Overview

(Presented by R. Gilmozzi)

Acknowledgments

- Science case: OPTICON
  - More than 100 astronomers
- Contributions from community
  - Adaptive Optics
  - Instrumentation
  - Co-phasing
  - FP6 ELT Design Study
- Contributions from Industry
  - Studies
  - Advice (e.g. better solutions)
  - Own resources

Thank you!

Objectives for the Blue Book

- Document ESO's conceptual work on OWL
  - Show the design evolution, proposed solutions, R&D results
  - Establish a cost and schedule estimate
  - Review the risks (are there any that we would not even consider taking - plenty we would prefer not to).
- Seek feedback from community
- Plan ahead with the community
  - Design phase
  - Topical meetings
- Priority given to feasibility of major subsystems
  - This is NOT a Preliminary Design for the project. This is a feasibility check.
  - Can we afford it and can it be built? (no and maybe - i.e. no show stoppers yet)
- Complementarities with FP6 study
  - Design phase will incorporate results of ELT DS

Objectives of Review

- Assess whether, or to what extent, the proposed technical feasibility solutions are reasonable, i.e.:
  - Assess the OWL approach, its strengths and weaknesses
  - Analyze feasibility issues
  - Evaluate cost and schedule estimates
  - Identify the principal risks of the project
  - Identify areas to be further explored
- Assess whether to proceed to the next phase, building on the experience of the present work, to:
  - Refine requirements
  - Assess programmatic and funding options
  - Iterate the design or set up and evaluate a new one, if appropriate
  - Enter Preliminary Design phase

Principles

- Assess feasibility of the major subsystems
  - Optics, mechanics, kinematics, enclosure
  - Relying on proven technology
    - i.e. address feasibility per se rather than best solutions
    - Better solution will be explored in the design phase, with the ones identified in Conceptual Design as “proven” backup
    - For example: Ag assumed for science, Al for feasibility
- Identify roadmap for subsystems needing R&D
  - e.g. adaptive optics, mirror substrates
  - Relying on promising developments, “reasonable” (in the eye of the beholder) extrapolations
    - e.g. adaptive M6: extrapolate size not actuator pitch
    - Identify risks and possible mitigating strategies
    - Identify fall back options
- Involve industry from the start

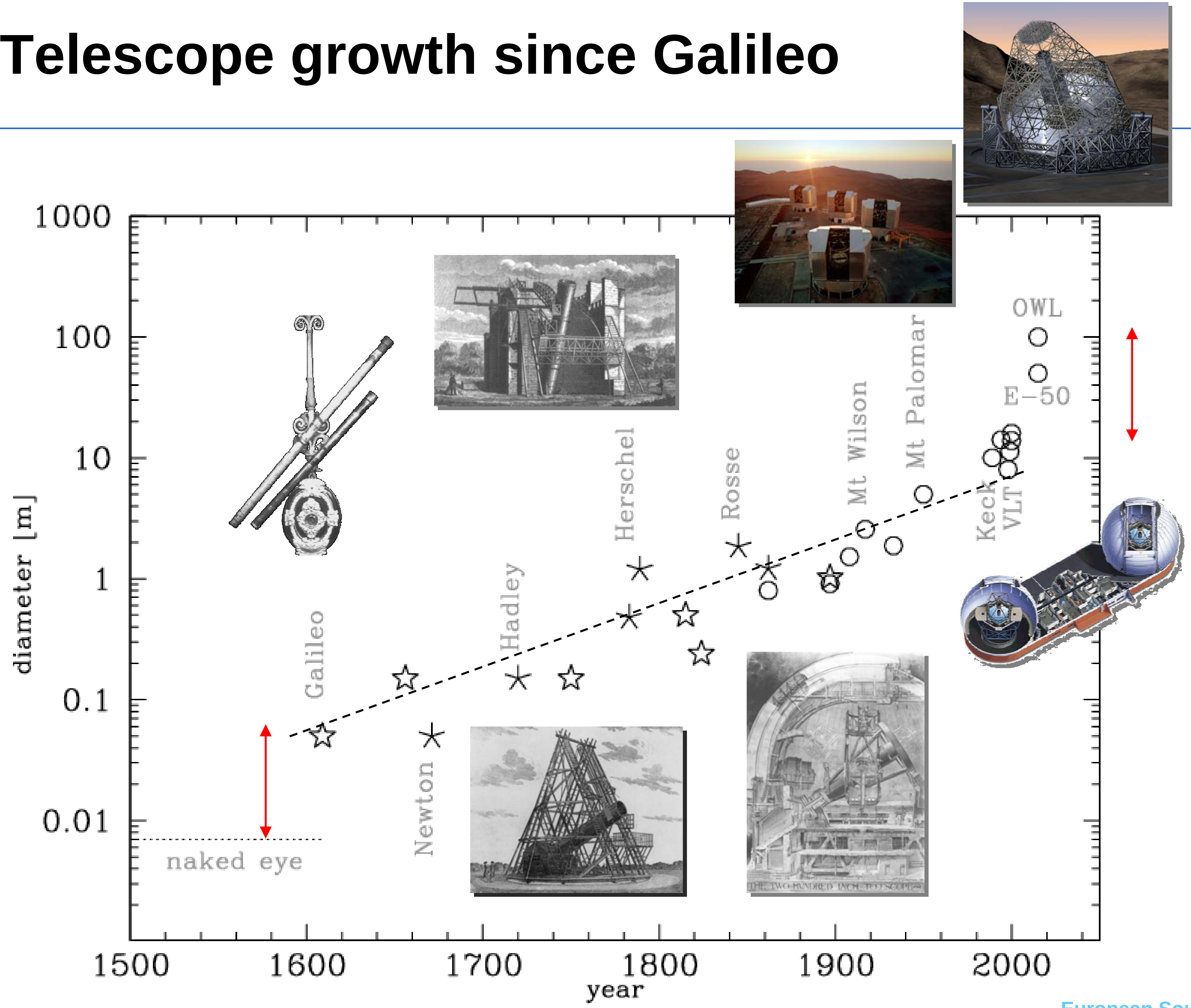
The Blue Book

- Different levels of ‘depth’
  - Prioritization (e.g. possible showstoppers)
  - Consequence of development (need to think harder)
  - Some areas started after others had been assessed
    - e.g. instruments after telescope design and preliminary I/F
    - Feedback needs to be folded back into the telescope design
  - Not an issue of quantity/quality of work
- Status
  - Advanced: optics, mechanics
  - Medium: AO, site, enclosure, maintenance, control
  - Moderate: science operations, instrumentation, adapter/rotator
  - Not addressed: SW, IT (except AO), data flow

Why 100m?

