CRAB nebula preliminary results obtained with the NIKA2 polarimeter

Alessia Ritacco (IAS-LPENS)

+ J. Aumont
+ NIKA2 Polar team:
  N. Ponthieu, J. Macías-Pérez, A. Maury, P. André, F.-X. Désert, H. Ajeddig, S. Leclercq, I. Myserlis

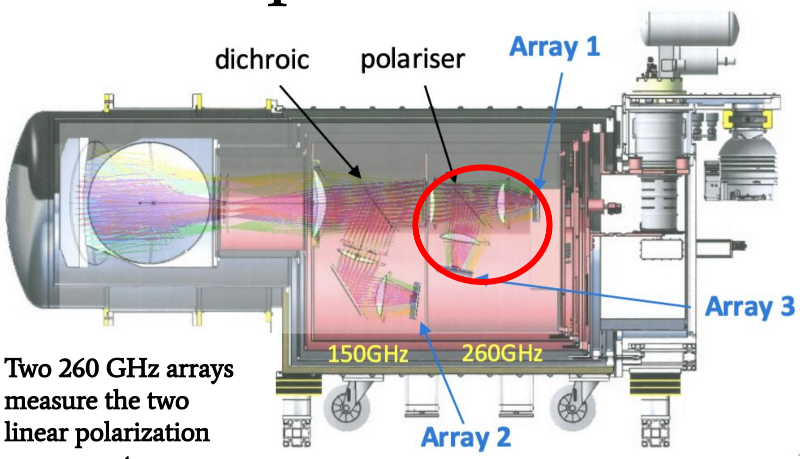
On behalf of the NIKA2 collaboration

Image Credit: NASA, ESA, NRAO/AUI/NSF and G. Dubner (University of Buenos Aires)

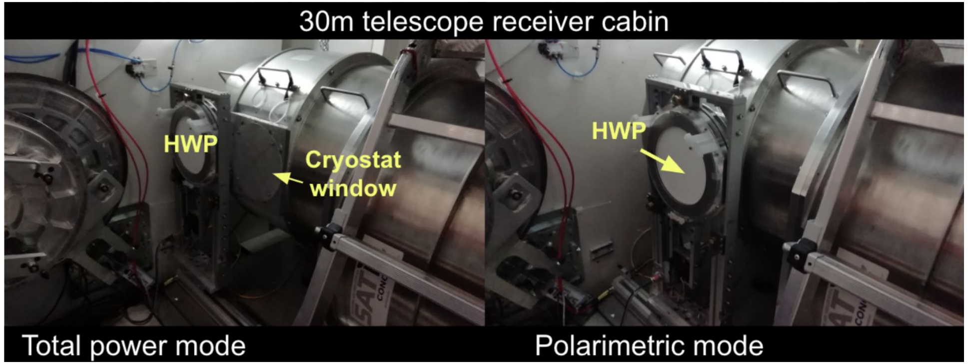
Outline

- Introduction to NIKA2 polarization detection strategy
- Previous observations on Crab nebula
- NIKA2 observations
- A sky calibrator for CMB experiments
- Conclusions

NIKA2 polarimeter on the sky

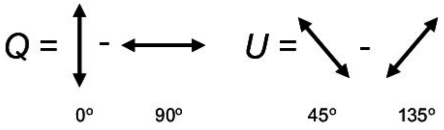


Two 260 GHz arrays measure the two linear polarization components



Ritacco+2016, 2017, 2020
Ajeddig+2020

Stokes parameters



Ideally:

