TRUTHS

Traceable Radiometry Underpinning Terrestrial- and Helio- Studies

Summary and Status

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1. Background

TRUTHS is a mission proposal originally submitted to an ESA call for Earth Explorer Opportunity Missions in 2001/2002 by an international team led by Nigel Fox of NPL, the UK national standards laboratory (equivalent to NIST). This call was for relatively low cost missions ~$100 M which could be built and deployed quickly and met priority science needs in one of a number of thematic areas e.g. Land, Atmosphere etc. In this context TRUTHS was unique as it underpinned a number of thematic areas and whilst being able to deliver a range of science objectives its principle objective was to establish " SI traceable benchmark reference standards" (in the optical domain), e.g. the Sun, Moon and various Earth targets, from space. It meets these objectives largely through the use of existing developed technologies and instruments e.g. imager and spectrometers but in this cases removes uncertainties and biases resulting from drifts and degradation through the utilisation of a novel calibration concept. In essence transferring the full calibration and traceability chain employed in terrestrial national standards laboratories such as NPL and NIST into orbit – from the primary standard cryogenic radiometer through to the calibration of spectral radiance of the full aperture of an Earth viewing imager. The use of this novel in-flight calibration methodology, mimicking exactly that utilised on the ground, justifies the claim that TRUTHS is in effect an "international standards laboratory" in space (at least for the solar spectral domain).

More details of this calibration strategy can be found in:

Fox, N.P, Aiken, J, Barnett, J.J., Briottet, X. , Carvell R., Frohlich C. , Groom. S. B., Hagolle, O., Haigh J. D, Kieffer, H. H., Lean, J., Pollock, D. B. , Quinn T., Sandford M.C.W. , Schaepman M. , Shine K. P., Schmutz W. K. , Teillet P. M. , Thome K. J. , Verstraete M. M., Zalewski E. , *Adv. Space Res*, **32** (2003) 2253-2261.

Which is attached here also**, a**nd also via a podcast at:

<http://feeds.feedburner.com/npl-lectures>

It should be stressed that the principle measurement instruments and their operational specifications, as proposed in the original TRUTHS submission, only need to be considered as indicative and are open to change and variation dependent on the specific needs identified by the community. Only the primary Cryogenic Solar Absolute Radiometer (CSAR) and associated calibration equipment (spectral calibration monochromator, SCM and filter radiometers) need be considered core, since it is this calibration methodology and its implementation that is the key element of this mission. All

other instruments e.g. imager, can be of differing technology (FT for example), and differing spectral or spatial resolution. However, for illustration, information on the baseline set of instruments that were originally proposed will be provided below.

2. Measured Parameters

The concept of TRUTHS is that it should establish baseline high accuracy measurements of all key spectral radiometric parameters related to incoming and reflected solar radiation, with a view that these "reference measurements" could be used to evaluate/correct biases and drifts of other in-flight instrumentation on board other satellites. These other instruments/spacecraft, having been designed for more specific tasks e.g. global and/or operational measurements. Although any individual parameter can be determined with unprecedented accuracy by TRUTHS own instrumentation, the driving requirement is to measure a range of parameters, in both Earth viewing and outward directions. The number and range of these different types of measurement means that TRUTHS itself, can only make targeted direct science measurements, and not truly continuous data sets. However, for many applications this is adequate and in the TRUTHS example would still allow for ~10 mins solar viewing per orbit for example.

Measurand	Spectral resolution nm	Spatial resolution m	Accuracy %
Total Solar Irradiance	**Total**	**-**	**0.01**
Solar Spectral Irradiance	**200 – 2500 (0.5 - 1)**	**-**	**0.1**
Lunar Spectral Irradiance and Radiance	**380 – 2500 (10)**	**-**	**<0.3**
Earth Spectral Radiance (five angles per target)	**380 – 2500 (10)**	**~ 25 (20 x 20 km)**	**<0.3**
via filter radiometers for Aerosols / E Rad Bud	**TBD**	**20 km (TBD)**	**<0.3**

Observing conditions (near polar 700 km)

Solar viewing - ~ 10 mins per orbit

Earth viewing ~ 10 sites (20 * 20 km) at 5 angles per orbit

It should be noted that in the above table a near polar orbit is specified this could also be a more oblique angle allowing for more direct simultaneous comparisons with other satellites. Similarly the swath could be increased probably at the expense of spatial resolution if this was felt to be more optimum. Continuous spectral resolution and relatively high spatial resolution were selected to aid the matching of spectral bands and footprints of other sensors. Sensors with large ground pixels can be calibrated through the use of satellites with wider swath but intermediate pixels acting as transfer standards in a similar manner.

