Searching for Our Cosmic Origins from the Edge of Space

We live in a Galaxy comprised of stars, planets, and people.

Where did it all come from?

Presented by Jenna Kloosterman
University of Arizona

Overview

I. Introduction
   A. Science Drivers
   B. Heterodyne receivers

II. Ground-based instrumentation
   A. SuperCam (345 GHz receiver for CO)
   B. ASTRO (492 GHz receiver for [C I])
   C. HEAT (810 GHz receiver for CO and [C I])

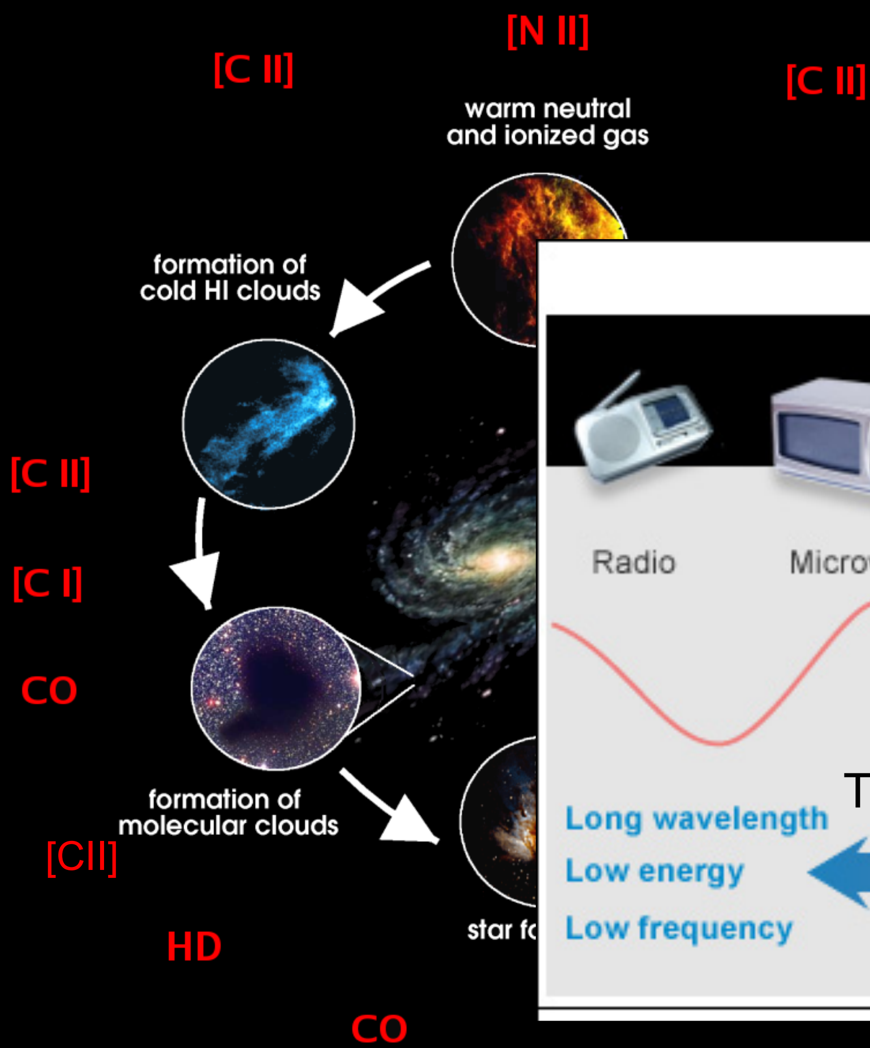
III. Balloon-borne missions
   A. STO
   B. [O I] receiver
   C. STO II
   D. GUSSTO

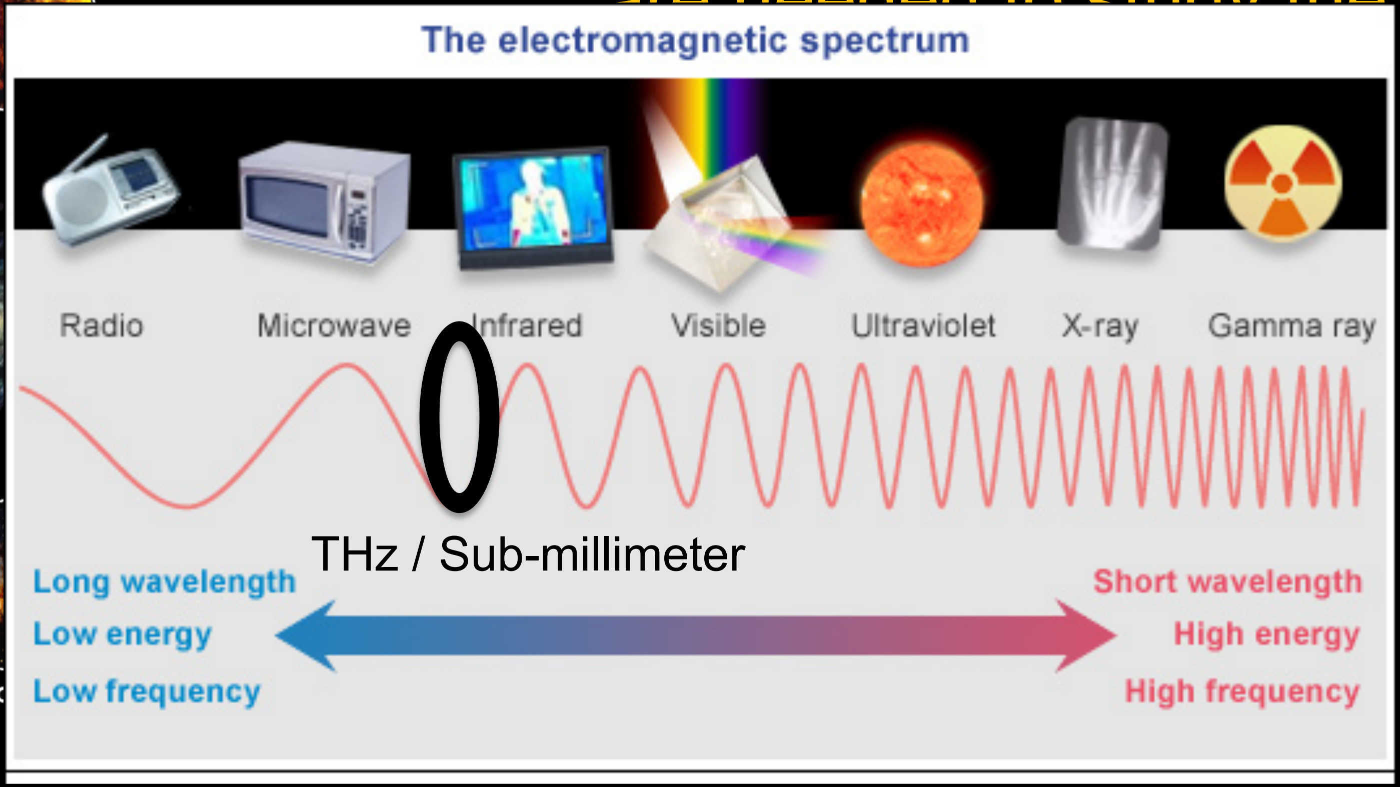
Key Questions:

- How and where are interstellar clouds made, and how long do they live?
- Under what conditions and at what rate do clouds form stars?
- How do stars return enriched material back to the Galaxy?
- How do these processes sculpt the evolution of galaxies?

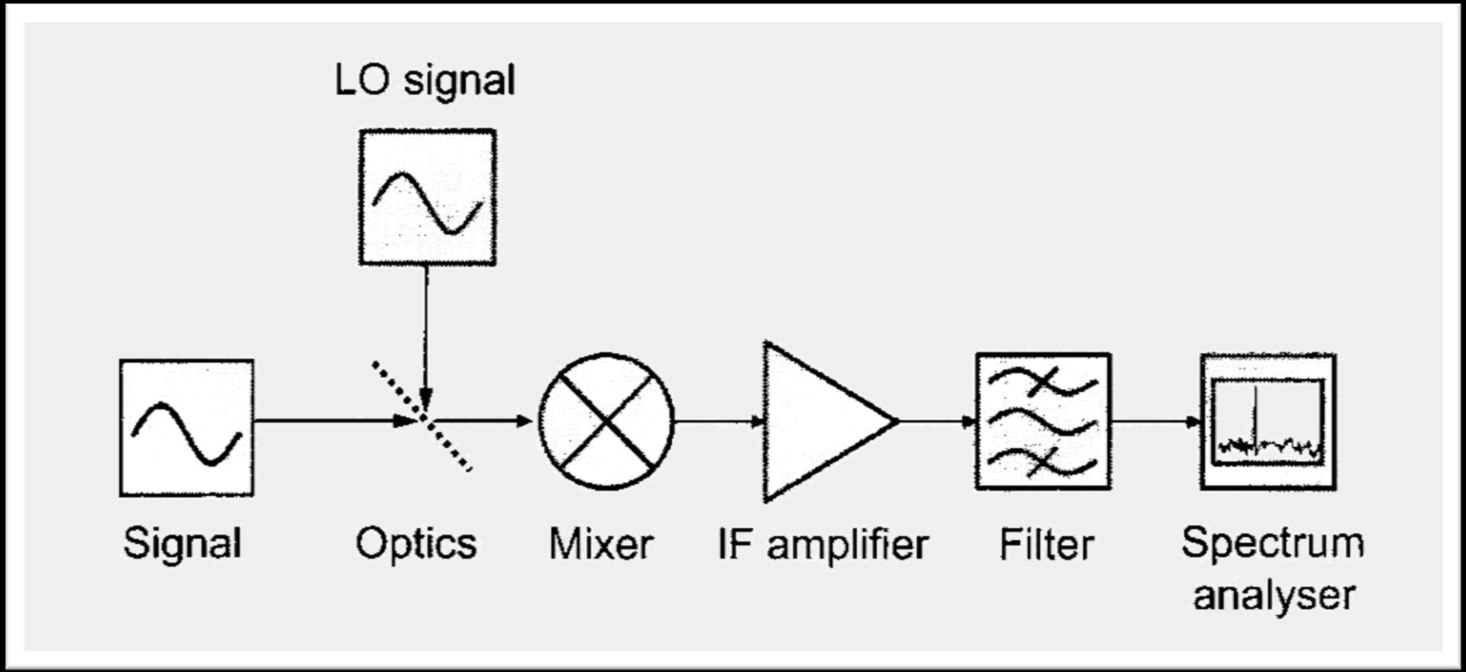
Life Cycle of Interstellar Medium (ISM)

Large Scale THz Spectroscopic Surveys are needed to study the





Heterodyne Receivers

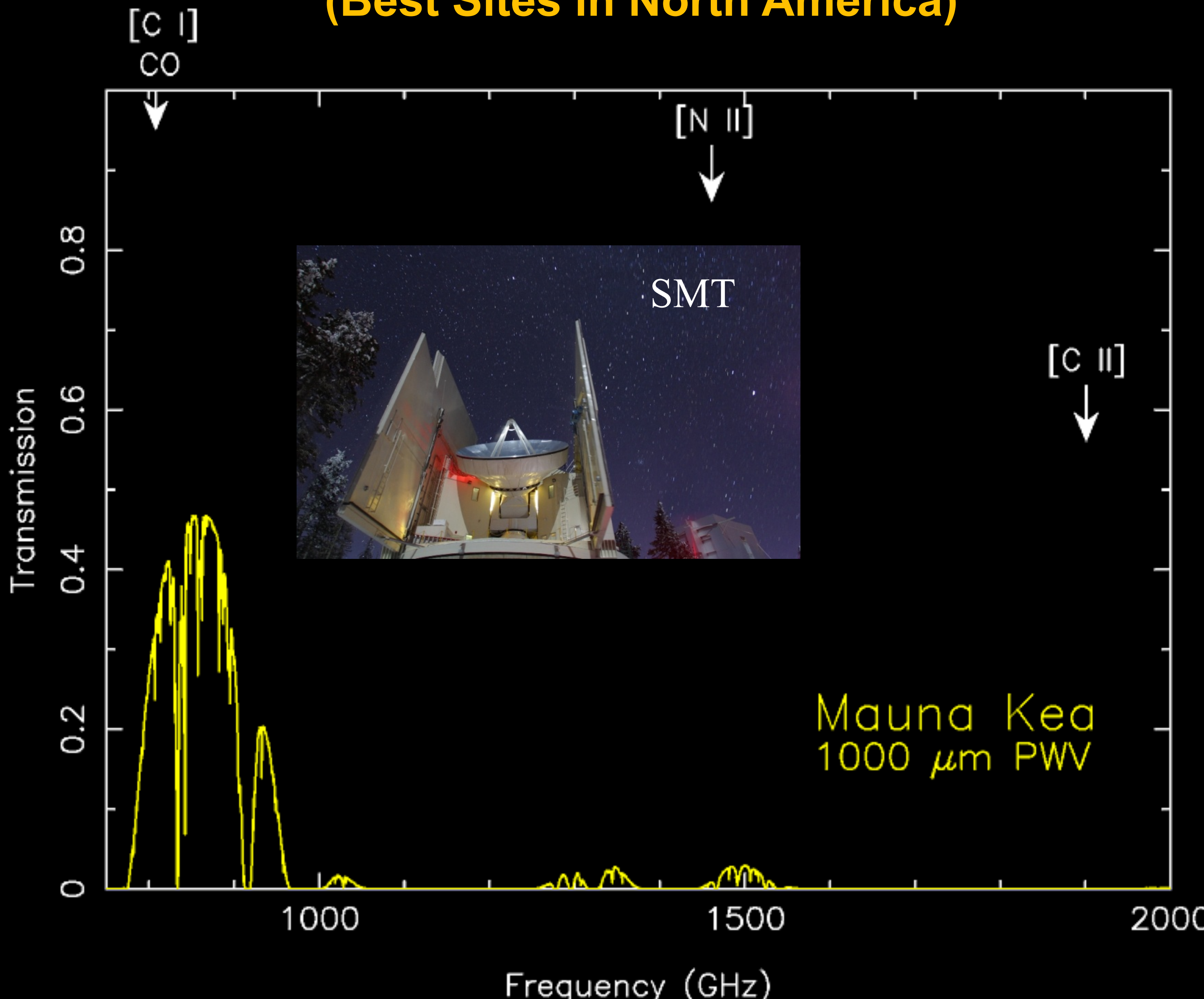


- Coherent detection
- High resolution ($\nu/\Delta\nu \geq 10^7$)
- Sensitivity
- Stability
- IF bandwidth
- Far field optical coupling

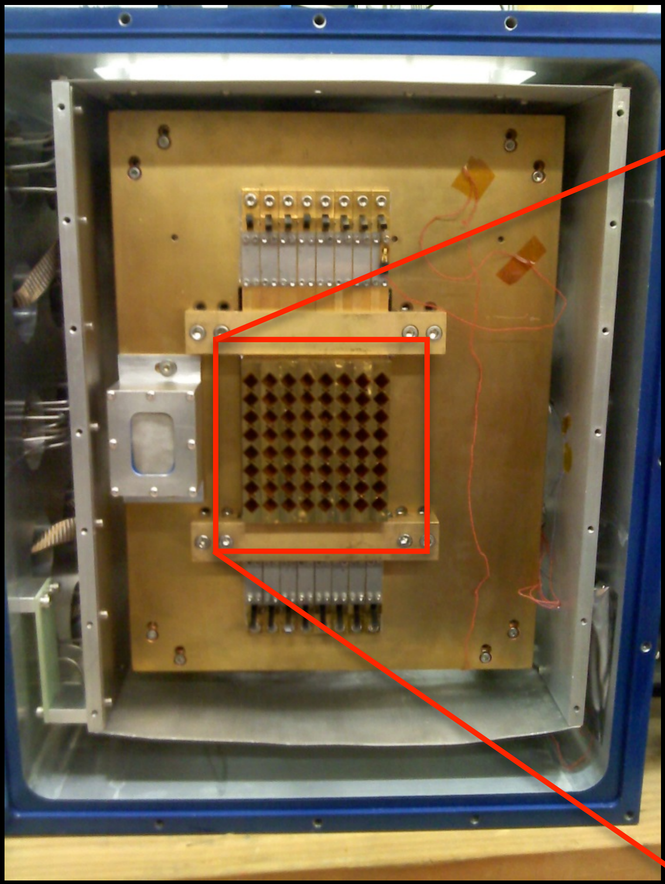
How do we go about studying the ISM?

