Occasionally the tectonic stress achieves a major advance and extends inland to greater depths; this relieves stresses not only in the Andes region but around the Pacific.

Acknowledgements
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Guinot, B., 1972, Astron. Astrophys., 19, 207. (I thank Dr Guinot for further data.)

Postscript on ‘Features of the Chandlerian Nutation’,

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Henry Abraham died on 9 December 1985. A few days earlier, he explained to me the work he had been doing in recent years, and gave me responsibility for his documents and notes. Amongst them were the manuscript for the above paper, prepared about 1979 but not submitted for publication then, and meticulous and extensive notes which examine further the questions raised by the paper. It has seemed to me to be appropriate to submit for publication the above paper as he wrote it, and to add a summary of his subsequent work as I interpret it.

The idea that great earthquakes might effect the rotation of the earth was revived in the 1960's when measurements showed the extent of earthquake deformations. The idea has received continued interest since that time. These three decades of geophysics have also been noted for the development of the concepts of ‘plate tectonics’, in which it is recognized that the earth is dynamic, and that earthquakes are an expression of relative motion between large surface blocks of the Earth.

In the paper above, Abraham notes coincidences of changes in the Earth's rotational energy and large earthquakes. His subsequent work was especially concerned with the further investigation and clarification of this matter. His thesis was that changes in the phase and amplitude of the Chandler nutation, motions of crustal mass, and earthquakes were all related to one another. His work, and the conclusions it led him to, took the following steps:

1. Taking Earth rotation data from Guinot (1972) Abraham tabulated second differences as a measure of change of phase and amplitude. The changes of phase, denoted ΔT, were described as 'shifts' of the rotation pole. The changes of amplitude, denoted Δ2T, were described as 'jolts' of the rotation pole, and ascribed to impulsive motions.
2. The longitude λ of the Chandlerian rotation pole was calculated at the midpoint of each of Guinot's intervals of time, on the basis of Guinot's data.
3. Earthquakes with magnitudes ≥ 7.9 were tabulated from Duba (1965).
4. Signs for ν, the east-west motion of mass of Pacific Ocean plates causing a change in nutation, were derived for each interval from the signs of Δ2T and λ.
5. The intervals associated with all ≥ 7.9 earthquakes in each seismic region were tabulated and entered with the Δ2T for each interval, its λ at that time, and the derived direction of motion ν. The entry in each interval was classified on the basis of the signs of λ and ν, so that four possibilities existed for the signs of λ and ν considered as a pair: (+ +), (+ −), (− +) and (− −).
6. Upon inspection of the data thus arranged, the sequences of abundances of ν in successive intervals near an earthquake were found to occur in two particular patterns. The seismically active regions of the Earth also fell into two categories:
   Region 1: Rynkysi, Peru-Andes, North America, Kasmir-China.
7. The patterns found indicated that with respect to chronological time, the common sequence of events observed was an earthquake in Region 2, followed by a
shift $\Delta^2T$, followed by an earthquake in Region 1, each in successive intervals.

Abraham recognised the wide implications that would follow from the establishment of such a pattern as described above. He noted the possibilities for a better understanding of when earthquakes would occur; of what causes the Chandler nutation to advance or retard; and of what maintains the nutation or causes its decay.

He would, I am sure, wish his notes and tables to be free for inspection by persons interested in these questions, and contact with the writer of this postscript is invited regarding them.

Invited Paper

Galactic Cosmic Ray Anisotropies in the Energy Range $10^{11} – 10^{14}$ eV.

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Abstract: A review is presented of the evidence for anisotropies of galactic origin in the charged cosmic ray particle intensity at median primary energies of detection in the range $10^{11} – 10^{14}$ eV. It concerns the period from 1958, when the first substantial long-term observations at energies of solar and sidereal modulation near $10^{11}$ eV commenced underground, until 1984, by which time results were available from a number of years of accurate observations with detectors of small air showers at energies near $10^{14}$ eV, too high for complicating effects of solar origin to be present. There is evidence for the existence of both unidirectional and bidirectional galactic anisotropies over the whole energy range. Tentative descriptive models are discussed in relation to advances both in solar and sidereal analytical techniques and in the ability of experimenters to account for and exploit the modulating influence of the heliomagnetosphere at the lower energies of detection.

Introduction

Although observations of anisotropies in the charged cosmic ray primary flux have extended up to energies around $10^{21}$ eV, this paper is confined to a review of experiments within a range of relatively low energies ($10^{11} – 10^{14}$ eV) where the counting rates of the detecting systems are high and the evidence for galactic anisotropies now seems to be definite. It is not proposed to refer to the evidence in detail but rather to give some idea of the methods of analysis used and to show what the essential developments have been in the experimental field over the last twenty years or so.

Approximately 90% of the particle radiation consists of protons. Therefore it will be convenient to refer to it generally in terms of particle energy although it will be understood that particle rigidity must be used in many of the calculations to allow for application to the heavier component.

Because of the scattering of the particles out of their helical paths while propagating through magnetised space from the cosmic ray source regions to the Earth, over lifetimes of the order of $10^7$ years, the radiation is characteristically highly isotropic and particle arrival times are statistically independent of each other. Clearly, there is no possibility of observing point sources of the radiation. What are observed are large-scale systematic spatial variations of small amplitude ($<0.1\%$) in the otherwise isotropic cosmic ray gas and changes in that anisotropic pattern with particle energy of detection and with time. The variations are observed in the counting rates, typically hourly, of fixed detecting systems—usually directional telescopes and, at the higher energies, air shower arrays—that rotate with the Earth. Because of the statistical uncertainties it is most desirable to achieve high counting rates. To this end, wide telescope apertures can be used, since the type of information is such that there is very little resulting loss of resolution. Again, since the index of the integral primary spectrum is negative, about $-1.5$, there are obvious statistical advantages in observing at the lowest practicable particle energies. Consequently, the bulk of experiments are carried out with wide angle telescopes near the low end of the energy range.

While information should certainly be obtainable about concentrations of cosmic ray sources, anisotropies otherwise tell us about the behaviour of the ionised and magnetised regions of space that are traversed by the particles en route from the sources. At the highest energies in the range galactic anisotropies should be directly observable. At the lower energies, distortion is caused by the heliomagnetosphere, because of its size, structure and time-varying behaviour. Moreover, superimposed anisotropies of heliospheric (solar) origin may be present. At these energies anisotropies can give important insights into heliomagnetic modulation, although the elucidation of galactic anisotropies becomes more difficult.

All told, investigations of galactic anisotropies should inform about such matters as the distribution of sources of the radiation, statistical acceleration processes for cosmic radiation in the galactic medium, bulk motions of the interstellar gas, the nature and degree of regularity of the galactic magnetic field (involving scale sizes of scattering centres) and about the heliomagnetosphere. It is the purpose here to review the progress that has been made in the detection and description of anisotropies that must precede identification with one or more of these galactic features.

Types of Anisotropies and Methods of Detection

Studies of galactic anisotropies have so far been concerned with two observed types, unidirectional and bidirectional. They may occur independently of each other or as components of a more complex total anisotropy. The unidirectional anisotropy shown as an example in Figure 1a is due to the motion of the solar system relative to a frame of reference in which the cosmic ray intensity can be regarded to be isotropic. A case in point would...