Surface brightness sensitivity

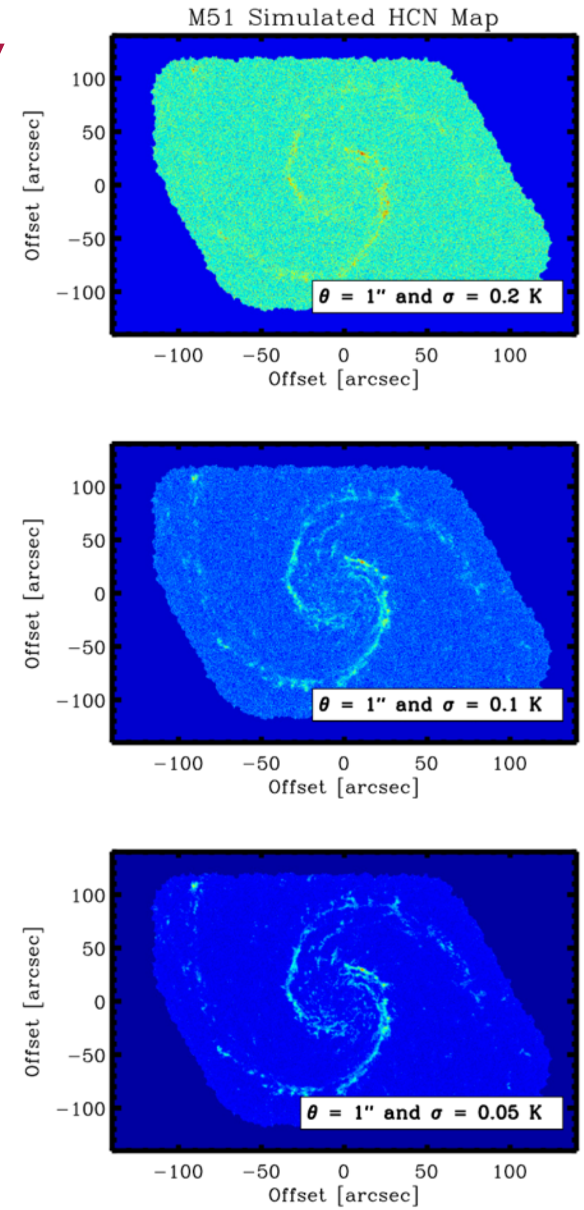
$$\sigma_{SB} = \frac{\lambda^2}{2k_B\Omega_{bm}}\sigma_{flux}$$

synthesized beam

you can increase SB sens. by *down-weighting* long baselines, increasing the beam size, but this throws data away.

What is the right compromise between *angular resolution* and *surface brightness sensitivity* for the "ensemble average" over key science cases?

Surface brightness sensitivity



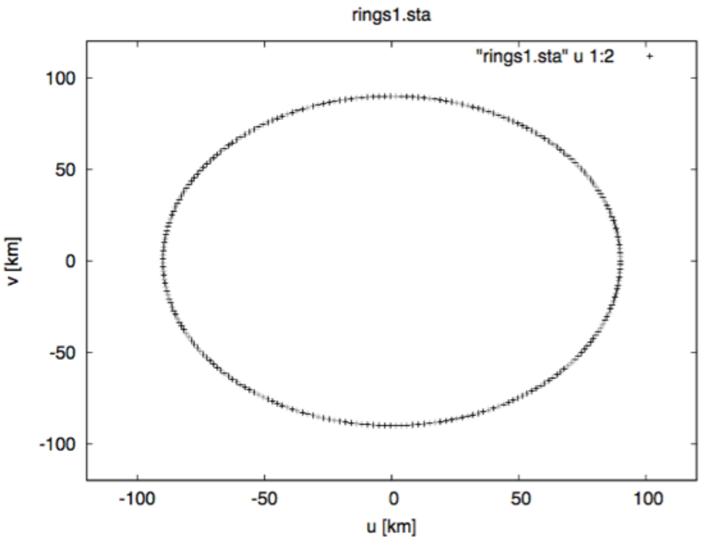
For *imaging* use cases, surface brightness sensitivity is usually a more relevant FOM than flux density sensitivity.

From NGVLA-7, Galaxy Ecosystem (Leroy et al.)

