Frequency-Dependent Tradeoffs in Array Configurations

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Large-N Review

- N is the number of *stations*
  - Imaging involves ~$N^2/2$ simultaneous baselines
  - Each station may consist of many antennas
  - N ≥ 200 (?) considered "large"
  - Values for N up to 1000 under consideration
- Large-N has advantages and drawbacks:
  - Better performance characteristics
  - Greater flexibility

    But

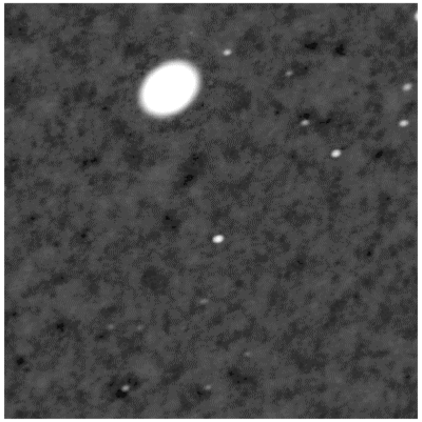
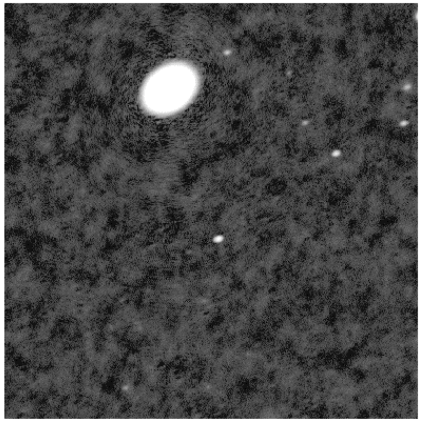
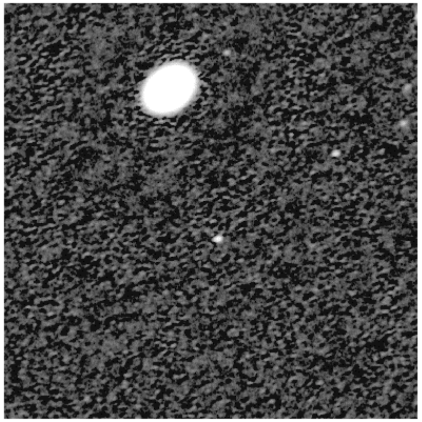
  - More costly in some areas
  - Greater development risk

Advantages

- Imaging fidelity and dynamic range
  - Superior (u,v) coverage, PSF
  - Better imaging of large, very complex fields
  - High fidelity snapshot and spectral line imaging
- Range of spatial frequencies accessible
  - Excellent coverage from 100 m to >1000 km
- Flexibility (e.g. subarrays)
- Postprocessing options, opportunities
  - Massive numbers of independent measurements
  - e.g. Much better atmospheric characterization
- Upgradability, continuing Moore’s law gains

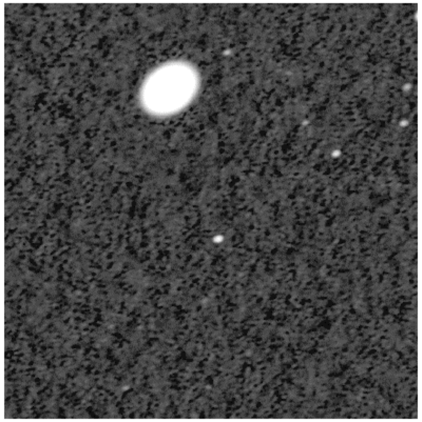
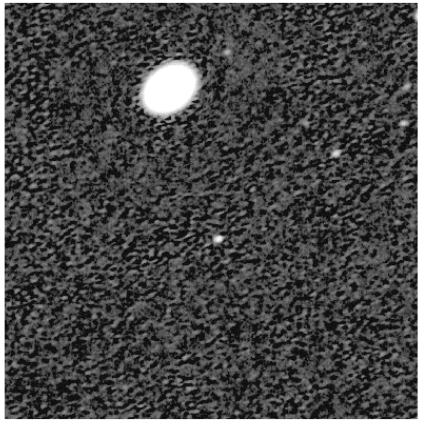
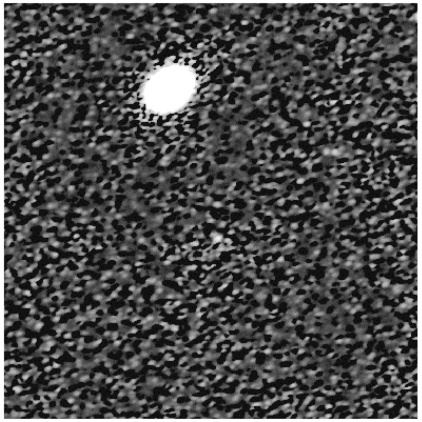
More is Better

