



Chapter 1

Scientific Highlights

The following presents a selection of highlights, intended to be representative of the scientific quality and range of research being undertaken at the ING telescopes.

THE SEARCH FOR EXTRASOLAR VERY LOW-MASS OBJECTS

WHT+ISIS, +WHIRCAM, INT+WFC, +PFC

Stellar clusters and associations offer a unique opportunity to study substellar objects in a context of known age, distance, and metallicity; they are laboratories of key importance in understanding the evolution of brown dwarfs. Deep- and wide-imaging surveys to search for low-mass objects have continued on the ING telescopes. Such surveys can probe the cluster luminosity and mass functions down to the substellar limit, and beyond in the case of the nearest and youngest open clusters. In particular, the Pleiades, a star cluster which is an ideal hunting ground for substellar objects mainly due to its richness of members, young age, proximity and scarce interstellar absorption, have revealed a large population. Recently, about 45 brown dwarf candidates have been discovered.

The extension of these studies to other clusters, especially in the younger regions, is therefore very important for confirming and enlarging these results. With this intention a survey in the young stellar cluster around the young multiple star σ Orionis was carried out. The cool nature of eight candidates (spectral types M6–M8.5) was spectroscopically confirmed. One of the latest type candidates, S Ori 45 (M8.5), is one of the least massive objects known to date, with a best estimate of its mass at 0.020–0.025 solar masses.

Praesepe is a nearby and rich Galactic open cluster within the Hyades moving group. Though similar to the Hyades in terms of age, kinematics and chemical composition, Praesepe's larger distance and smaller angular extent make it an excellent target for wide-area CCD surveys. However, the brown dwarf population of Praesepe is sensitive to both the age and distance of the cluster. If the cluster is 500 Myr old, then a recent survey would have found 3 good candidates. But if the cluster is 1 Gyr old, then only one might be a brown dwarf.

A NEW LOCAL GROUP GALAXY: THE CETUS DWARF GALAXY

INT+WFC

The observational Universe is built mostly from galaxies. For obvious reasons, most of the known (detected and catalogued) galaxies are intrinsically the largest and brightest ones, those which can be seen from the greatest distance and are most easily studied. Dwarf galaxies, however, dominate numerically in any volume-limited sample, and were probably even more numerous in the cosmological past. Despite their unassuming appearance dwarf galaxies hold the key to many questions of galaxy formation, structure and evolution. They also provide important constraints on the distribution and nature of dark matter, and star formation in low density environments.

The need for more data in all these matters, together with the relatively few known dwarf galaxies, make a search for more of them very worthwhile. However, almost by definition dwarf galaxies are difficult to detect and observe.

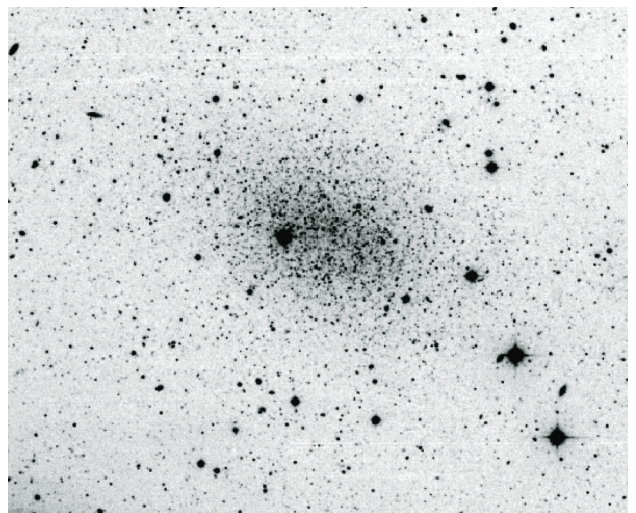
Searches for dwarf galaxies have been carried out in nearby galaxy groups with good results. However,

owing to their small intrinsic size, dwarfs in external groups are difficult to characterise morphologically, and it is only within and near the Local Group that the resolved stellar photometry necessary for construction of detailed star formation histories can be obtained. Thus it appears most promising to limit a search to the Local Group and its immediate environs.

To this end a visual examination of all 894 fields covered by the ESO-SRC and SERC equatorial surveys of the southern sky was performed. Objects resembling the Andromeda dwarf spheroidals and the Tucana dwarf, that is of very low surface brightness (VLSB), diffuse and large (1 to a few minutes of arc), were noted. Some of the more northerly candidates were followed up using the Wide Field Camera (WFC) on the Isaac Newton Telescope.

