XUV Photometer System (XPS)

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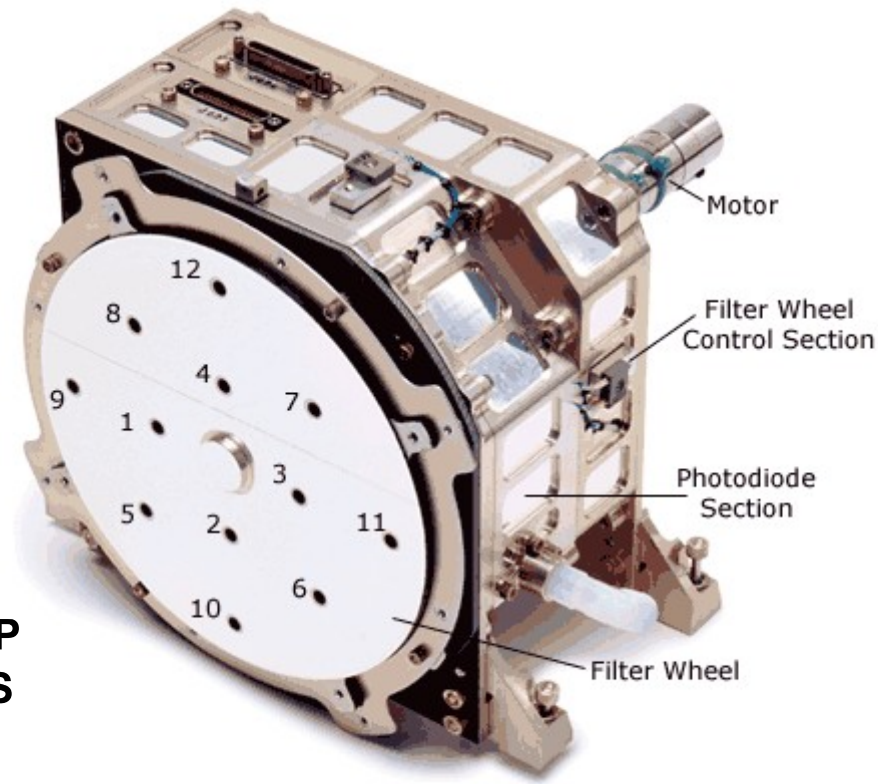
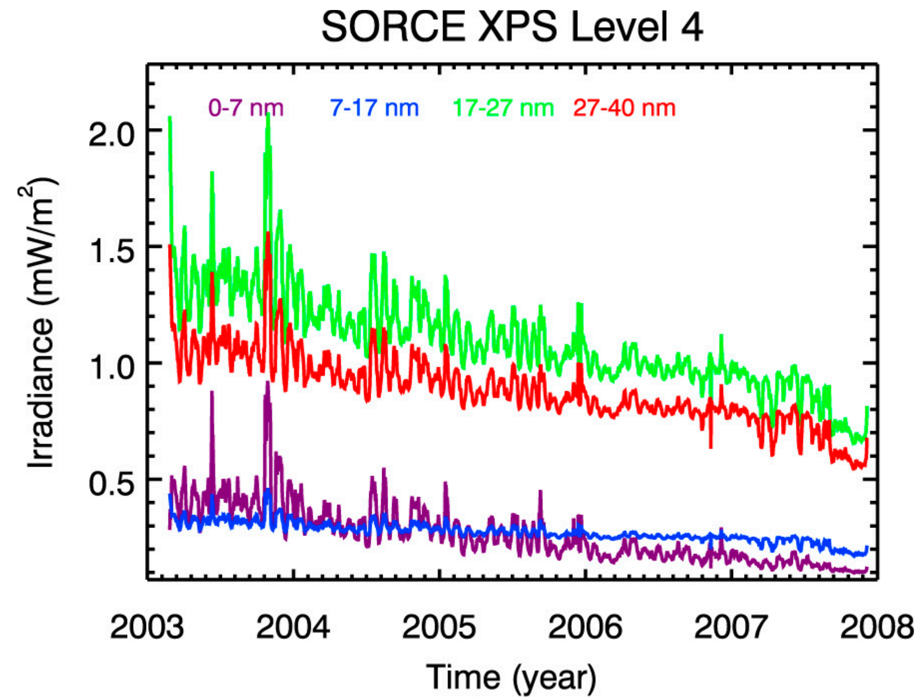


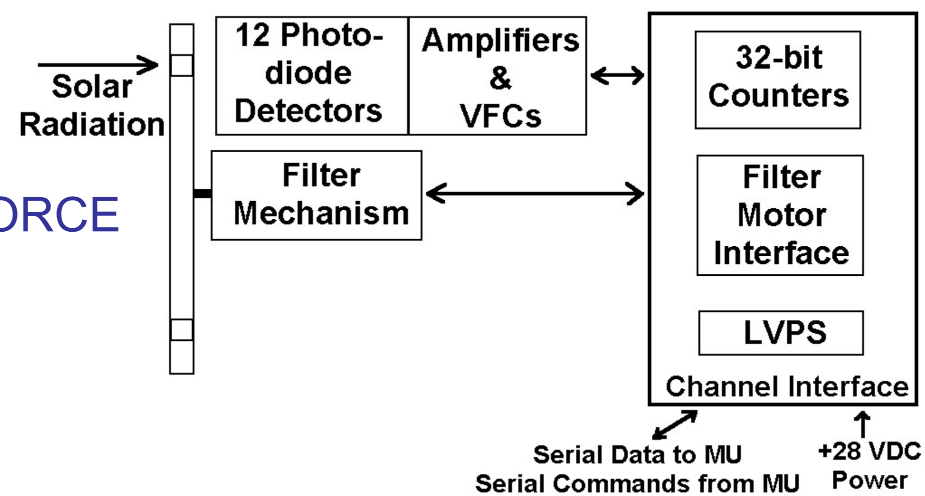
XPS Instrument Overview

Overview of XUV Photometer System (XPS)

