Polar faculae and the next solar cycle

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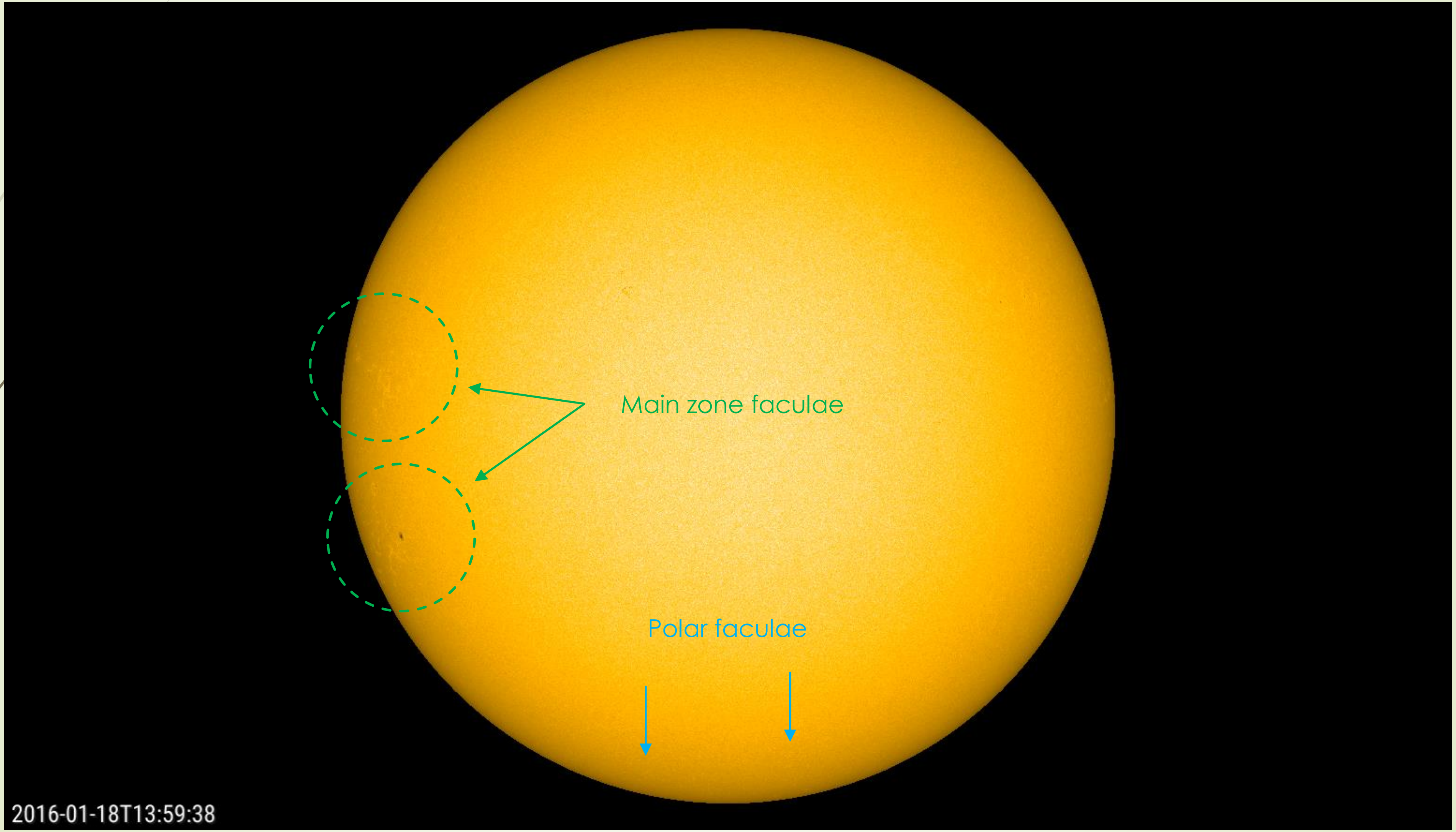
What are polar faculae?



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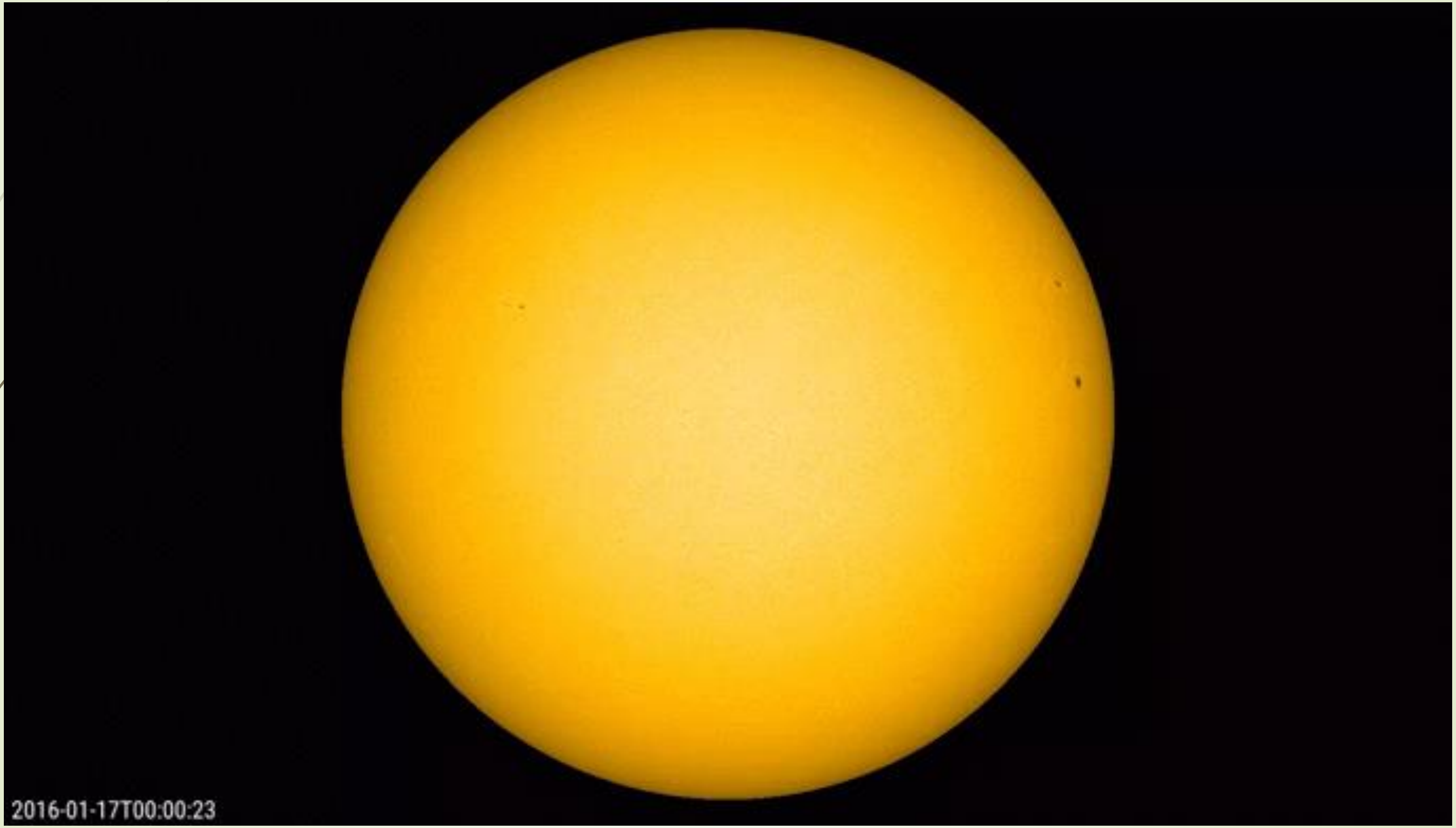