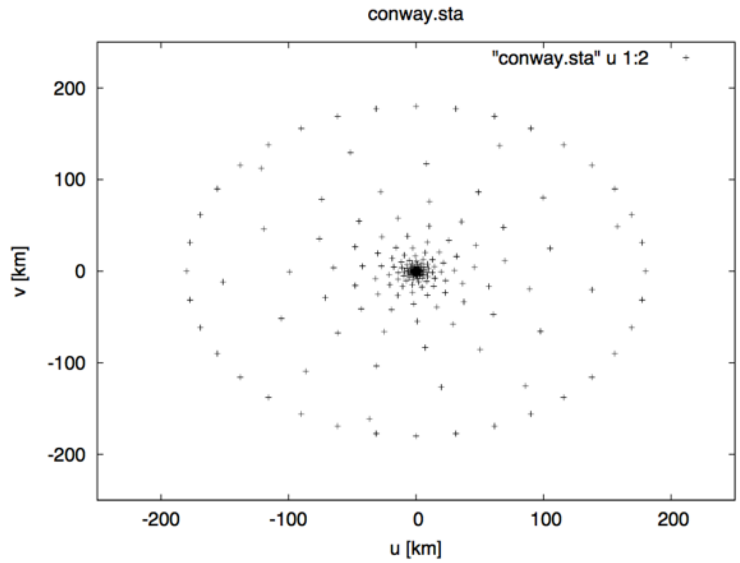
NRAO

Notional ngVLA configurations

- *Assumption*: NGVLA will not be highly reconfigurable for cost reasons.
  - configuration choice is crucial
  - the best possible design will make everyone a little bit unhappy!



Ring: many long baselines, good uv-coverage; doesn't taper well



"Conway": fewer long baselines, more short baselines & better taperability.

From ngVLA memo 3 (Clark & Brisken 2015)

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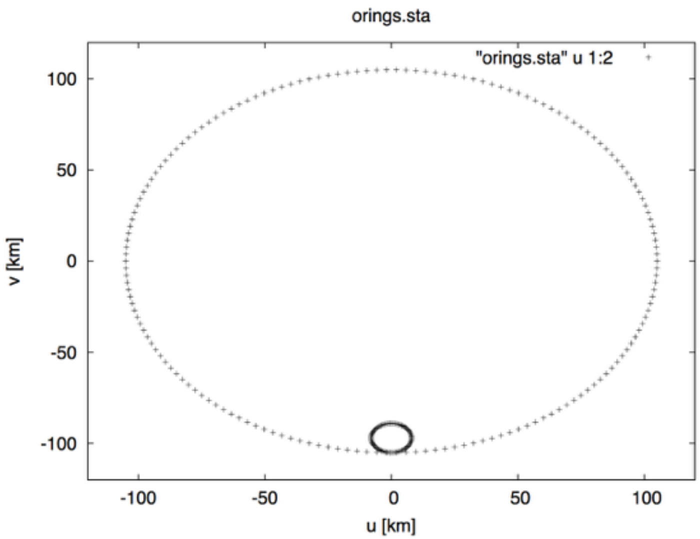

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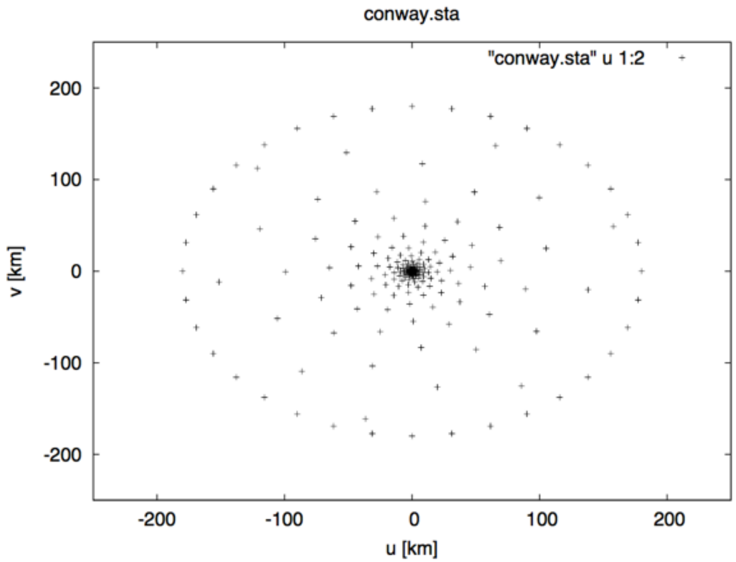

