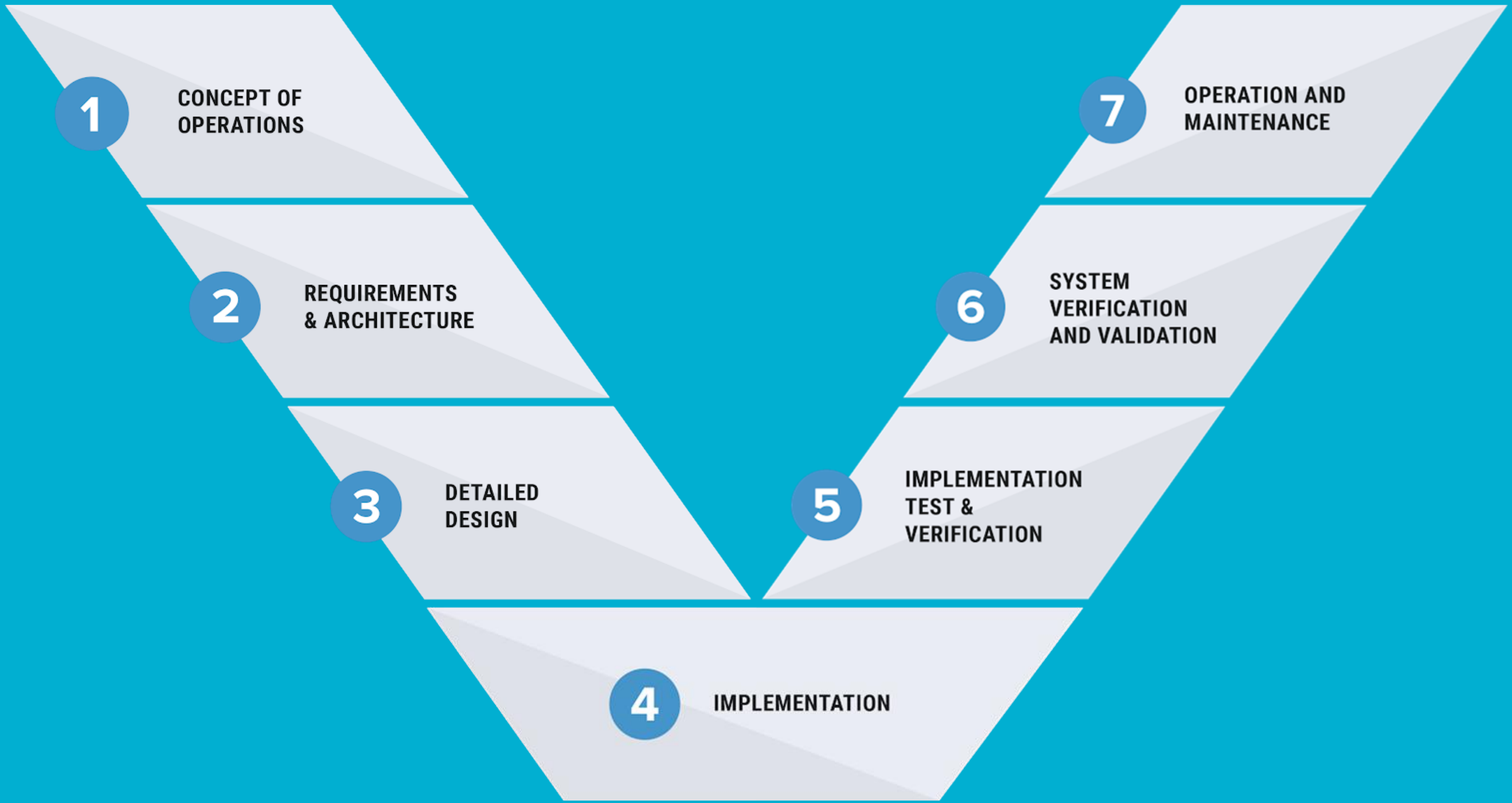
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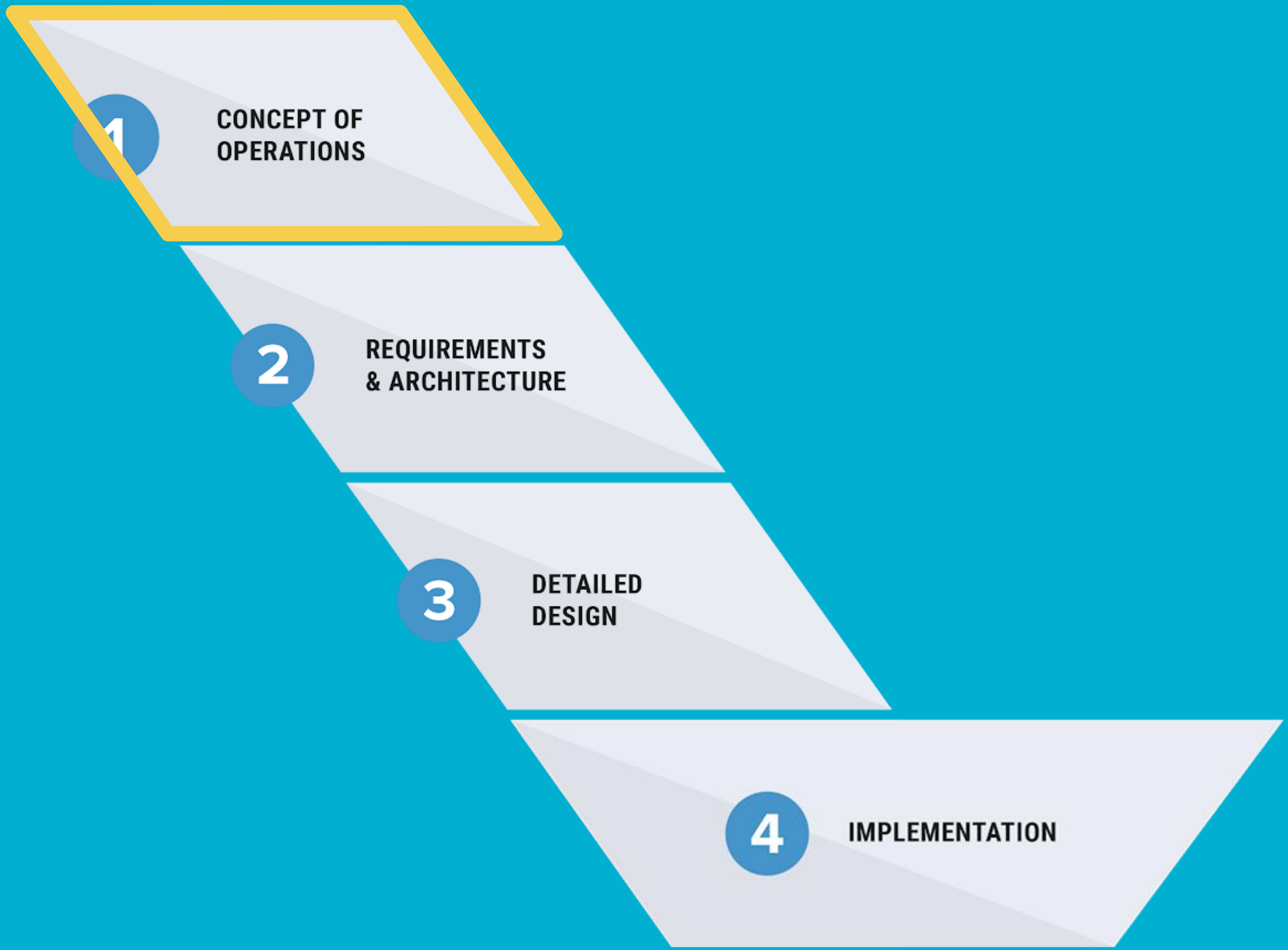
OPERATION AND MAINTENANCE

