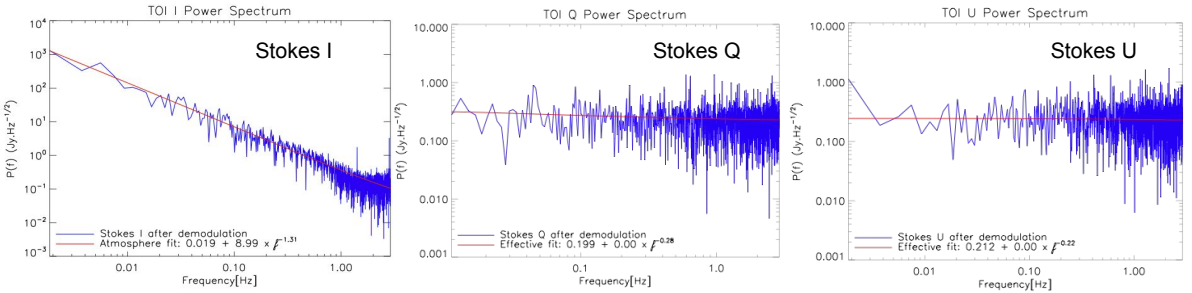


Ritacco, Ponthieu, Catalano et al. 2017, A&A, 599, A34

# NIKA/NIKA2 Data reduction software




## Reconstruction of the Stokes parameters I, Q, and U




The timelines can now be projected onto Stokes I, Q, and U maps.

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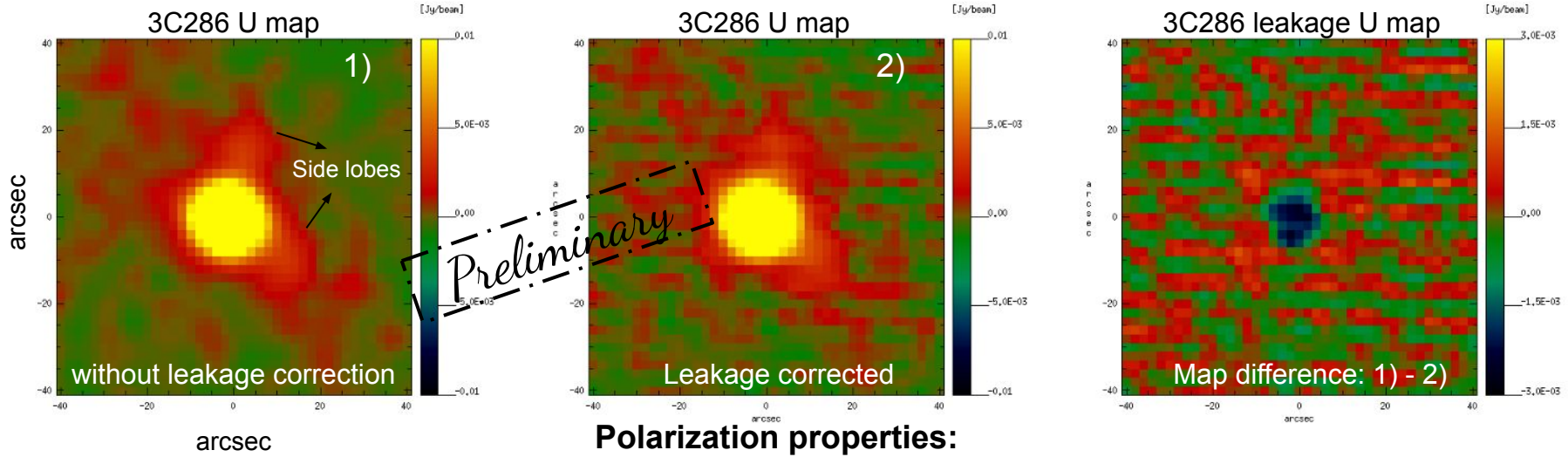
# Status of data analysis commissioning data

