EINSTEIN TELESCOPE ORGANISATION

Geometry Comparison Report

Methodology and Results

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ET-PP Meeting. Barcelona 02/11/2026

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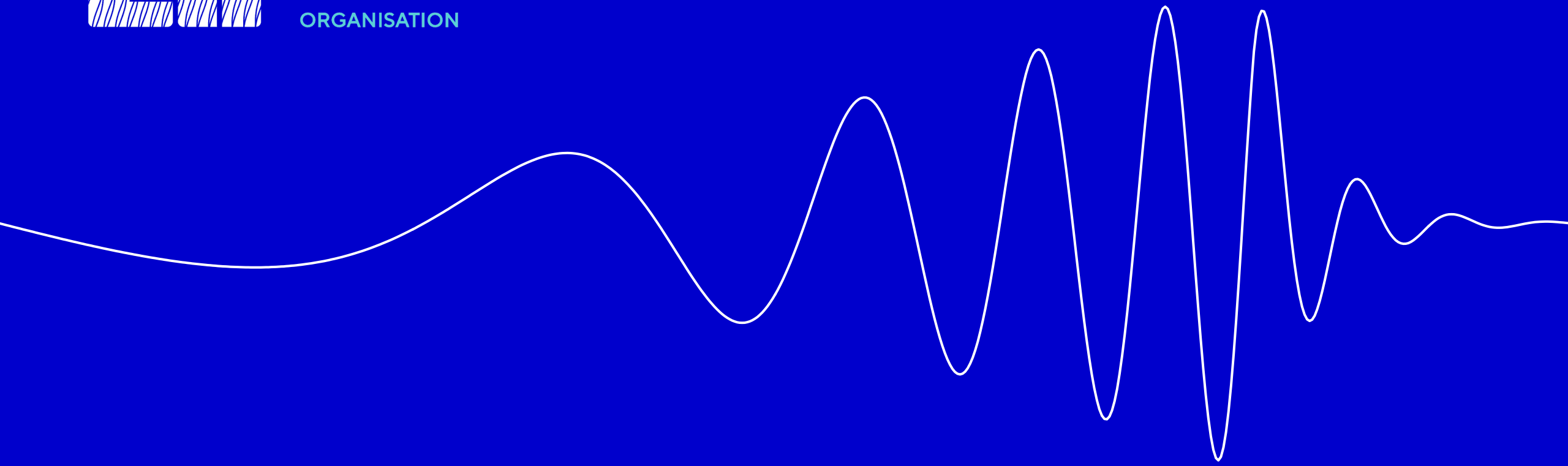


GCR methodology

GCR Mandate

- Board of Governmental Representatives (BGR tasked the Einstein Telescope Organization (ETO) with providing a comparative report on the two geometries, based on five key aspects:

1) scientific impact,

2) cost estimates,

3) risk analysis

4) governance models

5) socio-economic and environmental impacts.

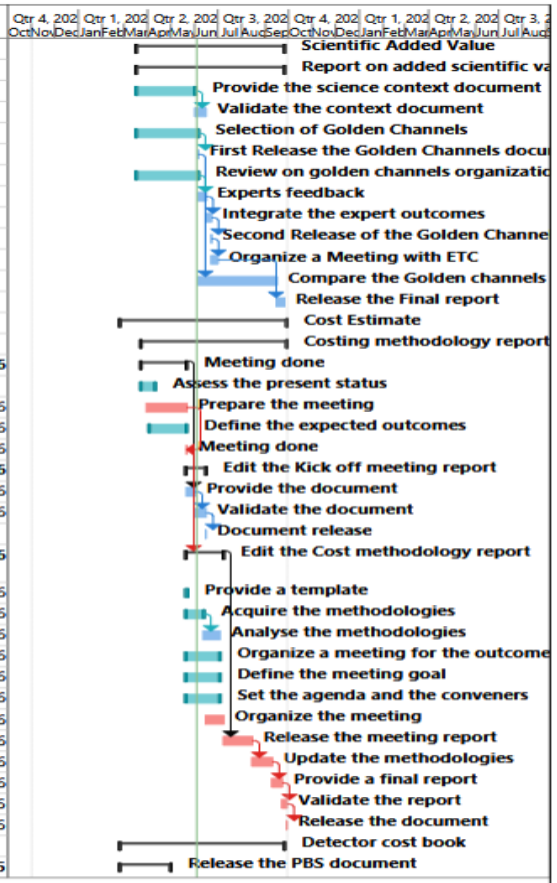
Boundary conditions

- To decouple this analysis from it was requested that the entire study be conducted based **on site-independent** concepts.
- The report should reflect the **collective input of the entire community** of stakeholders and experts associated with the Einstein Telescope project.
- Engaging the **stakeholders** for their specific contribution **a right balance** is maintained, considering that a competitive process for the selection of the project and site is underway.
- **Short timeframe** (delivery on 01/10/2026) to be discussed in the BGR meeting – 21/10/2026
- An efficient and authoritative **review process** is expected, for each aspect.
- **WP specificity**: In the various work packages, reviews were conducted on the final deliverables (reports) except for:

- WP1, where the crucial phase was the selection of the physical channels to be analyzed
- WP3, where—given the varied contributions from the experts—a robust methodology for analysis and comparison was required.
- Thus, in WP1, external experts analyzed the document on the selection of golden channels, and in WP3, they analyzed the document on the associated methodology.

