Experimental Probe of Inflationary Cosmology (EPIC)

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Science: Probing the Inflationary Epoch

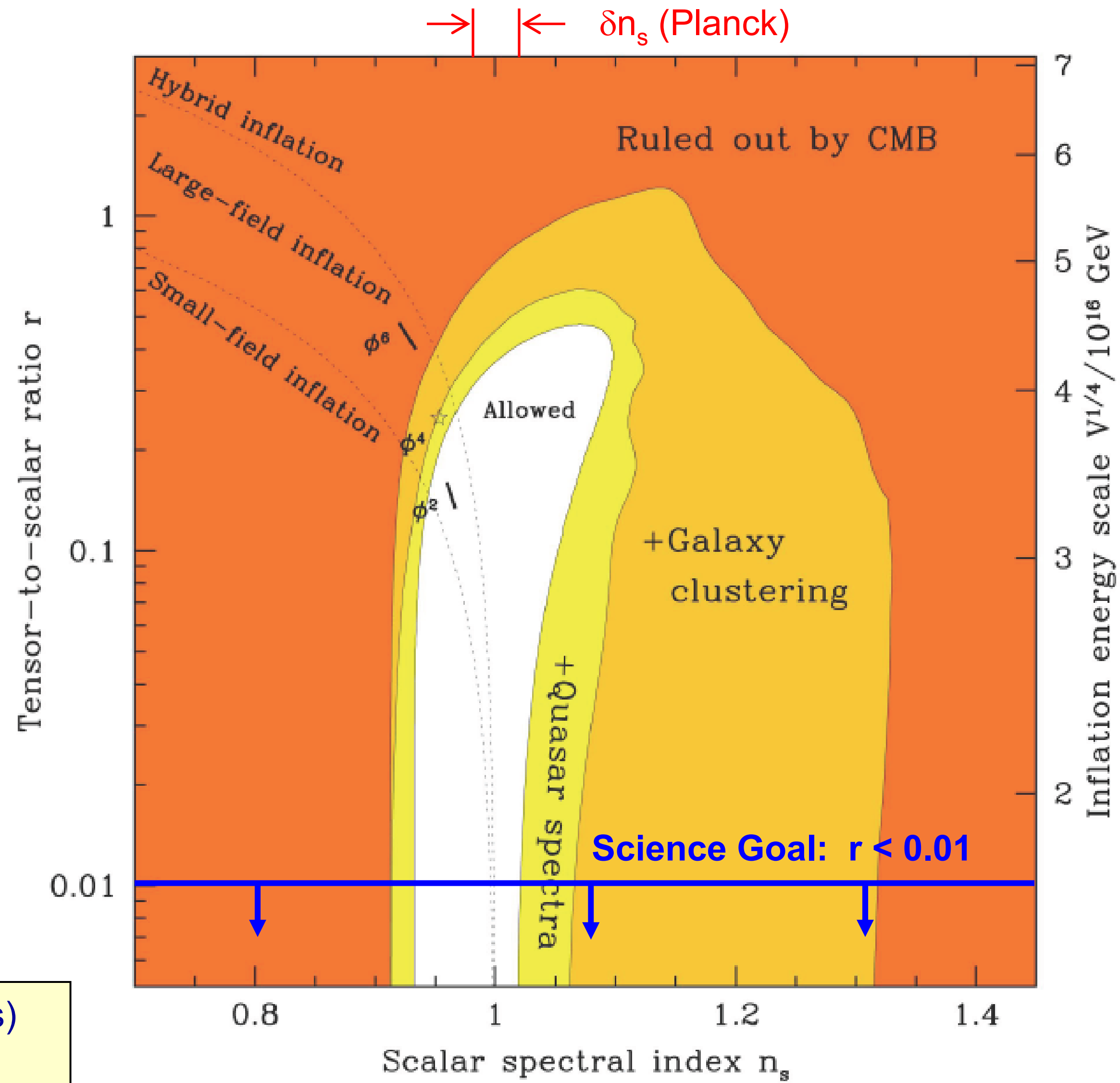
Primary Objective

Discover what powered the Big Bang… search for gravitational waves from the earliest moments of the Big Bang

NASA 2006 Strategic Plan

A measurement of Inflationary Gravitational-Wave (IGW) B-mode CMB polarization discriminates between models of Inflation

No other way to probe the energy scale of Inflation in the foreseeable future



"We find that, except for (inflation models) with numerous unnecessary degrees of fine-tuning… r ≥ 10^{-2}."

