Writing a good proposal

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Based on Joan Wrobel's lectures "Sensitivity" and "Proposal Writing" at NRAO's 2008 and 2010 Synthesis Imaging Workshops

Most important thing: scientific idea

Start with scientific idea

1. Select target list, you need:
   - Flux density
   - Angular size

   Can be a guess if you have a good reason for that guess.

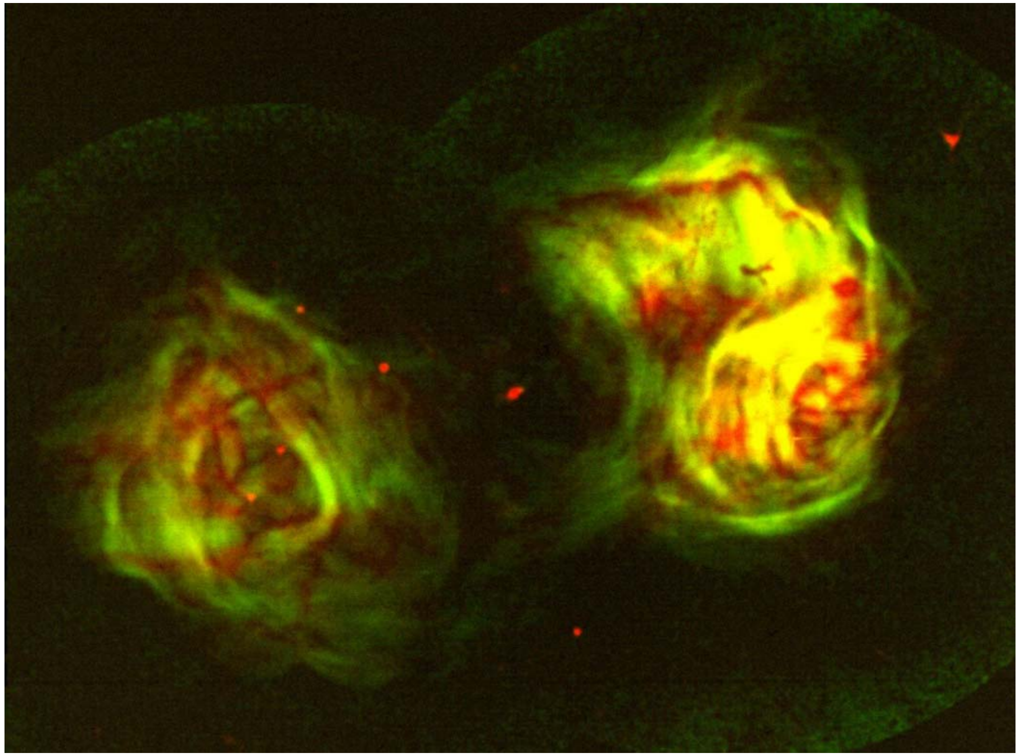
   - these depend on frequency so this and the next step are intertwined
2. figure out what telescope characteristics you need:
   - Frequency
   - Polarization
   - Spectral resolution
   - Sensitivity (bandwidth, time on source)
   - Largest angular size

   I will go into detail on these

   - Angular resolution – $\theta_{HPBW}=\lambda/B_{max}$ (rad) $\approx 2\lambda(cm)/B_{max}(km)$ (asec)

Select and evaluate trial array

- Start with most important requirements: usually frequency, angular resolution and/or sensitivity.
  - Select trial array
    - EVLA, VLBA, ALMA, MERLIN, EVN, GMRT, SMA, CARMA, ATA,, ATCA, LOFAR, LWA, ASKAP, MEERKAT …
  - Evaluate: sensitivity, angular resolution and largest angular size



Radio Galaxy Fornax A
VLA 1.4 GHz 1.0d x 0.7d R. Ekers
NRAO Image Gallery

Sensitivity (Power and T)