It should also be noted that Total Solar Irradiance and Earth/Lunar spectral radiance, in a defined subset of wavelength bands via filter radiometer,s are all default parameters derived as by products from the core on-board calibration instrumentation.

3. Calibration Methodology

The following provides a summary of the calibration methodology employed in TRUTHS.

3.1 Terrestrial

The terrestrial calibration methodology typically employed by a standards laboratory such as NPL or NIST is shown in the left hand column of Figure 1. At NPL, cryogenic radiometers (CRs) measure the radiant power in a monochromatic beam of radiation, from a laser, by comparing its heating effect with that of electrical power. Uncertainties of 0.001% can be achieved in this way. The now calibrated monochromatic beam is then used to illuminate a photodiode and thus determine its spectral response. This process is repeated at sufficient wavelength intervals (usually 50 to 100 nm) to allow interpolation of the slowly varying spectral response of the photodiode. These photodiodes can then be used to calibrate spectrally selective detectors (filter-radiometers) using a similar monochromatic beam of radiation but making measurements at much finer spectral intervals. The FR can have narrow or broad spectral response functions, e.g.1 nm for a monochromator or 100 nm for coloured glasses. The calibrated FRs are then used to measure the spectral irradiance or radiance of conventional polychromatic sources e.g. lamps directly. Often the Planckian radiation of an intermediate high temperature (3500 K) black body (UHTBB) is used to interpolate finer spectral intervals for irradiance and radiance measurements, its radiant temperature having been previously determined using a group of FRs across the spectral region of interest. Uncertainties as low as 0.02% in terms of spectral radiance can be achieved in this way, although often in practise the limitation is the performance of the conventional standard lamp being calibrated. These lamps are then used to disseminate radiometric scales to users either at the standards laboratory or at a

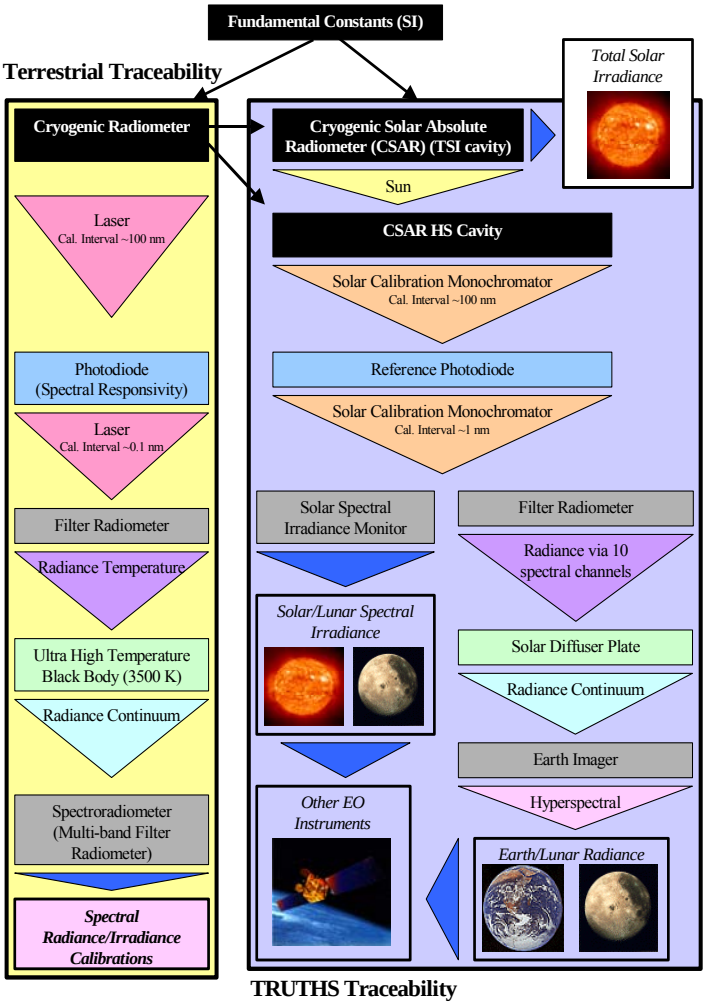

Figure 1. Calibration traceability chain for TRUTHS contrasted with that of an NMI

users site in conjunction with a standard laboratory. Both ensure formal traceability. More generally, however, lamps are simply sold to users and there is no formal comparison or independent review to evaluate the uncertainties achieved at these sites.