- Boyle, Steinhardt & Turok 2006, PRL 96, 111301

Weiss committee TFCR, astro-ph/0604101

Secondary Science Themes

Secondary Science Objectives

History of reionization

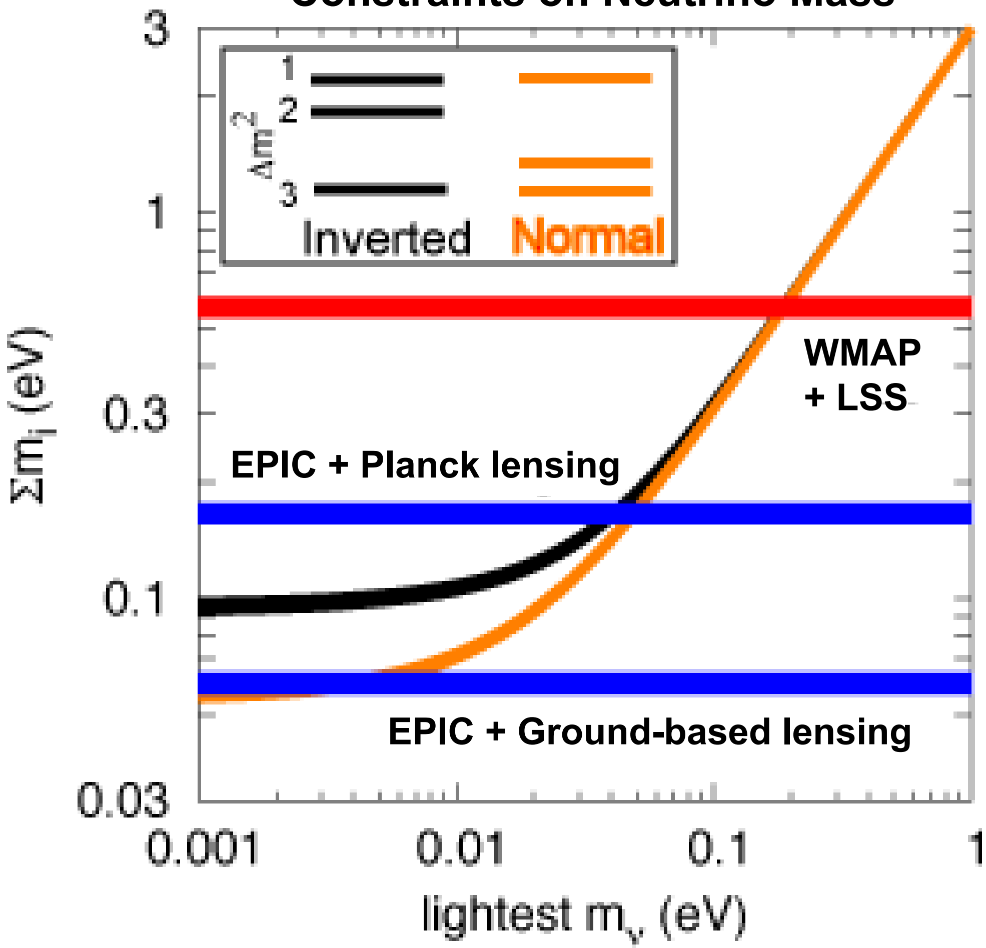
Scalar polarization to cosmic variance

EPIC complements ground-based large-aperture CMB polarimeters

- **neutrino masses:** $\delta\Sigma m_i = 0.05$ eV
- **dark energy:** $\delta w = 0.05$
- **lensing removal:** $r < 0.001$

EPIC is specialized for those measurements where space is an absolute necessity

Constraints on Neutrino Mass



Can directly test the recent atmospheric oscillation result: $\Delta m_i^2 = 2 \times 10^{-3}$ eV^2

M. Kaplinghat *et al*. 2003, PRL 91, 241301

Science Requirements to Instrument Parameters

Measurement Requirements*

Measure the entire B-mode spectrum covering the multipole range ℓ < 200

- low resolution $\Delta\theta \sim 1^\circ$
- all sky coverage *requires space*

Detect minimum r = 0.01 allowed by lensing foreground without cleaning

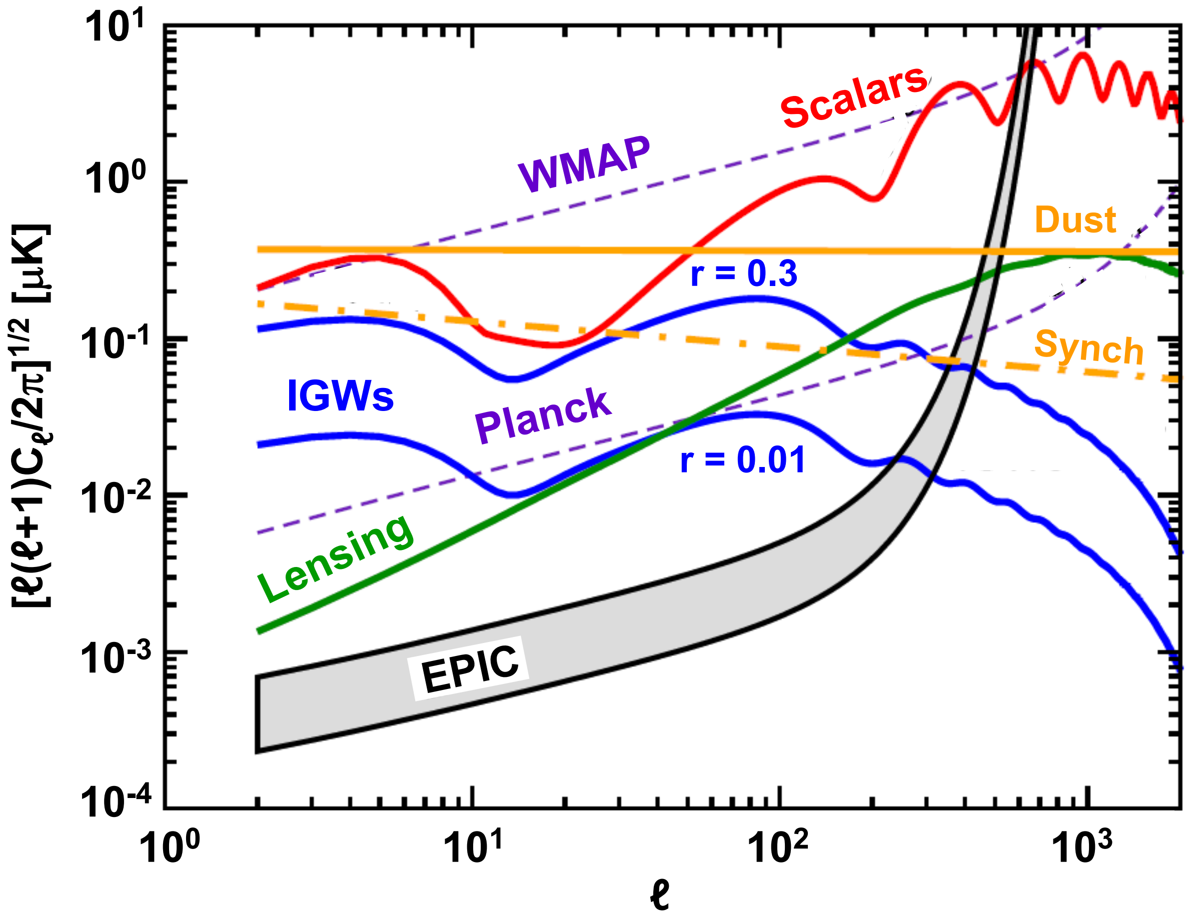
- sensitivity ~10x better than Planck *requires space*

