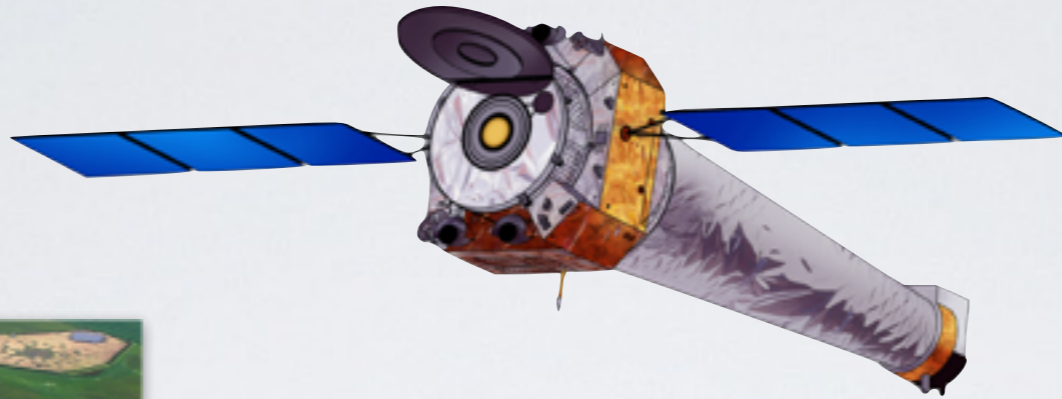


# X-RAY – RADIO SYNERGIES

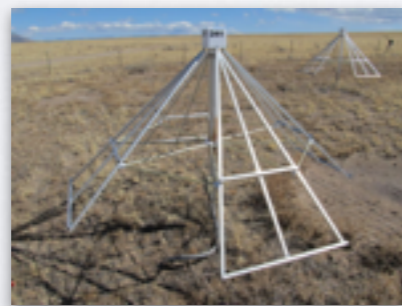


*Reinout van Weeren*

Harvard-Smithsonian Center for Astrophysics

# INTRO

- X-rays (keV) — radio (GeV)
- Era of surveys
- Radio:  $< 100$  GHz (not covering submm)
- Interferometers
- ICT driven progress
- Renewed focus on low frequencies



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# RADIO LANDSCAPE

- ATCA (1-100 GHz)
- WSRT (110 MHz -5 GHz)
- GMRT (150 MHz - 1.4 GHz)
- LOFAR (10-250 MHz)
- VLA (74 MHz - 50 GHz)
- VLBI ARRAYS (GHz and up)
- MWA (80-300 MHz)
- .....

