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ARAGO: A Light Robotic Observatory for Dome-C

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Abstract. The Advanced Robotic Agile Guest Observatory (ARAGO) is a project currently under phase A study to build a light robotic observatory. It is planned to build the 1m aperture telescope in Silicon Carbide, allowing to reach masses of less than 100kg, i.e. 200 to 300 kg including the optical corrector, filters, and instrumentation. The control, as well as high level data processing will be fully autonomous. Thanks to its thermal and mechanical characteristics, a SiC telescope is very well adapted to Antarctica use. In addition, its weight allows an easy deployment, and its full autonomy avoids problems of on site maintenance.

Key words. Telescopes: robotic

1. Introduction

Though Dome-C area may be more hospitable than other locations in Antarctica, the installation of experiments implies severe constraints, coming both from the climate and the logistics, which may imply important costs if one wants to re-use instruments developed for other environments, and/or does not take into account the specificity of the site, the available maintenance, links with the other countries, and the reduced logistic.

In the following we present the basic requirements any visible/IR observatory at dome-C should fulfil, and the Advanced Robotic Agile Guest Observatory (hereafter ARAGO), a project currently under development, aimed at deploying autonomous observatories in harsh, low-maintenance environments.

2. The basic requirements

Any experiment in Antarctica should complain with requirements coming from the specific climatology of the site, the lack of manpower for maintenance, the difficulty in logistics, and the reduced bandwidth for transmissions to other continents. We detail below some of them:

First the instrumentation should be easy to bring and to install. This comes from the difficulties of the logistics (and its cost), and the need to reduce the deployment operations as much as possible. Though this requirement may be easy to fulfil for modest instrumentation, this may be more difficult even with moderately large telescopes. We can derive several requirements:

– The instrument should be compact, to allow its transportation in one, or a lim-

ited number of standard sized containers.
- Its weight should be kept to a minimum. This not only eases the logistics, but it reduces the requirements on the platform and eases the whole installation process, as well as its removal at the end of the instrument life.
- The assembly, setup and adjustment should be reduced to a minimum, easy to do tasks. This means that the instrument should come as pre-integrated parts (including control and processing systems), whose adjustment has been already performed to a large extent.
- Standard parts should be use as much as possible, moreover if more than one instrument of the same type (e.g. an IR and a visible telescope should be installed on the long term).
- The instrumentation should be the simplest as possible, and whenever possible ready to use. This ensure a correct installation process, leading to a working apparatus.
- In the project development, the interfaces should be well defined and documented (electrical, mechanical, thermal, software...)

After its installation the lack of manpower on site, specially during the night, means that the maintenance should be kept to a minimum. We think also that given the difficulties and price of an annual maintenance, the instrumentation should work for years without major interventions, ideally, no maintenance intervention at all. This has several consequences.

- The experiment should be robust and reliable. Complicated instrument operating modes should be avoided. The failure of it may result in a very long period of closure, and/or a large burden on the reduced on-site staff.
- Even a fully robotic telescope needs some periods of maintenance. They should be kept to a minimum, both in number of maintenance operations, periodicity and duration. Our goal is to reach a reduced, simple maintenance, and a major maintenance (depending on the status of the coatings) every five years. In Antarctica, contrary to other sites, its seems not useful to clean the mirrors too often. A replacement of the consumable, e.g. the disks or archival devices may occur more frequently and may has to be performed by the local staff, but this is in form of simple, documented procedures. In any case, the maintenance operations should be as simple as possible, and no tuning or adjustment should be done over at least a year or more.

Since the telescope will be left unattended, this means that its operation will be autonomous, or eventually remote. However it may happen that the local team has to intervene on it, hence the operations should as simple as possible:

- As pointed out the impact on the local team has to be reduced to a minimum, ideally not at all.
- Hence the telescope should be fully autonomous (robotic) in all aspects. We will see below what it does mean in this context.
- Control procedures and human interfaces should be clear and well documented.
- The scheduling, control and data processing should be fully autonomous, reliable, and its result automatically computed and eventually disseminated.

The available bandwidth for telecommunications is expected to be very reduced from Dome-C. However, if autonomous, the telescope has to interact in some way with its users. Also, in case of failure, the diagnostic should be feasible from a remote place. This means that:

- The scheduling, control and data processing should be fully autonomous and reliable.
- The reduction software has to be able to detect several "interesting" event and to

re-schedule the telescope in a dynamic way.

- Some housekeeping and control information has to be transmitted: this does not need a high rate.
- Eventually some results (and/or images ?) may be transmitted in real, or near-real time,
- The need for a large storage of data arises, and its maintenance should be kept as simple as possible. Within a year, terabytes of data may be archived.

Certainly not all of these requirements are specific to the Antarctica. Some of them are common to any remote place, when manpower, or technical staff is lacking. The main difference is probably the climate, inducing severe constraints on the equipments. Also, though logistics may be a problem in many places, Antarctica seems one of the most difficult and costly. In the following we present the ARAGO project, which may be an appropriate answer to the Antarctica specificities.

