C+ Intensity Mapping in the Epoch of Reionzation and the TIME-Pilot Experiment

the TIME-Pilot Collaboration

Caltech / JPL

Jamie Bock
Matt Bradford
Bruce Bumble
Yun-Ting Cheng
Abby Crites
Steve Hailey-Dunsheath
Jonathon Hunacek
Roger O'Brient
Jason Sun

ASIAA

Tzu-Ching Chang
Patrick Koch
Chao-Te Li
Tashun Wei

UC Irvine

Asantha Cooray
Yan Gong
Bade Uzgil

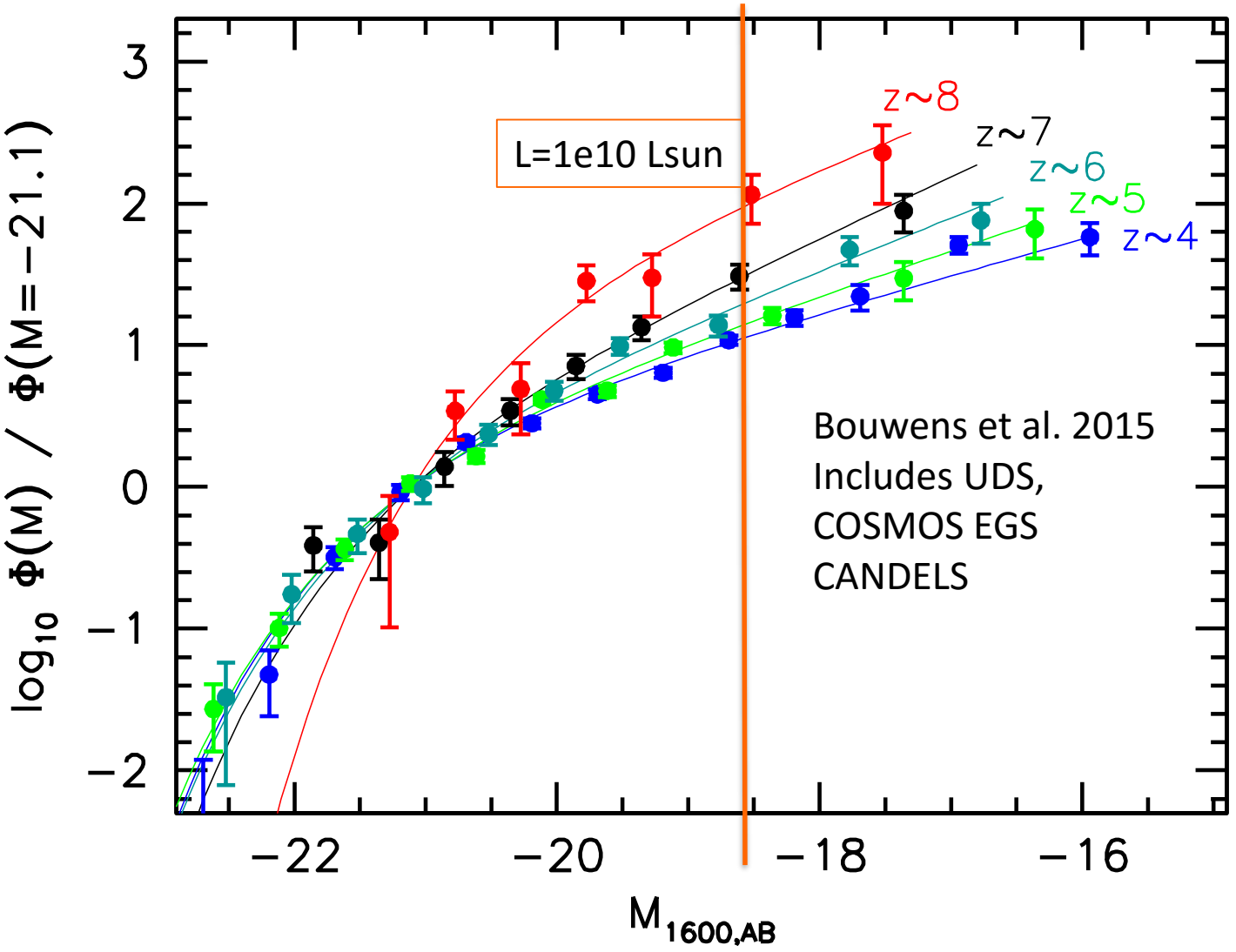
U Chicago

Erik Shirokoff

RIT

Michael Zemcov

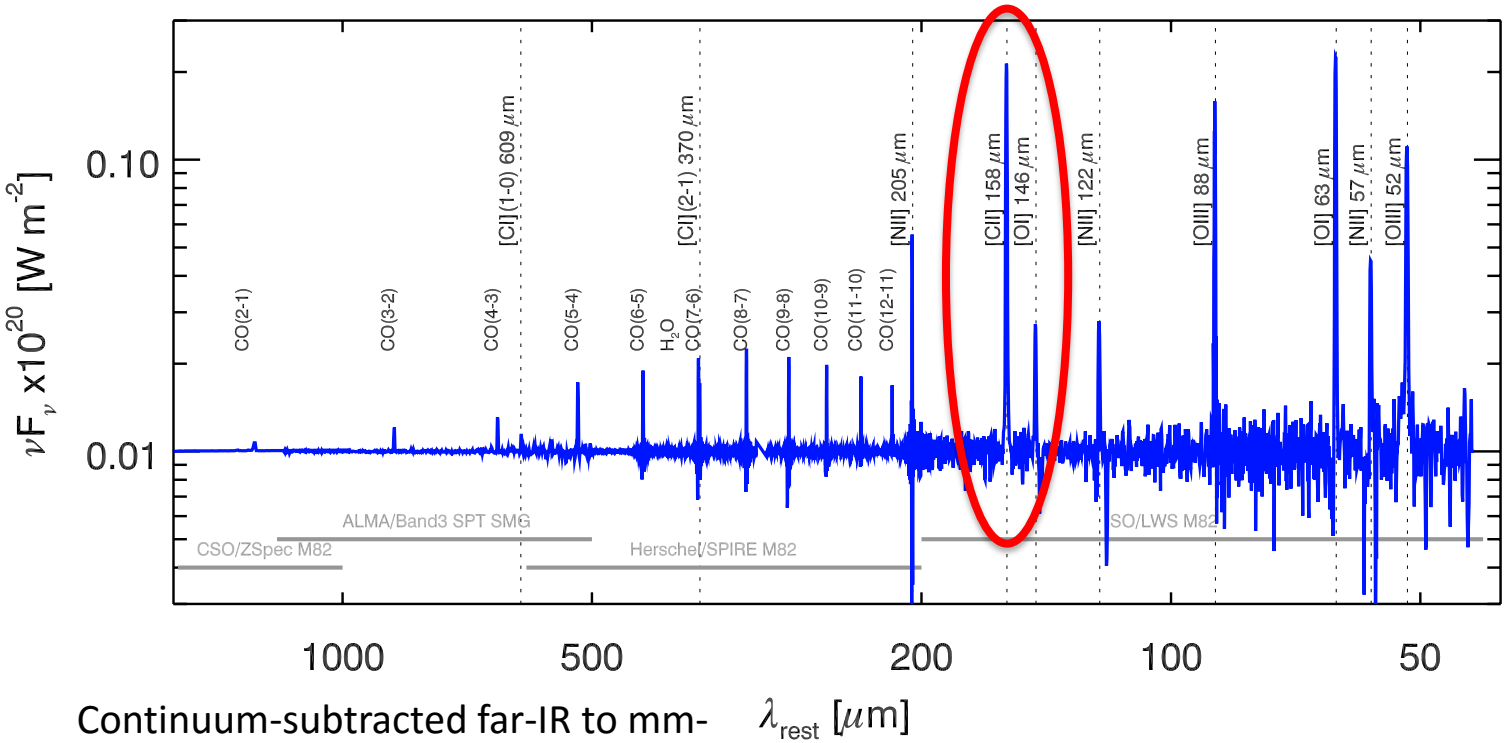
Motivation: Typical EoR Photon Originates in a Faint Galaxy



- Faint galaxies more important as we look back through reionization.
- The highest redshifts have divergent total light integrals.

