A step forward in studying Cosmic Microwave Background polarized signal: the LSPE/STRIP balloon experiment

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Large Scale Polarization Explorer

agenzia spaziale italiana

The Big Bang Theory

- First proposed by Georges Lemaître in 1927
- It predicts that the Universe starts to expand about **13.7 billion years ago** from singolarity
- At the beginning the Universe was in a Quark-Gluon plasma state extremely hot and dense ($\rho \approx 10^{25}\ \mathrm{g/cm^3}$ and $T \approx 10^{15}\ K$ @ $t \approx 10^{-8}\ s$)
- 3 major experimental evidences:

UNIVERSE EXPANSION

ELEMENT ABUNDANCES IN THE UNIVERSE

COSMIC MICROWAVE BACKGROUND

Cosmic Microwave Background (CMB)

- ~ 3.8 x 10^5 years after the Big Bang the temperature of the universe was ~ 3000 K, low enough to permit the **recombination between electrons and protons**

↓

- The **reduction of the Thomson scattering** cross section lets the photons free to propagate in the space

↓

- Thanks to the expansion of the Universe those photons are visible today as a background radiation in the microwave range: the **Cosmic Microwave Background**

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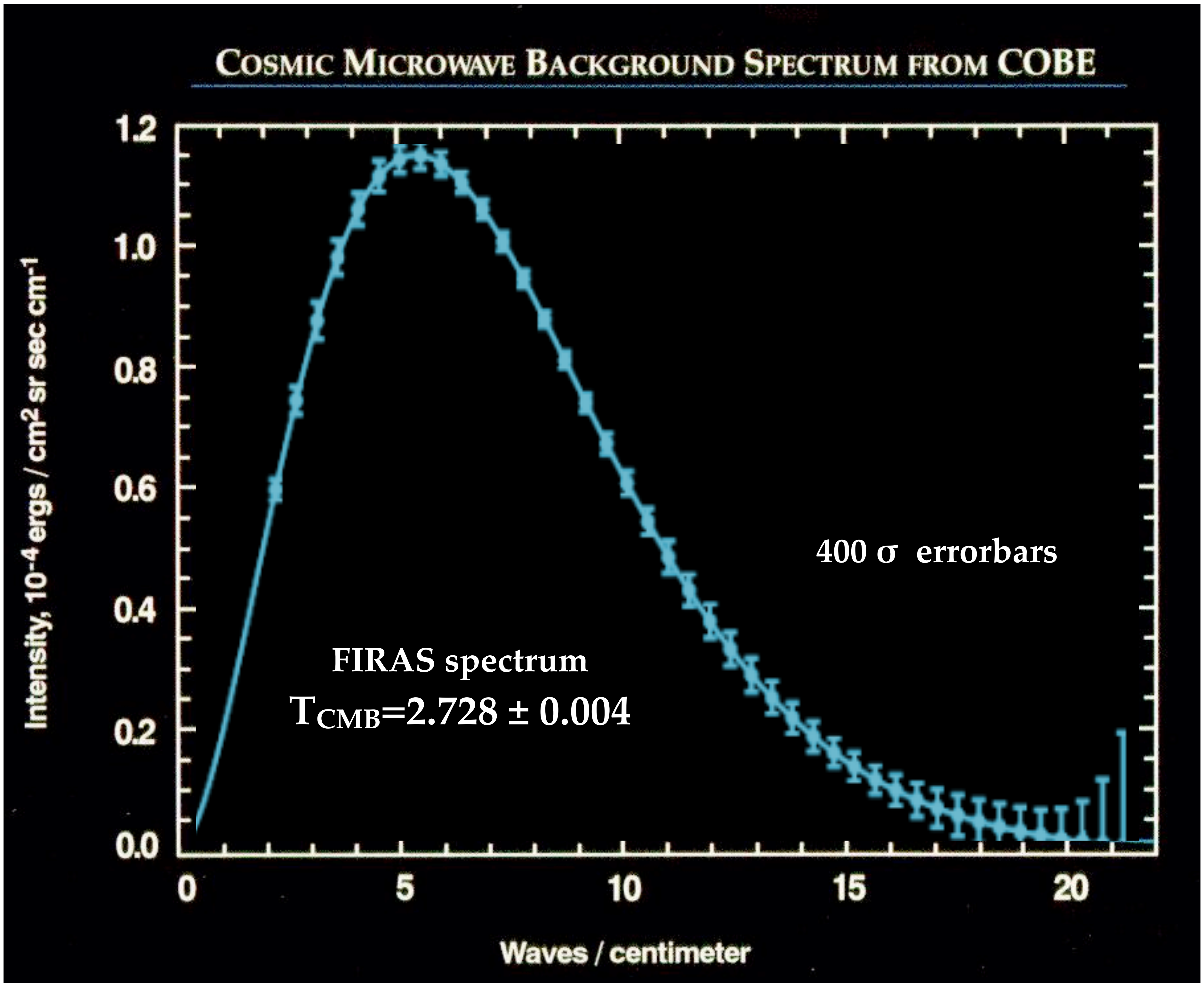
- The presence of a **uniform** and **isotropic** radiation in the Universe was first theorized by George Gamow in 1948 and experimentally observed by chance (!!!!!!) in 1964 by Arno Penzias and Robert Wilson (Nobel Prize 1978)

Cosmic Microwave Background (CMB)

- In 1989 the *COsmic Background Explorer* (COBE) has been the first space mission dedicated to CMB studies (Nobel Prize 2006 to John Mather and George Smoot)



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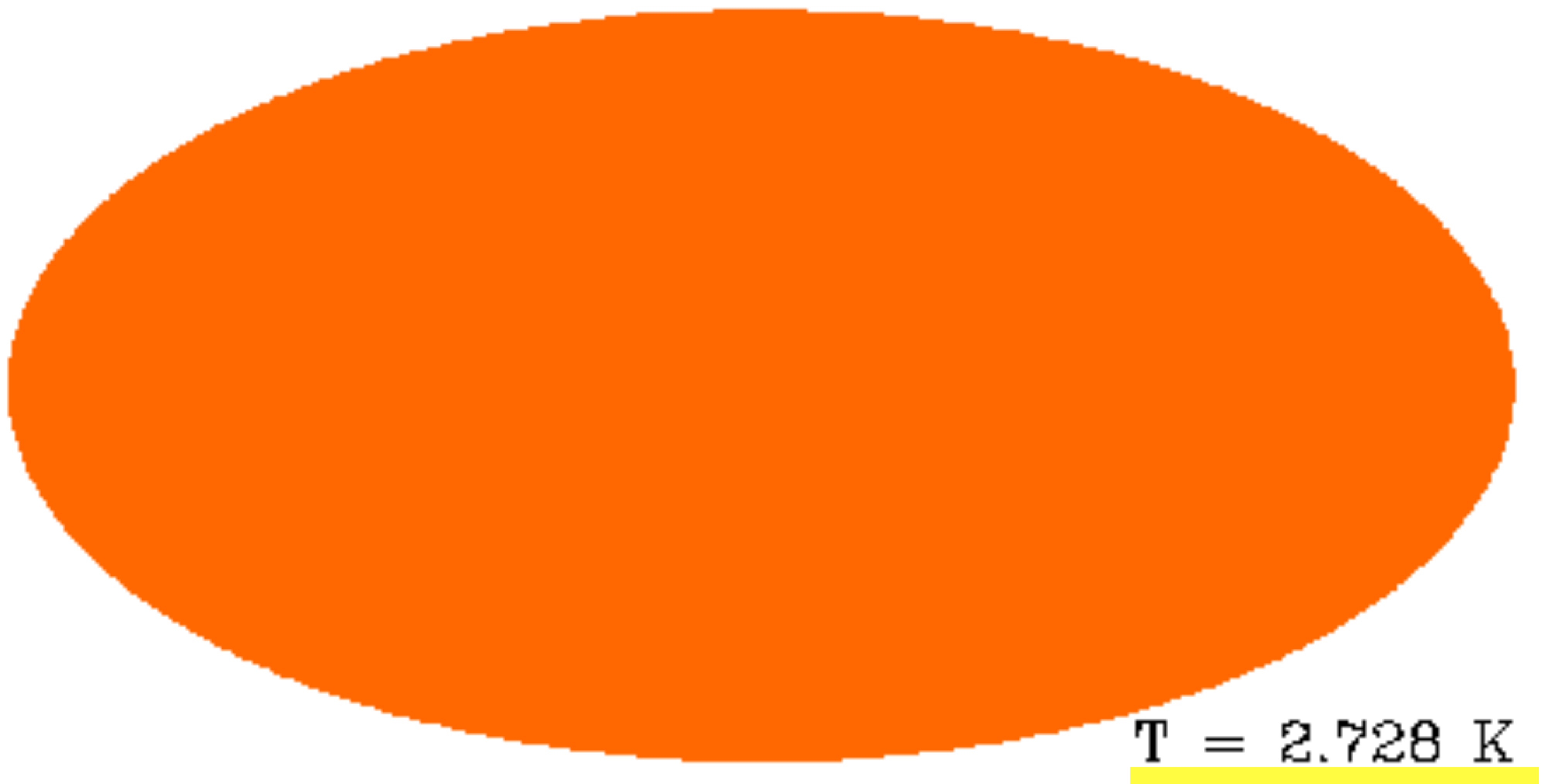
DMR maps



