

# Tracing the Life Cycle of Radio Sources: First Results from the VLBI Lockman Hole Survey

Theophilus Matsepane, Student (PhD)

University of Pretoria

Advisors: **Prof. J.P McKean** and **Dr. J.F Radcliffe**

---

AfAS conference Conference | 24/03/2026, Kasane, Botswana



UNIVERSITEIT VAN PRETORIA  
UNIVERSITY OF PRETORIA  
YUNIBESITHI YA PRETORIA



SARAO  
South African Radio  
Astronomy Observatory



This work is based on the research supported by IDIA and NRF (Grant number: 128943)

# Introduction: Why Deep Wide-Field VLBI?



**The Co-evolution Problem:** The relationship between **star formation (SF)** and the growth of **AGN** is key to understanding galaxy evolution.

- Observations show a **correlation** between **SMBH** growth rates and **SF rates** (Stanley et al., 2017).



**AGN Feedback:** AGN **jets** inject energy into the intergalactic medium, **influence SF** in host galaxies through complex **feedback processes**.



**VLBI's Role:** VLBI provides the **milli-arcsec resolution** necessary to separate the compact **AGN core** from the more extended **SF** emission within a host galaxy, especially at low radio power.





Image credits: SARA0, SSS, S. Dagnello and W. Cotton (NRAO/AUI/NSF)



# Scientific Aims I: Tracing the Life Cycle of Radio Sources

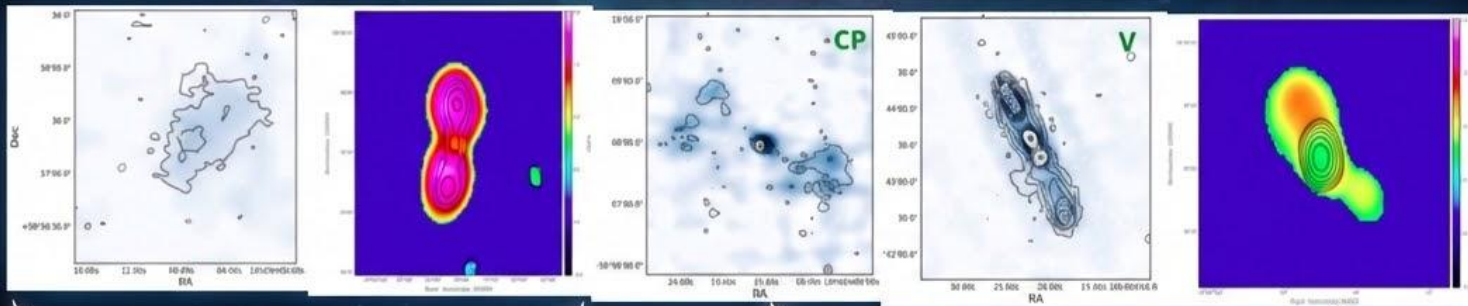
Goals: Investigating the Full Radio Source Life Cycle

## 1. Investigate Restarted Radio Sources:

-  Dying sources represent the final stage of evolution.
  - They are expected to show **no emission in high-frequency VLBI imaging**.
-  **Restarted AGN** exhibit a **bright core** and jet emission from the BH (Jurlin et al., 2020).
  - Goal:** To confirm **remnant** and **restarted candidates** (23 objects) already identified in the Lockman Hole region.

## 2. Determine Radio Source Triggers Across Cosmic Time:

-  We use **multi-frequency data** to classify sources by **spectral shape** (e.g., Peaked Spectrum, Compact Steep Spectrum).
-  VLBI helps confirm **young radio sources** characterised by small double-lobe structure (~100 cases confirmed).
  - Goal:** Determine pc- to kpc-scale **morphologies** of the 2192 ILT unresolved sources.