Control systematics below science goal

- *requires space*

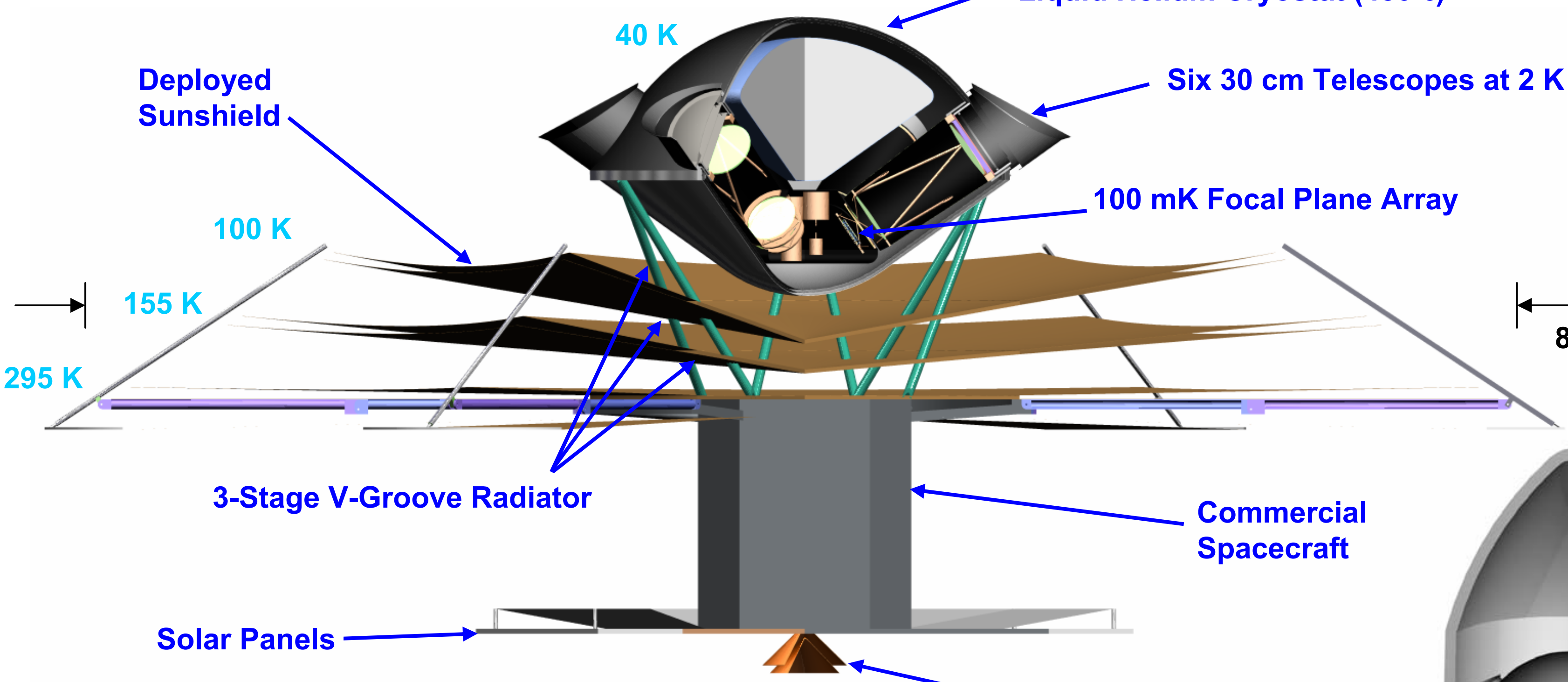
Wide band coverage to clean foregrounds

- 30 – 300 GHz range *requires space*



*Taken from TFCR (Weiss committee astro-ph/0604101)

