Unveiling the early universe with CMB spectral distortions

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Space-like environment on Moon

Radio astronomy at low frequencies

Optical astronomy

Gravitational wave astronomy

Far infrared astronomy
CMB spectroscopic interferometry

spectral distortions probe early universe energy input

aim: $\mu$ distortion $\sim 10^{-9}$

small scales $\sim$ 1990

y distortion

$T_0 = 2.725 \pm 0.001$ K
$|y| \leq 1.5 \times 10^{-5}$
$|\mu| \leq 9 \times 10^{-5}$

Pajer + Zaldarriaga 2012

Probing primordial energy input

\( \mu \) distortion is our best hope: over \( z = 5 \times 10^4 \) to \( 2 \times 10^6 \)

- \( z > 2 \times 10^6 \): bremsstrahlung + double Compton creates blackbody photons
- \( \mu = 1.4 \delta E_{\text{injection}} \) due to Compton scattering
  adds energy, conserves photon number, \( 2 \times 10^6 > z > 5 \times 10^4 \) : \( \mu \) distortion
- \( 5 \times 10^4 > z \): Thompson transfers energy : \( \gamma \) distortion

- Many papers on this: eg, decaying particles, primordial black holes…
- No guaranteed signal of exotica
- Robust probe of \( \Lambda \)CDM
Moon for CMB/IR spectroscopy

Unprecedented reach for a Fourier transform spectrometer

**PIXIE (x10^{-3} FIRAS)** rejected (twice) by NASA
55cm telescope + 1 detector
WHAT NEXT?

**SIMBAD:** Spectroscopic Interferometer for Microwave Background And Distortions

target $\mu \sim 10^{-9}$ with 10 detectors on 1.5m telescope + 4 modules

$\sim 10^{-5}$ FIRAS sensitivity

Maillard 2021
Far infrared science

- dual input Fourier transform interferometer
- fed by sky and reference blackbody at 2.7 K and bolometer array, cooling of telescope plus FTS to 2.5 K.
- 1.5 m telescope diameter, frequency range 90 to 2000 GHz
- Up to 4 modules in 1.5 ton payload.
- Sky scanning by lunar rotation
- Permanently shadowed cold crater at lunar south pole
- Aim for improvement over FIRAS by 5 orders of magnitude.

https://ideas.esa.int/servlet/hype/IMT?documentTableId=45087631495636486&userAction=Browse&templateName=&documentId=d7513ee471c4617ecf87df4e34e3f113
Going for primordial helium
a guaranteed signal
Lunar telescopes

- It’s futuristic (2030+) but will happen
- Space agencies are planning a lunar space station and a lunar village, so telescope logistics shouldn’t be a problem
- Really big projects in science have long lead times, eg a 100 TeV particle collider in ~ 2050
- Lunar telescopes can do unparalleled cosmology, unachievable on earth or even in space

FIR spectrometer to test $\Lambda$CDM
Detect H/He recombinations @ $z \sim 10^3 - 10^4$
Search for exotic early energy input