SUNSPOTS BEHAVIOR IN THE LAST SOLAR CYCLES

4th Sunspot Workshop, Locarno, Switzerland

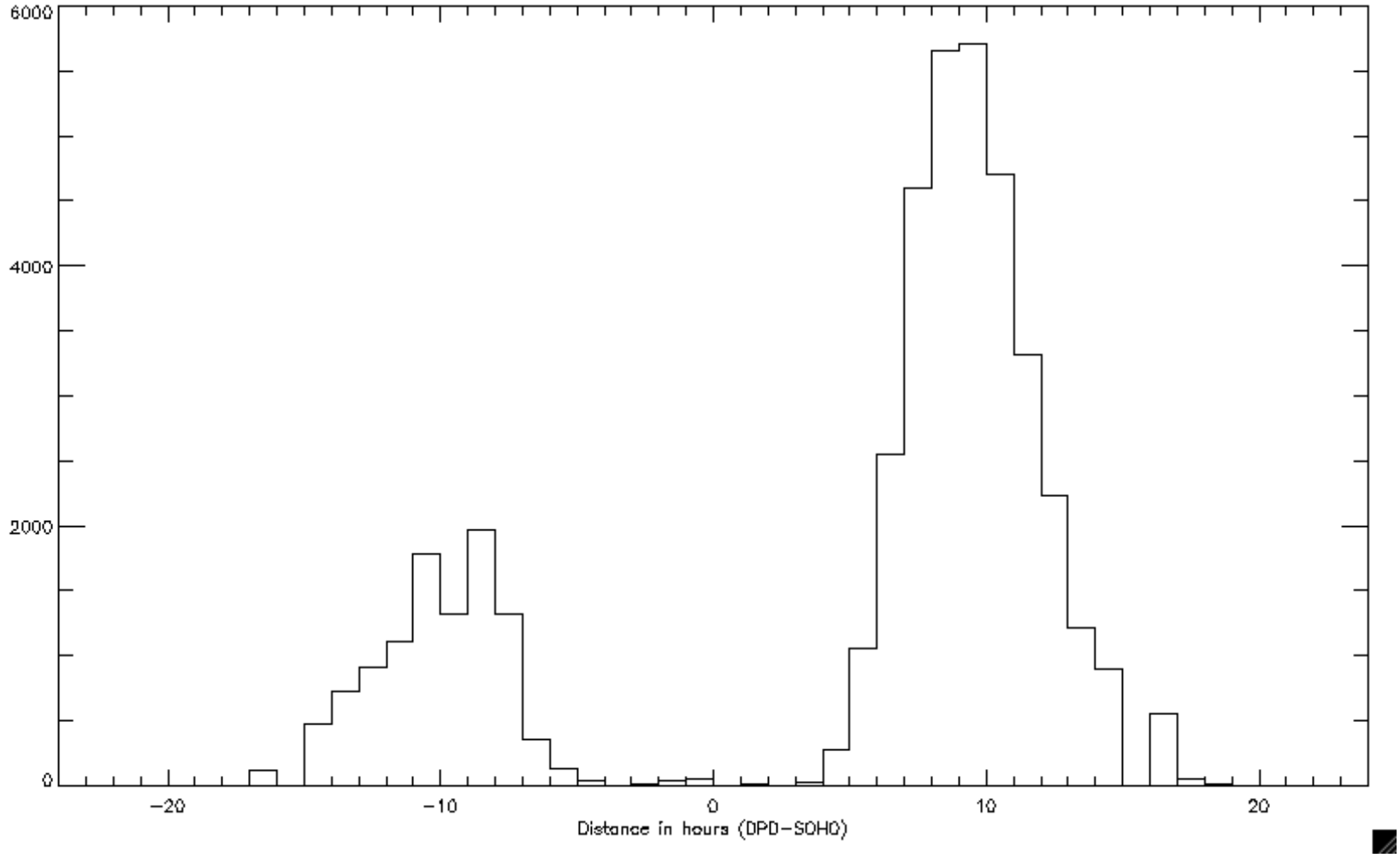
May 19-23 2014

Laure Lefèvre
Royal Observatory of Belgium
May 19th 2014

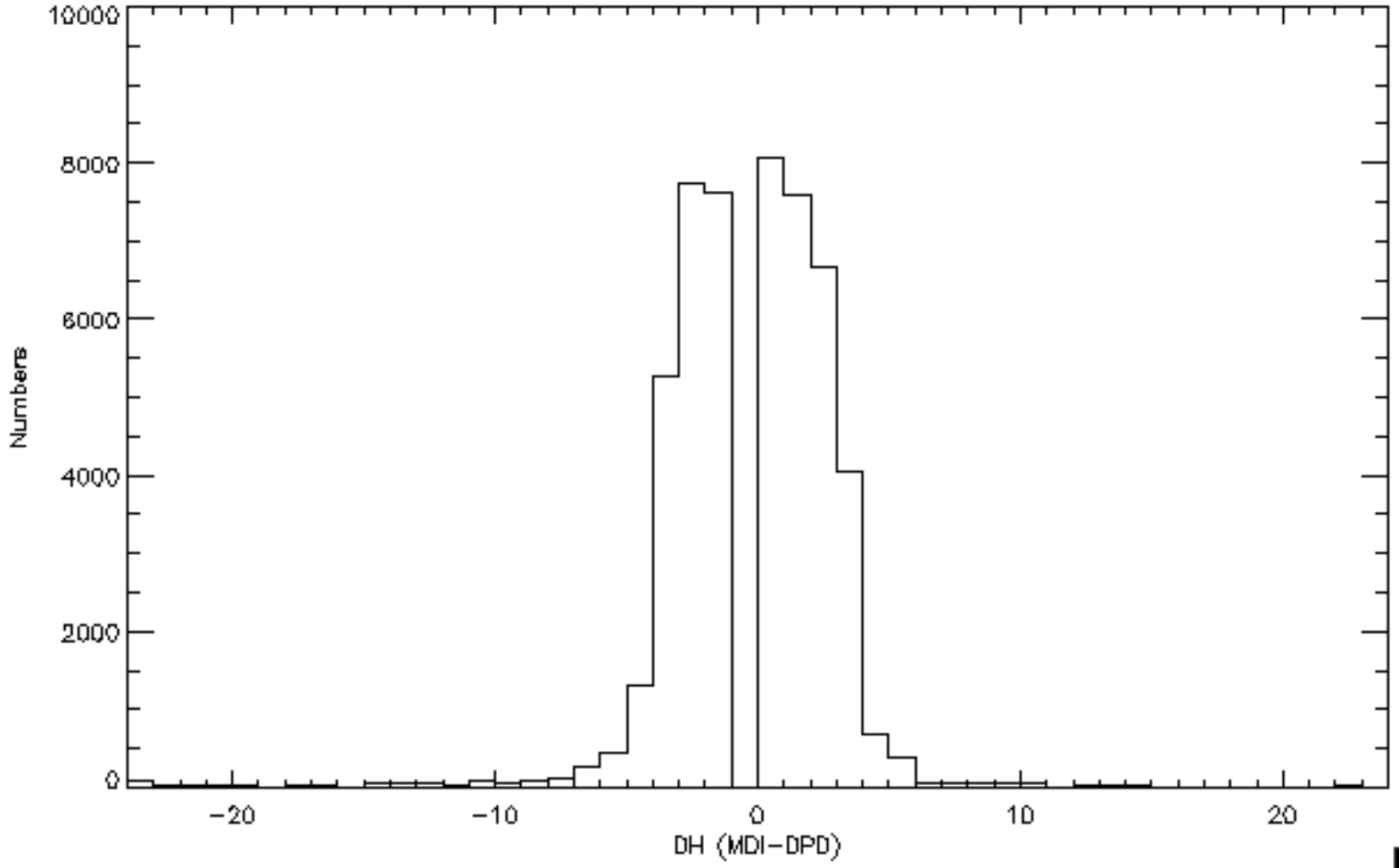
FOLLOW-UP

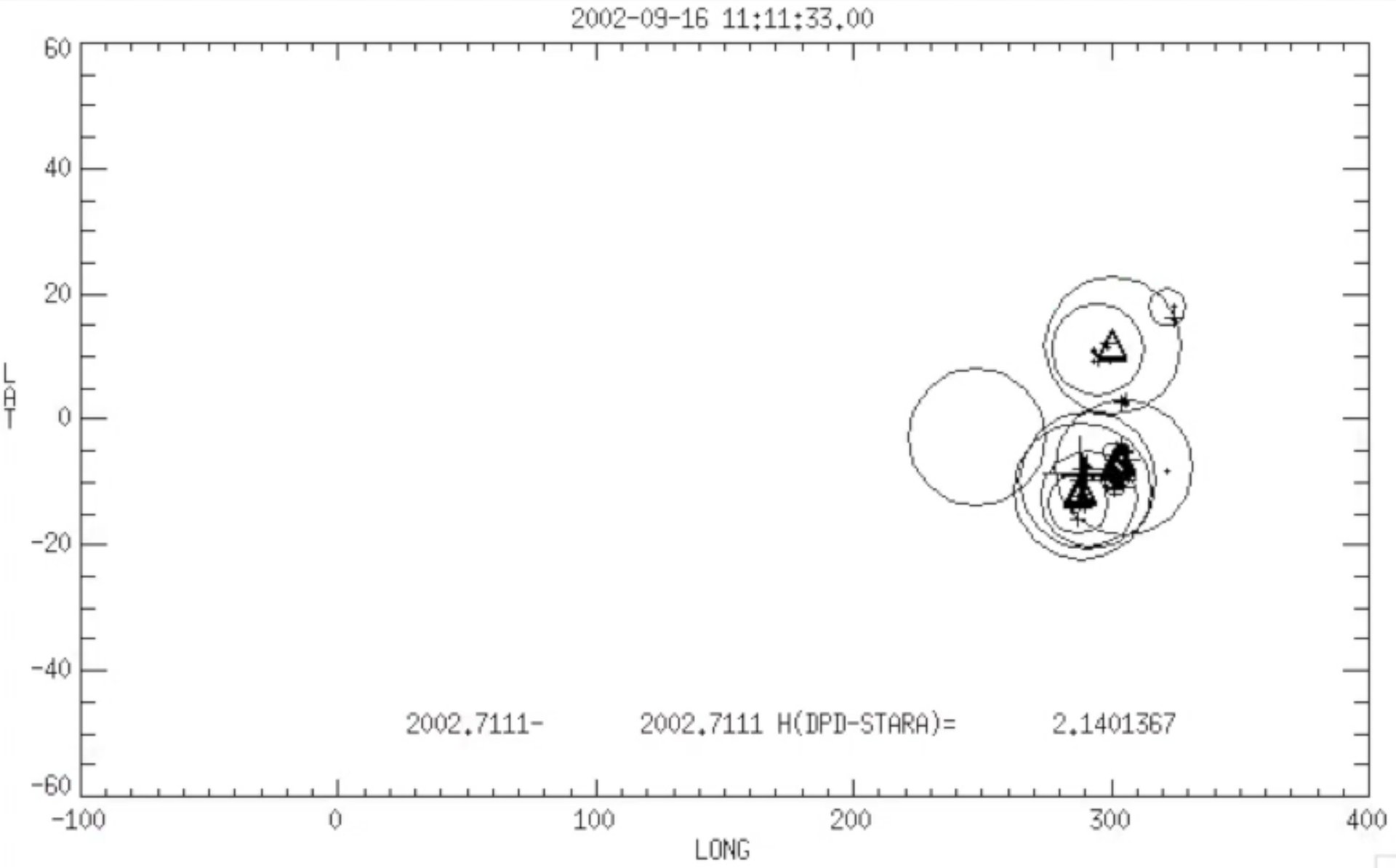
Comparison DPD versus STARA

Previous version

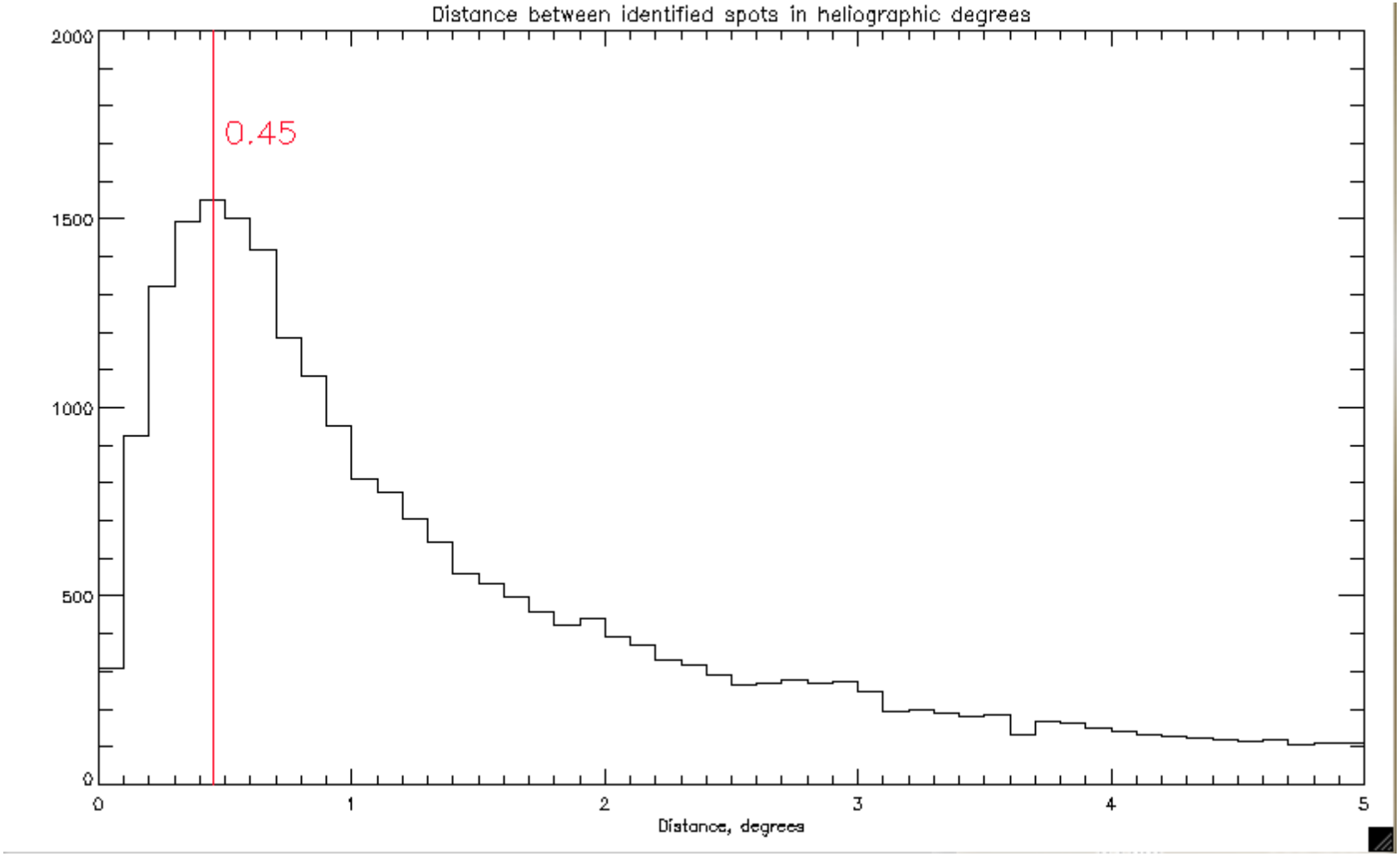


New version full cadence

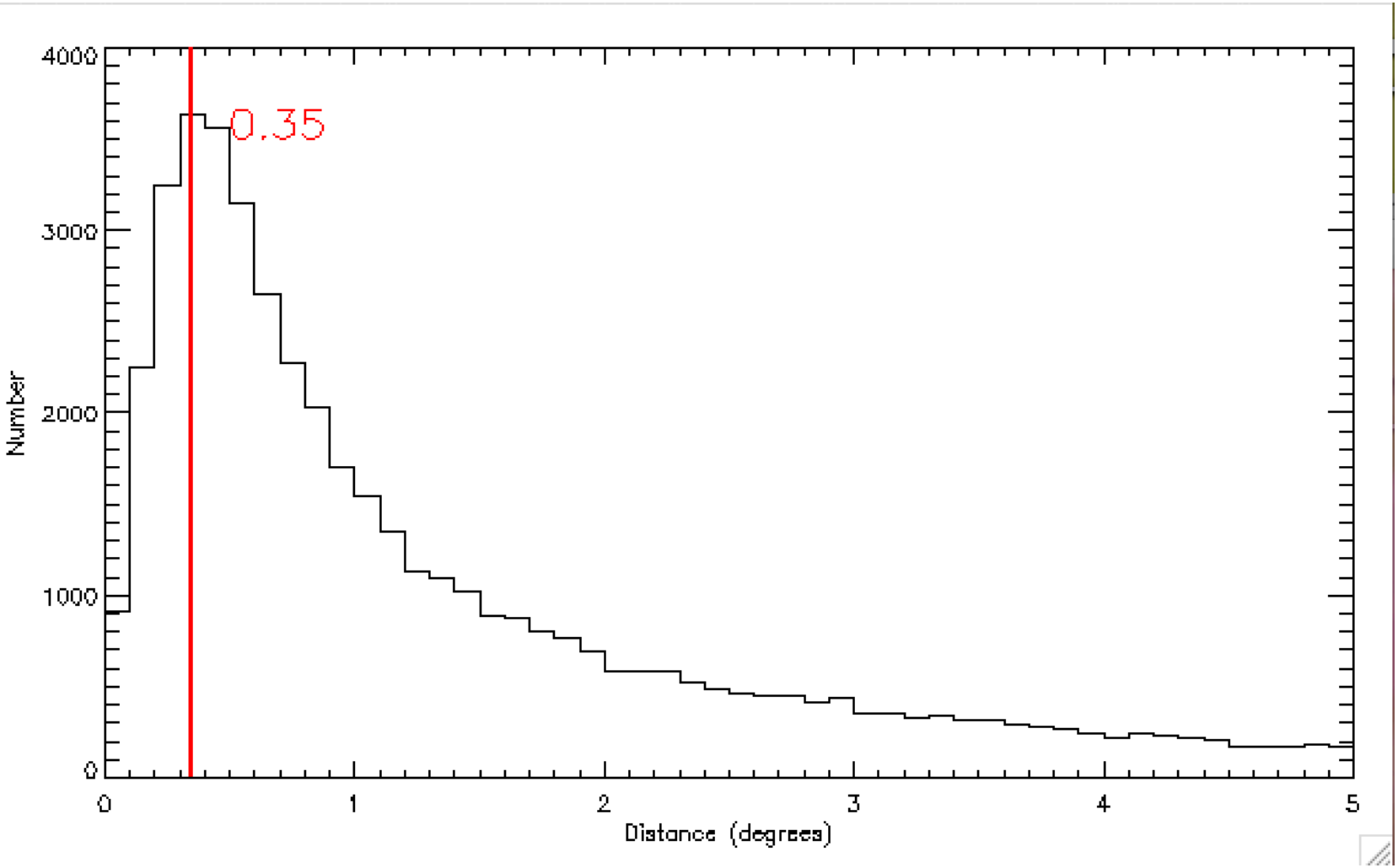


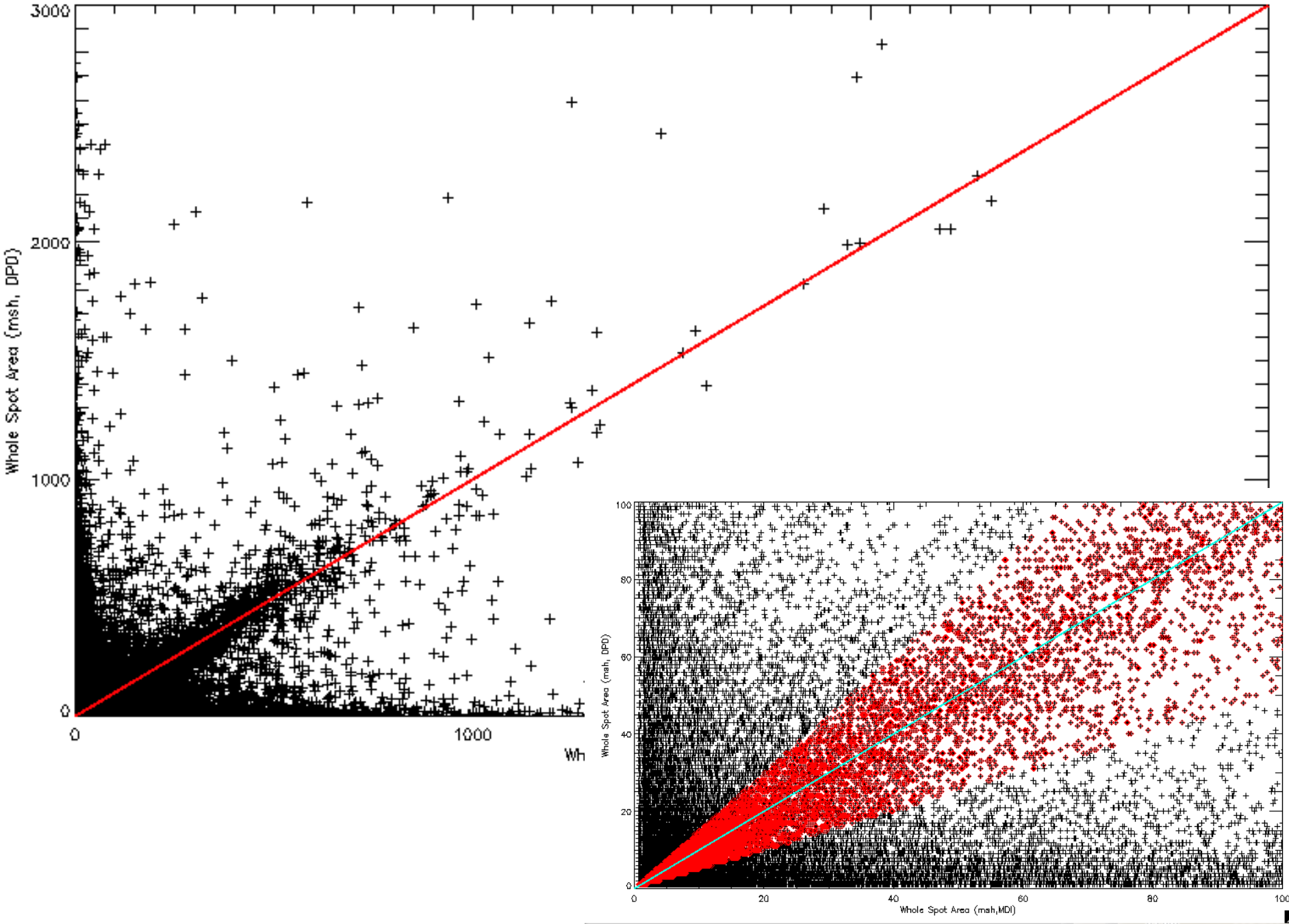

2002-09-16 11:11:33.00
60
40
20
0
-20
-40
-60
LAT
-100
0
100
200
300
400
LONG
2002.7111-
2002.7111 H(DPD-STARA)=
2.1401367

Distance between identified spots (before)

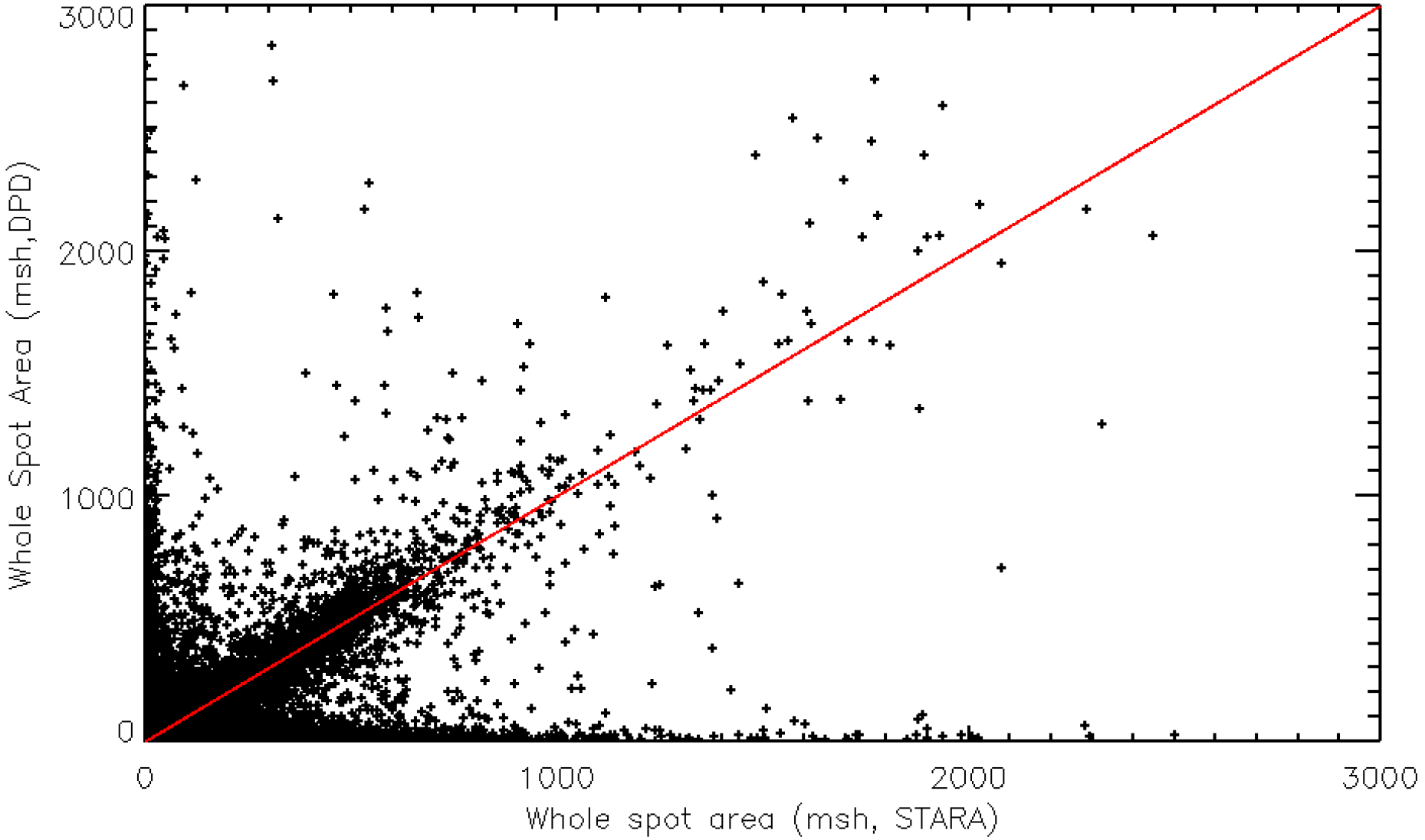


Distance between identified spots (now)

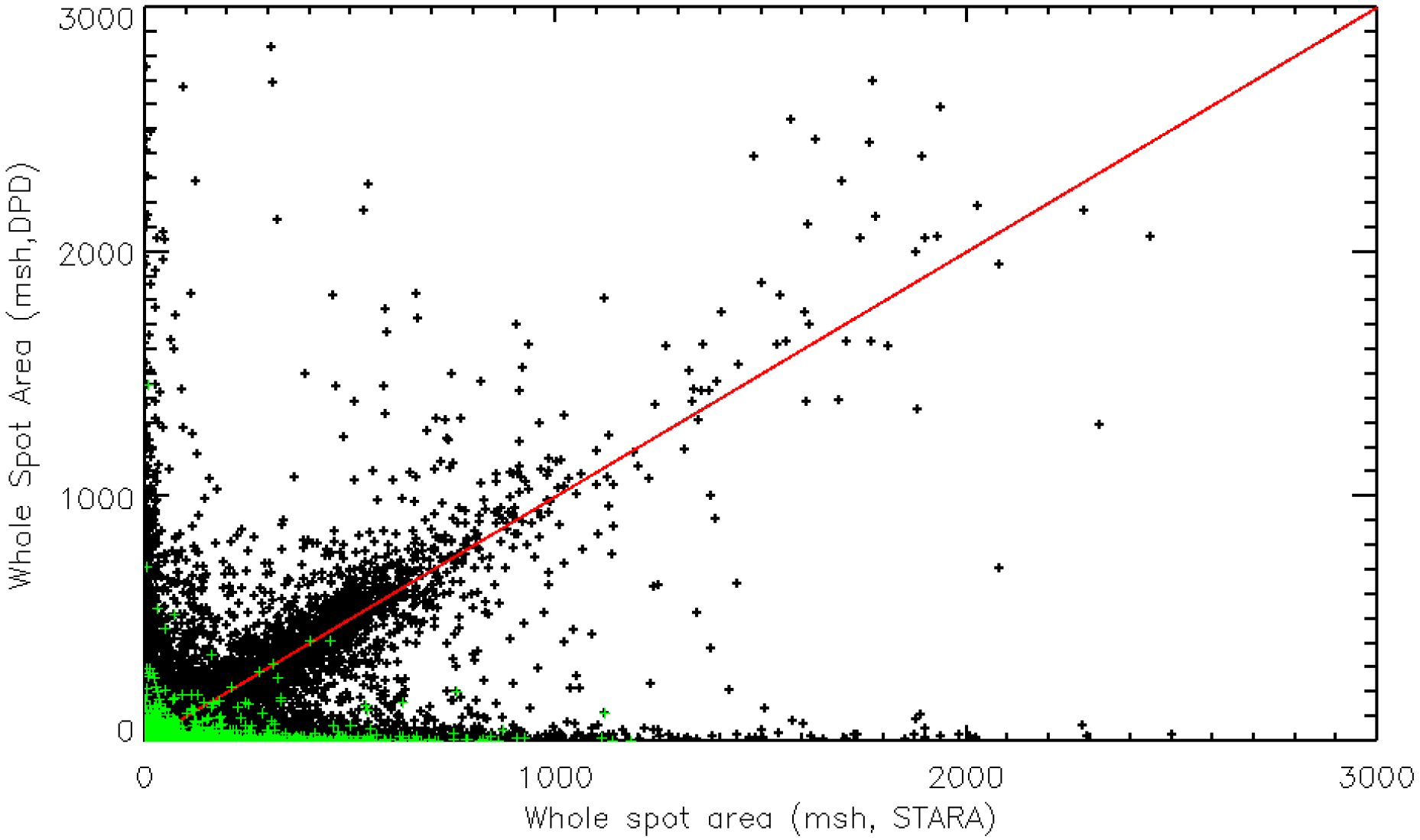



3000
2000
1000
0
Whole Spot Area (msh, DPD)
0
1000
Wh
100
80
60
40
20
0
Whole Spot Area (msh, DPD)
0
20
40
60
80
100
Whole Spot Area (msh,MDI)

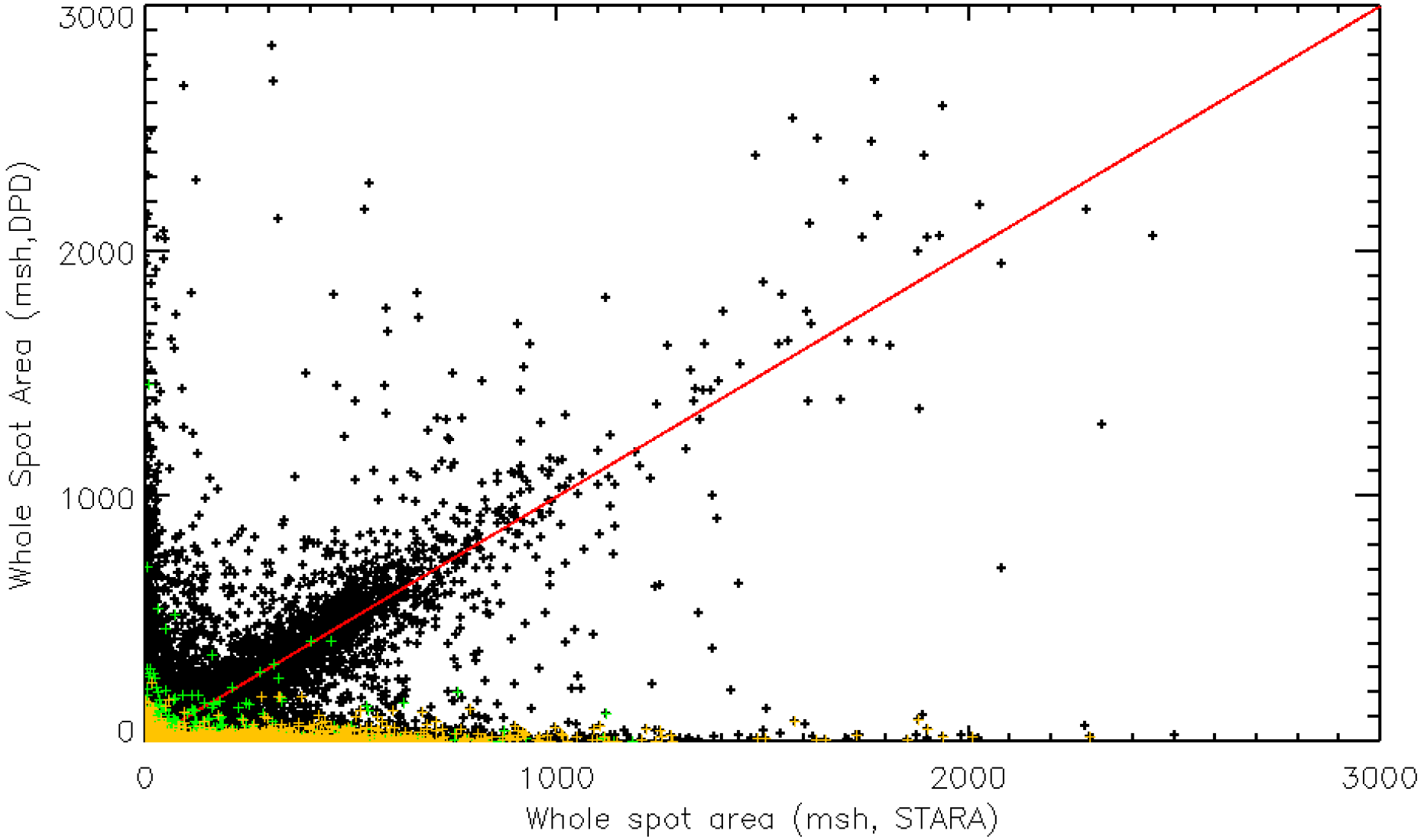
Now

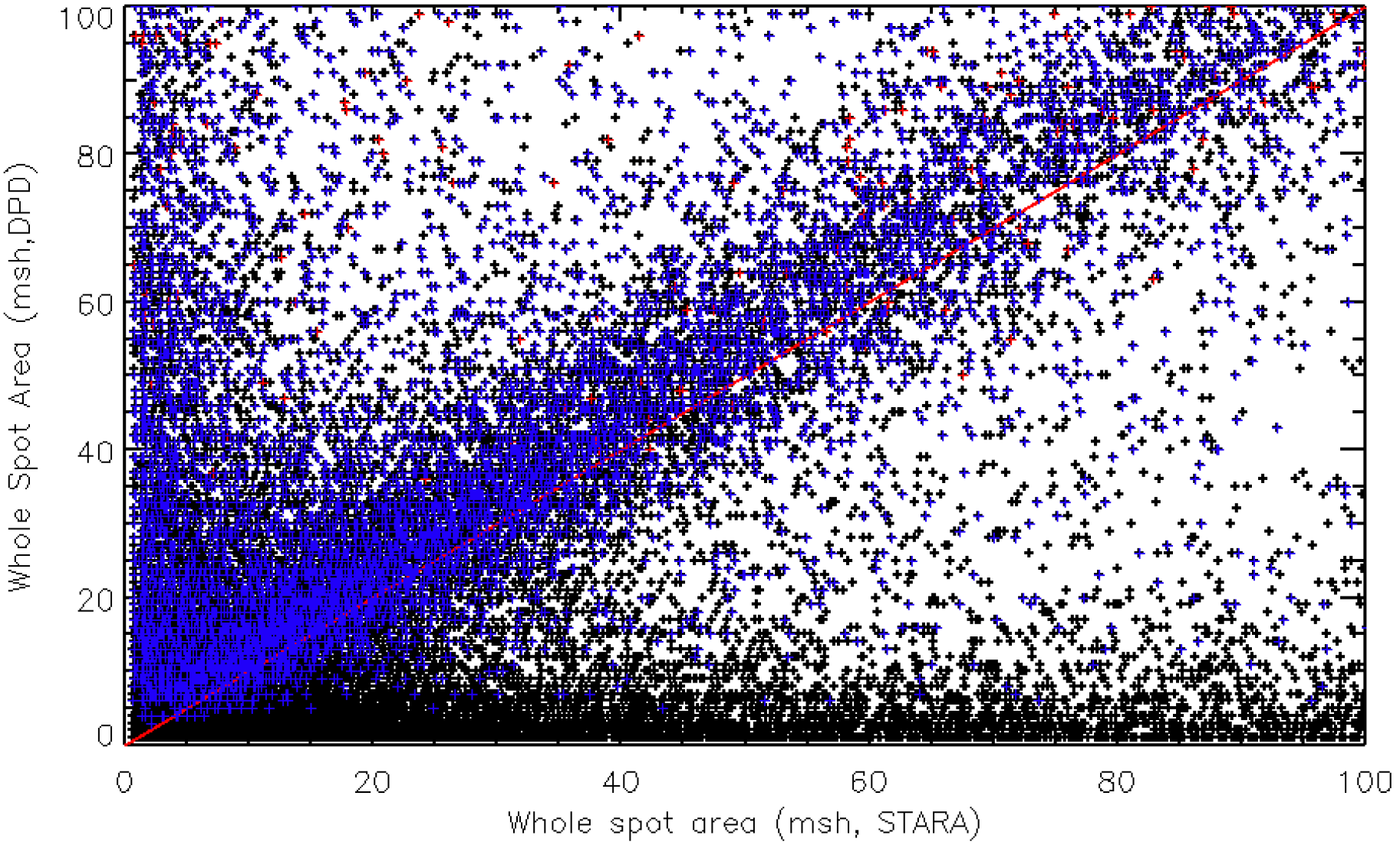

3000
2000
1000
0
Whole Spot Area (msh,DPD)
0
1000
2000
3000
Whole spot area (msh, STARA)

