Physikalisch-Meteorologisches Observatorium Davos
World Radiation Center

TOTAL SOLAR IRRADIANCE
PREMOS/PICARD and CLARA/NorSat-1

Werner Schmutz
with contributions by Gael Cessateur (PREMOS),
Benjamin Walter and Wolfgang Finsterle (CLARA)
and the PREMOS and CLAR teams

PMOD/WRC, Switzerland

Lake Arrowhead, CA, USA 20.3.2018-23.3.2018

Overview

- Introduction:

  Amplitude vs time scale of TSI variations and stability of long term trends
- New version PREMOS/PICARD data (27.7.2010-4.3.2014)
  - data version 1 (distributed version):
    linear correction of the sensitivity change
  - assessing the beginning to end-of-mission sensitivity change
    "ratios of ratios" (Ball et al. 2016, JSWSC 6, A32)
  - Data version 2:
    detector sensitivity change assessment by comparison to other space experiments
- What TSI accuracy do we need?
- News from CLARA/NorSat-1: 1st light 21.8.2017
- Conclusions

TSI varies on all time scales

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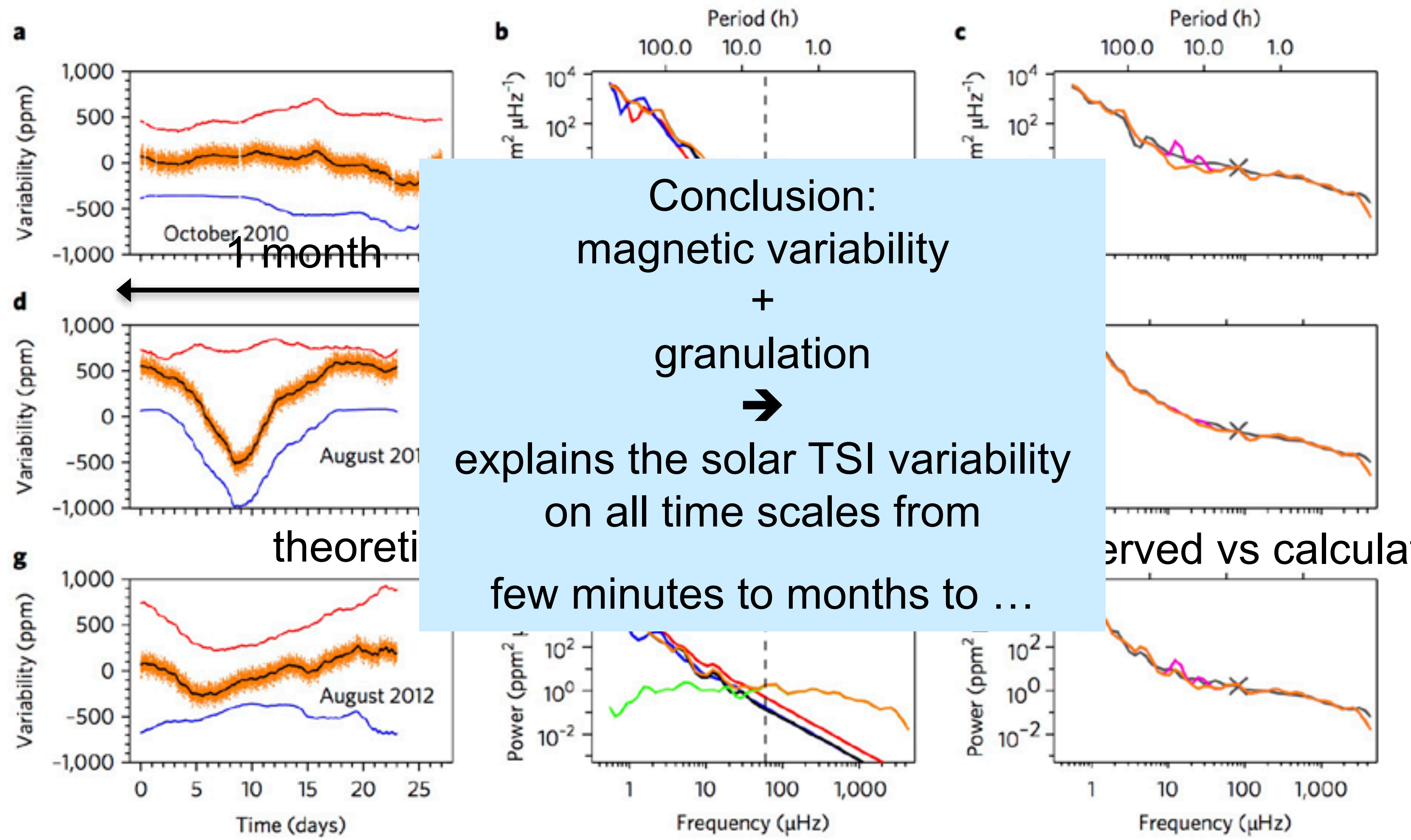


Conclusion:
magnetic variability
+
granulation
➔
explains the solar TSI variability
on all time scales from
few minutes to months to …

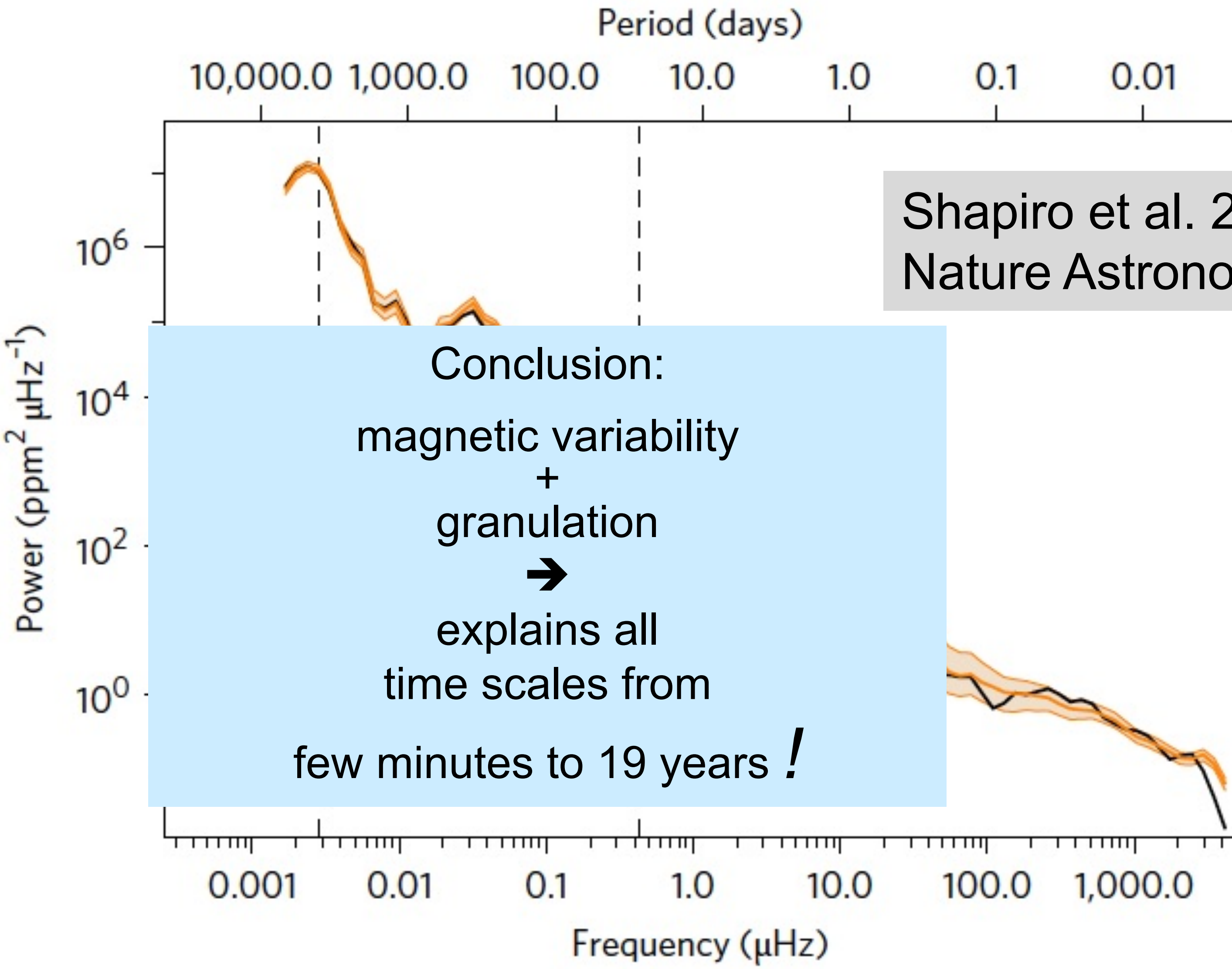
Fig. 1 | Short-term TSI variability at three intervals of very different activity level and variability of the Sun. a,d,g, Calculated TSI variations (orange), as well as calculated total magnetic (black), facular (red) and spot (blue) contributions to the TSI variation for the three 1-month intervals listed in Table 1. The plotted curves have been offset around zero for clarity. **b,e,h**, Global wavelet power spectra of the calculated TSI variations. In addition to the variability components shown in **a,d,g**, the granulation components (green) are plotted. Note that the green lines are not visible below 5 h (indicated by

Shapiro et al. 2017
Nature Astronomy 1, 612

Modelled solar variations

pmod wrc

Shapiro et al. 2017
Nature Astronomy 1, 612

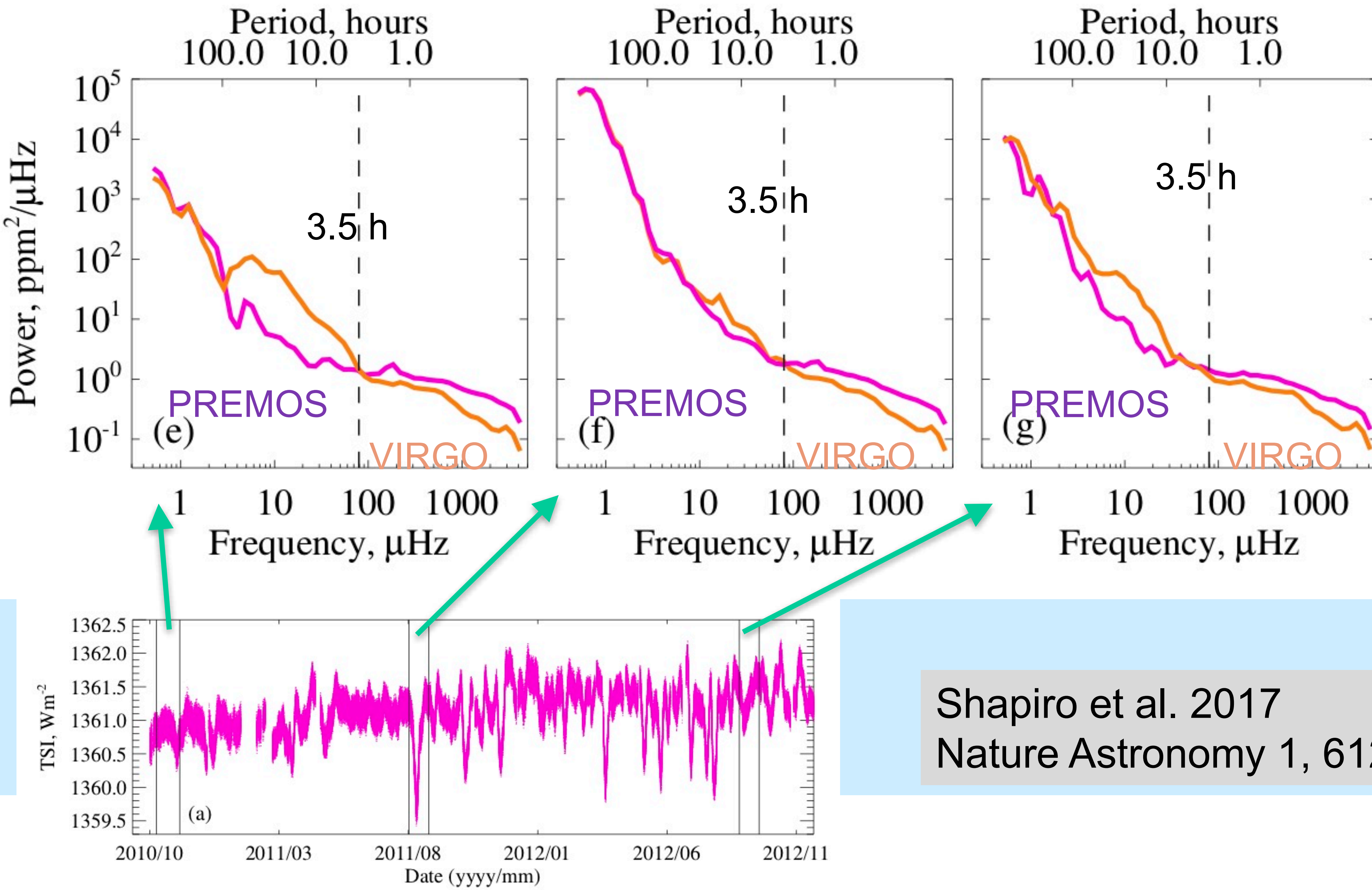


Conclusion:

magnetic variability
+
granulation
➔
explains all
time scales from
few minutes to 19 years !

Fig. 2 | TSI variability on timescales from 4 min to 19 years. Main panel, power spectra of modelled (black) and measured (orange) TSI variations.

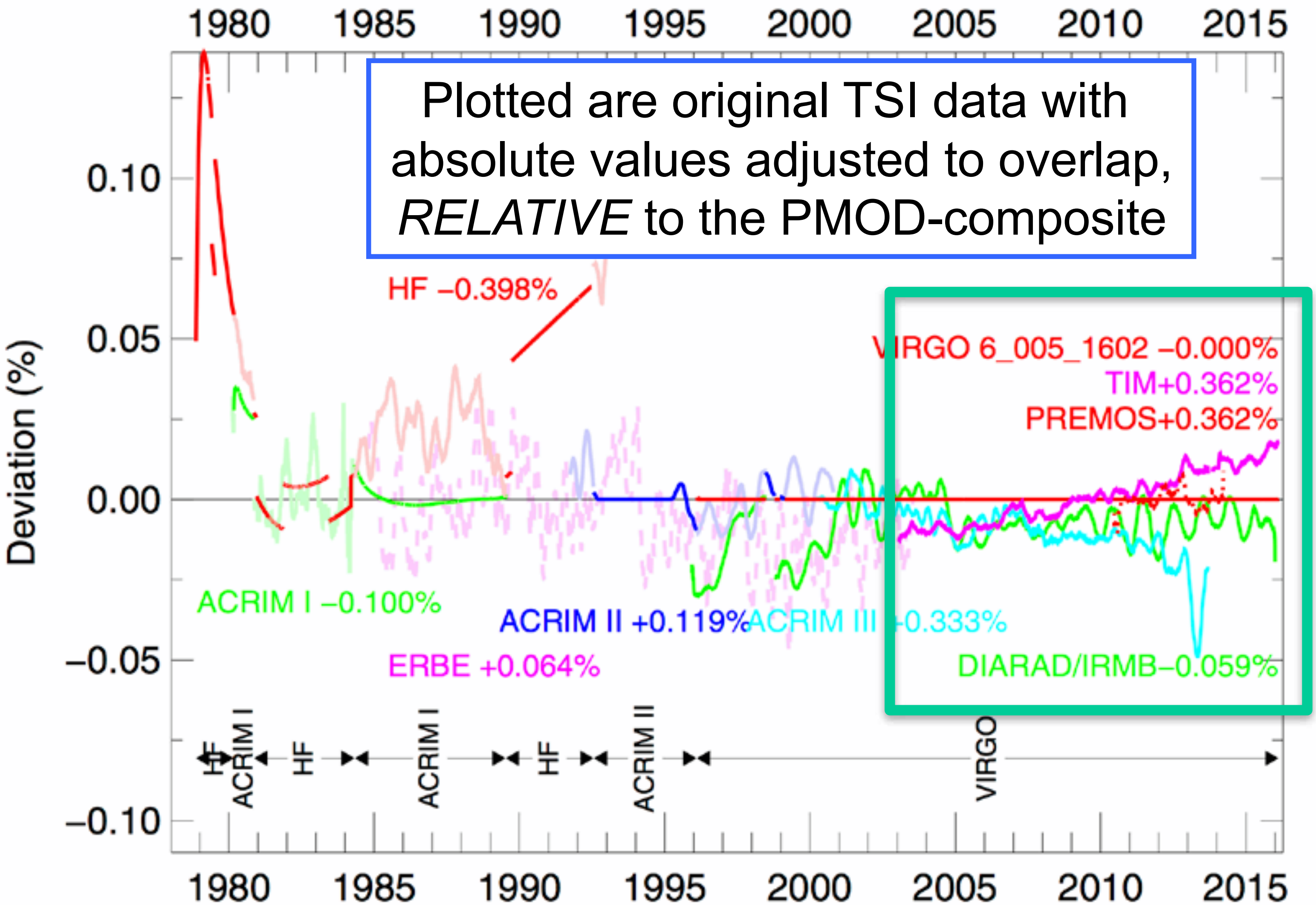
Different instruments have different strengths



