Innovative enclosure dome/observing aperture system design for the MROI Array Telescopes

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ABSTRACT

The close-pack array of the MROI necessitated an original design for the Unit Telescope Enclosure (UTE) at Magdalena Ridge Observatory. The Magdalena Ridge Observatory Interferometer (MROI) is a project which comprises an array of up to ten (10) 1.4m diameter mirror telescopes arranged in a "Y" configuration. Each of these telescopes will be housed inside a Unit Telescope Enclosure (UTE) which are relocatable onto any of 28 stations. The most compact configuration includes all ten telescopes, several of which are at a relative distance of less than 8m center to center from each other. Since the minimum angle of the field of regard is 30° with respect to the horizon, it is difficult to prevent optical blockage caused by adjacent UTEs in this compact array.
This paper presents the design constraints inherent in meeting the requirement for the close-pack array. An innovative design enclosure was created which incorporates an unique dome/observing aperture system. The description of this system focuses on how the field of regard requirement led to an unique and highly innovative concept that had to be able to operate in the harsh environmental conditions encountered at an altitude of 10,460ft (3,188m).
Finally, we describe the wide use of composites materials and structures (e.g. glass/carbon fibres, sandwich panels etc.) on the aperture system which represents the only way to guarantee adequate thermal and environmental protection, compactness, structural stability and limited power consumption due to reduced mass.

Keywords: dome, array, interferometer, composite structure.

1. INTRODUCTION

The Magdalena Ridge Observatory is sited on South Baldy, part of the Magdalena Ranger District of the Cibola National Forest in central New Mexico. A part of the observatory will be a long-baseline imaging interferometer, the Magdalena Ridge Observatory Interferometer (MROI). This will comprise an array of up to 10×1.4m-diameter "unit" telescopes that can be arranged in four different configurations. All the configurations are "Y" shaped, they differ in dimensions.

The unit telescope will utilise an elevation-over-elevation mounting, and will deliver a collimated beam of starlight of diameter 95mm, which will be fed out horizontally towards a beam-combining laboratory located near the center of the array.

Each unit telescope will be housed within a Unit Telescope Enclosure (UTE). Contrarily to most of the enclosures, the MROI UTE will not have the only purpose to protect the telescope from the surrounding environment, as it will be directly involved into the relocation operations of the array.

The UTE indeed shall be capable of being relocated to any of 28 fixed stations, whose pattern can be seen in Figure 1. Besides during the relocation, the telescope will be attached to the enclosure and retained within it until the whole enclosure/telescope combination has been moved to a new location. This is so as to protect the telescope from the environment during the relocation procedure and to avoid the delays and risk to both telescope and enclosure which would be entailed in removing the telescope from the enclosure at the beginning of the relocation and re-inserting the telescope back into to the enclosure at the end of the relocation procedure.

It is to be noticed that the length of the array arms varies from 23m minimum in the close-packed array up to 200m in the widest array configuration.

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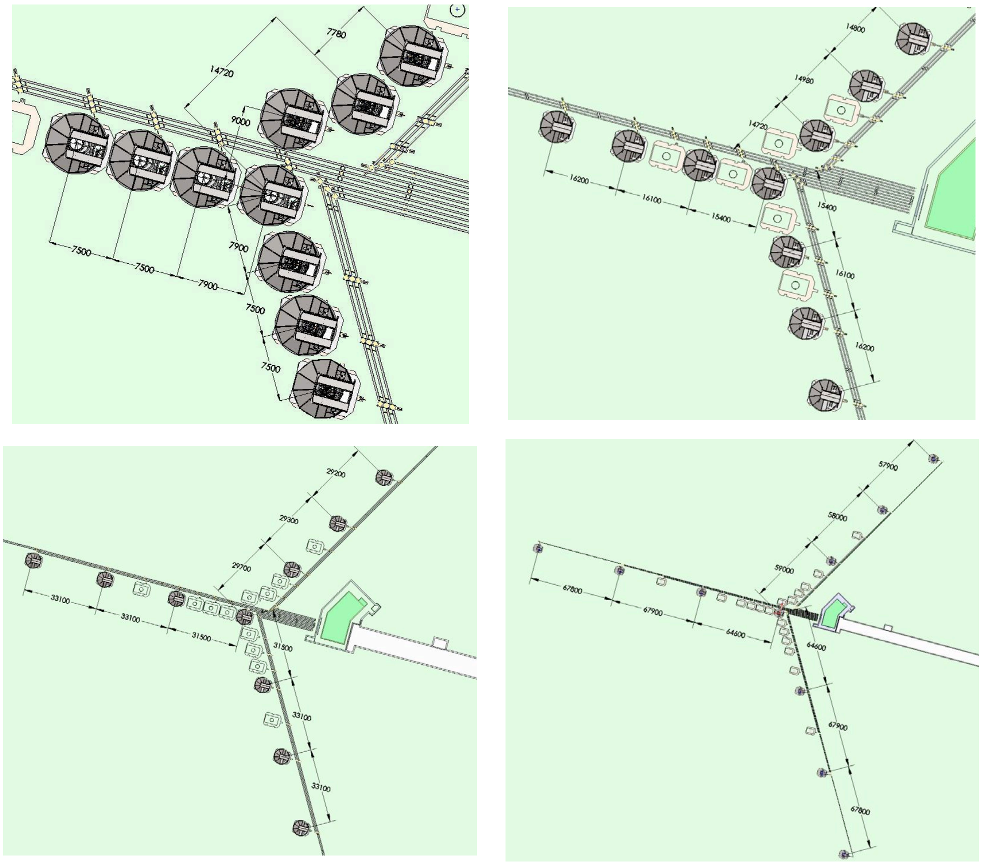