## *New survey instruments*

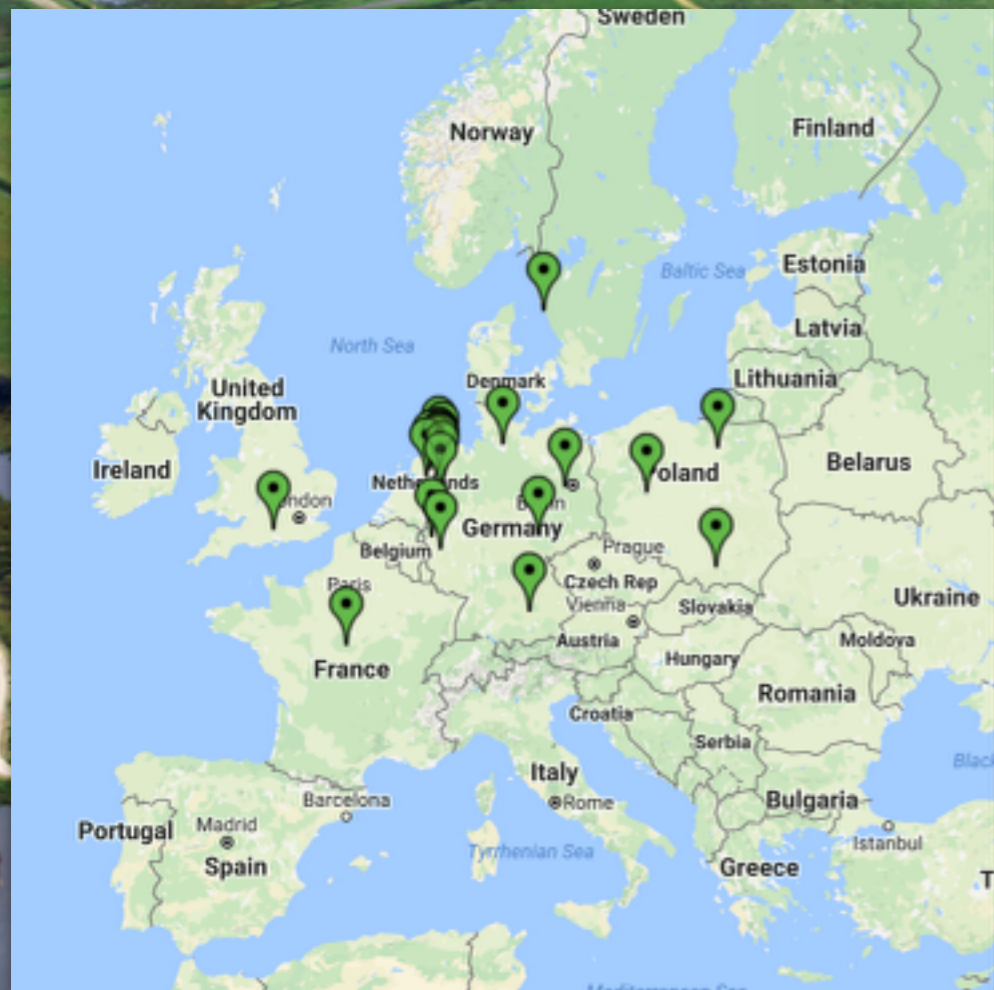
- ASKAP (0.7-1.7 GHz)
- MEERKAT (0.9-1.7 GHz)
- WSRT APERTIF (1.1-1.7 GHz)