3.2 TRUTHS CALIBRATION METHODOLOGY.

A schematic representation of TRUTHS' instrumentation is at Figure 2. An analogous calibration procedure to that used terrestially is proposed for TRUTHS and is illustrated at Figure 1 in the right hand column alongside, compared with the NMI methodology. The main difference is that TRUTHS will use solar radiation dispersed by a grating monochromator and a Spectral calibration monochromator (SCM) for spectral responsivity calibrations instead of lasers. Only short-term stability of the radiation from the SCM is required. Any long-term degradation is calibrated out each time it is used by reference to the onboard primary standard cryogenic radiometer, CSAR.

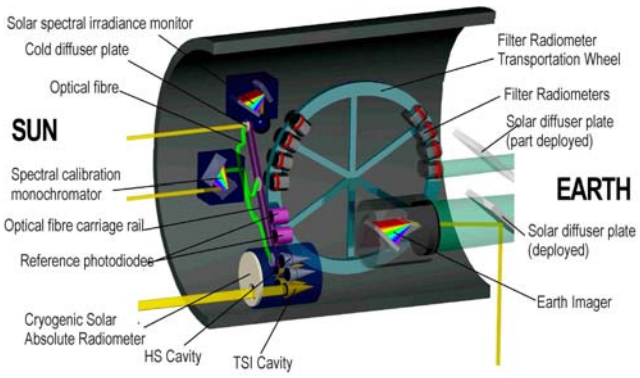

Figure 2. Schematic representation of the TRUTHS instruments and their interaction

Similarly, the spectral radiance of the Earth Imager (EI) is calibrated in-orbit through a measurement of solar irradiance reflected from the solar diffuser plate (SDP) instead of a high-temperature black body. However, in contrast to other EO missions, the spectral radiance of this system is measured directly in-orbit using FRs calibrated using the SCM. This practice removes errors due to drifts in spectral shape and absolute level caused by ageing or contamination.

3.2.1 CALIBRATION OF HIGH SENSITIVITY CAVITIES. Since the TSI cavities are optimised to measure power levels close to 25 mW they do not have sufficient dynamic range to measure the relatively low intensity monochromatic radiation from the SCM. This is done instead using the HS cavities, which have a dynamic range enabling them to measure signals of 1 mW to 10 µW with a SNR <1000:1 (i.e. 0.1%). The HS cavities having a signal resolution of <1 nW but variations in thermal background radiation limit this to around 10 nW for a nominal 10 second measurement period. However, although having electrical substitution capability at the high power range, their performance is really monitored/calibrated through comparison to the TSI cavities using TSI of the Sun as a source. This comparison is performed using a small 0.5mm diameter apertures, positioned in front of each of the cavities in turn, to reduce the signal level from the sun to within the dynamic range of both - a factor of 100 reduction over the 5 mm diameter. The absolute area of this small aperture does not need to be known as it is only used in relative mode to compare the response of the TSI and HS cavities with the same source.

3.2.2 CALIBRATION OF REFERENCE PHOTODIODES. In calibration mode the HS cavity is used with one of the 5mm diameter apertures and the external Solar shutter closed. Monochromatic radiation (dispersed from the Sun) from one of the outputs of the SCM is coupled to an optical fibre bundle. The optical fibre is mounted and supported so that its bending radius and stresses remain constant during its use. This is relatively easily

accomplished by appropriate positioning of instrumentation within the Satellite. The output of the fibre has a small lens to image the output from the fibre to a near collimated beam. This beam can then be directed to under-fill the aperture of the HS or an appropriate RP through the translation of the carriage supporting the optical fibre output. The HS determines the power of the beam which is then used to calibrate the spectral response of the RP. This process is repeated for all RPs at wavelength intervals of around 50 to 100 nm dependent on spectral region using appropriate output from each of the 3 optical fibres coupled to the exit slits of the SCM. Since ultimately irradiance and radiance are required for each RP a separate measurement is made in an aperture over-filled mode. In this mode a small roughened silica transmissive diffuser is positioned in between the output of the optical fibre and the aperture of the detector to generate a near lambertian radiation source (although of significantly reduced intensity) that can be used to compare irradiances. Since this secondary step is only determining an aperture area it can be carried out in a region of optimum power for each RP.

