Wide-field VLBI Surveys

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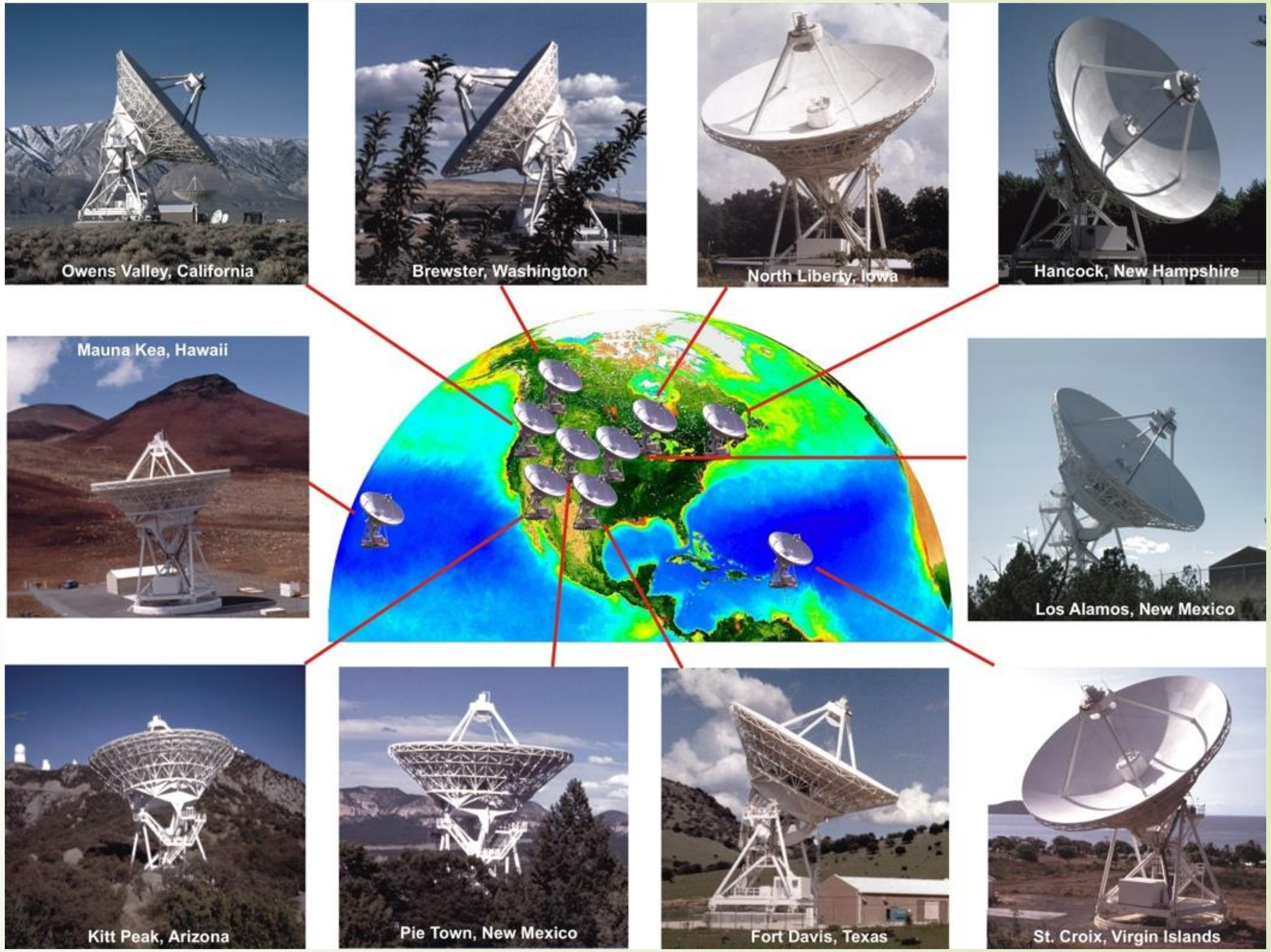


Credit: NRAO/AUI/SeaWiFS (NASA/GSFC)/ORBIMAGE

Regional VLBI Workshop
Mexico, Feb 26, 2019

First part:

Introduction to the wide-field VLBI technique

Early wide-field VLBI

- Field of View (FOV) restricted by:
  - Bandwidth smearing
  - Time-average smearing
  - Computational cost and data storage capabilities
- Traditionally, observations recorded on a tape and shipped
- Hardware correlator (spectral and temporal resolution limited)
- To avoid smearing effects, high spectral and temporal resolution needed (sensitivity compromised)

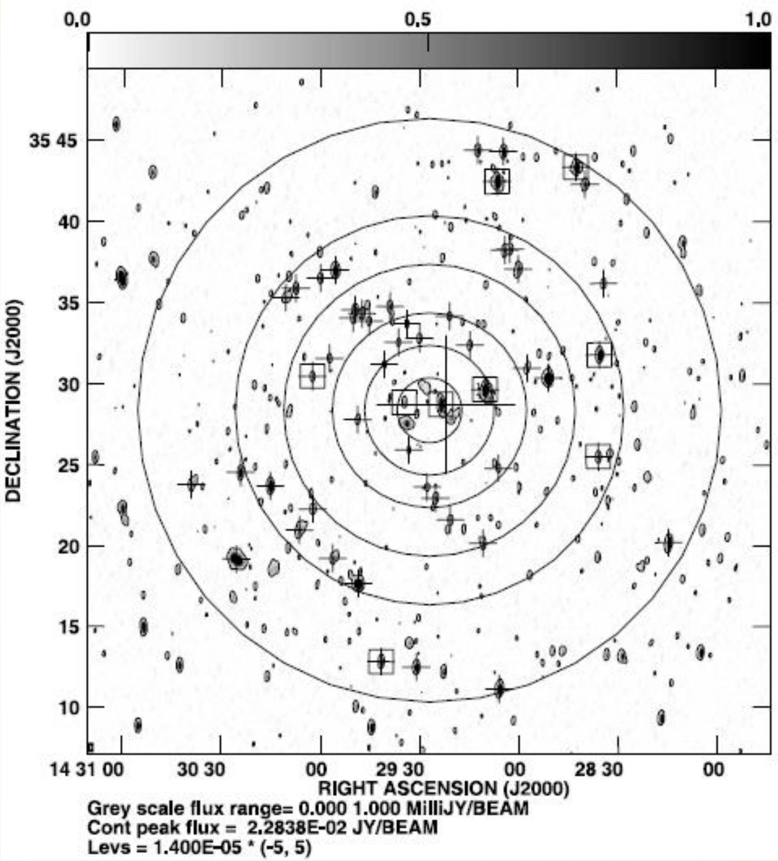
Early work

- EVN – Hubble Deep Field (HDF):

  Garrett et al. (2001). 1σ ~ 42 μJy/bm
  - $t_{average}$ 1s, 125 kHz channels.
  - 5 targets, 3 detected sources.
- VLBA+GBT – NOAO Bootes field:

  Garrett et al. (2005). 1σ ~ 9-55 μJy/bm
  - $t_{average}$ 0.5s, 62.5 kHz channels.
  - 61 targets, 9 detected sources.
- EVN (330 MHz) – two overlapping fields:

  Lenc et al. (2008). 1σ ~ 1-10 mJy/bm
  - $t_{average}$ 0.25s, 31.25 kHz channels.
  - 272 targets, 27 detected sources.



