SUNSPOTS BEHAVIOR DURING THE RECENT SOLAR MINIMUM

3rd Sunspot Workshop,Tucson, AZ

Jan. 22-25 2013

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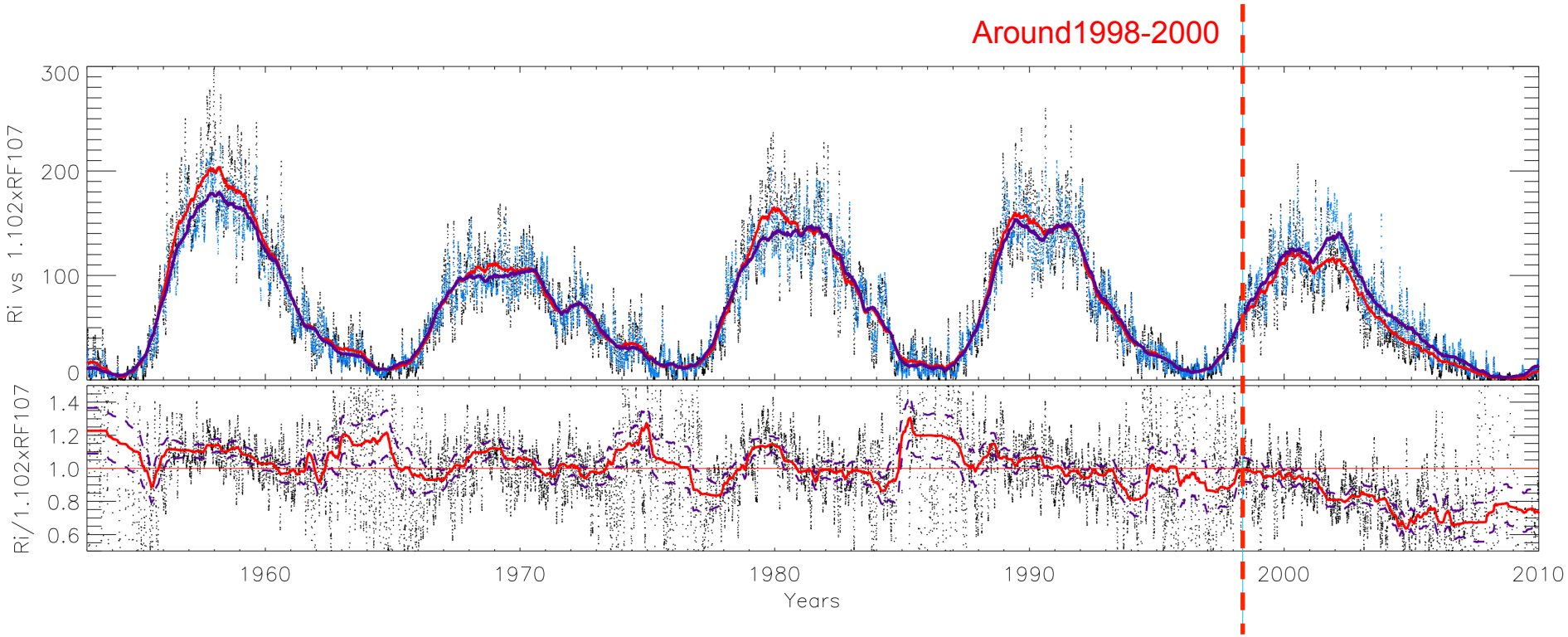
Royal Observatory of Belgium
January 24th 2013

WHAT PROMPTED THIS STUDY ?

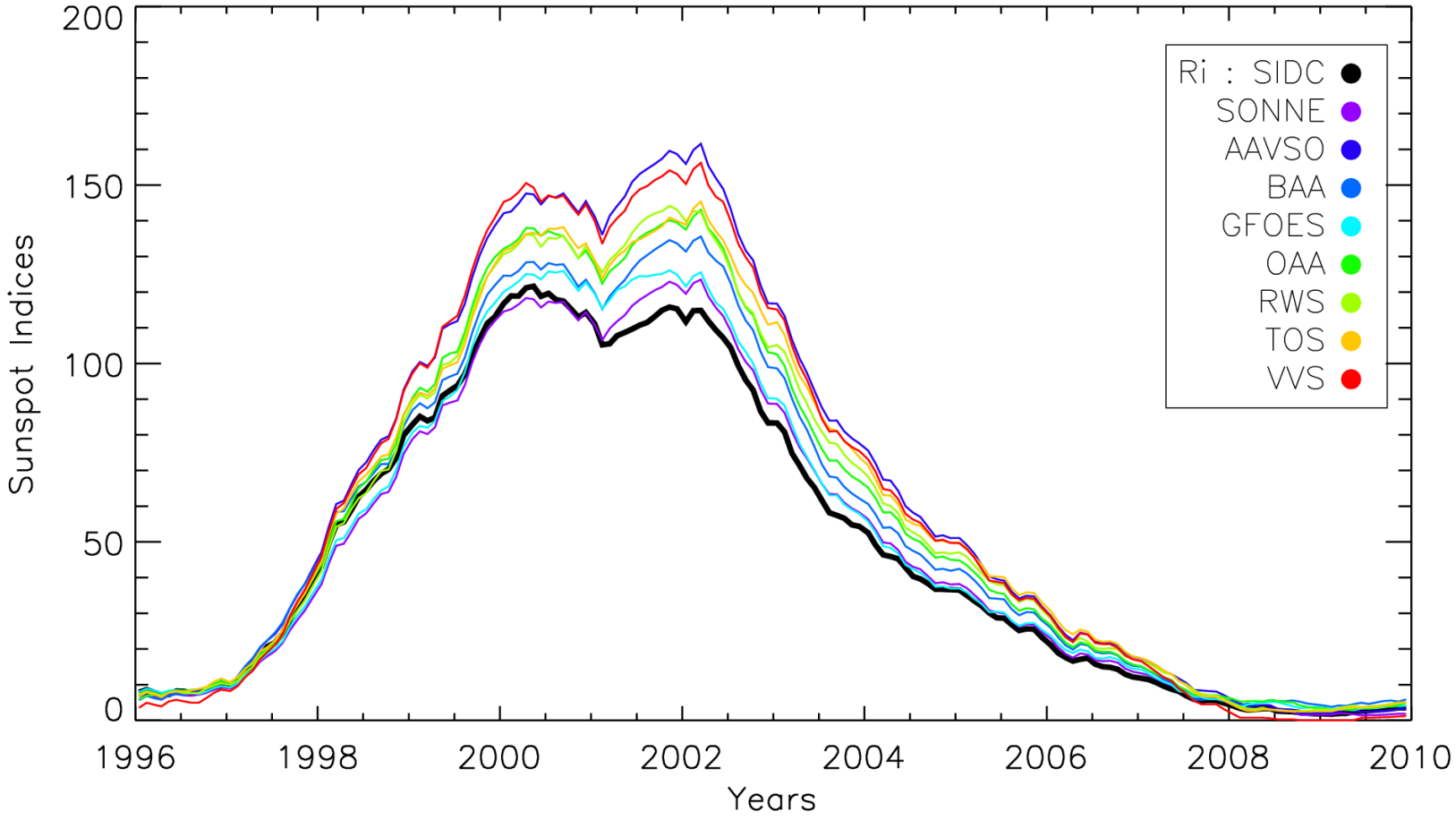
Unusual discrepancies

An unprecedented disagreement between R_i and $F_{10.7}$

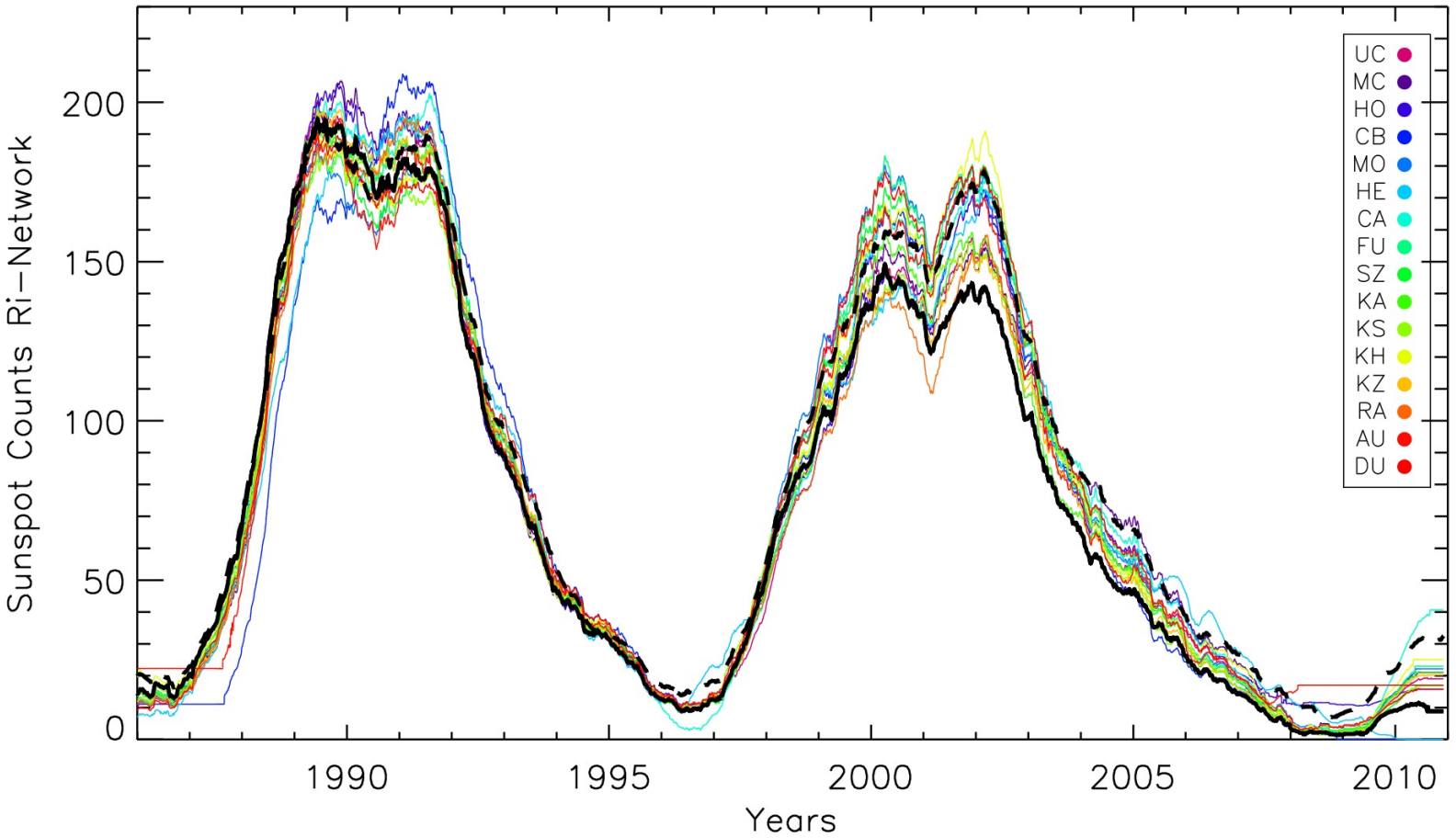


R_i compared with $R_2(F_{10.7})$ from Johnson (2010)

Indices disagreements: outside the R_i-network



Indices disagreements: inside the R_i-network



16 Stations : Kawaguchi, Fujimori, Kislovodsk, Kandili, Kanzelhöhe, Uccle, Helwan (Egypt), Camaguey (Cuba,CB),Holloman, Mac Kenzie, Mochizuki, Ramey, Coonabarabran (Australia,AU), Dubois (Belgium), Suzuki, Catania **+ Locarno + $R_2(F_{10.7})$**

Explanation: a deficit of a particular category of sunspots?

- Initial discrepancies of about 25%
- Seems to be a problem with the Locarno series (Cf. Frederic's Talk)
- Remaining difference is approx. 10%.
- Hypothesis: Smaller sunspots?

SMALL(ER) SUNSPOTS?

What are they? How to reach them ? What is the lower limit: between Sunspots and pores?

Sunspots versus pores

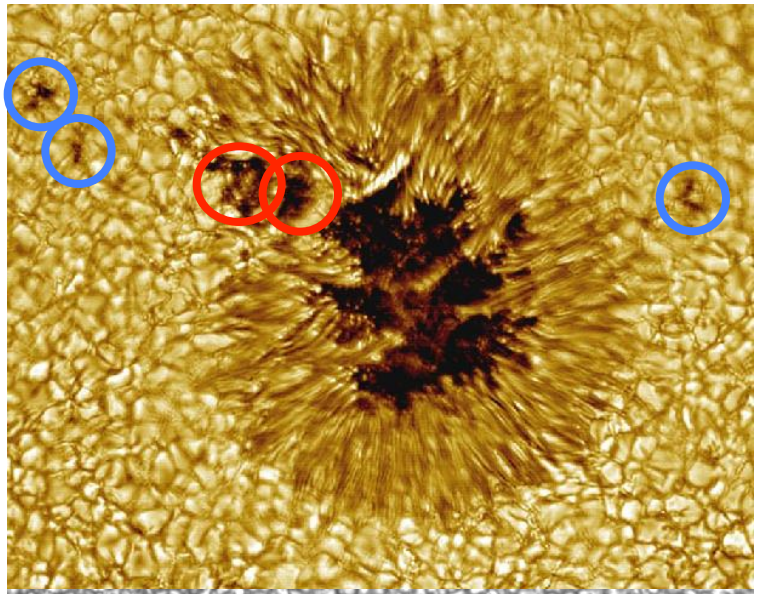
- Various definitions:

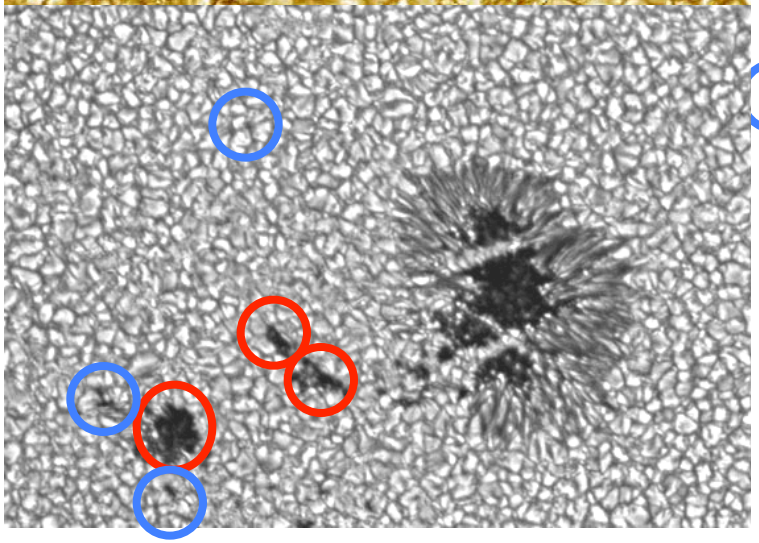
Source	Spot diameter	Spot lifetime	Pore diameter	Pore lifetime
Bray & Laughhead 1964	With penumbra		Without penumbra	
Waldmeier (Husar 1967)	>3" (2000km) = 1 granule	> 30 min	< 3"	< 30min
Bruzec & Durrant 1977	>10" (6000km)	> 1 day	< 5"	< 1 day
McIntosh 1981	> 4" (2500km) = 1 granule		< 4"	

- Best "observational" definition:

	Diameter	Lifetime	Outline	Contrast	Penumbra
Pore	< 4" < 2500km	< 30 min	Fuzzy Irregular	low	none
Sunspot	> 4" > 2500 km	> 30 min	Sharp ~ round	High Dark core	none or small

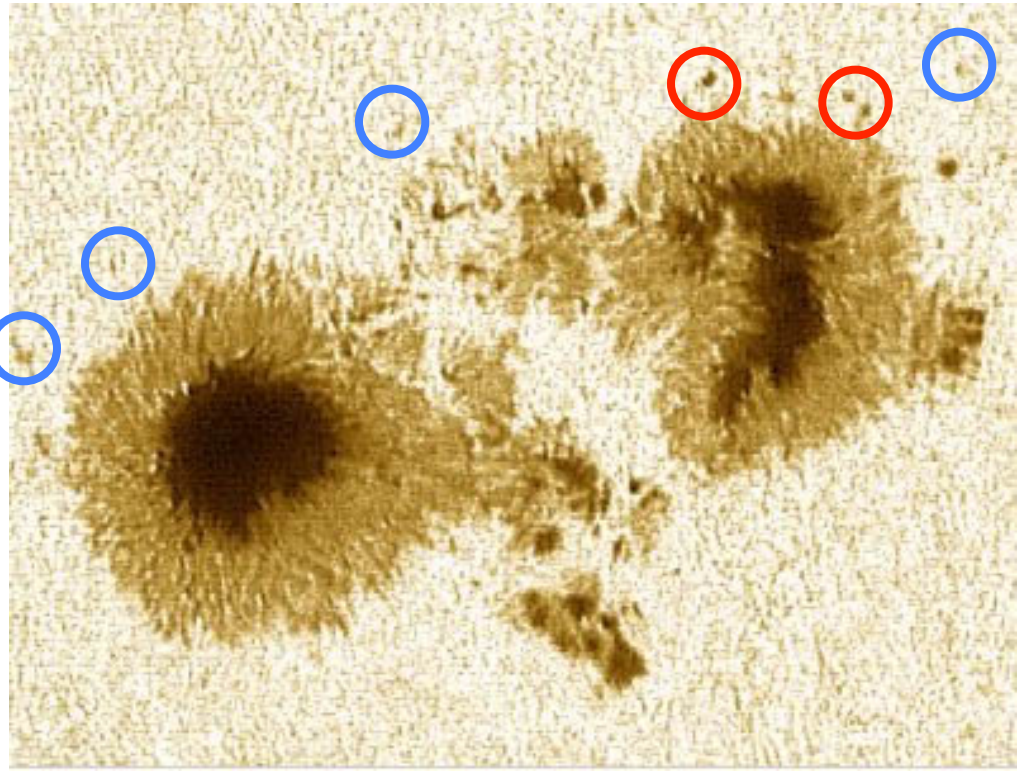
Pores and spots





Sunspot

Pore



F. Clette

Different resolutions/measurements

- Different datasets/instruments have different resolutions:

- SOHO/MDI: 2”/pix (relatively defocused, 2”/pixel sampled data and blurring caused by instrumental distortion → 2.5”/pix)
- HMI 0.5”/pix
- DPD (Guylia and Debrecen mainly) ≈ 1” at best seeing
- Mostly with a rather modest optical aperture (65 mm) : 2”

- Different ways of measuring the size also:

- overlay disks lack resolution below 10” (USAF/Mt Wilson data for example)
- Automatic/semi-automatic measurements (STARA/DPD)

Catalogs/datasets with information about individual sunspots?

- RGO → 1874-1982, daily sunspot areas only (no individual sunspots)
- Kodaikanal → 1906-1987, spots are not related to their groups
- SFO → 1986-2012, daily sunspot areas available from website, individual sunspot areas on demand (?)
- Kislovodsk → 2010-2012, very good dataset (no umbra/penumbra limit, except, umbral spots)
- DPD → 1977-2012, areas of groups and spots within those groups for each day.
- STARA output for cycles 23-24: spot information, no grouping

A CROSS-VALIDATION OF DPD AND STARA CATALOGS

Preliminary work: latest version of the catalog from January 10th.

