The Leighton Chajnantor Telescope

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IRSIG Telecon
2019/01/15
Overview

Summary

CSO history

LCT Concept, Science Opportunities, and Status

including ideas for community participation
LCT Summary

Move 10.4-m, 11 µm rms Leighton Telescope to CBI site inside ALMA

New, simple enclosure

Observing Program

Large (1000-hr) projects not otherwise possible, using cutting-edge instrumentation

Continued access for PI nights

Fully remote operations

Chilean and Chinese institutions to take lead on operations

Shanghai Normal University Key Lab for Astrophysics: C. Shu

Chilean work managed by CAS South American Center for Astronomy (CASSACA): Z. Wang (also SAO)

U de Concepcion Center for Astronomical Instrumentation (CePIA): R. Reeves
CSO History and Status
CSO History

Grew out of an effort by Leighton in the 1970s to open up the study of the molecular ISM

w/ Neugebauer and Moffat, proposed to NSF 3-element interferometer in Owens Valley + single-dish for high, dry site

Developed a technique for inexpensive construction of 10-m segmented, parabolic, homologous dishes capable of submm surface accuracy (1975-1980)

Funded by NSF, NASA, and Kresge Fdn

Constructed the Caltech High Bay, where the Palomar mirror was polished, w/Caltech undergrads!

Brought Tom Phillips from Bell Labs, where he had developed the SIS tunnel junction mixer (1970s) and embarked upon mm/submm astronomy, to Caltech as director-designate

NSF delayed start of CSO until completion of OVRO interferometer, funded CSO construction in 1984; first light 1987.
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CSO Construction
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Completed Observatory

Leighton and Phillips at the Inauguration
1990s: Primarily heterodyne instrumentation, first submm local ISM line surveys, searches in nearby galaxies, omnipresence of [CI], turbulence in ISM, studies of atmosphere in submm

Line surveys: Groesbeck+ (1992), Schilke+, Comito+
CSO History

2000s: First large continuum arrays, continued heterodyne work

Dev’t of remotely operable, tunerless wide-bandwidth balanced heterodyne receivers

SHARC II: 350 µm imaging and polarimetry
- Important SED point for dusty, star-forming galaxies (DSFGs) from submm surveys
- Dusty sources in our galaxy
- High resolution imaging of debris disks
- Polarimetry with SHARP optics module

Bolocam: 1 mm/2 mm imaging
- Extragalactic continuum surveys for DSFGs
- 220 deg² of the galactic plane to 15-30 mJy rms; longitude -10 to 54°, latitude ±0.5°
- 1’ resolution SZ imaging out to $R_{500}$ to $R_{\text{vir}}$

Z-Spec: direct detection spectroscopy across the 1 mm window
- CO ladder, $\text{H}_2\text{O}$, other molecular lines
- High-z [CII]
- Modeling of radiation environment in ISM

ZEUS: direct detection spectroscopy in 350 µm, 450 µm, 600 µm windows
- [CII] and other atomic species at moderate redshift ($z \sim 1-2$)
- Modeling of radiation environment in ISM
CSO History: Hydride Spectroscopy

Spectroscopy of hydrides

- \( \text{H}_3\text{O}^+ \) (Phillips+)
- \( \text{HCl} \) (Schilke+)
- \( \text{D}_2\text{H}^+ \) (Vastel+)
- \( \text{ND}_3 \) (Lis+)
- \( ^{13}\text{CH}^+ \) (Falgarone+)
- \( \text{CH}_2\text{D}^+ \) (Roueff+)

Importance of deuterium fractionation in the cold, dense ISM
CSO History: Comets

Spectroscopy of comets

Detections of many new cometary volatiles

First ground-based detection of HDO in comet Hyakutake: origins of Earth’s water?

Altwegg+ (2015)
CSO History: SHARC II 350 µm Imaging/Polarimetry

SHARCII provides crucial 350 µm SED point

Vaillancourt et al (2013):
SHARP measurements elucidate shock front created by stellar winds from OB stars

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CSO History: The ISM in High-Redshift Galaxies

Toward the future: a *Herschel*/SPIRE source at $z = 6.3$

One of the long-wavelength (500 µm) peakers in SPIRE Redshift discovered with CARMA, confirmed with Z-Spec, including [CII]
CSO History: Unbiased Surveys of the Galaxy

Bolocam Galactic Plane Survey

Coverage: 192 deg² near galactic plane

Galactic Central Molecular Zone

Sources with good velocity measurements
Detection of a 3000 km/s sub-cluster in MACSJ0717.5

Data 140 GHz

Data 268 GHz

Sub-cluster B (Model)

Red = tSZ
Green = kSZ
Purple = total

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CSO History

2010s: Continued new instrumentation development

Kinetic Inductance Detectors
Highly multiplexable superconducting detector technology invented at Caltech/JPL ~ 2000
Provides path to large CCD-like arrays of submm detectors