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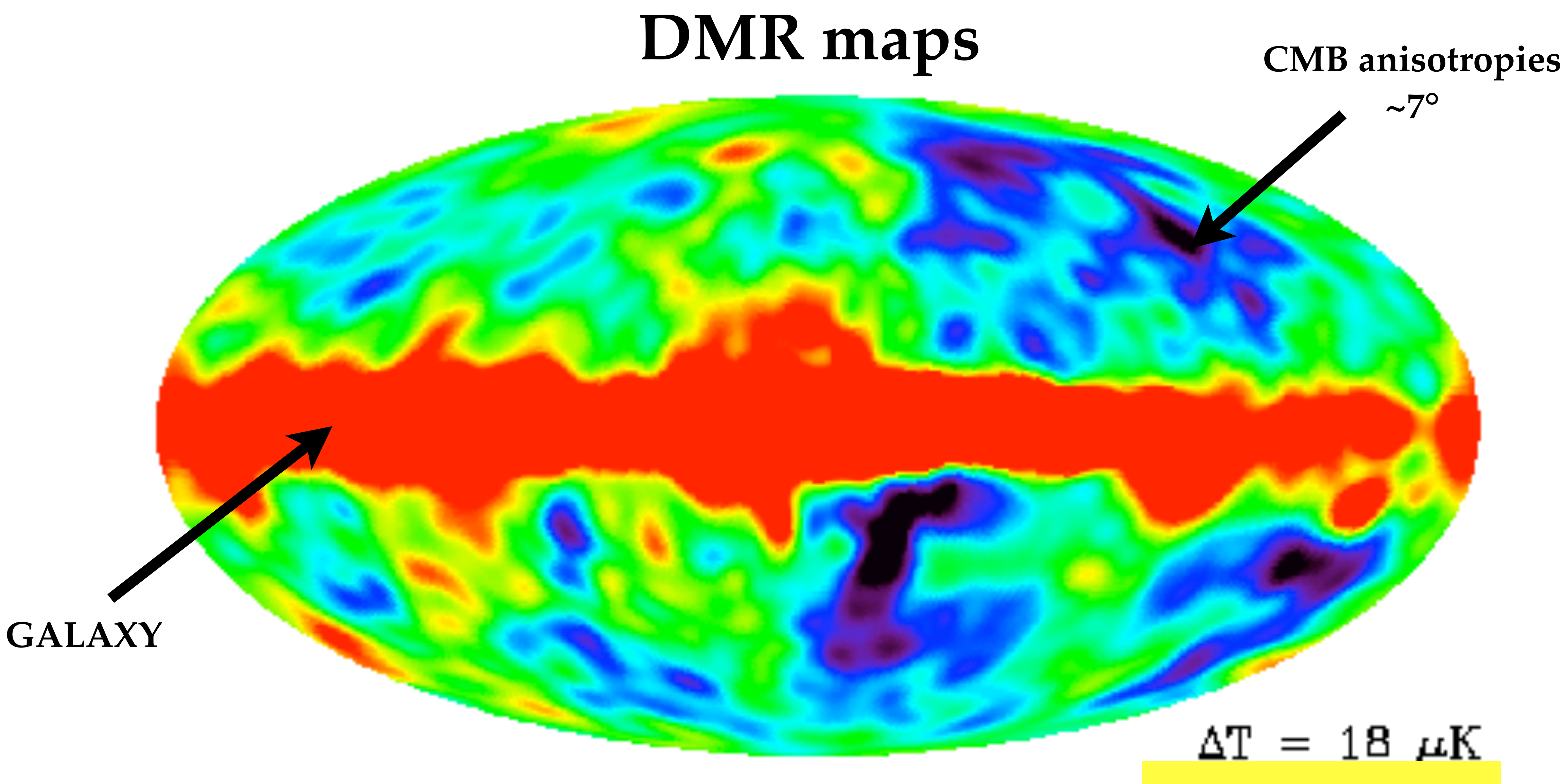
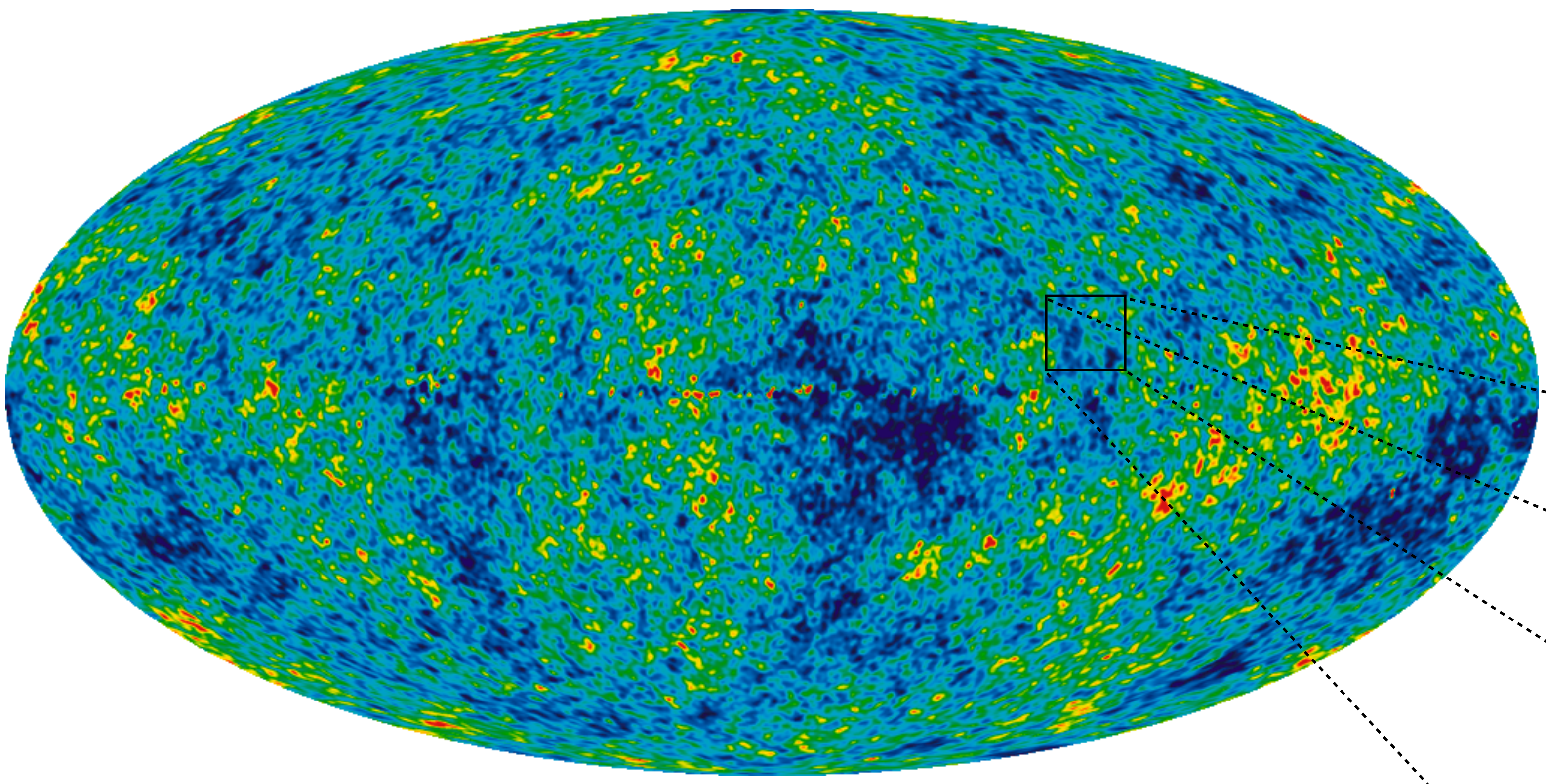
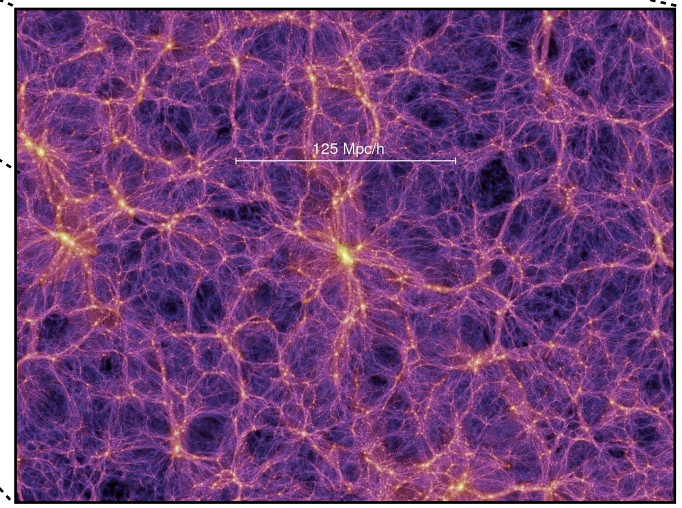


CMB temperature anisotropies

- Temperature anisotropies $\Delta T/T \simeq 10^{-5}$
- These anisotropies describe the composition of the primordial plasma and represent the seeds of structures visible today in our Universe



WMAP 7year Temperature map
14 billion years ago



Millennium simulation
today

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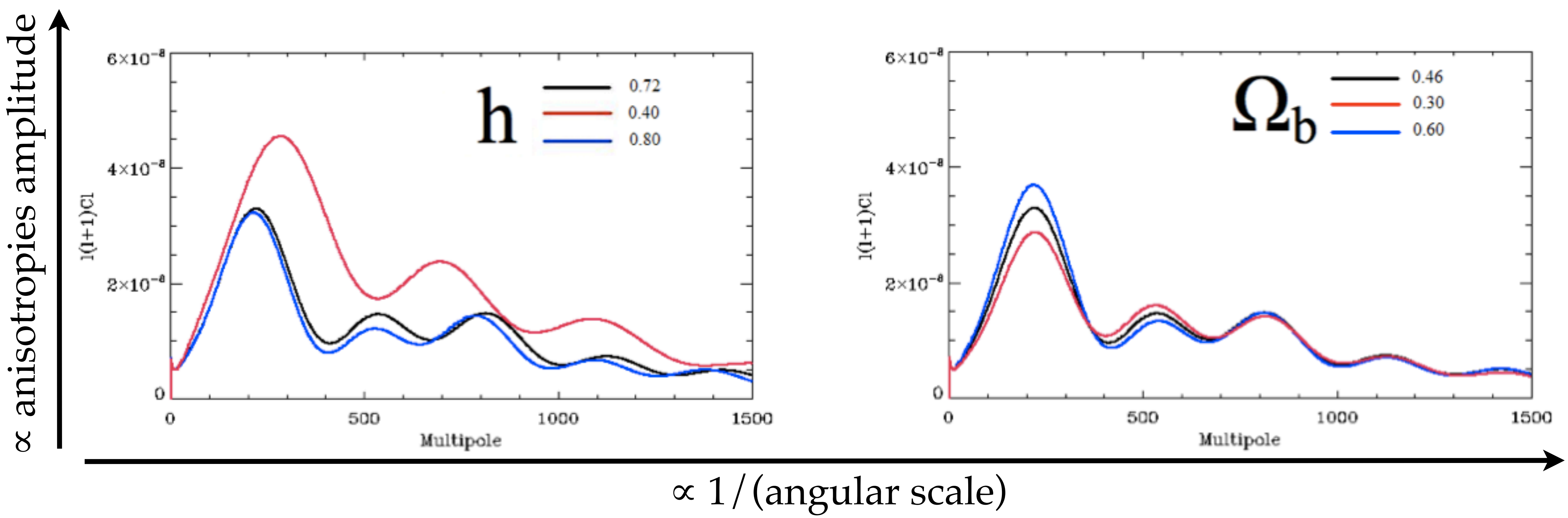
- The POWER SPECTRUM describes the amplitude of anisotropies as a function of the angular scale

- Its shape critically depends on the value assumed by cosmological parameters



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$\downarrow$

- The **Planck satellite** (ESA, 2009) cosmological data will give information about temperature anisotropies restricted only by foreground contaminations.