Shapiro et al. 2017
Nature Astronomy 1, 612

Long term TSI trend

Fig. from Fröhlich, JSWSC 6, A18 (2016)

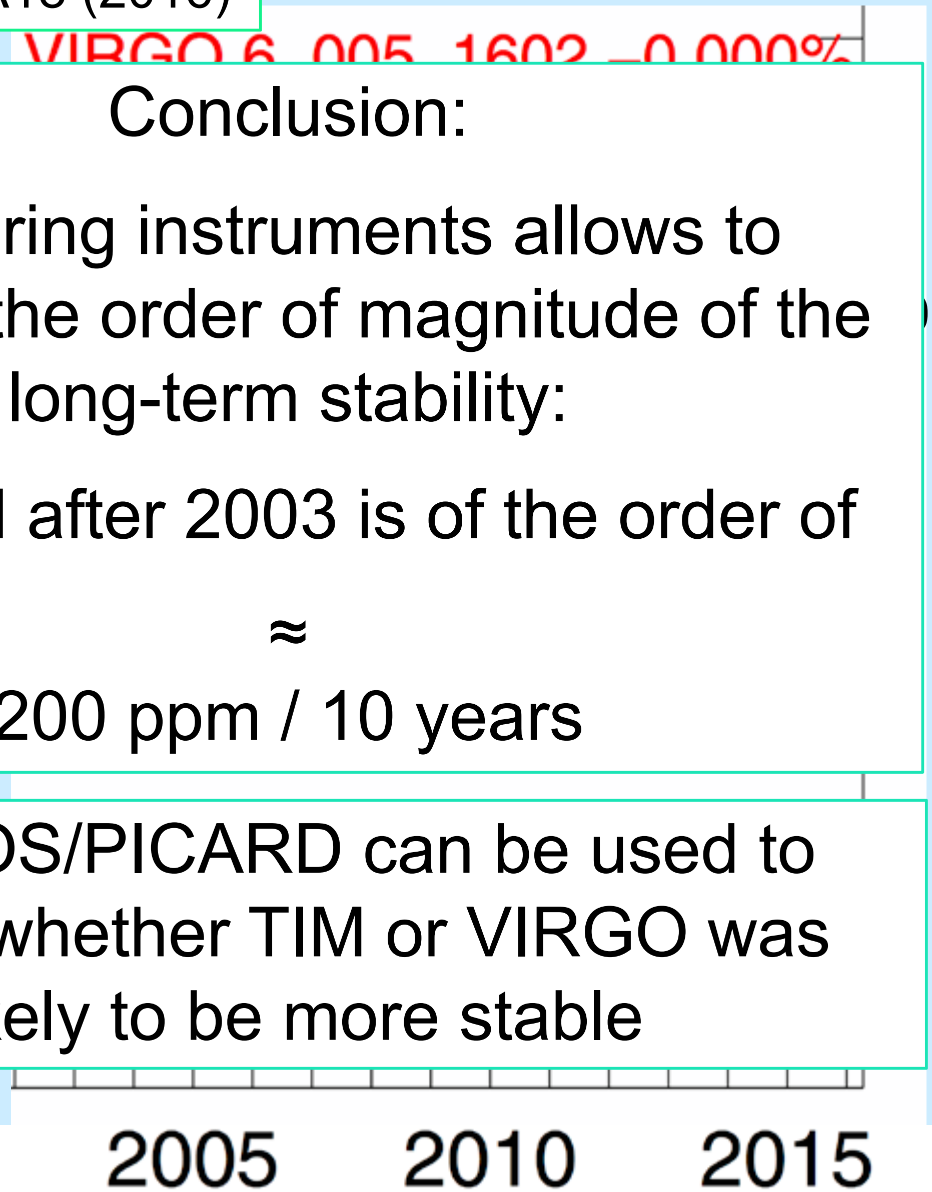


Diverging TSI trends

Fig. from Fröhlich, JSWSC 6, A18 (2016)

4 TSI space exp
- PREMOS data (2010-2014
- TIM (launched
- ACRIM III (20
- DIARAD/IRMB

… relative to VI (launched 1995



Conclusion:

comparing instruments allows to estimate the order of magnitude of the long-term stability:

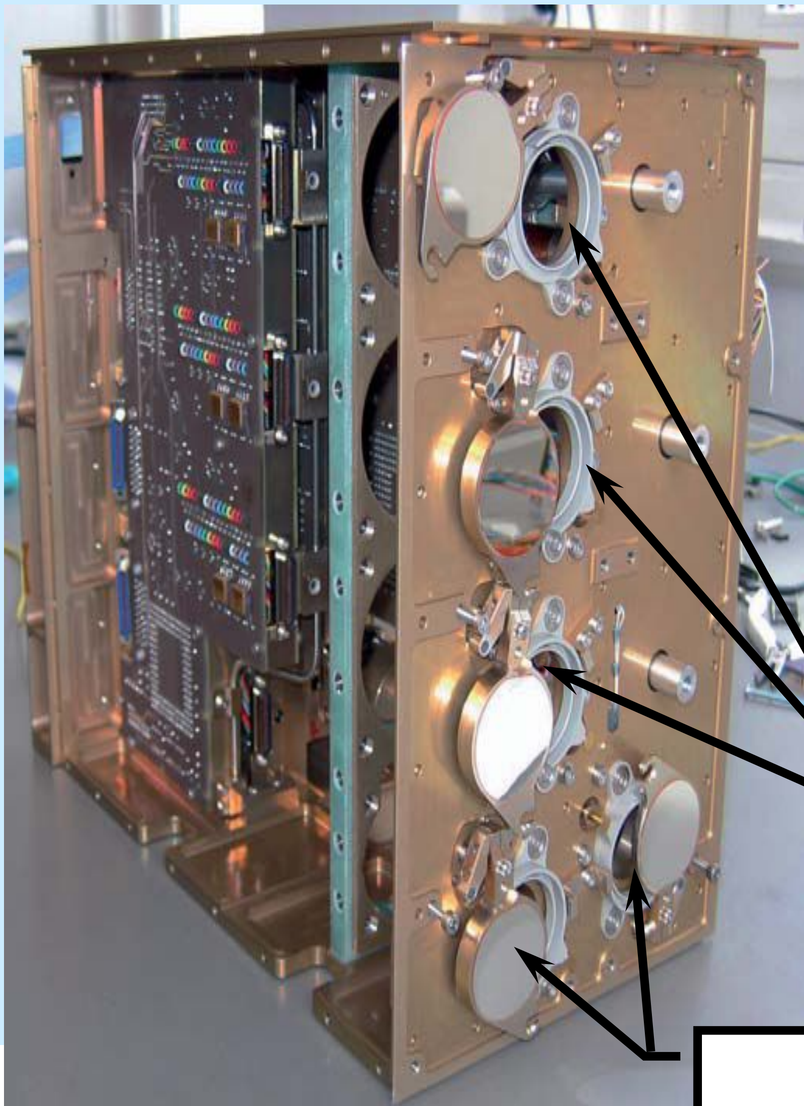
TSI-trend after 2003 is of the order of

≈

200 ppm / 10 years

PREMOS/PICARD can be used to assess whether TIM or VIRGO was likely to be more stable

PREMOS/PICARD (27.7.2010-4.3.2014)



PREMOS instruments:

Total Solar Irradiance

- 2 PMO6-type absolute radiometers

Spectral Solar Irradiance

- 12 filter radiometers @ 6 wavelengths

Absolute calibration

PREMOS is the first SI-traceable calibrated radiometer in space

First Light on 27. July 2010

PREMOS(TRF)/PICARD	**1360.9 +- 0.4 W/m²**
TIM/SORCE (V17)	1361.0 W/m²

→ TIM and PREMOS are consistent *!*

Schmutz et al. 2013, AIP 1531, 624, doi: 10.1063/1.4804847 (in 2013, TIM V13 was at 1361.3 W/m²)

Basics of sensitivity corrections of radiometers

Standard tool to correct for inflight degradation:

→ two or more radiometers (PREMOS has 2):

$\mathcal{A}$ – exposed operationally

$\mathcal{B}$ – exposed rarely for calibration only

Hypothesis*: $\mathcal{B}$ has the *same* sensitivity change as $\mathcal{A}$ *as a function of the exposure time

Until 3. February 2014: $\mathcal{A}$ total exposure: 600 days

$\mathcal{B}$ total exposure: 3.75 days

→ Sensitivity change is evaluated from the measured $\mathcal{A}$ to $\mathcal{B}$ ratio

Sensitivity change of $\mathcal{A}$ relative to $\mathcal{B}$

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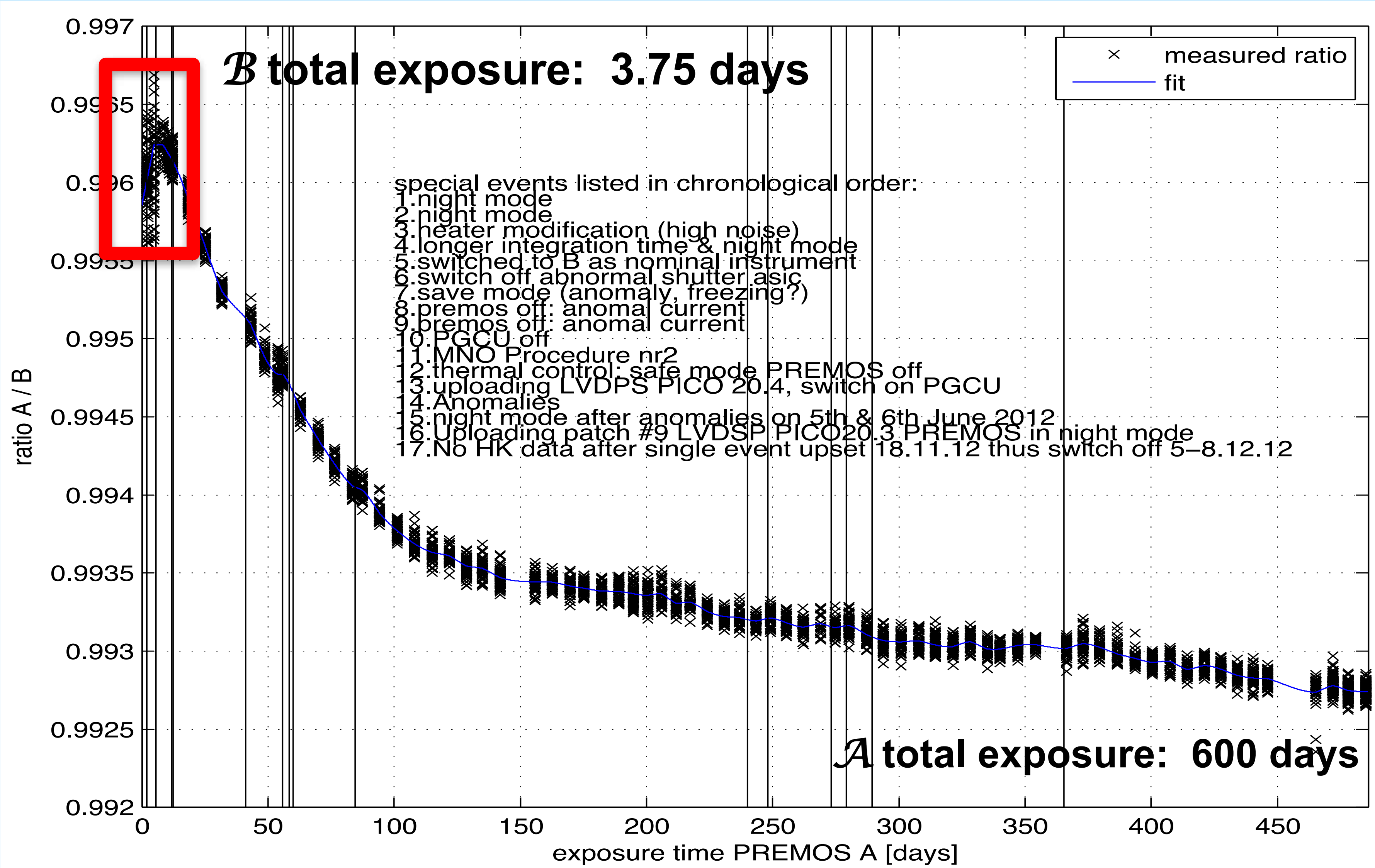
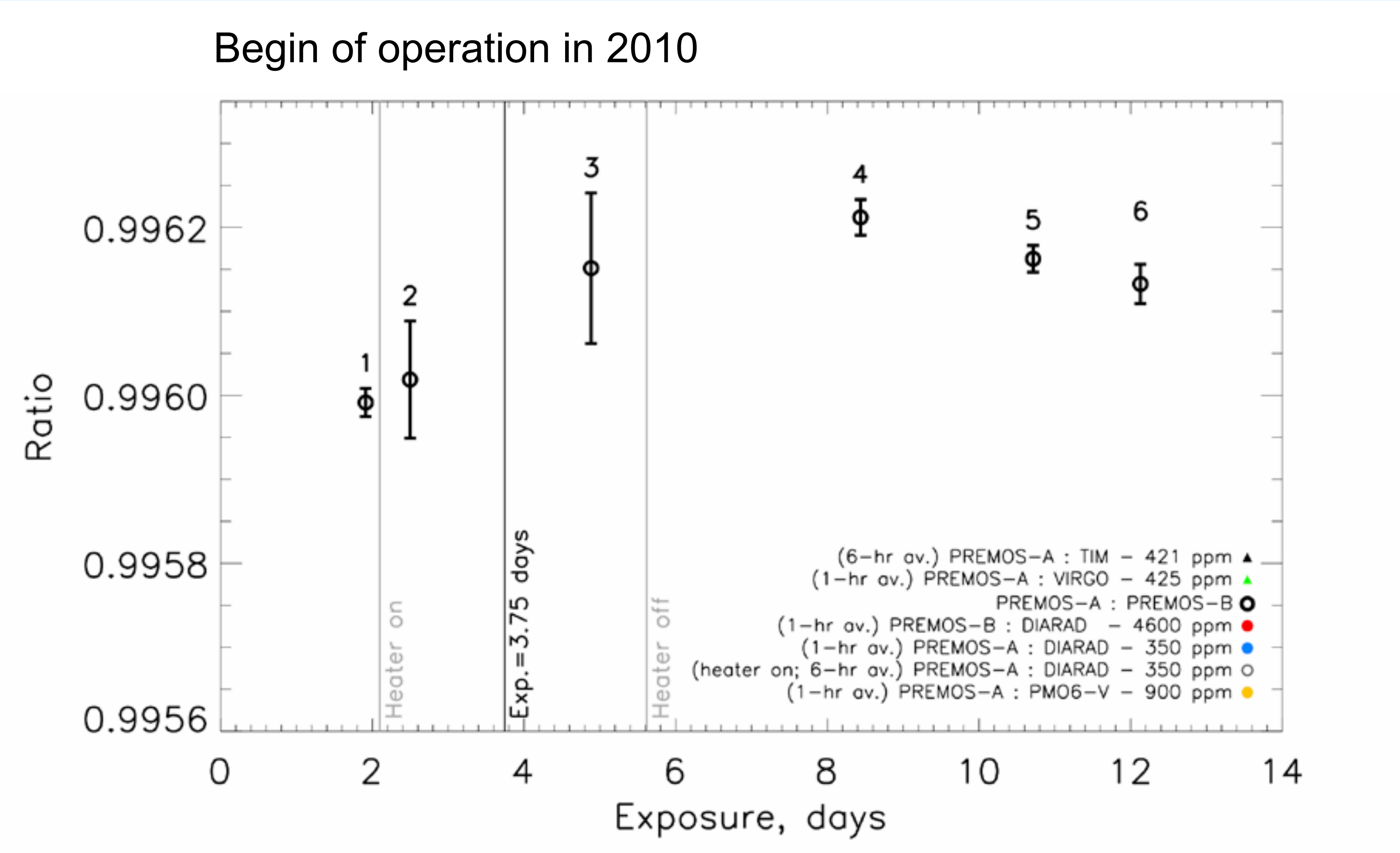