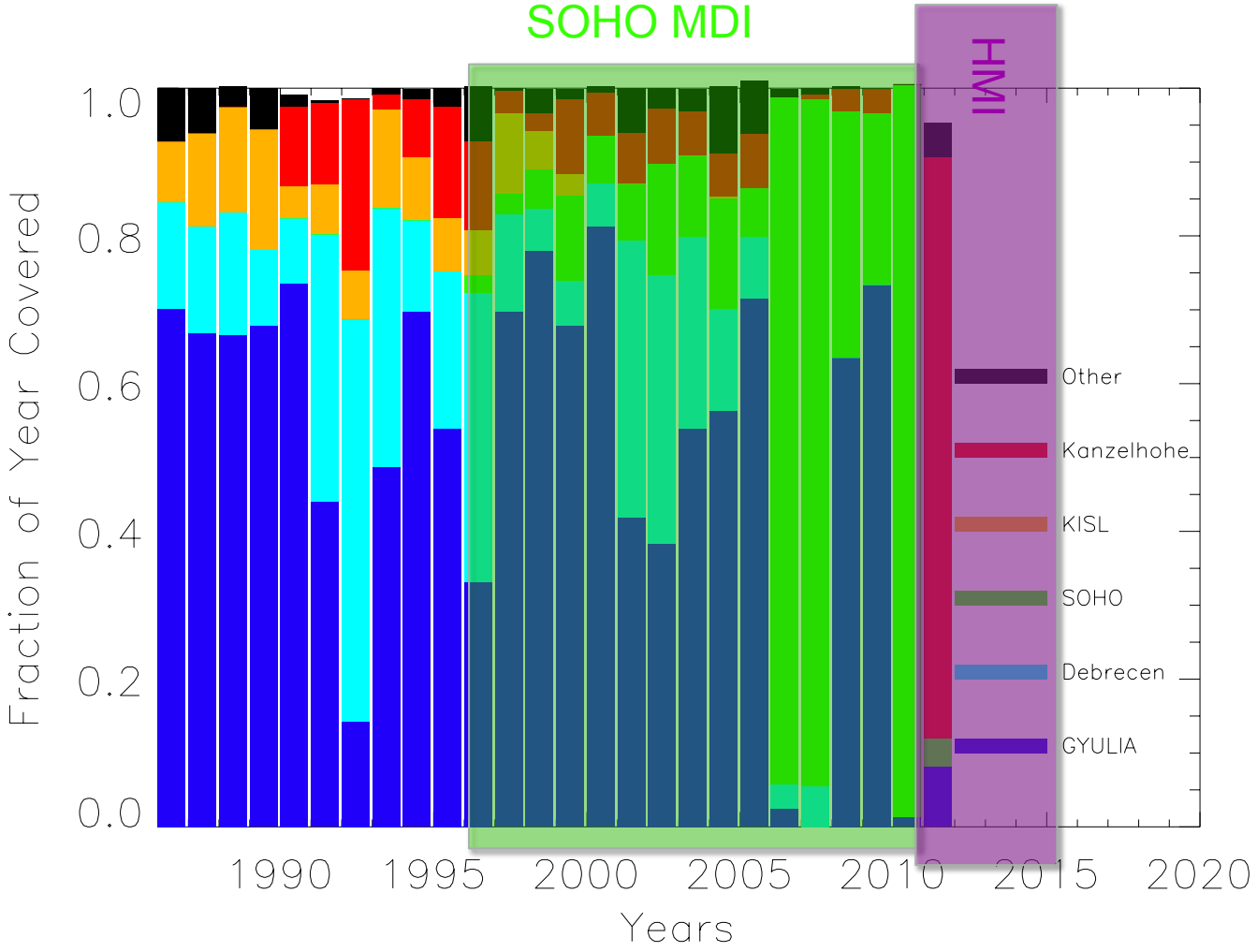
STARA MDI and HMI

- What? Images from SOHO/MDI and HMI
  - MDI: 4 images/day available in databases
  - HMI: an image every 15min approx.
- How? Watson et al. (2009) and Fraser's talk on Friday.
- First version of the catalogs (MDI and HMI) : v1
- Corrected on January 10th : v2

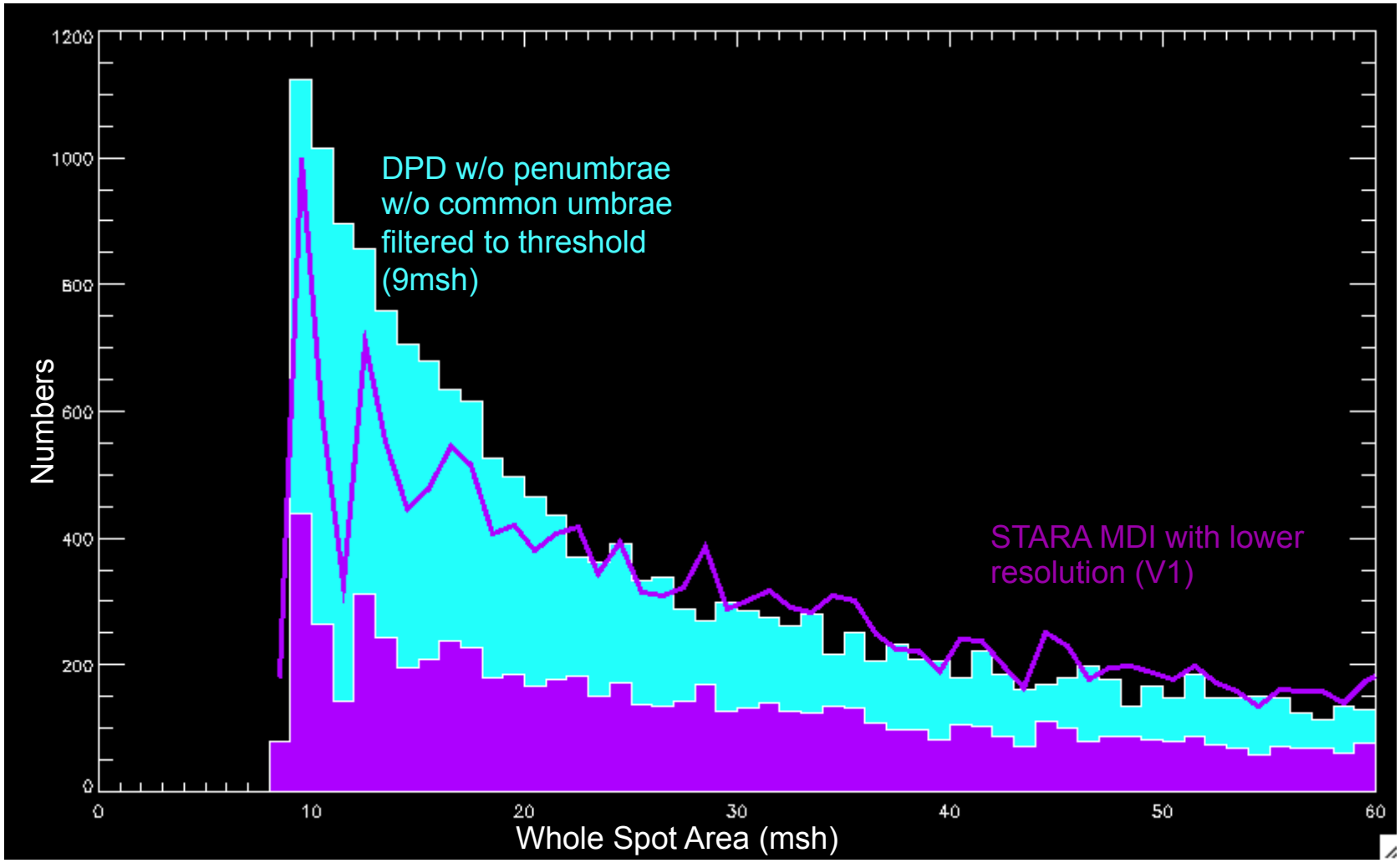
Debrecen Photoheliographic Data (DPD)

- What? Mostly local images from Gyulia and Debrecen
- How? Lajos Gyori et al. (1997) and Andras's talk this afternoon.
- Work still in progress
- Also uses SOHO images when no ground station could observe, or as a preliminary evaluation of the detailed information on the spots and groups (SDD).
- http://fenyi.solarobs.unideb.hu/