P only


3000
2000
1000
0
Whole Spot Area (msh,DPD)
0
1000
2000
3000
Whole spot area (msh, STARA)

Common pen (neg)




Whole Spot Area (msh,DPD)
Whole spot area (msh, STARA)
0
20
40
60
80
100

Summary

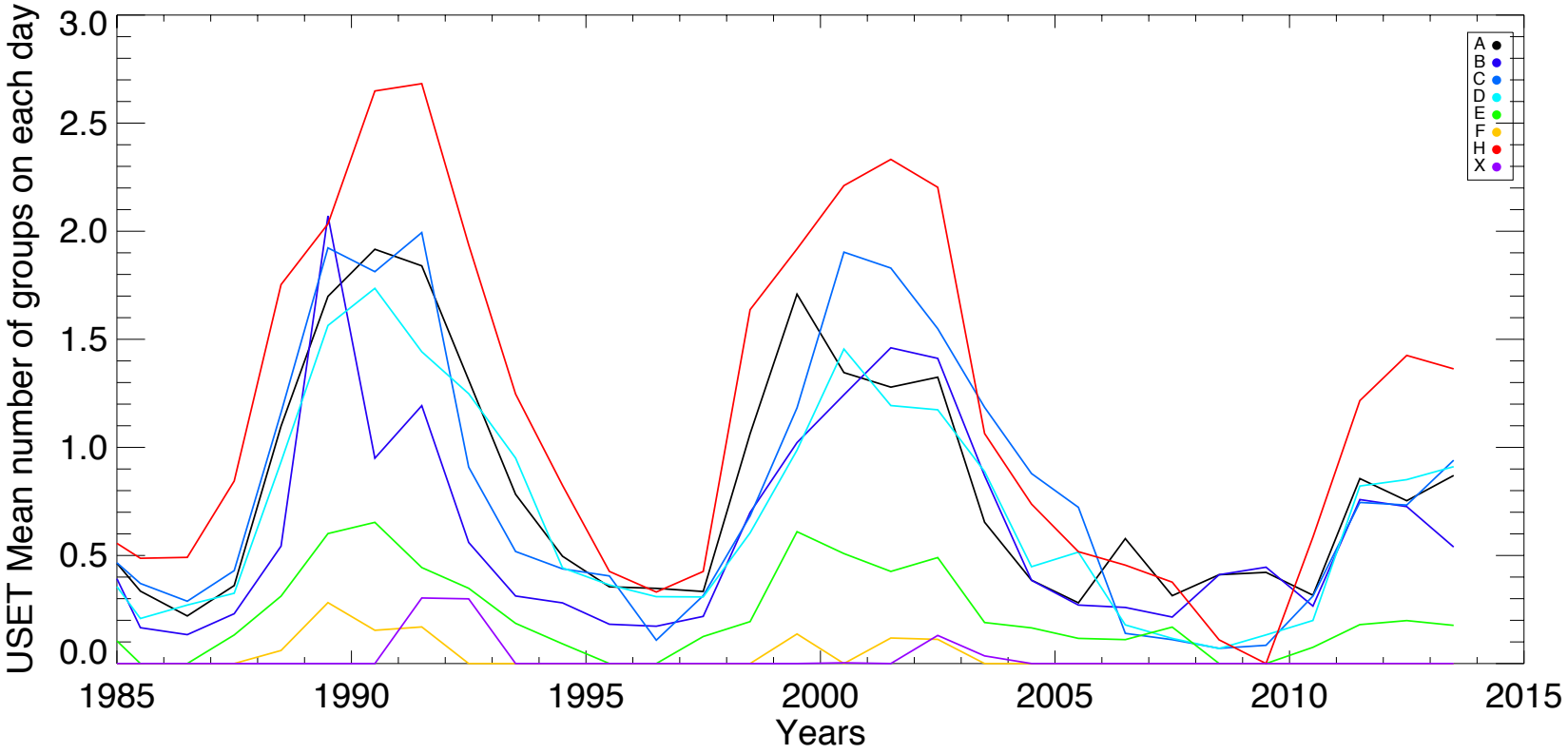
- 193000 lines = 57500 spots
- 93 % are identified with spots from DPD
- 7% unidentified (too far from spot in DPD)

- 10% penumbrae w/o umbrae (smaller)
- 20% common penumbrae (U+P negative replaced by U so too small)
- 26% common penumbrae (positive total too large)
- The rest (37%) DPD sizes OK (ratio is one)
- Very good correspondance in size
- Positions very close

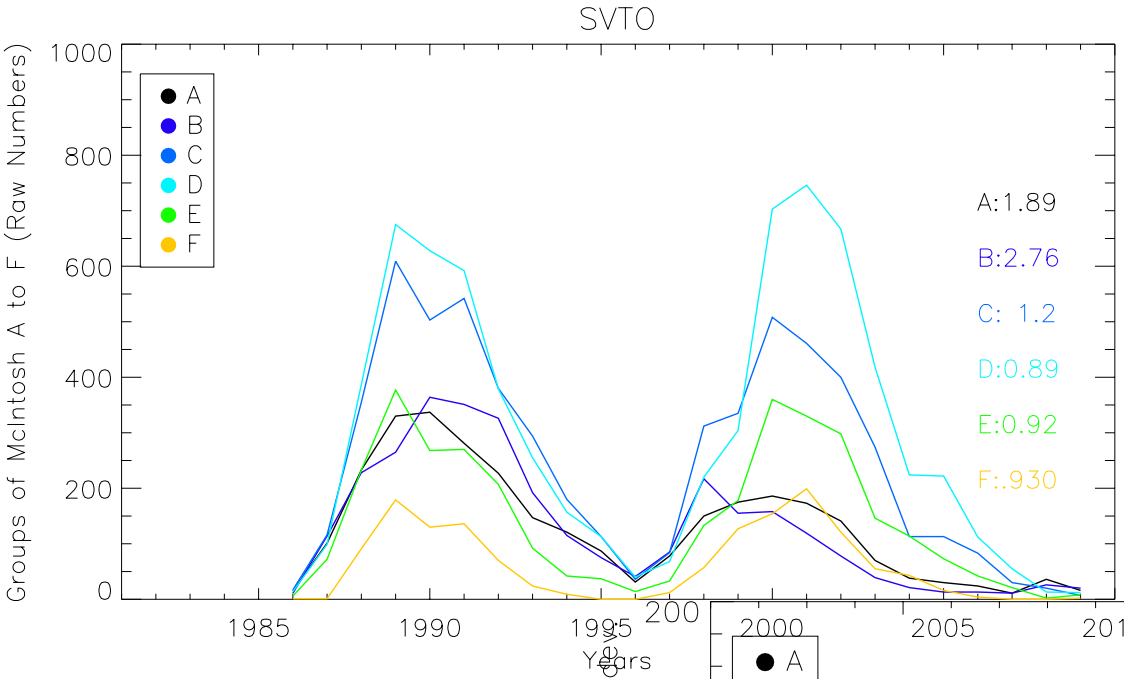
CATALOGS USAF/USET/DPD

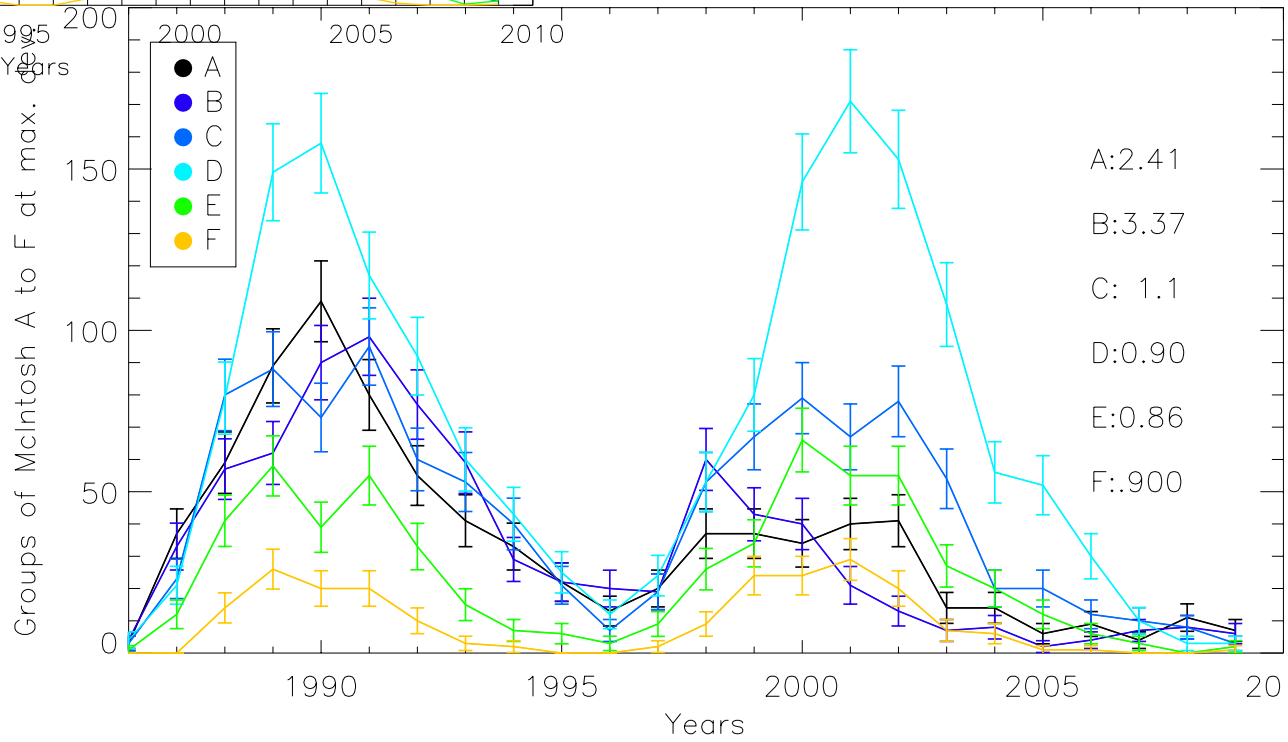
Nb groups of different types : A, B, C, D, E, F

USET

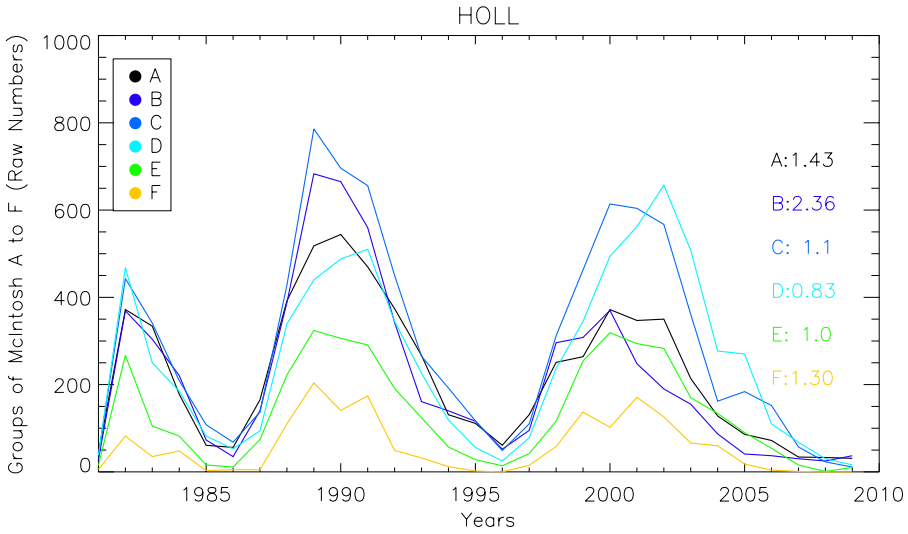

USET Mean number of groups on each day
3.0
2.5
2.0
1.5
1.0
0.5
0.0
1985
1990
1995
2000
2005
2010
2015
Years
A
B
C
D
E
F
H
X

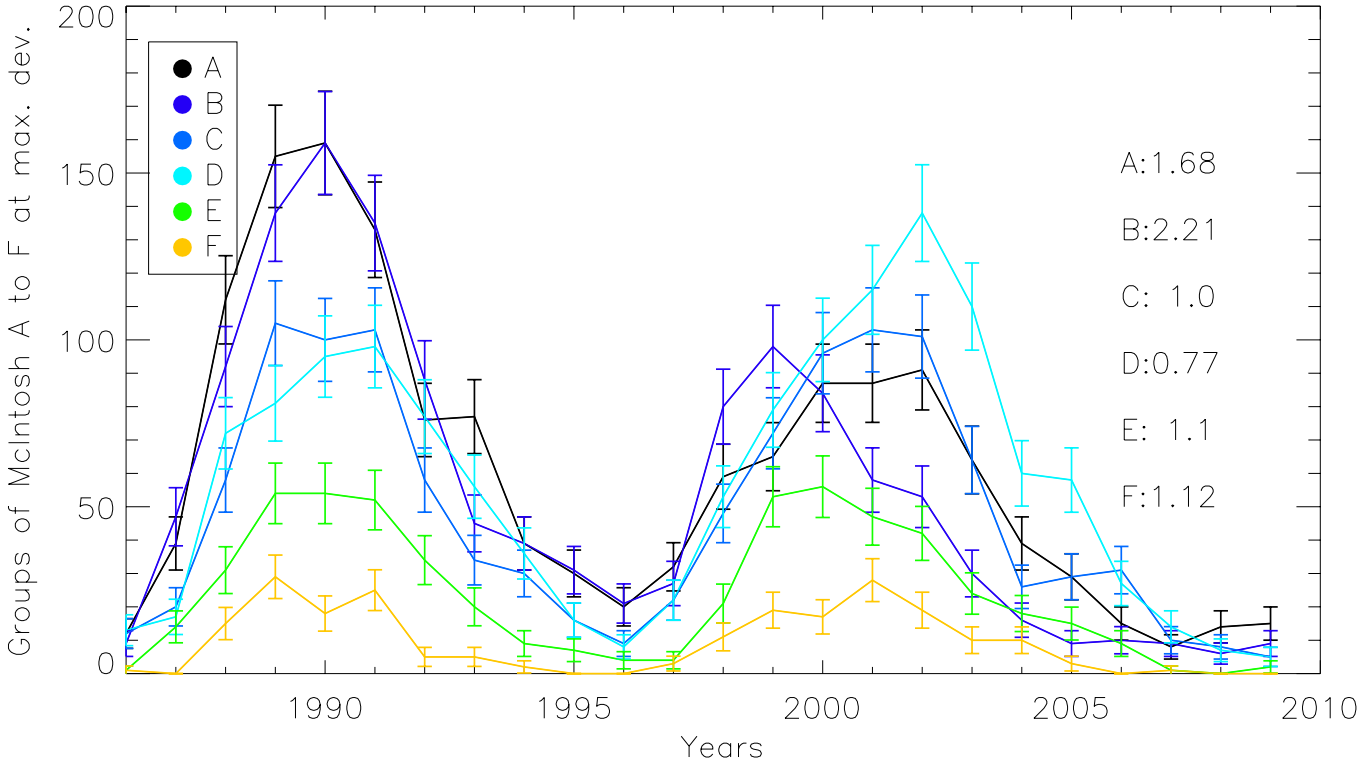
San Vito


SVTO
Groups of McIntosh A to F (Raw Numbers)
Years
A
B
C
D
E
F
A:1.89
B:2.76
C: 1.2
D:0.89
E:0.92
F:.930

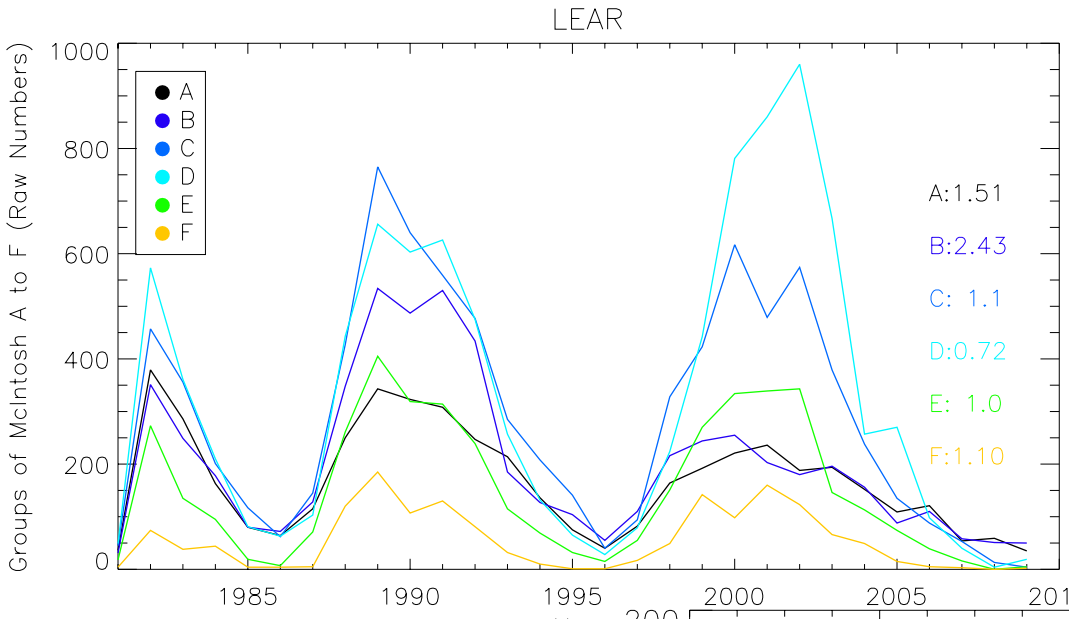

Groups of McIntosh A to F at max. cycle
Years
A
B
C
D
E
F
A:2.41
B:3.37
C: 1.1
D:0.90
E:0.86
F:.900

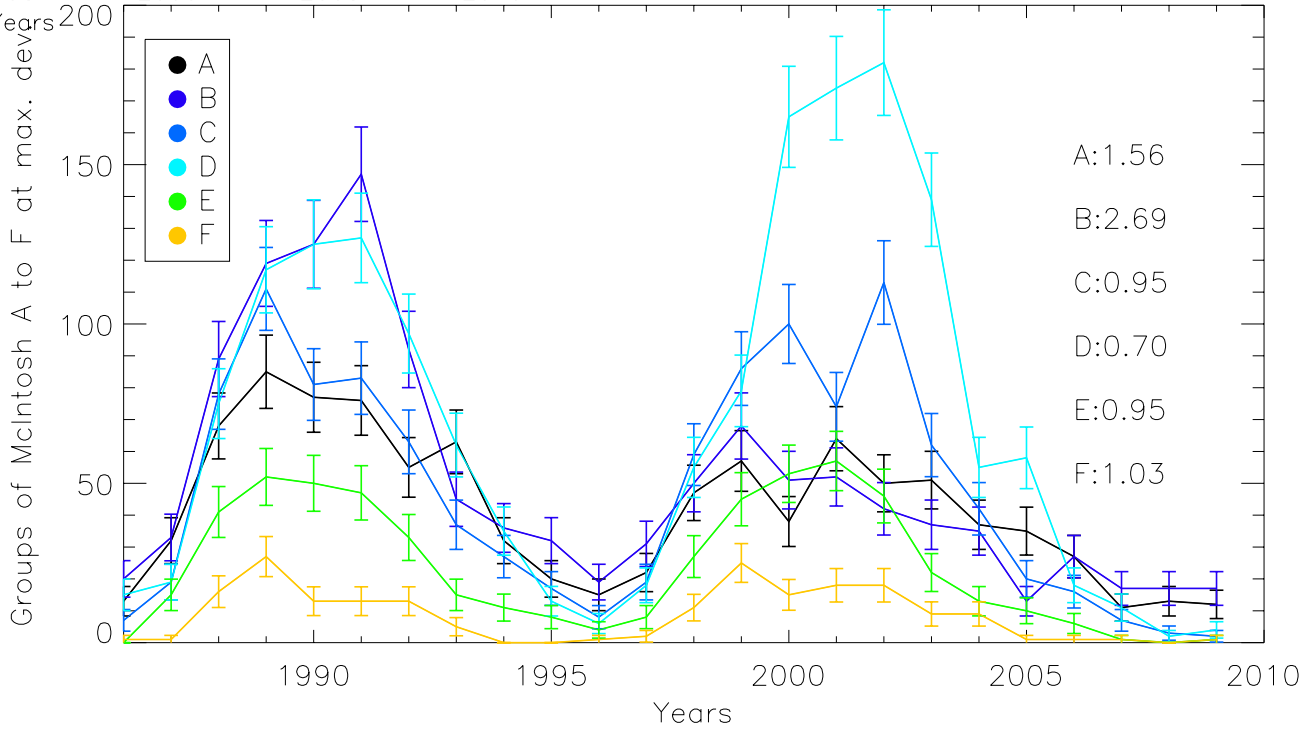
Holloman


HOLL
Groups of McIntosh A to F (Raw Numbers)
Years
A
B
C
D
E
F
A:1.43
B:2.36
C: 1.1
D:0.83
E: 1.0
F:1.30


Groups of McIntosh A to F at max. dev.
Years
A
B
C
D
E
F
A:1.68
B:2.21
C: 1.0
D:0.77
E: 1.1
F:1.12

Learmonth


LEAR
Groups of McIntosh A to F (Raw Numbers)
1000
800
600
400
200
0
1985
1990
1995
2000
2005
2010
Years
A
B
C
D
E
F
A:1.51
B:2.43
C: 1.1
D:0.72
E: 1.0
F:1.10

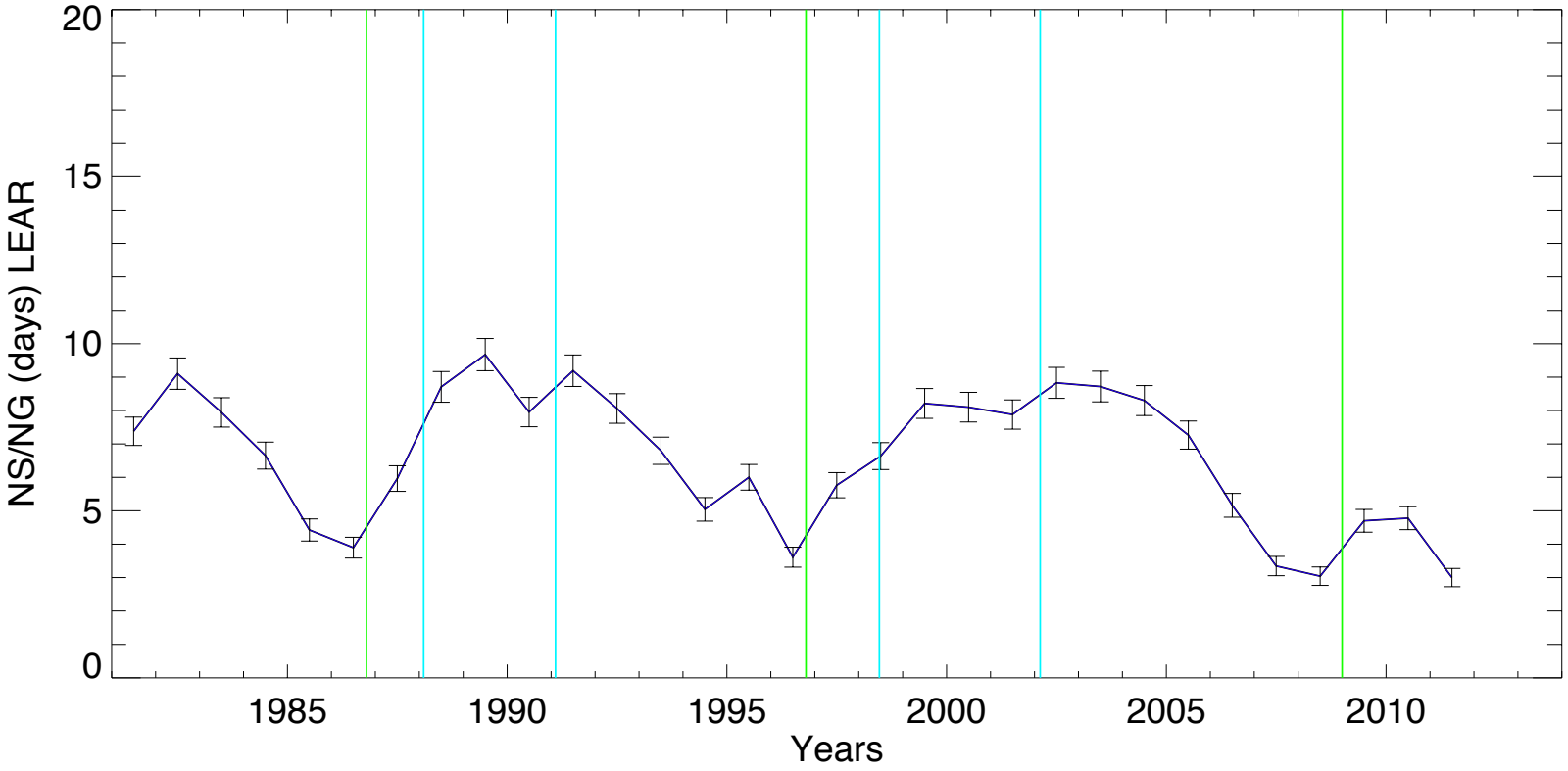

Groups of McIntosh A to F at max. dev
200
150
100
50
0
1990
1995
2000
2005
2010
Years
A
B
C
D
E
F
A:1.56
B:2.69
C:0.95
D:0.70
E:0.95
F:1.03

