CCAT and CCAT-p

Cerro Chajnantor Atacama Telescope (prime/pathfinder)

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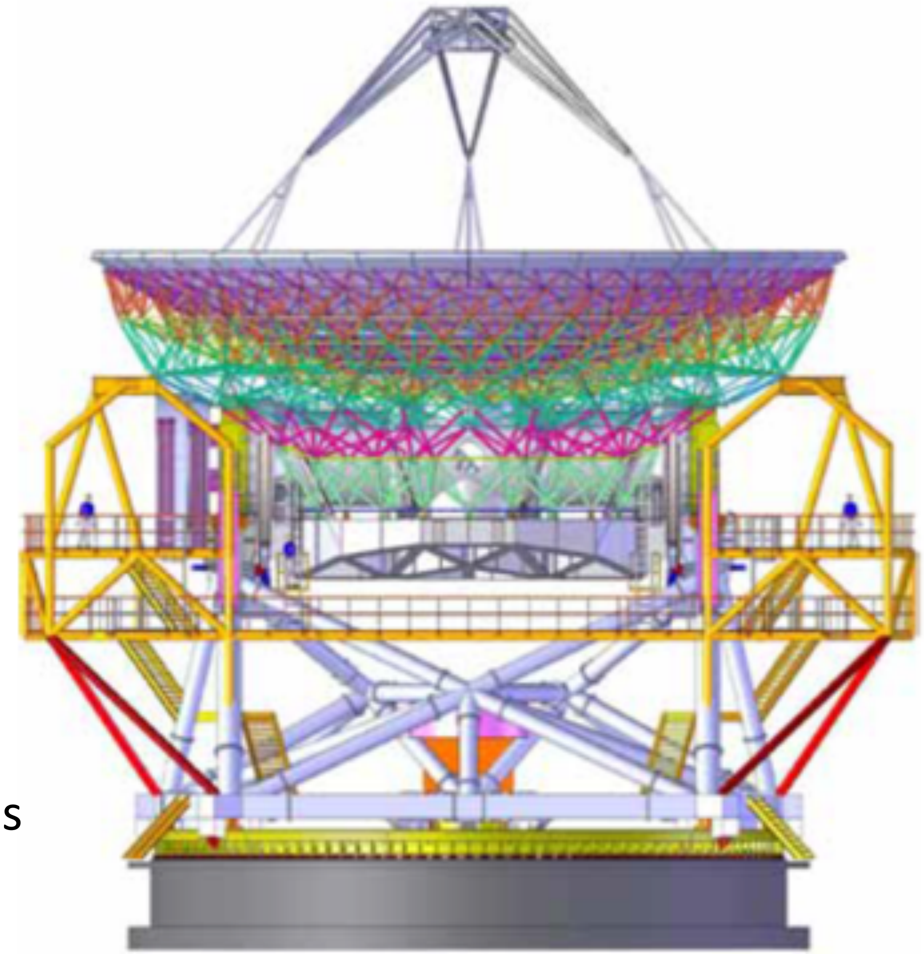
Bonn University / German ARC node

thanks for slides from G. Stacey, R. Giovanelli, M. Niemack, M. Haynes and the CCAT collaboration

Origianal CCAT design

- 25 m submm telescope
  - < 17 μm surface
  - > 0.5 ° field of view
  - State of the art instrumentation
- Cerro Chajnantor Site
- "University" style of operations
- Consortium members
  - Cornell University
  - Caltech
  - University of Colorado, Boulder
  - Consortium of Canadian Universities
  - Universities of Bonn and Cologne
  - AUI

Baseline



CCAT Scientific Inspiration

- Measure and characterize the history of dusty star formation in galaxies through cosmic time
  - Photometric surveys to resolve the FIR background
  - Spectroscopic surveys characterizing the energy sources: stellar populations, shocks and AGN activity
- Characterize the star formation process locally through submm spectroscopy and dust continuum emission
  - Over 10's of degree scales and through 5 orders of magnitude in scale for in the Milky Way
  - Complete maps over a variety of environments in nearby galaxies
- Probe the astrophysics of galaxy clusters through the Sunyaev-Zel'dovich effect (SZ)