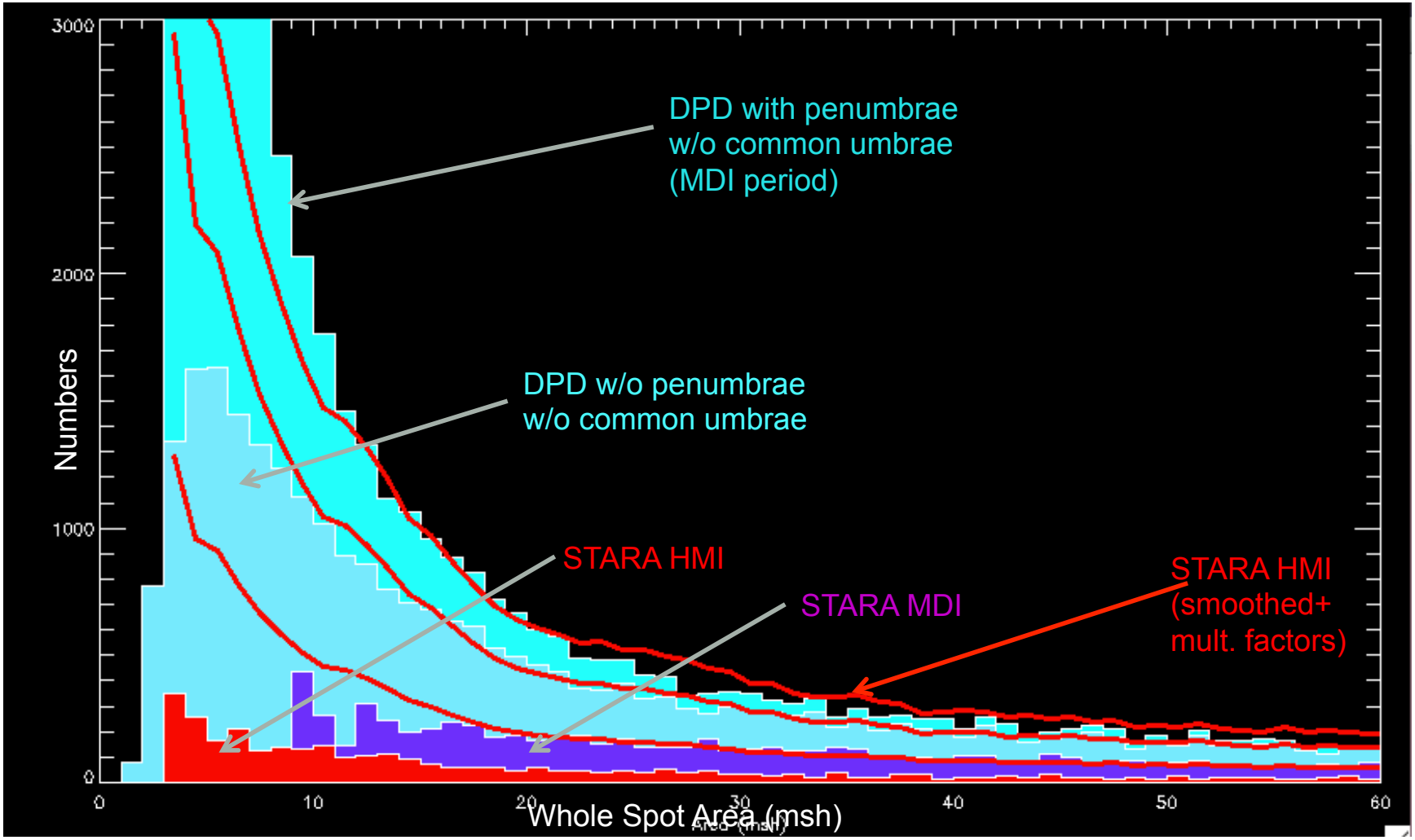
Data coverage DPD vs. MDI/HMI



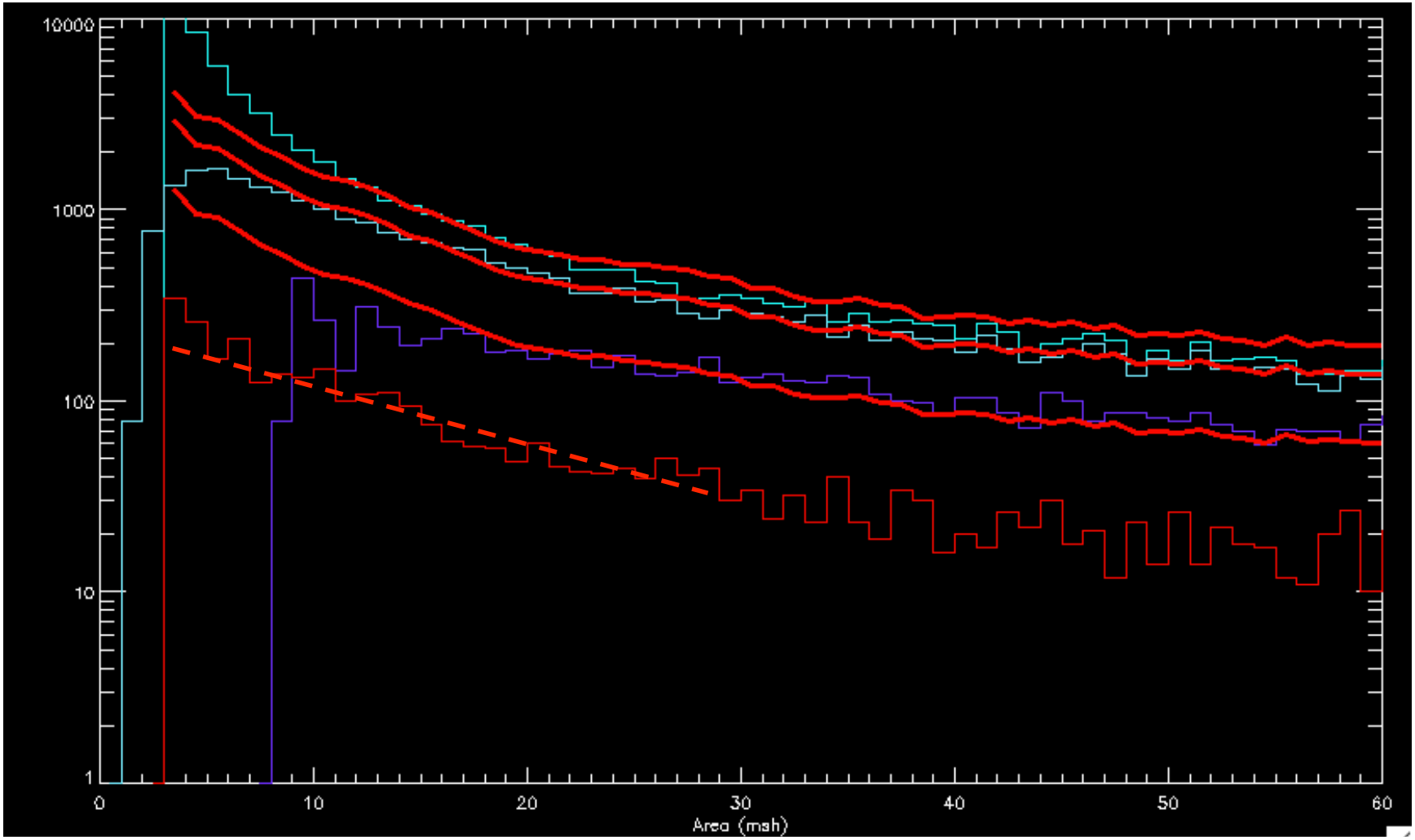
DPD to STARA MDI (v1) on same period



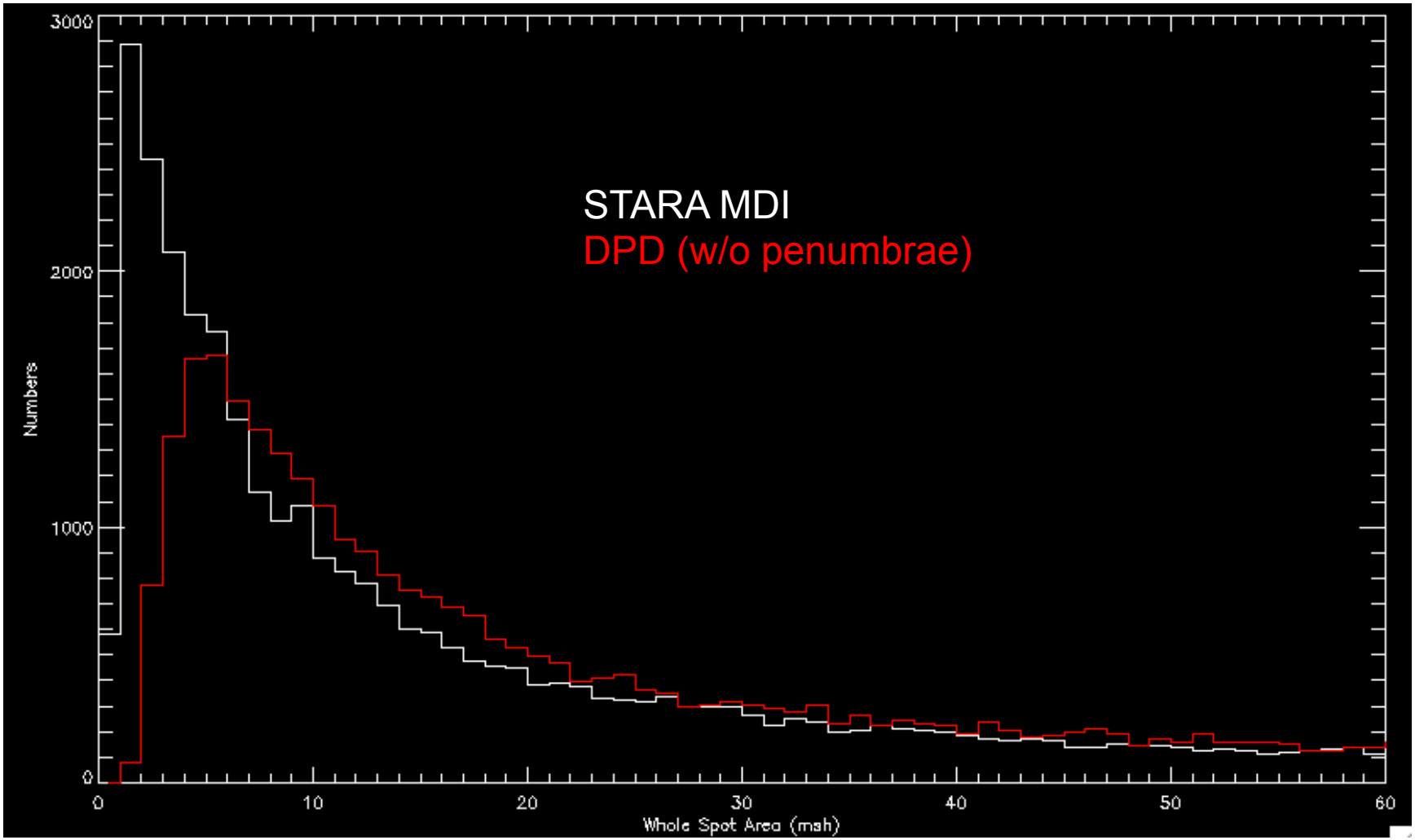
STARA MDI/HMI (v1) compared to DPD



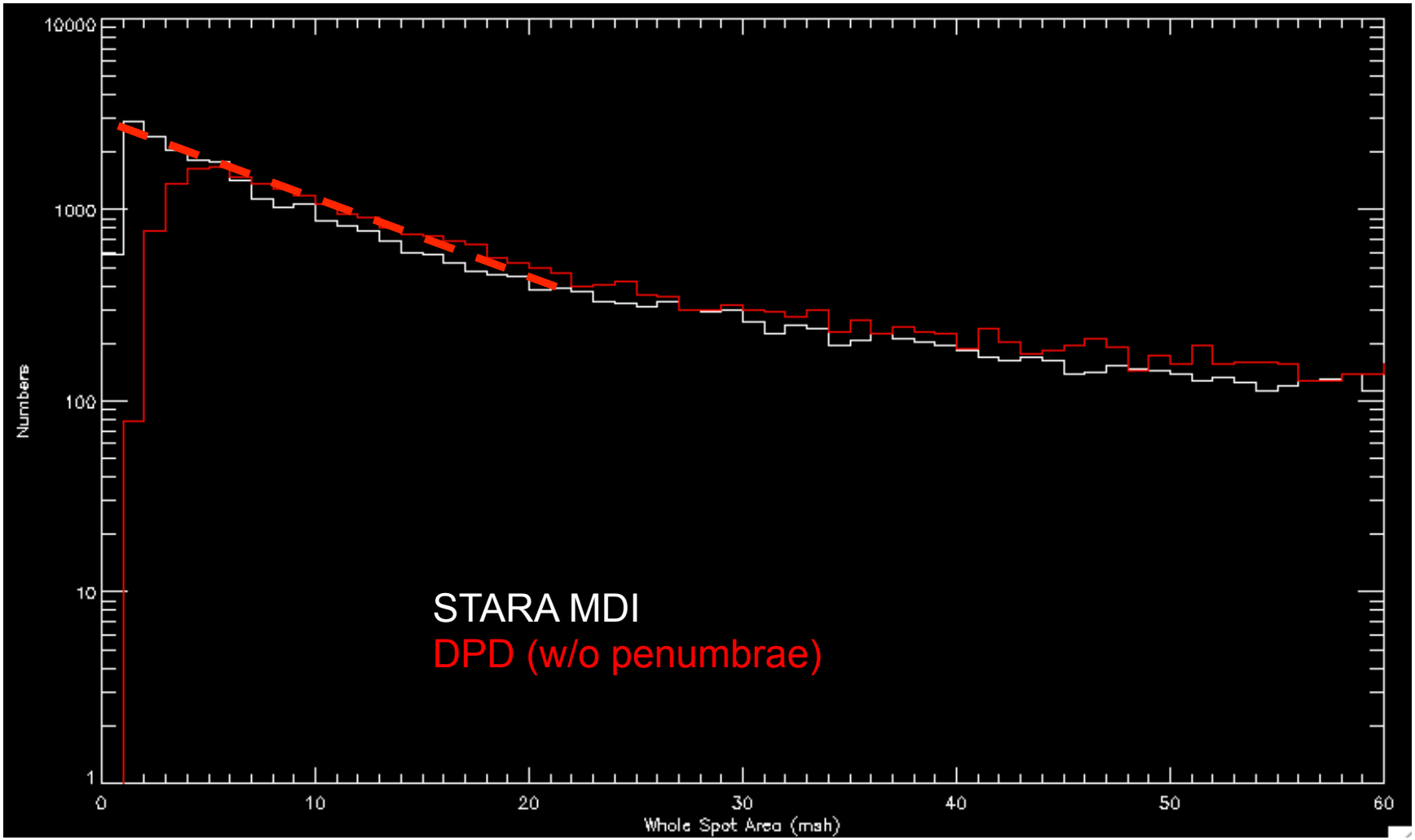
Approximately exponential distributions



STARA MDI (v2) to DPD data raw numbers compared on the same period

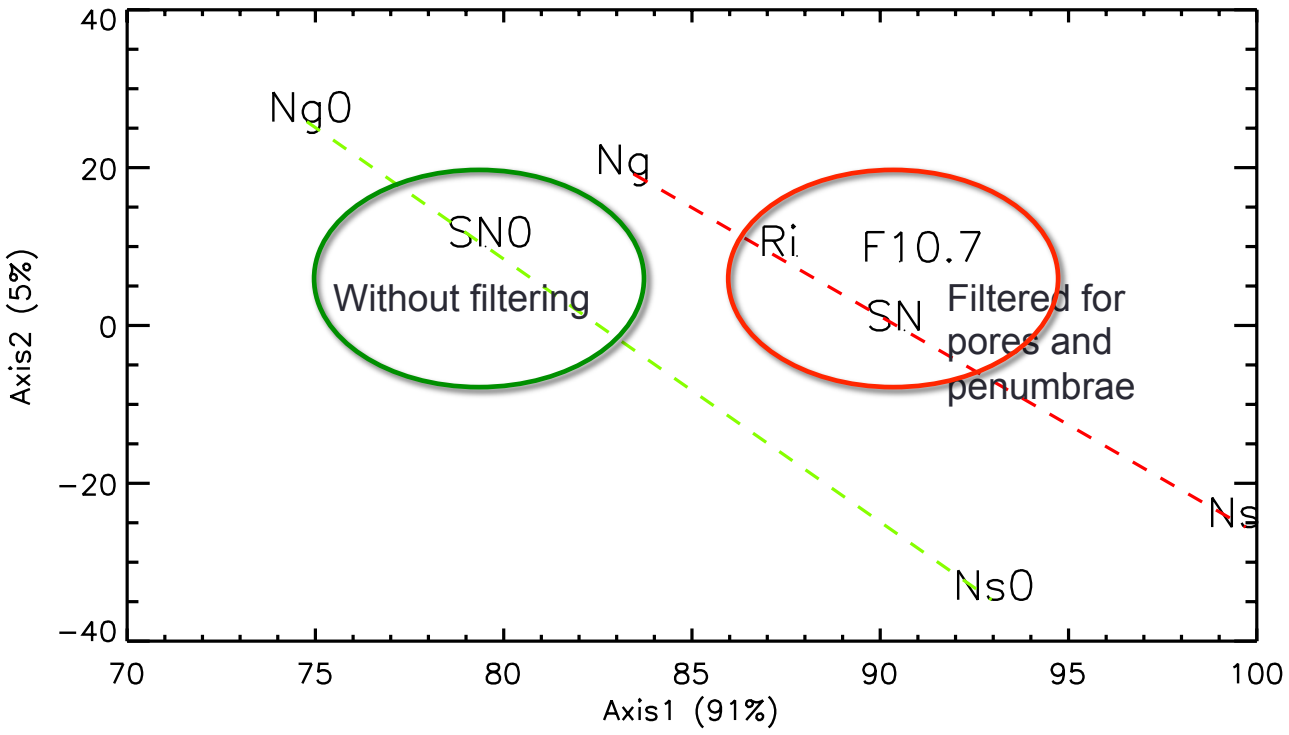


Exponential

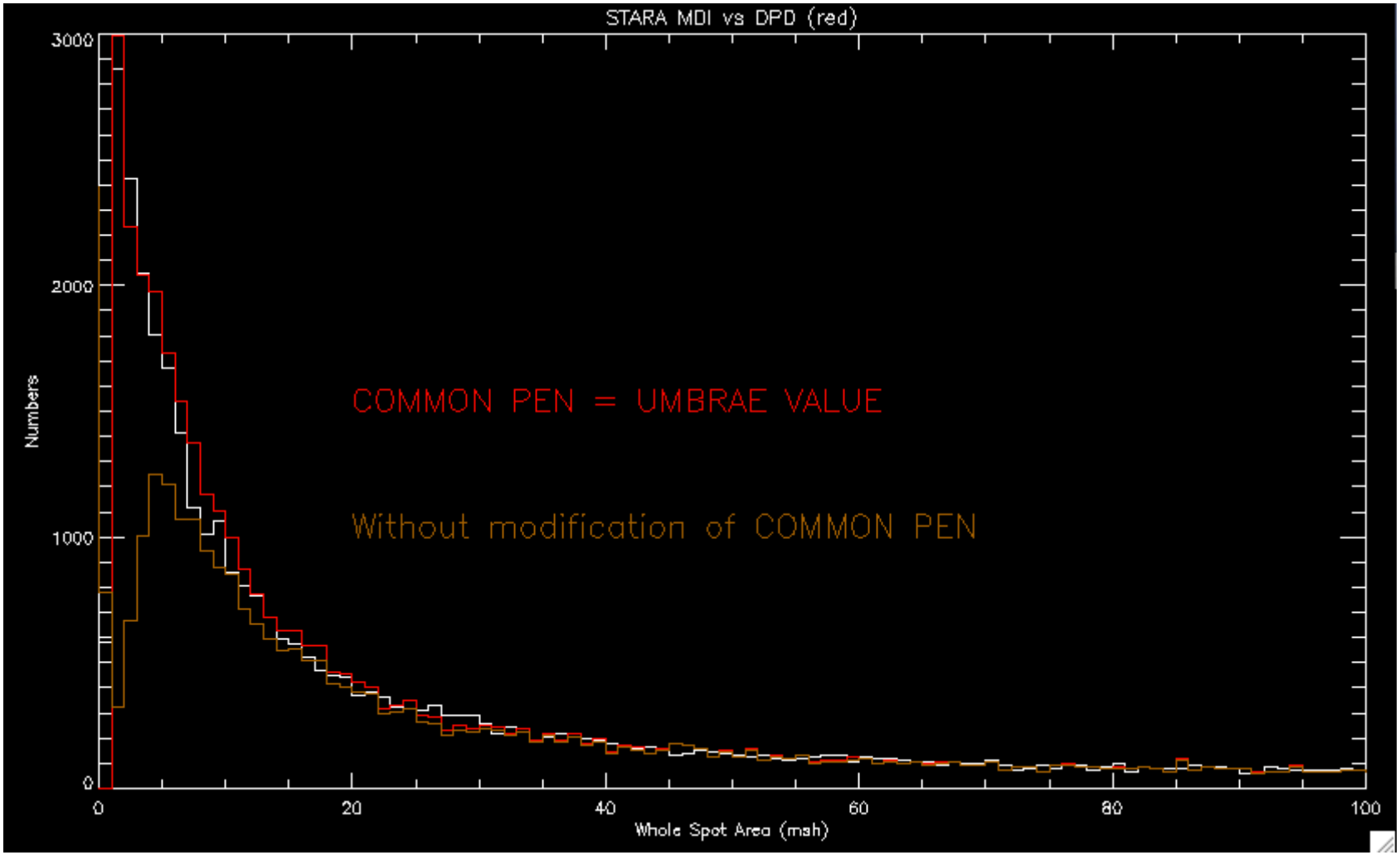


Result of the filtering we did apply

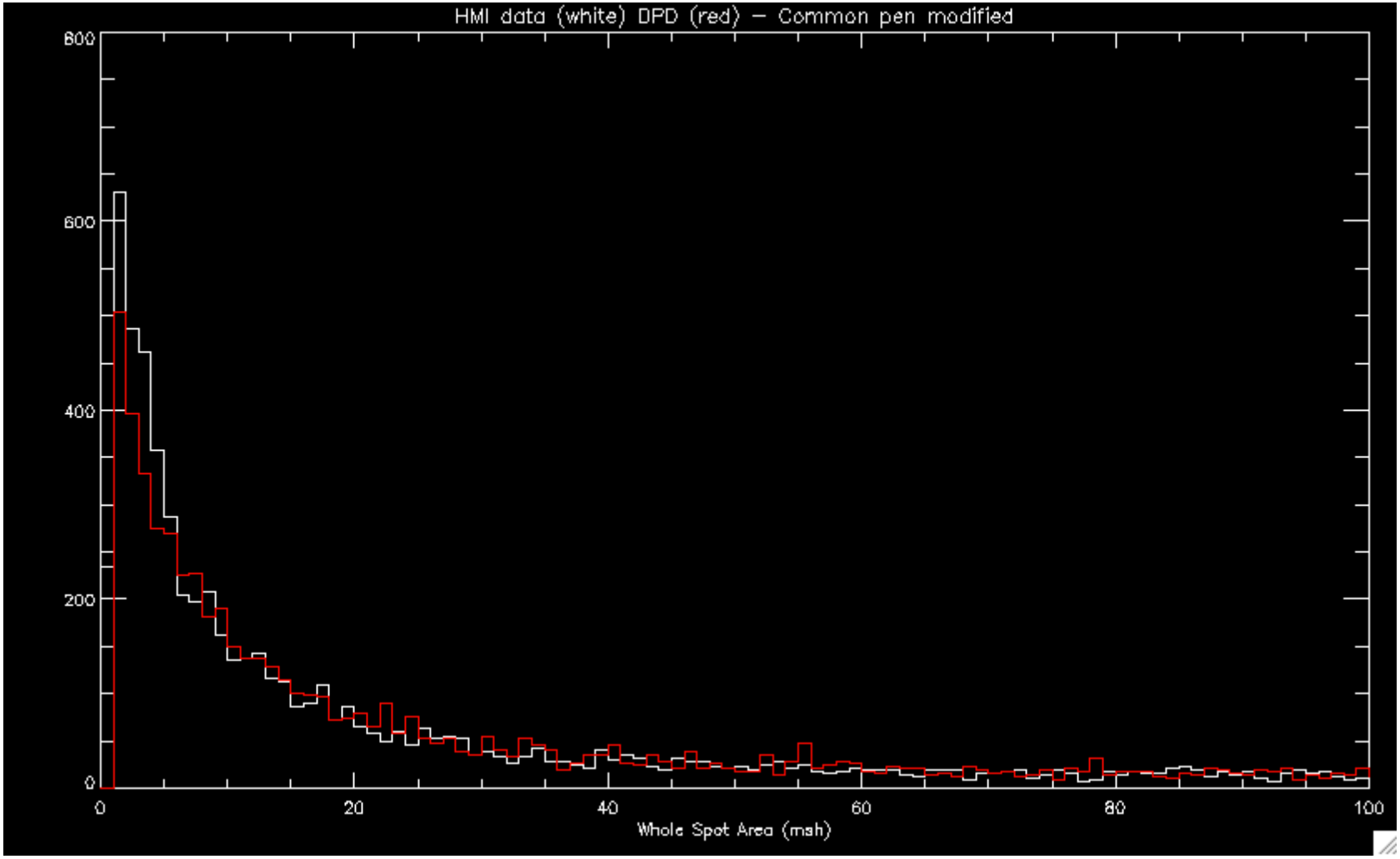
An interesting way of looking at it…



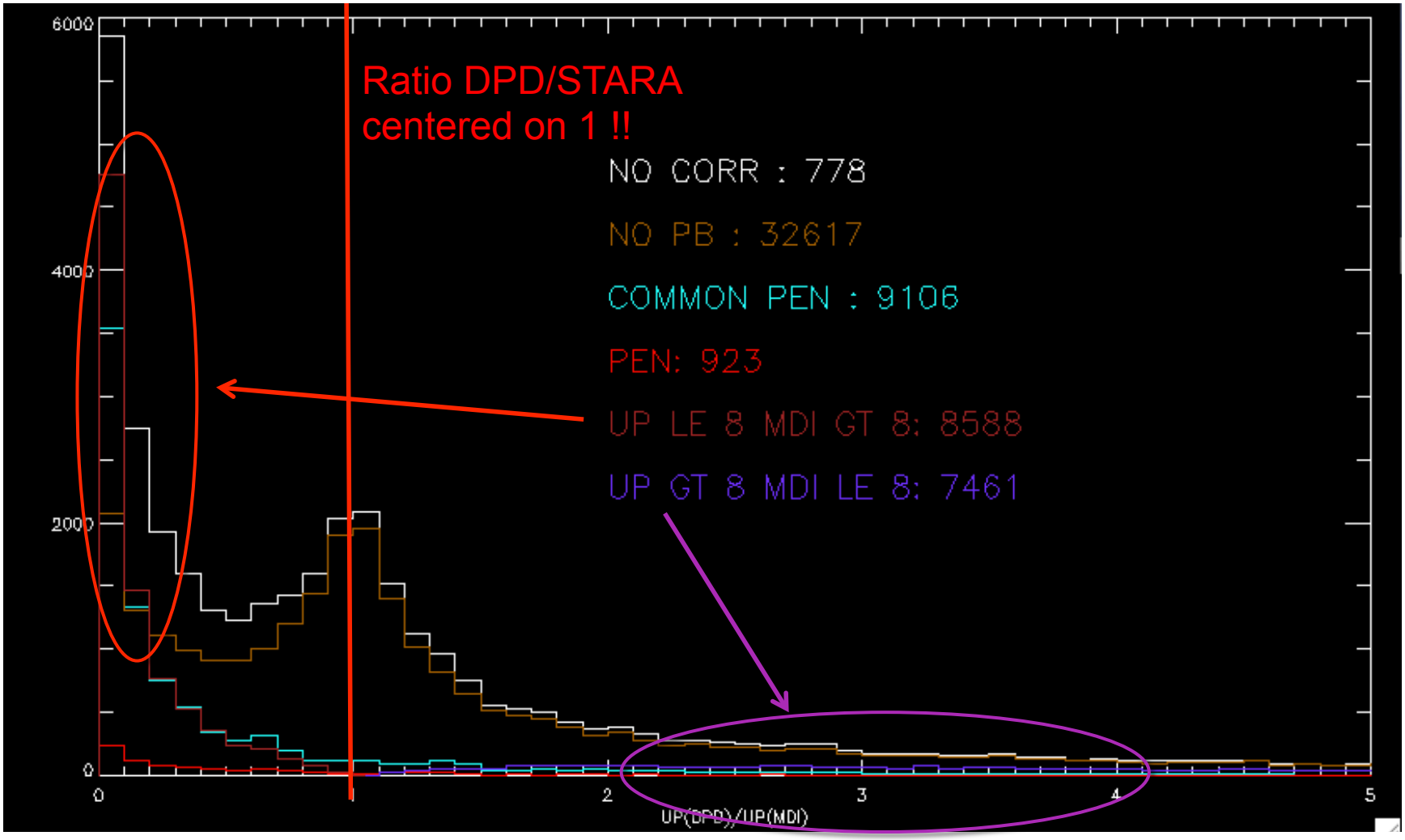
Identified spots between MDI and DPD



