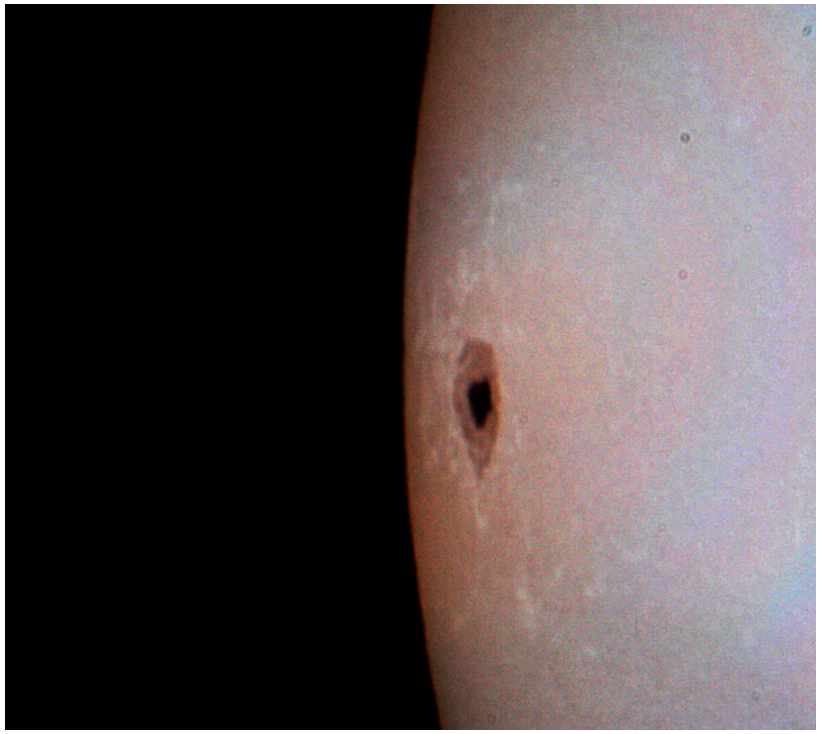
A revisit to the phenomenon of classic Wilson effect in sunspots



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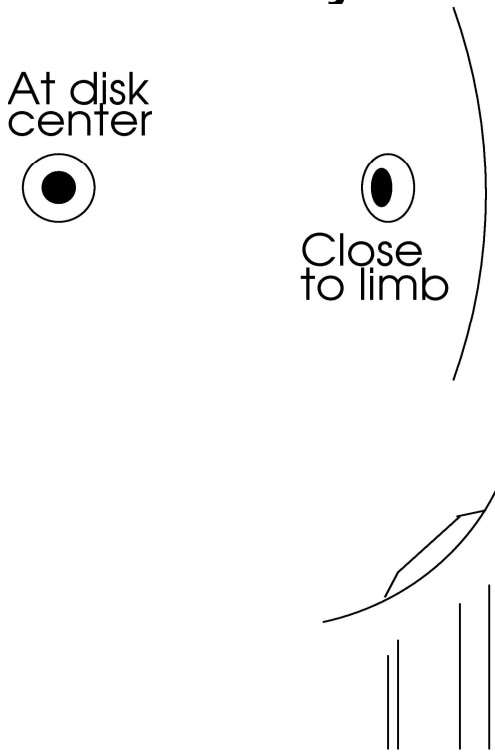
The Wilson effect

- Discovered in 1769 by A. Wilson
- Width of spot penumbra on disc center side reduces rapidly as it approaches the solar limb
- Effect caused by sauce pan shape of sunspot



