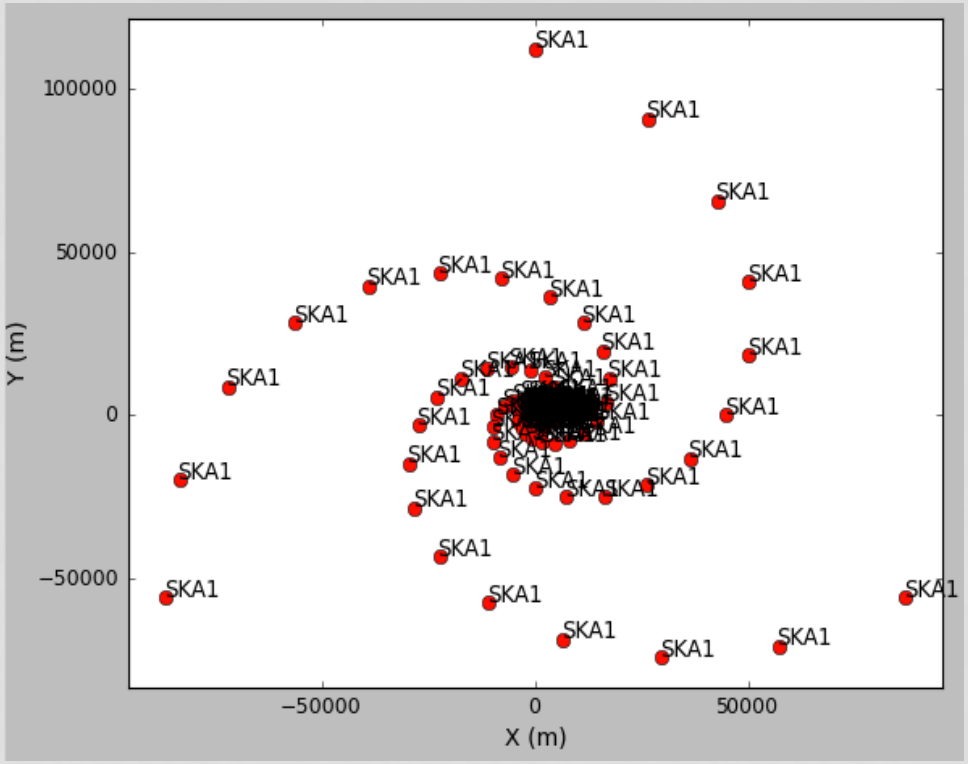
Can we do this science with SKA1-mid?

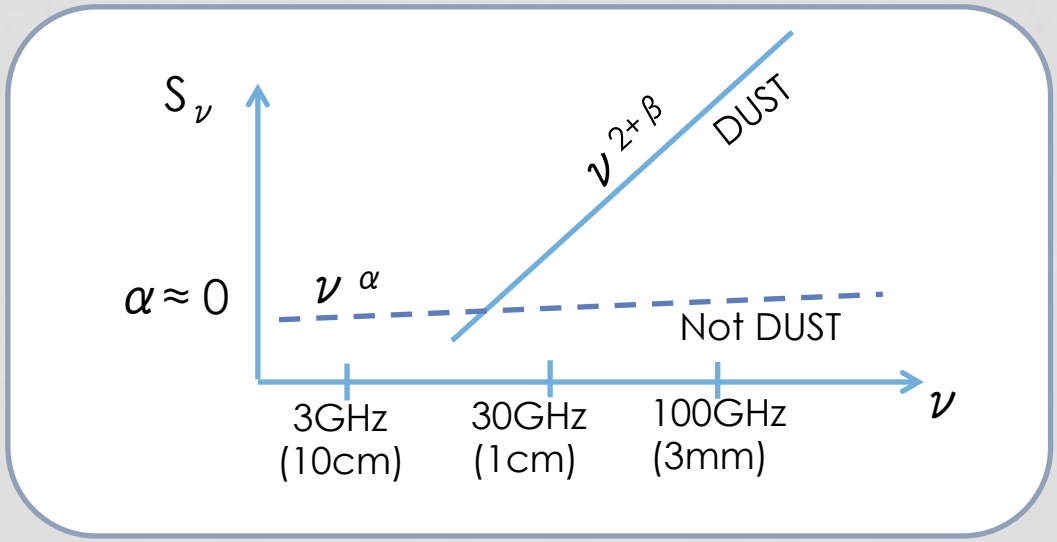
Let's start with the baseline design…

- SKA1-mid expected to go up to 3.05 GHz
- Proposed array configuration:
  - 133 dishes in ~1km core, +64 dishes out to 4 km, +57 antennas extending out to 100 km



