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Review Article

Science at High-Altitude Sites of ARIES – Astrophysics and Atmospheric Sciences

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In this article we discuss various frontline research activities those are being carried out in the fields of Astronomy and Astrophysics and Atmospheric Sciences at Aryabhatta Research Institute of Observational Sciences (ARIES) using the existing and upcoming observational facilities at two high latitude sites - Manora Peak and Devasthal. Both sites are located at Devabhumi of Nainital District, Uttarakhand in the central Himalayas. The important results obtained from these research activities are highlighted and upcoming international observational facilities in the institute are discussed.

Key Words: High altitude site; Astronomy and Astrophysics; Galactic and Extragalactic Astronomy; Atmospheric Science; Trace gases and Aerosols; Solar Physics; Ozone

Introduction

The Aryabhatta Research Institute of Observational Sciences (acronym ARIES) was founded on March 22, 2004 when a 50 year old State Observatory (well known as Uttar Pradesh State Observatory (UPSO) till the creation of Uttarakhand State on November 9, 2000) was converted in to an autonomous research institution under the Department of Science and Technology, Government of India. A detailed historical account of this event has been given by Sagar (2006). The UPSO came into existence on April 20, 1954 in the holy city of Varanasi (Uttar Pradesh) on the initiative of two visionaries, namely Dr. Sampurnanand, himself a Sanskrit scholar, the then education minister and later chief minister of Uttar Pradesh state and Dr. Awadesh Narayan Singh, an eminent professor of mathematics at Lucknow University. Dr. A. N. Singh was the first person to provide the leadership to UPSO in an honorary capacity. After the premature death of Dr. Singh, Dr. M.K.V. Bappu, a young and enthusiastic astronomer with a PhD from Harvard, USA took the responsibility of putting the institute on a sound footing during the period 1955-60. It was he who initiated the process of relocating the observatory from the dust and haze of theVaransi plains to clear blue sky of Nainital in 1955 and then in 1961 to its current location of Manora Peak (longitude 79°27’25.5" E, latitude 29°21’39.0" N, altitude 1951 m, Fig. 1), about 10 km from Nainital by road. The observatory with a gravity driven 25-cm, f/15 Cooke refractor telescope (Fig. 2) started photoelectric photometry of stars and comets in 1955 and thereby began,for the first time professionally in India the study of celestial objects (other than the Sun) .

From the International Geophysical Year (1957-58) for about two decades, the institute UPSO was the only center in India (amongst 12 centers globally)

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Fig. 1: The Google Earth image showing the infrastructure on top of Manora Peak

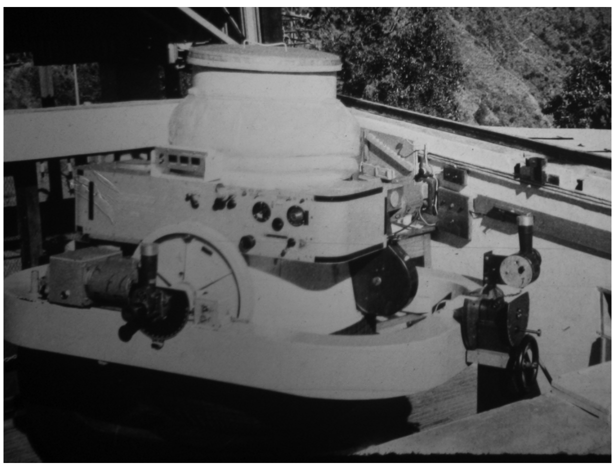


Fig. 2: Cooke refractor telescope

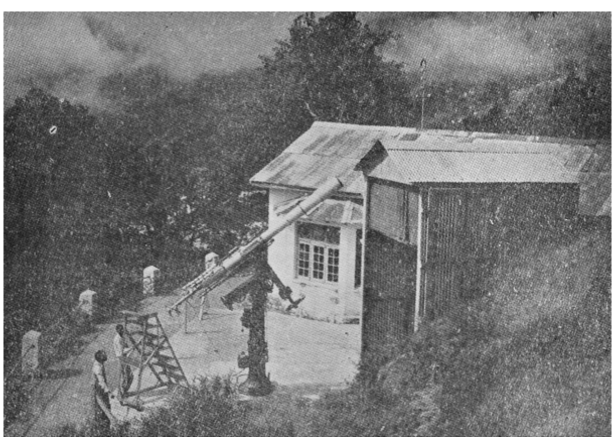


Fig. 3: Baker-Nunn Satellite tracking camera

for optical tracking of artificial satellites. The tracking of the satellites were carried out using a 79/51-cm f/1 Baker-Nunn Satellite tracking Camera (Fig. 3) and a precision timing system capable of recording up to ten millionth part of a second. This program was taken up in collaboration with the Smithsonian Astrophysical Observatory, USA with the aim to photograph the artificial Earth satellites against the starry sky background so as to determine the shape and size of the Earth, intercontinental distances, the nature and extent of the Earth's atmosphere, its magnetic field and meteorological observations, etc.

During 1960-82, the institute was led by Dr. S. D. Sinvhal who happened to be the first permanent employee of the UPSO joined in 1954. Under his directorship, many more large size optical telescopes were acquired, support facilities were set up and back-end astronomical instruments were developed indigenously at the institute (Sagar 2006). In 1972, a modern 104-cm reflector (known as Sampurnanand telescope) was supplied and installed by Ms/ Carl Zeiss, Jena. It has equatorial English mounting with f/13 Cassegrain and f/31 Coude foci. This telescope is still being used as the main observing facility of the institute.

Dr. M.C. Pande, an eminent Solar Physicist nurtured the institution as Director during 1983-1995. Prof. Ram Sagar, took over charge of the institution in 1996 and continued till January 2014. During this period and about 50 years after its founding, the observatory was converted into an autonomous institute under DST, Government of India, devoted to scientific research in the frontier areas of astrophysics and atmospheric sciences. The institute was given the name: Aryabhatta Research Institute of Observational Sciences as a tribute to one of the greatest ancient Indian astronomers, who was the first to state that the Earth goes round the Sun. The Institute's acronym, ARIES, incidentally also signifies the zodiacal sign of the Sun at its two historically significant epochs separated by half a century. First one is the birth of the organization on April 20th, 1954 by the Uttar Pradesh State Government and the second one is the taking over of the institute by the Government of India on March 22nd, 2004. Thus, the new name ARIES augurs well with its present mandate.

Manora Peak - the First High Altitude Observatory in Northern India

The transparent and blue skies of Manora Peak were the primary reasons for the choice of the location. There are three essential factors to make a ground based astrophysical observatory truly the best. They are (a) location of the observatory site must offer dark skies, dry and steady air, (b) optical excellence of the telescope and (c) mechanical quality of the telescope structure. It is the mixture of gases, dust, water vapour and other suspended particles in the Earth's atmosphere which impact the ability of a telescope to receive light and to clearly resolve images of celestial objects as they are constantly in motion. Major part of the electromagnetic radiation incident on the upper part of the Earth's atmosphere does not reach the ground but gets absorbed and scattered in the Earth's atmosphere which is transparent only to radio and optical windows. The optical window includes the entire visible region (390 nm 780 nm) plus the near ultraviolet, near infrared and some far infrared wavebands.

Variations in density of the Earth atmosphere along the path of light coming from a celestial object cause intensity fluctuations. The fast variations (on time scales of few tens of milliseconds) in the refractive index of a cell of air above a telescope will alter the apparent position of an object, normally over a range of a few arc seconds. This effect makes a point source appear smeared. Stars twinkle because of this effect, i.e., their light gets smeared across a seeing disc of a few arc seconds in diameter. The seeing at any location depends upon many factors like changes due to temperature, weather, pollutants and local micro-climate, etc. In the Earth's atmosphere, most of these activities are taking place below an altitude of 2 km. All the world's best performing optical telescopes are, therefore, located at altitudes generally >2 km, e.g., Mauna Kea in Hawaii, the Atacama desert-regions of the Chilean Andes and the Canary islands in the Atlantic Ocean. In this article, we present the development of two such Indian sites namely Manora Peak and Devasthal. Both sites are located at Devabhumi, Nainital, Uttarakhand in the central Himalayan region. In following sections, observational facilities available at Manora Peak site in the field of astronomical and atmospheric science are presented along with research activities being carried out with them. Emergence of Devasthal from a potential site to an observatory is also discussed subsequently.

Research Profile and Observational Facilities of ARIES

The main research areas of the institute include Atmospheric science and Astrophysics. Below we give an overview of those key research activities that are being pursued by the scientists in ARIES along with information about existing and upcoming observational facilities.

Atmospheric Science

It is well known that lower part (< 2 km) of the Earth atmosphere is directly and immediately influenced by human perturbations in the nature, e.g., anthropogenic emissions. Increasing levels of these emitted air pollutants (gases and aerosols), which are also radiative and chemically active, are of major concern for climate/weather changes and deteriorating air quality on the Earth. Although emissions of many air pollutants are either decreasing or almost constant over Europe and North America but levels of these pollutants are showing an increase over the rapidly developing and industrializing countries of Asia. Additionally, increasing anthropogenic sources together with the natural factors like higher solar radiation and large amount of water vapour (about 80% of the global budget) are making tropical Asian regions photo-chemically most active and important to study physical processes in the lower part of the Earth's atmosphere.

Observations related to meteorology at Manora Peak were initiated in 1963. However, the atmospheric research group at ARIES was formally established only in year 2002 with a humble beginning of aerosols optical depths observations. Considering the geographical importance of this high altitude site in the central Himalayas, observations of aerosols number concentrations, black carbon and radiation were initiated and an automatic weather station (AWS) was established in year 2002. Later trace gas observations were also initiated in 2006. Few observations are also being carried out at Devasthal, Pantnagar and Dehradun. Observations at Pantnagar and Dehradun are being carried out in collaboration with groups at G. B. Pant University of Agriculture and Technology, Pantnagar and Indian Institute of Remote Sensing, Dehardun respectively. In brief, research activities in atmospheric science group at ARIES are largely oriented towards better understanding of complex processes (physical, chemical and dynamical) which are governing lower part of the Earth's atmosphere. Some of these are being discussed here. Brief information about observational site, general meteorology, instruments and few upcoming facilities is also provided.

Observation Site and General Meteorology

As mentioned earlier, the site is located on a mountain top called Manora Peak (29°.37 N, 79°.45 E, 1951 m amsl) in Nainital. Sharply peaking mountains are located to the north and east of the observation site (Fig. 4). Mountains with altitudes < 1000 m are located to the south and west. The main town of Nainital is about 2 km line of sight away from the observational site. There is no industry in Nainital and the population is about 0.4 million. The nearby cities of Haldwani (423 m amsl) and Rudrapur (209 m amsl), which are 20-40 km from this site, have some small-scale industries and are located to the south, and the nearest major city, Delhi, is about 225 km away to the west.

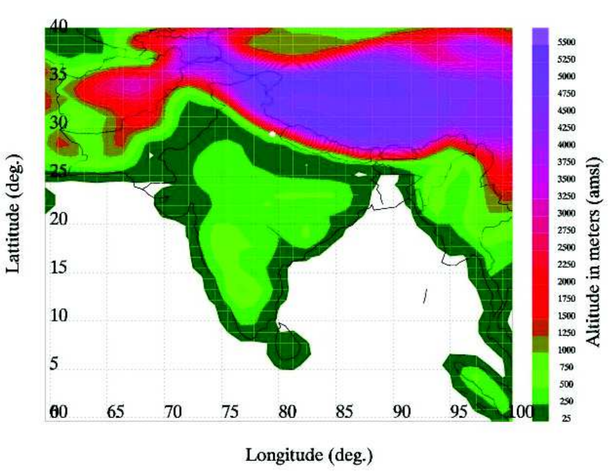


Fig. 4: Map showing the topography over the Indian Subcontinent. The location of Nainital is also Shown by the Circle

General winds prevailing during winter (January), late spring (May), summer/monsoon (June) and early autumn (September) are shown in Fig. 5, utilizing backward air mass trajectory. Generally, the wind pattern is westerly/north westerly in winter and it changes gradually to south westerly during June-July, while in May and September, air masses circulate mostly over the Northern Indian region. The trajectory patterns change again from south westerly to westerly/north westerly during October-November (not shown), which continue till March-April. Such changes in wind pattern are observed every year. It can be noted that air masses at this site do not arrive from north-eastern sector in any season because of high altitude mountains in that direction.

Instruments for Meteorology

As mentioned earlier, historically, surface based observations of meteorology parameters were initiated in July 1963 itself. Manual observations of rainfall, relative humidity and temperature were initiated during that period. Later observations of winds, sunshine hours and pressure were also initiated. Fig. 6 shows historical instruments for

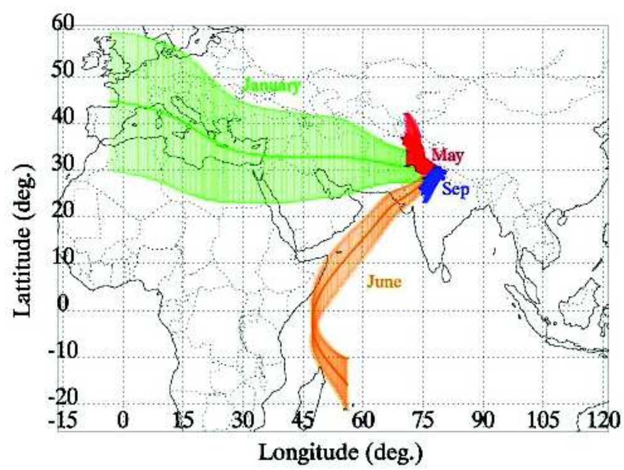


Fig. 5: Classifications of air masses arriving over central Himalayan region with display of westerly winds during winter (January) and south westerly during summer/monsoon (June). Late spring (May) and early autumn (September) are transition periods and winds are mostly circulated over the Indian subcontinent. These average patterns of trajectories are determined using each day trajectories (10 days backward) in respective months (Kumar *et al*., 2010)

Fig. 6: Historical instruments for recording sunshine hours and pressure, those are operational at ARIES

sunshine hours and pressure, based on strip/ chart recorder those were operational till recently at ARIES. Now, apart from manual observations, automatic weather station (Fig. 7) has also been setup for the observations of all meteorological parameters with a time resolution of 15-30 minutes.

