Long-term trends of magnetic bright points: The evolution of MBP size and modelling of the number of MBPs at disc centre

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In the frame of FWF Project: P27800:
The interaction of the solar granulation with small-scale magnetic fields

Der Wissenschaftsfonds.

Contents of the Talk

- Part I: Motivation and Introduction
  - Solar Magnetic Fields and the solar cycle
  - Appearance of MBPs
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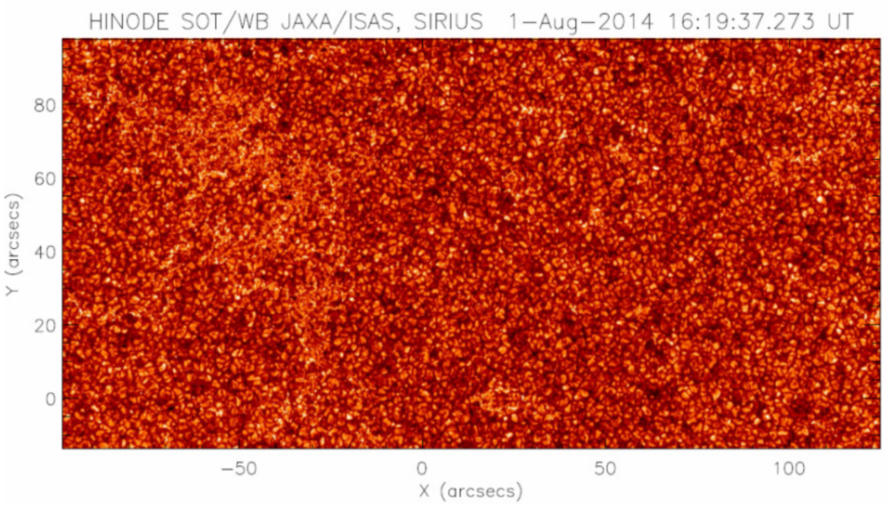
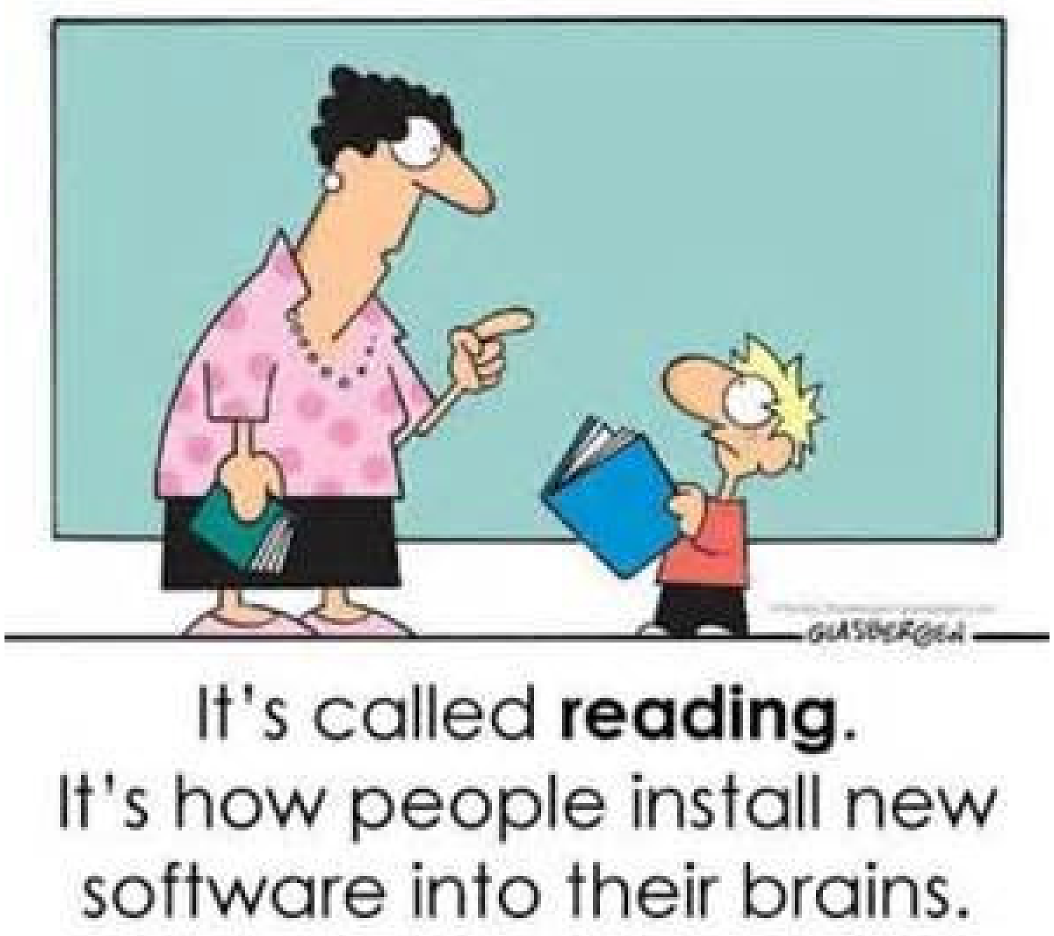
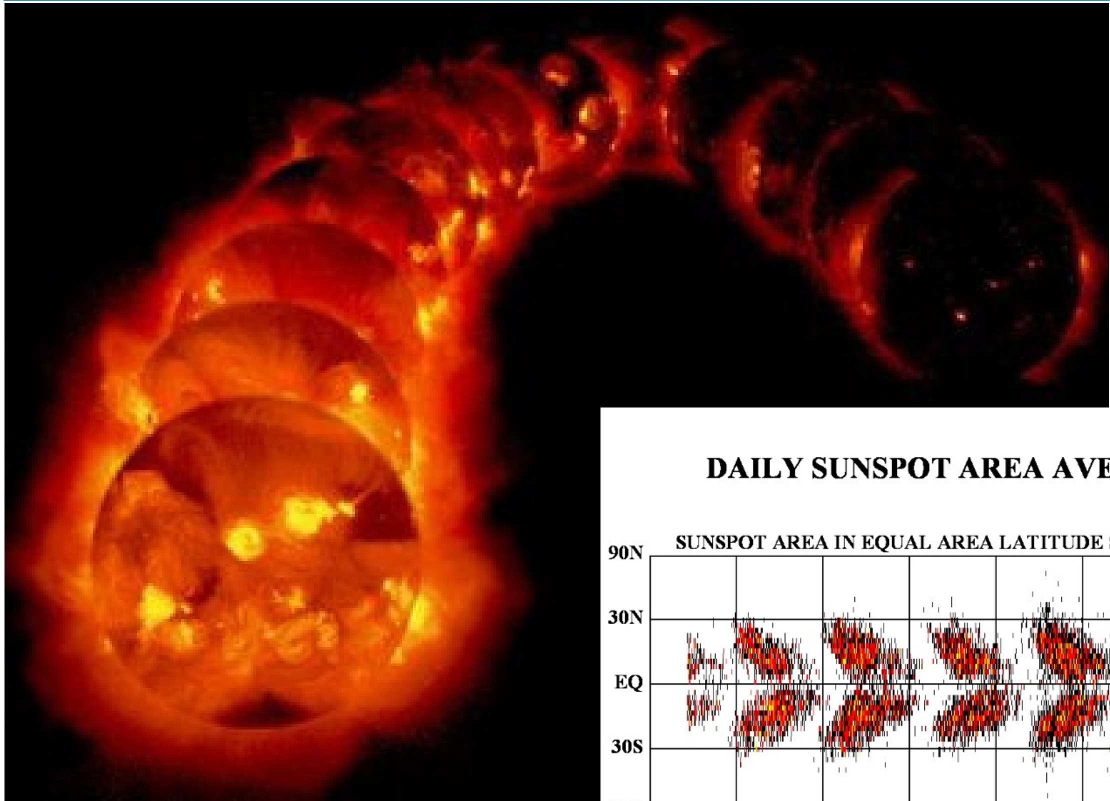
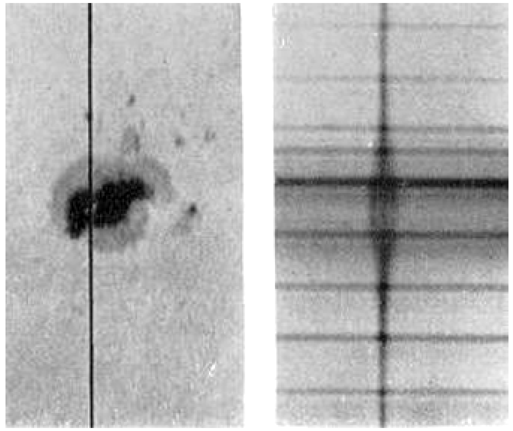
  - Size of MBPs at disc centre
  - Number of MBPs at disc centre
  - Correlation analysis
- Part III: Modelling and Conclusions
  - Modelling the change of MBPs as a function depending on the sunspot number

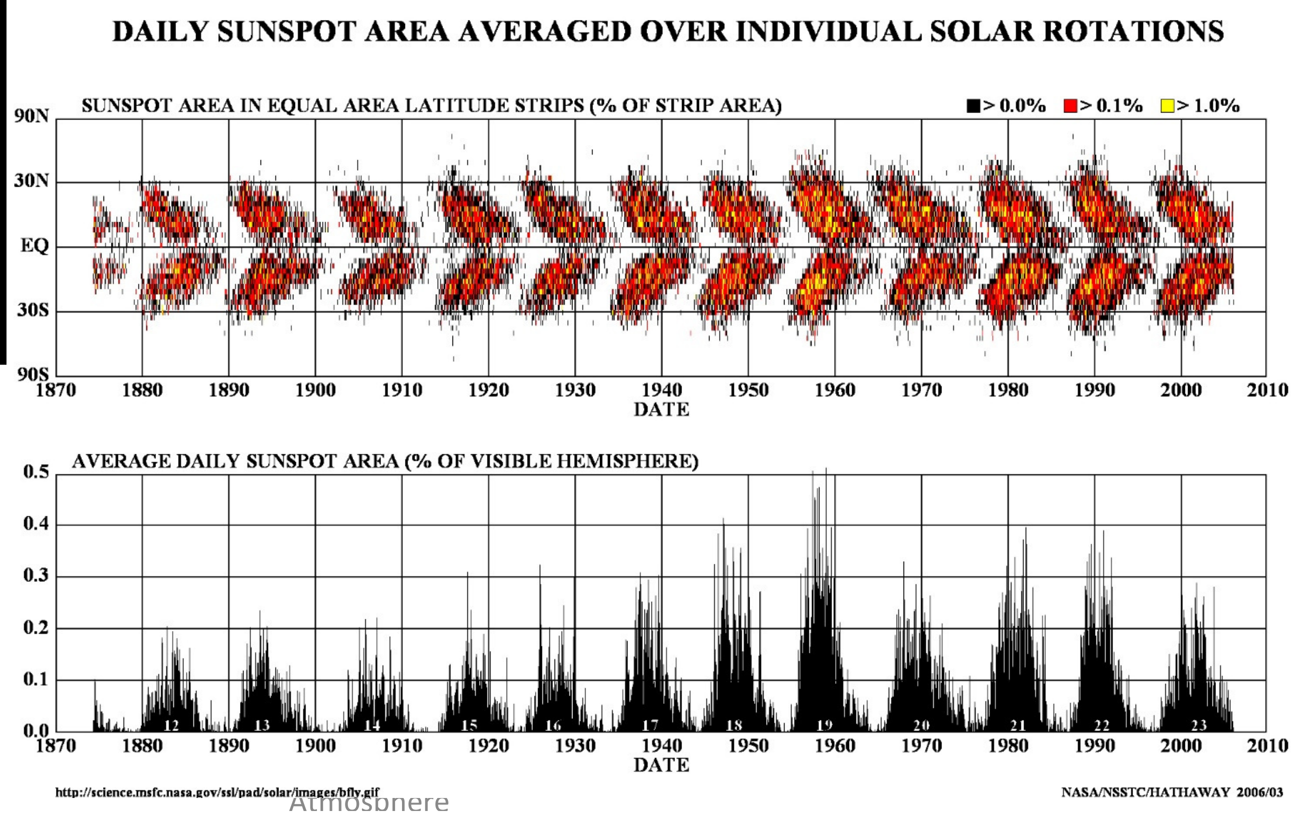


Part I: Basics about MBPs









Top right: Sunspot with spectrograph slit and the seen line splitting within the sunspot; right: Sunspot Butterfly diagram; top: The X-ray variable solar corona as seen by Japanese Yokoho mission;

