ETRAC Report
(Einstein Telescope Risk Assessment Committee)

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Charge - What is part of the assessment

Mandate of the ET Risk Assessment Committee

The ET Risk Assessment Committee (ETRAC) is defined and appointed by the ET Executive Board (EB) with the specific target to evaluate and compare the integration, commissioning, science and operation risks of the different ET configurations studied in the CoBA-Science document (ET-0291A-22). The reference documentation for this process includes:

1) The CoBA Science Document (ET-0291A-22)
2) The ET design report update 2020 (ET-0007B-20)
3) The 2011 ET CDR (ET-0106C-10)

This is the second step, in the ET collaboration realm, of the ET CoBA process.

Risk evaluation activities

The ETRAC will implement this evaluation in three steps:

1) Identify a list of risk categories
    a. The risks to be analyzed are grouped into risk categories like Commissioning, Performance, Human Resources, Timing, Complexity, Novelty ….
    b. Each category is populated by specific risks; the possible impact is described
2) Define a metric for each risk category
    a. The metric aims to evaluate the probability and the severity level of each risk as much as possible in a justified and quantitative way and possibly with a low level of arbitrariness
3) Apply the risk metrics to the sets of risks identified in point #1 and give a ranking to the ET configurations studied in the CoBA-Science document, through a detailed output document and summarized through a standard risk table representation (see Table 1 as example)

Charge - What is NOT part of the assessment

What is explicitly excluded from this Risk Assessment

The ETRAC risk assessment is realized within the framework of the CoBA process. For this reason the risks categories should rigorously avoid any evaluation of political and financial risks, to be evaluated under the ET Project coordination. Also the civil infrastructure construction risks are essentially excluded, to be evaluated by the Engineering Department. This risk evaluation investigates mainly but not only the integration, the detector construction, the commissioning, the operation and the future upgrades phases.

Assumptions

2.1 Assumptions

We select two ET configurations from the CoBA Science report to perform our risk evaluation:

- 1$\triangle$ 10 km: three co-located, nested detectors, each detector comprised of two interferometers in a xylophone configuration (**low-frequency** (**LF**) cryogenic interferometer @ 1550 nm, **high-frequency** (**HF**) room temperature interferometer @ 1064 nm);

- 2L 15 km: two detectors in different locations, each detector comprised of two interferometers in a xylophone configuration (low-frequency (LF) cryogenic interferometer @ 1550 nm, high-frequency (HF) room temperature interferometer @ 1064 nm).

As described in footnote 5, page 5 of the CoBA Science report, these two configurations have comparable volume of excavated rocks, which is one of the dominant cost drivers. Moreover, we note that these two configurations have the same total length of vacuum pipes 120 km, as described in detail in Sec. 7.1.

There might be additional configurations worth exploring (for example, longer or shorter L configurations), but we consider these variations incremental, and probably not significant enough to change the overall risk assessment.

In this analysis we assume that in both cases, $\triangle$ and 2L, the site infrastructure - comprising of tunnels, caverns, buildings - is completed, and we start our evaluation from the assembly of the vacuum system and interferometer components. **Risks associated with building the infrastructure are not part of our assessment.**

DRAFT

Methods

Box 2: Summary of methods

Two configurations were selected from the CoBA science report: a one 10 km triangular observatory (referred in this document as △), consisting of three co-located, nested detectors, and two 15 km L-shaped detectors, far apart. Each detector is in the same xylophon configuration, with a low-frequency (LF) cryogenic interferometer @ 1550 nm and a high-frequency (HF) room temperature interferometer @ 1064 nm. The approach followed by this committee follows these steps:

- analysis of the differences between △ and 2L configurations;
- selection of differences that lead to *differential risks* between these two configurations;
- grouping of the differential risks in categories, based on the consequences that the risks would have if they come true;
- description of the differential risks, and analysis that supports the risk assessment;
- assessment of the risk for each category;
- overall assessment and final ranking of the ET configurations.

Differences

Box 3: Summary of top-level differences between $\triangle$ and 2L configurations

- **Infrastructure considerations**
  - co-located detectors in $\triangle$; detectors far apart for 2L;
  - proximity in $\triangle$ between two detectors (for example, as shown in Fig. 3, vertex of detector A is close to the end stations of detectors B and C);
  - in $\triangle$ there are 4 pipes in each of the three tunnels, with the two pipes of each detector on top of each other vertically; in 2L, two pipes are horizontally next two each other in each tunnel.
- **Optical configuration**:
  - arm length: 10 km for the detectors in $\triangle$ and 15 km for the detectors in 2L;
  - opening angle of the arms: 60° for $\triangle$, 90° for 2L;
- **Total number of interferometers** needed to fully accomplish science goals: 6 for $\triangle$ and 4 for 2L.

