

The solar radiation as key source to be measured

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pmod wrc

Historical Background

- Solar Irradiance has been measured since more than 100 years for meteorological and climatological purposes
 - “Radiation climatology”
- Solar Irradiance standards have historically been governed by WMO
 - “Conventional” standards
- Laboratory standards for radiant power have been governed by BIPM within the SI
 - Industry applications
 - Research applications
- SI-traceable solar irradiance measurements are desirable for
 - Solar Energy applications
 - Meteo/climate observations and research: WMO joins the CIPM Mutual Recognition Arrangement (MRA) in 2010
- PMOD/WRC has become a Designated Institute (DI) for solar irradiance (designated by the Swiss NMI, METAS)
 - PMOD/WRC currently holds 6 active CMCs listed in the BIPM KCDB



SI- Base Units (kg, m, s, A,...)



Primary Calibration
(radiometric characterization)

WRR Standard
- Conventional SI/WMO Standard
- Solar Irradiance
- Artefact based
- Ambient Air
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Cryogenic Laboratory Standard
- SI
- Laser Power
- Vacuum
- est. 2007
CLASP

Cryogenic Solar Absolute Radiometer (CSAR) (Vac/Ambient)
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Cryogenic Radiometer (Vacuum)

± 3000 ppm

± 140 ppm

± 200 ppm

± 10 ppm

± 400 ppm

± 700 ppm

± 380 ppm

<± (300ppm)

Native Scale

WRR Scale
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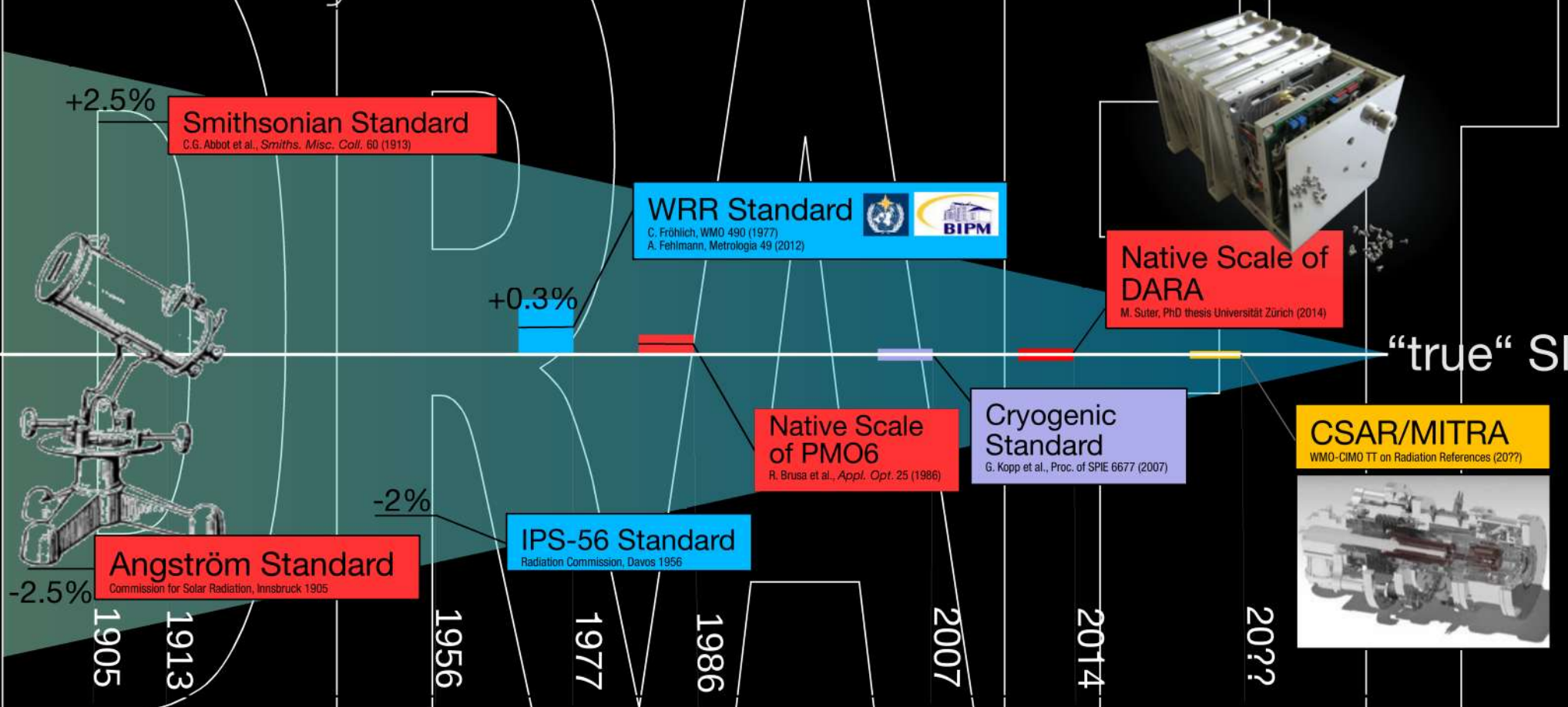
SI-Lab Scale
CLASP

