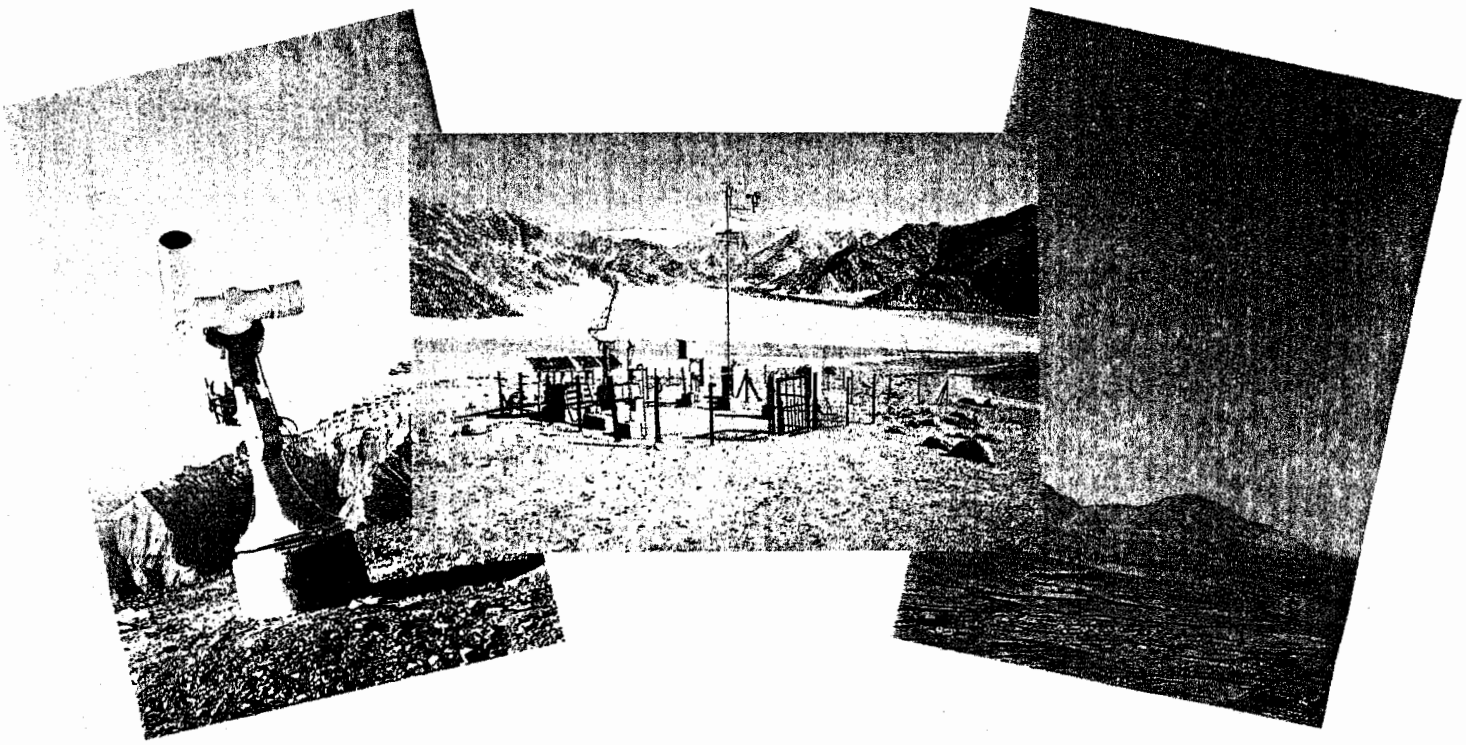
TECHNICAL REPORT ON

ASTRONOMICAL SITE SURVEY IN LEH - LADHAK (1984-1989)



Sponsored By

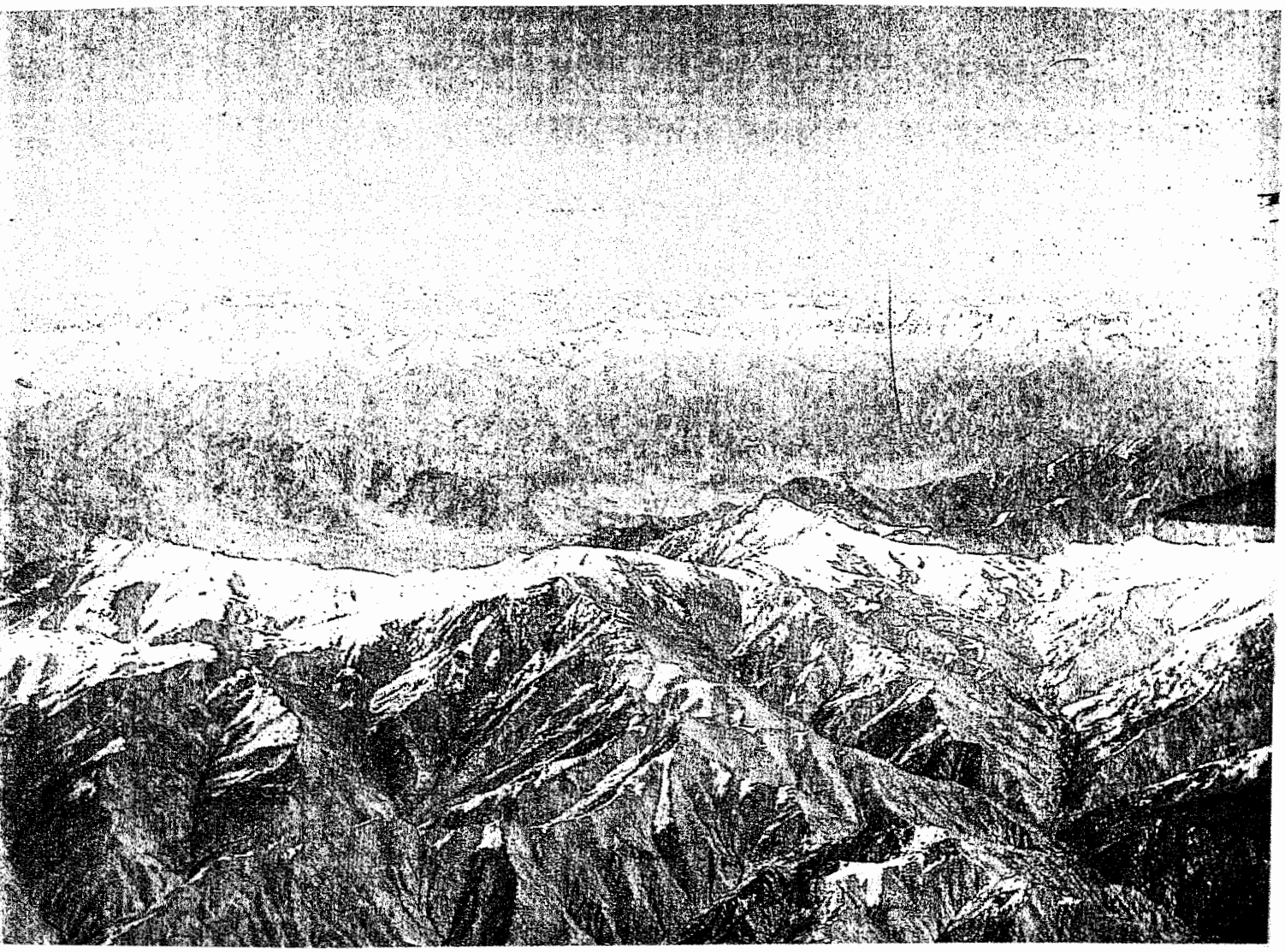
GOVERNMENT OF INDIA
MINISTRY OF SCIENCE & TECHNOLOGY
DEPARTMENT OF SCIENCE AND TECHNOLOGY
TECHNOLOGY BHAWAN
NEW DELHI 110 016