remnant

restarted

R. Morganti et al. 2021

## Scientific Aims II: Feedback & Energetics

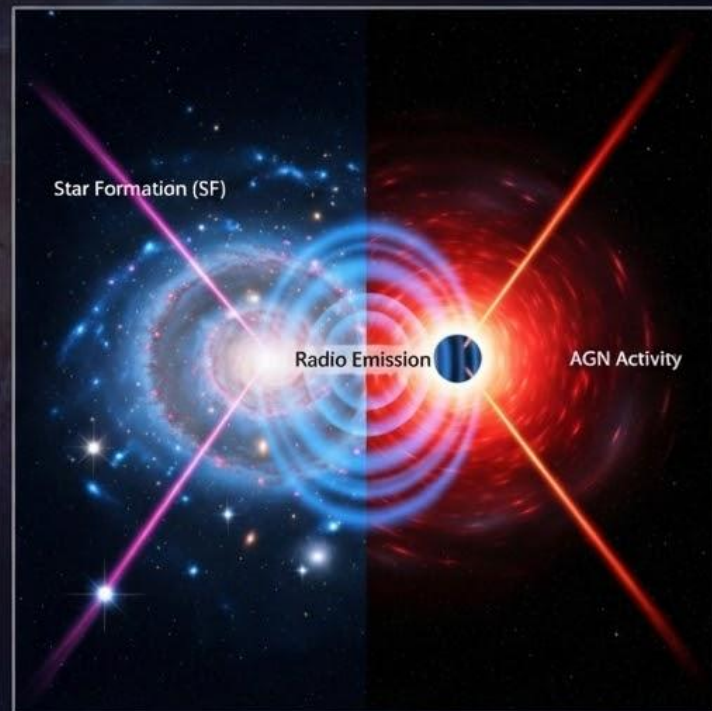
**Goals:** Quantifying Feedback and Jet Energetics

### 3. Decompose AGN-Star-Forming Galaxies:

- Radio emission in **radio-quiet AGN** is often a mixture of SF and AGN activity (White et al., 2015).
- Understanding jet-induced feedback requires separating the AGN from the SF contribution.
- **Goal:** Identify AGN cores and **subtract their contribution** from the total radio emission, thereby enabling accurate calculation of radio-derived SF rates.

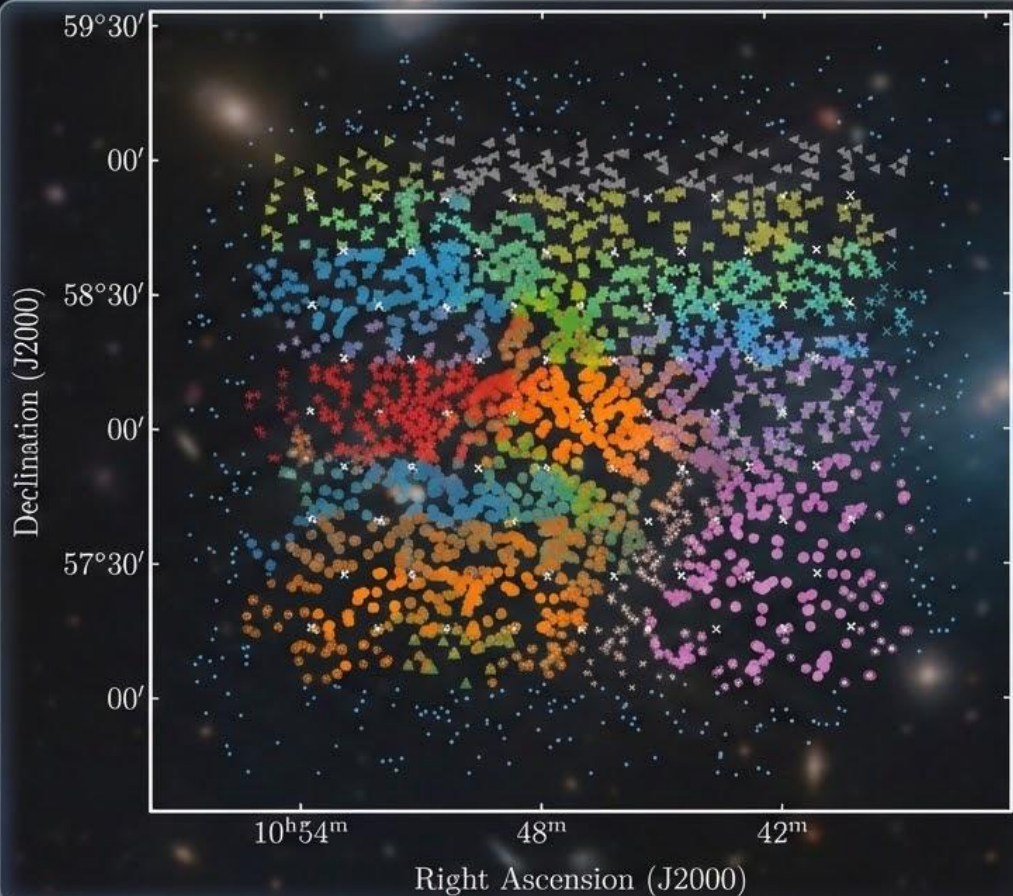
### 4. Understand AGN Dynamics and Jet Energetics:

- By combining EVN, e-MERLIN, and ILT imaging, we **trace the emission** from the BH out to the hotspots then to the radio lobes (Harwood et al., 2015).
- **Goal:** To determine whether the appearance of **hotspots and jets** is dependent on the energetics of the radio galaxies



Only meant for illustration, not a real image.

