Silicon Micromachined Integrated Array Instruments at Terahertz Frequencies

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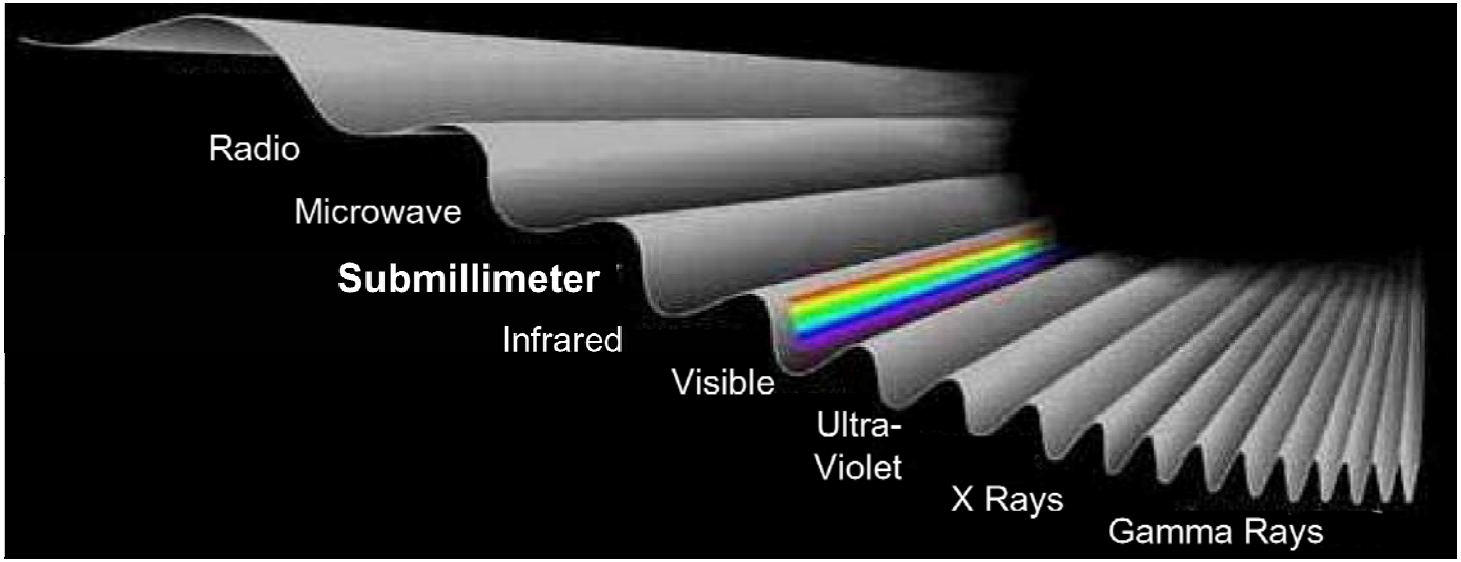
Government sponsorship acknowledged.

Terahertz (Submillimeter) Waves

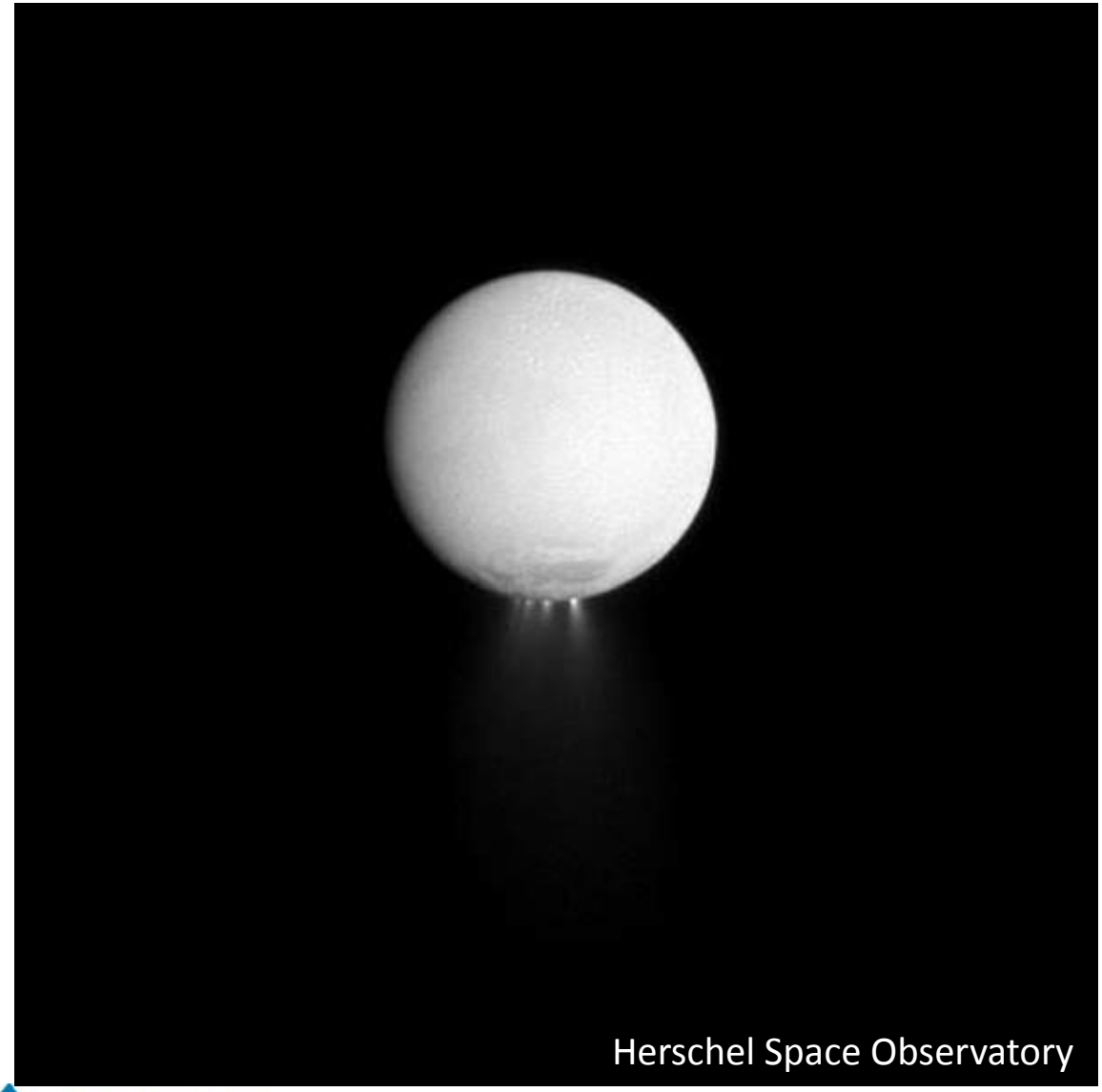


Loosely defined: 1 mm > λ > 100 µm

300 GHz < ν < 3 THz

Most of the radiation in the Universe is emitted at submillimeter-wavelengths, peaking at 3 THz (if we exclude Cosmic Microwave Background).

Terahertz Science: Planetary Bodies



Saturn's moon Enceladus rains down water on Saturn!

Now we know where the water vapor in Saturn's upper atmosphere come from!

Enceladus is the only moon in the Solar System known to influence the chemical composition of its parent planet.

Terahertz Science: Oxygen Molecule

2 August 2011 Last updated at 10:53 ET

1,171 Share

Oxygen finally spotted in space

"Hidden" oxygen may be released from dust grains and ice in star-forming regions

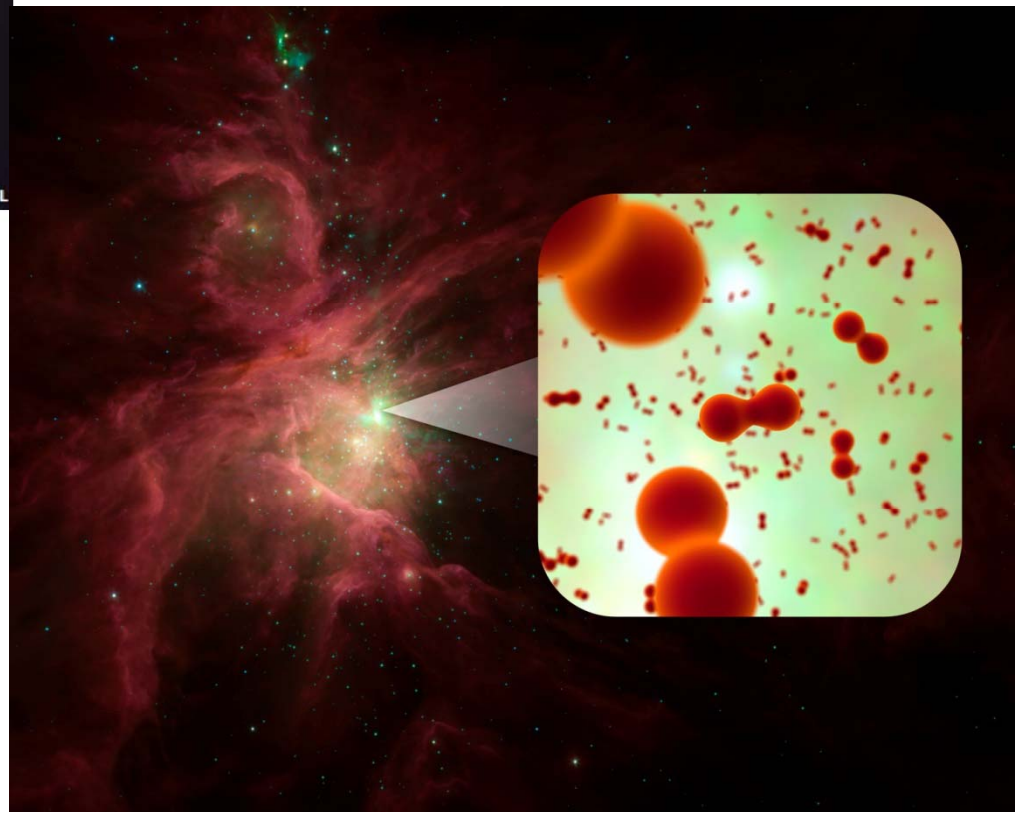
One of astronomy's longest-running "missing persons" investigations has concluded: astronomers have found molecular oxygen in space.

While single atoms of oxygen have been found alone or incorporated into other molecules, the oxygen molecule - the one we breathe - had never been seen.

