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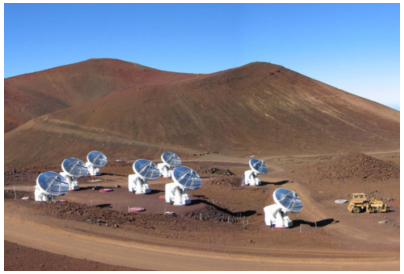
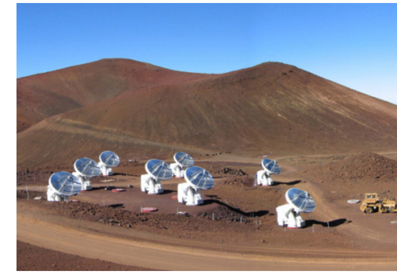


The Submillimeter Array: Future Plans

Edward Tong



The SubMillimeter Array (SMA)

The SMA is the world's first interferometer dedicated to submillimeter astronomy. It was started by the Smithsonian Astrophysical Observatory (SAO) and the Academia Sinica Institute of Astronomy and Astrophysics (ASIAA) of Taiwan joined the project after it had begun.

Location : Mauna Kea, Hawaii (elevation 4080 meters)

Antennas : 8 six-meter dish (6 from SAO and 2 from ASIAA)

Reflector Surface : 12 μm accuracy

Number of Pads : 24

Baselines : 28 --- ranging from 8 m (shortest) to 508 m

Operating Frequency: 180 – 700 GHz (0.33 – 1.7 mm wavelength)

Resolution : 0.1 – 0.5 arc sec

Pointing Accuracy : 1 arc second

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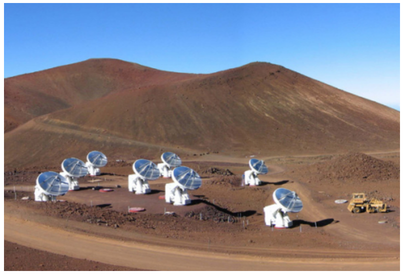
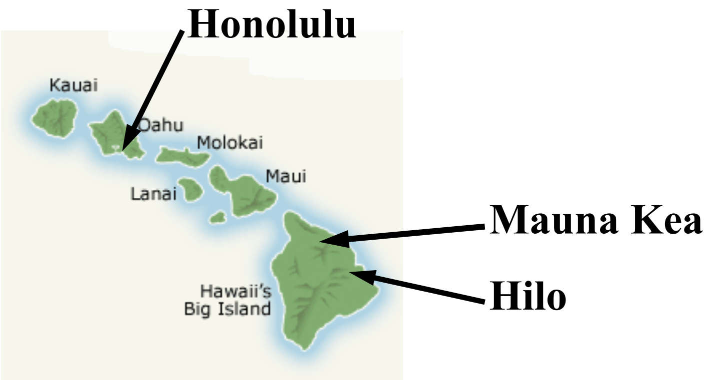
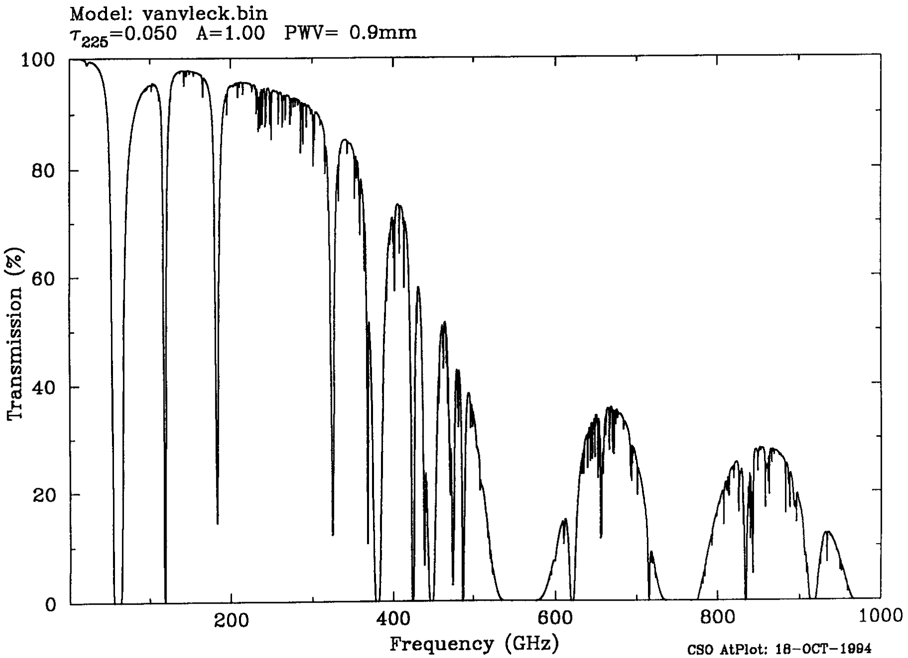
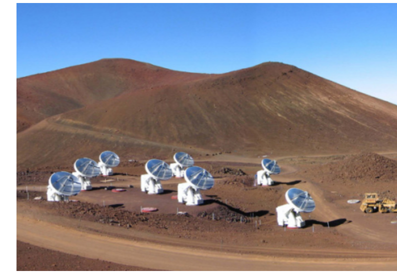