Fig 1. MROI Array configurations

The close-packed configuration represented a critical issue in the development of the design due to the narrow span between adjacent enclosures, which clearly have impacts on the accessibility of the enclosures, on the manoeuvring during relocation and above all on the mutual optical obstruction

Besides the standard performances that are usually required to an enclosure (i.e. structural resistance, structural stiffness, thermal insulation, air treatment during daytime etc.) the driving issues in the design of the MROI-UTE have been its transportability and the mutual optical obstruction when the array is in the close-packed configuration.

These aspects have led to an innovative compact enclosure design, so to reduce both its mass and its overall dimensions.

The present paper focuses on the development of the UTE design, and particularly on its coverage.

2. ENVIRONMENTAL CONDITIONS

The UTE must be designed to operate and survive without degradation within the environments described in this section.

The “Optimal Observing Environment” defines the environment in which the telescope and enclosure satisfy all performance specifications relating to the astronomical observing mode of the telescope.

The “Reduced Performance Observing Environment” is defined as the environment in which the enclosure can be opened and closed, the telescope can be operated, and the allowable mechanical, thermal and electrical stresses in all elements of the enclosure and telescope are not exceeded.

The “Survival Environment” is the environment in which the allowable mechanical, thermal and electrical stresses in all elements of the enclosure are not exceeded, and the structural integrity of the enclosure is maintained. The enclosure will normally be put into shut-down mode before these environmental conditions are encountered.

	OPTIMAL OBSERVING ENVIRONMENT	REDUCED PERFORMANCE OBSERVING ENVIRONMENT	SURVIVAL ENVIRONMENT
Time of day	Sun's upper limb below local horizon	Sun < 15 degrees above horizon	Unconstrained
Air temperature	-15°C to +20°C	-20°C to +20°C	-30°C to +40°C
Air temperature rate of change	-1.5°C/hr to +1.5°C/hr	Unconstrained	Unconstrained
Mean wind speed	1 m/s to 10m/s	0 m/s to 17m/s	0m/s to 35m/s
Maximum wind gust	15 m/s	25 m/s	55 m/s
Wind gust profile	1 m/s/s linear rise, 1m/s/s linear decay	Unconstrained	Unconstrained
Altitude	3,048m to 3,231m (10,000ft to 10,600ft)	0m to 3,231m (0ft to 10,600ft)	0m to 3,231m (0ft to 10,600ft)
Relative humidity	10% to 95%	5% to 95%	0% to 100%
Snow and ice load	< 25mm snow and < 10mm ice on enclosure.	Combined snow load and ice load < 50 kg/m2; combined snow and ice load center of gravity < 1.5 m from center of enclosure.	Combined snow load and ice load < 200 kg/m2
Precipitation	None	None	<120mm/hr rain (peak rate). Hailstones up to 3cm diameter: Minor cosmetic damage to enclosure allowed. Hailstones up to 6cm diameter: Functional and major cosmetic damage to enclosure allowed, telescope and optics protected.
Earthquake load	None	Maximum acceleration less than 0.2g along any axis, in the frequency range 0.5 Hz to 100 Hz	Maximum acceleration less than 0.3g along any axis, in the frequency range 0.5 Hz to 100 Hz.

3. CONCEPT DEVELOPMENT

3.1 Preliminary trade-offs

The dome aperture concept appeared as both the critical issue and the distinguishing component in the dome design since the first studies, as well as the optical blockage appeared as the main driving constraint.

Different solutions for the dome aperture were firstly studied internally by New Mexico Tech MRO project office, which carried out a trade off study among some conceptual design solutions.

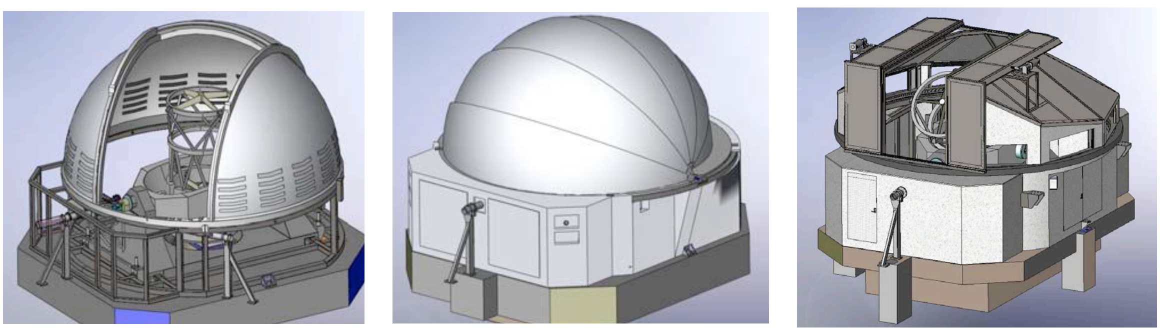


Fig 2. MROI UTE dome aperture different concepts (hemispherical, clam-shell, flat low profile)

The analyzed options (i.e. hemispherical and clam-shell) raised immediately the issues concerning the obstruction of optical Field Of Regard (FOR); those problems concerned not only the telescope that's housed inside the dome itself, but also the adjacent telescopes when arranged in close-packed array configurations.
The aim of lowering the dome structure drove to a flat profile with conventional slit doors.