TECHNICAL REPORT ON THE DST PROJECT ASTRONOMICAL AND ATMOSPHERIC OBSERVATIONS IN LADHAK REGION WITH LONG TERM VIEW OF SETTING UP A NATIONAL HIGH ALTITUDE ASTRONOMICAL OBSERVATORY FOR INFRA -RED AND OPTICAL STUDIES. (APRIL 1984 TO OCTOBER 1989)

Compiled by
ARVIND BHATNAGAR AND S.L.GANDHI
Udaipur Solar Observatory,
Udaipur.

April 1991

Sponsored by
GOVERNMENT OF INDIA
MINISTRY OF SCIENCE & TECHNOLOGY
DEPARTMENT OF SCIENCE AND TECHNOLOGY
TECHNOLOGY BHAWAN
NEW DELHI 110 016



TO SEE INTO BEYOND REQUIRE PURITY
AS LITTLE AIR AS MAY BE AND
THAT ONLY OF THE BEST IS OBLIGATORY
TO ASTRONOMER'S ENTERPRISE
MUST ABANDON CITIES AND FORGET PLAINS
ONLY IN PLACES RAISED ABOVE AND ALOOF FROM MEN
CAN ASTRONOMER PURSUE HIS RESEARCH

- PERCIVAL LOWELL

CONTENTS

FOREWORD

Promotion of Astronomy and Astrophysics is one of the thrust areas of the Department of Science & Technology (DST). Astronomers from research institutions and Universities in the country were encouraged by DST to formulate proposals for a National High Altitude Astronomical Facility. Accordingly, leading astronomers representing the Indian Institute of Astrophysics (IIA), Tata Institute of Fundamental Research (TIFR), Physical Research Laboratory (PRL), Udaipur Solar Observatory (USO), U.P. State Observatory (UPSO), Osmania University and Punjabi University made a reconnaissance visit to Leh-Ladhak, in association with the Defence Research and Development Organisation (DRDO) in 1982. Subsequently, a multi-institutional project to pursue ASTRONOMICAL AND ATMOSPHERIC OBSERVATIONS IN LEH-LADHAK REGION WITH LONG TERM VIEW OF SETTING UP A NATIONAL HIGH ALTITUDE ASTRONOMICAL OBSERVATORY FOR INFRA-RED AND OPTICAL STUDIES was sponsored by DST in 1984. Nine DST MONITORING-CUM-REVIEW COMMITTEE meetings were periodically held to take note of the progress of the project. A Workshop was held at UPSO Nainital in April 1985, to review the adopted and mid-term correction methodology. The DST also set up a Screening Committee under the Chairmanship of Prof. G. Srinivasan for evaluation of the work and to recommend corrective measures, if any. A meeting was also held in January 1987 under the Chairmanship of Dr. Vasant Gowariker, Secretary, DST to review the progress and take appropriate advance steps for implementing the recommendations at the end of the project. Accordingly, Prof J.C. Bhattacharyya prepared a concept report for a large national high altitude IR telescope.

This is one of the first systematic astronomical site surveys conducted in the country for location of a large telescope. A medium size telescope located at a good astronomical site can be several times more productive than a large telescope at a poor site. The DST was not only able to bring several institutions to collaborate and carry out the project work under one umbrella but also get valuable logistic support from DRDO. The Indian Meteorological Department (IMD) set up a METEOROLOGICAL OBSERVATORY and DATA COLLECTION PLATFORM (DCP) for continuous monitoring of meteorological data through INSAT-IB in record time. The Indian Air Force provided invaluable help in positioning a 6-inch coude telescope on Mt. Nimmu top by a helicopter and also provided useful Meteorological Data.

The equipment, methodology and the expertise developed during this project, will be useful in future site surveys for astronomical telescopes.

Finally, I will like to place on record my deep sense of appreciation to Dr. Arvind Bhatnagar and Shri S.L. Gandhi for the complete commitment, devotion and sacrifice with which they fulfilled their contributions to this project over an extended period of five years without any thought of credit or compensation.

R.R. DANIEL
Chairman
Review-Cum-Monitoring
Committee of the Project.

