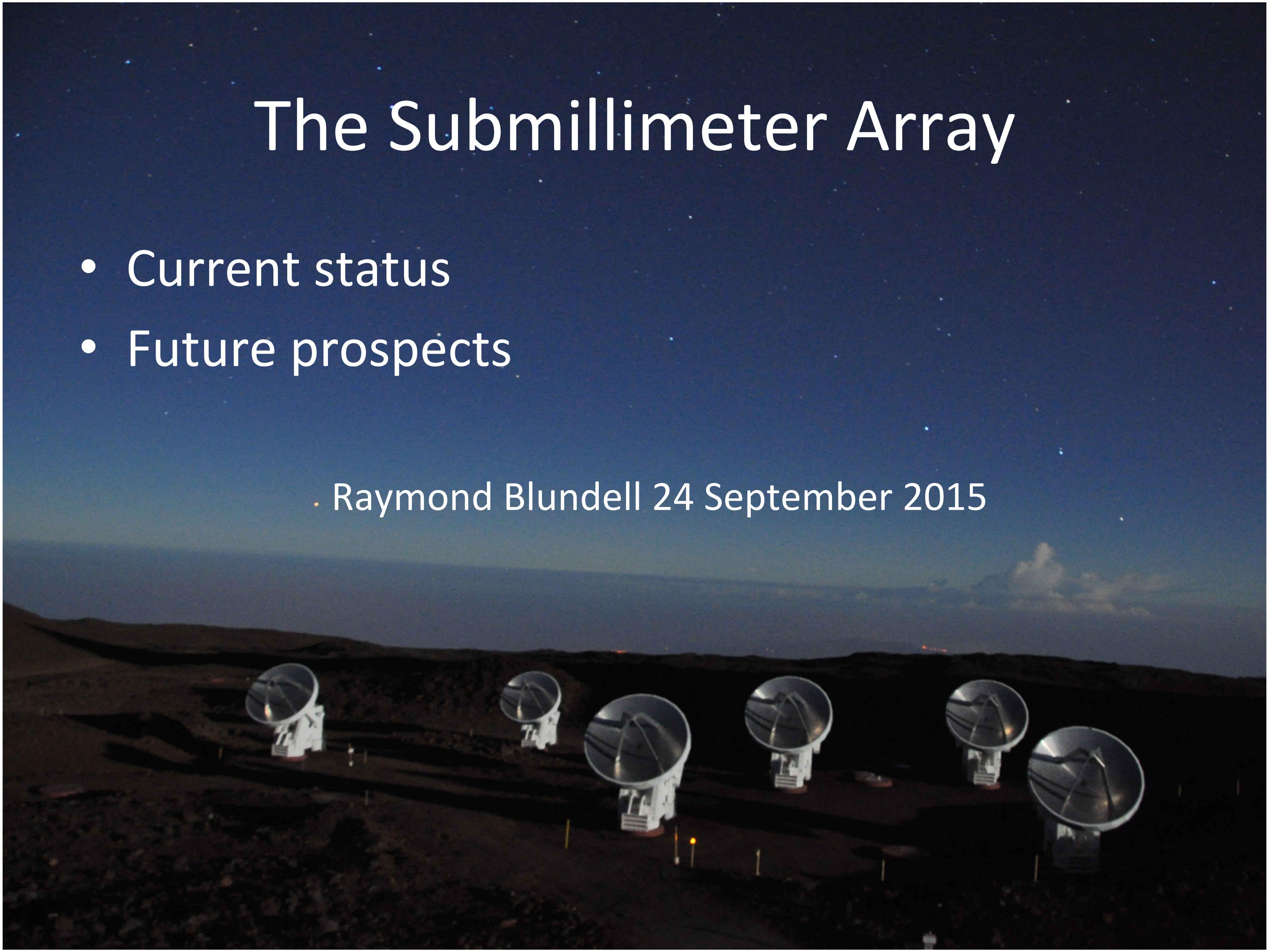
The Submillimeter Array

- Current status
- Future prospects

Raymond Blundell 24 September 2015



The SMA – a little history

- 1984 proposal for submm interferometer was developed at the request of Irwin Shapiro
- 1989 Smithsonian Institution received initial funding to design and build the SMA
  - Initially 6 x 6m antennas
  - 1996 ASIAA joined SMA with 2 more antennas
  - Additional sets of receivers
  - And 2x correlator hardware
- The SMA has been in continuous operation since its dedication in November 2003

Instruments available in 2007

- Low frequency receivers at 230 / 345 GHz
- Higher frequency receivers at 400 and 650 GHz
- 2 receiver operation possible
  - 1 low (<350 GHz) with 1 high (>350 GHz)
  - And dual polarization in the 330 – 350 GHz range
- IF bandwidth 2 GHz wide centered at 5 GHz
- DSB receiver operation
- Total bandwidth per receiver = 4 GHz

