v.31.1.

Cerro Chajnantor Atacama Telescope

CCAT-p^rime

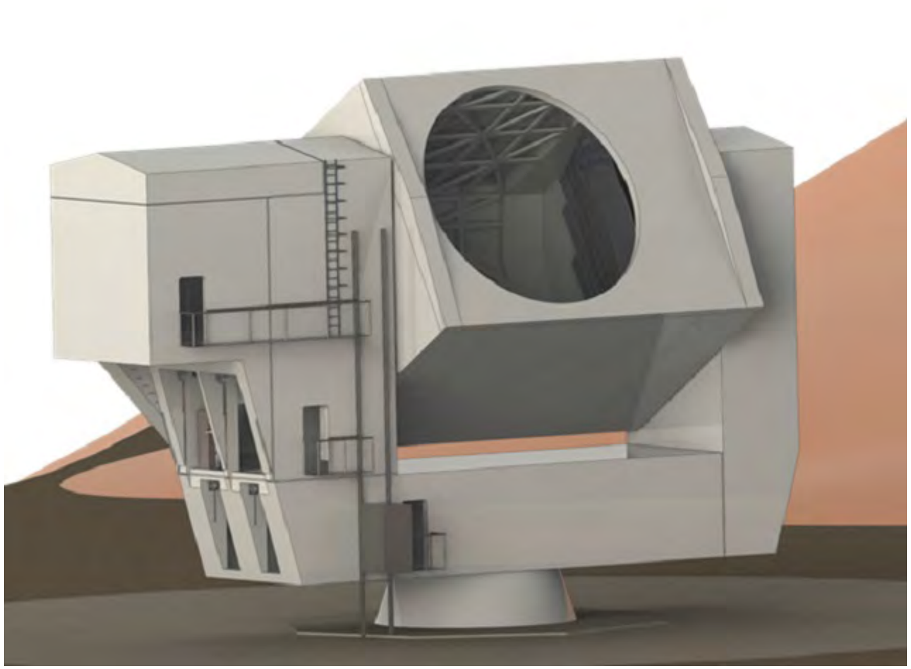
An Extreme Field-of-View Submillimeter Telescope

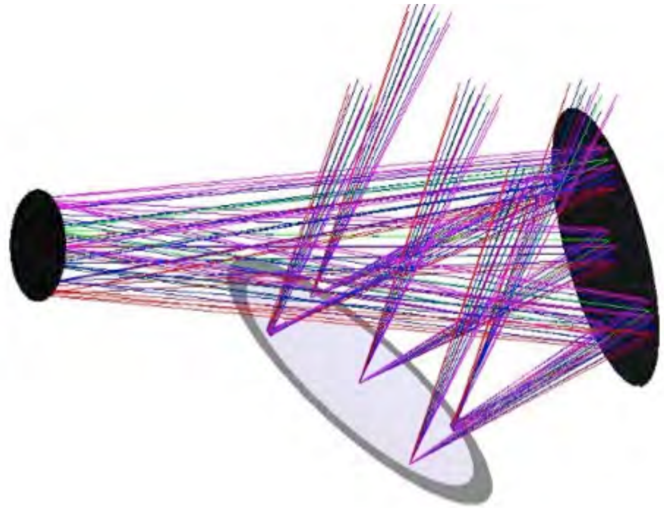
Frank Bertoldi

Bonn University

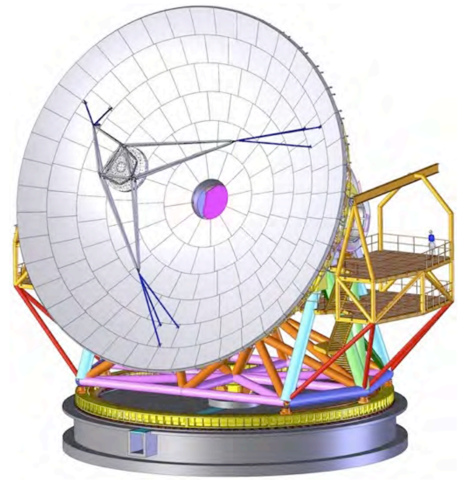
What is CCAT-prime?

A high surface accuracy, high throughput
6 m aperture, submm (0.2-3mm) telescope
for dedicated surveys



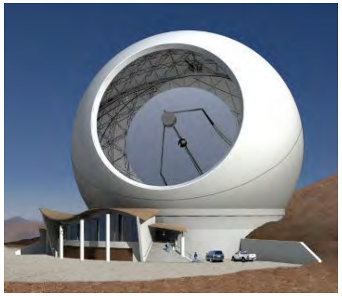


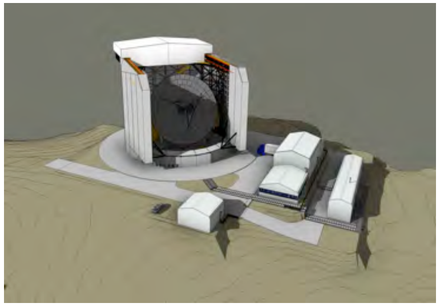
Cerro Chajnantor Atacama Telescope



25 m
FoV 30‘
<15 μm surface

2003	Partnership workshop Pasadena
2004	MoU Caltech, JPL, Cornell
2005	project office
2006	feasibility study review
2007-9	site selection, joining Colorado, Cologne/Bonn, AUI, Canada
2010	astro2010 recommendation
2011-14	Engineering Design Phase (NSF-supported): reference design
2013	EDP external review
2013-15	NSF MSIP proposals fail; Caltech, Colorado leave
2015	MTM, Vertex provided turn-key design studies & pricing
2016	CCAT terminated, CCAT-prime born





Who is CCAT-prime ?

University consortium with strong emphasis on training & development

- **Cornell University, Director: Terry Herter**
- **German consortium Univ. Cologne & Univ. Bonn**
  - joining: LMU (Mohr), MPA (Komatsu)
- **Canadian University consortium**
  - Waterloo, Toronto/CITA, British Columbia, Calgary, Dalhousie, McGill, McMaster, Western Ontario
- **Chilean University collaborators**
  - U. Chile, PUC, UCSC, UDP, and others
- **Prime-Cam collaborators**
  - U. Michigan, NIST, Stanford/SLAC, Cardiff U., and others

Funded by: private donor and Cornell university

DFG Großgeräte, Univ. Köln & Bonn, SFB956 (CHAI)

CCAT-p

Ministerio de Educación

Gobierno de Chile

CONICYT

Cornell University

Universität zu Köln

UNIVERSITÄT BONN

UNIVERSITY OF WATERLOO

CITA–ICAT

Licancabur 5920m
Toco 5604m
Chajnantor 5639m
El Chascon 5703m


h Google Maps
Cerro
Chajnantor

Cerro Chajnantor peak at 5640 m

TAO will be a 6.5m infrared-optimized telescope on the summit of Cerro Chajnantor, promoted by the Institute of Astronomy (IoA), the University of Tokyo & other Japanese facilities incl. the National Astronomical Observatory, ISAS/JAXA, and the University of Chile.

12 June 2017

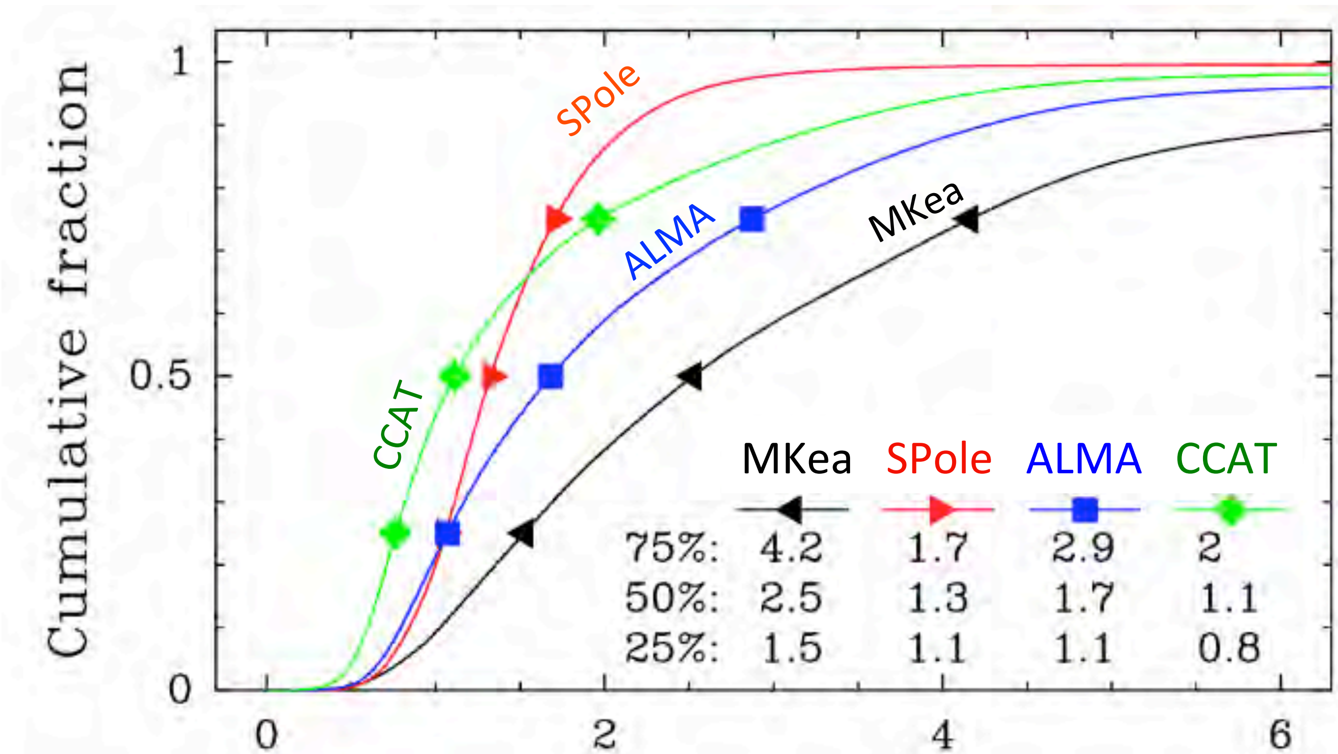
Why bother moving to the peak?