Observation of the primary calibrator 3C286




**Polarization properties:**

**intensity P** = sqrt($Q^2$+$U^2$)

**angle $\psi$** = ½*atan(U/Q)

**degree p** = sqrt($Q^2$+$U^2$)/I

# Status of data analysis commissioning data

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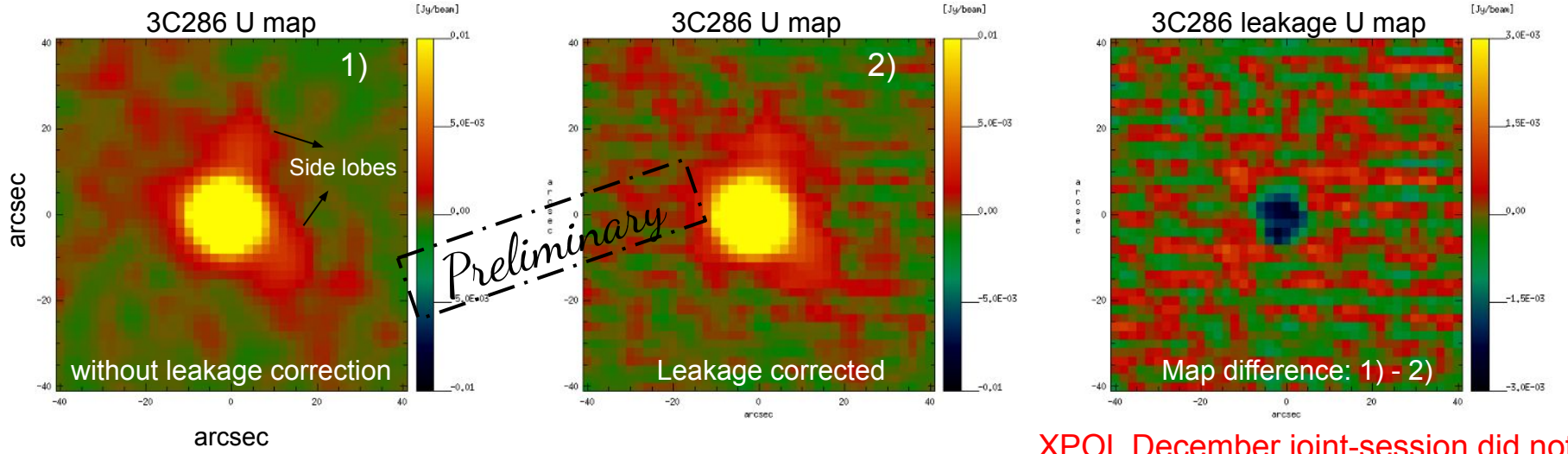



**1mm NIKA2** results:

p = 13.15 +- 0.13 + syst (calib uncertainty) % ;
Ψ = 44.52+-0.3 deg + syst (absolute angle calib + HWP precision)

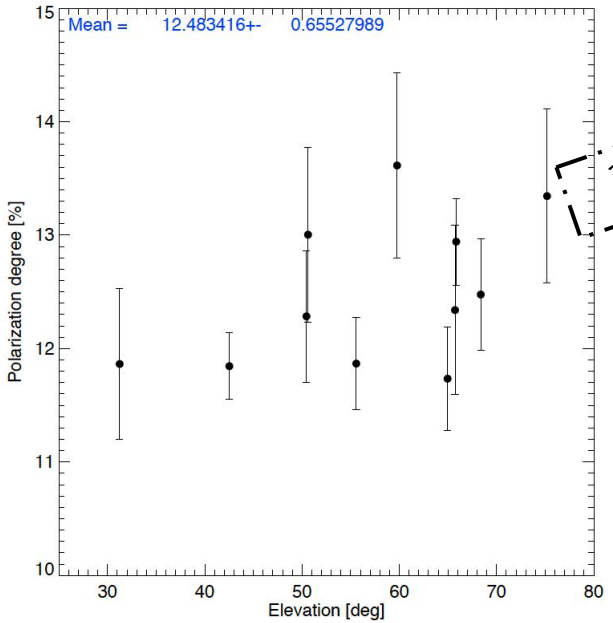
XPOL December joint-session did not give a reliable measure at 1mm !!

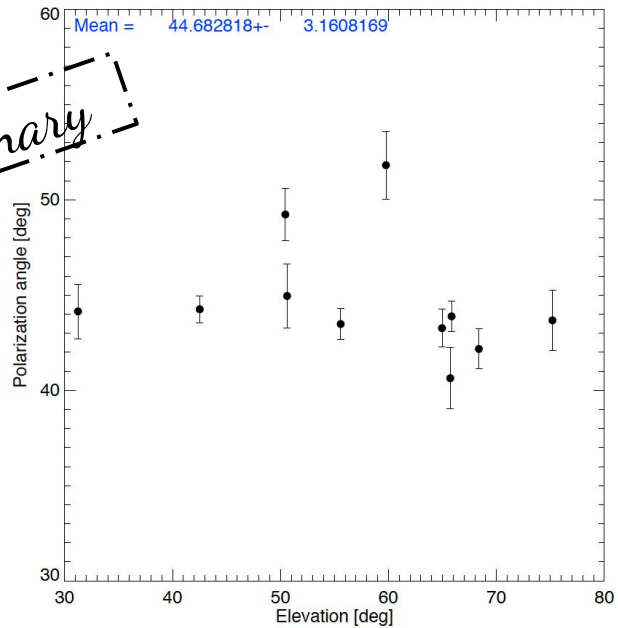
$p_{1mm}$ = 14.4 ± 1.8 %
$\Psi_{1mm}$ = 33.1 ± 5.7 deg

Agudo et al. A&A 541, A111 (2012)

