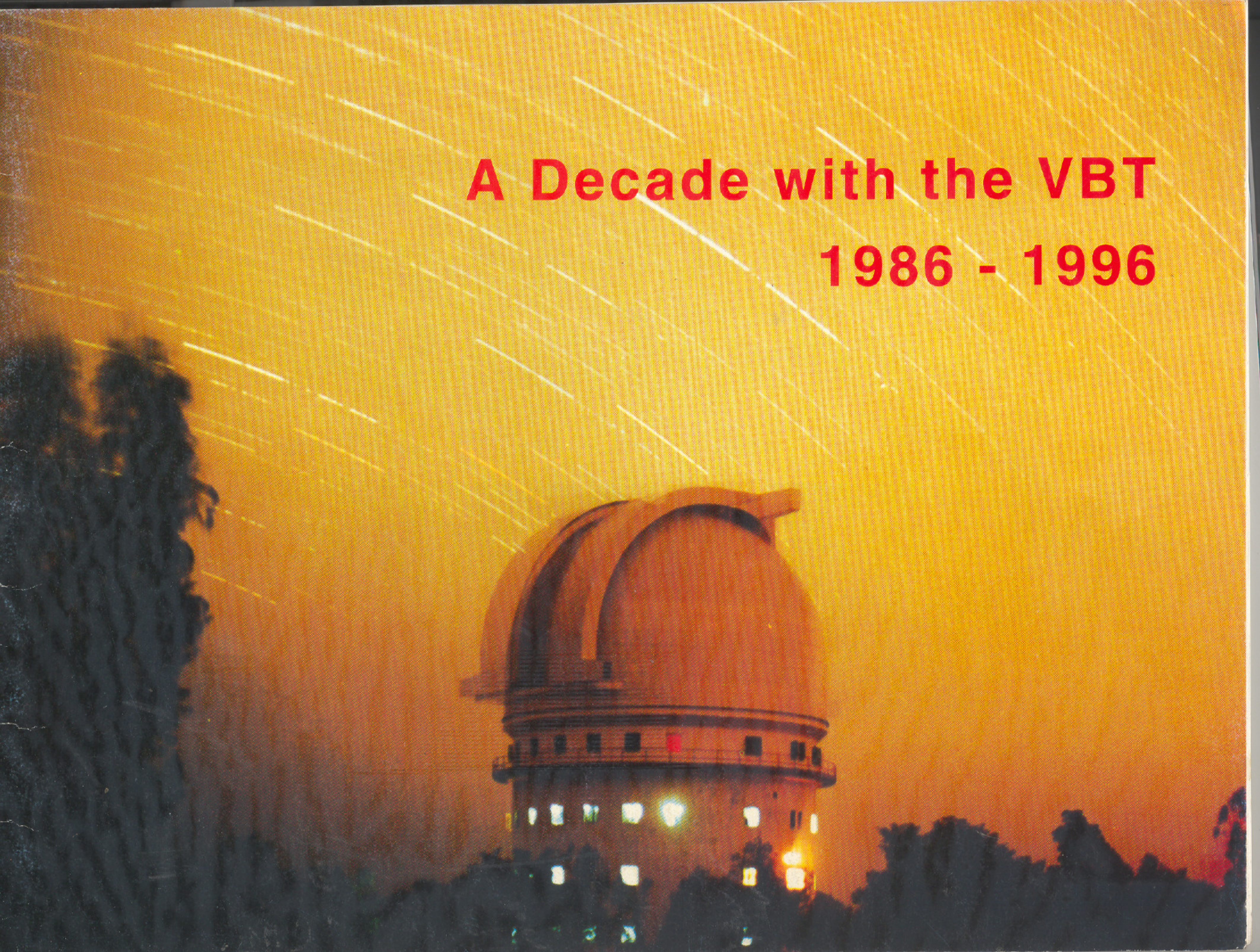
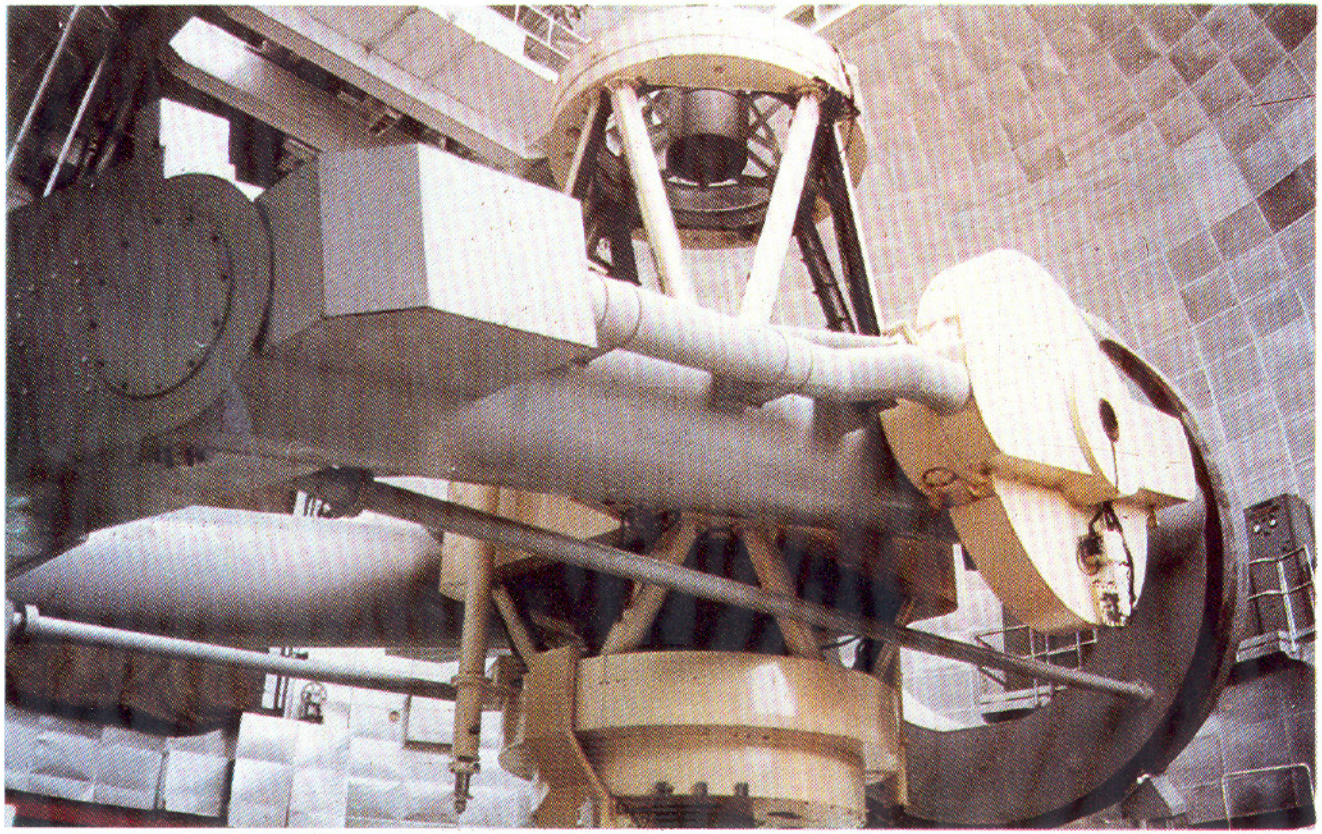
A Decade with the VBT
1986 - 1996



