

Roseland  
Centre  
for Solar  
Physics

Development of  
research with

tools for solar  
ALMA at RoCS

Sven Wedemeyer  
Roseland Centre for Solar Physics, Univ Oslo  
Oslo, 2 March 2020

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**Simulations**

**Observations**



**ALMA**



# ALMA @ RoCS

## PRIMARY MISSION

### TECHNICAL GOAL:

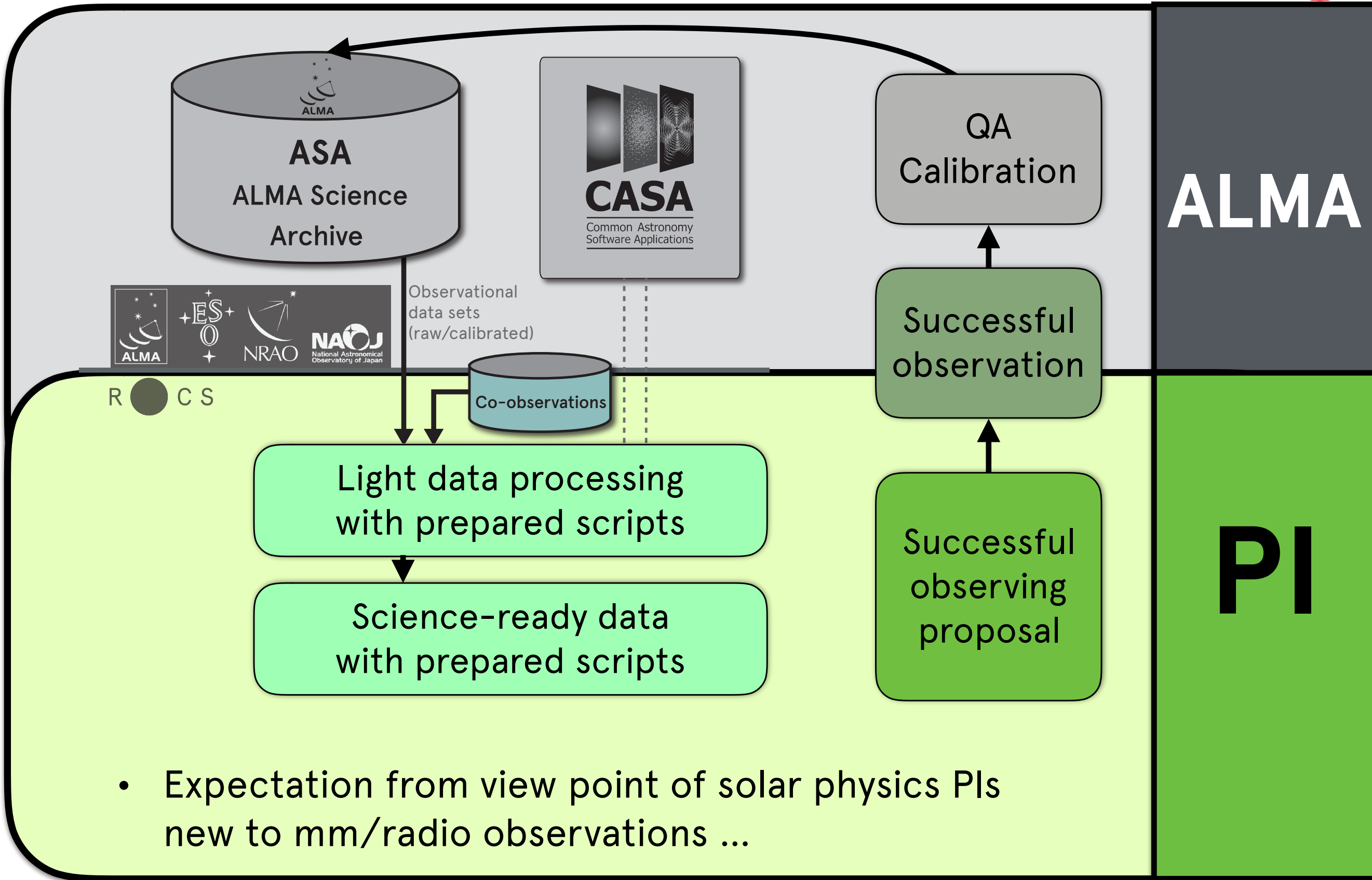
Develop and utilise **diagnostic tools** based on the solar observing capabilities of the Atacama Large Millimeter/sub-millimeter Array (ALMA)

### SCIENTIFIC GOAL:

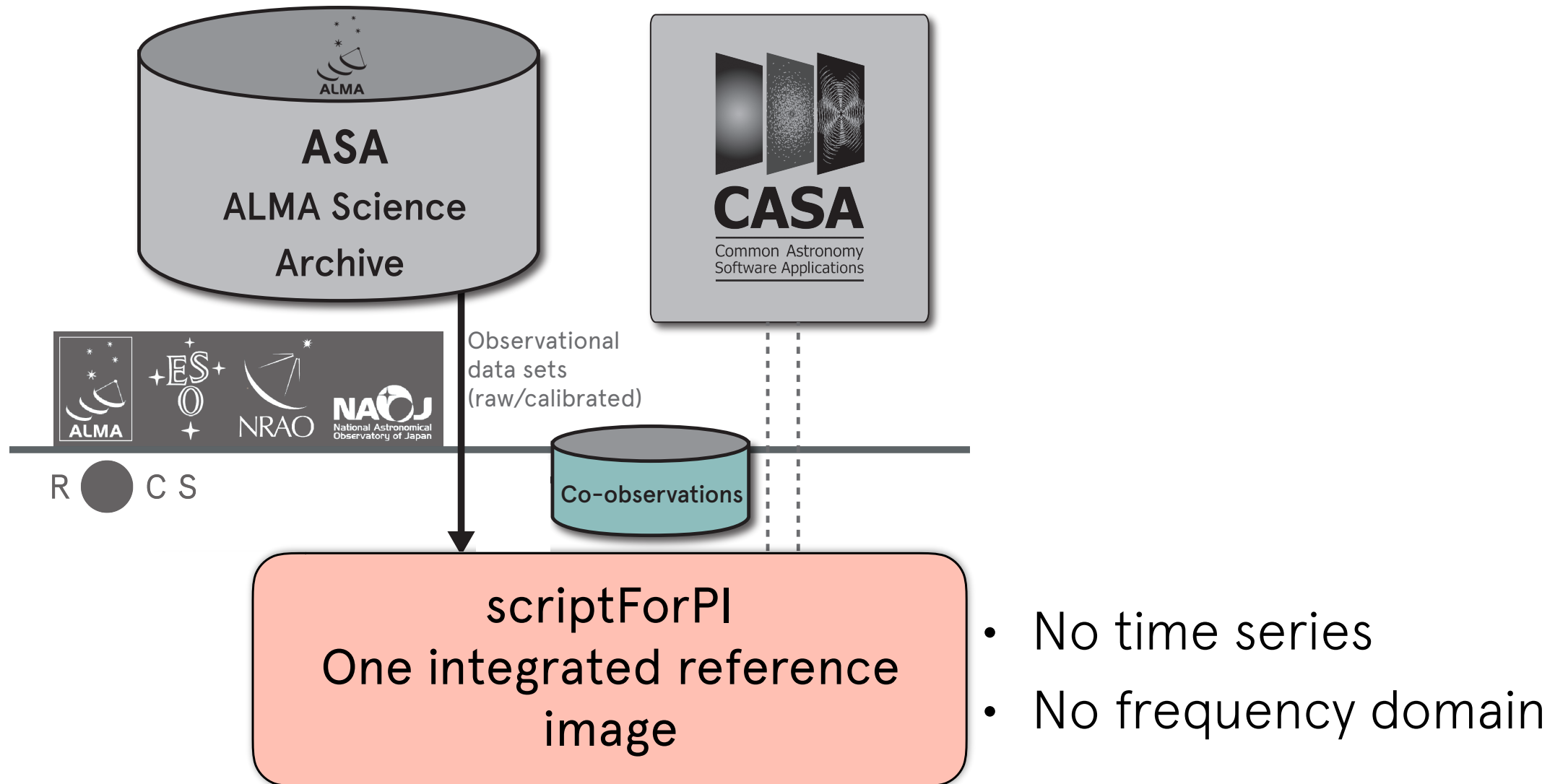
New complementary studies of the **small-structure, dynamics and energy balance of the solar chromosphere** with ALMA

The background of the slide is a composite image. On the left, there is a close-up of a server rack with a NASA logo on a cabinet. On the right, there is a night-time view of the ALMA observatory site, showing several large radio telescope dishes on a hillside. The word "ALMA" is written in large white letters in the bottom right corner.

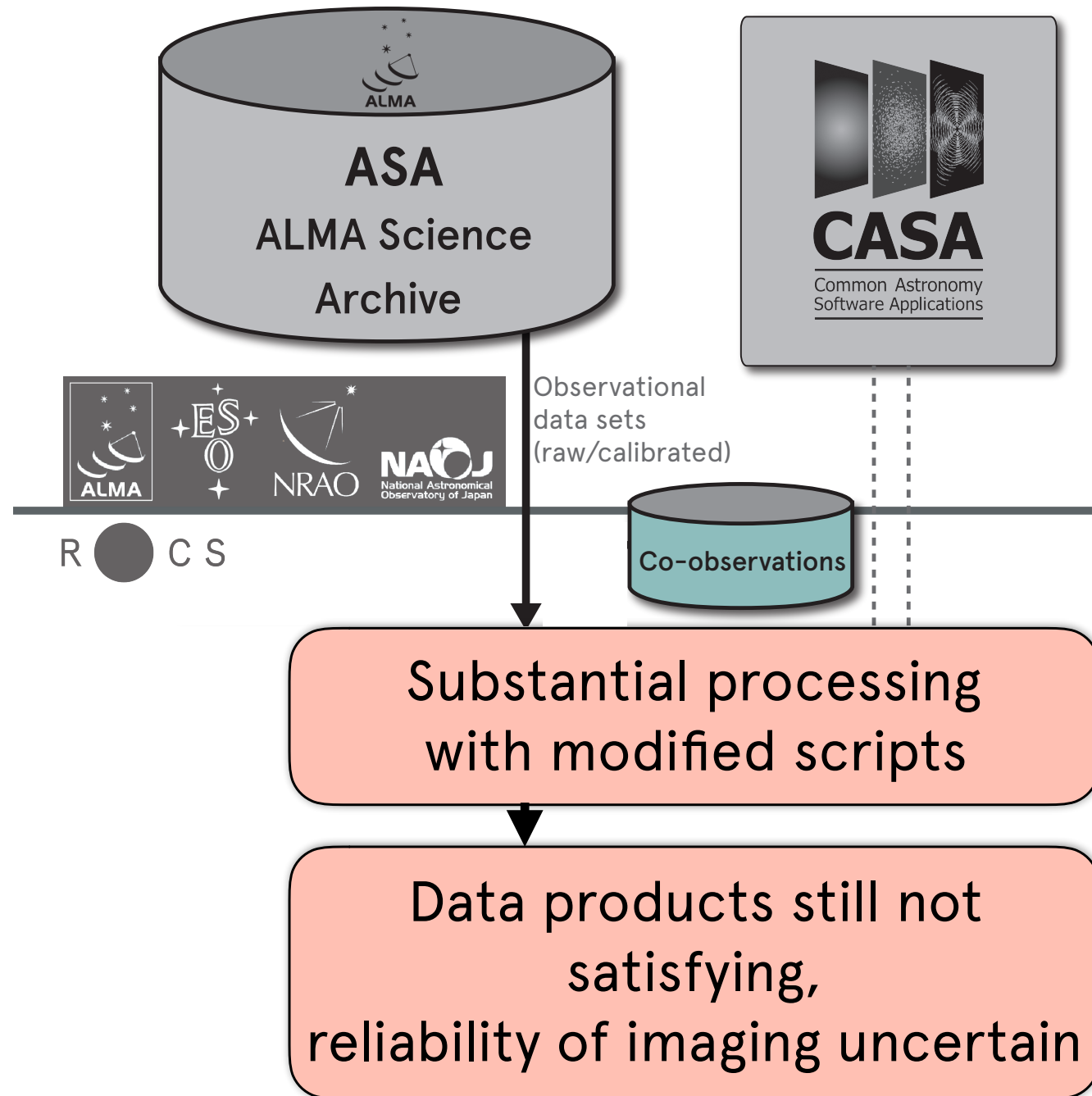
ALMA



- Expectation from view point of solar physics PIs new to mm/radio observations ...