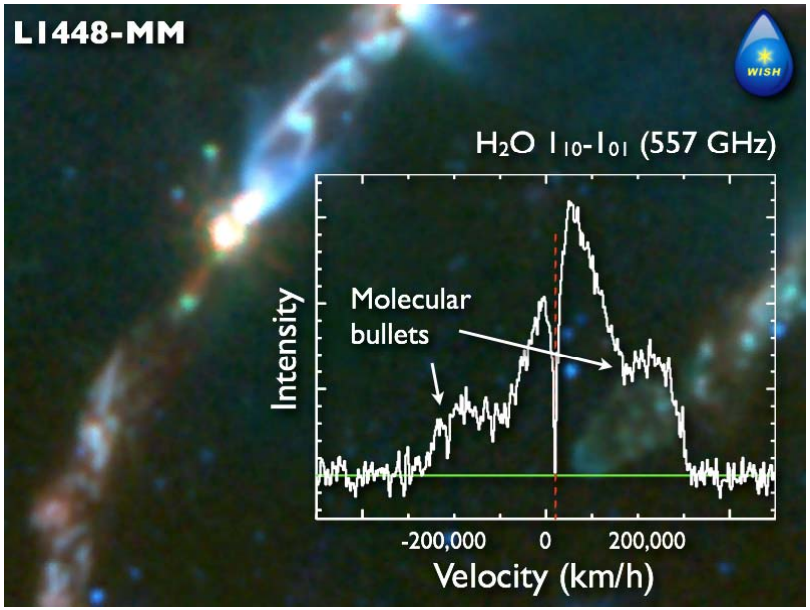
The Herschel space telescope spotted the molecules in a star-forming region in the constellation of Orion.

Ref: Paul Goldsmith et. al.,

Herschel Space Observatory's HIFI Instrument



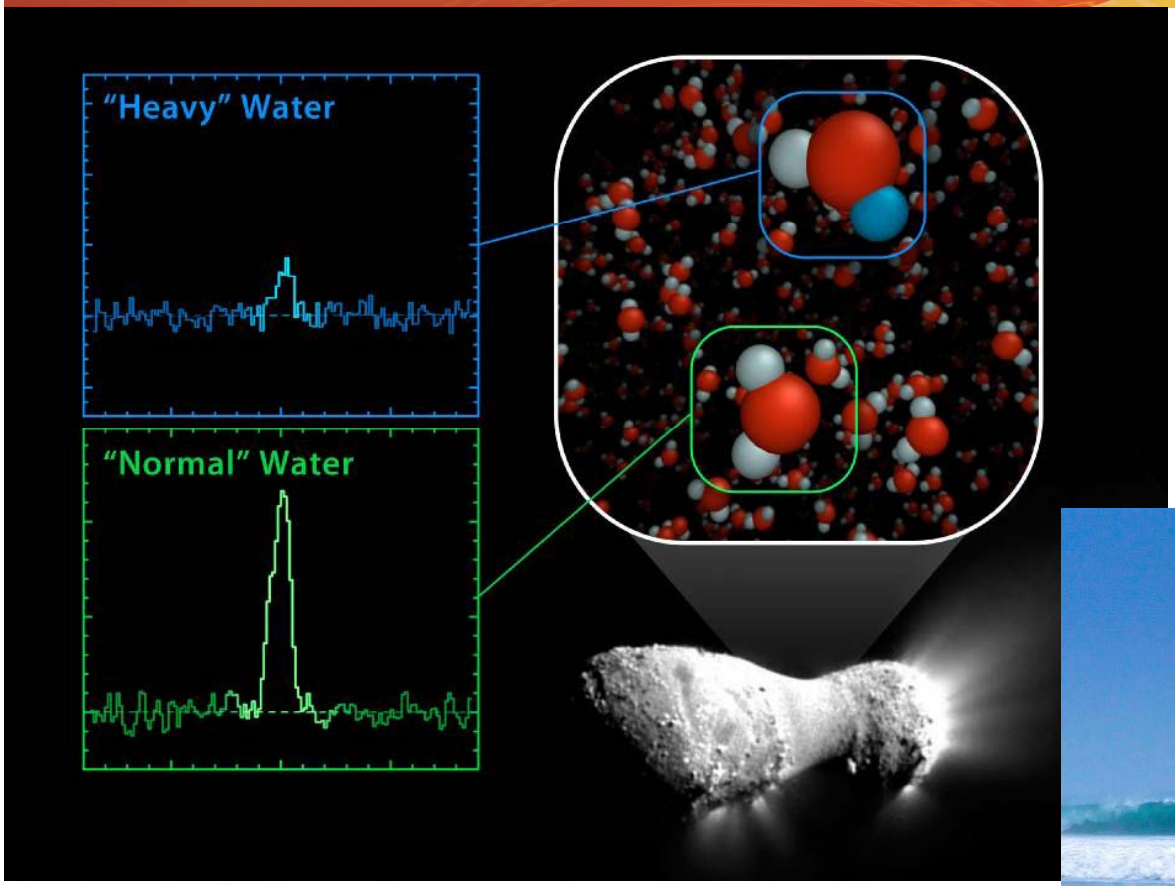
Terahertz Science: Water



Observations with Herschel-HIFI of water in a young Sun-like star reveal high-velocity "bullets" moving at more than 200,000 km/h from the star. This can be compared to the velocity of a bullet from an AK47 rifle, which is 2500 km/h or 80 times slower. It is a surprise that water molecules are observed at this high velocity - they should have been destroyed in the shock where temperatures exceed **100,000 degrees**.

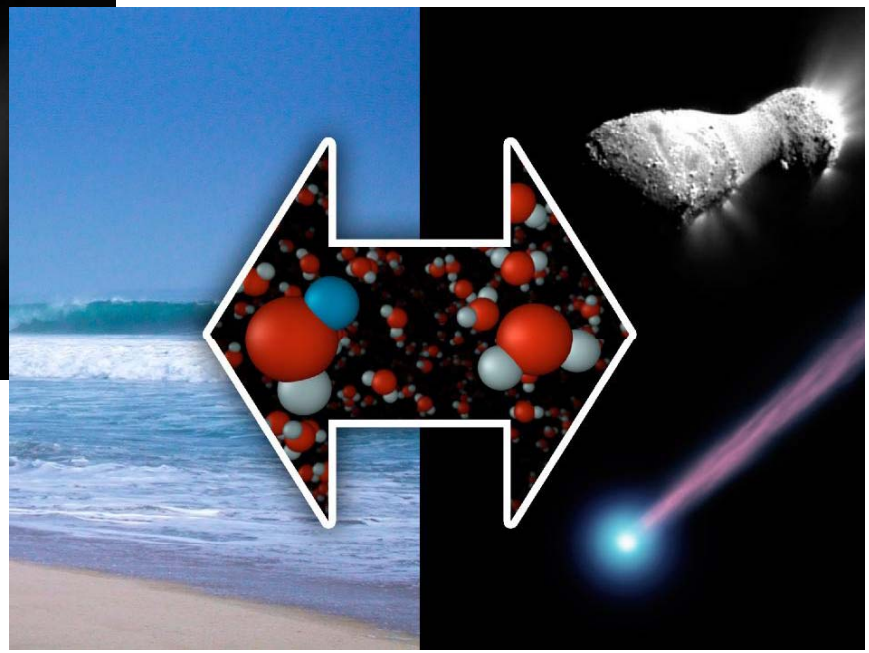
Observations reveal that water very likely reforms rapidly in the hot and dense shocked gas. **The conditions are so favorable that approximately 100 million times the amount of water in the Amazon river is formed, every second!**

Terahertz Science: Comets



Herschel Space Observatory's HIFI Instrument (JPL).

"Earth's water may have come from comets!"



