# LYRA

the **L**arge-**Y**ield **Ra**diometer onboard PROBA2

# Long-term irradiance observation and short-term flare prediction with LYRA on PROBA2

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**COSPAR 40th Scientific Assembly**
**Moscow, Russia, 02-10 Aug 2014**

# Contents

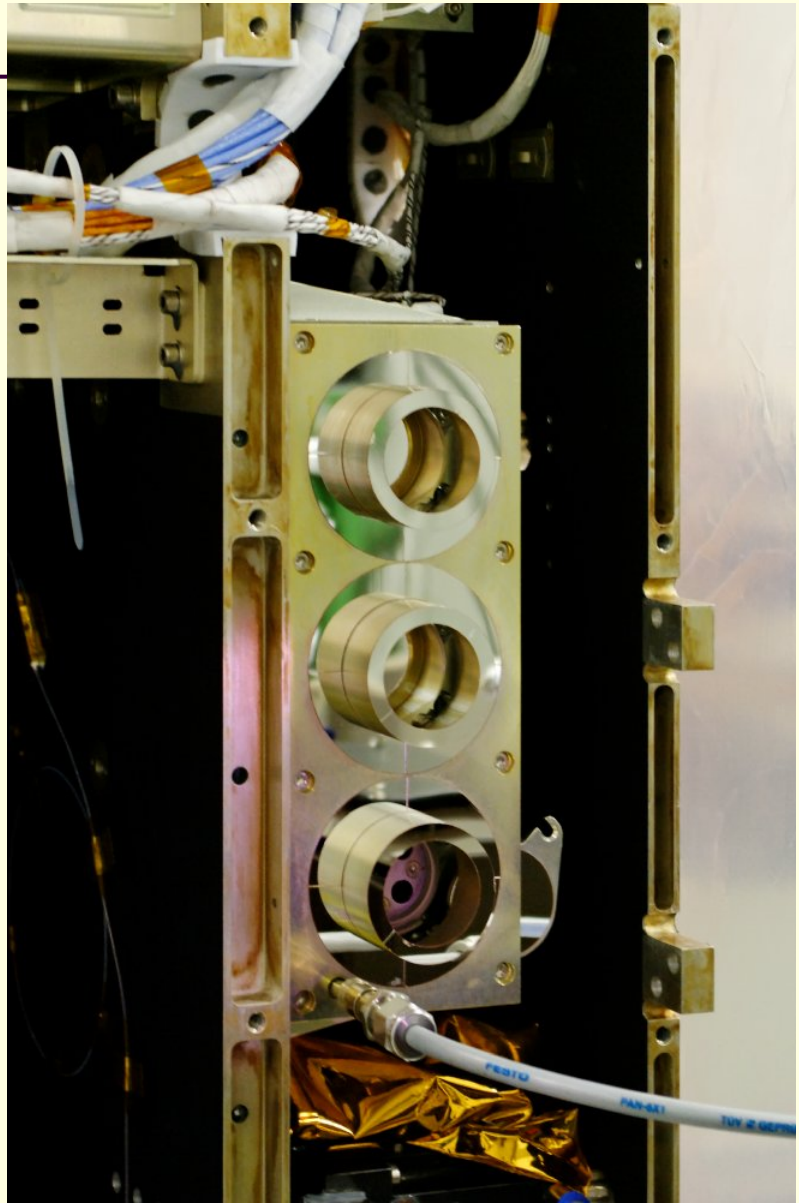
- LYRA: description, spectral response, data
- Long-term development, short-term forecast
- Results, future perspectives

# PROBA2: PRoject for On-Board Autonomy

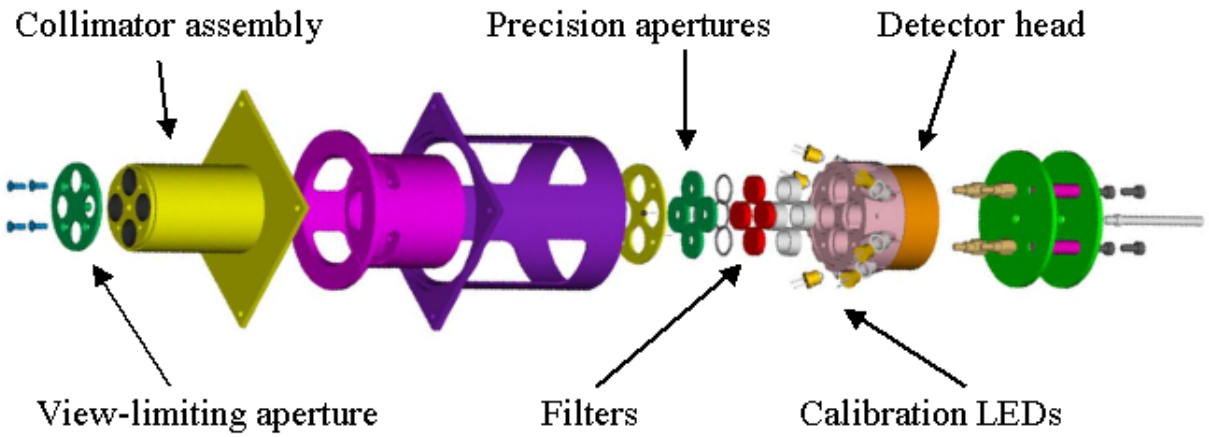
- ESA microsatellite in Sun-synchronous orbit, 725 km altitude
- Built in Belgium, commanded from ROB, launched 02 Nov 2009
- 17 technological experiments, 4 innovative instruments, for in-orbit demonstration (combined technology and science mission)
- LYRA and SWAP have been observing the Sun in EUV, continuously since Jan 2010

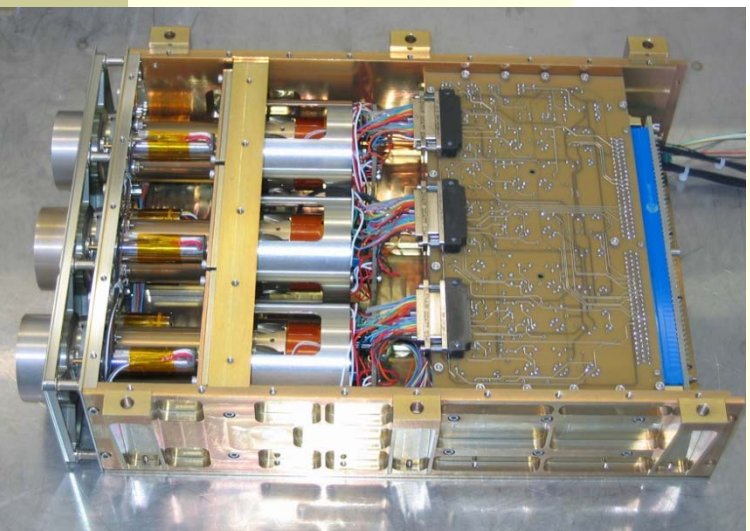

# LYRA: the Large-Yield RAdiometer

- 3 instrument units (redundancy)
- 4 spectral channels per head
- 3 types of detectors,
  Silicon + 2 types of
  diamond detectors (MSM, PIN):
  - radiation resistant
  - insensitive to visible light
    compared to Si detectors
- High cadence up to 100 Hz



