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Upgrading the Submillimeter Array wSMA and beyond

PANCHROMATIC SUBMILLIMETER ARRAY

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About The SMA

- The SMA is a reconfigurable mm/submm interferometer, capable of sub-arcsecond continuum and high-resolution spectroscopic measurements over large bandwidths
- Located at the best northern submm site – Maunakea, Hawaii
- Developed via partnership between SAO and ASIAA
- Science operations started in 2003, paving the way for ALMA
- Capabilities have been continually developed since
  - Started with 4 GHz instantaneous bandwidth, now 48 GHz
  - Polarimetric capabilities added
  - Dual frequency observing, with one polarization per band
- Highly productive, in-demand facility
- 3:1 oversubscription rate for open-skies observing
- > 1,000 publications, 50,000 citations
  - SMA data appears in many successful ALMA proposals
- Core areas of science include star-formation, protoplanetary disks, ISM, SMBHs, time domain astronomy, solar system objects, galaxy clusters, nearby and high-redshift galaxies, evolved stars.
- The SMA is a key station in the Event Horizon Telescope

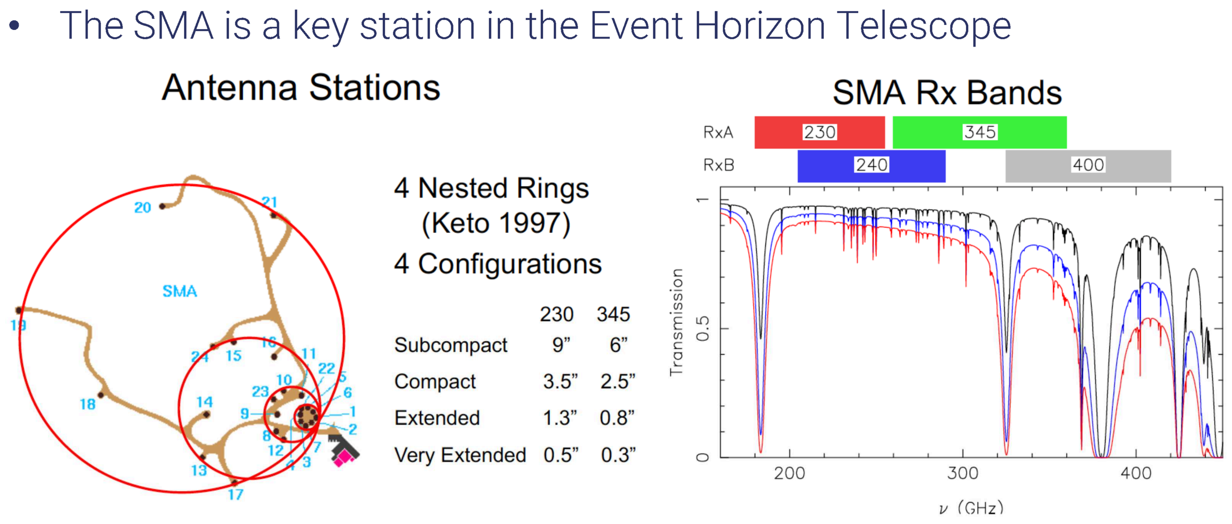

Fig. 1 (left) The SMA consists of eight 6m antennas that can be arranged in configurations with baselines of up to 508m. (right) The current four single polarized receivers overlap in sky coverage allowing for polarimetric observations.

- With the advent of ALMA, we have developed a strategy to keep the modest and flexible SMA at the forefront of sub-mm interferometry. This is laid out in the SMA white paper "Science with the wideband Submillimeter Array: A Strategy for the Decade 2017-2027"[1]
- As part of this, we are developing several upgrades to enhance the capabilities of the SMA, including replacement of the aging cryogenic receiver systems
- More recently, we have developed the concept of the "Panchromatic SMA", a mm/submm interferometer capable of observing simultaneously across the entire mm/submm spectrum accessible from Maunakea.