Mission Architecture



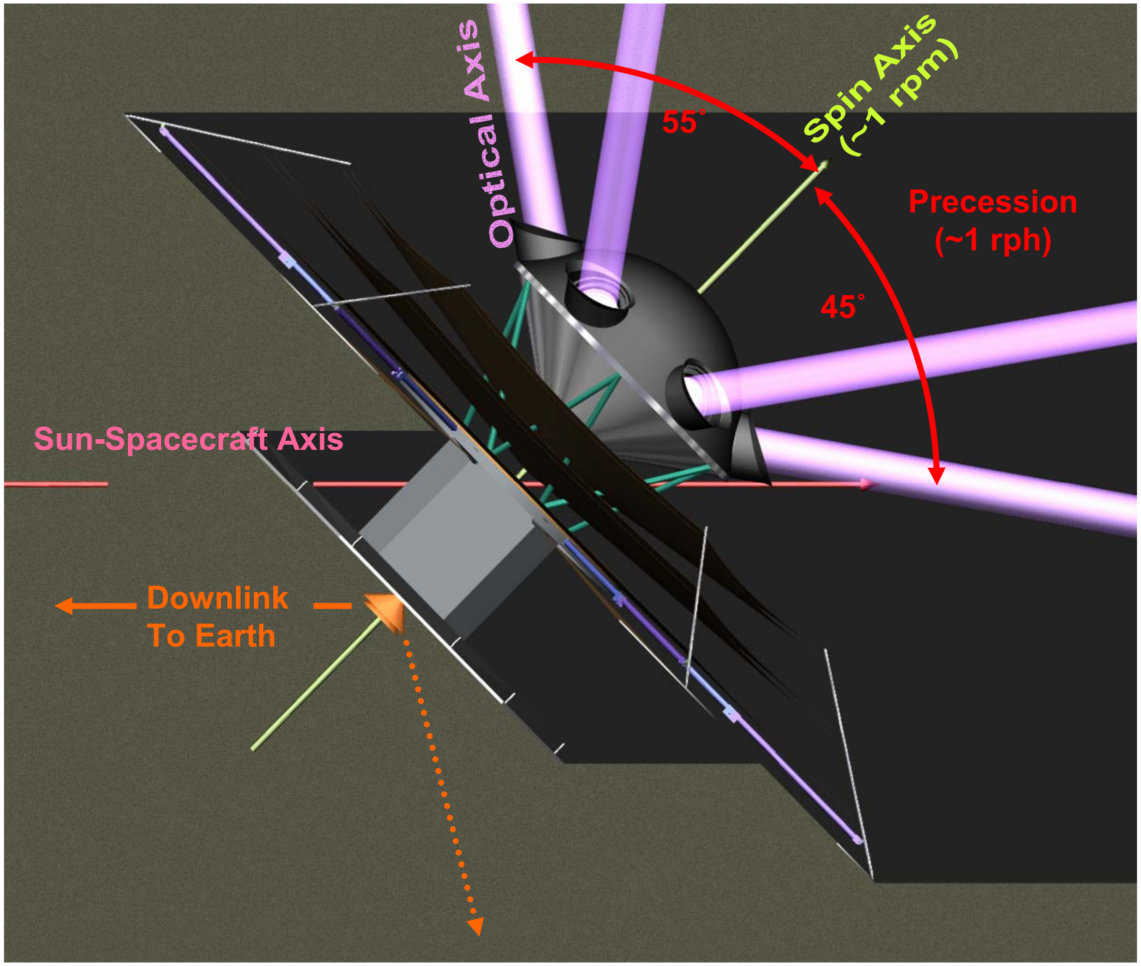
Main Features			
Frequency Bands	30 – 300 GHz	Orbit	L2 Halo
Resolution	0.9˚ at 90 GHz	Inflow Data Rate	87 kbps
Detectors	830 NTD Ge bolometers	Total Mass (CBE)	1320 kg
Req'd Lifetime	1 year	Total Power (CBE)	875 W
Aperture	30 cm	Delta-V	215 m/s

Delta 2925H 3-m

Simple & Tested Technological Approach

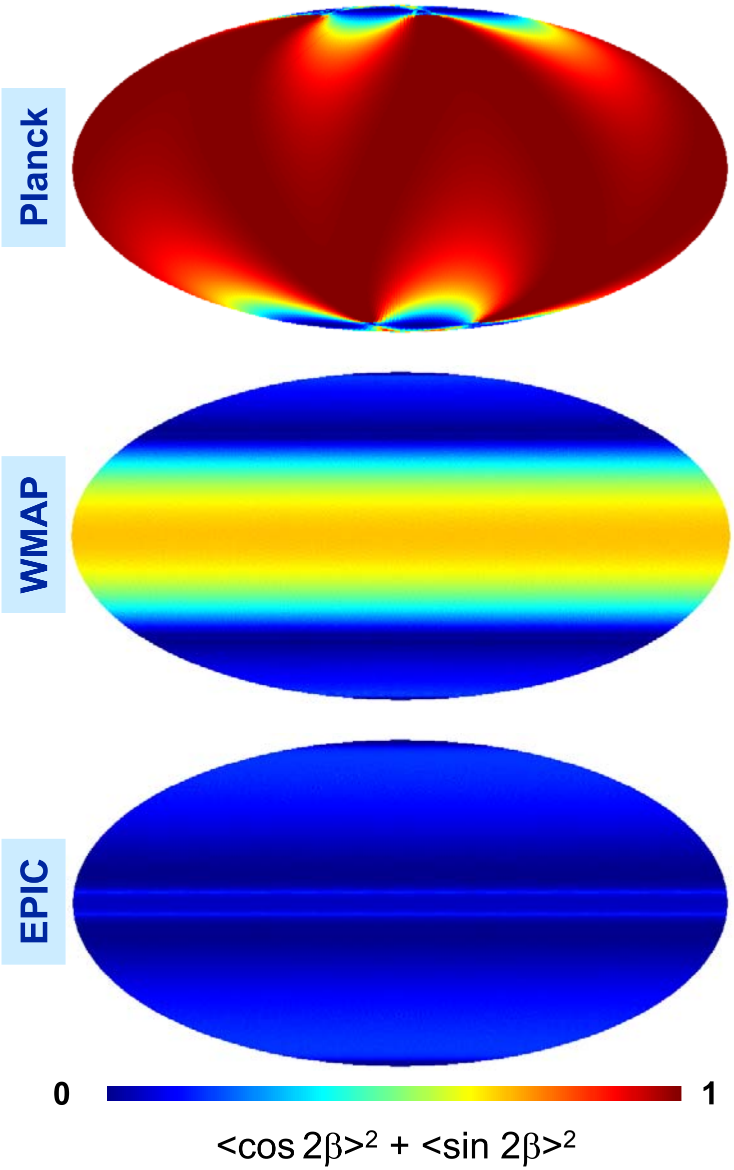
Technology	TRL	Heritage
Focal Plane Arrays (Baseline Mission)		
NTD Ge thermistors and readouts	8	Planck & Herschel
Dual-Polarization Antennas	4	
Wide-Field Refractor	6	BICEP
Waveplate (stepped every 24 hours)		
Optical configuration	6	SCUBA, HERTZ, etc.
Cryogenic stepper drive	9	Spitzer
LHe Cryostat	9	Spitzer, ISO, Herschel
Sub-K Cooler: Single-shot ADR	9	ASTRO-E2 (single-shot)
Deployable Sunshield	4-5	TRL=9 components
Toroidal-Beam Downlink Antenna	4-5	TRL=9 components