A Tale of Two Telescopes

By Miranda Eiben

Our Case Studies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Concept

- Goal:
    - General science survey instrument for the Large Millimeter Telescope (LMT)
        - Fills mm-wave niche between smaller single dish telescopes and interferometers
    - Replace the previous camera (AzTEC) on the LMT with more detectors

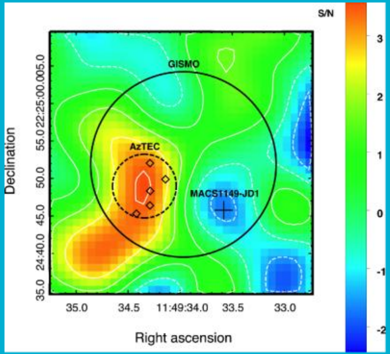
- Goal:
    - Constrain the tensor to scalar ratio (r) of primordial gravitational waves, which would provide direct evidence of inflation
        - Observe the power spectrum of B-mode polarization in the CMB at degree scales
    - Replace previous array of receivers (Keck Array) with more detectors

Observations: TolTEC

Far Away ⟷ **Close to Home**

Ultra Deep Galaxy Survey

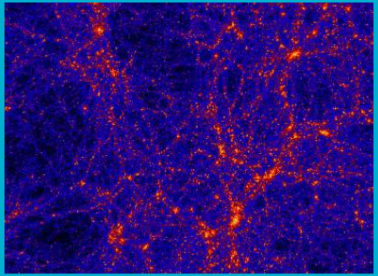
(0.8 sq deg.)



LIRG limit ($L_{IR}>10^{11}L_{-sun}$, S_{11}~0.025mJy rms).

Large Scale Structure Survey

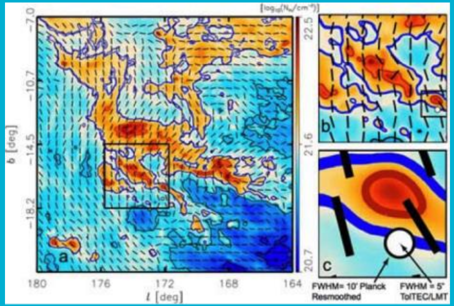
(40-60 sq deg.)



ULIRG limit ($L_{IR}>10^{12}L_{-sun}$, S_{11}~0.2mJy rms).

Fields in Filaments Survey

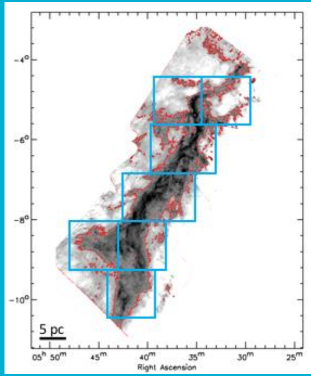
(0.4 sq deg.)



