SOHO CDS radiances and irradiances along the cycle

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SOLID EU FP7 network
First European Comprehensive SOLar Irradiance Data exploitation

1) SOHO/CDS-NIS calibration

- Del Zanna et al. (2001), A&A, 379, 708-734
- Del Zanna et al. (2005) Mem. Sait., 76, 953
- Del Zanna & Andretta (2006), ESA-SP 617
- Del Zanna & Andretta (2010), proc. IAU symp., no. 264, 78.
- Del Zanna et al. 2010, A&A, 518, A49
- Del Zanna & Andretta,2011, A&A, 528, A139

Note: the SOHO/GIS calibration is discussed in Kuin & Del Zanna (2007) Sol. Phys., 242, 187

2) He II 304 calibration

Include various inter-calibration comparisons

3) Hinode/EIS calibration using atomic data. Factor of 2 - unexplained

4) SDO/EVE flare V2/V3 spectra and checking the calibration with atomic data

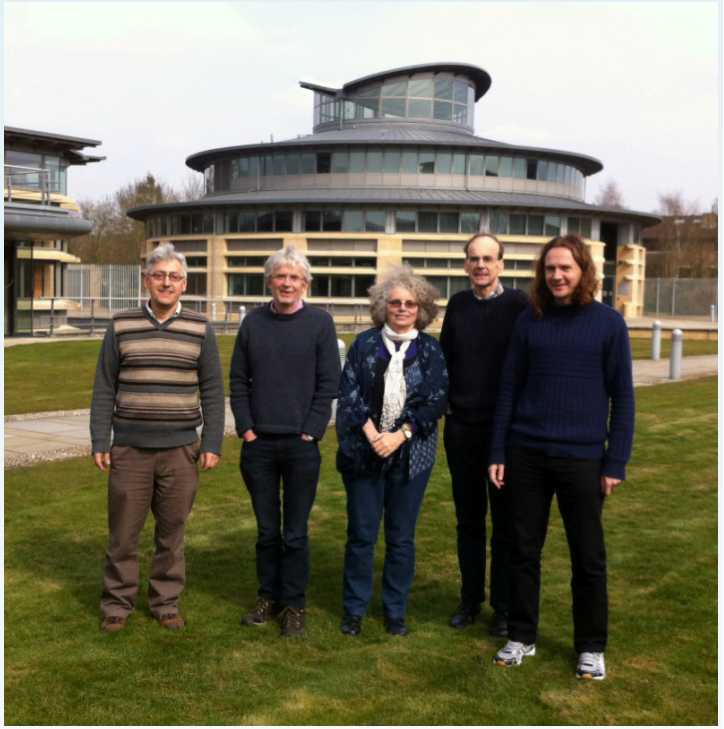
5) SDO AIA/EVE v.2/v3 direct cross-calibration – good

6) AIA/ EIS direct/indirect cross-calibration - good

7) QS reference spectra – soft X-rays and EUV (EVE) - good

My expertise

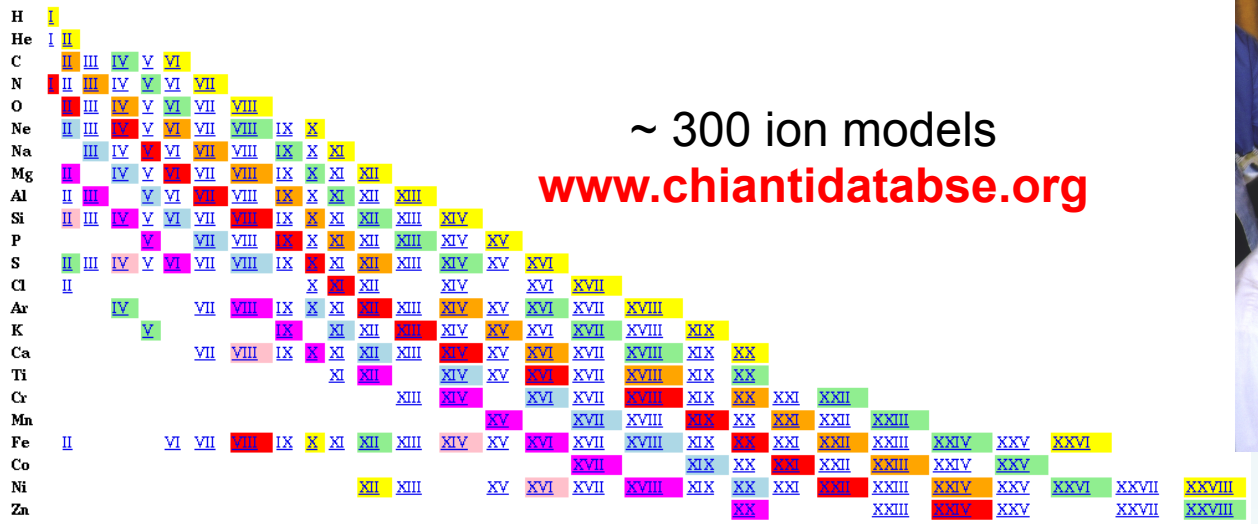
- Atomic data calculations **APAP Network**
  http://www.apap-network.org/



- Atomic data benchmarking and line identifications
- Spectral diagnostics
- EUV calibration (SOHO/ NIS, SOHO/GIS, Hinode/EIS)
- Atomic data provision

Atomic data distribution

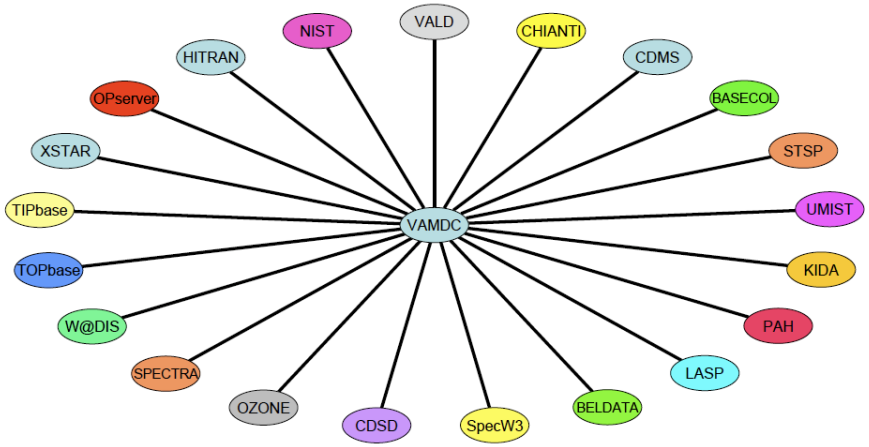
CHIANTI atomic package provides all atomic data and programs for collisionally-ionised optically-thin plasmas (line and continuum)



~ 300 ion models

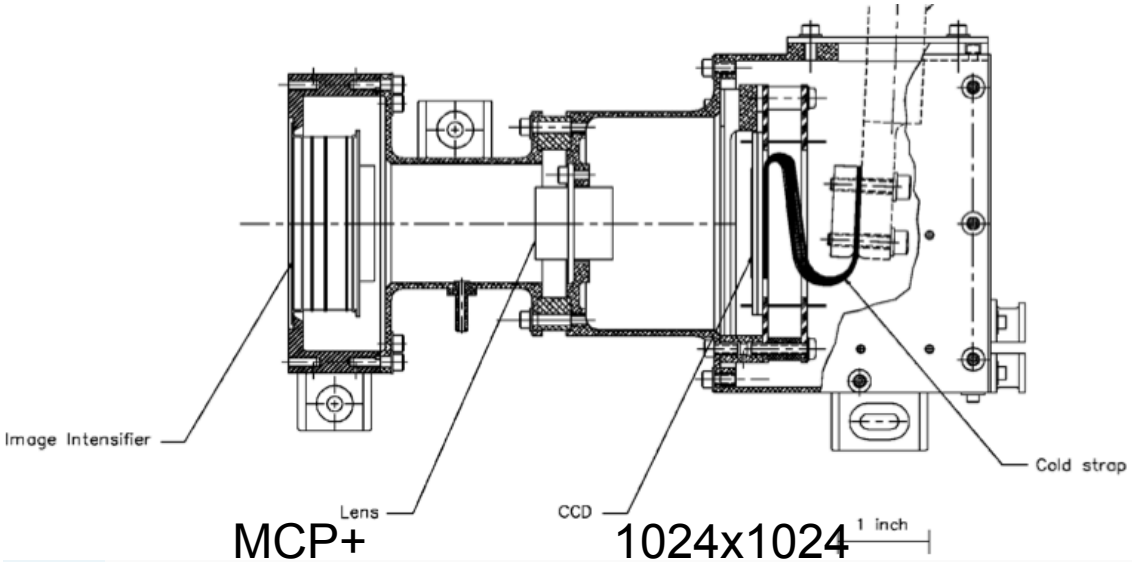
www.chiantidatabse.org

Latest V.7.1 (Landi et al. 2013), V.8 (Del Zanna+ 2013) will introduce new format.
Over 1000 direct citations, few 100s/year



CHIANTI data are available via the **Virtual Atomic and Molecular Data Center** (www.vamdc.eu), the largest collection of such data.