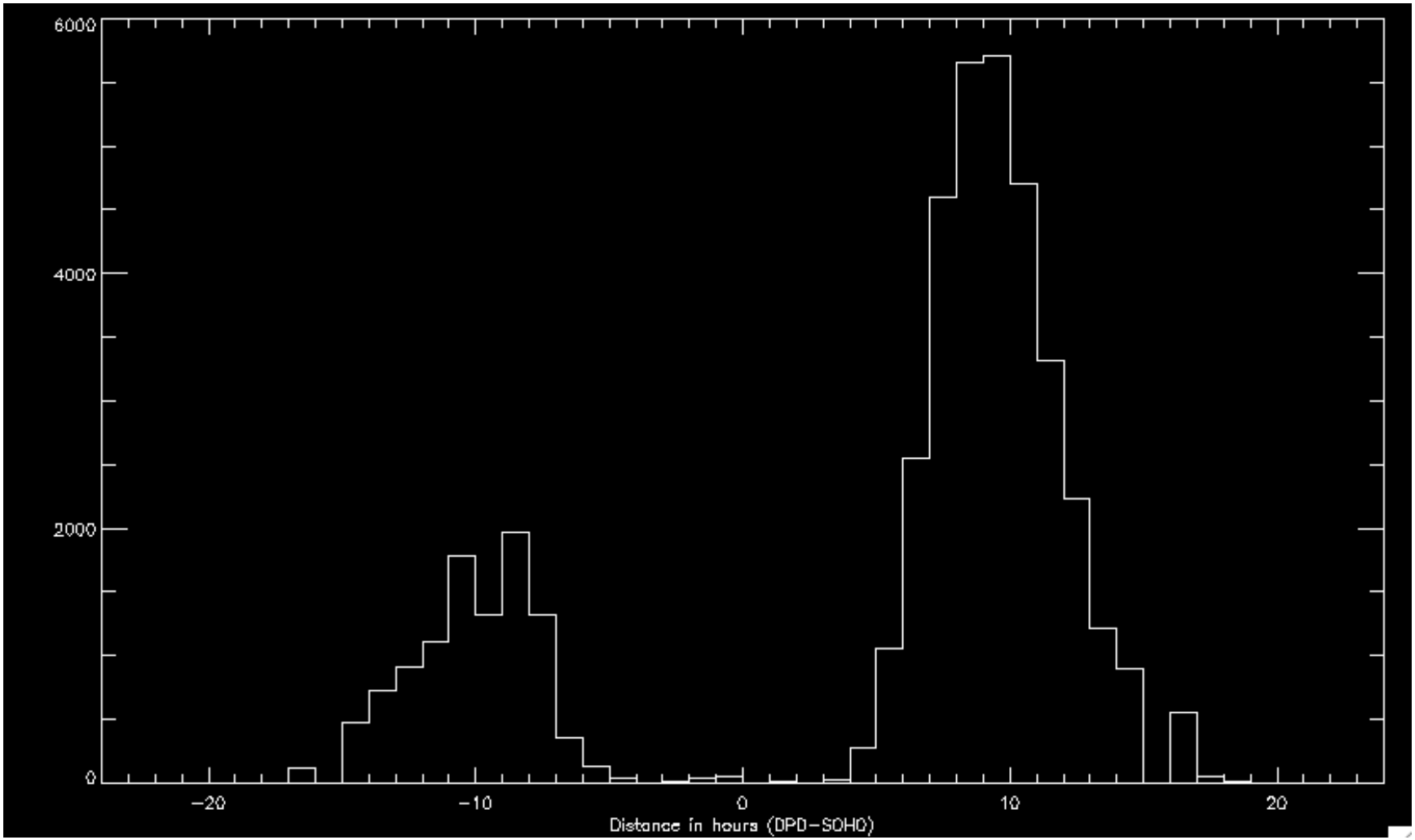
Identified spots between HMI and DPD



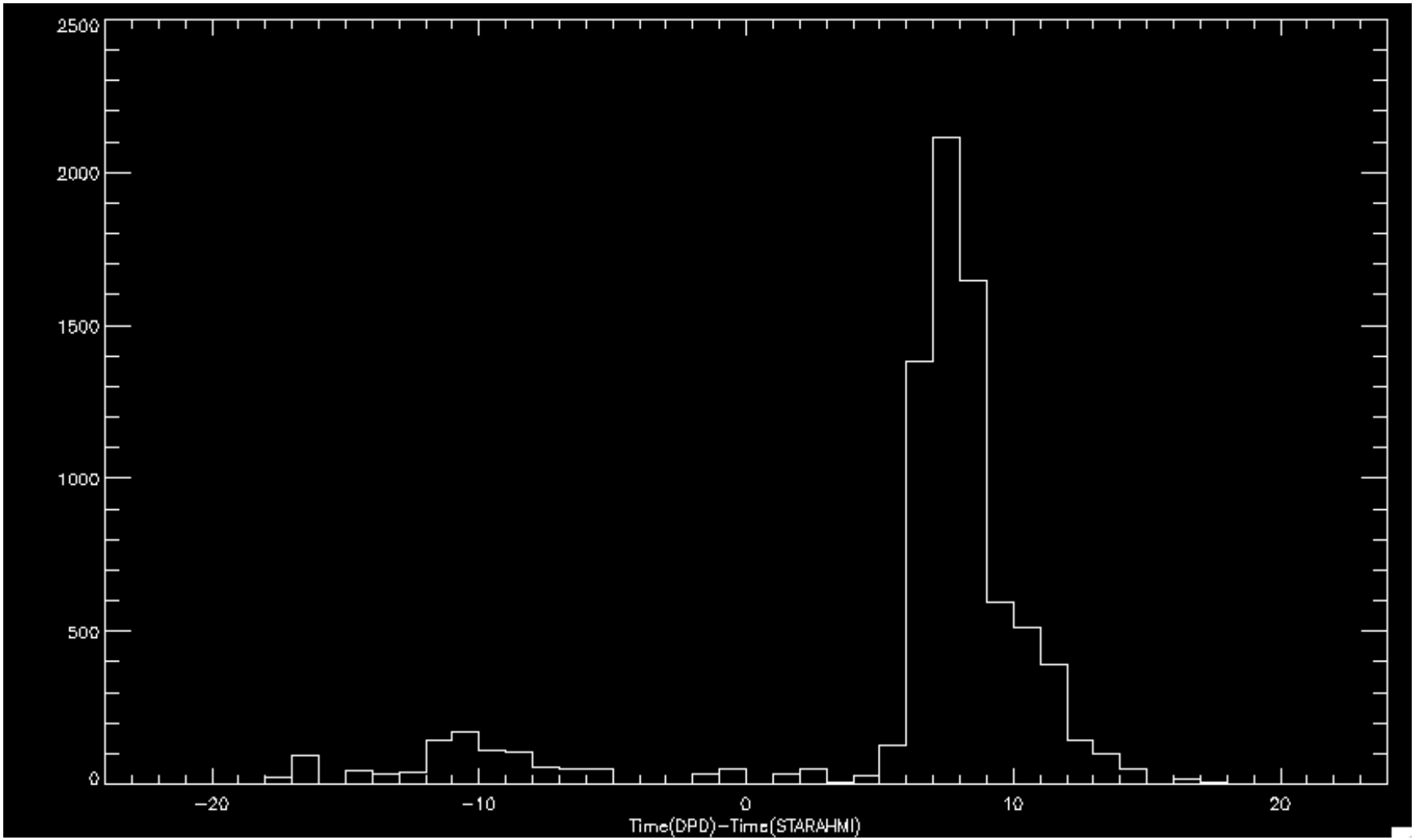
STARA areas vs. DPD areas: ratio



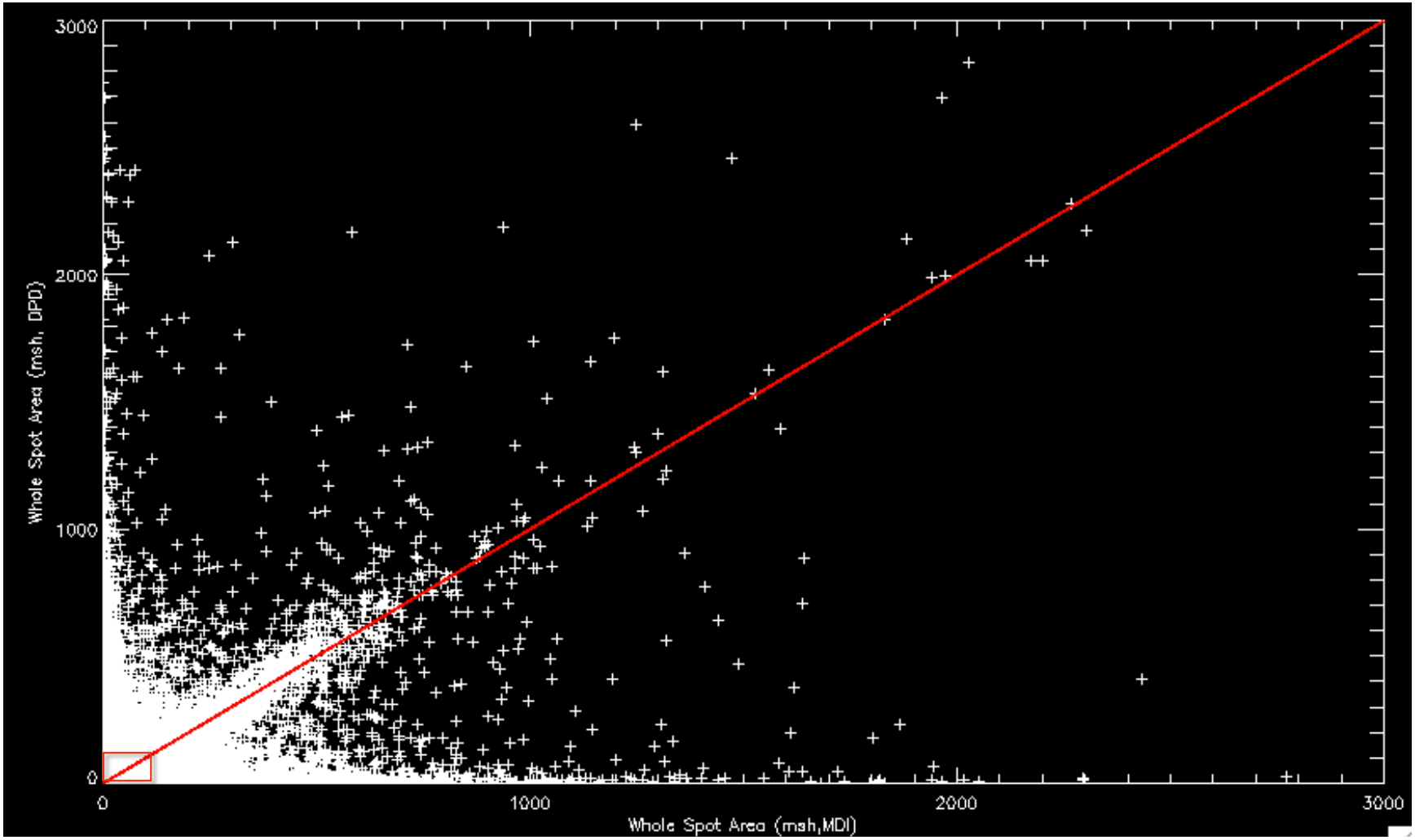
Time(DPD)-Time(MDI)



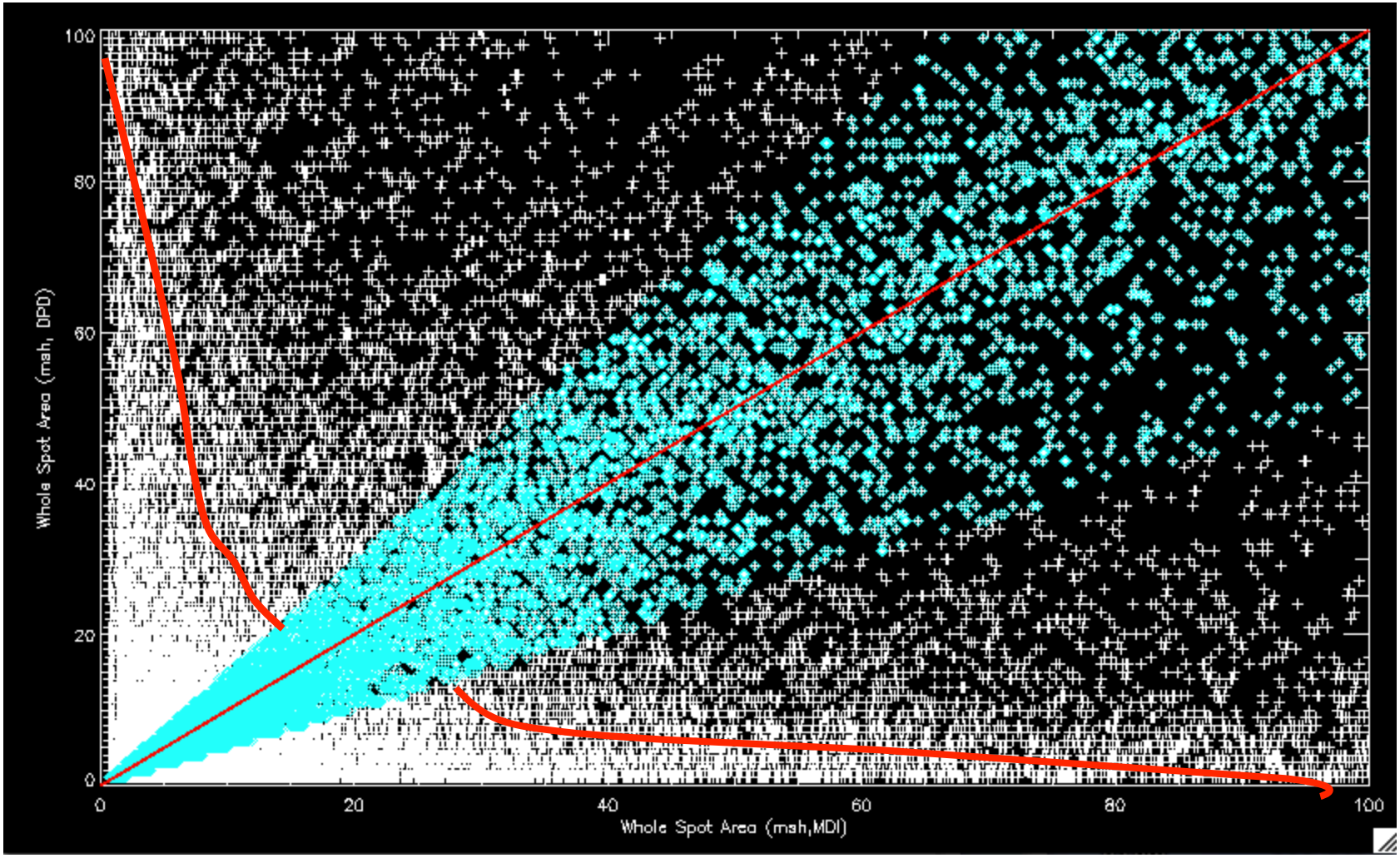
Time(DPD)-Time(HMI)



STARA areas vs. DPD areas

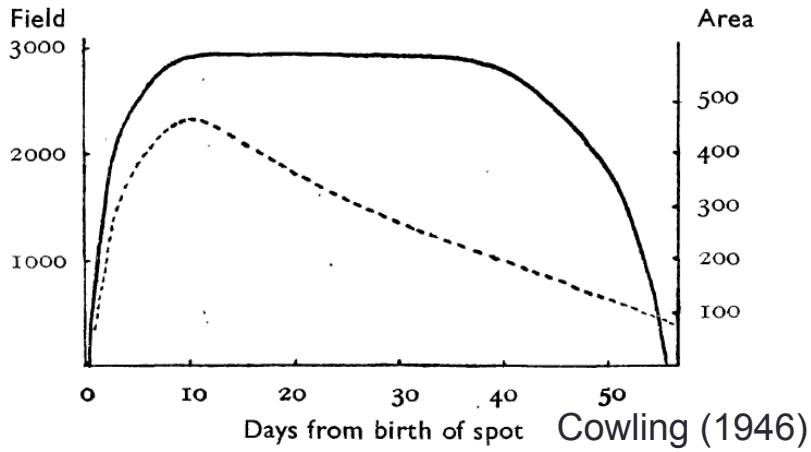


Effect of time difference: more impact on smaller spots !



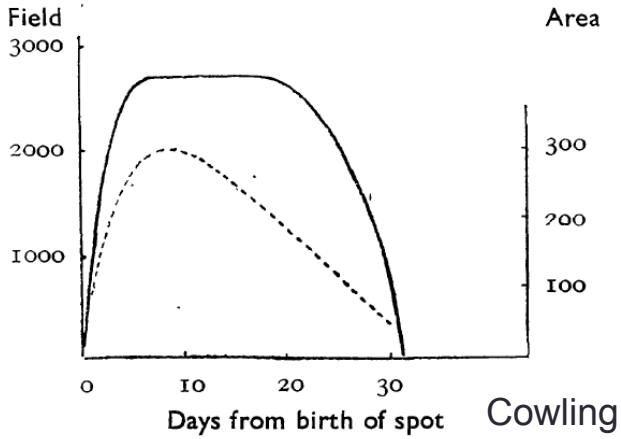
Smaller spots grow and decay faster

60d spot



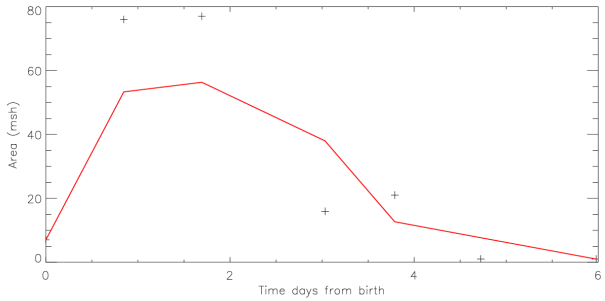
Cowling (1946)

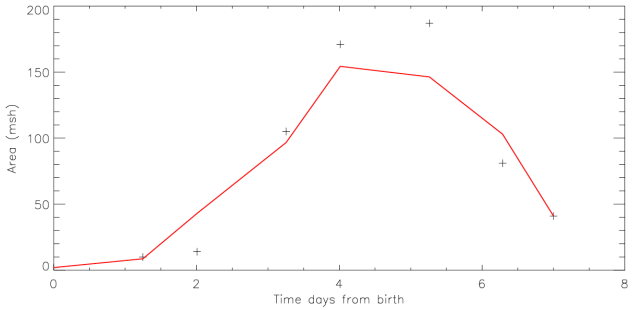
30d spot

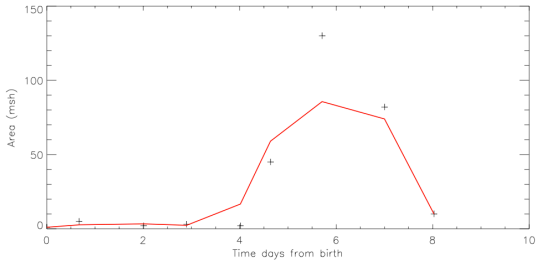


Cowling (1946)