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From ngVLA memo 3 (Clark & Brisken 2015)

SB sensitivity of notional ngVLA configurations

40 GHz natural-weight beam = 10 mas = 15K RMS in 6 hours (thermal continuum)

	Rings	Conway
1 K	39 mas	27 mas
0.1 K	195 mas	119 mas
0.001 K	900 mas	1100 mas

when tapered…

loss in resolution is due to collecting area which is being thrown away to increase SB sens. (converse is also true)

From ngVLA memo 3 (Clark & Brisken 2015)

SB sensitivity of notional ngVLA configurations

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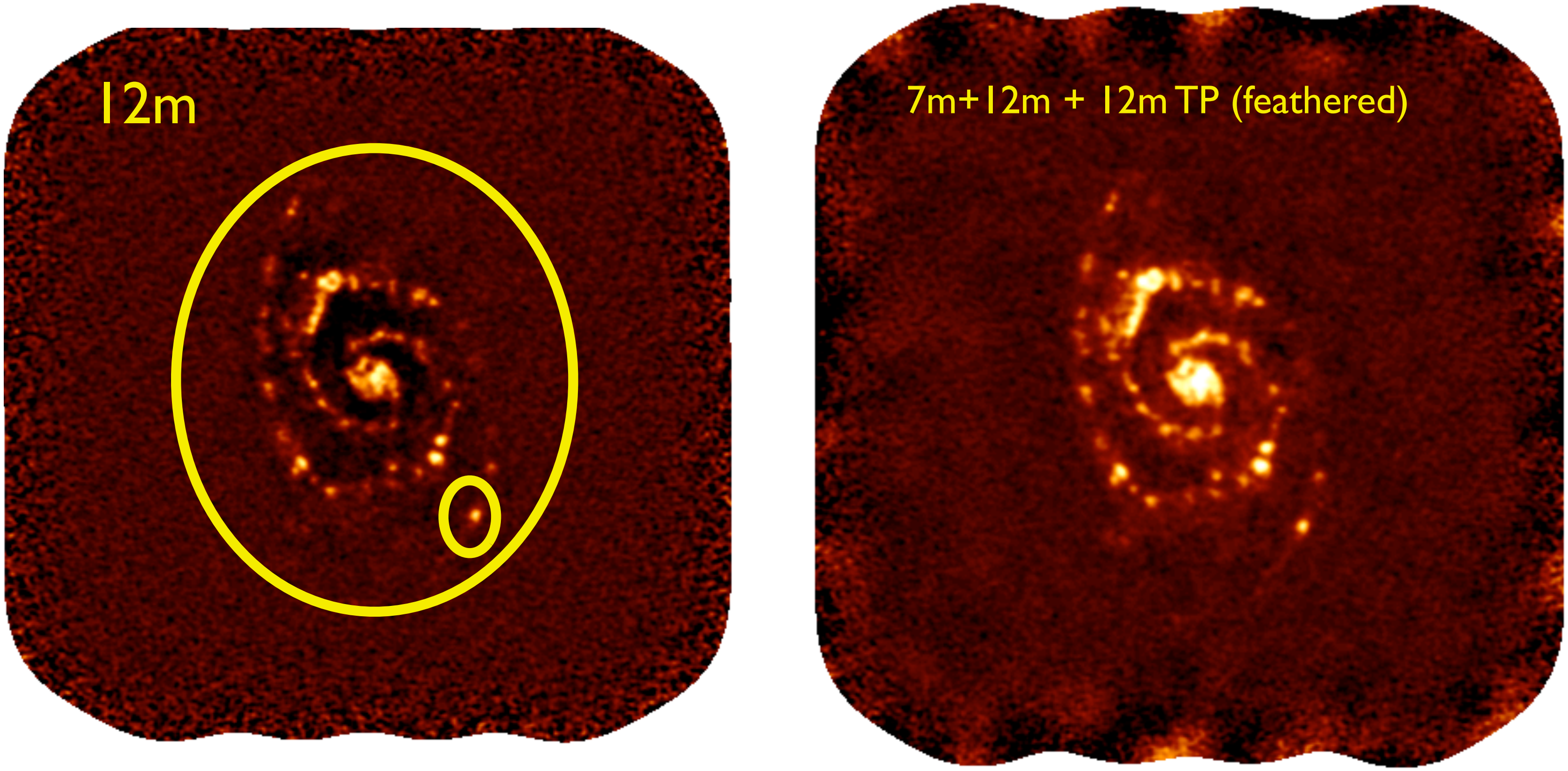
ALMA Band 1@ 40 GHz
6 hr = 1.8 microJy
C40-1 9" = 18 micro-K
C40-6 0.9" = 2 milli-K
(dnu=8 GHz; FOV 2.25x larger)