- Instrument Type: Filter Photometers
- Wavelength Range: 0.1-40 nm
- Wavelength Resolution: 1-10 nm
- Optics: Thin film filters
  - deposited directly on Si diodes
- Detectors: 12 Si photodiodes
  - 8 XUV, Ly-α, 3 bare
- Absolute Accuracy: 20%
- Long-term Accuracy: 1%/yr
- Field of View: 4° cone
- Mass: 3 kg
- Orbit Average Power: 9 W
- Orbit Average Data Rate: 0.3 kbits/s
- Redundancy: 3 redundant XUV diodes
- Flights: rocket, SNOE, TIMED SEE, SORCE

New Technology
Stable XUV Si Photodiodes
Low-noise Electrometers
Highly Linear VTFs with 32-bits

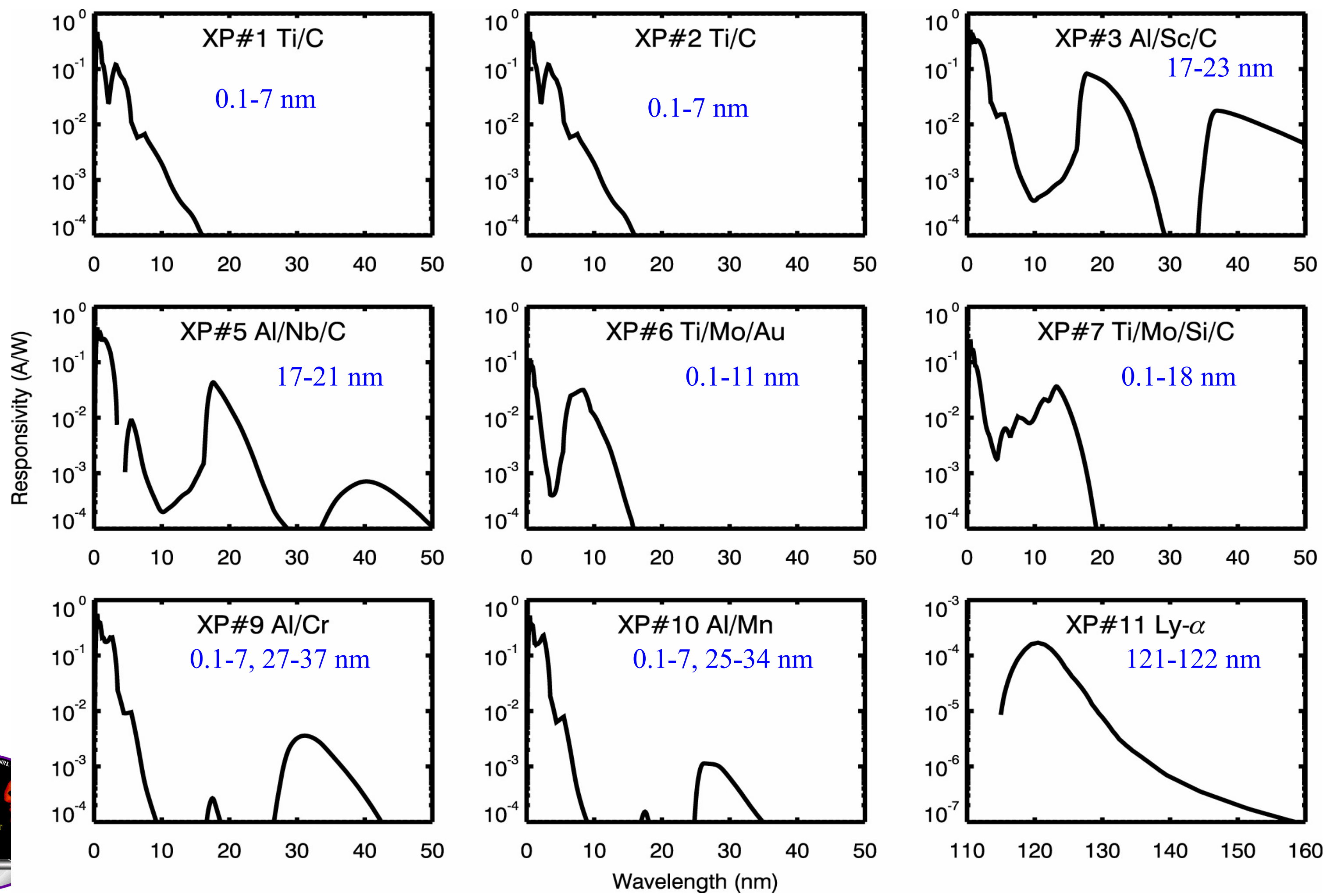




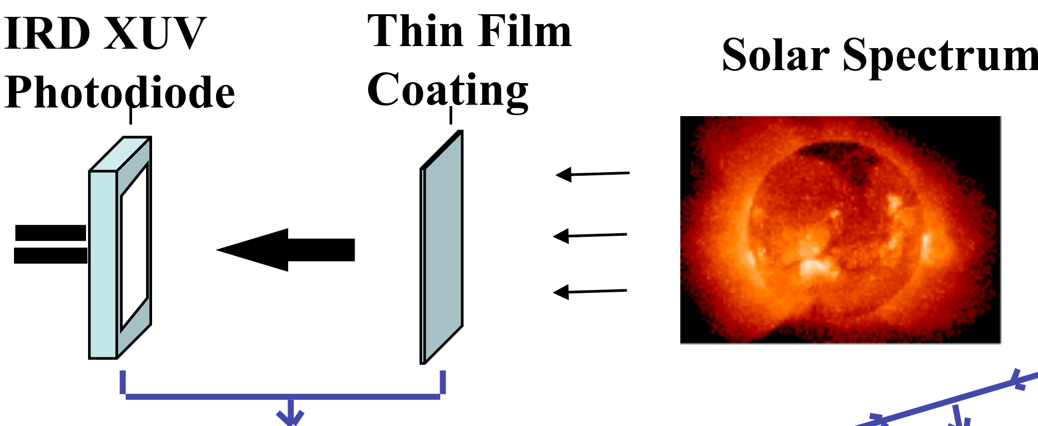
SORCE

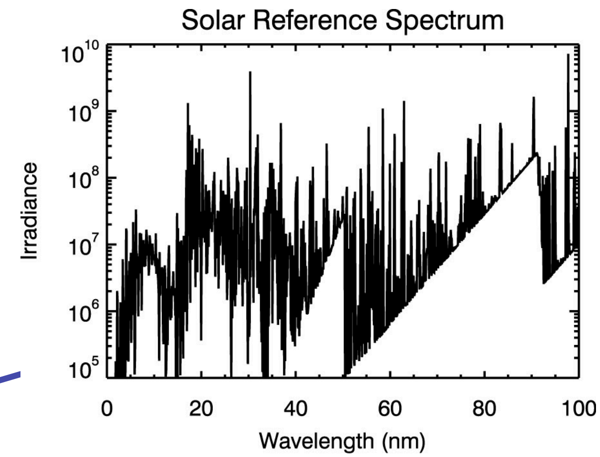
XPS Wavelength Coverage / Resolution

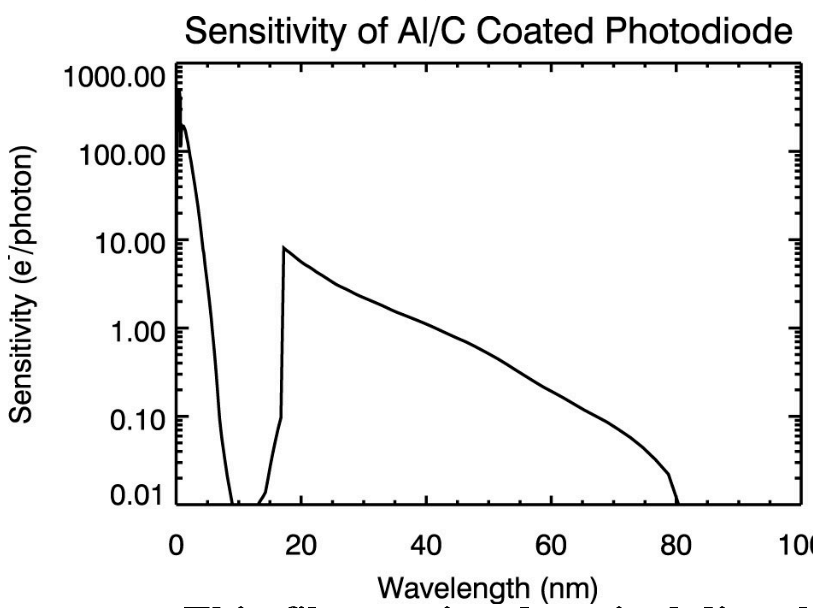
- Designed / selected filter coatings for specific broad bands
  - 0.1-7 nm, 7-17 nm, 17-24 nm, 24-34 nm, 121.5 nm
- TIMED SEE XPS and SORCE XPS are essentially the same
  - 12 photometers: 8 XUV, 1 Lyman-α, 3 bare (visible) diodes