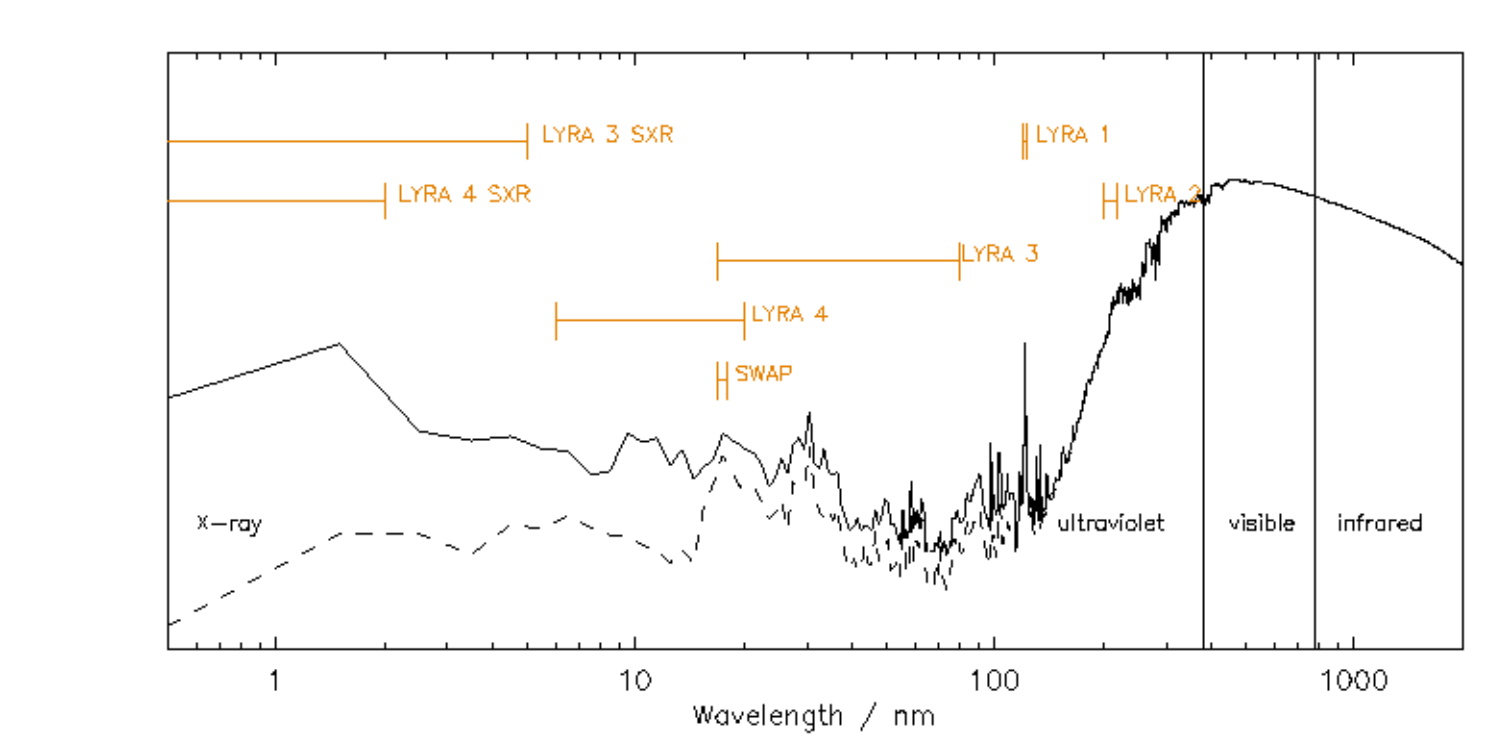
# LYRA design



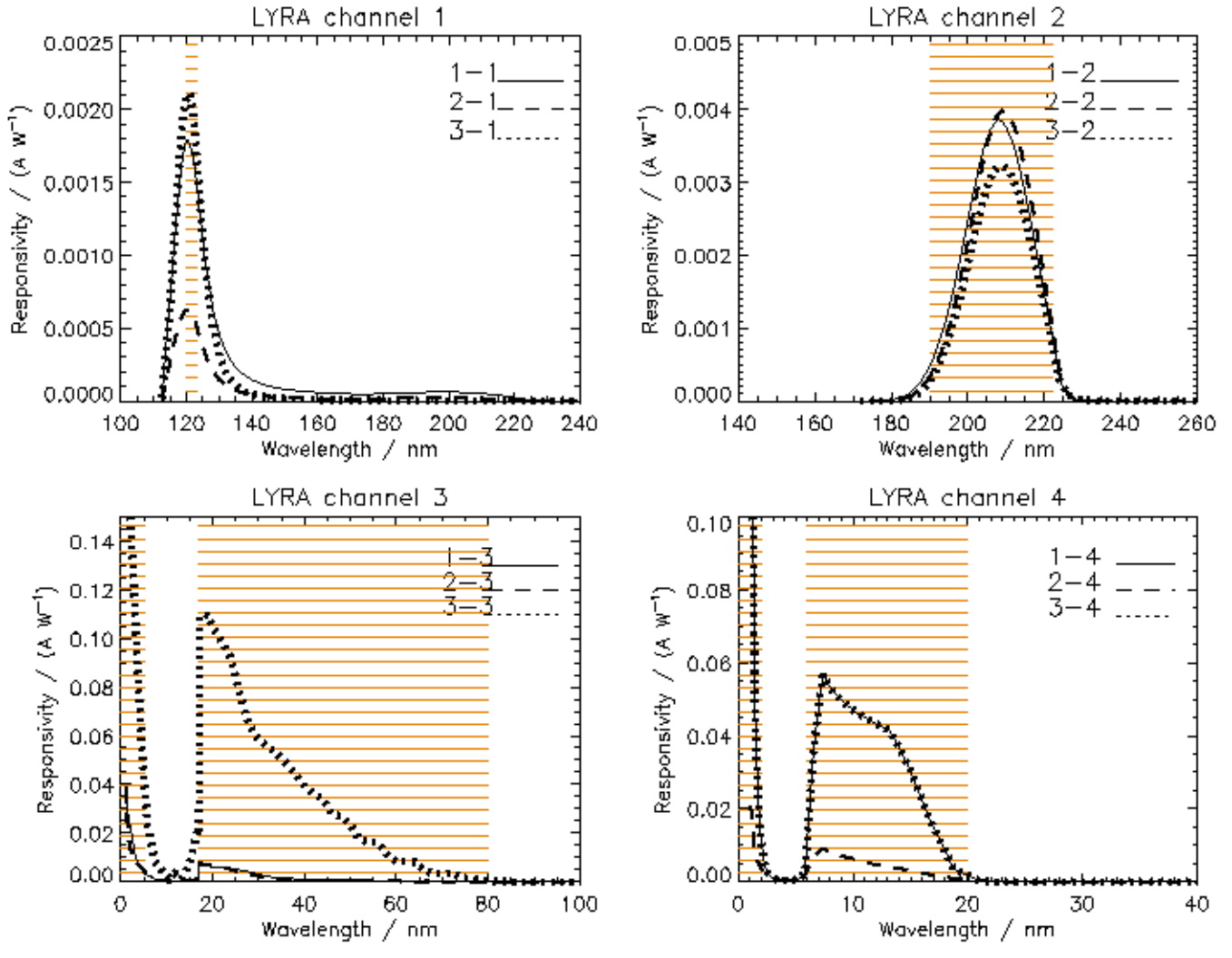
- Royal Observatory of Belgium (Brussels, B)
  Principal Investigator, overall design, onboard software specification, science operations
- PMOD/WRC (Davos, CH)
  Lead Co-Investigator, overall design and manufacturing
- Centre Spatial de Liège (B)
  Lead institute, project management, filters
- IMOMEC (Hasselt, B)
  Diamond detectors
- Max-Planck-Institut für Sonnensystemforschung (Lindau, D)
  calibration
- science Co-Is: BISA (Brussels, B), LPC2E (Orléans, F)…

# SWAP and LYRA spectral intervals for solar flares, space weather, and aeronomy

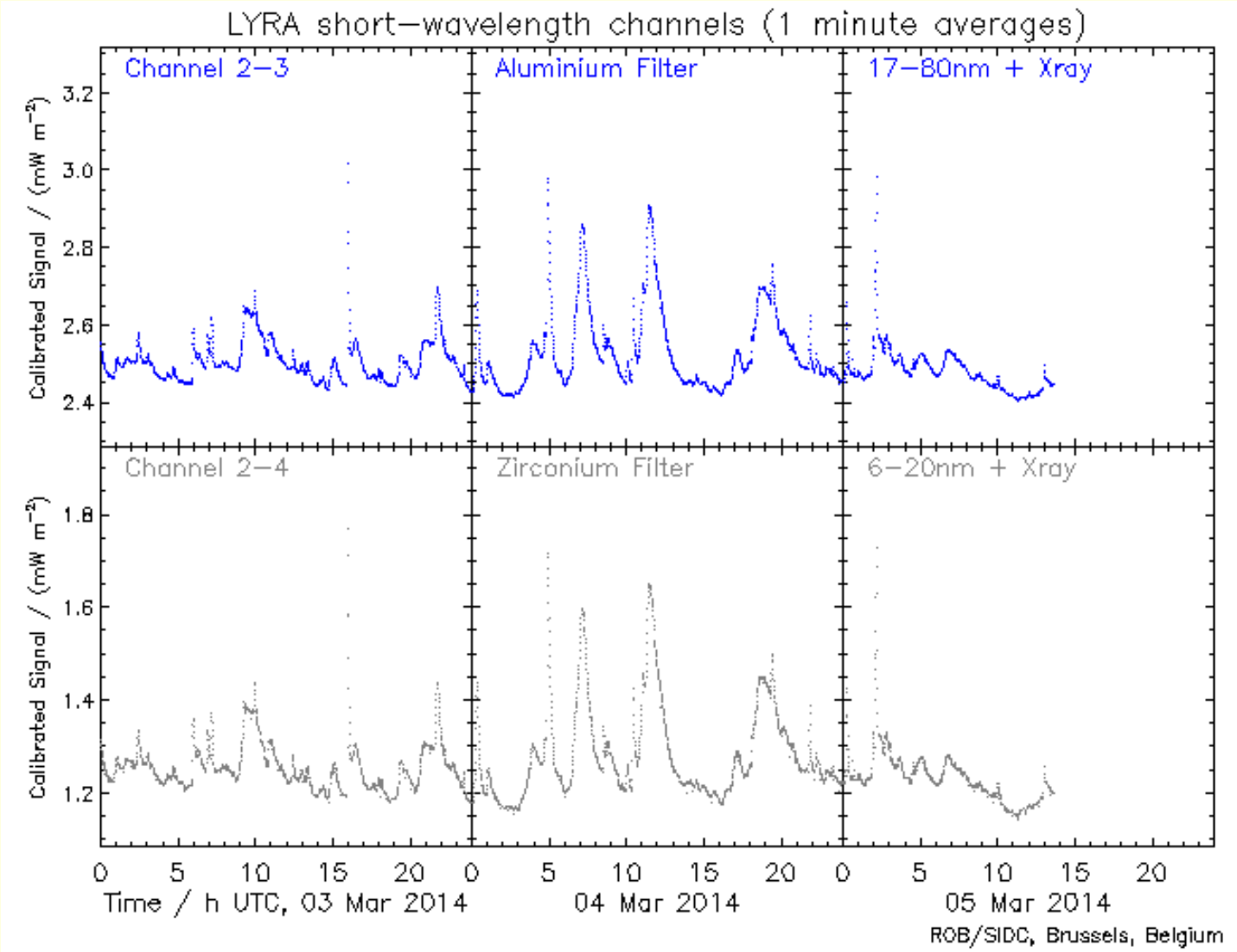



LYRA channel 1: the H I 121.6 nm Lyman-alpha line (120-123 nm)
LYRA channel 2: the 200-220 nm Herzberg continuum range (now 190-222 nm)
LYRA channel 3: the 17-80 nm Aluminium filter range incl the He II 30.4 nm line (+ <5nm X-ray)
LYRA channel 4: the 6-20 nm Zirconium filter range with highest solar variablility (+ <2nm X-ray)
SWAP: the range around 17.4 nm including coronal lines like Fe IX and Fe X