VBT

A Decade with the Vainu Bappu Telescope



Indian Institute of Astrophysics

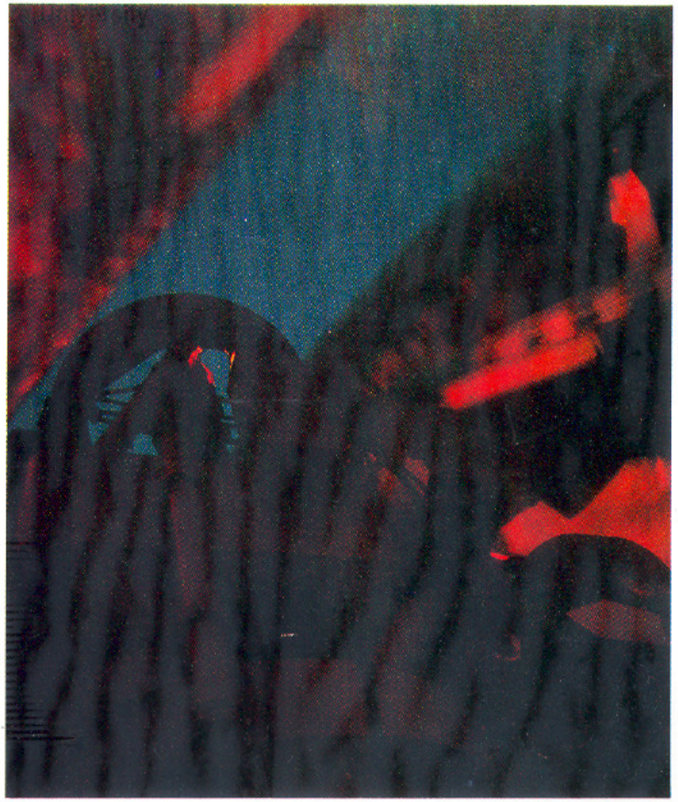
On 6 January 1996, India's largest optical telescope, the 2.3 metre Vainu Bappu Telescope (VBT) completes its ten years of operation. The indigenously built VBT, the dream of late Prof. M. K. Vainu Bappu, the first director of the Indian Institute of Astrophysics, was indeed a bold effort considering the fact that the largest telescope built till then was only 15 inch in diameter. The need for a large telescope in the country had been felt as early as 1945 and was recommended by the post-war committee on Astronomy headed by the famous astrophysicist M. N. Saha and supported by Sir C. V. Raman. It was Prof. Vainu Bappu who was instrumental in realising this proposal for a large telescope into reality. He proposed in 1971 that the telescope should be built indigenously to study:

1. the spiral structure of the Galaxy (particularly in the southern hemisphere).

2. stellar chromospheres, principally by the method of stellar spectroscopy.

3. morphological aspects of external galaxies and the chemical composition parameters in these stellar aggregates and their bearing on stellar evolution.

A concept report was prepared in 1976 and the telescope was completed in 1986 under the directorship of Prof. J. C. Bhattacharyya. It is located in the Javadi hills in the midst of a sandal wood forest near the small village Kavalur in the North Arcot district of Tamil Nadu, as part of the Vainu Bappu Observatory (VBO : Longitude 78°49'.6 E, Latitude 12°34'.6N, Altitude 725 m). The site offers pollution-free atmosphere, easy logistics, and relatively low latitude permitting access to both northern and southern skies. The advantage of this location can be appreciated from the fact that VBO is the only observatory which could observe the supernova 1987A in the Large Magellanic Cloud ($\delta = -69°$) as well as the supernova 1993J in M81($\delta = +69°$). The observatory houses a number of other telescopes of apertures 1.0 m, 0.75 m, 0.45 m (Schmidt) and 0.38 m.The Vainu Bappu Telescope is operated as a National Facility for Optical Astronomy.



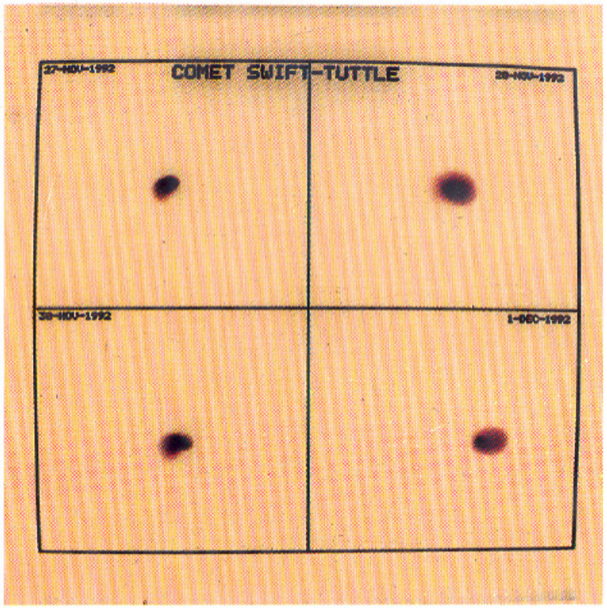
The 2.3m telescope was formally dedicated to the nation on 6 January 1986 by the then Prime Minister, the late Rajiv Gandhi, who also fittingly named both the telescope and the observatory after the late Prof. M. K. Vainu Bappu. The VBT became fully operational a little while later.

Regular observations with the telescope at the prime focus began in 1987-88. Observations at the Cassegrain focus started in December 1990. The VBT has a f/3.25 paraboloid primary mirror of 2.3 m diameter surfaced to an accuracy of $\lambda/10$. The image scale at the prime focus is 27 arcsec/mm and it is 6.7 arcsec/mm at the f/13 Cassegrain focus. The routinely available instruments at the prime focus are the CCD cameras for imaging in various filters, and a CCD spectrograph (Boller & Chivens) at the Cassegrain focus for medium to low resolution spectroscopy. A fibre-linked echelle spectrogaph is presently under construction. The telescope is also being used extensively by visiting astronomers, sometimes with their own focal plane instruments (like polarimeter, Fabry-Perot spectrometer,infrared photometer etc.).

Prof. S. Chandrasekhar having a look at the primary mirror.

Science with the VBT

The VBT's comparatively large collecting area has been used by a large number of astronomers from various institutions in the country and abroad. Wide ranging research programmes are being pursued with the VBT. Some of the results obtained from observations with the VBT are discussed below.