The project organization

ID	Task Mod	Task ID	Task Name	Duration	Start	Finish	Predecessors	Resource Names	Comments	Target Delivery Date
1		**1**	**Scientific Added Value**	**193 days**	**Tue 17/03/26**	**Fri 25/09/26**				
2		**1.1**	**Report on added scientific value**	**193 days**	**Tue 17/03/26**	**Fri 25/09/26**				
3		1.1.1	Provide the science context docume	77 days	Tue 17/03/26	Mon 1/06/26			Document to assess the pres	
4		1.1.2	Validate the context document	15 days	Mon 1/06/26	Mon 15/06/26	3FS-1 day		This document has to be vali	
5		1.1.3	Selection of Golden Channels	81 days	Tue 17/03/26	Fri 5/06/26				
6		1.1.4	First Release the Golden Channels d	1 day	Fri 5/06/26	Fri 5/06/26	5FS-1 day		Document descibing the sele	
7		1.1.5	Review on golden channels organiza	81 days	Tue 17/03/26	Fri 5/06/26			Implement an external feedt	
8		1.1.6	Experts feedback	11 days	Fri 5/06/26	Mon 15/06/26	7FS-1 day		Outcome of the feedback giv	
9		1.1.7	Integrate the expert outcomes	8 days	Mon 15/06/26	Mon 22/06/26	8FS-1 day		ETC have the possibility to ta	
10		1.1.8	Second Release of the Golden Chan	1 day	Mon 22/06/26	Mon 22/06/26	9FS-1 day		After experts feedbacks	
11		1.1.9	Organize a Meeting with ETC	9 days	Mon 22/06/26	Tue 30/06/26	10FS-1 day		Starting from the points esta	
12		1.1.10	Compare the Golden channels	103 days	Fri 5/06/26	Tue 15/09/26	6FS-1 day		The case is analysed in the c	
13		1.1.11	Release the Final report	11 days	Tue 15/09/26	Fri 25/09/26	11FS+76 days		The case is analysed in the c	
14		**2**	**Cost Estimate**	**217 days**	**Tue 24/02/26**	**Mon 28/09/26**				
15		**2.1**	**Costing methodology report**	**190 days**	**Mon 23/03/26**	**Mon 28/09/26**				
16		**2.1.1**	**Meeting done**	**60 days**	**Mon 23/03/26**	**Thu 21/05/26**			**Sharing the goal and the me**	**January 2026**
17		2.1.1.1	Assess the present status	19 days	Mon 23/03/26	Fri 10/04/26			Preliminary meeting to surve	
18		2.1.1.2	Prepare the meeting	53 days	Mon 30/03/26	Thu 21/05/26			Definition of the goal of the	January 2026
19		2.1.1.3	Define the expected outcomes	49 days	Fri 3/04/26	Thu 21/05/26			To be provided in a short do	January 2026
20		2.1.1.4	Meeting done	1 day	Thu 21/05/26	Thu 21/05/26	18FF			January 2026
21		**2.1.2**	**Edit the Kick off meeting report**	**26 days**	**Thu 21/05/26**	**Mon 15/06/26**			**Release of the Kick off meet**	**January 2026**
22		2.1.2.1	Provide the document	12 days	Thu 21/05/26	Mon 1/06/26	16FS-1 day			January 2026
23		2.1.2.2	Validate the document	15 days	Mon 1/06/26	Mon 15/06/26	22FS-1 day		This report should be validat	January 2026
24		2.1.2.3	Document release	1 day	Mon 15/06/26	Mon 15/06/26	23FS-1 day			
25		**2.1.3**	**Edit the Cost methodology report**	**49 days**	**Thu 21/05/26**	**Wed 8/07/26**	**20FS-1 day**		**The Host Consortia has to interview the companies**	**February 2026**
26		2.1.3.1	Provide a template	2 days	Thu 21/05/26	Fri 22/05/26			Decided in the kick off meeti	February 2026
27		2.1.3.2	Acquire the methodologies	23 days	Thu 21/05/26	Fri 12/06/26			Acquire of the HC Methodol	March 2026
28		2.1.3.3	Analyse the methodologies	22 days	Fri 12/06/26	Fri 3/07/26	27FS-1 day		Only for CI and TI. Find comn	May 2026
29		2.1.3.4	Organize a meeting for the outco	44 days	Thu 21/05/26	Fri 3/07/26			Sharing the first analysis	May 2026
30		2.1.3.5	Define the meeting goal	44 days	Thu 21/05/26	Fri 3/07/26				March 2026
31		2.1.3.6	Set the agenda and the conveners	44 days	Thu 21/05/26	Fri 3/07/26				May 2026
32		2.1.3.7	Organize the meeting	24 days	Mon 15/06/26	Wed 8/07/26				May 2026
33		2.1.4	Release the meeting report	38 days	Wed 8/07/26	Fri 14/08/26	25FS-1 day		For internal use	June 2026
34		2.1.5	Update the methodologies	27 days	Fri 14/08/26	Wed 9/09/26	33FS-1 day		Update the methodologies f	June 2026
35		2.1.6	Provide a final report	14 days	Wed 9/09/26	Tue 22/09/26	34FS-1 day		On methodologies guideline	July 2026
36		2.1.7	Validate the report	7 days	Tue 22/09/26	Mon 28/09/26	35FS-1 day		Validation by HC. In the kick	di 01/09/26
37		2.1.8	Release the document	1 day	Mon 28/09/26	Mon 28/09/26	36FS-1 day		Release and distribute the d	di 01/09/26
38		**2.2**	**Detector cost book**	**214 days**	**Tue 24/02/26**	**Fri 25/09/26**		**A.Variola**		
39		**2.2.1**	**Release the PBS document**	**66 days**	**Tue 24/02/26**	**Thu 30/04/26**		**Sorrentino Me**	**First version**	**End of 2025**



Project: Geometry Plan WBS-CI
Date: Thu 4/06/26

Task, Split, Milestone, Summary, Project Summary, Inactive Task, Inactive Milestone, Inactive Summary, Manual Task, Duration-only, Manual Summary Rollup, Manual Summary, Start-only, Finish-only, External Tasks, External Milestone, Deadline, Critical, Critical Split, Progress, Manual Progress