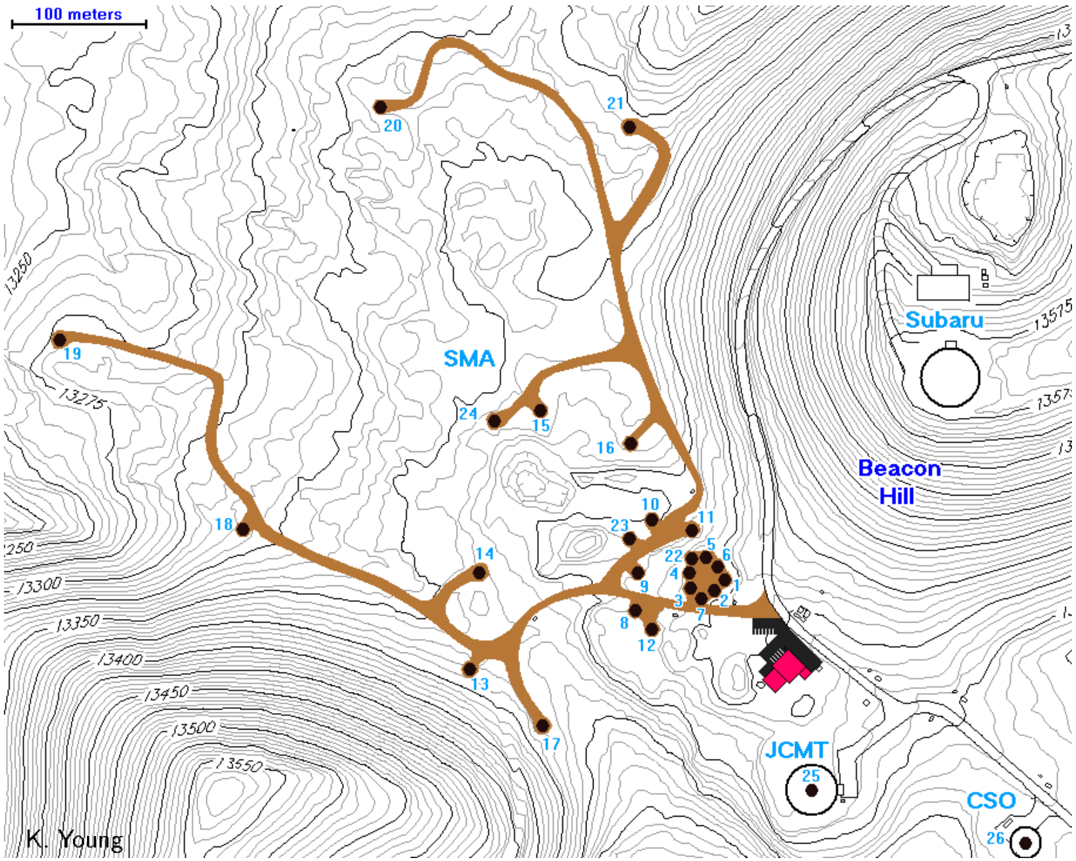
SMA Antennas





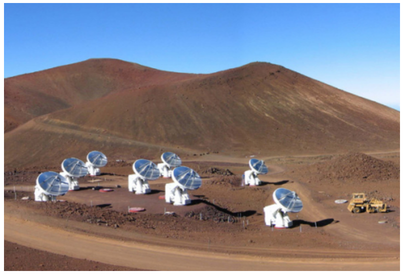
Expected Transmission on Mauna Kea



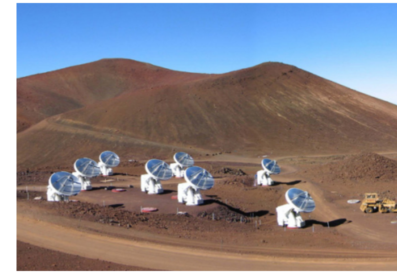


The antenna pad layout consists of 4 tangential rings, which allow for steps of about 2.7 in resolution. The min/max baseline lengths in the 4 configurations are 8/32, 14/87, 34/226 and 68/508 m.

Some testing with the 10-meter CSO (Caltech Submillimeter Observatory) and the 15-meter JCMT to form the ESMA has been carried out but little success has been achieved.



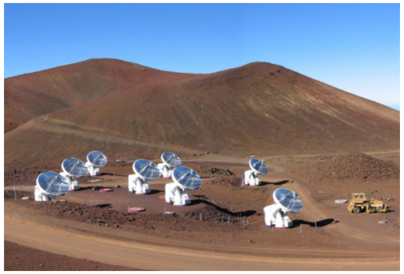
Full scale operation of all 8 SMA antennas on Mauna Kea began in 2003.



Current SMA Receiver Bands:

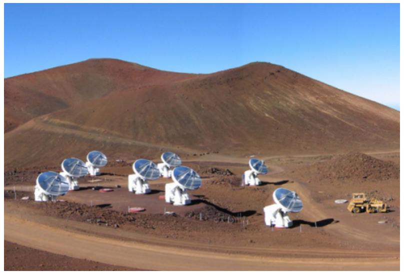
- **Polarization 1/Low Frequency Receivers**
  1. 200 GHz Rx (190 – 250 GHz), used for poor weather project
  2. 300 GHz Rx (250 – 355 GHz), in use ~40-50% of time
- **Polarization 2/High Frequency Receivers**
  3. 400 GHz Rx (330 – 420 GHz), relatively new receiver band
     overlap with 300 GHz Rx for dual polarization observation.
  4. 600 GHz Rx (640 – 700 GHz), not much in use because of weather.

Current IF: 4-6 GHz for dual Rx operation; 4-8 GHz for single Rx operation.