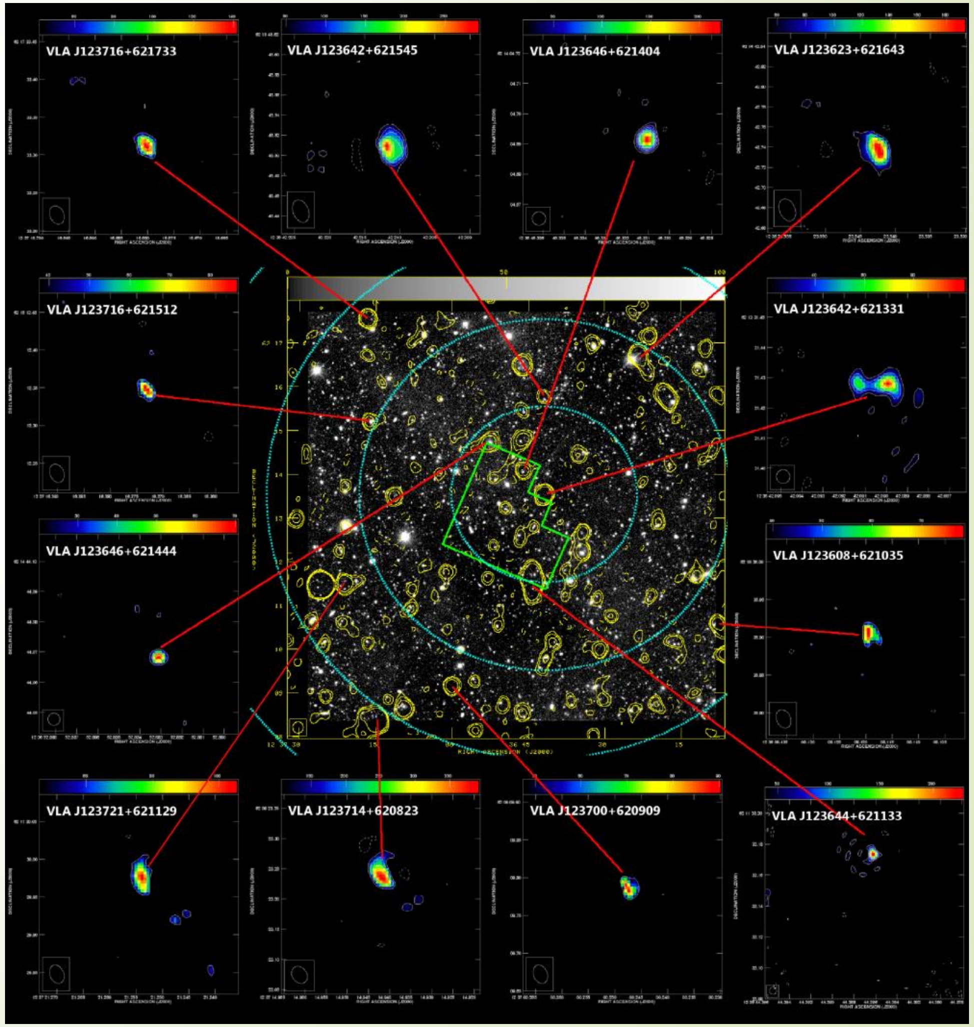
Garrett et al. (2005)

Early work

- Global VLBI array – HDF-North and Flanking Fields: Chi et al. (2013)

  1σ ~ 7.3-37 μJy/bm

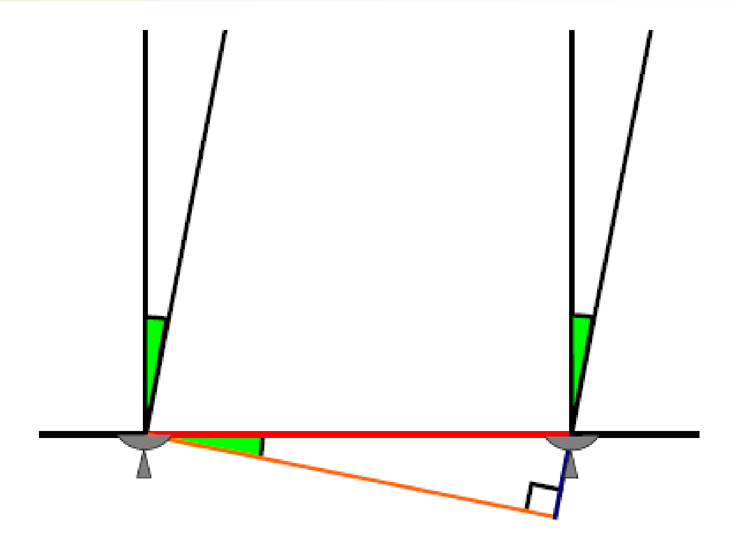
  - $t_{average}$ 0.25s, 31.25 kHz channels.
  - 48 targets, 12 detected sources.



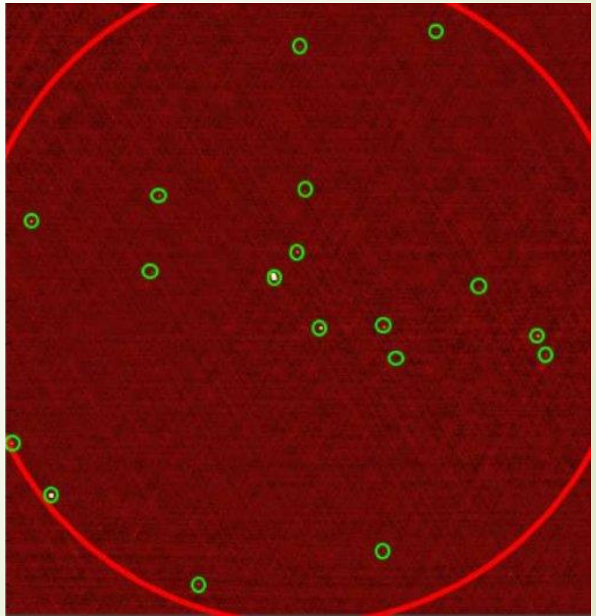
Chi et al. (2013)

Improvements

- High-performance computing
- Modern hard disk data-recording systems
- Software correlators
- Deller et al. (2007): DiFX (Distributed FX). Improved spectral and time resolution
- Deller et al. (2011): DiFX-2. Multi-phase centre mode (uv shift)



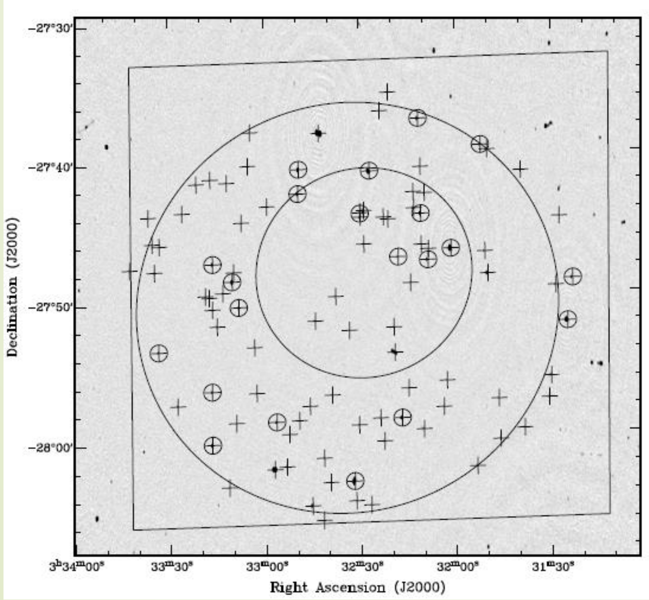
Red circle: 31' (antenna primary beam)
Green circles: 12" (field of view VLBI)



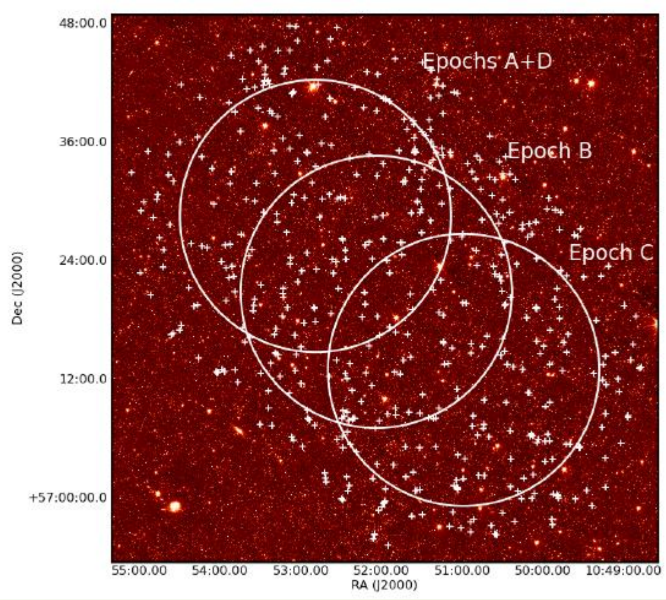
Deller et al. (2011)

Recent Surveys

- VLBA – Chandra Deep Field South: Middelberg et al. (2011)
  - 1σ ~ 55 μJy/bm
  - 96 targets, 20 detected sources.
- VLBA – Lockman Hole/XMM field: Middelberg et al. (2013)
  - 1σ ~ 24 μJy/bm
  - 217 targets, 65 detected sources.