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ETO
ETC
CERN
ESA
HC

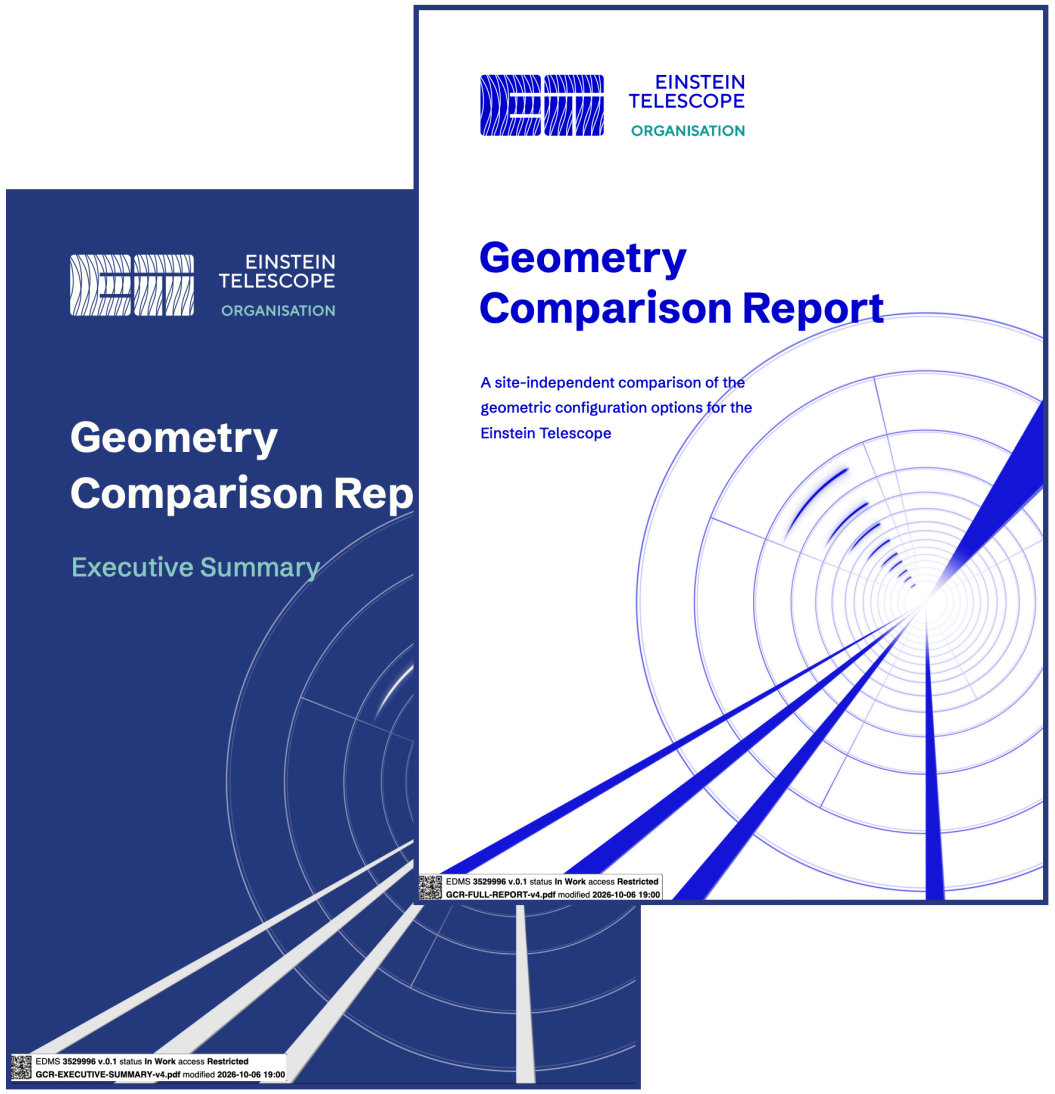
Expert-based work, drawing on European strength

- The reported was organised as a collaborative work that included all ET stakeholder but reached out to many experts beyond the core Einstein Telescope community.
- The work drew on the ET Scientific Collaboration, the Host Consortia and external organisations, including CERN, ESA, ESO, LVK, CTAO, ESS, SKAO and the ERIC Forum. In total, 39 editors, 34 analysts, 187 contributing experts and 19 reviewers took part.
- **The report is therefore a collective assessment, balanced across the ET communities.**

Reports delivered by ETO

- Report ready on schedule 01/10/2026
- Delivered to BGR on 07.10.2026
  - Executive summary, 22 pages, 3MB
  - Full report, 280 pages, 22MB

- Both documents include links to the public EDMS version of the GCR documents, which were made available on Friday 09.10.2026. The linked folders include associated documents such as, for example, the list of contributors, and all the excel tables with data, for sake of transparency.



