CPAD Instrumentation Frontier Workshop 2021

Argonne NATIONAL LABORATORY

Cosmic Acceleration

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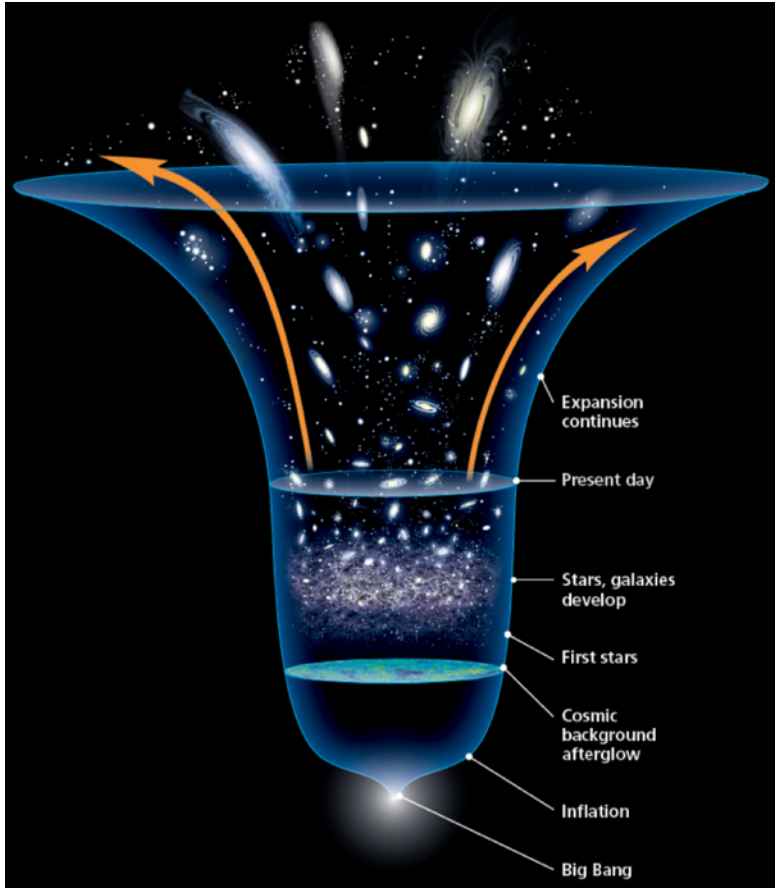
Cosmic Acceleration

Dark Energy

- Expansion of space-time is accelerating today.
- Vacuum energy predictions from only SM degrees of freedom fails to predict this acceleration.

Inflation

- Early epoch of acceleration is the preferred explanation for features of primordial universe.
- SM particles and interactions do not inflate the universe.



Cosmic Surveys

Studying cosmic acceleration requires measuring the cosmos.

Cosmic surveys are the preferred experimental technique.

Cannot change the universe.

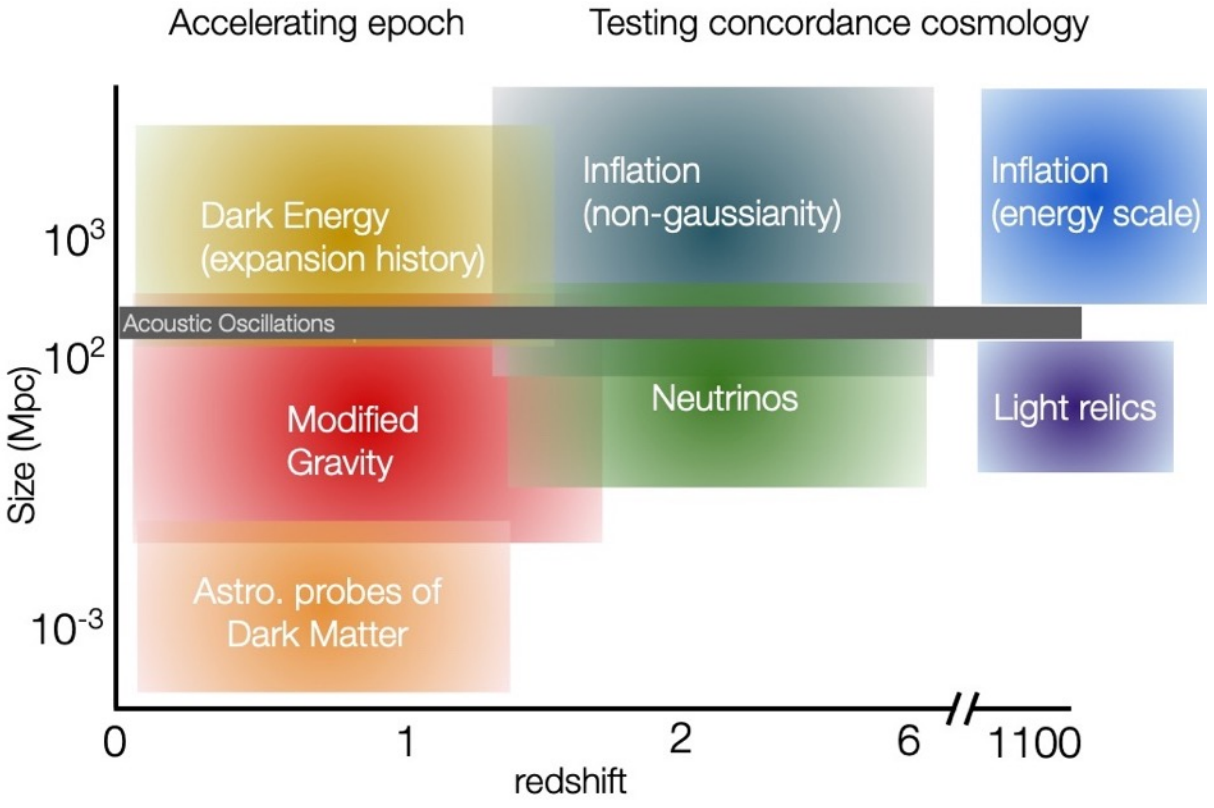
New cosmic surveys rely on new detectors technology.