- Radio astronomers refer to the power from signals in the antennas as equivalent temperature (T).
  - Rayleigh-Jeans approximation of radiation from a black body:

$$P = \kappa_B T \Delta\nu$$

$$= g^2 \kappa_B (T_{ant} + T_{sys}) \Delta\nu$$

g– voltage gain

T_{ant} *– antenna temperature (temperature from the source)*

T_{sys} *– system temperature (receiver noise+feed losses+spillover +atmospheric emission+ galactic background+cosmic background* $= T_{rec} + T_{feed} + T_{spill} + T_{atm} + T_{gal} + 2.725K$*)*

$\Delta\nu$ *– observing bandwidth*

For full derivation of these and following equations see the "Sensitivity" chapter of Synthesis Imaging in Radio Astronomy II by Wrobel and Walker.

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Sensitivity (K and SEFD)

- Antenna Gain or Sensitivity (K) in degrees/Jy
  - $K = T_{ant}/S$
  - *S is the source flux density (Jy)*
- System Equivalent Flux Density (SEFD) is the flux density that would deliver the same amount of power.
  - measure of the overall system performance.
  - $SEFD = T_{sys}/K$ *(Jy)*

Antenna	Diameter (m)	SEFD (Jy)
Effelsberg (Germany)	100	39
1 EVLA antenna (USA)	25	310
Medicina (Italy)	32	221
Haystack (USA)	36	606

Example SEFDs at 5 GHz

The two sensitivities you should care about I

1. Sensitivity on one baseline (ΔS_{ij})
   - Important because it tells you how strong a source has to be to self-calibrate and/or be a phase calibrator. The baseline sensitivity between two antennas i and j is:

$$\Delta S_{ij} = \frac{1}{\eta_s} \times \sqrt{\frac{SEFD_i \times SEFD_j}{2 \times \Delta\nu \times \tau_{acc}}}$$

     - η_s is the system efficiency factor (usually ~1)
     - τ_{acc} is the time accumulated on source
   - E.g., for a $\Delta S_{ij} \approx 10$mJy you will need a 50mJy phase calibrator to get 5σ phase solutions.
   - If antennas are identical simplifies to:

$$\Delta S = \frac{1}{\eta_s} \times \frac{SEFD}{\sqrt{2 \times \Delta\nu \times \tau_{acc}}}$$

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The two sensitivities you should care about II

2. Image sensitivity (ΔI_m)
   - Important because it tells you how faint a source you can detect in a given amount of time (τ_{acc}) and bandwidth ($\Delta\nu$).

$$\Delta I_m = \frac{1}{\eta_s} \times \frac{SEFD}{\sqrt{N \times (N-1) \times \Delta\nu \times t_{int}}}$$

     - N-- number of elements in the array
     - This assumes identical antennas
   - E.g., if $\Delta I_m \approx 10\mu$Jy/beam for a two hour observation a 100μJy source will be detected at 10σ. For a four hour observation ΔI_m will decrease by $\sqrt{2}$ to 7μJy/beam.
   - If you are lucky the telescope you want to use will have an on-line sensitivity calculator. Most do these days.

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Things I glossed over when talking about Sensitivity

What can degrade sensitivity (besides bad data and calibration errors):

1. Confusion : if you go deep enough you will encounter background sources, especially for short baseline/low frequency arrays.
   – Not a problem for VLBI, big problem for LWA
2. Dynamic range: there is usually a dynamic range limit so for very bright sources there is a noise limit that is higher than the theoretical noise.
3. Even "identical" antennas are not really "identical"
4. Using Fast Fourier Transforms degrades images towards the edges
5. Weighting
   – Best sensitivity for natural weighting (do not down weight any data)
   – But in some cases other weighting schemes (uniform, robust, tapering) are preferred which decrease the sensitivity.
6. Beam squint, non-coplanar arrays, w-projection, unmodeled spectral index across bandwidth, polarization leakage…

