Physikalisch-Meteorologisches Observatorium Davos
World Radiation Center

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Photometry Metrology for Earth Observation

Measuring absolute Total Solar Irradiance

PMOD/WRC is member of CCPR
and designated institute
by METAS (CH) and WMO

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Director PMOD/WRC

Consultative Committee for Photometry and Radiometry
23rd meeting, BIPM, Paris 22./23. October 2016

Overview

Measuring absolute Total Solar Irradiance

- Motivation
- The problem(s)
- Present status of absolute TSI instrument calibrations and stability of TSI record
- Future of PMOD/WRC TSI space experiments

Sun – climate correlation

The Sunspot minimum 1600-1700, the Maunder minimum,

coincides with a climate minimum, the so called little ice age

In 1658 king Karl X Gustav of Sweden marched his army over the ice of the belts to defeat Denmark

Reconstructions of solar irradiance

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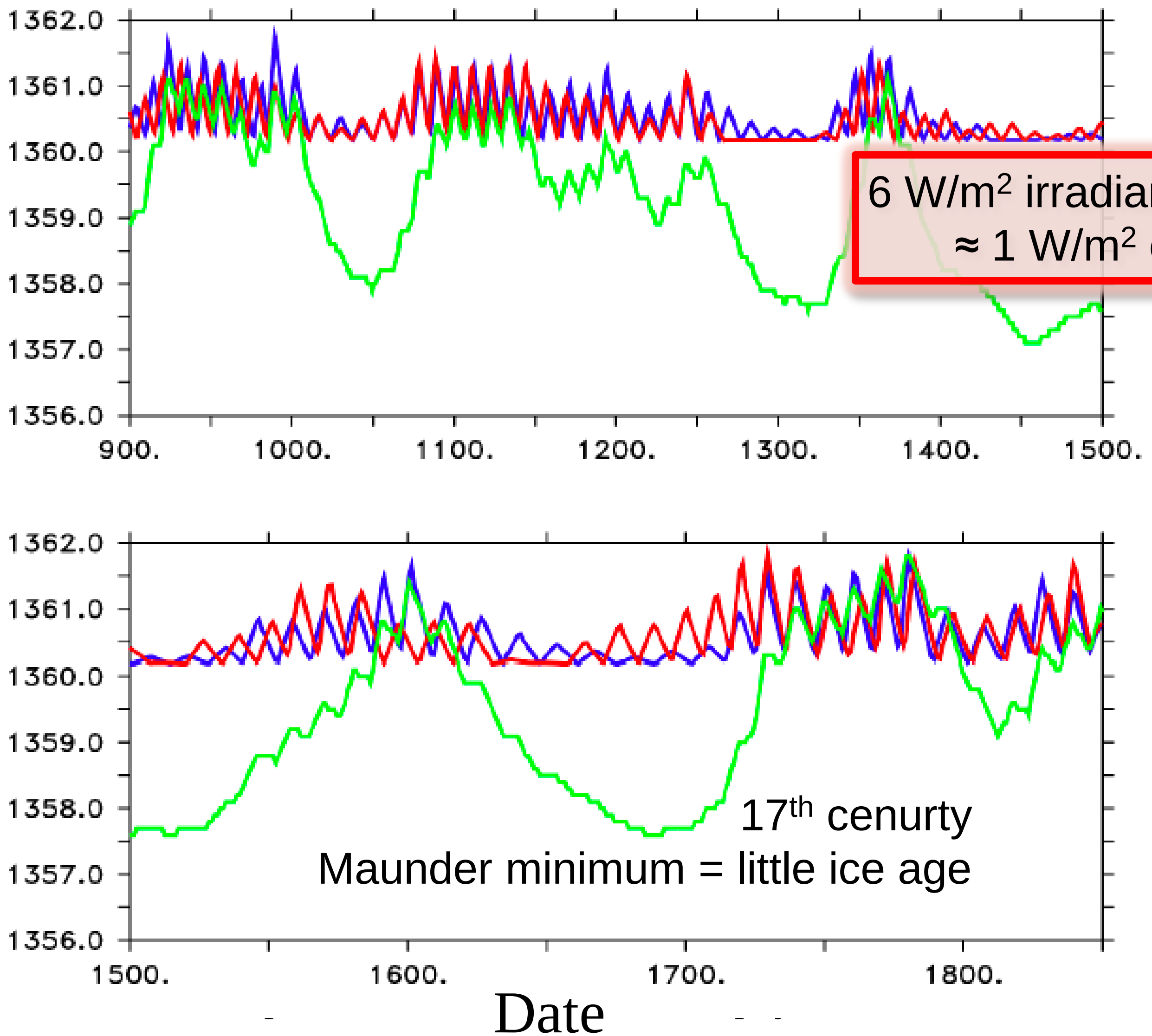

From PMIP4 irradiance forcing data (Jungclaus et al. 2016, in preparation)

What do we know?

There are Total Solar Irradiance in space observation since 1979 ….

→ What are the amplitudes of TSI variations over centennial time scales?

Is there an observed TSI-trend?