# Survey Strategy: Lockman Hole VLBI Observations & Data Reduction



- all sources
- EM164A (779/111.1)
- ▲ EM164B (651/93.0)
- ★ EM164C (663/97.6)
- ▼ EM164C (480/86.6)
- + EM164E (563/80.4)
- EM164E (563/80.4)
- ▲ EM164C (279/38.9)
- ▼ EM164H (481/86.1)
- × EM164I (583/75.1)
- EM164J (603/86.1)
- EM164K (472/67.4)

Total phase centres = 5839  
Phase centres / pointing = 75.8



## VLBI Survey Parameters



Telescope: 1.7 GHz EVN/e-MERLIN



Area: 2° x 2° Field



Strategy: 7 Pointings/Visit



Total Time: 198 Hours  
(11 Visits, 18h each)



Beam: 5.1 x 4.1 mas Resolution

## ILT 150 MHz Survey



RMS Noise: 30  $\mu$ Jy/beam



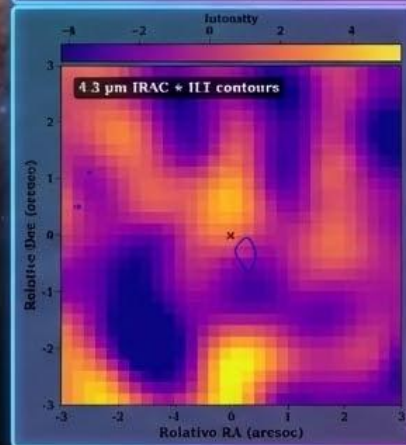
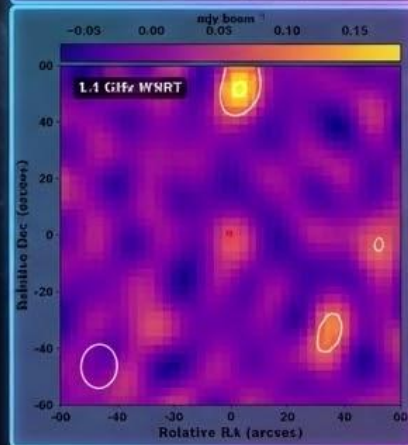
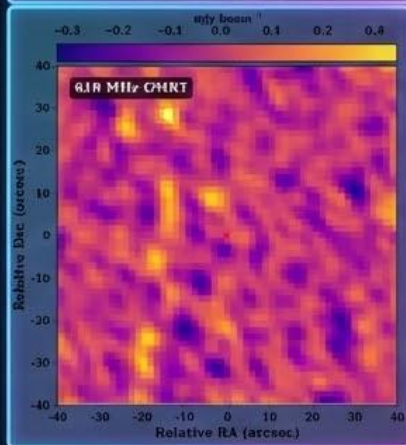
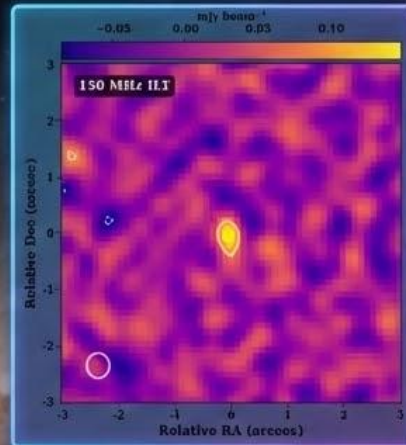
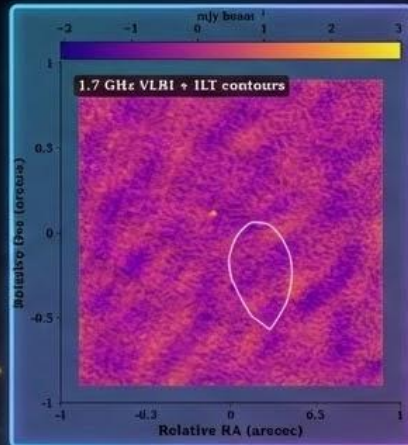
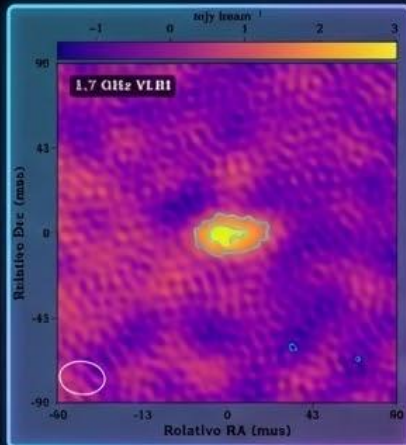
Unresolved Sources: 2483 Targets  
(Unresolved at  $>5\sigma$ , 300 mas)

