GIANT CELLS? WHY ARE THEY EXPECTED? WHAT CAN BE DONE TO FIND THEM?

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ABSTRACT: After a definition of Giant Cells two observational results are cited, which give indications for the existence of Giant Cells on the Sun. The rest of the contribution gives a summary of the attempts to find Giant Cells using mainly equipment of the Göttingen Solar Observatory in Orselina near Locarno/Switzerland within the last 4 years.

1. Introduction

In contradiction to the suggestion given by the title of this contribution it is not a review, but contains mainly results of attempts to find Giant Cells on the Sun performed at the Göttingen Observatory. It contains not only my results, but also those of the following institutes/persons:

(1) Universitäts-Sternwarte Göttingen:
   H. Balthasar
   A. Koch
   G. Küveler
   D. Stark
(2) Kiepenheuer-Institut für Sonnenphysik, Freiburg:
   E.H. Schröter
   D. Soltau
(3) Astronomisches Rechen-Institut, Heidelberg:
   H. Schwan
(4) Instituto Astrofisica Canarias, La Laguna:
   M. Pérez-Garde
   M. Vázquez

2. Definition of Giant Cells

I define Giant Cells on the Sun as large-scale velocity anomalies - except the differential rotation. The size of Giant Cells is larger than the size of supergranules and may be up to a fraction of the solar surface. The lifetime of Giant Cells may be some days to some months.
We may expect that these Giant Cells have closed currents of gas
  either on the surface of the Sun
  or in the convection zone.
But Giant Cells may also be only regions of accelerated or
decelerated material.
  Maybe Giant Cells show a periodic pattern on the Sun
- maybe not.

3. Indications for Giant Cells

I give two experimental results which indicate the existence of Giant Cells on the Sun. Some theoretical indications for Giant Cells were given in a talk by M. Stix
earlier during this conference.

(1) Within the years 1974 until 1976 high-precision computer-controlled observations of motions of Ca²⁺-mottles were performed at the Göttingen Solar Observatory. From the data obtained in 1975 a large-scale velocity pattern with closed currents was found. The size of the cells was
90° in longitude and about ± 20° in latitude. The velocity amplitude was ± 80 m/s and the lifetime about 6 weeks.

Using even more data in 1976 no closed currents could be found but only velocity anomalies - without correlations to plasma velocity anomalies.

The experimental procedure as well as the results are given by Schröter and Wöhl (1975, 1976) and Schröter et al. (1978). A more sophisticated analysis of the data is given by Schwan and Wöhl (1978).

(2) From plasma velocities obtained at Mt. Wilson since 1973 Howard (1979) showed the existence of several large-scale velocity anomalies near to the equator. The size of these cells was up to 60° in longitude and about ± 15° in latitude. There existed vertical velocities of about 40 m/s within the cells, which had lifetimes of several months.

4. Coordinate Systems

Observations of features on the Sun are mainly performed in heliographic coordinates. To compute the angles P and B₀, which determine the position of the rotation axis and the equator on the solar disk, the solar rotation elements Ω and i are used. I believe that the precision of these elements is not yet sufficient to determine positions on the Sun, when we attempt to reach the 1 m/s limit.
Most of the calculations for $P$ and $B_0$ use the rotation elements suggested by Carrington (1863):

\[
\begin{align*}
\Omega(1850) & \quad 73.67^\circ \\
i & \quad 7.25^\circ 
\end{align*}
\]

Using DOPPLER shift measurements of the solar plasma Wöhl (1978) found:

\[
\begin{align*}
\Omega(1850) & \quad (74.55 \pm 0.65)^\circ \\
i & \quad (6.77 \pm 0.31)^\circ 
\end{align*}
\]

Using Mt. Wilson data LaBonte (Solar Phys., in press) cannot find differences to Carringtons elements. But he does not calculate new elements, but only finds that the differences should be less than $\pm 1.2^\circ$ for $\Omega$ and less than $\pm 0.15^\circ$ for $i$.

When using the Greenwich Photoheliographic Results for positions of sunspot groups of the years 1940 until 1968 Stark and Wöhl (1981) find:

\[
\begin{align*}
\Omega(1850) & \quad (74.0 \pm 0.27)^\circ \\
i & \quad (7.15 \pm 0.03)^\circ 
\end{align*}
\]

Both deviations from the elements of Carrington show the same directions (bigger $\Omega$ and smaller $i$) and the same corrections were also indicated by several earlier observations (see Table 1 of Wöhl, 1978).