Target to achieve in coming few years:

- Dual linear polarization operation with 2 receivers (either same or different bands)
- Target bands: 230 and 345 GHz
- Ultra-wide IF: <1 - 18 GHz
- Sky coverage of 72 GHz (DSB operation)
- High resolution spectrum (<100 kHz) over selected zoomed window



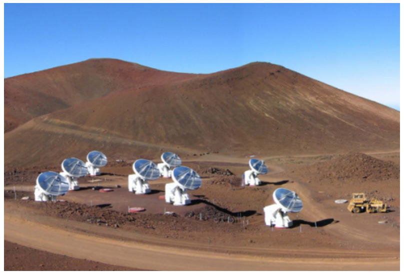
Ultra-Wide IF Operation for SMA

Why do we want to pursue very wide IF?

- **Increase continuum sensitivity:** $\Delta T = \dfrac{T_{sys}}{\sqrt{B\tau}}$

- **Catch more spectral lines with a single tuning**

- **With very wide IF, the extent of the spectral coverage ($F_{LO} \pm F_{IF\text{-}max}$) may be able to cover 2 emission lines with different transition orders from red-shifted objects.**



Realizable IF Bandwidth of SIS Mixers

- Real life SIS mixers carry extra capacitance due to the matching circuit
- SIS mixers operated by a Local Oscillator exhibits high output dynamic resistance, $\boldsymbol{R}_{\mathrm{dyn}}$, typically many times the value of $\boldsymbol{R}_{\mathrm{n}}$.
- SIS mixers are connected to an IF load of 50-ohm.Since this load impedance is much lower than $\boldsymbol{R}_{\mathrm{dyn}}$, it dictates the extrinsic time constant.

