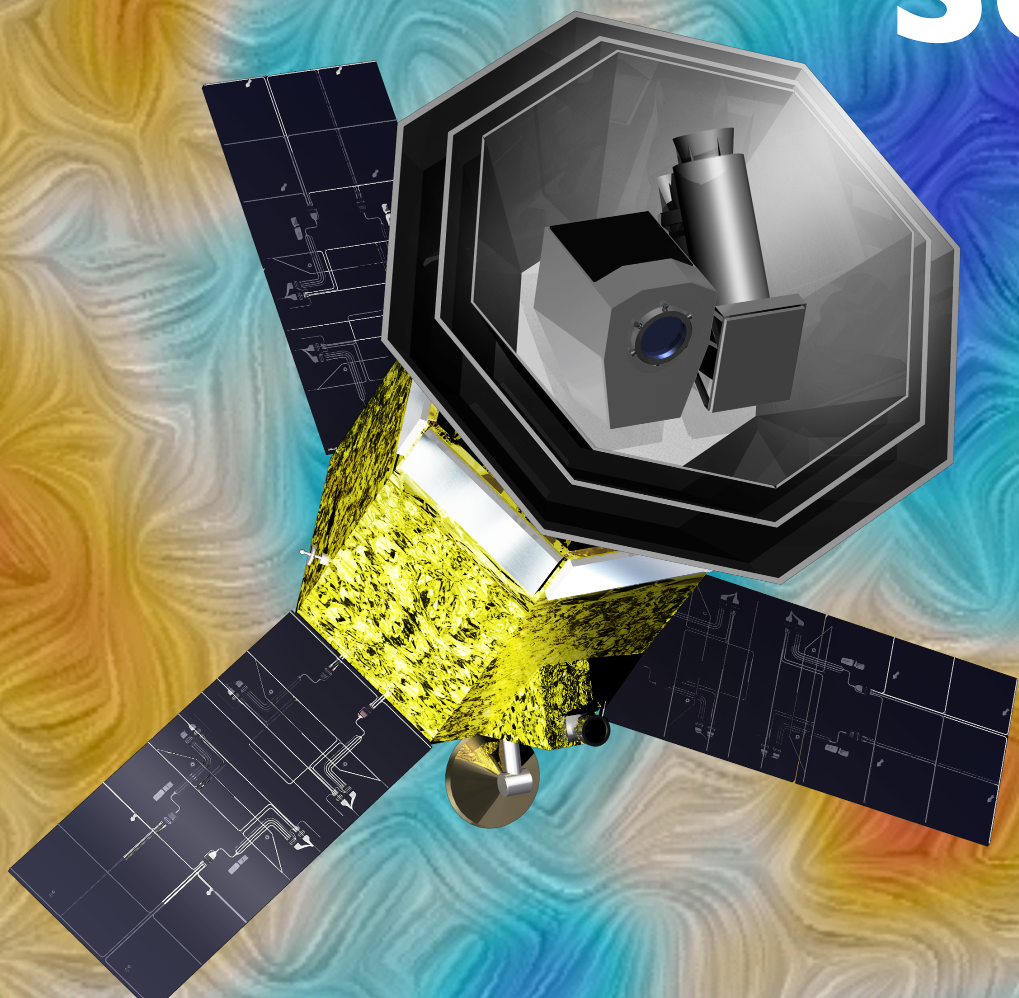
# LiteBIRD Science objectives



**M. Tristram**
**on behalf of LiteBIRD Collaboration**

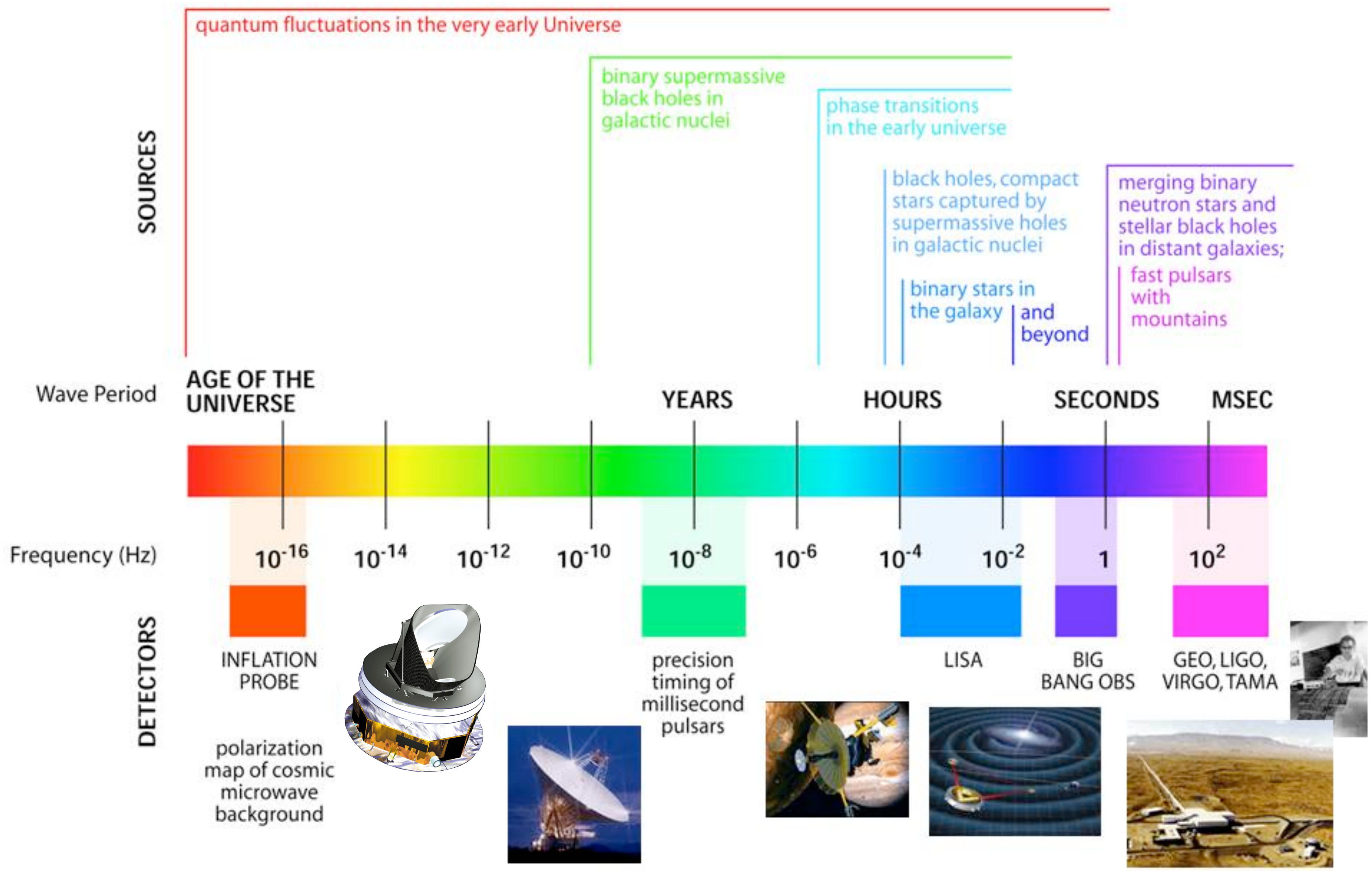
# LiteBIRD Science outcomes

- Primordial gravitational waves from inflation
  - B-mode power spectrum
  - Full success
  - Extra success
  - Beyond the B-mode power spectrum

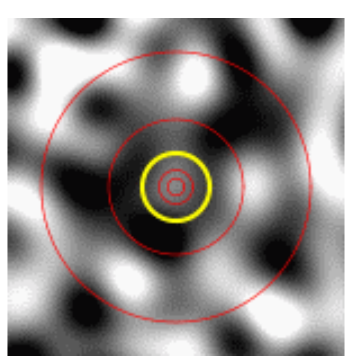
- Galactic science
- Optical depth and reionization of the Universe
- Cosmic birefringence

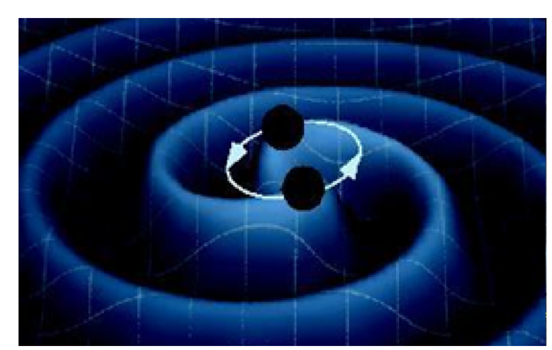
- Mapping the hot gas in the Universe
- Anisotropic CMB spectral distortions
- Elucidating anomalies with polarization
- Correlation with other data sets