Submillimeter sensitivity is all about atmospheric transmission.

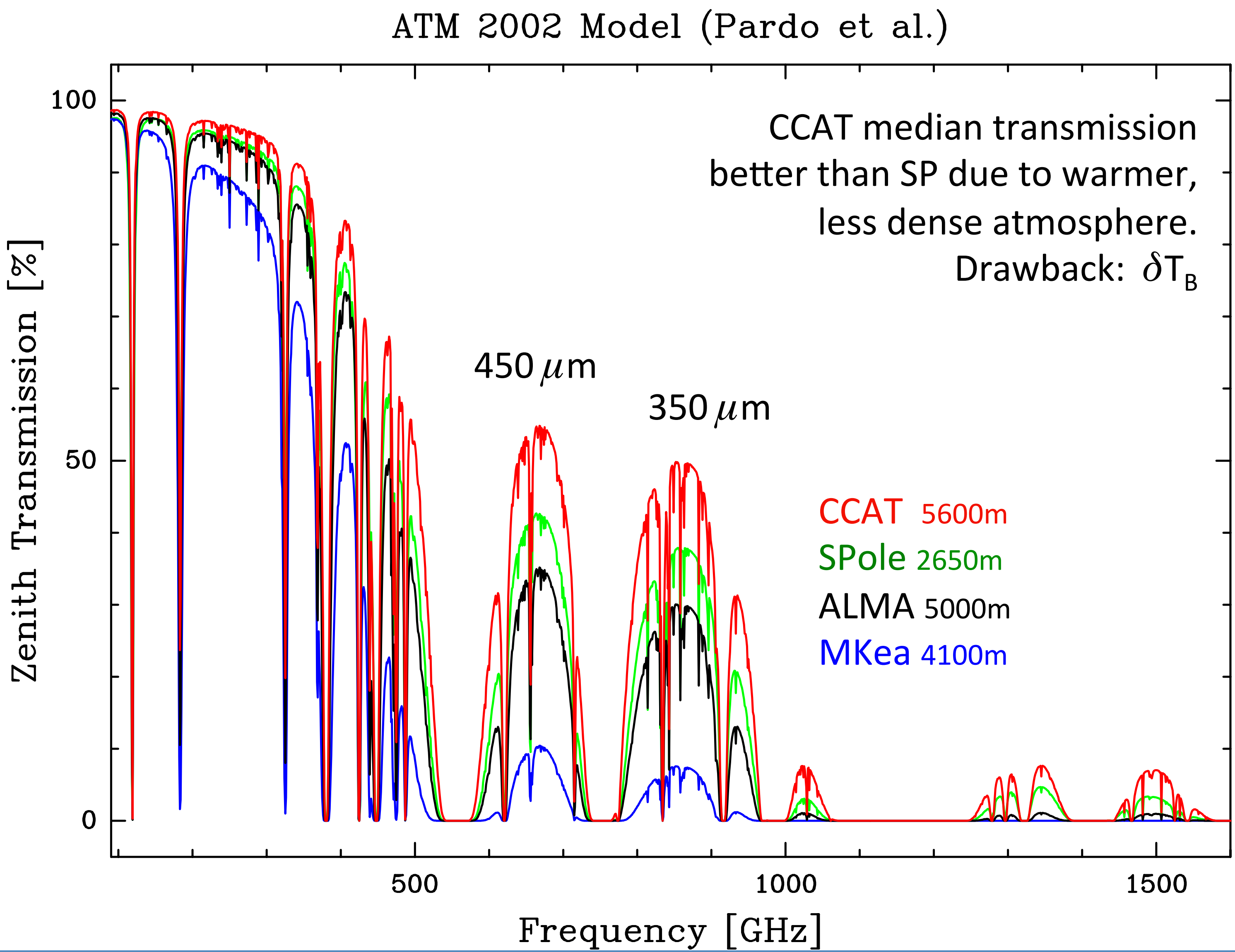
5100 m is good, 5600 m is better !

CCAT vs. ALMA sites: median H_2O 0.6 vs. 1 mm, $\tau(350\,\mu m)$= 1.1 vs. 1.7

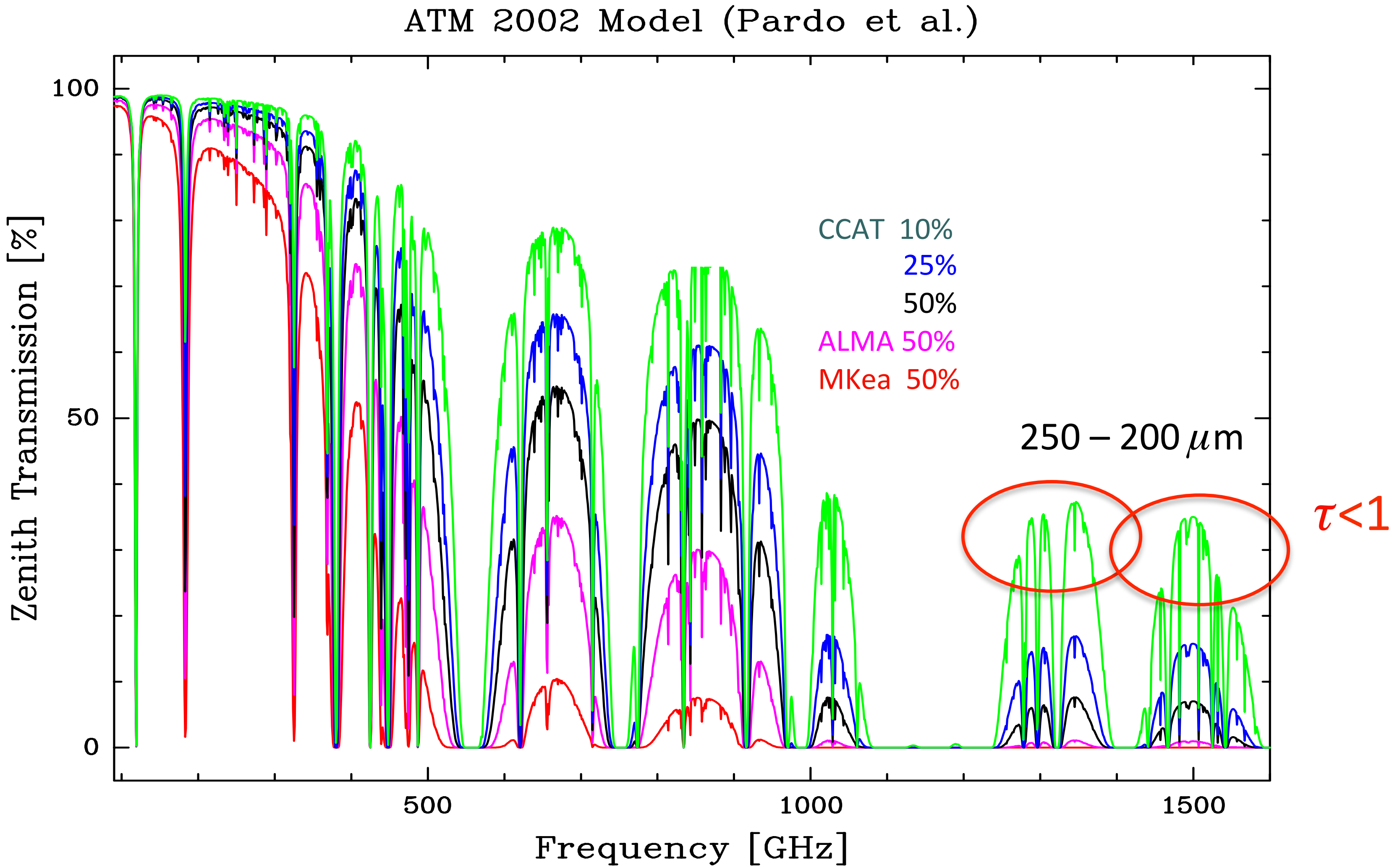
$\Rightarrow$ *factor of 2 in sensitivity*



