Solar Irradiance

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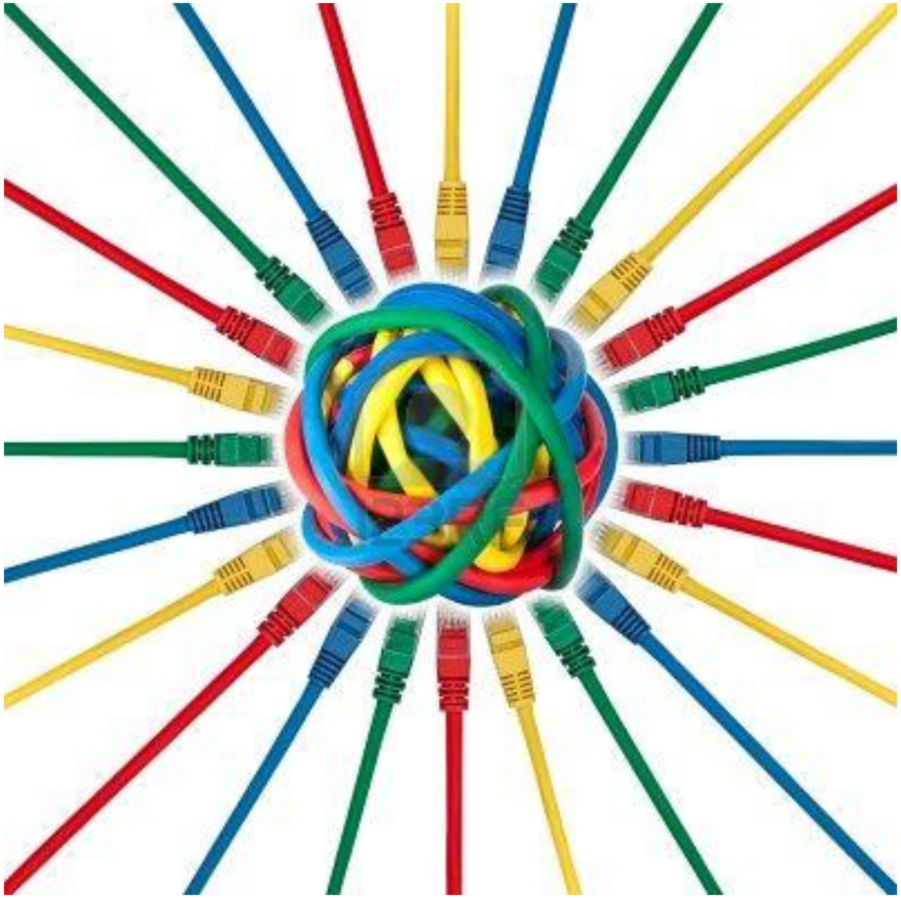


Solar *spectral* irradiance

Value, measurements, modeling, lacks and needs

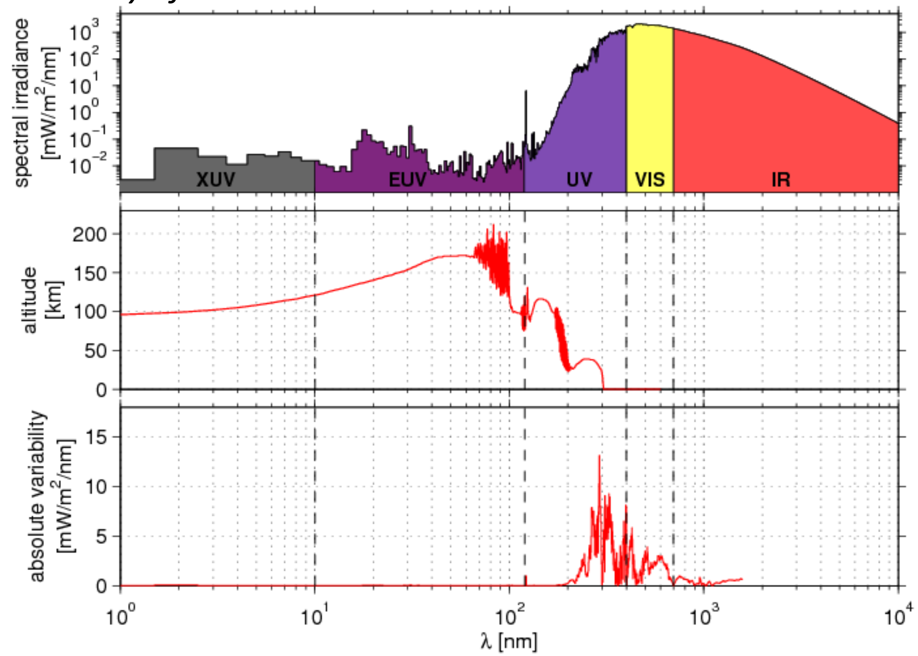
Interest of spectral irradiance (SSI) investigations (slide 1 of 57)

- TSI not directly addressed here
  - Talk duration and scope limited

A. SSI and especially its VUV range *are* relevant to climate studies
   - VUV is absorbed in the stratosphere, where it controls chemistry and dynamics
   - Ly α and 180-240 nm control production and destruction of ozone
   - 200-350 nm is the main source of heat in the stratosphere and mesosphere
   - *SSI needed for Global Circulation Models*

- Solar variability is irregular

Courtesy of T. Dudok de Wit



1. The shorter the λ the larger the variations
2. The larger the λ the larger the SSI

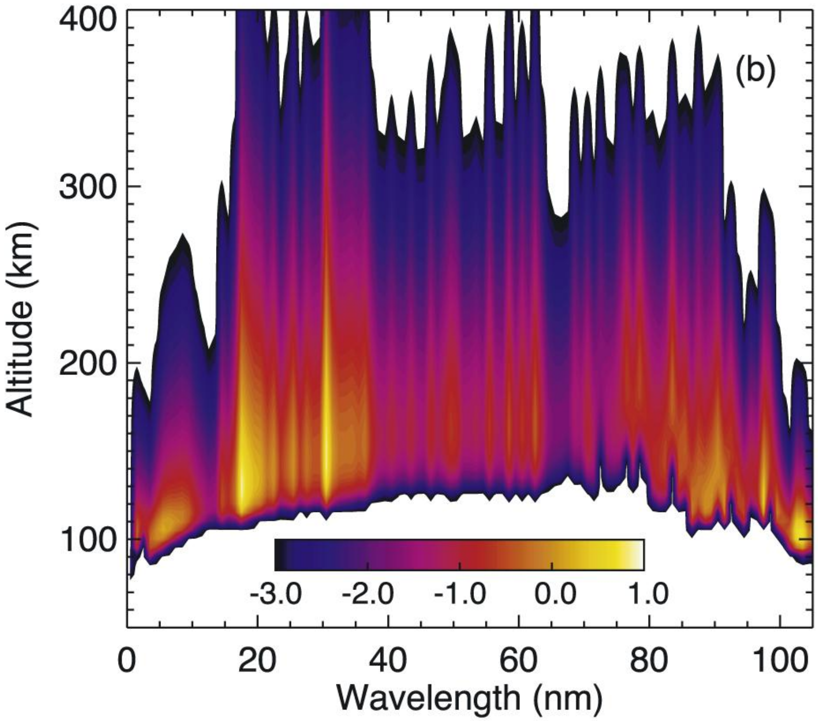
→ 200-350nm has the largest absolute variability

