TIME-Pilot Ionized Carbon ([CII]) Intensity Mapping Experiment

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The TIME Collaboration

Tomographic Ionized carbon intensity Mapping Experiment

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Cryogenics with L. Duband and T. Prouve at CEA
Overview

• Science Background
• TIME-Pilot Theory
• TIME-Pilot Instrument
• Survey Strategy
• Future Plans
The Big Bang

Recombination, Cosmic Microwave Background emitted

T = 0

Epoch of Reionization

T < 1 Gyr

z = 6 - 15?

Present Day

z = 0

T ~14 Gyr

Image from Robertson et al., 2010

Cosmic Dark Ages
z > 15-30?
t < 100-270 Myr

Rare Sources Form Ionized Bubbles

First Stars (z < 15-30?)

First Galaxies (z < 10-30?)

Neutral IGM

IGM Mostly Ionized
z = 0-6, t > 1 Gyr

Modern Galaxies Form

Dense, Neutral Pockets

Reionization
z < 6-15?
t < 1 Gyr

Image from Robertson et al., 2010
The Big Bang Recombination, Cosmic Microwave Background emitted

Epoch of Reionization $T < 1$ Gyr $z = 6 - 15$?

Present Day $z = 0$
The High Redshift Universe: Open Questions

- When did reionization take place?
- What was the duration of reionization?
- What types of sources were responsible for reionization?
The High Redshift Universe: Open Questions

- When did reionization take place?
- What was the duration of reionization?
- What types of sources were responsible for reionization?

How can we study reionization?

- Measure the intensity of a faint unresolved signal and take the power spectrum (as opposed to measuring individual bright sources)
  e.g. CMB

  this is similar to what 21cm experiments are doing
A New Concept: Measuring [CII] from Early Galaxies to Probe The Epoch of Reionization

- 158 micron ionized carbon fine structure line (1.9 THz)
- C+ serves as a tracer of star formation
- One of the brightest emission lines in galaxies

[Diagram showing HII Region, Far-UV illuminated Neutral Gas, Molecular cloud, and various ionized species like [OII], [SIII], [NII], and [CII].]
A New Concept: Measuring CII from Early Galaxies to Probe The Epoch of Reionization

- Redshifted to 200-300 GHz band from z~5.3 to z~8.5
- Complementary approach to 21cm that traces the neutral hydrogen
- Cross correlation gives bubble size

adapted from Gong et al. 2013
CII Power Spectrum

Work by Yun-Ting Cheng (ASIAA)
Challenges

need frequency and spatial resolution

Astrophysical Foregrounds: CO from Low Redshift Galaxies
Work by Yun-Ting Cheng (ASIAA)
Masking to remove CO

mask fraction of survey area
need sensitivity

Work by Yun-Ting Cheng (ASIAA)
Instrument Components

- Cryogenic receiver
- Transition Edge Sensors sensitive to mm-wavelength radiation (developed for CMB instruments)
- Grating spectrometer developed at Caltech/JPL
- Deploy on the James Clerk Maxwell Telescope (JCMT)

Concept: Use tested millimeter-wavelength technology to probe unknown physics during the epoch of reionization
TIME-Pilot Cryostat in the Lab at Caltech

SPICA/BLISS Cryo-Chain demonstrator (Prouve 2015)
DOI: 10.1016/j.cryogenics.2015.06.001
Transition Edge Sensor Detectors

- etched wafers
- silicon nitride with a gold absorber layer
- TESes are Ti and Al
- wiring is Nb

M. Kenyon/B. Bumble (JPL) with J. Hunacek (Caltech)

G1.7 Design and Fabrication of TES Detector Modules for the TIME-Pilot [CII] Intensity Mapping Experiment
Grating Spectrometers

- Split-Block Input Feedhorns
- Curved Grating (R ~ 100)
- Detector Modules

Similar to Z-Spec but more compact (lower R)
Prototype Gratings
Fabricated

Room-temperature optical testing at ASIAA by Chao-Te Li
The optical path for TIME-Pilot

Beam-splitter

Spectrometer banks

Absorbers

Support beams

Remaining substrate

Space for support beams, traces, and TESs

Fabricated Prototype

Spectrometer grating prototype

Clips

Absorbers

Support beams
Telescope: TIME-Pilot at the JCMT

- Science attainable from ~ 1 month at JCMT
# TIME-Pilot Instrument Specifications