- Data not ready for science
- Data not usable for scientific application as requested in observing proposal
- (Solar observing is a non-standard mode ...)



### Experimental phase

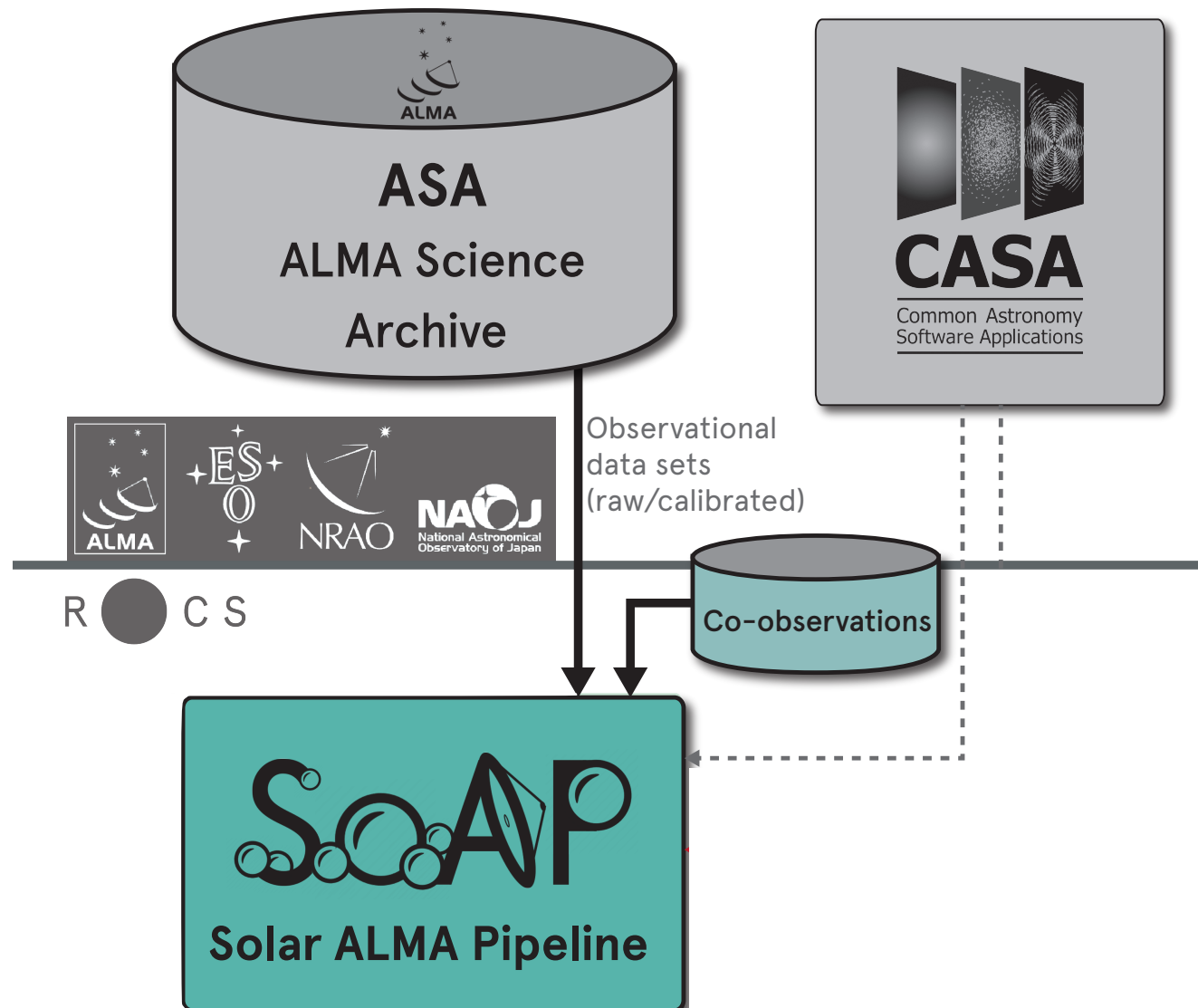
- Split in time series
- Split in spectral bands
- Data not ready for science

➡ How to set the parameters for CLEAN?

➡ Are the resulting images reliable?

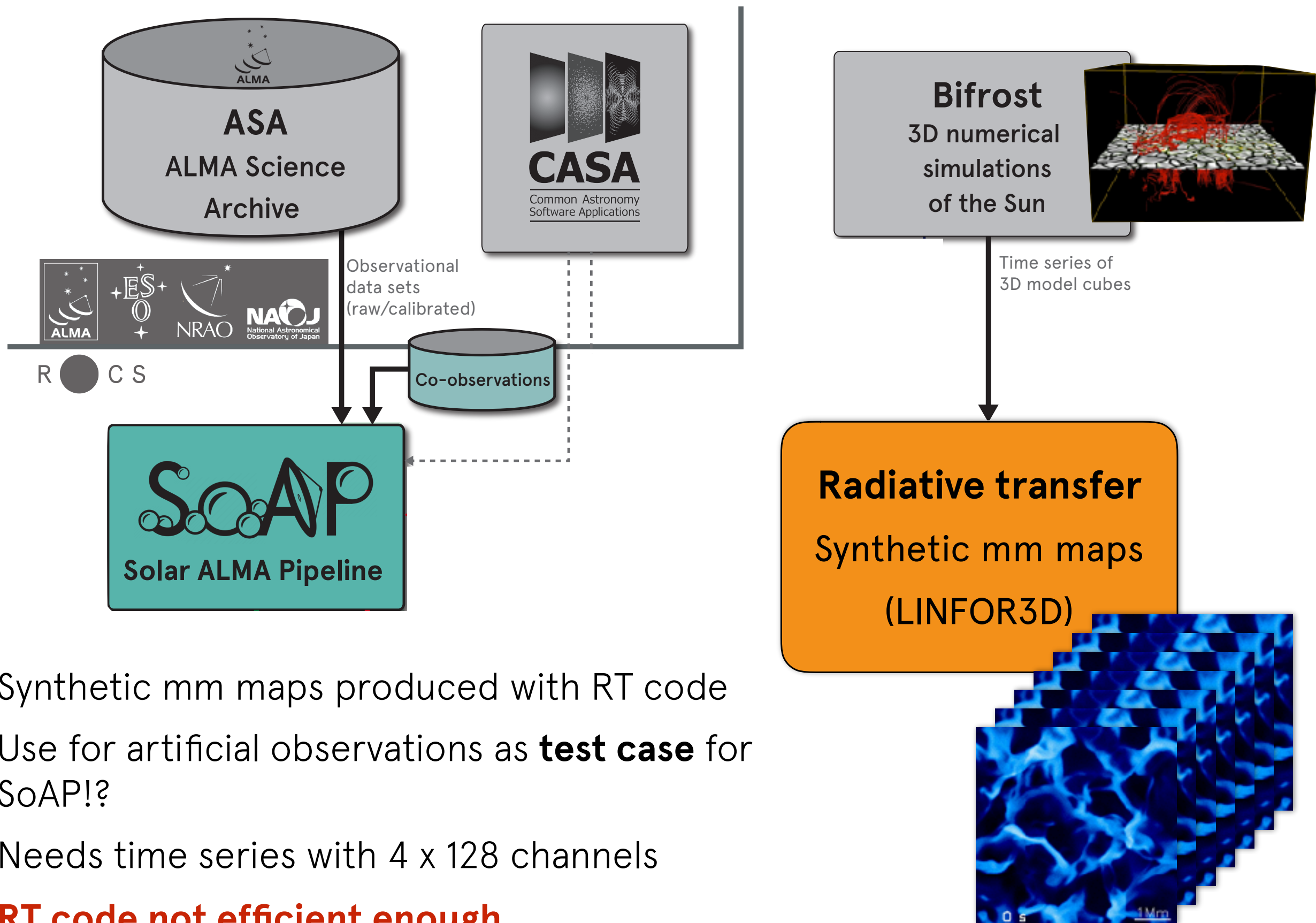
- Some features appeared/disappeared depending on parameters





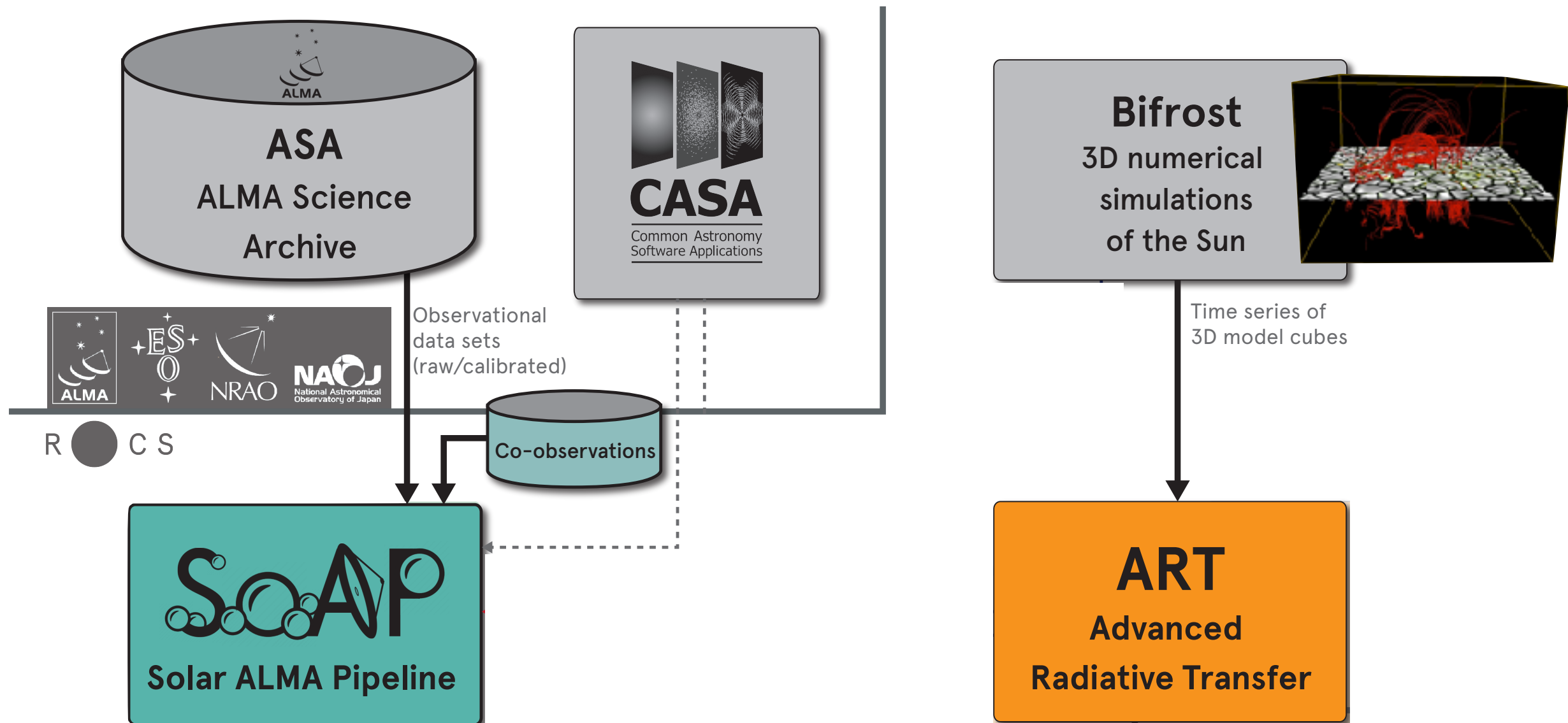
- Accuracy of the produced brightness temperatures?
- How to assess that?
- ➔ Needs a "ground truth" to compare to.