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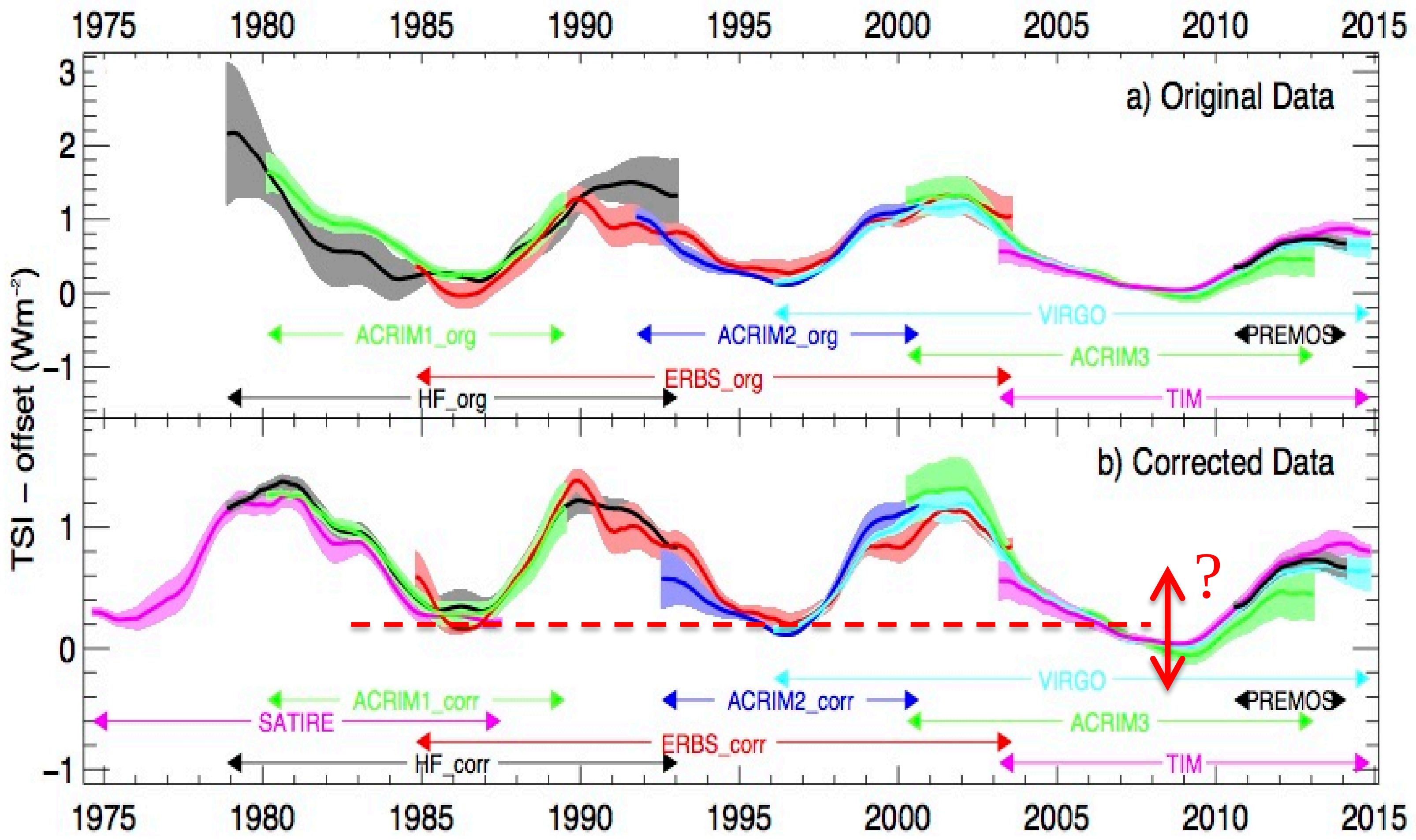

from Fröhlich (2016, PMOD/WRC website)