$$S = I + Q\cos(4\omega_t + 2\psi_t) + U\sin(4\omega_t + 2\psi_t)$$

ω_t: angle HWP wrt polarization reference frame

ψ_t: polarization angle projected on the sky reference frame

→ **More complicated than this, see Hamza's talk**

Crab nebula previous observations

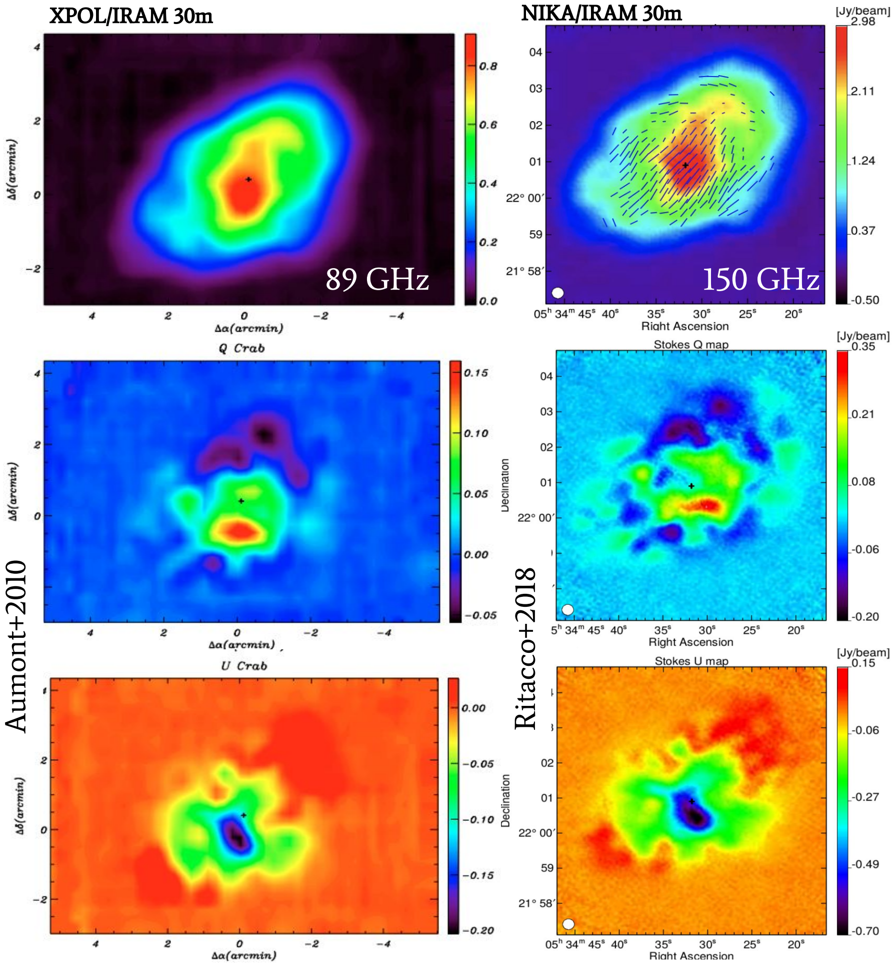
It is a **plerion-type supernova remnant,** observed from radio to X-rays

It consists of a pulsar, the synchrotron nebula, a bright expanding shell of thermal gas, and a larger very faint freely expanding supernova remnant (Hester 2008)

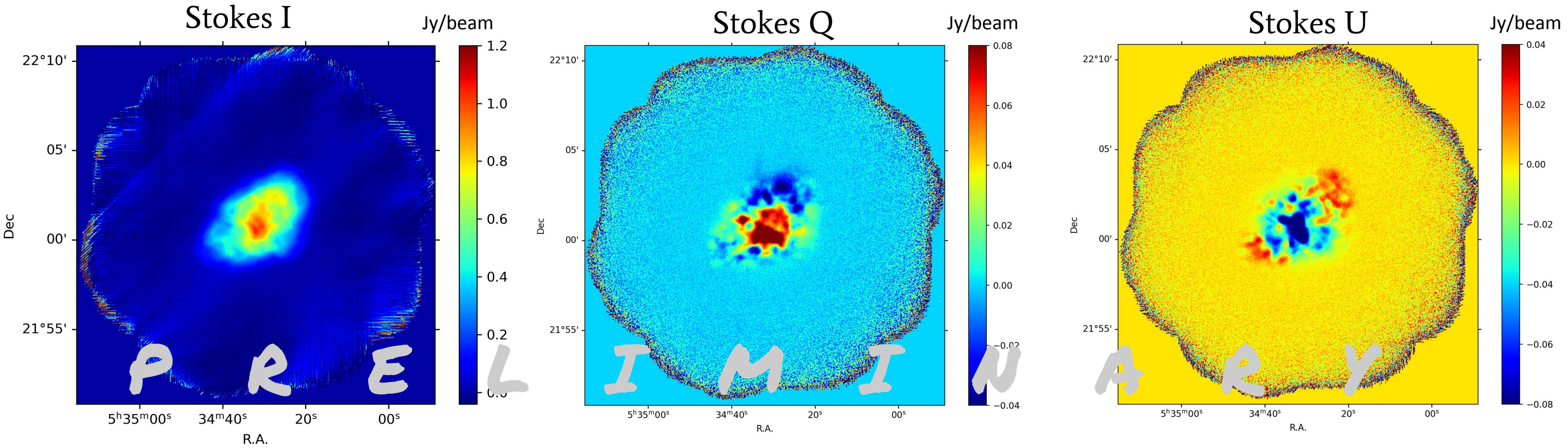
Most **intense polarized source** in the microwave sky, at angular scales of few arcminutes