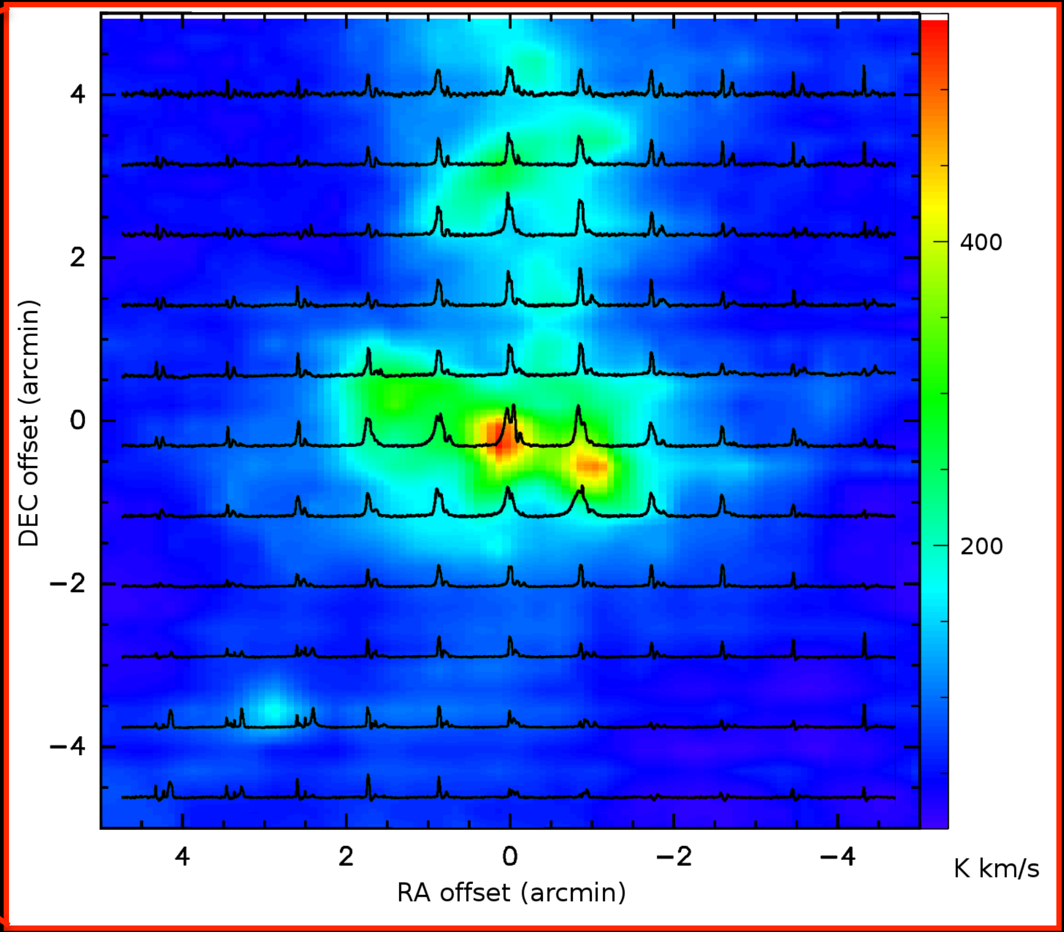
1. The Ground
   A. North America

THz Atmospheric Transmission
(Best Sites in North America)



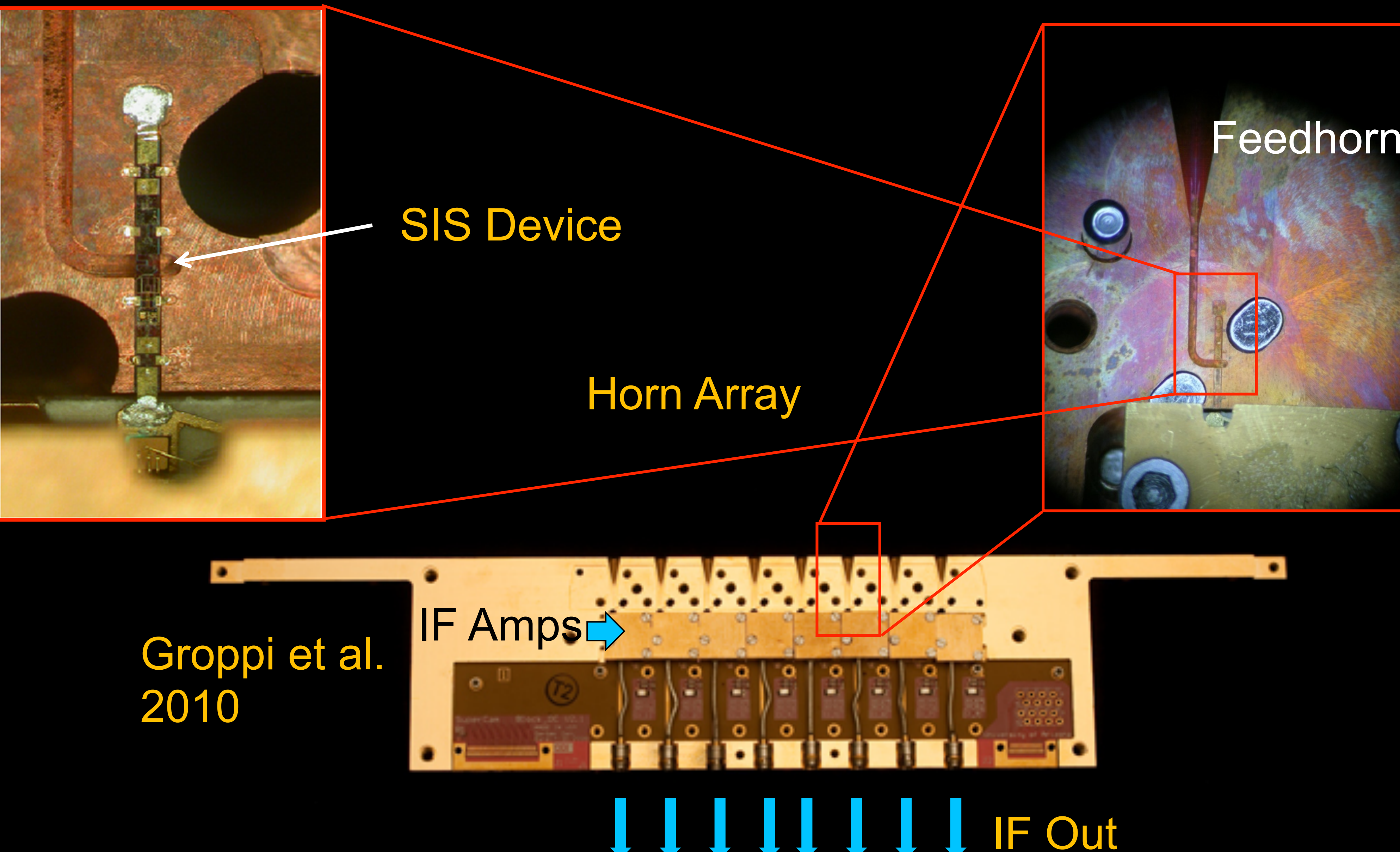
SuperCam





SuperCam's First Light Map of DR21 in ^{12}CO 3-2 from the SMT

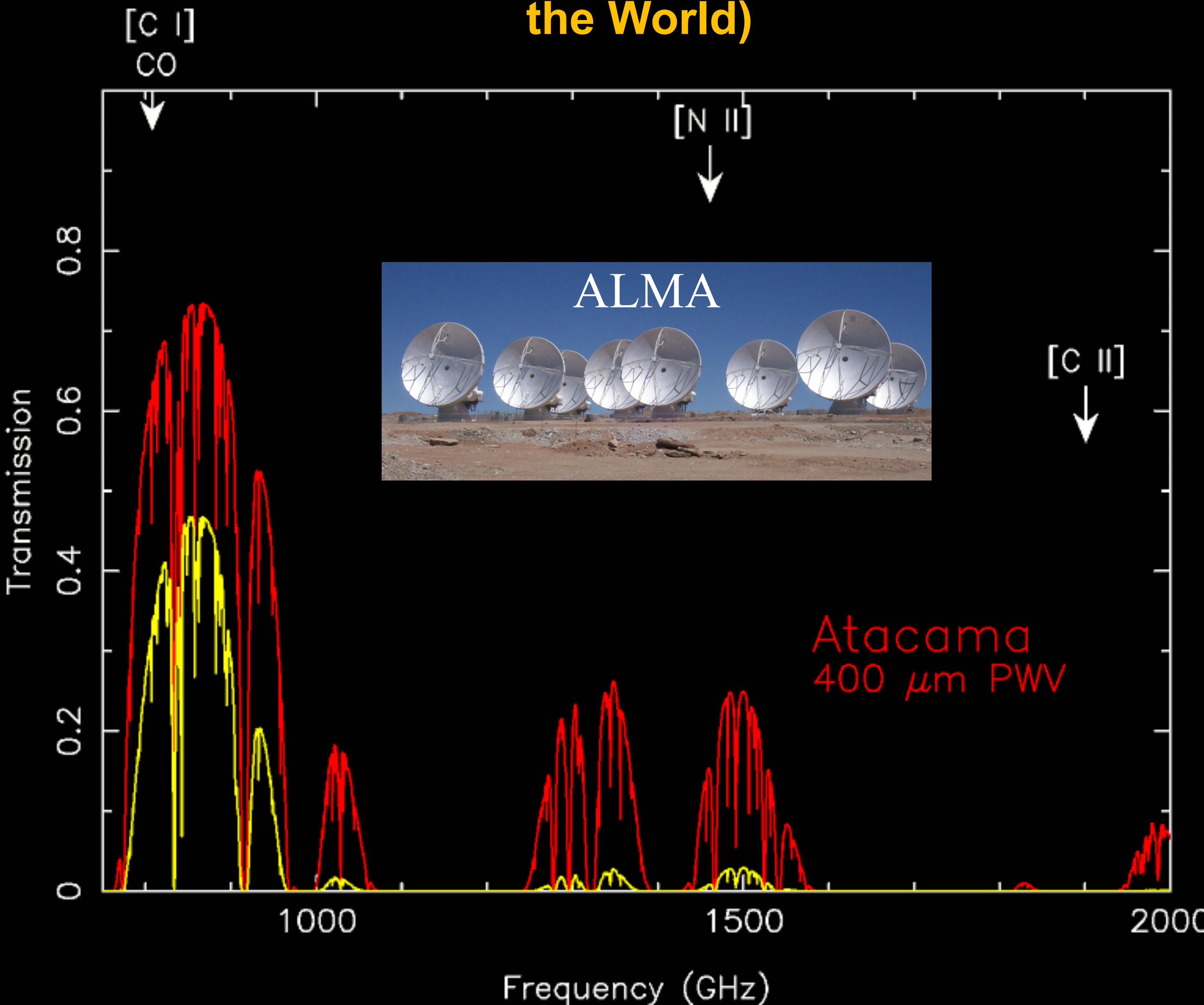
Anatomy of a SuperCam Subarray



How do we go about studying the ISM?

1. The Ground
   A. North America
   B. South America

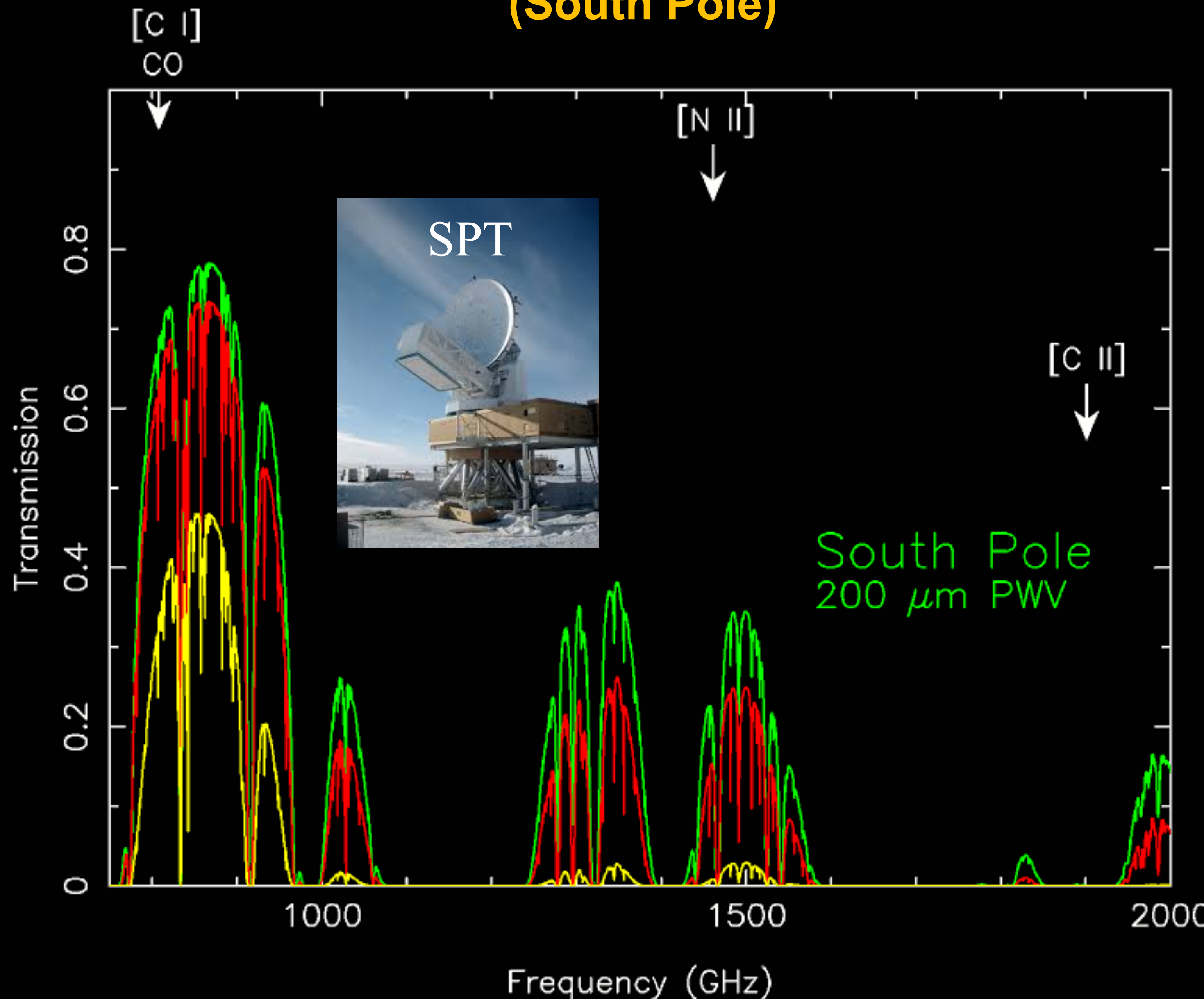
THz Atmospheric Transmission (Best Site Reasonably Accessible Site in the World)



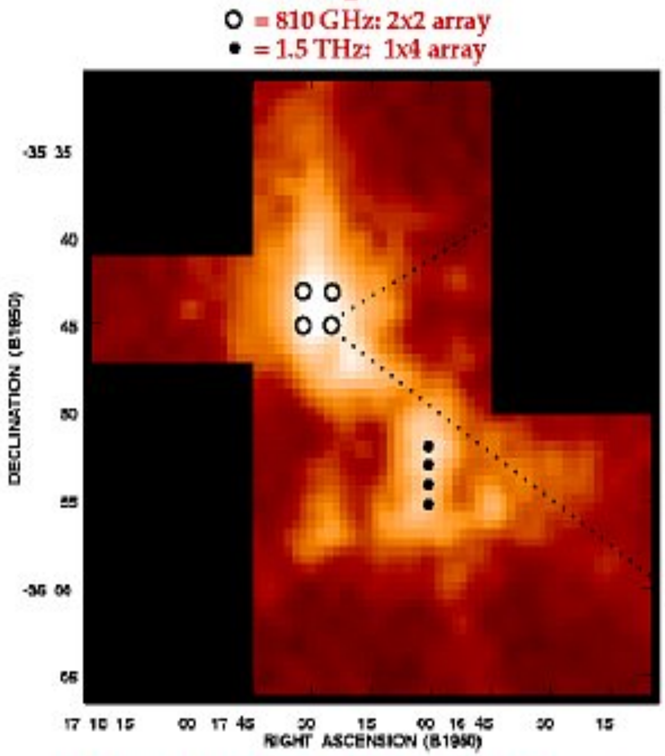
How do we go about studying the ISM?

1. The Ground
   A. North America
   B. South America
   C. South Pole

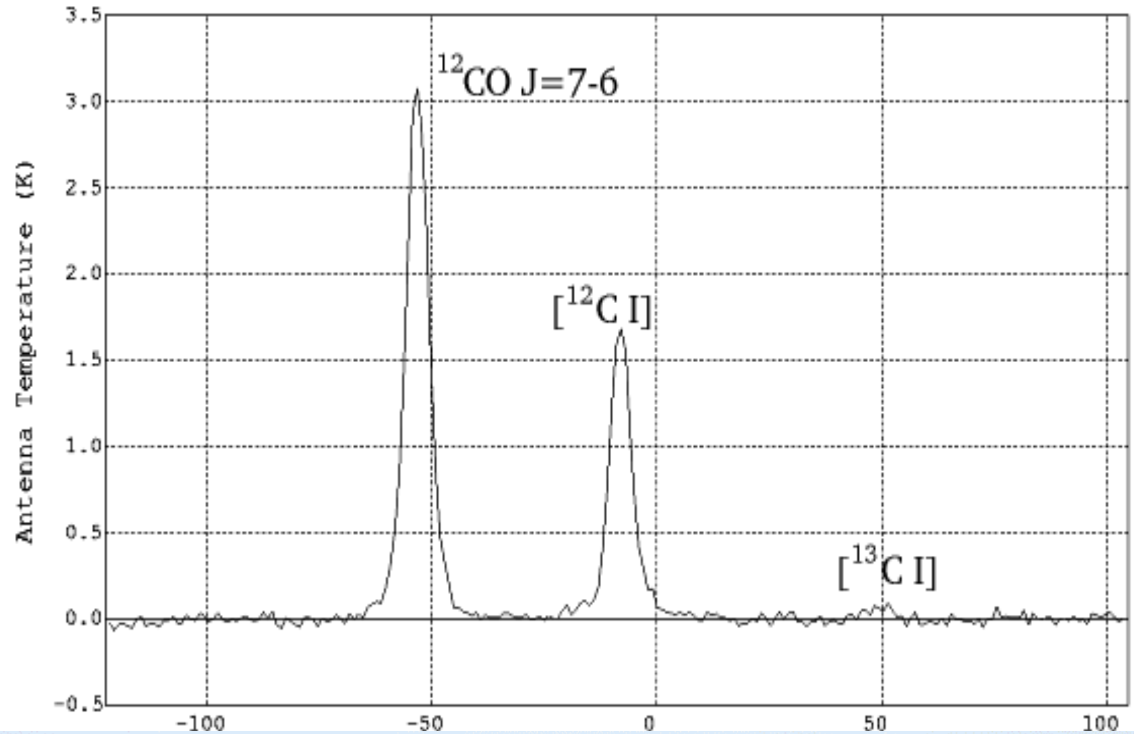
THz Atmospheric Transmission (South Pole)