## *Big leap between LISA and LiteBIRD*



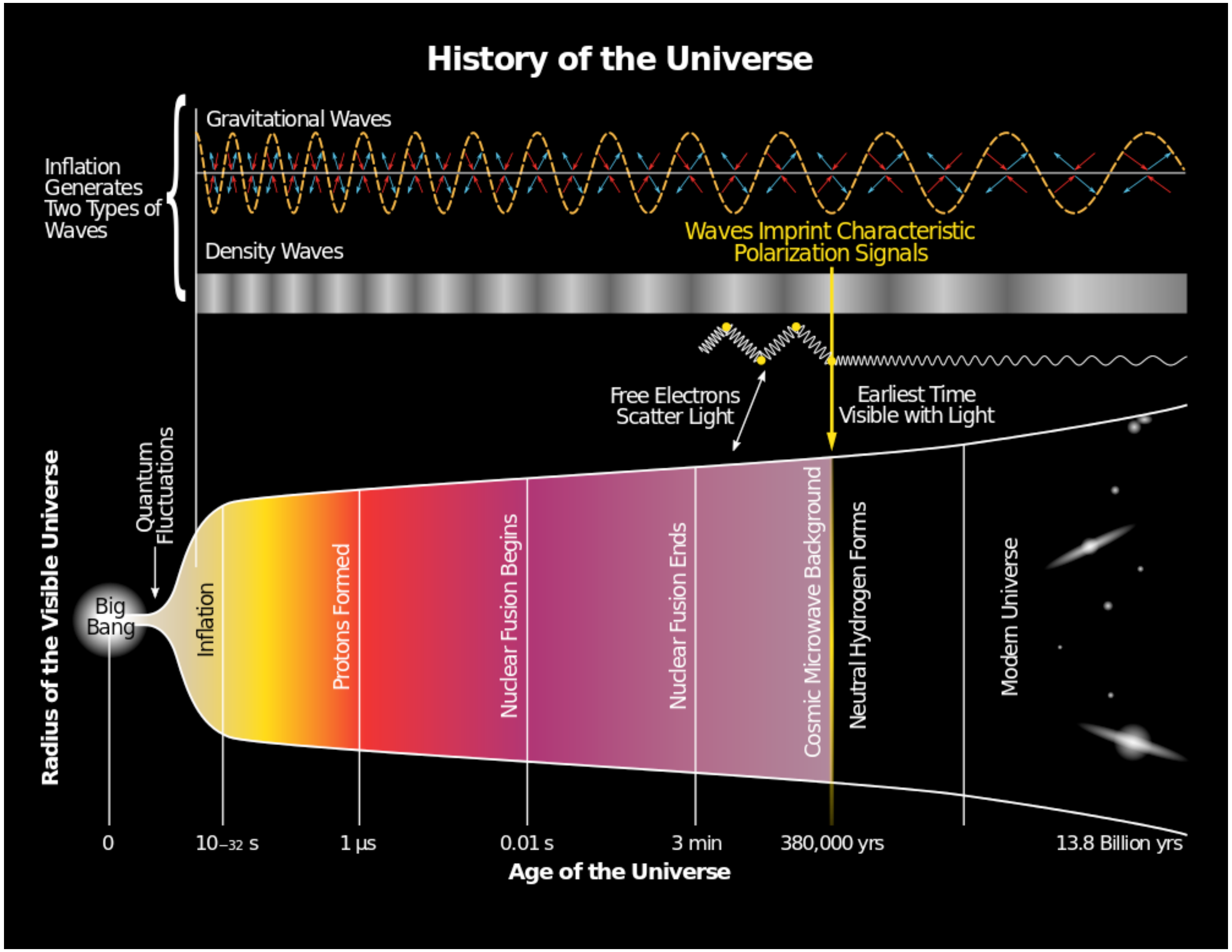

**LiteBIRD**
Gravitational waves with quantum origin





**LISA**
Gravitational waves with classical origin

# Primordial Gravitational Waves

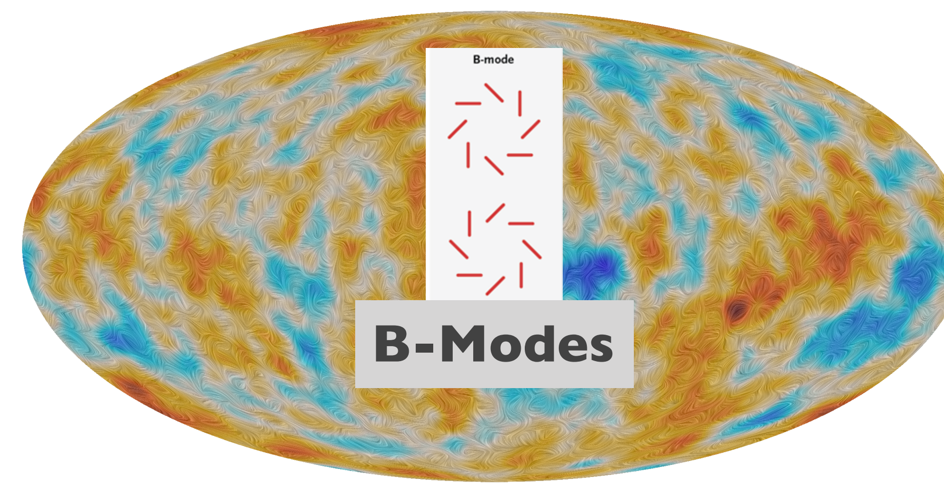



Inflation

Quantum fluctuation of spacetime

Primordial gravitational waves

“vortex”es in the CMB polarization map (called “B-mode”)




**Opportunity to probe the Cosmic Inflation but also to shed light on GUT-scale physics**

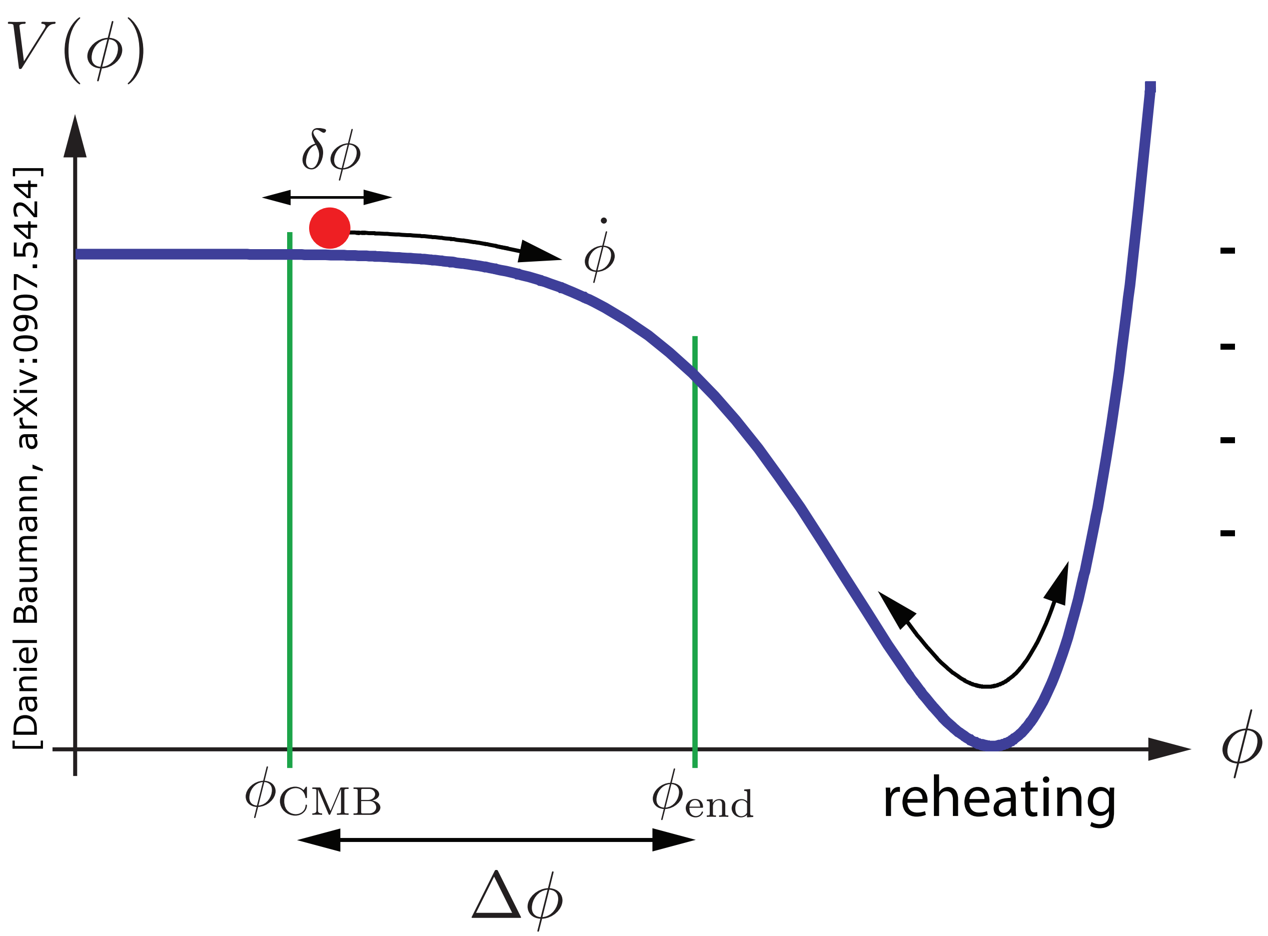
**Observational test of quantum gravity**

## *inflation* $\phi$

- **dynamics of an homogeneous scalar field in a FRW geometry is given by**

$$\ddot{\phi} + 3H\dot{\phi} + V_{,\phi} = 0 \qquad \text{and} \qquad H^2 = \frac{1}{3}\left(\frac{1}{2}\dot{\phi}^2 + V(\phi)\right)$$

- **inflation happen when potential dominates over kinetic energy (slow-roll)**




- where did **V(Φ) comes from** ?
- why did the field start in **slow-roll** ?
- why is the potential so **flat** ?
- how do we convert the field energy into **particules** ?

