Terahertz Heterodyne Arrays for Astronomy

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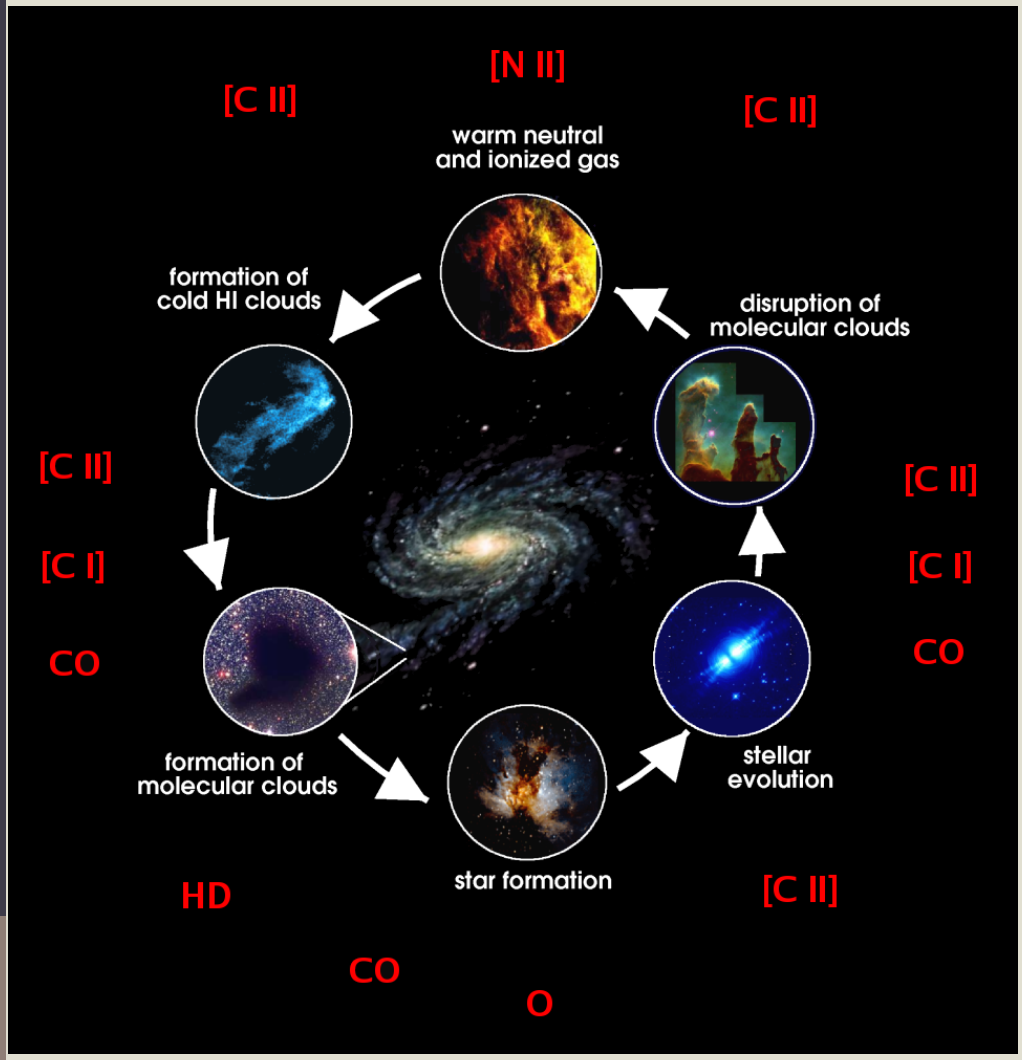
Key Science Questions

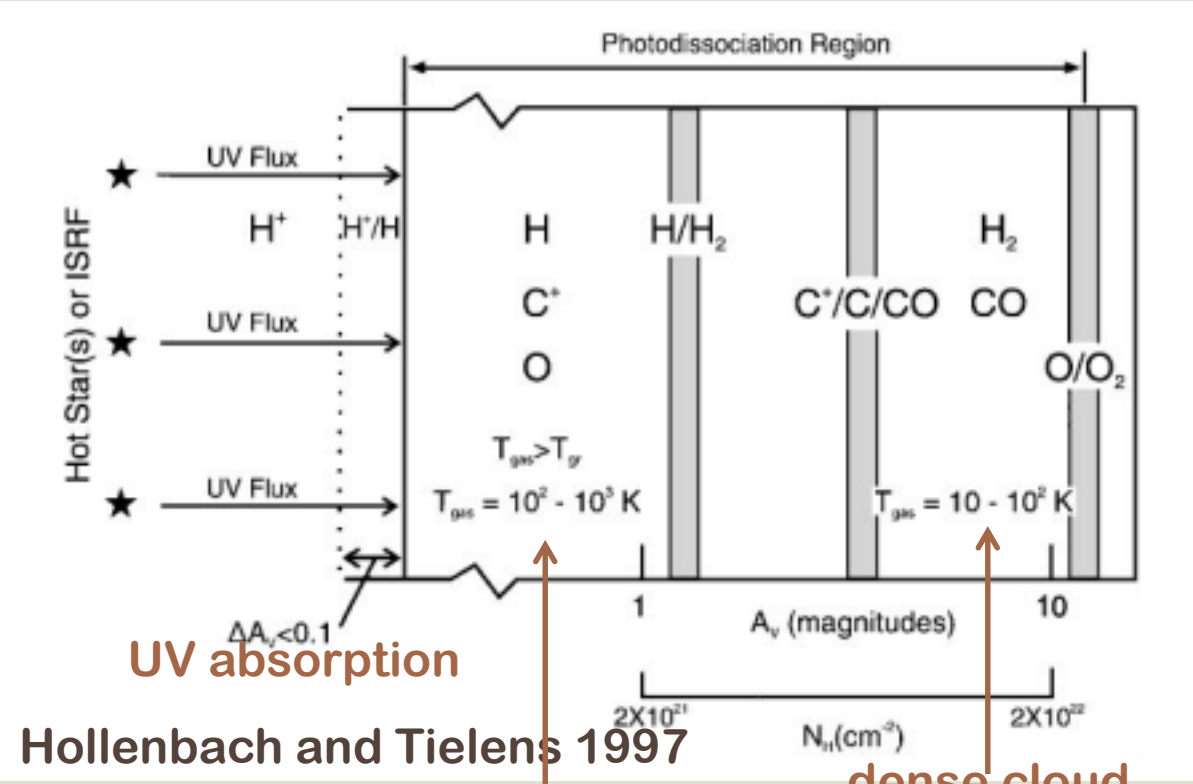


The lifecycle of the Interstellar Medium (ISM); Image Credit: C. Kulesa

- 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?

Photodissociation Regions (PDRs)

- PDRs are the boundary regions between the ionizing UV photons and cooler, denser, neutral regions in the galaxy
- Example: giant molecular clouds (GMCs)



Hollenbach and Tielens 1997

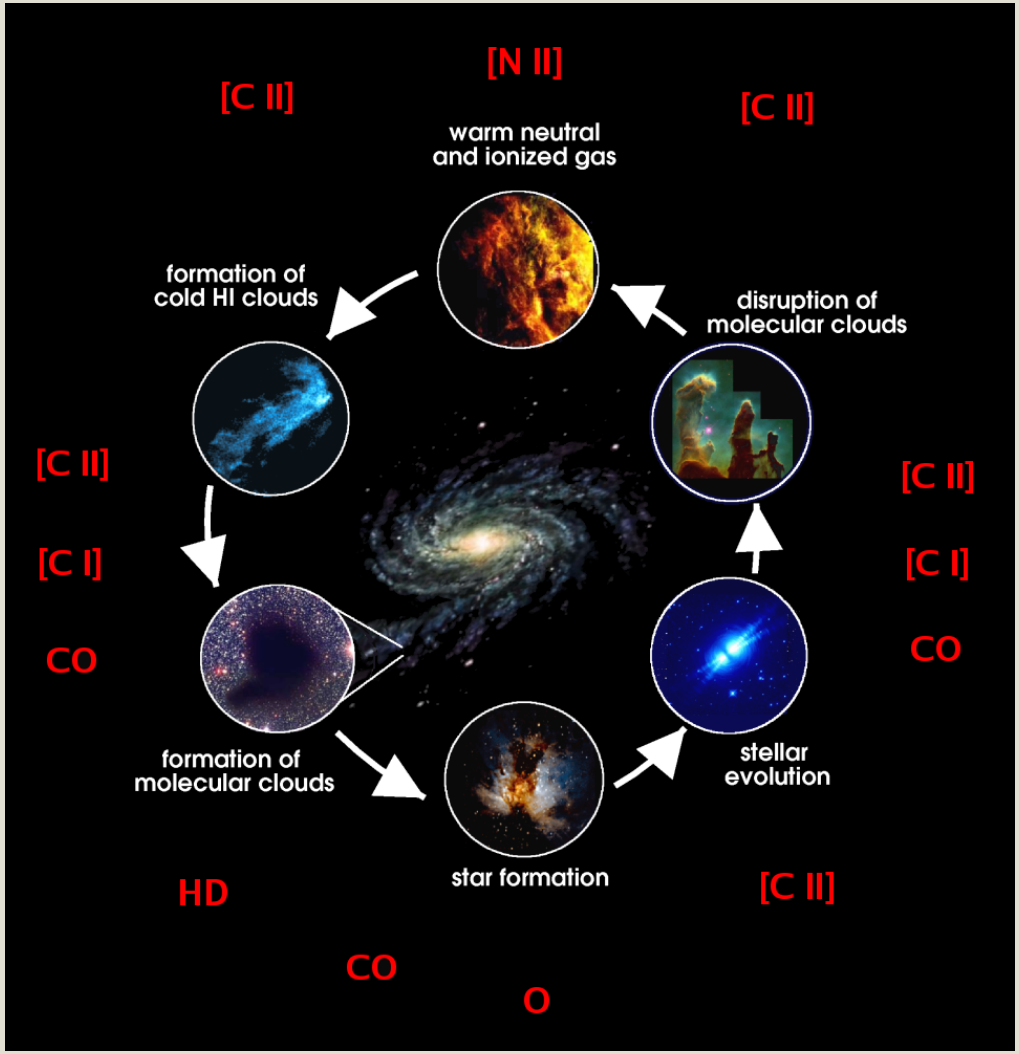
UV absorption

diffuse cloud properties

dense cloud properties

- A better understanding of PDRs will provide insight into how GMCs are formed in the ISM and the shielding they provide for stellar nurseries

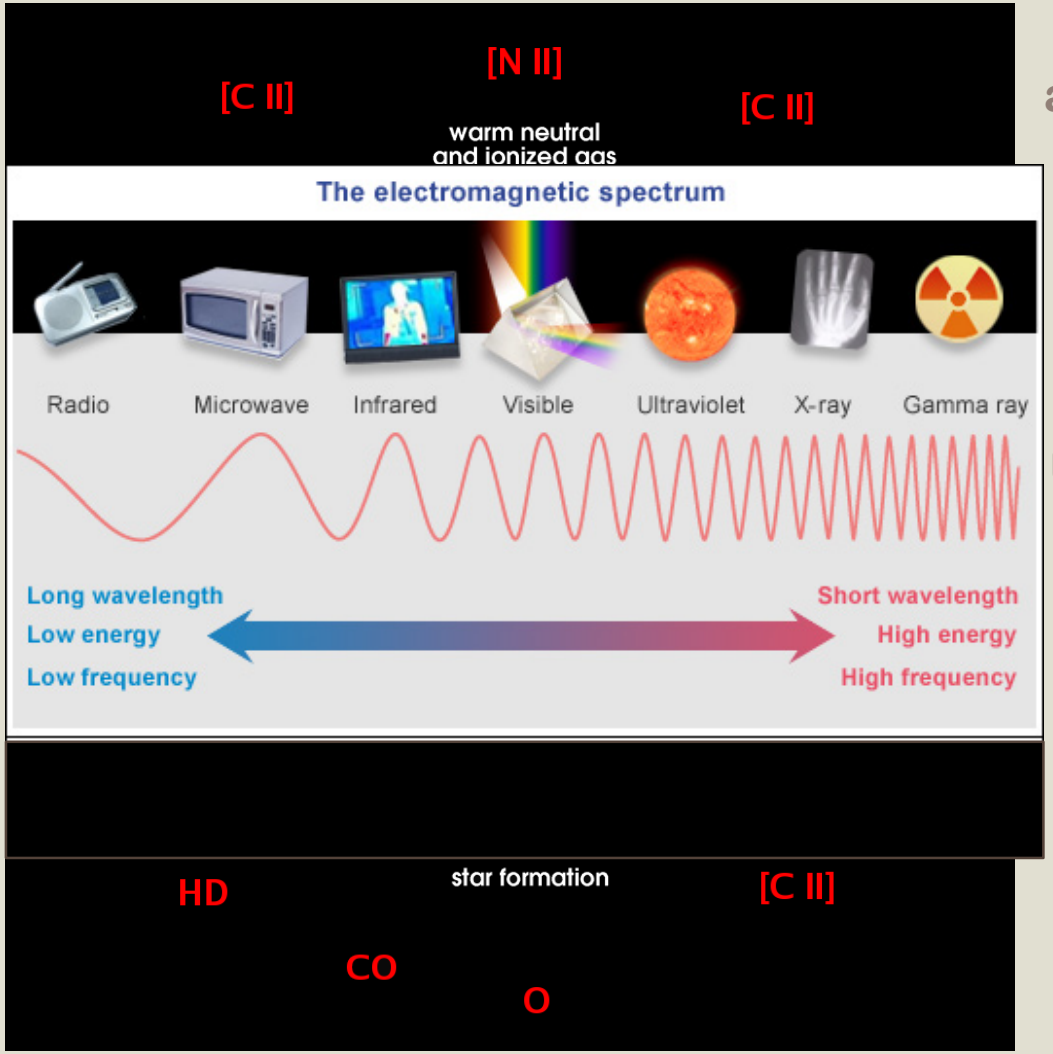
Life Cycle of Interstellar Medium (ISM)



What do all of these atomic and molecular tracers have in common?

Image Credit: Kulesa and Walker

Life Cycle of Interstellar Medium (ISM)



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Transitions in the THz/Sub-millimeter (300 GHz – 3 THZ)!

Image Credit: Kulesa and Walker

Life Cycle of Interstellar Medium (ISM)

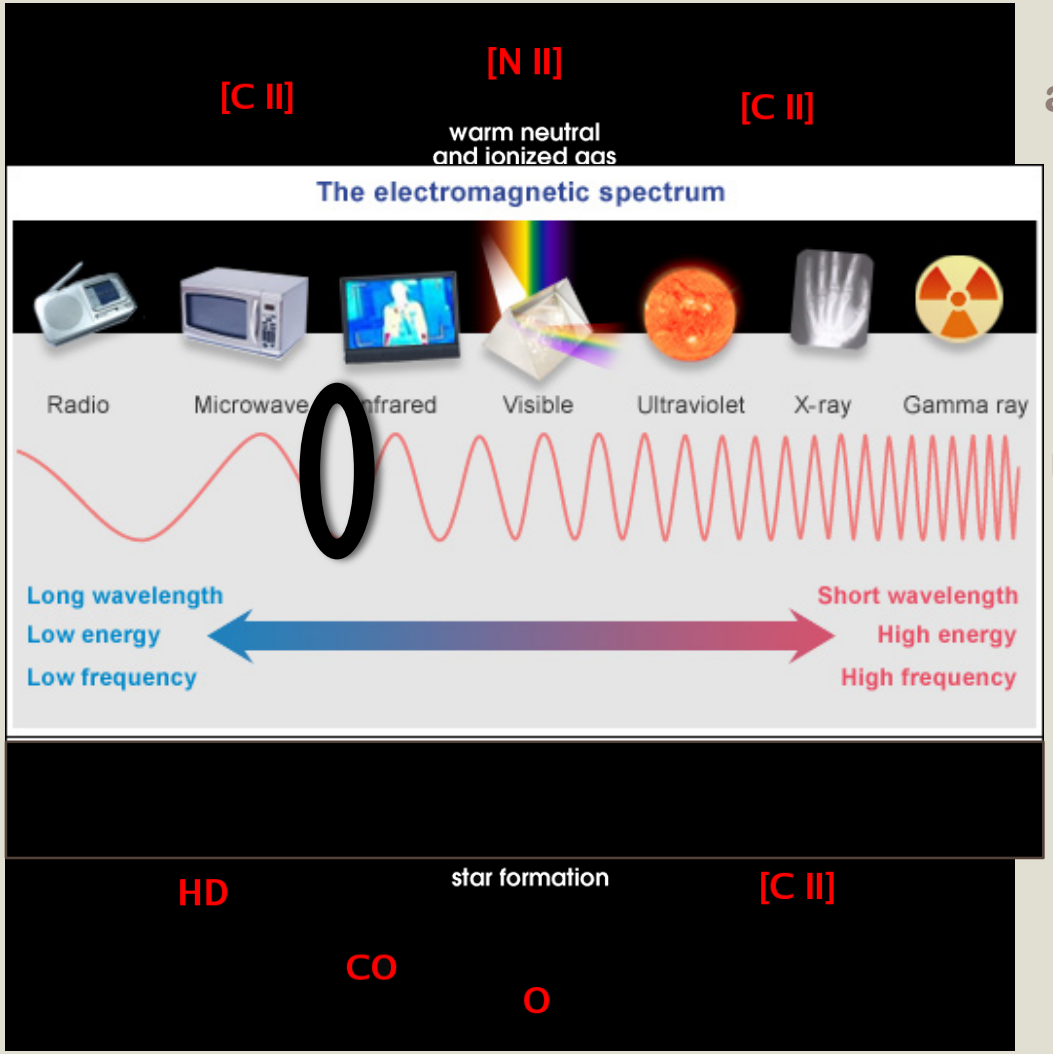


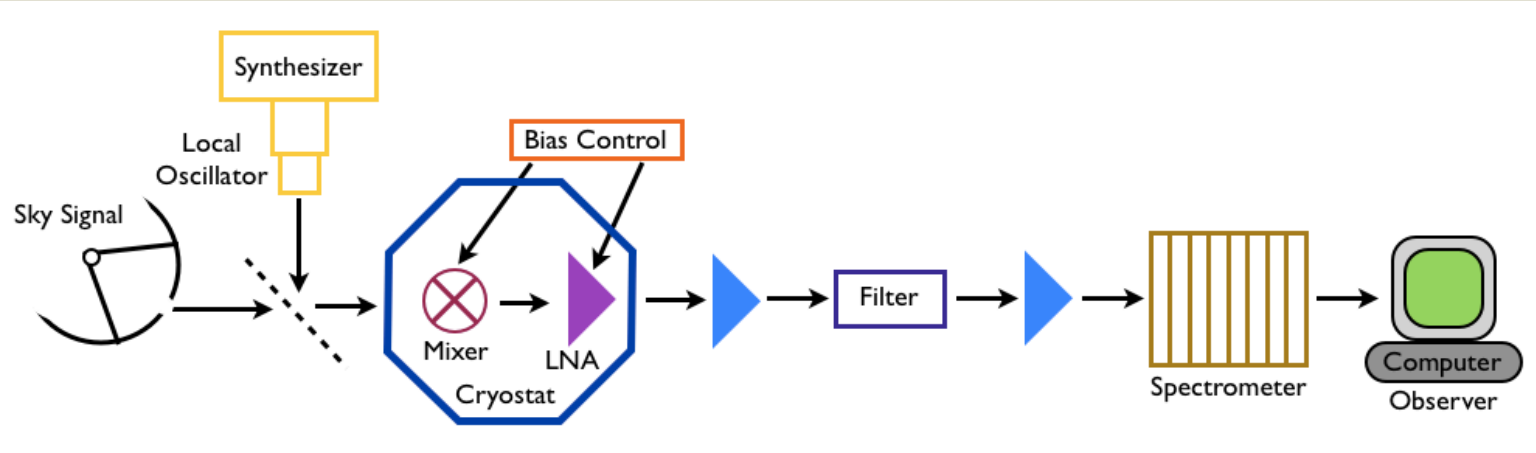
Image Credit: Kulesa and Walker

What do all of these atomic and molecular tracers have in common?