CATALOGS USAF/USET/DPD

Nb of spots per groups

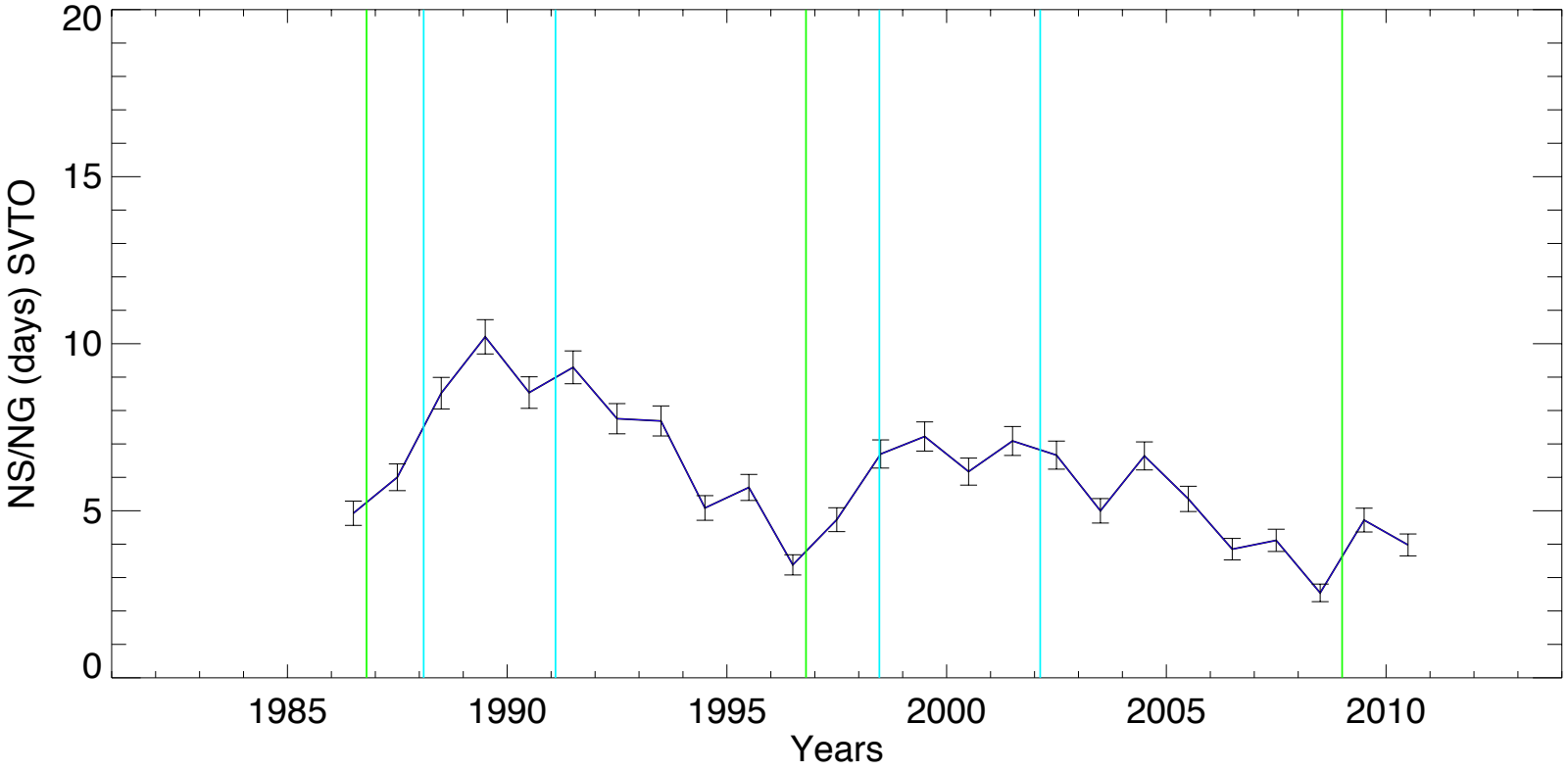
USAF LEARMONTH

STDEV	7.8203793	7.9354684	5.7057248	MAX	9.3103955	8.1290135
CLIP	6.1197761	5.9775006	2.5000000		7.8180739	7.4747422



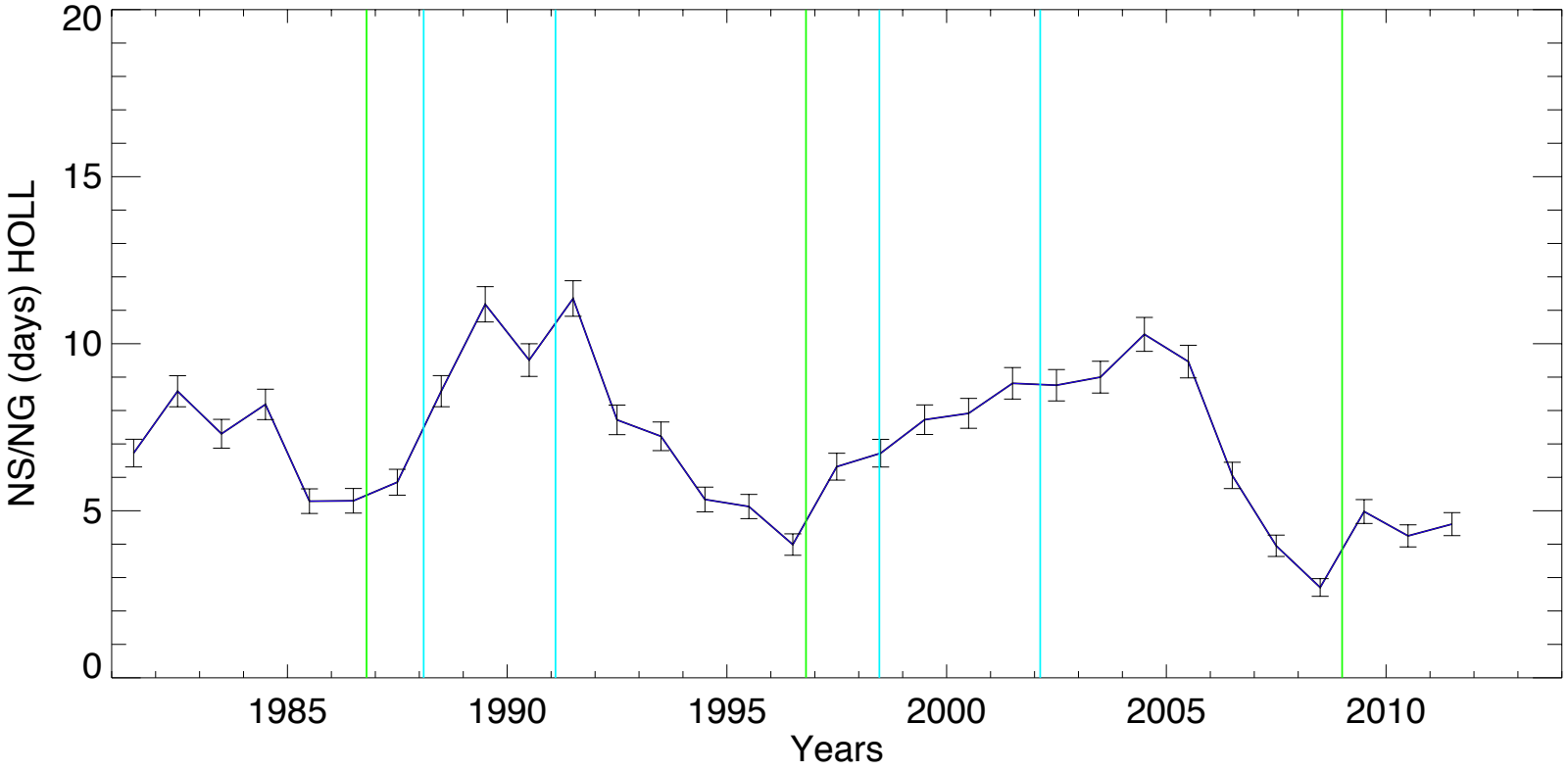
USAF SAN VITO

SVTO: 8.1072908 6.2592864 4.6994742 9.5182665 6.9381099
6.3547352 4.5189064 3.0000000 7.9954508 5.7706471



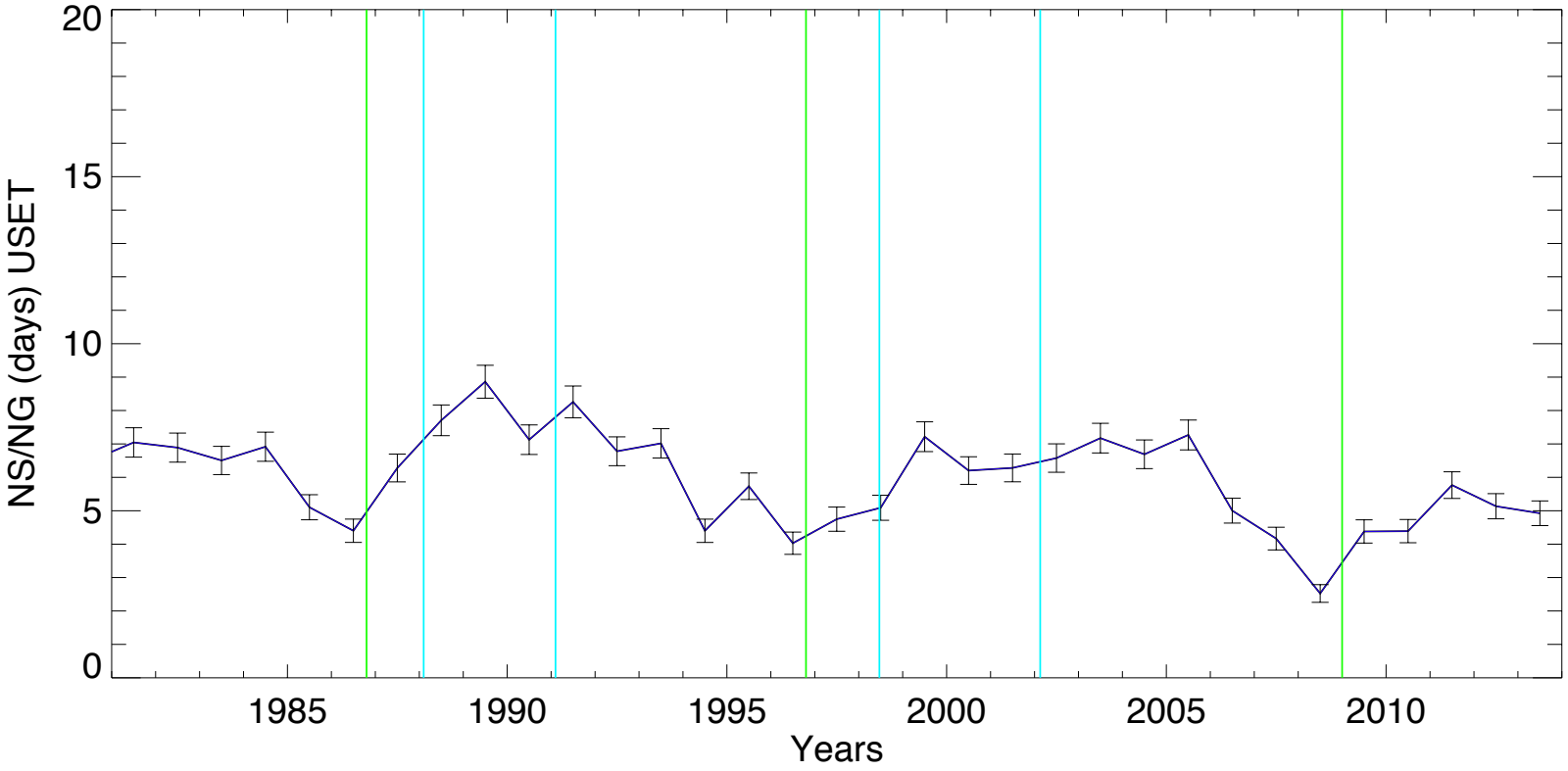
USAF HOLLOMAN

HOLL: 8.3852080 8.3393818 5.2428704 10.342604 8.2936754
5.9953721 6.2288690 2.5000000 8.7059216 7.0134415



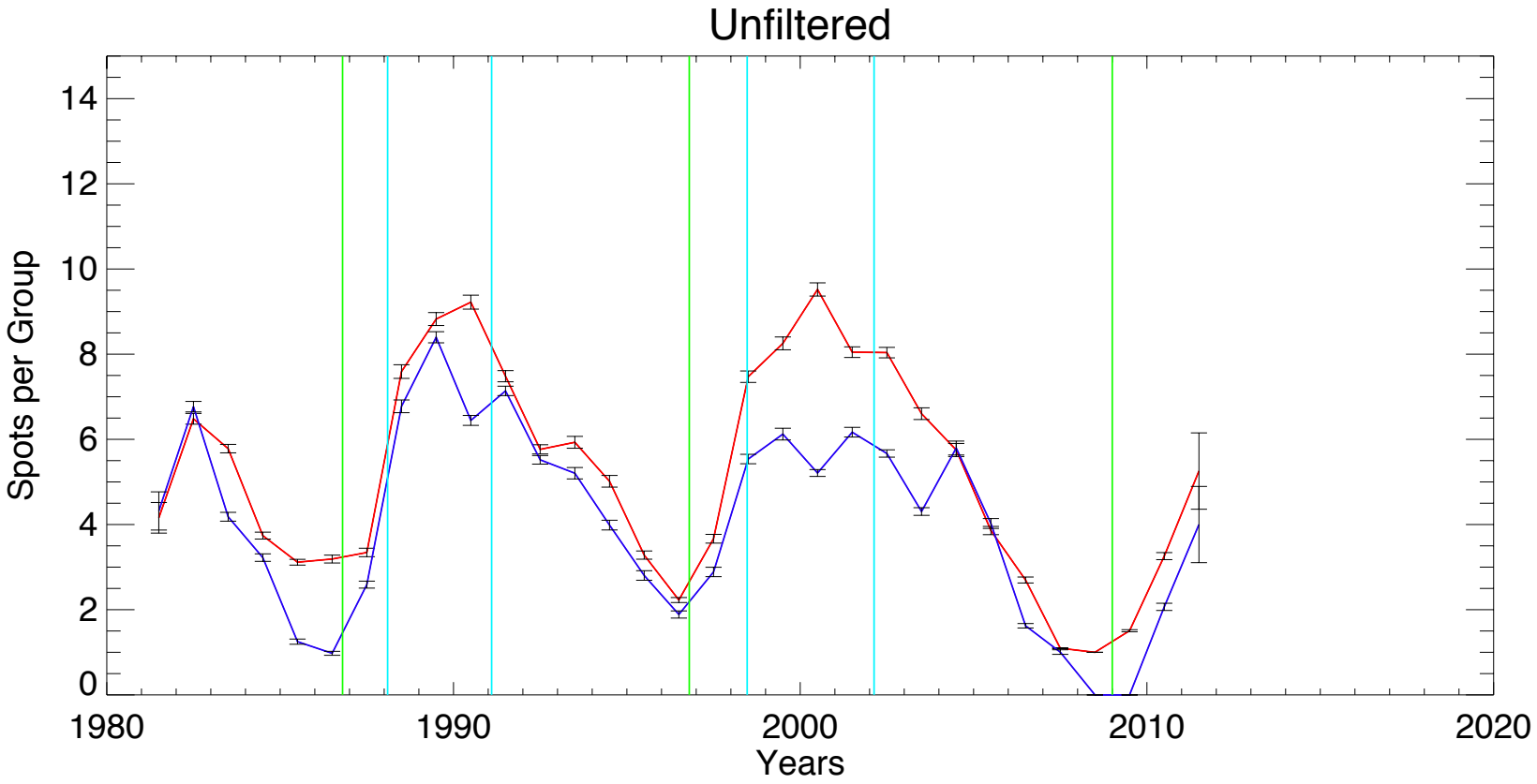
USET

USET: 7.3027289 6.8181175 5.3984990 8.5272130 6.5298482
5.6278894 4.9890458 3.9932116 6.8754729 5.4102948



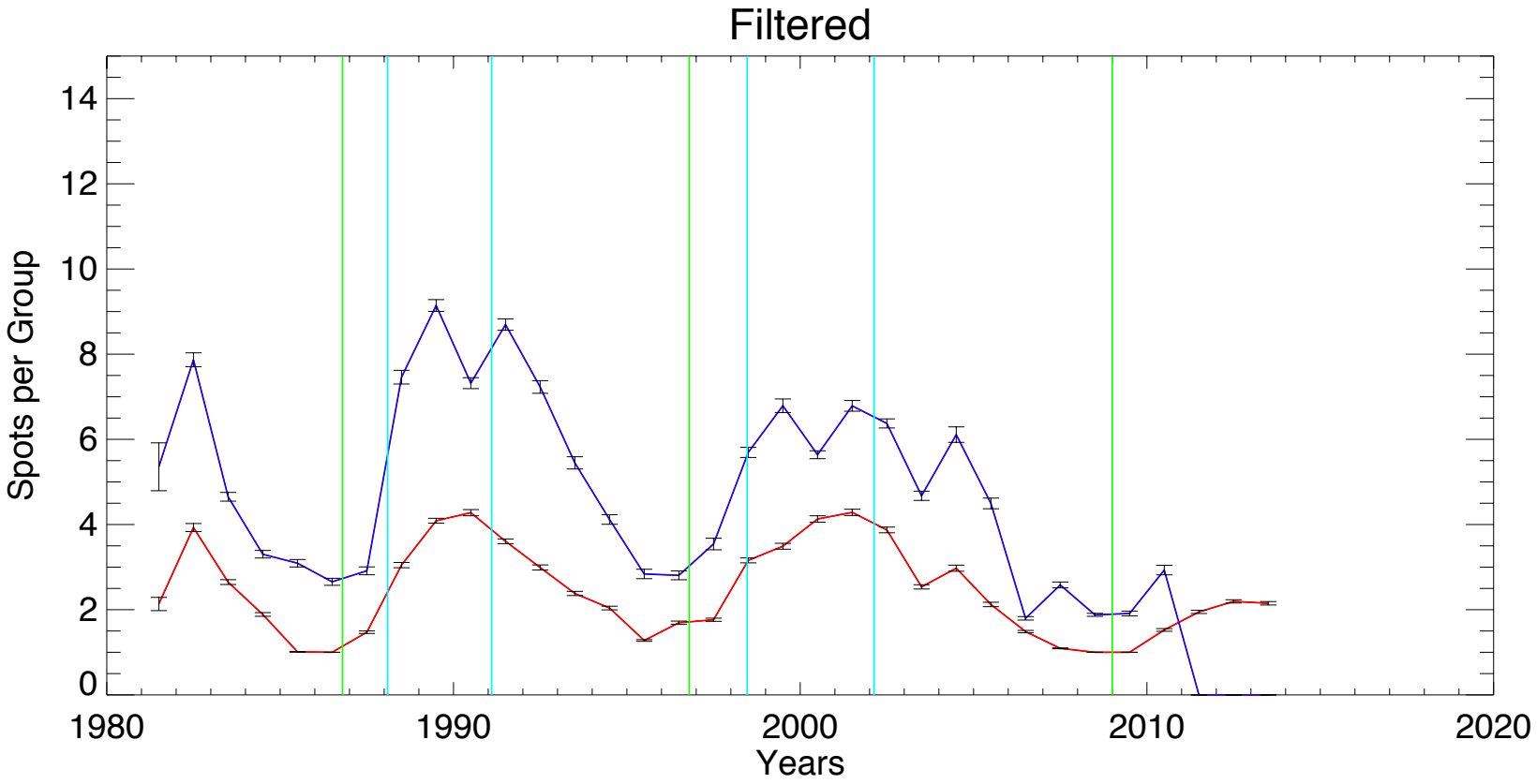
Debrecen

8.2202171	7.4594333	3.9771974	9.9372822	9.6911536
6.0054787	5.5021330	2.0000000	8.6400612	8.2963144



Debrecen

3.6859281	3.9009210	2.7235699	4.6002296	4.6411680
2.6630133	2.5067978	2.0000000	4.0063995	3.8814771



BEYOND THE ISSN

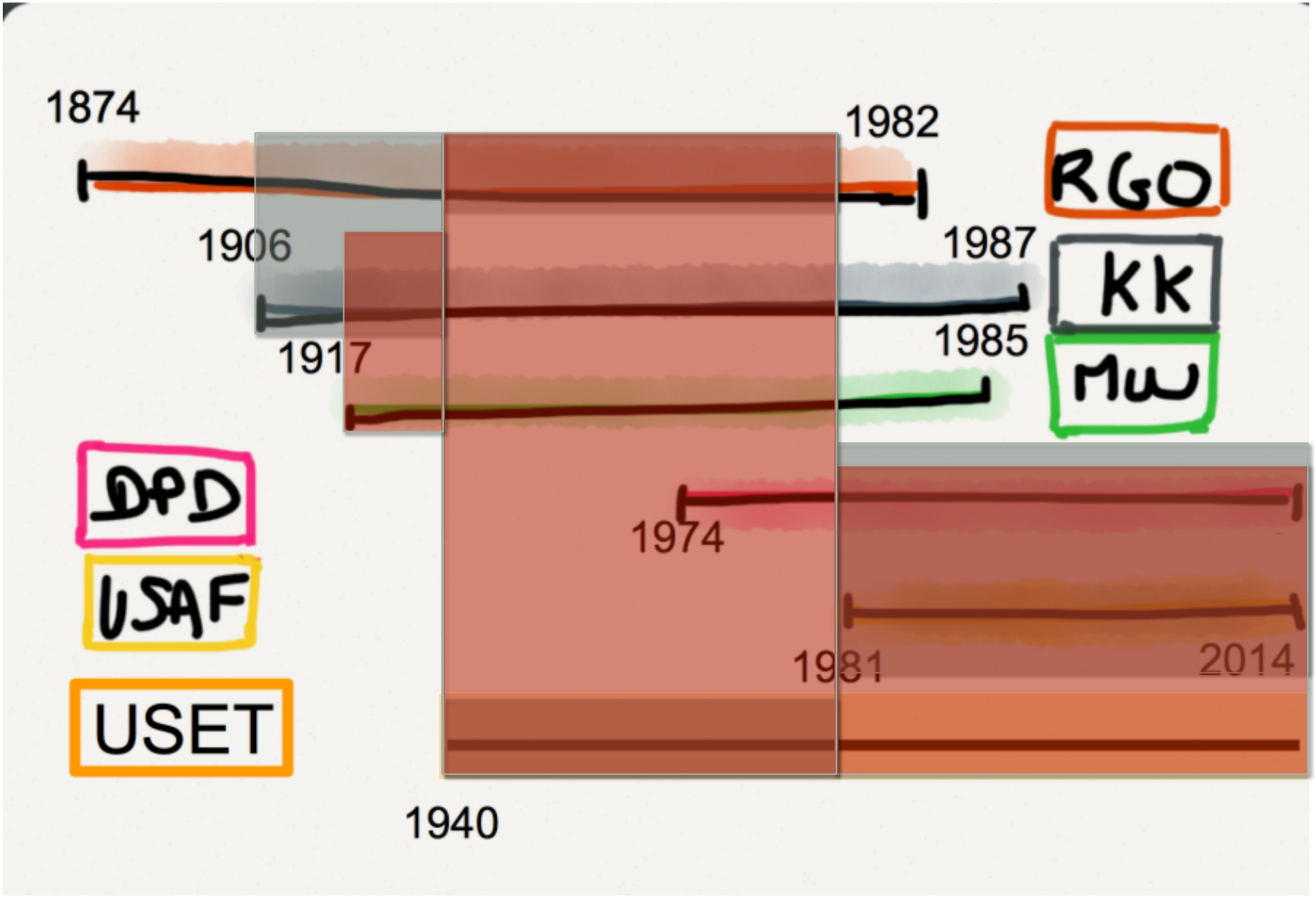
Sunspot catalogs reconstruction

Accessing detailed parameters

- Over more than a 100 years
- How do we do that ?

Different Sunspot catalogs

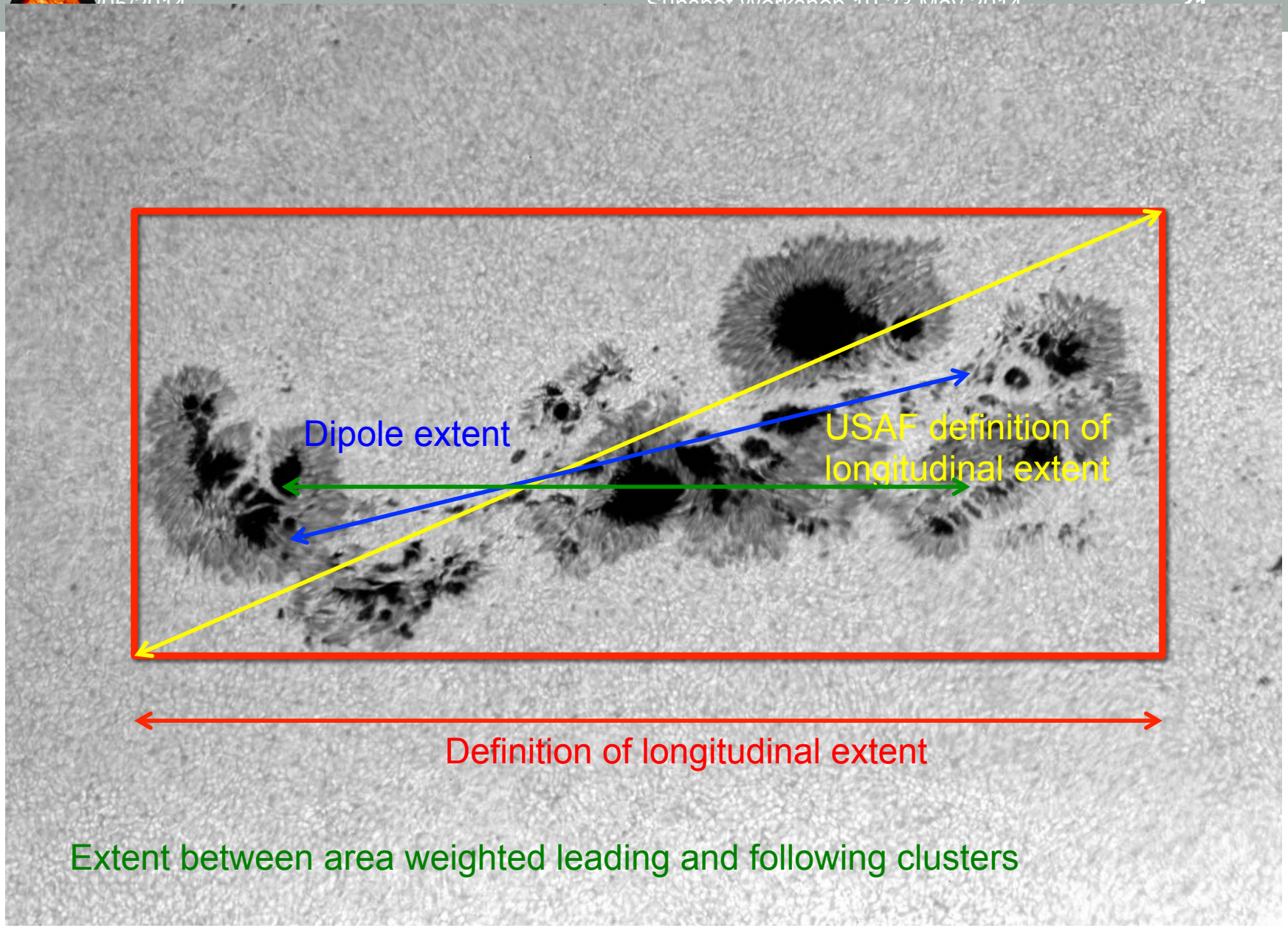
- Debrecen (groups and spots)
- USAF (groups)
- USET (groups)
- KK/MW (catalog of single sunspots + catalog of groups)
- RGO (groups)


1874
1982
RGO
1906
1987
KK
1917
1985
MW
DPD
1974
USAF
1981
2014
USET
1940

Parameters	DPD (1981-2014)	USAF (1981-2014)	USET (1940-2014)
Position	YES	YES	YES
Extent	POSSIBLE (all types of extent)	YES	POSSIBLE (extent dipole)
Size	YES	YES	NO
Nb of Spots	POSSIBLE	YES	YES
morphology	NO	YES	YES

Parameters	RGO (1874-1981)	KK/MW spots & Groups (1906-1982)	USET (1940-2014)
Group Position	YES	YES	YES
Group Extent	NO	POSSIBLE (spots)	Dipole extent
Group Size	YES	YES (spots)	NO
Nb of Spots	NO	YES (?)	YES
Morphology	NO/YES	NO	YES

- Of course there is some work to do
- Mainly because there are different standards
- One example



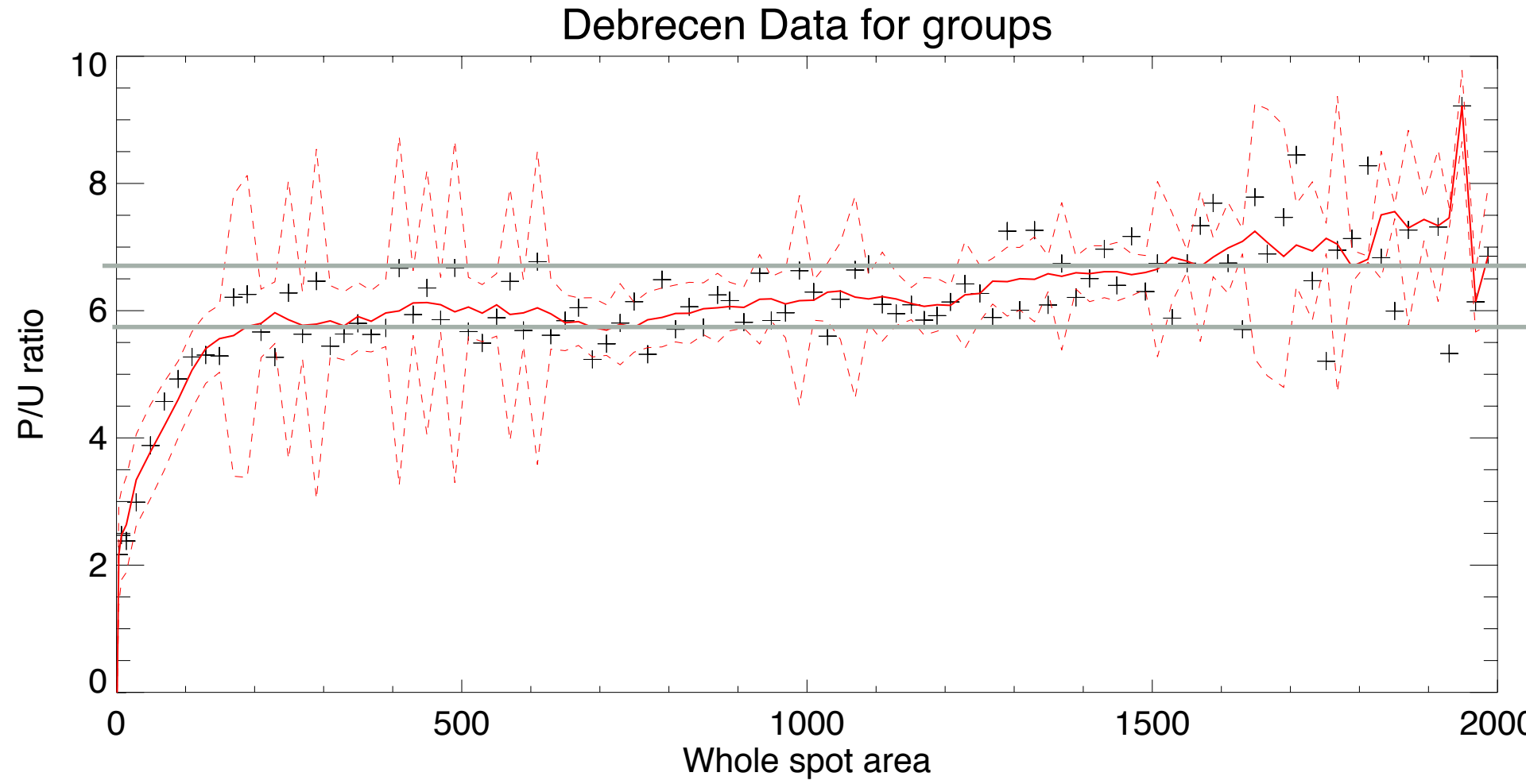
Extent between area weighted leading and following clusters

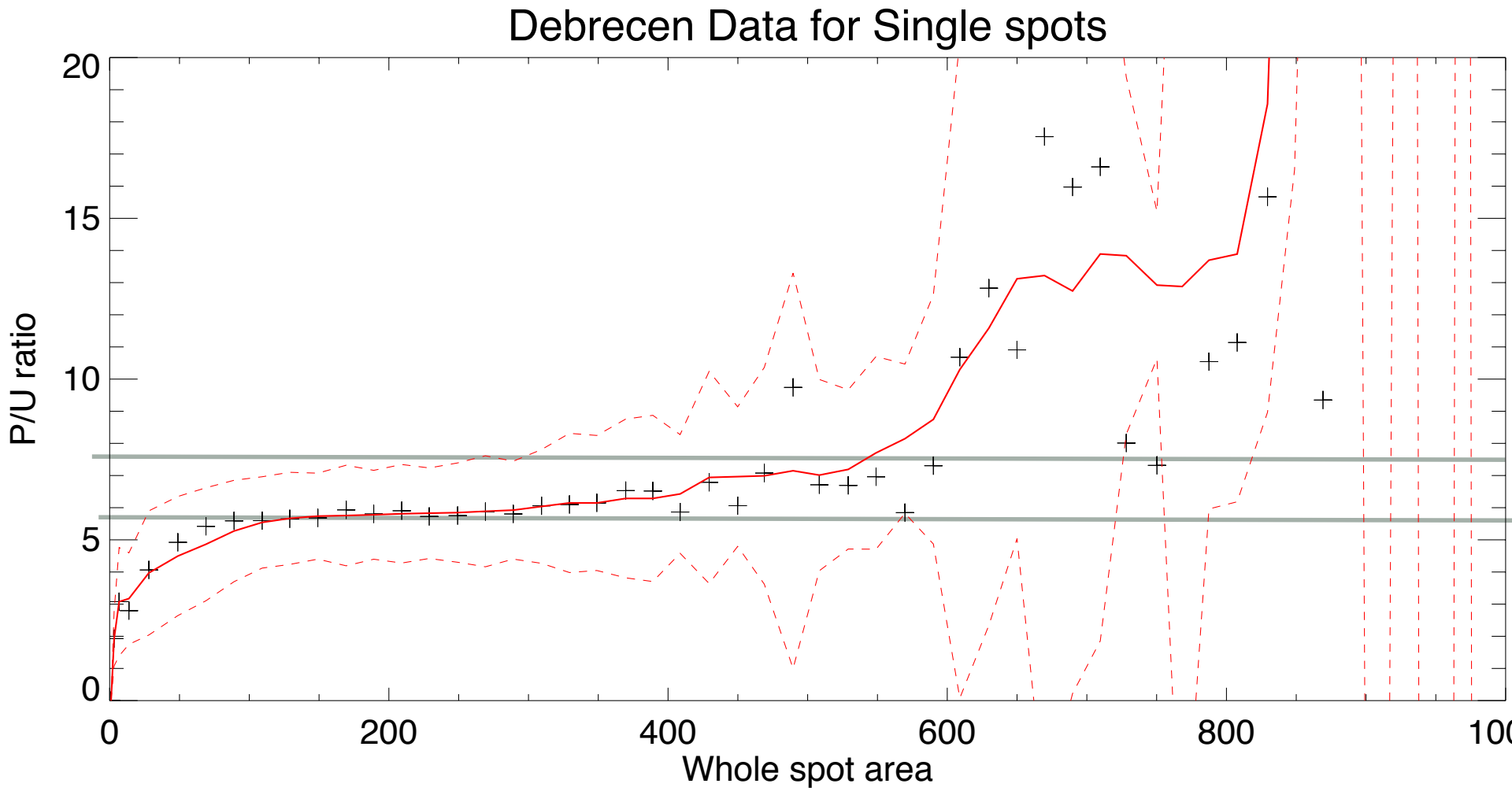
A Curious History of Sunspot Penumbrae

D. H. Hathaway[1]

PENUMBRA/UMBRA RELATIONSHIPS

Detailed Catalogs


Debrecen Data for groups
P/U ratio
Whole spot area
0
2
4
6
8
10
0
500
1000
1500
2000


Debrecen Data for Single spots
P/U ratio
Whole spot area
0
5
10
15
20
0
200
400
600
800
100

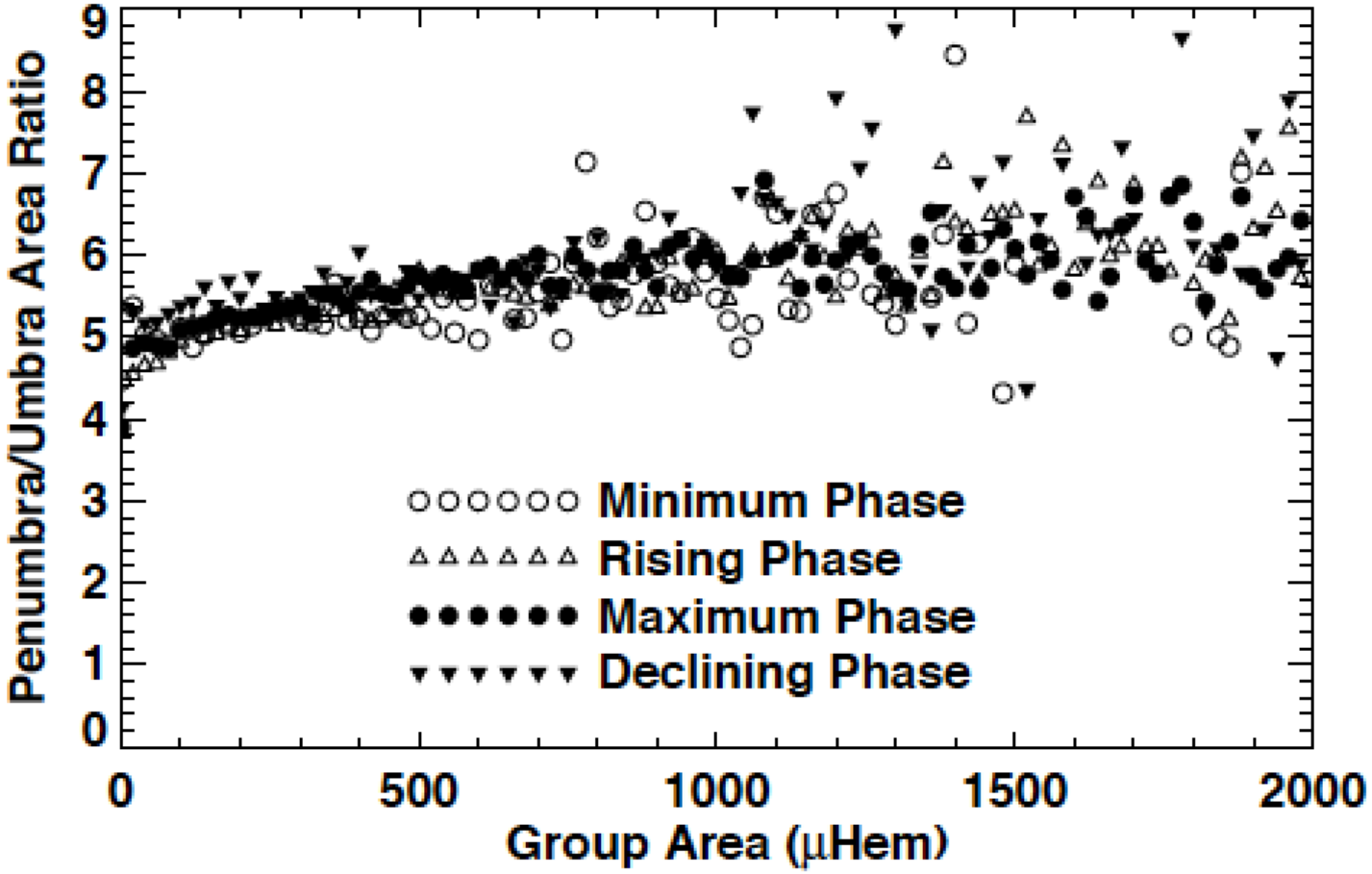
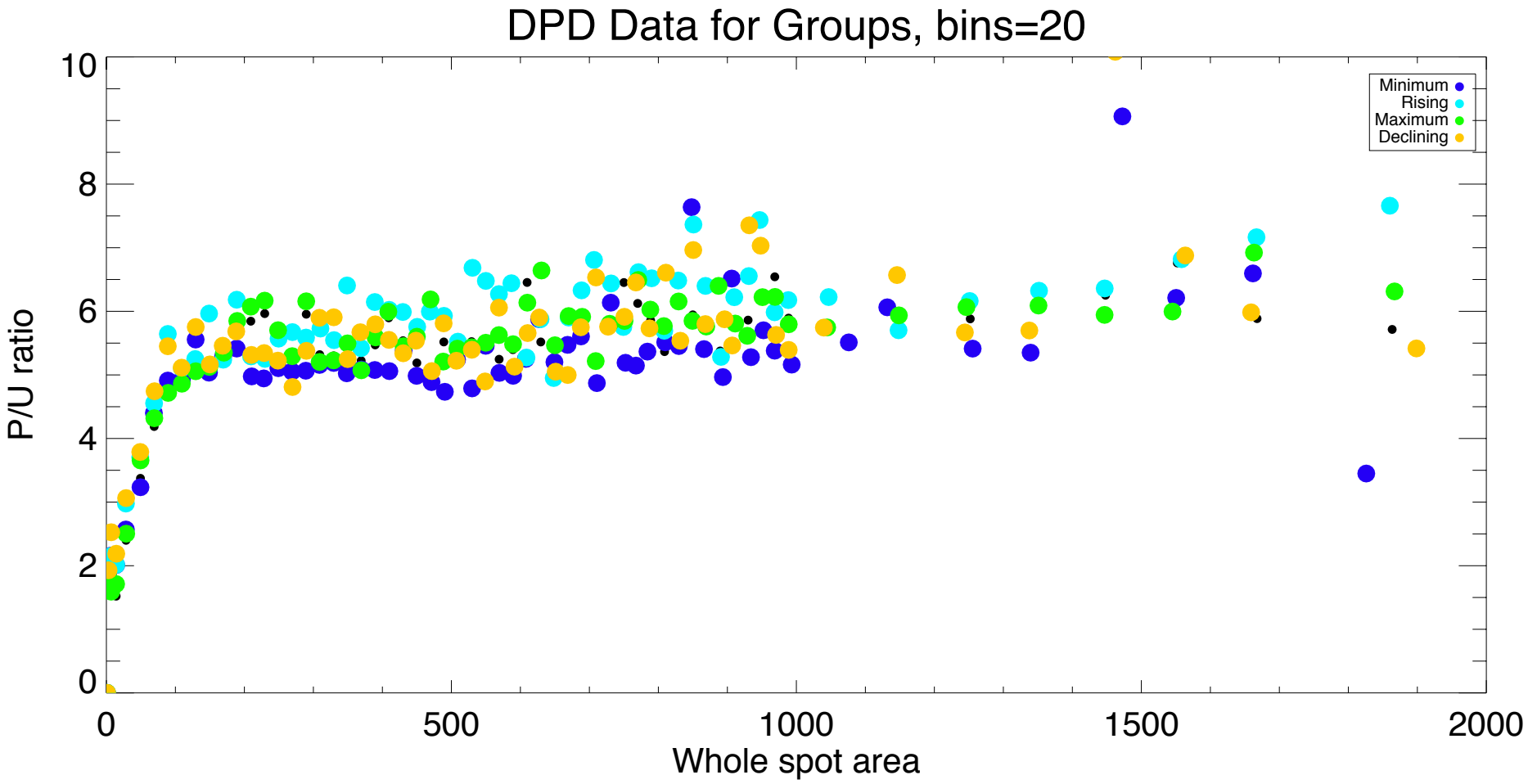
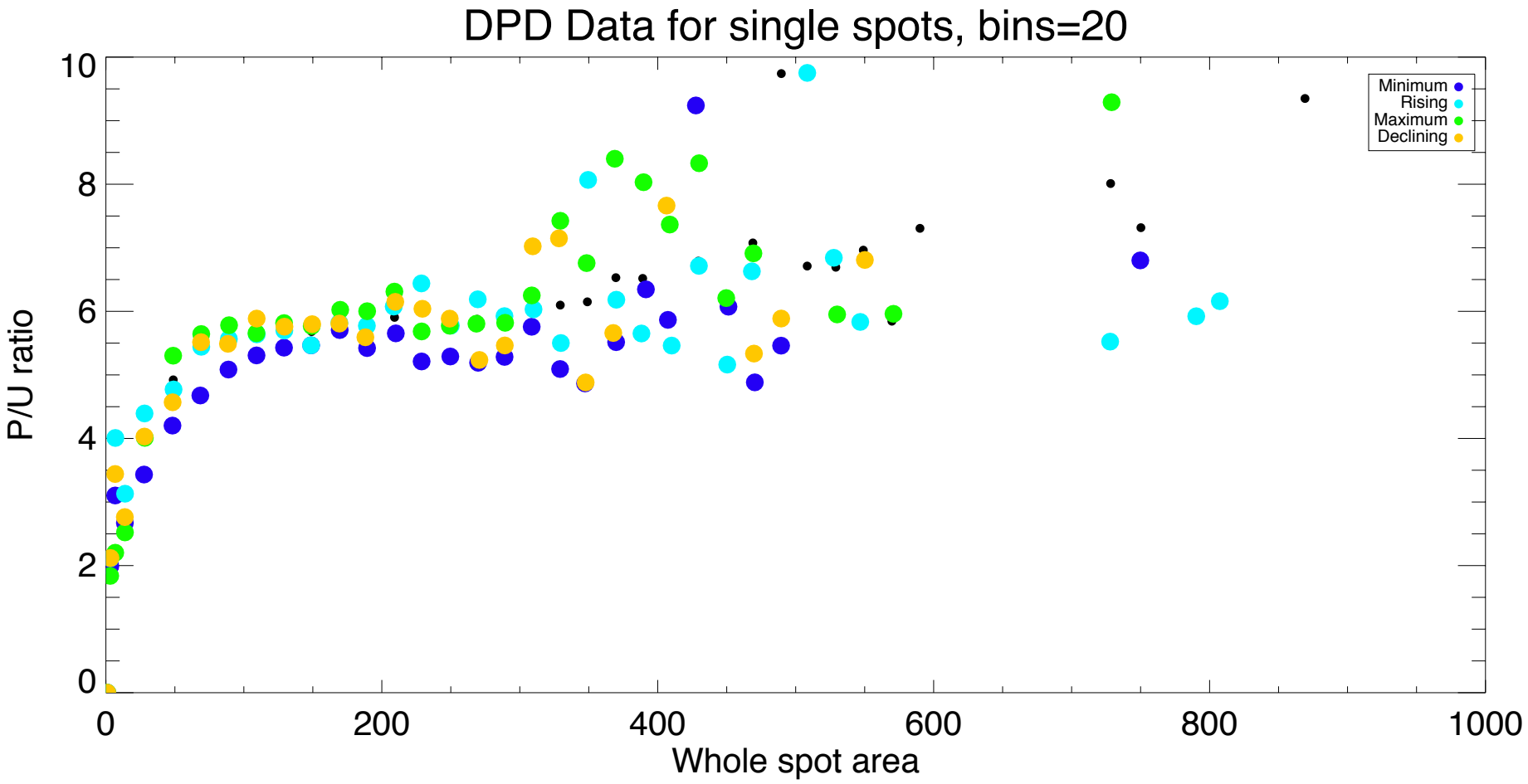


Figure 3. Penumbra-to-umbra area ratio as a function of total sunspot group area for sunspot groups at various phases of the sunspot cycle as indicated by the different symbols. This relationship does not change substantially with cycle phase.