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Largest Angular Scale

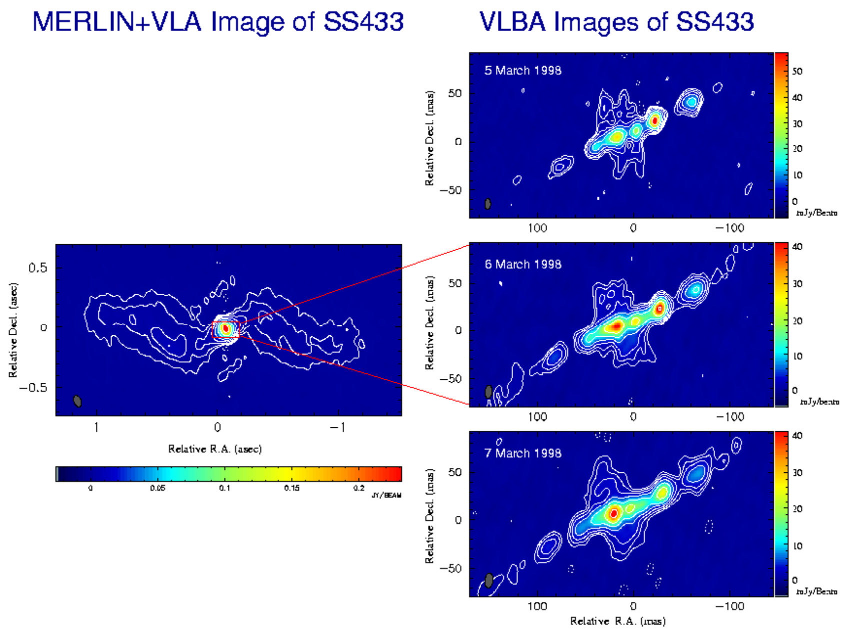
Definition: the largest structure in the source that can be reliably imaged

- The telescope *will not measure flux* on scales larger than

  $$\approx 2\lambda(\mathrm{cm})/B_{min}(\mathrm{km})\ (\mathrm{asec})$$

- But to reliably image something you need decent uv-coverage so the LAS is smaller than that the above calculation. This depends on the telescope but a good rule of thumb is the use twice the B_{min} so:

  $$\theta_{LAS} \approx \lambda(\mathrm{cm})/B_{min}(\mathrm{km})\ (\mathrm{asec})$$



Evaluate Trial Array (cont.)

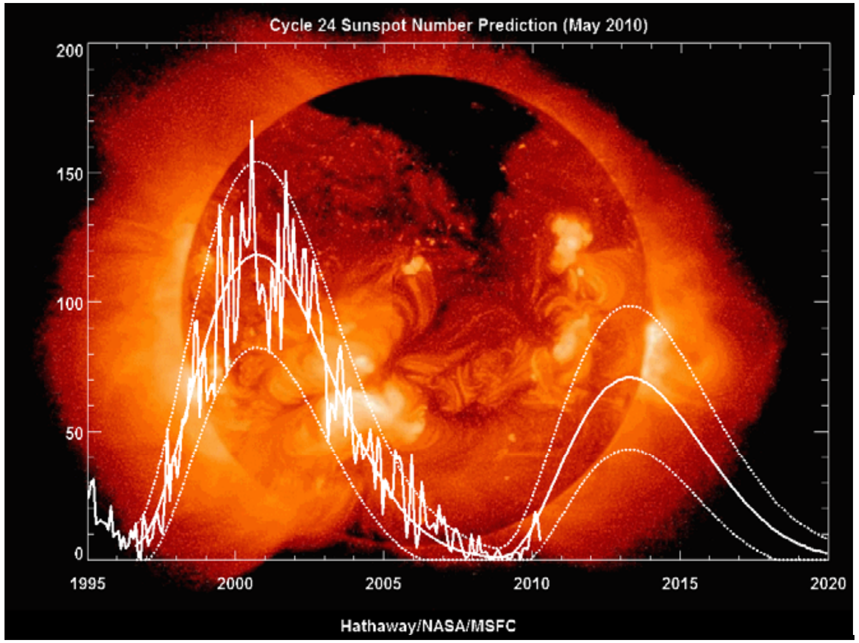
After the numbers work out then consider:

- Special needs
  - Redshifted HI ?
  - Redshifted CO ?
- Geometry
  - Target above elevation limit ?
  - Snapshot or full u-v coverage ?
- Image sensitivity
  - Dynamic-range limited ?