Transitions in the THz/Sub-millimeter (300 GHz – 3 THZ)!

Large scale THz spectroscopic surveys are needed to study the kinematics of large gas clouds in the Milky Way => heterodyne arrays needed!

Superconducting THz Heterodyne Receiver



Kloosterman 2014

- Coherent detection
- High spectral resolution ($R=10^7$)
- Sensitivity
- SIS or HEB Mixers

Life Cycle of Interstellar Medium (ISM)

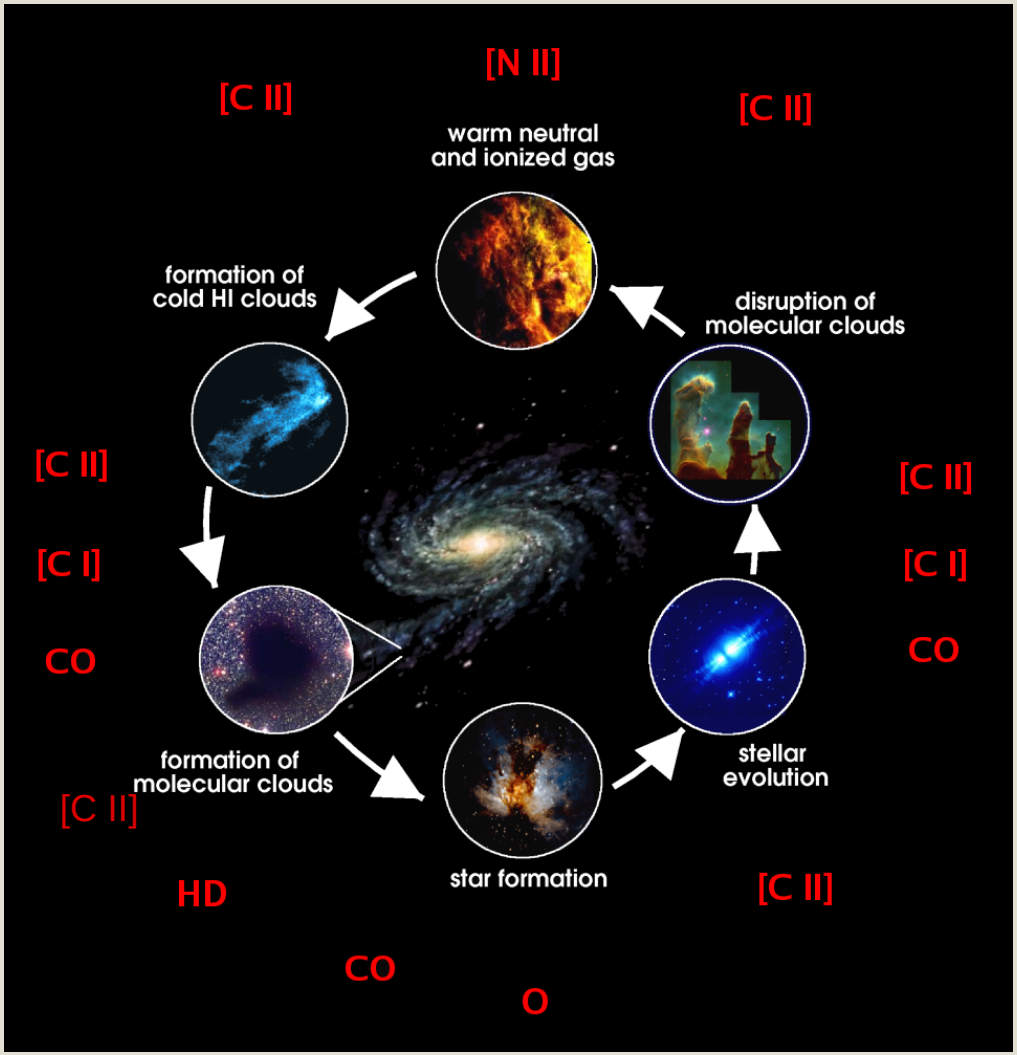
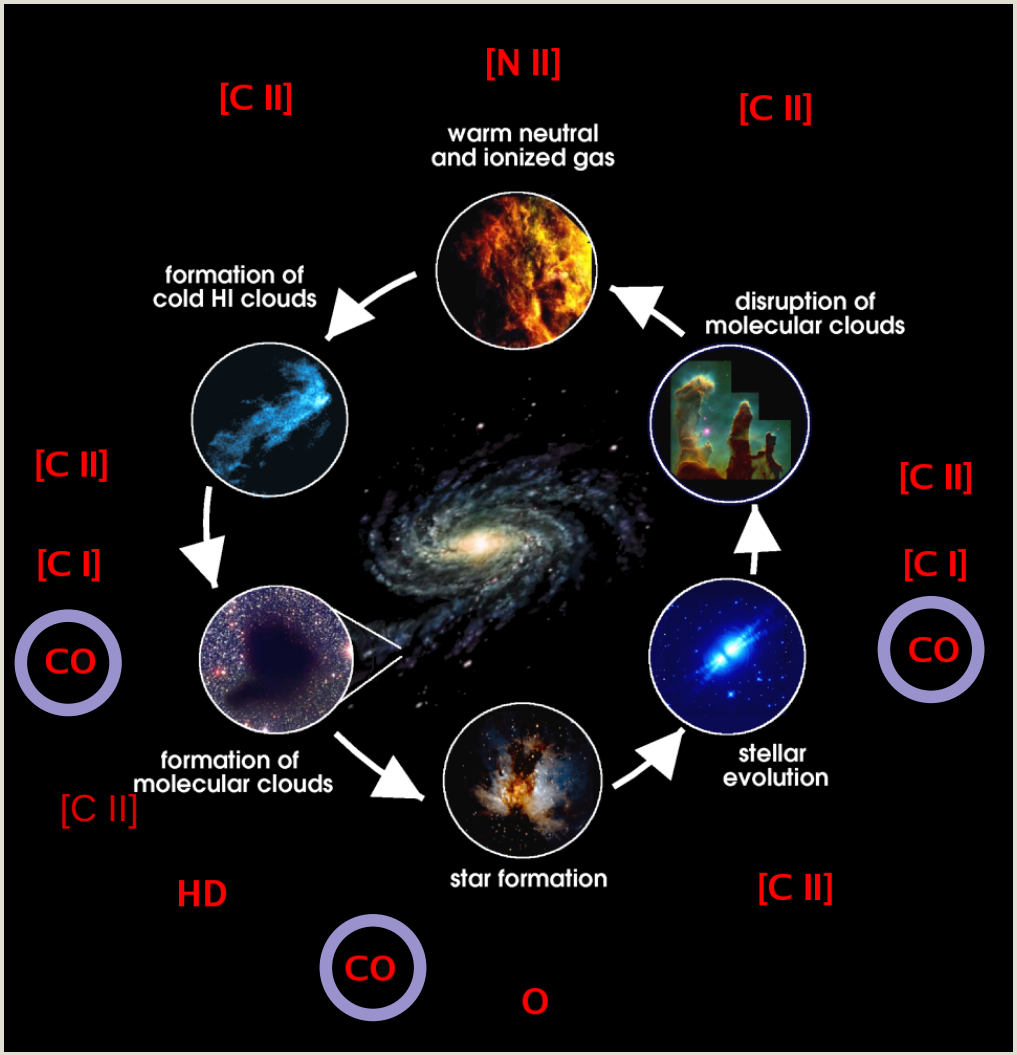


Image Credit: Kulesa and Walker

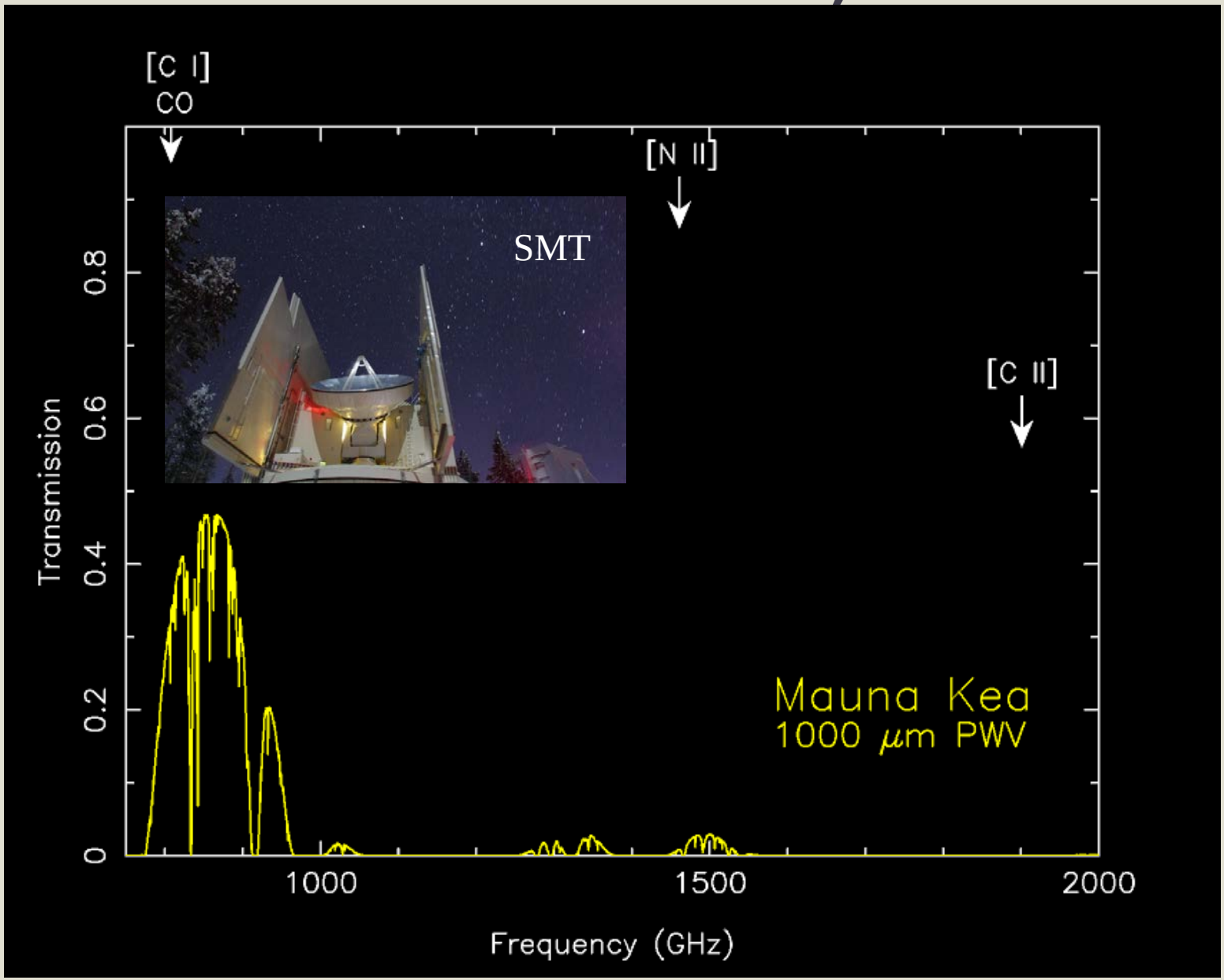
Life Cycle of Interstellar Medium (ISM)



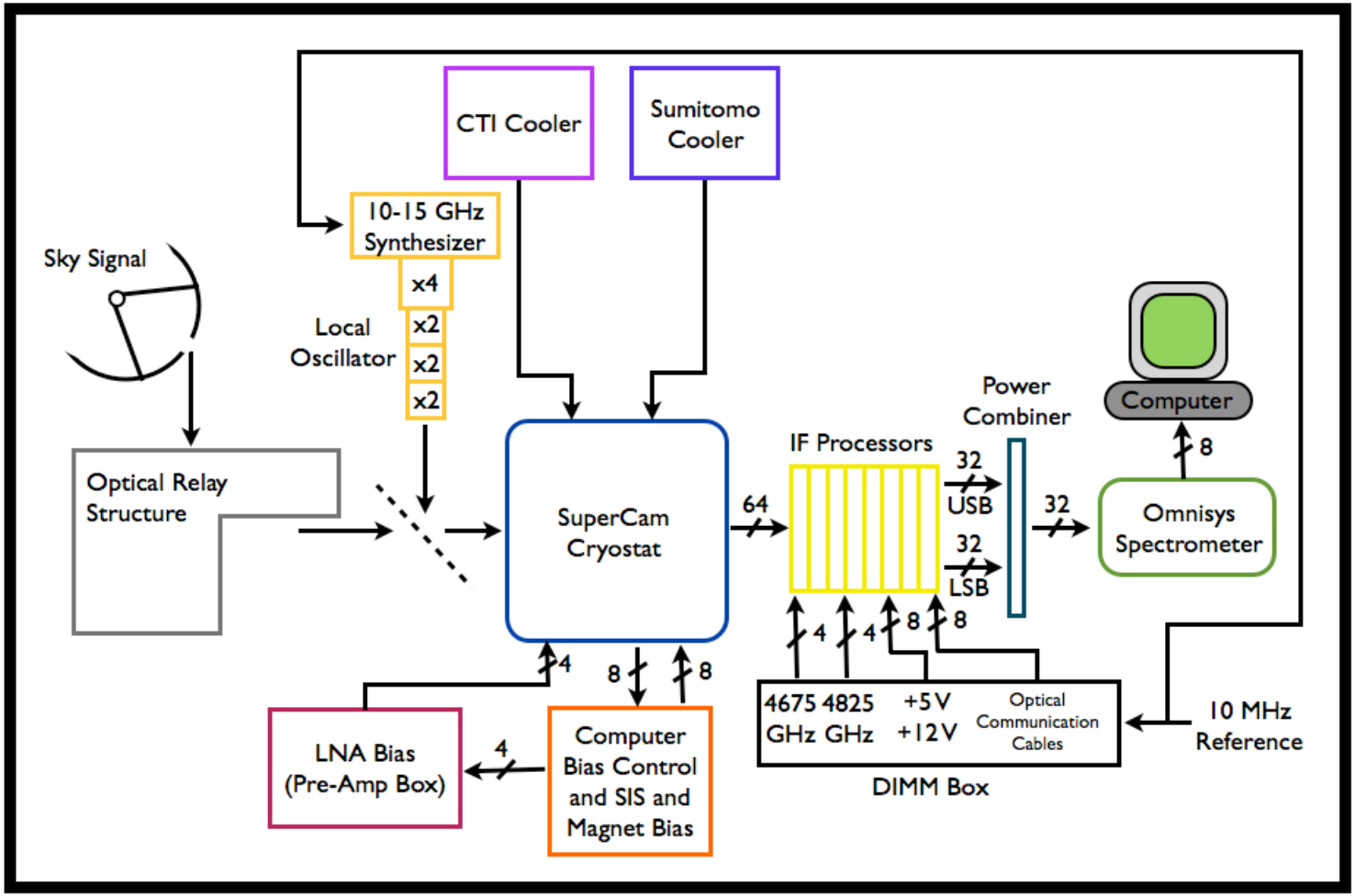
SuperCam
CO: λ = 0.8 mm, ν = 345 GHz

Image Credit: Kulesa and Walker

Atmospheric Transmission (Best Sites in North America)