# Primordial Gravitational Waves

***matter***

- **According to single field, slow-roll inflationary scenario, quantum vacuum fluctuations excite cosmological scalar and tensor perturbations**

$$\mathcal{P}_{\mathcal{R}}(k) = A_s \left(\frac{k}{k_0}\right)^{n_s - 1} \quad \text{scalar}$$

$$\mathcal{P}_{\mathcal{T}}(k) = A_t \left(\frac{k}{k_0}\right)^{n_t} \quad \text{tensor}$$

- **with the definition of the tensor-to-scalar ratio "r"** $r = A_t / A_s$

# Primordial Gravitational Waves

## *matter*

- **According to single field, slow-roll inflationary scenario, quantum vacuum fluctuations excite cosmological scalar and tensor perturbations**

$$\mathcal{P}_{\mathcal{R}}(k) = A_s \left(\frac{k}{k_0}\right)^{n_s - 1} \quad \text{scalar}$$

$$\mathcal{P}_{\mathcal{T}}(k) = A_t \left(\frac{k}{k_0}\right)^{n_t} \quad \text{tensor}$$

- **with the definition of the tensor-to-scalar ratio "r"** $r = A_t / A_s$

**which characterises the amplitude of GW and gives direct constraints on the shape of the potential**

- **energy scale of inflation** $V^{1/4}(\phi) \simeq 10^{16}\,\mathrm{GeV} \left(\frac{r}{0.01}\right)^{1/4}$

- **inflaton field excursion** $\frac{\Delta\phi}{M_P} \simeq \mathcal{N}_* \left(\frac{r_*}{8}\right)^{1/2} \simeq \left(\frac{r}{0.001}\right)^{1/2}$

- **derivative of the potential**

$$r = 8M_{\mathrm{Pl}}^2 \left(\frac{V_\phi}{V}\right)^2$$

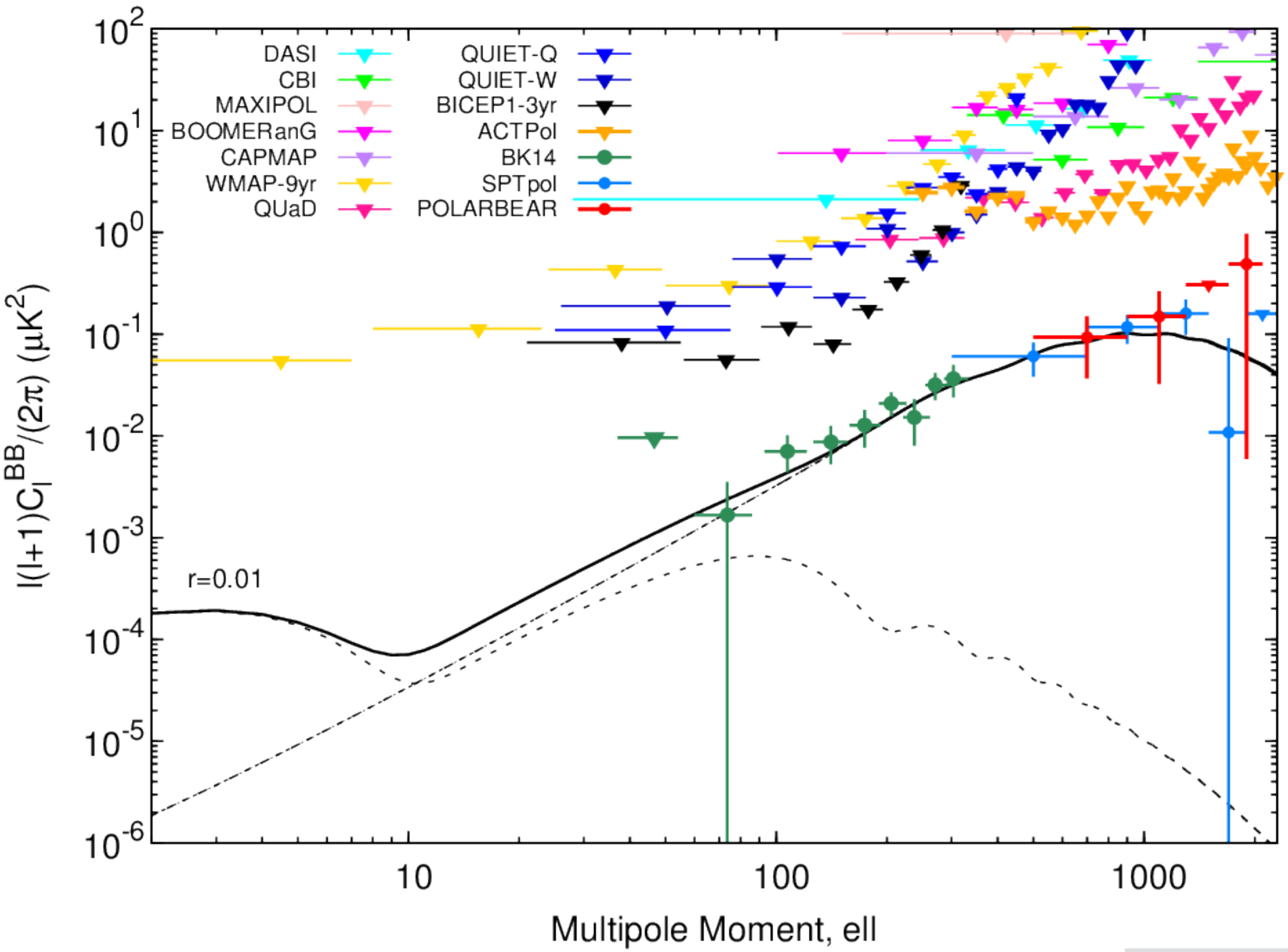
$$n_{\mathrm{s}} - 1 \equiv \frac{\mathrm{d}\ln \mathcal{P}_\zeta}{\mathrm{d}\ln k} \simeq -3M_{\mathrm{Pl}}^2 \left(\frac{V_\phi}{V}\right)^2 + 2M_{\mathrm{Pl}}^2 \frac{V_{\phi\phi}}{V}$$

# Primordial Gravitational Waves

- Planck data do not need convex potentials (n>1), multi-fields models or non-minimal kinetic term
- minimal models of particular interest include
  - the **Starobinsky model** "$R+R^2$" (first model introduced)
  - the **"Higg's inflation"** with non-minimal coupling from gravity introduced by quantum corrections in a curved space-time (the same shape as $R^2$)
  - inflaton based on a field appearing in the extensions of the standard model of particle physics (usually extensions based on super-symmetry)
  - …

***with LiteBIRD sensitivity we will be able to test a large classes of inflationary models, in particular those who naturally explain $n_s$=0.966 together with the characteristic variation of the potential***

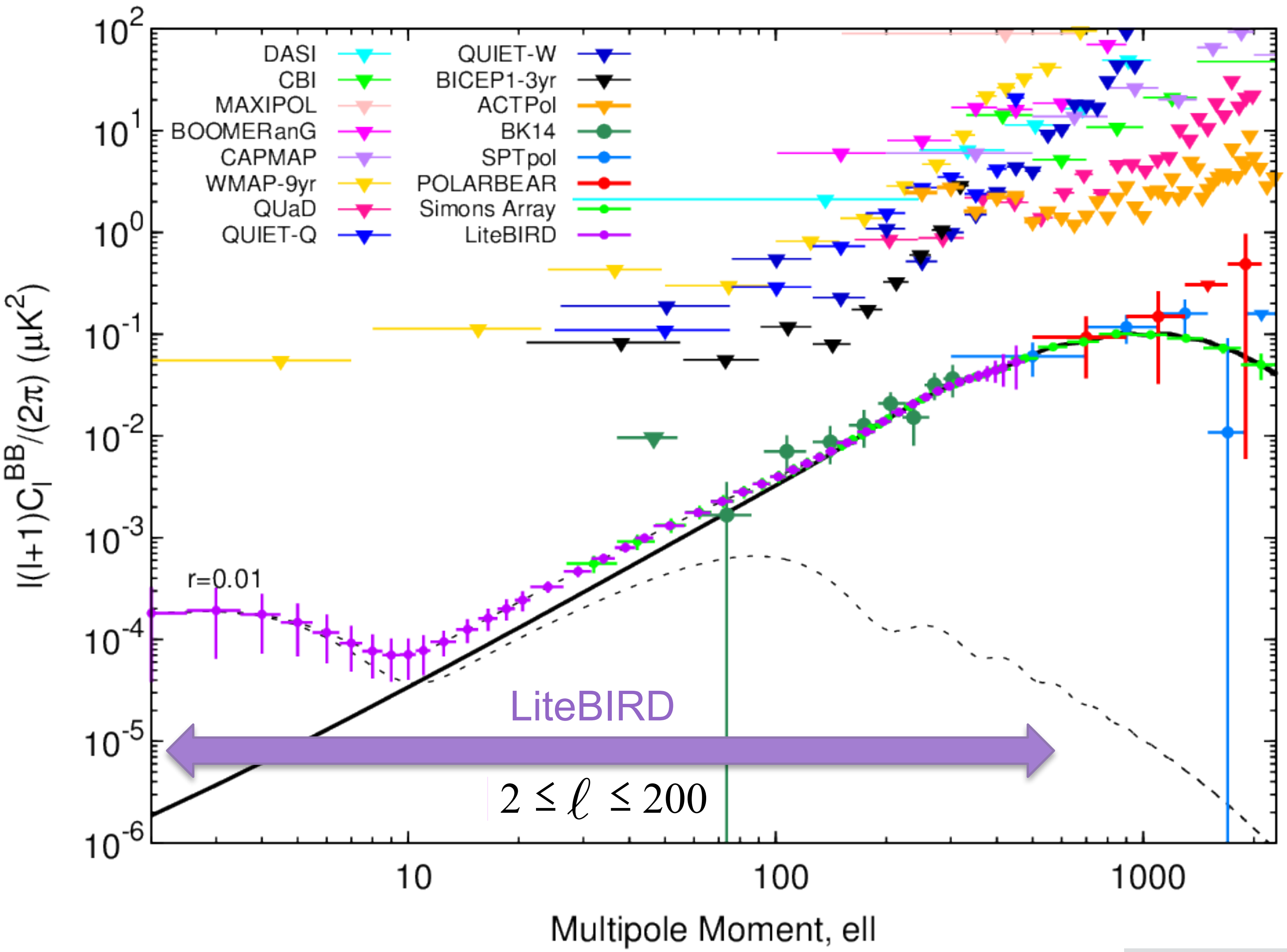
## *Current status of the B-mode measurements*