A whole hierarchy of magnetic fields exists:

Taken from:
Zwaan 1987:
Elements and patterns in the solar magnetic field

Table 1 The hierarchy of magnetic elements

Property[a]	Sunspot with penumbra: Large	Sunspot with penumbra: Small	Pore	Magnetic knot (micropore)	Faculae, network clusters	Flux fiber
Φ (10^{18} Mx $= 10^{10}$ Wb)	3×10^4	500	250–50	≈ 10	$\lesssim 20$	$\lesssim 0.5$?
R (Mm)	28	4	—	—	—	—
R_u (Mm)	11.5	2.0	1.8–0.7	≈ 0.5	—	$\lesssim 0.01$
B (in G $= 10^{-4}$ T)	2900 ± 400	2400 ± 200	2200 ± 200	≈ 1500–2000	—	≈ 1500
Overall contrast:	← dark					bright →
Cohesion:	← single compact structure			- - -	cluster of	
Behavior in time:	← remain sharp during decay, shrinking				—	modulated by granulation
Occurrence:	← exclusively in active regions		- - - -		both inside and outside active regions →	

Small-Scale Fields

Right: ***Jin et al. 2011 in***
The Sun´s small-scale magnetic elements in Solar Cycle 23;
Obviously there is a huge controversial debate going on!

1. *No cyclic variations:* Ca II K emission in solar quiet regions (White & Livingston 1981), modern X-ray bright point (XBP) observations (Sattarov et al. 2002; Hara & Nakakubo 2003), magnetic flux of networks (Labonte & Howard 1982), flux spectrum and total flux of network elements with flux $\leqslant 2.0 \times 10^{19}$ Mx (Hagenaar et al. 2003), and Stokes $\frac{Q}{I}$ profile (Trujillo Bueno et al. 2004).
2. *Anti-correlation of small-scale fields with the sunspot cycle:* The number of network bright points in very quiet regions (Muller & Roudier 1984, 1994), He I 10830 Å dark points in the higher chromosphere (Harvey 1985), early X-ray bright point observations (Davis et al. 1977; Davis 1983; Golub et al. 1979), and weak changes of emergence frequency of ERs with flux less than (3–5) $\times 10^{19}$ Mx (Hagenaar et al. 2003).
3. *Correlation with the sunspot cycle:* More ERs appeared during active solar condition (Harvey & Harvey 1974; Harvey 1989), the number (or magnetic flux) of network structures (Foukal et al. 1991; Meunier 2003), and flux distribution and total flux of network concentrations with flux $\geqslant 3.0 \times 10^{19}$ Mx (Hagenaar et al. 2003).

Observational characteristics

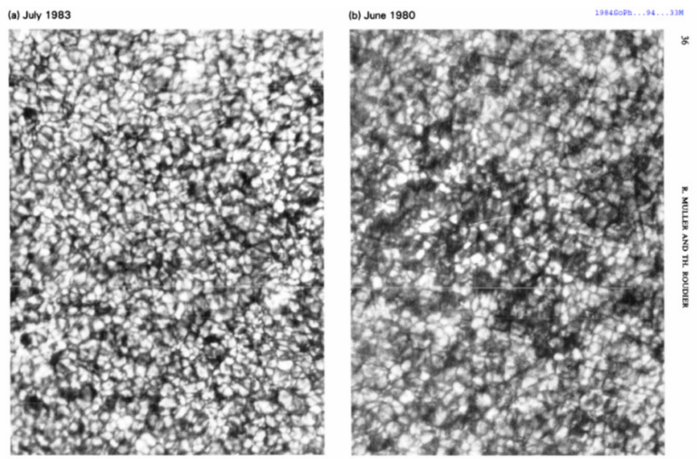


Fig. 2. The photospheric network, as observed with a 10 Å bandpass filter at 4308 Å. (a) Near solar minimum; (b) near solar maximum of activity. Network elements (or facular points) are visible as tiny sharp points located in intergranular lanes. Field of view: 84″ × 66″.

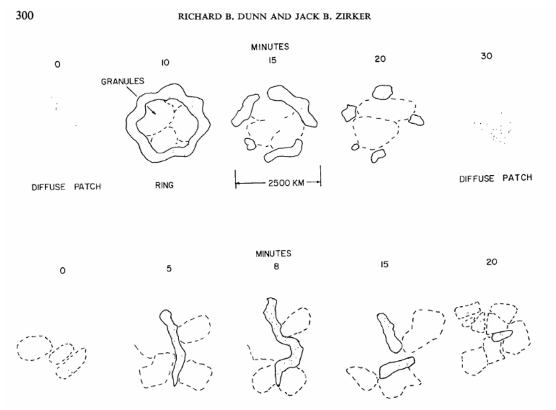
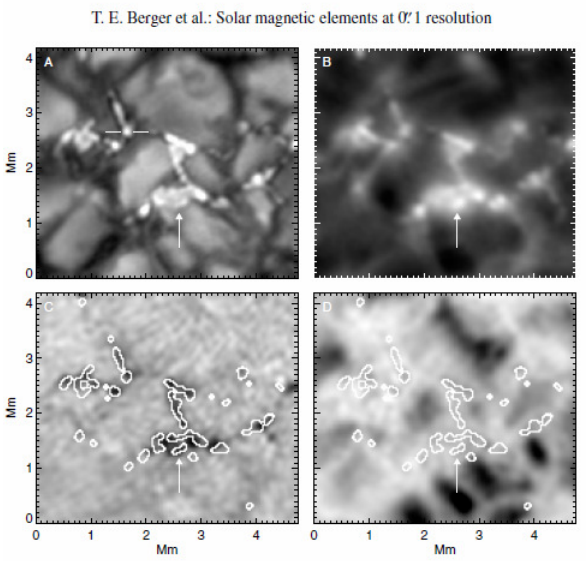
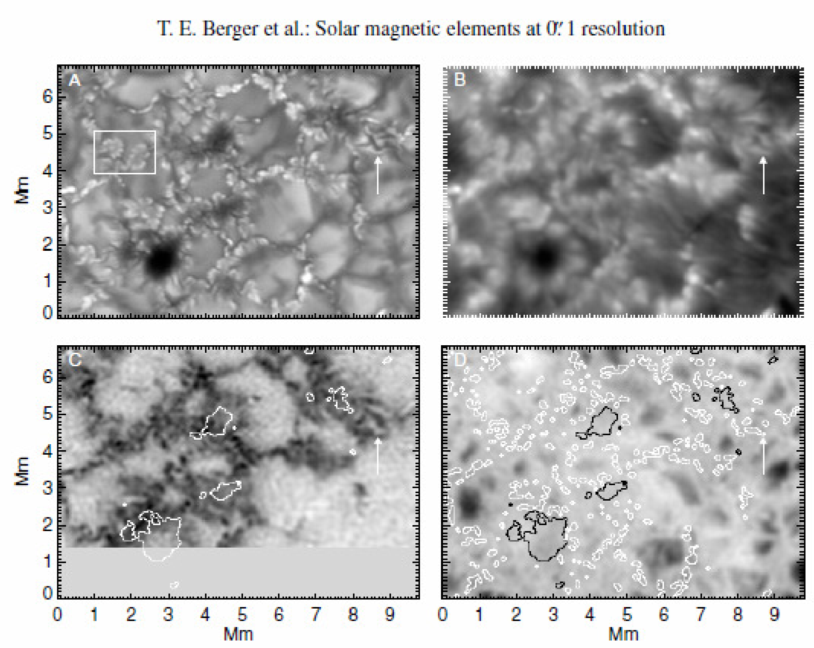


Fig. 7. Schematic showing the time evolution of a circle and line of crinkles. The schematic represents position 5 and 6 on the overlay for Figure 6.

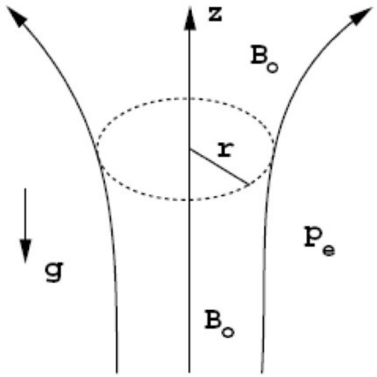
right top:
Among the first ro report about “solar filigree” ->
Dunn & Zirker 1973
left top:
probably the first time that the G-band gets used ->
Muller & Roudier 1984
right: “modern” high resolution observations ->
Berger et al. 2004



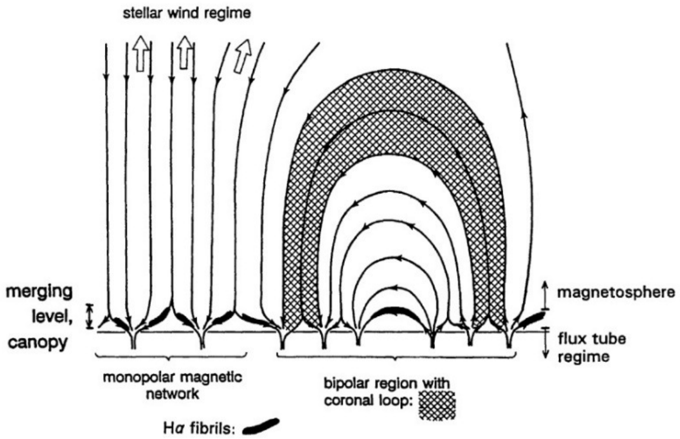


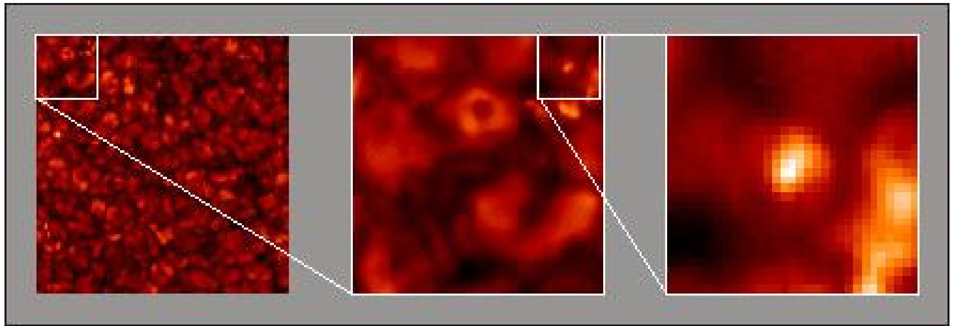
Magnetic Bright Points

- Small scale magnetic flux concentrations
  - kG fields
  - ~ 200 km diameters
  - Bright (especially in the G-band)
  - Found in intergranular regions
  - Lifetimes in min. range



- Theoretical Models
  - Single isolated flux tubes
    - In the higher atmosphere canopy structue
  - Created by convective collapse process





Atmospheric coupling:

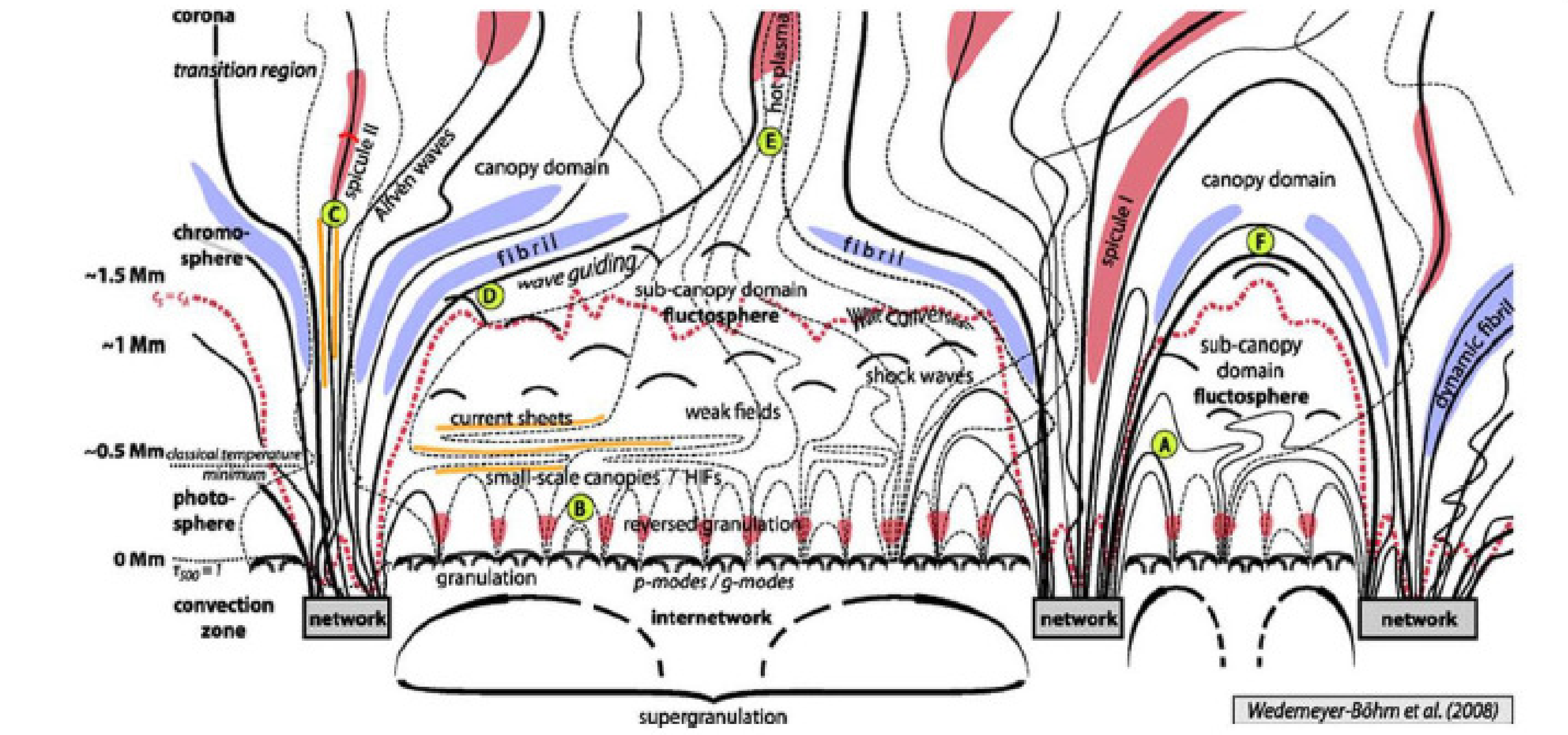
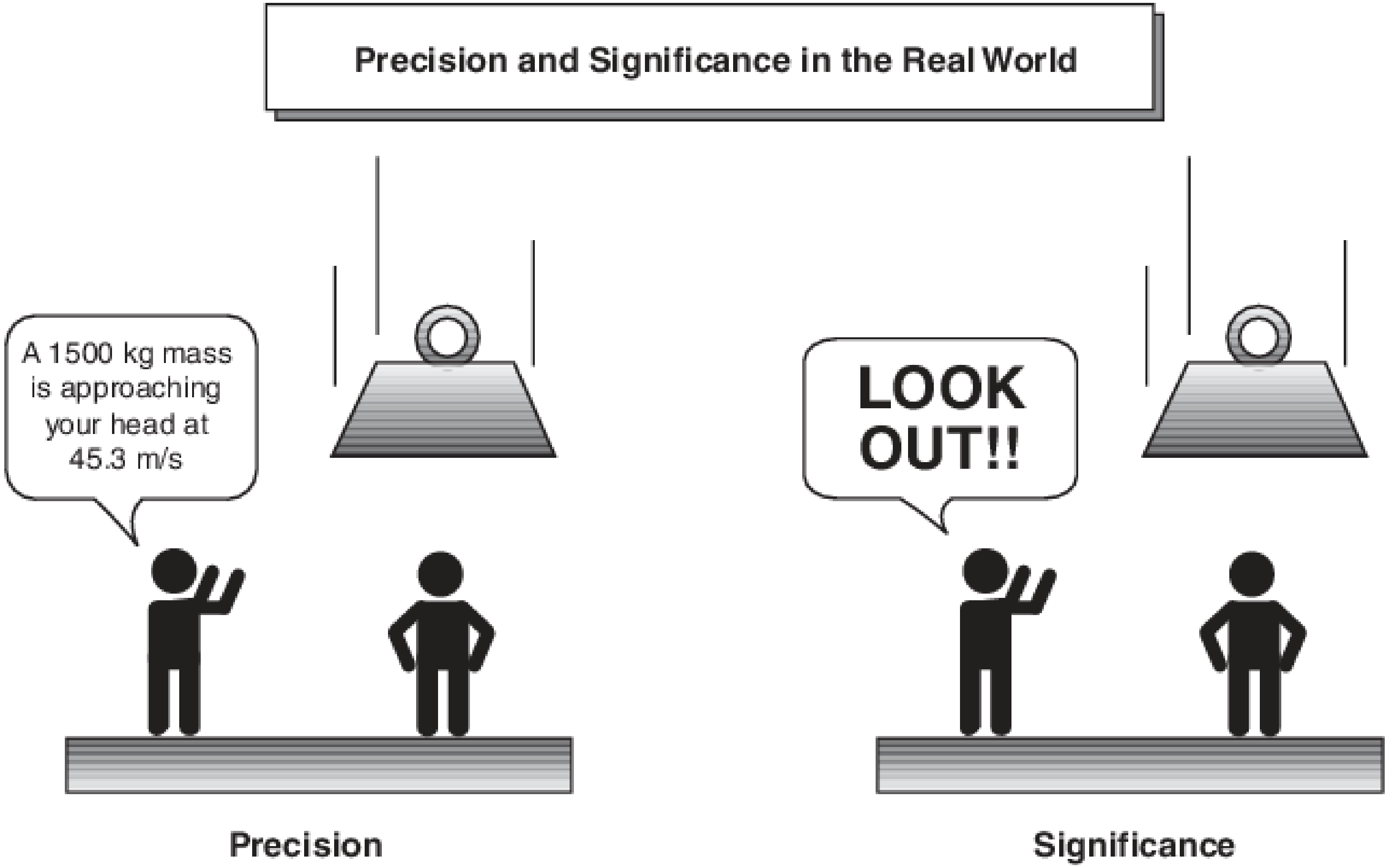
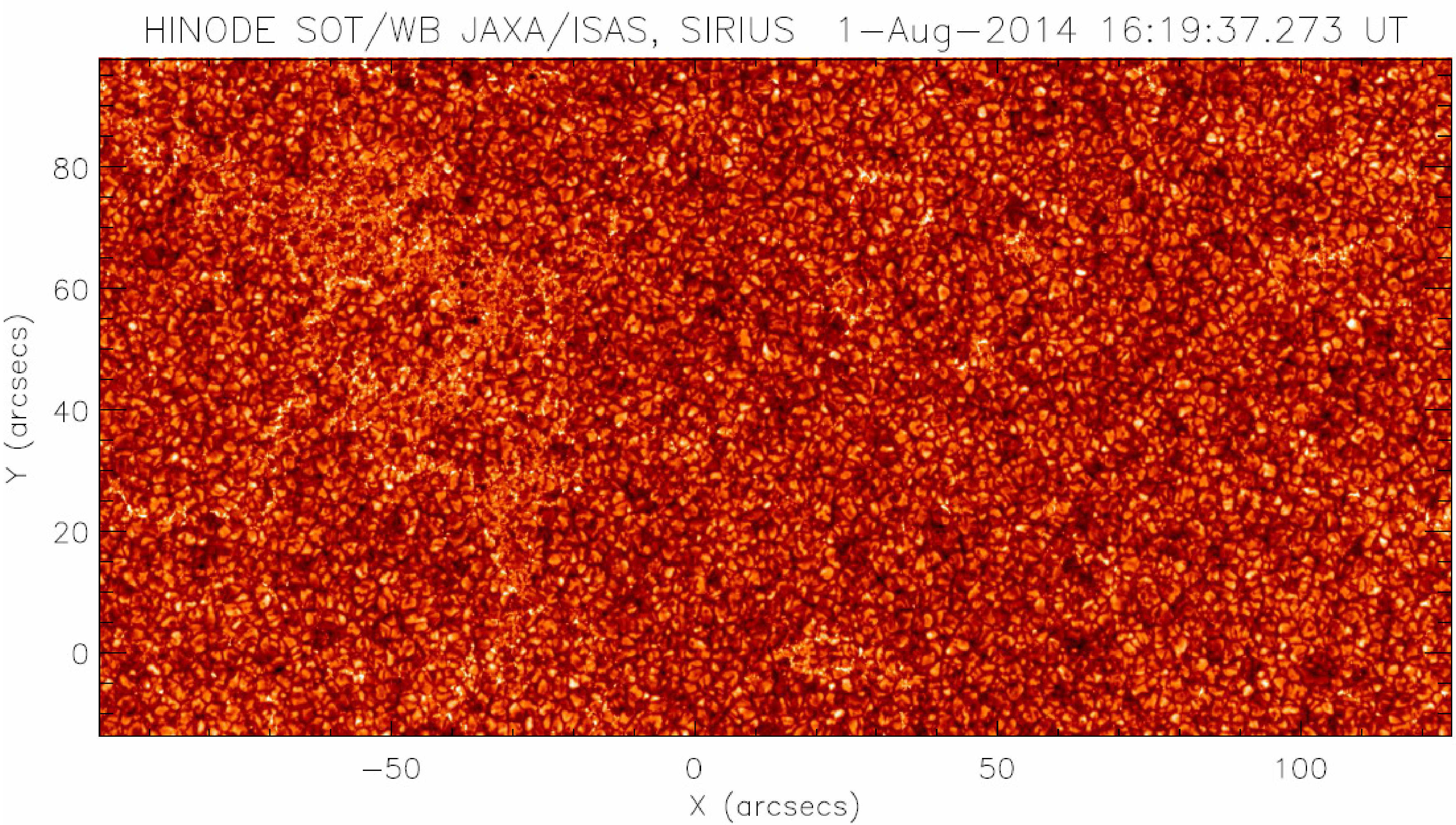


Fig. 2 Cartoon showing the structure of the lower atmosphere (Wedemeyer-Böhm et al. 2009)