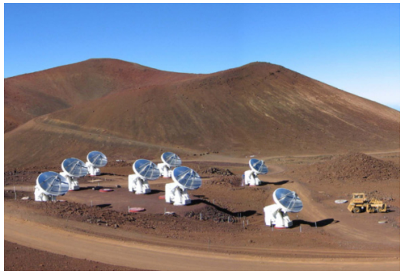
$$\boxed{F_{\mathrm{BW}} = \frac{1}{2\pi \cdot 50 \cdot (C_j + C_{\mathrm{tune}})}}$$

For current SMA receivers,

$$(C_j + C_{\mathrm{tune}}) \approx 0.3\,p\mathrm{F}$$

yielding $F_{\mathrm{BW}} \sim 10$ GHz

Key: Reduce capacitance!



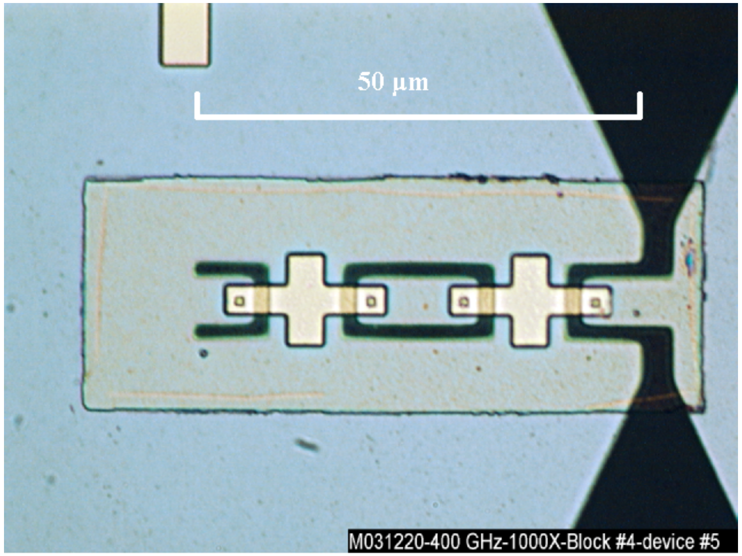
How to reduce mixer capacitance?

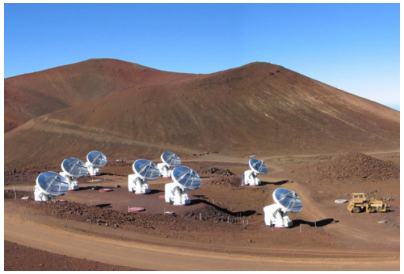
• Putting SIS devices in series: would also help to alleviate saturation effects with the wider IF bandwidth

• Avoid low impedance sections which add more capacitance

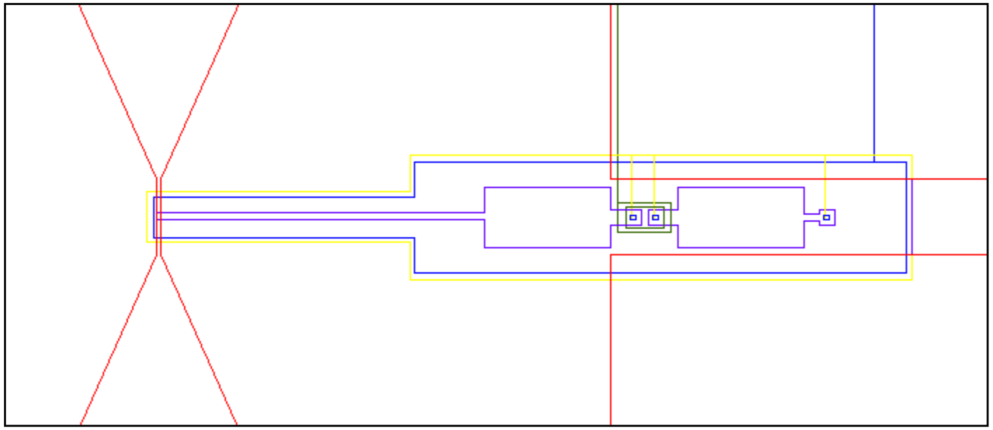
• A revolutionary design was proposed in 2003, devices made later that year by JPL and tested in 2004.