- Development of a data pipeline with scriptForPI as starting point
- Routine data processing resulting in stable time series of brightness temperature maps
- Co-alignment with other observations (SDO, IRIS,...)
- ➔ **Science-ready data!**



- Synthetic mm maps produced with RT code
- Use for artificial observations as **test case** for SoAP!?
- Needs time series with 4 x 128 channels
- **RT code not efficient enough**





- **PRACE Preparatory Access Type D (8/2017 – 6/2018)**

- Mikolaj Szydlarski, Marcin Krotkiewski (SIGMA2 / UiO)

- Per-core performance improvement of optimised code:

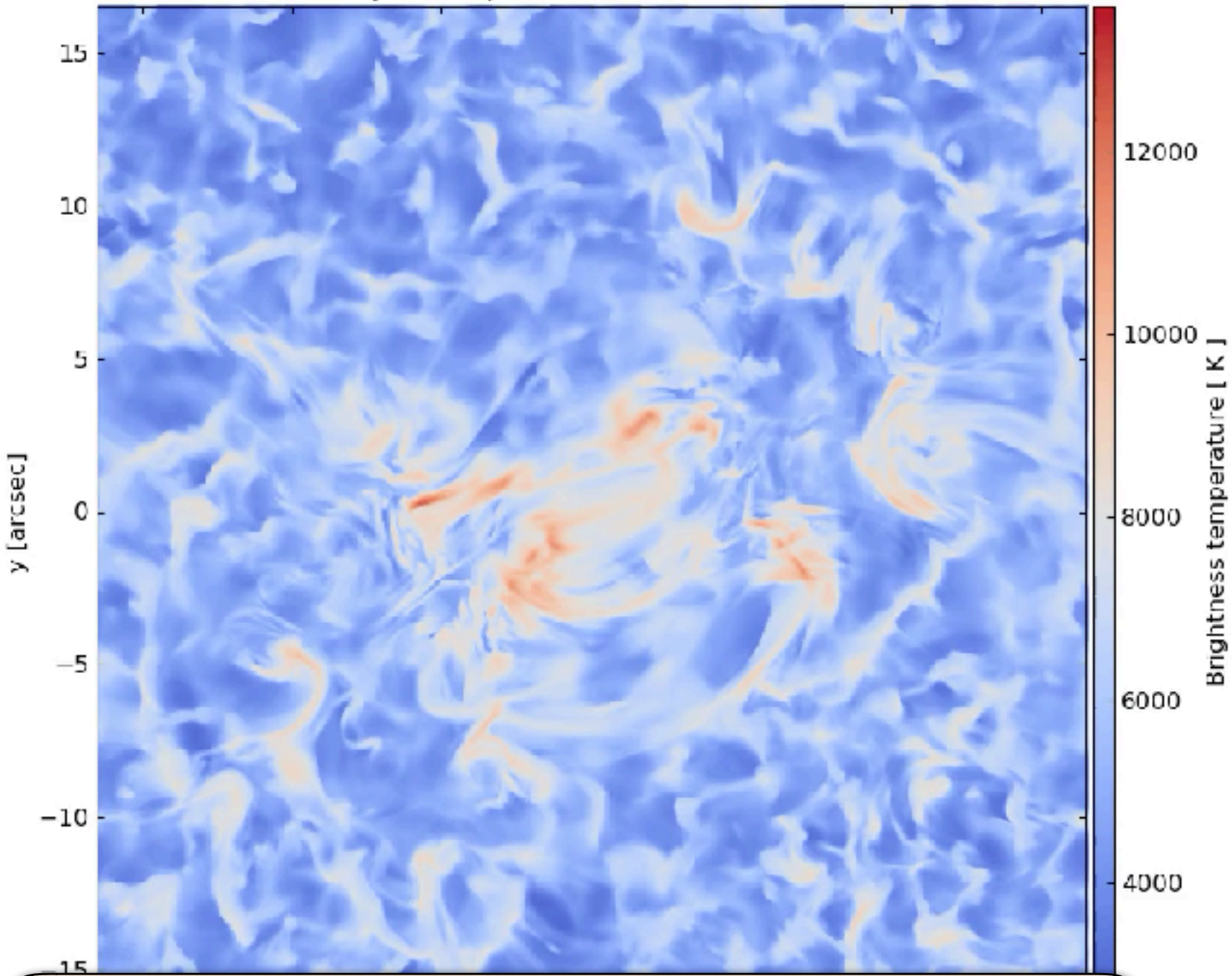
- MPI implementation scales with 95% efficiency on 2048 cores.

- **Optimized ART 110 times faster** in terms of time/core/wavelength for same problem size than previously used LINFOR3D

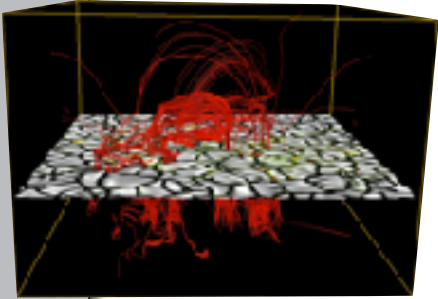
*(original version by Jaime de la Cruz Rodriguez, Stockholm University)*



Intensity for feq = 230.000 GHz : t=0.00 min



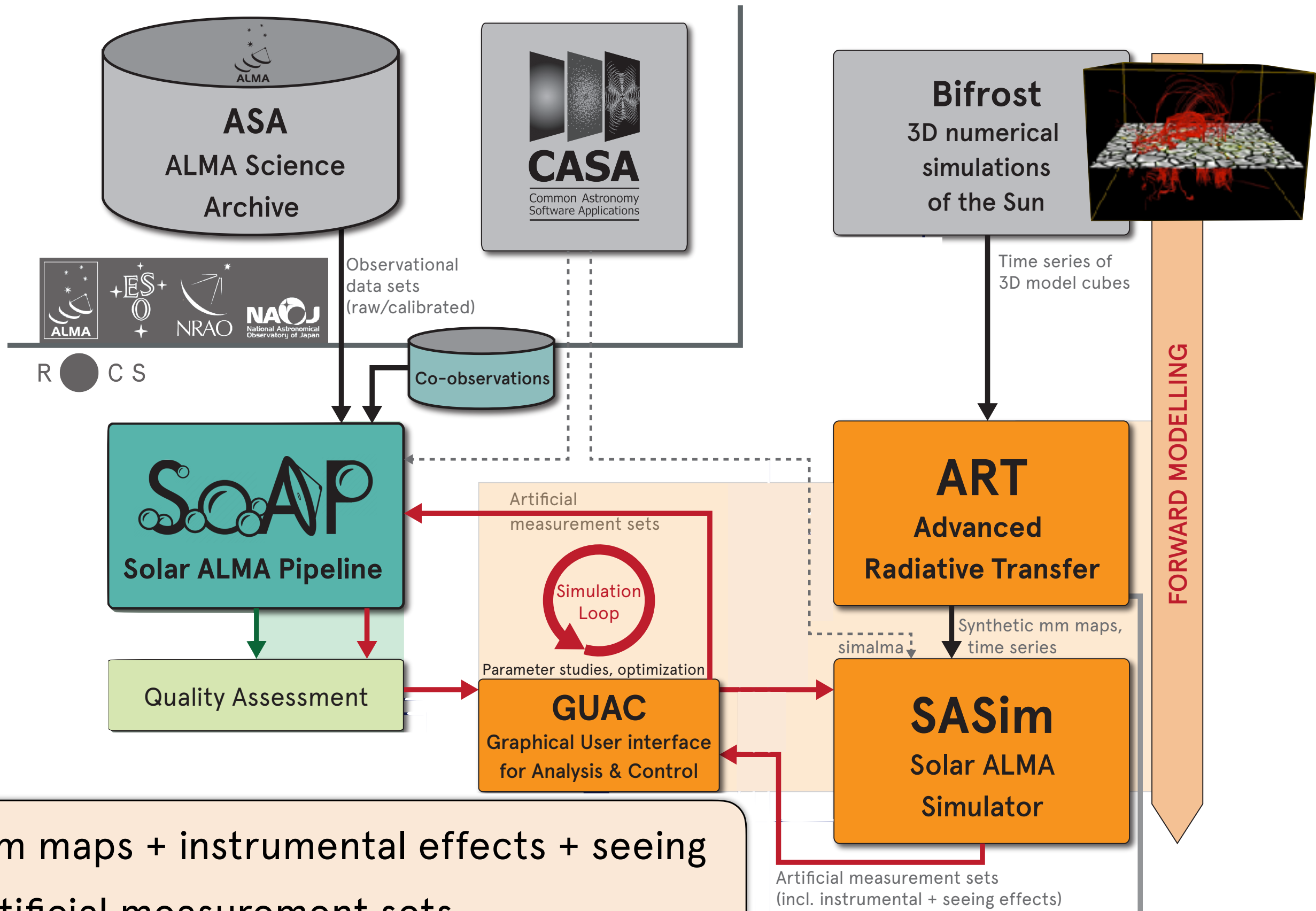
**Bifrost**  
3D numerical  
simulations  
of the Sun