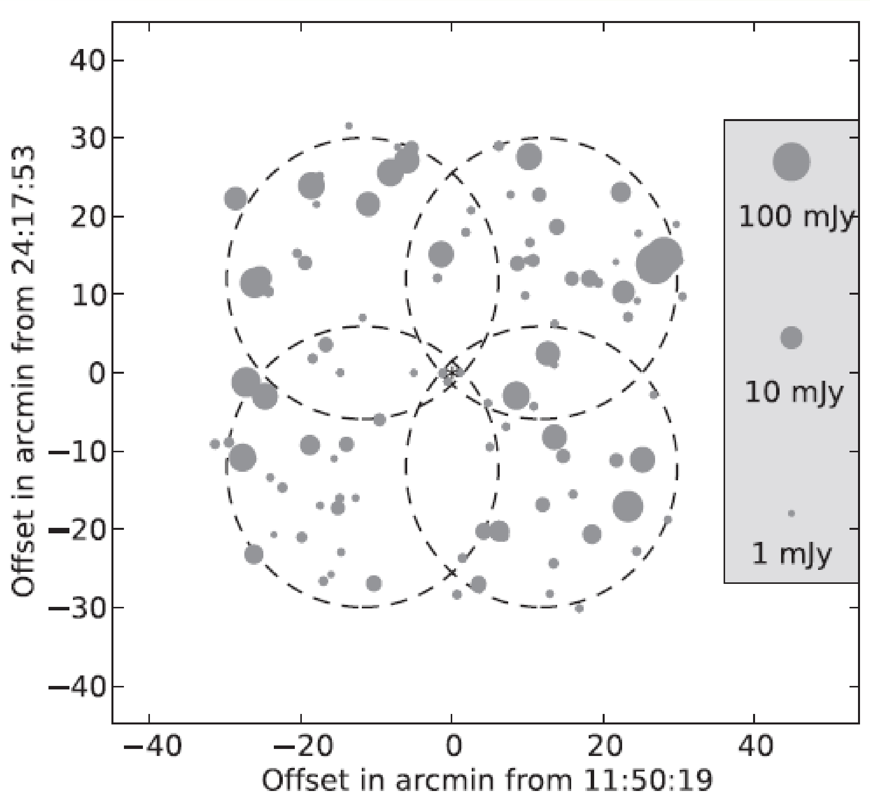
Middelberg et al. (2011)



Middelberg et al. (2013)

Recent Surveys

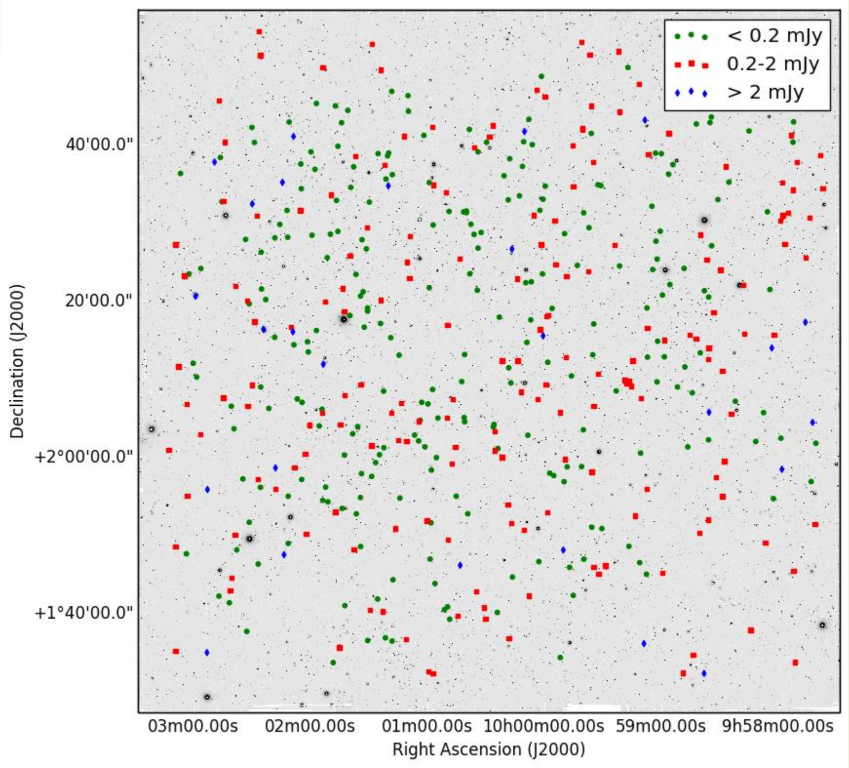
- VLBA – mJIVE-20 (mJy Imaging VLBA Exploration at 20 cm): Deller & Middelberg (2014)
  - ~25000 targets from the FIRST (Faint Images of the Radio Sky at Twenty cm) Survey.
  - 4965 detected sources.
  - 1σ ~ 148 μJy/bm



Deller & Middelberg (2014)

Recent Surveys

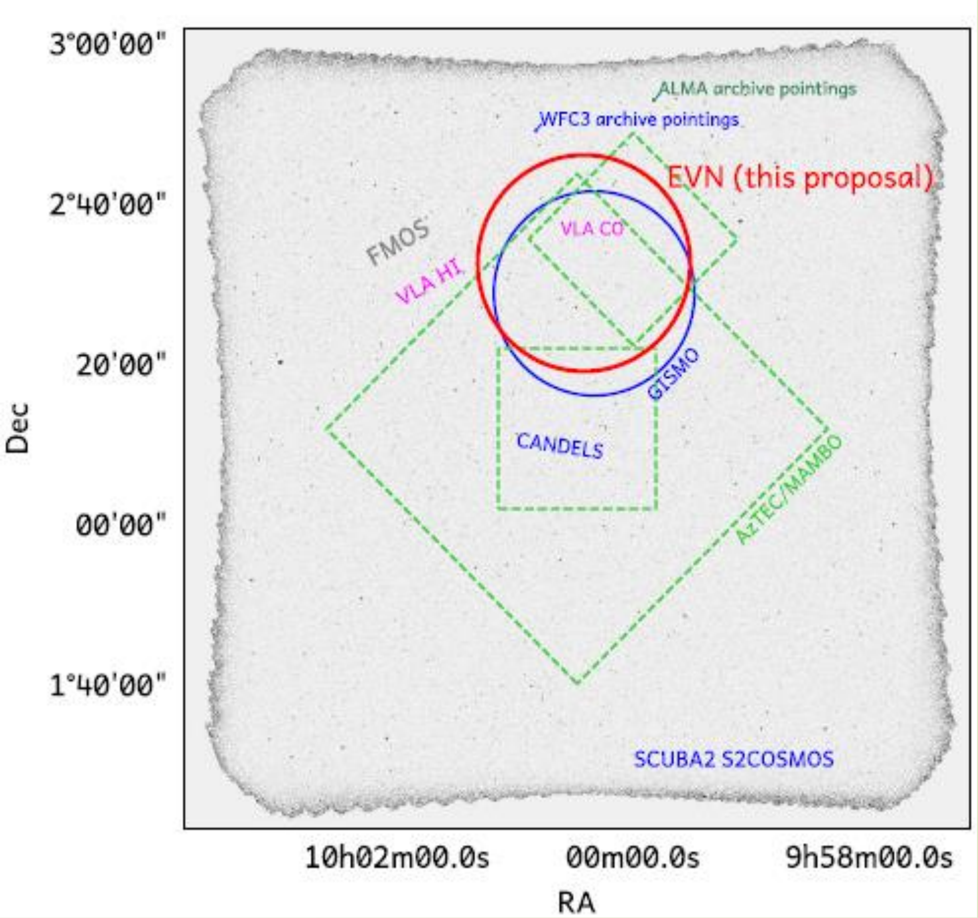
- VLBA – COSMOS Field: Herrera Ruiz et al. (2017)
  - 1σ ~ 10 μJy/bm
  - ~3000 targets, 468 detected sources.
- VLBA+GBT – region of COSMOS field: Herrera Ruiz et al. (2018)
  - 1σ ~ 3 μJy/bm
  - 179 targets, 35 detected sources.
- EVN – GOODS-N Field: Radcliffe et al. (2018)
  - 1σ ~ 9 μJy/bm
  - 699 targets, 31 detected sources.



Future Surveys

- EVN+eMERLIN COSMOS – PI: Jack Radcliffe (jack.radcliffe@manchester.ac.uk)
  - 1σ ~ 1 μJy/bm
  - ~400 targets estimated
  - ~130 detections expected

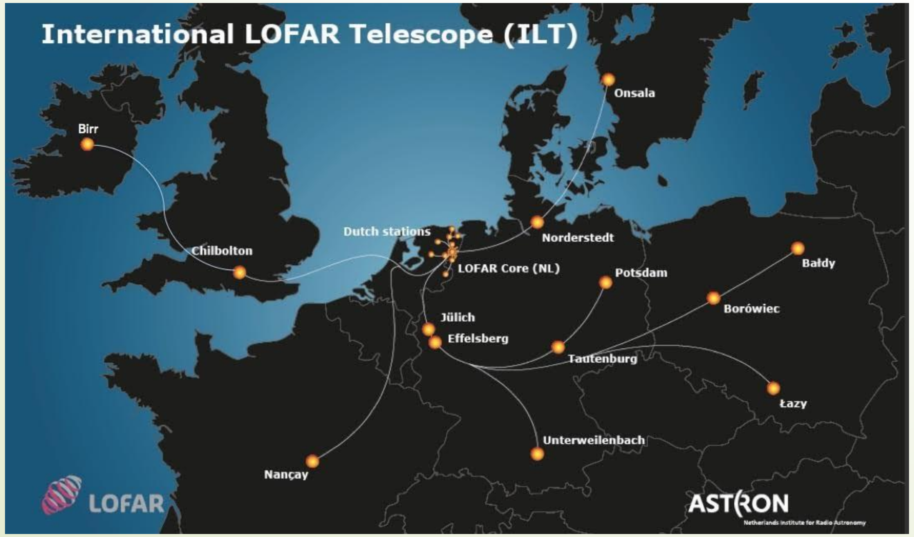
- VLBASS (VLBA Sky Survey) (EoI) – PIs: Jack Radcliffe & John McKean
  - 1σ ~ 0.1 mJy/bm
  - Targets from the VLASS (~4 million radio sources predicted).
  - A million detections expected.