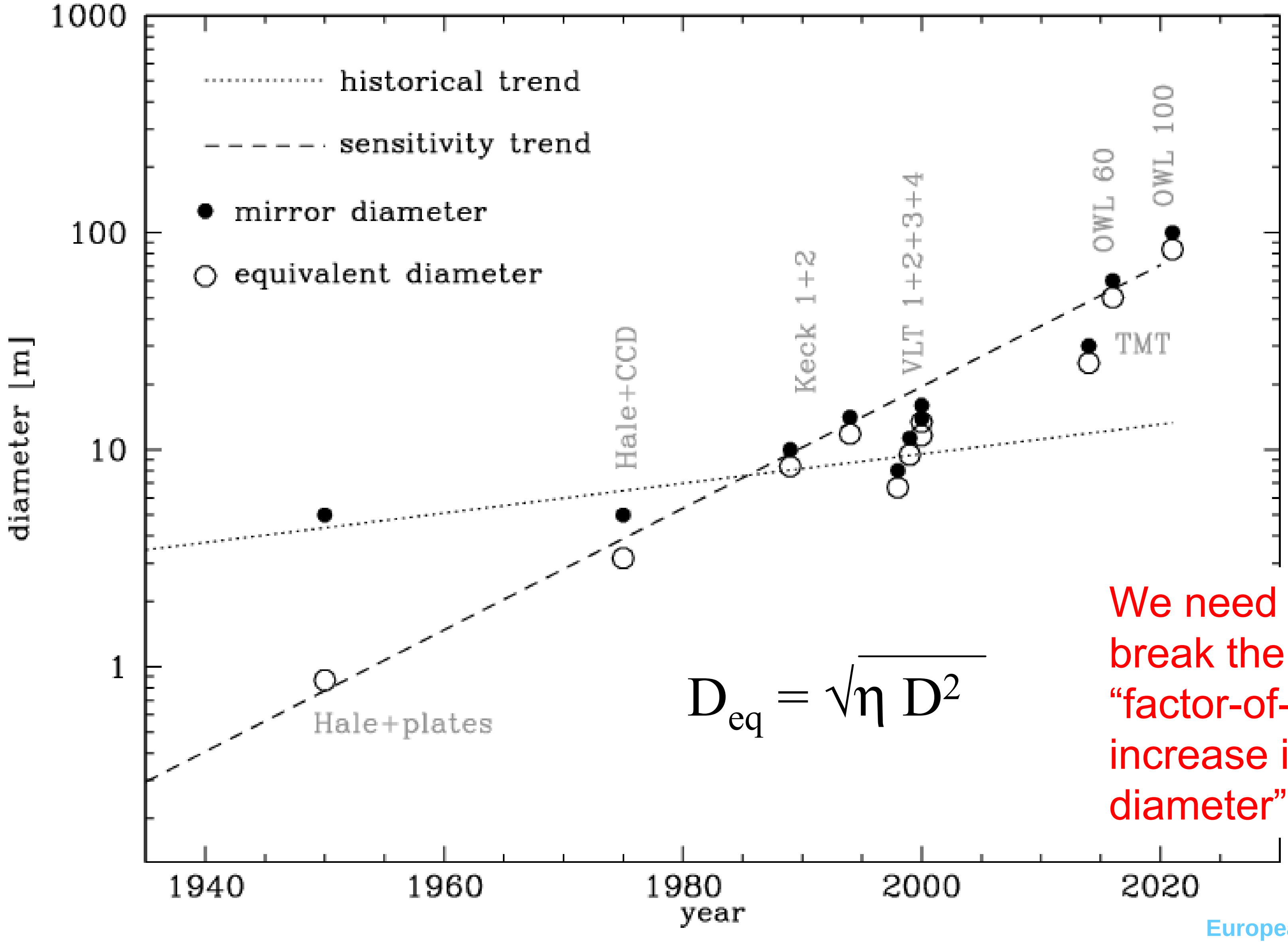
- Science case
  - Earth-like exo-planets
  - Resolved stellar populations
  - Spectroscopy of faintest objects to be discovered by JWST
  - Primordial stellar populations
  - Evolution of cosmic parameters, dark matter, dark energy
  - Direct determination of cosmic dynamics
- Technology
  - Segmentation (theoretically unlimited scalability)
  - Maturity of wavefront control techniques (especially AO)
    - High angular resolution not anymore a domain only of space
  - Radio telescopes of up to 100m an inspiring precedent
    - Though with more relaxed requirements (longer wavelengths)
  - Evolution of detectors

Telescope growth since Galileo



Detectors have improved more than diameters

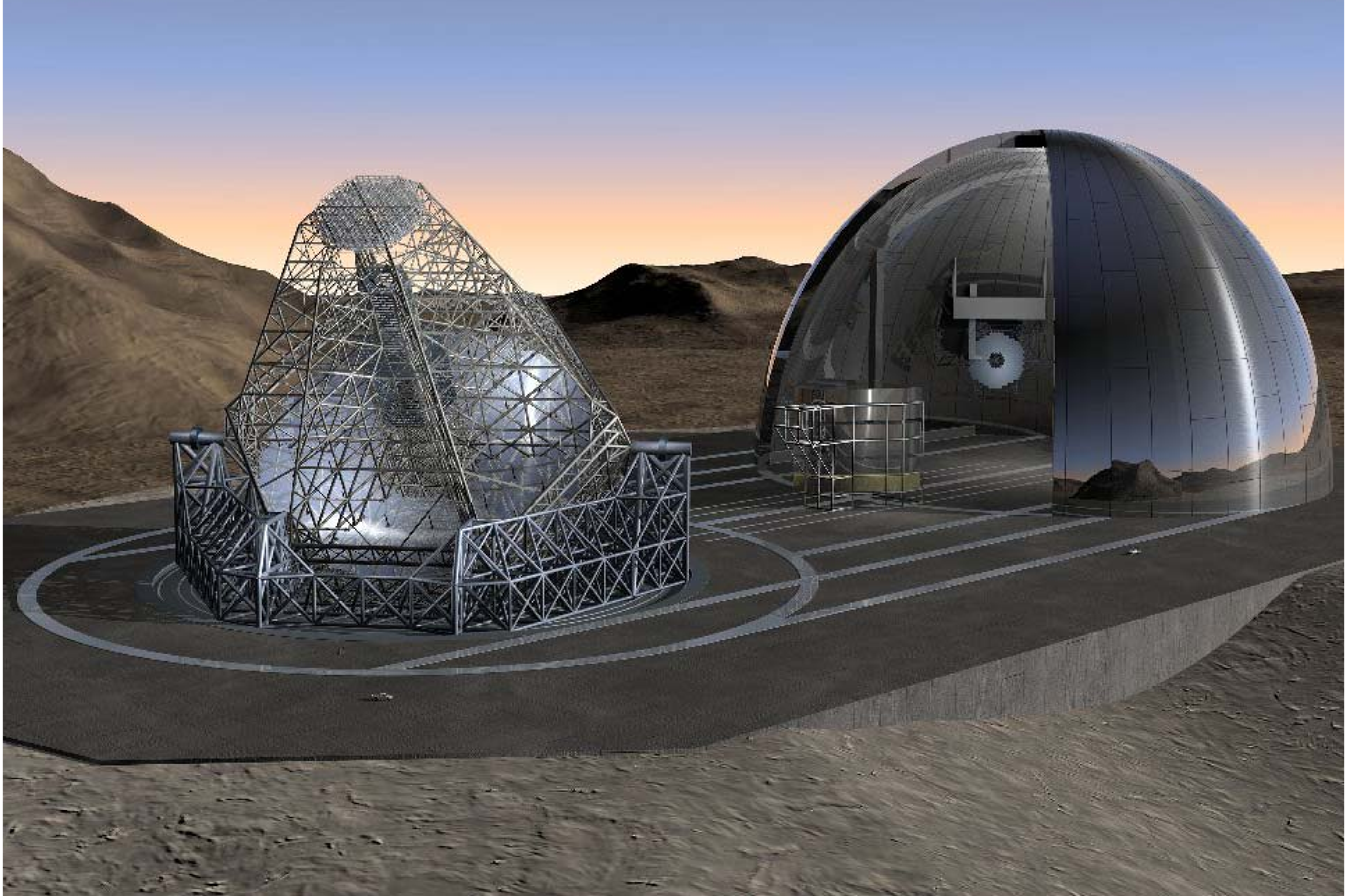
They represent 80% of the increase in sensitivity in the last 50 years



$$D_{eq} = \sqrt{\eta\, D^2}$$

We need to break the “factor-of-two increase in diameter” law

Overview



Design overview

- Spherical primary (cost driven choice - if smaller D possibly different mirror shape)
- Flat secondary (fold telescope, relax mechanical requirements)
  - Double segmentation concern
- Complex corrector (size ~ VLT twice over)
- AO integral part of optical design
- Alt-Az mount, fully steerable
- Open air operation (sliding enclosure)
- Lightweight structure, six-fold symmetry
- Built-in maintenance concepts

