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Prof. Philip R. Goode, Director  
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To whom it may concern,

This is a letter concerning the plan to equip the Big Bear Solar Observatory (BBSO) with a solar telescope of 160 cm aperture. I have received the project summary drafted by Profs. Goode (NJIT) and Kuhn (UH) and base my comments on this draft.

I know both proposers and their work well, hold them in high regard, and also have high respect for the qualities and track records of their teams. My conclusion is that this is an excellent and exciting plan, a logical step for the 2006-201+ era (since Solar-B fills the smaller-telescope niche from 2006 while ATST will initiate larger-aperture solar physics only after 2010), and very likely to be highly successful. I explain this conclusion below.

My own credentials are the following. I am a solar physicist at Utrecht University in the Netherlands and at Oslo University in Norway. I am program leader "Solar Astronomy" at Utrecht and project scientist (effectively director) of the Dutch Open Telescope (DOT) on La Palma in the Canary Islands. I also lead the European Solar Magnetism Network (ESMN). The DOT website, the ESMN website, and my own website (URL's specified above) furnish further information.

Let me first paint the landscape = optical solar observing on an international scale. The DOT and BBSO occupy comparable niches in solar physics, especially when the DOT is seen as a tandem sister to the SST, the brand-new Swedish Solar Telescope on La Palma from whose building the DOT is operated. The DOT is a 45-cm aperture multi-wavelength imager consistently applying speckle reconstruction to achieve long-duration tomographic imaging of the solar atmosphere at 0.2 arcsec resolution. The 96-cm SST employs adaptive optics (AO) plus phase-diverse restoration to obtain 0.1 arcsec resolution, and will be equipped with a spectrometer and magnetometers in addition to its imaging capability. The DOT-SST tandem is presently the

European counterpart to the US high-resolution efforts at NSO (the DST at Sacramento Peak) and BBSO. The SST is the first telescope to approach meter class resolution in solar physics. Its first images, recently published in *Nature*, dramatically prove that doubling angular resolution from 0.5-m to 1-m aperture brings dramatic change in the intrinsic nature of the solar scene.

Various plans now exist around the world to build larger than 1-m telescopes. It must be emphasized that only very recently it has become practical to do so. Solar telescopes have always been small compared to nighttime telescopes, with apertures ranging from 0.3 m to 0.7 m, but these "small" telescopes were effectively already too large in terms of angular resolution. Even at La Palma and BBSO the Fried parameter  $r_0$  describing atmospheric quality in terms of equivalent telescope aperture exceeds 20 cm only occasionally. Super-seeing commensurate with meter-class aperture may occur in perfect weather but waiting for that might take many years. Even half-meter telescopes are usually far too large. With respect to angular resolution there is no point in building larger solar telescopes if the atmospheric deterioration is not corrected (or avoided by going to space, orders of magnitude more expensive). The recent developments in speckle burst collection and reconstruction, phase-diverse imaging and reconstruction, and real-time adaptive optics and multi-conjugate adaptive optics currently cause a high-resolution revolution in which solar physics may finally get to the intrinsic scale of the basic phenomena underlying solar structures and dynamics. This is not only a matter of snapshot resolution, but requires consistent-quality high-resolution observing, simultaneously in different diagnostics, over considerable durations at high cadence. Just a cursory inspection of the DOT movies at <http://dot.astro.uu.nl> shows the importance of consistent long-duration sequence gathering: the sun is dynamic at every time scale, and it is essential to be able to study dynamical changes without perturbation from the changing seeing permitted by the earth's atmosphere.

The major plan is the NSO-led ATST development aiming at a 4-m class telescope. The principal driver for the 4-m aperture size is the need to gather enough photons: at high resolution solar observing is photon-starved. This sounds surprising to nighttime astronomers, but at high angular resolution the quantity to consider is intensity, not irradiance flux, and the solar intensity is just as low as from any other cool star. Aperture increase does not change the photon flux per diffraction-limited resolution element whereas the permitted integration time (set by the solar scene change speed, e.g., the sound speed) diminishes with increasing resolution. The number of photons available for detection therefore goes actually down with increasing aperture. The need for 4 m aperture therefore comes from the requirement to feed sufficient photon flux into spectrometers, full-Stokes spectropolarimeters and tunable Fabry-Perot interferometers whose narrow bandpasses decimate the photon take spectrally and whose application often requires very high S/N (as in polarimetry where images or spectra using only a small fraction of the light are subtracted). In these photon-limited applications optimal wavefront correction means restoring as many Zernike coefficients as the system order can reliably handle at a given angular resolution, say 0.1 arcsec.

