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An Evaluation Framework for Assessing Uses of Radio Telescopes

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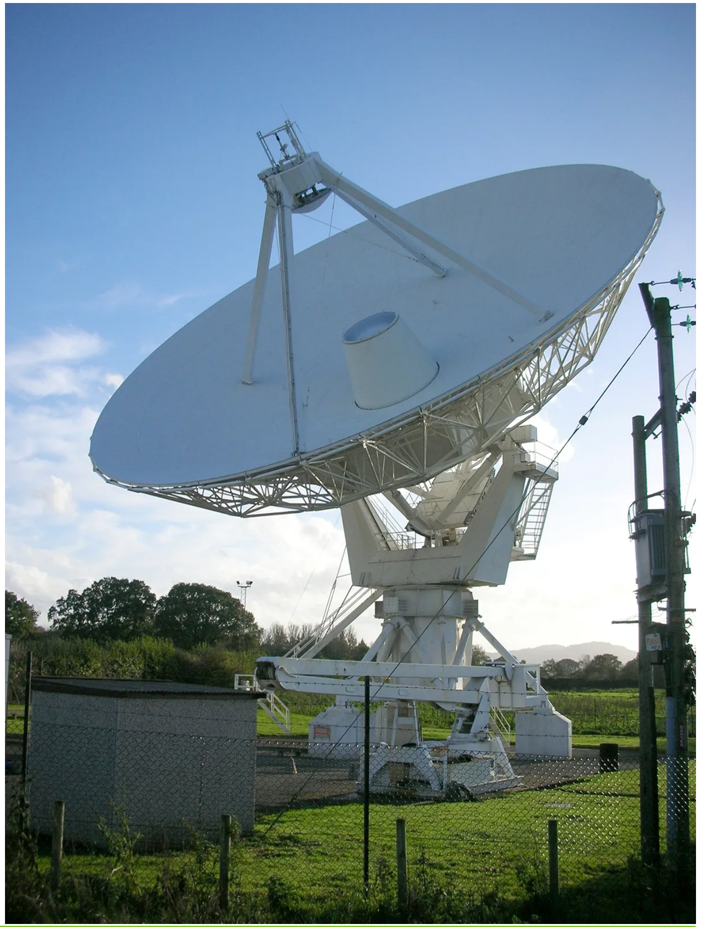
Introduction & Motivation

- Importance of radio telescopes in advancing astronomy.
- Key challenges in evaluating the scientific, technological and societal impacts.
- Objective: To develop an evaluation framework using Multi-Attribute Value Theory (MAVT).
- **Metsähovi Radio Observatory**: A Finnish radio observatory, contributing to both national and international research projects.
- Need for an Evaluation Framework:
  - As radio telescope technology advances, it's increasingly difficult to assess their scientific, technological and societal impacts without a structured approach.
  - Metsähovi, in particular, faces the challenge of balancing **costs** and **manpower**, which were identified as primary constraints during discussions with the observatory.
  - An evaluation framework, leveraging **Multi-Attribute Value Theory (MAVT)**, helps ensure decisions that are data-driven and take into account multiple factors including scientific output, public visibility and operational efficiency.
- What Metsähovi Gains from Radio Telescopes:
  - Participation in these projects brings **networking opportunities** with international collaborators.
  - Enhances **public visibility**, raising awareness of Finnish contributions to space research.
- Challenges:
  - Metsähovi wishes to be involved in most radio telescope projects, but this is likely not a practical strategy. By trying to participate in everything, they risk overextension and inefficient allocation of resources. The framework can help prioritize the most impactful projects.