Ratios $\mathcal{A}$ to $\mathcal{B}$



Ratios $\mathcal{A}$ to $\mathcal{B}$ compared to $\mathcal{A}$ to DIARAD and $\mathcal{A}$ to PMO6-V

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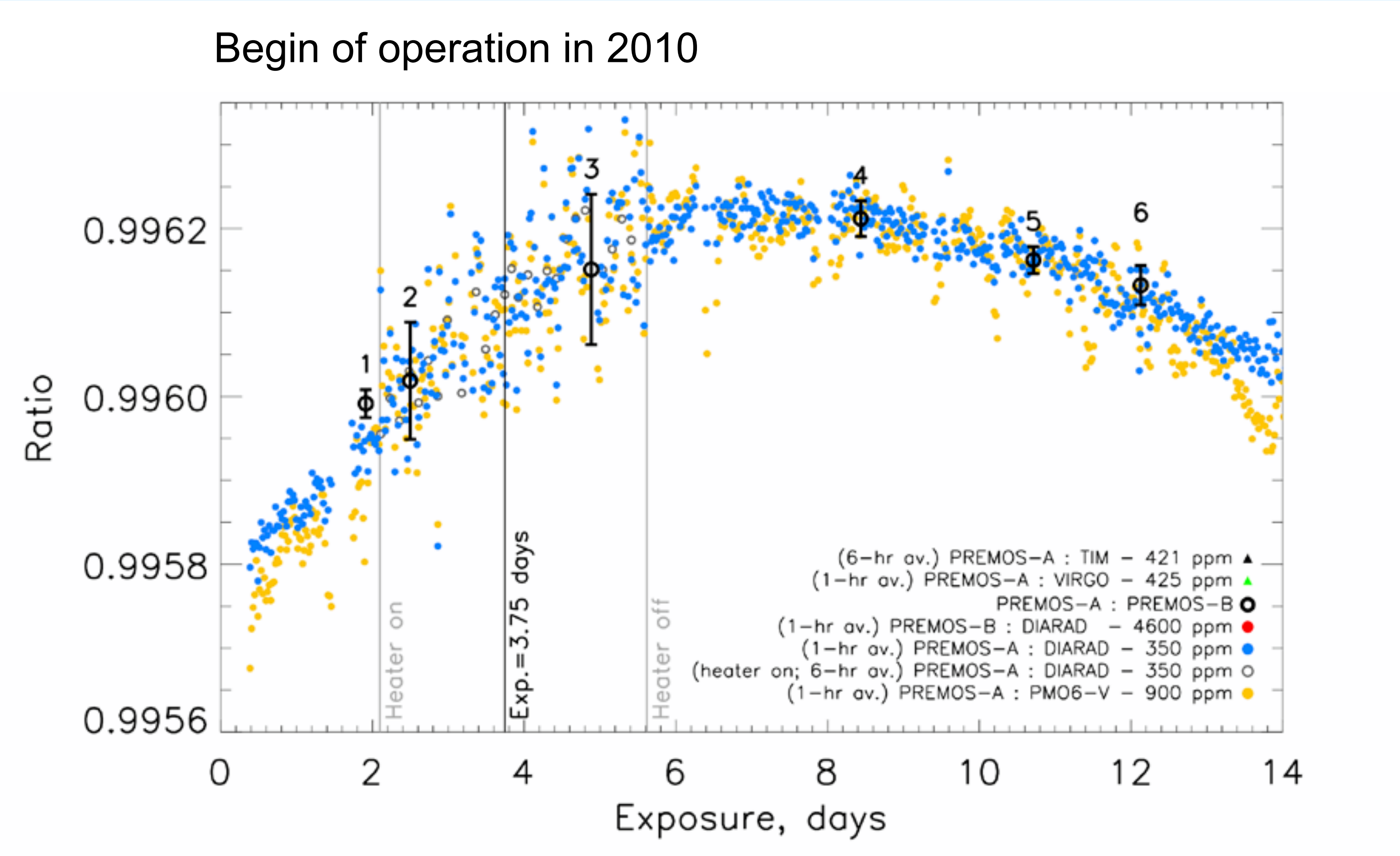


PREMOS data version 1

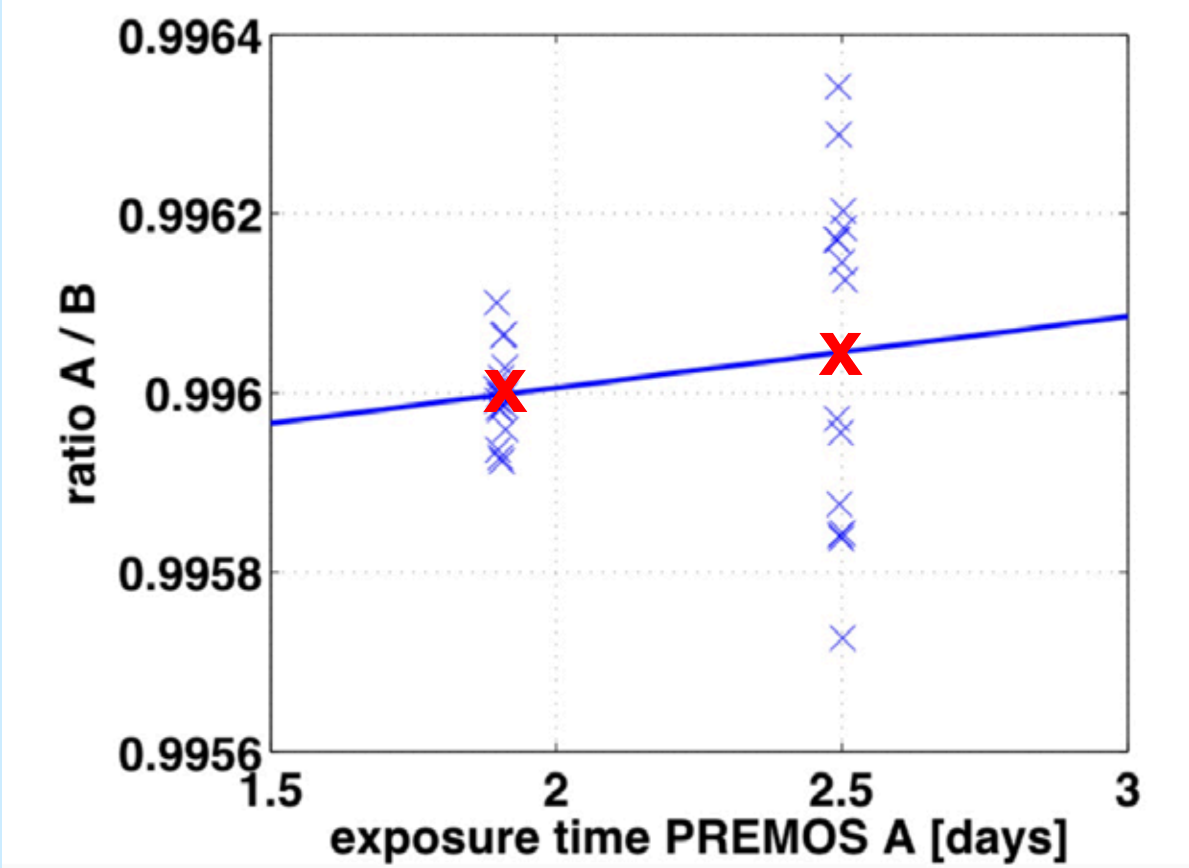
Correct sensitivity change of $\mathcal{B}$ with a linear increase:

Exposure time B until end of operation of A: 3.75 days

Exposure time B until end of operation: 13.5 days

Schmutz et al. 2013:

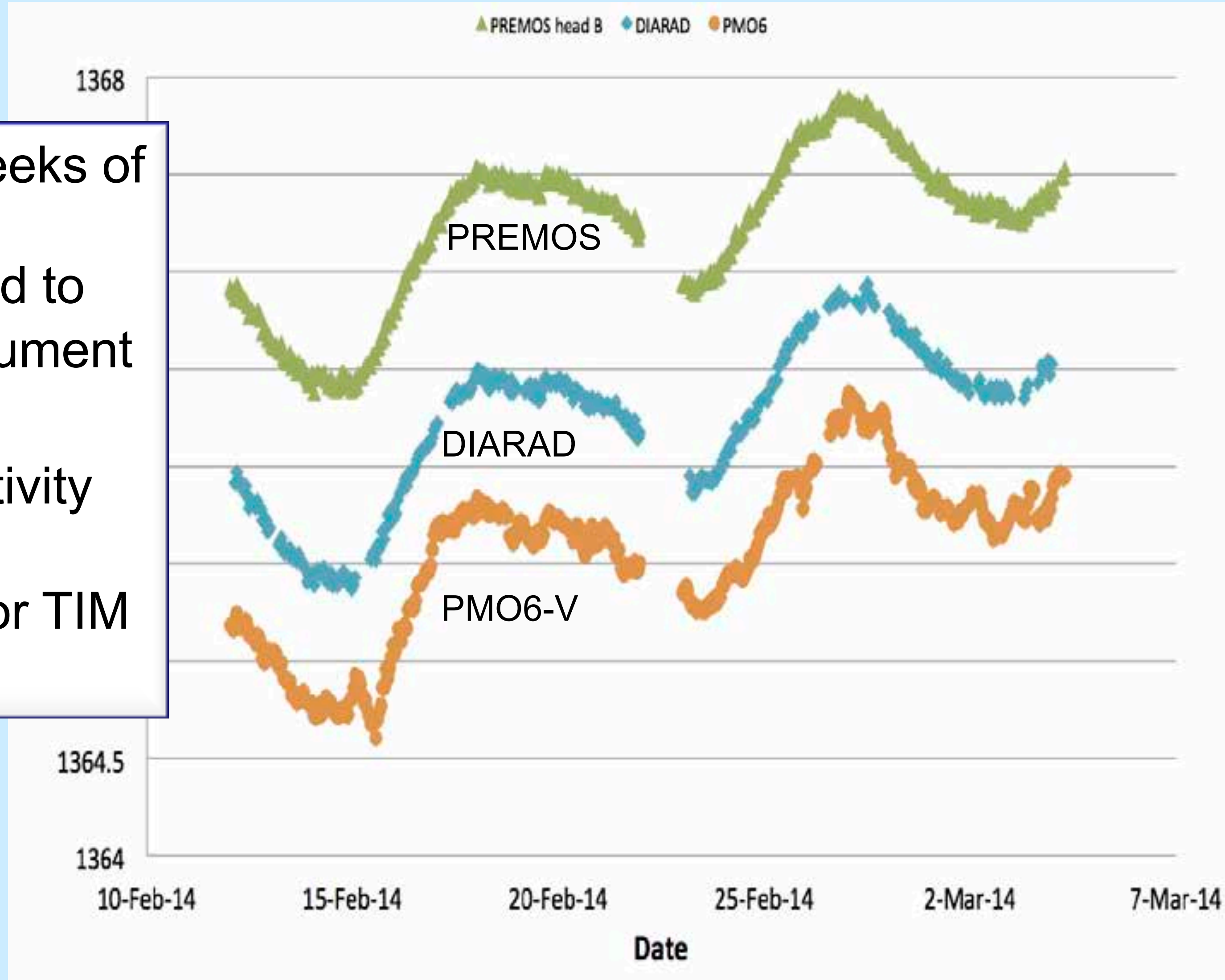
81.7 ppm per exposure day



PREMOS head $\mathcal{B}$
Feb-March 2014

During the last two weeks of PREMOS operation head $\mathcal{B}$ was switched to the operational instrument

→ evaluate $\mathcal{B}$ sensitivity change relative to DIARAD, PMO6-V, or TIM instruments …



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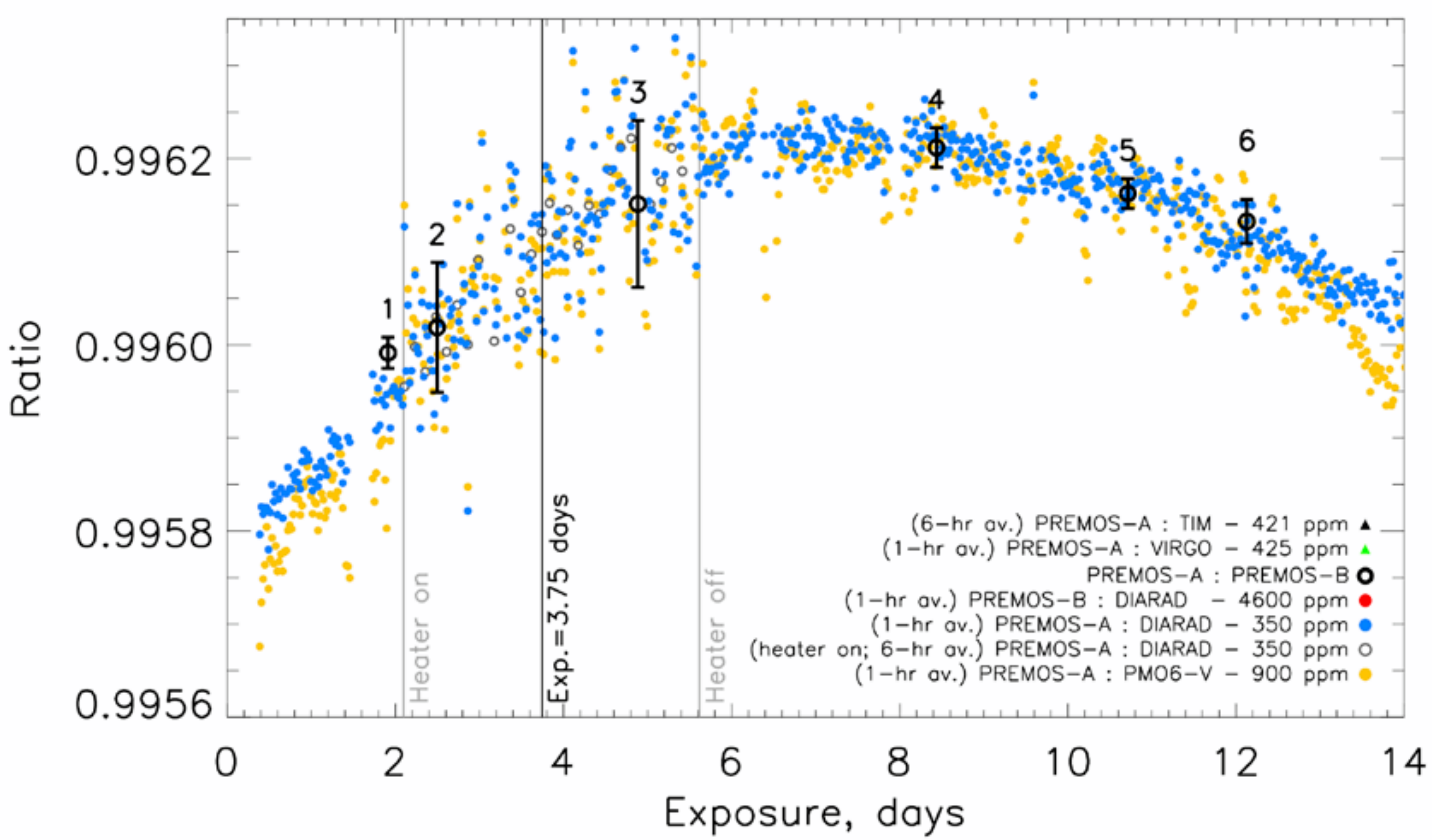
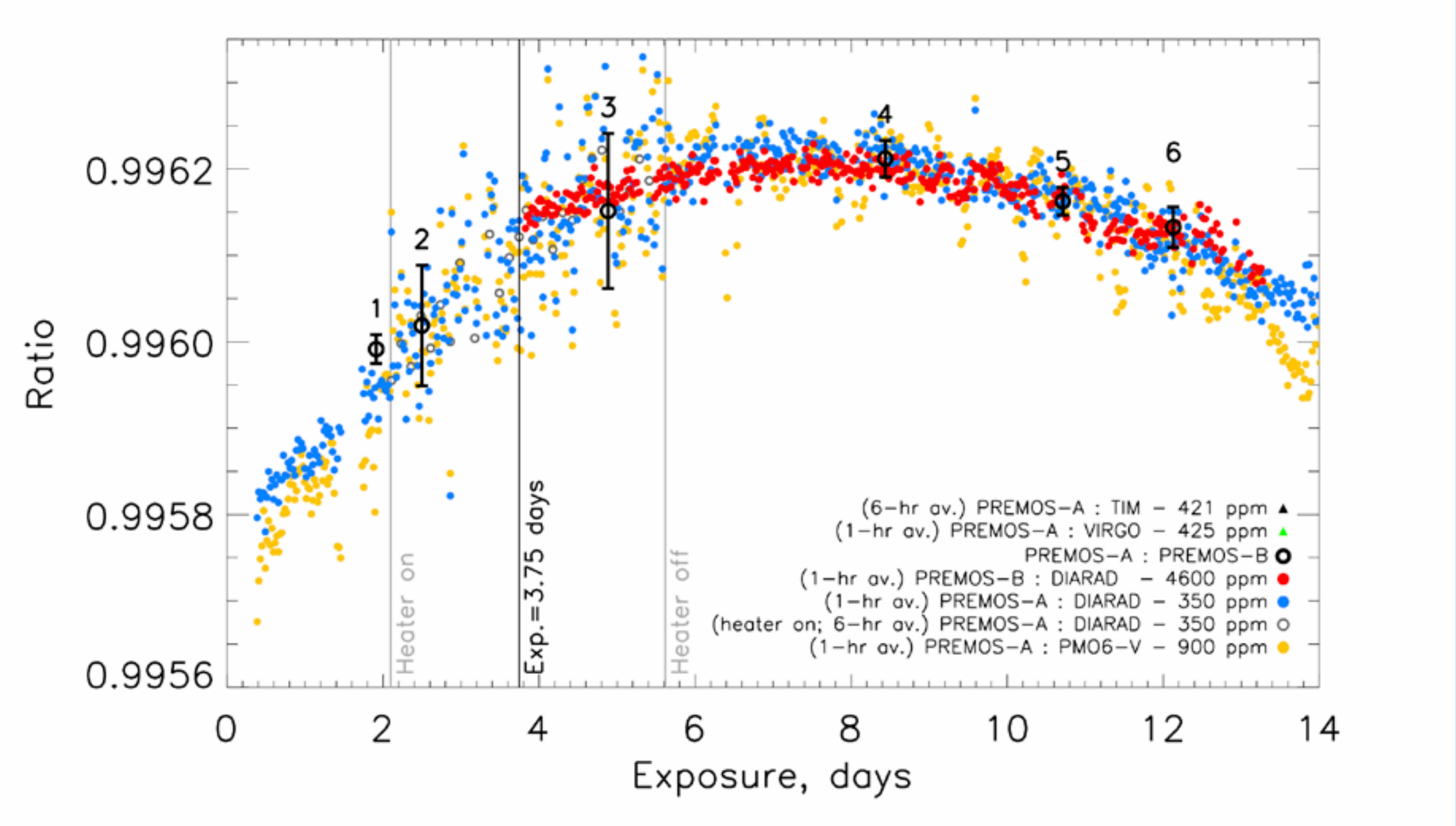