Highly polarized **synchrotron emission**

It is relatively **isolated in the microwave sky** within 1 degree scale



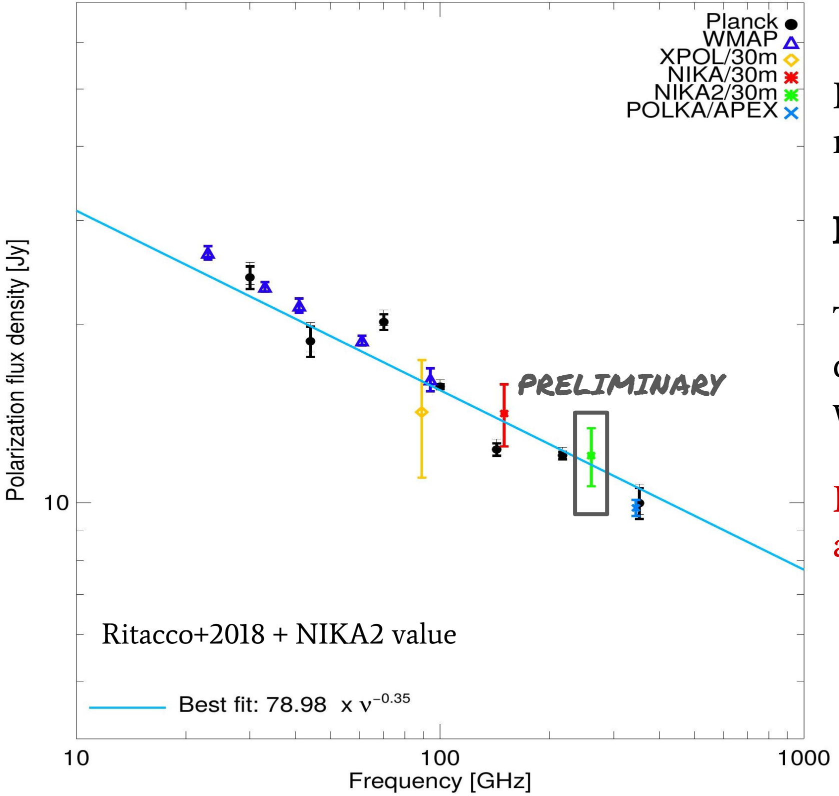
First high angular resolution detection at 260 GHz



Observations obtained from the commissioning campaign of November 2020

- Stokes I large scales recovering under improvement
- Stokes Q and U maps well reconstructed

Spectral density distribution (SED) in polarization



Polarized light flux estimated by using the most reliable commissioning campaign (Nov. 2020)

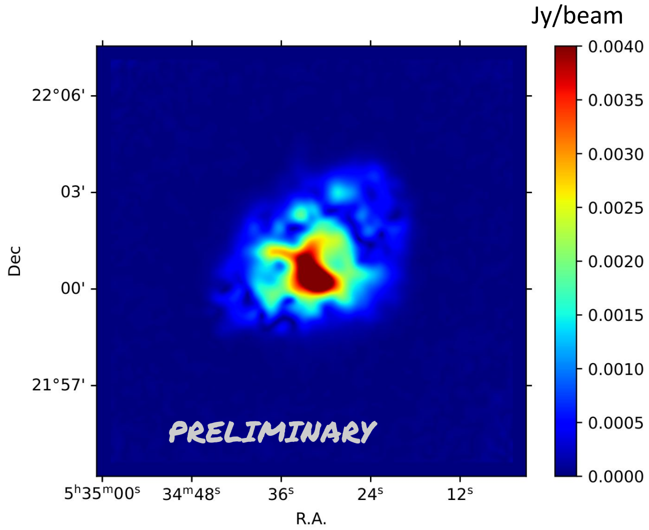
P = 13.22 ± 0.15 (dev. standard) **± 1.2** (10% calibr. error)

This measurement confirms the expected SED obtained by using Planck low resolution observations within 200-300 GHz.

In polarization there is no loss of large angular scales and the whole intensity is recovered.