Superconducting Microstripline
Enables “RF-style” circuitry at submm/mm wavelengths
Phased-array antennas covering wide bandwidths
Bandpass filters and filterbanks

MUSIC
4-band (850 µm - 2 mm) → 6-band (750 µm - 3 mm) imaging camera covering 14’ FoV using phased-array antennas and bandpass filters
Imaging of dusty galaxies, clusters and galaxies in Sunyaev-Zeldovich effects, nearby star formation

MAKO
Technology development toward 350 µm kilo pixel arrays using direct absorption KIDs

SuperSpec
“Spectrometer-on-a-chip” using superconducting filter banks and KIDs, 100-500 GHz
Observatory, Interrupted

c. 2010: A vibrant observatory
   Sustained scientific productivity
   Multiple new instruments in dev’t
   Preparing handoff to CCAT

An unfortunate series of events
2009: Decommissioning announcement:
   Maunakea site not viable past 2016
2011: NSF operating proposal declined
2013: End of University Radio Observatory program
2014: CCAT MSIP declined, consortium splinters
2015: CSO suspends operations

Strong motivation to find a path
   In the midst of developing new scientific capabilities with new instruments
   Telescope a unique resource: only 11 μm rms (850 GHz-capable), 10-m telescope
      No concrete path to US access to such single-dish capability
   Technology also reduced operating expenses
      Full remote observing 2013 onward
The Leighton Chajnantor Telescope
LCT Motivation

Most importantly: **Technology continues to move quickly**

- SIS mixer bandwidth can be fully used w/wider-bandwidth IF amps and digital spectrometers
- Multiband imaging arrays, focal-plane-array spectrometers multiply effective time
- 350 µm FoV can now be filled; would exceed SCUBA-2 450 µm capability
- Superconducting parametric amplifier: quantum-limited detection into the THz?

**Chile is a better millimeter and submillimeter site:** ~1.5-2x better opacity on average

- \( \lambda = 350 \, \mu m \) more regularly, less sky loading at \( \lambda = 850 \, \mu m \), better sky noise for \( \lambda \gtrsim 1 \, mm \)

**Leighton Telescope remains highest surface accuracy US-accessible 10-m aperture**

- 11 µm rms surface yields effective area equivalent to APEX 12-m (17 µm rms (→10 µm))

**CSO in process of being decommissioned: telescope could be lost forever**

**Telescope drives can be upgraded for fast scanning (~deg/sec) to freeze sky noise**

- Not conceived of at time of construction

**Field-of-view**

- FoV expanded by 3-4x in area with last mm-wave camera
- Expanded 350 µm FoV never utilized (7’ FoV, 30x current 350 µm camera FoV)

**1000-hr programs are disfavored on 100% user facilities**

- [CII] tomography, deep cluster integrations, 350 µm DSFG surveys, etc.

**Complements ALMA: preparatory data, zero-spacing fluxes, integral quantities**
Instrumentation Suite: Recent Past

Can operate both bands of 230/460 or 345/650 GHz Rx simultaneously, though both bands use same LO fundamental.

Only one of the two receivers can be operated at once.

- 230/460 Rx
- 345/650 Rx
- Z-Spec simultaneous coverage
- MUSIC simultaneous coverage
- SHARC II/SHARP one band at a time
Instrumentation Suite: Recent Past

Sidecab (left Nasmyth):
- 230/460 dual color Rx
- 345/650 dual color Rx

Right Nasmyth:
- SHARC-II/SHARP
- Z-Spec resides adjacent

Alidade: Cassegrain Focus
- MUSIC
- Future wide-FoV
- Special tests (surface measurement, FTS, etc.)

Broad instrument suite available at one time
Remote operation and instrument switching
Instrumentation Suite: Near-Term

- 230/460 Rx
- 345/650 Rx
- 230/460 Rx
- 345/650 Rx
- Implement modern 850 GHz Rx

- DSB → 2SB
- Wider IF bandwidth
- Multipixel arrays

- Simultaneous coverage
- SuperSpec/TIME: 3-16 pix in 200-300 GHz window now

- MUSIC
- Simultaneous coverage

- SHARC II/SHARP
  - One band at a time

Frequency [GHz]
Instrumentation Suite: Long-Term

- Quantum-limited kinetic inductance parametric amplifier
- SuperSpec/TIME: full-field IFU @ R = 1000
- Music w/pol
  - Simultaneous coverage
- Short-submm camera w/pol:
  - 30x FoV, 40x mapping seed

Frequency [GHz]

Resolving Power
LCT Site: Excellent for Submm/mm Observations

Opacity

1.5x better at 350 μm: 350 μm band usable more of the time with better sensitivity
225 GHz opacity ~2x better on average