## Data Reduction



VPIPE Pipeline on ilifu

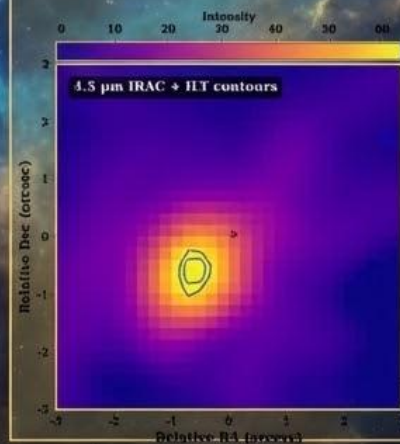
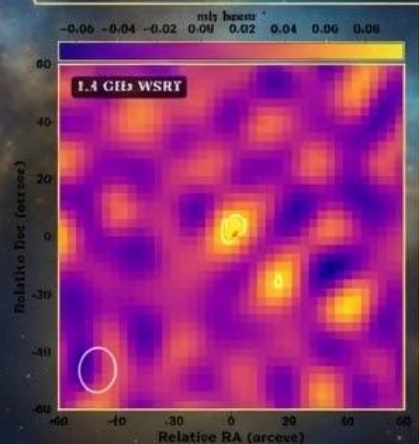
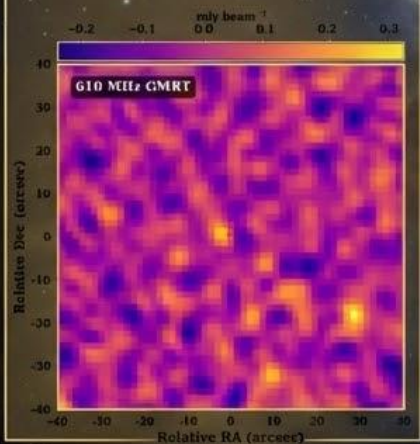
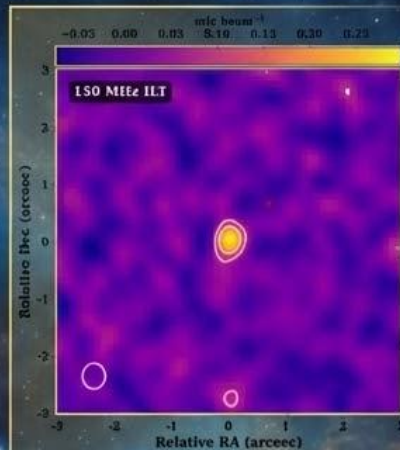
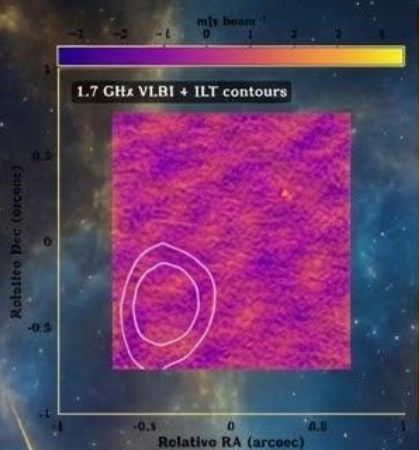
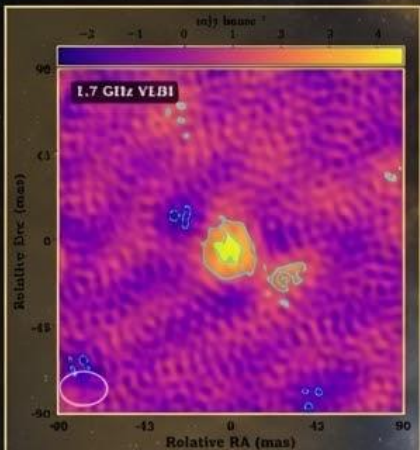
# Source 1: The Restarted Candidate