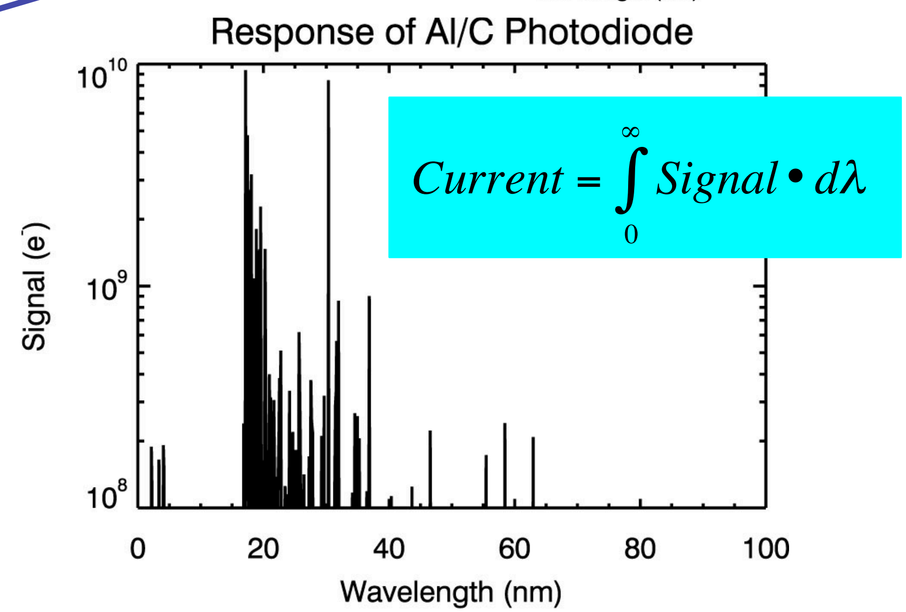


XPS Measurement Approach - Filter Photometer







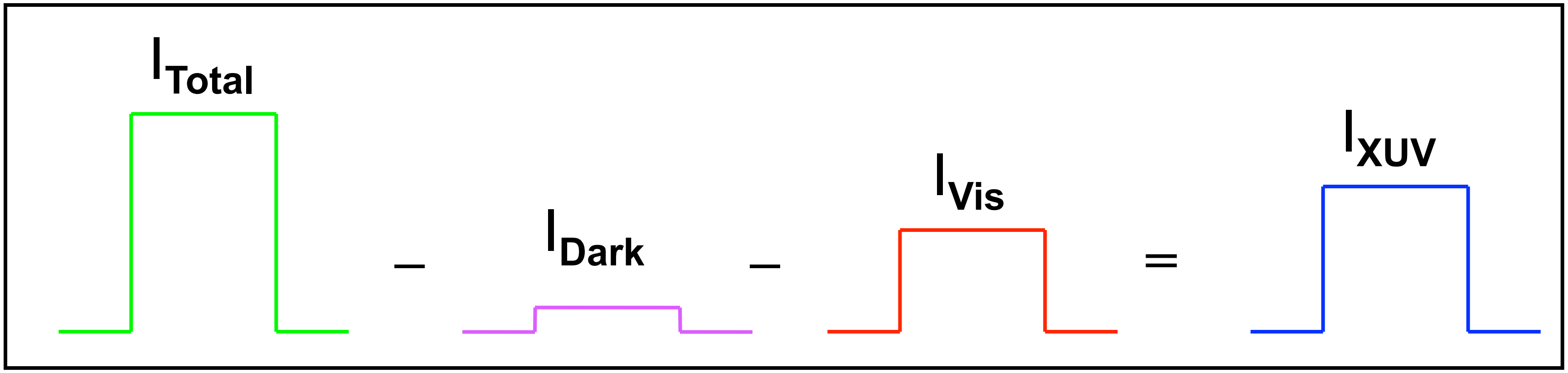


Thin film coating deposited directly on photodiode produces detector with a defined x-ray bandpass.

X-ray bandpass convolved with solar spectrum defines range of solar sensitivity.

SORCE

XUV Photometer Signal Contributions



– I_{Total} : integrated signal across all wavelengths that pass through the coating

– I_{Dark} : dark signal related mostly to DC offset of charge amplifiers and also to thermal noise of the Si photodiodes

– I_{Vis} : signal from long wavelength red-leaks and minor pinholes in thin-film metal coatings

- To measure I_{Vis} a fused silica window is placed in front of the photometer, absorbing XUV wavelengths. $I_{VisMeasured}$ results.
- $I_{VisMeasured}$ requires a window transmission correction to get I_{Vis}