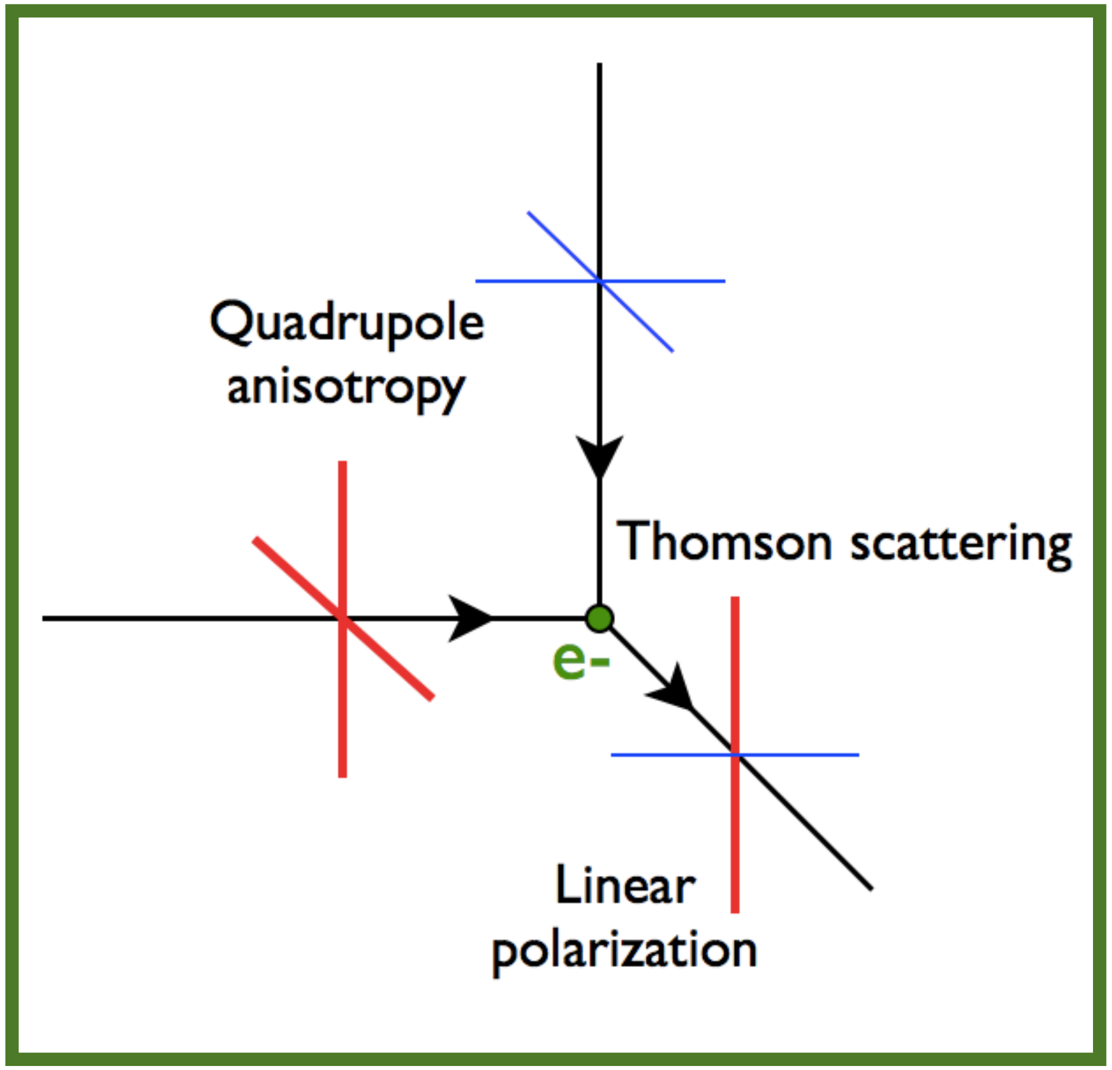
CMB polarization

- **The next generation of instruments will study the polarization characteristics of the CMB signal!!**

- The radiation is polarized thanks to Thomson scattering events during the epoch of recombination

↓

- To generate a net polarized signal a quadrupole anisotropy in the primordial plasma is needed



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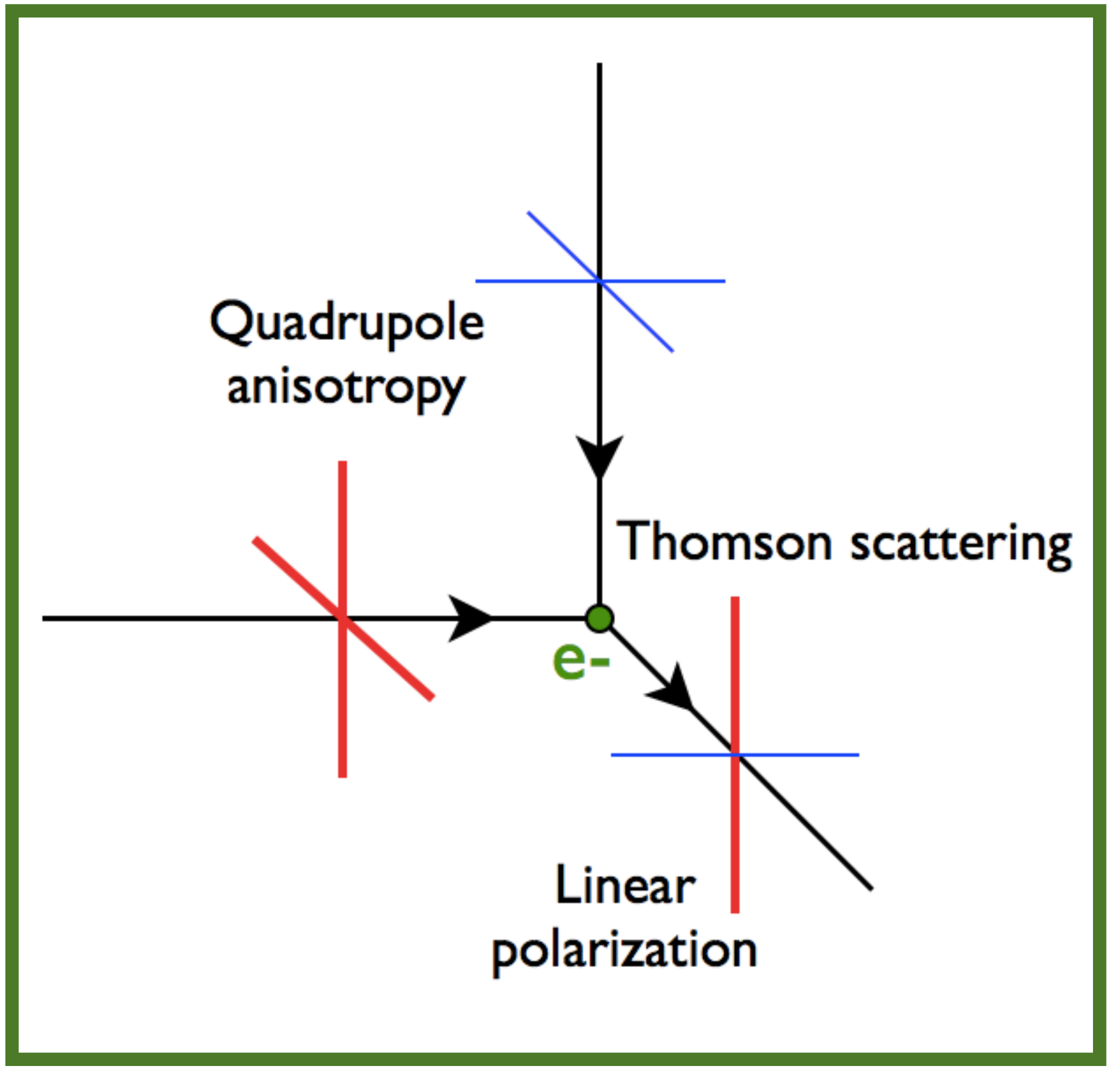


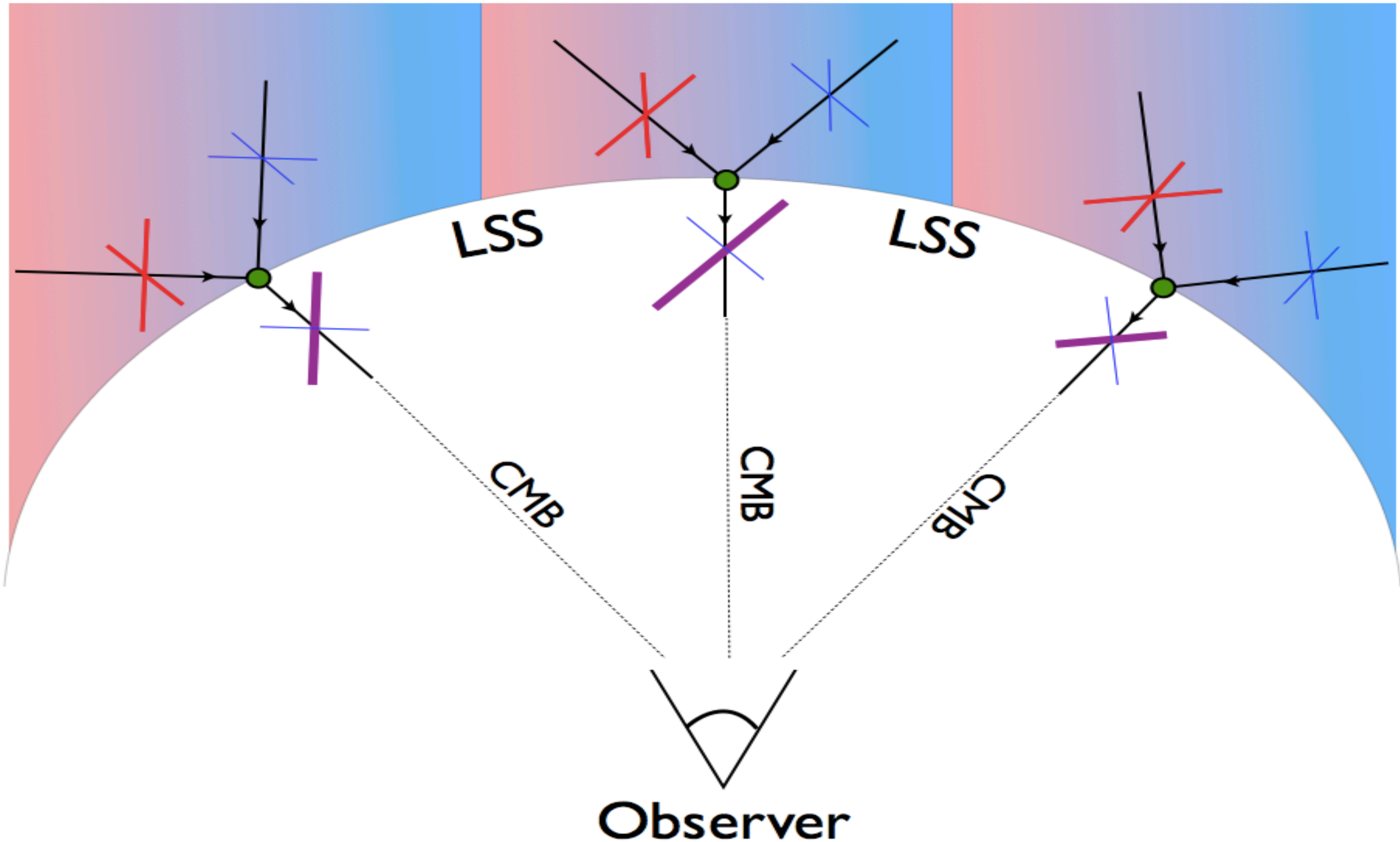
- This kind of anisotropy could have been created in different ways:

1) density fluctuation in the plasma (scalar perturbation)

2) vorticity in the plasma (vector perturbation)

3) gravitational waves that stretch and squeeze space (tensor perturbation)

CMB polarization



- The polarization pattern in the sky can be decomposed into 2 components:

  1) Curl-free component, called "**E-mode**": principally generated by density fluctuation
  2) Grad-free component, called "**B-mode**": principally generated by gravitational waves

Why studying CMB polarization?

