The NIKA polarimeter on science targets: dual-band images of Orion Molecular Cloud OMC-1 and Crab nebula observations at 150 GHz

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on behalf of the NIKA2 collaboration

Photo credit: Stefano Berta, IRAM

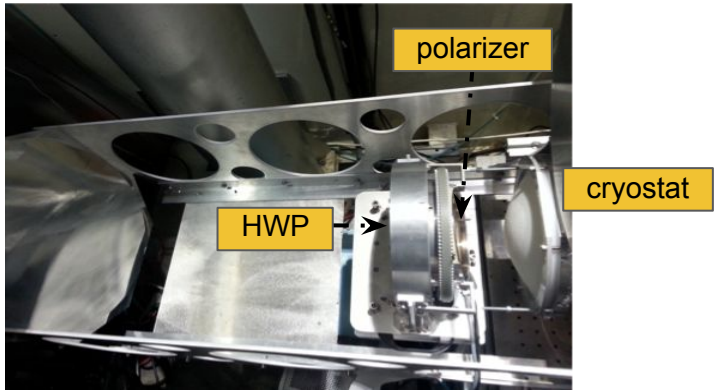
Outline

- Introduction to polarization observations with NIKA
- Orion molecular cloud OMC1 polarization observations
- Crab nebula as calibrator for CMB experiments: polarization observations at 150 GHz
- Conclusions

NIKA Pathfinder polarimeter

Tested during 2014-2015. One successful campaign in February 2015.

Ritacco et al. 2016 JLTP, 184, 724



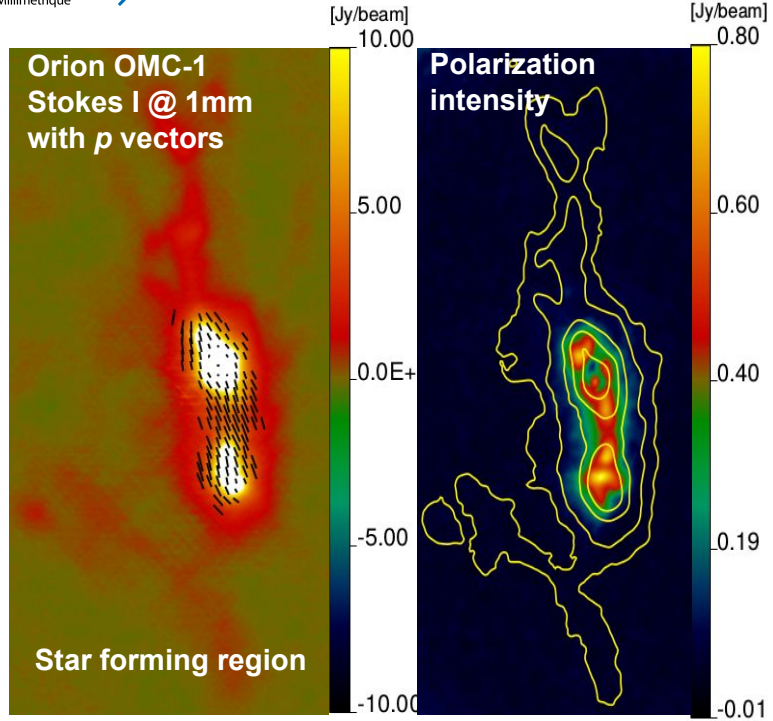
The continuous rotation of the HWP + polarizer + KIDs allows us to get a quasi-simultaneous measurement of the Stokes parameters I, Q, and U.

Performance of the NIKA polarimeter

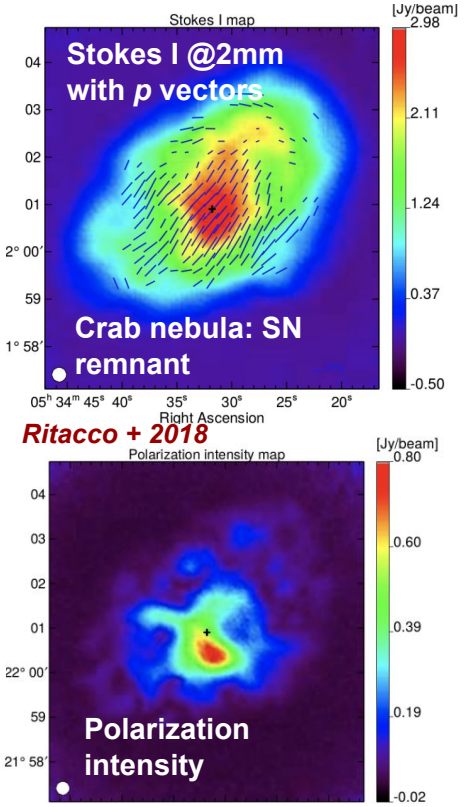
Array	1.15 mm	2.05 mm
Valid pixels	132	224
Field of View (arcmin)	1.8	1.8
Band-pass (GHz)	190–310	110–180
FWHM (arcsec)	12	18.2
Polarization capability	yes	yes
Sensit. on polarization (Q) (mJy s$^{1/2}$)	120	50
Sensit. on I in pol. mode (mJy s$^{1/2}$)	85	35
Sensit. on I in tot. power mode (mJy s$^{1/2}$)	42.5	17.7
Instrumental polarization residual	0.7%	0.6%
Syst. uncertainty on pol. angle	1.8°	1.8°