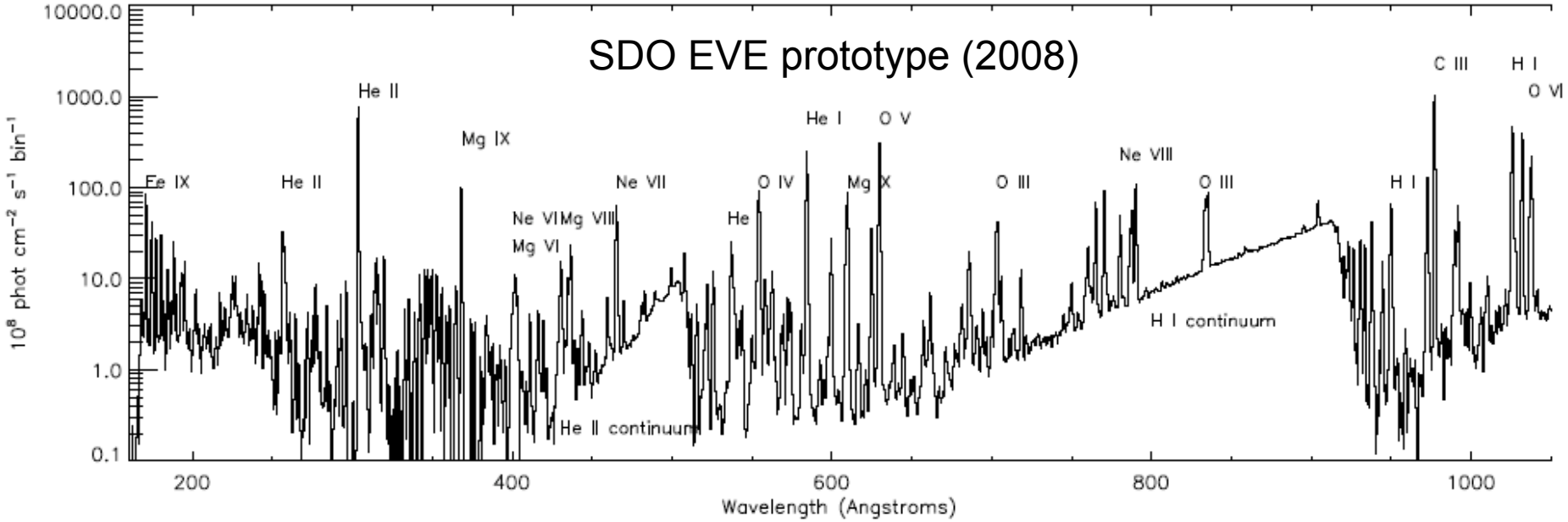
SOHO CDS



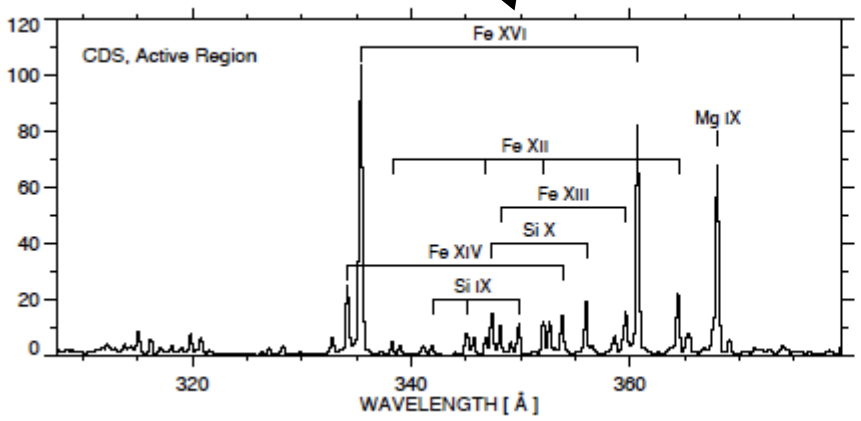
MCP+ phosphorus plate

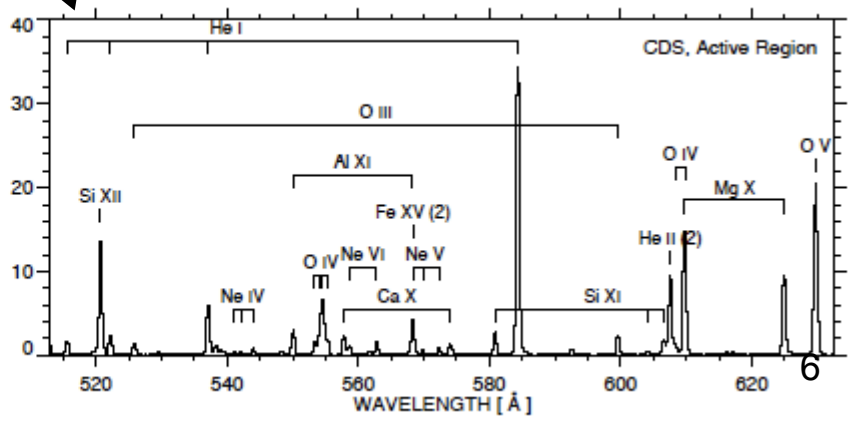
1024x1024 CCD (visible)

SDO EVE and SOHO CDS NIS



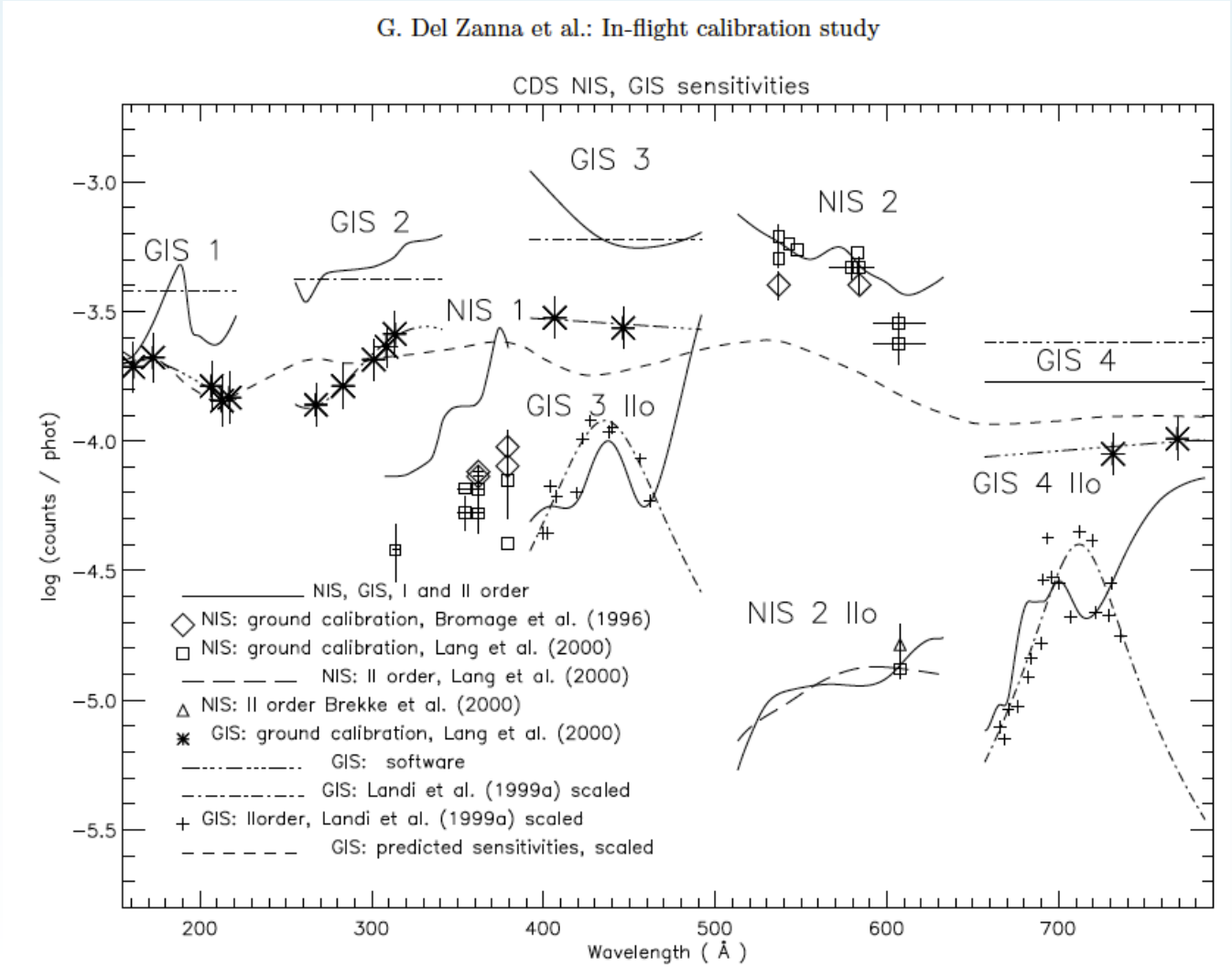
SOHO CDS NIS – launched 1995 – operational until 2013



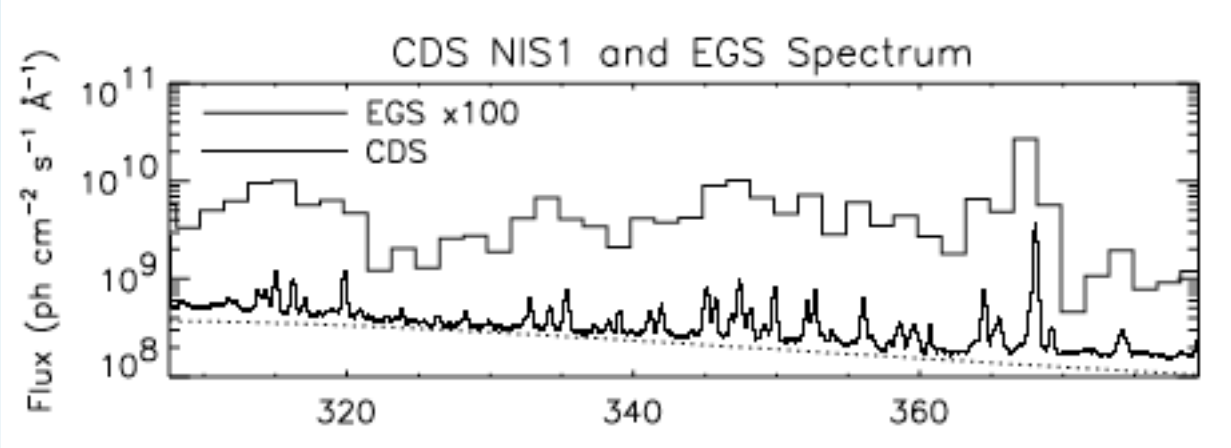


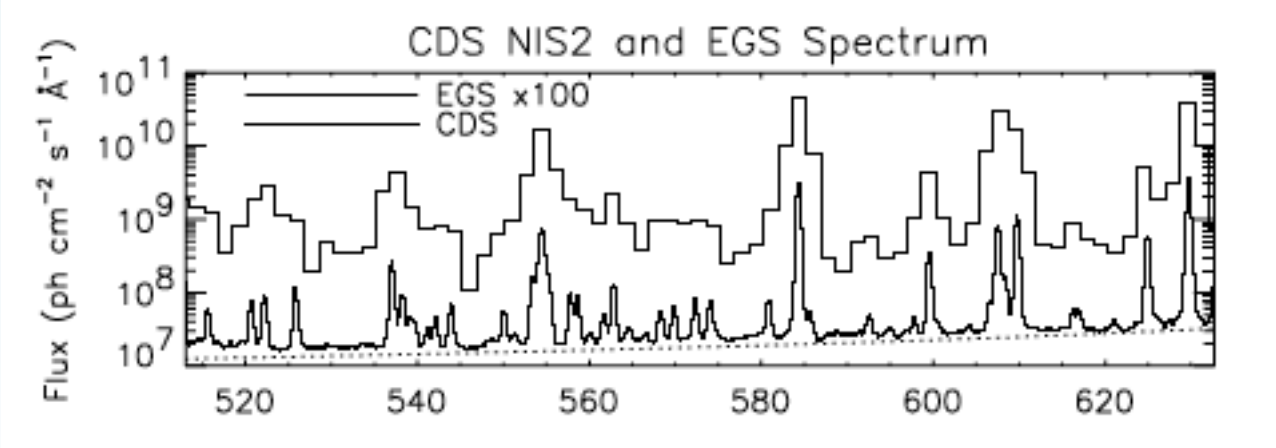
Ground CDS calibration incorrect

The line ratio technique, combined with the (only) underflight sounding rocket in 1997 was used to obtain the only in-flight calibration of all channels (Del Zanna et al. 2001, A&A, 379, 708-734)



NIS 1 problem attributed to undetected misaligment during the laboratory work.