# LYRA spectral response



# LYRA data product: 3day quicklook



# LYRA data product: flare list

2014 LYRA Flare List - Mozilla Firefox

File Edit View History Bookmarks Tools Help

http://proba2.oma.be/lyra/data/Flarelist/Flarelist.html

Most Visited Getting Started Latest Headlines

## 2014 LYRA Flare List

**Please note:**

- This list uses the "G14" and "G15" X-ray entries from the "Edited Events" lists of the NOAA Space Weather Predict
- The purpose of the list is to get an overview of the flares that LYRA observes and relate them to class, begin, max
- In the daily images (follow links below), the flares are marked at the top of the LYRA Zr-channel curve, with event corresponding to their temporal "begin".
- Images of intervals around each flare (1h before, 2h after) are linked to a list below this curve (follow event links), observing during this interval.
- In the flare images, event number and class are again marked at the top, corresponding to their "begin", while the GOES maximum is marked with a short vertical line. These images contain all four LYR
- From November to January, PROBA2 experiences "eclipse se it, the solar disk is occulted by the Earth, and the observed irradiances decrease to dark-curre y) hidden.
- Additional information can be found at the PROBA2 website LYRA 3day quicklook page.

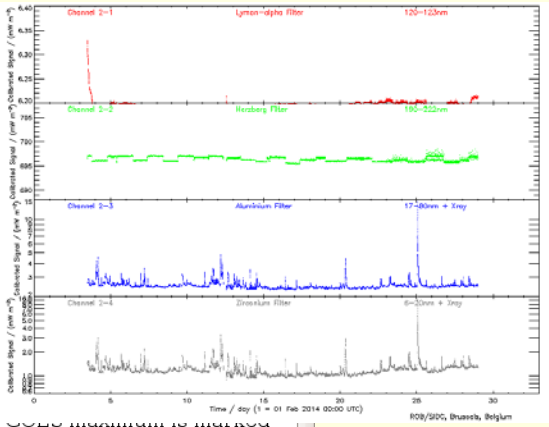
IDL program to read and display LYRA FITS files

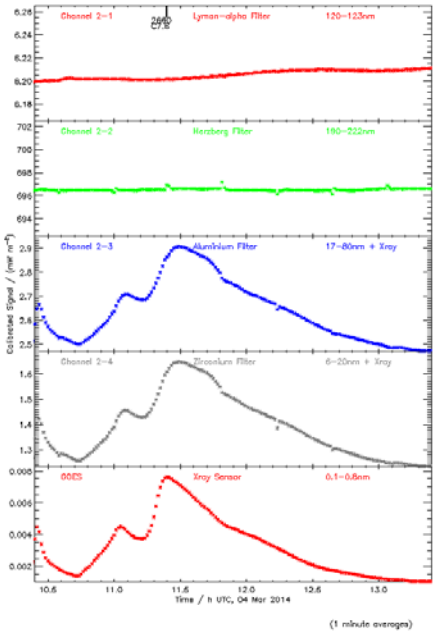
List of GOES flares since LYRA First Light 06 Jan 2010
new: List of daily flare statistics

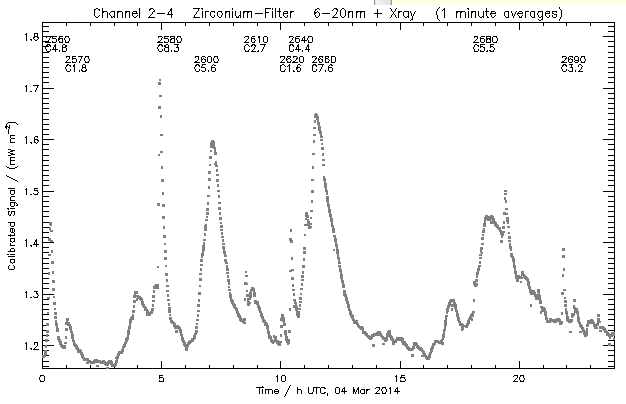
2010 page
2011 page
2012 page
2013 page

### March 2014

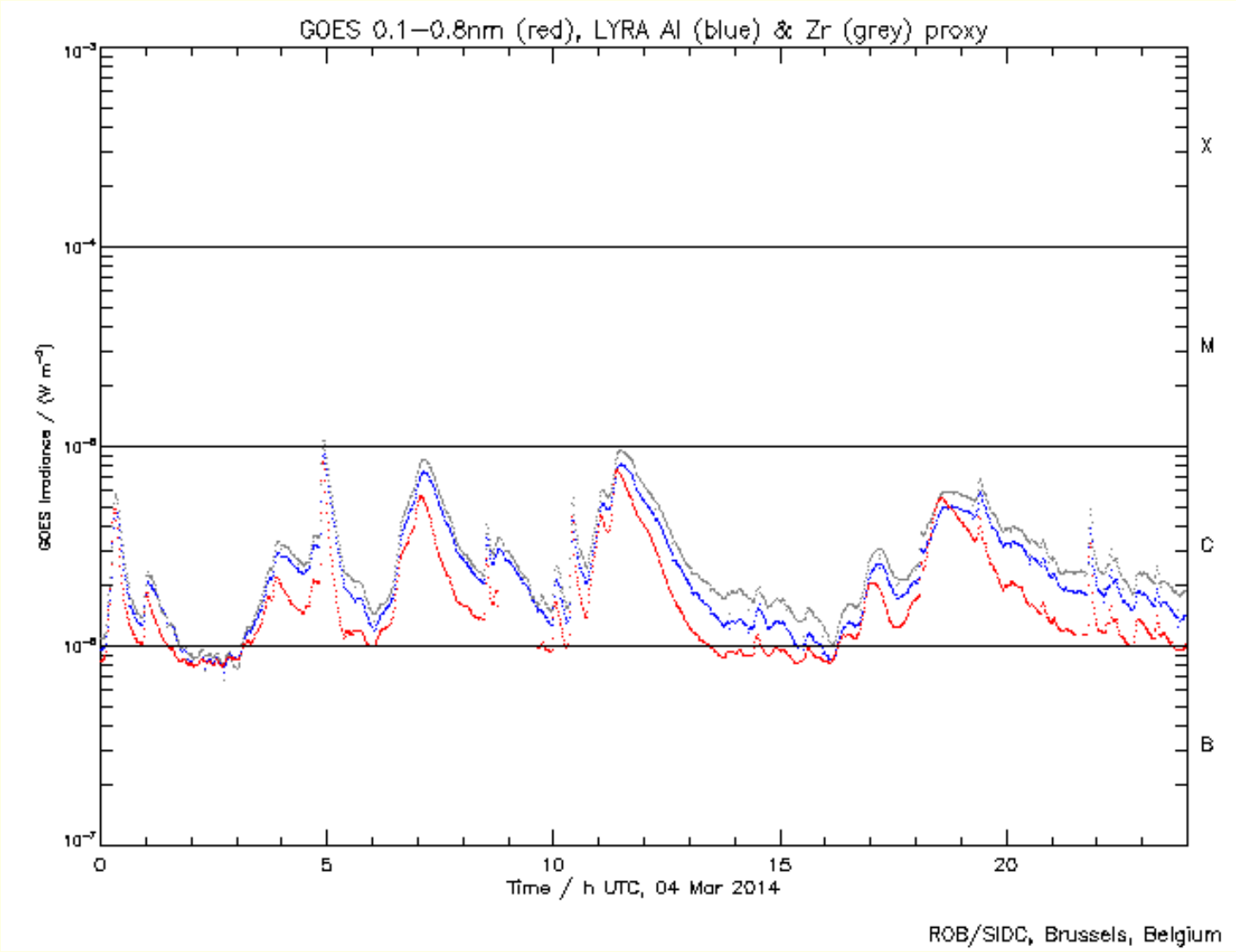
| | | | | | | |
|---|---|---|---|---|---|---|
| | | | | | Sat 01 | Sun 02 |
| Mon 03 | Tue 04 | Wed 05 | Thu 06 | Fri 07 | Sat 08 | Sun 09 |
| Mon 10 | Tue 11 | Wed 12 | Thu 13 | Fri 14 | Sat 15 | Sun 16 |
| Mon 17 | Tue 18 | Wed 19 | Thu 20 | Fri 21 | Sat 22 | Sun 23 |
| Mon 24 | Tue 25 | Wed 26 | Thu 27 | Fri 28 | Sat 29 | Sun 30 |
| Mon 31 | | | | | | |