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

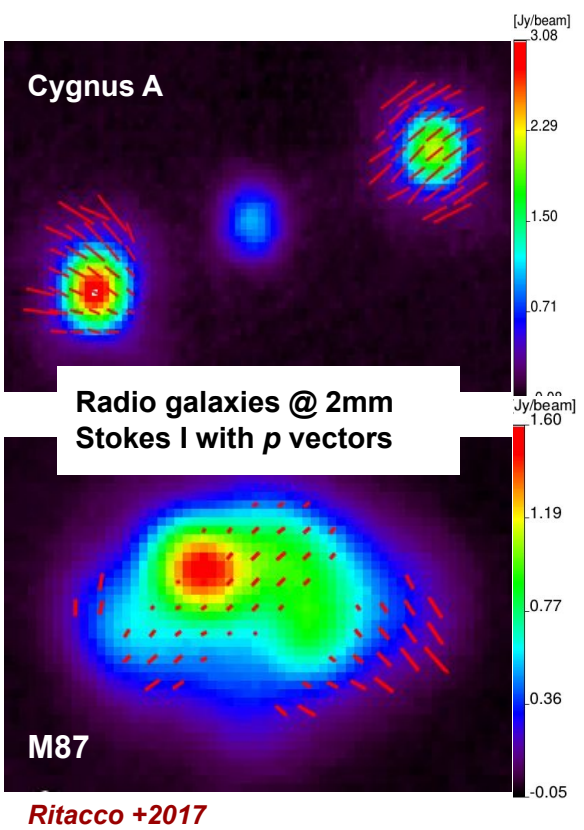
NIKA extended source polarization observations



Ritacco + 2017



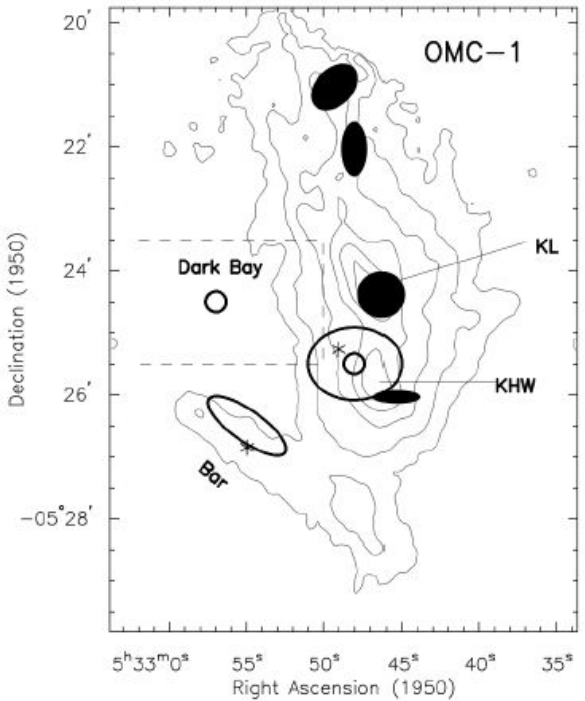
Ritacco + 2018



Ritacco +2017

Observing known sub-millimeter star forming regions: Orion Molecular Cloud OMC1

Orion molecular cloud OMC1



Intensity OMC-1 map observed at 350 μm by *Schleuning, 1998*.

The Orion Molecular Cloud (OMC-1) is the closest site of OB star formation.

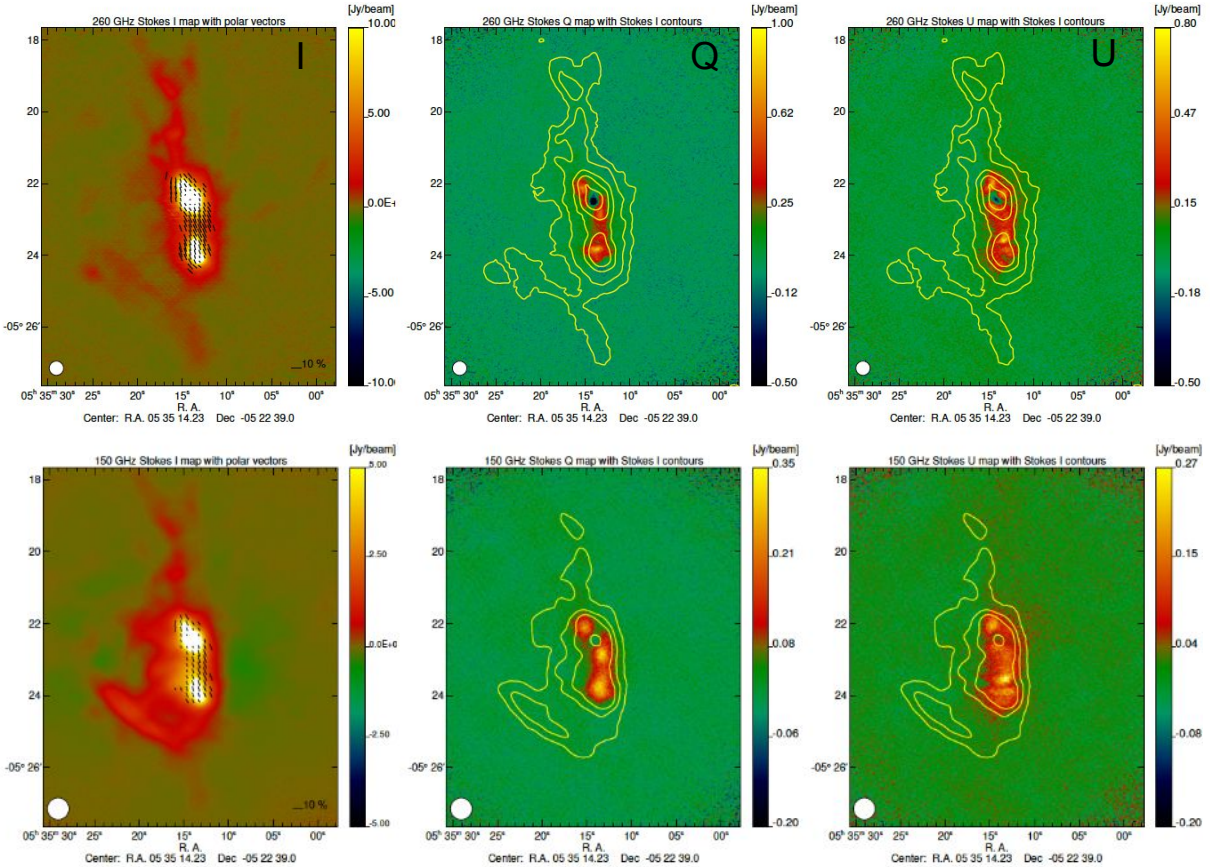
KL nebula: peak of the intensity flux;
KHM: sub-millimetre peak at 90 arcsec at south of KL along the ridge.