3. The ARAGO observatory

The ARAGO project Boër et al. (2002) builds over our previous experience on the robotic TAROT experiment (Télescope à Action Rapide pour les Objets Transitoire - Rapid Action Telescope for Transient Objects). In short the primary goal of this 25cm instrument Boër (2001) is the observation of Gamma-ray bursts on alert from a space instrument Boër (2001),Klotz et al. (2003). TAROT is currently in operation at the Calern Observatory (OCA - France) and a second instrument is build for an installation in early 2004 at the ESO, La Silla observatory. Its operations are fully robotic, and it features a high level of data processing, and a dynamic planning and re-scheduling. Lead by the need of deeper GRB observations, as well as the goal of detecting orphan afterglows, we started the conception of a new robotic observatory called ARAGO (Advanced Robotic Agile Guest Observatory) after the name of the leading French physicist and astronomer, which became minister during the Second Republic, and, as such, signed the decree abolishing slavery in the French republic and colonies.

Guided by the constraints detailed above, we started to design a medium sized telescope, light, flexible, easy to duplicate and to operate, and robust, in addition of being fully robotic. During this effort we had some consultation with our industrial partners, and we quickly became aware of the potential of a ceramic, the Silicon Carbide, as a material mature for our application. Several space and aerospace application of this material have already been made by industrials such as BOOSTEC (Tarbes, France) and EADS - Astrium (Toulouse, France). This effort was supported by several scientific institutes in France, and also institutional partners (see below).

3.1. Summary of material properties

We plan to use the SiC-100 ceramic for its several advantages. Table 1 displays its physical properties. In short, the main advantages relevant to our application are its very high specific strength, leading to a high factor of reduction in weight, and to the absence of barrel, and of mirror shape control, either active or passive.

Several manufacturers are able to polish SiC, and there is no limitation to the precision of shape which can be reached for an astronomical application. However, the residual porosity of the material may lead to diffusion: if this is a problem, a robust (though expensive) solution exists in form of a CVD coating.

Among its interesting properties, are its thermal conductivity, which avoid the need of a thermal control of the telescope, when combined with the fact that the whole telescope may be build with the same material. SiC is insensitive to temperature excursions, and gradients.

Finally, SiC has a somewhat low dilatation coefficient, is very robust against me-

Table 1. Physical properties of SiC 100. All quantities are given for 20^{oC} unless otherwise noted

Density	3.2 g/cm^3
Young Modulus	420 GPa
Specific Stiffness	133Mm^2/s^2
Poisson Ratio	0.16
Residual Porosity	3%
Coefficient of Thermal Expansion	1.5ppm/^{o}K at 220^{o}K
Specific Heat	680 J/kg/^{o}K
Thermal Conductivity	180W/m/^{o}K
Thermal Diffusivity	84×10^{-6}m/s^2
Thermal stability	90 MW/m
IR reflectivity	70% at 10.5μm, 99% at 12μm

chanical and thermal fatigue, has no sensitivity to humidity and can accommodate hard environments. Though a precise study of the parts is needed, its machining is relatively easy, and this material is well adapted to replication.

The processing of SiC is typical and is described e.g. on the BOOSTEC web site http://www.boostec.com . It leads to a blank preshaped mirror, which can be polished without major comments.

SiC telescope are already used for space and aerospace applications, such the Hershell sub-mm telescope, the SOFIA secondary, Gaia, several remote sensing satellite, etc... Its use for secondary mirror on ground is increasing. The aim of the ARAGO project, for its technological part, is the construction of a whole SiC telescope.

3.2. ARAGO

The advantages of using SiC in the construction of a ground telescope may be summarized as follow:

- The primary, secondary mirrors, and the structure are made of the same, thermally conductive material. The whole ensemble is in thermal equilibrium, hence there is no need for thermal control. When the temperature varies there is no need to refocus the telescope.
- The high specific stiffness of the material (see table 1) allows the suppression of the control of the mirror shape with the variation of inclination, either using astatic levels or active devices. Another advantage is the reduced width of the mirror. The actual design uses a $\approx$ 30kg primary, and the weight of the telescope part is about 80kg (primary - secondary - structure in between). These properties allows also a very effective low frequency filtering.
- There is no need for temperature control, since the whole telescope is within minutes at the outside air temperature. This is a great simplification with the current telescopes, even in the design of the dome and its temperature control. Another advantage, though it has to be investigated, is the possibility to cool effectively the whole telescope, e.g. for IR applications.
- Combined with the suppression of the barrel and of the control, the weight of whole instrument is reduced by a large amount, the moments of inertia are kept to a minimum, and the center of gravity is close to the primary. This call for a very compact design, allowing less power in the drives, reduced heat dissipation, etc.

