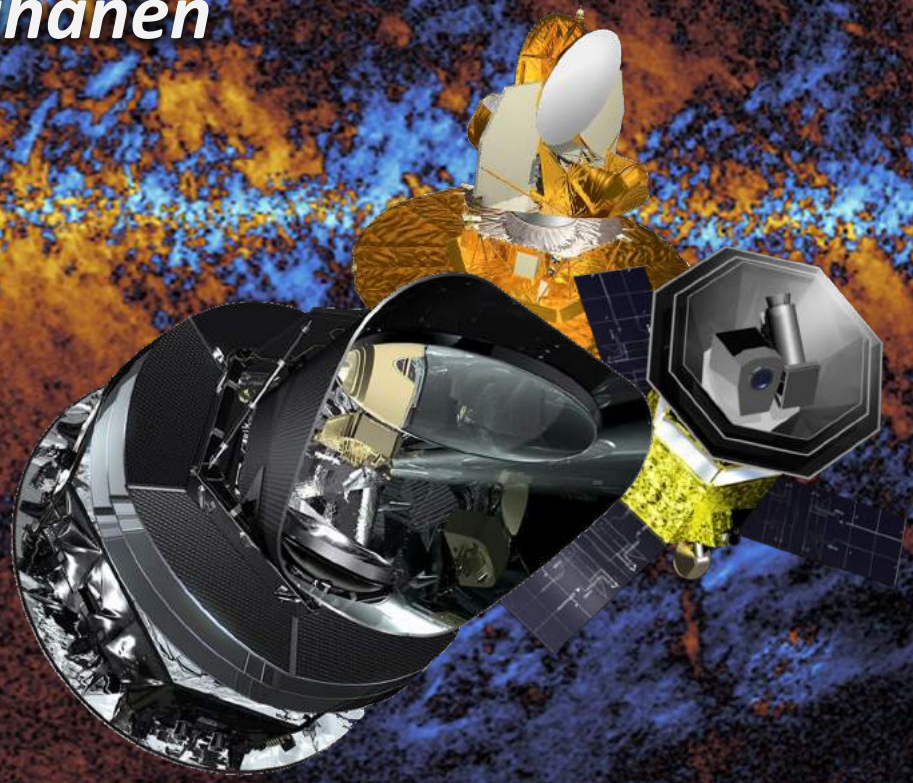
European Commission

Beyond PLANCK

BeyondPlanck
WP4: Map-making

Elina Keihänen



Final Review, December 15, 2020

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WP4: Map-making

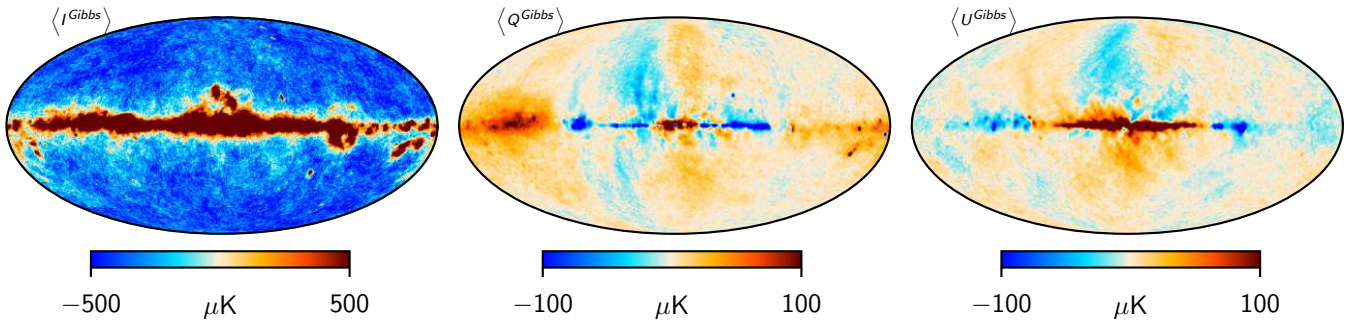
Purpose:
Implement the map-making step in BeyondPlanck pipeline

- Main responsibility: University of Helsinki
- Coordinator: Elina Keihänen
- People involved: Anna-Stiina Suur-Uski

Deliverables:
- 4.1. Prototype MADAM module
- 4.2. Tuned MADAM module
- 4.3. 4D map interface

What is map-making?