Mapping the polarization of the thermal emission of dust at mm or sub-mm wavelengths **is the principal means of probing the magnetic field geometry in molecular cloud cores.**

OMC1 NIKA polarization observations

260 GHz

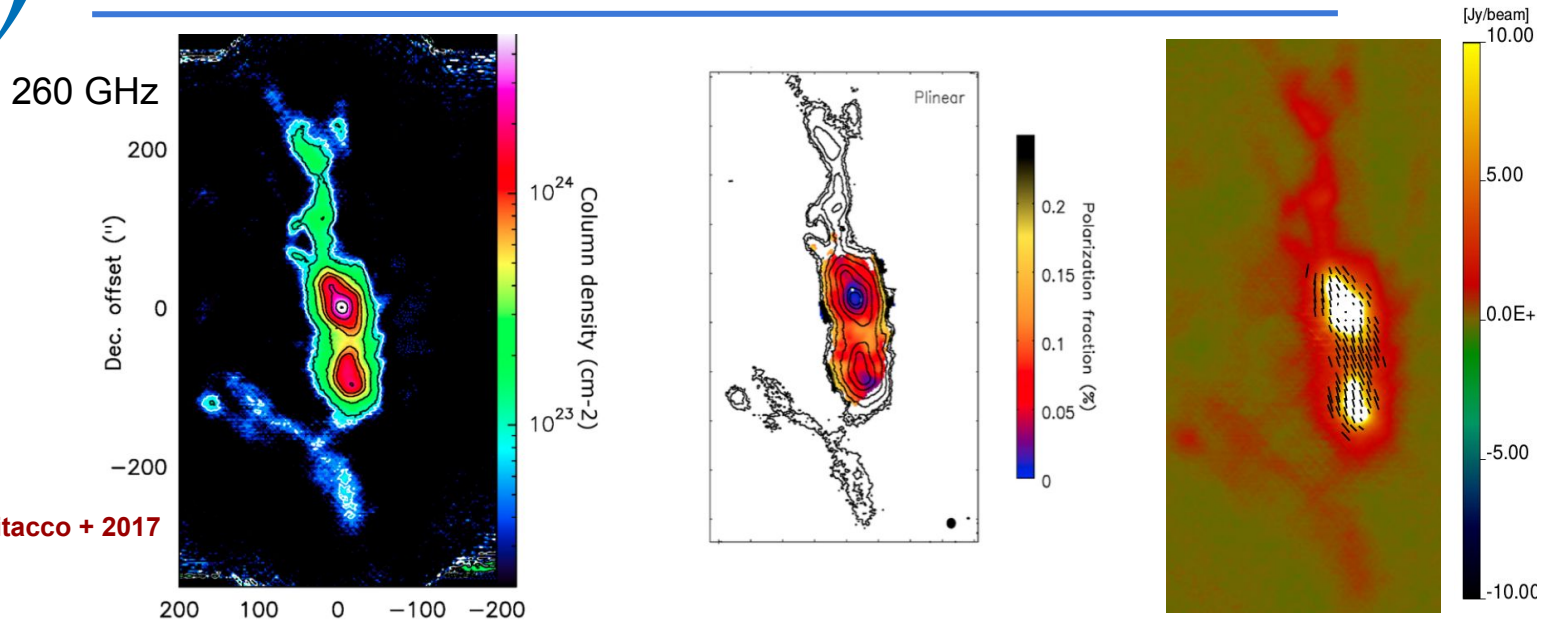
150 GHz



Leakage corrected Stokes I, Q, U 8' x 8' NIKA maps of OMC-1. Co-addition of 18 scans for a total observational time of ~5h. Polarization vectors over-plotted where polarization intensity $P > 2\sigma_P$.