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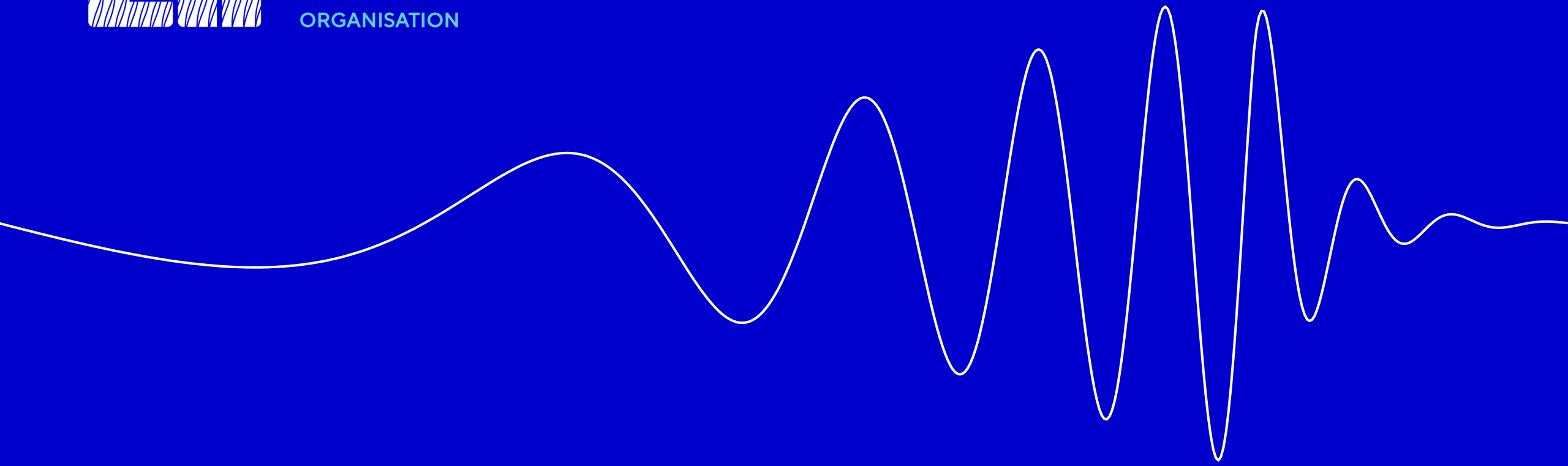
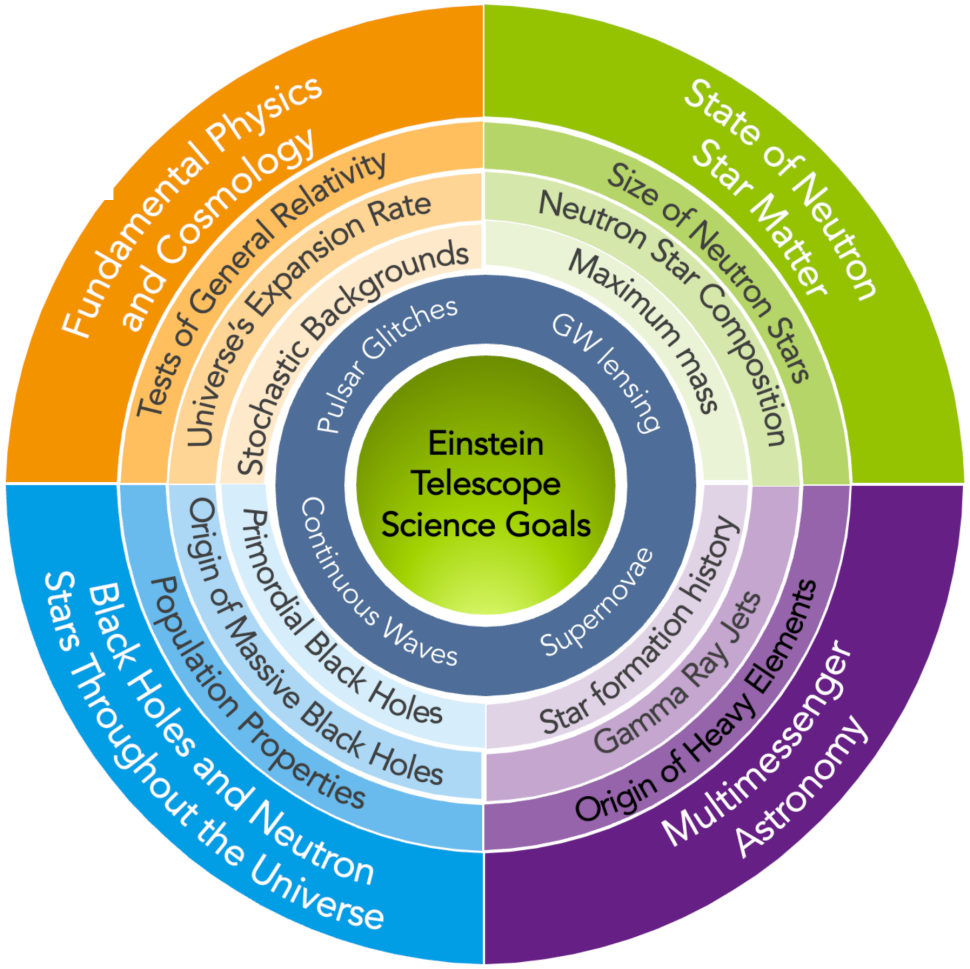


GCR Results

WP1

WP1 team & structure of the WP1 Chapter

- **WP1 Chapter "The Scientific Added Value": Executive Summary** plus **seven Sc**
  matter physics, cosmography, astrophysical & cosmological stochastic backgrou
  & tests of GR, continuous-wave & burst sources.
- For each theme: **Science Target** box → **Key Science Goals** box → quantitative **cr**
  metrics are also collected in a **Summary Table in Appendix A**.
- Other **Appendices:** detector locations, methodology (statistical analysis, popula
  duty cycle), limitations of the analyses, correlated noise.
- Comparison performed for **ET alone** (no other GW detector in the network).

