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IRAIT: a Telescope for Infrared Astronomy from Antarctica

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Abstract. We present the status of the project IRAIT (the Italian Robotic Antarctic Infrared Telescope), that will be hosted at Dome C in the Italo-French Concordia station on the Antarctic Plateau. We review the main scientific motivations of the effort, and describe the main characteristics of the telecope, which has been completed and is now under test at the Coloti-Montone site, operated by the University of Perugia, and its focal plane instrumentation.

Key words. Antarctica — infrared:general — telescopes — surveys — stars:formation — ism:clouds

The Dome C site (Candidi & Lori 2003), at 3200m above sea level, on the Antarctic plateau, jointly exploited by Italian and French teams in the framework of the Concordia project, presents exceptional cold and dry conditions. Site testing campaigns have been performed during the last years in summer time, and compared to other Antarctic sites (Valenziano 1995; Valenziano & Dall'Oglio 1999). New data extended to winter time are expected in the period 2002-2003 from (Storey 1998; Calisse 2002). Data collected so far, points towards Dome C being one of the best place known on Earth for high-quality, low-sky-background, observations in the mid infrared. Optimistic expectations on the sky conditions foresee that new windows may be opened in the spectral region between 20 and 40 μm, and that the 5-20 μm windows may be broader, more stable and less affected by absorption and emission than in any other place.

Many open problems in star formation, late stages of stellar evolution, planetary physics and extragalactic astronomy would obtain large benefits from an observatory in Dome C, with access to those exotic windows. However several difficulties must be overcome. First of all environmental conditions require robotic, remotely-controlled operations for the infrared telescope. Secondly, the IR–detectors require

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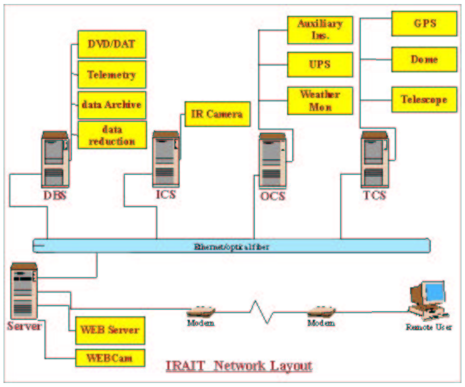

Fig. 1. The IRAIT computer network.

modern closed-circuit cryogenic equipment reaching very low temperatures (4-6 K).

We describe here the IRAIT project (Tosti et al. 1997; Busso et al. 2002), which is aimed at starting a permanent observatory in Dome C. It is based on a 80cm telescope, and it will be completed on the basis of a 4-year plan. The first two years (2003, 2004) will see the construction of the mid-IR camera and the start of its integration with the telescope, which is already built and under test. The following period will then see the expedition and the start of operations in Antarctica. We intend this last phase as our participation to implementation of the Antarctic base of Dome C, and we are ready to offer IRAIT as an European facility. In what follows we first recall the main scientific motivations for our efforts, then describe the telescope and the general design of the mid-IR camera (see also Corcione et al. 2003).

1. Scientific Motivation and Aims

Many exciting scientific targets easily come to an astronomer's mind, when thinking of an infrared observatory in Antarctica. Obviously only a limited part of them can be achieved with an 80cm telescope, but after a comparative analysis of the past and other future infrared projects we are confident that even a moderate-size telescope like ours will provide significant results in many fields.

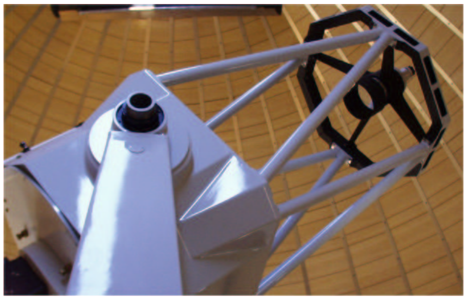

Fig. 2. View of the IRAIT telescope at the Coloti observatory.

After the IRAS, 2MASS and DENIS surveys the whole sky has been covered at almost all wavelengths of the infrared range from 0.8 to 100 m, except in the L' (3.8 μm) and M' (4.8 μm) atmospheric windows. At longer wavelengths, however, the IRAS data suffer for an extremely poor resolution, and surveys with higher resolving power are needed. Observations in the IRAS photometric bands at long wavelengths are extremely important for many astrophysical issues (see below). Although they can be performed from a conventional ground based "infrared" site, they are severely hampered by the sky and instrumental background emission. For this reason, no large-scale surveys have been performed nor are even planned from the ground beyond the 2μm window.