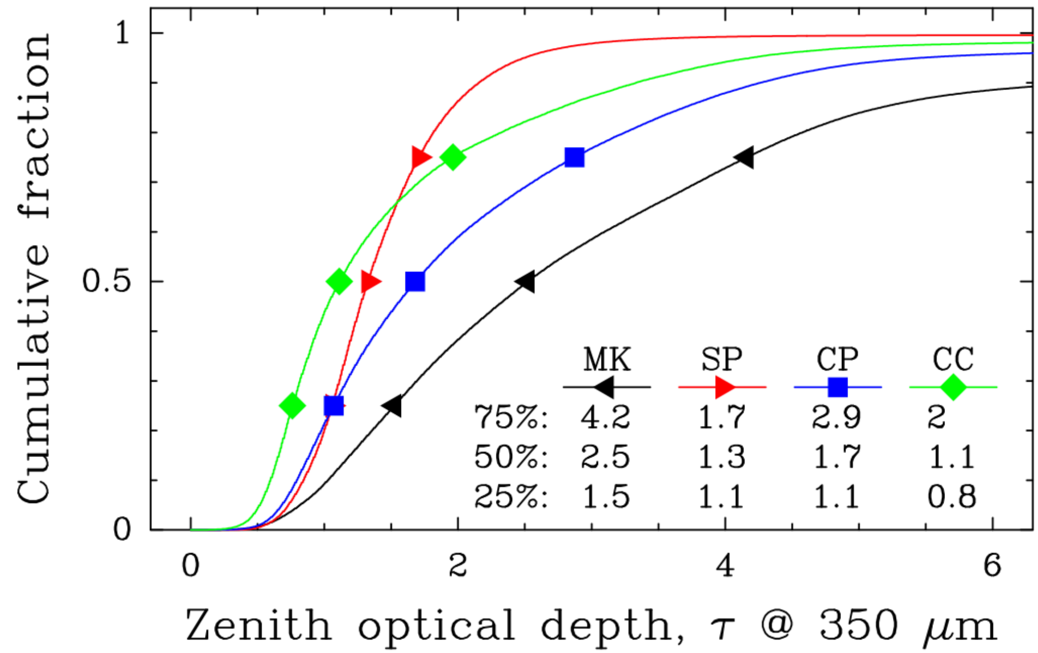
Why is the CCAT facility ideal for pursuing this science?

Location,
Location,
Location.

Cerro Chajnantor (5600m) has better observing than South Pole, Chajnantor (ALMA) plateau, Mauna Kea.

- 350 μm: routine
- 200 μm: best 10%
- longe λ : better sensitivty & efficiency

Radford & Peterson arXiv:1602.08795



- Simon Radford has been running tipping radiometers at primary sites for more than a decade
- Simultaneous period for CCAT vs. ALMA site: median is 0.6 vs. 1 mm H_2O : *factor of 1.7 in sensitivity*

Water Vapor Scale Height

	τ(350 μm)		PWV [mm]		WV
	Chaj. plateau	Cerro Chaj.	Chaj. plateau	Cerro Chaj.	scl. ht. [m] *
75 %	2.7	1.9	2.0	1.3	1280
50 %	1.5	1.1	1.0	0.6	1080
25 %	1.0	0.7	0.53	0.28	860

* WV scale height = $550\,\mathrm{m}/\ln(\mathrm{PWV_{cp}}/\mathrm{PWV_{cc}})$

Project History

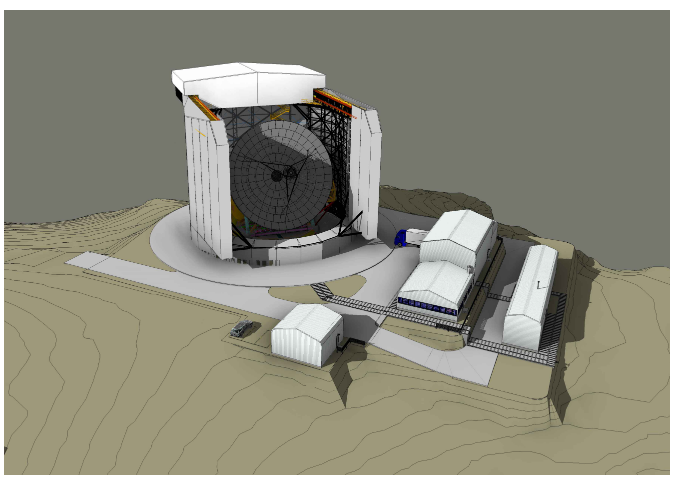
- October 2003: Partnership Workshop in Pasadena
- Feb 2004: MOU signed by **Caltech, JPL and Cornell**
- 2005: Project Office established at Cornell; Feasibility Study underway
- 2006 Jan: Feasibility Study Review
- 2007-2009: Consortium consolidation, design development. Site selection completed
- Partnership expands, to include **U. of Colorado at Boulder, Canadian consortium, Cologne-Bonn and Associated Universities, Inc.**
- Consortium Agreement drafted
- Paper submitted to Astro2010, proposing access to CCAT be open for US Astro community, with support from National Science Foundation