And let's be optimistic ☺

- A source of **1 mJy** total flux at **30 GHz**
  - 0.5 mJy → dust (disk) **+** 0.5 mJy → free-free emission (wind/jet)



- Assume $\beta = 0.5$, and $S_\nu \approx \nu^{2+\beta}$ (optically thin dust emission)
  - At 3 GHz ~ 1.6 μJy (vs. at 15 GHz ~ 90 μJy)
  - Protoplanetary disk is ×60 **fainter** at 3 GHz ☹

The problem with *free-free emission* at 3 GHz

- This contamination **dominates** the disk emission at 3 GHz

- Assuming unresolved source and optically-thin free-free ($\nu^{\alpha \sim 0}$)
  - At 15 GHz: **dust is 10%** of total emission
  - At 3 GHz: **dust is only 0.2%** of total emission

- To be able to image structure in the dust emission we need reasonably **good (>10^3) dynamic range** on small spatial scales

The *background sources* problem at 3 GHz

- We have ignored background sources at 3 GHz!
  - 1-10mJy background sources present within Primary Beam (PB)
  - $SKA_{PB} > VLA_{PB}$ → there will be more of them than for the VLA!
  - NB: need to be considered for **any** SKA imaging science
- 10-σ detection at 3GHz requires RMS noise ~0.16 μJy
- Need to achieve **dynamic range of 10^5** (<u>routinely!</u>)

The *confusion-limit* problem at 3 GHz

- Although the angular resolution is quite good
- The central SKA core (out to ~4km) gives 5" fringes:
  - **Additional noise from confusion**:

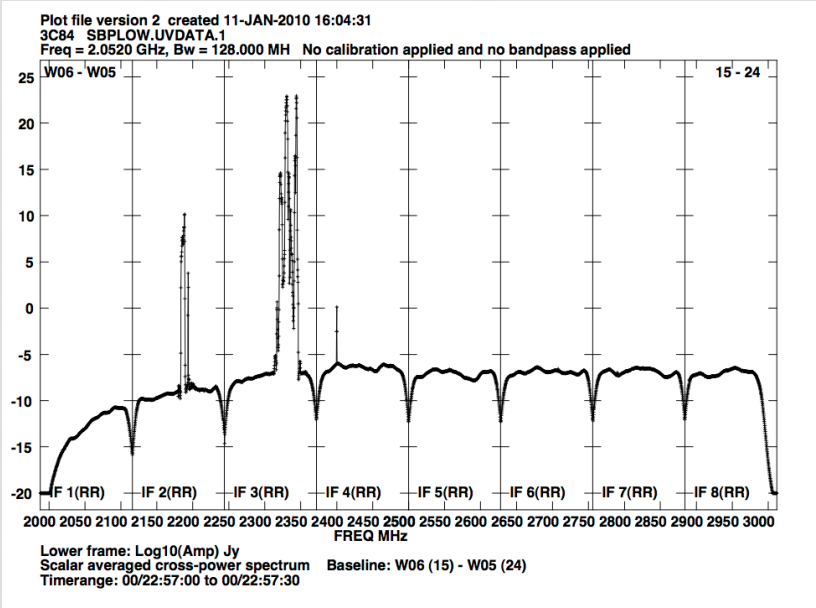
$$\sigma_{conf} = 1.2\left(\frac{\nu}{3GHz}\right)^{-0.7}\left(\frac{\theta}{8''}\right)^{10/3} \mu Jy$$

    - σ_{conf} **~ 0.25 μ Jy**
    - (NB: may be alleviated by "throwing out" the short baselines)