- CMB E-modes have been observed by several instrument
- CMB B-modes have never been observed, we only have put upper limit on their intensity

↓

- The observation of B-modes is one of the hottest topic in observational cosmology principally because:

1) **IT BREAKS THE DEGENERACY** OF THE TEMPERATURE POWER SPECTRUM

2) IT GIVES INFORMATION ABOUT THE **EPOCH OF REIONIZATIO**

3) IT PROVES THE **INFLATION THEORY**

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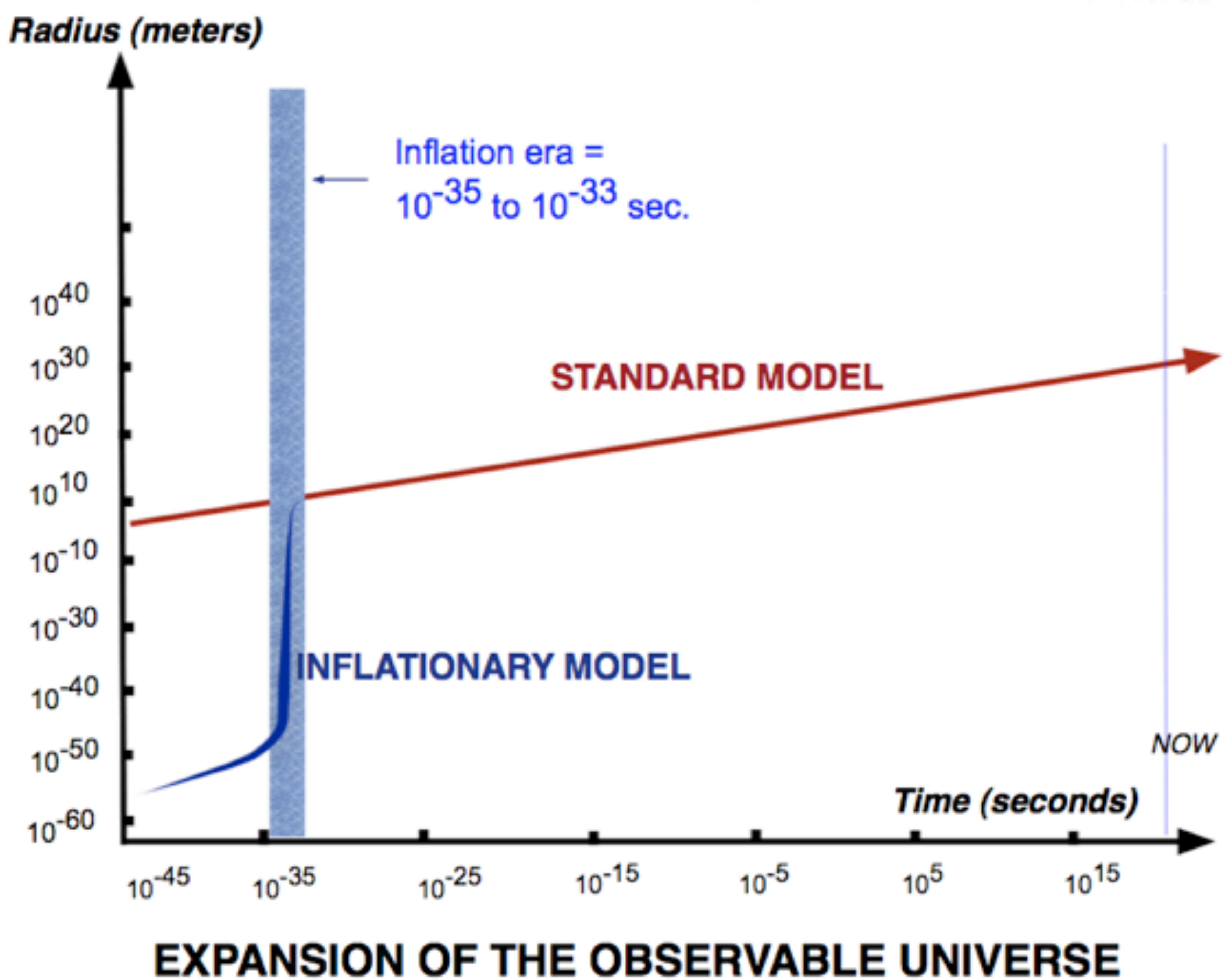
- The observ… …ology principally

1) **IT B… …URE** POWER

2) IT G… **…IONIZATION**

3) IT P



What to remember...

The CMB signal is extremely faint and weakly polarized! (~10%)

The polarization pattern in the sky can be decomposed in 2 modes

E modes are generated by density fluctuation
B modes are generated by gravitational waves

B modes have never been experimentally observed

Observation of B modes would eventually prove the Inflation theory!

Observing CMB polarization

- We want to observe an extremely weak signal ($\lesssim 1\,\mu K$)
- We need to build up **extremely sensitive instruments**

Instrument noise

Sky temperature (~ 2.7 K)

$$\Delta T \propto \frac{T_{noise} + T_{sky}}{\sqrt{\beta \tau N}}$$

Bandwidth

Integration time

Number of detectors observing the same sky region

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- **We also need to pay particular attention to the instrumental systematic effects!!**

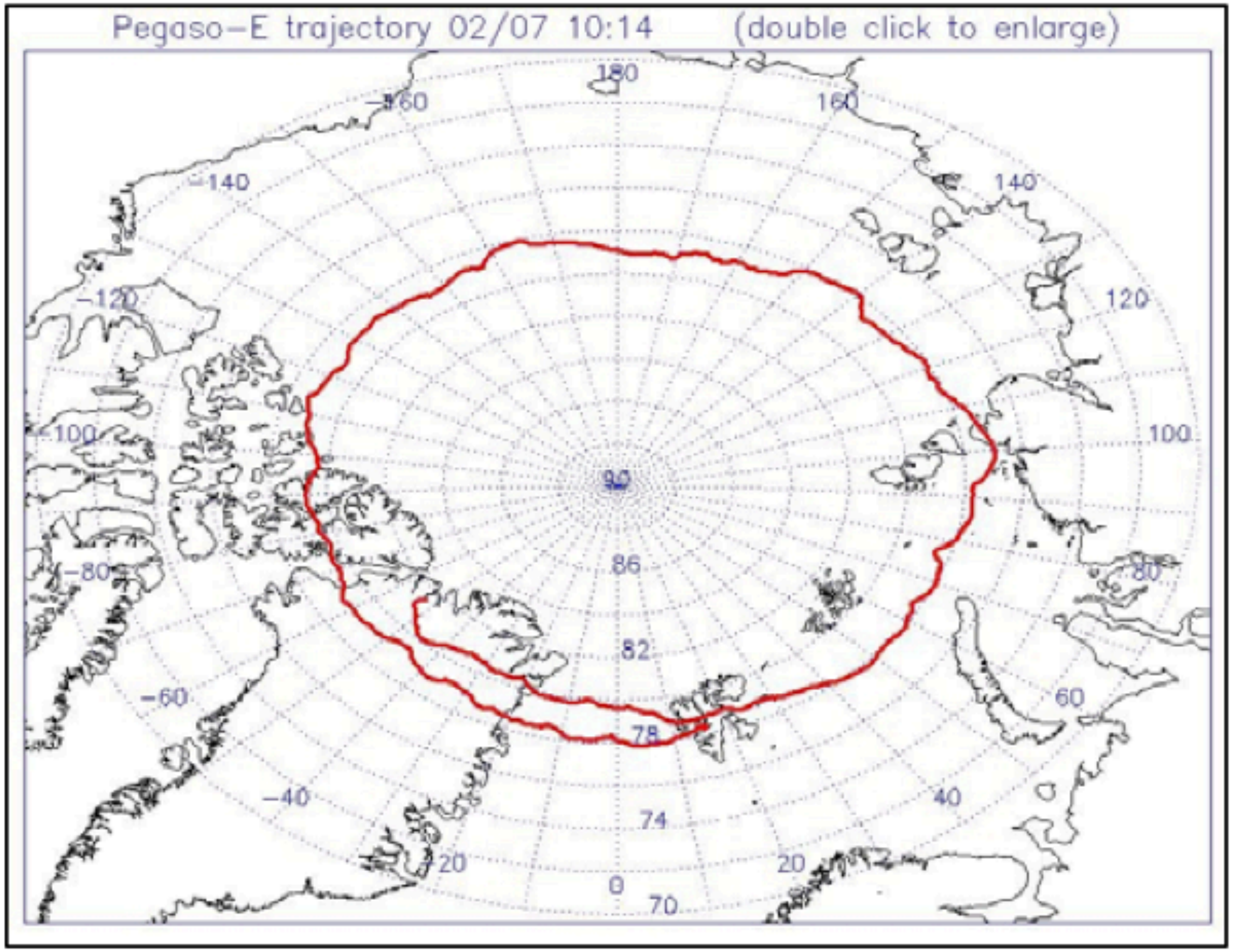
The Large Scale Polarization Explorer

- Two instrument on board of a stratospheric balloon:

SWIPE *(Short Wavelength Instrument for the Polarization Explorer)*: array of bolometers at 95, 145 and 245 GHz

STRIP (*STRatospheric Italian Polarimeter)* : polarimeters array at 43 and 90 GHz

- 15 days flight around North Pole during arctic night (2014/2015)