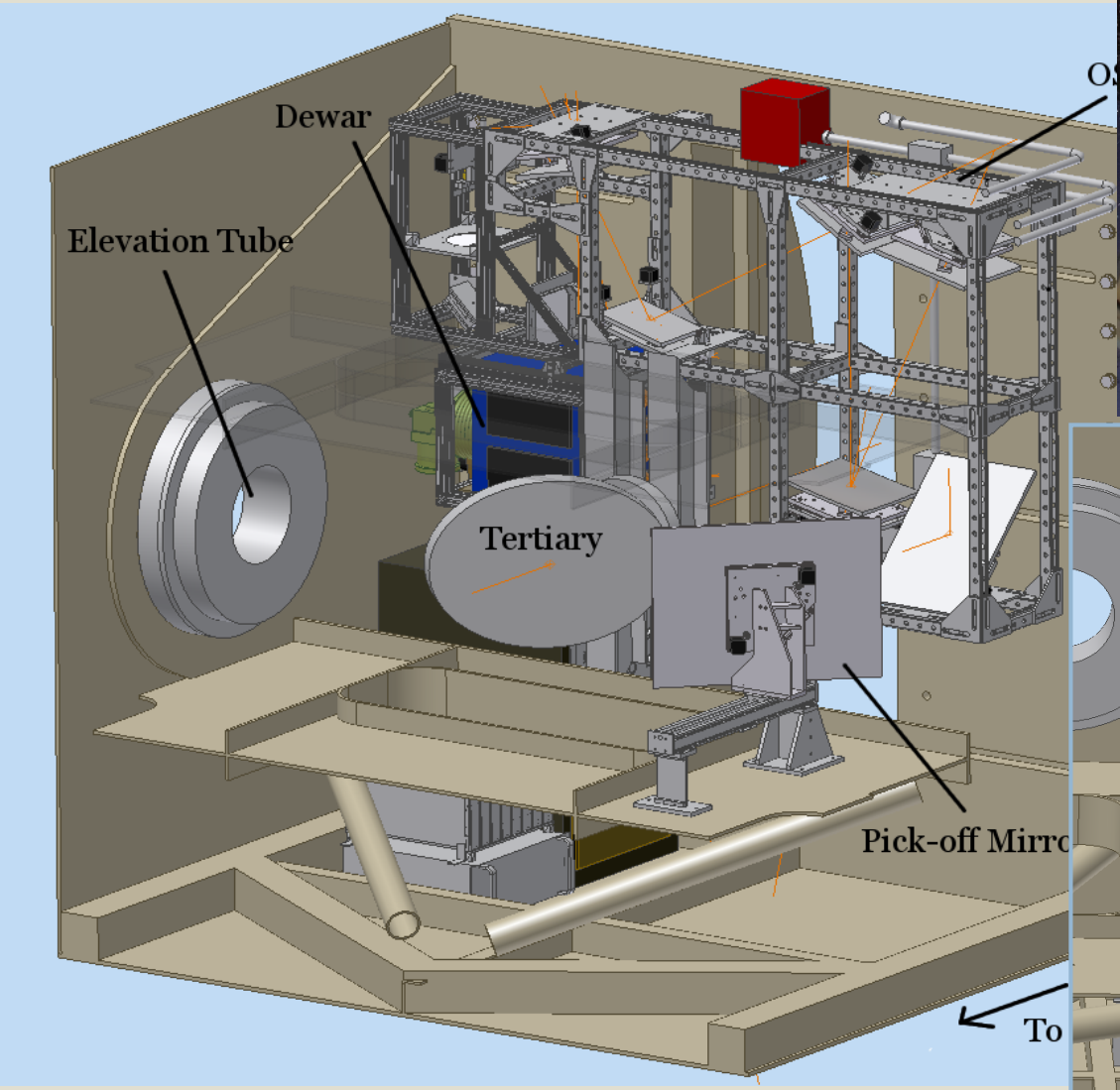


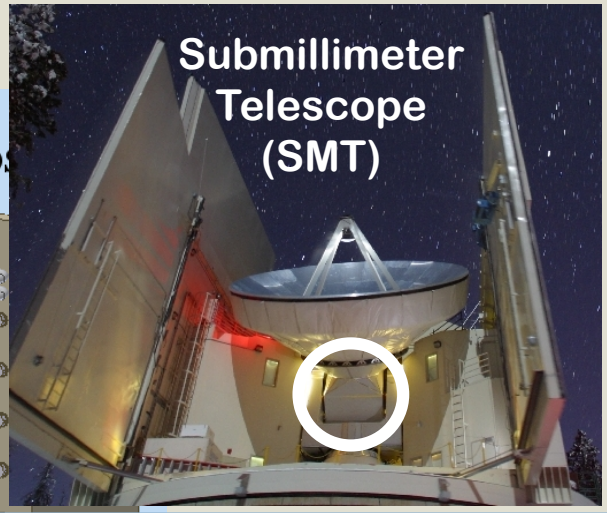
SuperCam Block Diagram

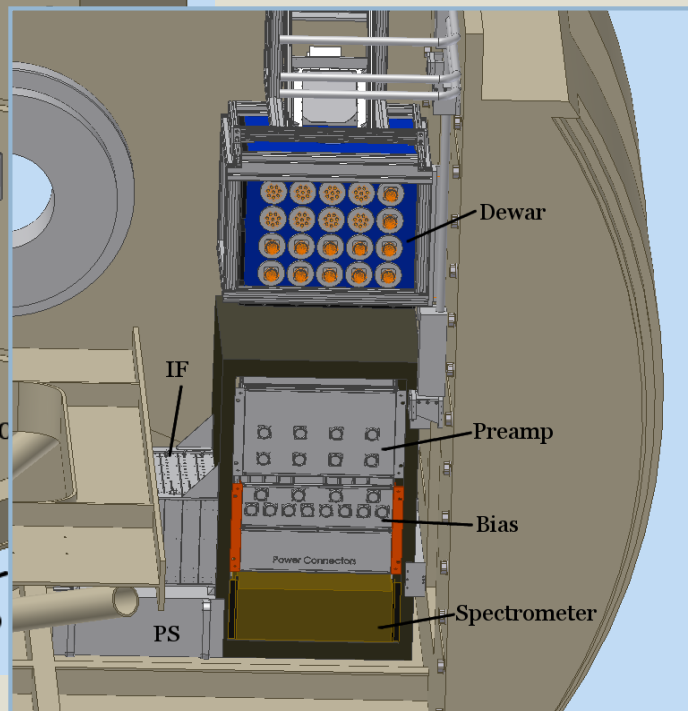


Kloosterman 2014

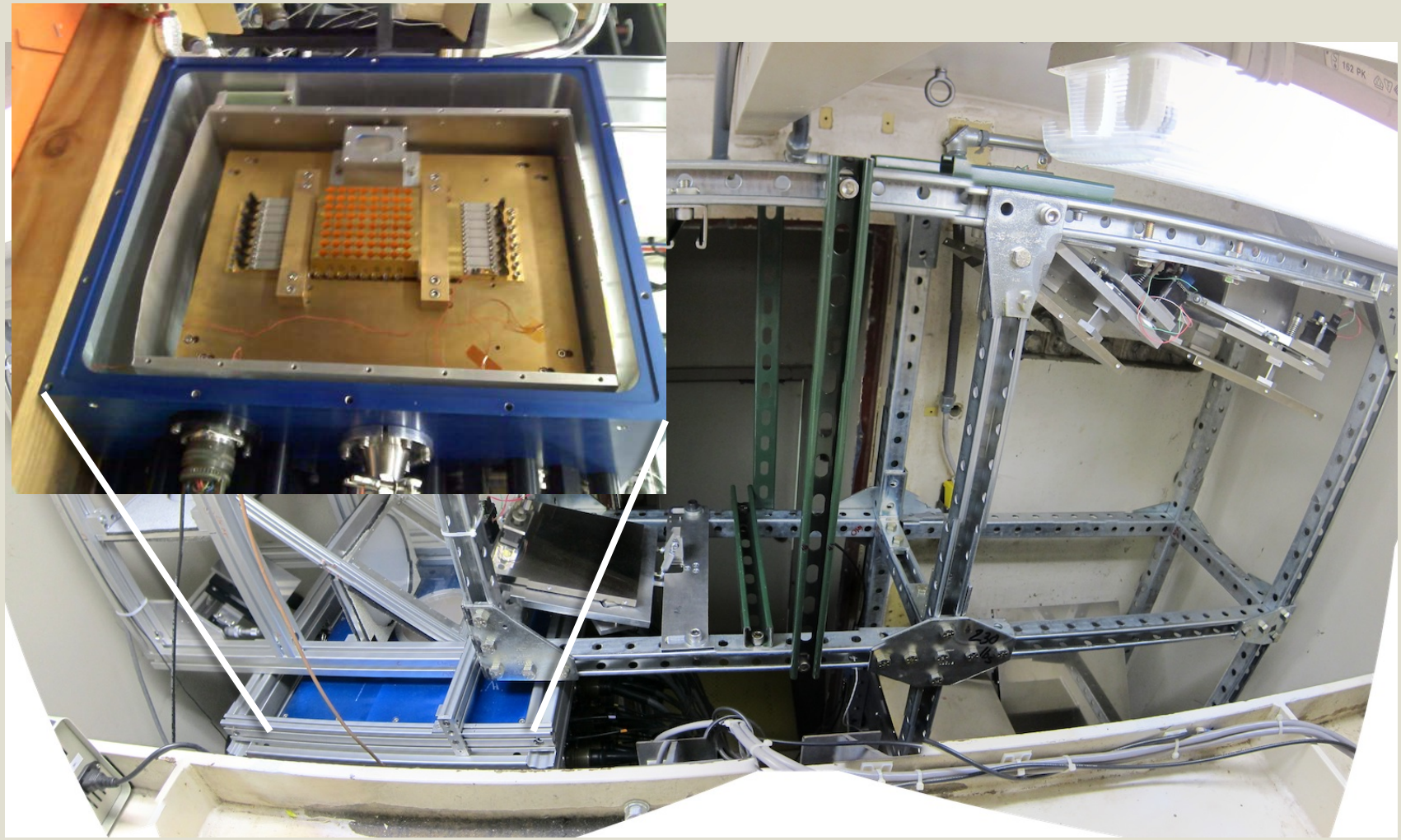
SuperCam: A 64-pixel imaging spectrometer at 345 GHz



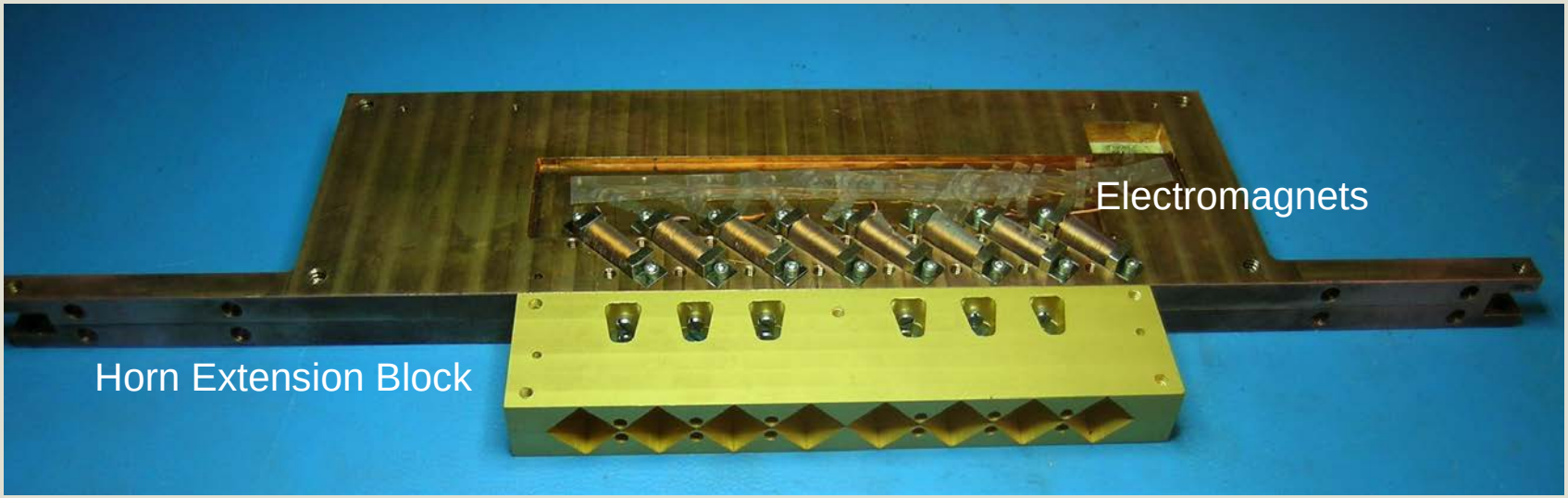


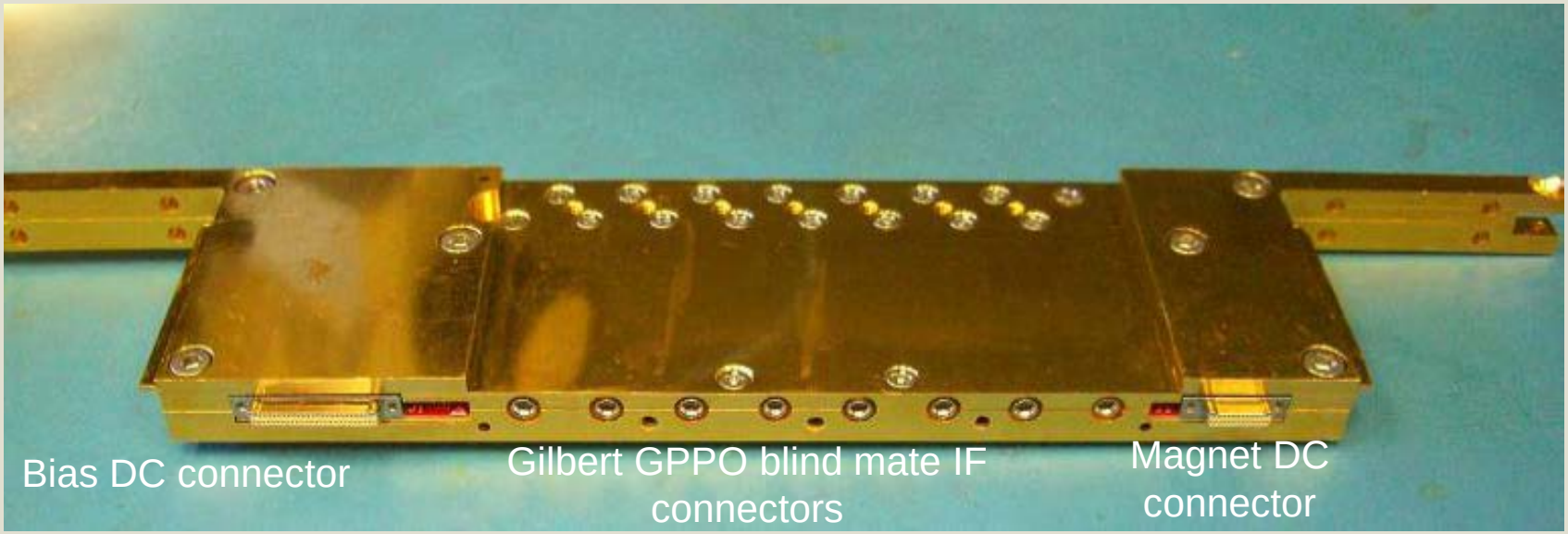


SuperCam Installed in the Apex Room of the SMT



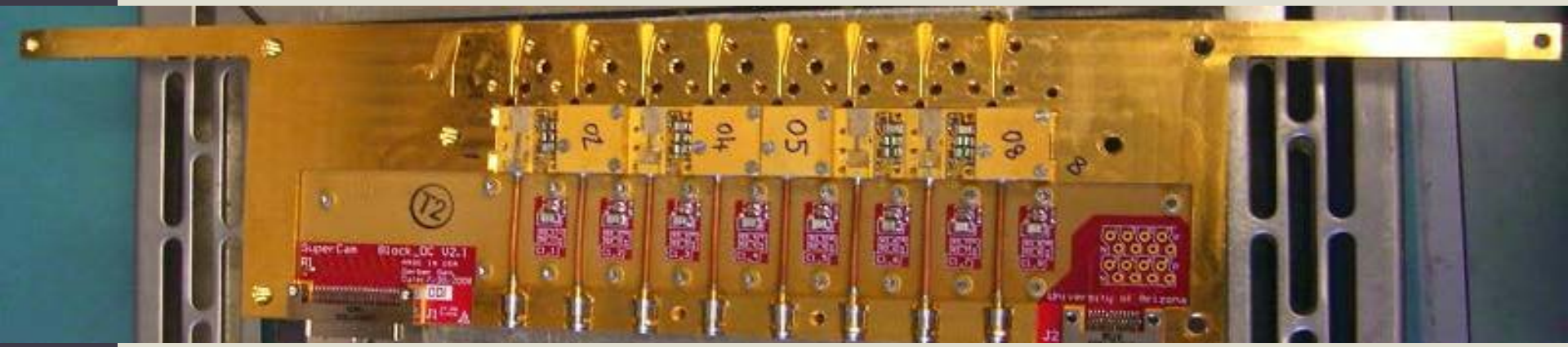
1x8 Mixer Module





Groppi et al. 2010

Anatomy of a 1x8 SuperCam Subarray



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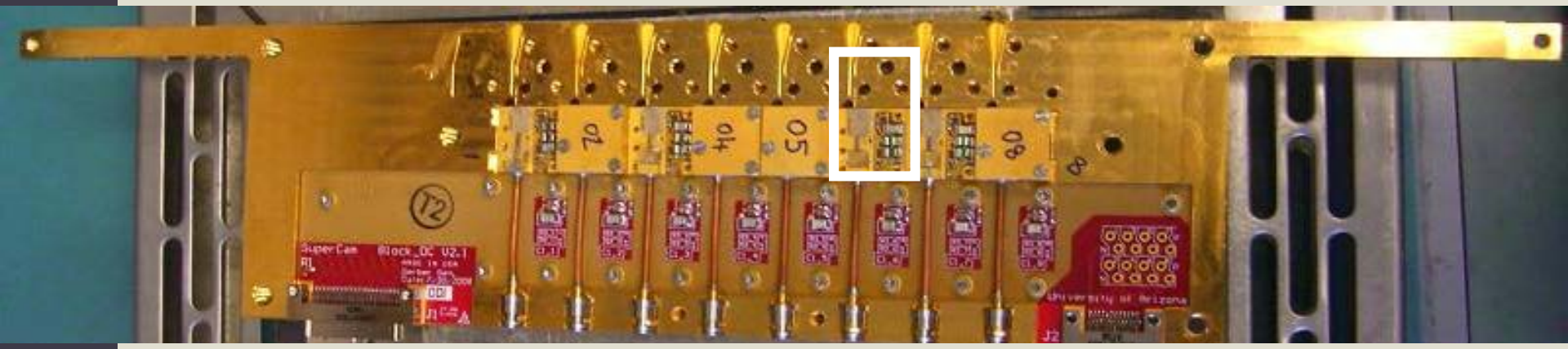

Groppi et al. 2010

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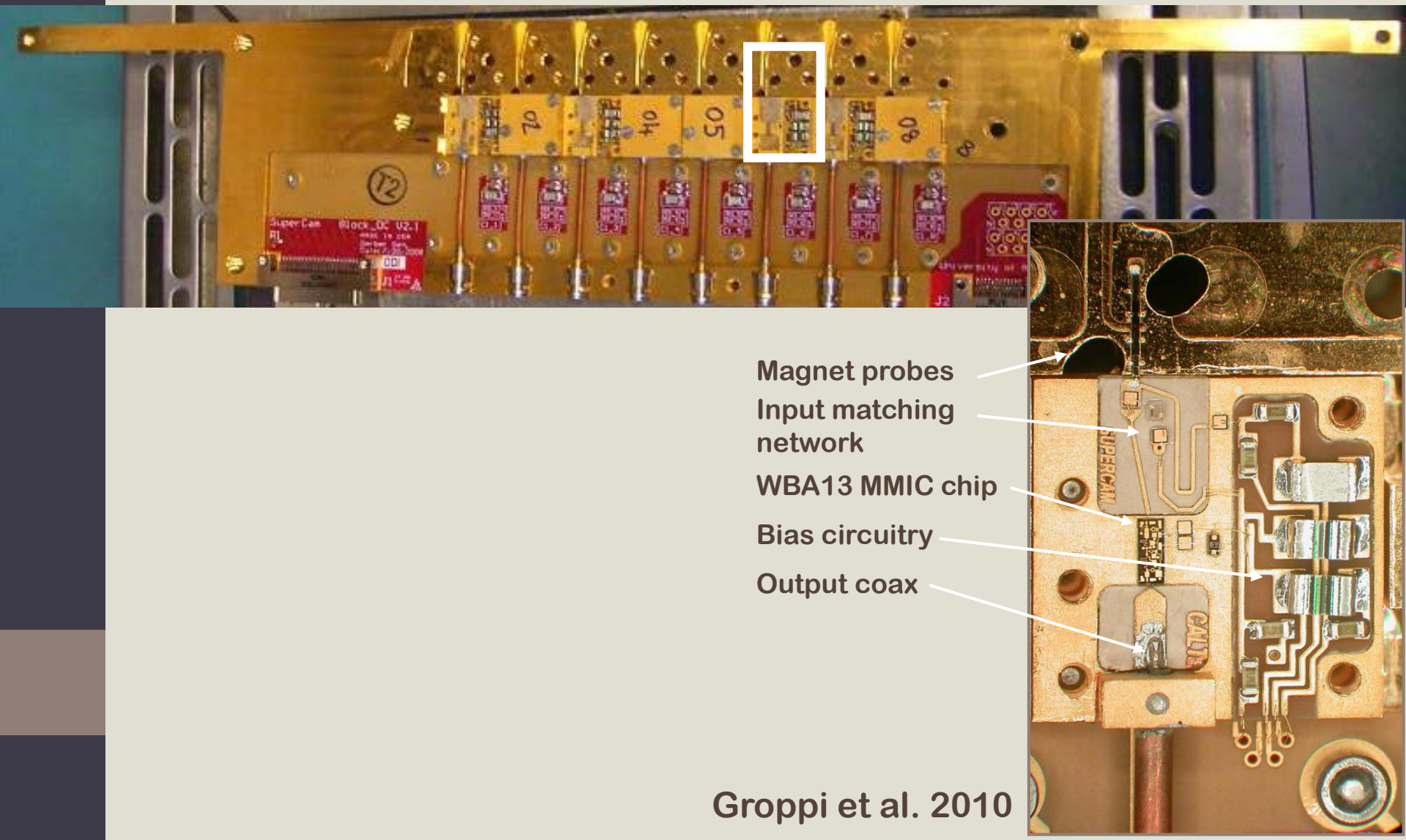