Interest of spectral irradiance (SSI) investigations (slide 56 of 57 ;-)

Beyond climatology, SSI is also of interest to:

B. Space Weather
- EUV ionizes the ionosphere
- Drives the thermosphere density
- → Satellite drag, GPS, radio perturbations…

C. Studies of other planets
  - McMullin et al 2008
    Solar EUV spectral irradiance throughout the 3-dimensional heliosphere
- Including Exoplanets, exobiology, primitive Earth, E.g.
  - Cnossen et al 2007 *Habitat of early life Solar X-ray and UV radiation at Earth's surface 4-3.5 billion years ago*
  - Mc Millan et al 1993, *Radial velocity observation of the sun at night*



Altitude-wavelength dependence of energy deposition from solar irradiance in $Log_{10}(Wm^{-4})$ - Solar minimum

From Solomon and Qian 2005

Interest of spectral irradiance (SSI) investigations (slide 57 of 57 ;-)

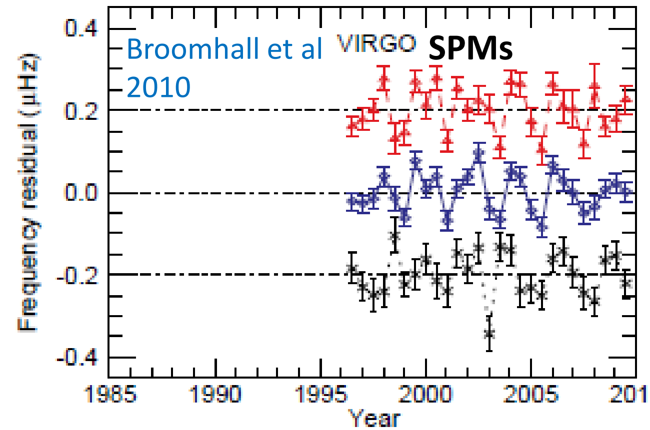
Beyond climatology, SSI is also of interest to:

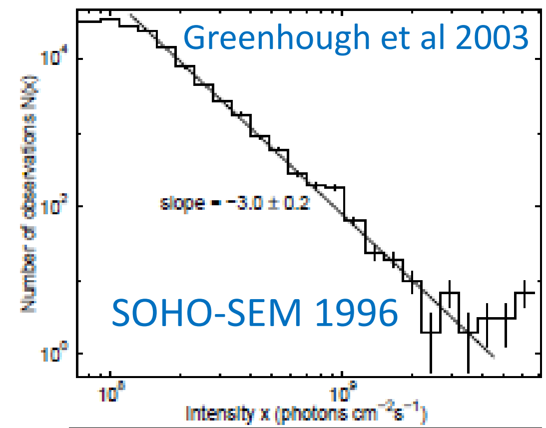
D. Design of space experiments

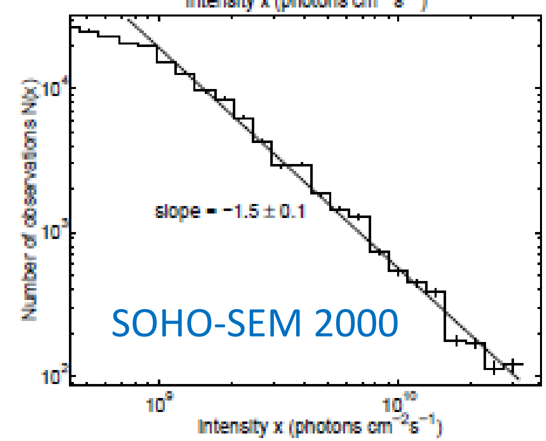
- Need for reference spectra
  - Thuillier et al 2004, or Woods et al 2009

E. Solar physics

- Understanding solar dynamo (helioseismology)
  - Broomhall et al 2010 *Are short-term variations in solar oscillation frequencies the signature of a second solar dynamo?*
    2yr & 1.4 yr periodicities in the upper CZ
  - Vita-Finzi 2010: *The Dicke cycle: A 27-day solar oscillation*
    Corona connected with the RZ
- Coronal heating
  - Greenhough et al 2003, *Statistical characterisation of full-disk EUV XUV solar irradiance and correlation with solar activity*
    Distributions of detrended fluctuations vary with activity
- Flare studies
  - LYRA detects stationary sausage mode oscillations during flare