Note: Sensitivity α √bandwidth

Operational considerations

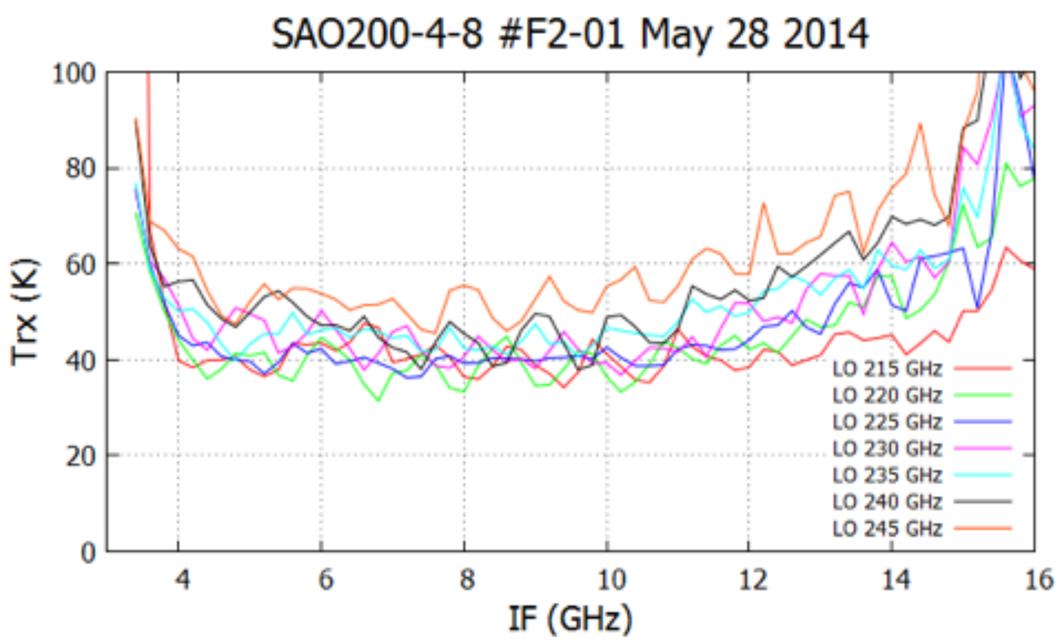
- Mauna Kea is a really good millimeter site
- Not so good in the submillimeter
- Typically spend 50% of the time at 230 GHz
- And 50% of the time at 345 GHz
- Very little time at higher frequencies
- 650 GHz observing campaign ~ 10 years ago
  - Limited scientific impact, receivers not state-of-the-art
- Have not used 650 GHz receivers since 2011
  - In fact have removed 650 GHz receivers from the array
  - They cost as much as 230 and 345 GHz sets combined

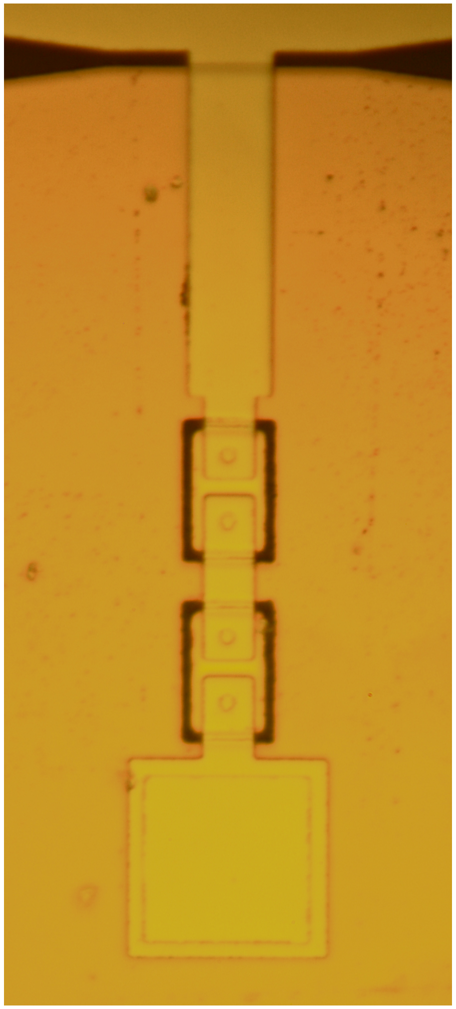
Improved sensitivity: wideband receivers and additional correlator capacity

- Current status – lower noise, wider bandwidth
  - 200 GHz and 300 GHz receivers equipped with wideband SIS mixers
  - IF bandwidth from mixers in excess of 12 GHz
  - New mixers also offer lower noise than previous generation
  - Additional correlator capacity available using new correlator (SWARM) – now running every night but at reduced speed (reduced bandwidth, 3 GHz not 4 GHz
  - Total available BW = 2 x 3 (SWARM) + 2 x 4 (ASIC)
    = 6 + 8 = 14 GHz (compared to original 2 x 2 GHz = 4 GHz)