^{12}CO J=4-3 map of NGC 6334

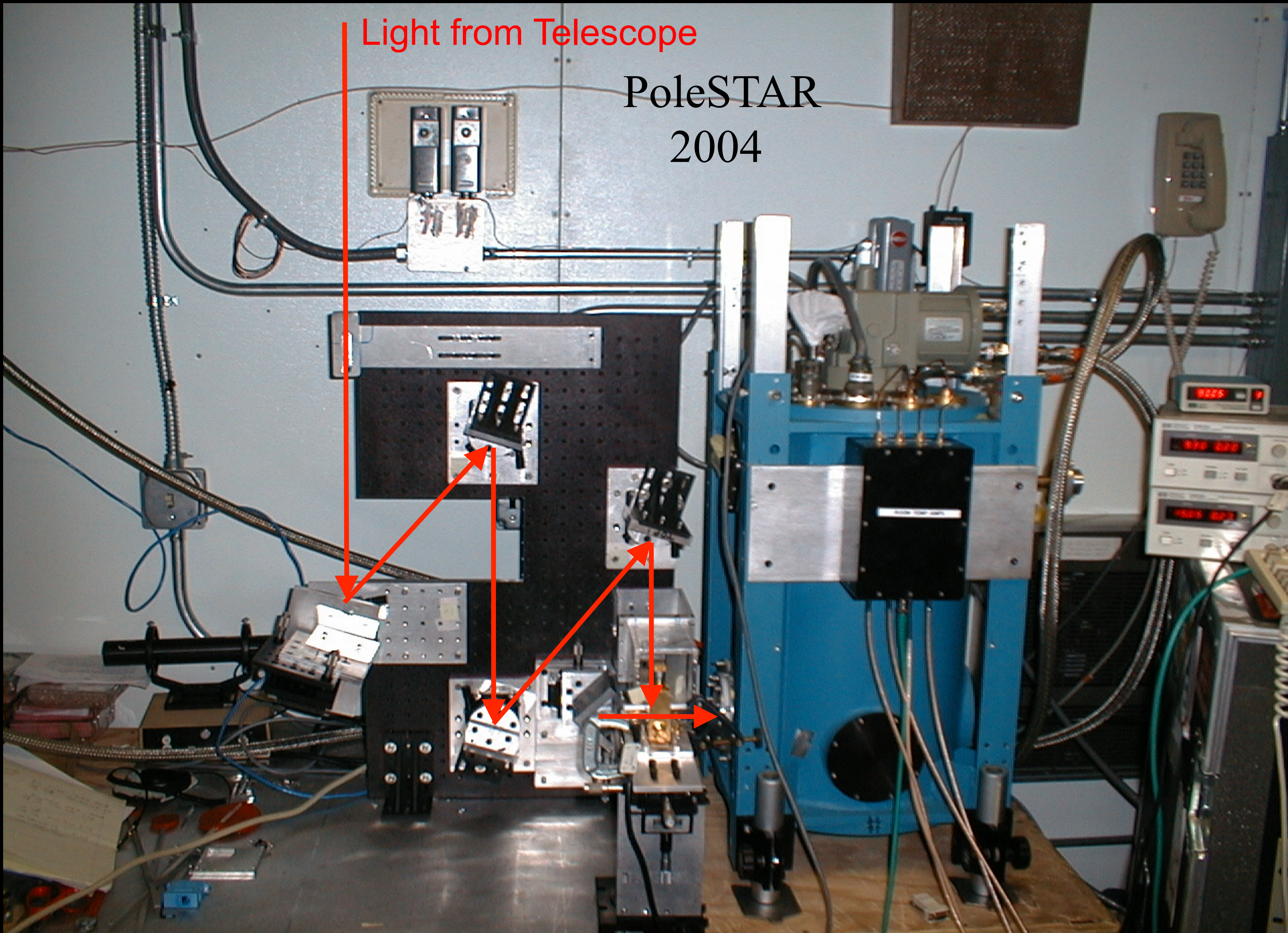


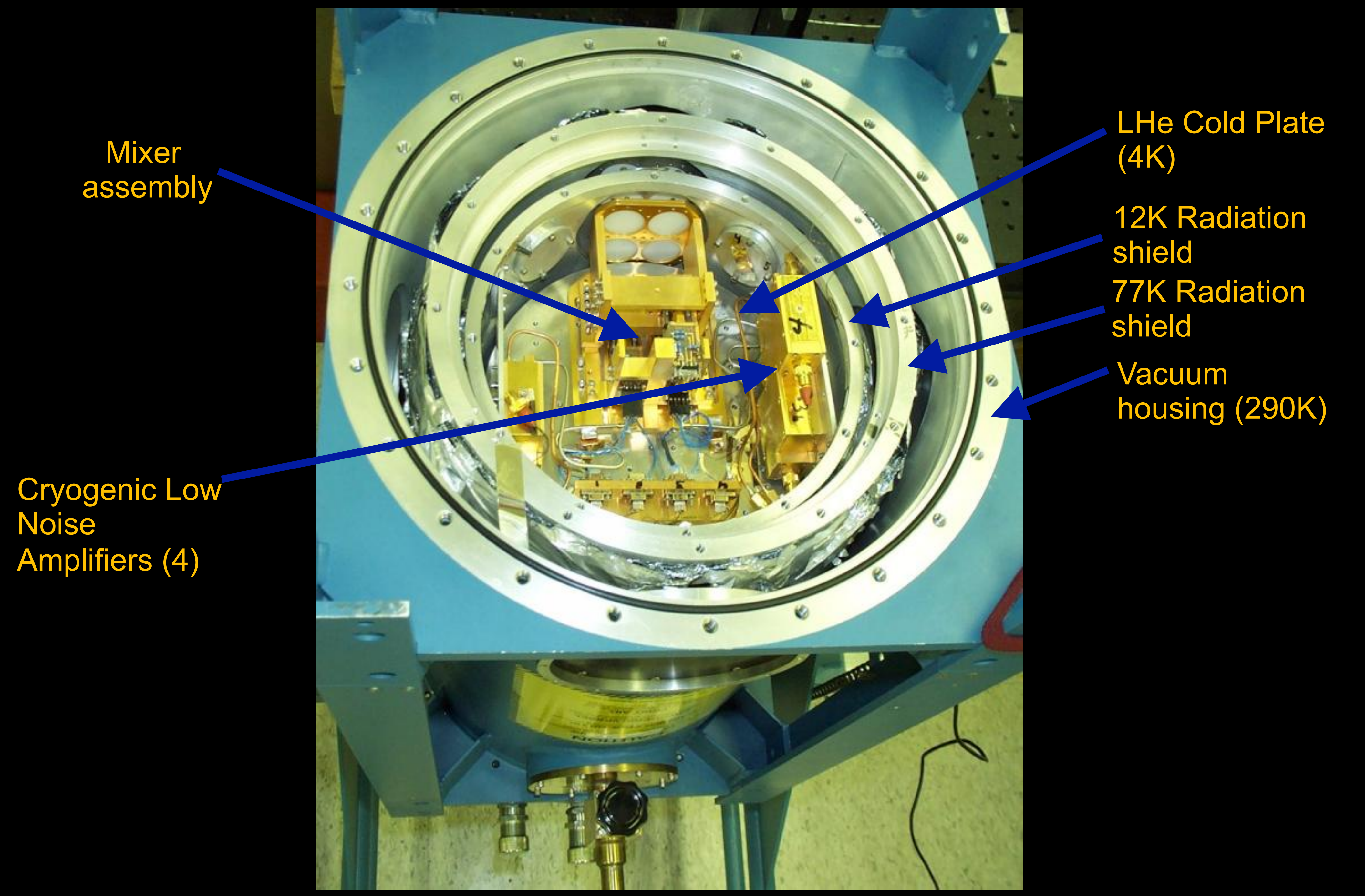
Mapped with the 1.7-m AST/RO telescope at the South Pole with the Arizona/Caltech 460/492 GHz receiver



AST/RO:

Antarctic Submillimeter Telescope and Remote Observatory


Light from Telescope
PoleSTAR
2004

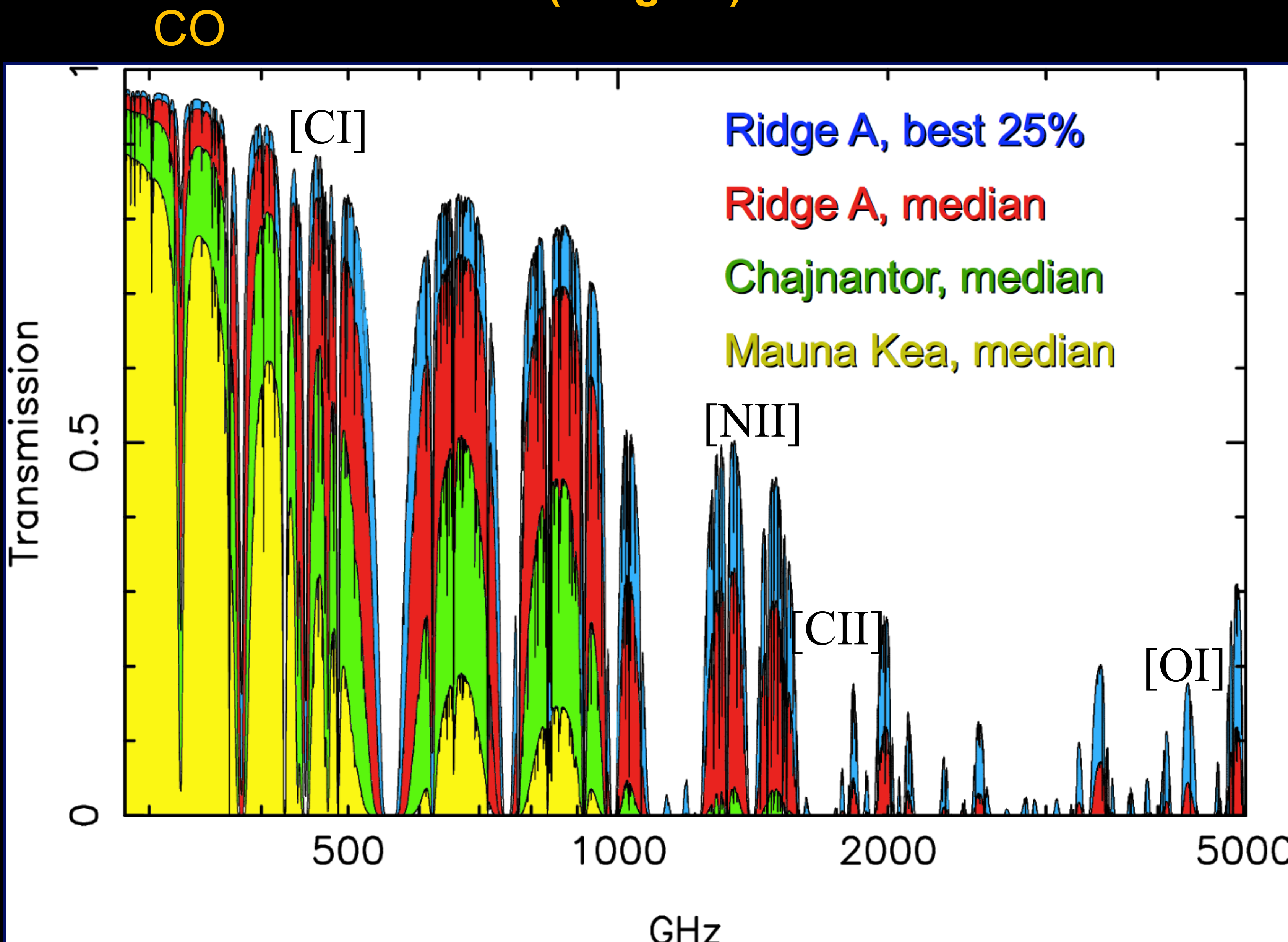


Mixer assembly
LHe Cold Plate (4K)
12K Radiation shield
77K Radiation shield
Vacuum housing (290K)
Cryogenic Low Noise Amplifiers (4)

How do we go about studying the ISM?

1. The Ground
    A. North America
    B. South America
    C. South Pole
    D. Ridge A

THz Atmospheric Transmission
(Ridge A)



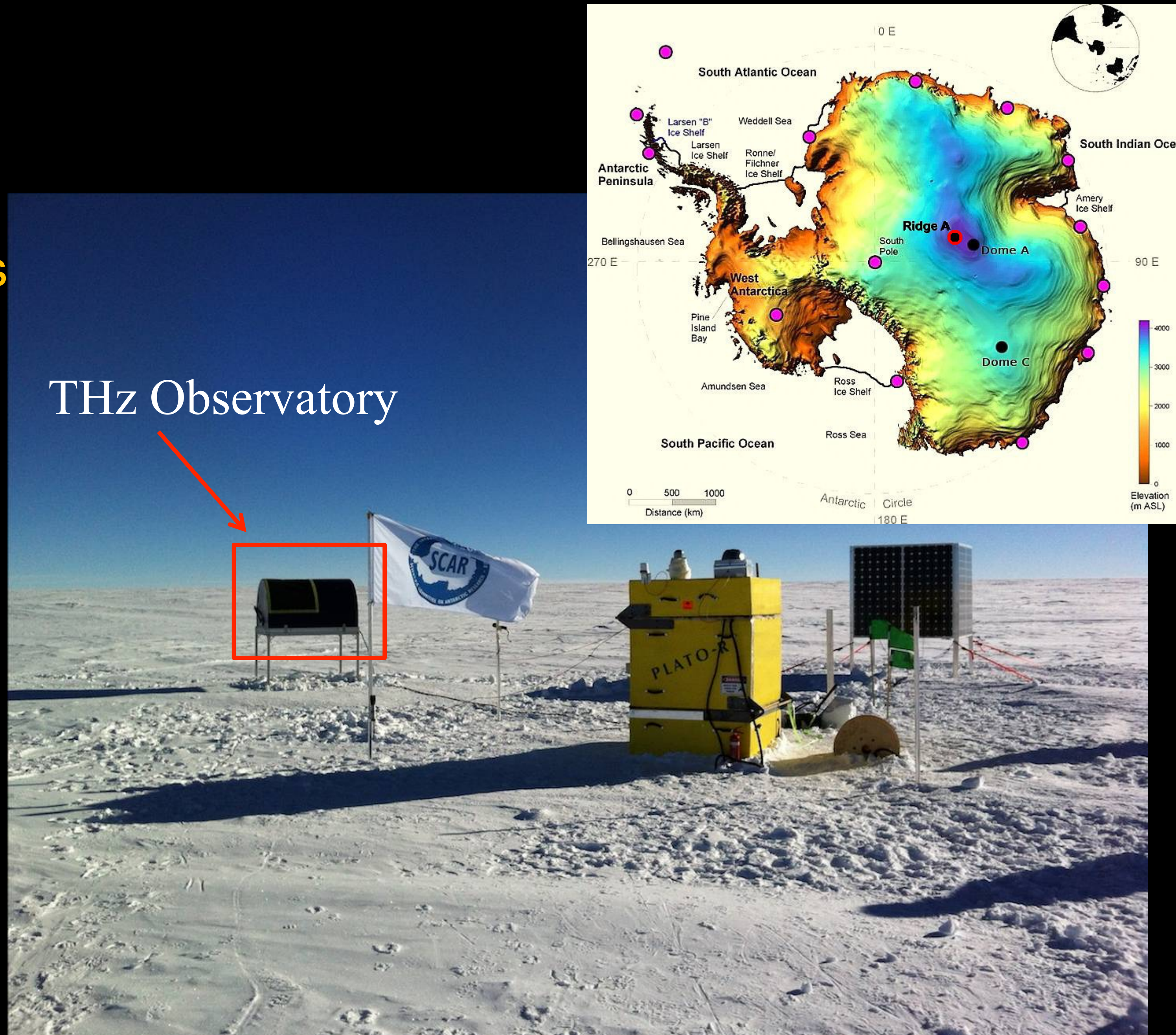
High Elevation Antarctic Telescope (HEAT) in 2012

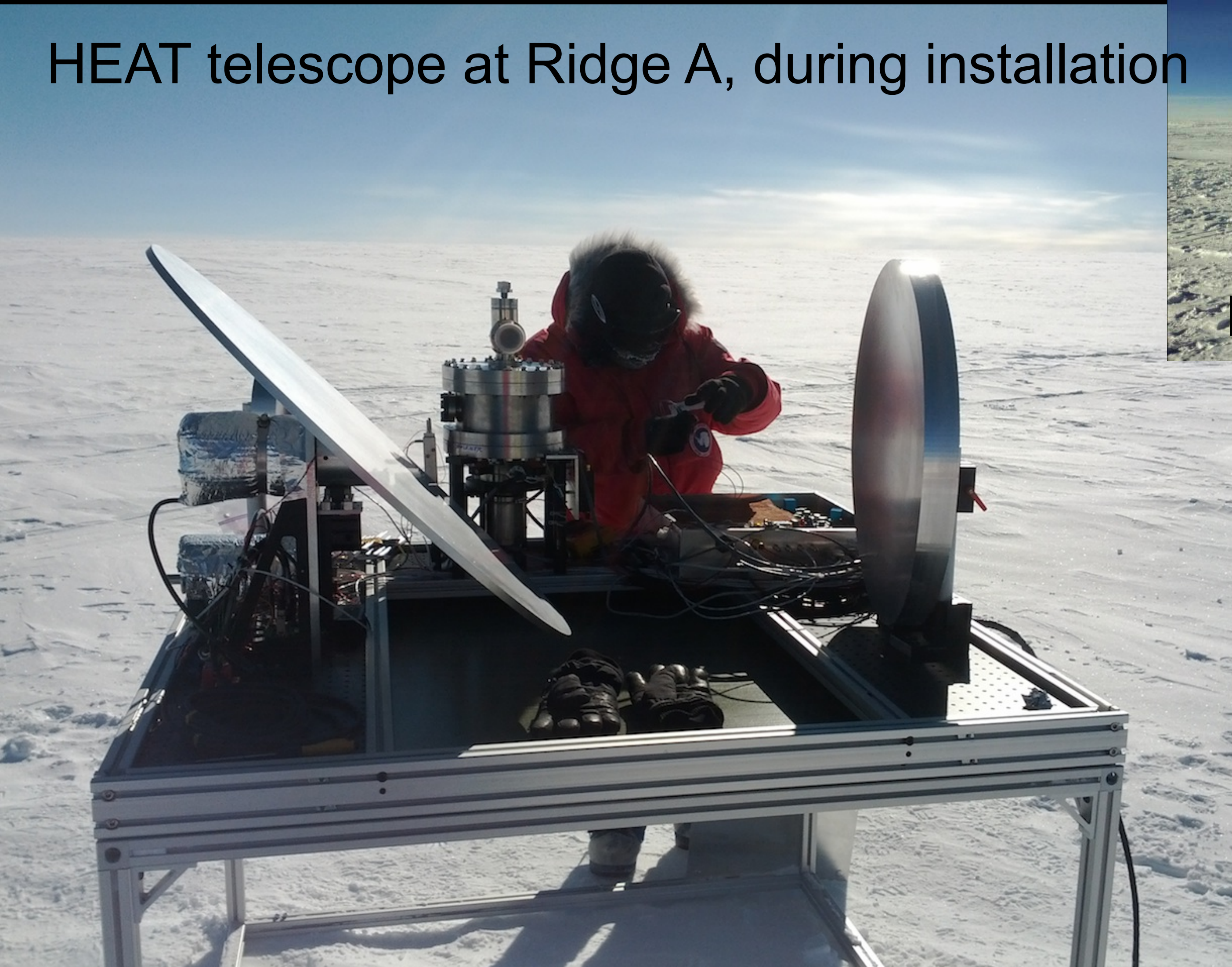
A new Terahertz Observatory on Ridge A

Cryocooled Schottky receivers at 492 and 810 GHz (2012)

A complete spectroscopic THz facility for 150 watts!

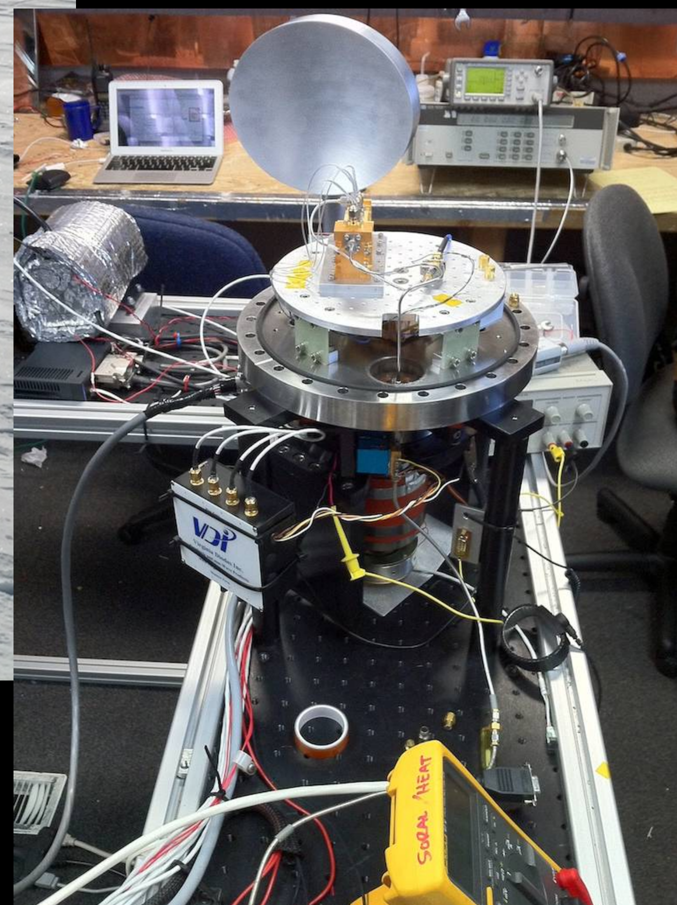
PI: Craig Kulesa





HEAT telescope at Ridge A, during installation

Deployed by Twin Otter



HEAT cryostat assembly
At South Pole

Continuing Science Drivers:

Goal 1: Determine the constituents and life cycle of interstellar gas in the Milky Way.