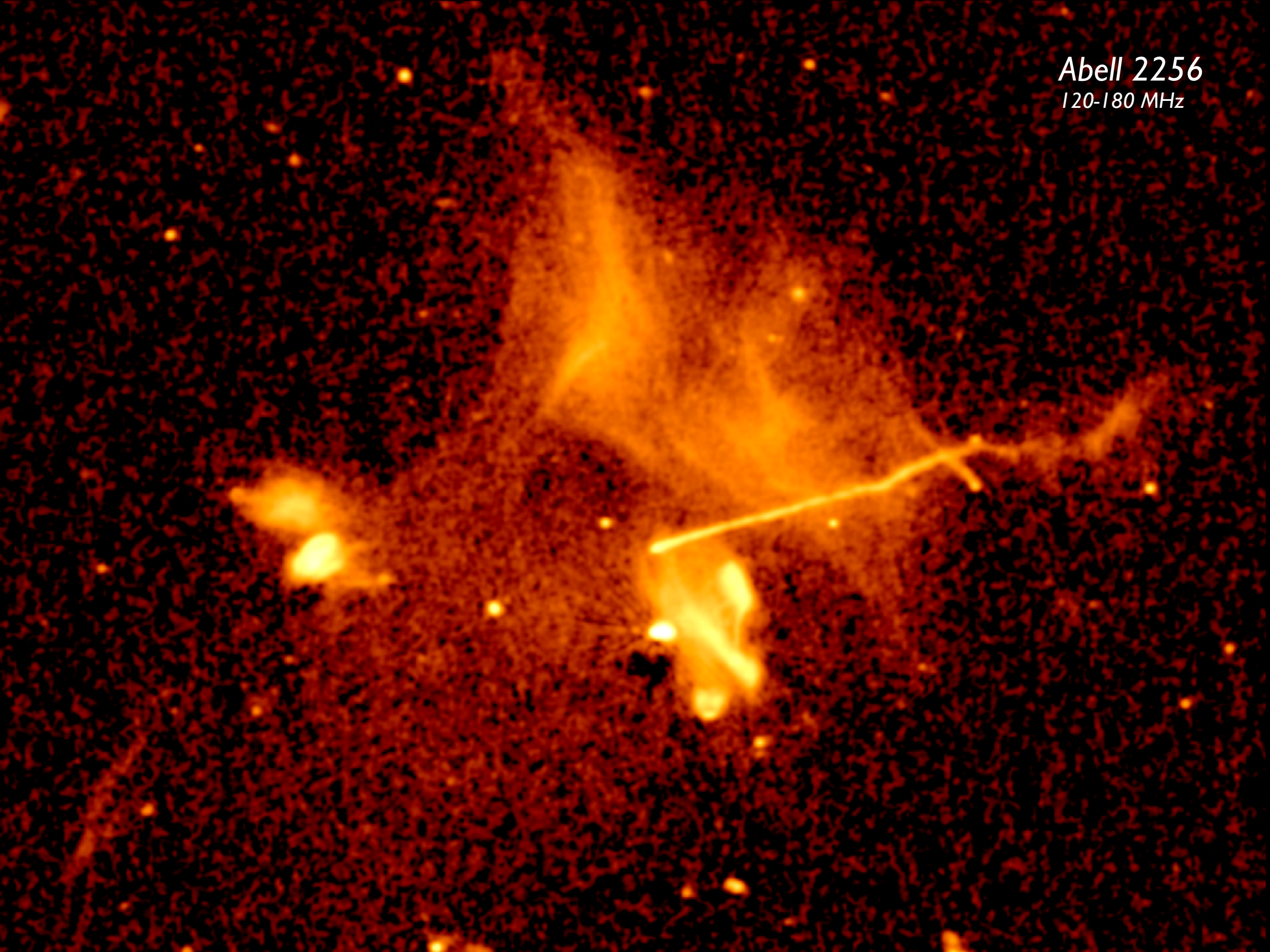
# LARGE SURVEYS

- EMU (deep, GHz, medium-resolution)
- WSRT APERTIF (GHz, deep, medium-resolution)
- VLASS (GHz, shallow, high-resolution)
- LOFAR (MHz, deep, high-resolution)
- GLEAM, TGSS, MSSS (MHz, shallow, low-resolution)
- NVSS, WENSS, SUMSS (shallow, low-resolution)