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

OMC1 polarization properties



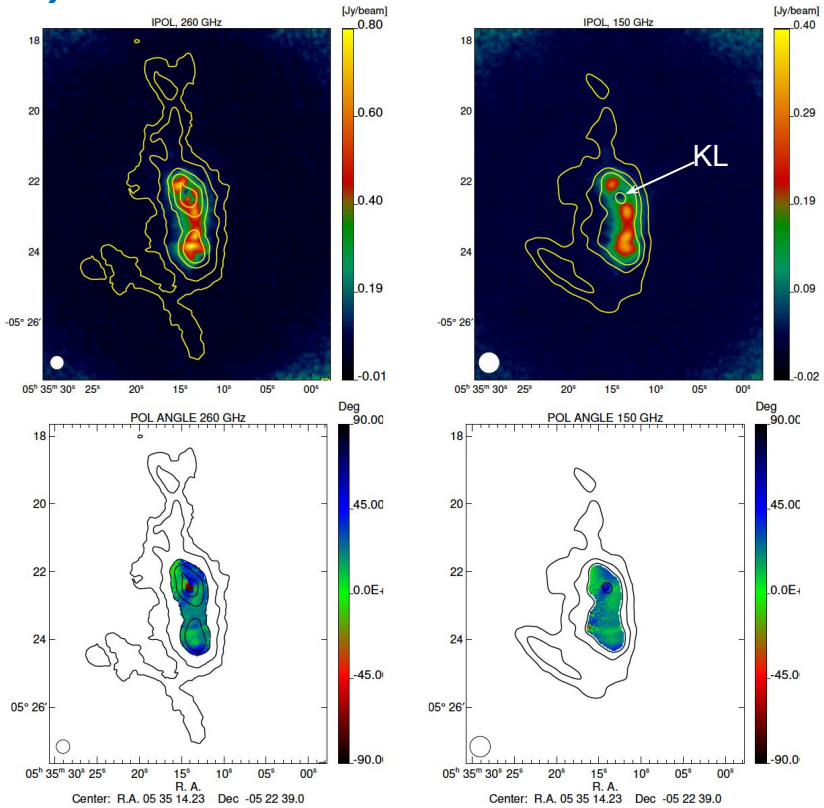
Ritacco + 2017

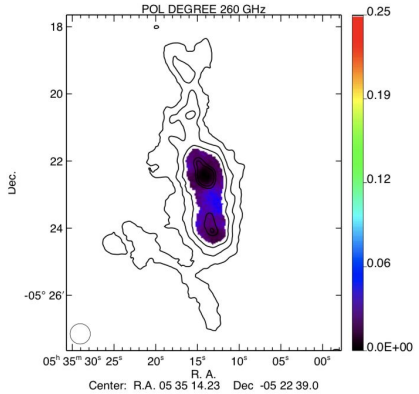
Very organized magnetic field topology with field lines oriented to the filament suggesting bending of the lines along the major axis of the filament towards the high-column-density cores.

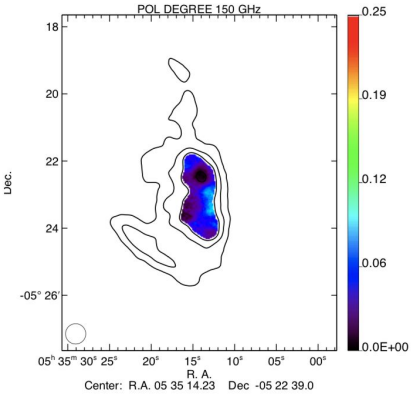
Interpretations:

- **B** dragged by large scale converging material accreting along the filament onto the core
- **B** pushed by the powerful winds of the Orion nebula.

OMC1 polarization properties







Depolarization effect observed at the KL nebula position.

We observe a polarization fraction that reaches a level of ~10% of the total intensity in regions where the diffuse intensity emission is observed (KHW region).

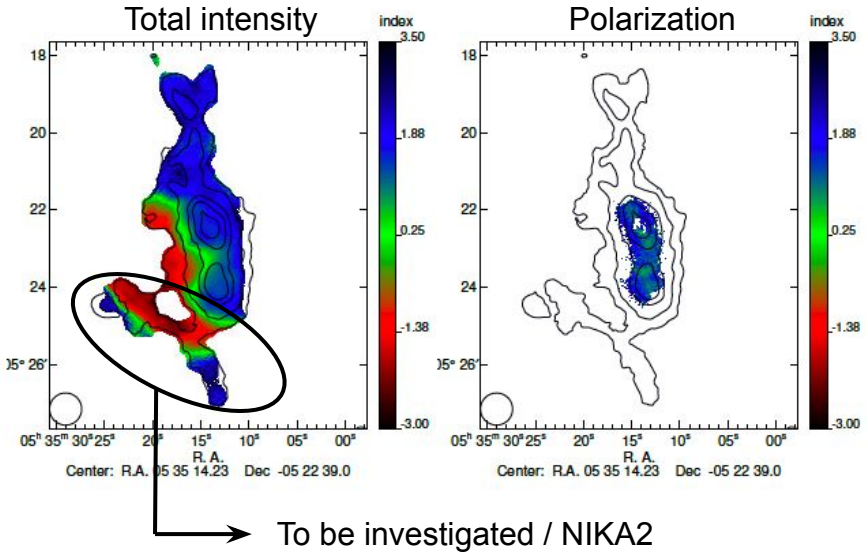
OMC1 spectral index

OMC-1 continuum emission is expected to be described by a thermal dust emission spectrum in the Rayleigh-Jeans approximation:

$$I_\nu = I_0 \frac{2}{c^2} k_B T_{RJ} \nu^{\beta_d + 2}.$$

Writing **β'** = β_d+2, the spectral index is therefore given by:

$$\beta' = \log\left(\frac{I_{\nu_1}}{I_{\nu_2}}\right) / \log\left(\frac{\nu_1}{\nu_2}\right).$$



Ritacco, A. 2016 PhD thesis

2.05 mm extended emission along the bar stronger than 1.15 mm.