200 GHz wideband mixer chips

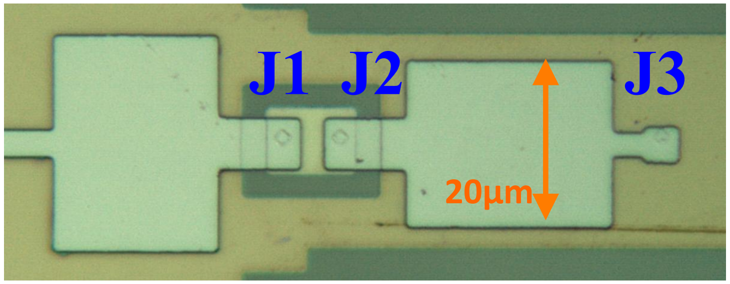
Initial tests with 4-junction design show good
Performance at up to 14 GHz IF
Receivers incorporating 4-junction design
Are now installed on all SMA telescopes

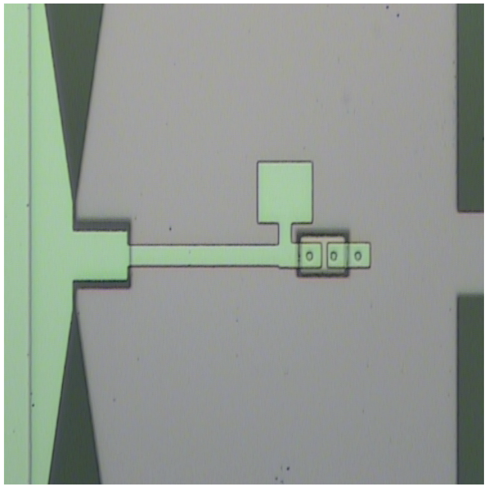




300 GHz wideband mixer chips

• Initial Mixer Chips came from IRAM





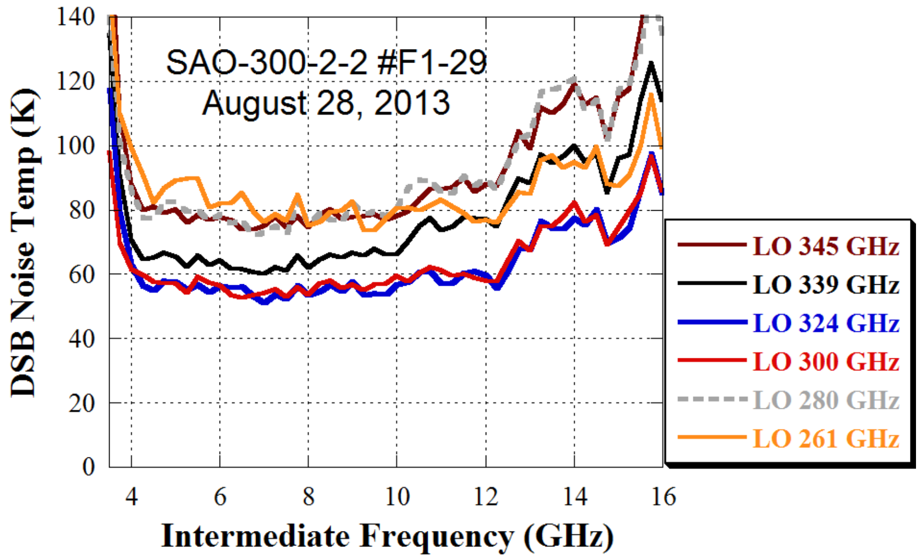
ASIAA Mixer Chip

• Junction size ~ 1.1 µm^2 (E-beam)
• J_c ~ 8 kA/cm^2 with low leakage
• Requires larger magnetic field
• Design is a scaled version of SMA-200
• Tuned to lower frequency because of larger spreading inductance.
• Installed in antennas 1, 5 & 7

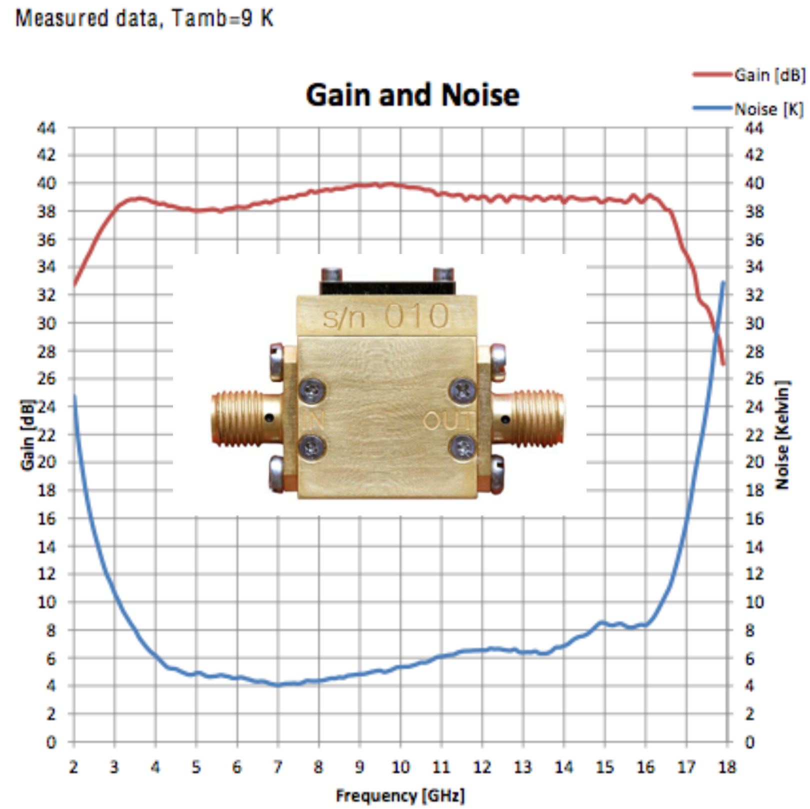
• Junction: 1.5 µm diameter
• J_c ~ 7 kA/cm^2 with acceptable leakage (R_{sg}/R_n ~ 10)
• More compact design with low output capacitance (C_{IF} ~ 0.18 pF)
• Design tuned to higher frequency.
• Installed in antennas 2, 3, 4, 5 & 8.