Wilson effect in a mature sunspot

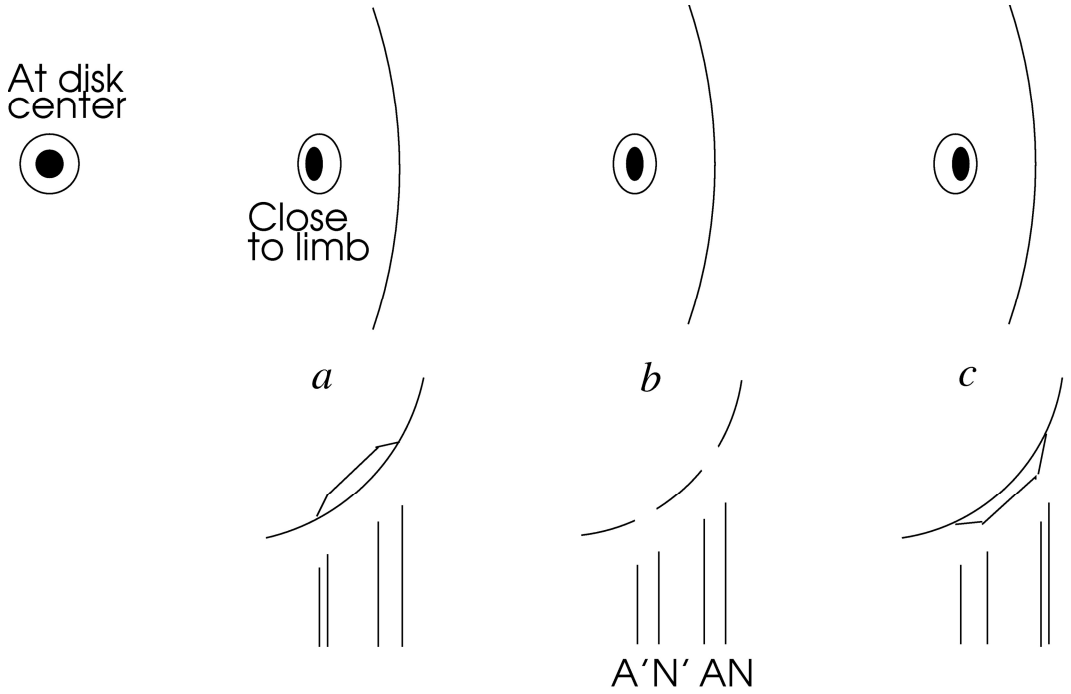
Physical conditions in umbrae

- Wide range of values reported by observers for Wilson depression (Z_w)
- Chitre(1963) estimated 500 km for 2500 G
- Gokhale & Zwaan (1972) reviewed observations and estimated Z_w of 600 ± 200 km
- Large number of cases with no Wilson effect or inverse effect reported but ignored
- Wilson depression taken to be present in all sunspots

Our studies at Kodaikanal

- 20 cm full disk photoheliograms
- 580 epochs of 253 sunspots out of >2000 selected for study
- Sunspots with well defined umbrae as well as penumbrae selected, irrespective of being single, accompanied or in complex groups
- Sunspots with light-bridges, split umbrae or broken penumbrae or those with high facular obscuration, were not chosen
- Measurements made on ‘original’ plates (not prints)

Technique & accuracy of measurement



Penumbral width parameter:

$$f = AN / A'N'$$

Measurements east-west < 30° and radial direction beyond this

Average of 4 measures at each of 4 different locations around mid-latitude of sunspot taken

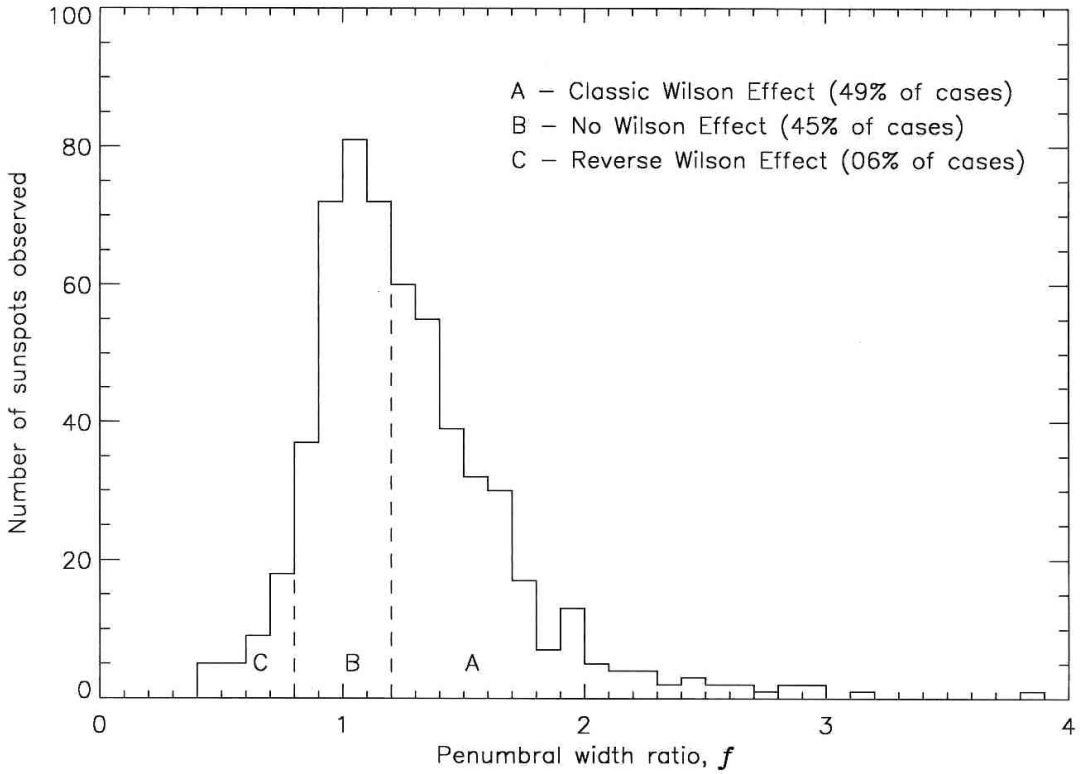
Howard's digitizing pad (Sivaraman, Gupta & Howard 1993)