GBT@40 GHz (single beam)
19" beam
6 hr = 50 micro-K
mapping ngVLA@40GHz FOV
(dnu=8 GHz)

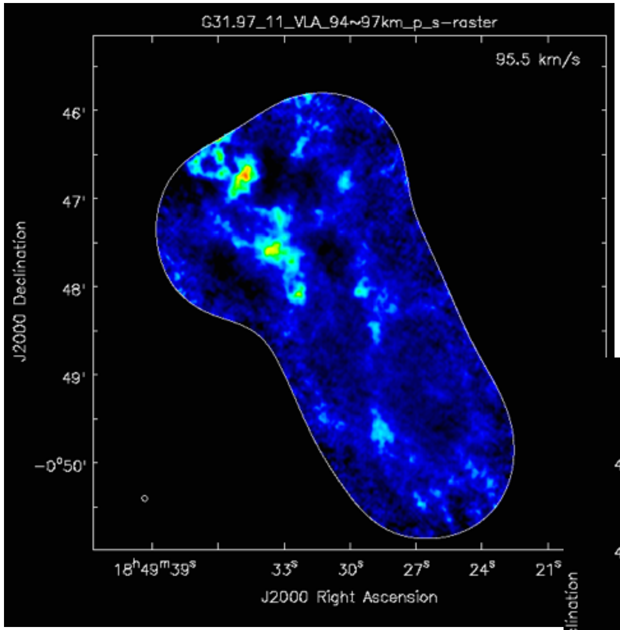
ALMA & GBT are in the same class as ngVLA (or better) for 1" resolution, high surface-brightness sensitivity imaging. [for GBT this comparison is a proxy for line sens.]

From ngVLA memo 3 (Clark & Brisken 2015)

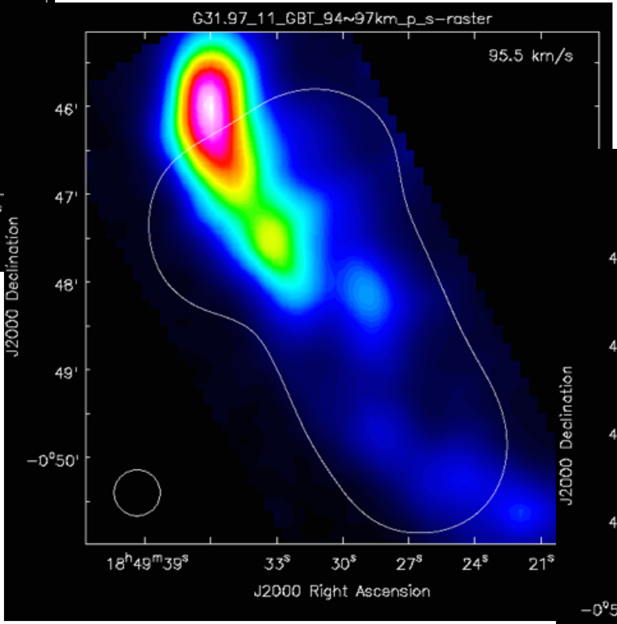


Good uv coverage down to the largest relevant angular scales is needed to accurately measure the fluxes of objects & features, which is needed to do physics

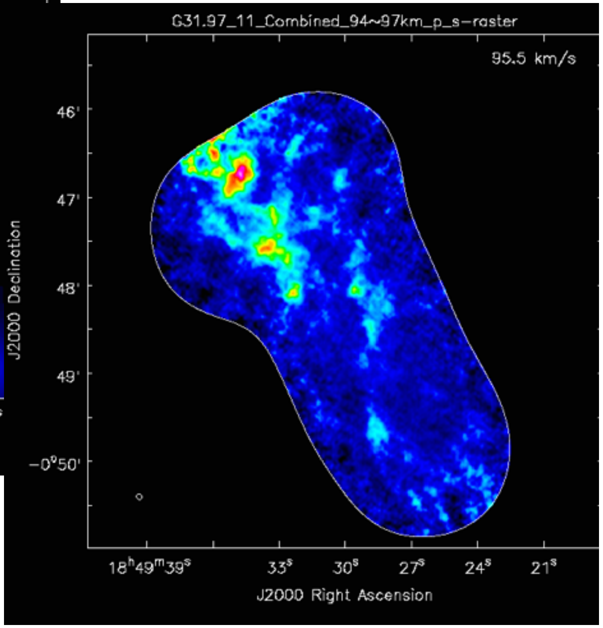
EVLA NH_3 (multi-scale CLEANed)