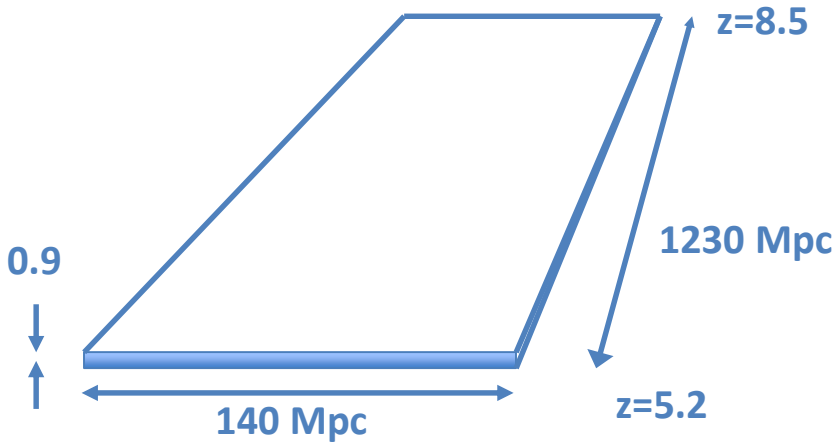
3-D Intensity Mapping of Spectral Lines

- Provides automatic redshift information.
- 3rd dimension adds additional modes to the dataset.
- Still carries sensitivity to the full population.
- Measurement is with a moderate-R, high-throughput spectrometer
- CII carries 0.1-1% to total luminosity in typical star forming galaxies – among the brightest of all spectral features
- CII well-matched to 1-mm atmospheric windows for z=5-9

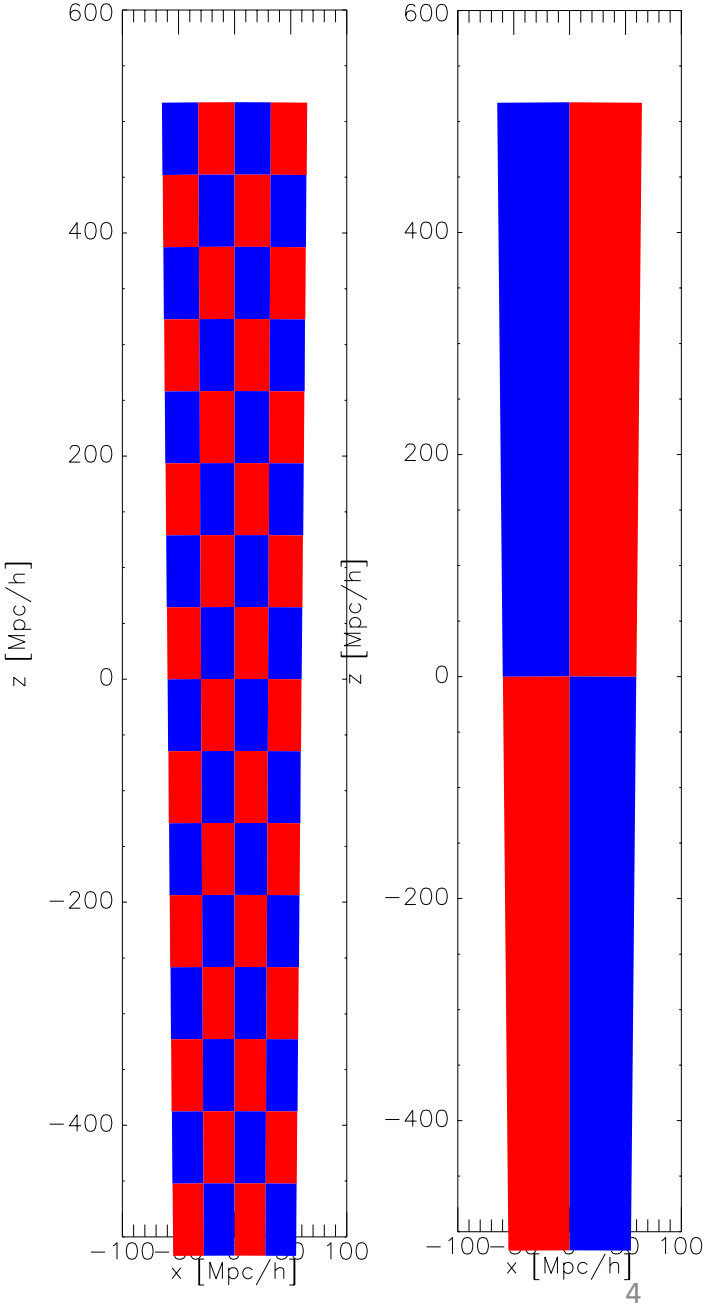


Continuum-subtracted far-IR to mm-wave spectrum of M82 – J. Vieira

TIME-Pilot survey geometry and instrument modes.



- Want to maximize per-pixel sensitivity – go deep with small area. But need to sample small k, drives to large size (don't want to rely on spectral direction solely).
- Our approach: 180-beams wide x 1 beam-thick rectangle on the sky
- Spectral coverage mapped into comoving coordinates gives large z direction: 195 to 318 GHz is z=5.0 to 8.7, a total of 1440 Mpc.



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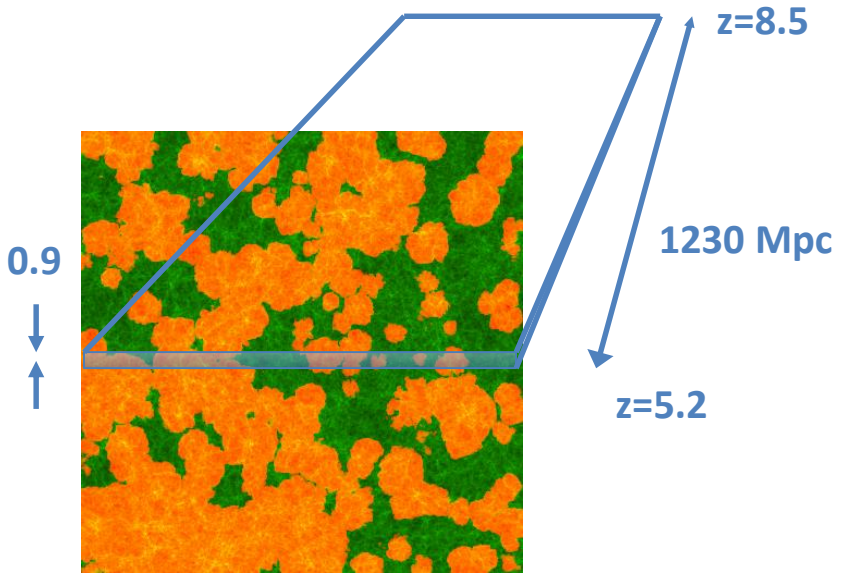
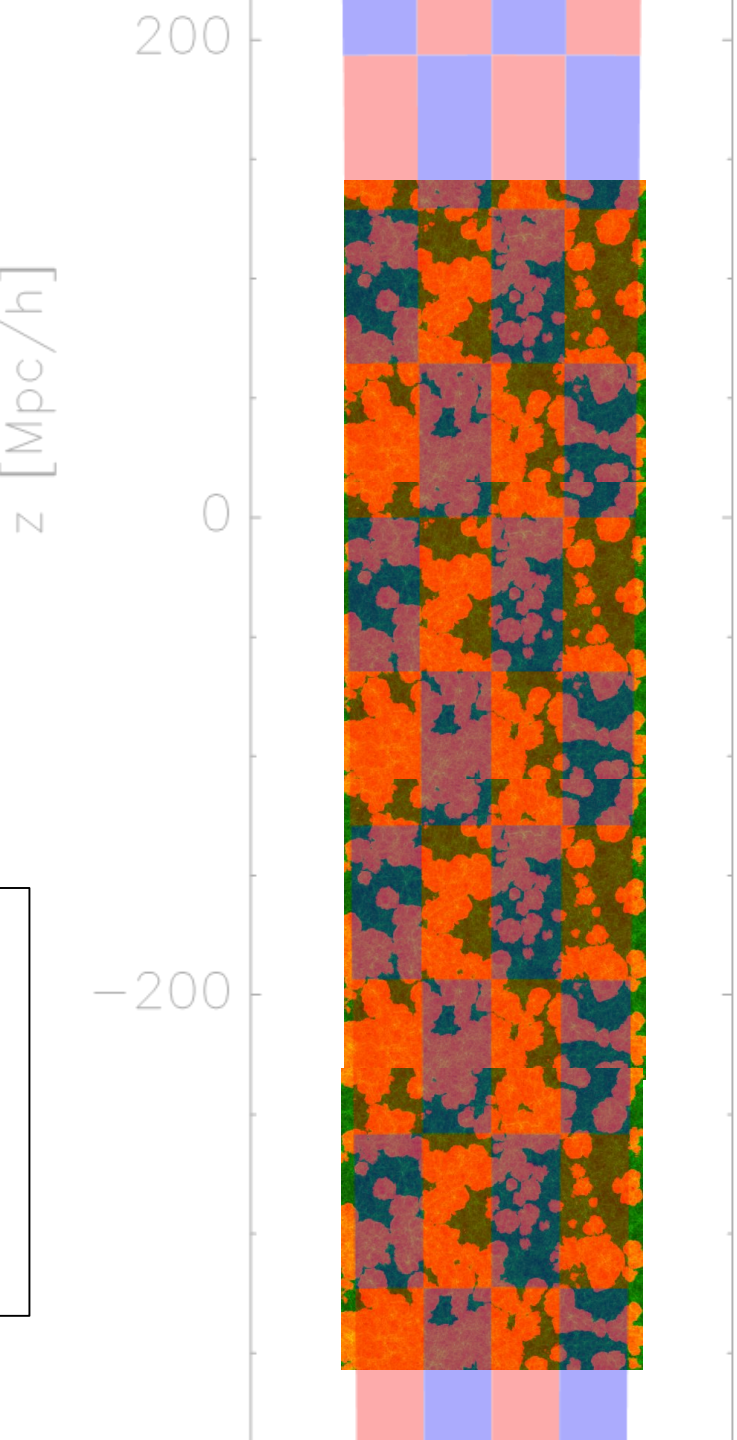
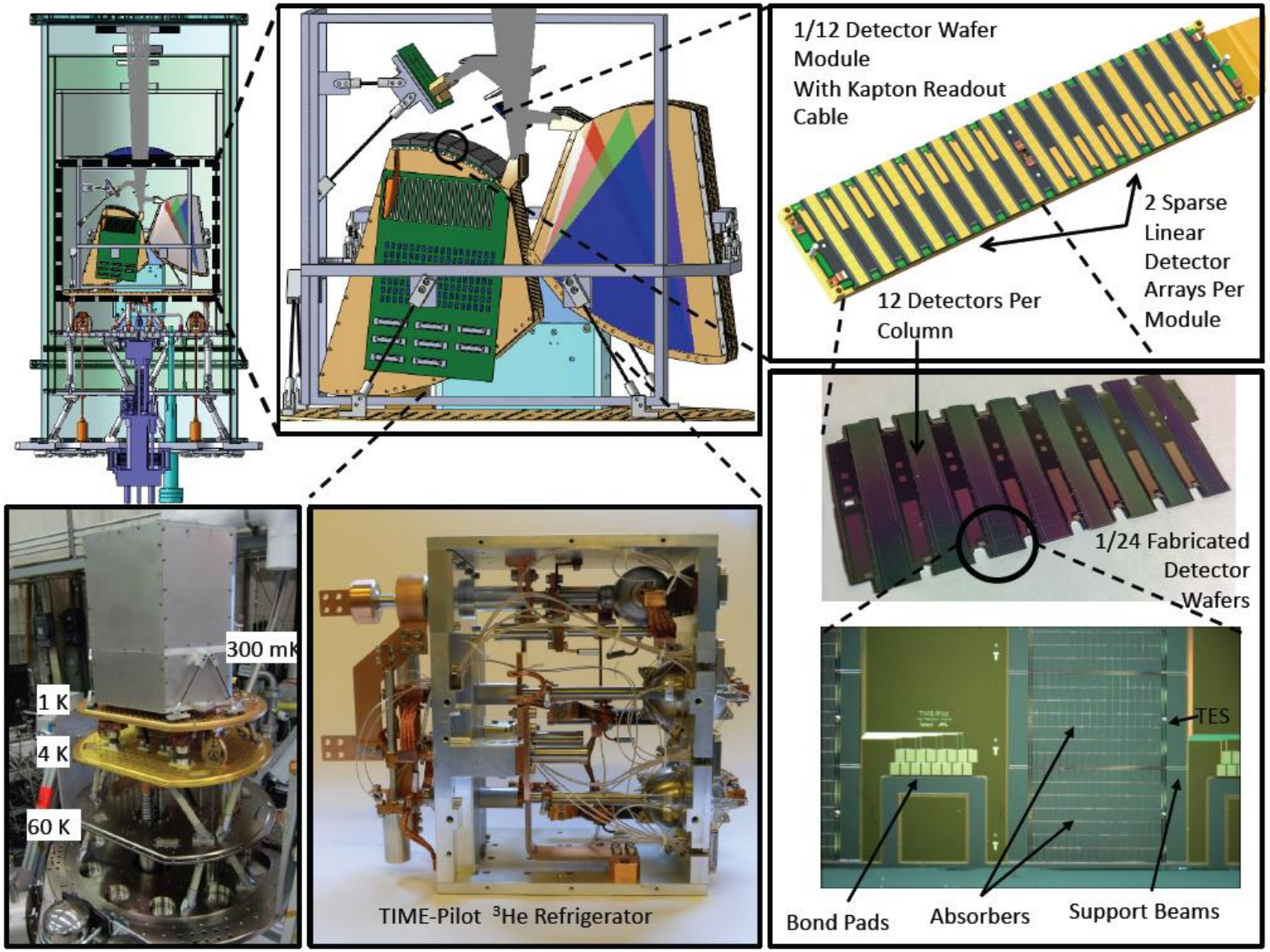