Long term TSI trend

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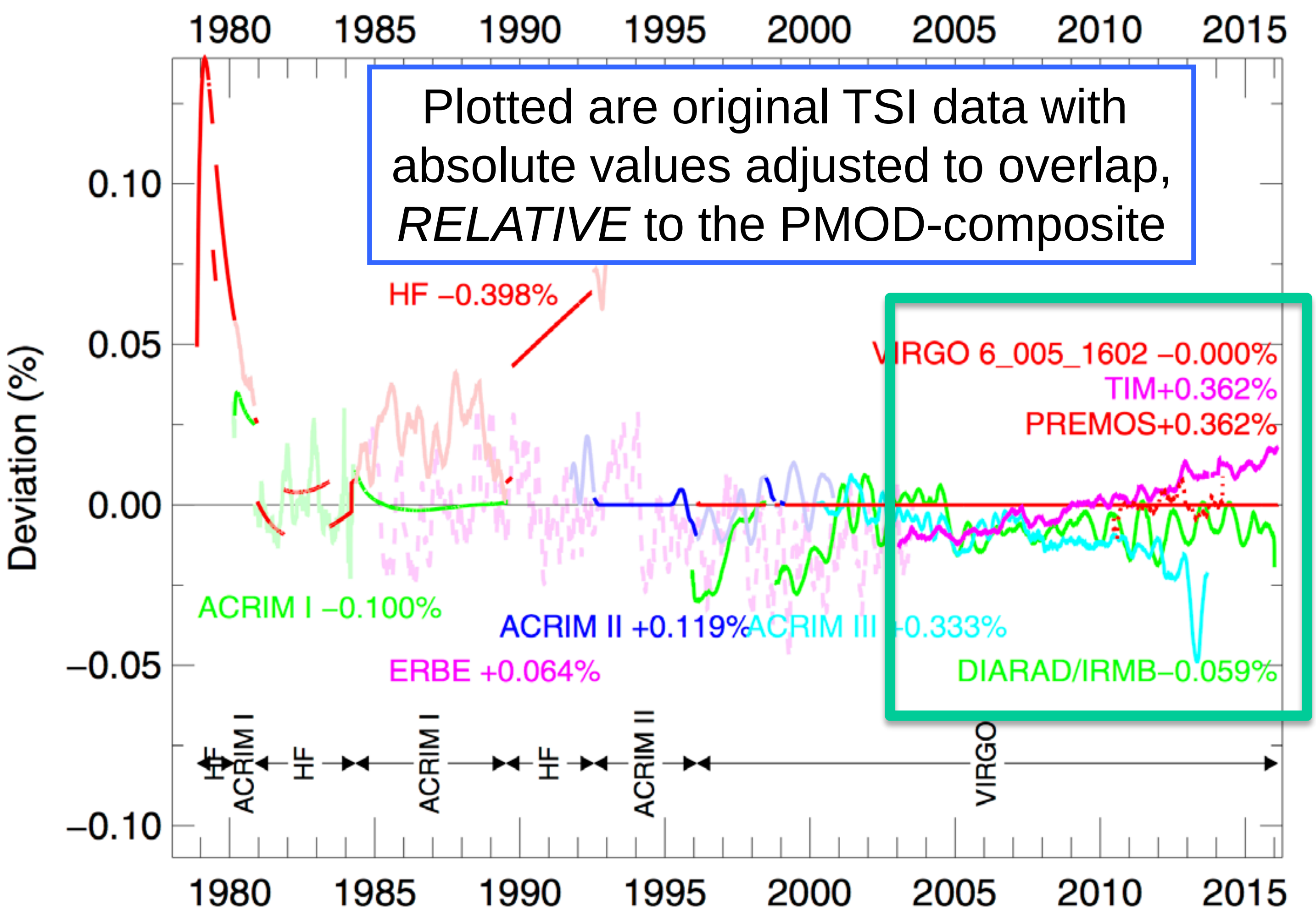
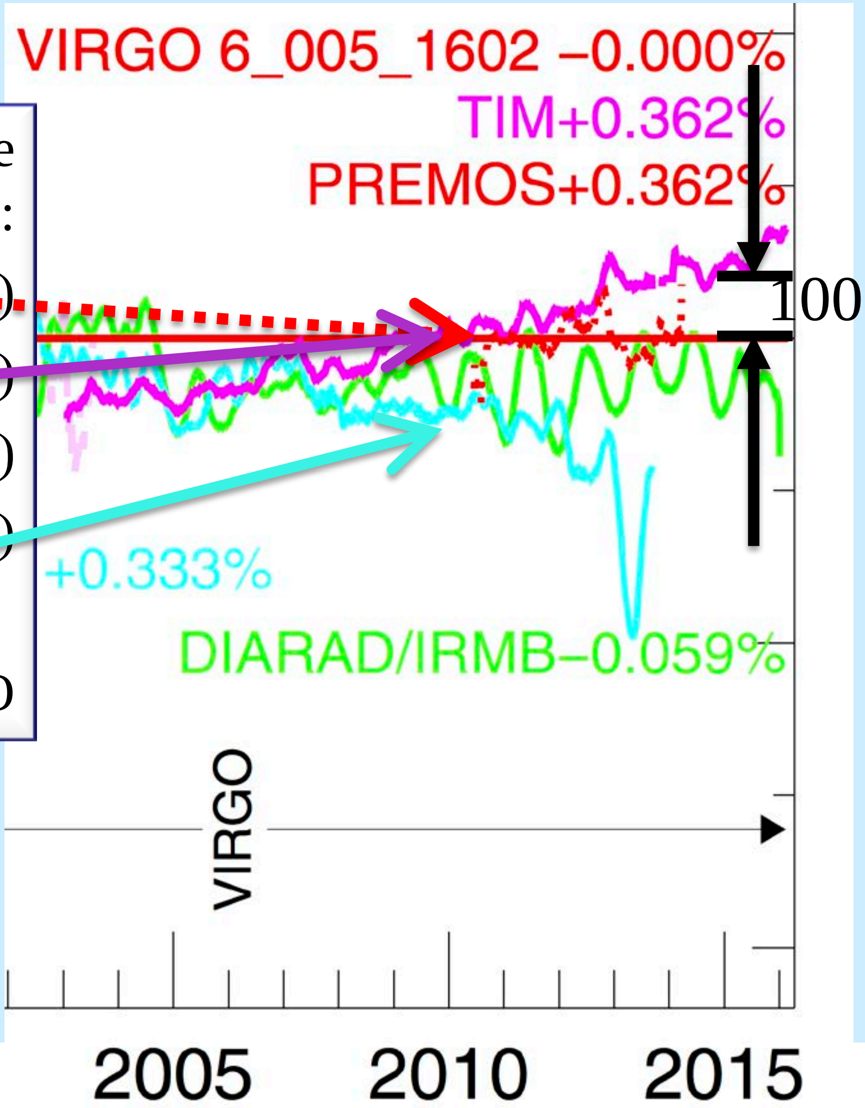