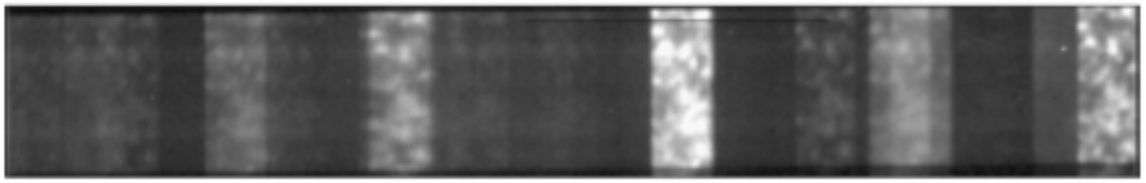
May 1997 rocket EGS (Brekke et al. 2000)

SOHO CDS NIS

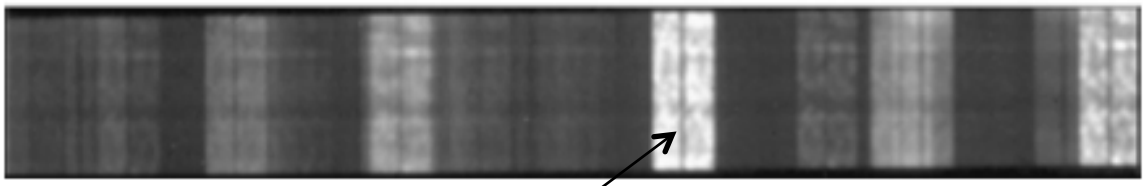
- Lang+ 2007 extended the line ratio technique.
- There were SERTS rocket flights
- Two ISSI workshops early on the mission

Comparisons CDS-SUMER, CDS-SEM only first four years of SOHO. Agreement only within 40%

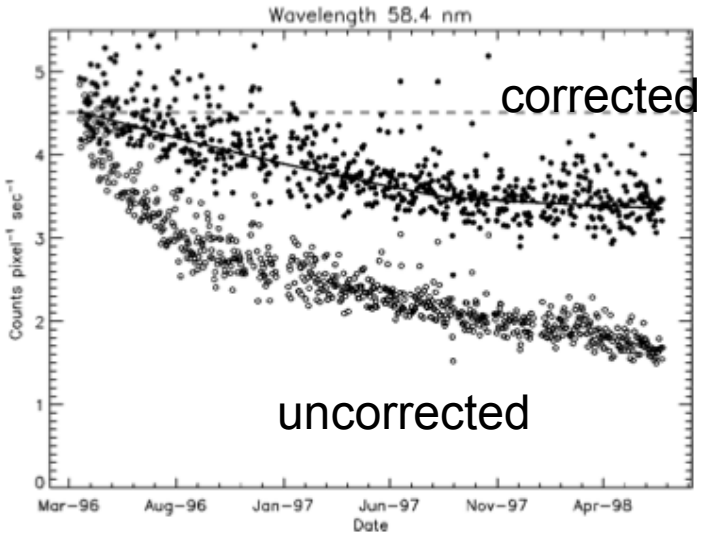
1996



1998



Burn-in in He I 584

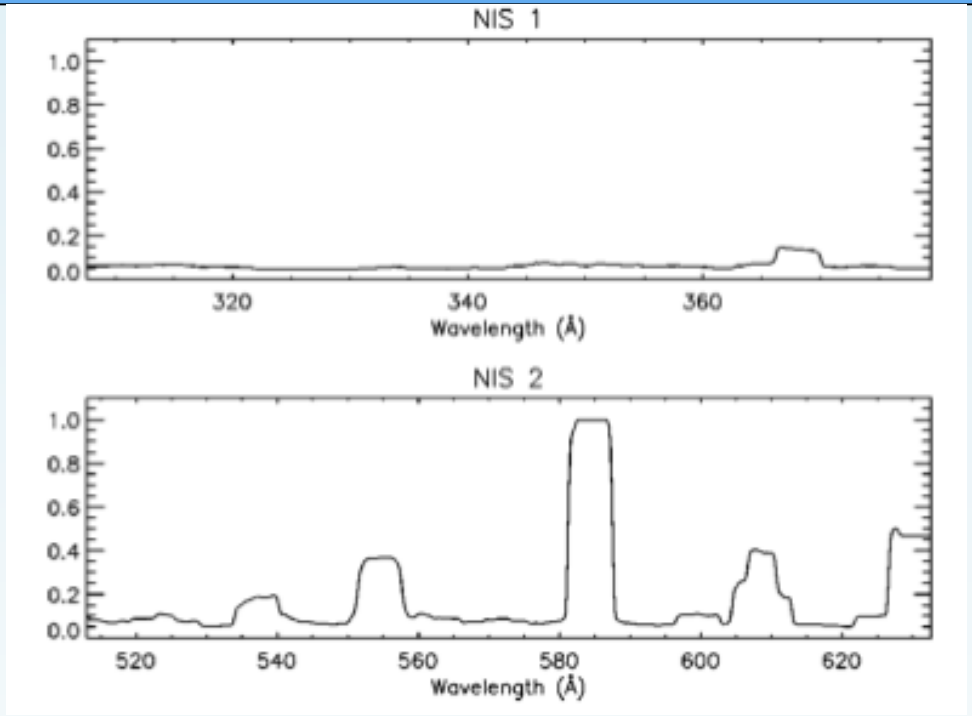


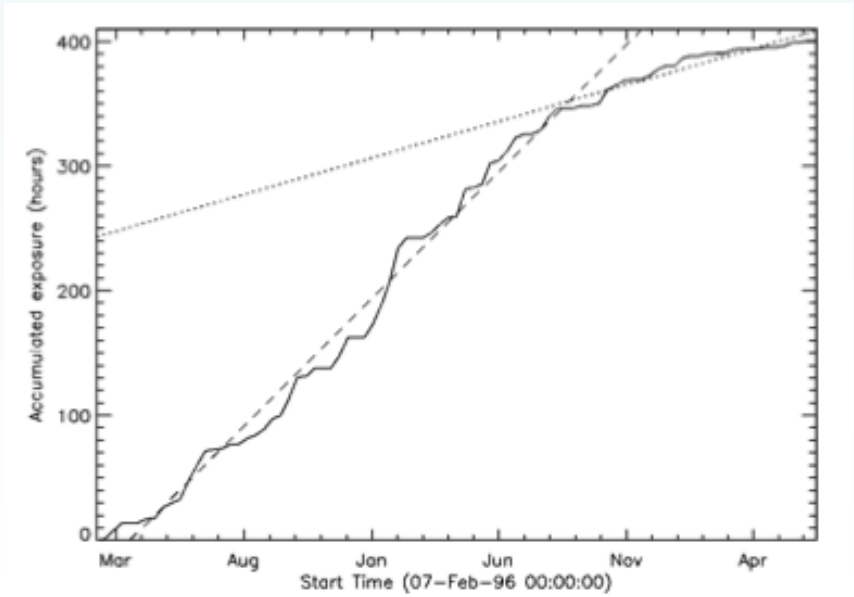
The correction to the use of the narrow slit is fairly straightforward and obtained from 90” slit data (Thompson 2000).

The ‘CDS standard long-term correction’ assumes a degradation due the use of the 90” slit.

The model turned out to be incorrect, over-estimating by 2004 the strong lines by factors of 2-3. To cut a 6-years long story short…

Calibration of the long-term gain depression (LTGD) in NIS

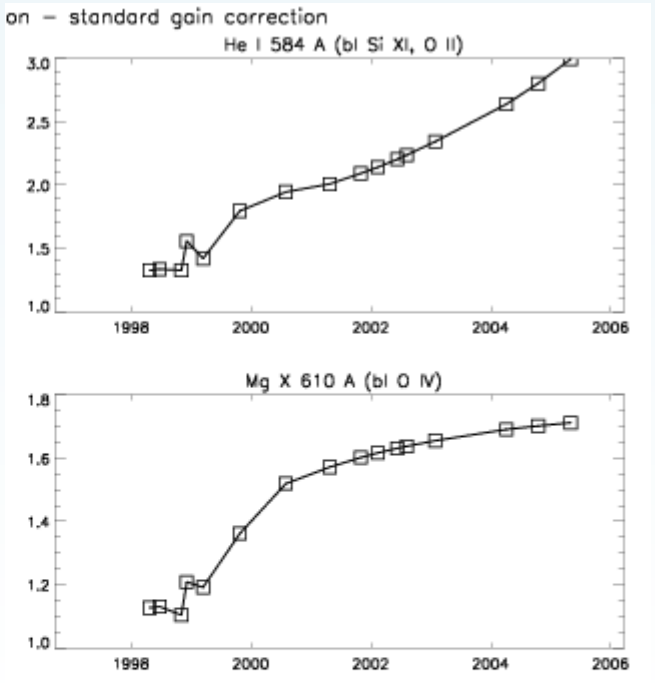


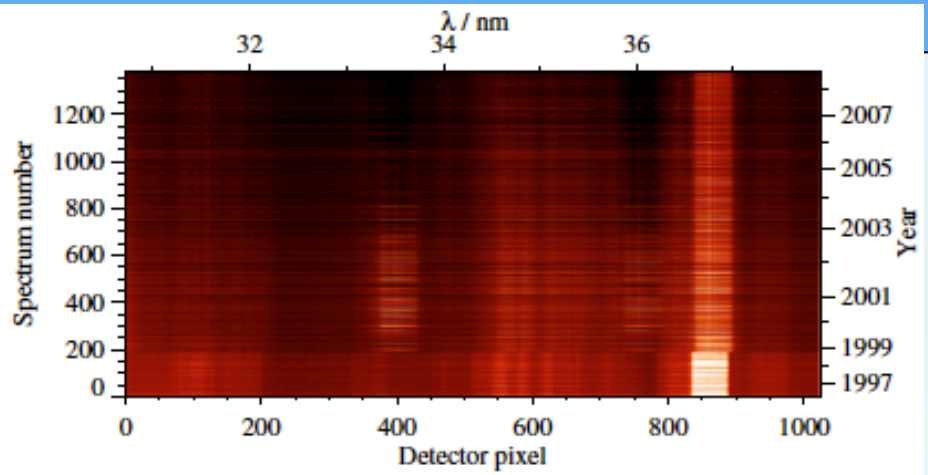


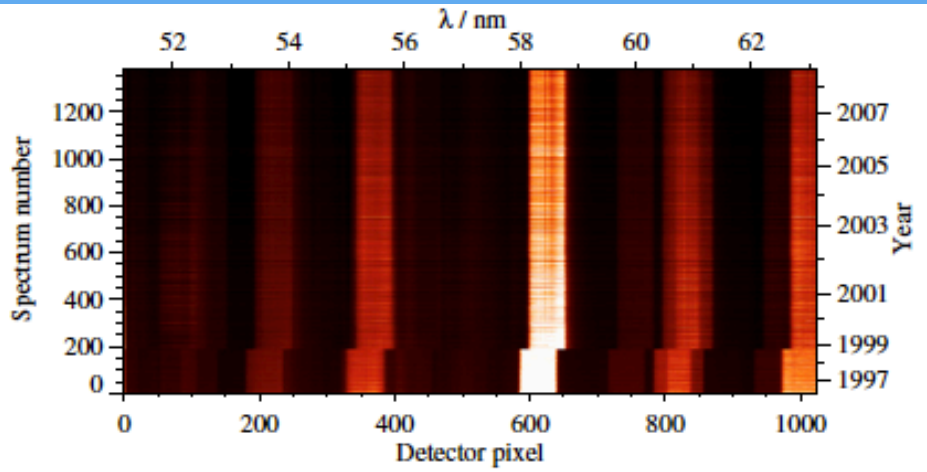
Was NIS LTGD 'standard correction' (Thompson 2000):

1) Due to the use of the 90"slit
2) Assume a standard QS spectrum
3) Estimate the total exposures

Gives correction factors of over 3 by 2006 for the strongest lines




λ / nm
32
34
36
Spectrum number
0
200
400
600
800
1000
1200
Year
1997
1999
2001
2003
2005
2007
Detector pixel
0
200
400
600
800
1000