- TP Survey geometry compares well with EoR structures
- For visualization: slice of an EoR simulation from Ilian Iliev (U. Toronto). 138 Mpc comoving slice: Orange = ionized, green = neutral
- (TP has many higher order modes as well.)



TIME-Pilot instrument concept



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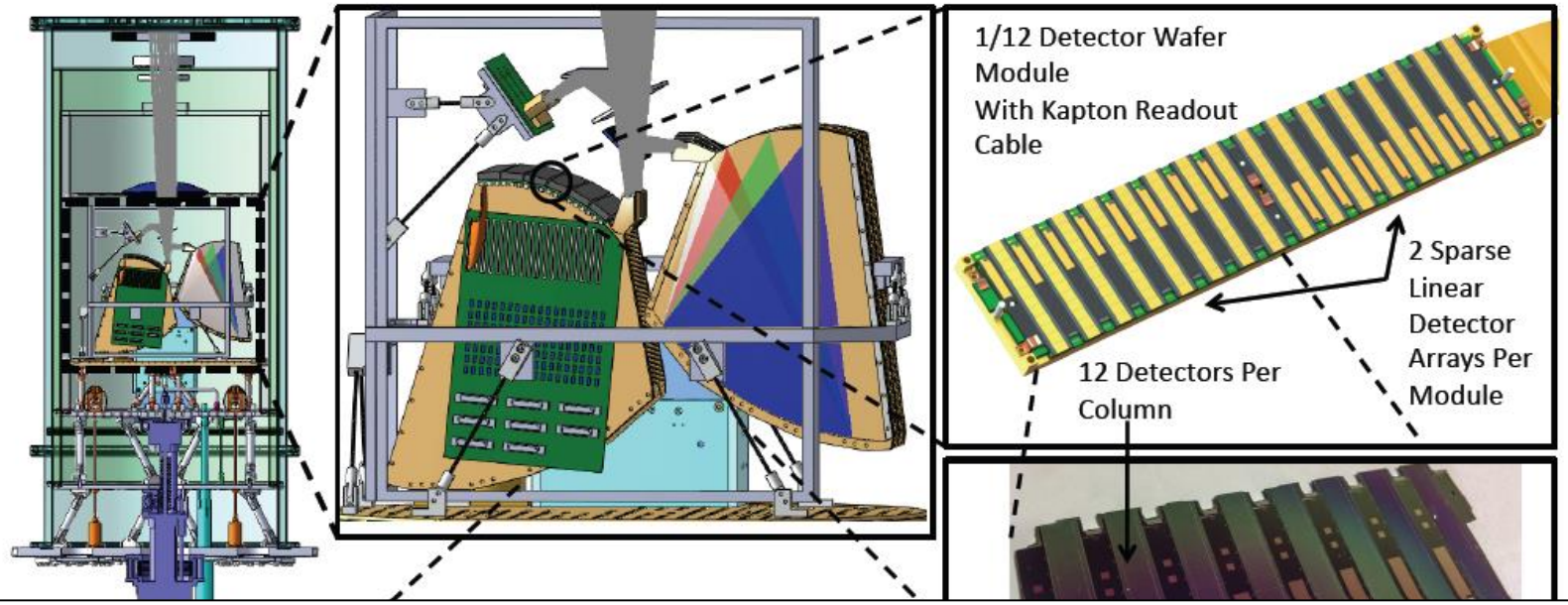
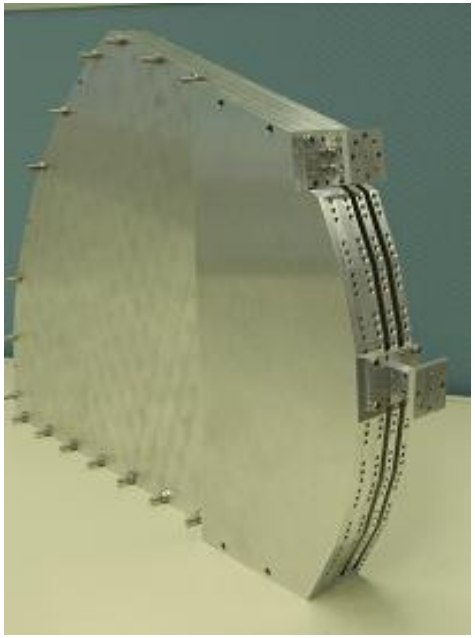
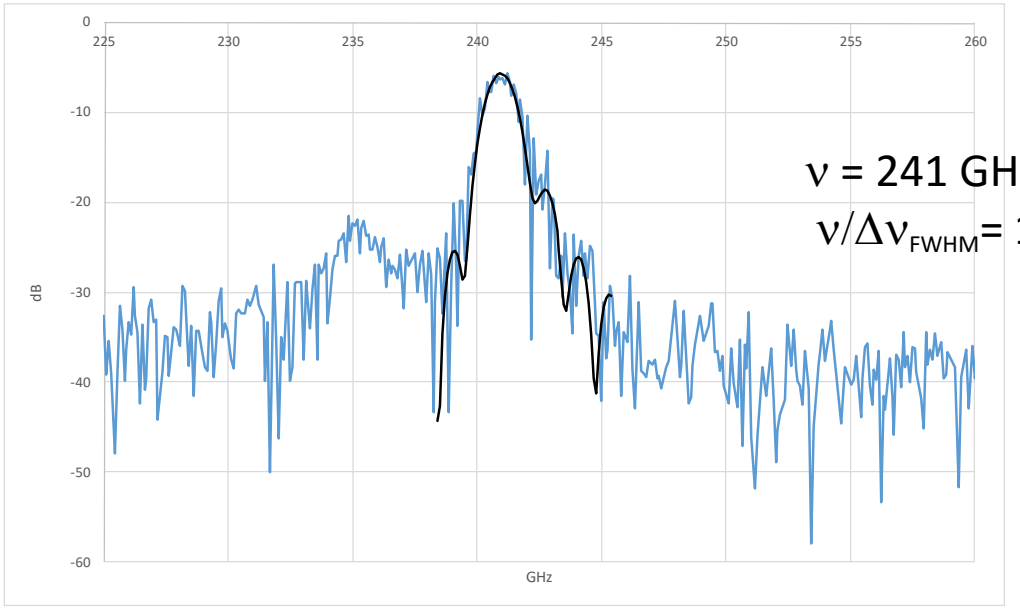
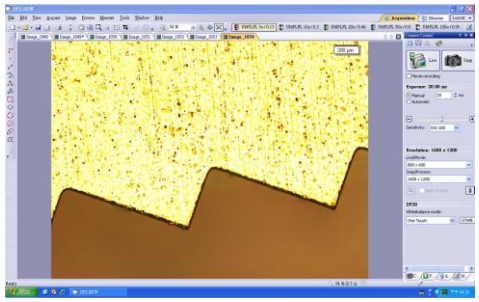