# Status of data analysis commissioning data

Observation of the primary calibrator 3C286: variation with the elevation



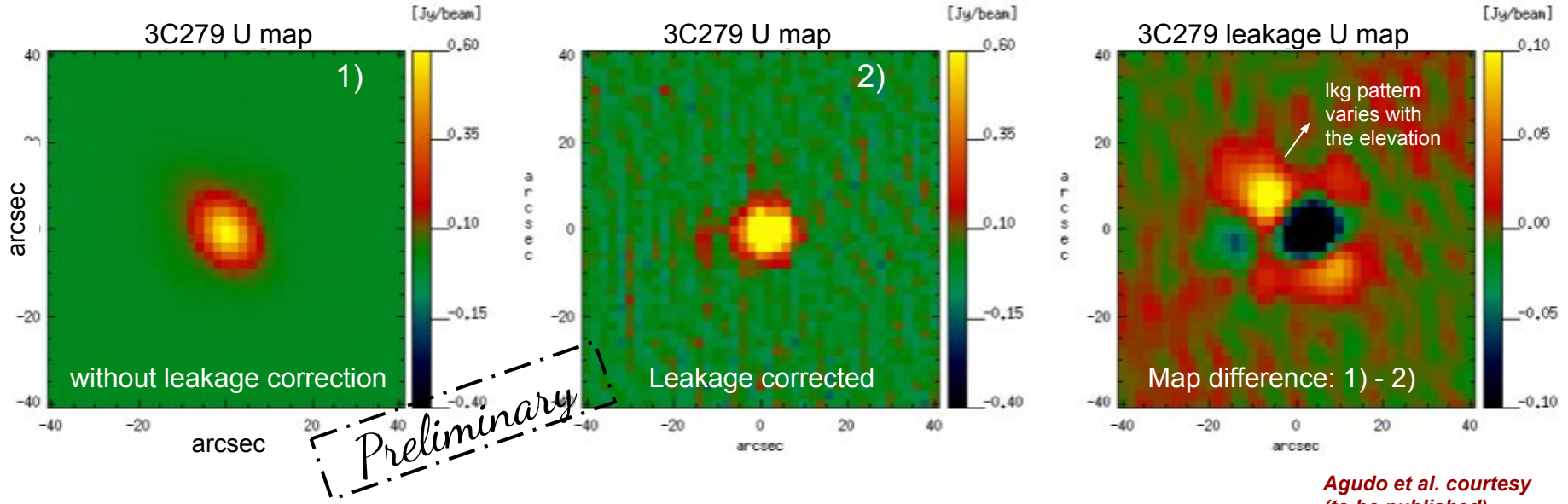




Preliminary


Outliers could be corrected by using a leakage correction per elevation (*see Hamza's talk*)

# Status of data analysis commissioning data

The blazar 3C279




*Agudo et al. courtesy (to be published)*

**NIKA2 1mm** results:

p = 7.52 +- 0.01 + syst (calib uncertainty) % ;

Ψ = 38.68+-0.03 deg + syst (absolute angle calib + HWP precision)

**XPOL 1mm** results:

p = 8.5 +- 1.3%

Ψ = 30.6 +- 4.1 deg

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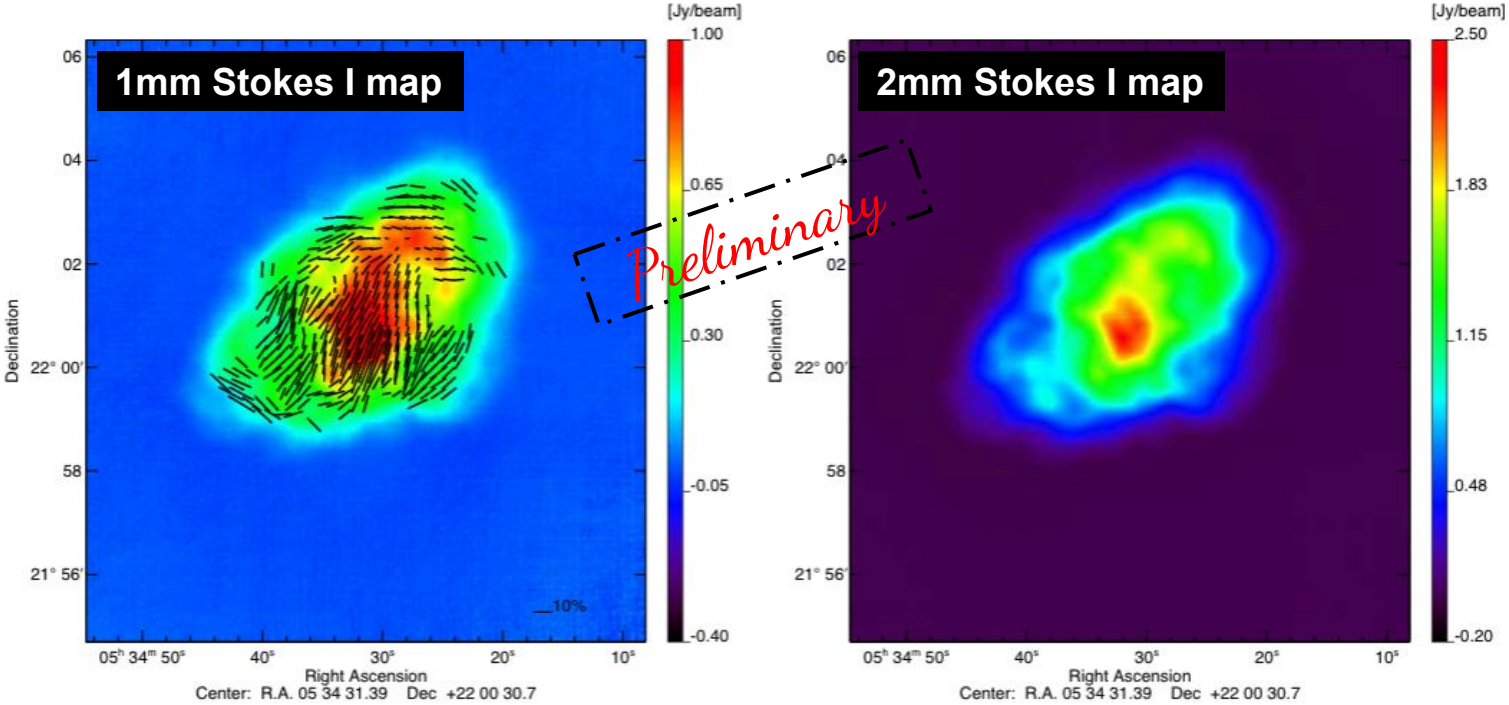
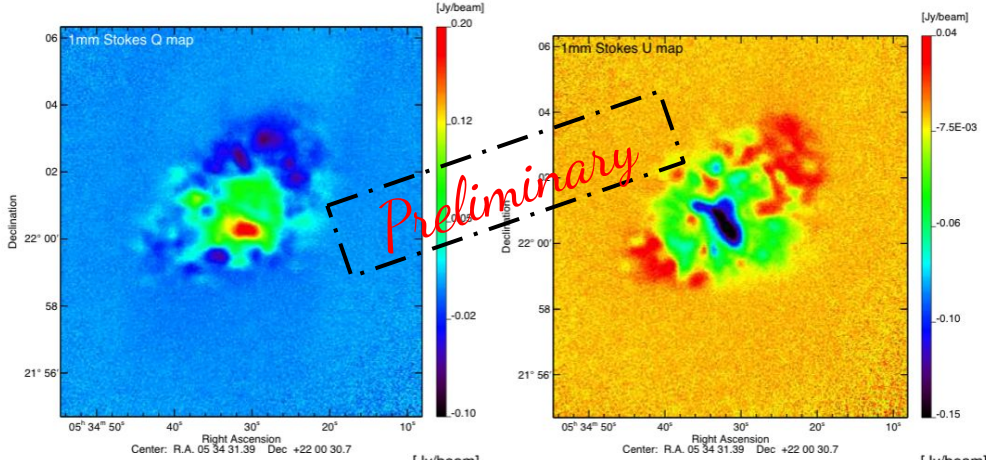
# Crab nebula polarization observations