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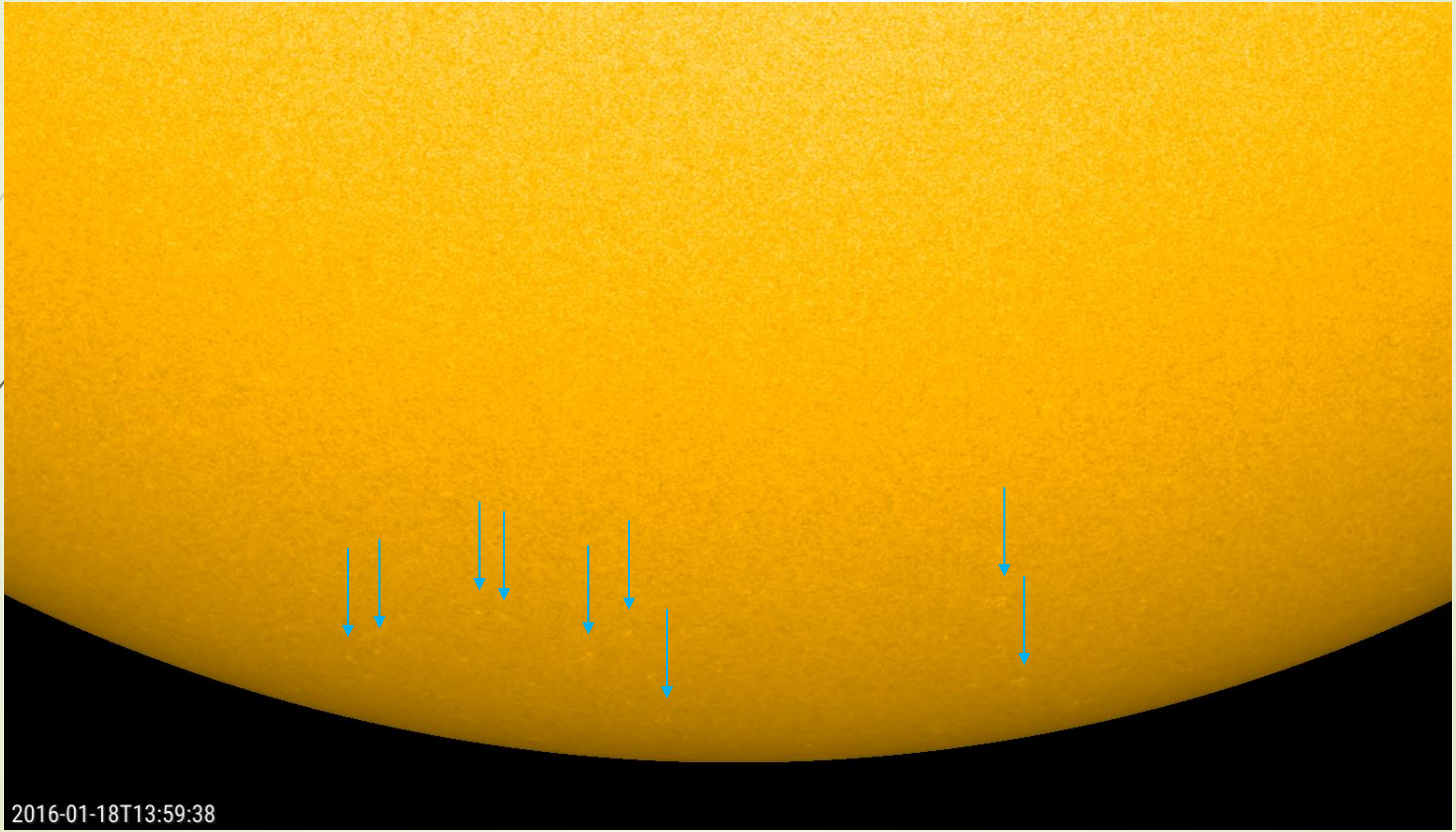
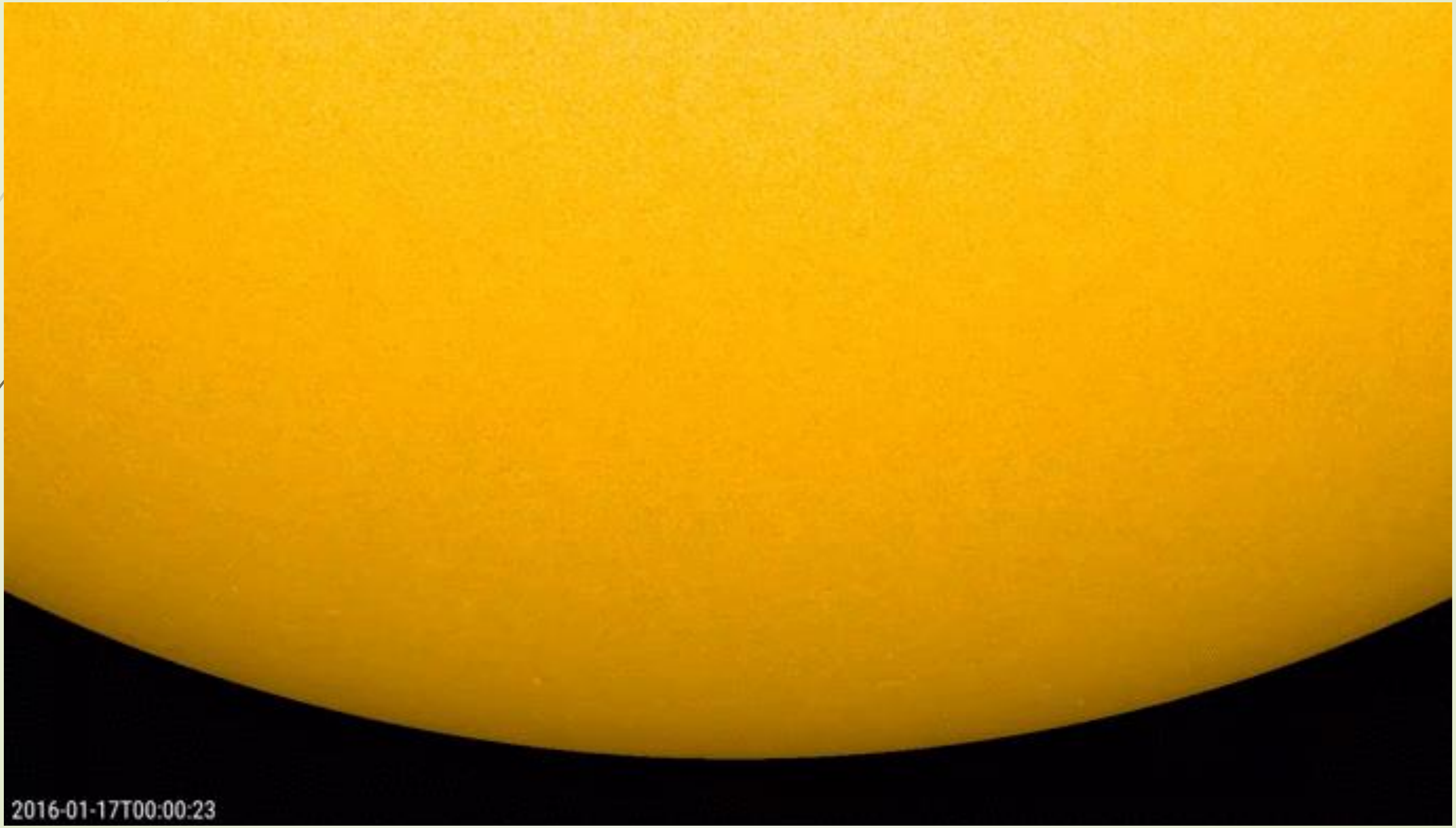


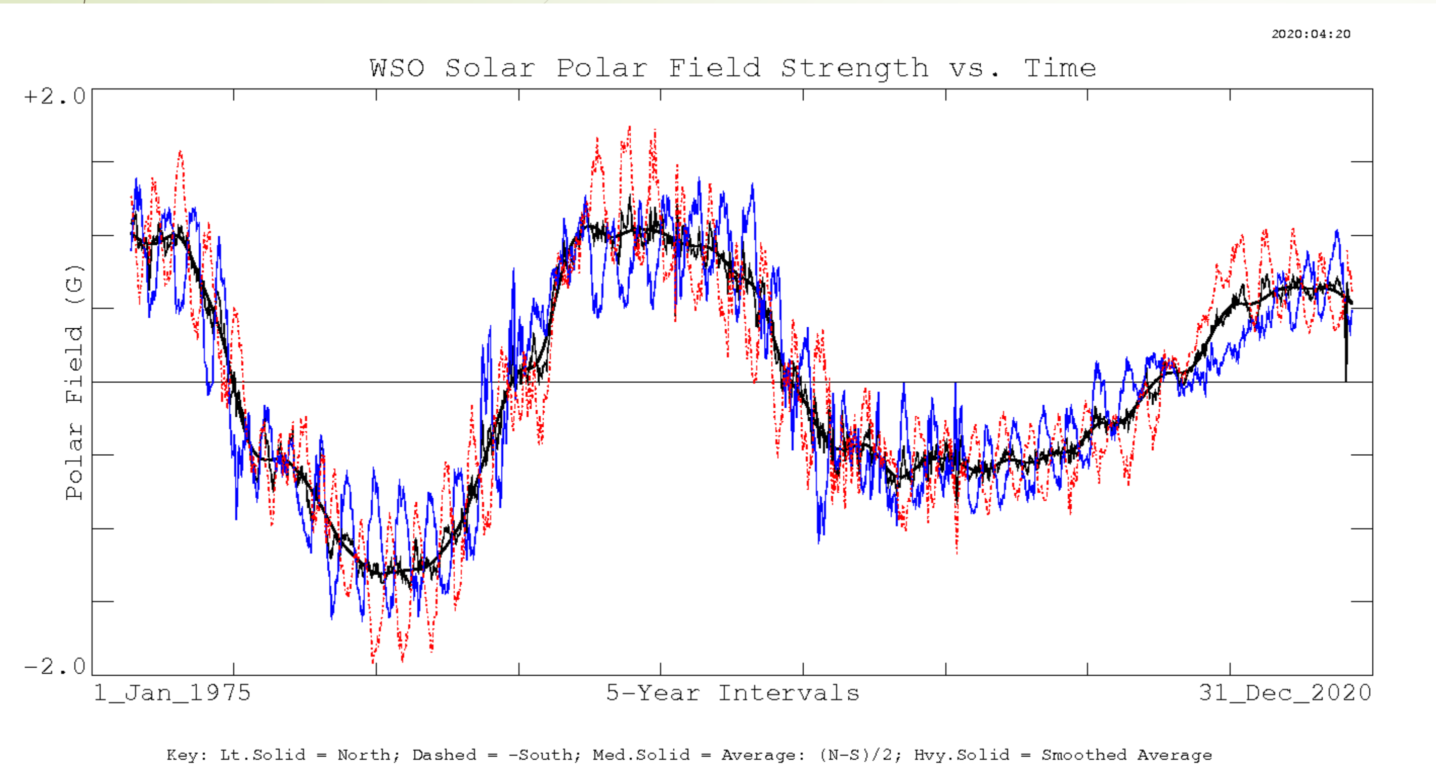
What are polar faculae?