The wSMA Upgrade

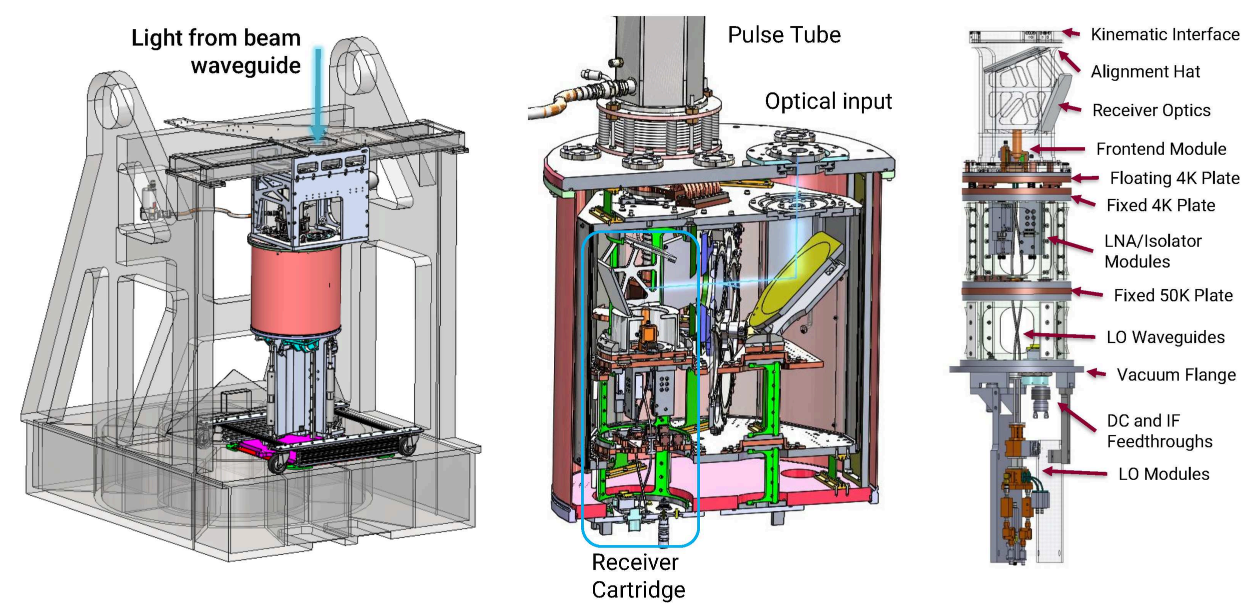

Fig. 2 The wSMA upgrade will replace the entire SMA receiver system between the beam waveguide and the receiver cabin floor with a new cryostat and optical alignment assembly (left). The cryostat (center) contains two dual polarized receiver cartridges (right) with DSB SIS mixers and waveguide LO injection.

- The wSMA upgrade will replace the aging SMA cryostats and single polarized receivers with new cryostats and dual polarized receivers.
- The upgraded cryostats are more compact, allowing space in the SMA receiver cabins for additional "guest" receivers.
- First prototype wSMA receiver has been installed in SMA Antenna 7 for on-sky testing and integration into the array.
- The first two production receivers will be deployed later this year, with two additional receivers in the following year.

