

# CMB-HD R+D

On behalf of the CMB-HD Collaboration

Based on CMB-HD Snowmass2021 White Paper (2203.05728)  
and CMB-HD Astro2020 RFI (2002.12714)

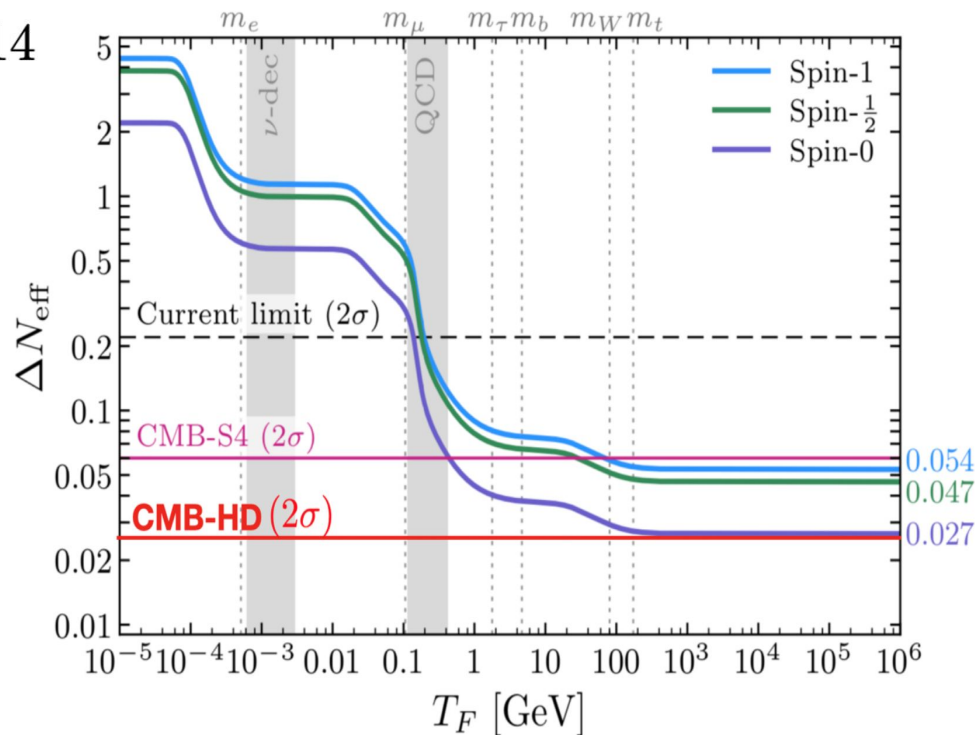
Presented by Neelima Sehgal on May 6th, 2022

# How key science requires new capabilities: Light Relics

Key light relic target:  $\sigma(N_{\text{eff}}) = 0.014$

Requires:

- Sky area = 50%
- Noise = 0.5  $\mu\text{K-arcmin}$  in temp
- Resolution = 15 arcsec at 150GHz to remove foregrounds enough to realize low instrument noise



# How key science requires new capabilities: **Inflation**

Key inflationary magnetic field target:

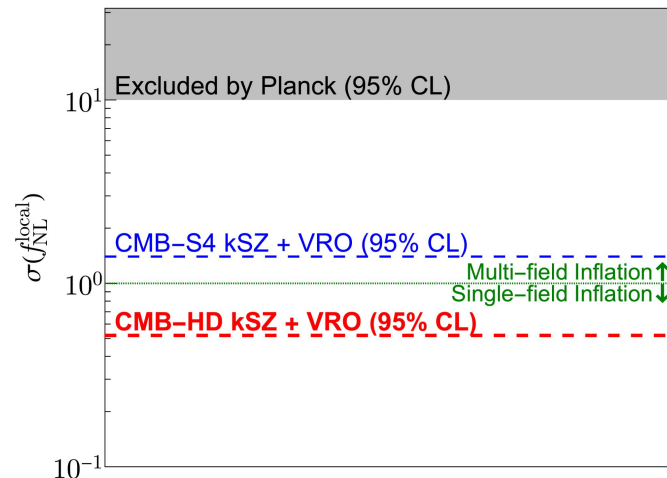
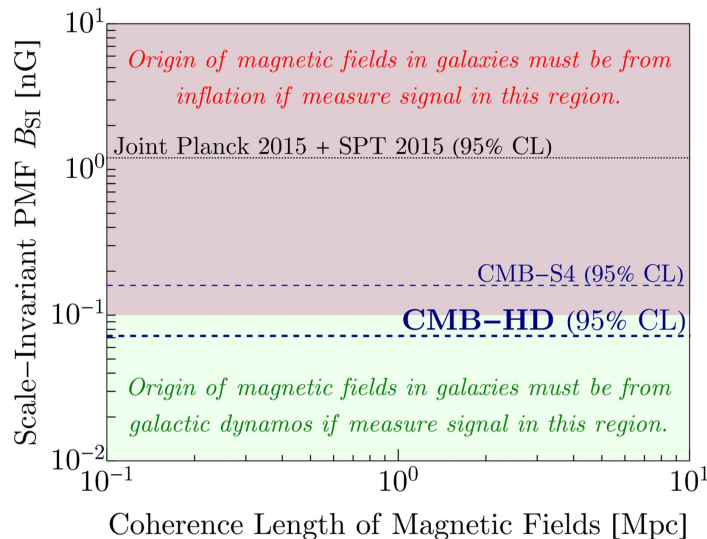
$$\sigma(B_{\text{SI}}) = 0.036 \text{ nG}$$