Time series of  
3D model cubes

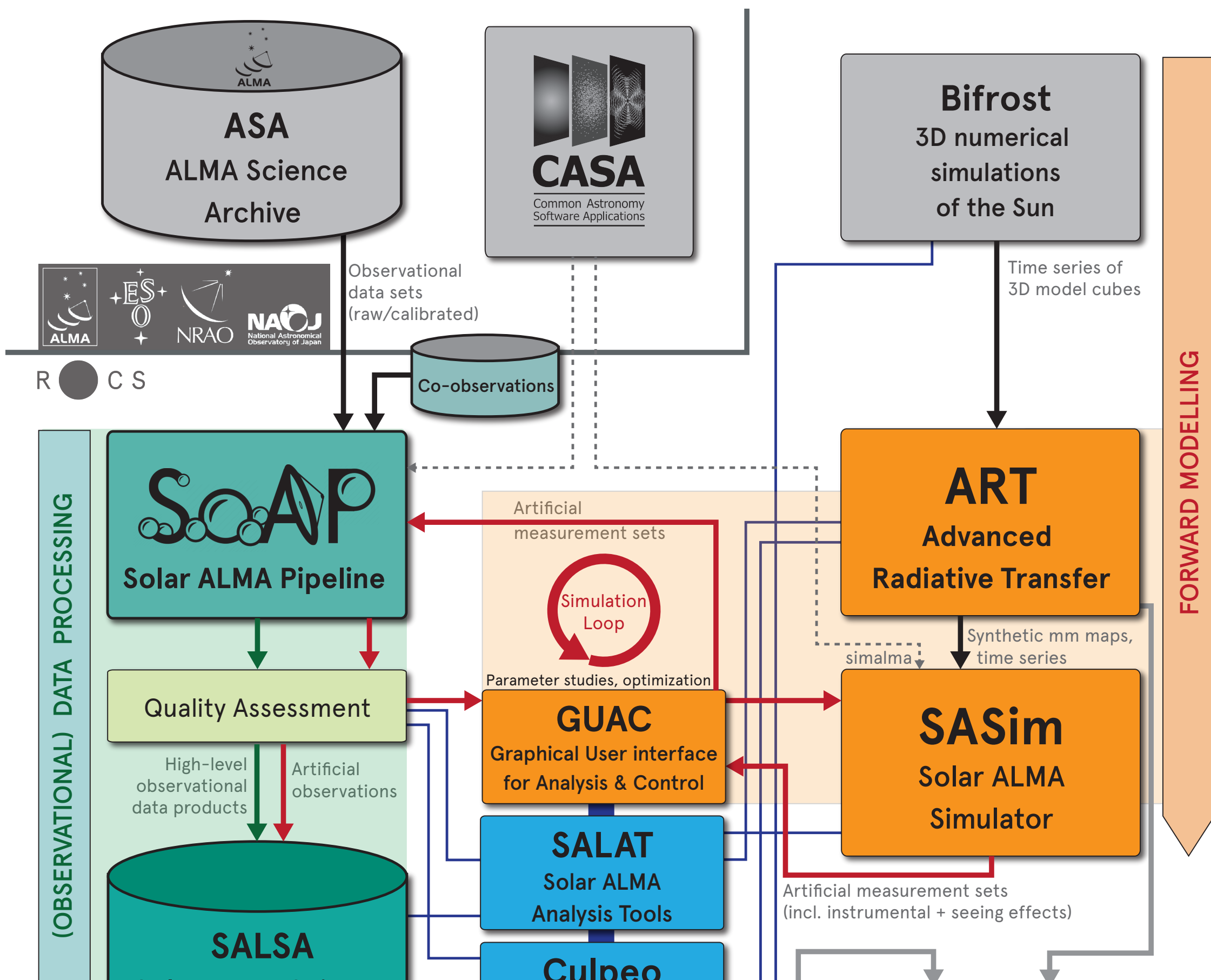
**ART**  
Advanced  
Radiative Transfer

- mm maps + instrumental effects + seeing
- ➔ Artificial measurement sets



- mm maps + instrumental effects + seeing
- ➔ Artificial measurement sets





**ASA**  
ALMA Science Archive

**CASA**  
Common Astronomy Software Applications

**Bifrost**  
3D numerical simulations of the Sun

ALMA ES O NRAO NAOJ National Astronomical Observatory of Japan

Observational data sets (raw/calibrated)

Co-observations

Time series of 3D model cubes

**Observation**

(OBSERVATIONAL) DATA PROCESSING

**SOAP**  
Solar ALMA Pipeline

Quality Assessment

High-level observational data products

Artificial observations

**SALSA**  
Solar ALMA Science Archive

**Simulation**

Artificial measurement sets

Simulation Loop

Parameter studies, optimization

**GUAC**  
Graphical User interface for Analysis & Control

**ART**  
Advanced Radiative Transfer

Synthetic mm maps, time series

**SASim**  
Solar ALMA Simulator

FORWARD MODELLING

**Analysis**

**SALAT**  
Solar ALMA Analysis Tool

**Culpeo**  
Interactive Data Visualisation Tool

Artificial measurement sets (incl. instrumental + seeing effects)

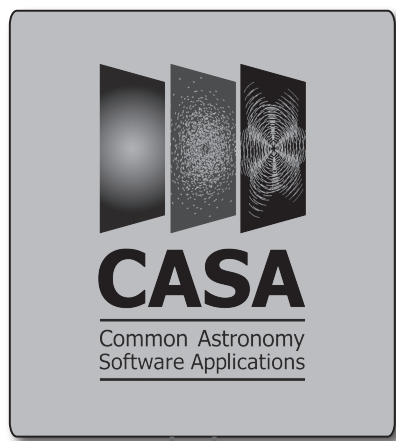
**Data Inversion**

Derived physical quantities

Observation

Simulation

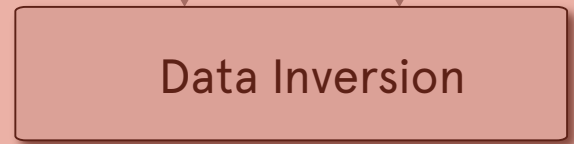
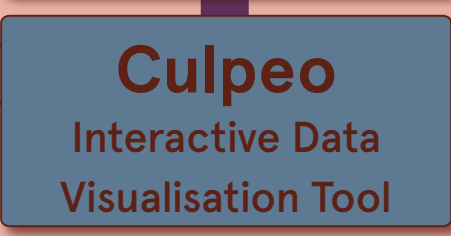
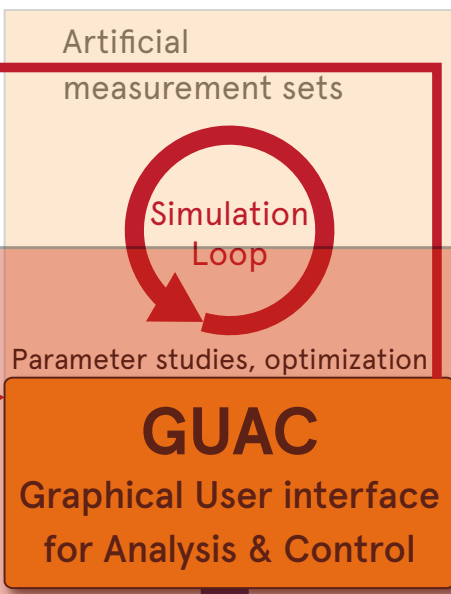
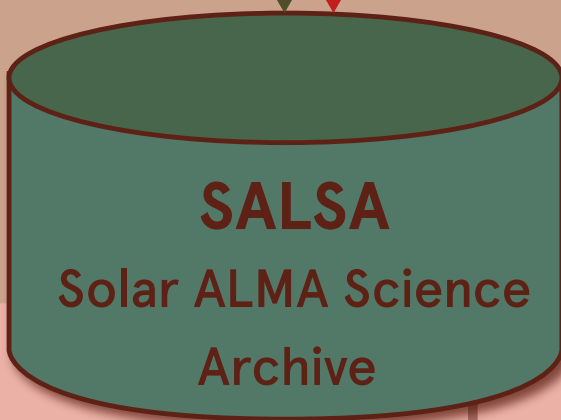
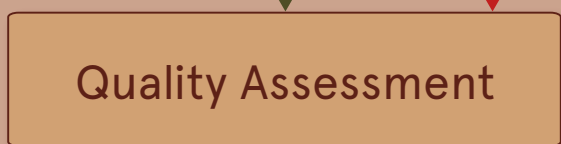
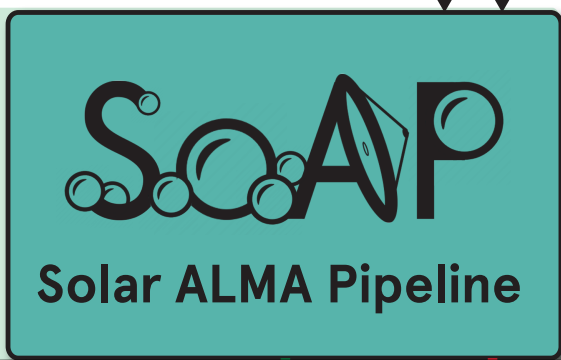
Analysis



Observational data sets (raw/calibrated)



Under development (OBSERVATIONAL) DATA PROCESSING



Under development FORWARD MODELLING

Under development

Derived physical quantities

High-level observational data products

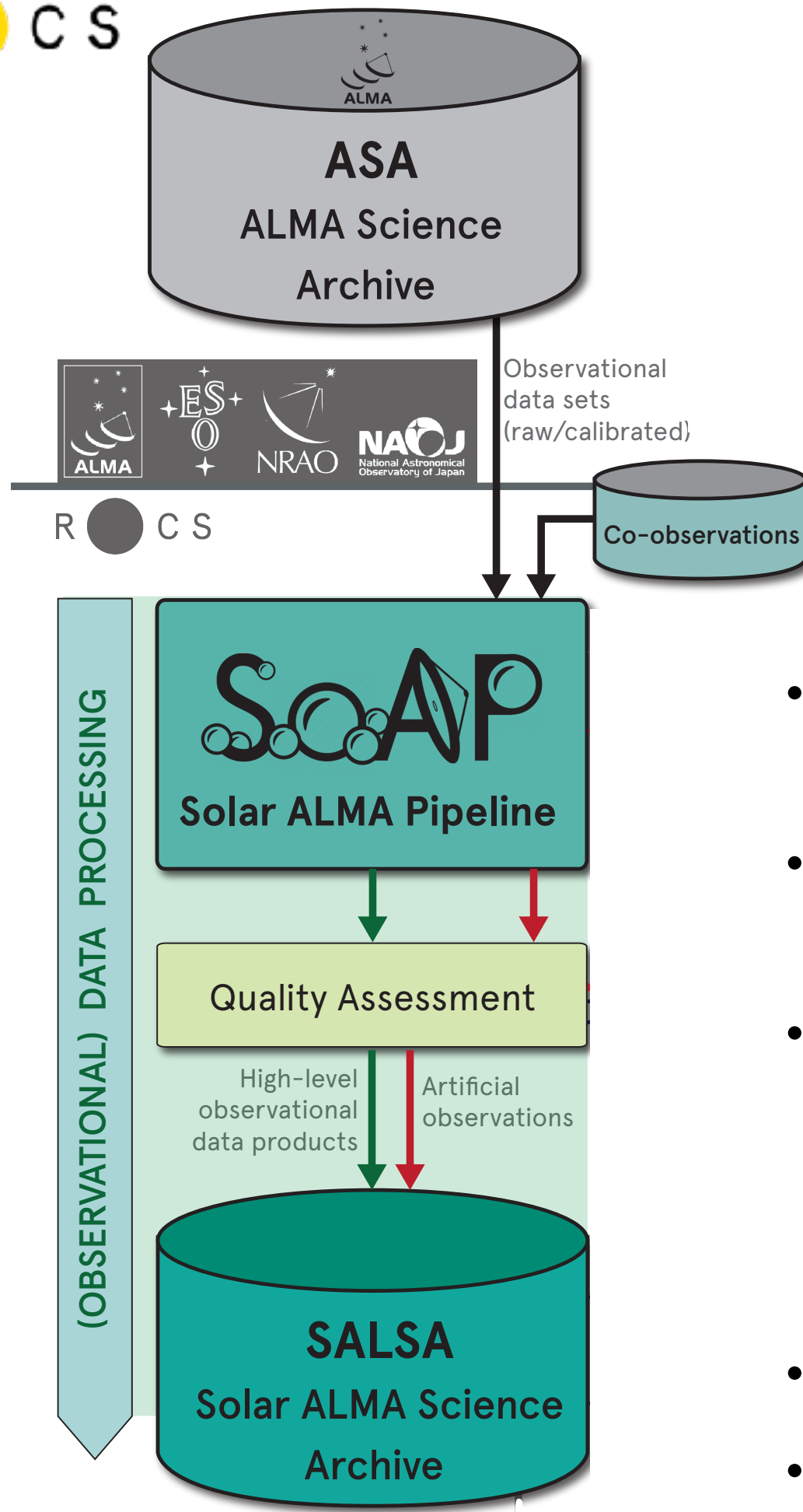
Artificial observations

synalma Synthetic mm maps, time series

Artificial measurement sets (incl. instrumental + seeing effects)







