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TolTEC: unveiling the hidden universe

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Abstract. We briefly describe the new continuum camera TolTEC and its scientific potential once it is installed on the 50m Large Millimeter Telescope (LMT). TolTEC will substitute the highly successful 1.1mm AzTEC camera, and will have multiband and polarimetric capabilities with the superb sensitivity provided by the set of detectors based on Kinetic Inductance technologies. TolTEC will be able to survey the skies at unprecedented depths and speeds in a number of astrophysical scenarios.

Key words. millimeter wave: instrumentation

1. Introduction

TolTEC[1] is a new large-format millimeter-wavelength camera built to take maximal advantage of the 50 meter Large Millimeter Telescope (LMT)[2]. It has 6300 Lumped Element Kinetic Inductance Detectors (LEKIDs) spread across three different bands (1.1, 1.4, and 2.0 mm), and sensitive to a single linear polarization of the incoming light. Each TolTEC observation will therefore result in nine different images of the sky - one for each of the Stokes parameters (I, Q, and U) for each of the three spectral bands. Table 1 provides the general technical specifications of TolTEC. Columns (1)-(4) list, respectively, the wavelength, the beam size, the number of pixels and number of detectors. The last two columns give the maximum (optimistic) and minimum (pessimistic) mapping speeds. The range of potential mapping speeds reflects our uncertainty in how well the atmospheric contamination will be removed. The factor of 7 between the maximum and the minimum is estimated from experience with the 1.1mm AzTEC camera (144 bolometers, Wilson et al. 2008) in the 32m LMT. There are, however, several reasons to expect that the atmospheric contamination will be removed more efficiently from TolTEC observations, mainly

[1] http://toltec.astro.umass.edu/
[2] www.lmtgtm.org

due to the increased number of detectors, the correlations between bands, and the high data acquisition rate (Bryan et al. 2018).

TolTEC was funded in 2016 by the Mid-Scale Innovations Program in Astronomical Science (MSIP) of the National Science Foundation (NSF, P.I. G. Wilson), and involves the participation of 7 institutions in 3 different countries: The University of Massachusetts Amherst, Arizona State University, the National Institute of Standards and Technology (NIST), Northwestern University, University of Michigan (USA), Instituto Nacional de Astrofísica, Óptica y Electrónica (INAOE, in México), and Cardiff University (Wales, UK).

TolTEC is expected to be installed and commissioned at the LMT during the first semester of 2020, starting the exploration of the coldest dust-obscured regions of the Universe. TolTEC will therefore provide unique information to understand the physical processes that dominate the star formation history, from molecular clouds in the Milky Way to the highest redshift galaxies back into the reionization epoch. It may as well allow the study and follow-up of energetic processes like AGN variability, Gamma Ray Bursts, gravitational wave events, etc. The sensitivity and angular resolution, provided by the combination of TolTEC and the 50m LMT (Table 1), will link up large scale measurements by instruments such as *Planck*[3], ACT[4], and SPT[5] with the detailed interferometric observations from ALMA[6], and will span all spatial scales across the entire Universe, from Solar System objects to the most massive galaxy clusters through the detection of the Sunyaev-Zel'dovich effect.

Four community-led legacy surveys (out of the 10 committed in the original NSF proposal) have been already defined (Sec. 2). Six more are yet to be planned, once the performance of the instrument on the LMT is determined. Open time for P.I. science and long-term projects (multi-season) will also be available. Figure 1 shows the Map Depth vs Map Area parameter space for TolTEC and some recent large-scale mm-wavelength surveys. TolTEC, combined with the 50m aperture of the LMT, has access to a large unexplored region of this parameter space (shaded area) due to both, its relatively high angular resolution (leading to a low confusion limit due to faint extragalactic sources) and its fast mapping speed. For comparison, Figure 1 indicates the map depth and area of: a survey of Frontier Field clusters on the 32m-LMT (Pope et al. 2017), two major ALMA projects (projects ID: 2015.1.00098.S; PI: K. Kohno and ID 2015.1.00543.S; PI: D. Elbaz, see e.g. Ueda et al. 2018; Fujimoto et al. 2018; Franco et al. 2018), the SCUBA-2 Cosmology Legacy Survey (Geach et al. 2017) and the SCUBA-2 Gould Belt Survey (Ward-Thompson et al. 2016; Kirk et al. 2018). The depths of all these surveys have been scaled to their equivalent at 1.1mm wavelength assuming a grey body with T > 20K and β=1.5. TolTEC represents a massive step forward for future millimeter-wave surveys.