- **VLBI Detection:** High brightness temperature ( $T_b > 10^5 \text{K}$ ) and extremely compact VLBI detection.
- **Mid-IR:** Classified as an Infrared-Faint Radio Source (IFRS).
- **Spectrum:** Shows an **inverted/GHz-peaked spectrum**, suggesting a young source or **complex absorption** physics (Synchrotron Self-Absorption or Free-Free Absorption).

**Conclusion:** This source shows characteristics consistent with an extremely compact **young AGN** or a **restarted phase**.

## Source 2: Radio-Loud AGN Host



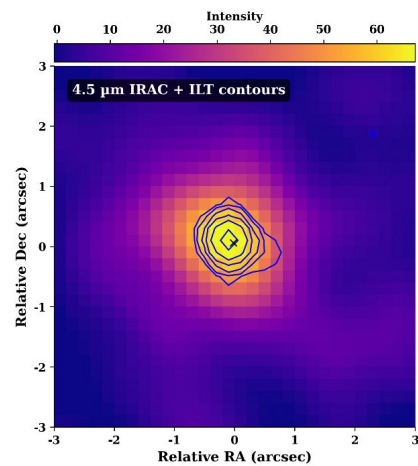
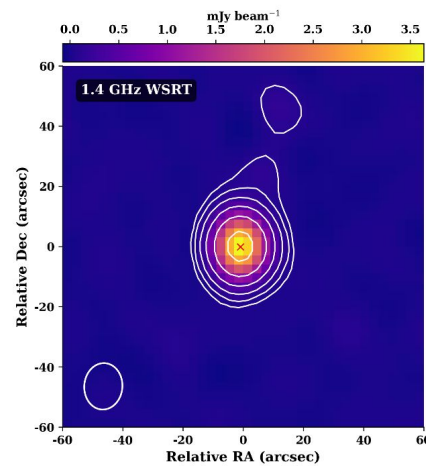
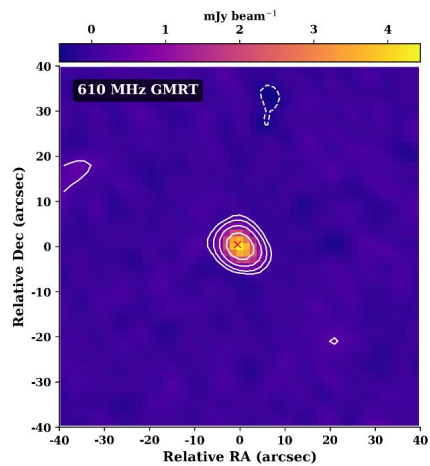
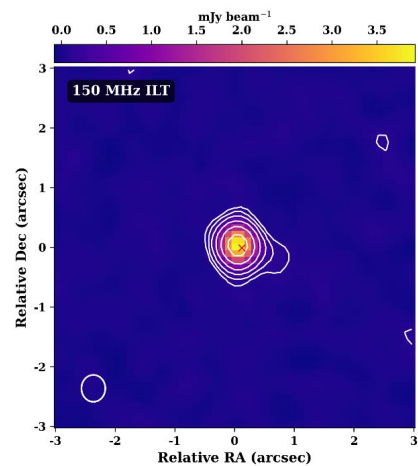
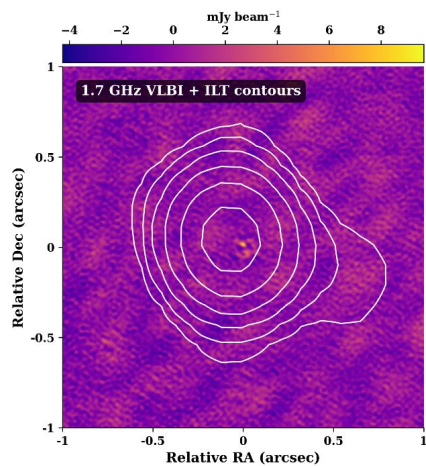
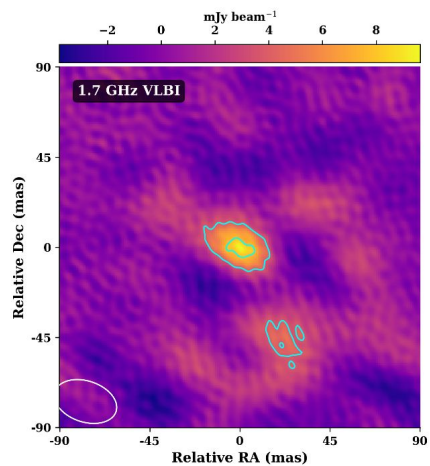
**MIR Emission:** Thermal emission from dust, likely heated by the **AGN** or recent SF.