5. Using of Tracers to search for Giant Cells

(1) The positions of sunspot groups from the Greenwich Photoheliographic Results of the years 1940 until 1968 were used by Balthasar and Wöhl (1981) to search for Giant Cells. They did not find any indication for Giant Cells and also no correlations of velocity changes with active longitudes. They determined changes of the coefficients $a$ and $b$ of the law of differential rotation $(\omega = a + b \cdot \sin^2 \phi; \phi =$ latitude) depending on the phase of the solar activity cycle and found meridional motions of about 2 m/s to the south in all latitudes. But this last result is not significant.

(2) Within the years 1974 until 1979 high-precision computer controlled measurements of positions of sunspots were performed several times daily at the Göttingen Solar Observatory. Most of the old, stable spots show changes of the rotation velocity of less than $\pm 5$ m/s within 12 days, some even changes of only $\pm 2$ m/s. It could be shown that spots in the same latitude may have very different rotation velocities with differences up to $1^\circ$/day.

These results are submitted in a paper by Koch, Wöhl and Schröter to Solar Phys., but they don't give indications for Giant Cells.
6. Using of DOPPLER shifted spectral lines to search for Giant Cells

In 1977 and 1978 we used a linear photodiode array (RETICON) with 128 diodes to search for Giant Cells in the solar plasma. The spectral resolution was about 10 mA, which is given by the size of the diodes and the resolution of the spectrograph. The spectral line Fe I 6301.5 Å of the Sun and the terrestrial reference line O₂ 6302.0 Å were used. The exposure time of the array was 0.4 s. The S/N after 100 averages was about 300. The positions of the lines were found by parabolic fits through 14 points of the line profiles. The spatial averaging on the Sun was about 5 arcseconds and the averaging in time was 5 minutes at every point of a grid

(± 70°, ± 60°, ± 50° and ± 40° in longitude, 0°, ± 10°, ± 20°, ± 30° and ± 40° in latitude) and 40 minutes in the disk center (for references). Useful data to search for Giant Cells were only obtained at the end of August and in September 1978.

The average rotation velocity at the solar equator was (2.775 ± 0.018) μrad/s compared with (2.775 ± 0.010) μrad/s from Mt. Wilson data without corrections and (2.807 ± 0.010) μrad/s after correction of Mt. Wilson data for scattered light. A similar discrepancy was also found in earlier comparisons of results from Locarno and Mt. Wilson. We did not find any correlations between changes of the rotation velocities measured at Locarno and Mt. Wilson.

From our data we found meridional motions of 32 m/s towards the equator in the northern hemisphere and of < 10 m/s towards the equator in the southern hemisphere. This result is in contradiction to those of several other authors, who find motions towards the poles. Using a fit technique and a harmonic analysis we find a pattern of Giant Cells from September 6 until 13, 1978 with an amplitude of about 150 m/s in the rotation velocity. The pattern found with the harmonic analysis (the differential rotation is subtracted) is given in the following table (B = latitude, L = longitude; the reference longitude L = 0° is valid for September 10, 1978, 0º UT) with velocities in units of 10⁻⁸ rad/s:
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More details of this project are given in the Spanish thesis of M. Pérez-Garde (1979) and in the publication of Pérez-Garde et al. (1981).

7. Projects and Plans for the future
Search for Giant Cells

(1) As indicated I believe that it is necessary to have more precise rotation elements of the Sun for useful investigations of velocities in the 1 m/s region. We try to use
(a) all Greenwich Photometrographic Results
(b) data from spot tracing at Locarno and
(c) data from spot observations at other observatories to perform this project.

(2) We may try to use all Greenwich Photometrographic Results to search for Giant Cells, but the hope is small to find them using sunspots, because the spots are spread too much over the whole surface of the Sun.
(3) Similar to the one-dimensional array we use now a two-dimensional RETICON 100 x 100 photodiode array for the same spectral region. The schematic diagram of the system to collect the spectral data (Texas Instruments 16-bit, 12 K - microprocessor connected to the existing HONEYWELL H 316 - minicomputer) is given below:
First tests were performed at Locarno in 1980 and we hope to use the new system for investigations of supergranulation, solar rotation and the search for Giant Cells.

Acknowledgement: I want to thank Dr. R. Howard for sending me results for comparison.

References
   (in press)
Carrington, R.C., 1863, Observations of the Spots on the Sun from November 9, 1853, to March 24, 1861, made at Redhill, London/Edinburgh
   (in press)
Pérez-Garde, M., 1979, thesis, La Laguna, Spain
Pérez-Garde, M., Vázquez, M., Schwan, H., and Wöhl, H.,
Schröter, E.H., Wöhl, H., Soltau, D., and Vázquez, M.,
   1978, Solar Phys. 60, 181