Characteristic	
Telescope diameter	100m
Focal ratio	6
Primary mirror focal ratio	1.25
Total field of view (diameter)	10 arc minutes
Unvignetted field of view (diameter)	6 arc minutes
Optical quality at the edge of the curved field	0.056 arc seconds RMS
Diffraction-limited field of view (diameter)	
Visible (0.5 µm)	2.37 arc mins
IR (2.2 µm)	4.08 arc mins
IR (5.0 µm)	6.00 arc mins
Secondary mirror diameter	25.6m
Central obscuration (linear)	35%

Low cost approach

(If cost $\propto D^{2.6}$ cannot be broken, a 100m is not conceivable)

- Serialized production of as many elements as possible
  - Consequence: spherical primary, fractal mechanics
    - Note: if aspherics cost (and related tradeoffs, e.g. tolerances) become competitive, spherical primary may be abandoned
- Use off the shelf components wherever possible
  - i.e. very little reliance on custom made parts
  - Actually almost everything is custom made, just so much of it that it does become a shelf item in terms of cost.
- Design telescope so that demanding requirements are at locations where we know how to tackle them (e.g. corrector)
- Use proven technology. Limit R&D to:
  - Areas that need it (e.g. adaptive optics)
  - Areas where performance/cost can be improved (e.g. SiC)
- Allow amplest time where R&D ***is*** required
  - e.g. progressive implementation of AO

Some consequences

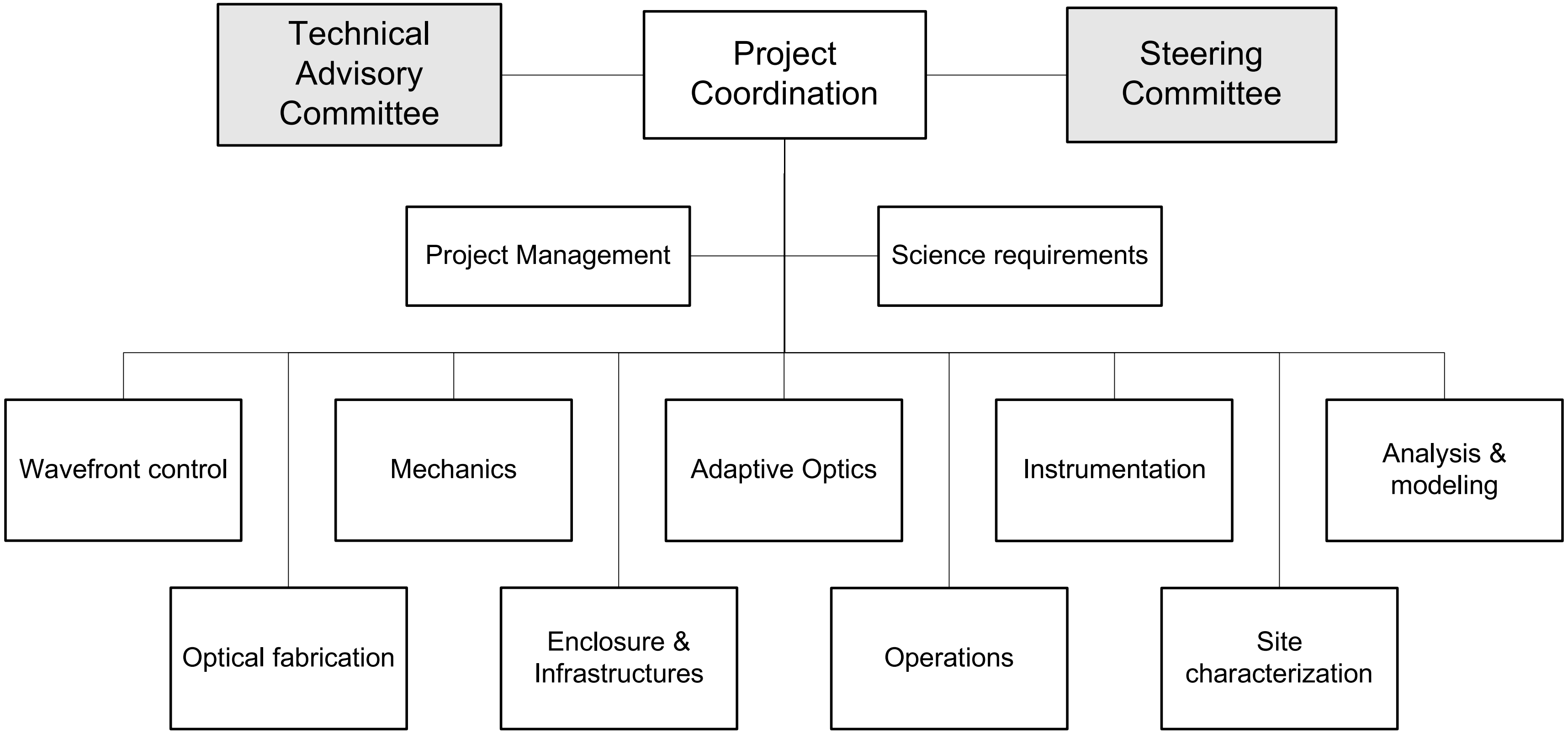
- Focal ratio
  - A field of view of 10 arcmin with a focal plane (i.e. adapter/ rotator) dimension of 2-m imply ~ F/6
  - Lowering the FoV requirement (or D < 100m) with the same focal plane dimension would allow longer F/ratios
- Monolithic mirrors ≤ 8.3-m
  - Some potentially more elegant optical solutions had to be abandoned (they needed monoliths > 8.3m)
- Inherent scalability of the design
  - Due to serialized production and design choices
- "Easy" mechanics reconfiguration
  - If different optical design eventually chosen
- Possibility of starting science operations before full integration of primary mirror

ELT Design Study

- A generic technology development programme, 2005-2008
  - Telescope design-independent
  - 26 partners, industry & academia, M€ 31.5, ESO as lead

European Southern Observatory
AMOS (B)
ASTRON (NL)
Australia National University (AUS)
CIMNE (SP)
Durham Univ. (UK)
FOGALE (F)
Galway University (Ir)
GRANTECAN (SP)
IAC (SP)
INAF (I)
INSU (F)
ITER (SP)
JUPASA (SP)
LEIDEN Obs. (NL)
LUND Univ. (S)
MEDIA C. I. (SP)
MPIA (G)
Oxford Univ. (UK)
SAGEM (F)
SESO (F)
Technion (Isr.)
UKATC (UK)
Universidad Politecnica Catalunia (SP)
Universite de Nice (F)
University Padova (I)