Plot courtesy of Jack Radcliffe

Future Surveys

- LOFAR (Low-Frequency Array) VLBI (110-240 MHz)
  - Pipeline improved and in testing stage (github/lmorabit).
- MeerKAT-VLBI
  - Southern hemisphere coverage.
  - North-south (east-west) baselines.



Science with wide-field VLBI

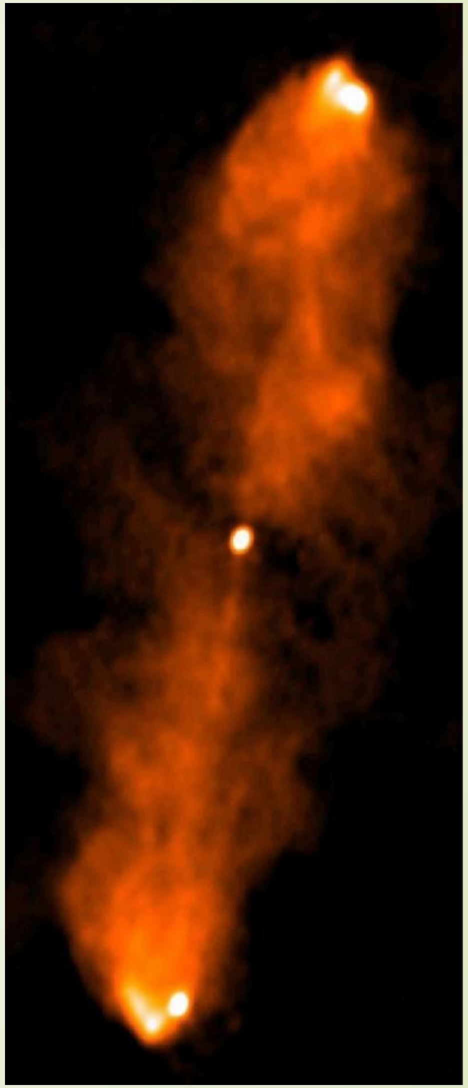
- Surveys at mas-scales
- Disentangle contributions from AGN and star-formation processes
- Interplay AGN – host galaxy
- Better understanding of feedback processes
- Study rare radio source classes
- Radio weak lensing cosmology
- Variability
- Astrometry
- Serendipity
- ...

Second part:

Wide-field VLBI and the faint radio population

Motivation

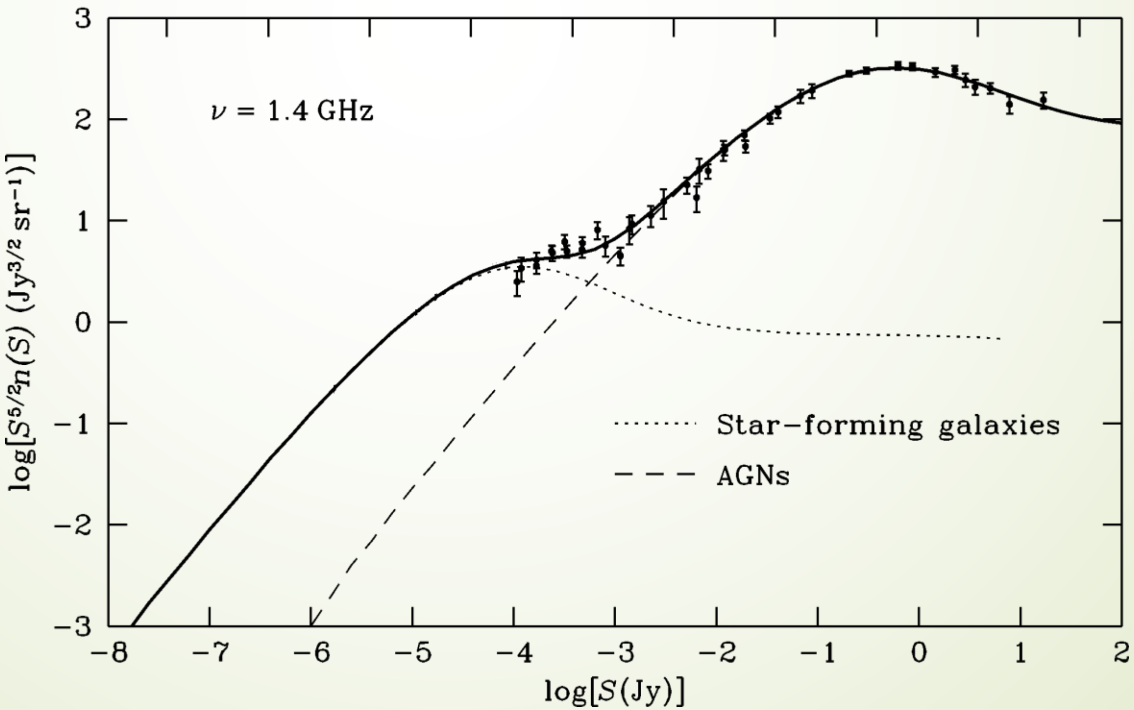
- AGNs play an important role in galaxy evolution
- Radio surveys indispensable
- Statistically study the faint radio population:
  - Radio source count distribution
- Sub-samples of rare or sparse objects:
  - Radio-quiet quasars (RQQs)
  - Spiral DRAGNs (Double Radio sources Associated with Galactic Nuclei)
  - Supermassive black hole (SMBH) binary systems



Sirothia et al. (2013)

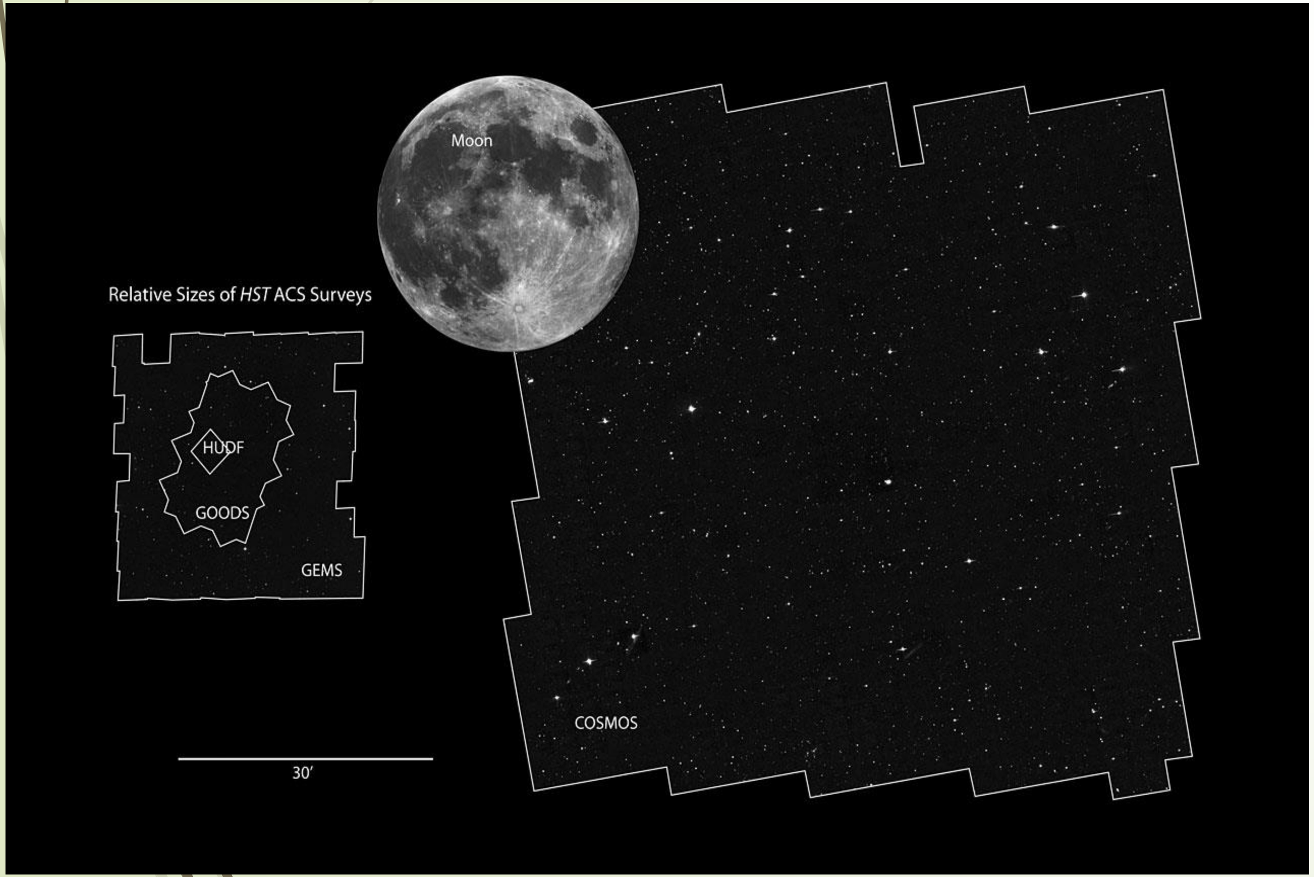
Radio source counts

- Measure AGN incidence in large samples of objects.
- Radio-loud AGN dominate at flux densities > 1 mJy.
- Sub-mJy radio sky, blend of star forming galaxies and radio-quiet AGNs.