3.2 Main requirements

The design of the UTE dome is mainly focused on the following requirements:

- no field of regard obstruction inside the UTE for any of the telescope allowed positions
- no field of regard obstruction for the any of the adjacent telescopes in the close – packed array configuration
- a 10 minutes exposure time required
- telescope wind protection
- telescope free movement inside UTE.

The main challenge was consequently to design an enclosure that would be as compact as possible.

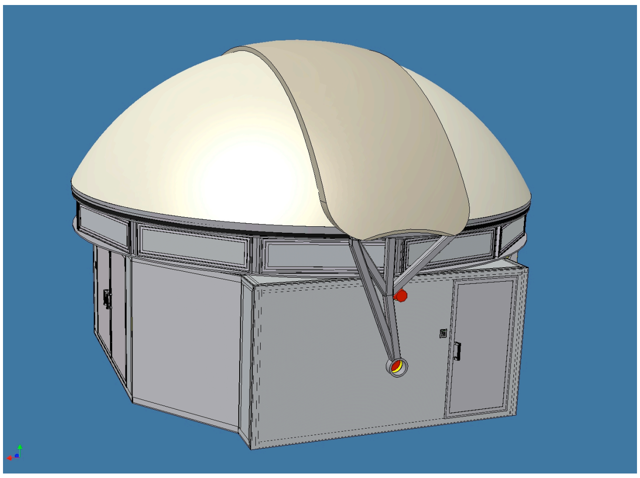
3.3 Final aperture configuration

The exigency of limiting the overall dimensions of the enclosure suggested to maintain the shutter as adherent as possible to the dome and led to a new concept in which the dome and the shutter are shaped onto two concentric spheres. The new concept proposed by European Industrial Engineering (EIE) have therefore been based on a spherical cap – Dome and a spherical lid – Shutter that slides over it.

A key aspect of the design is the idea to move the whole Shutter System from the rotating Dome to the fixed structure of the enclosure. This solution indeed involved some important benefits: first, it allowed to bypass the problem of integrating the shutter motion system into the dome, besides it avoided the need of any cable wrap or any slip ring contact system to transfer the electrical power and signal from the fixed part to rotating one. That choice resulted therefore in a considerable simplification of the Dome System, which became a simple rotating cover and in a significant reduction of the overall dimensions of the UTE.

The motion of the Shutter System have been entrusted to a couple of arms which enable the Shutter lid to rotate around an axis passing through the centre of the Dome/Shutter System. Both the Dome rotation mechanism and the lid have been designed so to allow the Shutter to slide and park onto the dome without obstructing the optical FOR or suffering any collision with the rest of the UTE.

In the earlier studies of this UTE concept the Shutter had been thought to rotate of 90° towards one side of the UTE.
This solution had been later abandoned due to some specific stations of the array where the Shutter would have collided with the Beam Relay System. This is the reason why in the final design the UTE has been provided with a flipping over Shutter which does not uncover the whole Dome, but that can be moved towards both sides, depending on the target and on the aperture position.