$$I_{Vis} = I_{VisMeasured} \,/\, T_{Vis\ Fused\ Silica\ Window}$$

SORCE

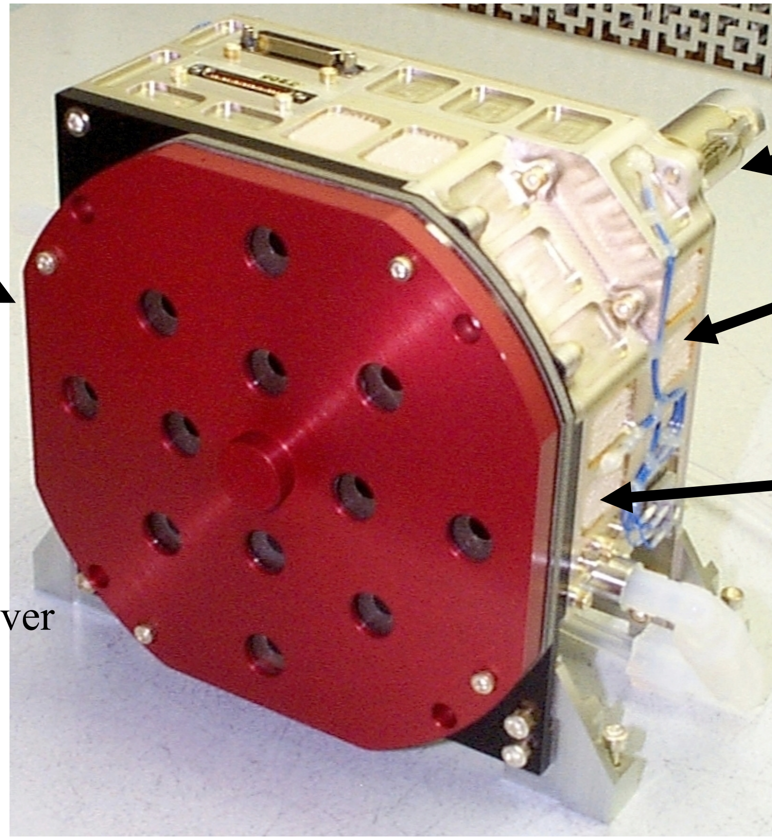
XPS Has One Mechanism

Filter Wheel

Motor

Filter Wheel Control Section

Photometer Section

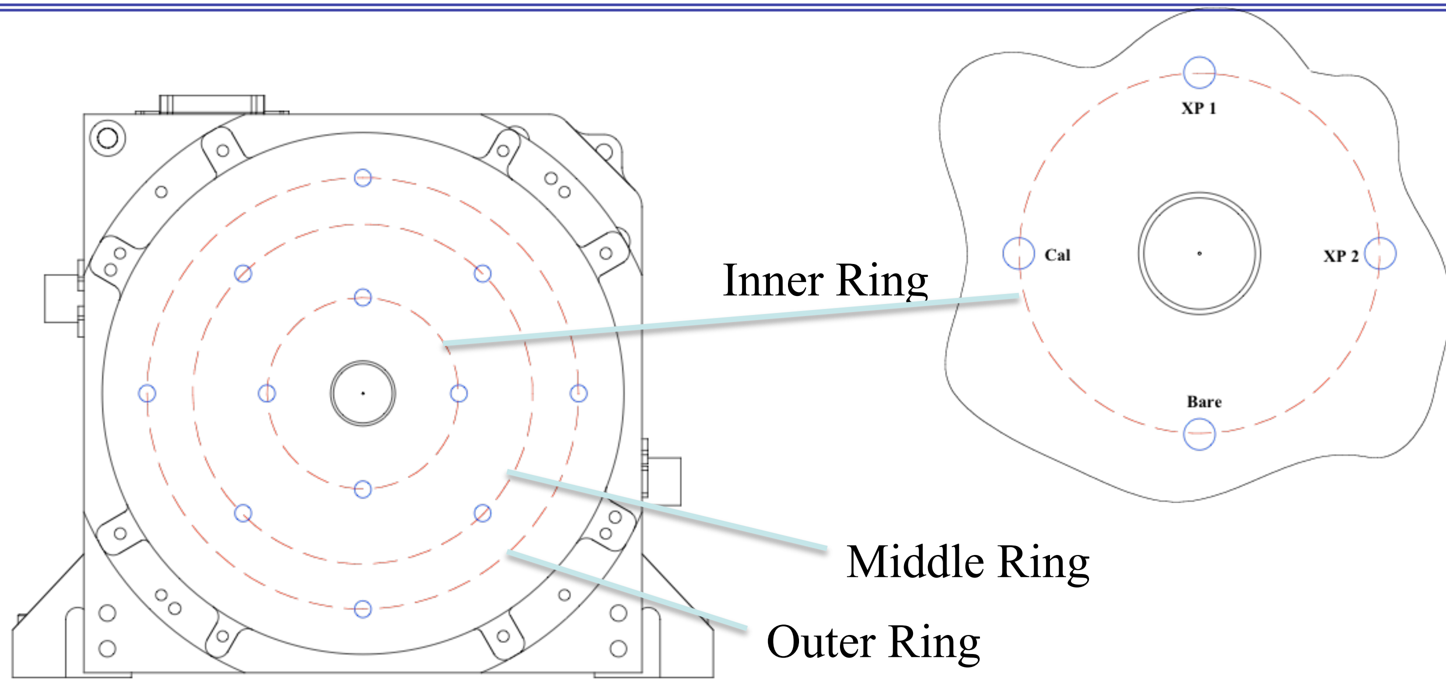


Red Front Plate
is Non-flight Purge Cover

A filter wheel mechanism is used to measure separately the XUV, dark, and visible signals for the XPS photometers.

- Filter Wheel has 8 positions
- Each diode has 5 dark, 1 open (XUV), and 2 windows (visible)

Aperture Layout



- 3 concentric rings of photometers, 4 photometers per ring, total of 12
- Each ring consists of a set of photometers with:
  - 2 primary XUV photodiodes
  - 1 bare photodiode
  - 1 redundant (calibration) XUV photodiode

XPS Filter Wheel Positions / Operations

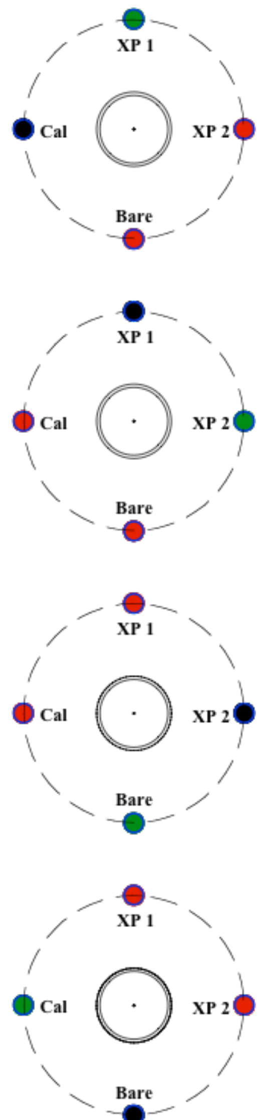
- Filter wheel has 8 positions
- Each photometer has 5 dark, 1 light, 2 FS windows

XP No.	Filter Coating	Filter Wheel Position							
		0	1	2	3	4	5	6	7
1	Ti/C	FS-1	Dark	Dark	Dark	FS-2	Dark	**Clear**	Dark
2	Ti/C	Dark	Dark	FS-2	Dark	**Clear**	Dark	**FS-1**	Dark
3	Al/Sc/C	FS-2	Dark	**Clear**	Dark	FS-1	Dark	**Dark**	Dark
4	None	**Clear**	Dark	FS-1	Dark	Dark	Dark	**FS-2**	Dark
5	Al/Nb/C	FS-2	Dark	**Clear**	Dark	FS-1	Dark	**Dark**	Dark
6	Ti/Mo/ Au	**Clear**	Dark	FS-1	Dark	Dark	Dark	**FS-2**	Dark
7	Ti/Mo/Si/ C	FS-1	Dark	Dark	Dark	FS-2	Dark	**Clear**	Dark
8	None	Dark	Dark	FS-2	Dark	**Clear**	Dark	**FS-1**	Dark
9	Al/Cr	**Clear**	Dark	FS-1	Dark	Dark	Dark	**FS-2**	Dark
10	Al/Mn	FS-1	Dark	Dark	Dark	FS-2	Dark	**Clear**	Dark
11	Ly-α	Dark	Dark	FS-2	Dark	**Clear**	Dark	**FS-1**	Dark
12	None	FS-2	Dark	**Clear**	Dark	FS-1	Dark	**Dark**	Dark

FS = Fused Silica window (2 per ring)

