Hipparcos

The Hipparcos and Tycho Catalogues, representing the results of the Hipparcos space astrometry mission, were released in final form in mid-1997. The data are available from a number of primary sources including the 17-volume printed catalogue and associated CD-ROMs (ESA SP-1200 and SP-1220), the Hipparcos Web site (astro.estec.esa.nl/Hipparcos), and the Centre de Données astronomiques de Strasbourg where, after two years, they are still by far the most frequently queried astronomical catalogues, representing more than 20% of all catalogue queries. The catalogue files have been transferred by ftp from 879 different Internet nodes in 1999 alone. The primary function of the ESA Hipparcos web site, visited by 58,000 users over the past two years, remains the provision and maintenance of the on-line catalogue search facilities and related features. More than 1100 papers based on the Hipparcos data (more than 400 refereed) have been entered into the ADS (Astrophysics Data System) database since 1996. The ESA web site includes relevant animations, as well as a series of 3D visualisations of a number of star fields, and is also the catalogue user’s interface with the help-desk support.

Interesting applications of the Hipparcos data abound, and include an elegant discovery of 'fossil' evidence for smaller precursor structures that are thought to have merged to form our Milky Way Galaxy. Clumps of stars are interpreted as the historical debris of a precursor object, with an eccentric orbital apocentre, and a period of 400 Myr. This event could account for about 12% of all metal-poor halo stars outside the solar circle, providing direct evidence that the bulk of the Milky Way’s population of old stars could have been provided in this way.

Hipparcos results have made a number of contributions to the ongoing studies of the properties of extra-solar planets, firstly by establishing distances and hence, from stellar evolutionary models, estimates of the host star’s age, luminosity and mass. An interesting contribution to the discussion of the dynamical stability of these systems has been made in the case of Upsilon Andromedae, where three planets are now known to be in orbit around the star, making it the first multiple planetary system discovered around a Main Sequence star other than our Sun. In addition to the inner planet in a 4.6-day orbit, with a minimum mass of 0.6 Jupiter masses, the two more distant planets have lower limits of 2.0 and 4.1 Jupiter masses. Hipparcos astrometry has been used to derive a firm mass estimate for the outer planet, implying an orbital inclination of 156 deg. Numerical studies indicate that the long-term stability of the system depends strongly on the planetary masses, since the orbits of the second and third planets bring their relative separation close enough to imply a possible chaotic motion.

An exciting recent result in astronomy has been the detection of the first extra-solar planetary transit event, observed for HD 209458, one of the most recent of the radial velocity planetary detections. The results confirm beyond any doubt that its radial velocity variations arise from an orbiting planet. The importance of this result and the relative strength of the transit signal have resulted in a number of independent confirmations of the HD 209458 transit, including the detection of the transit signals in the Hipparcos photometric data, acquired during 1989-93. Interestingly, the Hipparcos data set therefore contained the first recorded evidence for an extra-solar planet.
Ulysses

Unperturbed by any ‘millennium bugs’, the Ulysses spacecraft has continued its unique and highly successful out-of-ecliptic voyage. On 31 December 1999, the space probe was 42 deg south of the Sun’s equator, at a distance from the Sun equivalent to 4.2 times the distance between the Sun and the Earth (i.e. nearly 620 million kilometres). When comparing the current interplanetary conditions with those encountered by Ulysses at the same location more than six years ago, the effects of increased solar activity are evident. The stable solar-wind structures that swept over the spacecraft once per solar rotation in 1993 have given way to a much more complex and less repetitive configuration. While there have been several ‘close encounters’, Ulysses has not yet crossed the boundary into the fast solar wind flowing from the southern polar cap. Given the rapid increase in sunspot number at the present time, it remains to be seen whether or not this will, in fact, occur at all during Ulysses’ return to the polar regions.

The mission’s scientific output has continued to be impressive. Among the key results reported recently was the probable identification of Ulysses’ passage through the distant tail of Comet Hyakutake on 1 May 1996. First reported as a ‘density hole’ in the Ulysses solar-wind observations, the event was subsequently ‘rediscovered’ independently in the magnetic-field data and the ion composition measurements.

In another study, magnetic-field data acquired by Ulysses’ magnetometers during the first two polar passes in 1994 and 1995 have been used recently to infer global properties of the Sun’s coronal magnetic field extending back in time to the mid-19th century. Relying on the excellent correlation found between the so-called ‘aa’ index (a measure geomagnetic-field variability) and a coupling function that includes the radial component of the heliospheric magnetic field, an historical record of the coronal magnetic field has been constructed going back as far as 1868. A critical part of the calculation relies on the Ulysses finding that the radial component of the heliospheric field is independent of solar latitude. A particularly striking result is the conclusion that the inferred coronal field has increased by a factor of 2.3 in the past 100 years, perhaps as a result of chaotic changes in the solar dynamo. Although not well understood, a connection is believed to exist between the Sun’s magnetic field and its luminosity, suggesting possible implications for the global climate of the Earth.
Following up on their earlier work (published in 1995) on time-series analysis of Ulysses energetic-particle fluxes and possible identification of frequency modes belonging to gravity waves inside the Sun (also called ‘solar g-modes’), the Ulysses Hi-Scale team has now completed a thorough statistical analysis of its magnetic-field data. This latest work apparently confirms the presence of numerous discrete modes in the data, and the scientists involved conclude that at least half of the energy in the interplanetary medium is in the form of such modes. Although not yet universally accepted, if correct this result has far-reaching implications. However, the physical mechanism by which periodic variations are maintained remains unclear.