Powerful Scan Strategy; Simple Operations



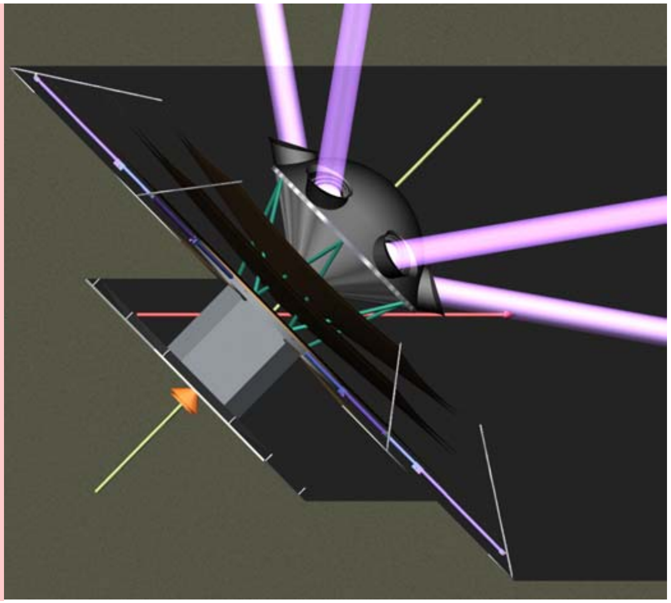
Modest Requirements on Spacecraft

Angular Uniformity in 6 Month Maps

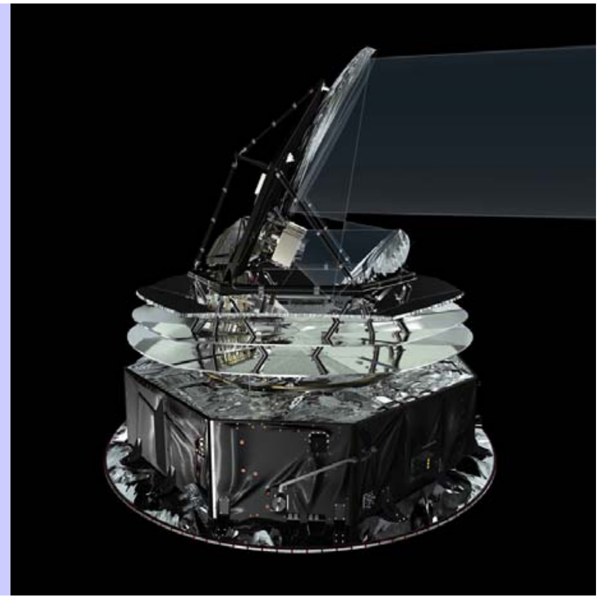


Comparing EPIC to Planck

EPIC



Planck



	EPIC	Planck	How EPIC compares
Scan Strategy	Spin/Precess at L2	Spin at L2	Optimized for polarization
Instruments	Single Instrument 100 mK Bolometers	Two Instruments 20 K HEMTs + 100 mK Bolometers	Much simpler integration Simpler cooler requirements
Cooling chain	Passive + LHe cryostat + ADR	Passive + Hydrogen sorption + 4 K Stirling + Open-cycle dilution	Avoids systems issues Can operate detectors in lab
Instrument hardware at TRL < 6	Antennas, sunshade (2007)	Bolometers, read out electronics, feeds, coolers, polarization analyzers (1998)	Readiness is higher
Data Analysis	Higher sensitivity Systematic error control built in	Higher resolution (maps 100x larger) Fewer detectors	Comparable

Conservative Mission Design

Instrument Architecture

High TRL approach
Single detector technology
Straightforward cooling chain

Modest Spacecraft

Requirements on structures, pointing, data, etc are not demanding
Spacecraft components are all off-the-shelf
Simple operations with a single observing mode