obtain a total of ~70,000 polarization vectors

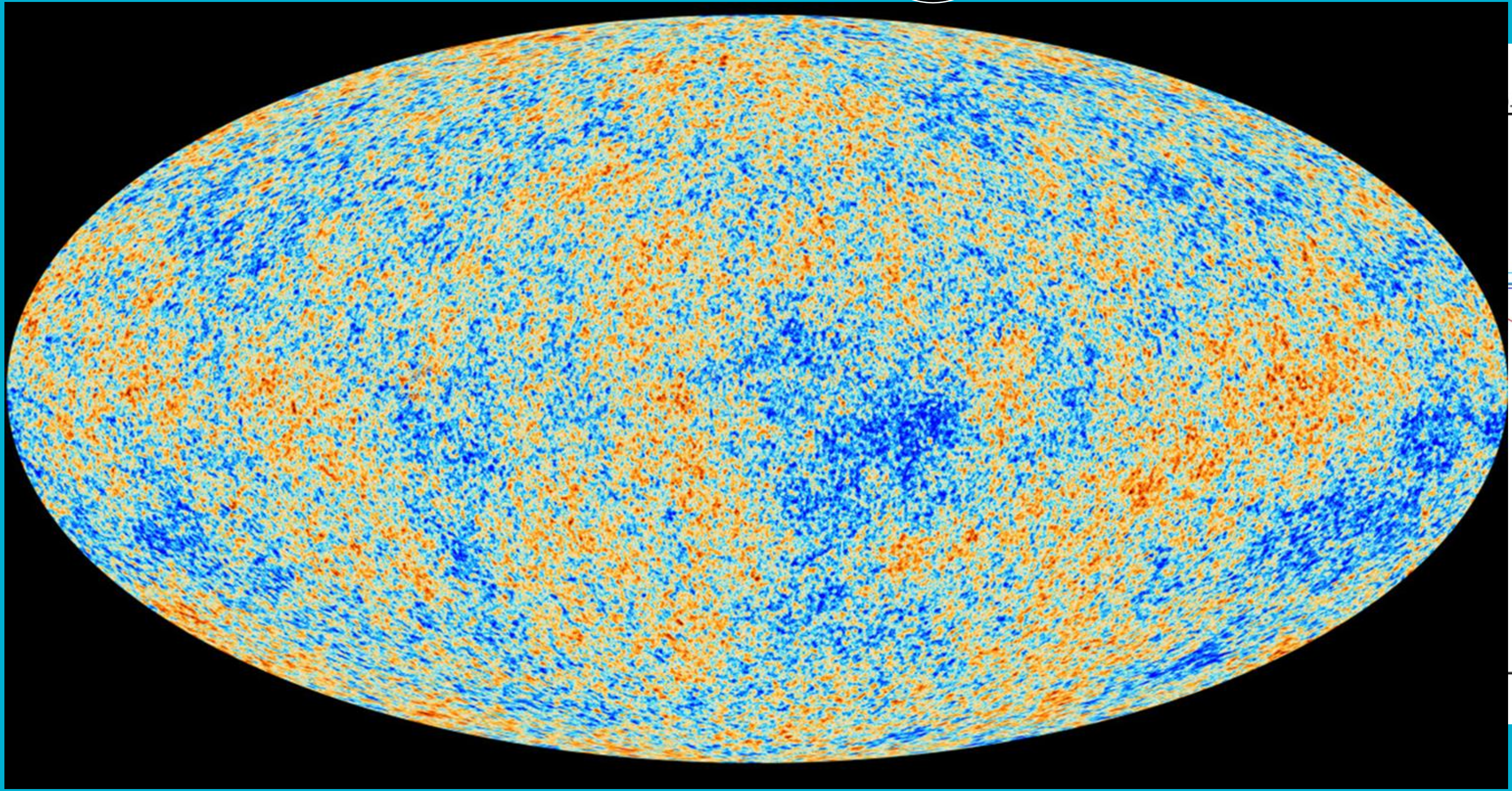
Clouds to Cores Legacy Survey

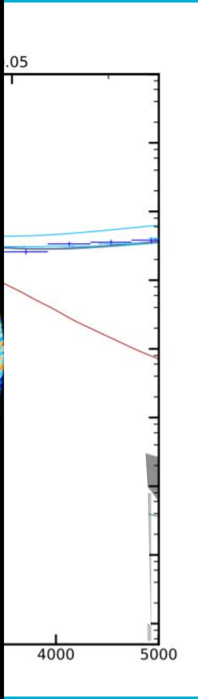
(44-88 sq deg.)



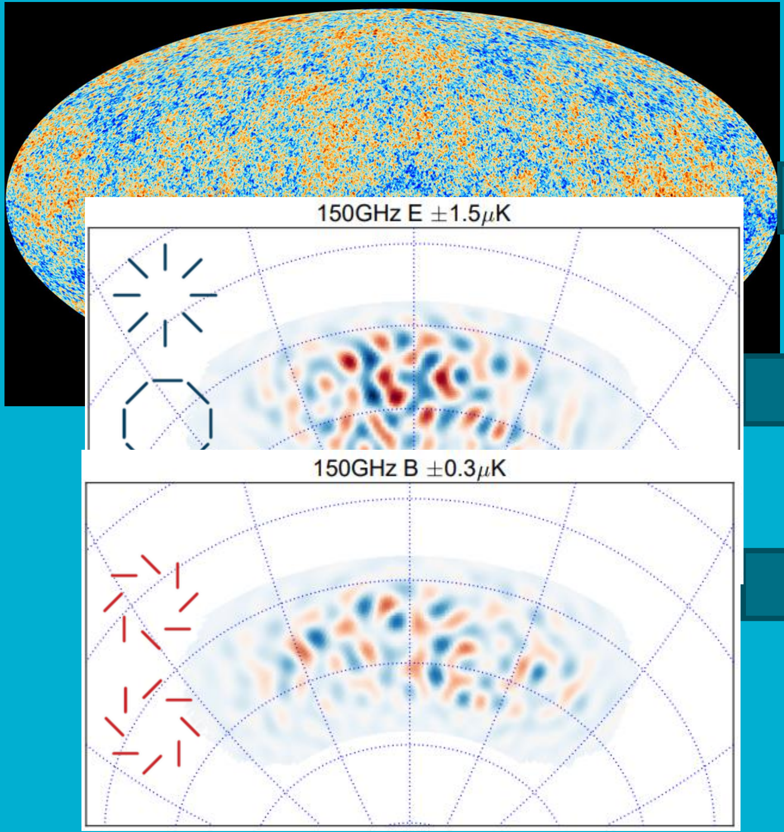
achieve core mass limits ($M>0.11M_{Solar}$, S_{11}~0.27 mJy rms.)