Infrared Space Observatory (ISO)

The year’s major milestone occurred in August when the last part of ISO’s vast data set entered the public domain. All of the nearly 30 000 scientific observations are now available to the world-wide astronomical community via the state-of-the-art ISO Data Archive (www.iso.vilspa.esa.es). The targets of these observations range from objects in our own Solar System, right out to the most distant extragalactic sources. They fully demonstrate the unprecedented sensitivity and capabilities that ISO brought to the detailed exploration of the Universe at infrared wavelengths.

Activities supporting the astronomical community focussed on enhancing not only the quality of the data, but also the facilities offered by the archive. Improved knowledge about the calibration of the instruments was encapsulated into new versions of the data-processing software and much closer links are now provided between the ISO archive, the scientific literature and other astronomical archives (e.g. that of the earlier IRAS mission).

ISO results continued to impact most fields of astronomical research, almost literally from cosmology to comets. The year saw a record number of ISO publications – just under 150 papers – in the refereed scientific literature and many more in conference proceedings. A few of the results that attracted public attention are summarised below.

Many important results came from the deep cosmological surveys made by ISO at near- and far-infrared wavelengths. Counting the sources detected in these images showed that the early Universe was forming more stars than now, and also more than had been expected based on measurements at other wavelengths. The Universe is filled with a faint glow in the infrared from the integrated light from all of the young galaxies. ISO has not only succeeded in resolving part of this diffuse cosmic infrared background into discrete sources for the first time, but has also detected spatial variations in its intensity, thereby providing important constraints on models of galaxy evolution.

One of the surprises from the IRAS satellite was the discovery of dusty disks around some of the most common stars, the so-called ‘Main Sequence stars’. ISO made a survey of nearly a hundred such stars to determine the frequency with which these disks occurred, and found that some 20% clearly had a disk. However, ISO’s intriguing result came when the ages of these stars were correlated with the presence or absence of a disk. It was found that all stars in the sample younger than 300 million years had a disk, while very few older than 400 million years had one. This age of 300 – 400 Myr for the apparent loss of the dusty disk is very similar to the age of our Sun when it was forming its planetary system, including the comets in the Oort Cloud. Thus, the disks of the older stars may have been removed by newly-formed planets.
ISO’s scientific results continue to consolidate the earlier technical and operational success of the mission. With all data now public and activities continuing on refining the calibration as well as data-reduction algorithms and on adding functionality to the archive, many more astronomical surprises and discoveries are still expected.

**Solar and Heliospheric Observatory (SOHO)**

SOHO began 1999 in Emergency Sun Reacquisition (ESR) mode, after its last onboard gyro had failed on 21 December 1998. In this mode, attitude control is accomplished by automatic onboard thruster firings. In a race against time — the ESR thruster firings consumed an average of 7 kg of hydrazine per week — engineers at ESTEC and Matra Marconi Space developed a modification to the onboard Attitude and Orbit Control Subsystem (AOCS) software to allow gyroless operation of the spacecraft. The patch was uploaded on 29 January and recovery from ESR started the following day. The first gyroless reaction-wheel management and station-keeping manoeuvre was performed on 1 February, making SOHO the first three-axis-stabilised spacecraft to be operated without a gyro. Over the next nine months, a full new gyroless AOCS software suite was developed, the pivotal element of which is the new Coarse Roll Pointing (CRP) mode, in which the momentum wheels are used not only for actuation, but also for measuring the changes in roll attitude. The new software was uplinked at the end of September and the in-flight commissioning was successfully completed on 4 October.

The availability of high-spatial-resolution data from one of the SOHO instruments, the Michelson Doppler Imager (MDI), opened a new window for looking inside the Sun. ‘Time-distance helioseismology’, now sometimes also referred to as ‘solar tomography’, is a new field of solar research developing primarily with SOHO/MDI data. It is an exciting and promising technique for probing the 3D structure and flows beneath the solar surface, and now offers the possibility of studying the birth and evolution of active regions below the Sun’s surface as we approach solar maximum. Recent applications of this technique to MDI observations have revealed a complicated structure of emerging regions in the solar interior, with emerging flux ropes travelling very rapidly through the upper 18 Mm of the outer layer of the solar globe, the so-called ‘convection zone’. The tomographic images also revealed sunspot ‘fingers’ — long, narrow structures at a depth of about 4 Mm — which connect the
sunspot with surrounding pores – small dark regions on the solar surface – of the same magnetic polarity. Pores with the opposite polarity, on the other hand, are not connected to the spot.