ACKNOWLEDGEMENTS

This multi-institutional project of site survey in Leh-Ladhak for an Astronomical Observatory, was sponsored by the Department of Science and Technology, Government of India. It was a very ambitious and challenging project, involving large number of people with varied expertise, institutions and organisations. The scientific objectives of the project were well defined from the beginning, but the mechanism to achieve these objectives remained rather nebulous, in spite of several meetings which took place before the project began. As the project started taking shape, very serious and unexpected problems cropped up, first due to the non-availability of the 24-inch telescope from the Punjabi University, shifting of the 20-inch Bhavnagar telescope from Kavalur to Leh, transportation of the FRP 5.6 metre diameter astronomical dome before the closure of roads due to snow (1984). Acute problems arose due to lack of logistic and manpower support to operate the field station at Leh and at Mt. Nimmu base camp. Further, poor communication facilities available in Leh-Ladhak made the problem even more difficult.

In spite of tremendous problems there was always a "silver lining" in the form of enormous encouragement and help received from a large number of senior scientists of the country, especially Prof. R.R. Daniel, Sr. Professor at TIFR, Bombay, Dr. Vasant Gowariker, Secretary DST, Prof. J. C. Bhattacharyya, Director IIA, Bangalore, Dr. P. J. Lavakare, Advisor, DST, Prof. S.P. Pandya, Director PRL, Ahmedabad.

We would like to mention briefly the historical backdrop of this project. In 1981, Dr. Raja Ramanna, the then Advisor to the Raksha Mantri enthusiastically endorsed this idea of site survey and offered all possible help, through their Field Research Laboratory in Leh. He put us (A. Bhatnagar) in touch with Dr. Krishnamurthy the then Chief Controller, and Shri S. L. Gandhi the then Director of Material and Agricultural Sciences, Defence Research and Development Organisation (DRDO). Dr. V. Arunachalum, the next Advisor to R.M., displayed much more enthusiasm and unstinted support for this project. Seeing Sri Gandhi's dynamism and readiness to go out of his way to shoulder responsibility, the project scientists were highly impressed and were encouraged to embark on this project.

The Department of Science and Technology took a very keen interest in this project. Were it not for Dr. Lavakare's constant monitoring and being always readily available for any help and advise, this project would not have been completed. Dr. Lavakare along with his number of colleagues at DST, notably Drs. K. R. Gupta, Sulbha Gupta and J. K. Sharma, took keen interest and helped us out through difficult periods.

At the time of formulating the scientific programme of the project, consideration of a very important component of the project namely - logistic problems were somehow under-estimated. This was perhaps, due to the inexperience of the scientists of working in difficult logistic conditions such as in Leh-Ladhak. We thankfully acknowledge the enormous help both in the form of logistics and manpower provided by the various laboratories of DRDO, namely the Defence Agriculture Research Laboratory (DARL), Almora and the Field Research Laboratory (FRL) Leh. Shri M. C. Joshi, Director DARL, took personal interest in this project and visited the project site many times and deputed several scientists, assistants and helpers to Leh-Ladhak for taking site survey observations, when astronomers from the participating institutions were not

available. The Officer-Commanding of FRL posted from time-to-time took interest and provided valuable help. Notably Lt. Col. Rao, Lt. Col. Chinna and Major Shandal went out of their way to see that logistic problems were sorted out or at least minimized. A very significant contribution for arranging of air transportation to Leh, of the 20-inch telescope made by Lt. Col. M. S. Sanga, the then Assistant Director, Material and Agricultural sciences, DRDO can not be forgotten. The Station Commander of the Air Force base, Leh helped us in installing the 15-cm Zeiss coude telescope on Mt. Nimmu and help of Air Comm. Natrajan of the Air Head Quarters for providing cloud coverage data is acknowledged.

The enthusiasm of the then Director General of Meteorology - Shri S. K. Das for this project is worth mentioning. He along with the then DDGI, Pune Dr. Srivastava and Dr. Sreedharan, Director Instruments, I. Met. D., provided the meteorological instruments and arranged to establish a Met. Observatory in record time of less than 2 months at Mt. Nimmu Base camp in October 1984 and in 1985 the Data Collecting Platform (DCP). Number of scientists from I.Met.D., visited Leh site for checking and calibration of the instruments. The present DGM, Dr. S.M. Kulshrestha has continued giving full support and help for the project. Shri O.P.N. Calla and Shri S. S. Rana of the Space Application Centre, Ahmedabad also contributed to the project by providing a 22 GHz., radiometer for estimation of water vapour. For measuring the precipitable water vapour, a portable meter given to PRL by Prof. Westphal of Caltech, USA was used. The Department of Non-Conventional Energy Sources (DNES) got interested in this project and provided free of cost several solar photo voltaic power panels. These panels worked very satisfactorily for almost 4 years in Leh-Ladhak. The help of a local contractor - Shri T. Morup, who had taken the challenge of constructing the telescope pier on Mt. Nimmu and the rest house at the Base Camp, is acknowledged.

Last, but not the least, this project would not have started and been completed, were it not for enormous contributions made by a large number of individuals from the participating institutions, namely DRDO (FRL & DARL), IIA, Bangalore, TIFR, Bombay, PRL, Ahmedabad, UPSO, Nainital, Osmania University, Hyderabad, Punjabi University and of course USO, Udaipur. We would have liked to acknowledge and thank all the people by name who worked so hard and devotedly for several years under very harsh environmental conditions for the success of this project, but the limitation of space constrains us to do so.

A. Bhatnagar
Project Co-ordinator

Photo credit :
All colour pictures reproduced in this report were photographed by Dr. Arvind Bhatnagar, except those mentioned in the captions.

1. HISTORICAL BACKGROUND

The suggestion to look for an astronomical site in Ladhak region located more than 3,000 metres, above mean sea level was mooted in November 1981 at a meeting organized by ADCOS held under the Chairmanship of the late Prof. M. K. Vainu Bappu. At this meeting it was pointed out that the Ladhak region remains relatively clear during the monsoon period, when rest of the country experiences cloudy sky due to monsoon conditions. It was also noted that only at such high altitudes, precipitable atmospheric water vapour will be low enough for high quality infrared observations.