# SALSA

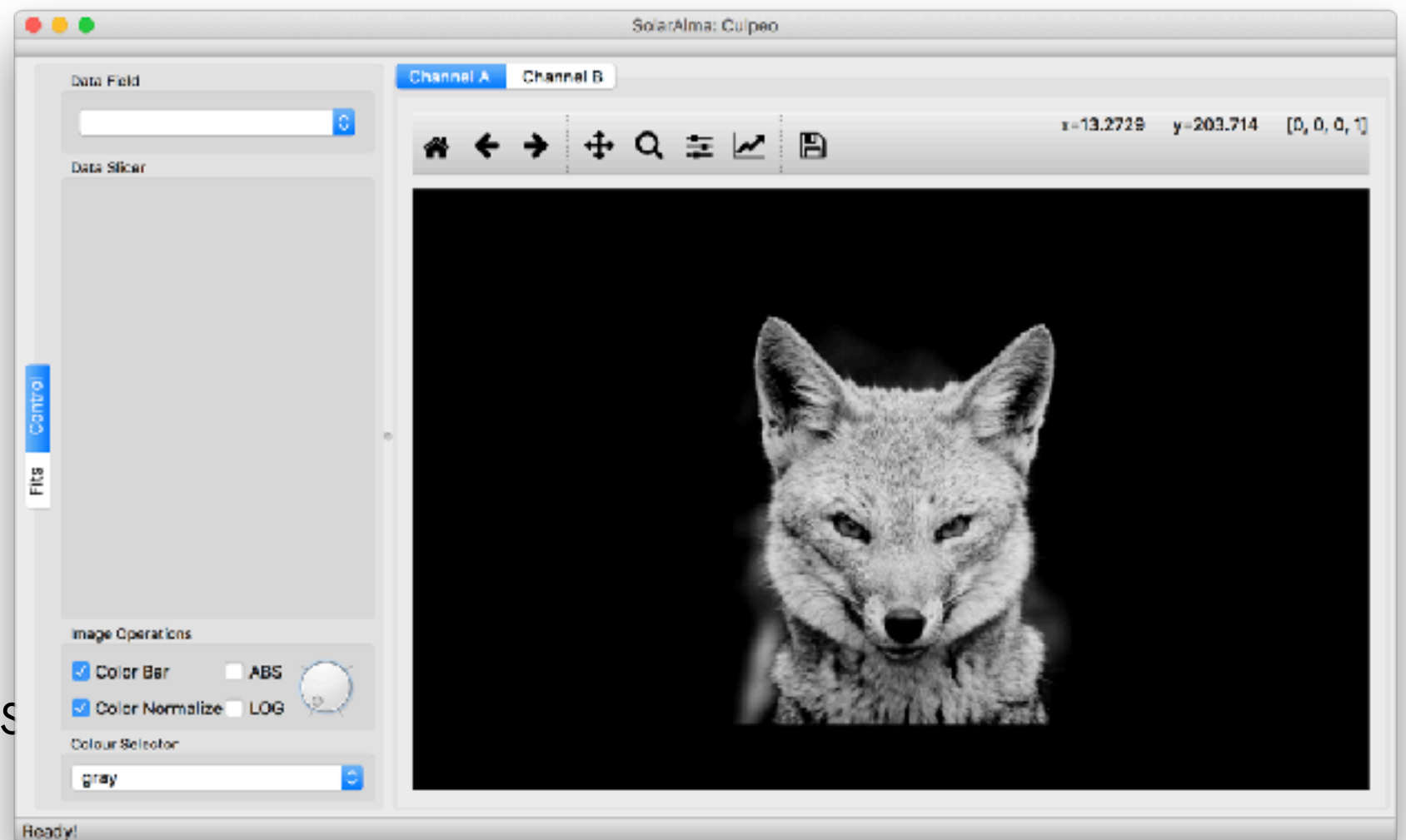
## Solar ALMA Science Archive

- Science-ready data
- Data usable by non-expert users (i.e. without expertise in solar mm)
- Only high-level data products as produced with SoAP
- No duplication, no conflict with official ALMA Science Archive
- Planned: Integration into the (Hinode) **Science Data Centre Europe** hosted here at ITA/UiO
  - Web-interface
- Eventually opened to the public
- International collaboration wanted

# CULPEO

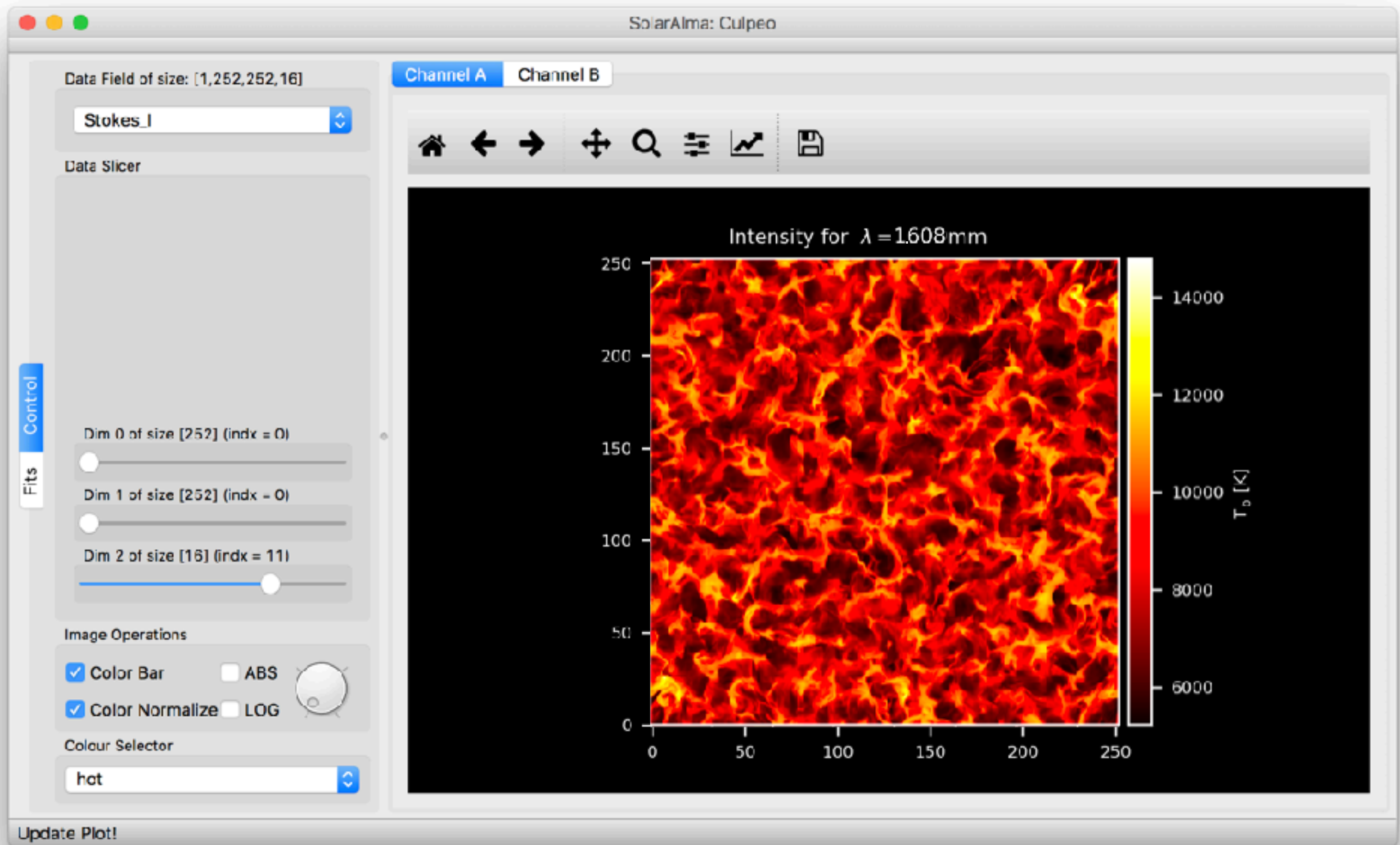
## INTERACTIVE DATA VISUALISATION & ANALYSIS

- Quick-look & analysis tool for:
  - 3D simulations
  - synthetic mm maps
  - ALMA observations
- Python-based (multi-OS) GUI
- Handles 4D cubes  $[x,y,t,v]$ ,  $[x,y,z,t]$ ,...
- Real-time radiative transfer (GPU accelerated)
- Launch pad for more focused analysis tools



# CULPEO

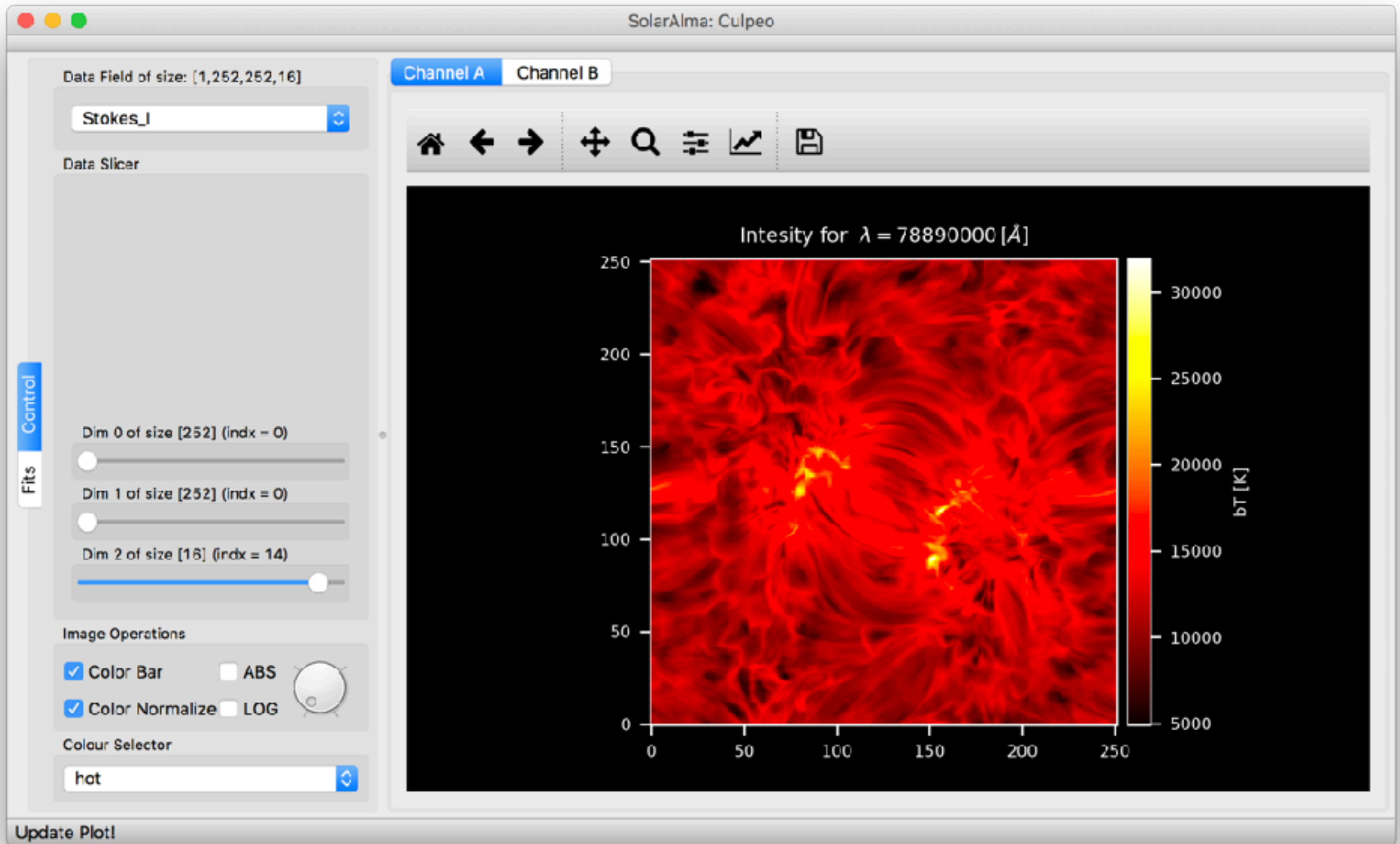
## INTERACTIVE DATA VISUALISATION & ANALYSIS





