The ballots contained the names of leaders of ten Canadian political parties and space for a write-in-candidate. The dual-column butterfly ballot was designed so that the leaders of the two dominant parties appeared in the first and second positions in the first column (Fig. 1). Stockwell Day, leader of the Canadian Alliance Party, was in the first position, corresponding to the position occupied by George W. Bush’s name in the Palm Beach County butterfly ballot, and Jean Chrétien, leader of the Liberal Party, was in the second position, corresponding to the position of Gore’s name. The leader of another party, expected to receive few votes, was the first name to appear in the second column. Specifically, Joe Clark, leader of the Progressive Conservative Party, was in the position corresponding to that of Buchanan in the Palm Beach County ballot. The remaining candidates were from parties that were expected to receive only a few votes.

Participants (n = 324) randomly received one of the two types of ballot (single- or double-column) and voted for a prime minister by darkening the circle beside their preferred candidate’s name; they then evaluated any confusion caused by the ballot format (calculated using the mean, M, of two items on 7-point scales, with high scores indicating greater confusion; Cronbach’s α = 0.96) and reported the name for whom they had intended to vote.

The results showed that the butterfly ballot (M = 3.69, n = 161) was more confusing than the single-column format (M = 2.14, n = 163; t(322) = 8.23, P < 0.0001); however, none of the students made any errors. Although greater confusion might be expected to lead to higher error rates, we were not surprised by the lack of error in this sample because it involved students skilled at completing complex scoring sheets. We therefore decided to collect data off campus from a sample more representative of the general population.

The design of these ballots was similar to the ones used by the students, except that by 9 November 2000 we were able to modify the butterfly ballot to resemble exactly the format used in Palm Beach County (but without punch holes; Fig. 1). Participants (51 males, 62 females and 3 respondents without punch holes; Fig. 1) were randomly assigned to one of the two ballots; they were then directed to one of two polling booths to vote for a prime minister. We subsequently asked the participants to evaluate ballot confusion in the same way as the student sample had ( Cronbach’s α = 0.82), to report for whom they had intended to vote, and to give their gender, age and ethnic background, and finally to place their ballots in a ballot box.

Four people failed to complete both confusion items. The results indicated that the butterfly ballot was more confusing (M = 3.52, n = 53) than the single-column ballot (M = 2.30, n = 59; t(110) = 3.32, P < 0.002). There were four errors, all of which occurred on the butterfly ballot (that is, 7.55% (4/53) error rate on the butterfly ballot compared with 0% on the single-column ballott, likelihood ratio χ²(1) = 5.47, P < 0.02). Three of the four errors occurred against the candidate who occupied the same position on our butterfly ballot as Gore on the Palm Beach County ballot — this candidate’s votes were unintentionally given to the candidate who was in the same position as presidential candidate Buchanan (that is, of the 15 people who intended to vote for Chrétien, 20% erroneously voted for Clark instead, which corresponds to a Gore–Buchanan error on the Palm Beach County ballot). Thus, the butterfly ballot appears to cause systematic errors in the casting of votes.

Considering only those participants exposed to the butterfly ballot, there was no relation between age and errors (r = 0.05, n.s.), or between the amount of confusion and errors (r = 0.07, n.s.). Furthermore, participants who made errors (M = 4.00, n = 4) did not differ in their confusion from those who did not commit errors (M = 3.45, n = 49; t(51) = 0.53, n.s.).

We asked participants after voting whether they were aware of the butterfly ballot controversy in Palm Beach County, as it might have influenced their responses. In the student study, no one was suspicious of the ballot format; in the second study, only three voters were hypothesis suspicious and none of these made errors. If anything, then, it appears that awareness of the ballot issue was associated with careful voting.

The results from these two studies indicate that the butterfly ballot is more confusing than a single-column ballot. Our study on the second group of voters suggests that the butterfly ballot may cause systematic errors in voting which could cast doubt on the validity of the results from the Palm Beach County vote. With the butterfly ballot, vote counts systematically vary from the intention of the electorate.

It is unclear whether a biasing ballot format does or should have legal standing in adjudicating disputes after an election. But given the centrality of elections to the democratic process, it is remarkable that biasing formats continue to be used. Low-cost application of social science theory and methods would help to prevent such controversy in the future.

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Timing of the Martian dynamo

On Mars, the strong magnetization in the highland crust of the southern hemisphere and the absence of magnetic anomalies at the Hellas and Argyre impact basins have been taken as signs that the core dynamo that once drove the planet’s magnetic field turned off more than 4 billion years (Gyr) ago. Here, we argue instead that the Martian dynamo turned on less than 4 Gyr ago and turned off at an unknown time since then. High spatial resolution magnetometry in both Martian hemispheres is needed to reveal the true history of the Martian dynamo.

The discovery by Mars Global Surveyor of remnant crustal magnetization was strong evidence that Mars — which now has no magnetic field — once had a core dynamo1. The onset and duration of dynamo action place strong constraints on a planet’s thermal evolution. The persistence of the Earth’s dynamo for the past 3 Gyr is attributed to the solidifying of the...
inner core2, with the consequent release of latent heat and with gravitational energy powering the magnetic field.

Terrestrial planets with a liquid core and no solidification of the inner core may lack a dynamo — as proposed for Venus4,5. Although vigorous thermal convection in a liquid core could theoretically generate a magnetic field6, no examples of this have been found in the terrestrial planets so far.

Therefore, although an early dynamo driven by the cooling of a hot liquid core is possible, the most likely scenario for a terrestrial-type dynamo is onset after the beginning of inner-core solidification and shut-off when the core is substantially frozen.

