EIE GROUP

International Conference

Submillimeter and Millimeter Astronomy: Objectives and Instruments

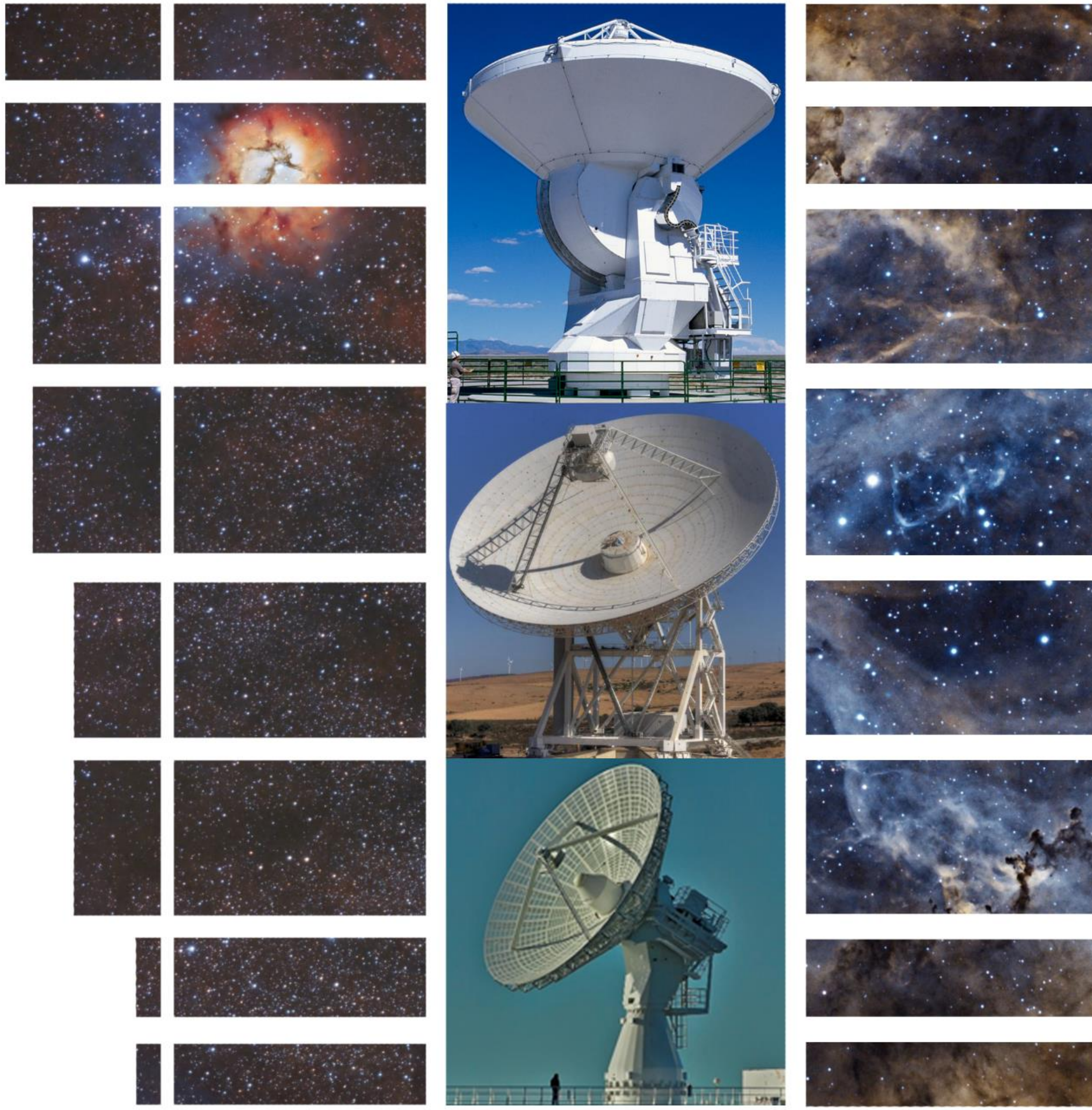
AstroSpaceCenter, Moscow

12-16 April 2021

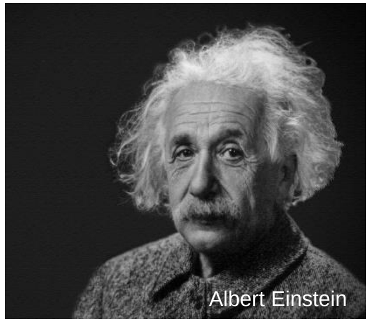
G. Marchiori, M. Tordi, M. Scomparin

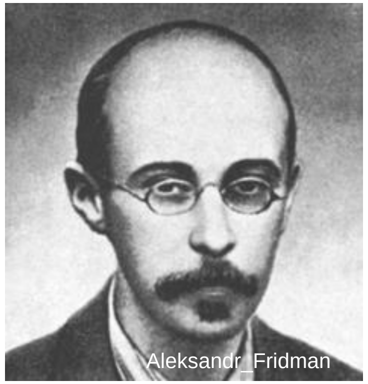
On the Development of Radio-Antennas for mm/sub-mm Observations

An industrial perspective



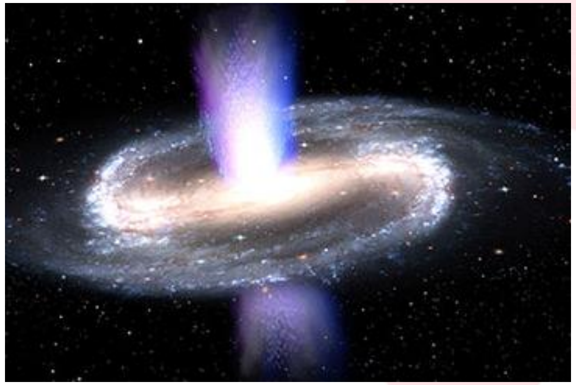
Theories. Experiments.





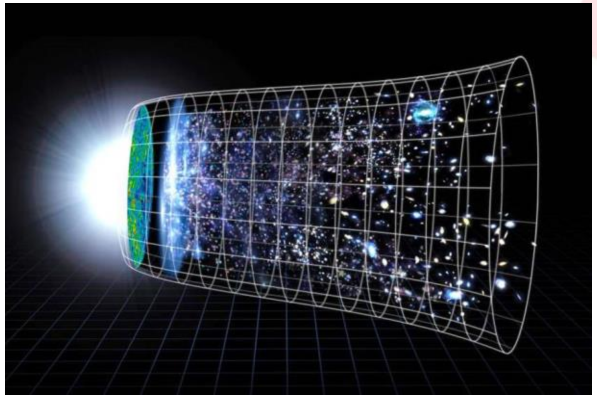
- Standard Model of Particle Physics
- Theories of Modified Gravity
- General Relativity & Gravitation
- Field Theory
- Quantum Mechanics
- Others

Relativistic Astrophysics



- Supermassive black
- Plasma,
- Gravitational waves
- High energy phenomena;
- Galaxies
- Active galactic nuclei
- Interstellar medium (molecular clouds, dust and star formation)
- …

Cosmology



- Lambda-CDM Model
- Inflation Theory
- Gravitational waves
- Dark Energy;
- Early Universe
- CMB
- Baryon asymmetry
- …

EIE Group Srl

ASTRONOMY & BIG SCIENCE

EIE Group operates globally since 1989 and it is recognized worldwide for its expertise in leading and managing complex engineering projects, delivering complete turn-key systems & subsystems for Astronomical Domes, Telescopes, and Radio/Sub-mm Antennas.

AEROSPACE & DEFENSE

EIE Group provides a wide range of services and engineering solutions for the aerospace industry, including design and realization of optical, mechanical and thermal ground support equipment.