Instruments for Aerosols

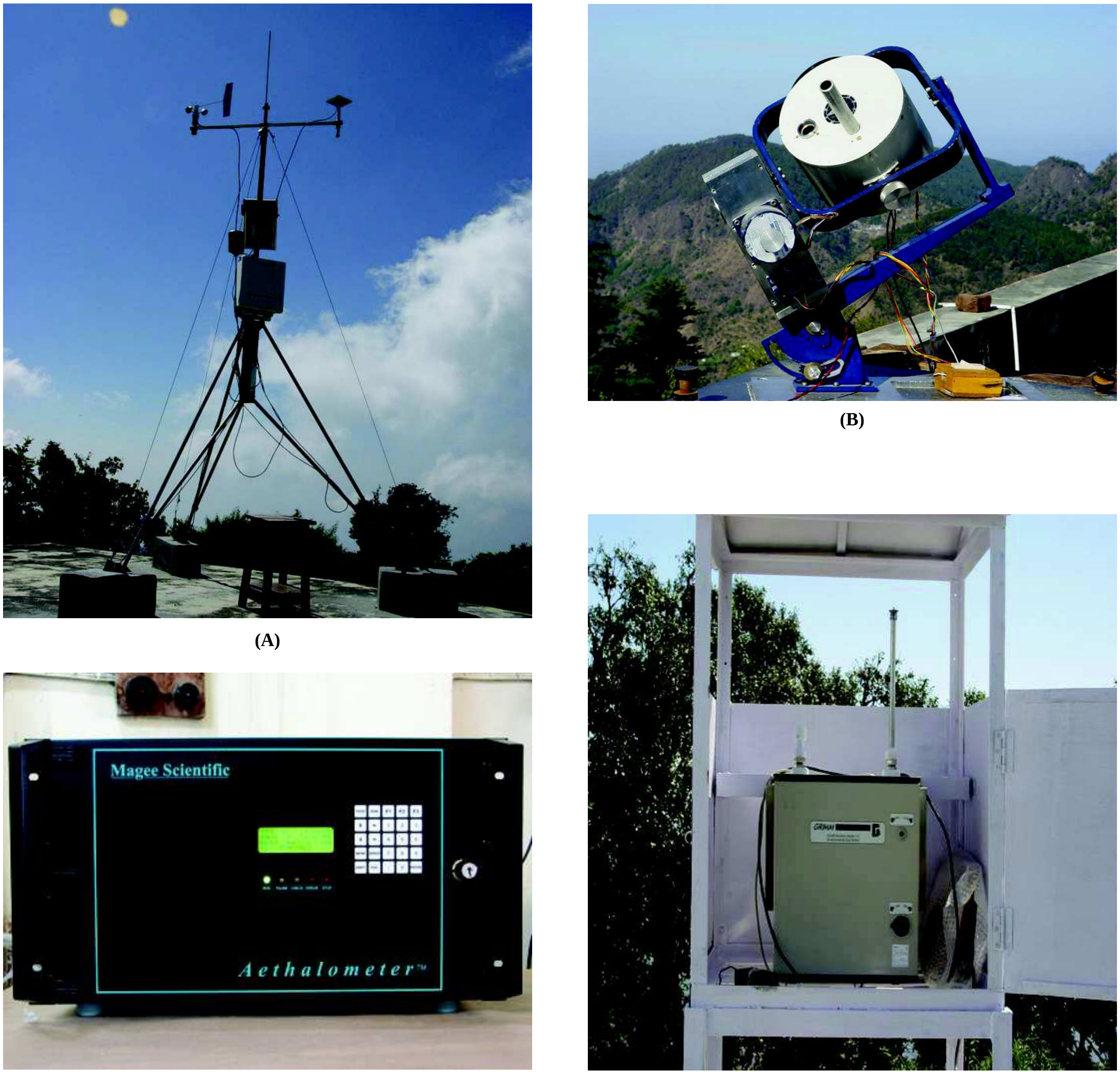
Both Multi-Wavelength solar Radiometer (MWR) (Fig. 7) and hand held Micro-tops, measure ground reaching solar flux at narrow wavelength bands in visible and near IR regions. They are used for monitoring of aerosol optical depth. The optical particle counter (GRIMM) employed for the observation of aerosol number concentrations operates on the principle of counting particles optically, by detecting the pulse of radiation scattered at 90 degree by individual particles in the sampling flow. BC mass concentrations are measured at 7 wavelengths (0.37, 0.47, 0.52, 0.59, 0.66, 0.88 and 0.95 µm) using an aethalometer, which measures attenuation of light beam at all wavelengths, transmitted through the aerosol sample continuously deposited on a quartz filter tape. Now ARIES is in the process of setting up many other instruments for observations of aerosols.

Instruments for Trace Gases

Continuous observations of surface ozone are made since October 2006. Earlier, these observations were initiated using an ozone analyzer from Environment S.A., France (Model O3 41 M), later this instrument was replaced with an instrument from TECO, U.S.A (Model 49 i). Both of these instruments are based on the well-known technique of UV absorption. The instrument aspirates the air from a height of about 5 m above the ground level through a teflon tube with a flow rate of about 1 liter per minute. The minimum detection limit of both instruments is about 1 ppbv and the response time of these systems are 10-20 seconds.

Continuous measurements of carbon monoxide (CO) are being made using an online analyser based on gas filter correlation (GFC) technique. NO-NOy (NOy - NO, NOx, PAN, N_2O_5, HNO_3, etc.) analyser uses chemiluminescence reaction of nitrogen oxide (NO) with ozone (O_3) to provide continuous observation of nitrogen oxides. NOy is measured by converting it into NO by an external molybdenum converter heated to about 325° C. Sulphur di-oxide analyser operates on pulsed fluorescence technique in which excitation of SO_2 molecule by ultraviolet (UV) light is followed by its decay to lower energy state with light emission at a different UV wavelength. Set-up of all these instruments is shown in Fig. 8 while their detailed descriptions are given by Sarangi *et al*. (2014).

Air samples are also being collected with a frequency of one-three samples per week in pre-



(A) (B) (C) (D)

Fig. 7: (A) Automatic weather station (AWS), (B) Multi wavelength radiometer (MWR), (C) Aethalometer and (D) Optical particle counter operational at ARIES

evacuated glass bottles using a metal bellows pump for the analysis of greenhouse gases (CO_2, CH_4, N_2O, SF_6 etc.), CO, CH_4, and NMHCs. These air samples are then analysed with the help of a gas chromatograph equipped with a Flame Ionization Detector (FID) together with a methanizer at Physical Research Laboratory, Ahmedabad and also at National Institute for Environmental Studies, Tsukuba, Japan. Instruments being used at ARIES for measurements of aerosols and trace gases are listed in Table 1. Recently, ARIES has also setup a facility for the measurement of vertical ozone distribution using balloon.

Key Results in the Area of Atmospheric Science

Atmospheric Aerosols

It is a well-established fact that aerosols, which are

Table 1: Brief information about different measuring instruments at ARIES

Species	Measurement technique	Instrument
Ozone	UV Absorption	Thermo (49 *i*)
CO	NDIR Spectroscopy	Thermo (48 *i*)
NO	Chemiluminescence	Thermo (42 *i*)
NO_y	Chemiluminescence	Thermo (42 *i*)
SO_2	Pulsed Fluorescence	Thermo (43 *i*)
CH_4, NMHCs, CO_2, N_2O, SF_6	Weekly air sampling	Analysis using GC-FID
Black Carbon	Optical Absorption	Magee Scientific (AE - 42)
Aerosol number concentration	Optical particle counting	Grimm Aerosol Technik (1.108)
Aerosol Optical Depth	Solar Flux Attenuation in the atmosphere	MWR from SPL and MICROTOPS from Solar Light Co., USA
Meteorology	Automatic Weather Station	Campbell Scientific, Canada; Dynalab, India

Fig. 8: Set of the instruments for O_3, CO, NO-NOy, SO_2 operational (ISRO Environmental Observatories Project) at ARIES

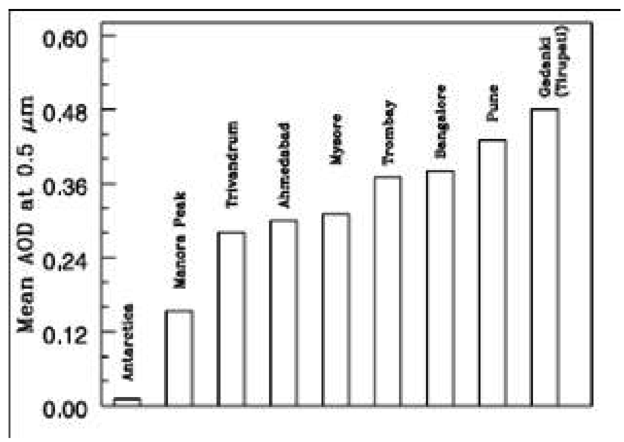


Fig. 9: A comparison of Aerosols optical depth among Nainital, Antarctica, coastal sites, urban and rural sites (Sagar *et al.*, 2004)

tiny suspended particles in the atmosphere, can modify the radiation budget of the Earth's atmosphere by absorbing and scattering the incoming solar radiation as well as outgoing terrestrial radiation. First ever observations of aerosols optical depth over the central Himalayas show that wintertime values over this region is comparable with those over Antarctic, implying a very pristine environment (Fig. 9) (Sagar *et al.*, 2004). While summer time aerosols optical depths (AODs) are very high and comparable to the urban regions. A detailed analysis suggested that summertime higher aerosols loading are due to dominating contribution of coarse sizes aerosols, in-contrast, fine size aerosols dominate in winter. Additionally, aerosols optical depths at different wavelengths show two distinct domains with different correlation, suggesting at-least two diverse and prominent sources of aerosols in summer.

It is found that daytime and night-time variations in black carbon, aerosols number concentrations, and aerosols optical depth are largely due to convective eddies those are lifting the trace species from densely populated valley region. Estimate shows that aerosols radiative forcing is +4.9 W m^{-2} over the central Himalayas, highlighting the large differences with urban sites where aerosols radiative forcing are found to be as high as +71 W m^{-2} (Fig. 10). The derived aerosols radiative forcing using observed surface radiative flux compares well with the modelled values during winter.

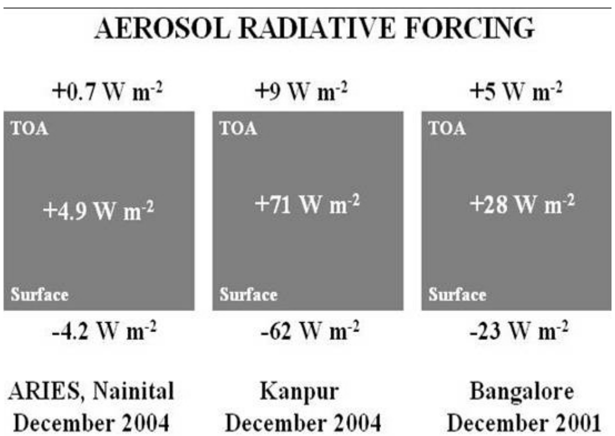


Fig. 10: Aerosols radiative forcing at Nainital, Kanpur and Bangalore (Pant *et al*., 2006)

During an Integrated Campaign for Aerosol, gases and Radiation Budget (ICARB), measurements of aerosol and trace gases were carried out at Nainital and several other sites. Nainital, showed very low values of AOD and Black Carbon (BC), even lower than that of the island station Port Blair, indicating the prevalence of cleaner environment over Nainital. Additionally, Nainital showed an opposite diurnal pattern in BC (Fig. 11), when compared with main-land and island sites, with an afternoon high and a late night or early morning low BC values. Generally, diurnal variations at all stations are mainly caused by the dynamics of local Atmospheric Boundary Layer (ABL).

Aerosols observations at Nainital were also used to derive the columnar size distribution (CSD) function of aerosols from spectral AOD data for the period January 2002 December 2005 (Fig. 12). The CSD, retrieved from spectral AODs are, in general, bimodal with a prominent secondary mode occurring

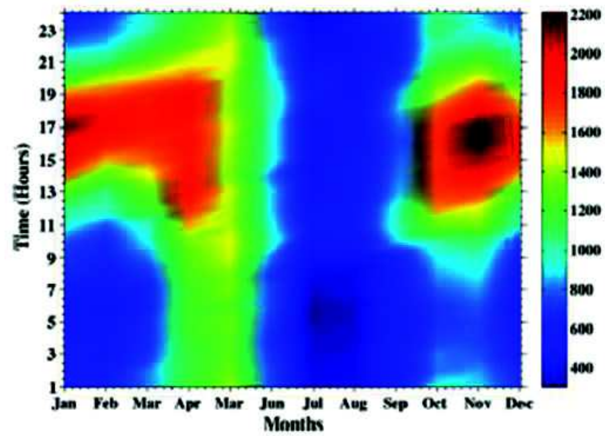


Fig. 11: Diurnal variations in Black carbon at Nainital during November 2004 to December 2007 (Dumka *et al*., 2010)

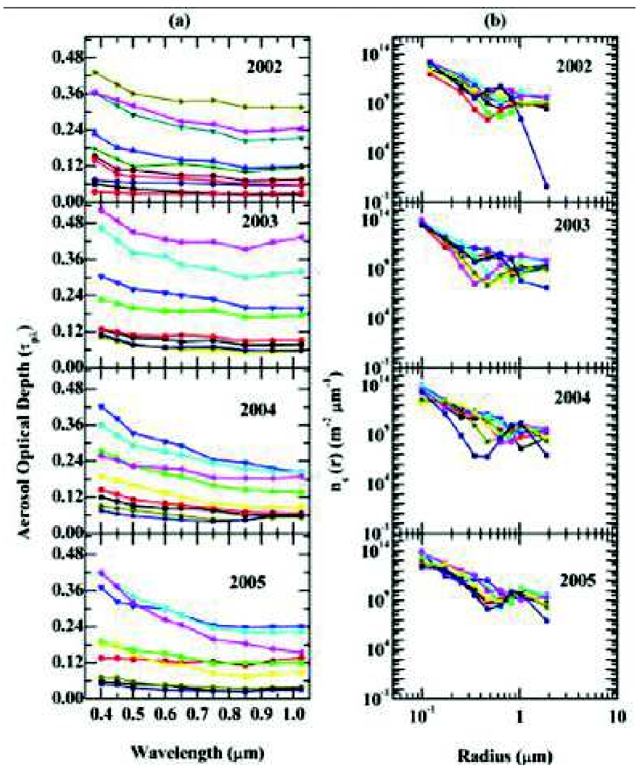


Fig. 12: (a) Spectral AOD re-estimated from the retrieved CSD. (b) Composite plot of CSD retrieved from the Spectral AOD (Dumka *et al*., 2009)

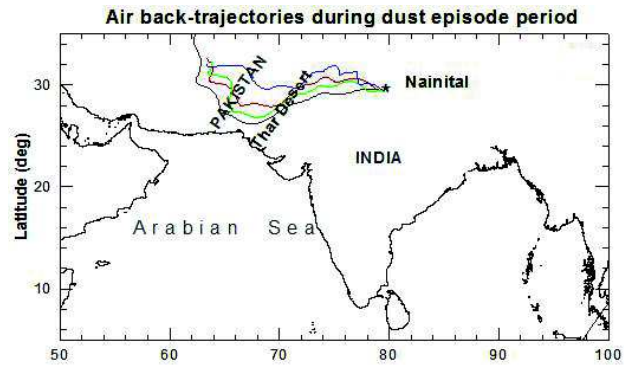
at a fairly large value of radius (r > 0.5μm), while the primary mode appearing to show below the radius about 0.1 μm. The effective radius, total aerosol number content and columnar mass loading computed from deduced CSD shows minimum values during winter (November to February) and maximum during summer (March to June) months. The share of sub-micron and super micron aerosols to the total aerosol number concentration (Nt) indicates the dominance of sub-micron aerosols to the Nt and it accounts for > 90% during the study period.

