

High resolution observations of the Sunyaev-Zel'dovich effect with NIKA

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<http://ipag.osug.fr/nika2>

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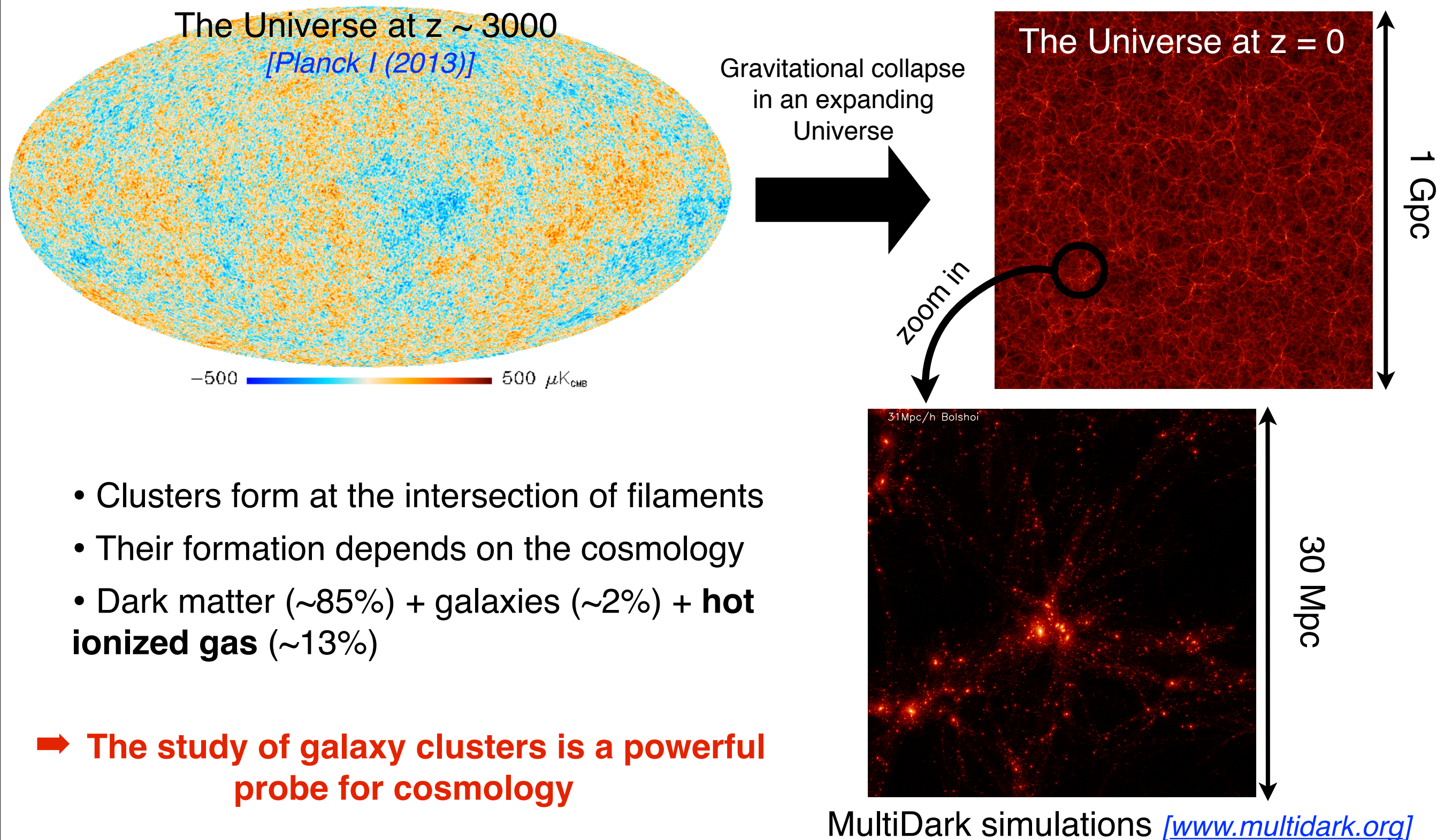


Outline

1. The **Sunyaev-Zel'Dovich** effect as a probe for large scale structures
2. **NIKA**: a **KID**-based camera at the IRAM 30m telescope
3. From raw data **to maps**
4. First Sunyaev-Zel'Dovich **results** with the *NIKA* prototype

The Sunyaev-Zel'Dovich effect as a probe for large scale structures

From primordial fluctuations to galaxy clusters



Galaxy clusters observables

Optical:

- 100-1000 galaxies per cluster
- **Lensing mass** (dark matter)
- $M_{\text{tot}} \sim 10^{14} M_{\odot}$

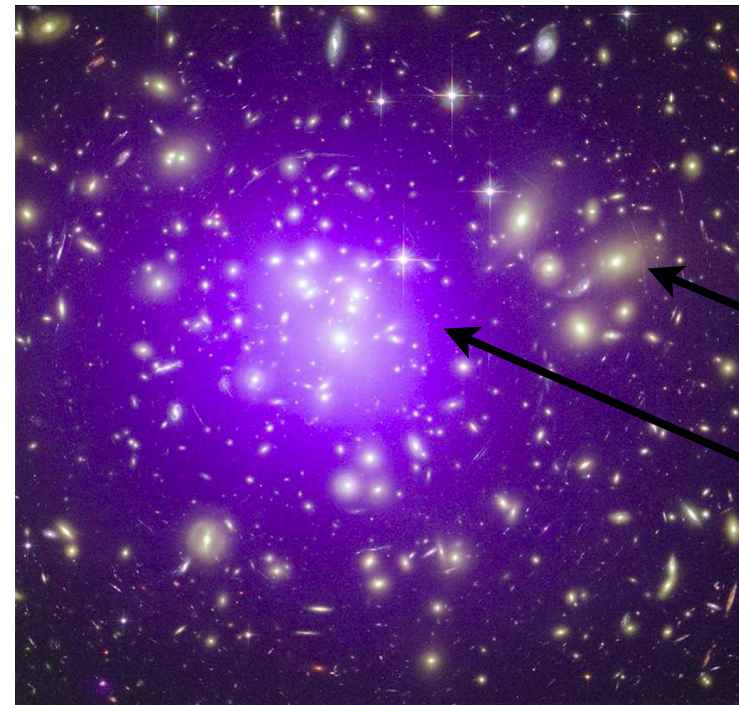
X-ray:

- **Gas density** from bremsstrahlung
- **Temperature** from spectroscopy
- $T_g \sim 10^8$ K
- **Mass** from **hydrostatic** equilibrium

Radio:

- Non-thermal emission

➔ **Detailed physical understanding from multi-wavelength approach**

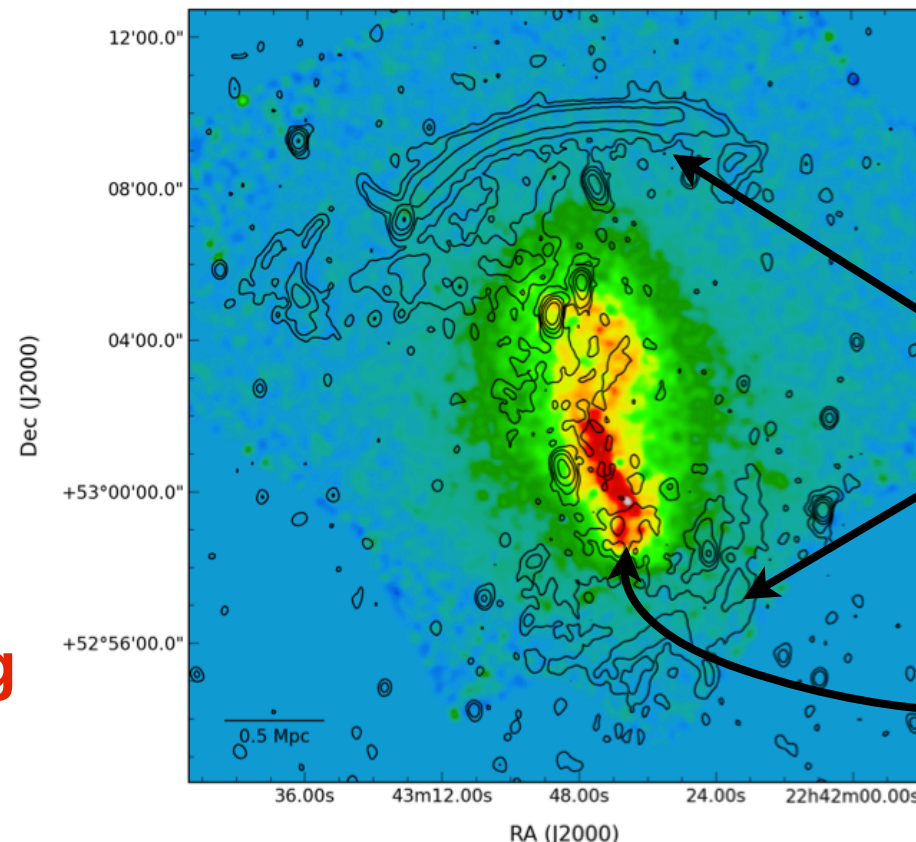


Abell 1689

[A. Kravtsov & S. Borgani (2012)]

Optical

X-ray



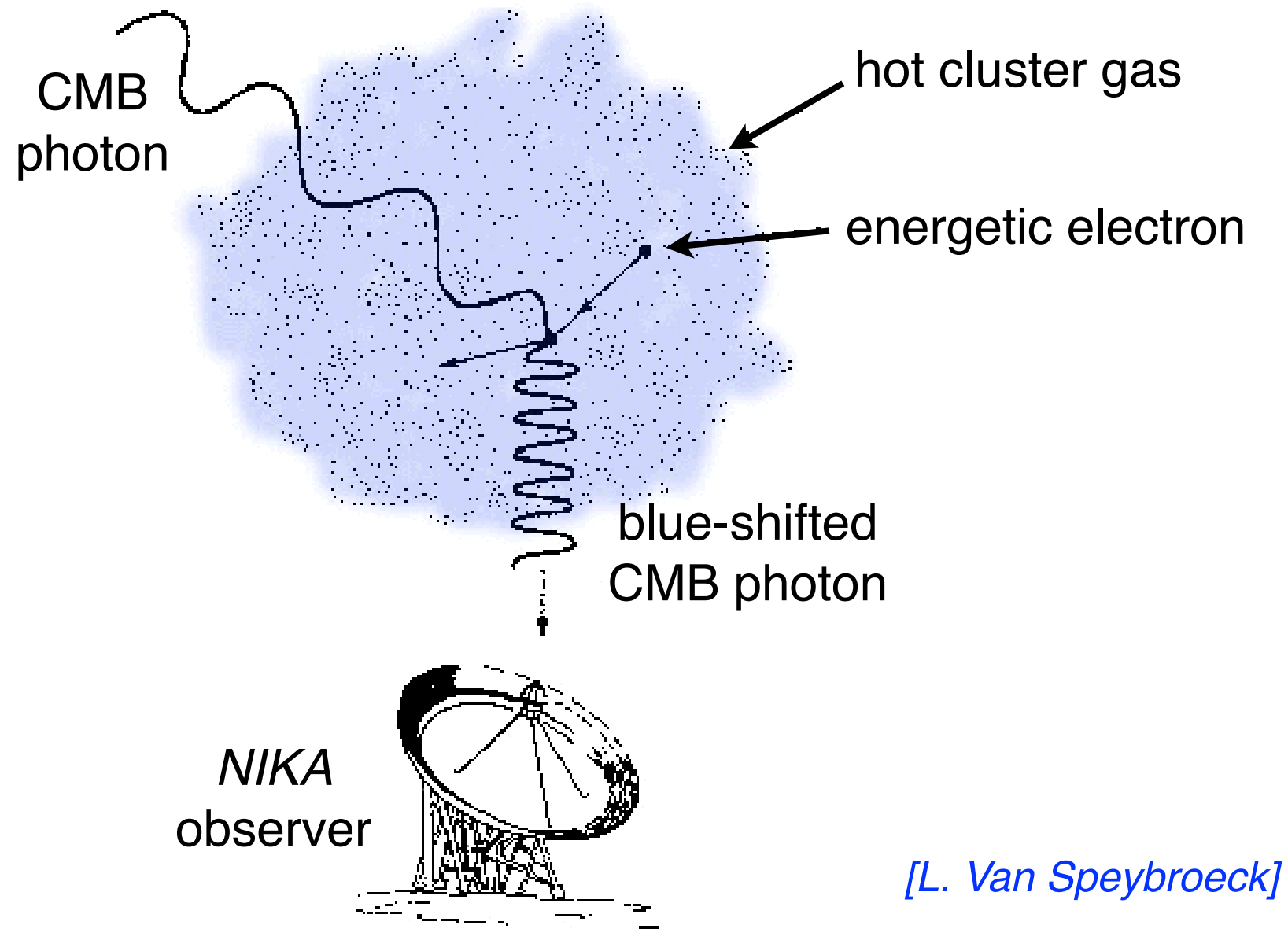
CIZA J2242.8+5301

[G. Ogrean (2014)]