In a subsequent meeting on 29 April 1982, Prof. Bappu emphasised that a site survey should be undertaken to examine whether Leh-Ladhak region is as good a site as it is generally thought to be. He mentioned that "our aim should be to make such measurements and observations over a period, which will enable us to decide once for all, the quality of astronomical observations that can be made from Ladhak."

Other astronomers also had a similar view that Ladhak was likely to be a promising site for IR astronomical observations. This was partly based on the 30 years Meteorological Climatological Tables of observations from 1931 to 1960 for Leh. This table is reproduced in the Appendix giving Cloud Coverage, Rainfall, Wind and other meteorological parameters. The low rainfall and the number of clear days indicated that the site was worth a thorough investigation.

2. PRELIMINARY RECONNAISSANCE

In September 1982, a team of astronomers headed by Prof. R.R. Daniel visited Leh-Ladhak for a preliminary survey of the area. The team collected the following general information of this region:-

(a) CLOUD COVERAGE AND SKY TRANSPARENCY.

Leh-Ladhak is a Trans-Himalayan region, where generally monsoon does not reach and the annual precipitation is scanty. Also, because of the rarefied atmosphere, the sky is very dark whenever there are no clouds.

(b) AIR DRYNESS AND RESULTING WATER PRECIPITATION.

The entire area is a high altitude cold desert. The average annual rainfall as per the 30 years of climatological data is only 115 mm.

(c) WIND

The Leh valley is by and large free from gales and very high winds.

(d) NATURAL AIR POLLUTION

The dust content in the air seems to be low near Mt. Nimmu, which is about 25 km from Leh town, as there the terrain is generally gravel. However, it was pointed out that during summer months the dust from Sahara and other deserts sometimes may rise even up to 5,000-6,000 metres in the Himalayan region. Very preliminary examination indicated possibility of clarity of the sky though not as good as one would expect for an altitude of 4,000 metres. After the monsoon and snow fall the sky transparency usually improves considerably.

(e) NATURAL LIGHT POLLUTION

The 34° N latitude of Leh is not high enough to be affected by aurora borealis etc.

(f) SELECTION OF MT. NIMMU.

Leh is connected by road from Srinagar and Manali which is open during the summer months from July to October. During rest of the year, the access to Leh is only by air. The initial impression of the team was favourable. A quick survey of the region extending about 50 km, along the road on either side of Leh and inspection of possible sites in the accessible neigbourhood showed that Mt. Nimmu at a height of 4100 metres is potentially a most attractive site

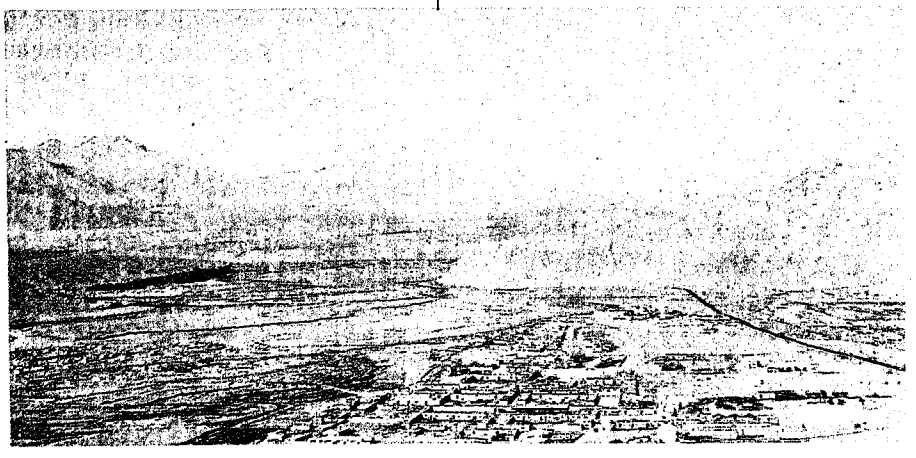


Figure 1. Panoramic view of Mt. Nimmu and surrounding region showing Leh-Srinagar highway.

due to the following considerations;

that, Mt. Nimmu is an isolated mountain peak, having no higher peak near the immediate vicinity of about 10 km radius. The top of Mt. Nimmu has a large flat area for locating number of telescopes and other facilities. The reconnaissance team went up to the top and confirmed the availability of a fairly large stretch of flat land at the top. This mountain peak is located in a long valley running east-west of more than 150 km long stretch. The shape of the peak is convex and therefore may provide laminar air flow.

(g) SEISMIC ACTIVITY OF THE REGION

Regarding the seismic activity, it is reported by WADIA INSTITUTE OF HIMALAYAN GEOLOGY that " the town of Leh lies along the Indus Suture Zone. Seismically the area has not witnessed any major seismic event in the recent past (as per published literature). The town and its surroundings, however fall in the influence of major events occurring in Pamir, Hindukush, Kinnaur and Kangra, e.g., in Kangra earthquake of 1905 it was in iso-seismal 5-6 while for Kinnaur earthquake of 1975 it lay in iso-seismal 4-5. For the Pamir and Hindukush earthquakes of 1939, it was in iso-seismal 3-4. Thus the town of Leh and surrounding lie in seismic zone of 4-5 intensity (maximum). According to Kaila and Narain (1976) the town is situated in between two seismic highs of Srinagar in the west and Kailash in the east. But their influences is also minimal. (low A value of 2 only)."

(h) ARTIFICIAL AIR AND LIGHT POLLUTION

Mt. Nimmu top is about 3 km away from Leh-Srinagar metalled highway and there appears to be hardly any danger of air pollution due to traffic and industry. The terrain near and around Mt. Nimmu is generally gravel and thus dust does not rise due to the road traffic.

Mt. Nimmu is about 25 km from the Leh town. There appears to be no danger due to artificial light pollution from the city lights as in the foreseeable future no industrialization is expected in that region. Leh has a population of about 15,000-20,000 and is situated in a valley surrounded by high mountains. Two high mountain ridges separate Leh and Mt. Nimmu. Hence the town is not directly visible from Mt. Nimmu peak.