Less than 10d spots



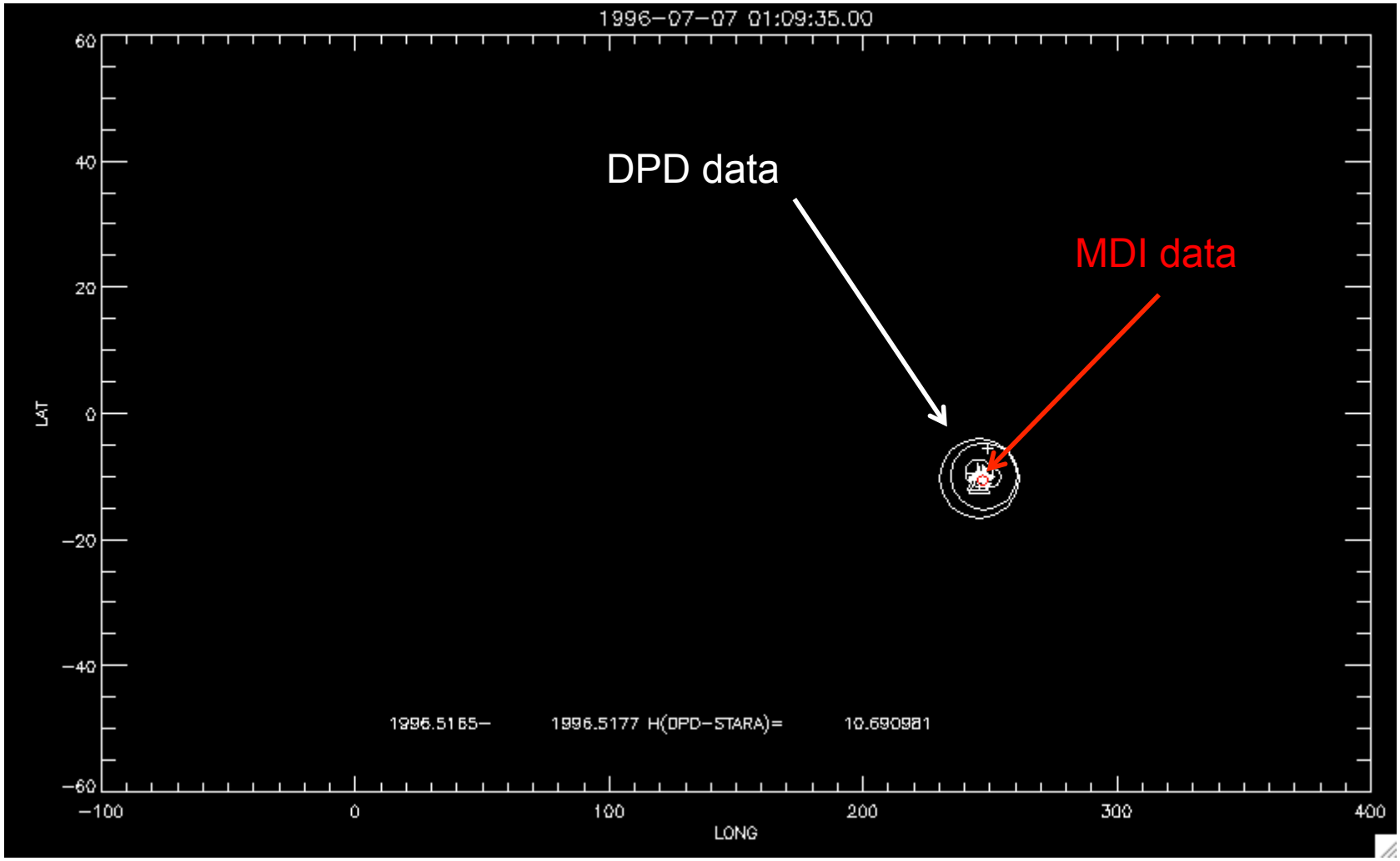




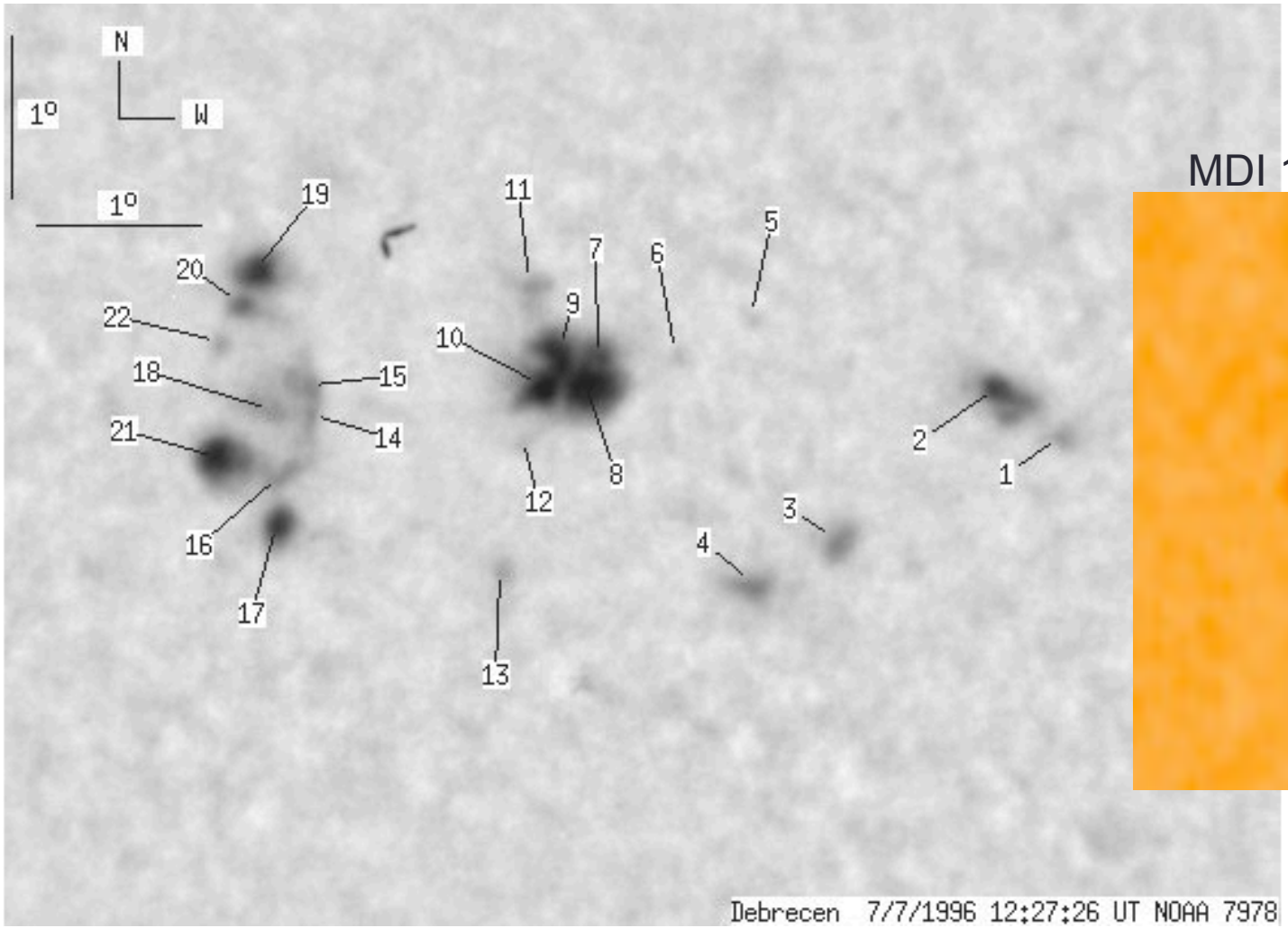
A CONCRETE EXAMPLE

Time difference and its consequences

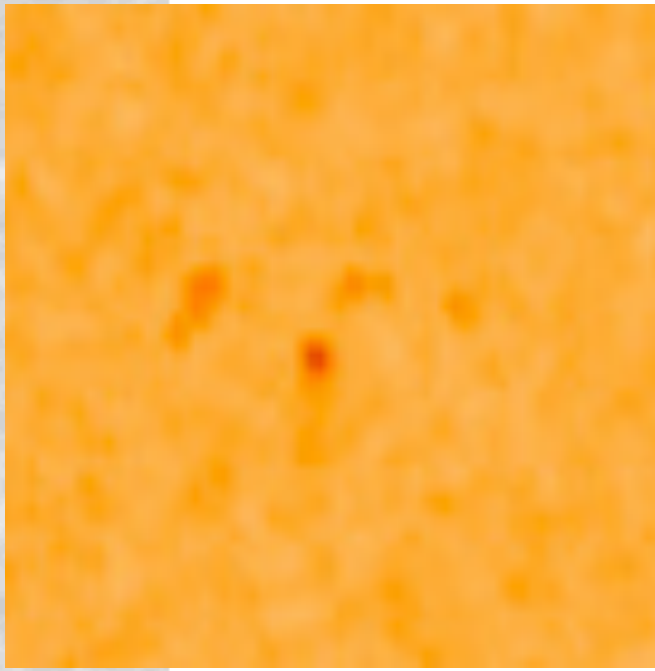
DPD (white) / MDI (red) comparison



Debrecen 1996/07/07 12:27UT

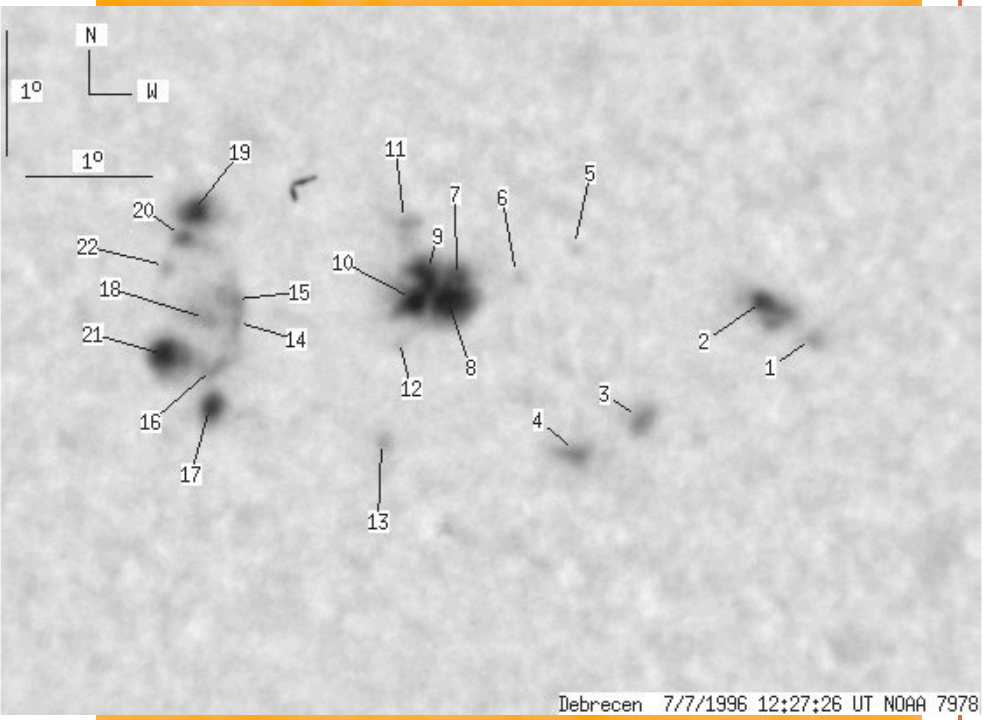


MDI 1:09 UT

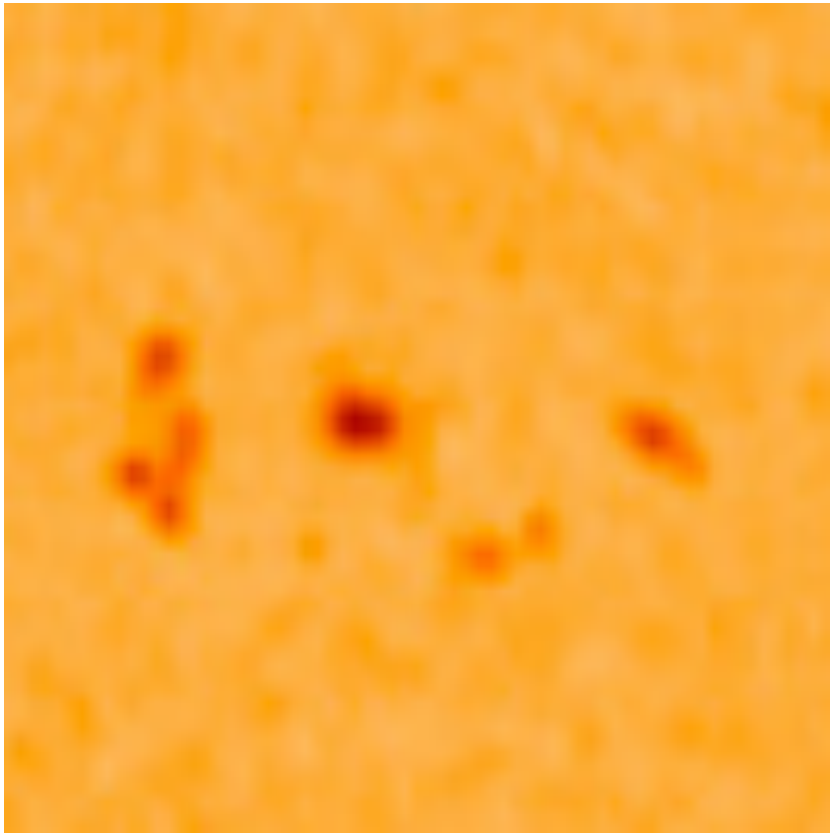


SOHO MDI

1:09



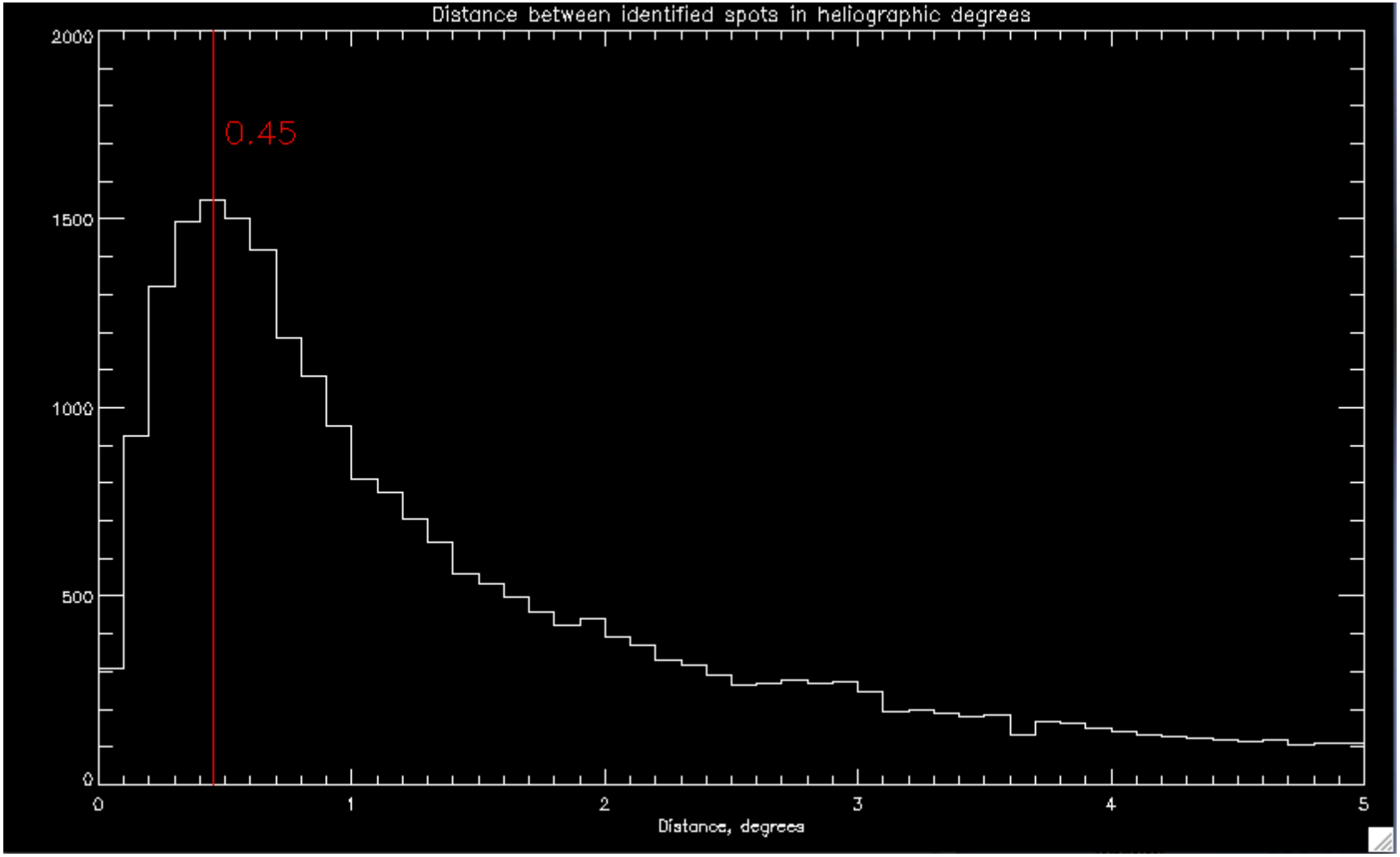
13:06



Results of this cross-validation:

- Each method has its own advantages/disadvantages.
- Set of images different
- Same number of spots on the same period (≈43400 in STARA against ≈43700 in DPD)
- Discrepancy in smaller sunspots: probable cause is the largely different observation times.
- Very good identification of spots between 2 completely independent datasets/methods.
- As of now, some of the STARA data are also “penumbrae”: approx. 25000 out of the 43000.
- New cross-validation to make with 4 images/day to check conclusions.

Distance between matching spots MDI/DPD



WHAT HAPPENS TO SUNSPOTS THEN?

A first definition of small(er) sunspots

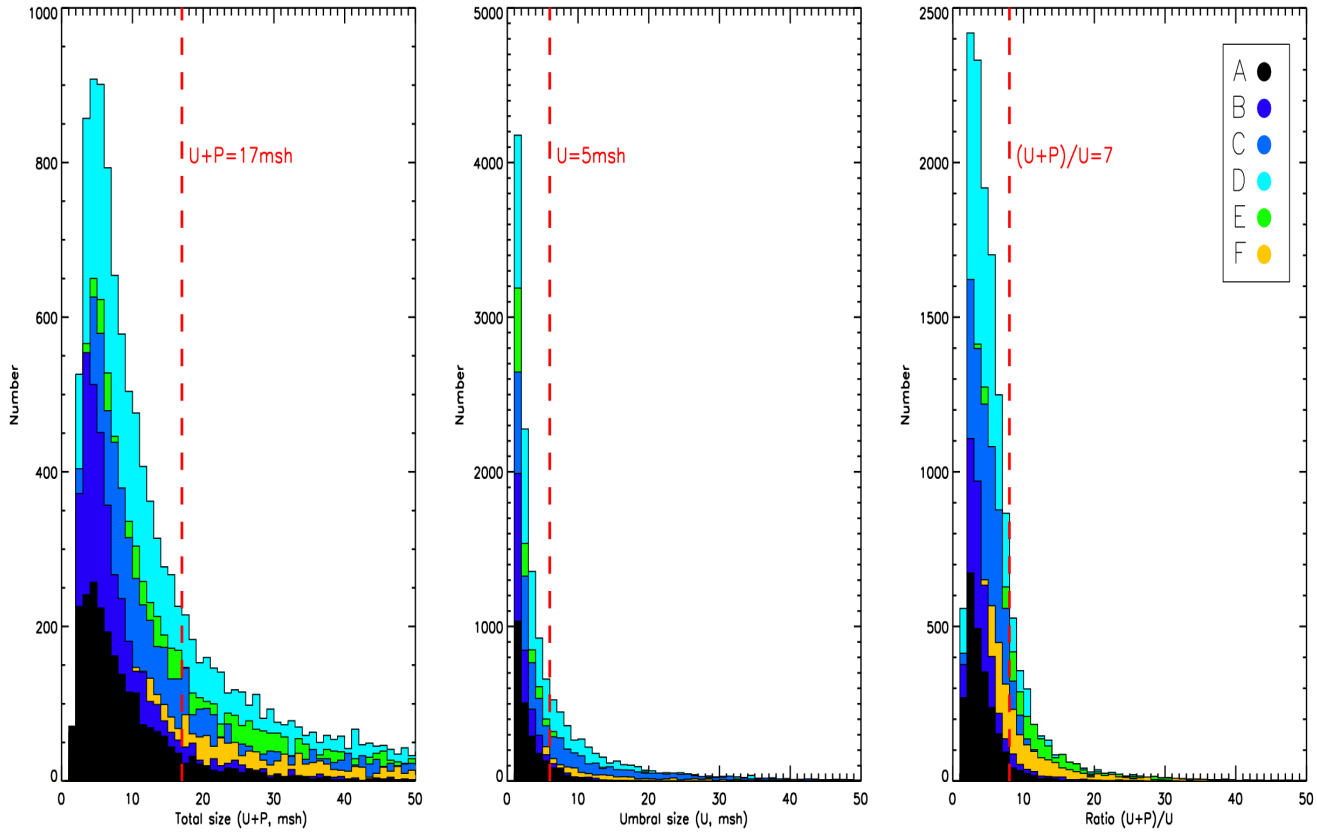
- From the distribution of sizes (next slide)

- "Small"= ((U+P)/U LE 7 AND U+P GT 0) AND (U+P LE 17)
  - U GT 0 would count common penumbrae
- "Large"= ((U+P)/U GT 7 AND U GT 0) OR (U+P GT 17)

- Both categories exclude penumbrae LE 17msh
- The small category excludes penumbrae altogether
- The large category contains only the largest penumbrae, which have a great chance of being real spots
- Both categories exclude « common penumbrae » (which could have an effect)

Why this criterium?

- 90% of spots in A and B groups have U+P ≤ 17 msh, U ≤ 5 msh and (U+P)/U ≤ 7



Small spots (1)

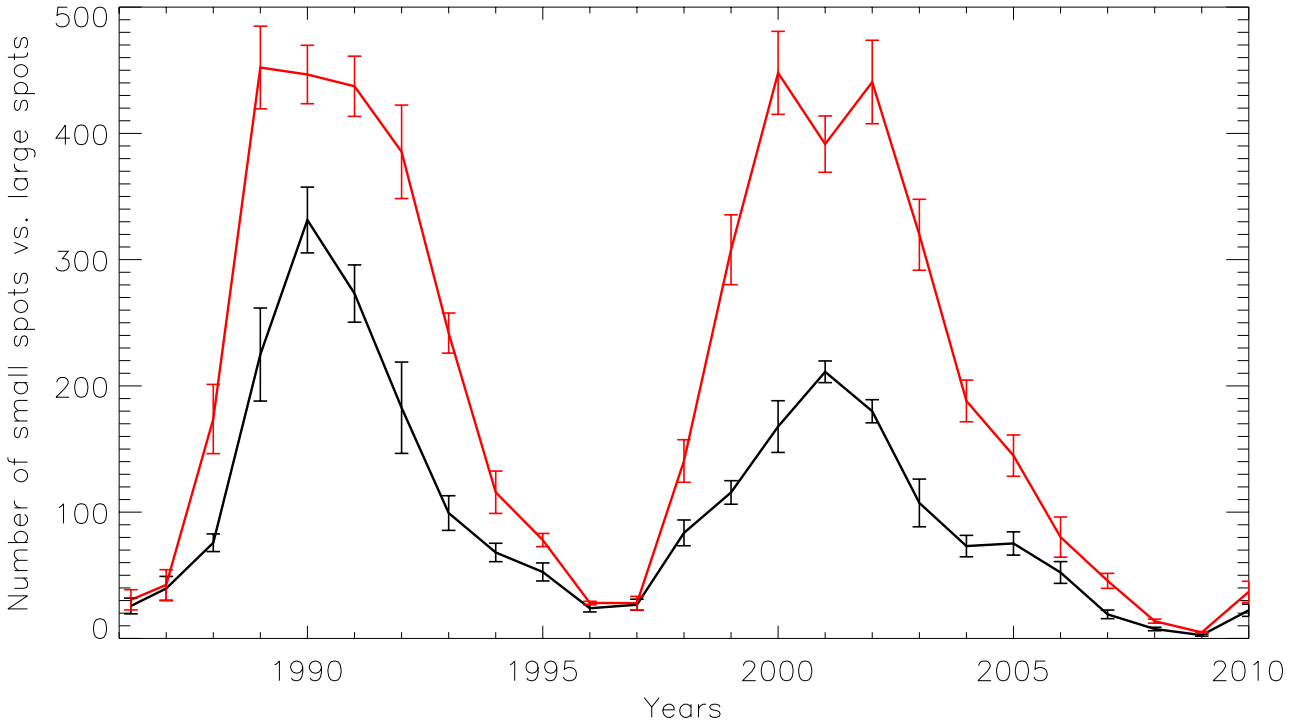
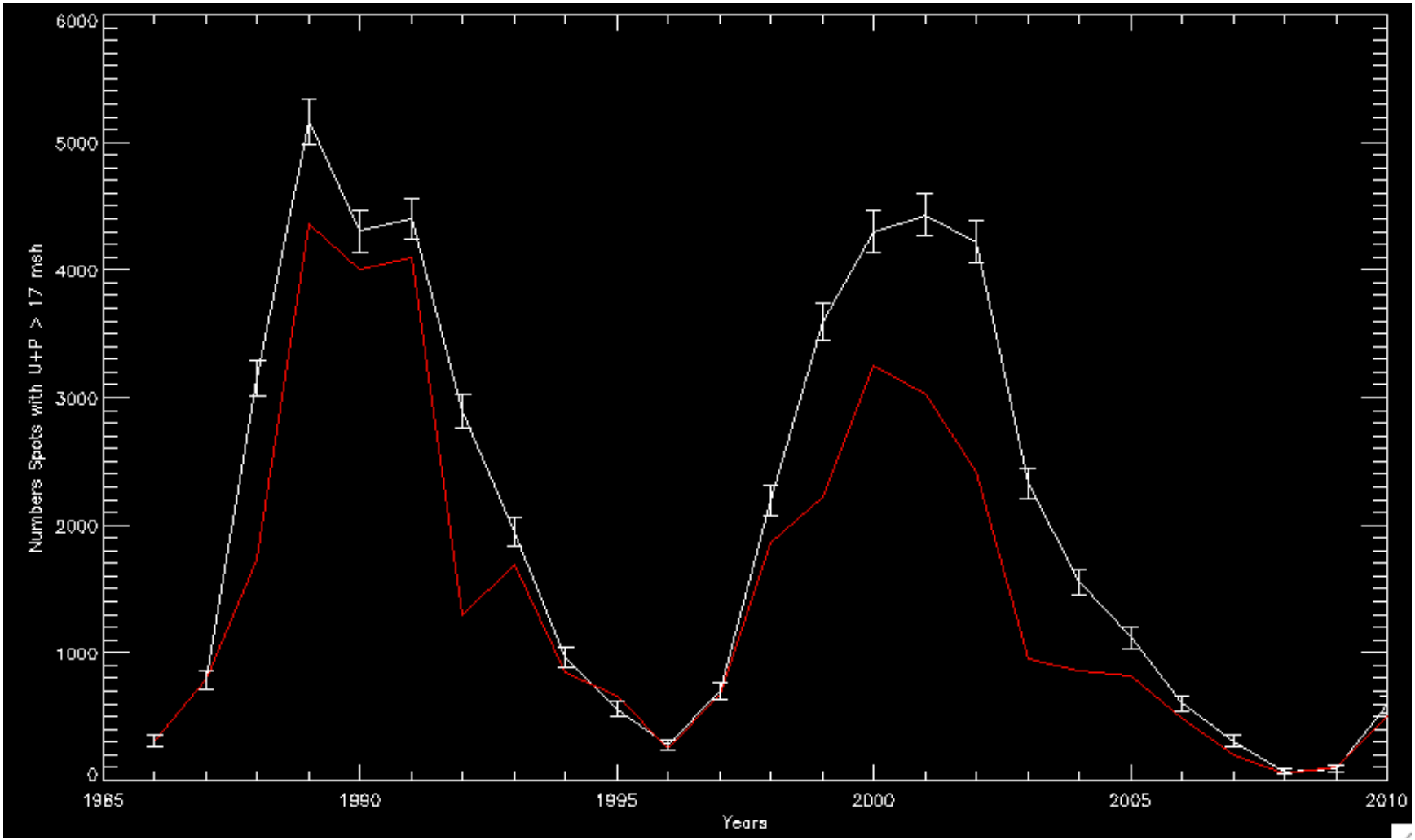


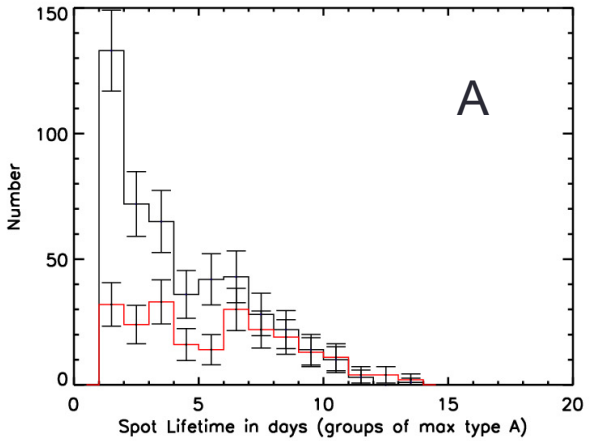
Fig. 4. Number of small (black line, U+P ≤ 17msh AND U+P/U ≤ 7) and large individual spots (red line, U+P > 17msh OR U+P/U >7) during cycles 22 and 23. The monthly average sunspot counts were smoothed with a one-year running mean and are given with corresponding error bars.