ELT Design Study



Technical Advisory Committee

Project Coordination

Steering Committee

Project Management

Science requirements

Wavefront control

Mechanics

Adaptive Optics

Instrumentation

Analysis & modeling

Optical fabrication

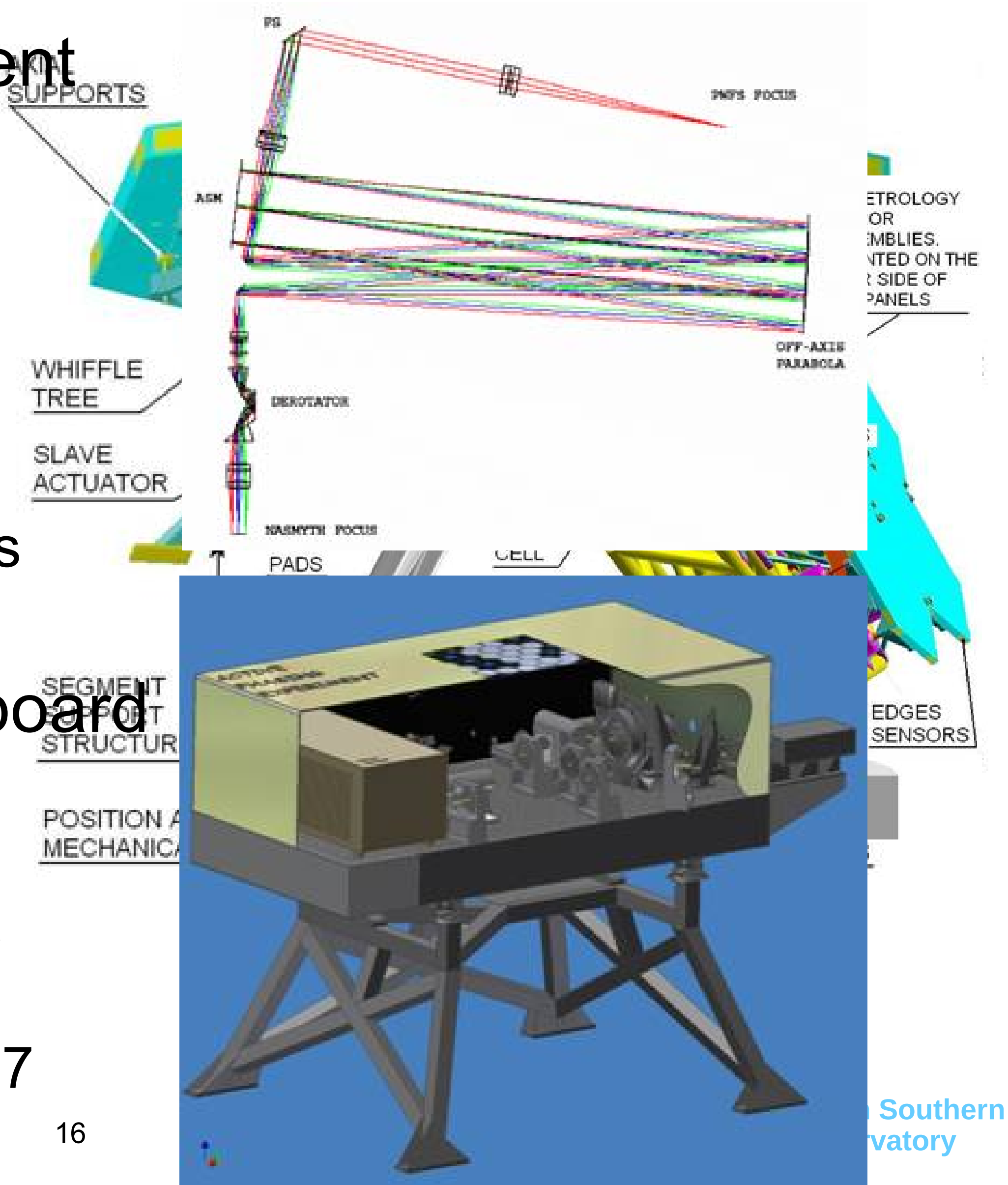
Enclosure & Infrastructures

Operations

Site characterization

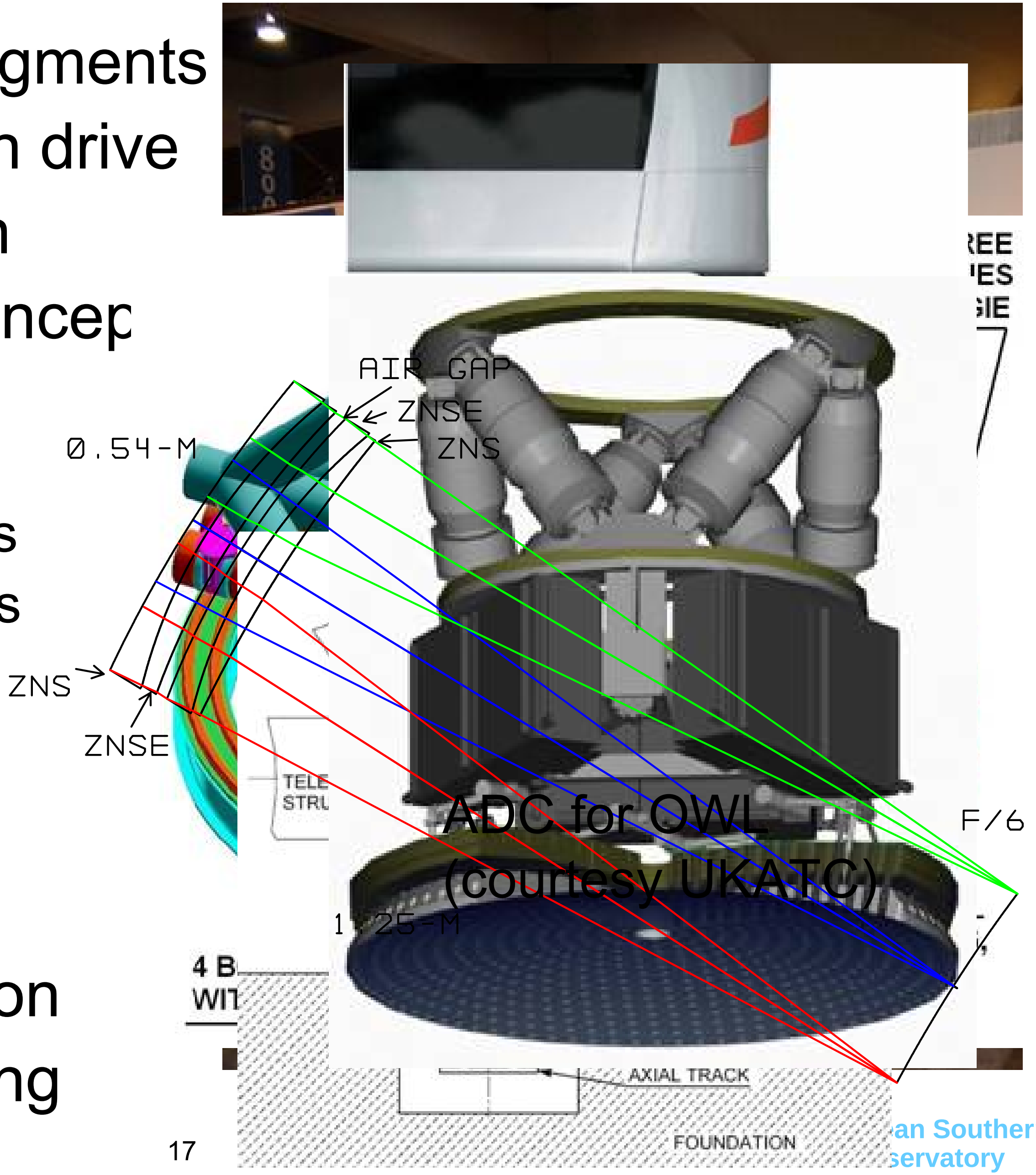
ELT DS - Highlights

- Position actuators, position sensors
- Active Phasing Experiment
  - Transforming the VLT into a segmented *AND* active telescope
  - Testing integrated wavefront control
  - Evaluating up to 4 on-sky phasing techniques
  - PDR in December
- Wind Evaluation Breadboard
  - Testing high frequency wind rejection
  - Representative conditions and hardware
  - Installed on la Palma, 2007