# LOFAR

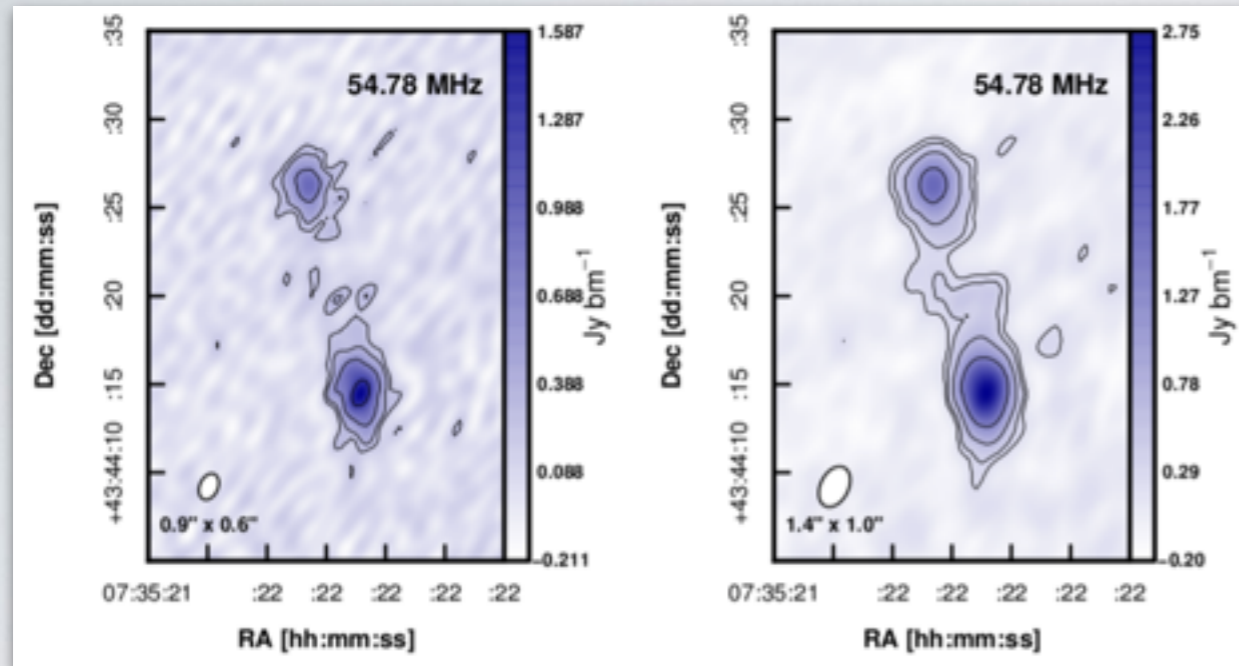


Abell 2256  
120-180 MHz

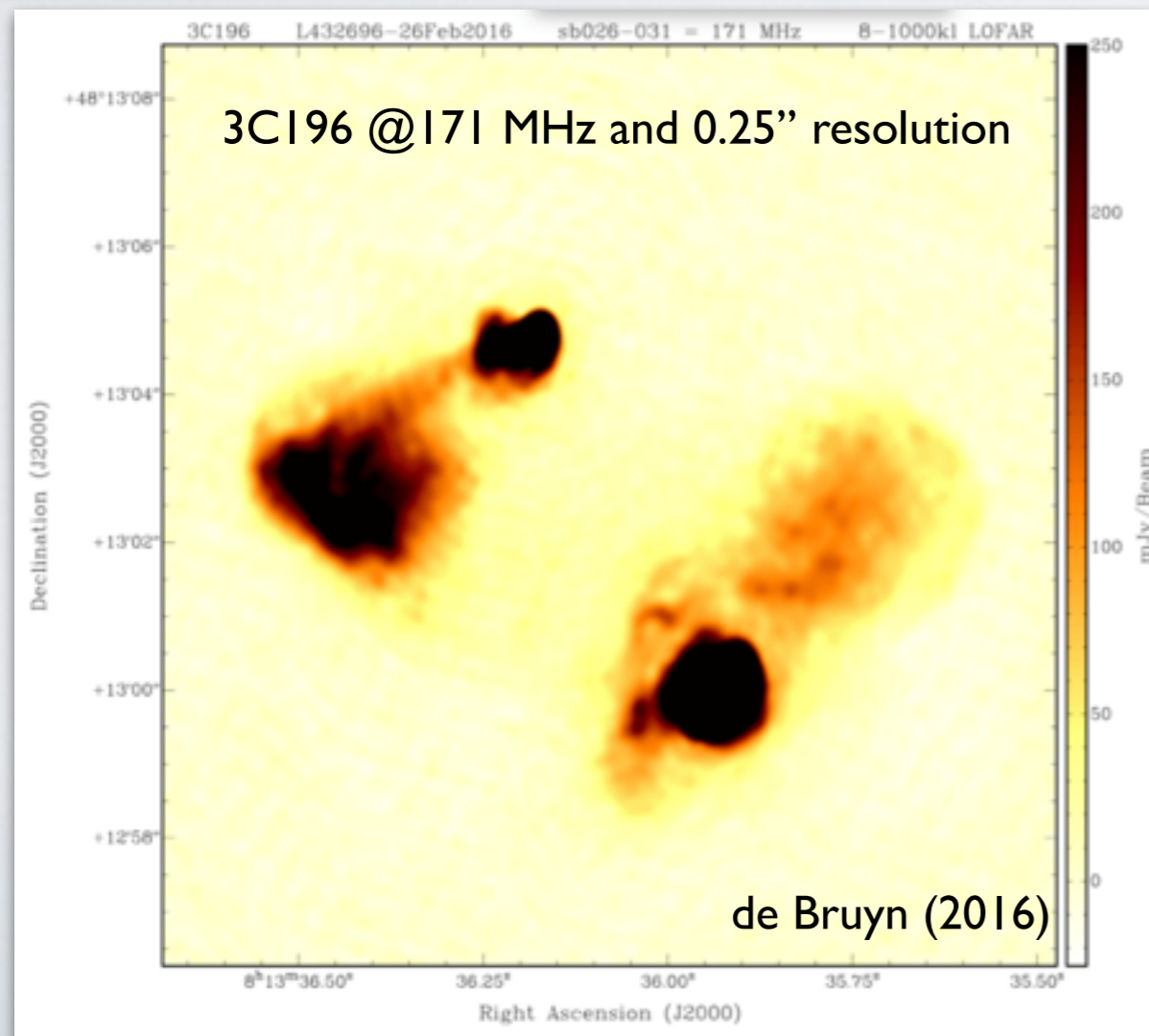


4C43.15 @ 55 MHz and ~1" resolution

Morabito et al. (2016)