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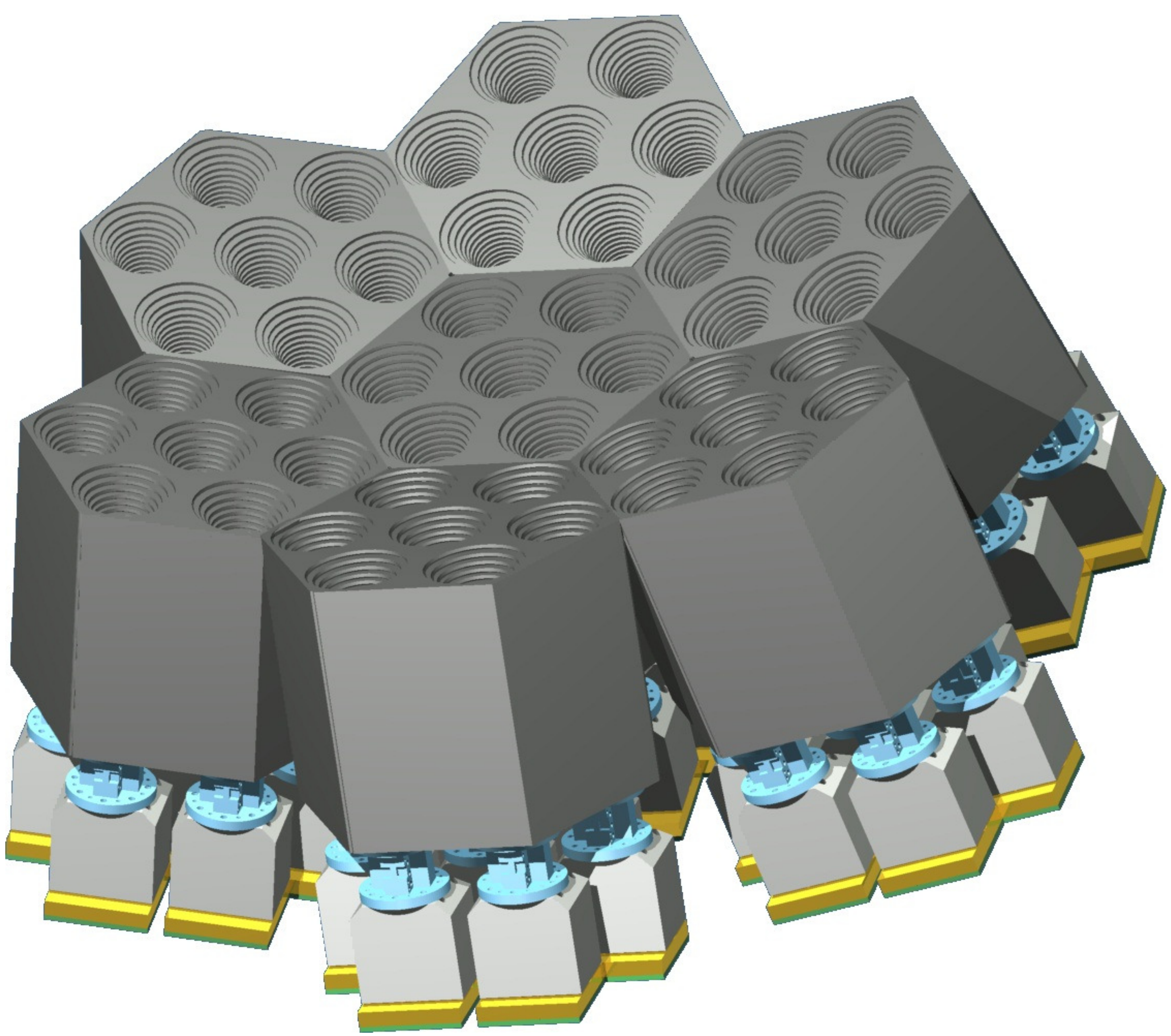
Sensitivity improvement factor w.r.t. Planck

STRIP 43 GHz	STRIP 90 GHz	SWIPE 95 GHz	SWIPE 145 GHz	SWIPE 245 GHz
2.2	**0.6**	**2.7**	**3.2**	**4.9**

The STRIP instrument

- 49 detectors observing the sky @ 43 GHz + 7 detectors @ 90 GHz
- Each detector is made up of a corrugated feed horn+OMT+polarimeter
- Each detector can measure simultaneously stokes U and Q parameters
- The instrument is coupled with a Dragonian dual reflector telescope (aperture ~60 cm)



Keeping systematic effects under control

Understand the possible sources of systematic effects and their impact on scientific data

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Build up a pipeline that simulates the functioning of the STRIP polarimeters including a modeling of the systematic effects.

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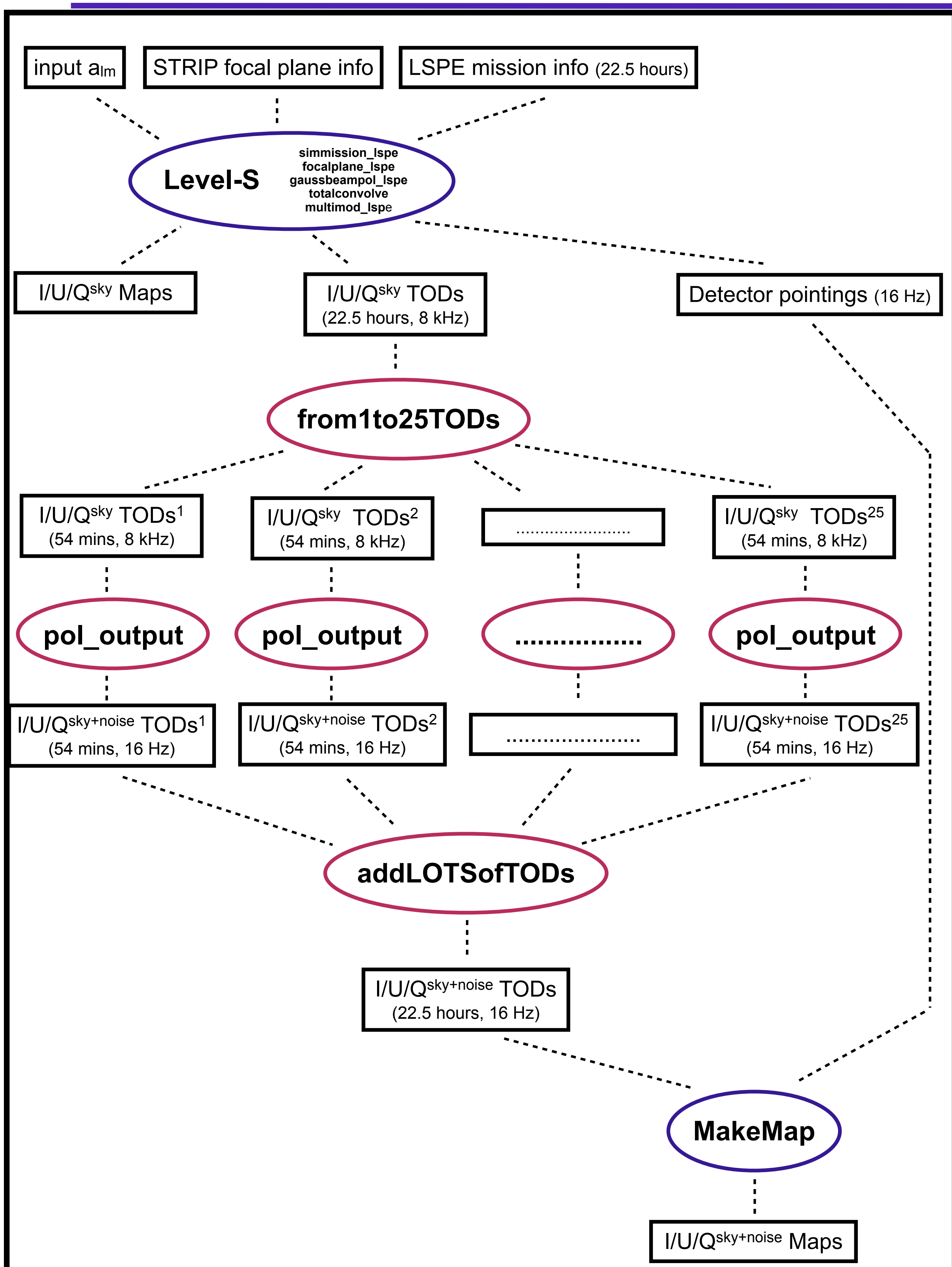
Implement the best strategy to keep systematic effects under control (hardware configuration, calibration strategy, algorithm to remove residual effects, ...)