N=200

12 hrs | 4 hrs | 1 hr

N=100

Costs and drawbacks

- Correlation and postprocessing BW $\propto N^2$
- Data transport bandwidth $\propto N$
- Physical connectivity costs $\propto N^{\beta}$, $0 < \beta < 1$
- Station construction costs $\propto N^{\gamma}$, $0 < \gamma < 1$
- Increased complexity in some areas
- Greater risk (need new algorithms) in some areas

N is only one axis of multidimensional design parameter space - optimum value is complex question

Tradeoffs

- Many other design parameters to consider, e.g.
  - Station composition, layout, size and FOV
  - Receiver sophistication/cost
  - Distribution of collecting area with radius
  - Multibeaming parameters
  - Beamforming approach (e.g. nulling, calibratability)
  - …….
- Parameters affect each other
  - Tradeoffs required

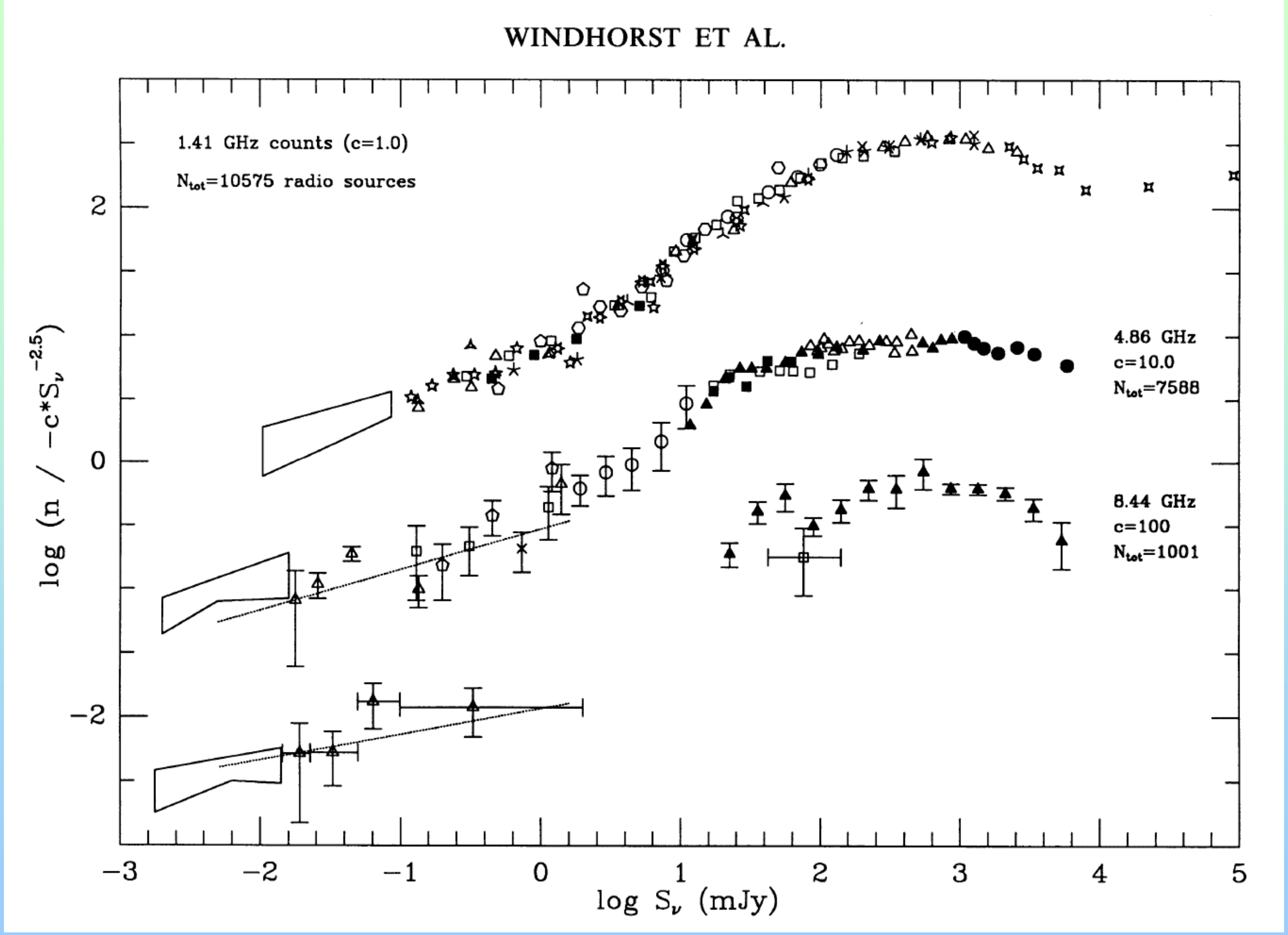
How do these tradeoffs depend on frequency?