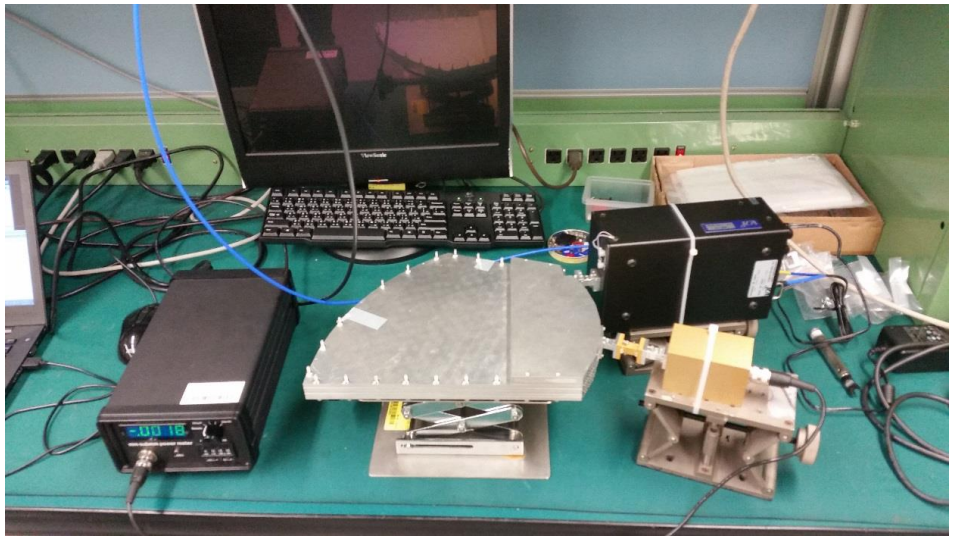
- 32 waveguide grating spectrometers
  - As used in Z-Spec
  - R=100, 60 detectors each covering 186-324 GHz.
  - At least 42 channels each for science, up to 18 can be atmospheric monitors.
- 1800 absorber-coupled TES bolometers
  - time-domain (NIST) SQUID MUX, as per SCUBA-2, BICEP-2.
  - NEP of 3e-18 well in hand after BLISS / SPICA development.
- Novel ‘slab’ survey geometry with most of low-k information coming from spectral dimension.
  - Requires careful deconvolution between instrument modes and astrophysical k bins.