Diverging TSI trends

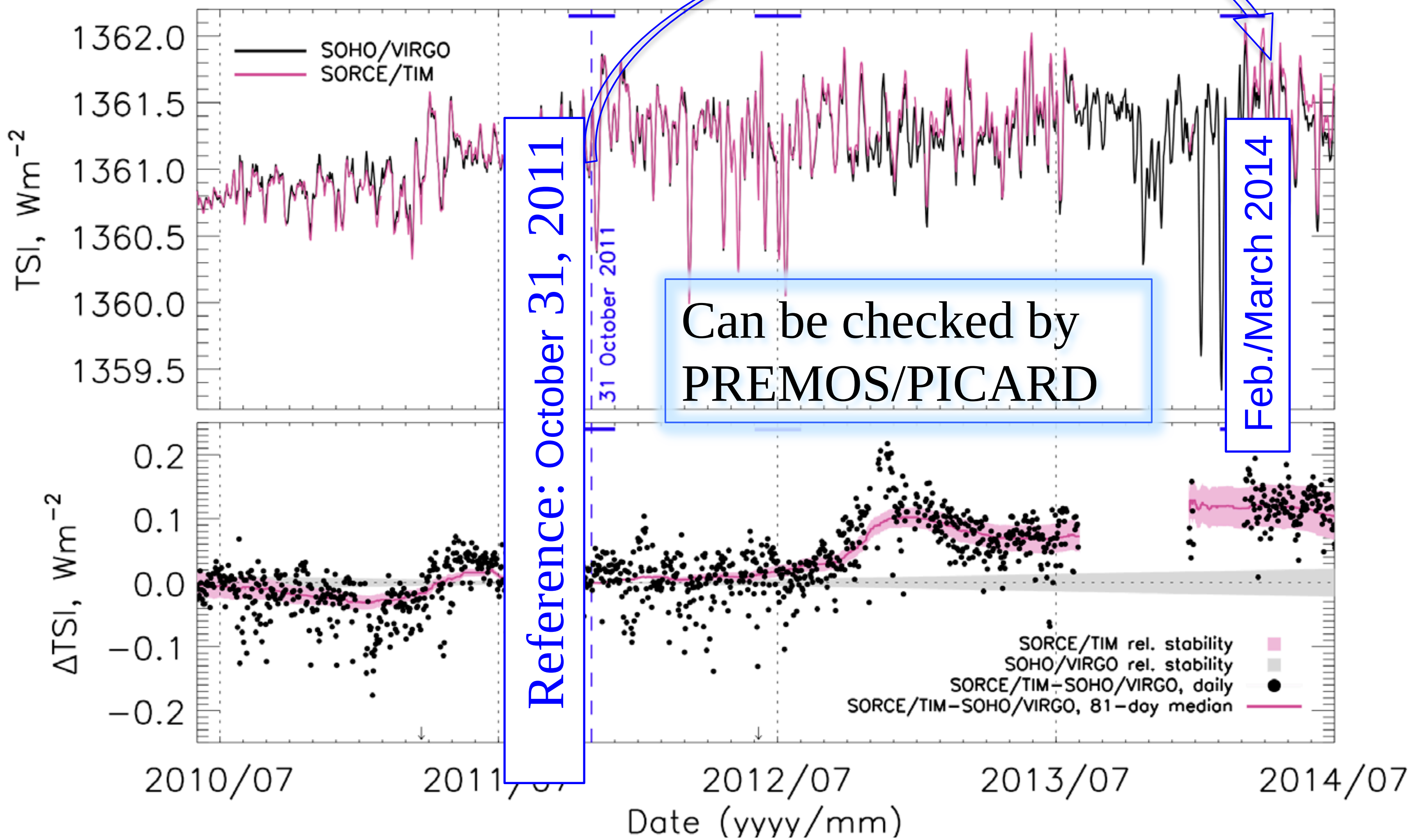
In 2010 there were
4 TSI space experiments:

- PREMOS (2010-2014)
- TIM (launched 2003)
- VIRGO (launched 1995)
- ACRIM III (2000-2013)

… relative to VIRGO/SOHO



TIM/SORCE vs VIRGO/SOHO



PREMOS/PICARD vs TIM and VIRGO

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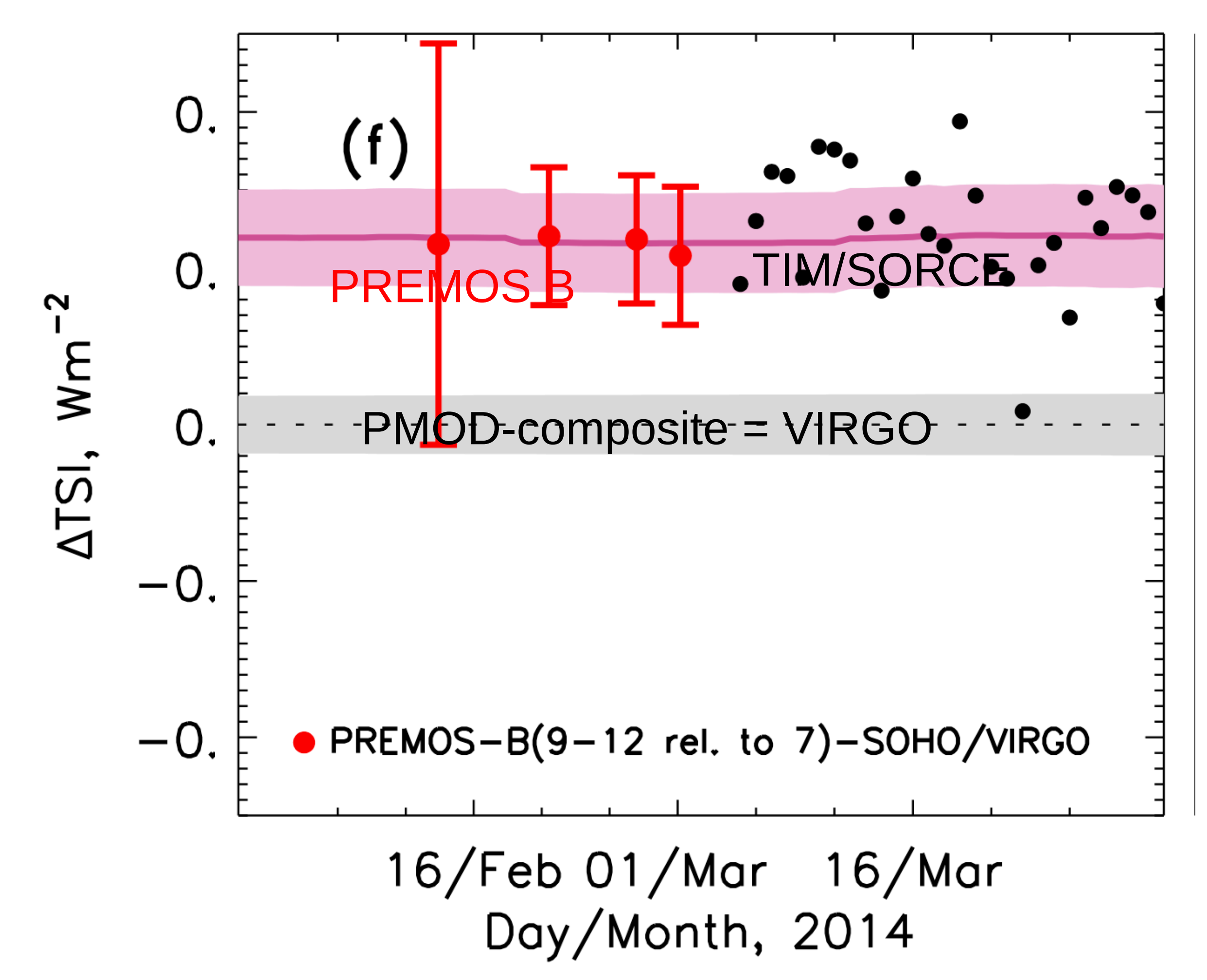

Ball et al. (JSWSC 2016, in press)

Ball et al. 2016 conclude

PREMOS $\mathcal{B}$ sensitivity correction has an uncertainty

October 2011 to February 2014 ratio: +-0.02 Wm^{-2} (over 2.3 yr)

→ 6 ppm per year

PREMOS $\mathcal{B}$ agrees with TIM

(October 2011 to March 2014)

→ TIM stability confirmed to ≤ 6 ppm/yr

PREMOS $\mathcal{B}$ disagrees with PMOD composite

Difference: 0.12 Wm^{-2} or 90 ppm after 2.3 years

→ PMOD-composite stability not better than ≥ 38 ppm/yr

(not known: systematic or random ?)