1.4 GHz double radio relic

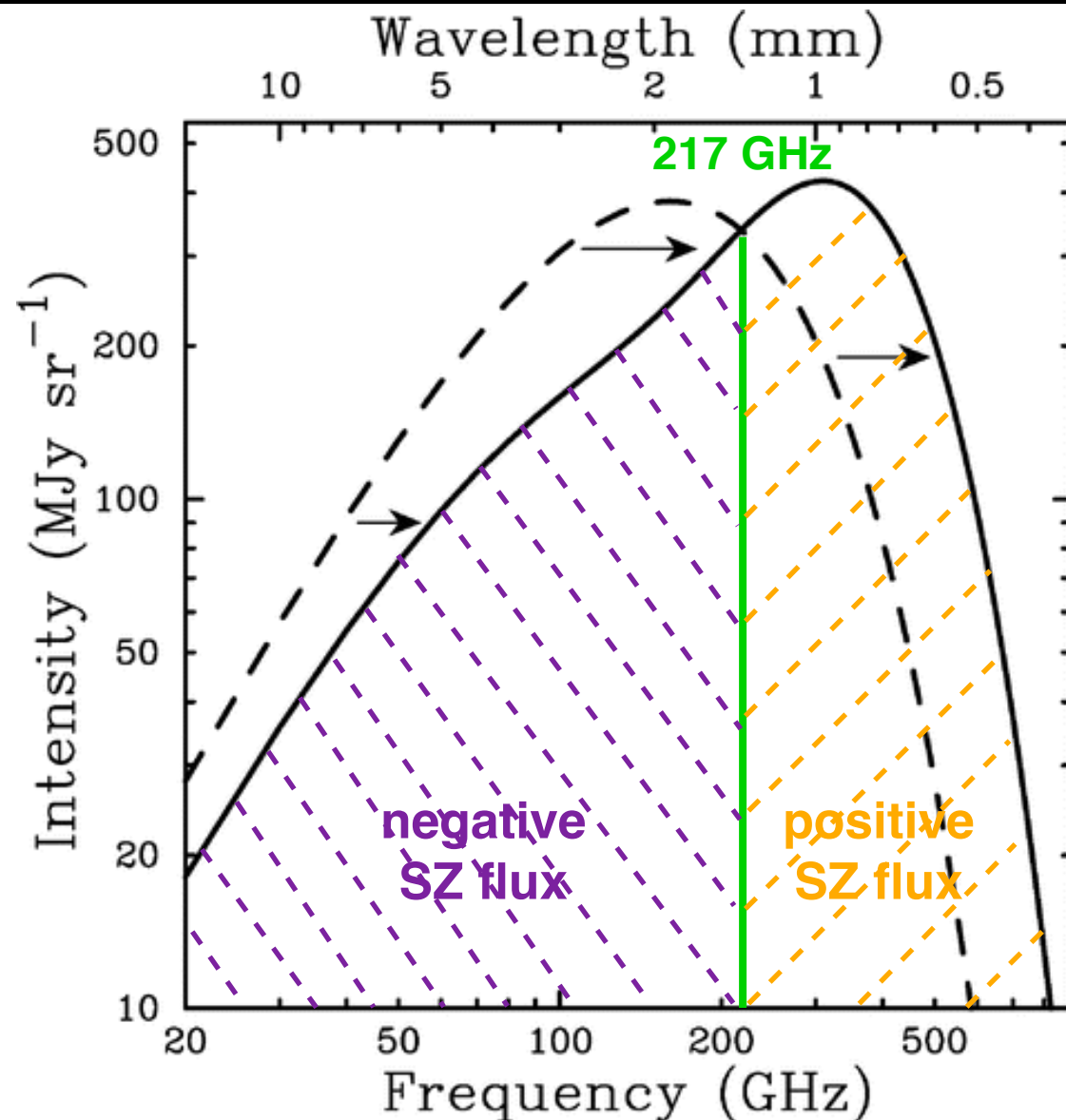
Chandra X-ray (color)

Another observable: the Sunyaev-Zel'Dovich effect (SZ)



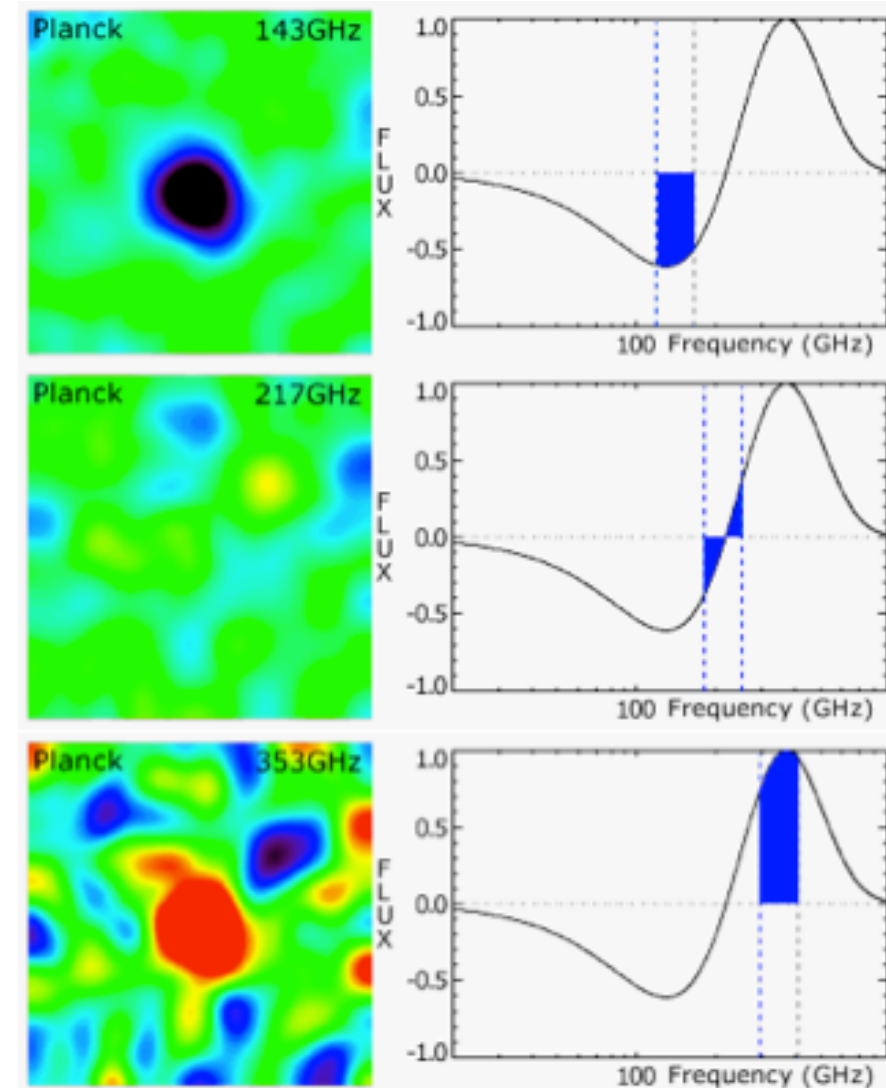
➡ The SZ effect is the inverse Compton scattering of CMB photons on hot electrons in clusters

Another observable: the Sunyaev-Zel'Dovich effect (SZ)



[J. E. Carlstrom et al. (2002)]

- SZ = CMB spectral distortion
- No redshift dependence



[ESA HFI/LFI consortia]

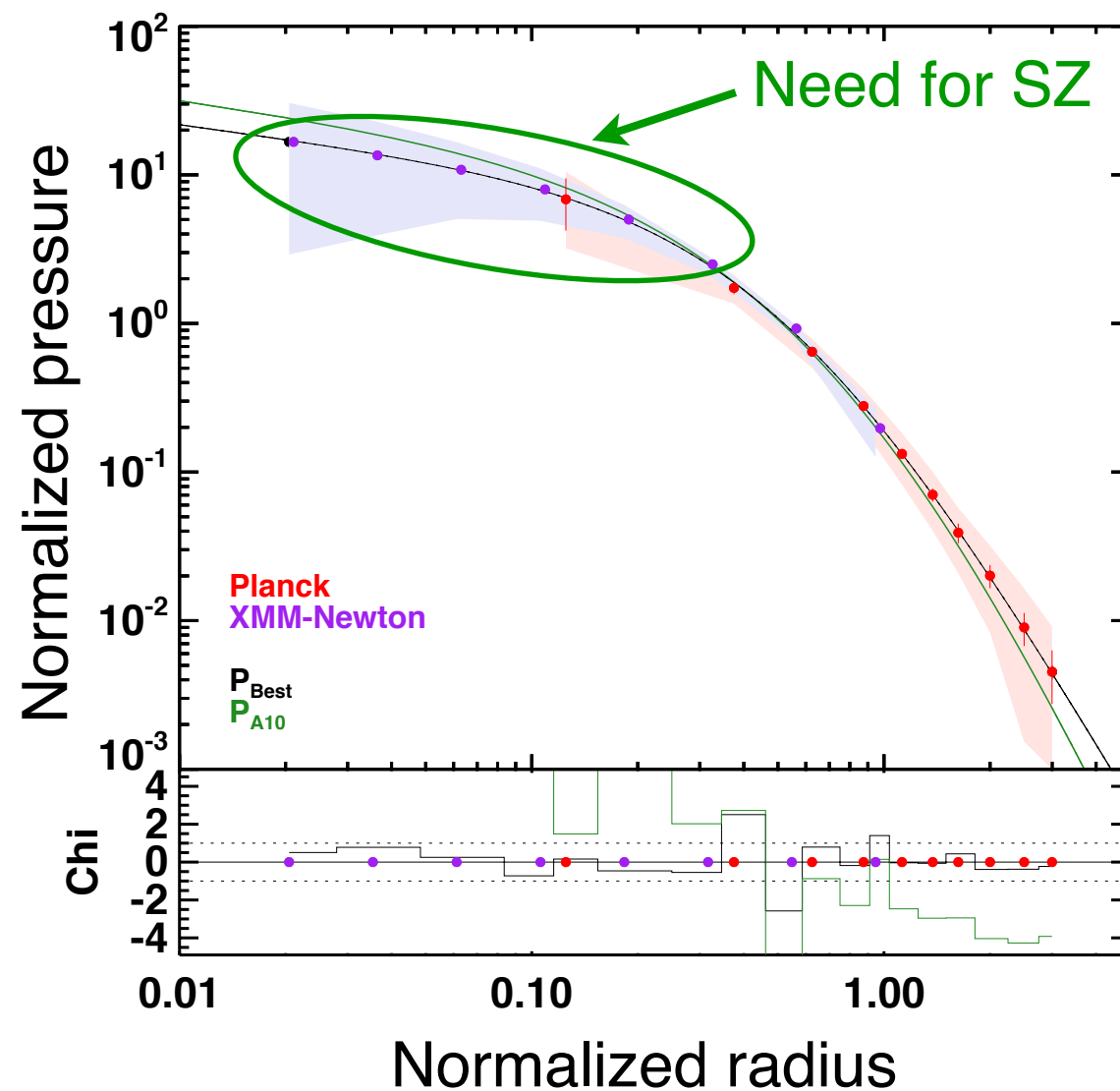
$$SZ_{\text{flux}} \propto \int P_e dl$$

➡ The SZ effect probes the pressure in clusters

SZ flux - mass scaling relation

$SZ_{\text{flux}} \rightarrow \text{thermal pressure} \rightarrow \text{thermal energy} \rightarrow \text{hydrostatic mass}$

- SZ flux - **total mass** calibration required for cosmology [*Planck XXIX (2013)*]
- **Bias** due to deviations from equilibrium to be handled
- Need to look at clusters in **details**
- Need to look at **high z** clusters