The possibilities for more reliable space-weather forecasts have been greatly improved by SOHO observations. Comparison of the timing of Earth-directed Coronal Mass Ejections (CMEs) observed by the LASCO coronagraph with the geomagnetic storm index (Kp) in the days following the CMEs illustrates the key role SOHO plays in the current international space-weather warning system. Out of 25 front-side halo CMEs seen by LASCO and by SOHO’s Extreme-ultraviolet Imaging Telescope (EIT) during 1996 and 1997, over 85% caused geomagnetic storms with Kp values greater than or equal to 6, and only 15% of such storms were not predicted. In contrast, the accuracy of such forecasts before SOHO in 1995 was poor: only 27% of 173 geomagnetic storms were forecast correctly, while 63% of 126 forecasts were false alarms.

The Superconducting Camera Project (S-CAM)

The development of superconducting tunnel junctions for use at optical and ultraviolet wavelengths has progressed rapidly at ESA, such that serious ground-based applications can now be considered as a scientific demonstration of the power of this new technology. The S-CAM employs a 6 x 6 pixel array of tantalum-based tunnel junctions covering the rather small field of ~ 4 x 4 arcsec. The array is housed and cooled in a liquid-helium (He) cryostat, which also incorporates an He sorption pump to bring the base temperature down from ~1 K to the operating temperature of 300 mK. The spectral coverage ranges from the ultraviolet to the optical (~300 – 700 nm), limited at short wavelengths by the atmospheric cut-off and at long wavelengths by the cut-off of a series of infrared filters. Every photon detected by the array has its energy (wavelength), pixel number and time of arrival recorded with a resolution of ~5 microsec.

S-CAM was installed at the Nasmyth focus of the William Herschel Telescope (WHT) on La Palma in February. This observation run was essentially a technology demonstration to determine the instrument’s strengths and weaknesses, as well as the optimum operational procedures. In this initial run, the resolving power ($\lambda/\Delta\lambda$) was quite low (~5 at 500 nm) and the photon event rate was limited to ~1 kHz/pixel. A number of observations were, however, conducted to demonstrate the capability and power of this new technology, the most important being the detailed study of the Crab Pulsar to examine the spectral dependence of the pulse profile with phase.

Having established the instrument’s baseline capabilities, S-CAM was returned to the WHT in December to conduct a full scientific observing programme. In this second run, the resolving power was increased to $\lambda/\Delta\lambda$ ~10 at 500 nm and the event rate increased to 5 kHz/pixel. In this run, all previously encountered technical problems were overcome and the camera operated flawlessly. A number of astronomical observations of smaller objects (cataclysmic variables, pulsating white dwarfs and pulsars) were performed to determine the spectral dependencies of many of the time-varying phenomena existing in these objects. These observations are now undergoing detailed analysis.
Earth Sciences

Radar altimetry has become a major observation technique for oceanography and several ways of exploiting these data have been studied within the Earth Sciences Division. Identifying the origin of changes in sea level is a major problem as there are many potential causes. Using sea-surface temperature maps for the Mediterranean derived from satellite observations, it has proved possible to estimate the steric effect (i.e. water expansion in summer and contraction in winter). In addition, the impact of atmospheric forcing (i.e. atmospheric pressure and wind stress) on sea-level variation has been assessed using a regional circulation model. This work will contribute directly to Envisat radar-altimeter calibration and validation activities.

In support of the Earth Explorer Land Surface Processes and Interactions Core Mission, multi-sensor hyper-spectral data were acquired in 1999 by different airborne and ground-based systems during the so-called DAISEX campaign over Spain. The purpose of this experiment was to establish the feasibility of quantitatively retrieving geo/biophysical variables from such an instrument. The availability of such data would significantly advance knowledge of land surface processes. One of the interesting results to emerge from this work was the observation of the ‘hot spot’ for the first time in hyper-spectral data. This is the increase in reflectance that can be detected when the target is observed in the same direction as it is illuminated by the Sun. It contains information on plant structure, an important variable for process modelling.

A further ground-based campaign called CLARE’98 (in the UK) has demonstrated the advantages of combining lidar and radar data to observe clouds and aerosols, helping to set the scene for the Earth Explorer Earth Radiation Core Mission. Three aircraft from France, Germany and the United Kingdom, as well as a wealth of ground-based instruments, participated in this activity. An example of the results is given in the accompanying figure, which shows simultaneous lidar backscatter and radar profiles measured from the French aircraft. The complementary nature of such observations is clear. Another aircraft, which performed in-situ measurements of ice and water cloud, confirmed the existence of these features. An image taken by a NOAA satellite at the same time only indicated a uniform upper cloud layer. This campaign has demonstrated that only by making co-located radar and lidar measurements will it become possible to derive ice and water contents and ice-crystal/droplet-size information for clouds from space.