The project

- Goals: Create a reliable AGN catalogue and analyse the AGN component in the faint radio population.

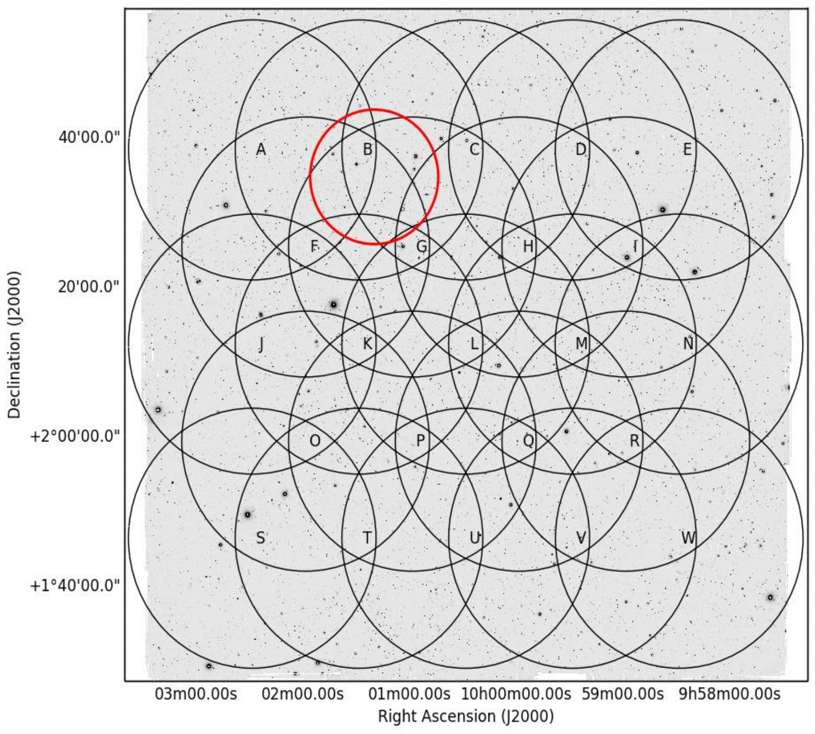


http://cosmos.astro.caltech.edu/page/public

- First step: ~ 3000 COSMOS radio sources (VLBA).
- Second step: ~ 200 COSMOS radio sources (VLBA+GBT).

Observations

- VLBA data: 23 Pointings
  (rms noise 10 μJy/beam)
- VLBA+GBT data: 1 Pointing
  (rms noise ~ 3 μJy/beam)
- 1.4 GHz
- Input catalog:
  VLA Schinnerer+10



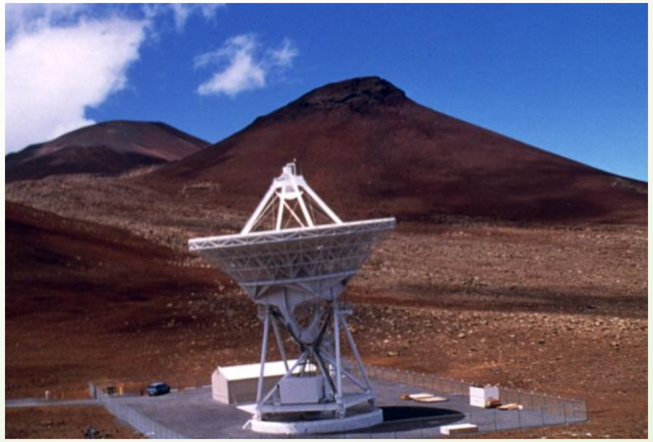
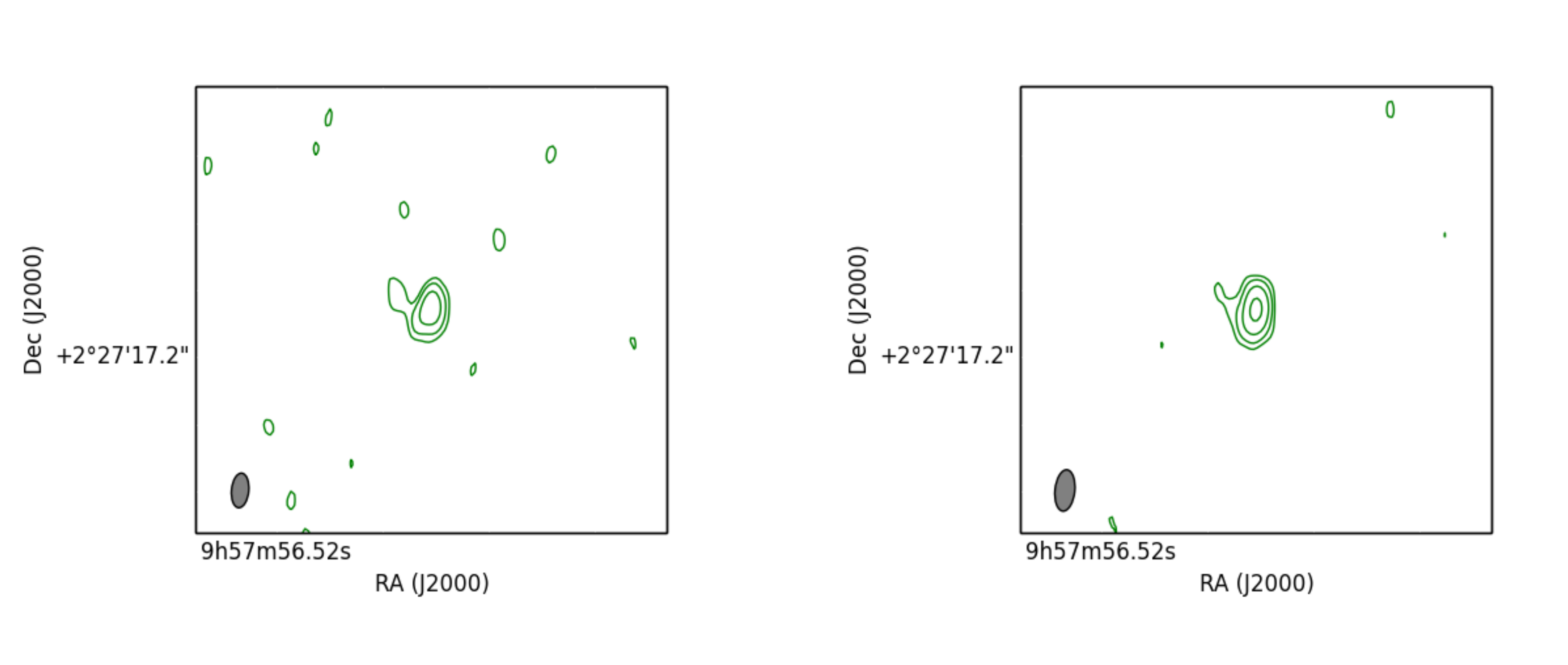


Image courtesy of NRAO/AUI


Credit: NRAO/AUI/NSF

Calibration

- AIPS (ParselTongue)
- Specialised steps for wide-field VLBI:
  - Multi-source self-calibration
  - Primary beam correction
  - Data combination



