Observing the entire Universe: Big Bang to Dark Sector

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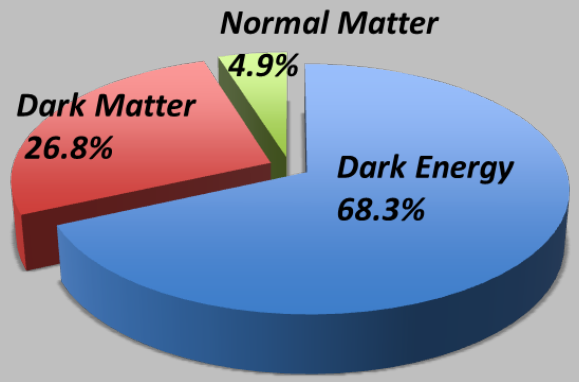
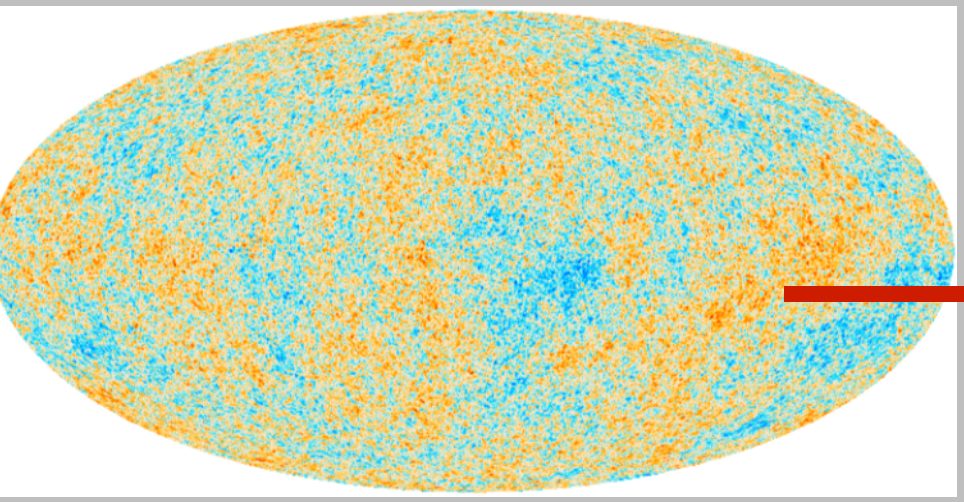
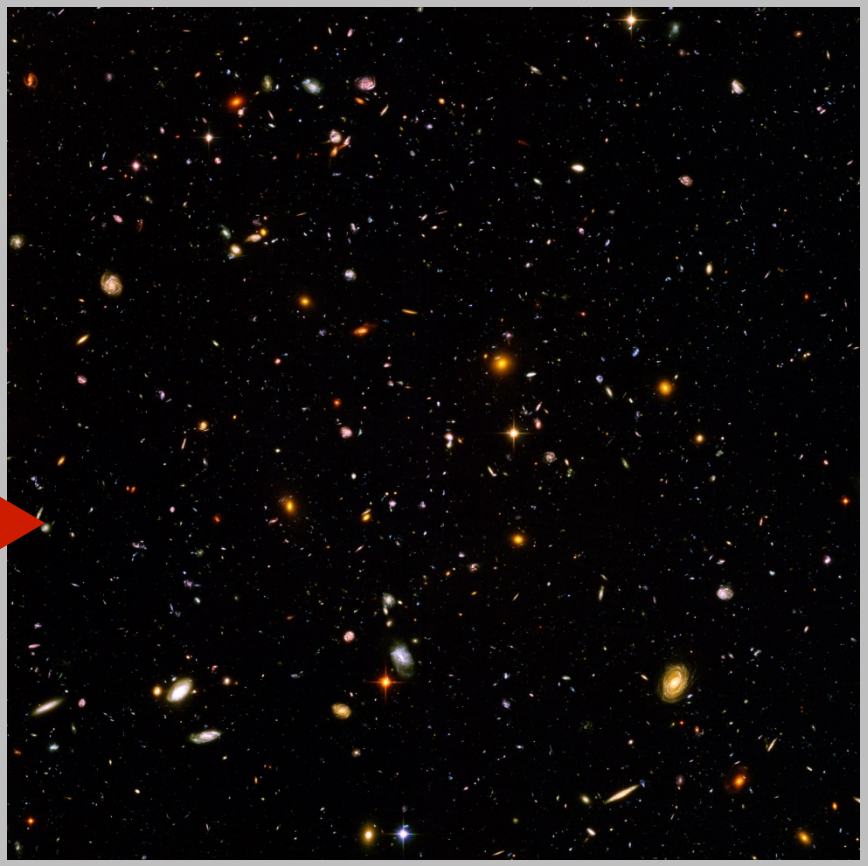
What we know





