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Technical feasibility of the reconfiguration of 8-m class telescopes

M. Kraus

European Organisation for Astronomical Research in the Southern Hemisphere

Abstract: Transportation of large telescopes is required for array reconfiguration of next generation optical interferometers. Loads of 1000 tons or more can be reliably handled with available industrial transport technologies. The design of current large telescopes needs to be modified only in some less critical areas to be adopted for relocation. A strawman design on the basis of the VLT telescopes shows a possible architecture of movable large telescopes.

1 Introduction

For future interferometers an array of 8 to 10 m class telescopes is proposed with baselines up to 1 km or even 10 km. This paper treats technical issues related with the transportability of large telescopes to assess the possibility of reconfiguration.

First, existing transport technologies are explored and their usefulness for large telescope transport is discussed.

Second, the design architecture of large telescopes using the VLT as an example is investigated on transportability and necessary design modifications are identified.

Third, for the selection of potential sites, parameters affecting telescope transportability are spotted. In the following the term *large telescope* is used for a typical 8 to 10-m class optical telescope such as the VLT. A weight of 1000 tons is assumed as a conservative estimate for a transportable large telescope.

2 Transport technologies for loads above 1000 tons

A screening of existing technical solutions for heavy weight land transport has revealed four technologies: Crawlers, steel wheels on rails, rubber tired vehicles with a large number of wheels and air cushions. Other technologies exist like magnetic levitation, but they are not considered because applications for comparable heavy weight transport could not be found.

2.1 Crawlers

Crawlers for heavy loads are used since more than fifty years already. Prominent solutions are the NASA rocket transporter and open mine excavators. Vehicles weighing more than

Figure 1: Large open mine excavators with crawlers realized more than 30 years ago.

10000 tons have been constructed and operated reliably for many years. Crawlers have low requirements on the underground preparation, they do not require roads and can move on levelled soil with sufficient characteristics. Due to many moving parts exposed to soil increased maintenance effort is expected compared to other solutions. Problems may also arise when the crawlers move over telescope foundations. Any delicate installations like telescope coupling interfaces need to be protected. The maximum speed achievable is small, therefore for long distance transports crawlers may be less suitable. They can be designed to climb high slopes if necessary,can handle moderate curve radii and can be considered a possible technology for large telescope transportation.

Applications of crawlers for moving astronomical equipment are not known.

2.2 Steel wheels on rails

The traditional technology of steel wheels and rails can transfer large loads and provides smooth and reliable motion. This technology is applied in many cranes and operates under industrial conditions in indoor and outdoor applications. The maximum load which can be supported by one commercially available steel wheel of 630 mm diameter is circ. 60 tons. With a support structure which distributes the load on 4 wheel sets comprising 4 wheels each a load of 1000 tons can be handled. Similar applications have been realized for large shipyard cranes.

The design of a carriage consisting of steel wheels should be possible without technical risk and the associated construction costs are estimated low. However, the rail system to carry the load of a large telescope requires careful civil engineering and the construction cost are estimated high, depending on the available soil characteristics and required distances.

Other disadvantages of wheel/rail systems are that only straight or slightly curved rail tracks can be constructed.

Steel wheels with rails are suitable only for movement of telescopes over short distances and on levelled terrain. Steel wheels on rails are used in numerous astronomical projects, such as the VLA and the VLTI ATs. The VLA uses classical railroad technology with limited wheel loads and not crane type wheels and rails as suggested above.

2.3 Rubber tired module transporters

Modern module transporters are combinations of individual units (modules) which consist of a flat steel frame and so called wheel boogies. The modules can be coupled longitudinally and laterally to units which can carry up to 15000 tons.

The wheel boogies include a hydraulic support system which distributes the load among all wheels and compensates road irregularities.

The module transporters are equipped with Diesel engine driven power packs which supply the hydraulic motors attached directly to the wheels and also the hydraulic suspension system.

Figure 2: Wheel boogie of module transporter.