TIME-Pilot waveguide spectrometer

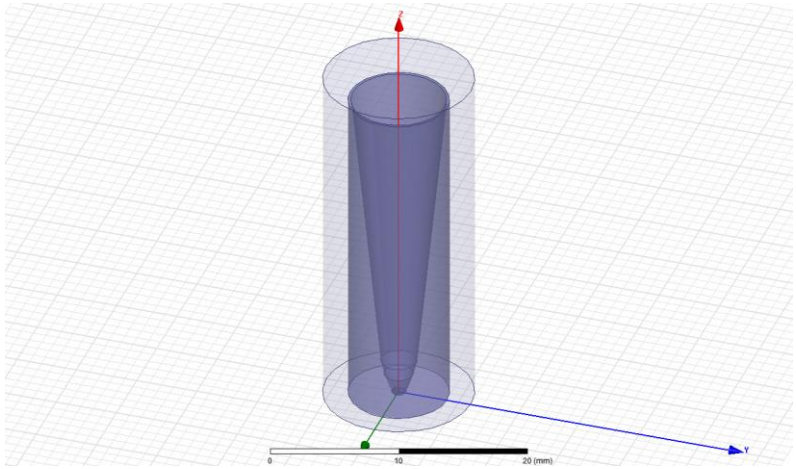


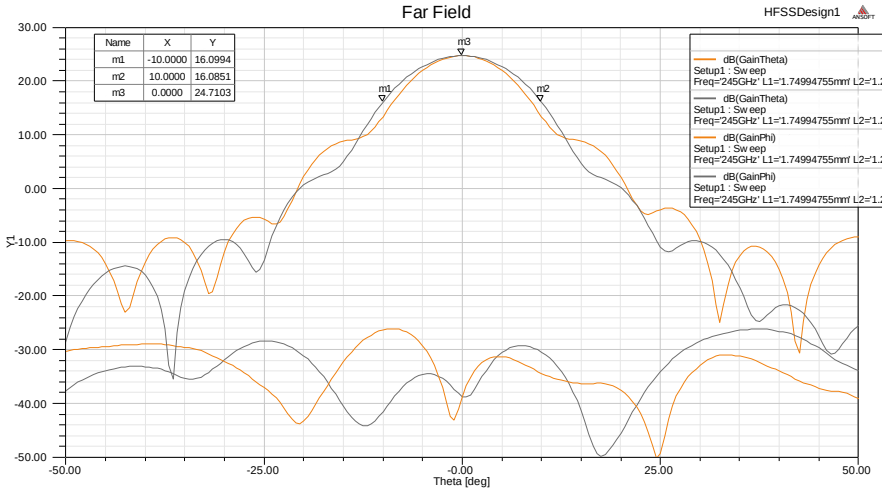


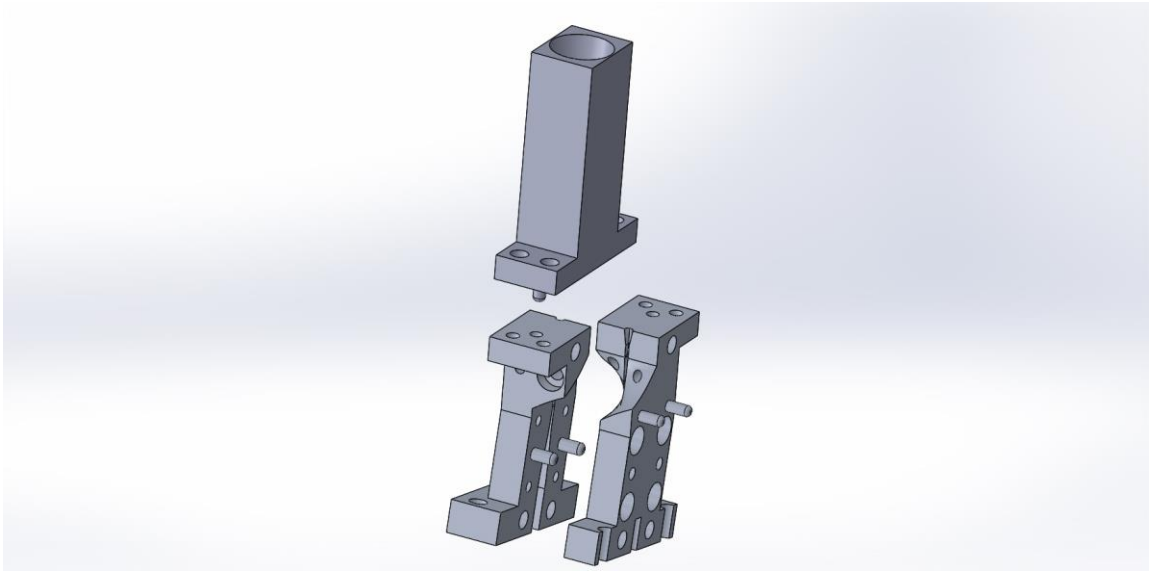




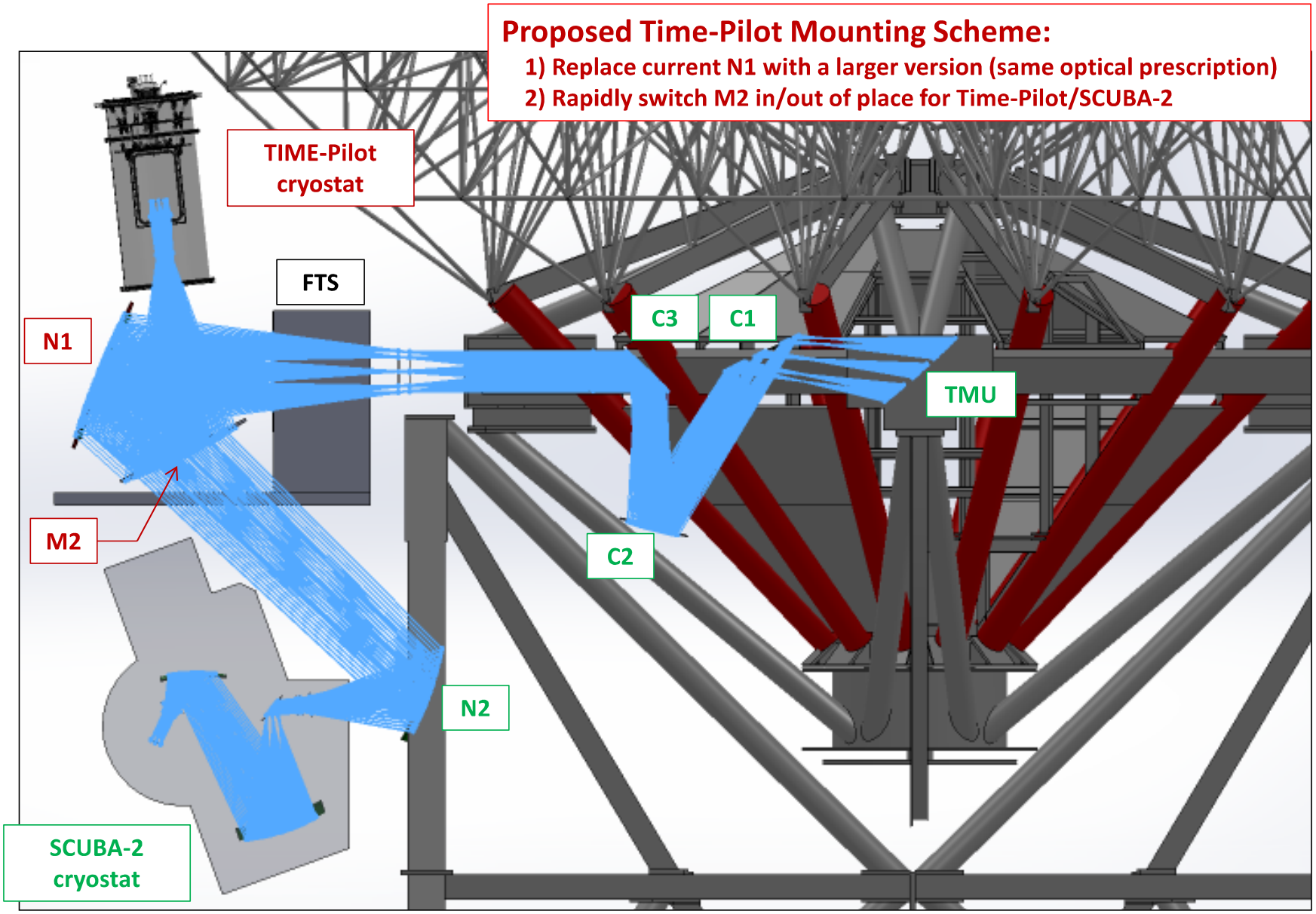
Multi-Flare-Angle (MFA) feed and waveguide twist







Operation of TIME-Pilot at JCMT



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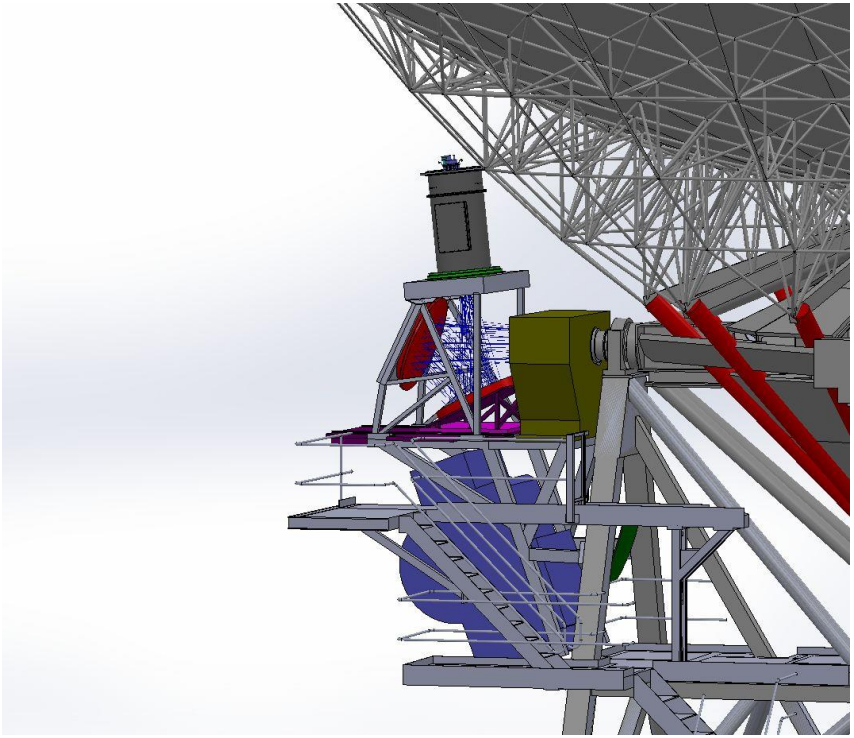
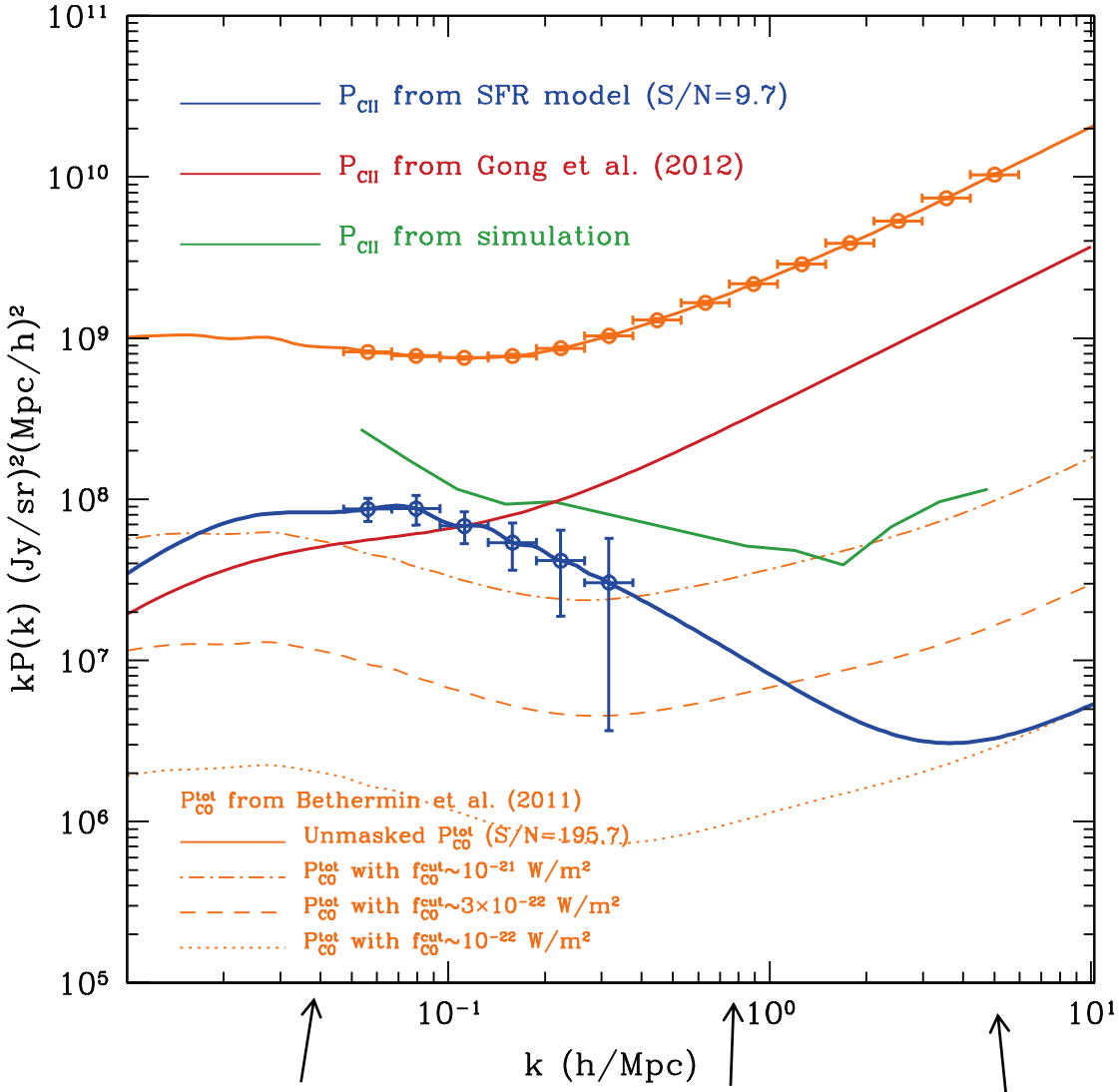


- TIME Pilot would fit above the SCUBA-2 instrument on the Nasmyth platform. Adding PTC-415 lines, pump lines, and compressors are possible.
- To do:
  - Mounting design
  - Mirror design and fabrication
  - Telescope flexure tests with extra weight
  - Install power for compressor and chiller

TIME-Pilot Dataset – Expected Sensitivity



Halo-halo clustering (linear term, encodes total CII emission)