<table>
<thead>
<tr>
<th>Parameter</th>
<th>Photometers</th>
<th>Grating LF Band</th>
<th>Grating HF Band</th>
</tr>
</thead>
<tbody>
<tr>
<td>Estimated end-to-end optical efficiency</td>
<td>0.3</td>
<td>0.3</td>
<td>0.3</td>
</tr>
<tr>
<td># of Bolometers per sub-band</td>
<td>1</td>
<td>24 (8×3)</td>
<td>36 (12×3)</td>
</tr>
<tr>
<td>Atmospheric PWV monitor channels</td>
<td></td>
<td>10: 183 – 199 GHz</td>
<td>6: 305 – 326 GHz</td>
</tr>
<tr>
<td>( \nu / \delta \nu ) per detector</td>
<td>5</td>
<td>92 – 122</td>
<td>90 – 120</td>
</tr>
<tr>
<td>NEI on sky per detector [(MJy sr)(^{1/2}) sec]</td>
<td>0.3</td>
<td>3.3 – 4.0</td>
<td>5.3 – 8.3</td>
</tr>
<tr>
<td>NEFD on sky per detector [mJy sec(^{1/2})]</td>
<td>6</td>
<td>37 – 44</td>
<td>42 – 56</td>
</tr>
</tbody>
</table>

## TES Bolometer Parameters

<table>
<thead>
<tr>
<th>Parameter</th>
<th>TES安全因数 (= (P_{elec} / P_{opt}))</th>
<th>Detector + MUX NEP ([10^{-18} \text{W Hz}^{-1/2}])</th>
<th>Photon NEP ([10^{-18} \text{W Hz}^{-1/2}])</th>
<th>Absorber size [mm]</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>3</td>
<td>40</td>
<td>60</td>
<td>(\phi 4.0)</td>
</tr>
<tr>
<td></td>
<td>3 – 5</td>
<td>9.7</td>
<td>14 – 17</td>
<td>3.0 × 3.48</td>
</tr>
<tr>
<td></td>
<td>5 – 8</td>
<td>13</td>
<td>16 – 24</td>
<td>3.0 × 2.32</td>
</tr>
<tr>
<td>TIME-Pilot Instrument Specifications</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>-------------------------------------</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Total # of Detectors</td>
<td>1920</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Number of Grating Spectrometers</td>
<td>16</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Spectral Bins</td>
<td>60</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Instantaneous FOV</td>
<td>11 arcmin x 0.35 arcmin</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>NEP</td>
<td>~1 e -17 W/Hz</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Spectral Range</td>
<td>183 - 326 GHz</td>
<td></td>
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</tr>
</tbody>
</table>
TIME-Pilot in the context of bubble size during the EoR

Galaxies

TIME-Pilot

HUDF

Ionization

z=7.32 \ x_i=0.54

HUDF= 11'x11'

Lidz+ 2009

130/h Mpc=1.2 deg
TIME-Pilot in the context of bubble size during the EoR

- 0.9 Mpc
- 1440 Mpc (z = 5.0 to 8.7)
- 140 Mpc (~1 degree)

- Ionization: z=7.32, x_i=0.54
- TIME-Pilot

HUDF= 11'x11'
TIME-Pilot Summary

- Pilot instrument using a line intensity mapping technique to study the epoch of reionization
  - mapping a large field
  - mapping faint signals
  - using C+
- Complementary to 21 cm and galaxy measurements
- LTD Technology leads to new science

- Instrument Only
- Science attainable from ~1 month at JCMT
- Use all proven technologies
- Results in ~2 years
- Get a first detection of [CII]
- Verify that [CII] is bright (theory predictions are very uncertain)
- Justify dedicated telescopes (both ground- and space-based)
- Learn how to deal with a new type of data set
Future Plans
On-Chip Spectrometers for the Next Generation Instrument
(scale up to ~10,000 detectors)

O’Brient et al. 2014 SPIE Proceeding
Lithographed spectrometers for tomographic line mapping of the Epoch of Reionization

Future Plans
Lots of other exciting mm-wavelength spectrometer technologies and instruments here at LTD and in the community

SuperSpec
WSPEC

TESes
MKIDS

on chip filters banks gratings waveguide
Thank You

Split-Block Input Feedhorns

Detector Modules

~23 cm

Curved Grating (R~ 100)