Median *Zenith* Transmission



Chajnantor Site opens up THz Windows



Crossed-Dragone Optics Design

high throughput, 8 deg field-of-view, flat focal plane, zero geometric blockage

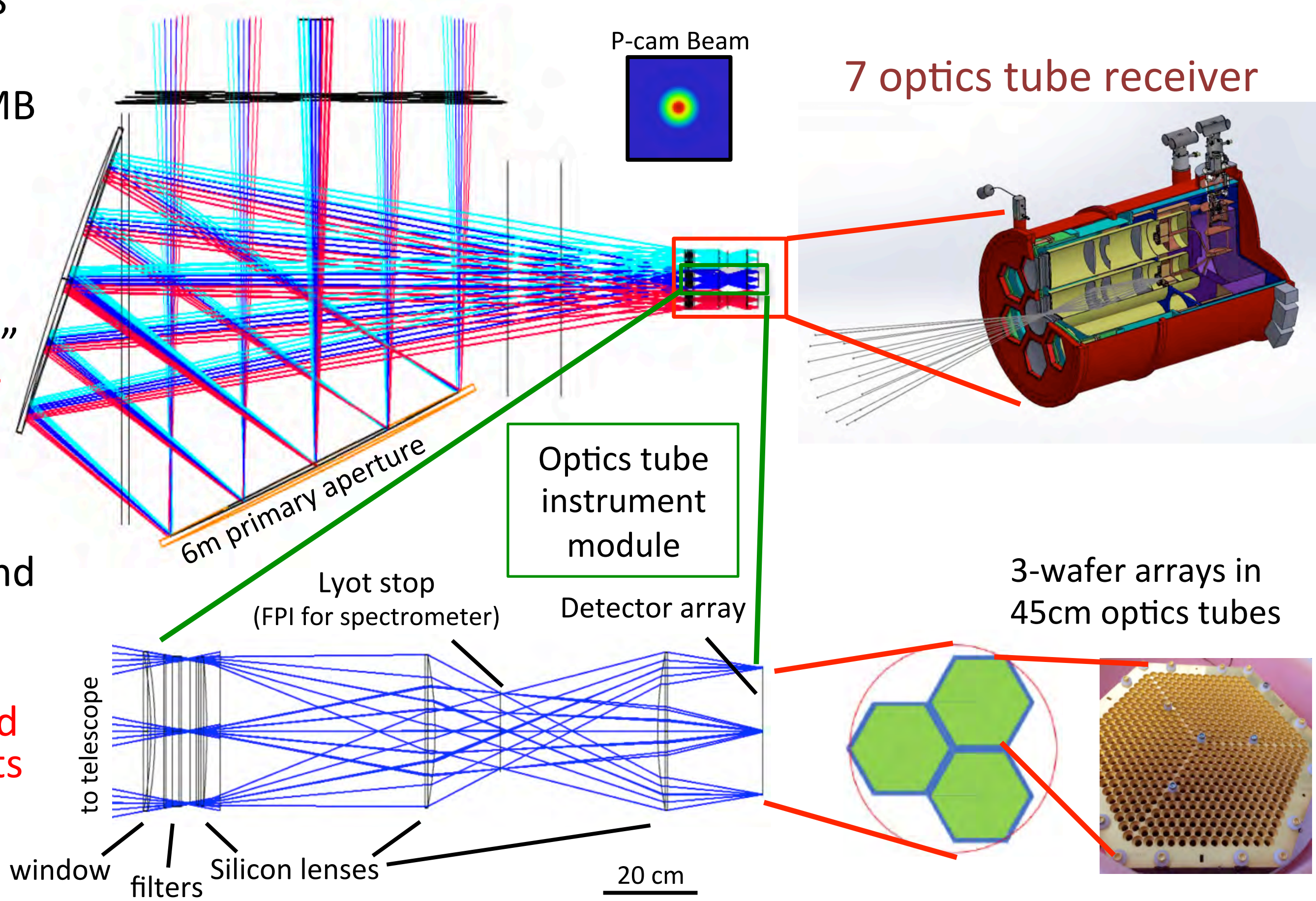
Concept by C. Dragone 1978

Used in “small aperture” CMB experiments
(QUIET, Atacama B-Mode Search, QUIJOTE)

Designs for “large apertures” to map the CMB ~10x faster
(Niemack 2016, Applied Optics)

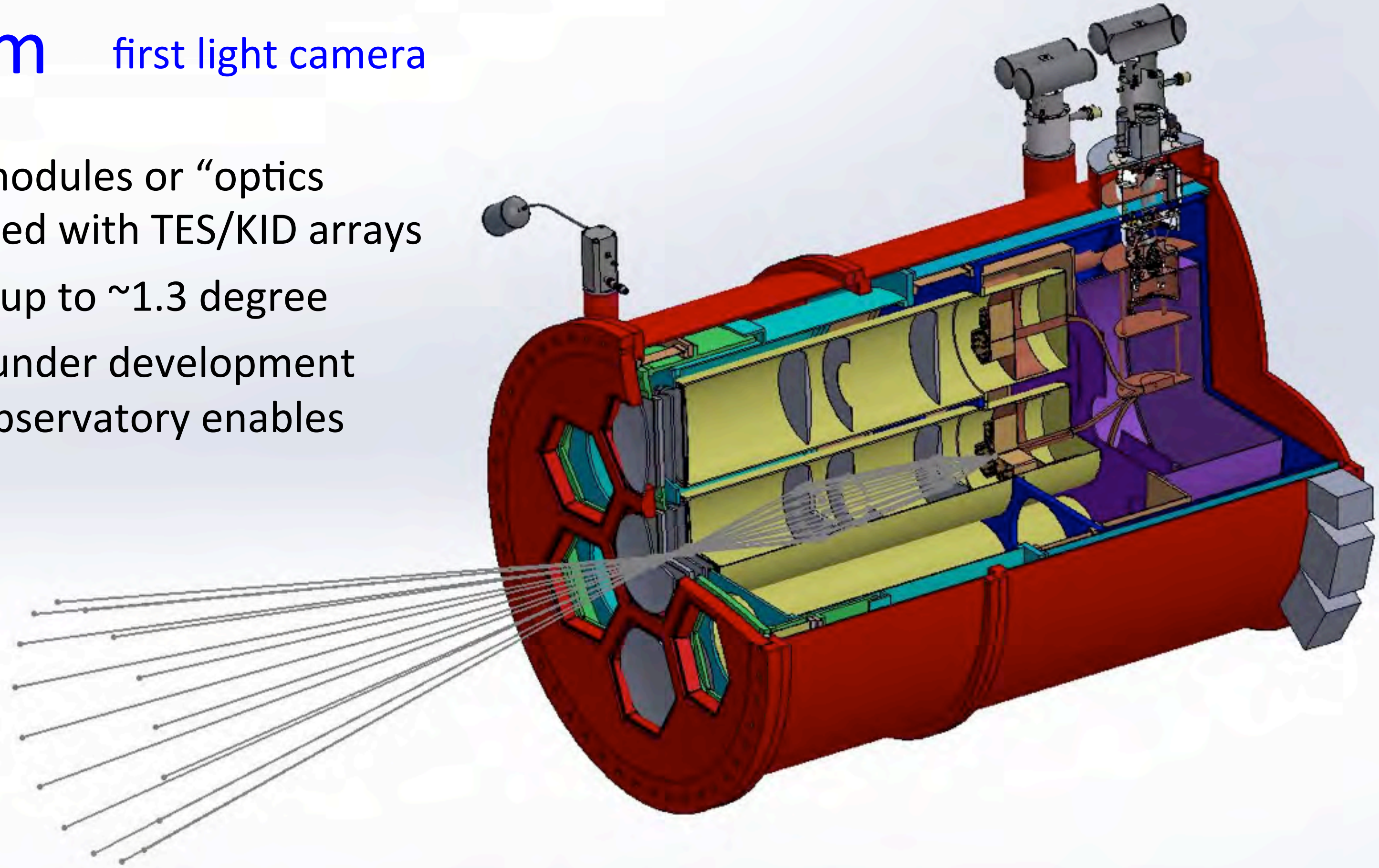
Working with *Simons Observatory* on telescope and receiver optics designs

6m aperture coma-corrected f/2.6 design for both projects
(Parshley, Hills, Mauskopf, Dicker, Gallardo and others)



Prime-Cam first light camera

- 7 instrument modules or "optics tubes" populated with TES/KID arrays
- Each tube FoV up to ~1.3 degree
- Modul design under development with Simons Observatory enables upgrades



Plan for first 3 optics tubes: 2 broadband (bb) one spectrometer (sp)

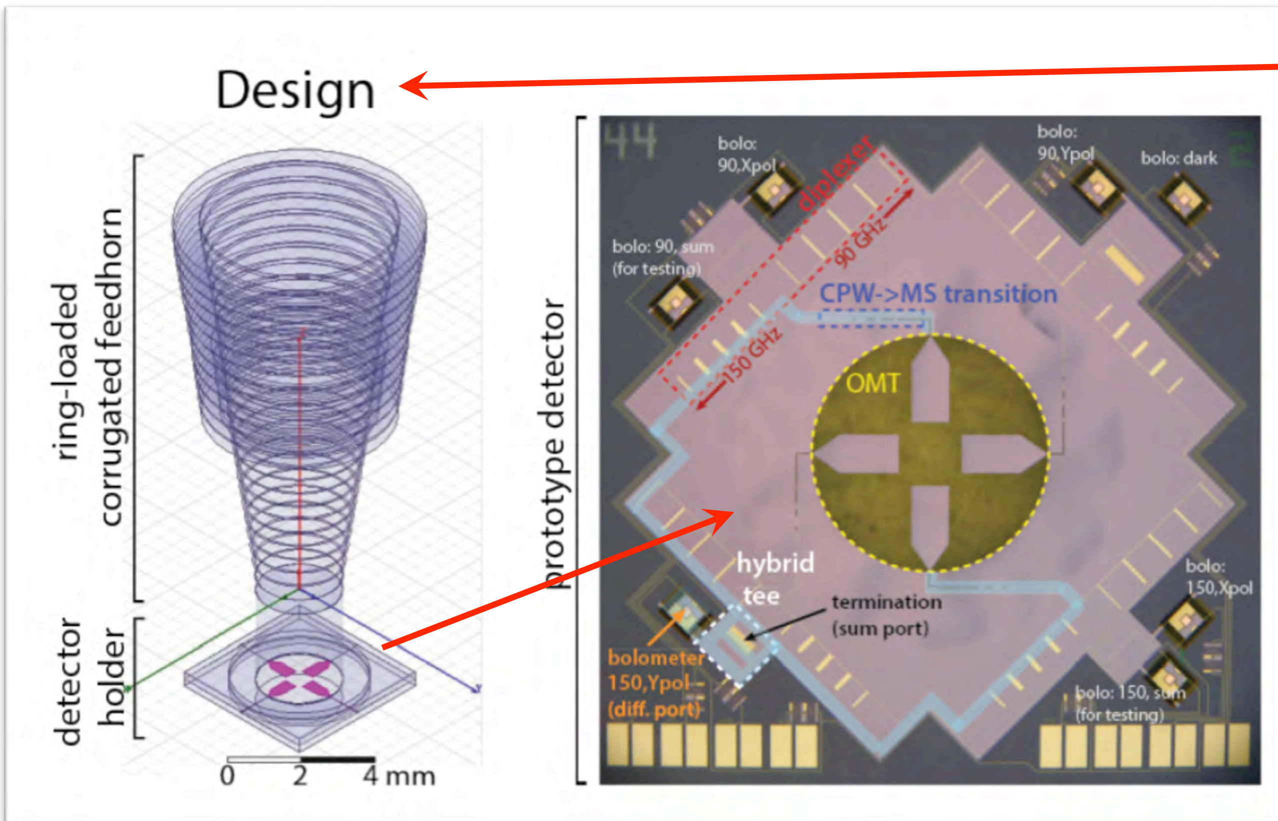
Science cases[a]	Type[b]	Frequencies[c] (GHz)	Resolution (arcsec)	Detectors type	Detectors #	Survey Areas[d] (deg^2) pilot	Survey Areas[d] (deg^2) full
SZ, CMB, SF	bb, pol	230, 270, 350, 410	60, 50, 40, 35	TES	9000	100	12,000[e]
EoR, SZ	sp	230, 270, 350, 410	60, 50, 40, 35	TES	6000	4	16
SZ, SF	bb	860	15	KID	18,000	both	both