Sky noise

Sky noise rms scales linearly with opacity/PWV
More critical for wide-field mapping at mm wavelengths

Figure 5. Cumulative distributions of broad band 350 μm zenith optical depths measured on Maunakea (MK), at the South Pole (SP), on the Chajnantor plateau (CP), and on Cerro Chajnantor (CC).
LCT Enablers: Telescope

Leighton Telescope is eminently transportable

Limited surface retuning if primary moved in one piece

50 µm rms for OVRO moves

APA move demonstrates prospect of move of intact primary

Full move plan dev’d by RSS

APA move to Kitt Peak

Scenes from the move of the OVRO Leighton Telescopes to CARMA site
LCT Enablers: Site

Caltech est’d site for CBI and QUIET

Site allows expansion to meet LCT needs

Inside ALMA: excellent physical access, proximity to utilities, safety
LCT Enablers: Site

CBI foundation pad

entrance at SE corner
LCT Enablers: Site

Lighted, no heat/oxygen

Heat/light/oxygen
diesel generators

lightning protection
diesel fuel tank

lightning protection
LCT Science

Unique programs address compelling science questions Possible only because of site and instrumentation Executable only because of commitment to ≥ 50% of time for 1000-hr-scale programs New: many not conceived until post 2010 Other programs not possible in old operating model

<table>
<thead>
<tr>
<th>Science Target/ Astro2010 PQ/DA</th>
<th>Desired Science Measurement</th>
<th>Ensuring Capabilities</th>
<th>Req'd Survey Parameters</th>
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<tbody>
<tr>
<td><strong>EoR:</strong> Constraining total [CII] emission from reionizing galaxies to test reionizing photon budget (PQ1, PQ2, PQ3, PQ4, PQ8; DA2)</td>
<td>[CII] power spectrum SNR: &gt;10 (5) for z=5.3-6.2 (z=6.2-8.5) SFR history SNR: &gt;5 (5) for z=5.3-6.2 (z=6.2-8.5) H2 history SNR: &gt;5 in each of 5 bins z=0.5-2</td>
<td>TIME provides multi-pixel high-sensitivity, low-resolution spectroscopy • R<del>100 for 200-300 GHz • NEFD</del>100 mJy/√s • 16 pixels • 1 beam x 14' FoV</td>
<td>100 hr survey of 2 fields, each 1 beam x 1.3'</td>
</tr>
<tr>
<td><strong>IGIMICMC/GM:</strong> Test for non-thermal, pressure (~50% @ R200) and non-thermal, velocities ~500 km/s at R200 in M200 = 10^{15} M⊙ clusters (PQ2, PQ3, PQ7, PQ8, PQ10)</td>
<td>tSZ: SNR ~ 200 measures non-thermal pressure fraction to ~1% precision (absolute) kSZ: σ_1 = 100 km/s per sq. amin. at r &lt; R200, gives SNR = 5 per sq. amin. for 500 km/s non-thermal velocities</td>
<td>MUSIC provides wide-FoV imaging simultaneously in multiple bands to measure tSZ, kSZ, and contaminants: • 6 bands 90-405 GHz • NEFD~15, 20, 35, 60, 120 mJy/√s at 90, 150, 220, 290, 350, 405 GHz • 14' FoV</td>
<td>1200 hr survey of 20 clusters</td>
</tr>
<tr>
<td>Energetic transients in dense CSM: Detect transients with high peak freq. (&gt;100 GHz) at 5-10 yr (search radius 150 Mpc) (DA1)</td>
<td>1 mJy rms in multiple bands near 300 GHz to isolate emission peak out to r = 150 Mpc 2 mJy rms @ 850 GHz flux to probe extent of sync spectrum for nearenhmore luminous srces</td>
<td>MUSIC provides simultaneous multi-band photometry to isolate peak across &gt;5:1 bandwidth</td>
<td>Fast-rising OIR transients: MUSIC: 20-min/night, grid in log(days) SHARC2: 5-hr integrations during plateau w/few day cadence, best 25% T_{150}</td>
</tr>
<tr>
<td>Galaxy transition from star-forming to quiescence (PQ4, PQ7, PQ8, PQ10)</td>
<td>SFR: 6 mJy rms @ 850 GHz → 20% SFR measurements M_{200, B}: 1 mJy rms in 2-3 bands @ 300 GHz → 20% flux errors</td>
<td>SHARC2 provides 850 GHz photometry MUSIC provides multi-band photometry over dust RJ tail (and may constrain free-free and sync too)</td>
<td>1000-hr survey of all ~500 visible WISE W1W2 dropout, 1 hr/sec each w/ MUSIC and SHARC2</td>
</tr>
<tr>
<td>Role of magnetic fields in star formation on scales between Planck and ALMA (PQ5, PQ6)</td>
<td>1% polarized dust emission @ 300, 850 GHz to get field orientation in various dust pops. Zeeman splitting in CN and SO for line-of-sight field strength</td>
<td>MUSIC provides polarioty in multiple bands near 300 GHz SHARP provides 850 GHz polarimetry Future 100 GHz MMIC Focal Plane Array will do Zeeman splitting</td>
<td>900-hr survey of 100 Planck sources; 3, 6 hrs/sec each with MUSIC and SHARC2</td>
</tr>
<tr>
<td>Role of dust grain size distribution in star (PQ5) and proto-planetary disk (PQ6) formation</td>
<td>Constraining dust β by measuring Sed to 2, 4, 5 mJy rms at 220, 290, 350 GHz (10x precision of ATLASGAL, BGPS)</td>
<td>MUSIC provides measurements of dust Sed on RJ tail in multiple bands near 300 GHz, separates free-free and sync; power law identifies grain size</td>
<td>500 hr survey of 500 sq. deg. of galactic plane</td>
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1200-1500 hrs/yr for surveys