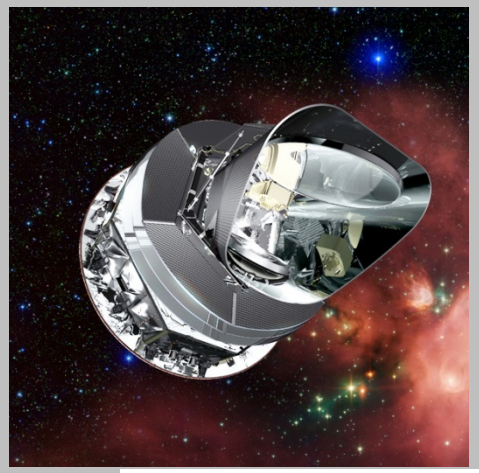


CMB fluctuations (Planck) grow over time to be the structures we see today (Hubble UDF)

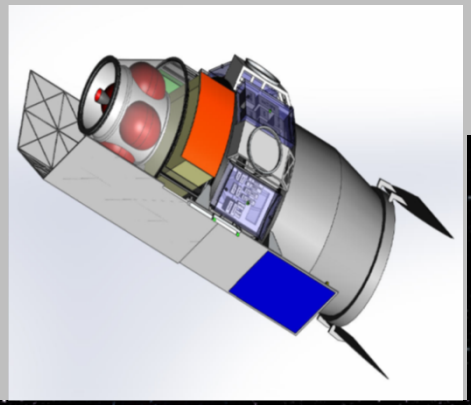
Setting the Stage

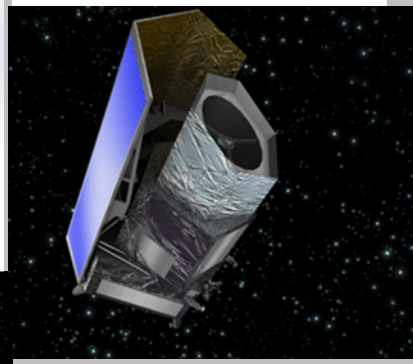
- ~ all sky surveys have (Planck) or will (Euclid, WFIRST) 'bookend' the growth of structure
- in ~10 years we'll have seen 'the full picture' in early temperature fluctuations but only a representative sample of galaxies (the nearer ones)
- Is there more information in the CMB?
- Do we need to see the rest of the galaxies?