Candidates were initially examined by taking short exposures in the R band. With good seeing this enables stellar objects to $R \sim 23$ to be detected. At this depth objects close to or within the Local Group should begin to resolve into stars, with the tip of the giant branch becoming readily visible. If a candidate appeared to resolve into stellar components, further broadband observations in V and I together with narrow-band $H\alpha$ were obtained. The initial exposure of an uncatalogued object in the constellation Cetus showed a diffuse swarm of faint stars. Further exposures were taken in order to characterise the new object.

The Cetus dwarf has a smooth, diffuse appearance and appears to be a dwarf spheroidal of type dE3.5. A color-magnitude diagram in V, V-I shows a clear giant branch but no sign of recent star formation. From the position of the tip of the giant branch, a reddening-corrected distance modulus of 24.45 ± 0.15 and a



Combined V-band image of the Cetus dwarf with a total exposure of 1800s taken using the Wide Field Camera on the Isaac Newton Telescope. The obvious visible stars in the dwarf galaxy are all red giants. The area shown is approximately 11×11 arcmin corresponding to one-half of the central CCD of the four WFC CCDs.

metallicity of -1.9 ± 0.2 is derived. With an implied heliocentric distance of 775 ± 50 kpc, and a corresponding Local Group barycentric distance of 615 kpc, the Cetus dwarf lies well within the boundaries of the Local Group. Although the Cetus dwarf is unlikely to be directly associated with any other Local Group galaxy, it does lie in the general direction of the extension of the Local Group toward the Sculptor Group.

HIGH VELOCITY CLOUDS

WHT+UES

Scattered across the sky are hundreds of clouds of hydrogen gas, moving at such high velocities that they clearly stand out from the usual interstellar material in the Milky Way. These High-Velocity Clouds (HVCs) have remained enigmatic since their discovery in the 1960s. Their origins and role in Galactic evolution remain poorly understood, largely for lack of information on their distances.

The HVCs might result from gas blown from the Milky Way disk into the halo by supernovae, in which case they would enrich the Galaxy with heavy elements as they fall back onto the disk. Alternatively, they may consist of metal-poor gas —remnants of the era of galaxy formation, accreted by the Galaxy and reducing its metal abundance. Or they might be truly extragalactic objects in the Local Group of galaxies.

Distance estimates of HVCs have long been based on models or indirect arguments. The only direct method uses the presence or absence of interstellar absorption lines at the HVC's velocity in spectra of stars at different distances. The presence of absorption shows the HVC to lie in front of the star; absence places it beyond, provided that the expected absorption is well above the detection limit. So far distance measurements are lacking.

HVC complex A, also called chain A, was the first HVC discovered and has been studied in detail. It is a 30° -long filament, containing several well-aligned concentrations with velocities between -210 and -140 km/s. Spectra from the Hubble Space Telescope set a firm lower distance limit, $d > 4 \pm 1$ kpc for chain A. Astronomers have now also measured an upper limit, $d < 10$ kpc, for the upper end of chain A, using UES spectra of the RR Lyrae star AD Ursae Majoris.

This is the first time a firm distance bracket for a large high-velocity cloud is obtained.

According to this distance bracket, chain A is placed in the Milky Way halo (2.5 to 7 kiloparsecs above the Galactic plane), rather than at an extragalactic distance, and its mass is constrained to between 10^5 and 10^6 solar masses. The obtained distance bracket excludes models for its nature and origin requiring a distance of the order of 1 kpc or less, such as relationships to local molecular clouds, or collision of an intergalactic cloud with the Galactic disk. It also rules out chain A being a Galactic satellite at ~ 50 kpc distance, or a protogalactic gas cloud at ~ 500 kpc distance, or a member of the Local Group of galaxies, as proposed recently for HVCs in general.

The location of chain A in the Galactic halo still allows several models for its origin. For its height $2.5 < z < 7$ kpc to be consistent with a Galactic-fountain model, a sufficiently hot halo would be required. The small-scale structure observed in chain A would then be due to instabilities formed in the downward flow of cooling clouds. Alternatively, chain A may represent gas captured from intergalactic space. In that case, collision with an ionised halo extending high above the Galactic plane may have served to decelerate the gas to its present velocity, and to form the small-scale structure. In this accretion model, the question whether the origin of chain A lies in the Magellanic system (as debris from encounters between Milky Way and Magellanic Clouds), or far away in the Local Group (as remnant of Local Group formation), remains open: location in the Galactic halo does not preclude such a distant origin.