λ / nm
52
54
56
58
60
62
Spectrum number
0
200
400
600
800
1000
1200
Year
1997
1999
2001
2003
2005
2007
Detector pixel
0
200
400
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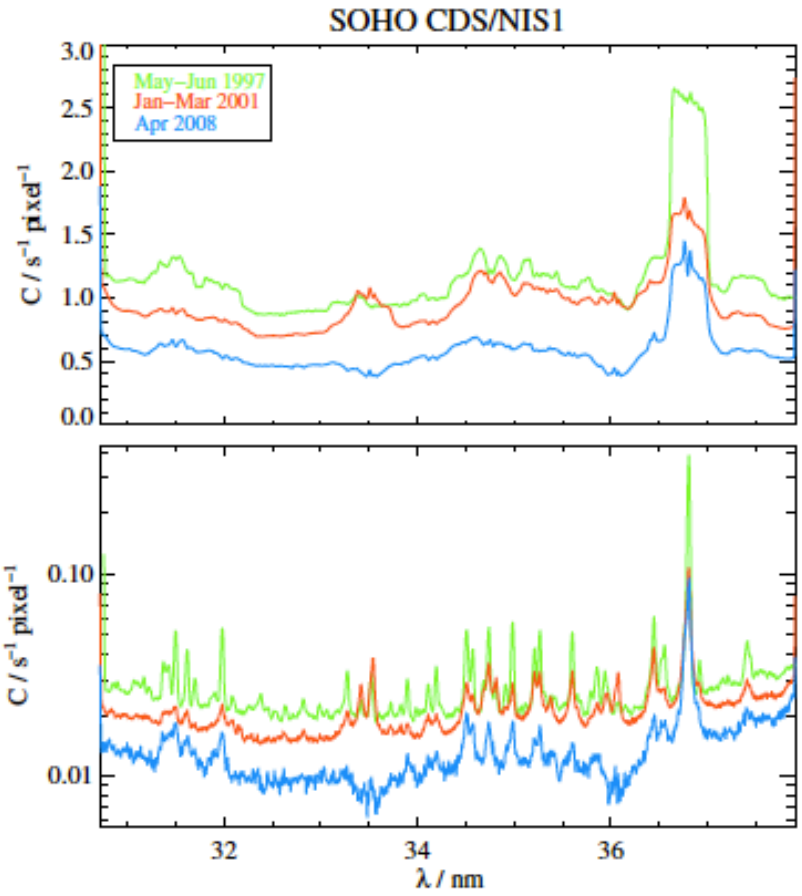
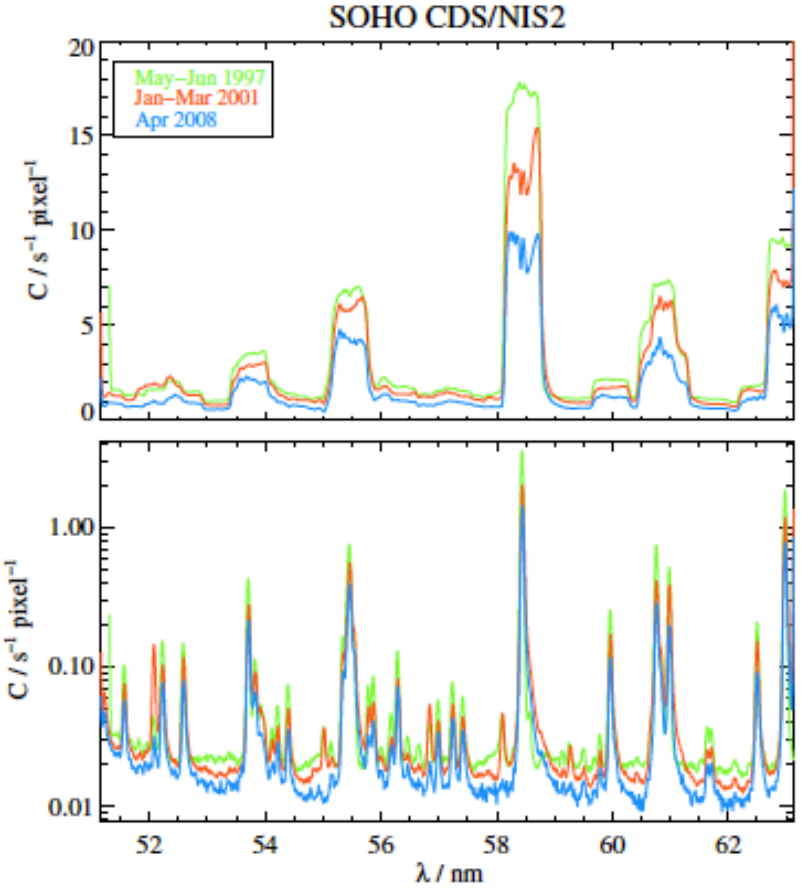
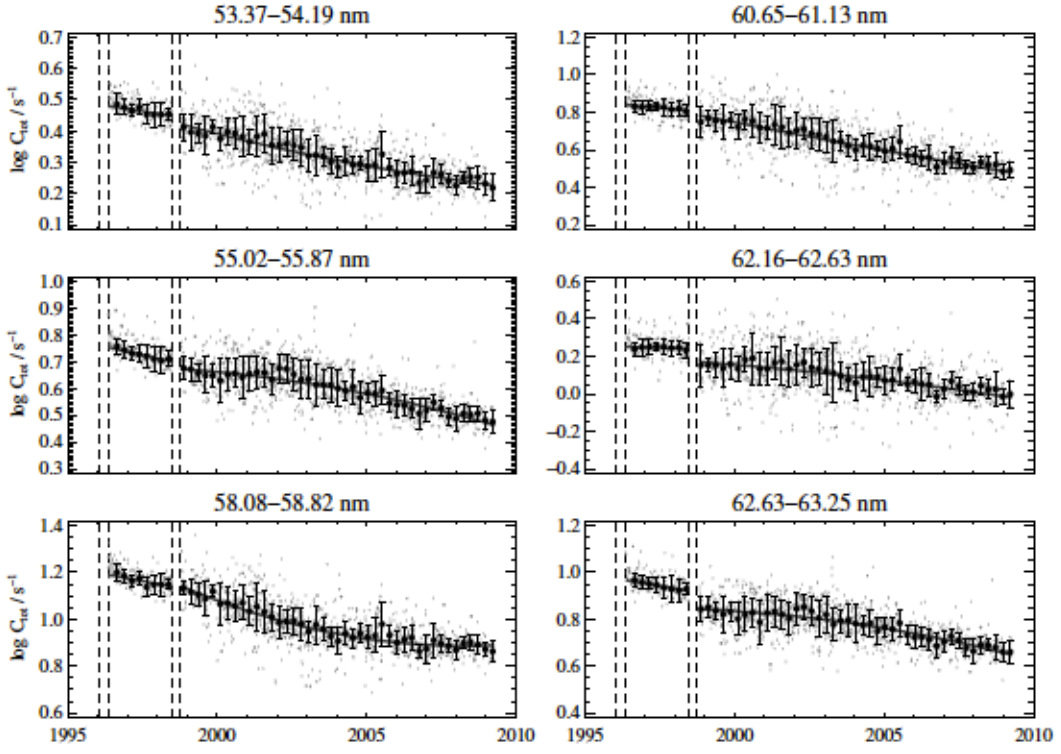
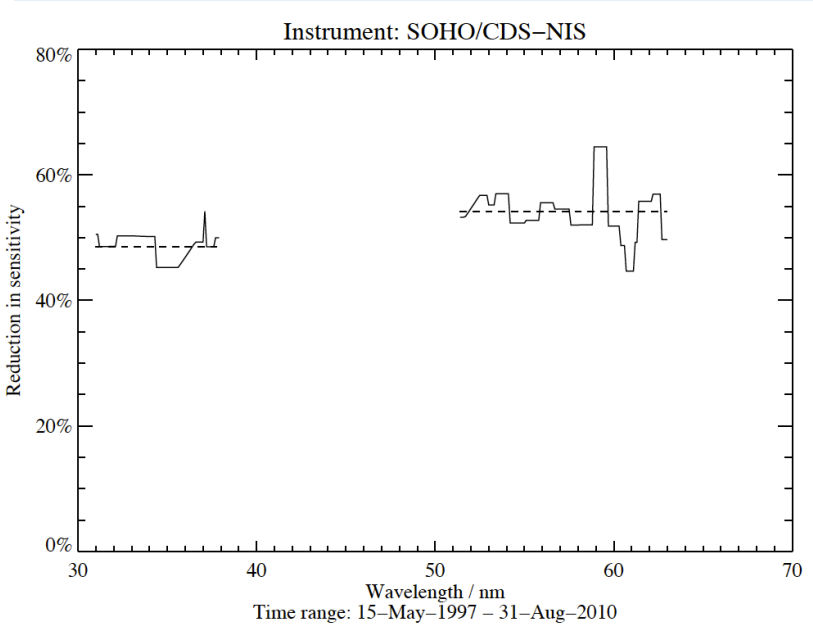

SOHO CDS/NIS1
May–Jun 1997
Jan–Mar 2001
Apr 2008
C / s⁻¹ pixel⁻¹
0.0
0.5
1.0
1.5
2.0
2.5
3.0
0.01
0.10
λ / nm
32
34
36


SOHO CDS/NIS2
May–Jun 1997
Jan–Mar 2001
Apr 2008
C / s⁻¹ pixel⁻¹
0
5
10
15
20
0.01
0.10
1.00
λ / nm
52
54
56
58
60
62

Count rates in QS with 90” slit





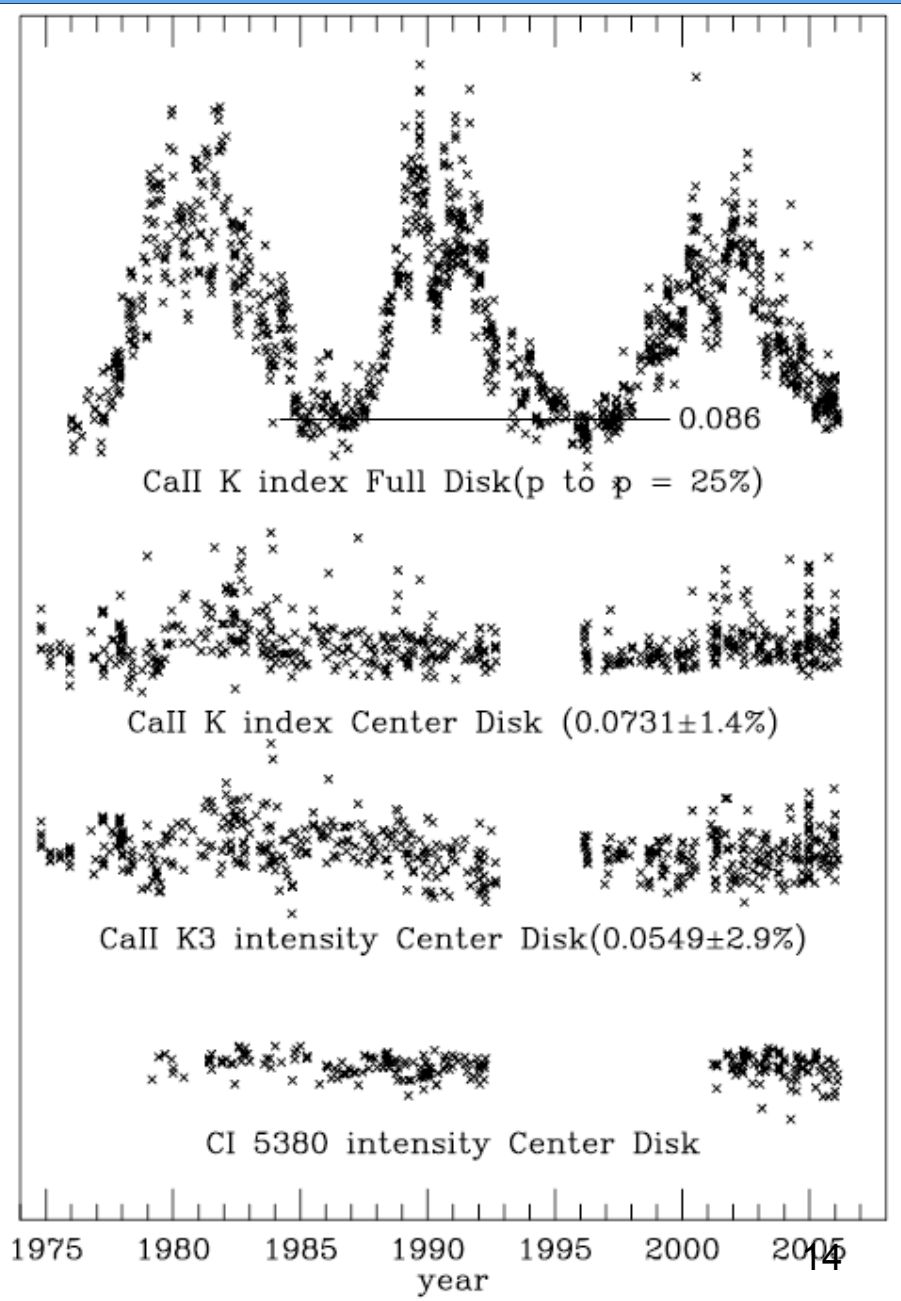
The new corrections have been found studying the behaviour of quiet Sun regions as observed routinely with the wide 90” slit (NIMCP monitoring) during 1996—2010 and assuming radiances do not change.