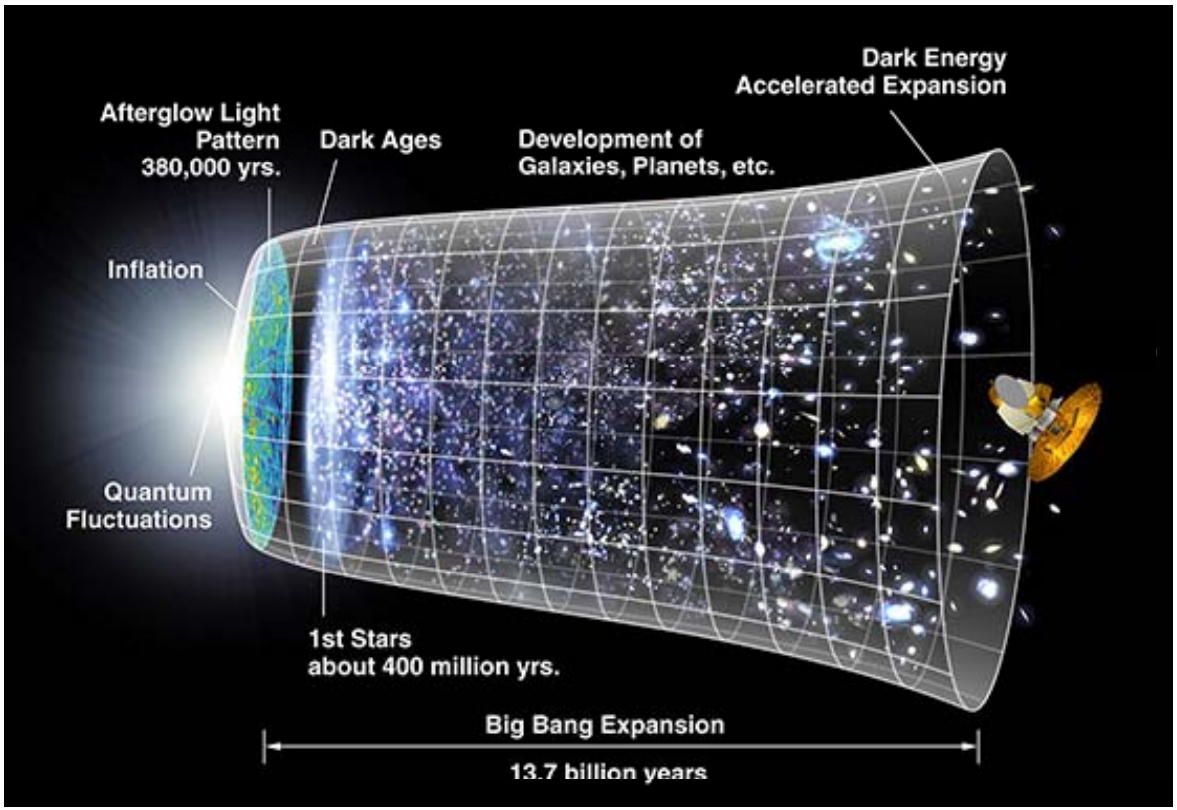
LETTER Nature, October 2011

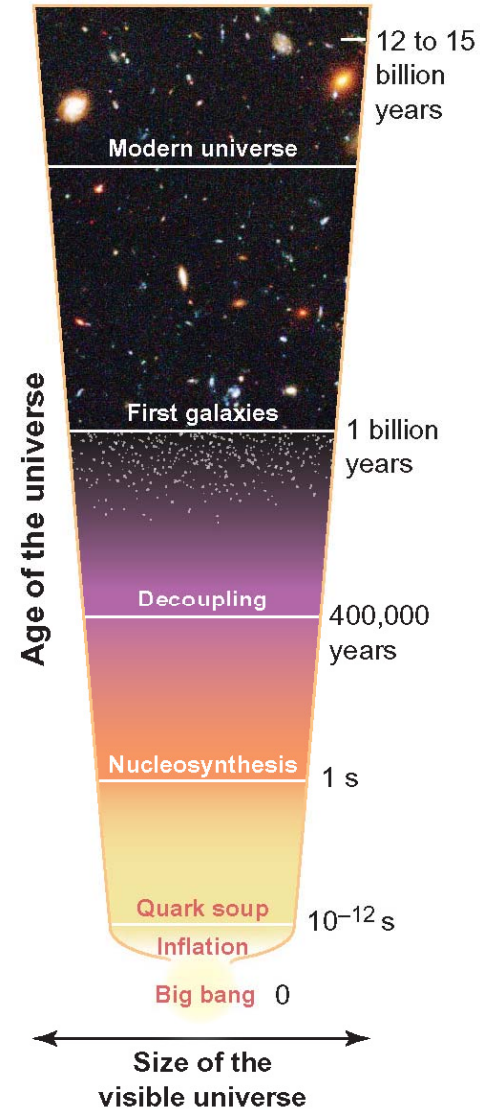
doi:10.1038/nature10519

Ocean-like water in the Jupiter-family comet 103P/Hartley 2

Paul Hartogh[1], Dariusz C. Lis[2], Dominique Bockelée-Morvan[3], Miguel de Val-Borro[1], Nicolas Biver[3], Michael Küppers[4], Martin Emprechtinger[2], Edwin A. Bergin[5], Jacques Crovisier[3], Miriam Rengel[1], Raphael Moreno[3], Sławomira Szutowicz[6] & Geoffrey A. Blake[2]

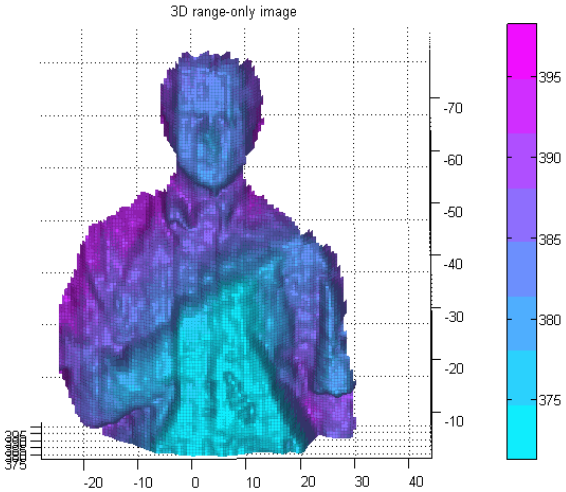
Terahertz Science: The Big Bang



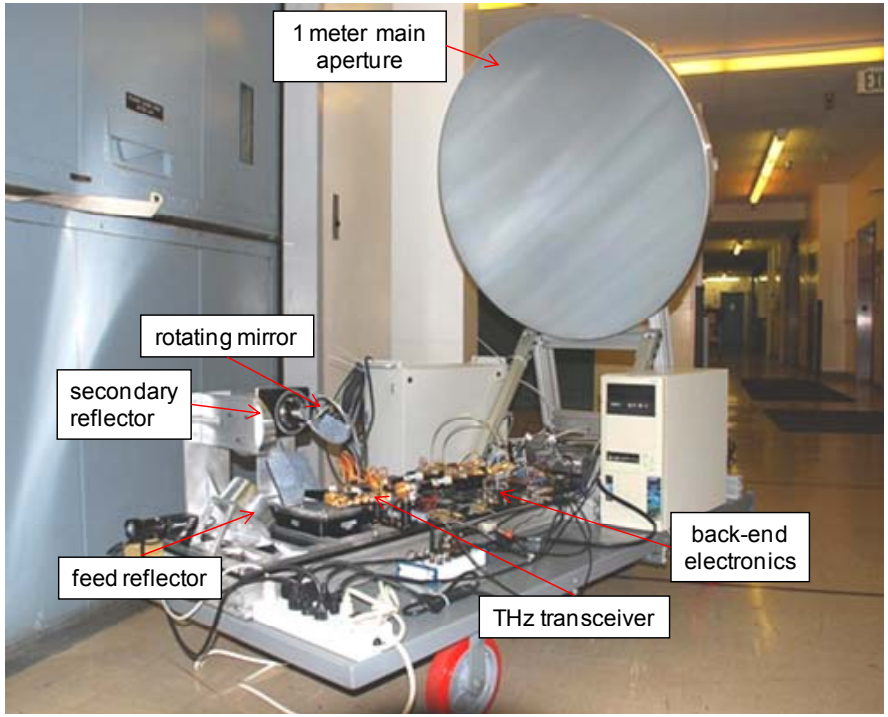


History of our Universe: Started with a Big Bang, and here we are, after 14 billion years!

Security Applications at Terahertz



Single Pixel Instruments



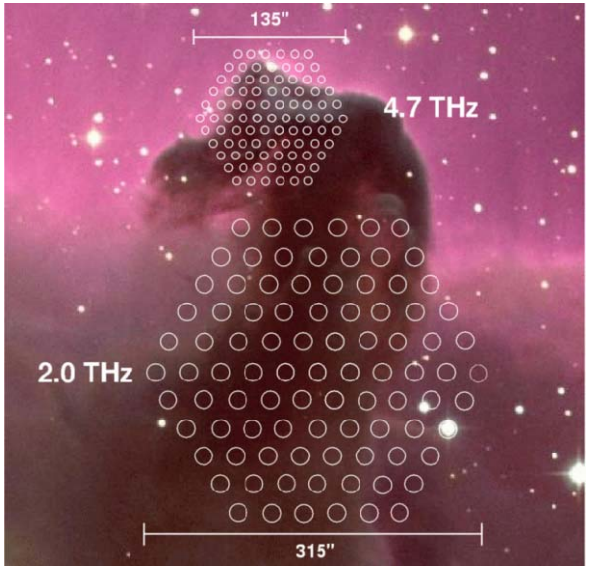
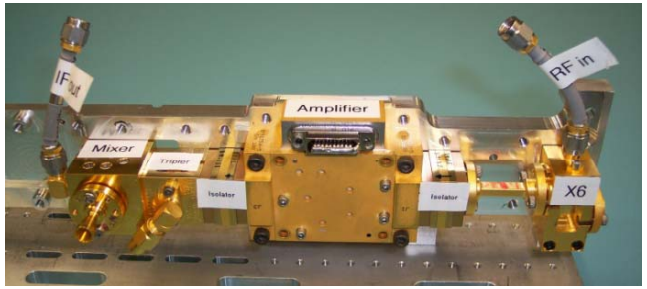


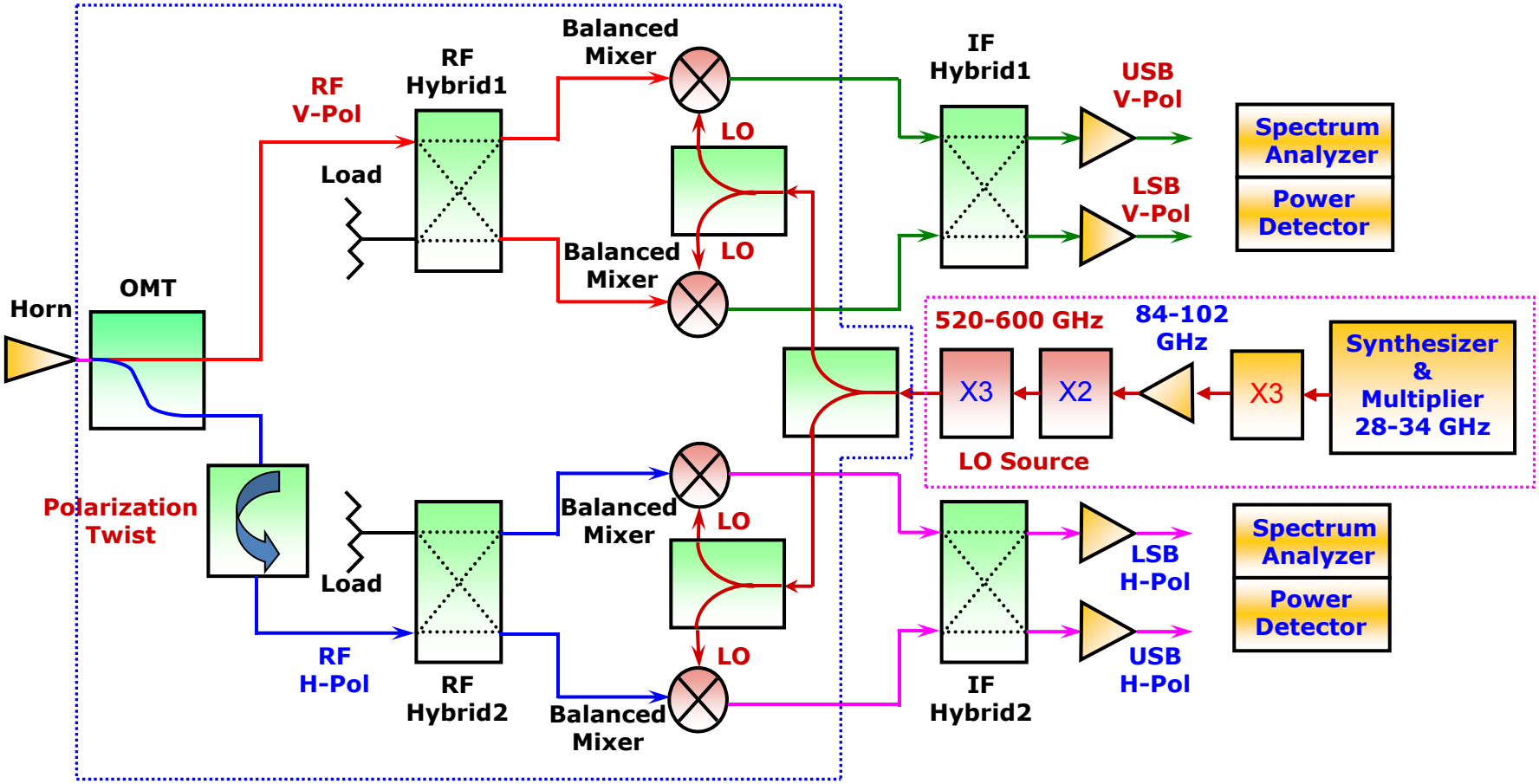
Image courtesy: Chris Walker

- Current generation heterodyne instruments are mostly single-pixel.
- Mapping of large scale areas (star forming regions) is the key for future space missions.