Detector concept for Prime-Cam

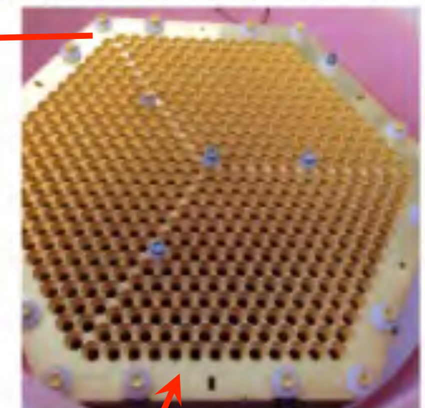
(with NIST, Michigan, Stanford/SLAC, and others)

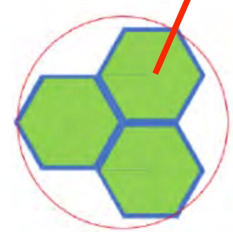
- Feedhorn-coupled multichroic TES arrays with 4 bands per feedhorn: 740, 860, 1100, 1300 μm
- Feedhorn coupled MKID array at 350 μm (NIST)
- 3x 15cm feed detector arrays tiled in each optics tube

Heritage:
Advanced ACTPol
BLAST-TNG



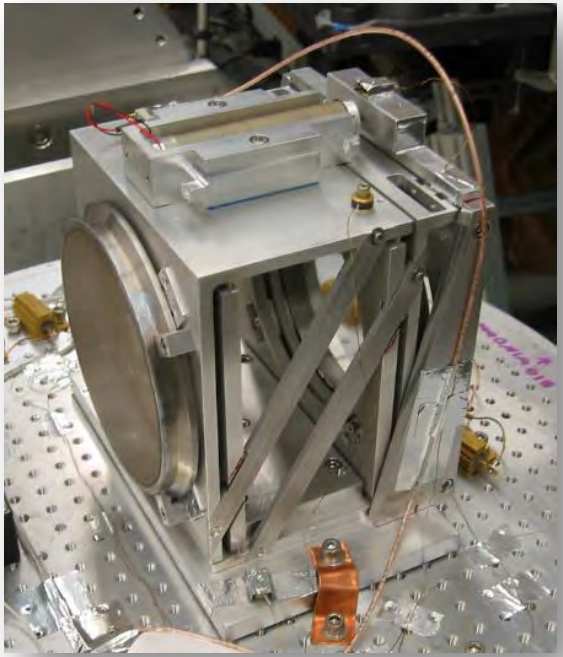
Multichroic feedhorn array

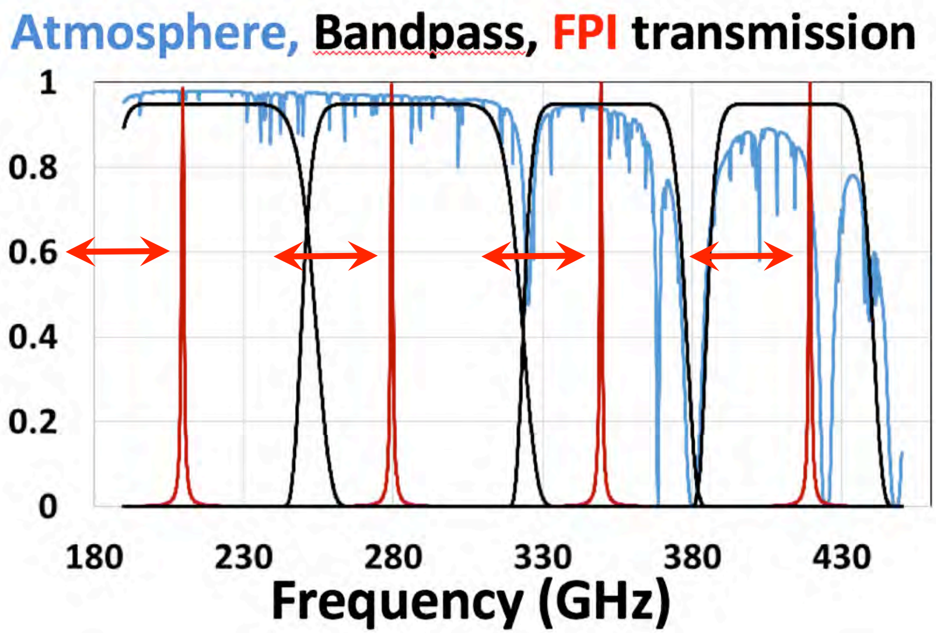




3-wafer optics tube

Fabry-Perot Interferometer for Intensity Mapping



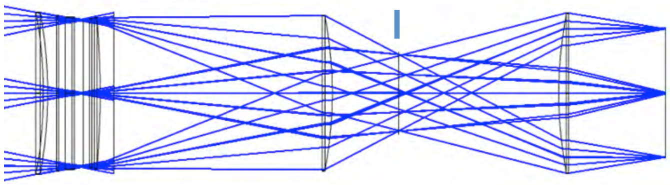


Heritage:
FPI at 112 μm for HIRMES on SOFIA

Scan 185-440 GHz range in 4 bands across ~1 deg^2 per optics tube simultaneously

→ [CII] 158 μm at z=3.3-9.3
→ [OIII] 88 μm at z>6.7
→ CO 2-1 and higher at virtually any z

FPI for spectrometer
at Prime-Cam module Lyot stop



Galactic Ecology instrument:

CCAT Heterodyne Array Instrument "CHAI"

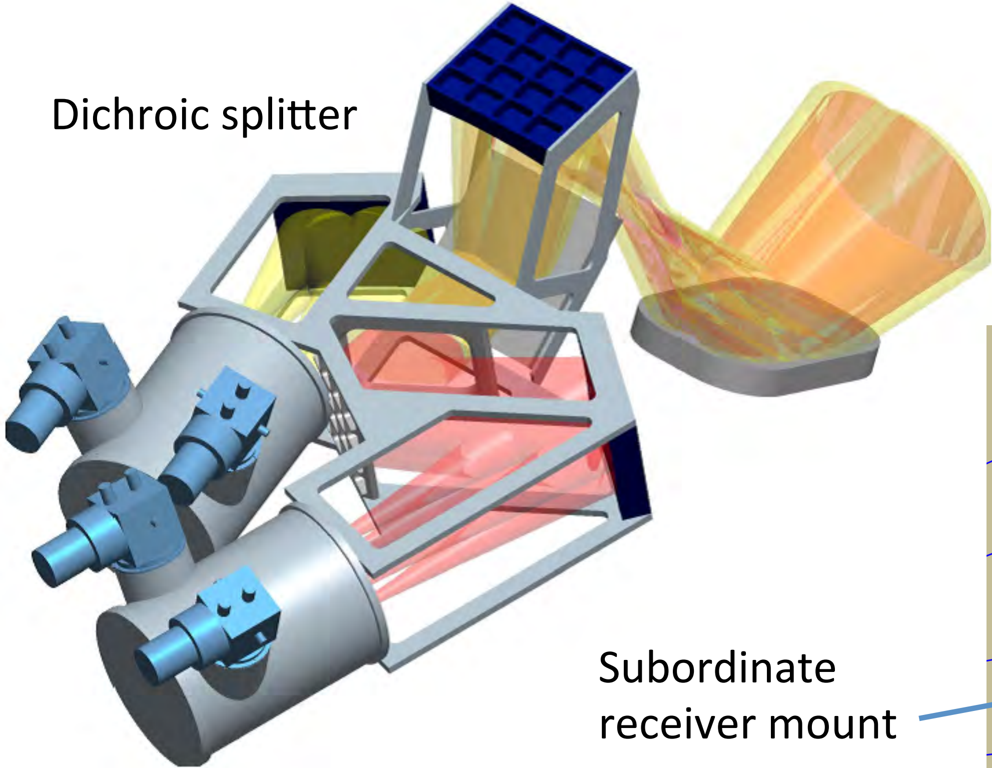
CCAT-p

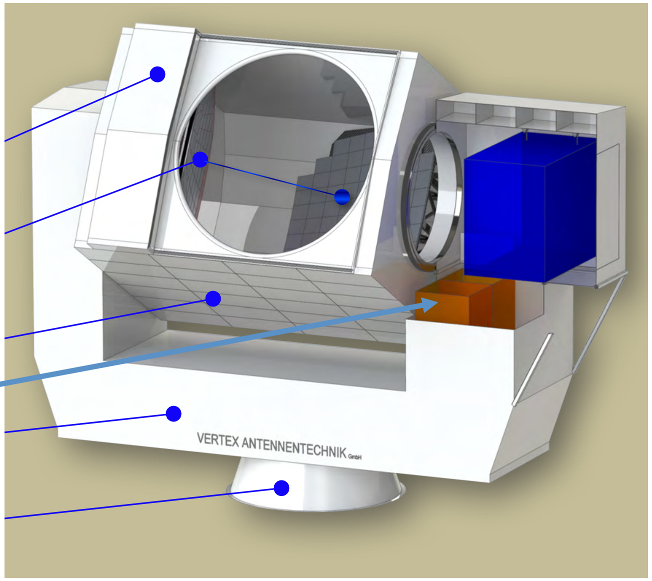
SFB 956

Universität zu Köln

Graf, Stutzki et al.