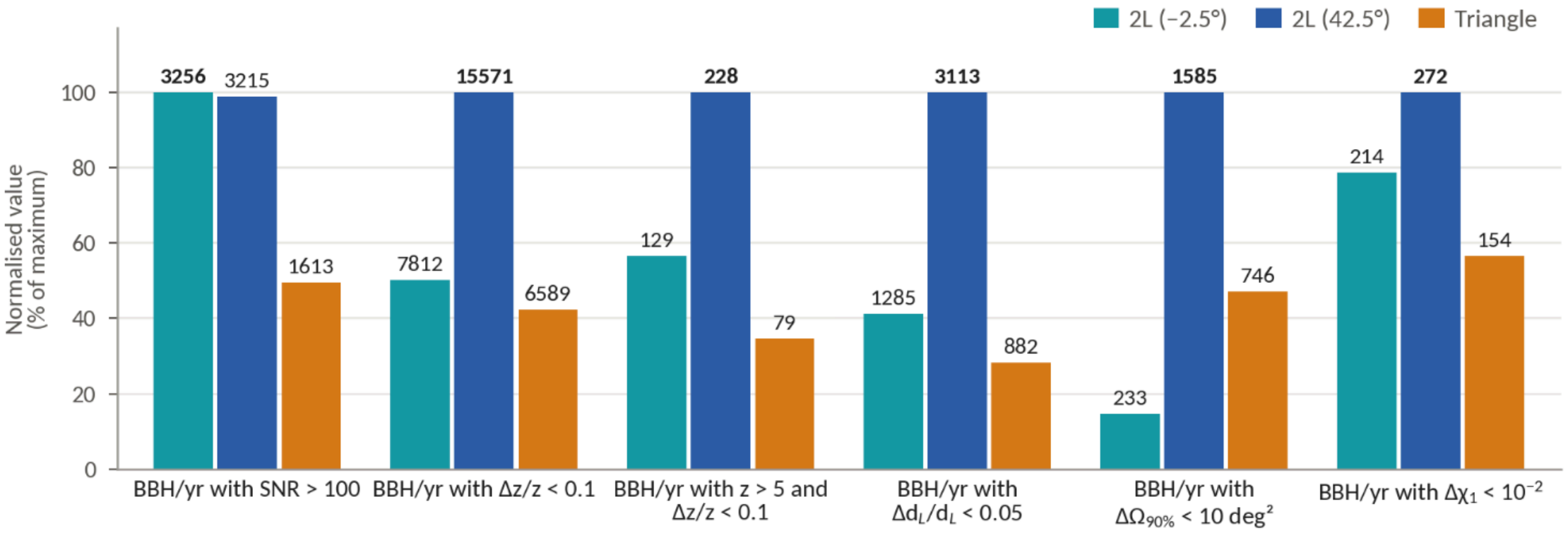


Naming of detector geometry configurations used

- **Triangle (Δ):** an equilateral triangular configuration with 10 km arms.
- **2L (−2.5°):** two distant detectors with 15 km arms rotated by −2.5° relative to e
- **2L (42.5°):** two distant detectors with 15 km arms rotated by +42.5° relative to

WP1 - Scientific Added Value. Example of one channel analysis

Example golden channel: Exquisite Observation of Binary Black Holes



WP1 - Scientific Added Value outcome

- Both the triangular design with 10km arms and the double-L configuration with 15 km arms **meet the Einstein Telescope science requirements successfully**.
- The report indicates that the **2L geometry is better suited to address the broadest range of these channels.**
- The analysis also reveals that no single geometry maximises every aspect of the ET science case. In particular, **the angular orientation between the two L-shaped detectors offers a parameter to be optimised.**

WP2

WP2 - Five cost categories

- **1. Detector:** analogy + parametric, based on ET-Pathfinder and Virgo/LIGO upgrade data; 13 node types plus distributed systems
- **2. Arm Vacuum:** parametric and bottom-up, based on requirements & design data; covers pipe, filter cavities, bake-out, monitoring & control
- **3. Computing:** personnel & capacity from the ET-PP Computing Model; ancillary services by analogy with LVK costs
- **4. Interface Systems:** cryogenics (CERN analogy), cleanrooms (parametric), scaffolding (Virgo/CAOS analogy), NNC boreholes (expert judgement)
- **5. Lifecycle:** commissioning + operation (maintenance & observation), scaled from Virgo experience using complexity factors

PBS-based, three-tier structure from System to Equipment; Equipment is the minimum “ready for costing” unit.

Procurement uses equipment quantity, unit cost, conversion where required, and escalation to mid-2026.

Integration is generally embedded in procurement/system-level cost; local effort is shown separately in FTE and MWh.

WP2 - Main key assumptions and exclusions

- **EC 2026:** monetary values in k€
- **Rough Order of Magnitude:** non-committing estimate
- **80 / 20:** observation / maintenance time assumption

- Excluded: WBS/site-dependent personnel, Host Consortia civil & technical infrastructure, general services, decommissioning, predevelopment and model-philosophy costs.
- Cost-risk mitigation margins are excluded in this version.
- Computing hardware renewal is excluded because long-term renewal costs are highly uncertain and largely common to both configurations.
- The estimate must be revised when the design, PBS, quantities, assumptions, economic conditions or input data change materially.

WP2 - Lifetime Cost

Cost of the ET scientific instrumentation (also known as 'detector cost')	2L	Triangle
Total Procurement and Integration cost [B€]	1.14	1.48
Commissioning – Operational cost [k€/y]	9,628	13,696
Commissioning – Person-power [FTE/y]	364	470
Commissioning – Energy [MWh/y]	40,172	57,173
Operation (80%Observation, 20% Maintenance) – Operational cost [k€/y]	6,236	8,608
Operation (80%Observation, 20% Maintenance) – Person-power [FTE/y]	142	144
Operation (80%Observation, 20% Maintenance) – Energy [MWh/y]	34,884	49,501

WP2 - Lifecycle

- Lifecycle costs are linked to the other cost items and are therefore presented in association with them. The lifecycle cost scope covers both the **commissioning** and **operation** phases.
- **Operation** costs include energy consumption, personnel costs, maintenance activities and system replacements. They are further divided into two categories: **observation** and **maintenance** costs.
- **Commissioning** costs are system-dependent and are described in the following subsections.

Lifecycle item	Commissioning 2L	Commissioning Triangle	Delta (2L – Triangle)	2L/Triangle
Operational cost k€/y (b)				
Person-power FTE/y (c)	360	466	-106	77%
Energy consumption MWh/y (d)	42,143	59,055	-16,912	71%

Lifecycle item	Observation 2L	Observation Triangle	Delta (2L – Triangle)	2L/Triangle
Operational cost k€/y (b)	10,500	18,300	-7,800	57%
Person-power FTE/y (c)	132	136	-4	97%
Energy consumption MWh/y (d)	33,713	46,767	-13,054	72%

Lifecycle item	Maintenance 2L	Maintenance Triangle	Delta (2L – Triangle)	2L/Triangle
Operational cost k€/y (b)	10,500	18,300	-7,800	57%
Person-power FTE/y (c)	160	157	3	102%
Energy consumption MWh/y (d)	42,073	58,967	-16,894	71%

Operation

WP2 - Lifetime Cost outcome

- The report **provides a cost methodology for the ET project** and an estimate for the cost of the scientific instrumentation hardware, referred to as ‘detector costs’.
- Exclusions: cost estimation excludes the technical and civil infrastructure and computing hardware renewal.
- Due to project maturity, the reported figures must not be interpreted as a project budget or a full comparison in itself.
- The report shows **that the detector costs are higher for the triangular geometry**.