What are polar faculae?

Feature	**Main zone faculae**	**Polar faculae**
Outlook	Veined, patchy, irregular	Dot-like, isolated
Latitude	< +/- 50°	> +/- 60°
Lifetime	Days to weeks	Hours to days
Brightness (I_{ph} = 1)	1,09-1,16	1,03-1,10
Main activity	SC maximum	SC minimum

Why?



Magnetic field data of the solar poles are used as input for precursor techniques *to predict the amplitude of the next solar cycle*.
E.g. Schatten (2005), Svalgaard (2005).

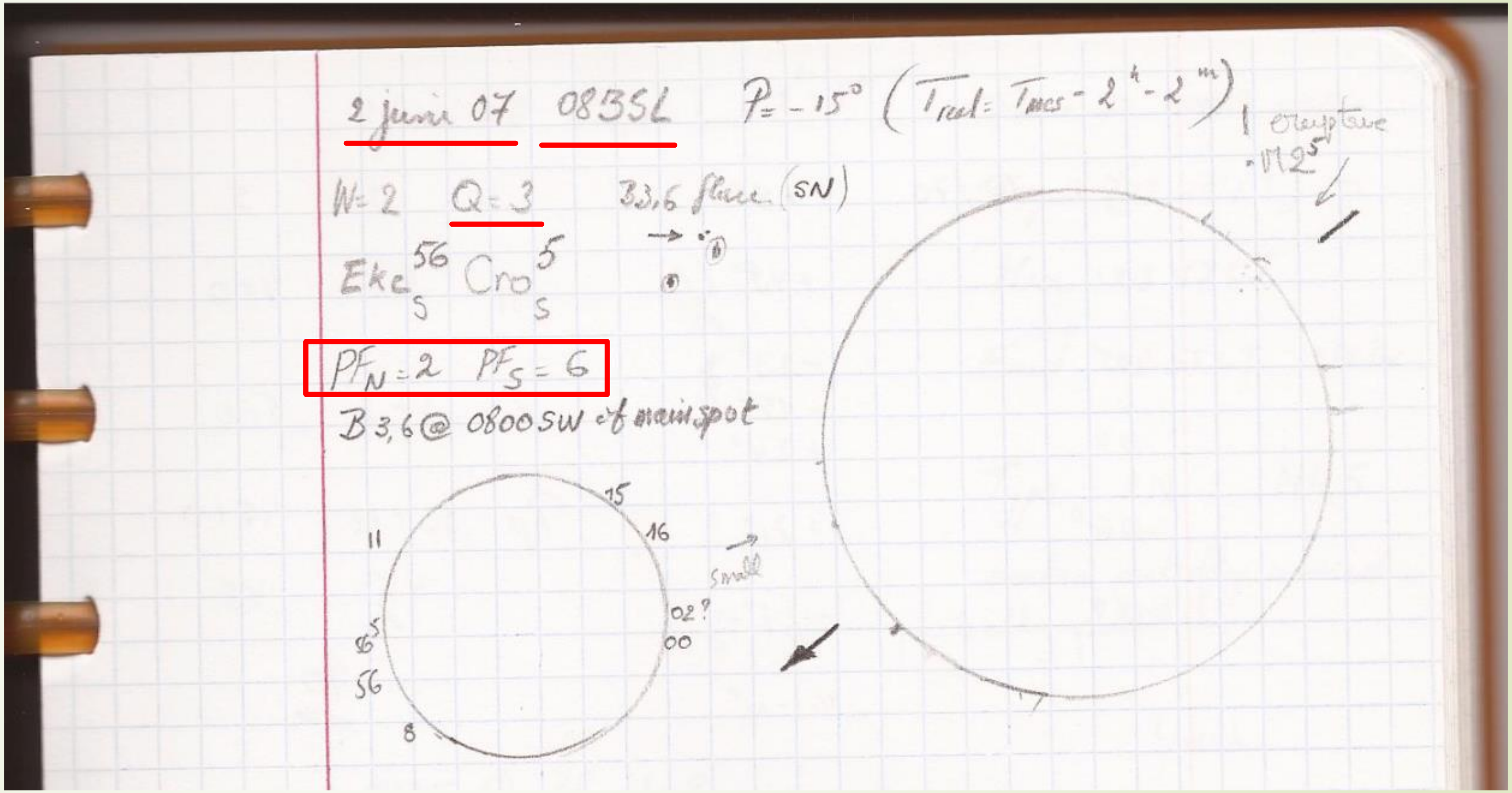
3.3. Counts of Polar Faculae

[11] Faculae, Latin for torches, are bright features seen near the Sun's limbs. They are associated with given amounts of magnetic flux, allowing their count to serve as a rough measure of magnetic flux, when the field is not directly observed with a solar magnetograph. They are essentially a "poor man's magnetograph" and thus allow us a rough direct measurement of the solar field. Their importance [*Sheeley*, 1991; F. Dubois et al., world net of polar facular observers, data located at http://www.digilife.be/club/Franky.Dubois/polar.htm, 2005; N. Sheeley Jr., private communication, 2005] has made them an object of study for solar observers who are interested in global, quiet solar phenomena. The most recent polar faculae (F. Dubois et al., world net of polar facular observers, data located at http://www.digilife.be/club/Franky.Dubois/polar.htm, 2005) show reduced levels, however, they were made by a different set of observers and observatory than N. Sheeley Jr. (private communication, 2005). Nevertheless, Sheeley using observations from Mount Wilson asserts that faculae do provide a good proxy for the WSO observations. Faculae are a great source of observations to back up non-sunspot field observations, particularly in the polar areas. Additionally these important features have a questionable structure (hillocks vs. wells) [see *Schatten et al.*, 1986].

Schatten (2005)