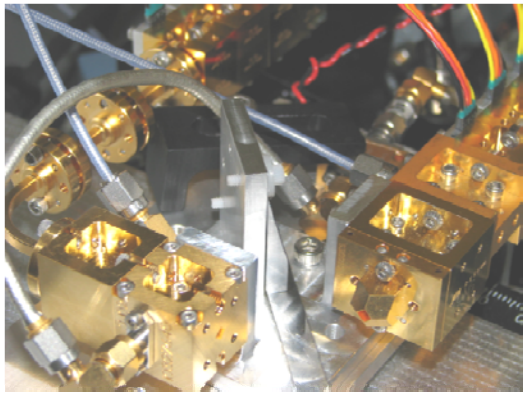


Heterodyne Receiver Front-End at 1.9 THz

Single Pixel Heterodyne Receivers

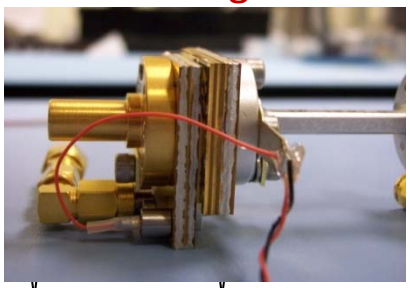


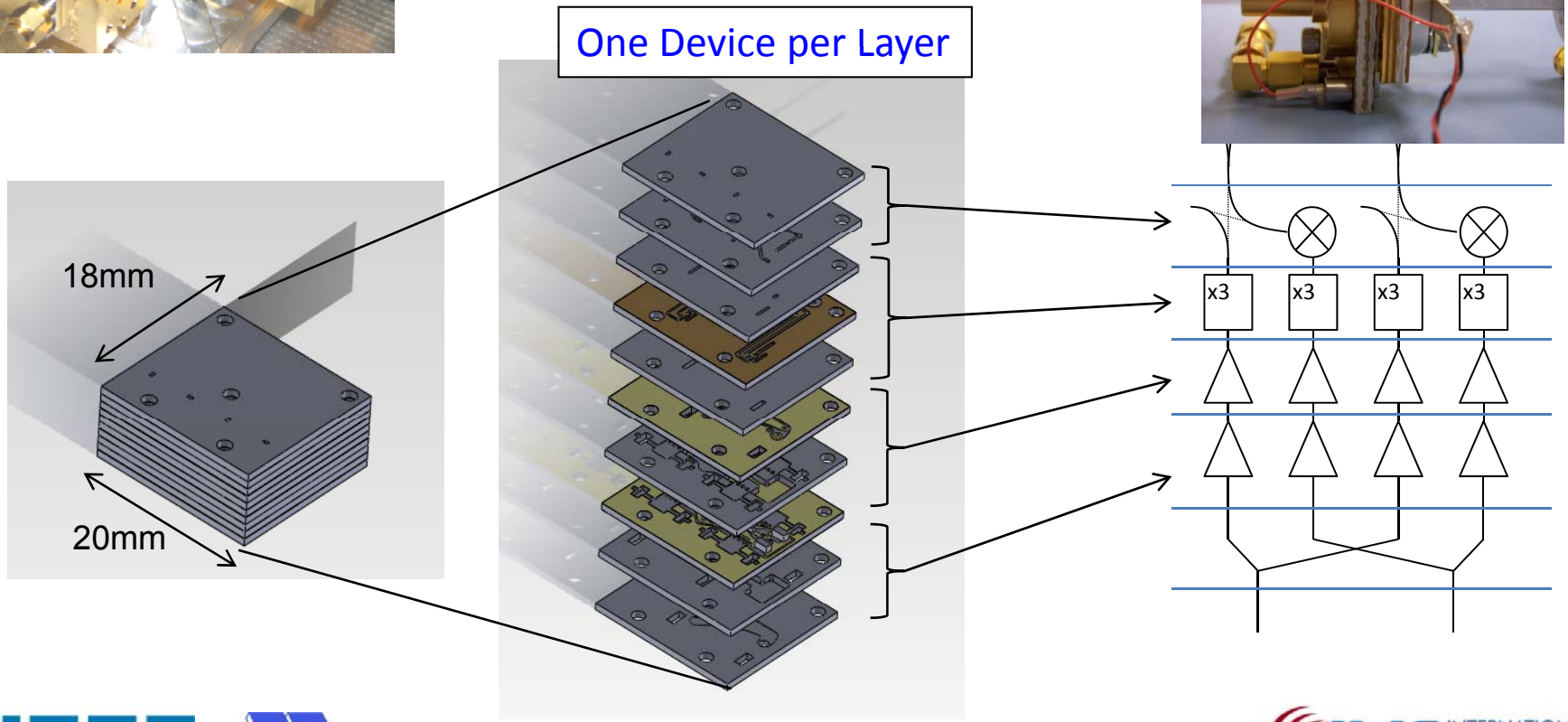
Stacked Silicon Micromachined Design



System-on-a-chip achieved by 3-D integration:

- Stacking each functional component reduces each layer's complexity
- Enables a highly integrated package while still remaining modular
- Vertical routing of bias and IF connections





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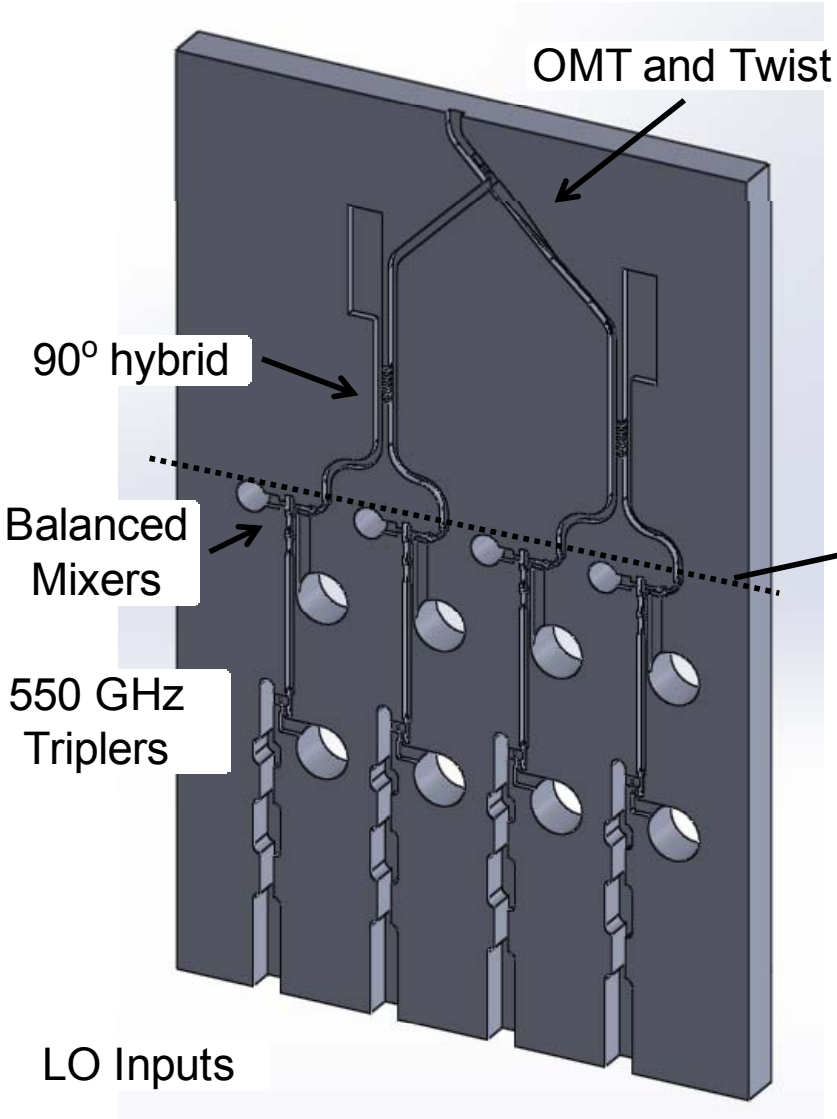
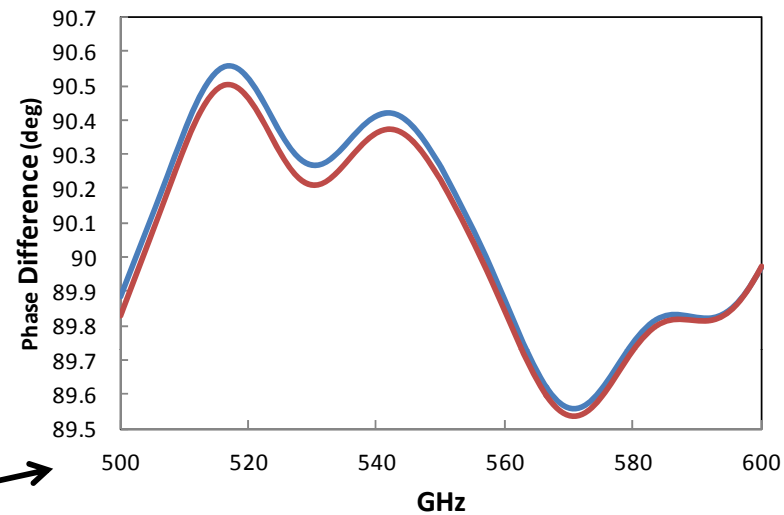
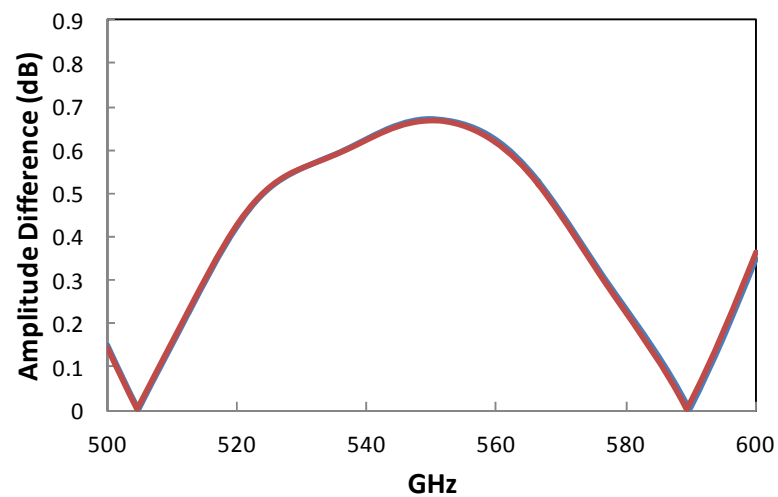