CSAR Scale

Radiant Power

Measurement (Solar Irradiance) [W/m²]

History of Solar Irradiance Scales



Traceability Chain for Solar Irradiance



ISO 9059
ISO 9846
ISO 9847



- Field pyrhemometers
- Field pyranometers
- Reference pyrhemometers
- Reference pyranometers

- World Radiometric Reference (WRR)
- Established by WMO (CIMO Guide)
- Recognized by BIPM through CIPM MRA
- CMCs approved (KCDB)
- Currently no traceability to SI base units
- Isolated traceability- "island"

Proposed future Solar Irradiance



ISO 9059
ISO 9846
ISO 9847

WRR

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Traceability Chain for

- Field pyrheliometers
- Field pyranometers
- Reference pyrheliometers
- Reference pyranometers

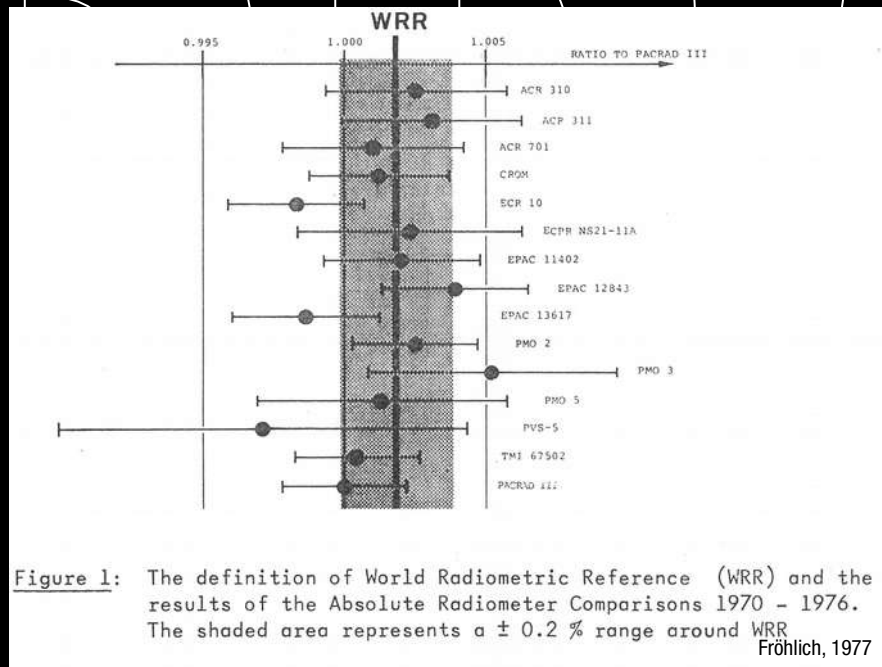
Cryogenic Solar Absolute Radiometer (CSAR)
BIPM key comparisons



SI- Base Units

m	kg	K	mol	cd	A	s
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Definition of the World Radiometric Reference (WRR)



- The **WRR** was defined in 1977 by averaging the **native scales** of 15 cavity pyrheliometers
- It is since then realized by a group of absolute cavity pyrheliometers, the World Standard Group (WSG)
- The World Radiation Centre (WRC) is mandated by WMO to maintain and operate the WSG and to disseminate the WRR