Due to the free rotation of every wheel boogie the module transporter is very manoeuvrable and can move in any direction and can realize any rotation.

Module transporters are the up-to-date and standard equipment of all modern forwarders for heavy loads and are also common in shipyards for moving ship sections for assembly.

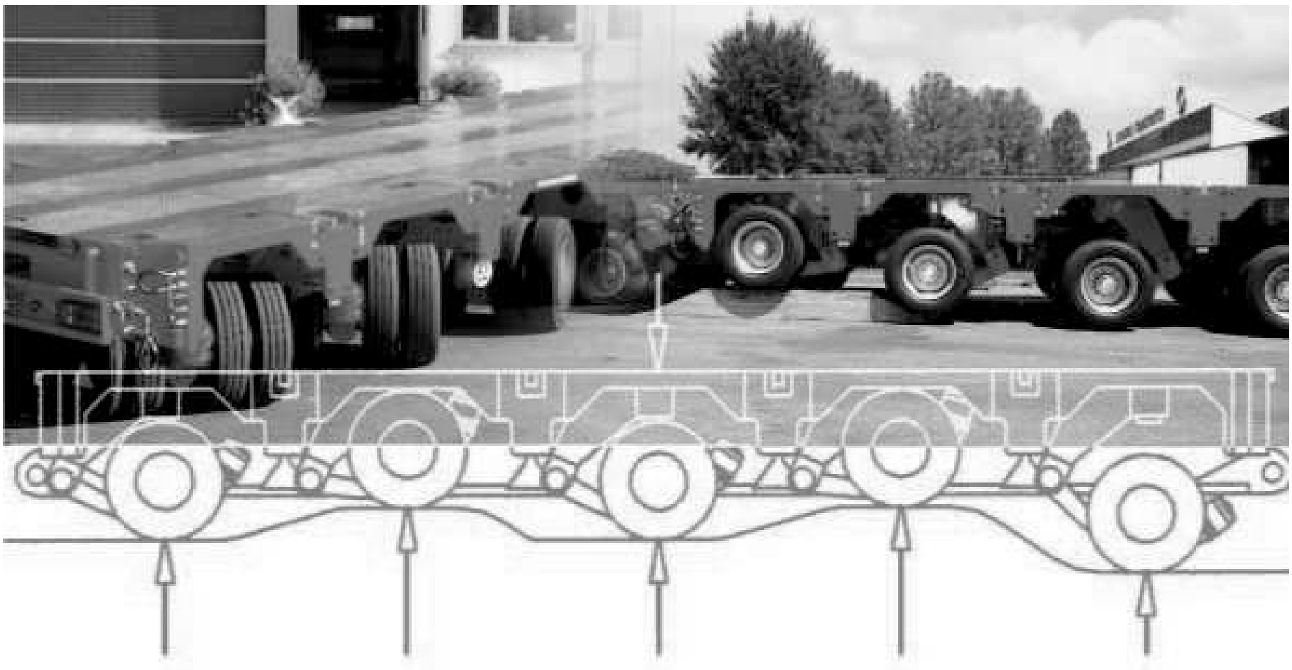

Figure 3: Features of a module transporter.

The transport of a ship section with a typical weight of 1000 tons is a comparable task to the relocation of a large telescope.

For the telescope transport a special frame adapted to the telescope design would be constructed which is equipped with standard wheel boogies and power packs. The cost for a system to move 1000 tons is circ. 2 Million Euro according to supplier information.

Module transporters can move with a speed of up to 12 km/h depending on the load and can negotiate slopes of up to 10% depending on the layout of the hydraulic drive system. The underground can be paved or unpaved surface with sufficient load carrying capacity. Soil with insufficient characteristics must be exchanged against gravel. Dry road conditions are recommended to provide enough friction although wet surface or snow covered road is not excluded.

Module transporters are considered a suitable and cost effective technology for large telescope transport considering carriage and road construction cost.