Ratio PREMOS-$\mathcal{B}$ to DIARAD
2014 Feb12 - March 4



Using $\mathcal{A}$ to $\mathcal{B}$ ratios

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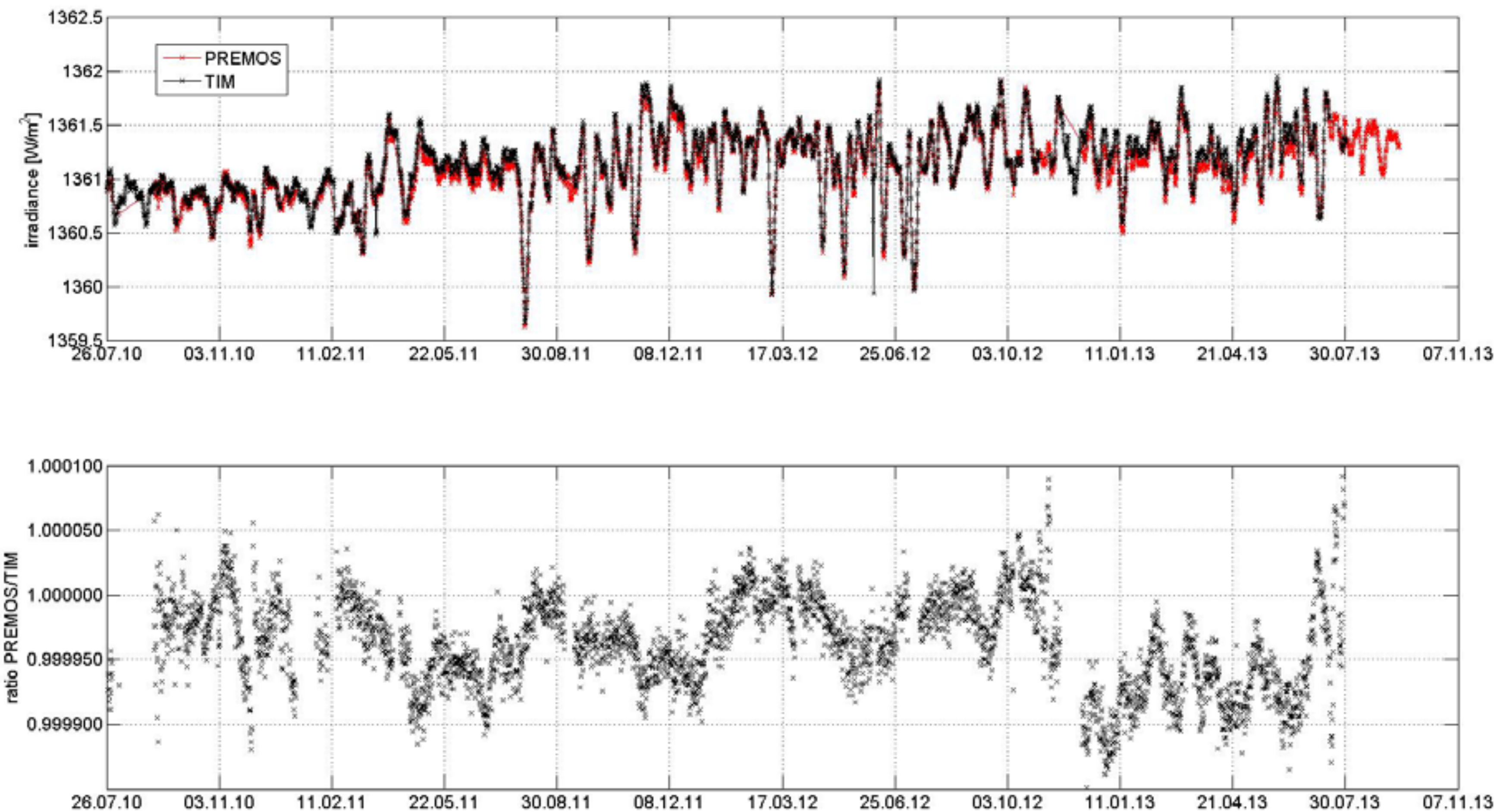
Hypothesis is verified:

$\mathcal{B}$ **(in 2014** starting at t_E=3.75 days) had the *same* sensitivity change as $\mathcal{A}$ **(in 2010)** as a function of the *exposure time*

→ Use the measured $\mathcal{A}$:$\mathcal{B}$ ratios in 2010 to correct for the sensitivity changes of head $\mathcal{B}$ from 2010 to 2014

PREMOS calib. V1 versus TIM



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Using $\mathcal{A}$ to $\mathcal{B}$ ratios

pmod wrc

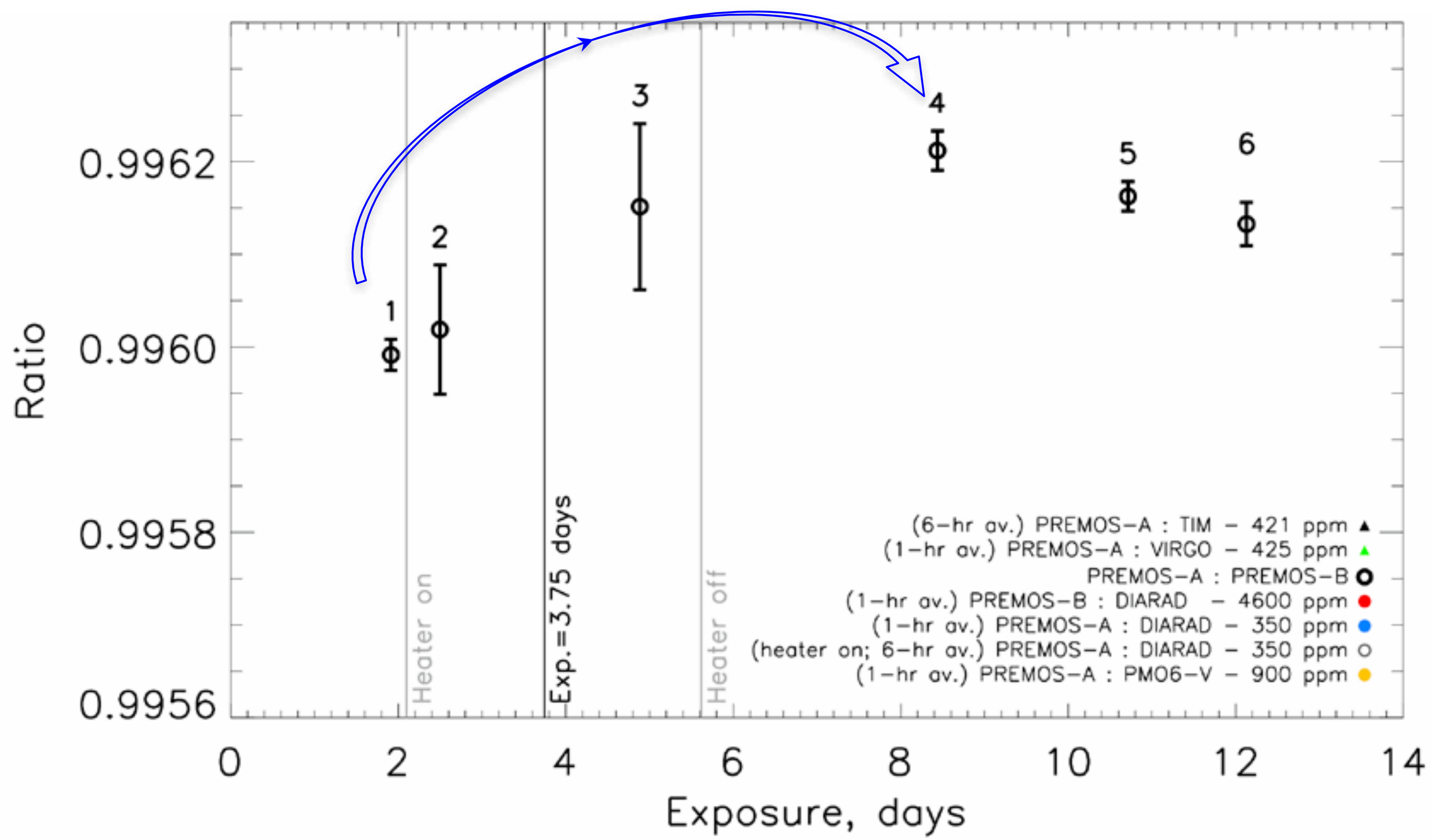
Ball et al. 2016, JSWSC 6, A32

Use the measured $\mathcal{A}$:$\mathcal{B}$ ratios in 2010 to correct for the sensitivity change of head $\mathcal{B}$ in 2014:

1) Determine the accumulated exposure time t_E of head $\mathcal{A}$ for the measured $\mathcal{A}$:$\mathcal{B}$ ratios 1, 2, .., 6, …
2) Determine the dates of head $\mathcal{B}$ when it has accumulated the corresponding dose
3) Use **“ratios of ratios”**, e.g. ratio-4/ratio-1, to correct for the sensitivity change of head $\mathcal{B}$ in 2014 *relative* to the date when B had accumulated the same exposure time as A in 2010 for ratio-1