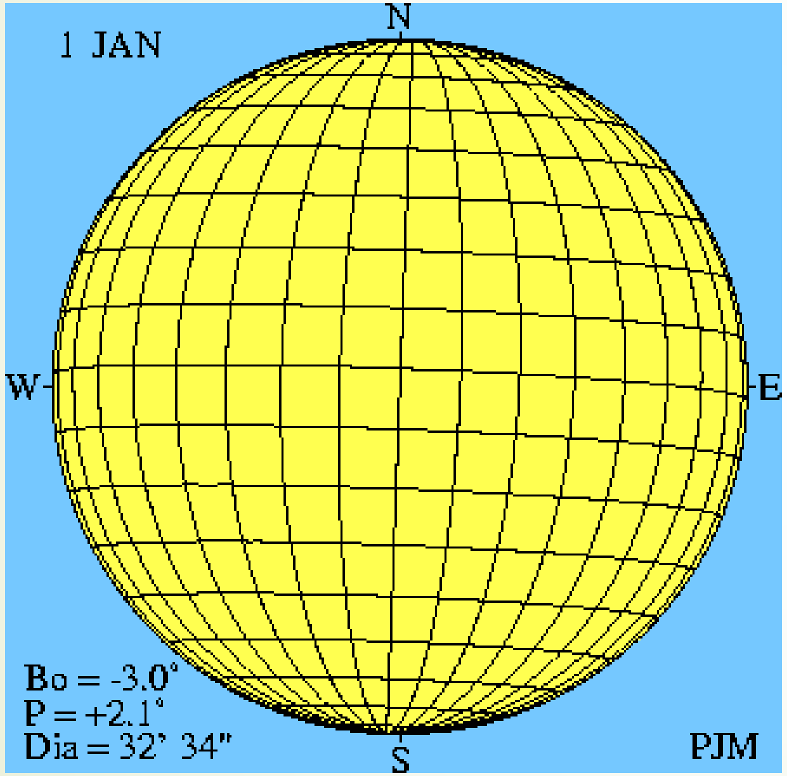
Observing and recording PF

C8 - 68* - blue filter - Cardboard or towel



Date – time – seeing – number of PF for each hemisphere

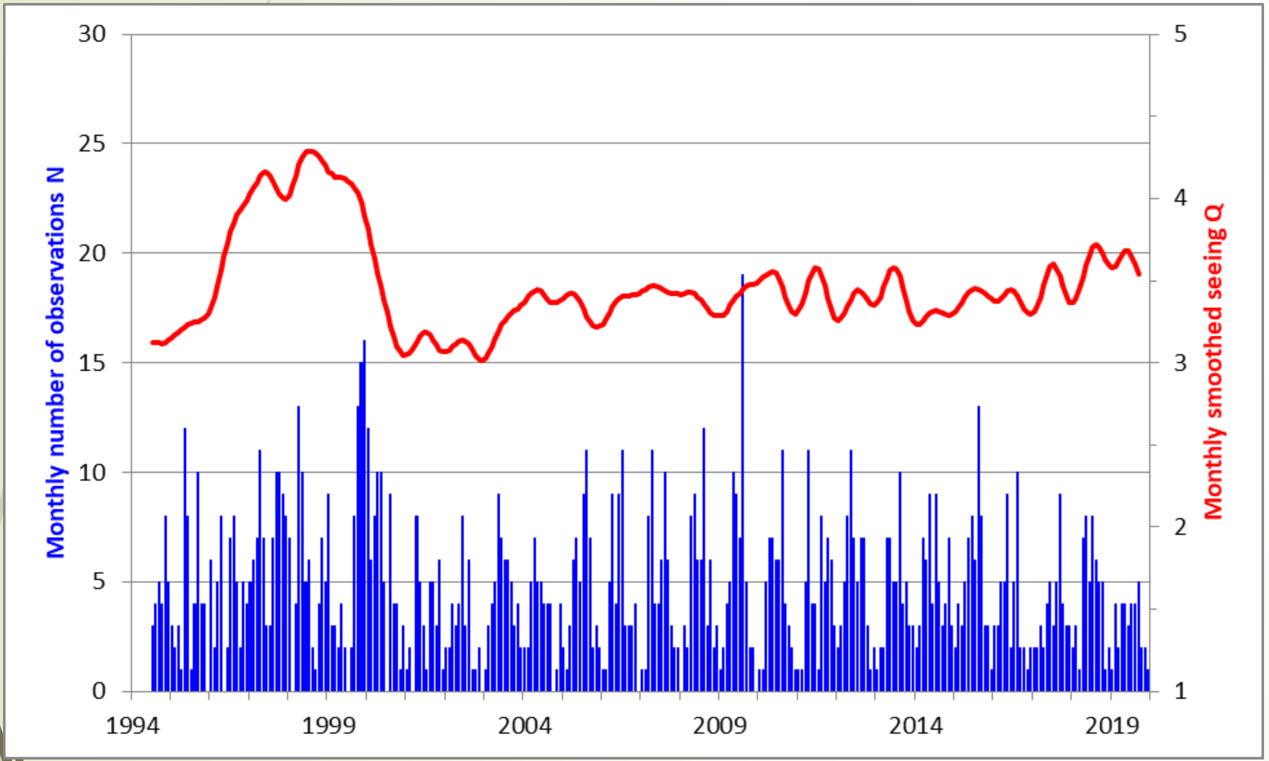
B_0: Heliographic latitude of the centre of the solar disk



Credits: Peter Meadows
http://www.petermeadows.com/html/sunfromearth.html

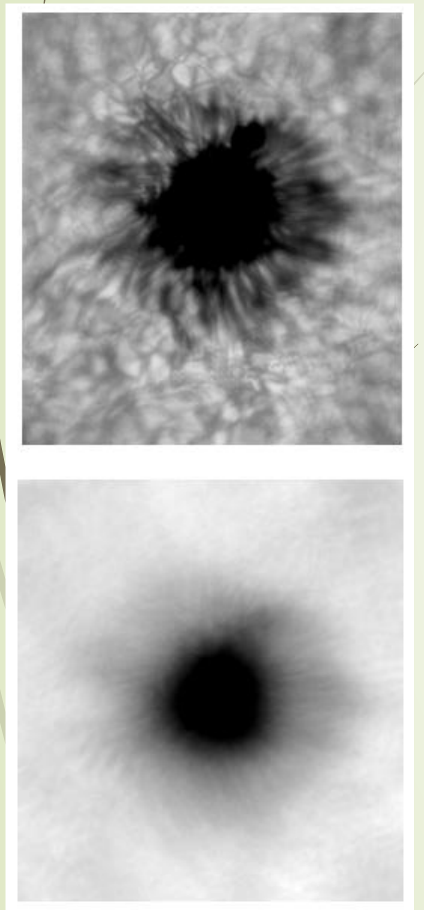
- PF values not corrected for B_0 angle
  - Similar to Sheeley (2008)
    - "… The south deck consisted of the five best images during the February 15 - March 15 interval when the south pole is most visible from Earth. The north deck consisted of the five best images obtained during the August 15 - September 15 interval when the north pole is most visible. …"
  - Seasonal variation
  - Focus on smoothed maxima

Observaria

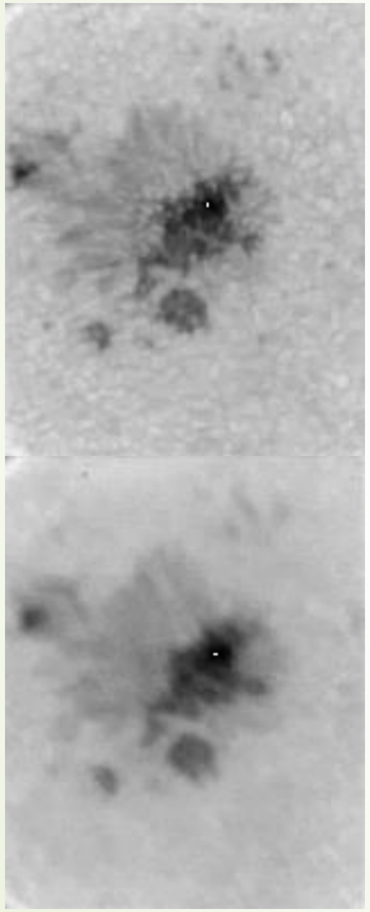


- September 1995 – March 2020
  - 1617 observations
  - 5-6 observations per month
    - Seasonal variation (summer/winter)
- Mid 1996 – mid 2000
  - Higher Q-values (better seeing)
    - San Antonio, Texas, USA
- From 2003 onwards
  - Small jump in Q
  - Favor observations with better seeing conditions over larger number of observations.

Quantifying seeing conditions



Deqing and Yongtian (2012)
DOI: 10.5772/52834

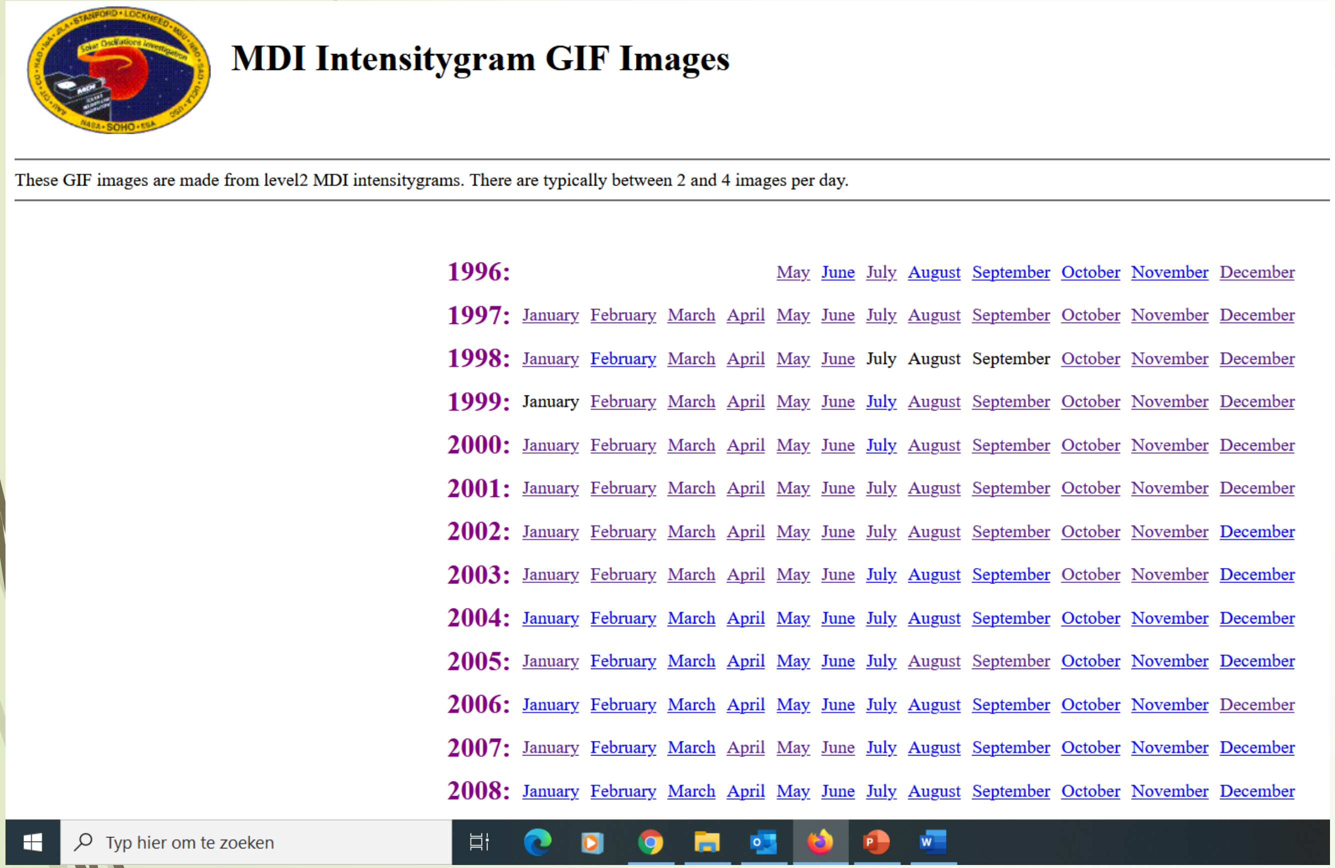


NSO Sunspot Dunn solar telescope (0.7 meter aperture) in New Mexico, USA
Credit: R. Deqing, California State University Northridge)
https://www.alpao.com/adaptive-optics/alpao-applications.html

Q	Description white light
5	Near-perfect image. The granulation is visible over the entire solar surface. There are no vibrations at the solar edge. The fine structure in the penumbra can be well observed.
4	Very small groups and faculae are visible. The granulation is well visible.
3	Also the smaller spots are visible. The shape of the penumbrae is well visible. The largest faculae can be seen as well.
2	Only the biggest spots can be observed. Both umbrae as penumbrae are visible.
1	Only the biggest spots are visible. Penumbrae are not visible, only the umbrae.