Although the RPs have a very wide linear dynamic range of more than 10 orders of magnitude for silicon, the HS requires a minimum power level of 5 μW because of background thermal noise. The uncertainty of this calibration step is <0.1%. This uncertainty is dominated by the random errors associated with the stability of the radiation from the SCM. The only other significant potential sources of error are wavelength uncertainty from the SCM but this is monitored using the wavelength calibration sources (see later).

After an initial out-gassing period it is expected that only small changes will occur in the spectral resonsivity of the RPs since they are never exposed to optical radiation other than from the optical fibre onboard the spacecraft. It is likely that they will only need a calibration every 3 to 6 months.

3.2.3 CALIBRATION OF FILTER RADIOMETERS. Radiation from the SCM is similarly used to calibrate the response of the various FRs. In this case the output from the optical fibre is passed through the diffuser and alternatively illuminates a RP or a FR. In this way calibrating the spectral radiance responsivity of the FR against the RP. This process is carried out at the relatively fine spectral intervals of 0.5 to 1 nm to define the rapidly varying spectral response function of the individual FRs. Since the RP has an absolute calibration this transfers to the FR. All the TRUTHS' FRs are calibrated in this way, Earth viewing and diffuser viewing, by rotation of the FRTW so that they lie in the calibration plane. The viewing geometry of the FRs and the RPs have been chosen to be similar so as to minimise second order effects associated with any residual non-uniformity of the radiation leaving the silica diffuser. The uncertainty of this calibration procedure is estimated to be <0.1%, (0.02% is achieved terrestrially). The dominant component being calibration source drifts, which since they originate from the Sun are relatively small over the few seconds taken to transfer the calibration from the RP to FR. Such calibrations will be performed on a weekly basis early in the mission until ageing effects are stabilised and then on infrequent occasions to dependent on drift rates.

3.2.4 CALIBRATION OF SOLAR SPECTRAL IRRADIANCE MONITOR. The calibration of the SSIM follows a similar procedure to that previously described. In this case the optical fibre moves between the RPs and the entrance aperture of the SSIM, a small Spectralon integrating sphere. Since the radiant power of the monochromatic beam from the fibre has been calibrated by the RP this calibrates the response function of the SSIM. All

components of the SSIM, entrance diffuser, gratings, mirrors, and diode response are exposed in the same manner as they are when viewing the Sun and thus any degradation is calibrated out. Since the SIM measures irradiance the entrance aperture also needs to be calibrated at one wavelength and this is performed with the diffuser in front of the fibre at a high power part of the spectrum.

Again the dominant uncertainty is drift in the calibration source and wavelength accuracy and it is estimated that this calibration procedure will have an uncertainty of around 0.1%. Small additional sources of error may arise from non-uniform damage, ageing and scattering on optical surfaces particularly the entrance integrating sphere in the UV region. However, the effects of this are likely to be of secondary order and are largely monitored through the above procedures.

3.2.5 CALIBRATION OF THE EARTH IMAGER. The radiance response of EIs is often calibrated/monitored in-orbit by viewing a reference radiance source. Ideally this should fill the complete field of view of the imager so that it mimics the full optical path that the array detectors of the imager see when viewing the Earth. This is often performed using solar irradiance (SSI) reflected or transmitted by a diffuser to produce a lambertian radiance source. The limitations in this method are the absolute value of solar spectral irradiance and likely spectral drift of the diffuser. Significant efforts have been made to try to understand and reduce the size of these errors but most only claim to have confidence in using the techniques to monitor change.