(i) ACCESSIBILITY TO THE TOP

The road between Leh and Mt. Nimmu remains open even during winter months. Accessibility to the top did not appear to be insurmountable. The team felt that Mt. Nimmu satisfies the requirements for considerations as an astronomical observatory site.

The Department of Science & Technology took note of November 1981 ADCOS's meeting and the reconnaissance team's reports of September 1982. Subsequently, at the 1983 Ahmedabad meeting at PRL, it was decided by the scientists to formulate a multi-institutional project to pursue--

ASTRONOMICAL AND ATMOSPHERIC OBSERVATIONS IN LADHAK REGION WITH LONG TERM VIEW OF SETTING UP A NATIONAL HIGH ALTITUDE

3. SEARCH FOR OTHER POSSIBLE SITES

ASTRONOMICAL OBSERVATORY FOR INFRA-RED AND OPTICAL STUDIES.

The possibility of locating possible sites other than Mt. Nimmu in Ladhak was also explored. In 1985, a team carried out a survey of 232 km long region between Leh and Kargil and about 50 km on Leh-Manali road, to locate more suitable sites. The search was for a mountain peak, which could be made easily accessible from the Srinagar-Leh-Manali highway and has a fairly flat area on the top suitable for establishing a large observatory.

This team could not locate a site better than Mt. Nimmu in this region, because most of the prospective sites were surrounded by high mountain peaks and were quite inaccessible. The Mount Nimmu peak is easily accessible from the main highway and is only 25 km from Leh town and accessible throughout the year.

Figure 2. View of Mt. Nimmu top.

4. DST APPROVAL FOR THE PROJECT, BUDGET ETC.

This inter-institutional project of site survey for high altitude observatory in Leh-Ladhak for IR telescope, was finally formulated in February 1984, after several meetings and a workshop held in 1982, 1983 and in early 1984, of scientists from the participating institutions. The project was approved by DST in May 1984 and funds were released in August 1984. As this was an inter-institutional project, specific tasks required for implementation of the project were assigned to the various participating institutions and accordingly the necessary funds were made available to each of the eight institutions. The original and revised sanction of the budget by DST is given below :

	Institution	Original	Revised
		(Rupees in lahks)	
1.	Defence Research & Deve. Orgn.	11.02	11.52
2.	Udaipur Solar Observatory	7.77	12.54
3.	Physical Research Laboratory	0.98	0.60
4.	Tata Institute of Fundamental Res.	4.03	3.50
5.	Indian Institute of Astrophysics	4.54	4.80
6.	Punjabi University	0.35	0.27
7.	U.P. State Observatory	0.29	2.02
8.	Osmania University	0.61	0.45
	Total	29.59	35.70

As the project started taking shape, number of unforeseen problems cropped up. For example, it was proposed that the 60-cm Zeiss telescope of the Punjabi University, Patiala would be made available for the project for astronomical observations from Leh-Ladhak, but unfortunately this telescope was not available. Hence, an alternate solution was sought by making use of a very old 50-cm Bhavnagar telescope of IIA. It was a major problem to transport this heavy telescope by air from Bangalore to Leh and to reach there before August/September 1984. It was through the untiring efforts of Major M.S. Sanga and Mr. S.L. Gandhi, with the help of the Indian Air Force, that the telescope could be air lifted and positioned in October 1984 at Skara-Leh. The 5.6 metre diameter FRP astronomical dome could not be transported before the roads were closed in October 1984. Hence, the telescope had to be kept in a round 6-feet high wall enclosure for nearly 1 year without a proper dome. However, telescope was protected from rain and snow with the help of a FRP canopy, which had to be removed for taking observations. Due to the logistic difficulties, it was very difficult to make even minor alterations and repairs required for the telescope. It was due to the ingenuity and wide experience of the IIA workshop team, that the 50-cm telescope could be installed within 2-3 months. Although, a site near the base of Mt. Nimmu was selected for installation of the 50-cm telescope by a team of scientists in July 1984. But in view of the operational difficulties it was decided to keep the telescope at Skara-Leh near the DST-Laboratory-cum-guest house site For visiting scientists, observers and laboratory, a spacious house with 8 rooms was rented near the Field Research Laboratory in village Skara-Leh, which served as a Laboratory-cum-guest house.

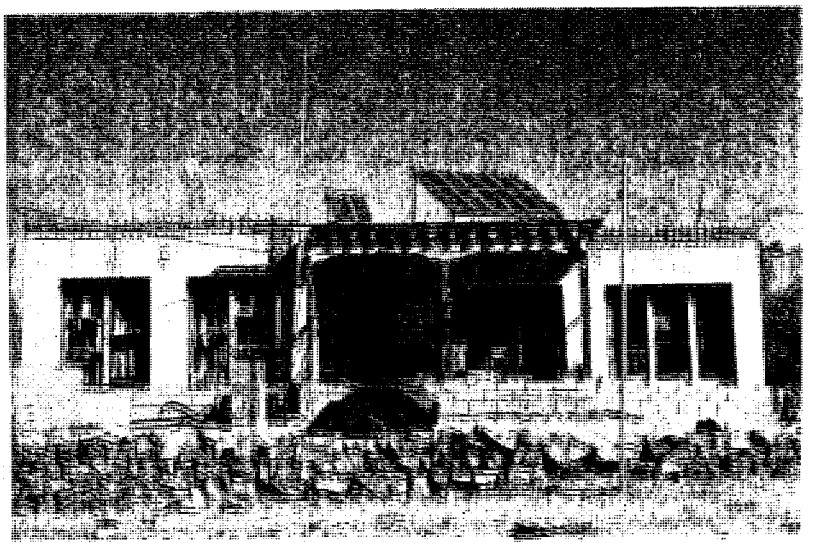


Figure 3. Base Laboratory-cum-Guest hostel at Skara-Leh site.

The project faced a major crisis in October 1984 when the Field Research Laboratory (FRL) of DRDO, declined to operate the grant and provide the necessary infrastructure support. At this stage the project had already "taken-off," a nice house for the laboratory-cum-guest house was rented, major instruments were positioned or were in the process of installation. Hence, this responsibility of running the station and to provide infrastructure support etc., was given to the Udaipur Solar Observatory and to the Project Coordinator.

