What Photometric Images Have (and Haven't) Taught us About TSI

Stephen Walton, San Fernando Observatory

Cal State Northridge

SORCE 2004
October 28, 2004

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We also gratefully acknowledge the continuing support of CSUN, NASA, and NSF for the photometry program at SFO.

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- Our Data: SFO Photometric Images

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  - Bolometric Image and “Image”
- Summary and Future Work

Overview

Goal: Understand the sources of variability of the total solar irradiance S and its dependence on wavelength

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- What might we learn from newly available bolometric images?

SFO Photometric Images

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- CFDT1: $5'' \times 5''$ pixels
  - Began operation in 1985
  - 672.3 nm, 10 nm bandpass (average level 0.98 continuum)
  - 393.4 nm, 1 nm bandpass added Spring 1988
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  - 997.0 nm, 10 nm bandpass
  - 780.0 nm, 10 nm bandpass added 2003

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- $I_q(\mu)$: quiet sun limb darkening curve in same units as $I(x, y)$
- Contrast $C(x, y) \equiv \frac{I(x,y)}{I_q(\mu)} - 1$

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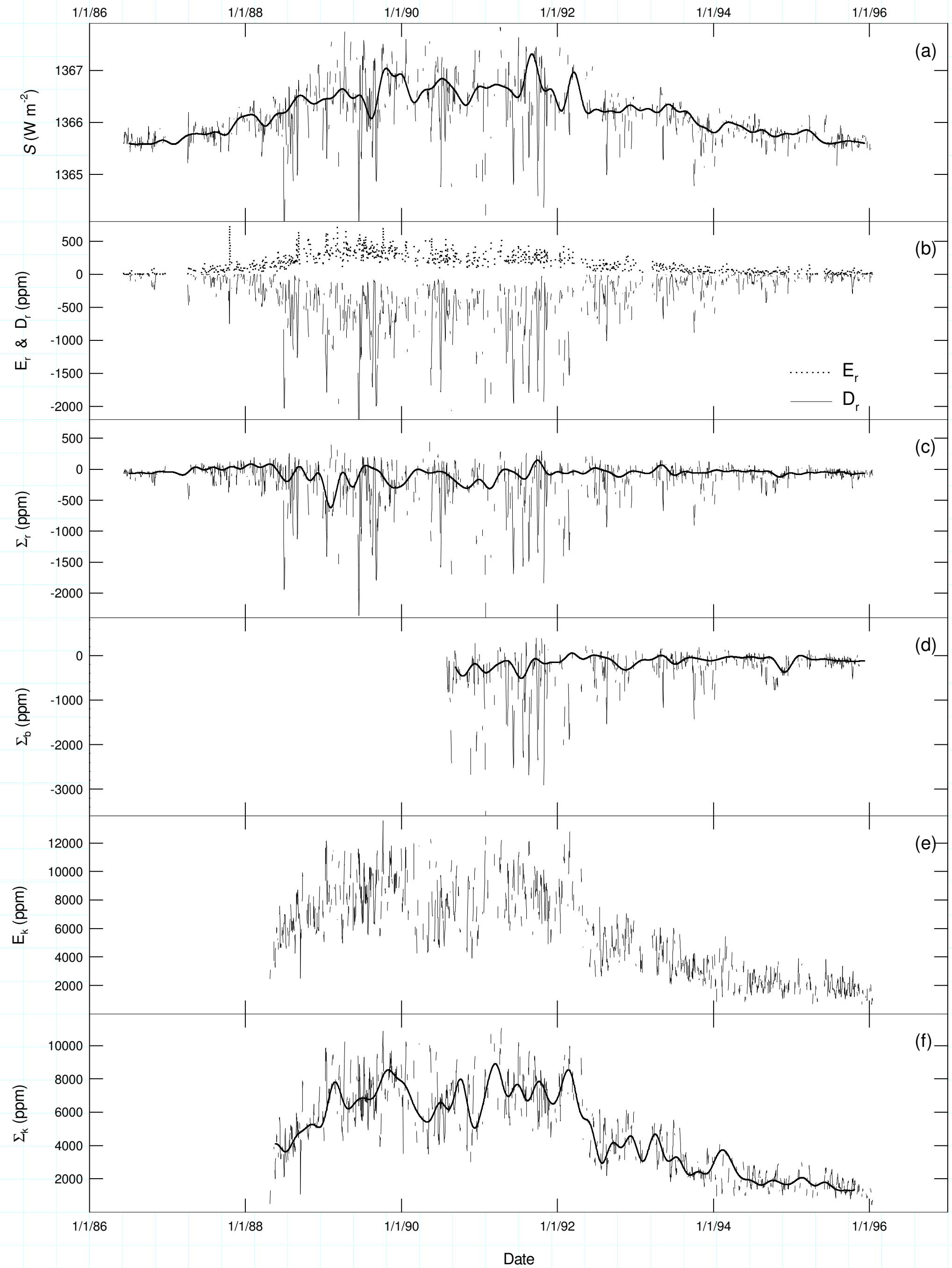
- S modeled using linear regressions of various combinations of these indices.



1/1/86
1/1/88
1/1/90
1/1/92
1/1/94
1/1/96
S (W m-2)
1367
1366
1365
(a)
Er & Dr (ppm)
500
0
-500
-1000
-1500
-2000
(b)
Er
Dr
Σr (ppm)
(c)
Σb (ppm)
-3000
(d)
Ek (ppm)
12000
10000
8000
6000
4000
2000
(e)
Σk (ppm)
(f)
Date