Groppi et al. 2010

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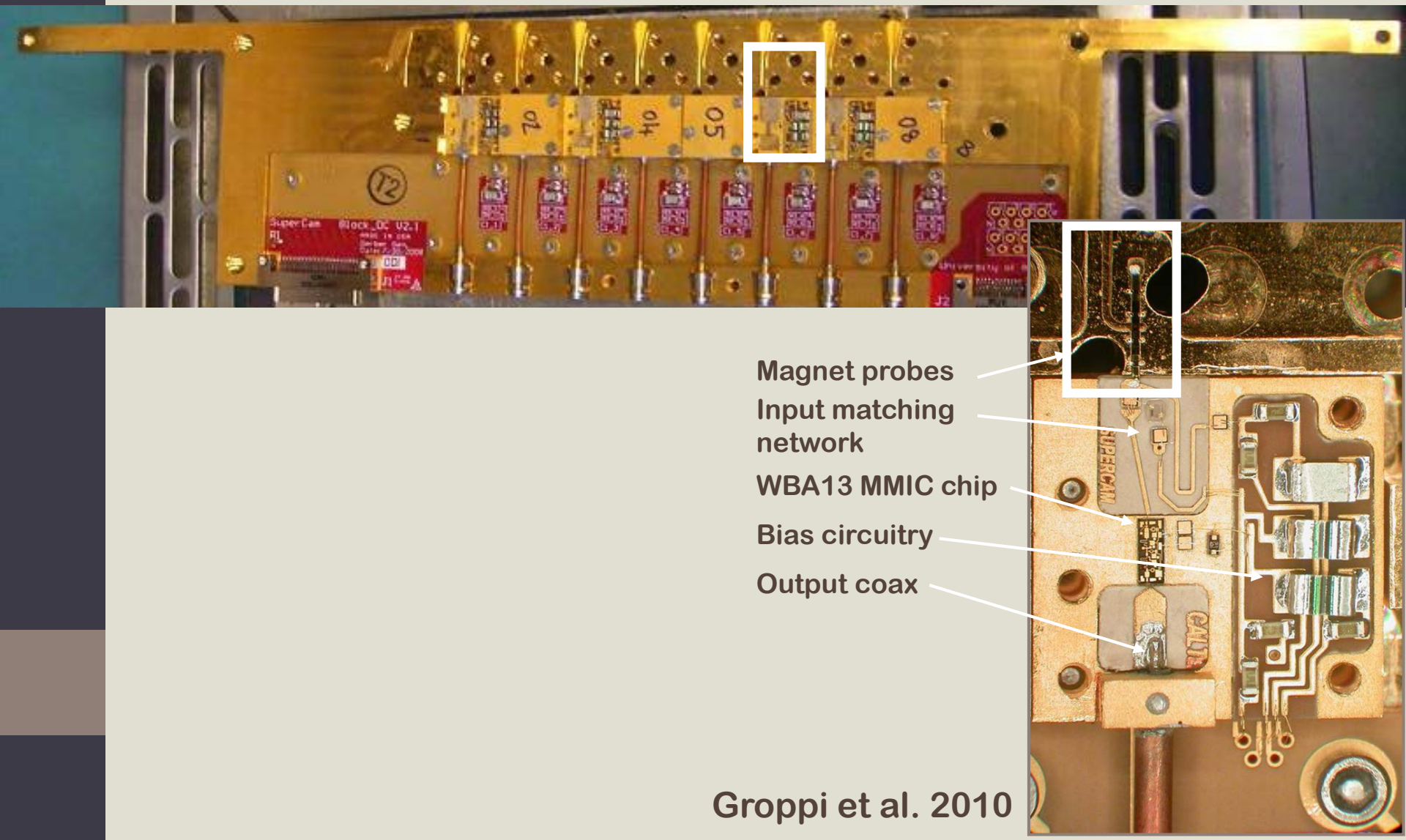

Groppi et al. 2010

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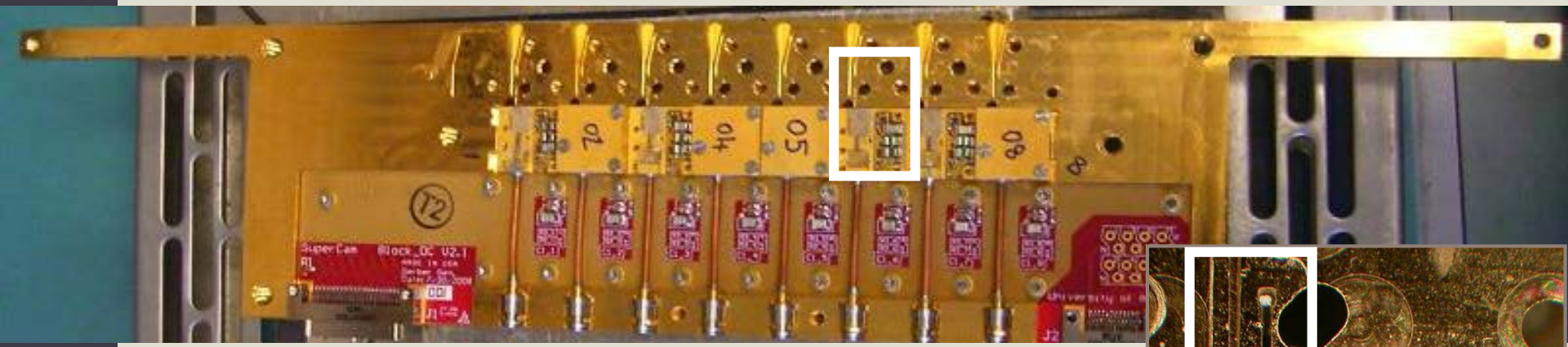
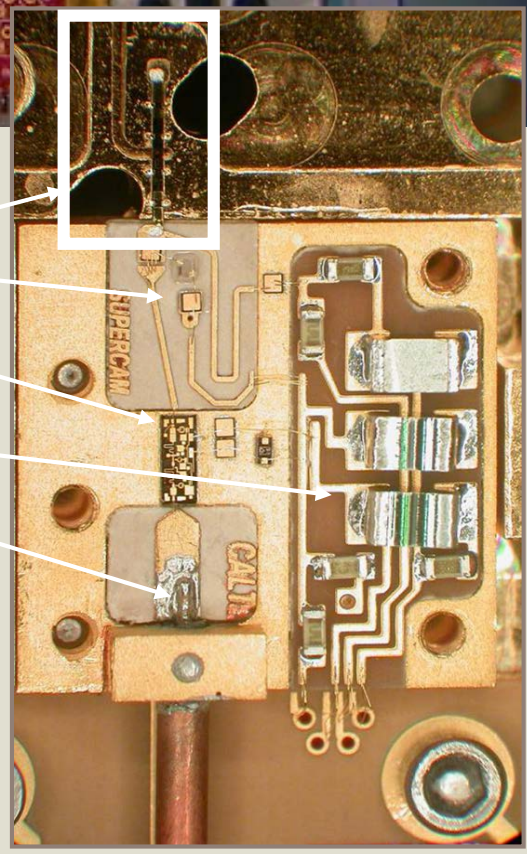
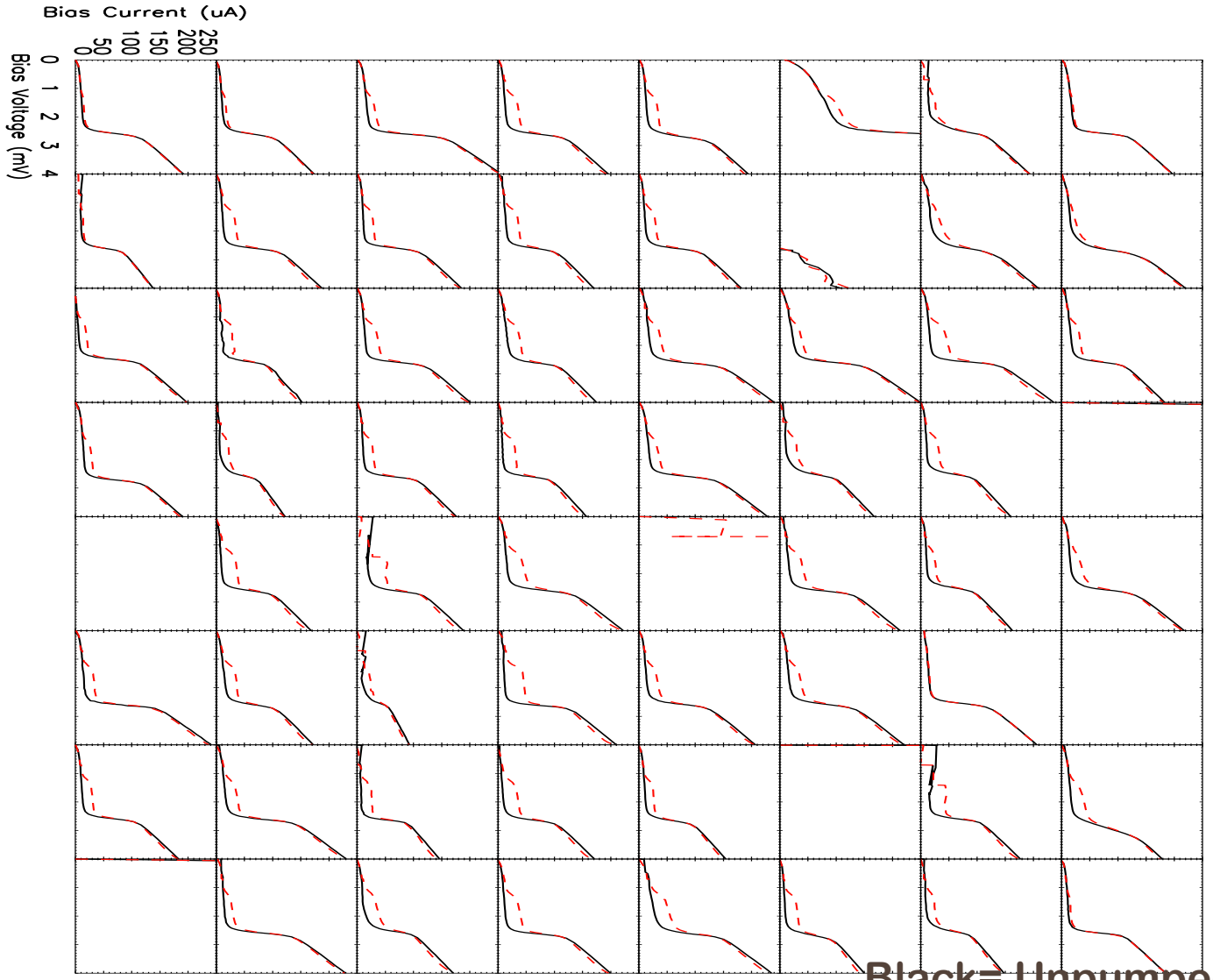




Groppi et al. 2010

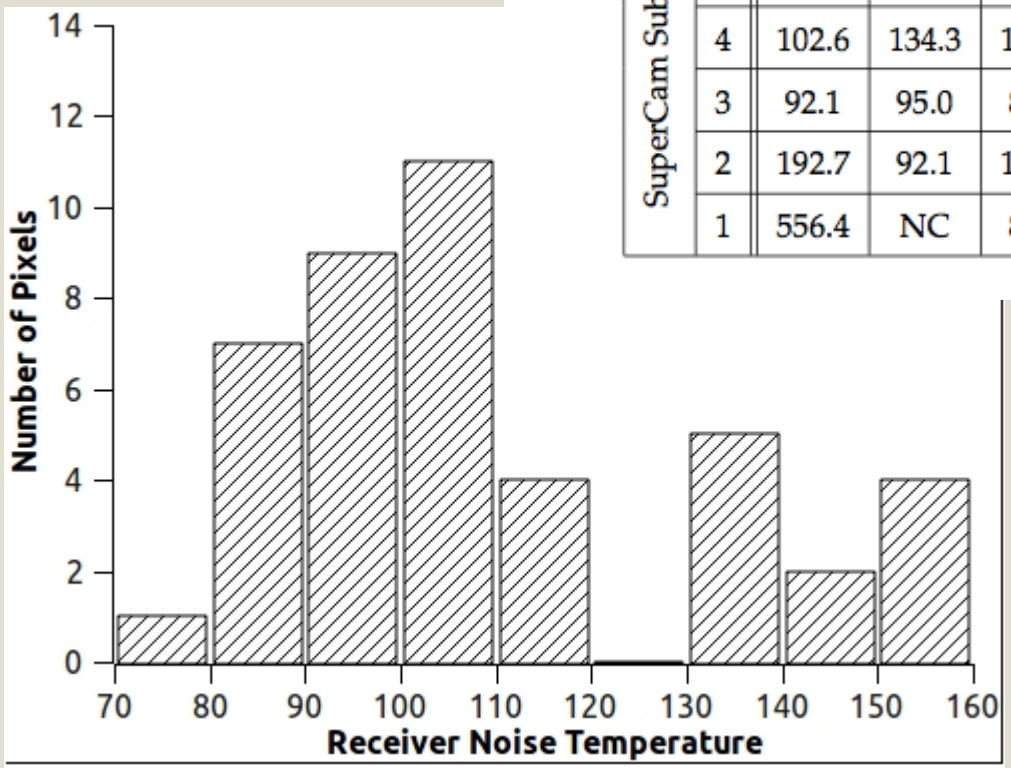
SuperCam I-V Curves



Black= Unpumped
Red=Pumped

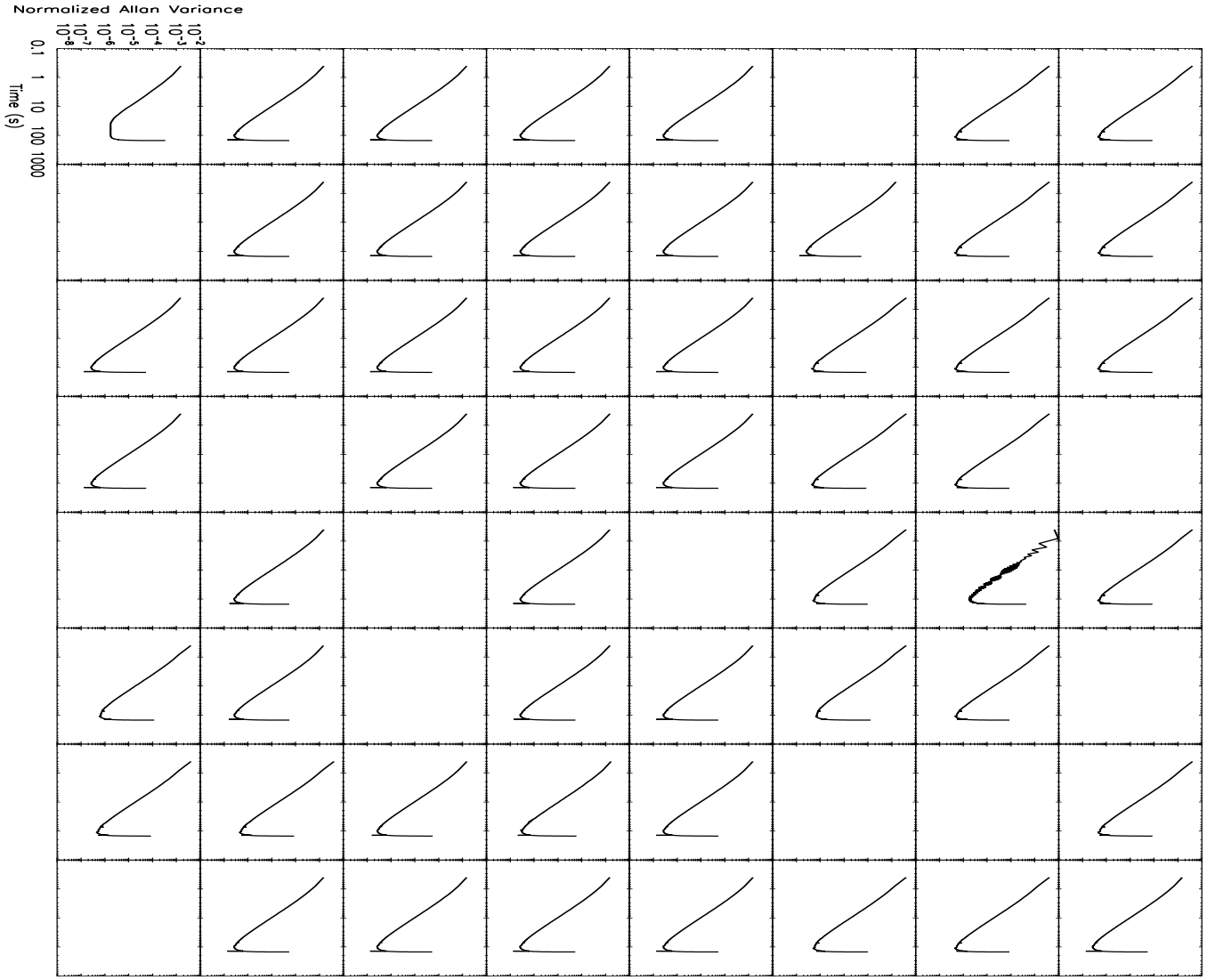
Receiver Noise Temperature

SuperCam Subarray Number	Pixel Number 1	2	3	4	5	6	7	8
8	458.5	228.8	153.3	NC	156.0	NC	109.2	253.3
7	153.3	243.1	110.9	132.1	116.3	458.5	NC	141.1
6	NC	79.1	148.3	156.0	102.6	138.8	NC	132.1
5	95.0	86.7	102.6	93.6	NC	105.8	118.1	107.5
4	102.6	134.3	105.8	102.6	81.5	95.0	420.0	89.4
3	92.1	95.0	88.0	85.4	NC	NC	92.1	104.2
2	192.7	92.1	102.6	NC	92.1	136.5	116.3	99.5
1	556.4	NC	89.4	84.1	NC	105.8	340	NC