On the manpower front, it was proposed in the project proposal that observers and scientists would be drawn from the participating astronomical institutions, who would stay at Leh for a period of 2 months and also take observations required for the site survey along with the 50-cm telescope. Hence, in the proposal, no provision was made for salaries of the project personnel. But in actual practice, no observers or scientists volunteered to stay at Leh-Ladhak for a period of 2 months. A search was made for suitable person or persons who had astronomical background and managerial capability to man the station. In November 1984, in view of the logistic difficulties, it was decided

to appoint an observer and a manager from the local population on temporary basis, until some better arrangement could be made. Mr. Arvind Paranjpye from IIA, volunteered to stay at Leh for this project, but it was a major work for a single hand, hence a request was made, through Shri S.L. Gandhi to Shri M.C. Joshi, Director, Defence Agriculture Research Laboratory (DARL) Almora, to provide, 3 or 4 qualified scientific assistants for taking site survey observations and man the station. The Director, DARL indeed continuously provided scientific personnel and helpers for smooth running of the station. It may be mentioned that the astronomers for whom the efforts were being made, were most reluctant to stay at Leh-Ladhak for taking observations for the site-survey. Due to the logistic difficulties especially manpower and infrastructure problems, the site survey data obtained from November 1984 through August 1986, had large gaps. Some of the essential instruments, such as the Double Beam Telescope for seeing measurements and the Micro-thermal Tower and the mule track upto Mount Nimmu top were not available until mid 1986, therefore the project had to be extended by 2 years. In view of the possible delay in designing and fabrication of the Double Beam Telescope, it was decided in November 1985 to acquire a 15-cm aperture coude telescope from Zeiss, for "seeing" measurement using the polar trail method. This telescope was obtained on very high priority basis from Carl Zeiss, Jena, in April 1986. It was tested and arrangement for polar trail photography was made at Udaipur in May 1986 and transported to Leh-Ladhak in August 1986, when the road opened. The telescope was installed on Mt. Nimmu in September 1986, with the help of Air Force helicopters. The micro-thermal tower was installed in August 1986 and the meteorological instruments in September 1985, on top of Mt. Nimmu. Among the major difficulties in operating in Leh-Ladhak region is that the effective operating period for transportation of heavy equipment and building construction etc., is confined only to 4/5 months from July through November, out of the 12 months. If certain tasks could not be accomplished during the summer months, then they have to be postponed for the next year. Hence, this project was delayed by nearly 2 years, beyond that envisaged. After trying various possibilities to solve the manpower problem it was decided in early 1986, that regular observers (scientific assistants) and helpers should be employed for this DST project, who would be 100% responsible for site survey data collection and data analysis. Hence from June 1986 until the end of project, 3 scientific assistants for taking observations to be stationed at Leh-Ladhak and 2 scientific assistants for data analysis were employed by DARL, Almora and UPSO Nainital respectively. For liaison with DRDO, DARL, FRL, DST and management of the project, the services of Shri S.L. Gandhi, as an Honorary Project Officer was obtained.

5. PARAMETERS FOR SITE SURVEY

For any ground based major astronomical observatory, the site of the telescope is an extremely important parameter in view of the efficiency, quality and quantity of observations. A medium sized telescope located at a good astronomical site can be several times more productive than a large telescope at a poor site. The characteristics of site parameters are dictated by the type of astronomical observations being planned. In recent times, all over the world, number of extensive site surveys are being carried out to look for promising observatory sites for optical, Infrared, milli-meter and sub-millimeter wave astronomies. During the last three decades interest in Infrared wavelengths has grown to such an extent that most major observatory site surveys give high priority to Infrared (IR) observations. To qualify as a good site for IR work, it is essential that the precipitable water vapour (PWV) above the site (under clear sky conditions) should be around 1-2 mm for a good fraction of time. The amount of water vapour above a site depends in a complex way on the atmospheric stratification and global circulation pattern. However, logic and abundant evidence indicate that the first order effect is dependent on the elevation and to some extent on the latitude of the site. It has been observed that PWV decreases with increasing latitude.

In Figure 4 is shown the infrared absorption bands due to the atmospheric gases (O_2, H_2O, CO_2, CH_4, N_2O, O_3). It will be noticed that the major absorbing constituent is the water vapour in 5-7 micron and 18-100 micron spectral bands. Other terrestrial gases also significantly contribute. Thus by proper choice of the site, where the precipitable water vapour is minimum, it is possible to observe faint stellar sources in these IR and sub-millimeter spectral windows.

It is generally accepted that site parameters of purely atmospheric nature are:-

(i) cloud coverage,
(ii) air dryness and precipitation,
(iii) atmospheric turbulence (seeing)
(iv) sky brightness
(v) extinction, and
(vi) wind speed and direction.