Accuracy of measure on pad high but limited by seeing on plate

Total errors within 10%, in agreement with best reported before

Sunspots within 40° – 80° of CMD used for measurements

Results



285 display classic Wilson effect

260 have no Wilson effect

35 show inverse Wilson effect

580 epochs of 253 sunspots

f	Wilson effect	category
> 1.2	classic	A
0.8 – 1.2	no	B
< 0.8	inverse	C

Definition of ranges:

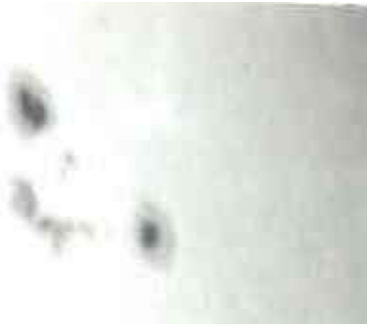
95 % of all selected sunspots lying within 30° of CMD have *f* in the range 0.8 – 1.2

Takes into account un-sharp edges

A

KKL 16044 / McMath 15175

75E / March 05, 1978 / f = 2.85



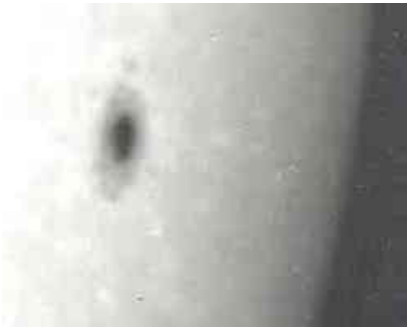
KKL 16998

55W / May 17, 1980 / f = 2.73

B

KKL 16042 / McMath 15172

56W / March 11, 1978 / f = 0.90



KKL 17138

64W / Sep 19, 1980 / f = 0.95

C

KKL 17742

71W / Feb 03, 1982 / f = 0.72

KKL 16956

70W / Apr 12, 1980 / f = 0.75

KKL 17138

52 E / Sep 10, 1980 / f = 0.64

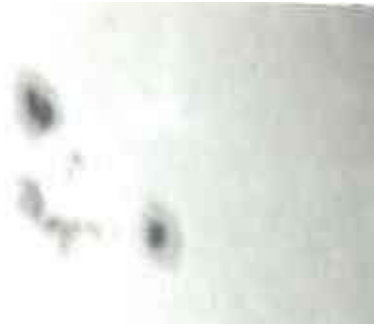
explanation?

Role of magnetic fields

- Solar geophysical data used to confirm sunspot types complexity, and other parameters (antipodal)
- Solar data bulletins of USSR Academy of Sciences used for B measurements of sunspots and pores (minimum of 500 Gauss)/(a few hours away)
- Kodaikanal B measures used for a small number of sunspots, especially if SDB data is missing
- Kodaikanal K spectroheliograms used to study associated plage properties

A

Single isolated sunspot

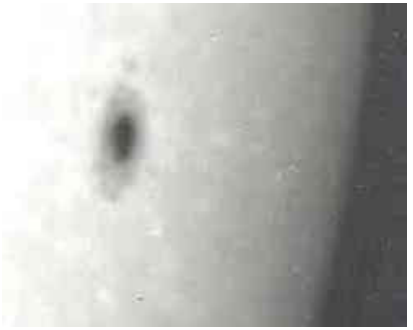


Accompanied by sunspot and pores of same polarity, only one tiny pore of opposite polarity