2. TolTEC legacy surveys

Four hundred hours of LMT time, between 2020 and 2021, have been committed to complete the four defined TolTEC legacy surveys (100hr each), two galactic and two extragalactic. Data will be made public in 2 consecutive releases. Registration to the working groups is open to the community through the TolTEC's web page.

2.1. Galactic surveys

- **Clouds to Cores (C2C)**: the main goal of this survey is to explore the collapse of giant molecular clouds into star-forming cores. The expected depth will allow to achieve core mass limits of M > 0.11 $M_\odot$ ($S_{1.1mm}$ ~ 0.27 mJy at 1σ), covering an area between 44 and 88 sq.deg (depending on final mapping speeds). The selected fields to be studied are: Orion-A, Perseus, Orion-B,

[3] https://www.nasa.gov/mission_pages/planck

[4] https://act.princeton.edu/

[5] https://pole.uchicago.edu/

[6] https://www.almaobservatory.org/en/home/

Table 1. General technical specifications of TolTEC.

Wavelength mm	Beamsize (FWHM) arcsec	# of pixels	# of Detectors	MPS max. $deg^2/mJy^2/hr$	MPS min. $deg^2/mJy^2/hr$
2.0	9.5	450	900	69	10
1.4	6.3	900	1800	20	3
1.0	5	1800	3600	12	2

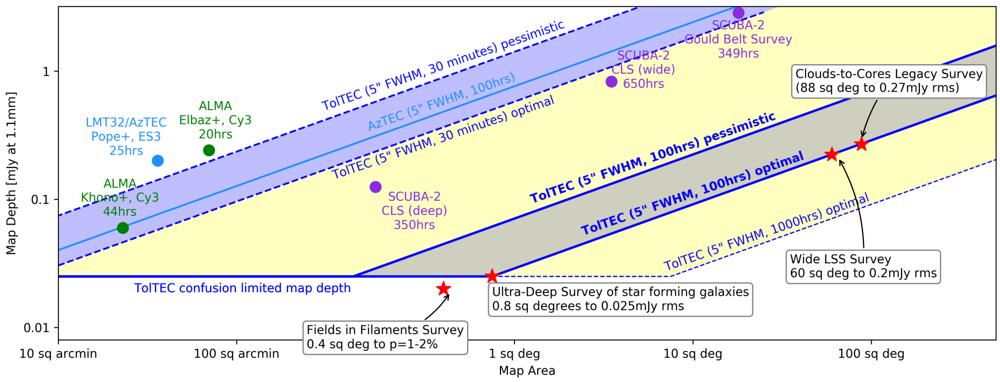

Fig. 1. Map Depth vs Map Area diagram showing the confusion limit of TolTEC/LMT and lines corresponding to fixed integration times (30 min, 100 hr and 1000 hr). The expectation for the 4 legacy surveys are marked with red stars. For comparison, recent surveys with AzTEC on the 32m LMT, ALMA and SCUBA-2/JCMT are indicated with light blue, green and purple circles respectively.

Auriga-Cal, MonR2, Cygnus-X, Aquila-S, Aquila-N, Ophiuchus and CepOB3.

– **Fields in Filaments (FiF)**: this survey will map magnetic fields in filaments through dust polarization. Its depth has been defined in order to obtain a total of ~70,000 vectors (assumes p = 1-2%). Covering a total area ~ 0.4 sq.deg (depending on final mapping speeds), the FiF survey will map: Serpens South, B211/213 in Taurus, B1 in Perseus, OMC2 and 3 in Orion, Rho Oph (C, E, F), Snake, and Milky Way Bone Candidate filament 5.

Extra-galactic surveys

– **Large Scale Structure (LSS)**: this survey has been designed to probe the relationship between the spatial distribution of star forming galaxies and the LSS. In order to cover a large enough area to achieve the scientific goals (40-60 sq.deg, depending on final mapping speeds), the detection threshold of this survey will be limited to $S_{1.1mm} \sim 1$ mJy (at 5σ), still allowing for the detection of ULIRG type objects with $L_{IR} \gtrsim 10^{12}$ $L_\odot$. The selected fields included in the LSS are: ECDFS, XMM, COSMOS, NEP, Bootes.

– **Ultra-Deep Survey (UDS)**: the main goal of this survey is to tie the connection between the entire LIRG population, with $L_{IR} \gtrsim 10^{12}$ $L_\odot$, to their optical counterparts. It will cover a total area of ~ 0.8 sq.deg. (depending on final mapping speeds) down to the confusion limit (i.e. a depth $S_{1.1mm} \sim 0.025$ mJy). The fields included in this survey are the CANDELS fields in UDS, COSMOS, and GOODS-S, and have been selected to overlap with the available high quality ancillary data.

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