Where are the sunspots?
Measuring Solar Activity

[Graph showing solar activity over time with labels for Dalton Min. and Modern Maximum]

2
The “average” solar cycle

- $R_{\text{max}}$: 117 +/- 42
- $T_{\text{max}}$: 51 +/- 13
- $D$: 132 +/- 16 months
SC23 vs. “average” SC

(Preliminary data)

$R_{\text{max}}$: 125.9 – Normal
Double max.: OK (1 out of 3 SC)
$T_{\text{max}}$: 49 months – Normal

$D = 151$ months?
SC23 vs. SC 01-22

SC23 is the longest cycle of the last 180 years. Only SC06 (153 months) and SC04 (169 months) were even longer.
How to recognize a SC24-group?

High latitude (25-30°)

Reversed magnetic polarity
The 24 groups of SC24
(Jan 2008 – Sep 2009)
A lóóóót of spotless days

Evolution SC23-24 transit

Minimum in December 2008?
Slow jetstream reason of absence sunspots?

→ Chicken-or-the-egg problem

Remarkably inactive Northern hemisphere!
Deep and long minimum

We have to go back to SC17 and SC15 for such a deep minimum
Deep and long minimum

Length or depth of the minimum cannot be used to make reliable predictions of the next SC-maximum!
Solar wind

- Lowest “pressure” since start observations in 1963
  - Speed OK
  - Density, temperature and magnetic field strength of the solar wind are 20-35% lower
  - Proxies (Svalgaard et al.) since 1890 => OK

- Heliosphere shrinks
  - Cosmic rays increase
    - “Ceiling”

- Similar for other solar parameters
Predicting is difficult, especially the future

Niels Bohr
### Predictions for Solar Cycle 24

<table>
<thead>
<tr>
<th>Rank</th>
<th>Name</th>
<th>Type</th>
<th>Technique</th>
<th>(T_{\text{begin}})</th>
<th>E.M.</th>
<th>(T_{\text{max}})</th>
<th>E.M.</th>
<th>(R_{\text{max}})</th>
<th>E.M.</th>
<th>(T_{\text{red}})</th>
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<td>Schatten</td>
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<td>SODA-index</td>
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<td>Magnetic Laplace (10 years in advance of R)</td>
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<td>De Jager, Dhub</td>
<td>stat-phys</td>
<td>Non-linear dynamo model and longterm oscillations in (R_{\text{max}}) and (a_{\text{max}})</td>
<td>Jun 08</td>
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<td>Geomagnetic precursor method based on 4-az-index</td>
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<td>16</td>
<td>Dhub et al.</td>
<td>stat-phys</td>
<td>Geomagnetic precursor method based on 4-index (SC17-23 only)</td>
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<td>4</td>
<td>2012</td>
<td>4</td>
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<td>Max. SC24 45+4 months after SC Min.</td>
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<td>Jiang, Chatzopoulos, Choudham</td>
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<td>Statistics on sunspot parameters</td>
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<td>Nonlinear methods (Marsden and Stephenson-May algorithm)</td>
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<td>24</td>
<td>Teng Xu</td>
<td>statistics</td>
<td>Empirical Mode Decomposition and AR model on sunspot numbers</td>
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<td>85</td>
<td>27</td>
<td>Jan 06</td>
<td>(1, 2, 3)</td>
<td>Method predicts SC23-3 min in 2007</td>
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</table>
3 types of methods

- **Statistical methods (27)**
  - Examples
    - Kontor: Fourrier-spectrum
    - Kilcik: Non-linear methods
  - SC24max: 112 +/- 24

- **Physical methods (9)**
  - Examples
    - Svalgaard, Schatten, Choudhuri: Magnetic field solar poles
    - Dikpati: Meridional stream and magnetic memory
  - SC24max: 83 +/- 14

- **Mixed methods (9)**
  - Examples
    - De Jager, Duhau: Non-linear dynamo-model with R and aa-index
    - Hathaway et al.: Geomagnetic precursor-techniques
  - SC24max: 117 +/- 25
• Most statistical methods predict average maximum
• Most physical methods predict low maximum
• Weak camp vs. Strong camp
  – Weak camp gives more importance to magnetic fields at the solar poles + high diffusion magnetic fields
  – Strong camp gives more importance to precursor techniques over several preceding solar cycles + low diffusion magnetic fields
SC24 Prediction Panel
April 2007

Solar Cycle 24 Sunspot Number Prediction
Data Through 31 March 2007

Low Prediction (Smoothed)  High Prediction (Smoothed)  1-Sigma Error
Smoothed Monthly Values  Monthly Values

Updated 2007 April 20
NOAA/SEC Boulder, CO USA
SC24 Prediction Panel
May 2009

ISES Solar Cycle Sunspot Number Progression
Data Through Apr 09

Updated 2009 May 8
NOAA/SWFC Boulder, CO USA
SC24 Prediction Panel
May 2009

Or ... a new Maunder Minimum?
The Maunder Minimum

- Between 1645 and 1715 almost no sunspots
  - Till 1705 no more than 1 group visible at the same time
  - Most of the time singular, shortlived, low-latitude spots
- Strongly concentrated in the southern hemisphere
  - On relatively low latitudes (<20°)
- Sudden beginning followed by gradual recovery


Ribes et al. (1993)
The Maunder Minimum

• Maunder Minimum confirmed
  – John A. Eddy (1976)
    • Aurorae-observations
    • Solar eclipses
      – Pre-1715: no mention of corona!
  – Hoyt & Schatten (1995)
    • Additional observations
      – Daily observations for period 1645-1715 and after 1820!

• Isotopes $^{14}$C (tree rings) and $^{10}$Be (polar ice) confirm existence of (longer lasting) solar cycle during (part of) this period
  – Solar dynamo appears to be still working during this period!
  – 11-year SC no permanent feature of sunspot activity
Lower magnetic field strength => Higher temperature umbra => sunspots less visible

Will sunspots have disappeared by 2015?
Pro & Contra Livingston & Penn

• **Contra**
  - Limited number of observations
  - Concentrated in descending branch of SC23
  - Is it OK to extrapolate lineary?
    • E.g. 1980: 5000 Gauss!

• **Pro**
  - Rate between Radio-flux and Sunspotnumber
    • Leif Svalgaard
  - Percolation-theory
    • Schatten et al. (2007)
Pro & Contra Livingston & Penn

- Pro 1
  - Rate between Radio-flux and Sunspotnumber
    - Leif Svalgaard
    - Less spots for same radioflux
      - Due to Zürich => SIDC?
Pro Livingston & Penn

- Current theory on formation of sunspots
- Pro 2
  - Percolation-theory
    - Schatten et al. (2007)
    - New theory on sunspot generation
    - Sunspots develop from the coalescence of smallscale structure of the same magnetic polarity
    - Basic ideas confirmed by Hinode (2007)
    - Theory can not explain all features of sunspot groups
      - To be continued…

http://science.nasa.gov/headlines/y2007/images/trilobite/Hinode_lower.mov
What *can* this mean for SC24?
Conclusions

• Still *no* certainty on the start of SC24
  – Probably in December 2008
• Long and deep minimum
  – Not seen in 100 years
• Predictions for maximum SC24
  – Consensus *at this moment*
    • Maximum certainly not as high as SC21/22
      – Probably rather moderate (Max SSN: 90 +/- 20)
    • *If* inactivity persists (e.g. mid-2010)
      – Dalton-like minimum similar to early 19th century possible (Max SSN: 50)
    • *If* inactivity persists for a few more years
      – New Maunder minimum?
        » Livingston&Penn, Schatten
Questions?
Current theory on sunspot generation