South Asian Dust Episode

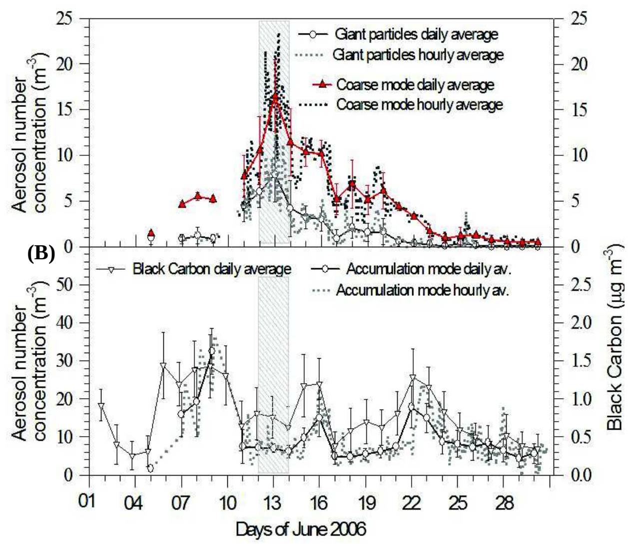
Observations at ARIES, Nainital provided a proof, for the first time, that summertime transport of dust from Thar Desert is able to influence air-quality and radiation budget over the central Himalayan region. A dust storm blew through the Thar Desert on 12th June 2006, which has significantly influenced aerosol physical and optical properties over the central Himalayas on 13th June 2006 (Fig. 13). Dust particles greatly influenced the aerosol number concentrations in the coarse and giant modes on 13th June 2006 found to be five and ten times higher as compared to their respective monthly mean values. AOD values also showed two to four times increase, particularly at longer wavelengths suggesting increase in the concentrations of coarse and giant particles. This is supported by three to five times increase in angstrom turbidity coefficient (β) and significant reduction in angstrom wavelength exponent (α). Absence of enhancements in black carbon and accumulation mode particles suggests negligible changes in the influences of anthropogenic activities at the site during the study period.

Boundary Layer Lidarand Rayleigh and Mie lidar (Nd:YAG)

Vertical distributions of aerosols are also being studied at ARIES, Nainital using a portable micro pulse Lidar system which is also known as Boundary Layer Lidar (BLL) (Fig. 14). Although the Lidar was operated from a sparsely inhabited tropospheric site, nevertheless the height distribution of aerosol layers are found to be extended up to the summit of 2 km above the ground level (AGL). The backscatter ratio (BSR) varies from 10 to 20 having lowest values during post-monsoon and highest during pre-monsoon period. The observed boundary layer height during the post monsoon was shallower compared to that during the pre-monsoon period. Occasionally the Lidar profiles reveal the presence of cirrus clouds at an altitude of 8-10 km AGL. The extended Lidar observations over Manora Peak not only provided the profiles of aerosol extinction coefficient but also significantly substantiate the elevated aerosol layers and clouds, which are important in the study of climate modelling.



(A)

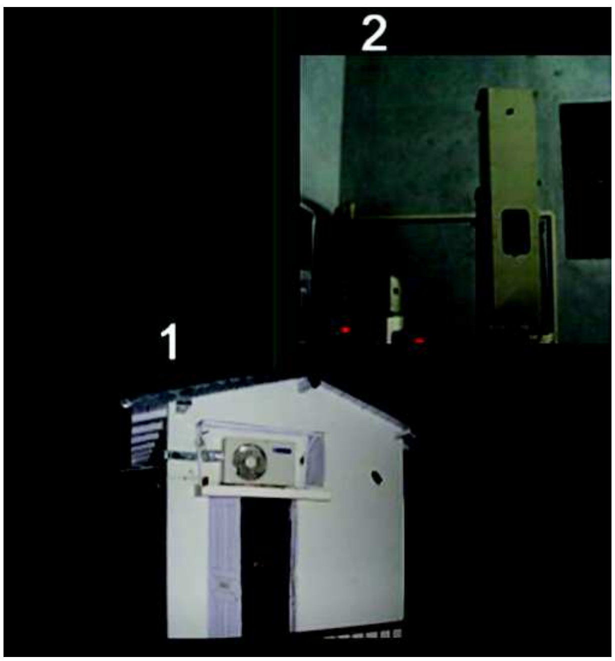


(C)

Fig. 13: Event of a dust episode during June 2006. (A) Six day back air trajectories at Nainital showing transport from Thar desert. (B) Aerosol number concentrations for OPC data in coarse and giant mode, and (C) accumulation mode particles and mass concentration for Aethalometer in June 2006. Scales of aerosol number concentrations are different in Figs. B and C. Shaded area shows the period of dust storm (Hegde *et al*. 2007)

A high power Lidar system is also being setup at ARIES for the atmospheric exploration upto ~80 km altitude. There are two telescopes having 840 mm and 380 mm diameter. The Mie Lidar using smaller 380 mm optical telescope is functional and

(A)



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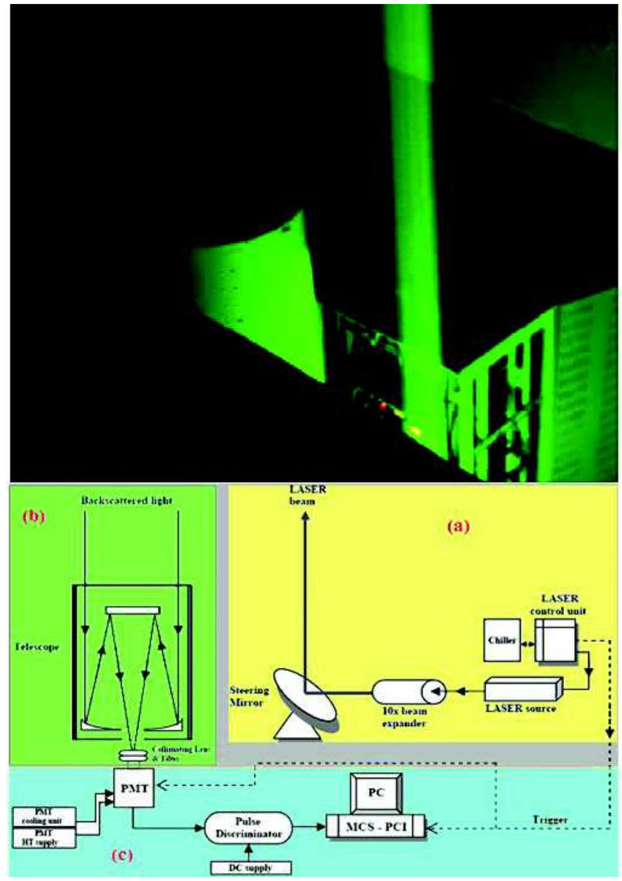


(C)

Fig. 14: (A) System for Bounday Layer Lidar (BLL) (B) A view of the BLL and (C) Higher power Lidar setup

being used for studies in the lower altitude region (2-30 km) while the Rayleigh Lidar using bigger 840 mm telescope is in the process of installation and testing which will be used for studies in the higher altitude regions (above 30 km). A detailed technical and scientific information about both newly developed Mie and Rayleigh lidar are given by Bangia *et al*. (2011a, 2011b).

Ozone, CO, NO-NO$_y$, CH$_4$ and SO$_2$

About 10% of ozone resides in the troposphere (below ~17 km). Despite this relatively small fraction, tropospheric ozone governs the chemistry of the atmosphere. Tropospheric ozone is an important precursor of highly reactive hydroxyl radical. Now it is well known that higher concentrations of ozone in the boundary layer have deleterious effects on biological life and vegetation. Ozone in the lower troposphere is mainly produced by photochemistry involving pollutants that are released from various industrial and other anthropogenic activities. Another source of tropospheric ozone is downward transport from the stratosphere. Realizing the nearly nonexistenceof trace gases observations in IGP-region and the central Himalayan region, ISRO has recently funded studies for observations of trace gases. This site is one of the representative observational locations for Northern Indian region. Apart from the regional representative site, it is also better located to study the influence of intercontinental transport, mainly from Southern Europe and Northern Africa (Fig. 15).

Observations of trace gases over the central Himalayas show that the photochemical ozone production is generally not significant over this region (Fig. 15). Diurnal variations in ozone do not show daytime photochemical build-up, like those observed at any urban or rural site. First ever observations of NOy, together with ozone and CO, from Indian region show slight enhancement during daytime, unlike in ozone and diurnal patterns are attributed mainly to the dynamical processes (Fig. 16).Springtime higher levels of ozone (~58 ppbv), CO (~215 ppbv), NOy (~1918 pptv) and SO_2 (~345 pptv) have been attributed mainly to regional pollution supplemented with northern Indian biomass burning (Sarangi *et al.*, 2014). Additionally, downward transport from higher altitudes is estimated to enhance surface ozone levels over Nainital by 6-19 ppbv. Ozone-CO and ozone-

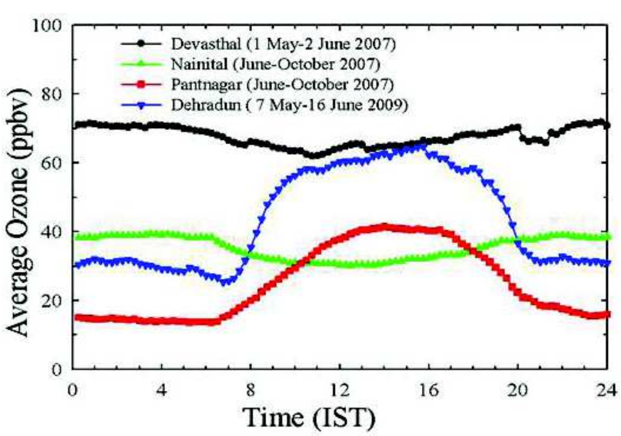


Fig. 15: A comparison of diurnal variations in ozone at Nainital, Devasthal, Pantnagar and Dehardun

NOy slope values clearly show incomplete *in-situ* photochemistry and highlight the role of dynamical processes in controlling the levels of ozone and other pollutant in this central Himalayan region. The higher CO/NOy value also confirms minimal influence of fresh emissions in this region. In contrast, SO2/NOy slopes are high (>0.4) both during pre-monsoon and monsoon periods, indicating impacts of point sources (Naja *et al.*, 2014). Enhancements in ozone, CO and NOy during high fire activity period are estimated to be 4-18%, 15-76%, and 35-51%, respectively. Despite higher CO and NOy concentrations, ozone levels in this region are nearly similar to those at other global high-altitude sites. A correlation analysis between ozone levels over a site in the IGP region and Nainital along with the mixing depth data suggests that emissions and photochemical processes in the IGP region influence the air quality of pristine Himalayan region, particularly during midday hours of spring. Ozone seasonality over the IGP region is different than that over southern India (Ojha *et al.*, 2012).

Biomass Burning

Analysis of forest fire data from space-borne sensors showed occurrences of maximum fire in spring (Fig. 17) and those are also contributing to higher levels of trace species over this region and perturbing the regional air-quality. Fire induced enhancements in surface BC, AOD (0.5 µm) and ozone are estimated to be 1802 ng m^{-3} (~145%), 0.3 (~150%) and 19 ppbv (~34%) respectively. These enhancements are seen at all levels (Fig. 18) (Kumar *et al.*, 2011). The present analysis highlights that the Northern Indian biomass burning can induce an additional cooling at the surface (-27 W m^{-2}) and top of the atmosphere (-8 W m^{-2}) in the lesser polluted high altitude regions of the central Himalayas. This cooling leads to an additional atmospheric warming of 19 W m^{-2} and increases the lower atmospheric heating rate by 0.8 K day^{-1}.