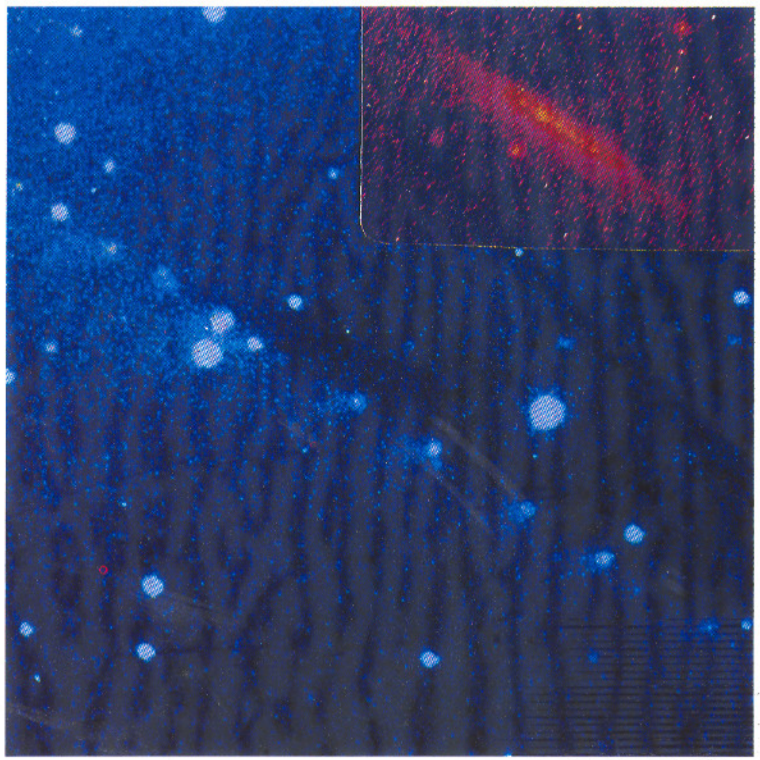


Solar System Astronomy

In the area of solar system research, observations of comets, mutual eclipse events of the Jovian satellites and search and studies of asteroids, a continuing legacy of the famous astronomer and director of the Madras Observatory (1861 - 1891), N. R. Pogson, have been some of the major programmes being carried out with the VBT.

Comets are thought to contain some of the pristine material from which the solar system formed, and can be described as conglomerates of dirty ices. The composition of the coma and the way matter is lost from the nucleus as they enter the inner solar system, closer to the sun, are yet to be understood. In the case of the comet Swift-Tuttle the ejection of gas and dust occurs in the form of jets coming out of the nucleus as dramatically displayed in the images of the comet taken with the VBT. The time series of exposures also show that the cometary nucleus rotates with a period of 2.7 days. The spectroscopic and polarimetric studies from the VBT show that in comet Austin the dust grains in the coma are larger than those in the tail.

The most spectacular phenomenon involving a comet took place in July 1994 when comet Shoemaker-Levy 9 (SL 9) collided with the planet Jupiter. Astronomers at VBT monitored the evolution of SL 9 soon after its discovery by Eugene and Carolyn Shoemaker and David Levy in March 1993 as a fragmented comet with twenty-one pieces strung out like "pearls on a string".It was on a collision course with Jupiter. The figure shows two of the CCD images taken with the VBT in May 1993 (inset) and March 1994 respectively. During the ten-month interval the length of the chain of the cometary fragments had increased by a factor of 4. Collisions of the fragments with Jupiter took place during 16-22 July, 1994. Spectroscopy of the impact spots was carried out with the Boller & Chivens spectrograph on the VBT while other smaller



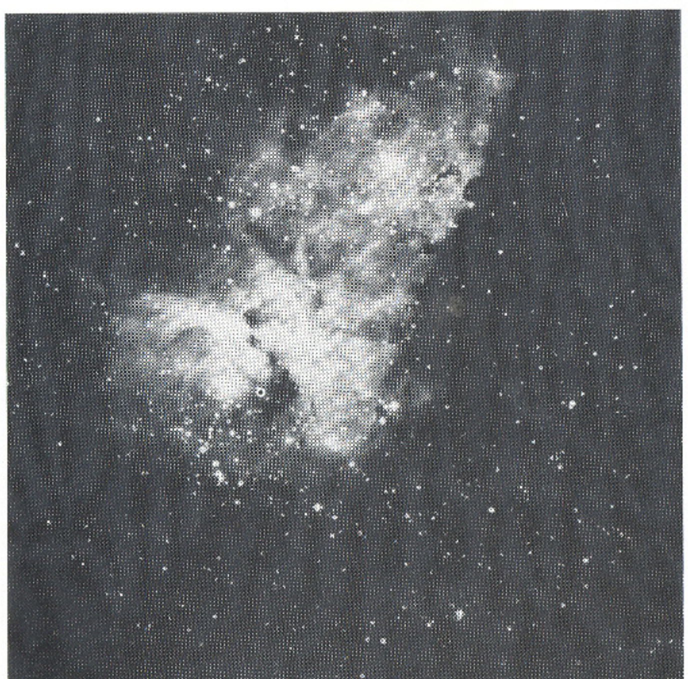
telescopes at VBO were used for imaging and infrared photometry. The VBT spectra show that the impact spots have excess flux in the methane bands.

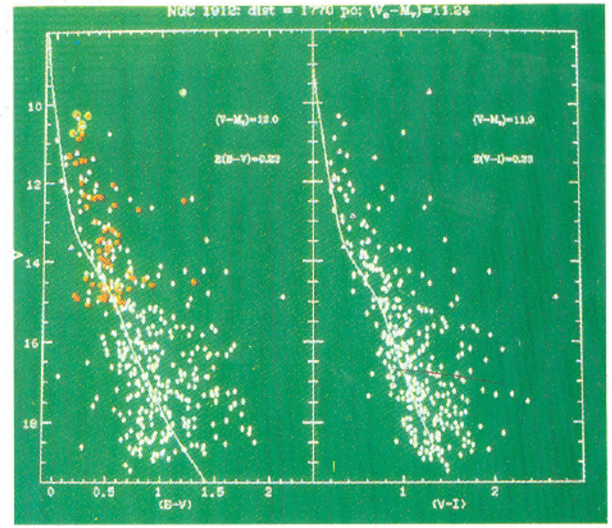
Important information about the surfaces and atmospheres of planets and their satellites can be obtained by observing the relatively rare mutual eclipse events involving these bodies.The mutual eclipse events of the satellites of Jupiter were recorded during the mutual eclipse season of 1990-91. Twice during a Jovian year, the equatorial plane of the planet crosses the ecliptic. During a few months around this time, the Galilean satellites of Jupiter frequently occult each other when any two of them are aligned with the Earth or the Sun. From the model fitting of the light curves it was found that the scattering over the surface of the satellite Io is better described by the Lommel-Seeliger's law than the Lambert's law.

Stellar and Galactic Astronomy

Star Formation:

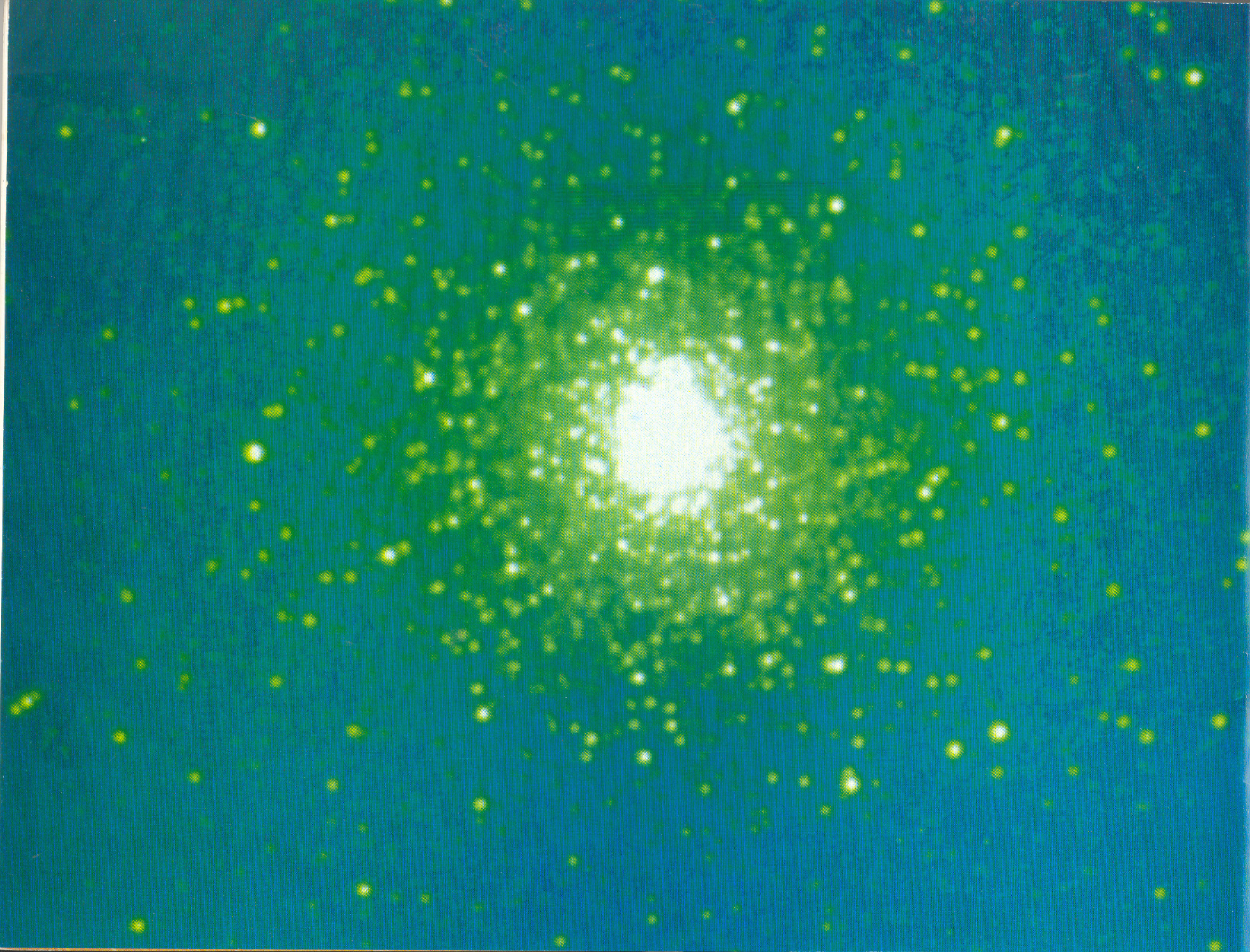
Stars and planetary systems like the solar system are born deep within the high-density cores of dusty interstellar clouds.The protostellar objects remain obscured in the optical due to absorption of light by dust for quite some time until the dusty shrouds are removed from around the young stars by energetic winds and radiation. The infrared window is best suited for studies of protostars and their environments, whereas stellar properties can be probed optically. With the VBT, young premain-sequence Herbig Ae/Be stars and other visible manifestations of star-formation like the Herbig-Haro objects are being studied by CCD imaging and spectroscopy in star-forming regions in Orion and the Gum Nebula complex.





Star Clusters:

Star clusters act as laboratories for many astrophysical processes including star formation, stellar evolution and stellar dynamics. They also serve as ideal probes to investigate the structure and evolution of the Milky Way and other galaxies. CCD imaging of star clusters, young and old, open and globular, clusters containing objects of special interest like planetary nebulae have been done at the prime focus of the VBT. A CCD colour-magnitude diagram, down to a magnitude limit of V = 21 mag, gave the distance to the cluster NGC 2818 and the associated planetary nebula as 3.8 ± 0.1 kpc.The mass of the main-sequence progenitor of the planetary nebula was found to be ≥ 2.58 $M_{\odot}$. A deep CCD photometric study of the open cluster NGC 2453 yielded a distance of 6 kpc for the cluster while planetary nebula NGC 2452, earlier thought to be probably associated with NGC 2453, is at a distance ≤ 3.5 kpc. The two objects are thus not physically associated at all. Shown here is a colour- magnitude diagram for NGC 1912.



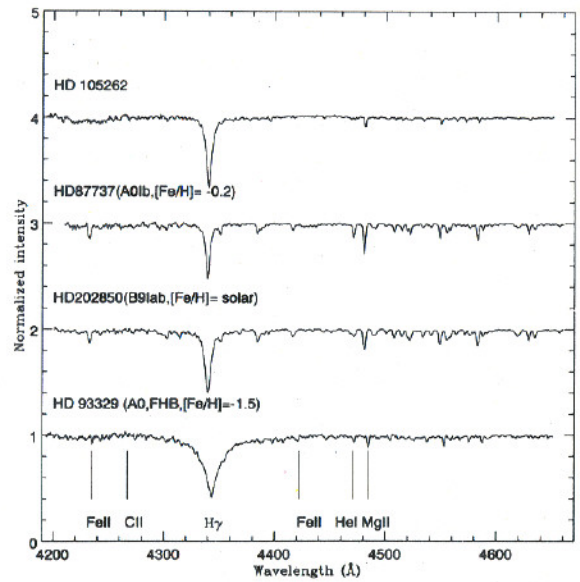
Late Stages of Stellar Evolution:

The VBT has been extensively used for spectroscopic studies of stars in their late stages of evolution. How stars of intermediate mass become white dwarfs in the normal course of evolution, particularly from the stage of asymptotic red giant, is very uncertain. Stars in this stage of evolution not only lose mass extensively but also spread into interstellar medium important elements like ^{7}Li, ^{19}F and s- processed elements like Ba, Eu etc. which they have manufactured inside and mixed to the surface. In the process of mass loss they also make dust in the circumstellar environment. The role of dust and its condensation, mass loss, the distribution of gas in the circumstellar environment, the mixing and processing of several chemical elements are several aspects of great current interest in the context of different paths the stars take to end their lives. Several of these objects are being studied spectroscopically and in imaging mode with VBT.

Hydrogen deficient stars(NSV 6708, R CrB etc.) and the WC 11 stars (CPD -56° 8032, He 2-113, M 4-18 etc.) have been monitored spectroscopically. No trace of a binary companion can be seen. The nebulae surrounding them have been studied from the spectra and also the physical conditions have been modelled. Observations of M 4-18 showed ten times under-abundance of N and S relative to sun in the nebula of this object.

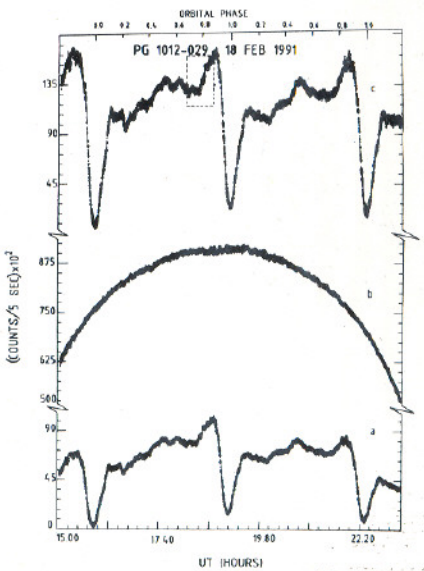
Spectra of the RV Tauri star AR Pup show that in addition to Hα emission the star shows Na I D lines in emission at certain phases. A study of the linear polarization changes in the R CrB star V 854 Cen during the minimum as well as the maximum suggested that the dust ejections in the star occur roughly in the same plane and a scattering region almost perpendicular to the plane of ejection of dust is seen during the deep minimum.