Science beyond just cosmic acceleration

- Neutrinos
- Dark Matter
- New particles
- Physics “beyond the concordance model”

Cosmic Survey Science

Dark Energy, Inflation and more



Cosmic acceleration driven science requirements for next gen surveys

Extract all available information about dark energy by fully sampling the late-time accelerating epoch

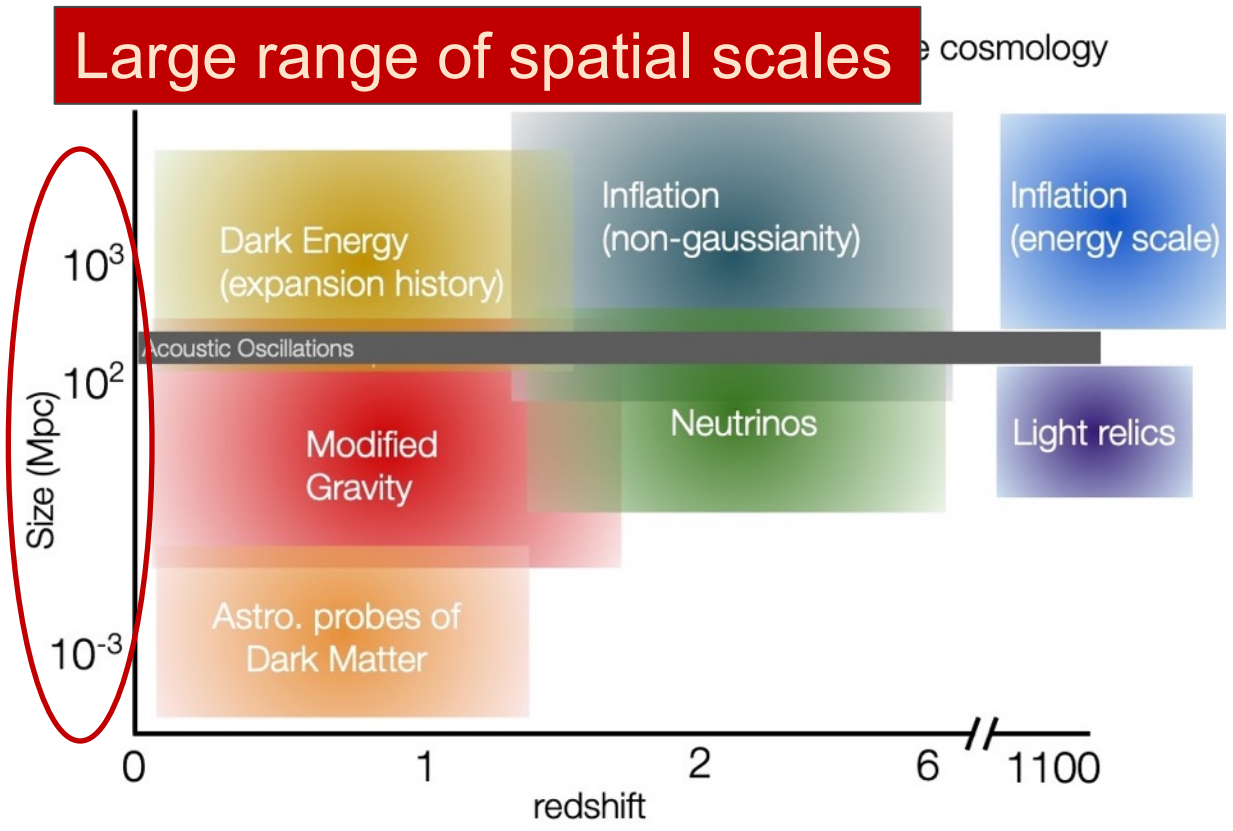
Distinguish between single-field and multi-field inflationary models by exploiting the large survey volume available at z > 1.5

After the completion of DESI, LSST, and CMB-S4, a Stage-V program will need to characterize the distribution of matter using

- **the largest volumes possible** to optimize cosmological measurement precision
- **a large range of spatial scales** for sensitivity to a full suite of cosmological parameters
- **the broadest possible range in redshift** to fully measure the evolution of the cosmos