Predominantly uni-polar

B

Same group follower (sunspot) pores influence



Accompanied by opposite polarity pore, enough to affect

Predominantly bi-polar

C

3 to 5 opposite polarity pores plus *many pores* B not measured

Emerging follower, *many pores* of mixed polarity in between

Many pores of opposite polarity, 2 of same polarity in young EFR

Bi-polar young active

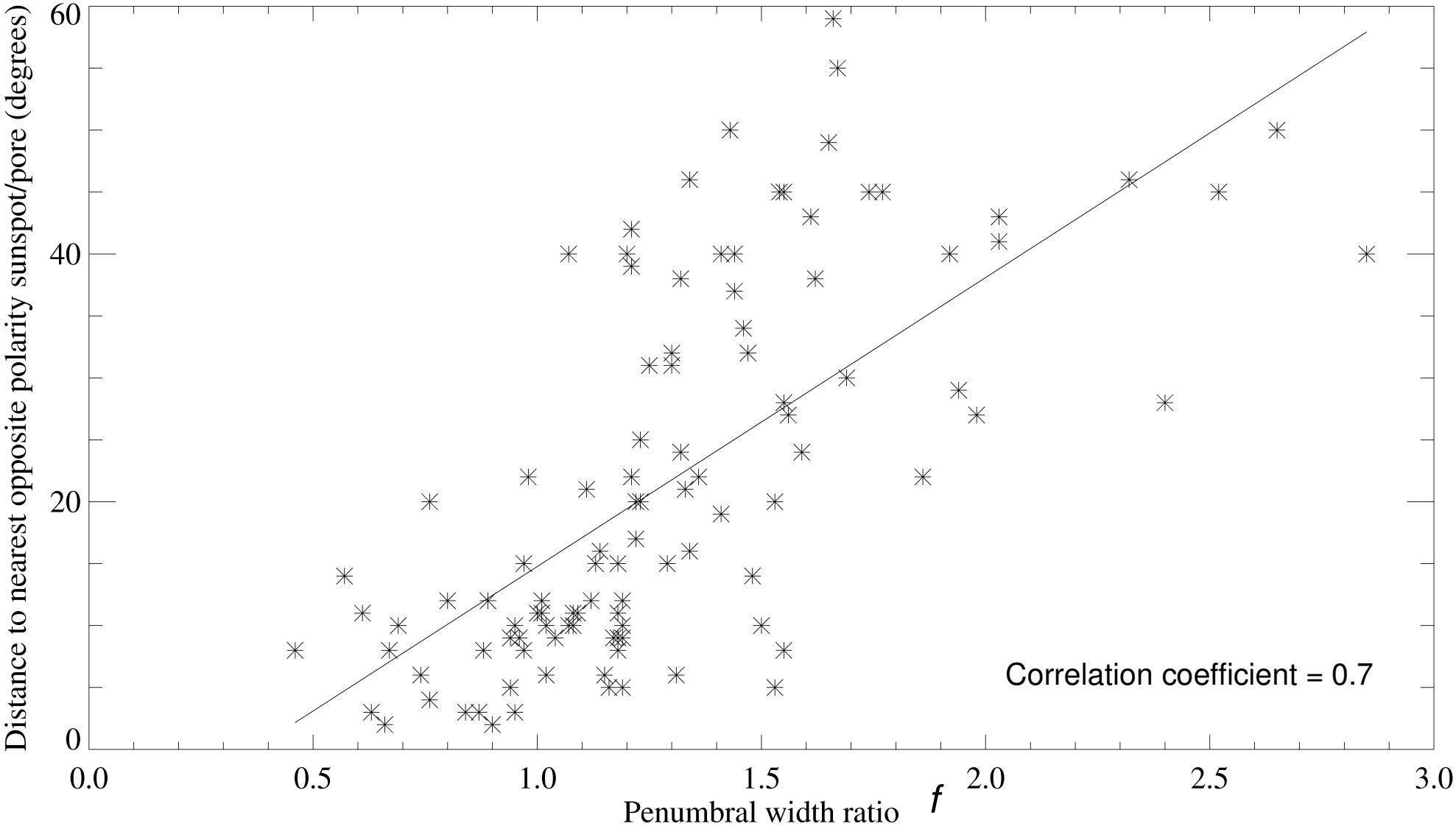
The three categories

- Single isolated evolved/old/mature spots (open field lines) show the classic Wilson effect – category A
- Even if it is a young spot but has predominantly unipolar field, it displays Wilson effect and belongs to category A
- Sunspots with neighboring opposite polarity spot(s) or pore(s) of comparable field strength (not open field lines!), display no Wilson effect – category B
- The effect of opposite polarity neighbour is discernible even if it is 15 to 20° away, and even if it belongs to an adjacent group

The three categories contd.

- Sunspots closely accompanied by a large number of pores of *mixed polarities* (young active regions with complex magnetic field connectivity!) exhibit inverse Wilson effect – category C
- These are typical EFRs associated with proper motions of spots and pores

Impact of magnetic neighbourhood



Relation to properties of sunspots

Examined properties such as:

1. intensity, velocity, & magnetic oscillations in umbrae
2. EUV plumes observed
3. presence or absence of bright rings and umbral dots
4. Gradient of Evershed flow velocity in penumbrae

With respect to categories A, B, & C

Trends noticed, need more studies

(a) EUV plumes seem to appear over A spots while only enhanced emission is seen over B and C spots

(b) Bright rings appear only in A spots (in B type, those not associated through *K plage* to any neighbour have partial brightening!)