Polar vector are over-plotted where P > 3$\sigma$

# Crab nebula polarization observations at 260 GHz

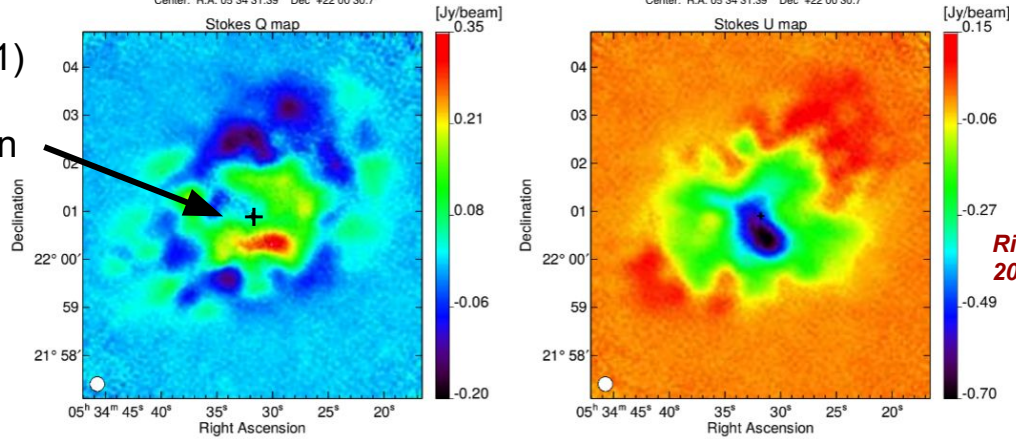
NIKA2




1mm
(260 GHz)

NIKA(1)

pulsar position

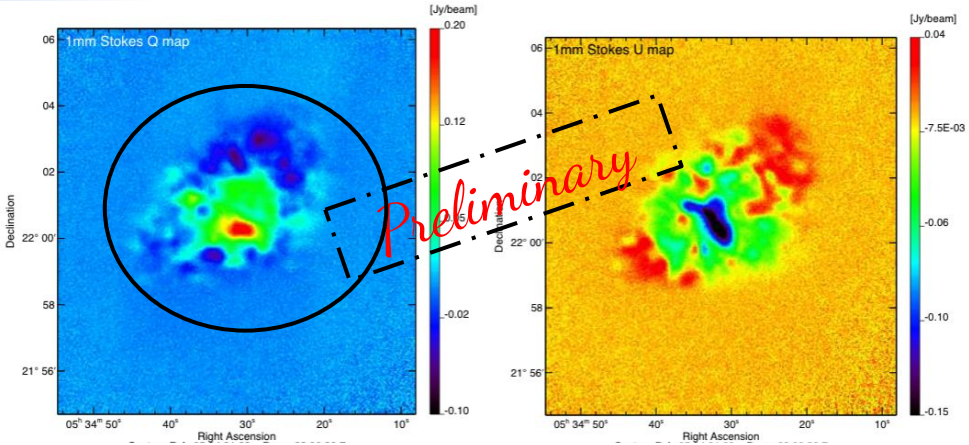



2mm
(150 GHz)

*Ritacco, Macias-Perez, Ponthieu et al. 2018, A&A, 616, A35*

# Crab nebula polarization observations at 260 GHz

NIKA2




Polarization properties obtained by integrating the flux across the source (7 x 5 arcmin size):

I = 158.04 +- 0.18 +- (syst) Jy

P = 12.35 +- 0.01 +- (syst) Jy

Ψ = -86.9 +- 0.07 +- (syst) deg (galactic coord.)