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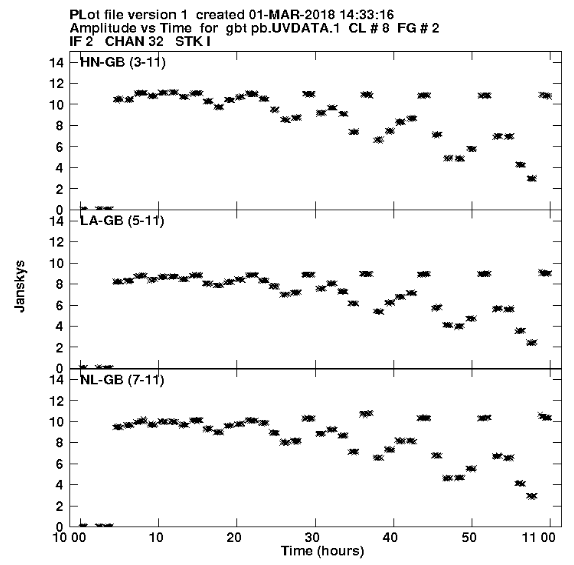
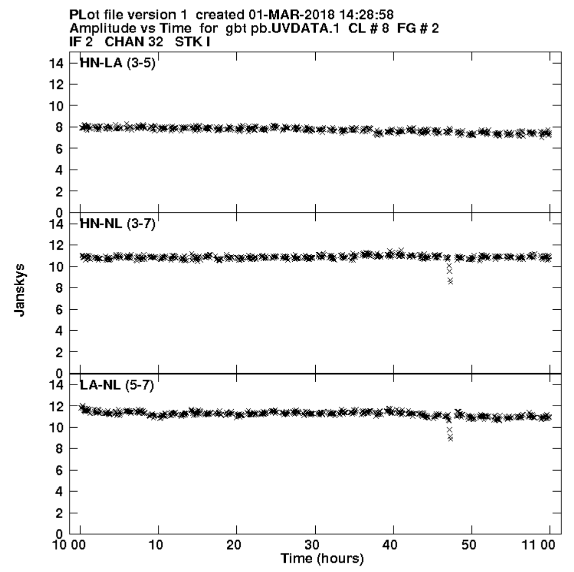
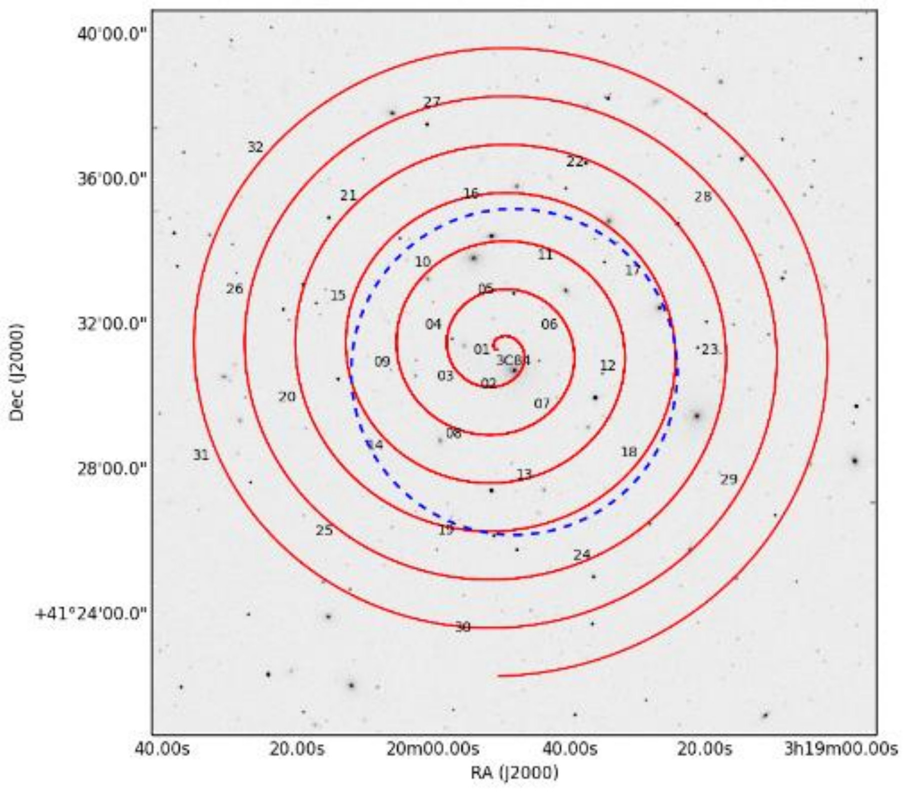
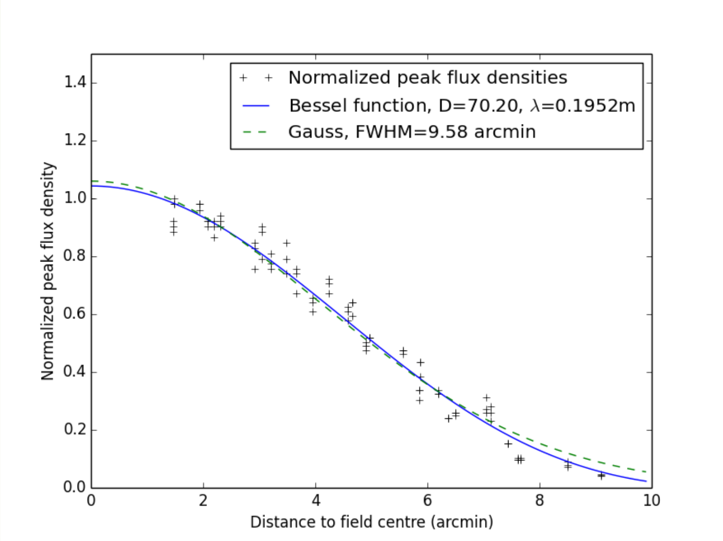
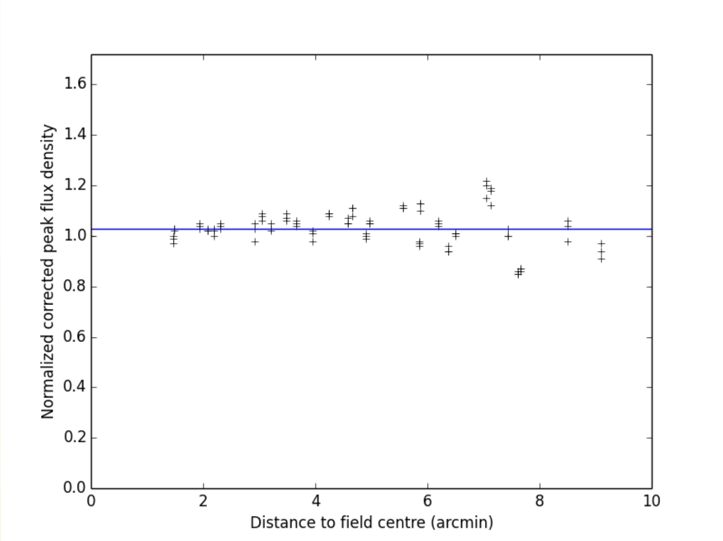
GBT primary beam response





