Science with mini-trackers on SALT

Introduction for science day discussion, 13 July 2021

The idea behind mini-trackers (MTs) on SALT is to make use of the large field of view of the spherical primary mirror to enable observations of several additional targets simultaneously with whatever observation SALT is doing.

Overview of what MTs are and how they might operate We hope to deploy 4 MTs. Each consists of a robotic arm that carries a spherical aberration corrector (mini-SAC) and feeds an instrument. The arm can position the mini-SAC anywhere inside a $\simeq$50 to 100 sq.deg. patrol field, the footprint of which on the sky depends on where SALT is pointing. The mini-SAC will have a small science field of view (perhaps 1 arc min across) with a larger field for acquisition and guiding. Fig. 1 shows 4 MTs, as seen when looking down on the primary mirror.

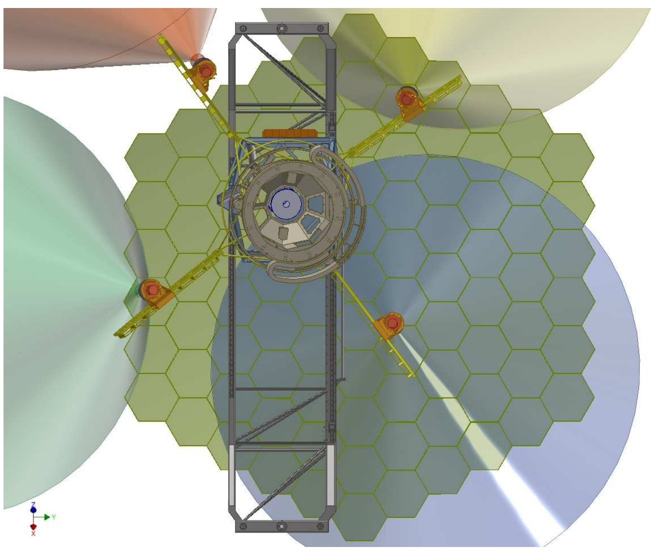

Figure 1. Mini-SACs (orange) on tracker arms (yellow) as seen from above the primary mirror. The arms rotate on a pin close to the edge of the main payload structure, and the mini-SACs can slide up and down the arm. The cones show the incoming beam of each mini-SAC, so the blue circle overlapping much of M1 is the pupil of the MT in the bottom right. Note that, depending on where the main tracker is and where a given MT is relative to the main tracker, it may correspond to a large telescope, or have in effect 0 aperture.

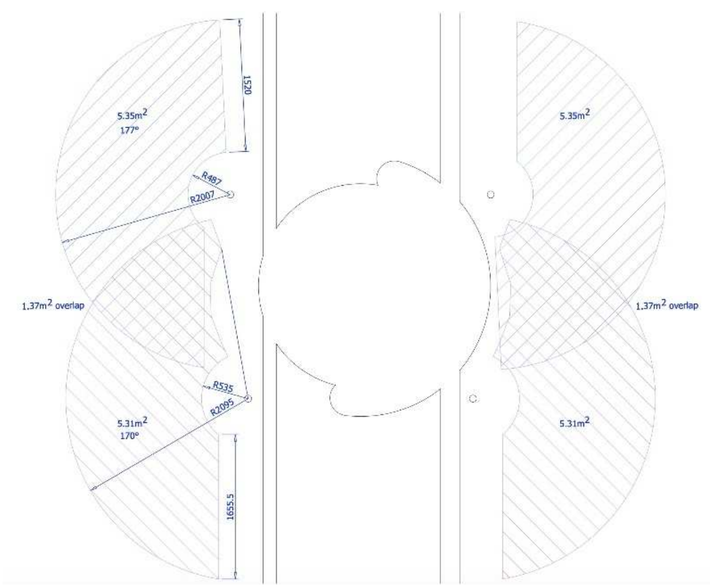

Figure 2. The patrol fields of the 4 MTs; these are each about 100 sq.deg., with about 30% overlap between adjacent patrol fields. The design will be changed to shift this to smaller r, since a MT at the end of these arms typically corresponds to too small a telescope (see below). Also, because some ϕ, r range is needed to track, the real useful part of the patrol field will be smaller than the physical range of the arms shown here.

The arms rotate around a pin on the inner end, and the mini-SACs can move along the arm. The allowed ϕ, r range gives an annulus sector (windscreen wiper pattern; see Fig. 2), which is the patrol field. The patrol field size we expect is somewhere around 80 sq.deg., with perhaps 50% overlap between the two MTs on the same side of the main tracker beam. Inside its patrol field, a MT can slew to a target, acquire it, and track and guide on it, until the main tracker slews to its next target.