Goal 2: Witness the formation and destruction of star forming clouds.

Goal 3: Understand the dynamics and gas flow into and within the Galactic Center.

Goal 4: Understand the interplay between star formation, stellar winds and radiation, and the structure of the ISM in the Large Magellanic Cloud (LMC).

Goal 5: Construct Milky Way and LMC templates for comparison to distant galaxies.

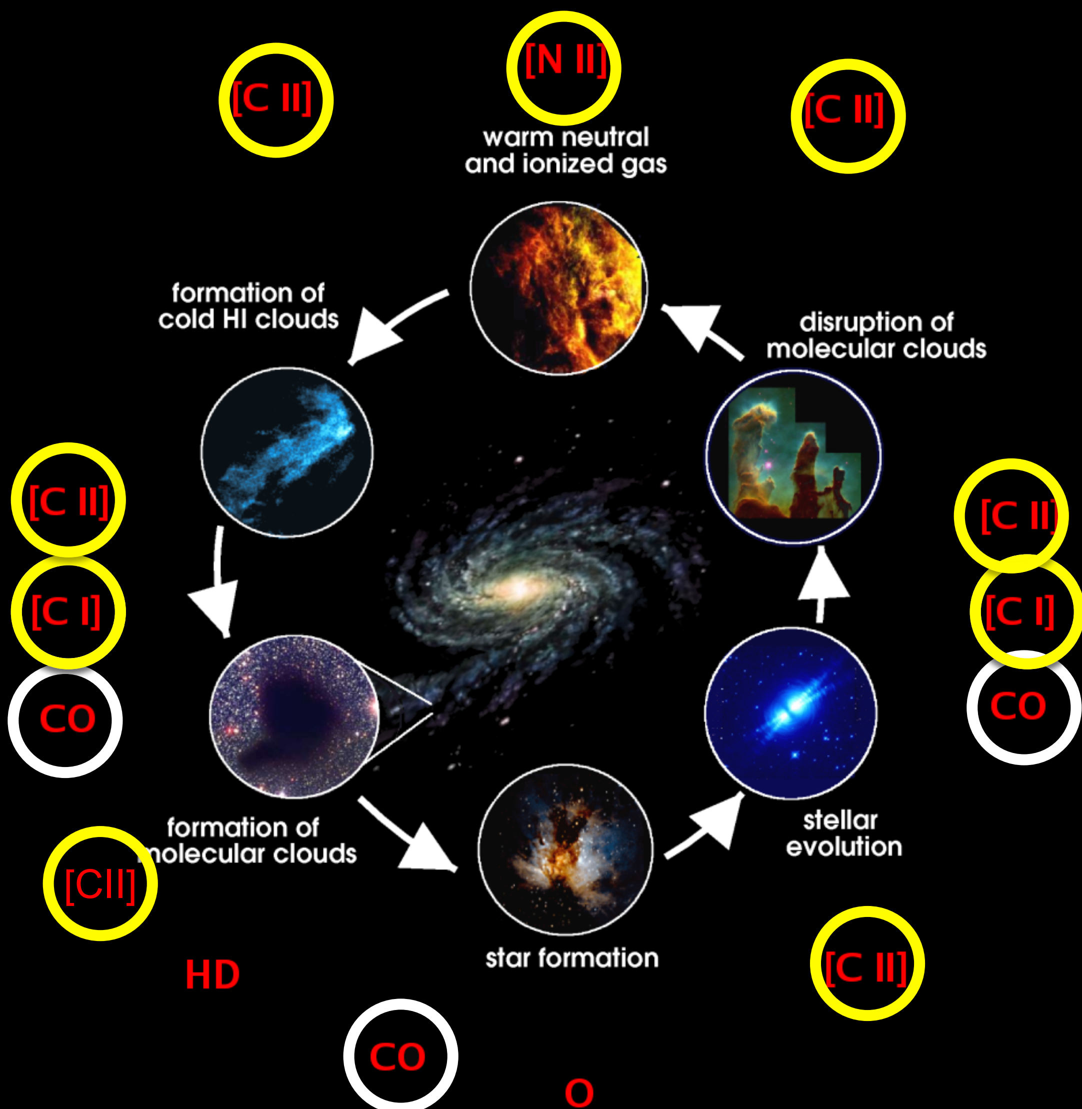
Balloon flights will serve as a Rosetta Stone for understanding the inner workings of other galaxies

How do we go about studying the ISM?

1. The Ground
   A. North America
   B. South America
   C. South Pole
   D. Rid[illegible] A[illegible]

2. Near-Space/Space
   A. Airplanes
   B. High Altitude Balloons
   C. Space Missions

Life Cycle of Interstellar Medium (ISM)



SuperCam, ASTRO, and HEAT

STO

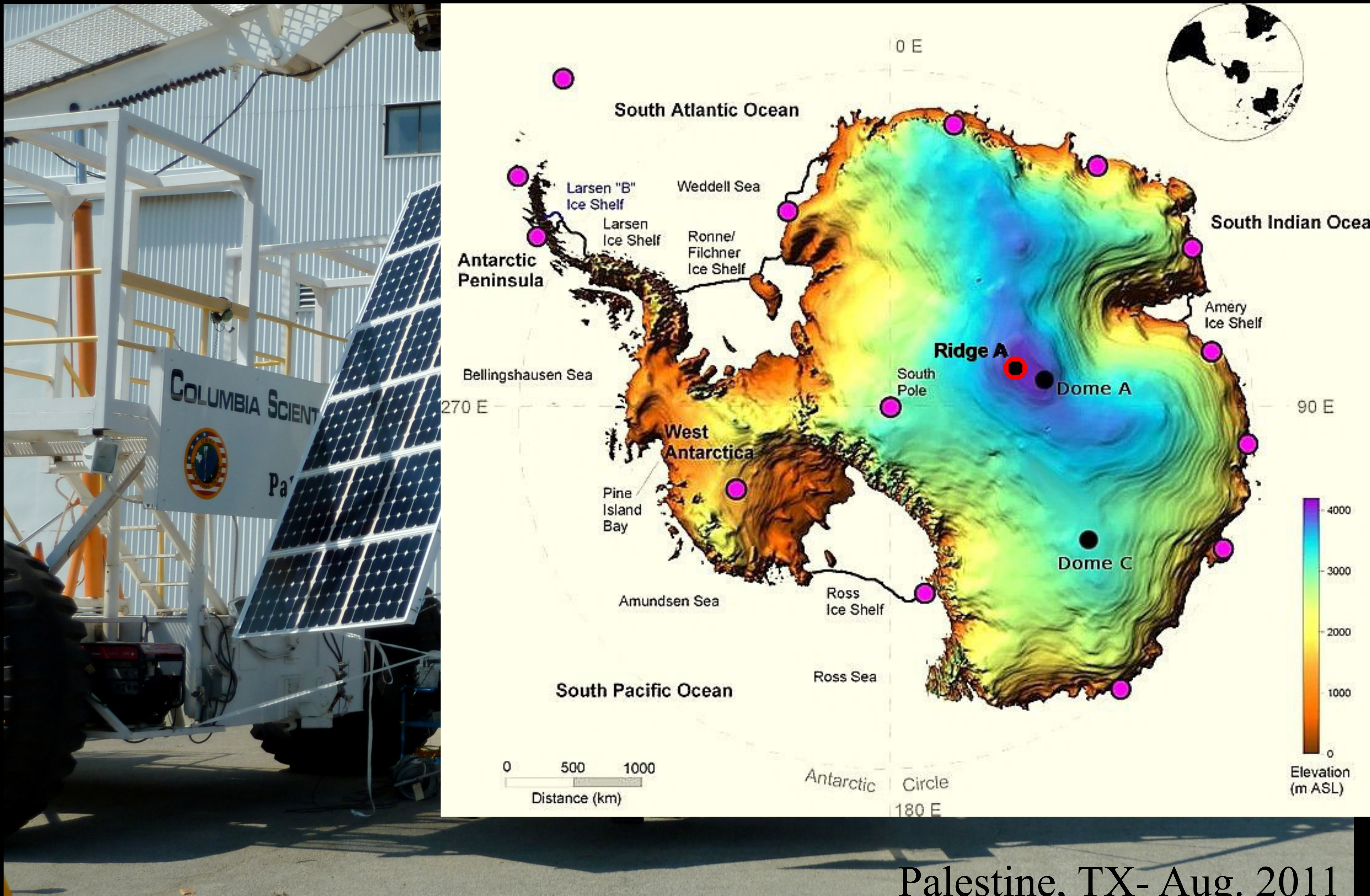
Selected Spectral Lines:

CO: λ = 0.8 mm, v = 345 GHz

[NII]: λ = 205 μm, v = 1.46 THz

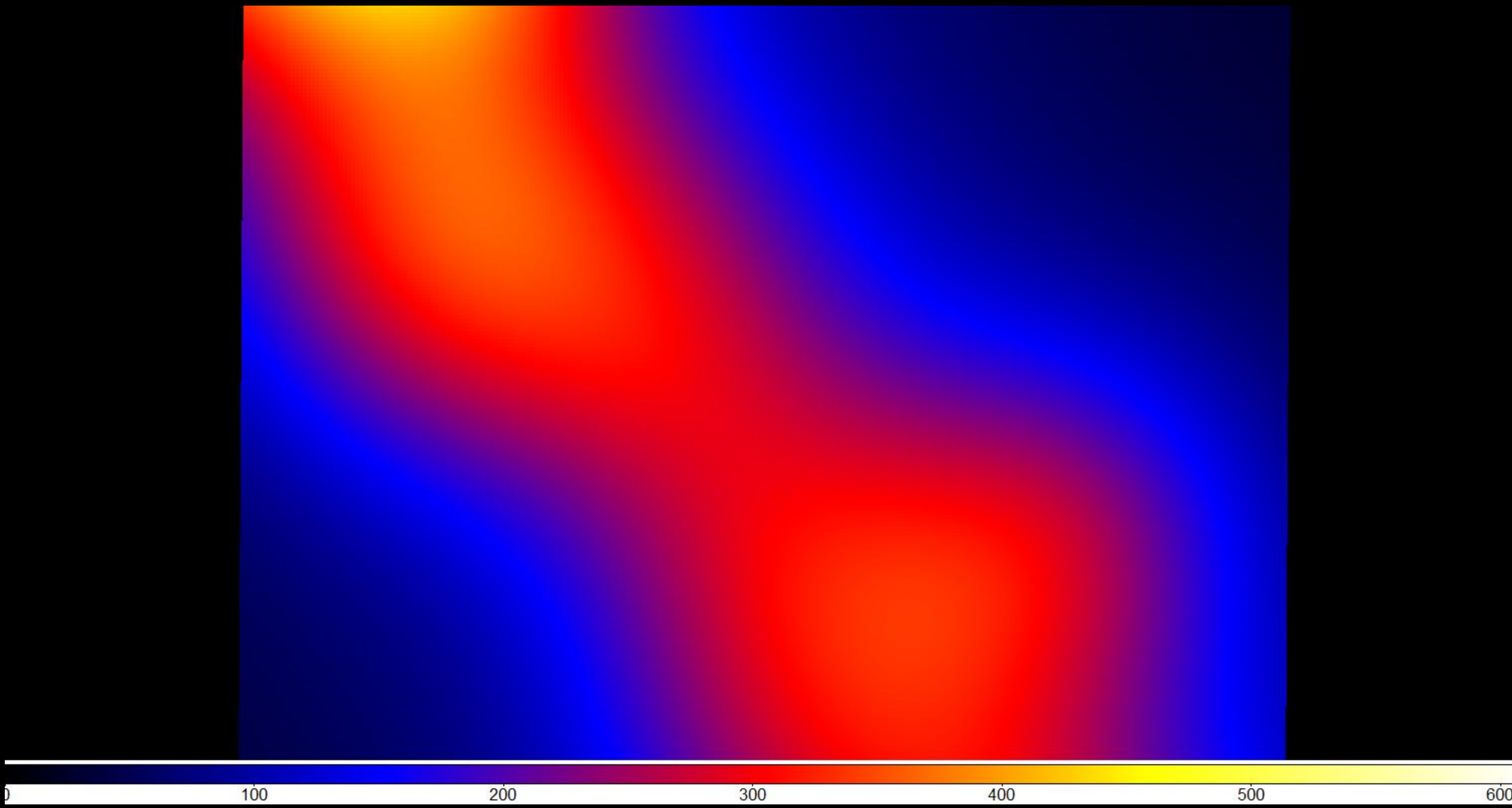
[CII]: λ = 158 μm, v = 1.9 THz

Stratospheric THz Observatory (STO)



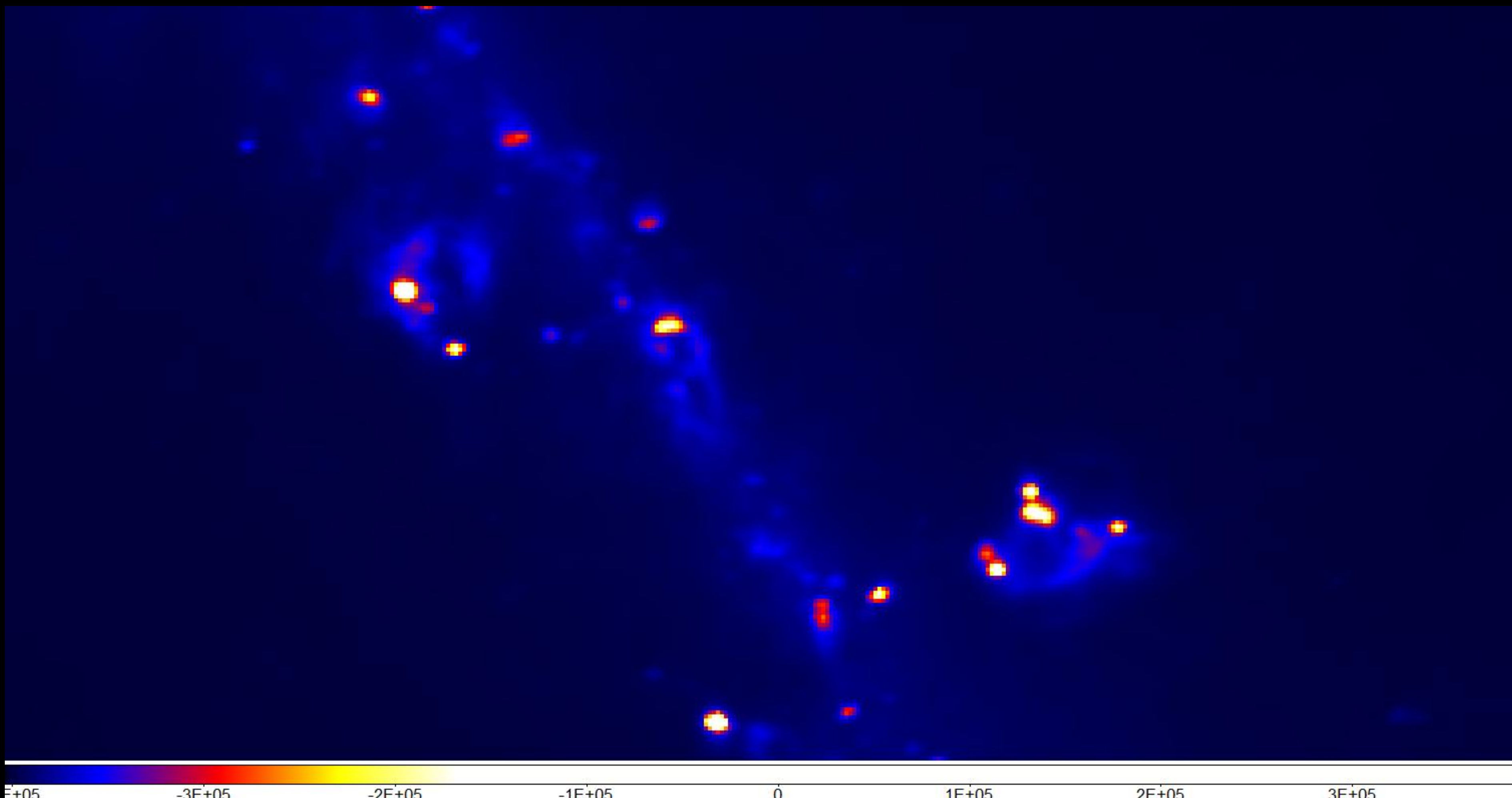
Palestine, TX- Aug. 2011

Modest Apertures Vastly Improve Available Angular Resolution



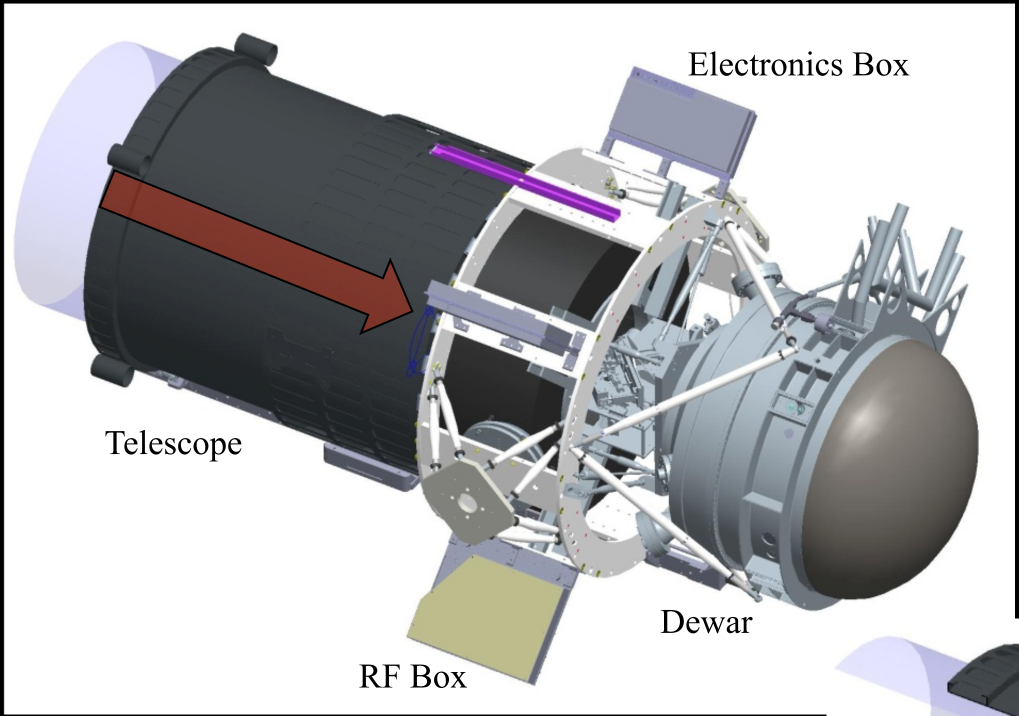
Galactic Plane Region Near **l** = 340   IRAS 60 μm Smoothed to 3°