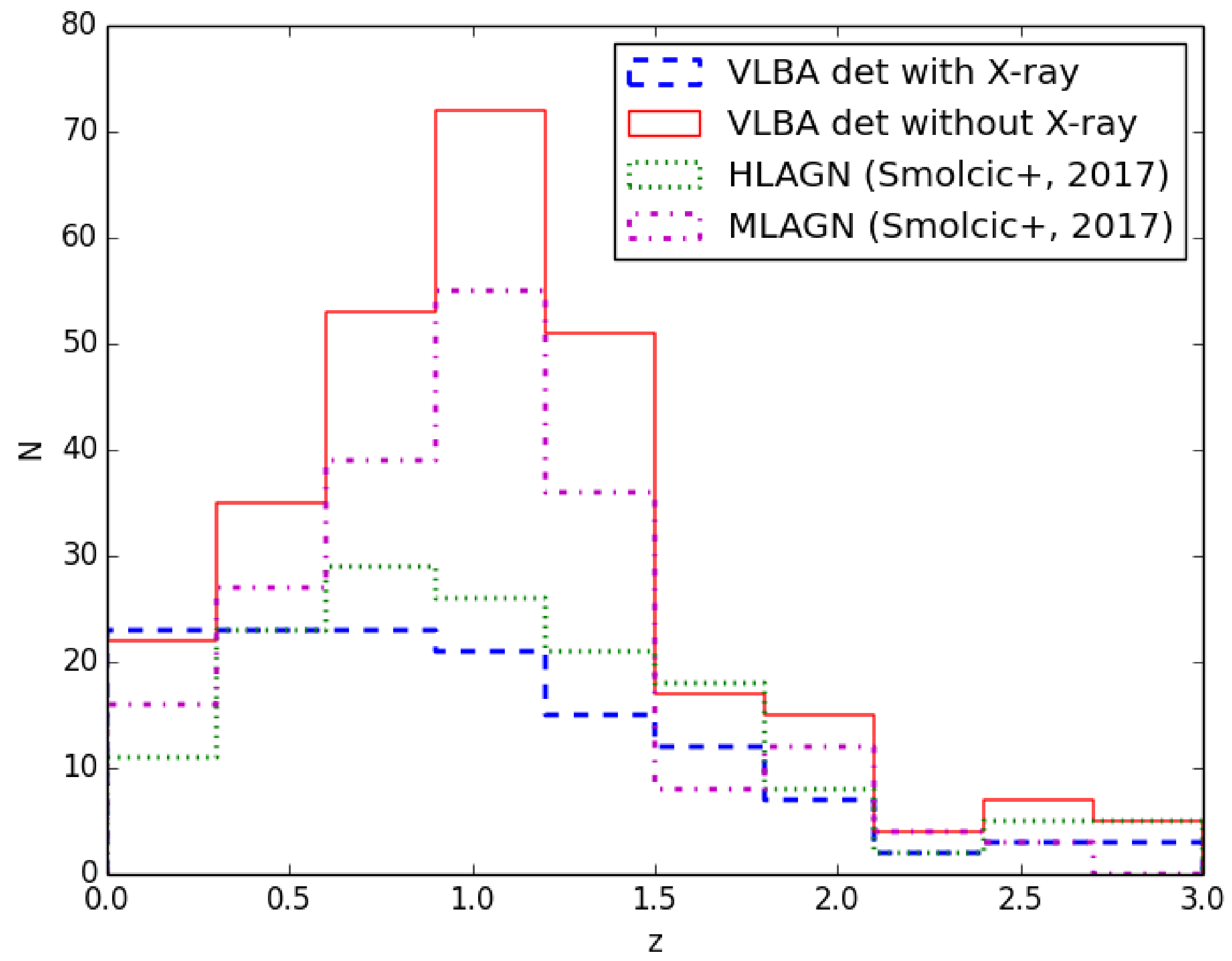






VLBA data

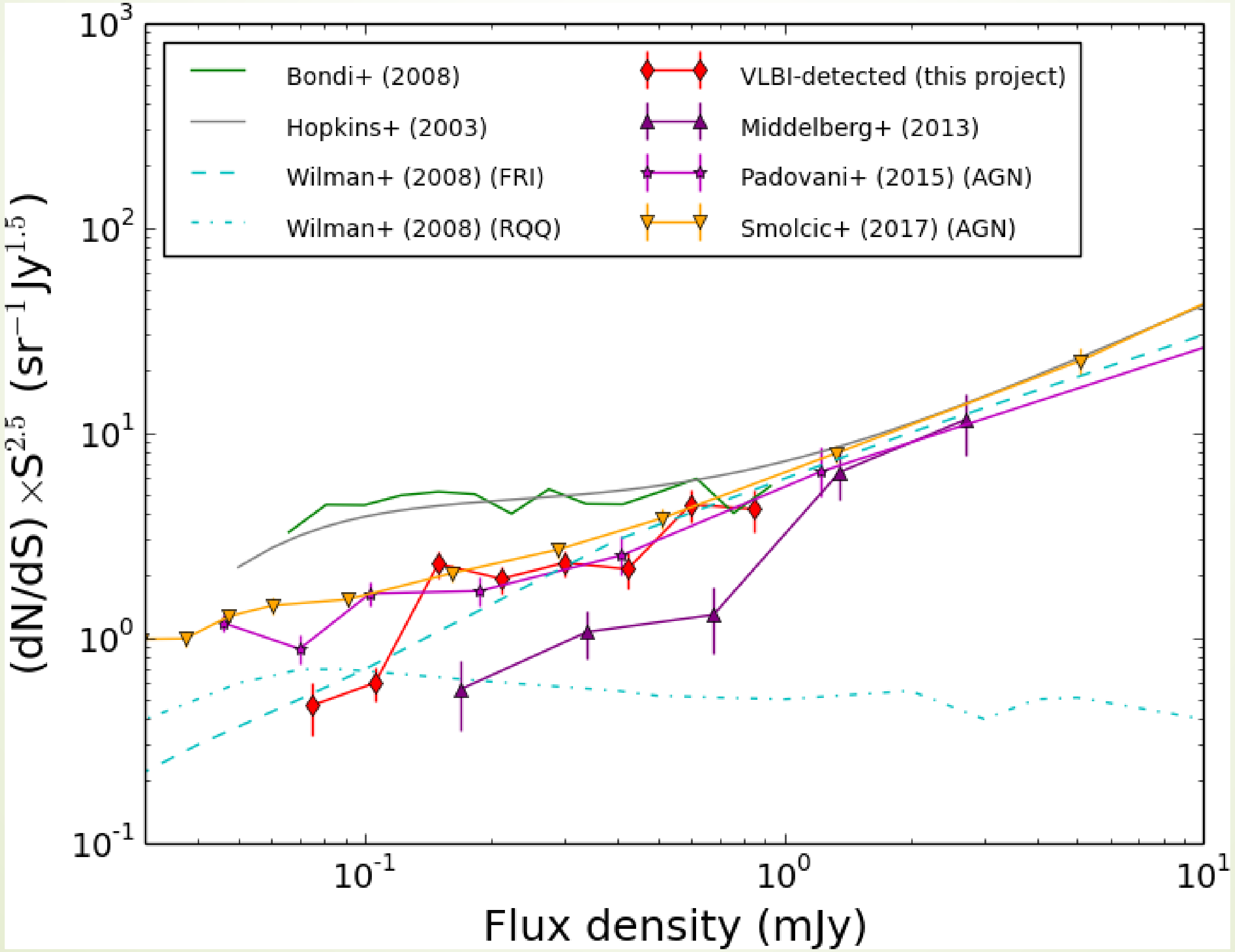
- X-ray counterparts



Herrera Ruiz et al. (2017)

VLBA and VLBA+GBT data

- Euclidean-normalised radio source counts (40-55%)



Herrera Ruiz et al. (2018)

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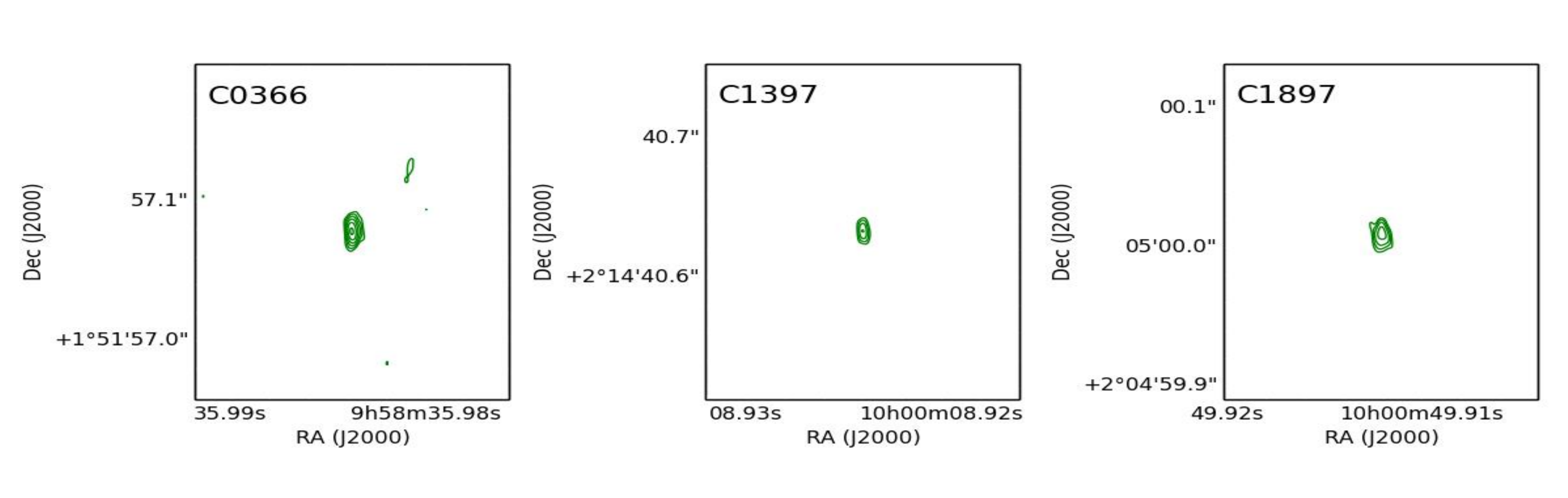
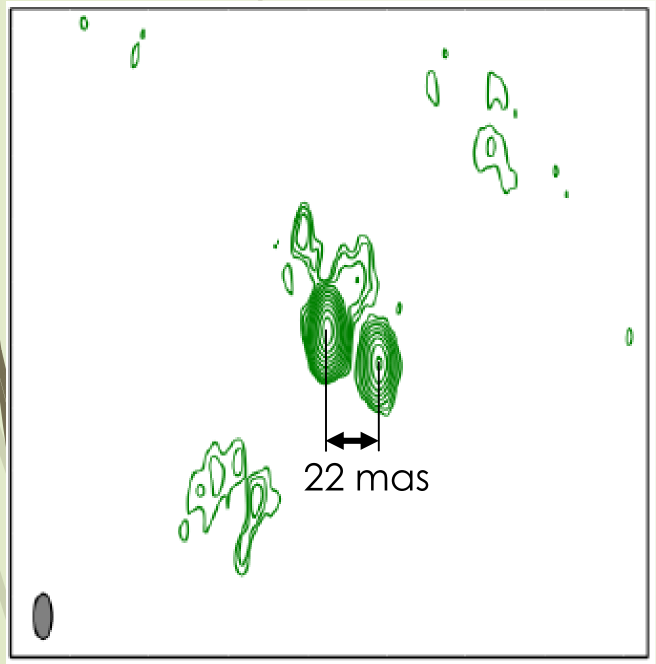
VLBA-detected Radio Quiet Quasars