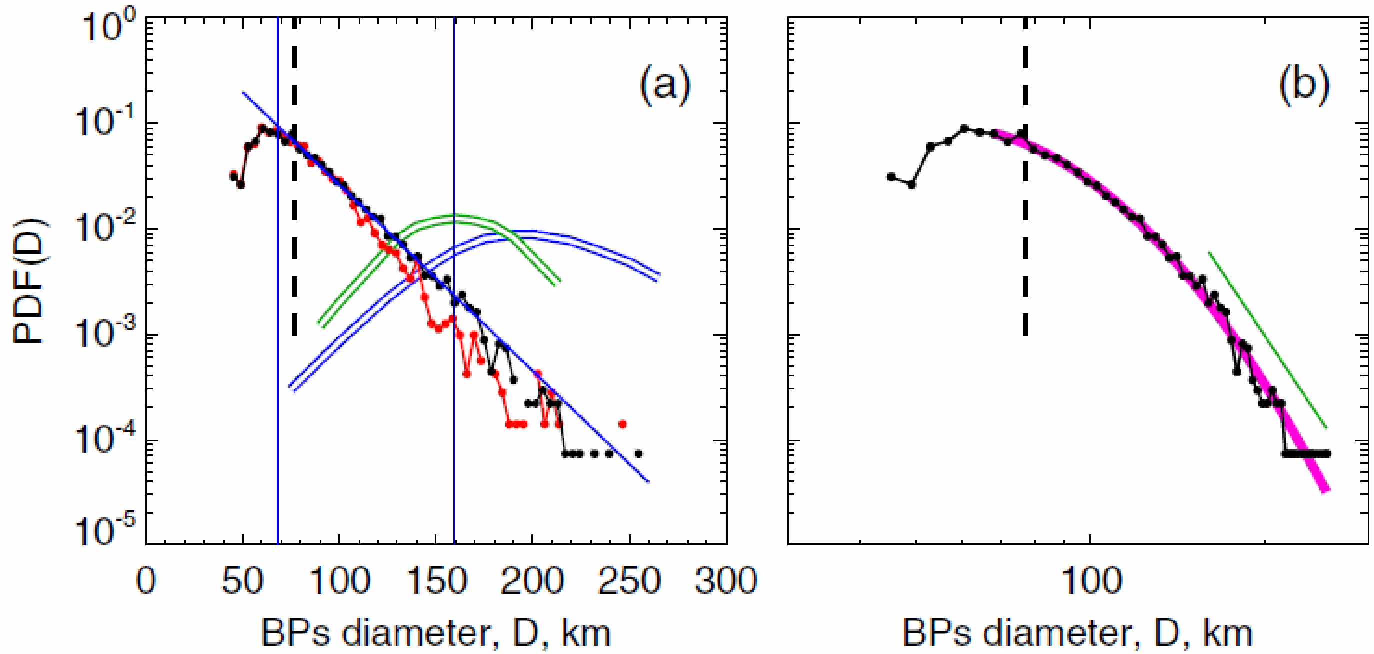
Part II: Long-time variations of MBPs




HINODE SOT/WB JAXA/ISAS, SIRIUS 1−Aug−2014 16:19:37.273 UT
80
60
40
20
0
Y (arcsecs)
−50
0
50
100
X (arcsecs)

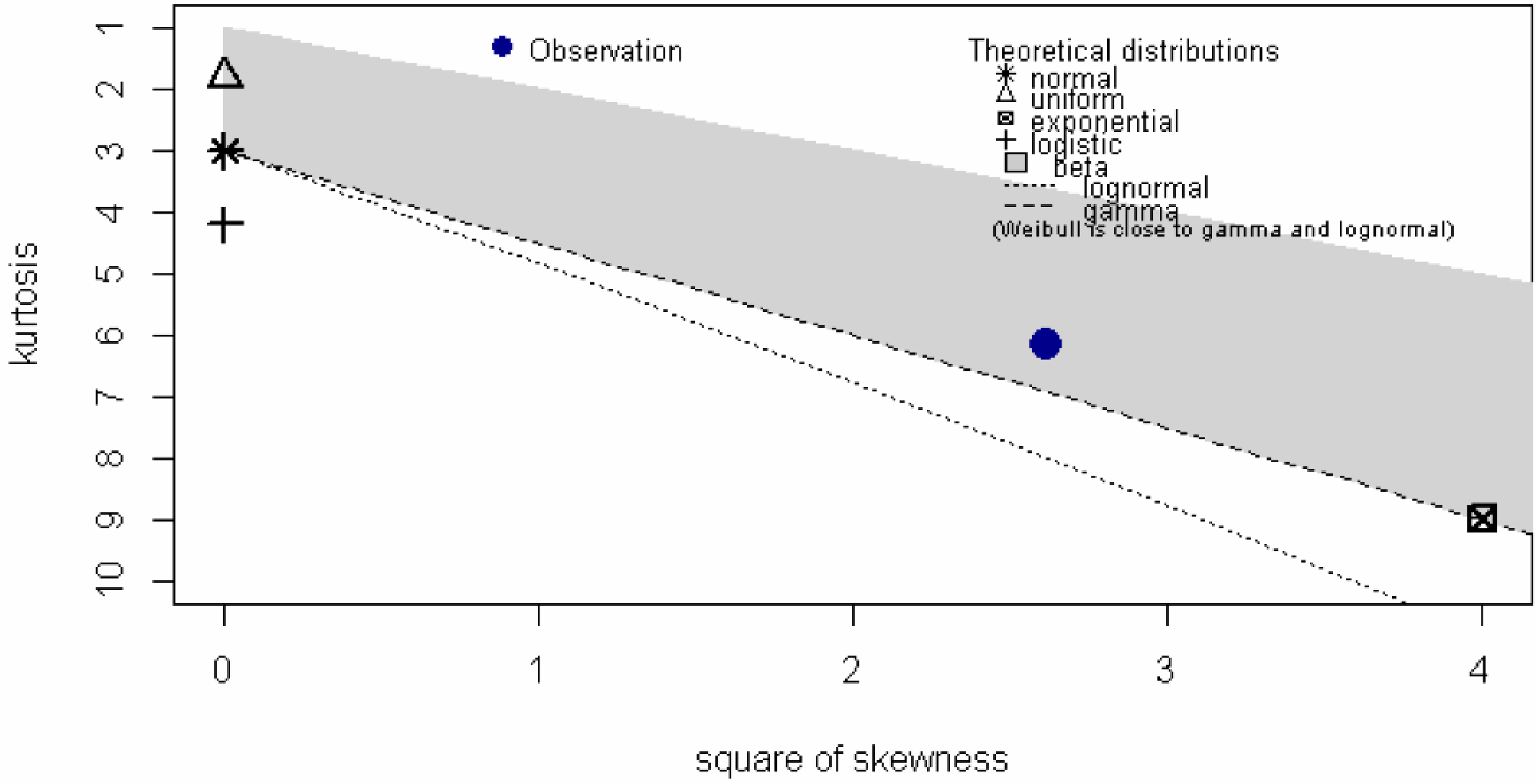
- MBP size distributions:

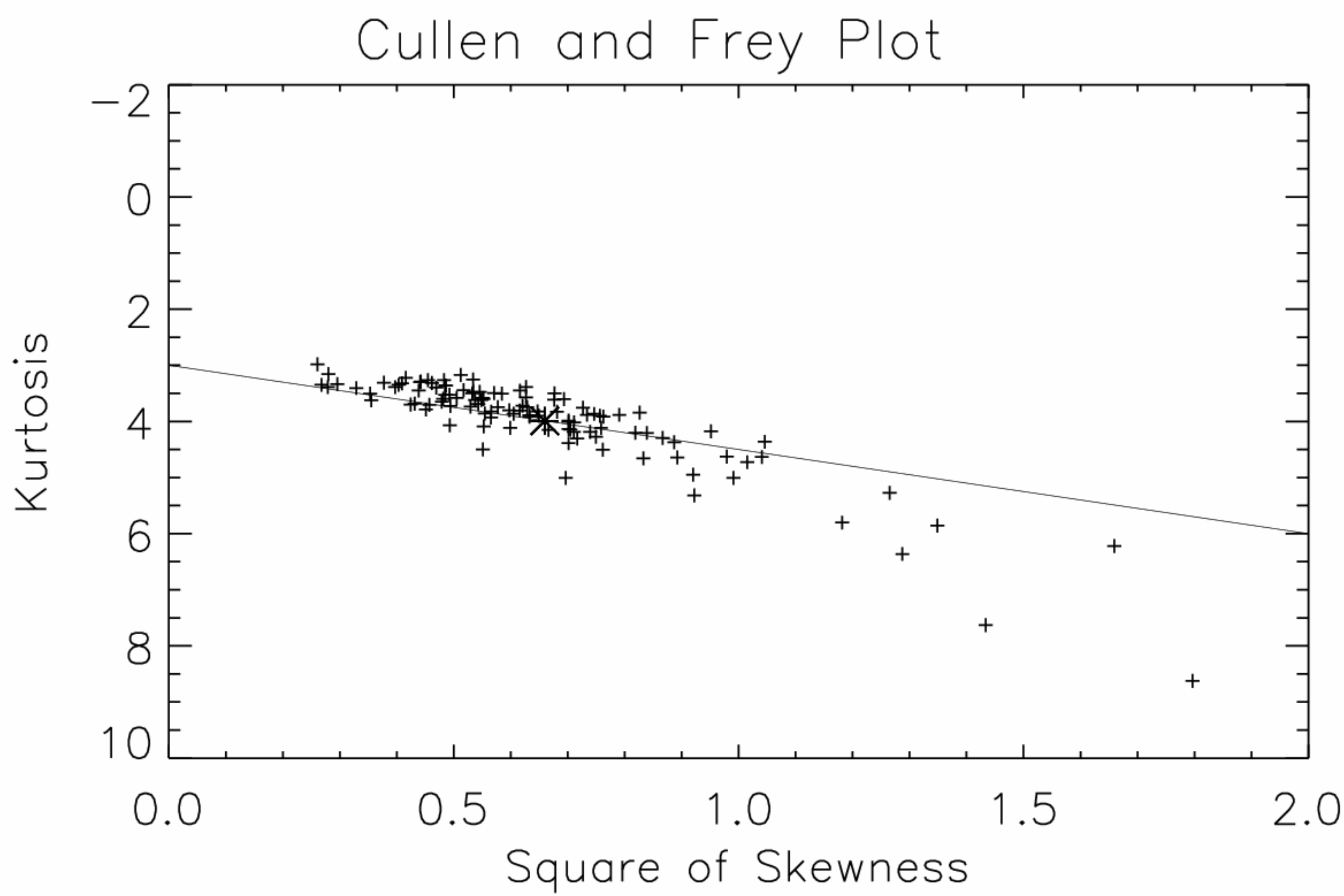
e.g. Abramenko et al. 2010

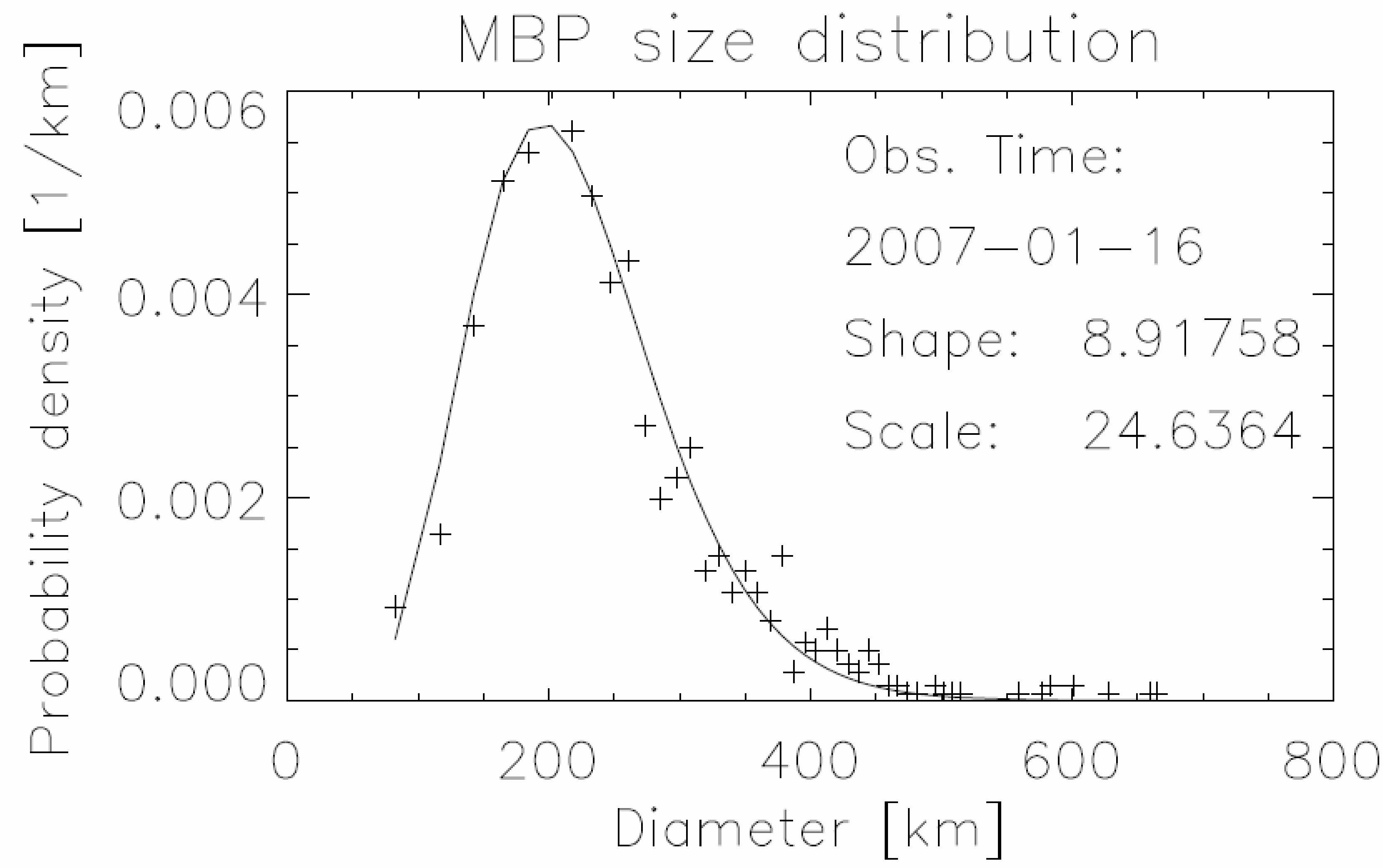


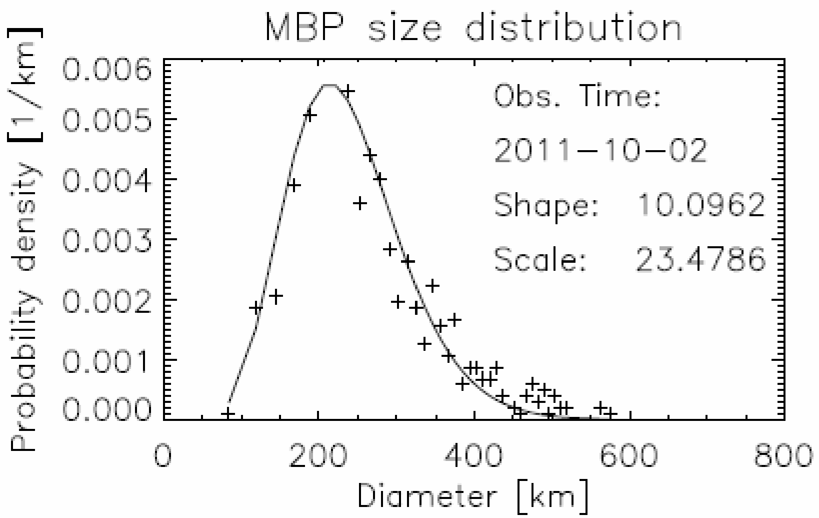
Parameter	D (km)
Exponential distribution	
c_1	0.404 ± 0.091
β	-0.406 ± 0.0008
χ^2	0.26
Δ	68–159
Power-law distribution	
c_2	15.50 ± 1.18
α	-8.27 ± 0.51
χ^2	0.60
Δ	160–254
Log-normal distribution	
m	4.157 ± 0.034
s	0.382 ± 0.018
χ^2	0.030
Δ	>67

Cullen and Frey graph

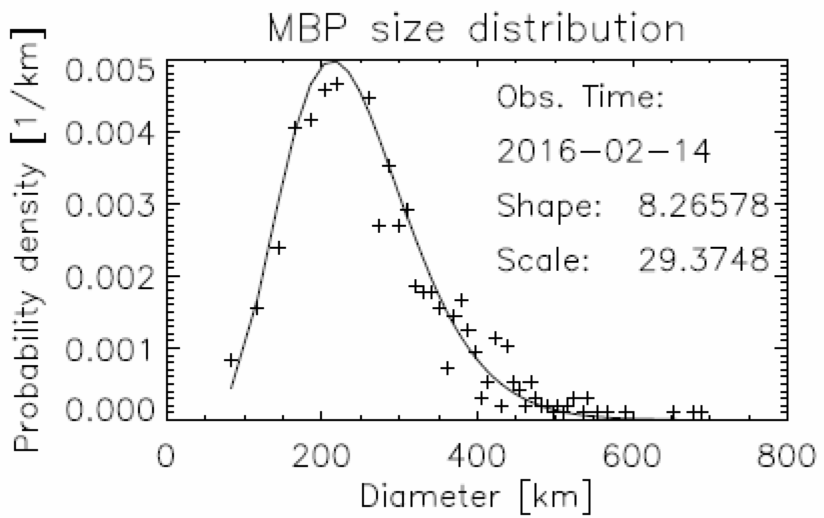



Cullen and Frey Plot
Kurtosis
-2
0
2
4
6
8
10
0.0
0.5
1.0
1.5
2.0
Square of Skewness

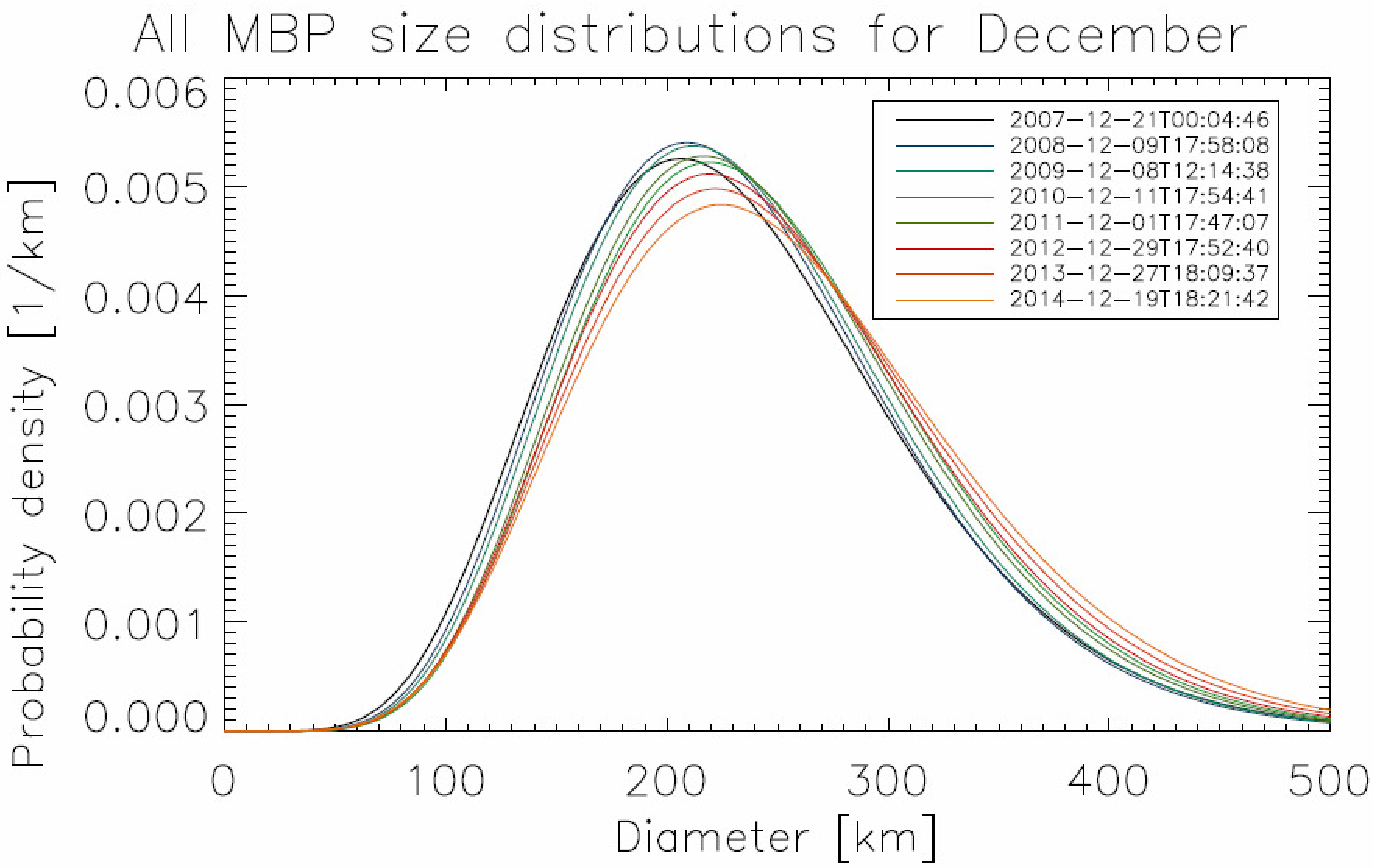

MBP size distribution
Probability density [1/km]
0.006
0.004
0.002
0.000
0
200
400
600
800
Diameter [km]
Obs. Time:
2007-01-16
Shape: 8.91758
Scale: 24.6364

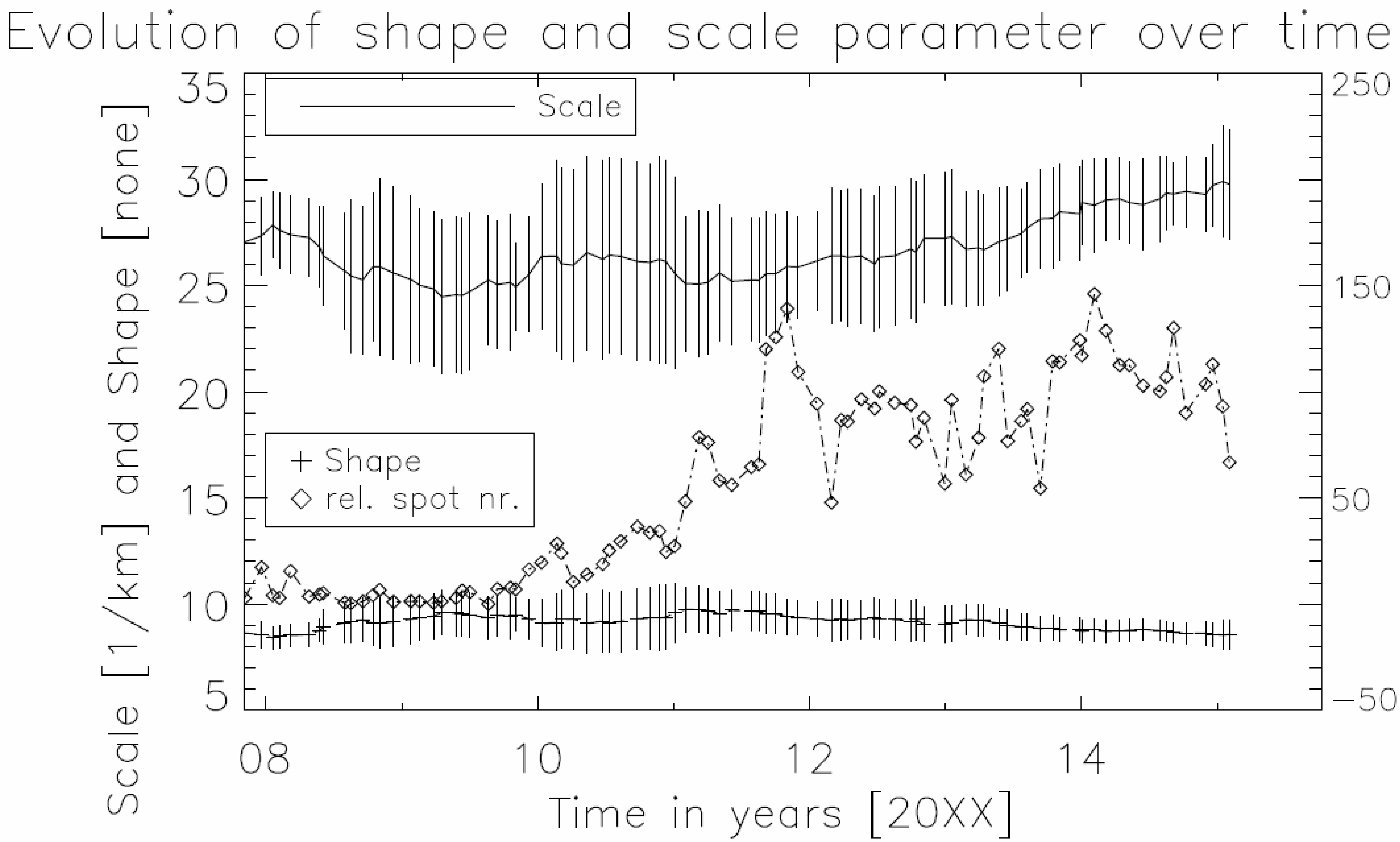


$$f(x;\alpha,\beta) = \frac{\beta^\alpha x^{\alpha-1} e^{-\beta x}}{\Gamma(\alpha)} \quad \text{for } x > 0 \text{ and } \alpha, \beta > 0,$$



Possible Interpretation:
The MBP size is really distributed according to an exponential function but truncated to the smaller sizes by the telescope resolution (diffraction limit). Thus the scale parameter tells us about the physics and the shape parameter about the telescope and the quality of observations.