300 GHz wideband mixer chips

Wideband SMA-300 GHz receiver noise



IF > 12 GHz made possible with new 4 – 16 GHz LNA from Sweden.



Low Noise Factory #LNF-LNC4_16A

Potential improvements to SMA sensitivity

- Streamlining the optics
  - Numerous reflecting surfaces between calibration load and cryostat window
  - Room temperature wire grid polarizer
  - Room temperature LO injection mesh coupler
  - Thick lens in front of feed horn at ~ 100 K

Estimated noise contributions from optics:

About 10 K at 230 GHz and 20 K at 350 GHz

About 30 % of total 'receiver noise'

Other potential improvements to SMA sensitivity

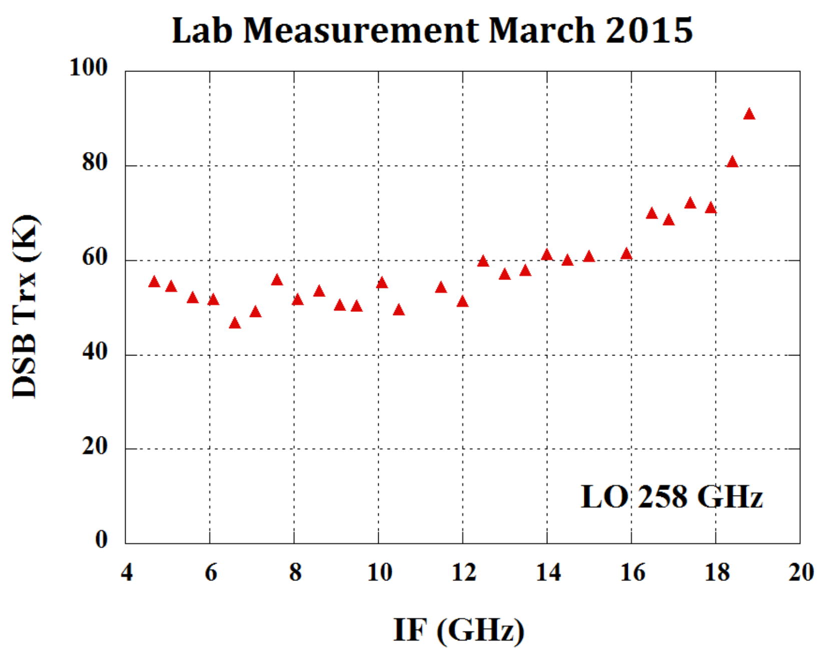
- 230 GHz is at the high end of current 200 GHz band
  - Propose to realign receiver bands:
    - Low band 210 GHz – 270 GHz (LO)
    - High band 280 GHz – 360 GHz (LO)

- Enable full dual polarization in each band
  - Currently have dual polarization capability at 345 GHz using a combination of 345 GHz and 400 GHz receivers but not in the 230 GHz band – add a second 230 GHz receiver set
  - This gives additional factor of $\sqrt{2}$ in sensitivity

Note: need to maintain capability to observe in 200 and 300 GHz bands simultaneously

Even more improvements to SMA sensitivity

- Further increase IF bandwidth: 4 – 18 GHz IF
- 14 GHz bandwidth x 2 sidebands x dual polarization
- = 14 x 2 x 2 = 56 GHz bandwidth (= 16 x original specification)
- This corresponds to 4 x original sensitivity