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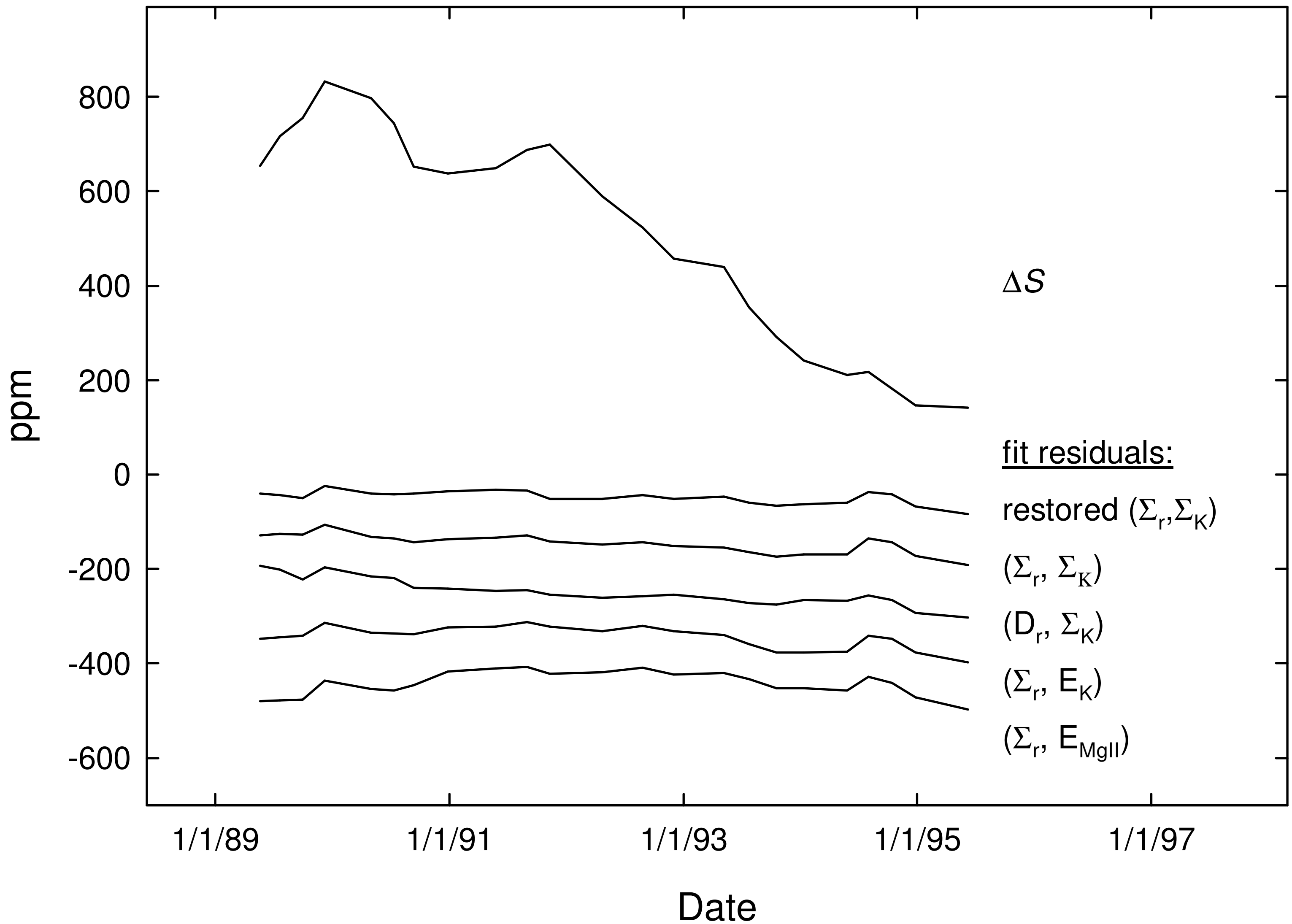
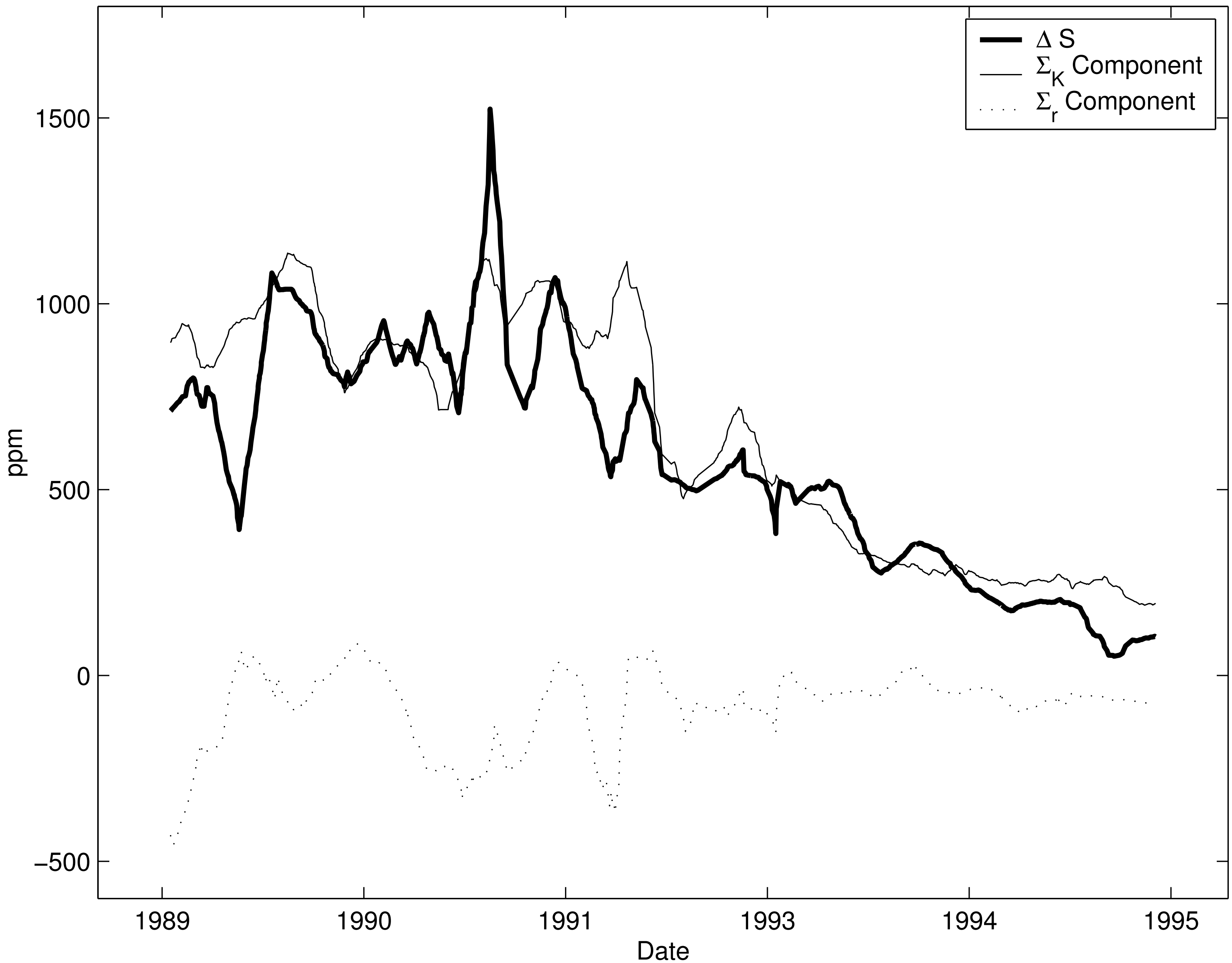
- For quantitative analysis, we use a model of the form $S = S_0 + a\Sigma_r + b\Sigma_K$. This matches observed composite S for all of cycle 22 (June 1988–Sept 1996) with $R = 0.96$ and $\sigma = 0.18$ W m^{-2} (130 ppm).