Balloon-Borne Observations

Observations of ozone vertical distribution and meteorological parameters are made using balloon-borne sensors for the first time in the central Himalayan region, which shows prominent seasonality in the lower troposphere (Fig. 19). The

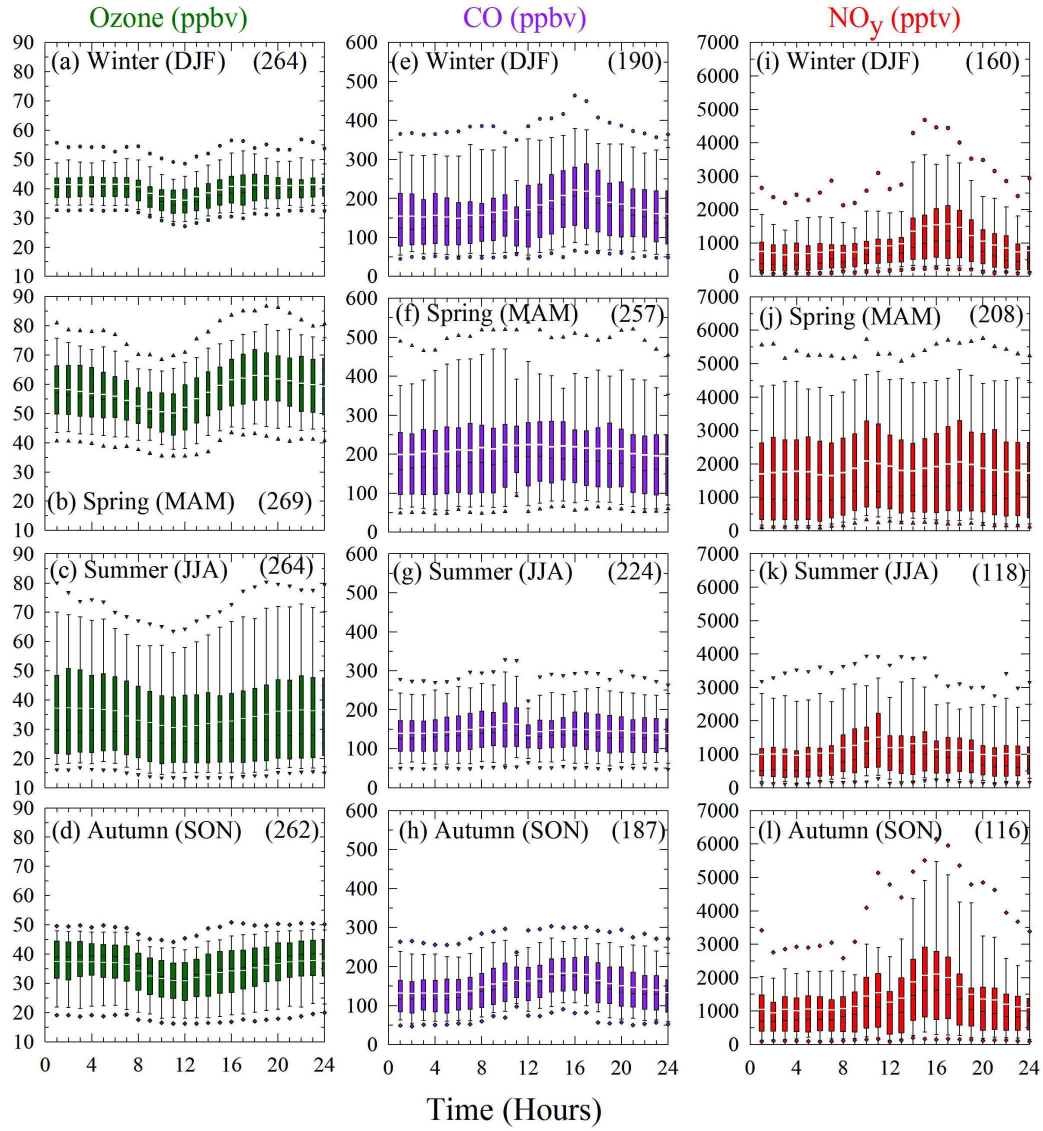


Fig. 16: Boxplot showing diurnal variations in hourly averaged ozone, CO and NOy during four seasons for 2009-2011. Number of days of observation is also mentioned in the bracket (Sarangi *et al.*, 2014)

lower tropospheric ozone minimum coincides with highest values of relative humidity (80-100%) during the summer-monsoon. However, ozone mixing ratios in the middle-upper troposphere show less pronounced and different seasonality. A stratospheric intrusion event during winter is observed, which enhances the ozone levels by ~180% in the middle-upper troposphere. Ozone levels in 2-4 km altitude range are higher by about 20 ppbv during the springtime high fire activity period over the northern India (Ojha *et al.*, 2014). Moreover, a comparison with ozone profiles at Ahmedabad confirms the influences of pollution from IGP that is supplemented with the contribution of northern Indian biomass burning. It is suggested that regional photochemistry and biomass burning processes play controlling role in the lower troposphere, while, the middle-upper tropospheric variations are driven by dynamical processes including advection and stratospheric intrusion.

Modelling of Trace Gases

For the first time, using WRF-Chem model, annual simulations of tropospheric ozone and related species

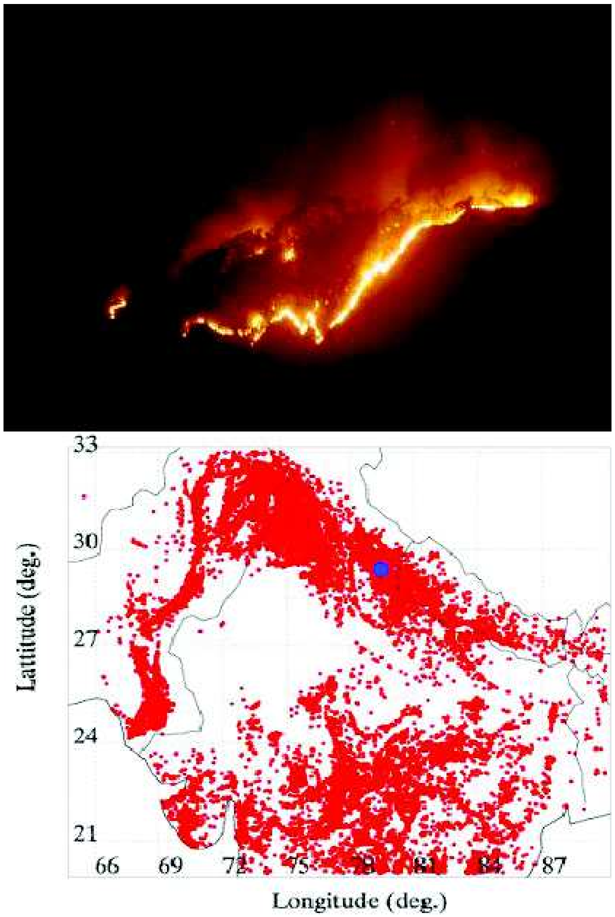


Fig. 17: Fire over the Northern Indian region during 2008. Location of Nainital is shown by blue filled circle

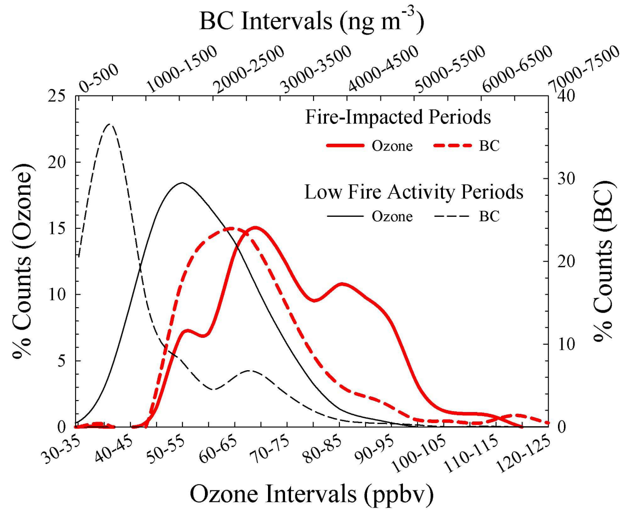


Fig. 18: Frequency distribution of Ozone and BC mass concentrations during fire-impacted and low fire activity periods (Kumar *et al.*, 2011)

over South Asia have been carried out by Kumar *et al.*, (2012). The model-simulated ozone, CO and NOx are evaluated against ground-based, balloon-borne and satellite-borne (TES, OMI and MOPITT) observations. The model results indicate clear regional differences in the seasonality of surface ozone over South Asia, with estimated net ozone production during daytime over inland regions of 0-5 ppbv h^{-1} during all seasons and of 0-2 ppbv h^{-1} over

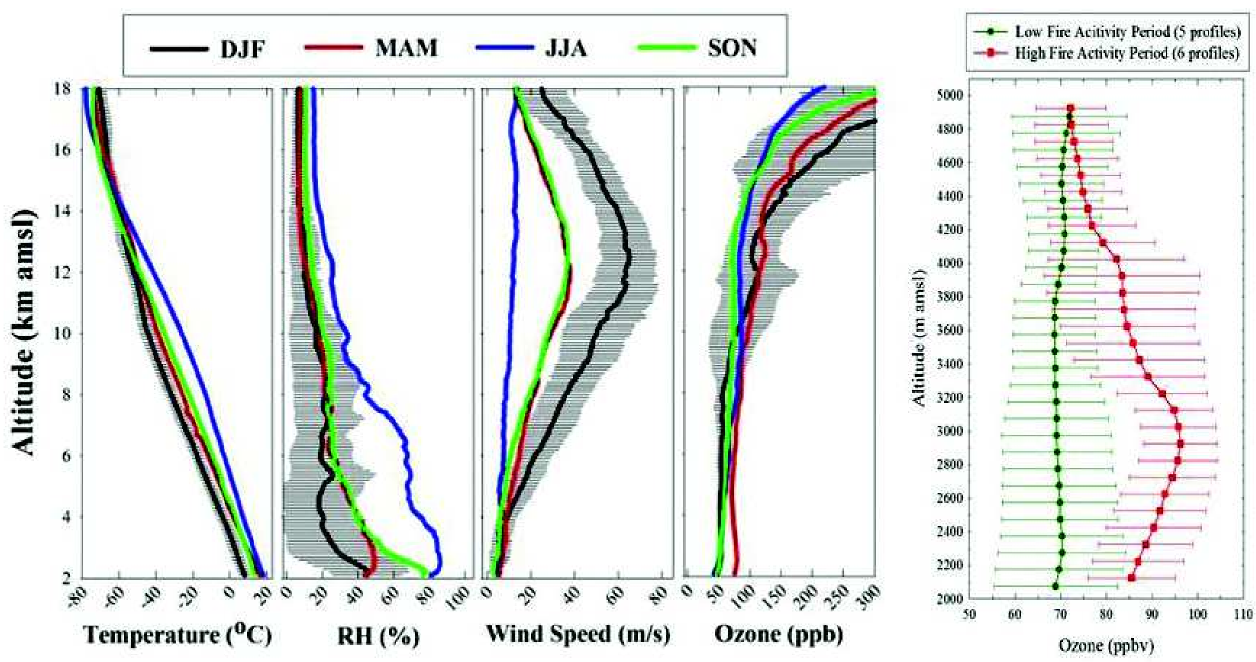


Fig. 19: Seasonal variations in the vertical distribution of temeprature, relative humidity, wind speed and ozone. Ozone enhancement during the fire activity period is also shown on the right side (Ojha *et al.*, 2014)

marine regions during outflow periods. The model results indicate that ozone production in this region is mostly NOx-limited. This model is also used for tracing back the different source types and regions using CO tracer (Fig. 20). Model results show that wintertime CO in the boundary layer and free troposphere over India is mostly due to anthropogenic emissions and to CO inflow respectively. In the boundary layer, the contribution from anthropogenic sources dominates (40-90%), while in the free troposphere the main contribution is due to CO inflow from the lateral boundaries (50-90%).

ARIES ST Radar (ASTRAD): An Upcoming Observational Facility

Globally there are networks of wind profiler available for studying Stratosphere and Troposphere regions. In India, Himalayan region is void of such observational facility and the locations of ARIES, Nainital is best suited for this purpose. In view of this, a wind profiler is being set up at ARIES. Due to its operational region, it is also called as a Stratosphere Troposphere Radar. The ST Radar system at ARIES, Nainital, is designed to operate at 206.5 MHz and will provide continuous vertical profile of winds with high temporal and spatial (vertical) resolution, under all weather conditions. The radar system is configured as an active phased array using state-of-art solid state Transmit Receive Module (TRM) and Digital Signal Processing (DSP) techniques to obtain the end product. This system has an array of 588 Yagi (3-elements) in a circular aperture on equilateral triangular grid arrangement with the inter element spacing of 0.7λ. This radar system is indigenously developed in India and antennae array is installed on a roof top for the first