Simulation to outputs of Hybrids

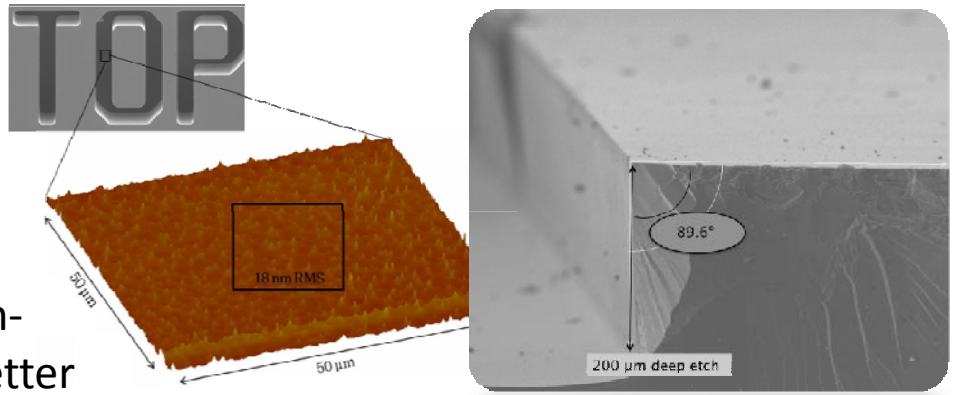




Silicon Micromachining

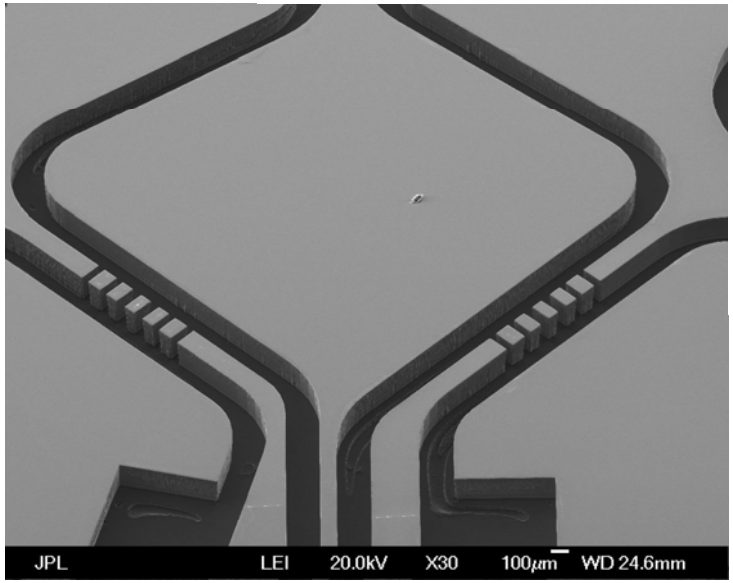
Silicon Micromachining

- Etch silicon wafer with plasma using a photolithographic pattern



Advantages:

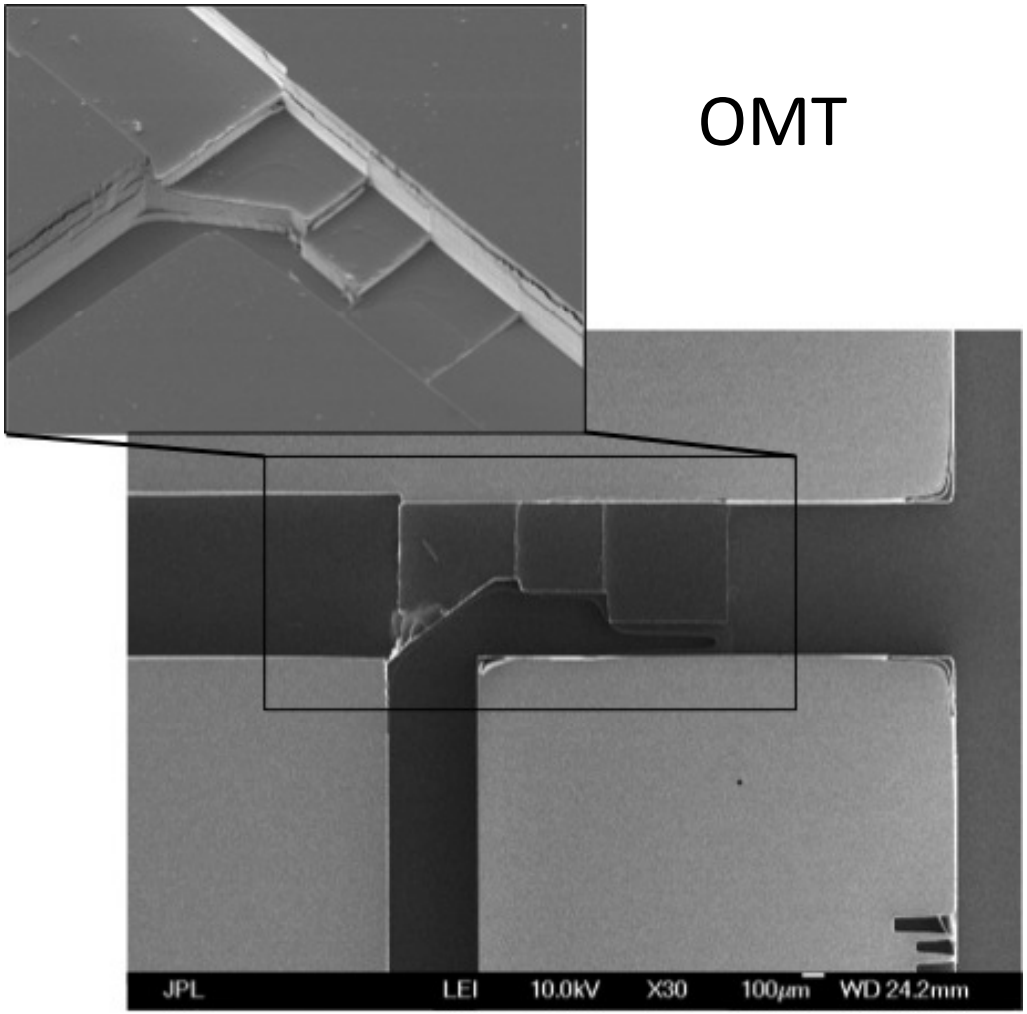
- Potential for lower cost because of batch-processed device fabrication, yielding better uniformity too.
- Lithographically precise feature definitions
- Integration of bias & IF lines on silicon itself. Future potential for integrated CMOS silicon devices.
- Potential for higher density 2D transceiver arrays.

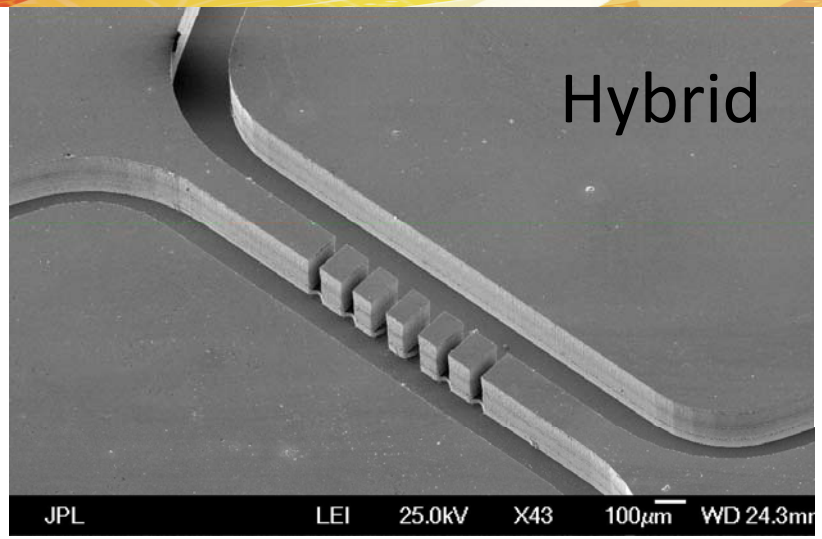


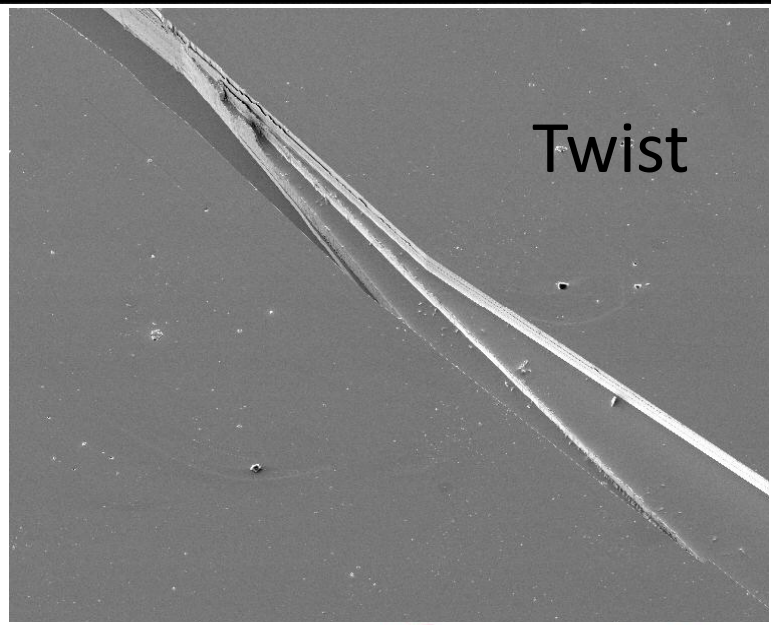
Disadvantages:

- Immature technology: need for process development.
- Challenge of wafer alignment.