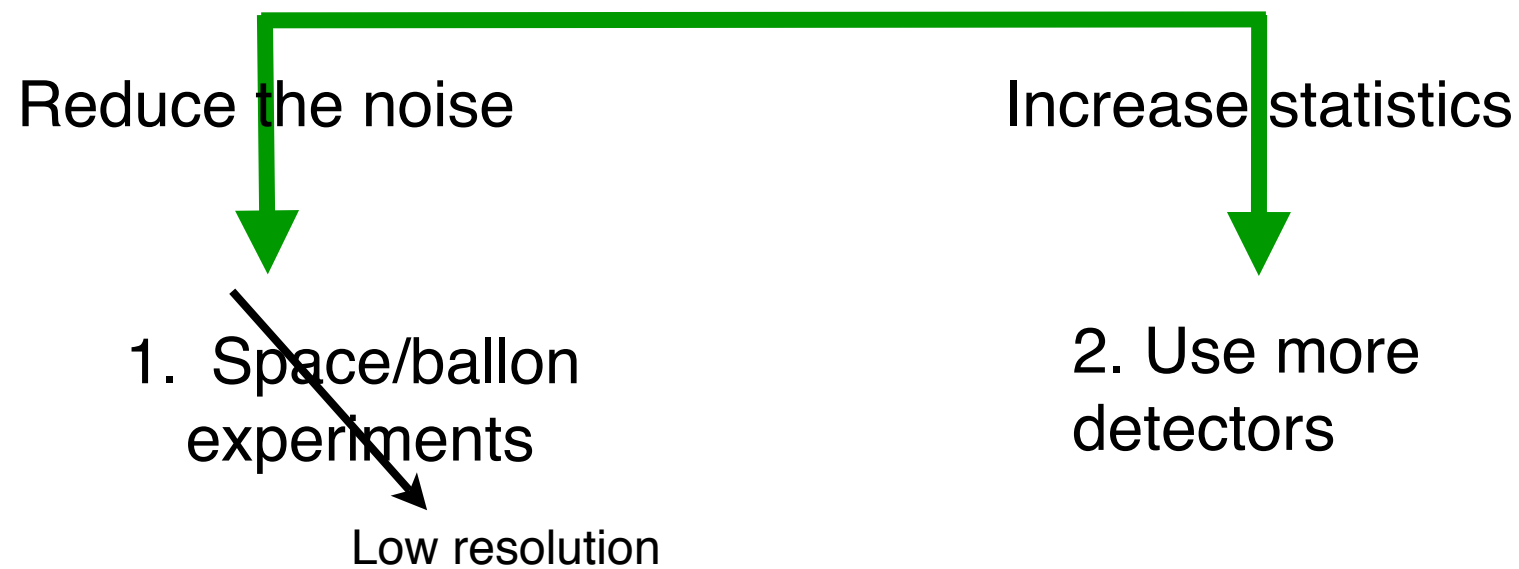
[*Planck intermediate V (2013)*]

➡ High resolution SZ observations are needed (+ multi-wavelength)

NIKA: a KID-based
camera at the IRAM
30m telescope

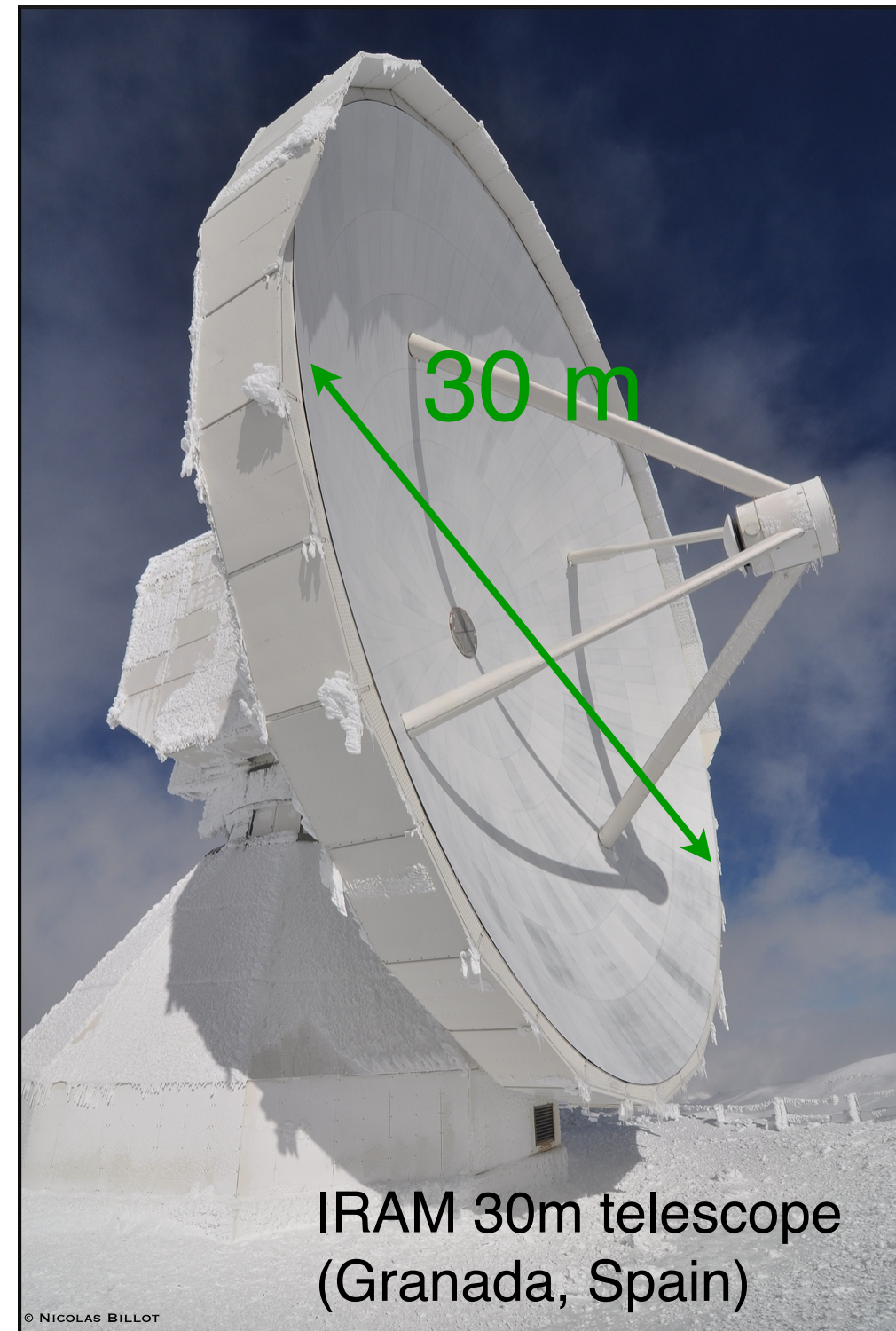
Towards the next generation of mm wavelength instruments

How to improve high resolution SZ observations?



Kinetic Inductance Detectors (KIDs) offer an alternative to bolometers for large array instruments

The New IRAM KID Arrays (NIKA):
➔ Developed in Grenoble (Neel+IRAM+LPSC+IPAG)

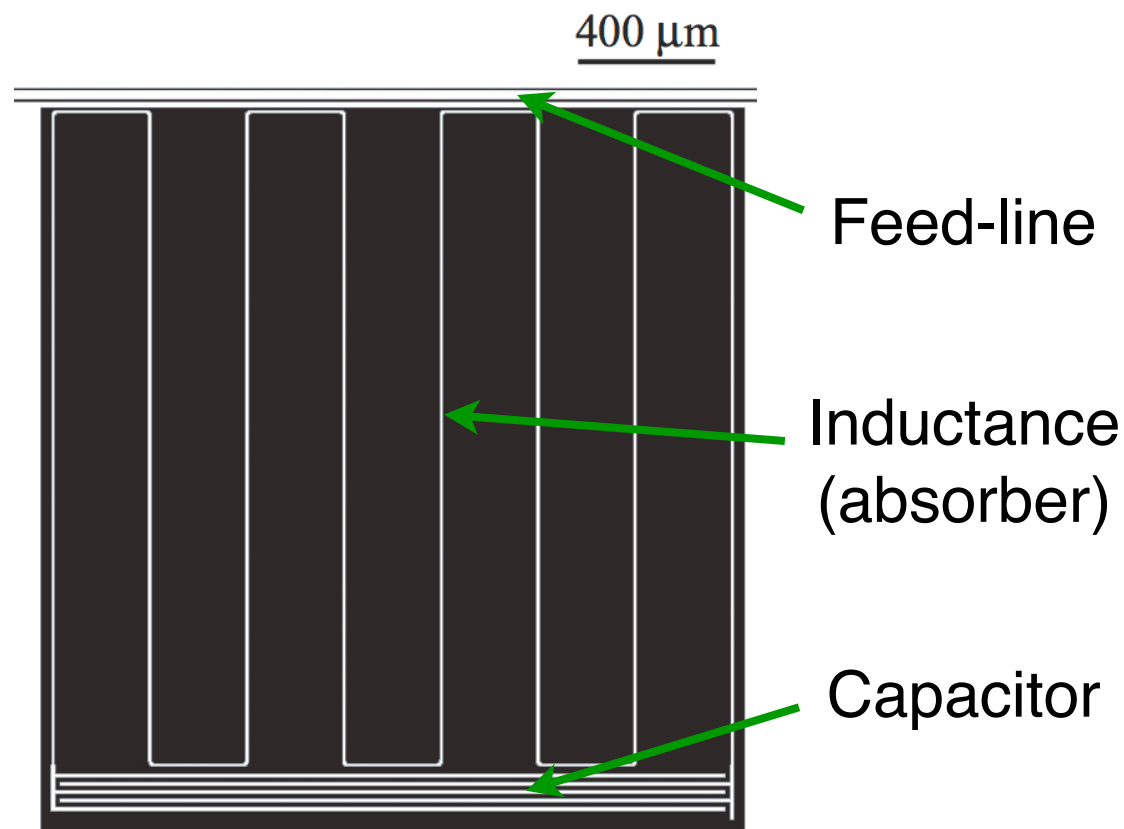


[N. Billot]

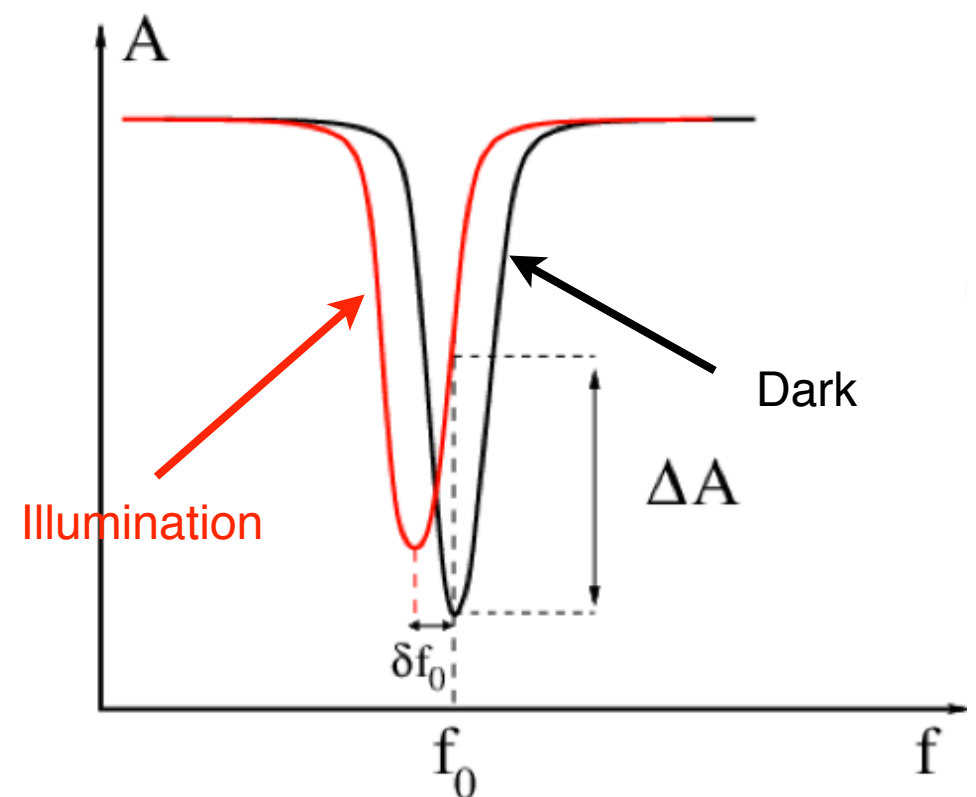
The Kinetic Inductance Detectors (KIDs)

- KIDs are high-Q superconducting RLC **resonators**
- Absorbed photons change the kinetic inductance by breaking **Cooper pairs** (charge carriers)

$$\delta f_0 \propto \delta L_k \propto P_{opt}$$



Single KID (aluminum on silicon wafer)
[A. Monfardini et al. (2010)]



Transfer function of a single KID

➡ KIDs probe optical power via the shift of their resonance frequencies

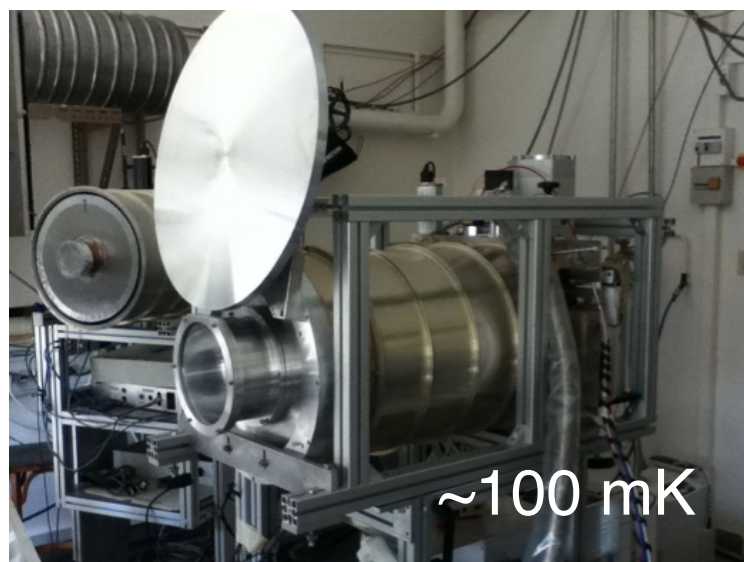
The NIKA and NIKA2 projects

The IRAM 30m telescope:



- 12'' resolution at 260 GHz
- 17'' resolution at 150 GHz

The dilution cryostat:

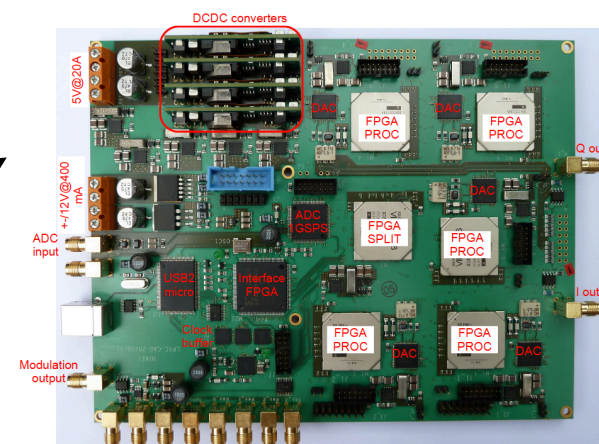


The dedicated optics:

- 6.5' (1.8') field of view
- Beam splitting in two bands
- Filters + mirrors + lenses

The dedicated NIKEL readout electronics

[O. Bourrion et al. (2012)]



made in LPSC

The two KID arrays:

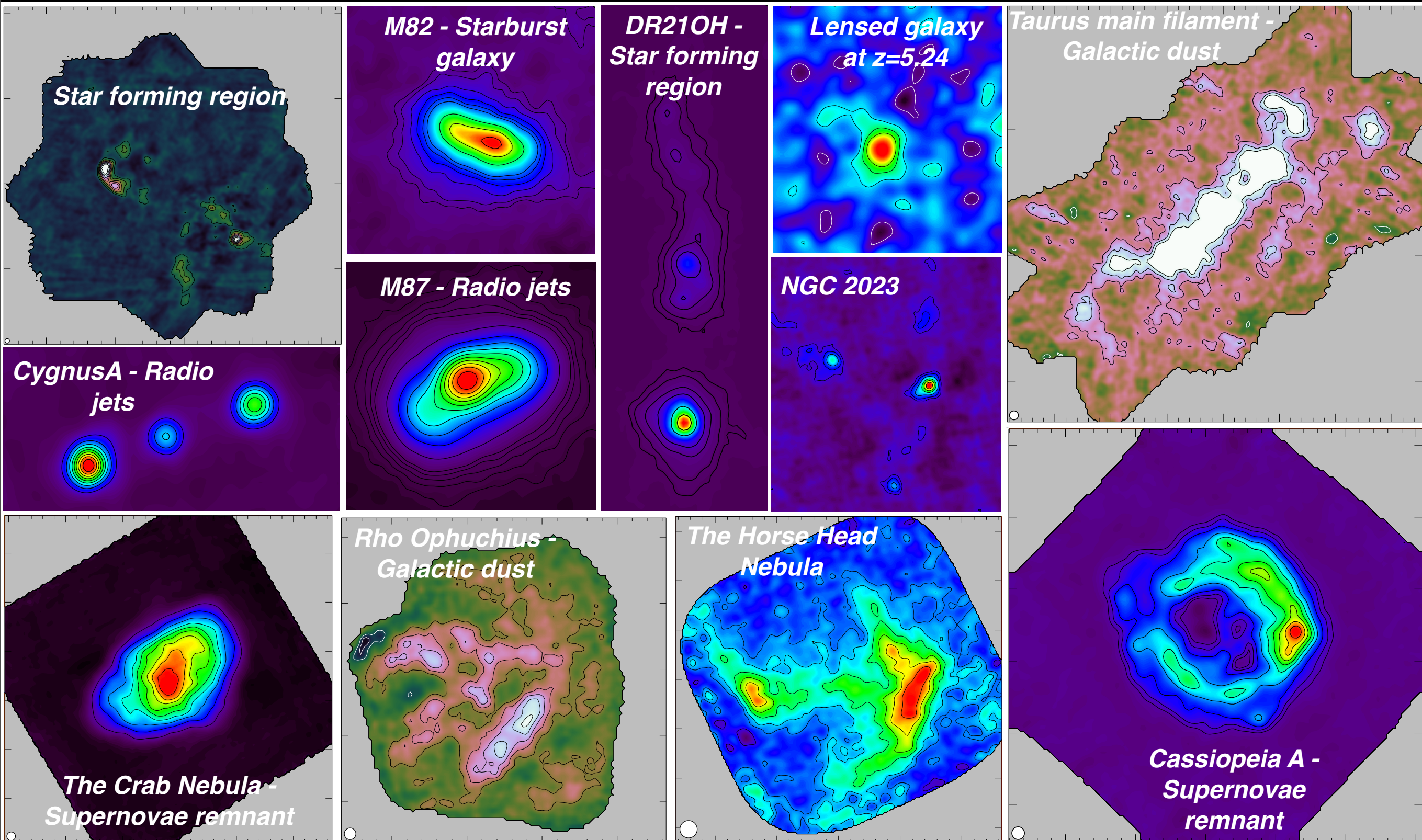
- 2x2000 (224) KIDs at 260 GHz
- 1000 (132) KIDs at 150 GHz
- State-of-the-art sensitivity

NIKA2
(NIKA prototype)

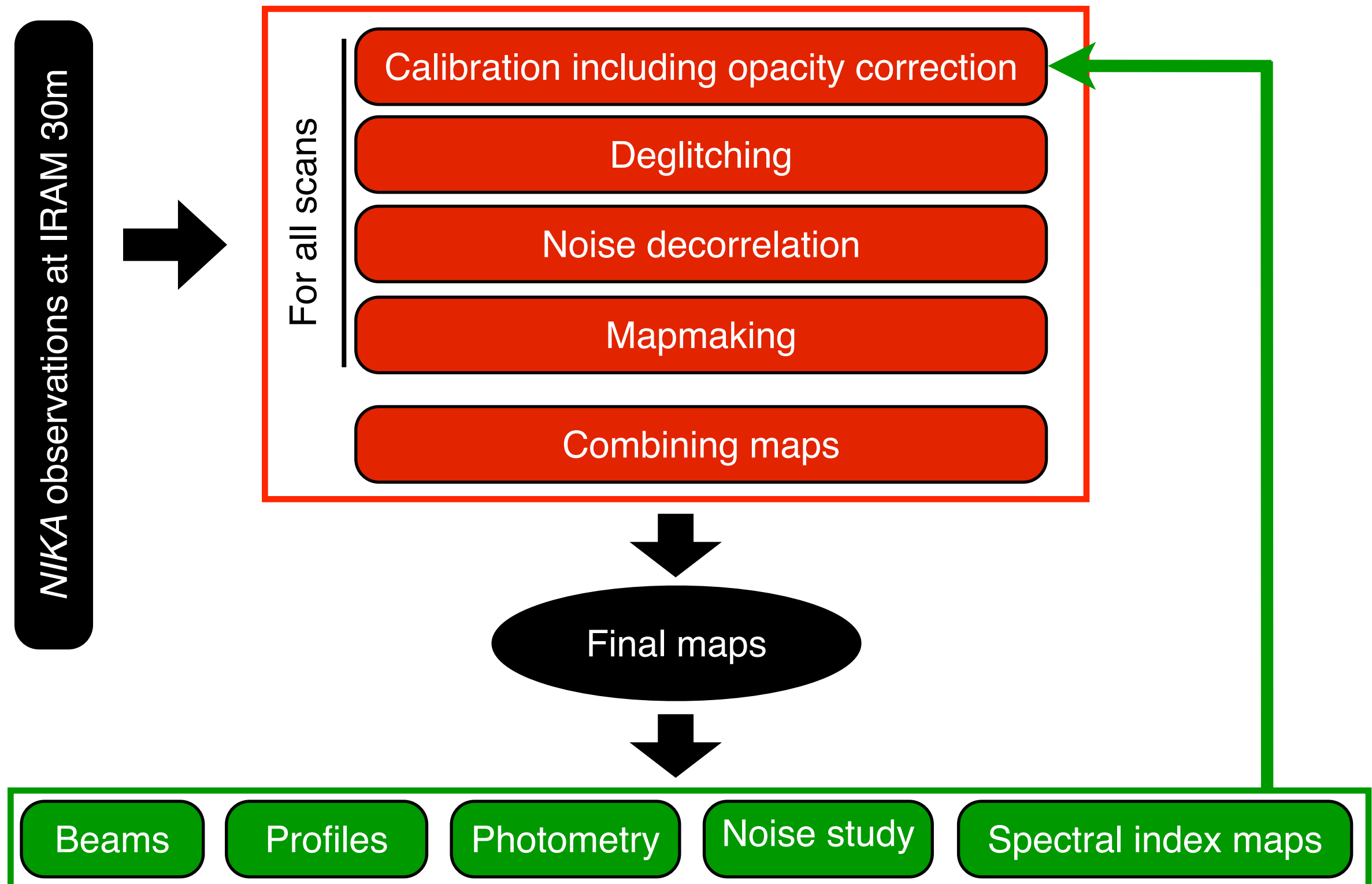
➔ **NIKA2 will be commissioned by 2015**

From raw data to maps

NIKA observations



From raw data to maps: the *NIKA* reduction pipeline

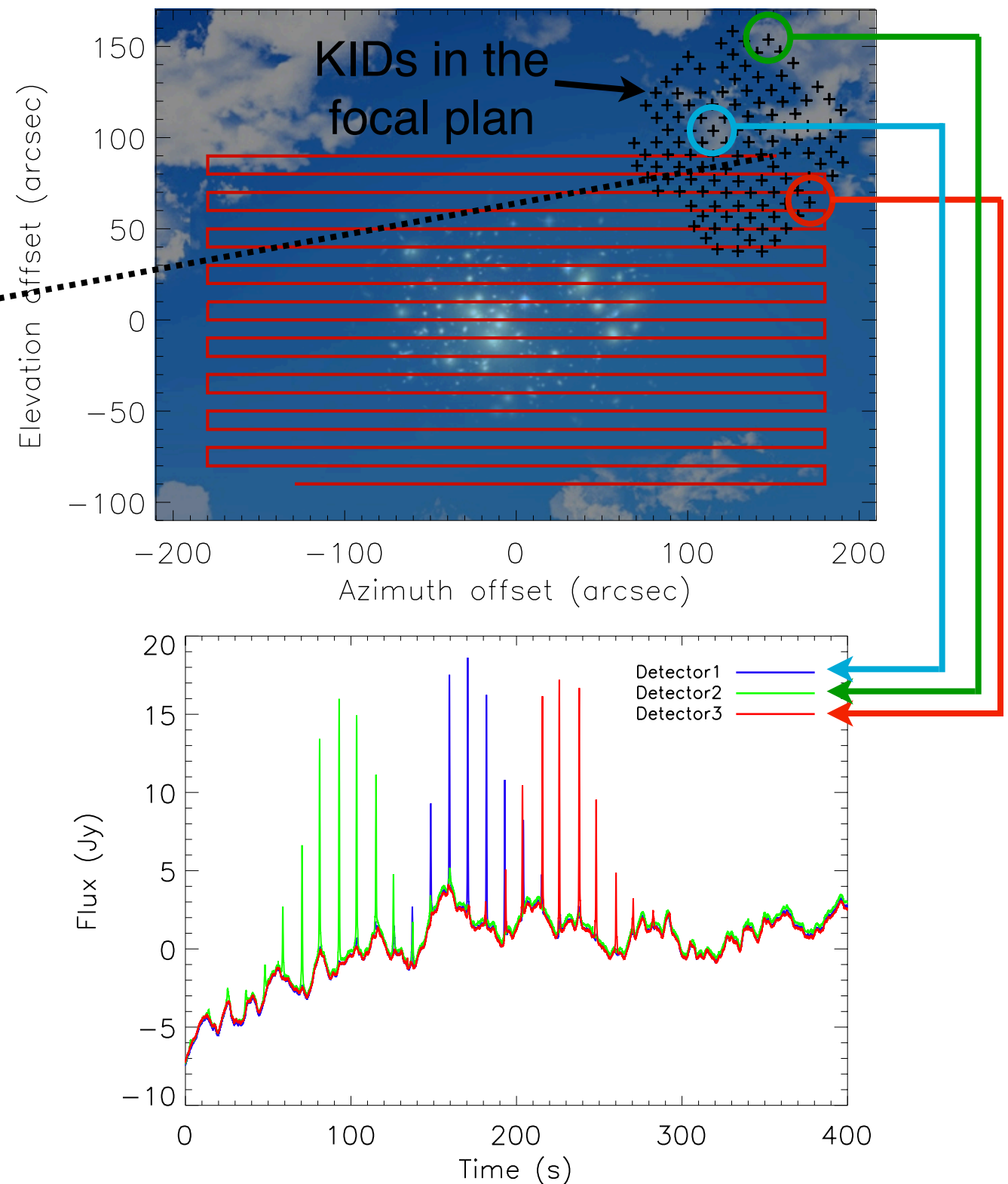


From raw data to maps: scanning strategy



[N. Billot]