Max-Planck-Institut für Radioastronomie





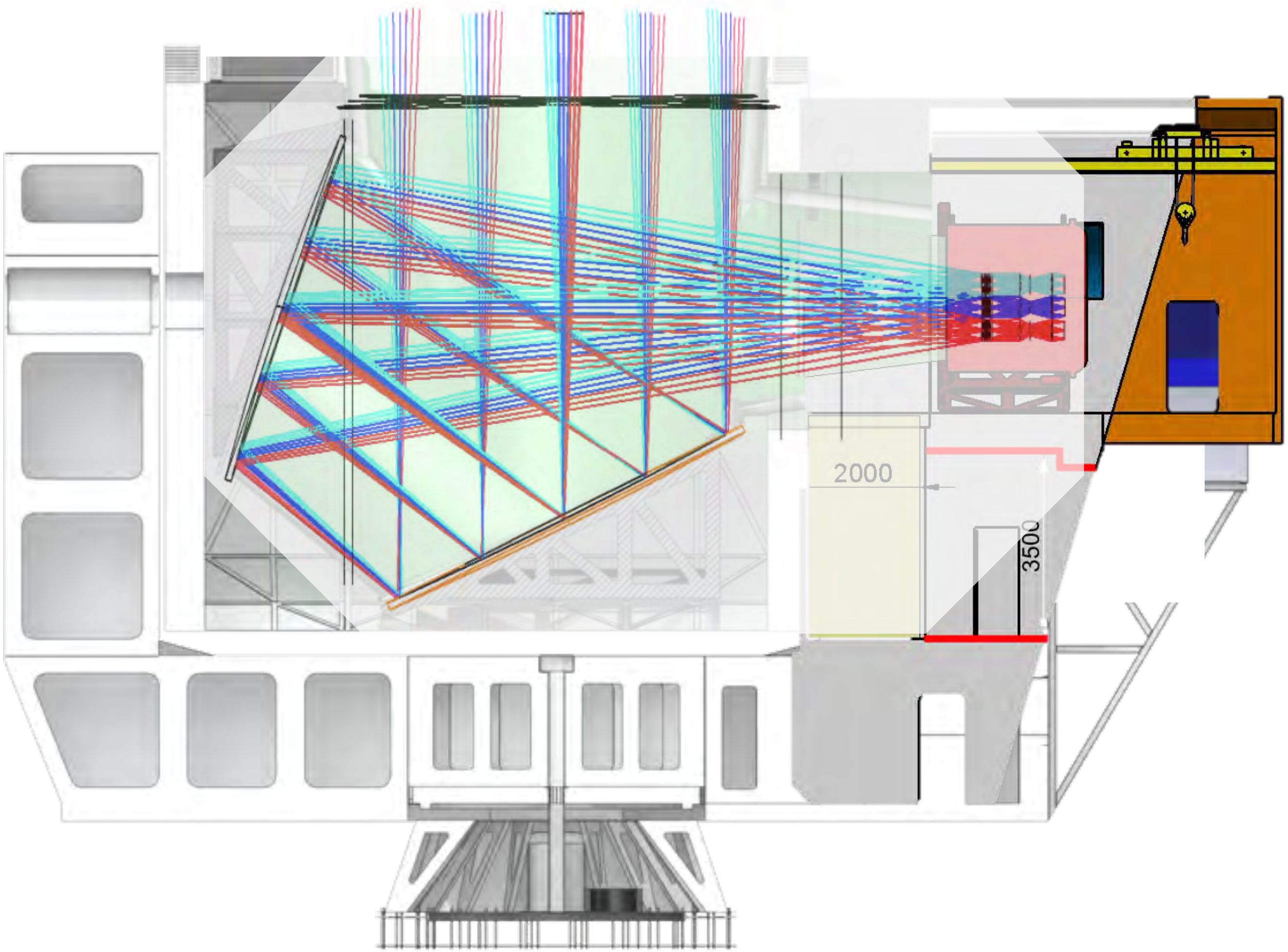
- Heterodyne, dual frequency array
- 500 GHz (600 μm) and 850 GHz (350 μm): CO 4-3,7-6 [CI]2-1,1-0
- 64 pixels (baseline), 128 pixels (goal) in each band

Crossed-Dragone Optics Design

coma-corrected f/2.6 with 5.5m free aperture

high throughput, 8 deg field-of-view, flat focal plane, zero geometric blockage

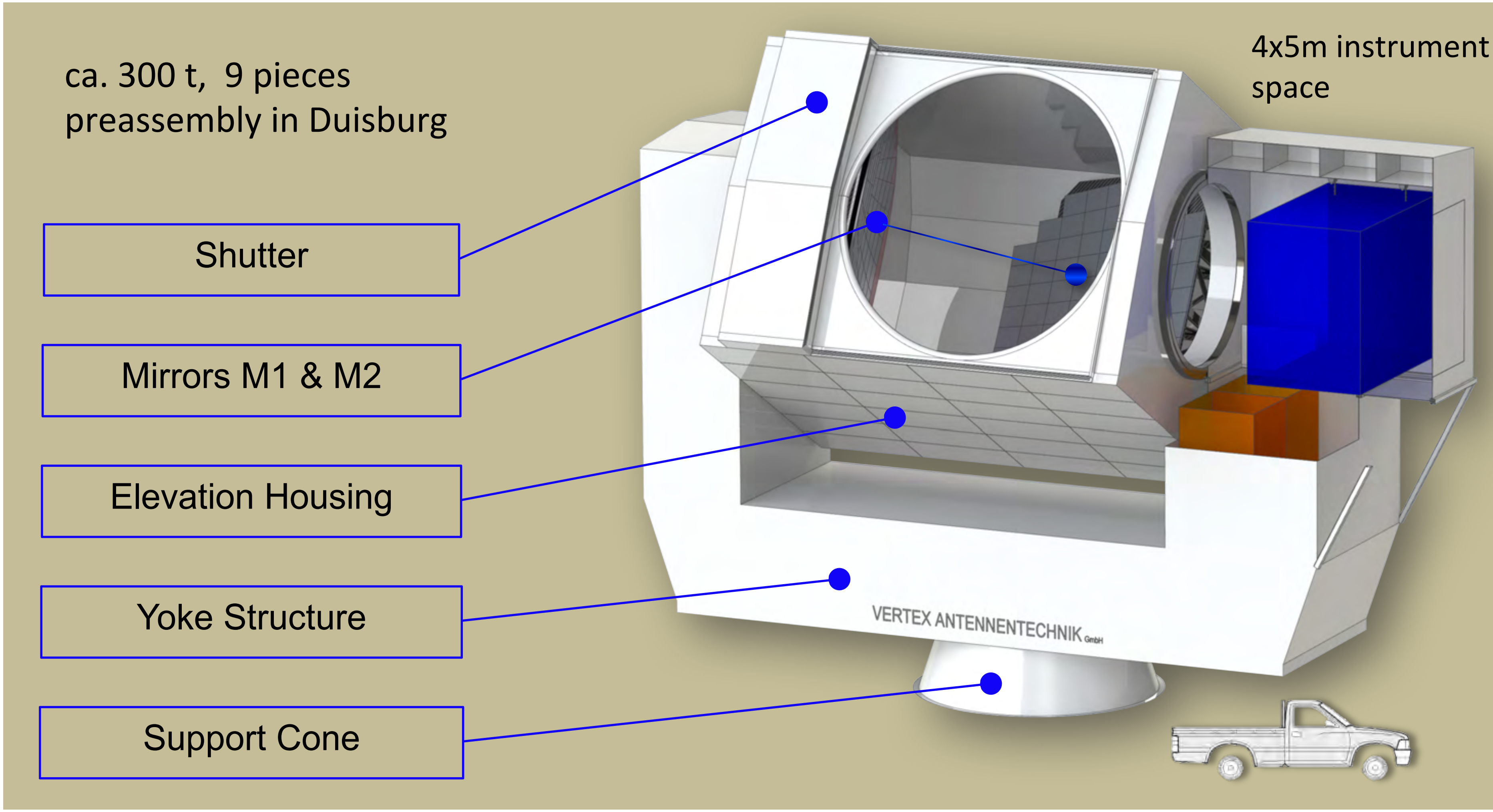
telescope emissivity < 2%, total system emissivity < 7%



CCAT-prime

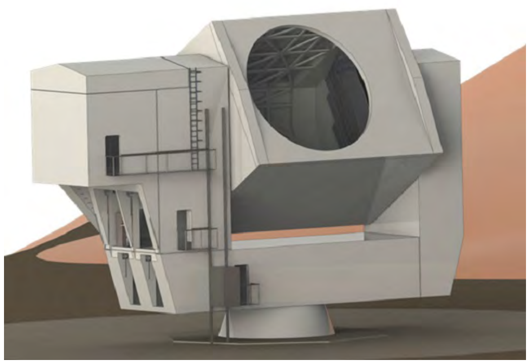
designed and built by Vertex Antennentechnik GmbH, Duisburg

CCAT-p



CCAT-prime Schedule

Telescope: 4 year construction (6/2017 to 6/2021)
- 20 months detailed design
- 13 months fabrication incl. trial assembly in Duisburg
- 3 months shipping & receiving
- 12 months assembly/checkout