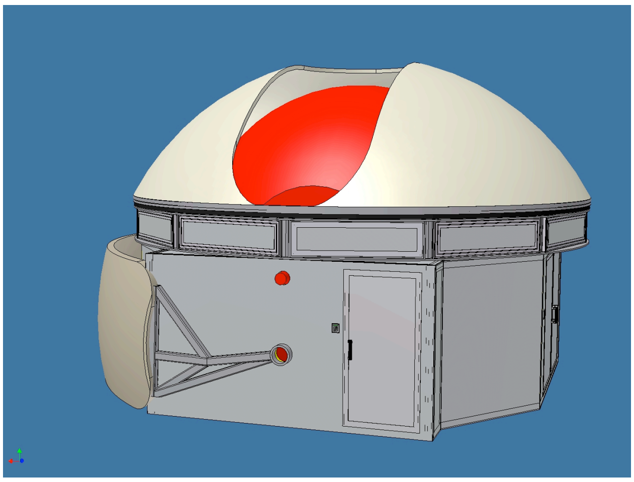


Fig 3. UTE Early studies

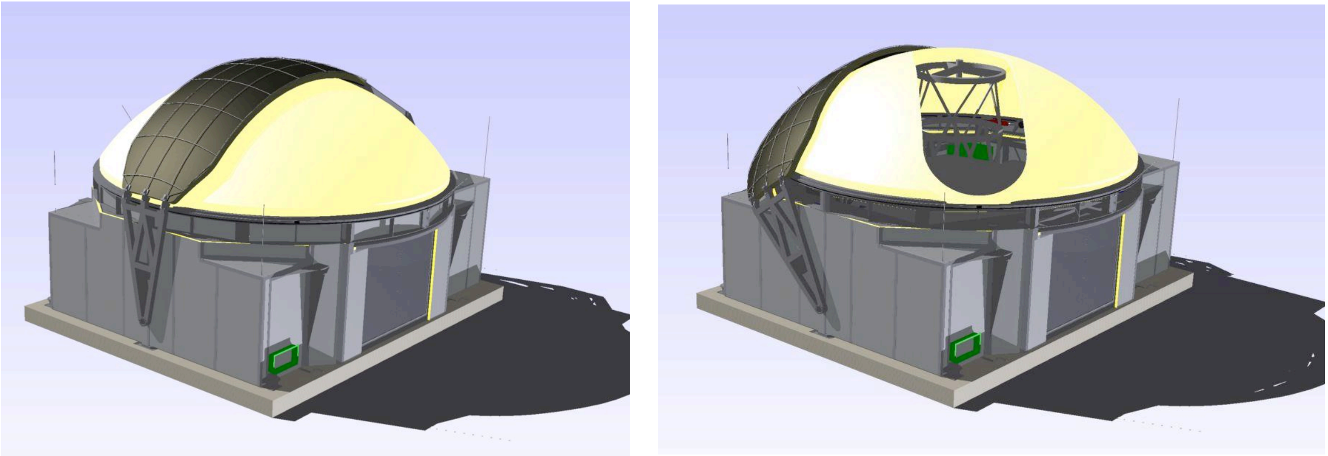


Fig 4. UTE final design with shutter (left) and fully opened (right)

It is to be pointed out that the Dome aperture has been dimensioned so to permit the Telescope to track any target in the sky within a ten minutes exposure time. Thanks to this expedient, the Dome does not require to be rotated during the prescribed exposure time as the aperture is big enough to guarantee clear telescope tracking; that minimize any type of mechanical vibration which may affect the Telescope observation. Moreover this solution avoid to flip over the shutter during any exposure.
Finally, it is possible to state that the UTE hardware allows also to track along with the telescope, guaranteeing till a maximum range of 180° without any interruption; for wider angles a Shutter flip over become necessary.

Another key aspect of the final design is the choice of composite structures for the UTE covering. Composites indeed has been preferred to more conventional solutions such as a load bearing steel structure covered by isolating panels. Thanks to this solution the thermal insulation function has been directly integrated into a self-supporting structure, with significant advantages in terms of the overall dimensions of the enclosure. Moreover composites allowed to design considerably lighter structures and this choice had important reflections on the sizing of the motion systems as well as in controlling the overall weight of the UTE, which represented a critical issue for relocation sake.

3.4 Optical Field Of Respect Verification

The UTE geometry has been designed and checked so to prevent any possible optical obstruction during the observation. A detailed verification has been carried out through a 3D analysis: the Optical Field Of Regard has been represented by the envelope of the telescope optical beam along all the allowable telescope orientations, then all the UTE components has been verified to not interfere with it. The UTE geometry has been verified to not obstruct the Optical Field Of Regard neither of the telescope that's housed in it, nor of the adjacent ones. Particular attention has been paid to the close – packed array configurations.

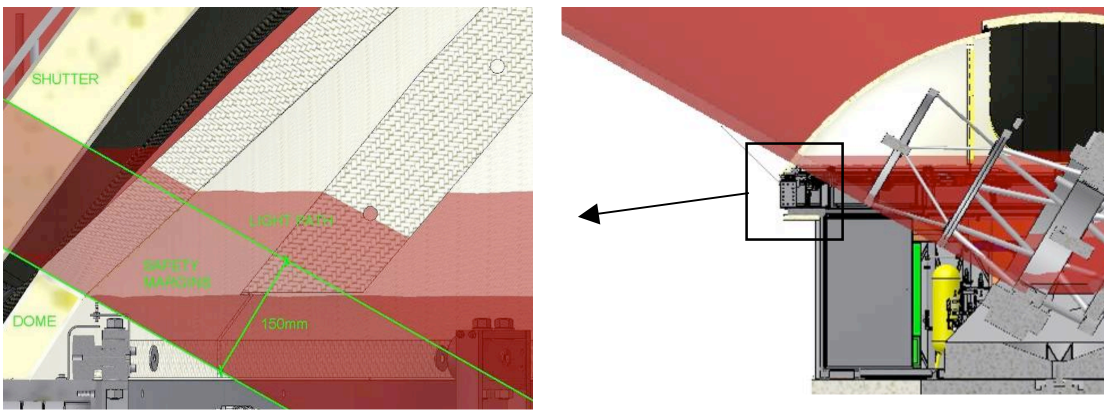


Fig 5. FOR obstruction analysis with UTM detail at altitude angle of 30°

Both the figures highlight that the EIE compact UTE design and its innovative dome aperture allowed to guarantee narrow elevation angles (30° from the horizontal) and extreme closeness of adjacent stations.