Measuring the SSI

Performance criteria ↓

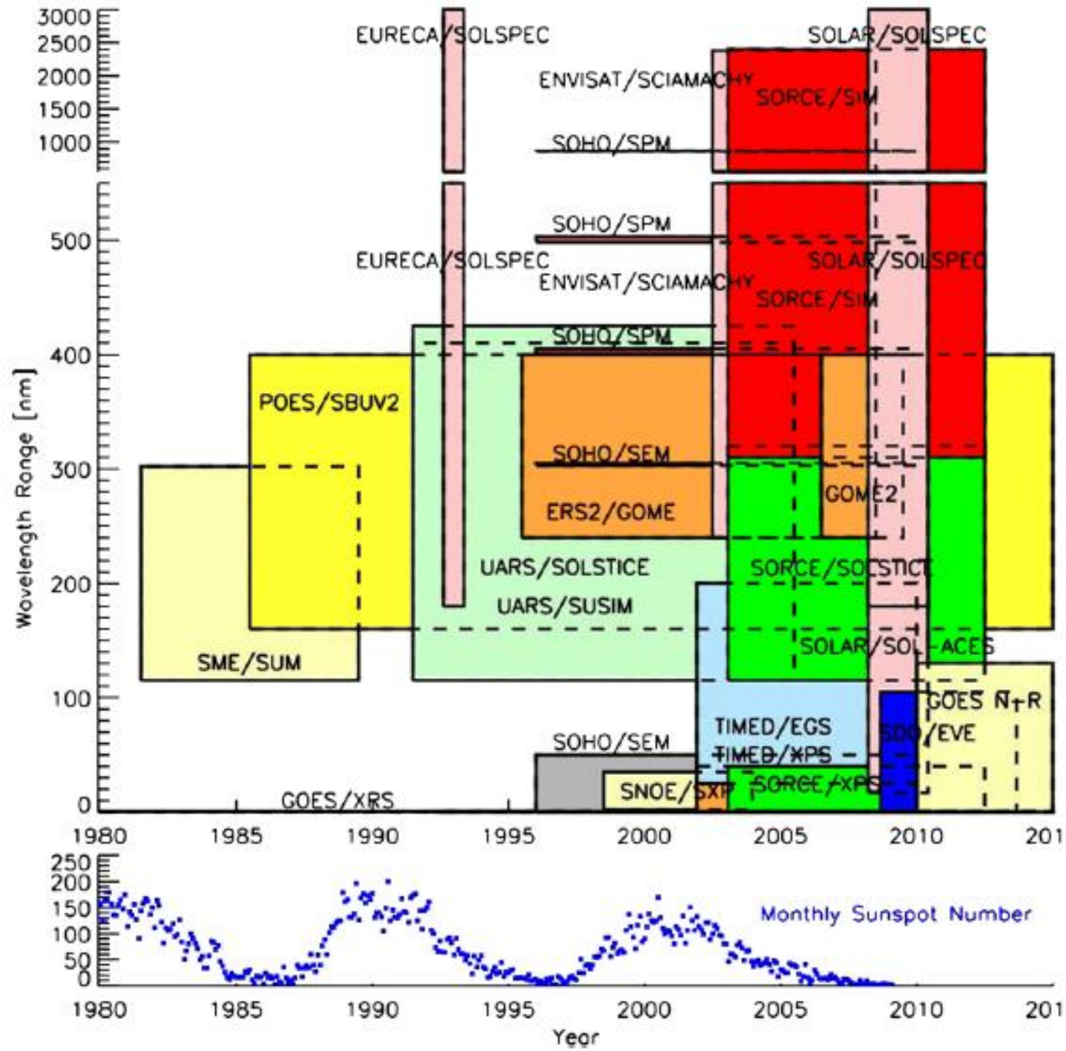
Green is nice to have

Yellow is a limitation

	Spectrometers	Filter Photometers	Imagers
Cadence	Low (> 10s)	High (10 Hz and more)	Low (typ. 10 sec)
Duty cycle	Low	High	Low
Lifetime	TBD	TBD	TBD
FOV	OK	OK	OK
Spatial resolution	n/a	n/a	Yes
Spectral resolution	Narrow	Wide band with possible spectral contamination	Wide band with possible spectral contamination
Sensitivity	Low	High	Medium
Calibrability (in flight)	Difficult (calrocs needed)	Redundancy & cal lamps	Morphology can be preserved Cal lamps
Mass and volume	Heavy	Light	Medium

Send swarms of cheap fast sensitive photometers … all over the heliosphere…

Recent and current SSI measurements (1 of 3)



From Domingo et al 2009

Recent and current SSI measurements (2 of 3)

Mission and instrument		Cadence	Time range	Spectral range					Ly-a	MgII c2w
				XUV	EUV	VUV	NUV	VIS NIR		
Series of GOES-XRS	P	3 s up to 2 Hz	1974-*	x						
SME-SUM	S		1981-1989			x			x	x
Series of POES-SBUV2	S	24h	1985-*			x				x
UARS-SUSIM	S	24 h	1991-2005			x	x		x	x
UARS-SOLSTICE	S	15/day	1991-2001			x	x		x	x
ERS2-GOME	S		1995-2003			x	x			x
SOHO-VIRGO-SPM	P	1 min	1996-*					x		
SOHO-SEM	P	15 s	1996-*	x	x					
SNOE-SXP	P	95 min	1998-2002	x	x					
TIMED-SEE/EGS	S	95 min	2002-*		x	x			x	
TIMED-SEE/XPS	P	95 min	2002-*	x	x				x	
ENVISAT SCHIAMACHY	S		2003-*				x	x		x
SORCE-SOLSTICE II	S	~6 hr	2003-*			x			x	x
SORCE XPS	P	5 min	2003-*	x	x				x	
SORCE-SIM	S	~6 hr	2003-*				x	x		x
Series of GOES-EUVS	P	10 s	2005-*	x	x				x	
MetOpA-GOME2	S		2006-				x			x
PHOTON-PHOKA	P	0.4	2009 01-10	x	x				x	
PHOTON-SPHINX	S	0.01	2009 01-10	x	x					
ISS-SOLAR-SOLACES	S	15/day	2009-*		x	x			x	
ISS-SOLAR-SOLSPEC	S	15/day	2009-*			x	x	x		x
PROBA2-LYRA	P	0.05 s	2010-*	x	x	x			x	
SDO-EVE	S+P	10 s	2010-*	x	x				x	
PICARD-PREMOS	P	1 min-10Hz	2010-*				x	x		

J.-F. Hochedez
EGU 2011

Recent and current SSI measurements (3 of 3)