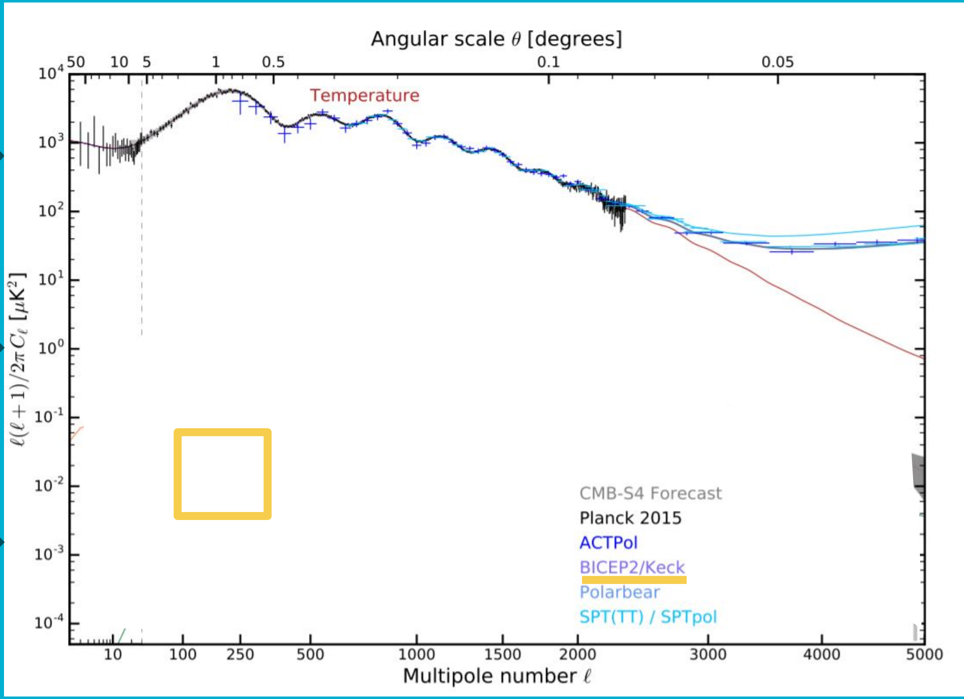
Observations: BICEP Array





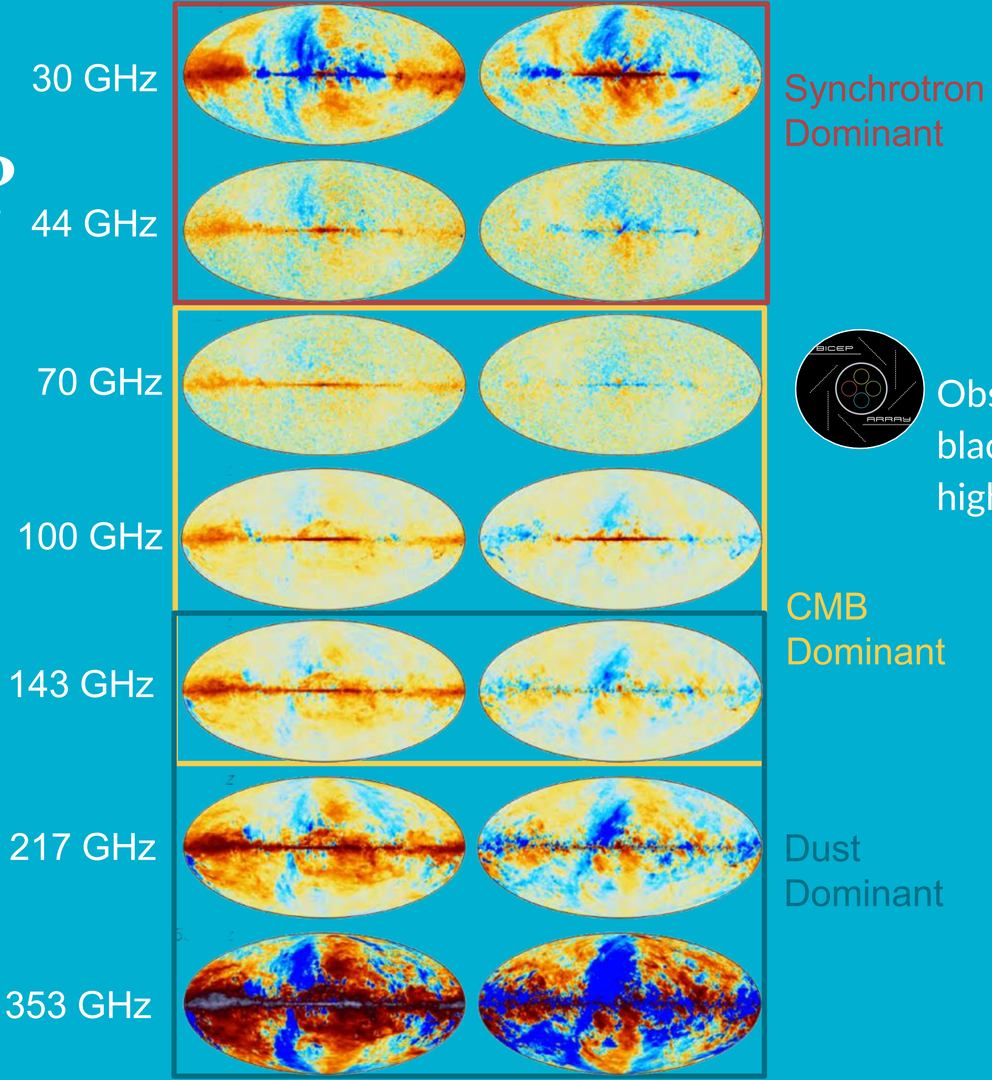
Observations: BICEP Array





Why the Millimeter?

Observe Galactic dust emission and redshifted UV and IR extragalactic emission to moderate resolution



Observe CMB (2.725K blackbody) emission to high sensitivity

Telescope Location

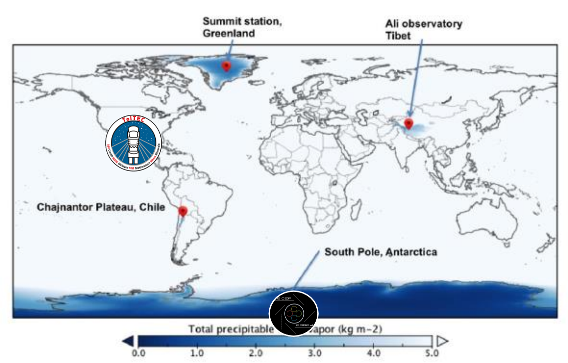
Ground vs. Space

- Atmosphere is (reasonably) transmissive in the millimeter

- Wants moderately high resolution (arcsec scale)
  - Difficult to make a many meter dish in space
- Wants high sensitivity, low resolution (arcmin scale)
  - Difficult to observe sky to high sensitivity for decades in space

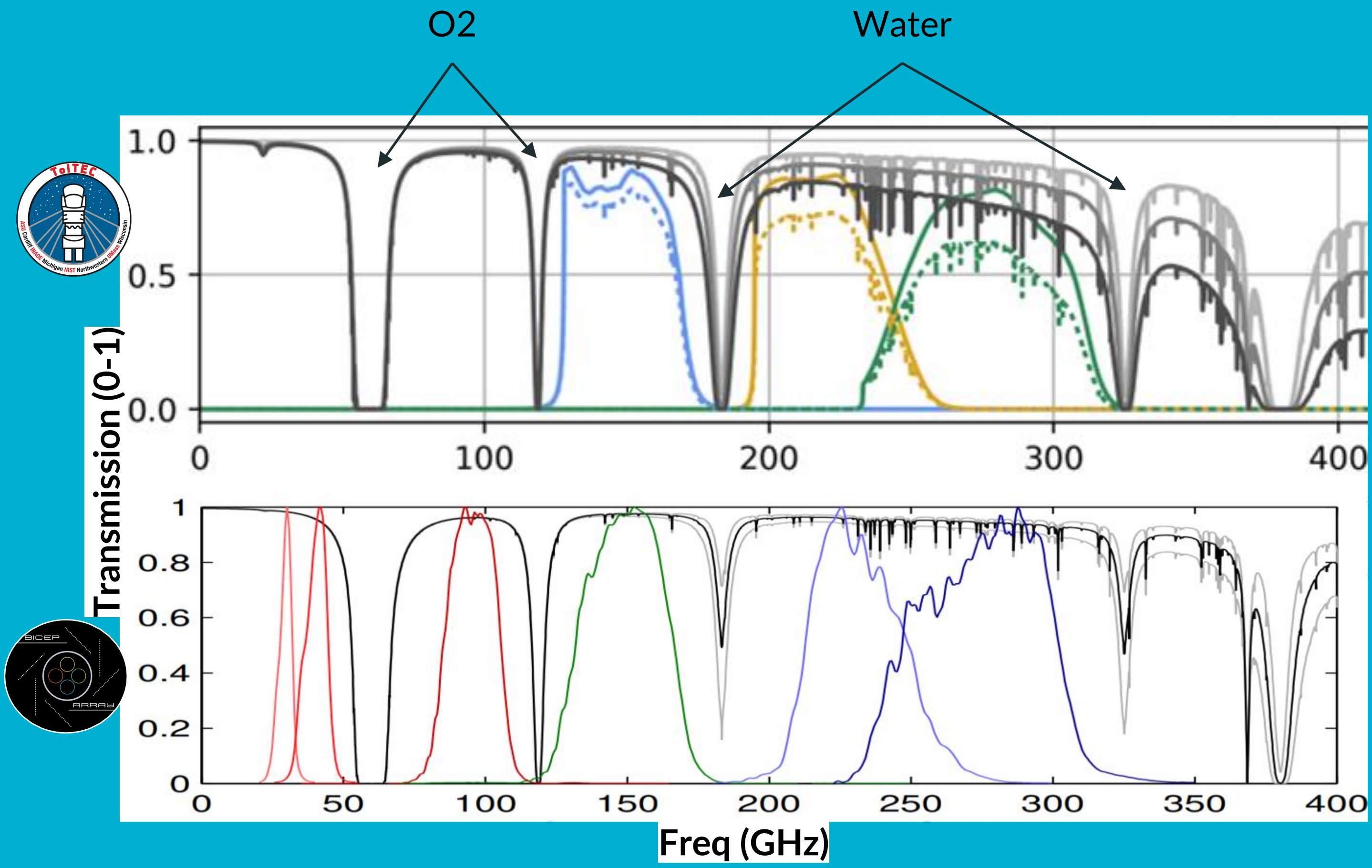
Where in the World?