WP3

WP3 - Risk

- To fulfil the site independent constraint the risks were collected covering six categories:

1) Financial
2) Political
3)Organizational
4) Scheduling
5) Scope
6) Technical.

Table 1: Overview of experts and stakeholders involved in identifying risks

	Financial	Political	Organisational	Scheduling	Scope	Technical
Number of experts and stakeholders involved in identifying risks	20	23	24	26	20	44
Number of Risks	**43**	**67**	**147**	**52**	**86**	**312**

This was done through a rolling-wave data collection process and through interviews with stakeholders and subject-matter experts. In total, 707 risks were collected from more than 68 unique contributors. The final analysis was based on a **statistical approach**. For each category, the risks associated with a particular severity score have been counted.

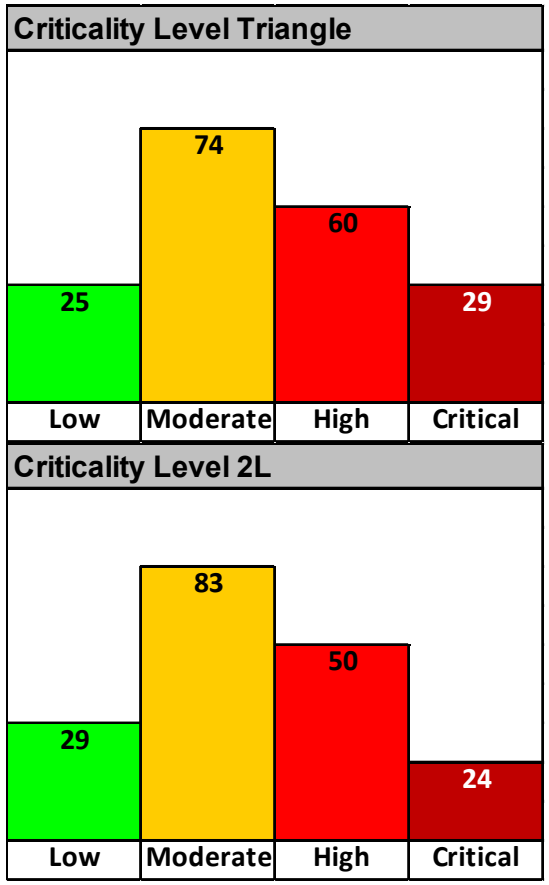
WP3 - Risk

Example: distribution of technical risks

Table 29: Count of technical risks per Likelihood and Severity for the Triangle and 2L geometries

Likelihood	Triangle				
L5	0	1	4	5	0
L4	0	7	14	15	9
L3	0	14	27	33	5
L2	0	7	18	8	3
L1	7	5	4	2	0
Severity	S1	S2	S3	S4	S5

Likelihood	2L				
L5	0	1	2	4	0
L4	2	7	7	12	8
L3	1	18	32	30	9
L2	1	12	16	10	1
L1	11	1	0	1	0
Severity	S1	S2	S3	S4	S5



WP3 – Risk outcome

- Risk analysis: The risk analysis does not show one geometry to be preferable over the other in all the explored fields.
- However, the nature of the identified risks differs between the two approaches: while the triangular geometry shows a **stronger exposure to risks associated with technical challenges and scientific exposure**, the 2L geometry is more exposed **to risks related to governance and organisational aspects.**

WP4

WP4 - Governance

- WP4 has carry out:
  - a SWOT analysis
  - a study of Organisational Risks and Opportunities
- No Governance exists at present, so six realistic scenarios were designed, based on three aspects and different options for each of these:
  - Possible geometry - options: **Triangle and 2L**
  - Geographical configuration - options: **single site** (for triangle only) and **multi-site** (for both triangle and 2L)
  - Final legal entity - options: the European Research Infrastructure Consortium (**ERIC**) and the Intergovernmental Organisation (**IGO**).

WP4 Highligth - SWOT: single-site vs multi-site

Single-site

- Strengths: simpler governance, one central authority, faster decision-making
- Weaknesses: concentrates political and economic return and risks in one host country; “losers” might disengage
- Opportunities: strong host-state commitment anchors stability; single regulatory framework
- Threats: reduced political coalition and less buy-in from non-host countries; total dependence on one host’s continued support

Multi-site

- Strengths: distributes risks and political and reputational stakes across more Member States; successful models exist (ELI, ESS)
- Weaknesses: significantly higher governance complexity and coordination burden
- Opportunities: a dedicated central governance office can offset most of the added coordination risks; genuine 2L: shared visibility and benefits, hence stronger incentives for long-term host commitment; naturally fits into the current IGWN
- Threats: site distribution may reflect political rather than scientific requirements

WP4 – Governance outcome

- The **governance model can and should follow, not drive, the geometry and site decisions.**
- Both geometrical configurations are considered viable and carry distinctive risks and opportunities in terms of governance, but **the multi-site option associated with the 2L configuration emerges as offering a more favourable balance of opportunities and risks**.
- It was also highlighted that for both geometries, strong central coordination and management is a crucial condition for successful ET governance.

WP5

WP5 - Workflow

From documentary review to expert consultation and comparative assessment

- **Phase 1 – Development of the documentary and bibliographic base:** reports on large RIs; literature on socio-economic and environmental impacts
- **Phase 2 – Identification of the four analytical macro-dimensions:** Table 1; translation into operational indicators and proxies (Appendix B)
- **Phase 3 – Discussion with experts:** 6 semi-structured interviews; online questionnaire to 15 experts
- **Phase 4 – Integrated analysis:** content analysis; synthesis of recurring themes; comparison across interviews and questionnaire
- **Phase 5 – Comparative outputs:** relevance of indicators (Appendix B); differential evaluation of key indicators (Table 2); candidate KPIs for future MCA (Table 3)

WP5 - What the comparison currently suggests

Different risk and value profiles — not a universally superior configuration

Triangle

Potential advantages

- Lower estimated excavation volume: ≈ 2.8 Mm³
- Single-site economies of scale and more standardised procurement
- Fewer regulatory and institutional interfaces
- Avoids some duplication of high-tech facilities

Main pressures / risks

- Greater technical coordination, phasing and commissioning complexity
- Concentrated environmental and material-relocation pressure
- Benefits and burdens are geographically concentrated

2L

Potential advantages

- Lower technical complexity per individual detector
- Broader European scientific and institutional cooperation
- Wider access to regional resource and innovation ecosystems
- More geographically distributed training, knowledge and industrial pathways

Main pressures / risks

- Higher cumulative excavation volume: ≈ 3.1 Mm³
- More administrations, legal systems and organisational cultures
- Need for strong, neutral central governance
- Risk of asymmetry or partial completion

Interpretation: geometry changes the type and distribution of complexity; it does not eliminate complexity.