The Evershed flow

- Evershed (1909) reported a positive gradient of velocity in radial direction with the velocity being maximum at penumbra-photosphere boundary
- Abetti observed a negative gradient in large number of sunspots with flow pattern varying from spot to spot (Schröter 1965)
- Our preliminary findings suggest that spots observed by Evershed are largely of A type while those studied by Abetti are mostly of category B
- We need to examine this aspect more carefully, now that the digitization process is on at Kodai

Conclusions

- The presence, absence or inversion of Wilson depression in sunspots depends upon its magnetic bipolarity (open field lines, closed ones, or complex) w r to its entire surrounding
- It appears that the opacity above umbra is some how affected by the closing of field lines

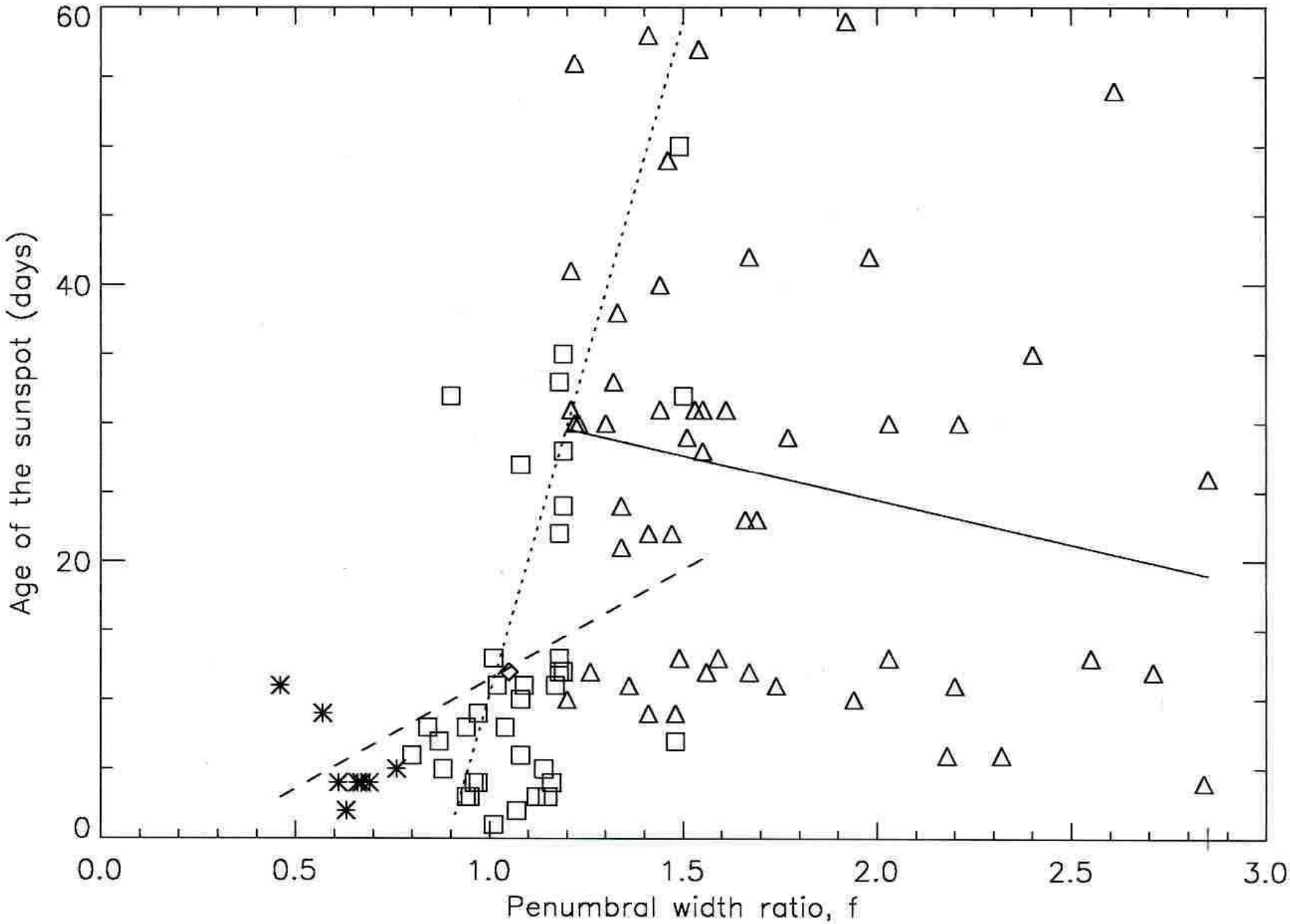
Thank you very much!