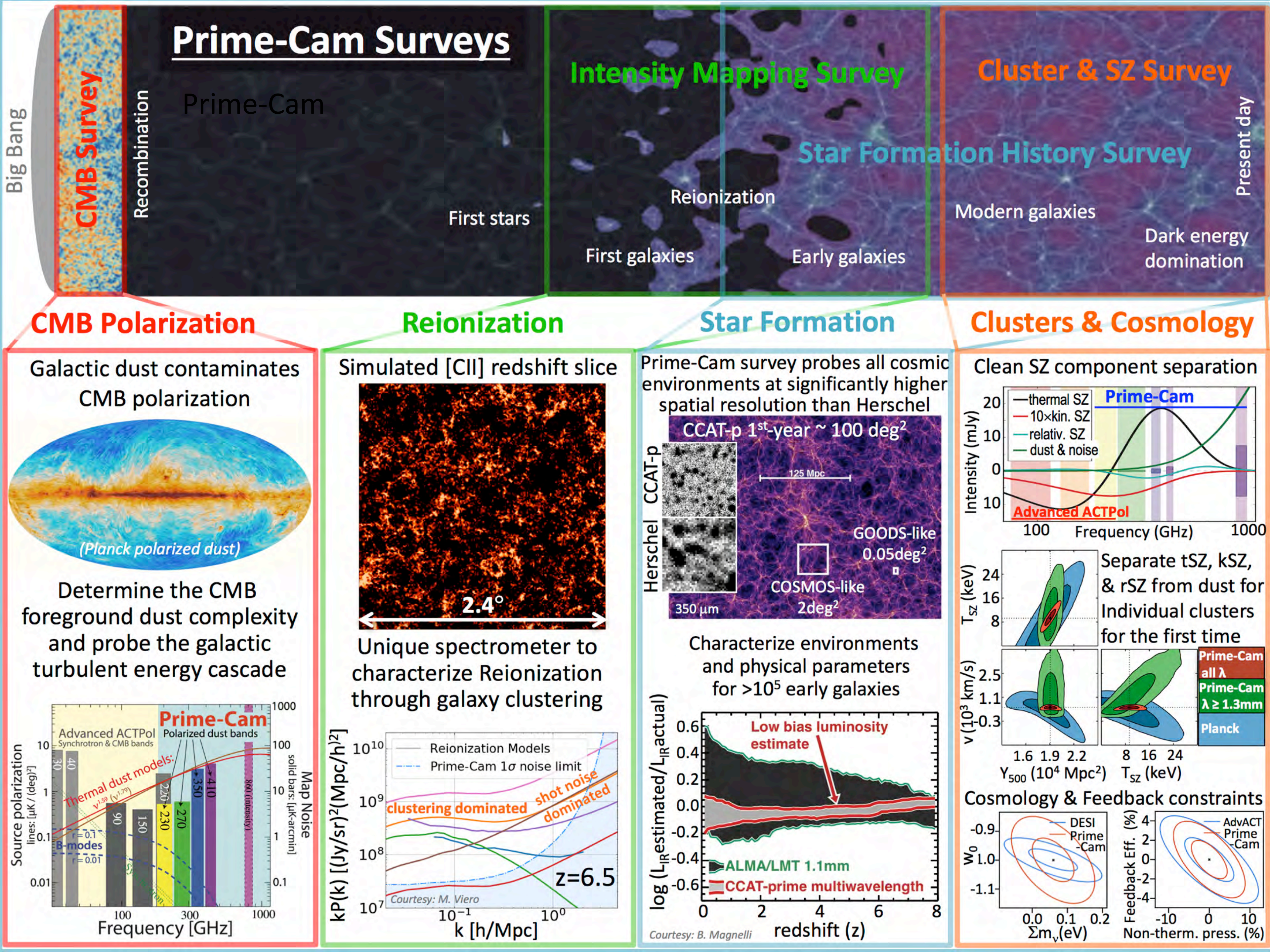


Cameras under design & construction, $€ still being raised (NSF: MSIP, DFG: SFB, …)

Possible platform for CMB "Stage IV" survey in future

Project has started, but still welcomes new partners.

www.ccatobservatory.org



Prime-Cam Surveys
Prime-Cam
Big Bang
CMB Survey
Recombination
First stars
Intensity Mapping Survey
First galaxies
Reionization
Early galaxies
Star Formation History Survey
Cluster & SZ Survey
Modern galaxies
Dark energy domination
Present day
CMB Polarization
Reionization
Star Formation
Clusters & Cosmology
Galactic dust contaminates CMB polarization
(Planck polarized dust)
Determine the CMB foreground dust complexity and probe the galactic turbulent energy cascade
Advanced ACTPol
Synchrotron & CMB bands
Prime-Cam
Polarized dust bands
Thermal dust models:
B-modes
Source polarization lines: [μK / (deg)²]
Map Noise solid bars: [μK-arcmin]
Frequency [GHz]
Simulated [CII] redshift slice
2.4°
Unique spectrometer to characterize Reionization through galaxy clustering
Reionization Models
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clustering dominated
shot noise dominated
z=6.5
Courtesy: M. Viero
kP(k) [(Jy/sr)²(Mpc/h)²]
k [h/Mpc]
Prime-Cam survey probes all cosmic environments at significantly higher spatial resolution than Herschel
CCAT-p 1st-year ~ 100 deg²
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Herschel
125 Mpc
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ALMA/LMT 1.1mm
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log (L_IR estimated/L_IR actual)
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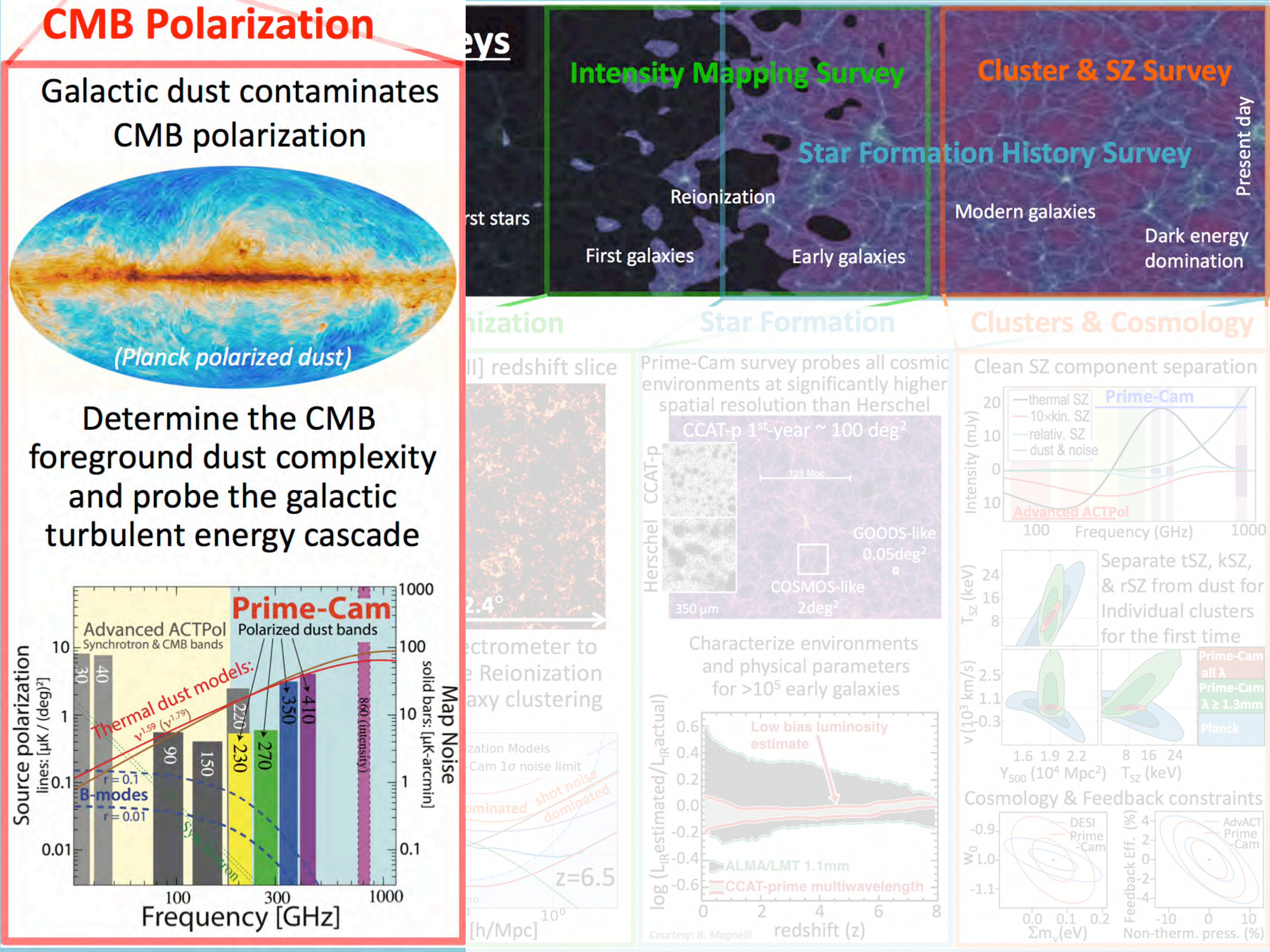

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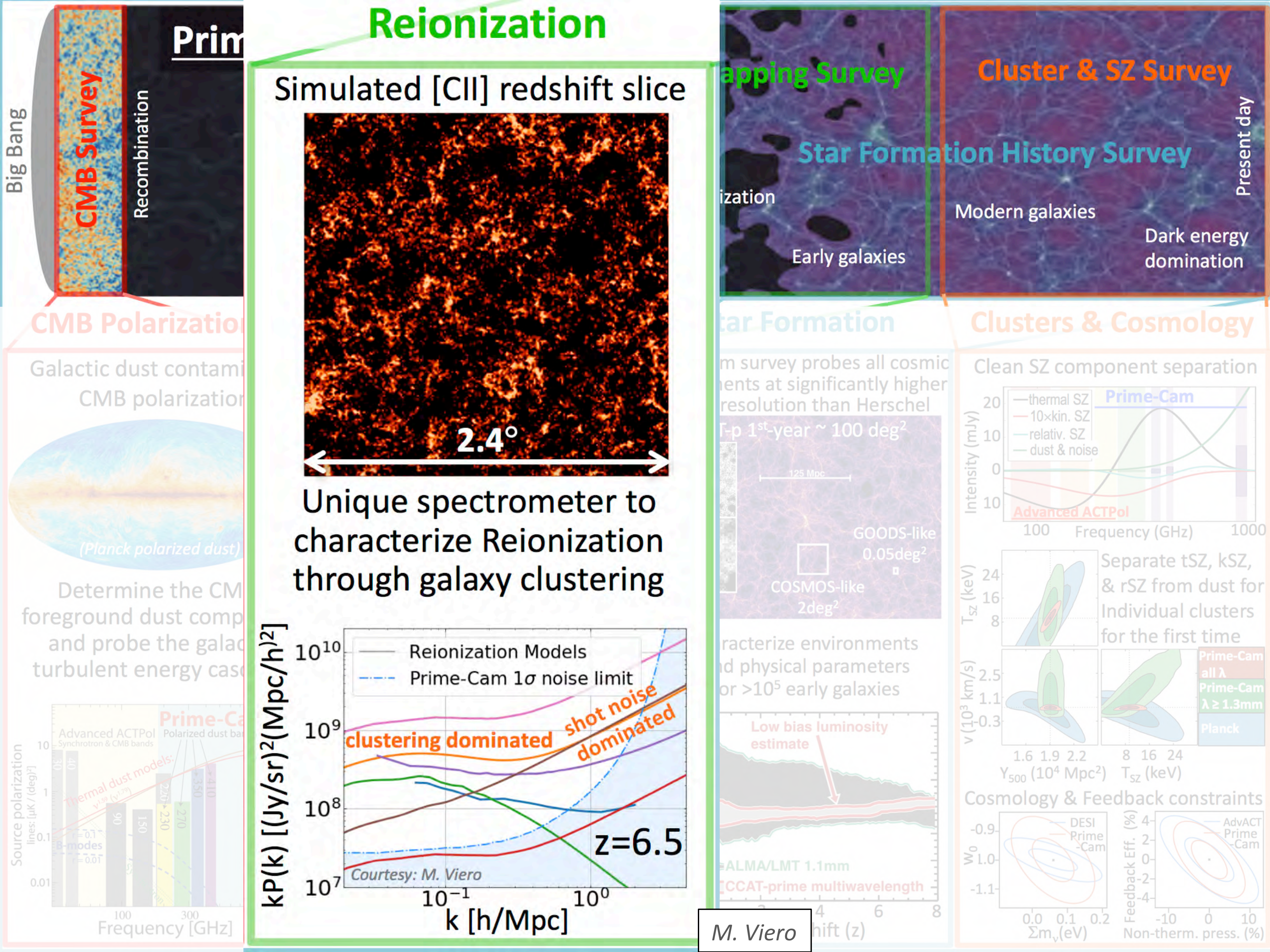