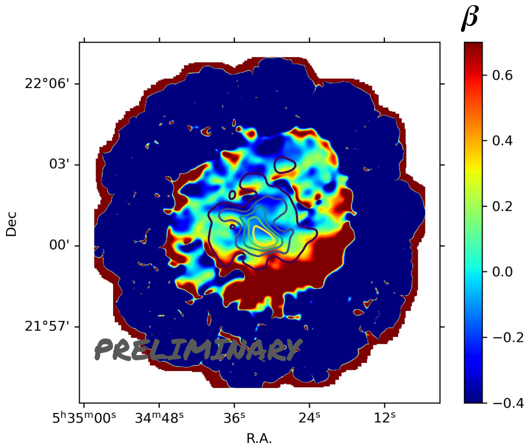
Crab nebula polarization distribution

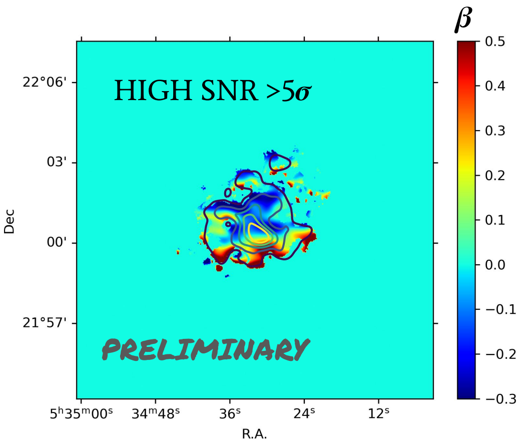
Polarization intensity @ 1mm



Spectral index map 1mm/2mm

$\beta = \log(I_{\nu 1}/I_{\nu 2})/\log(\nu 1/\nu 2)$





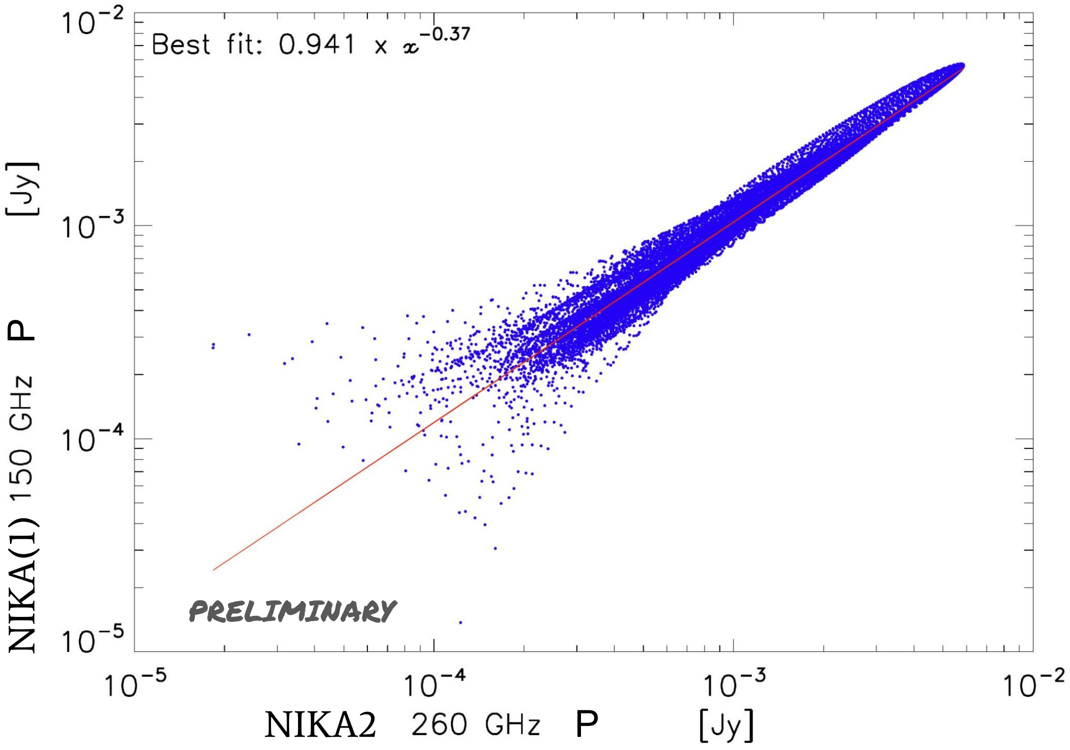
First reconstruction of the **spectral index** spatial distribution at mm wavelengths