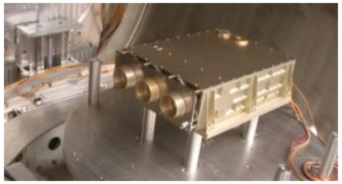
Mission and instrument		Cadence	Time range	Spectral range XUV	EUV	VUV	NUV	VIS NIR	Ly-a	MgII c2w	Wavelength (nm)	Resolution (nm)	Accuracy and other comments	Reference paper
Series of GOES-XRS	P	3 s up to 2 Hz	1974-*	x							0.05-0.4 & 0.1-0.8		Accuracy 30% - Flare classification	Donnelly, Cowley 197 GOES 11-12-14-15
SME-SUM	S		1981-1989			x			x	x	115-302		Poor accuracy, degradations	Barth et al 1983
Series of POES-SBUV2	S	24h	1985-*			x				x	252.0-339.8	1.1	Accuracy 2%, precision 1% - 12 bands	
UARS-SUSIM	S	24 h	1991-2005			x	x		x	x	115-410	1	Accuracy 2%	Brueckner et al 1993
UARS-SOLSTICE	S	15/day	1991-2001			x	x		x	x	119-419	0.2		Rottman et al 1993
ERS2-GOME	S		1995-2003			x	x			x	240-400			
SOHO-VIRGO-SPM	P	1 min	1996-*					x			402 - 500 - 862	5 nm	Redundancy	Fröhlich et al 1995
SOHO-SEM	P	15 s	1996-*	x	x						0.1-50 + 30.4			Judge et al 1998
SNOE-SXP	P	95 min	1998-2002	x	x						2-8 + 2-16 + 5-20 + 15-35 + open			Bailey and Korde 2000
TIMED-SEE/EGS	S	95 min	2002-*		x	x			x		25-200	0.4		Woods et al 2005
TIMED-SEE/XPS	P	95 min	2002-*	x	x				x		0.1-35 + 121	5-35	Accuracy <20% - 12 photometers	Woods et al 2005
ENVISAT SCHIAMACHY	S		2003-*				x	x		x	240 - 2380	0.24-1.5	GOME like	Skupin et al. 2005
SORCE-SOLSTICE II	S	~6 hr	2003-*			x			x	x	115-310	0.1	Accuracy < 5%, drift <0.5% / yr Gap w/ UARS to be covered	Snow et al 2005
SORCE XPS	P	5 min	2003-*	x	x				x		0.1-35 + 121	1-10	Accuracy <20% - 12 photometers	Woods et al 2005
SORCE-SIM	S	~6 hr	2003-*				x	x		x	310-2400	0.25-33	Redundancy	Harder et al. 2005
Series of GOES-EUVS	P	10 s	2005-*	x	x				x		4-129 (10 + 30 + 20&50 + 10&40&70 + 120)	~25nm	Onboard Goes N, P, R	
MetOpA-GOME2	S		2006-				x			x	240-400 TBC			
PHOTON-PHOKA	P	0.4	2009 01-10	x	x				x		0.5-11 + 0.5-7&27-37 + 116-125		Accuracy: 6%	Kotov et al 2010
PHOTON-SPHINX	S	0.01	2009 01-10	x	x						0.1-3			Sylwester, Gburek, 20
ISS-SOLAR-SOLACES	S	15/day	2009-*		x	x			x		16-65 + 25-99 + 39-151 + 115-226 + 17-70 + 100-127	0.5-2.3	Accuracy 3-5%	Schmidtke et al 2006
ISS-SOLAR-SOLSPEC	S	15/day	2009-*			x	x	x		x	180-370 + 350-950 + 900-3000		Accuracy 1-3%	Thuillier et al. 2003
PROBA2-LYRA	P	0.05 s	2010-*	x	x	x			x		1-70 + 1-40 + 115-125 + 200-220	20-50 nm	Redundancy, diamond detectors	Hochedez et al 2006
SDO-EVE	S+P	10 s	2010-*	x	x				x		0.1-122	0.02 - 0.1 - 1	20% accuracy, 2% precision	Woods et al
PICARD-PREMOS	P	1 min-10Hz	2010-*				x	x			210 + 215 + 266 + 535.75 + 607.16 + 782.30	0.6 - 25		Schmutz et al 2009

See also: http://faesr.ucar.edu/

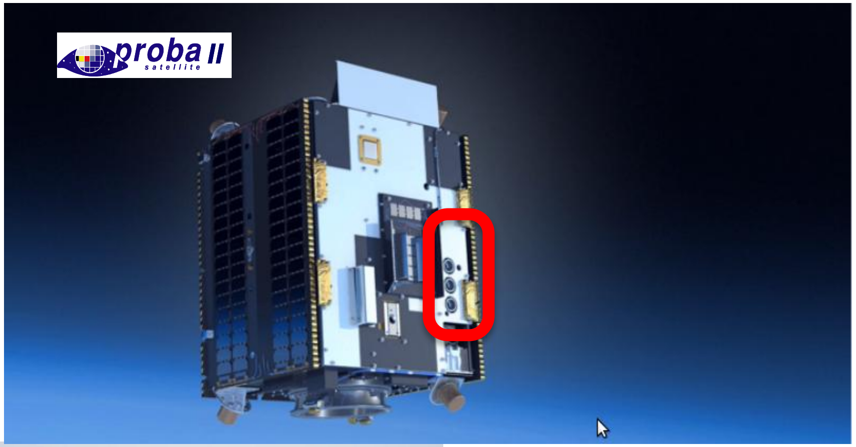
FAESR is the online resource of facilities and instruments for atmospheric and earth system research

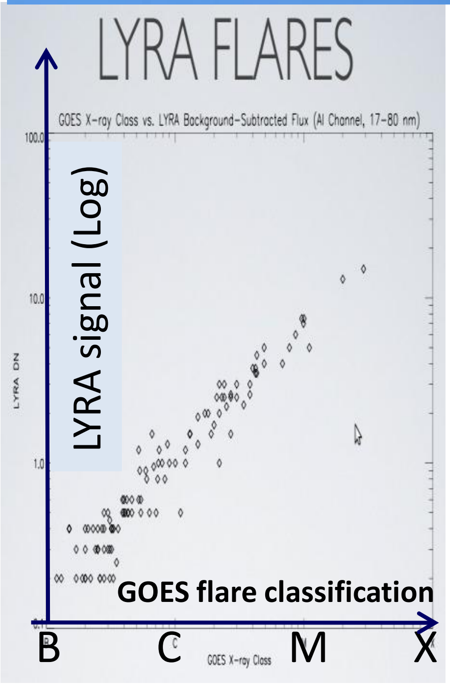
LYRA the "Large Yield Radiometer Ah!"

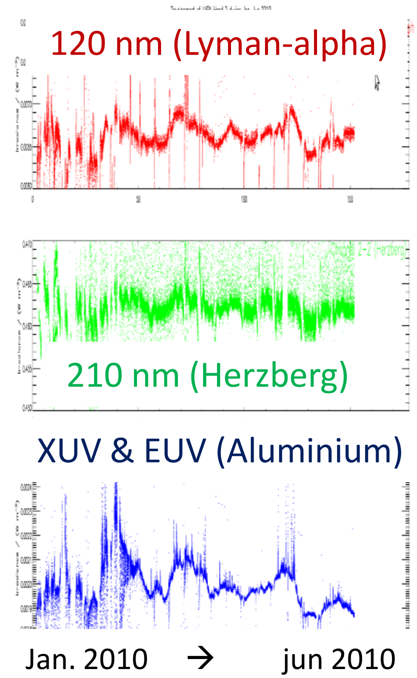
- LYRA proposed in 2002 for ESA-PROBA2
- Built by a Belgian-Swiss partnership
  - with contributions from Germany, Japan, USA, Russia
- First light: January 2010
- 3 units with 4 filter photometers each
  - Herzberg (220 nm)
  - Lyman-alpha (120 nm)
  - Aluminum (EUV + XUV)
  - Zirconium (EUV+XUV)
- First diamond UV detectors in space
- And also
  - High cadence (up to 100 Hz)
  - 3 redundant units calibrated on the BESSY synchrotron
  - 24 LEDs