This difference could be also indicative of dust grain properties changing along the bar.

β' reaches a value of ~2 in the region with a detection of P > 2 σ_P on both spectral index maps.

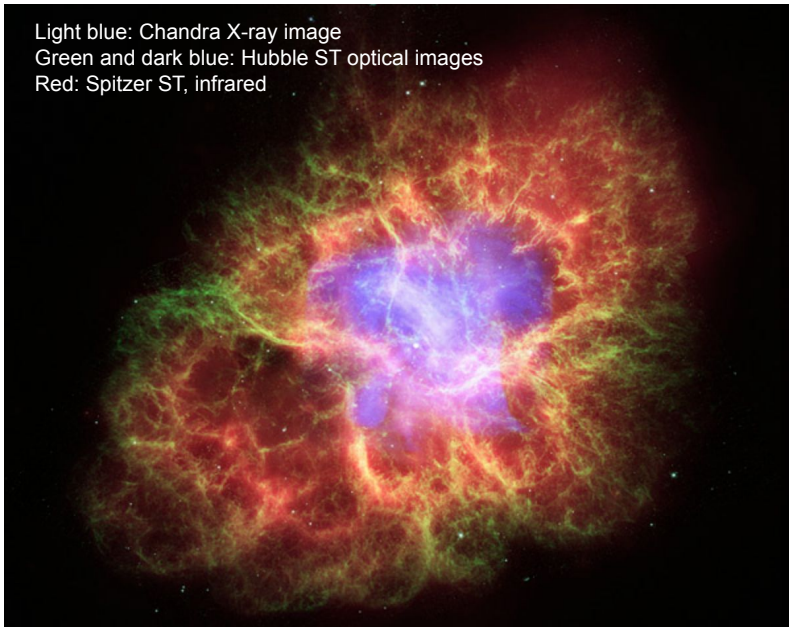
The Crab nebula: a standard candle for polarization CMB experiments

Crab nebula: context

Well observed source in total intensity across the electromagnetic spectrum from radio to X-rays.

Supernova remnant, synchrotron emission powered by the central pulsar through its jet

Most intense polarized source in the microwave sky at angular scales of few arc-minutes



Open questions:

- lack of observations in polarization in a wide range of frequency;
- behaviour of the polarized emission from small to large angular scales.

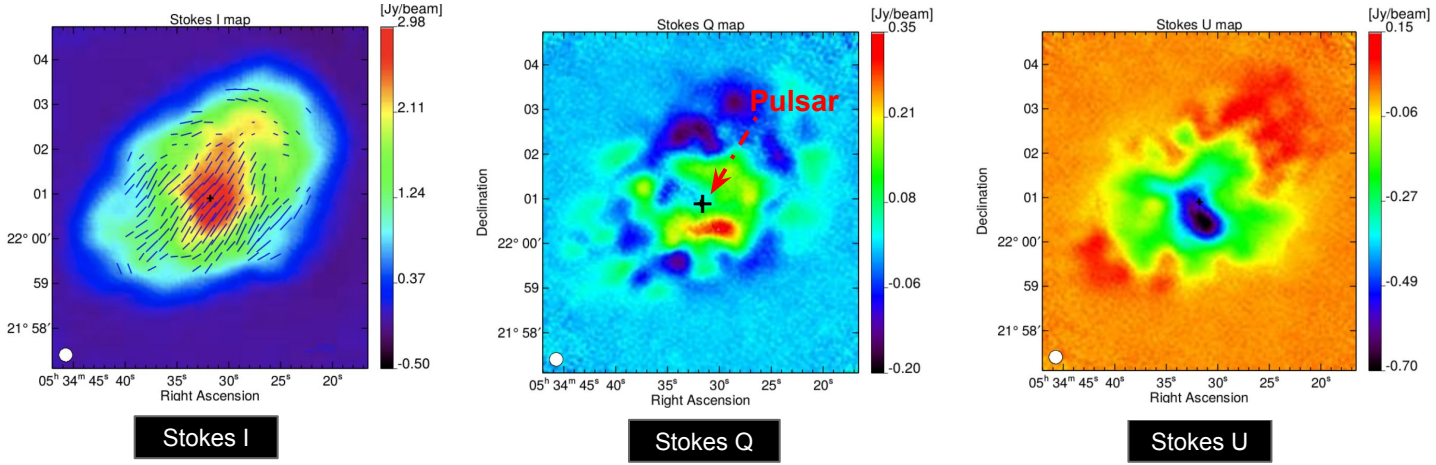
NIKA/NIKA2 polarimeter high resolution observations provide important information in the millimeter wavelengths range

Credit: X-ray: NASA/CXC/ASU/J.Hester et al.;
Optical: NASA/ESA/ASU/J.Hester & A.Loll;
Infrared: NASA/JPL-Caltech/Univ. Minn./R.Gehrz

