imagination much more than the morning's batch as now people were looking towards the space research of the late 1980s.

Space astrometry had an instant appeal, bringing space science and technology to bear on one of the fundamental tasks of astronomy, the observation of the positions of stars and planets as a function of time. The increase in accuracy from ground-based observations has been very limited in the last half-century and no breakthroughs seem to be around the corner. Space astrometry would give positions to between 0.001 and 0.003 arc s (0.04 arc s is the present best for ground-based work); proper motions (the star's velocity perpendicular to the line of sight) could be measured to about ± 0.002 arc s yr^{-1} after 3 years of observation, such accuracy requiring 50 years at present; parallax (stellar distance) of stars of 11th magnitude, as opposed to 7.5 magnitude at present could be measured to $\pm$ 0.001 – 0.004 arc s (in contrast to $\pm$ 0.013 arc s from the ground). This increased accuracy has enormous astrophysical significance —improving the definition of the cosmic distance scale, calibrating Cepheid variables, increasing the accuracy of stellar luminosity and cluster age estimations being only a few examples to which it might be applied.

The Solar Probe also caused much discussion. Using a Jupiter gravity assist this can get to within 10 solar radii of the Sun's surface. The mission definition scientists decided that the problems of thermal control and telemetry coverage within the corona could be overcome. Scientific objectives are the measurement of the solar gravitational field (J_2), the testing of Einstein's theory of general relativity and the measurement of the rate of change of Newton's constant of gravitation. Also a whole series of experiments dealing with particles and fields in the expanding corona would be flown. A Climatology satellite, to obtain measurements of the Earth's radiation budget and especially a value of the solar constant to $\pm 0.1\%$ (as opposed to $\pm 1.5\%$ at present) was widely welcomed as was a more unusual Dumb-bell Mission. Here two satellites launched into a near polar Earth orbit are deployed so that they are 10 to 20 km apart but tethered together by a long wire. Measurement of the tension variations in the tether gives the gravity field anomalies in the Earth's upper crust. The tether would also be used to measure induced electric fields and the two satellites would be used for active and passive magnetospheric experiments. Finally, an ultraviolet and X-ray satellite (10–1000 Å) with two Baez telescopes and a spectrograph on board was considered. A year's observation with this satellite would provide a 5 arc min resolution map of the whole sky plus detailed spectra of new sources.

Although one could not help getting the feeling that Britain was a small fish in the ESA pool (which is itself small in comparison to NASA and the USSR's Space Agency) whenever brains combine, new ideas are forthcoming and Britain and Europe can still provide ideas even if they cannot compete in finance and firepower.

Phase changes at 650 km

from Peter J. Smith

IT has often been assumed that the Earth's 650-km seismic discontinuity, which involves a large increase in bulk modulus as well as seismic velocity, is largely the result of a phase change in the olivine component of the mantle. Anderson (*Science*, **157**, 1165; 1967), for example, attributed this discontinuity to the disproportionation of spinel to a structure with the properties of mixed oxides—a phase involving the simple oxides, a Sr_2PbO_4 structure or perovskite plus periclase, all of which have similar densities. But as Anderson himself now admits (*Geophys. Res. Lett.*, **3**, 347; 1976), there are problems with this interpretation which suggest that the discontinuity in question may have little to do with transformations in olivine after all.

For example, although the disproportionation of spinel to oxides involves a large increase in density, it also involves an increase in coordination, increasing the average silicon-oxygen separation and reducing the repulsive forces between ions. The increase in bulk modulus is therefore much reduced (and may even be converted into a decrease) compared with that expected from a transformation with no associated change in coordination—a point previously made by Liebermann and Ringwood (*J. geophys. Res.*, **78**, 6926; 1973). In fact, the elastic moduli of spinels and mixed oxides are similar. On this basis, disproportionation as envisaged would be expected to produce a decrease, rather than an increase, in seismic velocity.

Because this is clearly unsatisfactory, Anderson now suggests that the 650-km discontinuity is primarily the result of phase changes in the pyroxene and garnet components of the mantle rather than in the olivine. The basic premise upon which this proposition rests (and detailed evidence for which is promised in a later report) is that the bulk moduli of silicate and oxide solid solutions are almost independent of iron content. In particular, as Mg^{2+} is replaced by Fe^{2+} in systems such as pyroxenes, olivines and garnets, the density increases in accordance with the Birch formula but the bulk modulus increases or decreases only slightly. The bulk modulus cannot therefore be used to make deductions about the composition of the mantle. It is, on the other hand, a good indicator of crystal structure, its magnitude's increasing from pyroxene to α-olivine to β-spinel to garnet to γ-spinel to oxides in pyroxene proportions to perovskite.

With this in mind, Anderson has attempted to extrapolate the bulk moduli (K) and densities (ρ) of the various regions of the mantle to a pressure of 1 bar and a temperature of 20 °C and has compared the resulting K-ρ points with the K-ρ curves for the appropriate crystal structures. He thus deduces that between depths of 200 and 400 km (Region I) the mantle is predominantly olivine and pyroxene with subordinate garnet, the pyroxene to garnet ratio being 7 : 2 to satisfy the bulk modulus. Region II, between 400 and 500 km, is close to β-spinel and is consistent with olivine-pyroxene-garnet with a higher proportion of garnet than Region I. Anderson concludes that Region II comprises olivine in the β phase, pyroxene and pyroxene–garnet solid solution with garnet structure.

By contrast, Region III, which lies between 500 and 650 km, is closer to garnet. Its most likely composition is ($\beta+\gamma$)-olivine and pyroxene–garnet solid solution, all the pyroxene now having entered the garnet structure. However, because of uncertainties in the data upon which the K-ρ curves are based, Region III could be entirely β-spinel and garnet. The properties of Region IV (650–800 km) are consistent with this layer's being either mixed oxides or γ-spinel plus stishovite (SiO_2). And finally, Region V, below 800 km, could be either mixed oxides with more stishovite than Region IV or perovskite plus MgO.

In the light of these phase changes Anderson thus proposes that it is the pyroxene–garnet component, transforming from the garnet structure to the mixed oxides or perovskite structure, which is chiefly responsible for the 650-km discontinuity. Unfortunately the thermodynamic data currently available are insuficient to enable the reaction boundary between the mantle pyroxene-garnet solid solution and mixed oxides to be calculated. However, calculations made assuming this complex garnet to behave as almandine–pyrope garnet imply that the transition is sharp (perhaps less than 12 km thick on the basis of admittedly inadequate data and questionable assumptions), a property required by some of the seismic data.