SIDC seeing scale – Steps of 0,5 used.

Seeing: Calibrating with SOHO/MDI

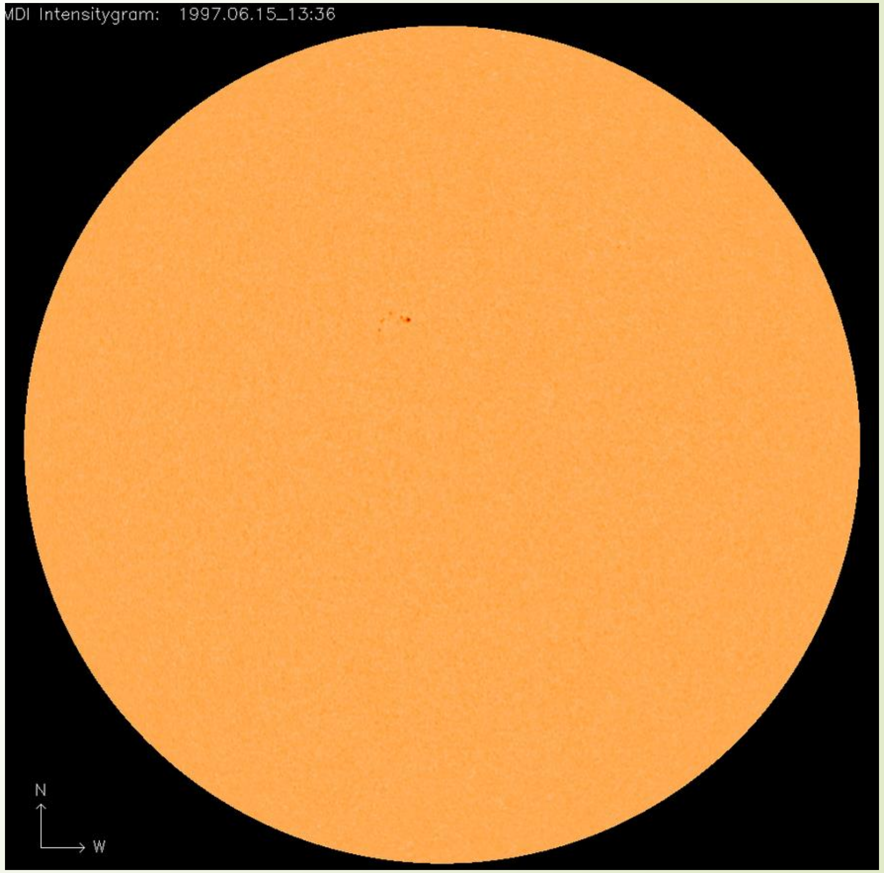


MDI Intensitygram GIF Images

These GIF images are made from level2 MDI intensitygrams. There are typically between 2 and 4 images per day.

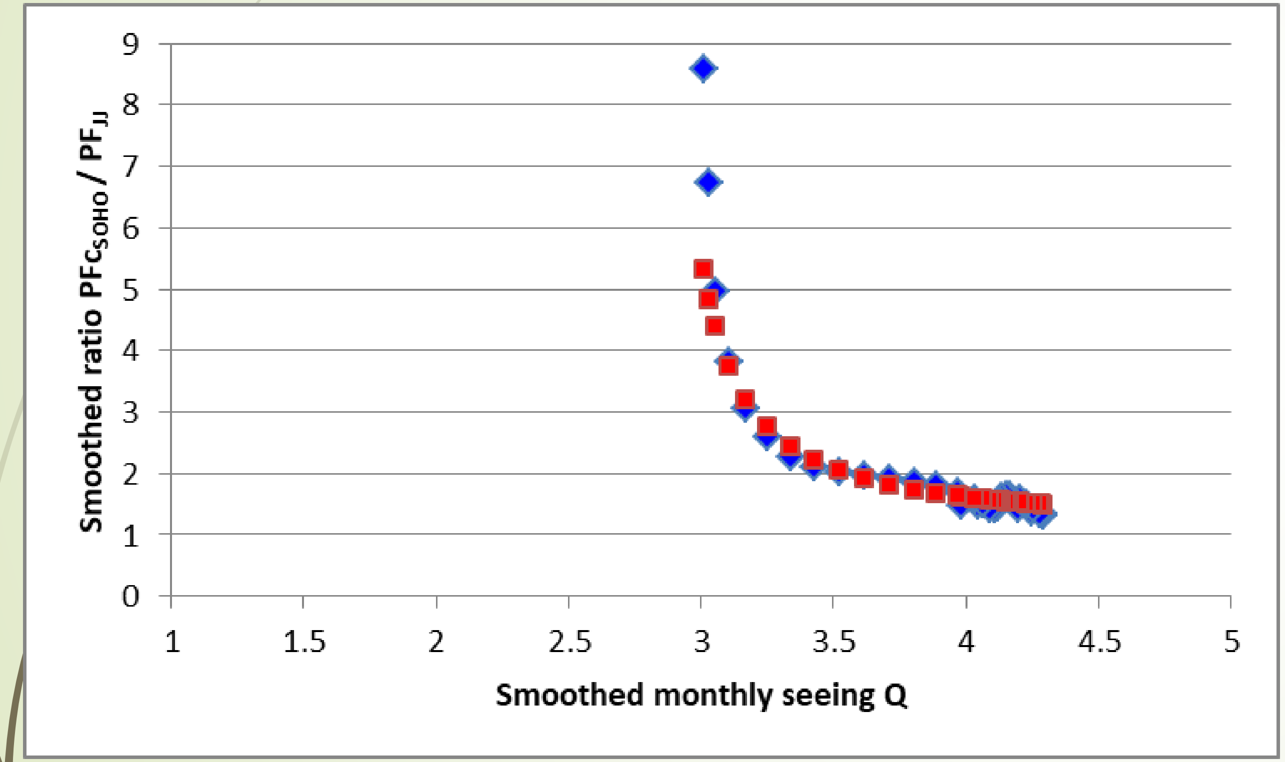
1996:					May	June	July	August	September	October	November	December
1997:	January	February	March	April	May	June	July	August	September	October	November	December
1998:	January	February	March	April	May	June	July	August	September	October	November	December
1999:	January	February	March	April	May	June	July	August	September	October	November	December
2000:	January	February	March	April	May	June	July	August	September	October	November	December
2001:	January	February	March	April	May	June	July	August	September	October	November	December
2002:	January	February	March	April	May	June	July	August	September	October	November	December
2003:	January	February	March	April	May	June	July	August	September	October	November	December
2004:	January	February	March	April	May	June	July	August	September	October	November	December
2005:	January	February	March	April	May	June	July	August	September	October	November	December
2006:	January	February	March	April	May	June	July	August	September	October	November	December
2007:	January	February	March	April	May	June	July	August	September	October	November	December
2008:	January	February	March	April	May	June	July	August	September	October	November	December