Like SALT, the MTs are of course moving-pupil telescopes. Also, since SALT typically aims to use the best tracks (those that result in a large effective aperture for the main SAC) and MTs are off-center, they are effectively smaller telescopes. Fig. 3 shows the effective apertures of SALT and the 4 MTs over a single SALT track. For this particular track, SALT was equivalent to an 8.6 m telescope, whereas the MTs had effective apertures between 6.5 and 7.3 m.

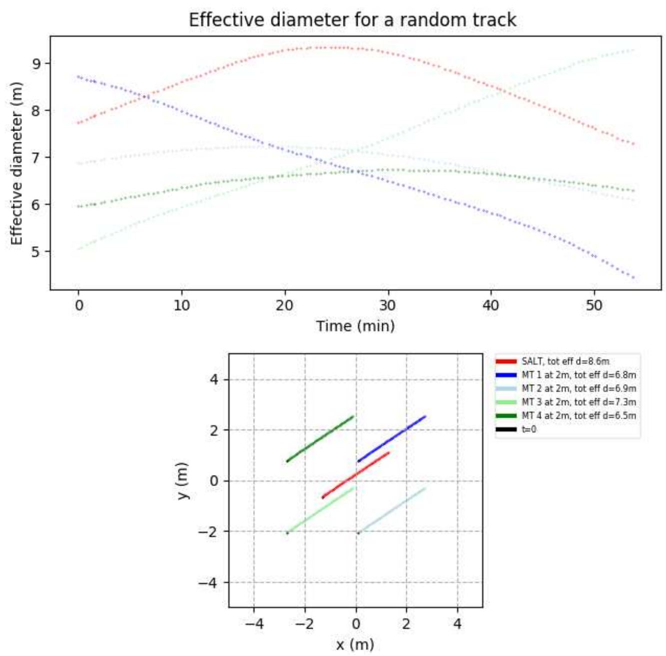

Figure 3. Bottom panel: a random track in tracker x, y coordinates (axes show position in meters), with the main tracker in red, and the mini-trackers in green and blue. Top panel: the effective aperture of SALT and the MTs, as a function of time since the start of the track (expressed as the diameter of a circle with area equal to overlap of the pupil and primary mirror). For this illustration, all 4 MTs are at a distance of 2 m from the center of the main tracker, and the arms are at 45° angles to the x, y axes. We have assumed that the SALT SAC is 11 m aperture, with 3.5 m central obscuration, and that the mini-SACs are 9 m aperture, with a 2 m central obscuration.

SALT keeps a database of tracks were done in past observing semesters. We have assumed that 2019 was a typical year, and used all 2019 observations for the calculations shown below. Fig. 4 shows the fraction of “useful tracks” (defined as a track for which a MT is at least a 3.5-m telescope, for at least 20 minutes) as a function of the distance between a MT and the center of the main tracker.

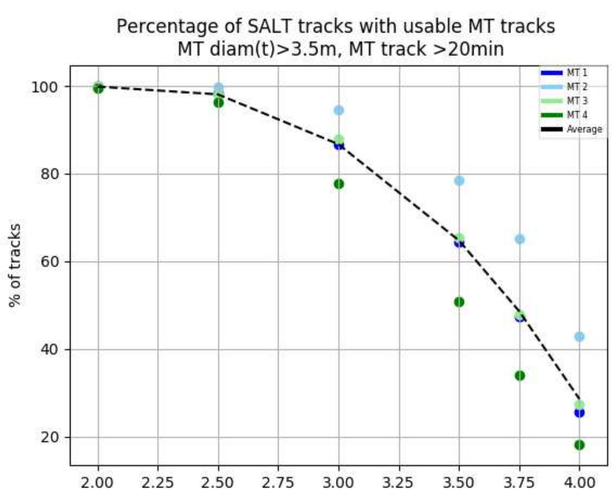

Figure 4. Fraction of SALT tracks that are usable by MTs, as a function of distance between MTs and the center of the main tracker. Here we again assume that the arms are all at 45° angles to the x, y axes. Roughly half the patrol field is inside the radius where the useful tracks drop to 80%. The intention is to move the arms in and make them a bit shorter in a future design, to limit this to a maximum distance of 3 m away from the center. This will lead to patrol fields being about 20% smaller than shown in Fig. 2, and with a bit more overlap between them.