***Ritacco et al. 2018, A&A, 616, A35*** *(see next talk):*

$I_{217}$ (Planck) = 172.73 +- 1.6 Jy

$P_{217}$(Planck) = 12.23 +- 0.17 Jy

$\Psi_{217}$(Planck) = -87.93 +- 0.25 deg

**Weighted averaged value (23-217 GHz) = -87.7 +- 0.3°**

**Values consistent with the expectations but the total intensity flux (transfer function to be checked) !!**

# Crab nebula polarization observations at 260 GHz

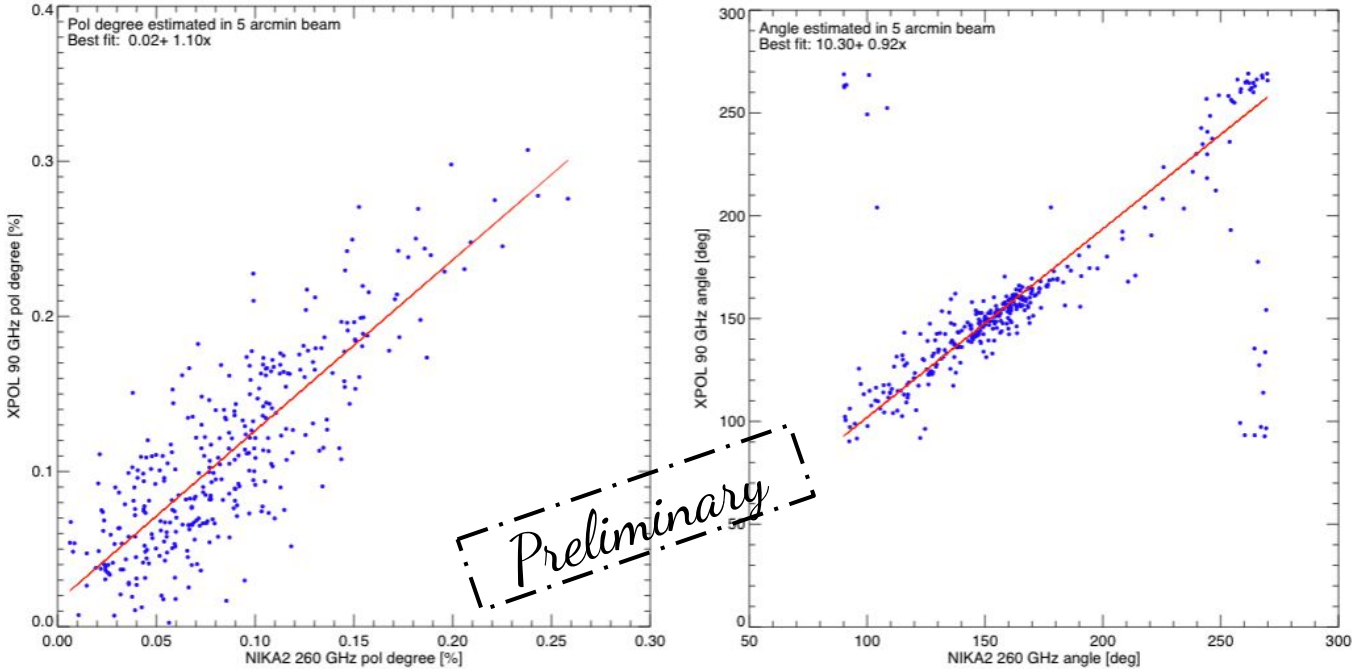
Table presented in *Ritacco et al. 2018* updated with NIKA2 values

Preliminary

| | | $p$ [%] | $\psi_{eq}$ [°] | |
|---|---|---|---|---|
| Pulsar | POLKA | 18.2 ± 4.8 | 147.1 ± 7.5 | |
| | XPOL | 17.5 ± 1.2 | 150.2 ± 2.0 | |
| | SCUPOL | 14.8 ± 2.8 | 143.5 ± 4.4 | |
| | NIKA | 17.9 ± 2.2 | 138.8 ± 1.5 ± 2.3 | |
| | NIKA2 | 14.05 ± 1.9 | 149.08 ± 0.12 | +syst |
| Intensity Peak | POLKA | 19.4 ± 4.4 | 148.1 ± 6.5 | |
| | XPOL | 21.0 ± 1.2 | 149.0 ± 1.6 | |
| | SCUPOL | 16.4 ± 4.8 | 151.8 ± 8.4 | |
| | NIKA | 20.3 ± 0.7 | 140.0 ± 1.0 ± 2.3 | |
| | NIKA2 | 16.6 ± 2.2 | 150.9 ± 0.12 | +syst |