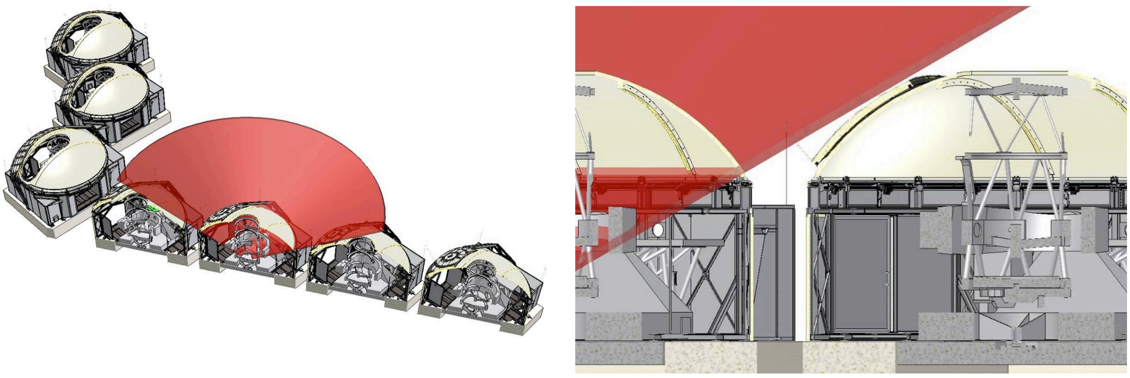


Fig 6. FOR obstruction analysis for close-packed array configuration

3.5 Wind and Finite Element Analyses

The telescope confined inside UTE needs to be protected adequately by wind influence during observation. A campaign of wind simulations with four different direction flows (see Fig. 7) have been performed to assess the aerodynamic behaviour of both the dome and the shutter inside and outside the UTE.
Furthermore, two UTE configurations were studied:

- UTE with louvers closed
- UTE with louvers opened

That has been essential because the louvers are really important system for telescope ventilation/protection purposes. The louvers closed configuration analysis is useful to investigate the protection of the telescope from the wind; the louvers opened configuration gives feedbacks on ventilation performances guaranteed by UTE for the telescope.

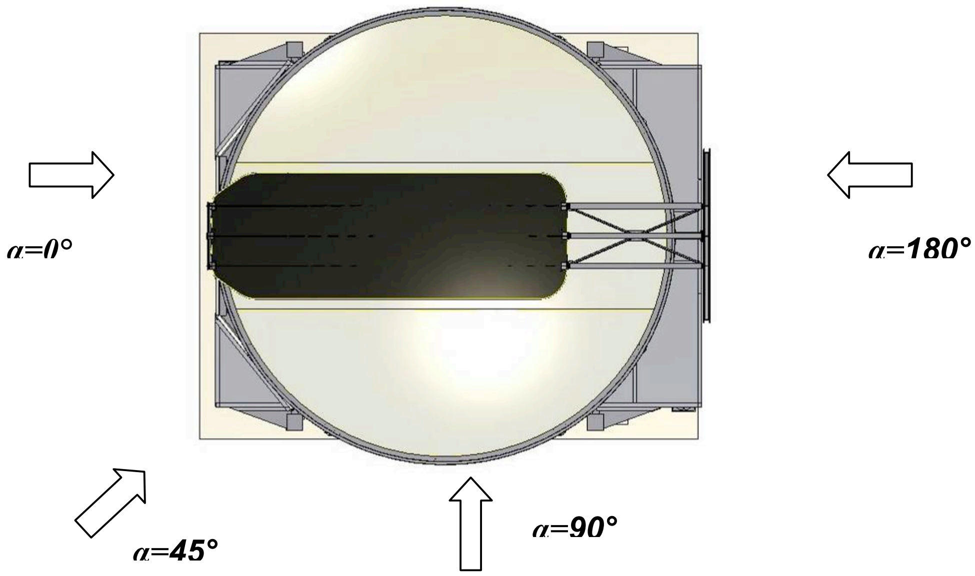


Fig 7. CFD simulations wind directions

The results of these analyses gave good results for what regard the survival UTE behaviour as well as for ventilation and protection of the telescope.

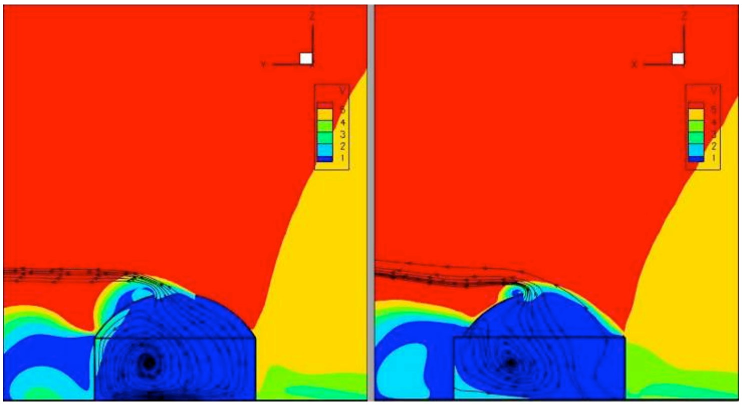


Fig 8. Louvers closed analysis

In particular, the UTE guarantee a reduction of at least 50% of the external wind speed for the lower part of the telescope. At the same time the louvers aperture allow to have in all outside wind conditions a ventilation of 1m/s air flow around the primary mirror.