Large Mission Resource Reserves

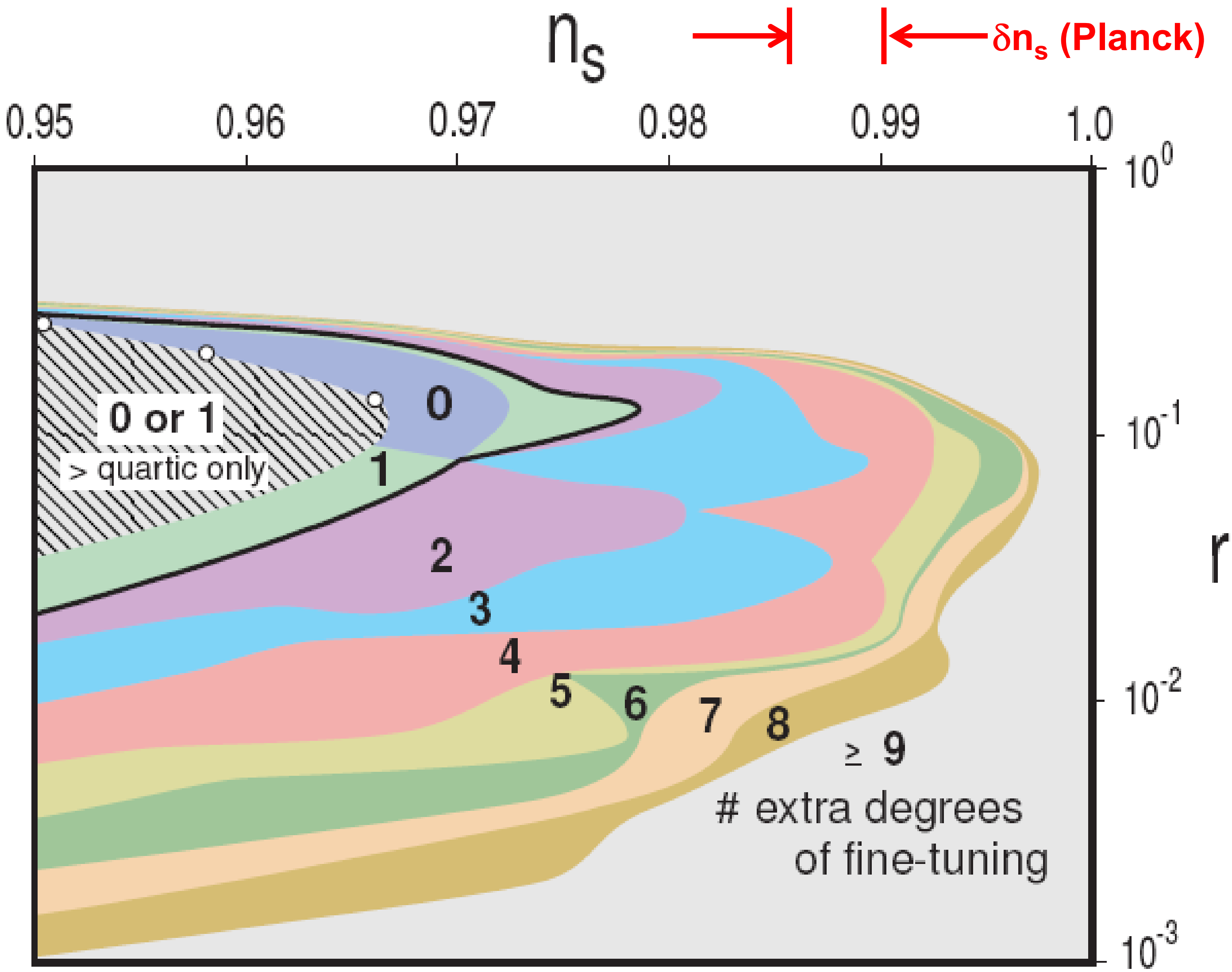
43 % contingency on all mass components + 95 % margin
43 % contingency on all power components + 10 % margin
100 % contingency on data rate
At least 100 % contingency on mission life

Mission Costs

Calculated with JPL's Parametric Mission Cost Model (PMCM)
Costs based on a 43 % contingency applied to every subsystem
We extended phase C/D to 4 years due to cryogenic instrument
Instrument cost agrees with a grass-roots analysis based on Planck & Herschel
Estimate agrees with a delta-cost comparison to Spitzer

Backup Materials

Probing Models of Inflation



Boyle, Steinhardt & Turok 2006, PRL 96, 111301

CMB Polarization as a Test of Inflation

1999 National Academy of Sciences *Gravitational Physics: Exploring the Structure of Space and Time:* "Observations of CMB polarization fluctuations could lead to the detection of a stochastic background of gravitational waves from the early Universe"

2001 *Astronomy and Astrophysics in the New Millennium:* "Gravitational waves excited during the first instants after the Big Bang should have produced effects that polarized the background radiation. More precise measurements of the properties of this polarization—to be made by the generation of CMB missions beyond Planck—will enable a direct test of the current paradigm of inflationary cosmology, and at the same time they will shed light on the physics of processes that occurred in the early Universe at energies far above those accessible to Earth-bound accelerators."

2003 National Research Council *Connecting Quarks with the Cosmos*, "Measure the polarization of the cosmic microwave background with the goal of detecting the signature of inflation"

2005 NSF, NASA and DOE *Task Force on Cosmic Microwave Background Research*: "Our highest priority… is a program to measure the large-scale CMB polarization signal… to test whether GUT-scale inflation occurred… limited only by astrophysical foregrounds

Modest Spacecraft Requirements

	Parameters	Units	EPIC Requirement
Structures	Payload Mass	kg	898 (includes 43 % contingency)
	Spacecraft Dry Mass	kg	713 (includes 43 % contingency)
	Mass margin	kg	1702 (95 % margin on Atlas V 401)
	Orbit		Sun-Earth L2 Halo
	Launch vehicles		Atlas V 401, Delta IV 4040, Delta II
	Mission Design Life	yrs	> 2
Power	Payload Power	W	272 (includes 43 % contingency)
	Spacecraft Power	W	981 (includes 43 % contingency)
	Solar Panel Area	m^2	7.8
	Power margin	W	127 (10 % margin)
C&DH	Data Downlink Rate	kbps	500
	Data Storage Capability	GB	1
ACS	Attitude control		3-axis momentum compensated
	Pointing knowledge	arcsec	30
	Pointing control	degree	1
Propulsion	Propellant system		Hydrazine
	Propellant mass	kg	172
	Delta-V budget	m/s	215 (includes contingency)