From an analysis of VBT observations of IRAS sources with far-IR colours similar to those of planetary nebulae, several new post-AGB stars and proto-planetary nebulae (e.g. IRAS 08187-1905, 05233-0626, 05341+0852) were discovered. Spectra of many of these stars show emission lines of hydrogen indicating post-AGB mass loss that would transform these objects into planetary nebulae. The chemical composition of the high-latitude metal-poor post-AGB supergiant HD 105262 was



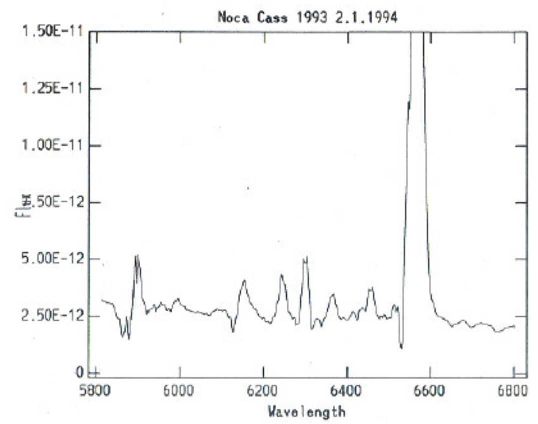
found to be carbon rich (C/O = 1.2) and shows anomalies in Si/Fe. Its space motion relative to the Sun is found to be 700 km/sec, which is much larger than the escape velocity from the Galaxy.

The oscillations of white dwarfs provide us great deal of information on their structure, chemical composition and even mass. High speed photometric monitoring of cataclysmic variables and pulsating white dwarfs has yielded very interesting new results. Observations of PG 1012-029 were used to refine both the period (3^h 14^m 59^s) and its derivative. They also led to the discovery of the presence of two short periods outside the eclipse. Monitoring of PG 1159, in the WET programme, not only showed that the light variations are due to non-radial g-modes but also allowed an estimate of the mass as 0.586 M_0, and a rotation period of 1.38 days with a magnetic field of 6000 gauss.



Sky-subtracted light curve of data recorded on 18 February 1991: a of PG 1012-029, b of a nearby field star, c extinction-corrected data of PG 1012-029

Close binaries with white dwarf companions display spectacular outbursts of light and mass ejection from the system - the novae and recurrent novae. Such systems provide us an opportunity to study the formation of gaseous discs around the degenerate objects and also some of the exotic nuclear processes like the rp- process. Several novae and recurrent novae (Her 1991, Oph 1991, Pup 1991, Sgr 1992, Cyg 1992, Sco 1992, Aql 1993, Cas 1993,Oph 1994 #2, T CrB, RS Oph, T Pyx and the classical nova GK Per) have been monitored with the VBT. Physical conditions like density and temperature in the ejected shells and the masses of the ejecta were determined. For Nova Cyg 1992 the mass of the ejected shell was found to be 10^{-5} M_0.



The identity of the species responsible for the diffuse interstellar bands has been a mystery since their discovery some 70 years back. Discovery of a family of these bands in emission around a hydrogen deficient R CrB star indicating carbon rich molecular nature of the species prompted a systematic survey of these bands in different stellar environments with VBT.

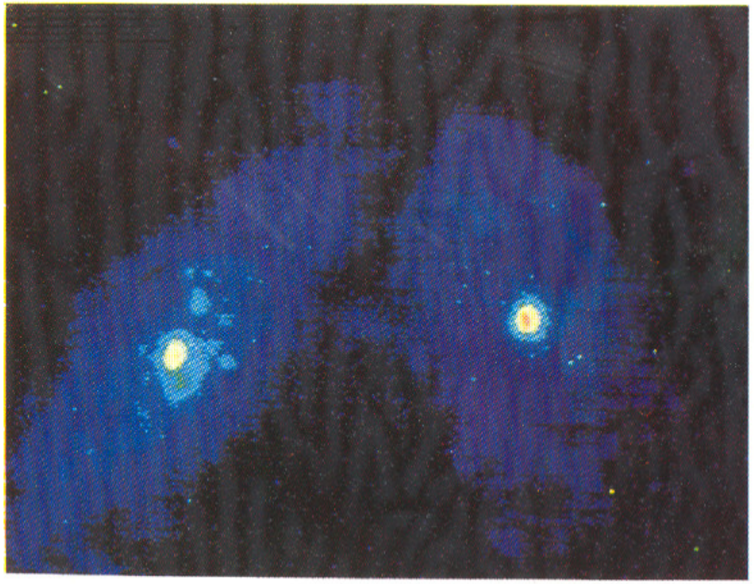
Extragalactic Astronomy

Most of the observational programmes in extragalactic research necessarily need the VBT, and it has been in regular use for several such studies, many of them being long-term programmes.The telescope has been used to study star-forming regions in nearby galaxies, surface photometry of field galaxies and X-ray clusters of galaxies, mapping of absorbing dust and Hα emission in elliptical galaxies, starburst galaxies, galaxies in compact groups and spectroscopy, photometry and polarimetry of extragalactic supernovae, quasars and active galactic nuclei.

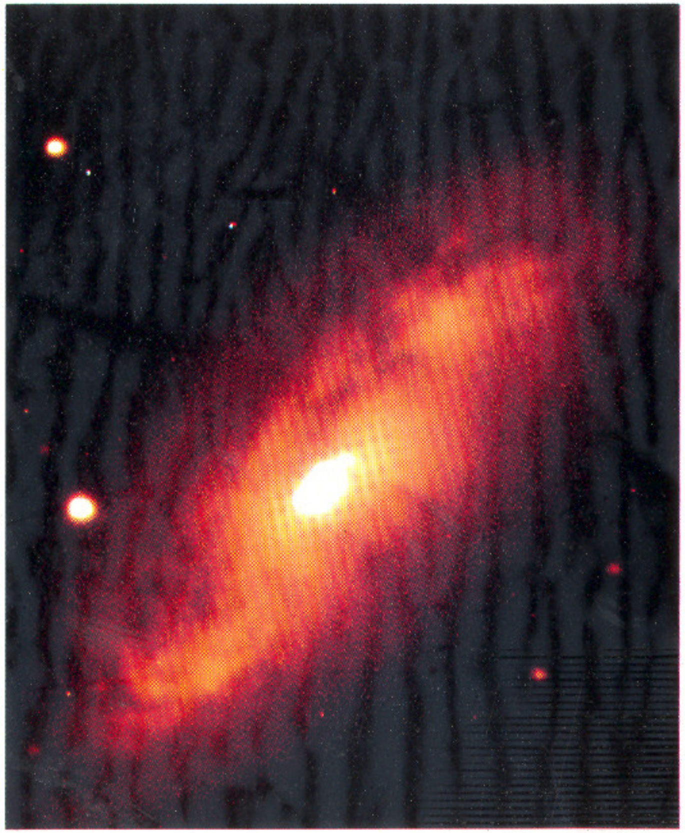
Synthetic aperture CCD photometry of giant extragalactic HII regions (GEHRs) in nearby galaxies was carried out in order to understand the process of formation of massive stars in these galaxies. The GEHRs require more than one event of star formation in the last 10 Myr.