Purpose of the WRR

- Like any other standard, the purpose of the WRR is to enable accurate and stable measurements and to homogenize measurements with respect to location and time
 - Compare solar irradiance measurements in different places on the Earth
 - Compare solar irradiance measurements at different times
- For climatological purposes, the quest for long-term stability outweighs the need for higher absolute accuracy
- The WRR was designed to enable world-wide homogeneity and long-term stability of solar irradiance measurements
- The stability of the WRR is assured via International Pyrheliometer Comparison IPC, which are held every 5 years at PMOD/WRC

since 1959



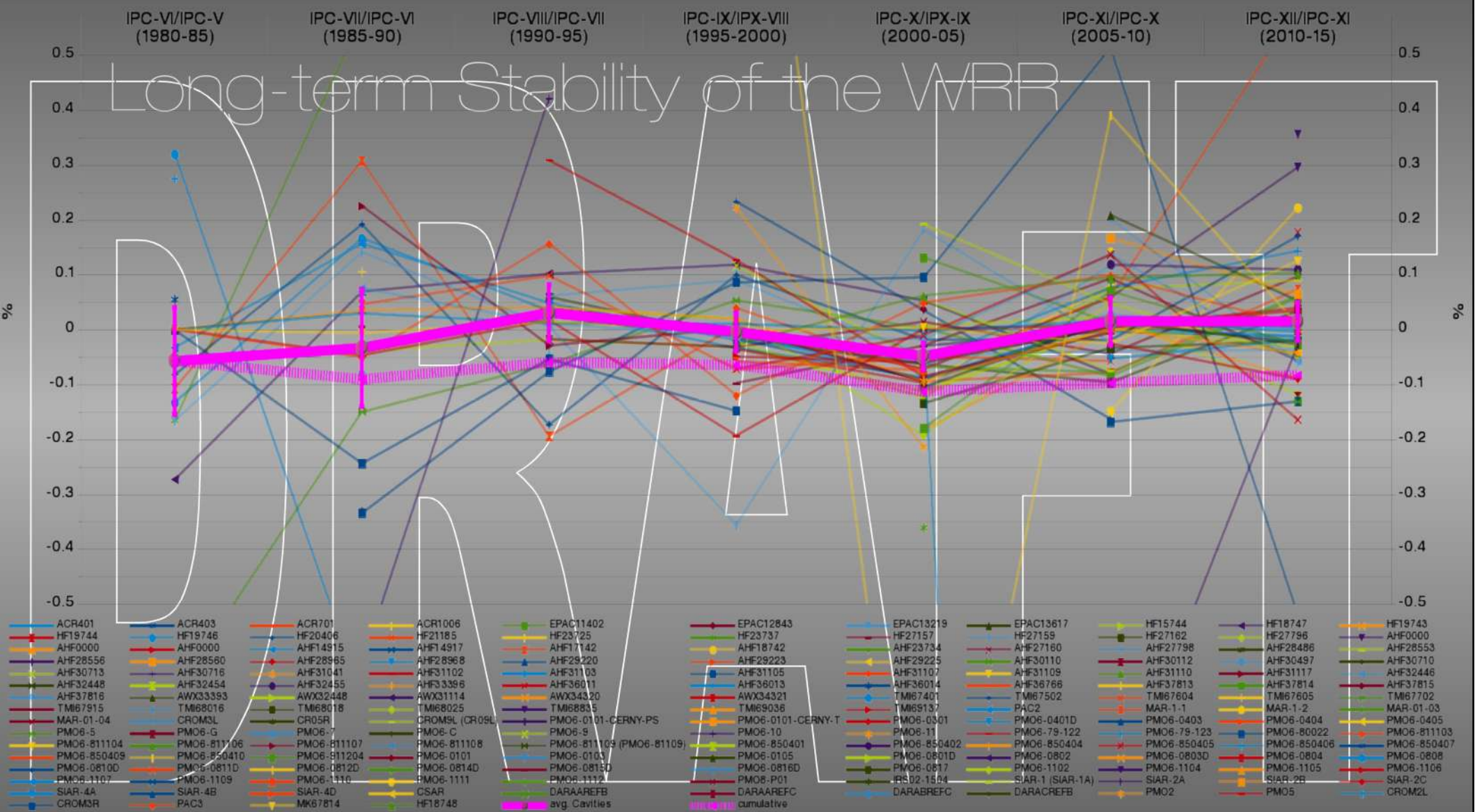
2015: The 12th International Pyrheliometer Comparison