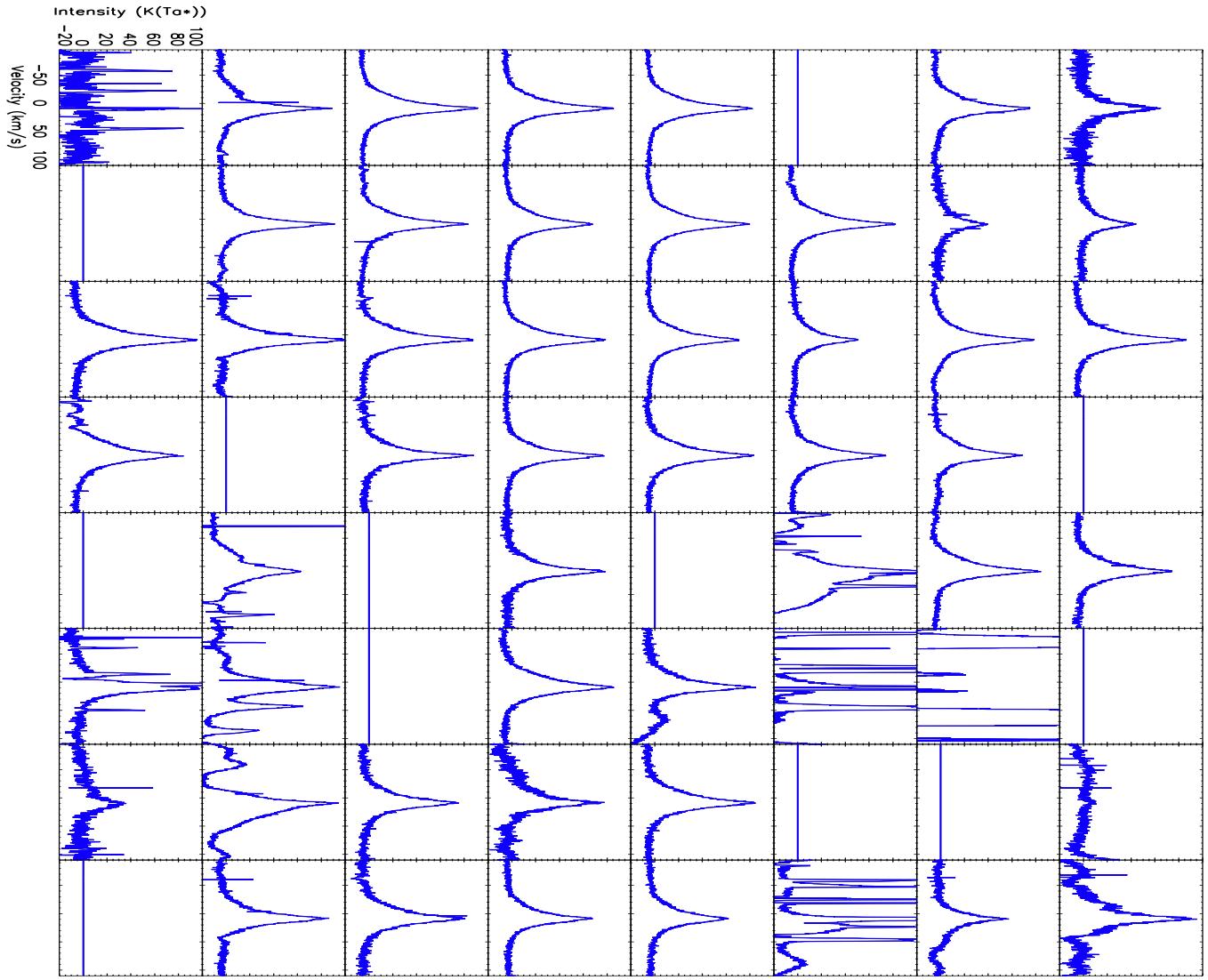


- 81% of pixels working!!!
- Noise-weighted median T_{rx} = 104 K

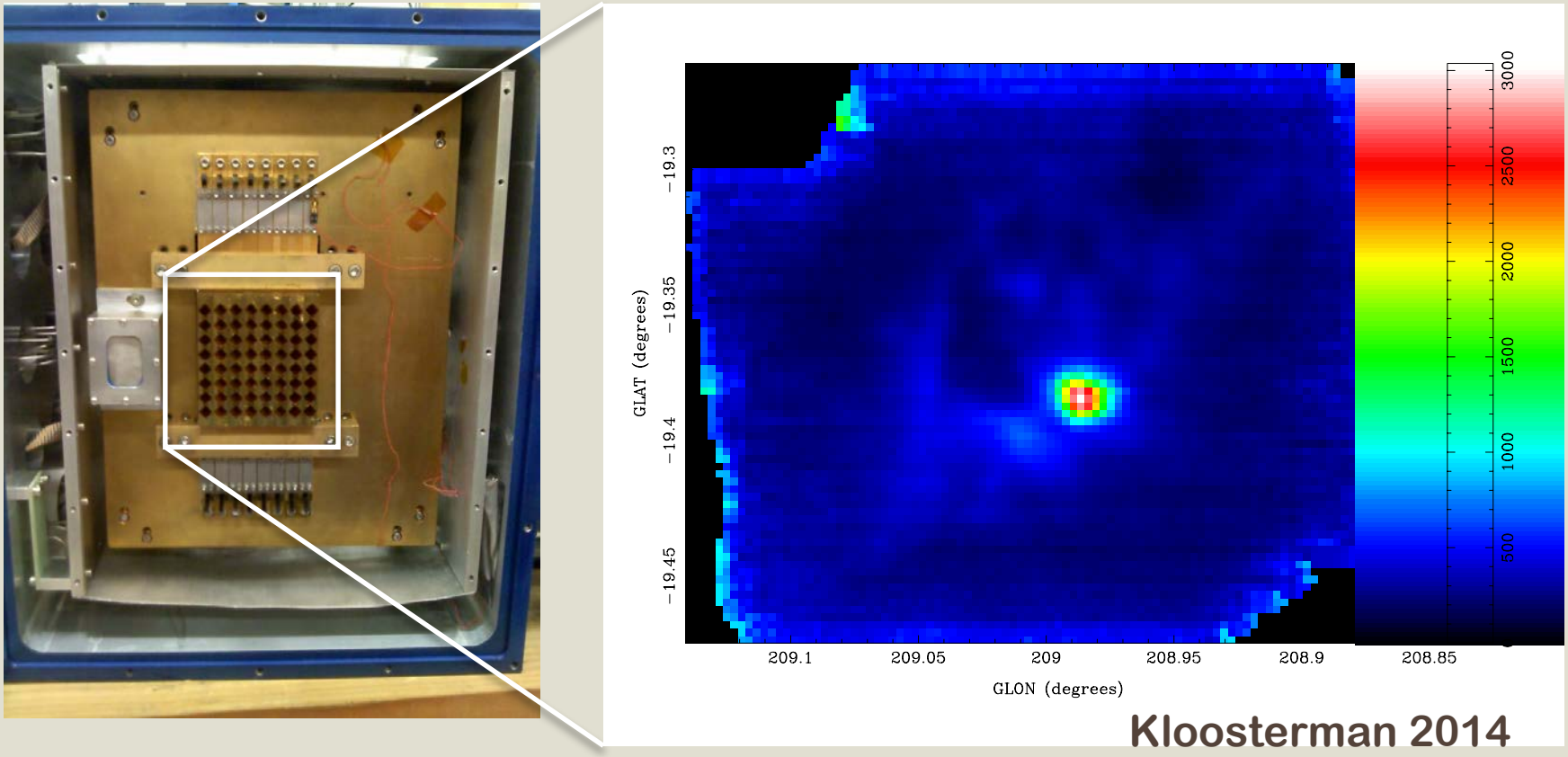
SuperCam Allan Variance



SuperCam Spectra of Orion A



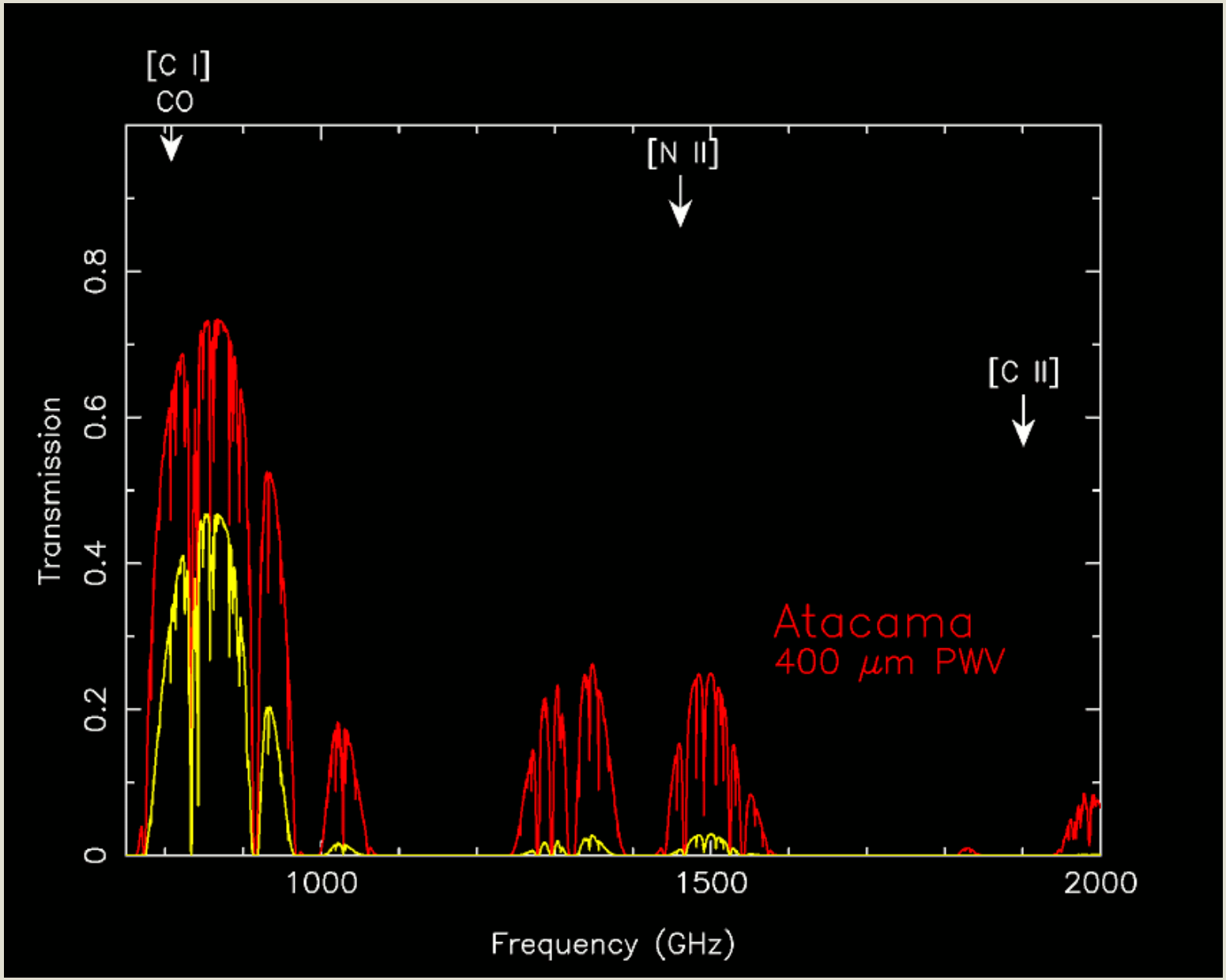
SuperCam



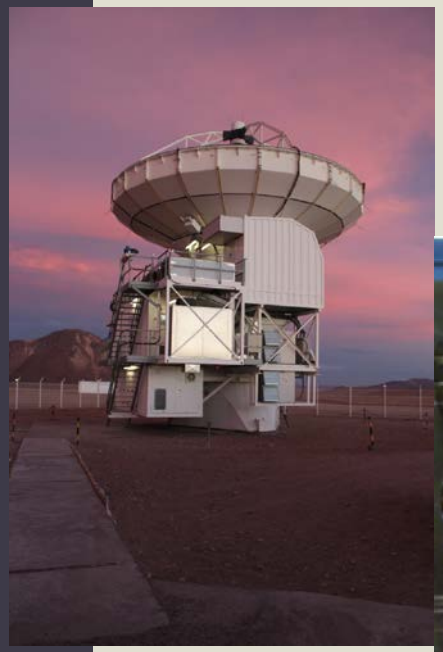
Kloosterman 2014

SuperCam Map of Orion A Molecular Cloud from the SMT, May 2013

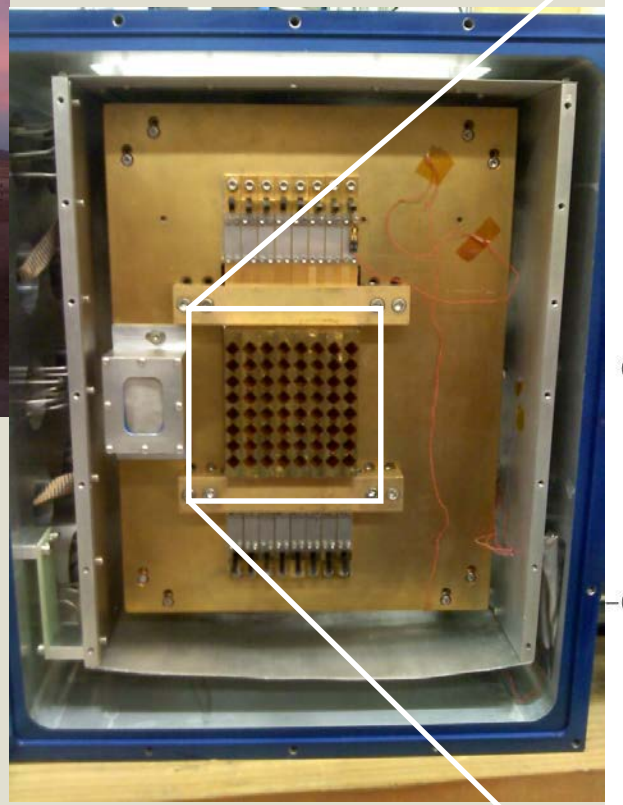
Atmospheric Transmission
(Best Site Reasonably Accessible Site in the World)



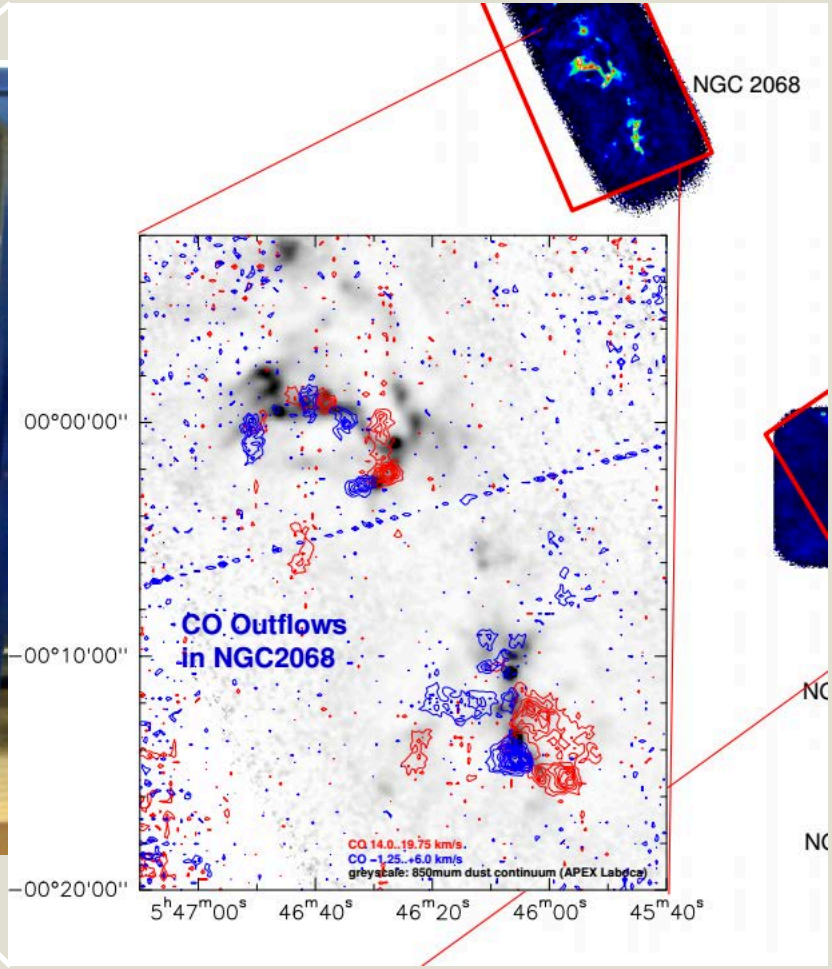
CO Survey Instrument: SuperCam



APEX



Stanke et al., 2015, *in prep*



Life Cycle of Interstellar Medium (ISM)