The Moon provides support for this hypothesis. Correlation of Apollo subsatellite magnetometer data with lunar geology shows that magnetic fields were stronger over Imbrian age units than pre-Imbrian, consistent with a late dynamo turn-on7. Lunar palaeointensity data show that a dynamo turned on relatively abruptly about 4 Gyr ago and that the magnetic field became weaker over 1 billion years8. This late onset of the lunar dynamo may mark the beginning of inner-core solidification.

The belief that the Martian dynamo stopped after only several hundred million years has led to theories such as the cessation of a plate-tectonic style of mantle convection more than 4 Gyr ago9. But we are not convinced that this early dynamo interpretation is correct, and believe the onset time of the Martian dynamo is uncertain.

Rather than requiring a dynamo that turned on and off over 4 Gyr ago, the evidence suggests that the dynamo did not begin until well after this. Only the weakness of the present Martian magnetic field limits its duration. The absence of magnetic anomalies at the Hellas and Argyre basins implies that the Martian dynamo did not exist until after the bulk of the southern hemisphere's crust had formed. If it was operative then, the crust should have been magnetized. Large impacts that subsequently punched holes in the crust would have produced distinctive magnetic anomalies. As no anomalies associated with impact basins have been observed, the bulk of the crust in the south is not magnetized and there was no Martian dynamo at crustal formation or when the basins formed at about 4 Gyr or earlier. Impacts into the previously unmagnetized crust of a Mars with a magnetic field should have created magnetic anomalies. Although we cannot rule out the possibility that the dynamo turned on after the southern crust formed and stopped before the major impact basins were formed, it is easier to explain its turn-on after 500 Myr of core evolution than its turn-off before this time. Models of core cooling suggest that a dynamo lasts longer than a few hundred million years, especially as core cooling leads to inner-core solidification that powers the dynamo as long as the inner core continues to grow10. This dynamo action might await the onset of inner-core growth, which could take 500 Myr or more. So although dynamo action could be shortened by a change in Martian mantle convection from a plate-tectonic regime (efficient core cooling) to a rigid-lid regime (inefficient core cooling)9, we still believe that the onset did not occur until after 500 Myr of core evolution and the formation of the major impact basins.

If the dynamo turned on after the giant impact basins formed, then the magnetized southern regions must either be later magnetic additions to the crust (after 500 Myr of evolution) or thermal reworking of older crust. Although, on average, the crust has cooled over time, local regions have been heated by upwelling plumes. The non-uniformity of the magnetization in the south suggests that it arose mainly from localized heating and cooling events that postdate the global cooling to below the Curie point of the southern highland crust. As there does not seem to be magnetic activity in most of the magnetized regions, these heating events must have been due to upwellings smaller than those responsible for Tharsis and the Elysium volcanoes.

There is no unambiguous constraint on the dynamo turn-on time other than its absence at present. The remanence of the SNC (Shergotty, Nakhla and Chassigny) meteorites with formation ages of 1.3 Gyr to 180 Myr is consistent with ancient surface fields of 500 to 5,000 nanotesla (ref. 10), but there could be such fields at the surface of Mars even today. Nevertheless, the presence of localized magnetic anomalies in the younger crust of the northern hemisphere11 indicates that the dynamo could not have turned off too quickly. Strongly magnetized terrain also extends from the southern hemisphere highlands into the Tharsis region, one of the youngest surfaces on Mars, emplaced well after the heavy bombardment12.

We believe that high spatial resolution magnetometry with balloons or airplanes in both northern and southern hemispheres would resolve the nature and timing of the magnetization, much as shipborne magnetometers improved our understanding of the Earth’s dynamo and plate tectonics.

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ATP-dependent proteases

Docking of components in a bacterial complex

Proteases are enzymes that cut up other proteins for the purposes of tailoring or degradation. Some depend on ATP as an energy source for unfolding protein substrates, and these are often organized into rings of ATPase subunits stacked co-axially onto rings of protease subunits1. Boheler et al.2 have reported a crystal structure for the ATP-dependent protease complex HsU(V) (also known as ClpQY) from Escherichia coli. They claim this consists of a double hexamer of the protease HsI(V) flanked by hexamers of an ATPase, HsI(V), which mainly lie in a ring of ATPase domains whose I-domains protrude to form a smaller ring that binds HsI(V). Based on cryo-electron microscopy of HsU(V) in buffer conditions that support enzymatic activity, they find that the HsI(V) rings bind in the opposite orientation — that is, their I-domains protrude distally instead of making contact with HsI(V). Redefinition of this interaction has implications for the functional architecture of the complex.

The components of HsU(V) share features with other protein structures: HsI(V) is similar in sequence and fold to the protease Some β-subunit3, and the ATPase domain of HsI(V) resembles the D2 domain of the protein NSF (for N-ethylmaleimide-sensitive fusion protein)4, apart from containing an insertion of a 133-residue intermediate (I) domain. In the reported crystal structure of HsU(V), the I-domain ring is in contact with HsI(V). This configuration is inverted relative to that suggested by negatively stained electron micrographs, which show the wider, denser ring of HsI(V) in contact with HsU(V). Boheler et al. attribute these earlier observations to a flattening artefact, and expand on the functional implications of the contacts between the I-domain and the protease.

We observed HsU(V) preserved virtually in its native state by cryo-electron microscopy. The averaged side view at 30 Å resolution agrees well with our negatively stained rendition of the complex (compare Fig. 1a to b, c): in both cases, the wider, larger ring of HsI(V) is adjacent to HsU(V). In this respect,