**r < 0.07 (95% CL)**

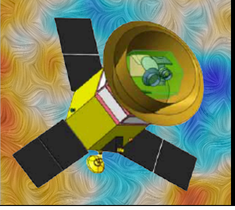
**BICEP2**

### *LiteBIRD Expectation*




**$\sigma_r < 0.001$ (for r=0)**

**LiteBIRD only (no delensing)**



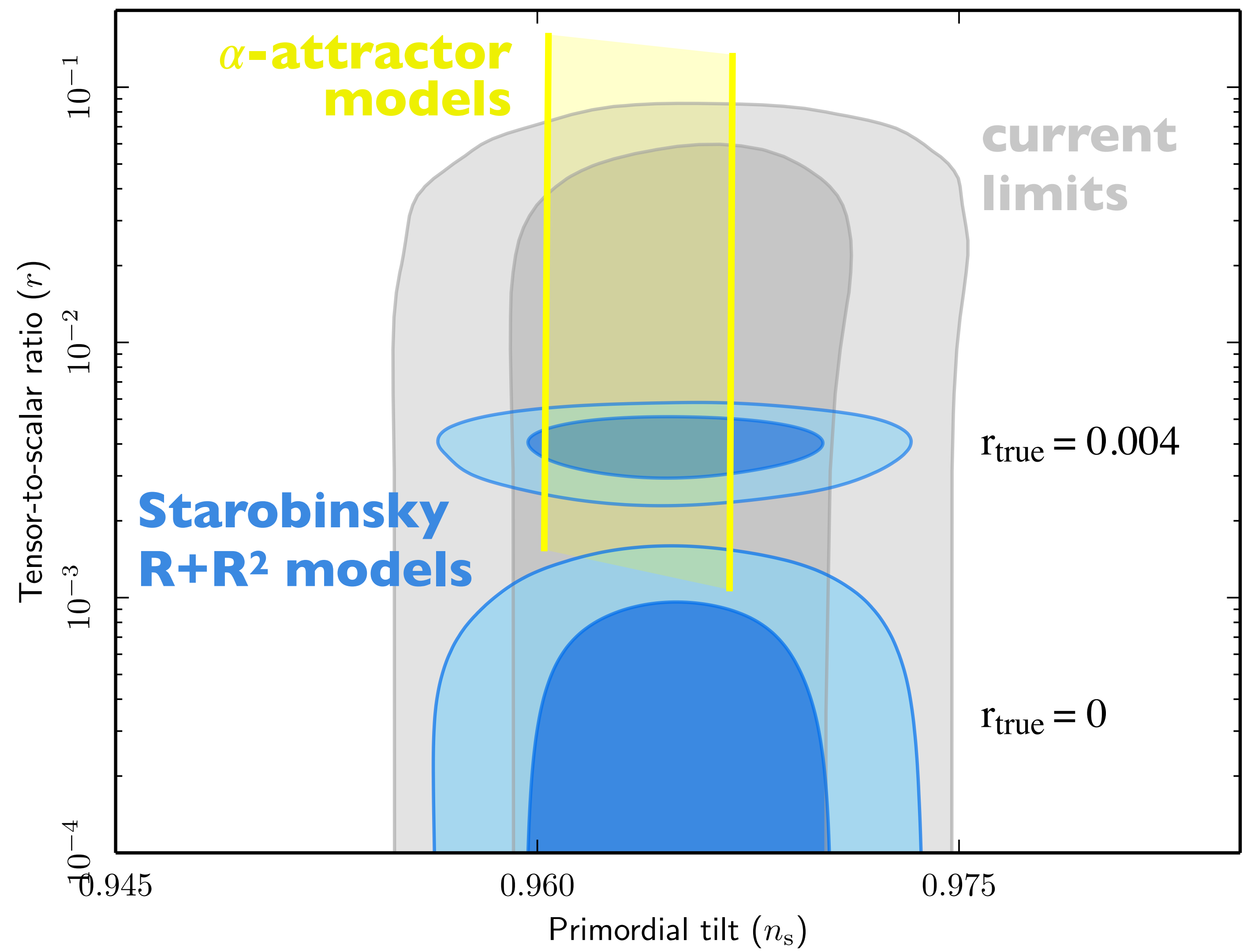
# Primordial Gravitational Waves

## Full Success

- $\sigma(r) < 10^{-3}$ (for r=0, no delensing)
- $>5\sigma$ observation for each bump (for $r \geq 0.01$)

## Rationale

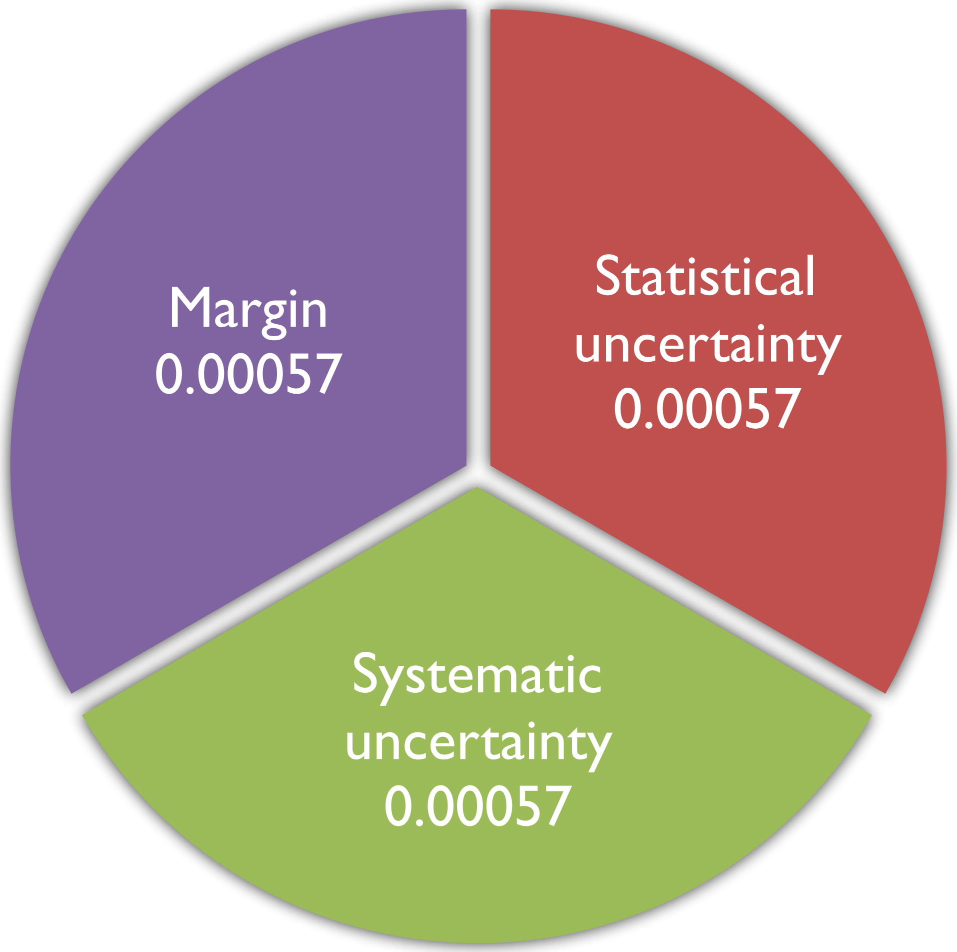
- Large discovery potential for $0.005 < r < 0.05$
- Simplest and well-motivated $R+R^2$ "Starobinsky" model will be tested
- Clean sweep of single-field models with characteristic field variation scale of inflaton potential greater than $m_{pl}$ *[Linde, JCAP 1702 (2017) no.02, 006]*



# Primordial Gravitational Waves

## Full Success

- $\sigma(r) < 10^{-3}$ (for r=0, no delensing)
- >5$\sigma$ observation for each bump (for r≥0.01)




### Statistical uncertainty
- foreground cleaning residuals
- lensing B-mode power
- 1/f noise

### Systematic uncertainty
- Bias from 1/f noise
- Polarization efficiency & knowledge
- Disturbance to instrument
- Off-boresight pick up
- Calibration accuracy