- Map-making:
  - One (heavy) processing step in conventional CMB processing
  - Input: Calibrated time-ordered data (TOI)
  - Output: Frequency maps of in temperature and polarization (CMB+foregrounds)



  - Provides input to next processing steps (component separation, cosmological parameters)

- **Removal of correlated noise**

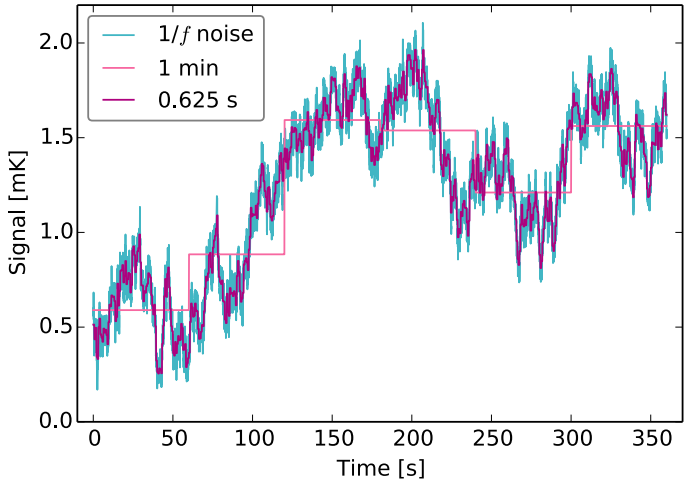
Map-making methods

- Traditional map-making methods fall into two categories:
  - Maximum-likelihood (GLS) methods
  - Destriping methods

- GLS

$$\boldsymbol{m} = (\mathrm{P}^T \mathrm{C}^{-1} \mathrm{P})^{-1} P^T \mathrm{C}^{-1} \boldsymbol{y}$$

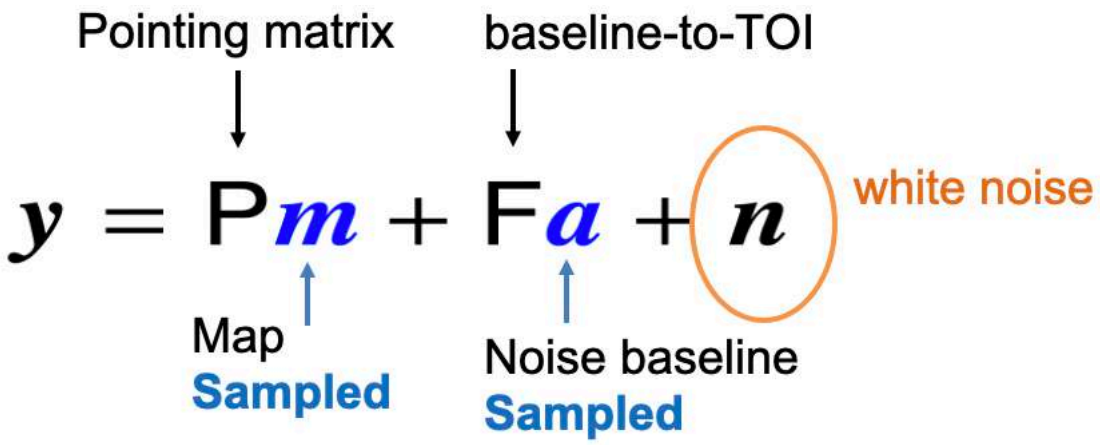
- Destriping:
  - Correlated noise modelled as a sequence of offsets, “baselines”
  - Baseline length as parameter



- LFI DPC uses Madam destriper for map-making
  - Baseline lengths 0.25-1.0 sec

Map-making through Gibbs sampling

- New: map-making through Gibbs sampling
- Make correlated noise a Gibbs variable
- Formalism borrowed from destriping