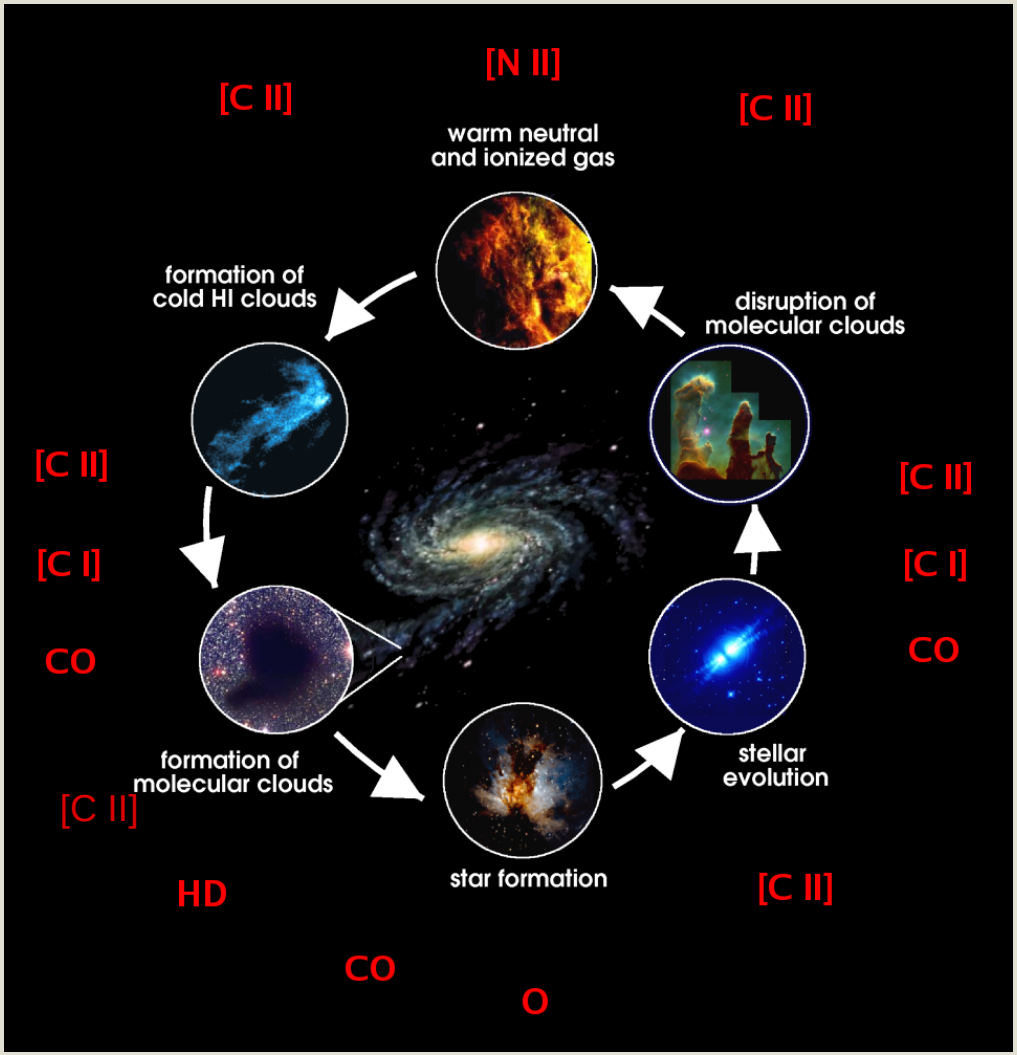


Image Credit: Kulesa and Walker

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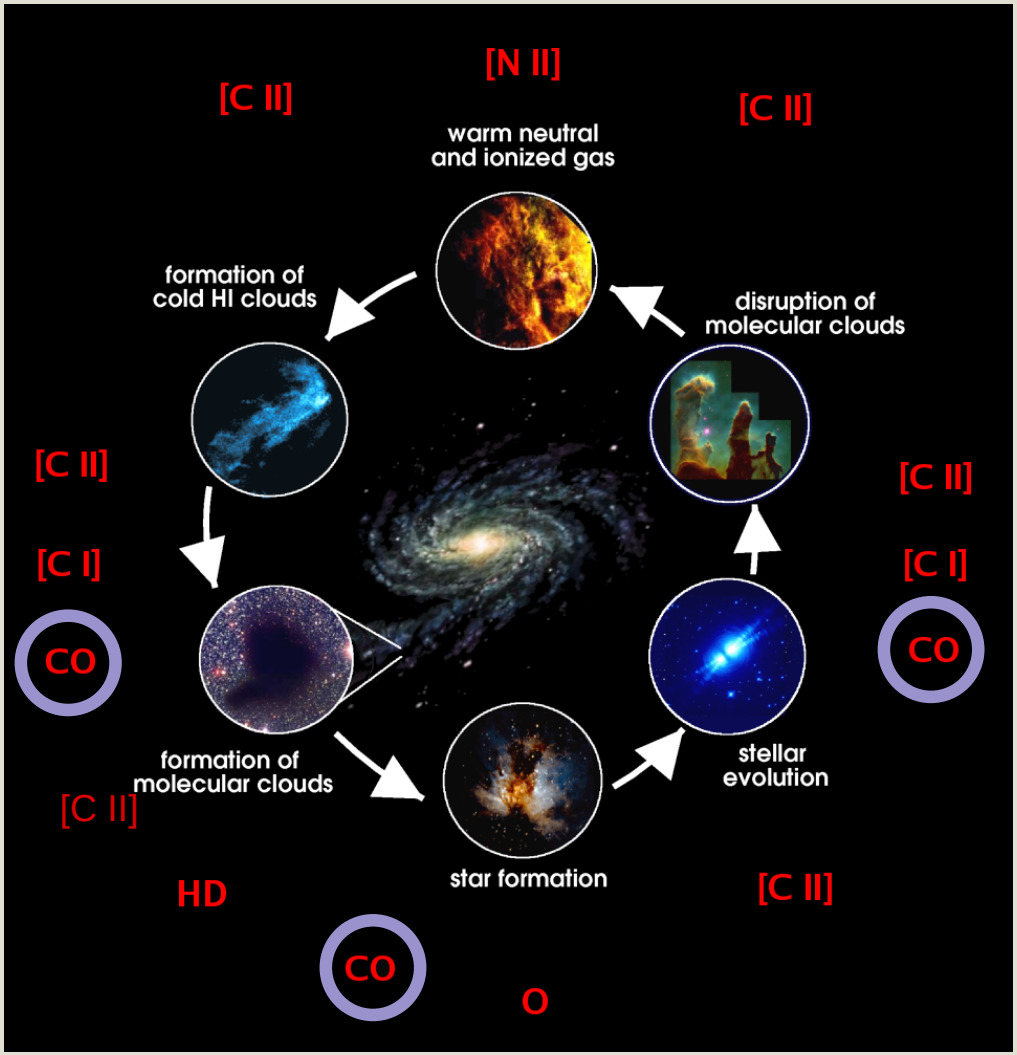
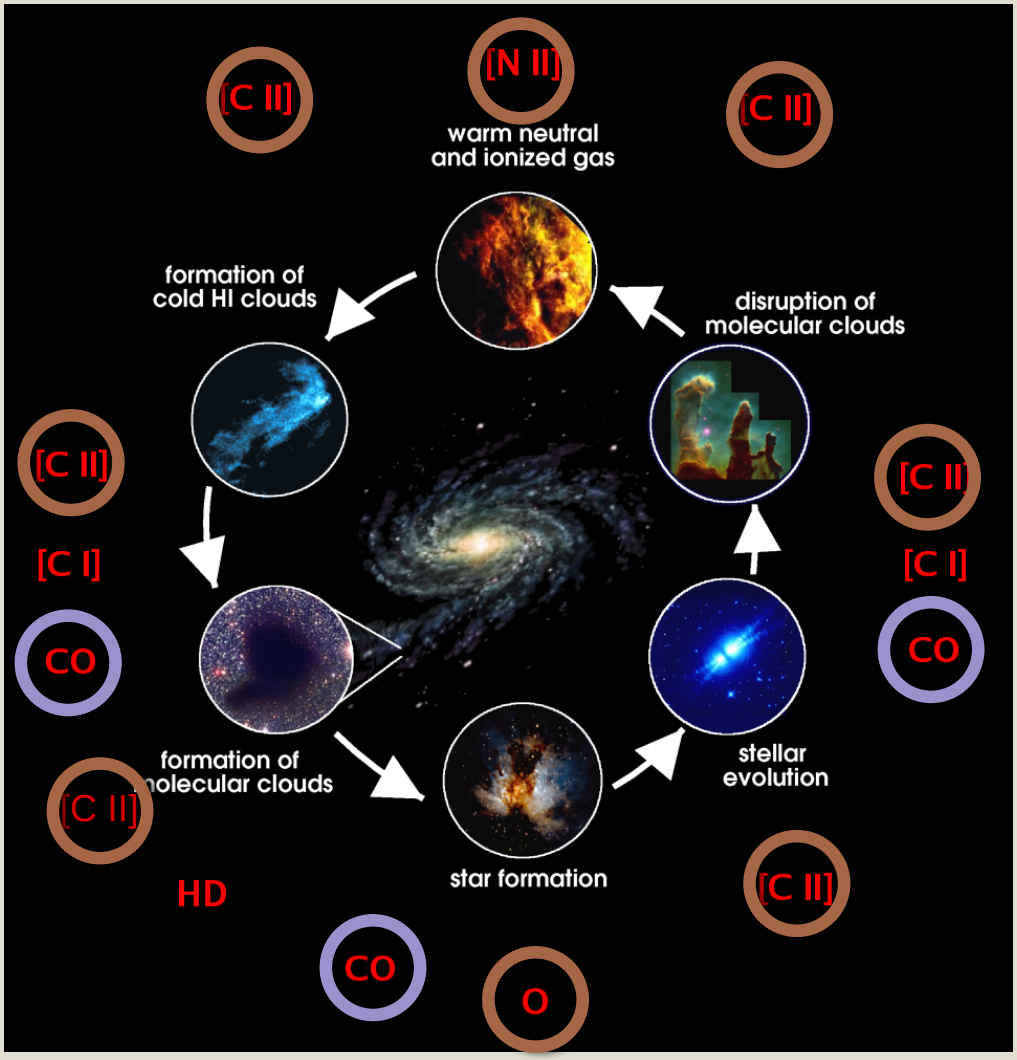


SuperCam
CO: λ = 0.8 mm, ν = 345 GHz

Image Credit: Kulesa and Walker

Life Cycle of Interstellar Medium (ISM)

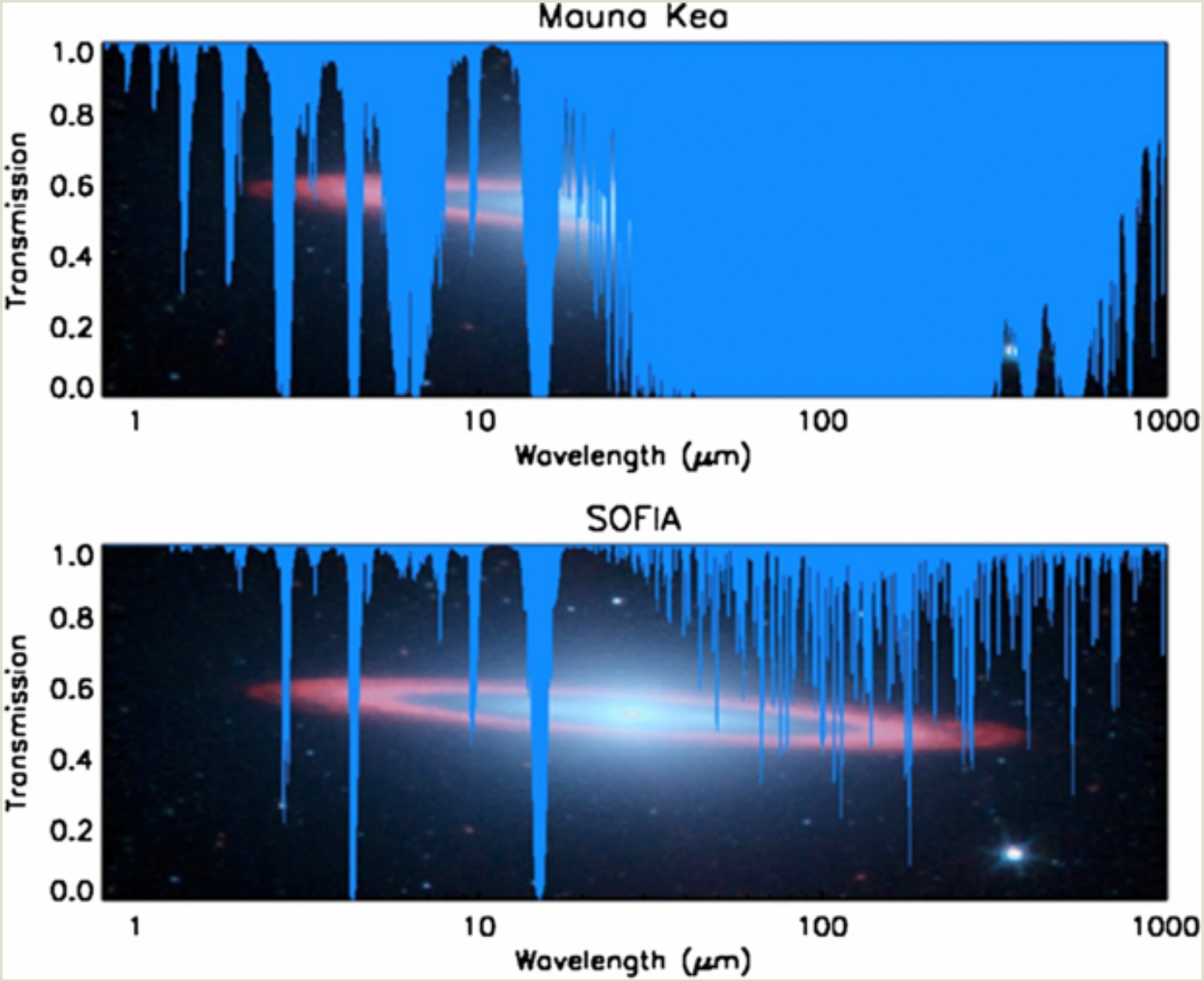


SuperCam
CO: λ = 0.8 mm, ν = 345 GHz

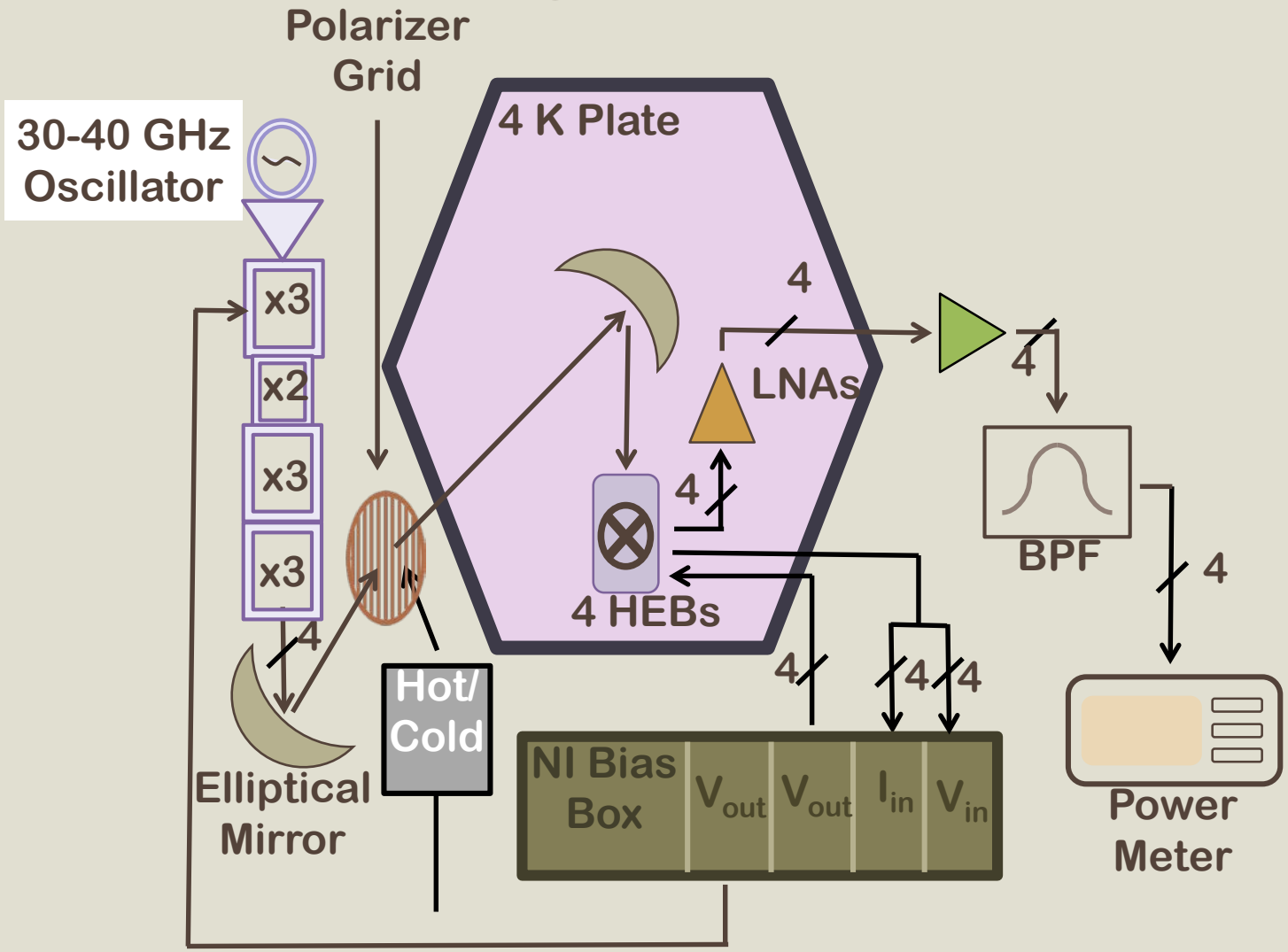
STO/STO-2/GUSTO/SHASTA
[NII]: λ = 205 μm, ν = 1.5 THz
[CII]: λ = 158 μm, ν = 1.9 THz
[OI]: λ= 63 μm, ν = 4.74 THz

Image Credit: Kulesa and Walker

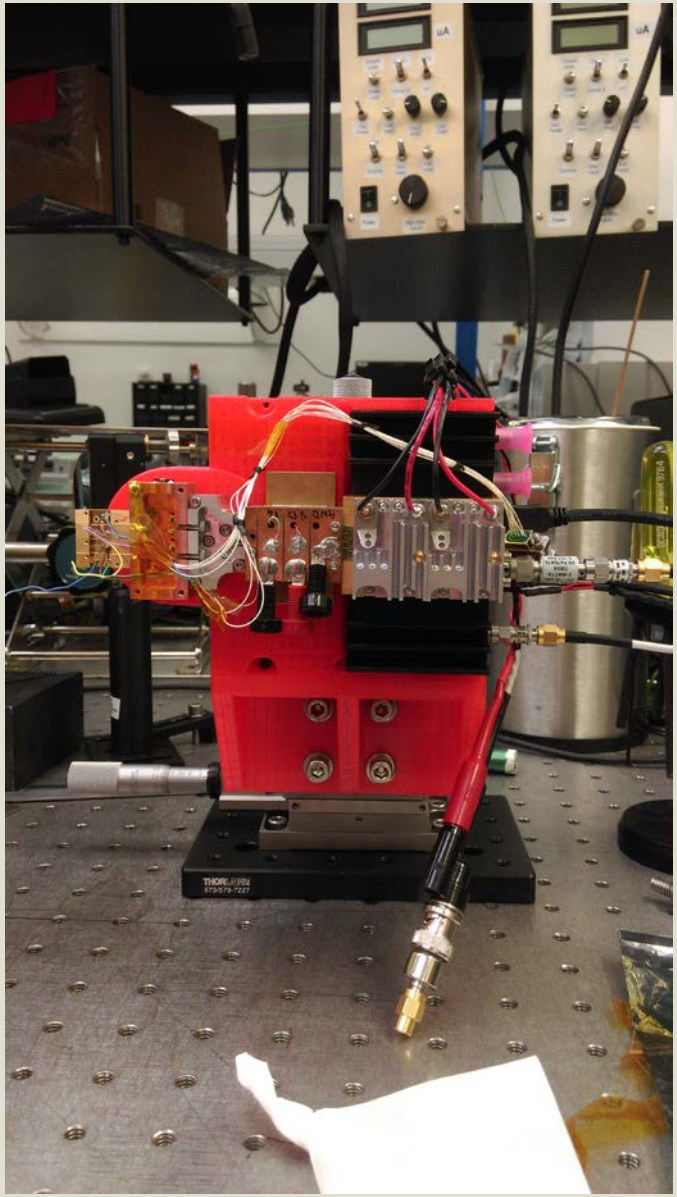
Atmospheric Transmission (SOFIA/Sub-Orbital)