About Us

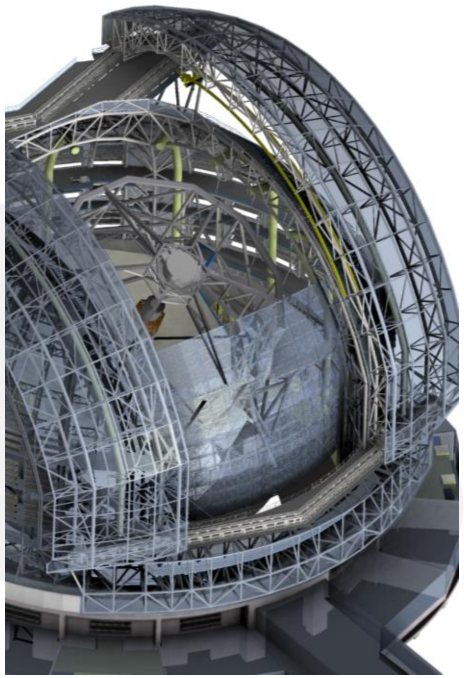
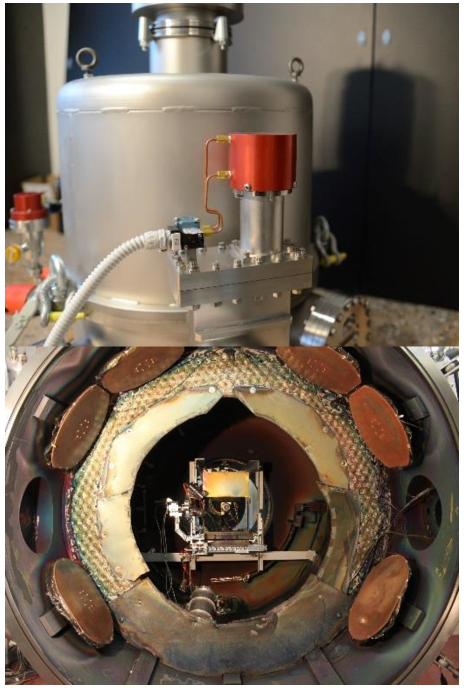
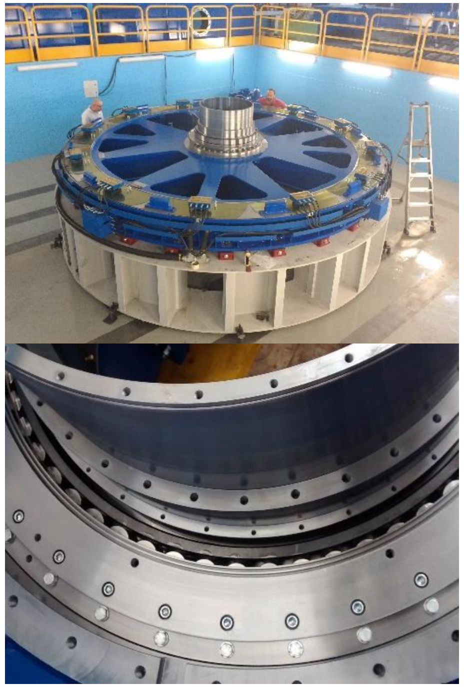
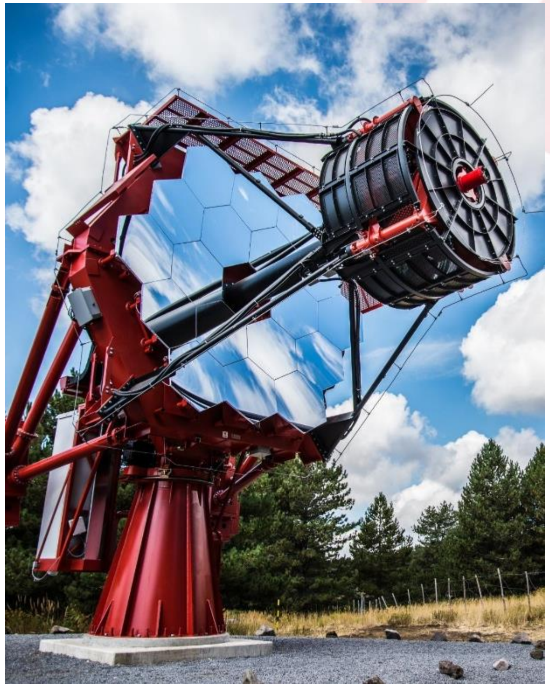
EIE GROUP is an International EPCC Company, operating globally in Big Science areas such as Astronomy, Astrophysics, Aerospace, Large Scientific Technological Facilities and Renewable Energy.

Our Mission

Promoting technology and scientific innovation through products and services for the Industry and Science, and generating value for its clients and scientific partners.

Our Vision

EIE GROUP intends to consolidate and reinforce its position as an international Leader in the design and development of cutting-edge astronomical projects, scientific instrumentation with high technological impacts, defense applications.


Our Locations

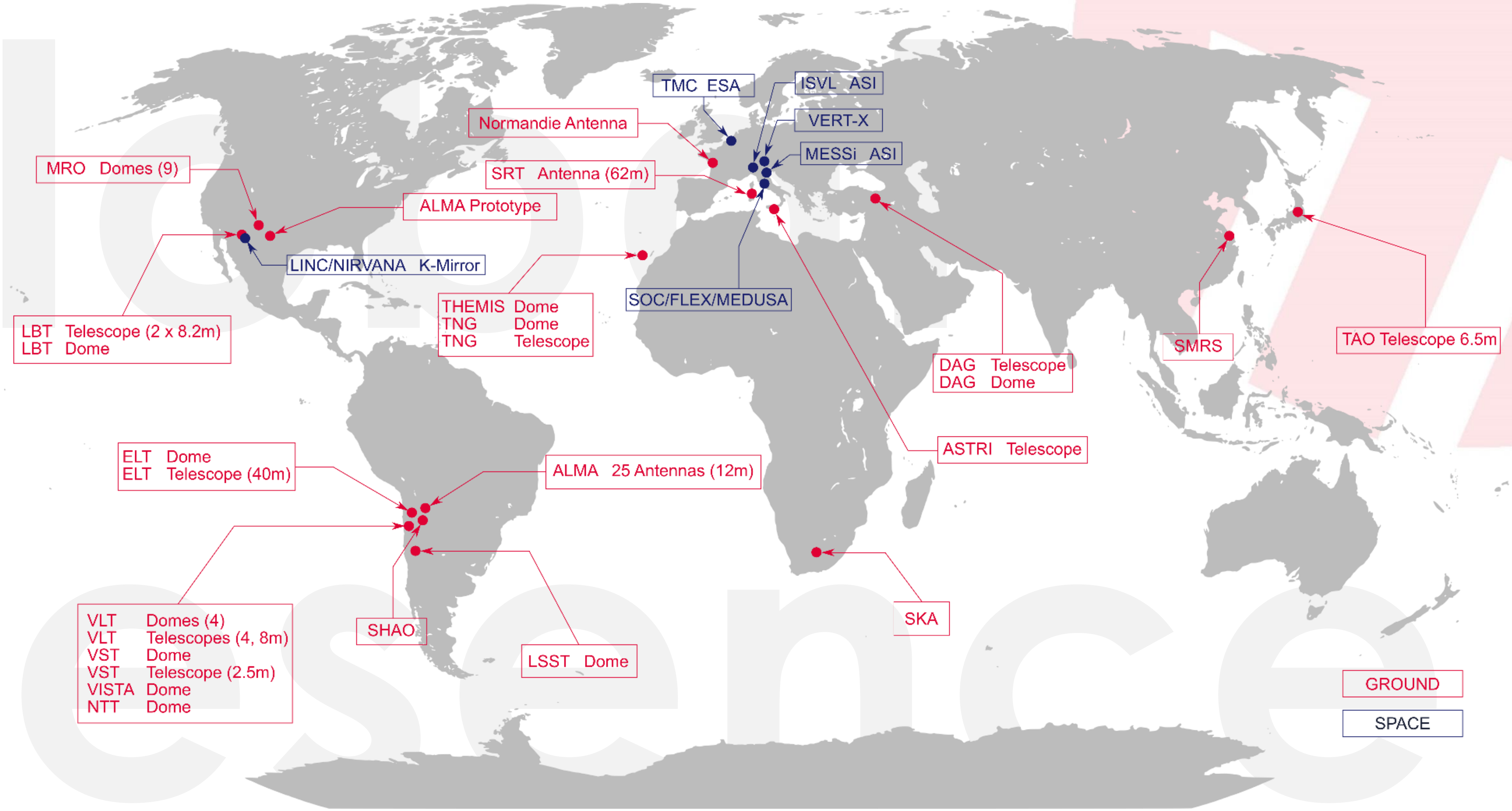
ITALY
EIE GROUP Srl
Via Torino, 151A
30172 Venezia-Mestre

CHILE
EIE CHILE
Santiago de Chile

USA
EIE USA
Tucson (AZ) *(ongoing)*

Global Presence

CHILE • FRANCE • ITALY • JAPAN • NETHERLANDS • SOUTH AFRICA • SPAIN • TURKEY • USA • CHINA



EIE PROJECTS AND REALIZATION

EIE and ALMA. Beyond Excellence.