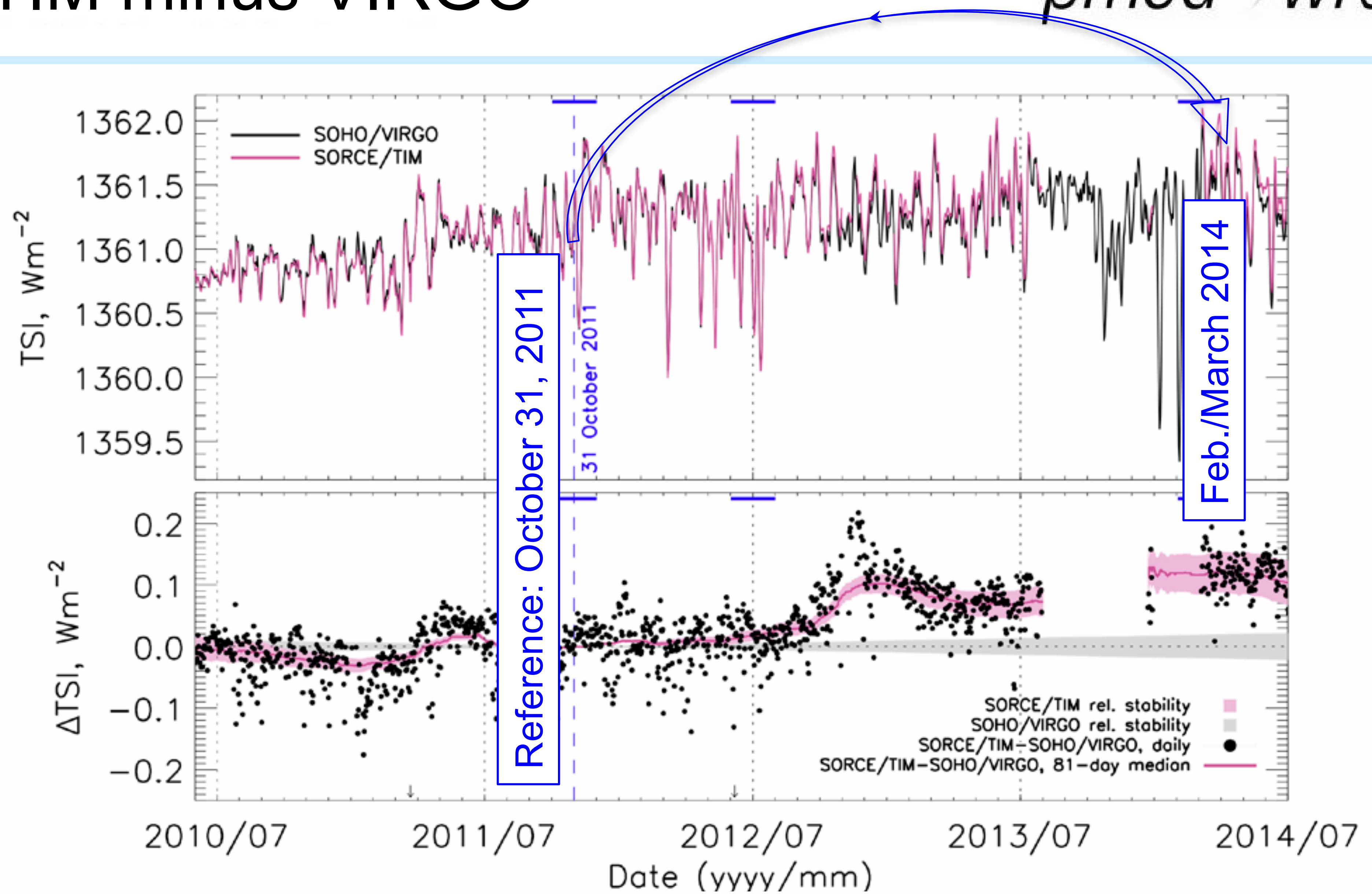
Ratios $\mathcal{A}$ to $\mathcal{B}$

Begin of operation in 2010

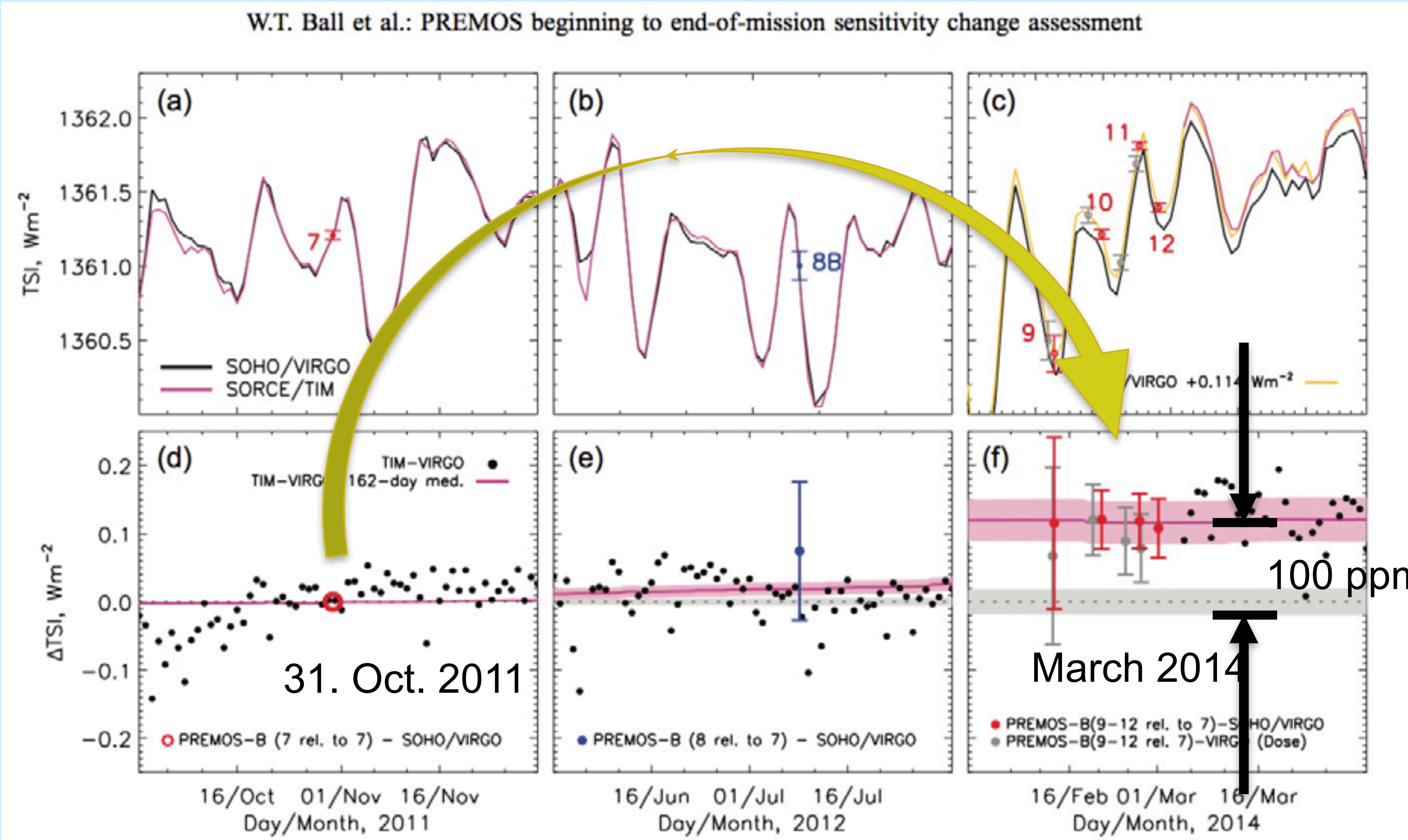


Until 4. Feb 2014 B had 3.75 days of exposure

TIM minus VIRGO



Using ratios $\mathcal{A}$ to $\mathcal{B}$: Step 3



Conclusions by Ball et al. (2016)

PREMOS $\mathcal{B}$ "ratios of ratios" 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

→ TIM stability confirmed to ≤ 6 ppm/yr

PREMOS $\mathcal{B}$ disagrees with PMOD composite (version 2016!)

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

→ PMOD-composite stability approximately ≥ 38 ppm/yr

(not clear: systematic or random ?)

PMOD-composite **cycle-cycle minima uncertainty:**

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

Is there an observed TSI-trend?

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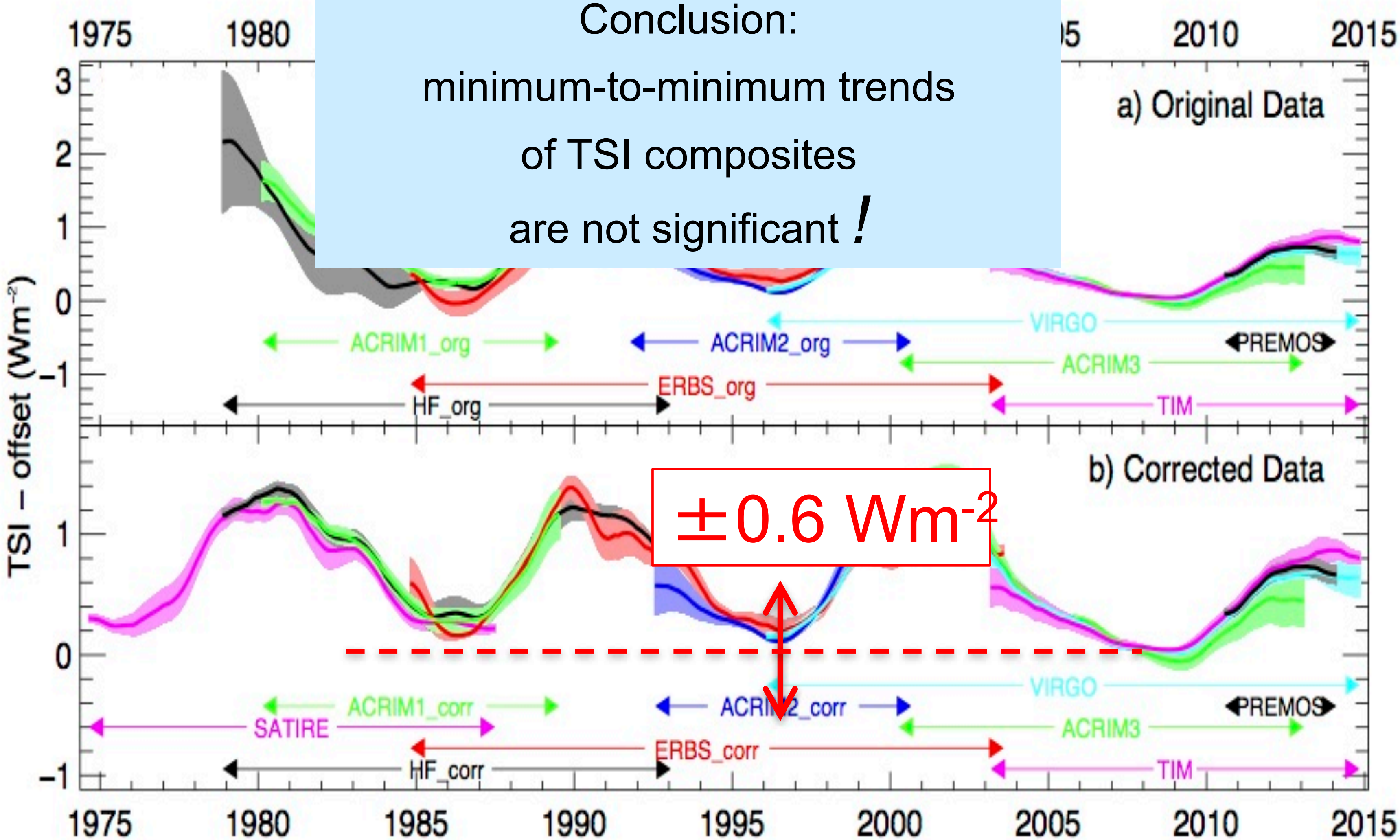

Conclusion:
minimum-to-minimum trends
of TSI composites
are not significant !

from Fröhlich (2016, PMOD/WRC website)

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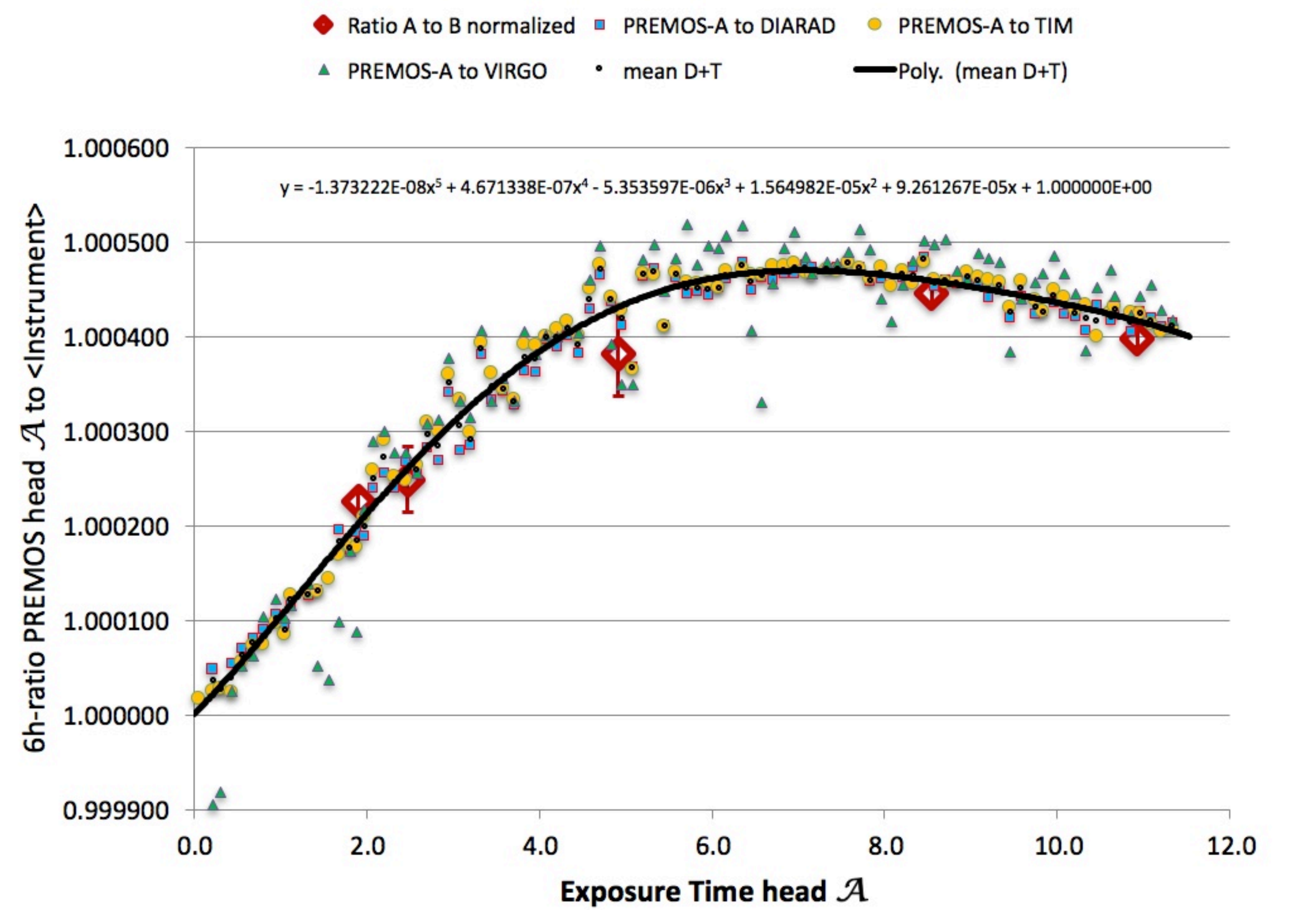
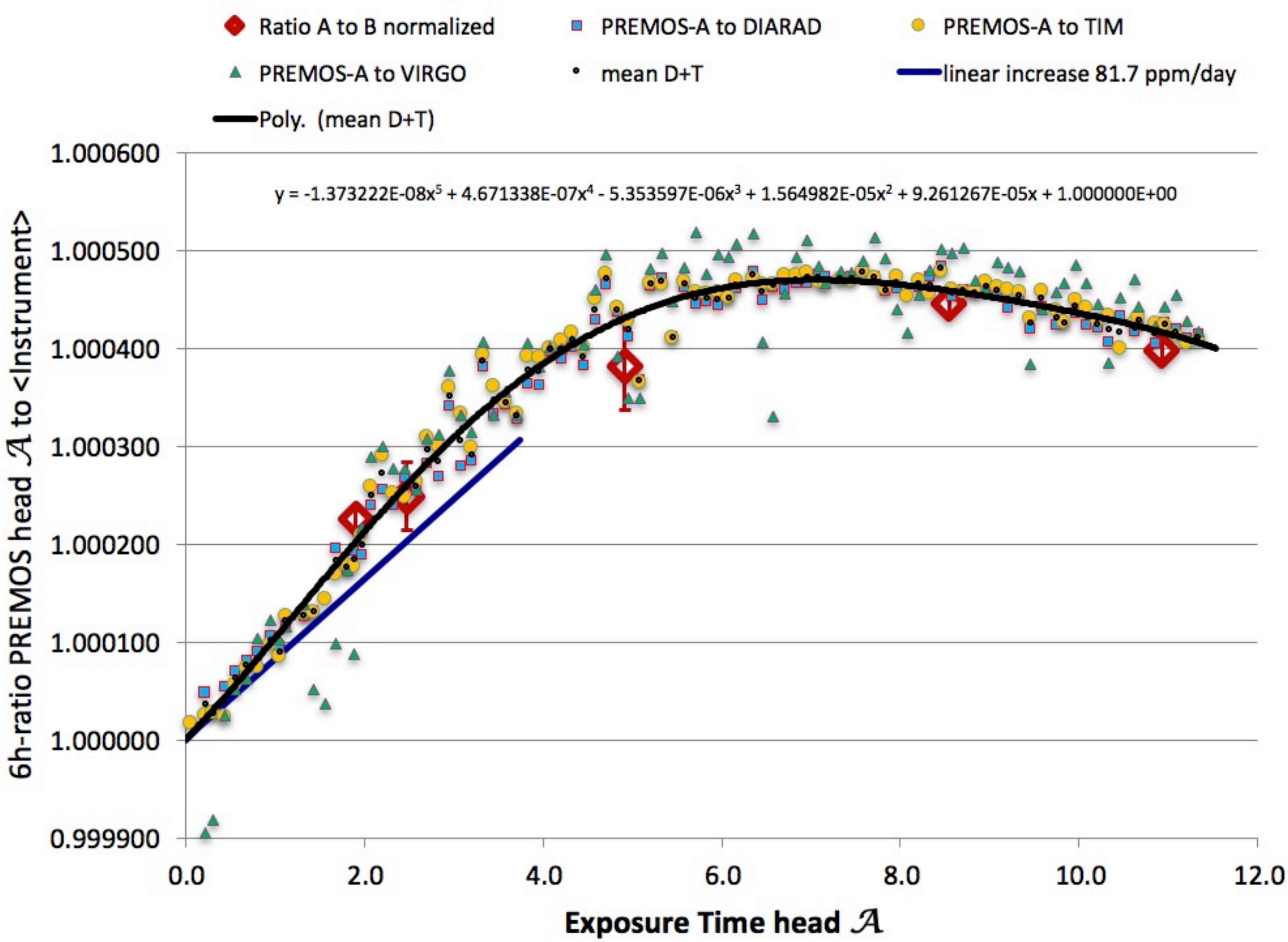
PREMOS-A to <instrument>
21-Jul – 26-Sep 2010