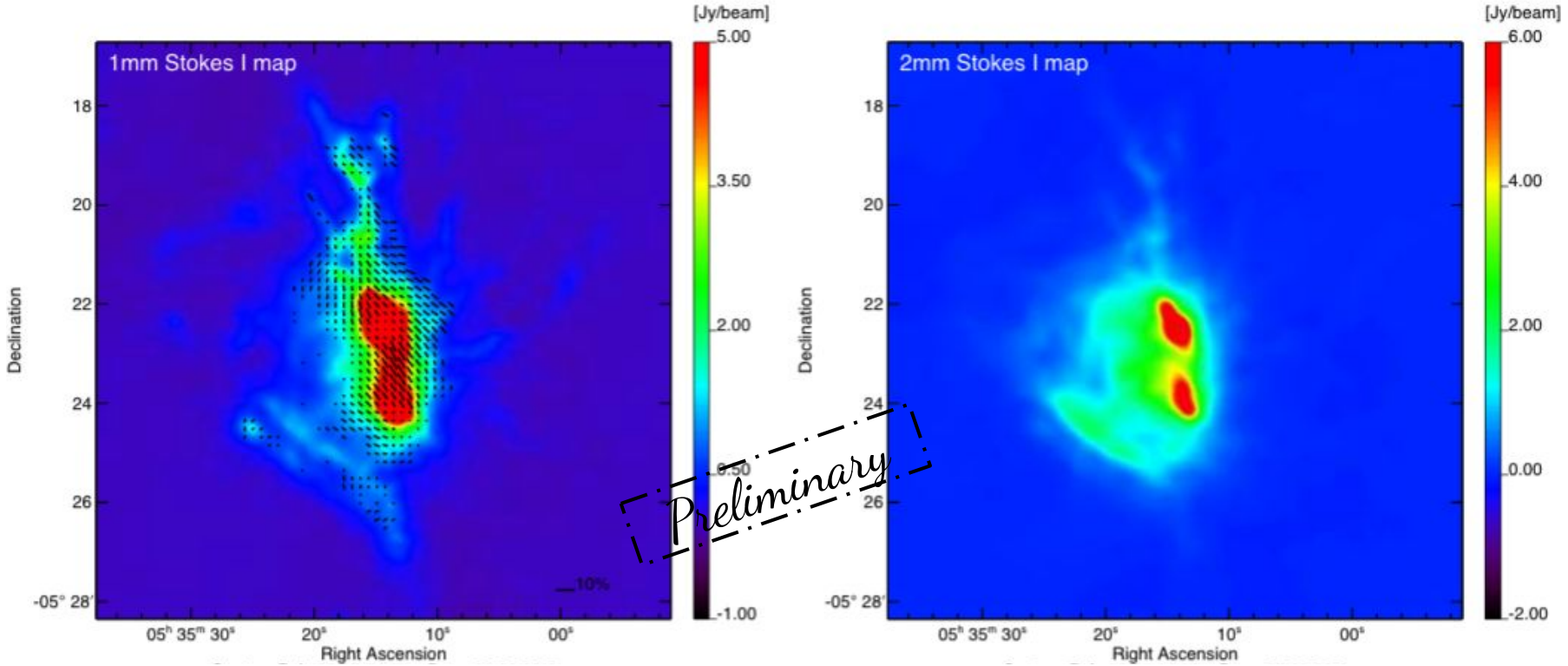
**At the pulsar and intensity peak positions we find a very good agreement with previous observations in the millimeter range.**