The wider IF also makes LO requirements much simpler

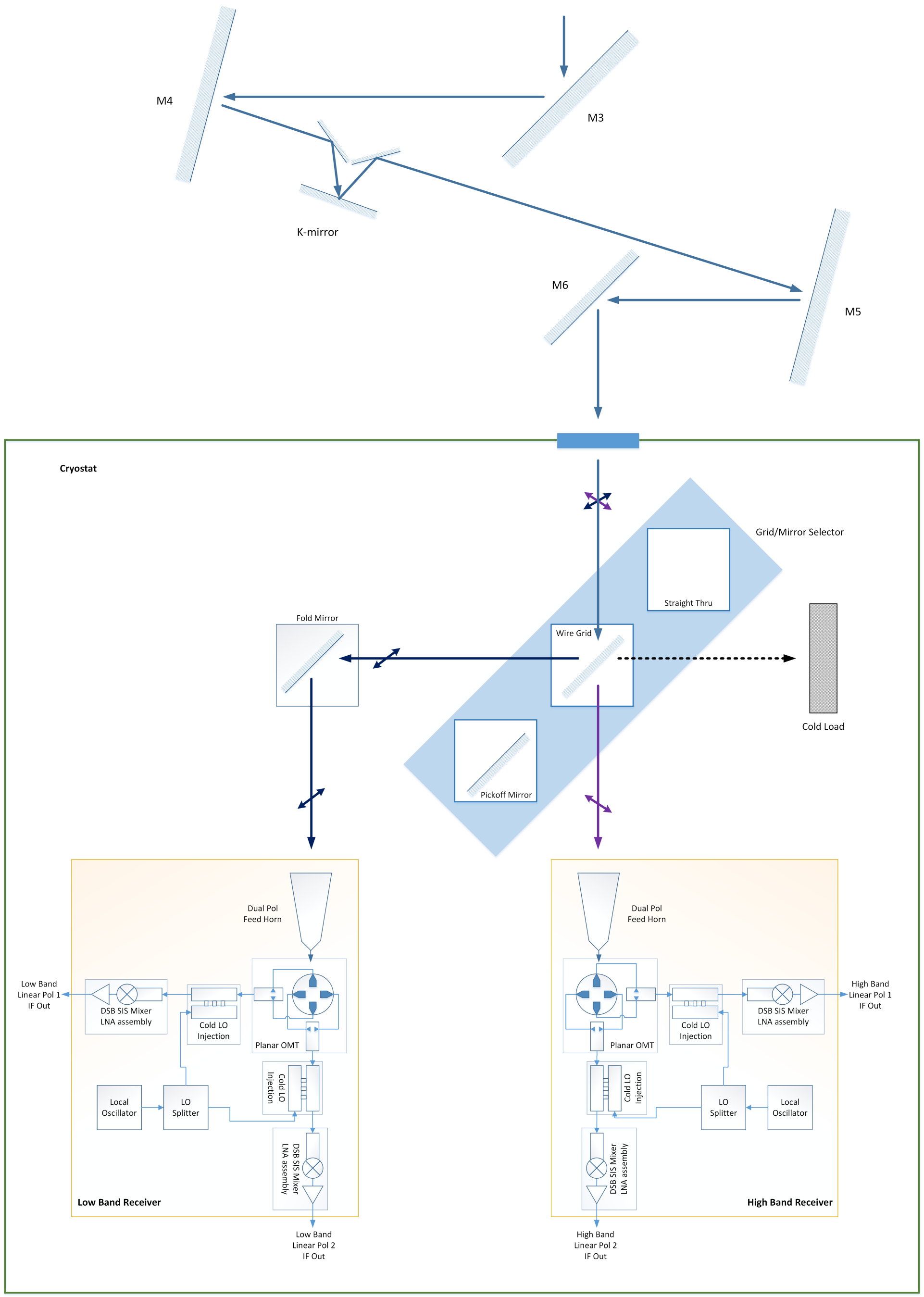
Single LO at 350 GHz gives LSB at 332 – 346 GHz and USB at 354 – 368 GHz

