Talking Points for 'Asymmetric Solar Polar Field Reversals'

1. Title page, authors Leif Svalgaard, Yohsuke Kamide

2. Japanese researchers [Hinode] recently claimed [right panel] that they had observed 'for the first time' a polar field reversal in only one hemisphere, and thus that the Sun is now a quadrupole 'for the first time', and that that meant an overthrow or severe revision of current dynamo theories. The left panel shows a [Japanese] newspaper clipping from 1991 reporting that the two poles had the same polarity for about two years. Perhaps the claim is due simply to unawareness of the literature and observations of the past. In this talk, we set the record straight.

3. Outline. Direct observations of solar polar magnetic fields and the polar field reversals inferred from those. Observations of hemispheric asymmetries in solar activity: sunspots, sunspot groups, and how to objective determine which hemisphere was the most active. Seeing that the asymmetry in activity simply leads to different times for reversals of the polar fields in the two hemispheres. Possible longer-term periods.

4. First precision measurements of solar polar fields at Wilcox Solar Observatory [WSO]. Large aperture size [black rectangles show what we call the 'polar field']. The graph shows 30-day averages taken every ten days. We confirmed the strong annual modulation with the heliographic latitude of the Earth, which was already suggested by Babcock. We determined that the field was radial and showed a strong concentration towards the poles [the $\cos^8\theta$ dependence]. This result has been verified several times later with the exponent varying from 7 to ~10. Shows polar field strongest at solar minimum, reversing at solar maximum.

5. Already the early observations showed non-uniformly scattered polar flux concentrations. Confirmed by the Hinode observations [lower right] which the next slide shows in detail.

6. The "Polar Magnetic Landscape" [2007-03-15] observed by Hinode showing about two dozens kilogauss field elements [with the same polarity]. Foreshortening makes it difficult to accurate measuring the field near the pole.

7. The Nobeyama Radioheliograph provides an alternative way of assessing the polar fields as we shall now show.

8. Nobeyama observes at 17 GHz [λ1.76 cm]. The data is shown as 'brightness temperature', T_B. Active regions are hot and bright and there is general limb brightening [annulus] as expected for an optically thin medium. We can quantify the limb T_B by computing the average brightness temperature in a small area [yellow-outlined square] as a function of position angle around the limb.

9. T_B as a function of position angle in 1992-2006. The 'butterfly' diagram of solar activity is clearly seen [**E**ast limb in the middle]. The poles [**N** and **S**] have hot [bright]

patches that show a yearly modulation just like the magnetic field. At solar maximum or shortly thereafter [2000-2001] the polar bright patches disappear [as do the magnetic field concentrations] when the poles reverse polarity.

10. The correlation between 17 GHz brightness temperature and magnitude of the WSO polar fields. South Pole shown in red colors, North Pole in blue.

11. No bright patches at solar maximum. So, no magnetic flux of the kind [kilogauss] that makes patches, thus the polar fields at maximum are not an equal mixture of opposite polarities. There simply aren't any.

12. At solar minimum the polar fields are strong and the polar microwave patches are numerous and hot. The patches live long enough to allow determination of solar rotation. The MWO/WSO polar fields are shown at lower right.

13. Approaching solar maximum, the patches disappear. There are none left at the North Pole on 2011-11-14 to 16 [left panel]. The magnetic field in the North is also disappearing [at green vertical line on the WSO graph].

14. Eight months later [i.e. now], the South Pole has begun to lose its patches, while [new polarity] patches begin to appear in the North.

15. SDO's HMI instrument shows that the dominant polarities in both WSO-size apertures [yellow squares] have become 'orange' [i.e. positive – BTW a poor choice of color scheme, deviating from the long-established convention: blue = positive (out of surface), red = negative (into the surface)]

16. Babcock discovered in 1959 that the South Pole clearly revered sign in early 1957, but that the North Pole remained positive until November, 1958 [not shown in his Figure]. This was a real surprise and may have been important for his 1961 solar cycle model.

17. Waldmeier quickly suggested that the different times of reversals [as observed by Babcock] were simply a consequence of a corresponding asymmetry in solar activity. The 'Rush to the Poles' shown by his measurements of occurrence of prominences supported that the polar fields had reversed, as Waldmeier had already suggested that filaments and prominences lie over magnetic neutral lines.

18. Upper panel: Monthly sunspot numbers separately for Northern Hemisphere [blue] and Southern Hemisphere [red]. Heavy lines are running one-year averages. The thin green line is the total smoothed sunspot number, scaled down by a factor of five. The letters **N** and **S** denote which hemisphere was most active around solar maximum. Lower Panel: Same, except using the number of active regions per month [sunspot groups] from the Greenwich [and later] catalog. The regions are counted once per day.