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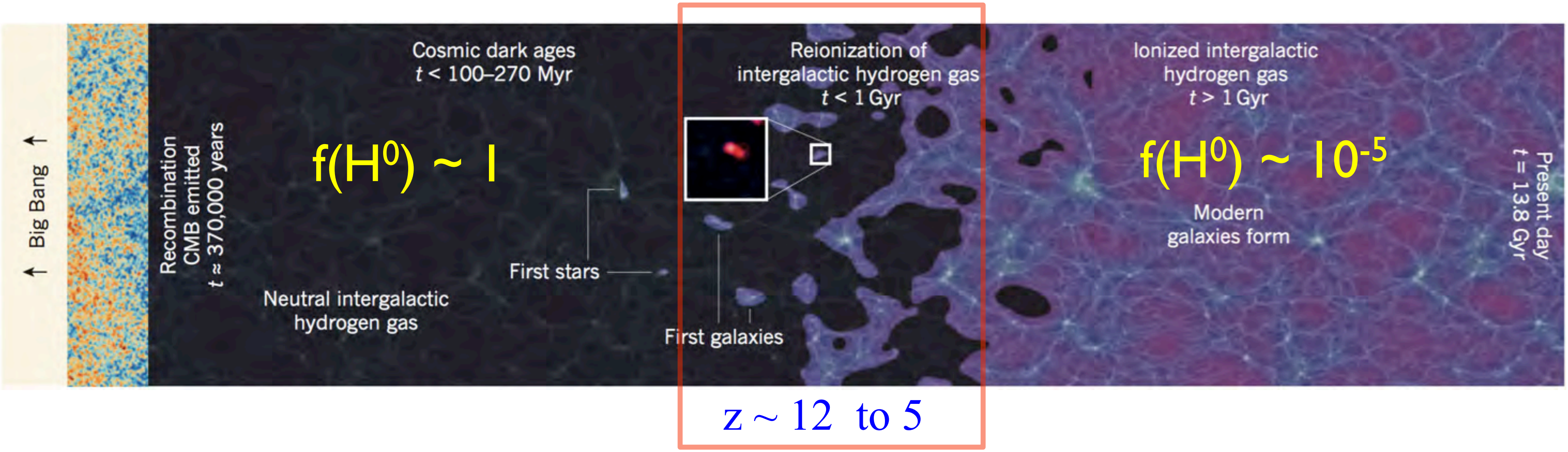
Intensity Mapping of [CII] throughout EoR

Measure large-scale spatial fluctuations of faint galaxies via [CII] 158 μm line.

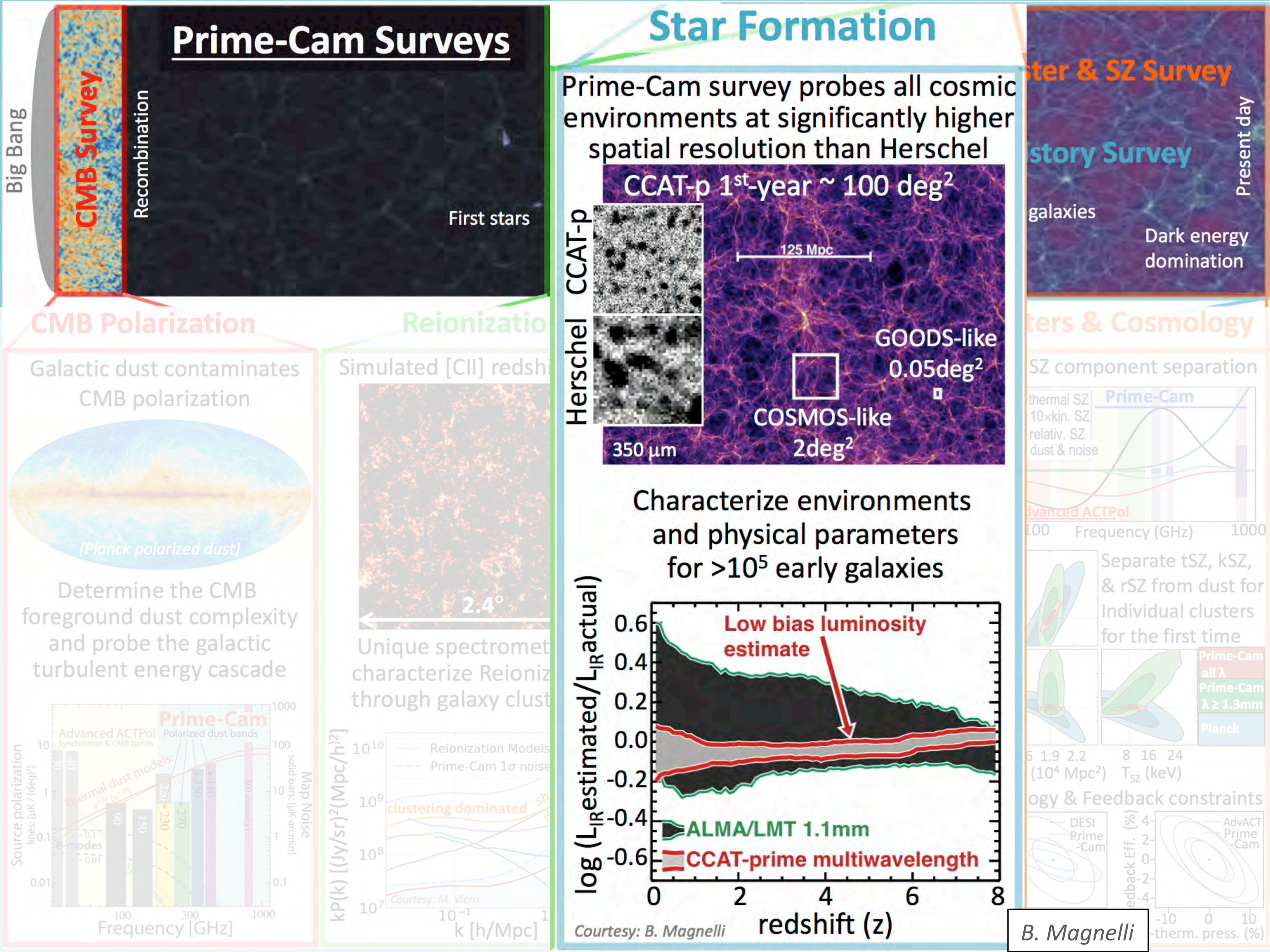


Reveals the process of reionization and the underlying dark matter distribution over the cosmic time when the first galaxies formed. Understand *topology* & *timescale* of reionization, i.e., how and when galaxies first formed, the *properties of sources* of reionization.

Resolution into individual galaxies not required.
Clustering scale 0.5-1 Mpc (1-2') at z=3.5-9, good match : 40"@1mm, R~400, 16sqd

Inverse view: combine with 21 cm HI, tracing neutral ISM concentrations.

Potential for non-Gaussianity searches in future?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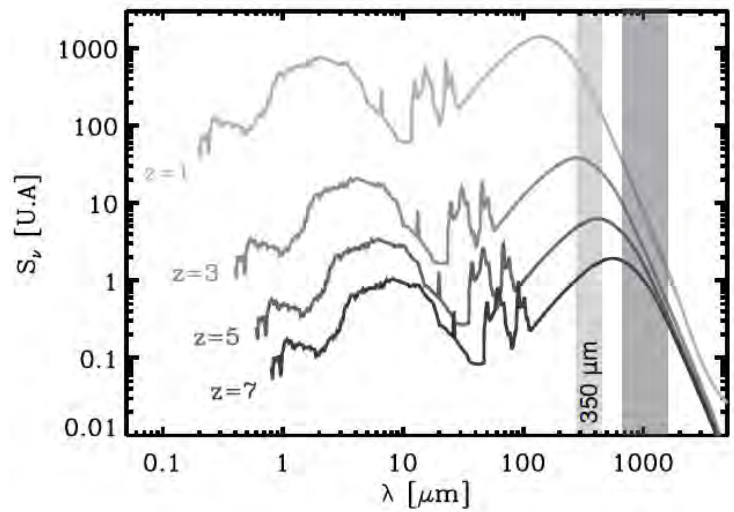
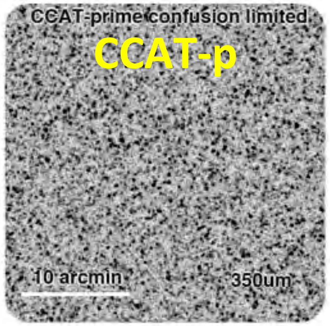
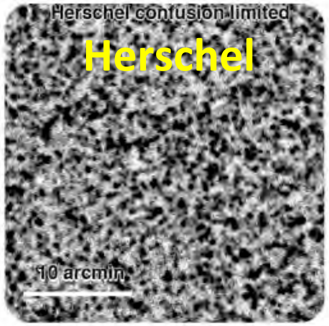
Obscured SF over Cosmic Time

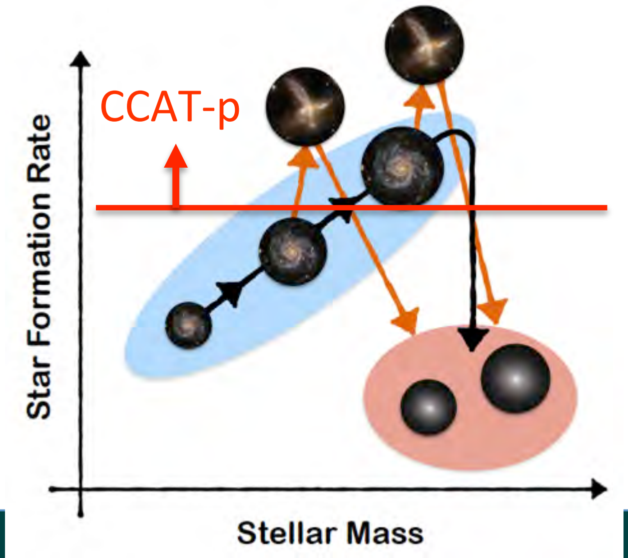
1. Must trace FIR at 350 μm
2. Larger CCAT-p aperture pushes Herschel confusion limits down by ~3
3. Need ~100 sqd survey to beat variance.