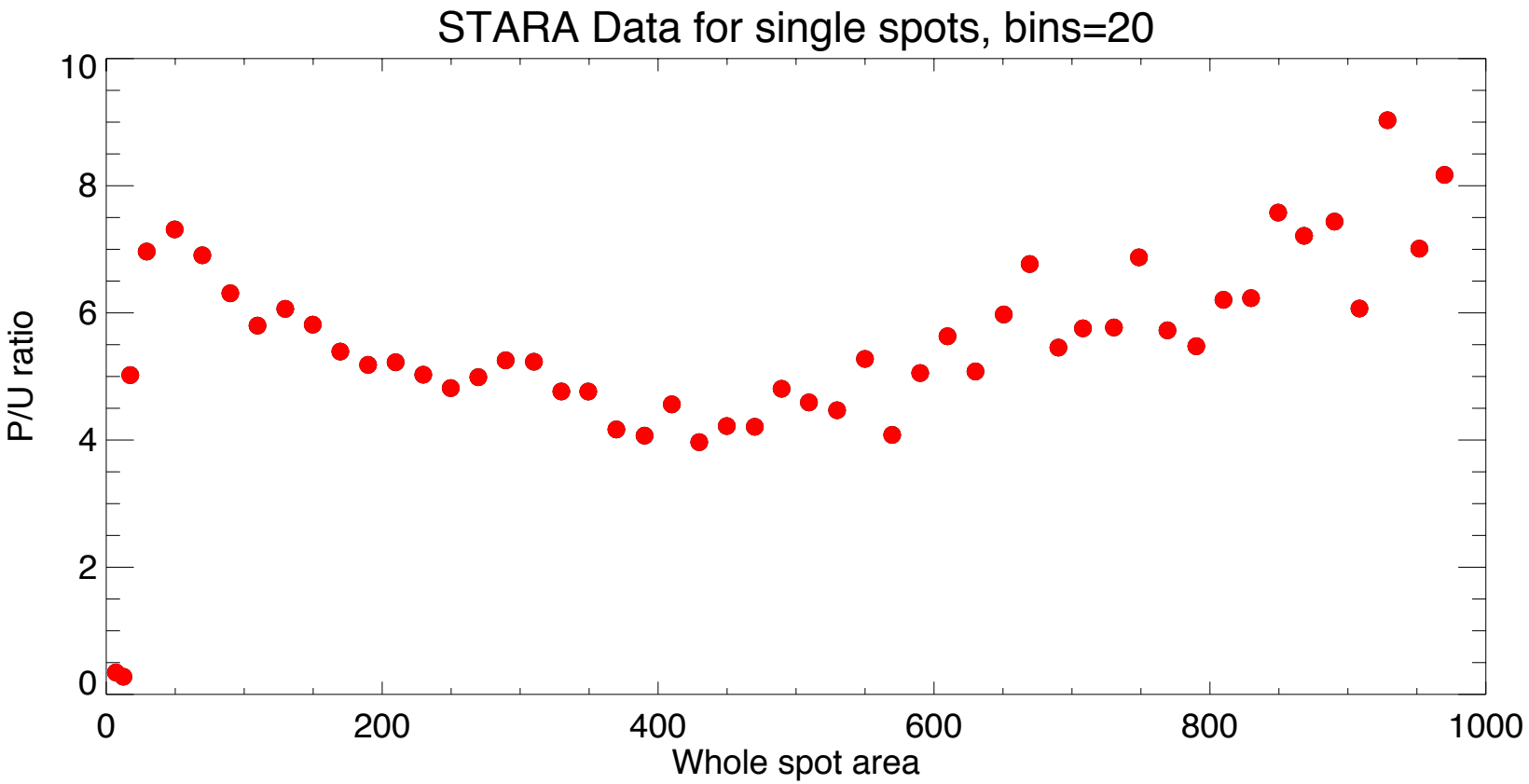
Groups Debrecen (different phases)



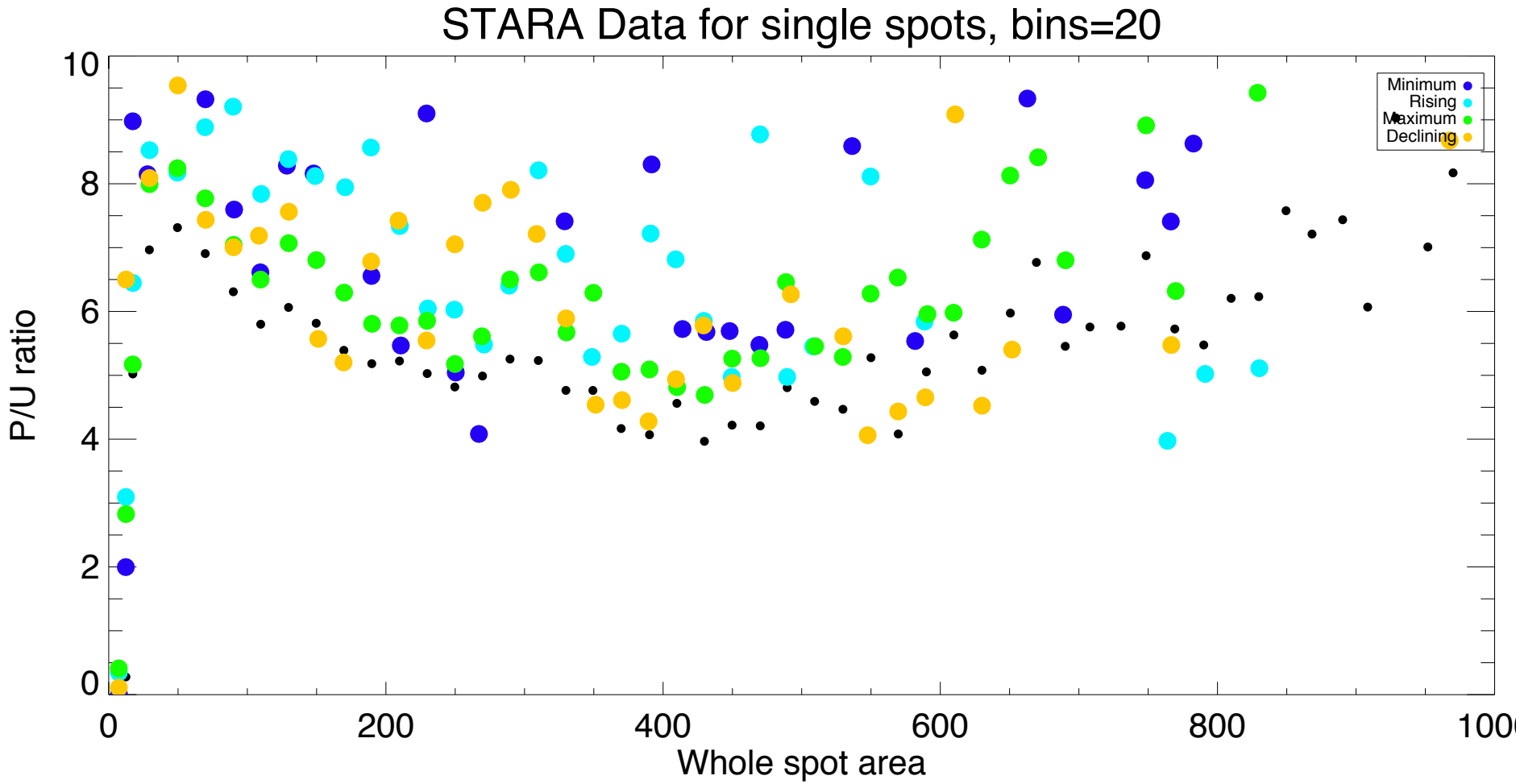
P/U for Debrecen spots

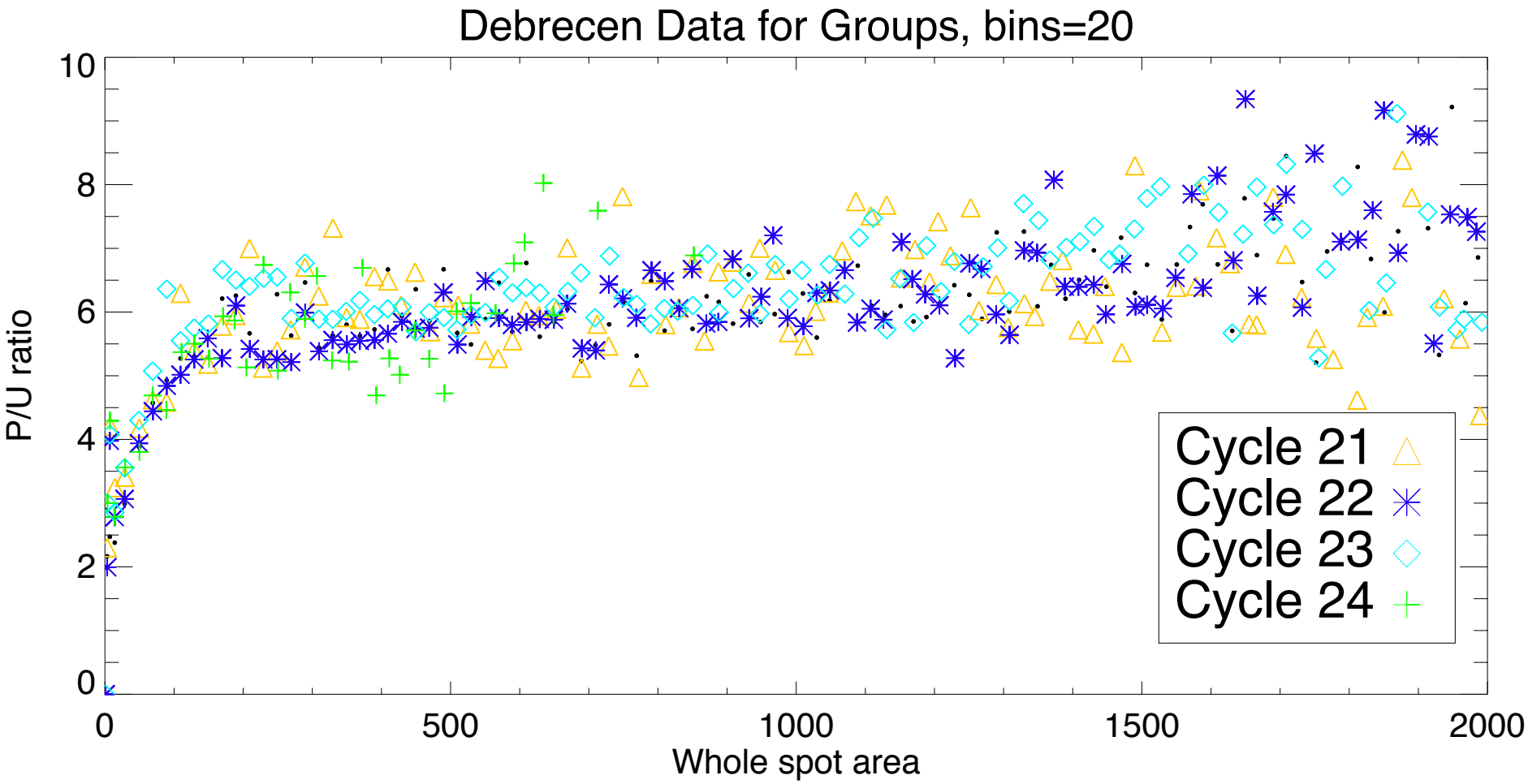


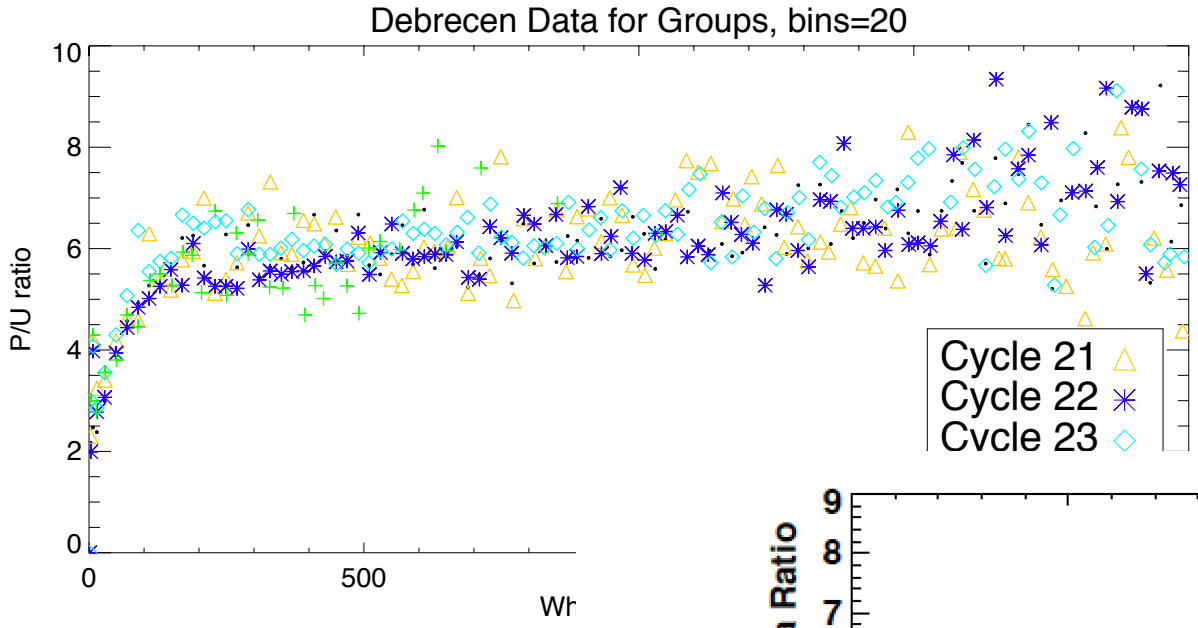
P/U for STARA sunspots



P/U for spots (STARA)




Debrecen Data for Groups, bins=20
P/U ratio
Whole spot area
0
2
4
6
8
10
0
500
1000
1500
2000
Cycle 21
Cycle 22
Cycle 23
Cycle 24



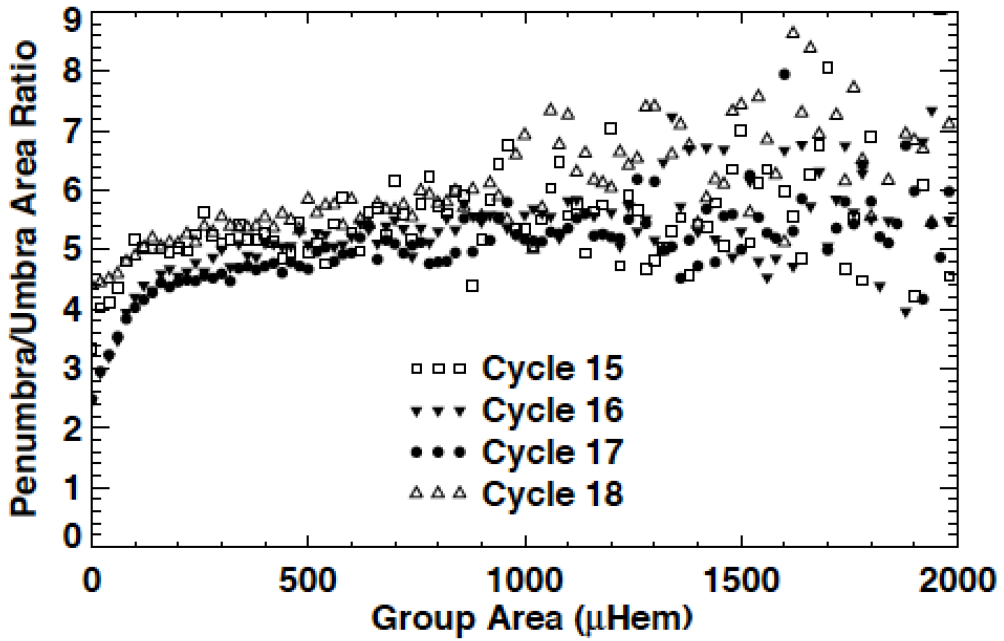
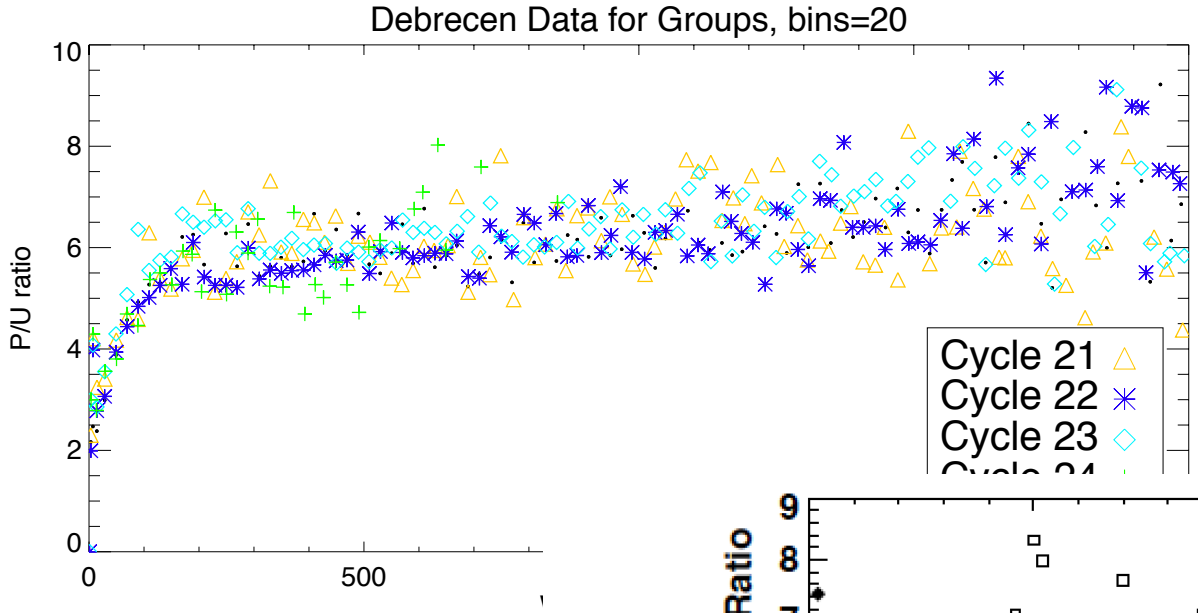


Figure 5. Penumbral-to-umbral area ratio as a function of total sunspot group area for sunspot groups in sunspot cycles 15-18 as indicated by the different symbols. These sunspot cycles exhibit a substantial *decrease* in penumbral areas for small sunspot groups.



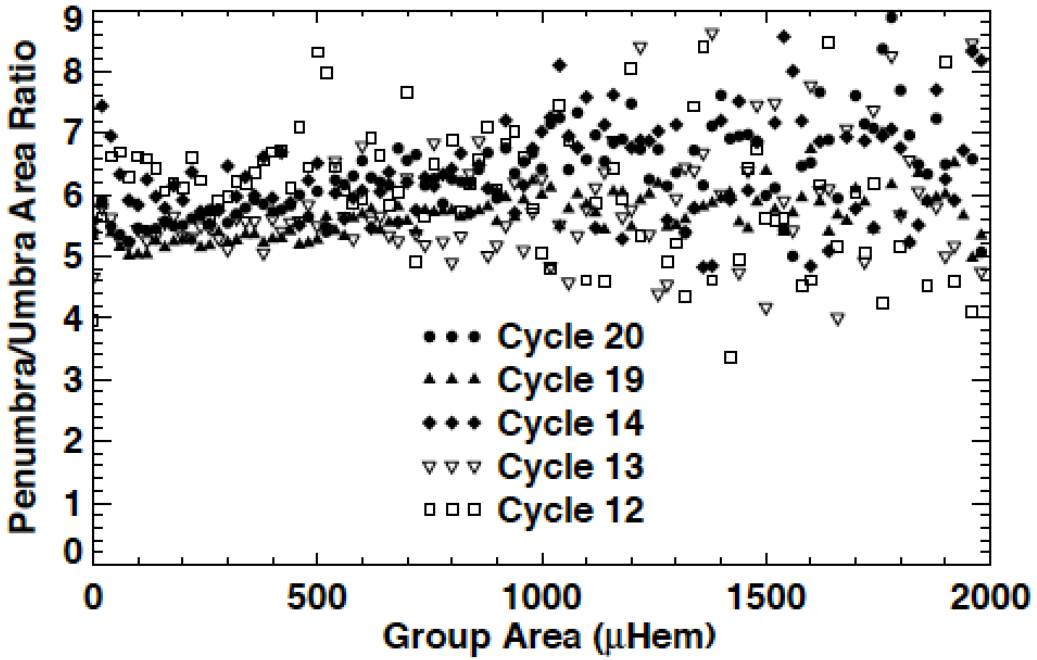
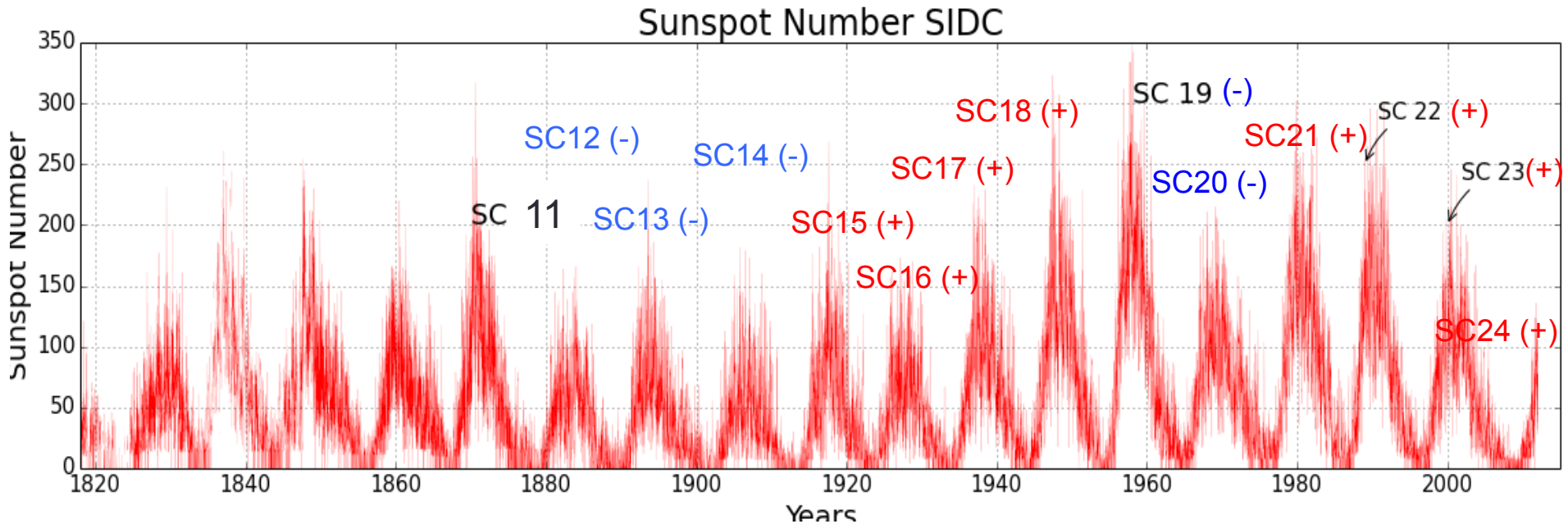


Figure 4. Penumbral-to-umbral area ratio as a function of total sunspot group area for sunspot groups in sunspot cycles 12-14 and 19-20 as indicated by the different symbols. These sunspot cycles exhibit an *increase* in penumbral areas for small sunspot groups.


Sunspot Number SIDC
Sunspot Number
Years
0
50
100
150
200
250
300
350
1820
1840
1860
1880
1900
1920
1940
1960
1980
2000
SC 11
SC12 (-)
SC13 (-)
SC14 (-)
SC15 (+)
SC16 (+)
SC17 (+)
SC18 (+)
SC 19 (-)
SC20 (-)
SC21 (+)
SC 22 (+)
SC 23(+)
SC24 (+)

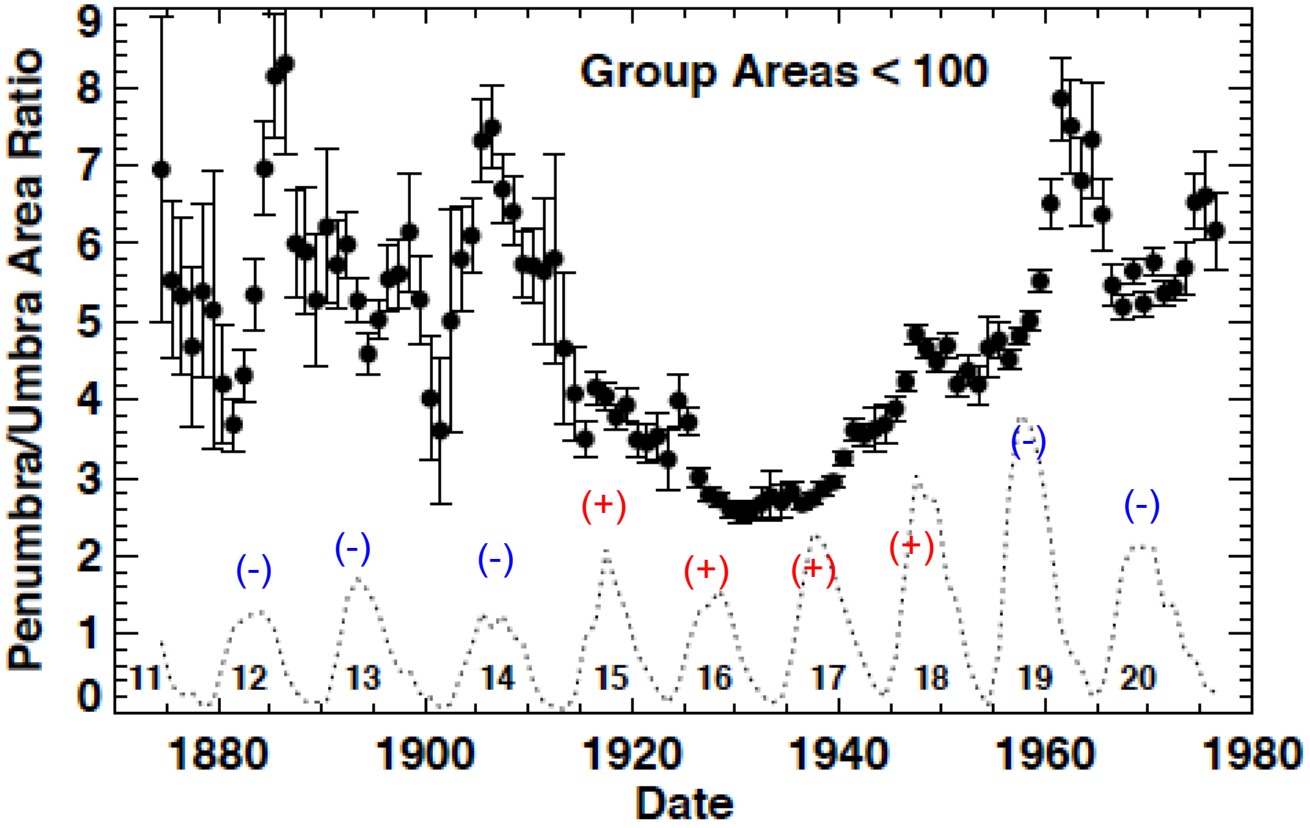
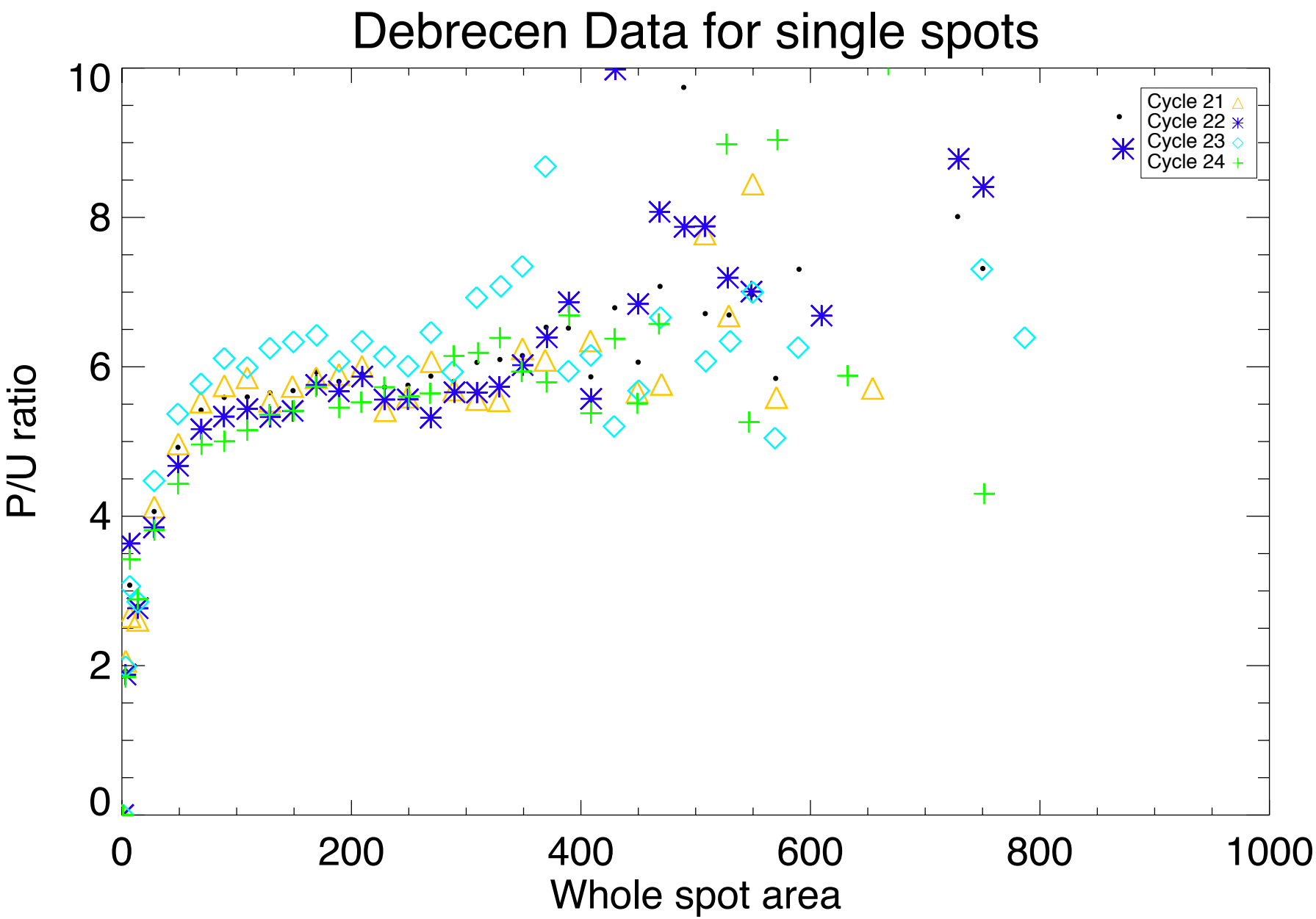
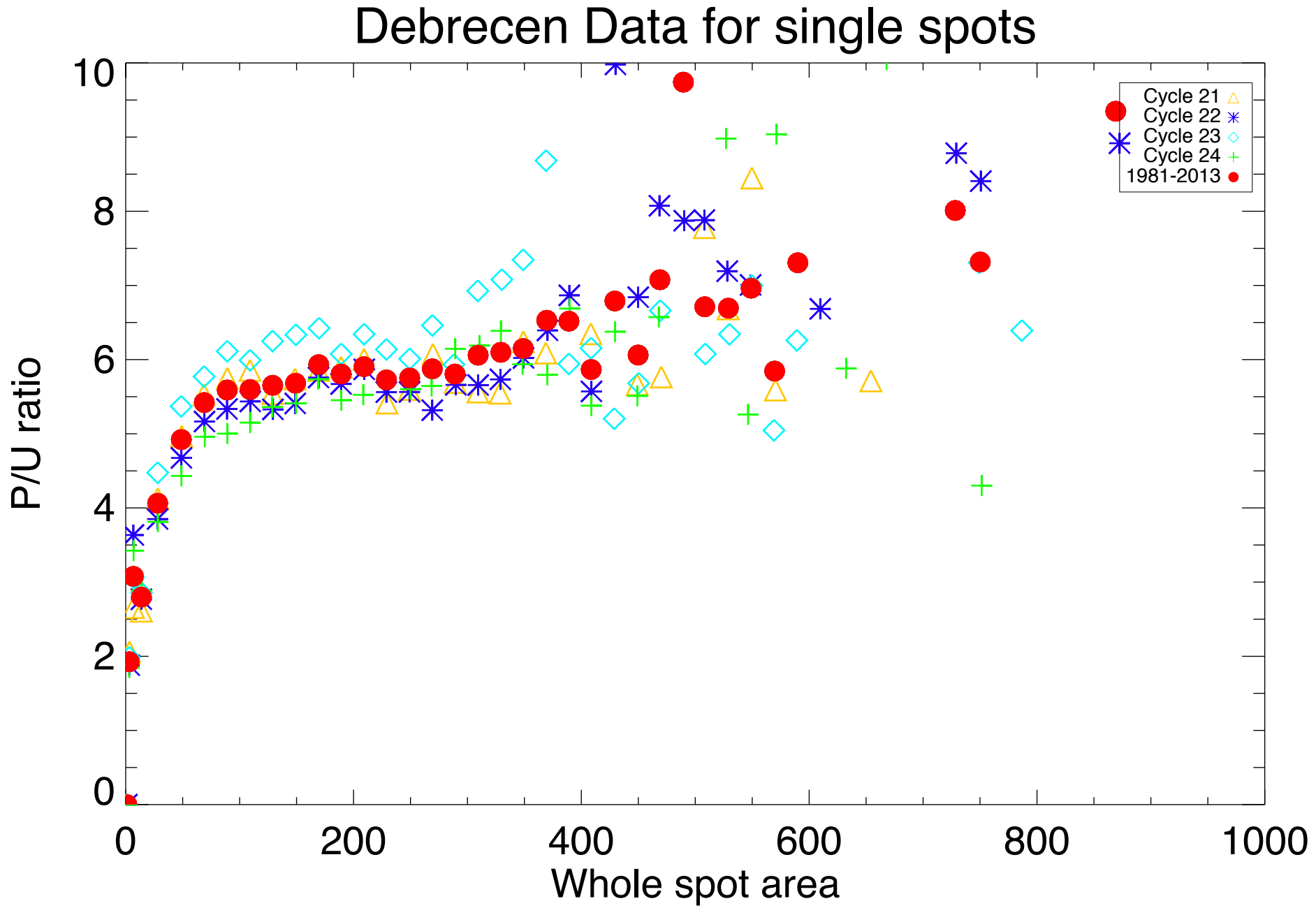


Figure 7. Yearly averages of the penumbral-to-umbral area ratio as a function of time for sunspot groups with areas < 100 μHem are shown by the filled circles with 2σ error bars. The yearly sunspot number divided by 50 is shown with the dotted line for reference. From 1905 to 1960 the penumbral areas of these small sunspots decrease to less than half their former areas and then returned to previous levels.

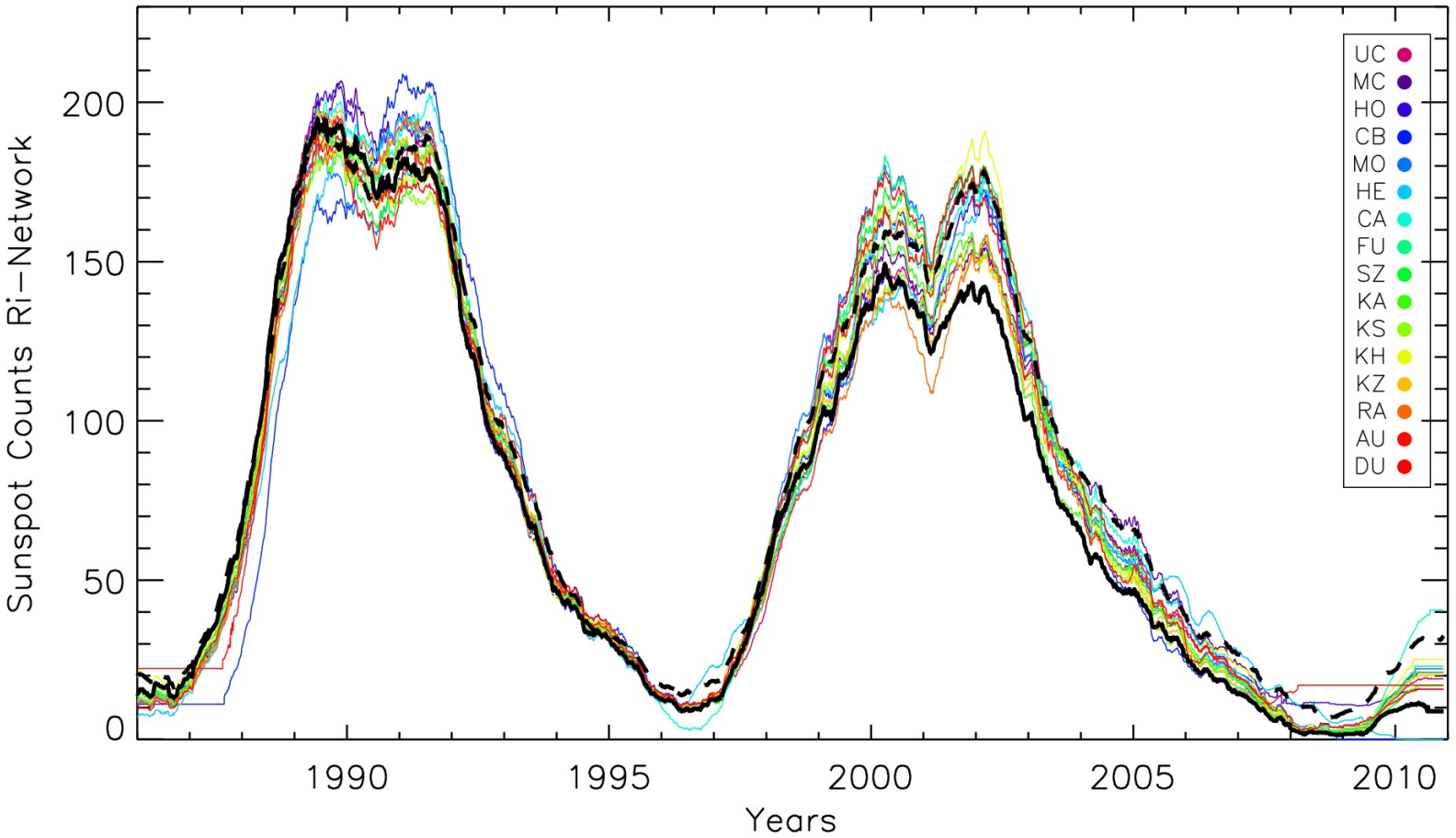

Debrecen Data for single spots
P/U ratio
Whole spot area
0
2
4
6
8
10
0
200
400
600
800
1000
Cycle 21
Cycle 22
Cycle 23
Cycle 24

THE END


Debrecen Data for single spots
P/U ratio
Whole spot area
0
2
4
6
8
10
0
200
400
600
800
1000
Cycle 21
Cycle 22
Cycle 23
Cycle 24
1981-2013

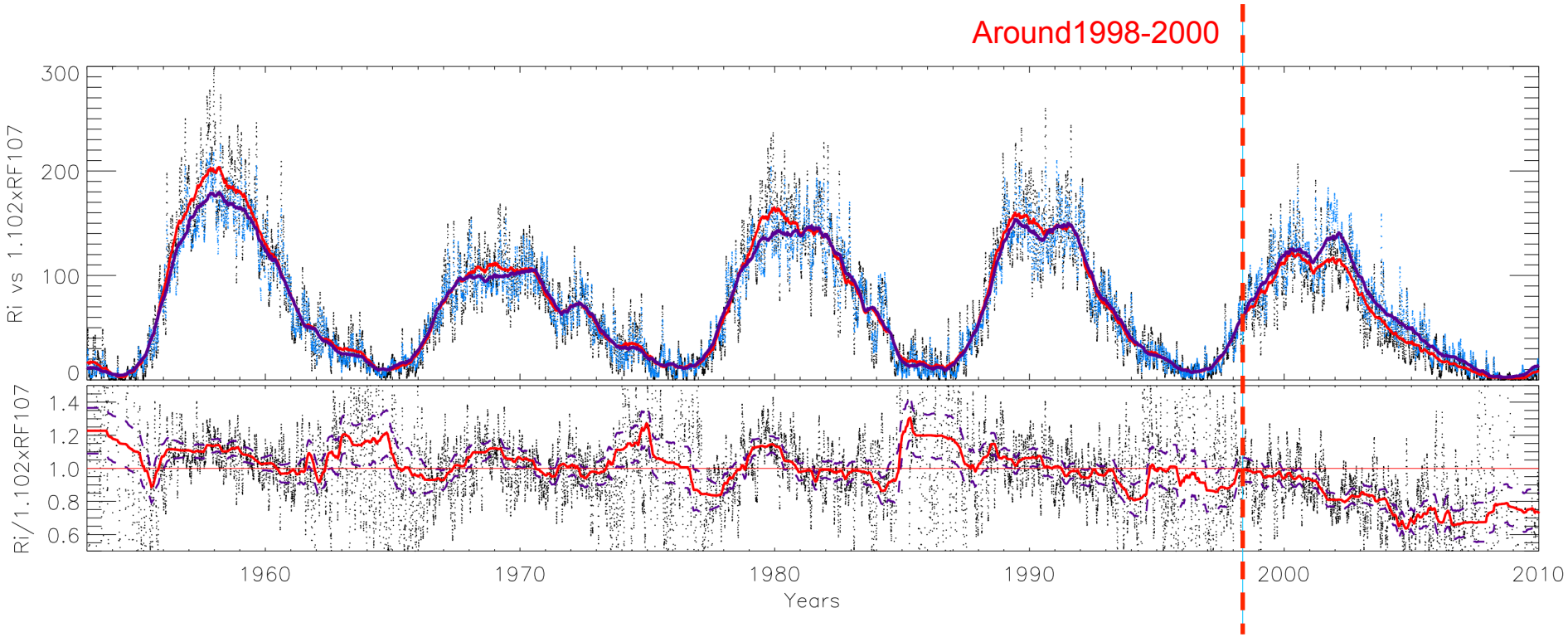
Title

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 + $R_2(F_{10.7})$**

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



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

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 still 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