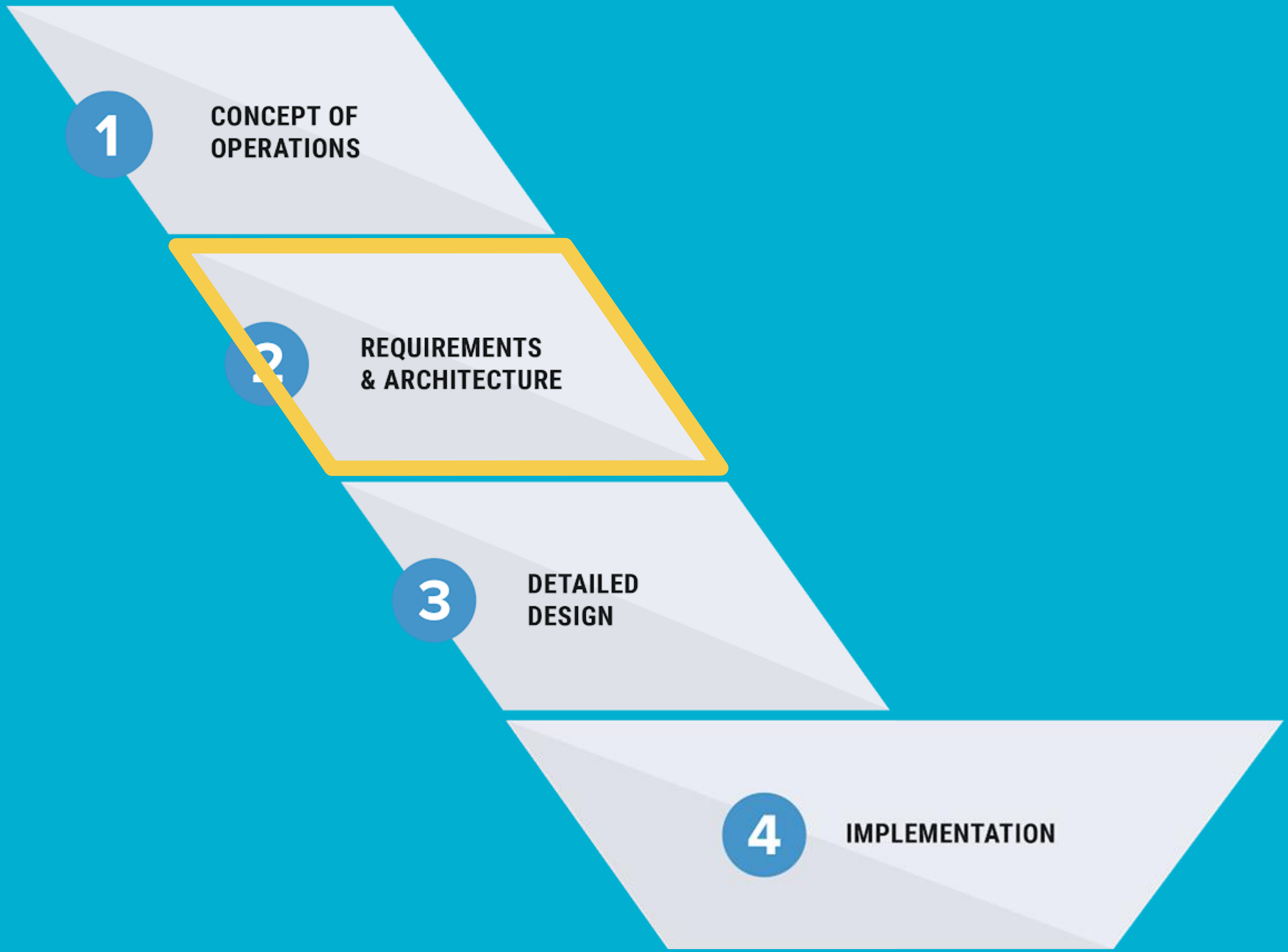
- Need a high desert
  - Deserts tend to be at lats +/- 15 to 30deg around equator
    - Mexico, Chile, Australia
  - Other geographical conditions (like distance from the ocean)
    - South Pole



Bands

Ground-based millimeter wavelength observational bands are limited by atmospheric windows