• The 4-junction series array synthesized a distributed mixer with a wide IF bandwidth > 20 GHz

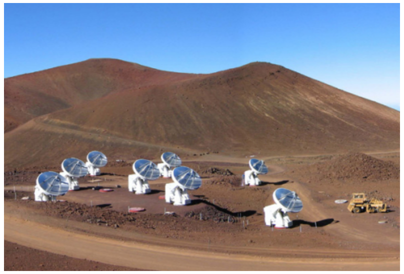




Current Design: 3 junction distributed array



- New design under exploration, in collaboration with NAOJ
- ready for I-stepper exposure before earth quake hit Japan
- similar device development with ASIAA, Taiwan



Enabling Technologies:

- ultra-wide band low noise cryogenic amplifier
- wide band cryogenic isolator
- wide band optical transmitter/receiver
- fast Analog/Digital Convertor
- mature FPGA technology

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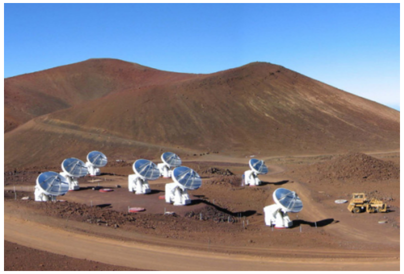
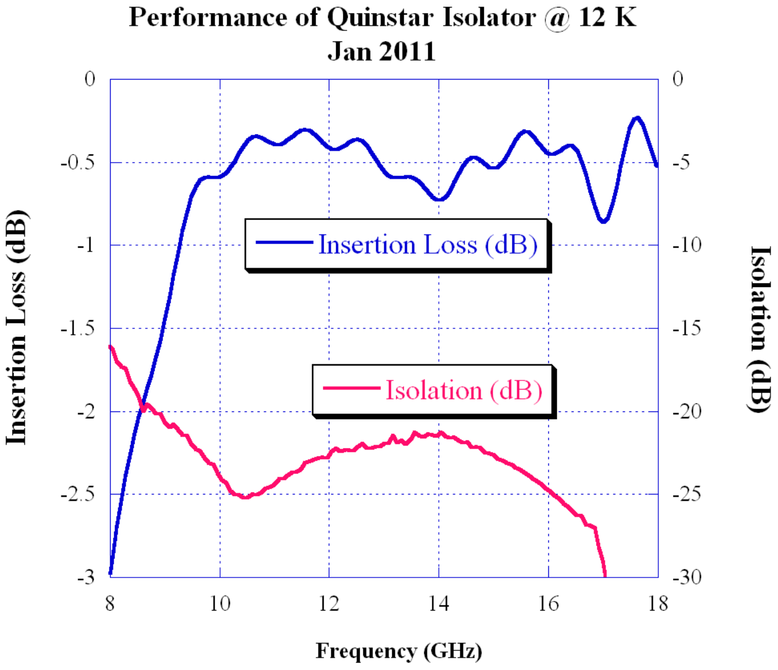
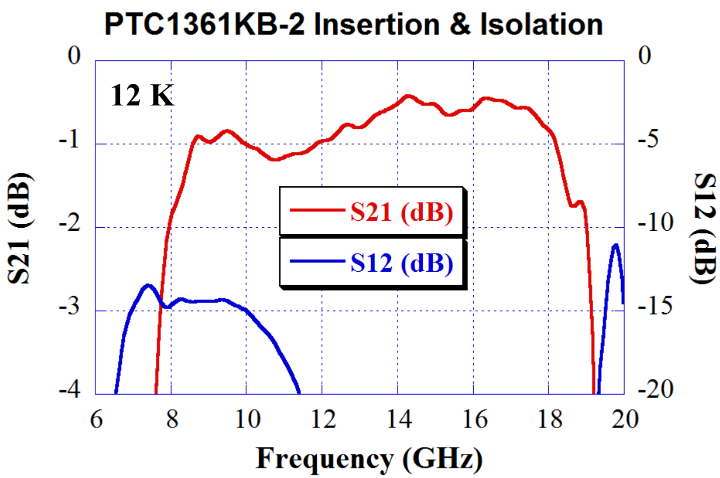
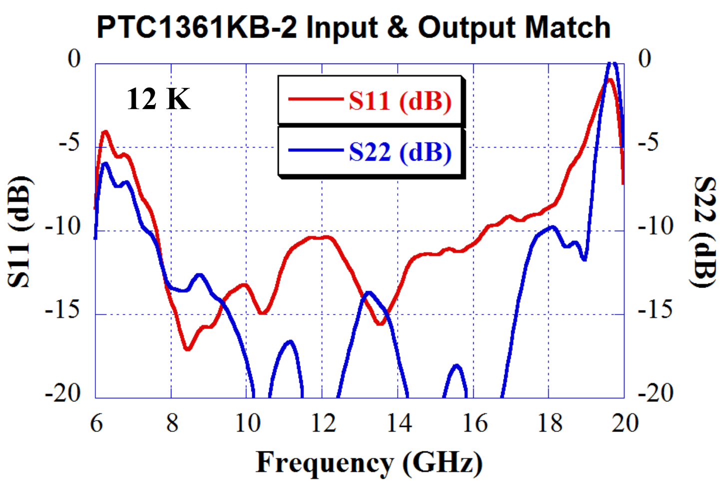