Future space missions in this spectral range are sometimes primarily dedicated to pointed observations, like in the cases of SIRTF (Deutsch & Bicay 2000) and NGST (Angel et al. 1998; Robberto 2003). Otherwise they are aimed at surveys of limited areas (IRIS: see e.g. Onaka 2000). Missions fully dedicated to wide field surveys such as NGSS, a four colors all-sky survey (Seguel et al. 2000)(Seguel et al. 2000), or PRIME, a 0.8 to 3 μm all sky survey (Zheng et al. 2000), are not yet approved. Furthermore, large telescopes (Keck, Gemini, VLT, NGST) are (or will be) equipped with very sensitive imaging, or spectroscopic instruments working in the 3-20 μm range. Some will soon have interferometric capabilities in the same spectral range (e.g. VLTI, LBTI). There is therefore a strong need for establishing exhaustive catalogues of relatively faint sources and atlases in the 3-20 μm range for the preparation and calibration of the observing programmes to be conducted with these instruments. Dedicated telescopes are currently being designed for the wavelengths near 1-2 μm (e.g., VST, VISTA, etc), to provide future targets for telescopes of the 10m class. A similar effort should be done beyond 2 μm, and we believe we can provide it.

As a first application of our Antarctic telescope we shall therefore discuss projects that adopt a survey mode of operation on limited areas in selected fields of stellar evolution studies (e.g. initial and late phases of high and low mass star evolution). For reasons of space we are forced to skip other relevant fields, like studies of the surface composition of asteroids from their mid-IR colors, and extragalactic research, e.g. that devoted to star-bursts in nearby galaxies, which are well within the reach of an 80cm telescope in Antarctica. As an example of pointed mode operation we discuss the possible observations of variable sources like Blazars, a subclass of AGNs.

1.1. ISM and Star Formation

One of the main objectives of IR observations at Dome C, is to perform a deep and large-scale survey between 3 and 20 μm of Southern Hemisphere star forming regions. This will allow a search for very young stellar objects (YSOs), and a correct census of the young stellar population in giant molecular clouds (GMC) and dark clouds (DC). A study of their initial mass function (IMF) will be possible from these observations. We propose three subjects for this mid-IR surveys of star forming regions:

a) *Southern Dark Clouds.* An homogeneous imaging survey, performed at 10 and 20μm, is important to identify easily the YSOs associated with the DCs, and to make statistical studies of low-mass star formation. It will be possible also to correlate the global characteristics of the DC derived from the existing radio data, with the measured properties of the YSOs, obtained from the analysis of their spectral energy distributions.

b) *The Chamaeleon Complex Molecular Cloud.* The Chamaeleon complex is one of the most interesting regions for studying very low-mass star formation, given its proximity to the Sun (D$\approx$160 pc) and its high galactic latitude (b$\sim$ 14° - 17°). The complex is formed by six dark clouds (Cha I, Cha II,Cha III, DC302-16.9,G295-17, and G298-13) extending for about 10 squared degrees. Given its low declination ($\approx$ -78°), the region is particularly suitable for Antarctic observations. New young brown dwarfs can be detected from large scale mid-IR images.

c) *The Giant Molecular Cloud NGC 6334.* The giant molecular cloud/HII region, is unique among the star forming complexes in having at least seven distinct sites of massive star formation detected from radio and far-IR observations. This southern region ($\delta \sim$ -37°), covers an area of about 2 squared degrees, and is considered as an ideal laboratory to study the effects of stellar UV radiation, on the surrounding interstellar medium. Detailed infrared studies of NGC 6334 cover only a small part of the complex. The only large-scale IR imaging survey was obtained with the SPIREX telescope at South Pole, in the narrow and broad-band filters at 3 and 4μm (Burton et al. 2000). Thermal dust imaging at 12 and 20 μm were also obtained toward three centers of NGC 6334 (NGC 6334 F, A, and V)(Kraemer et al. 1999; Persi et al. 1998). All these observations have shown the importance of a more wide thermal survey in understanding the processes of massive star formation.