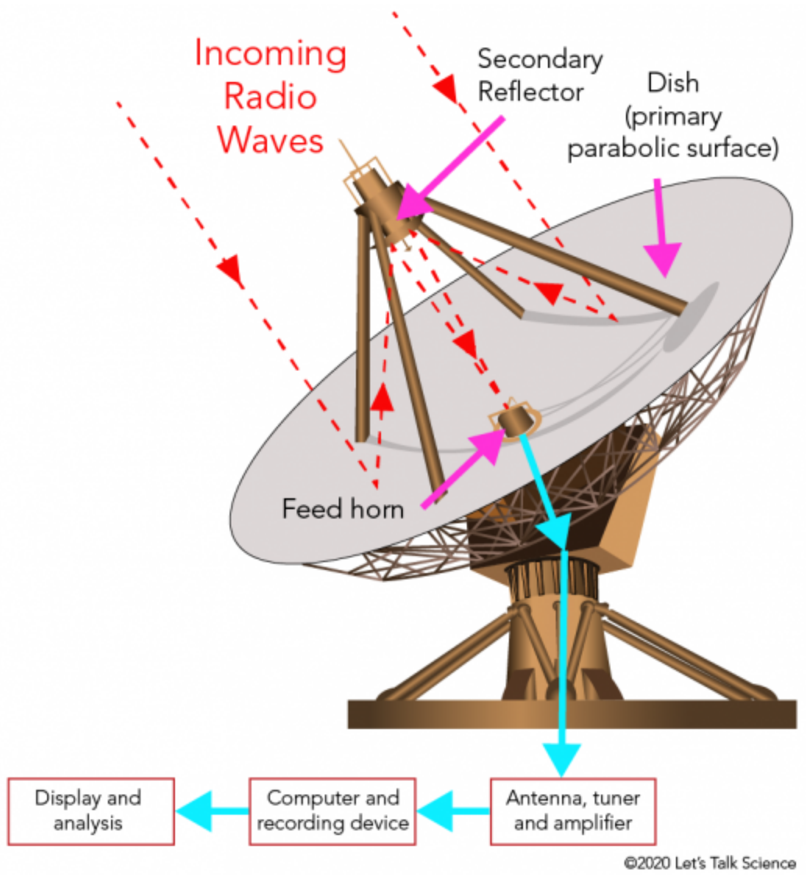


Theoretical Background

- **Radio Telescopes:** Physical instruments used to detect radio waves from space. Overview of the technology: focusing on key specifications such as sensitivity, resolution and frequency range.
- **Utility Theory:** Helps in making decisions by ranking alternatives based on preference.
- **Multi-Attribute Value Theory (MAVT):** Framework for evaluating complex alternatives with multiple objectives.

Characteristics of Radio Telescopes

- **Key Attributes:**
  - **Sensitivity:** Measures the telescope's ability to detect faint signals. Larger dishes (shown as the parabolic surface) improve sensitivity by collecting more radio waves.
  - **Resolution:** Defines how clearly the telescope distinguishes between close objects. A larger dish focuses waves more precisely, improving resolution.
  - **Frequency Range:** The range of radio waves a telescope can observe. The feed horn and antenna capture a wide range of frequencies to study different cosmic phenomena.
  - **Location:** Remote, high-altitude locations minimize radio interference, crucial for clear data collection.
  - **Technological Components:** Key parts include the dish, feed horn, antenna, tuner, amplifier and computer system, all shown in the picture, to process and analyze incoming signals.
- Importance of collaboration (e.g., ALMA and the Event Horizon Telescope) in maximizing scientific output.