New 8 – 18 GHz Cryogenic Isolator







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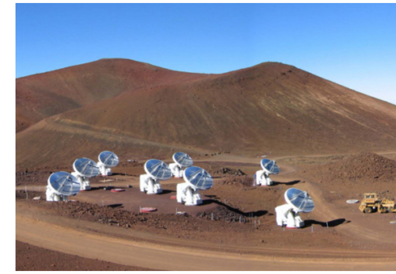


Plan for Wide IF Receiver Implementation

Current Configuration

SIS mixer

6" stainless coax

Bias Port

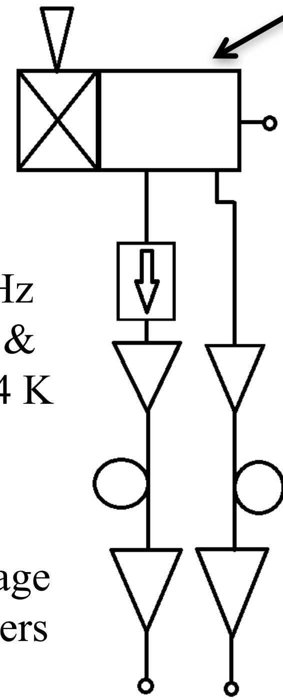
4-8 GHz Isolator & LNA @ 4 K

17" stainless coax

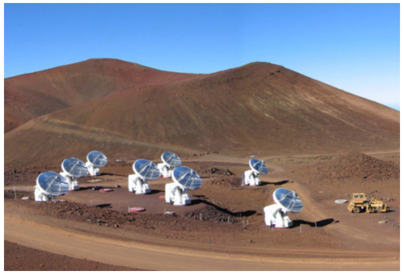
2^{nd} Stage Amp @ 20 K

Cryostat Output

Proposed Baseline

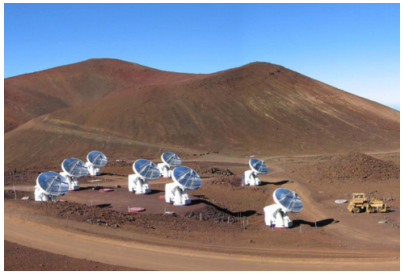


Cryostat Outputs: **8-18 GHz** & **0.1-8 GHz**



Preliminary Specifications for New SMA Wideband Correlator

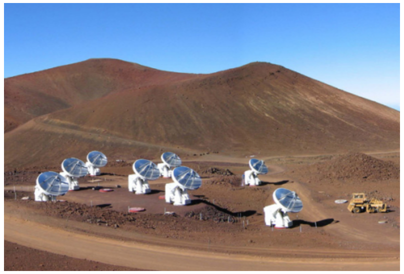
feature	full offering	initial release	remarks
number of antennas	8		2 Rx each. No eSMA support
total bandwidth	18 GHz	9 GHz	for each of two receivers
number of sidebands	2		upper and lower 18 GHz each
simultaneous receivers	2	1	dual freq. or dual pol. 230 & 345 GHZ
baselines	56	28	28 per Rx, full Stokes
finest continuum resolution	0.55 MHz		16384 channels / 9 GHz block
coarsest continuum resolution	70.3 MHz		128 channels / 9 GHz block
spectral bands	6		maximum simultaneous hires bands
finest spectral line res.	25 kHz		best possible SMA res
zooming band width	500 MHz		widest single spectral line
fastest dump rate	0.65 s		single full Walsh cycle
dynamic range	30 dB		weak spectral line near strong
baseline to baseline isolation	30 dB		crosstalk from baseline to baseline
sideband isolation	30 dB		crosstalk USB <—>LSB
maximum baseline delay	2 km		assumes current SMA configuration
simultaneous autocorrelations	16		Can autocorrelate each antenna
phased array bandwidth	8 GHz	4 GHz	4 GHz $\times$ dual pol.
celestial holography mode			might need faster dump



How Fast an ADC do we need?

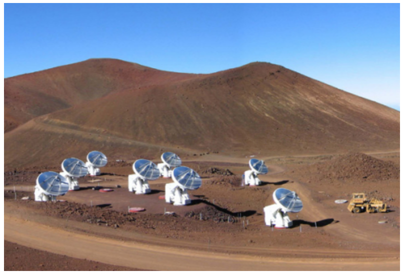
- Faster ADC will give simpler analog processor
- Higher bit rate requires faster FPGA in additional to huge DEMUX ratio