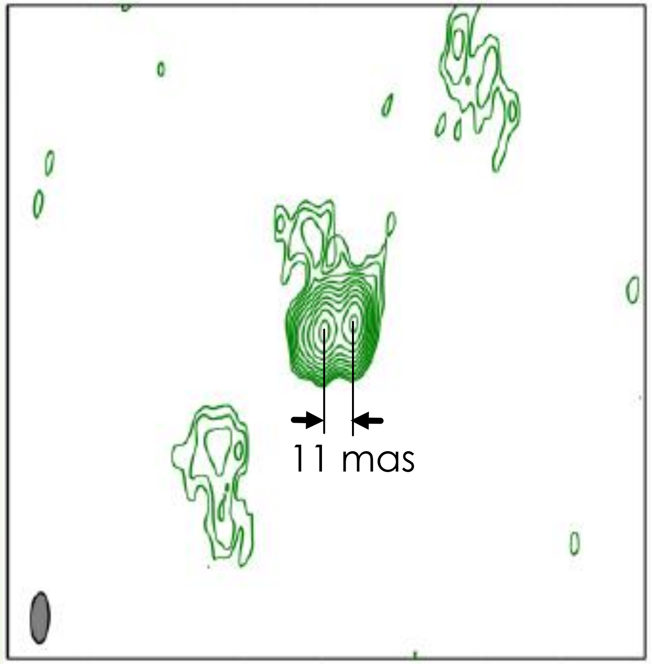
ID	q_{24}	R_i	R_x	P_{5GHz}	R	R_V	L_x	q_{24obs}	DW^a
C0366	✓	✓	×	×	✓	✓	✓	✓	✓
C1397	✓	✓	×	✓	✓	✓	✓	✓	✓
C1897	✓	✓	✓	✓	✓	✓	✓	✓	✓

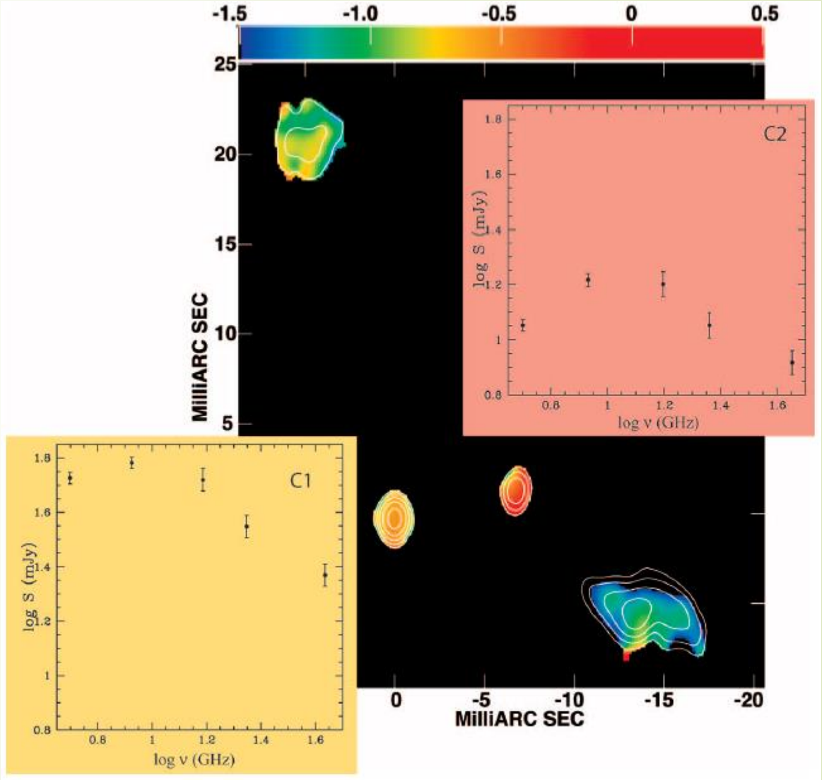
Herrera Ruiz et al. (2016)



Binary black hole systems



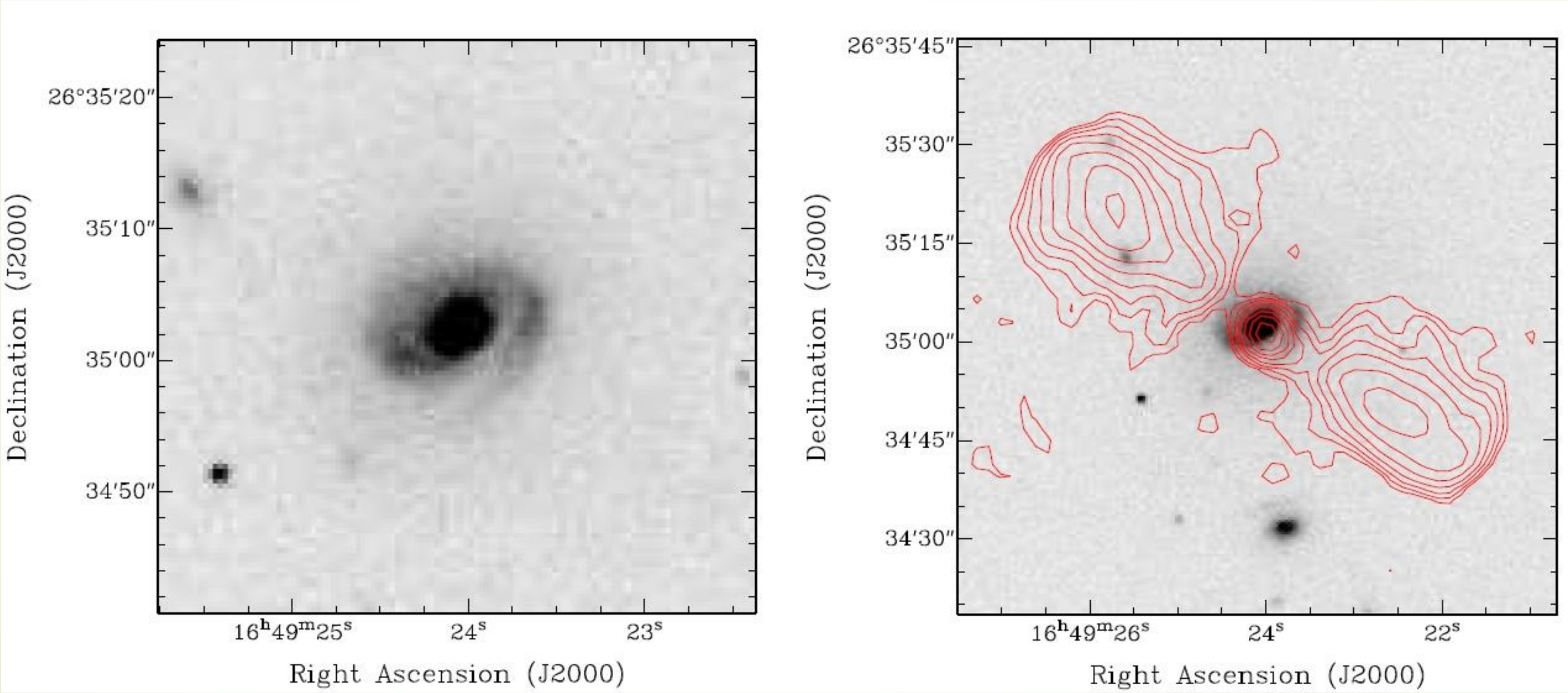




Rodriguez et al. (2006)

Spiral DRAGNs

- DRAGN = Double-lobed Radio sources Associated with Galactic Nuclei



Mao et al. (2015)

Summary

- Wide-field VLBI has been developed and improved to make possible observations of large portions of the sky at mas-scales.
- Current and future VLBI surveys and facilities look promising for further progress.
- The use of multiple AGN identification methods is important for unbiased AGN pupulation.
- From the VLBA-COSMOS, 40-55% AGN contribution to the faint radio population.