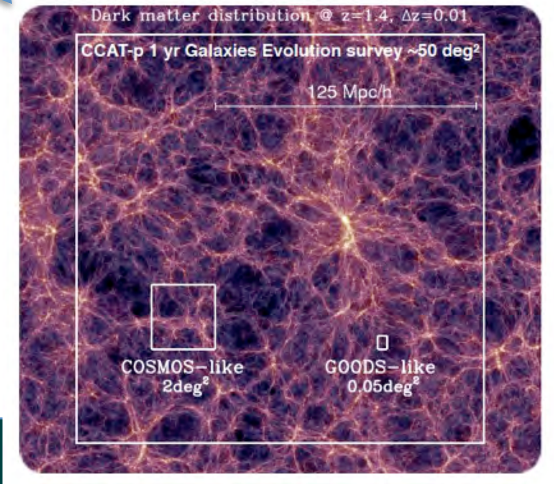


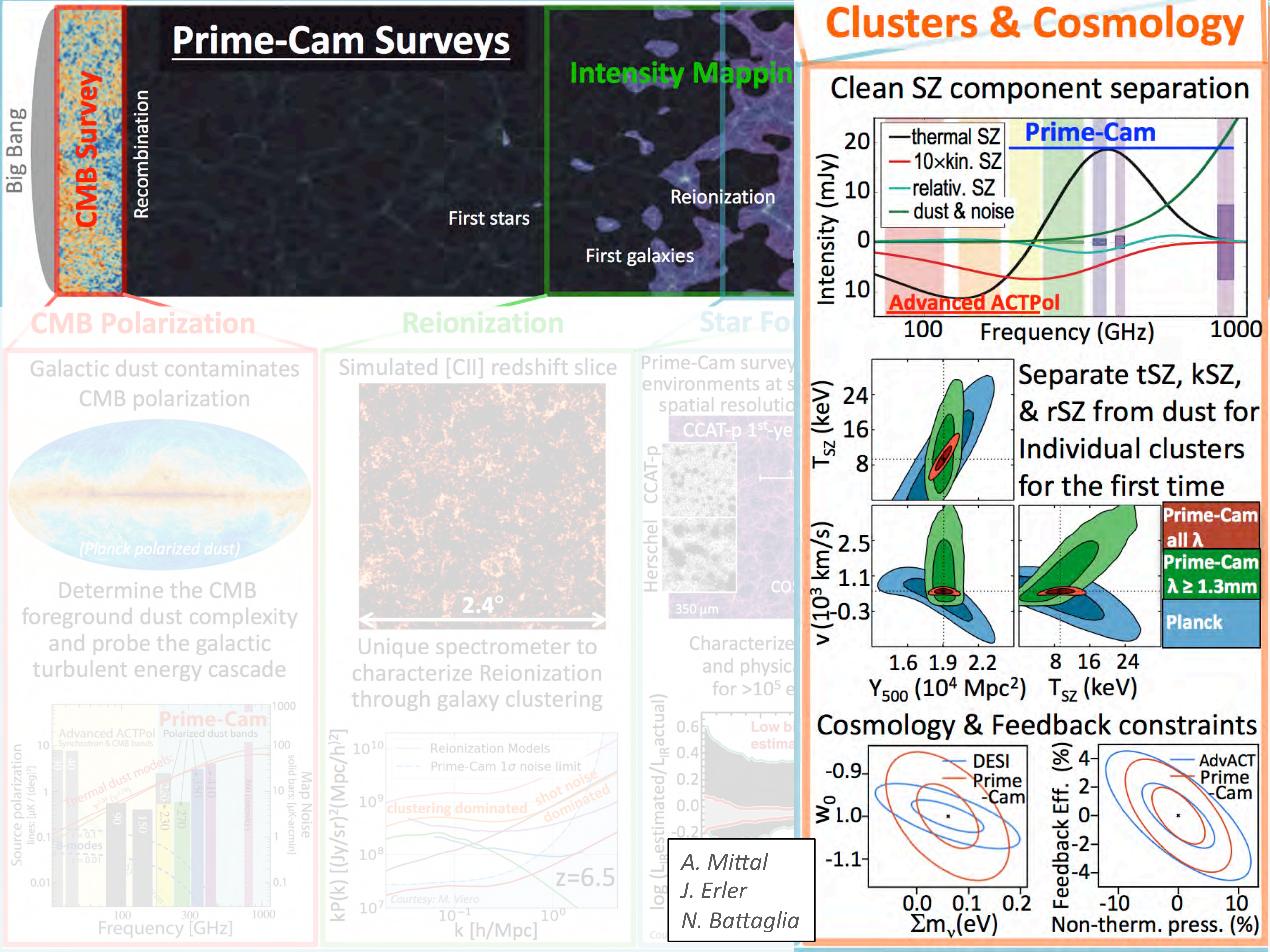




→ Track galaxy evolution during the most active epoch of star formation.







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A. Mittal
J. Erler
N. Battaglia

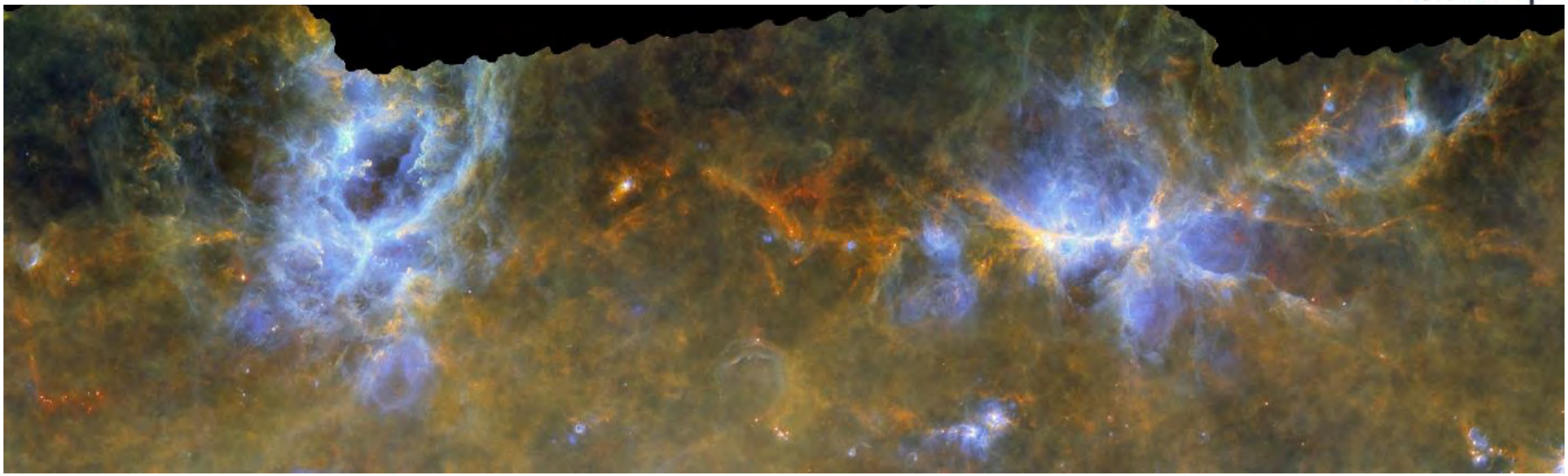
CCAT-p cluster SZ outlook

- The spectral coverage of of CCAT-p will be similar to Planck HFI, with roughly 5-15 times better sensitivity (not at 860 GHz), allowing separation of SZ effects, dust, and foregrounds.

- CCAT-prime will be the first SZ survey experiment to provide kSZ and rSZ measurements in large samples (>100) of clusters,
  - to enable cosmological modeling with direct kSZ number counts, rather than pairwise kSZ.
  - through rSZ temperature measurements provide independent mass calibration of clusters, a crucial ingredient for cosmology.

- Without PRISM, COrE, PIXIE: CCAT-p is the unique opportunity.

GEco: Galactic Ecology Science



- 15" imaging over 200 sq. deg. scales of the Milky Way, LMC, SMC to study:
  - Mass budget: [CI] tracing gas temperature and mass
  - Turbulent dissipation: mid-high-J CO & ^{13}CO tracing gas excitation, shocks
- Tracing variable flow of gas into cores and young stars

CCAT-p

- Unique **site** enables unique **science**
- Novel **telescope design** maximizes surface brightness sensitivity. Extraordinary **throughput** optimal for large-area survey science
- **Paving the road** & lowering risk for a large-aperture submm telescope (at the same site?)

Looking ahead:

Efforts to build a 25-50-meter submillimeter telescope !

CCAT-p

Atacama Large-Aperture Submm/mm Telescope (AtLAST)

RadioNet

ESO

A workshop to discuss science/technical aspects of

the **At**acama **L**arge-**A**perture **S**ubmm/mm **T**elescope (AtLAST)

ESO-HQ, Garching b. München, Germany

January 17-19, 2018

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