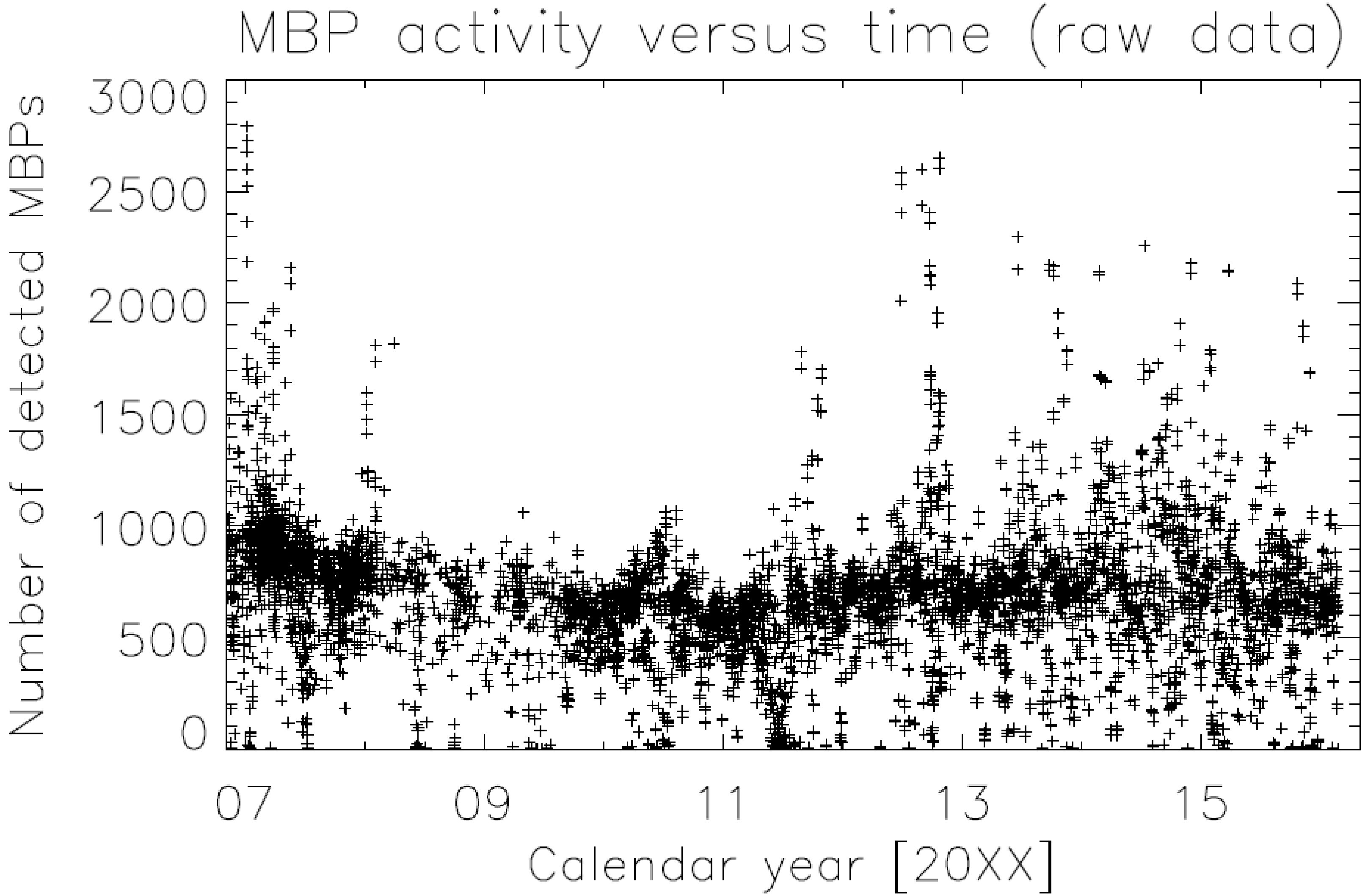

All MBP size distributions for December
Probability density [1/km]
Diameter [km]
0.006
0.005
0.004
0.003
0.002
0.001
0.000
0
100
200
300
400
500
2007−12−21T00:04:46
2008−12−09T17:58:08
2009−12−08T12:14:38
2010−12−11T17:54:41
2011−12−01T17:47:07
2012−12−29T17:52:40
2013−12−27T18:09:37
2014−12−19T18:21:42


Evolution of shape and scale parameter over time
Scale
+ Shape
◇ rel. spot nr.
Scale [1/km] and Shape [none]
35
30
25
20
15
10
5
250
150
50
−50
08
10
12
14
Time in years [20XX]

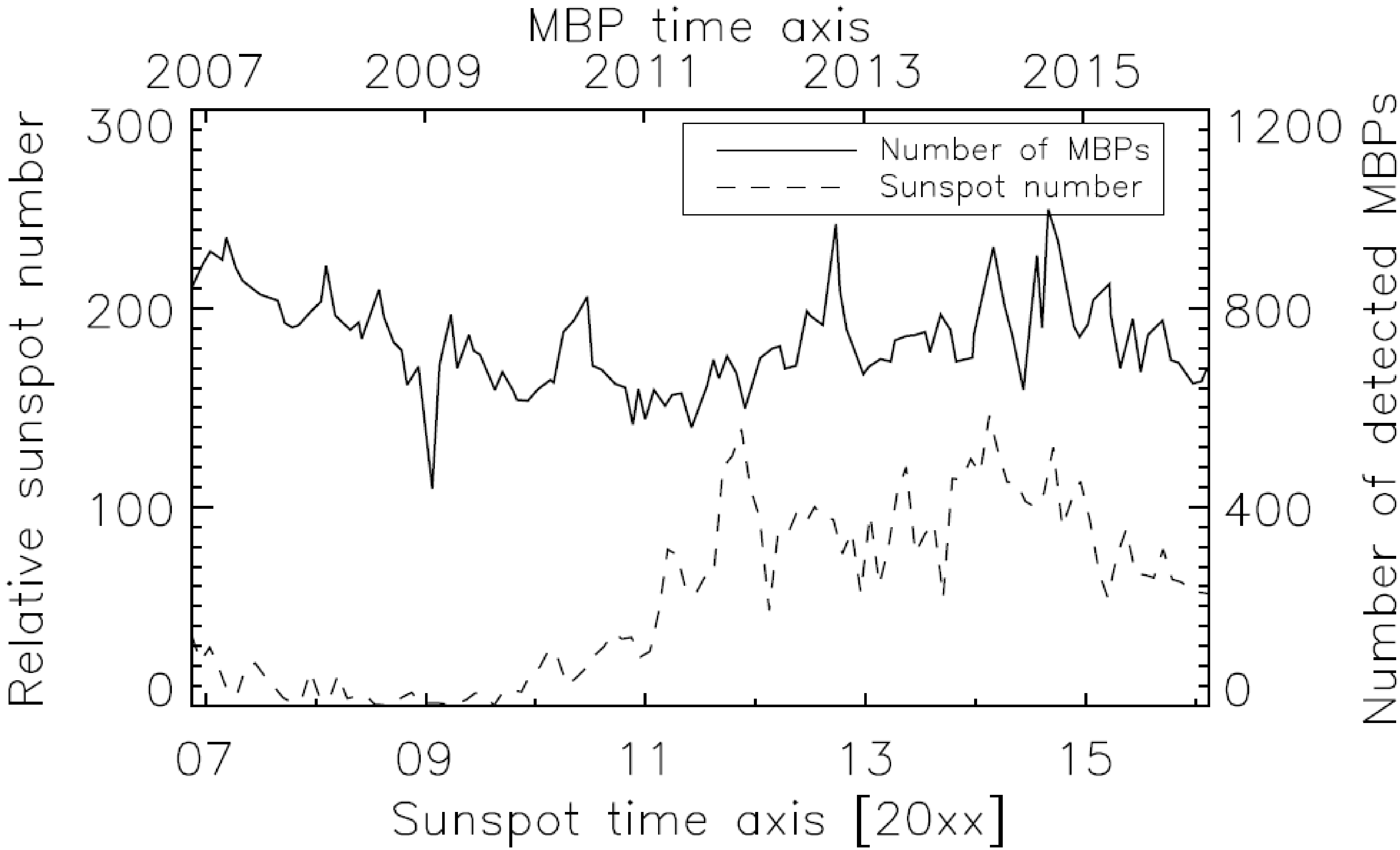
- The main observational findings for the size distribution:
  - The size distribution of MBPs follows a Gamma distribution
  - The size of MBPs is variable with the solar cycle showing larger scale paramters during more active times and lower scale parameters, i.e. smaller sizes and steeper distributions during less active Sun
  - Moreover the shape parameter is variable indicating a changing telescope quality

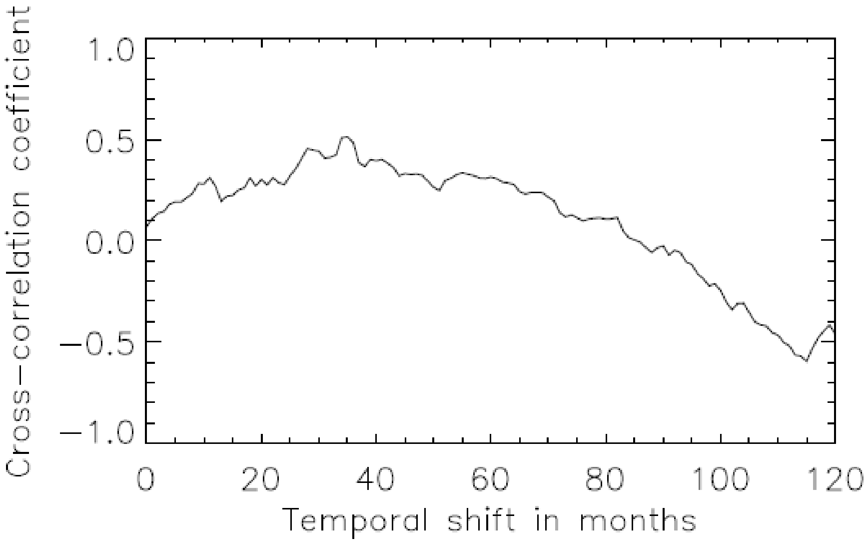
- Interpretation:
- The 2 paramters of the Gamma distribution can be interpreted as
  - Scale parameter true physica size dependence follows an exponential function and is variable with the solar cycle
  - Shape parameter can be interpreted as diffraction limit cut off and thus models the telescope quality and principle resolution limit