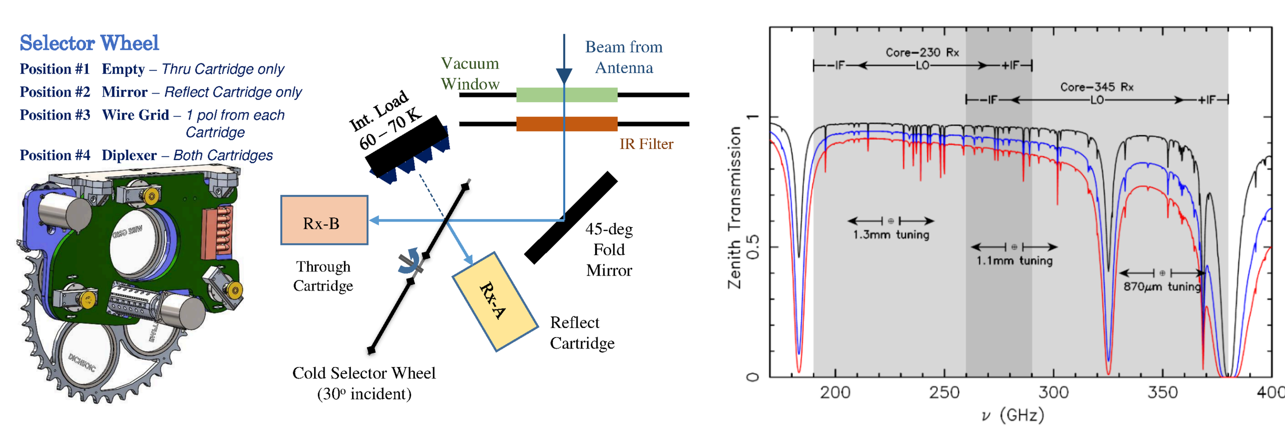

Fig. 3 A cryogenic selector wheel (left) is used to couple the two receiver cartridges to the optical input. The four positions of the wheel allow for two polarizations of one cartridge to couple to the input (position 1, 2), or one polarization from each cartridge, to couple to the input (position 3, wire grid). A fourth position will hold a dichroic[2] for dual band, dual polarization observations, over a limited bandwidth. The two cartridges will cover two overlapping RF bands, centered at 230 GHz and 345 GHz (right).

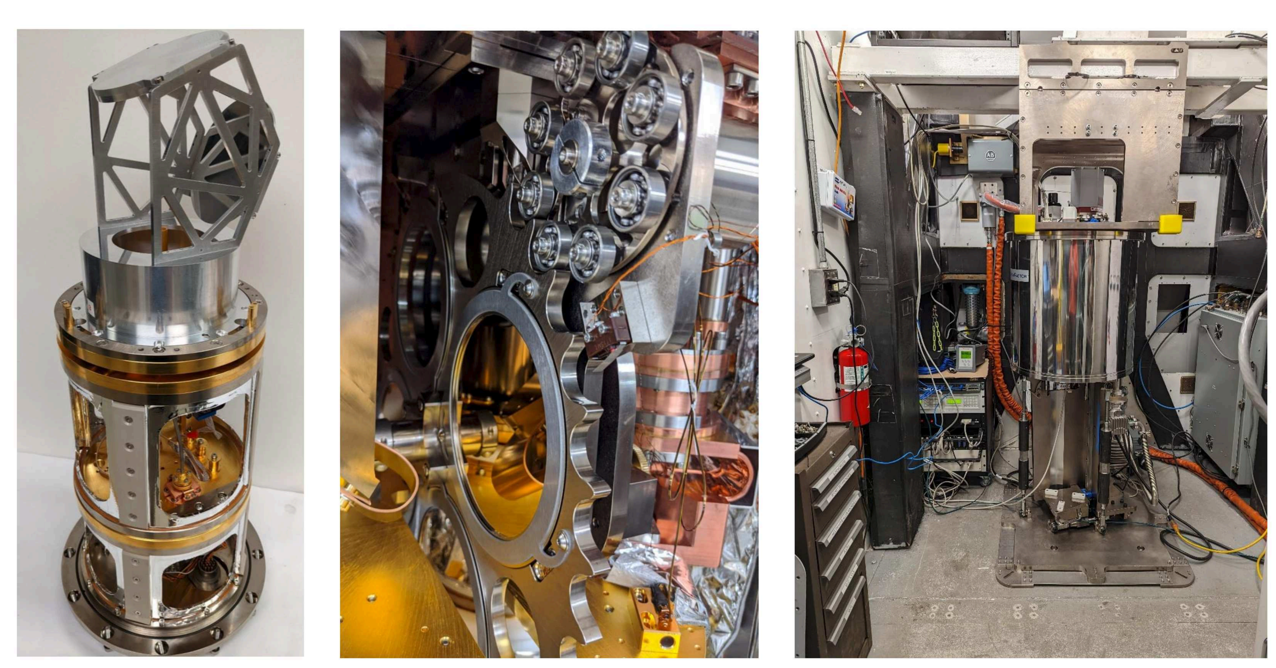

Fig. 4 (left) Populated prototype receiver cartridge. (center) cryogenic selector wheel drive mechanism. (right) Prototype receiver installed in SMA Antenna 7, in January 2024.