Further improvements to the SMA

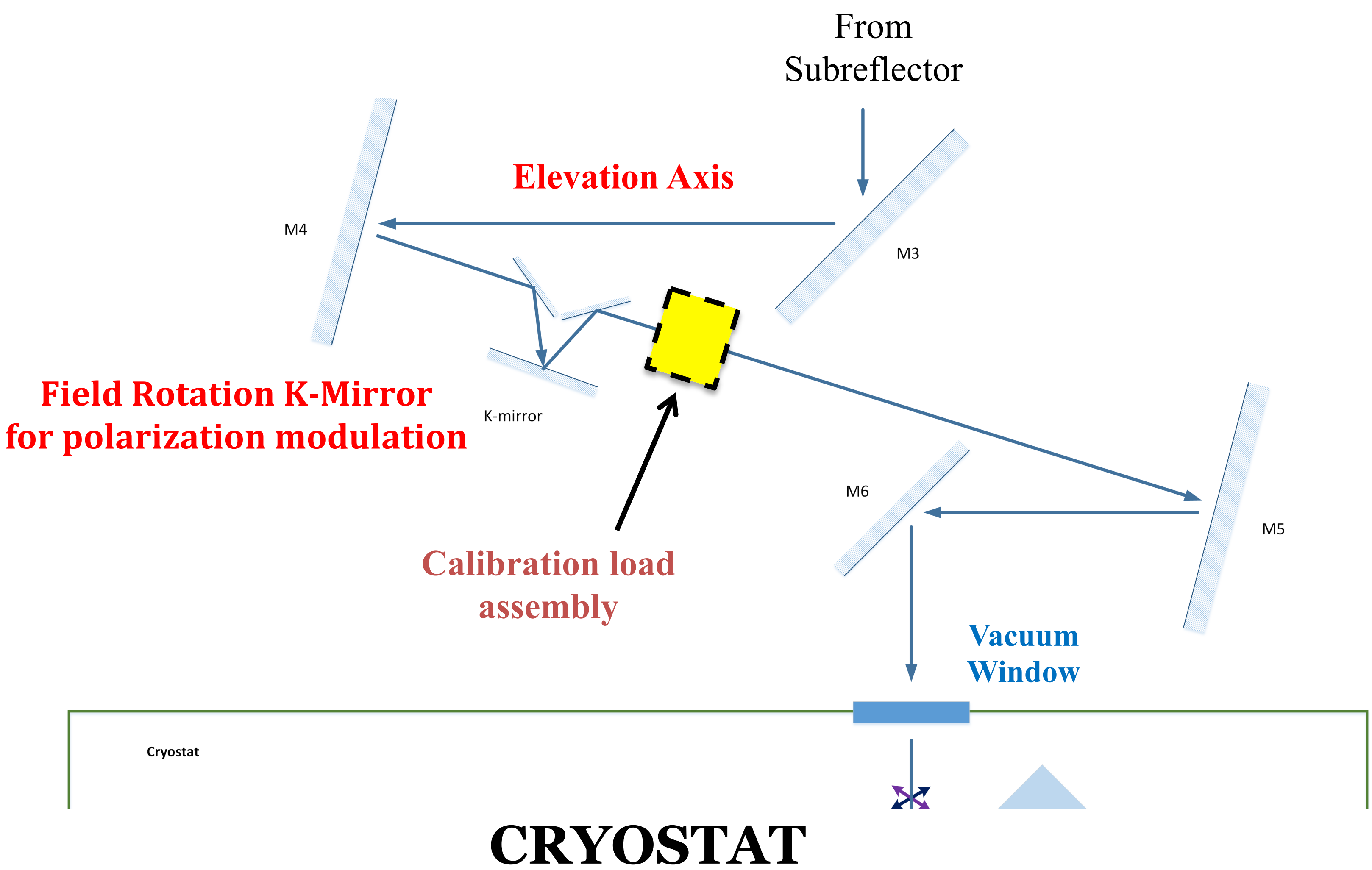
- Polarimetry remains a significant capability at the SMA, but:
  - The 300 GHz and 400 GHz receiver sets are used in their overlap frequency region for polarimetry observations
  - Non-identical receiver sets: different noise / gain performance
  - Separate, and different feeds with small, non negligible, pointing offsets
  - At 230 GHz we use single receivers and a switchable quarter wave plate to obtain full Stokes parameters – very inefficient
  - Eliminating switchable waveplate would improve sensitivity by an additional factor of $\sqrt{5}$
  - This gives a factor of $\sqrt{16}$ x $\sqrt{5}$ ~ 9 times original sensitivity
- The new scheme will incorporate identical mixers coupled to the sky via an orthomode transducer and single feed horn
- 230 and 345 GHz receivers will be housed in a single cryostat
- Additional location will be made available for guest instruments

Proposed scheme

- Preserve the M4 -M5 - M6 optics plate located on top of the receiver cabin.
- No optics cage between the cryostat and 4-5-6 optics plate.
- Single vacuum window on cryostat.
- Local Oscillator is injected using a waveguide coupler in the cold.
- LO modules to attach directly to cryostat.
- 4 IF output ports from cryostat