1.2. Late Stages of Stellar Evolution

Low mass stars (LMS) and intermediate mass stars (IMS), in their late evolutionary stages populate the sequence in the H-R diagram known as the Asymptotic Giant

Branch (AGB). Here they undergo radial pulsations in various modes, which trigger an intense mass loss, responsible for the creation of a circumstellar envelope of gas and dust (see e.g. Habing 1996). This envelope is often opaque to visible photons coming from the central star, due to dust grains condensing above the stellar extended atmosphere; it is nonetheless a source of thermal infrared (IR) radiation, especially in the range 2–40 μm (see e.g. Busso et al. 1996). For this reason, and for the optical properties of silicates, amorphous carbon and silicon carbide (SiC), which are the main constituents of circumstellar grains, these near– and mid–IR wavelengths are a preferred diagnostic tool to investigate the physical and chemical composition of dusty circumstellar environments around AGB stars (Willems & DeJong 1986; van der Veen & Habing 1988; Waters et al. 1996; Epchtein et al. 1990; Guglielmo et al. 1997).

A survey of AGB colors at long wavelengths can therefore contribute to the classification of red objects not seen in the visible, characterize their circumstellar envelopes, establish their mass loss rates, study broad features from dust emission of different compounds. Another important result that can be obtained is the inventory of different AGB types in stellar systems of different properties. It is known, for example, that at low metallicities, like those of Magellanic Clouds or of the Galactic halo, the number ratio between carbon stars and M giants increases, but firm limits of mass within which the C-star phenomenon can occur at different metallicities are not known.

Such limits would be very useful for allowing an improvement in our knowledge on the final phases of stellar evolution and on the nucleosynthesis and chemical evolution in nearby Galaxies, especially for elements like C, N, O and the neutron rich species belonging to the s-process, currently ascribed to AGB stars (Busso et al. 1999). This kind of knowledge can be obtained primarily from stellar systems of known distance modulus, like the Magellanic Clouds, because there the luminosities and, hence, the masses of AGB stars can be determined rather unambiguously (apart from local reddening processes). Searches for C-stars, Mira variables, post-AGB supergiants on their way to becoming white dwarfs, and for the Planetary Nebulae deriving from their envelope loss are key projects for our IR facility. Similar searches were attempted previously in the LMS and SMC; however, we would like to obtain a complete inventory, which is not possible from space-borne experiments of limited life, like ISO (the same will be true for future IR missions). The result can instead be reached today through surveys in near and mid-IR wavelengths from Antarctica.

From the distance modulus of LMC, the luminosities of AGB stars of different mass and the fact that most of their flux is radiated at IR wavelengths, we can estimate the performances required by the observing instrument: these must reach sources as faint as 7 − 8 magnitudes (in the 5-10 μm region). This is within the reach of a survey performed with a moderate-size telescope, provided it is placed in a site like Dome C.

1.3. Extragalactic Variable Sources: Blazars

Some galaxies show a very bright light emission coming from the nucleus of the galaxy, and are, therefore, called active galactic nuclei (AGN). Their luminosity is attributed to the presence of a supermassive black hole of $10^6 - 10^9$ $M_\odot$ (depending on the luminosity) dragging nearby matter into them, and forming a huge accretion disk. Jets coming from the inner part of some AGNs, are detected easily by radio telescopes. Antarctica is an ideal place where to carry out high quality mid-infrared observations, with a relatively low sky background, of the IR continuum of Blazars. They AGNs, having a jet which points toward us, and a variable non-thermal continuum emis-

Effective Primary Dia	800 mm
Clear Aperture	750 mm
Primary focal length	2400 mm
Telescope focal length	16000 mm
Linear obscuration ratio	0.18
Unvignetted Field of View	10 arcmin
Back focal length	800 mm
Cassegrain scale	12.5 "/mm

Table 1. The IRAIT main characteristics

sion, extending from radio to gamma-rays. The Compton Gamma Ray Observatory (CGRO), discovered that blazars (BL Lac objects, flat spectrum radio-loud quasar, highly polarized and optically violent variable quasars), are the most powerful extragalactic γ-ray sources up to GeV energies. Their overall spectral energy distributions (SEDs) show a typical double-bump structure. The first one, can be peaked either in the IR/optical (low-energy peaked blazars LBL, or "red blazars") or in the UV/X-ray bands (high-energy peaked blazars HBL, or "blue blazars") (Padovani & Giommi 1995). The intensity and the polarization of this component exhibit strong modifications, explained in terms of Synchrotron (S) emission from relativistic electrons in the plasma jet. The second spectral component extends from X to γ-rays, and it is generally explained by Inverse Compton (IC) of seed photons, whose origin is still unclear. They can be emitted by the same electron population (Synchrotron Self-Compton, SSC, models) (e.g. Marscher & Gear 1985; Maraschi et al. 1992) or produced outside the jet (External Compton, EC, models) (e.g. Dermer et al. 1992, 1997; Sikora et al. 1994).