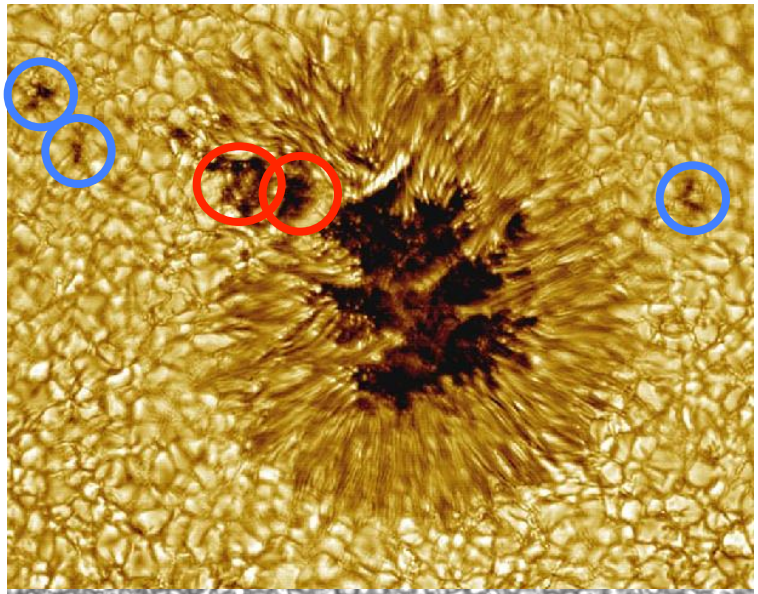
- Various definitions:

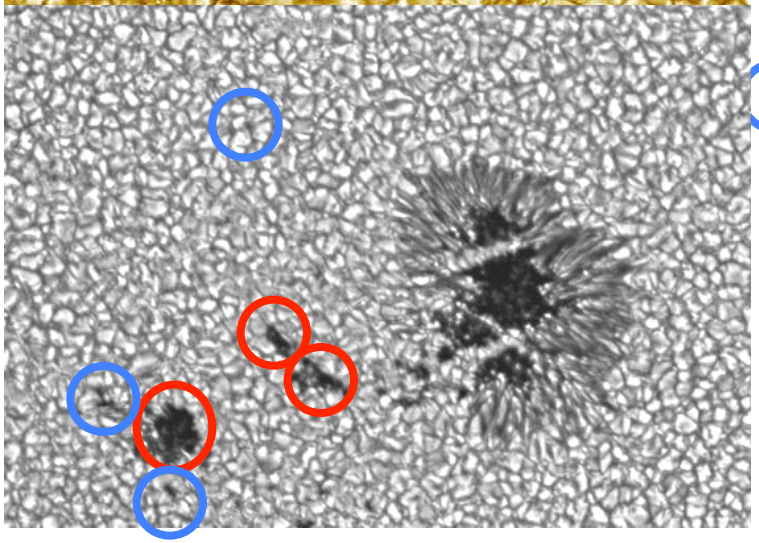
Source	Spot diameter	Spot lifetime	Pore diameter	Pore lifetime
Bray & Laughhead 1964	With penumbra		Without penumbra	
Waldmeier (Husar 1967)	>3" (2000km) = 1 granule	> 30 min	< 3"	< 30min
Bruzec & Durrant 1977	>10" (6000km)	> 1 day	< 5"	< 1 day
McIntosh 1981	> 4" (2500km) = 1 granule		< 4"	

- 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

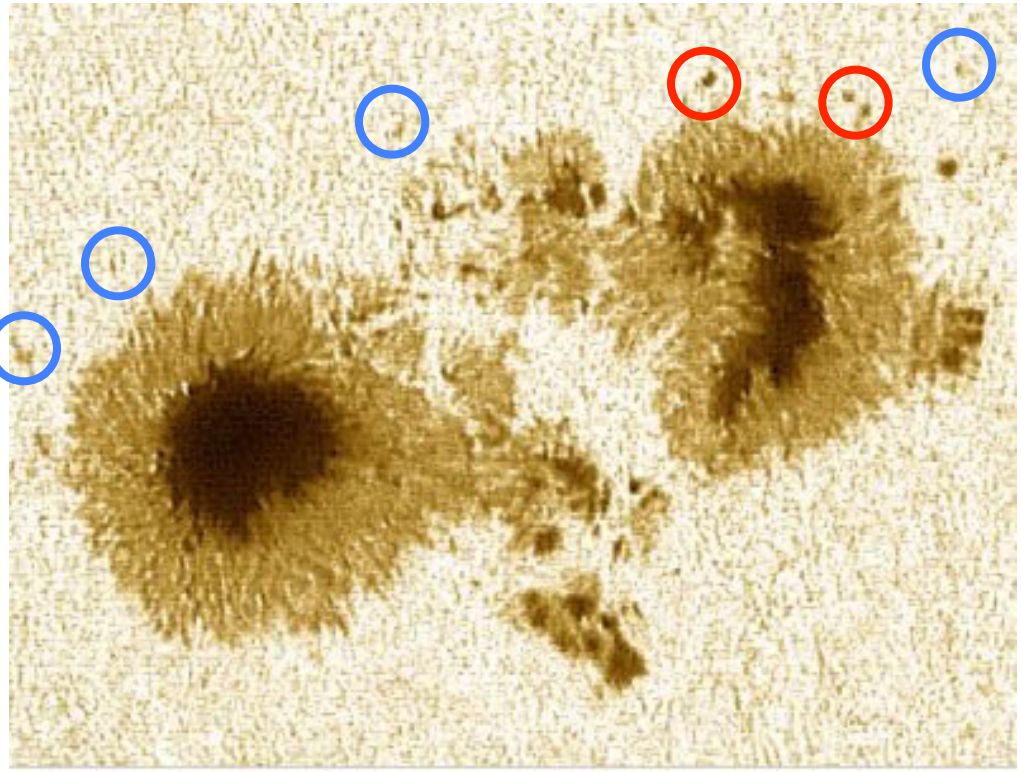
Pores and spots





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.

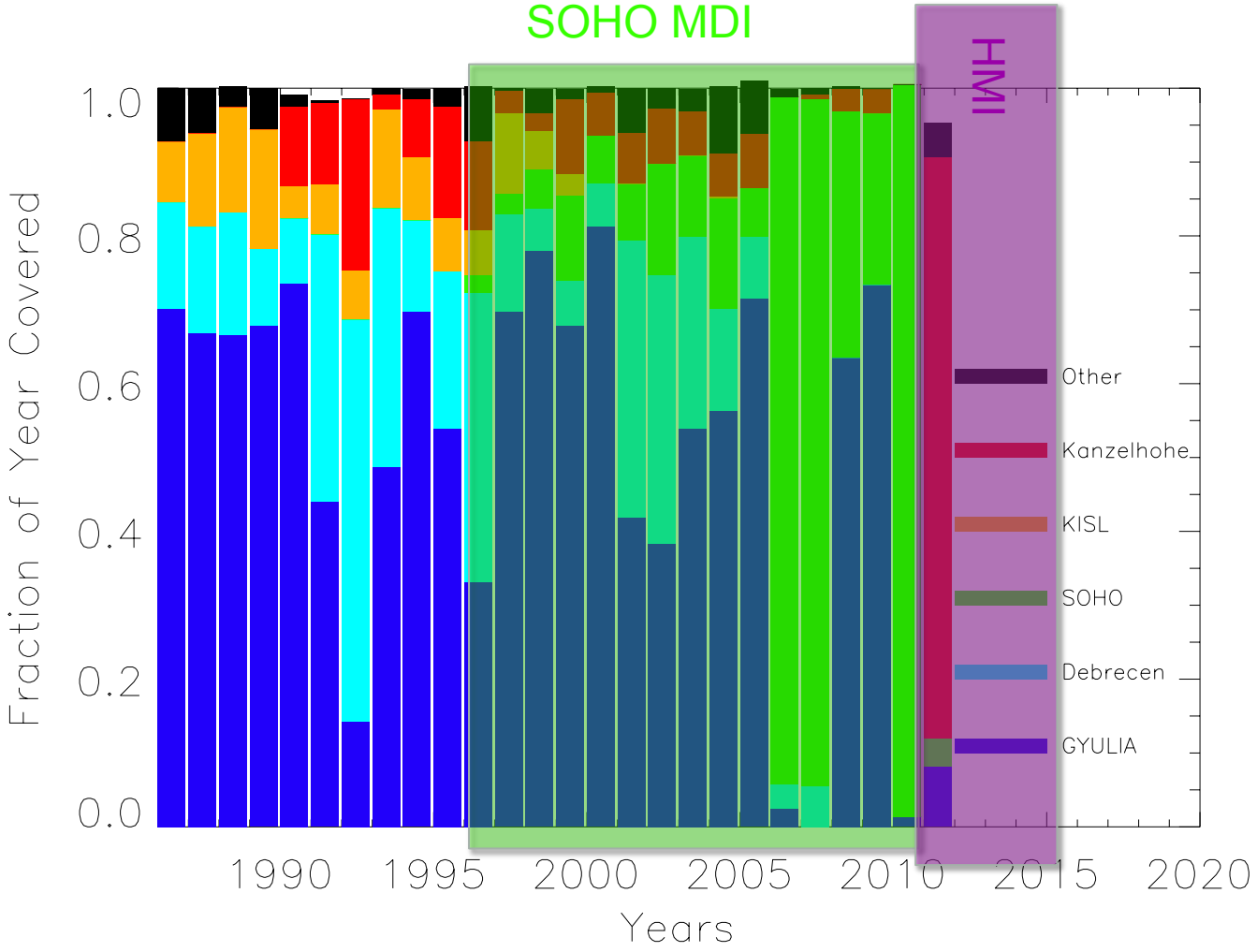
STARA MDI and HMI

- 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

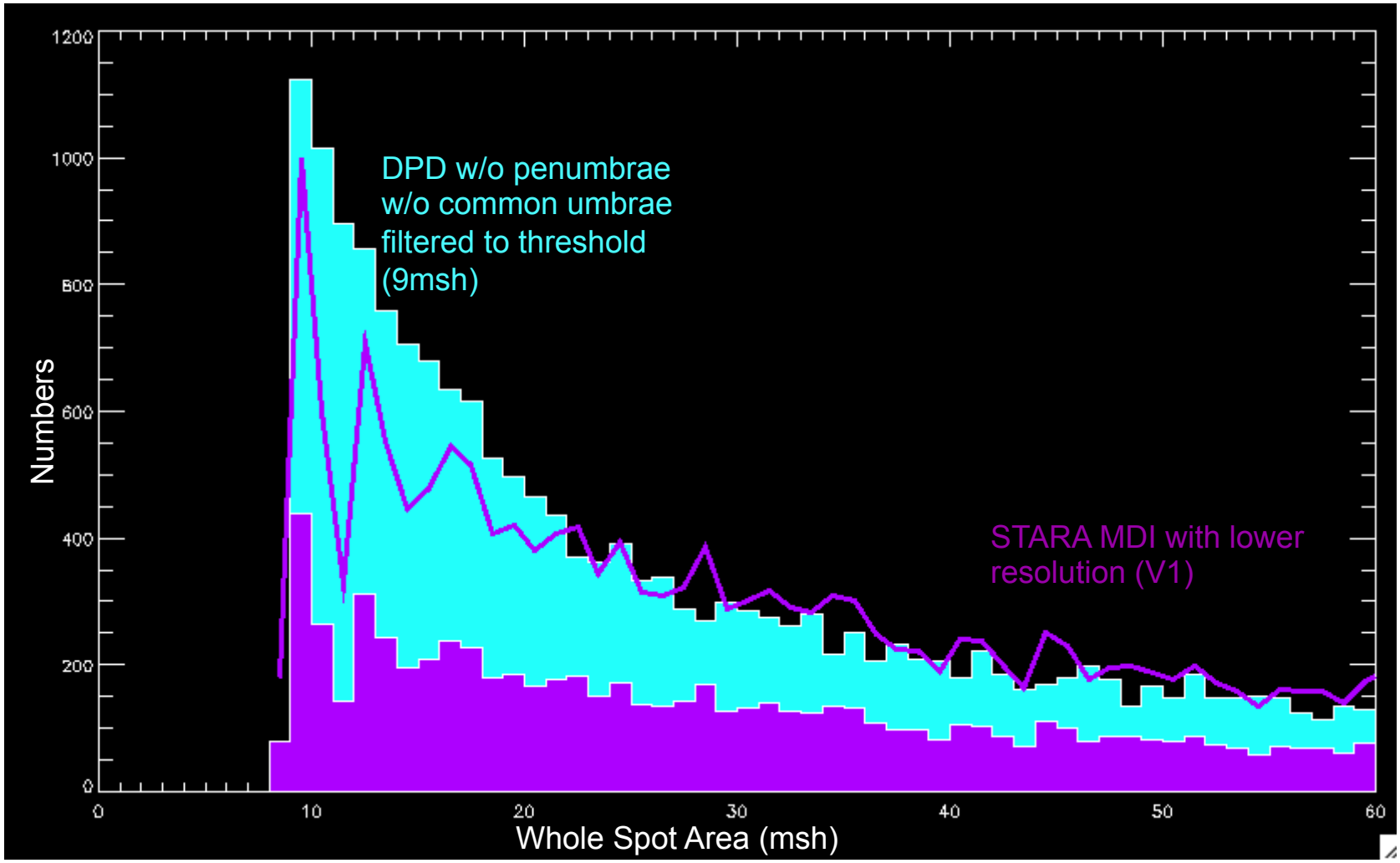
Debrecen Photoheliographic Data (DPD)