Spectral index

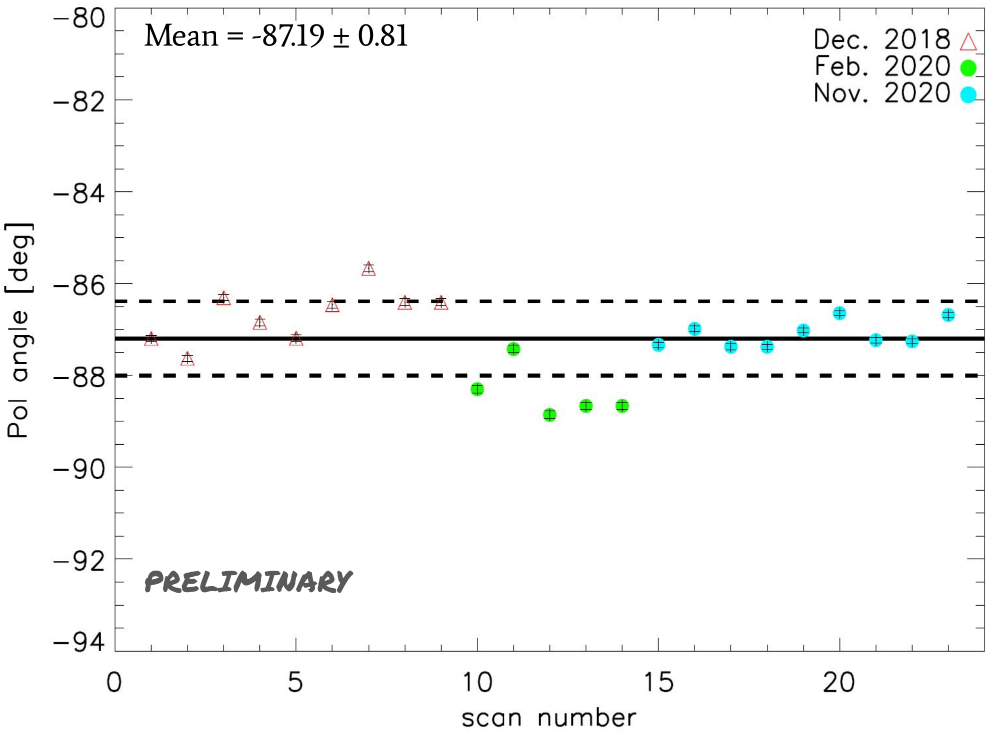
From the correlation between the map at 150 GHz (NIKA1) and 260 GHz (NIKA2) we can derive the spectral index.

Integrating over the whole source we find:
β = -0.372 ± 0.001

Consistent with SED estimation with all experiments (Ritacco+2018)



Polarization angle stability (commissioning data)



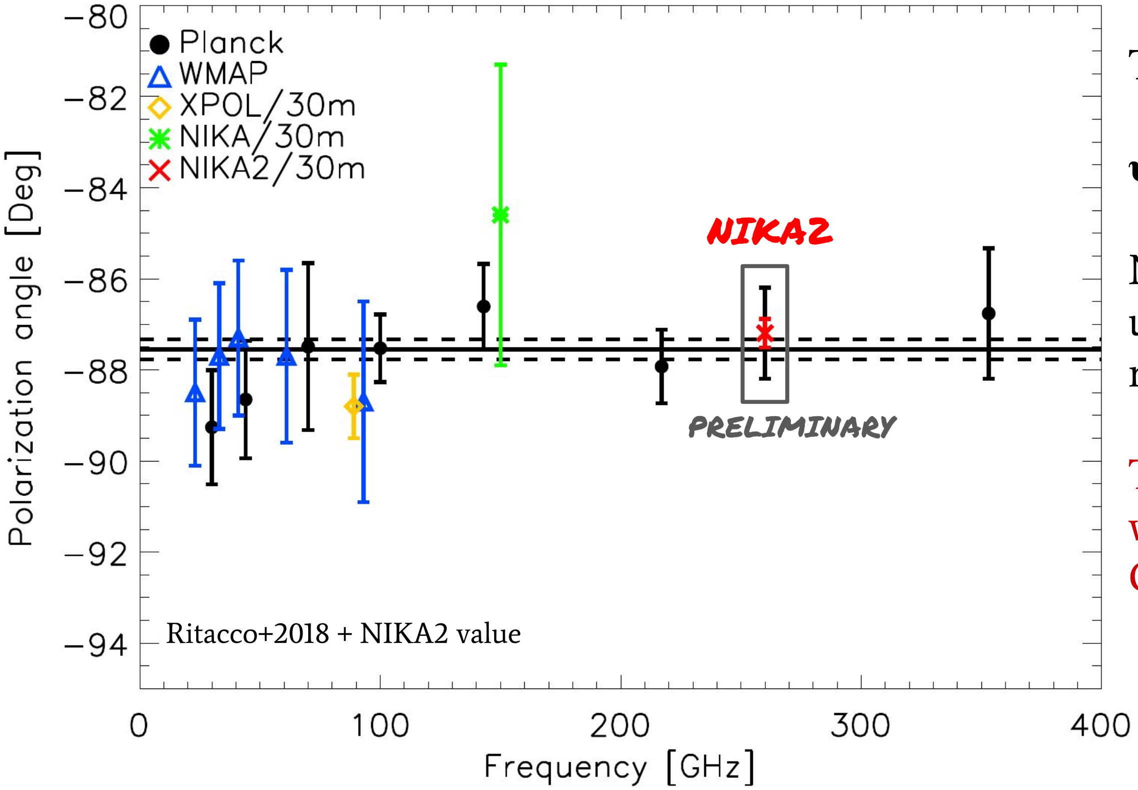
An offset of 5.6 deg (TBC) has been applied as estimated by commissioning cross calibration analysis

- **Dec. 2018** and **Feb. 2020** show instability but consistent within 2σ

- **Nov. 2020** campaign data more stable with mean value of **-87.23 ± 0.29 deg (computed as dispersion of the angles)**

For further science analysis we consider an uncertainty of 0.29 degrees as NIKA2 polarization angle total uncertainty.