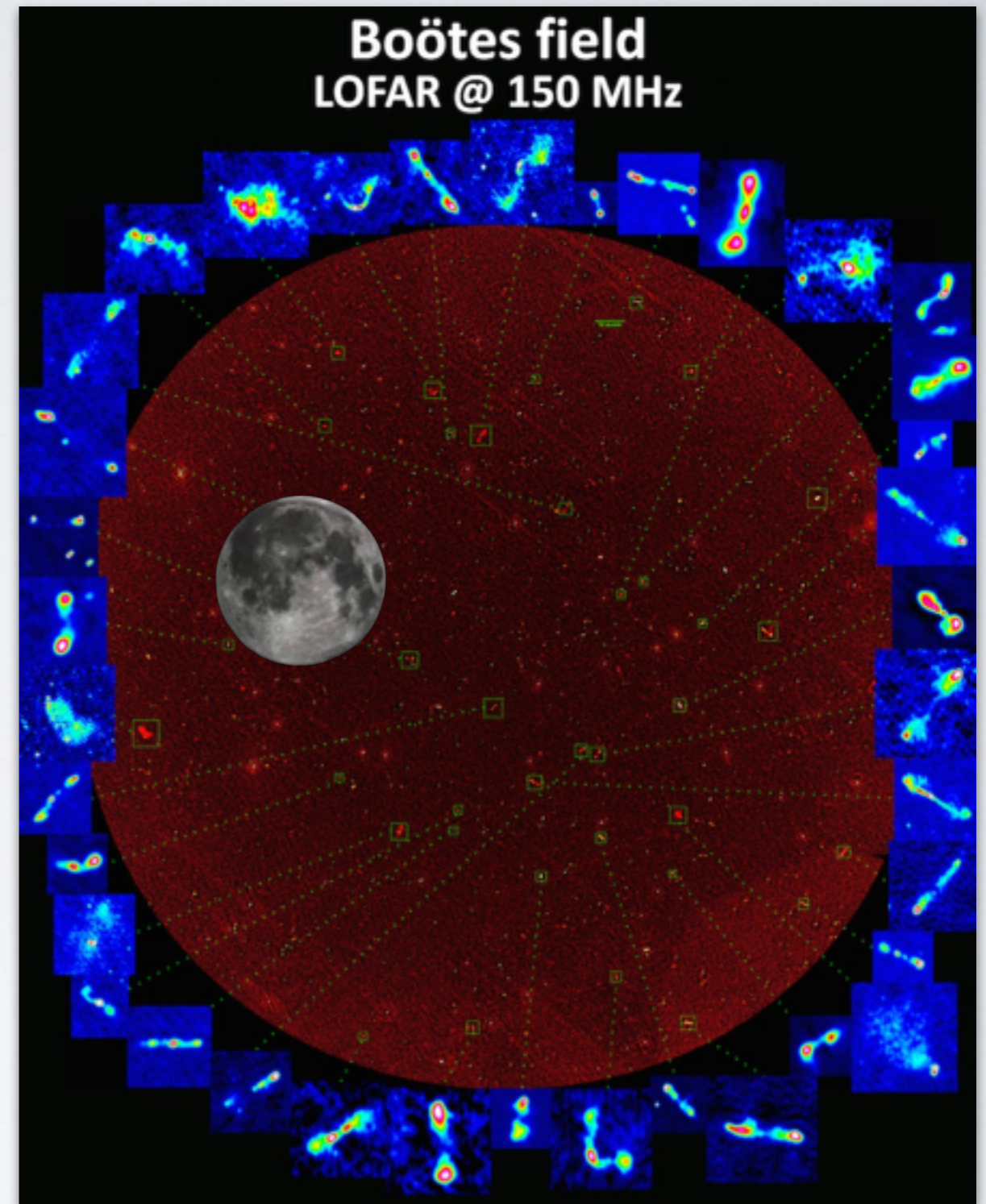


3C196 @ 171 MHz and 0.25" resolution



de Bruyn (2016)

5" resolution, 0.1 mJy depth