# Primordial Gravitational Waves

## Extra Success

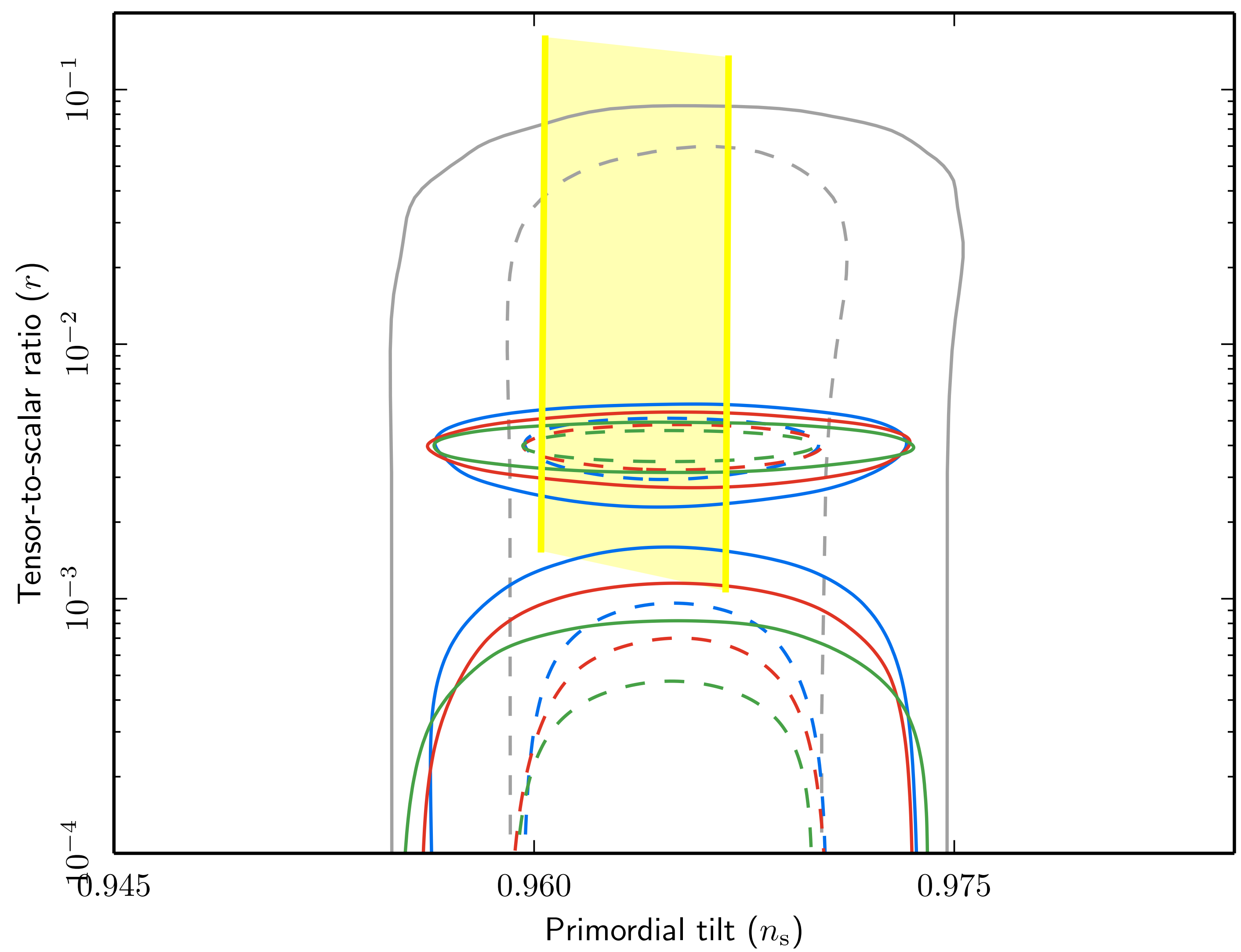
- improve $\sigma$(r) with external observations
- delensing improvement to $\sigma$(r) can be a factor $\geq$ 2

Aiming at detection with >5$\sigma$ in case of Starobinsky model

Baseline

+ delensing w/Planck CIB & WISE

+ extra foreground cleaning w/ high-resolution ground CMB data



# Beyond the B-mode power spectrum

- within single field slow-roll inflation, the tensor perturbation obey the vacuum equation $\Box h_{ij} = 0$
- inducing the following statistical properties
  1. nearly scale invariant power spectrum $n_t = -r/8$
  2. nearly Gaussian probability distribution
  3. parity-conserving probability distribution

# Beyond the B-mode power spectrum

- within single field slow-roll inflation, the tensor perturbation obey the vacuum equation $\Box h_{ij} = 0$
- inducing the following statistical properties
  1. nearly scale invariant power spectrum $n_t$ = -r/8
  2. nearly Gaussian probability distribution
  3. parity-conserving probability distribution

**tensor tilt $n_t$**

- current upper-limit on tensor-to-scalar: r < ~0.01
- better sensitivity expected on tensor tilt: $\sigma(n_t)$ > ~0.003

impossible to verify the consistency relation !

BUT

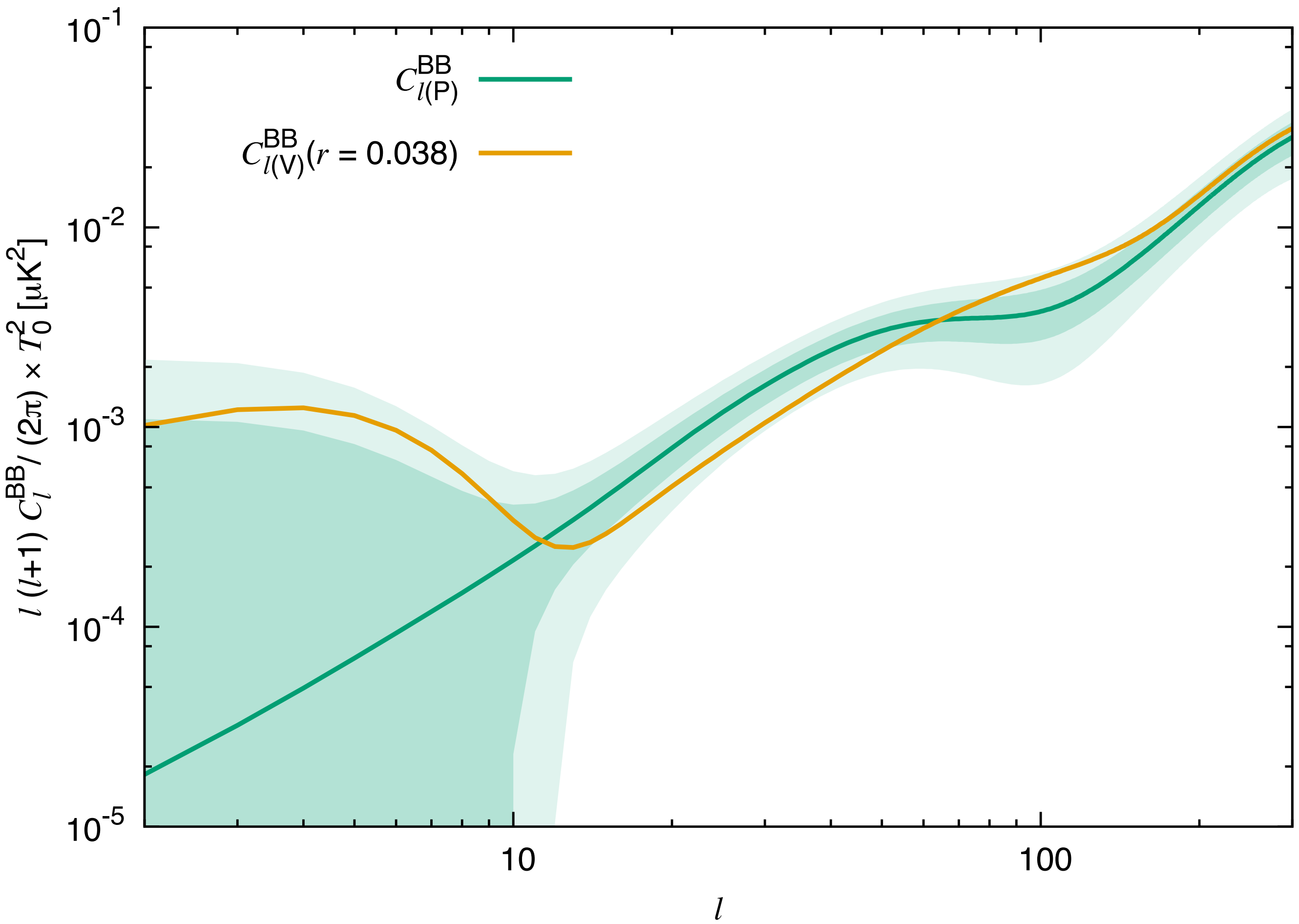
other mechanism than single-field slow-roll inflation predict deviations from scale-invariant $P_k$ (e.g. gravity inflation, open inflation, SU(2)-axion model, multi-field inflation…)

constraints on the primordial tensor power spectrum can distinguish between inflation models

e.g. PCA [Campeti et al. 2019, arXiv:1905.08200]

# Beyond the B-mode power spectrum

- within single field slow-roll inflation, the tensor perturbation obey the vacuum equation $$\Box h_{ij} = 0$$
- inducing the following statistical properties
  1. nearly scale invariant power spectrum $n_t = -r/8$
  2. nearly Gaussian probability distribution
  3. parity-conserving probability distribution




**Non-Gaussianity**

indistinguishable with BB for $\ell$>10 alone

non-Gaussian features using BBB bi-spectrum

Exemple: “Pseudoscalar model”
[Namba, Peloso, Shiraishi, Sorbo, Unal, arXiv1509.07521]

# Beyond the B-mode power spectrum

- within single field slow-roll inflation, the tensor perturbation obey the vacuum equation $$\Box h_{ij} = 0$$
- inducing the following statistical properties
  1. nearly scale invariant power spectrum $n_t = -r/8$
  2. nearly Gaussian probability distribution
  3. parity-conserving probability distribution

## Parity-violating

- parity-violating coupling of a scalar field to the electromagnetic tensor induces a rotation of the polarization direction