Polarization angle stability within 23-353 GHz



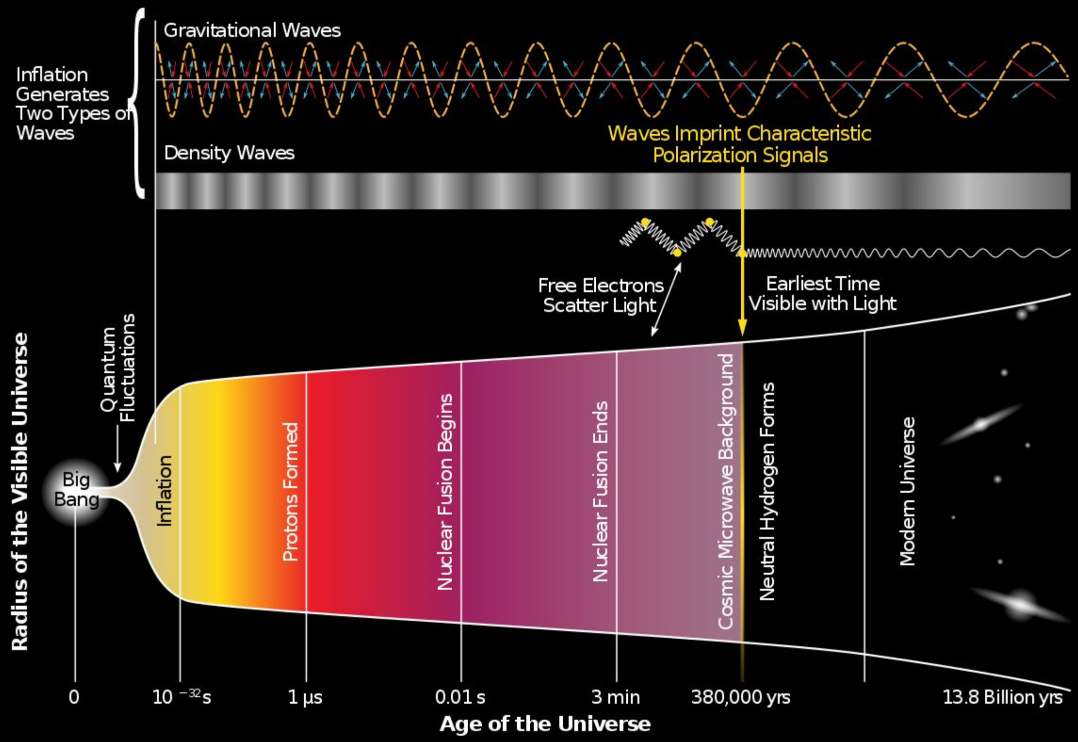
Total weighted polarization angle

ψ = -87.55 ± 0.22 deg

NIKA2 polarization angle removes the uncertainty on the polarization angle reconstruction at higher frequencies.

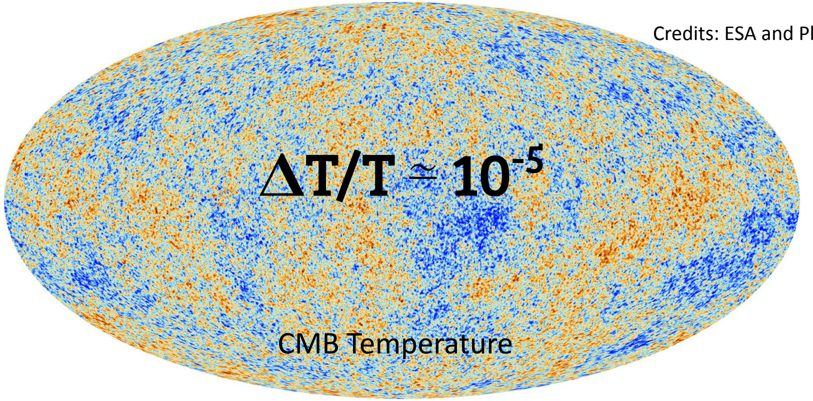
The stability of the polarization angle with frequency is the key to use the Crab nebula as a sky calibrator.