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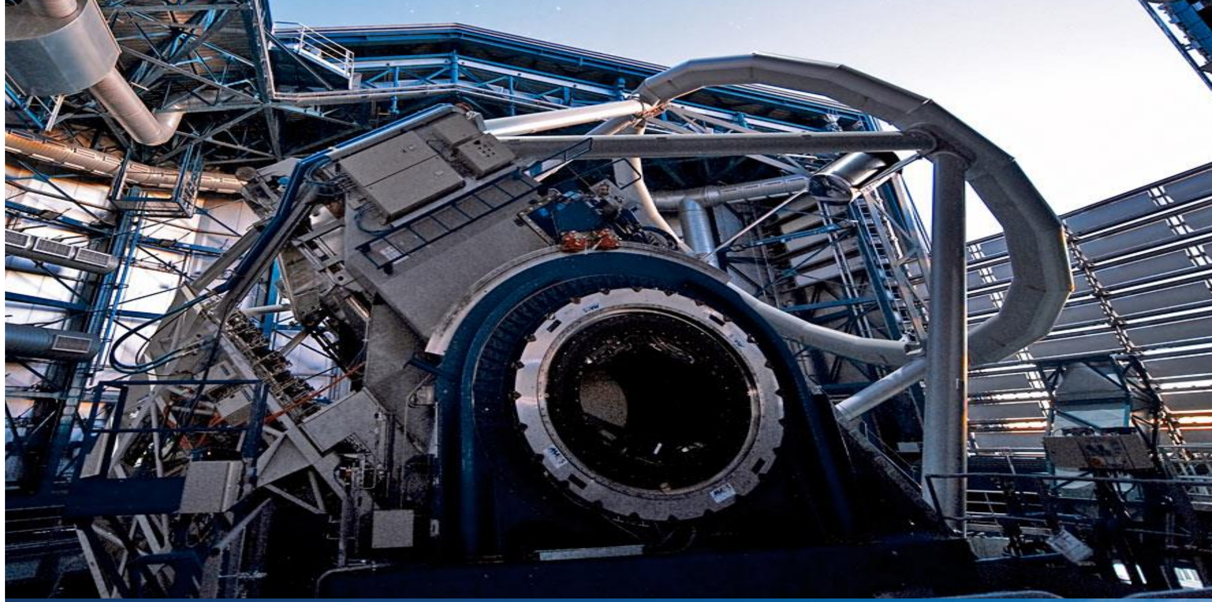
OUR ROLES & RESPONSIBILITIES

EIE operates in the field of large astronomical projects as project leader for what concerns the design and engineering part. Depending on the project size and complexity, the manufacturing, transport and installation can be performed in cooperation with other companies.

Two major examples are for instance the four VLTs and the Atacama Large Millimeter Array.

- Very Large Telescopes – Consortium, EIE (sub)
- Large Binocular Telescope – Consortium, EIE (sub)
- ALMA – Consortium AEM, EIE (prime)



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ON THE DEVELOPEMENT OF NEW SCIENTIFIC INFRASTRUCTURES

- On the basis of our past experience in large astronomical projects, not only specifically related to radio-mm science, but also for what concerns large optical telescopes like VLT, LBT, etc., we would like to provide some information on how such projects evolved, from a rough initial idea to the first light of the instrument.
- Without claiming to be applicable to every context, nevertheless such experiences can provide a useful insight on how a fruitful collaboration between companies and scientific institutions can lead to the realization of astronomical facilities.
- In general, the development of such demanding research infrastructures requires the convergence of scientific requirements and engineering specifications.
- Furthermore, it is of outmost importance to develop a project structure which obeys to managerial criteria, in terms of definition of roles and responsibilities, information management (configuration management, repositories, etc.), schedule management, financial flows during the project (particularly during the construction phases), risk management.

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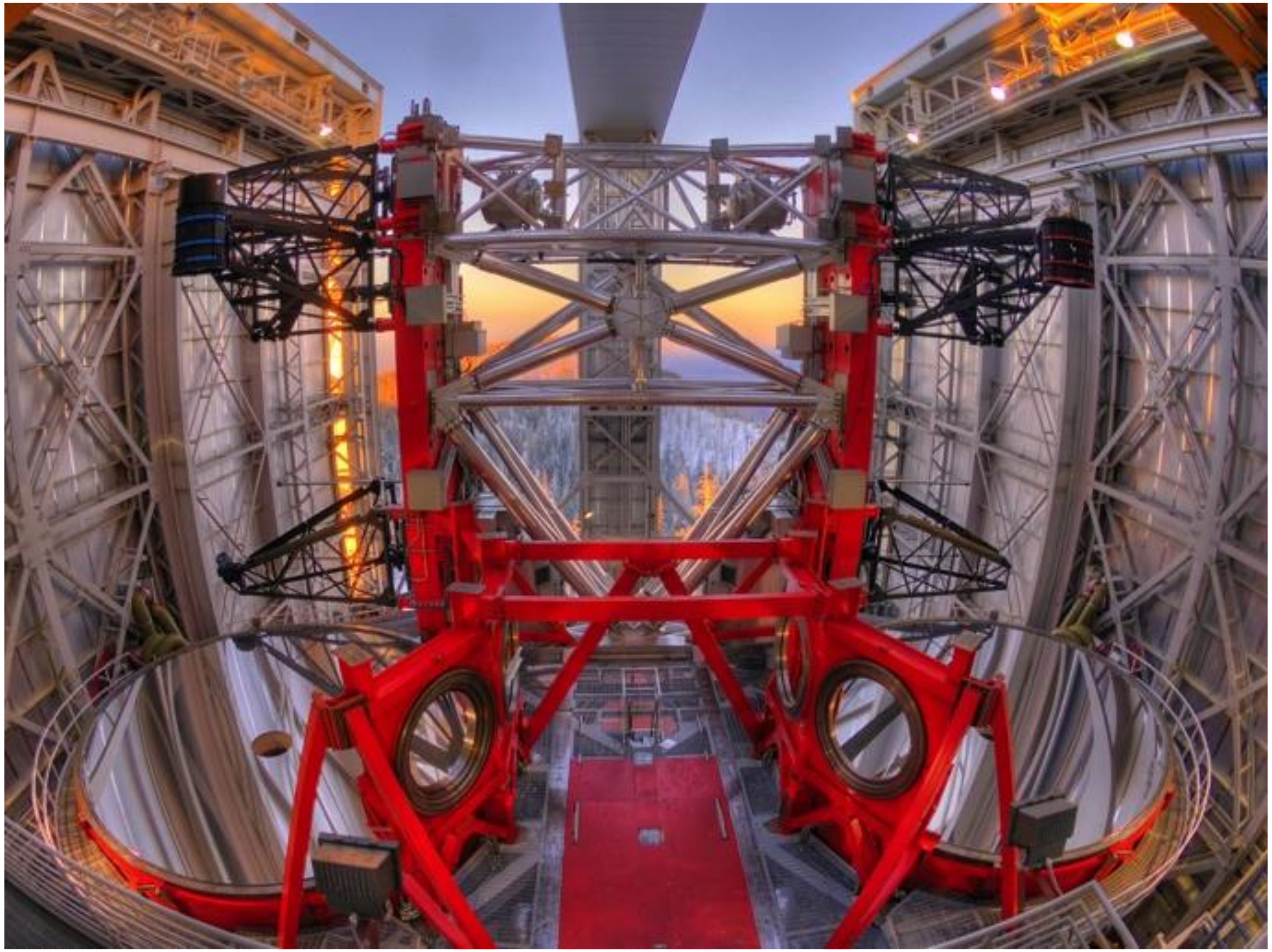
ON THE DEVELOPEMENT OF NEW SCIENTIFIC INFRASTRUCTURES

- During today's and tomorrow's conference sessions, several talks provided and will provide information about the scientific side (scientific case, site selection, instruments [tomorrow]).
- The definition of the science case provides the motivation by which the design and construction of the facility is required.
- The involvement of engineering and construction companies at an early stage helps in properly address the project in terms of budget definition and technical feasibility.
- On such a basis, we would like to suggest a possible roadmap towards the implementation of a sub-mm observatory.
- The roadmap is also meant to be a way to present what kind of information are typically necessary to develop the design, and when.