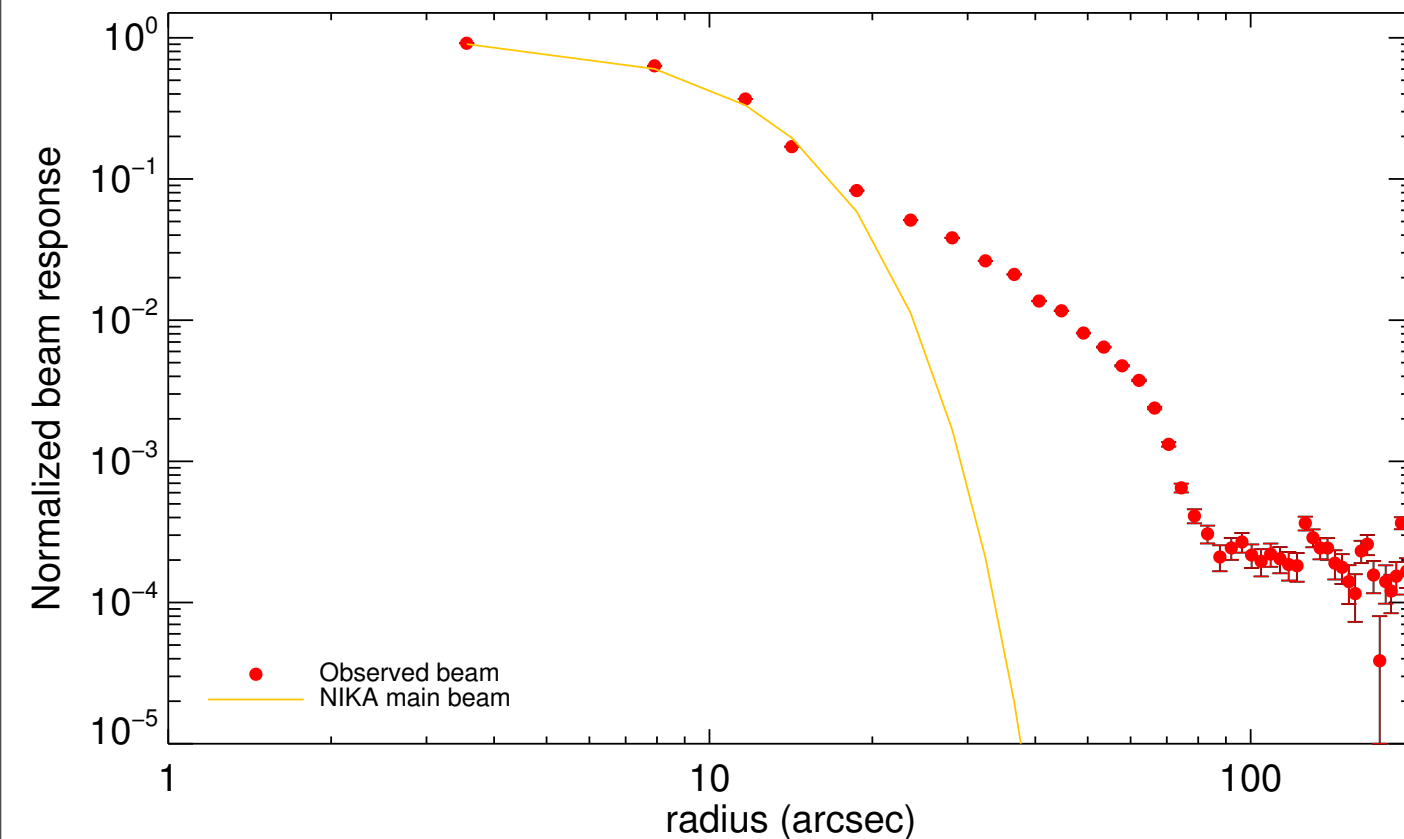
➡ The signal is modulated by the scanning strategy



From raw data to maps: calibration

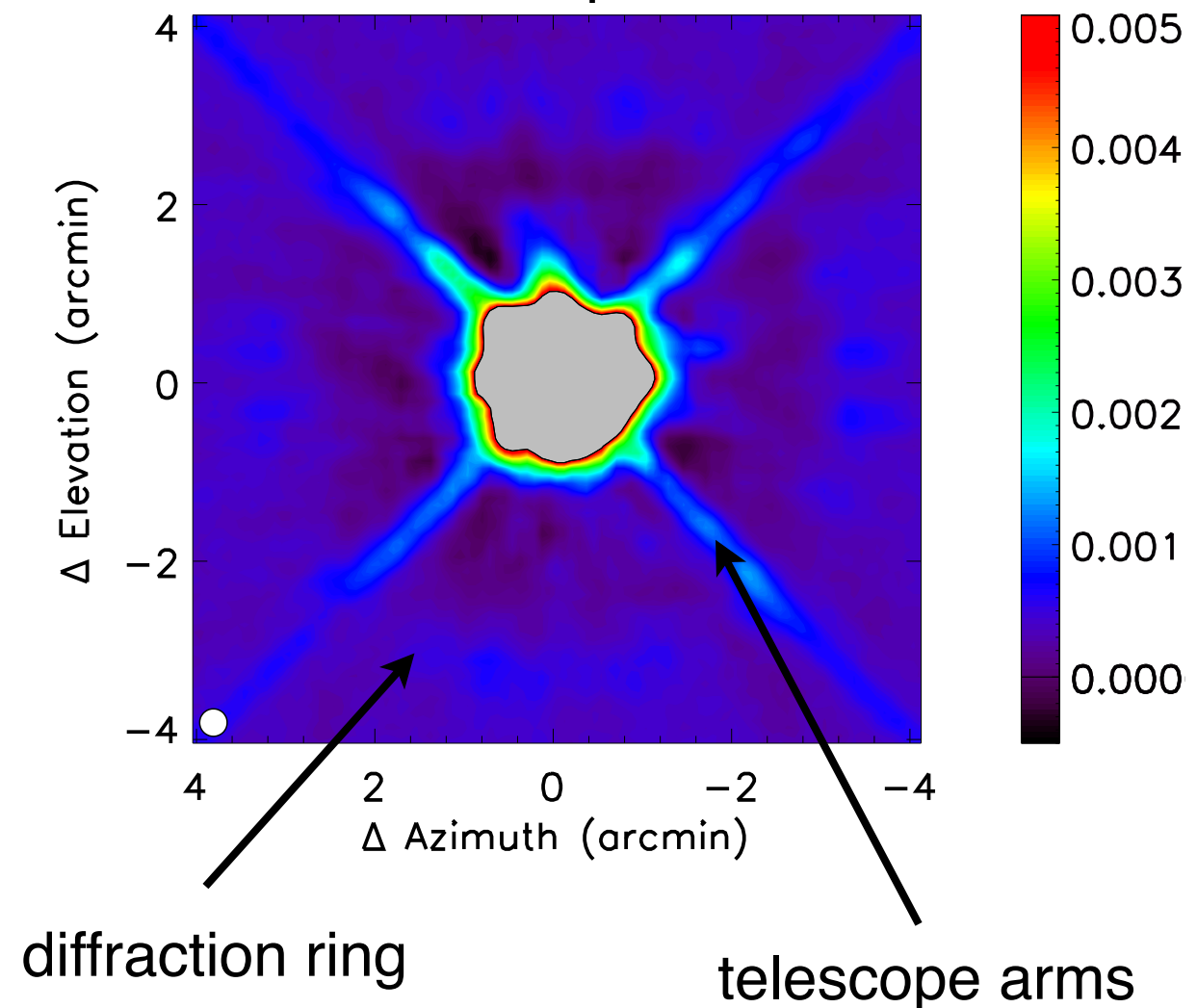
- The *NKA* calibration is done for point sources
- SZ diffuse emission requires a good knowledge of the angular response

Beam profile on Uranus



[A. Catalano, M. Calvo, N. Ponthieu,
R. Adam et al. (2014)]