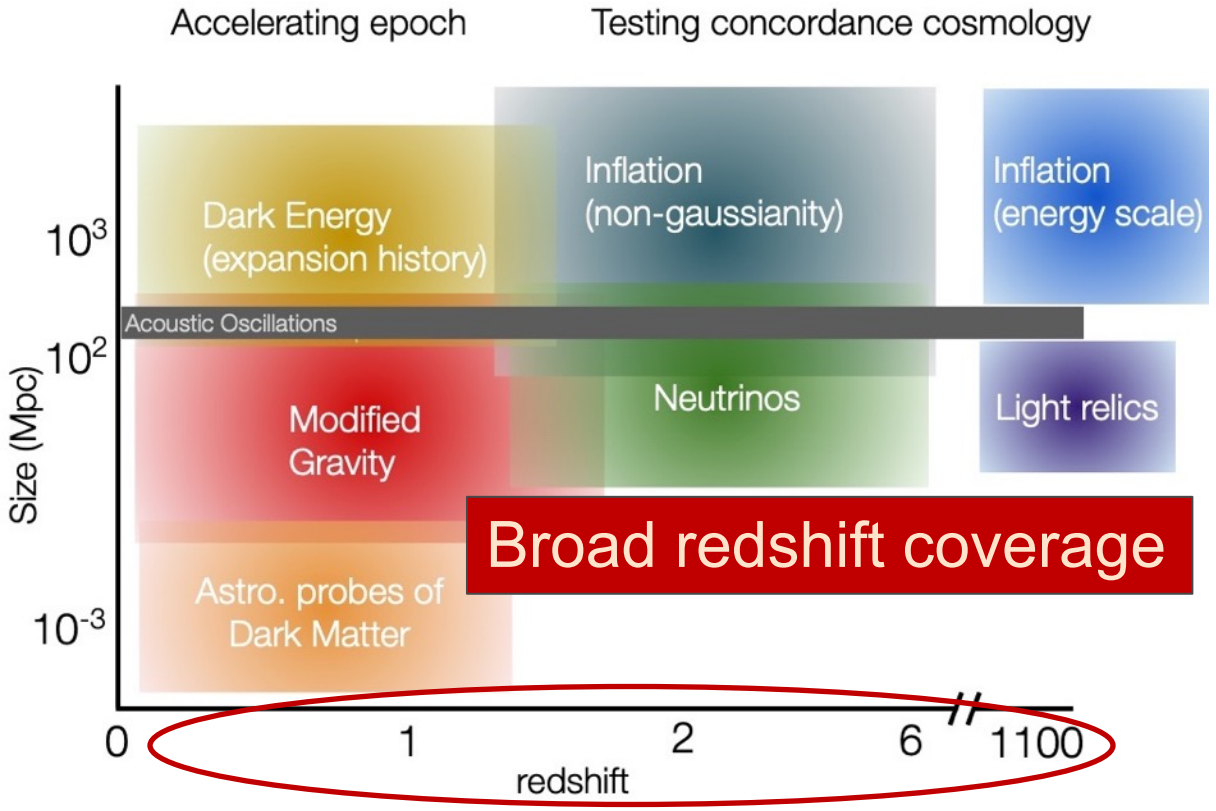
Cosmic Survey Science

Dark Energy, Inflation and more



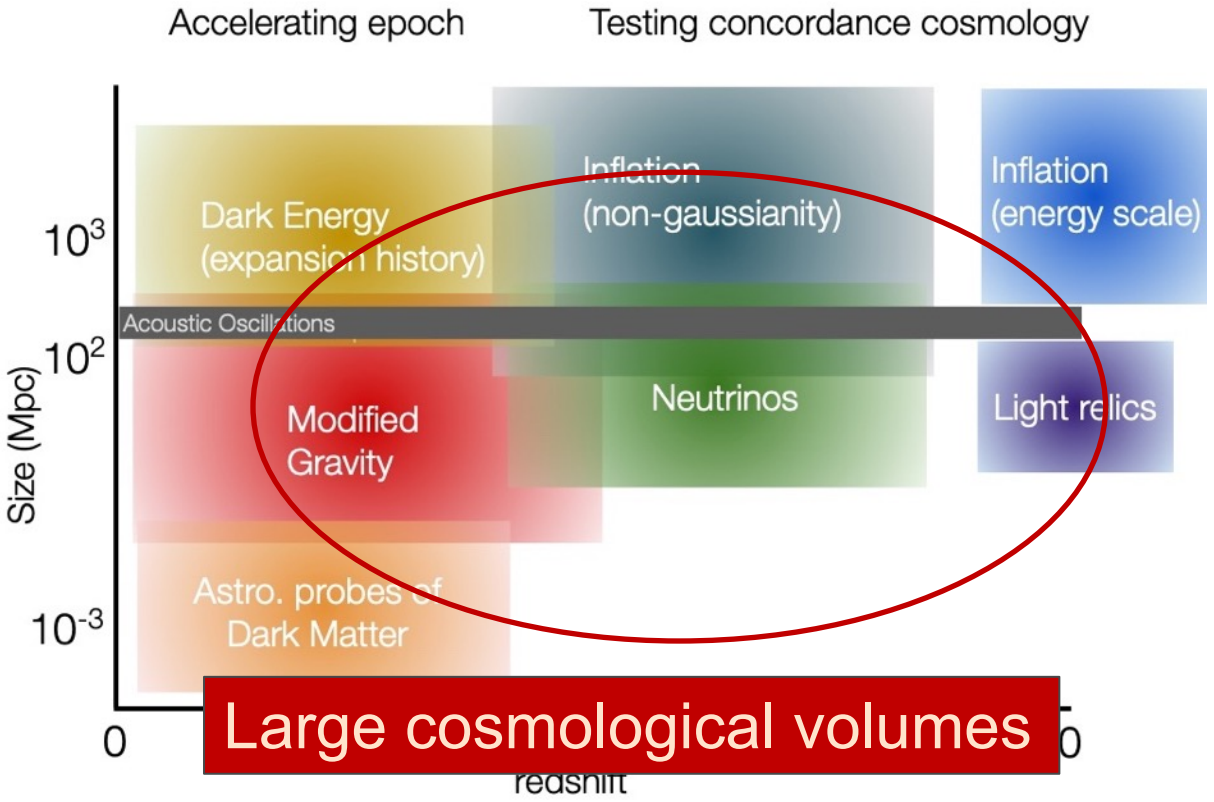
Cosmic Survey Science

Dark Energy, Inflation and more



Cosmic Survey Science

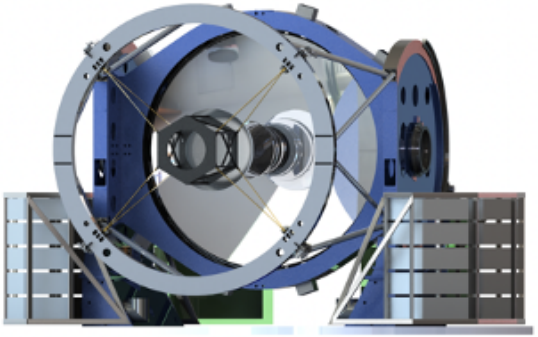
Dark Energy, Inflation and more



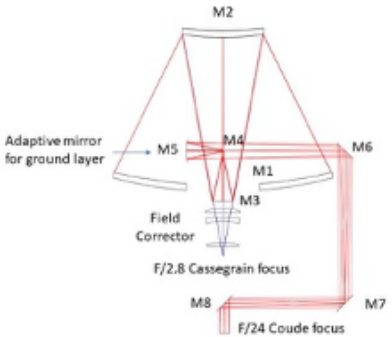
Optical-infrared survey facilities

Increase spectroscopic survey redshift to z~4 at very high density

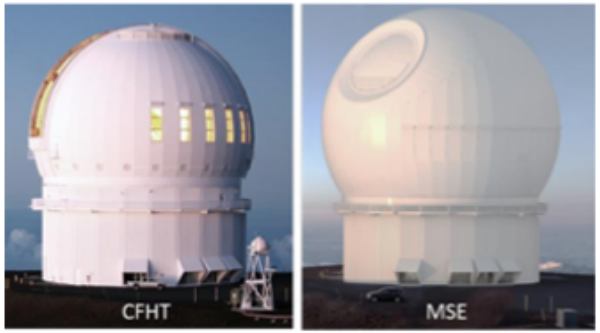
- DESI will achieve sub-percent precision on BAO scale for z<1.5, however number density of measured galaxies needs to increase by an order of magnitude to fully characterize small scale modes and growth of structure
- LSST, Euclid, WFIRST data sets: targets for the next generation spectroscopic survey