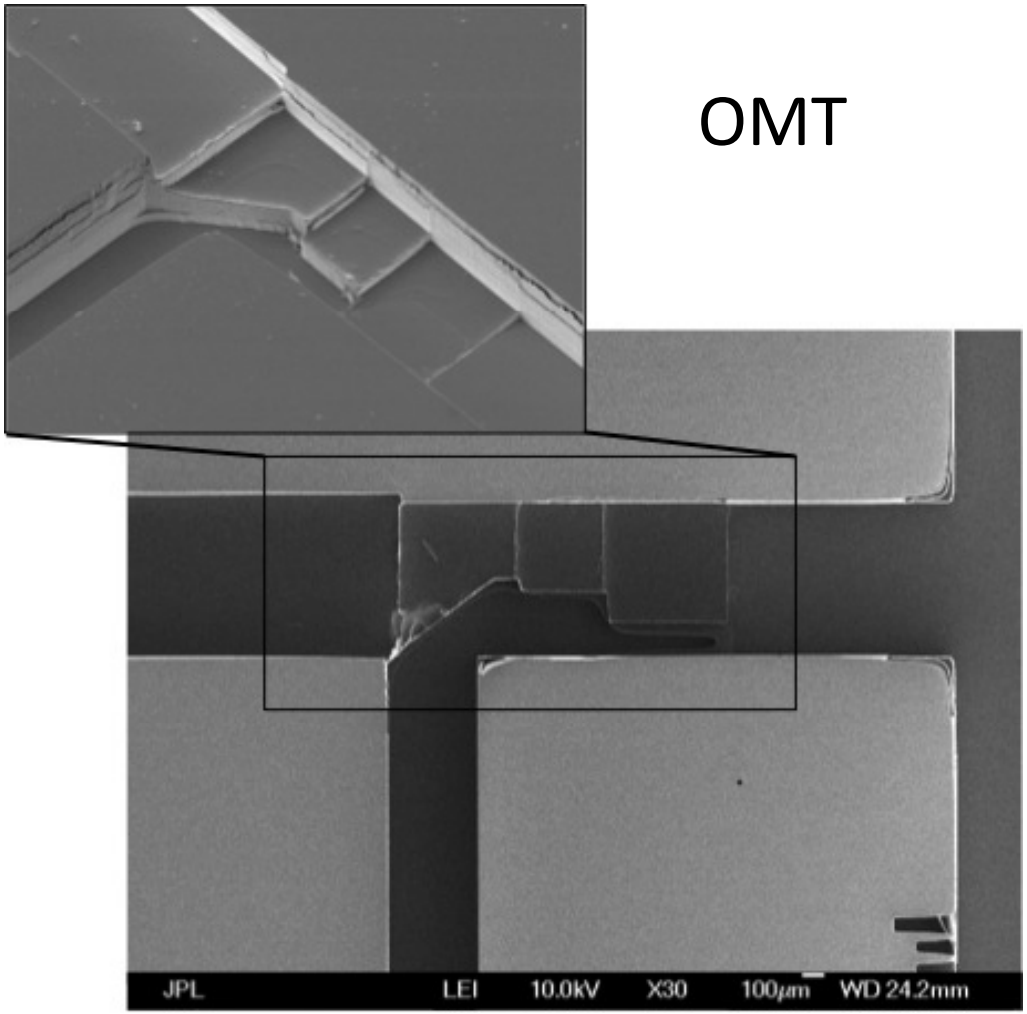
Fabricated Devices

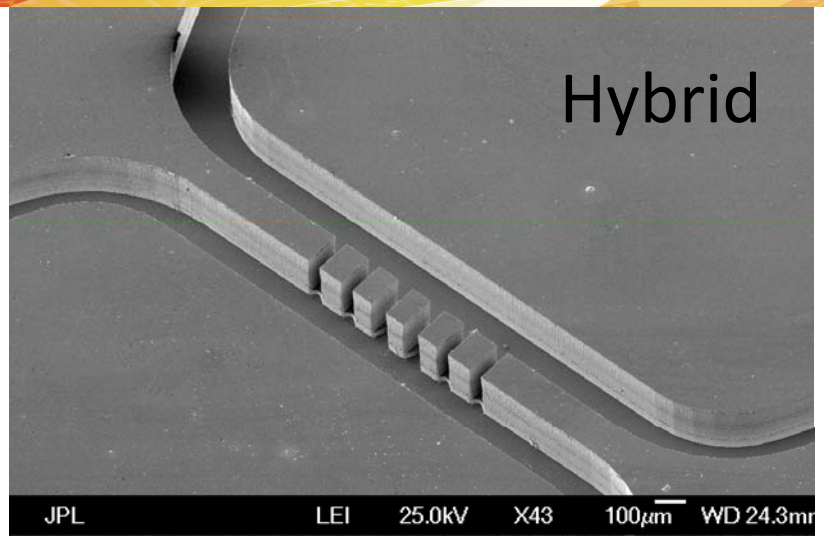


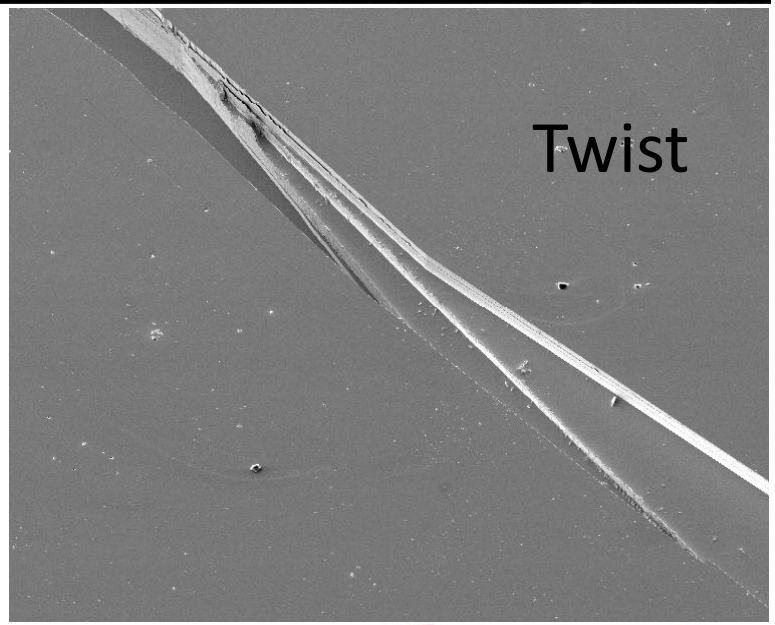




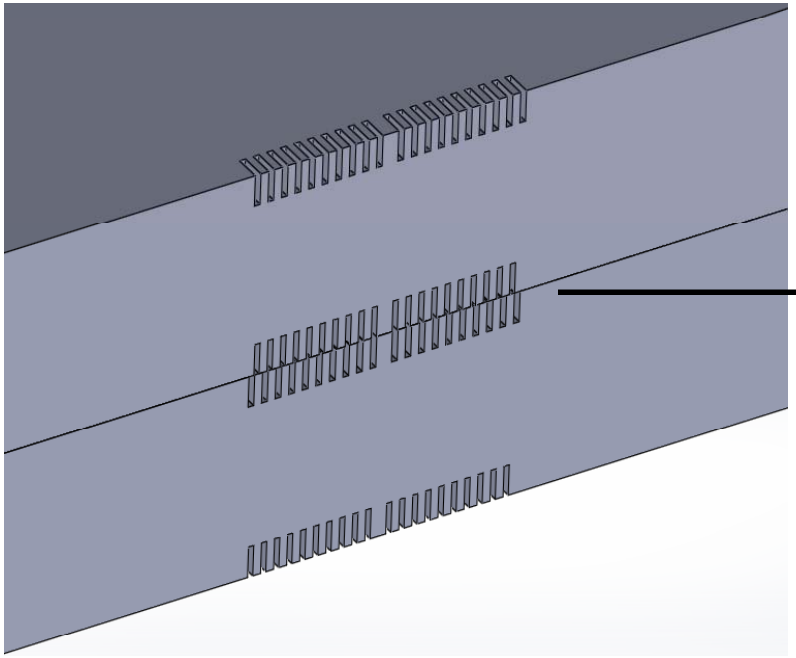
Fabricated Devices



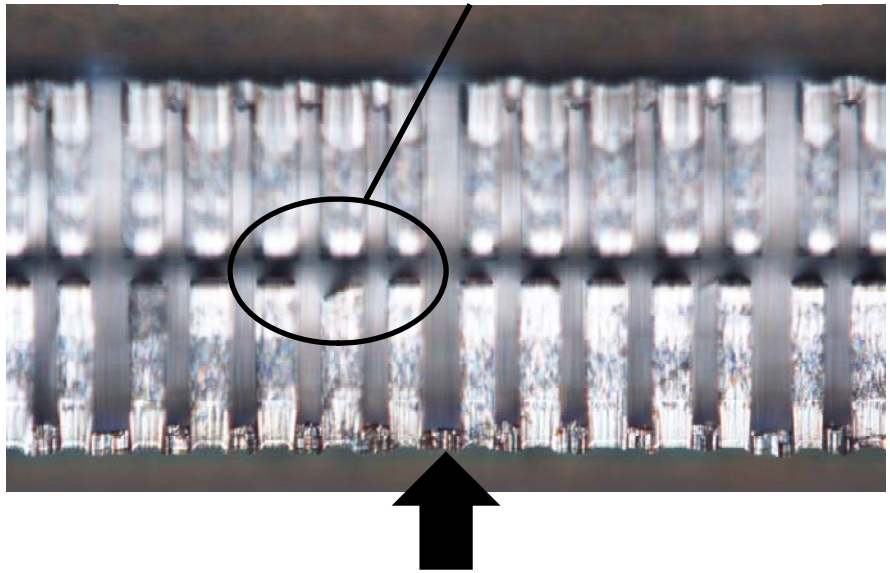




Layer Alignment



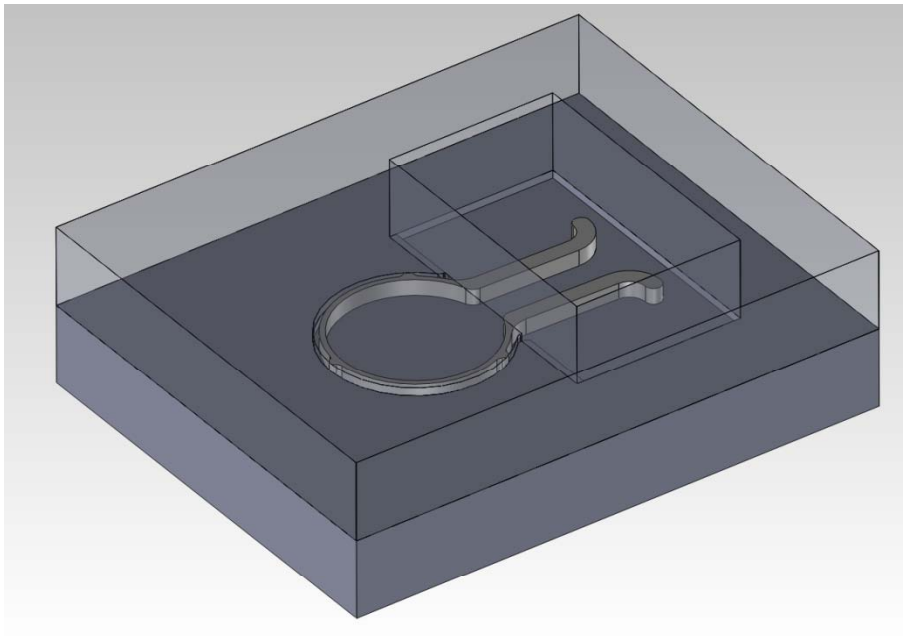
Axis misalignment 1um +- 1um

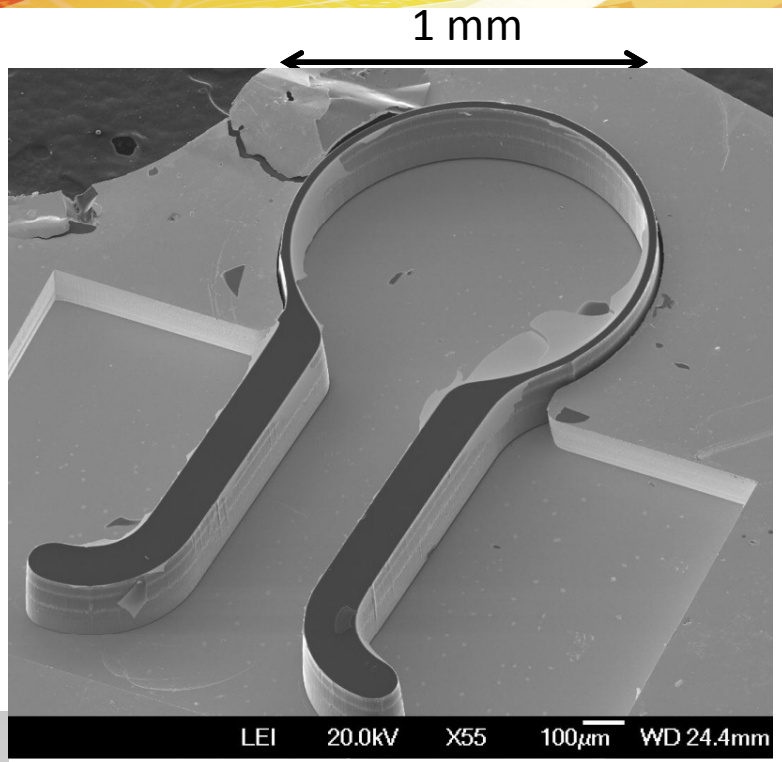