800
600
400
200
0
-200
-400
-600
ppm
1/1/89
1/1/91
1/1/93
1/1/95
1/1/97
Date
ΔS
fit residuals:
restored (Σ_r, Σ_K)
(Σ_r, Σ_K)
(D_r, Σ_K)
(Σ_r, E_K)
(Σ_r, E_{MgII})



Δ S
Σ_K Component
Σ_r Component
ppm
1500
1000
500
0
−500
1989
1990
1991
1993
1994
1995
Date

Conclusions on Models of S

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- Modeling effects on climate due to UV variations are important, because the rest of the spectrum likely does not vary much.

Feature Contributions to S

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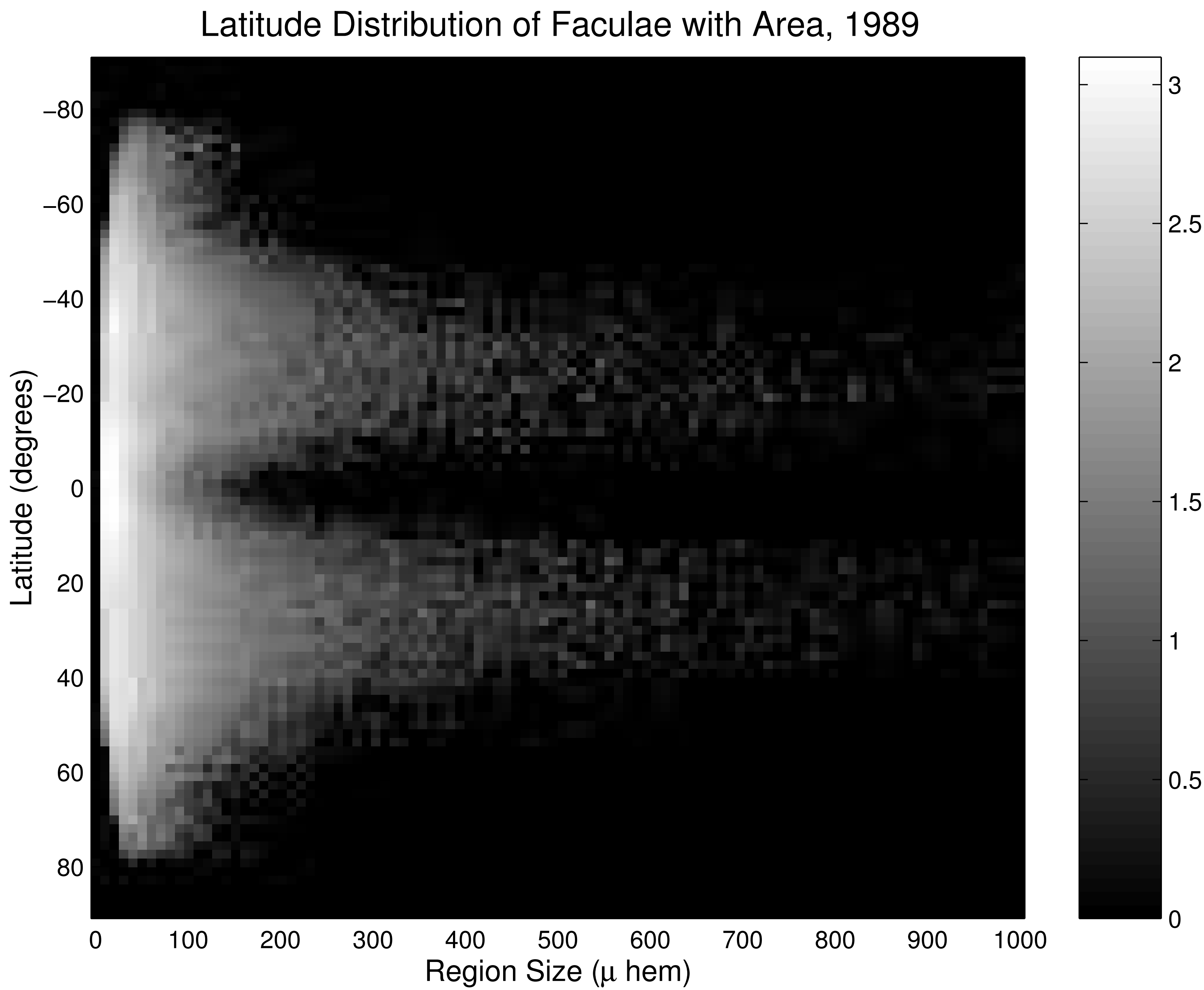
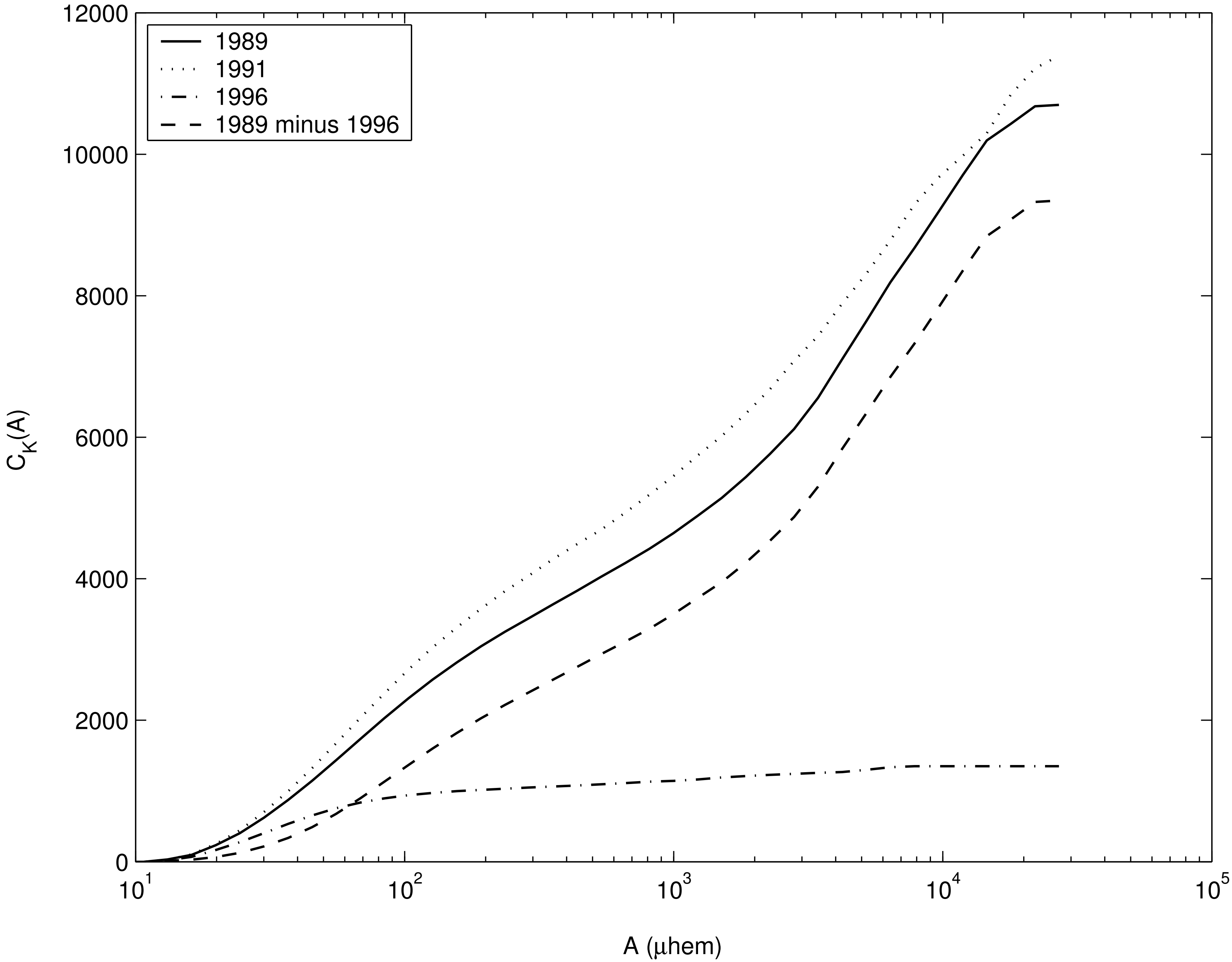
- The eleven year variation in Σ_K is dominated by changes in the excess E_K
- Thus, photometry of individual bright K features should tell us the relative contribution of each feature to the 11-year variability in S