OPTICAL STJ OBSERVATIONS OF THE CRAB PULSAR

WHT+S-CAM

A totally new concept in optical detector instrumentation made its first appearance at the WHT. The Superconducting Tunnel Junction (STJ) Camera (S-Cam), designed and built by members of the Astrophysical Division of the European Space Agency, is a high-efficiency photon-counting system which provides position and arrival time of each detected photon, along with the photon energy.

A tunnel junction consists of two conductors separated by a tiny gap of insulating material or even a vacuum.

If the gap is thin enough, electrons can tunnel across anyway, and if the conductors are superconductors, the junction displays very useful quantum-mechanical properties and electrical non-linearities. An arriving photon breaks apart the pairs of electrons responsible for the superconducting state, which can then be collected. Each individual photon creates a large number of free electrons, in proportion to photon energy. Thus by measuring the charge released by each detected photon, these can be sorted in energy, or wavelength. The main advantages of STJs is that they operate at high speed at very low temperatures, dissipate very little power and are very small.

The first observations of an astronomical object using an STJ device took place at the William Herschel Telescope in February 1999. The Crab pulsar was observed using a 6×6 array of Tantalum STJs, covering an area of about 4×4 arcsec², cooled with the help of a bath of liquid helium to a temperature within a degree of absolute zero. This object, a neutron star spinning about 30 revolutions per second and one of the few pulsars that is known to emit optical pulses, was an ideal target for verifying the STJ camera's photon counting and timing capabilities. The astronomers recorded a light curve for the pulsar in two bands simultaneously over the wavelength range 310–610nm, based on data acquired over a ten-minute interval, with an arrival-time accuracy of 5μs. The light curve clearly shows the characteristic two beams of light which shine out, like a lighthouse, one weak and long and the other bright and short, in each revolution. The color didn't change through the pulses.

The astronomical impact of these results may have been modest, but it has presented a glimpse of what STJ technology holds in store for the future.

COSMIC FLOW OF GALAXIES ACROSS ONE BILLION LIGHT YEARS OF THE UNIVERSE

INT+IDS, JKT+CCD

According to the 'cosmological principle', the large-scale Universe should be smooth and well behaved. Distant galaxies ought to be evenly distributed in space, and their motions should correspond to a pure 'Hubble flow', a uniform expansion of space in all directions. In other words, the Universe, in some average sense, is

homogeneous and isotropic. But galaxies have other "peculiar velocities", over and above the general cosmic expansion.

Although the cosmological principle is one of the central tenets of cosmological theory, it is obvious that the Universe is not exactly homogeneous and isotropic. Matter is not smoothly distributed, but organised into galaxies, galaxy clusters and even superclusters of galaxy clusters. This complex hierarchy of density fluctuations is, according to 'inflation theory', a result of the gravitational amplification of low-amplitude 'ripples' that were present in the very early Universe. But there should be a scale beyond which gravity has not had sufficient time to produce structures, and beyond which the Universe should therefore appear homogenous.

Besides generating spatial patterns, gravity also generates velocities. In a perfectly uniform Universe, everything moves away from everything else with a velocity that is proportional to the distance between. This is known as the Hubble law. But the presence of density fluctuations distorts this uniform Hubble flow by introducing peculiar motions.

All galaxies execute some kind of peculiar motion, as a consequence of the gravitational influence of the lumpy distribution of material around them. In the densest galaxy clusters —known as Abell clusters— where gravitational forces are very strong, galaxies move around with peculiar velocities of ~1,000 km/s generated by the deep potential well in which they reside. On scales larger than individual clusters, the concerted action of entire superclusters produces a calmer, more coherent flow towards regions of above-average density, and away from regions of below-average density. These 'streaming' motions contain clues to the size of the largest structures doing the pulling and thus furnish an important test of cosmological models.

In 1988, a study of streaming motions in a sample of elliptical galaxies revealed evidence for a systematic flow, simple modelling of which suggested that it could be explained by a hypothetical object about 60Mpc away from the Milky Way, which became known as the 'Great Attractor'.

To map cluster motions, astronomers have to work out how much their velocity —easy to determine from redshift— departs from the velocity that the overall

cosmic expansion would give to an object at that distance. That means determining their distance without relying on redshift, a much tougher requirement. The usual strategy is to find some observable feature of galaxies that is thought to indicate their actual brightness or size, then compare it with the brightness or size observed from Earth to get distances.