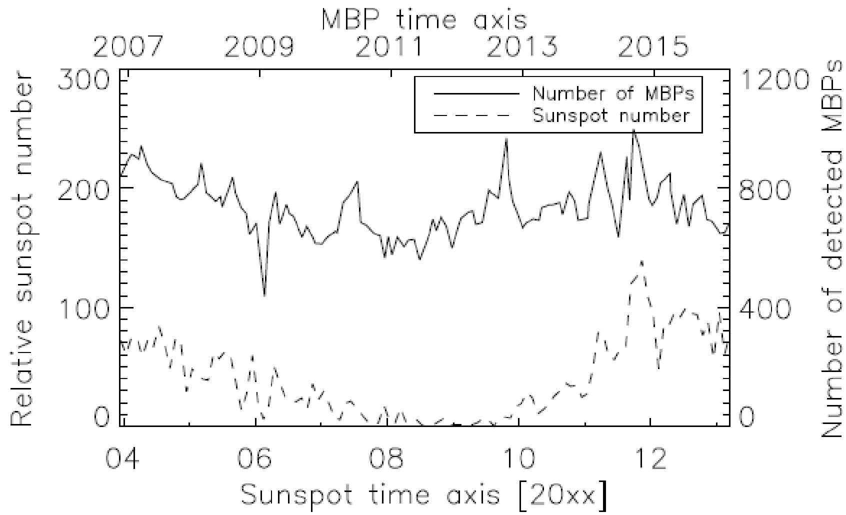
- For more details see:
  Utz D., et al. 2018, A&A, under preparation: Long-term trends of magnetic bright points. II. Number of magnetic bright points at disc centre

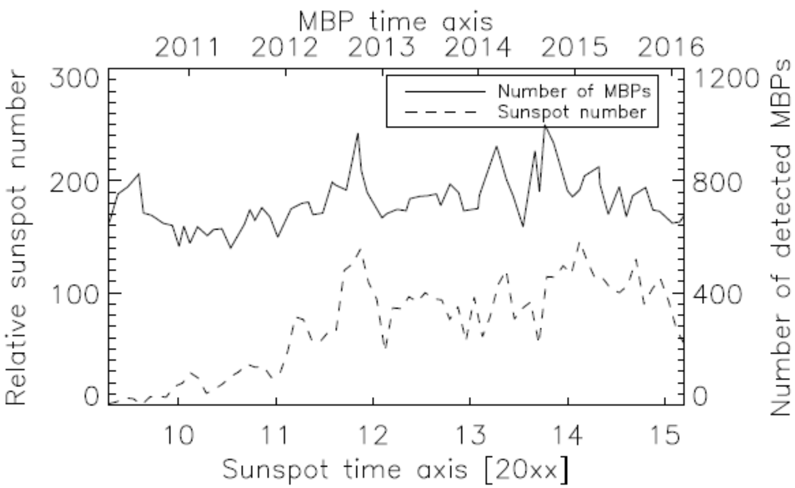

MBP activity versus time (raw data)
Number of detected MBPs
3000
2500
2000
1500
1000
500
0
07
09
11
13
15
Calendar year [20XX]

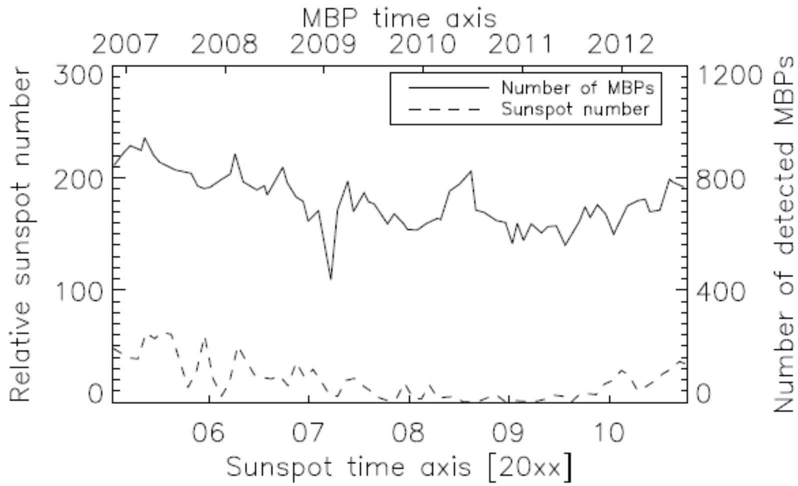
Monthly median MBP number at disc centre




Cross-correlation coefficient
1.0
0.5
0.0
−0.5
−1.0
0
20
40
60
80
100
120
Temporal shift in months

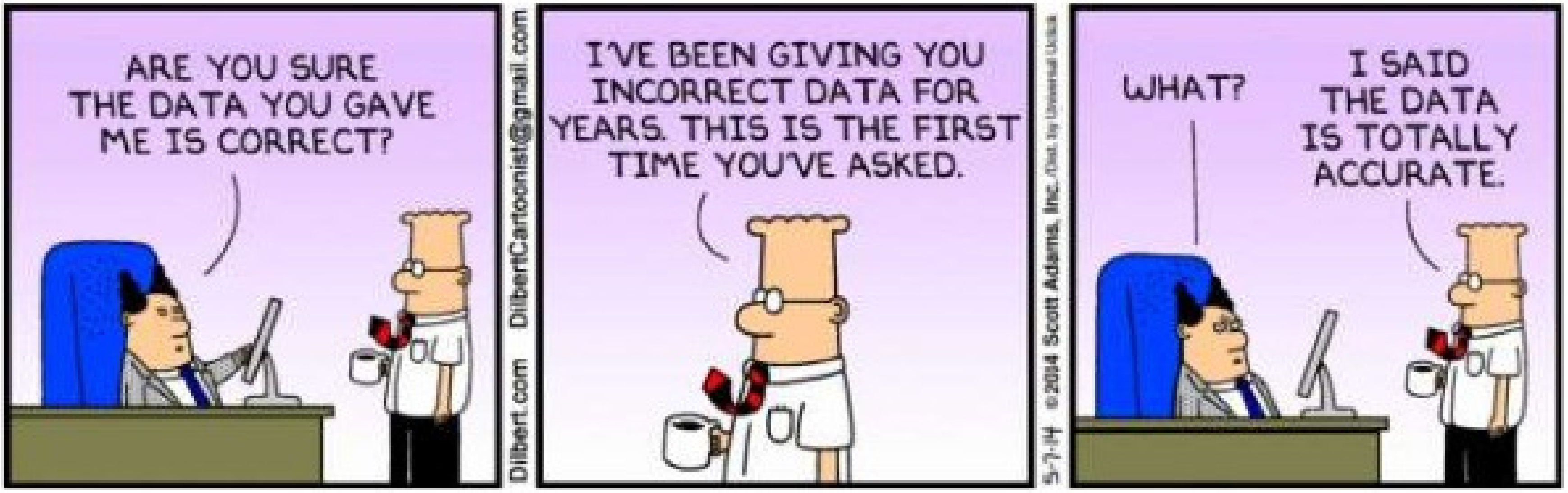

MBP time axis
2007
2009
2011
2013
2015
Number of MBPs
Sunspot number
Relative sunspot number
300
200
100
0
1200
800
400
0
Number of detected MBPs
04
06
08
10
12
Sunspot time axis [20xx]


MBP time axis
2011
2012
2013
2014
2015
2016
Number of MBPs
Sunspot number
Relative sunspot number
300
200
100
0
1200
800
400
0
Number of detected MBPs
10
11
12
13
14
15
Sunspot time axis [20xx]

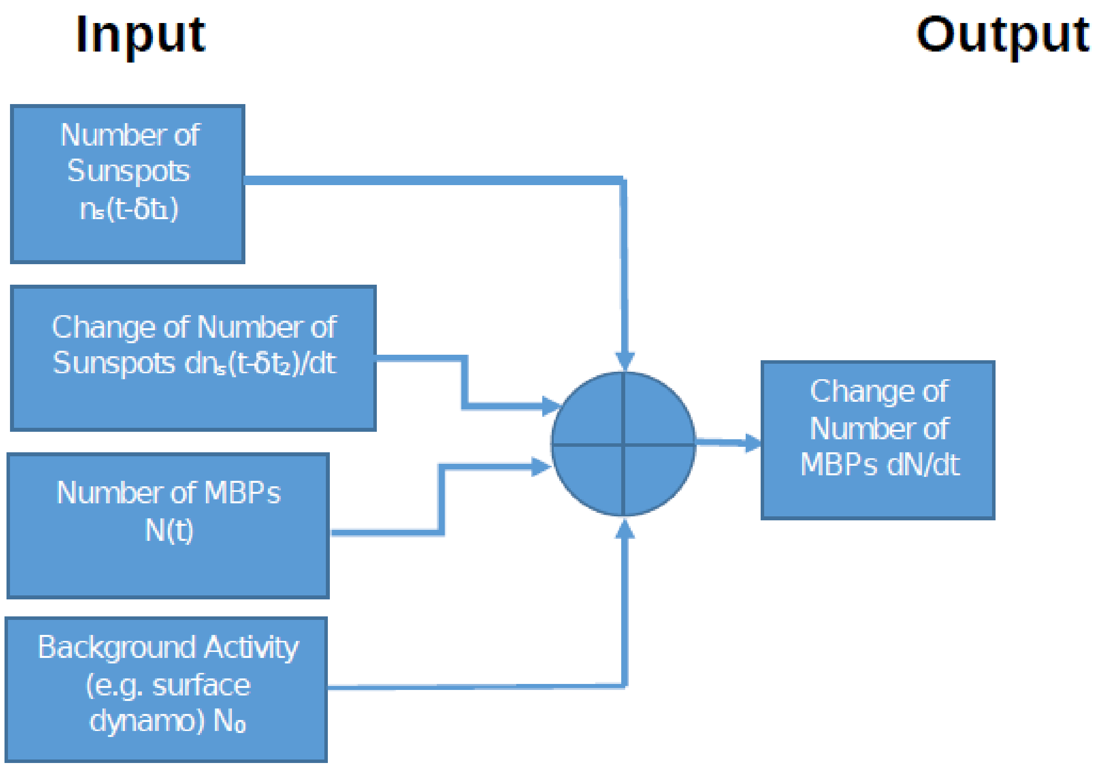

MBP time axis
2007
2008
2009
2010
2011
2012
Number of MBPs
Sunspot number
Relative sunspot number
300
200
100
0
1200
800
400
0
Number of detected MBPs
06
07
08
09
10
Sunspot time axis [20xx]