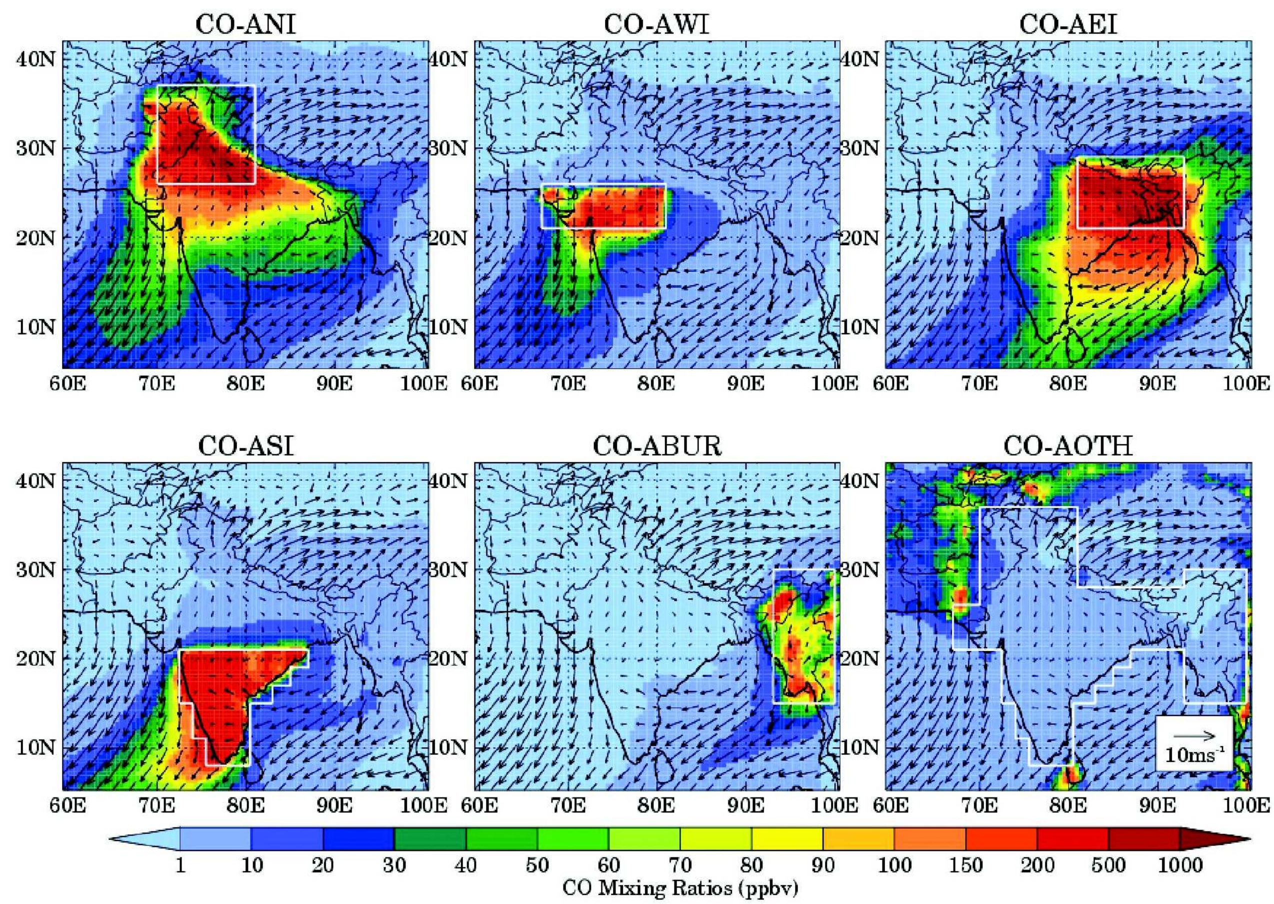


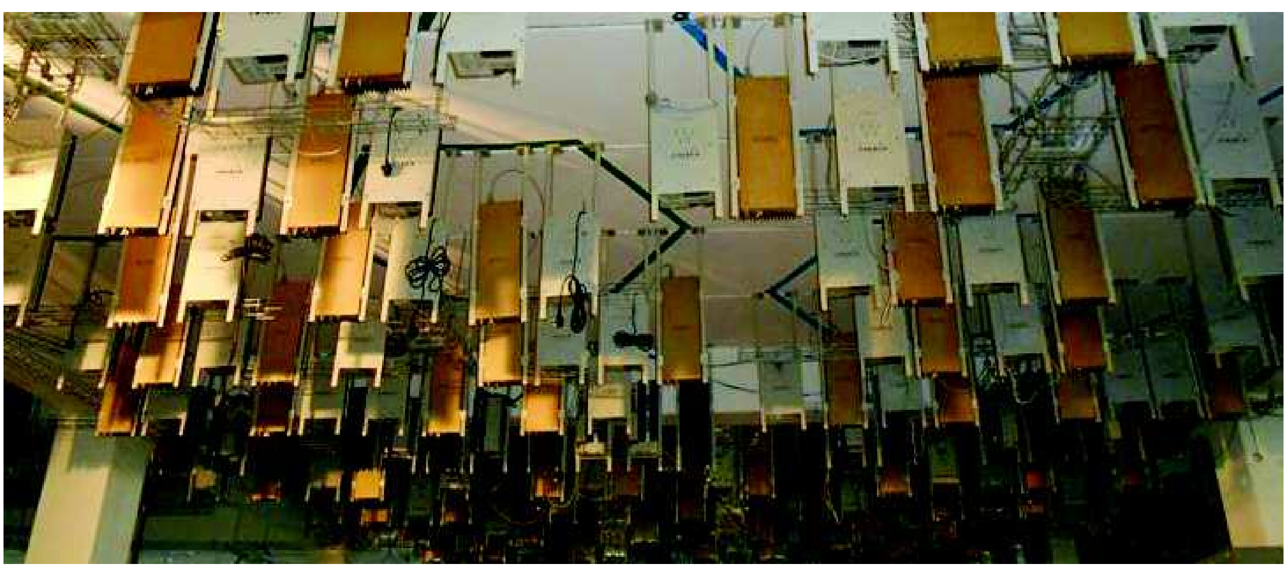
Fig. 20: Spatial distribution of surface CO emitted from anthropogenic sources in Northern India (CO-ANI), Western India (CO-AWI), Eastern India (CO-AEI), Southern India (CO-ASI), Burma (CO-ABUR) and other regions (CO-OTH) averaged at the surface during January-February 2008. Average 10 m wind vectors are also shown (Kumar *et al*., 2013)

time (Fig. 21). Presently, it is in the process of initial verification test at the site.

Astrophysics: Science of Celestial Bodies

For much of the history of observational astronomy and astrophysics, almost all observations were performed in the visual part of the electromagnetic spectrum with initially our eyes and later optical telescopes. The traditional optical wave band continues to play a pivotal role in observational astronomy even today in spite of the emergence of many new observing facilities in various wavelength regions during the past few decades, such as radio, infrared, X-ray and γ-ray windows. This is because of the rich concentration of diagnostics of the physical processes in the optical band. Thus, whereas astronomy through other wavebands has been quite effective in the discovery of new celestial objects and phenomena, one has to almost inevitably turn to optical observations of those objects in order to

(A)



(B)

Fig. 21: (A) Panoramic view of the Antennae (588 numbers) array installed over the roof-top of ARIES ST Radar building. (B) Transmit and Receive Module (TRM) (588 numbers) hanging from the ceiling

establish their identity and meaning in astrophysical terms. The thrust area of ARIES is therefore, to develop world class facilities in optical waveband. This is essential since the good astronomical sites in India play a crucial role internationally. The important factor here is their geographical locations (Longitude: 79 deg East) for the observations of transient and variable sources which require 24 hours continuous monitoring. The good sites in India are located between Canary Islands (15 deg West) and Eastern Australia (155 deg East), therefore, the observations which are not possible in Canary Islands or Australia due to day light can be obtained from the Indian sites.

At ARIES, the main areas of astrophysical research interests include solar, planetary, stellar, galactic and extra-galactic astronomy including stellar variability, X-ray binaries, star clusters, nearby galaxies, quasars, and inherently transient events like supernovae and highly energetic gamma-ray bursts (see Sagar 2006 and references therein). A brief description of theseis given below.

Sun and Solar System Studies

The Sun is the most exotic object in our solar system. It contains 98% mass of our solar system and its inherent atmospheric magneto-plasma dynamics constitute its hot atmosphere significant for further exploration. Observations of ultraviolet, x-ray emissions and supersonic wind from the Sun provide an evidence of million degree hot plasma in its outer atmosphere corona, which is still a front-line research problem in solar physics. The major riddles are to understand the physics of hot solar corona (10^6K) above the cooler photosphere (5800 K) of the Sun, and acceleration mechanism of supersonic wind as well as transient events (e.g., flares, eruptive prominences, jets and spicules, CMEs, solar wind, etc.). Therefore, a few scientists at ARIES aim to explore the outstanding problems of coronal heating and dynamics of transient events for which there are two most promising theories namely magnetic reconnection and magneto-hydrodynamic (MHD) waves. The complex magnetic field of the solar atmosphere may play an important role in forming the mega-kelvin hot solar atmosphere and occurrence of transient phenomena. Coupling of the magnetic field and the atmospheric plasma generates a variety of MHD waves. Either the magnetic fields, which connect the solar photosphere with its outer corona, may guide these MHD waves from the surface layers upwards, or these waves can be generated in different parts of solar atmosphere *in situ*. These waves (e.g., Alfven, slow and fast magneto-acoustic waves) can transport the energy into the corona leading to the plasma heating and can also energize various transients in the solar atmosphere. Recent high-resolution observations from space (e.g., Transition Region and Coronal Explorer (TRACE), Solar and Heliospheric Observatory (SOHO), Hinode, STEREO, SDO, IRIS) and ground-based observations (e.g., CoMP, DOT, ROSA, Nobeyama Radio-heliograph , SST) provide the abundant evidence of the ubiquitous presence of MHD waves in all layers of solar atmosphere (De Pontieu *et al*., 2007; Okamoto *et al*., 2007; Tomczyk *et al*., 2007; Erdelyi and Taroyan, 2008; Jess *et al*., 2009, Srivastava and Dwivedi, 2010; McIntosh *et al*., 2011; Wedemeyer-Böhm *et al*. 2012; Srivastava and Gooseens, 2013 and references therein). Using these high resolution imaging, spectral information and MHD seismology technique, a new diagnostic tool has been developed for understanding the physical conditions in the solar and stellar plasma. These MHD waves remain one of the key candidates for coronal heating and wind acceleration. Another rapidly growing research field is the study of quasi-periodic MHD pulsations in solar and stellar flares in the context of their triggering, which is also revealing the mechanisms for the energy conversion, particle acceleration and plasma diagnostics (e.g., Roberts *et al*., 1984; Nakariakov and Melnikov, 2009; Pandey and Srivastava, 2009; Srivastava *et al*., 2013, and references therein). These results are based on extensive observational detection of oscillatory patterns in the white light, microwave and X-ray emissions generated in the solar and stellar flares. They also provide important clues about the physics of the hot atmospheres of Sun and Sun-like stars, and impose rigid constraints on the relevant theories.

Contrary to above theory, in the closed field regions of solar corona which includes flares, coronal active regions, and the quiet-Sun, the most of the heating seems to be provided by magnetic reconnection as the power law distribution of flares and nano-areas has a power-law slope of 1.5 for thermal and non-thermal energies (Aschwanden 2004). This provides the clues that most of the energies lie in the largest flares driven by magnetic reconnection. The coronal loops, which are the major building blocks of the solar corona, seem to be heated impulsively on time scales of a few minutes and then cool down (see Klimchuk *et al*. 2008). This impulsive heating of solar loops again indicates towards reconnection modes responsible for the plasma dynamics and heating in the solar corona. The magnetic reconnection models may also be a good proxy to understand the transient phenomena and heating of solar atmospheres (see Aschwanden, 2004). The solar flares and associated dynamical process constitute the class of large-scale transients/ eruptive phenomena.

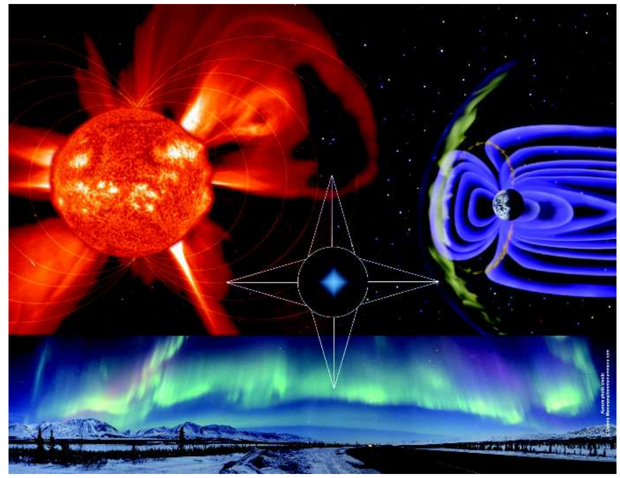


Fig. 22: The solar eruptions governed by complex magnetic field of Sun, and its connection with Earth's upper atmosphere (top-panel). An aurora in the atmosphere of Earth's north pole: asecondary Earth's upper atmospheric discharge due to the interaction of solar charged particles with Earth's magnetosphere (bottom panel) [Credit: Solar and Heliospheric Observatory]

Another aspect of the large-scale solar transient phenomena and activity is their direct correlation with the *in situ* physical conditions of the Earth's upper atmosphere, which is known as "Space Weather". The temporal variation of large-scale solar magnetic activity, which is known as eleven year solar cycle, more frequently launches flare generated radiations and energetic particles, as well as coronal mass ejections (CMEs) in the helio-sphere. The supersonic wind in the helio-sphere is anomalously distributed in its composition and velocity during a full solar cycle. Therefore, they affect the local physical conditions of the Earth's magnetosphere and produce geomagnetic storms in the ionosphere (Fig. 22). A few solar as well as atmospheric scientists at ARIES are figuring out these important aspects of Sun-Earth connection using space and ground based observations and theoretical modelling. They aim to explore the new science using the recent multi-wavelength space borne observations (e.g. from different instruments onboard SOHO, TRACE, Hinode, STEREO, RHESSI, SDO, IRIS, etc.) and complementary ground based observations from their major observational facility (Fig. 23, 15-cm Coude Solar Tower Telescope) at ARIES. The study of transient events and MHD waves in the Sun-like stars is also an important and fast emerging area of research

Fig. 23: 15 cm Coude tower telescope at ARIES

here, which is bridging the collaborative research between solar and stellar scientists who have common interest to study the solar and stellar seismological aspects. The Solar Tower Telescope is equipped with the fast CCD cameras and various extremely narrow filters for imaging the Sun at various wavelengths. The advanced environments of data-analysis, statistical analysis, as well as the MHD simulation and computational facilities are also available at ARIES for pursuing the solar research.

ARIES is one of the high altitude sites in India for astronomical observations. It is located at a height of 2000 m from mean sea level at Manora Peak near Nainital in India. This site is not only most suitable for the stellar observations but also having favourable conditions for the solar observations and studies related to atmospheric science. During the site survey for installing a suitable size of solar telescope, the Fried parameter is found to be 3.0 cm which quantitatively expresses the image degradation due to atmospheric turbulence. This measurement indicates good solar observing conditions at Manora Peak where the viewing conditions are always quite stable (seeing between 1" and 2") even up to 12.00 hrs every day. This measurement was found comparable with other solar observatories in India, e.g., Udaipur Solar Observatory, for the favourable conditions of solar observations (Sridharan *et al*., 2002). Devasthal site of ARIES (latitude 29°22’26" North, longitude 79°40’57" East) is also being developed for both solar and stellar observations, which is situated at an altitude of 2500 m (Fig. 24). The mean seeing value, wind speed and number of clear nights per year, etc. indicate that atmospheric conditions at Devasthal site are comparable to a number of international sites for astronomical observations (Sagar *et al*., 2000). Its suitability for 2-m class National Large Solar Telescope (NLST) is also being investigated.

The significant findings of the solar research group at ARIES are mostly related with the multi-wavelength observations and modelling of impulsive flares and associated transient phenomena, statistical study of North-South asymmetry of the soft X-ray index, distribution of H-alpha areas, space-weather, etc. during solar cycle 23 (e.g., Uddin *et al*., 2004; Joshi *et al*., 2006). Discoveries of multiple acoustic and sausage oscillations in the solar loops and the leakage of fast magneto-acoustic oscillations through the magnetic network core in higher corona shed new lights on the dynamics of solar atmosphere (Srivastava *et al*., 2008a, 2008b, Srivastava and Dwivedi, 2010). The co-spatial evolution of photospheric Doppler velocities and brightened kernels of 28th Oct. 2003 solar flare (Fig. 25) also describe unique features of the dynamics of flaring active regions at the Sun (Venkatakrishnan *et al*., 2008). The sausage-pinch instability is firstly discovered in solar corona (Srivastava *et al*., 2013), while the role of various instabilities have been

Fig. 24: The North-South ridge near 1.3 m telescope dome at Devasthal, ARIES (latitude 29°22’26" North, longitude 70°40’57" East, altitude:2500 meter above mean sea level) where site survey activities for 2-m National Large Solar Telescope (NLST) have been started

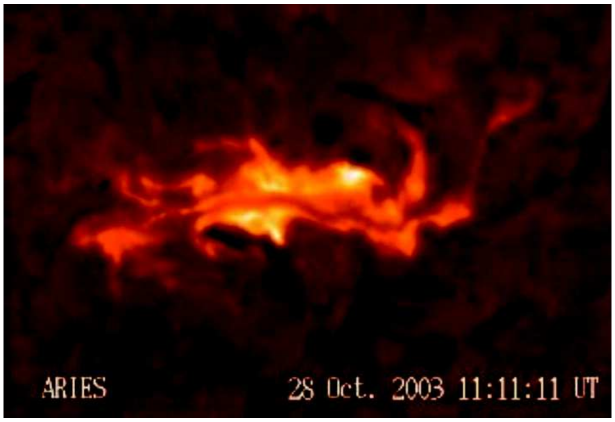


Fig. 25: The 4B/X17.2 class solar flare on 28th October 2003 as observed by 15-cm Coude Solar Tower Telescope at ARIES, Nainital

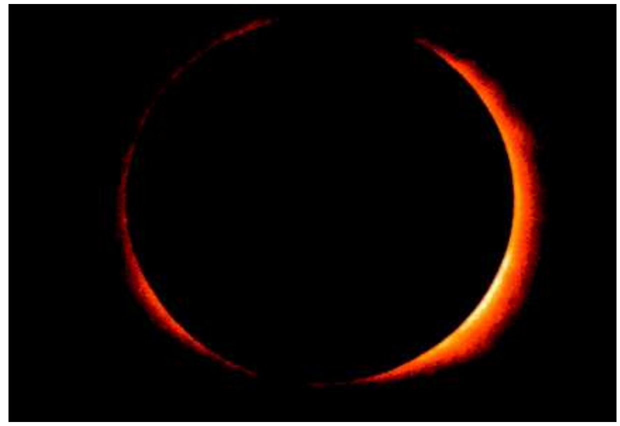


Fig. 26: The Solar Corona observed at Fe X 6374 A° red emission line during total solar eclipse on 22nd July 2009 from Anji, China

extensively studied in eruptive regions (Kumar *et al*., 2010). Another potential discovery was the application of solar analogy of MHD seismology to the magnetized atmosphere of Sun like stars (e.g., Xi-Boo, Proxima Centauri) (Pandey and Srivastava, 2009; Srivastava *et al*., 2013).