The Streaming Motions of Abell Clusters (SMAC) Collaboration looked at elliptical galaxies and determined their absolute size by measuring the mean surface brightness in the central part of the galaxy and how fast stars are darting around within it —indicated by the broadening of spectral lines. Then they compared these to similar known galaxies close to Earth. They applied the constructed distance indicator to about 700 galaxies in 56 rich clusters spanning a volume some 1.2 billion light years in diameter. Many telescopes were used in this survey, including the INT and the JKT.

The SMAC survey went far beyond the proposed location of the Great Attractor and they still see outward motion of galaxies beyond it. The reported bulk flow is of amplitude 630 ± 200 km/s with respect to the cosmic microwave background. This flow is robust against the effects of individual clusters and data subsets, the choice of Galactic extinction maps, Malmquist bias, and stellar population effects. The direction of the SMAC flow is about 90° away from the flow found by other astronomers, but it is in good agreement with the gravity dipole predicted from the distribution of X-ray-luminous clusters.

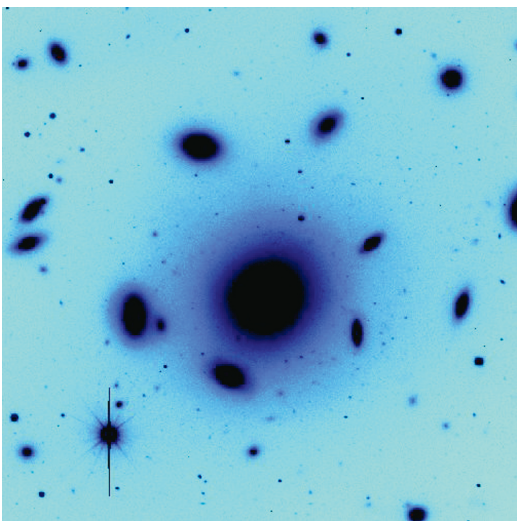


Image of the galaxy cluster Abell 1656 studied by the SMAC team with the Isaac Newton Group of Telescopes. The SMAC survey was based on measurements of 699 galaxies in 56 galaxy clusters like Abell 1656.

GAMMA RAY BURSTS: NEW LIGHT ON THE UNDERSTANDING OF THESE OBJECTS

WHT, INT, JKT

In 1999 the ING telescopes discovered and followed up more optical afterglows of Gamma-Ray Bursts (GRBs), like the extremely intense GRB 991208. Moreover, the observations carried out by the ING telescopes have been used to shed new light on the understanding of these objects. Below we extend on two interesting topics related to GRB research.

Gamma-ray Burst 990123

Gamma-ray bursts are believed to be the largest explosions in the Universe since the Big Bang. However, the origin of these bursts have remained a mystery since their discovery more than 30 years ago. The bursts occur almost daily and shine at least a billion times brighter than any other phenomenon in the Universe, including quasars. The bursts last anywhere from a few milliseconds to several minutes, then disappear forever. The bursts are followed by afterglows that are visible for a few hours or days at other wavelengths.

GRBs are thought to arise when an extremely relativistic outflow of particles from a massive explosion interacts with material surrounding the site of the explosion. Multi-wavelength observations, following their light-curves, are needed to understand the nature of the explosions.

The time scale of the decay since the gamma-ray explosion is detected is about 10 days: the brightness of the optical counterpart can decrease about fifteen magnitudes over this period. Therefore, a quick and accurate determination of the position of the optical counterpart and the follow-up photometry of the source is crucial, which requires a global observing campaign, involving many telescopes.

On 23 January 1999 one of the brightest GRBs ever seen was detected by the BATSE satellite. For the first time, observations at optical, infrared, sub-millimetre and radio wavelengths were obtained of an entire gamma-ray burst. In this effort the Jacobus Kapteyn Telescope was involved, contributing to the photometric

light-curve at multiple wavelengths. These observations revealed that the optical and gamma-ray light curves are not the same. This was also the first time that the three different regions involved in the emission process were seen: the internal shocks causing the GRB, the reverse shock causing the pronounced optical flash, and the forward shock causing the afterglow.

If the blast radiated the same amount of energy in all directions as it did towards Earth, its energy would be equivalent to that of almost two neutron stars and irreconcilable with current theories of GRBs. However, the speed at which the radiation faded over the following two days suggests that material was ejected from the explosion in two cones, one of which pointed towards the Earth. This would make it easier to explain GRBs by conventional mechanisms such as the shock waves formed following the death of a massive star.