We can also find a distribution of expected MT apertures. For a real observation, the MT arms will all be at different angles and the mini-SACs at different positions along the arms. But we can look at the two extremes to find the limits. Fig. 5 shows the distributions of effective apertures for the 4 MTs, when fixed at a distance of 2 m (left hand panel) and 4 m (right hand panel) from the center of the main tracker, resulting from all SALT tracks done in 2019. As already mentioned, the design of the arms will change to shift the patrol fields closer the SALT target. As a result, both these extremes will shift to larger aperture, and for a realistic year of observations, you can expect a broad distribution of effective apertures between 3.5 and about 8 m, with a mode near 5 m.

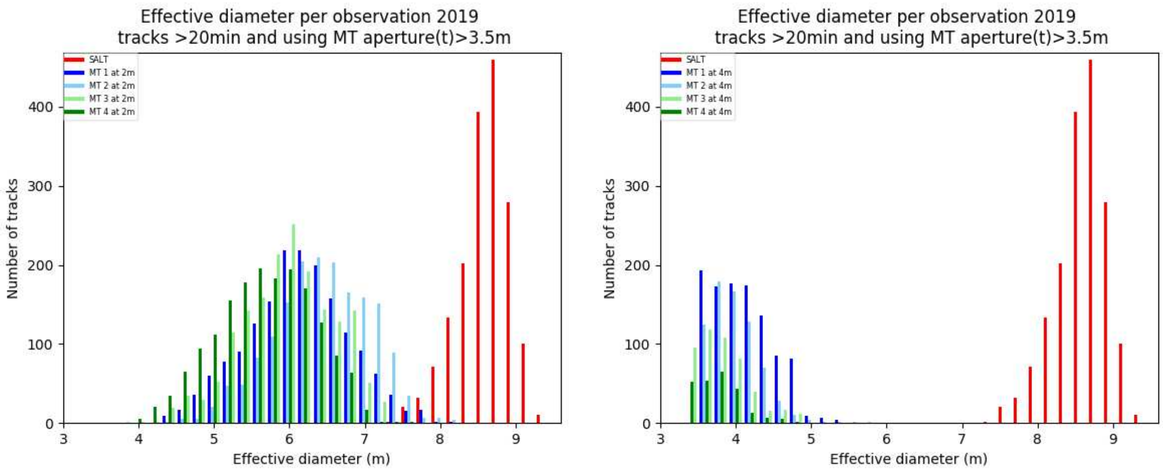

Figure 5. Distributions of effective apertures for useful tracks run in 2019. Effective aperture is the size of a normal telescope that would have seen the same number of photons from the same source, if it observed it for the same time as the total track duration (in other words, for a point in the track we calculate the area of the overlap between the pupil and M1, multiply with the time interval for which that area is a good approximation, sum these products, and divide by the total track duration). SALT is shown in red and the MTs in blue and green. The left hand panel is for MTs at 2 m from the center of the main tracker (closest in they can get); the right hand panel is for MTs at 4 m from the center (farthest out).

Summary of key points We expect that SALT will operate as normal, while MTs observe whatever targets are possible during a given SALT track. MTs are constrained to point within about 15 deg of SALT, and the patrol field that each MT can access is expected to be perhaps 80 sq.deg. Furthermore, a MT observation must fit into the SALT track during which it is taken, and MTs also cannot be used when SALT is doing a polarimetric observation (polarimetry with SALT and short SALT tracks will mean that the MTs are idle for around 10% of observing time). With an effective aperture of roughly 4 m and up, and a typical exposure limited to around 30 minutes, a reasonable conservative flux limit for low-resolution spectroscopy with MTs is about 21st magnitude. We envision 4 identical optical spectrographs (probably small IFUs), covering at least 400 to 700 nm (probably a bit more) at resolving power of roughly 1,000.

The most important limitations to keep in mind when thinking of science applications are

- Sensible science programs will involve thousands of targets, spread across the sky
- In most cases, observations with MTs will not allow for any time constraints or repeat visits
- Low completion must be acceptable – spectra of any subset of your target list should be useful to you
- The MTs are not 10-m (or 8-m) class telescopes – targets fainter than $\sim$21st magnitude will be a challenge

Potential science cases There is a large range of projects that require spectra of a few 1,000 objects, spread across the sky (very expensive to obtain one by one on a large telescope, but too low sky density to use MOS). We have mainly considered ID spectroscopy of transients from LSST and other transient surveys (see the accompanying document for the science case).

We would like to hear about programs that the SALT community would be interested in pursuing with MTs, as this will inform the decision as to whether or not to seek funding to support further development of this concept.