ATST will be the international solar physics workhorse, but only after its completion around 2010, so during the next decade. No wonder that there are projects aiming at smaller aperture to get a pre-taste of the high-resolution cake earlier during the present decade. A brief overview:

- SST: Swedish 1-m aperture vacuum refractor, La Palma, operational;
- GREGOR: German 1.5-m aperture open on-axis Gregorian, Tenerife, largely funded, operational after 2005;
- SUNRISE: German-led balloon-borne 1-m on-axis Gregorian, funding requested, first flight

- perhaps in 2004;
- MAST: Indian open 1-m reflector, proposal stage;
  - DOT<sup>++</sup>: Dutch upgrade of the DOT to 1.5-m aperture, proposal stage;
  - NST: BBSO New Solar Telescope, 1.6-m aperture open off-axis Gregorian = present proposal.

Except for the SST and SUNRISE, all projects utilize the "open" principle, relying on wind flushing and possibly enforced air flow control to inhibit internal telescope seeing and building on the successful demonstration of wind flushing by the strong La Palma trade winds by our own DOT. None of the projects preempts the need for ATST for the reasons explained above: quantitative diagnostics need larger aperture in order to gain sufficient S/N even at lower than diffraction-limited resolution. Most of the above projects therefore aim at more limited capability: GREGOR primarily at spectrometry, DOT<sup>++</sup> only at speckle imaging, SUNRISE at Solar-B-like capability at double the Solar-B aperture.

All of these projects supersede Solar-B (launch late 2005) which at 50-cm aperture may be seen as the combination of the DOT (or the late Swedish SVST) and the HAO/NSO Advanced Stokes Polarimeter in space. This statement can also be turned around: if Solar-B functions nominally, there is not much sense in operating and maintaining ground-based half-meter solar telescopes from 2006 onwards unless they fill a special and specific niche. It is therefore very logically to build and operate meter-class telescopes during the half-decade in which Solar-B does and ATST does not yet operate. After 2010, solar physics will undoubtedly need more than just one single multi-meter telescope (compare with the present flurry in 8-m-and-larger nighttime telescope building); it is logical that towards the end of the decade proposals will arise to add multi-meter telescopes to the ATST during the next decade.

So far the landscape. It obviously has a niche for a 1.6-m telescope at BBSO, as US counterpart to the European efforts (not literally meaning competition; I for one look forward to sequence extension by DOT-NST tandem observing, BBSO taking over when the sun sets at La Palma) and as a science learning step towards ATST. In view of the BBSO track record, science specialisms, and site quality, aiming at an order of 1.5-m telescope is the logical step to take. Making it an open off-axis reflector is just as logical.

I fully support the proposal. Scientifically, it encompasses the science niche which will be covered in my own upcoming DOT<sup>++</sup> proposal to Dutch funding agencies. In a nutshell, this is the transition in structure and dynamics of the solar magnetic field from the photosphere to the corona; in simple words, the issue how photospheric fluxtubes connect to and constrain coronal loops. This is widely seen as one of the principal research areas in solar physics, and to be fundamental for understanding solar space weather modulation.

The DOT<sup>++</sup> will be limited to multi-wavelength imaging only, using speckle reconstruction exclusively, for reasons of manpower, cost ceilings, and also because the DOT lacks the capability to feed solar images onto horizontal benches in an optics lab but needs inflexible, fixed hardware solutions for secondary optics and image acquisition along the telescope itself. The aims for the DOT are therefore far less ambitious than for NST, which will combine easily and flexibly accessed horizontal optics tables with high-order adaptive optics, real-time speckle reconstruction (we do only post-processing at the DOT), and Fabry-Perot spectropolarimetry.

One might expect that I, as DOT director and DOT<sup>++</sup> proposer, should see NST as dangerous competition, a nasty bigger brother across the ocean. Far from it, and not only because NST

will be much less limited than DOT<sup>++</sup> in its science applications. Yet apart from the general philosophy of collaboration – wide-spread in solar physics because the sun sets us larger problems than we can handle – and yet apart from the opportunity for DOT<sup>++</sup> – NST tandem sequence observing mentioned above, the background to bear in mind is that in the second half of this decade, the SDO mission will flood solar physics and solar physicists with its continuous high-cadence many-wavelength full-disk image streams at 1 arcsec resolution. Ground-based high-resolution telescopes are likely to be constrained even then by say 4K×4K chips at 0.03 arcsec pixels to only 2-3 arcmin fields, a tiny fraction of the apparent solar disk. We will desperately need multi-telescope observing to enrich low-resolution SDO data mining sufficiently with high-resolution inspection of what the sun is really doing at its more intrinsic scales. Additionally, every solar physics group in the worldwide community must educate itself in high-resolution solar physics on the way to ATST.



Robert J. Rutten