Modest Apertures Vastly Improve Available Angular Resolution



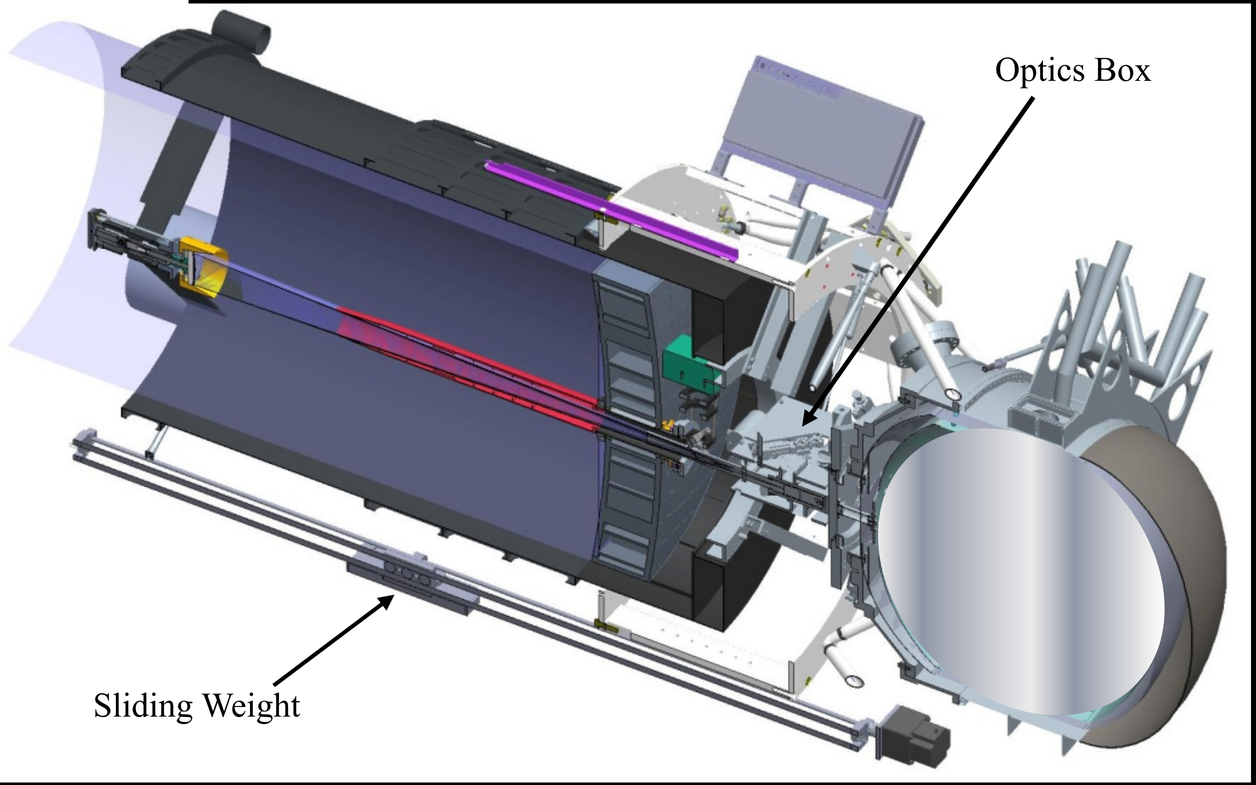
Galactic Plane Region Near **l** = 340   IRAS 60 μm 2’ Resolution

STO Science Flight Configuration



Telescope Specifications:

- 1^{ary} aperture: 80 cm
- Length: ~1.2 m
- F-ratio: F/17.5
- ½ angle FOV: 3.5 arcmin
- 1^{ary} material: ULE glass honeycombed
- Weight: 420 lbs



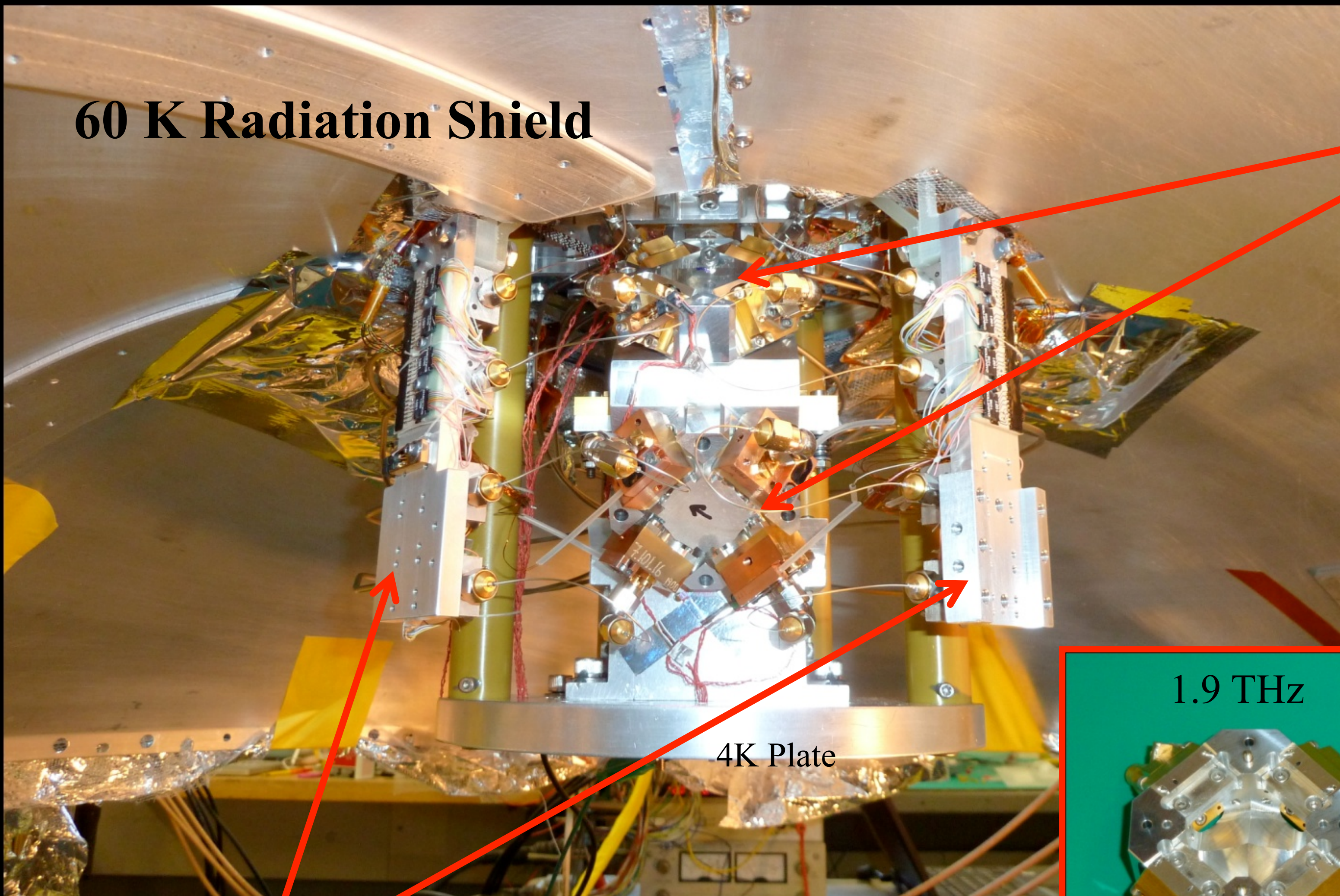
— 2 -4 Pixel HEB Mixer arrays
  — HEB mixers down-convert high frequency sky signals to microwave frequencies
— Cryogenic System keeps FPA @ 4K with 100 l liquid He cryostat

Schottky Receiver for warm mission when cryogens exhausted

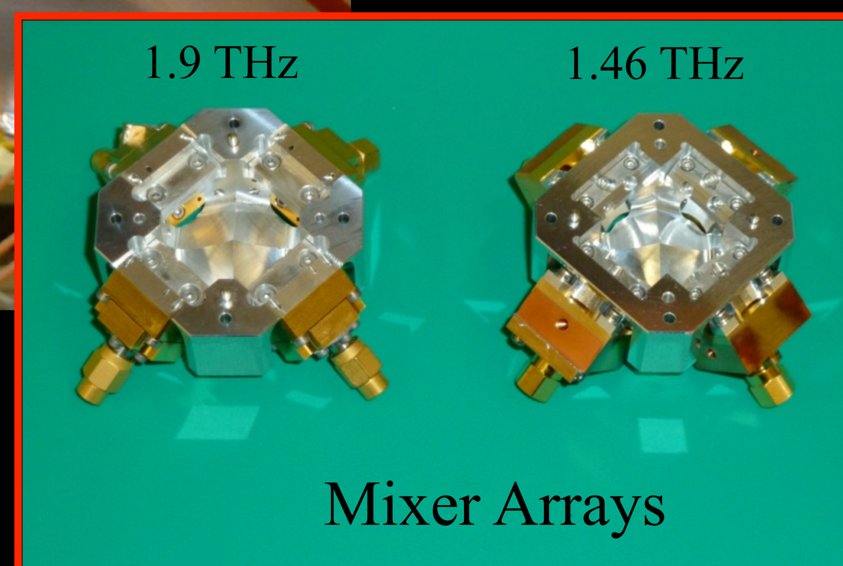
— Survey of [CI] @ 492 GHz

FPU Insert → What's Under the Hood

Mixer Arrays



IF Amplifiers Assemblies



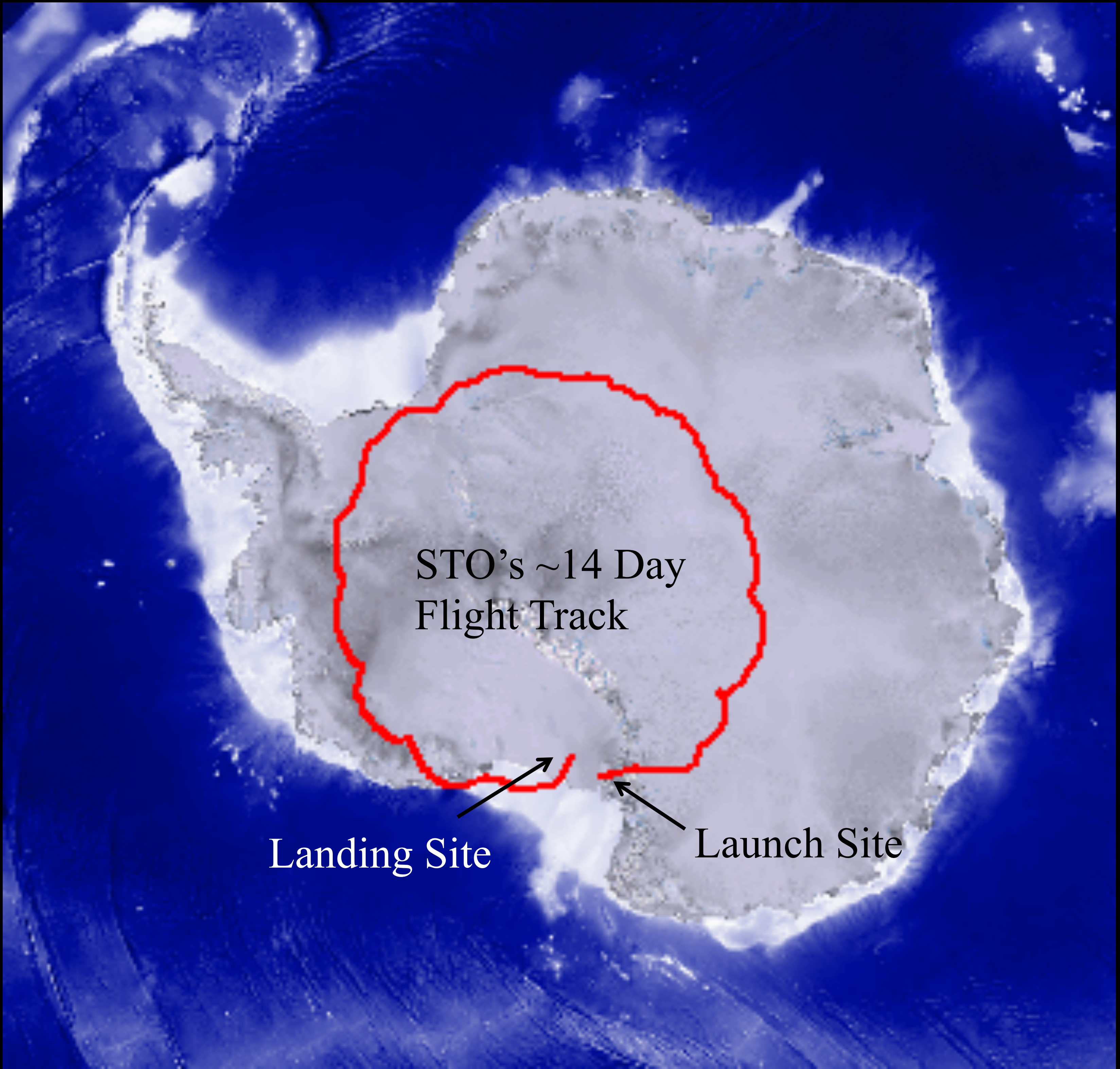
STO Movie

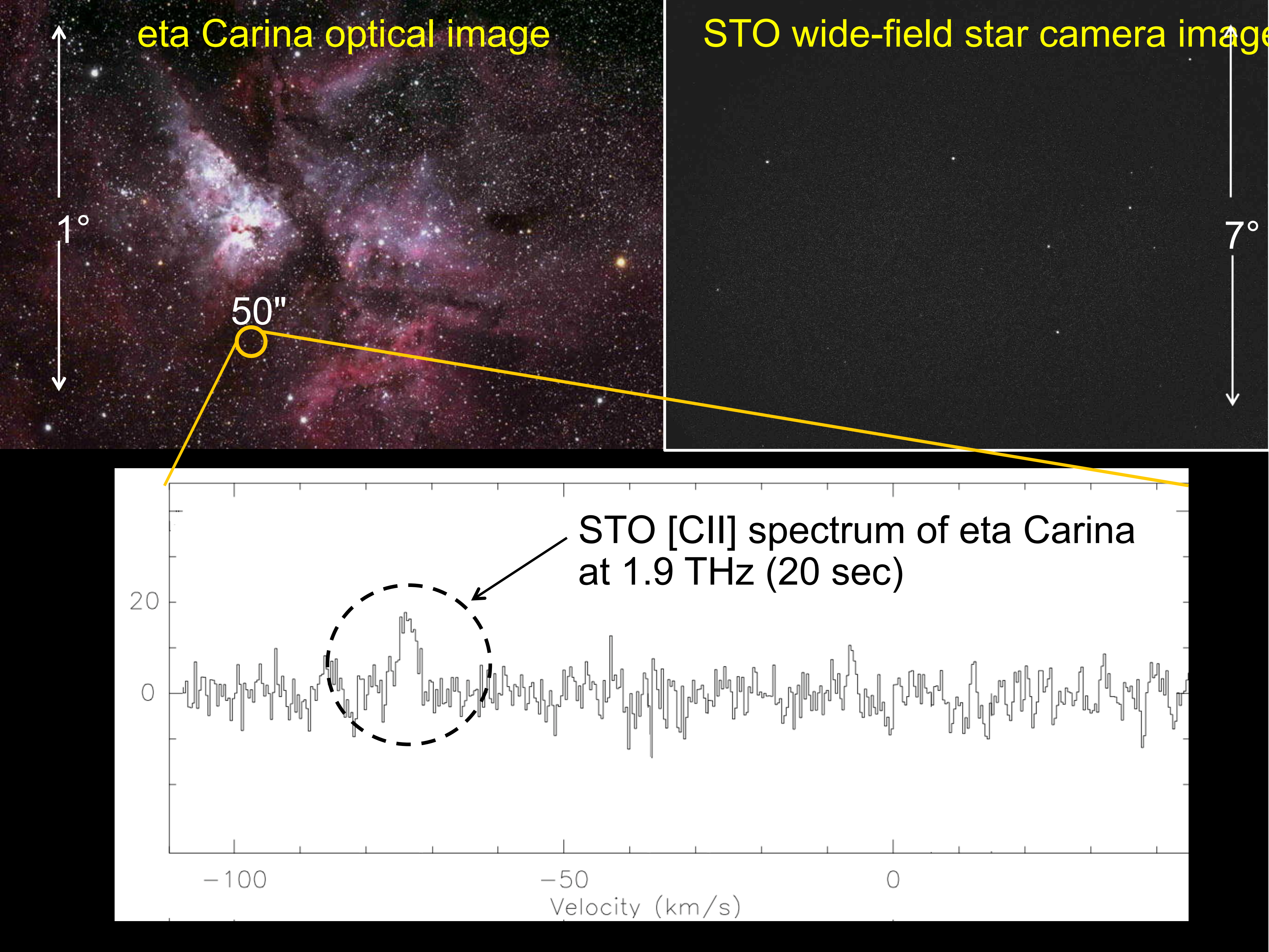
Bill Rodman

November – January: 2011/12

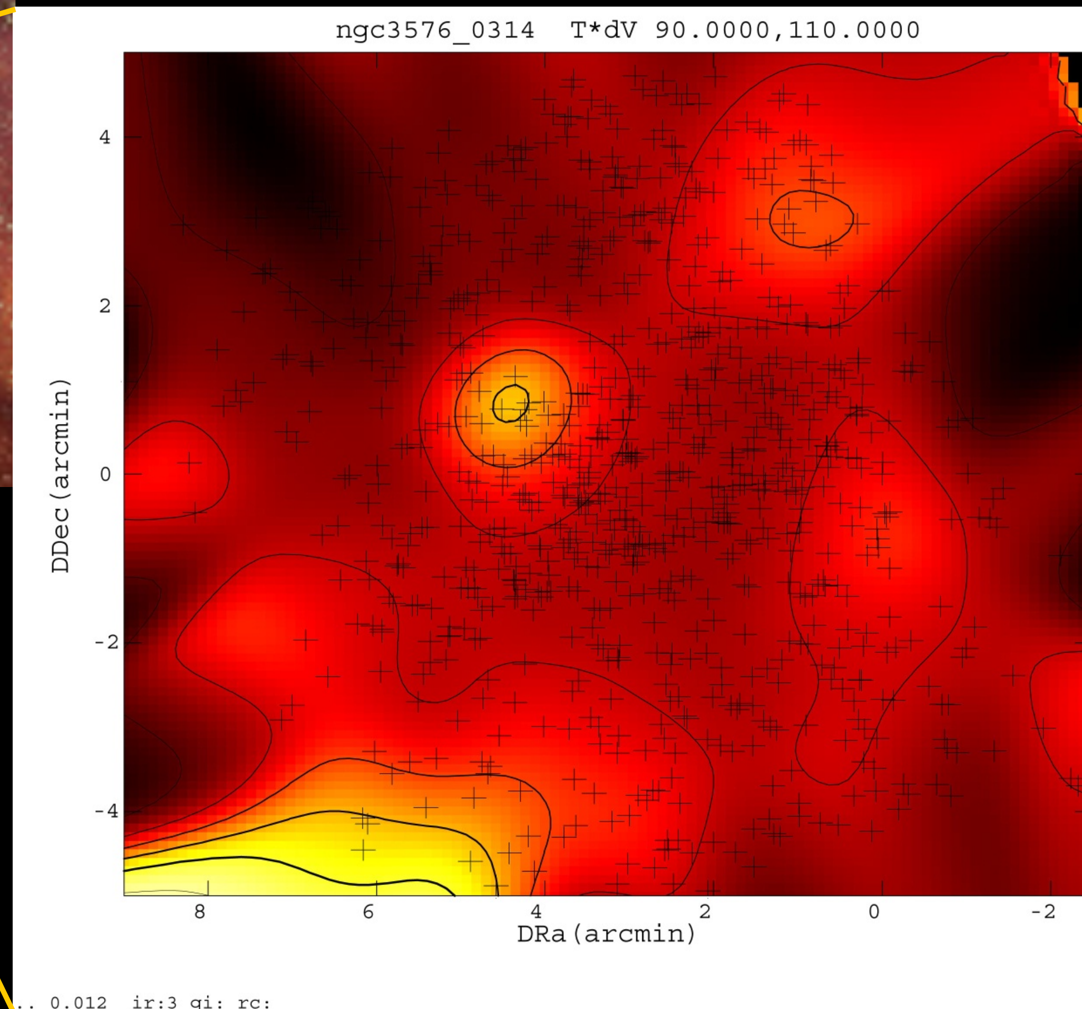
Looking Down….