# CULPEO

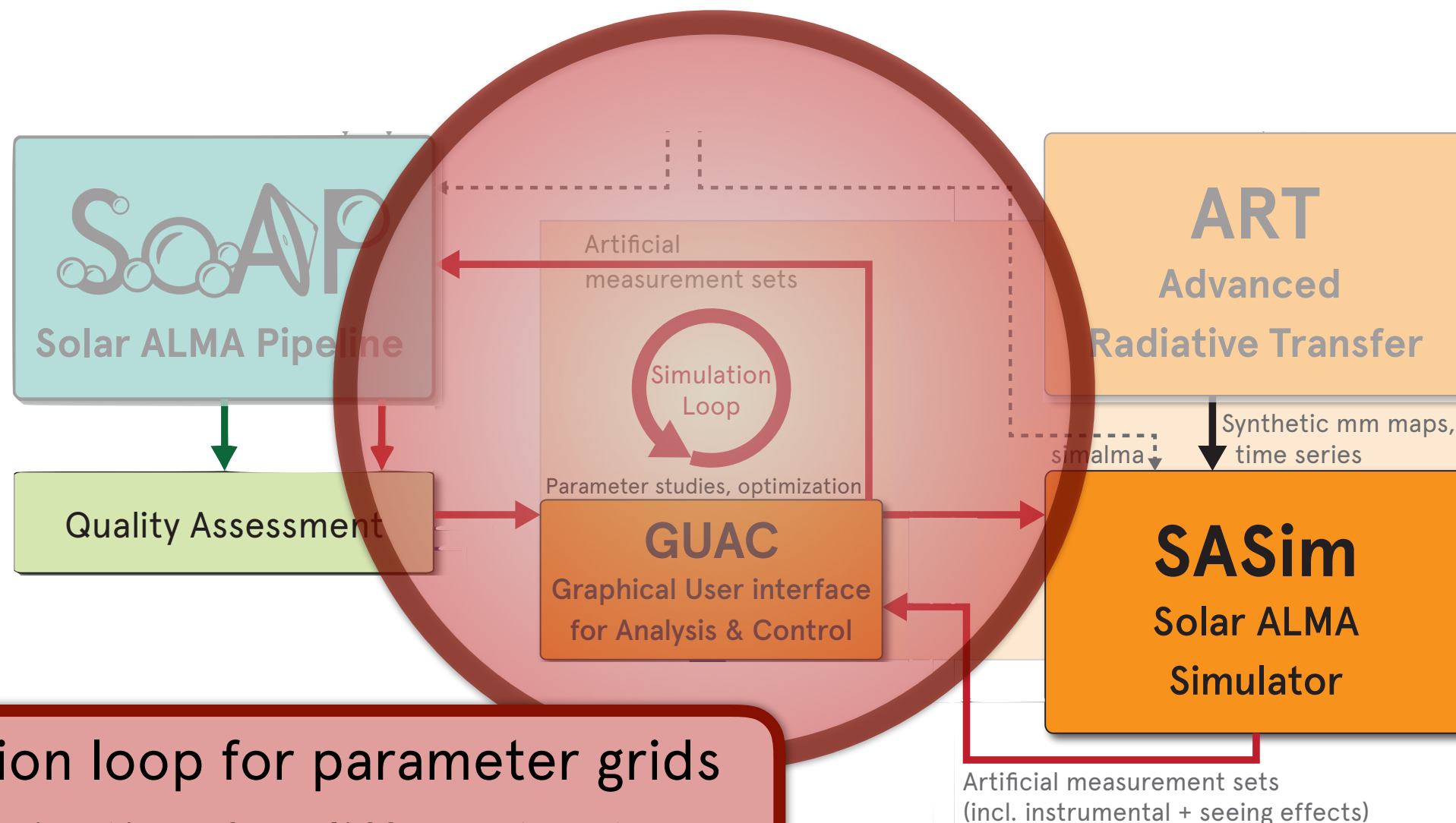
## INTERACTIVE DATA VISUALISATION & ANALYSIS



# SASIM

## SOLAR ALMA SIMULATOR

- Starting point: simalma
- Developed in connection with ESO ALMA Development Study
- Primary aim: simulation-based optimisation of high-cadence solar imaging



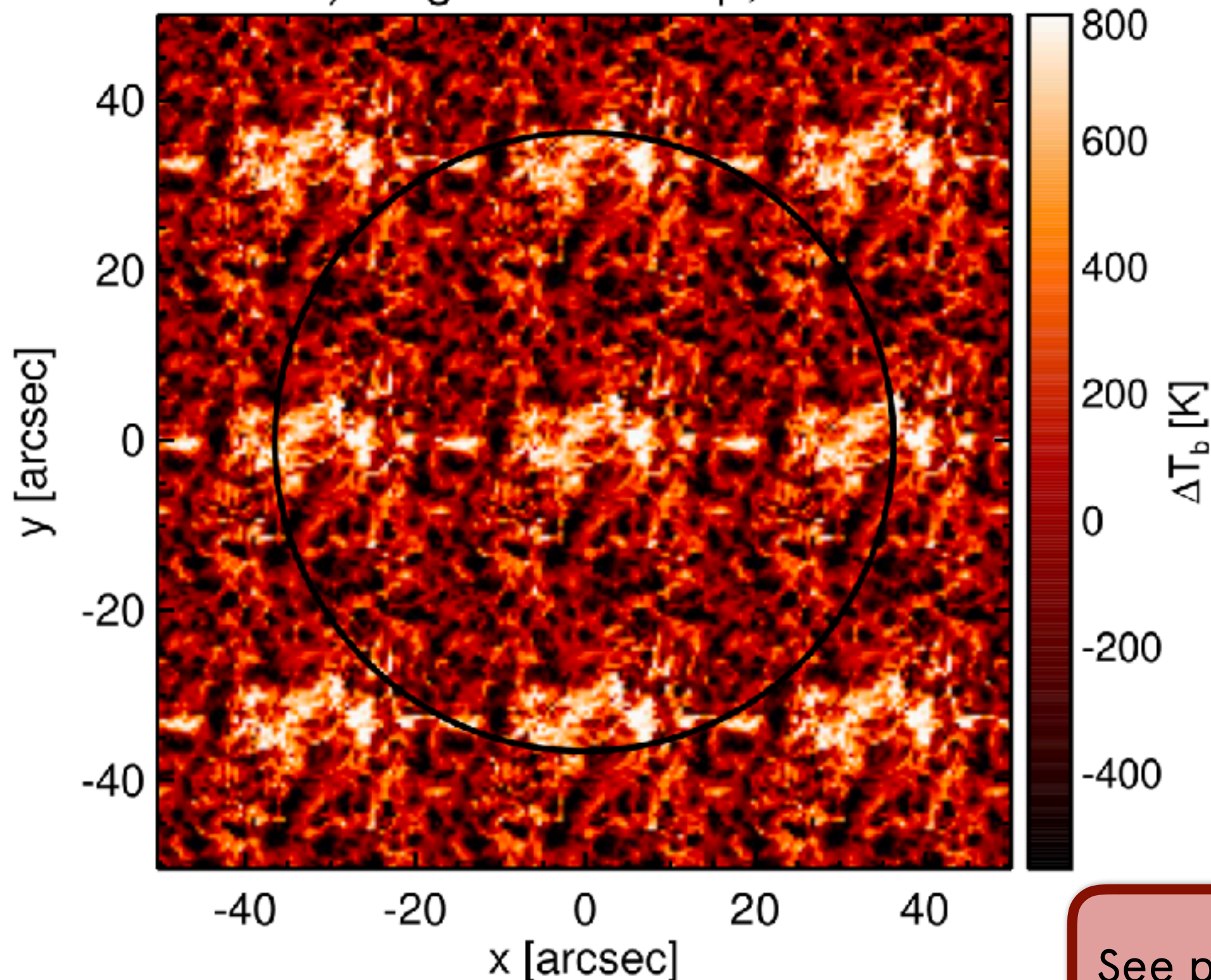
- Simulation loop for parameter grids  
➔ Optimisation for different set-ups



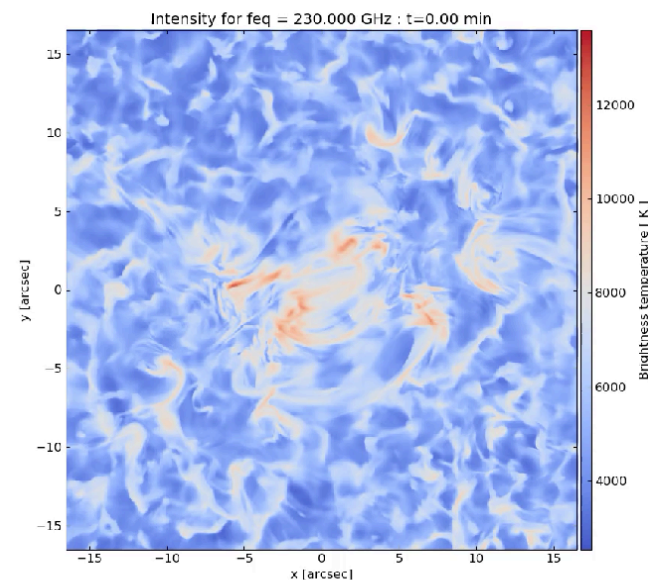
## Band 3

## One snapshot only

a) Original mm map, SB4



- Synthetic mm map (periodically repeated for increased extent)