WP5 - Socio-economic and environmental impact outcome

- When it comes to socio-economic impact and sustainability, many details depend on local opportunities and future, international partnership agreements.
- An in-depth study of environmental sustainability and socio-economic performance is required once the shape and location of the Einstein Telescope observatory have been chosen.
- This analysis, in the form of a differential evaluation, already shows that neither configuration is superior in all domains; instead, the two present entirely different risk and operational profiles.
- This leads to a call for deciding **the geometry on science and technology first**.

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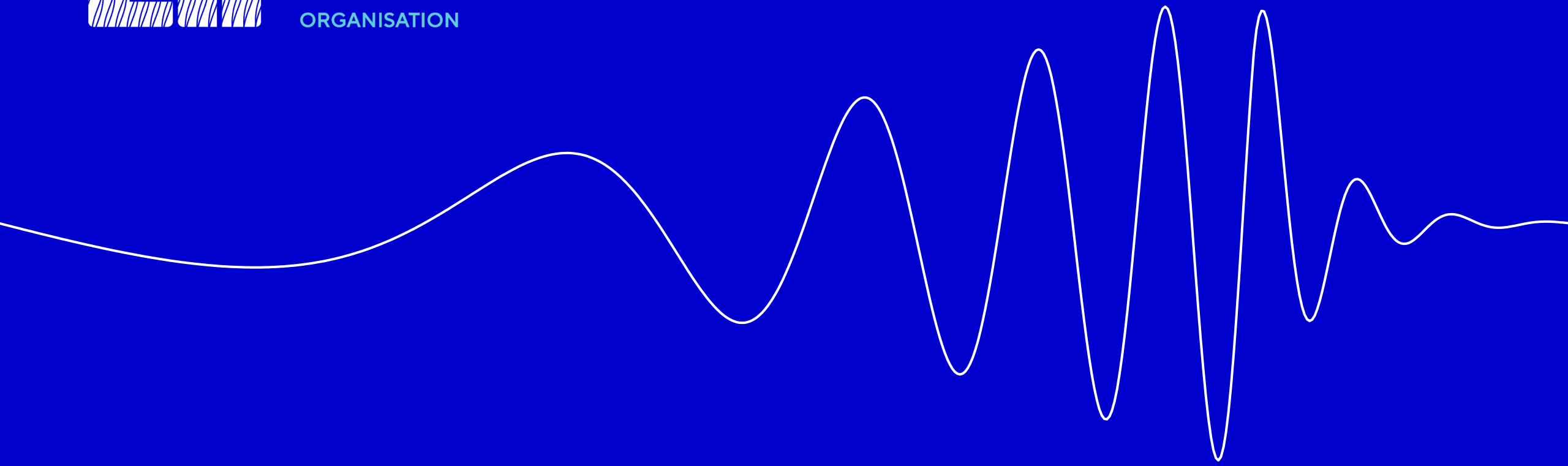

GCR Results - Summary

SUMMARY

- Science - Both the triangular design with 10km arms and the double-L configuration with 15 km arms **meet the Einstein Telescope science requirements successfully. 2L geometry is better suited to address the broadest range of selected channels**
- Costs - **The detector costs are higher for the triangular geometry**
- Risks - The triangular geometry shows a **stronger exposure to risks associated with technical challenges and scientific exposure;** the 2L geometry is more exposed **to risks related to governance and organisational aspects.**
- Governance - **The governance model can and should follow, not drive, the geometry and site decisions. The multi-site option associated with the 2L configuration emerges as offering a more favourable balance of opportunities and risks**.
- Impacts - Neither configuration is superior in all domains; instead, the two present entirely different risk and operational profiles. This leads to a call for deciding **the geometry on science and technology first**.