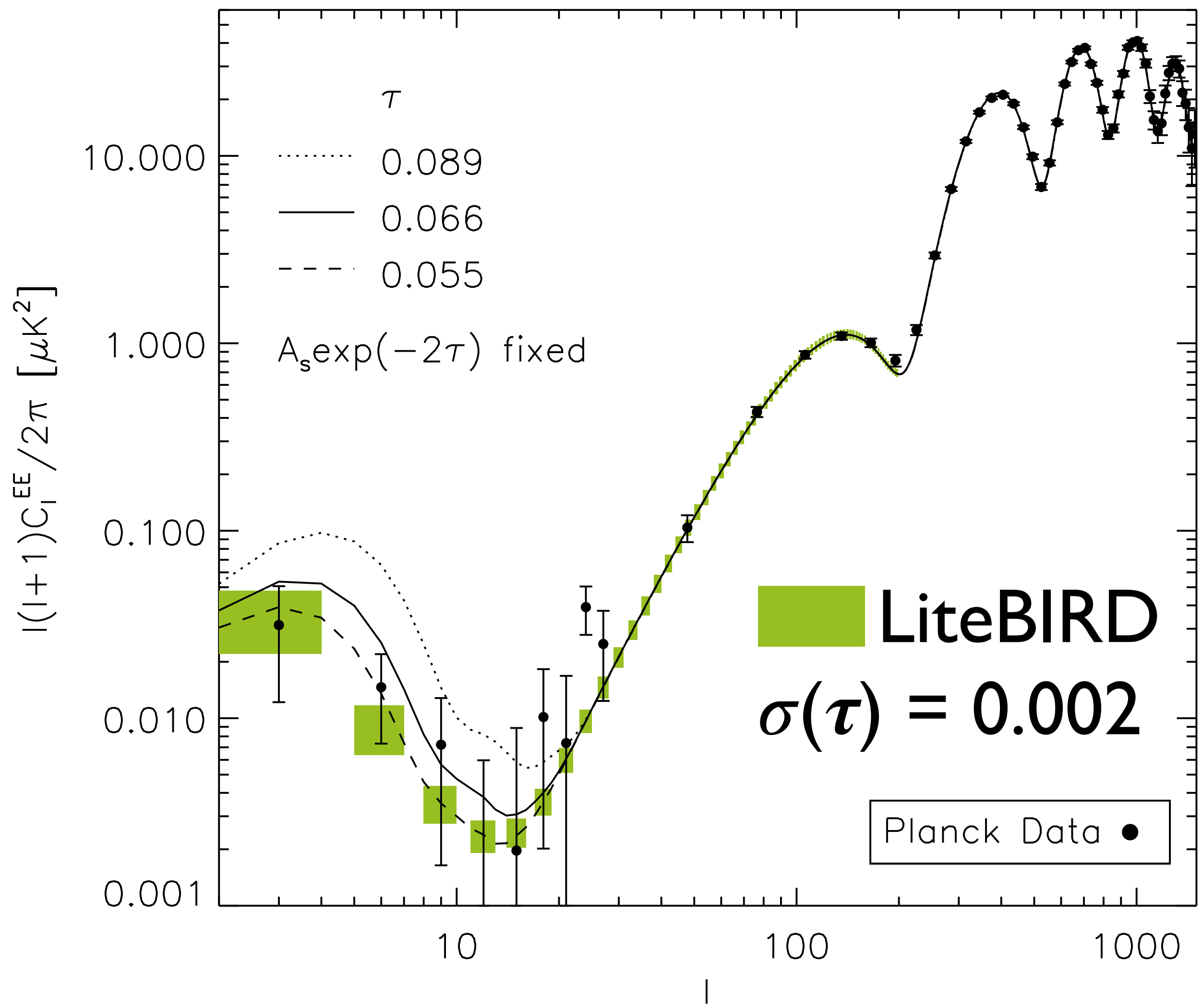
$$\begin{aligned} C_\ell^{TB,\mathrm{obs}} &= (2\Delta\alpha)\ C_\ell^{TE}, \\ C_\ell^{EB,\mathrm{obs}} &= (2\Delta\alpha)\ C_\ell^{EE}, \\ C_\ell^{BB,\mathrm{obs}} &= (2\Delta\alpha)^2 C_\ell^{EE}. \end{aligned}$$

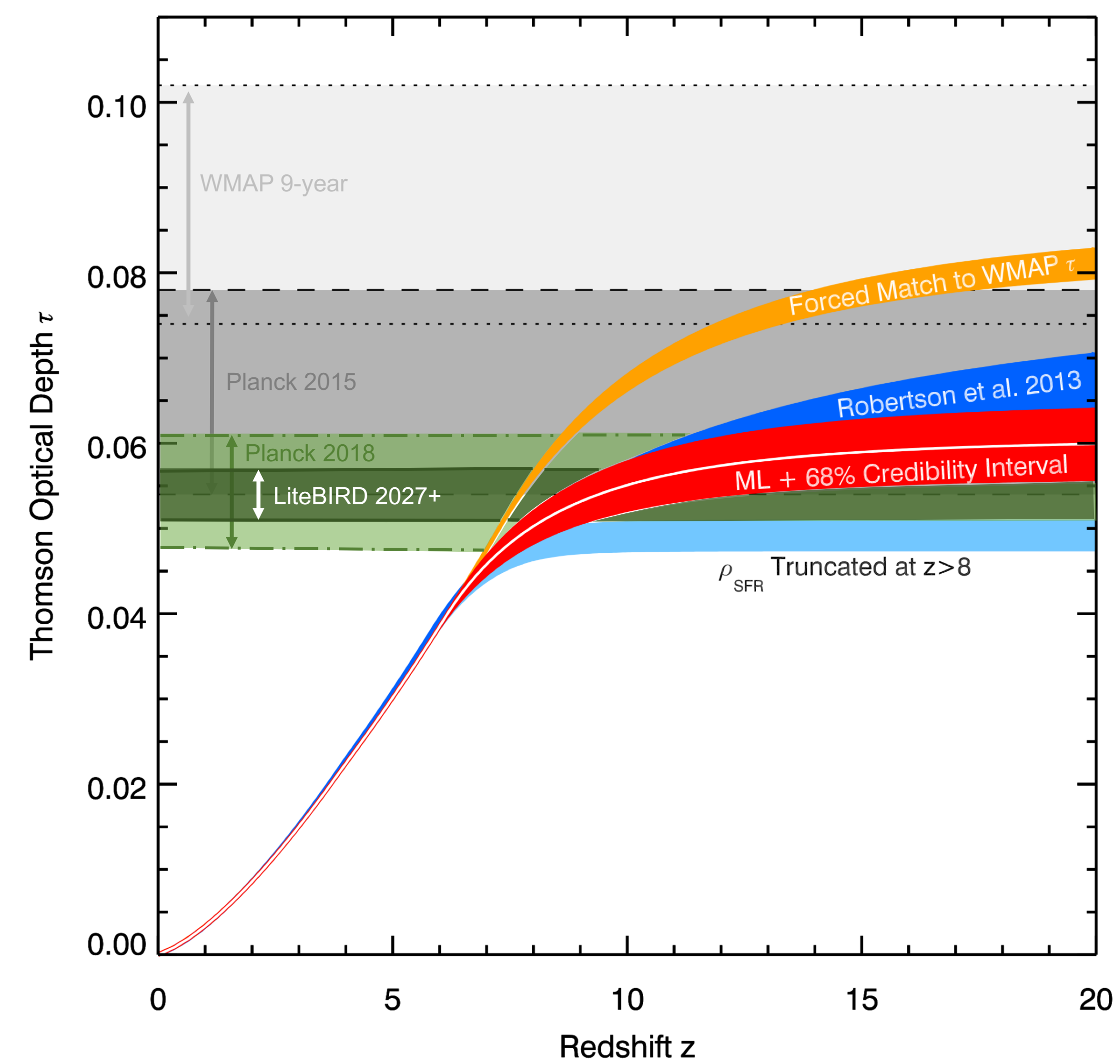
➡ TB and EB non longer zero

- homogeneous effect **degenerated** with miscalibration of polarization angles
- but
  - constraints on Faraday rotation from primordial magnetic field (with anisotropies of $\Delta\alpha$)
  - parity-violating gravitational waves (with spectral shape in $C_\ell$)

# Reionization

A cosmic variance limited measurement of EE on large angular scales will be an important, and guaranteed, legacy for LiteBIRD