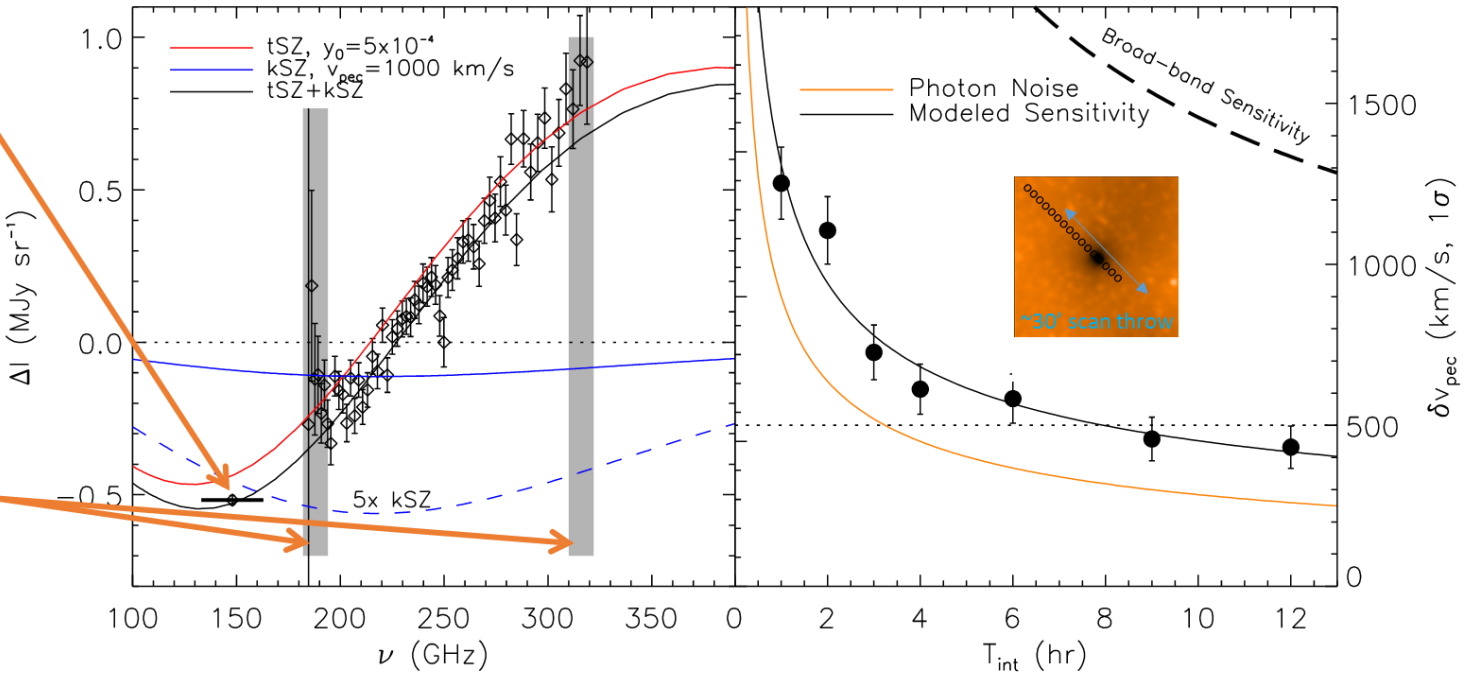
Inter-halo clustering

Shot noise

- [CII] autocorrelation spectra over the full TP band.
- [CII] EoR signal strength not known, consider various models.
  - Constant SFR
  - Gas physics calculation
  - Millennium sim x 3e-3
- Error bars correspond to 240 hours on target w/ JCMT.
- CO from z ~ 0.5 to 3 (multiple lines) is dominant signal in raw map (shown referred to CII survey geometry), but can be masked using galaxy catalogs.
- Cross correlations at CO frequencies with galaxy surveys can provide a CO census

TIME-Pilot for Kinematic Sunyaev-Zeldovich Effect Measurements

- TIME-Pilot includes an 11-pixel dual-pol 150 GHz array to provide broad-band sensitivity where the SZ effect is close to minimum.
- Guard channels near water lines are used to regress time-varying atmospheric emission from the science bands.
- **Together, this strategy optimizes our ability to disentangle thermal SZ effect from the smaller kinematic component.**



Simple line scans optimize observation efficiency, making TIME-Pilot significantly more sensitive to kSZ than broad-band 2-D mapping instruments.

TIME Pilot Development Schedule

- Year 1 : Instrument Fabrication and Integration
  - cryostat, He3 cooling system, MCE SQUID readout, cryogenic cables in hand
  - optical design, prototype spectrometer, prototype TES bolometer array, end to end cryogenic system integration and test completed
  - prototype TES array performance test, prototype focal plane board, 32 grating spectrometers, observing software
- Year 2 : Integration and Characterization
  - Instrument integration test, relay mirrors, mount, instrument rotator, engineering campaign
- Year 3 : Commissioning and Observing

TIME Pilot Development Schedule

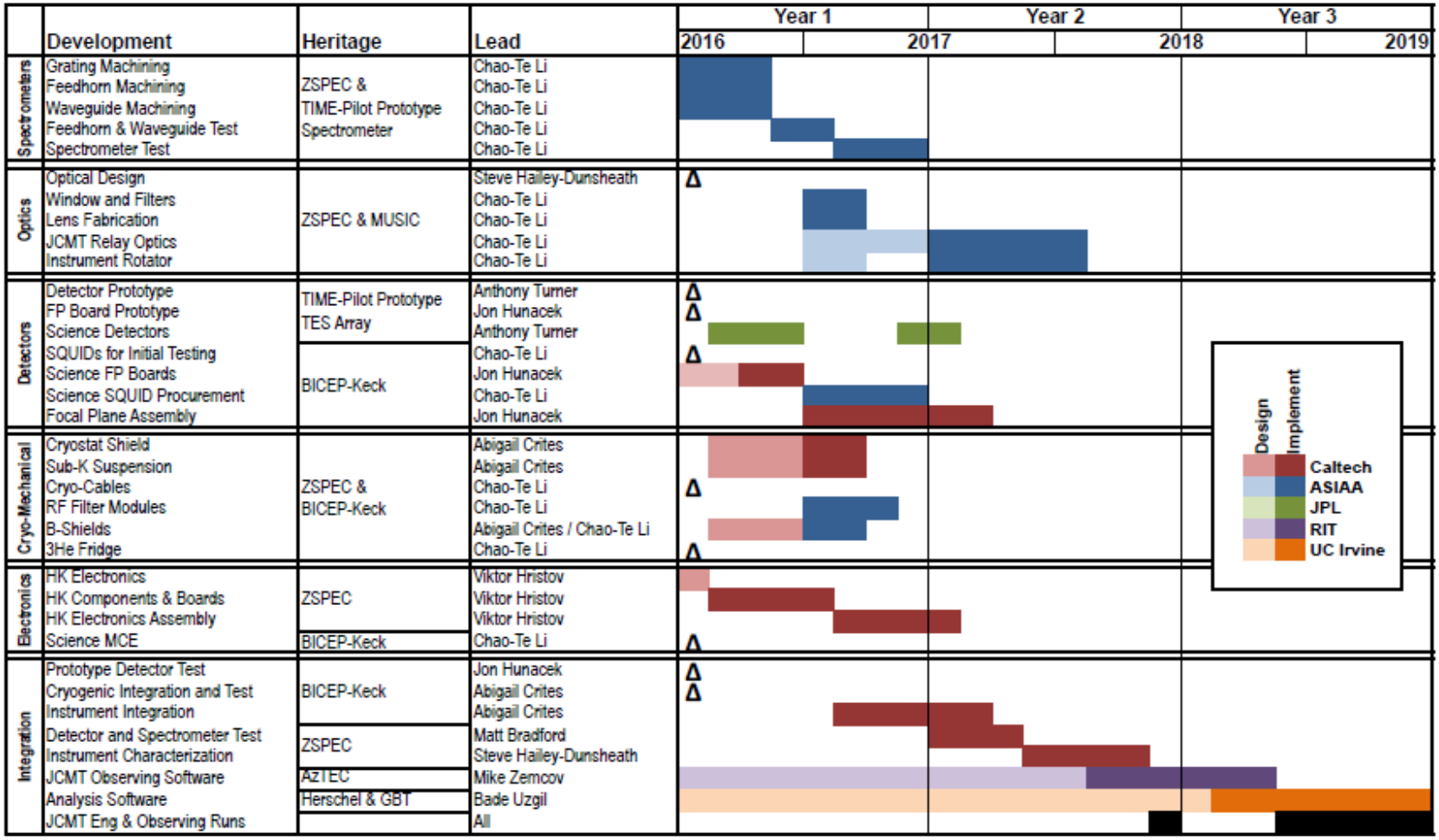
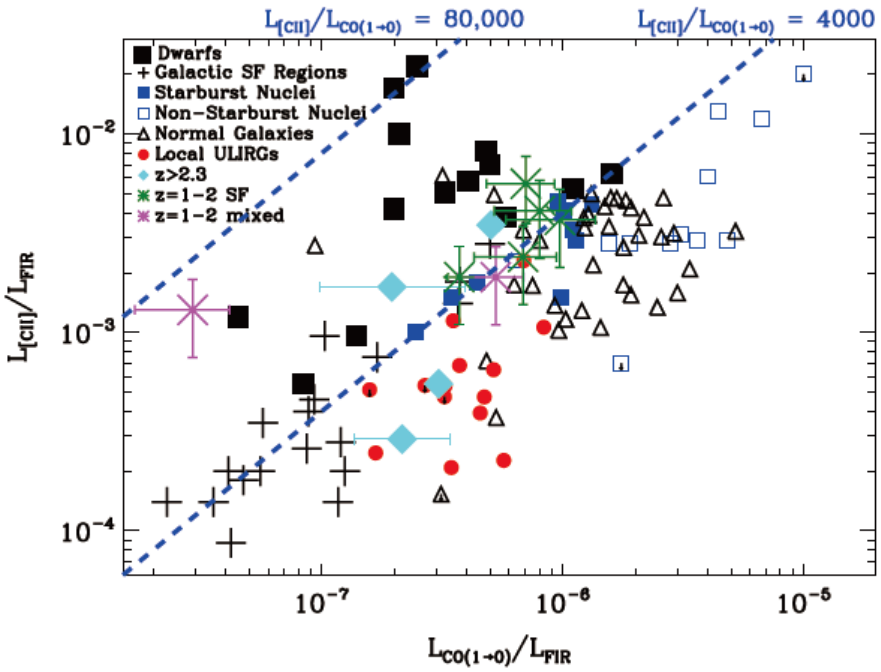
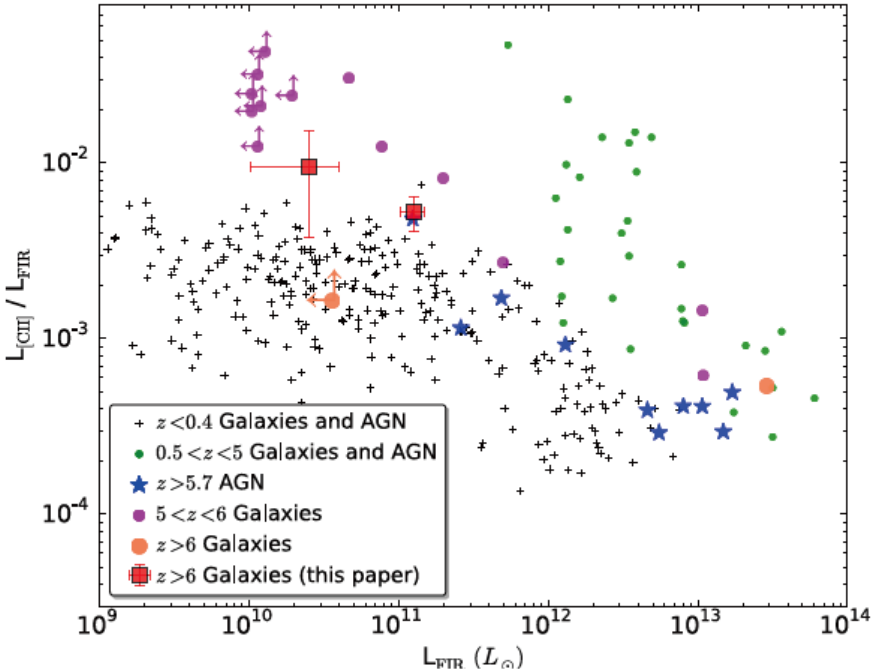