The *RFI* problem in the 3 GHz S-band

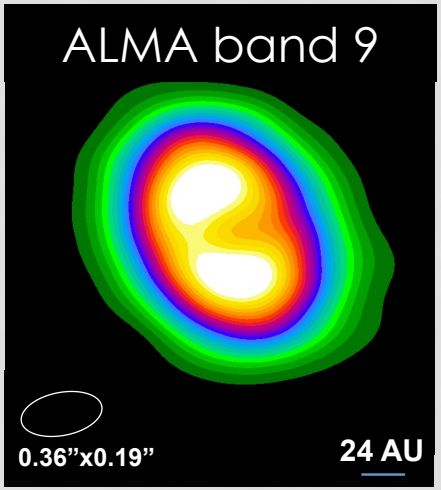
- The 2 - 3 GHz window is filled with geostationary satellite emission and others… (at VLA Dec ~ -5; Orion)

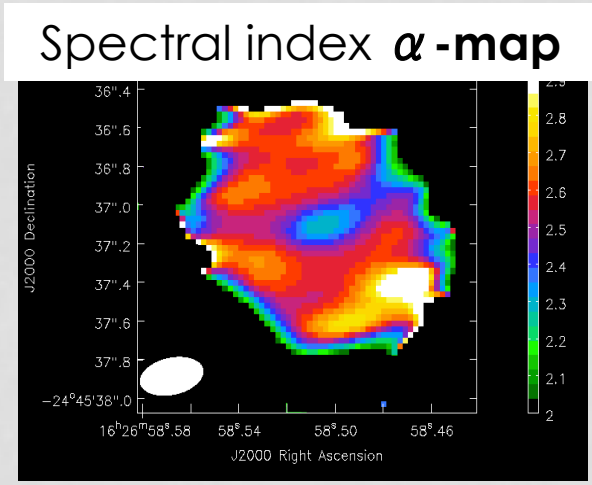
Frequency (MHz)	Description	Origin	Classification
2178.0-2195.0	??		Intermittent
2106.4	High alt baloon	NM, FT Sunmer	Intermittent
2204.5	Test telemetry	NM, FT Bliss	Intermittent
2180-2290	Satellite downlink	OHD?GSO/MEO	Continuous
2227.5-2231.5	??	NM, WSMR?	Intermittent
2246.5-2252.5	??	NM, WSMR?	Intermittent
2268.5-2274.5	??	NM, WSMR?	Intermittent
2282.5-2288.5	??	NM, WSMR?	Intermittent
2314.5-2320.5	??	NM, WSMR?	Intermittent
2320.0-2332.5	Sirius DARS	OHD/GSO-Tundra	Continous
2324.5-2330.5	??	NM, WSMR?	Intermittent
2332.5-2345.0	XM DARS	OHD/GSO-Equatoral	Continuous
2334.5-2340.5	??	NM, WSMR?	Intermittent
2387.5	High alt baloon	NM, FT Sunmer	Intermittent
2400.0-2483.5	Microwave Ovens	Everywhere	Continuous
2400.0-2483.5	WiFi(802.11b) Wireless	Everywhere	Continuous
2483.5-2500.0	GlobalStar downlink	Everywhere	Continuous
3700.0-4200.0	Satellite downlinks	OHD	Continuous



The problem with *angular resolution* at 3 GHz

- A uniform-weighted beam for SKA1-mid:
  - At 3 GHz ~125 mas
    - **Can't match the resolution** of VLA at 30 GHz (~60-100 mas, A+B)
    - Or that of full ALMA (better than 20 mas)

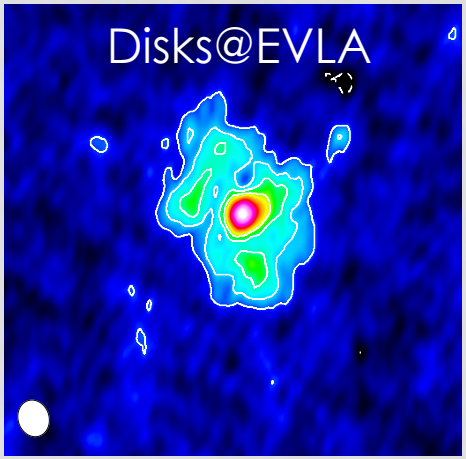




$\beta \approx 1$

$\beta \approx 0.5$

$\beta \approx 0$



- Fortunately, at 15 GHz ~ 25 mas

The problem with high frequency band at 3 GHz

- All in all, **3 GHz band is not well-suited for dust studies** in protoplanetary disks:

- Free-free emission dominates at 3 GHz
  - Not what we are interested
- Background sources contaminate 3 GHz PB
  - Need >10^5 dynamic range
- Confusion-limit is still a problem for inner core
- RFI can be severe at S-band
- Angular resolution is poor compared to others

Let's be optimistic again! ☺

- Assume that a band ~15 GHz is part of SKA1-mid design:
  - Not limited by background sources as 3 GHz band
    - No need to obtain high dynamic range in order to achieve advertised sensitivity.
  - Confusion is less important ($\sigma_{conf} \sim \nu^{-0.7} \times \theta^{10/3}$)
  - Fractional contamination from free-free is less significant:
    - Dust emission at 15 GHz is x20-125 brighter than at 3 GHz

Does SKA1-mid *at 15 GHz* fare well against VLA?

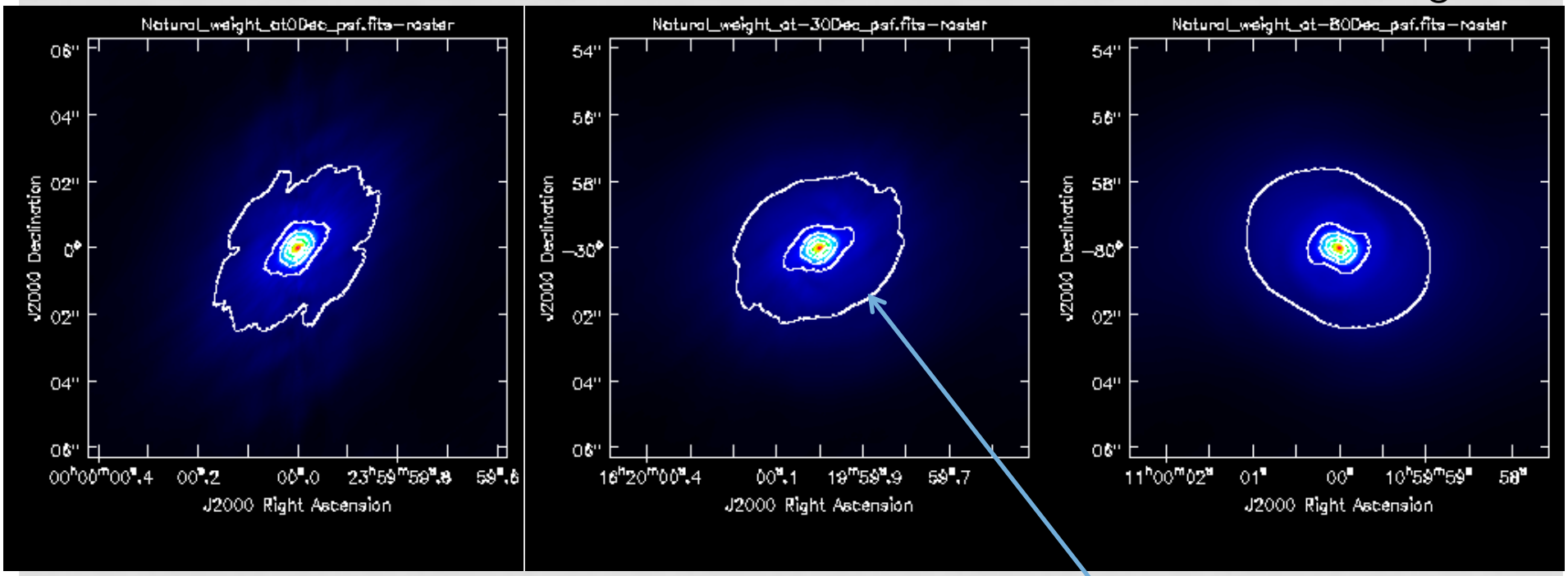
- VLA resolution is 200 mas at Ku band
- Better with SKA1-mid (**x2-8 better resolution**!)
  - Science: **study grain growth at quite small spatial scales**
- What about sensitivity?
- Let's look at visibility weighting schemes for a moment…

Beam shape vs. weighting schemes

Dec = 0 deg

Dec = -30 deg

Dec = -80 deg



12"

Incredibly difficult to deconvolve! **Clean bias** limits the dynamic range.