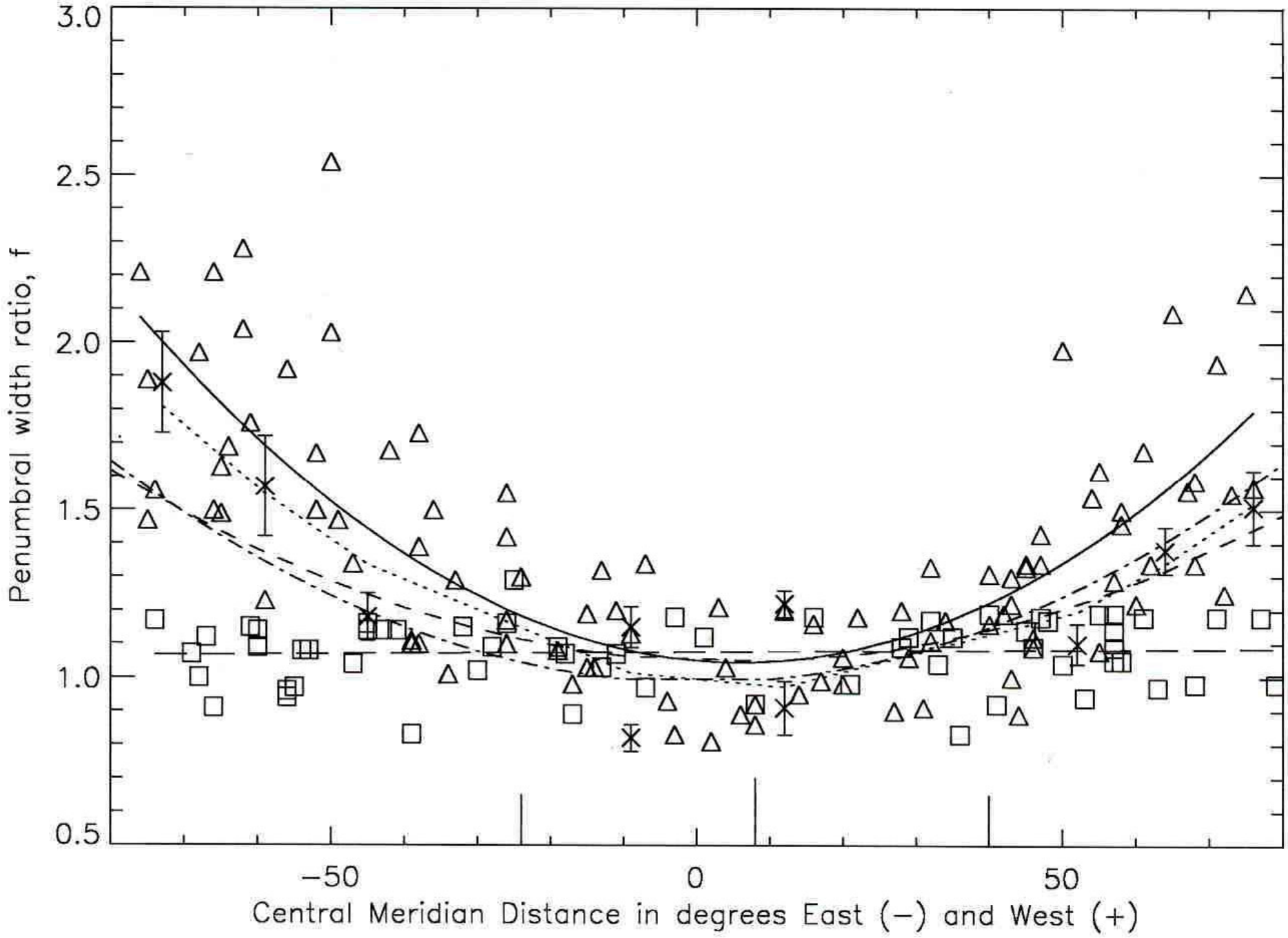
Contradicting observations

- Chistyakov (1962) made careful measurements on 252 spots (epochs) and found that 86 of them do not show the effect, many had an inverse effect!
- Bray & Loughhead(1958), Wilson & Cannon (1968), Wittman & Schröter(1969), Wilson & McIntosh (1969) did center-to-limb photometry and found support for the Wilson depression
- Prokakis(1974) and Obashev et al.(1982) measured over a hundred spots each and found that 30% of them had no or an inverse effect! Similar observations were reported earlier by Abetti(1955), Bray & Loughhead(1964), and later by Hejna & Solovev(1985)
- Collados et al.(1987, 1988) observed 145 epochs of 17 spots and concluded that inverse effect is not the exception but the rule!