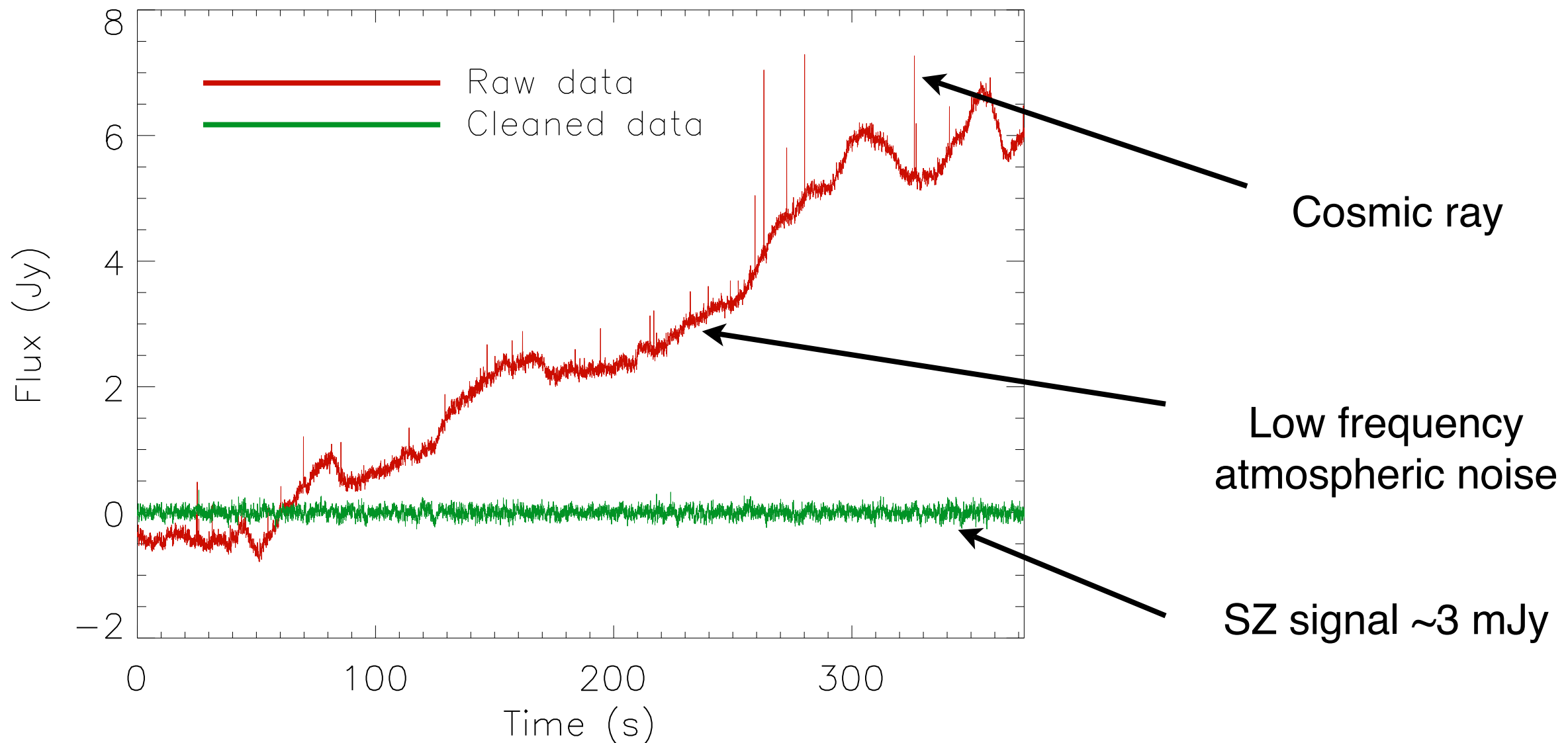
Beam map on Saturn



➡ SZ map calibration

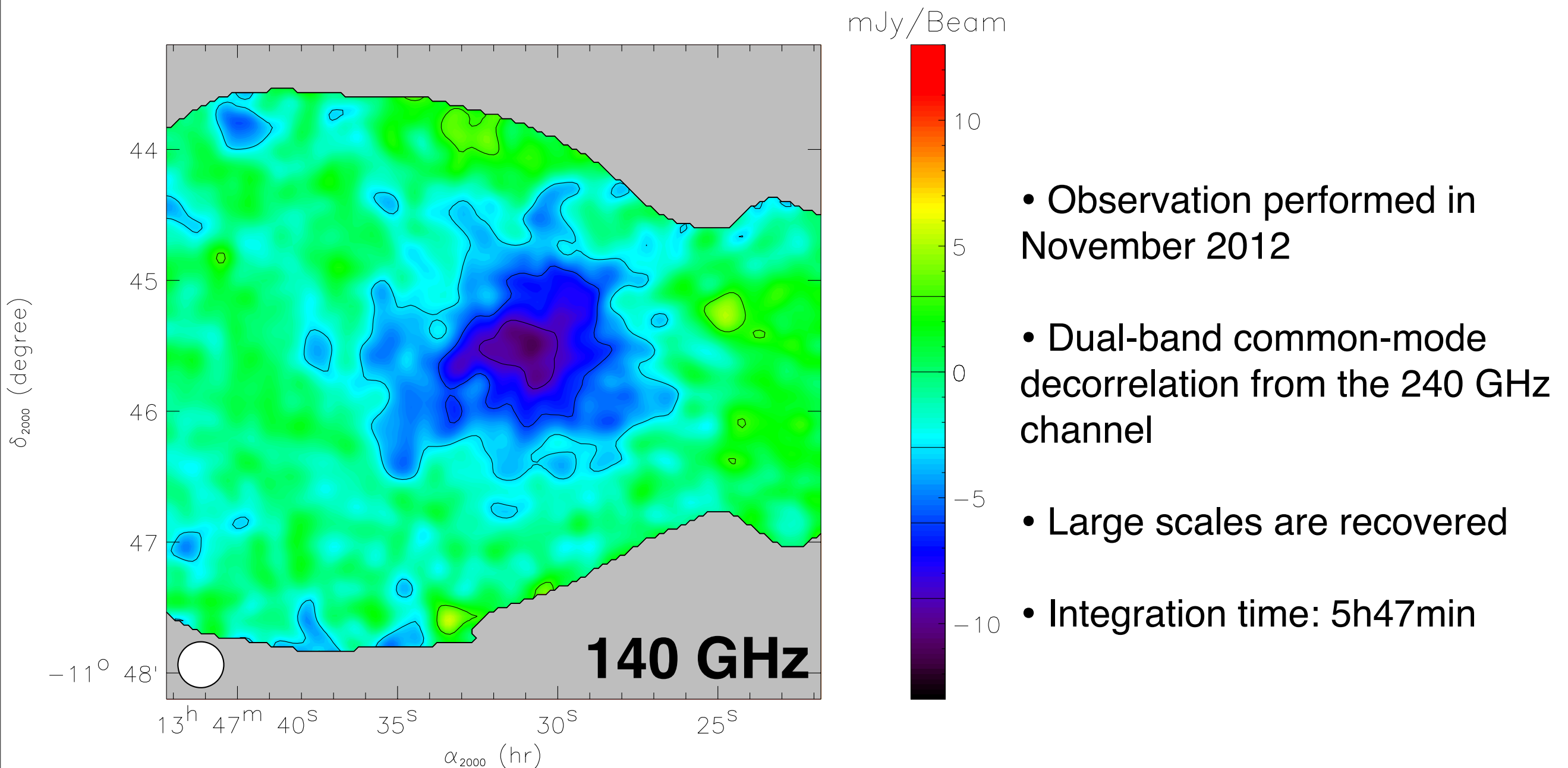
From raw data to maps: atmospheric removal

$$d(t) = P_{\vec{r}(t)} \text{Flux}_{SZ}(\nu) + A(t, \nu) + E(t) + N(t)$$



➡ The correlated noise is removed combining the detectors timelines

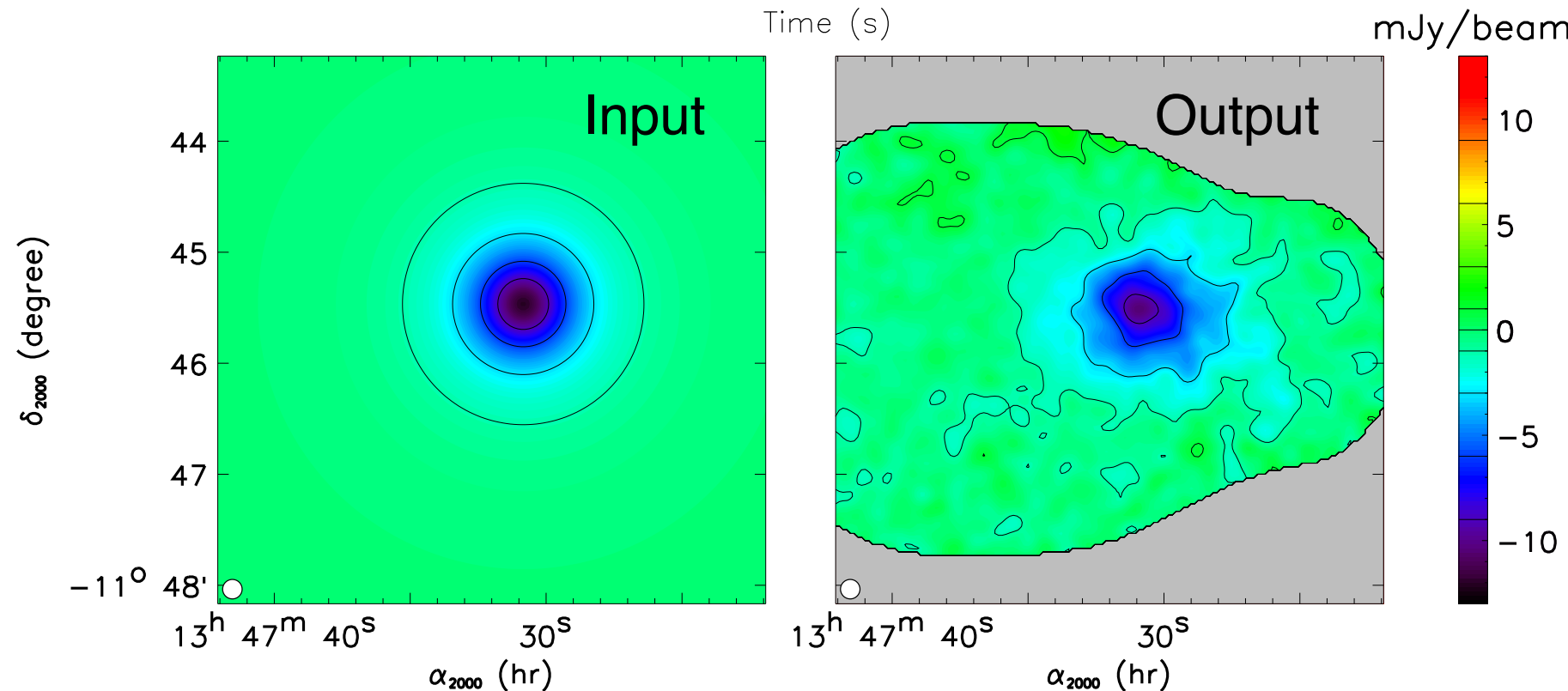
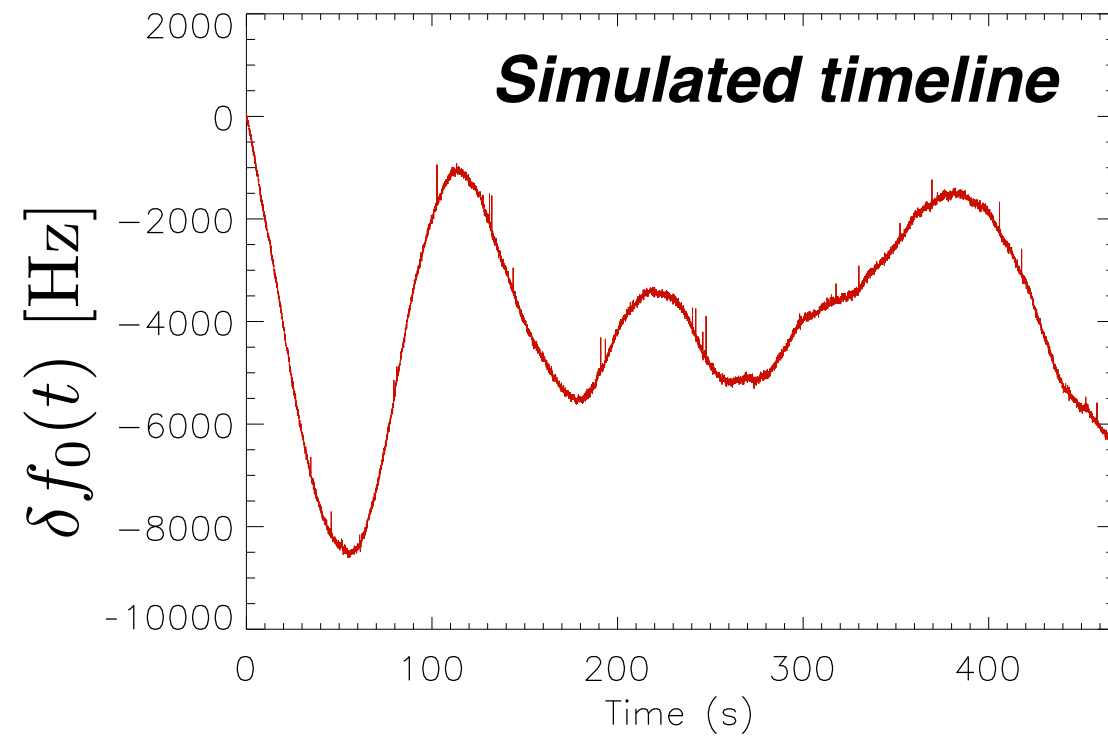
First results with the *NIKA* prototype: RX J1347.5-1145 ($z=0.45$)



➔ **The first SZ observation with KIDs, using the *NIKA* prototype**
[R. Adam, B. Comis, J. F. Macías-Pérez et al. (2013)]

From raw data to maps: validation and characterization on simulations

1. Simulation of a source
2. Convolution to the beam
3. The map is converted into timelines using:
 - a scanning strategy
 - a detector simulation
4. Realistic noise is added:
 - electronics + detector
 - atmosphere
 - cosmic rays
5. The pipeline is applied to the simulated data



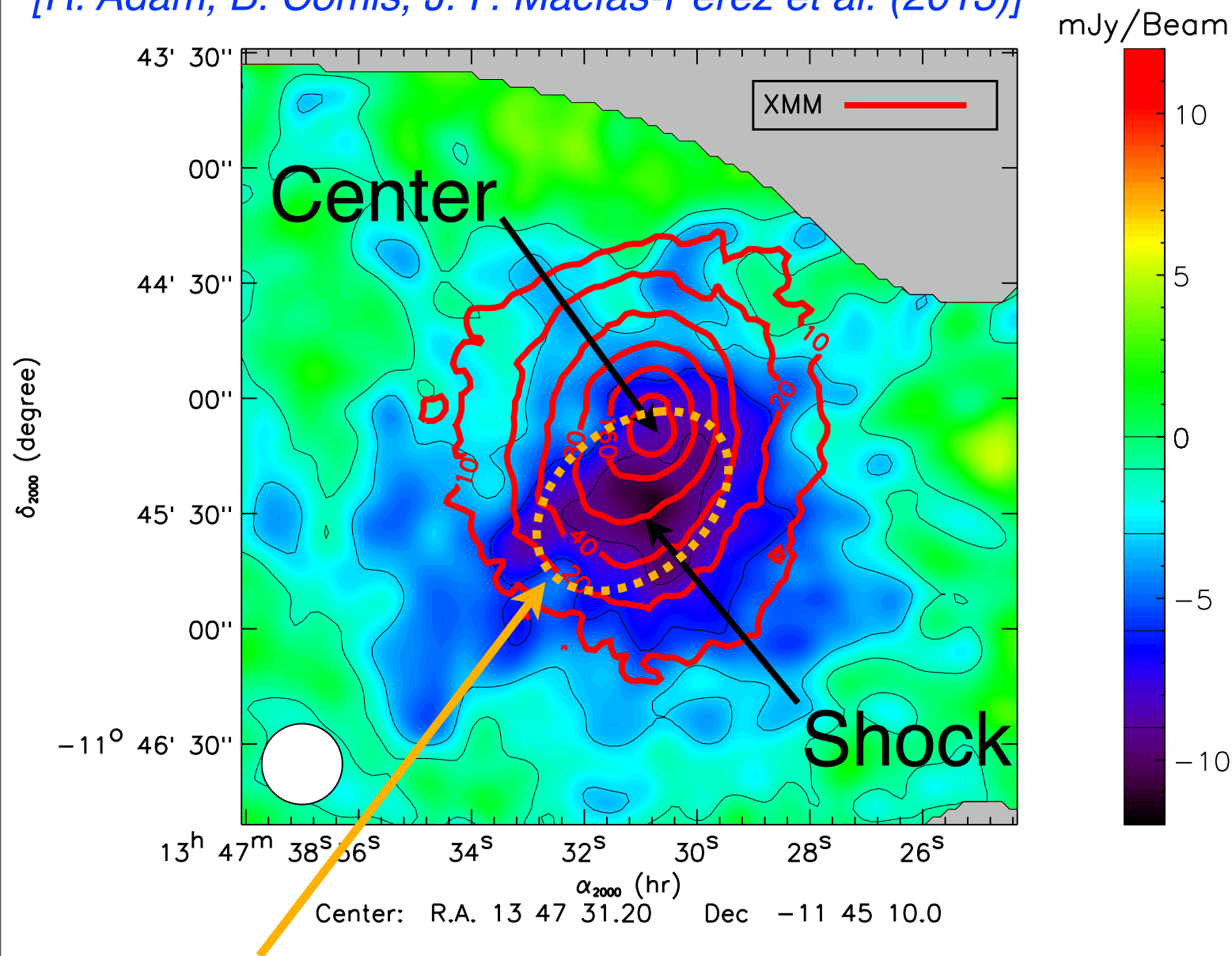
➡ The pipeline is validated and the transfer function is characterized