Key primordial non-Gaussianity target:

$$\sigma(f_{\text{NL}}^{\text{local}}) = 0.26$$

Requires:

- **Sky area** = 50%
- **Noise** = 0.5 uK-arcmin in temp
- **Resolution** = 15 arcsec at 150GHz to remove foregrounds enough to realize low instrument noise



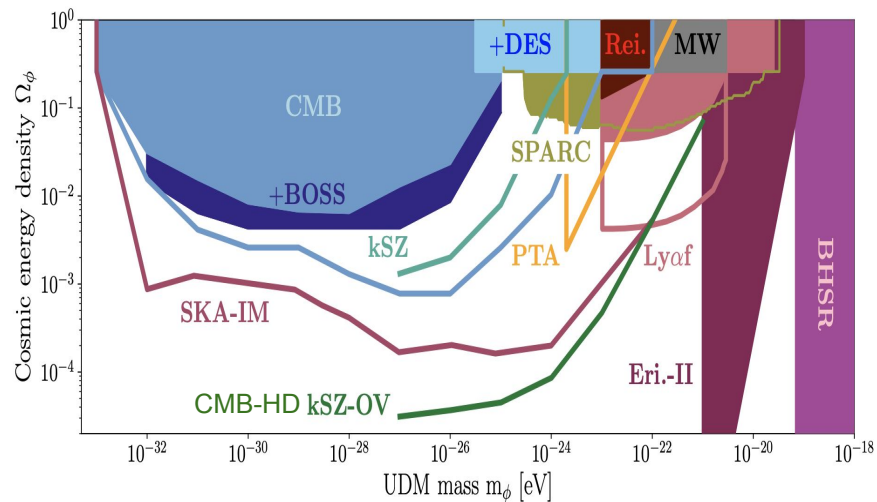
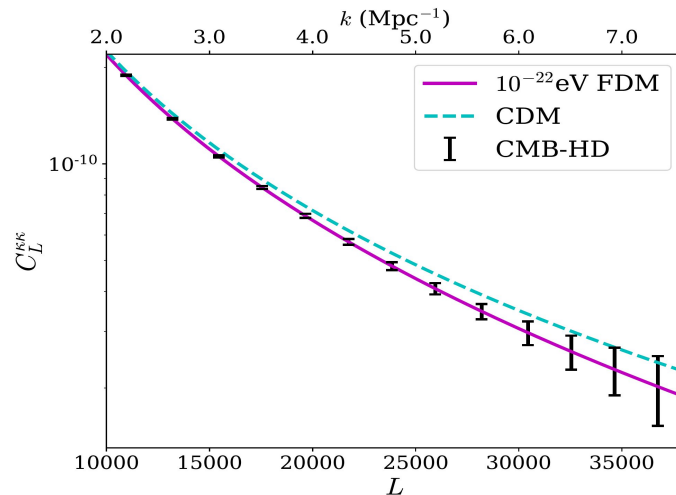
# How key science requires new capabilities: Dark Matter

## Key dark matter targets:

1. Distinguish between CDM and 2 keV or  $10^{-22}$  eV FDM model at  $5\sigma$  level
2. Make map of dark matter in the Universe on small scales
3. Measure the matter power spectrum on small scales with gravitational lensing