Post-Anomaly is Position 6

Filter Wheel Operation



Position 1

Position 3

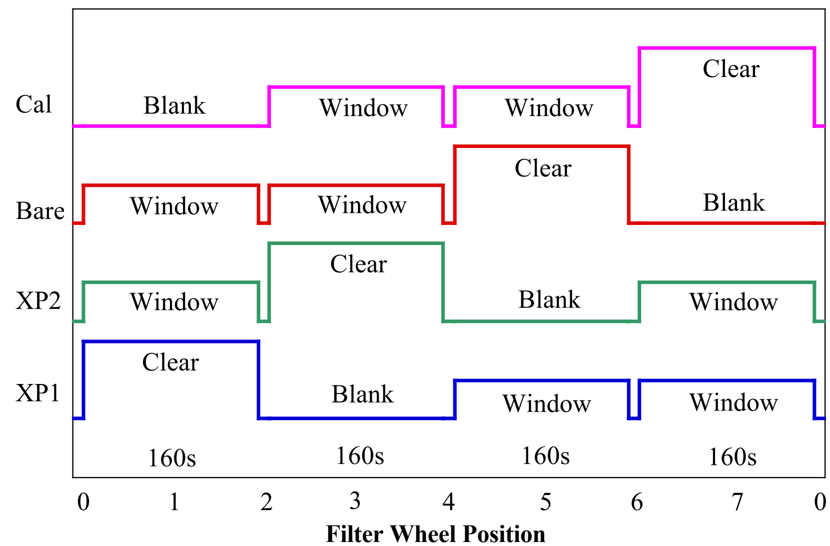
Position 5

Position 7

On the rotating Filter Wheel, each ring has

- – 1 Clear aperture
- – 2 Fused silica windows
- – 1 Blank (additional 4 positions also blank)

These cycle past each of the photometer apertures during one revolution of filter wheel



TIMED SEE: Filter wheel rotated each orbit

SORCE: Filter wheel rotated around every 5 minutes

XPS Flights and Current Status

- 12 rocket flights since 1992
  - prototype TIMED SEE XPS used since 1997
- SNOE version of XPS: 1998-2000
- TIMED SEE XPS: Jan. 2002 – present
  - XPS filter wheel anomaly in July 2002
    - Stuck in position 6 – operations have continued on in this position
    - Suspect issue is due to vespel part in mechanism detent system
- SORCE XPS: Mar. 2003 – present
  - XPS filter wheel anomaly in Dec. 2005
    - Stuck in position 0 but started to work 2 days later - continues to work OK
    - New XPS operations approach started in 2006 with 1-minute cadence in position 6 and monthly calibrations that use the filter wheel

XPS Data Products

First # is for TIMED SEE, Second # is SORCE

- Level 0b/1: raw data
- Level 1/2: irradiance data
  - simple algorithm: Irradiance = XUV_Signal * Factor
  - but complicated to understand for broad bands..
- Level 2/3: daily average of Level 1 irradiances
- Level 4: spectral model that matches Level 1
  - next slide
- Level 3: insertion of XPS Level 4 data into 1-nm bins for composite spectra on TIMED SEE and SORCE

XPS Level 1/2 Simple Irradiance Algorithm

- Irradiance = Signal * Factor
  - "Signal" is first corrected for dark and visible contributions
  - "Factor" has many parameters

$$E_i = \frac{\left(I_{i,total} - I_{i,dark} - I_{i,visible}\right)}{f_{i,E\_total} \bullet < T_{i,xuv} > \bullet A_i \bullet f_{i,xuv\_fov}} \bullet k_E \bullet f_{Degrade}$$

- Visible Signal is based on in-flight measurements
  - Transmission is measured by the "visible" diodes

$$I_{i,visible} = \frac{\left(I_{i,window} - I_{i,dark}\right)}{T_{window}} \bullet \frac{f_{i,clr\_fov}(\alpha_{xuv}, \beta_{xuv})}{f_{i,vis\_fov}(\alpha_{window}, \beta_{window})}$$

$$T_{window} = \frac{\left(I_{b,window} - I_{b,dark}\right)}{\left(I_{b,clear} - I_{b,dark}\right)} \bullet \frac{f_{b,clr\_fov}(\alpha_{clear}, \beta_{clear})}{f_{b,vis\_fov}(\alpha_{window}, \beta_{window})}$$

- "Reference Spectrum" is required
  - One factor is the ratio of the total signal to the signal over a limited band. Band width is adjusted so this factor is close to 1.
  - Another factor is average transmission value over the band.
  - "Reference Spectrum" is average of solar cycle Min and Max (NRLSSI)

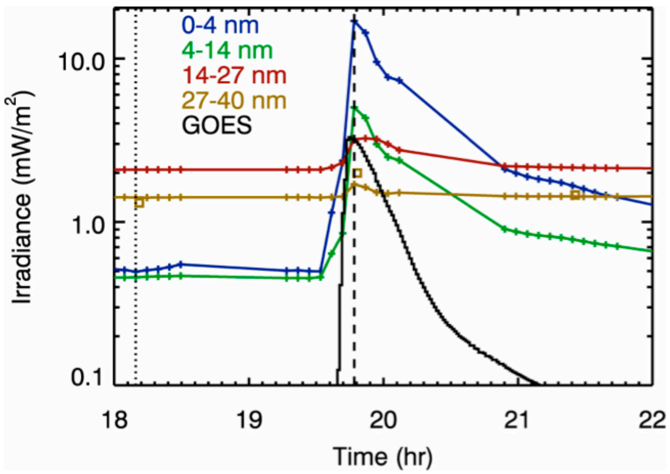
$$f_{i,E\_total} = \frac{\int_0^\infty T \bullet E \bullet d\lambda}{\int_{\lambda_1}^{\lambda_2} T \bullet E \bullet d\lambda}$$