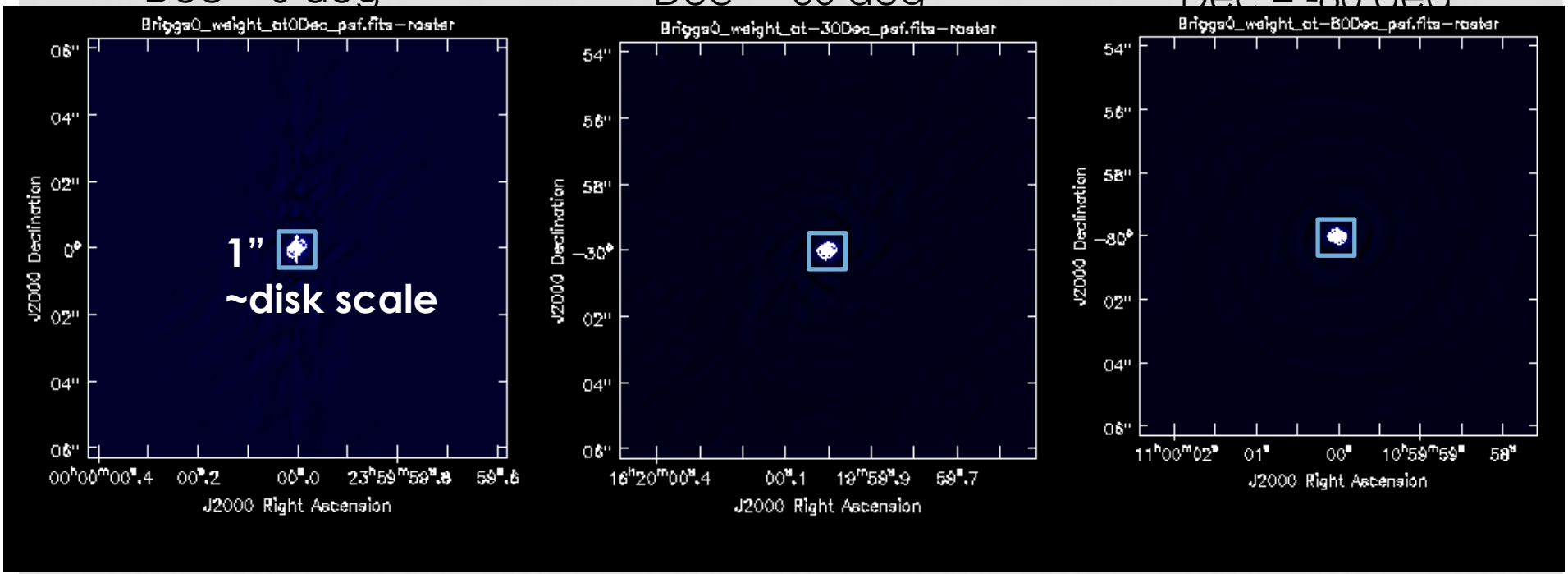
Natural weighting of SKA1-mid

Beam shape vs. weighting schemes

Dec = 0 deg

Dec = -30 deg

Dec = -80 deg



12"