Scientists at ARIES participated in a number of expeditions related to solar eclipse observations. The total solar eclipse expedition to Anji, China, was successfully performed on 22nd July 2009. The high cadence imaging of solar corona during total solar eclipse may provide the evidence of the role of fast MHD waves in the heating of this mega-kelvin solar atmosphere. The measurements of surface ozone and local atmospheric conditions at Anji, China have also been performed by team in order to understand the effect of totality on the atmosphere of Anji, China.

Galactic and Extragalactic Astronomy

The Telescope

The 104 cm Sampurnanand telescope (Fig. 27) was and still is the main work horse for the observations in the optical astronomy at ARIES. The telescope is a Ritchey-Chretien (RC) reflector with a Cassegrainand a Coude focus with equatorial 2-pier English mounting. RC is a specially designed Cassegrain telescope to eliminate coma, thus enabling to observe a large field-of-view compared to a more conventional configuration. The Cassegrain focus reflector is a design of telescope in which a combination of a primary concave mirror and a secondary convex mirror are used. The Coude telescopic focus is used primarily for spectroscopy. The word ‘coude’ originated from French meaning “bent like an elbow” since in this arrangement light from the primary mirror is reflected along the polar axis to focus at a fixed place away from the telescope, or in an entirely seperate (often called the coude) room, where larger equipment can be fitted without interfering with the telescope’s balance. The telescope is also equipped with 3 finder telescopes. They are 26.4 cm, f/14, reflector; 20 cm, f/15, refractor and 11 cm, f/7, refractor. The 20 cm and 10 cm finder telescopes are equipped with eyepieces which cover around 20 and 90 arc minute field-of-view respectively. The 20 cm refractor is also used for guiding the main (104-cm) telescope.

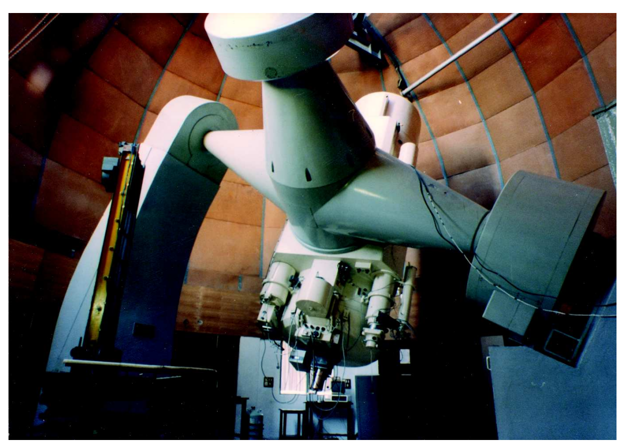


Fig. 27: The 104-cm Sanpurnan and Telescope

The Back-End Instruments

The charge-coupled device (CCD) cameras are in use at ARIES since 1989. A Tektronics 384x576 CCD detector with 24µm pixel size covering an area of 2'x3' on the sky was the first camera to be installed in 1989. Then a Tektronics 1024x1024 grade 1 CCD with 24µm pixel size was acquired in 1992. This camera covers an area of 6'x6' of the sky. In 1999, Wright 2048X2048 CCD camera with 24µm pixel size was commissioned which is used extensively even today. It covers an area of 13'x13' of sky and operates at a temperature of 160K. Latest addition to this fleet of CCD cameras is a Pixcellent 1242x1158 CCD camera with 22:5µm pixel size acquired in 2005 with an adjustable readout rate from 25 to 167 kHz. Modern CCD camera attached to 104-cm telescope combined with a good site like Manora Peak is capable of carrying out deep UBVRI photometry of 20 magnitude sources with an accuracy of about 0.01 magnitude.

The filter sets available at ARIES are Johnsons UBV and Cousins RI. Differential photometry using CCD can detect variations of 1, 5, 10 and 20 milli-magnitude in a star with apparent magnitude of 10, 15, 18 and 20 respectively (see Figs. 28 and 29).

The ARIES Imaging POLarimeter (AIMPOL) was developed in-house in 2004 (Fig. 30) and since then it is in use. The instrument measures linear polarization in BVRI bands and has a field-of-view of around 8 arc minute. ARIES also has a Photo-multiplier Tube (PMT) based fast photometer capable of detecting light variations of 0.2 milli-magnitude during good sky scintillation conditions (see Fig. 30). There is also a HR-320 spectrograph which is used along with the Tektronics 1k CCD detector to take low resolution spectra of bright stars up to 12 magnitudes. It uses a circular aperture and is best suited for estimating continuum and broad emission features in stars. In order to make observations in infrared region, ARIES has an infrared photometer built at ARIES which employs InSb based photovoltaic detector and a pre-amplifier electronics (see Fig. 31).

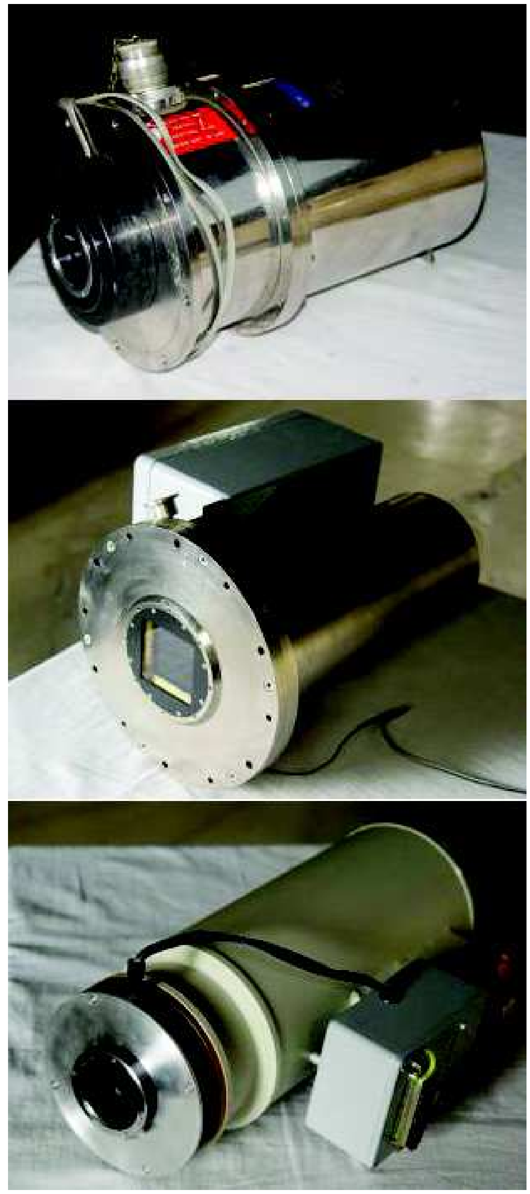
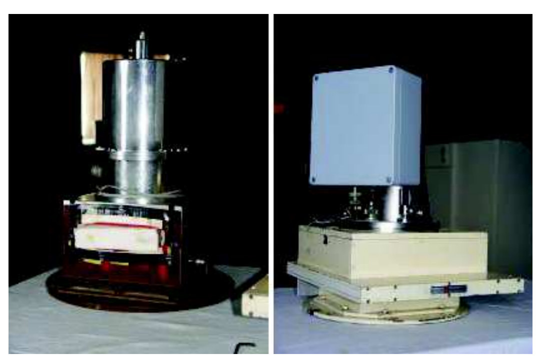


Fig. 28: Top to bottom: 1k Tektronics CCD, 2k Wright CCD and 1k Pixcellent CCD



(A) (B)

Fig. 29: (A) 1k Tektronics CCD camera with filter unit. (B) 2k Wright CCD camera with filter unit

Fig. 30: The polarimeter (AIMPOL) and the Fast photometer mounted at the Cassegrain focus of the 104-cm telescope

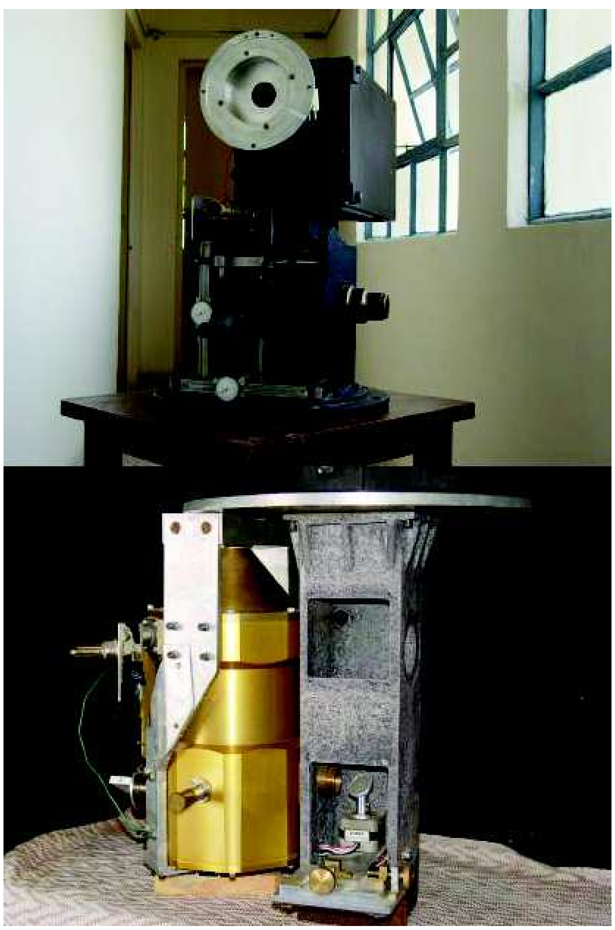


Fig. 31: The low resolution spectrograph (top) and the Infrared photometer (bottom)

A Glance Through Some of the Scientific Results from 104-cm Telescope

The 104-cm telescope has produced a number of very exciting scientific results in various fields of astrophysics. Observations taken with the telescope have contributed to > 400 research papers published in journal of international repute and > 30 PhD thesis. We briefly narrate a few of the key scientific results below.

Variable Stars and Astro-Seismology

ARIES has been active in observing pulsations in chemically peculiar roAp stars and δ-Scuti stars and variability in binary systems, cataclysmic variables, Cepheids and blue stragglers in star-clusters (Sagar 2006). ARIES started a campaign to search for pulsating roAp and δ-Scuti stars in the Northern Hemisphere, where only a few roAp stars were known earlier. A list of nearly 200 probable candidates was selected. For this survey a three channel fast photometer was designed and developed at ARIES. Our search resulted in the discovery of four δ-Scuti and one roAp star. This work was carried out in collaboration with the ISRO Satellite centre (ISAC), Bangalore, South African Astronomical Observatory (SAAO), S. Africa and University of Lancashire, United Kingdom. In Fig. 32, we show a typical light curve of an evolved Am star, HD 98851, obtained on HJD 2451594.

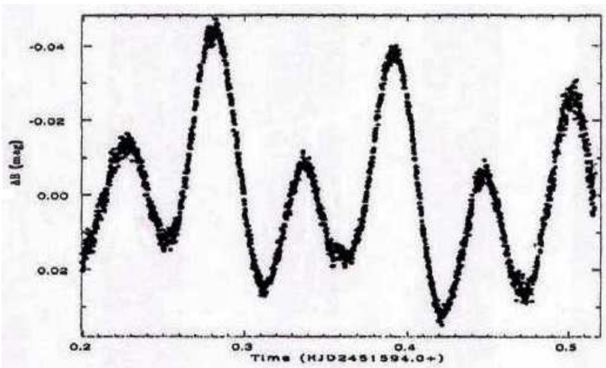


Fig. 32: A light curve of an evolved Am star, HD 98851 obtained on HJD 2451594 by Joshi *et al*. (2003)

Studies of EUV-Bright and Soft X-ray Sources

Many new soft X-ray sources discovered in surveys with the Einstein and ROSAT satellites have been observed in optical bands from ARIES. The optical, radio and X-ray observations indicate that these systems may be RS CVn-like objects. However, evidence for binary and also the photometric properties of these objects are still unknown. A list of about twenty five such northern hemisphere objects has recently been compiled, and they are being monitored with ARIES telescopes using CCD cameras as an N-star photometer. Optical variability has been detected in five of the ten objects observed so far (see Fig. 33). This work was carried out in collaboration with scientists from Tata Institute of Fundamental Research (TIFR), Mumbai and NASA, USA.