Keeping systematic effects under control



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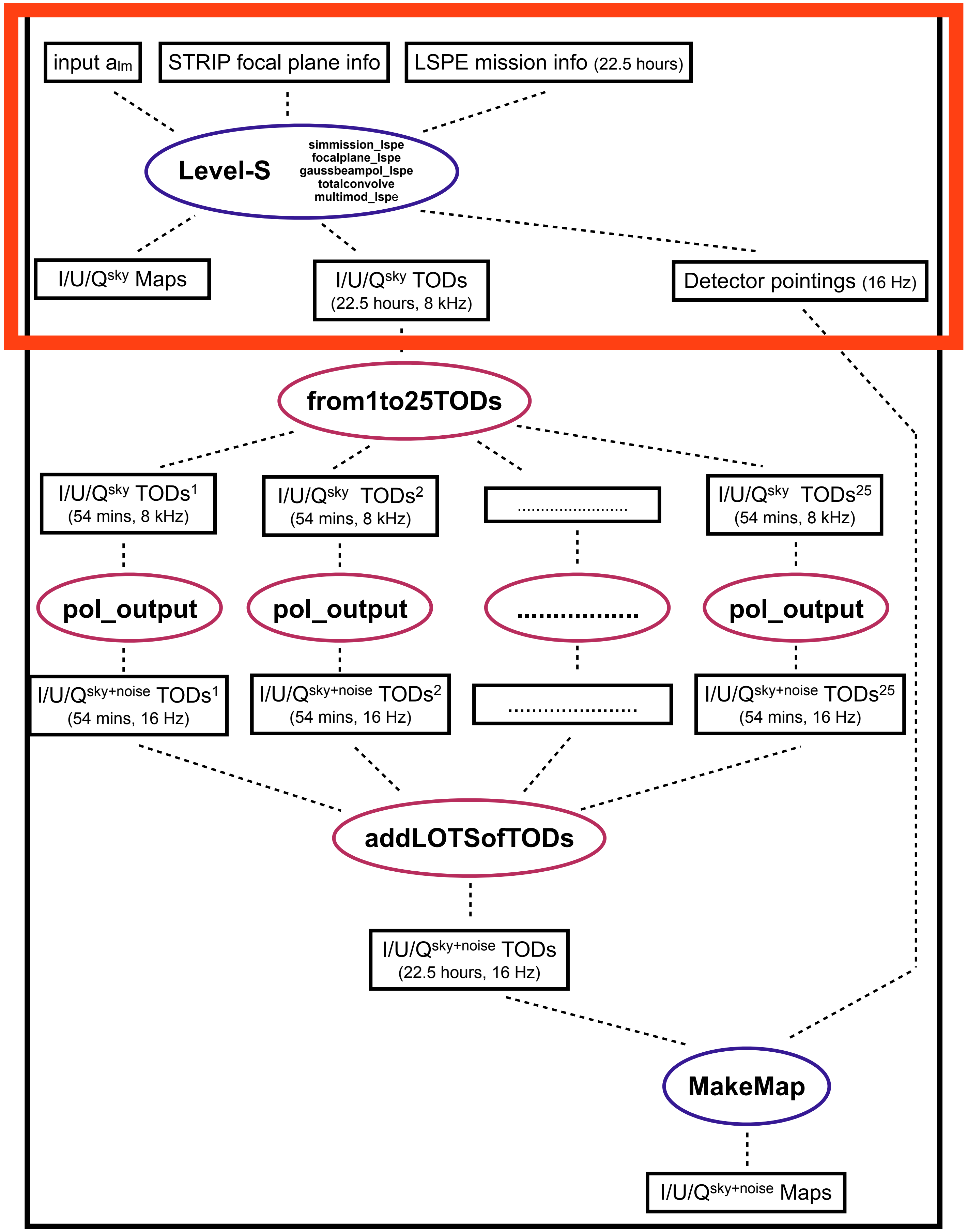
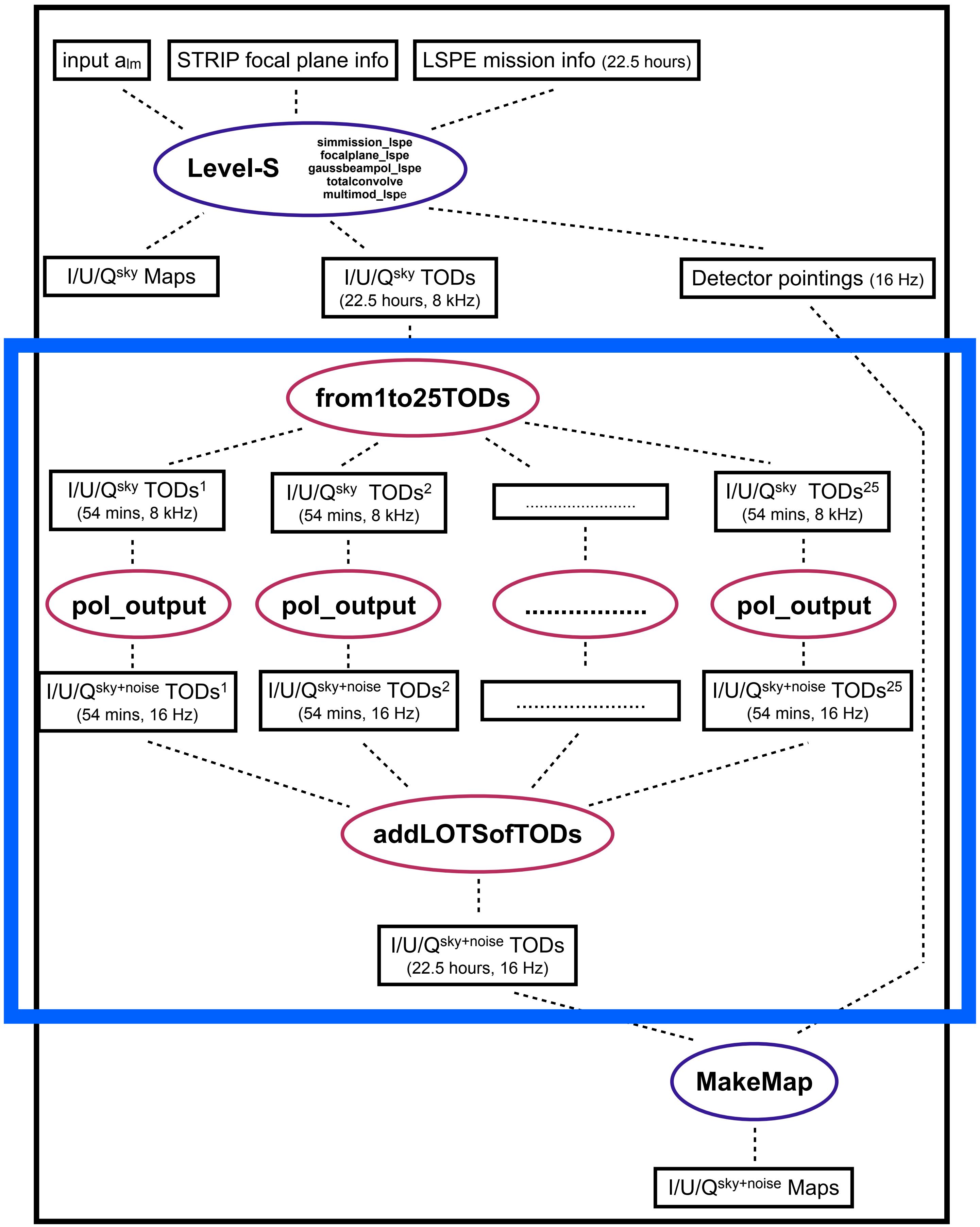


Simulates how the instrument observes the sky:

- mission information
- scanning strategy
- focal plane geometry
- convolution with the beam

Keeping systematic effects under control

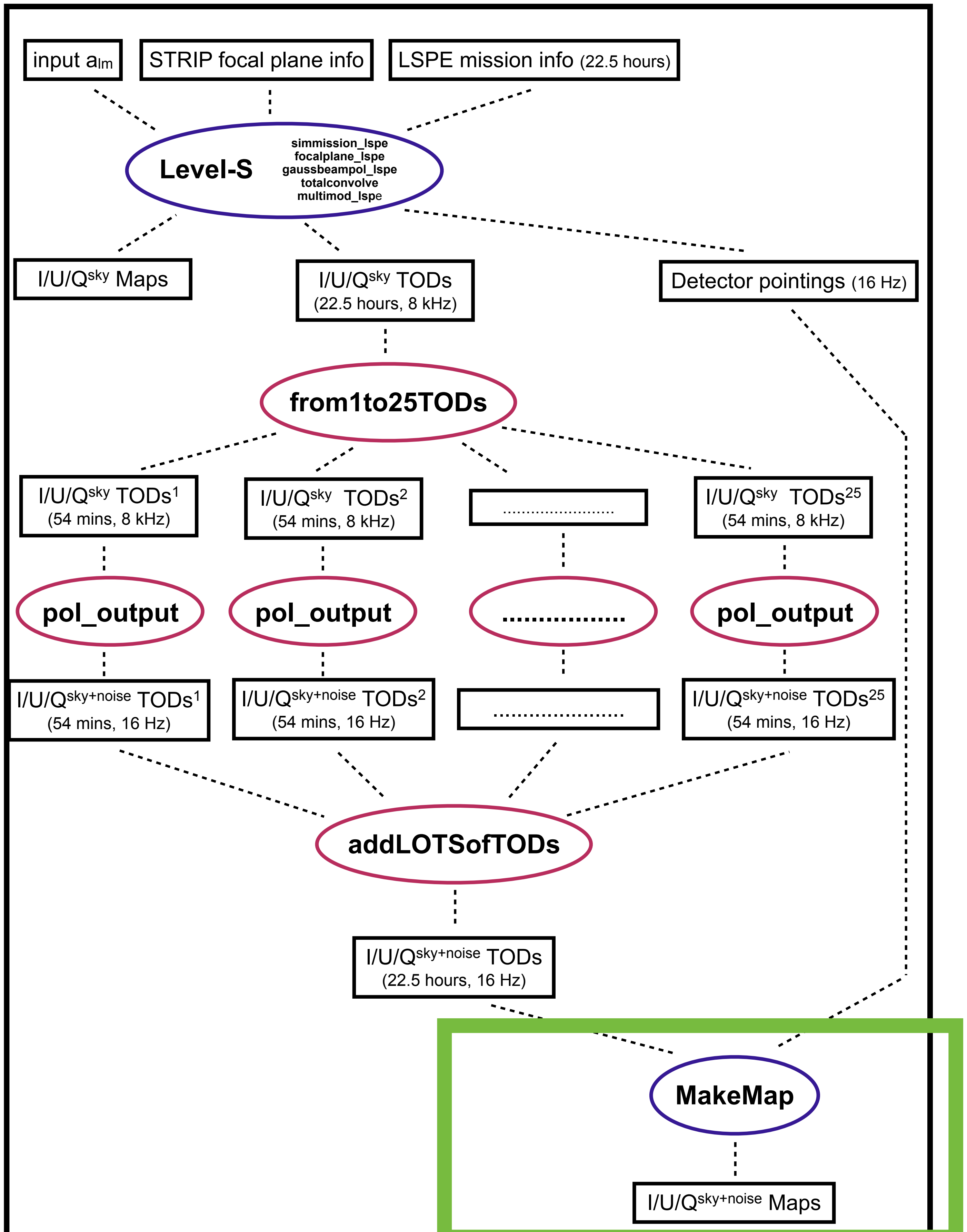


Simulates the polarimeters behavior including systematics:

- non-idealities
- 1/f noise
- I-to-Q/U leakage
- bandwidth effects
- uncertainties on polarization angle
- periodic effects