Figure 10: TIME-*Pilot* development schedule; triangles denote activities already completed.

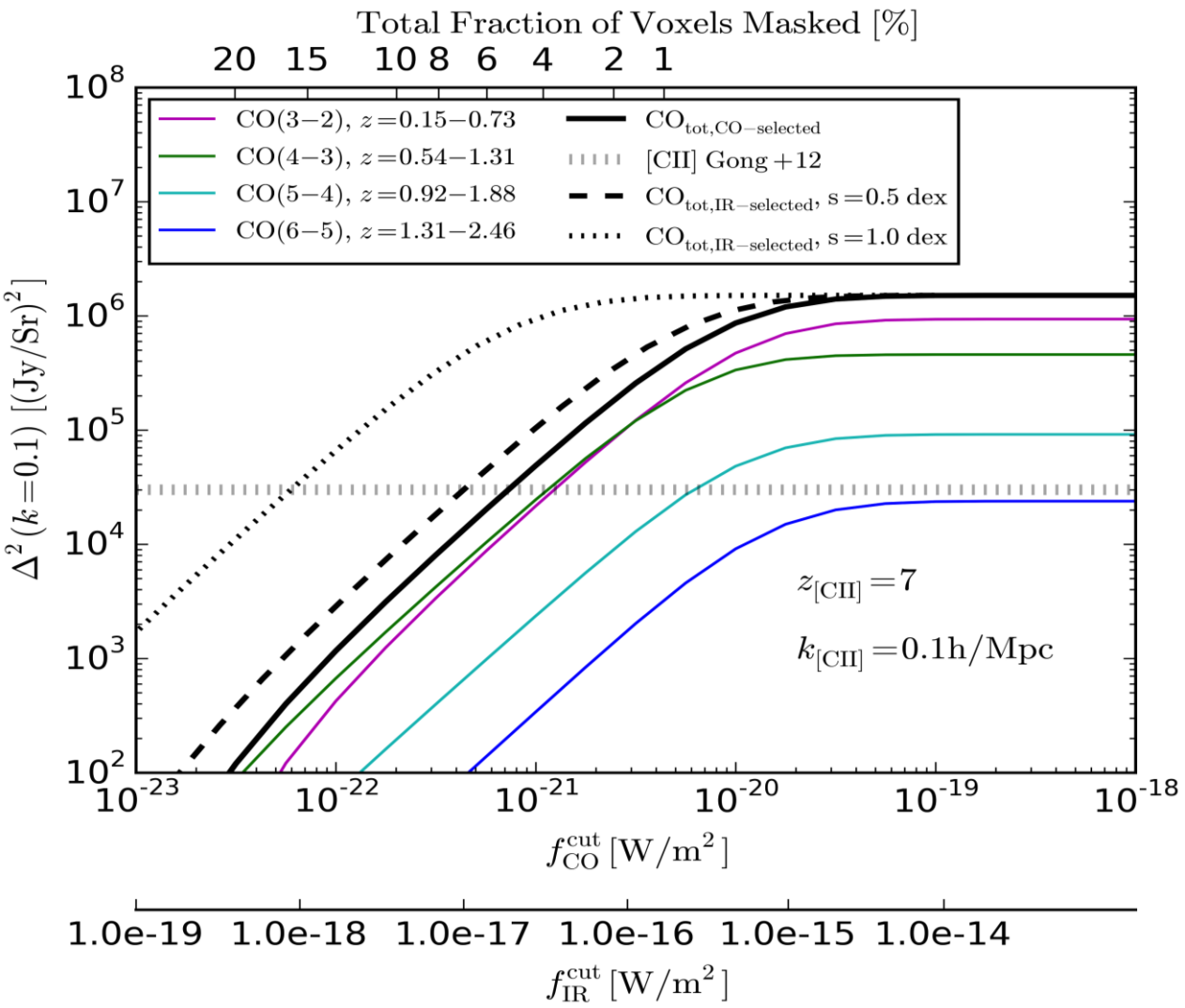
TIME Pilot targets CII emission in re-ionizing galaxies

- typically 4000 times more luminous than CO 1 → 0 in local galaxies
- even higher for the EoR systems since they resemble the low metallicity dwarf galaxies
- CII to bolometric luminosity ratios > 10^{-3} from high z measurements





Masking of low-z CO Galaxies



Amplitude of linear term: CO dominates raw variance in slab

But can remove CO signal by selecting based on total IR luminosity.

- Includes scatter in IR / CO luminosities)
- Reaches down to about 1e9 Lsun galaxy.

Only ~10% of survey voxels need to be removed. ~700 galaxies.

Need to tie optical / near-IR fluxes to total IR luminosity.

Also will need the 700 redshifts.

A well-studied field (e.g. COSMOS) with many redshift already available will be selected.