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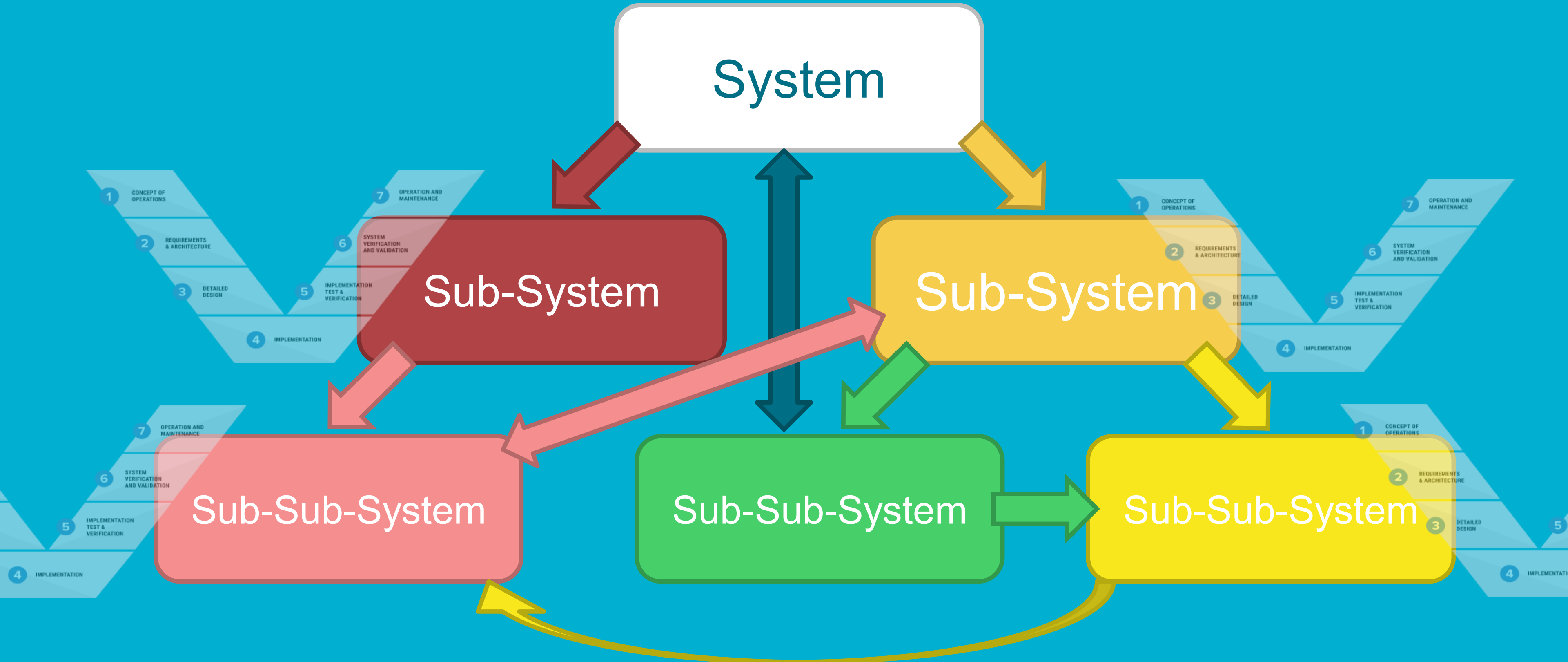
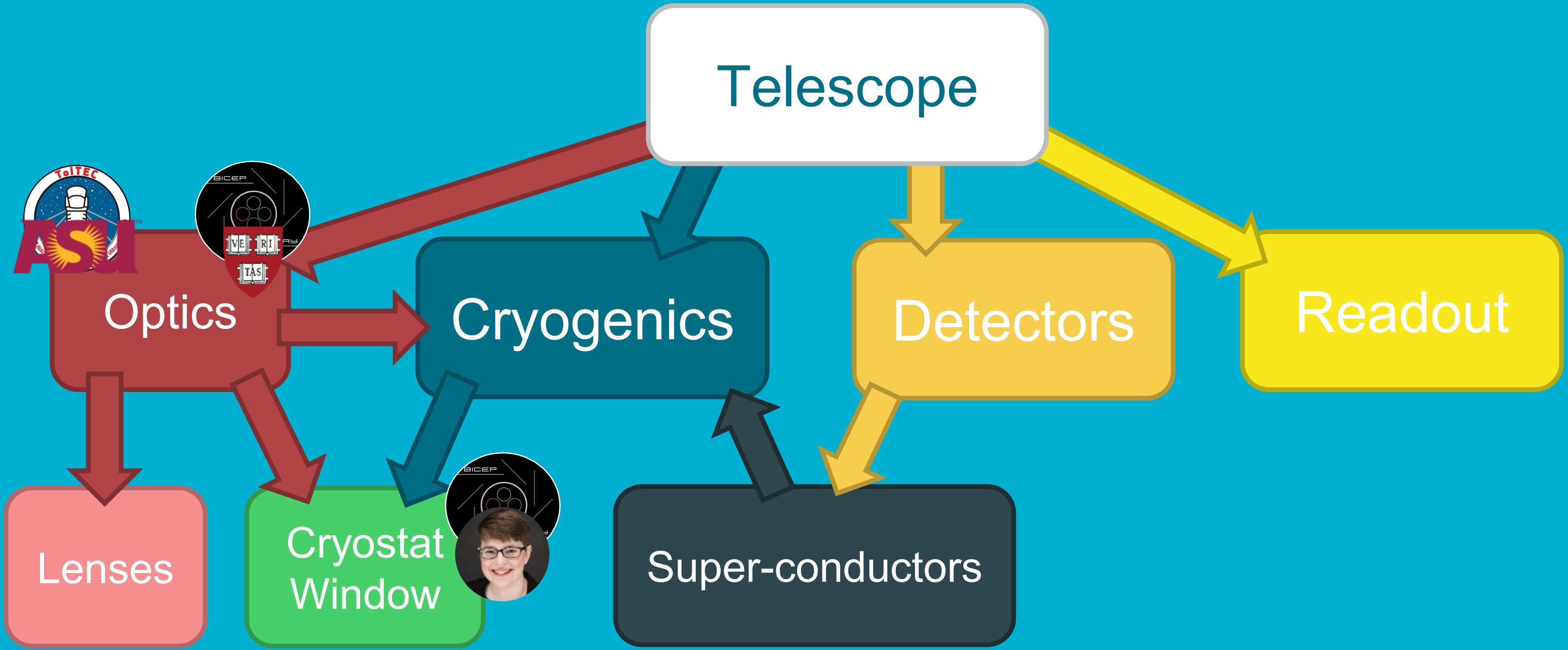
Architecture of a System