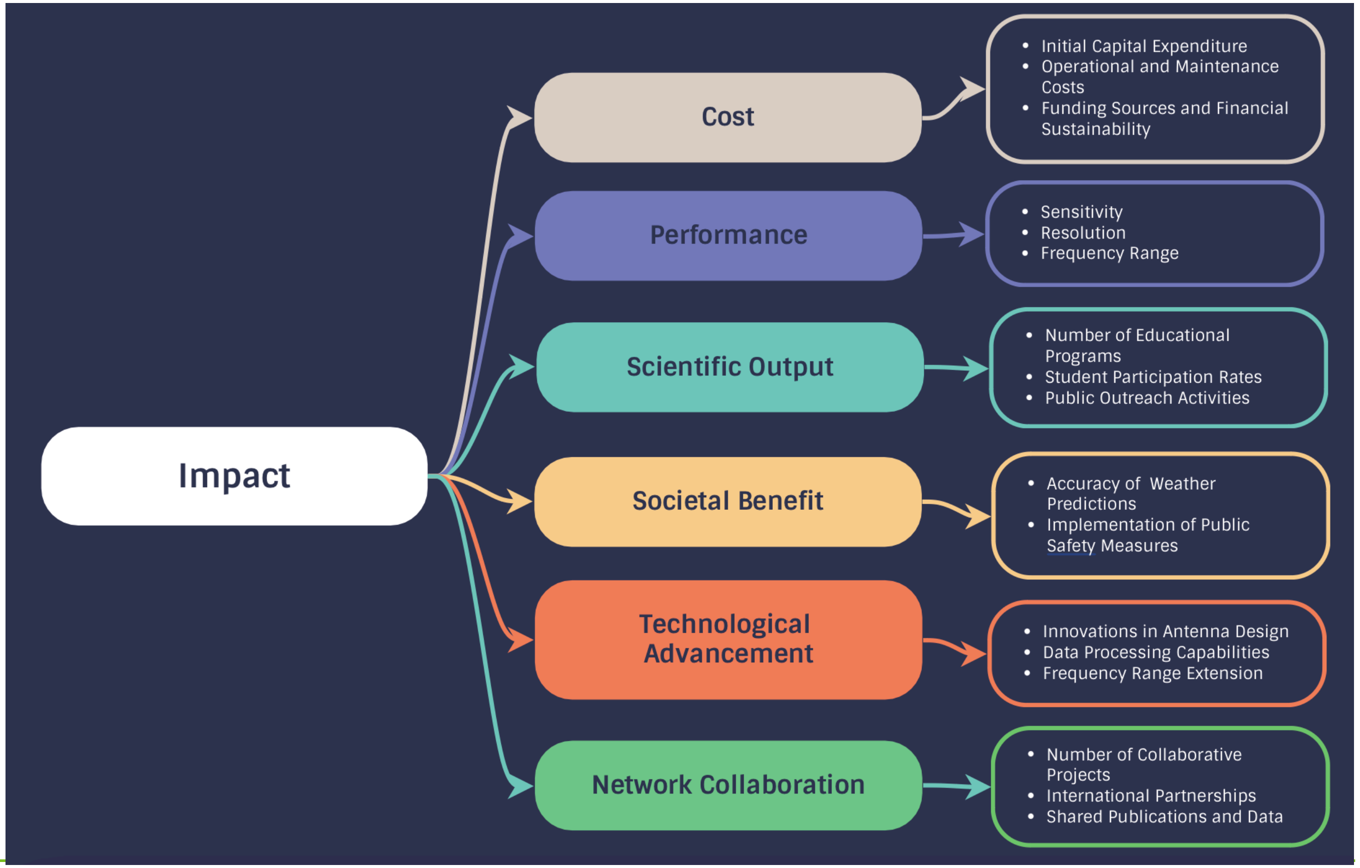


Framework Overview

- Developed to assess alternative uses of radio telescopes across different dimensions: scientific, technological, educational and societal impacts.
- Utilizes a multi-layered approach to evaluate short-term, mid-term and long-term impacts.
- Allows stakeholders to make decisions about where to allocate resources and how to prioritize research projects.

Evaluation Attributes

- **Scientific Results:** Number of publications, breakthrough discoveries, citations.
- **Societal Benefit:** Space weather predictions, public safety measures.
- **Educational Impact:** Student involvement, public outreach.
- **Technological Capabilities:** Antenna design, data processing capacity.
- **Cost and Collaboration:** Financial investment and international partnerships.



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Methodology

- **Developing Metrics:**
  - Defining indicators for each attribute (e.g., number of publications, precision of space weather forecasts), to assess the performance and impact of each attribute in evaluating radio telescope projects.
  - Evaluating attributes directly can be challenging, so we use indicators (or "proxies") to simplify the process. For example, instead of measuring societal impact directly, we can use the number of outreach programs as an indicator. This makes the evaluation more feasible while still capturing the attribute's essence.
  - Example metrics for technological capability: Sensitivity, resolution and frequency range.