## Requires:

- Sky area = 50%
- Noise = 0.5  $\mu\text{K-arcmin}$  in temp
- Resolution = 15 arcsec at 150GHz



# Needed Instrumentation Capabilities

**Telescopes:** two new 30-meter-class off axis crossed Dragone

**Detector count:** each telescope would field 800,000 detectors (200,000 pixels) for a total of 1.6 million detectors (400,000 pixels)

**Site:** Cerro Toco in the Atacama Desert

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**Duration of survey:** 7.5 years

**Survey specs:** 20,000 square degrees (50% of sky), 0.5  $\mu$ K-arcmin in temp in 90+150 GHz channels, 15 arcseconds at 150 GHz

# Technology to be Developed: Telescope Design

While we have a preliminary outline of the CMB-HD telescope/instrument design, a more thorough telescope **design study is needed** including:

- a) a concept study that will explore a range of design parameters and cost vs tradeoffs that will meet the scientific goals and requirements for the project
- b) an engineering design that will produce a construction-ready design for CMB-HD
- c) a price proposal

**Cost for design study estimated to be \$4 million** based on other design studies

Contract a company such as Vertex or OHB Digital to do this

# Technology to be Developed: Scaling up Detector and Readout Production and Testing Facilities

Baseline design of CMB-HD based on dichroic, polarization-sensitive TES bolometers at 30/40, 90/150, and 220/280 GHz

- a) Detector technology, cooling technology, and readout technology already successfully demonstrated by experiments in Chile and the South Pole
- b) Detector noise specifications required for CMB-HD have already been demonstrated in the field
- c) 1.6 million detectors (400,000 pixels) required

Large number of detectors requires scaling up of detector and readout production and testing facilities

# Technology to be Developed: Scaling up Detector and Readout Production and Testing Facilities

## Paths to scale up detector and readout facilities:

- a) Existing facilities that make and test TES detectors, such as JPL and NIST, can scale up production to some extent
- b) DOE labs, such as Argonne and SLAC, develop fabrication facilities
- c) Commercial vendors can be employed

(Currently CMB-HD forecasts assume an observing efficiency of 20%, as also assumed by SO; an increase in observation time and/or observation efficiency can lower detector count)



# Technology to be Developed: Achieve High Packing Density of Detectors in Receivers

Each CMB-HD cryostat will hold between 13 and 26 optics tubes (depending on final optimization of tube size versus cost and focal plane usage)

Optics tubes distributed in ratio 1:4:2:2 for 30/40, 90/150, 220/280, and 280/350 GHz

Each optics tube will hold 500 to 4000 pixels (depending on frequency)

- a) Assuming  $2 f * \lambda$  spacing of detectors and a conservative 50% filling factor of the focal plane, can fit ~132,000 pixels per telescope
- b) **Baseline design assumes more optimistic filling factor of 75%**, yielding 200,000 pixels per telescope

## Technology to be Developed: Achieve High Packing Density of Detectors in Receivers

Loss of focal plane is due to gaps between wafers, optics tubes, and cryostats

Development needed:

Develop more efficient focal plane use, possibly using recent advances in low-loss silicon to have a warm first lens sitting outside the cryostat

## Technology to be Developed: Cooling of large-diameter (>2 meter) telescope receivers to 100 mK

CMB-HD preliminary design assumes seven cryostats for each telescope, each with a diameter of ~2.5 meters (focal plane area is about 7.3 meters, which contains the seven cryostats)

It is a challenge to cool large diameter receivers to 100 mK

Precursor surveys, such as SO and CMB-S4, will be demonstrating and achieving this

## Technology to be Developed: Laser Metrology System to Account for Thermal Effects on 30-meter Dishes

Given the large dish size of CMB-HD, a laser metrology system is required to correct for thermal, gravitational, and wind effects on timescales of tens of seconds

Such a laser metrology system is currently being tested on the GBT 100-meter and Nobeyama 45-meter telescopes at millimeter wavelengths

# Technology to be Developed: MKID Detector Development

If MKID detectors can be robustly demonstrated to achieve comparable sensitivity to TES detectors at millimeter-wavelengths, then MKIDs could replace TES detectors

- a) This would reduce the cost of CMB-HD considerably
- b) MKIDs are less complex to fabricate and are naturally multiplexed, simplifying their readout

The ToITEC and CCAT-prime projects will soon advance large-format, polarization-sensitive MKID arrays at frequencies ranging from 90 to 280 GHz relevant for CMB-HD; NIKA2 and Olimpo have already demonstrated background limited performance at these wavelengths