MegaMapper



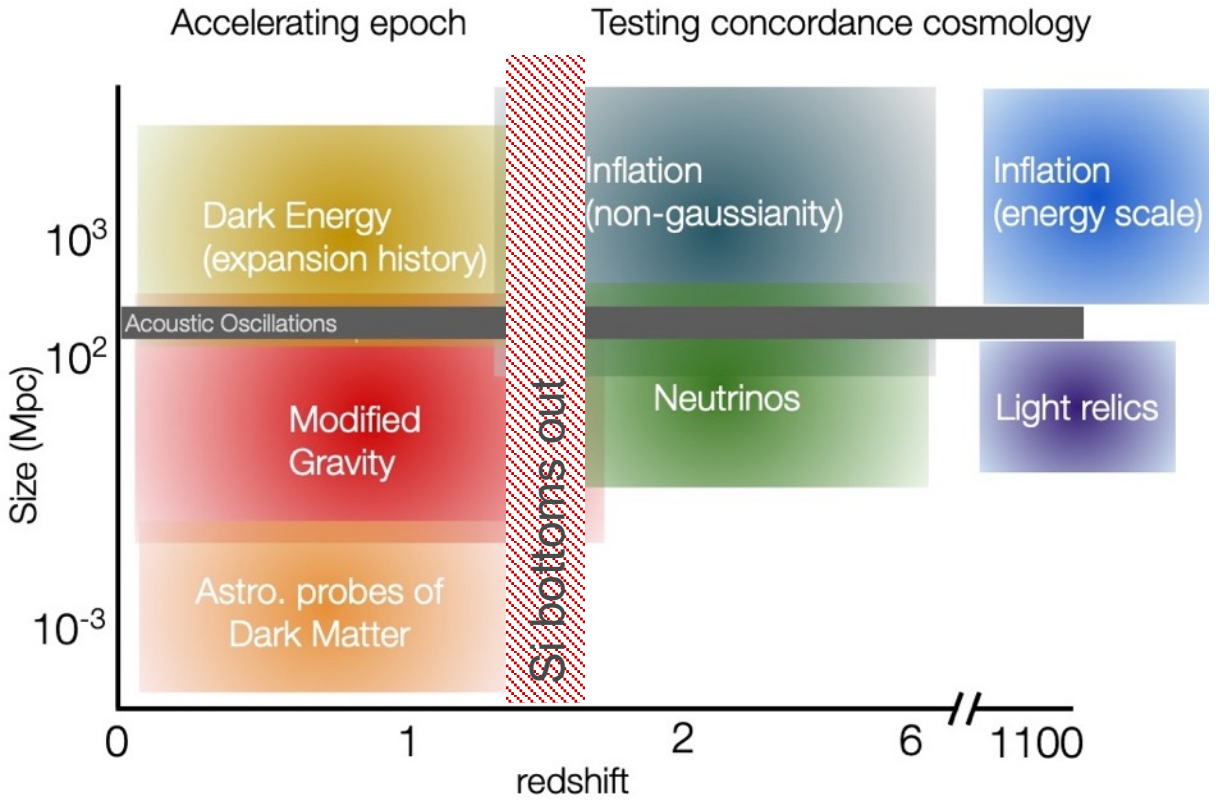
SpecTel

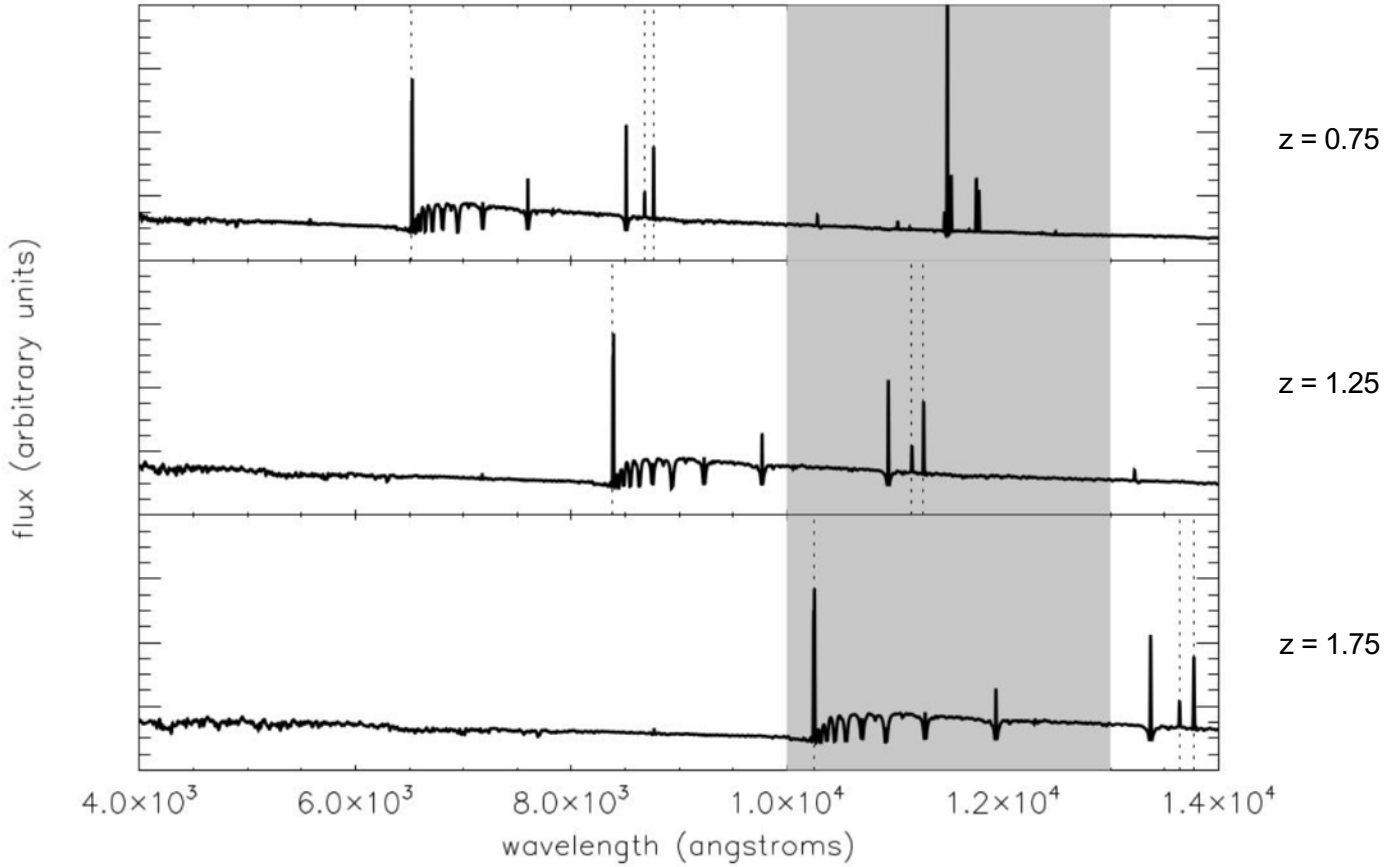


MSE

Cosmic Survey Science

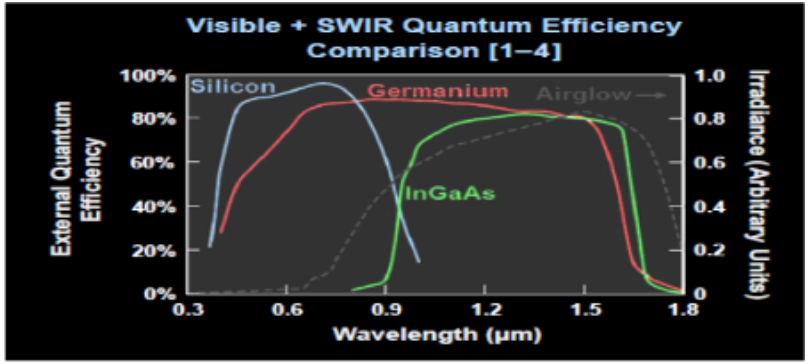
Dark Energy, Inflation and more

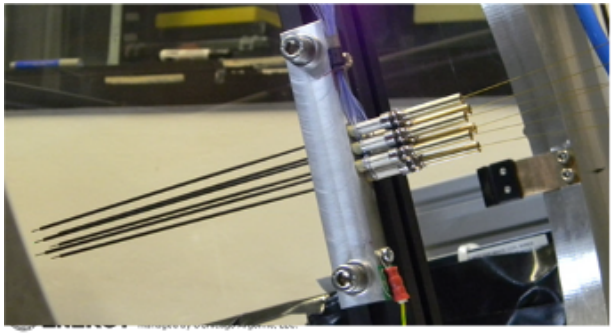


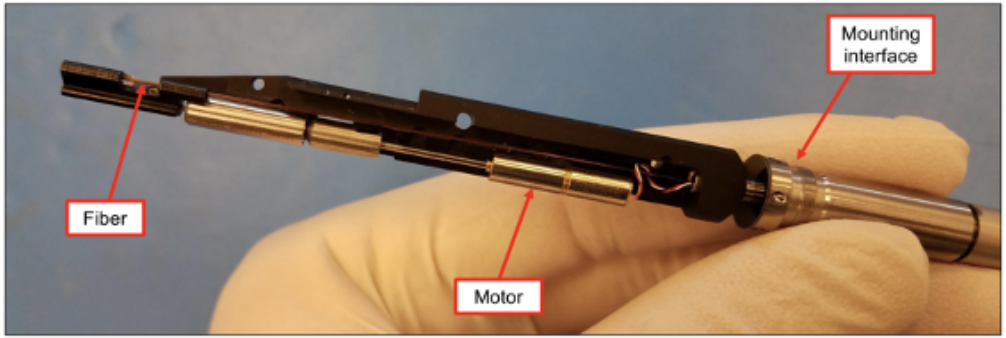


Requirements: Optical-infrared spectroscopy

- Sensitivity at wavelengths beyond the 1eV Silicon cutoff.
- Ten-fold increase in multiplexing relative to current experiments