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EARLY STUDIES & CONCEPT DESIGN

Top Level Requirements

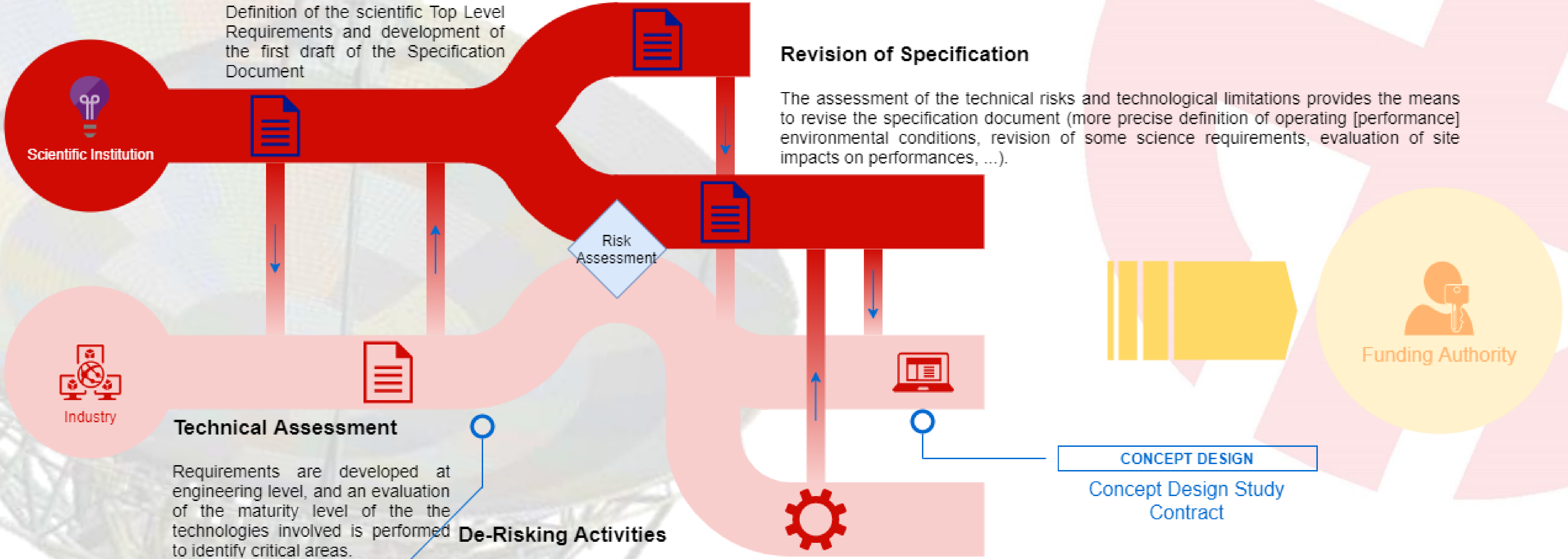
Definition of the scientific Top Level Requirements and development of the first draft of the Specification Document

Sites Surveys

Identification of suitable sites for the establishment of the observatory.

Revision of Specification

The assessment of the technical risks and technological limitations provides the means to revise the specification document (more precise definition of operating [performance] environmental conditions, revision of some science requirements, evaluation of site impacts on performances, ...).



Technical Assessment

Requirements are developed at engineering level, and an evaluation of the maturity level of the the technologies involved is performed to identify critical areas.

De-Risking Activities

Alternatively, depending on budget availability, a de-risking activity can be initiated to improve the Technical Readiness Level of some critical technologies. For extreme submm/mm antennas, this might refer to the development of specific solutions for segment phasing, the development of cost-effective solutions for low roughness panels, thermal management.

INITIAL STUDIES / FEASIBILITY

Self-funded, in-kind contribution, ordinary budgets

CONCEPT DESIGN

Concept Design Study Contract

DE-RISKING ACTIVITY (HW DEV.)

Prototyping Contract

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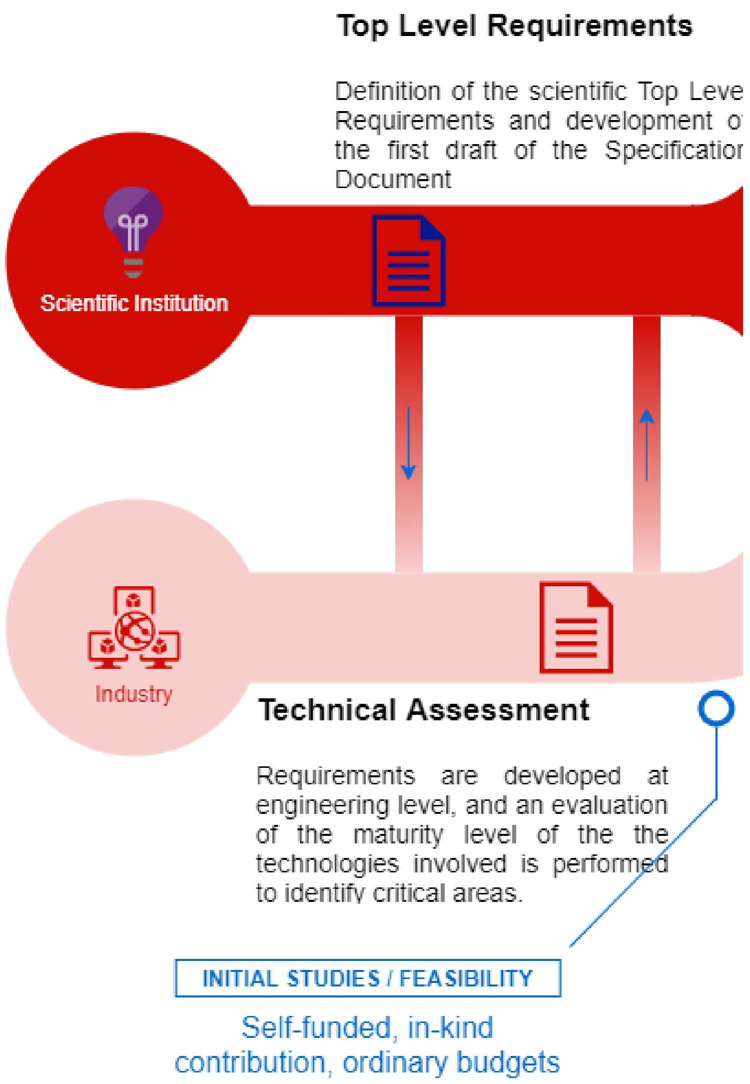
EARLY STUDIES & CONCEPT DESIGN

Expected outputs – INITIAL STUDIES

- Science Case
- Top Level Requirements
- Technical Assessment & Risk Analysis
- Overview of possible sites for installation, including (past site characterization from the astronomical point of view):
  - Detailed and informative descriptions about logistic, i.e.:
    - Availability of roads from main connection points like harbours, airports, main cities to the installation site
    - On-site availability of power, water, TLC, including a short technical description (voltage, maximum power, outages, bandwidth, etc.)
  - Typical meteorological conditions during the year, in order to assess the time available for on-site activities.
  - Any available information on site seismic conditions
  - Geotechnical Inspection reports if available