TRUTHS provides a unique solution to this problem. Its calibration methodology is the same as with other missions i.e. the deployment of a SDP made of spectralon to reflect SSI to irradiate the full entrance aperture of the EI. However, the difference is that the absolute spectral radiance of the SDP can be measured in-orbit. This is carried out by rotating the FR using the FRTW to view the radiance of the SDP directly. The SDP can be deployed so that it is illuminated with the same solar angles and that the FRs view it with the same viewing angles as when it is fully deployed in from of the EI. The rotation of the FRTW allows different FRs to view the SDP to detect spectral effects. The FRs themselves are mounted as pairs so that they view different portions of the SDP to detect any non-uniformity. Since the FRs are regularly recalibrated, the EI is always fully calibrated. Therefore the uncertainty is again dominated by the SNR characteristics of the instruments, resulting in an uncertainty of 0.1% for the calibration procedure. Thus when summed in quadrature with all other uncertainties the EI will have an uncertainty in its measurement of radiance of <0.2%, a factor of 10 better than any existing imager. As an alternative the FR can view the Earth and or Moon without the SDP in place and then simultaneous viewing of the EI and the FR can allow a calibration transfer in this way, providing some redundancy in the diffuser and also to a lesser extent the EI itself.

4. TRUTHS baseline payload instrumentation

The following list of instruments were incorporated into TRUTHS a brief descriptor will be given with a nominal name which indicates their function for completeness. For each of these there is a specific nominal design identified. However, with the exception of the CSAR, these designs can all vary according to availability, partnerships etc. For example the Solar Spectral Irradiance Monitor (SSIM) identified here could in principle be SIM of SORCE (modified slightly to allow use of the calibration methodology of TRUTHS).

4.1 Earth Imager (EI): - This is currently based on an upgrade of APEX which is an aircraft based hyperspectral imager being built for ESA. Another option under consideration is a upgraded version of CHRIS currently flying on the ESA Proba mission.

4.2 Solar Spectral Irradiance Monitor (SSIM): based on a set of grating based linear diode array based spectrometers, relatively simple in design and passive in terms of movements

4.3 Filter Radiometers (FR): Single photodiode, with coloured glass based spectral filters and mechanical aperture based view limiting geometry. FR's spectral bands chosen to span the spectral range of the imager and where appropriate be similar to those of existing sensors e.g. Landsat. Some FRs could have very broad spectral bands to more directly meet the needs of the Earth radiation budget community. Some FRs would be based around the use of a glan-thomson polariser and thus allow polarisation resolved measurements to aid atmospheric correction of the imager and also for aerosol studies. The FOV of the FRs is nominally to match that of the EI. They can view both the Earth/Moon and diffuser plate, both methods can serve to calibrate the EI. Viewing the Earth/Moon allows for some redundancy in the event of EI or diffuser failure.

The FRs move to face the solar axis (in calibration mode) and to Earth axis for use, via a rotation wheel.

4.4 Reference Photodiodes (RP): Simple photodiodes, silicon trap based for visible and via an integrating sphere (to minimise non-uniformities) for NIR. These photodiodes serve as a more sensitive intermediate transfer standard to calibrate full spectral response of the FRs. They are calibrated at points across the spectrum directly against the primary standard CSAR.

4.5 Spectral Calibration Monochromator (SCM): Baselined as three double grating spectrometers sharing a common entrance and common drive mechanism to cover the full spectral range 200 to 2500 nm. Disperses solar radiation to provide tuneable monochromatic radiation for calibration system. Radiation from the monochromator is directed on to either CSAR, RP, FR or SSIM using an optical fibre bundle (one per monochromator). Methodology is in common use terrestrially and providing no significant change in the bending radius, system is short term stable and reproducible. Longer term degradation of fibres and monochromator is of course calibrated out via the CSAR during operation. Throughput of the SCM fiber system dictates the sensitivity requirements for the CSAR (~1 μW is worst case).

4.6 Cryogenic Solar Absolute Radiometer (CSAR): This is the key instrument of the portfolio serving as both primary standard (link to SI) and also for measurements of TSI. CSAR is essentially an electrical substitution radiometer (ESR) similar in operational principle to many others used both terrestrially and in space. For example all TSI measuring instruments, TIM, ACRIM, VIRGO etc are ESRs. However, the difference is that in the mid 1970s Quinn and Martin of NPL took this concept and cooled it to liquid Helium temperatures to build the first cryogenic radiometer (CR). In so doing many of the dominant sources of uncertainty common to ESRs operating at ambient temperatures became negligible – non-equivalence, noise, drift, Ohmic power loss, absorbtance … because the thermal diffusivity of materials improved by a factor of 1000 and superconductivity could also be exploited. Thus, a relatively large cavity can be