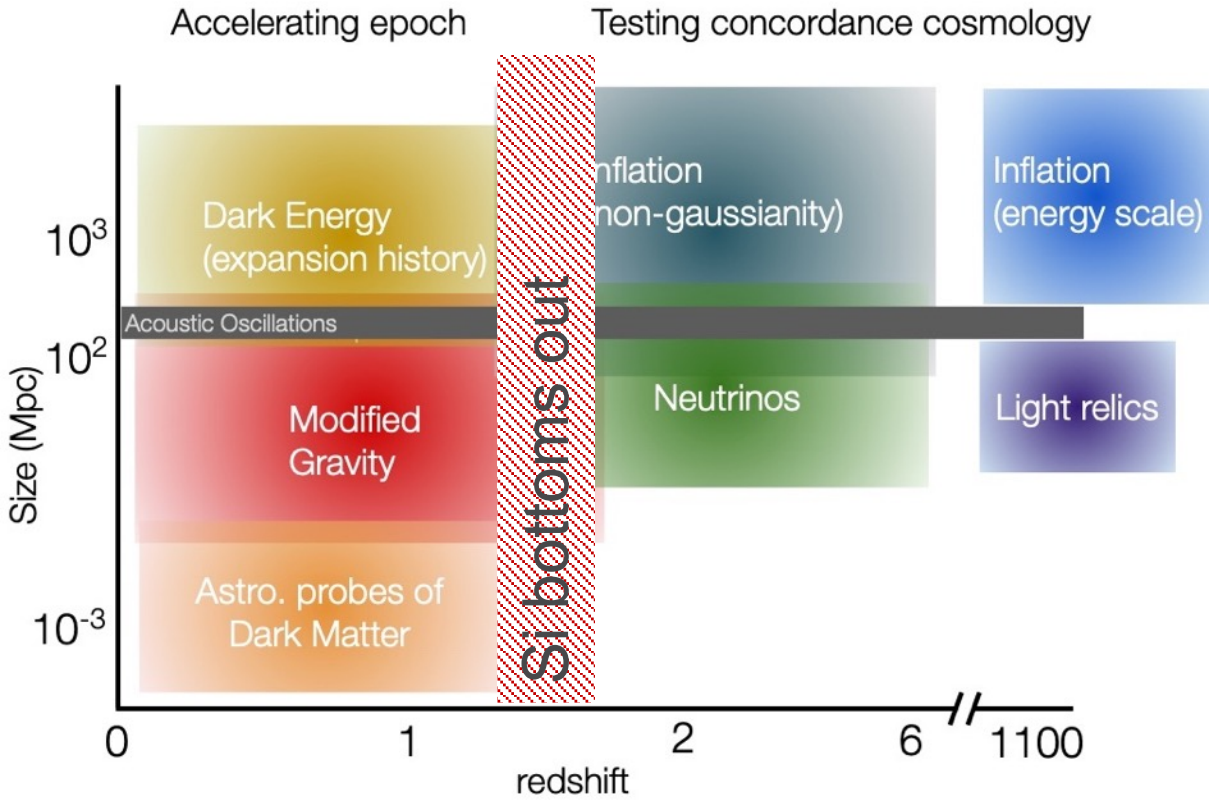






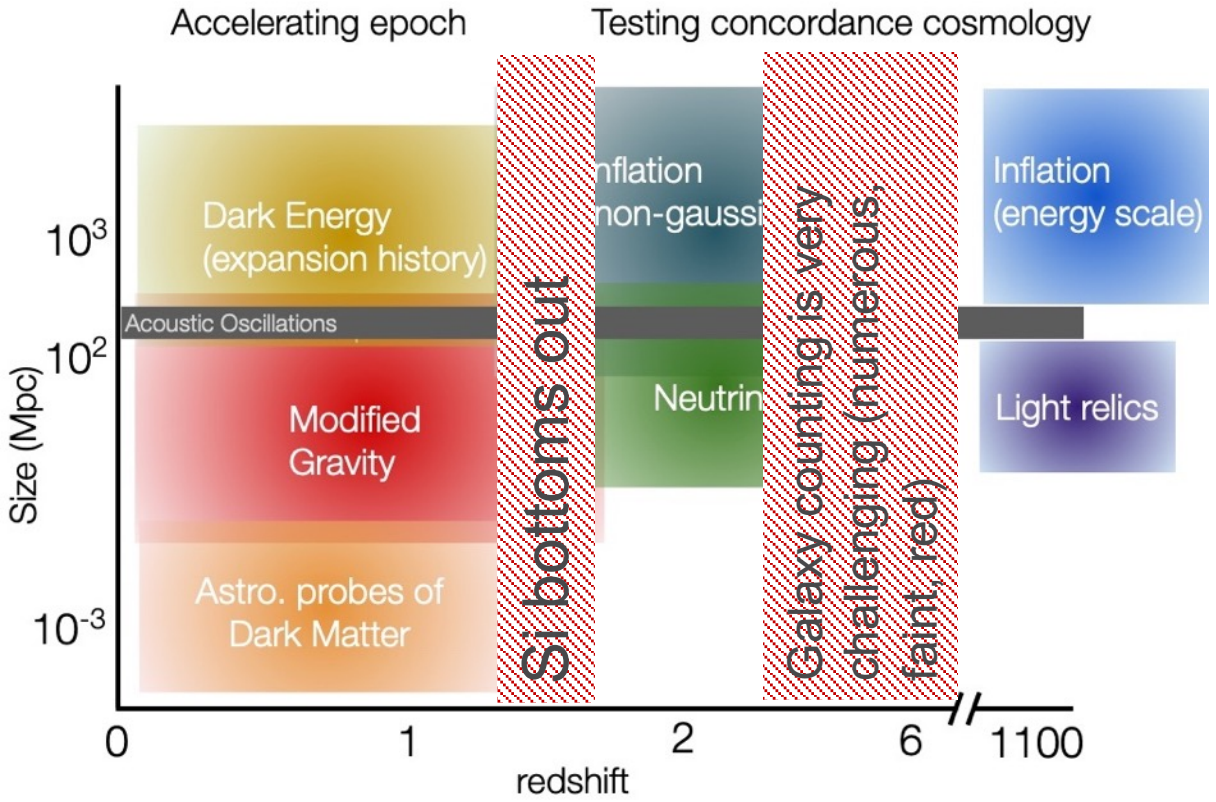
Cosmic Survey Science

Dark Energy, Inflation and more



Cosmic Survey Science

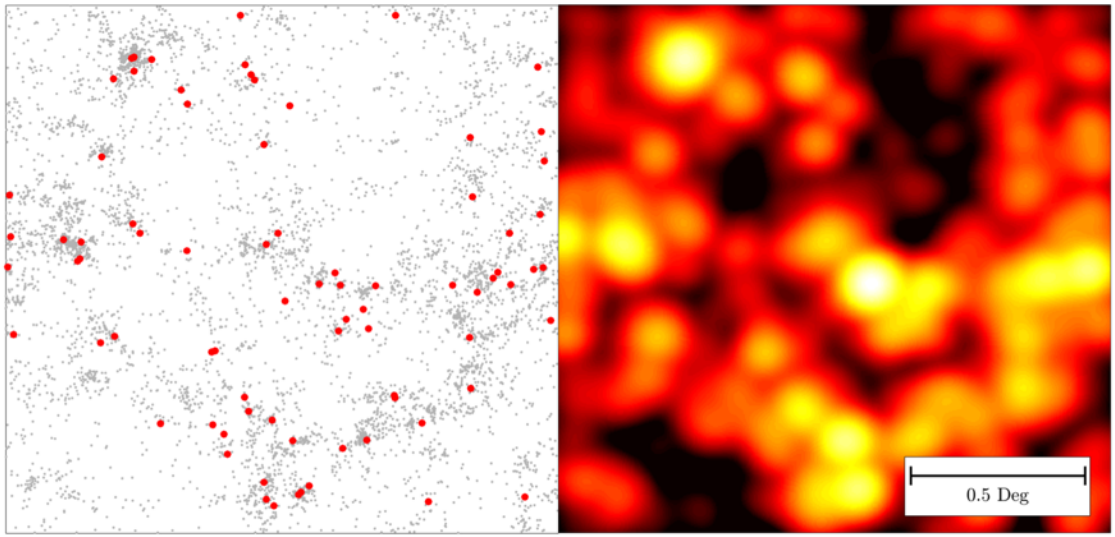
Dark Energy, Inflation and more



Survey technique

Line Intensity Mapping

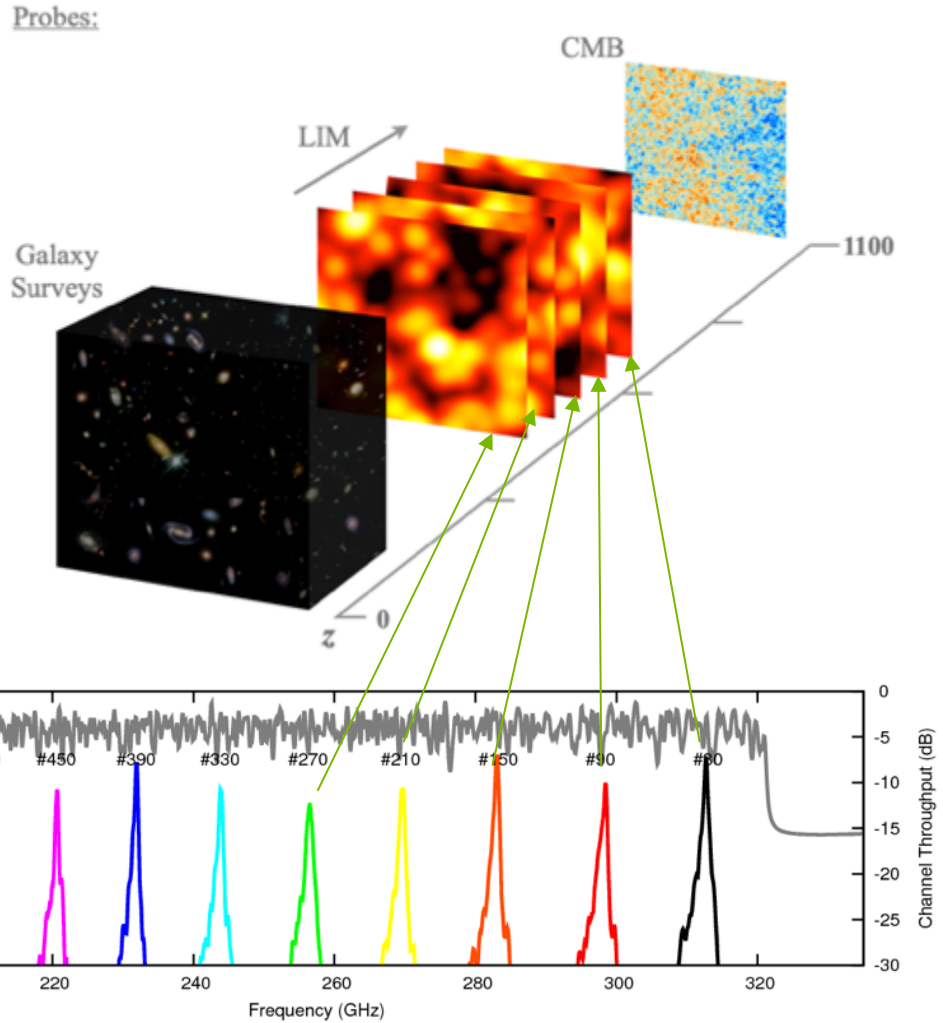
- Measure (w/ low spatial resolution) narrowband optical flux
- Captures flux from all emitters (including faint ones) along line of sight.
- Traces large scale distribution of matter.



Line-Intensity Mapping: 2017 Status Report
arXiv:1709.09066

3D spatial-spectral data cube

- For sufficiently narrow bands, signal is dominated by emission from certain lines. E.g. 21-cm, CO/[CII], Ly-α, H-α, H-β, [OII], [OIII]
- Redshifting moves line emission to different observing bands.
- Measures (low res) maps of matter at multiple slices in z.