Overall degradation similar at all wavelengths.
New correction: assume that radiances in TR lines are constant.
GDZ long-term correction is being used to calibrate the final NIS data.

Using the quiet Sun as a standard candle..

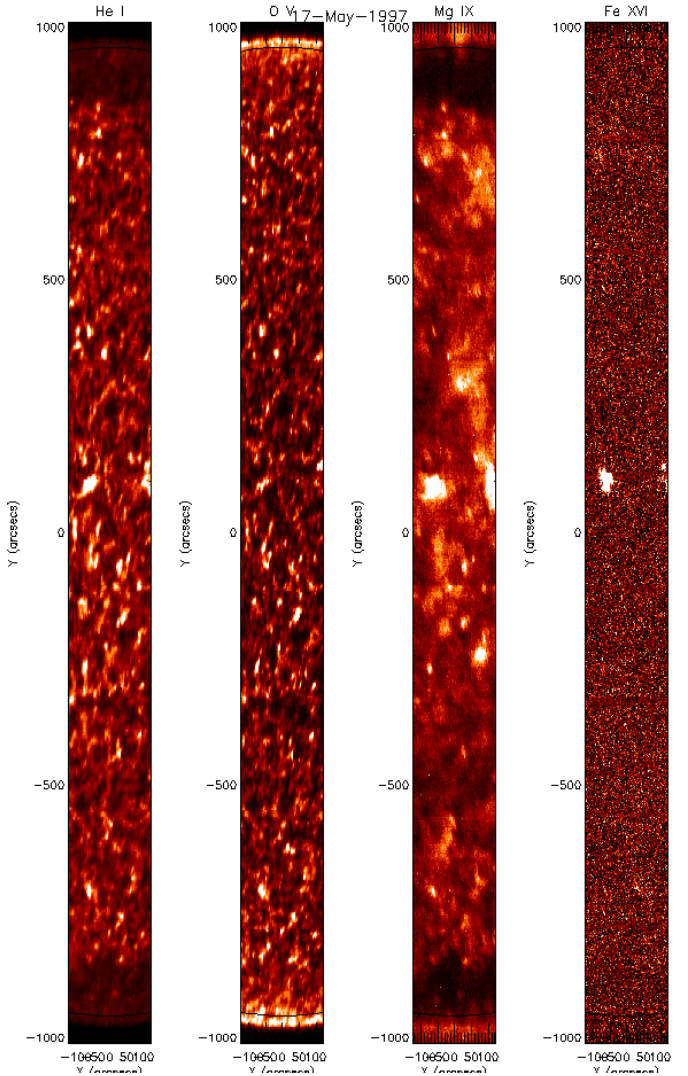
There are no obvious long-term variations of the 'quiet Sun' at chromospheric levels (Livingston et al. 2007)

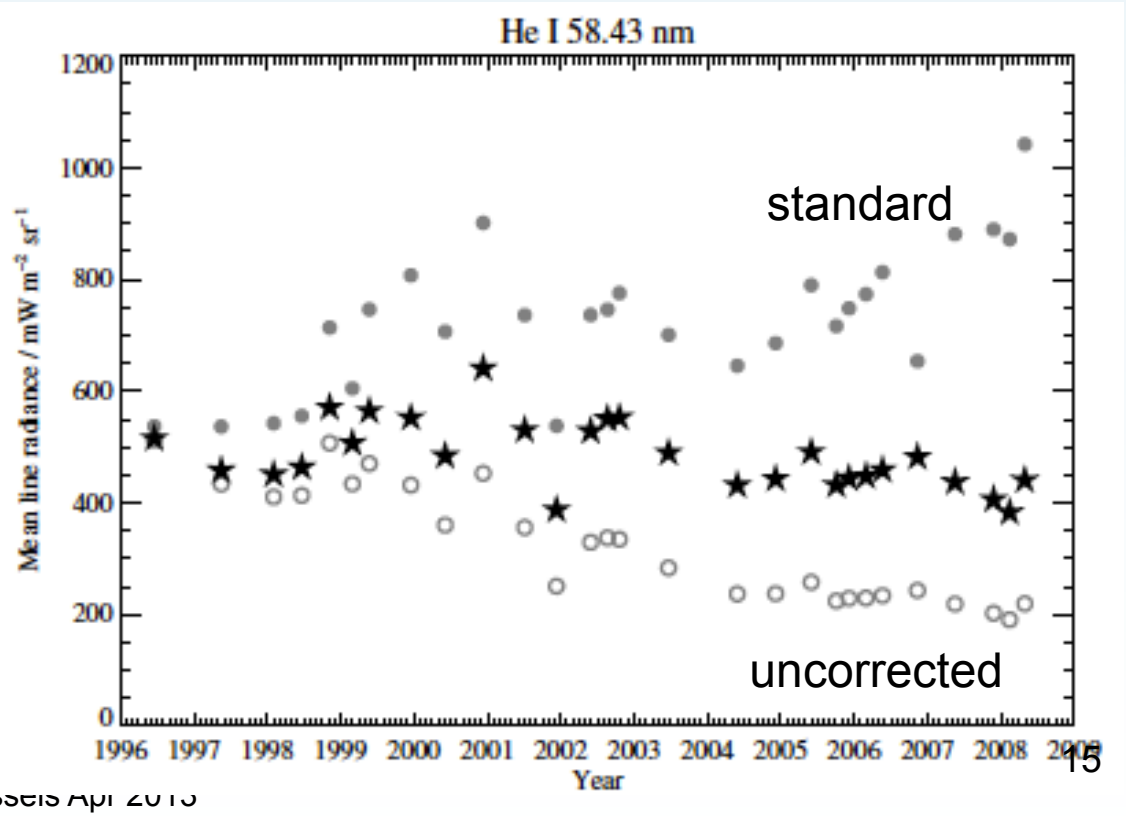
We assume that low-T lines have constant radiances in the quiet Sun



Synoptic

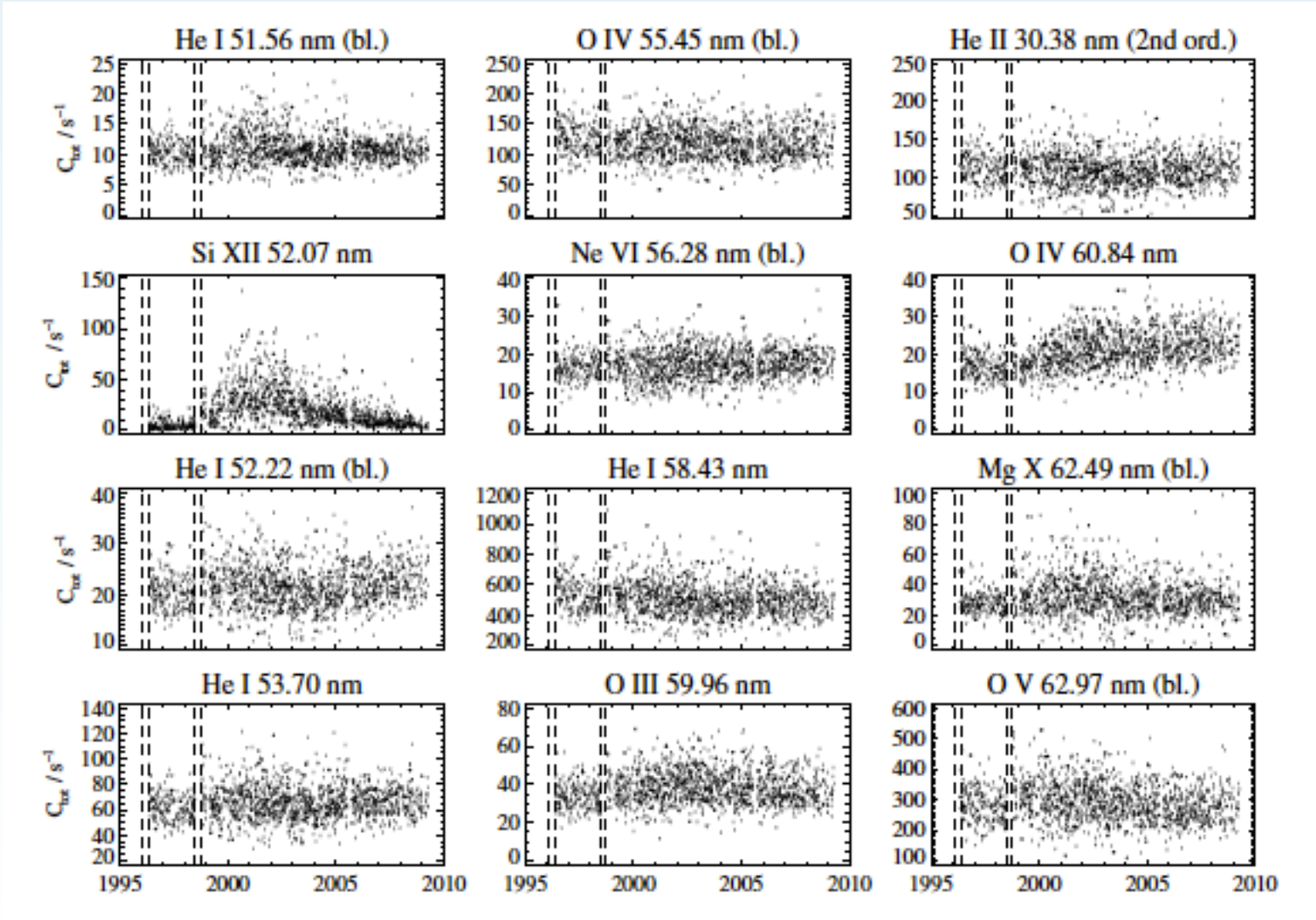
We have analysed a sample of the 13 years of NIS synoptic observations to study the radiance distributions. He I radiances over-estimated by a factor of 3 by 2010