PLANCK



Euclid Consortium



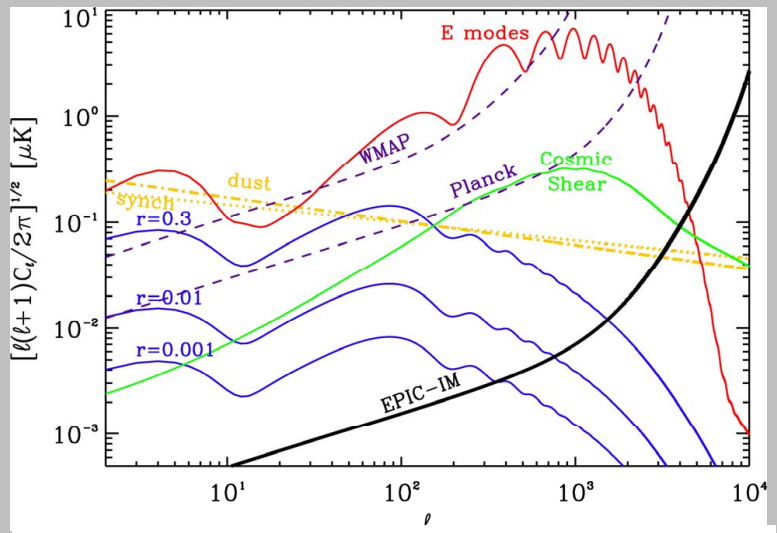


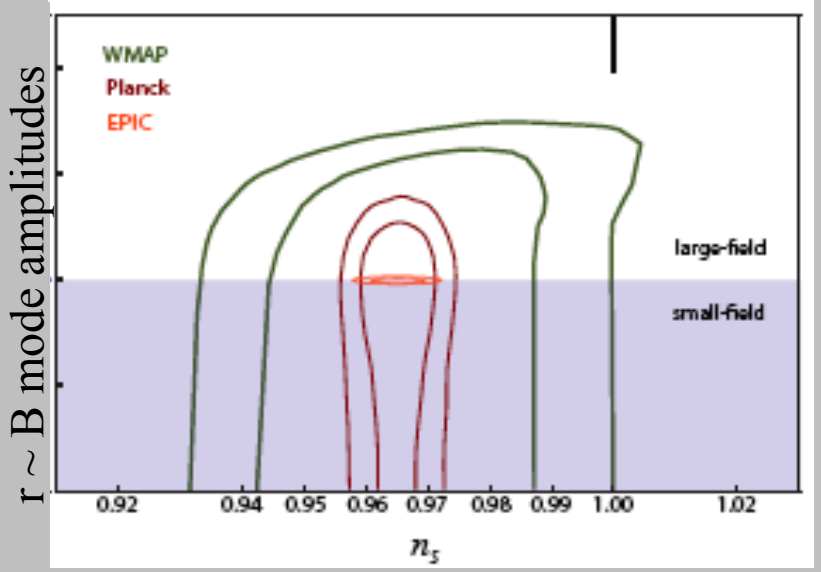
WFIRST
Wide-Field Infrared Survey Telescope

CMB Still Contains Still More Information

- **The polarization of the CMB, and in particular its "B mode", offers a direct probe of inflation, the moment where matter perturbations are generated, ~10^{-32}s after the big-bang**
- **Detection of B modes would be a "smoking gun" for inflation: the holy grail of CMB experiments**
- **The amplitude of B mode, quantified by the tensor to scalar perturbations ratio, r, is directly proportional to the Energy Scale of Inflation to the fourth power**
- **There is much more to learn. We are sensitivity limited**
- **Polarization of the CMB offers a potent probe of the dark matter distribution at high redshift via lensing**

B mode angular power spectrum





From Bock++09, EPIC study; Slide credit Olivier Doré

Spectral Index of Primordial Power Spectrum

Measure All the Galaxies

- Euclid will measure ~10^9 galaxy shapes (photometry) and ~10^7 spectra
- WFIRST numbers are similar using a narrower and deeper survey
- But there are ~10^{11} galaxies in the Universe
- ~ half the Universe is obscured by the Milky Way
- But can we measure the rest of them?
- **Can we get fluxes, shapes, and spectra for ~10^{10}-10^{11} galaxies?**

Photometry

- We want flux and shapes (e.g. for weak lensing and galaxy evolution) in multiple bands, UV to IR, up to z~10
- The Hubble UDF already resolves nearly all the galaxies it sees, and it sees nearly all the galaxies there are in a very small field
- JWST will come even closer, likely resolving the first galaxies but over small areas
- Even larger telescopes could collect light faster
- Wide field cameras would allow surveys of the whole extragalactic sky
- At far IR, it will be more difficult to measure them all, but half of the energy of the universe is at these wavelengths; we must pursue this too!

Spectroscopy

- Spectroscopy is harder, more exposure time is needed
- But >10m class space telescopes could likely get spectra for even the most distant galaxies
- Slitless spectroscopy may be possible, but confusion will make this difficult for very deep fields
- Subaru PFS and MS-DESI will multiplex to get a few 10^3 spectra at once
- Another order of magnitude (or 2) multiplexing on even larger space telescopes than discussed previously might get us within range of taking spectra of 10^{10} galaxies

Why?

- Early history of inflation is encoded in the CMB polarization; our understanding of the history of the Universe is incomplete
- The complete nature of dark matter and dark energy (and gravity) are likely to elude us even after the advances enabled by WFIRST and Euclid
- A complete census would provide the data needed to solve all(?) the problems of galaxy evolution; theoretical understanding would have to catch up!
- We would have a complete map of the Universe and its constituents

Measuring ~all the galaxies and mapping a complete history of the growth of structure is a Grand Challenge- we should rise to it

Tech Needs

- CMB polarization requires sensitive bolometers and receivers
- Photometry and spectra in the UV to NIR require:
  - —Optical communication (it's going to be a lot of data!)
  - —Advanced detectors (we need many Gpix to cover wide fields)
  - —Lightweight deployable mirrors (we want 10-30 meter space telescopes)
  - —Multiplexed spectra (we need to improve on systems planned for the coming decade)
- Far infrared will require large cryogenic telescopes and advancements in detectors; a full survey may lie beyond a 30 year timescale
- Planck, Euclid and WFIRST will tell us how to do the surveys
- We need to spend the money over the next 2 decades to enable the technology

The Path Forward

	10 yr	20 yr	30 yr	Tech needs
CMB/Inflation	Tech develop	All-sky CMB Polarization measurements, and improved theoretical models of inflation		Polarization sensitive bolometers and receivers
Dark Sector	WFIRST/Euclid	$\sim 10^{11}$ photometric measurements	$\sim 10^{11}$ spectroscopic measurements	Deployable mirrors, multiplexed spectra, optical downlink, advanced detectors