Gibbs sampling procedure

- Draw samples from conditional likelihoods

$$\boldsymbol{m}' \leftarrow P(\boldsymbol{m} \mid \boldsymbol{a}; \boldsymbol{y}, \mathsf{C}_w)$$
$$\boldsymbol{a}' \leftarrow P(\boldsymbol{a} \mid \boldsymbol{m}; \boldsymbol{y}, \mathsf{C}_w, \mathsf{C}_a)$$

- Map-making is broken into two manageable steps

1) Map binning:

$$\boldsymbol{m}' = (\mathsf{P}^T\mathsf{C}_w^{-1}\mathsf{P})^{-1}[\mathsf{P}^T\mathsf{C}_w^{-1}(\boldsymbol{y} - \mathsf{F}\boldsymbol{a}) + \mathsf{C}_w^{-1/2}\boldsymbol{\omega}_1]$$

2) Correlated noise:

$$\boldsymbol{b} = \mathsf{C}_w^{-1}(\boldsymbol{y} - \mathsf{P}\boldsymbol{m}') + \mathsf{C}_w^{-1/2}\boldsymbol{\omega}_2 + \mathsf{C}_a^{-1/2}\boldsymbol{\omega}_3$$
$$\boldsymbol{a}' = (\mathsf{C}_w^{-1} + \mathsf{C}_a^{-1})^{-1}\boldsymbol{b}$$

white noise

- Solved by pointing period. Baseline length down to to 1 sample!
- Maximum-likelihood mode or sampling mode

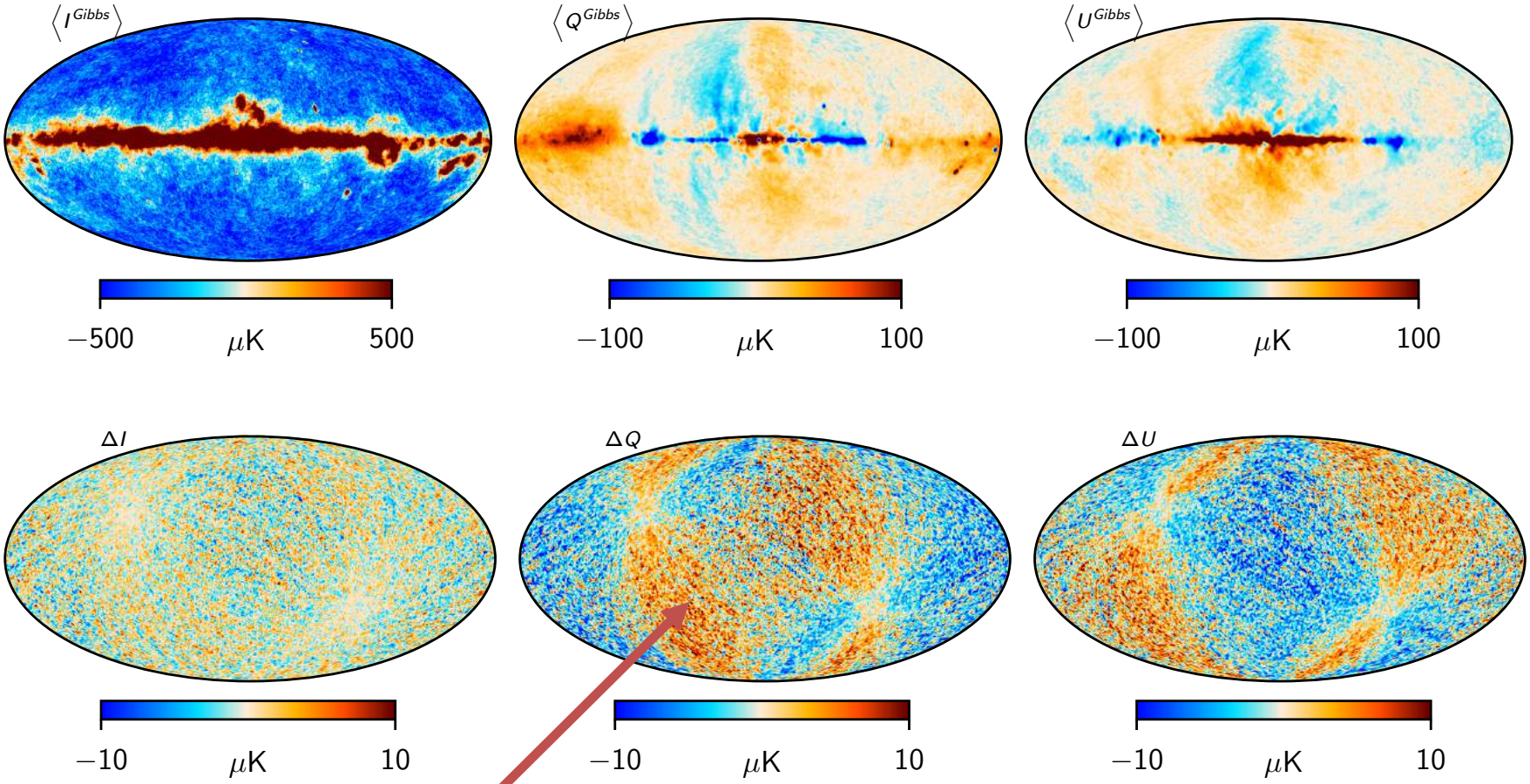
BeyondPlanck II. CMB map-making through Gibbs sampling