constructed to obtain an absorbtance >0.99998 and yet with easily measurable temperature rises. This cavity forms the critical interface between electrical and optical units. In a CR the only remaining significant source of uncertainty in equating electrical and optical energies is the absorbtance of the cavity and its long term stability. *A very high absorbtance value as in the case of a CR means that even large degradations in its reflectance and thus absorbtance can occur before the uncertainty of most of the TRUTHS measurands are affected.* The technology was later adopted for radiometric applications by Fox and Martin in the early 1980's, undertook a number of design improvements and was exploited commercially, becoming the primary standard of choice at many of the worlds standards laboratories.

In 1990 NPL first designed CSAR for measuring TSI in space. In this proposal, submitted to ESA, it was recognised that liquid helium as a coolant was non-viable for long term space applications and so CSAR was designed around a mechanical cooling engine (now the Astrium 20 K cooler). The project was not funded even though it received top gradings from the peer review because it required national (UK) funding which was not forthcoming as solar radiometry was not a UK priority. Of course the advantages of mechanical cooling were also applicable to terrestrial applications and so NPL designed a new radiometer based on a terrestrial stirling cooler. This demonstrated the principle and also became the new primary standard of NPL and the radiometer of choice for many new customers. The basic technology of CSAR has thus been in use terrestrially for more than 15 years.

It should be noted that other than the first cryogenic radiometer of Quinn and Martin all other radiometers have been used in radiant power mode i.e. they have not employed any limiting aperture as is required for TSI measurement.

CSAR as used for TRUTHS has not changed significantly in design in terms of TSI measurement, it still proposes to have three cavities for redundancy although also will now have redundant apertures as well. However, for TRUTHS it is also required to measure relatively low monochromatic power from the SCM for its calibration role and here the improved sensitivity available from cryogenic operation becomes critical, although needing an additional lower mass cavity. Drivers for higher sensitivity have also been present within the terrestrial community and so this aspect of the design has also already been demonstrated.

The two stage Astrium 20 K stirling cooler upon which CSAR is based has now been fully space qualified by ESA with a lifetime in excess of 11 years and so is ready for spaceflight.

In April 2007, NPL and World Radiation Centre (WRC) PMOD of Davos in Switzerland obtained funding from their respective countries to design and build a CSAR. Initially for deployment on the ground with the intent of replacing the World Radiometric Reference (WRR), in this case it will measure TSI through a vacuum window, the transmittance of which will be measured in a novel manner. CSAR will be designed for space flight but of course not use space qualified components such as the cooler, until a spaceflight opportunity is confirmed.

Although NPL has no significant credibility in terms of space engineering, the WRC has a significant track record, for similar (although non cryogenic) instruments and so this makes an excellent partnership.

Since the ground based design will take account of the interfaces etc of the Astrium space cooler and already needs to be vacuum compatible it will be relatively easy to build space hardware from this prototype. Funding to build a space based version is a available from the Swiss Government subject to a confirmed spaceflight.

The following table summarises the main electro-mechanical characteristics of the TRUTHS payload.

Instrument		Volume (mm^3)	Mass (kg)	Power (W)	Data rate (bits/s)	Operation	Manufacturer
CSAR	Radiometer	145×145×350	9	NA	300	Power: always, data: for Sun measurements	WRC/NPL
	Electronics	300x260x160	4	7	100	Always	BI
	Cooler *+ electronics*	245×400×150 *290x200x100*	12 *6*	150	100	Always	Astrium
SCM		250×250×400	15	8	100	For calibrations	JY
SSIM		100×250×250	15	8	50k	For Sun measurements	TNO
RPs		50×50×150	1	4	100	For calibrations	RAL/NPL
FRTW and FRs		700 radius, 70 width	10		400	For calibrations and Earth measurements	RAL/NPL
TASS		140×70×175	1	2	100	For Sun measurements	WRC-PMOD
PMO radiometers		180×190×400	10	8	300	For Sun measurements	WRC-PMOD
EI		715×245×650	25	20	1.7G	For Earth Measurements	OIP
Framework + thermal			15	10	NA	NA	RAL
Mechanisms (12)			10	5		As required	RAL
Total			133	185			

It should of course be noted that the manufacturers are indicative and subjective to change, and of course the dominant power requirement comes from the cooler of CSAR.