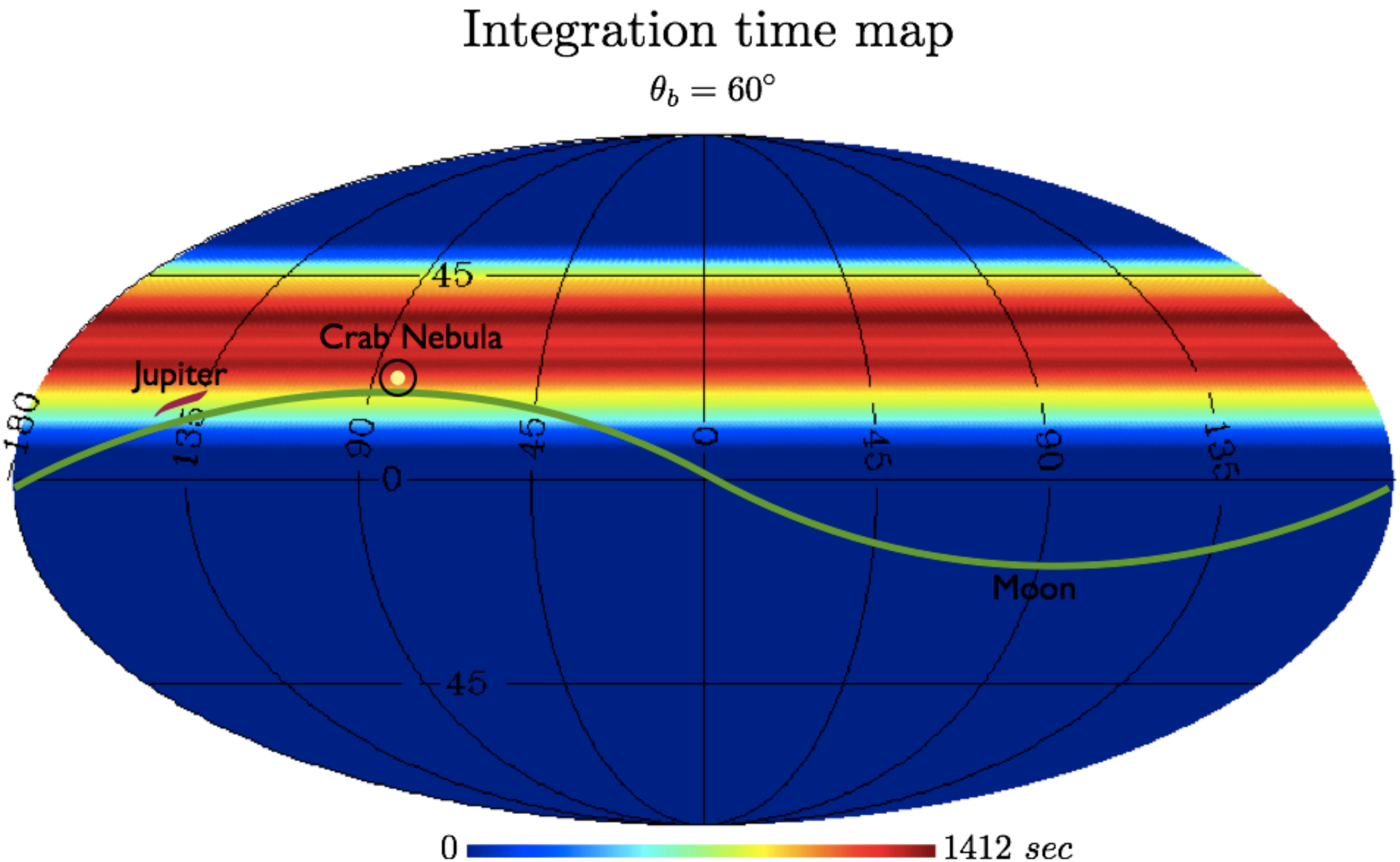
……

Keeping systematic effects under control



Projects all the considered effects on map and power spectra to understand their final impact

First (very preliminary) results



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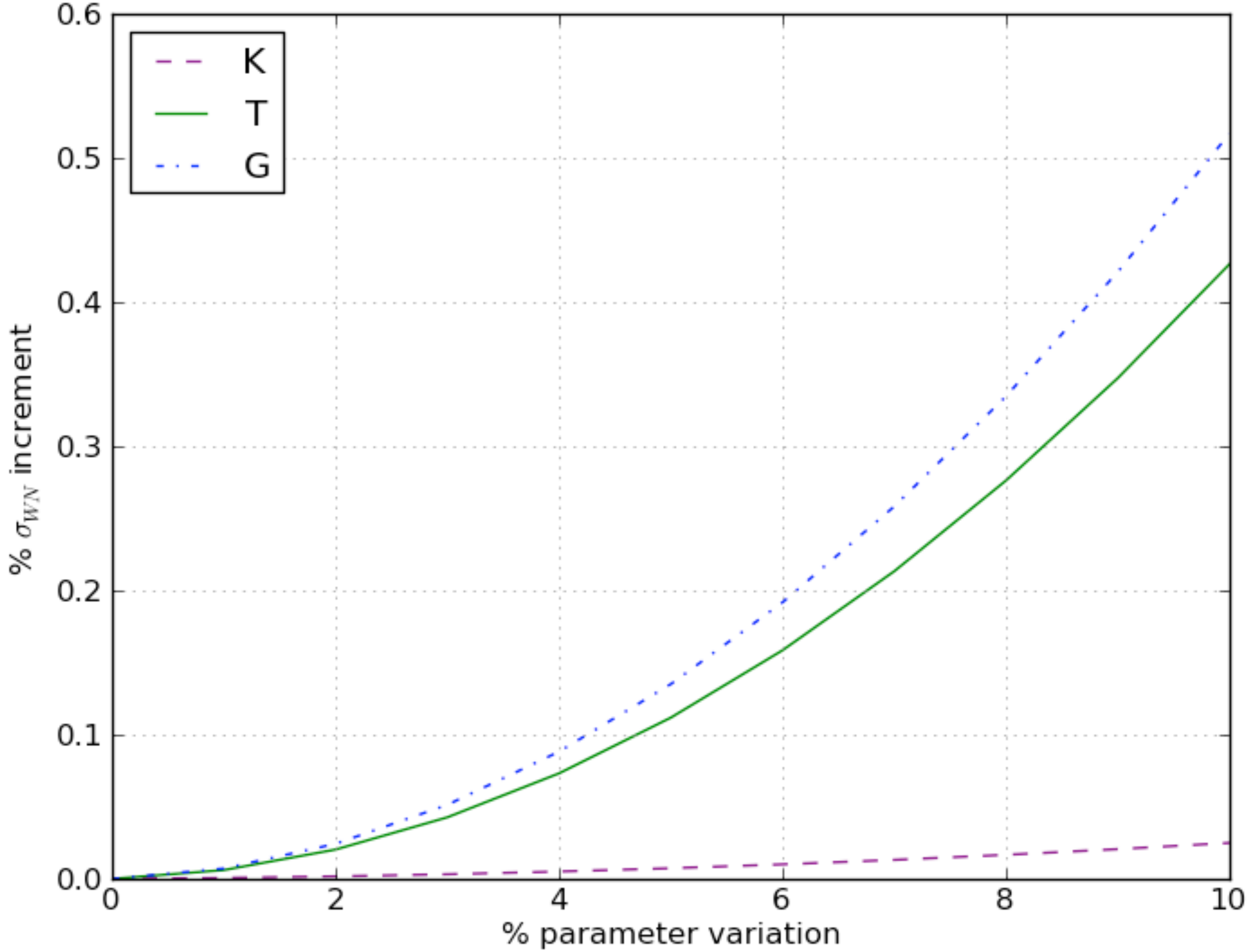

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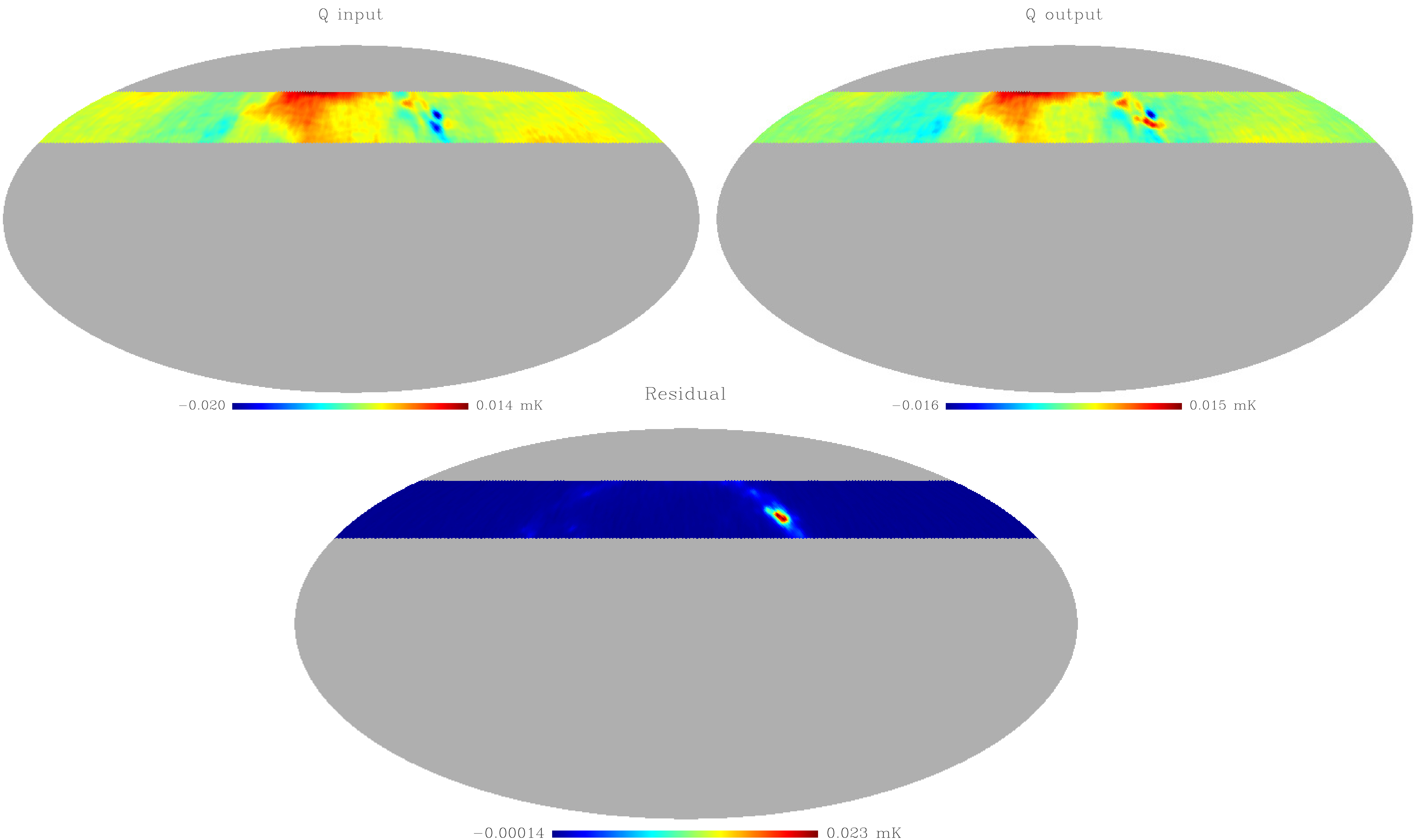