Interpretation of the Sunyaev-Zel'Dovich results with *NIKA*

SZ results: RX J1347.5-1145

complementarity with X-ray and radio data

[R. Adam, B. Comis, J. F. Macías-Pérez et al. (2013)]



- The X-ray emission is due to bremsstrahlung from hot electrons

$$X \text{ ray} \propto n_e^2 \sqrt{T_e}$$

$$SZ \propto P_e \propto n_e T_e$$

- SZ is well adapted for the **measurement of shocks**
- RX J1347.5-1145 is an ongoing merger (strong SE extension)

Radio halo [C. Ferrari et al. (2011)]

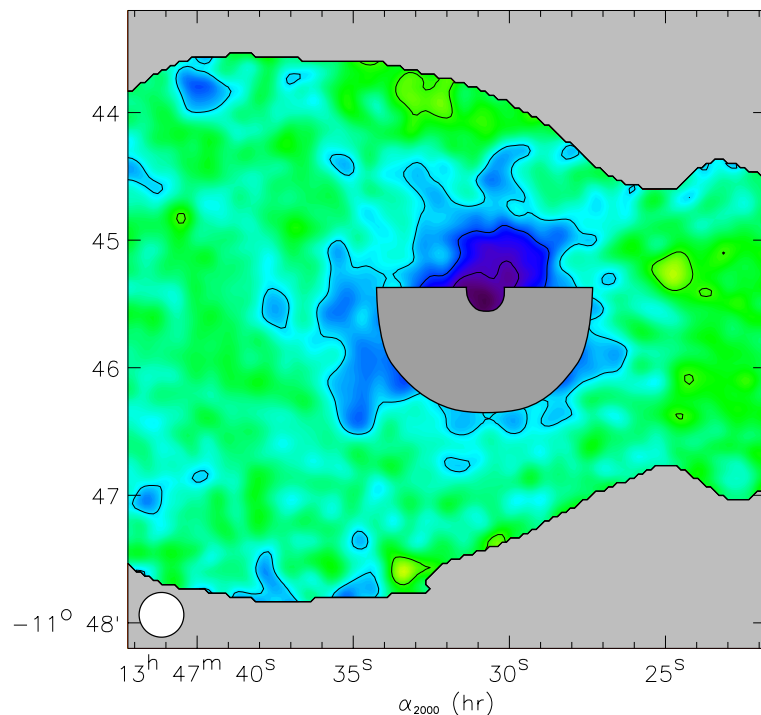
➡ **Detection and SZ mapping achieved**

SZ results: RX J1347.5-1145

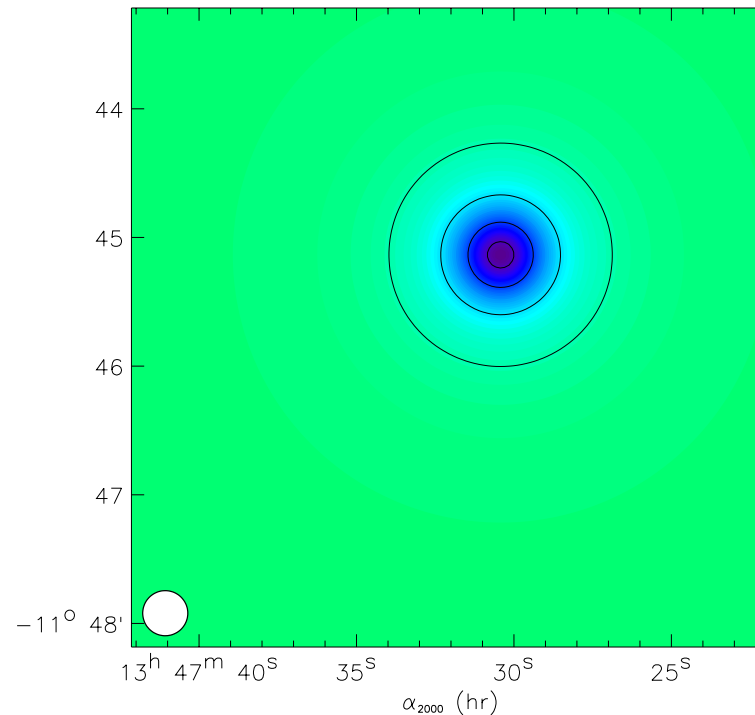
pressure distribution

- We fit the relaxed North region of RX J1347.5-1145 using a gNFW **pressure profile** parametrization [*D. Nagai et al. (2007)*]

data



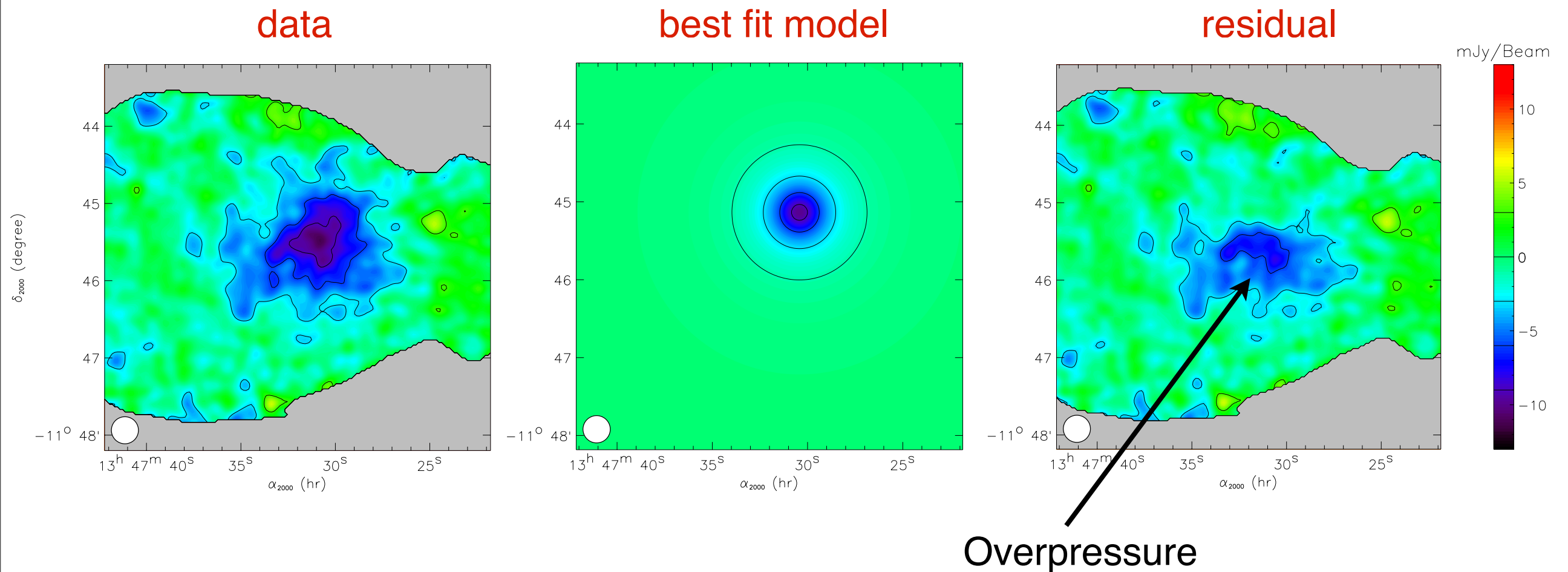
best fit model



SZ results: RX J1347.5-1145

pressure distribution

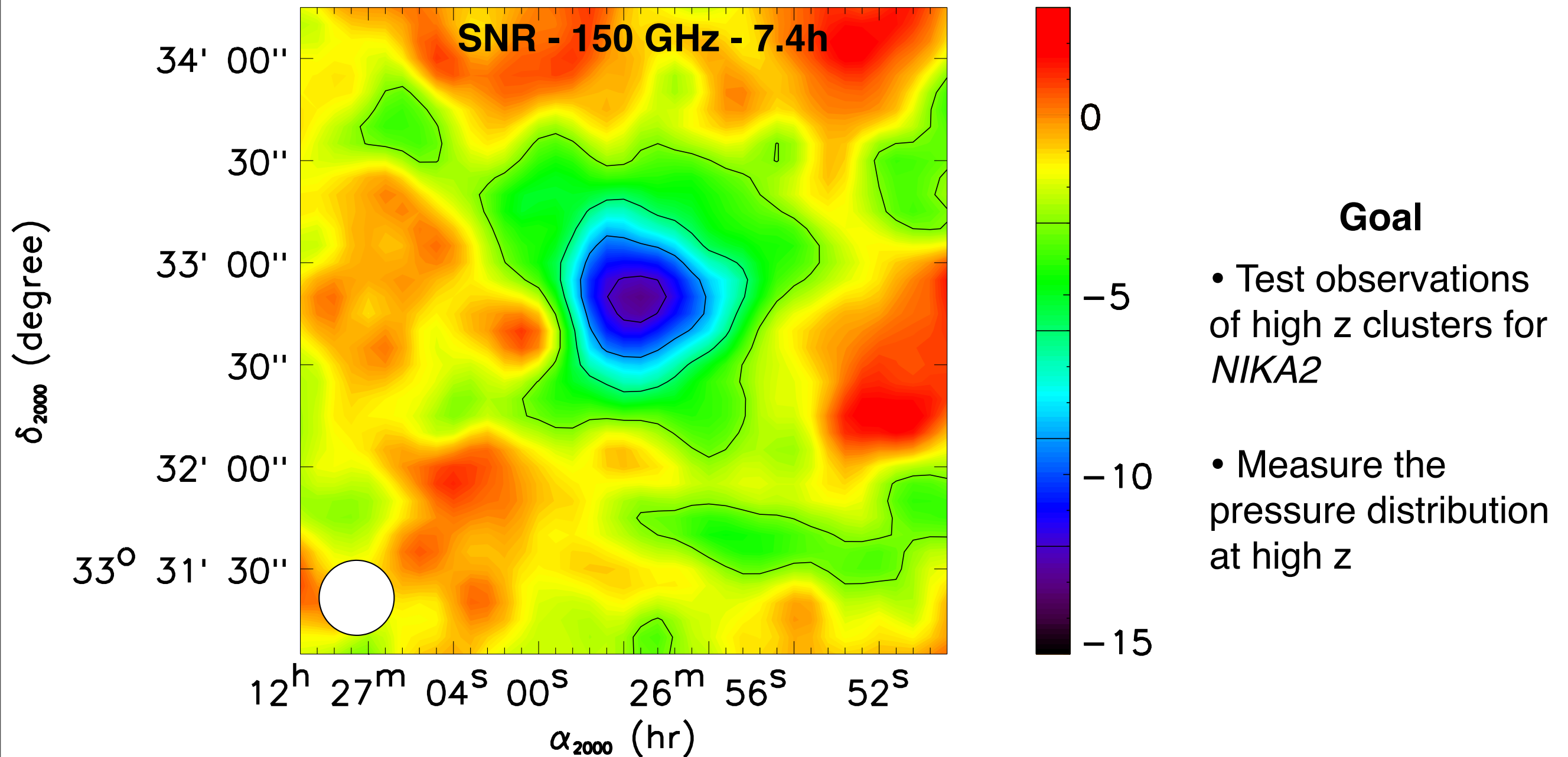
- We fit the relaxed North region of RX J1347.5-1145 using a gNFW pressure profile parametrization [*D. Nagai et al. (2007)*]



➡ RX J1347.5-1145 = relaxed cool-core + merger (20%)

Work in progress

CL J1226.9+3332 - $z=0.89$ (preliminary, 02/2014)