- 2012: NSF EDP grant
- Fall 2013: external design review
- Fall 2013: NSF-MSIP proposal to NSF, May 2014: declined
- Fall 2014: Caltech leaves CCAT

Engineering Design Phase 2011-2014

- Detailed designs and interfaces for sub-systems and sub-assemblies:
  - primary/secondary/tertiary CFRP segments, precision actuators, primary truss elements (CFRP struts, Invar nodes), enclosure, summit facility,
  - prototyped and tested, competitive bids
  - ready for construction phase

- Access road design
- Site seismic analysis
- Site concession from Chile
- Corporation structure

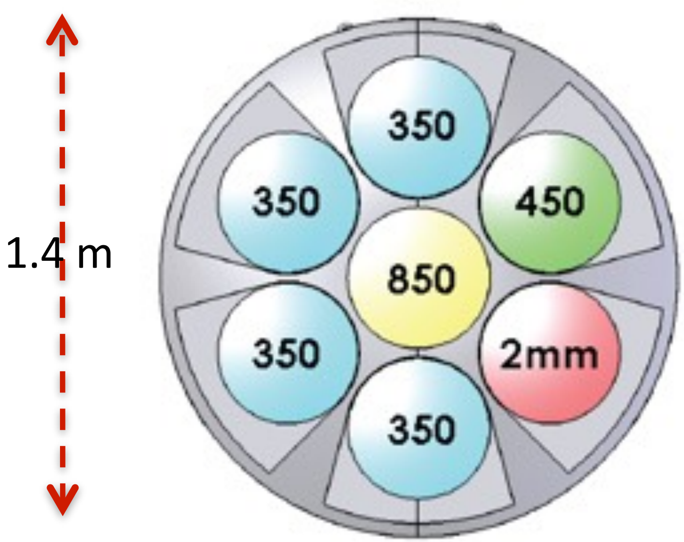


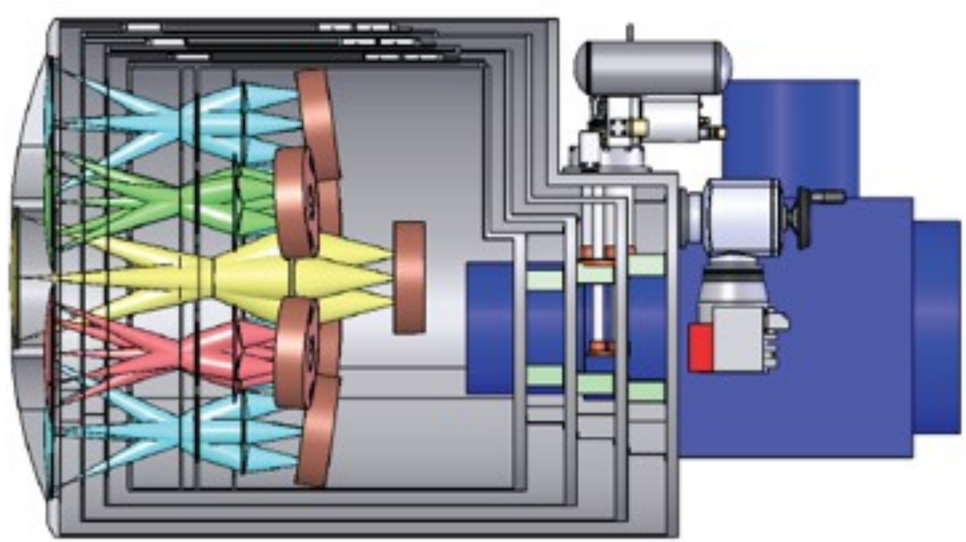
Camera Developments: C-Cam, C-MOS, CHAI

- 4 color camera – split into 7 sub-cameras (6.0' FoV)
  - 4 – 350 μm sub-cameras; 11,900 λ/D (= 2.9") pixels each
  - 1 – 450 μm sub-cameras; 7,200 λ/D (= 3.7") pixels
  - 1 – 850 μm sub-camera; 2,000 λ/D (= 7.0") pixels
  - 1 - 2000 μm sub-camera; 360 λ/D (= 16.5") pixels