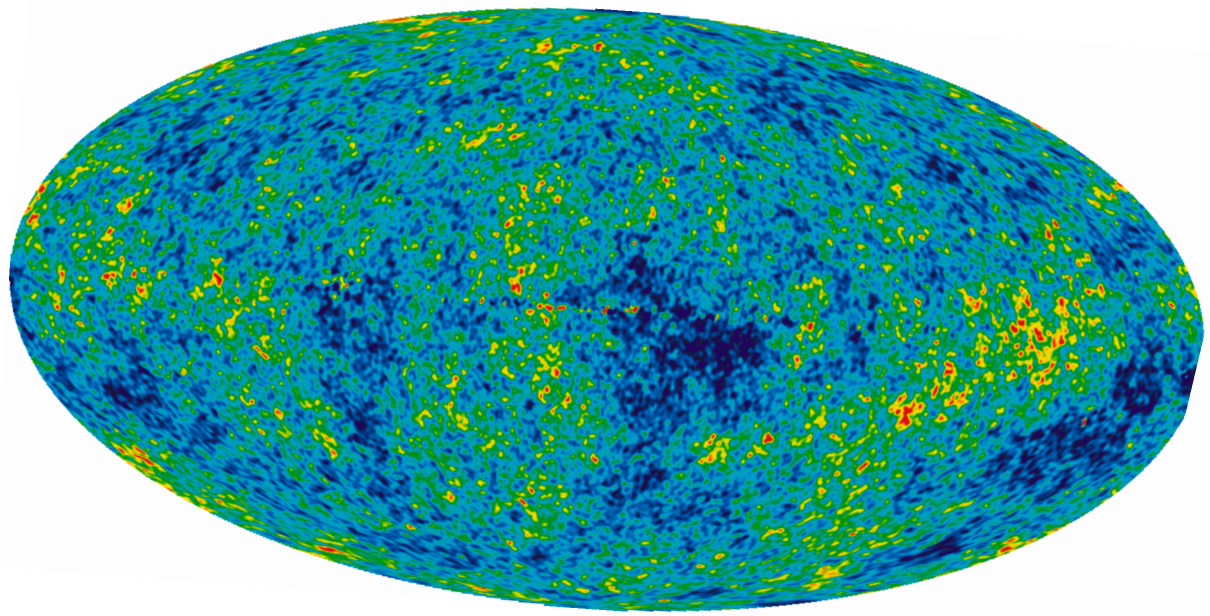

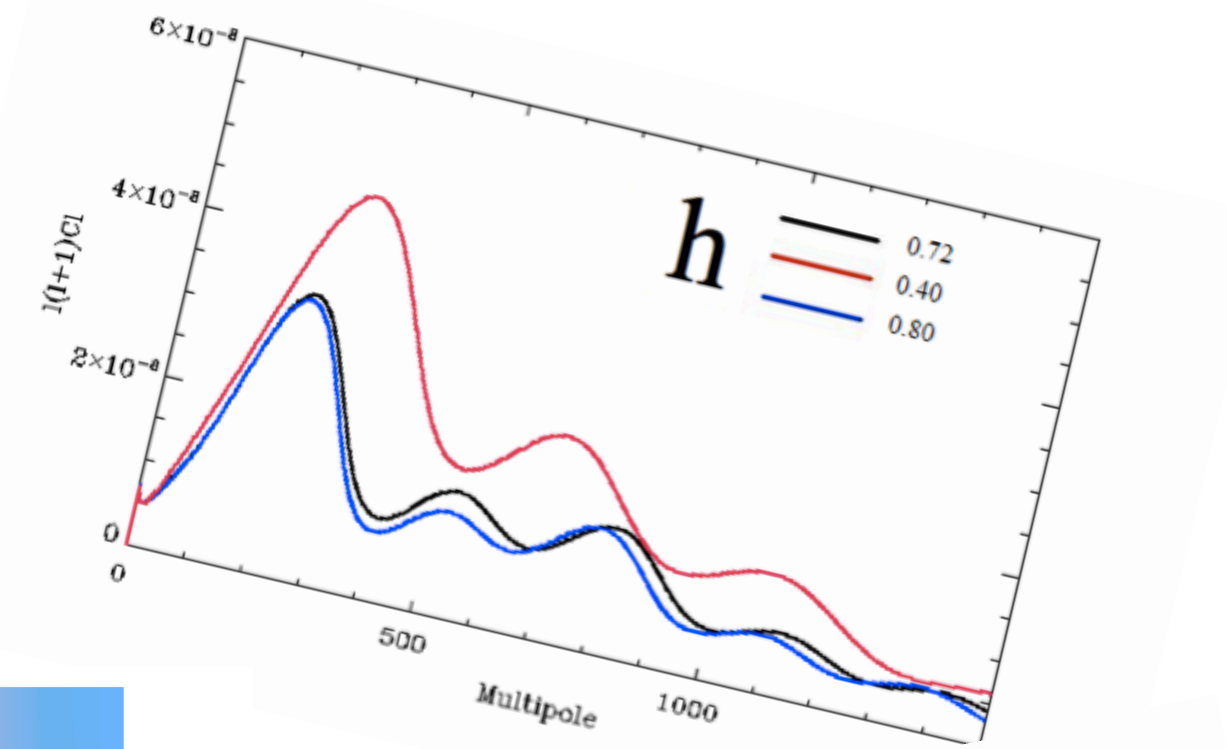
6×10⁻⁸
4×10⁻⁸
2×10⁻⁸
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1000
Multipole
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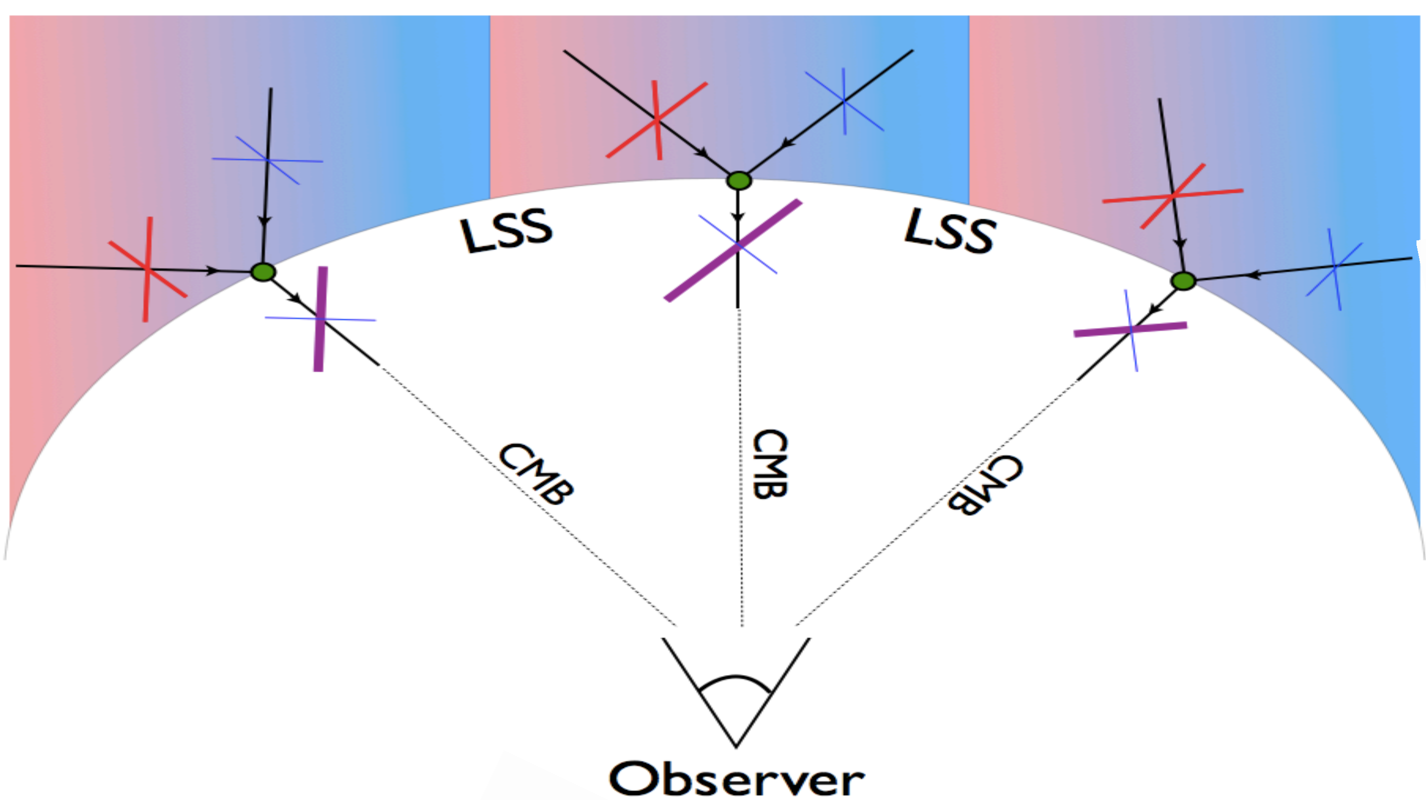
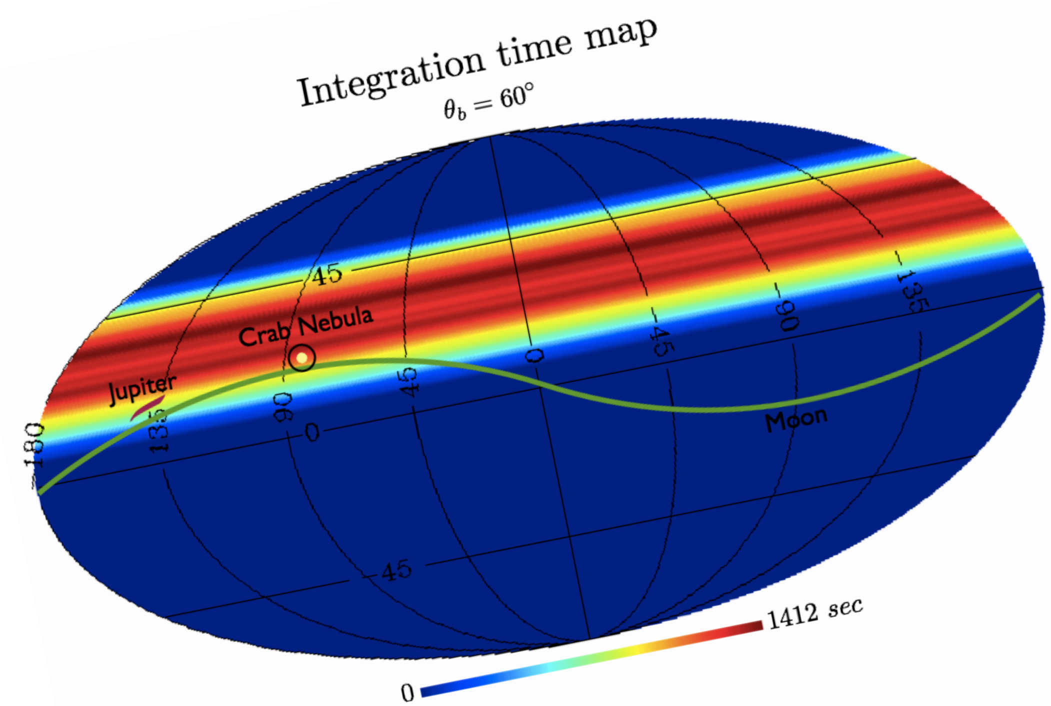
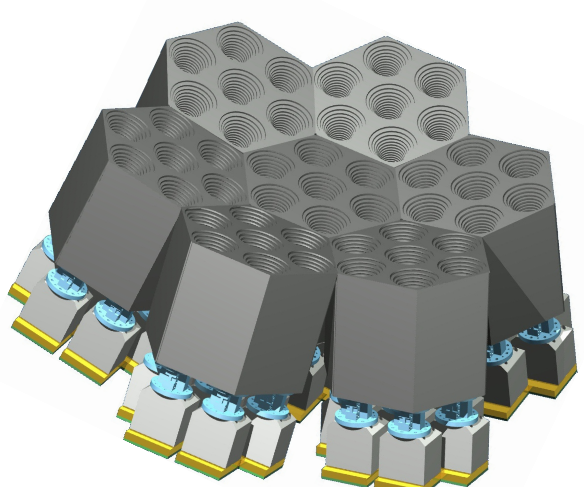

LSS
LSS
CMB
CMB
CMB
Observer


Integration time map
$\theta_b = 60°$
Crab Nebula
Jupiter
Moon
0
1412 sec



THANK YOU!