# XPOL-NIKA2 pixel to pixel comparison




**Good correlation between polarization degree (left) and angle (right) maps of XPOL and NIKA2**

# Orion Molecular Cloud OMC1



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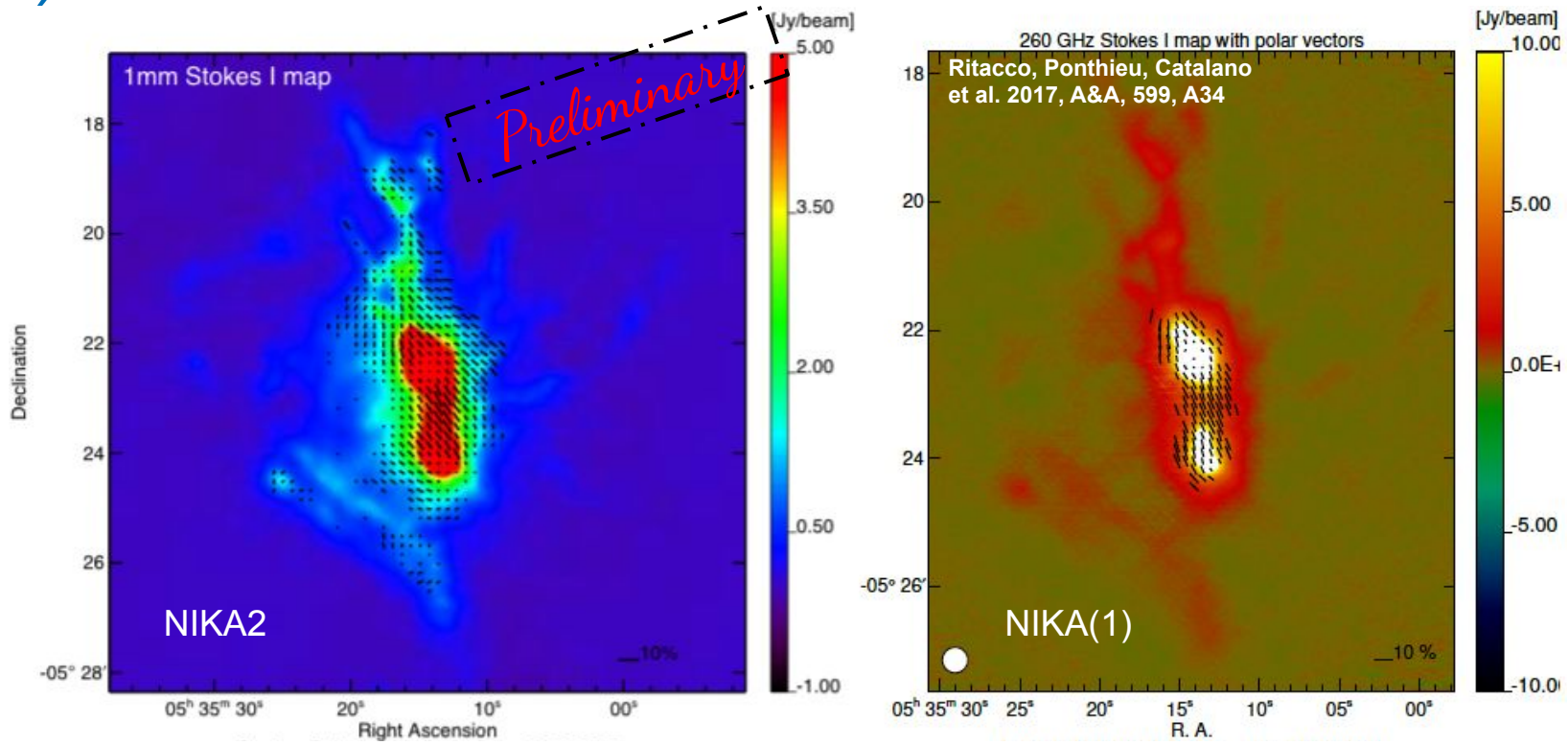
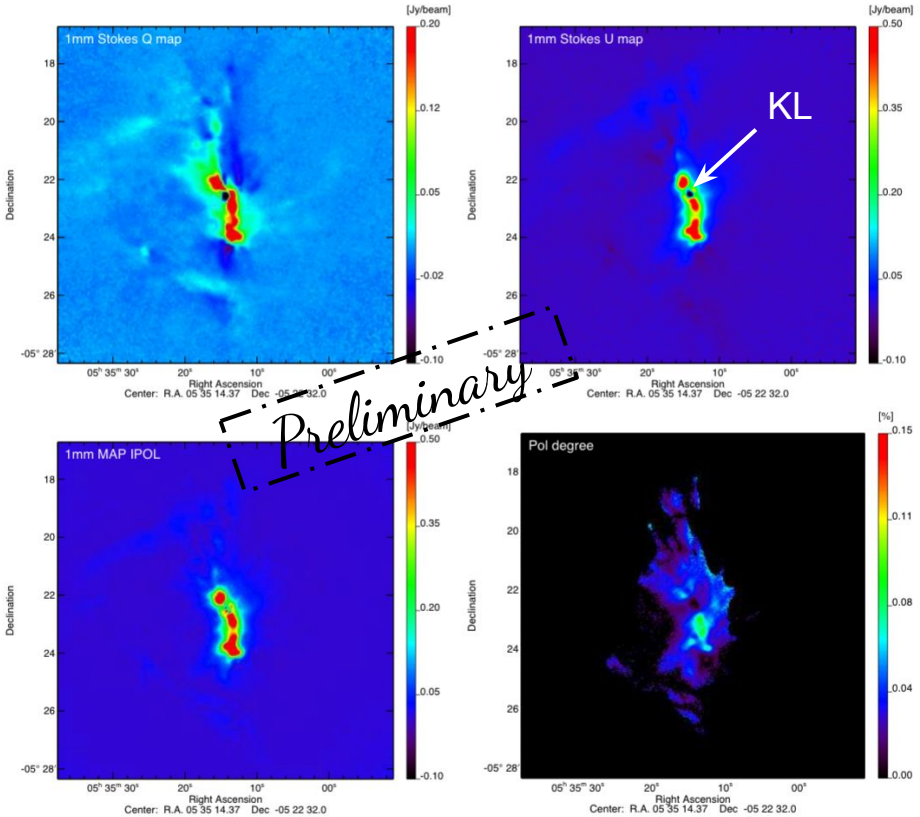



Polarization vectors over-plotted where P > 2$\sigma$

# Orion Molecular Cloud OMC1




Very detailed polarization maps.

Depolarization effect observed at KL nebula position (peak of total intensity) as expected.

Polarization comes from the dust along the filament.