Readiness of Key Instrument Technologies

EPIC Technology Readiness (c. 2007)		
Technology	**TRL**	**Heritage**
Focal Plane Arrays		
NTD Ge thermistors and readouts	8	Planck & Herschel
Antennas	4	
Wide-Field Refractor	6	BICEP
Waveplate	6	SCUBA, HERTZ, etc.
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Deployable Sunshield	4-5	TRL=9 components
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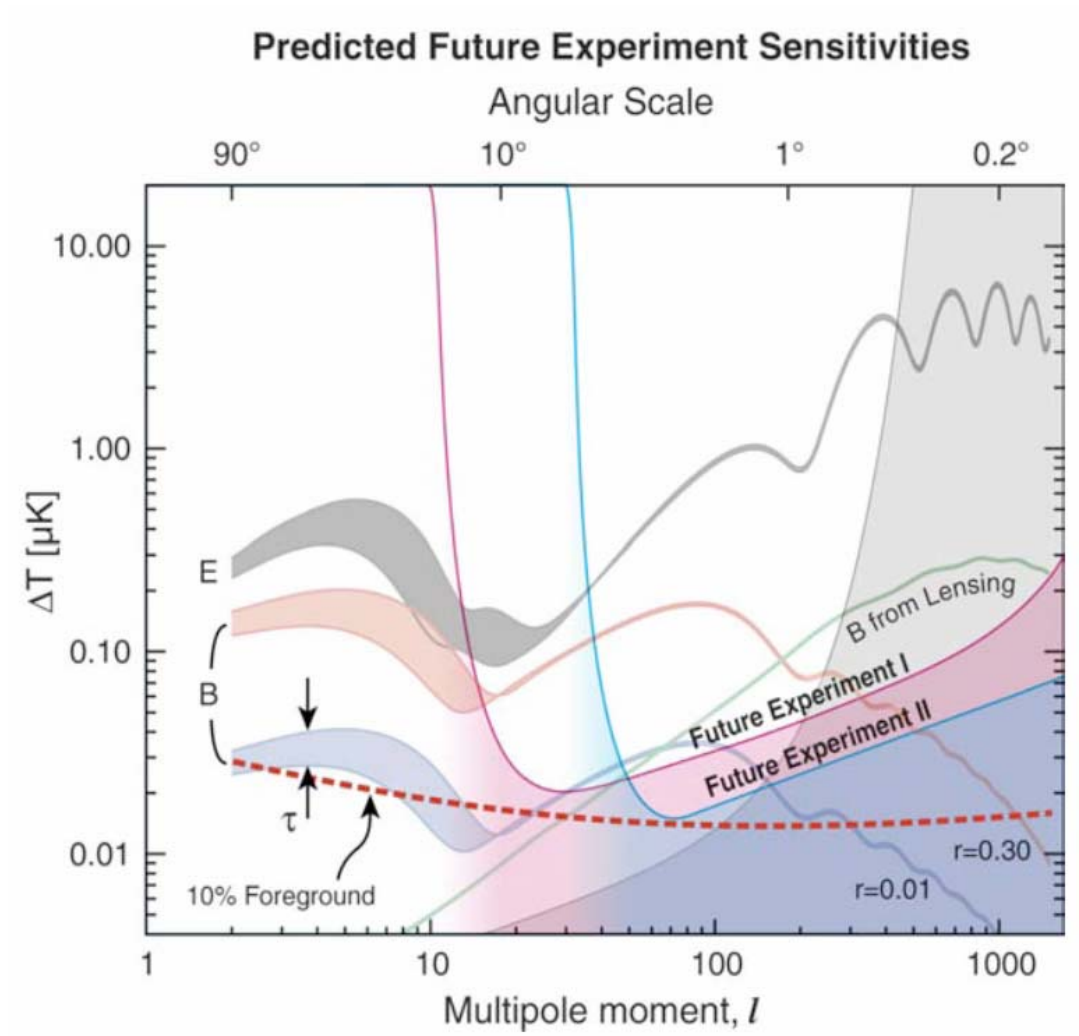
Planck Technology Readiness (c. 1998)		
Technology	**TRL**	**Heritage to TRL = 6**
NTD thermistors and readouts	5	Boomerang (1999)
Electronics	5	Archeops (2002)
Feedhorns & Filters	4-6	Archeops (2002)
Cooling Chain		
20 K Hydrogen Sorption	4-8	Planck CQM (2005)
4 K Stirling	9	
100 mK Open-Cycle Dilution	5	Archeops (2002)
Test of Integrated System	-	Planck CQM (2005)
Polarization Sensitive Bolometers (PSBs)	-	B2K (2003)