Latitude Distribution of Faculae with Area, 1989
Latitude (degrees)
−80
−60
−40
−20
0
20
40
60
80
0
100
200
300
400
500
600
700
800
900
1000
Region Size (μ hem)
3
2.5
2
1.5
1
0.5
0



1989
1991
1996
1989 minus 1996
12000
10000
8000
6000
4000
2000
0
$C_K(A)$
10^1
10^2
10^3
10^4
10^5
A (μhem)

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- Computations show roughly 80% of the solar cycle change in S is due to features larger than 100 millionths of the solar hemisphere.

- Direct measurements of D_r and E_K are less likely to be misleading than assumptions about the contrasts of solar features.

And now. . .

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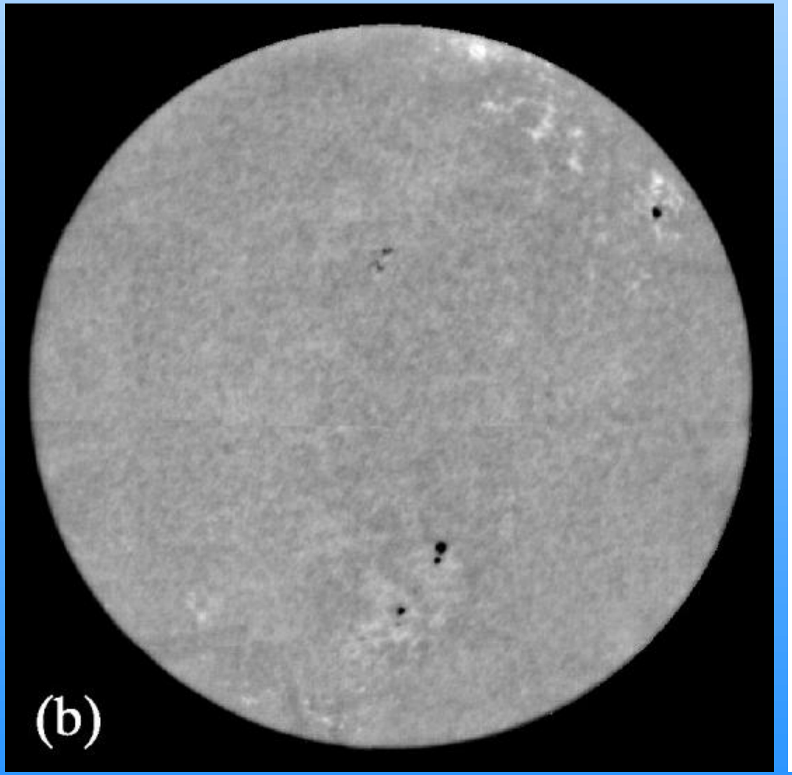
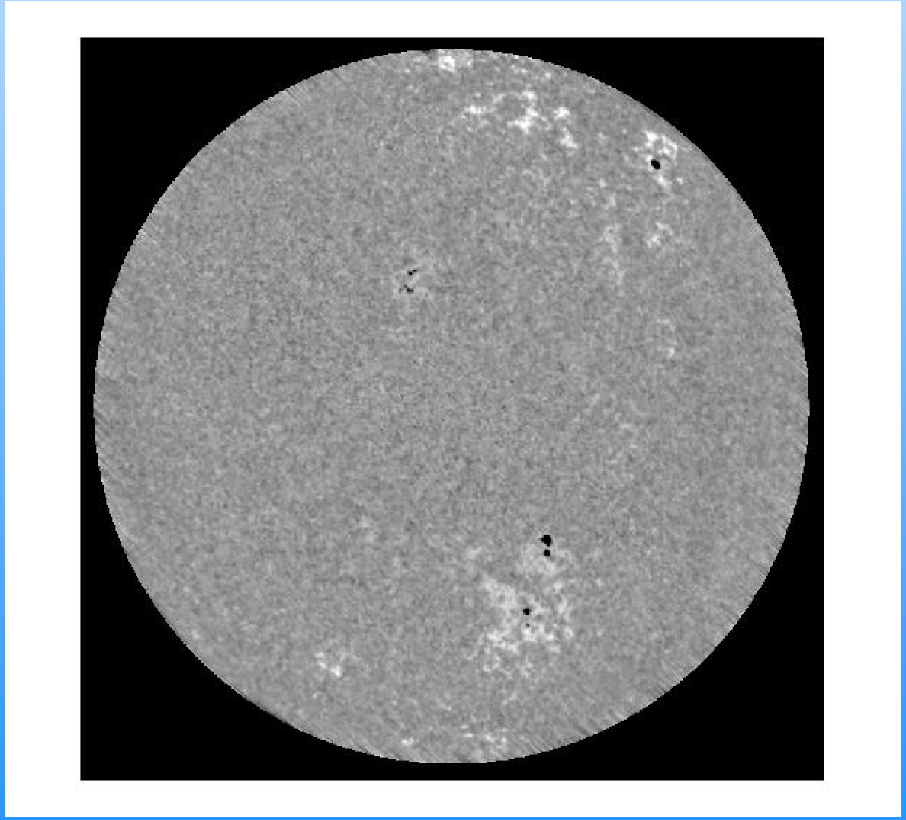
SBI Bolometric and SFO “Bolometric” Images for 1 September 2003