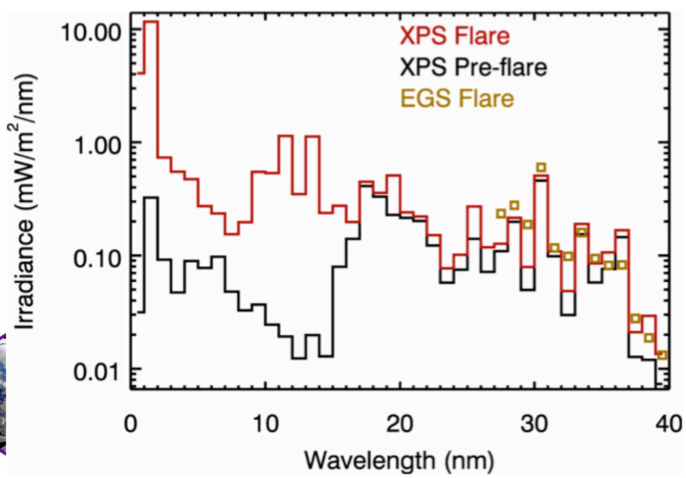
$$\left\langle T_{i,xuv} \right\rangle = \frac{\int_{\lambda_1}^{\lambda_2} T \bullet E \bullet d\lambda}{\int_{\lambda_1}^{\lambda_2} E \bullet d\lambda}$$

This works fine for non-flare data.

Motivation for Level 4 Spectral Model

- Improve the XUV irradiance during flare events
- Provide higher spectral resolution than the broad bands of the XPS





<u>Example flare time series and spectra.</u>

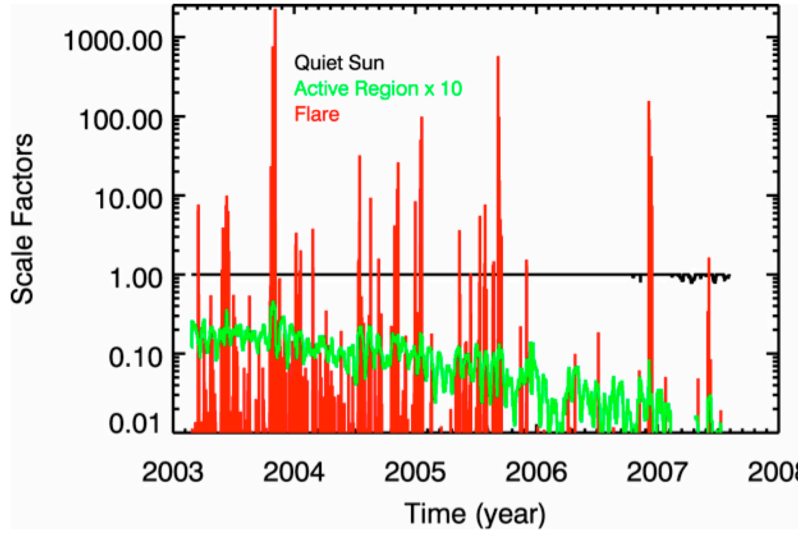
In the top panel, the time series of the large X28 flare on 4 November 2003 is shown for several bands from the new XPS Level 4 product, along with the GOES 0.1-0.8 nm X-ray measurement. As for this example, the 0-4 nm band is often the dominant emissions during a flare but is a minor contribution at other times.

In the bottom panel, the spectrum near the peak of the flare (dashed line in top panel) is compared to the pre-flare spectrum (dotted line in top panel). The majority of the irradiance increase is shorter than 15 nm. The XPS Level 4 model results are in reasonably good agreement with the SEE EGS spectral measurements at longer than 27 nm.

XPS Level 4 Spectral Model uses CHIANTI Spectra

- Two daily components fit to daily minimum value
  quiet Sun (QS) - $E_{Min}(\lambda)$
  active region (AR) - $E_{AR}(\lambda)$
- **Flare** component (above daily min.) - $\mathbf{E_{flare}(T,\lambda)}$
  flare temperature from GOES X-ray data

Level 4 Results are Irradiance Spectra, Flare Temperature, and three Scale Factors (f_{Min}, f_{AR}, and f_{Flare})



Input: XPS Measurement - photometer current (I), responsivity (R)

$$I_{measure} = I_{day\_min} + I_{flare}$$

$$I_{day\_min} = f_{Min} \bullet \int_0^\infty R(\lambda) \bullet E_{Min}(\lambda) \bullet d\lambda + f_{AR} \bullet \int_0^\infty R(\lambda) \bullet E_{AR}(\lambda) \bullet d\lambda$$

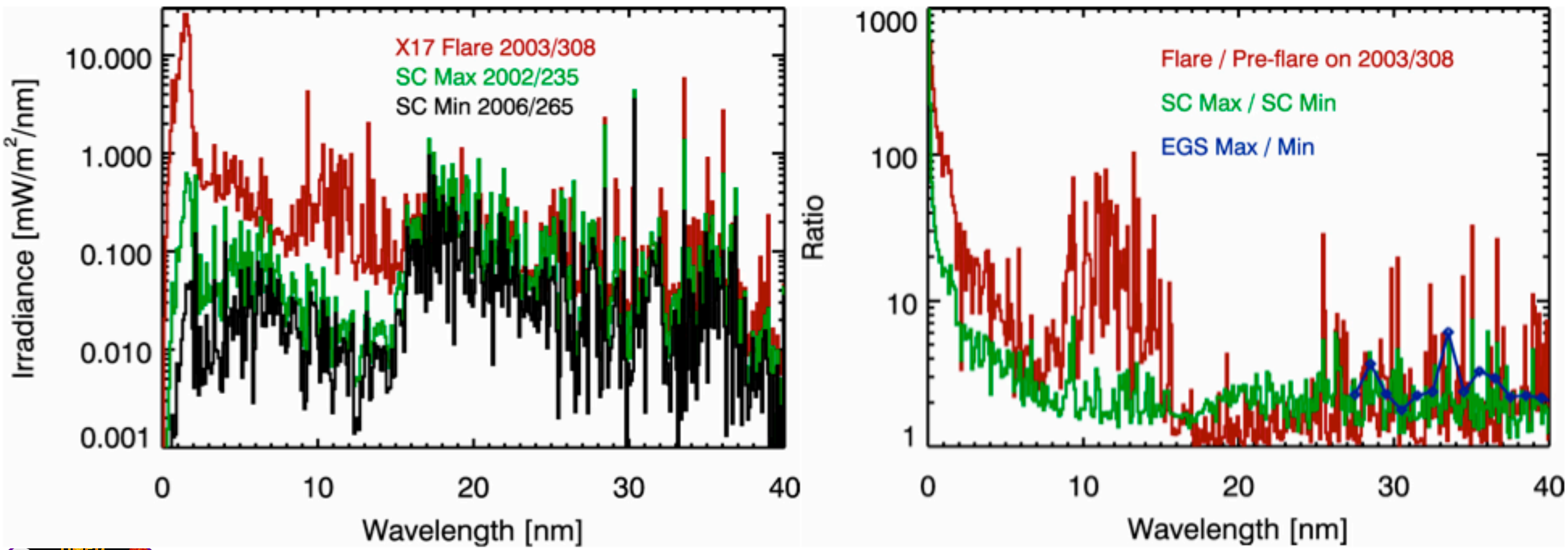
CHIANTI Spectral Models
[Dere *et al.*, 1997; Landi *et al.*, 2006]