ELT DS - Highlights

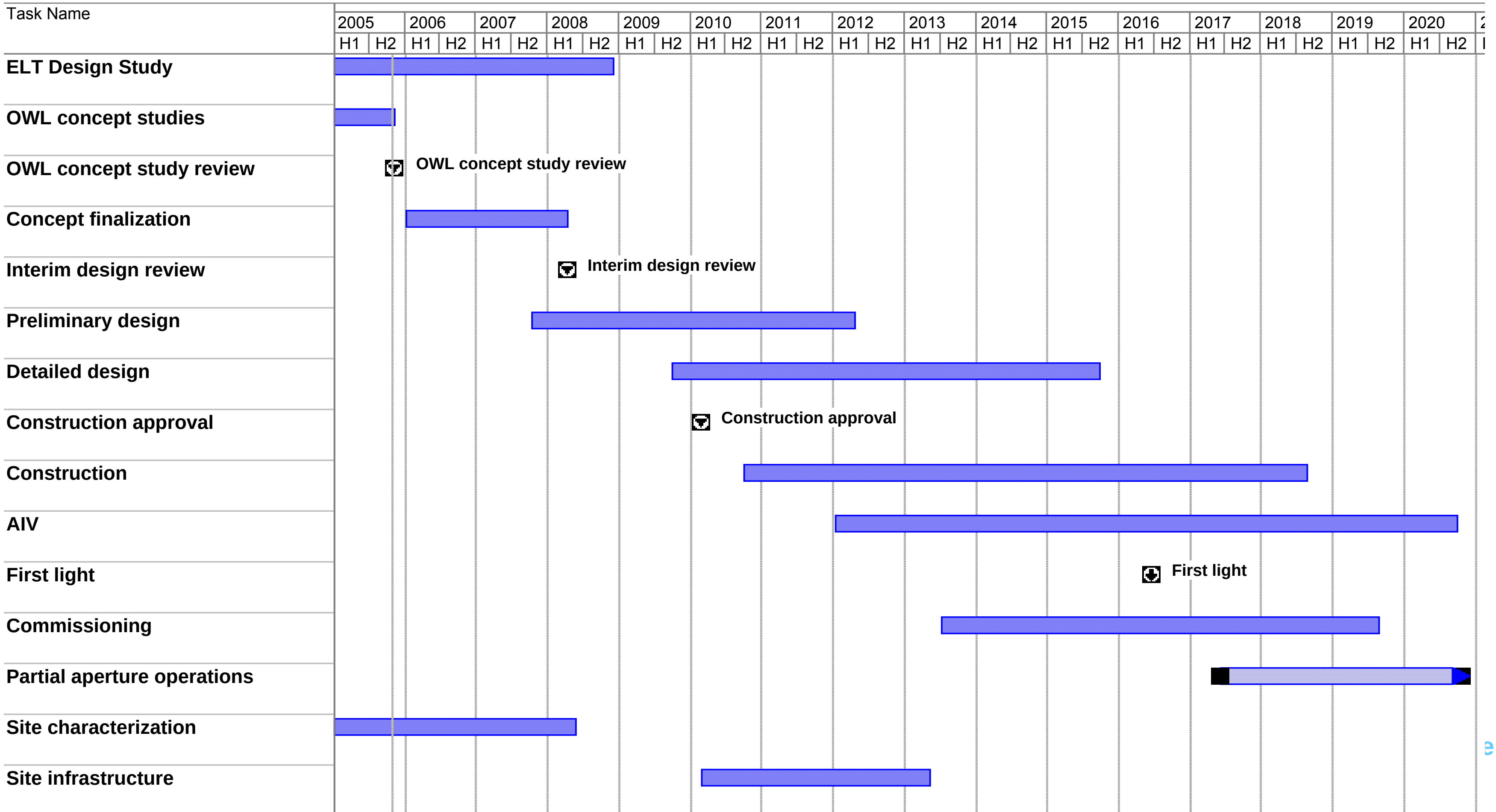
- Silicon Carbide segments
- Breadboard friction drive
- Magnetic levitation
- Adaptive optics concep and technologies
  - Point designs
  - Mirror technologies
  - Novel AO concepts
  - Reconstruction
  - Simulations
- Operations
- Instrumentation
- Site characterization
- Integrated modelling



ADC for OWL (courtesy UKATC)

Schedule

- Current Integrated Master Plan includes 2400 entries
  - Follows Product Structure tree
- Design phase (35.5 M€ + 85 FTE)
  - Does not include explicitly the time and budget (15M€) necessary to validate the technology for lowest cost estimate



Cost estimate(s)

- Based on industrial competitive studies (60%) and allocations (extrapolation from VLT)
- Three estimates
  - ***Best*** estimate: proven technology + conventional substrates + highest cost enclosure

    1.255 B€
  - ***Lowest*** estimate: promising technology + advanced substrates + low cost enclosure

    up to 300 M€ savings
  - ***Highest*** estimate: uses only highest industrial estimates

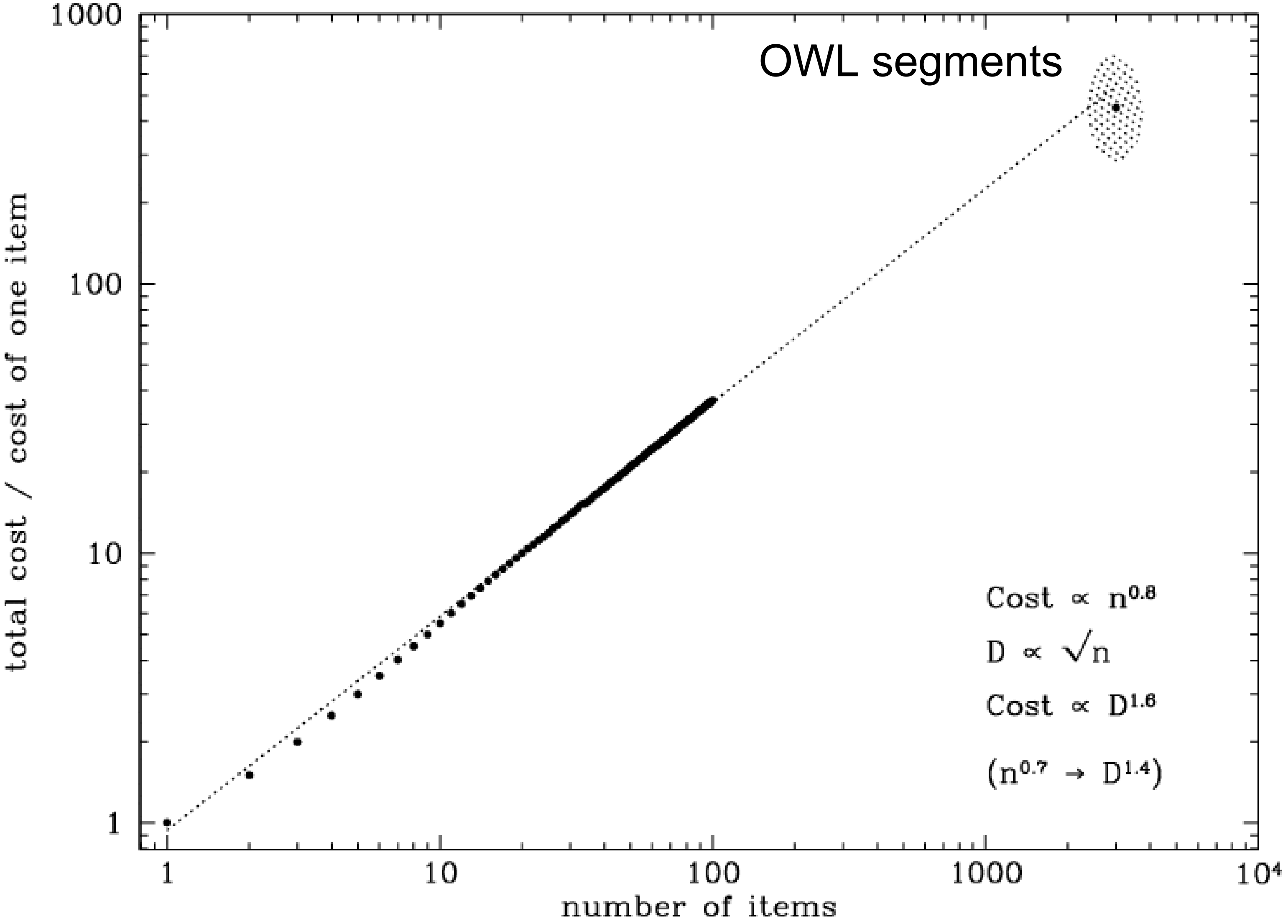
    1.398 B€
  - Included in cost: design phase, construction, initial instruments (50 to 70 M€), 10% contingency, no ESO manpower