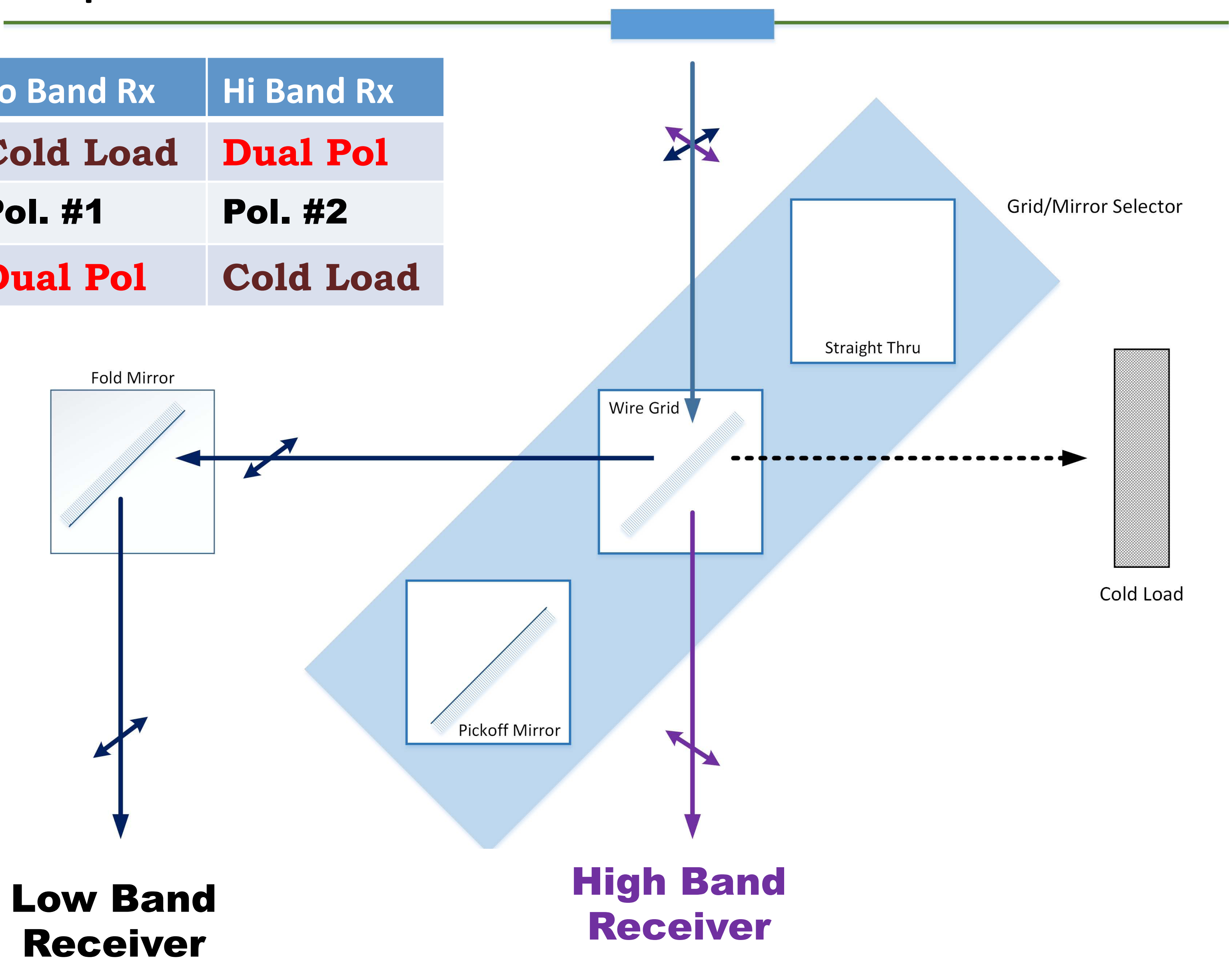


Optical arrangement



Cold optics

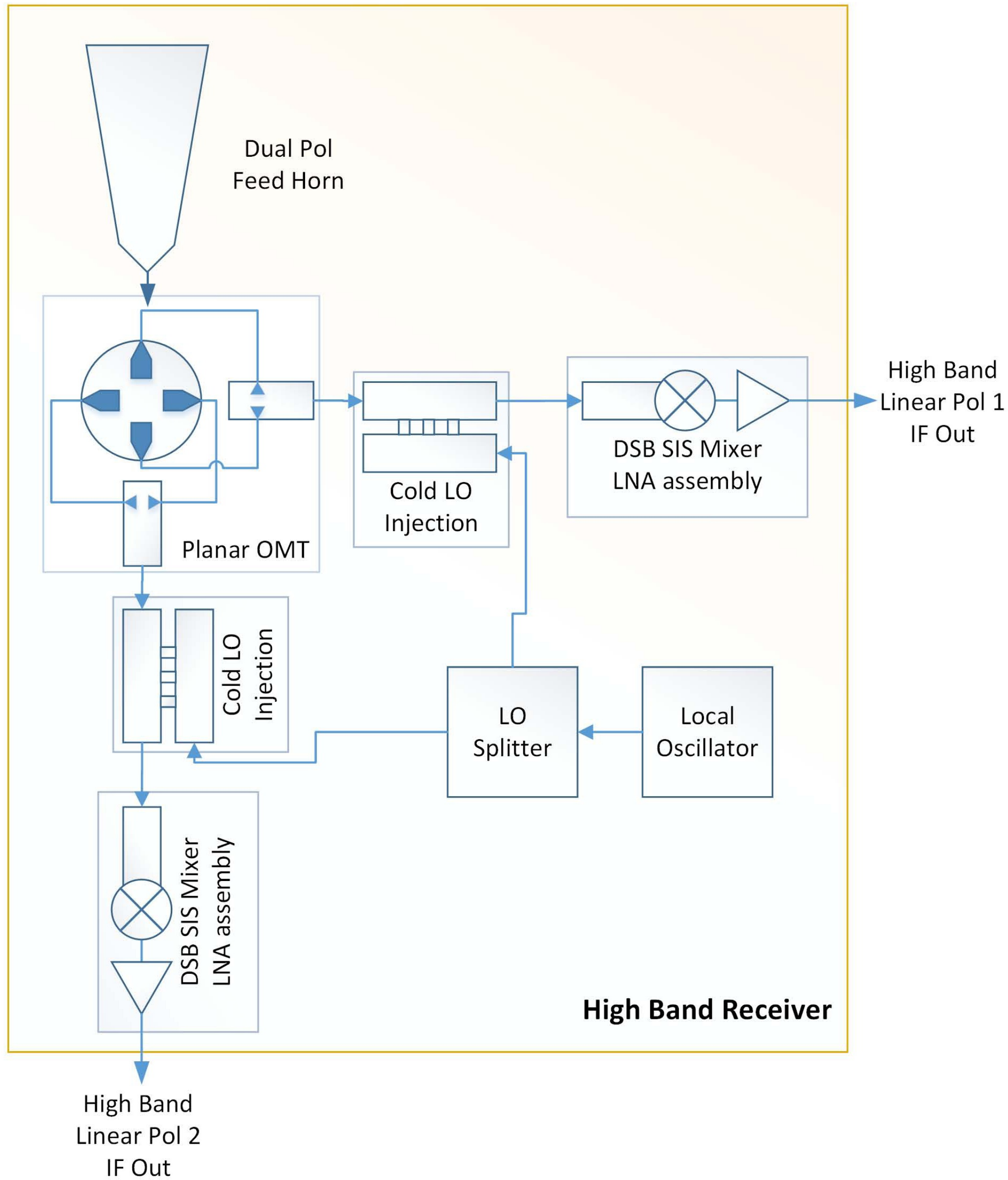
Selection	Lo Band Rx	Hi Band Rx
Thru	Cold Load	Dual Pol
Grid	Pol. #1	Pol. #2
Mirror	Dual Pol	Cold Load