# LYRA data product: GOES vs. LYRA proxies



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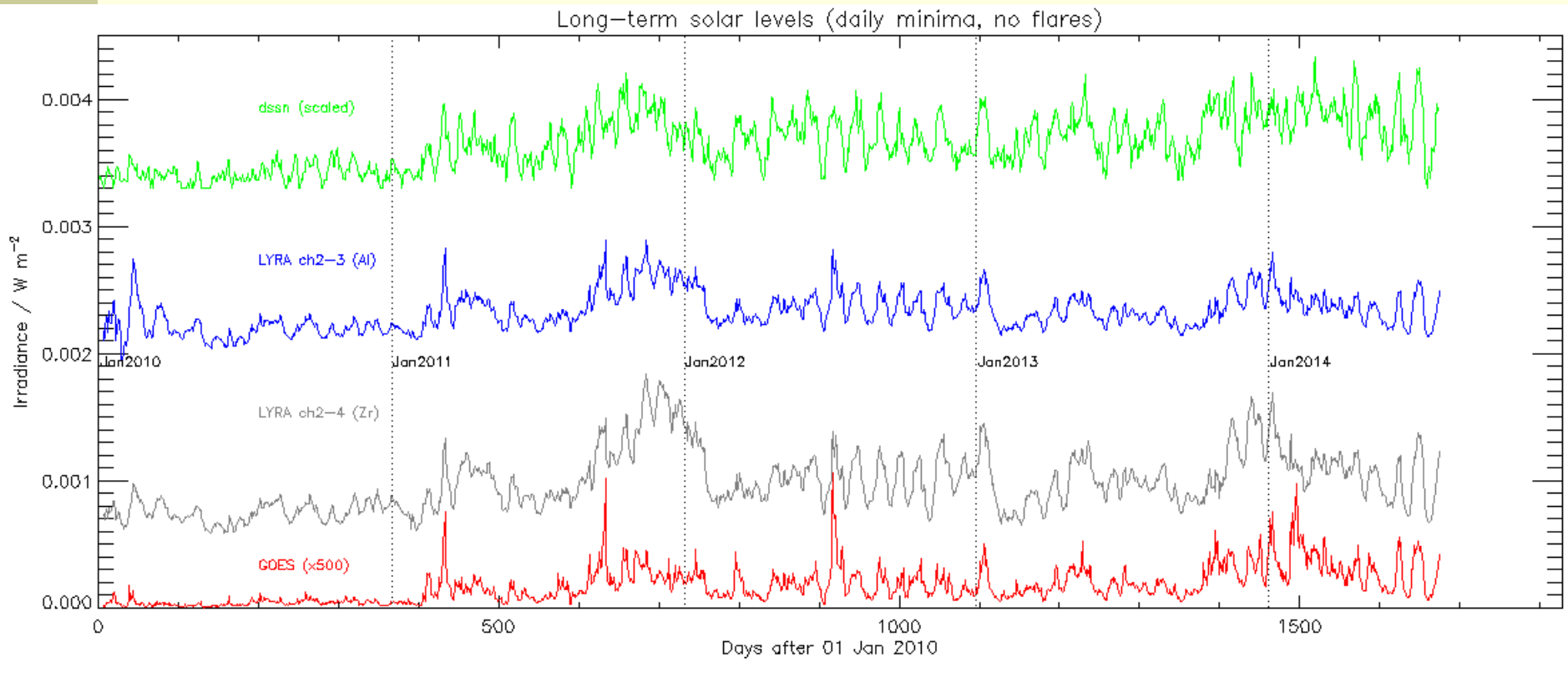
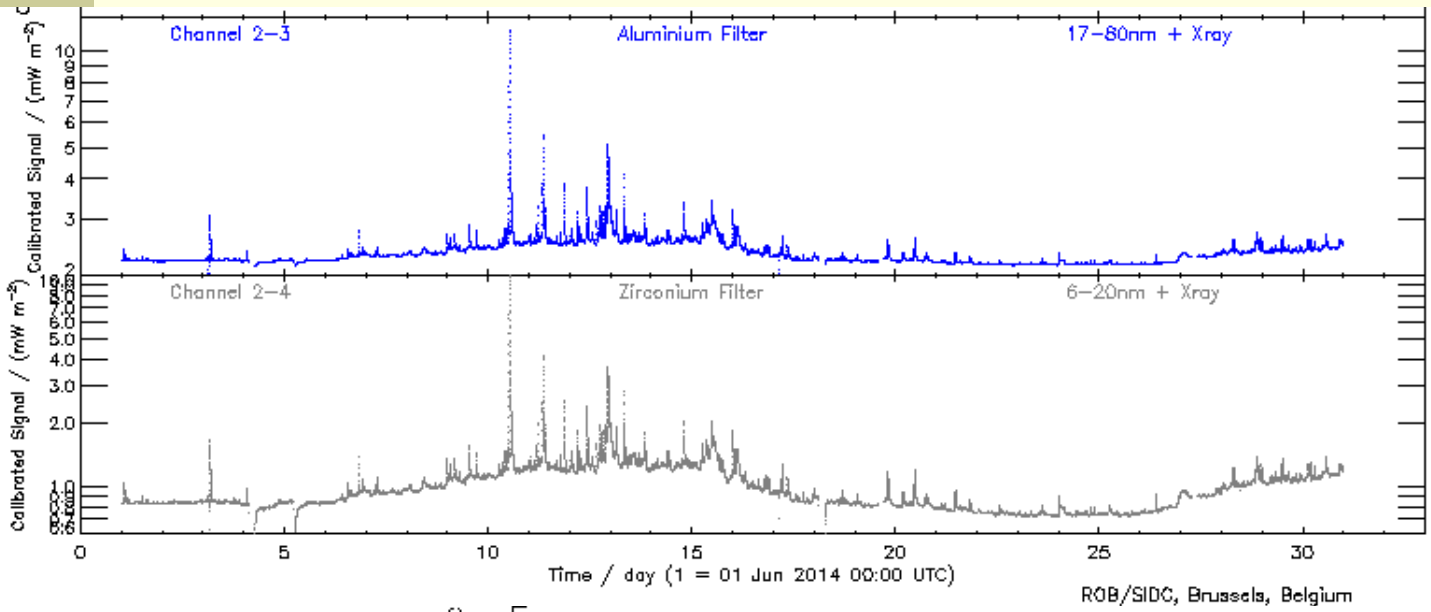
# LYRA data product: Long-term solar levels

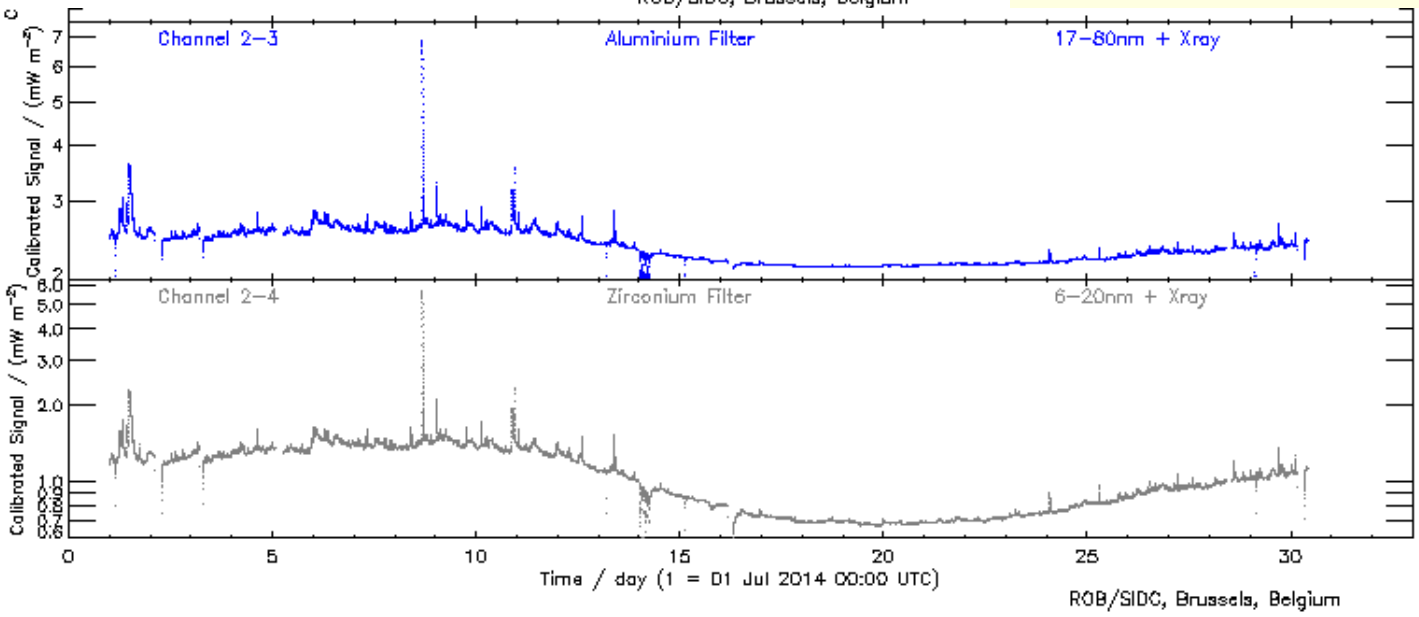



Keywords: spectral range (vis., EUV, SXR), temp. range (quiet corona: 1-2 MK, AR: ~4 MK, flares: higher), cycle max vs. 27-day var.