57,160 pixels

- Detector Technology: TES or KID devices





2015 Descope

1. RFPs for conceptual design contract issued to two companies
   fixed price for design & fabrication of telescope
2. Reviews in Sep/Dec 2015: 25m, 12mm, 20' FoV, 5600m ~ within limits.
   No enclosure necessary.
   Uncertainties are assembly at high site: extra cost ca. 15%.
3. MSIP proposal submitted in Sep. 2015: declined in Dec. 2015.

THE KING IS DEAD
LONG LIVE THE KING

CCAT-p

- Enable forefront science
- Exploit CCAT partnership framework
- Build on experience gained from CCAT project

CCAT-p

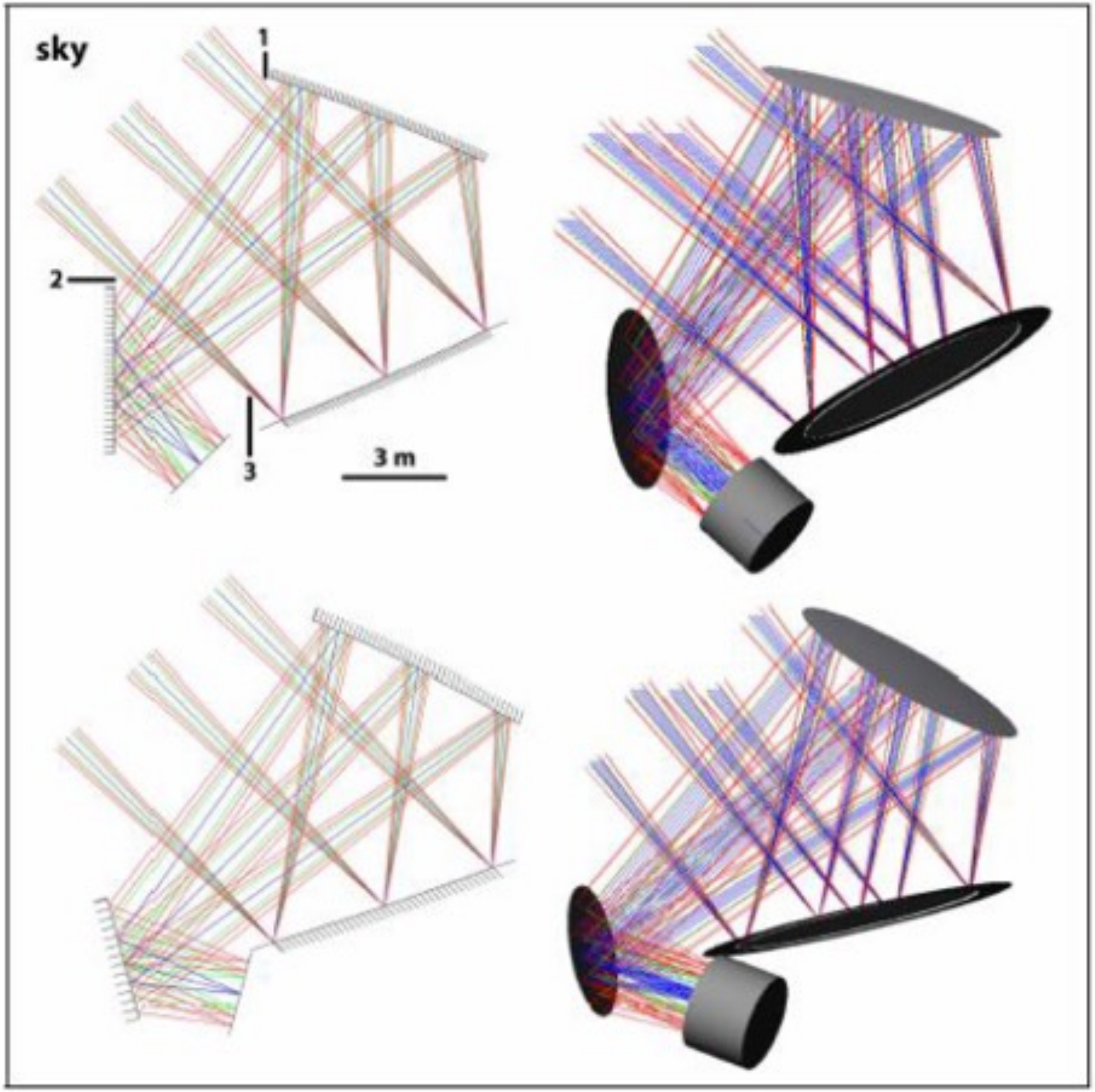
Design currently under discussion:

6-meter off-axis submm telescope located at CCAT site at 5600 meters on Cerro Chajnantor

- Surface accuracy of <10 μm (7 μm goal)
- High site gives routine access to 350 μm, 10% best weather to 200 μm, advantage at longer λs
- Novel off-axis crossed-Dragone design (Niemack 2016) yielding high throughput, wide field-of-view, flat focal plane immediately plus potential as Stage IV CMB observatory
- Targeted science programs taking advantage of aperture size, throughput, mapping speed, superb site, dedicated time, undertaken by partners (not PI-science)

Maximum telescope size set by road access: no assembly at top necessary

Crossed Dragone Design



- f/3
- High throughput
- Wide FoV
- Flat focal plane
- Accommodate > 10^5 detectors at longer λs; even more at shorter.

Niemack, 2016
astro-ph/1511.04506
Applied Optics 15, 1688

Instrumentation

- **P-Cam**: Modular, wide-field imaging camera for **kSZ**
  - Based on design of CCAT SWCam; reconfigurable
  - One module at 350 μm for first light ; others TBD
  - Optimized layout for kSZ
- **CHAI**: Heterodyne array spectrometer for **GEco**
  - Under construction at UCologne (J. Stutzki)
- **"P-Spec"**: Imaging spectrometer for **IM/EOR**
  - P-Cam(+FP): initial modification of P-Cam as an imaging Fabry-Perot interferometer
  - Future development of grating MOS?
- **"P-CMBcam"**: future CMB camera

Science Case

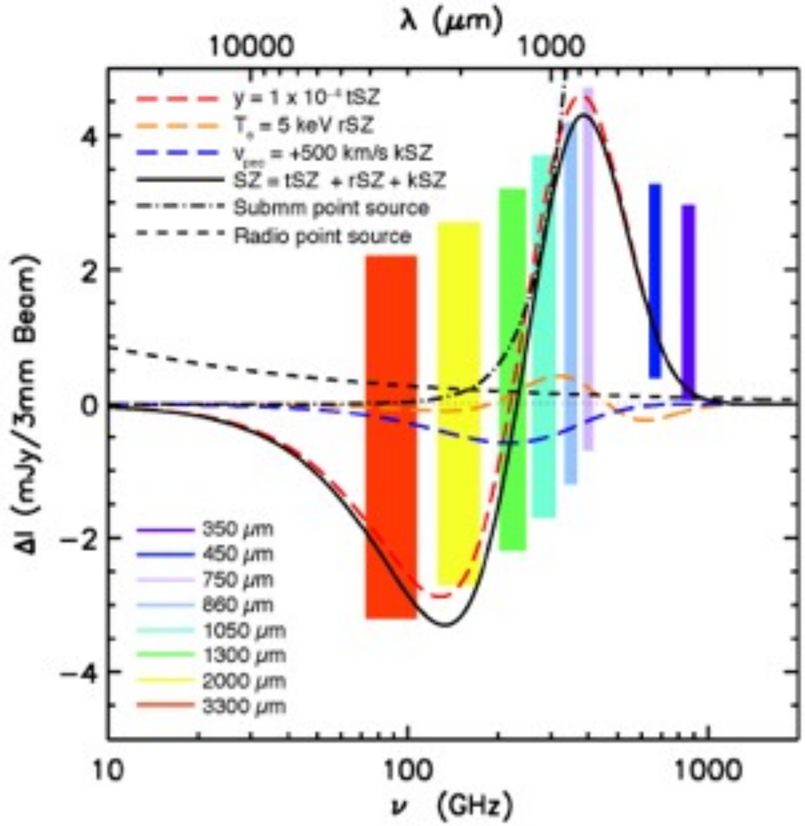
kSZ: kinematic Sunyaev-Zel'dovich signature
GEco: "Galactic ecology" studies of the dynamic ISM
IM/EOR: Intensity mapping of [CII] at z = 6-8