Architecture of a Millimeter Telescope



Example Requirements: Cryostat Window

Problem: Everything Emits Millimeter Radiation

Solution: Make Everything Cold

Problem: Heat Transfer

Solution: Eliminate Convection with a Vacuum

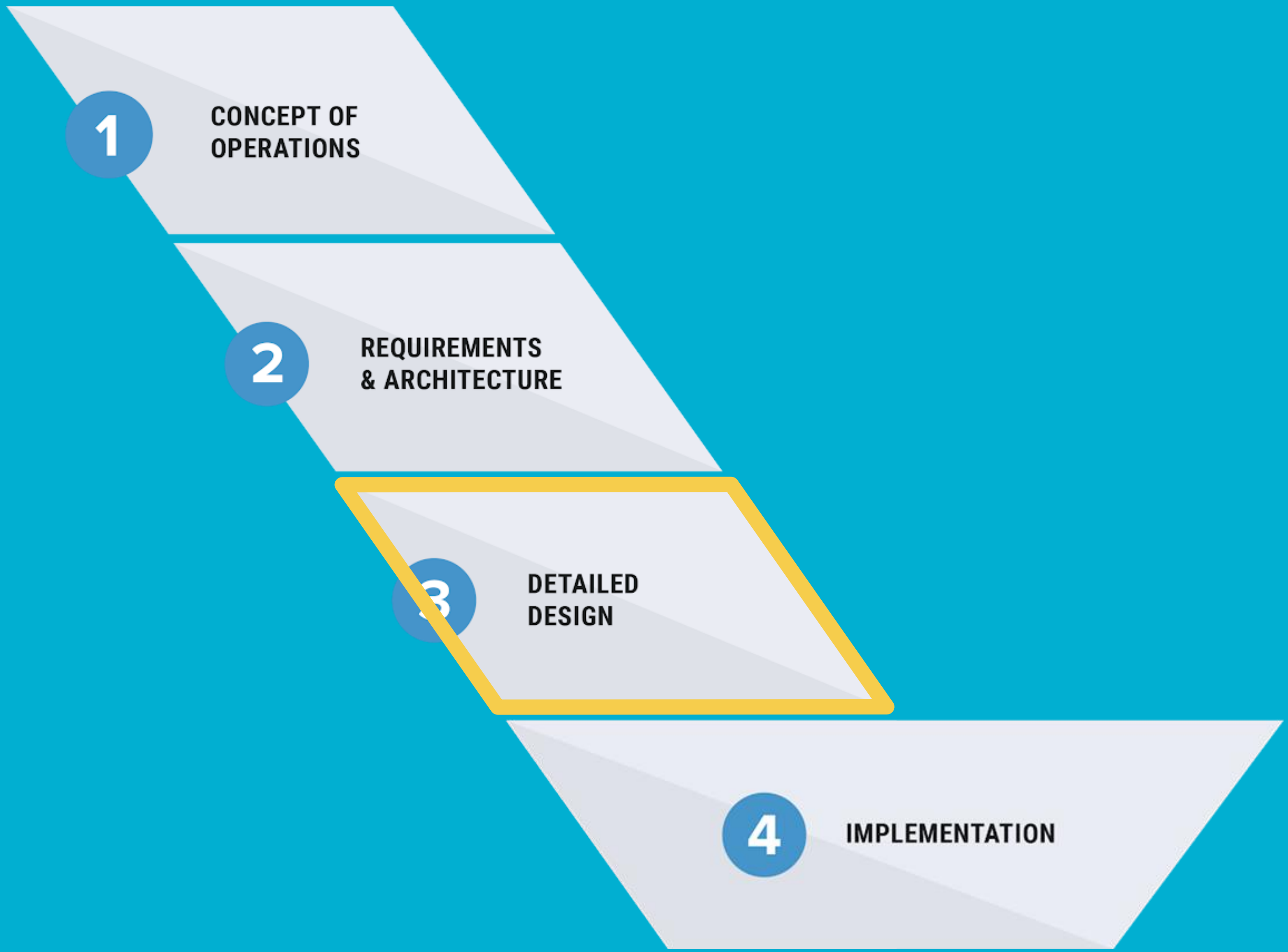
Problem: The Atmosphere is Heavy

Problem: Strong Materials Are Reflective/Absorptive

Solution: A transmissive window!

REQUIREMENT: The window must be strong enough to hold out the atmosphere.

REQUIREMENT: The window should not absorb more than X% radiation.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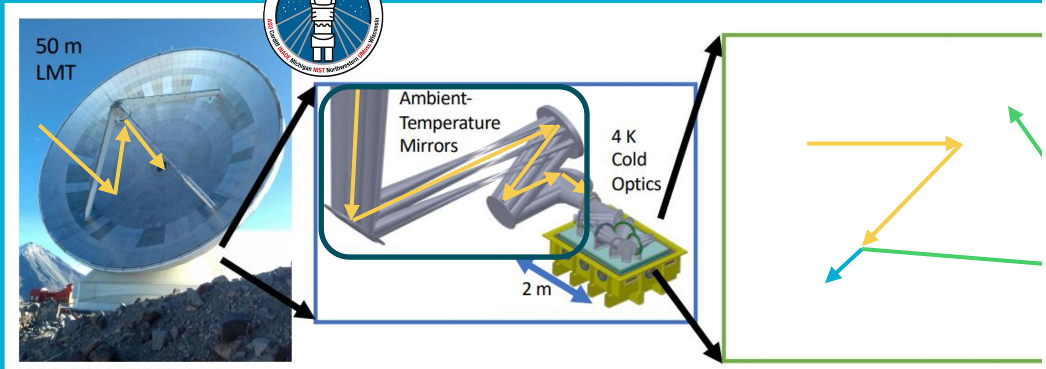
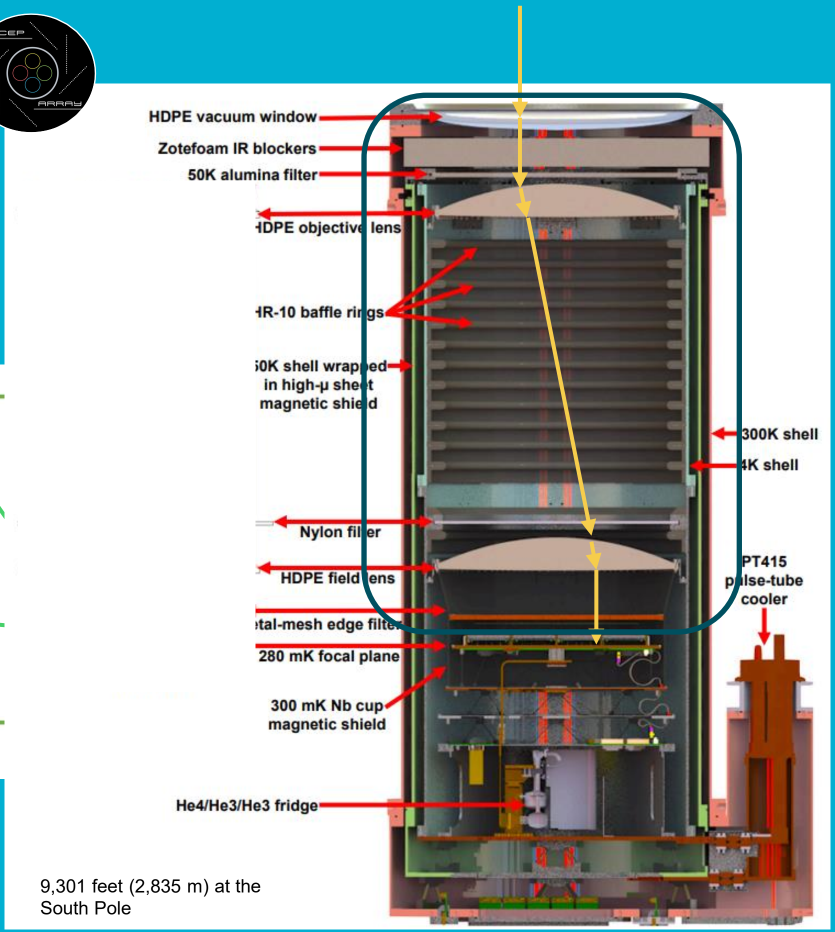
Optical Design



15,030 feet (4,580 m) on
Volcán Sierra Negra, Puebla, Mexico



9,301 feet (2,835 m) at the
South Pole

x4 (slightly modified for different freq)

Window Design

- Both TolTEC and BICEP Array changed the window design for their upgrades.
- Why change a design that worked for the previous iterations?