Links between supernovae and GRBs strengthen

The discovery of both an X-ray and optical afterglow to GRB 970228 by the William Herschel Telescope and the Isaac Newton Telescope revolutionised the study of gamma-ray bursters. The mean temporal and spectral properties of this afterglow appeared to be consistent with the relativistic fireball model. However, now that more data has been gathered on several GRBs, not all of them appear to fit the fireball model. One of them is GRB 970228.

Studies of this GRB, including observations from the WHT and INT, found evidence of extreme reddening of the afterglow with time, which is difficult to explain in the fireball model. Re-analysing the light-curves of the afterglow at different wavelengths suggested a link with a possible rare type of supernova explosions, which strengthens ideas that at least some type of GRBs are produced following the collapse of a massive star.

HR 8752, A HYPERGIANT NEAR THE BORDER OF INSTABILITY

WHT+UES

Hypergiants are supergiant stars with strongly developed large-scale atmospheric velocity fields, excessive mass loss, and extended circumstellar

envelopes. They are rare objects, only 12 of them being known in our Galaxy. There are indications that yellow hypergiants are evolved stars, evolving from the red supergiant phase to the blue phase. However, stars with effective temperature near 9,000 K have density inversions, which may indicate instability. This has led to research on the 'yellow evolutionary void'. Inside the void the atmospheres are moderately unstable. The process of approaching the void has not yet been studied and this is a field in which no observations have guided theory so far. A monitoring of stars approaching the void will help to understand the nature of the instabilities and the hydrodynamics of unstable atmospheres and finally to answer the most important question of whether or not these stars can pass the void.

It is believed that the Galactic hypergiant HR 8752 is presently bouncing against the yellow evolutionary void. From UES spectra astronomers reported for the first time the finding of spectroscopically recorded large changes of the effective temperature, from 5,000 K in 1969 to about 8,000 K in 1998, which cannot be ascribed to the regular variability of a supergiant atmosphere. This finding is based on a unique combination of high-resolution optical spectra that span a period of about 30 years. Thus, HR 8752 turns out to be the first cool supergiant that shows the effects of stellar evolution from a study of its 30 year old spectroscopic history.

Now that HR 8752 approaches the yellow evolutionary void three possibilities arise: 1) The star might return to the point when the effective temperature was 4,000–5,000 K; 2) It might explode as a supernova or, 3) It might occupy the void, which would mean that theory should change. Observations in the coming years will tell us the next evolutionary stage.

THE ORIGIN OF EARLY-TYPE STARS FOUND IN THE GALACTIC HALO

WHT+UES, +ISIS, JKT+CCD

Among the faint, blue stars that are observed at intermediate and high Galactic latitudes, there exists a small subset of objects that are spectroscopically indistinguishable from normal, young Population I B-type stars found in the Galactic disk. The majority of this subset are plausible 'runaway' stars, recently formed in the Galactic disk and subsequently ejected by

some mechanism. However, in a few cases these apparently normal stars are found at large distances from the Galactic disk, and their evolutionary ages are too short for the objects to have attained their current Galactic locations.

There is no doubt that star formation at large distances from the Galactic plane is controversial. However, shock induced star formation between halo high velocity clouds has been postulated as the origin of the apparently young, distant B-type stars where formation *in situ* seems to be the only possible explanation for their existence.

From recent echelle spectroscopy of 21, apparently normal, high Galactic latitude, early-type stars of solar metallicity drawn from the Palomar-Green survey, astronomers concluded that distances, ages, and velocities are consistent with escape from the Galactic plane. In other words, all these objects are 'runaway' stars, formed in the Galactic disk and subsequently ejected, possibly by supernovae explosions or dynamical interactions. In particular high-resolution, high signal-to-noise ratio spectra of HD 100340 showed that this is a normal main-sequence B-type star, at a distance of 2.6kpc above the Galactic plane. A kinematical analysis strongly suggests that HD 100340 formed in the Galactic disc, and was subsequently violently ejected towards the halo, as a result of the dynamical evolution of a stellar cluster.

EVIDENCE FOR A MASSIVE BLACK HOLE IN THE S0 GALAXY NGC 4342

WHT+ISIS

Several lines of evidence suggest that Active Galactic Nuclei (AGNs) are powered by accretion onto super-massive black holes. The much higher volume-number density of AGNs observed at redshift $z \sim 2$ than at $z \sim 0$ suggest that many quiescent (or 'normal') galaxies today must have gone through an active phase in the past, and therefore harbour a massive black hole as well. Such a black hole will significantly influence the dynamics of the galaxy within a certain distance, imposing conditions to the profile of the velocity dispersion of the stars surrounding this massive object.