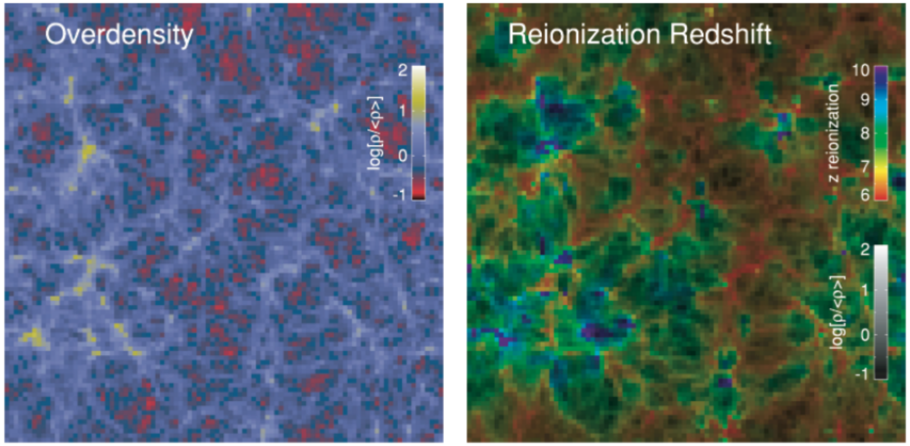
Plus potential for:
CMB: Stage IV ground-based CMB observatory

Sunyaev-Zel'dovich effects

- SZ effects
  - Thermal – strong spectral signature
  - Kinetic – traces CMB spectrum
  - Relativistic – small spectral correction
- Blind thermal SZ surveys will continue with ACT/SPT
  - Both lack spectral resolution for good direct kSZ constraints
- Direct kSZ constraints can probe gravity and dark energy in new ways
  - Goal ~100 km/s on ~1000 clusters
  - Break cosmology degeneracies!