Many things affect config. optimization

- Field complexity, required dynamic range
- Range of spatial frequencies
- Importance of spectral lines in complex fields
- Importance of snapshot imaging (e.g. transients)
- RFI and mitigation requirements
- Site properties

And so on …….

Source counts



For example:

Station size ~50 meters
Reasonable T_{sys} and bandwidth assumptions
12 hour integrations with 1 km^2
Continuum sky properties ….

	F.O.V. (sr)	S_{max}	Rms noise	Blank sky d.r.	# sources >5σ
20 MHz	**9×10^{-2}**	**600 Jy**	**0.1 mJy**	**6×10^{6}**	**8×10^{7}**
80 MHz	**5.6×10^{-3}**	**12 Jy**	**3 μJy**	**4×10^{6}**	**5×10^{7}**
225 MHz	**7.1×10^{-4}**	**540 mJy**	**200 nJy**	**2.7×10^{6}**	**3×10^{7}**
400 MHz	**2.3×10^{-4}**	**150 mJy**	**60 nJy**	**2.5×10^{6}**	**3×10^{7}**
1.4 GHz	**1.8×10^{-5}**	**2.4 mJy**	**30 nJy**	**8×10^{4}**	**3×10^{5}**
5 GHz	**1.4×10^{-6}**	**60 μJy**	**20 nJy**	**3×10^{3}**	**4×10^{3}**
15 GHz	**1.6×10^{-7}**	**15 μJy**	**20 nJy**	**750**	**650**
43 GHz	**1.9×10^{-8}**	**4 μJy**	**50 nJy**	**80**	**35**

Frequency dependencies

- Required D.R. decreases as freq. increases
- Sky complexity decreases as freq. increases
  - Imaging problem changes drastically
  - Optimum design approach changes profoundly
- Other things change as freq. increases:
  - correlator load increases (bandwidth & spectral lines)
  - Isoplanaticity improves, SNR decreases
    - Calibration gets easier, then harder again
  - Bigger dishes favoured, multibeaming compromised
  - Science may favor different areal weighting
  - etc.

Specifications and consequences

- F.O.V. 1 degree @ 1.4 GHz
- Resolution 0.1 arcsec @ 1.4 GHz
- Spectral channels 10^4
- Spatial pixel count 10^8
- Instantaneous beams > 100
- Sensitivity Aeff/Tsys = 20,000 m^2/K

1.3×10^9 pixels

F.O.V < 0.1 deg @ 1.4 GHz

Meaningless at high freq

Meaningless at low freq

Current specifications are:

- Internally inconsistent
- Unattainable for certain regions of parameter space
- Insufficient to guide many design studies

Suggestions

Specifications as a usable tool for designers

- Develop multidimensional specification matrices
  - Specify adequate & desired parameter values
  - Cover ranges of frequency, resolution etc.
- Map science priorities onto regions of matrices
  - Tells us how hard to try in various areas
  - No one concept can meet all performance goals
- Develop figures of merit for comparison purposes
  - Focuses development activities
  - Promotes mixing and merging of technologies
  - Helps identify natural technological dividing lines

Array designs by frequency

- 150 MHz
  - Moderate N (scattering limits resolution range)
  - Emphasis on multibeaming, agility, omni antennas
  - Just like LOFAR
- 1.5 GHz
  - Large N, very wide range of spacings
  - Tiles, lenses? Maximum collecting area.
- 15 GHz
  - Low-moderate N, paraboloids, no multibeaming
  - Widest possible bandwidth, high spectral resolution
  - Just like EVLA, but more sensitive?

What is SKA?

- Fundamentally, SKA represents
  - Exploitation of new technological opportunities
  - Bursting "radio astronomy lag" bubble
- SKA is *not*
  - About a square kilometer
  - A replacement for all radio telescopes
  - A single giant facility which does it all
- SKA is a set of technologies, applied to & developed for:
  - EVLA phase 2
  - e-MERLIN
  - LOFAR, ATA
  - New cm array(s)
  - …….

Next Generation Radio Telescopes

Summary

- Current SKA specifications imply huge tradeoffs
  – Refine specs, make more flexible & meaningful
- Different arrays for different frequencies
  – Perhaps there should be 2 or 3 arrays, not one?
- Useful to think in terms of larger enterprise
  – Multiple complementary next-generation arrays
  – Global renaissance in radio astronomy
  – SKA need not (cannot) fill all niches