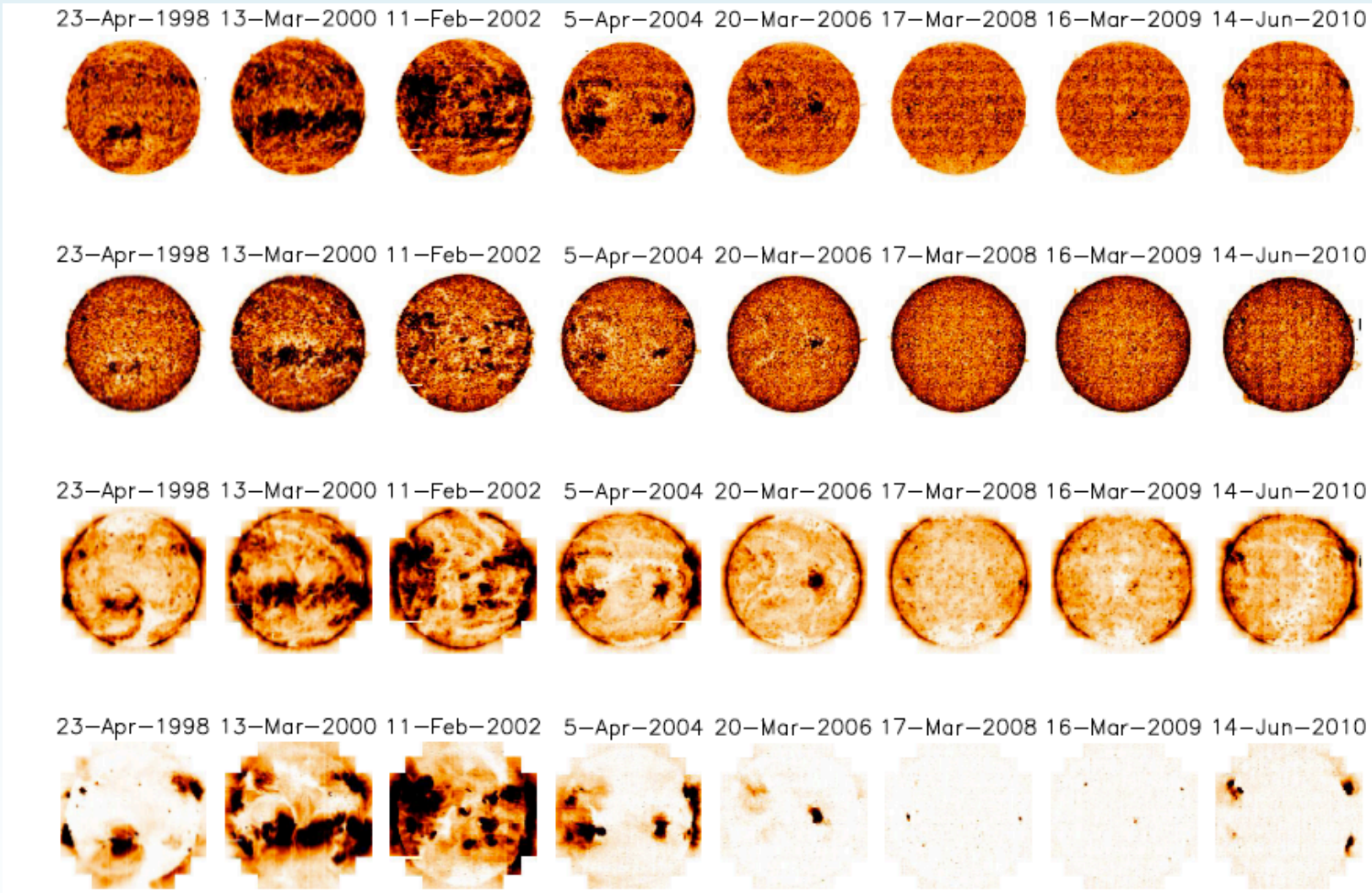


Count rates in QS with 2” slit

After the new long-term correction



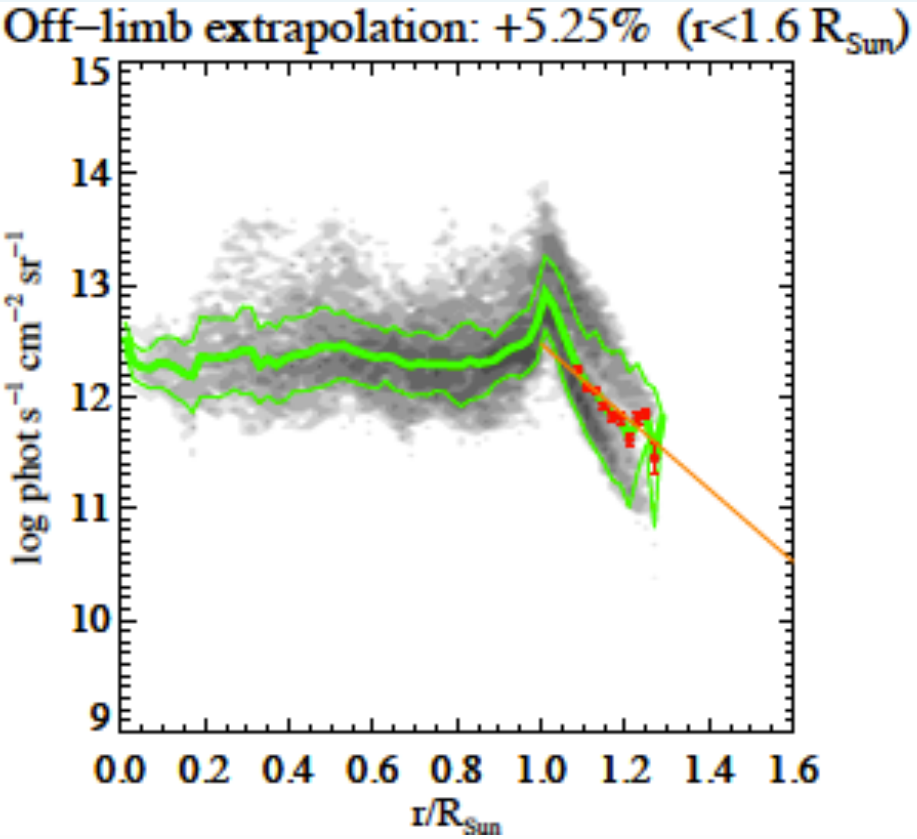
SOHO CDS NIS USUN: first EUV radiances along a cycle

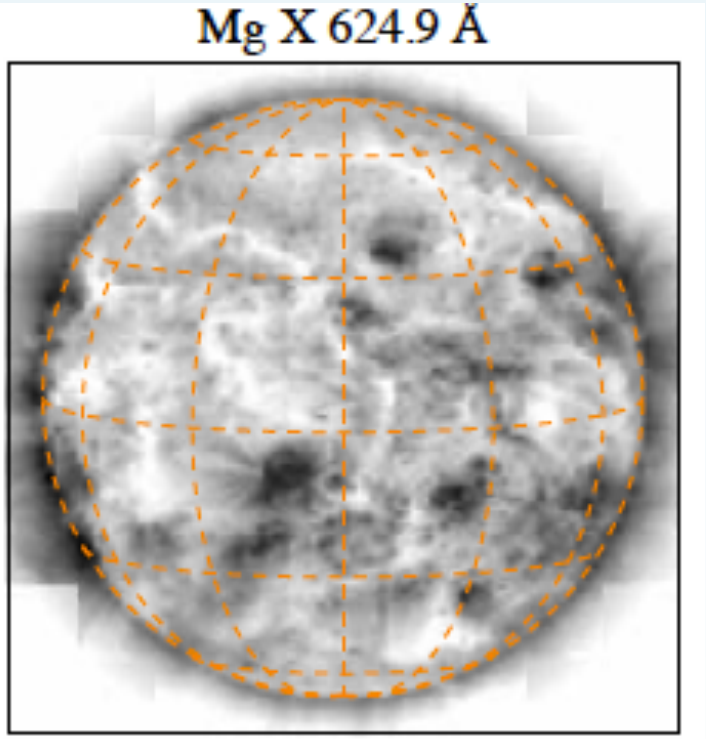


Obtaining irradiances from radiances

First, we interpolate the radiances (CDS subsamples the Sun by a factor of 4—6)

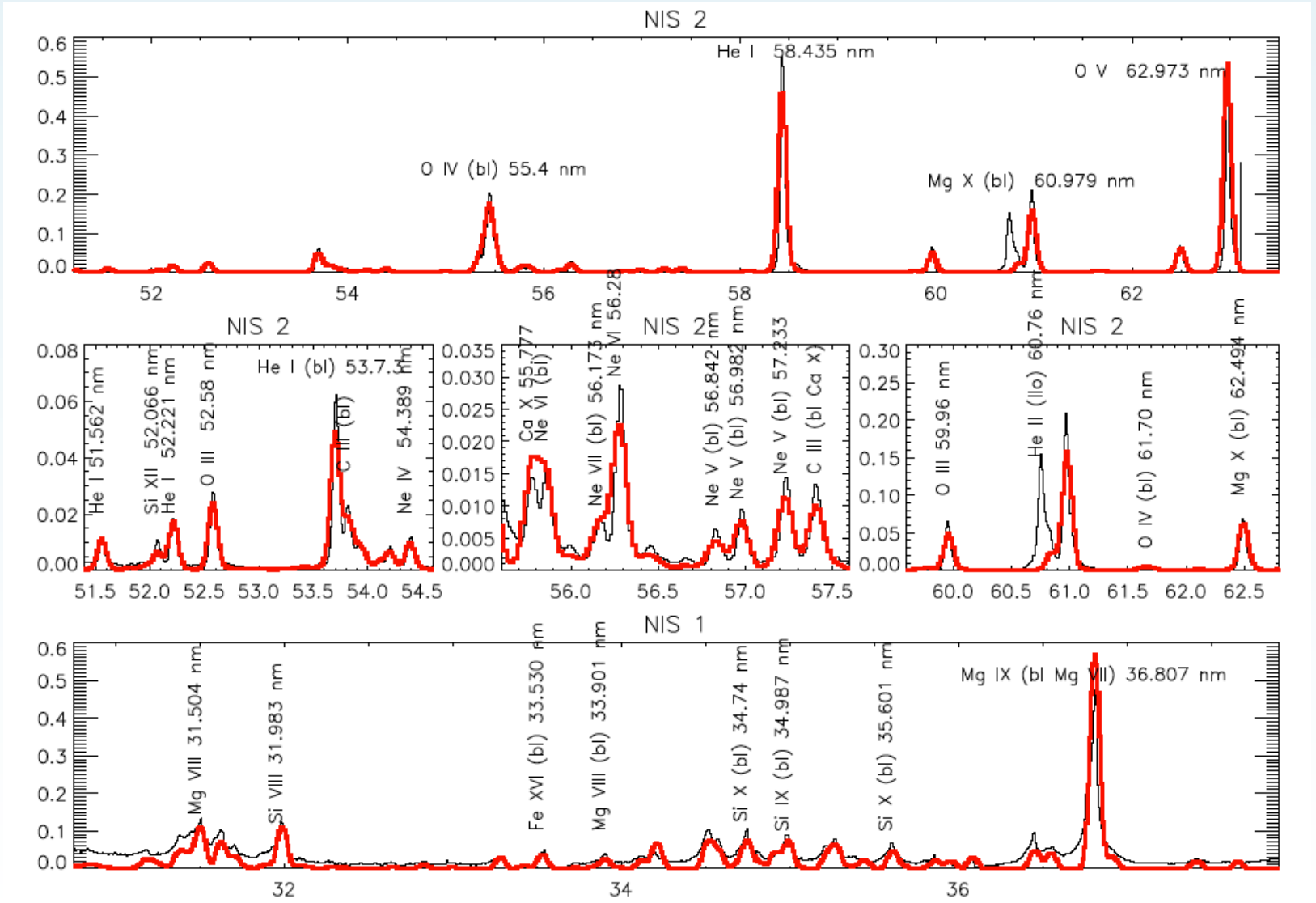
The radiances of the observed Sun are totalled, and an estimated contribution from the not observed off-limb corona is added. Typically, for coronal lines, this addition is just a few percent.