PREMOS-$\mathcal{A}$ to <instrument>
21-Jul – 26-Sep 2010



PREMOS-$\mathcal{B}$ to VIRGO
Sep. 2010 vs Feb. 2014

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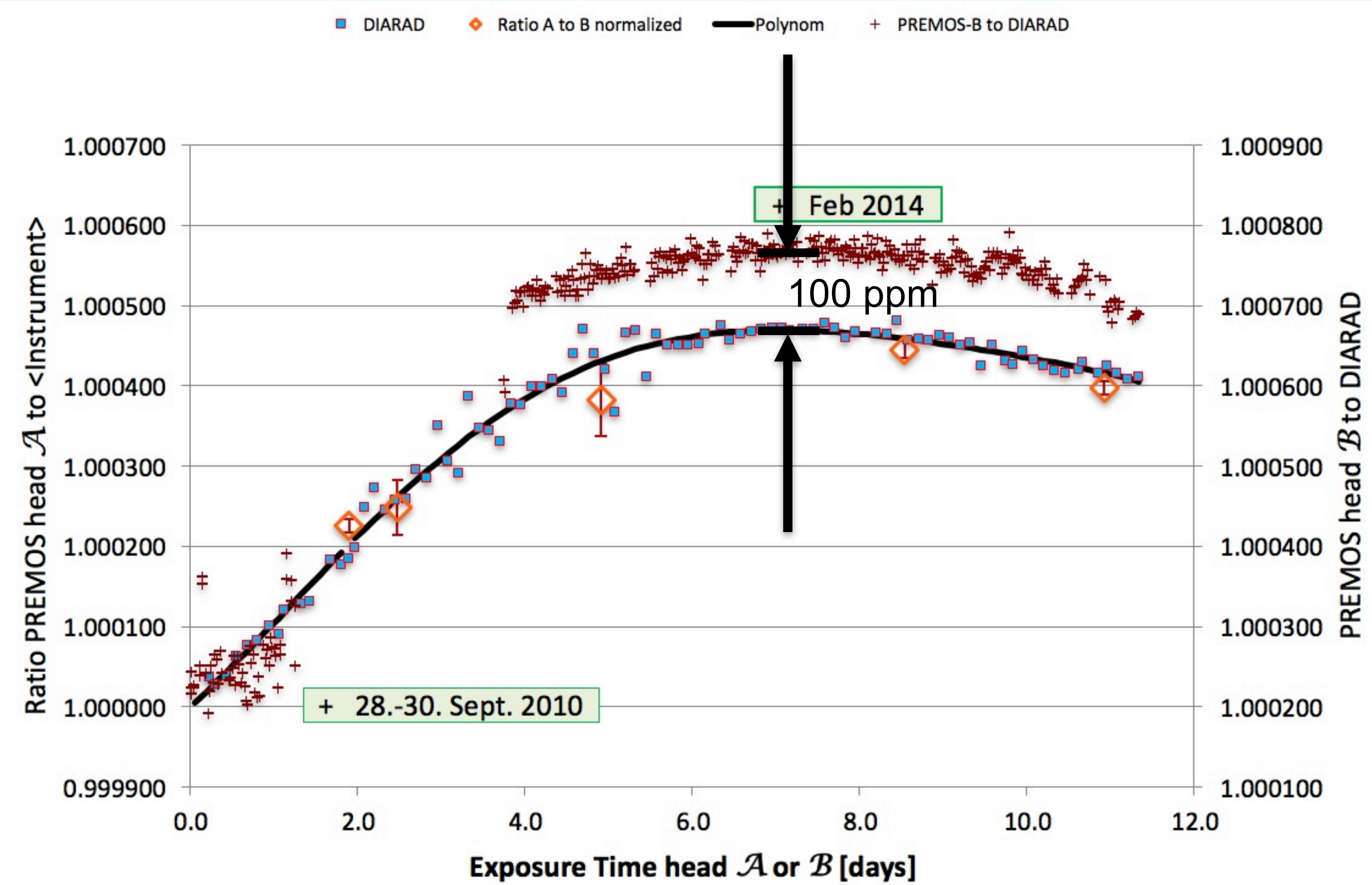

Overview (repeat)xs

pmod wrc

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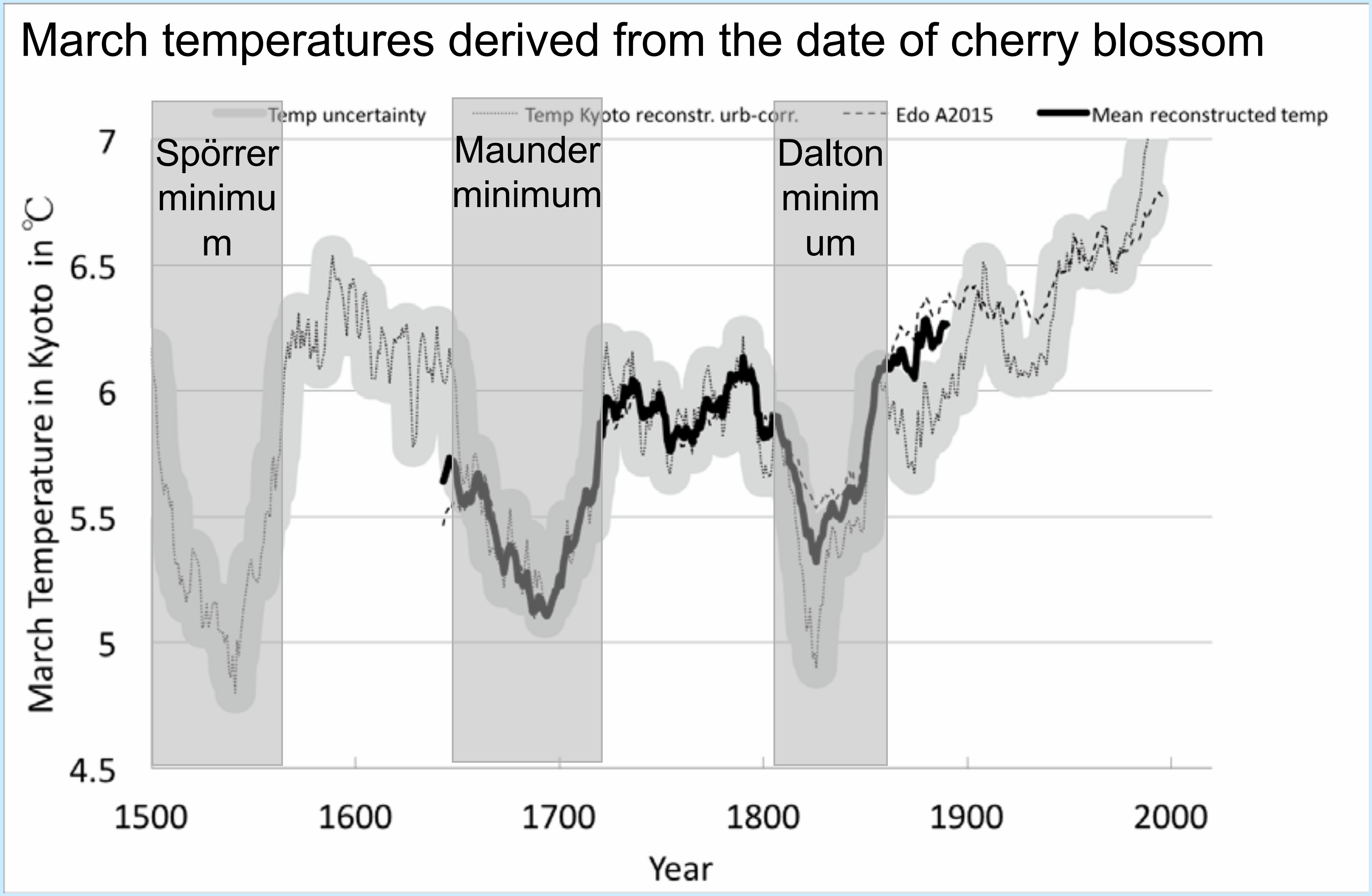
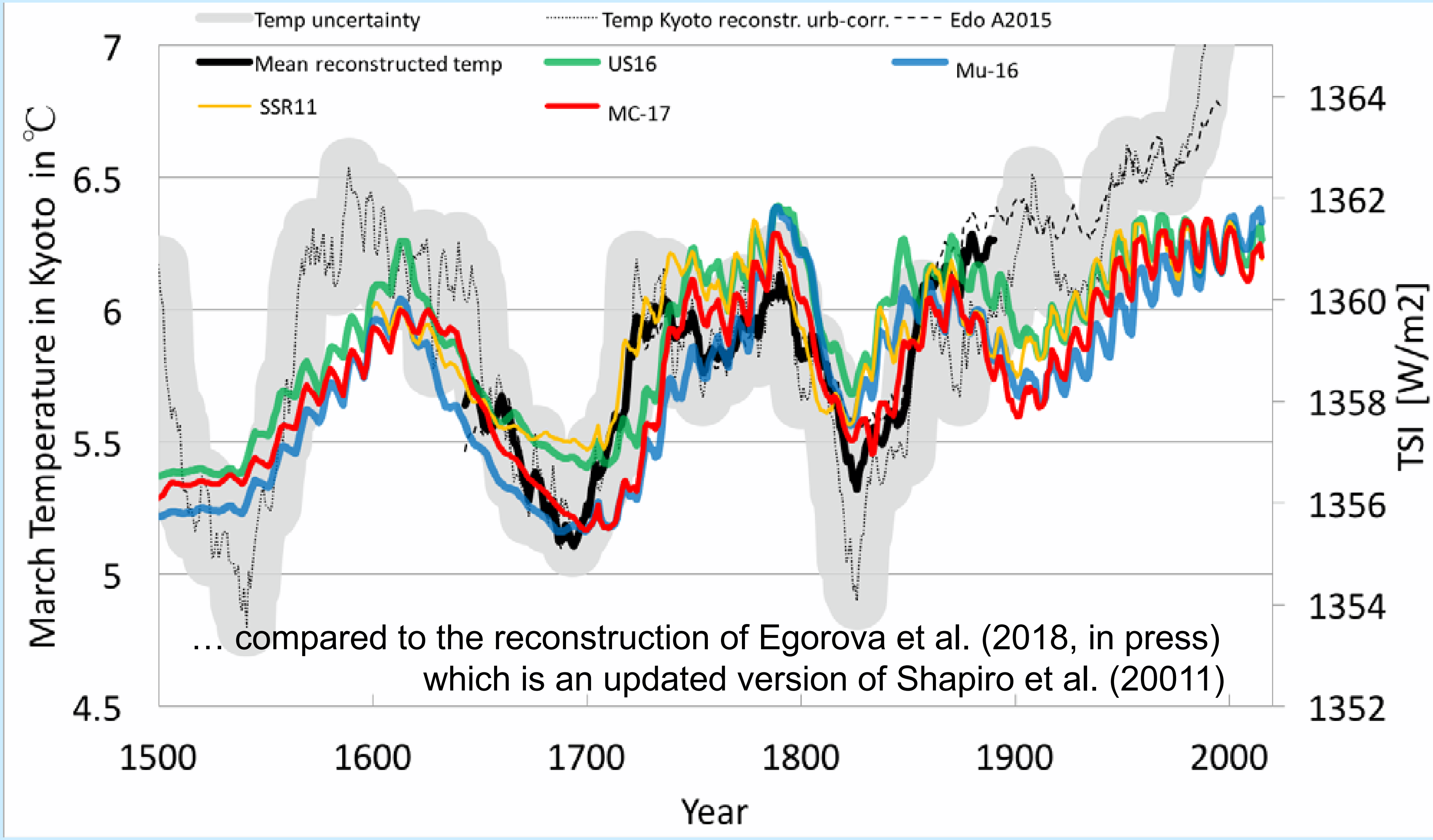
Reconstructed temperature in Kyoto and Edo bay (Tokyo)



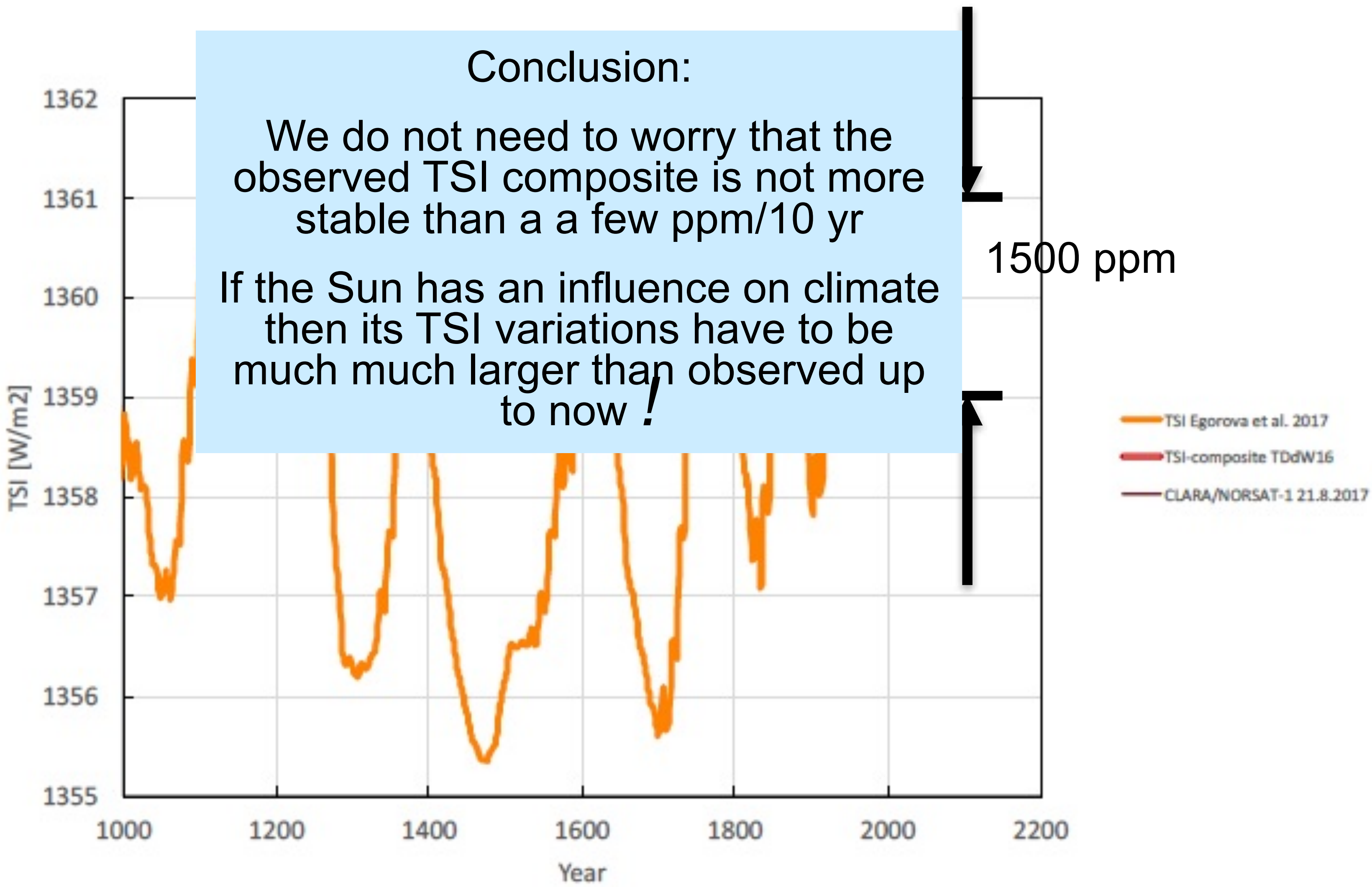
Aono & Kazui (2008); Aono (2015)

Reconstructed temperature in Kyoto and Edo bay (Tokyo)



Reconstructed (and guessed to 2030) TSI development

pmod wrc



Conclusion:

We do not need to worry that the observed TSI composite is not more stable than a a few ppm/10 yr

If the Sun has an influence on climate then its TSI variations have to be much much larger than observed up to now !

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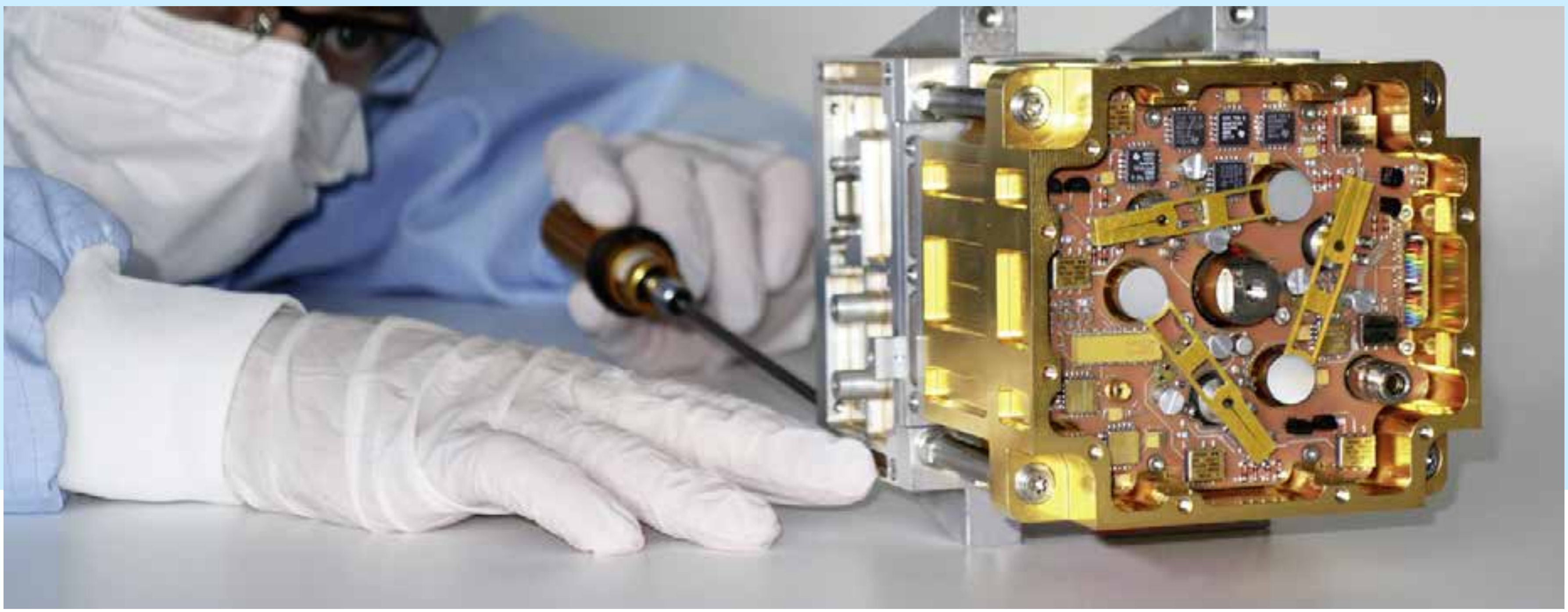
Innovation