Receivers

Incorporate elements already under development

- Smooth wall Feed Horn (LZ)
- Planar OMT (PG)
- LO Coupler (PG/LZ)
- LO Splitter (PG)
- Wideband SIS Mixer (ET)
- Wideband Isolator (LZ)
- Low Noise Amp (ET)
- YIG-based LO (ET)



What about higher frequencies?

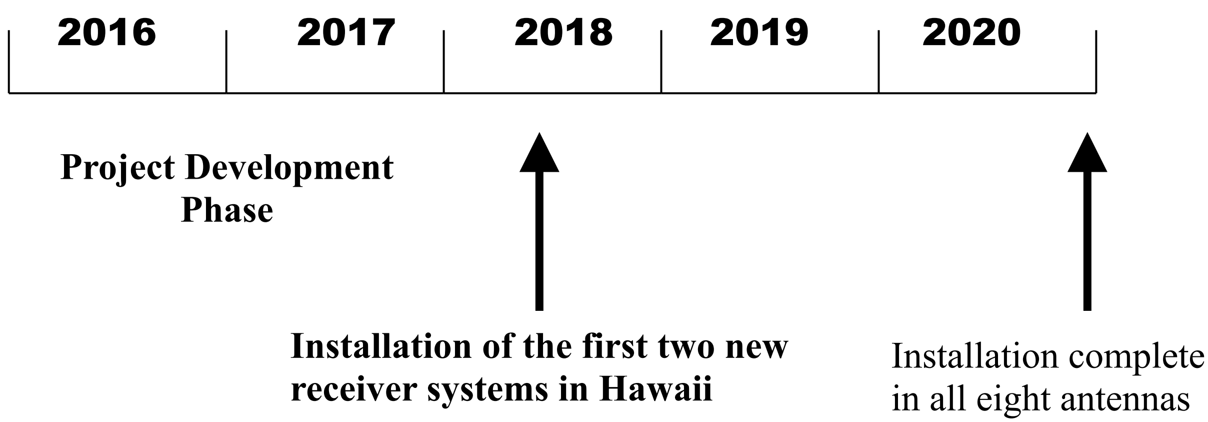
- The 650 GHz receiver sets were by far the most costly to fabricate, but with signifcantly poorer performance than the 230 / 345 GHz sets
- However, significant funding and effort for the Herschel Observatory and ALMA has led to excellent performance, about 10 times better than our initial receiver sets
- At SAO we have a very small receiver group fully occupied with building state of the art receivers for the lower frequency bands
- Collaborate with outside group that has Herschel / ALMA heritage
- New receiver set up will have room for guest receiver sets
- Could accommodate receivers in the 490, 650 or 850 GHz bands

Analog subsystem and correlator

- Increased bandwidth requires new fiber transceivers
- If we simply add more SWARM hardware, would need 7 times the current SWARM capacity – operating at full speed to achieve 56 GHz total bandwidth. We currently have 6 GHz from SWARM at 8/11 speed and 8 GHz from ASIC correlator
- Also need a new generation of low cost analog down-converters
- Digital systems advancing rapidly (both clock rate and data handling capacity) – can wait a couple of years before we need to decide exactly what to build
- Plan to phase out old ASIC correlator once the second tranche of SWARM is operational later this year

Project summary and timeline

- Dual Polarization Receivers with 4 – 18 GHz IF
- Two band Operation: LO tuning 210-270 GHz & 280-360 GHz
- RMS noise of 0.4 mJy @ 350 GHz LO with 14 GHz IF BW + dual pol
- RMS reduced to 0.3 mJy with streamlined optics & receiver enhancements
- Significantly improved sensitivity for polarimetry (factor of 9)
- New receiver systems will be backward compatible with existing ones



Summary

Have been improving sensitivity by adding bandwidth

Planning to equip the SMA with submm receivers

Interest is high despite (because of ?) ALMA

Have interest from other institutes

SAO – ASIAA partnership remains strong

We plan to operate through the lifetime of our current lease