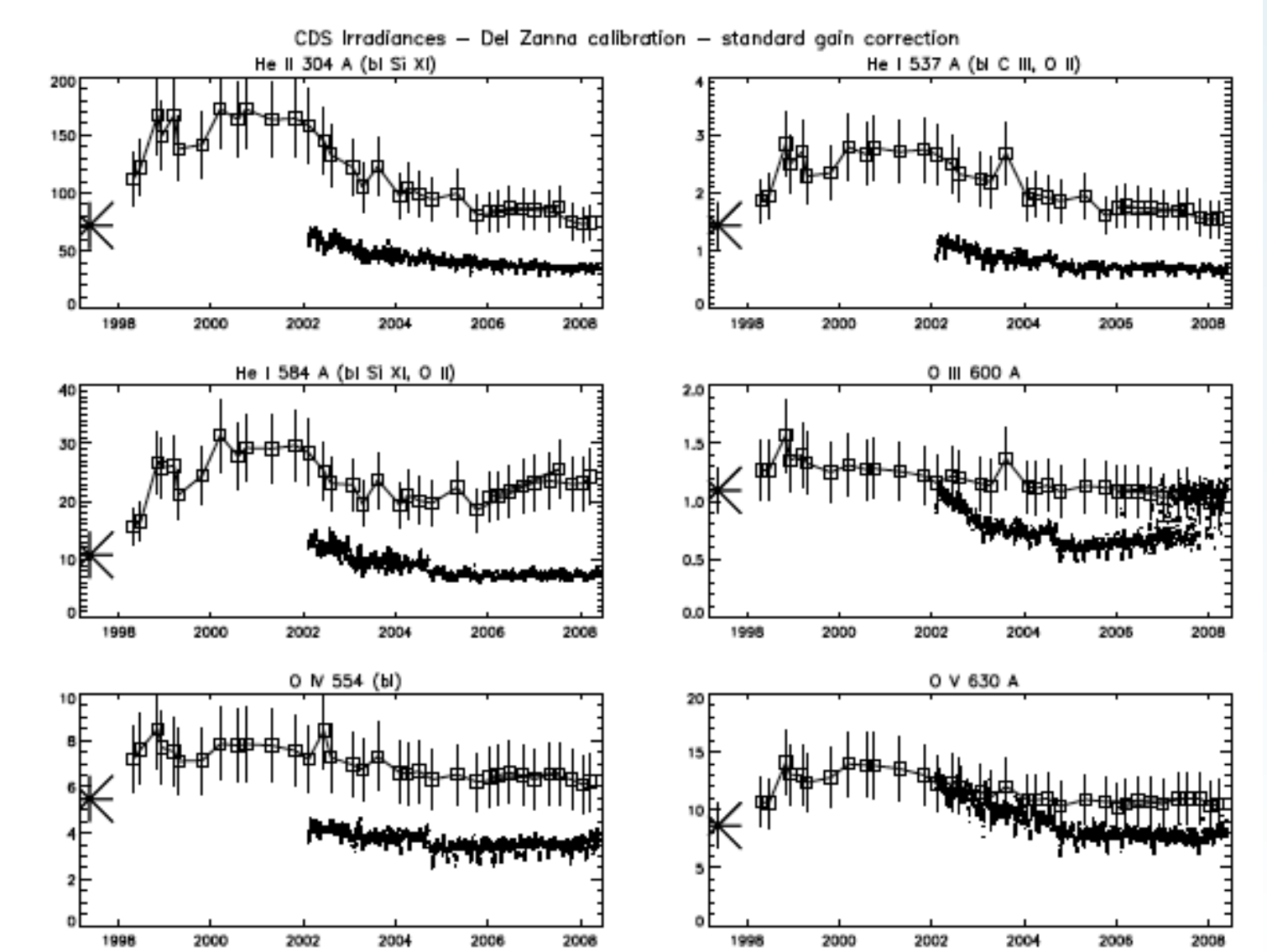
NIS vs. SDO PEVE

These spectral irradiances do not contain a correction for the missing off-limb contribution. Black: CDS - Red: SDO/EVE 2008 prototype (Del Zanna et al. 2010)

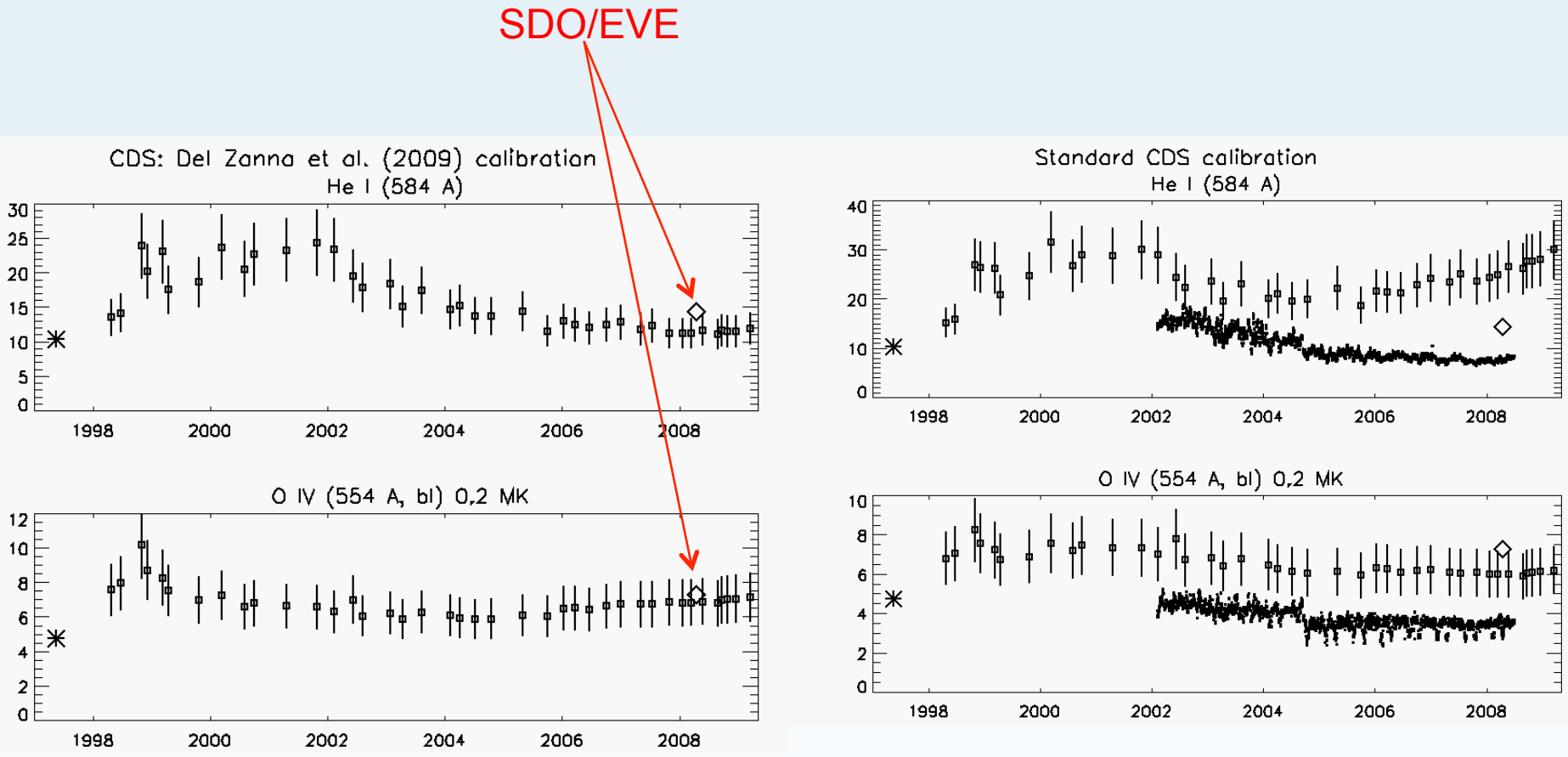


CDS vs. TIMED/SEE EGS - Aug 2008

It took 5 years of comparisons (+1 for the referee), starting in 2005…



SOHO NIS irradiances vs. EVE prototype



We have compared the TIMED/EGS measurements (dots), that have been absolutely calibrated between Feb 2002 and Oct 200, taking into account the lower EGS resolution.

Table 2. Historical records of irradiance measurements.

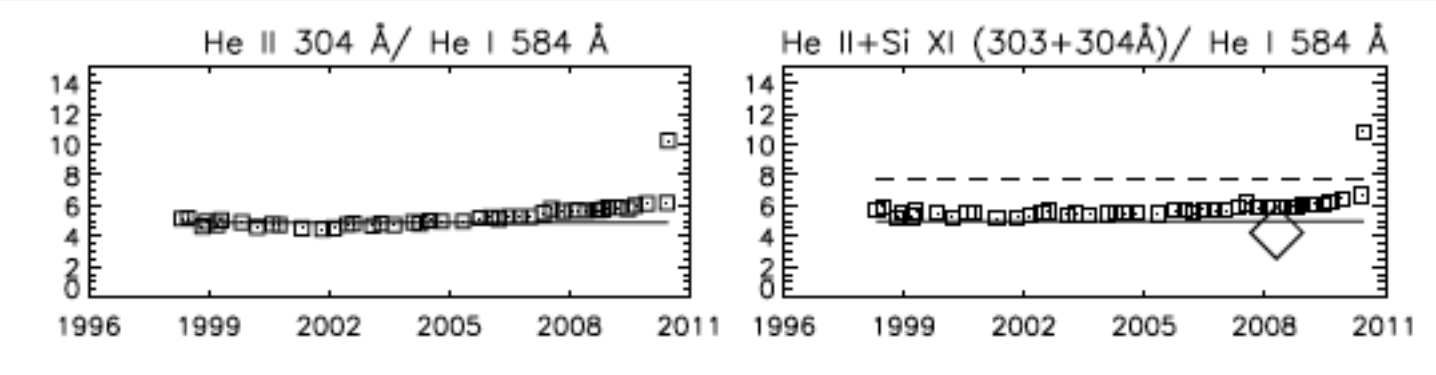
No.	Date	F	Reference	Instr.
1	1961-08-23	100	Hall et al. (1969)	Rocket
2	1962-06-5	88	Hall et al. (1969)	Rocket
3	1963-07-10	78	Hall et al. (1969)	Rocket
4	1963-12-12	81	Hall et al. (1969)	Rocket
5	1965-08-12	78	Hall et al. (1969)	Rocket
6	1965-11-9	81	Hall et al. (1969)	Rocket
7	1966-03-30	99	Hall et al. (1969)	Rocket
8	1966-07-22	107	Hall et al. (1969)	Rocket
9	1966-08-26	130	Hall et al. (1969)	Rocket
10	1967-01-17	117	Hall et al. (1969)	Rocket
11	1967-03-22	150	Hall et al. (1969)	Rocket
12	1967-05-27	214	Chapman & Neupert (1974)	OSO 3
13	1967-06-11	97	Chapman & Neupert (1974)	OSO 3
14	1967-08-12	139	Chapman & Neupert (1974)	OSO 3
15	1967-08-15	127	Hall et al. (1969)	Rocket
16	1967-09-30	132	Hall et al. (1969)	Rocket
17	1968-02-19	138	Hall et al. (1969)	Rocket
18	1969-04-04	177	Malinovsky & Heroux (1973)	Rocket
19	1969-04-17	155	Freeman & Jones (1970)	Rocket
20	1971-11-09	102	Higgins (1976)	Rocket
21	1972-08-23	123	Heroux et al. (1974)	Rocket
22	1973-11-2	84	Heroux & Higgins (1977)	Rocket
23	1974-04-23	74	Heroux & Higgins (1977)	Rocket
24	1992-10-27	169	Woods et al. (1998)	Rocket
25	1993-10-04	122	Woods et al. (1998)	Rocket
26	1994-11-03	86	Woods et al. (1998)	Rocket

Note: F is the 10.7 cm radio flux in 10^{-22} W m^{-2} Hz^{-1}

The problems with the He II 304 (1)

Historically, there have been large discrepancies between measurements obtained by various instruments. The early CDS/TIMED-EGS and SDO/EVE 2008 flight comparisons (Del Zanna et al. 2010) were not good.