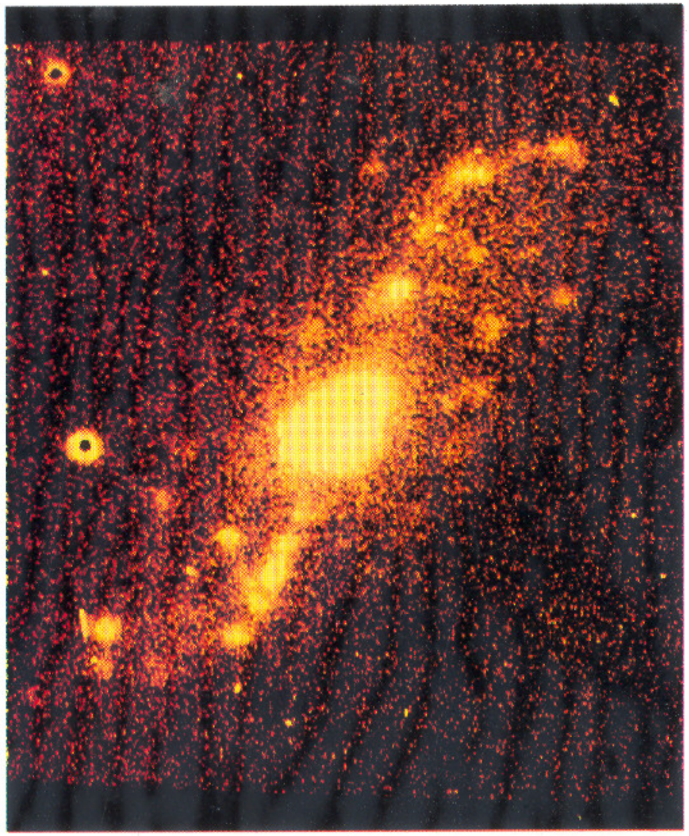
Imaging of elliptical galaxies selected on the basis of their radio and X-ray properties yielded significant results. A dust shell with E(B-V) = 0.12 was discovered in the galaxy NGC 3607 and Hα emission from this elliptical was confirmed. The masses of the neutral and ionised hydrogen in the galaxy were estimated to be 4×10^{7} and 6×10^{4} M_{o} respectively. Recent star-formation was shown to be a viable cause of Hα emission.

VRHα imaging of several, primarily X-ray selected, early-type galaxies (NGC 1399, 1600, 2563, 4203, 4636, 4753 and 5044) was used to measure the Hα+[NII] emission from the central regions. The observed emission-line luminosities imply a mass of 10^{5} M_{o} in ionised gas. The presence of ionised gas is found to be associated with the presence of dust rings and lanes. In some cases, shell-like enhancements are found in the background stellar population as well. All these appear to be manifestations of accretion and merger events.

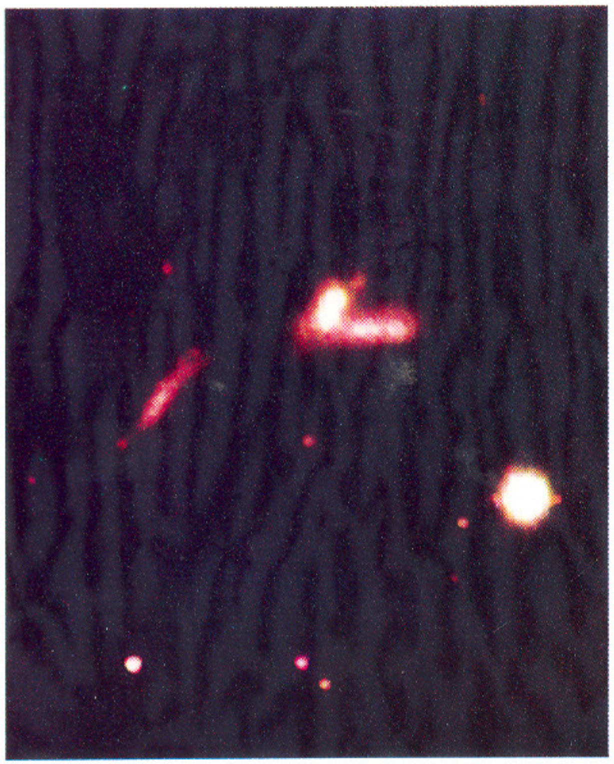


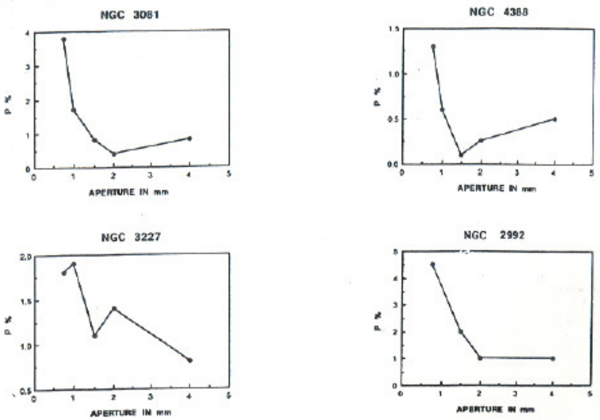
Broad band surface photometry of the radio galaxy 3C 270 (NGC 4261) showed the presence of a dust lane oriented close to the major axis of the galaxy. The dust lane is interpreted as the projection of a disc inclined at 75° to the plane of the sky and perpendicular to the radio axis. The disc could be the reservoir of gas supply to the nucleus that has triggered the nuclear activity.





Compact groups of galaxies are dense concentrations of galaxies with densities comparable to those in the centres of rich clusters. They are ideal sites for galaxy interactions and mergers. CCD imaging in V, R and $H\alpha$ of the compact group HCG 62 has been carried out with the VBT to search for any excess warm ionised gas associated either with a global cooling flow or with the individual galaxies. The continuum-subtracted $H\alpha$ image of the group is shown here. Emission is detected from the central regions of the galaxies. HCG 62b shows an annular ring-like feature. The observed $H\alpha$ luminosities and masses are much lower than those seen in normal cooling flow clusters.



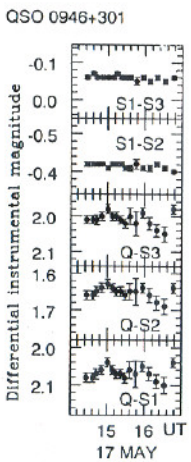


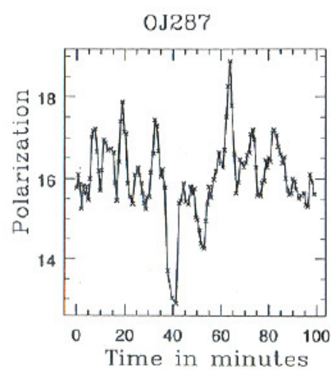
The figure shows polarisation in Seyfert Galaxies for different apertures. As the aperture is decreased, the relative contribution from the galaxy, compared to nucleus, decreases. This shows enhancement in polarization indicating the generation of Synchroton radiation from the nucei of the galaxies.