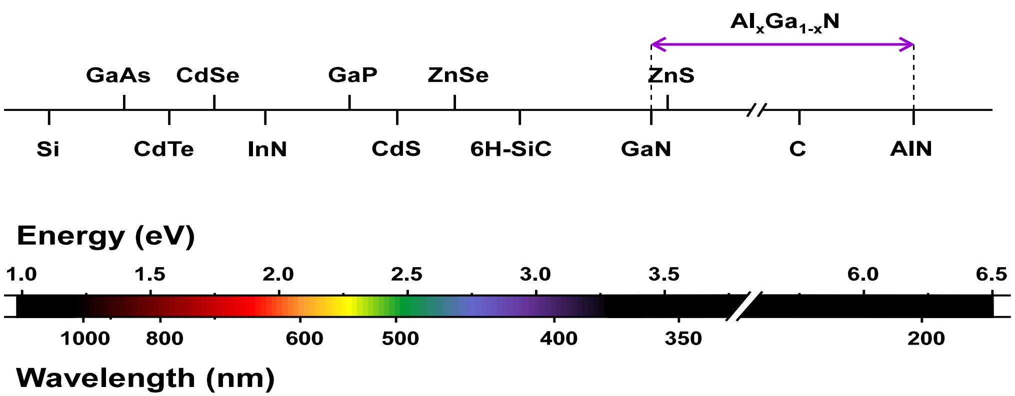
- First results
  - Long term variability seen in all channels
  - MHD stationary waves sensed in flares (sausage mode)
  - … more to come
- Calibrated data online





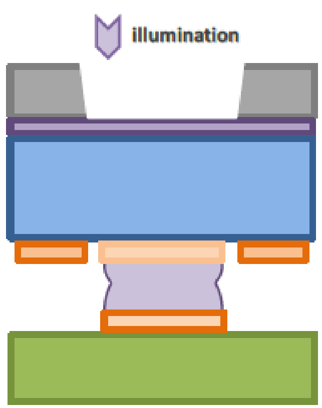


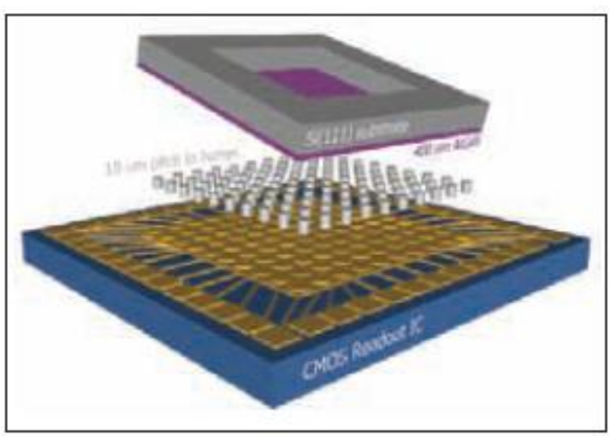
UV detectors made of diamond or nitrides

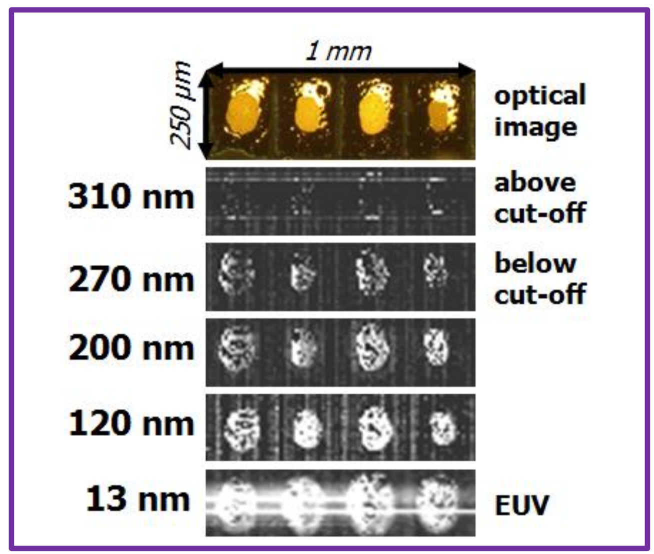


1. No dark current → warm detectors
   → simplified instrument
   → less polymerization → QE maintained
2. More robust detector against p+, n, γ, UV…
   → QE maintained
   → less 'cosmic ray hits' artifacts
3. Solar-blind → less filters which otherwise degrade