E. Keihänen[3⋆], A.-S. Suur-Uski[3,7], K. J. Andersen[11], R. Aurlien[11], R. Banerji[11], M. Bersanelli[4,9,10], S. Bertocco[8], M. Brilenkov[11], M. Carbone[14], L. P. L. Colombo[4], H. K. Eriksen[11], M. K. Foss[11], C. Franceschet[4,10], U. Fuskeland[11], S. Galeotta[8], M. Galloway[11], S. Gerakakis[14], E. Gjerløw[11], B. Hensley[2], D. Herman[11], M. Iacobellis[14], M. Ieronymaki[14], H. T. Ihle[11], J. B. Jewell[11], A. Karakci[11], R. Keskitalo[1], G. Maggio[8], D. Maino[4,9,10], M. Maris[8], A. Mennella[4,9,10], S. Paradiso[4,10], B. Partridge[6], M. Reinecke[13], T. L. Svalheim[11], D. Tavagnacco[8,5], H. Thommesen[11], M. Tomasi[4,9], D. J. Watts[11], I. K. Wehus[11], and A. Zacchei[8]

- Paper available online: http://arxiv.org/abs/2011.06024
  - Theoretical background for the map-making algorithm of BeyondPlanck
  - Results based on simulations

Gibbs map

Gibbs map = mean of the Gibbs chain



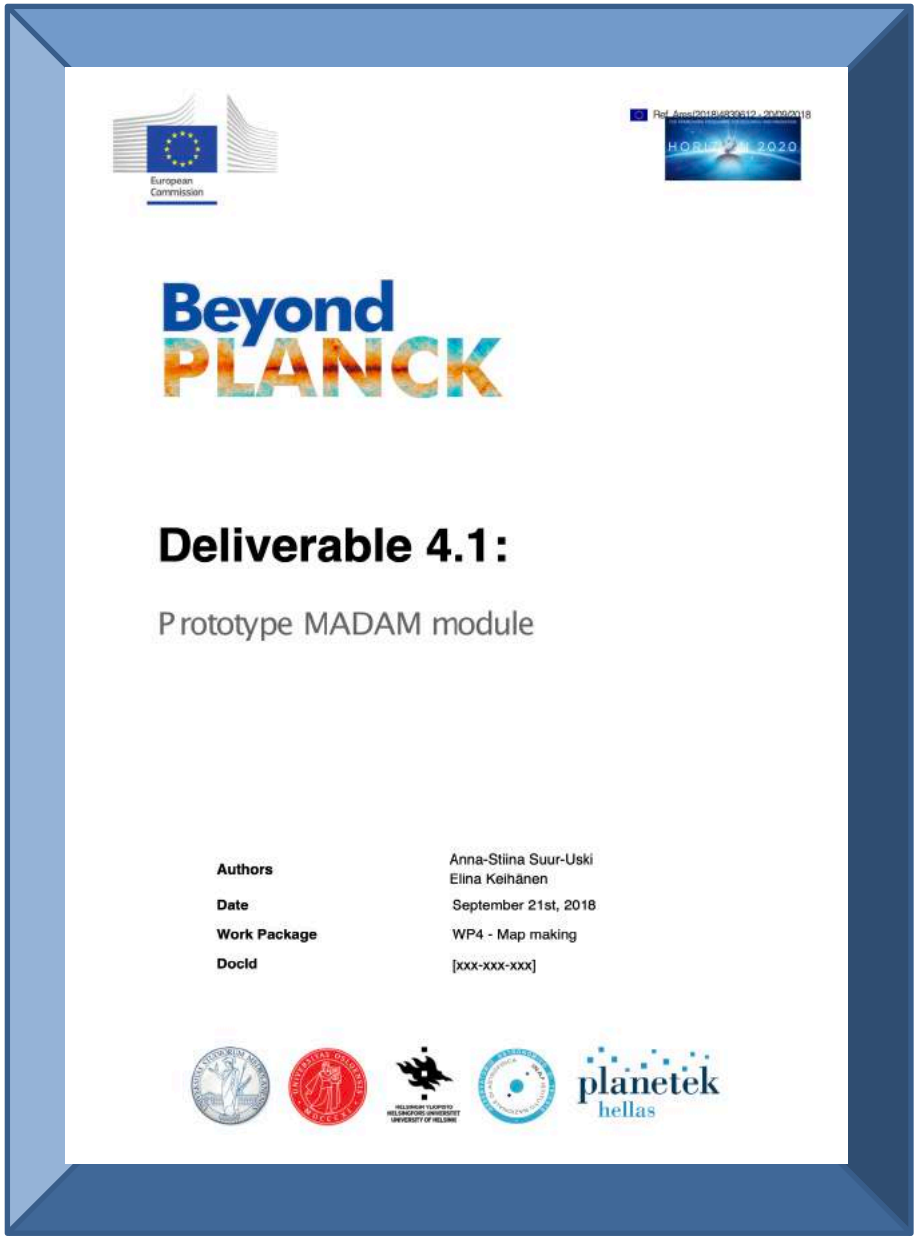
Bandpass leakage
Cannot be solved in map-making alone.
We need global Gibbs sampling!

4.1: Prototype MADAM module

Deliverable 4.1.
Prototype MADAM module

- Install the MADAM map-making code (3.8.3) on the Oslo cluster. Test on simulated data.