5. Payload configuration.

The baseline concept of TRUTHS is for a self-contained small satellite. In this case the satellite platform would be flexible in terms of pointing and have two active (in terms of instruments) axis, Solar and Earth/Lunar, although it may be appropriate for the solar axis to also view the Moon for additional measurements of irradiance. The orbit was originally proposed as either: near polar to follow existing orbital sensors or in a more oblique angled orbit so as to allow more regular simultaneous crossovers with other sensors.

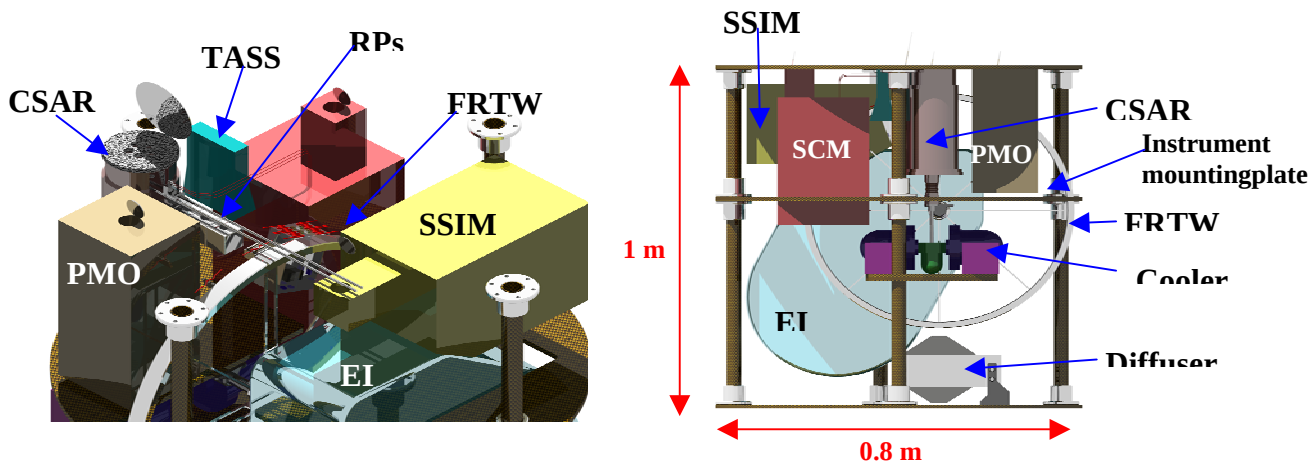

Figure 3: Integration of TRUTHS instruments

As described above, only the CSAR, SCM and FR are core to the calibration concept and these could be incorporated onto another spacecraft platform if appropriate.

6. Satellite bus

The baseline specification for the satellite bus for TRUTHS is described below, although as indicated above orbit can be considered as TBD.

Weight	~410 kg including a maximum of 150 kg for the TRUTHS Sensor
Overall dimensions	~1.8 x 1 x 1.2 m^3 (Launch configuration) incl. 0.8 x 0.8 x 1 m^3 P/L
Orbit	sunsynchronous at 700 km altitude RAAN 11:00
Design life	5 years (+2 years extension)
Operation modes	basically sun pointing, earth pointing for imaging on command, stand-by during eclipse
Power	average power of ~ 250 W with a peak value of ~ 320 W incl. 150 W P/L average power, 180 W P/L peak power primary power generation by deployable solar panels (GaAs, ≈ 3,4 m^2), NiH_2 batteries
Thermal	passive with radiators (TRUTHS sensor elements are actively controlled)
Attitude control	three axis stabilisation system, pointing accuracy: ±0,08° (±1km on ground), pointing knowledge ±0,001°, pointing stability ±0,001°/s, maximal slew rate 0.5°/s based on star sensors, sun sensor, magnetometers, reaction wheels, magnetic torquers
Onboard Data Handling	data handling based on DSP processor operating system: real time multitasking
Sensor Control Computer	Instrument, Storage and Communication Controlbased on DSP processor
Data storage	100 Gbit, Science data volume 1000 Gbit/day (maximal 100 Gbit/orbit)
Telemetry and tracking	TM/TC protocol CCSDS compatible TM: S band, Bit rate: 512 kbps, TC: S band, Bit rate: 4 Kbps
Communication	X band link: 320 Mbps, link data volume ~1200 Gbit/ day (incl. overheads), downlink time per day ~ day 63 min (~7 contacts per day)