History of the Universe

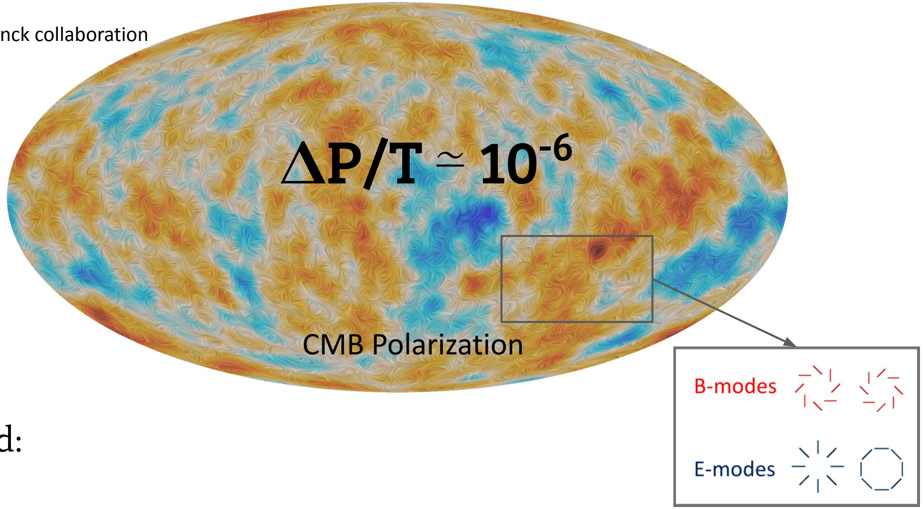


Probing the primordial Universe

Planck satellite provided the best full-sky maps of Cosmic Microwave Background (CMB) in both temperature and polarization.



Credits: ESA and Planck collaboration



CMB polarization patterns can be expressed:
E-modes, of even parity, and the **B-modes**.

B-modes can only be produced by primordial gravitational waves in the early universe.

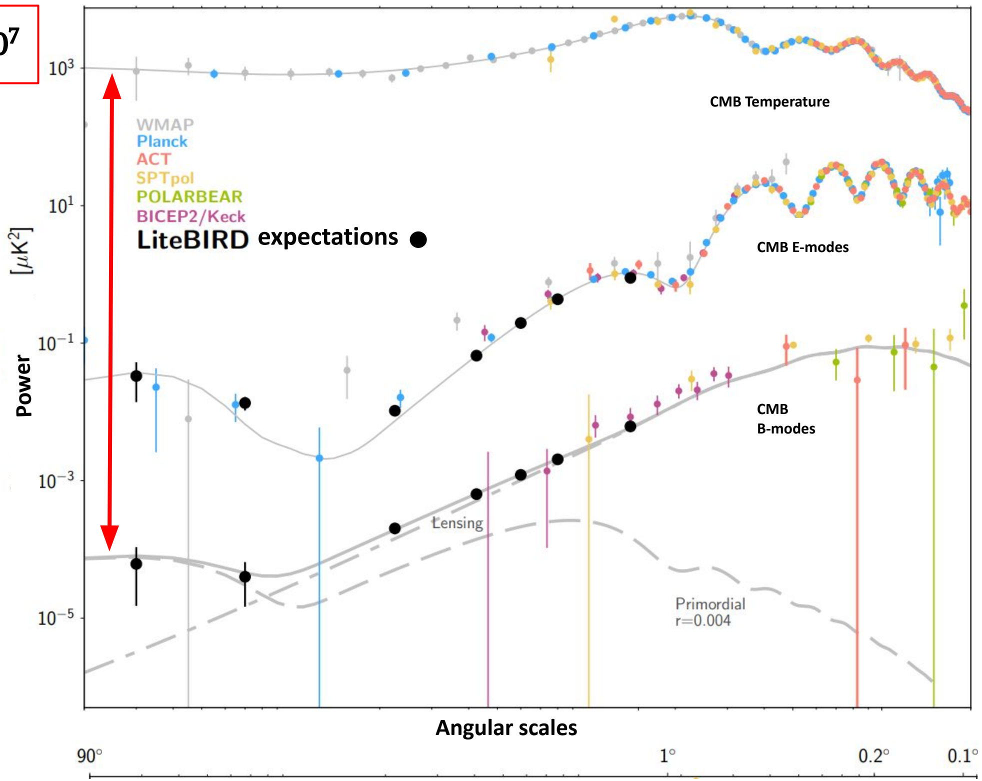
If detected, will probe the existence of the inflation and give us access to a physics beyond the current Standard Model.