Crab nebula: NIKA observations at 150 GHz

High angular resolution observations at high frequencies are needed to understand the variation of the polarization properties

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

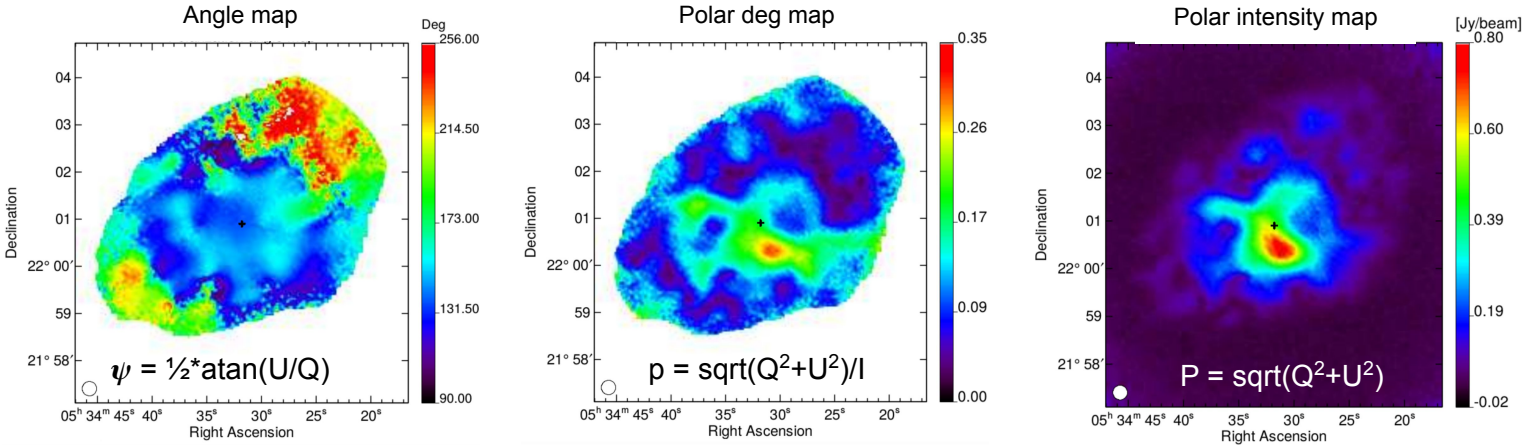


Polarization vectors, indicating both the degree and the orientation, are over-plotted on I map where P > 3σ.

~ 2.7 hours of observation - sky opacity τ: 0.1-0.3

Crab nebula as calibrator for CMB experiments

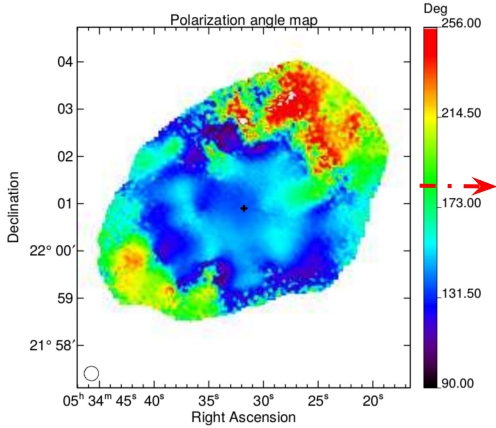
Cosmic microwave background (CMB) polarization experiments have beamwidths comparable to the extension of the source.

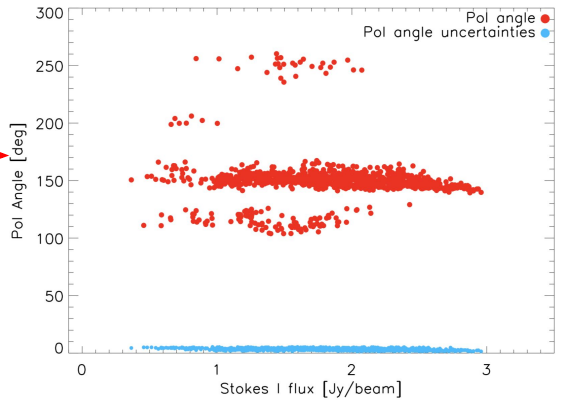


The polarization degree and angle expected to be constant when integrated across the source

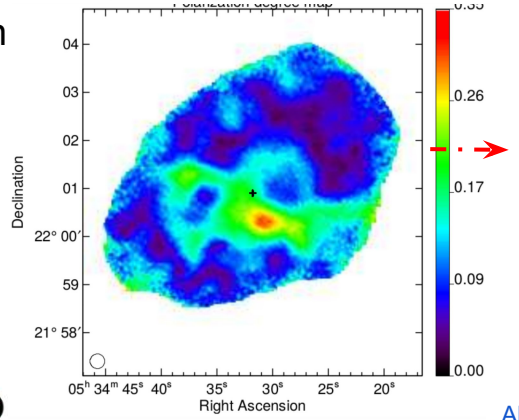
Polarization degree and angle spatial distributions