Looking Out….


STO's ~14 Day
Flight Track
Landing Site
Launch Site


eta Carina optical image
1°
50"
STO wide-field star camera image
7°
STO [CII] spectrum of eta Carina
at 1.9 THz (20 sec)
20
0
−100
−50
0
Velocity (km/s)

NGC 3576
STO [CI]



Distance ~ 3000 ly
Diameter ~50 ly

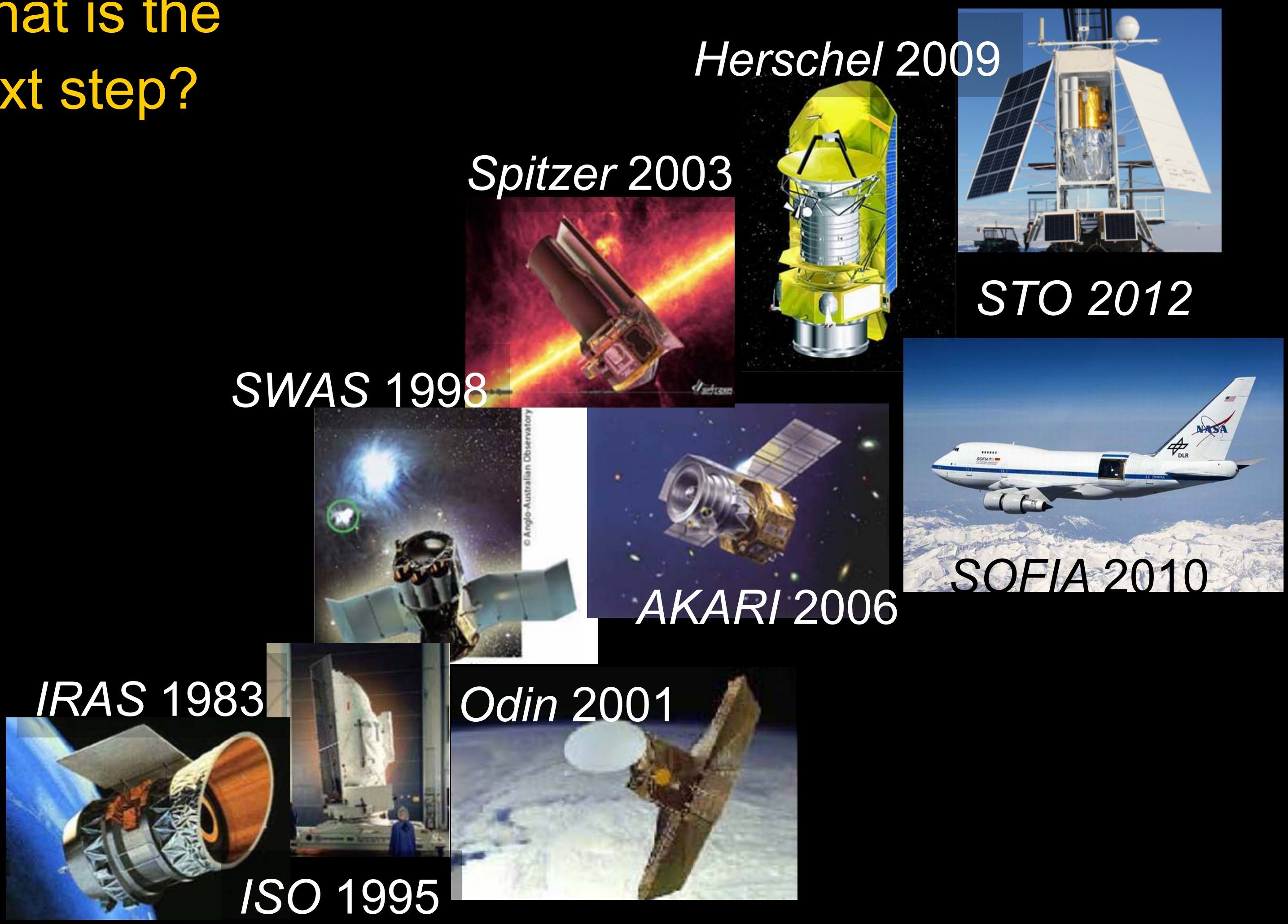
Coming Down….Payload on the Parachute

STO Recovery Operations

- Payload in good shape!
- Expect a 2nd Flight in 2015

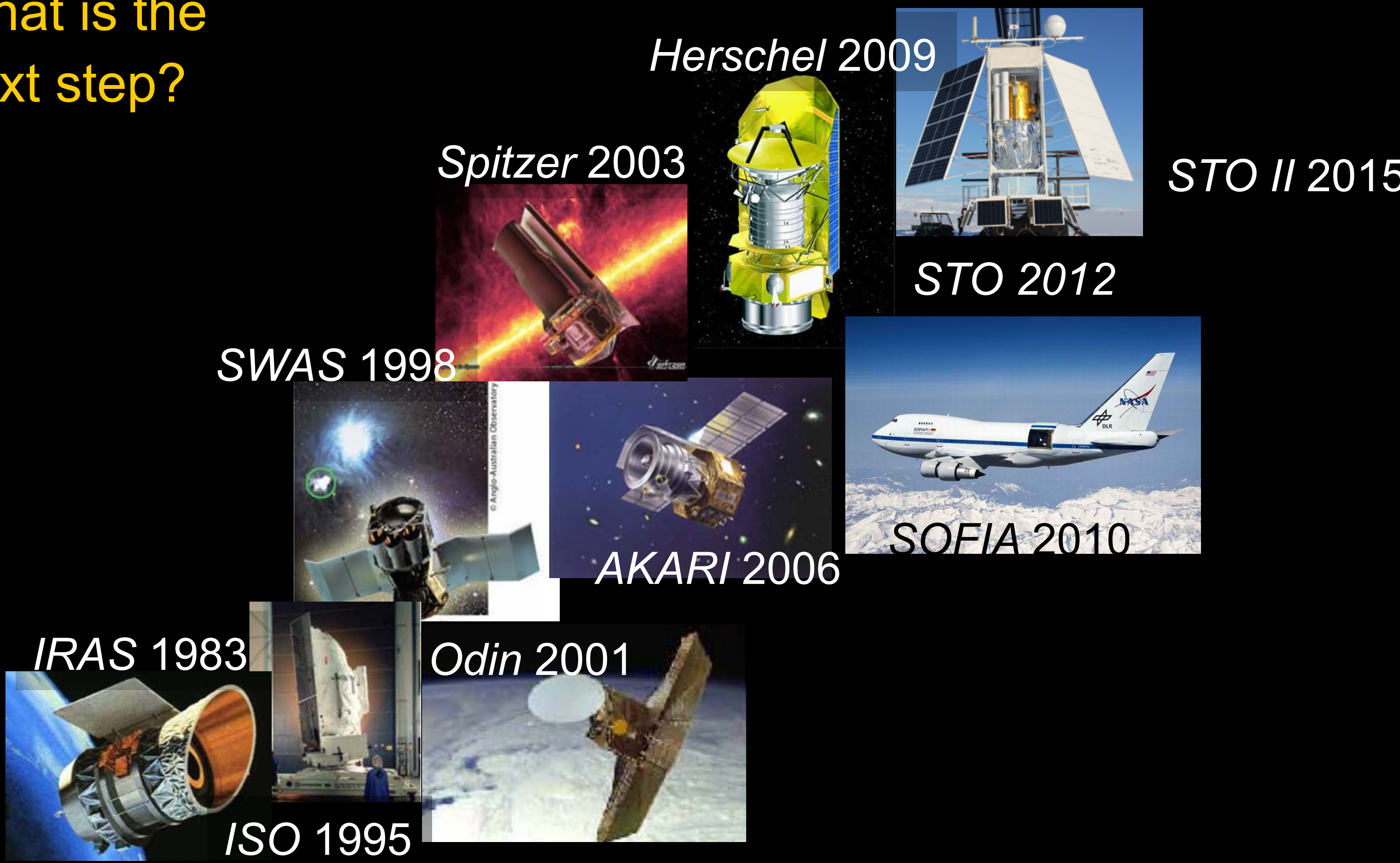
IR/THz Missions

What is the
next step?



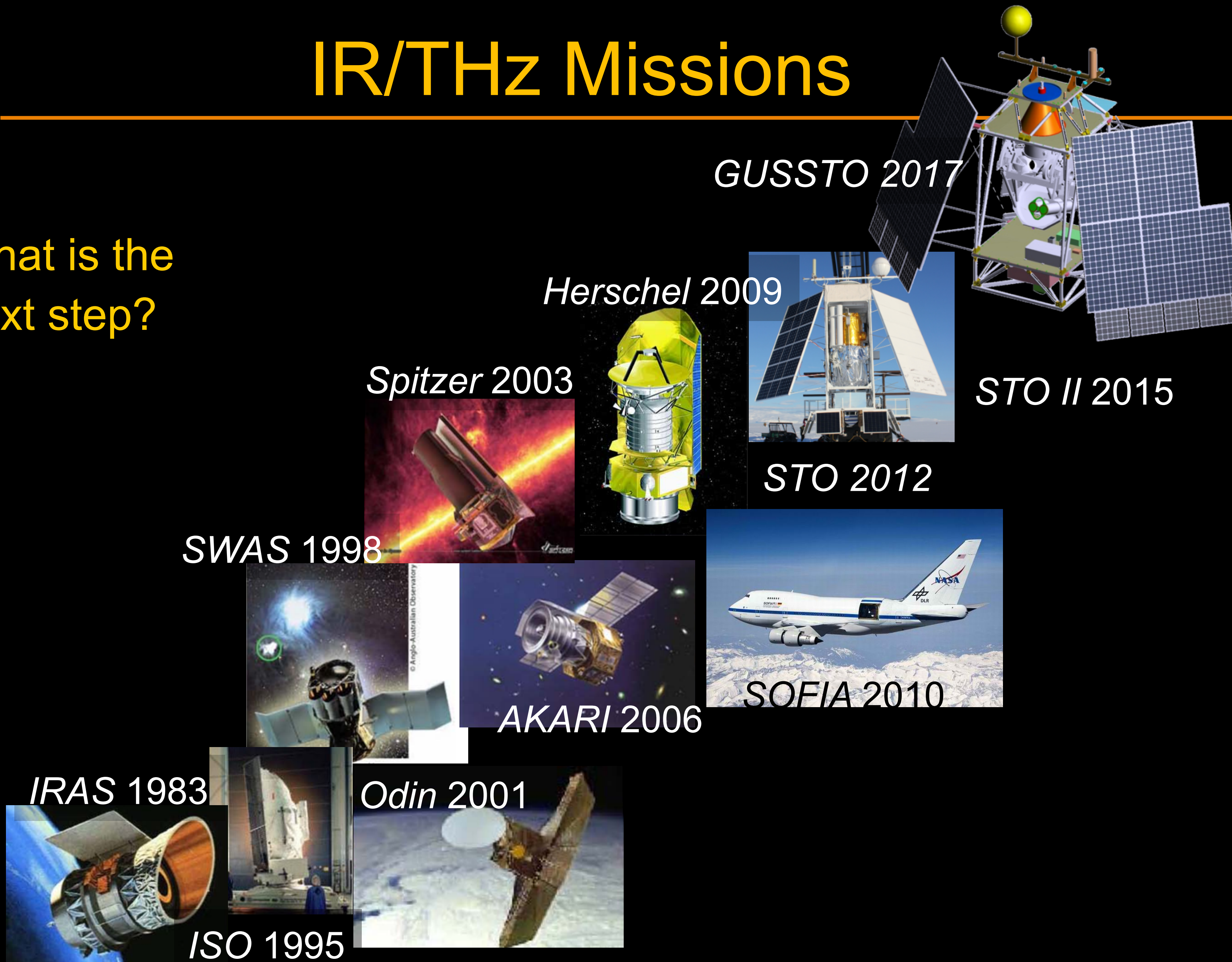
IR/THz Missions

What is the next step?

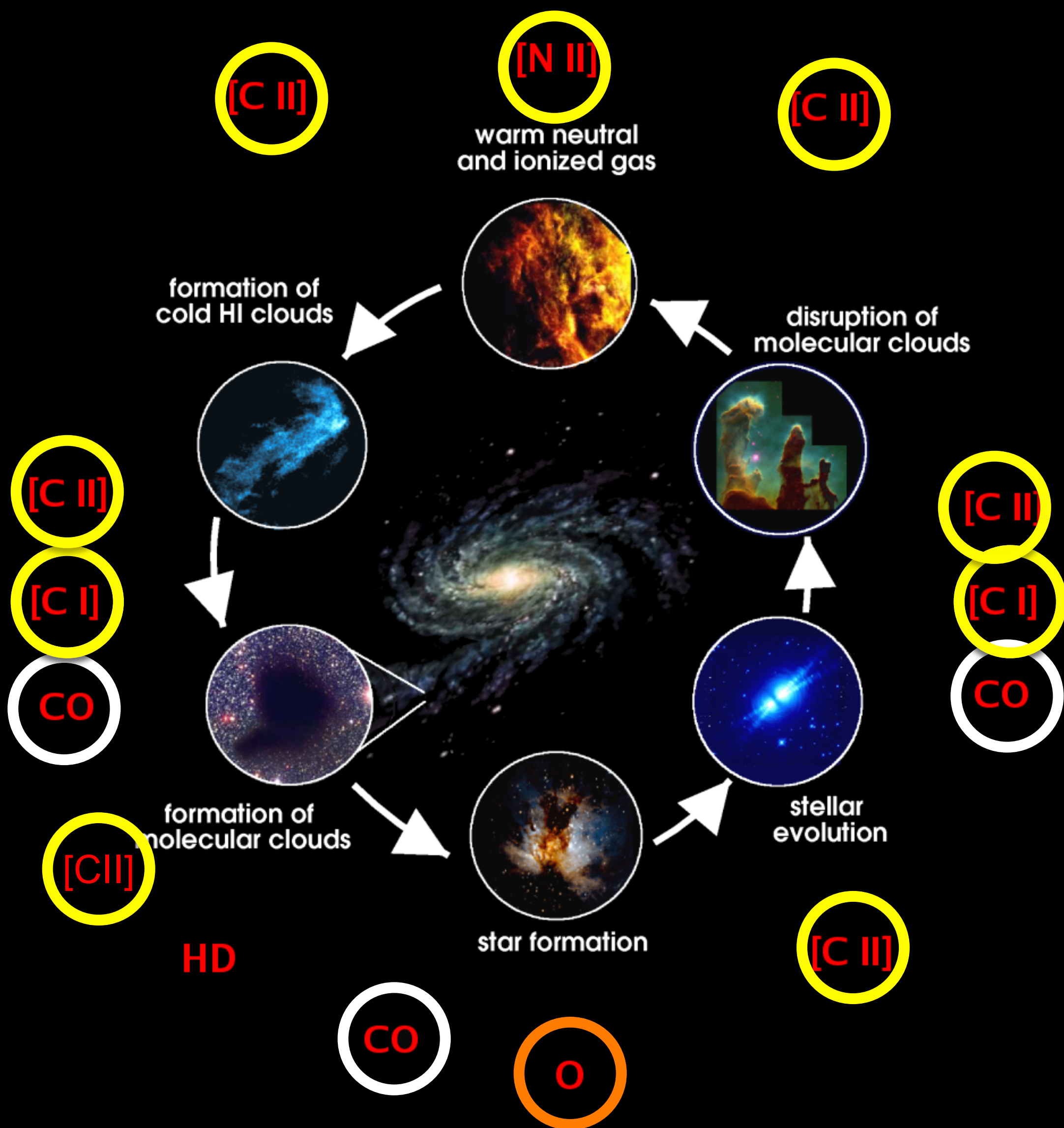


IR/THz Missions

What is the next step?