Results - Case Study: ALMA

- ALMA is one of the most advanced radio telescope arrays in the world, designed to study the universe at millimeter and submillimeter wavelengths. ALMA stands for the **Atacama Large Millimeter/submillimeter Array**.
- Located in the Atacama Desert in **Chile**, one of the highest and driest locations on Earth, which is ideal for minimizing interference from the atmosphere.
- ALMA consists of **66** high-precision antennas, each up to 12 meters in diameter, spread across the desert plateau.
- ALMA is a collaboration between Europe, North America, East Asia and the Republic of Chile. It is operated by the European Southern Observatory (ESO), the U.S. National Radio Astronomy Observatory (NRAO) and Japan's National Astronomical Observatory (NAOJ).
- **Selected Attributes:**
  - ALMA's scientific contributions: Leading discoveries in astronomy and high publication rates.
  - **Societal Impact:** Role in enhancing space weather predictions.
  - **Educational Impact:** Student and public outreach.
  - Evaluation of ALMA using MAVT: ‘’High’’ utility score.

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Utility Function Example

- Example of how the utility function works. By assigning weights to each attribute (citation counts, expected publications), we can calculate an overall utility score.
- A short part of the **Example Calculation:** The utility score aggregates different attributes, like publications, discoveries and citations, into a single value using weighted averages. In this example, we arrive at a utility score of **0.652** for ALMA, indicating high performance across several attributes. "High" performance depends on how the utility score compares to that of other telescopes, which has not been considered here. The value alone does not provide context unless compared to benchmarks or other telescope evaluations.

$$U_{\text{science}}(x) = w_{31}\frac{x_7}{500} + w_{32}\frac{x_8}{10} + w_{33}\frac{x_9}{1000}$$

- **Where:**
- x_7 = number of scientific publications.
- x_8 = number of breakthrough discoveries.
- x_9 = number of citations per publication.
- w_{31}, w_{32}, w_{33} = weights assigned to each attribute, reflecting their importance in the overall evaluation.
- **500** represents the expected number of publications annually.
- **10** is the number of breakthrough discoveries.
- **1000** is the expected number of citations per publication.

#	Attribute	Description	Possible Values
		Cost (Weight: 0.2)	
1.1	Initial Capital Expenditure	Total initial investment required for setup	[0, 10]
1.2	Operational and Maintenance Costs	Annual operational and maintenance costs	[0, 10]
1.3	Financial Sustainability	Sources of funding and overall financial viability	{0, 1}
		Performance (Weight: 0.2)	
2.1	Sensitivity	Measurement of the telescope's sensitivity	[0, 100]
2.2	Resolution	Image resolution capability of the telescope	[0.01, 1] arcseconds
2.3	Frequency Range	Frequency range captured by the telescope	[0, 100GHz]
		Scientific Output (Weight: 0.2)	
3.1	Number of Publications	Number of research publications expected annually	[0, 500]
3.2	Breakthrough Discoveries	Number of major scientific discoveries	[0, 10]
3.3	Citation Counts	Number of citations per publication	[0, 1000]
		Educational Impact (Weight: 0.15)	
4.1	Educational and Outreach Involvement	Combined impact of educational programs, student participation and public outreach activities	[0, 10]
		Societal Benefit (Weight: 0.15)	
5.1	Accuracy of Space Weather Predictions	Accuracy of predictions provided to the public	[0, 100%]
5.2	Public Safety Measures	Implementation of safety measures derived from space weather data	{0, 1}
		Technological Advancement (Weight: 0.05)	
6.1	Innovations in Antenna Design	Number of new innovations in antenna design	[0, 10]
6.2	Data Processing Capabilities	Efficiency of data processing and analysis systems	{0, 1}
		Network Collaboration (Weight: 0.05)	
7.1	Collaborative Network Benefits	Benefits from national and international collaborative projects	[0, 50]

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Utility Function Attributes

Conclusion

- Framework provides an approach to evaluating radio telescopes balancing short-term gains with long-term goals.
- ALMA as a case study demonstrates the framework's practicality and applicability, while also highlighting areas for improvement in future evaluations.
- **Future Work:** Applying the framework to other international telescopes and expanding attributes for environmental impact assessment.

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Thank you!