Taking into account these theoretical predictions a study was undertaken of the lenticular (type-S0) galaxy NGC 4342. This study involved a combination of HST and WHT imaging and spectroscopy. The data obtained from these observations were compared with theoretical models describing the dynamics and morphology of the galaxy. Spectra obtained with the WHT have revealed a very steep central rotation curve and a strong central increase in velocity dispersion. These data suggest a large central mass concentration. However, although the dynamical evidence for the presence of a massive dark object in NGC 4342 is compelling, it does not automatically imply evidence for a black hole. If it exists, the mass of the super-massive black hole must be approximately between 3 and 6×10^8 solar masses. Then NGC 4342 would have one of the highest ratios of black-hole mass to bulge mass.

DISCOVERY OF YOUNG STARS IN NGC 185, A DWARF ELLIPTICAL GALAXY

JKT+CCD

Since the early work of Baade elliptical galaxies were considered to be essentially old, coeval systems with ages comparable to those of Milky Way Population II globular clusters. In the light of recent data, however, there is evidence that the majority of the Local Group dwarf elliptical (dE) galaxies have undergone recent star formation activity.

The study of the stellar content of dE galaxies by means of their color-magnitude diagrams provides the most direct method of establishing whether they have had star formation episodes since the initial primeval event and even to locate in time, in a more precise way, that initial star formation event. The Local Group dE galaxies offer a unique opportunity to study their evolution in detail by this means.

NGC 185 is a dE companion of the Andromeda galaxy. The presence of a dozen of bright, blue stars and two conspicuous dust patches in the central area of NGC 185 was firstly noted by Baade in 1951. These "Population I" features indicated that NGC 185 did not fit the concept of dE galaxies as pure Population II systems. For this reason, NGC 185 was classified as a peculiar dE galaxy.

A recent study of NGC 185 shows that the luminous, blue stars discovered by Baade are in fact young stellar clusters at the distance of the galaxy. Furthermore, the recent analysis of the star formation history of NGC 185 using synthetic color-magnitude diagrams shows that the bulk of the stars were formed in an early epoch of its evolution. After that, star formation proceeded at a low rate until the recent past, the age of the most recent traces of star formation activity detected in the galaxy being some 100 Myr. These conclusions rule out the possibility of NGC 185 being an old galaxy formed by Population II stars only.

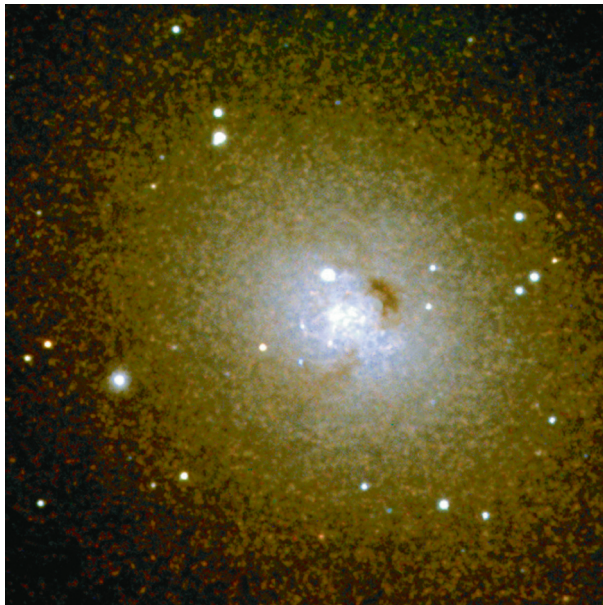


Image of the central region of NGC 185, obtained from a combination of B, V, and R images from the Jacobus Kapteyn Telescope.

CLOSING IN ON THE PRIMORDIAL POWER SPECTRUM OF MASS FLUCTUATIONS

WHT+ISIS

Modern cosmology is based on the hypothesis that structure in our Universe arose from the action of gravity on small initial density perturbations. The power spectrum of these initial fluctuations, $P(k)$, is a fundamental discriminator between different cosmological theories, it offers a direct way to constrain any free parameters they might have, and it would also serve as a valuable baseline for the interpretation of cosmological phenomena.

One route to $P(k)$ uses observations of microwave background anisotropies. However, estimates of the mass $P(k)$ derived from such measurements depend on the assumed values of the cosmological parameters. Much effort has been spent on trying to infer $P(k)$ from surveys of the galaxy distribution. Deriving an estimate of the primordial matter $P(k)$ from galaxy measurements requires at the very least an understanding of how the present day distribution of galaxies is related to the primordial distribution of mass. Even with a theory of galaxy formation, the complexity of the processes involved makes it difficult to recover $P(k)$ directly.