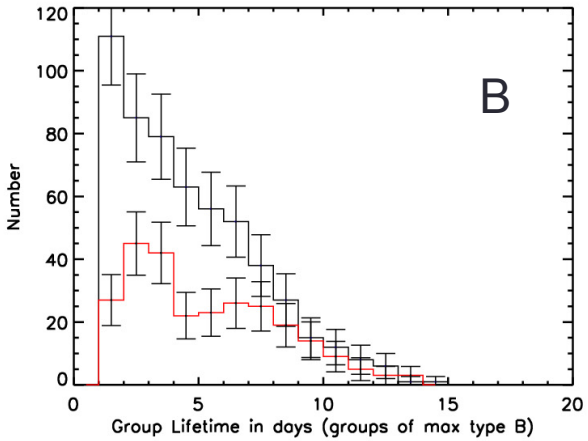
Small spots (2)

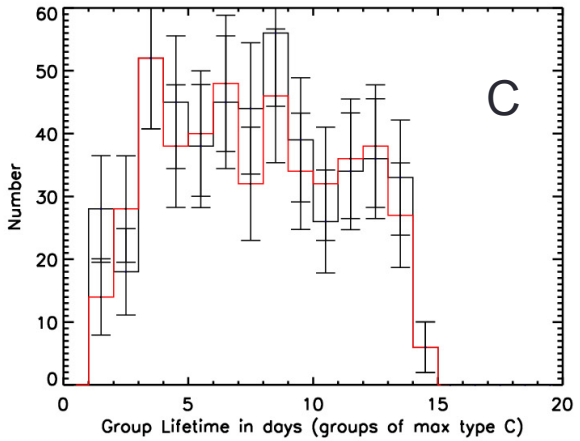


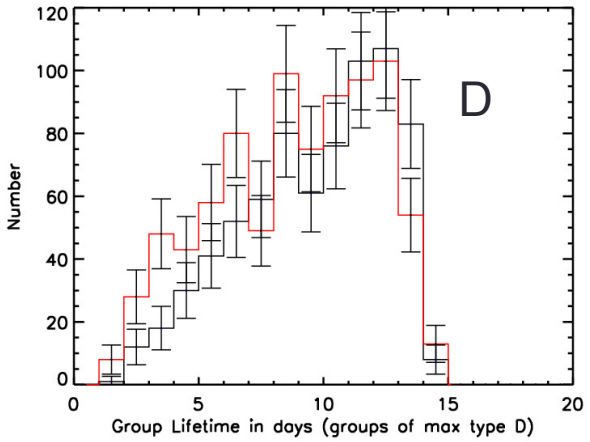
Small spots (3): Lifetime of groups

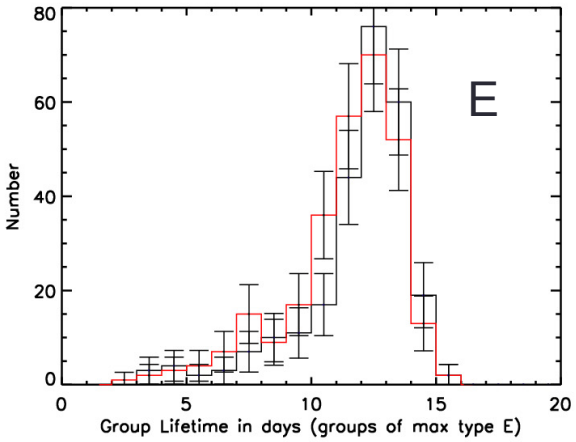
Cycle 22
Cycle 23

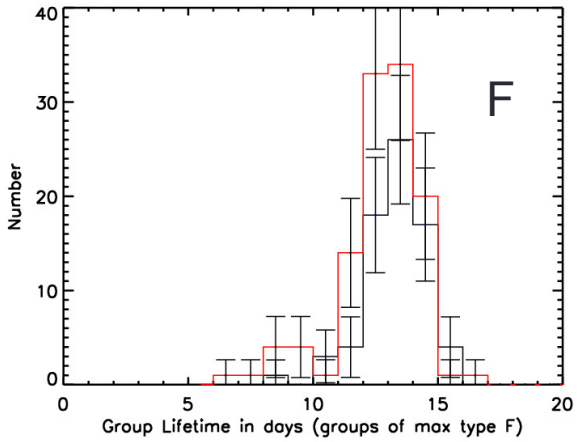




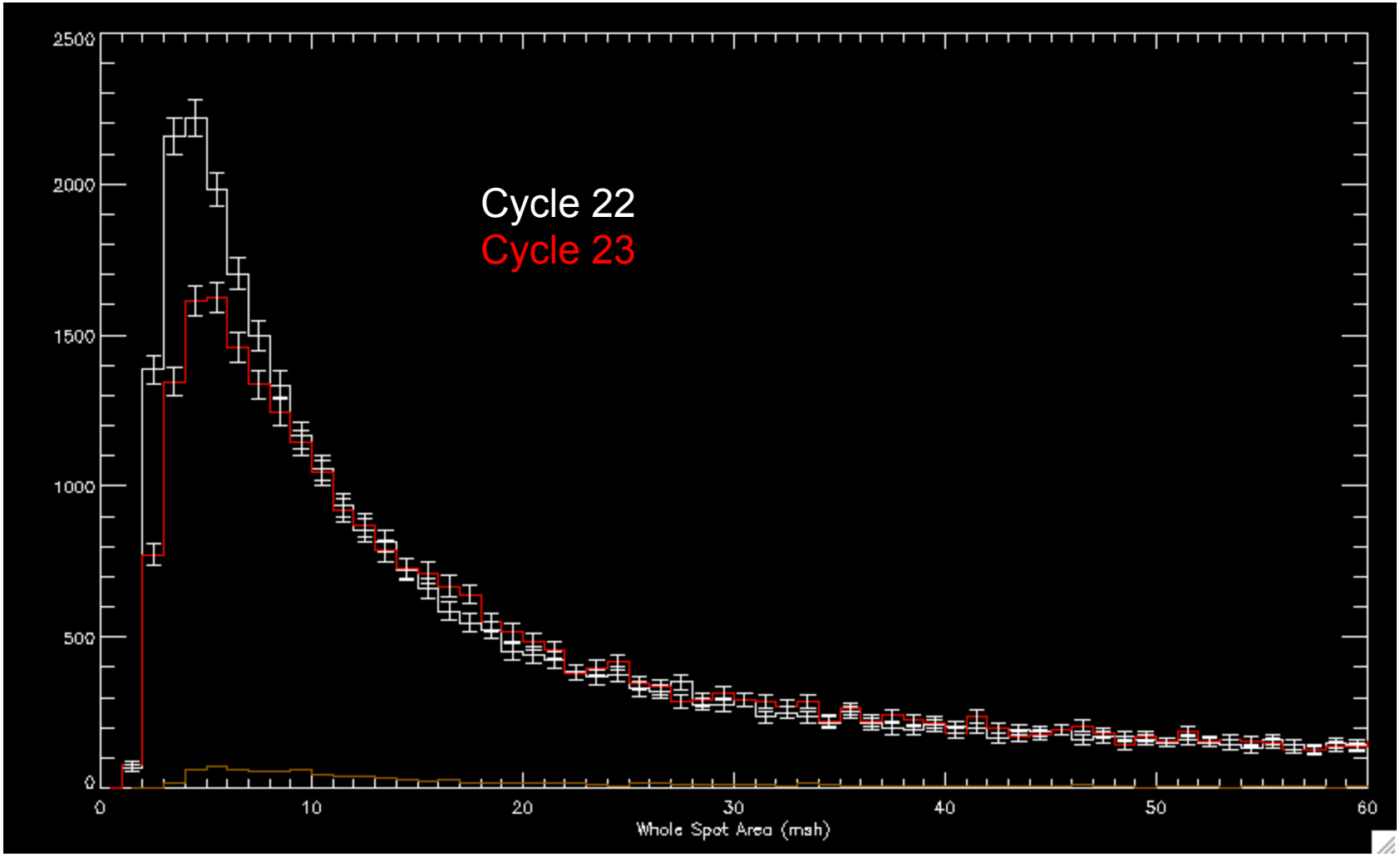




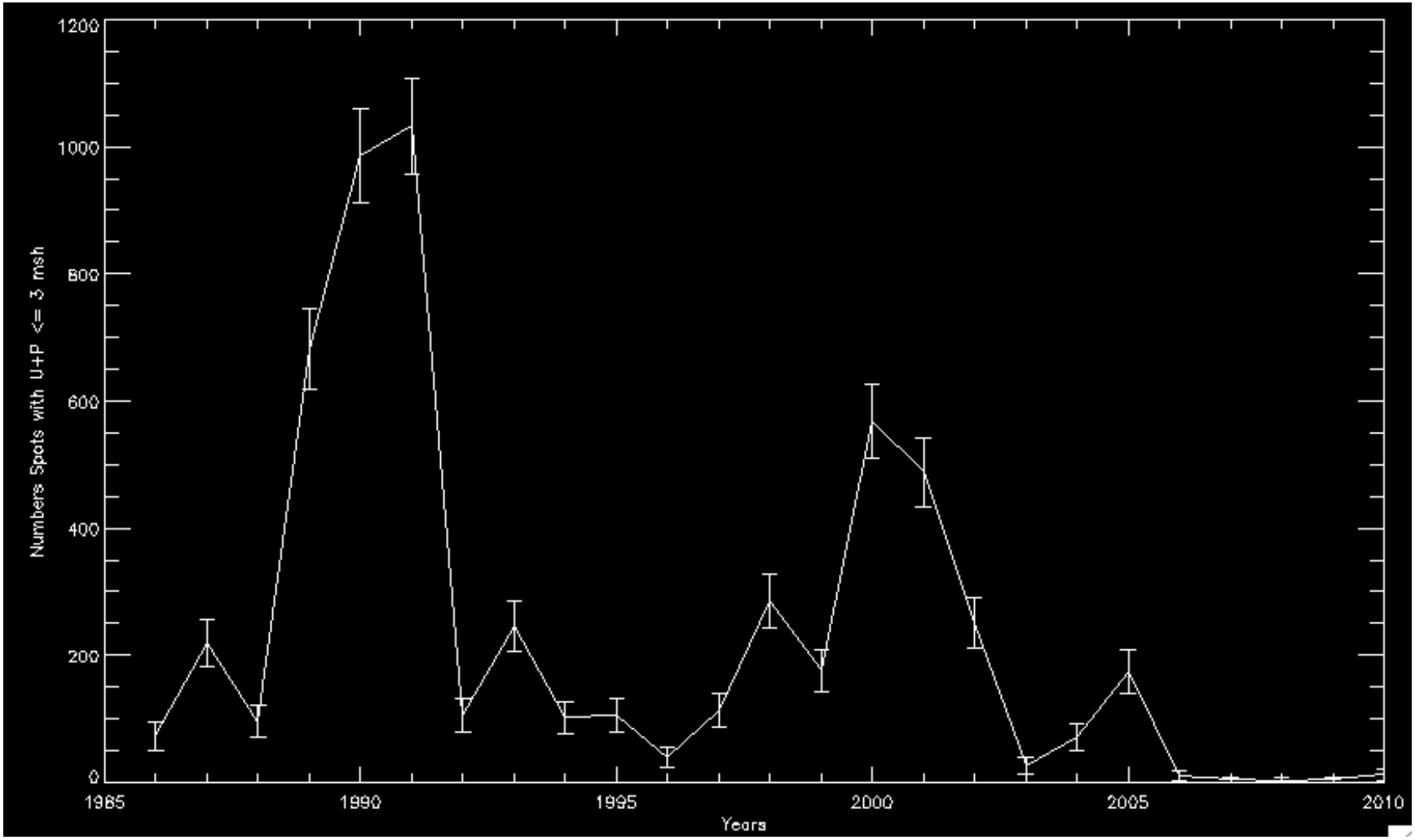




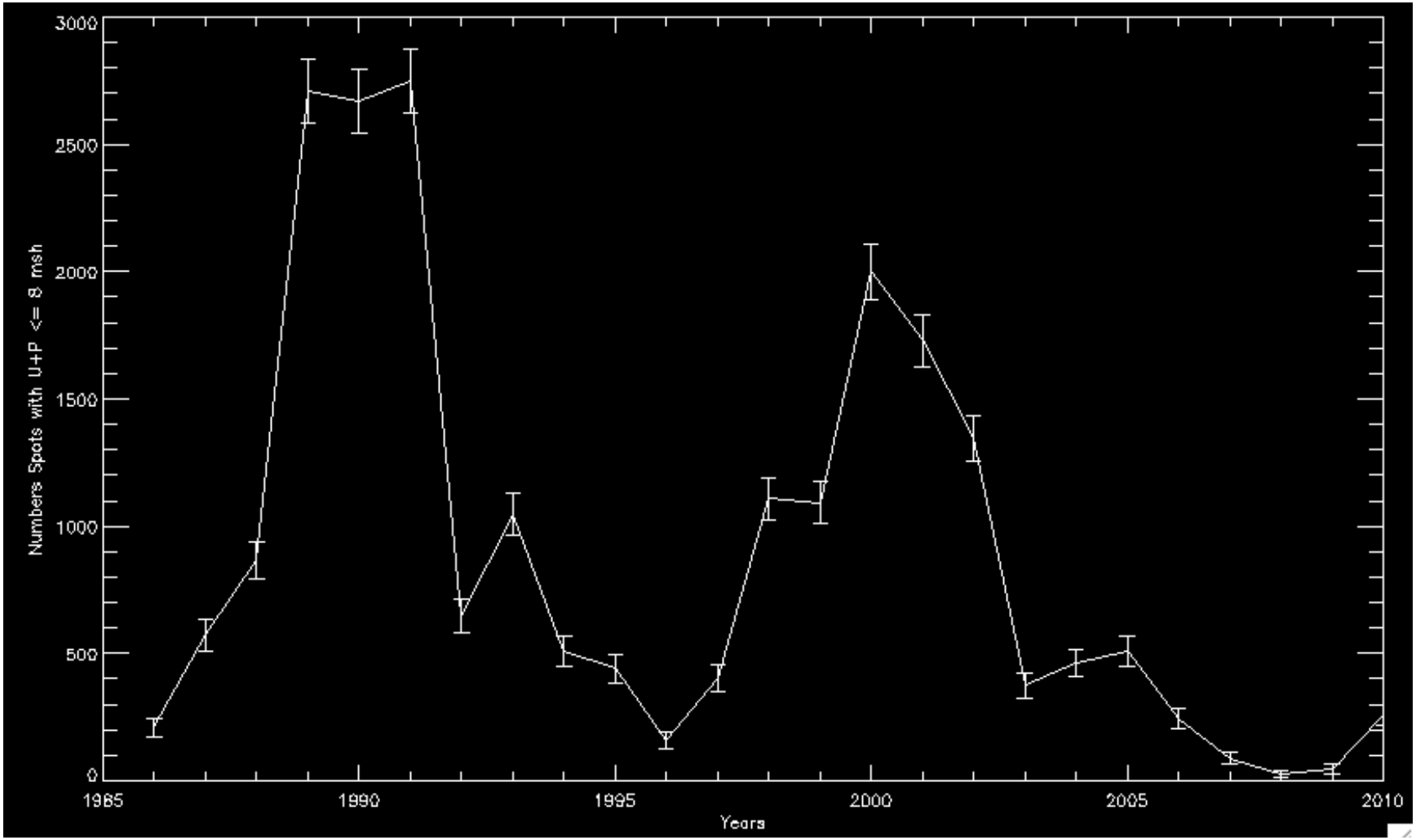
Distribution of Spot Sizes between solar cycles 22 and 23



<4 msh

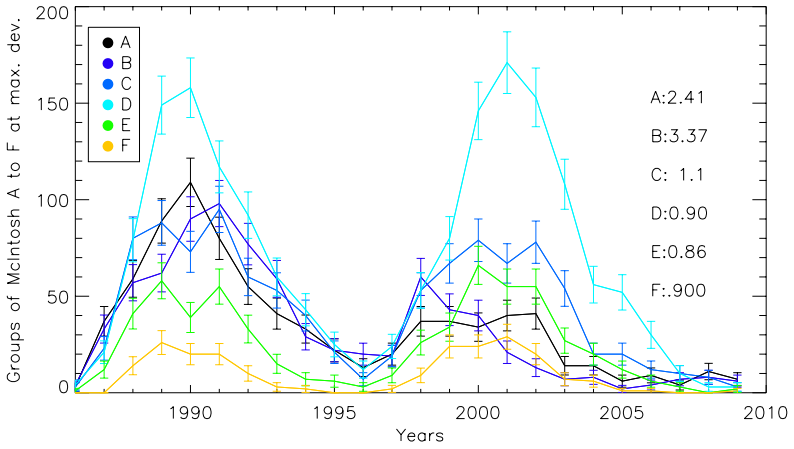

Numbers Spots with U+P <= 3 msh
1200
1000
800
600
400
200
0
1985
1990
1995
2000
2005
2010
Years

< 9msh

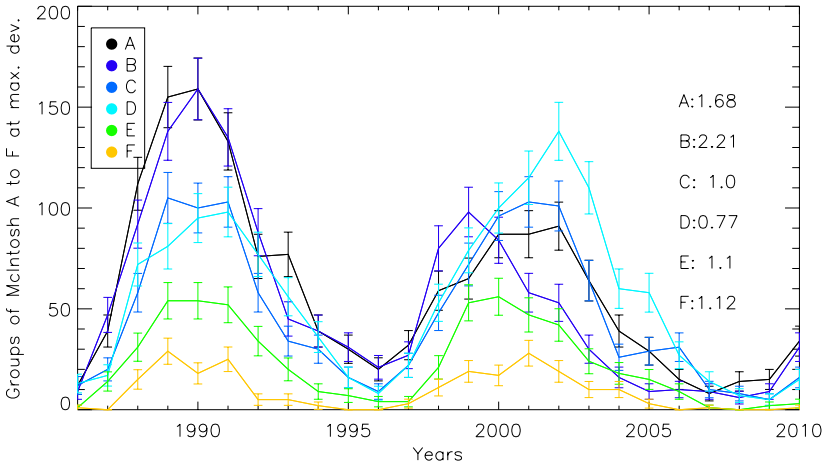

Numbers Spots with U+P <= 8 msh
3000
2500
2000
1500
1000
500
0
1985
1990
1995
2000
2005
2010
Years

USAF: 3 stations agree

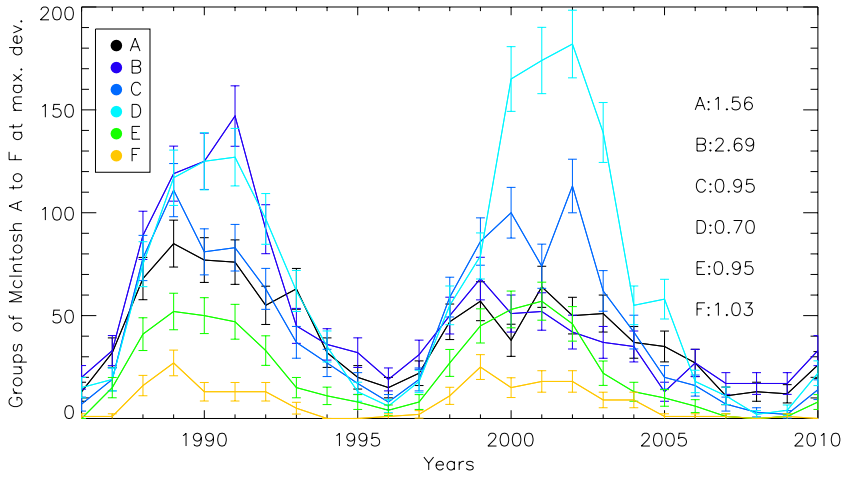
San Vito



Holloman



Learmonth



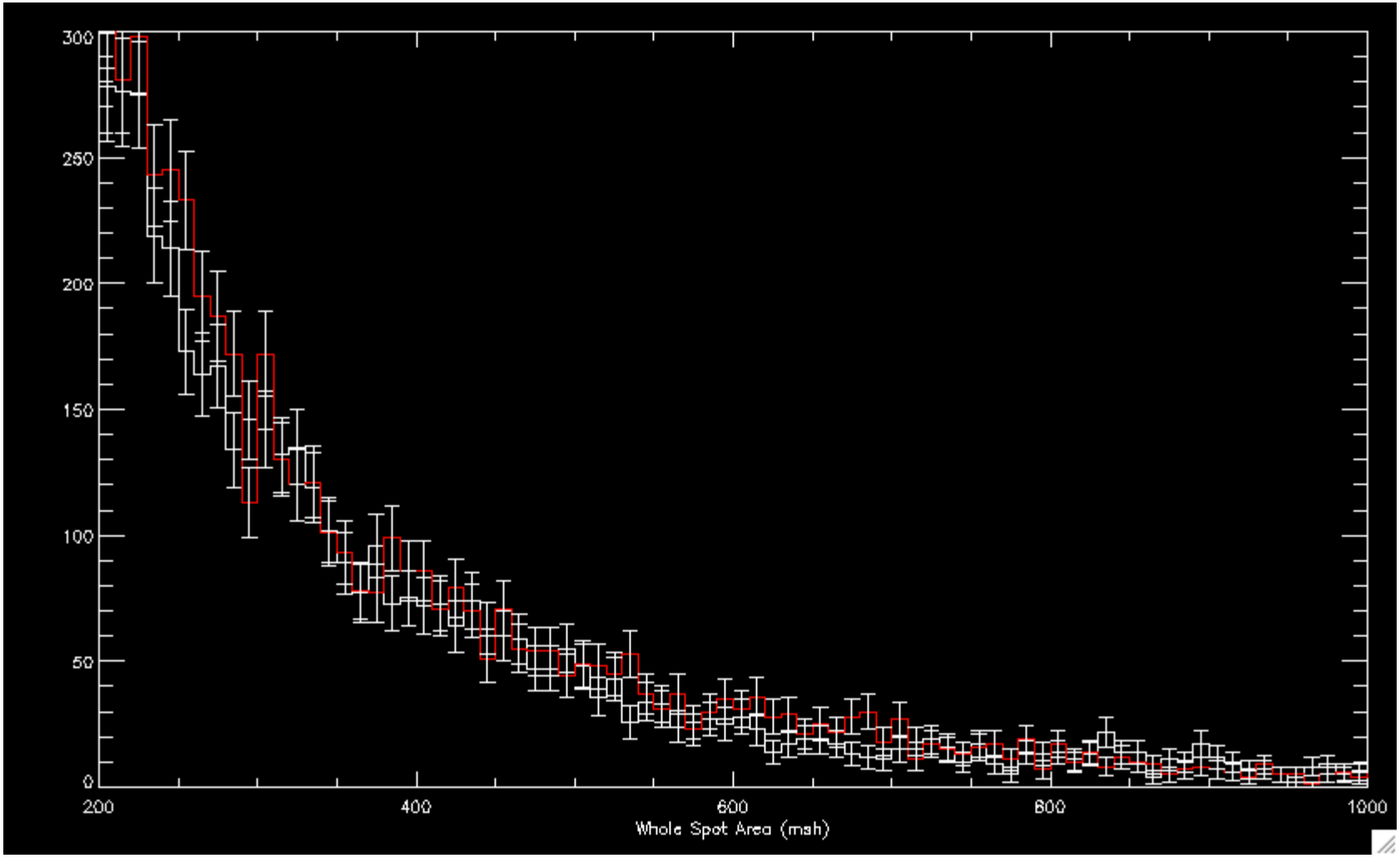
Smaller spots

- Whatever definition we take, there is a decreased number of the smaller spots between cycle 22 and cycle 23.