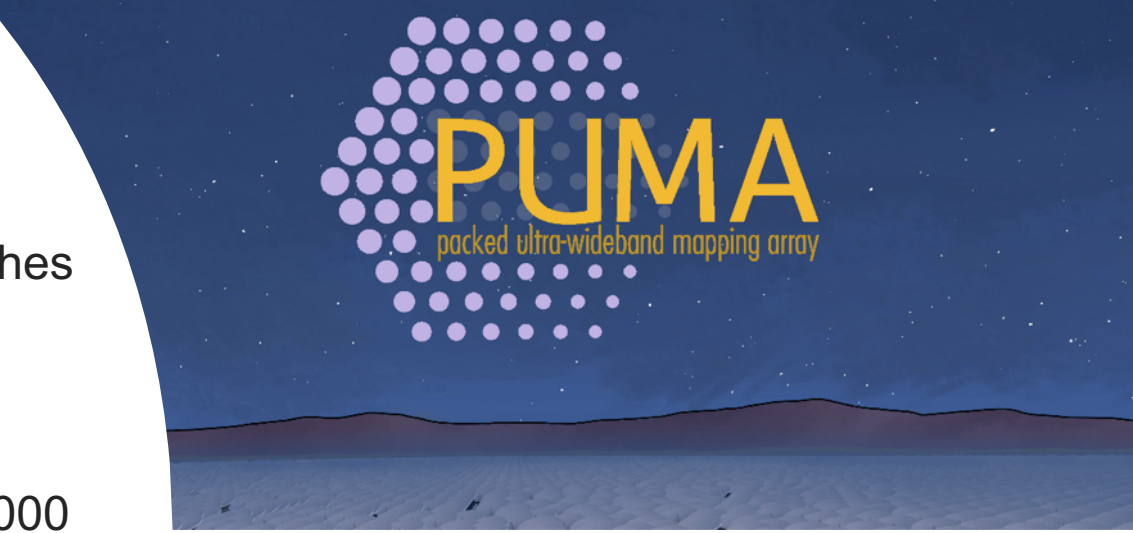
21-cm survey facilities

5,000-30,000 close-packed dishes for LIM out to z~6.

Requires:

- direct, sub-ps synchronized digitization at each of the ~1000 dishes separated by up to a km
- network technologies that can process tens of petabytes of raw data per second with modest power consumption

synergistic with streaming DAQ development for collider applications



Mm-wave survey facilities

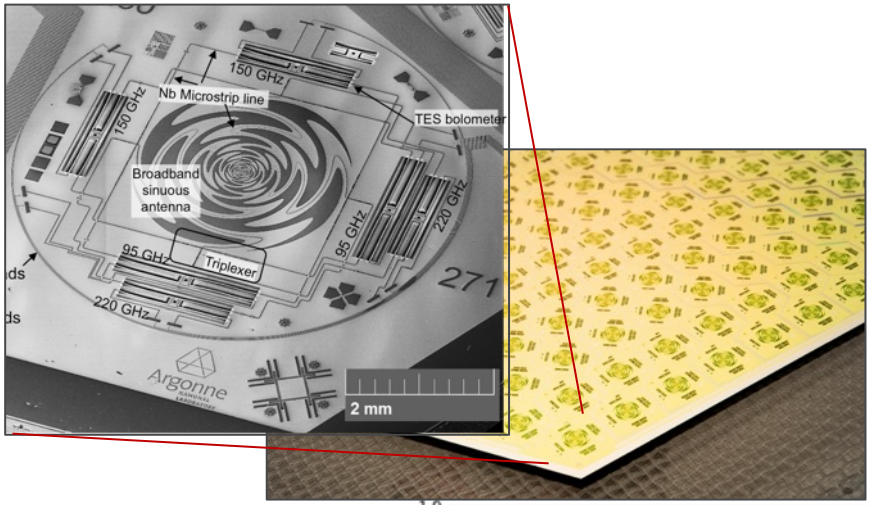
High resolution imaging

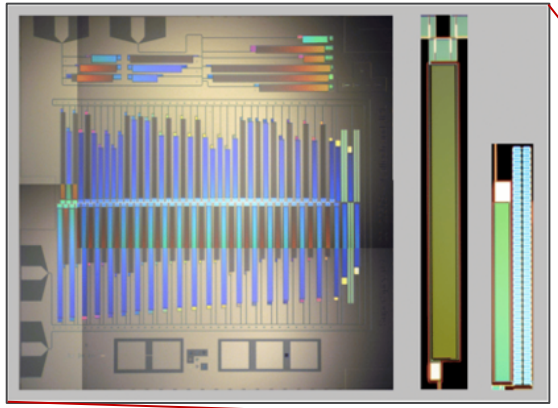
- High angular resolution measurements of CMB damping tail, CMB lensing, CMB scattering (Rayleigh, kSZ/tSZ)
- Requires:
  - Large telescopes for angular resolution
  - Lots of detectors (e.g. 1.6M for CMB-HD)

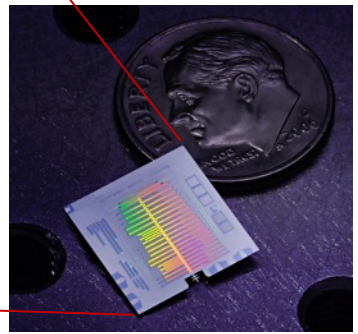
On-chip spectroscopy

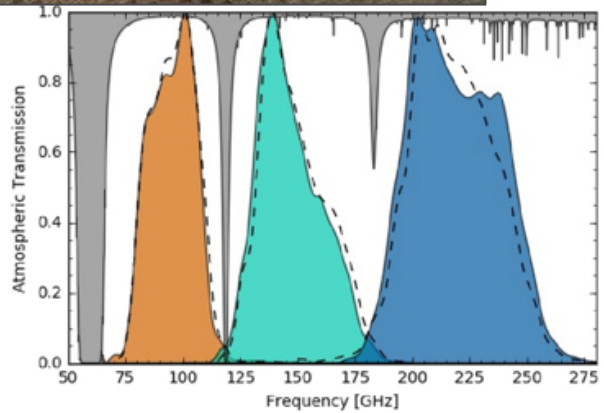
- LIM survey out to z~6 using CO/[CII] emission
- CMB instruments well suited to large angular scale measurements
- Requires:
  - On-chip spectrometers (R~200)
  - A lot (~1M) detectors w/ high density readout