- 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/

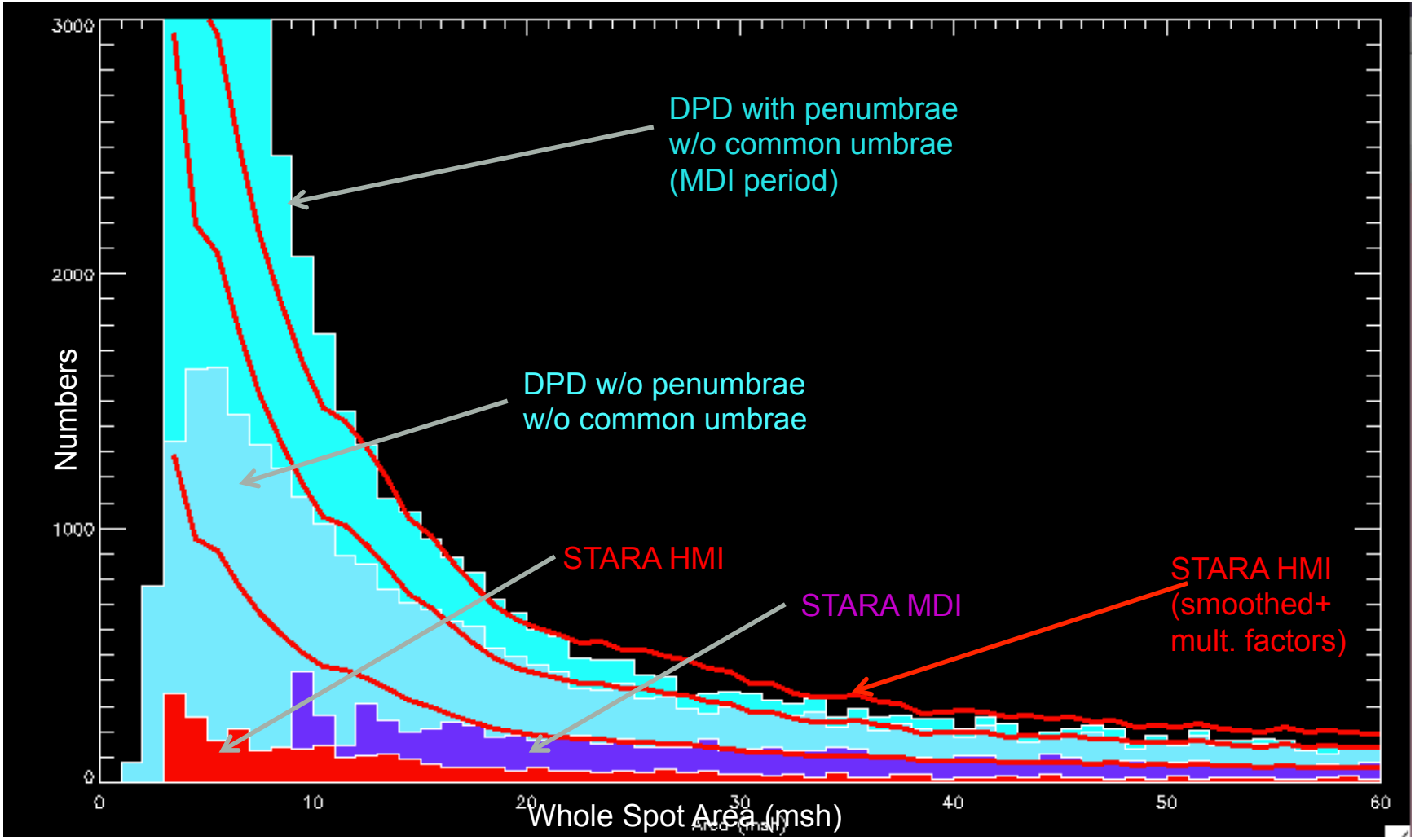
Data coverage DPD vs. MDI/HMI



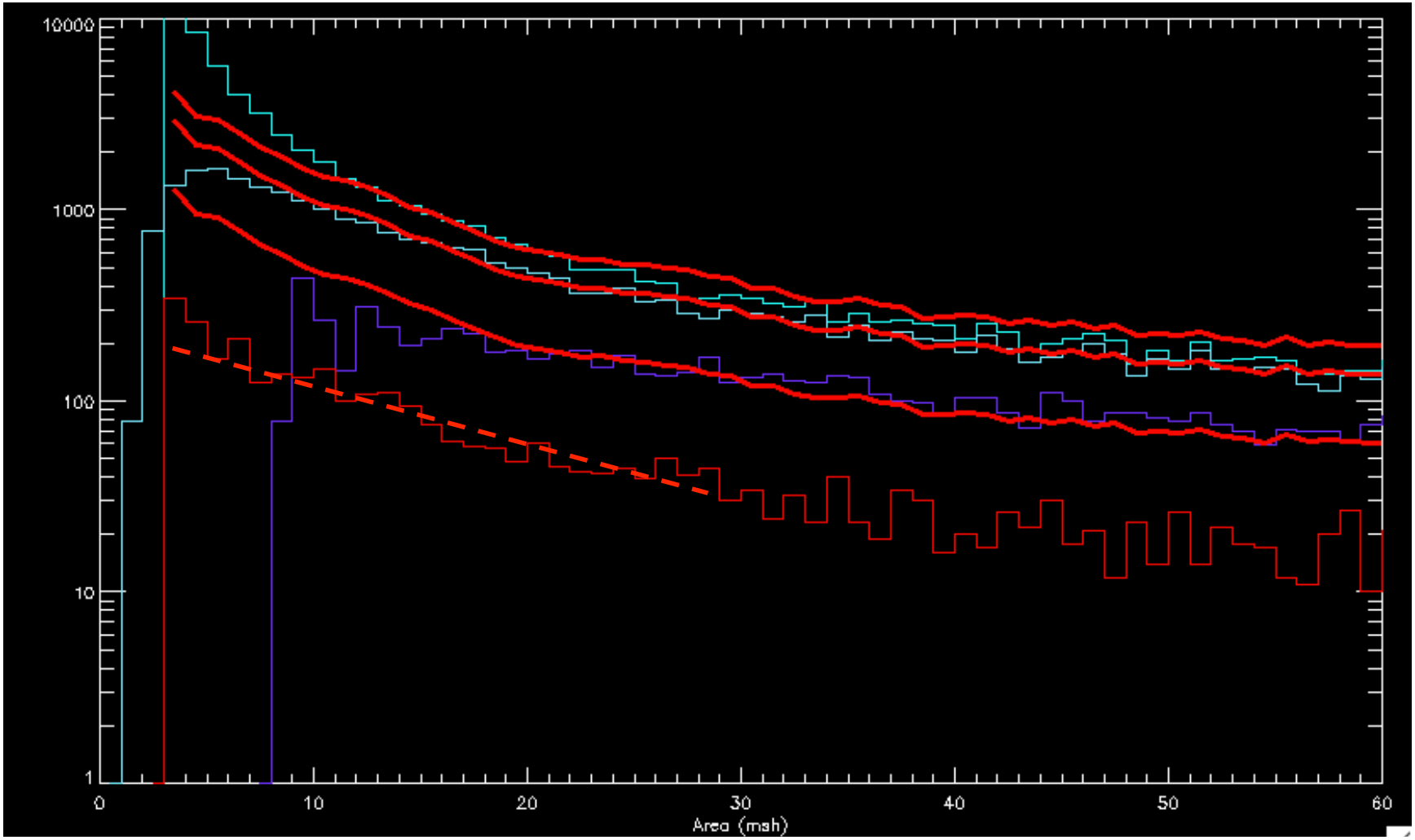
DPD to STARA MDI (v1) on same period



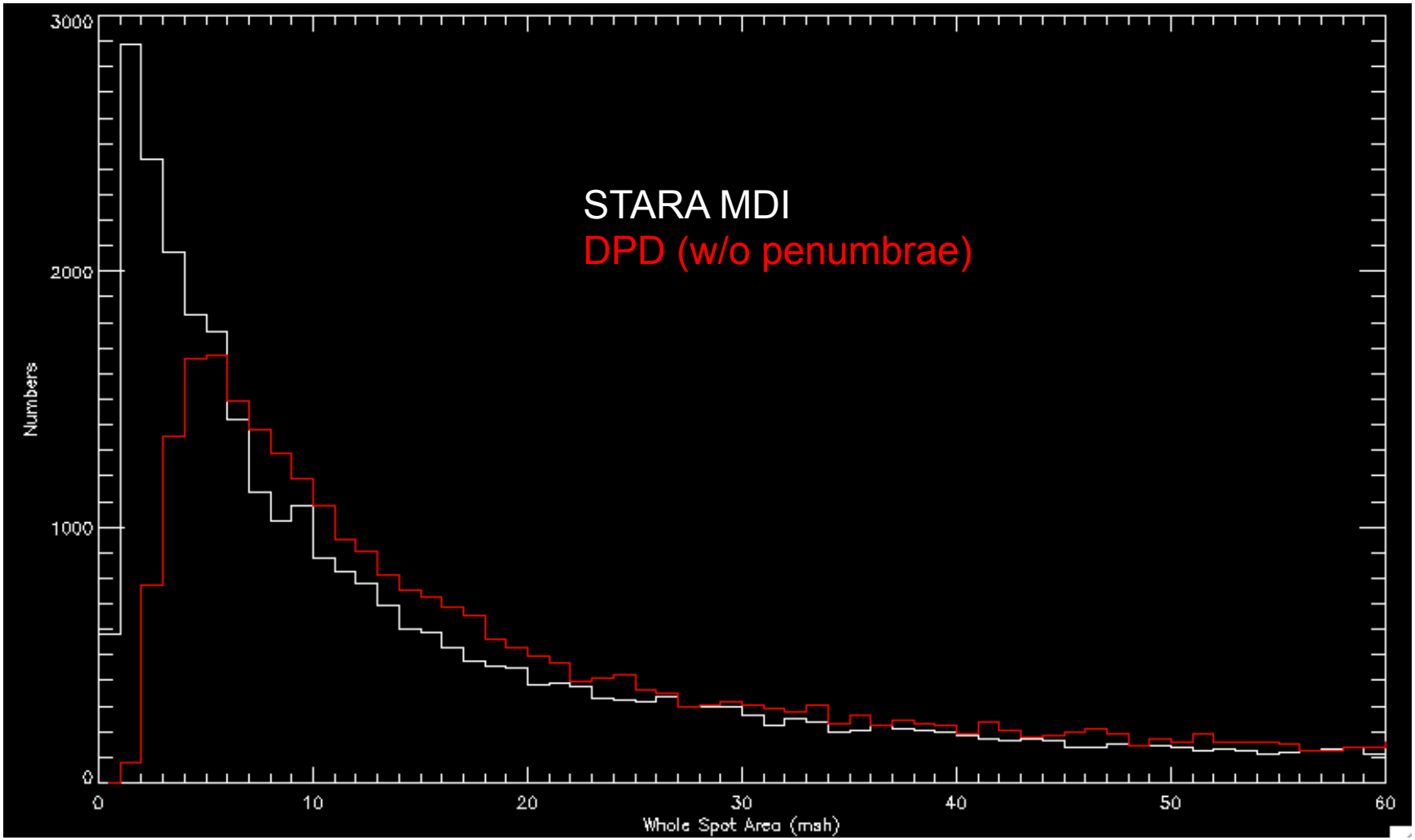
STARA MDI/HMI (v1) compared to DPD



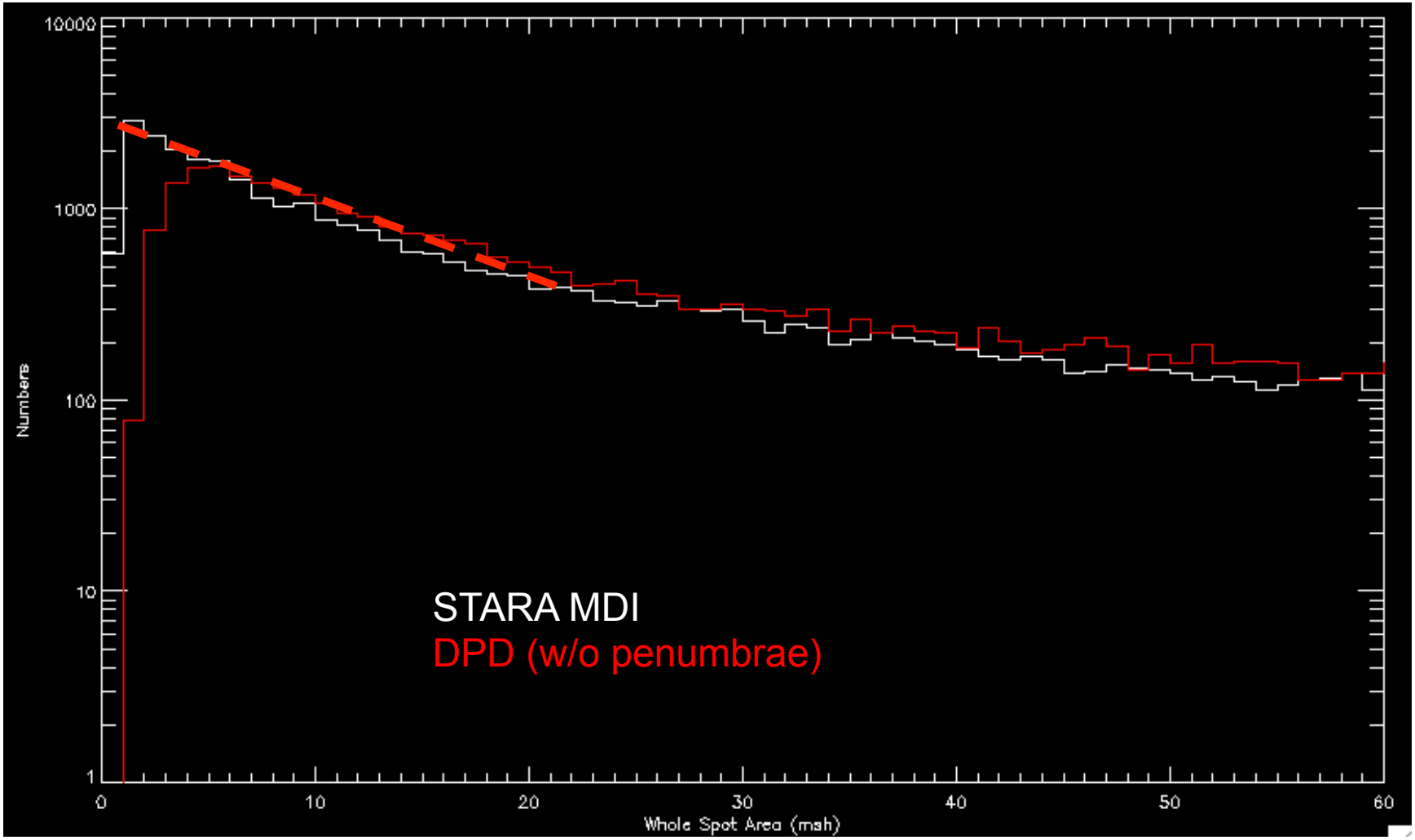
Approximately exponential distributions



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

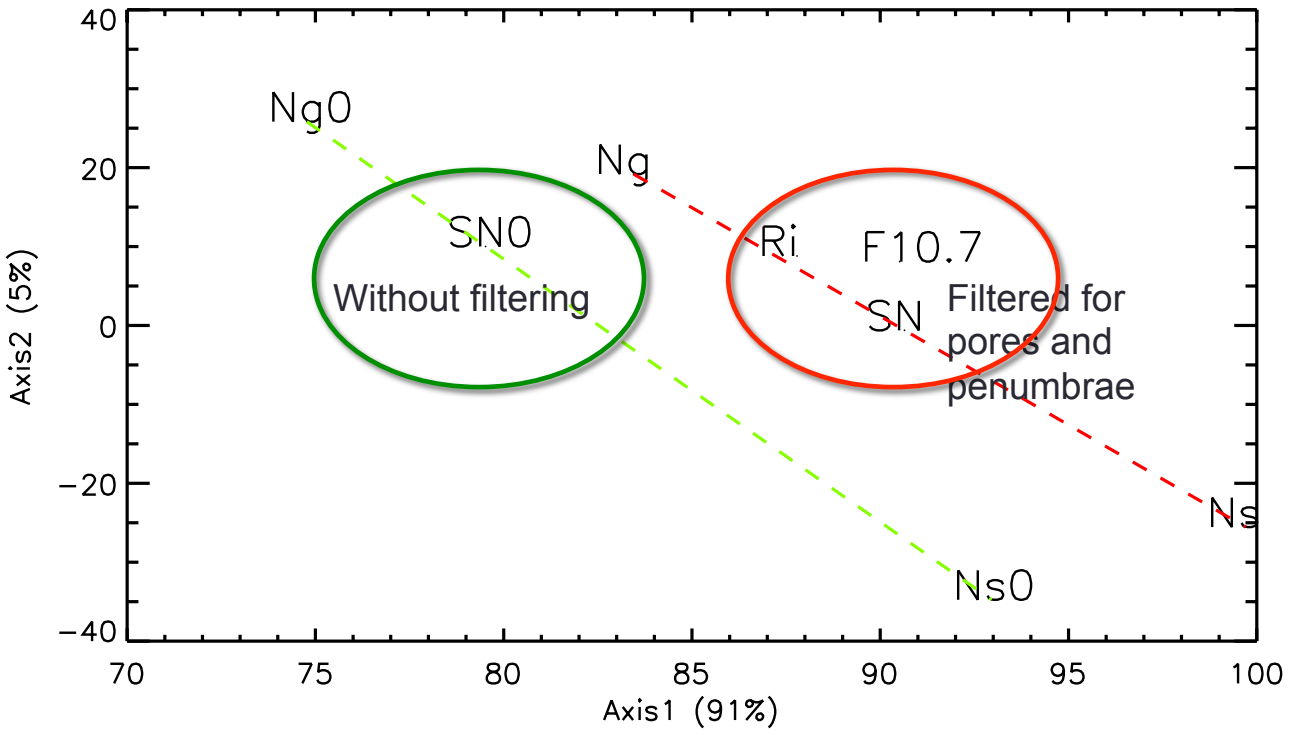


Exponential

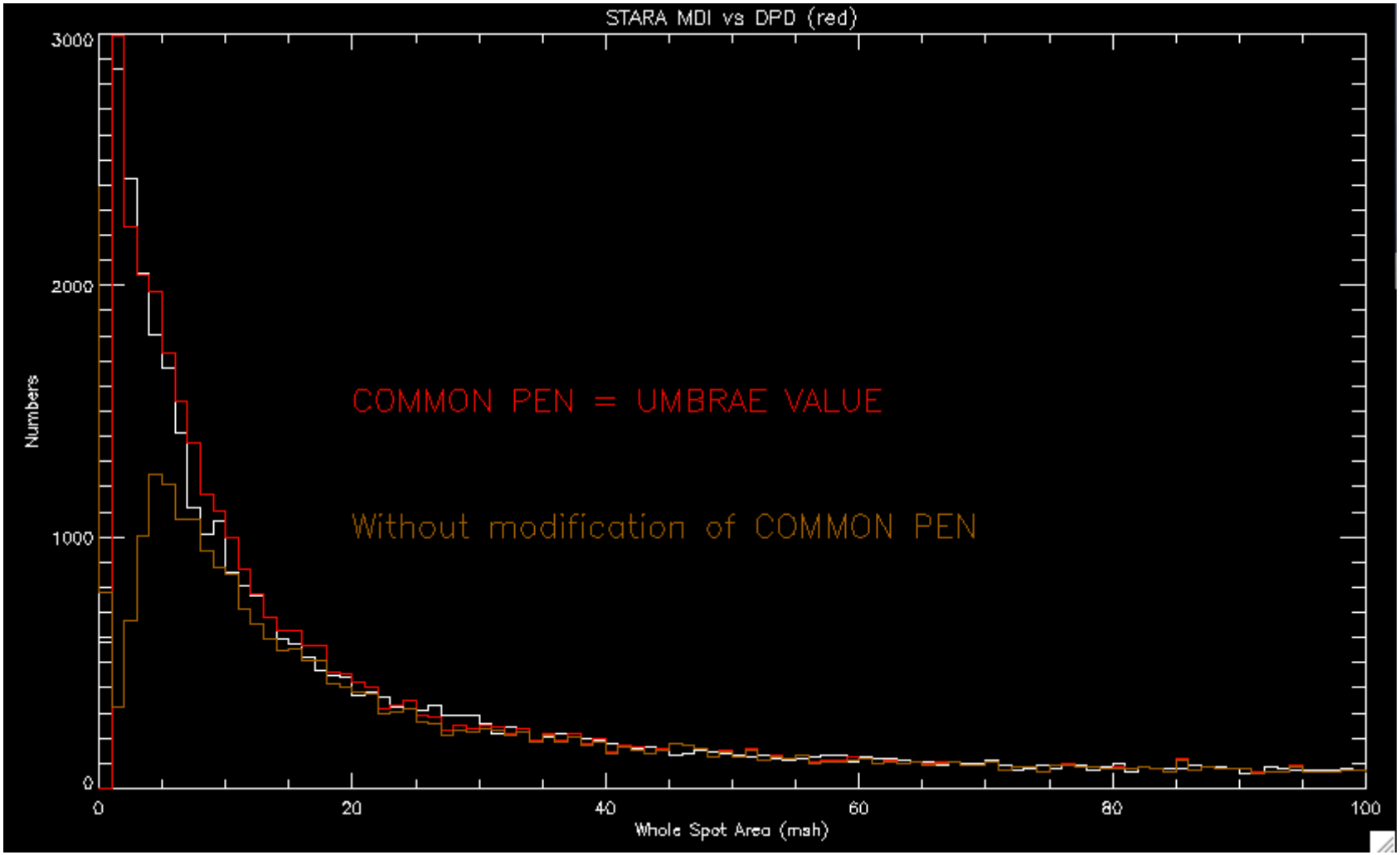


Result of the filtering we did apply

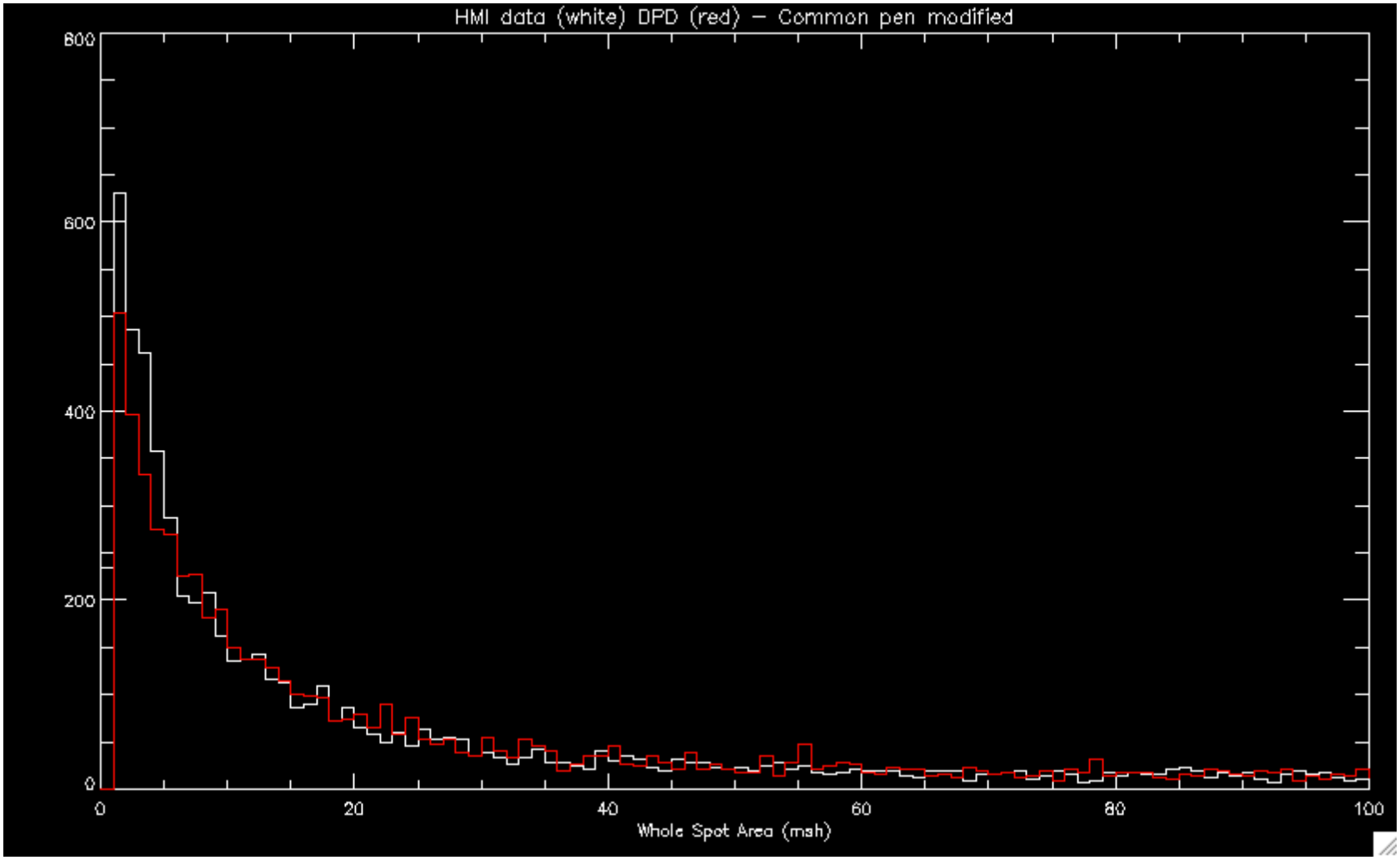
An interesting way of looking at it…



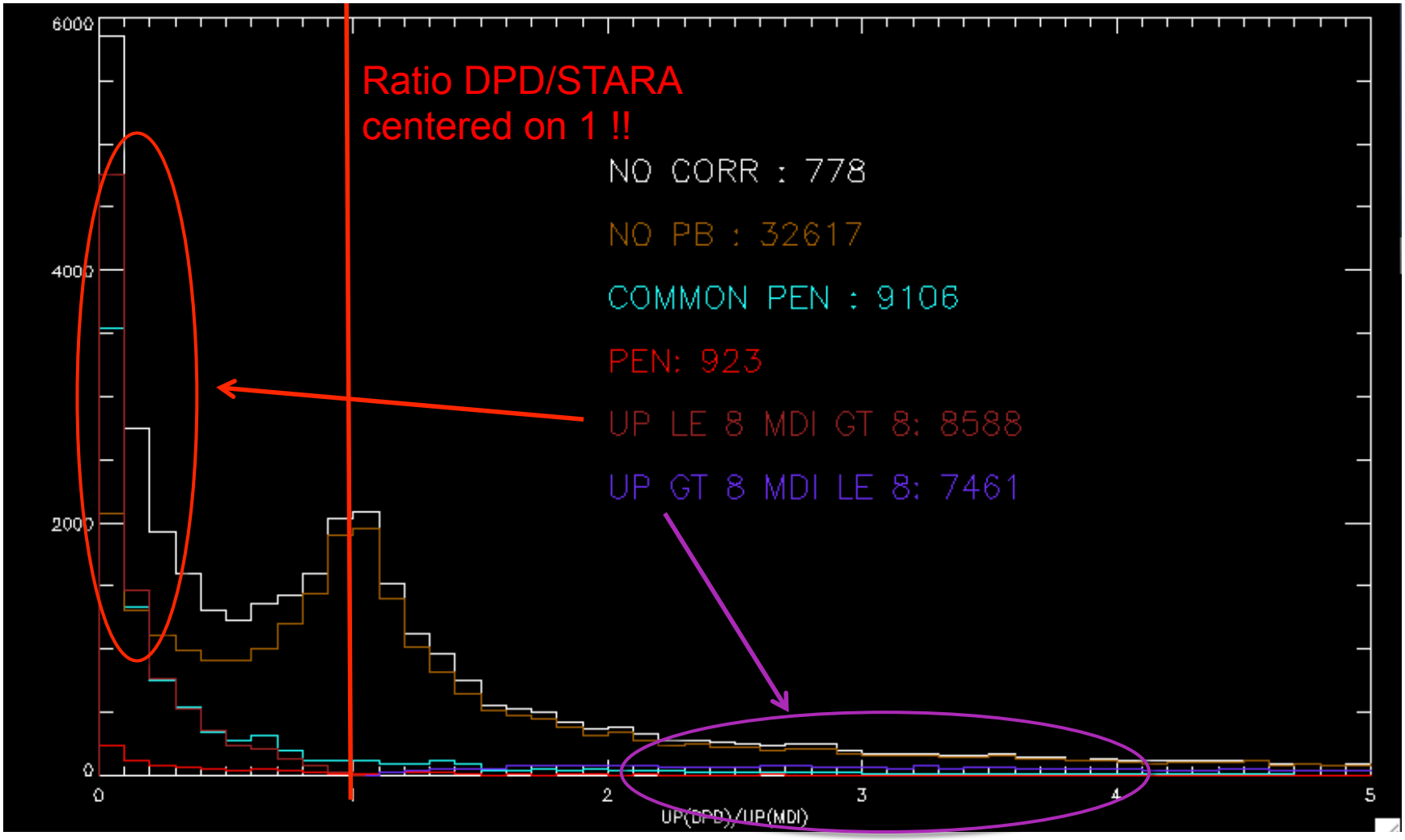
Identified spots between MDI and DPD



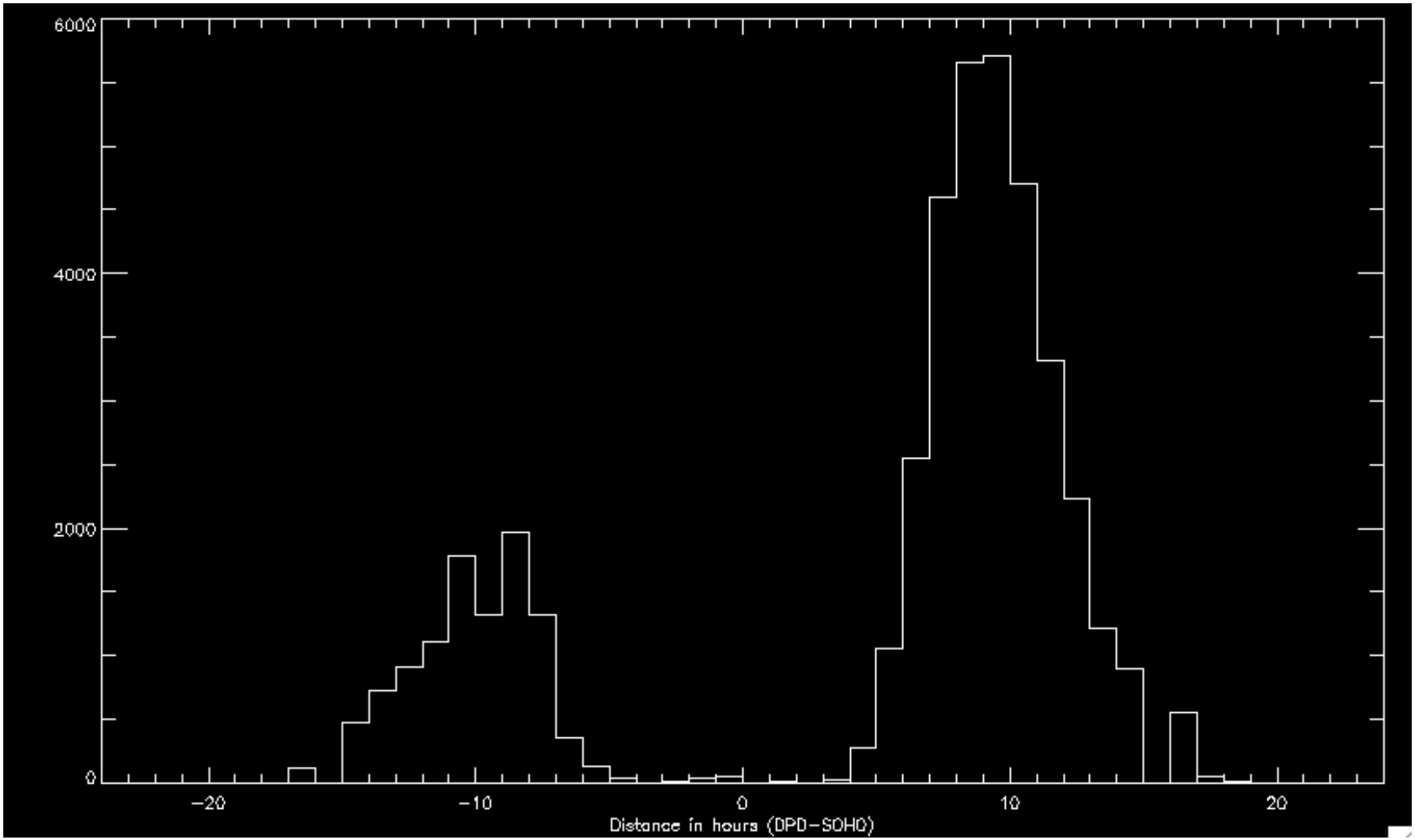
Identified spots between HMI and DPD



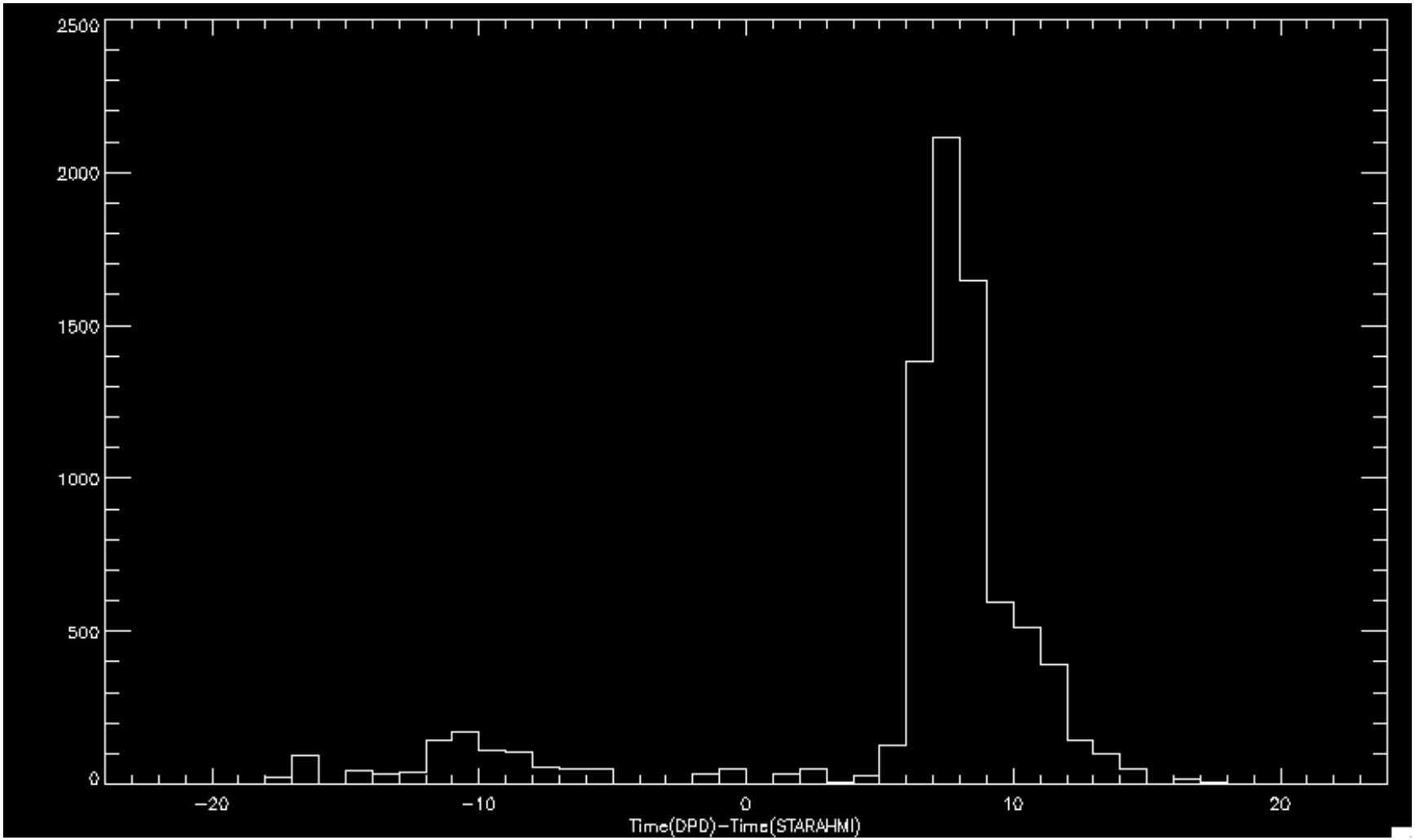
STARA areas vs. DPD areas: ratio



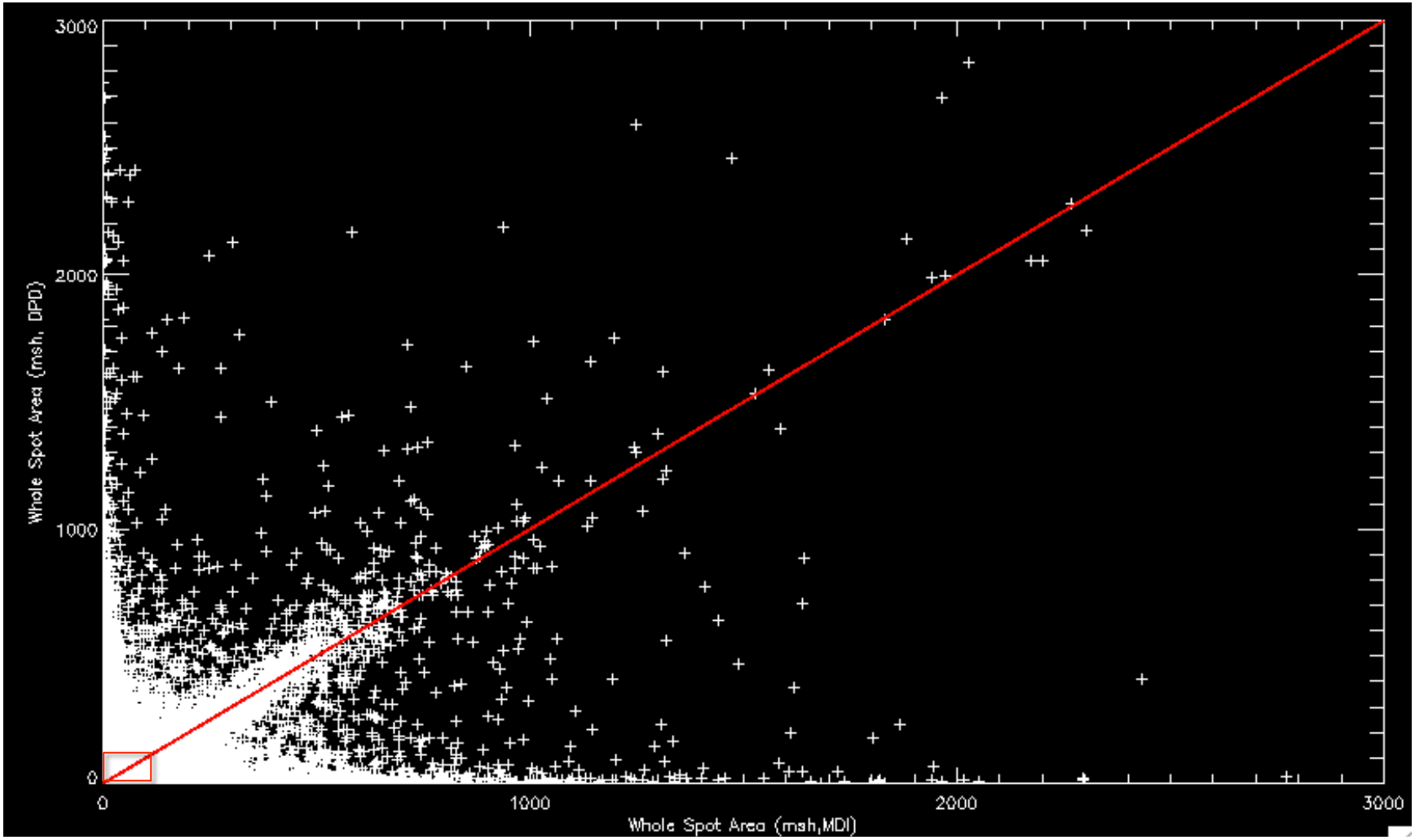
Time(DPD)-Time(MDI)



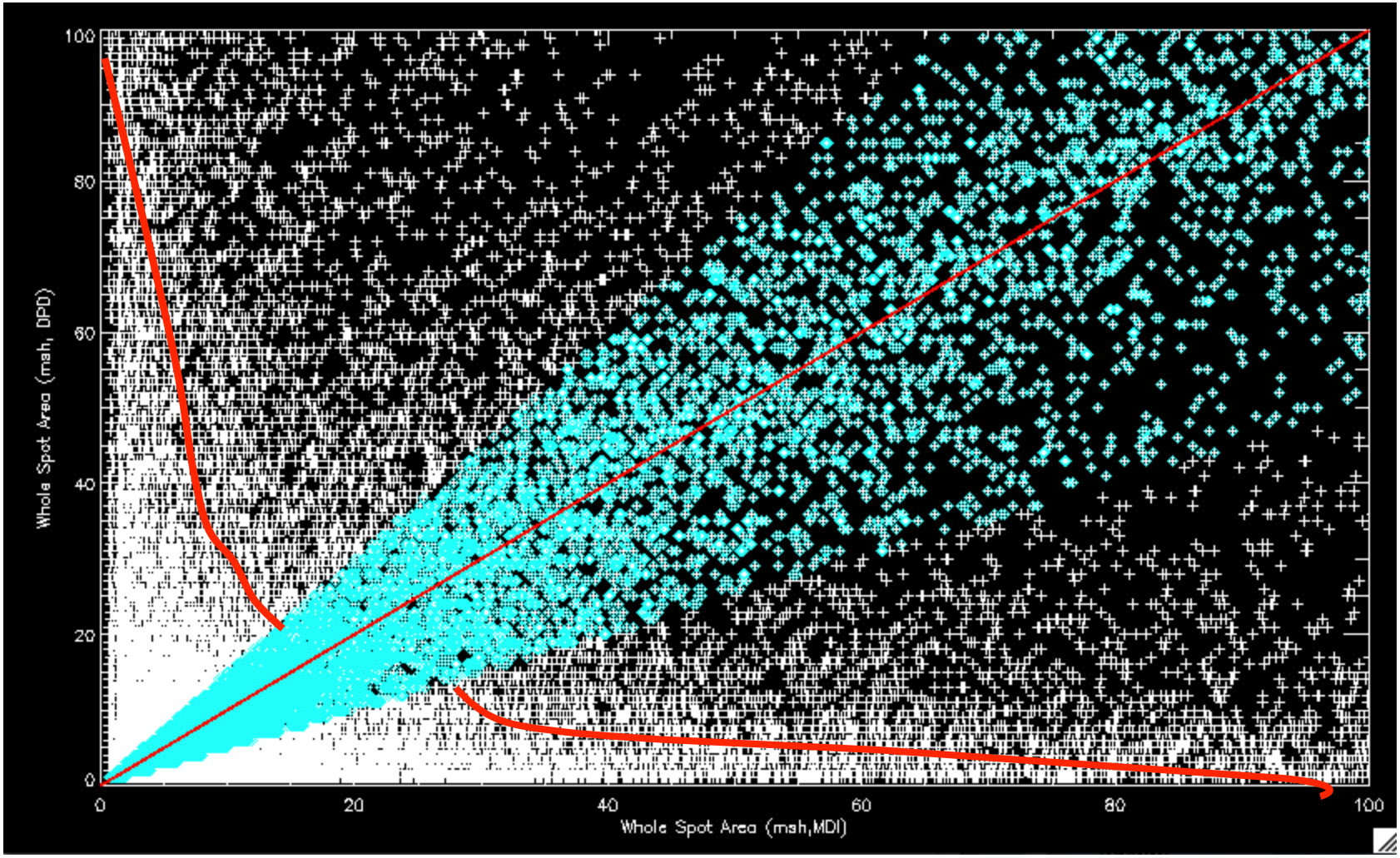
Time(DPD)-Time(HMI)



STARA areas vs. DPD areas

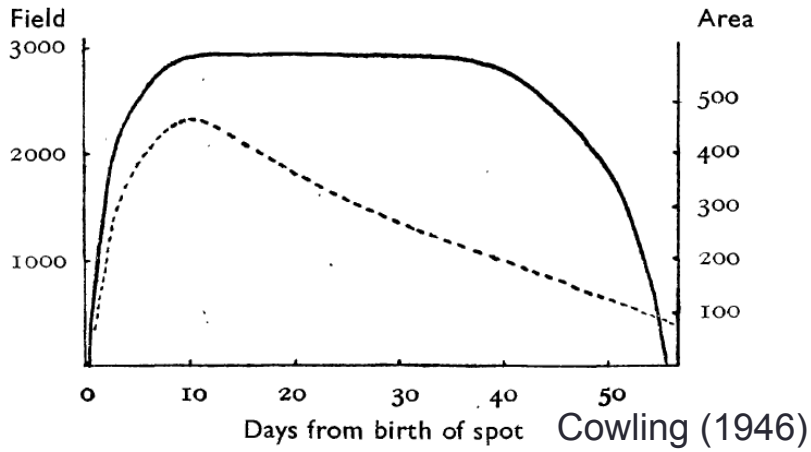


Effect of time difference: more impact on smaller spots !



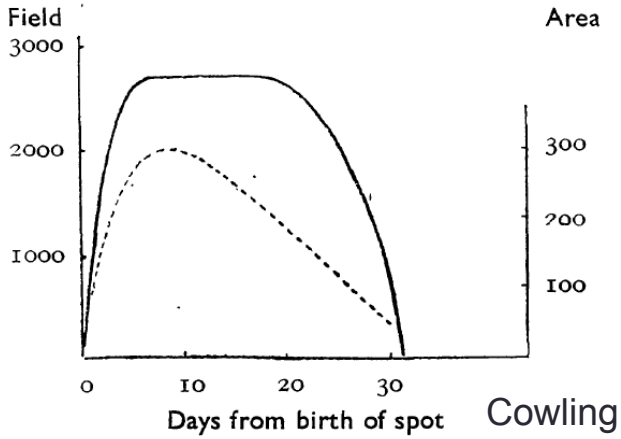
Smaller spots grow and decay faster

60d spot



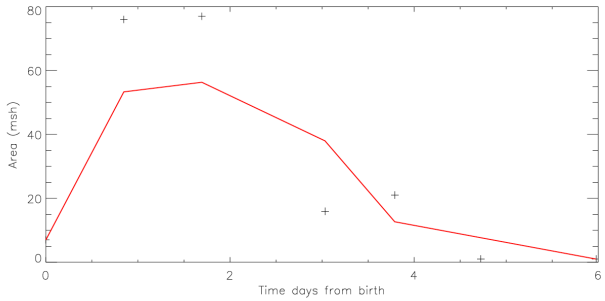
Cowling (1946)

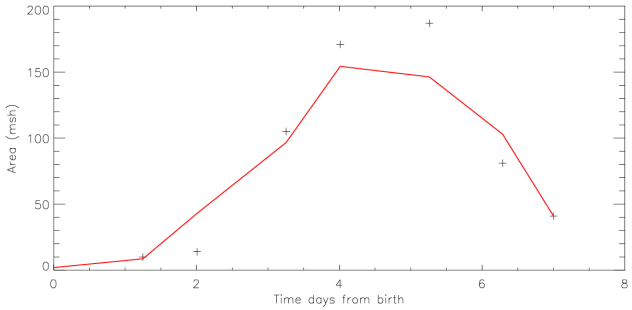
30d spot

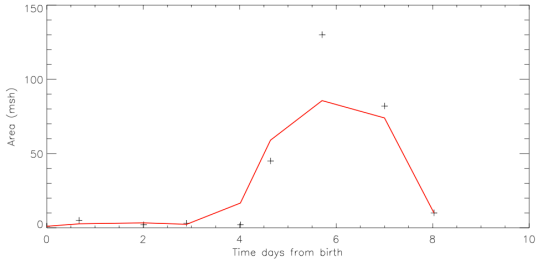


Cowling (1946)