A modified module transporter is foreseen for the ALMA antenna transport.

2.4 Air cushions

Air cushions are a modern technology for transport of large and heavy items. They consist of a bellow shaped rubber ring and a system of nozzles. Compressed air is supplied to the rubber ring which seals a circular volume against the floor and the air pressure inside the circular volume provides uplift force. Air cushions need smooth concrete or steel surfaces without cracks for efficient operation. Large air compressors are required to provide the necessary amount of compressed air.

Figure 4: Air cushions with control unit

Air cushions can move heavy loads in any direction with very low friction forces. Due to the low friction the fact that they lift and lower the load by few centimetres when switched on or off they can position heavy loads easily and with high precision.

For controlled linear movement a separate guiding and drive system, e.g. by friction wheels is required. Exactly levelled runways are required for the efficient application of air cushions.

The cost of air cushions compared to their load capacity is very low. For a complete system the cost for the underground preparation, compressed air supply and driving and guiding system must be added.

Air cushions are a suitable technology for large telescope transport over short distances. Another interesting application is to use air cushions for the precise positioning when setting down a large telescope on its coupling points.

Air cushions are used in the transport system for VLT M1 cell re-aluminisation.

	Distance	**Curve Radius Radius**	**Slopes**	**Under-ground**	**Best Use**
Module transporter	> 10 km	All curves possible	Max 12 %	Compacted ground, gravel	Fast, Cost effective
Crawler	> 10 km	> 50 m	∼ max 3 % (tbd)	natural levelled ground	Poor Soil conditions
Rails / Steel wheels	< 200 m	Only straight	No slope	Rail on concrete foundation	Short straight distance
Air cushions	< 50 m	All directions possible	No slope	Smooth concrete surface	Fine alignment

Table 1: Summary and comparison of transport technologies

3 Impacts of transportability on telescope design

For an investigation of transportability effects on telescope design, a strawman design of a transportable VLT is proposed. The VLT design is used as an example for a large telescope. Ideas from the VLTI AT design are used for the enclosure. The transporter configuration suggested is close to the VLA transporter, which moves below the telescope and lifts it exactly under the centre of mass.

For the purpose of this investigation the VLT unit telescope can be divided in the following parts:

- Telescope with rotating structures, main mirrors and instruments
- Telescope pier with telescope foundation
- Enclosure rotating part
- Enclosure foundation

3.1 Telescope Structure

The telescope structure with the main mirrors can remain basically unchanged, only the instrument platforms shall be removed or trimmed to reduce the overall volume. Concerning transport vibrations it can be assumed that the VLT seismic requirements cover all accelerations from transportation and no changes in delicate systems like mirror support or bearings are required. The weight of the VLT moving structures of circ. 400 tons is kept.