# Orion Molecular Cloud OMC1

Comparison with high resolution experiments

Preliminary

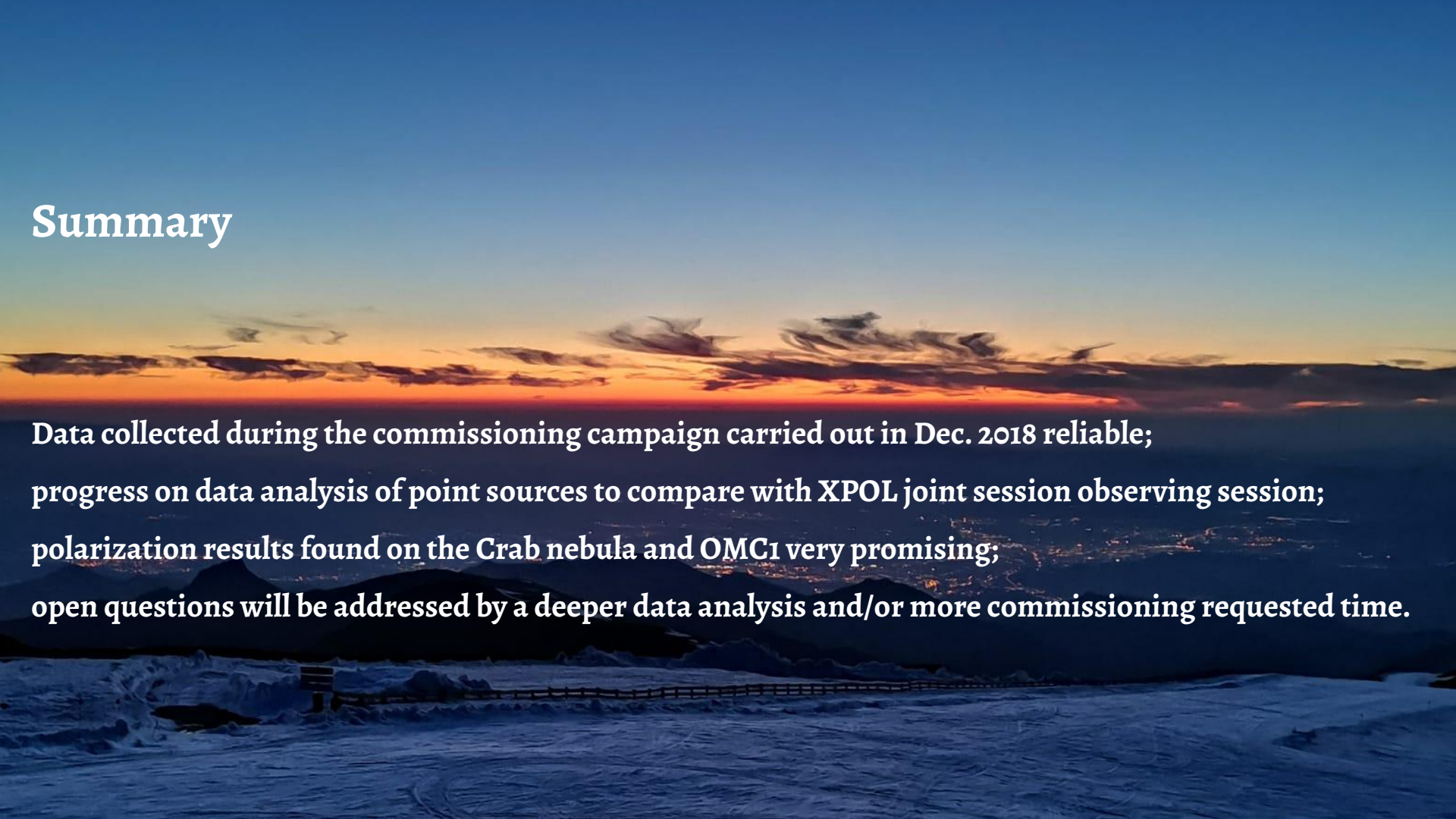
| | POLKA [870 $\mu$ m] | SCUPOL [850 $\mu$ m] | NIKA [1.15 mm] | NIKA2 [1.15 mm] | |
|---|---|---|---|---|---|
| p[%] | $0.7 \pm 0.2$ | $0.7 \pm 0.1$ | $0.6 \pm 0.2$ | $0.81 \pm 0.02$ | +syst |
| $\psi$[deg] | $32.8 \pm 7.6$ | $40.8 \pm 5.4$ | $37.73 \pm 3.56$ | $34.7 \pm 0.6$ | +syst |

**At KL nebula position the NIKA2 polarization results are consistent within 1$\sigma$ with previous measurements.**

# Open questions

- **Absolute calibration polarization angle precision**
  calibrator on the secondary mirror ?!
- How to constrain the variation of the **instrumental polarization for all possible elevations**
  (see next talk)
- Control of the systematics and **estimation of the NEFD**
  (we are getting there, deeper analysis needed)
- Unexpected **noise gradient observed on polarization maps**, so far corrected at pipeline level
  (it did not appear on NIKA maps)
- Verification of the **angle calibration on several targets**
  (needed to confirm the Crab nebula and OMC-1 observations)

# Summary



Data collected during the commissioning campaign carried out in Dec. 2018 reliable;

progress on data analysis of point sources to compare with XPOL joint session observing session;

polarization results found on the Crab nebula and OMC1 very promising;

open questions will be addressed by a deeper data analysis and/or more commissioning requested time.


Thank you all for your attention !
Picture taken on the first week of May 2019, we still had snow !!

# Backup slides

# Noise subtraction characterization

3C286 maps **without** noise subtraction in Q and U

3C286 maps **with** noise subtraction in Q and U