The Panchromatic SMA

- The wSMA upgrade is an enabling step to allow further development of the SMA's capabilities.
- We propose[3] to take advantage of the SMA's modest size and our recent development of low-loss dichroics[2] to develop simultaneous observation capabilities across the mm/submm spectrum.
- The first step beyond the wSMA "Phase I" upgrade is to enable simultaneous 3mm, 1.3mm and 850μm observations by adding a 3mm W-band LNA based receiver, upgrading to sideband separating receivers, and adding optical diplexers (currently under development for the ngEHT[4]) to build the wSMA "Phase II"
- We also propose to develop multi-frequency receiver cartridges with wider, diplexed IFs that extend down to near DC[5], and to deploy 750μm and 650μm receivers in an additional "guest" receiver.
- Multi-frequency capabilities will greatly enhance both regular observations and that of time-dependent and evolving sources

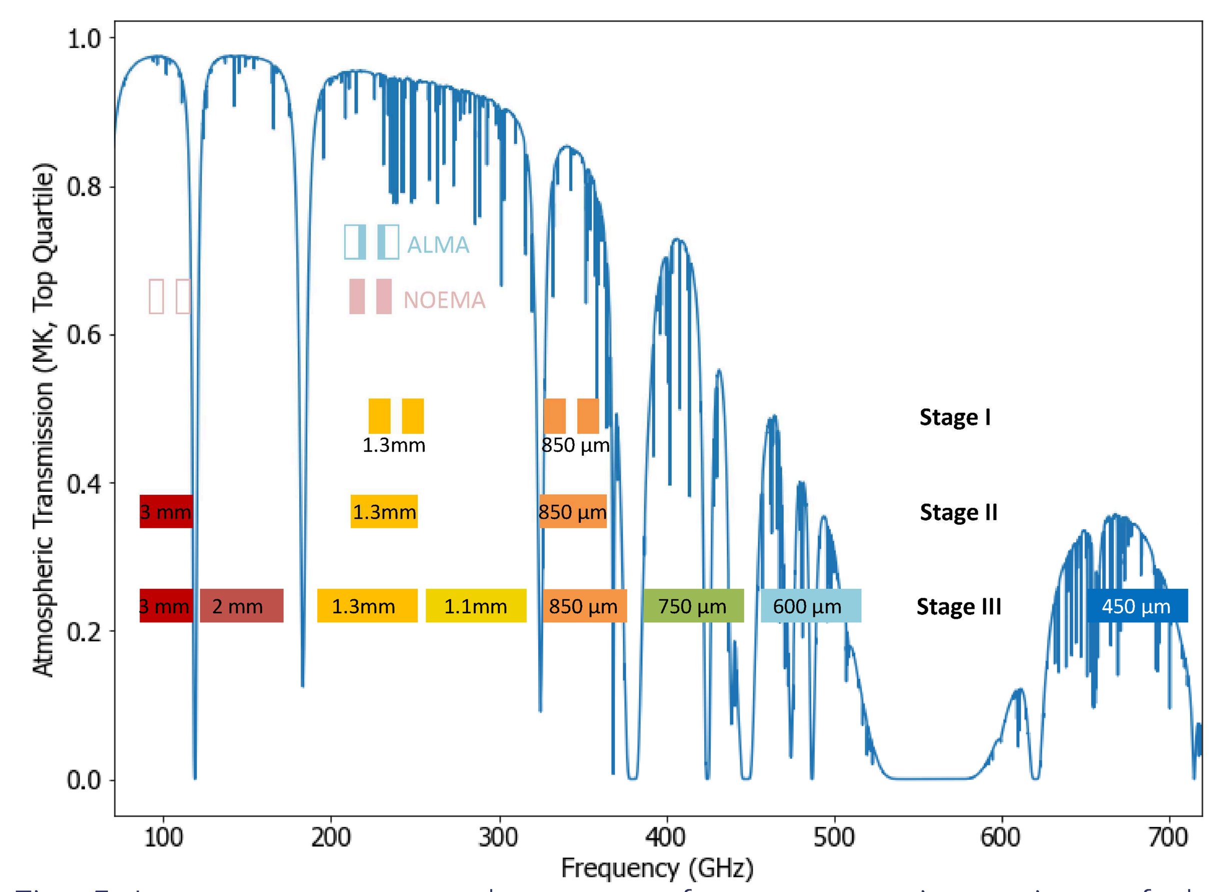

Fig. 5 Instantaneous spectral coverage for representative tunings of the proposed upgrade, versus that of existing facilities. Compared with ALMA (currently 8 GHz instantaneous bandwidth for one band at a time unless subarrayed, 32 GHz proposed for ALMA2030) and NOEMA (currently 16 GHz instantaneous bandwidth in one band, dual band observing proposed), the Stage II and III Panchromatic SMA would offer roughly one and two orders of magnitude increase in instantaneous spectral coverage, respectively.