IPC-XII: 28. September - 16. October 2015

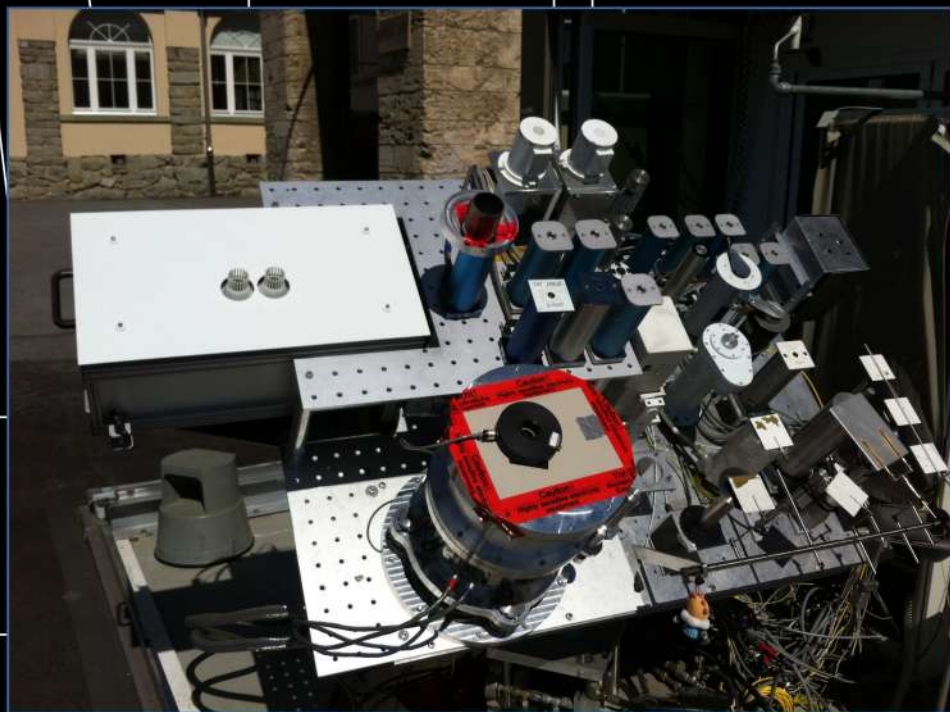
WRR-to-SI Traceability

- All solar irradiance related CMCs refer to the WRR
 - WRR is the end point of the traceability chain for solar irradiance
- Several comparisons between the WRR and SI scale for radiant power have found that both scales agree to within $\pm 0.3\%$ (Metrologia 28, 1991; Metrologia 32, 1995; Metrologia 45, 2008)
- Total solar irradiance (TSI) radiometers in space with primary calibration (native scale) hinted at a potential WRR-to-SI scale difference (Solar Physics 230, 2005)
- A significant scale difference ($0.34 \pm 0.18\%$) was confirmed on the ground using new and dedicated experiments and laboratory facilities (Metrologia 49, 2012)
- At the same time, efforts have started to establish traceability of the WRR to SI base units
 - Cryogenic Solar Absolute Radiometer (CSAR)



The Cryogenic Solar Absolute Radiometer (CSAR)

- PMOD/WRC in collaboration with METAS (Switzerland) and NPL (UK) have designed and built the CSAR
- Monitor for Integrated Transmittance (MITRA) with unprecedented accuracy (150 ppm)
- **Primary calibrations** of all components (**native scale**)