Best cost estimate (all phases)

Project Management (including contingency)	**143.6**
Project Engineering	**12.4**
Site infrastructure	**87.4**
Enclosure	**169.6**
Telescope structure & kinematics	**186.6**
Optomechanical subsystems	**552.1**
Instrumentation	**72.0**
Laser Guide Stars Subsystem	**10.7**
Central Control Systems	**19.5**
Site characterization	**0.8**
TOTAL	***1254.6*** M€

Advantages of serialized production

e.g. optical components (data from a supplier)

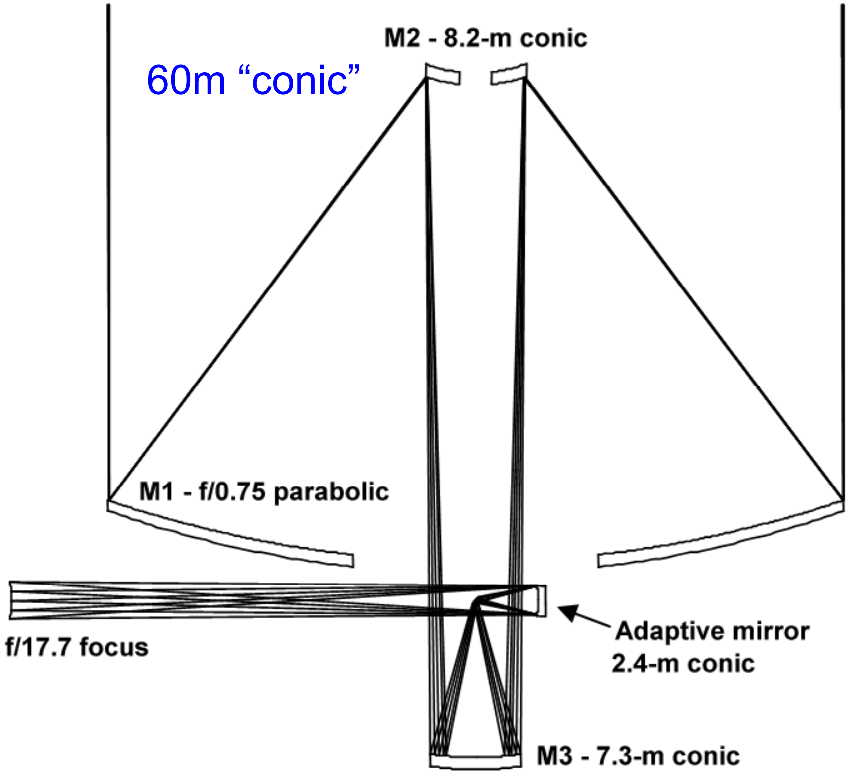


Scalability

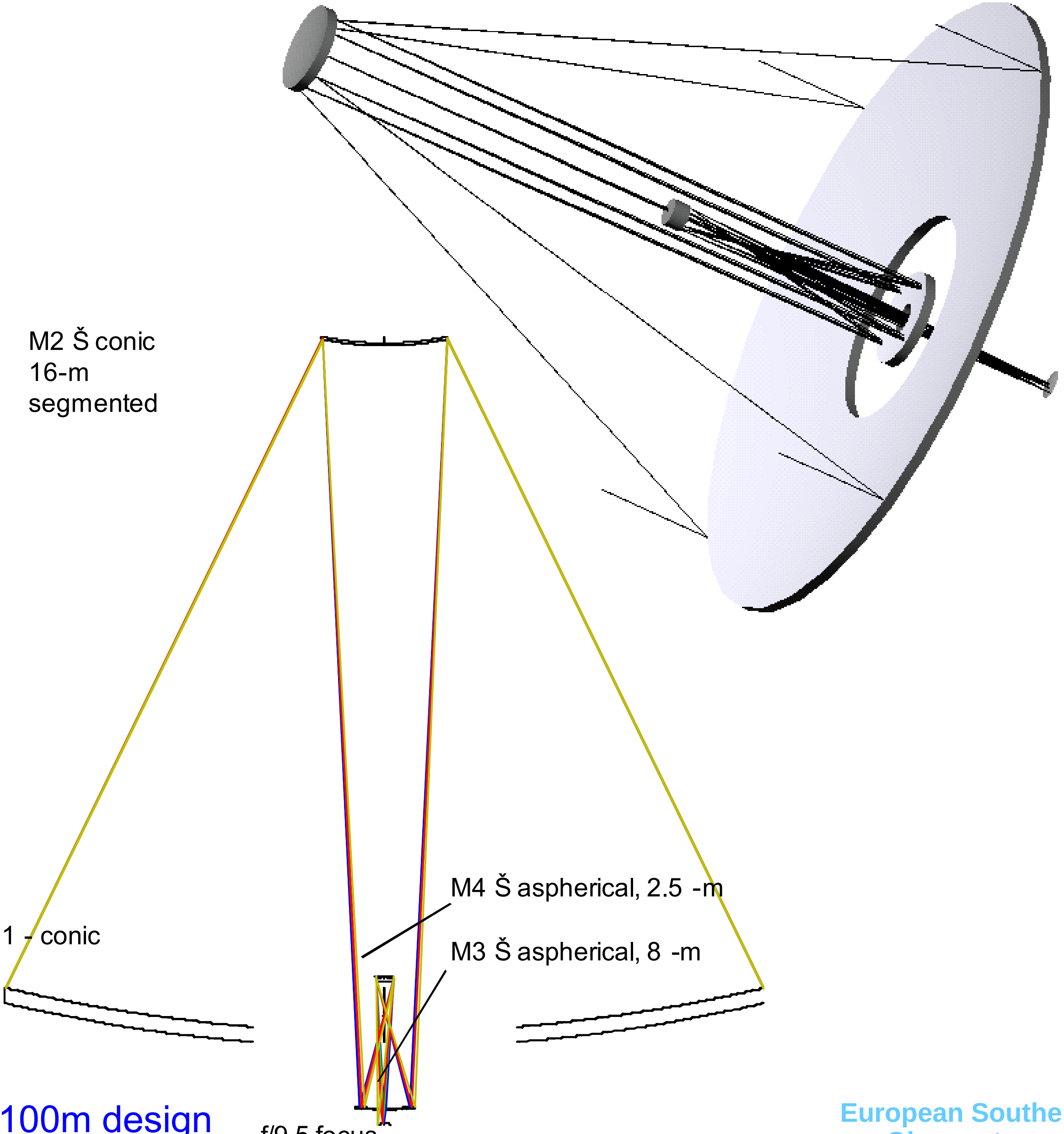
- Serialized production is inherently scalable
  - "Building blocks" remain the same
- The OWL design takes advantage of this
  - Scalable in the range 60m to 120m (preliminary estimate)
- If smaller D, optical design may be revisited
  - e.g. designs that at 100m needed monolithic mirrors > 8.3m may become attractive again at smaller diameters
  - Easier to achieve long F/ratios
- OWL cost law: $\propto D^{1.4}$
  - Due to mass production + design solutions
- "Science scalability" not fully assessed
  - Some science cases have strong dependence on D
    - Exo-earths $\propto D^4$, quantum optics $\propto D^6$ etc

Wider design palette for D < 100m

60m "conic"