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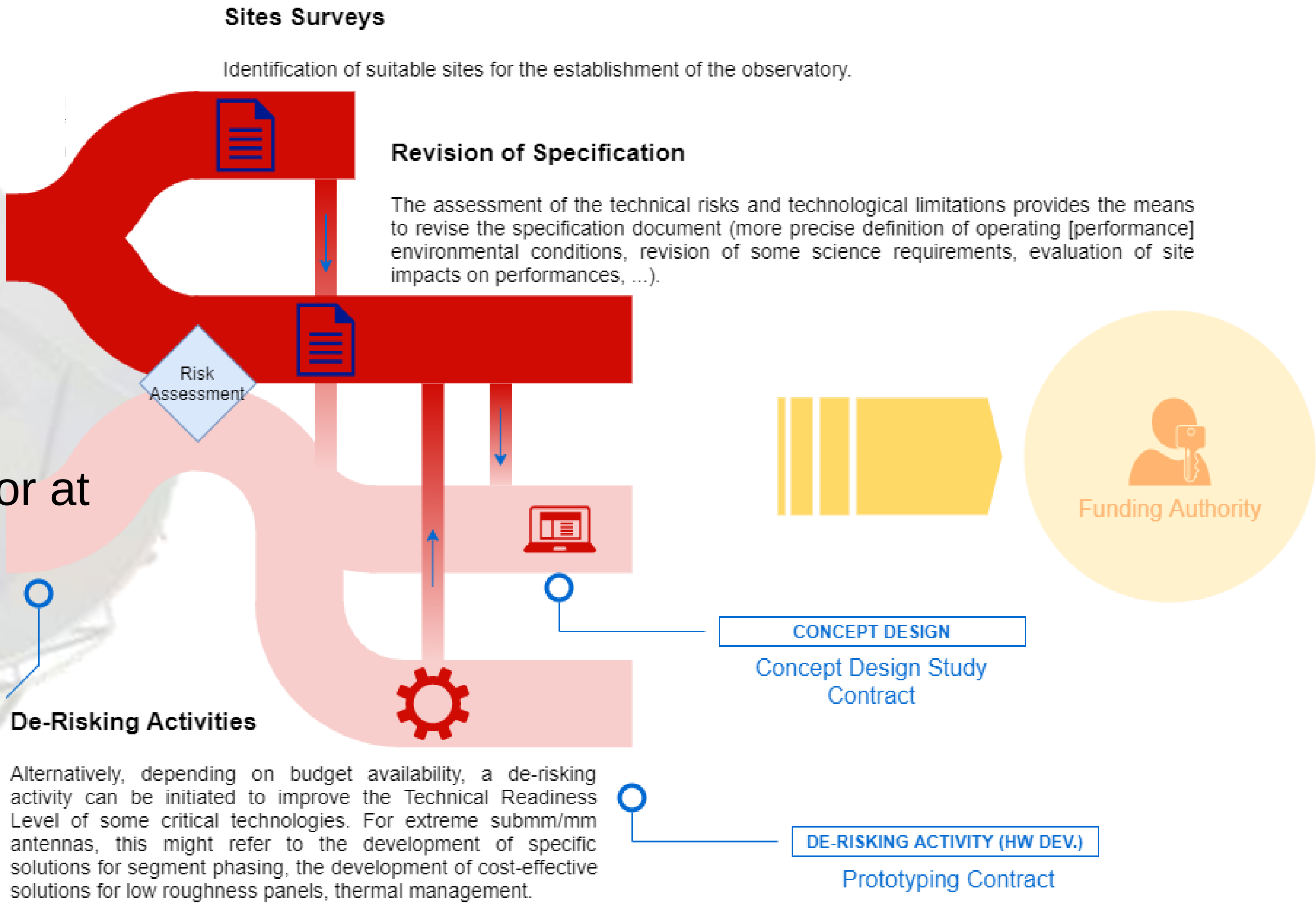
EARLY STUDIES & CONCEPT DESIGN

Expected outputs – CONCEPT DESIGN STUDY

- Conceptual Layout update
- Preliminary Calculations
- Risk Analysis Update
- Update of Sites Surveys
- Preliminary Budget (with contingencies!) for at least the following main cost elements:
    - Design
    - Prototyping (in case de-risking activities are taken into consideration)
    - Manufacturing
    - Packing & Transport
    - Erection on site & Commissioning
    - Operating costs



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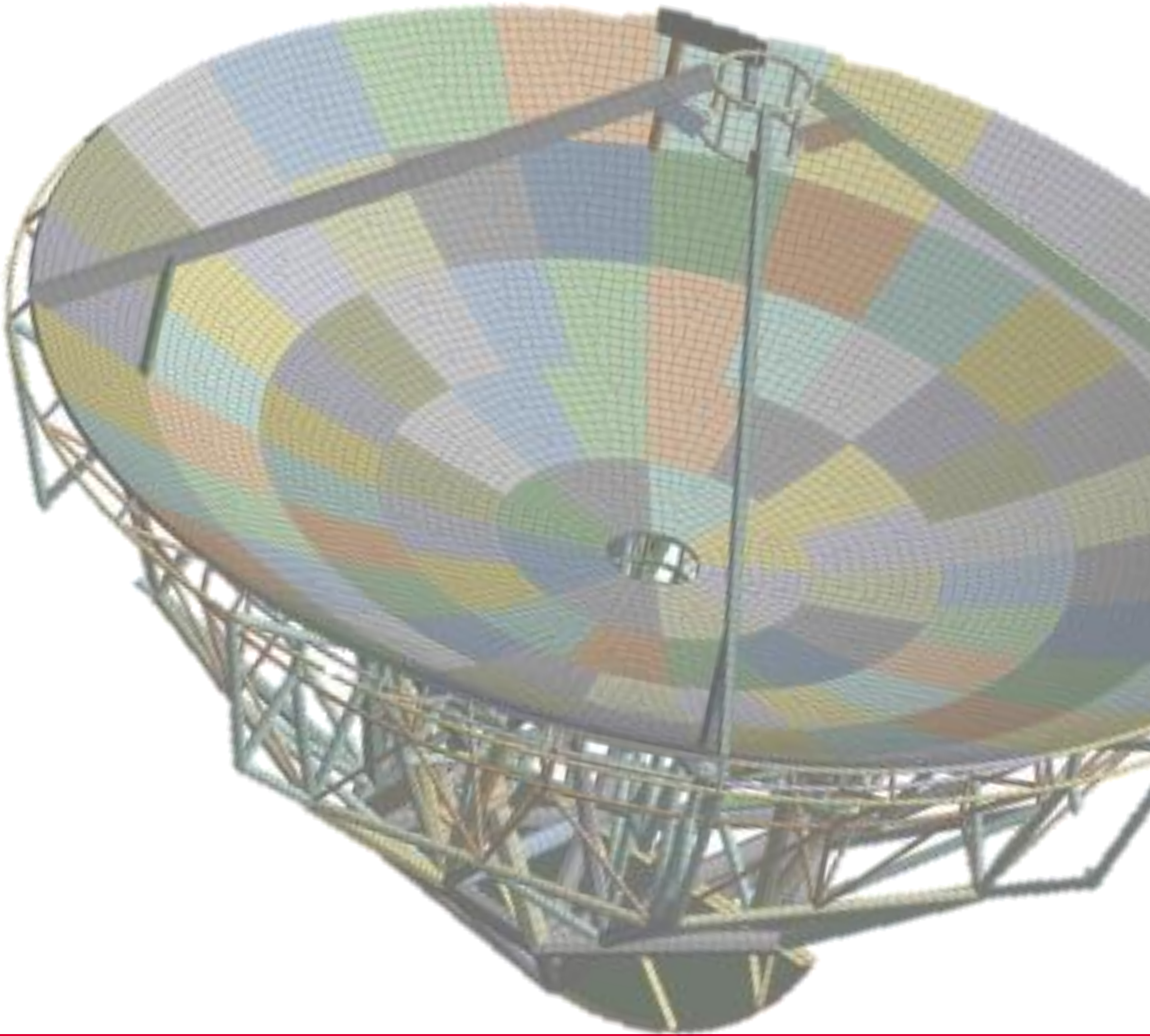
CONCEPT DESIGN – A CRUCIAL MOMENT

- In the framework of the Concept Design Study the trade-off between different antennas concepts can be analysed, in terms of performances, risks, and cost.
- Trade-off studies are important to properly address the project development using design-to-cost methodologies.
- Such preliminary evaluation provides a more solid ground for the definition of the budgets necessary for final design, manufacturing, transport, installation and commissioning.
- It is usually performed in parallel with the development of purely scientific activities, like the definition of first light instruments, the development of international collaborations, deeper investigations on astronomical sites, the definition of the observatory governance (scheduling, governing bodies, etc.), etc.