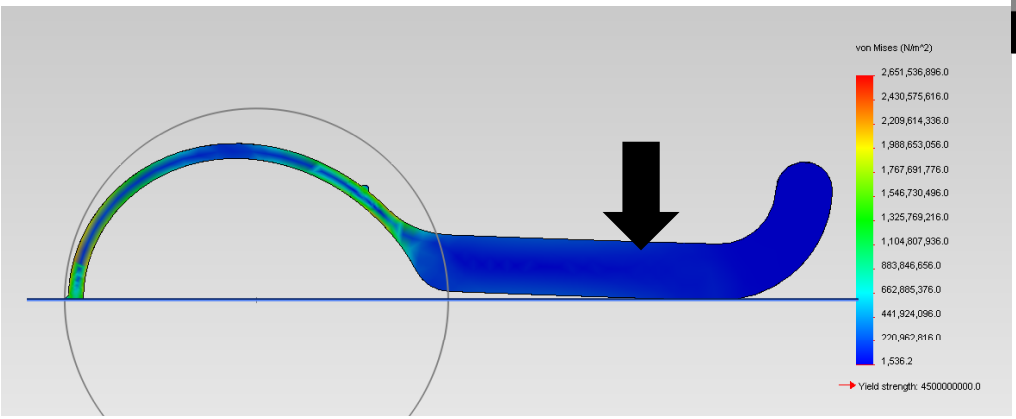
Central Mark

- **Enables characterization of alignment schemes**
- **Improves hand alignment**

Compression Pins



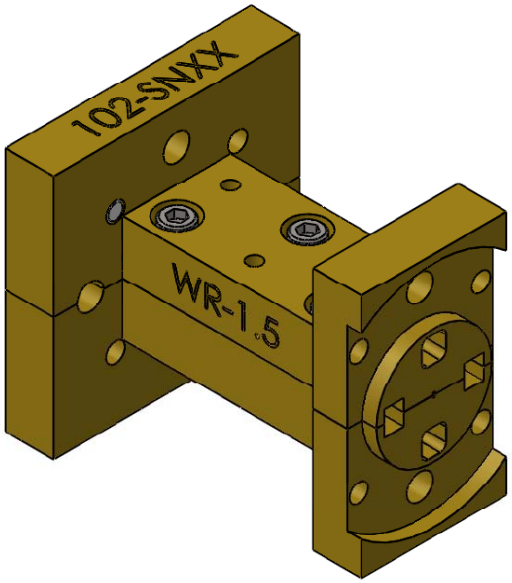


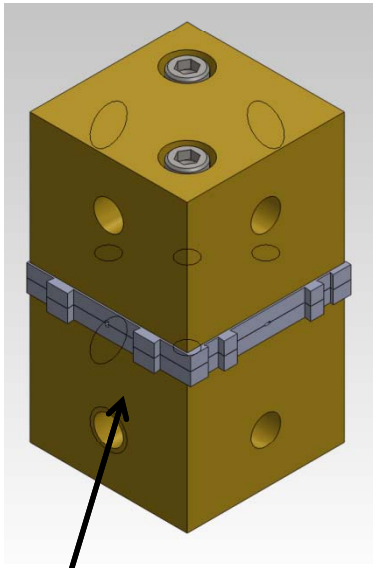


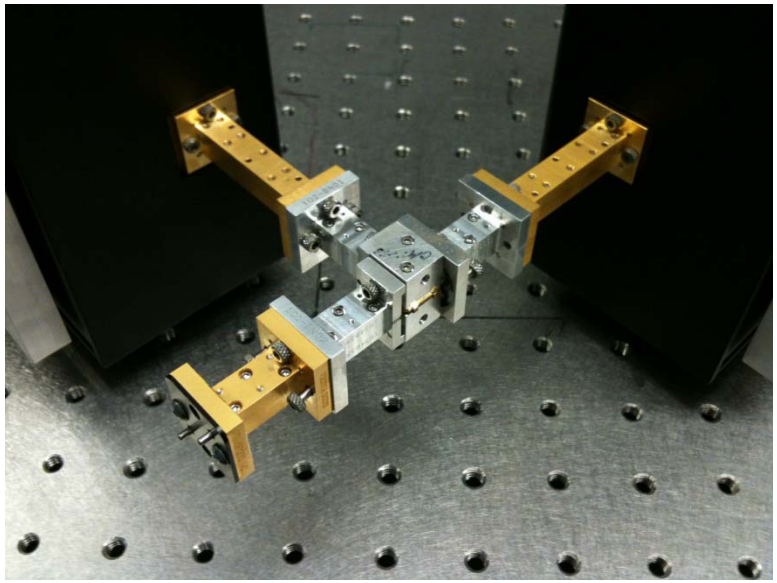
- **Compression pins simplify assembly of layers**
- **Improves alignment accuracy compared to static pin**