Extrapolate → TSI-composite

cycle-cycle minima uncertainty:

11 x 38 ppm = 418 ppm → 0.6 Wm^{-2} *!*

Extrapolating the disagreement

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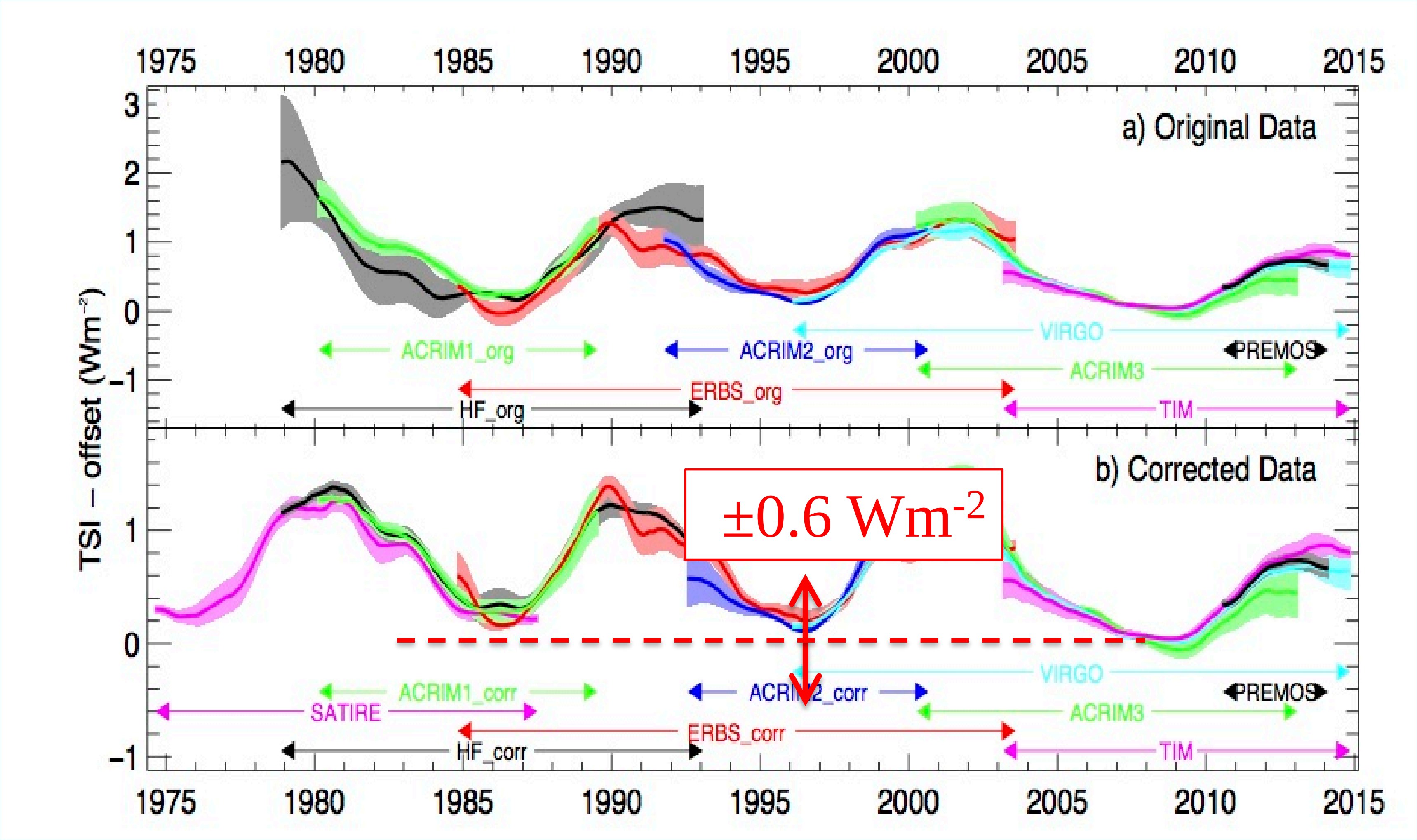
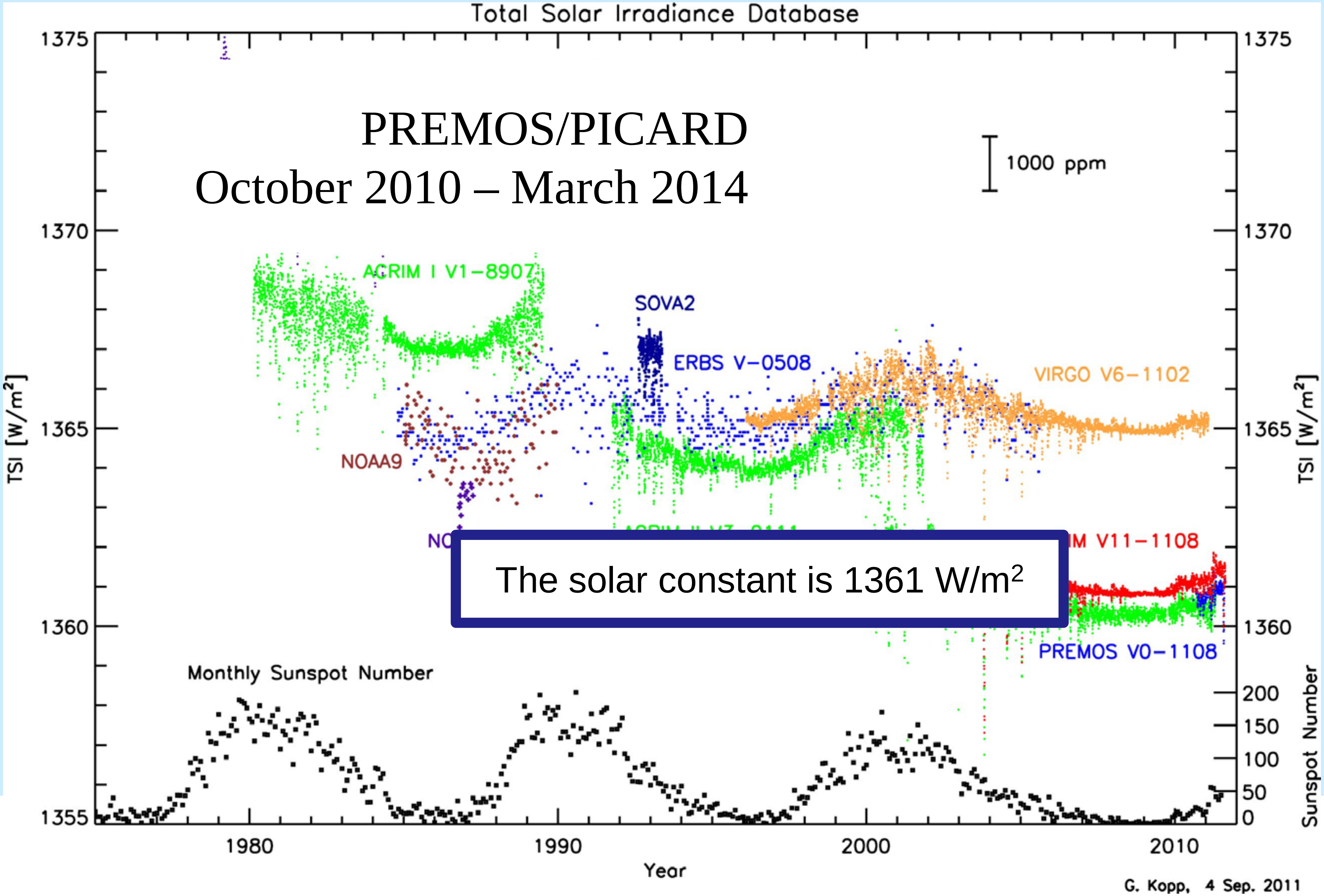