2011: 256x256 prototype sensitive to EUV et VUV

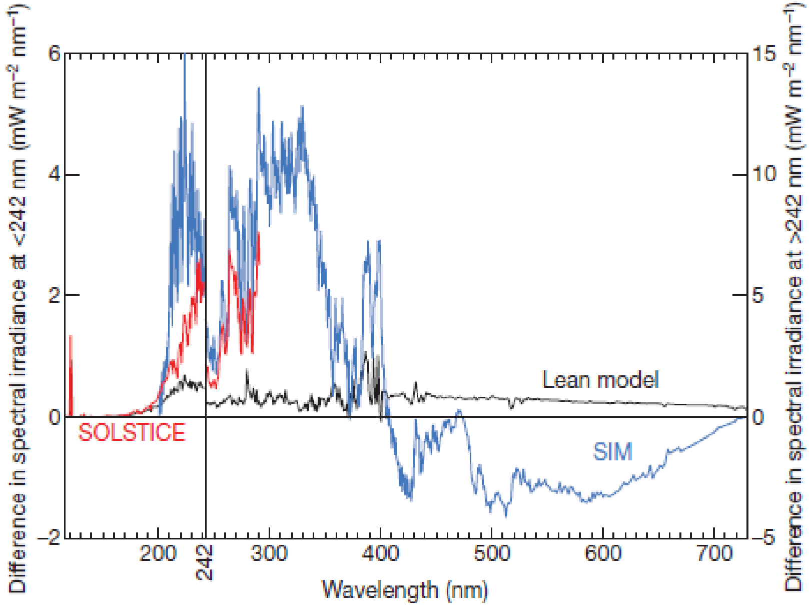






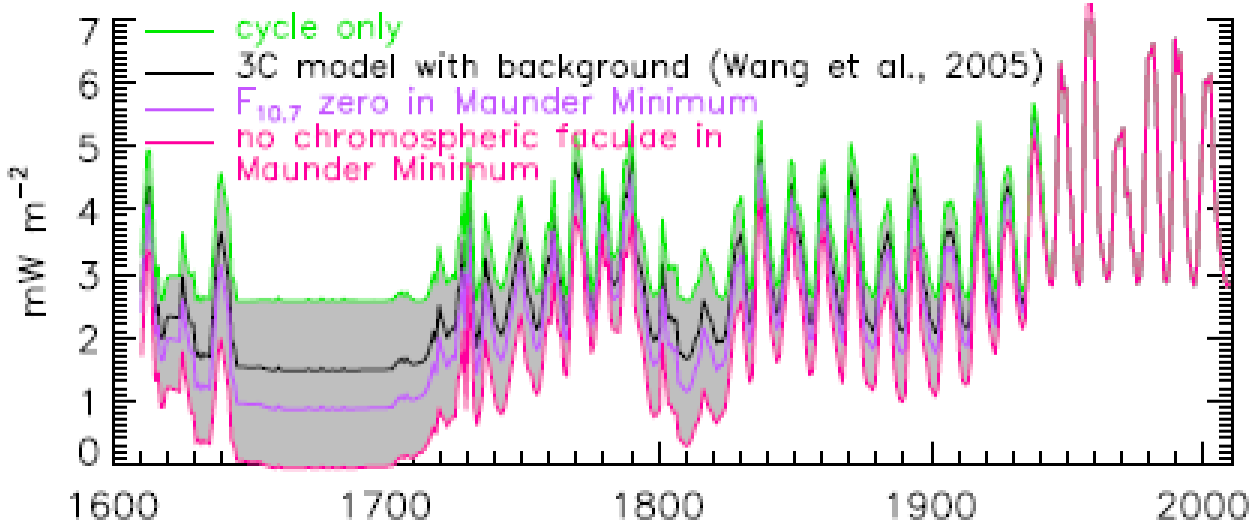
- Today we are ‘treated’ with data
  - Spectrometers and photometers monitor the electromagnetic spectrum

- What to do next?
  - Keep observing
    - Some instruments are ageing
    - Discrepancy in the red/NIR →
      - where variability is lowest
    - Last 3 cycles were similar
    - Shall cycle 24 be different?
    - Coordinate monitoring worldwide?
  - Cross-calibrate and consolidate comparable data
    - E.g. spectra from SCHIAMACHY, SIM, and SOLSPEC
    - Validation and ISO standardization cf. Gueymard 2006
  - Merge and unify data from
    - photometers, spectrometers, and imagers
    - Via models



Haigh et al, **Nature 2010**

Models



0-120 nm irradiance models
Lean et al 2011

- Purposes:
  - Reconstruct SSI towards the past
  - Reconstruct SSI over other spectral ranges
  - Forecast
  - Validate physical understanding

- But they can diverge a lot. How to validate them?
  → Confront
    - better models and
    - more accurate and precise measurements

  → Then, Explain the discrepancies and upgrade the models
    - E.g. does gravitational energy (viz. Sun radius) play a role in the irradiance budget?

The SSI *above* and *below* Lyman-α

The measurements (their principle, optics, detectors…) are different

Moreover:

< 120 nm		**> 121 nm**
• Corona – TR (mostly)	⟷	• Photosphere – chromosphere (mostly)
• Hot thin corona (mostly) + some TR	⟷	• Cool optically thick continuum & Warm thick chromosphere + TR
• Emission lines (mostly)	⟷	• Lines in absorption (mostly)
• Nowcasting models use coronal segmentation	⟷	• Nowcasting models use fractional areas of photospheric intensity images /magnetograms

Yet, we are bound to exploit the same proxies (SSN) for models and SSI reconstructions

See work by Dudok, Lilensten, Cessateur, Vieira, Kretzschmar

Yet, "The whole atmosphere must be seen as an integral phenomenon"

Wedemeyer-Böhm Lagg Nordlund 2008

Coupling from the photosphere to the chromosphere and the corona

Tentative lists of existing models

>120 nm - VUV-VIS

Model name	Spectral range nm	Type of input	Characteristics	Reference paper (incomplete list)
SATIRE-S	220-240 and 270-160 000	Magnetograms	LTE Filling factors, CLV	Fligge et al 1998 Wenzler et al 2006 Krivova Solanki Unruh 2011
COSI SolMod3D	10-100 and 100-700	Magnetograms EIT	NLTE, molecular lines Spherical Scheme	Haberreiter Rozanov Schmutz 2002 Shapiro et al 2010 Haberreiter 2011
SRPM	200-100 000	7 atmosphere component from PSPT (soon HMI): intergranular cell, quiet and active network, faculae, plage, sunspot umbra and penumbra	NLTE 1D semi-empirical atmospheric models	Fontenla et al 2009
SWAN	Lyman-alpha	SRPM heritage + SWAN + “far-side helioseismic imaging”	Forecast potential	Quemerais & Bertaux 2002 Fontenla et al 2009
Rome		4 atmosphere components from PSPT	dark magnetic from continuum, bright magnetic from chromosphere	Penza et al 2003
NRLSSI	120-100 000	>300nm : sunspot blocking function (continuum) & Mg index <300nm: Mg index alone	Center to limb variations (CLV)	Lean et al 2005
SOTERIA			Neural network	Vieira et al 2011
…				

Model name	Spectral range nm	Type of input	Characteristics	Reference paper (incompletelist)
NRLEUV2	1-120	Full disc CaIIK	DEM based Limb brightening	Warren et al 2006
S2K	1-121	Measurements	Empirical ISO	Tobiska 2006
HEUVAC	5-57,5	F10.7 & EUVS	Empirical Based on F74113	Richards et al 1994, 2006
FISM	0.1-193 nm	MgII c2w, Ly-a, 30.5nm, F10.7, 36.5nm, and 0-4nm Flare Proxies: GOES 0.1-0.8 nm and time derivative	Relations based on TIMED SEE & UARS SOLSTICE 1 minute cadence – flare oriented	Chamberlin Woods Eparvier 2007
…				

<120 nm - XUV-EUV

N.A. Krivova et al. / Journal of Atmospheric and Solar-Terrestrial Physics 73 (2011) 223–234 229