Evaluation of Individual Components

1 mm

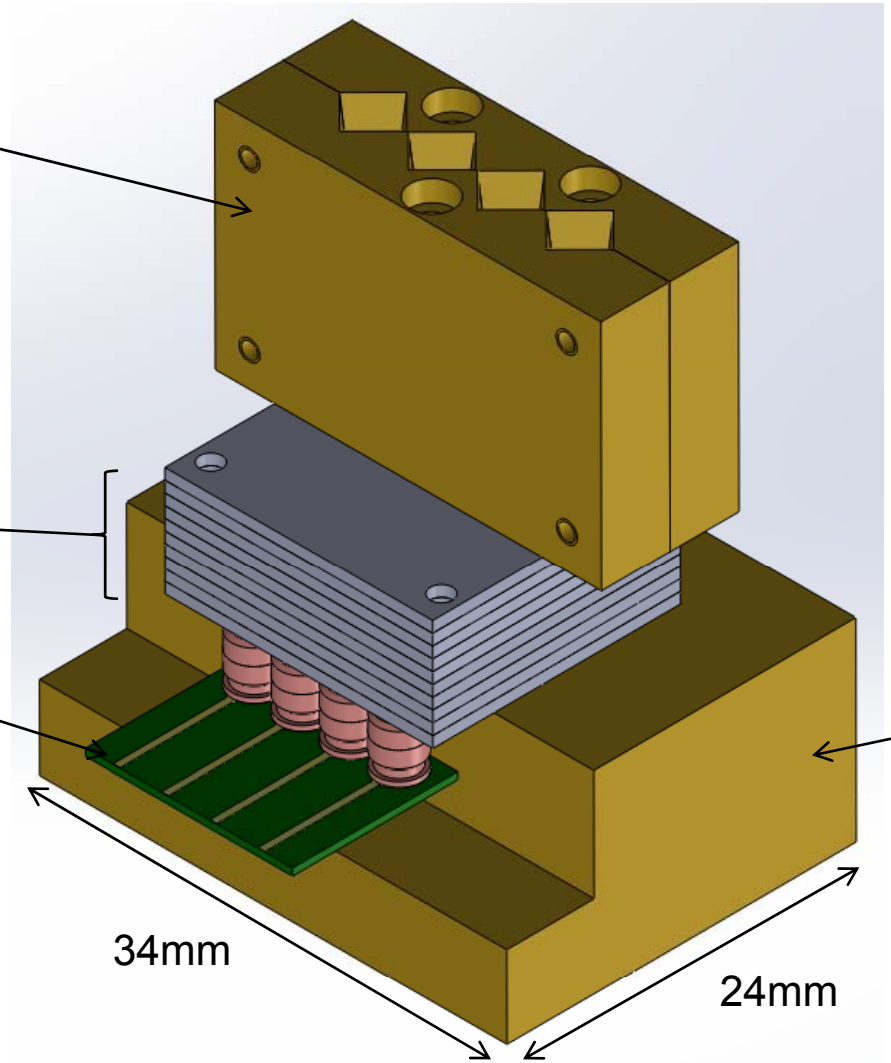


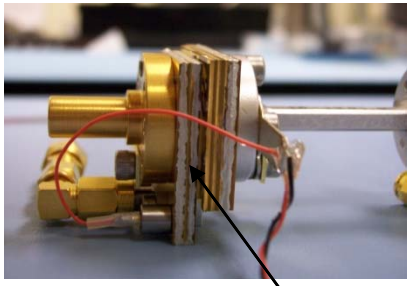




Precision pockets line up with bosses etched into the silicon

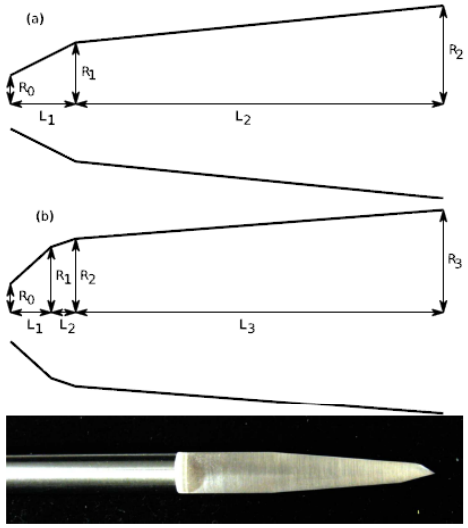
Multi-Pixel Radar Architecture

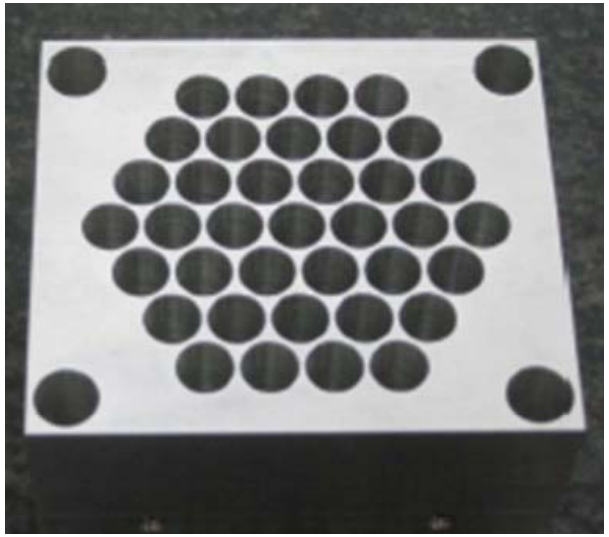


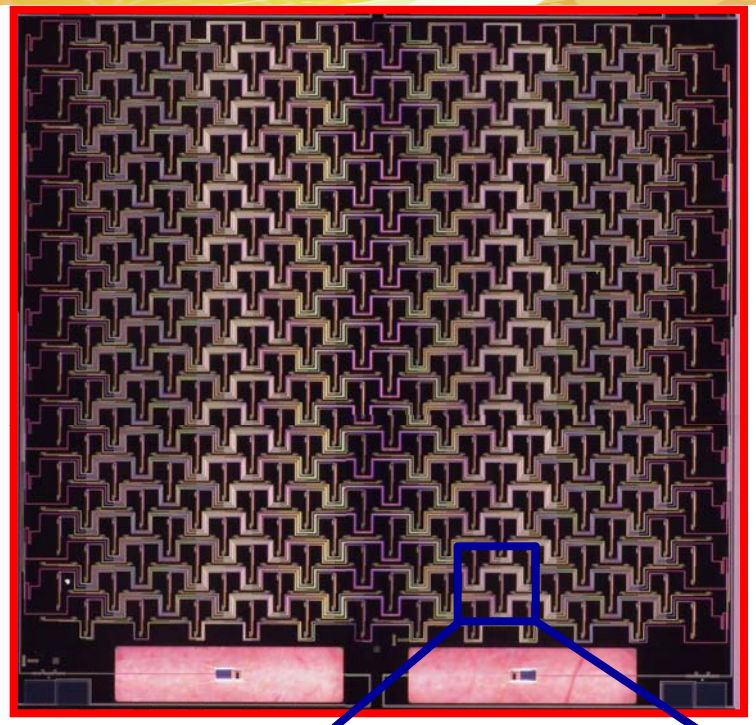


25x25x10 mm^3

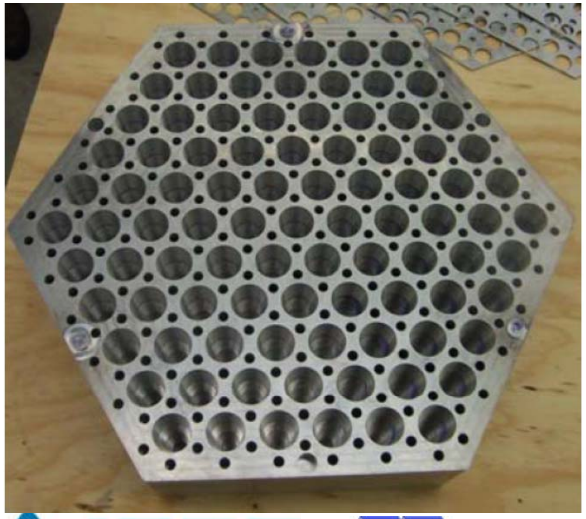
Antenna Arrays

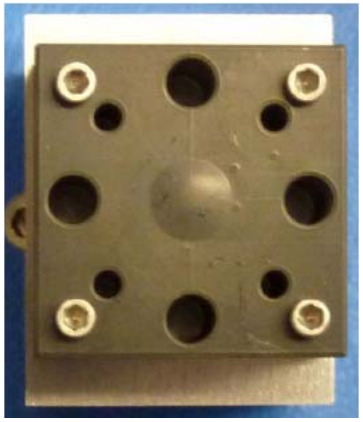


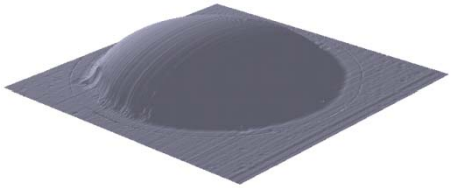


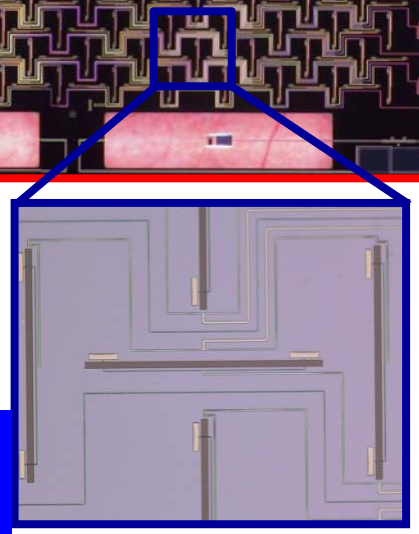


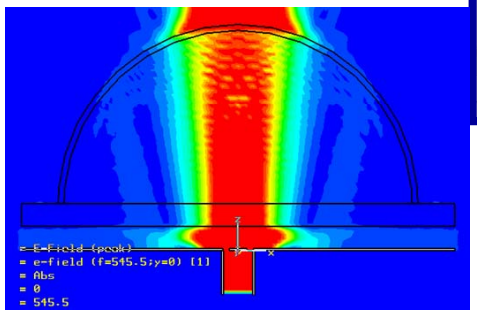
Ref: J. Leech et al., "Experimental investigation of a low-cost, high performance focal –plane horn array," IEEE Trans. Terahertz Sc. Tech., vol. 1, no. 2, Jan. 2012.







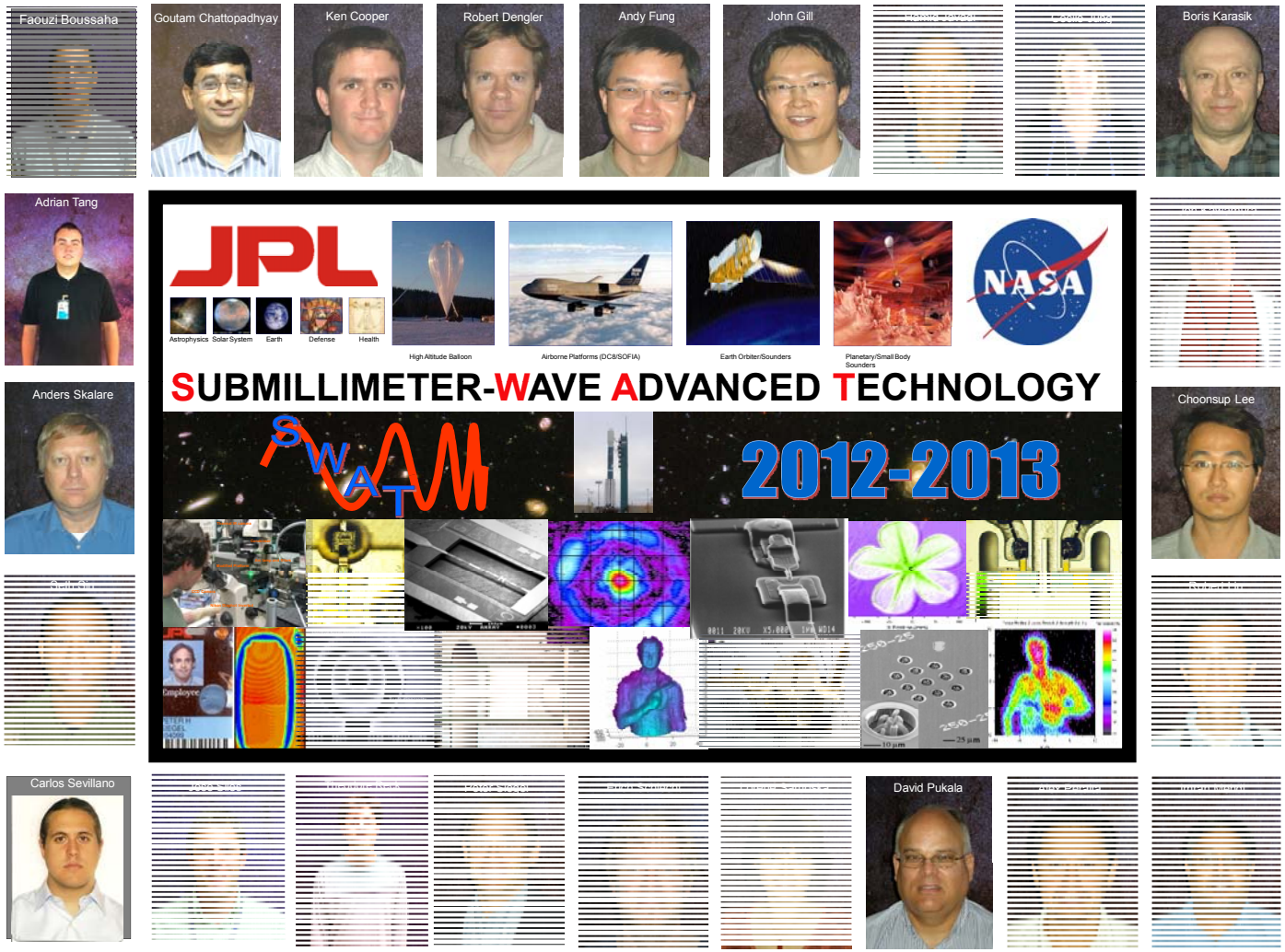




Summary

- People have recently started looking into designing multi-pixel heterodyne arrays at terahertz frequencies.
- Multiple copies of single pixel instruments is not the solution.
- Vertical integration of subsystems will play a critical role in future terahertz array instruments.
- Silicon micromachining allows integration of multi-pixel instruments in a compact package.
- Alignment of the silicon wafers is and issue and is being solved through silicon compression pins.

Acknowledgement



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