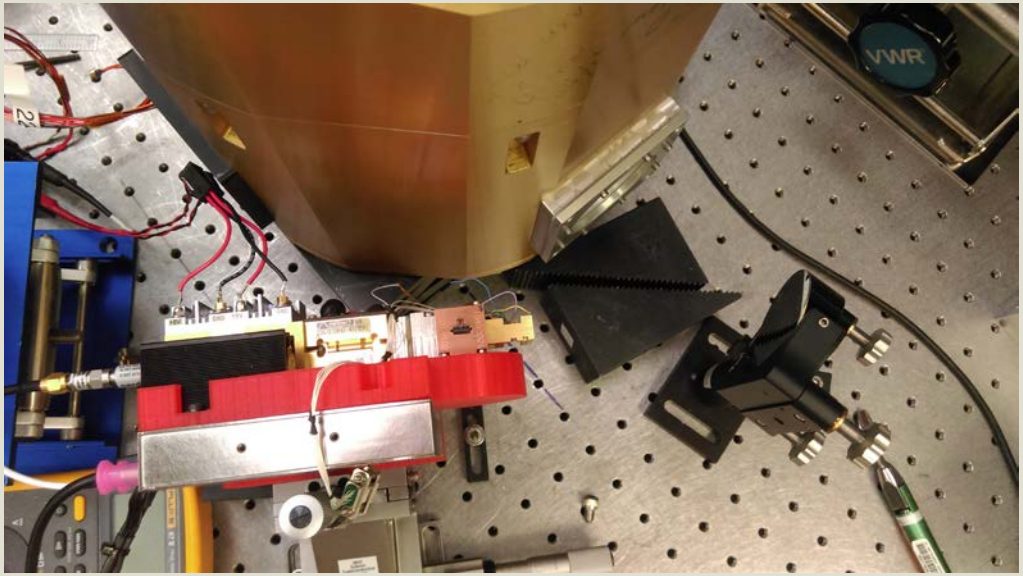


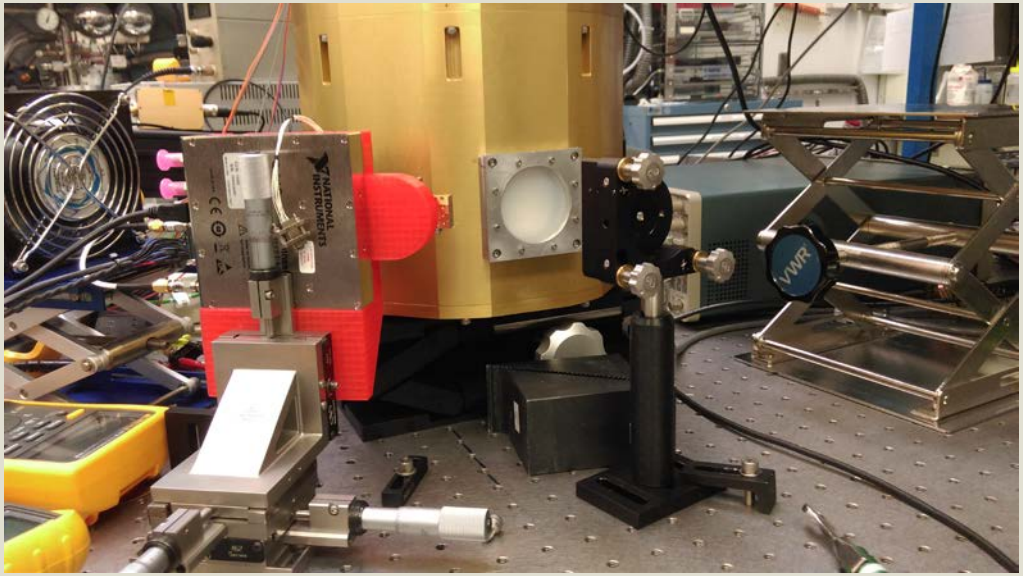
Lab Setup for Prototype Array at 1.9 THz