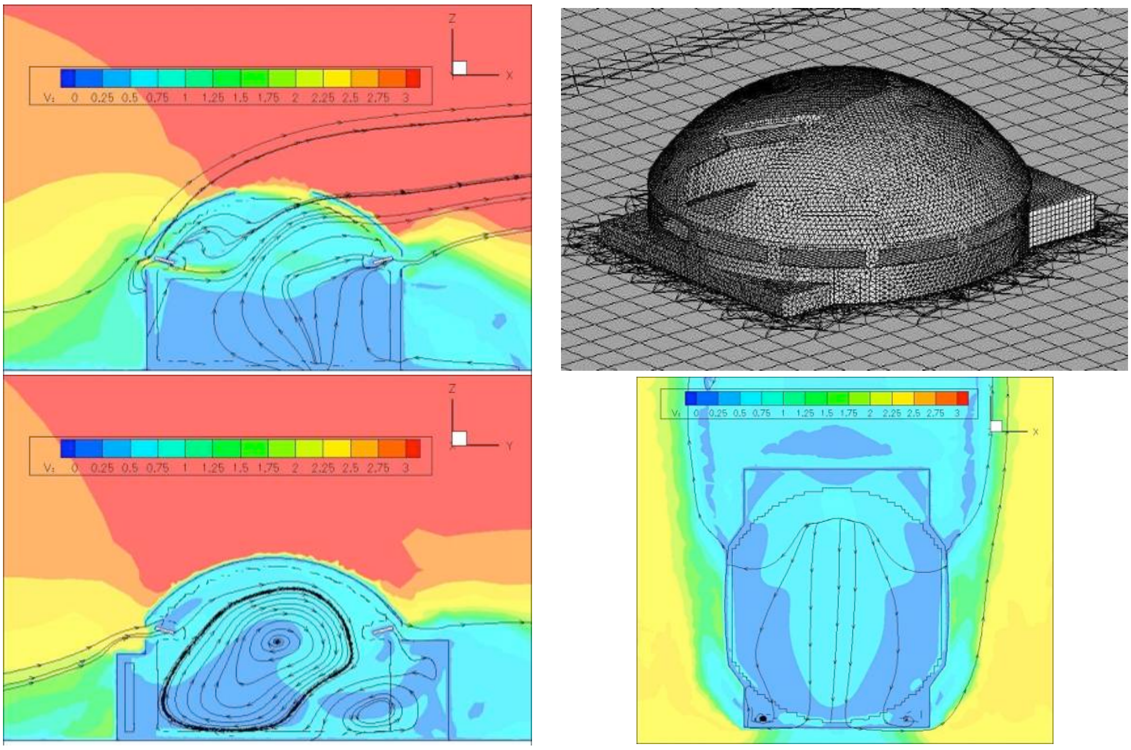


Fig 9. Louvers opened UTE model and post-processing results

Finally, careful finite element analysis (FEA) have been performed to investigate the relative displacements between dome and shutter to guarantee correct behaviour during relative movements between them.

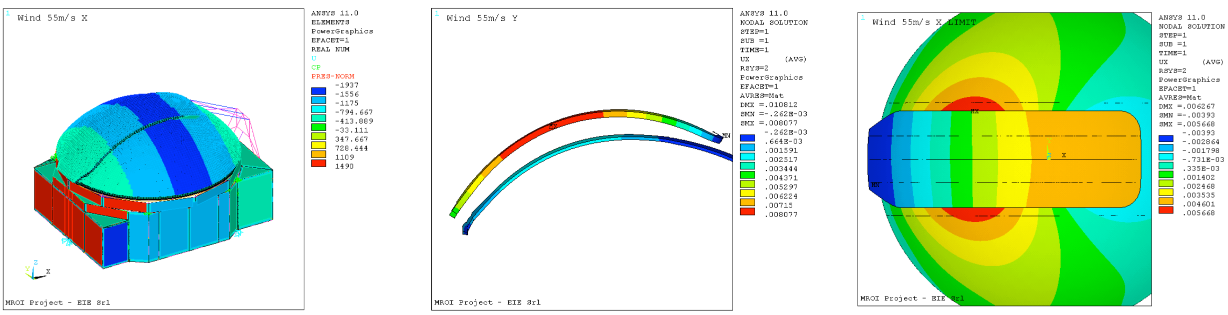


Fig 10. Examples of FEA for the dome-shutter systems

3.6 Telescope free motion inside UTE

The studies of all sub-systems were continuously followed by a parallel work aimed to guarantee that all spaces and volumes were compatible with all the telescope configuration during pointing and tracking operations. The results are visible in the following figure, which highlights very well the careful optimization carried out to have all necessary systems installed properly on the UTE which is at the same time very adherent to telescope motions envelope.