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FROM CONCEPT DESIGN TO COMMISSIONING

Establishment of Observatory

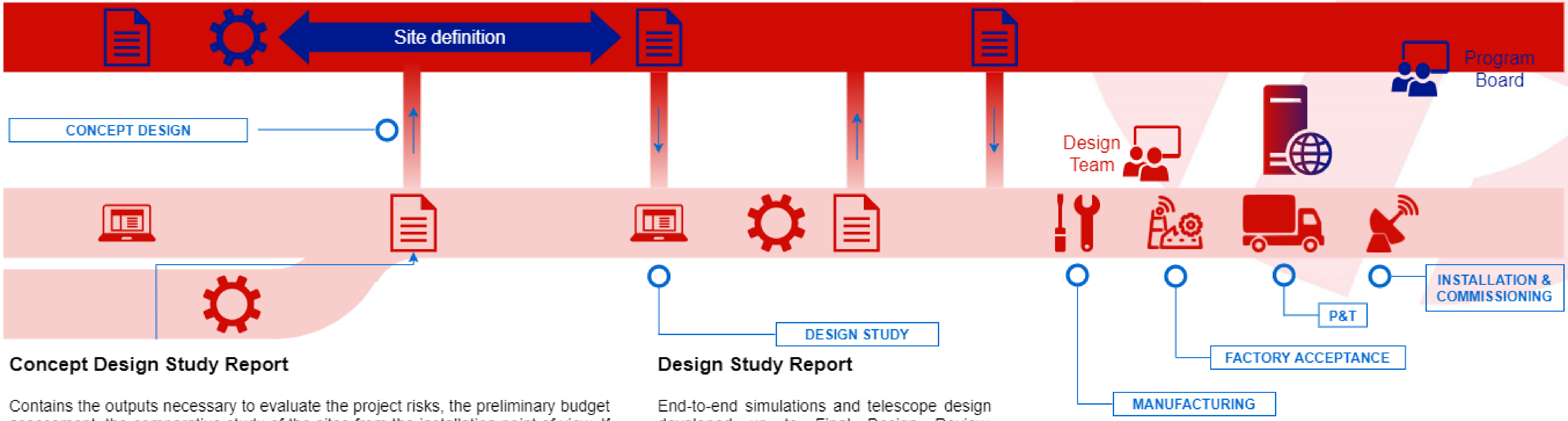
Following the results of the CDSR, the technical requirements are further developed and frozen. Sites are examined in depth. A detailed Statement of Work to address the Final Design and the Construction activities is developed.

If de-risking activities were not developed before and if they are deemed necessary, prototyping activities on some specific technical area can be performed between Concept Studies and Design activities.

Further activities on scientific side are performed (governance, international collaborations, budgets, science case, instruments, auxiliary facilities, ...)

Observatory Definition Document

Iterations on software interfaces can proceed, additional information on maintenance activities are provided.



Concept Design Study Report

Contains the outputs necessary to evaluate the project risks, the preliminary budget assessment, the comparative study of the sites from the installation point of view. If de-risking activites are already developed, the results of the prototyping are presented; if not, an update of the main technical risk area is provided along with remediation strategies.

Design Study Report

End-to-end simulations and telescope design developed up to Final Design Review. Prototyping activities can be carried out during the development of the design.

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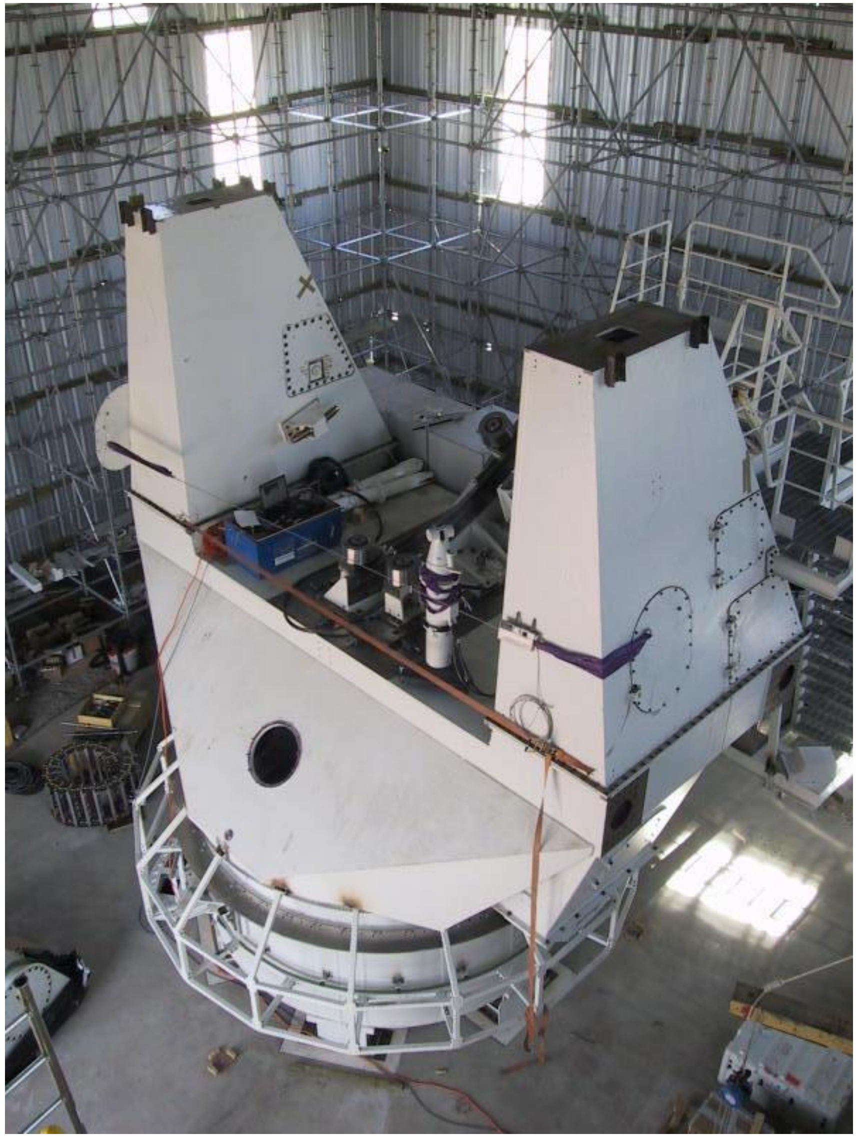
ON PROTOTYPING, IN GENERAL

- Prototyping / de-risking activities are mentioned in several points along the roadmap.
- Prototyping is generally difficult to justify at an early stage of the design, since it unavoidably increases cost at a project stage where budget expenditures are typically low.
- Nonetheless, it is a powerful way to properly address the development of the project as a whole.
- It is not only a matter of understanding what can be practically realized with available technologies: it is a matter of what can be done with state-of-the-art technologies **and** at affordable prices.



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ON PROTOTYPING, IN GENERAL

- Even more so, it is not only a matter of identifying critical technologies (edge sensors, laser trackers, ultra-low roughness panels, etc.): it is also a matter of understanding what are the critical areas and what is the most effective approach to solve the problem (for instance, thermal control).
- Therefore, prototyping can be useful to improve the TRL of specific elements / sub-systems, and also to check the effectiveness of an approach to cope with some identified problems (for instance, control system for active surface compensation).

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ON PROTOTYPING: OF WHAT?

- One of the crucial aspects for observations at sub-mm wavelength is the surface accuracy of the main dish.
- Surface figure shall be kept within the operating range, taking into account for the effects of gravity, temperature gradients, wind.
- An extended version of ALMA (15-m) can achieve 20 microns surface accuracy without active surface compensation.
- Going beyond this limit requires a complete re-design of the back-up structure and active optics compensation is necessary to get < 20 μm surface accuracy.
- For instance, ESMT (Khaikin et al. 2020) is based on a 21m antenna and preliminary analysis showed the necessity to modify the back-up structure and to implement active surface control to achieve the desired scientific targets.

SURFACE ERROR BUDGET ALMA-15 [μm]

Structure	Error Source	RMS Error
Panels	Manufacturing	4.5
	Aging	2.0
	Gravity	5.0
	Wind	0.9
	Absolute Temperature	0.8
	Temperature Gradients	3.8
BUS	Gravity (Ideal)	5.5
	Gravity (Departure from ideal)	2.0
	Aging and Moisture	2.0
	Wind	1.1
	Absolute Temperature	7.0
	Temperature Gradients	0.7
Panels Mounting	Gravity	0.0
	Panel Location in Plane	3.0
	Panel Adjustment out-of-plane	2.0
	Wind	0.0
	Absolute Temperature	2.0
	Temperature Gradients	2.0
Sub-reflector	Manufacturing	5.8
	Aging	2.0
	Gravity	0.1
	Wind	0.1
	Alignment (coma error)	1.7
	Absolute Temperature	1.0
	Temperature Gradients	0.1
Holography	Measurement	15.0
Other errors not included		2.0
Total Surface Accuracy (RSS)		21.1