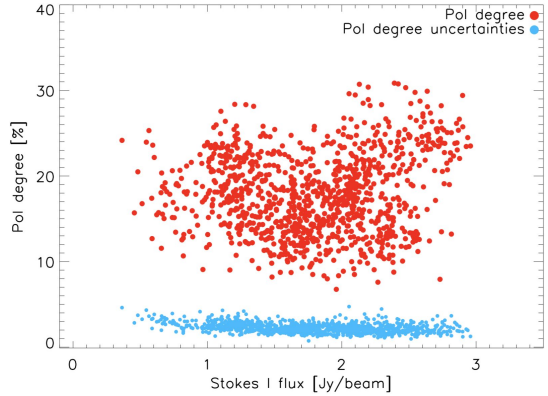
Polarization angle





Polarization degree





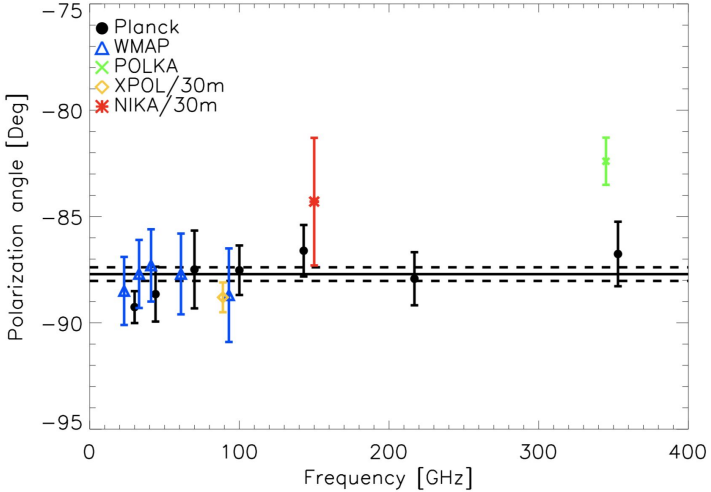
Right panels: The values of ψ, **p** are noise bias corrected as a function of total intensity map (Stokes I). The condition $I_{pol} > 5\sigma_{Ipol}$ is satisfied.

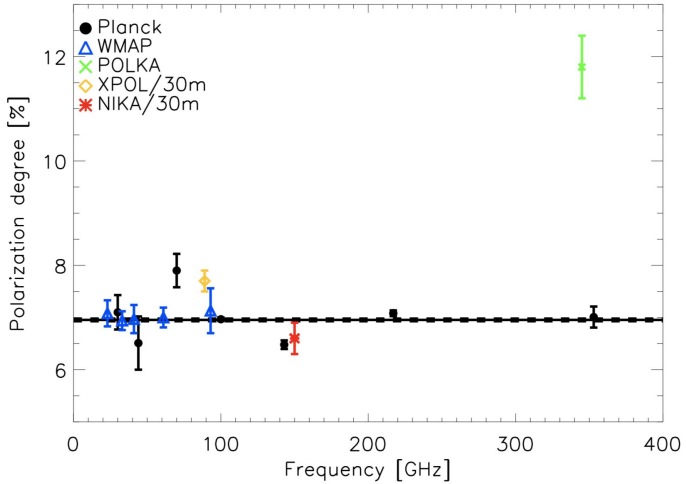
We observe a **relatively constant polarization angle** $140 < \psi_{eq} < 150$.

The distribution of the **polarization degree appears highly dispersed** around a mean value of 20%.

Polarization degree and angle estimates across the source

NIKA and Planck satellite high-frequency values are estimated by using aperture photometry techniques