GBT NH_3



Feathered



W. DiRienzo et al. (2015)

ngVLA: questions around surface brightness

- Configuration / distribution of baseline lengths
- is there a distinct sub-array providing the short spacings, or are shorter spacings integral?
  - do these antennas have smaller diameter?
  - does the sub-array observe the same things for the same amount of time?
- could a subset of antennas be reconfigurable?
- what total power capability is needed & how do you provide it?
  - all dishes have TP capability? (like some early ALMA concepts)
  - build new dishes - how many & how big? what instrumentation?
  - use existing telescopes like GBT - what instrumentation? how long to observe?

Case study: ALMA

- Main array: 50x12m
- short-spacing array: 12x7m subarray
  - operates independently
  - separate correlator
  - integration times up to 5x higher than main array, to match most compact 12m-array SB sens.
- 4x12m TP antennas
  - operate independently from 12m & 7m arrays (nominally)
  - use 7m (ACA) correlator
  - Tint(TP array) ~ 10x Tint(12m array) needed to match most compact 12m-array SB sens.

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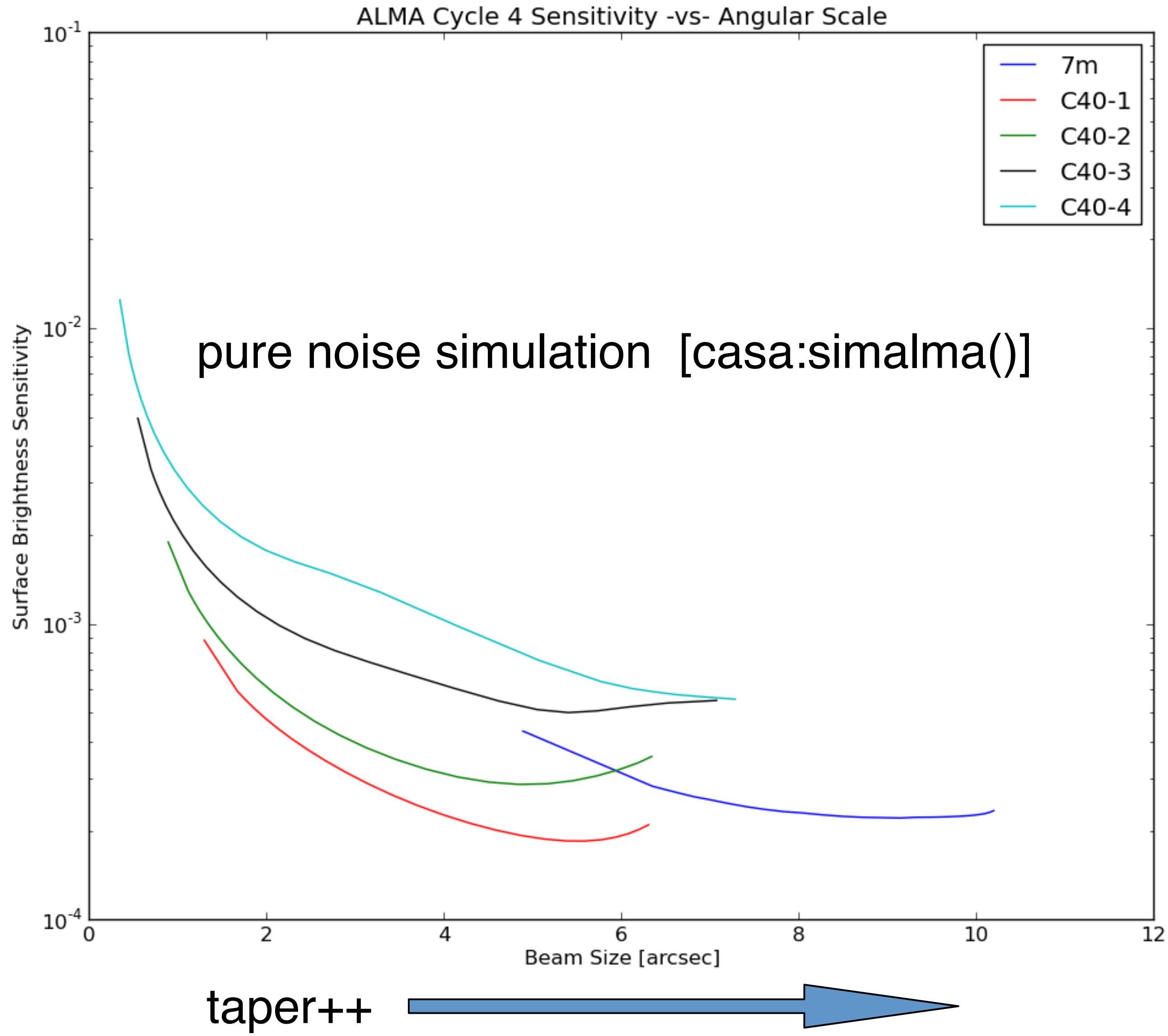
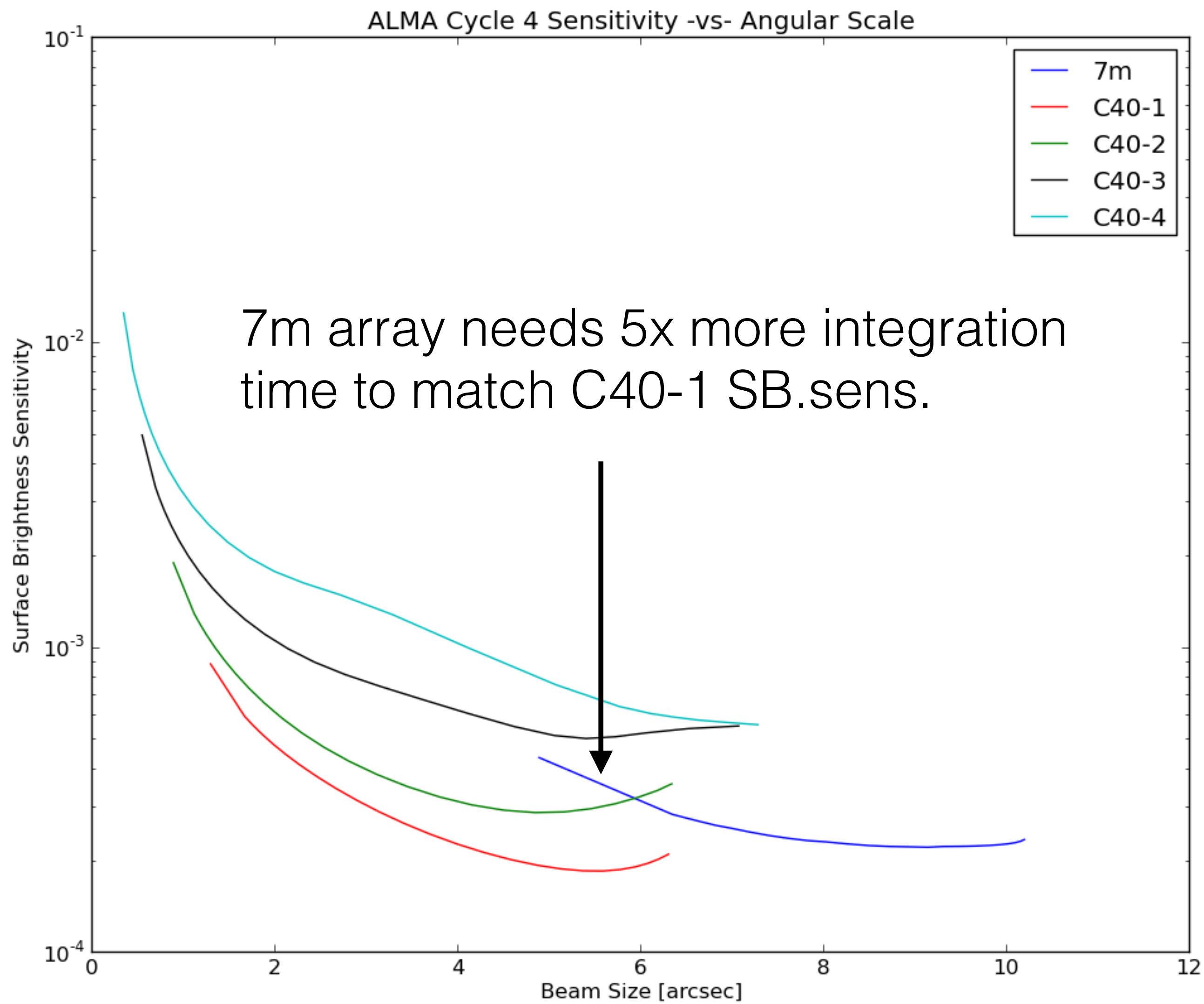
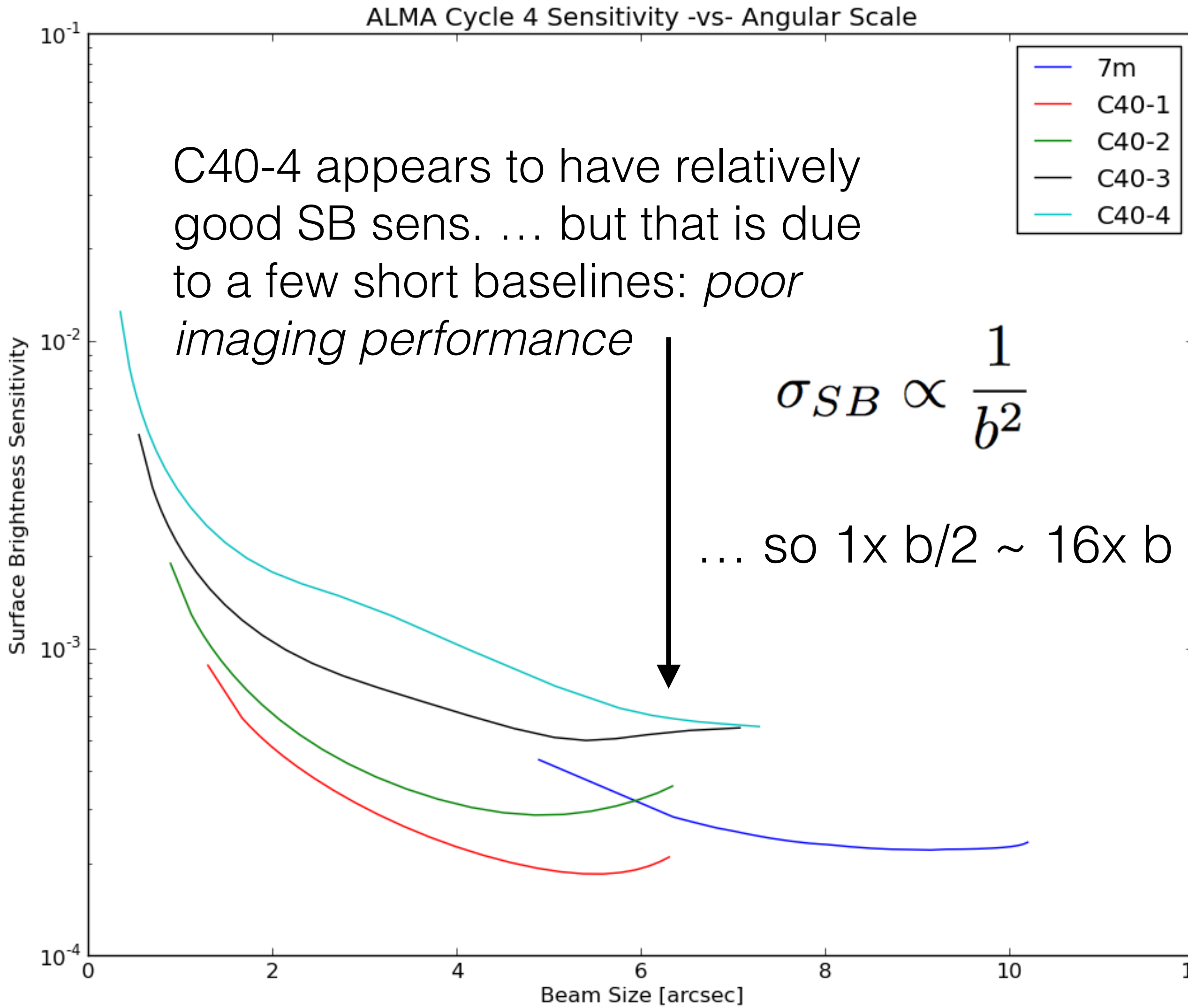