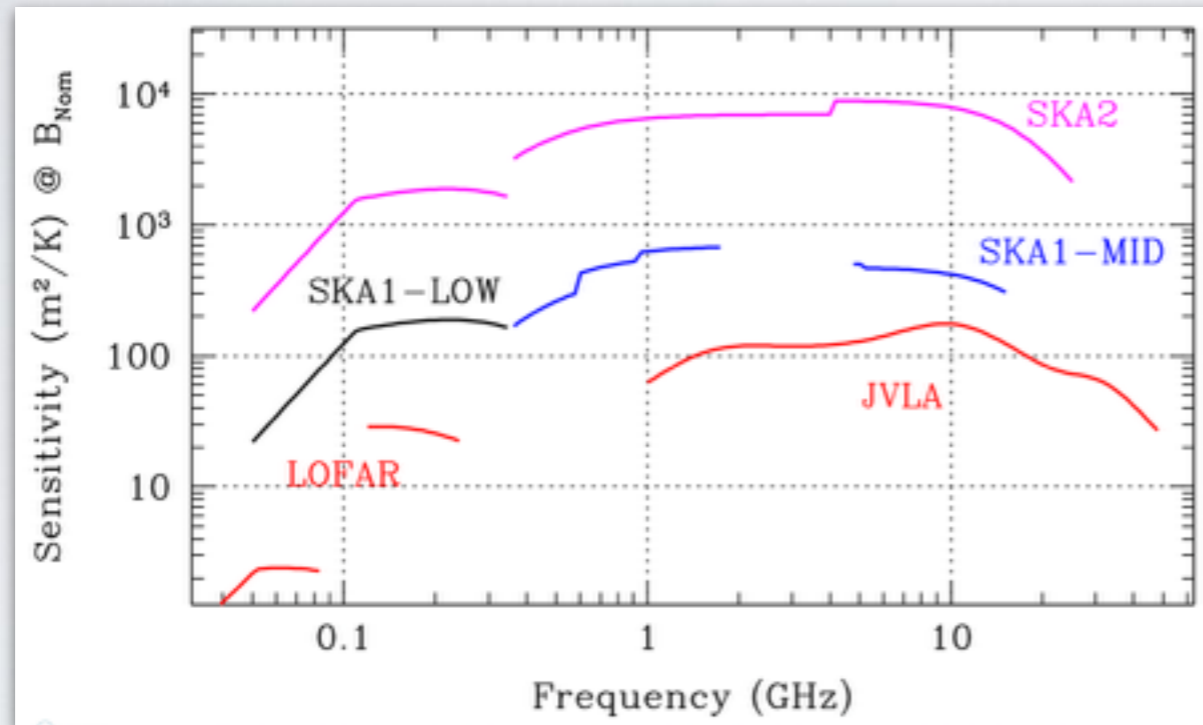
Williams et al. (2016)

Full northern sky to this depth...