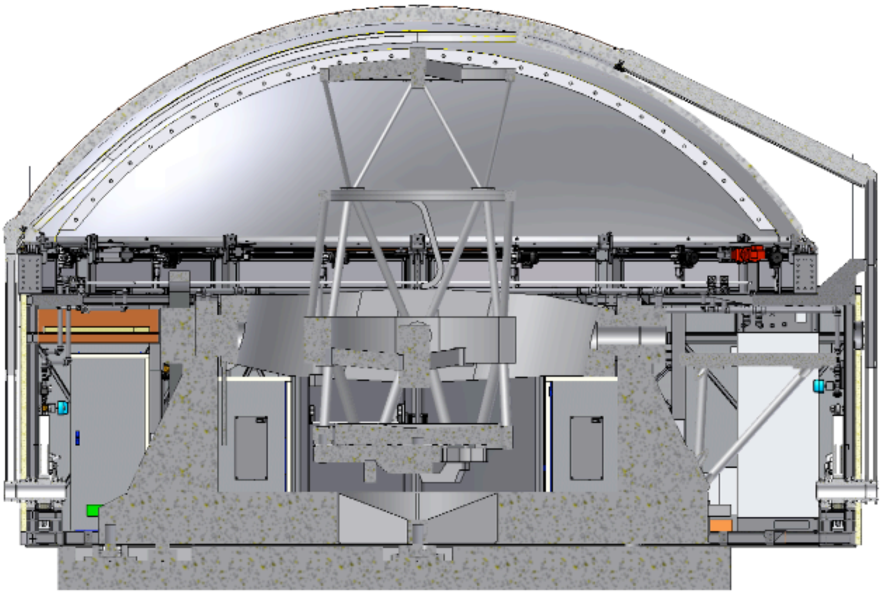


Fig 11. UTE plus UT cross section

4. COMPOSITE STRUCTURE DESIGN

4.1 Dome

The compactness and the lightness requirement for the UTE coverage have been achieved by designing a composite structure.

In order to obtain both a lightweight and stiff structure, a sandwich panel solution have been studied. Sandwich structures indeed allow to obtain much stiffer panels with a minimum weight increase. Besides a proper material choice allows to integrate the thermal insulation function directly in the load bearing structure.

The dome panel is a 60mm thick sandwich, having glass fibre – epoxy resin skins and a 50mm rigid foam core.
The glass fibre reinforcement guarantees adequate mechanical performances of the structure and represents a cost effective solution compared to other fibres.

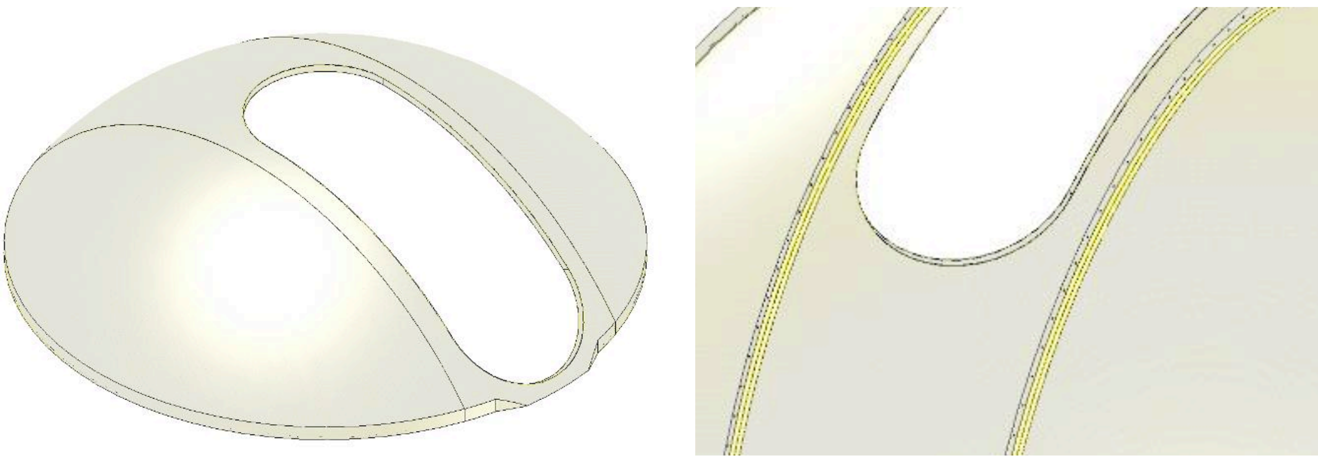


Fig 12. Dome pictures

The dome structure were subdivided in three parts for the sake of transportability; two of these three parts are mirrored so to reduce the number of moulds necessary for the composite skin manufacturing and thus reduce the associated costs. A dome skirt is also provided all around the dome to provide adequate protection to the dome rotation mechanism and the seal from the dirt and the harsh environment of the MRO Interferometer site.