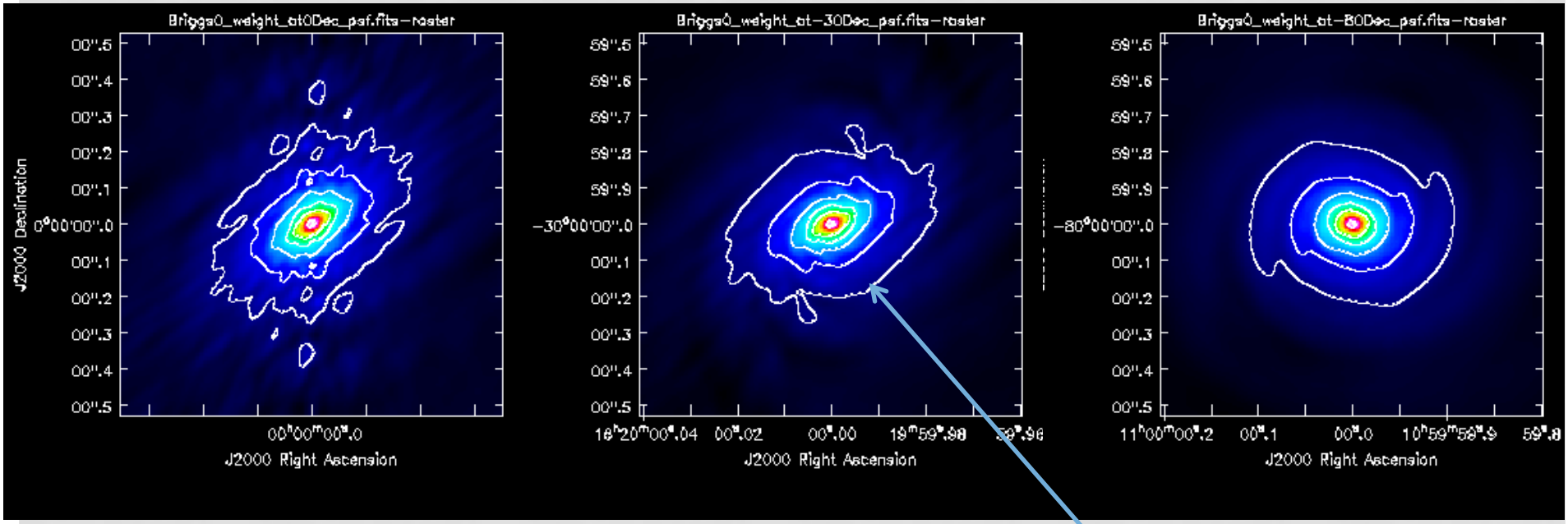
Briggs weighting (r=0) of SKA1-mid

Beam shape vs. weighting schemes

Dec = 0 deg

Dec = -30 deg

Dec = -80 deg



1''

Still difficult to deconvolve and affected by clean bias

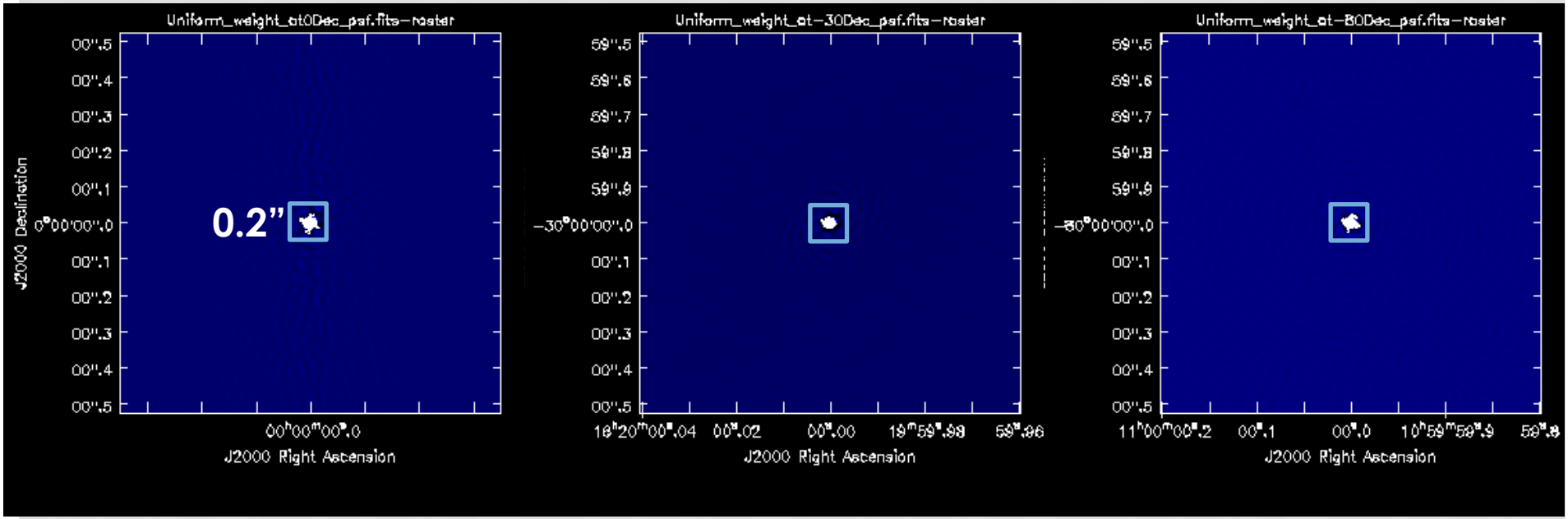
Briggs weighting (r=0) of SKA1-mid

Beam shape vs. weighting schemes

Dec = 0 deg

Dec = -30 deg

Dec = -80 deg



1”