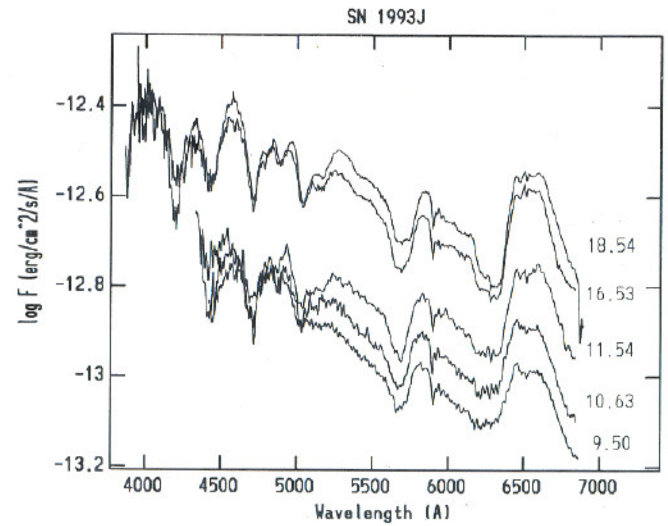
What powers the activity in active galactic nuclei, QSOs etc. is a great puzzle. Several models involving black holes with accretion discs have been proposed. Microvariability in light and polarisation are expected to provide clues to the nature of the nuclear engine.

Polarimetric measurements of a CD galaxy (A0779) and many active galaxies (Seyferts NGC 2992, 3081, 3227, 4388 and Mrk 421) have been made with the VBT. Evidence was found for the nonthermal nature of radiation from the nuclei of the CD galaxy and the Seyferts. Short period microvariability was also detected in Mrk 421.

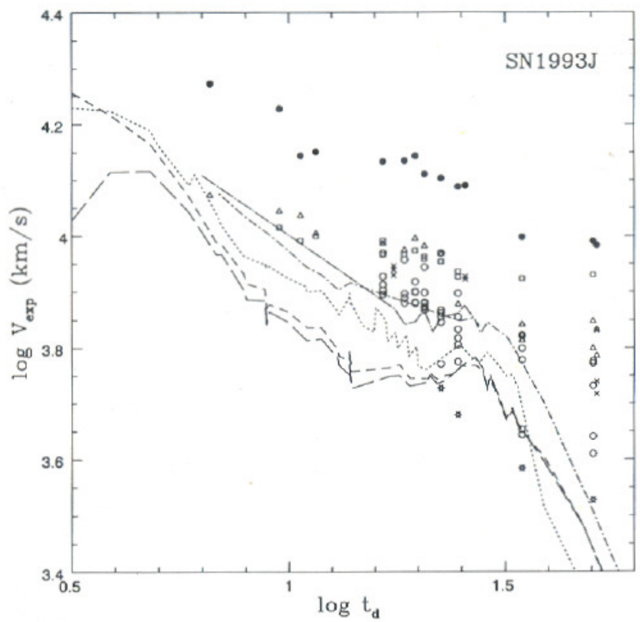
Massive stars end their lives in a spectacular fashion by exploding as supernovae (some of them leave a remnant neutron star) and feed the interstellar medium with the nuclear processed material from their interiors. A number of extragalactic supernovae (SN 1987A in LMC, SN 1989B in NGC 3627, SN 1991A in an anonymous galaxy,SN 1991T in NGC 4527, SN 1992A in NGC 1380 and SN 1993J in M81) have been monitored from the VBO, many of them observed with the VBT in addition to telescopes of smaller apertures. SN 1993J was a bright supernova in M81 and the best-studied Type IIb. The data from VBT was combined with that from the 1-m Zeiss reflector at VBO to study the

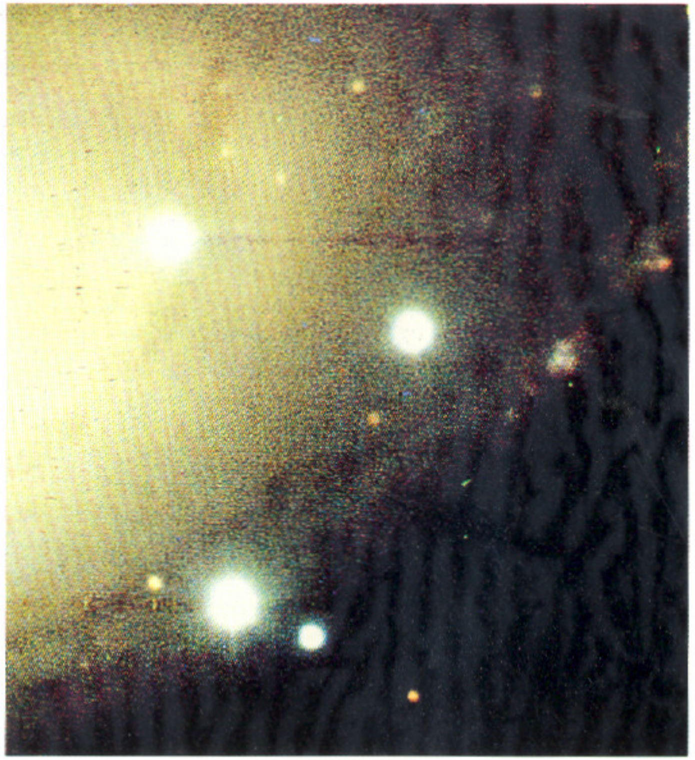






A programme to investigate the possible photometric microvariability of radio-quiet quasars was begun with the VBT in 1992. Differential CCD photometry has clearly shown the presence of intra-night variability in QSO 0946+30. This result favours models where flares on quasar accretion discs are responsible for the microvariability.





evolution of the photosphere. Since the distance to M81 is known fairly accurately, the expanding photosphere method was used to determine the distance to the supernova in order to estimate the intrinsic accuracy of the method which was found to be better than 40%, independent of the distance. The spectra in the initial period indicated over -abundance of nitrogen suggesting that the pre-supernovae stars had the surface material that had gone through CNO cycles and further suggesting that it had gone through a cool supergiant phase where such deep mixing could occur.