Typ hier om te zoeken



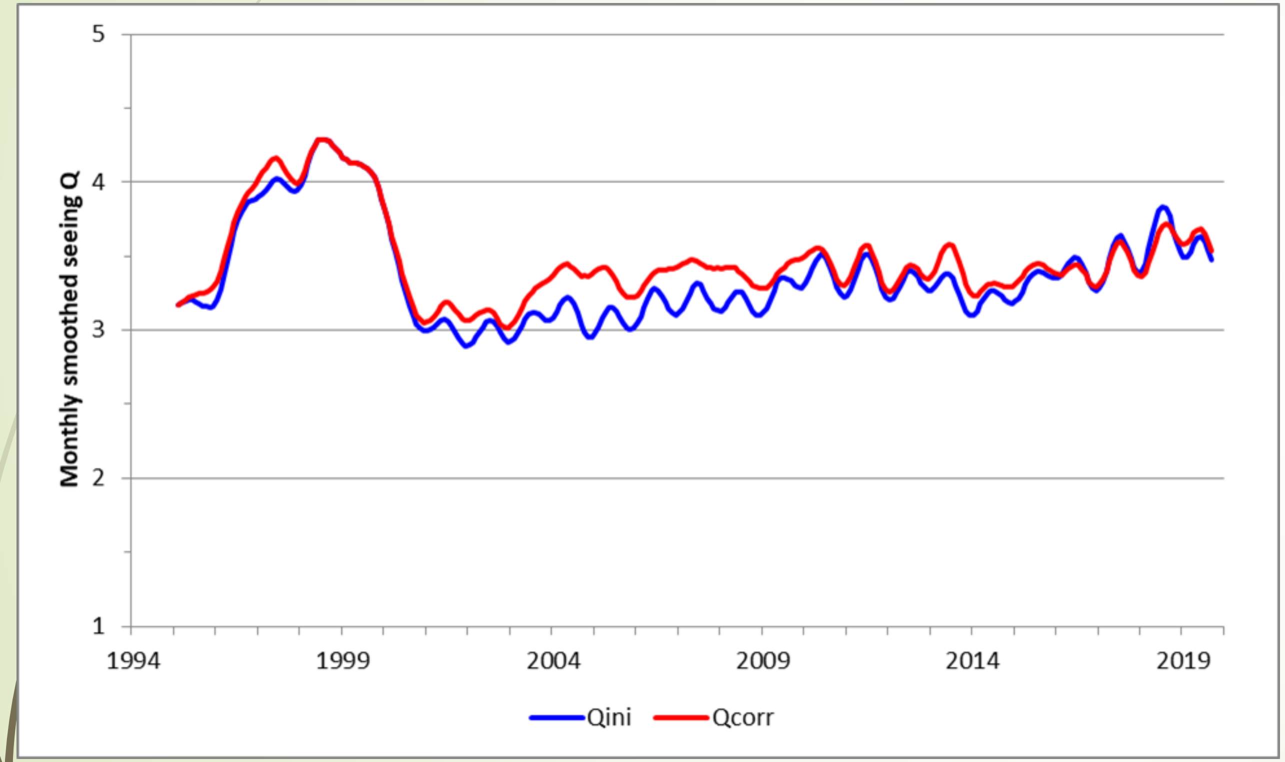
http://soi.stanford.edu/production/int_gifs.html

Seeing: Calibrating with SOHO/MDI



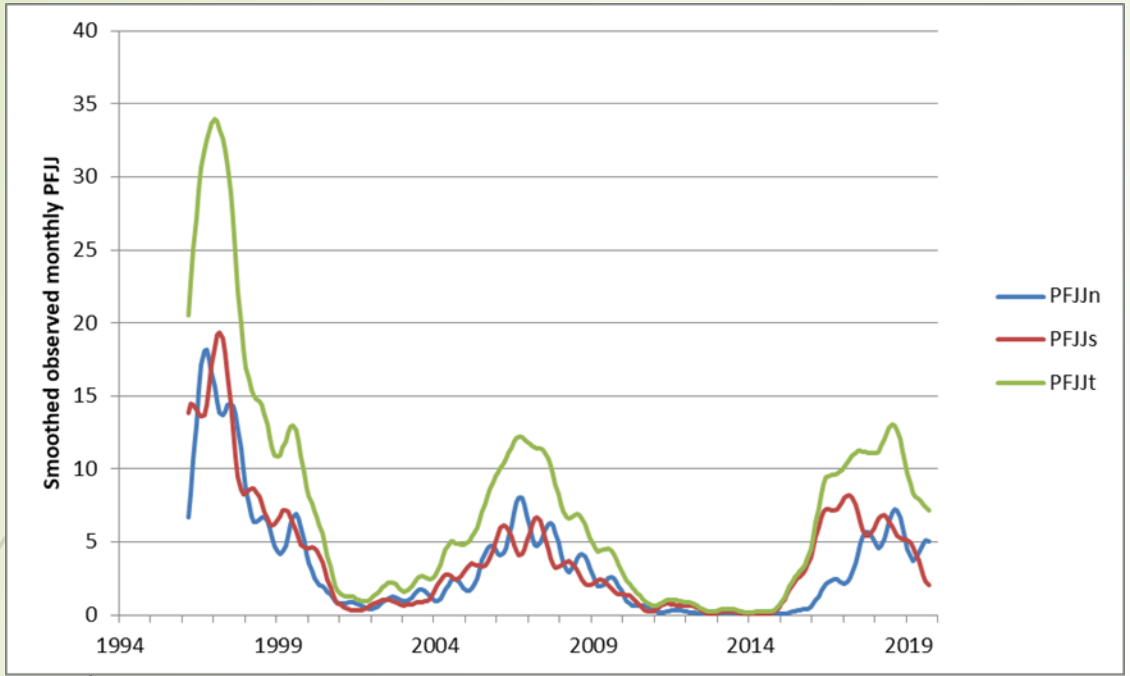
- Jan 1998 – Dec 2000
  - Observed (blue) and approximated (red) smoothed ratio PFc_{SOHO}/PF_{JJ} as a function of smoothed seeing Q
  - Ratio = (Q-2.15)/(Q-2.85)
- Reference Q: 3,5
  - $PFc_{JJ} = PF_{JJ}*(Q-2.15)/(2.077*(Q-2.85))$
  - Avoid too large corrections for PF:
    - Q=3: corr. F.: 2,728
    - Q=5: corr. F.: 0,638
- Steep rise with lower Q is observationally sound
  - PF are "washed out" by turbulence
  - Removal of all obs. with Q < 3
    - 1383 observations

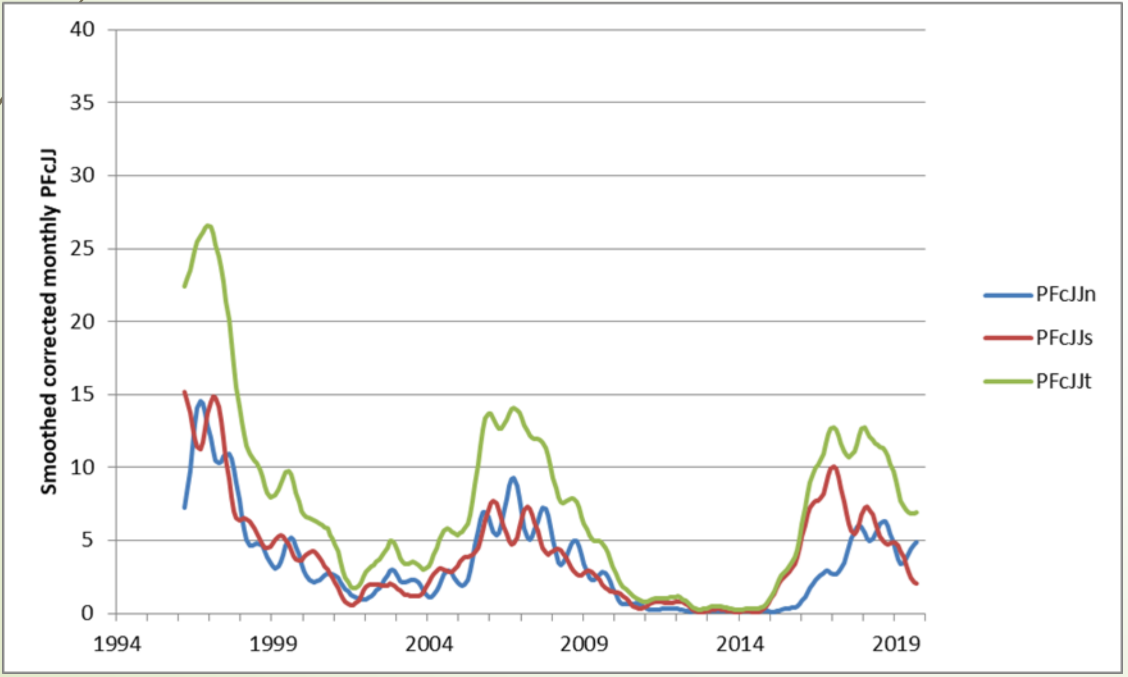
Quantifying seeing conditions



- Evolution of the smoothed seeing Q
  - The blue line (Qini) concerns the data prior to the correction for bad days, i.e. before removing the observations with $Q < 3$.
  - The correction is mostly upwards (better seeing; Qcorr), and particularly noteworthy for the 2003-2009 timeframe.