CoBA Science Report, page 134

6. For some important aspects of the Science Case, the 2L with 15 km arms at 45°, already in the HF-only configuration, is comparable the 10 km triangle in a full HFLF-cryo configuration.

In particular:

- For parameter estimation of BBHs, the 2L with 15 km arms at 45° in the HF-only configuration is comparable to the 10 km triangle at full HFLF-cryo sensitivity, with better performance of luminosity distance, less good performance on mass reconstruction, and equivalent performances on all other parameters and in SNR distribution, see Fig. 6. The performance of the 2L-15km-45° configuration is also equivalent to that of the 10 km triangle for what concerns 'golden BBH events', see the lower row of Fig. 8.

- From the right panel of Fig. 37 we see that, for the measurement of the neutron star radii and the consequences for nuclear physics that we can derive from it, the 2L with 15 km arms at 45° already in the HF-only configuration has performances very similar to that of the full 10 km triangle HFLF-cryo.

- For all the items discussed above, where the LF instrument does not contribute (joint GW+X-ray afterglow and partially GRB detections, stochastic backgrounds growing as f^{α} with $\alpha > 0$, tests of physics near the BH horizon, post-merger signal of BNS coalescences, sub-solar mass BH), the 2L-15km-45° in the HF only configuration will be superior to the 10 km triangle with the full HFLF-cryo sensitivity.

Differential Risks - I

4.1 Infrastructure considerations

4.1.1 △ has co-located detectors

- Risk due to Newtonian Noise in co-located detectors;
- Risk due to locally coincident environmental disturbances;
- Risk of reduced duty-cycle in △ due to co-located detectors;

4.1.2 2L detectors are far apart

- Risk of difference in sensitivity in 2L due to sites far apart;
- Risk related to complexity due to sites far apart in 2L;
- Risk of not having sufficient personnel for 2L;

Differential Risks - II

4.1.3 △ has 4 pipes in each tunnel

- Risk of delays in the assembly, installation and testing of the 4 vacuum pipes in each tunnel of △;
- Risk in △ due to LF pipe passing below the HF input and end towers;
- Risk of reduced flexibility to upgrades in △ due to space constraints

4.1.4 △ has vertex of one detector close to end stations of the other two

- Risk of interference in △ between detectors at each stage of the project, from installation to maintenance

4.2 Optical configuration (Opening angle and arm length difference)

- Risk of new noise sources due to untested 60° angle between arms in △
- Risk related to optical configuration due to 60° opening angle in △;
- Risk in △ for not being extendable in length;
- Risk due to higher g-factor of the △ 10 km long arm cavities;

Differential Risks - III

4.3 Total number of interferometers needed to accomplish science goals

- Risk of delays due to larger number of detectors to be installed, commissioned, operated and maintained in $\triangle$
- Risk of reduced duty-cycle in $\triangle$ due to large number of interferometers needed to meet science goals;
- Risk of not having sufficient personnel for $\triangle$;
- Risk of missing scientific opportunities in the network

Risk Categories

Box 4: Risk categories

We have established the following risk categories, based on the consequences the differential risks would have if they came true:

1. **Risk of not achieving design sensitivity**
2. **Risk of schedule delays (with respect of project schedule)**
3. **Risk of unexpected problems due to higher complexity**
4. **Risk of reduced duty-cycle and coverage**
5. **Risk associated with human resources**
6. **Risk of reduced flexibility to upgrades**
7. **Risk of missing science opportunities**

Risk Assessment

		Severity			
		Minor	Marginal	Critical	Catastrophic
Probability	Very Likely	High	High	Very High	Very High
	Likely	Medium	High	High	Very High
	Possible	Low	Medium	High	Very High
	Unlikely	Low	Medium	Medium	High
	Very Unlikely	Low	Low	Medium	High

Figure 2: Risk metric: Definition of the risk level and color code.

For each differential risk:

- 1-2 people from ETRAC took the lead on studying the issue in detail;
- in mostly all of the cases, inputs from experts have been requested
    - some experts have been invited to our meetings to answer our questions (special thanks to Paolo Chiggiato (CERN), Jan Harms (GSSI), Maria Marsella (Roma-La Sapienza))
- Text has been reviewed by several members of the committee, final assessment has been discussed, and, if necessary, modified to reach unanimous consensus within the committee
- Very smooth process, special thanks to the ETRAC members

Next Steps

- The report has been sent to the ET Executive Board
- First discussion in the closed session last Wednesday
- More in depth discussion in the near future
- In parallel, a risk mitigation plan will be put in place by the right entity
- Reminder: this report is just one piece of the more complex CoBA process