Del Zanna & Andretta (2011) assumed that the NIS responsivity at 584 A (based on a 1997 LASP EGS flight) was correct, and adopted a responsivity for the He II 304 that would produce a 304/584 ratio as measured by Heroux et al. (1974).
This ratio is known to be very stable:



The resulting He II irradiances are in good agreement with those measured by the SDO/EVE 2008 prototype.

Del Zanna & Andretta (2011) suggested that previous Skylab ATM, TIMED/SEE, SERTS and EUNIS measurements were incorrect.

The problems with the He II 304 (2)

Comparisons between our CDS NIS measurements and EUNIS measurements led to the discovery of two significant software errors, one in the EUNIS and one in the CDS software (for the second order lines). Not all the CDS published measurements were affected though.

The EUNIS 2007 flight was calibrated at RAL against a transfer standard (calibrated at BESSY).

EUNIS observed the He II 304 in first order on the quiet Sun.
Excellent agreement, within a relative 6%, between the EUNIS 2007 and CDS radiances is found, when the Del Zanna et al. (2010) NIS long-term corrections and the Del Zanna & Andretta (2011) sensitivity are adopted. Wang et al. (2011).

So for the first time we now have good agreement between EUNIS, CDS, and SDO/EVE !

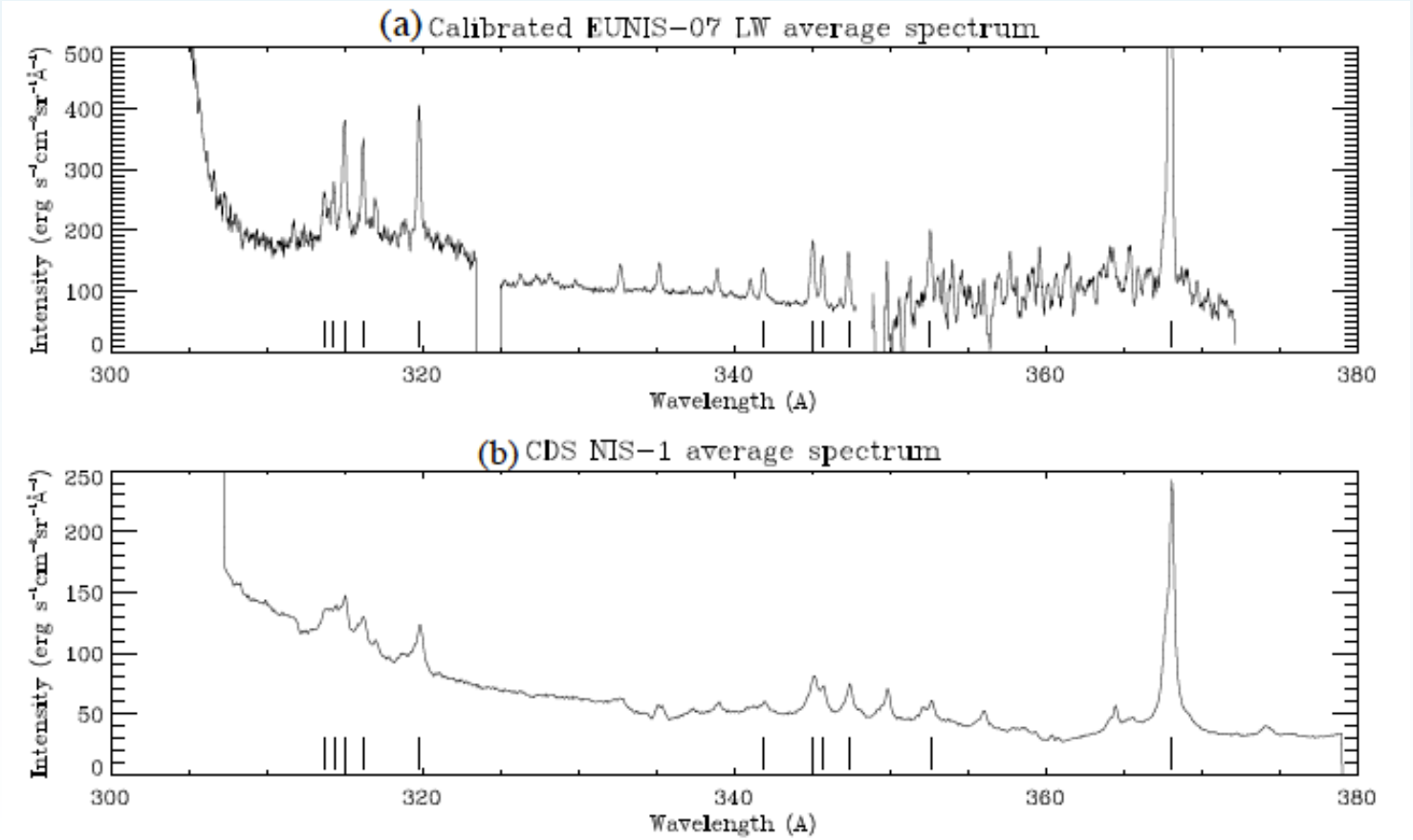
EUNIS 2007 vs. CDS NIS 1

EUNIS was flown in 2007 and calibrated on the ground in may 2008 at RAL using the same secondary standard used for CDS, which was calibrated against the syncrotron BESSY-II.

Near-simultaneous CDS NIS observations of the quiet Sun were obtained.

Very good agreement (10%) between the radiances of the strongest line (Mg IX 368) is found when the Del Zanna sensitivities and long-term corrections are applied.

Wang+ 2011, ApJ, 197, 32



EUNIS 2007 vs. NIS 1 (Wang+2011)

Quiet Region Line Intensities (erg s^{-1} cm^{-2} sr^{-1}) for EUNIS-07 LW and CDS[a]

Wavelength (Å)	Ion	I_{E07}	I_{CDS}^{SN}	I_{CDS}^{GZ}	I_{CDS}^{S}	I_{E07}/I_{CDS}^{SN}	I_{E07}/I_{CDS}^{GZ}	I_{E07}/I_{CDS}^{S}
303.78	He II	4759	5244	4484	4290	0.91 ± 0.13	1.06 ± 0.15	1.11 ± 0.16
313.76	Mg VIII	25.2	31.7	25.9	14.1	0.79 ± 0.11	0.97 ± 0.14	1.79 ± 0.25
314.31	Si VIII	25.1	36.1	30.0	24.1	0.70 ± 0.10	0.84 ± 0.12	1.04 ± 0.15
315.01	Mg VIII	62.3	37.6	31.7	22.0	1.66 ± 0.23	1.97 ± 0.28	2.83 ± 0.40
316.20	Si VIII	39.2	44.7	38.7	26.6	0.88 ± 0.12	1.01 ± 0.14	1.47 ± 0.21
319.81	Si VIII	60.5	48.6	45.5	26.4	1.24 ± 0.18	1.33 ± 0.19	2.29 ± 0.32
341.91	Si IX	15.0	17.0	15.4	13.9	0.88 ± 0.12	0.97 ± 0.14	1.08 ± 0.15
345.04	Si IX	34.0	66.8	60.9	46.5	0.51 ± 0.07	0.56 ± 0.08	0.73 ± 0.10
345.67	Fe X	20.6	14.7	13.4	15.7	1.40 ± 0.20	1.54 ± 0.22	1.31 ± 0.19
347.34	Si X	24.0	27.6	25.6	22.2	0.87 ± 0.12	0.94 ± 0.13	1.08 ± 0.15
352.58	Fe XI	30.3	19.9	20.0	20.4	1.52 ± 0.22	1.51 ± 0.21	1.49 ± 0.21
368.11	Mg IX[b]	285.8	262.4	252.4	172.1	1.09 ± 0.15	1.13 ± 0.16	1.66 ± 0.23

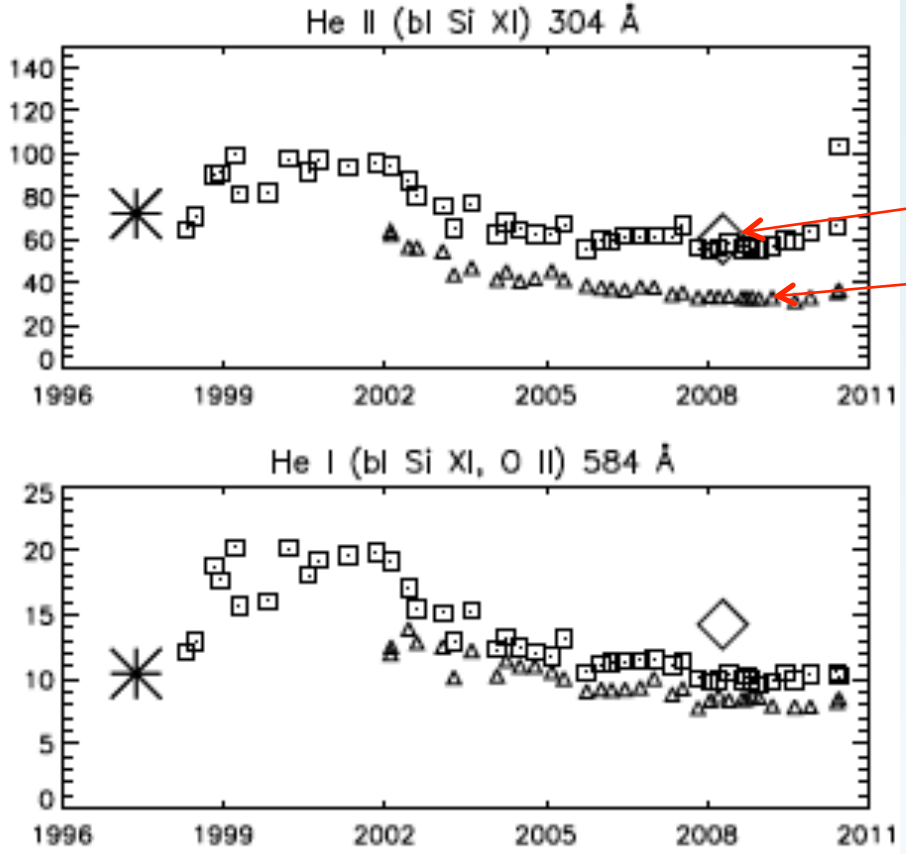
Notes.

[a] Column 1 is the wavelengths which are measured from the EUNIS-07 LW spectrum. Column 2 is the ion name. Column 3 (I_{E07}) is the EUNIS-07 line intensity. Column 4 (I_{CDS}^{SN}) is the CDS line intensity with the standard calibration and the new long-term correction. Column 5 (I_{CDS}^{GZ}) is the CDS line intensity with the Del Zanna et al. (2001) calibration and the new long-term correction. Column 6 (I_{CDS}^{S}) is the CDS line intensity with the standard calibration and standard long-term correction. Columns 7–9 are the EUNIS-to-CDS line intensity ratios.

[b] The listed line intensity for Mg IX 368.1 Å includes the emission from the blended line, Mg VII 367.7 Å.

Note: all CDS data have been calibrated (2012) adopting the Del Zanna LTGD

SOHO NIS irradiances vs. EVE and TIMED/EGS



Boxes:CDS NIS

SDO/EVE prototype

TIMED/EGS

Overall good agreement !

Note: the NIS He II irradiance is obtained with a new suggested responsivity (Del Zanna & Andretta 2011)

Summary and further work

Synoptic observations have been the key to measure the in-flight degradation.

Rocket flights calibrated on the ground are necessary.

The NIS sensitivity has dropped by only a factor of about two in 13 years. Very little degradation was seen in GIS. Very good indeed. Lesson: CLEANLINESS !

The calibration method will be extended to cover the entire lifetime of the CDS instrument (SOLID FP7 network).

Further comparisons