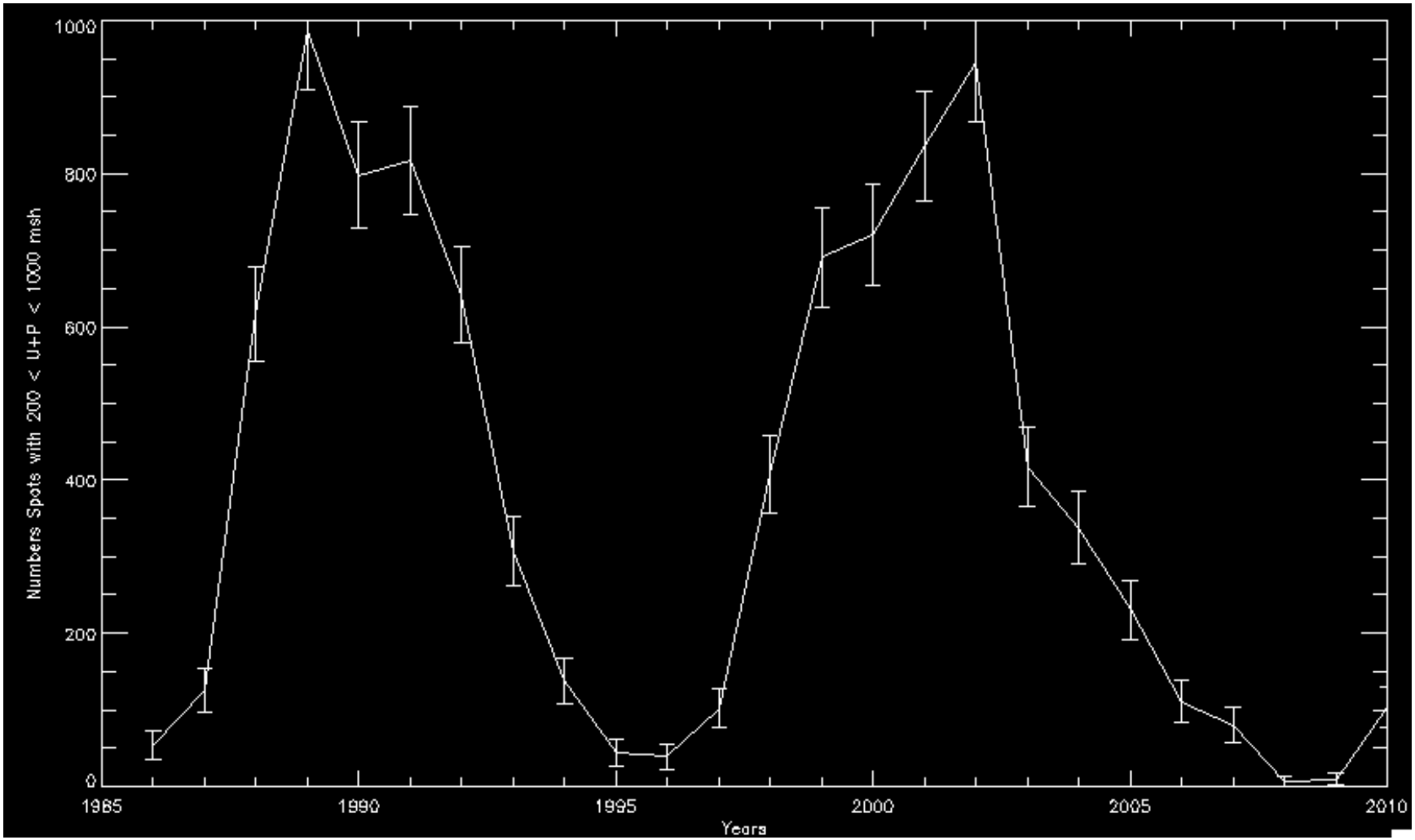
LARGE OR VERY LARGE SPOTS

What happened to them ?

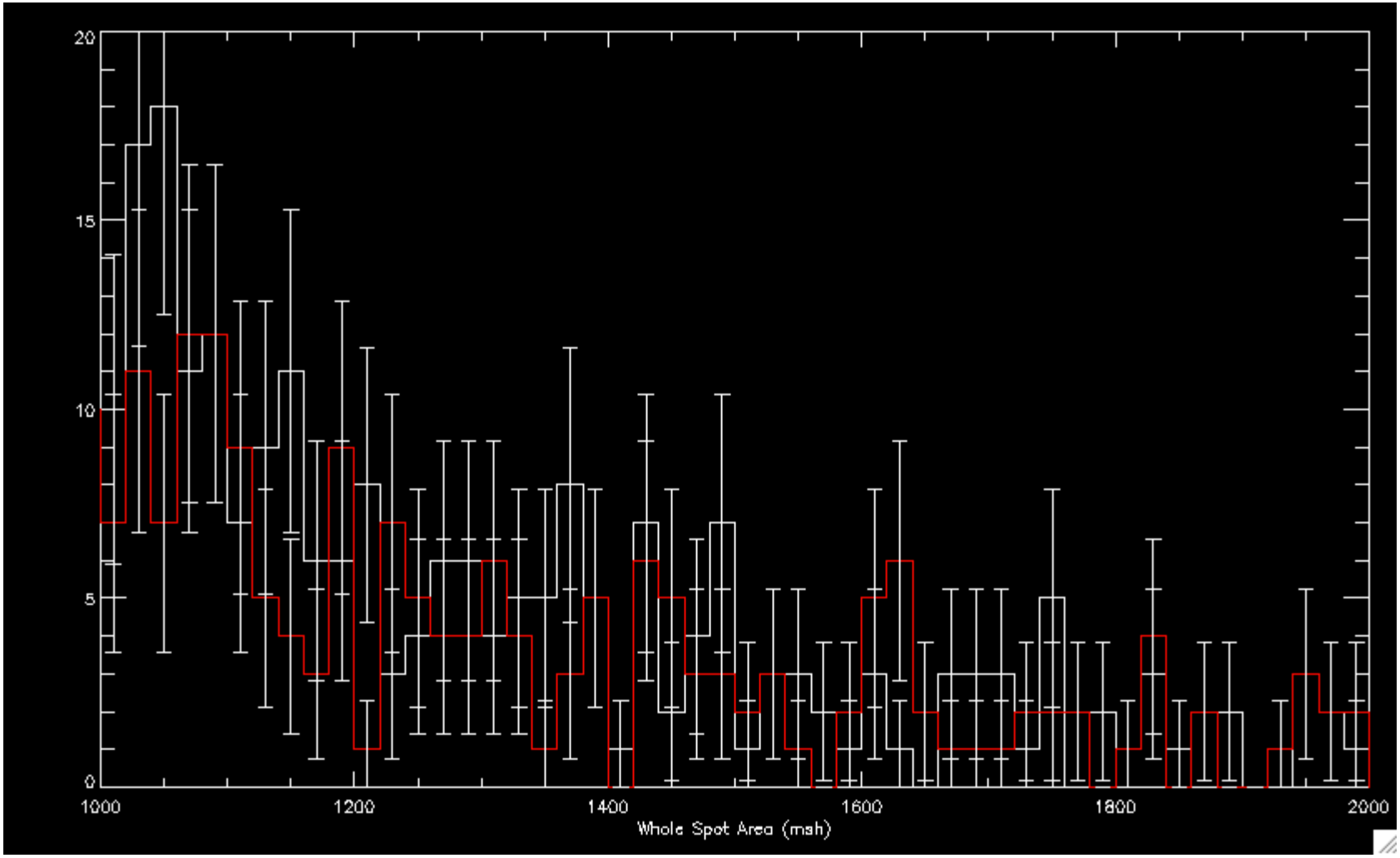
Large spots


300
250
200
150
100
50
0
200
400
600
800
1000
Whole Spot Area (msh)

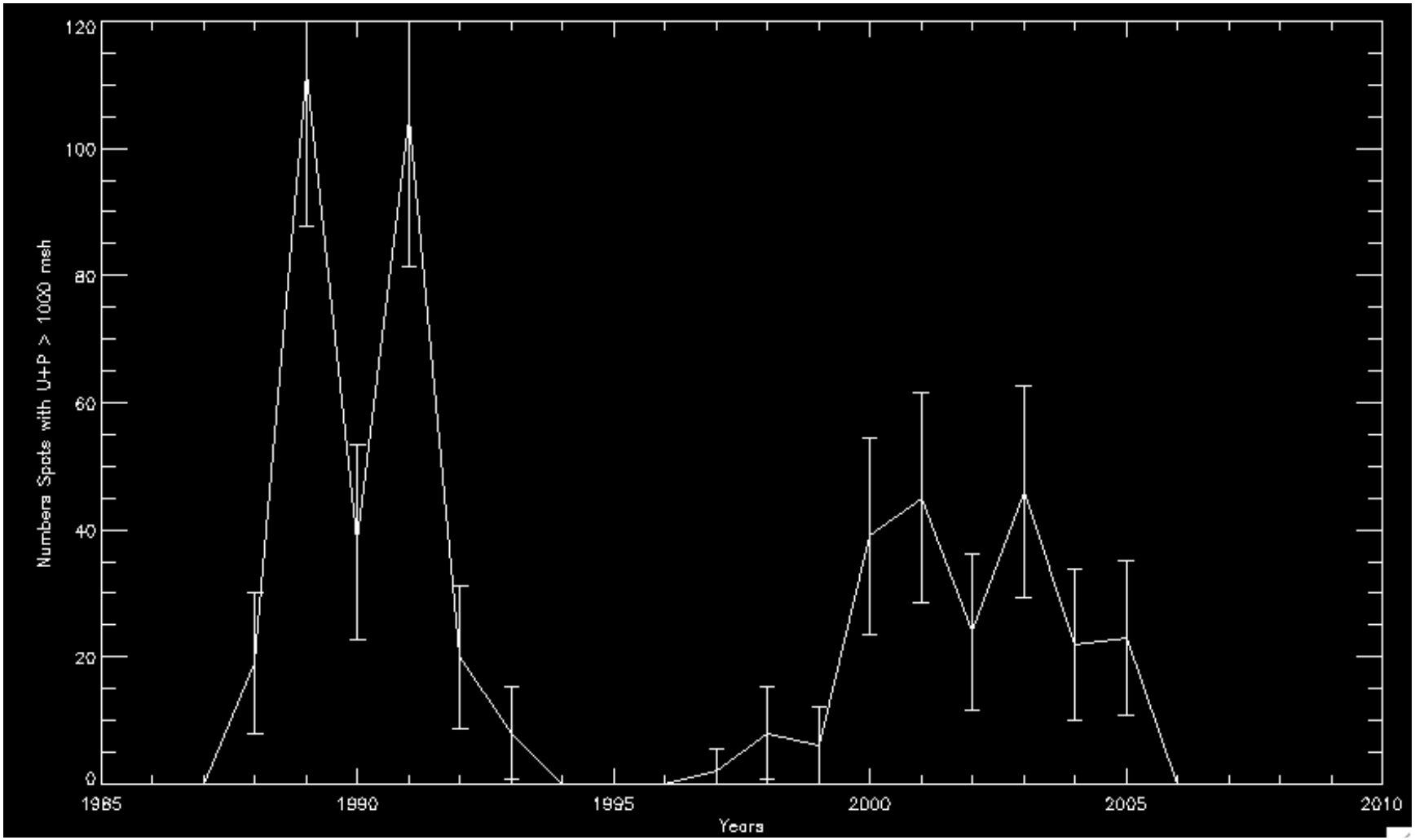
Large spots


1000
800
600
400
200
0
Numbers Spots with 200 < U+P < 1000 msh
1985
1990
1995
2000
2005
2010
Years

Very Large spots



Very large spots: total number of appearances per year



Conclusions

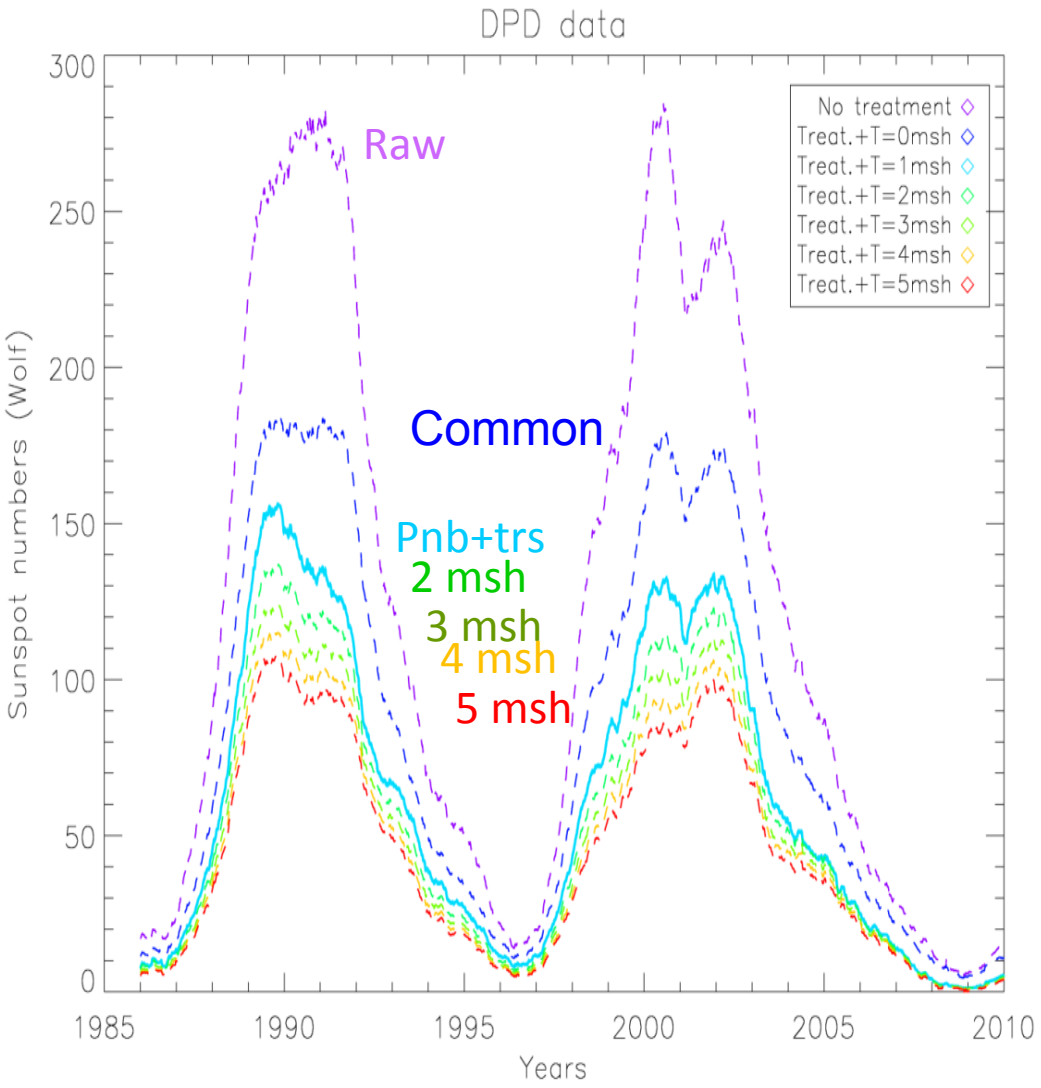
- The DPD and STARA catalogs identify the same spots with 2 different methods on the same period.
- Data are very similar in both catalogs
- DPD data indicate that a significant part of the smaller spots disappear between cycle 22 and 23.
- There does not seem to be a significant difference in the number of large and very large spots between cycles 22 and 23 in this consistent dataset.
- USAF data indicate a decrease in the number of A and B groups (constituted of only small spots).
- As Laurence said, there is a decrease in the number of spots per groups in cycles 23 and 24 (a difference in sunspot numbers can hardly be attributed to a very small number of large spots decreasing).
- All clues point in the same direction: there seems to be less smaller spots in cycle 23 compared to cycle 22.

THE END !