7. Reference test sites and calibration transfer

In TRUTHS we proposed the use of a set of "reference test sites such as the Moon, and a number of characterisable and instrumented (or able to be) Earth Deserts e.g. Railroad valley, as a means of transferring the calibration from TRUTHS to other sensors. In this case local conditions e.g. wind, moisture …can be monitored by autonomous equipment

deployed at the site, with TRUTHS providing regular updates of the targets spectral radiance. The ground pixel and spectral band of the sensor under calibration being matched from the highly resolved data of TRUTHS. The use of Geostationary satellites, with high signal to noise characteristics can also be utilised to monitor the stability of more remote sites increasing the number which can be utilised by TRUTHS as transfer standards.

Large pixel sensors (outside the swath of TRUTHS) could be calibrated through the use of sensors with an intermediate pixel size, or the swath of TRUTHS increased.

Studies from CNES using POLDER indicate that accuracies of ~< 0.5% would be achievable for such calibration transfers, with the resultant uncertainty dominated by atmospheric and surface direction effects. The latter may be reducible through the BRDF measurement capability of the TRUTHS platform.

8. ESA review of mission

TRUTHS was not successful when proposed to ESA in 2001/2002. At this time the scientific case for this type of mission was not adequately made by the proposal nor a recognised priority of the community. The following feedback indicates the reasons behind the ESA decision, which although are now more easily debated, at the time the use of TRUTHS methodology and its benefits were not clearly made. The methodology itself, with a few minor queries, was accepted as being appropriate.

> ***Need, Usefulness and Excellence***
> *The need to have well calibrated measurements in Earth observation missions is self- evident. The proposal however fails to show how other missions would use TRUTHS measurements in any convincing manner.*
>
> *The evaluation of the coverage of science objectives by system requirements is arduous as the science objectives are unclear. Indeed if the aim is merely to provide accurate, calibrated measurements of Earth spectral radiances and of solar and lunar irradiance, the mission can be classified as a solution.* ***To the best of the reviewers' knowledge, there is presently no strong need for absolutely accurate Earth spectral radiances since other errors dominate the radiometric error budgets of planned missions.***
>
> ***Uniqueness and Complementarity***
> *From the viewpoint of measurement accuracy, TRUTHS is unique, however, its scientific use is not very clear since other uncertainties (e.g. modelling, atmospheric correction) are larger than those in TRUTHS.*
>
> ***Degree of Innovation and Contribution to the Advancement of European Earth Observation Capabilities***
> *TRUTHS would use challenging calibration technology and would transfer labquality measurement procedures to a space-borne instrument. In this respect it would be highly innovative.*

The user interest could not be clearly identified since the scientific objectives are poorly defined.

9. Summary and Conclusion

The calibration methodology of TRUTHS, through transferring into space the primary techniques employed in terrestrial national standards laboratories, offers the most accurate and timely means of establishing "SI traceable benchmark calibration references from space" in solar spectral band.

Whilst some of the operational detail of such a mission is open to debate, the use of a cryogenic radiometer as a primary standard provides a unique solution. Although not as yet built for spaceflight, CSAR is currently under development and could be ready for launch within a three year period. Most of the basic design already exists and has been breadboarded/demonstrated in terrestrial applications already. Funding for space based version of CSAR can be obtained subject to a confirmed flight opportunity.

NPL is currently discussing funding opportunities within the UK and Europe to support all the other elements of the TRUTHS mission, with a view to it potentially forming part of a collaborative venture with the US to establish an overall CLAREO like mission. This includes all the other instruments, satellite bus and launch, the latter probably utilising the expertise of Surrey Satellite Techology Ltd which is geographically very close to NPL.

NPL would of course be happy to consider a variety of collaborative options with the US on this mission and recognises the importance of ensuring that any such "calibration mission" meets the needs of all stakeholders and is internationally accepted, which is best achieve through a US/EU partnership. It is possible that such a mission could be formally recommended to GEOSS or CEOS and of course it also provides an operational solution to the GSICS group of the WMO.