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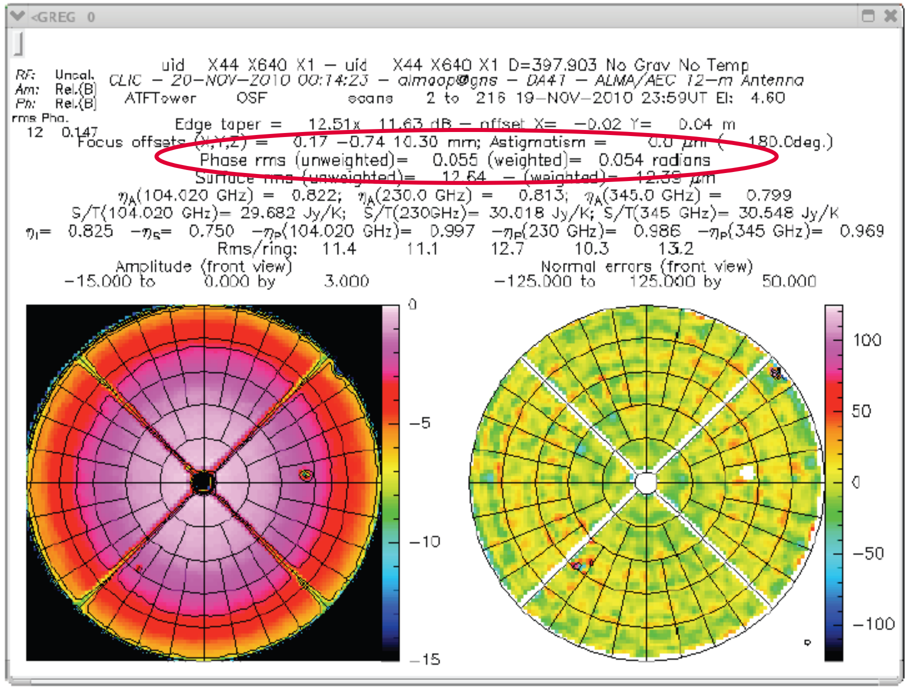
HOW LONG IT TAKES TO ACHIEVE FIRST LIGHT?

- It depends on the science case and what it implies in terms of engineering effort.
- Being rather far from existing telescopes means that some additional time shall be dedicated to preliminary studies / precursors / prototyping (budget shall be increased accordingly).

Telescope	Active Surface	Feedback	Surf Accuracy	Status	Diameter	Accuracy/ Diameter
CSO	yes	holography	0,015	de-comm.	10,4	1,442
JCMT	yes	FEA	0,024	operating	15	1,600
IRAM	yes	FEA	0,055	operating	30	1,833
ASTE	no	-	0,035	operating	10	3,500
LMT	yes	FEA	0,055	operating	50	1,500
APEX	no	-	0,015	operating	12	1,250
GLT	no	-	0,016	operating	12	1,333
ACT	no	-	???	operating	6	1,667
SPT	no	-	0,025	operating	10	2,500
CCAT-p	no	-	0,01	under const	6	1,667
AtLAST	yes	Tbd	0,02	concept	50	0,400
ALMA (b)	no	-	0,013	operating	12	1,083
ALMA (w)	no	-	0,022	operating	12	1,800
CCAT	yes	-	<0,015	canceled	25	0,600
ESMT	yes	FEA/Thermal/…	<0,021	concept	21	1,000



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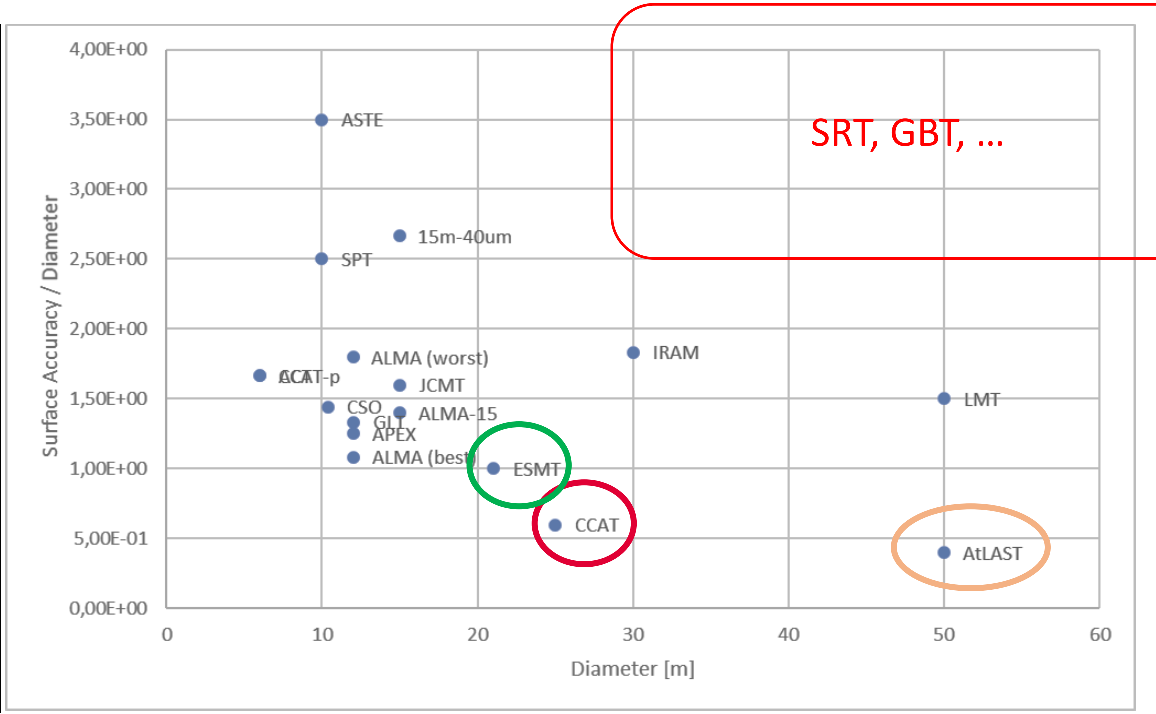

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HOW LONG IT TAKES TO ACHIEVE FIRST LIGHT?

- Active surface control is successfully implemented in large aperture.
- Improving the surface accuracy while increasing the dish diameter pushes the cost rapidly high.
- Ambitious attempts led to large cost increase and project termination.

Telescope	Active Surface	Feedback	Surf Accuracy	Status	Diameter	Accuracy/ Diameter
CSO	yes	holography	0,015	de-comm.	10,4	1,442
JCMT	yes	FEA	0,024	operating	15	1,600
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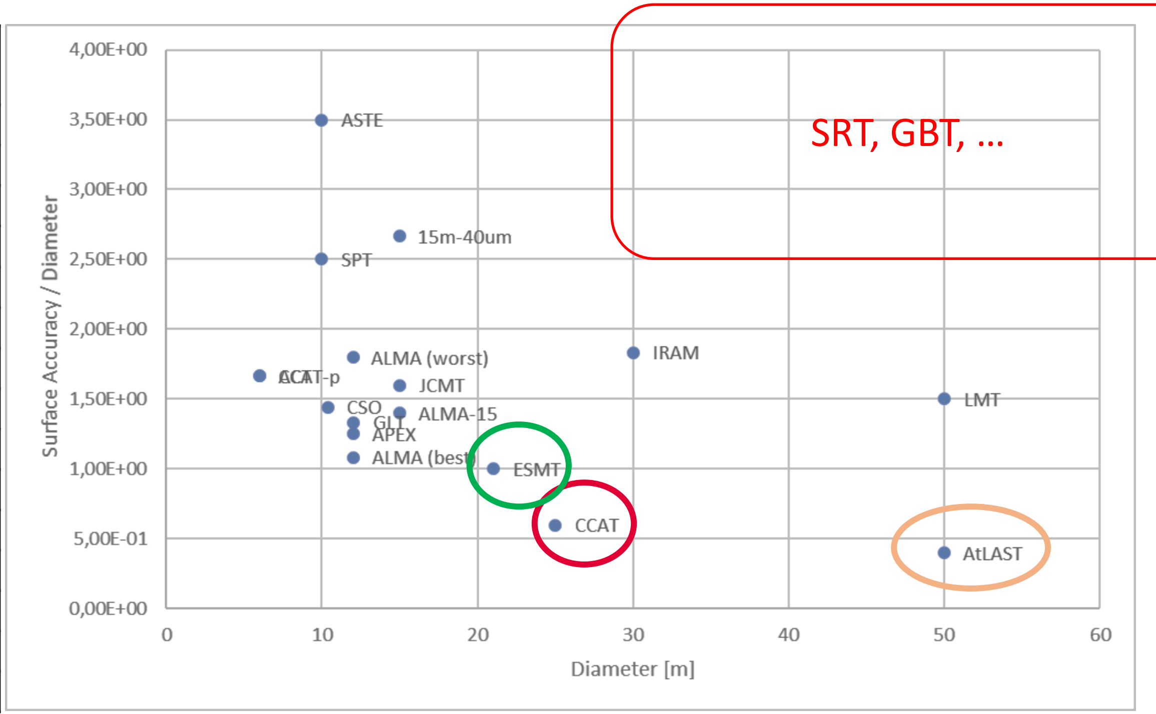

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HOW LONG IT TAKES TO ACHIEVE FIRST LIGHT?