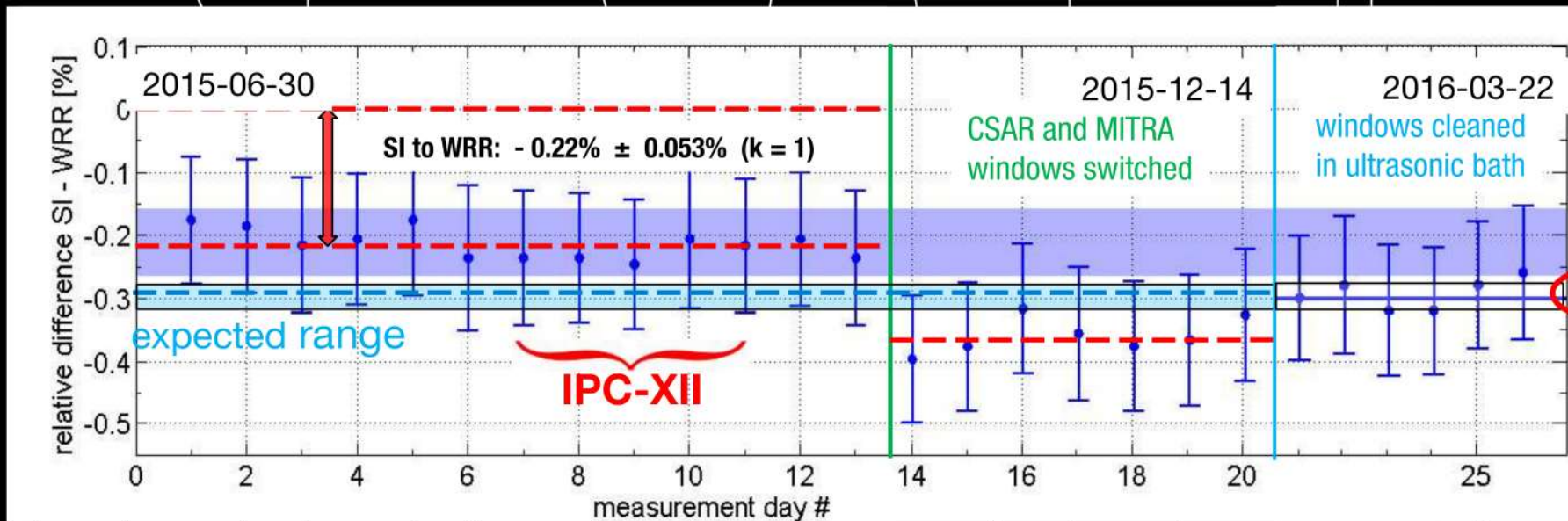
METAS

NPL

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CSAR-to-WRR Scale Comparison

(work in progress)

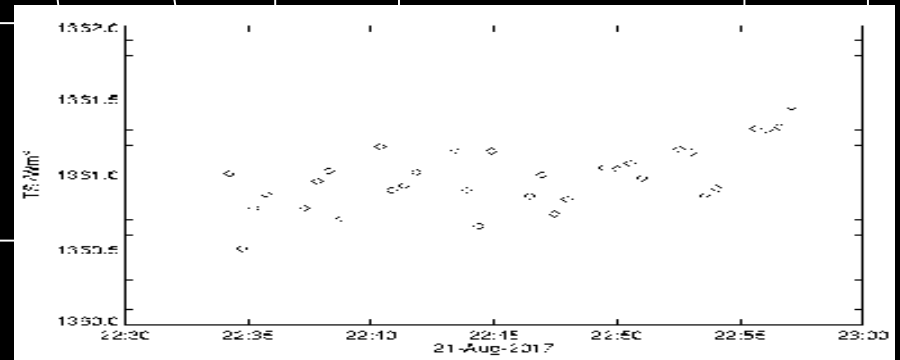
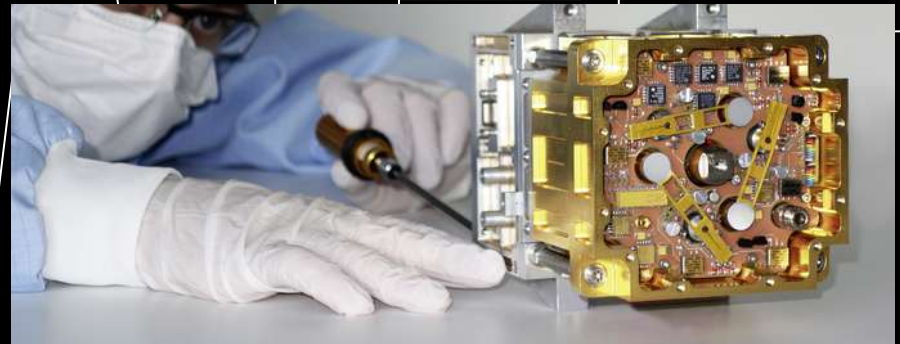


Item	Uncertainty ($k = 1$)
MITRA	0.036%
Window contamination	0.035%
CSAR	0.014%
Repeatability (Statistical)	0.021%
WRR	0.030%
Overall SI-WRR intercomparison	0.064%

CSAR: 0.052%
(Goal: 0.01%)

Latest Confirmation of WRRR-to-SI

- The Compact and Lightweight Absolute Radiometer (CLARA) was launched on 14 July 2017
 - Calibrated against NIST-traceable cryogenic radiometer (SI Lab Scale)
- First light on 21 August
 - 1360.9 Wm^{-2} , i.e. $\sim 0.3\%$ lower than the WRR-traceable VIRGO



Conclusions

- Solar irradiance has been measured since more than 100 years for meteo, climate, and research purposes
- Attempts to harmonize and homogenize the solar radiation measurements have led to a number of radiation standards and irradiance scales, either conventional or traceable to SI
- Since 1977 the World Radiometric Reference (WRR) serves as a conventional standard for solar irradiance measurements world-wide
- In 2012 the WRR was found to deviate from SI by $\sim 0.3\%$
- Work is in progress to close the traceability gap between the WRR and SI by use of cryogenic technology