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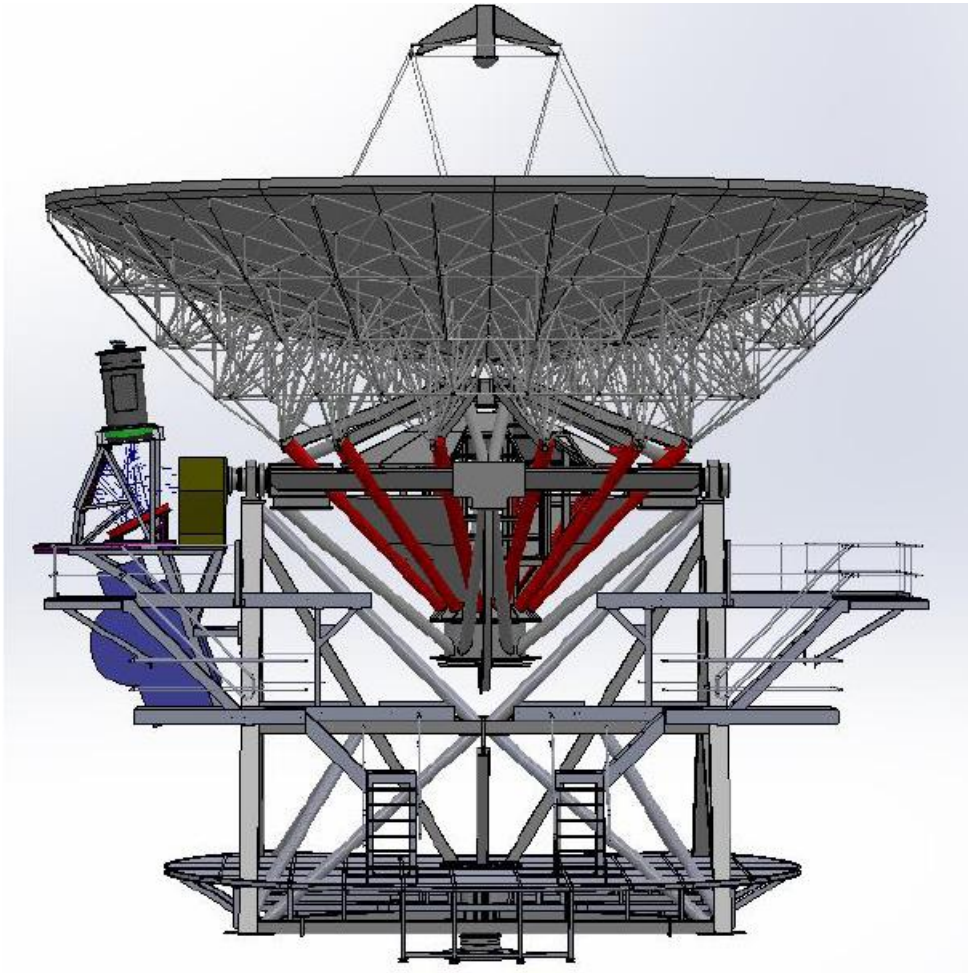

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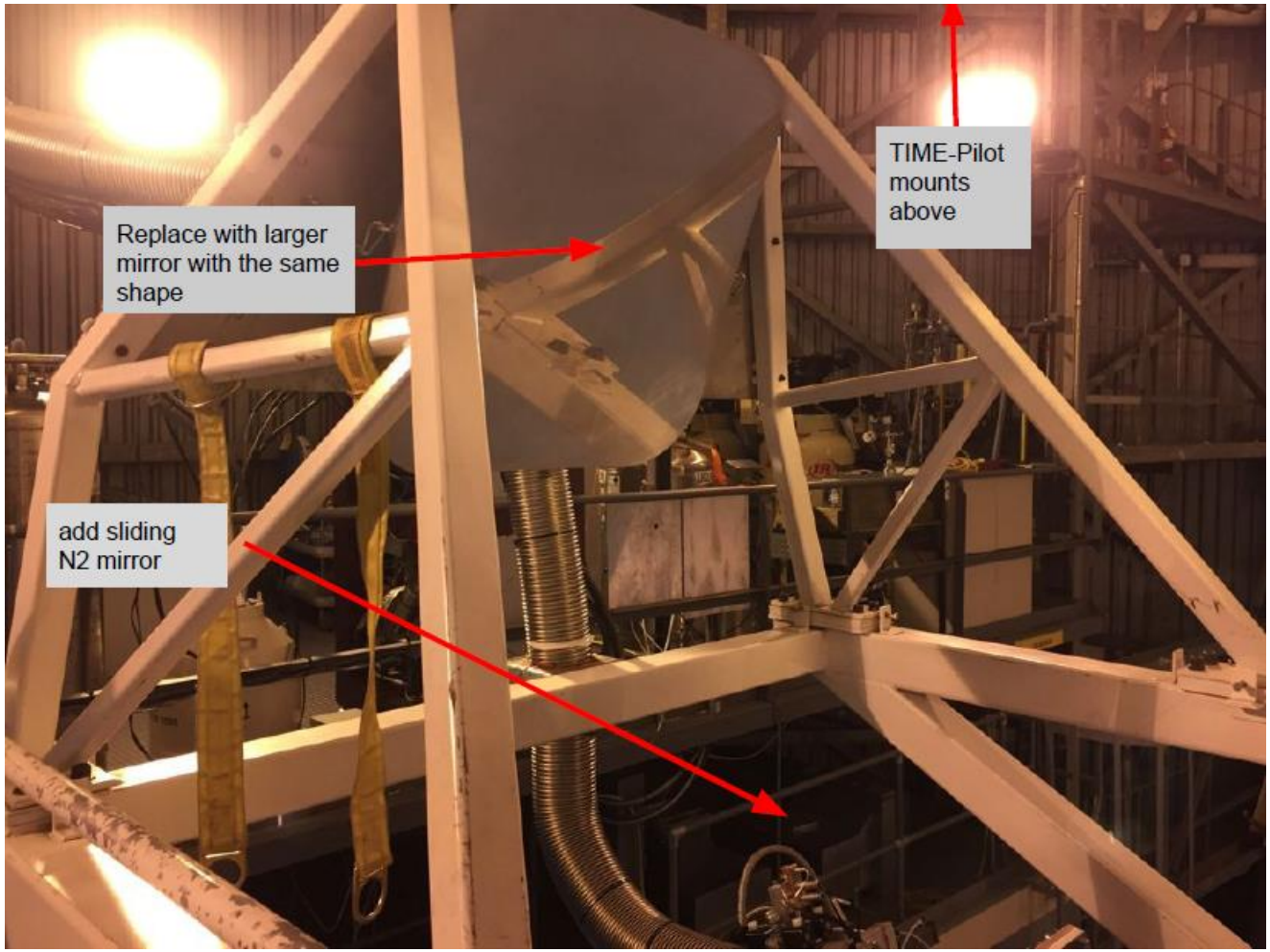

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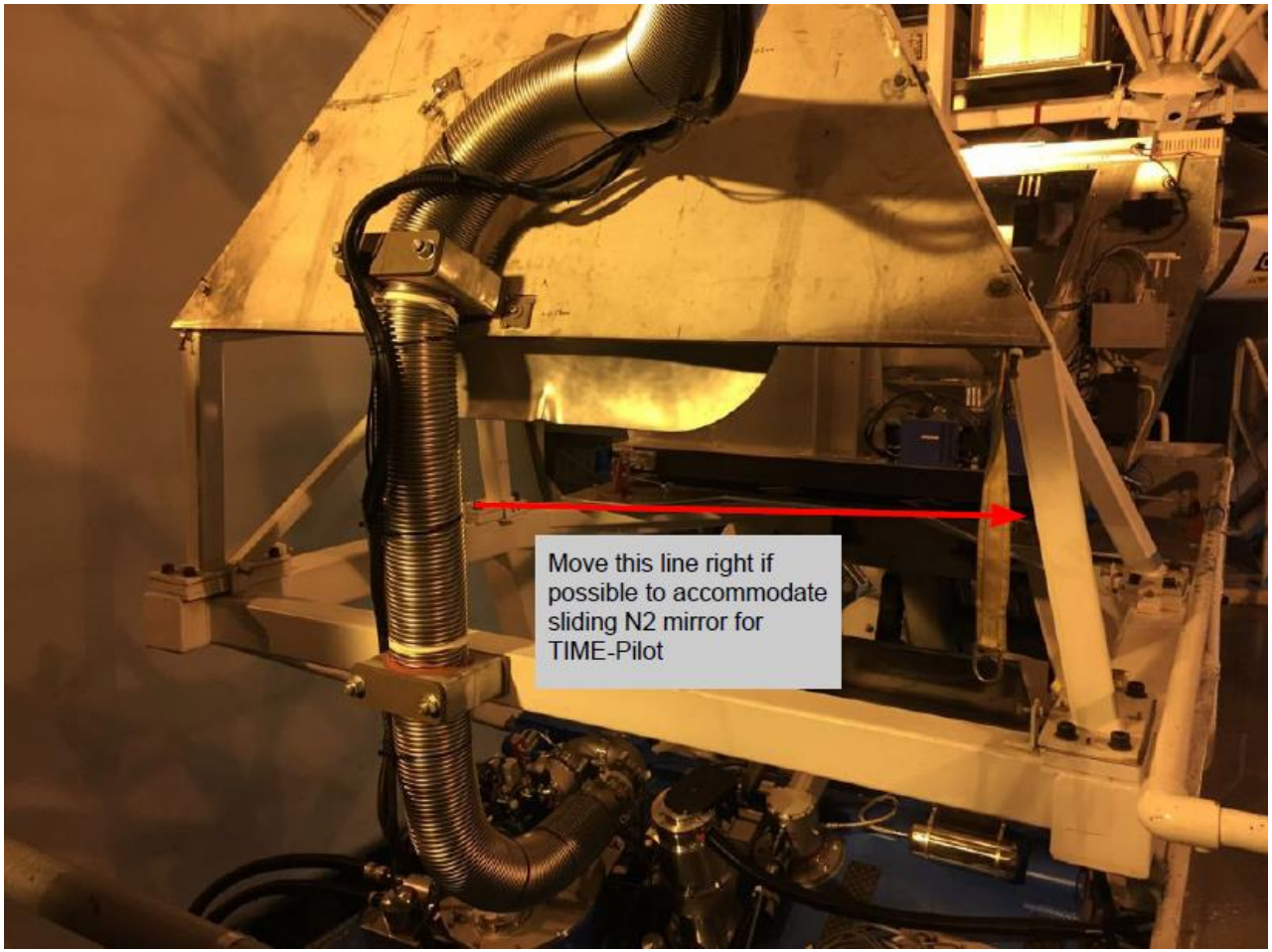
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