19. Solar cycle 24 is beginning to look like cycle 14 [as 23 also looked like 13]. Left panel shows daily whole-disk sunspot numbers [yellow], 27-running mean [red], and 1-yr

running mean [black]. Weak cycles seem to have those wild swings. Right panel compares the two cycles separately for each hemisphere [North = blue, South = red] determined from the total number of sunspot groups per month.

20. To determine which hemisphere supplies most magnetic flux around solar maximum we integrate the sunspot number in each hemisphere from 1945 on. The difference between the North and South integrals will have a dip if the South supplied most flux and a bump if the North did.

21. On the Supersynoptic charts from Mount Wilson [MWO] the polar field reversals are clearly seen [marked with ovals]. A supersynoptic chart is a series of normal synoptic charts strongly compressed in time and time-reversed. Carrington rotations are denoted on the top of each strip. Negative polarity [towards the surface] is read, positive is blue. Note the half-dozen surges of flux that are involved in reversing a pole.

22. As an aside [but important, I think], the charts clearly show that both polarities migrate towards no poles, with very little crossing the equator. Seen from the pole the migrating flux patterns make two spirals, one of each polarity, if plotted in the fixed Carrington longitude system. In a system rotating with the plasma, the migration is simply polewards.

23. This is, of course, no news. From AAS meeting in Taos NM, 1980. Both polarities must be migrating polewards. Also, note the finding that “the solar polar magnetic field arises from discrete injections of field from active region latitudes”

24. All of this was clear already in 1964…

25. A large UMR with negative polarity [red oval] is moving polewards. Note also the positive ‘ghost’ UMR [green oval to the right of the red] that may eat away some of the negative flux, but one can hope that enough survives to reverse the South Pole.

26. The polar fields are found in Polar Coronal Holes [with field lines open into the solar wind]. During a polar field reversal, the holes also disappear, giving us a proxy for the time of polar field reversal. Here are shown two different ways of observing the disappearance of coronal holes during the reversal. One can observe the boundary of the holes at the limb [left panel] or on the disk [right panel]. The limb data go back to the 1940s.

27. The distribution in latitude over time of ‘peaks’ of strong coronal Green Line emission by Waldmeier and Altrock. The ‘Rush to the Pole’ is evident. There is some indication that the emission maxima follow and ‘extended cycle’ of 15-17 years, thus beginning their equatorward progression several years before the visible sunspots appear.

28. The ‘Torsional Oscillation’ [dreadful name], TO, also suggests that ‘something’ starts well before the visible cycle.

29. Some other compilations of TO data [Frank Hill, Roger Ulrich]. The MWO map is marred by an asymmetry in rotational speed between the hemispheres: the northern rotates a bit faster. In the extraction of the TO, the same rotation was assumed for both hemispheres. The poleward branch is mysterious.

30. There is a large-scale toroidal magnetic field [discovered by Duvall, Svalgaard & Scherrer back in 1978] in the sense that the magnetic field in the Eastern Hemisphere does not balance that in the Western. This effect also suggests something starts well before the new cycle shows its spots.

31. The concept of an 'extended cycle' has been challenged by Robbrecht et al. who have a different interpretation of the data [although their 'data' is from calculated potential field models]. In any event, "the data may be weak, but the theory is weaker". The extended cycle and how it may relate to the TO are not understood. The cartoon has some suggestive terms. Our theoretical understanding is not much better than the cartoon.

32. Before the polar field reversal was even discovered, Waldmeier studied the N-S asymmetry using sunspot and sunspot group observations back to the 1870s and thought he could see a pattern [as shown] consisting of three to four cycles of one polarity leading, followed by three to four cycles of the opposite polarity leading. From modern data, it is not clear if the pattern is synchronized with the 90-100 yr Gleissberg cycle as he suggested.

33. Other people also report a possible Gleissberg cycle or at least a repeating pattern. If this pattern holds we might expect some cycles in the near future where the South leads instead of the North [which has been leading the past several cycles].

34. Having data about N-S asymmetry in activity which we relate to corresponding asymmetries in polar field reversals, we may ask: "how to we know that the polar fields actually reverse near the maximum of every cycle" before the actual observations began? A 22-year cycle in geomagnetic activity [from maximum to maximum] related to the 'dominant' polarity of the HMF observed at Earth [as we move above and below the solar equator in the course of a year] has been traced back to the 1840s, so we know that reversals occurred 'as they should' back to then.

35. The cosmic ray modulation by solar activity bears a signature of the polarity of the polar fields. The explanation is too long to give here [a topic for another talk, perhaps]. Ice cores hold a many millennium-long record of Beryllium 10 produced by cosmic ray spallation of Nitrogen and Oxygen in the Earth's atmosphere [globally the annual production is 2 ounces!]. In principle [and with future refinement of the data acquisition] we should be able to determine polar field reversals using 10Be. The data is not quite good enough yet.

36. Conclusions and Speculations speak for themselves.