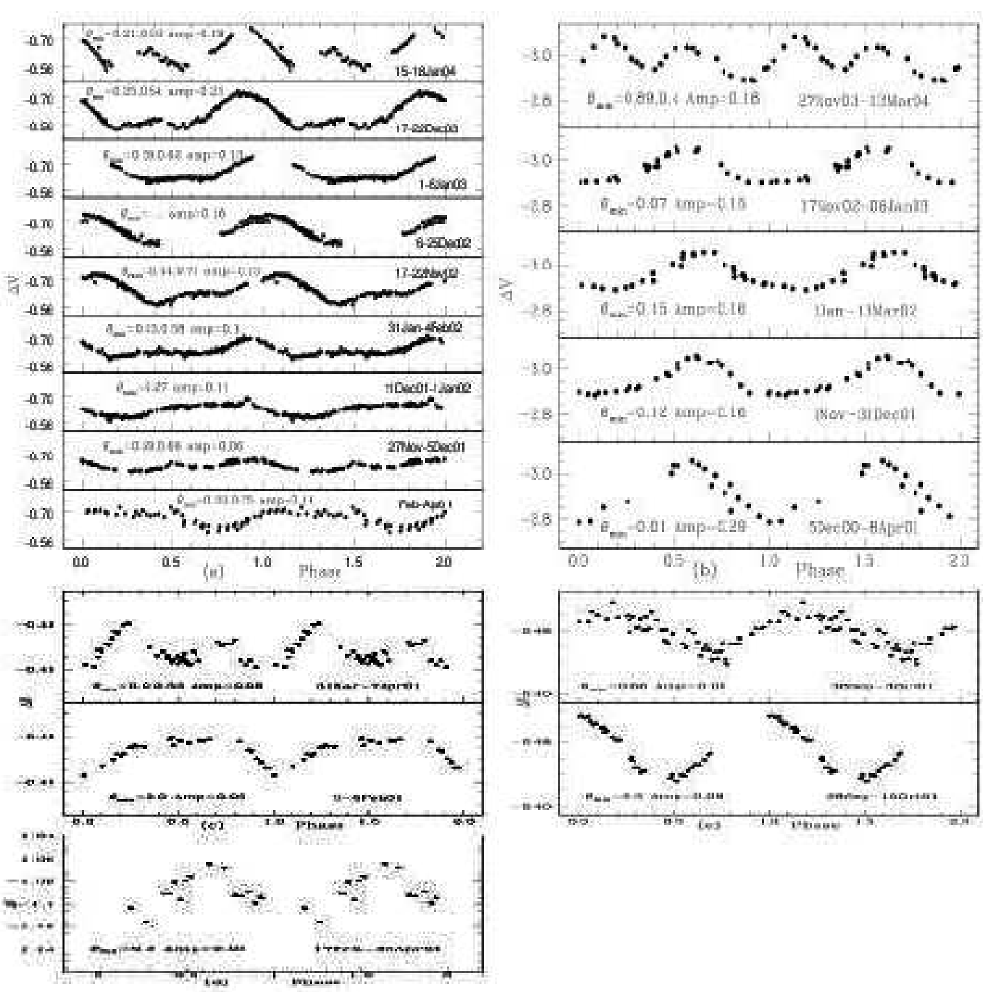


Fig. 33: V-band light curves of the five chromospherically active stars FR Cnc, HD 81032, HD 95559, LO Peg and HD 160934. They are identified X-ray sources by ROSAT satellite (Pandey *et al*., 2005a, 2005b)

Study of GRB Afterglows and Supernova

Broadband photometric CCD observations of several GRB afterglows have been obtained using 104-cm telescope. In fact, the first Indian optical observations of an afterglow of a GRB 990123 were made at ARIES on 23rd Jan 1999 (Fig. 34). Since then observations of more than 20 afterglows have been successfully carried out till the end of 2013. Amongst these, the earliest optical observations of GRB 000301C in R band and GRB 030329/SN 2003dh in UBV I bands have been carried out from ARIES, taking advantage of its geographical location as mentioned above. These observations in combination with the published one including those at other wavelengths are used to study the properties of afterglows. The optical afterglow light-curves, spectral energy distributions and calculated energetics of these bursts are used for putting observational constraints on the popular GRB progenitor's models. Many supernova events have also been monitored from the observatory at regular intervals for many months. ARIES has both national and international scientific collaborations for these works, and the observations from the observatory have been recognized internationally (Misra and Sagar 2009; Sagar and Pandey 2013). The institute participates in a coordinated program to follow-up GRB afterglow in many wavelengths in collaboration with Raman Research Institute (RRI), Bangalore, Giant Metre-wave Radio Telescope (GMRT) at National Centre for Radio Astrophysics (NCRA), Pune, Himalayan Chandra Telescope (HCT) of Indian Institute of Astrophysics, Bangalore, and the European network of observatories.

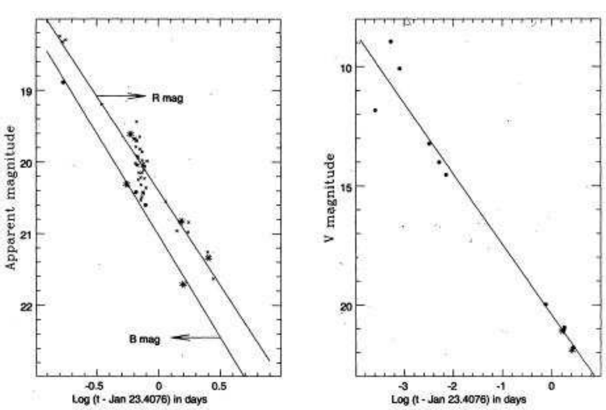


Fig. 34: BVR photometric light curves of the optical transient of GRB 990123. Points identified with asterisks are from 104-cm telescope (Sagar *et al.* 1999)

Star Clusters as a Tool for Stellar Evolution

The 104 cm telescope has been used extensively for obtaining observations of several galactic star clusters and a few globular clusters located in our Milky-way galaxy. The observations have led to the studies of open clusters pertaining to their star formation efficiency, age distribution, mass function (MF) and luminosity function. Spatial structure and the interstellar extinction in young open star clusters have also been studied. The slope of the mass function above 1 solar mass for young star clusters (age < 100 Myr) is found to be universal with a slope of Salpeter value within uncertainties of its observational determination (Sagar and Kumar 2012). This program has given many well recognized results of fundamental importance in the field of star-clusters. In Fig. 35, we show a plot of the MF for the Stock 8 open cluster region. In the mass range $\sim 1.0 = M/M_{o} < 13.4$, the MF can be represented by a power-law having a slope of -1.38 ± 0.12.

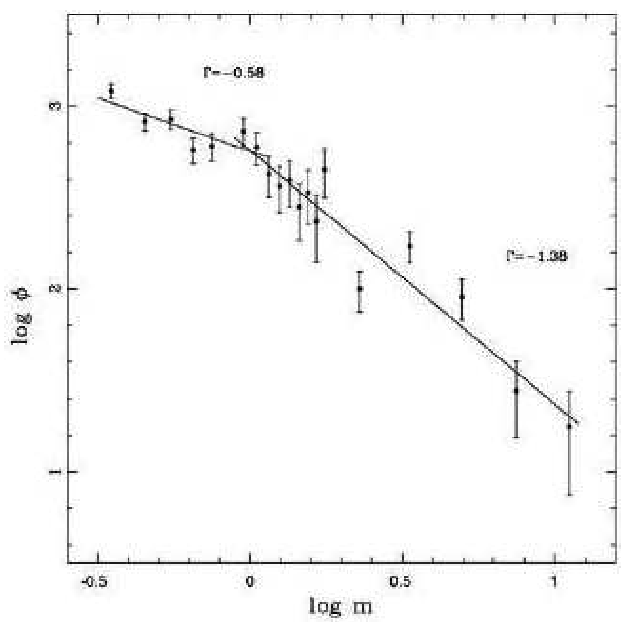


Fig. 35: A plot of mass function (MF) for the Stock 8 young open cluster region (Jose 2008)

Optical Variability of Powerful Active Galactic Nuclei

The sensitive observations to detect intra-night optical variability of milli-magnitude amplitudes in radio-quite Quasars are being carried out at ARIES. The observations obtained so far, indicate that at least some radio-quiet quasars do exhibit micro-variability, albeit somewhat less often, typically for shorter times, and usually less violently than that exhibited by radio-loud quasars and blazars. The optical light curves of 8 sets of optically bright and intrinsically luminous AGNs have been obtained using the 104 cm telescope at ARIES on at least three epochs spanning more than 100 nights of observations. Each set consists of (i) one radio-quiet quasar (ii) one radio-loud quasar and (iii) a blazar, all matched in red shift and optical luminosity. A systematic study based on this sample indicates that there is no basic difference between the central engines powering the radio-quiet and radio-loud quasars. The coordinated GMRT based radio observations, satellite based X-ray observations and optical observations from ARIES are being regularly carried out.

Dark Matter in the Galaxies

In 1998, an observing program was started at ARIES to look for possible gravitational micro-lensing events towards M31 galaxy under the Nainital micro-lensing survey. The lensing is believed to be caused by massive particles MACHOs in the halo of the galaxies, which are considered as possible dark matter candidates. To search for micro-lensing events towards M 31, a technique called the Pixel Method has been developed in collaboration with a French AGAPE (Andromeda Gravitational Amplification Pixel Experiment) group. The optical observations from the observatory for four continuous years have been compiled and one possible micro-lensing event has been detected (see Fig. 36).

Polarimetric Studies of Open Star Clusters and Star Forming Regions

Polarimetry of background stars of interstellar clouds is a powerful technique by which one can not only study the properties (i.e., shape, size etc.,) of interstellar dust but can also study the plane-of-sky magnetic field orientation between the observer and the stars. Use of stars of an open cluster has an added

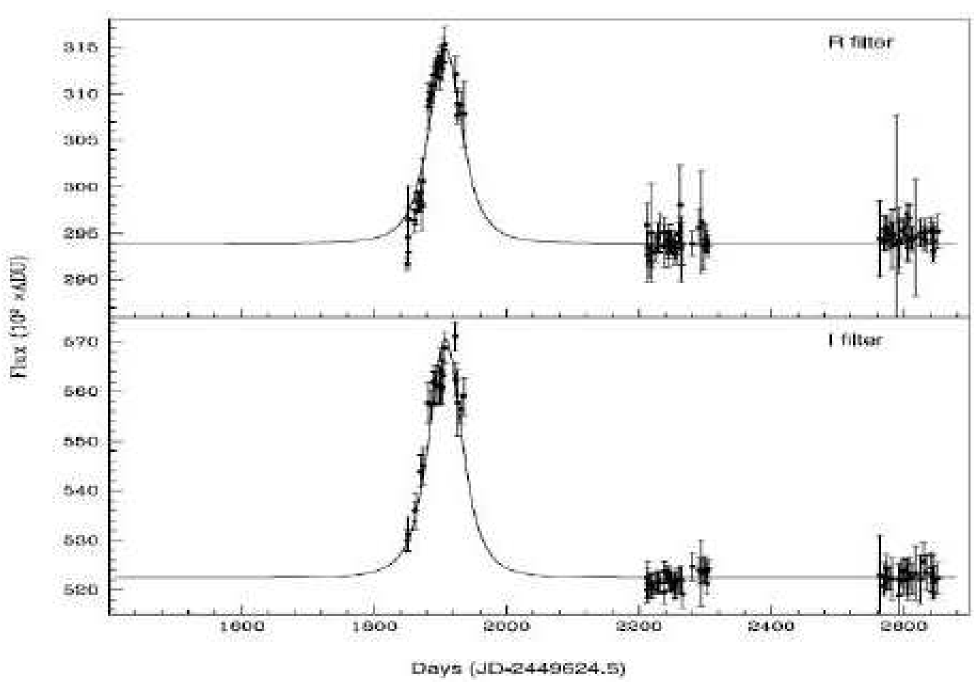


Fig. 36: The R and I band pixel light curves of NMS-E1 in the upper and lower panels respectively. The continuous lines represent the results of the 7-parameter Paczynski fit. (Joshi *et al.*, 2005)

advantage that the knowledge of distance, extinction etc. of the cluster stars can be utilized to make a more meaningful study of the foreground dust properties. So we have made studies of a number of open clusters using the AIMPOL and 104-cm telescope (as an example we show our results on an open cluster NGC 654 in Fig. 37). Magnetic fields play an important role in the formation of stars. But the relationship between the field orientation inside the clouds (from sub-mm observations) and those outside the clouds have not been studied systematically. We have initiated a program to choose the clouds with sub-mm observations to measure the field orientation outside the cloud and study their relationship.

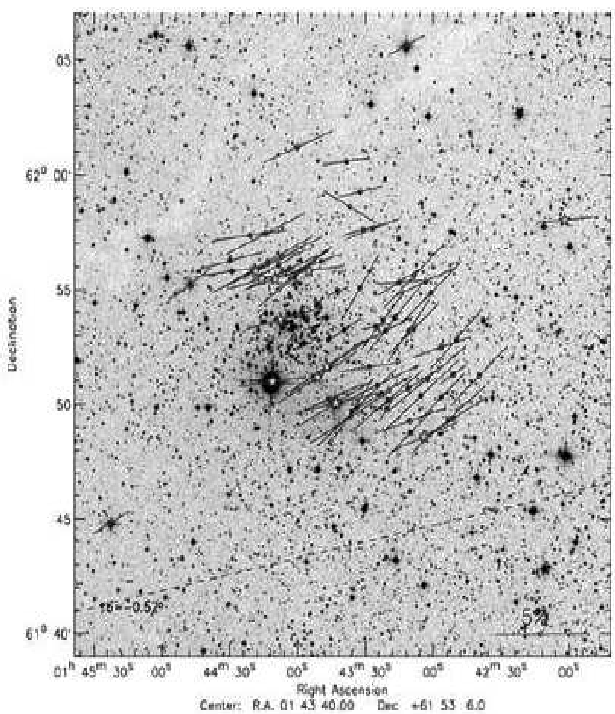


Fig. 37: The 28´X28´ R-band DSS image of the field containing NGC 654, reproduced from Digitized Sky Survey. The position angles, in the equatorial coordinate system, are measured from the north, increasing eastward. The polarization vectors are drawn with the star as the centre. Length of the polarization vector is proportional to the percentage of polarization PV and it is oriented parallel to the direction corresponding to the observed polarization position angle V. A vector with a P of 5 per cent is shown for reference. The dashed line represents the Galactic parallel at b = -0.52 degree. Stars with membership probability > 0.70 are identified with closed star symbols in green (Medhi *et al*. 2008)

Search for Variable Stars in Open Clusters

A systematic search for variable stars in a number of young open clusters was carried out using the 104-cm telescope. Some scientifically interesting results are obtained in the NGC 1893 star cluster (Lata *et al*. 2012). Light curves of some of the stars from NGC 1893 are shown in Fig. 38. They clearly demonstrate astrophysical importance of different types of variables present in a star cluster.

Devasthal–Transformation from a Site to an Observatory

ARIES has developed Devasthal as an observatory. Devasthal is about 55 km by road towards east of Nainital. The altitude of 2540m of the site makes it one of the most promising high-altitude sites in India. The Devasthal site offers excellent dark skies (darkness per square arc sec sky, V=21.8 mag) due to the lack of large scale human settlements. The seeing defined as the amount of blurring of a point source due to the Earth’s atmosphere has been quantified using extensive measurements taken with differential image motion monitor installed around 2-m above the ground level. These observations along with the micro thermal fluctuation measurements carried out at 2, 6, and 12m above the ground indicate that the sub-arc second (0.7) seeing can be obtained if the telescope is installed at about 8m above the ground. The yearly clear spectroscopic nights are ~ 210. These factors make the site comparable to the best sites like in Chile and La Palma. Further details on the site are published by Sagar *et al.* (2000). The existing and upcoming optical telescopes at Devasthal observatory are detailed below.