# SKA PHASE I

Construction phase ~2018-2023



## SKA low

- Australia
- 50 - 300 MHz

## SKA mid

- South Africa
- 300 - 1700 MHz
- Meerkat extension

|   | SKA1   |
|---|--|
| <b>The Cradle of Life &amp; Astrobiology</b>                      | <p>Proto-planetary disks; imaging inside the snow/ice line (@ &lt; 100pc), Searches for amino acids.</p> <p>Targeted SETI: airport radar 10<sup>4</sup> nearby stars.</p>  |
| <b>Strong-field Tests of Gravity with Pulsars and Black Holes</b> | <p>1st detection of nHz-stochastic gravitational wave background.</p> <p>Discover and use NS-NS and PSR-BH binaries to provide the best tests of gravity theories and General Relativity.</p>  |
| <b>The Origin and Evolution of Cosmic Magnetism</b>               | <p>The role of magnetism from sub-galactic to Cosmic Web scales, the RM-grid @ 300/deg<sup>2</sup>.</p> <p>Faraday tomography of extended sources, 100pc resolution at 14Mpc, 1 kpc @ z = 0.04.</p>  |
| <b>Galaxy Evolution probed by Neutral Hydrogen</b>                | <p>Gas properties of 10<sup>7</sup> galaxies, &lt;z&gt; = 0.3, evolution to z = 1, BAO complement to Euclid.</p> <p>Detailed interstellar medium of nearby galaxies (3 Mpc) at 50pc resolution, diffuse IGM down to N<sub>H</sub> &lt; 10<sup>17</sup> at 1 kpc.</p> |
| <b>The Transient Radio Sky</b>                                    | <p>Use fast radio bursts to uncover the missing "normal" matter in the universe.</p> <p>Study feedback from the most energetic cosmic explosions and the disruption of stars by super-massive black holes.</p>   |
| <b>Galaxy Evolution probed in the Radio Continuum</b>             | <p>Star formation rates (10 M<sub>Sun</sub>/yr to z ~ 4).</p> <p>Resolved star formation astrophysics (sub-kpc active regions at z ~ 1).</p>   |
| <b>Cosmology &amp; Dark Energy</b>                                | <p>Constraints on DE, modified gravity, the distribution &amp; evolution of matter on super-horizon scales: competitive to Euclid.</p> <p>Primordial non-Gaussianity and the matter dipole: 2x Euclid.</p>   |
| <b>Cosmic Dawn and the Epoch of Reionization</b>                  | <p>Direct imaging of EoR structures (z = 6 - 12).</p> <p>Power spectra of Cosmic Dawn down to arcmin scales, possible imaging at 10 arcmin.</p>  |



# DATA POLICIES, PROPOSALS

- Most data available in online archives (visibilities not images)
- Proprietary Period: 1-1.5 yrs
- Mostly “open skies”
- ~ Two proposal rounds per year
- TOO and joint studies
  - Radio telescopes can observe 24hr/day
  - Most big radio telescopes in the north (changing)
- No GO funding
- *Chandra - NRAO joint proposals*

# X-RAY — RADIO SYNERGIES

- Radio mode feedback in cluster and groups
  - High-resolution low-frequency (ghost cavities)
- AGN population studies
  - Large samples of radio AGN from surveys
- Radio emission from the Cosmic Web/WHIM accretion shocks
  - $n_e, T \rightarrow$  X-rays
  - challenge: soft band response
- Magnetic fields in hot plasmas via Faraday Rotation ( $RM \propto \int B_{\parallel} n_e ds$ )
  - $n_e \rightarrow$  X-rays
- Radio deep fields
  - complementary X-ray data ?
  - challenge: large radio survey areas
- Compact objects, pulsars, SNR, planets, galaxy evolution (star formation via radio continuum, HI surveys), transients, .....