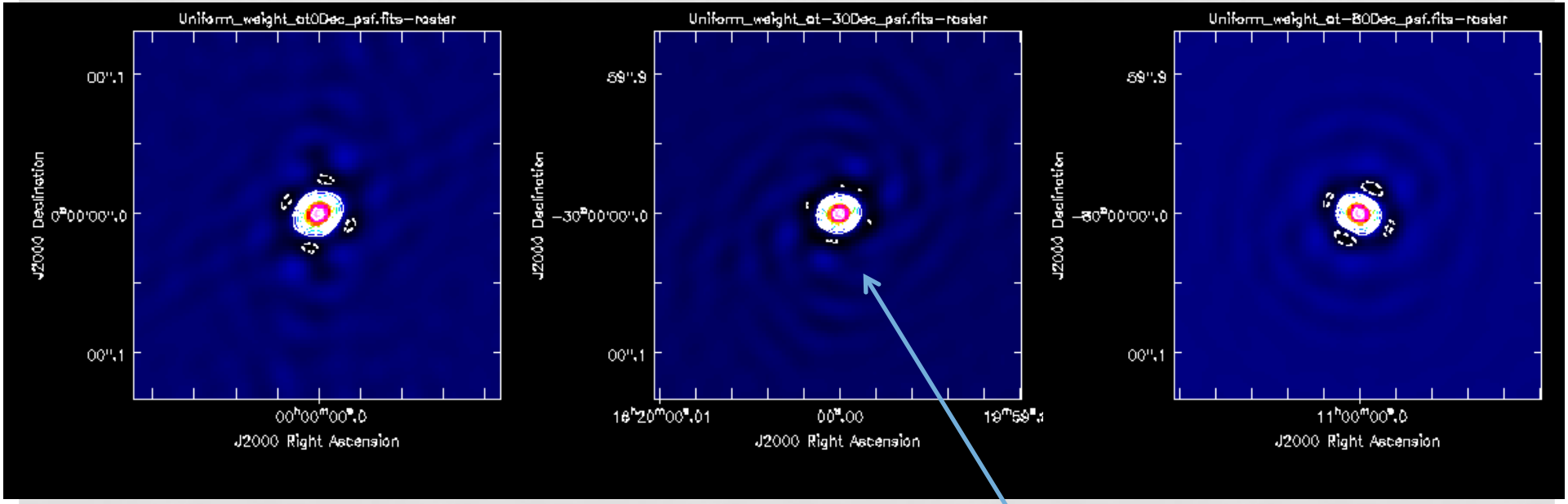
Uniform weighting of SKA1-mid

Beam shape vs. weighting schemes

Dec = 0 deg

Dec = -30 deg

Dec = -80 deg

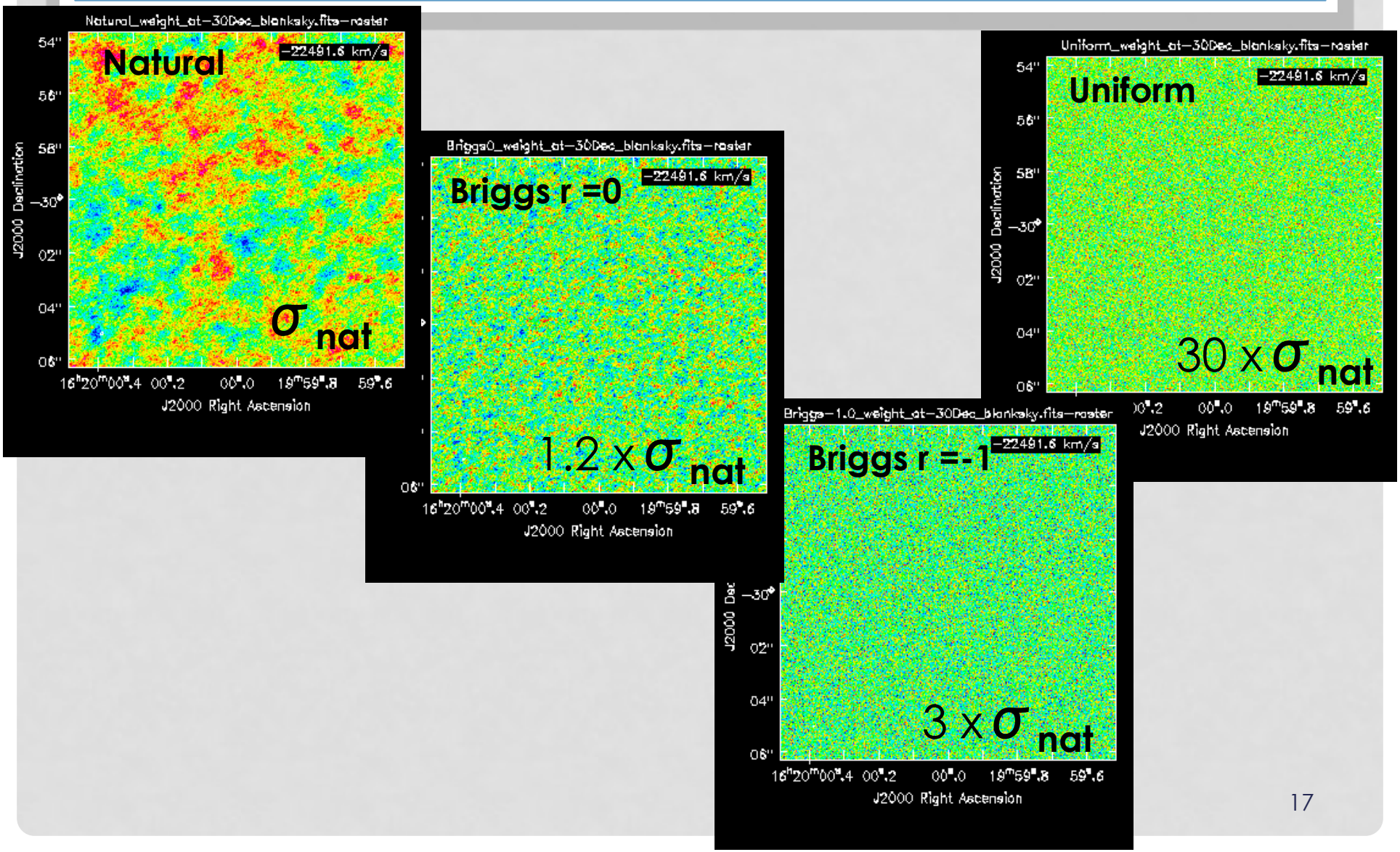


0.2"

Easier to deconvolve, but need to **demonstrate dynamic range can be achieved**

Uniform weighting of SKA1-mid

But uniform weighting comes with a price…



Does SKA1-mid *at 15 GHz* fare well against VLA?

- A beam that can be deconvolved will be <0.05" resolution

- What about sensitivity?
  - Disks@EVLA: 0.1" @ 30 GHz → Tb = 10 K
    0.1" @ 15 GHz → Tb = 7 K (β =0.5)

- To detect **Tb = 7 K in 0.05" beam** we need **RMS = 0.3 μ Jy/beam**
  - Baseline design document: $\sigma \sim 0.13\,\mu$ Jy/beam in 8hrs
    - assumes natural weighting: can't use because deconvolution problems
  - Science performance memo: $\sigma \sim 8\text{x}\,\sigma_{nat}$~**1 μ Jy/beam**
  - Conclusion: **~10x more time** because sensitivity is degraded due to weighting → **benefit of large collecting area is lost** (since short baselines have to be down-weighted)

Summary

- The **3 GHz band is not the optimal band to study dust** continuum emission from protoplanetary disks:
  - Problems with free-free emission and background source contamination, confusion-limit, RFI, and poor angular resolution
- A **15 GHz band will alleviate most of these problems**:
  - Not much free-free, RFI, background sources, confusion limit, and angular resolution is much better.
- However, **it remains to be shown that the sensitivity will not suffer dramatically from the current antenna configuration,** so that future protoplanetary disk studies can be carried out with SKA1-mid.