A new generation of the Davos space radiometers:

CLARA = Compact Light weight Radiometer

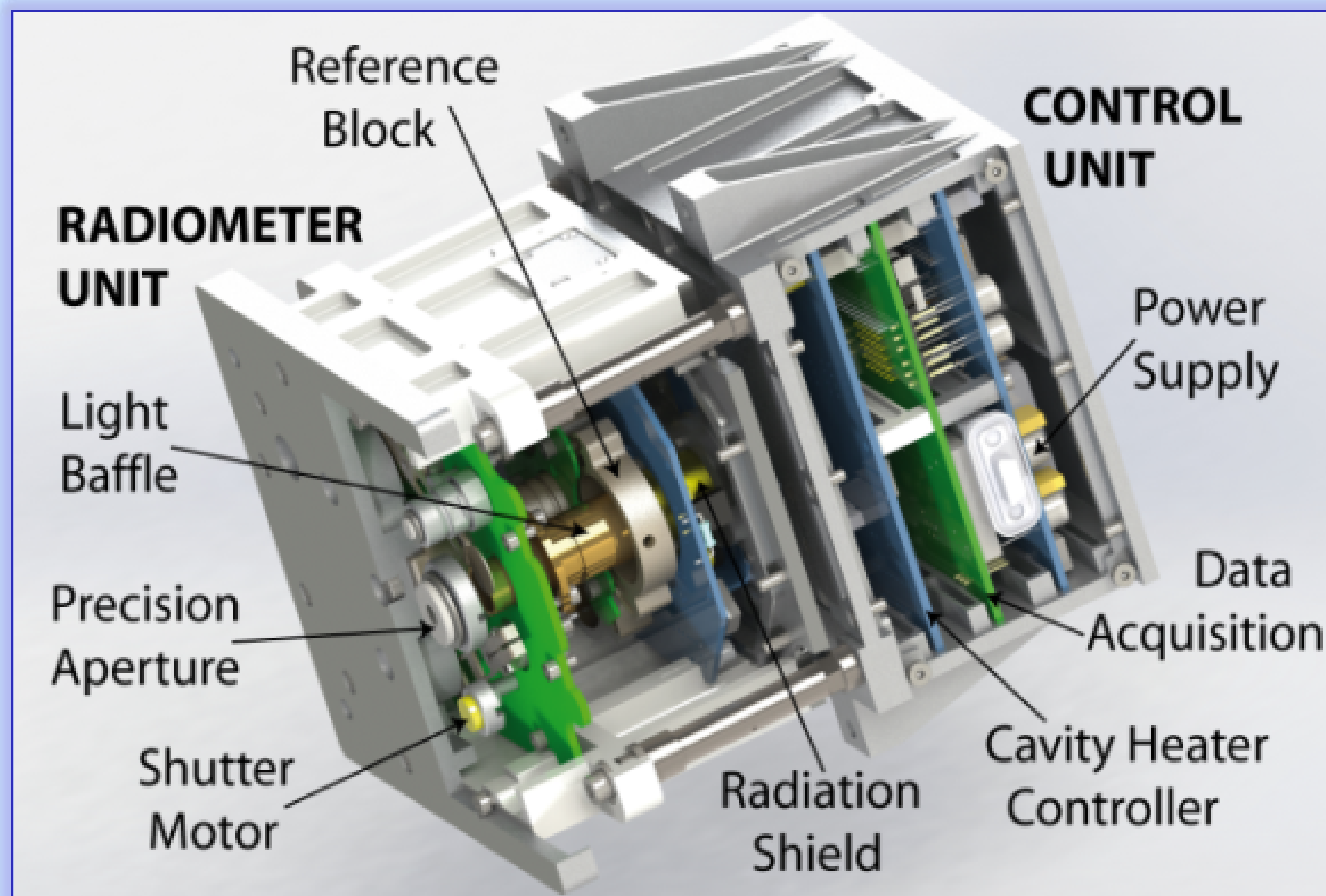
- Mass: 2.21 kg
- Dimension: 12.8 x 15.8 x 13.8 cm
- Average power consumption: 4.5 W

→ *suitable for Micro- / Nanosatellites*



CLARA/NorSat-1

Precision apertures in front !



CLARA Innovations

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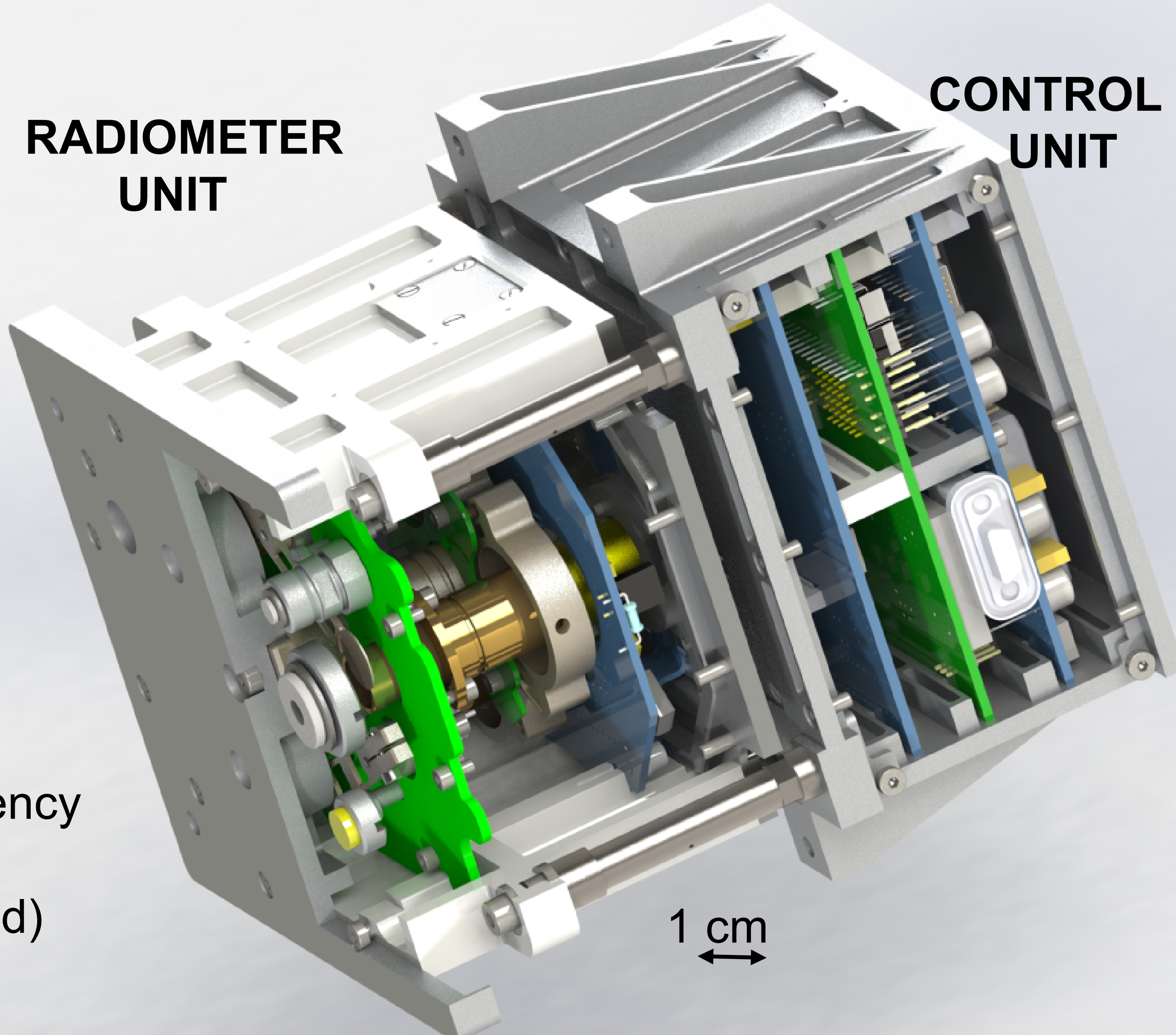
Innovation1:

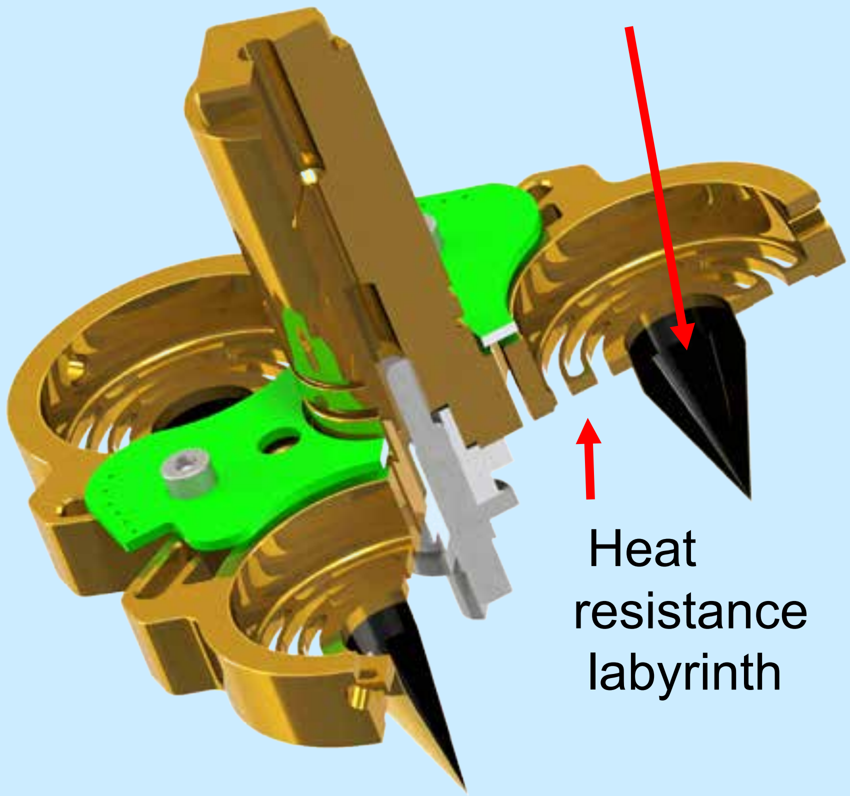
- Radiometer box and control unit in different boxes. The radiometer unit is thermally fully isolated



Innovation-2:

Digital controller
→ measurement frequency 30 sec
(15 s open – 15 s closed)
(PMO6V 120 sec)

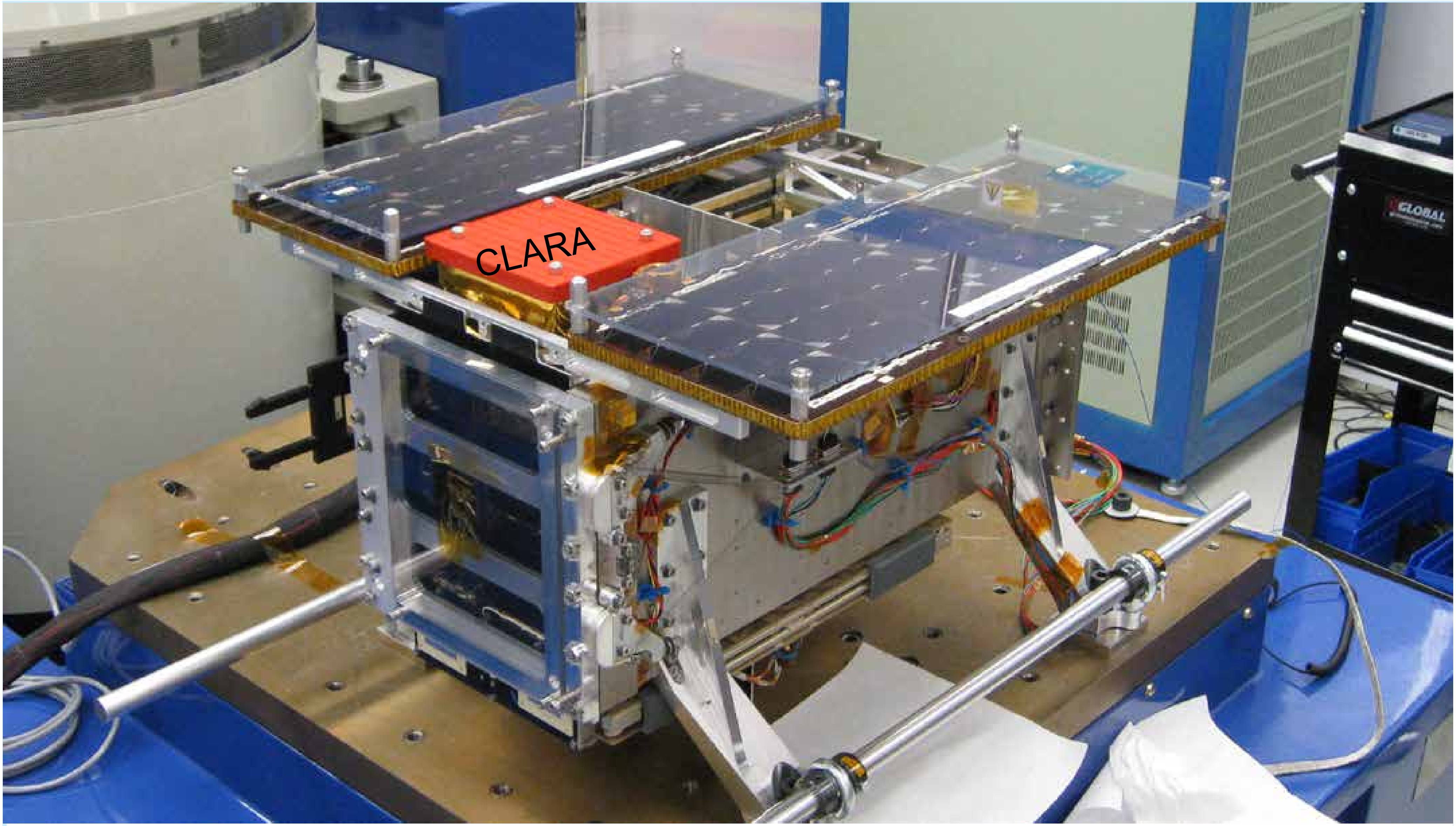
CLARA Innovations



Innovation-3:

- Three cavity design for degradation tracking and redundancy
- New Cavity and heatsink design to minimize size and weight of the instrument

CLARA/NorSat-1



TRF-calibration

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Calibration at TSI Radiometer Facility (TRF) in Boulder, Colorado

		TRF Ground (532 nm laser, vacuum)						Space (solar spectrum, vacuum)								
		Channel A		Channel B		Channel C		Channel A			Channel B			Channel C		
	Characterization item	Value	σ	Value	σ	Value	σ	Value	σ_{Native}	σ_{Lab} Scale	Value	σ_{Native}	σ_{Lab} Scale	Value	σ_{Native}	σ_{Lab} Scale
Native Scale	Aperture area ($1/C_{apert}$) (mm^2)	19.6299	28	19.6242	28	19.6235	28	19.6299	28	–	19.6242	28	–	19.6235	28	–
	Aperture temperature	–	39	–	39	–	39	–	39	39	–	39	39	–	39	39
	Absorptivity (C_{abs})	1.002 056	288	1.002 198	308	1.002 048	287	1.002 225	311	92	1.002 372	332	88	1.002 217	310	92
	Pointing (absorptivity)	–	–	–	–	–	–	–	30	30	–	30	30	–	30	30
	Diffraction (C_{diff})	1.000 491	24	1.000 491	24	1.000 491	24	1.000 867	31	31	1.000 867	31	31	1.000 867	31	31
	Non-Equivalence (C_{ne})	1.000 007	4	1.000 007	4	1.000 007	4	–	–	–	–	–	–	–	–	–
	Dark correction (C_{dark})	–	–	–	–	–	–	1.000 830	65	65	1.000 830	65	65	1.000 830	65	65
	Heater voltage (C_U)	0.999 200	1600	0.999 200	1600	0.999 200	1600	0.999 200	1600	160	0.999 200	1600	160	0.999 200	1600	160
	Shunt voltage (C_I)	0.999 200	1600	0.999 200	1600	0.999 200	1600	0.999 200	1600	160	0.999 200	1600	160	0.999 200	1600	160
	Shunt resistance	–	40	–	40	–	40	–	40	40	–	40	40	–	40	40
	Lead heating (C_{lh})	1.000 950	25	1.001 084	25	1.001 009	25	1.000 950	25	–	1.001 084	25	–	1.001 009	25	–
	Shutter delay issue	–	–	–	–	0.998 600	700	–	–	–	–	–	–	0.998 600	700	700
	Calibration factor	**1.001 902**	**2282**	**1.002 179**	**2285**	**1.000 551**	**2387**	**1.003 273**	**2286**	**–**	**1.003 555**	**2289**	**–**	**1.001 920**	**2391**	**–**
Comparison to Laboratory scale	Repeatability	–	236	–	217	–	258	–	–	–	–	–	–	–	–	–
	Scattered light	0.999 920	40	0.999 920	40	0.999 920	40	–	–	–	–	–	–	–	–	–
	Aperture placement	1.000 650	225	1.000 650	225	1.000 650	225	–	–	–	–	–	–	–	–	–
	TRF calibration uncertainty	–	393	–	393	–	393	–	–	–	–	–	–	–	–	–
	CLARA/TRF ratio	**1.001693**	**512**	**1.001221**	**504**	**1.001409**	**523**	1.001693		512	1.001221		504	1.001409		523
	SI cryogenic laboratory scale calibration factor:							**1.001577**	**–**	**576**	**1.002331**	**–**	**567**	**1.000510**	**–**	**912**