The 1.3-m Telescope

A 1.3m aperture telescope was installed and dedicated to the nation in 2010. Its technical details as well as observing capabilities are described by Sagar *et al*. (2011). The prime objective of this telescope is to carry out photometric monitoring of variable objects and transient sources in the sky. The telescope is being used to carry out long exposure photometric observations of galactic and extragalactic objects. The building and sliding dome for 1.3m telescope are

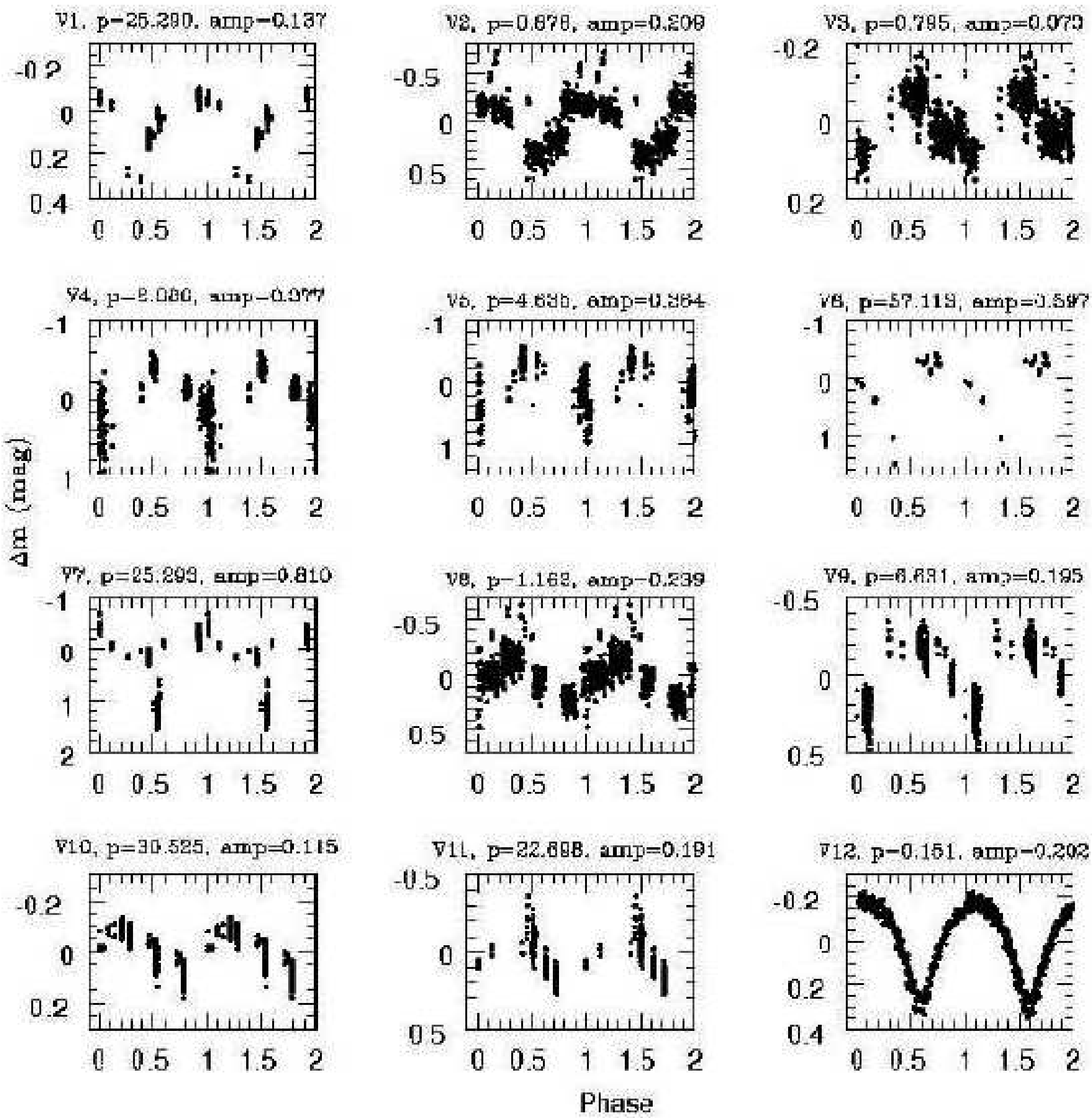


Fig. 38: A number of long period and short period variables obtained towards the field containing the young open cluster NGC 1893 (Lata *et al.* 2012)

shown in Fig. 39.

The 3.6-m New Technology Telescope

ARIES is installing India's largest optical telescope which is expected to be operational by 2015. The Devasthal Optical Telescope (DOT) will have an aperture of 3.6-m. This telescope is constructed using several new technologies making it light weight and cost effective compared toa similar classical telescopes. The fundamental telescope optics parameters are a F/2 thin mirror primary, F/9 effective focal ratio, RC configuration with a back focal distance of 2 m. The telescope performance is set to have 80% energy within 0.45 arc sec diameter in 30 arc min field over 350 to 3000 nm wavelength range. The primary mirror will have a meniscus shape with a thickness-to-diameter ratio of about 1 to 22 and the total weight of the machined mirror after a Cassegrain hole of 600 mm will be 4000 kg. The secondary mirror has a diameter of 900 mm. The polishing accuracy

Fig. 39: The building and sliding dome for 1.3m telescope

Fig. 40: A fully assembled 3.6m DOT in AMOS factory of Belgium

of the primary and secondary mirror surfaces will be with a typical wave-front accuracy of 30 nm RMS at 600 nm wavelength. The telescope will have an Alta-Azimuth mounting with a zenith blind spot of less than 5 degree. Further technical details of the telescope are given in Sagar (2007) and Sagar *et al*. (2012).

The design of a telescope is strongly based on the avoidance of wave-front aberrations. But any movement of telescope tube will change to some extent the alignment of the telescope and the forces acting on the primary mirror can produce wave-front aberrations. The classical telescopes normally are made of thick and stiff mirrors that can avoid the above mentioned flexure. But in 3.6-m DOT, the primary mirror is thin, only 16.5 cm in thickness, which makes it quite flexible. Therefore, its shape will be maintained by active supports pressing against its back under the control of a computer. The reasons for selecting a relatively thin mirror with active supports are both economical and technological. As a rule of thumb, the cost of a conventional telescope climbs as $D^{2.7}$, where D is its diameter, while the cost of a telescope with active optics grows only as D^2. Therefore, thin mirror actively supported telescopes are economical and also based on modern technology.

In the case of a telescope with an active support a system of sensors and computer-controlled motors analyses and adjusts the shape of the primary mirror and the position of the secondary mirror automatically. This is achieved by the real time corrections (while the observations are going on) through the use of active optics. In layman's language, the optical system of the telescope continuously checks itself and optimizes automatically. The use of active optics was first demonstrated by ESO in their New Technology Telescope (NTT) in 1989. A wave-front analyzer is used to analyze the aberrations in the image formed by the telescope with a typical integration time > 10s to average out the atmospheric fluctuations. The control system transforms the information on aberrations to the requisite forces and movements to be applied to the mirrors, and finally the mirror actuators apply these forces and movements. In case of a monolith mirror (the kind that is used in 3.6-m DOT), the actuators on the primary mirror would be force actuators. Fully assembled 3.6m DOT in AMOS factory of Belgium is shown in Fig. 40.

With the inclusions of new technologies in the 3.6-m DOT, e.g., the active optics and a new design for the telescope enclosure to reduce the blurring of the images due to thermal gradient inside it, combined with a good site at Devasthal, astronomers will get a highly efficient telescope by the year 2015 to carry out exciting research in various fields of Astronomy and Astrophysics.

The 4-m Liquid Mirror Telescope

ARIES is going to install a liquid mirror telescope of 4 m size at Devasthal. It is a part of an international effort called “The International Liquid Mirror Telescope (ILMT)”. The ILMT uses Liquid Mirror technology wherein the primary mirror of the telescope is a rotating container with highly-reflecting liquid in it. The surface of the spinning liquid (mercury) takes the shape of a paraboloid (see Fig. 41). As liquid mirror cannot be tilted, they cannot track a celestial object like conventional telescopes do. The tracking is done artificially by using a technique called time delayed integration (TDI), which uses a CCD detector that tracks by electronically stepping its pixels. The field-of-view of the telescope will be 30' × 30'. The ILMT will carry out direct imagery using a 4K × 4K thinned CCD as the detector working in the TDI mode. At Devasthal, the liquid mirror telescope will monitor a strip of sky of 0.5 degree of declination. This survey will last for about five years. The CCD detector will give nightly integration times of about 90 sec. The limiting magnitudes expected to achieve are 23.5 in blue filter and 25.8 for co-added nightly observations of the same region. The information will be stored on disks so that the night observations can be co-added with a computer to lead to long equivalent integration times. The main goals to be achieved by this project are gravitational lens studies and search for supernova. In addition to these, the project is expected to produce an unprecedented sample of variable stars and extragalactic objects. More technical as well as scientific information on this project has been given by Poels *et al*. (2013).

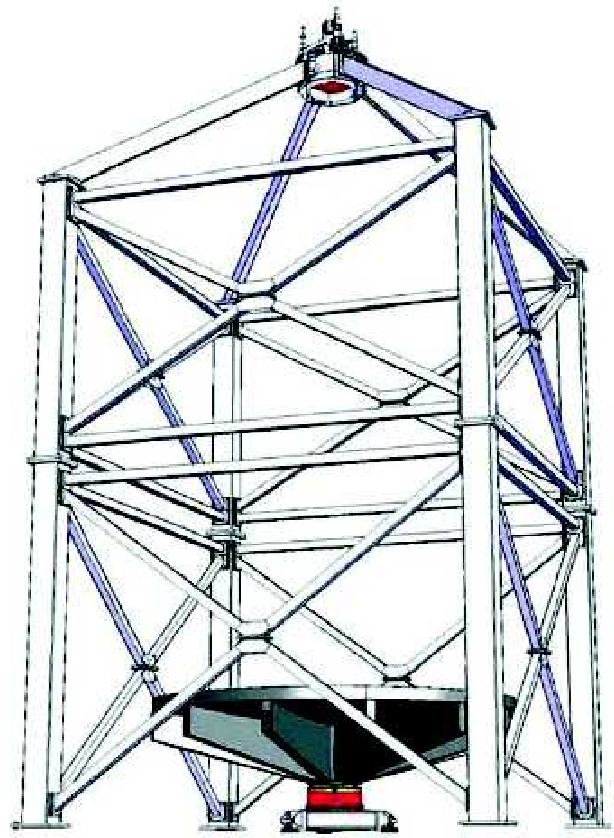


Fig. 41: A sketch showing the components of the liquid mirror telescope assembled together. The vertical steel frames hold the corrector and CCD detector at the top

Summary and Conclusions

Taking advantage of the geographical location of both Manora Peak and Devasthal sites, scientists and other staff of ARIES have not only carried out valuable observations in the field of atmospheric science and astrophysics but also derived number of nationally and internationally recognised interesting scientific results. A few of them are mentioned below:-

(1) First ever and long duration (> 5 years) observations of aerosols over the central Himalayas show that during wintertime, pristine environment of this region is dominated by fine aerosols (radius < 0.1 μm) which is comparable with those over Antarctic. In-contrast, summertime bigger aerosols loading is comparable to those over urban regions. It is

due to dominating contribution of coarse aerosols (radius > 0.5 μm) fromat-least two diverse and prominent sources of aerosols. Aerosols radiative forcing over the central Himalayas is estimated to be very low (+4.9 W m-2) in comparison to those over urban sites (+71 W m-2). For the first time, an observational proof has also been provided that summertime transport of dust from Thar Desert is able to influence air-quality and radiation budget over the central Himalayan region. The extended Lidar observations over Manora Peak substantiated presence of the elevated aerosol layers and clouds, which are important in the study of climate modelling.

(2) Observations of trace gases (Ozone, CO, NO-NOy, CH_4 and SO_2) show that the photochemical ozone production is generally not significant over the central Himalayas. Despite higher CO and NOy concentrations, ozone levels in this region are nearly similar to those at other global high-altitude sites.

(3) Observations of ozone vertical distribution and meteorological parameters are made using balloon-borne sensors for the first time in the central Himalayan region. Modelling of these observations suggest that regional photochemistry and biomass burning processes play controlling role in the lower troposphere, while, the middle-upper tropospheric variations are driven by dynamical processes including advection and stratospheric intrusion.

(4) Multiple acoustic and sausage oscillations in the solar loops and the leakage of fast magneto-acoustic oscillations through the magnetic network core in higher corona were discovered. These will shed new lights on the dynamical study of solar atmosphere.

(5) A number of different types of variable stars have been discovered in the star clusters as well as in field regions of the Milky-way galaxy. They are useful to understand the theory of pulsation in stars as well as stellar evolution.

(6) The first Indian optical observations of an afterglow of a GRB 990123 were made at ARIES on 23rd Jan 1999. Amongst the large number (>20) of successful optical observations, the earliest optical observations of GRB 000301C in R passband and GRB 030329/SN 2003dh in UBV and I passbands have been carried out from ARIES, taking advantage of its geographical location as mentioned above. The optical afterglow light-curves, multi-wavelength spectral energy distributions and the calculated energetics of these bursts are used for putting observational constraints on the popular GRB progenitor's models. Our observations support core collapse model for progenitor of long-duration GRBs.

(7) The photometric, spectroscopic and polarimetric observations of a number of star clusters have led to the studies of their star formation efficiency, age distribution, mass function (MF) and luminosity function. Spatial structure and the interstellar extinction in young open star clusters have also been studied. The slope of the mass function above 1 solar mass for young star clusters (age < 100 Myr) is found to be universal within observational uncertainty.

(8) The observations to detect intra-night optical variability of milli-magnitude amplitudes in radio-quite Quasars have been carried out for more than 30 powerful active galactic nuclei at ARIES. The observations obtained so far, indicate that at least some radio-quiet quasars do exhibit micro-variability, albeit somewhat less often, typically for shorter times, and usually less violently than do radio-loud quasars and blazars. These observations also indicate that there is no basic difference between the central engines powering the radio-quiet and radio-loud quasars.

ARIES is also playing major role in installation of modern observing facilities of international standards namely 3.6 meter glass and 4 meter liquid mirror optical telescopes in the areas of astrophysics and 206.5 MHz ST Radar and a host of other instruments to measure trace gases and aerosol properties in the area of atmospheric sciences. The

Institute would therefore, like to expand its ongoing collaborative programmes with universities and research institutions of the country and abroad. Thus, with its dedicated staff and expanding research facilities, ARIES is expected to make an increasingly valuable contribution to the country's scientific and technological development.

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