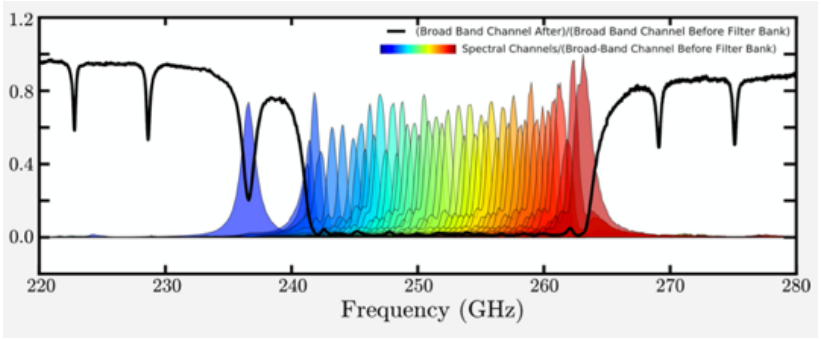
Mm/sub-mm detectors



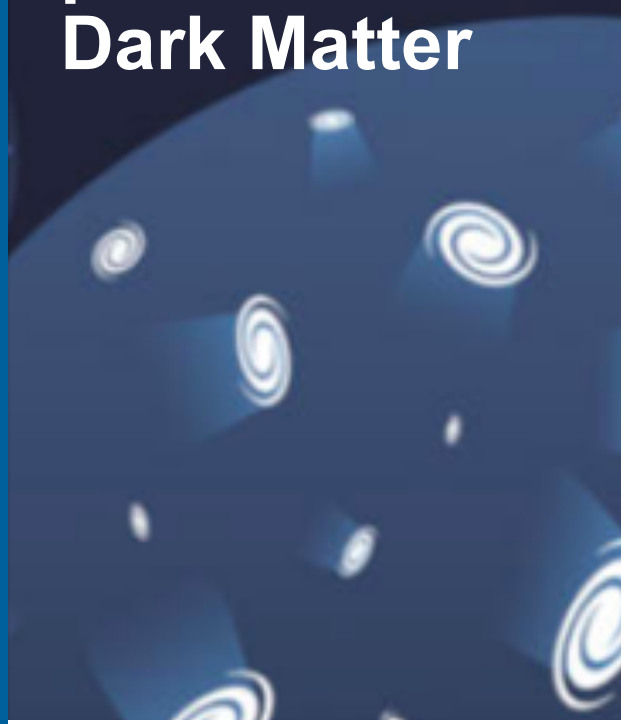








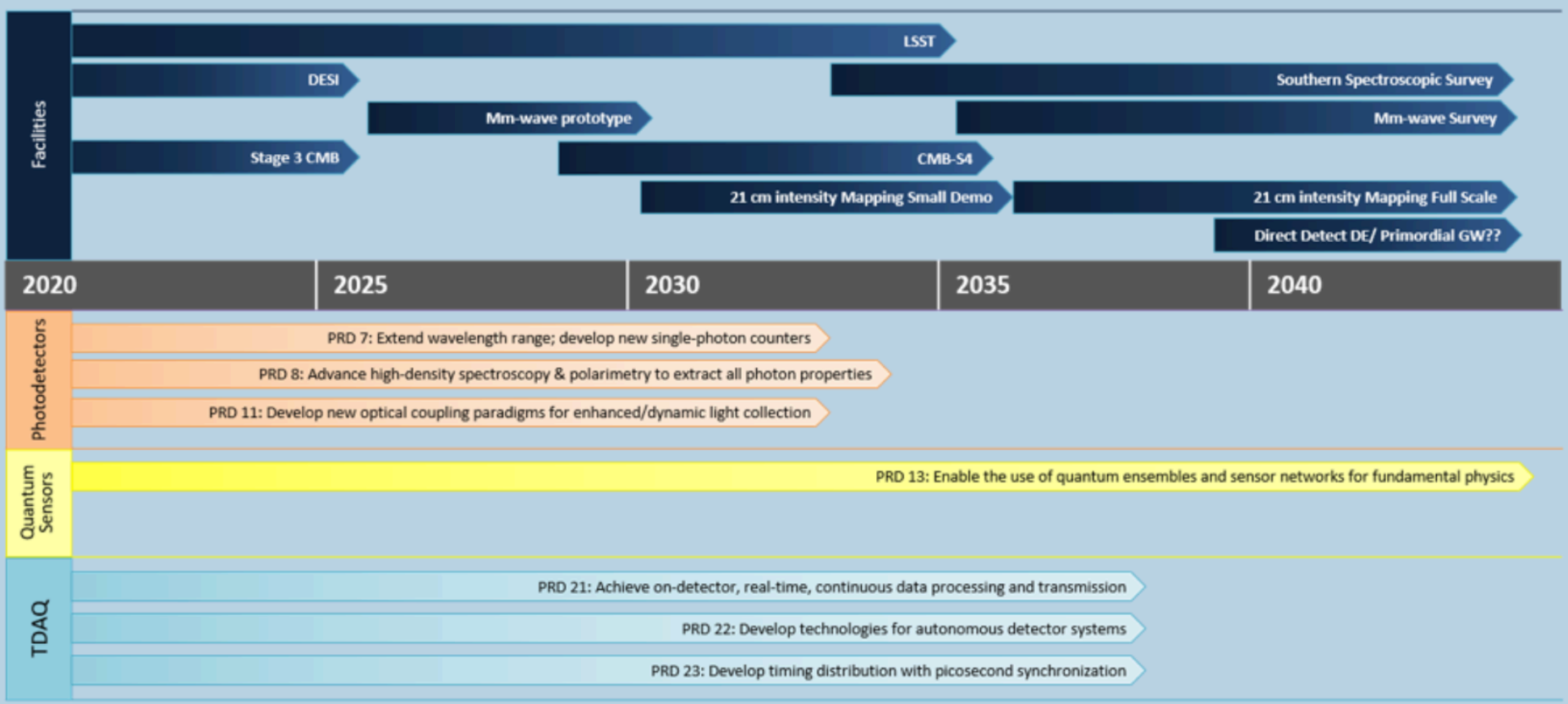
Astrophysical probes of Dark Matter



- Search for 3.5 keV line in X-ray emission spectra from local galaxy clusters.
  - Requires CCDs with low noise.
- Dark matter structure at small scales is sensitive to DM self interactions
  - Local dwarf galaxies: studied with low noise CCDs
  - High resolution CMB lensing maps: studied with CMB detectors on high angular resolution telescope with sufficient frequency coverage to remove foregrounds

Science Goal	Measurement	Technical Requirement (TR)	PRD
Fully sample the epoch of late-time cosmic acceleration	500M Galaxy spectra (R∼3000) to z<4	For Optical/IR spectroscopy TR 4.1: Sensitivity at wavelengths beyond the 1eV Silicon cutoff. TR 4.2: Ten-fold increase in multi-plexing relative to current experiments	7, 11, 26
Distinguish between single vs. multi-field inflation by measuring f_{NL} down to 1	Multiple Intensity mapping surveys to measure flux from 2.9B galaxies to z<6	For 21-cm Intensity Mapping: TR 4.3: Pico-second timing synchronization across ∼km TR 4.4: Direct digitization and real-time calibration	21, 22, 23, 26
		For mm-wave Intensity Mapping: TR 4.5: On-chip mm spectrometers with R>200 TR 4.6: Fabrication and readout of 1M detectors	7, 8, 26

- PRD 7: Extend wavelength range and develop new single-photon counters to enhance photodetector sensitivity
- PRD 8: Advance high-density spectroscopy and polarimetry to extract all photon properties
- PRD 11: Develop new optical coupling paradigms for enhanced or dynamic light collection
- PRD 21: Achieve on-detector, real-time, continuous data processing and transmission to reach the exascale
- PRD 22: Develop technologies for autonomous detector systems
- PRD 23: Develop timing distribution with picosecond synchronization
- PRD 26: Addressing challenges in scaling technologies



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