# Daily level, variance, flare size



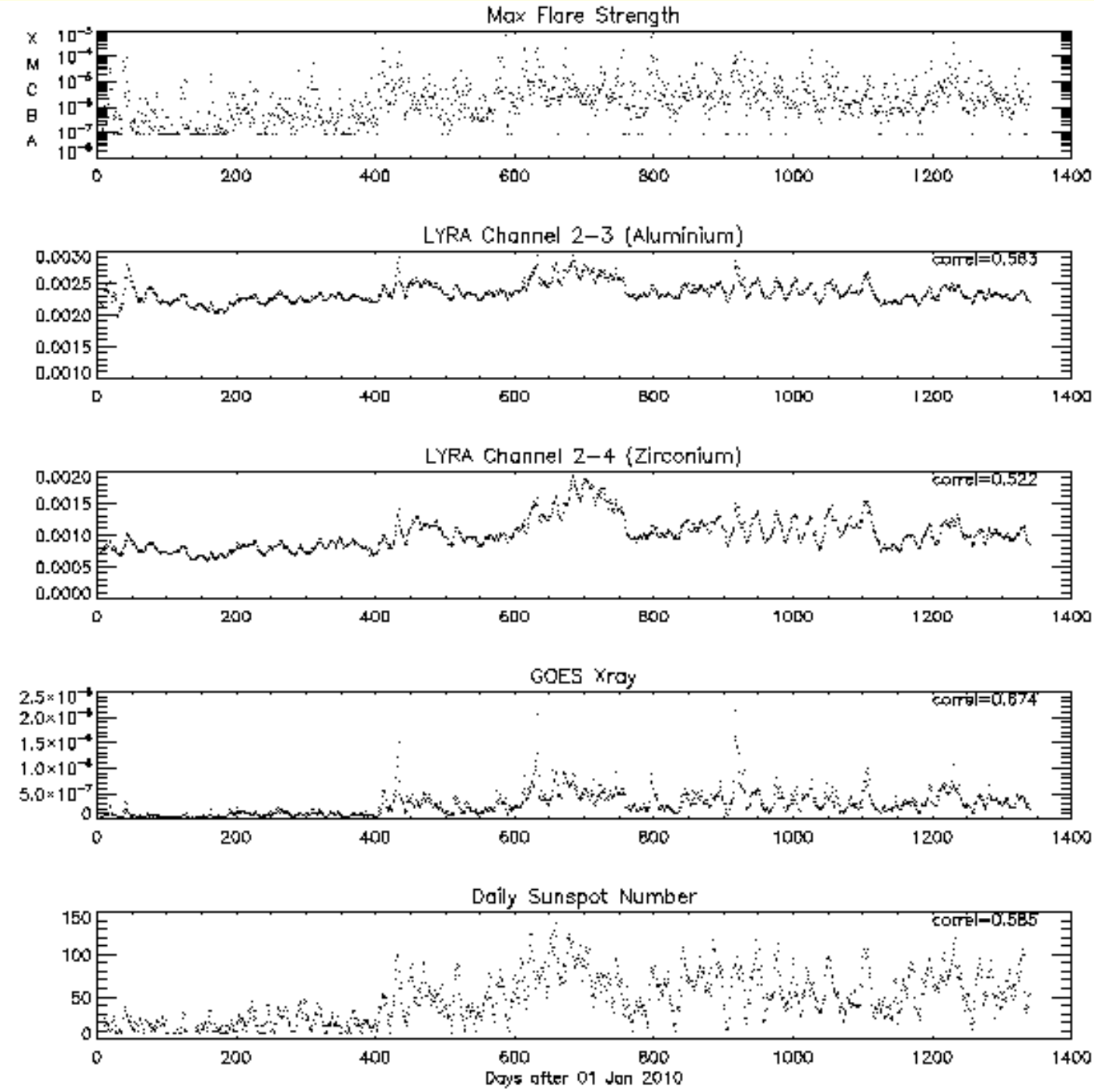

June 2014




July 2014

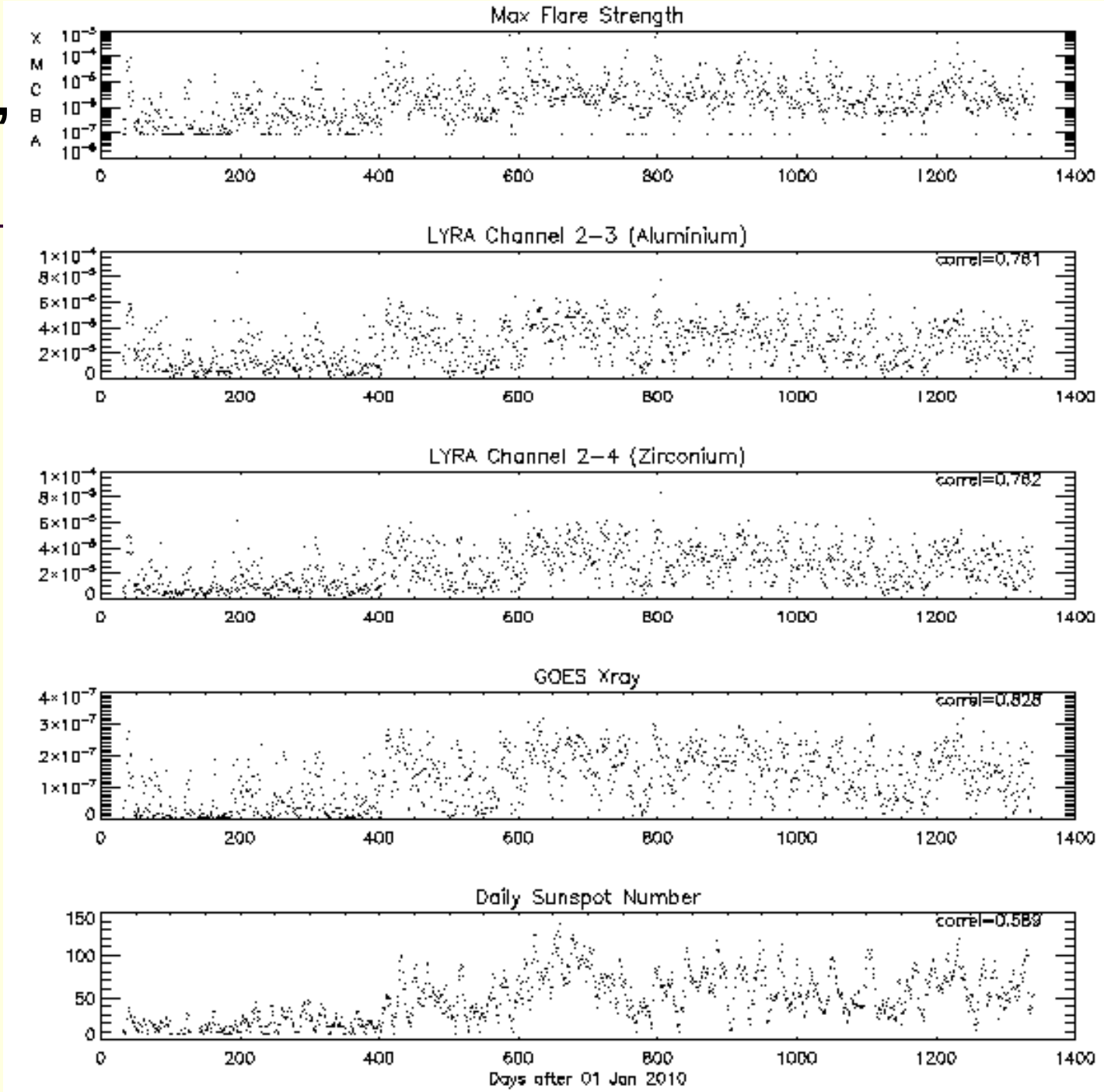
# “Level”

Significant daily minimum, without flares or instrumental artefacts



# “Variance”

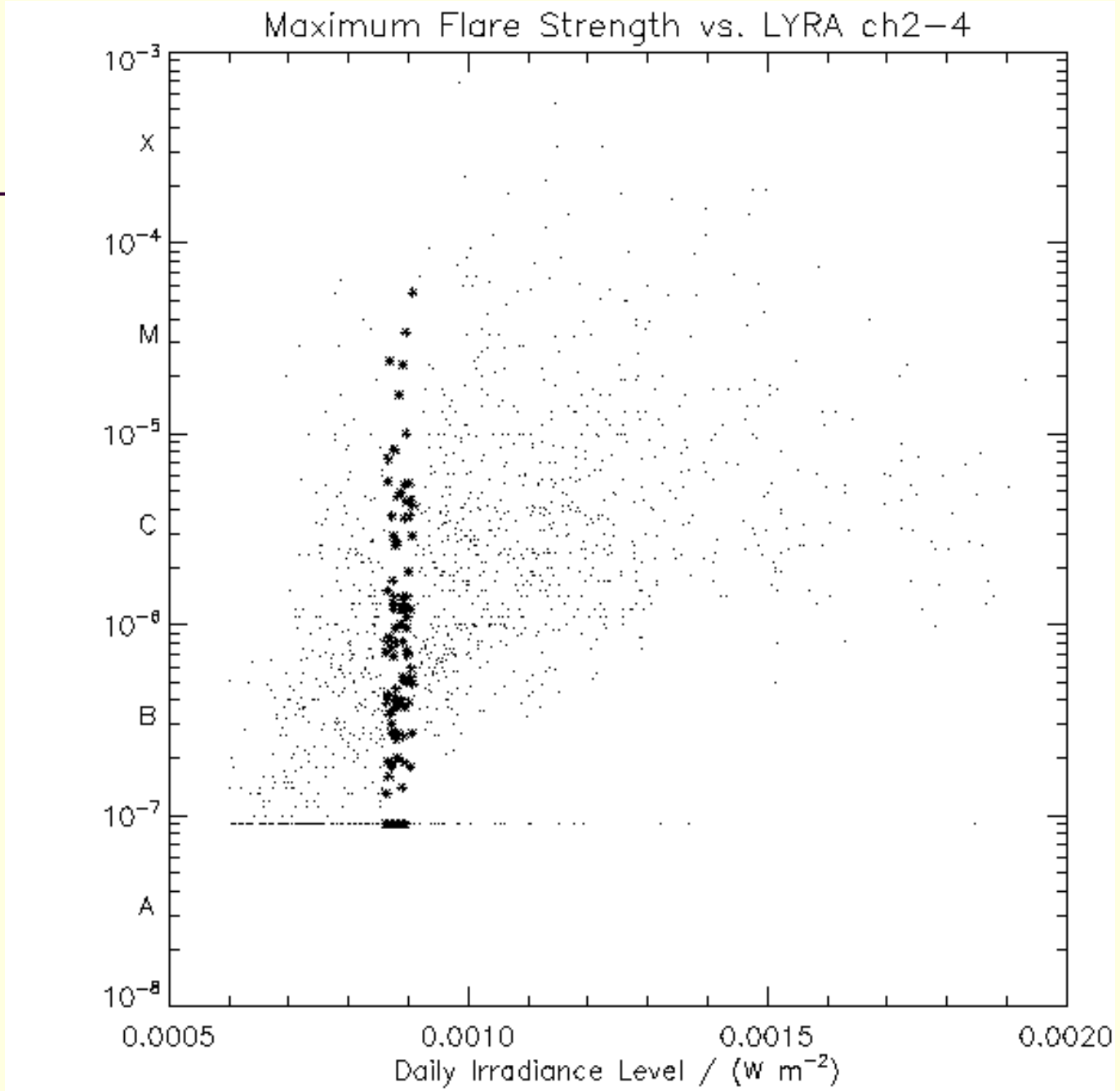
Daily minor-flaring activity, standard deviation in small corridor