Parameters linked essentially with location are:-

(i) altitude above the atmospheric inversion layer,
(ii) topography of the site,

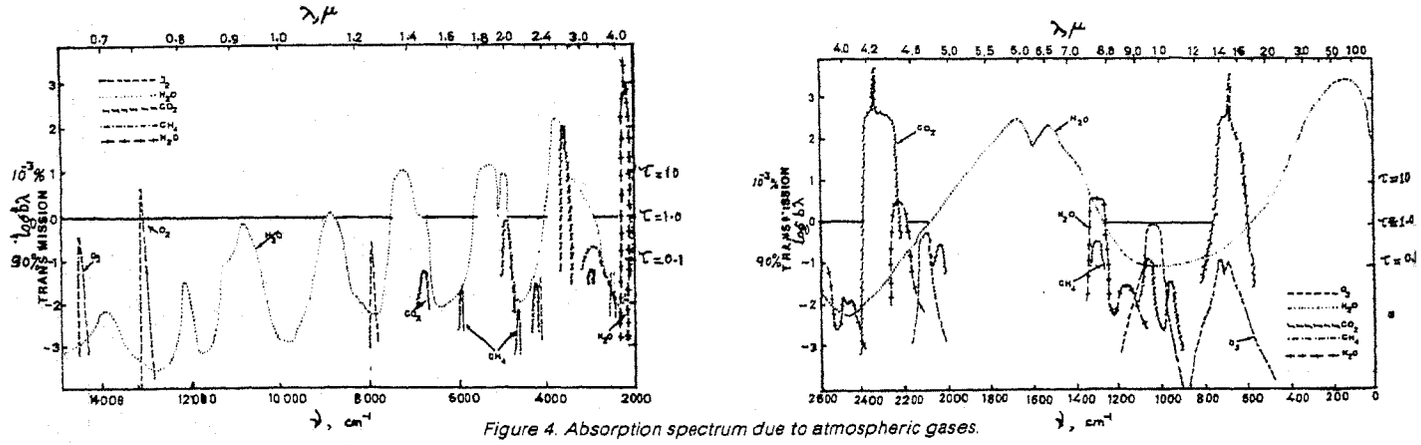


Figure 4. Absorption spectrum due to atmospheric gases.

6. SPECIAL INSTRUMENTS AND SOFTWARE DEVELOPED FOR SITE SURVEY AND EQUIPMENT USED

(iii) temperature stability,
(iv) air pollution,
(v) light pollution, and
(vi) seismic activity.

Parameters connected with human created sources of interferences are:-

(i) artificial light pollution,and
(ii) artificial air pollution.

Parameters connected with actual operations are:-

(i) convenience of location,
(ii) availability of water, electricity and essential food supplies,
(iii) general accessibility of station to ensure maintenance of equipment etc., and
(iv) access by air and road.

For astronomical site surveys, major instruments required are for meteorological and astronomical observations. The meteorological instruments are generally of standard design and are readily available and were provided by the Indian Meteorological Department, while for the astronomical observations the necessary equipment had to be designed, fabricated or acquired and modified for the required data. TIFR, USO, PRL and IIA groups made significant contributions in designing and fabrication of the necessary equipment. In the following is given a brief description of the various equipment developed for this site survey programme.

The Tata Institute of Fundamental Research (TIFR) built an ALL SKY CAMERA using a 180 degree Fish-eye lens attached to a 35 mm camera back, to photographically record the cloud coverage during night time for checking visual estimates made by observers.

The Udaipur Solar Observatory (USO) group also designed and fabricated a simple and inexpensive All Sky Camera using an aluminized convex mirror and a 35 mm camera. This group also developed an optical arrangement using 15-cm aperture Zeiss coude telescope, for polar trail photography and software for analysis of voluminous meteorological data. USO designed and fabricated an insulated light weight hut for observers at Mt. Nimmu top, making use of the natural solar heating.

For measuring the star motion resulting from turbulence in the atmosphere a double beam telescope was constructed for this project by the TIFR group. This group also fabricated microthermal sensors and a 12-metre high tower for measuring the temperature fluctuations of air above the ground at three heights (3.6, 7.2 and 12 metres).

Figure 5. All Sky Camera using aluminized convex mirror and 35 mm camera back.

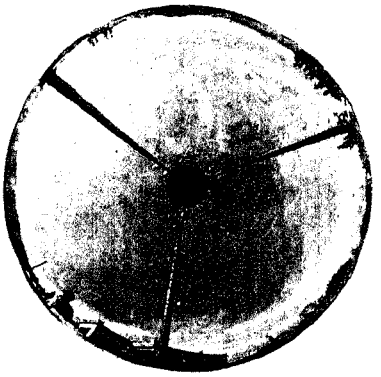


Figure 6. 360-degree daytime exposure of cloud coverage obtained using convex mirror all sky camera.