ALMA Cycle 4 Sensitivity -vs- Angular Scale
7m
C40-1
C40-2
C40-3
C40-4
pure noise simulation [casa:simalma()]
Surface Brightness Sensitivity
10^{-1}
10^{-2}
10^{-3}
10^{-4}
0
2
4
6
8
10
12
Beam Size [arcsec]
taper++


ALMA Cycle 4 Sensitivity -vs- Angular Scale
Surface Brightness Sensitivity
Beam Size [arcsec]
7m
C40-1
C40-2
C40-3
C40-4
0
2
4
6
8
10
12
10^{-1}
10^{-2}
10^{-3}
10^{-4}
7m array needs 5x more integration time to match C40-1 SB.sens.



C40-4 appears to have relatively good SB sens. … but that is due to a few short baselines: *poor imaging performance*

$$\sigma_{SB} \propto \frac{1}{b^2}$$

… so 1x b/2 ~ 16x b

sensitivity is only part of the picture: uv-coverage is critical

Experience from ALMA: small antenna sub-array for short spacings

- Advantages:
  - interferometrically sample shorter spacings than possible with one antenna size — precisely matching longer-BL data.
  - sub-array mode increases telescope throughput for projects that don't need the full range of BLs
  - very helpful to "bridge the gap" to single dishes with same D as main array
- SB sens. of compact ALMA array is extremely formidable!
  - a small-N, small-D antenna array needs considerably more time to provide matching SB sens. (few to 5 in time)
  - … precludes routine operation as a single array; requires independent sub-arrays
  - … which costs you the (small-D) x (large-D) baselines. There are many of these and they would improve the imaging & antenna calibration (particularly of the small-D antennas)
- other disadvantages: creating & maintaining multiple antenna designs costs more; likely reduces point source sensitivity (for fixed $$$).

Total power considerations

single dishes & interferometers are different

- ***hardware requirements*** **-** single dish receivers & electronics must be more stable; continuum & spectral line imply different receiver architectures.
- ***observing modes***: it is ***not*** feasible to observe TP simultaneously
- similarity is closest in narrow bandwidth spectral line case; differences greatest for wide-band spectral line & continuum.
- ***don't use one for the other, you need purpose built systems.***

ngVLA total power requirements

- Operational range ~1 - 115 GHz
- To maximize flux recovery and image quality, you want a single dish of D > 1.5xBmin
  - For ngVLA this is at least: D > 1.5 x (1.5 x 18m) ~ 40m , probably more
- *Matching criterion*: equal surface brightness sensitivity when the INT is tapered to comparable beam size as the SD (see ALMA Memo 598 for a similar but simpler version of this calculation for ALMA)
- For a single dish to match modern synthesis arrays generally requires many single dishes, large single dishes, lots of time, or focal plane arrays.

GBT meets these requirements

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ngVLA strawman scenario

- single antenna design
- Sufficient baselines to cover all key science cases; sub-array mode available to multiplex projects that don't need the full range.
- If the science justifies zero spacings, use an existing, relatively large single dish with FPAs
  - GBT is already built, has a large focal plane, and is fully functional over the relevant frequency range
    - For the scale of investment under consideration re-focusing it toward ngVLA support should be a non-issue
    - *Needed*: calculate FPA size needed to match ngVLA SB.sens. in available observing time (for GBT - 20 GHz: 2000 hrs/yr; 90 GHz: 800 hrs/yr)
  - expensive to provide TP support for all possible ngVLA use cases: consider key capabilities individually — e.g., initially focus on *mapping spectral lines*.
- ALMA B1 - B3 also naturally complement & extend the SB sens. & angular scale coverage of ngVLA. **problems:**
  - coverage at < 30 GHz
  - sufficient ALMA availability to support ngVLA demand?

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concluding thoughts: what we need

- to know what the community is excited about: ***key science use cases***
- numbers:
  - needed resolution
  - … at what surface brightness sensitivity @ resolution
  - the *largest angular scales you need to do your key science*
    - physical scales → objects & samples → angular scales
  - … at what SB sens. @ LAS