Using MKIDs at lower frequencies requires further MKID development

# Technology to be Developed: Demonstration/Development of Effective Foreground Cleaning with Simulations

A challenge for CMB-HD data analysis is to **remove astrophysical foregrounds**

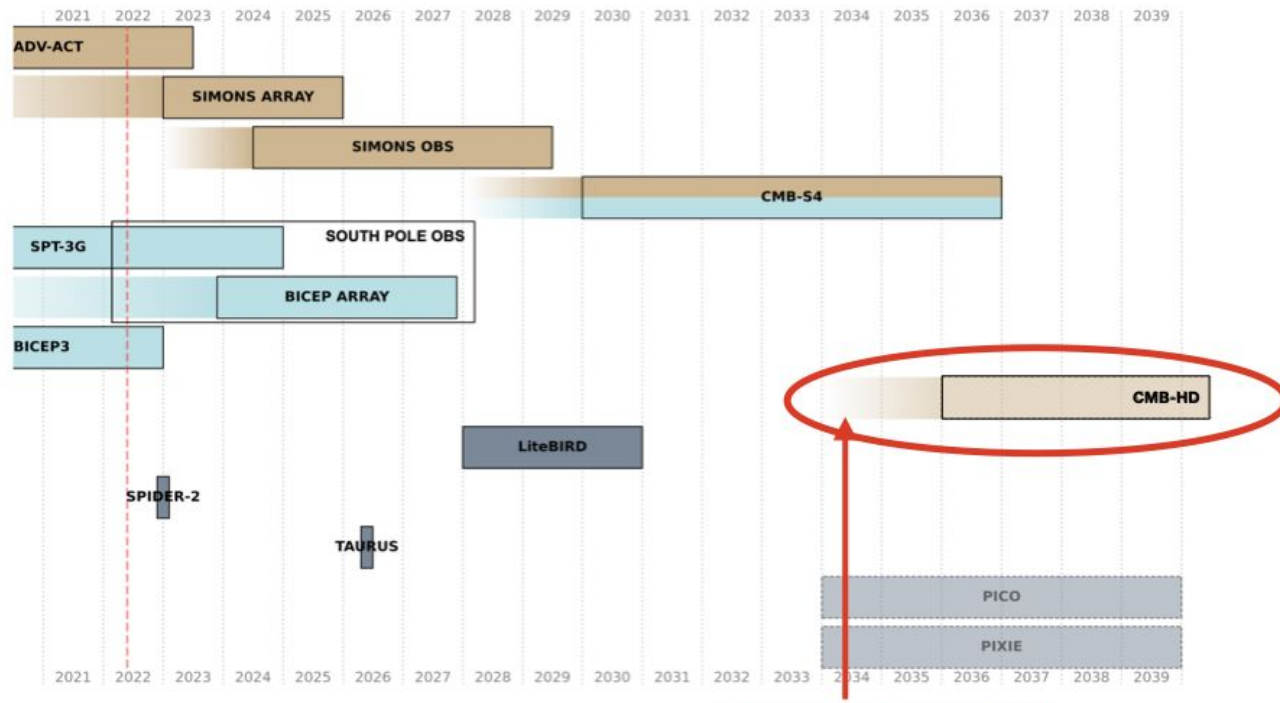
CMB-HD will mitigate foregrounds by having seven frequency channels, and very high resolution to remove extragalactic sources down to unprecedented flux levels

Further development needed:

1. While preliminary demonstrations of foreground-cleaning are promising, **full demonstrations of foreground mitigation using realistic simulations is warranted**
2. **Support for exploration of novel foreground cleaning techniques is also recommended** given the new regime of observations CMB-HD opens up

# Timeline

## *Snowmass2021 Cosmic Frontier: CMB Measurements White Paper*



Detectors on-sky by 2034

# Research and Development Roadmap

**Immediate** goals to achieve:

- Approval of design study by either DOE or NSF (or both)

- Support for foreground mitigation studies performed by theorists/analysts

**Near-term** development that will happen and should be further supported:

- Demonstration of cooling of large diameter receivers by precursor CMB surveys

- Demonstration of laser metrology system by GBT and Nobeyama

**Longer-term** goals:

- Development and demonstration of MKID detectors at millimeter-wave frequencies

- Development of techniques for more efficient focal plane use, including possibly a warm first lens

- Ramp up of detector testing and fabrication facilities