- Fast ADC may not have enough analog bandwidth
- 18 GHz = 9 GHz x 2 (fastest option) or 2 GHz x 9 (baseline option)

ADC Sample Rate (GHz)	Chunk Width (GHz)	No. of Chunks per ant/pol	Total Chunks
5	2	9	144
10	4.5	4	64
14	6	3	48
20	9	2	32



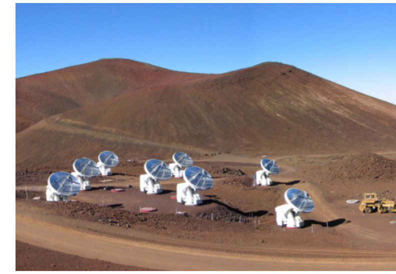
Current Status of Fast Analog/Digital Convertor

ADC rate (GSa/s)	BW (GHz)	# bits	Manuf.	~ cost	remarks
5	2	8	e2V	$300	ASIAA developing a board
3	4		National Semiconductor		
10	18	4	ADSANTEC	$800	Over 600 units shipped
12.5	8	8	Maxtek	$17K	Mature module (Tektronix)
20	13	8	Agilent		Proprietary module
20	8	5	e2V	$7K	IRAM using @ 8 GSps
26	26	3+	Hittite		In development
30	14	6	Micram	$10K	Lower speed unit available



Issues of Correlator Design

- Fast ADC desirable but need identify a reliable design within short time frame
- Correlator would be of FX(F) design
- CASPAR hardware geared for SKA type application may not be optimal for SMA operation with only 28 baselines
- FPGA with large number of LVDS ports are desirable but cost of FPGA may be significant if we push to use the latest generation
- SMA does not have sufficient manpower/expertise on fast digital electronics
- Talking with industry to see if we can get cost/effective hardware



Summary

• Extension of IF bandwidth to cover <1 – 18 GHz range promises to increase sensitivity of SMA and extend spectral coverage.

• To achieve wide IF bandwidth, SIS junction capacitance has to be reduced. Novel SIS designs exist to extend the available IF bandwidth.

• Amplifier technology is moving along the direction of wider band operation. Wide-band cryogenic isolator exists and is being developed.

• Correlator development is tied to evolution of fast electronics, the landscape of which is fast changing.

•Working with various institutes to develop all the technologies needed for the upgrade.