$\pm$ 0.77 W m^{-2} $\pm$ 0.77 W m^{-2} $\pm$ 1.24 W m-

≙ 576 ppm

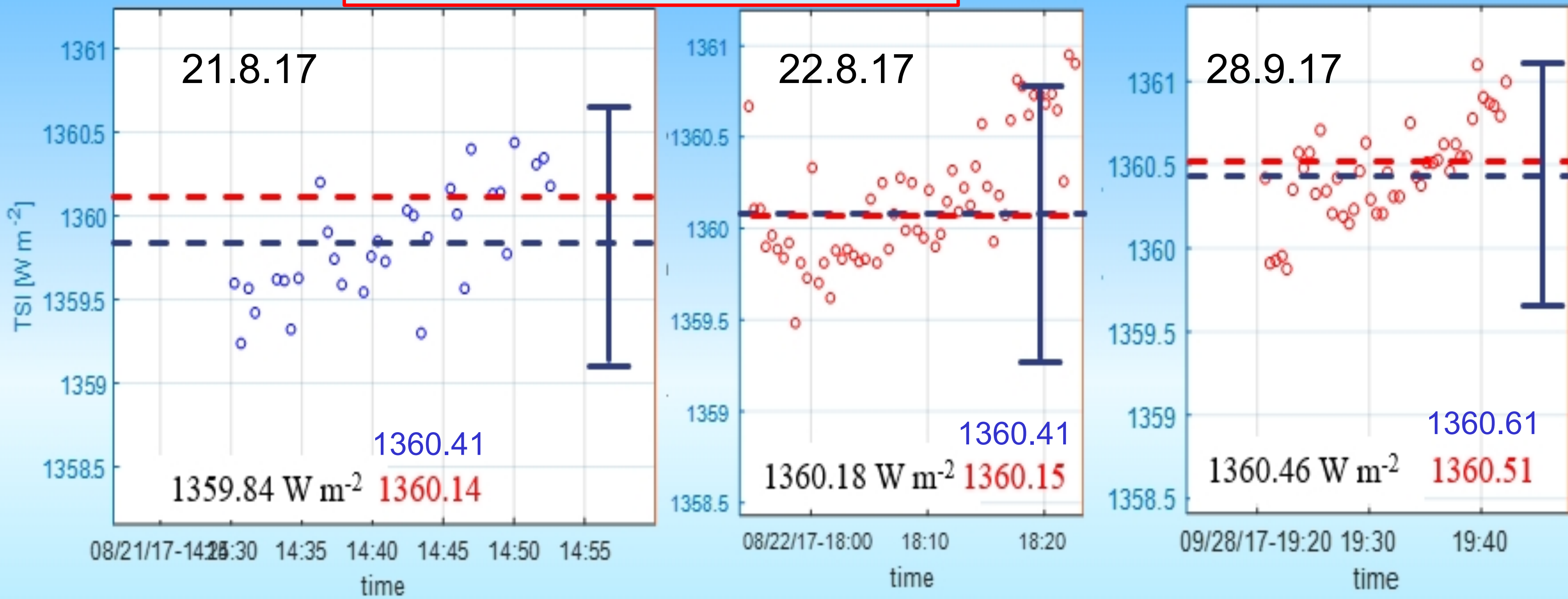
Walter et al. 2017, *Metrologia* 54, 674

1st light TSI value cavity B

pmod wrc

Channel B: → uncertainty = ± 0.77 W m^{-2}

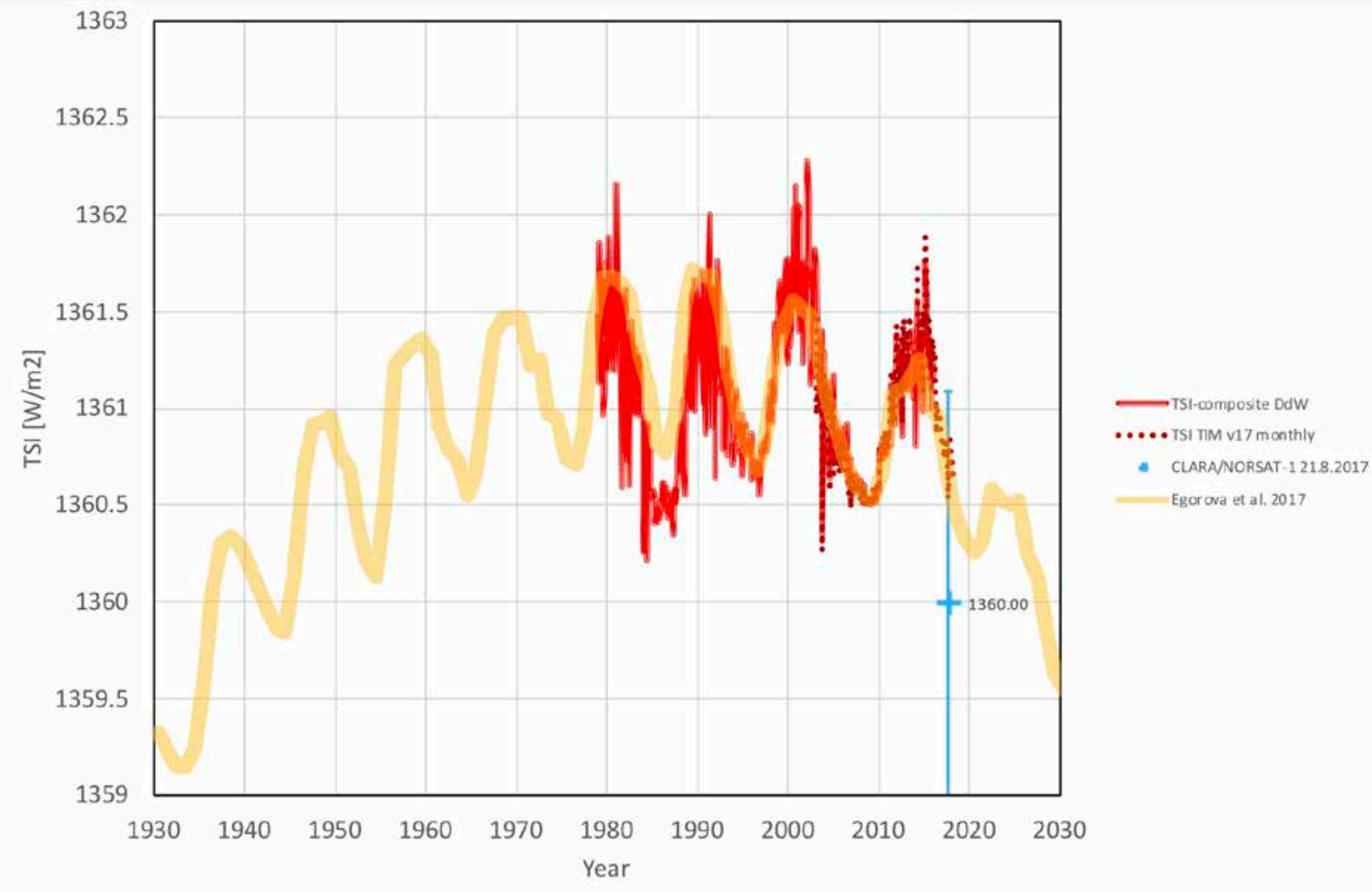
Mean 21+22.8.17: 1360.0 Wm^{-2}



Daily averages of virgo

6h TIM value at orbit time

Comparison to composite and TIM



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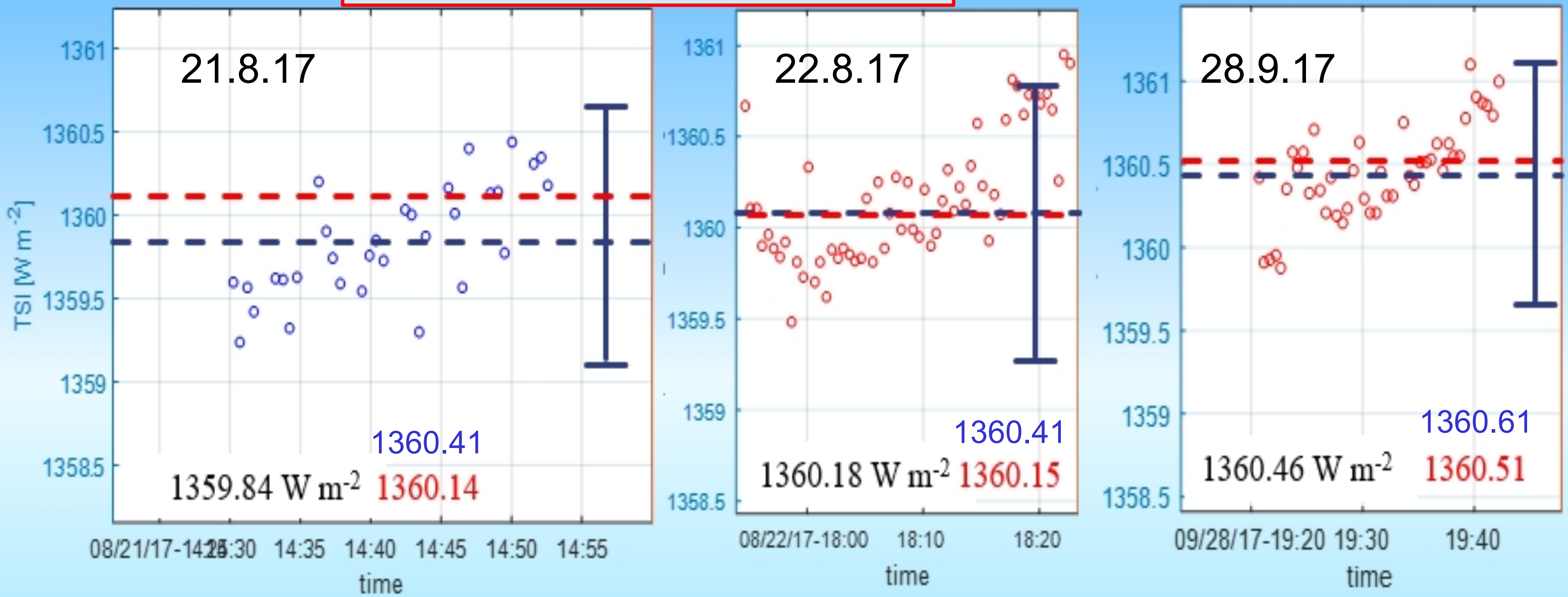


Daily averages of virgo

6h TIM value at orbit time

Summary CLARA/NorSat-1

- Launched on 14.7.2017
- Preliminary 1st light value of cavity B on 21./22.8.2017

  1360.0 ±0.77 W/m^2

- Three cavity design should provide excellent long term stability of CLARA/NorSat-1 …

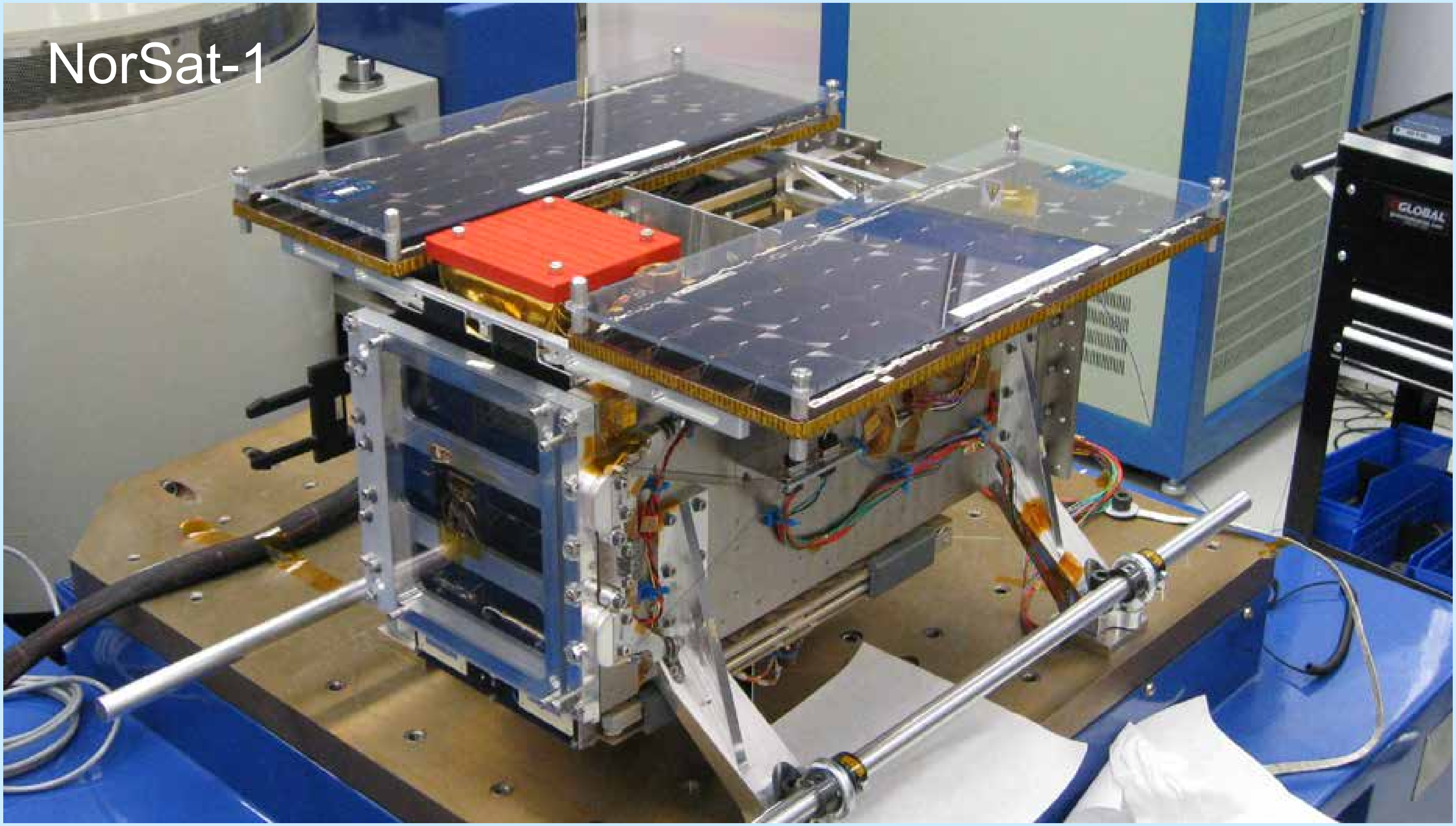
… to be seen !

Conclusions

- ➔ TSI-composite has a problem 2013/2014 at the transition from the *VIRGO-ACRIM-III-TIM-PREMOS* to the *VIRGO-TIM-TCTE* period
- ➔ Ball et al. (2016) assessment of the relative calibration of PREMOS/PICARD supports the TSI record of TIM and disagrees with VIRGO
- ➔ PREMOS data vs2 confirms stability of TIM
- ➔ TSI-composite may have a tend of the order of a few 100 ppm/10 yr for > 1996
- ➔ This TSI record accuracy is sufficient for climate impact estimates
- ➔ CLARA/NorSat-1 is a new operational radiometer to help establishing the long term stability of the TSI-composite

Thank you for your attention !

pmod wrc



Correcting A using the corrected B channel