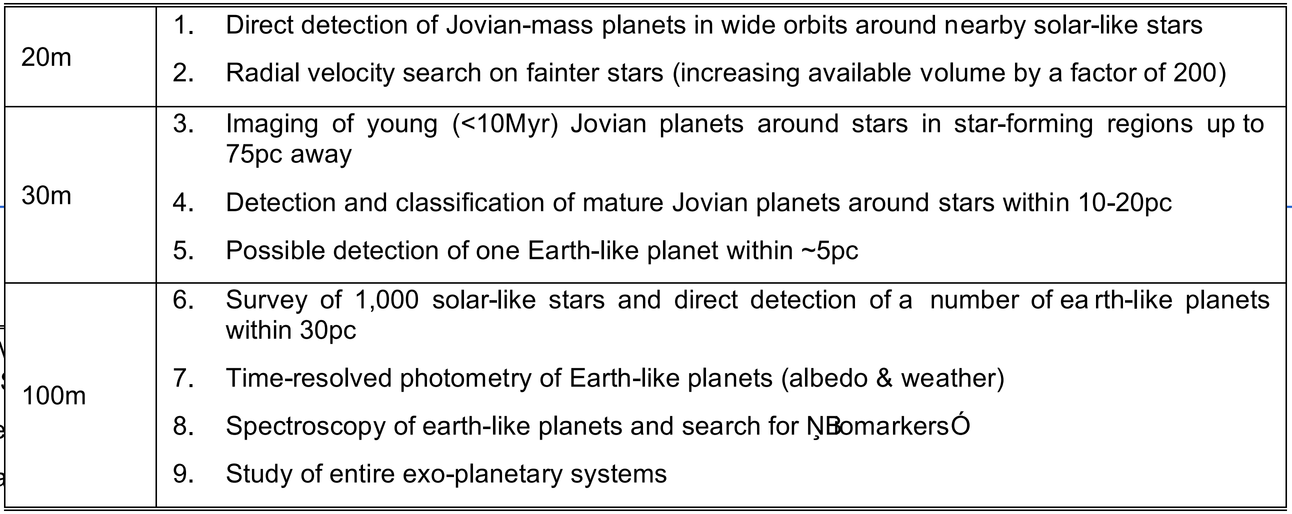


60m "beam compressor"

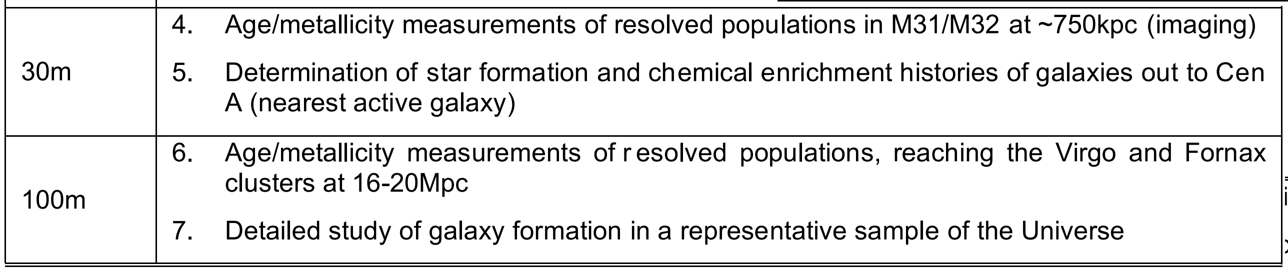


A different (scalable) 100m design

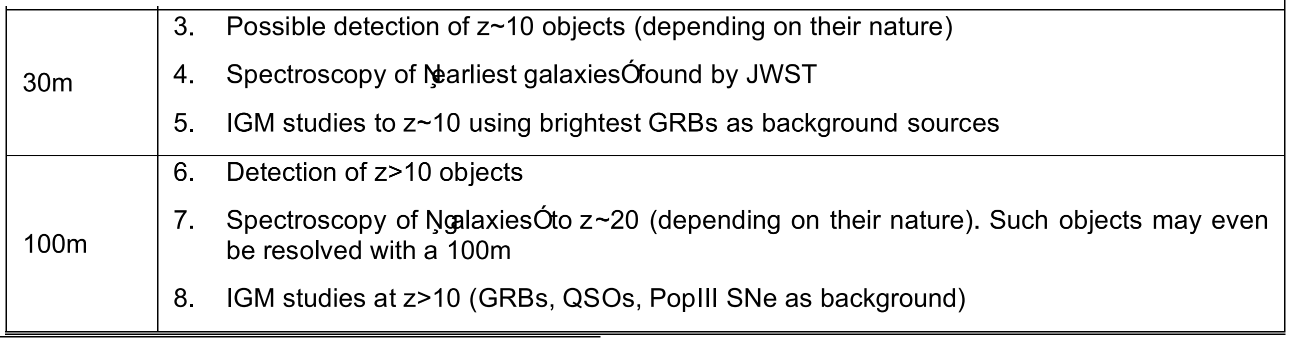
Scalability (science)



20m	1. Direct detection of Jovian-mass planets in wide orbits around nearby solar-like stars 2. Radial velocity search on fainter stars (increasing available volume by a factor of 200)
30m	3. Imaging of young (<10Myr) Jovian planets around stars in star-forming regions up to 75pc away 4. Detection and classification of mature Jovian planets around stars within 10-20pc 5. Possible detection of one Earth-like planet within ~5pc
100m	6. Survey of 1,000 solar-like stars and direct detection of a number of earth-like planets within 30pc 7. Time-resolved photometry of Earth-like planets (albedo & weather) 8. Spectroscopy of earth-like planets and search for ŅBomarkersÓ 9. Study of entire exo-planetary systems

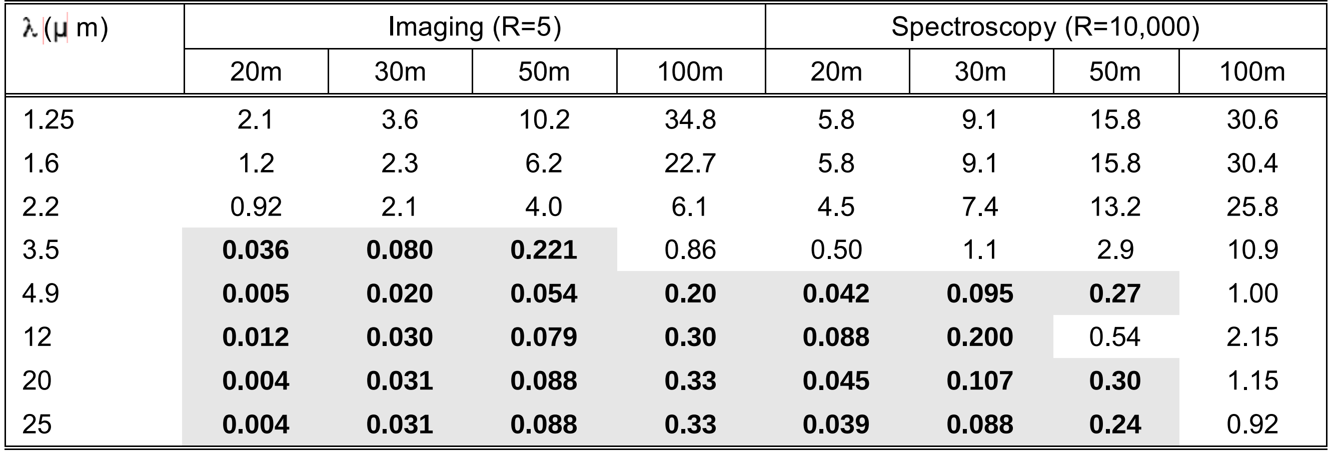


20m	1. Resolution of the oldest stellar populations in M spheroidals (Sculptor, Fornax, Carina) and the 2. Resolution of the brightest giant stars in galaxie 3. Observations of halo giants in Local Group gala
30m	4. Age/metallicity measurements of resolved populations in M31/M32 at ~750kpc (imaging) 5. Determination of star formation and chemical enrichment histories of galaxies out to Cen A (nearest active galaxy)
100m	6. Age/metallicity measurements of resolved populations, reaching the Virgo and Fornax clusters at 16-20Mpc 7. Detailed study of galaxy formation in a representative sample of the Universe



	ine spectroscopy from 6<z<10 f z~10 objects (depending on their nature)
30m	3. Possible detection of z~10 objects (depending on their nature) 4. Spectroscopy of Ņearliest galaxiesÓfound by JWST 5. IGM studies to z~10 using brightest GRBs as background sources
100m	6. Detection of z>10 objects 7. Spectroscopy of ŅgalaxiesÓto z~20 (depending on their nature). Such objects may even be resolved with a 100m 8. IGM studies at z>10 (GRBs, QSOs, PopIII SNe as background)