# “Level”

100 values (*) closest around LYRA ch2-4 selected from 1300 observations
=>
estimated distribution of flare strengths

Same for LYRA ch2-3, GOES, DSSN
=>
forecast based on 400 values



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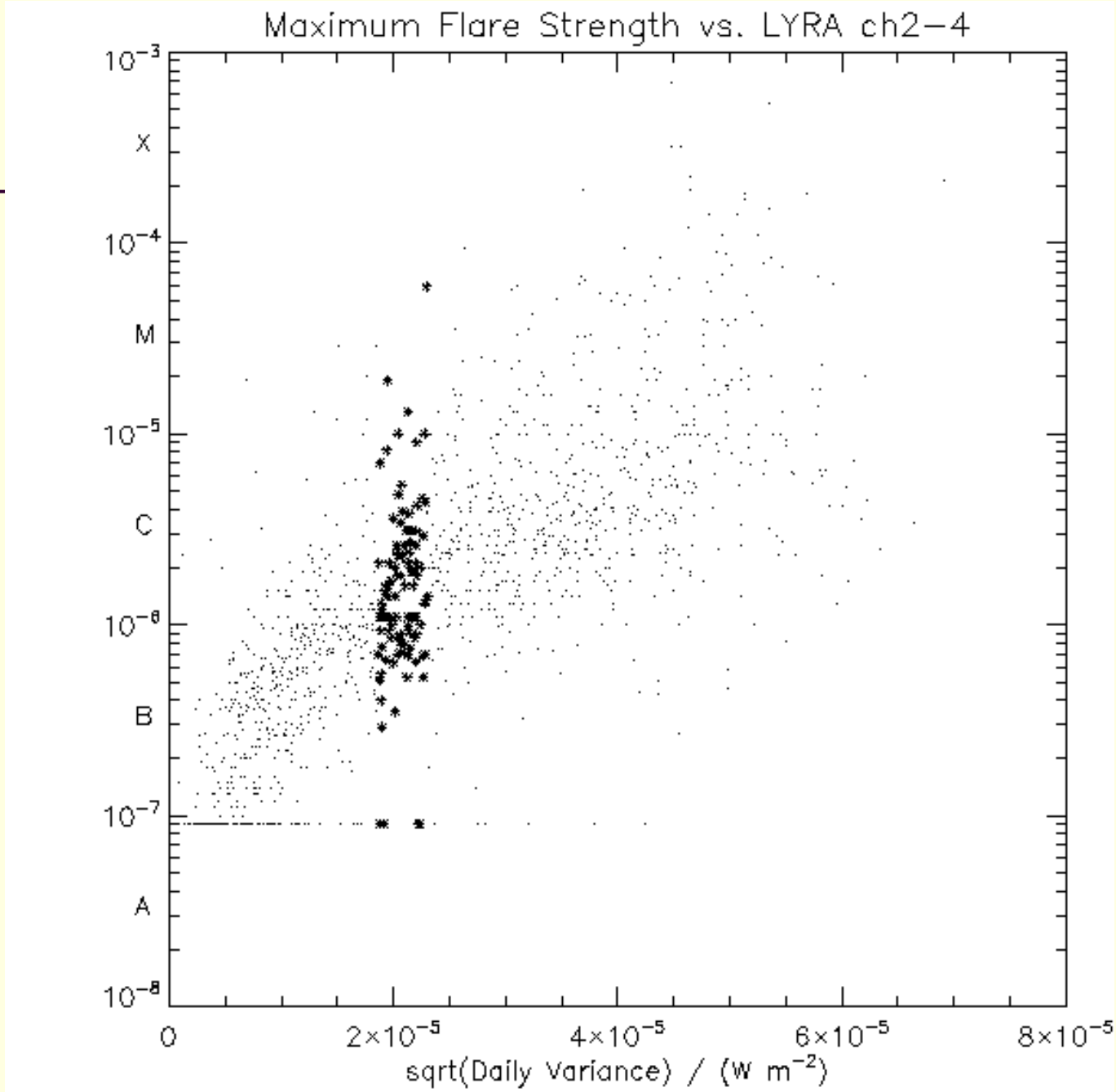
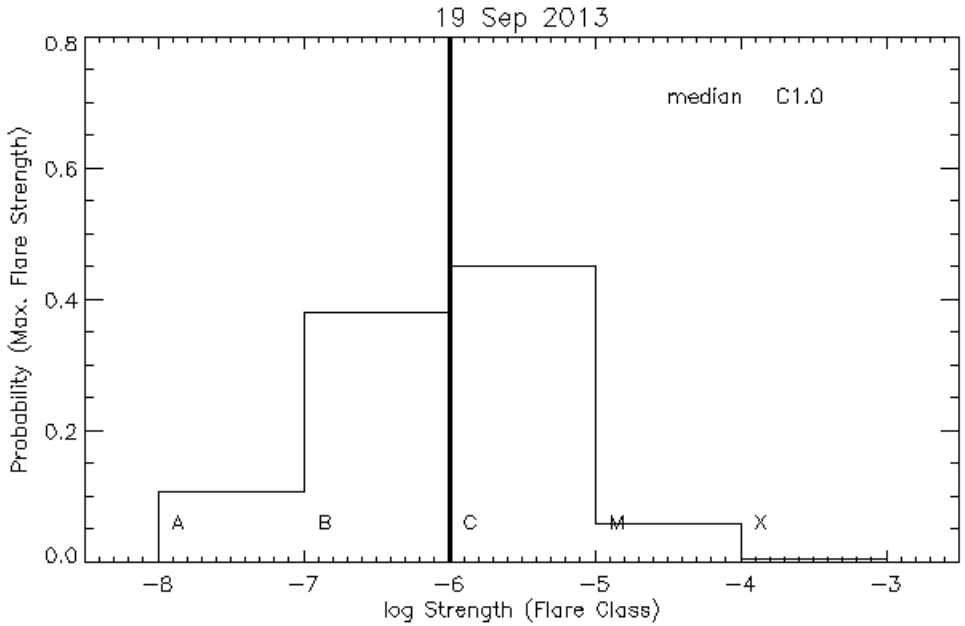


# “Level” – daily forecast

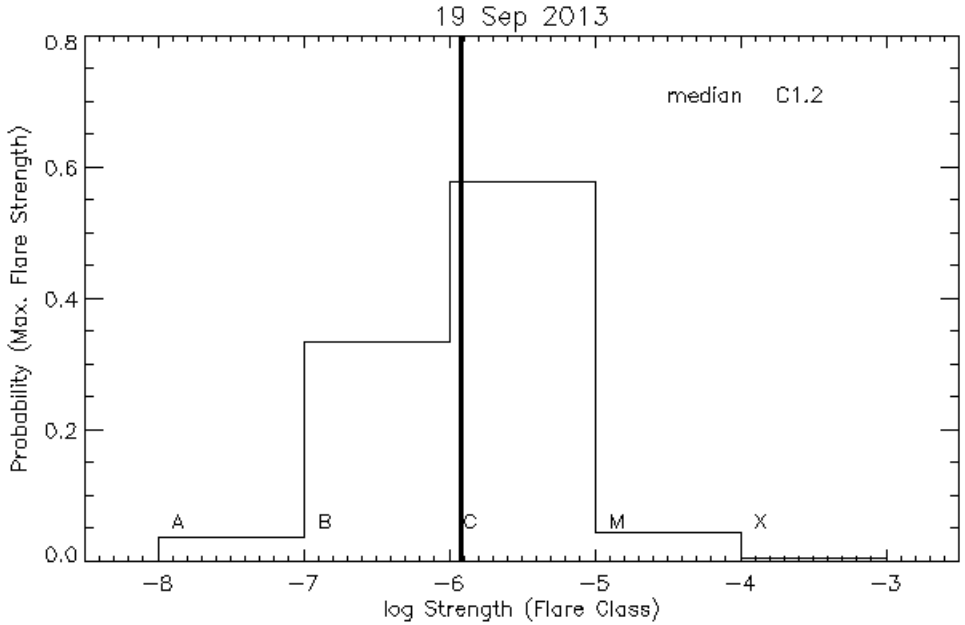
**Estimated Flare Probability**




| based on | | A[%] | B[%] | C[%] | M[%] | X[%] | median |
|---|---|---|---|---|---|---|---|
| LYRA ch2-3 = | 0.00223394 | 24 | 49 | 23 | 4 | 0 | B3.7 |
| LYRA ch2-4 = | 0.000884117 | 11 | 48 | 35 | 6 | 0 | B7.3 |
| GOES Xray = | 2.95000e-07 | 3 | 22 | 67 | 8 | 0 | C1.8 |
| est. ISN = | 44.0000 | 5 | 33 | 55 | 5 | 2 | C1.2 |
| together | | 10.75 | 38.00 | 45.00 | 5.75 | 0.50 | C1.0 |
| realized | | | | | | | C1.8 |