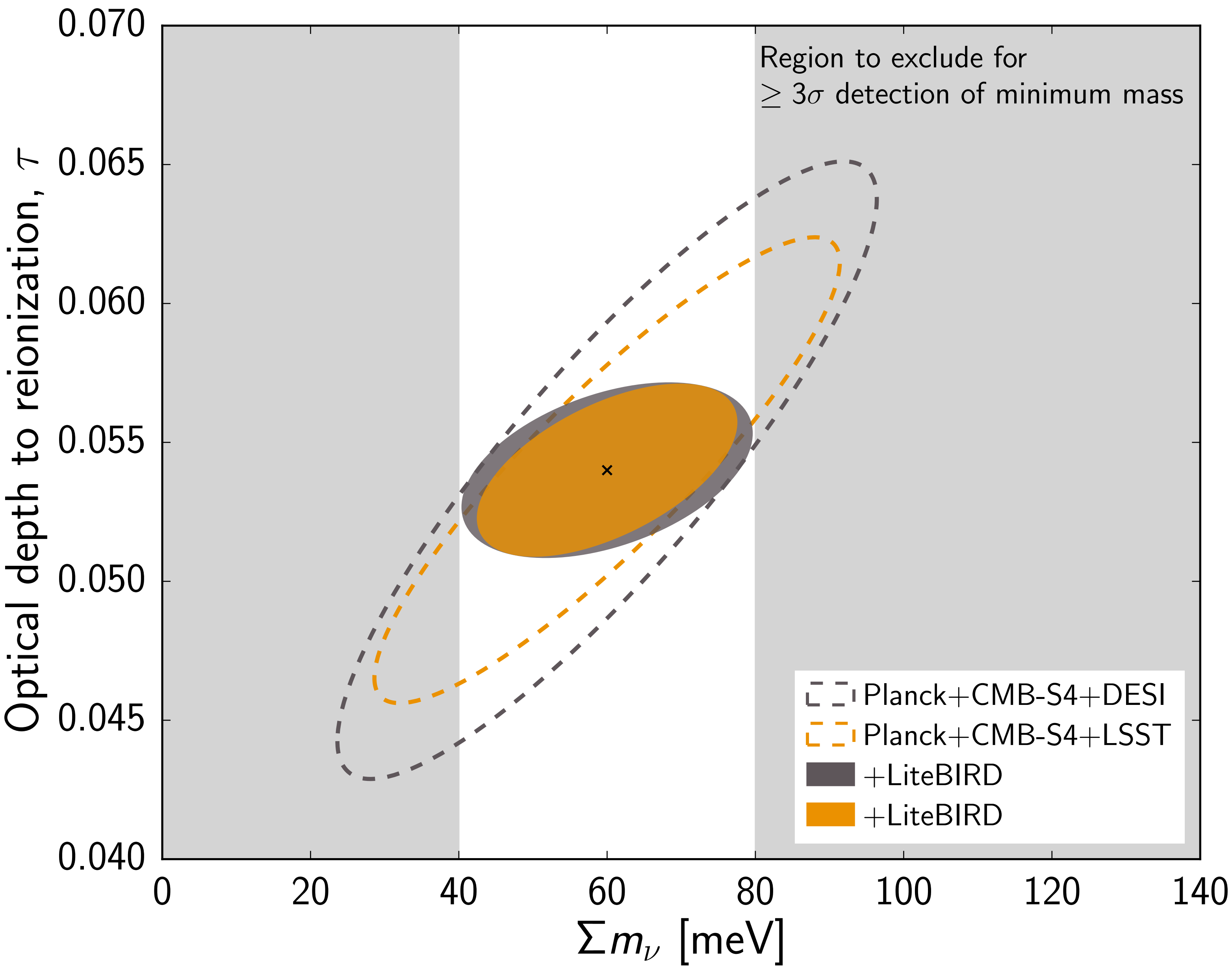




$\sigma(\tau)$ better than current Planck constraints by a factor 2

# Neutrino sector

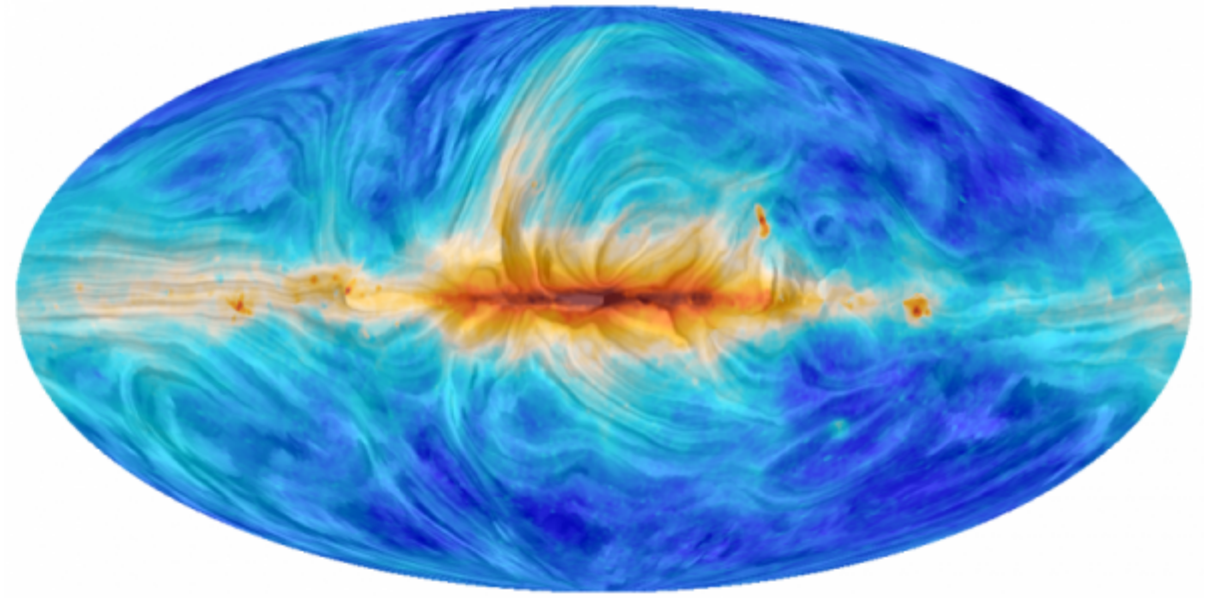
- Improvement in reionization optical depth measurement implies:

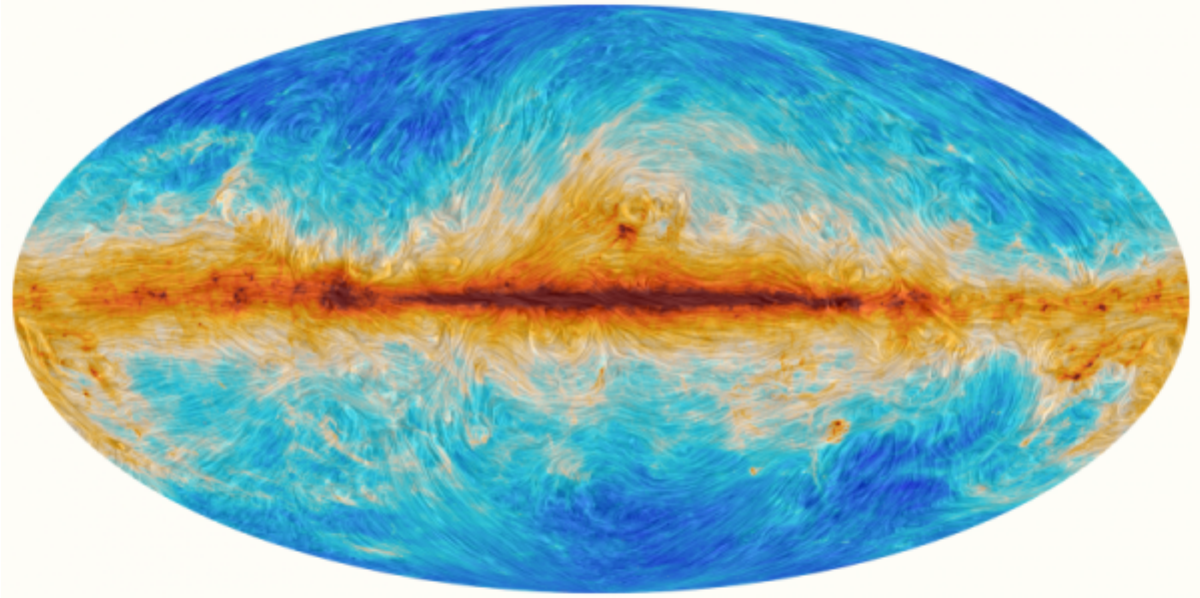
- $\sigma(\Sigma m_\nu)$ = 15 meV
- determine neutrino hierarchy (normal v.s. inverted)
- measurement of minimum mass ($\geq 3\sigma$ detection NH, $\geq 5\sigma$ detection for IH)