Problem: The Atmosphere is Heavy

Force $= P_{ATM}\pi r^2$
P_{ATM} = atmospheric pressure
r = radius of window

Problem: Strong Materials Are Reflective/Absorptive

Absorption $\approx e^{-\alpha t}$
α = material constant
t = material thickness

Window Design

- Both increased their aperture by ~2 times

Problem: The Atmosphere is Heavy

$$\text{Force} = P_{ATM}\pi r^2$$
$$P_{ATM} = \text{atmospheric pressure}$$
$$r = \text{radius of window}$$

Problem: Strong Materials Are Reflective/Absorptive

$$\text{Absorption} \approx e^{-\alpha t}$$
$$\alpha = \text{material constant}$$
$$t = \text{material thickness}$$

Force = 1.6e3 lbs = 7.1e3 N

Force = 9.5e3 lbs = 4.2e4 N

Window Design

Problem: The Atmosphere is Heavy

Problem: Strong Materials Are Reflective/Absorptive

- Optical Tests:
  - FTS Transmission
  - Instrument Loading
- Mechanical Tests:
  - Failure modeling
  - Tool drop tests

- Optical Tests:
  - FTS Transmission
  - FTS Polarization differences
  - VNA Reflection (anti-reflection optimization)
  - VNA Scatterometer
  - Instrument Loading
    - PLC and elnod forebaffle on/off (loading and scattered power)
    - Load curve sky dip
- Mechanical Tests:
  - Failure modeling
  - Strength (stress vs strain)
  - Gas permeation
  - Tool drop tests
  - Creep measurement and modeling
  - Extreme temperature test (dry ice)

Window Design

Problem: The Atmosphere is Heavy

Problem: Strong Materials Are Reflective/Absorptive

Goal: Get Really Good Sensitivity

Solution: Wider Aperture

Problem: Makes these two problems REALLY BAD

Solution: New window technology

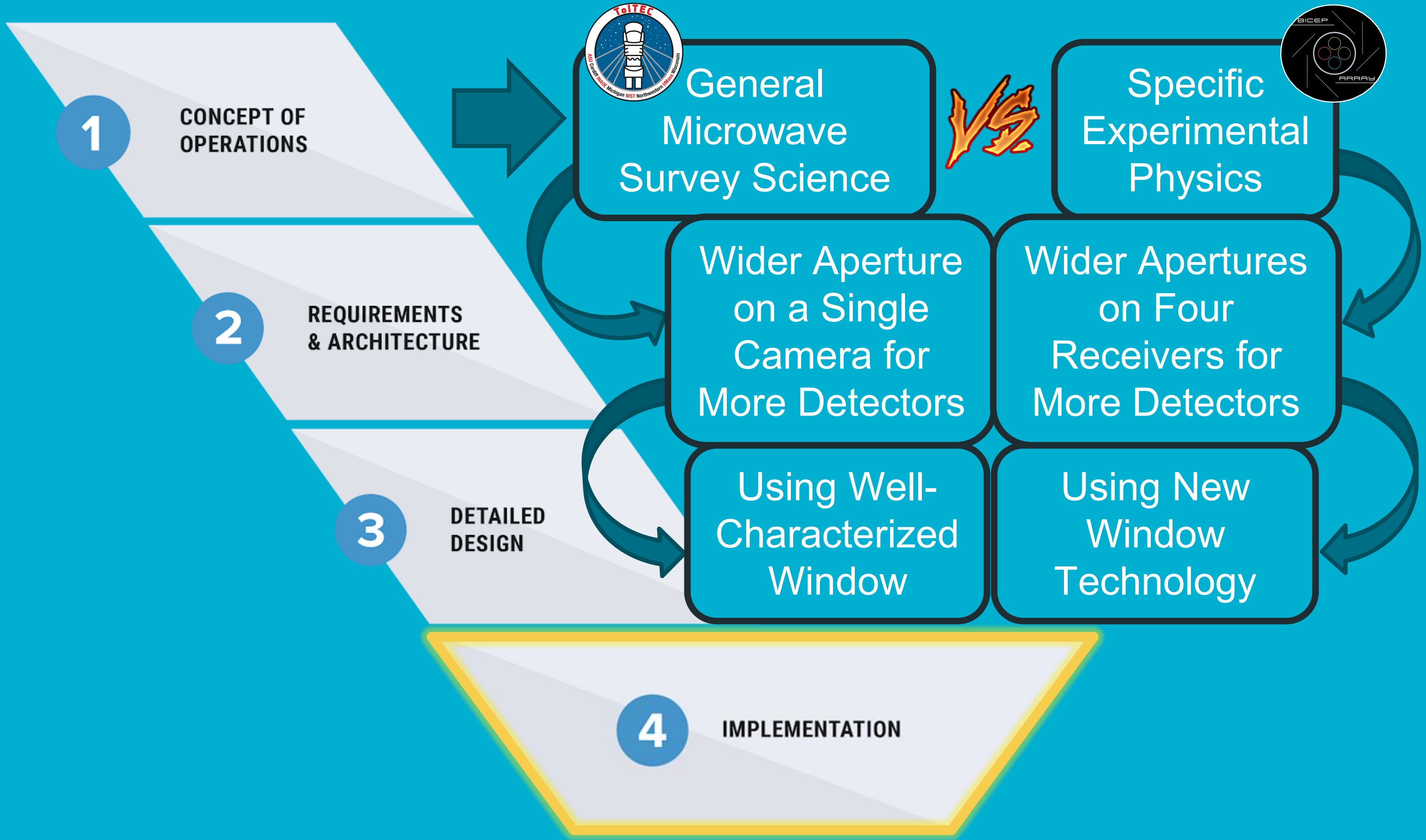
Riskier

Goal: Get Wide Range of Interesting Science

Solution: Wider Aperture

Solution: Use windows proven on other instruments

Already Well-Characterized



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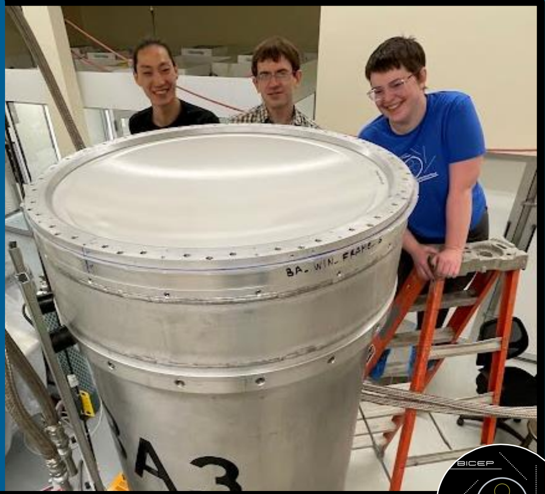
General Microwave Survey Science
VS
Specific Experimental Physics
Wider Aperture on a Single Camera for More Detectors
Wider Apertures on Four Receivers for More Detectors
Using Well-Characterized Window
Using New Window Technology



ToITEC
ASI Cardiff INAOE Michigan NIST Northwestern UMass Wisconsin

BICEP ARRAY