Of course, these advantages should be compared to the inconveniences one may find in using SiC. We try to summarize them as follows:

- Though SiC is far less fragile than glass, the whole telescope uses a ceramic. This means that specific development and operation procedure are to be used, avoiding as much as possible manual intervention. Also, specific maintenance tools and procedures have to be developed. Since the aim of the project is to build a fully autonomous telescope, this can be seen hardly as a disadvantage.
- The residual 3% porosity, though it should not be confused with rugosity,

Table 2. Preliminary characteristics of the ARAGO observatory

Weight of telescope parts	$\leq$ 100kg
Total weight of moving parts (including instrumentation)	300kg
Aperture	100cm
Total weight on pilar	600kg
Field of view	1.5 deg
Prototype pixel size	0.7 arcsec
Maximum axis speed	60 deg /s
Maximum acceleration	120 deg /s^2
Time to slew to target	1 second
Filter wheel	6 positions
Camera readout speed	1 second
Camera readout noise for 1 sec. readout	$\leq$ 8e$^-$

may produce diffusion, and a loss in contrast. If this is a problem, a SiC CVD coating cures the problem completely. Scattering is much less a problem at longer wavelengths, but this may introduce constraints for bright objects such as the Sun or the Moon, or eventually bright stars.

It should be noted that ARAGO is a whole observatory concept. Autonomy and non-attended operations will be pushed toward their limits, and maintenance kept as low as possible. Whatever the site, we do foresee re-aluminization only every five years. The telescope will arrive fully adjusted and tuned at its operation site. The assembly will consist in simple, well documented, procedures. Main current parameters of the ARAGO telescope are shown on table 2.

During a five year period, the main maintenance operation will be the cleaning of the mirror, if needed. Every five years (depending on the telescope status) a large maintenance is foreseen, which implies a removal from the site, re-aluminization at the factory, re-assembly and tuning, and reshipping on site. This policy ensure that on site though maintenance is kept to a minimum the telescope will always be at a high operational level, and optically at its best. We plan also that all shipping should be made in standard containers, in order to reduce logistic complexity and cost.

ARAGO is also a whole observatory coming with its "dome", its autonomous control system, sensing devices for the environment, telescope status, etc... The instrumentation, though powerful, will be simple and robust (e.g. 1 telescope for imaging, 1 for spectroscopy...), and will not feature many mode changes. Though it is robotic, hence there is no need to control it either on site or remotely, an interface with the control system will be designed, based on our experience. It will allow to know the telescope status, current operations (e.g. pointing, flat-fielding...), environmental and housekeeping parameters, and, eventually, to take full control of the experiment. This web-based interface will be the same on site and at a remote place. The use of the bandwidth will be extremely low.

ARAGO will also feature a high level data processing system. It will process the calibration data, and normal frames. At present, not only our system is able to process normal images from the sky, but also trailed images for the search of orbital debris Alby et al. (2003). Source lists will be compared to catalog (including data from ARAGO), and to previous images of the same region, in order to detect new sources and their variability. These results will be disseminated. If a new object is recognized as potentially "interesting" according to the user's criteria, a message will be send to other instruments, and also to the ARAGO scheduling system for replanning new observations, eventually with an updated position, as it is already the case for Gamma-Ray Burst sources and satellites in TAROTBoër (2001b).

The TAROT scheduling system, the MAJORDOME Bringer et al. (2001), has already a good efficiency, though its horizon is not large enough for ARAGO. We are currently studying and designing a new system, based on SyncCharts André (1996) which will allow an efficient long term planning and a good short term reactivity Moisan et al. (2002). Both of these system allow dynamic scheduling, and re-planning of the observations, even on the long term, according to local conditions, telescope status, results from the processing system, and external events such as TOO, even when they are time critical (as it is the case for GRBs, see e.g. Boër (2003)).

4. Discussion and conclusions: ARAGO in Antarctica

In the current framework, the design of a 1m SiC telescope is a very cost-effective solution. Its duplication should be very easy, even if the optical solution changes, or in the case of its use at another wavelength. The prototype telescope will be placed at the "Observatoire de Haute-Provence" (OAMP-CNRS) in France, and tested both from a technological and scientific point of view. Constraints for other environments, such as Antarctica will be introduced in the design. At that point, the telescope can then be duplicated and shipped to Dome-C. The maintenance and understanding of the behaviour of the Dome-C ARAGO will be eased with the availability of a demonstrator at OHP, where changes in software (or other changes) can be tested, before on site implementation, which can then be performed remotely and safely.

Another way we want to follow, is the development of a mid-sized telescope (2-3m), which needs the use of a segmented mirror, eventually in form of brazed petals (as for the Hershell satellite). Though the price is more expensive and the design more complicated to study, there is no technical major problems for this size increase. The experience gained in the 1m ARAGO will be directly used for the larger one.

We think that the actual 1m prototype can be developped in a timely manner, and shipped to Dome-C. The material used is very well adapted to cold environments. Its thermal properties allow the use of ARAGO along the year (in infrared) without major problems or complicated thermal control. The reduced weight leads to a cost effective alternative, both in logistics and implementation. The development of a specific instrument for Antarctica warranties an optimized efficiency in operations, i.e. a maximized scientific return. Its development within a regional framework allows for an opening of the collaboration to other partners in an European framework.

We think that the use of ARAGO at Dome-C, and more generally of SiC telescopes, should be very seriously considered, since it alleviates many problems due to the environment and logistics.

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