Life Cycle of Interstellar Medium (ISM)



SuperCam, ASTRO, and HEAT

STO

STO II / GUSSTO

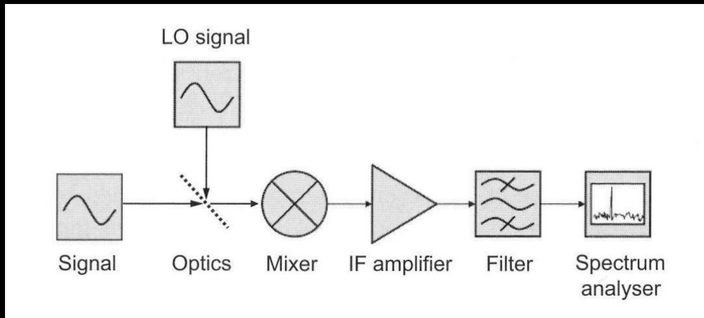
Selected Spectral Lines:

CO: λ = 0.8 mm, ν = 345 GHz

[NII]: λ = 205 μm, ν = 1.46 THz

[CII]: λ = 158 μm, ν = 1.9 THz

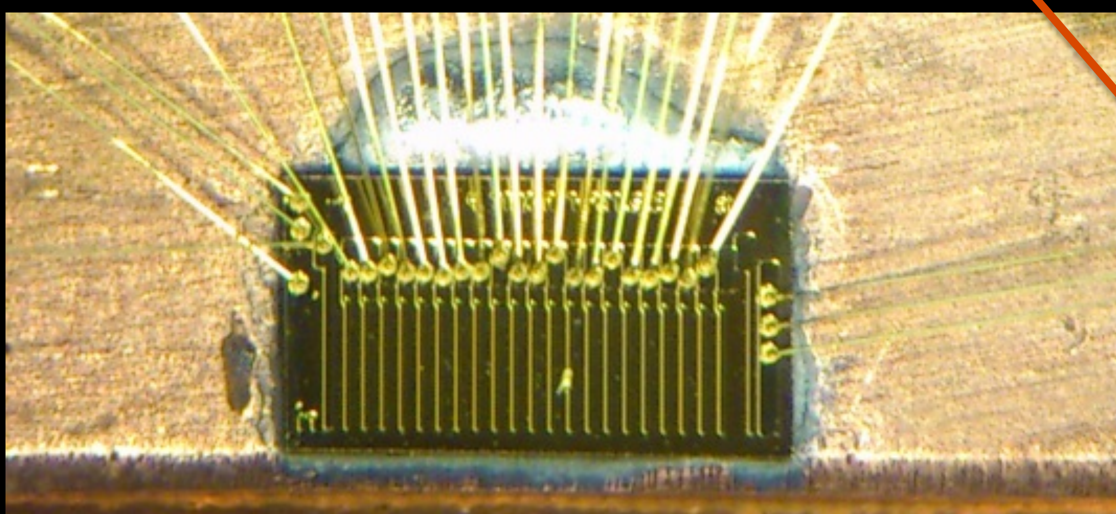
[OI]: λ= 63 μm, ν = 4.745 THz



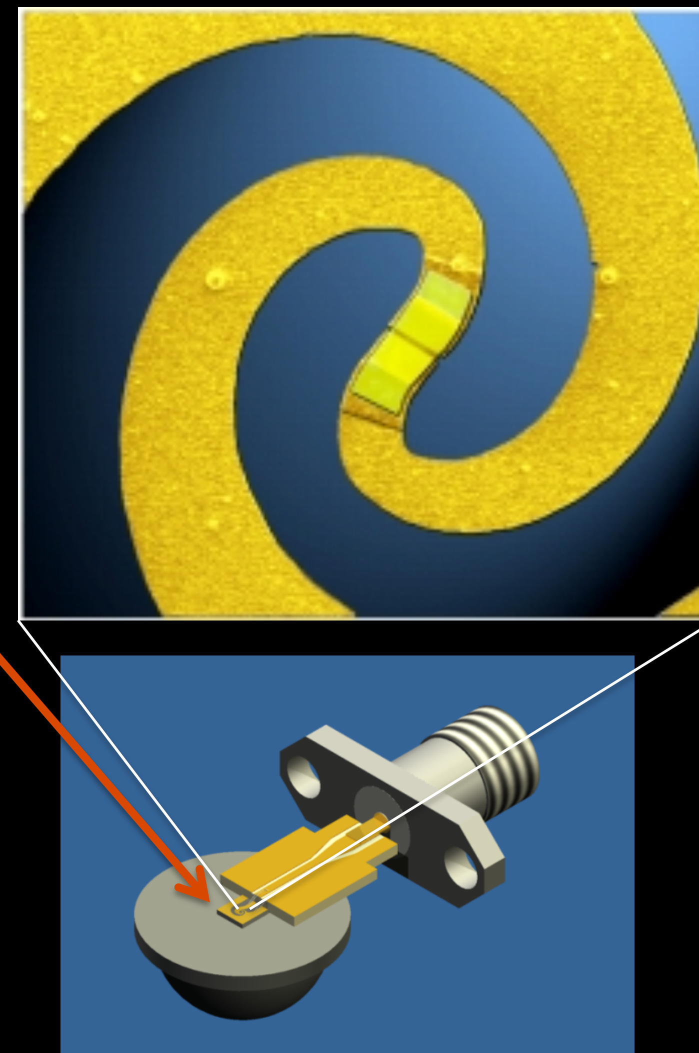
4.7 THz Receiver Development

For GUSSTO/STO-II

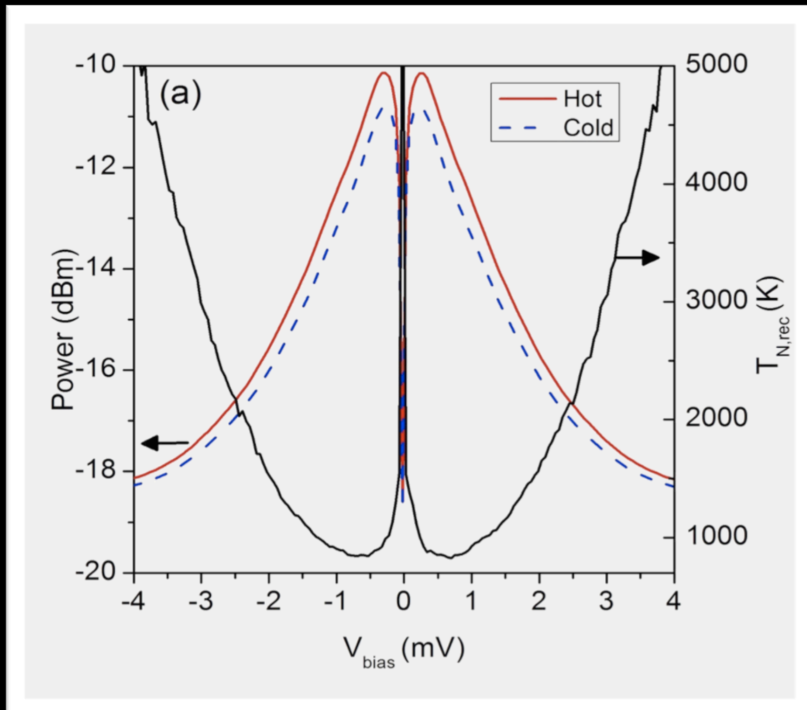
- Mixer: Hot Electron Bolomenter (HEB)
- Local Oscillator: 4.7 THz Quantum Cascade Laser (QCL)

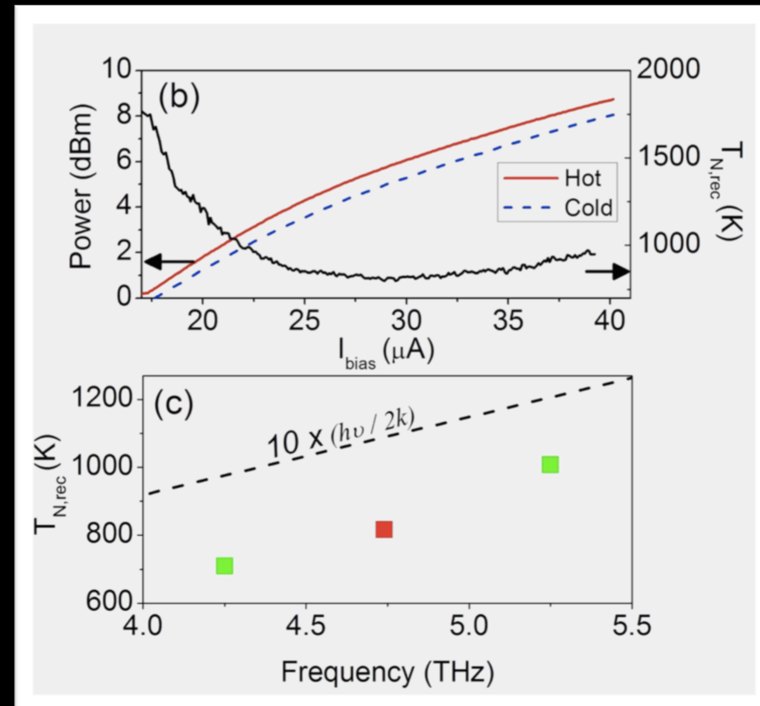


21 QCLs packaged together



Receiver Noise Temperature





- 3 methods used to measure y-factor at 4.7-THz - the bias voltage sweep method, the bias current sweep method, and the hot/cold chop (not shown) - average T^{DSB} = 815 K!!!
- HEB is most sensitive when biased to 0.65 mV and 29 μA – we corrected our measurements for direct detection effects
- At 4.25 THz, measured 750 K
- At 5.25 THz, measured 950 K

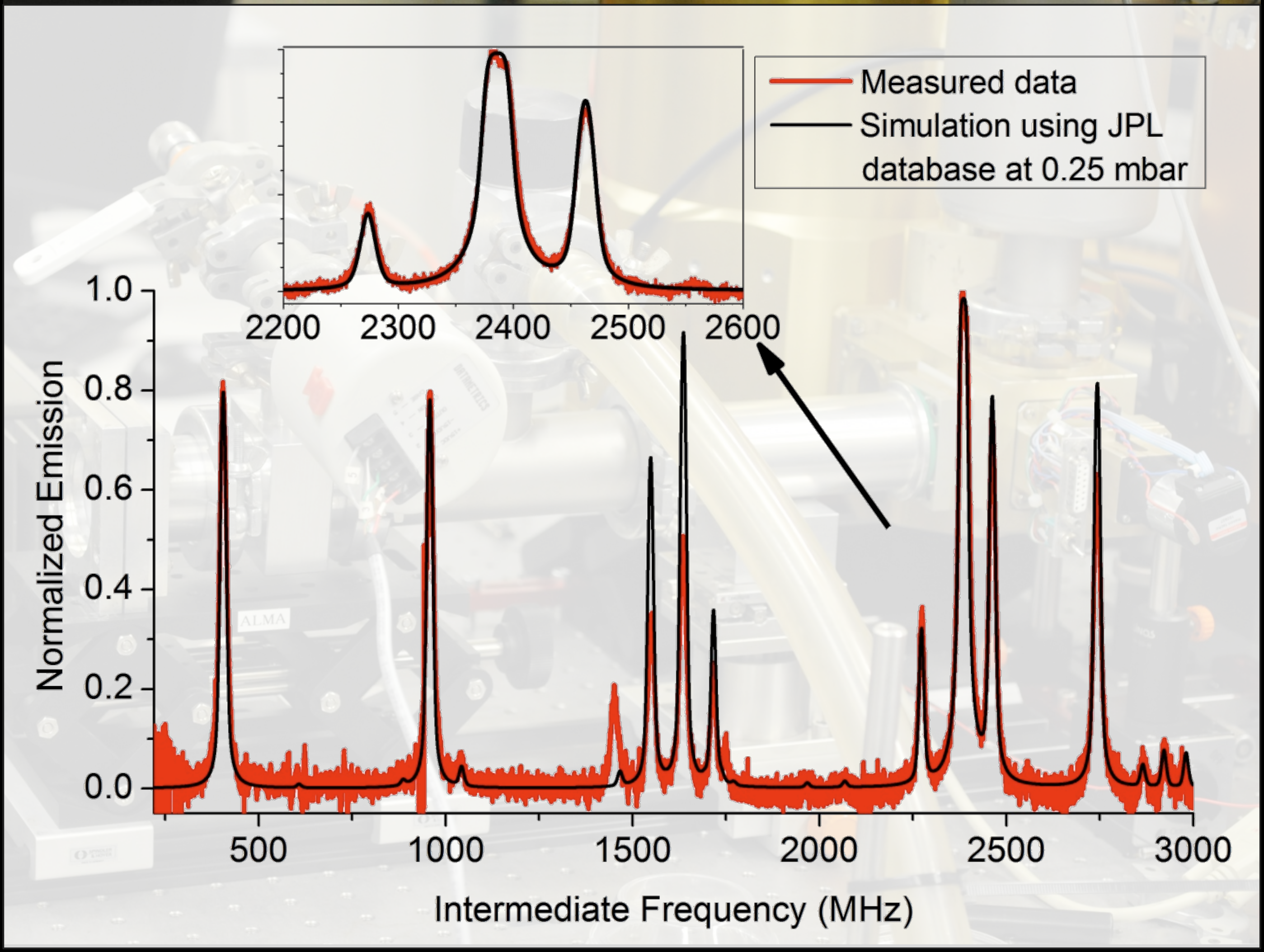
$$T_{N,rec} = \frac{T_{eff,hot} - YT_{eff,cold}}{Y - 1}$$

Methanol Gas Spectroscopy at 4.7 THz

Methanol gas spectroscopy used to verify performance

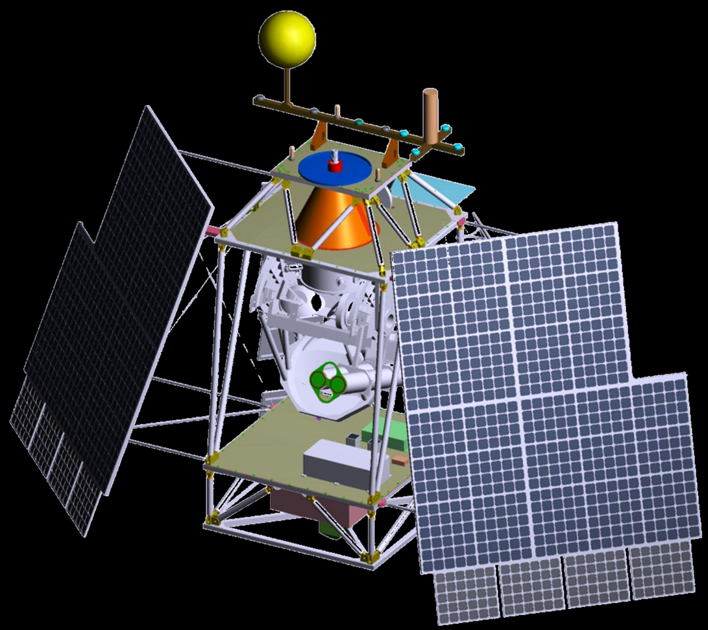
Good agreement with model demonstrates:

- HEB sensitivity
- IF linearity
- Receiver stability
- LO frequency
    - QCL: 4.7404 THz
    - [O I]: 4.7448 THz
    - -> ~4.3 GHz IF



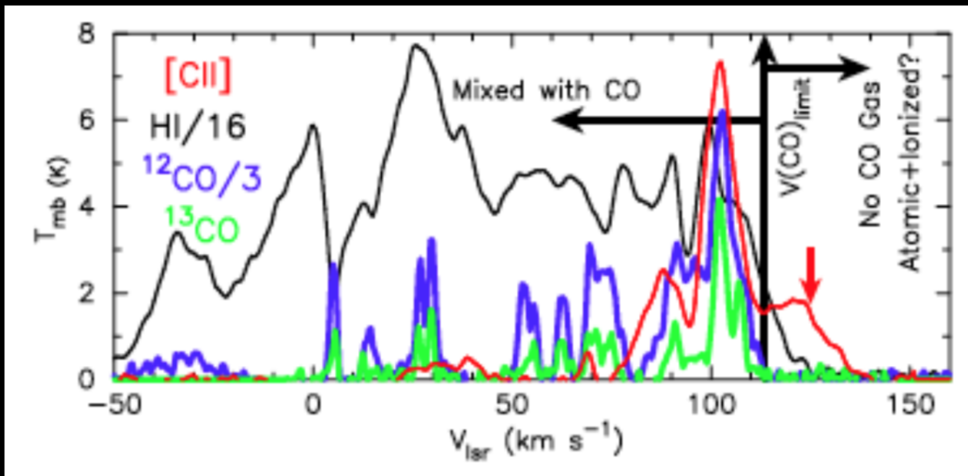
GUSSTO+: 100+ Day Flight on SPB

- Astrophysics small complete mission MO
- Completed Concept study (Phase A) on Sept 29, 2012
- Propose again in 2014
- Participating Institutions:
  - UofA, APL, JPL, CIT, Ball Aerospace, ASU, MIT, SRON(NL), TUDeflt (NL)



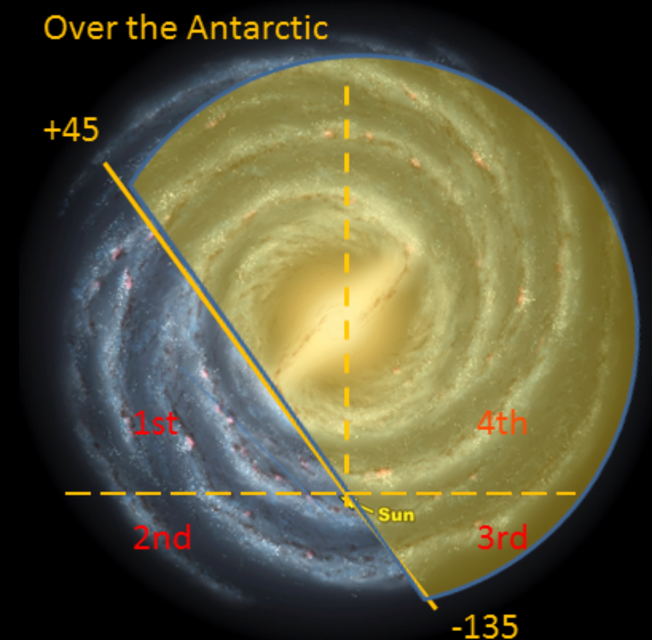
GUSSTO	Instruments
Telescope	1 meter off-axis Gregorian
Target Frequencies	[OI]: 4.7448 THz, [CII]: 1.9013 THz, [NII]: 1.4588 THz
Angular Resolution	50 arc seconds
Receiver Type	3x 16-Pixel HEB Mixer Array
System Noise Temp	~1500K (DSB)
Spectrometer	Digital Correlators
Spectrometer Bandwidths	2 , 4, and 5.5 GHz - Corresponds to 414, 632, 319 km/s for [NII], [CII], [OI]
Spectrometer Resolution	2.15, 5.37, and 6.45 MHz – Corresponds to 0.44, 0.85, 0.41 km/s for [NII], [CII], [OI]
Cryogenic System	Helium (~4K) Hybrid Cryostat
Instrument Mass	340 kg (includes 25% contingency mass)
Instrument Power	977 W (in science mode), 500 W (in sleep mode)
Platform	LDB or ULDB Gondola
Launch Vehicle	Zero or Super Pressure Balloon

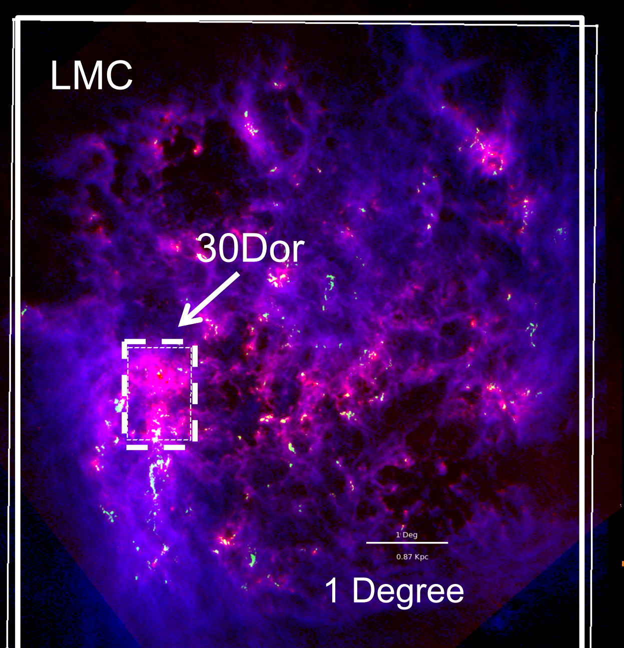
Observational Objectives:
[CII], [OI], & [NII] Surveys of MW and LMC



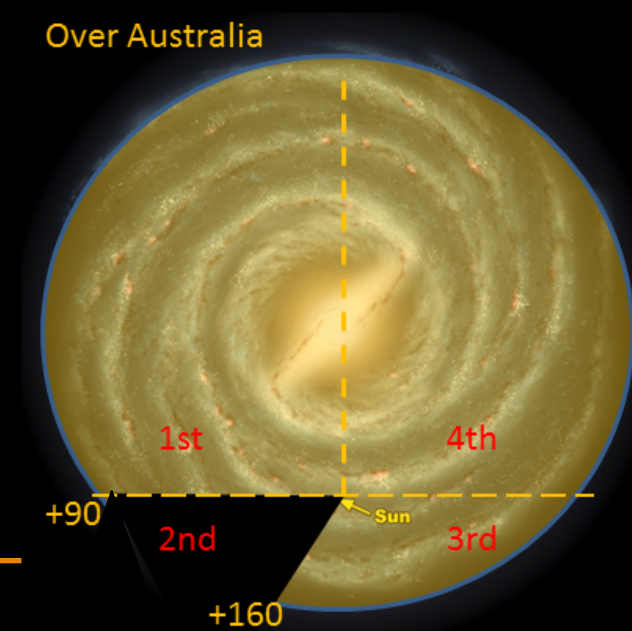
Above: Single line of sight (LOS) spectrum of [CII] (*Herschel HIFI)* towards a Galactic source. *GUSSTO 's* surveys will observe **><u>100,000</u> <u>LOS</u>, more than *100x* what was done with *Herschel* HIFI.**

Galactic Plane Visibility from Antarctica:





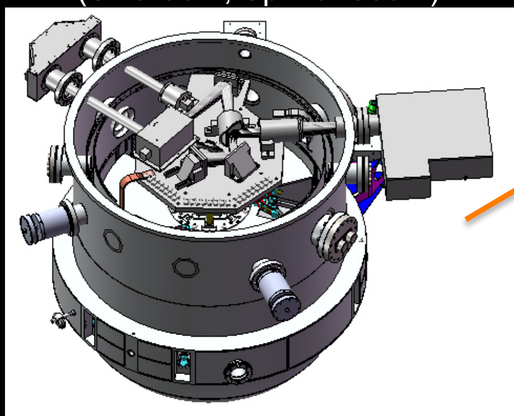
The Large Magellanic Cloud (LMC) in HI (blue), CO (green), *Spitzer* 160µm emission (Red). The <u>solid box</u> represent<u>s</u> the area for the large–scale mapping with GUSSTO. The <u>dashed</u> box is the proposed 30 Dor deep integration map.