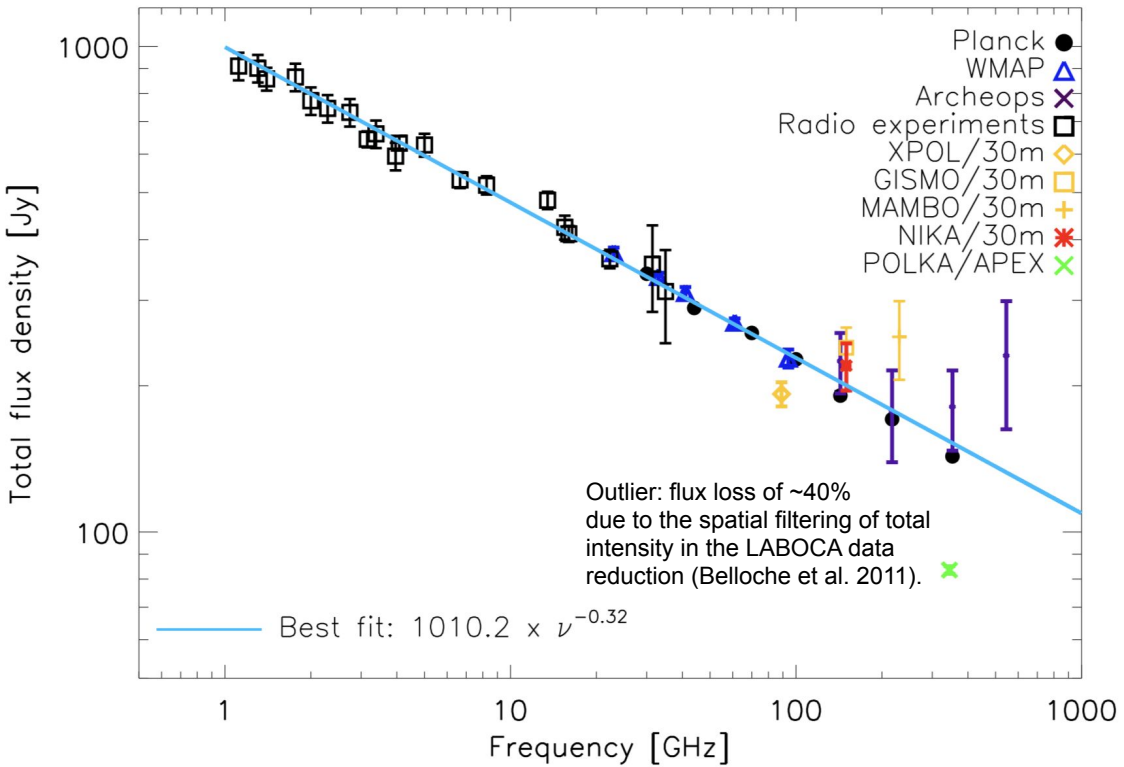


Polarization angle constant at arcmin scales between 23-217 GHz with a value of ψ = -87.7 +- 0.3 deg

Strong case for a constant polarization degree below 217 GHz. Weighted averaged value: p = 6.95 +- 0.03 %

Very important for the calibration of next generation of CMB experiments (see Jonathan's talk)

Spectral energy distribution in total intensity

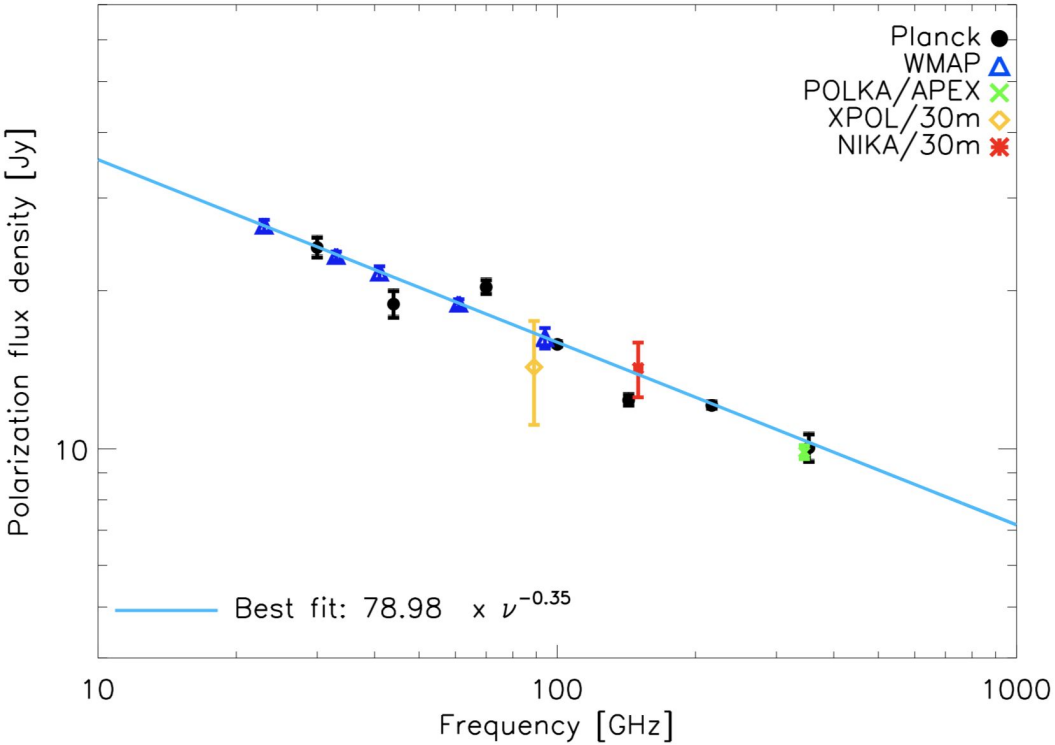


The HFI Planck fluxes estimated using the new 2018 release.

Best-fit model and data corrected for the fading of the source. Assuming the single power law model $\mathbf{I_\nu = A(\nu/1\ GHz)^\beta}$ and by χ^2 minimization we obtain
A = 1010.2 +- 3.8 Jy ;
β= -0.323 +- 0.001

Slightly different from previous studies (see ***Macias et al. 2010, ApJ, 711, 417***) due to the addition of WMAP and Planck data.

Spectral energy distribution in polarization



Assuming the single power law model $I_\nu = A(\nu/1\ \mathrm{GHz})^\beta$ and by χ^2 minimization we obtain

A = 78.98 +- 7.82 Jy ; β_{pol}= -0.347 +- 0.026

Polarization spectral index is consistent with the total power index.

Synchrotron radiation is the fundamental mechanism that drives the polarization emission of the Crab nebula.

Conclusions

- NIKA Polarimeter has been used as test bench for NIKA2-Pol during 2014-2015
- **Calibration and performance** of the NIKA-polarimeter are reported in *Ritacco, Ponthieu, Catalano, et al. 2017, A&A, 599, A34*
- **Orion Molecular Cloud OMC1** revealed a very well organized magnetic field topology along the filament
- NIKA **Crab nebula 150 polarization results** together with WMAP and Planck (release 2018) satellites observations are used to trace for the **first time the spectral energy distribution in polarization**
  - **strong case for a constant polarization angle in the mm range (23-217 GHz)**
    See *Jonathan's talk* for the implication on the measure of the CMB B-modes.