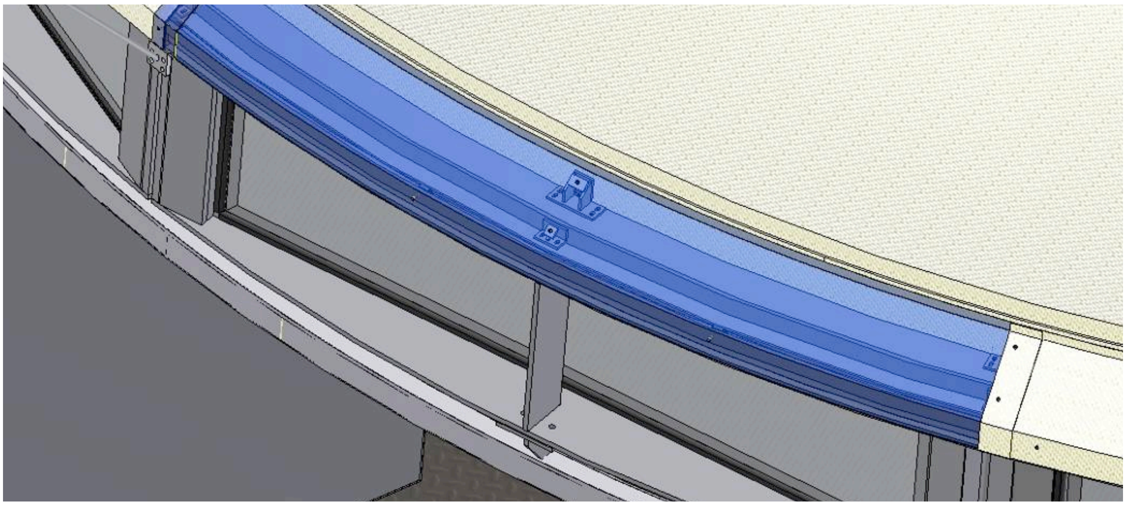


Fig 13. Dome skirt fixing detail

On the contrary, due to the shutter geometrical configuration, calculations pointed out that, compared to the dome, a stiffer panel was needed to guarantee the proper deformations of the shutter and the seal adhesion under gravity, wind and ice loads.

The shutter lid is therefore made of a 110mm thick sandwich panel, having carbon fibre – epoxy resin skins and a 100mm thick rigid foam core. Besides internal stiffening ribs have been foreseen in order to improve the transmission of shear loads between the outer skins.

The choice of carbon fibre reinforcement instead of glass fibre is due to performance requirements.

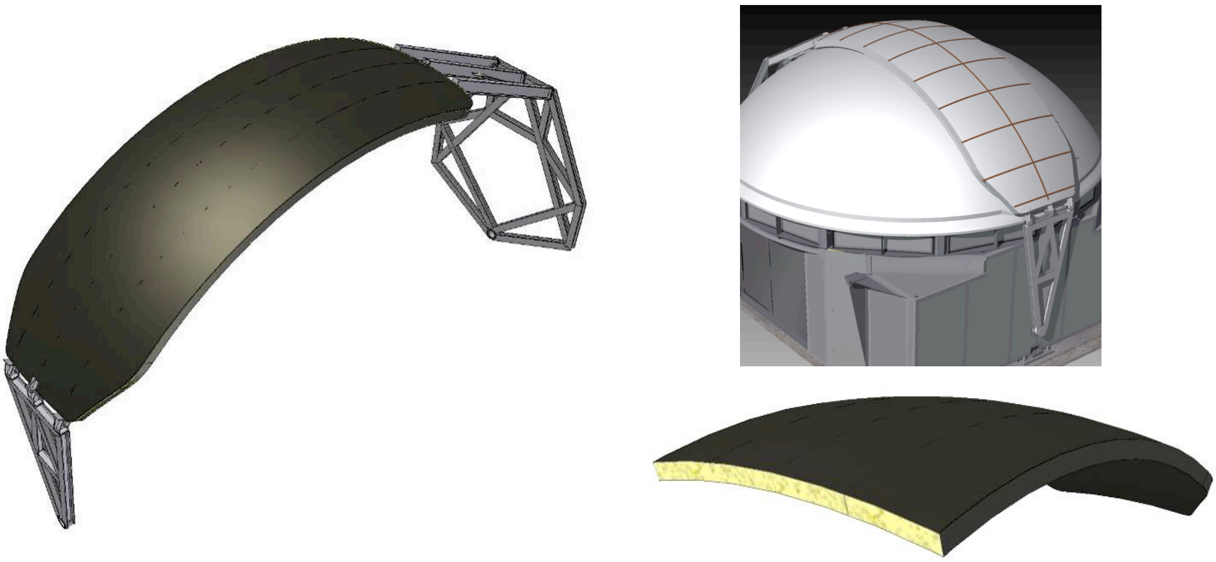


Fig 14. Composite shell and structure pictures

An epoxy resin system has been chosen due to its good temperature and chemical resistance and to its low CTE and shrinkage during cure; moreover epoxy resins are self-extinguishing and have excellent adhesive properties.

Concerning the core, PVC rigid foam core materials do have both good thermal insulation and mechanical properties and represent a cost effective solution.

As each enclosure will be provided with its own air-terminal lightning protection system, the dome surface has been considered to be not directly hit by the lightning strike (zone 1A). Nevertheless, in order to guarantee ultimate protection to the composite structure, a metallic mesh will be embedded into the outer layer of the panel skin.

5. CONCLUSIONS

The development of an innovative enclosure for the Magdalena Ridge Interferometer (MROI) has been presented in this paper. In the close-packed array of the MROI indeed several of the telescopes are at a relative distance of less than 8m center to center from each other. Since the minimum angle of the field of regard is 30° with respect to the horizon, the optical blockage caused by adjacent UTEs in this compact array raised immediately as the key issue for the enclosure design.

The need of an exceptionally compact Unit Telescope Enclosure led to a unique dome/observing aperture system. The shutter design and the extensive use of composite materials mainly mark out the MROI – UTEs from other more conventional enclosures.

Particularly, the shutter mechanism has been moved from the rotating structure to the fixed one. This solution resulted in a drastic simplification of the Dome System which, deprived of all the auxiliary systems and mechanisms, became a simple rotating cover. Besides it involved a significant reduction of the overall dimensions of the UTE.

Finally, the choice of designing both the Dome and the Shutter as self supporting composite structures, represented the keystone to guarantee adequate thermal and environmental protection, compactness, structural stability and limited power consumption due to reduced mass.

Fig 15. UTE definitive concept

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