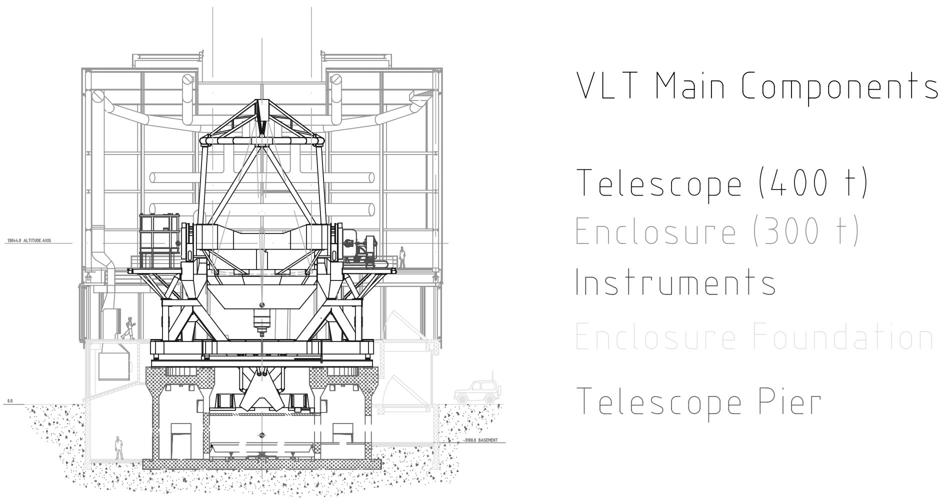

Figure 5: Cross section of VLT with main components

3.2 Telescope Foundation

The telescope foundation of the VLT, which includes the pier and serves as the interface from the azimuth rotating structure to ground needs a complete new design. In case of a transportable telescope individual foundations have to be built at each station. Precisely aligned coupling interfaces need to be integrated in each station where the telescope is detached from ground for transport and anchored after transport. The coupling interfaces must provide high stiffness to allow sufficient control bandwidth and must support all operational and survival loads like earthquake accelerations. An iso-static support with 3 points only may not be feasible because of the high loads per support point. A hyper-static support must be considered which demands high dimensional accuracies for the coupling interfaces.

For the VLTI ATs commercial coupling interfaces are used with a hyper-static configuration. It is assumed that a similar principle can be also applied for large telescopes and the development effort needed is moderate.

A telescope transporter can position its load to a typical accuracy of ± 100 mm. To achieve the final positioning accuracy the telescope pier can be equipped with aircushions near the coupling interfaces which facilitate a precise and automatic centring of the telescope over coupling interfaces.

The telescope station foundations need to be designed with a flat upper surface to allow the telescope transporter to drive over.

3.3 Telescope Pier

Between the coupling interfaces on the foundation and the azimuth rotating structure of the telescope a new pier needs to be designed. If a classical bearing technology is used like hydrostatic bearings or roller bearings the new pier must provide an extremely precise interface with tolerances of typically 20 microns over a distance of 15 meters on the upper surface. In classical non moving telescopes this tolerance can be provided by precision alignment of tracks on massive concrete foundations which can take several weeks and cannot be considered for regular telescope relocation.

The new pier design must also consider the interface for the telescope transporter. A space of typically 1.5 meter height and 15 m width must be provided under the pier structure to allow the telescope transporter to enter and lift the telescope for transport. Alternatively the pier structure can be directly equipped with wheel boogies, depending on the transport frequency and cost optimization.

The design of a pier structure which is based on a foundation with classical mechanical tolerances of ± 0.2 millimetres and providing the accuracy needed for a typical telescope azimuth bearing can be considered a challenging task with the associated risk. Recent astronomical projects with movable telescopes like VLTI ATs or ALMA spent considerable resources in this area having to cope with much lower dimensions and weight.

Alternative bearing technologies like magnetic levitation or active compensation of track errors could be a possible solution.

The design of the pier of a transportable telescope in combination with the azimuth rotation bearing is considered as a critical technical area for the relocation of large telescopes where further development is needed.

3.4 Enclosure

The rotating section of the enclosure shall be reduced in diameter and height to fit tightly around the telescope, similar to the enclosure designed for the VLTI auxiliary telescope. This reduces transport volume and mass. Forces caused by deflections can be better controlled in a more compact structure. The design of a VLTI AT type enclosure for a VLT size telescope is considered not critical.

However, with a compact enclosure the telescope maintenance concept must be revised. A large building which can house a complete movable large telescope similar to the VLA antenna hangar must be considered for the infrastructure of a large telescope array. Minor maintenance shall be performed inside the compact enclosure. Major maintenance requiring large cranes shall be performed with the telescope moved into the telescope maintenance building.

3.5 Enclosure foundation

The non-rotating section of the VLT enclosure needs to be replaced by a different design with decoupling interfaces to the enclosure foundation. There shall also be an opening to let the telescope transporter go under the telescope pier. Also an interface to the telescope transporter to lift the enclosure together with the telescope needs to be provided. Below the non-rotating part of the enclosure a classical foundation is required. The non-rotating section of the enclosure and the associated foundation are considered not critical and can be constructed using classical civil engineering technology.