From the Science Book



λ (μ m)	Imaging (R=5)				Spectroscopy (R=10,000)			
	20m	30m	50m	100m	20m	30m	50m	100m
1.25	2.1	3.6	10.2	34.8	5.8	9.1	15.8	30.6
1.6	1.2	2.3	6.2	22.7	5.8	9.1	15.8	30.4
2.2	0.92	2.1	4.0	6.1	4.5	7.4	13.2	25.8
3.5	**0.036**	**0.080**	**0.221**	0.86	0.50	1.1	2.9	10.9
4.9	**0.005**	**0.020**	**0.054**	**0.20**	**0.042**	**0.095**	**0.27**	1.00
12	**0.012**	**0.030**	**0.079**	**0.30**	**0.088**	**0.200**	0.54	2.15
20	**0.004**	**0.031**	**0.088**	**0.33**	**0.045**	**0.107**	**0.30**	1.15
25	**0.004**	**0.031**	**0.088**	**0.33**	**0.039**	**0.088**	**0.24**	0.92

Comparison with JWST

Scalability: requirements

Requirement	Dependence on D	Comments
Collecting area	D^2	
Wavelength coverage	D^0	Set by science requirements. Achieving shorter wavelength AO may depend on D
Focal ratio	D^0	But different DÕs may allow different designs with different F/ratios
Image quality (opt design)	D^0	e.g. ŅDiffraction limit over 5 arcminÓ
Diffraction limit	D^{-1}	
Emissivity	D^0	Depends on reflectivity and baffling
Field of View	D^0	Depends on science case.
Transmission	D^0	Equals $\{\Pi_i \eta_i$ –É $\}$ i=1,$N_{mirrors}$
Focal stations	D^0	Larger telescopes may have more room for instruments
Sky coverage	D^0	
Zenith avoidance	D^1	Depends on maximum rotation speed of the structure
Image quality (AO)	D^0	Req depends only on science
Diffraction limit	D^{-1}	
Number of actuators	D^2	
Operational lifetime	D^0	
Technical downtime	D^0	Maintenance may take longer (but not be necessarily more complex) for larger DÕs
Operating costs	$D^{1.5}$ (?)	Depends mostly on cost law but with a fixed component
ADC residual dispersion	D^{-1}	Constant in terms of pixels

Risks

- Environment
  - Natural phenomena: earthquakes, storms, ice
  - Atmospheric effects: wind, turbulence, refraction
  - Contamination: light pollution, dust, contrails
- System
  - Technology: adaptive mirrors, detectors, substrates
  - Control: phasing, tracking, open air operations
  - Manufacturing: segments, thin shells, aspheric mirrors
- Mitigating actions
  - Design evolution, backup solutions, site selection
  - R&D (e.g. FP6 ELT DS activities), specific studies
  - Breadboards, experiments, demonstrators

Example of risks & mitigating actions

- Risk: Effect of differential refraction displacements
- Solutions: post-processing, optics to reformat focal plane
  - e.g. assessment of post-processing feasibility:

	Effect in 2ÕFoV, K band				Effect in 1ÕFoV, V band				Effect in 0.5ÕFoV, V band			
	Sep in RA		Sep in DEC		Sep in RA		Sep in DEC		Sep in RA		Sep in DEC	
Decl	Displ [mas]	∆T [min]	Displ [mas]	∆T [min]	Displ [mas]	∆T [min]	Displ [mas]	∆T [min]	Displ [mas]	∆T [min]	Displ [mas]	∆T [min]
35	-2.88	12	-2.15	15	-1.46	6	-1.09	8	-0.73	11	-0.55	15
25	-1.75	19	-0.92	36	-0.89	9	-0.47	18	-0.44	19	-0.24	35
15	-1.24	27	-0.48	> 60	-0.63	13	-0.24	34	-0.31	26	-0.12	> 60
5	-0.97	34	-0.27	> 60	-0.50	17	-0.14	> 60	-0.25	34	-0.07	> 60
-5	-0.83	40	-0.16	> 60	-0.42	20	-0.08	> 60	-0.21	39	-0.04	> 60
-15	-0.76	44	-0.08	> 60	-0.38	22	-0.04	> 60	-0.19	43	-0.02	> 60
-25	-0.73	45	-0.02	> 60	-0.37	22	-0.01	> 60	-0.19	45	-0.01	> 60
-35	-0.75	44	0.04	> 60	-0.38	22	0.02	> 60	-0.19	44	0.01	> 60
-45	-0.81	41	0.11	> 60	-0.41	20	0.06	> 60	-0.21	40	0.03	> 60
-55	-0.95	35	0.23	> 60	-0.48	17	0.12	> 60	-0.24	34	0.06	> 60
-65	-1.20	28	0.45	> 60	-0.61	14	0.23	37	-0.30	27	0.11	> 60
-75	-1.68	20	0.91	36	-0.85	10	0.46	18	-0.43	19	0.23	36
-85	-2.76	12	2.18	15	-1.39	6	1.11	7	-0.70	12	0.56	15

Risk mitigation through R&D

e.g. Adaptive Optics:

- Substantial R&D investment
  - By both ESO and the community
    - OWL Preliminary design phase: 12 M€
    - OWL Phase C/D: 7 M€
    - FP6 ELT Design study: 6.6 M€
    - OPTICON Joint Research Activities: 8 M€
    - VLT Precursors (MAD, AOF, PF): ~ 20.5 M€
    - Total: ~ 54 M€

Risk management

- Risk Review at start of design phase
  - Iterate risk assessment
  - Prioritize risks
  - Identify mitigating actions
  - Identify backup solutions

Cost	Quality	Schedule	Impact / Value SEVERITY
Cost increase to OWL Project > XX MEuro	Failure to deliver a major product to an acceptable standard	Delay of > 6 months of a Top Event from the IMS	CRITICAL
Cost increase to OWL Project between CC and XX MEuro	Failure to meet key criteria against OWL specification and no work around currently identified	Delay of 2 Š 6 months of a Top Event or 4 Š 6 months of a major event from the IMS	HIGH
Cost increase to OWL Project between BB and CC MEuro	Failure to meet key criteria against OWL specification but work around identified	Delay of 0 Š 2 months of a Top Event or 2 Š 4 months of a major event from the IMS	MEDIUM
Cost increase to OWL Project between AA and BB MEuro	Failure to a criteria against OWL specification that does not significantly affect overall performance	Delay of 0 Š 2 months of a major event from the IMS	LOW

Where to now?

- Affordability?
  - Will it be cost effective? (can we afford it?)
  - Will it be timely? (can we afford not to build it?)
- We will take the input and recommendations from the review, discuss with our partners in institutes and industry and assess the way forward.
- Start a design iteration
  - To incorporate instrument feedback
  - To include financial considerations
  - OWL is a concept, not a telescope !