Part III: Modelling and Conclusions

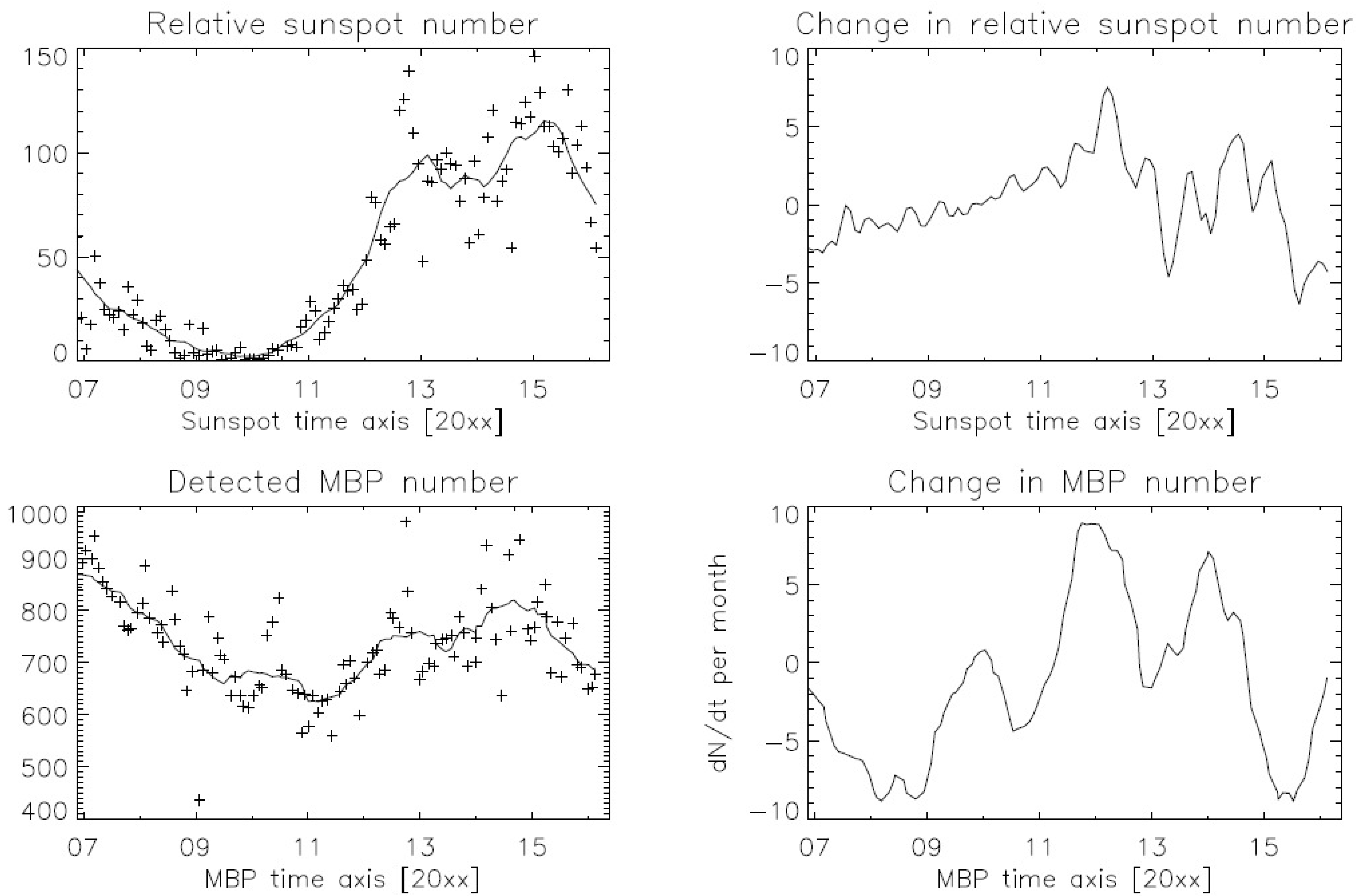
Higher Data Quality



cloudera



$$\frac{dN(t)}{dt} \propto a n_s(t-\delta t_1) + b\frac{dn_s(t-\delta t_2)}{dt} + c(N(t)+N_0)$$


Relative sunspot number
150
100
50
0
07
09
11
13
15
Sunspot time axis [20xx]
Change in relative sunspot number
10
5
0
−5
−10
07
09
11
13
15
Sunspot time axis [20xx]
Detected MBP number
1000
900
800
700
600
500
400
07
09
11
13
15
MBP time axis [20xx]
Change in MBP number
dN/dt per month
10
5
0
−5
−10
07
09
11
13
15
MBP time axis [20xx]

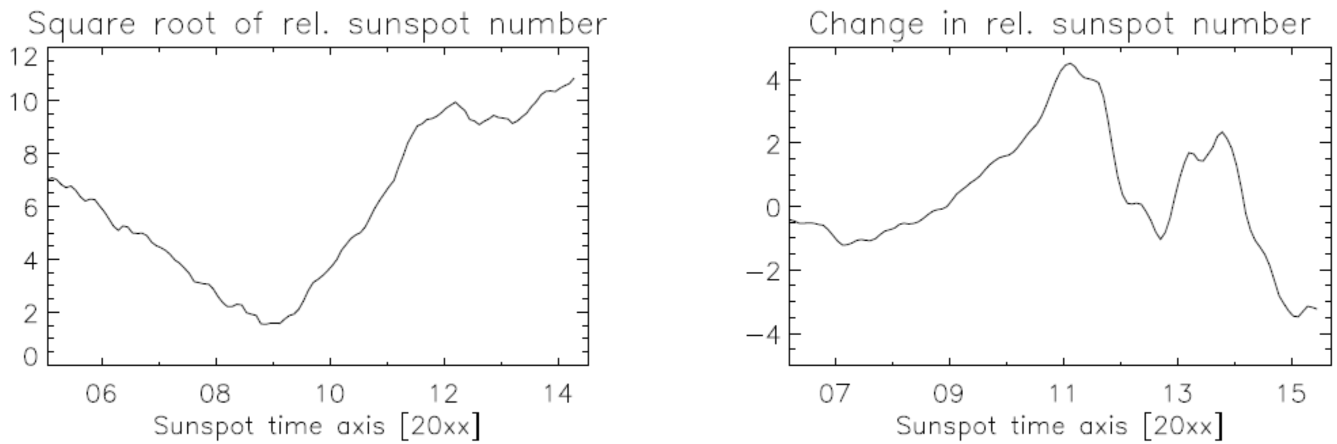


Fig. 10. the actually obtained best fitting candidates for the input parameters of the predictive model. From left top to right bottom: the square root of the relative sunspot number for fitting the change in the number of MBPs (shifted by 22 months) and the monthly derivative of the square root of the relative sunspot number (shifted by 8 months). Both curves are shown as yearly running smooths and thus slightly different from the ones depicted in the Fig. 9. For the obtained fitting parameters (weights of the different curves) see Table

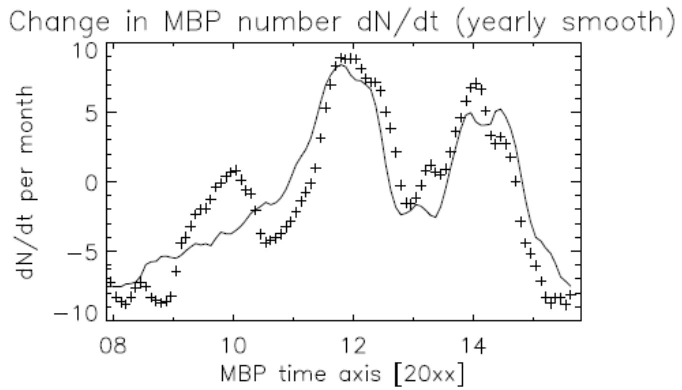


Fig. 11. the detected change of the number of MBPs after applying an annual running mean filtering shown with crosses and the fitted change of MBPs according to Eq. 2. for the longest possible data set period from May 2007 to August 2015.

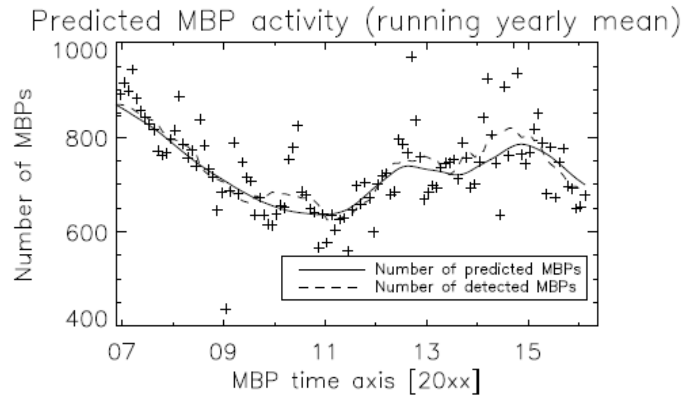
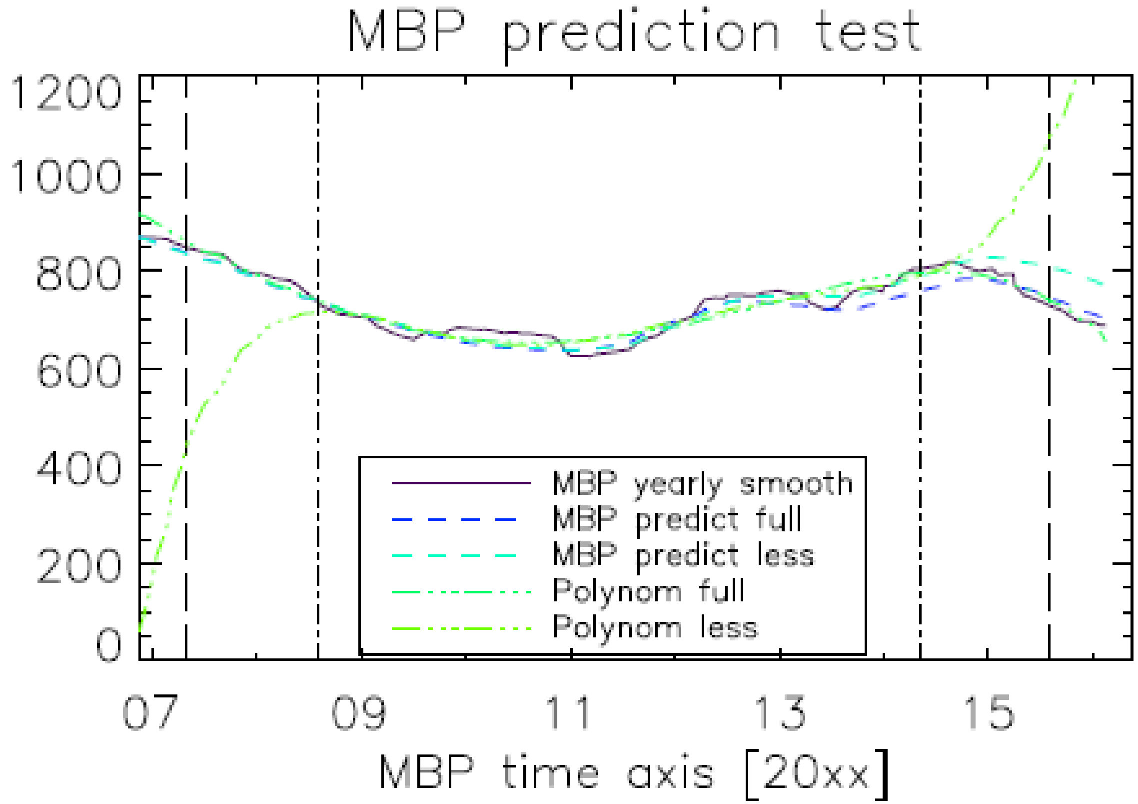


Fig. 12. the actual measured number of MBPs at disc centre (crosses) together with an annual running smooth of the actual data dashed line and the predicted number of MBPs at disc centre (solid line) obtained via a single starting number of MBPs and the fitting parameters listed in Table 1 and Eq. 2.

Table 1. gives the best fitting coefficients found for the general fitting of the dN/dt behaviour for the temporal change of the detected MBPs measured at the disc centre for a yearly running smoothing of all parameters.

modeling period	a [month^{-1}]	b	c [month^{-1}]	N_0	δt_1 [month]	δt_2 [month]
May 2007 / August 2015	2.728	0.962	-0.018	255	22	8
July 2008 / May 2014	2.575	1.516	-0.038	448	23	10



- The main observational findings:
  - The small-scale magnetic field activity (see by MBPs) is related to the solar cycle
  - But there are different time lags for the descending and ascending phase of cycle 23/24
- Modelling:
  - The sunspots should be responsible for the magnetic field activity in the network
  - Leading to a model with 4 major input paramters
- Interpretation:
  - With caution due to the many fitting parameters and low certainty (a multitude of possible solutions exist)!
  - While the number of MBPs seems to be dominated by the old sunspot flux in the decreasing phase (large „a“ coefficient and high time lag), the number of MBPs is driven more directly during the rising phase (lower „a“ number with nearly no temporal shift).
  - During the rising phase the MBP decay parameter „c“ is increased as well as the number of background MBPs (factor ~ 2.5) indicating that the plasma dynamics is much higher during the rising phse leading to a faster transport of flux out of the center of the Sun (increased decay parameter) as well as to a larger background activity (increased small-scale dynamo).
- For more details see:
  Utz D., et al. 2016, A&A, 585, 39: Long-term trends of magnetic bright points. I. Number of magnetic bright points at disc centre and Utz D., Muller R., Van Doorsselaere T., 2017, PASJ: Temporal relations between magnetic bright points and the solar sunspot cycle under review

...and that concludes my federal report on the status of global warming. Now, special agent Coffield here will be placing you all under arrest for having classified information.

Thank you for your attention and the whole Hinode team for the great data and work done over all the years!

Cartoons taken from the internet