Supernova Remnant Crab Nebula
VLA 5GHz 7' x 5' M. Bietenholz

Evaluate Trial Array (more)

- Enough field of view ?
  - Primary beam attenuation
  - Bandwidth smearing
  - Time-average smearing
  - Non-coplanar baselines
- Optimal timeframes ?
  - Time of day
  - Season
  - Year ~ sunspot number
- If trial array fails, pick another
- If trial array passes, search its archive for suitable data
  - Write proposal



Sun TRACE X-rays

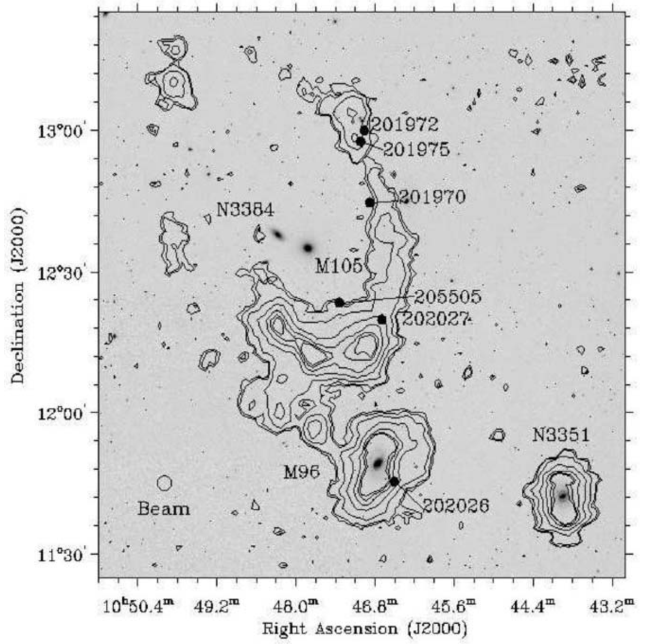
Finally: Write the proposal

Draft a scientific justification

- Write to astrophysically-literate but non-expert reviewers
- Give science context and motivation
- Pose specific science questions
- State specific science goals
- Describe target selection criteria
- Say how the proposed observations will …
  - Answer the science questions
  - Achieve the science goals
- Include a clear and concise technical justification.
- Remember that reviewers will be reading tens of proposals so:

  Be quantitative!   Be clear! Lists are good!

200 kpc HI Ring in Leo Group
Arecibo 1.4 GHz S. Stierwalt
Primordial versus tidal ring ?
Look for dark halos in dwarfs



Yet another temperature: Brightness Temperature

Definition: Rayleigh-Jeans temperature of a black body that would radiate the same power/unit area/unit frequency interval/unit solid angle as what is measured.

$$T_B = \frac{c^2}{2\kappa_B \upsilon^2} \frac{S}{\Omega}$$

– S is the flux density.

- For an *optically thick thermal source* this is the *real* temperature of the source.
- For an *optically thin thermal source* this is the *lower limit* of the temperature of the source.
- For a non-thermal (e.g., synchrotron radiation, maser emission…) source it has no relation to temperature but can show that the emission mechanism *is* non-thermal:
  – $T_B \sim 10^{12}$: so high nothing could be that hot
  – $T_B \sim 10^7$: so high that it would be radiating like crazy in other bands (like the X-ray) and that is not seen.

Yet another temperature: Brightness Temperature

Why do you care in a proposals lecture?

- It is another way to evaluate a telescope
- You can calculate the Tb sensitivity of a telescope

$$T_{B,\min} = \frac{2\ln 2}{\pi}\frac{c^2}{\kappa_B}\frac{\Delta I}{\upsilon^2\theta_{HPBW}}$$