However, the Ly α forest seen in quasar spectra can be used to study mass fluctuations, but with two important differences. First, the framework of standard cosmology provides us with a well-motivated theory of Ly α formation. Second, the situation described by the theory is simple and leads to the prediction that an approximately local relationship holds between the absorbed flux in a quasar spectrum and the underlying matter density, a relationship that can be inverted to learn about matter clustering. In particular, $P(k)$ itself can be recovered over a limited range of scales. The astronomers applied this procedure to a sample of 19 quasar spectra from a survey of damped Ly α systems carried out with the William Herschel Telescope.

The slope of the primordial power spectrum of mass fluctuations, $P(k)$ at a mean redshift of $z=2.5$ is found to be $n=-2.25$. $P(k)$ has never previously been measured at the scales of this work. The most significant theoretical implication of this result is that inflation and cold dark matter models, originally motivated by considerations of microwave background anisotropies at $z\sim 1000$ and large-scale structure at $z\sim 0$, predict a $P(k)$ that is at least roughly consistent with this measurement.

OTHER SCIENTIFIC HIGHLIGHTS BRIEFLY

The Faint Star Variability Survey

The first phase of the planned five-year program to study faint objects, the so-called Faint Star Variability Survey, was completed. The astronomers recorded the brightness of celestial objects in several wavebands from blue to near-infrared, every 5–10 minutes throughout the night. The images are being analysed in order to search for faint red or blue objects as well as to

record their variability. The survey results also provide detailed information on the nature and distribution of stars within the Milky Way galaxy, faint objects within our Solar System, galaxy clusters, quasars, and faint dwarf galaxy companions to our own Galaxy. This survey operates within the framework of the Isaac Newton Group's Wide Field Survey.

The Supernova Cosmology Project

The discovery of the accelerating expansion of the Universe by the Supernova Cosmology Project was already a scientific highlight in 1998 and named by the journal 'Science' as breakthrough of the year 1998. The paper with all the discovered type Ia supernova data was published in 1999 and it has become one of the most cited ING papers. In order to reduce the systematic errors in the measurements obtained by the Supernova Cosmology Project, the European Supernova Cosmology Consortium started a long-term project on the WHT, INT and JKT to discover and follow-up supernovae at intermediate redshifts.

The QDOT survey

The QDOT all-sky redshift survey is principally aimed at producing the first reliable quantification of the large-scale distribution of galaxies on scales greater than $10h^{-1}\text{Mpc}$. The QDOT survey results were made public in 1999. The catalogue consists of infrared properties and redshifts of an all-sky sample of 2387 IRAS galaxies brighter than the IRAS PSC $60\mu\text{m}$ completeness limit ($S_{60} > 0.6\text{Jy}$), sparsely sampled at a rate of one-in-six. Astronomers used FOS-1 and FOS-2 spectrographs on the INT and WHT respectively.

Jets from quasar 4C 74.26

4C 74.26 is a double-lobed radio source associated with a $V\sim 15$ quasar at a redshift of 0.104. The radio source is one of the largest known to be associated with a quasar. High signal-to-noise ratio spectropolarimetry using ISIS spectrograph of 4C 74.26 has revealed that in polarised light the $H\alpha$ emission line is redshifted by about 2000km/s . This is compelling evidence for scattering by a high-speed outflow. Arguments based on unified models and the one-sided nature of the radio jet suggest that the jet axis is inclined at an angle less than 45° to our line of sight. If the scattering outflow is co-axial with the jet, its velocity must be larger than 5000km/s .

Imaging stellar surfaces

The availability of high-resolution imaging methods now allows the detailed scrutiny of the surfaces of the

nearest cool evolved stars. The photospheric surfaces of five long-period variables were imaged in the optical/near-IR with a standard optical set-up at the Nasmyth focus of the WHT using a collimating lens, a pupil plane mask and magnification optics to convert the telescope into a multi-element interferometer. All of the sample stars exhibited strong departures from circular symmetry. The stellar surfaces were seen to change over time, with characteristic time-scales ranging from several months to a year.