# “Variance” – daily forecast

**Estimated Flare Probability**




| based on | | A[%] | B[%] | C[%] | M[%] | X[%] | median |
|---|---|---|---|---|---|---|---|
| LYRA ch2-3 = | 2.07391e-05 | 4 | 41 | 50 | 5 | 0 | C1.1 |
| LYRA ch2-4 = | 2.07291e-05 | 4 | 30 | 61 | 5 | 0 | C1.4 |
| GOES Xray = | 1.04609e-07 | 2 | 30 | 65 | 3 | 0 | C1.4 |
| est. ISN = | 44.0000 | 5 | 33 | 55 | 5 | 2 | C1.2 |
| together | | 3.75 | 33.50 | 57.75 | 4.50 | 0.50 | C1.2 |
| realized | | | | | | | C1.8 |

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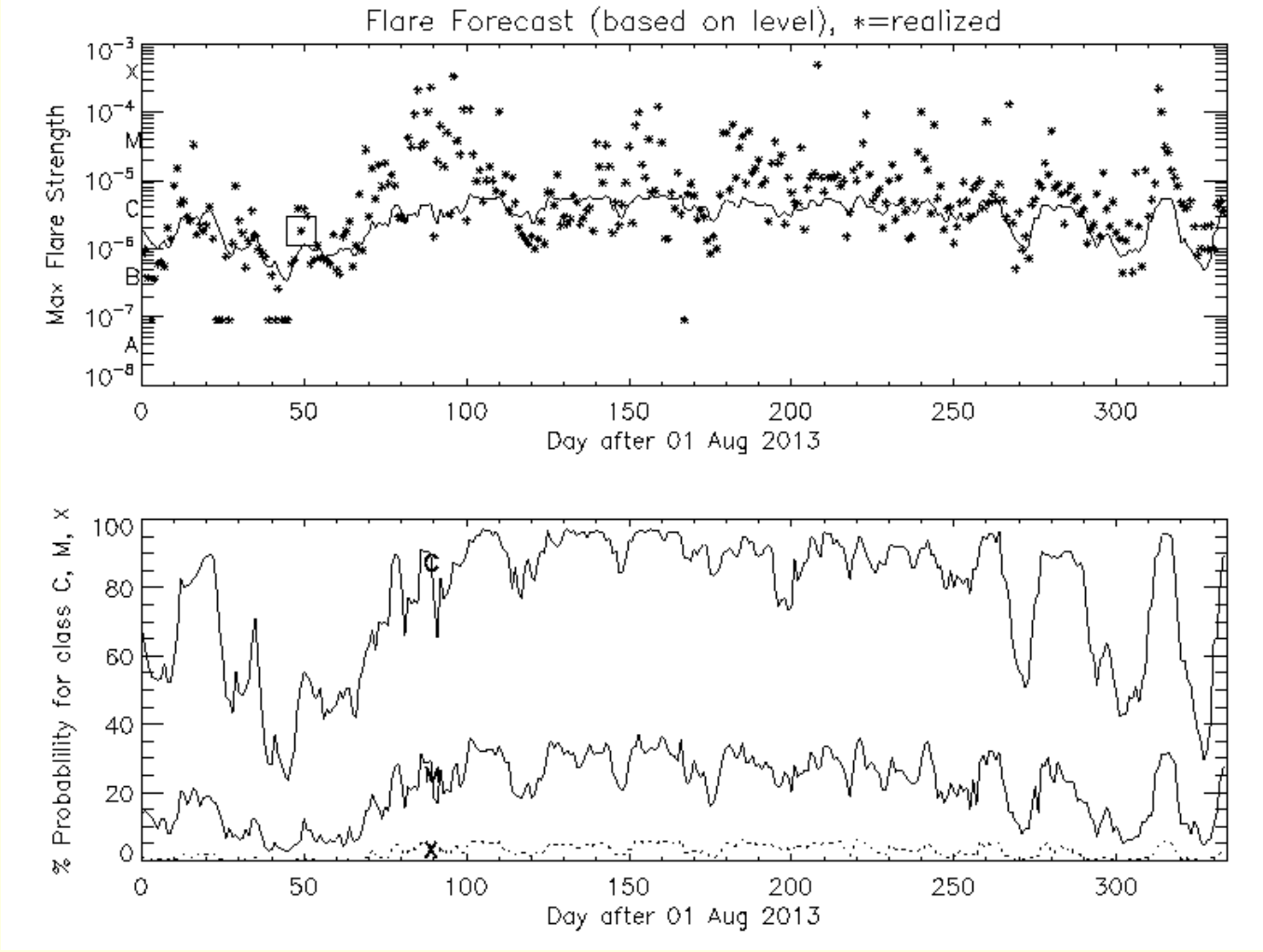
# Forecast method “Level”

Test Aug 2013 – Jul 2014

Method changes slower than “Var”

Median leads to underestimation during high activity

Probabilities reflect situation better than simply median



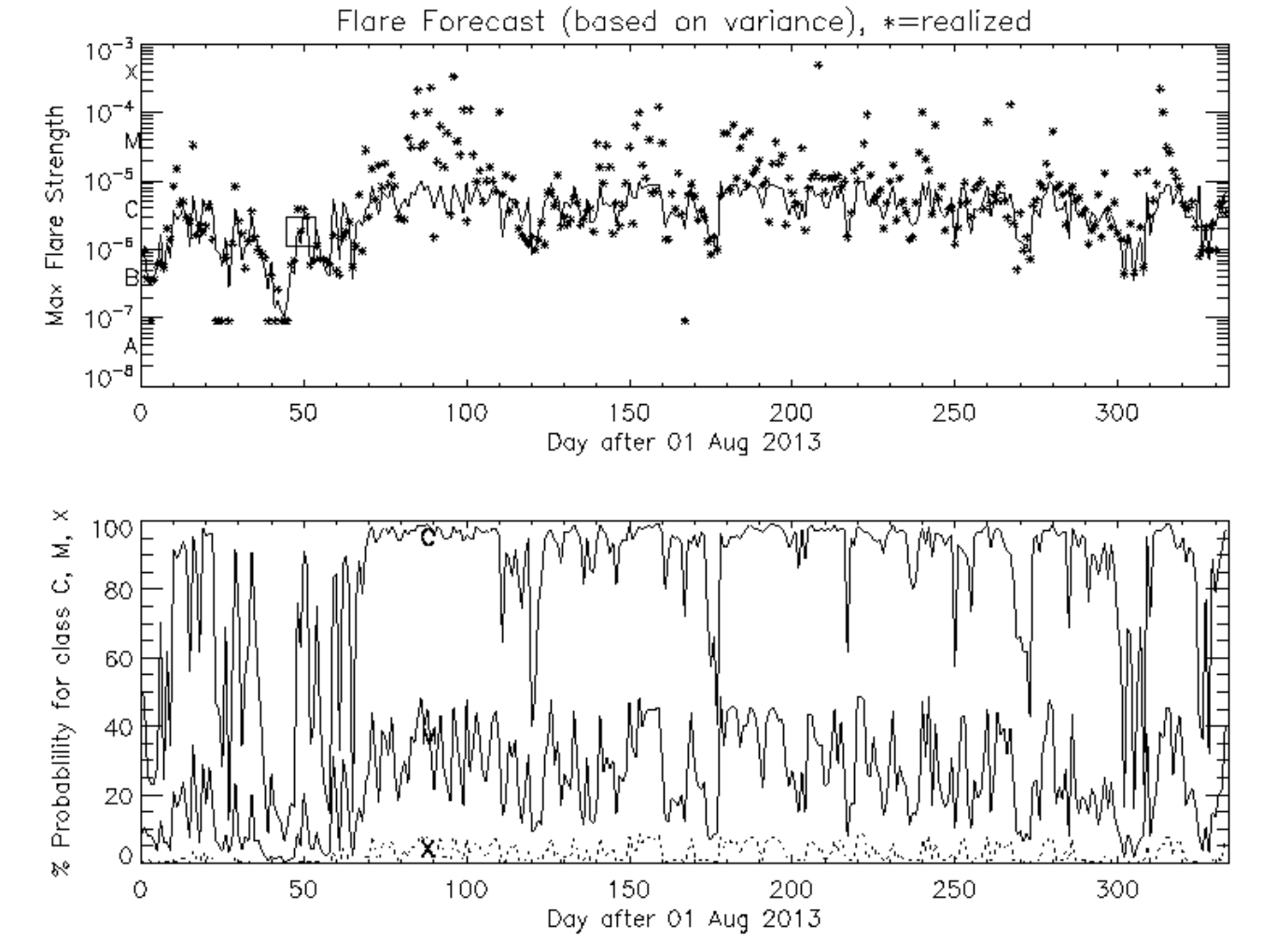
# Forecast method “Variance”

Test Aug 2013 - Jul 2014

Method follows closer than “Lev”

Median leads to underestimation during high activity

Probabilities reflect situation better than simply median



# Forecast verification measures (I)

- Root mean squared error (RMSE) — Skill score
  - Level = 0.60 [orders of magnitude] — 0.03
  - Level Day-1 = 0.62 — -0.03
  - Variance = 0.48 — 0.38
  - Variance Day-1 = 0.57 — 0.13
  - Persistence = 0.61 — 0.00
  - constant C1.5 = 0.84 — -0.90
- Skill score definition
  - 1 – MSE / MSE(ref)
  - ref = Persistence model
  - 0: as useful as reference model
  - <0: worse than reference model
  - 1: perfect forecast