Less than 10d spots



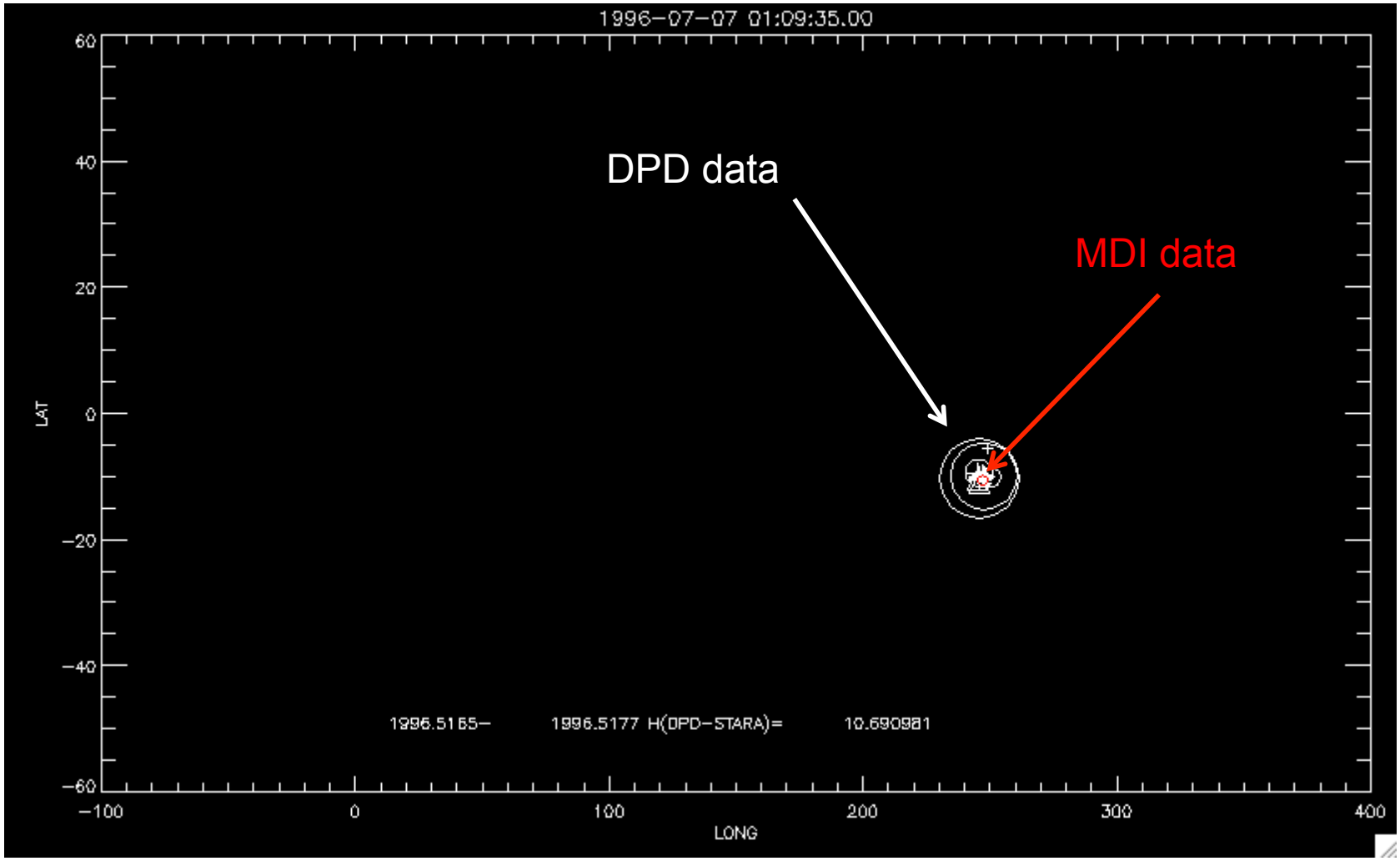




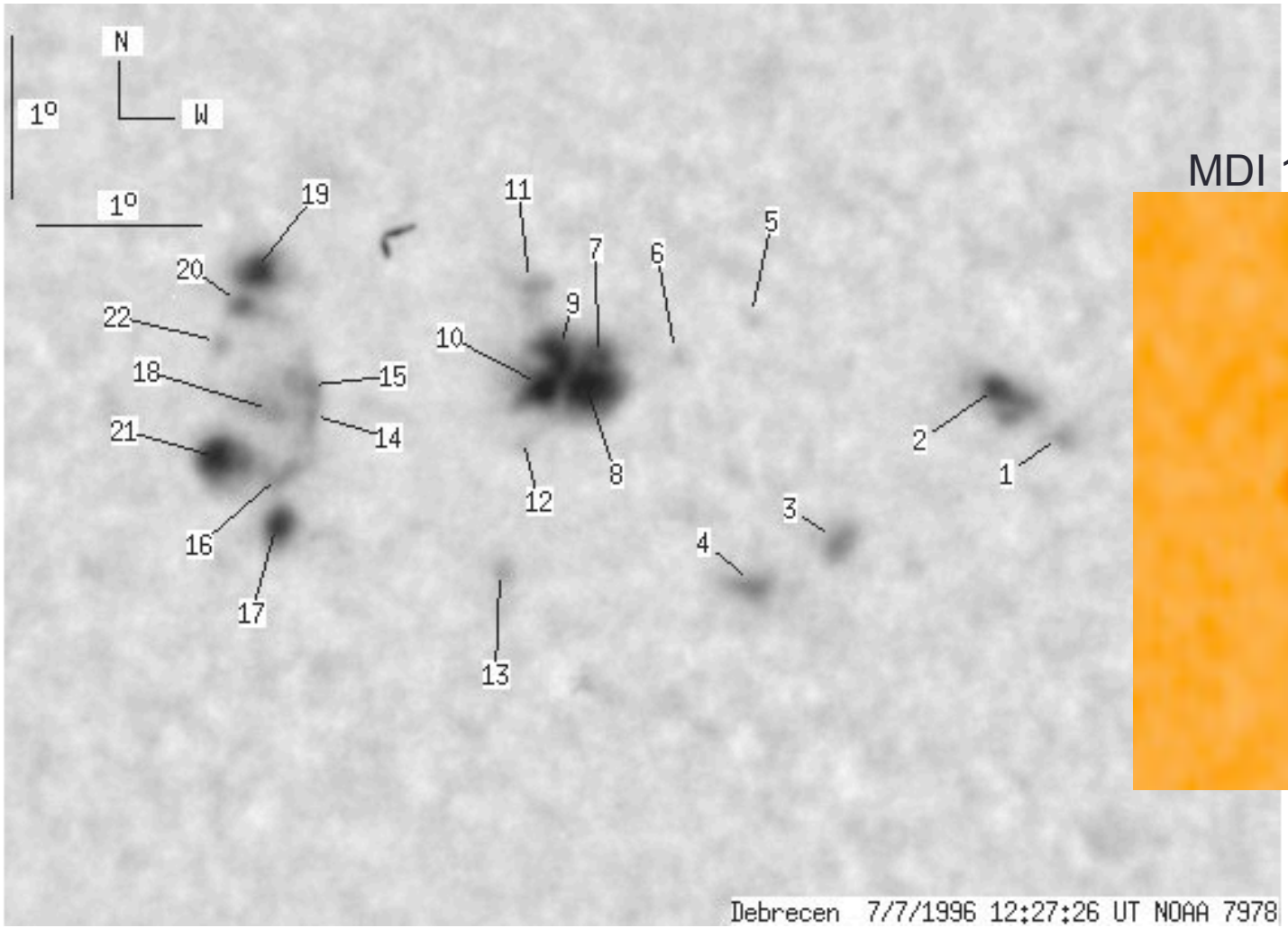
A CONCRETE EXAMPLE

Time difference and its consequences

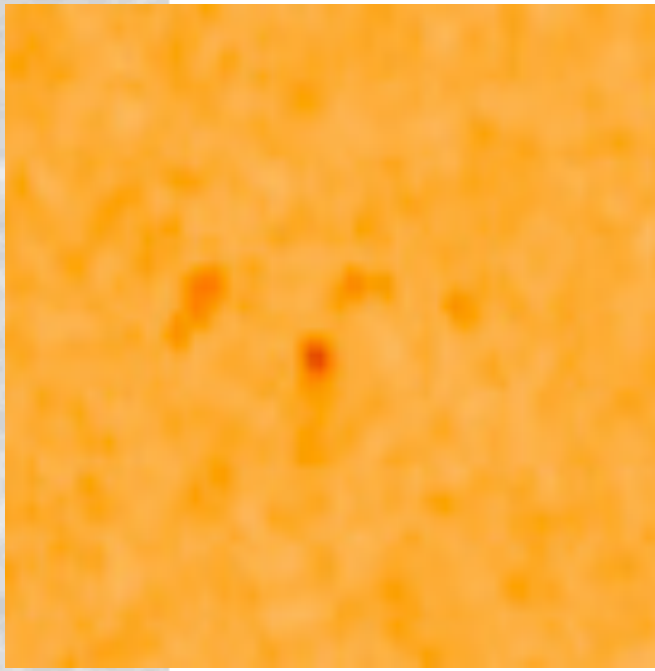
DPD (white) / MDI (red) comparison



Debrecen 1996/07/07 12:27UT

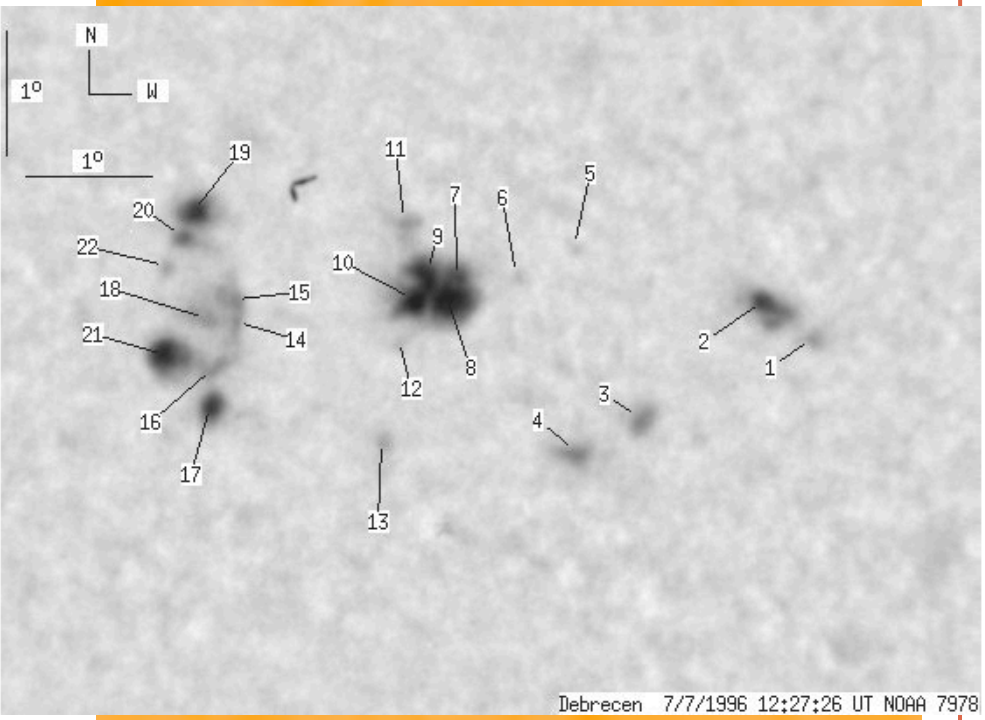


MDI 1:09 UT

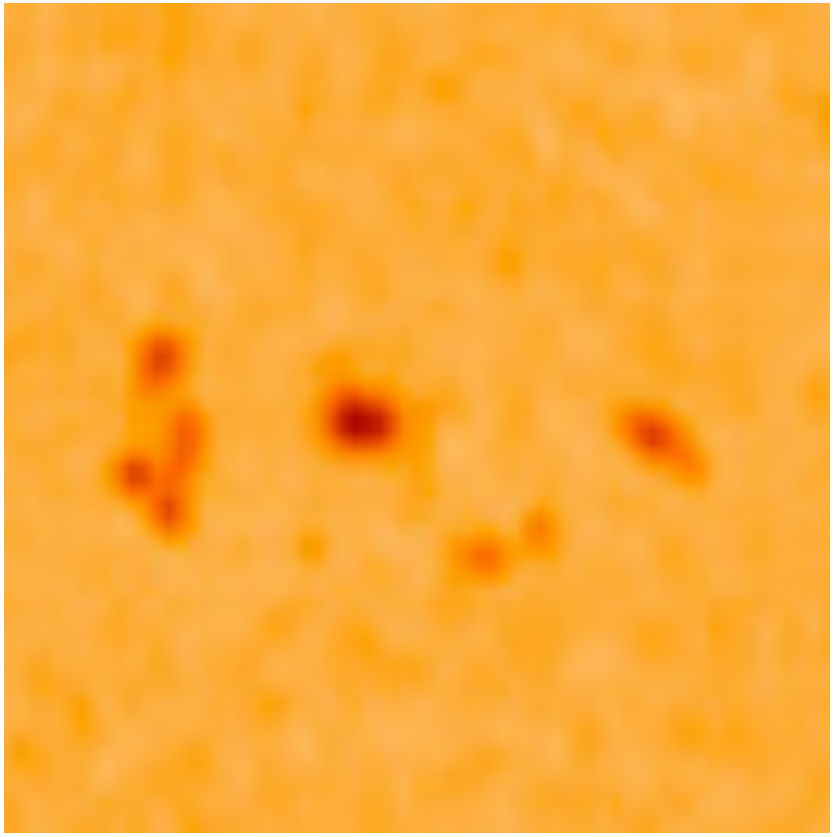


SOHO MDI

1:09



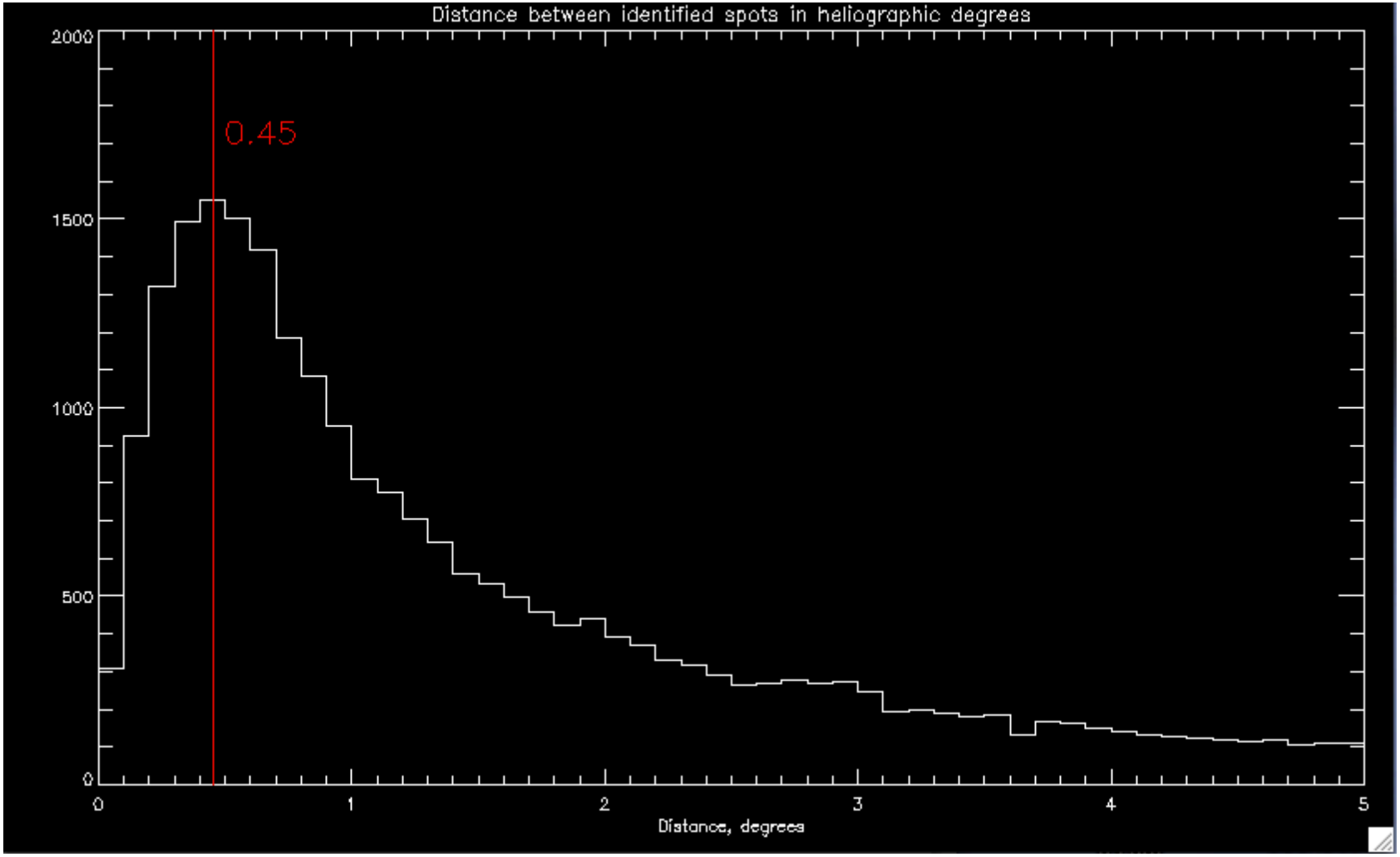
13:06



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

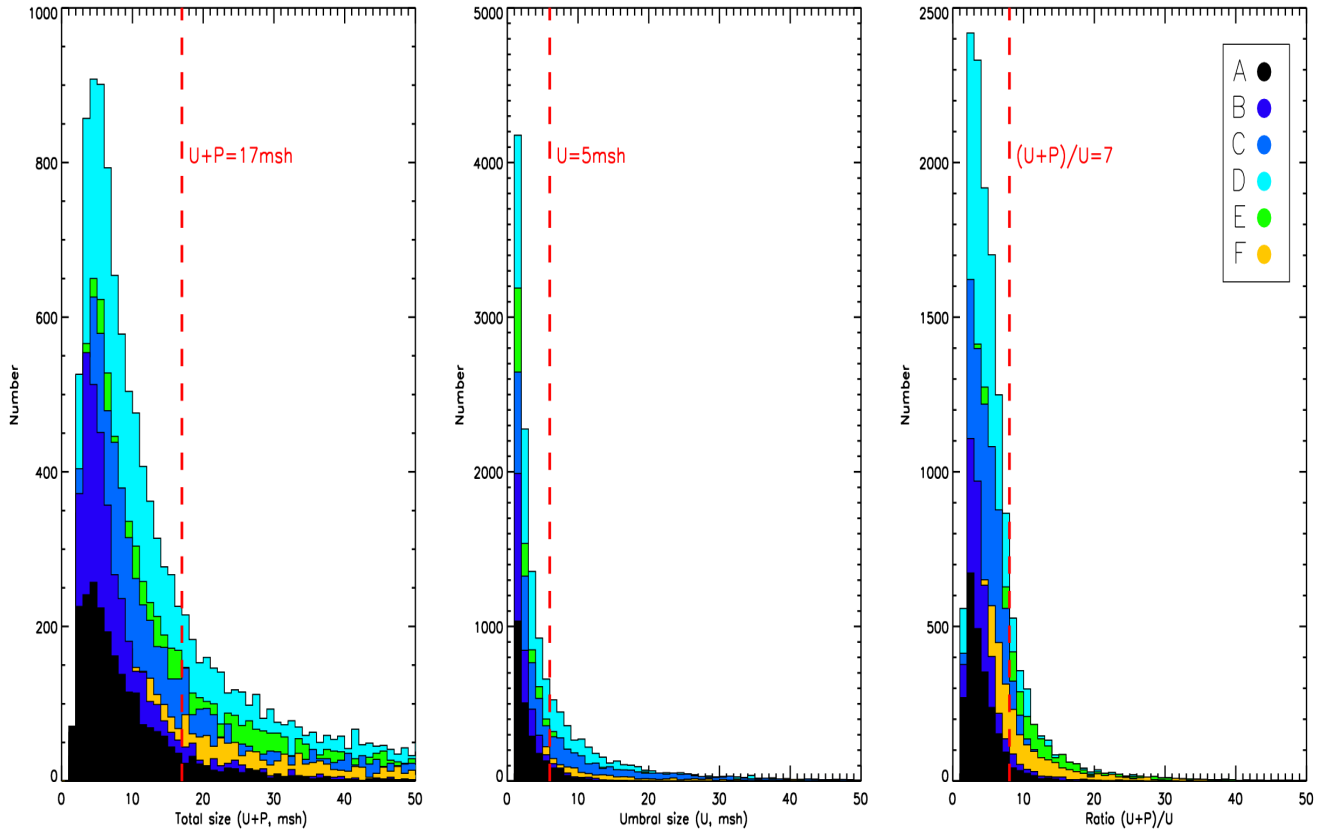
- From the distribution of sizes (next slide)

- "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)

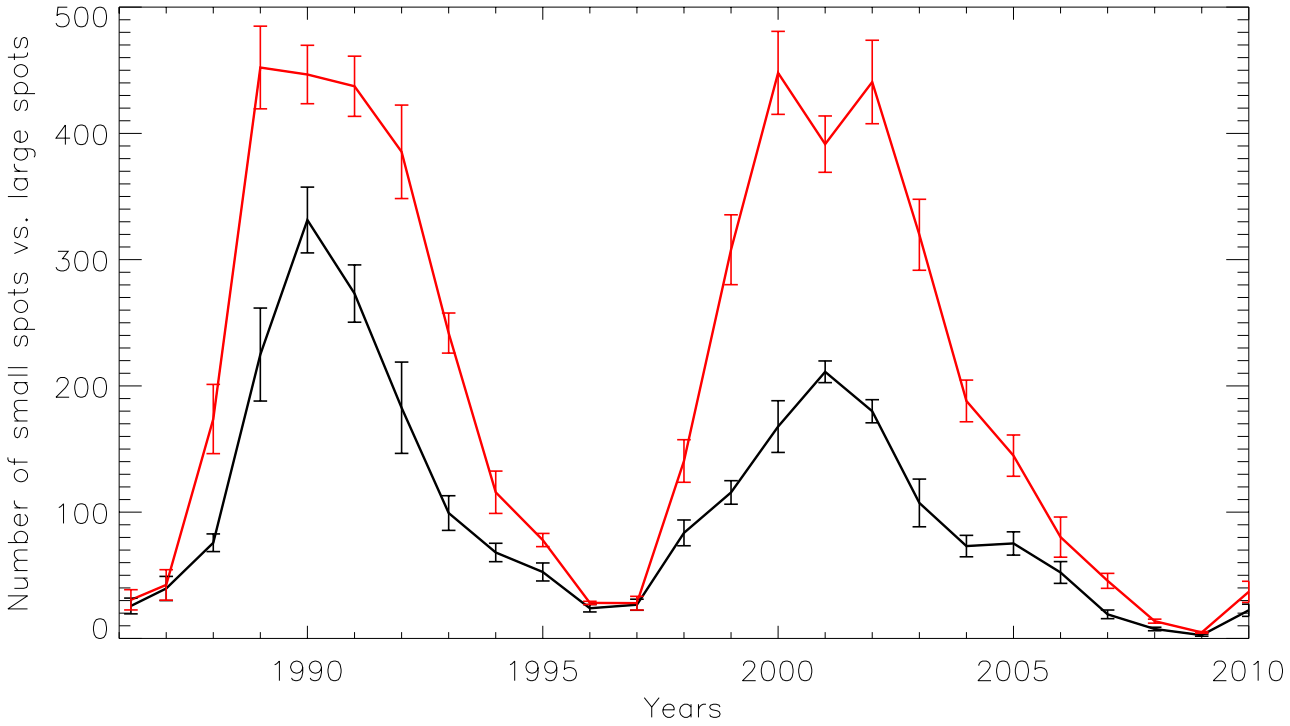
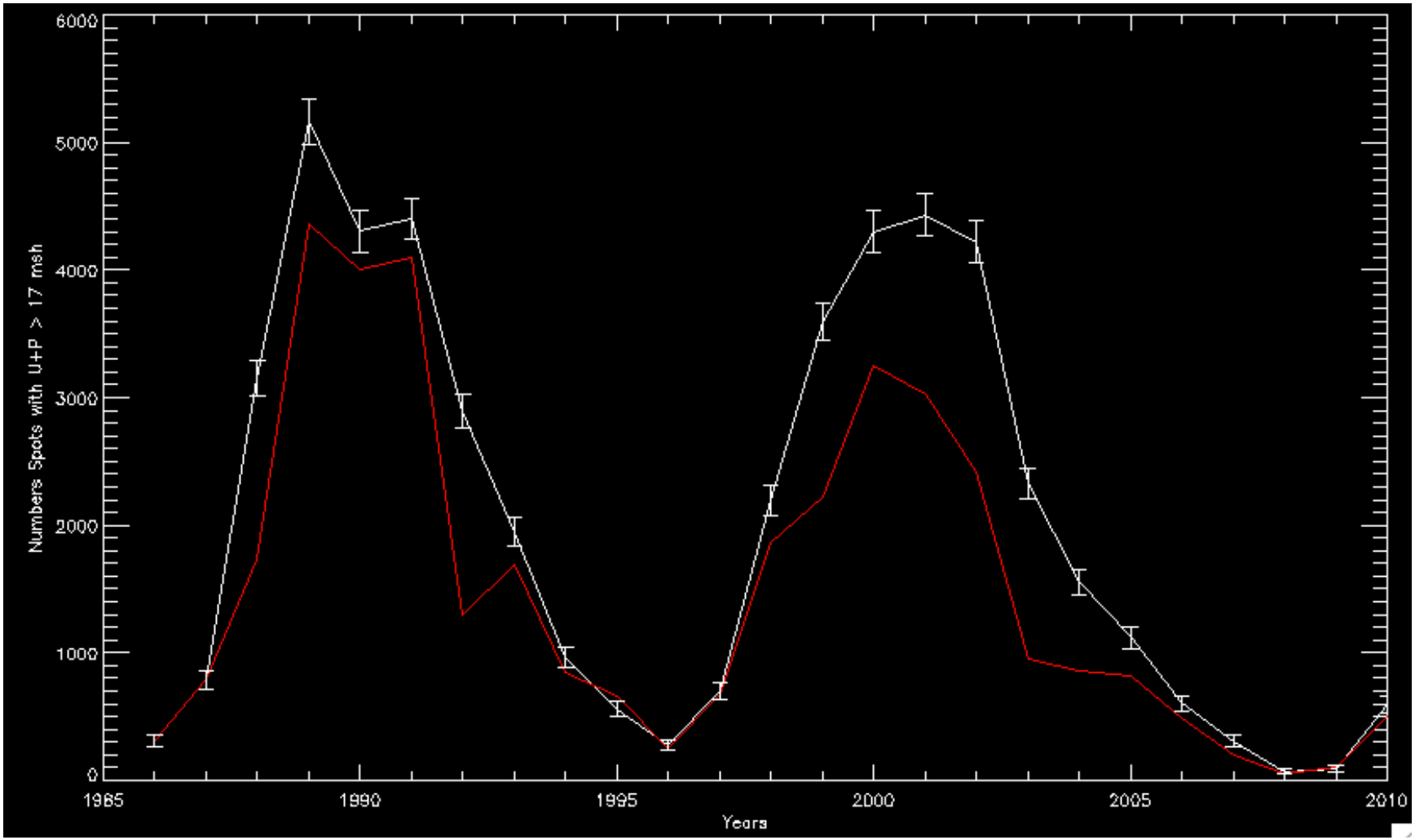


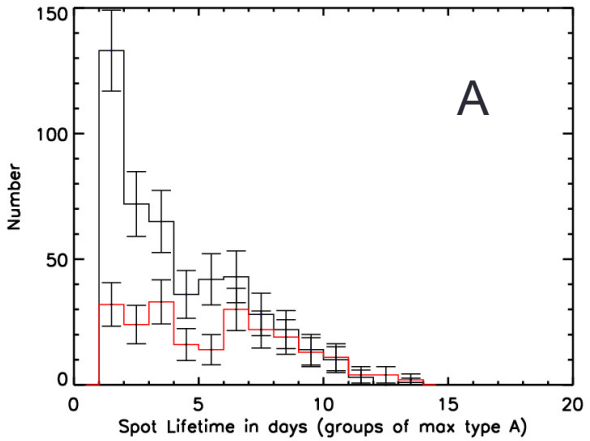
Fig. 4. Number of small (black line, U+P ≤ 17msh AND U+P/U ≤ 7) and large individual spots (red line, U+P > 17msh OR U+P/U >7) during cycles 22 and 23. The monthly average sunspot counts were smoothed with a one-year running mean and are given with corresponding error bars.

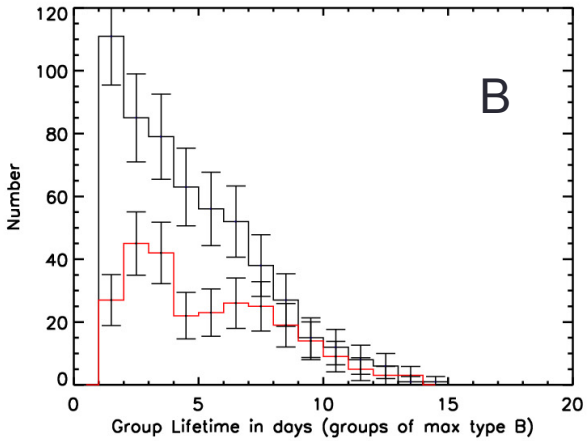
Small spots (2)

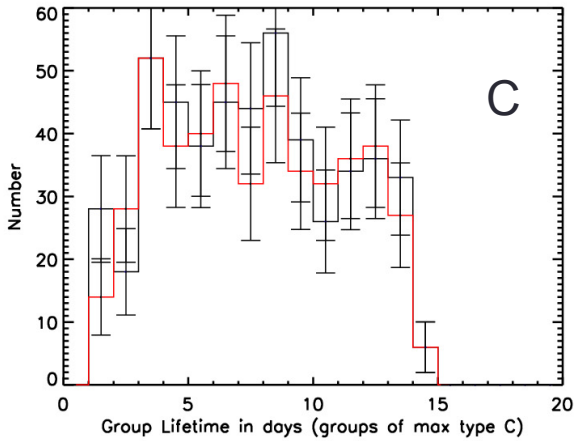


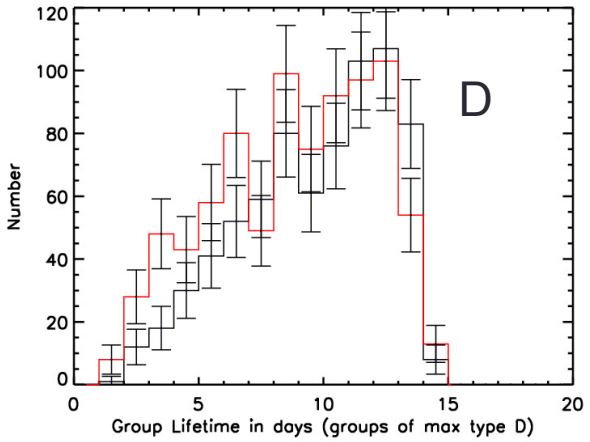
Small spots (3): Lifetime of groups

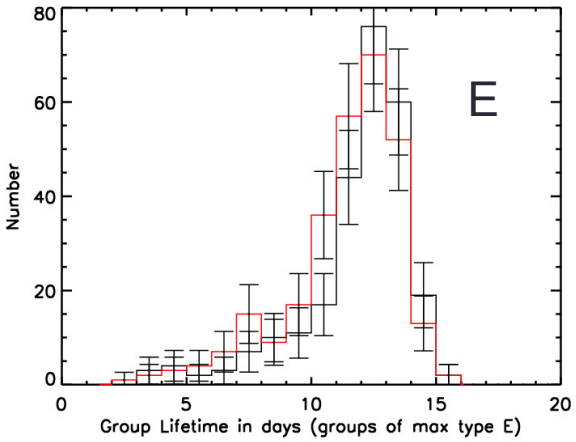
Cycle 22
Cycle 23

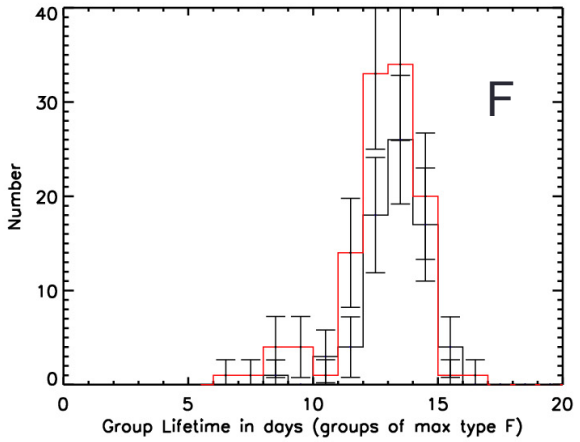




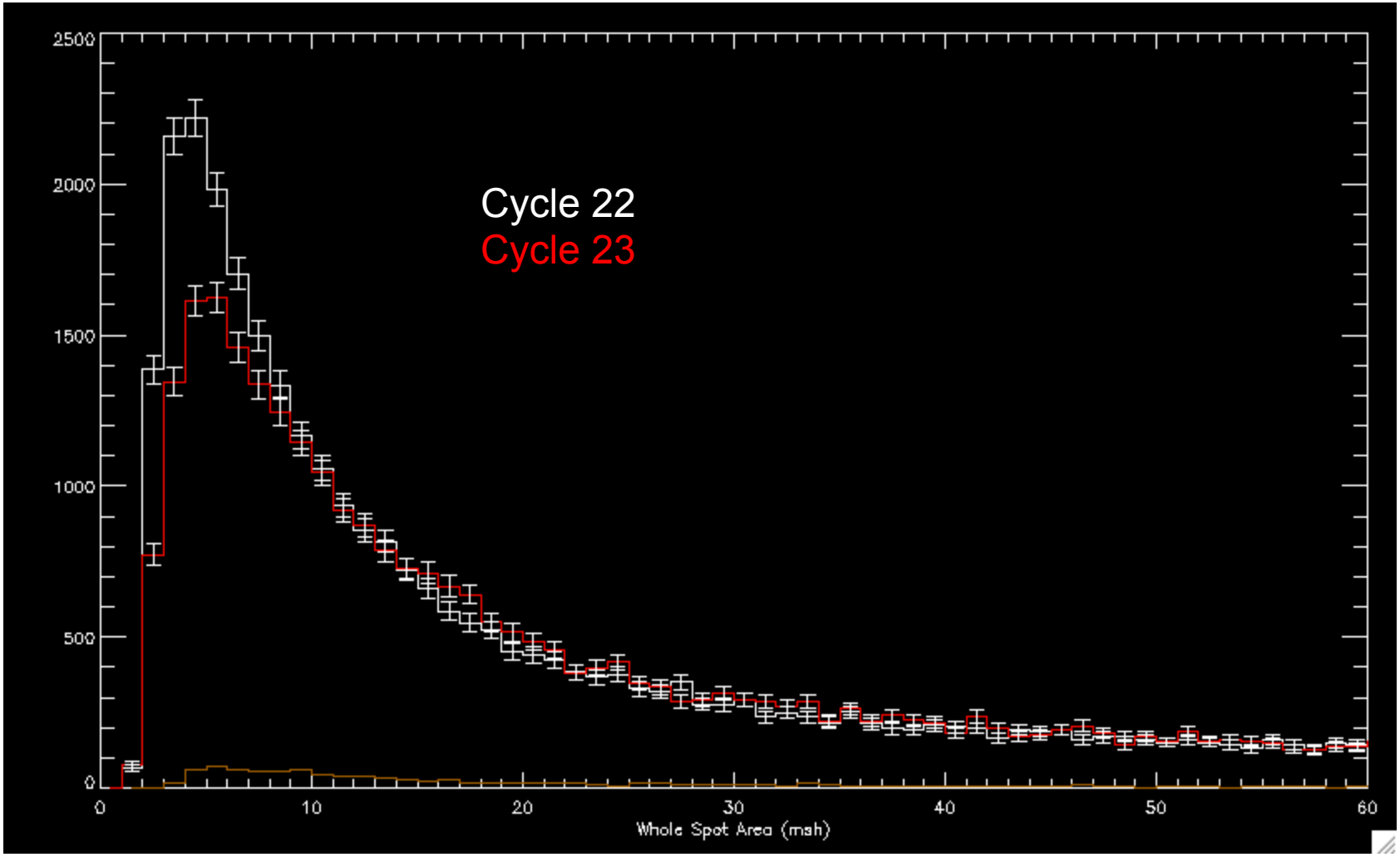




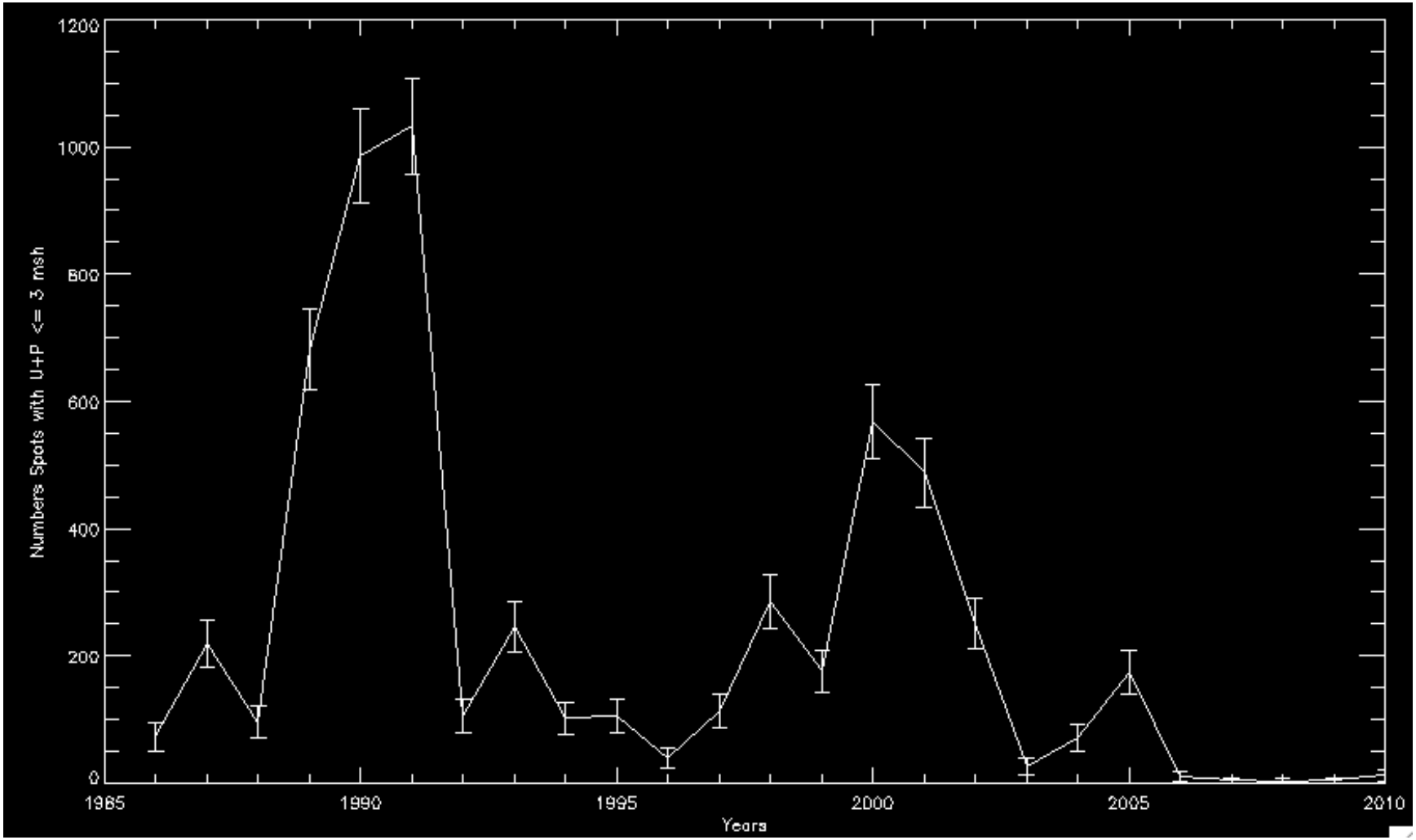




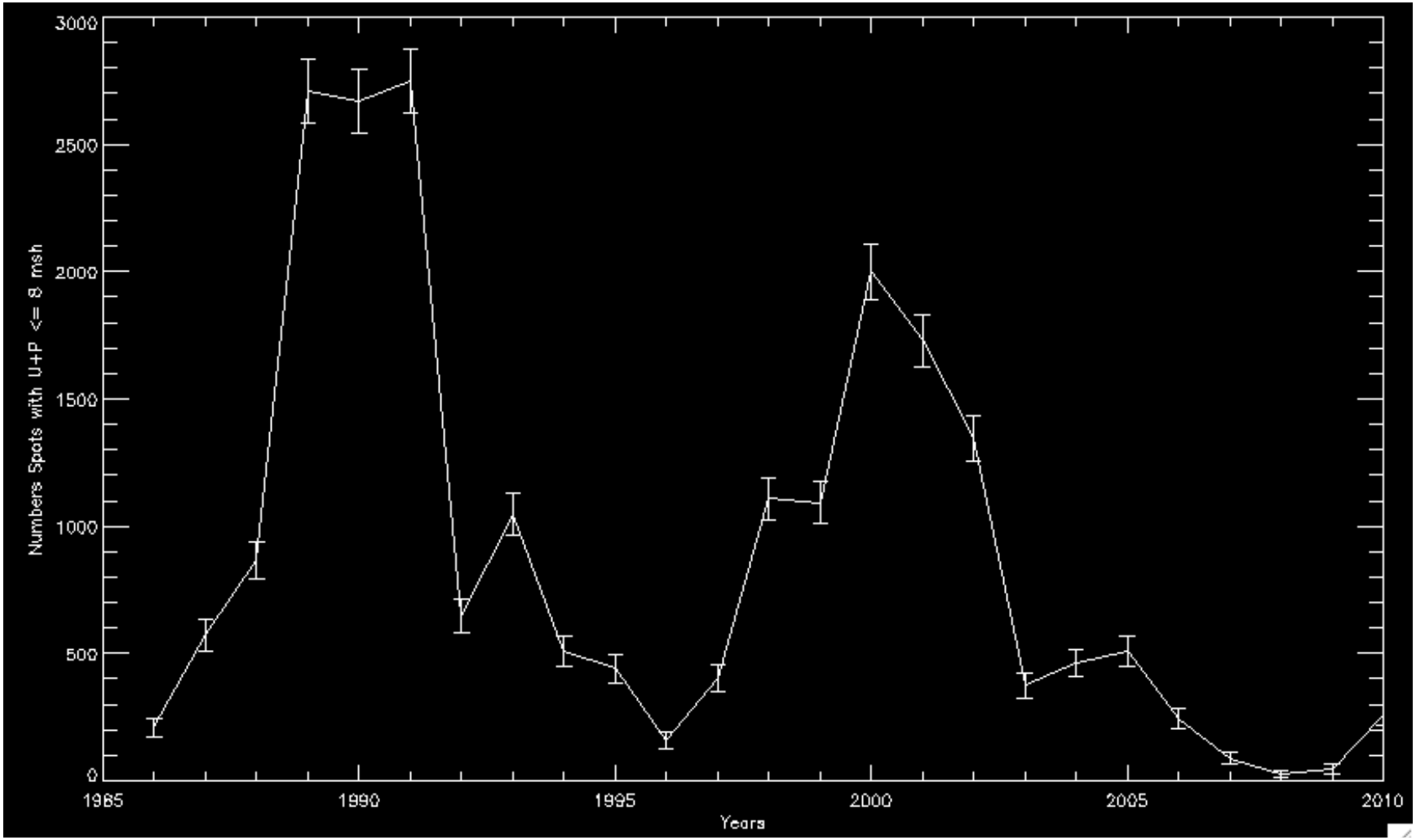
Distribution of Spot Sizes between solar cycles 22 and 23



<4 msh

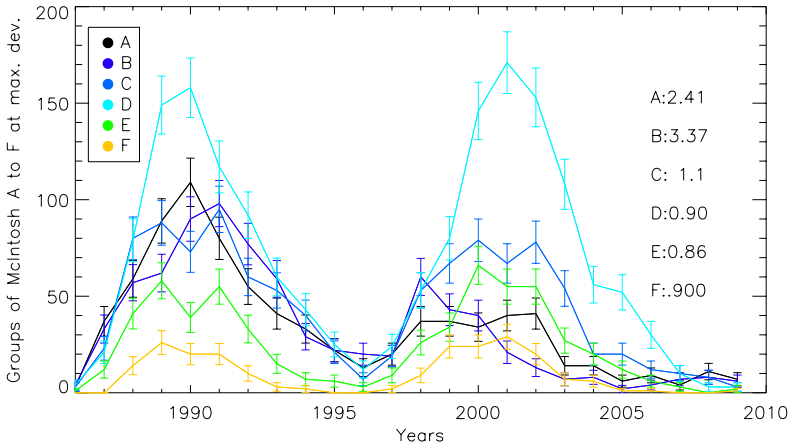

Numbers Spots with U+P <= 3 msh
1200
1000
800
600
400
200
0
1985
1990
1995
2000
2005
2010
Years

< 9msh

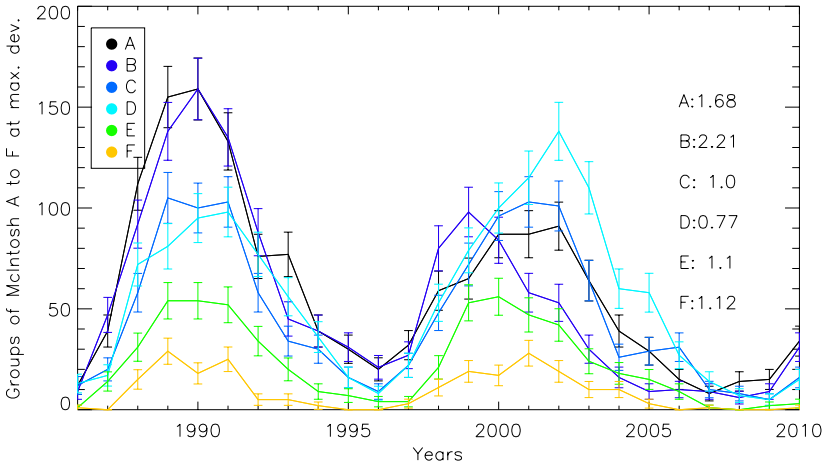

Numbers Spots with U+P <= 8 msh
3000
2500
2000
1500
1000
500
0
1985
1990
1995
2000
2005
2010
Years

USAF: 3 stations agree

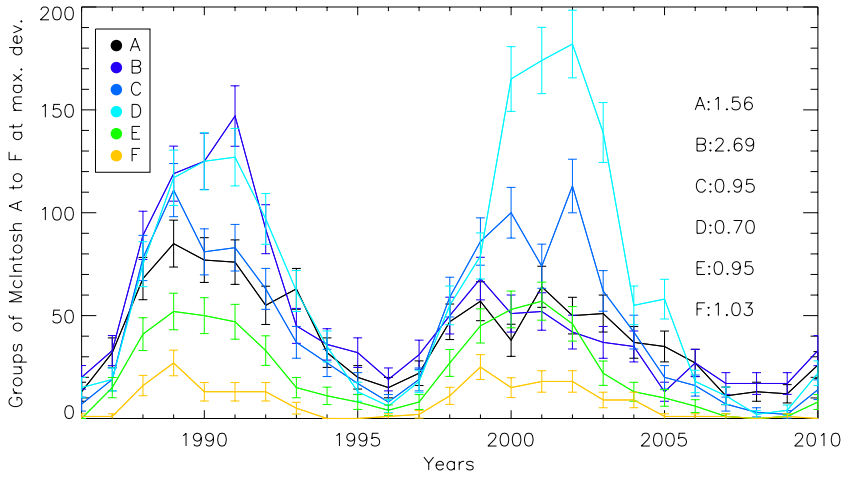
San Vito



Holloman



Learmonth



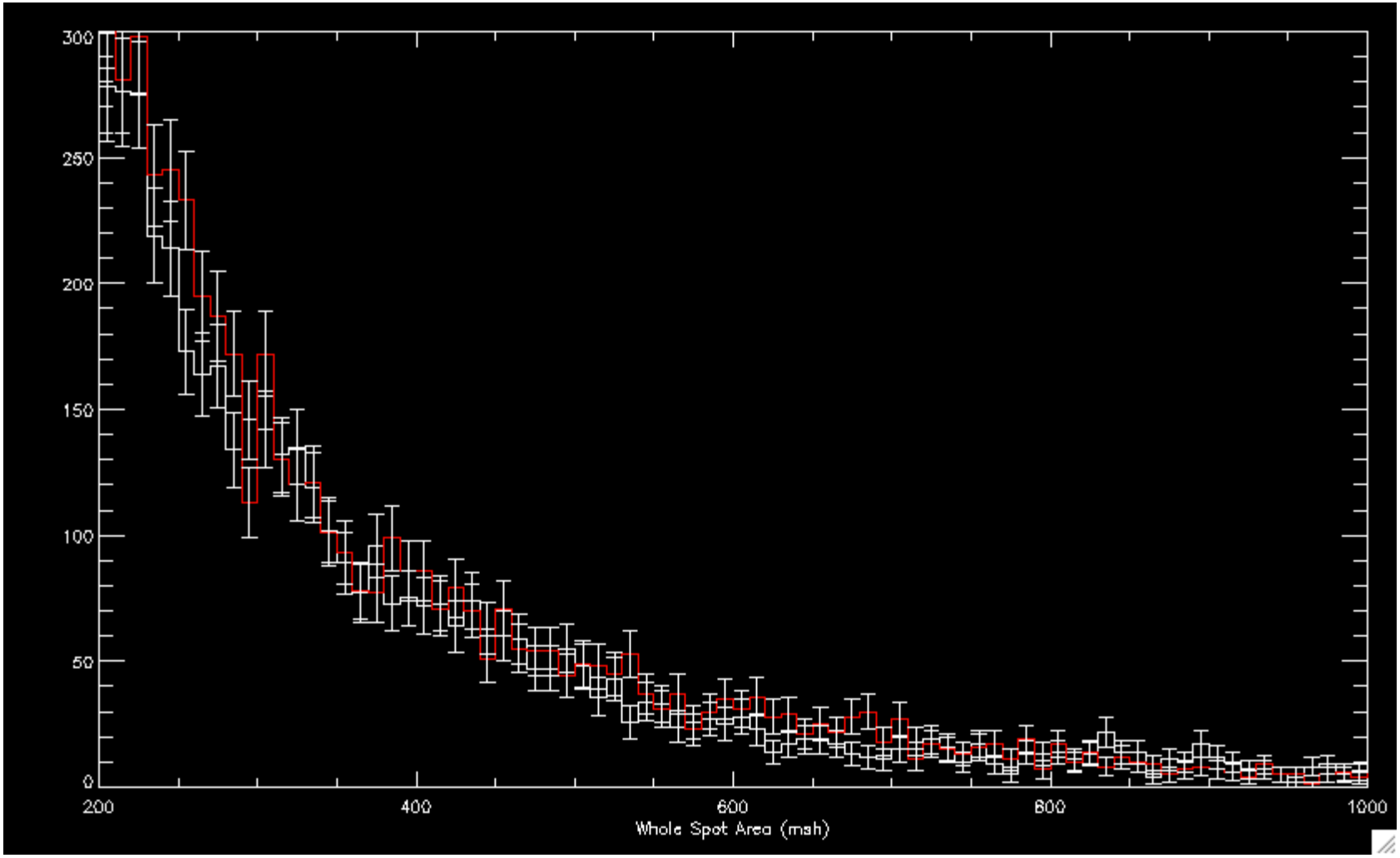
Smaller spots

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

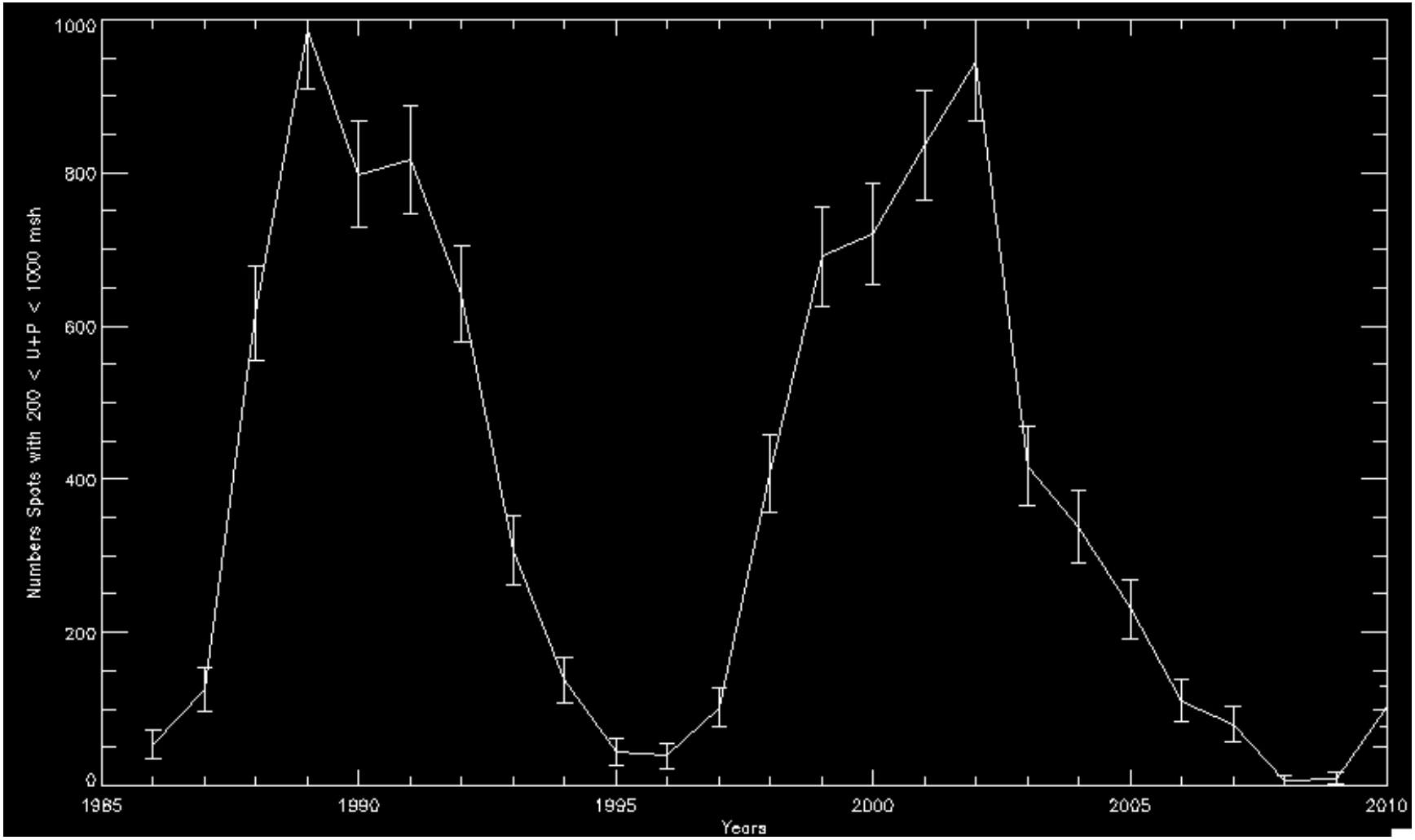
LARGE OR VERY LARGE SPOTS

What happened to them ?