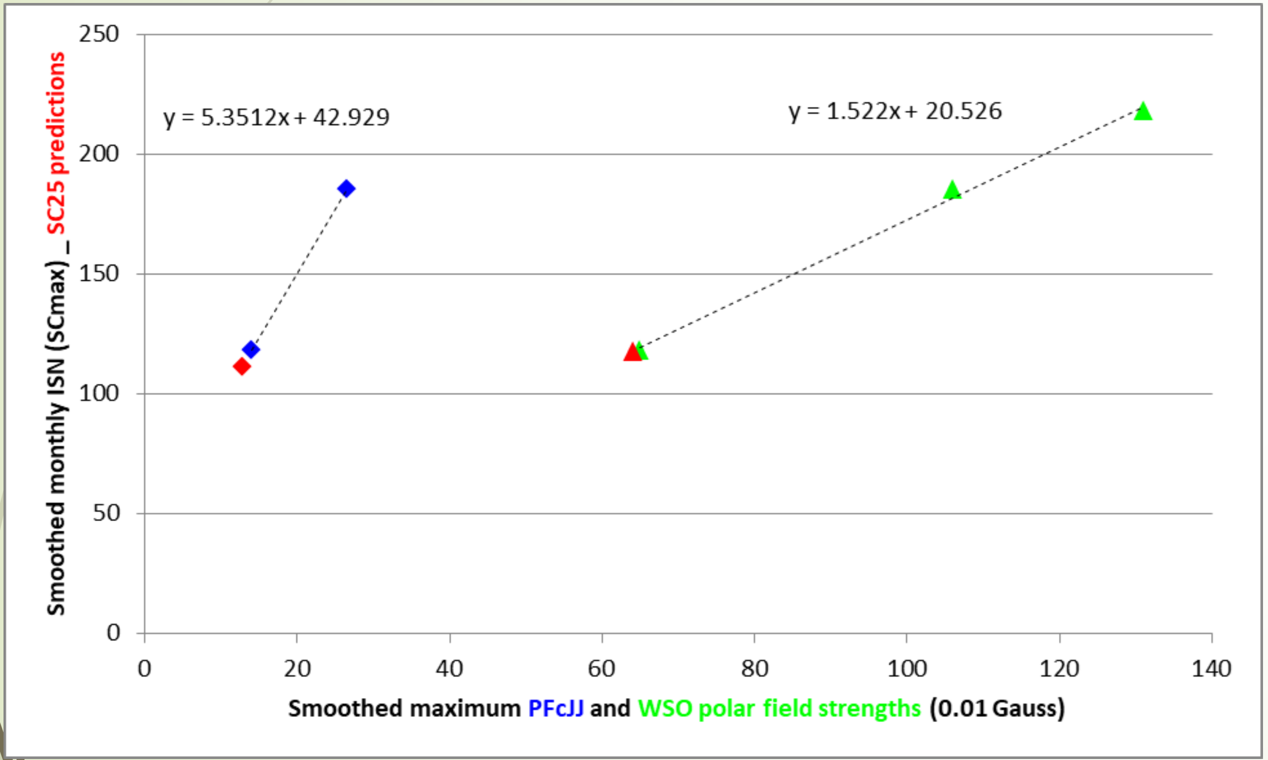
Correcting PF for Q





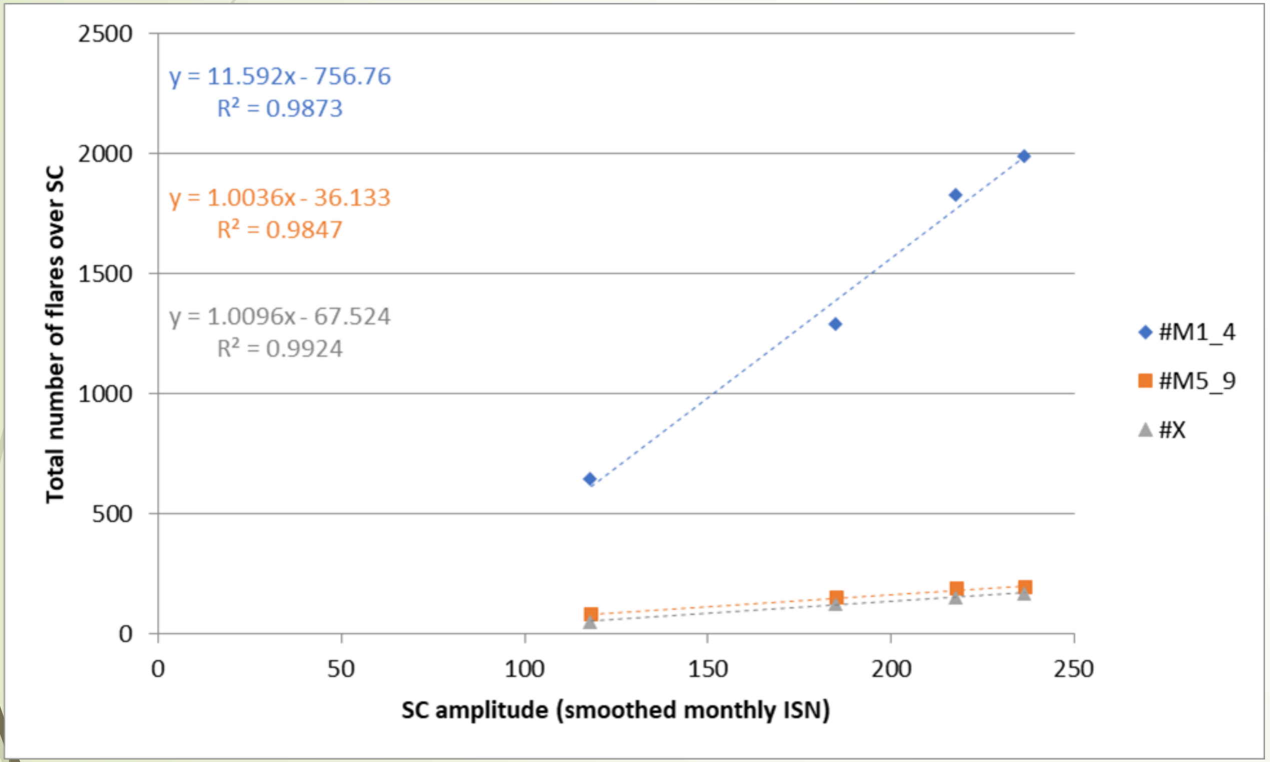
- Smoothed monthly values of observed PF (top) and seeing corrected PFc (bottom).
  - The correction concerns both
    - the removal of bad seeing days (top)
    - a baselining of all observations to Q = 3.5 (bottom)
- Correction for seeing particularly for period 1996-2000 with very good seeing conditions
  - PF max resp. 26,6 , 14,1 , 12,8
  - Clear double peak, with PF southern pole dominating first peak

Converting PF numbers to SC amplitude



- The square of the correlation coefficient r^2 is unity for the PFc_{JJ} (only 2 datapoints) and 0.9969 for WSO (3 datapoints; $p < 0{,}02$).
- The SC25 predictions based on the currently observed maximum PFc_{JJ} and WSO polar field strength are in red.
- Both methods give comparable amplitudes for the upcoming SC
  - PFc_{JJ} predicts 111.3 (rounded to 115)
  - WSO data predict 118 +/- 3 (p: 0,018)
- Hence, these prediction methods seem to indicate that ***SC25's amplitude will be similar or slightly lower than that of SC24.***
- Error margin for SC25 amplitude pred.:
  - Twice the StDev obtained from WSO data (first two data points)
  - **SC25 max: 115 +/-30**

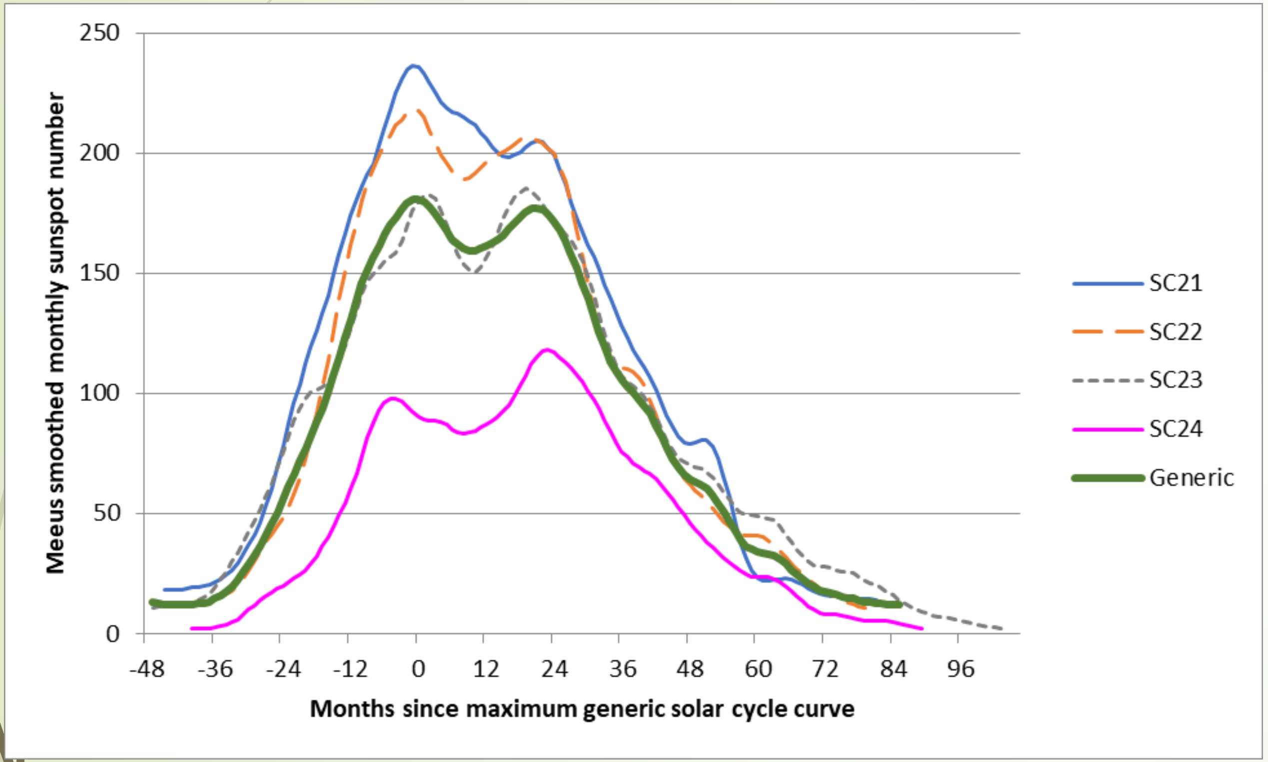
From SC amplitude to flare predictions



- *Preliminary 1: flare numbers for previous SC*
- The total number of flares per solar cycle in each category, against the maximum smoothed monthly sunspot number of the respective cycle
  - 3 categories: M1_4, M5_9, X