3.6 Strawman design summary

The proposed strawman design of a transportable VLT considers design concepts from several existing astronomical projects. The telescope design is taken from the VLT unit telescopes, the enclosure architecture is similar to the VLTI ATs, the transporter concept is the same as used

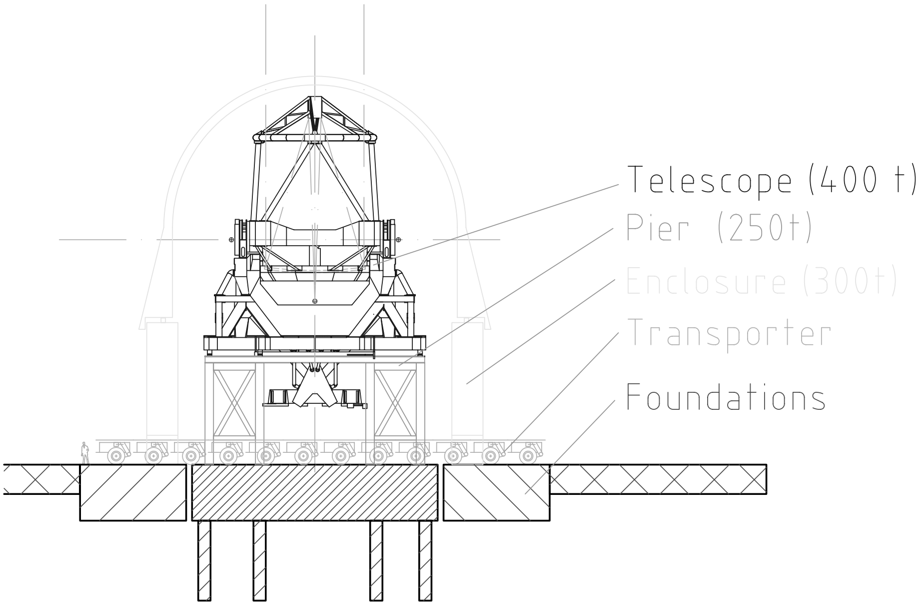

Figure 6: Strawman design of a transportable VLT

in the VLA and the transporter technology is used also in the ALMA antenna transporter. Only existing technologies used also in these projects are considered.

The only area where development is needed is for the telescope pier and the attached azimuth bearing.

Further developments of telescope specific technologies especially in the area of active correction and compensation may provide savings on mass and relaxation of alignment and fabrication tolerances.

4 Site selection aspects

Besides the astronomical and atmospheric parameters also the telescope transport needs to be considered in a possible site selection. The main issue is the construction of suitable roads which may become a significant cost factor. The telescope transport should be limited to dry road conditions although transport on wet or snow covered roads is technically not excluded. The road slope should be limited to circ. 3%. Higher slopes are technically possible but increased complexity of the transporter and transport operation would be the consequence.

A road with a width of circ. 20 meters needs to be constructed with the associated earth movements. Soil with insufficient load carrying capacity or rock which requires extensive blasting would increase the road construction cost substantially. If the foreseen cannot be a plateau, the road construction issue shall be considered very early.

The above discussed transport technologies would not be suitable for telescope transport on ice as found in Antarctica. Specially designed crawlers may be an option but the maximum load would have to be reduced. Also ergonomic problems linked to the environmental conditions would have to be solved because heavy load transportation always requires human intervention, for example for the telescope decoupling.

5 Conclusions

Reconfiguration of 8 to 10-m class telescopes appears to be feasible with present technologies. Reliable and cost effective industrial solutions are available for transport of much heavier loads. Present large telescope designs would have to be adapted in some limited areas only for transportability. Adapting novel telescope technologies and design strategies as envisaged for OWL will further improve also transportability.

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References

Surdej, J, et al, 2004, Proceedings of the 37th Liège International Astrophysical Colloquium