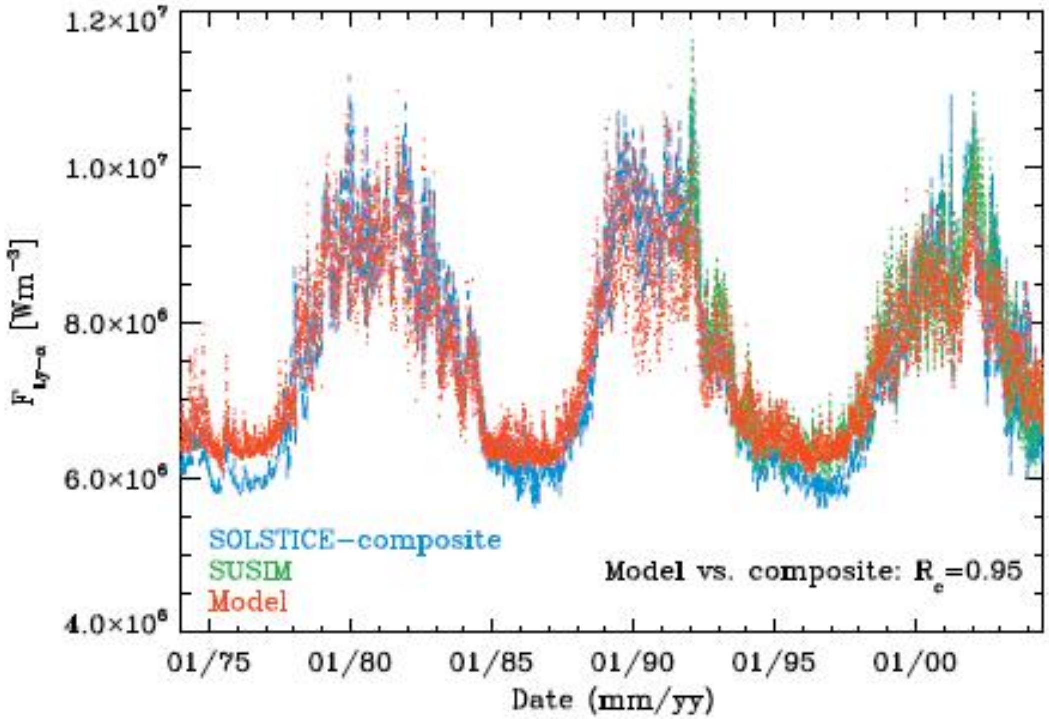


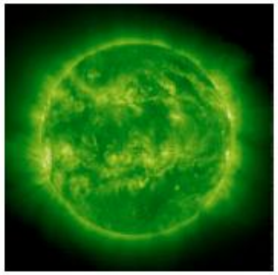
Fig. 6. Solar Ly-α irradiance since 1974: reconstructed by SATIRE-S (light grey crosses; in online version red), measured by the SUSIM instrument (grey dashed line; in online version green) and compiled by Woods et al. (2000; black dotted line; in online version blue). From Krivova et al. (2009). (For interpretation of the references to colour in this figure legend, the reader is referred to the webversion of this article.)

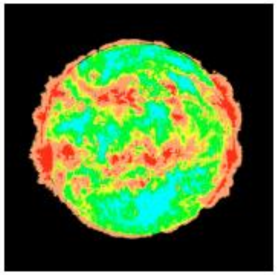
Nice success of the SATIRE-S model, but using an empirical extension, based on a correlation analysis of SUSIM data

Magnetogram-based SSI models

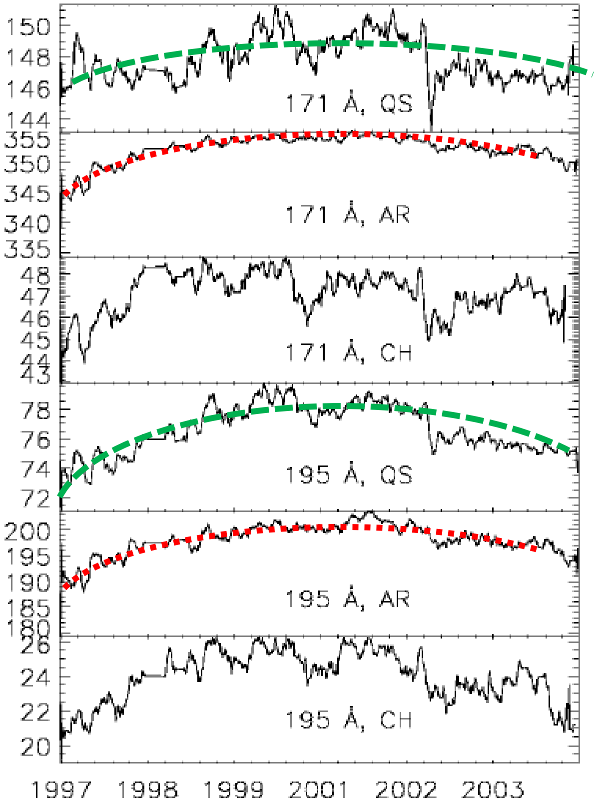
- Such models assume
  1. Irradiance variability to be solely controlled by photospheric magnetism
  2. Magnetic structures to have an univocal & constant spectral radiance
- Is this true?
  - If yes, SSI series can be extended to the past with magnetograms or their proxies
- Yet it is worth testing precisely the above 2 assumptions
  - by reconciling best SSI models with precise SSI measurements
  - Possible deviations could hint at additional mechanisms
    - E.g. Steiner Ferriz-Mas 2005
      Connecting solar radiance variability to the solar dynamo with the virial theorem

Constant QS?