# Forecast verification measures (II)

- Contingency table (for binary events: either – or)

| | | Observation | |
|---|---|---|---|
| | | Y | N |
| Forecast | Y | a (hit) | b (false alarm) |
| | N | c (miss) | d (correct rejection) |
| Example: Persistence | | 268 | 19 |
| forecasting flare > C1.0 | | 20 | 27 |

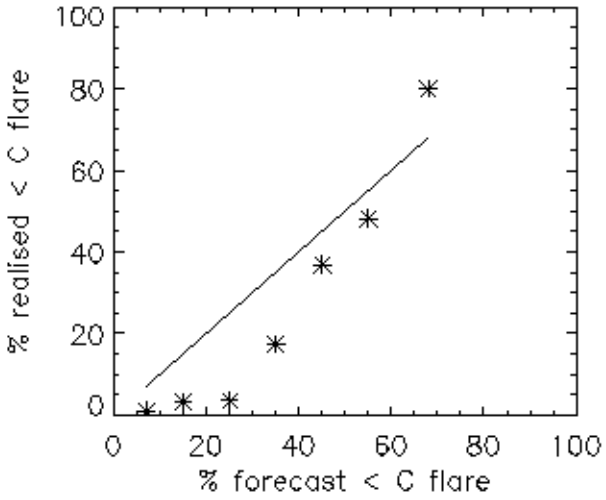
- Skill score definition
  - Example: True Skill Statistic
  - TSS = (ad - bc) / ((a+c)*(b+d))
  - 0: no skill; useless like constant or random forecast
  - <0: even worse
  - 1: perfect forecast

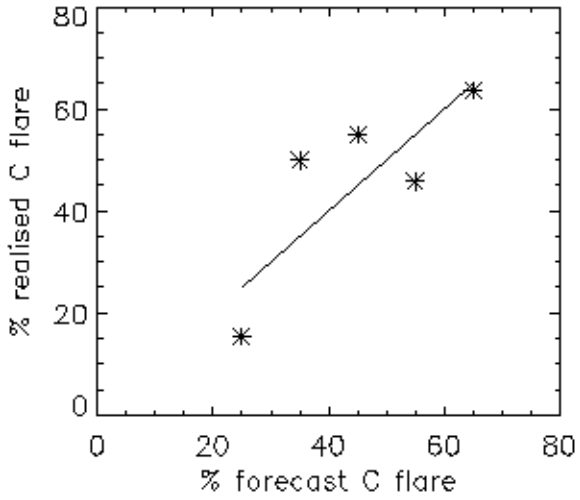
# Forecast verification measures (III)

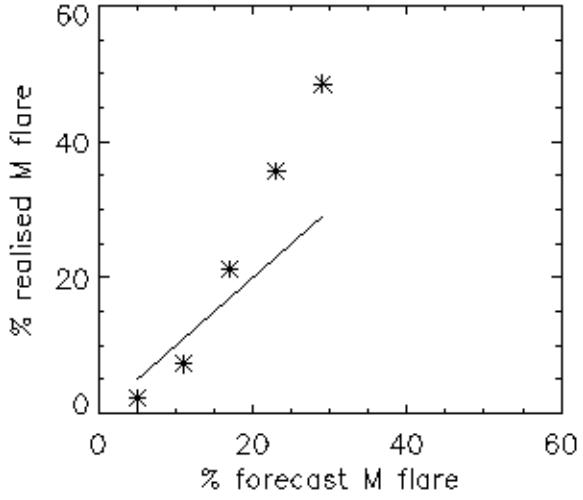
- Forecasting flare > C1.0 Skill score
  - TSS(Level) = 0.44
  - TSS(Variance) = 0.72
  - TSS(Persistence) = 0.52
- Forecasting flare > M1.0 Skill score
  - TSS(Level) = 0.00
  - TSS(Variance) = 0.00
  - TSS(Persistence) = 0.34

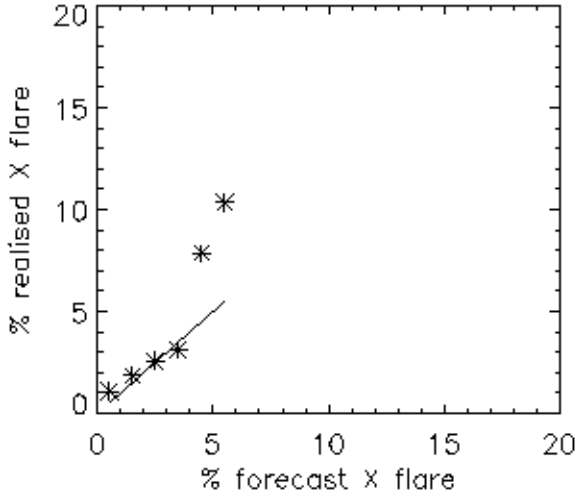
# Forecast verification measures (IV)

- Reliability function ("Lev")



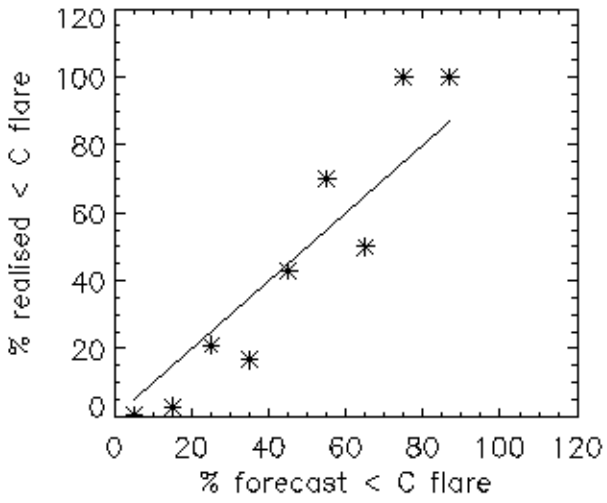



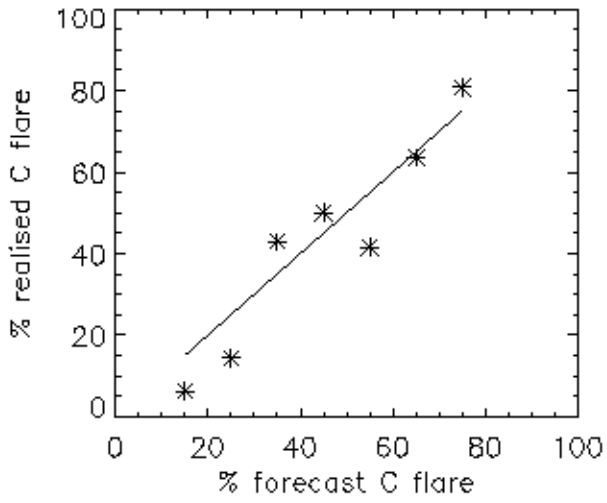



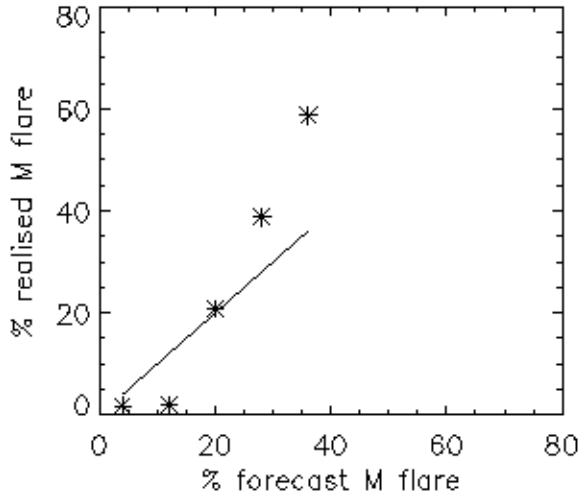



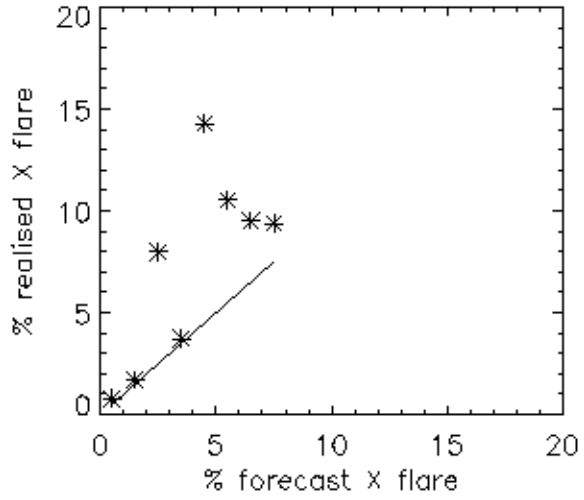
# Forecast verification measures (V)

- Reliability function (“Var”)



# Questions for the future

- Second activity peak of cycle 24 – does it change the statistics?
- How can the methods be improved?
- Can the two methods be integrated?
- Which forecasting parameter is the most reliable?
- Can the parameters be weighted accordingly?
- Are space weather forecasters interested?
- [I heard that most methods have difficulties with rare events like M- and X-flares]

# Please visit

- http://solwww.oma.be/users/dammasch/flares/FlareProbability.html
- http://solwww.oma.be/users/dammasch/flares/FlareProbabilityVar.html
- and of course the official PROBA2 website
- http://proba2.oma.be/

- ***Thank you for your interest !***