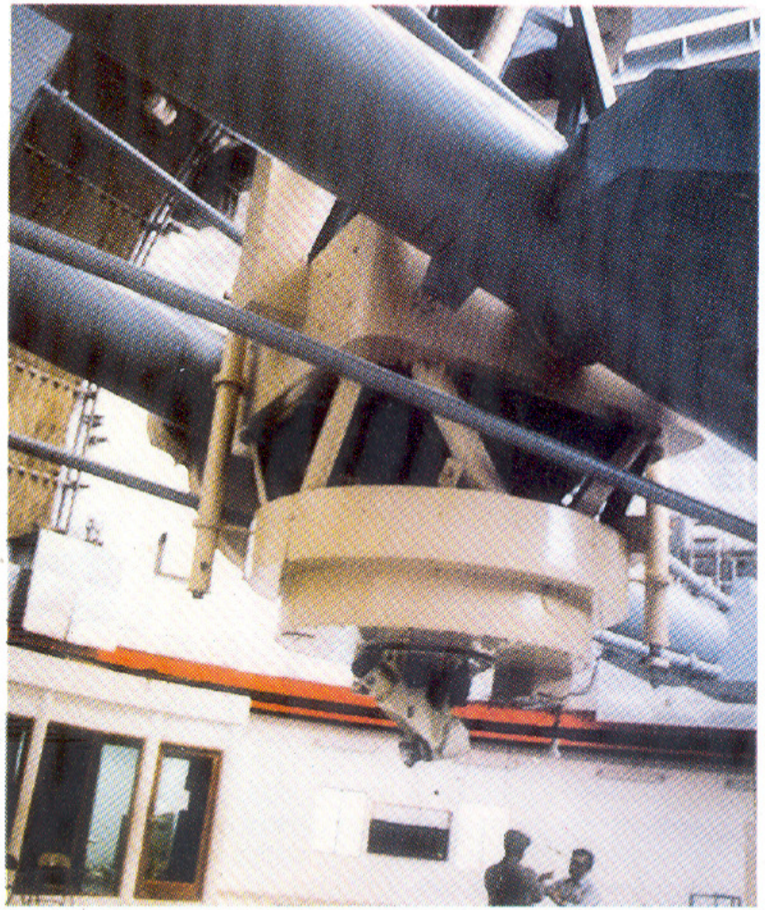
Future

Several improvements to the existing facilities, particularly the backend instrumentation, are being planned or under developement. A matched CCD Cassegrain spectrograph for intermediate and low resolution spectroscopy with a provision of long slit is being procured.The fiber linked high resolution coude spectrometer, presently under development,would provide spectral resolution between 70000 to 20000 for point sources. This spectrometer is also being planned to provide accurate radial velocities for programmes like searching for faint companions etc.

Another anticipated improvement is the development of an infrared imaging camera with a large format chip in collaboration with Prof. M. Ueno of the university of Tokyo.

Many studies being pursued with VBT also need observations in the infrared wavelengths(e.g. starforming regions, dusty AGB envelopes etc.). A high altitude telescope for IR studies is being planned.

The best utility of a medium size telescope like VBT is in its use for systematic studies of a few astronomical programmes. Many programmes now being carried out with VBT are of this kind.Slowly VBT is realising the dreams of its founder Prof. Vainu Bappu.



Astronomer Royal Prof. A. Wolfendale at VBT.

Based on user-feedback, it is estimated that the current down-time of the telescope due to technical problems is only 11% and fast decreasing, whereas another 43% of the time is lost to weather. The observations from the VBT have led to over 25 research publications in refereed journals so far. The rate of publication has increased from an average of 1 per year during 1989-91 to 8 per year during 1994-95. In addition, 8 papers have appeared on instrumentation and about 20 reports have appeared in conference proceedings. Three Ph.D. theses have relied on the data from the VBT, and three more are in their final stages. Many more students have been using the telescope to gather data for their thesis projects.The list of publications given below is not complete. It will be appreciated if readers bring to our notice omissions if any.

Performance and Publications

The demand for observing time on the VBT is always much in excess of the time available. The telescope is typically over-subscribed by a factor of 3 to 4, especially during the trimester January-March which is the prime observing season at Kavalur. A significant fraction of the observing proposals are from other countries.

A. Journals

1990: CCD Observations in VRI bands of the galactic cluster NGC 2818 with the VBT (R. Surendiranath, N.K. Rao, R. Sagar, J.S. Nathan,K.K. Ghosh). JA&A 11, 151-166.

1992: Photopolarimetric studies of Comet Austin (U.C. Joshi,A.K. Sen, M.R. Deshpande). JA&A, 13, 267--277.

1992: VRI photometry of M67 for CCD standardization at 2.3m VBT (P.N. Bhat, K.P. Singh, T.P. Prabhu, A.K. Kembhavi). JA&A, 13, 293--305.

1993: A search for intra-night optical variability in radio quiet QSOs (Gopal-Krishna, R. Sagar, P.J. Wiita). MNRAS, 262, 693--699.

1993: Testing the mechanisms for optical micro-variability of powerful active galactic nuclei (Gopal-Krishna, R. Sagar, P.J. Wiita).BASI, 21, 441-445.

1993: UBVR polarimetry of the peculiar R CrB star V854 Centauri (N. Kameswara Rao, A.V. Raveendran). A&A, 274, 330.

1994: Dust and ionised gas in NGC 3607 (K.P. Singh, T.P. Prabhu, A.K. Kembhavi, P.N. Bhat). ApJ, 424, 638.

1994: Rapid searches for counterparts of GRB 930131 (B.V. Shaefer et al.,). ApJ, 422, L71-L75.

1994: BVRI photometry of Dipper Asterism region in M 67 (G.C. Anupama, A.K. Kembhavi, T.P. Prabhu, K.P. Singh, P.N. Bhat). A&A,103, 315-320.

1994: Mutual phenomena of the Galilean satellites: an analysis of the 1991 observations from VBO (R. Vasundhara). A&A, 281, 565--575.

1994: High speed photometry of PG 1012--029 (B.N. Ashoka, S. Seetha,T.M.K. Marar, K. Kasturirangan, U.R. Rao, J.C. Bhattacharyya). A&A, 283,455-462.

1994: SN 1993J in M81: The first two months in the optical region (T.P. Prabhu et al.: 12 authors). A&A, 265, 403-412.

1994: SAO 75669: A late type giant behind the molecular cloud MBM 12 (H.C. Bhatt, R. Sagar, A. Subramaniam, U. Gorti, T. Chandrasekhar, N.M. Ashok, S. Ragland). A&A, 289, 946-948.

1994: Embedded clusters in giant extragalactic H II regions: I.BVRH photometry (Y.D. Mayya). AJ, 108, 1276-1291.

1995: Intra-night optical variability in optically selected QSOs (Gopal-Krishna, R. Sagar, P.J. Wiita). MNRAS, 274, 701-710.

1995: Distribution of ionized gas in X-ray bright early-type galaxies (K.P. Singh, P.N. Bhat, T.P. Prabhu, A.K. Kembhavi). A&A(in press).

1995: A deep BVI photometric study of the open cluster NGC 2453 (D.C.V. Mallik, R. Sagar, A.K. Pati). A&AS, 114, 1.

1995: A photoionization model of the nebula around WC 11 star M4-18 (R. Surendiranath, N. Kameswara Rao). MNRAS 275, 685-698.

1995: Embedded clusters in giant extragalactic H II regions: III.Extinction and star formation (Y.D. Mayya, T.P. Prabhu). AJ (in press).

1995: A dust lane in the radio galaxy 3C 270 (A. Mahabal,A. Kembhavi, K.P. Singh, P.N. Bhat, T.P. Prabhu). ApJ (in press).

1995: HD 105262: A high latitude metal-poor post-AGB supergiant with large proper motion (B.E. Reddy, M. Parthasarathy, T. Sivarani).A&A (in press).

1995: Optical microvariability in radio-quiet QSOs (R. Sagar, Gopal-Krishna,P.J. Wiita) MNRAS (in press).

1995: Hα imaging of Hickson's Compact Group 62 (M. Valluri, G.C. Anupama)MNRAS (submitted).

1995: CCD photometry of IRAS sources with far-IR colours similar to planetary nebulae (B. Eswar Reddy, M. Parthasarathy) A&A (submitted).

Instrumentation

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