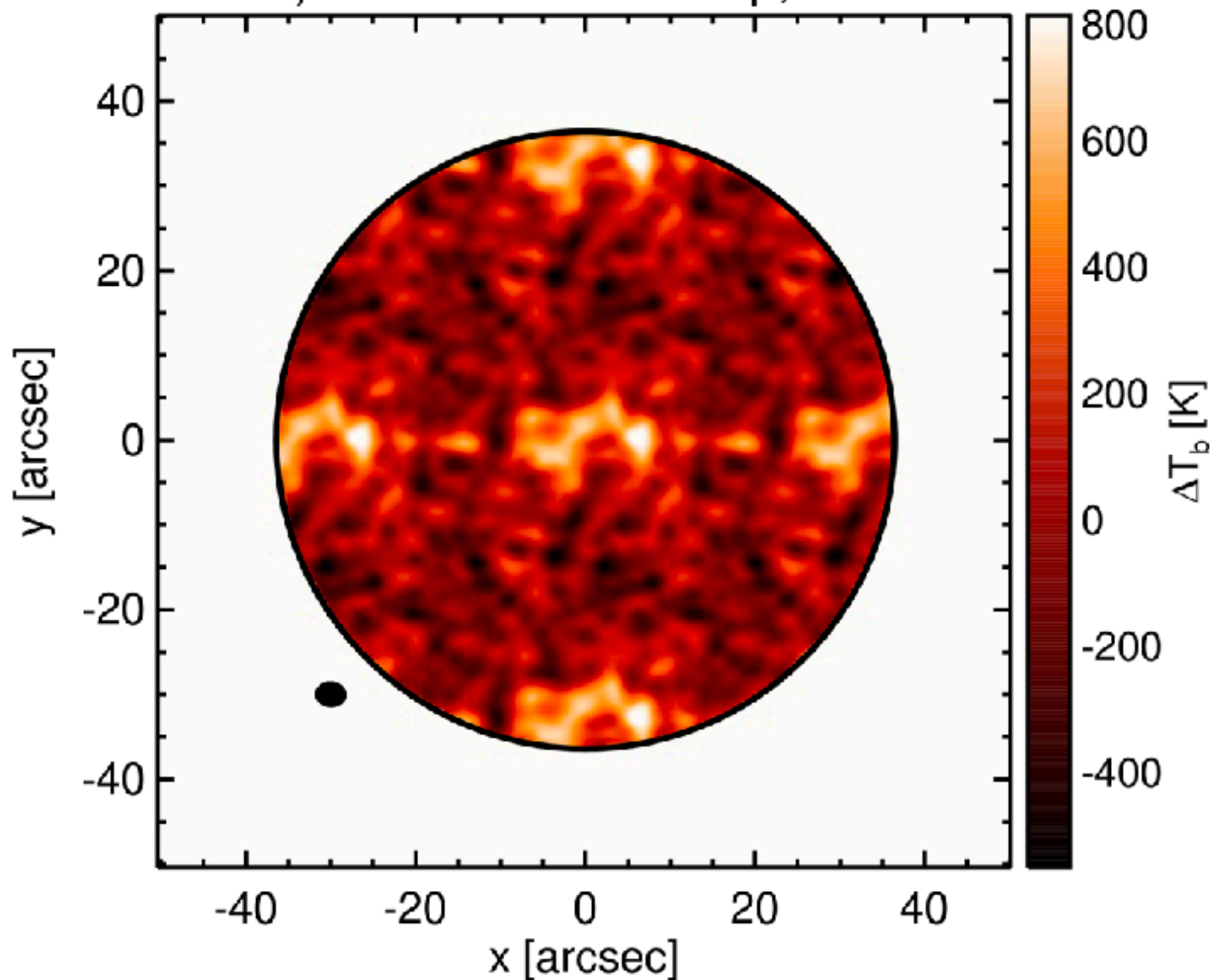
See poster by Henrik Eklund



# FIRST EXPERIMENTS

## Band 3

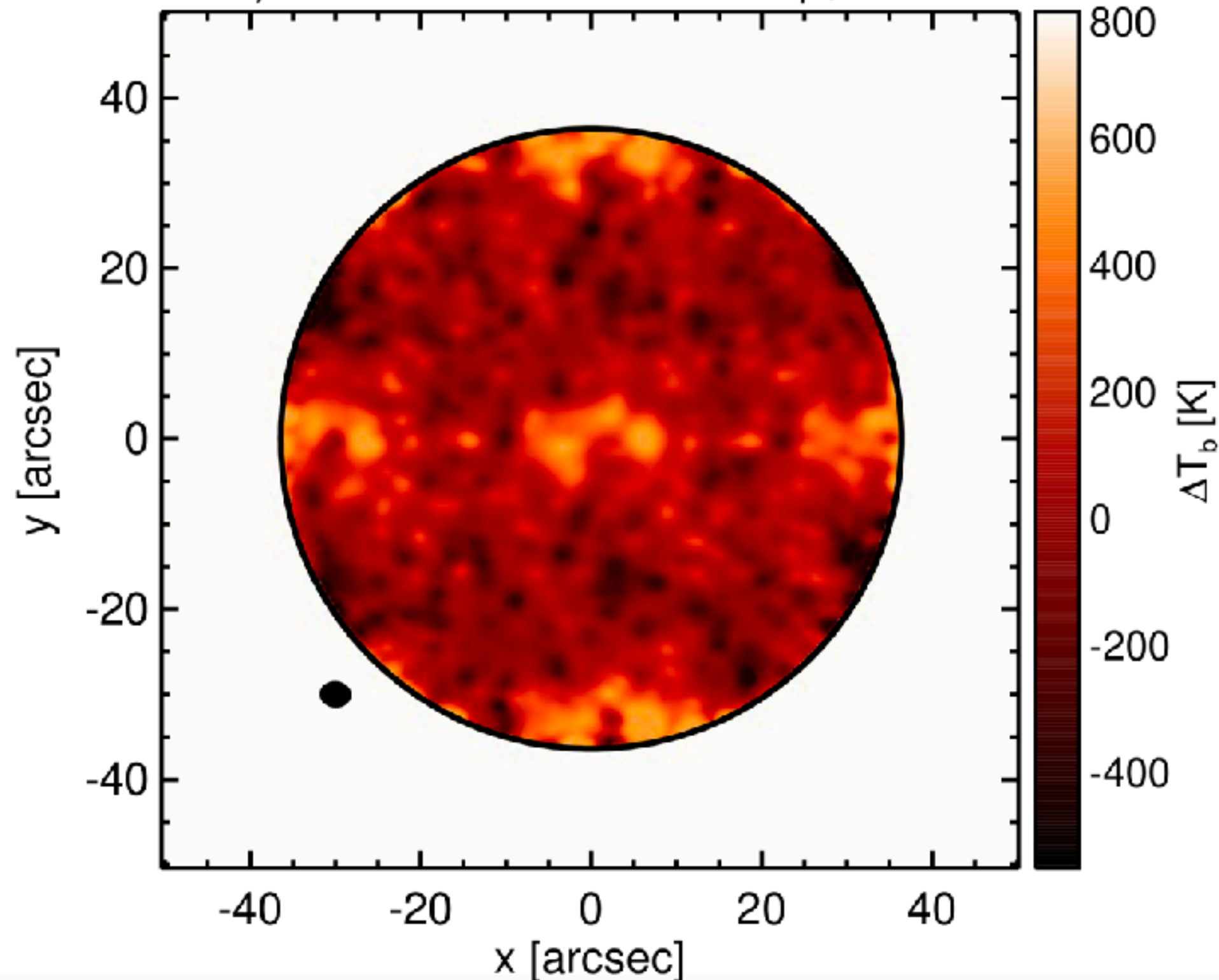
b) Convolved mm map, SB4



- Result for perfect image reconstruction and complete uv coverage
- Small scales lost here due to angular resolution and limited number of baselines

## Band 3

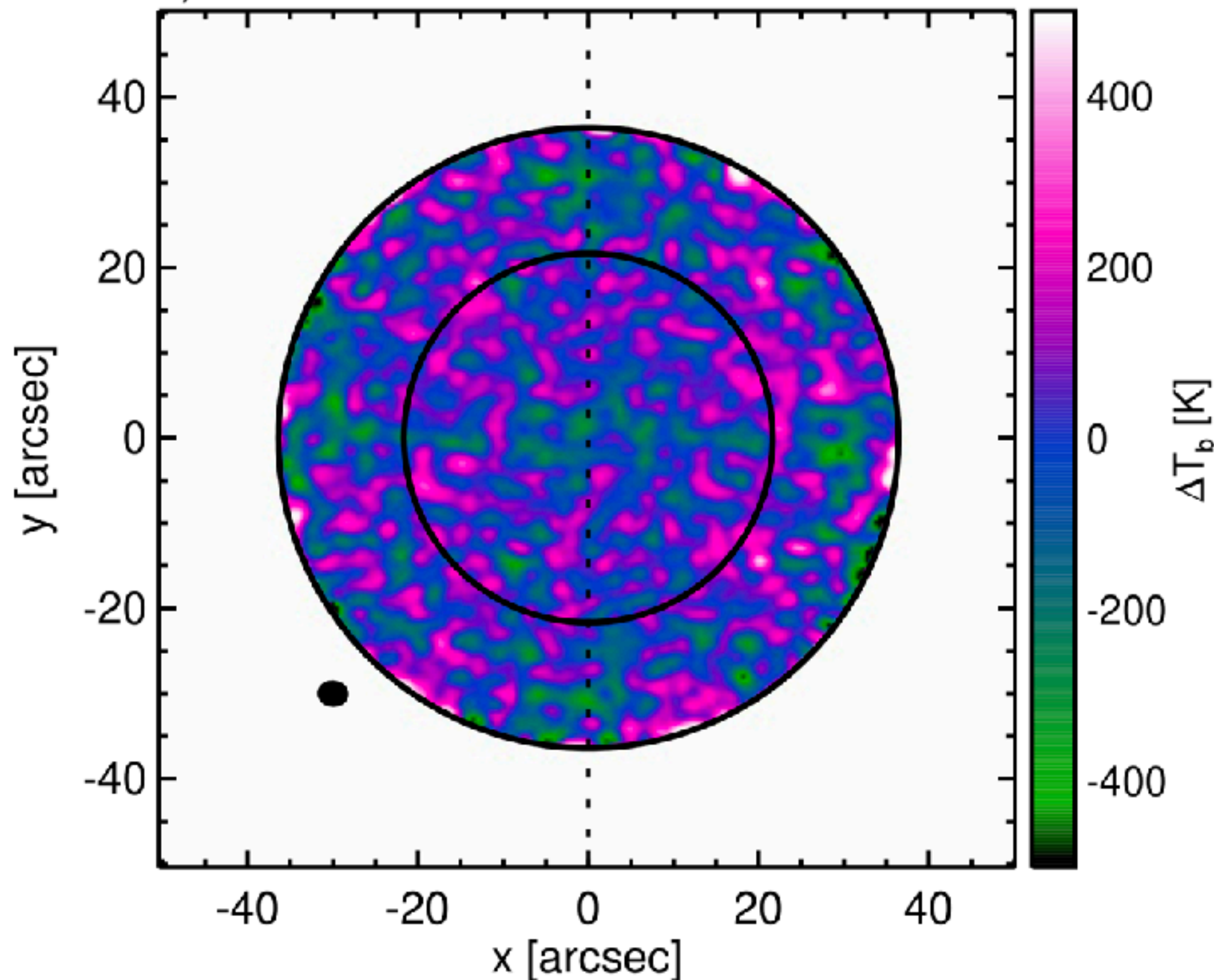
c) Reconstructed mm map, SB4



- Reconstructed map
- Same parameters as currently used for real Cycle 4 ALMA observations
- Reconstruction not perfect

## Band 3

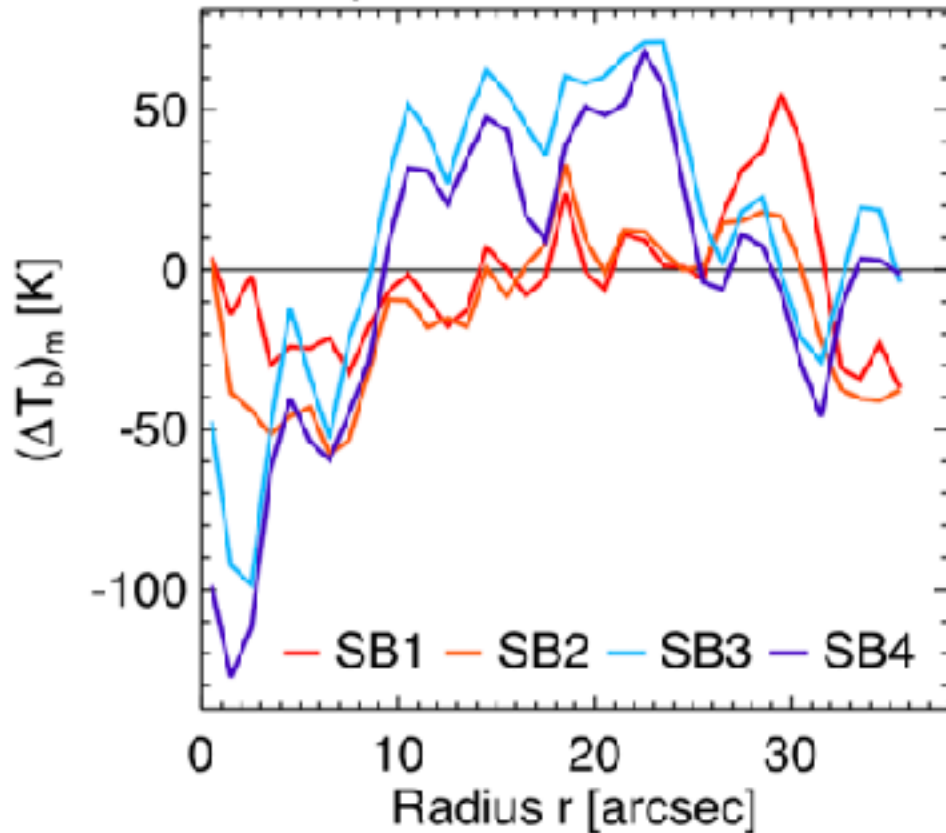
d) Residual: reconstructed - convolved



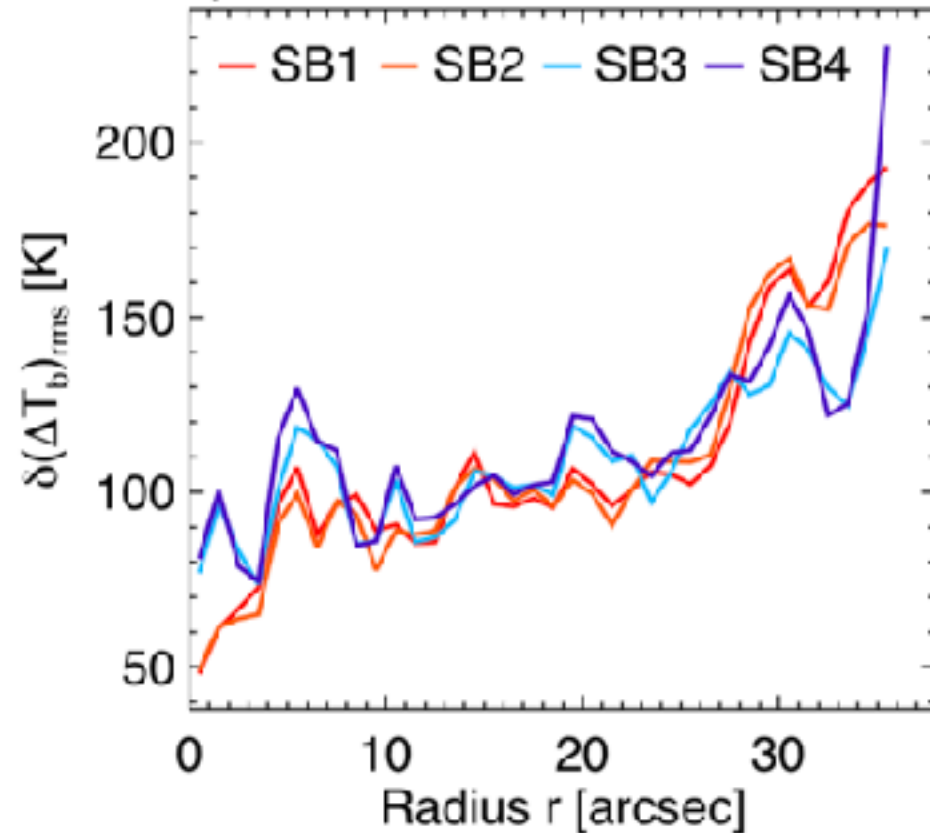
- Comparison of input and output
  - Residuals can be used as primary quality indicator
- ➔ To be repeated for parameter grid