CCAT SWCam and LWCam bands over SZ signatures





CCAT-p

IM/EOR: Intensity Mapping of [CII] from the EOR

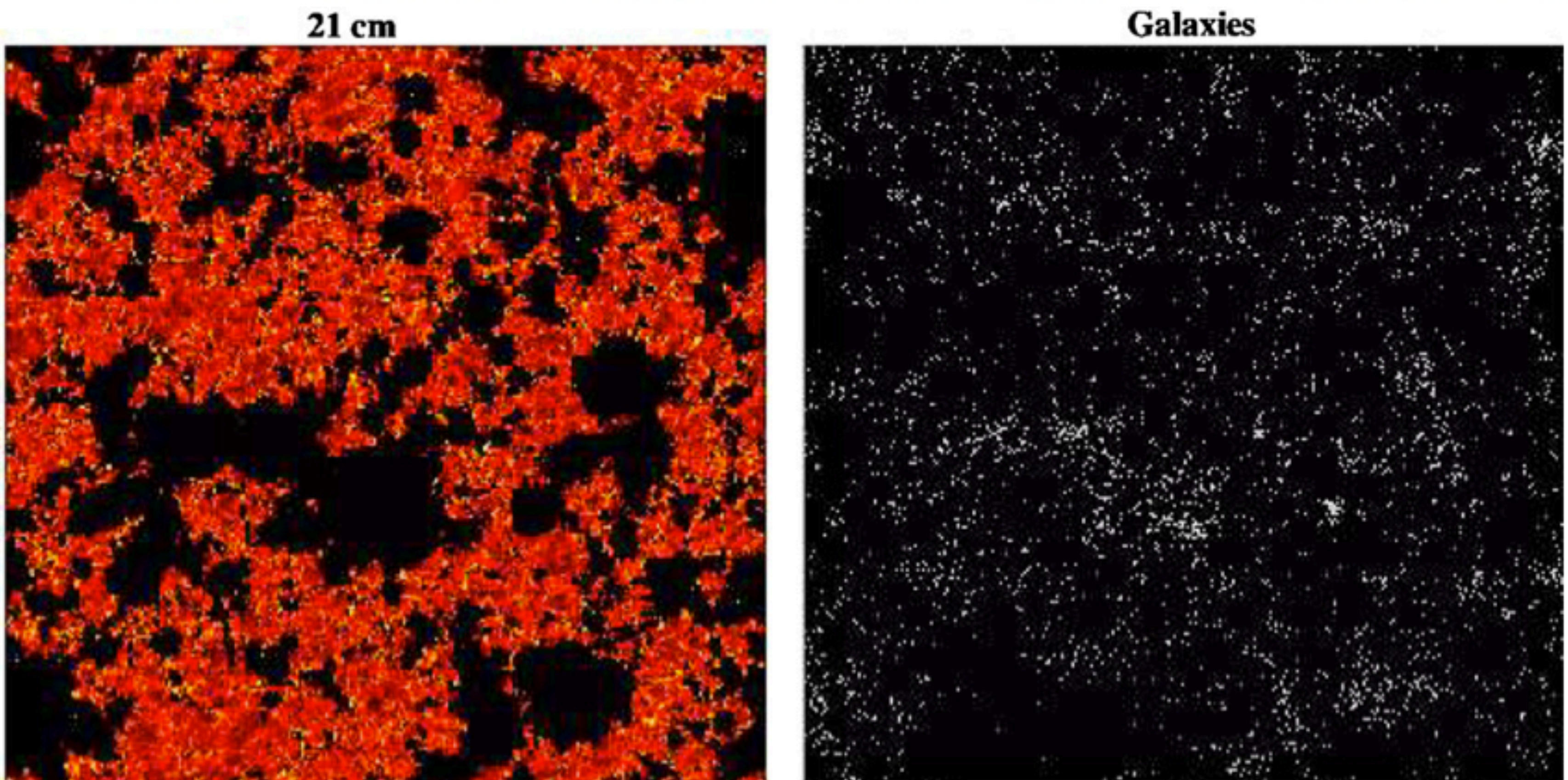
- Measure large scale spatial fluctuations of collective aggregate of faint galaxies via redshifted [CII] 158 μm line (+possibly other lines at other z's)
  - Resolution into individual galaxies not required
    - Clustering scale at z = 6-8 of few arcmin good match for 6-m aperture (1′ @ 1mm) plus mapping speed
  - Need moderate spectral resolution R~300-500
    - Spectral imaging technology will improve with time
  - Instantaneous bandwidth over mm band (1.1-1.4 mm requirement; goal of 0.95-1.6 mm to get z = 5 to 9)
    - Identify interloper lower z CO lines
    - Atmospheric stability of high site advantageous

[CII] advantage:

- No radio frequency interference
- Can be done before full SKA built

Full power in combination with HI 21cm experiments

- HI 21cm: traces neutral gas not yet re-ionized
- [CII] 158μm: traces ionization sources (star forming galaxies)



GEco: Galactic Ecology of the dynamic ISM

- Spectral (+continuum) mapping of fine structure and mid-/high-excitation CO lines as diagnostics of physical conditions and motions
  - Lines trace coolants in regions of molecular cloud/star formation in range of SF environments
  - High site essential for shortest submm λs/THz
  - Maps at (15″$\times$ λ/350μm) resolution over degree scales of MW including GC plus MCs (low metallicity)
  - Builds on SOFIA (2.5m) with better resolution and much more observing time
  - CHAI under construction (J. Stutzki, UCologne)

CMB: Future Stage IV CMB Observatory

- Next generation CMB mapping
  - Probe inflationary gravity waves at tensor-to-scalar ratios as low as 0.001
  - High-significance measurement of neutrino mass sum
  - High-throughput, wide-field, flat focal plane design at high site even on modest aperture telescope would enable mapping CMB 10X faster than ACTPol or SPT-3G
    - CCAT-p would offer existing platform for deployment of cameras with > 10^5 detectors, likely developed with DOE funding on 5+ year timescale.

Discussions with potential partner institutions are on-going; our partnership is still open, but we need to move quickly.