shown at last the last CCPR 2014 …



Absolute calibration of TSI

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- PREMOS is the first SI-traceable calibrated radiometer in space

First Light on 27. July 2010

PREMOS (TRF-calibrated*)	**1360.9 +- 0.4 W/m²**
TIM/SORCE (characterized)	1361.3 W/m²

Absolute end-to-end calibrations of space experiments for irradiance levels of >1000 W/m^2 are all made at one facility, the TSI Radiometer Facility (TRF) at LASP in Boulder, USA, which is traceable to the NIST cryogenic radiometer.

TIM/SORCE, PREMOS/PICARD, and TCTE (launch 2013) are consistent

** Schmutz et al. 2013, AIP 1531, 624, doi: 10.1063/1.4804847*

TRF- facility calibration facility Boulder CO, USA

IAU resolution 2015

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IAU = International Astronomical Union

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NOMINAL VALUES FOR SELECTED SOLAR AND PLANETARY QUANTITIES: IAU 2015 RESOLUTION B3[*,†]

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Table 1
Nominal Solar and Planetary Conversion Constants Set Forth by IAU 2015 Resolution B3

Solar Conversion Constants	Planetary Conversion Constants
$1\mathcal{R}_\odot^{\rm N} = 6.957 \times 10^8$ m	$1\mathcal{R}_{\rm Ee}^{\rm N} = 6.3781 \times 10^6$ m
$1\mathcal{S}_\odot^{\rm N} = 1361$ W m^{-2}	$1\mathcal{R}_{\rm Ep}^{\rm N} = 6.3568 \times 10^6$ m
$1\mathcal{L}_\odot^{\rm N} = 3.828 \times 10^{26}$ W	$1\mathcal{R}_{\rm Je}^{\rm N} = 7.1492 \times 10^7$ m
$1\mathcal{T}_\odot^{\rm N} = 5772$ K	$1\mathcal{R}_{\rm Jp}^{\rm N} = 6.6854 \times 10^7$ m
$1(\mathcal{GM})_\odot^{\rm N} = 1.3271244 \times 10^{20}$ m^3 s^{-2}	$1(\mathcal{GM})_{\rm E}^{\rm N} = 3.986004 \times 10^{14}$ m^3 s^{-2}
	$1(\mathcal{GM})_{\rm J}^{\rm N} = 1.2668653 \times 10^{17}$ m^3 s^{-2}

Note. Although chosen to be as close to the measured quantities as feasible, given the observational uncertainties for practical reasons, these values should *not* be considered the true solar/planetary properties. They should be understood as conversion values only.