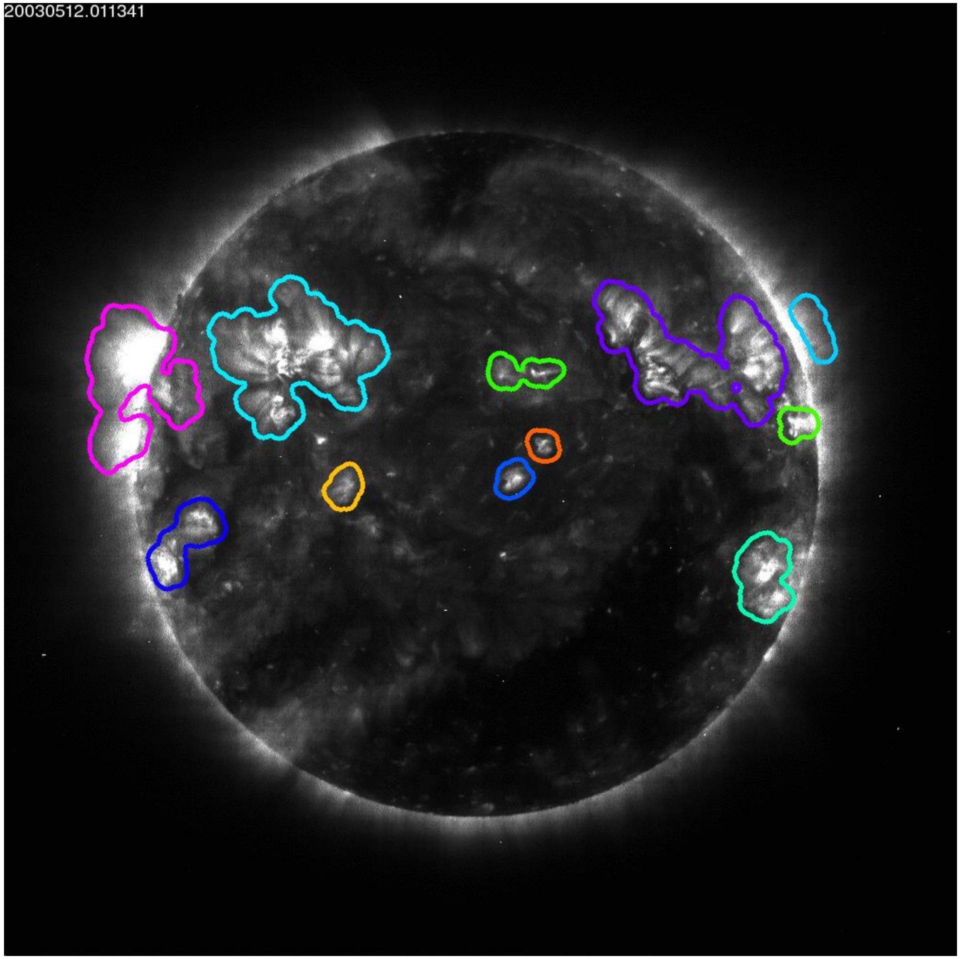




Average brightness of
AR, QS, CH (SOHO EIT)



Barra et al 2009



C. Verbeek and the SDO SPOCA project

Conclusion

- Validate & specify the SSI needs

  e.g.

  – Shapiro et al 2011
  Sensitivity of the Earth's middle atmosphere to short-term solar variability and its dependence on the choice of solar irradiance data set

  – Haigh et al 2010
  An influence of solar spectral variations on radiative forcing of climate

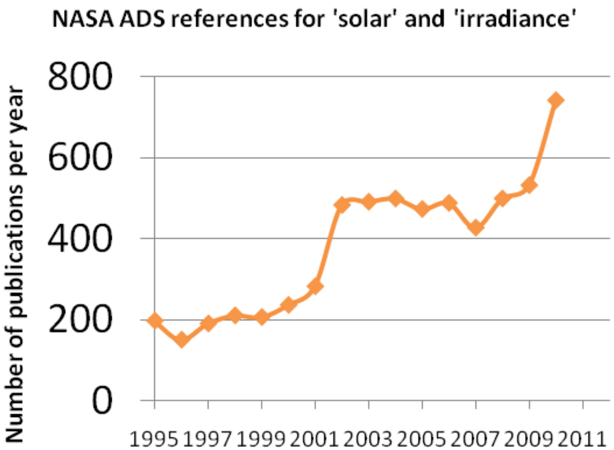
- A possible vision

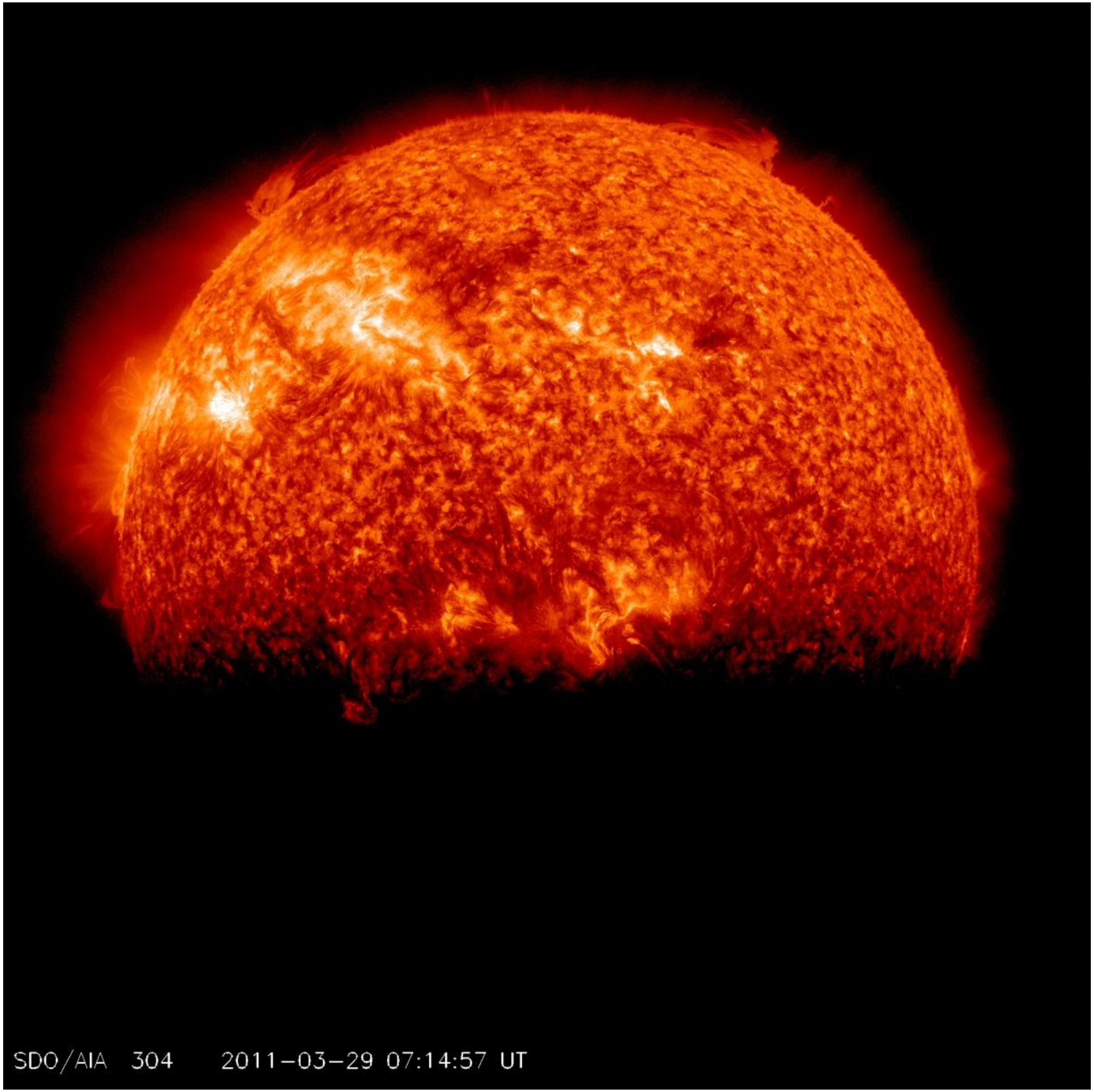
  – A swarm of photometers or better,
  low spatial resolution calibrated imagers in the heliosphere

  – Regular rockets → calibrated spectra

  – Continued int'l dialogue re. instruments, data, models…

    - LISIRD

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