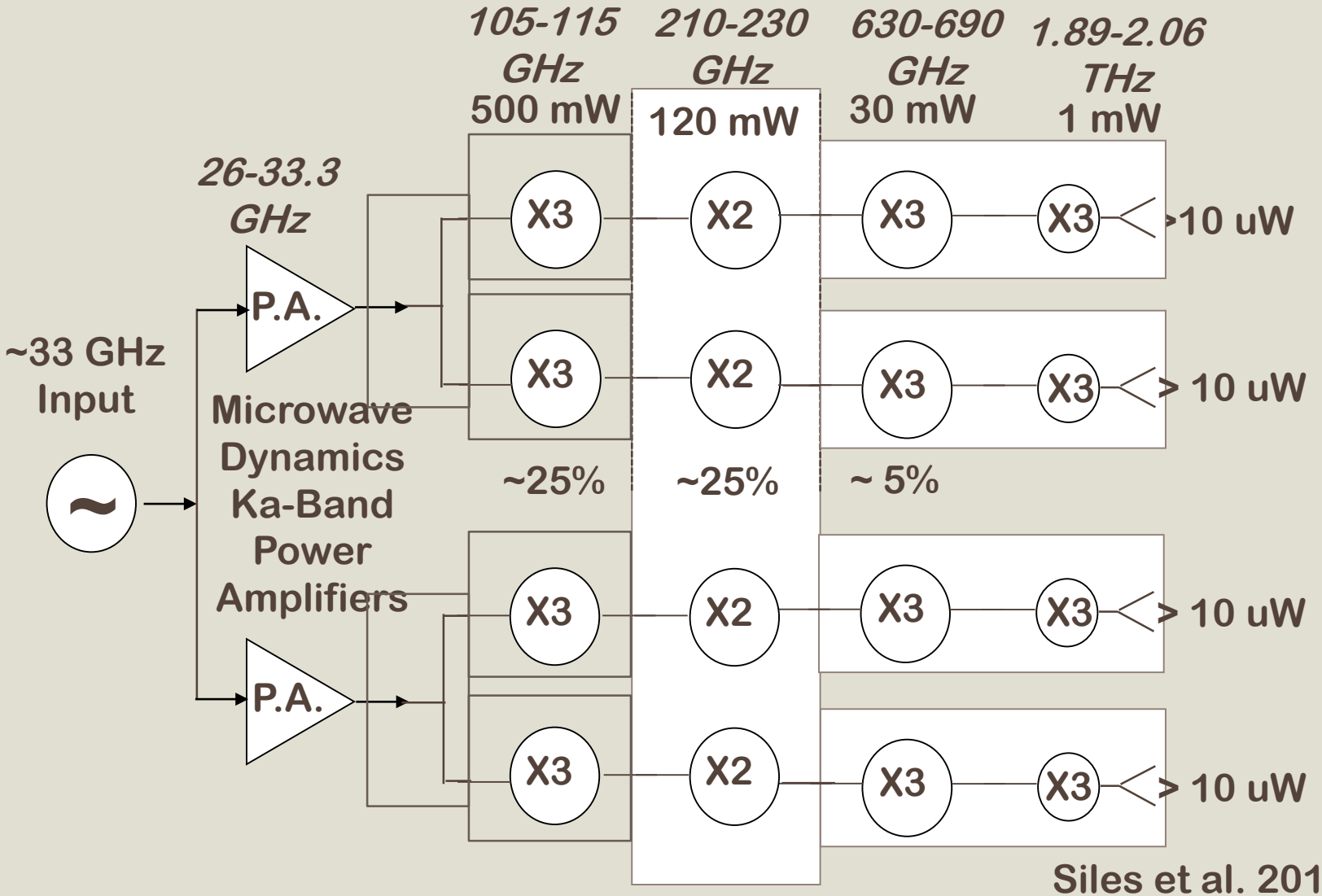
Lab Setup







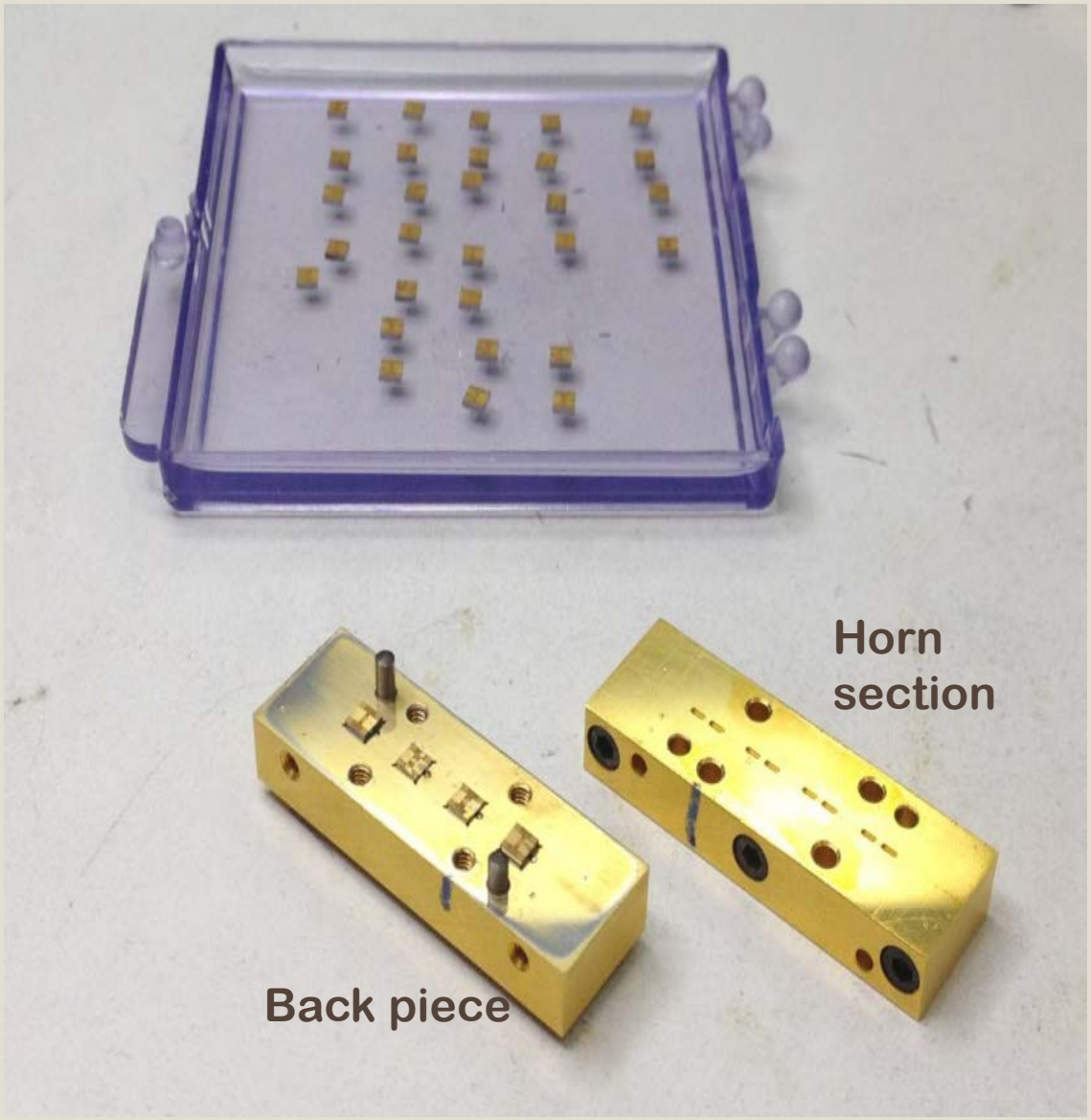
1.9 THz Local Oscillator



Siles et al. 2014

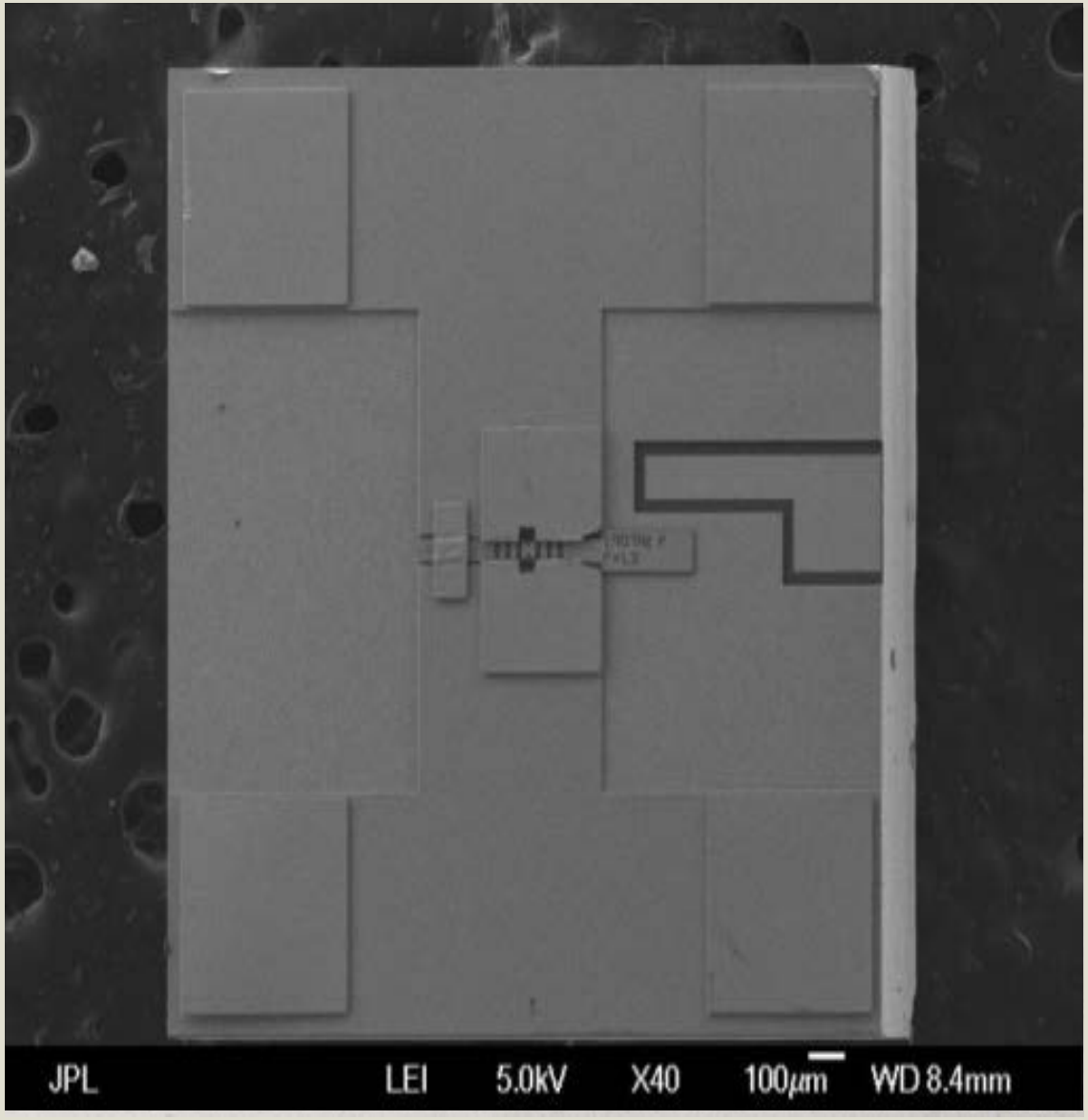
Mixers

SOI Chip-HEB Technology

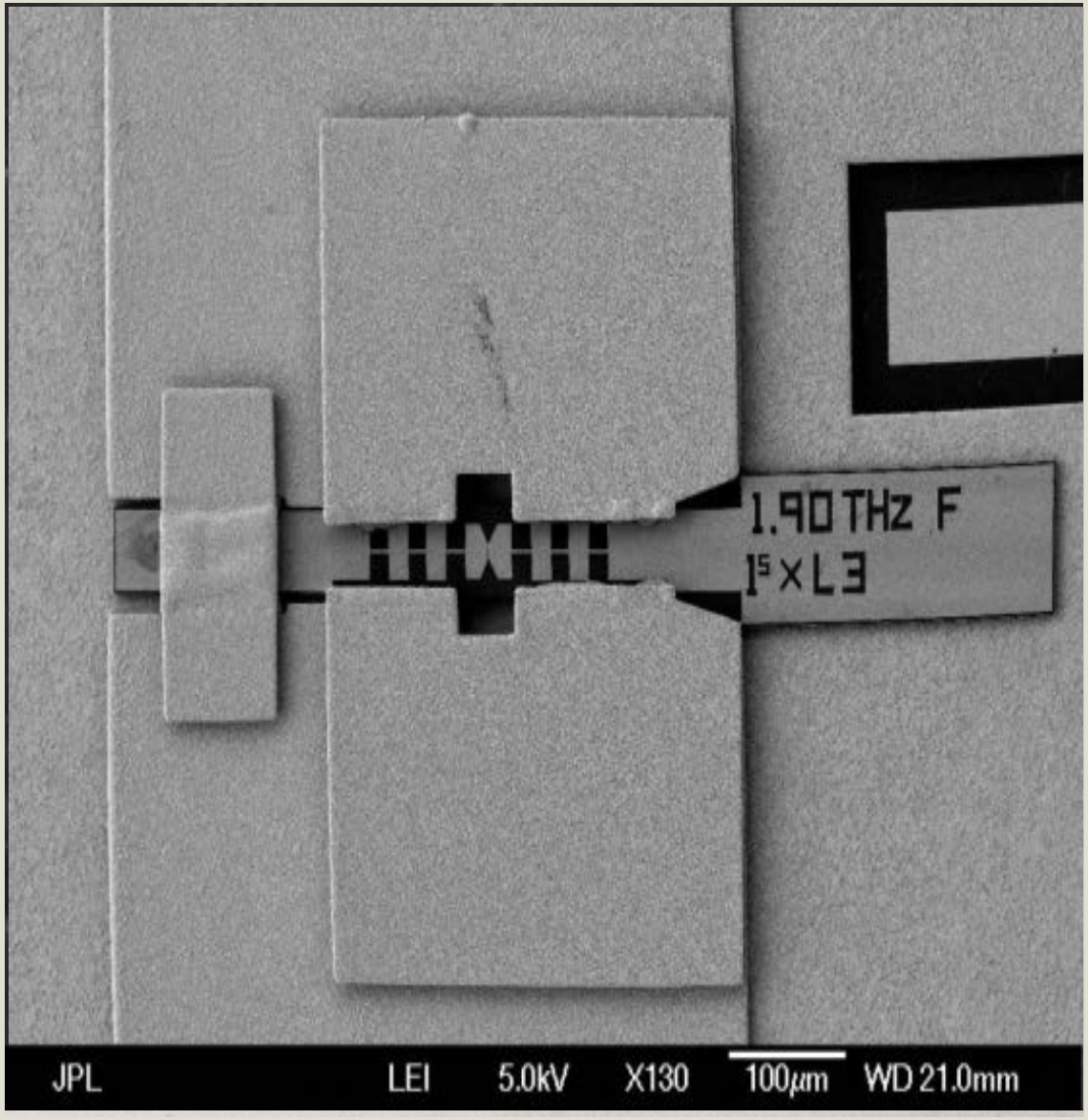


Mixers

SOI Chip-
HEB
Technology

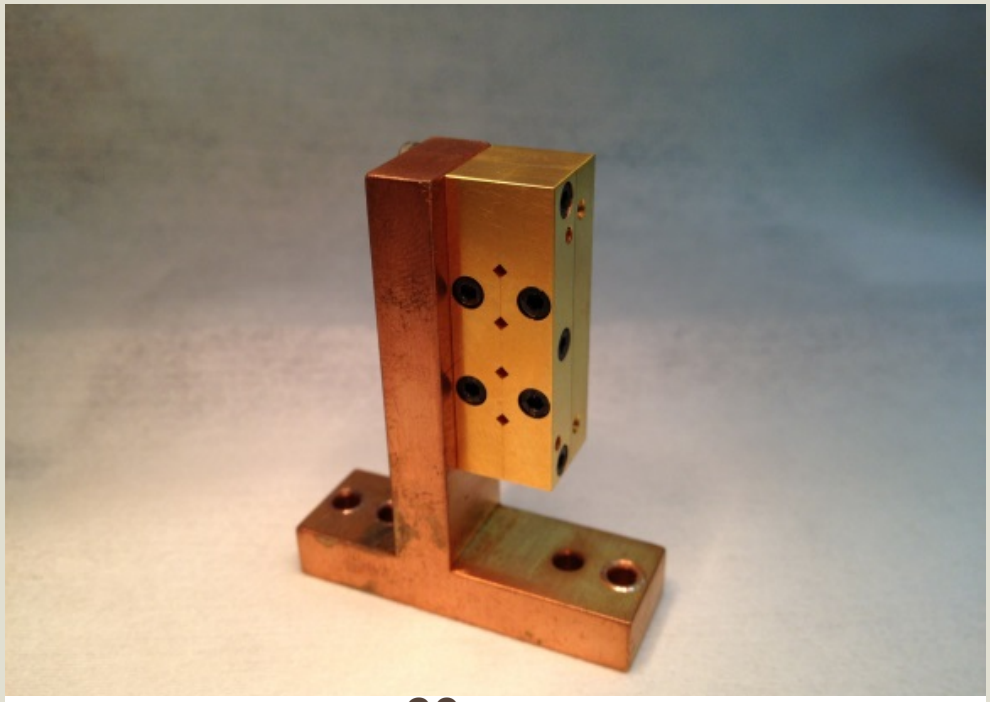


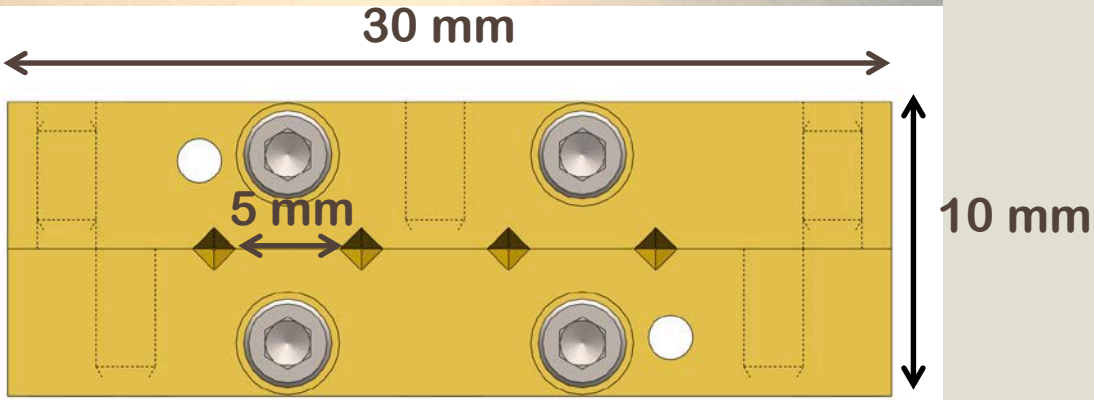
Mixers

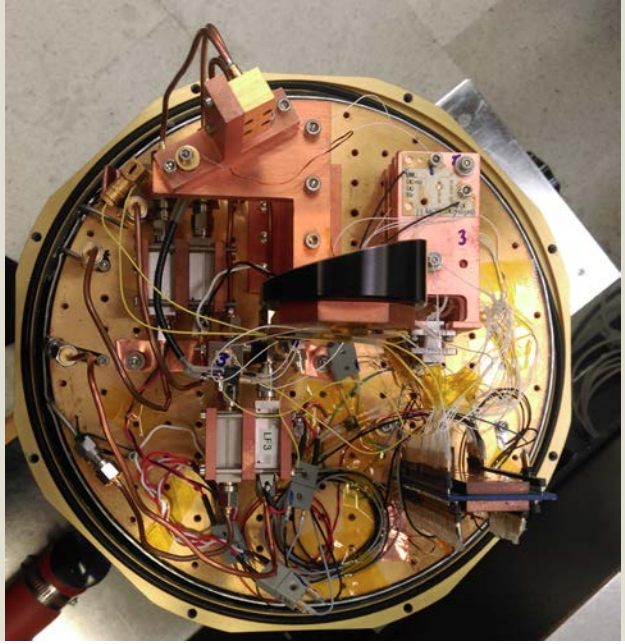


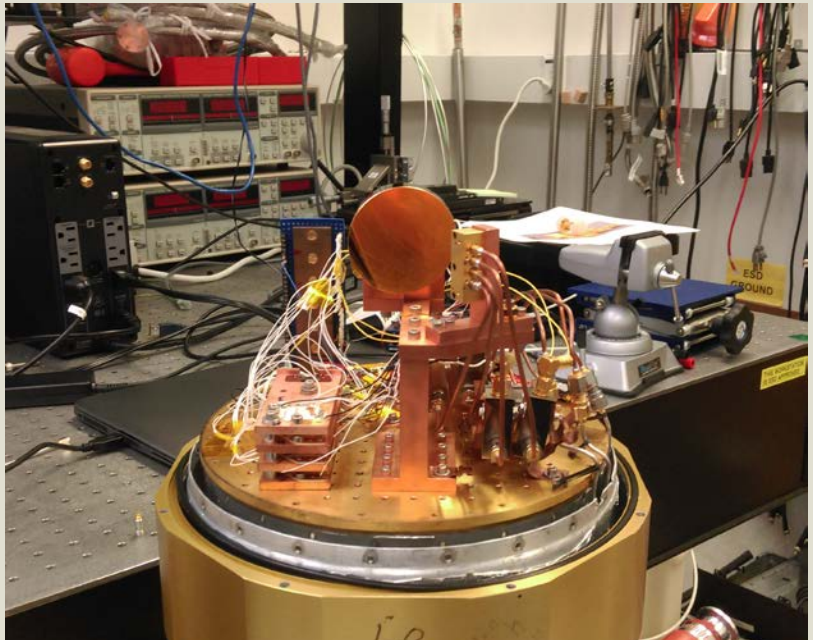
SOI Chip-HEB Technology

4-Pixel Mixer Block

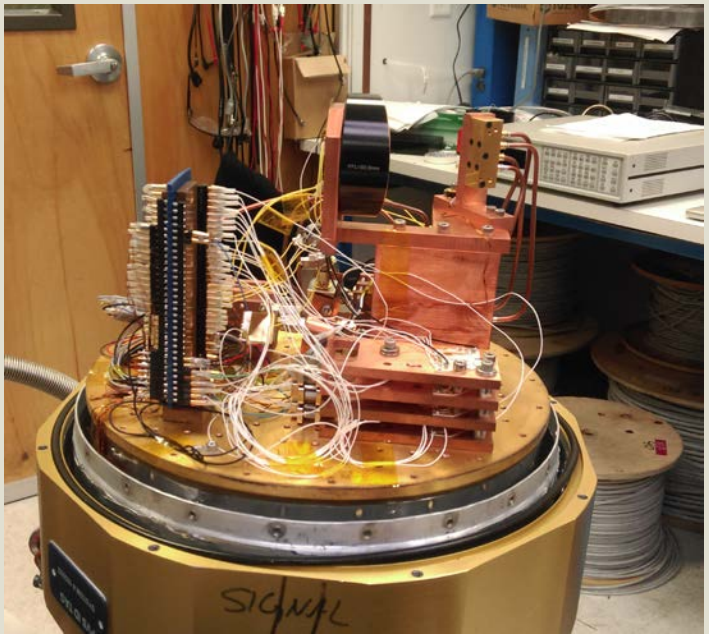


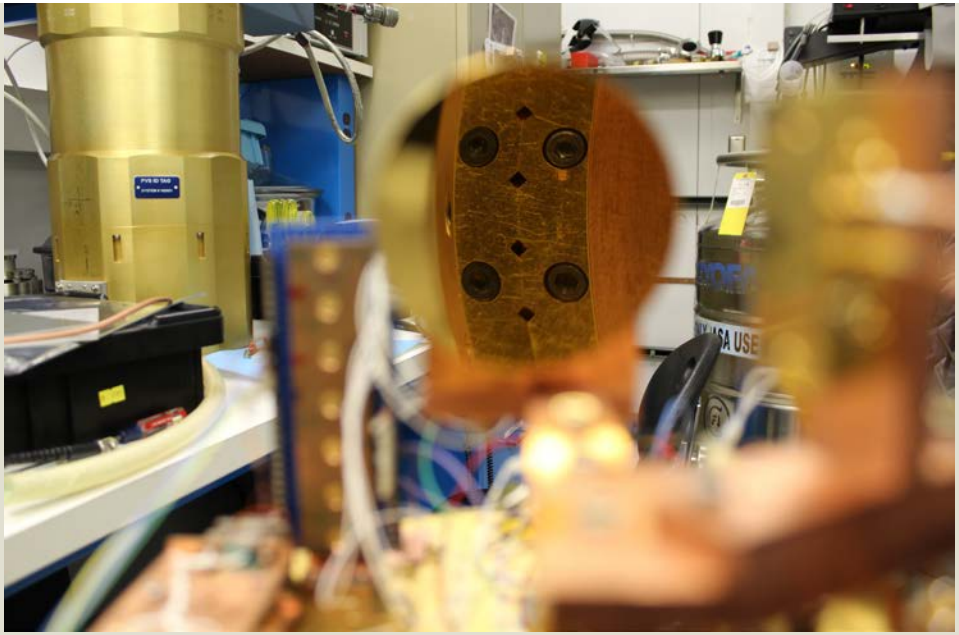




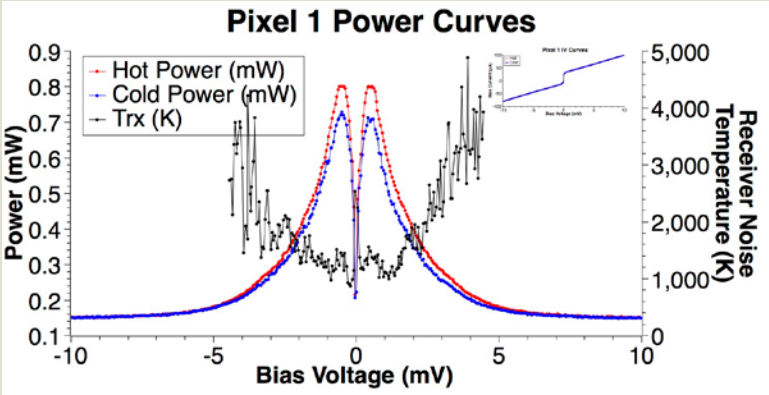


4 Pixel Array Inside the Cryostat

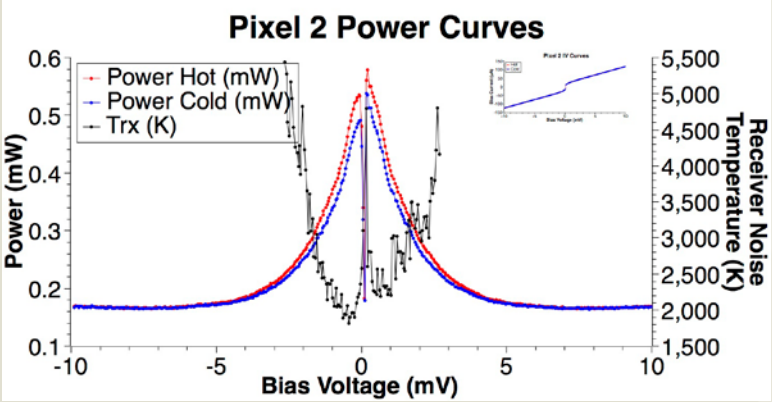




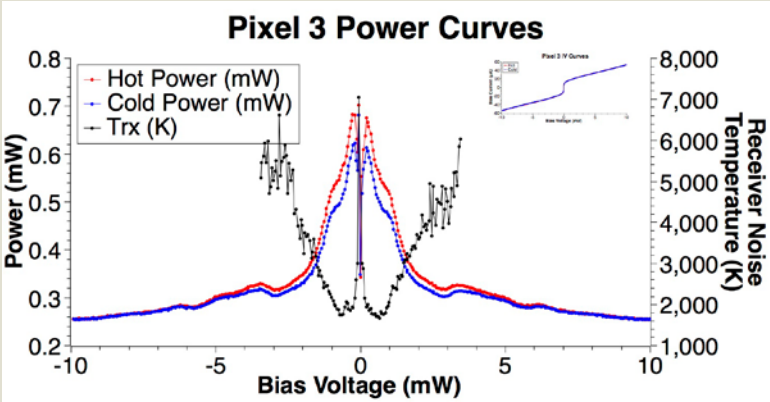
Results



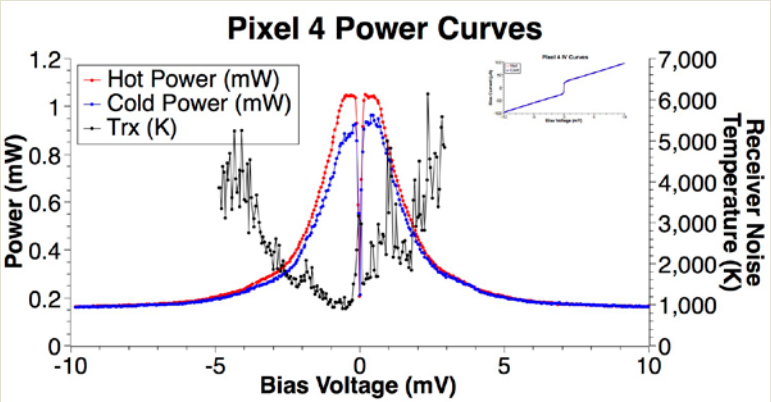
T_{rx} = 900 K



T_{rx} = 1800 K

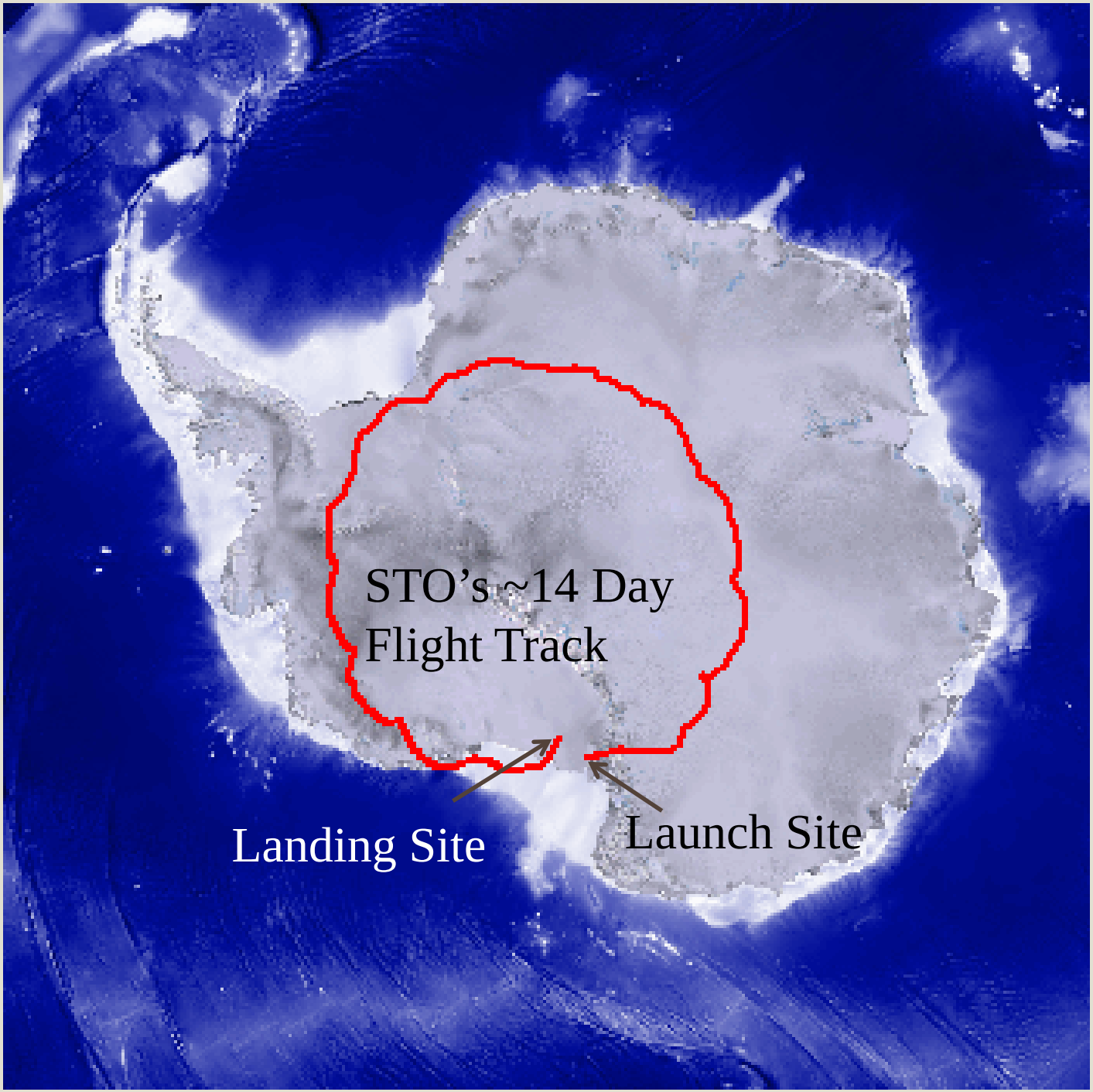


T_{rx} = 1700 K



T_{rx} = 900 K

STO-2 Hang Test


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

STO Recovery Operations

Summary

- 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
- Atomic and molecular spectral lines resonate in the THz/sub-millimeter region of the electromagnetic spectrum
- Heterodyne receivers provide sensitivity and high spectral resolution in order to study the kinematics of PDRs/GMCs
- SuperCam has provided a framework for large format THz heterodyne receivers
- 1.9 THz 4-pixel prototype array will be used to develop 8 to 16 pixel array for GUSTO/SOFIA