Ground-Based & EPIC Complement Each Other



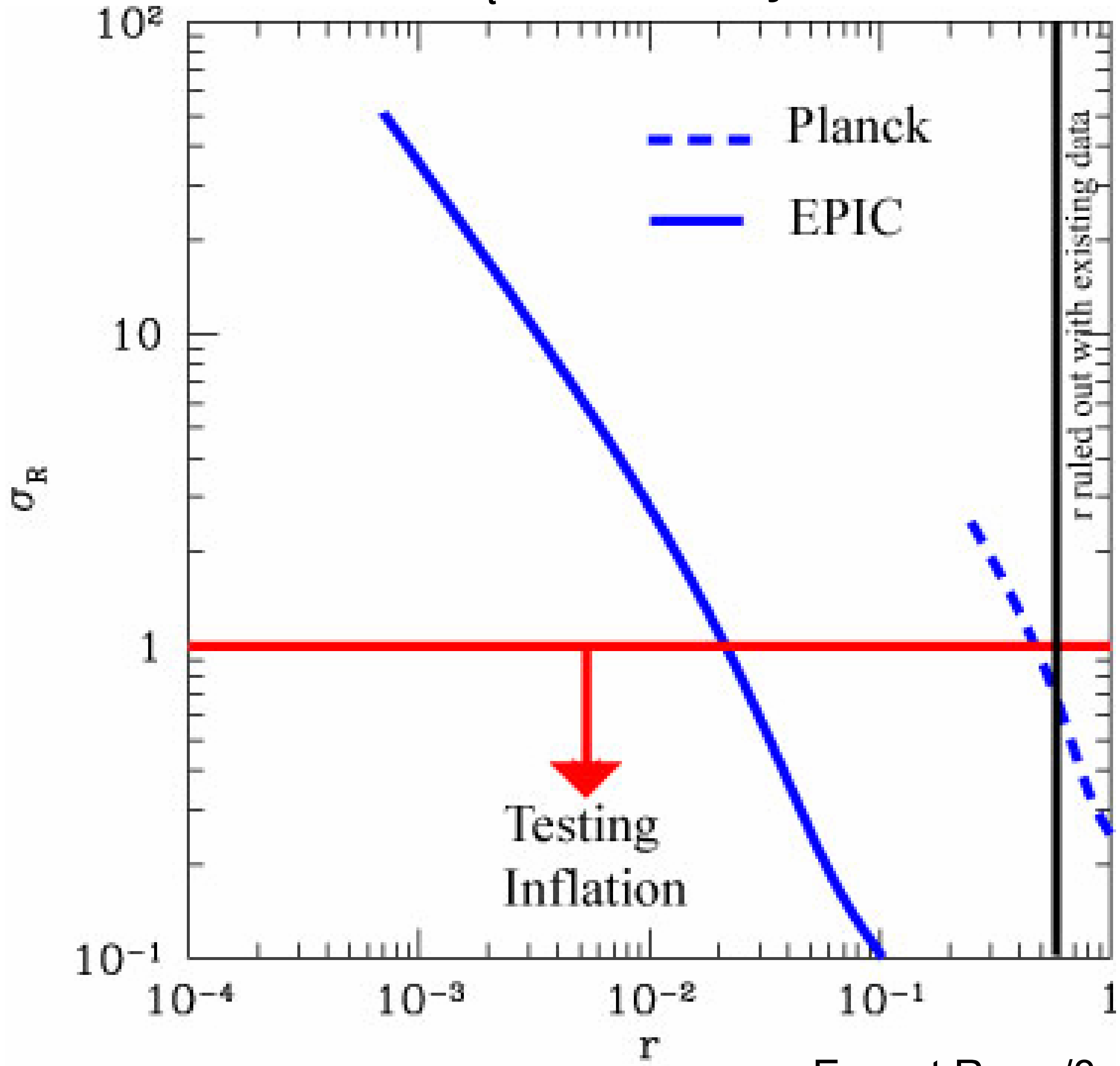
Combined Themes

- Dark Energy Equation of State
- Neutrino Masses
- Lensing Removal

Weiss committee TFCR, astro-ph/0604101

Value of Measuring Entire IGW Spectrum

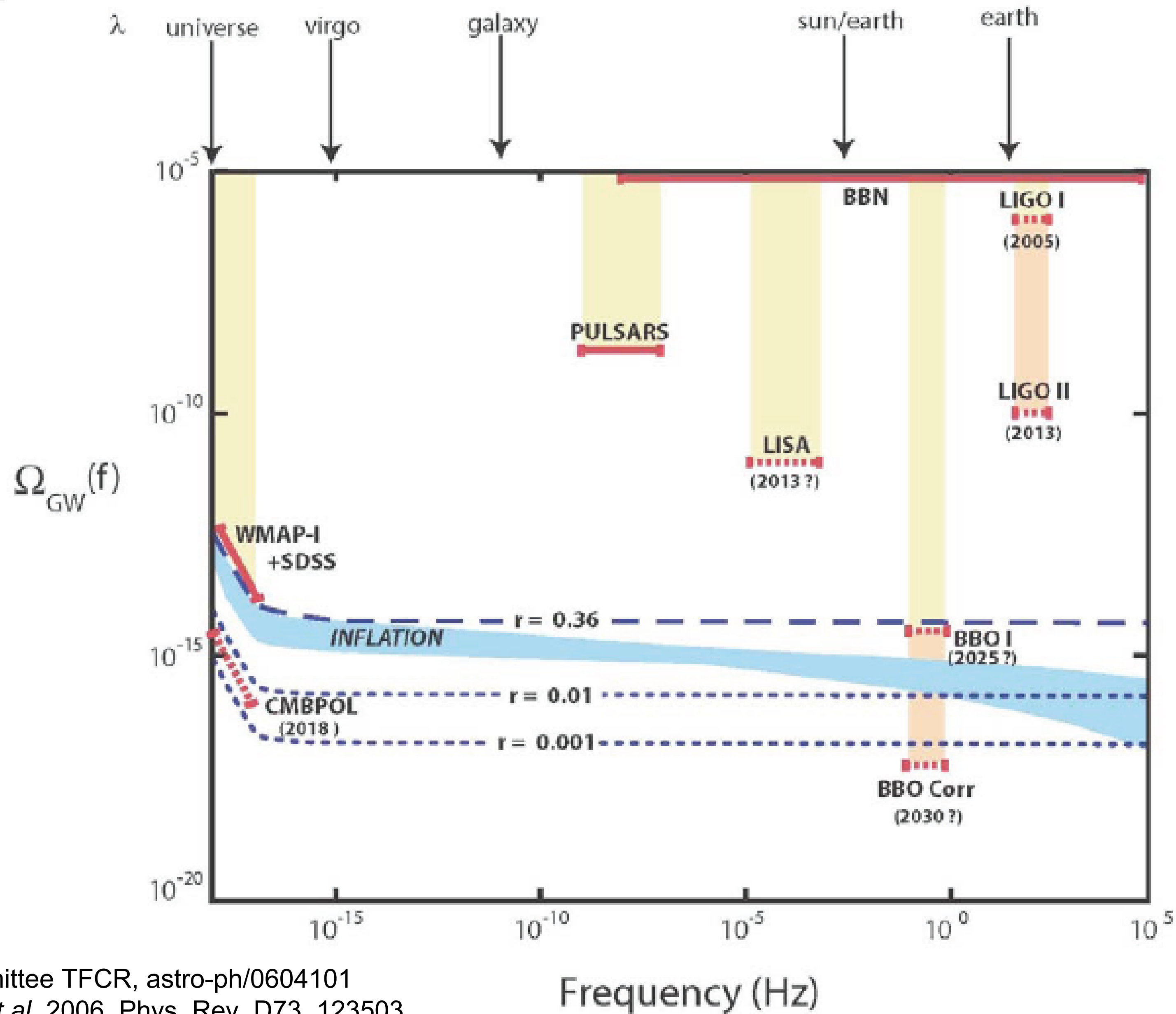
Test of n_t-r Consistency Relation



Expect $R = -r/8n_t = 1$ for slow-roll inflation
Can test this to < 25 % if r > 0.04

T.L. Smith *et al*. 2006, Phys. Rev. D73, 123503

Comparing CMB and Direct Detection



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