**Multi-band Detection:** Detection in both VLBI and Mid-IR (MIR) suggests the presence of a **compact jet base** (VLBI) and either **SF** or a **dusty torus region** (MIR).

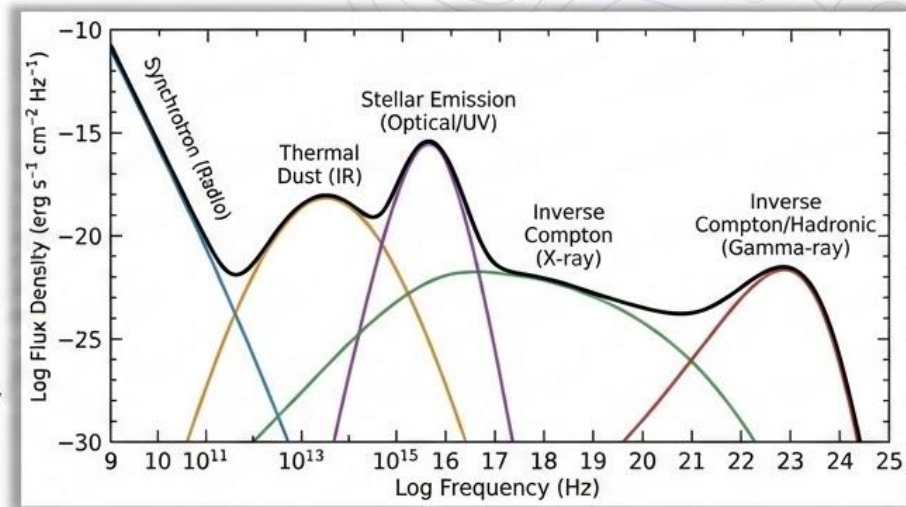
- Consistent with a normal **radio-loud AGN host galaxy**.

# Source 3: Young radio galaxy



## Source 3: Spectral analysis

- **Low-Frequency Slope:**  $\alpha_{150}^{610} = -0.32 \pm 0.03$ . Optically thin (but flat).
  - Emission from **composite structure**.
  - Beams are large enough to detect both the **compact core** and the slightly **extended lobes** emissions.
- **Turnover:**  $\alpha_{610}^{1400} = +0.10 \pm 0.04$ . Synchrotron Self-Absorption (The Peak).
  - This **rising index** confirms the **AGN** nature of the source
- **High-Frequency Slope:**  $\alpha_{1400}^{2300} = -1.27 \pm 0.15$ . Optically Thin (Extremely Steep).
  - The source becomes transparent again.
  - **Scenario A:** The electrons are cooling very rapidly (spectral ageing).
  - **Scenario B:** Small beam resolving out the extended emission.



The spectral energy distribution

**Conclusion: Likely a young compact AGN that is evolving inside its host galaxy.**

# Conclusions and Future Work

## Current Results (1/11 Visits):

- ✧ From the first visit data, we detected **14 VLBI candidates** at  **$4.3\sigma$** .
- ✧ This initial visit **provides a valuable overview of the entire survey**.
- ✧ The detected sources already show potential to address most of our scientific aims.

## Survey Prospects:

- 📡 The current detection rate is highly promising.
- 📡 If the detection rate remains consistent, we anticipate finding **~105 potential cm-VLBI sources**.
- 📡 This would make the VLBI Lockman Hole Survey one of the **largest deep wide-field cm-VLBI surveys** ever conducted.
- 📡 This survey is the cornerstone for the upcoming Southern Hemisphere VLBI surveys, such as **SKA-VLBI** and African VLBI Network (**AVN**).