Complementary material

Filtering further… no significant improvement

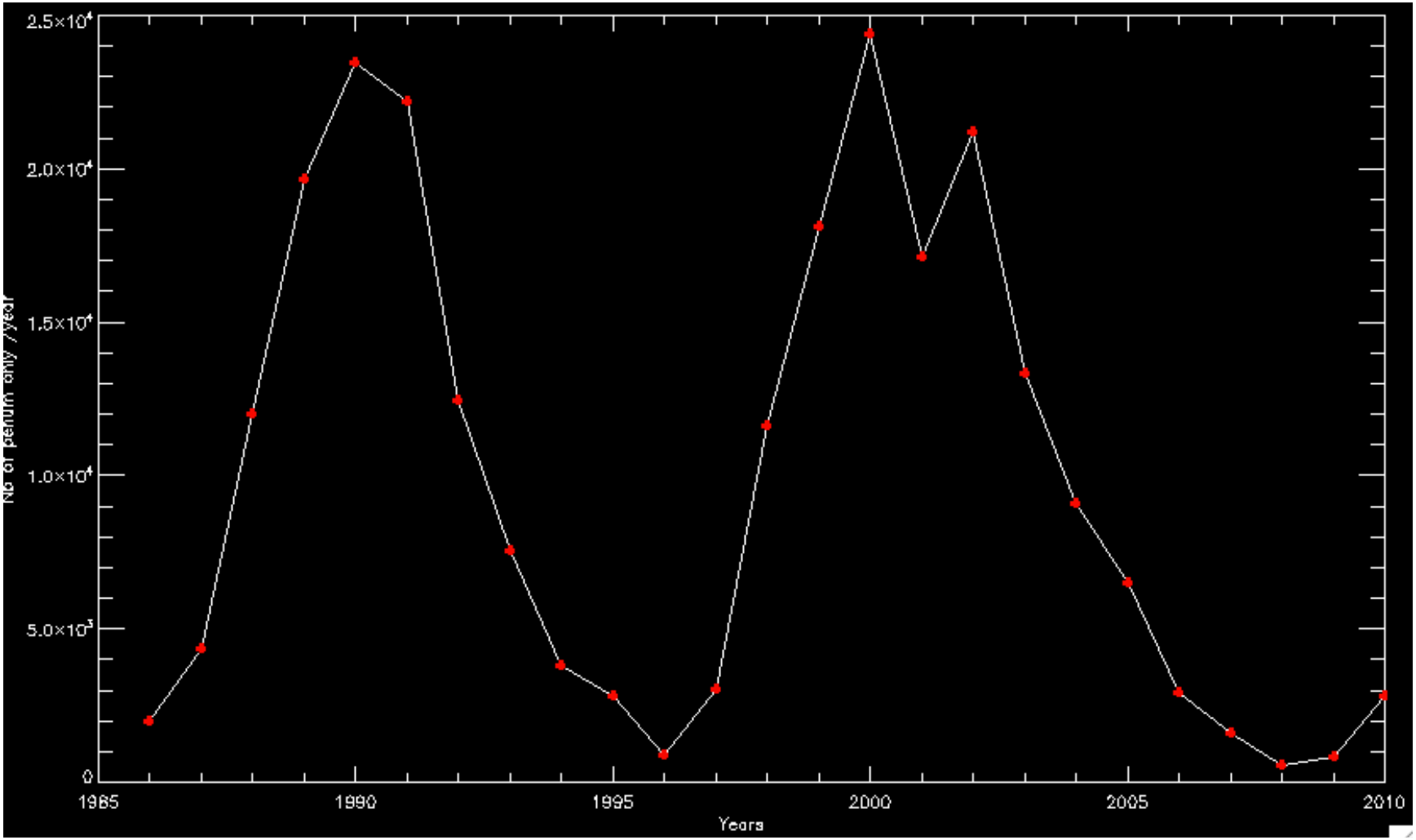
- Strong change for T=1 msh: (D= 1,92” = 1400km)
  - Scale: W= R_i
  - Correlation increases (matching cycle envelope)
- Smaller and progressive change for T> 1 msh:
  - Scale: W < R_i
  - No more change in the cycle envelope



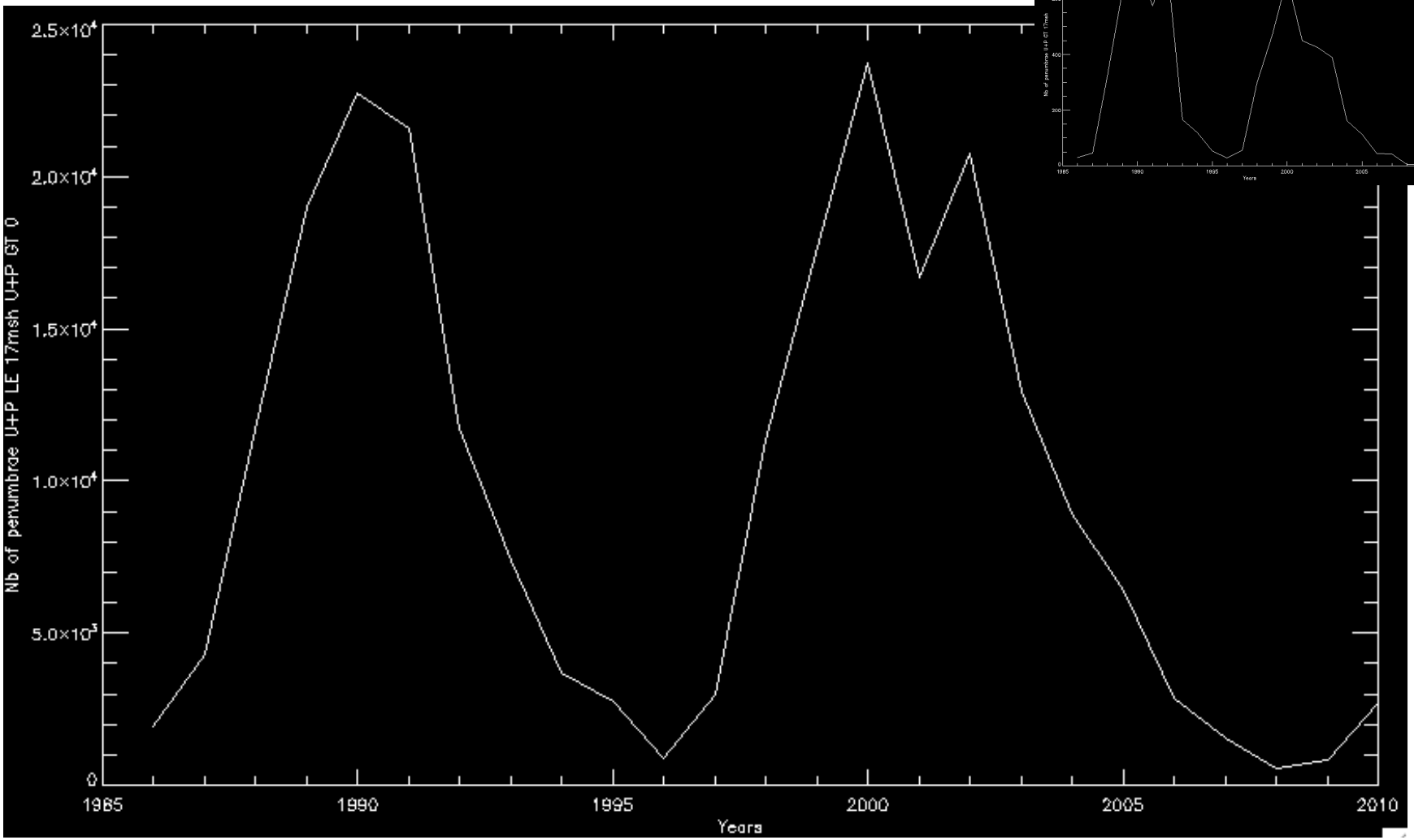
How to filter these structures from the catalog ?

- Should they all be removed ?
- In the catalog there are 54973 groups and 503173 spots (263789 penumbrae, approx. 52%)
- 15640 groups (28%) are penumbrae (48173 spots, 22%)
- They cannot be rejected out of hand, because they are not all absent from other catalogs
- 8495 of these groups exist in the USAF catalog (represent 29237 spots and 80% of these groups are A and B groups).
- 7145 are groups that do not exist in the USAF catalog and they represent only 18936 spots.
- Additional criteria: for example only 20% of penumbrae larger than 17msh are in the “to be rejected” category. While more than 60% of the smaller penumbrae have to be rejected. Make more tests to determine the right size.

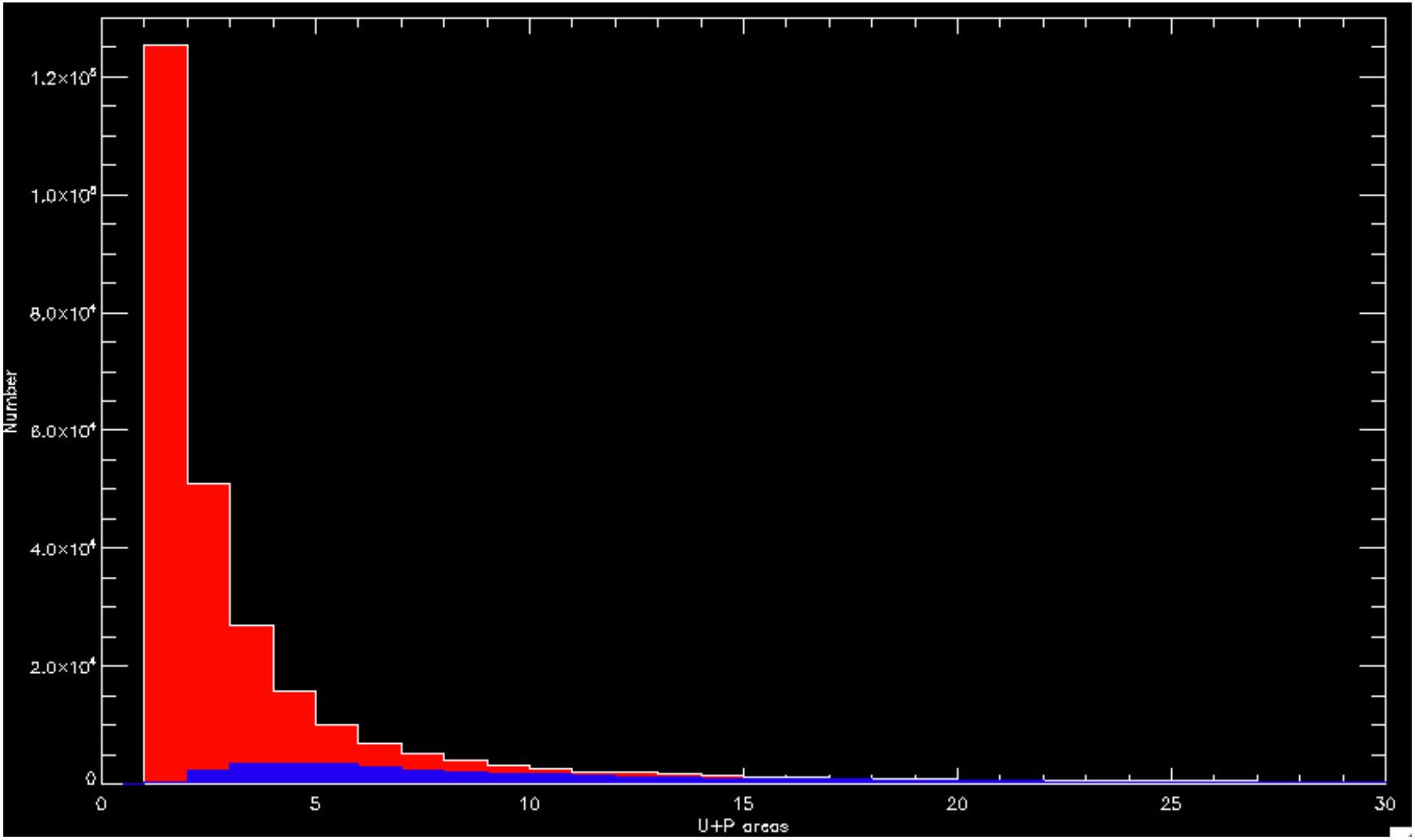
Penumbra only spots



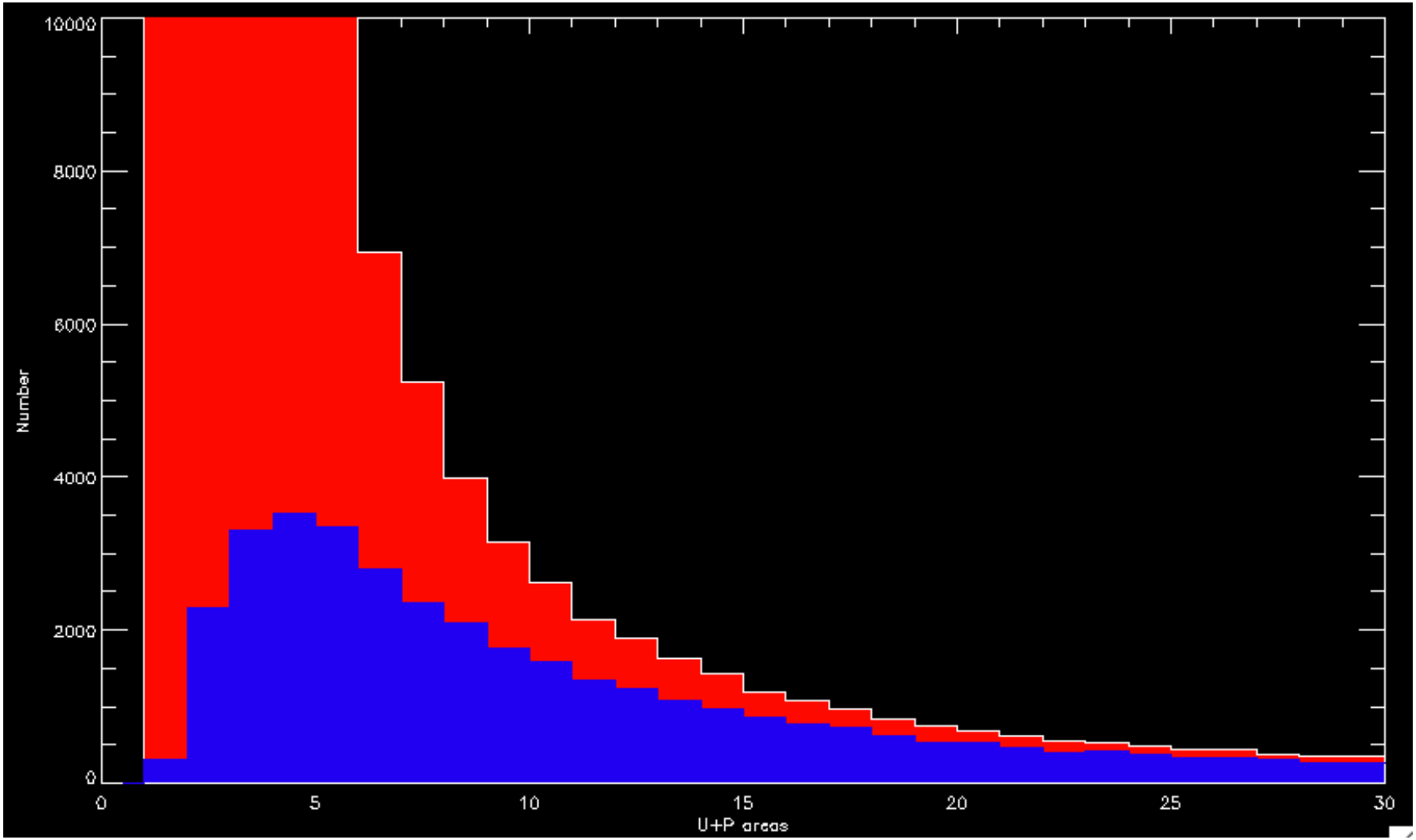
Large and small penumbrae only



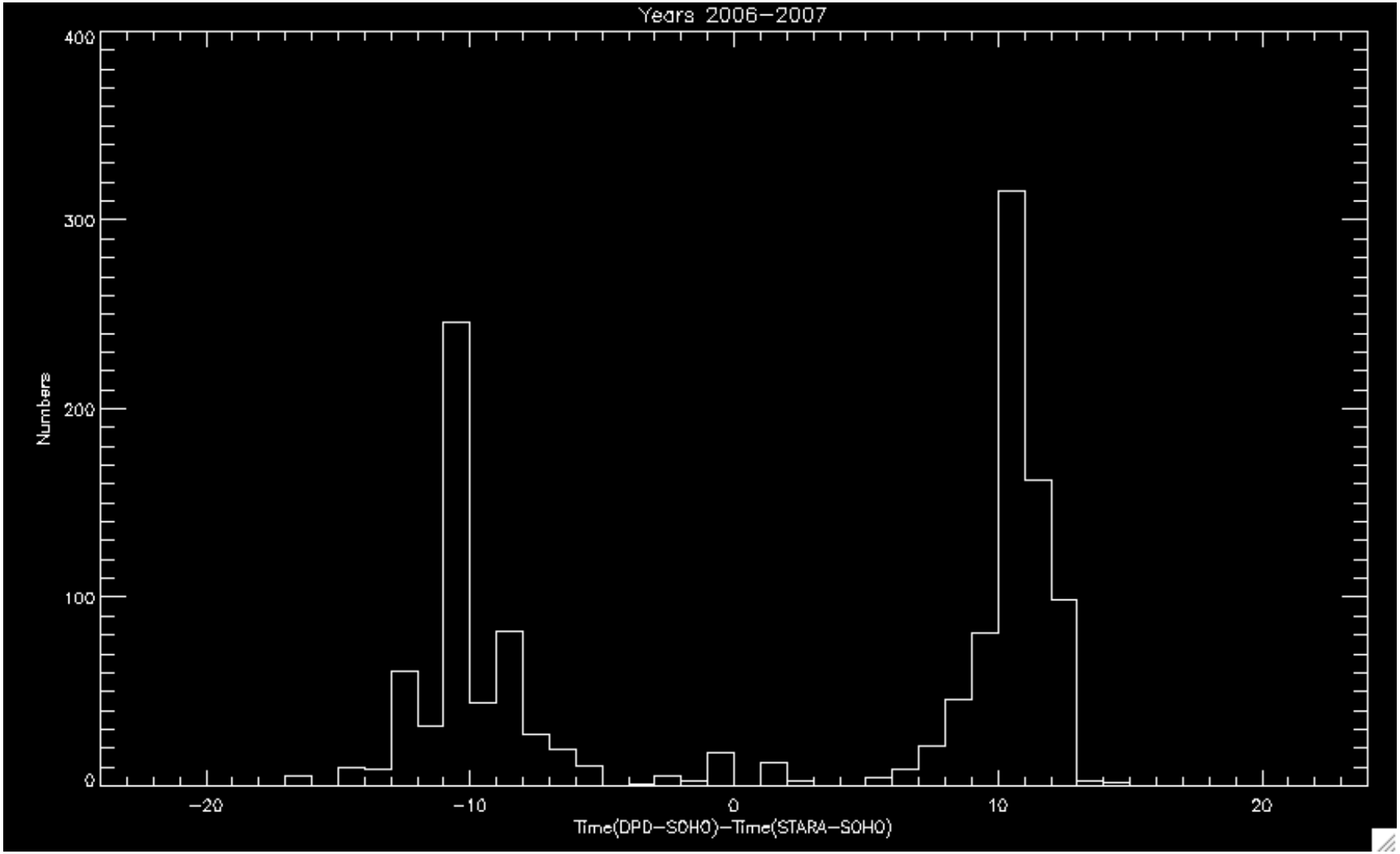
Blue: penumbrae filtered out



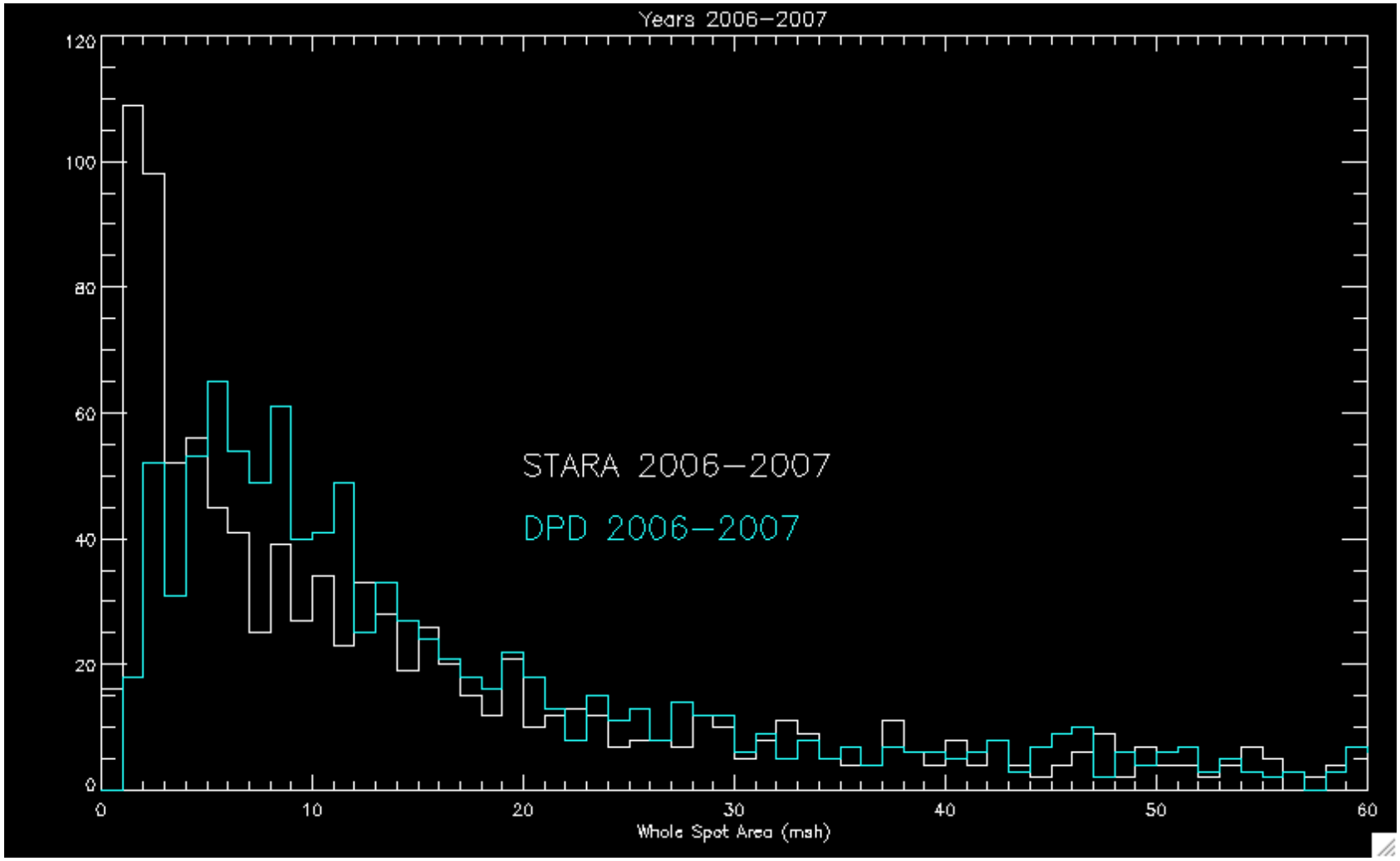
zoom



Time(DPD)-Time(STARA):2006-2007



Comparisons of distribution of matched spots.



Millionth of solar hemisphere ?

- 1 msh = sqrt(5)"x sqrt(5)"=2.23607"x2.23607"

Solar area conversion			
Msh	Square km	Square degrees (°)	Arcsec (")
1	2-3 million		2.5x2.5
10	30 million	0.2	9x9
48.5		1	
100	300 million	2.1	
250	761 million	5.2	
600	1826 million	12.4	
1200	3653 million	24.7	

- 2" → 1300km → limit between 1 and 2msh (depending on the sunspot shape, disk, irregular shape etc…)