Data Availability

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The SFO Web site is `http://www.csun.edu/sfo`. Daily CFDT1 images are available for download; our photometric indices will appear there soon.

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- This FIR shows TSI influences extend both ways in time from spot emergence.
-
- See poster by Dora Preminger, this meeting.

A Few Comments on Solar Features

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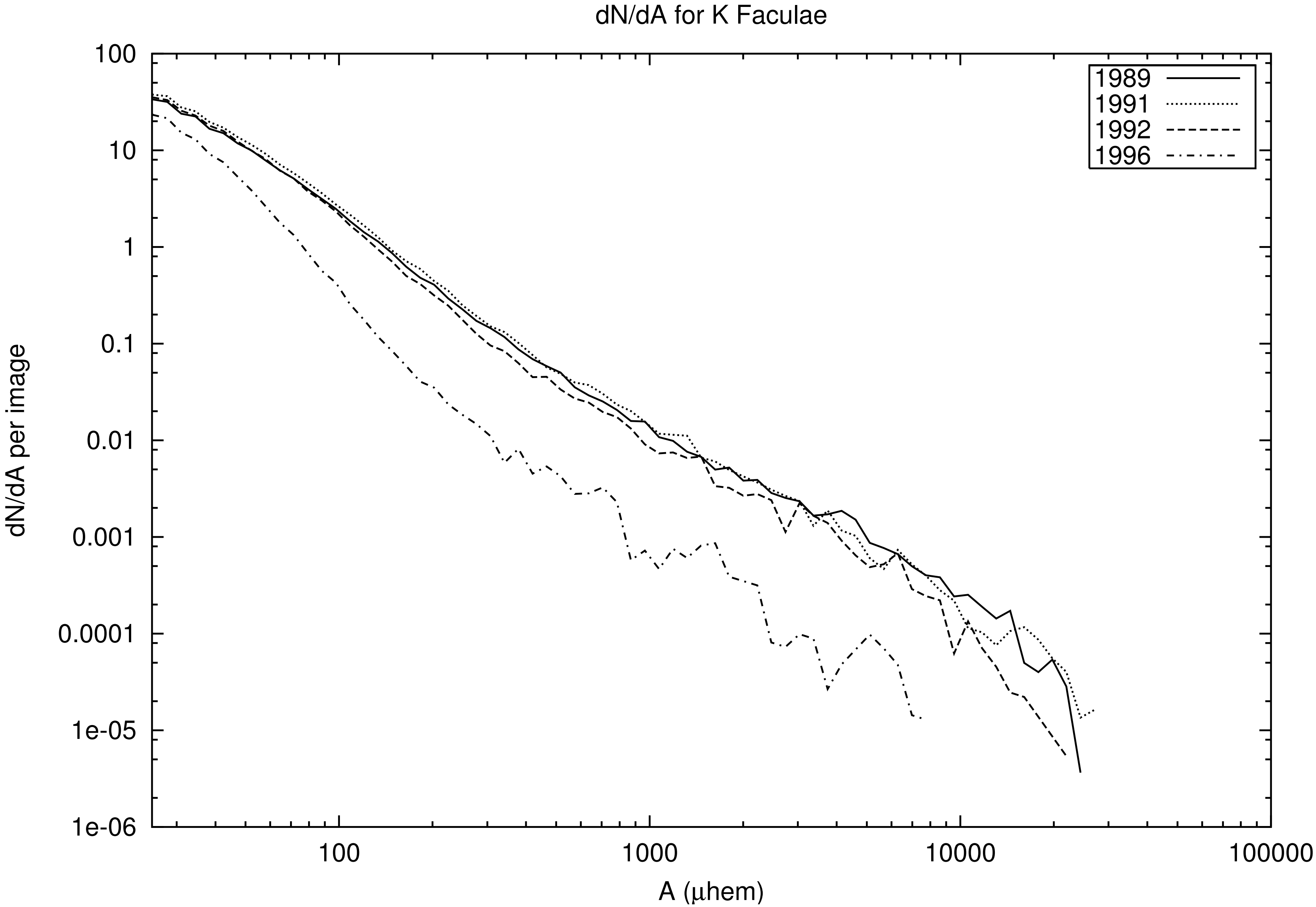
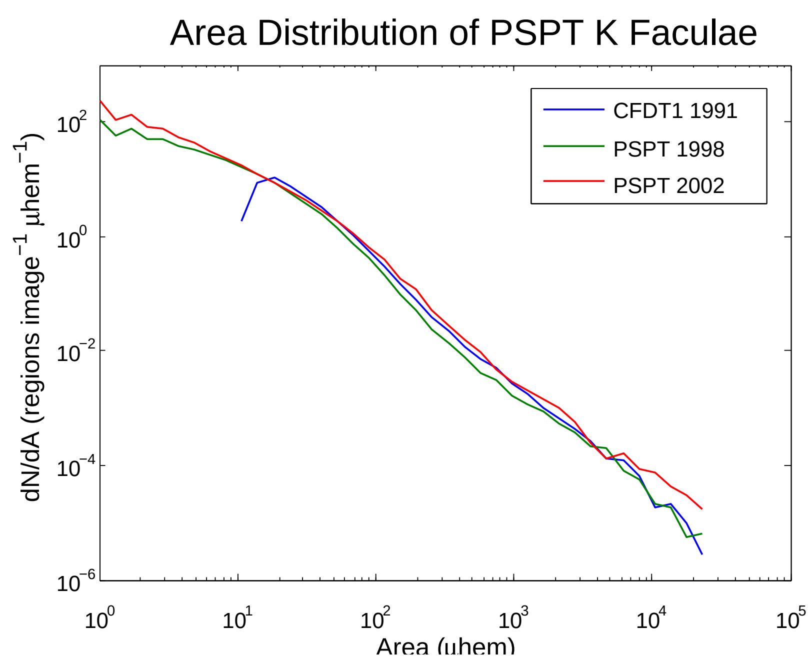
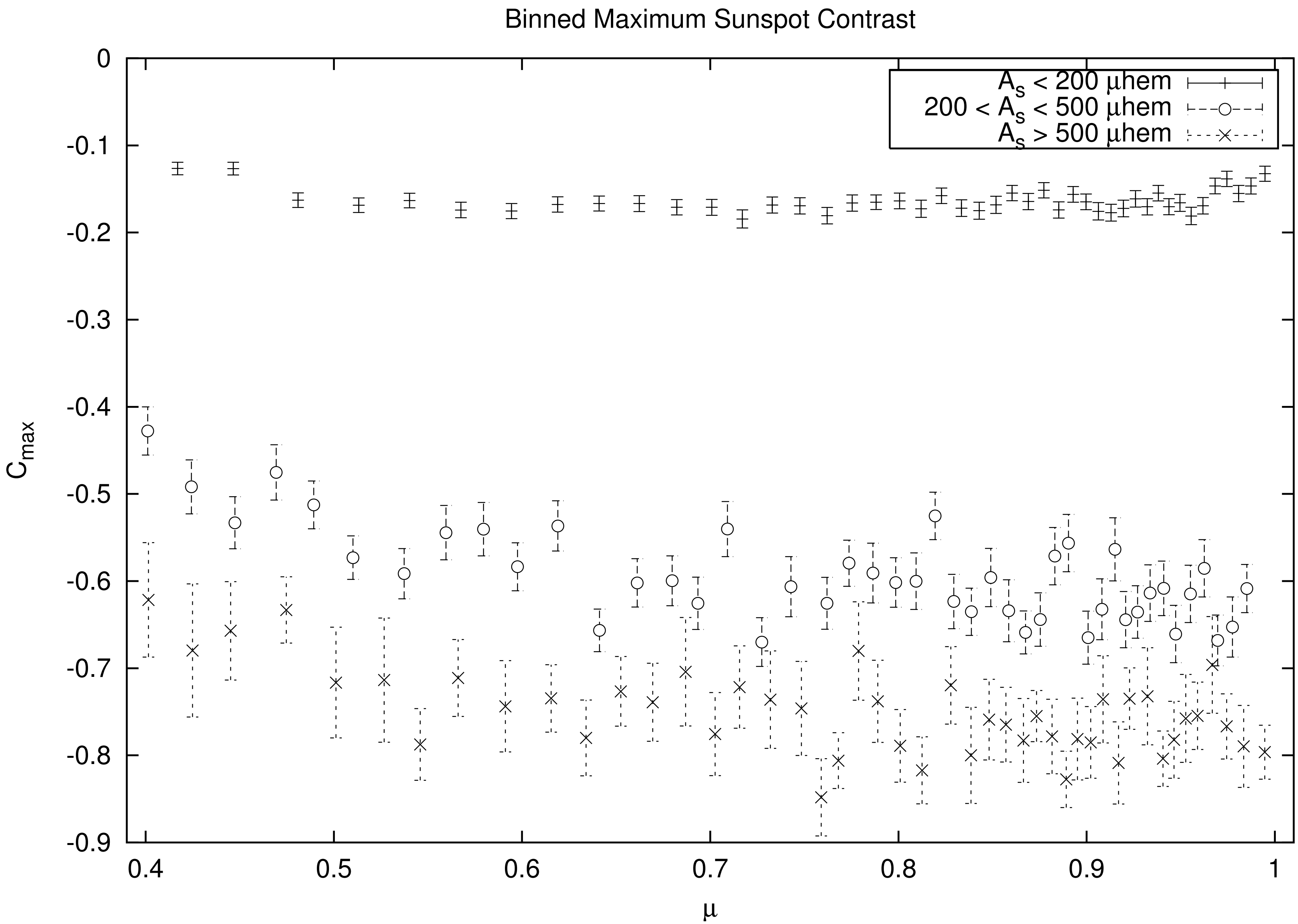
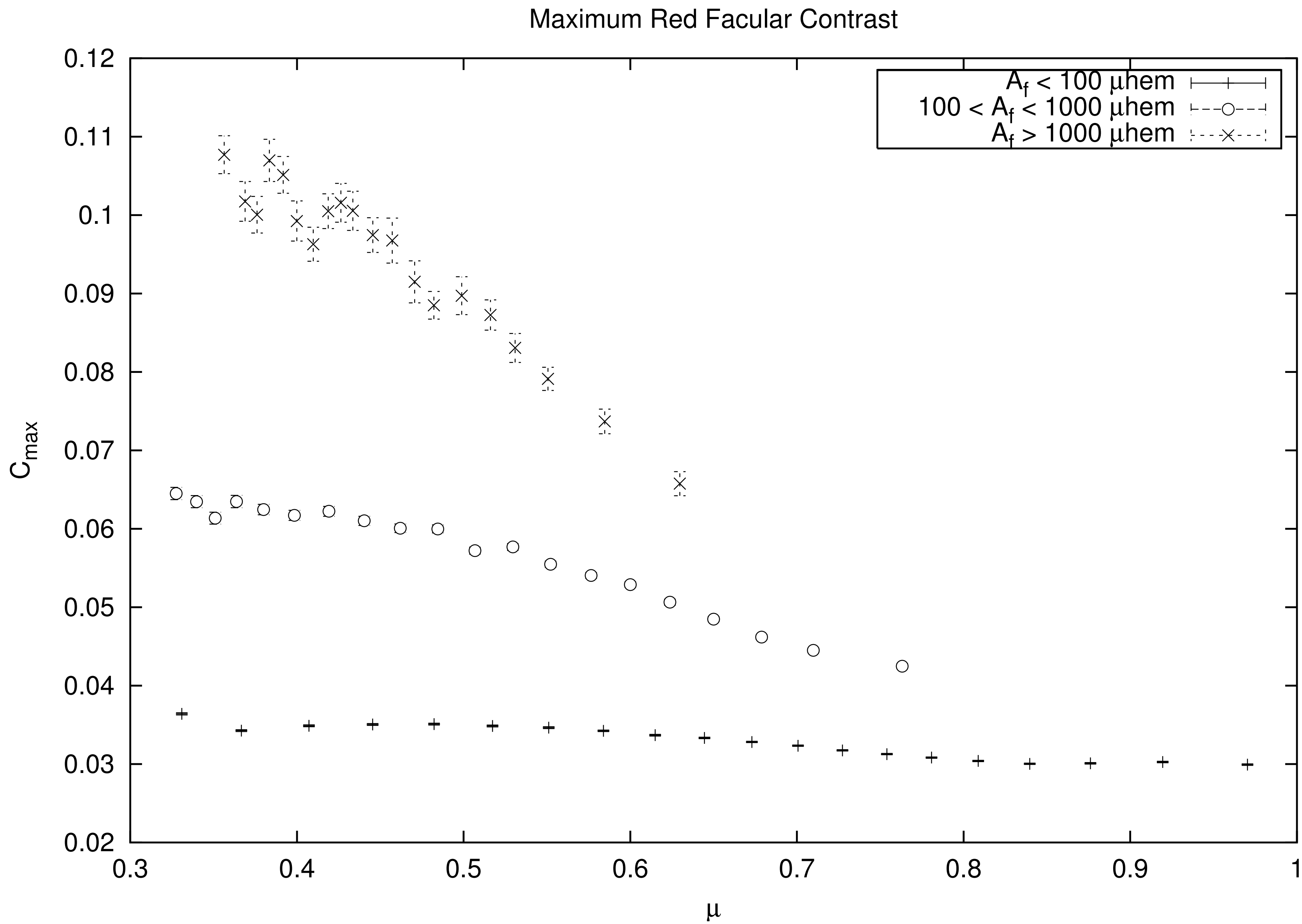
- Allows direct identification of continuum faculae on red images
- Also examined pixels on red images which were co-spatial with Ca II K facular pixels
- A total of 18 000 sunspots, 147 000 continuum faculae, and 850 000 K faculae studied