Milestone	Receiver Band	RF Range (GHz)	Inst. BW (GHz)	Typ. T_{sys} (K, SSB)	Continuum Sensitivity per band (mJy/beam)	Line Sensitivity 1 km/s channel (mJy/beam)
Current SMA	"230"	172-254	24	222	0.221[a]	39.0[a]
	"240"	198-278	24	222	0.221[a]	39.0[a]
	"345"	242-376	24	702	0.755[a]	104.1[a]
	"400"	320-424	24	1494	1.582[a]	186.1[a]
wSMA Stage I	1.3 mm	190-290	24	147	0.128[a]	22.5[a]
	850 μm	260-380	24	484	0.405[a]	55.7[a]
wSMA Stage II[b]	*3 mm*	*84-116*	*30*	*44*	*0.026*	*7.4*
	1.3 mm	*190-290*	*40*	*107*	*0.052*	*12.0*
	850 μm	*260-380*	*40*	*358*	*0.167*	*29.5*
wSMA Stage III[c]	*3 mm*	*84-116*	*32*	*44*	*0.026*	*7.4*
	2 mm	*120-170*	*50*	*65*	*0.029*	*9.0*
	1.3 mm	*190-250*	*60*	*111*	*0.045*	*12.5*
	1.1 mm	*255-315*	*60*	*162*	*0.063*	*15.8*
	850 μm	*325-375*	*50*	*407*	*0.165*	*32.9*
	750 μm	*385-445*	*60*	*1681*	*0.351*	*97.2*
	600 μm	*455-515*	*60*	*2430*[d]	*0.540*[d]	*119.6*[d]
	450 μm	*650-710*	*60*	*2929*[d]	*0.791*[d]	*121.9*[d]

[a] Assumes two bands operating simultaneously with one polarization per band.
[b] Three bands operating simultaneously with two polarizations per band, sideband separating receivers, diplexed zero IF
[c] 600 + 450 μm receiver operating in guest port position, dual band 1.3+1.1 mm and 850 + 750 μm cartridges in wSMA cryostat, dual band 3 + 2 mm sidecar receiver.
[d] Sensitivities estimated assuming top quartile of weather, ~1mm PWV.

Table 1. Estimated sensitivities for a typical 8 hour observation track for different stages of the wSMA upgrade/Panchromatic SMA.

Other Upgrades

On-the-fly Mapping

The relatively large size of the SMA's primary beam allows it to rapidly map large areas using mosaicking or on-the-fly mapping. Software updates to allow for on-the-fly mapping are in progress, along with work to use the autocorrelation output of the SWARM correlator for simultaneous total power measurements.

Flux calibration accuracy

The SMA routinely achieves submillimeter absolute calibration accuracy of better than 10%. With additional development of calibration techniques, combined with the new wSMA receiver, we believe that 1% calibration precision can be achieved.

Solar and near-sun observing

The SMA antennas were designed to be capable of solar observing, although some cabling in the quadrapod is not specified for the solar heat loads. We are currently upgrading one antenna for solar observing, and plan to upgrade all antennas in the near future[6].

This will allow the SMA to carry out both independent solar observations and to observe simultaneously with the Daniel K. Inouye Solar Telescope (Maui), as well as tracking comets etc. near the Sun.

Focal-plane arrays

The guest instrument position enabled by the wSMA upgrade will allow for mapping campaigns with focal-plane array receivers. Up to 4 pixels at 230 GHz or 7 pixels at 345 GHz can fit through the existing SMA beam waveguide. Combined with a robust on-the-fly mapping mode, such arrays could rapidly map nearby galaxies or large clouds.

References

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We acknowledge the significance Maunakea has for the indigenous Hawaiian people; we are privileged to study the cosmos from its summit.