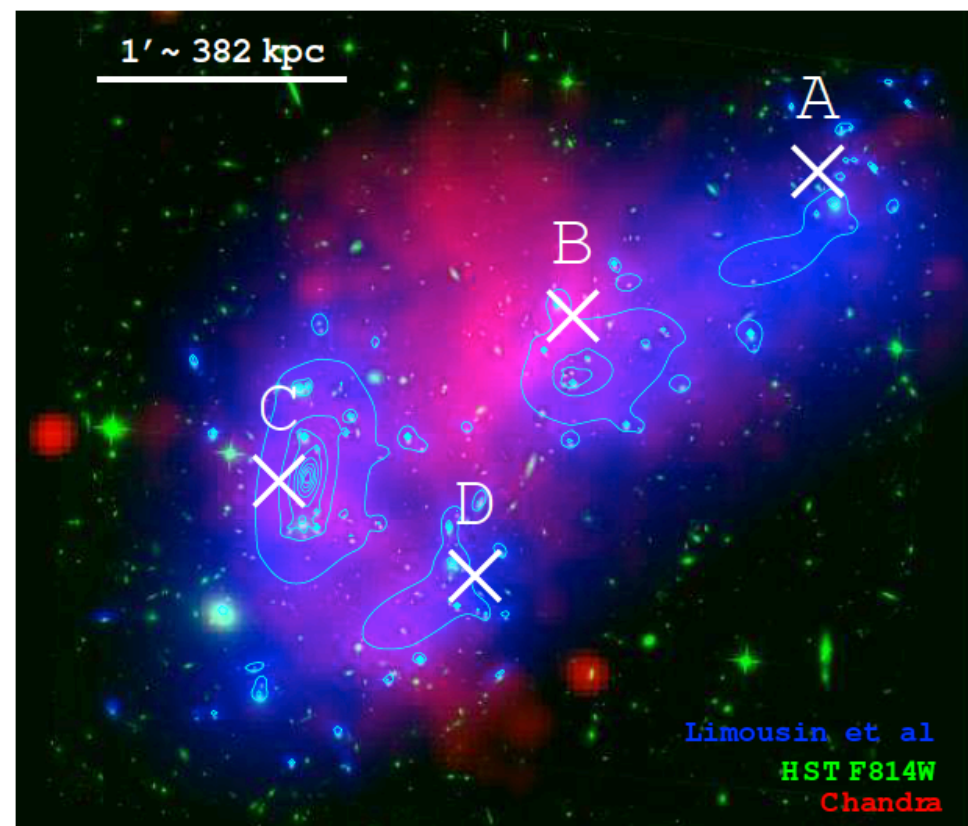
➡ **SZ mapping of high redshift cluster**

[P.I.: R. Adam and B. Comis]

MACS J0717.5+3745 - $z=0.55$

An exceptionally disturbed cluster

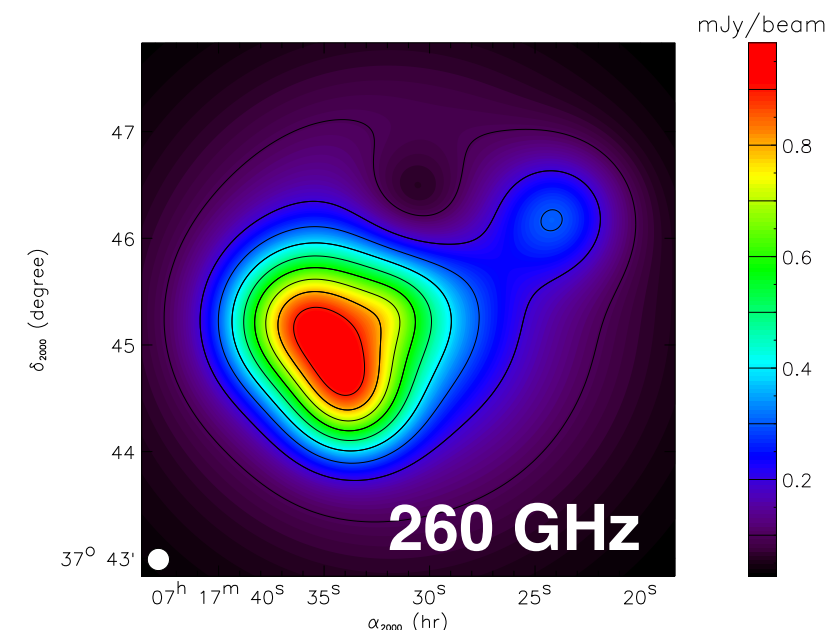
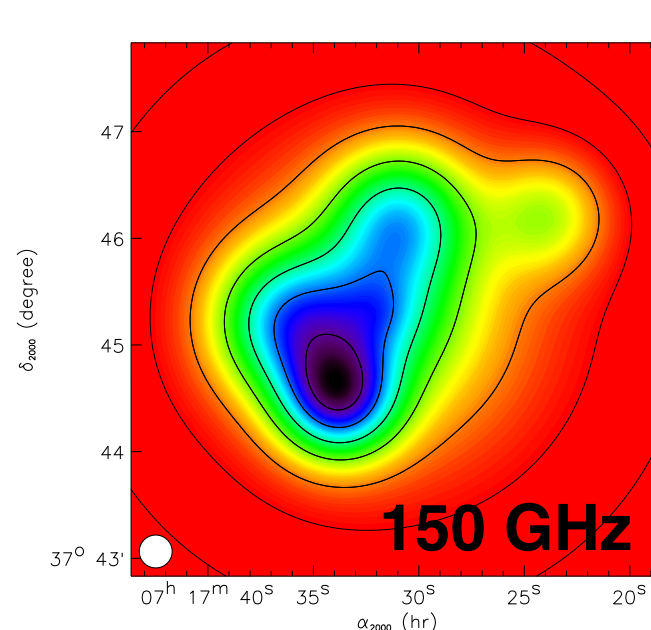
- Triple merger
- 4 optically identified groups
- Temperature up to 30 keV
- Line-of-sight velocities up to 3000 km/s (sub-cluster B)



[J. Sayers, T. Mroczkowski et al. (2013)]

Simulations of the expected SZ signal

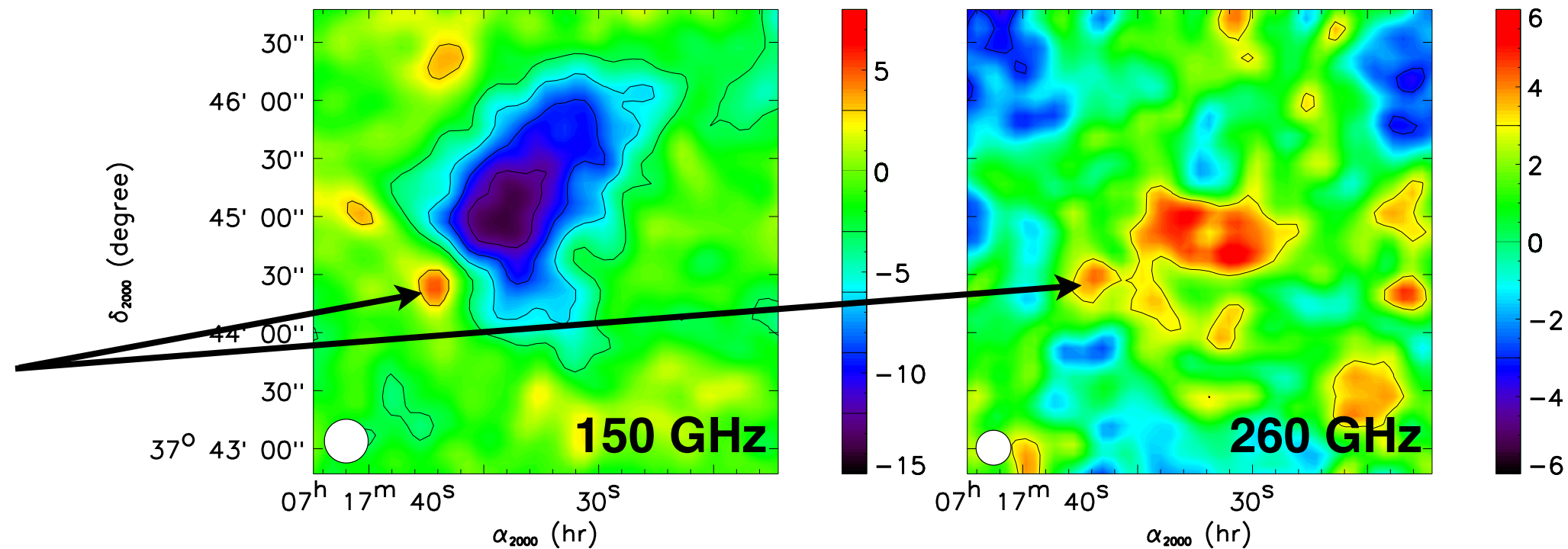
- Thermal SZ
- Kinematic SZ (*i.e.* SZ from line-of-sight velocity)
- Relativistic corrections



MACS J0717.5+3745 - $z=0.55$ (preliminary, 02/2014)

NIKA data

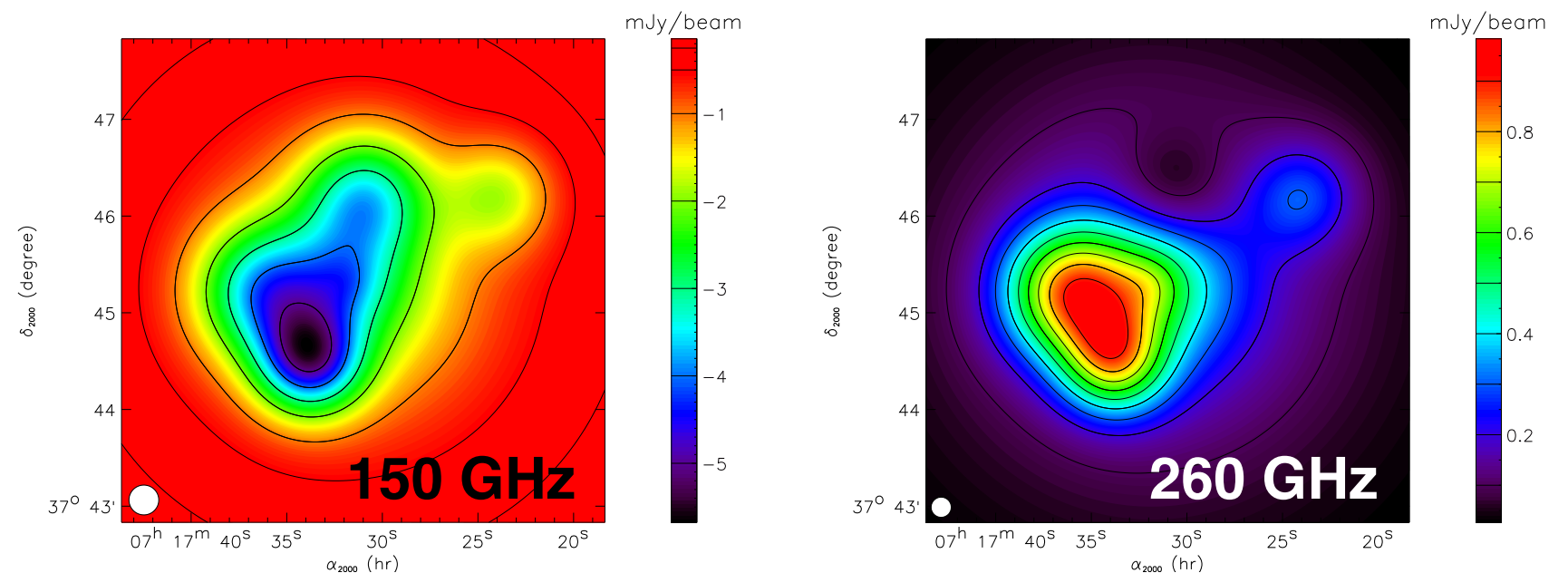
- 5.3h on source shown here (SNR)
- Detection of a foreground galaxy



[P.I.: R. Adam and B. Comis]

Simulations of the expected SZ signal

- Thermal SZ
- Kinematic SZ (*i.e.* SZ from line-of-sight velocity)
- Relativistic corrections



➡ SZ mapping of a very disturbed cluster at 150 and 260 GHz

Conclusions and perspectives

- We demonstrate the capability of *NIKA* for SZ observations
- We have built a dedicated analysis software, also used for external astronomers
- *NIKA2* construction: ongoing
- Cosmological *NIKA2* SZ large programs in preparation

Forthcoming work

NIKA

- February 2014 data to be analysed in details
 - Possible first kSZ mapping
 - High z pressure profile
- More *NIKA* SZ observations planned in November [*P.I.: B. Comis, R. Adam and G. Pratt*]
 - Pilot project for *NIKA2*
 - Another cluster for kSZ

Planck

- Polarization systematics removal and impact on cosmological parameters
- First Planck polarization release expected in October 2014