A detailed study of blazars flux variations, may provide considerable information on the emitting region dynamics and on the jet properties.Indeed variability has led to the development of shock models, in which the emission of the quasi-steady underlying jet, is boosted by the formation of shocks, travelling down the jet (Marscher & Gear 1985). IRAS observations showed that for LBL, a large fraction of the bolometric luminosity is radiated at mid-IR range (Impey & Neugebauer 1988), with rapid (time scale of weeks) and large amplitude variability. The knowledge of the possible variability modes of blazars, in the near mid-IR bands, is therefore very useful to understand also the significance of the correlation with the flux observed in other bands.

2. The Telescope

2.1. Telescope Design, Mounting and Movements

The telescope built for this research (Fig. 2) is a f/20 Cassegrain-like reflector, with a 0.8m parabolic primary mirror and a wobbling secondary mirror suitable for the specific techniques of IR observations. It will be equipped with a Mid IR–camera built in Italy, and possibly with a near-IR camera built in France. The telescope is presently installed at Coloti (Fig. 3), an observational facility of the University of Perugia[1], where we shall test it and the infrared cameras for both normal operation and remote control.

In order to minimize the telescope radiative emission, the optical system takes into account the size of the IR array. The secondary mirror is used as the entrance pupil so that the edge and the mount of the primary mirror are not visible from the focal plane. The optical characteristics of the telescope are listed in Table 1. The hole of the primary mirror is larger than strictly necessary, so that it will be possible to test the telescope with secondary mirrors having different focal ratios (the one mounted now is actually f/10). (A cold stop is also included in the camera optics, as well as a cold demagnification optical system ahead of the detector, as described later). The telescope has rigid alt–azimuth mounting.

All movements of the telescope are through worm and worm–wheel drivers on the Altitude and Azimuth axes. We used a 360 teeth worm-wheel having a diameter of 640 mm for the Altitude axis and

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[1] see `http://wwwospg.pg.infn.it/`

a 360 teeth worm-wheel having a diameter of 740 mm for the Azimuth axis. The worms were coupled to the motor shafts without any further gear reduction stages, thus the value of the total gear–ratio is 360:1. The position of the axes is revealed by incremental encoders with impulse of zero (18000 pulses/ rev which yield a total resolution of 0".05 on sky for both the axis). The maximum velocity of the movement is of 1.5 degrees /s and the telescope is limited to observations of objects that are at least 15 degrees above the horizon. The telescope is limited to complete azimuth rotations of not more than 270 degrees in the same direction to avoid problems with the cables. We used DC brushless motors for both the axes. The main advantages offered by this type of motor are: high power/weight ratio; high continuous accelerations; low inertia; excellent reliability; reduced sizes; notable capability of overloaded; minimal maintenance; rotation uniform also in regime of low velocity; high efficiency; high velocity; maximum couple to almost all the velocities; low level of noisiness; small generation of heat.

2.2. Telescope Control, Auxiliary Equipment and Software

The motor controllers we used are optimized to work in systems of distributed control in which more than one axis must be checked independently; they manage the position, speed and current loops. The power stage of each motor is integrated in the controller. The controllers are AC powered (18-30 V) and the motors were designed to operate at 24 V. Each controller is linked to the computerized Telescope Control System by a RS-232 serial line. A dedicated software module was developed to manage the controller's instruction set and the communication protocol. All the fast and time–critical functions necessary to control the servo–feedback loop during slewing, tracking, and guiding of the telescope are provided by dedicated programs written using the controller high-level programming language. Other necessary devices that are integrated into the system are a GPS receiver for time synchronization, a conditioning system to protect all the computers and electronic systems and a weather monitor system (temperature, pressure, wind velocity and direction, humidity, snow, clouds).

A dome to protect the telescope has been designed (Gasparoni et al. 2003) and two solutions have been selected: either an insulated double container with a fold-off canopy over it where the telescope can remain unshielded from sides, or a true, more conventional dome. The final choice is pending.