- An ESMT-like antenna (21m / <20 μm RMS) should have active surface control for both gravity and temperature. Efforts along this direction should be taken into proper account.
- Nonethless, it appears to be a reasonable request.

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CSO	yes	holography	0,015	de-comm.	10,4	1,442
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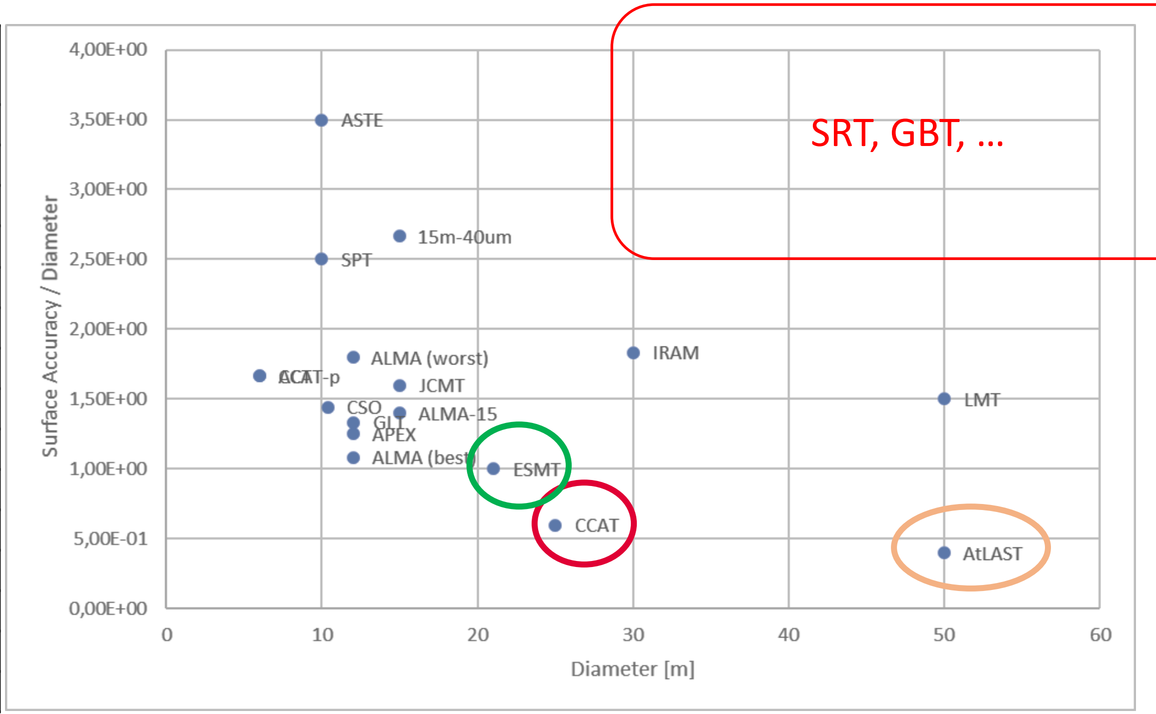

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HOW LONG IT TAKES TO ACHIEVE FIRST LIGHT?

- Without taking into account for the development time of precursors or prototyping activities, a complete concept design for a 21m / sub-mm antenna might last about 6 months.
- Final design activities would take about 6-8 months, manufacturing and factory integration & testing will take about 12 months.
- Transport & installation depends on the site.

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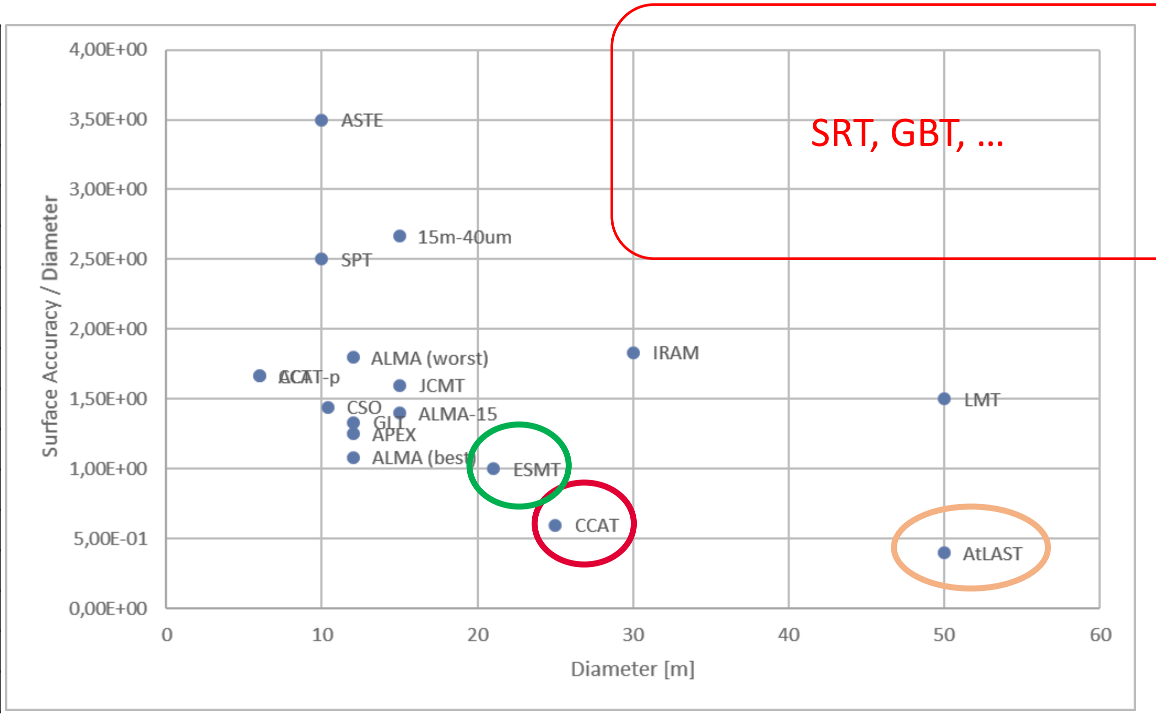

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SITE DEFINITION, MANAGERIAL INTERFACES

- As long as there are sufficient information about logistic issues related to the various possible installation sites, such selection can be post-poned to a later stage.
- It is preferable to know where the facility has to be installed before the beginning the detailed design activities.
- The definition of a Control Board, with a clear definition of roles and responsibilities, and a stable composition, on both sides of the table, is of paramount importance for the management of the project along the entire process.

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SITE DEFINITION, MANAGERIAL INTERFACES

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SITE DEFINITION, MANAGERIAL INTERFACES

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INTERNATIONAL COLLABORATION & GEO-RETURN

- The collaboration with local companies is advantageous in many senses.
- Governmental funds are often linked to a technological return on the country. In this case, the collaboration with local high-tech companies can easily satisfy the geo-return policies.
- Local companies are of fundamental importance when dealing with site characterization, civil works construction, logistic issues.
- Local contact points can finally easy the exchange of information, which might be prevented by linguistic barriers, habits, different ways of approaching problems, priorities.

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CONCLUSIONS

In a speech given during IAU General Assembly in 2018 (Commission B4 - IAU/URSI Working Group on Historic Radio Astronomy), Jacob Baars made an insightful and informative review of the evolution of large single dishes.

Let me quote his concluding remarks: *«If you want to acquire a state of art telescope, you have to start with establishing a solid science case upon which the necessary telescope performance specification can be build. In early discussions with experts from industry translate these to achievable structural, mechanical and control specifications. Make those solid; don't start with including "goals"! Goals are expensive and remain uncertain.»*

EIE is available in supporting the Russian Astronomical community in developing the definition of the projects on sub-mm ground based observatories, providing help in transforming performance requirements into manageable engineering specifications.

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An industrial perspective