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Transition of TSI record 2014

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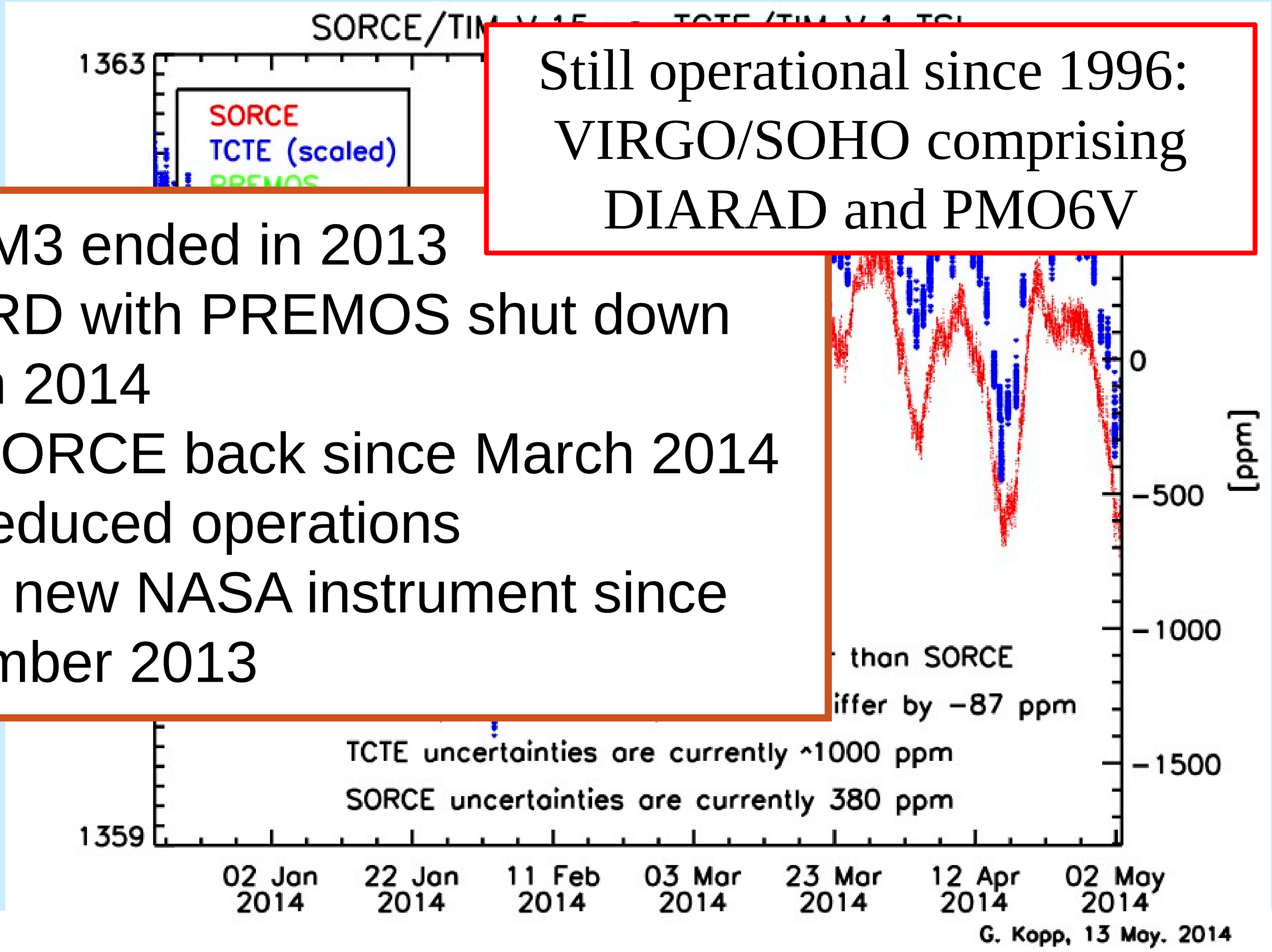
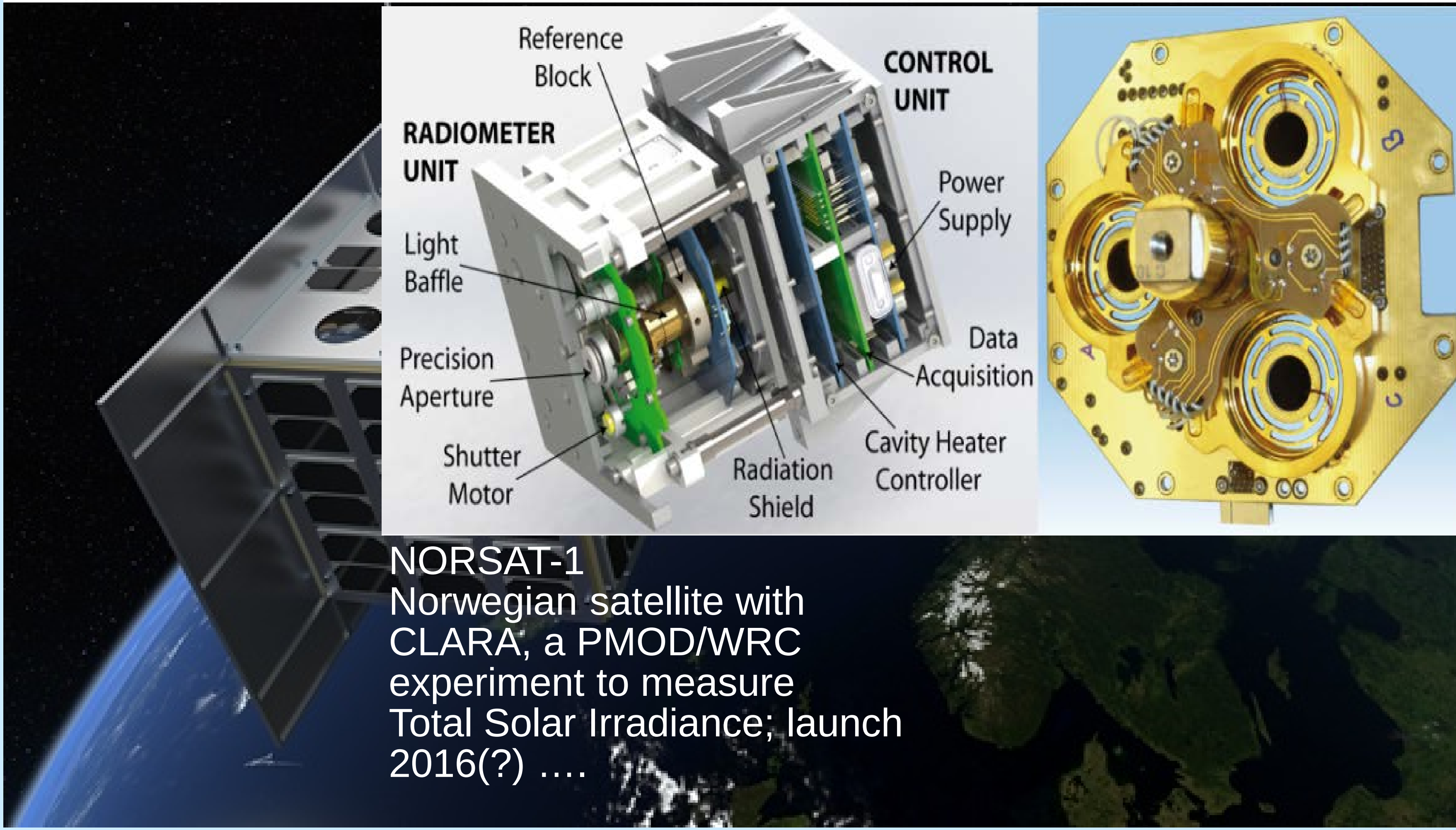