- Delivered: September 20th 2018
- Accepted: January 22nd 2020

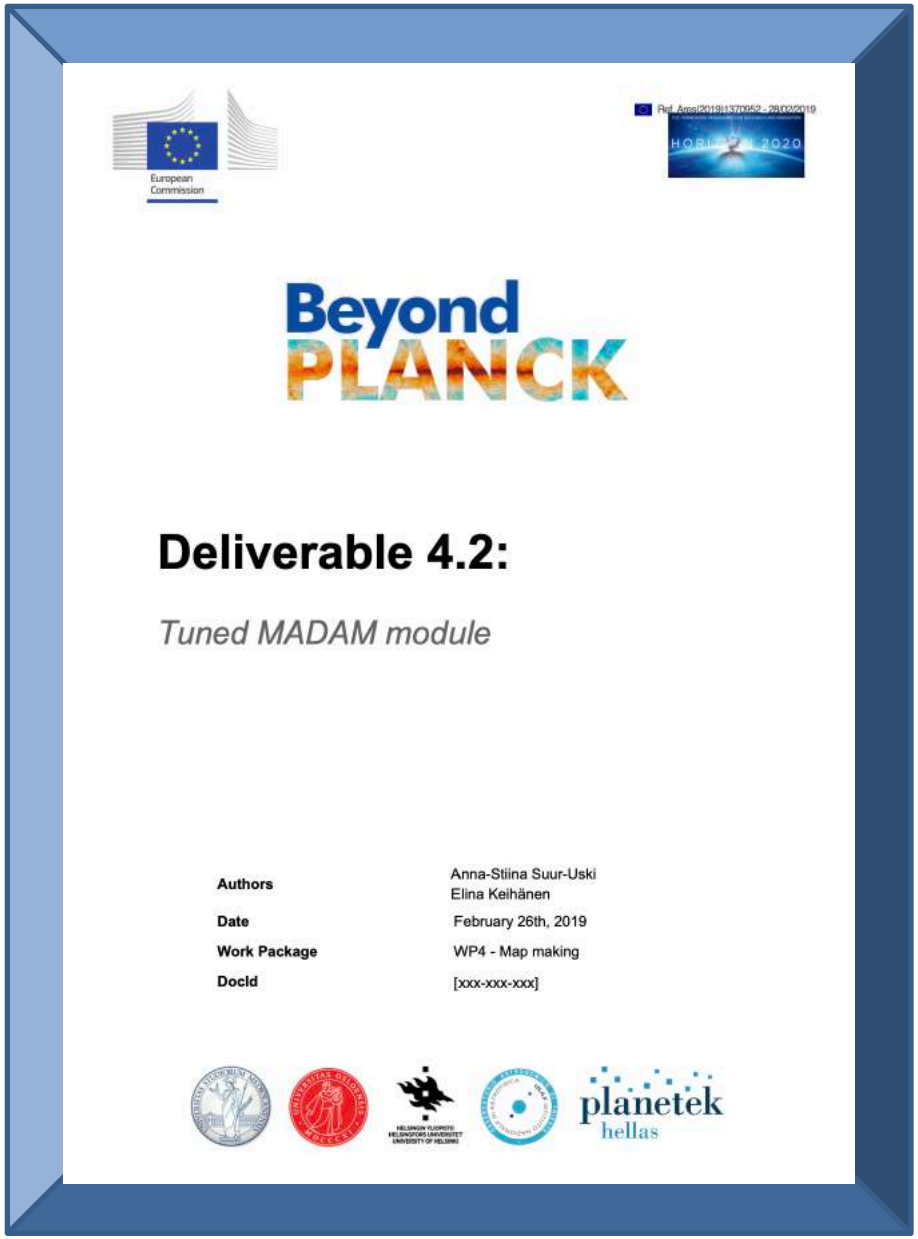


4.2: Tuned MADAM module

Deliverable 4.2.
Tuned MADAM module

- Interface the MADAM map-making code with BeyondPlanck data model.
- New Madam version 3.9.0

- Delivered: February 28. 2019
- Accepted: January 22. 2020



4.3: Commander 4D map interface

Deliverable 4.3.
Commander 4D map interface

- Submitted: November 30. 2020
- Beam-deconvolution module (WP5) takes as input 4D map data objects:
  4D map = compressed TOI, or enhanced Healpix maps with information on beam orientation.
- “4D” refers to four parameters: pointing (theta,phi), beam orientation (psi), and time (pointing ID).
- Same objects serve as input for a number of auxiliary tools, for instance construction of partial sky maps.
- Commander3 outputs the required information as HDF5 data objects per core.
  HDF5to4Dmap tool (python) converts this into the standard FITS file

PM overview

Participant	EU-funded person months	In-kind person months
Helsinki	**8**	**0**
Total	**8**	**0**
Budgeted	**10**	
Deviation	**-2**	

Work

Overview of work done within WP4:

- Madam map-making code was installed on Oslo cluster and interfaced with the data model -> deliverables 4.1 and 4.2
- HDF5to4Dmap tool for conversion of Commander outputs into 4D map format -> deliverable 4.3
- A new way of constructing sky maps as part of Gibbs procedure, was proposed and tested with an external test code.
  Based on Gibbs sampling of the correlated noise component
  -> BP II

Funding

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- "*BeyondPlanck*"
  - COMPET-4 program
  - PI: Hans Kristian Eriksen
  - Grant no.: 776282
  - Period: Mar 2018 to Nov 2020

Collaborating projects:

- "*bits2cosmology*"
  - ERC Consolidator Grant
  - PI: Hans Kristian Eriksen
  - Grant no: 772 253
  - Period: April 2018 to March 2023
- "*Cosmoglobe*"
  - ERC Consolidator Grant
  - PI: Ingunn Wehus
  - Grant no: 819 478
  - Period: June 2019 to May 2024