4500 hrs survey time in 3-4 yrs

many programs would seed ALMA followup: new classes of targets

new surveys as new capabilities become available

vigorous instrumentation dev't and fast deployment a necessity

PI time: ideal for ALMA preparatory data
LCT Roles

Shanghai Normal University

Lead for Chinese involvement
Oversight of CASSACA effort in Chile
  New enclosure design/construction
  Site infrastructure
Interface to Chinese user community
  (via CASSACA/NAOC)

Universidad de Concepcion

Lead for Chilean Involvement
Operations lead
Interface to Chilean user community

Caltech

Technical heritage
  → technical leadership role during deconstr/move/recom phase
Continued technology development
  primarily in bolometers and parametric amplifier
Continued science leadership
  esp. large surveys using new instrumentation

New Receiver Labs at ShNU/UdeC

Refurbish/build SIS heterodyne receivers
  345/650 at ShNU, 230/460 at UdeC
Involvement in future developments
  array receivers, 850 GHz, param. amp.
  joint with PMO
Personnel
  ShNU staff Dr. Duo Cao worked with CSO experts to test SIS Rx’s 2018
  UdeC ramping up expertise via visits to Caltech, ShNU
LCT Progress and Status

Late 2015/early 2016: Readhead midwives collaboration to move CSO to CBI site in Chile

- Caltech (Golwala)
- Chinese Academy of Sciences South American Center for Astronomy (CASSACA; Zhong Wang, former OVRO postdoc),
- Universidad de Concepcion (Reeves, former CBI/QUIET engineer/postdoc)

2016

- Conceptual Design Report (CDR) written
- RSS contracted to estimate move cost: $1.4M + contingency

2017

- Shanghai Normal University brought in as Chinese university partner
- CDR results in “preliminary and provisional approval” from ALMA to use the CBI site pending approval of Foreign Ministry and CONICYT

2018

- PM Gary Parks engaged to develop full cost/schedule estimate
- Foreign Ministry approves LCT on basis of preexisting CBI approval
- ShNU receives ~50% of funds needed to undertake project, deemed “national project”
- Terms for CONICYT approval developed with CONICYT Astronomy director

2019

- Submit NSF MRI and MSRI proposals
LCT Funding Model and Community Participation Ideas

Planning/Project Development

Caltech/CASSACA discretionary funds, ~$400k spent to date

Disassembly/Move/Recommissioning (DMR) Phase: ~$8M

ShNU funds in hand ~50%

In-kind manpower contribution from UdeC and CASSACA

Caltech seeking NSF funds for 2nd half in exchange for survey data access

Operations Phase: ~$1M/yr

CASSACA in-kind manpower

2 techs, 1 engineer

UdeC in-kind manpower

Technical Manager, 1 engineer, 1 programmer/IT, admin support, including hosting local operations office

ShNU cash contributions

Community involvement ideas:

NSF MRI or MSRI funds are buy-in, provide access to survey data: $4M

Tech demo nights in exchange for NSF ATI/NASA SAT funding

10 nights for $100k/yr? Provides on-sky testing of PI instruments or of NASA mission pathfinders

PI nights or survey participation in exchange for NSF operations funding

$300k-$400k/yr for 30-40 nights PI time or survey participation?

PI instruments

Science access in exchange for serving instrument to user community?
Conclusions

CSO has long and accomplished history of opening submm windows, continuing cutting-edge instrumentation development

Decommissioning of CSO presents deadline for use of unmatched Leighton Telescope

LCT project planning is moving forward
  
  Developing full project plan, budget, schedule
  Working on completing funding, developing opportunities for community participation