Satellites of Saturn

Observations of the major satellites of Saturn have been continued to improve the orbital theories of the satellites in preparation for the NASA/ESA Cassini/Huygens mission which will reach Saturn in 2004. From 1,514 measurements made in 1995 and 1997 with the Jacobus Kapteyn Telescope, astronomers obtained observations of Tethys, Dione, Rhea and Titan with root-mean-square residuals of $0.08\text{--}0.10\text{arcsec}$.

Galaxy clusters

An extensive study of 10 distant rich clusters of galaxies made from observations collected since 1994 with the WHT and other telescopes was published in 1999. The data presented included positions, photometry, redshifts, spectral line strengths, and classifications for 657 galaxies in the fields of the 10 clusters. The catalogue is composed of 424 cluster members across the 10 clusters and 233 field galaxies. These data were used to study the formation of galaxies in these distant clusters.

Sakurai's object

The extraordinarily rapid evolution of the born-again giant star, also known as Sakurai's object following discovery in 1996, has been investigated thanks to observations carried out with the ING telescopes (WHT+ISIS, +UES, +Aux Port Camera, INT+IDS). The evolution can be traced both in a continued cooling of the stellar surface and dramatic changes in chemical composition on a timescale of merely a few months. The abundance alterations are the result of the mixing and nuclear reactions which have ensued due to the final He-shell flash which occurred during the descent along the white dwarf cooling track. Since Sakurai's object shows substantial abundance similarities with the R CrB stars and has recently undergone R CrB-like visual fading events, the "birth" of an R CrB star may have been witnessed for the first time ever. Sakurai's object

thus lends strong support for the suggestion that at least some of the R CrB stars have been formed through a final He-shell flash in a post-AGB star. Optical imaging and long-slit spectroscopy of the planetary nebula surrounding Sakurai's object showed that this is a typical evolved planetary nebula. The observations are only consistent with white dwarf cooling tracks if the stellar mass lies between 0.5 and 0.8 solar masses.

Boxy bulges and bars

It has been suggested that the boxy and peanut-shaped bulges found in some edge-on galaxies are galactic bars viewed from the side. Using ISIS spectra, astronomers investigated this hypothesis by presenting emission-line spectra for a sample of 10 edge-on galaxies that display a variety of bulge morphologies. Generally, bulges classified as more boxy show the more complicated kinematics characteristic of edge-on bars, confirming the intimate relation between the two phenomena.

Jupiter's Great Red Spot

The Great Red Spot is the most prominent and long-lived feature on Jupiter. Despite the fact that it has been observed for more than 300 years, many unanswered questions on this oval region still remain. One of the most striking characteristics is its coloration. A different material and/or particle size distribution compared to its surroundings could explain this feature. From high-quality CCD observations acquired at the Nasmyth focus of the WHT astronomers concluded that the difference in colour between the Great Red Spot and its surroundings could be mainly due to different particle size, rather to a different composition, i.e. different refractive index.

T Tauri stars

Several studies on T Tauri stars were carried out in 1999 using the ING telescopes (WHT+UES, INT+IDS). Hourly monitoring of several T Tauri stars allowed astronomers to discern a wide range of physical

processes at work, such as the slow rotation of the stars, magnetic flaring activity, variable accretion and obscuration by circumstellar material. In particular, measurements of magnetic field strength derived from the differential change of the equivalent width of photospheric Fe I lines showed that ignoring magnetic fields in T Tauri stars could result in errors in effective temperature and underestimates of veiling.

Galaxy evolution

How early-type galaxies were formed and evolved is a key issue in extragalactic astronomy which remains controversial. The evolution of early-type galaxies in clusters seems to be well expressed by the so-called single-burst model, in which galaxies experience a starburst at the initial phase of their formation and then evolve passively without any subsequent star formation. However, it is fairly controversial whether the single-burst model holds for early-type galaxies in the field environment. From deep CCD imaging using the Multiple CCD (MCCD) camera on the WHT astronomers found that early-type galaxies in the field environment do not have the same evolutionary history as described by the single-burst model.

Lithium abundance in stars

According to the standard big bang nucleosynthesis model, lithium is one of the few elements synthesised in the first minutes of the Universe. In this scenario the primordial synthesis of lithium is very sensitive to the baryon/photon ratio, and the astronomical determination of its primordial abundance can constrain the baryonic contribution to the density of the Universe. Since the discovery of a rather uniform lithium abundance, the so-called lithium plateau, in the hotter halo dwarfs at about a value $\log n(\text{Li})=2$, there has been a long debate on whether or not this abundance reflects the primordial one. In 1999 the research on this topic continued and several papers containing data from WHT+UES and INT+IDS were published showing new Li measurements from metal-poor stars.