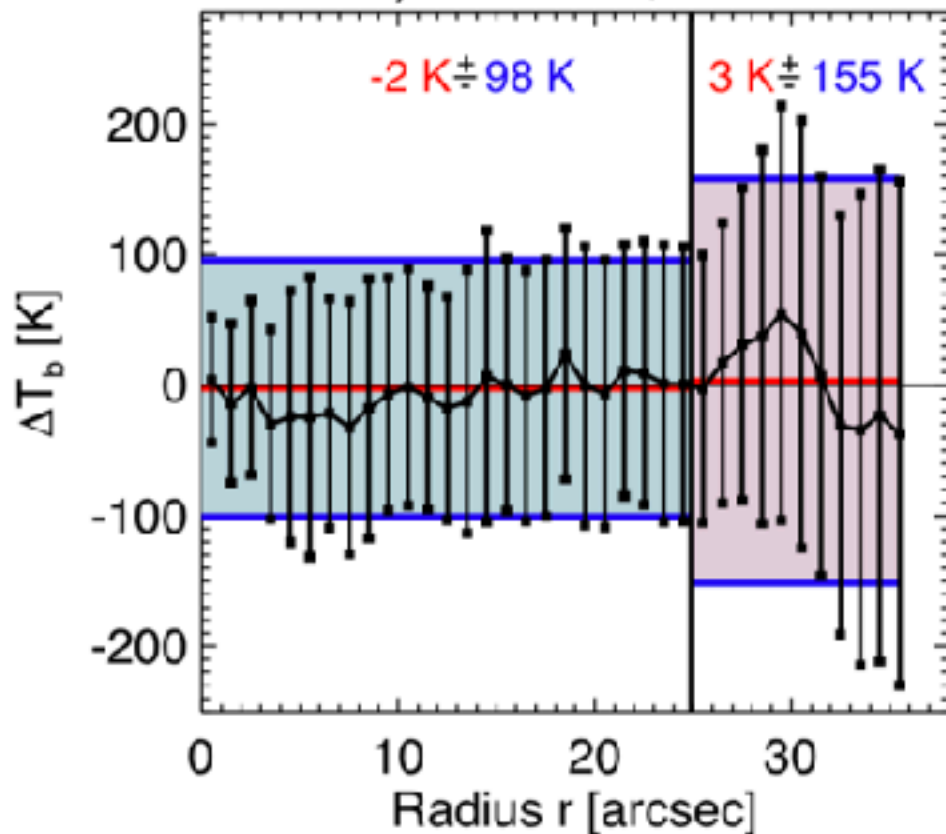
a) Residual, median



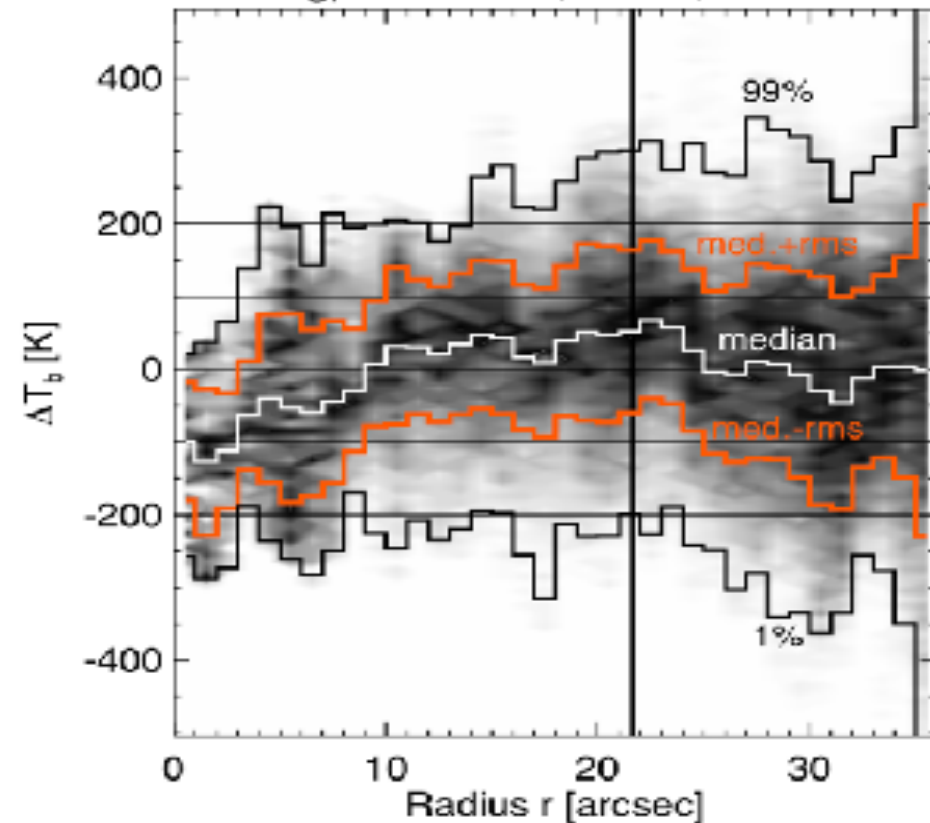
b) Residual, standard deviation



c) Residual, SB1



g) Residuals, radial, SB4

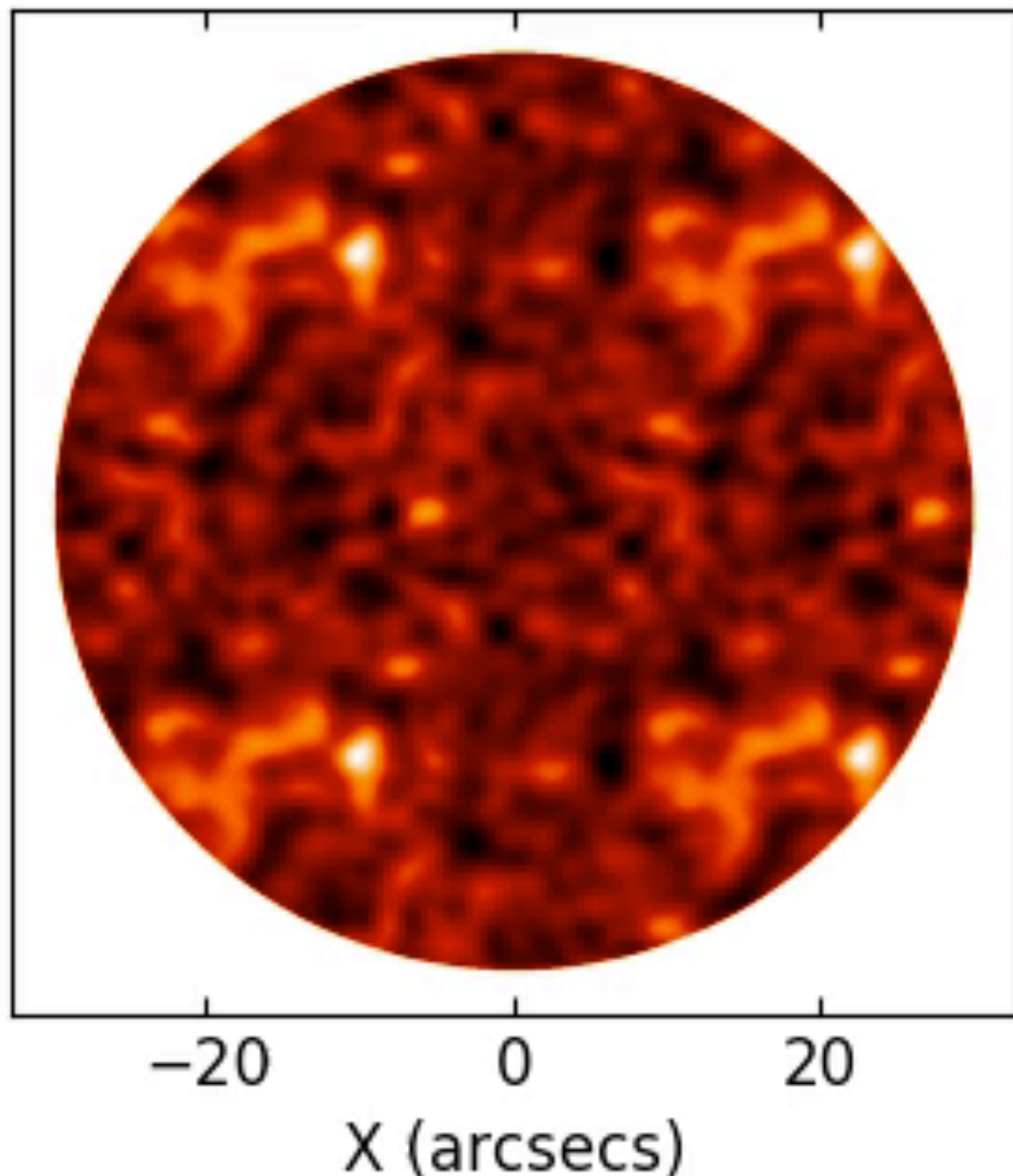


# SASIM

## SOLAR ALMA SIMULATOR

Case: Cycle 5.1

Convolved



## ARRAY CONFIGURATION

*Produced by Szydlarski, Gilchrist-Millar et al.*

- To be developed into a versatile tool for testing new observing modes and optimised imaging of resulting data

## OBSERVATIONS

- User-friendly data pipeline
- Optimisation for different scientific applications
- Co-alignment with other solar observations (ground-based/space-borne)
- Database for processed data for everybody (incl. non-expert users)



## ANALYSIS & VISUALISATION

- User-friendly interactive tools
- Multi-purpose visualisation & analysis tools for various data products from observations and simulations
- Versatile tool library (python/CASA/IDL)

## SIMULATIONS

- Realistic models of the solar atmosphere
- Detailed modelling of instrumental and seeing effects
- Simulation loop for testing and optimising imaging routines and new observing modes
- Artificial observations in support of interpretation of observations

# OUTLOOK

- Development of tools for solar research with ALMA is an integral activity of the Rosseland Centre for Solar Physics.
  - Dedicated resources and efforts
  - International collaboration

**★AIM: Providing easy access to science-ready data for the solar physics community**







Rosseland  
Centre  
for Solar  
Physics