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Thank you

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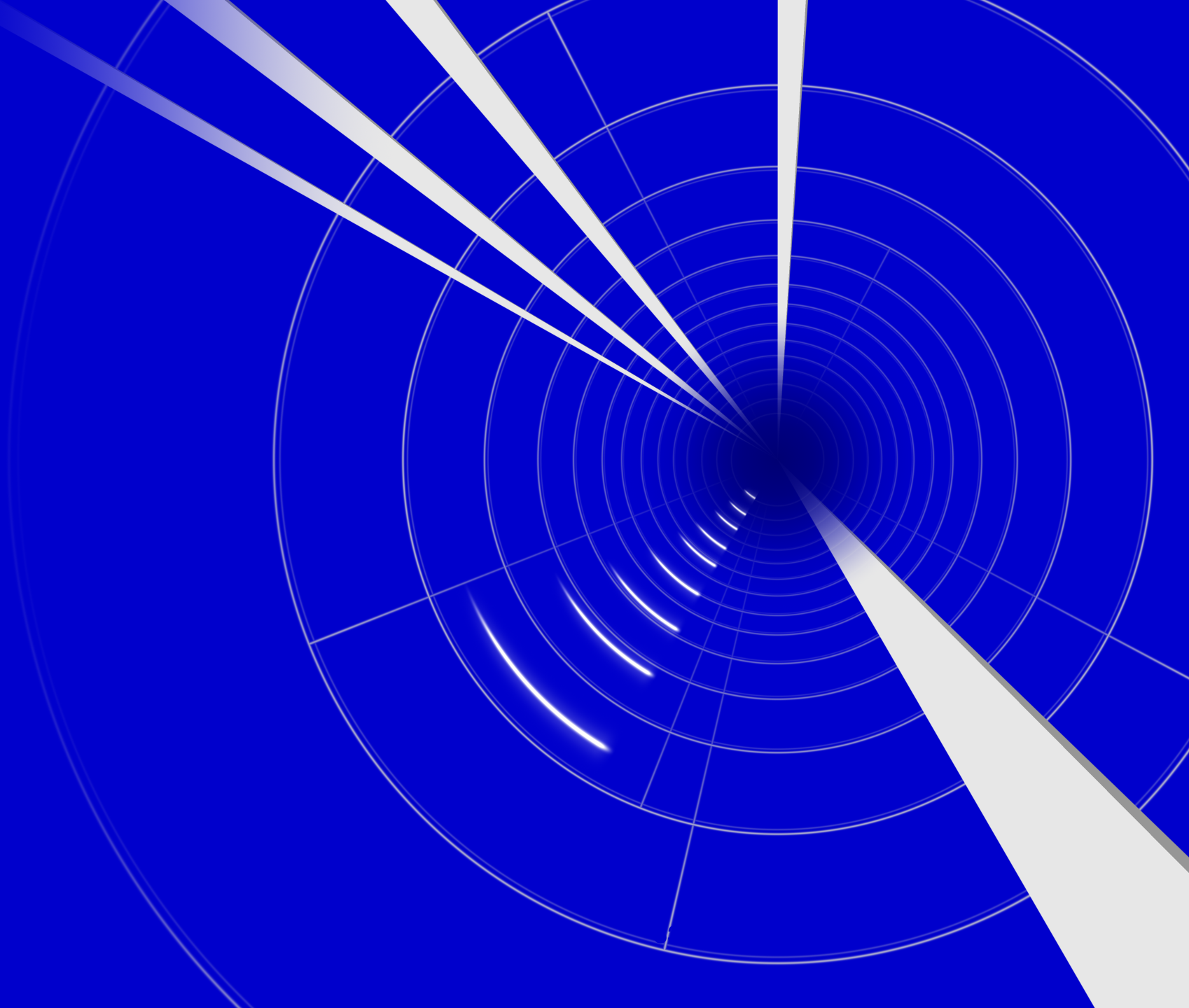

WP4 - SWOT: ERIC vs IGO

ERIC

- Strengths: faster, in principle less complex establishment; purpose-built EU framework
- Weaknesses: real-world timelines often comparable to IGO, and less advantageous for completely new large-scale RIs like ET; EU-centred, weaker global standing; VAT exemption is a wishful statement in practice
- Opportunities: 15+ years of accumulated ERIC experience to draw on; (potentially) strong EU funding alignment
- Threats: regulatory dependency on the EU; easier for a contributor to exit than under an IGO treaty

IGO

- Strengths: strongest institutional authority and global standing; far stronger long-term commitment mechanism
- Weaknesses: slow, heavy establishment; harder to amend or adjust membership once ratified; exit is costly
- Opportunities: broader political coalition (e.g. non-EU); early clarification of roles, contributions and authority; solves VAT exemption once and for all
- Threats: establishing a wholly new IGO is rarely attempted; long ratification timelines can negatively impact momentum

WP1 - Study limitations in WP1 Executive Summary

What the comparison does not yet include

The results assume ET operating alone, and we quote forecast statistical uncertainties rather than results from full parameter estimation.

The report does not include the impact of transient, non-Gaussian detector noise on either geometry.

The null stream has not been applied nor compared it with glitch-mitigation strategies available to the 2L configuration.

The working groups also has not explored the self-calibration of ET using loud binary black-hole signals. Moreover, the standard time-shift method of estimating the noise background, in which triggers from different detectors are displaced by more than their light-travel time, may not be applicable when ET data are dominated by astrophysical signals.

Finally, the working group did not include other observatories operating concurrently with ET, which would improve sky coverage and further break localization and polarization degeneracies.

WP4 - The six governance scenarios as input

Legal form (ERIC / IGO) × site configuration (single-site / multi-site – triangle / 2L): 6 scenarios

Scenario	Legal form	Geometry	Number of sites
1a	ERIC	Triangle	Single site
1b	ERIC	Triangle	Multi-site
2a	IGO	Triangle	Single site
2b	IGO	Triangle	Multi-site
3a	ERIC	2L	Dual site (for multi-site)
3b	IGO	2L	Dual site (for multi-site)

WP1 - Feedback on “Golden Channels” from non-ETC scientists

- **Non-ETC “reviewers”: Daniel Holz** (U. Chicago), **Alexander Nitz** (Syracuse U.), **Raffaella Margutti** (U. California, Berkeley), **Jocelyn Read** (California State U., Fullerton), **Gabriele Vajente** (Caltech), **Nico Yunes** (U. Illinois, Urbana-Champaign).
- Provided **comments on detector setup, overall science metrics, details of methodology**, as well as on statements and phrases in the document we shared that appeared unclear.
- **[NY]** “Comparison goes beyond Δ or 2L geometry” – tried to indicate the main driver of differences wherever possible, e.g., detector length, separation, angle, etc. It may not be possible to disentangle the different contributions in all cases.
- **[AN]** “Exact procedure for how the PE runs validate the FIM results is not explicit” – added in the text a sentence specifying that we will compare the full PE/FIM results at the individual-event level (with 1d and 2d marginal KL divergence) and at the population level, as for the impact on the comparison between the two ET configurations.
- **[AN]** “Matching up the pre-merger times to specific instrument needs” – after checking various telescope slew times, added a 5-minute warning.
- **[JR]** “EOS is not the only quantity of interest in nuclear physics” – rephrased the text, highlighting that it is the most easily accessible and likely the most important quantity.
- **[RM]** in the context of GRB counterparts, suggested adding “the expected number of NS-bearing mergers seen on-axis” – incorporated as “subset with viewing angle < π/12” (~15 deg).