CLIMATOLOGICAL TABLE

STATION : Leh LAT. 34 09' N. LONG. 77 34' E. HEIGHT ABOVE M.S.L. 3514 METRES BASED ON OBSERVATIONS FROM 1931 TO 1960

MONTH	STATION LEVEL PRESSURE	AIR TEMPERATURE MEAN (OF) DRY BULB	WET BULB	DAILY MAX.	DAILY MIN.	HIGHEST IN THE MONTH	LOWEST IN THE MONTH	EXTREMES HIGHEST	DATE AND YEAR	LOWEST	DATE AND YEAR	HUMIDITY RELATIVE HUMIDITY	VAPOUR PRESSUR	CLOUD AMOUNT ALL CLOUDS	LOW CLOUDS	RAINFALL MONTHLY TOTAL	RAINY DAYS	TOTAL IN WITH YEAR	TOTAL IN WETTEST WITH YEAR	DRIEST 24 HOURS	HEAVIEST AND YEAR	MEAN WIND SPEED
	mb	C	C	C	C	C	C	C		C		%	mb	Oktas of sky		mm		mm	mm	mm		km p h
JANUARY I	665.0	-11.2	-13.0	-2.8	-14.0	3.2	-19.0	8.3	29	-28.3	11	61	1.5	5.2	1.4	11.8	1.4	41.4	0	24.4	28	3.4
II	663.9	-5.6	-7.9						1916		1899	51	2.1	4.5	1.3			1893			1893	
FEBRUARY I	664.6	-8.7	-10.4	0.8	-11.8	6.5	-16.8	12.8	28	-25.6	2	59	1.9	4.8	1.4	8.6	1.1	42.2	0	16.8	25	3.8
II	662.7	-1.3	-4.7						1953		1943	46	2.3	4.6	1.1			1896			1903	
MARCH I	665.5	-2.4	-5.9	6.4	-6.3	12.5	-12.0	19.4	29	-19.4	8	55	2.7	4.5	1.2	11.9	1.5	38.6	0	16.0	2	5.3
II	663.0	4.3	-0.7						1908		1903	43	3.3	5.1	1.4			1903			1930	
APRIL I	667.4	3.8	-0.4	12.4	-1.2	17.3	-5.2	23.9	29	-12.8	2	50	3.9	3.7	0.8	6.5	0.8	32.0	0	22.1	14	6.7
II	664.6	9.2	2.4						1941		1903	32	3.3	4.9	1.4			1896			1896	
MAY I	667.6	8.8	2.6	17.1	2.8	21.8	-0.9	28.9	23	-4.4	16	39	4.2	3.4	1.0	6.5	0.7	68.6	0	22.3	14	6.8
II	664.0	13.6	5.3						1893		1886	27	4.1	4.7	1.6			1897			1951	
JUNE I	665.8	12.6	5.6	21.1	6.7	27.0	2.4	33.9	9	-1.1	4	39	5.6	3.1	0.9	4.3	0.5	28.7	0	19.6	30	6.5
II	662.3	18.5	8.1						1882		1886	24	5.1	3.5	1.2			1894			1955	
JULY I	664.6	15.9	9.4	24.7	10.2	29.8	5.8	33.3	9	0.6	8	49	8.5	3.7	1.3	15.7	1.9	75.4	0	25.6	28	5.2
II	661.6	21.7	11.7						1883		1929	34	7.8	3.7	1.4			1948			1882	
AUGUST I	665.2	14.8	9.3	24.2	9.6	28.6	5.9	32.2	2	2.8	25	54	8.9	4.2	1.2	19.5	2.3	111.5	0	51.3	22	4.8
II	661.6	21.3	12.2						1946		1941	36	7.9	4.1	1.5			1933			1933	
SEPT- I	667.3	10.6	4.9	20.9	5.4	24.4	0.9	30.6	4	-4.4	30	47	5.8	2.9	0.9	12.2	1.4	68.6	0	25.9	19	4.6
EMBER II	663.7	18.6	9.5						1883		1940	32	6.3	2.8	1.1			1893			1893	
OCTOBER I	669.5	4.3	-0.6	14.2	-0.9	19.7	-5.3	25.6	2	-7.8	30	45	3.5	2.1	0.5	7.1	0.5	88.4	0	39.1	5	5.0
II	665.8	10.7	3.2						1916		1923	28	3.4	2.5	0.8			1955			1955	
NOVEMBER I	668.6	-3.2	-6.0	7.8	-6.6	12.5	-10.5	20.0	1	-13.9	29	45	2.3	2.6	0.5	2.9	0.4	16.2	0	16.2	4	5.0
II	666.1	4.3	-1.0						1929		1934	34	2.7	3.1	0.5			1959			1959	
DECEMBER I	666.9	-8.1	-10.5	1.6	-11.1	6.7	-16.2	10.8	3	-25.6	25	54	1.7	4.4	0.9	8.0	1.0	35.3	0	15.2	23	3.8
II	665.1	-1.6	-4.3						1891		1937	42	2.2	4.2	1.1			1944			1944	
ANNUAL I TOTAL OR	666.5	3.1	-1.3	12.5	-1.4	30.0	-20.8	33.9		-28.3		50	4.2	3.7	1.0	115.0	13.3	231.1	25.4	51.3		5.1
MEAN II	663.7	9.5	2.8									36	4.2	3.9	1.2			1894	1889			
NUMBER I	30	30	30	30	30	30	30	80		80		30	30	30	20	30	30	80	80	80		30
OF YEARS II	10	10	10									10	10	10	10							

CLIMATOLOGICAL TABLE

STATION : Mt. Nimmu top (Leh) LAT. 34 09' N. LONG. 77 54' E. HEIGHT ABOVE M.S.L. 4070 METRES BASED ON OBSERVATIONS FROM OCTOBER 1986 TO OCTOBER 1988

MONTH	STATION LEVEL PRESSURE	AIR TEMPERATURE MEAN (OF) DRY BULB	WET BULB	DAILY MAX.	DAILY MIN.	HIGHEST IN THE MONTH	LOWEST IN THE MONTH	EXTREMES HIGHEST	DATE AND YEAR	LOWEST	DATE AND YEAR	HUMIDITY RELATIVE HUMIDITY	VAPOUR PRESSUR	CLOUD AMOUNT ALL CLOUDS	LOW CLOUDS	RAINFALL MONTHLY TOTAL	RAINY DAYS	TOTAL IN WITH YEAR	TOTAL IN WETTEST WITH YEAR	DRIEST 24 HOURS	HEAVIEST AND YEAR	MEAN WIND SPEED
	mb	C	C	C	C	C	C	C		C		%	mb	Oktas of sky		mm		mm	mm	mm		km p h
JANUARY I				-9.1	-15.7	-3.8	-22.5	-2.5	27	-28.0	9			4.6								10.0
II									1987		1987											
FEBRUARY I				4.9	-11.2	-3.3	-12.8	2.0	23	-13.5	17			5.3								15.0
II									1987		1987											
MARCH I				-3.2	-10.5	3.0	-15.0	6.5	28	-18.0	27			5.4								13.9
II									1987		1988											
APRIL I				4.9	-2.8	11.3	-7.3	14.0	29	-7.5	1			4.5								21.7
II									1988		1988											
MAY I				8.6	0.7	15.0	-4.0	17.0	30	-4.0	10			4.9								22.0
II									1988		1987											
JUNE I				12.5	4.8	21.0	0.0	24.5	26	-0.5	9			3.9								24.8
II									1988		1987											
JULY I				18.4	8.7	24.8	4.0	25.0	23	2.0	16			4.7								25.5
II									1987		1987											
AUGUST I				18.3	9.2	24.0	4.8	25.5	14	4.5	25			4.8								26.3
II									1988		1988											
SEPT- I				14.8	5.2	21.0	-2.5	21.5	5	-2.5	28			3.3								25.5
EMBER II									1987		1987											
OCTOBER I				6.4	-2.6	12.5	-6.8	15.0	6	-8.5	31			3.0								16.1
II									1987		1987											
NOVEMBER I				1.1	-6.6	6.0	-11.3	8.5	2	-12.5	28			2.4								15.4
II									1986		1986											
DECEMBER I				-5.6	-12.1	1.3	-19.3	3.5	6	-24.0	23			4.2								11.1
II									1986		1986											
ANNUAL I TOTAL OR MEAN II				5.2	-2.7	24.8	-22.5	25.5		-28.0				4.3								18.9
NUMBER I OF YEARS II																						