Constraints on the CMB B-modes detection

Sensitivity gain 10^7

B-modes
r parameter ~ 10^{-3}

Hazumi+2021



LiteBIRD

JAXA Space mission

Expected launch: 2029

Polarization system as NIKA2

Frequency range:
40-402 GHz

Current challenges

- Big arrays of high sensitive detectors to increase SNR
- Instrumental systematic effects control
- Accurate component separation of foreground emissions
- Absolute calibration of the polarization angle

Absolute polarization angle challenge

A miscalibration of $\Delta\psi_{Gal}$ will lead to a mixing of E and B modes. In the CMB and because $C_l^{EE} >> C_l^{BB}$, this is often referred to as an "E to B leakage" and reads

$$\tilde{C}_\ell^{BB} = C_\ell^{BB} \cos^2 2\Delta\psi_{Gal} + C_\ell^{EE} \sin^2 2\Delta\psi_{Gal}$$

$$\Delta C_\ell^{BB} \simeq (2\Delta\psi_{Gal})^2 C_\ell^{EE}$$

Spurious bias component

Ground calibration: very good but **need to be validated during operations**

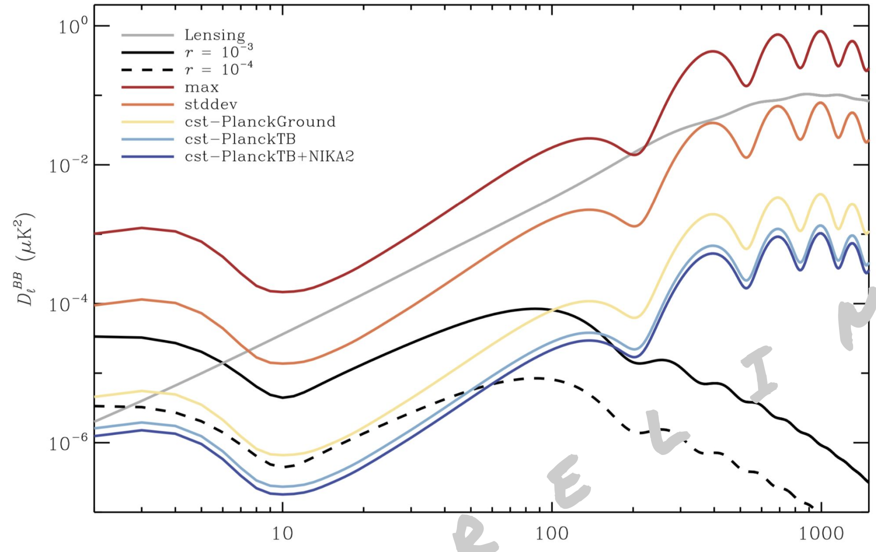
External calibration source: good accuracy but **never done before, instrumental limits ?!**

Self-calibration: no scientific signal from TB and EB → only instrumental **Losing constraints on fundamental phenomena**

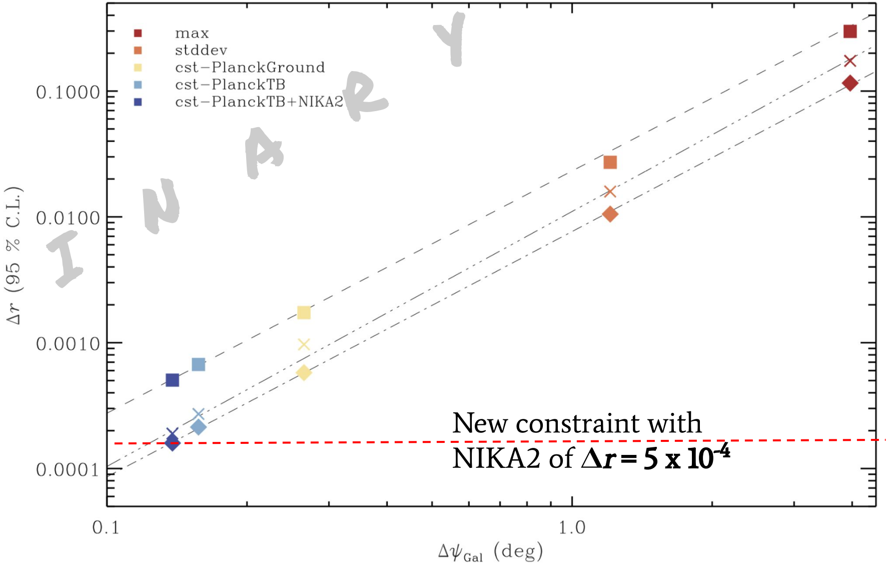
Sky calibration: **frequency dependence, time variability** → Best option: **CRAB NEBULA**

Constraints on CMB B-modes detection

Power spectrum bias from E–B mixing due to miscalibration



Computing limit of ***r*** parameter detection



Accounting for NIKA2 polarization angle

NIKA2 polarization angle stability improves the uncertainty Δr by 30% w.r.t previous studies (Aumont+2020)

PROMISING FOR CMB SCIENCE

Conclusions and perspectives

- First analysis on NIKA2 Crab nebula polarization data looks promising for future scientific extended sources
- NIKA2 has shown good stability in terms of polarization reconstruction

Crab nebula as calibrator for CMB experiments:

- NIKA2 gives so far the best stability with time of the polarization angle but strong assumption on uncertainty
- Investigation on the instrumental absolute offset calibration angle