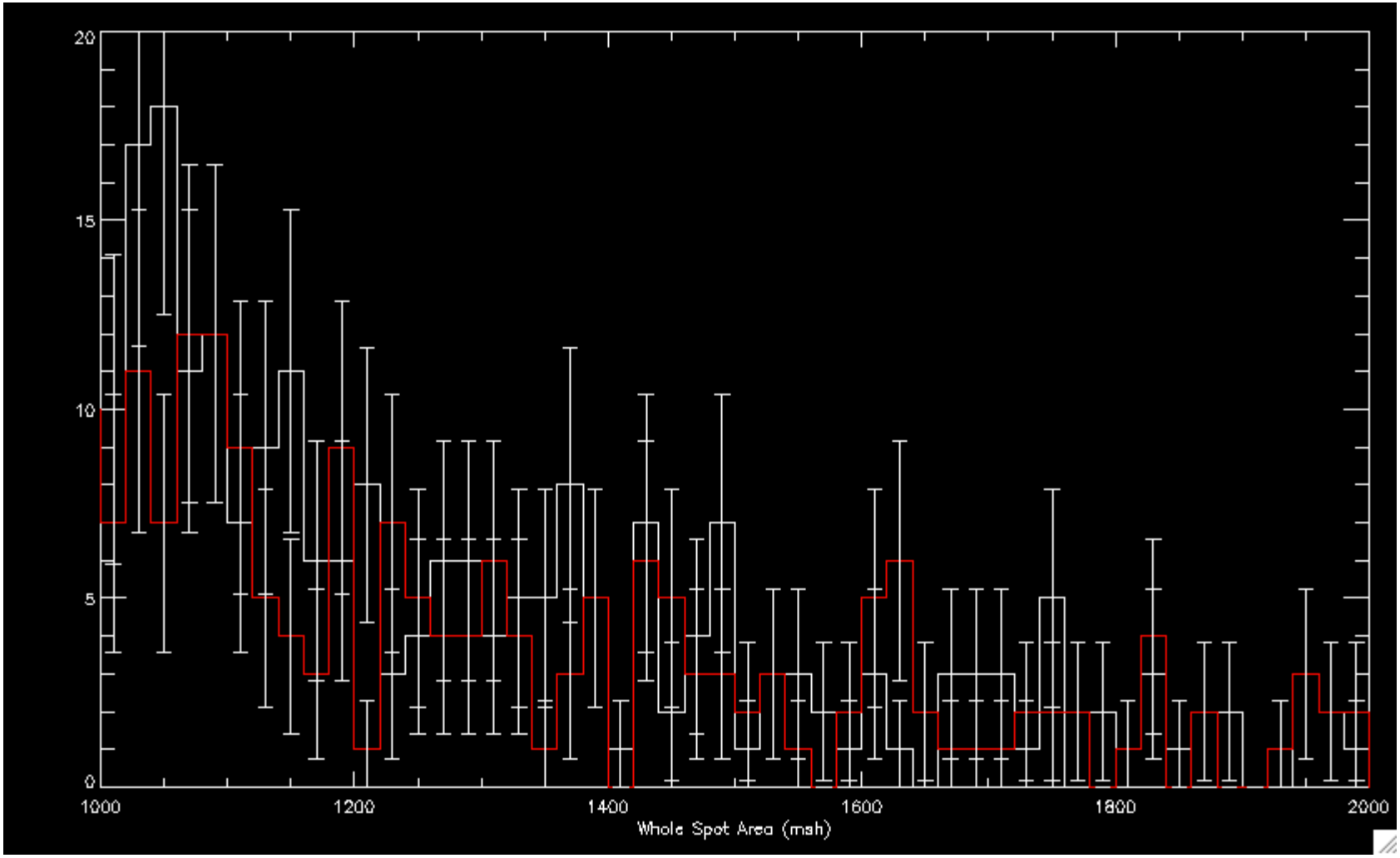
Large spots


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

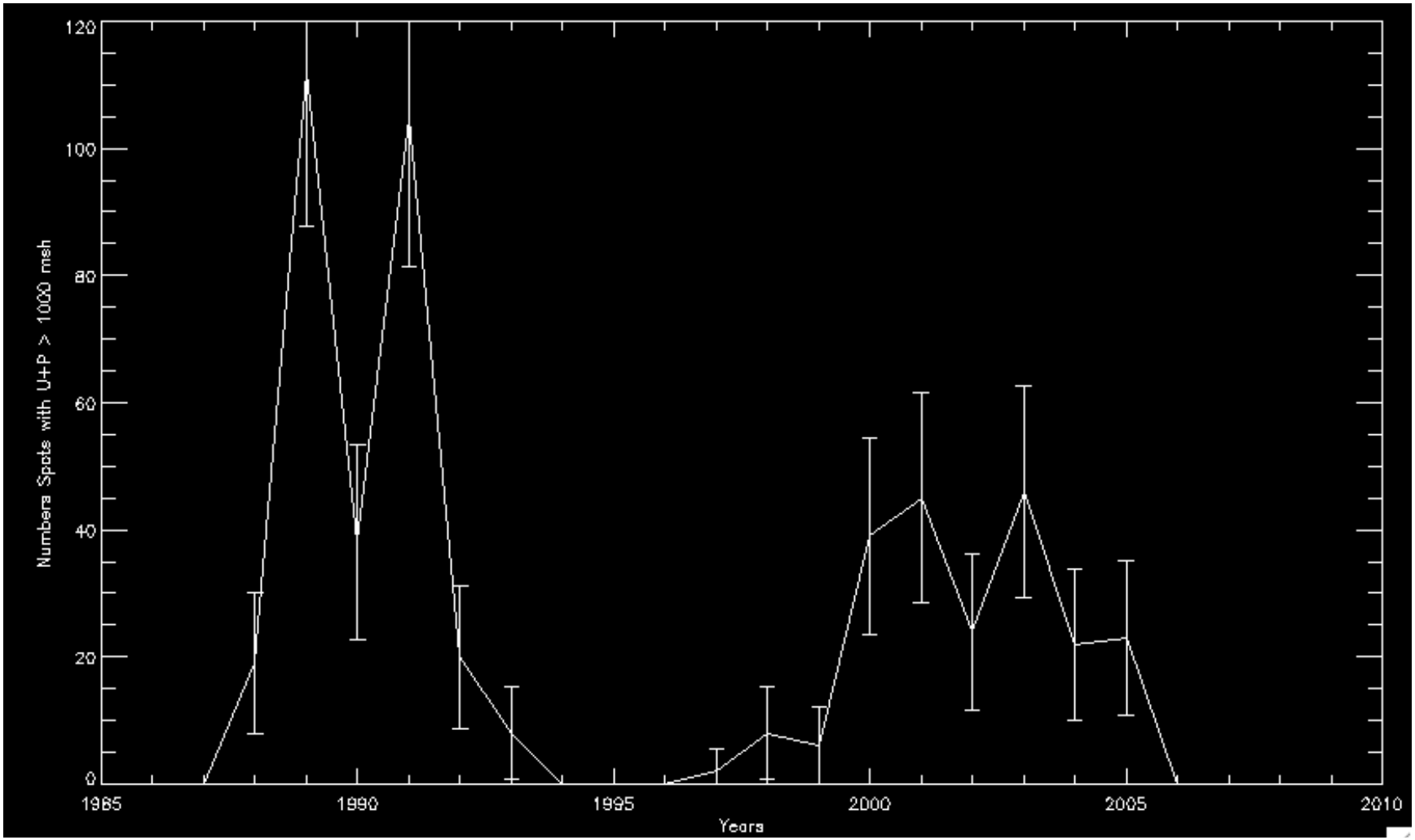
Large spots


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

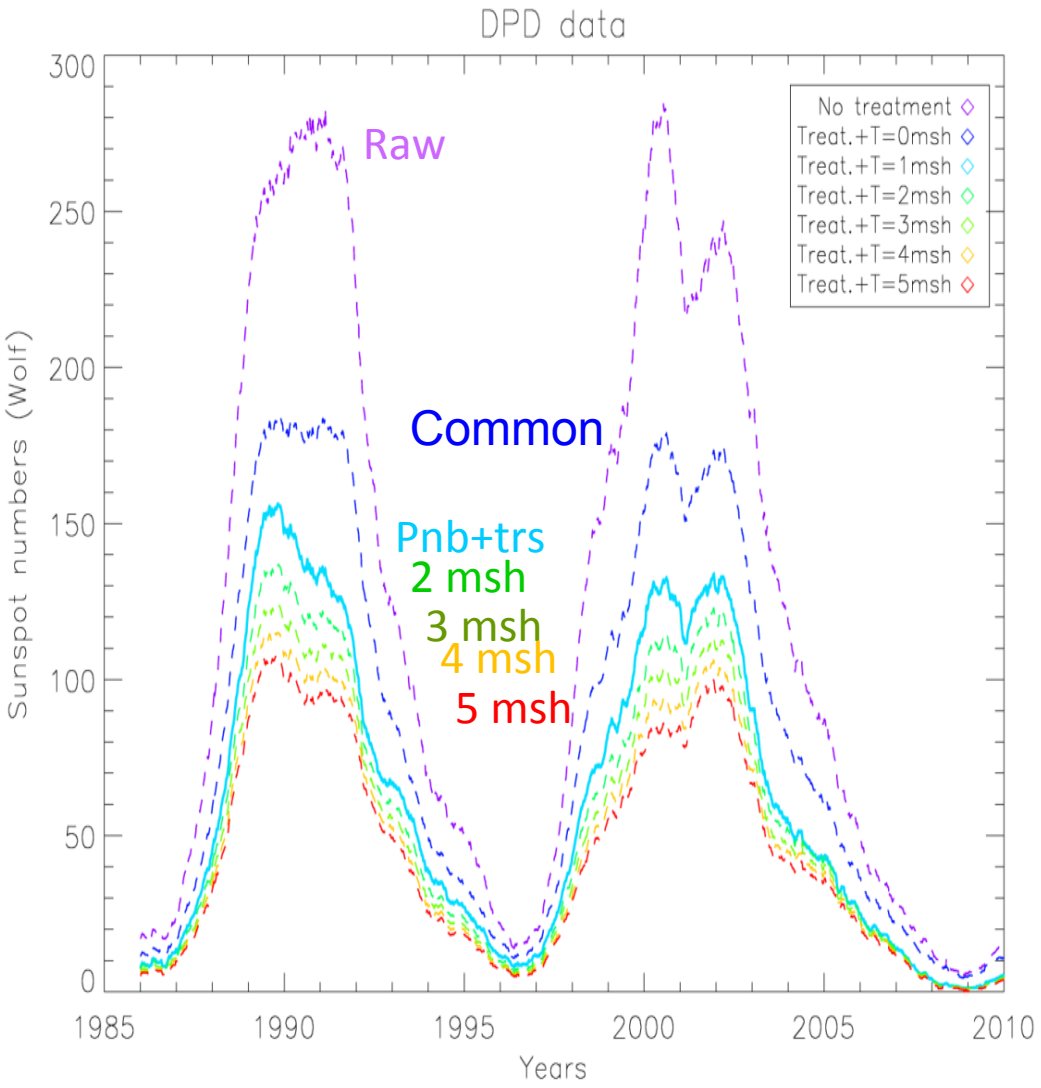
- The DPD and STARA catalogs identify the same spots with 2 different methods on the same period.
- Data are very similar in both catalogs
- DPD data indicate that a significant part of the smaller spots disappear between cycle 22 and 23.
- There does not seem to be a significant difference in the number 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

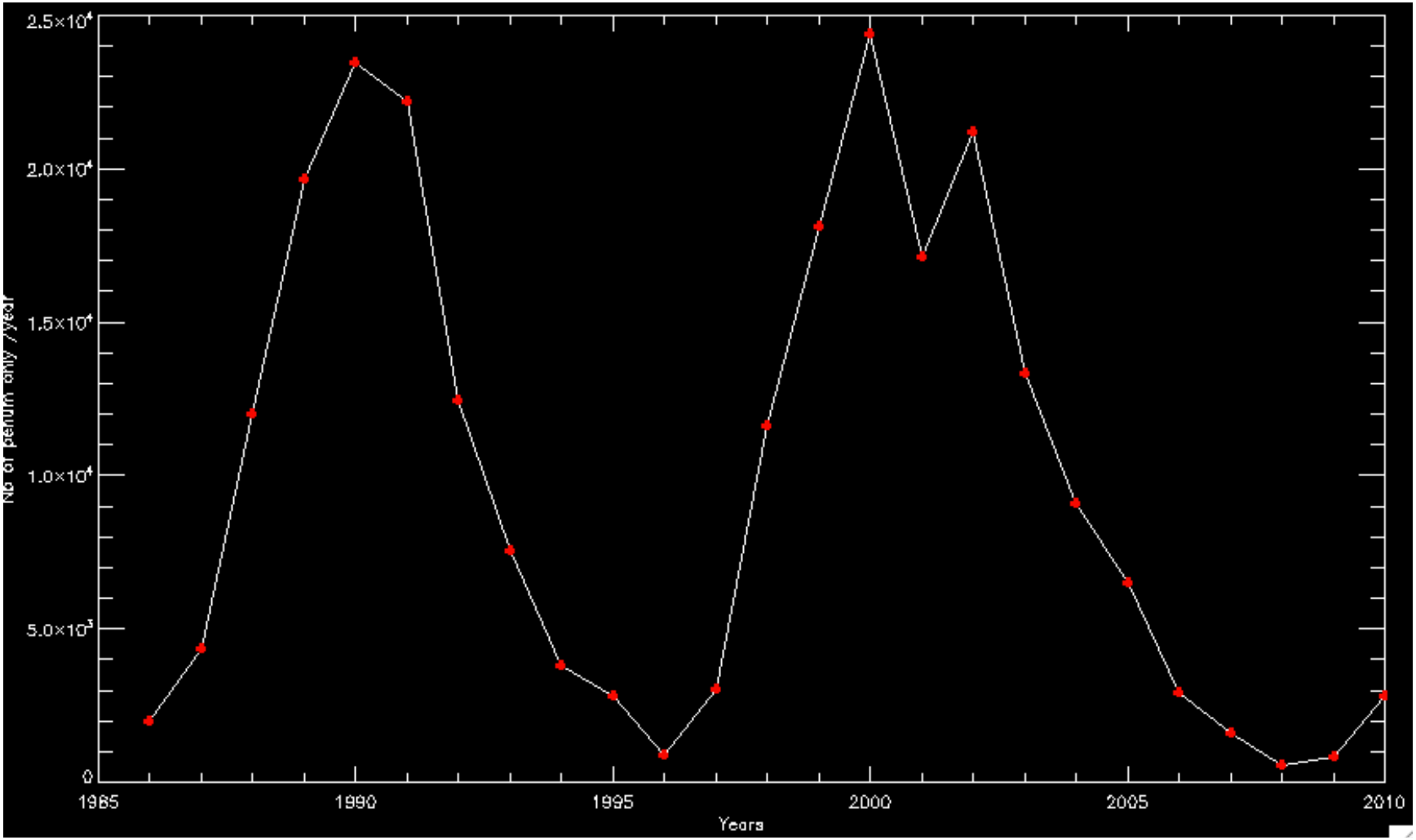
- Strong change for T=1 msh: (D= 1,92" = 1400km)
  - Scale: W= R_i
  - Correlation increases (matching cycle envelope)
- Smaller and progressive change for T> 1 msh:
  - Scale: W < R_i
  - No more change in the cycle envelope



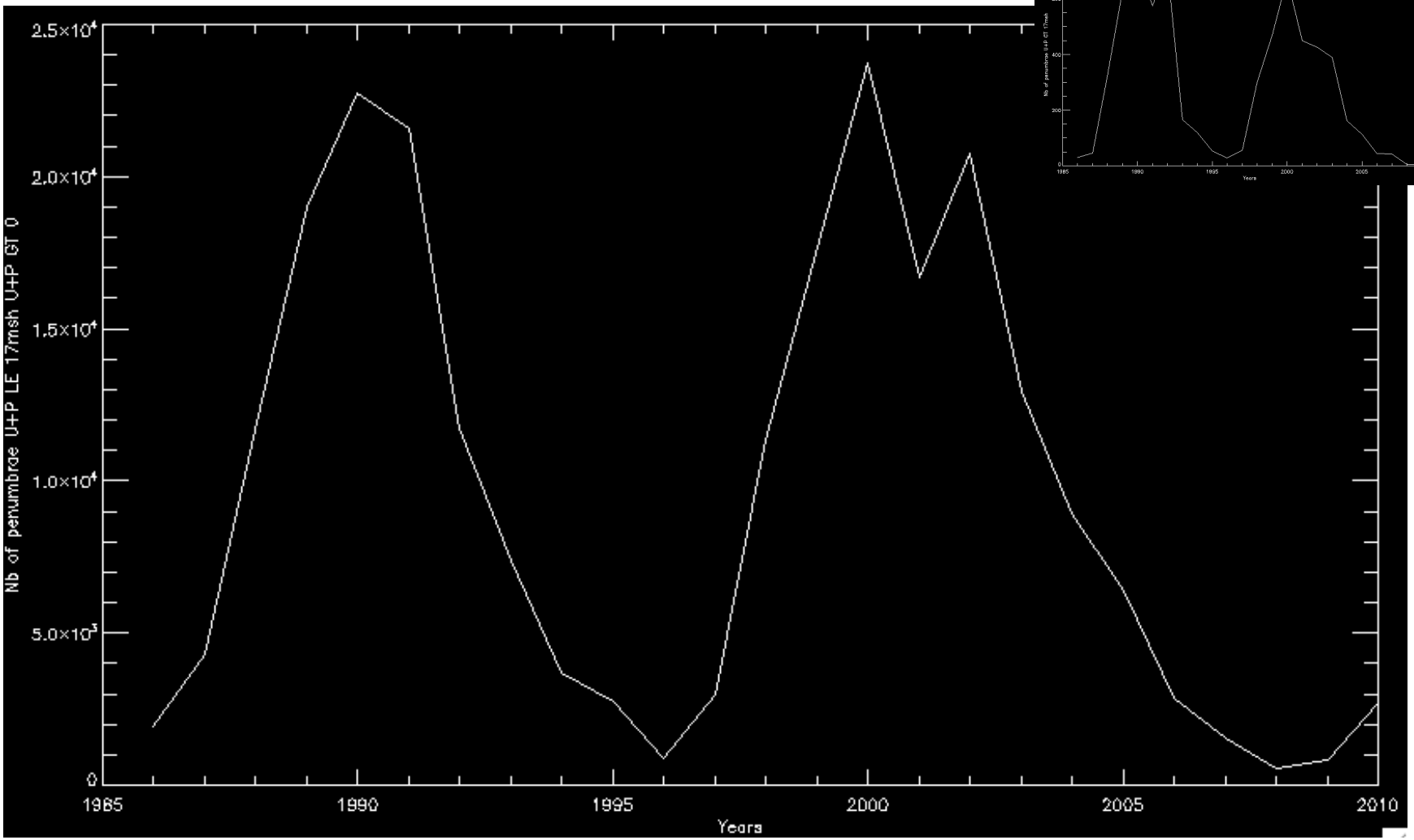
How to filter these structures from the catalog ?

- 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.

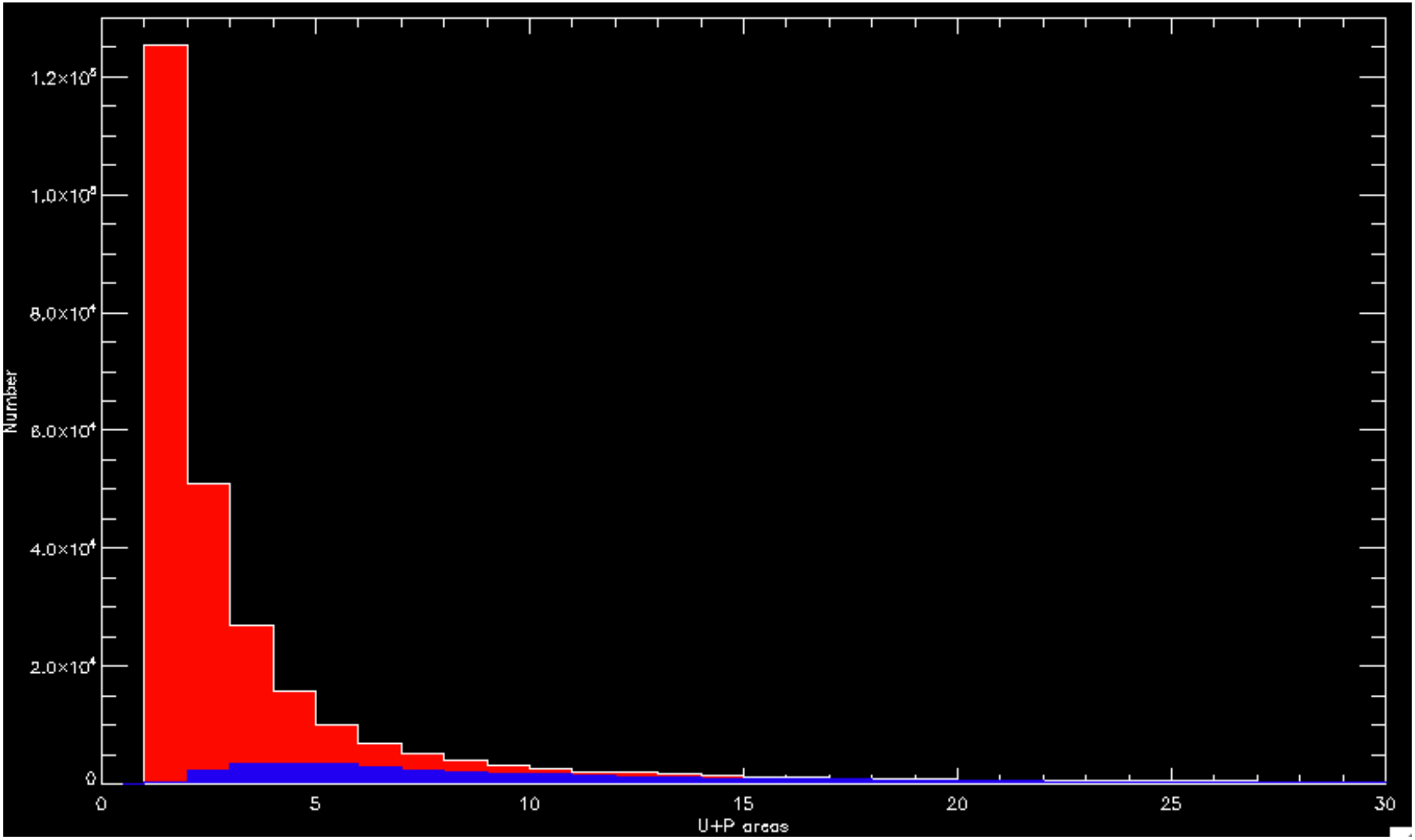
Penumbra only spots



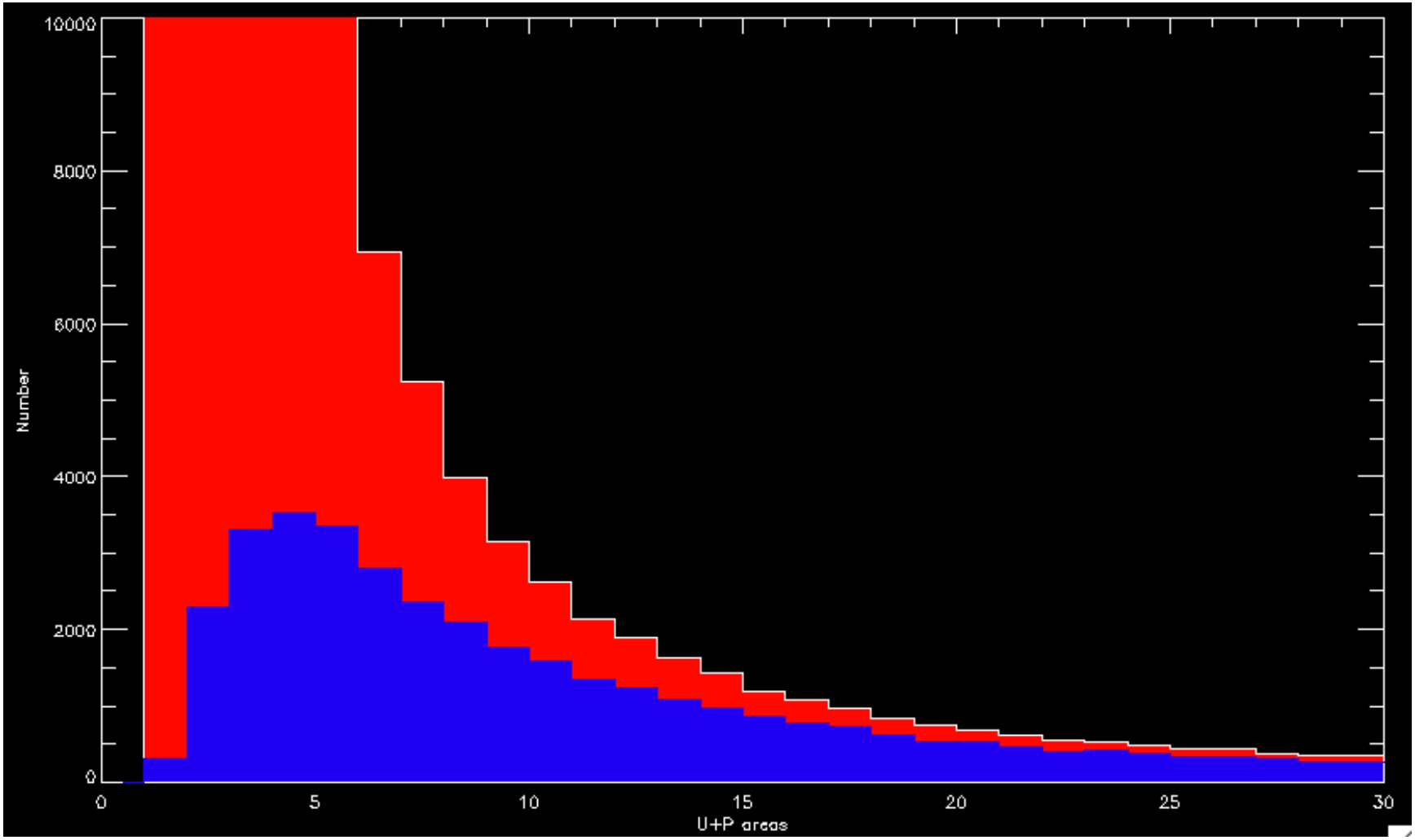
Large and small penumbrae only



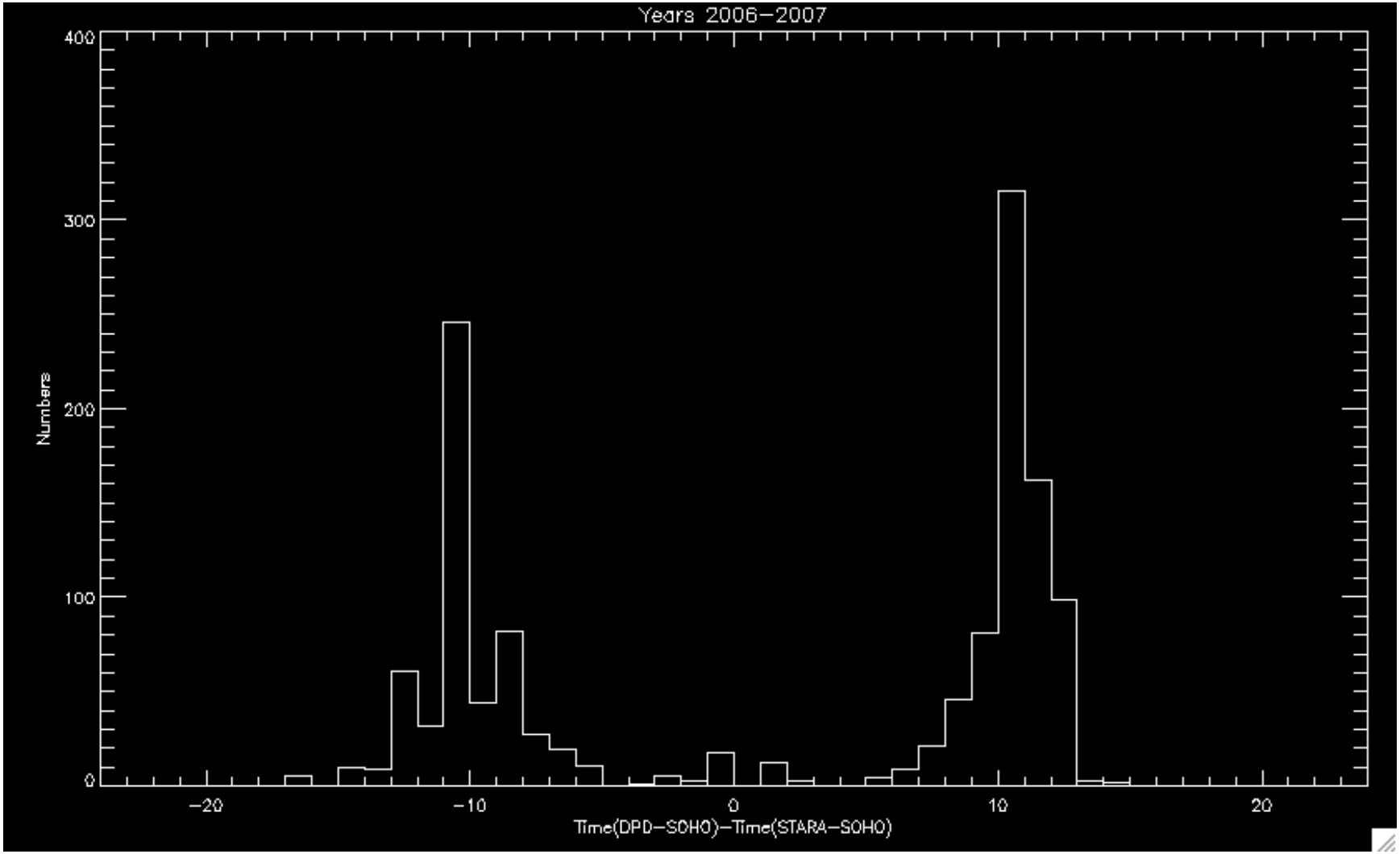
Blue: penumbrae filtered out



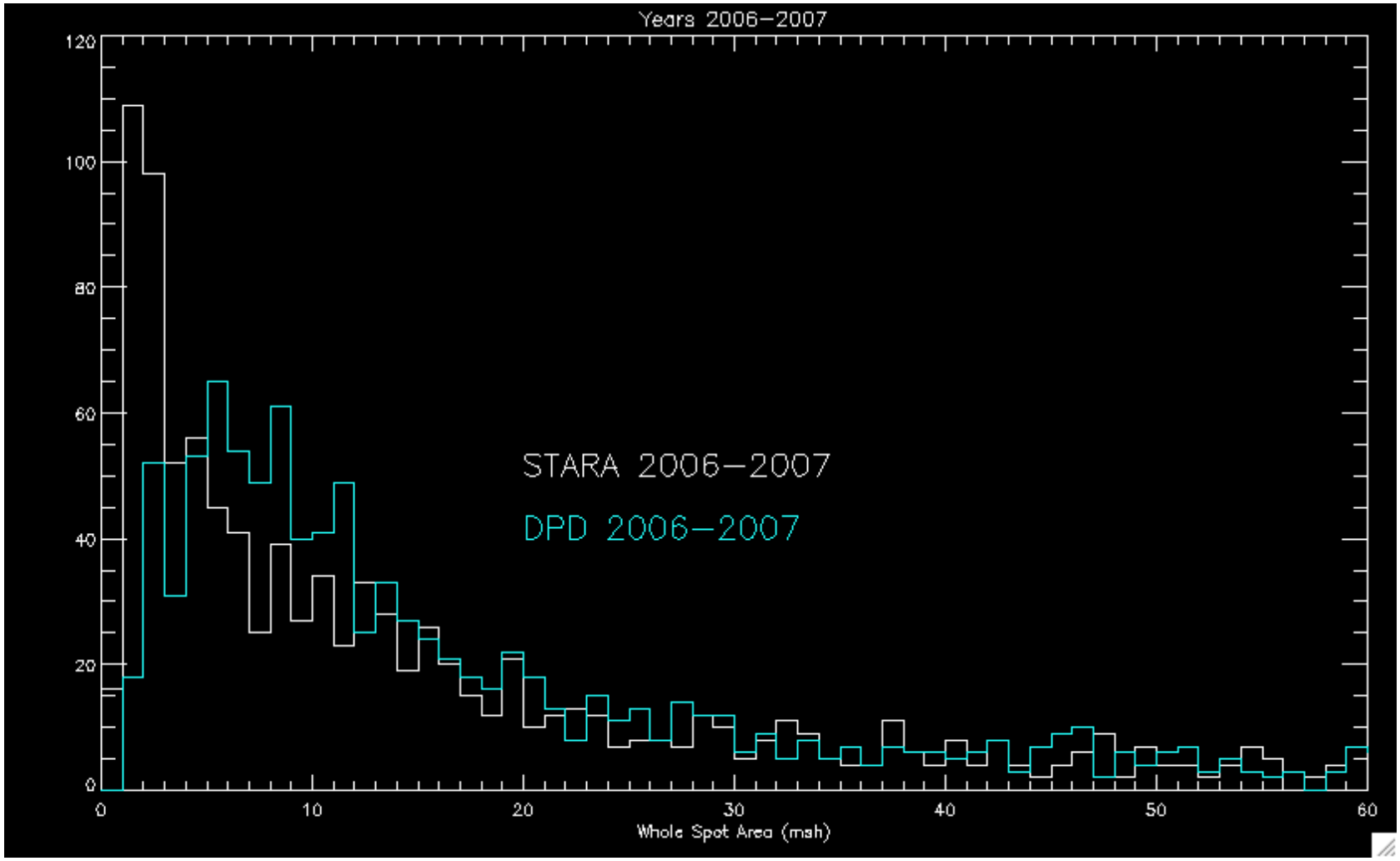
zoom



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…)