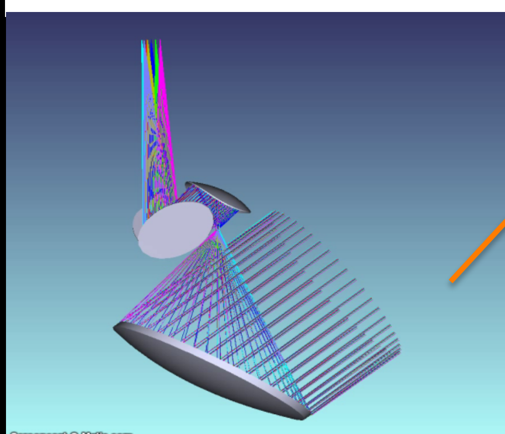


GUSSTO Payload Architecture

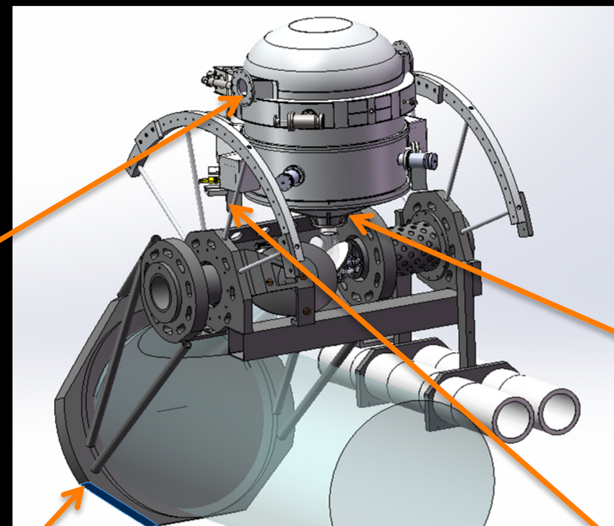
Heritage from STO, AST/RO, Herschel, HEAT, SuperCam

Cryostat (127 L Hybrid)
(STO 95 L, Spitzer 360 L)

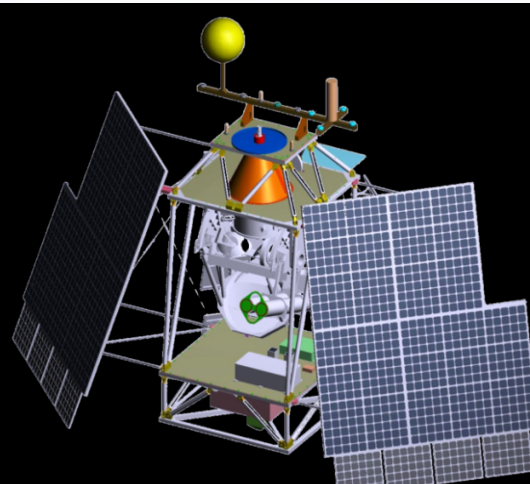




Telescope 1.1m CFRP
(AST/RO 1.7m, *ODIN* 1.1m: CFRP)

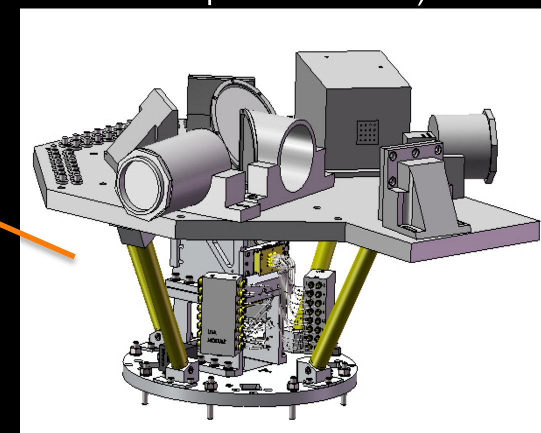


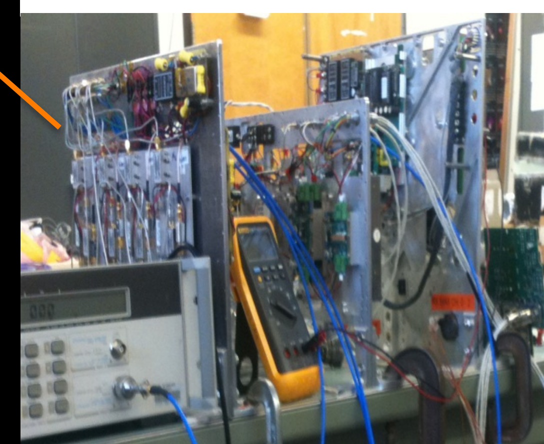
Science instrument



Gondola: “spacecraft bus”

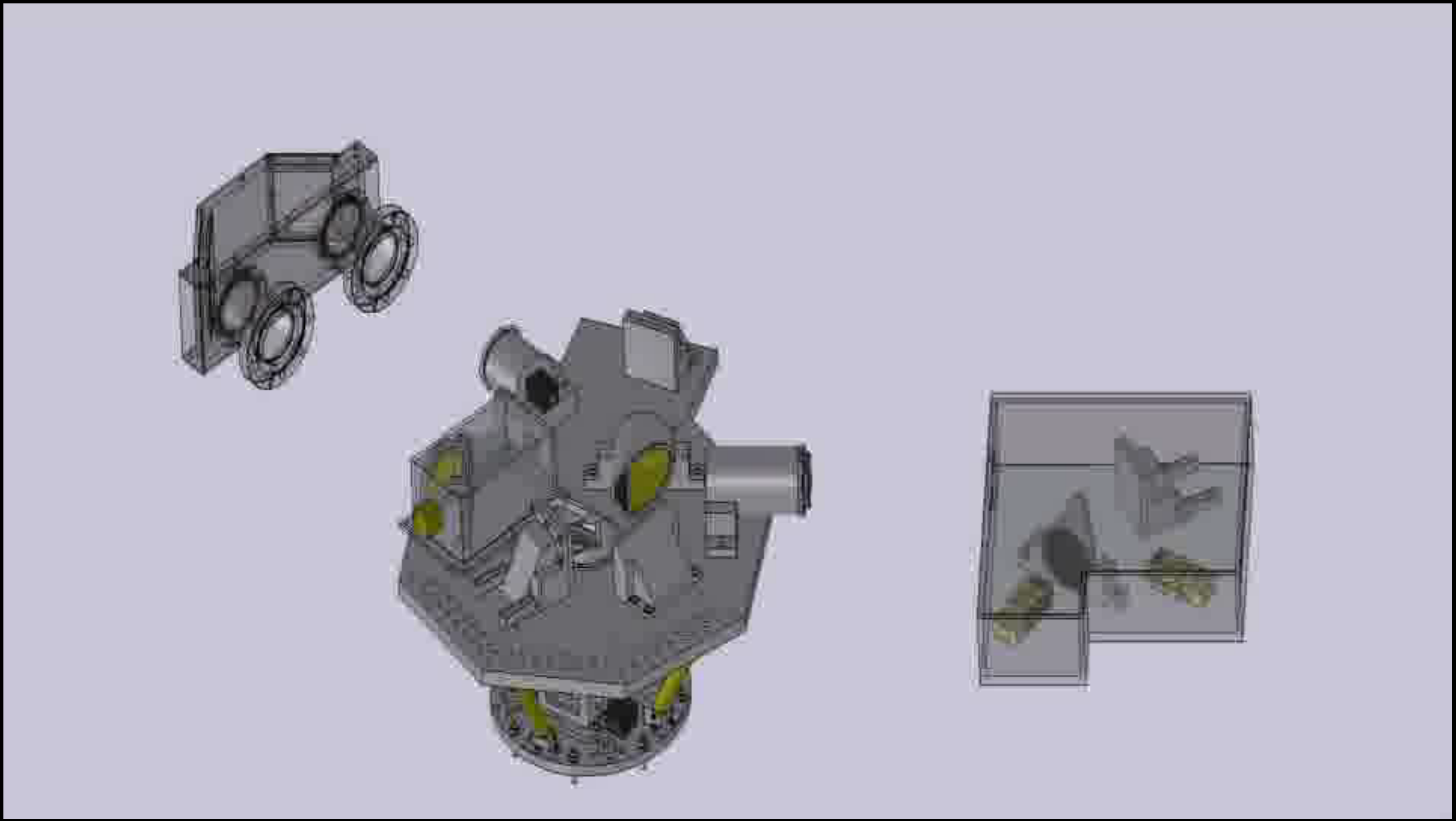
Focal Plane Unit 48 ch.
(*STO* 8 ch., *Herschel* 12 ch., SuperCam 64 ch.)





Electronics and Software
(*STO*, SuperCam, HEAT)

GUSSTO Beam Propogation



GUSSTO Directly Benefits JWST and ALMA

Provides "the missing puzzle piece"…

GUSSTO:

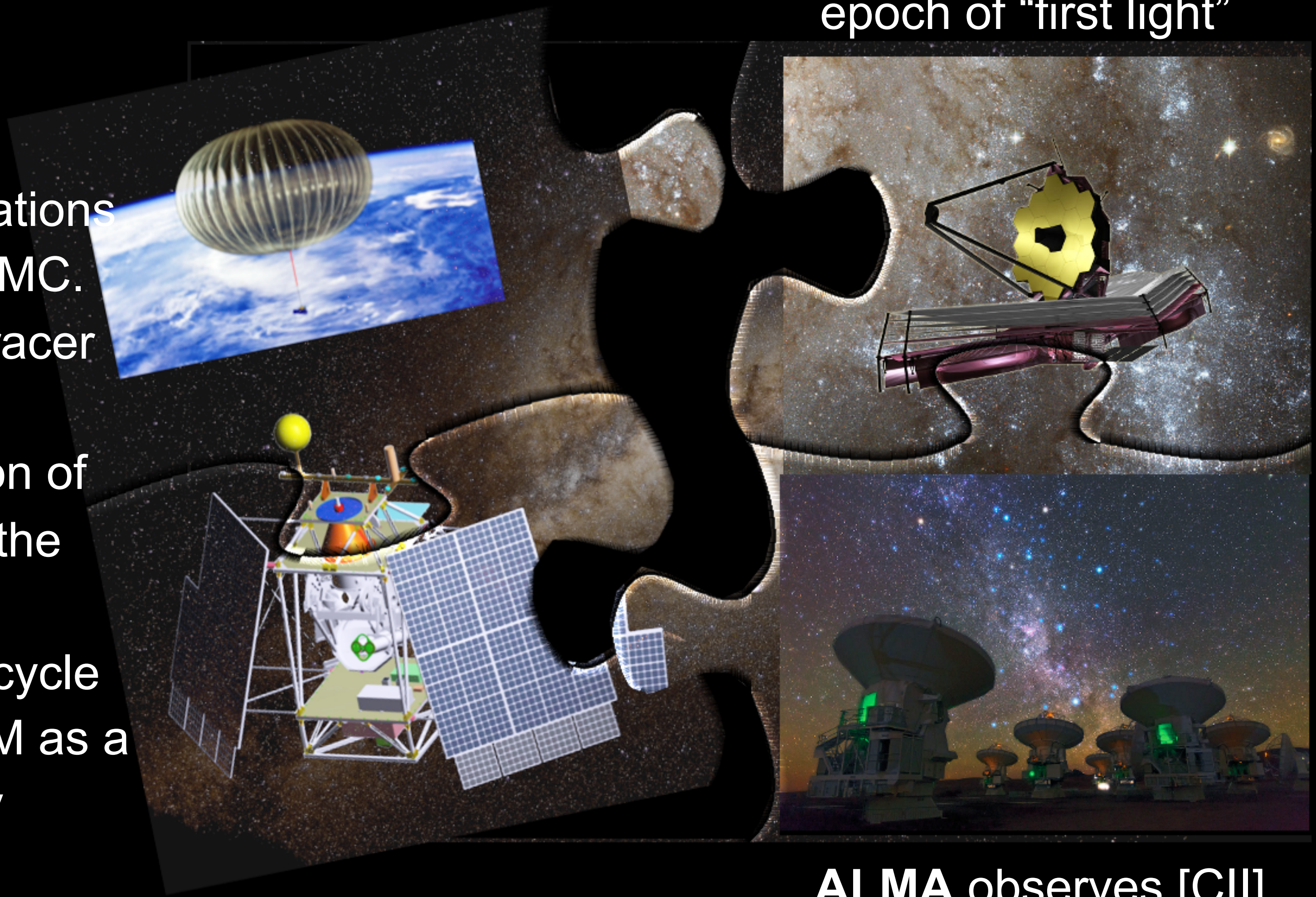
-Tethers far-IR extragalactic observations to the Milky Way & LMC.

-Calibrates [CII] as tracer of star formation.

-Observes the fraction of "CO-dark H_2 gas" in the Galaxy.

-Determines the life cycle & structure of the ISM as a component of galaxy evolution.

JWST will observe epoch of "first light"



ALMA observes [CII] near epoch of "first light"

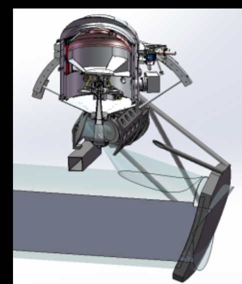
Summary and Conclusions

- The study of the lifecycle of the ISM helps to answer questions about our cosmic origins by exploring the dust and gas from which we formed.
- Heterodyne receivers provide sensitivity and high spectral resolution in order to study the kinematics of giant molecular clouds from which stars form.
- Atomic and molecular spectral lines resonate in the THz/sub-millimeter region of the electromagnetic spectrum.
- Ground-based instrumentation can probe atmospheric windows, but for all other observations, space-based platforms are needed.
- Balloon-borne missions for THz astronomy provide us with enough power for our instruments and the possibility of several flights.
- STO flew in January 2012 in Antarctica with receivers tuned to detect [C II] and [N II] at 1.9 THz and 1.46 THz respectively.
- Future flights such as STO II or GUSSTO will hopefully include an [O I] receiver at 4.7 THz.

A Unique Opportunity for Ground-Breaking Science

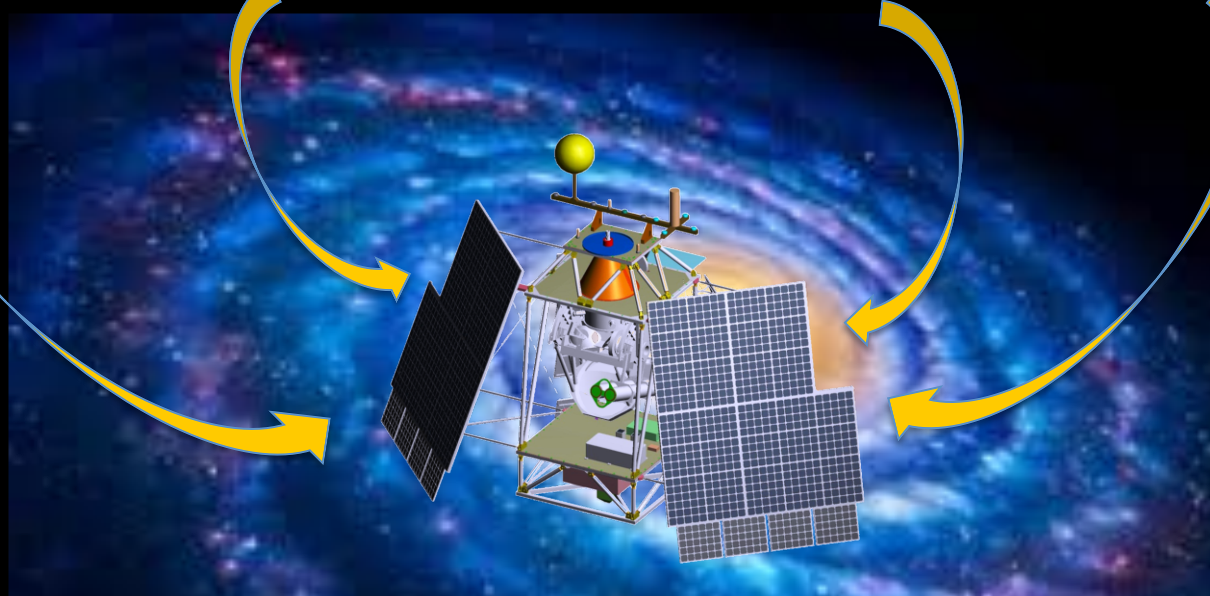
Science

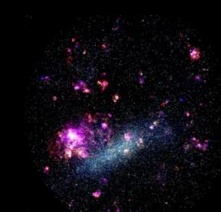
Instrument



Facilities

SPB





THz Balloon-Borne Astronomy

The time is now!