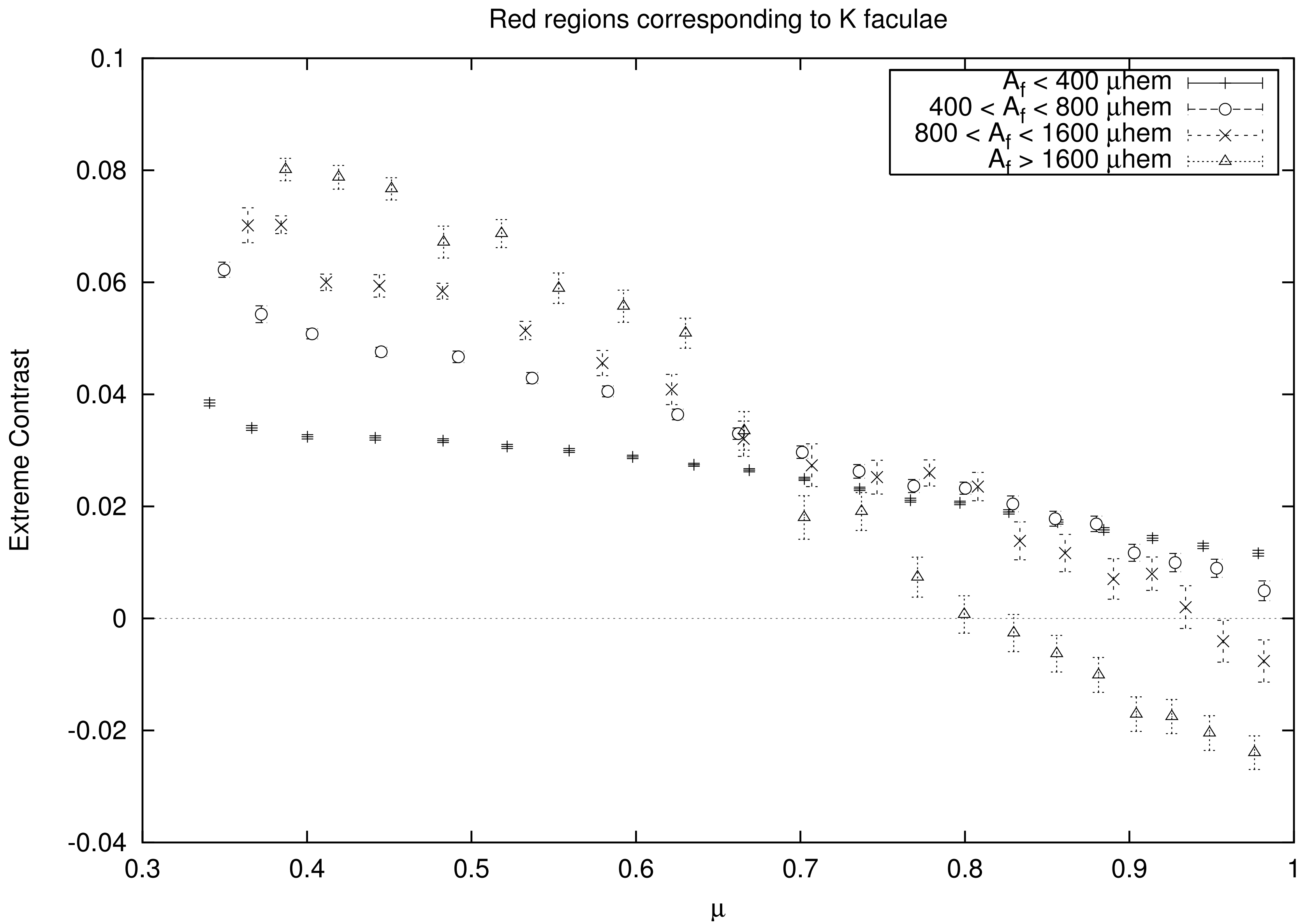
dN/dA for K Faculae
1989
1991
1992
1996
100
10
1
0.1
0.01
0.001
0.0001
1e-05
1e-06
100
1000
10000
100000
A (μhem)
dN/dA per image