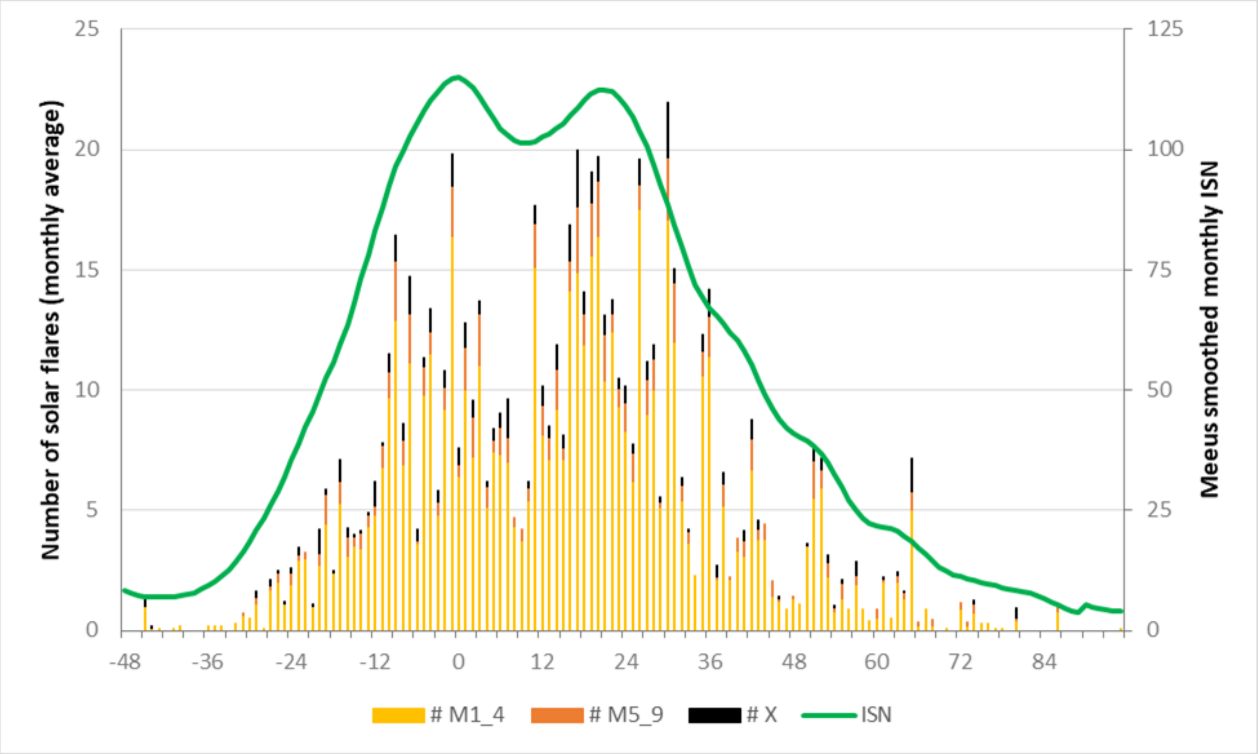
Category	r^2	p	StDev
M1_4	0,987	0,020	68
M5_9	0,985	0,002	7
X	0,992	0,000	5

From SC amplitude to flare predictions



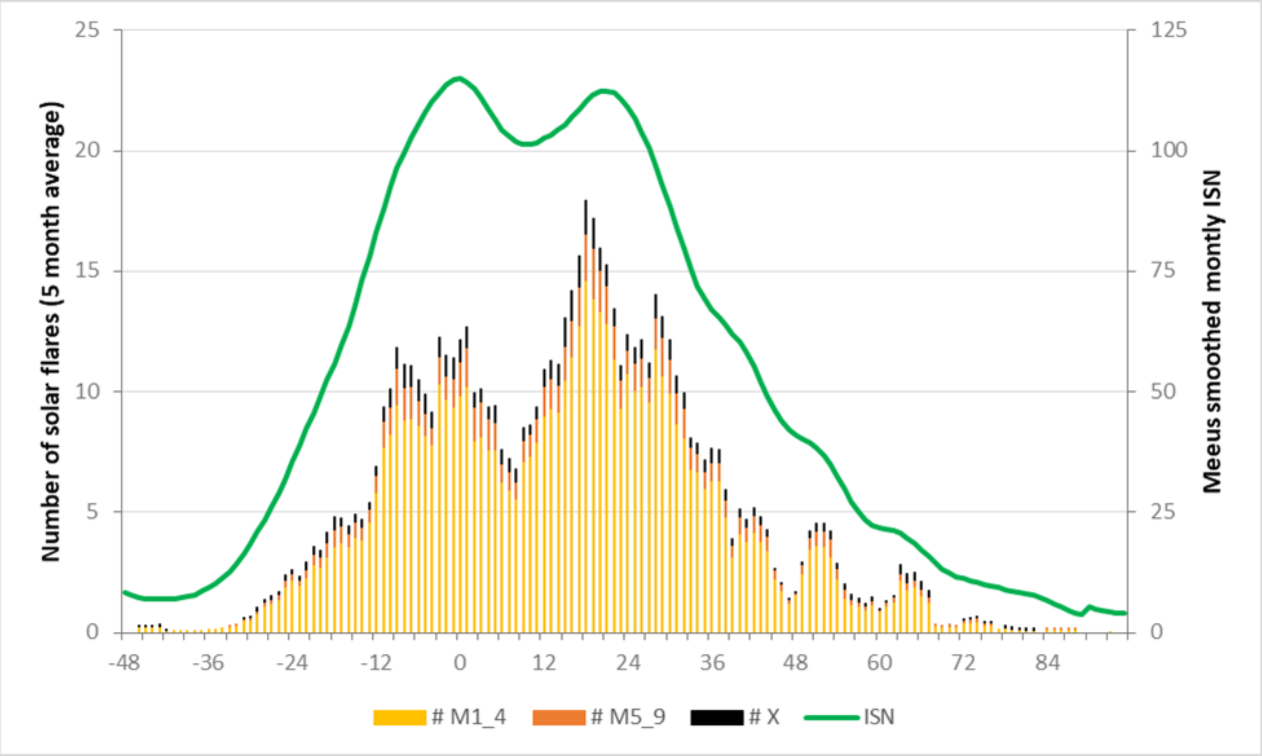
- *Preliminary 2: create double-peaked SC with amplitude predicted for SC25*
  - To guide the eye!
- Smoothed monthly sunspot number for SC21 to SC24
- Shifted in time such that the peaks coincide as much as possible
  - Regardless of maximum
  - Peaks fit within 6 months of each other
    - Resp. 8 and 5 months
- The generic curve (fat green) is then the monthly average over the 4 cycles, with maximum at month (0)
- This maximum smoothed monthly ISN of about 180 requires rescaling to match the expected SC25-maximum (115).

From SC amplitude to flare predictions



- Monthly number of solar flares in each class
  - Based on the average of the previous 4 cycles
  - Shifted in time to match the generic solar cycle curve (green line)
  - Rescaled to the flare numbers that can be expected for SC25 (704 +/-58)
    - Resp. 576 +/-68, 79 +/-7, 49 +/-5
  - Numbers are quite spiky
    - Only 4 datapoints (4 SC)
    - rather large standard deviations
      - 19 +/- 9
    - To be expected ivo the erratic nature of the solar flare production

From SC amplitude to flare predictions



- 5-monthly averaged number of solar flares in each class
  - Based on the flare numbers from the previous 4 cycles
  - Rescaled to the flare numbers that can be expected for SC25
  - Shifted to match the generic solar cycle curve (green line)
    - General trends more clearly
    - Flaring activity can be expected to be larger and more energetic (more X-class flares) during the second peak.
      - 1st peak: 12 +/- 7
      - 2nd peak: 18 +/- 8

Conclusions

- (amateur) Polar faculae observations can provide at least a quantitative prediction of the next solar cycle
  - Correction for seeing
- SC25 is predicted
  - To have similar amplitude as SC24
    - 115 +/-30
  - Double peaked
  - Both peaks of about equal strength
  - Activity on southern hemisphere dominates first peak
- Flaring activity (M & X) during SC25 is thought to be similar as in SC24
  - First peak dominated by ARs in southern hemisphere
  - Second peak higher than first one
- Paper submitted to JSWSC
  - Under review