# Galactic science

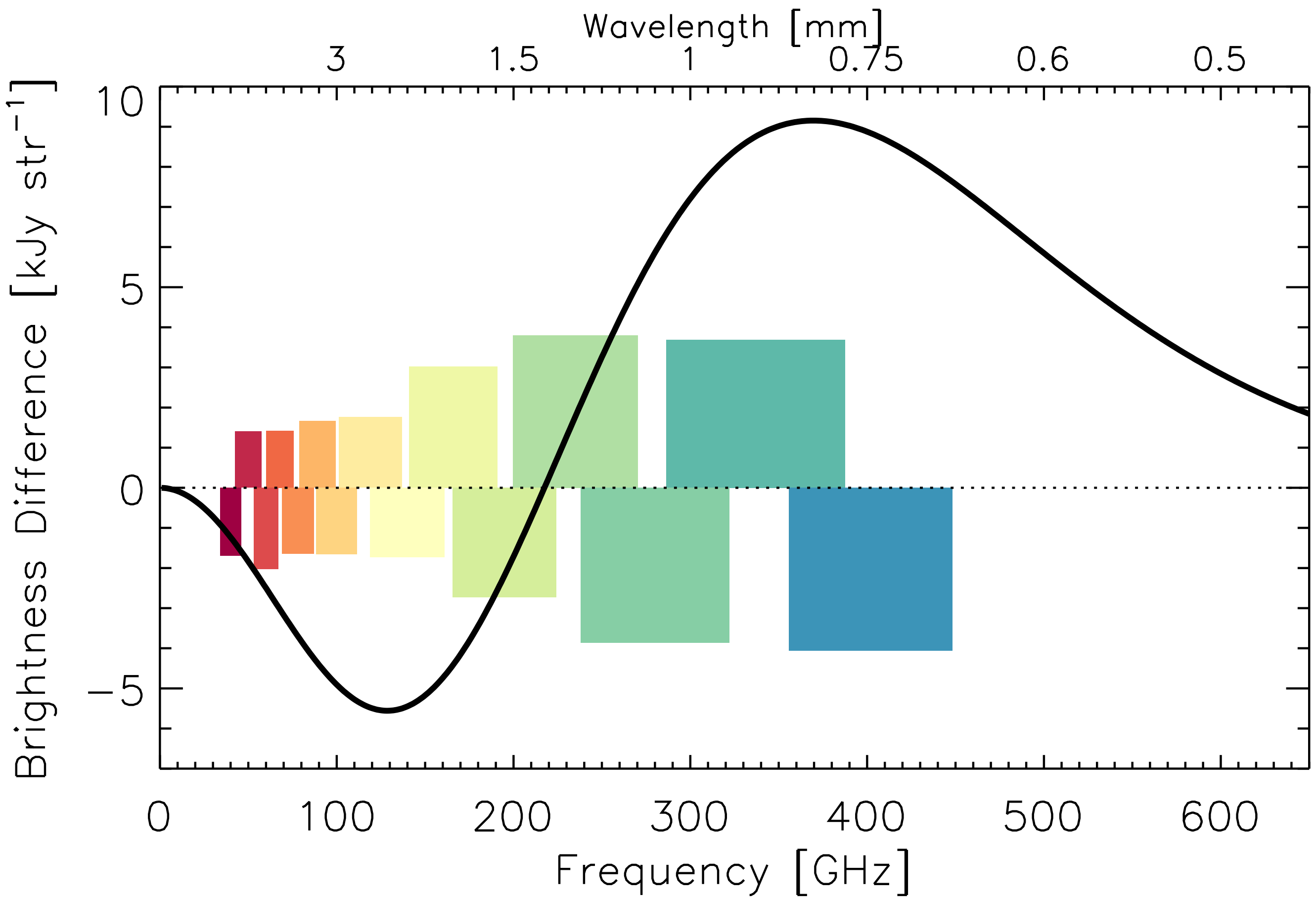
- With frequency range from 34 to 448 GHz and access to large scales LiteBIRD will gives constraints on
  - Characterisation of the foregrounds SED
  - Large scale Galactic magnetic field
  - Models of dust polarization grains

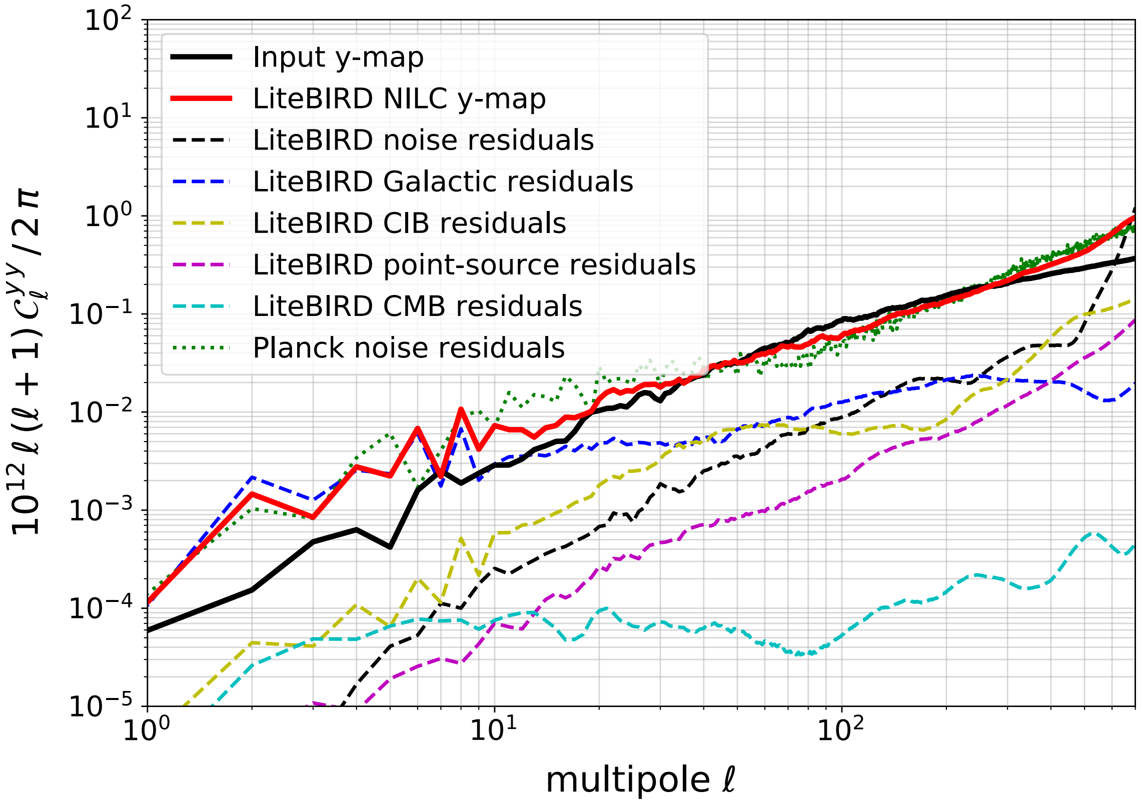

Synchrotron


Dust

# Mapping the hot gas in the Universe

- significant improvement on the SZ y-map in terms of foregrounds residuals thanks to the 15 bands



# Spectral distortions with LiteBIRD

- Anisotropic CMB spectral distortions could be measured well
  - Forecasts better than PIXIE ! (15 bands are many)
  - Multi-field effects or non-Bunch-Davies initial conditions
    - spatially-varying chemical potential distributions [Pajer-Zaldarriaga-2012, Ganc-Komatsu-2012]
    - Effects on $C_\ell^{\mu\mu}$, $C_\ell^{\mu T}$

- Frequency Space Differential measurements for detecting any spectral distortion [Mukherjee-Silk-Wandelt 2018]
  - Use inter-frequency differences only

interesting theoretical ideas need experimental assessment:

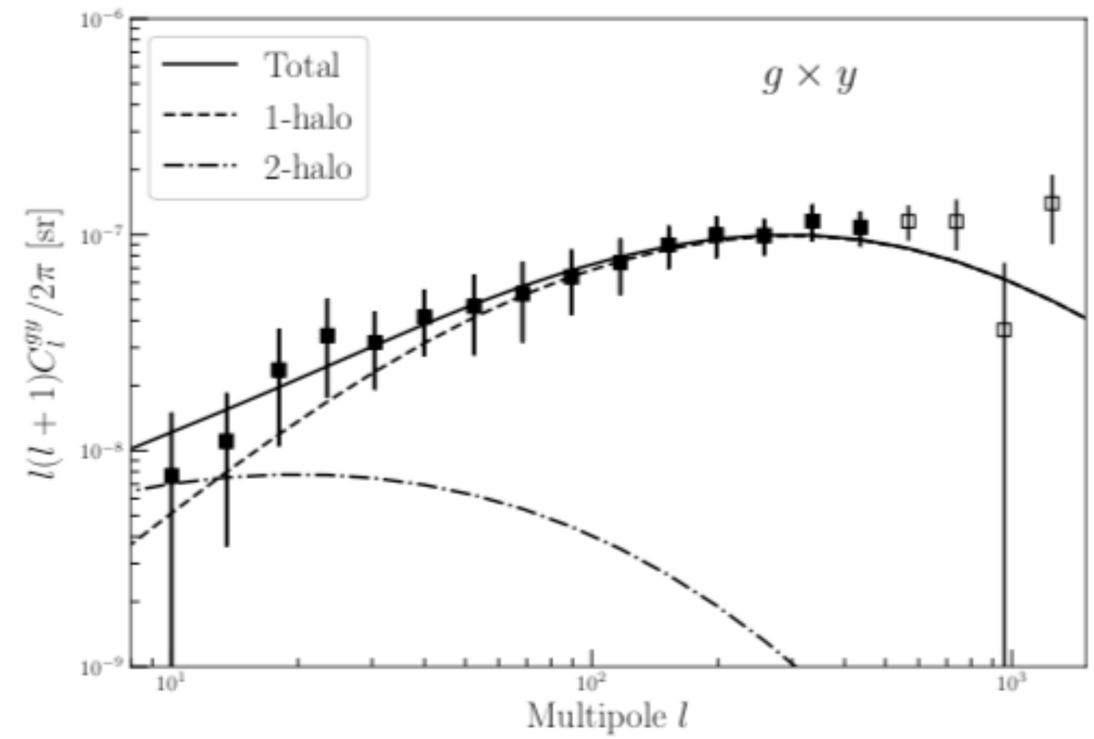
- include 1/f noise, systematic errors, etc…
- use advantages of multi-color detectors
- use "controlled imperfection" of HWP for gain calibration

# Synergy with other probes

- Galaxy surveys

full-sky map of hot gas
(thermal SZE)
$\otimes$
3D distribution of the matter
(galaxy survey)

how gas traces the matter in the Universe




- Integrated Sachs-Wolf effect

improvement on ISW signal (~20%)

- Lensing

LiteBIRD E-modes
+
CMB-S4 high-resolution

improve our knowledge of the projected gravitational lensing produced by the large-scale structure

# LiteBIRD Science outcomes

- Primordial gravitational waves from inflation
  - B-mode power spectrum
  - Full success
  - Extra success
  - Beyond the B-mode power spectrum

- Galactic science
- Optical depth and reionization of the Universe
- Cosmic birefringence

- Mapping the hot gas in the Universe
- Anisotropic CMB spectral distortions
- Elucidating anomalies with polarization
- Correlation with other data sets