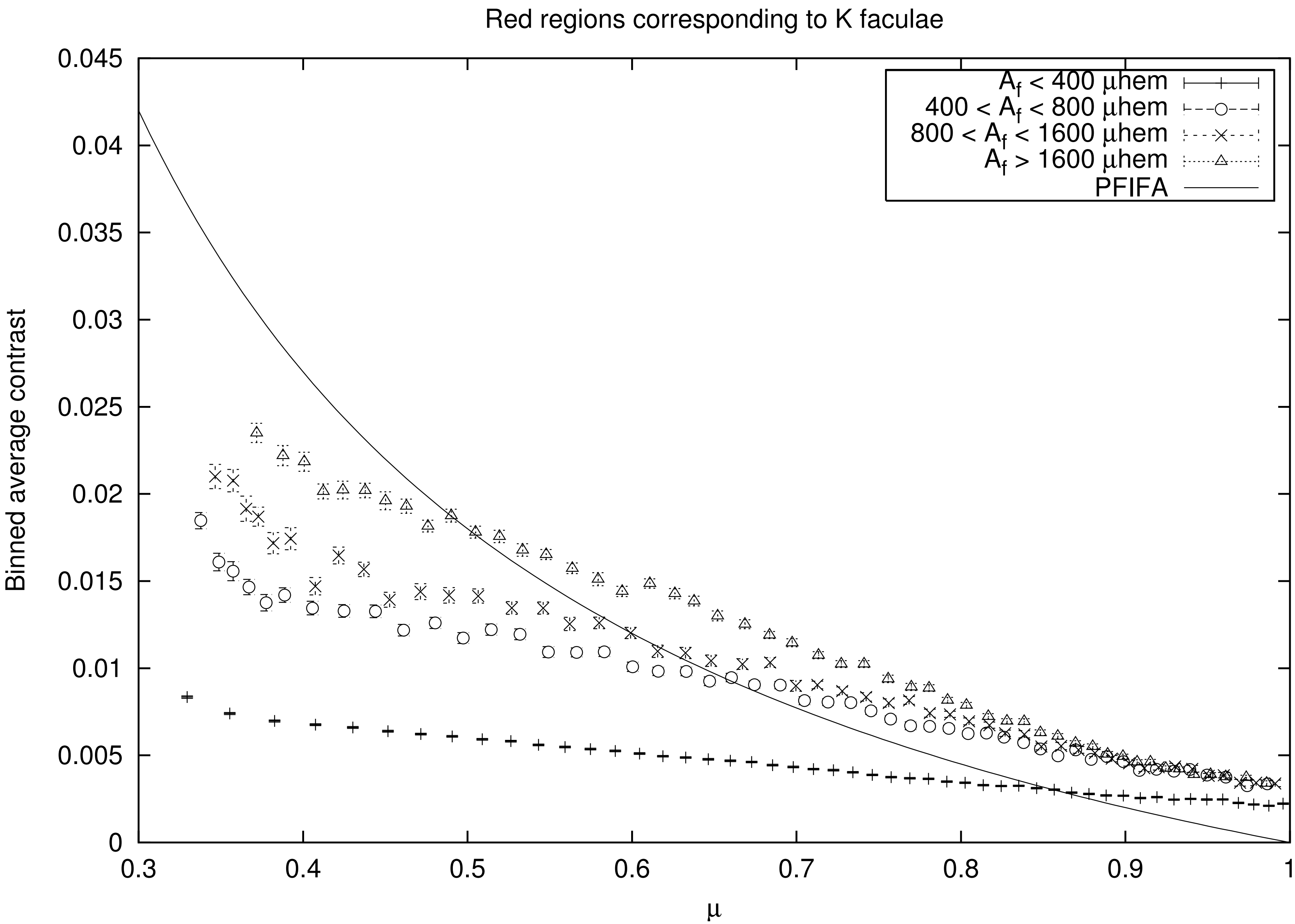

Area Distribution of PSPT K Faculae
CFDT1 1991
PSPT 1998
PSPT 2002
dN/dA (regions image^{-1} μhem^{-1})
Area (μhem)
10^{2}
10^{0}
10^{-2}
10^{-4}
10^{-6}
10^{0}
10^{1}
10^{2}
10^{3}
10^{4}
10^{5}


Binned Maximum Sunspot Contrast
A_s < 200 μhem
200 < A_s < 500 μhem
A_s > 500 μhem
C_max
μ
0
-0.1
-0.2
-0.3
-0.4
-0.5
-0.6
-0.7
-0.8
-0.9
0.4
0.5
0.6
0.7
0.8
0.9
1



Maximum Red Facular Contrast
A_f < 100 µhem
100 < A_f < 1000 µhem
A_f > 1000 µhem
C_{max}
µ
0.12
0.11
0.1
0.09
0.08
0.07
0.06
0.05
0.04
0.03
0.02
0.3
0.4
0.5
0.6
0.7
0.8
0.9
1


Red regions corresponding to K faculae
Extreme Contrast
μ
0.1
0.08
0.06
0.04
0.02
0
-0.02
-0.04
0.3
0.4
0.5
0.6
0.7
0.8
0.9
1
A_f < 400 μhem
400 < A_f < 800 μhem
800 < A_f < 1600 μhem
A_f > 1600 μhem



Red regions corresponding to K faculae
Binned average contrast
μ
A_f < 400 μhem
400 < A_f < 800 μhem
800 < A_f < 1600 μhem
A_f > 1600 μhem
PFIFA
0
0.005
0.01
0.015
0.02
0.025
0.03
0.035
0.04
0.045
0.3
0.4
0.5
0.6
0.7
0.8
0.9
1

“Carry-Away” Conclusions for TSI Modeling

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“Carry-Away” Conclusions for TSI Modeling

1. All faculae and sunspots are not created equal
2. We suggest, following Steinegger *et al.* among others, that (at minimum) area-dependent sunspot & facular contrasts should be used for TSI modeling
3. While some features which are bright in K are dark in continuum, on average bright in K $\Rightarrow$ bright in continuum