Contradictions galore

- Some of the observers found asymmetries in the effect between eastern and western hemispheres
- They ascribed them to tilt of sunspot axis or intrinsic elongation or shortening of eastern or western portions of penumbrae
- Meyer et al.(1977) showed that sunspots should be vertical due to magnetic buoyancy and a tilted axis will be highly unstable (torn apart by surrounding convection)
- Hejna & Solovev(1984) argued that tilted spots will be submerged beyond 55° CMD on the side of tilt
- Therefore, tilt & exaggerated intrinsic properties are untenable


60
40
20
0
Age of the sunspot (days)
0.0
0.5
1.0
1.5
2.0
2.5
3.0
Penumbral width ratio, f

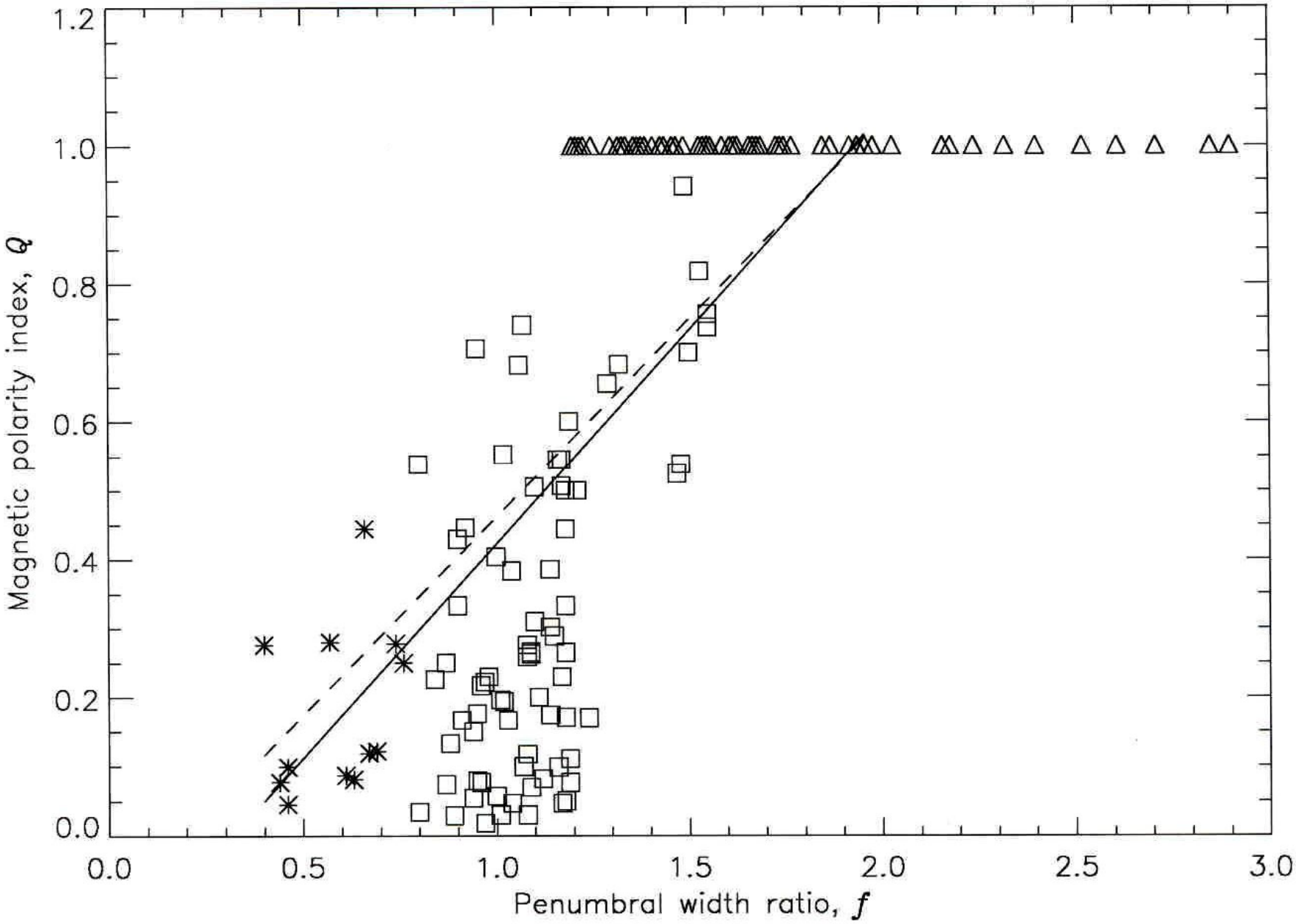

3.0
2.5
2.0
1.5
1.0
0.5
Penumbral width ratio, f
−50
0
50
Central Meridian Distance in degrees East (−) and West (+)