$$E_{L4}(\lambda) = f_{Min} \bullet E_{Min}(\lambda) + f_{AR} \bullet E_{AR}(\lambda) + f_{Flare} \bullet E_{Flare}(T,\lambda)$$

Output: XPS Level 4 Irradiance Spectra (0.1 nm resolution)
flare Temperature (T), 3 scale factors

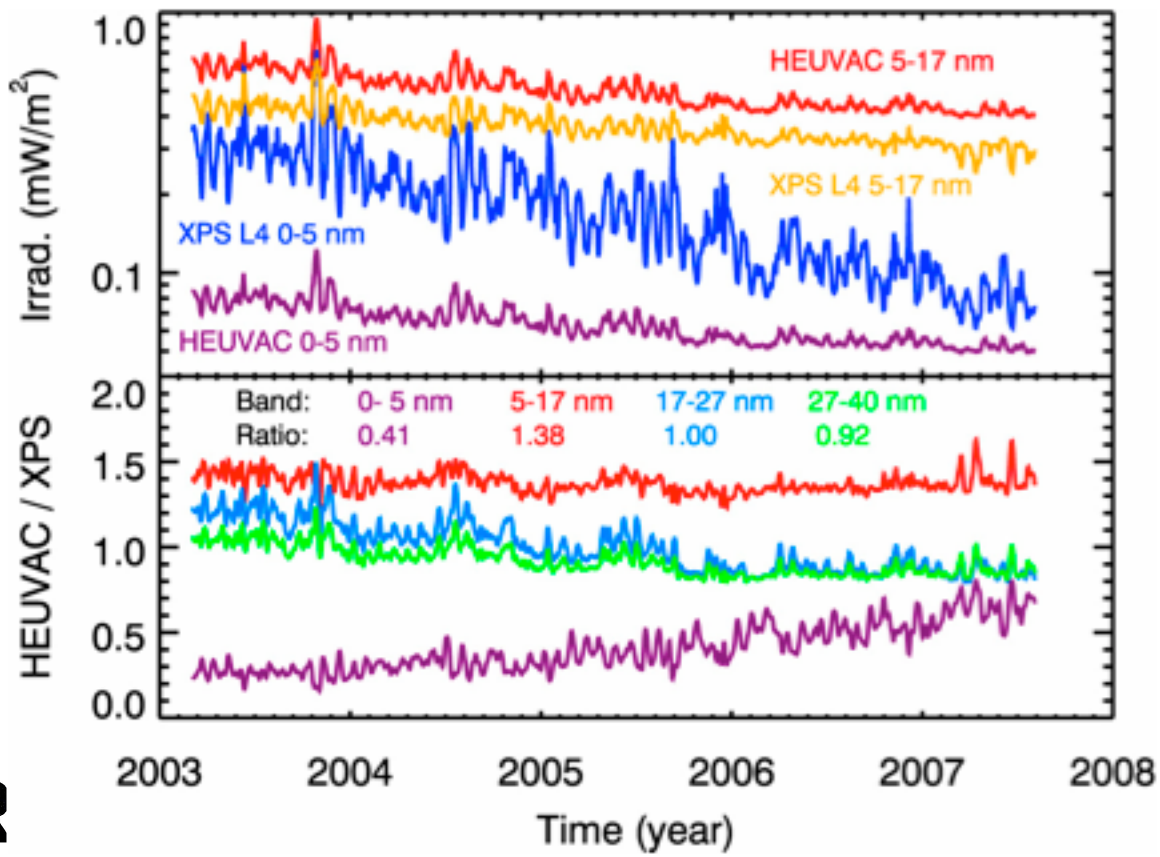
Example Solar Flare Variation

- Variations for the large flares are larger than solar cycle variations
- Flare variations dominate shortward of 15 nm
- Level 4 active region scale factor represents the fractional disk covered by active regions



Comparison of XPS Level 4 to HEUVAC Model

- HEUVAC model is by Richards et al. [2006]
- The top panel shows the irradiances for the 0-5 nm and 5-17 nm bands as they differ the most.
- The bottom panels shows the ratio of HEUVAC to XPS Level 4 bands.



Lessons Learned from XPS Instrument

- Calibration (accuracy) Lesson
  - Use multiple calibration techniques / references to achieve best accuracy
- Spectral Resolution Lesson
  - Easier to interpret results with higher spectral resolution
    - i.e., data processing results can be dependent on spectral models when working with broad band photometers
- Filter Wheel Mechanism Lessons
  - Better to use direct drive, or at least few gears
  - Motor control should have forward/reverse direction and, if possible, redundant winding
  - Braycote (wet) lubrication better for gears (versus dry lub)