Still operational since 1996: VIRGO/SOHO comprising DIARAD and PMO6V

- ACRIM3 ended in 2013
- PICARD with PREMOS shut down March 2014
- TIM/SORCE back since March 2014 with reduced operations
- TCTE new NASA instrument since December 2013

Preliminary TCTE and SORCE results courtesy of Greg Kopp

The next TSI experiment: CLARA/NORSAT-1



NORSAT-1
Norwegian satellite with CLARA, a PMOD/WRC experiment to measure Total Solar Irradiance; launch 2016(?) ….

CLARA calibration at TRF

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Scale	Characterization Item	TRF Ground (532 nm laser, vacuum) Channel A Value	Channel A σ [ppm]	Channel B Value	Channel B σ [ppm]	Channel C Value	Channel C σ [ppm]
Native Scale	Aperture area (1/ C_{apert}) [mm^2]	19.6299	28	19.6242	28	19.6235	28
	Aperture Temperature	-	31	-	31	-	31
	Absorptivity (C_{abs})	1.002060	354	1.002202	378	1.002051	352
	Pointing	-	-	-	-	-	-
	Diffraction (C_{diff})	1.000491	18	1.000491	18	1.000491	18
	Non-Equivalence (C_{ne})	1.000007	4	1.000007	4	1.000007	4
	Heater Voltage Measurement	-	3180	-	3180	-	3180
	Shunt Voltage Measurement	-	3180	-	3180	-	3180
	Shunt Resistance Measurement	-	80	-	80	-	80
	Lead heating (C_{lh})	1.000950	50	1.001084	50	1.001009	50
	Scattered Light (C_{scl})	0.999690	150	0.999690	150	0.999690	150
	Calibration Factor	**1.003200**	**4515**	**1.003477**	**4517**	**1.003251**	**4515**
Cryogenic Lab Scale	Repeatability	-	145	-	109	-	179
	TRF Comparison Factor	1.000650	285	1.000650	285	1.000650	285
	Calibration Factor	**1.003261**	**4526**	**1.002595**	**4527**	**1.004269**	**4527**

Scale	Characterization Item	Space (solar spectrum, vacuum) Channel A Value	Channel A σ [ppm]	Channel A σ $[ppm]^2$	Channel B Value	Channel B σ [ppm]	Channel B σ $[ppm]^2$	Channel C Value	Channel C σ [ppm]	Channel C σ $[ppm]^2$
Native Scale	Aperture area (1/ C_{apert}) [mm^2]	19.6299	28	-	19.6242	28	-	19.6235	28	-
	Aperture Temperature	-	31	31	-	31	31	-	31	31
	Absorptivity (C_{abs})	1.002192	375	21	1.002343	400	22	1.002183	372	20
	Pointing	-	30	30	-	30	30	-	30	30
	Diffraction (C_{diff})	1.000867	31	13	1.000867	31	13	1.000867	31	13
	Non-Equivalence (C_{ne})	1.000830	65	65	1.000830	65	65	1.000830	65	65
	Heater Voltage Measurement	-	3180	258	-	3180	258	-	3180	258
	Shunt Voltage Measurement	-	3180	258	-	3180	258	-	3180	258
	Shunt Resistance Measurement	-	80	80	-	80	80	-	80	80
	Lead heating (C_{lh})	1.000950	50	-	1.001084	50	-	1.001009	50	-
	Scattered Light (C_{scl})	0.999690	150	-	0.999690	150	-	0.999690	150	-
	Calibration Factor	**1.004536**	**4517**	-	**1.004822**	**4519**	-	**1.004586**	**4517**	-
Cryogenic Lab Scale	Repeatability	-	-	145	-	-	109	-	-	179
	TRF Comparison Factor	1.003261	-	285	1.002595	-	285	1.004269	-	285
	Calibration Factor	**1.001271**	-	**498**	**1.002221**	-	**489**	**1.000316**	-	**509**

Conclusions

➔ TSI-composite has a problem 2013/2014 at the transition from the
VIRGO-ACRIM-III-TIM-PREMOS to the
VIRGO-TIM-TCTE period

➔ New assessment of the relative calibration of PREMOS/PICARD supports the TSI record of TIM and disagrees with VIRGO (*Ball et al. 2016, JSWSC in press)*

➔ *The next TSI experiment will be CLARA/NORSAT-1*
TRF end-to-end calibrated!
launch end 2016/beginning 2017

Community support for TSI (and SSI) monitoring is still needed:
<u>It is important to get multiple and overlapping irradiance data !</u>

CALARA , to be flown
on the Norwegian
satellite NORSAT-1
launch 2016(?) ….

Thank you for
your attention !