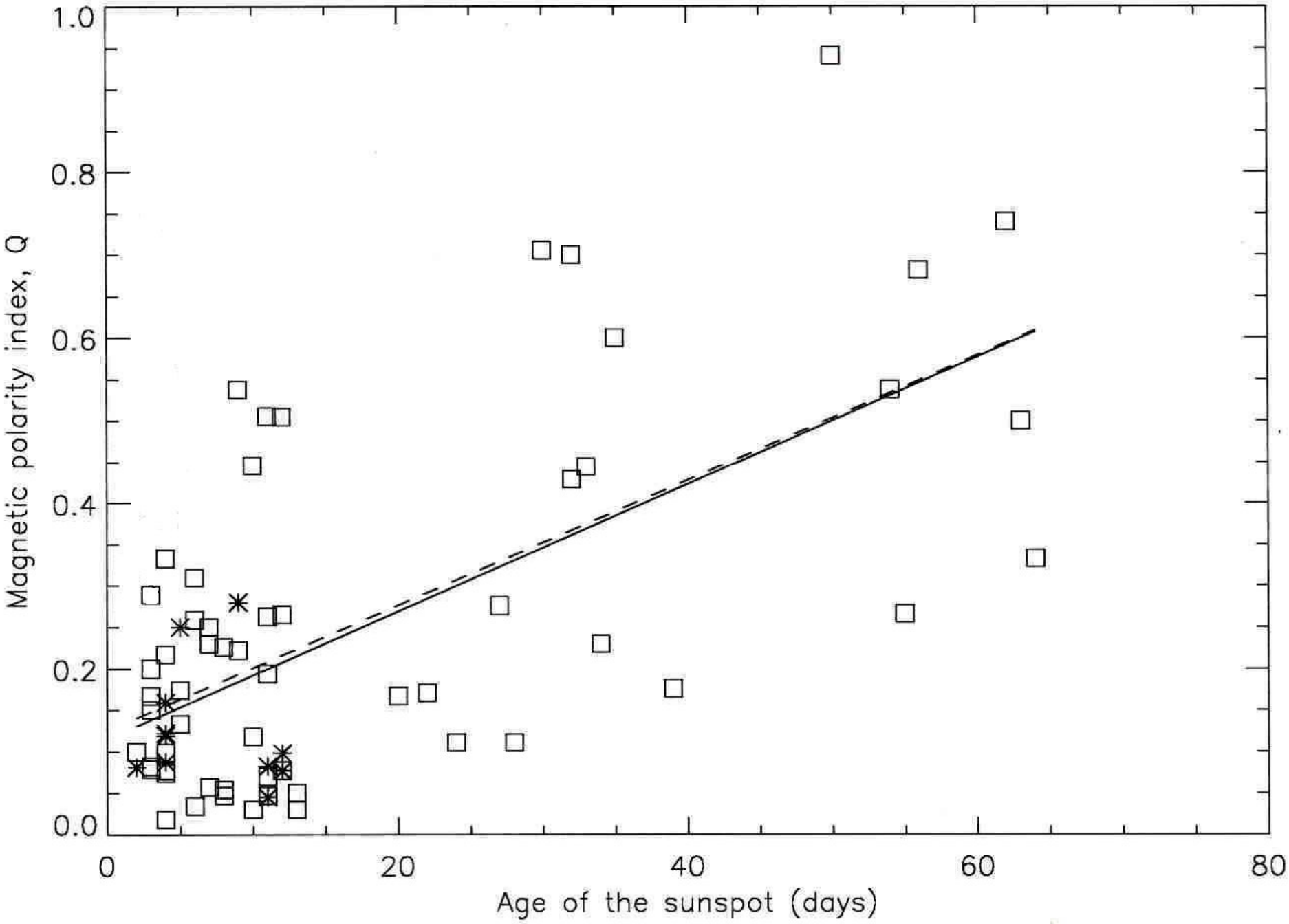
Magnetic bipolarity index

We define a *magnetic bipolarity index* for sunspots as follows:

$$Q = \frac{|\sum B_+ - \sum B_-|}{|\sum B_+| + |\sum B_-|}$$

B_+ and B_- are the longitudinal magnetic field strengths in Gauss, N/S respectively, within a distance of 15° from the sunspot


Magnetic polarity index, Q
Penumbral width ratio, f
0.0
0.2
0.4
0.6
0.8
1.0
1.2
0.0
0.5
1.0
1.5
2.0
2.5
3.0


1.0
0.8
0.6
0.4
0.2
0.0
Magnetic polarity index, Q
0
20
40
60
80
Age of the sunspot (days)