The control system of the telescope is under development in collaboration with the Technology Commission of *Programma Nazionale delle Ricerche in Antartide* (PNRA), who is responsible of the development of a centralized and coordinated management of all the scientific experiments supported by PNRA in Italy. In order to define a control system architecture making the implementation of the software easier, we followed the prescription of the NASA/NBS Standard Reference Model for Telerobot Control System Architecture. It has been designed to operate both from the Antarctica base and, occasionally, from Europe. Remotely, it will be possible to prepare, modify and upgrade the scheduling; use the data obtained by the IR-Camera; control the progress of the schedule; monitor the system with full access to all the tasks; recover system alarms; interrupt and reboot the system; upgrade the system software; backup the system parameters and scientific data; test the optical, mechanical and electronic parts of the system. The object-oriented control software, was designed to run under Windows NT 4.0 operating system and it is written in C and C++. In order to test different hardware solutions for the final design of the Antarctic telescope, we introduced a Telescope Control Macro Language (TCML). TCML is a script language which includes commands to perform all the tasks

Fig. 3. The Coloti Observatory near Montone (Perugia, Italy), an observational facility jointly operated by the Regione Umbria and the University of Perugia.

needed to operate in an automatic way an astronomical telescope. It derives from the past experience we have in building robotic telescopes (Tosti et al. 1995).

3. The Italian Mid-IR Camera

The camera is designed to operate with the Boeing (ex-Rockwell) high-flux Si:As or Si:Sb 128x128-pixel Focal Plane Arrays (FPA) for ground based, high background observations. The pixel size is 75 μm. These detectors can operate with high quantum efficiency in the range 5 - 27 μm (Si:As) or 5 - 40 μm (Si:Sb). So far we acquired experience in operating with such devices using the He-cooled dewar and the acquisition electronics of the TIRCAM (TIRgo InfraRed CAMera) camera (Persi et al. 1994) in its latest upgrade (TIRCAM II, see Persi et al. 2001), developed by the groups in the Institute of Space Astrophysics and Cosmic Physics (IASF), and in the Astronomical Observatory of Torino (OATO). In the final configuration the cooling will be assured by a closed-circuit cryogenic system working at a temperature of about 6 K.

The camera will be equipped with a demagnification optical system, designed to obtain the best compromise between spatial resolution and optimal sampling of the source images: during the test period it will be optimised to observe at 10 μm. In the first phase we plan to use the Si:As array, so here we outline the methods through which we will achieve our goal, divided according to the various sub-systems of the camera/telescope unit, needed to operate such array.

The front-end electronics is fully described in Corcione et al. (2003), and it is an update version of that used for used for the TIRCAM II project (Persi et al. 2001). The photometric system will include standard filters in the mid-IR (the N and Q filters, plus filters at 8.7, 9.8, 10.3, 11.2, 12.4 μm, each 1 μm wide, and a circular variable filter (CVF) for spectrophotometry. Considering the excellent transparency of the atmosphere and the low temperature of the Dome C site, we are performing a series of checks and upgrades to our instrumentation, as suggested by a specialized consulting engineering company (Gasparoni et al. 2003), to ensure that the telescope and camera emissivity is kept low enough to exploit the benefits of the Antarctic site. According to the models we presently have of the final outcome of this improvements, we estimate a transmission efficiency of the whole system near 0.7; the quantum efficiency of the detector is near 0.8; for a PFOV of 3 arcsec/pixel and a very favorable temperature condition (-50 °C), we can derive a background noise of 2.7 mJy in 1 hour of integration at 10 μm; at 20 μm this number should be doubled. A more realistic average performance, for winter operations, may be worse that the given estimates by a factor of two, but this still involves exceptionally small background noise levels, as compared to what can be normally obtained in good astronomical sites with a small telescope.

4. Future Developments

In order to make the telescope fully compatible with the Dome C climatic condition, we shall now implement a series of upgrades to the existing telescope (optimizing thermal characteristics, insulating exposed parts etc.); we shall also finish and interface the IR camera. In the mean time we have pursued the creation of an international network for exploiting IRAIT also as a test bench for future, larger projects. As a result, researchers from the Observatory of Nice (N. Epchtein) and from the University of New South Wales (J. Storey et al.), have been particularly active in providing us with suggestions and help. There is a plan for transforming IRAIT into an Italo-French telescope at 50% share, according to which a second camera, for shorter wavelengths (1.2 - 5 μm) might be provided by a French project. We thus hope that our relatively small instrument can become one of the starting points for building a modern international observatory at Dome C.

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