



# Of Beams & Sausage: WF WB HDR Imaging Lessons From JVLA

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& R. Perley (NRAO)

R. Perley & RATT  
3C147 L-band  
JVLA D & C-config  
(6+8 hrs)

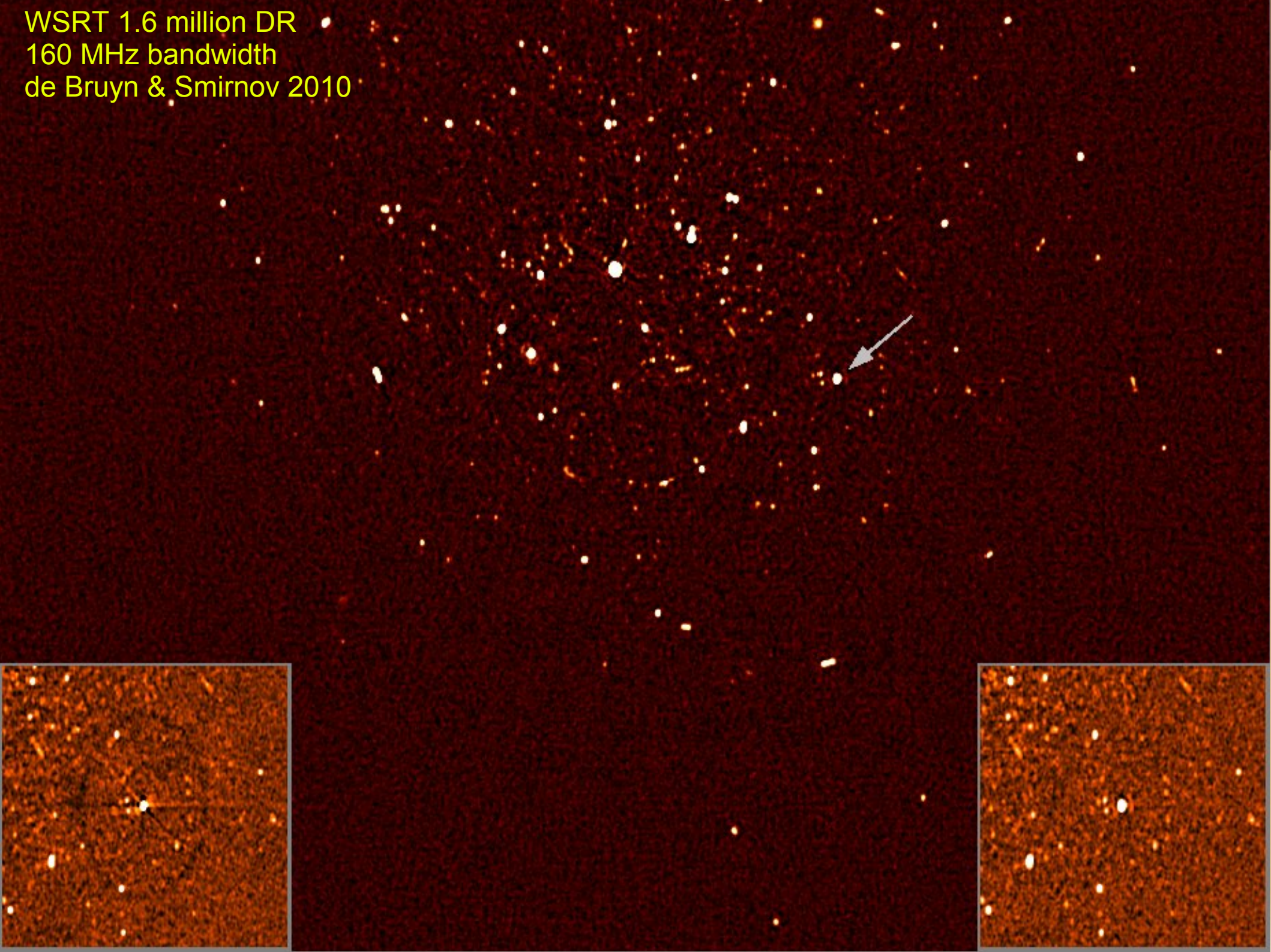
22.82 Jy peak  
4.5  $\mu$ Jy noise  
5 million DR  
confusion limited

*“A high quality radio map is a lot like a sausage, you might be curious about how it was made, but trust me you really don't want to know.”*  
– Jack Hickish, PhD (Oxford)

Imaging into second PB sidelobe

~640 MHz bandwidth

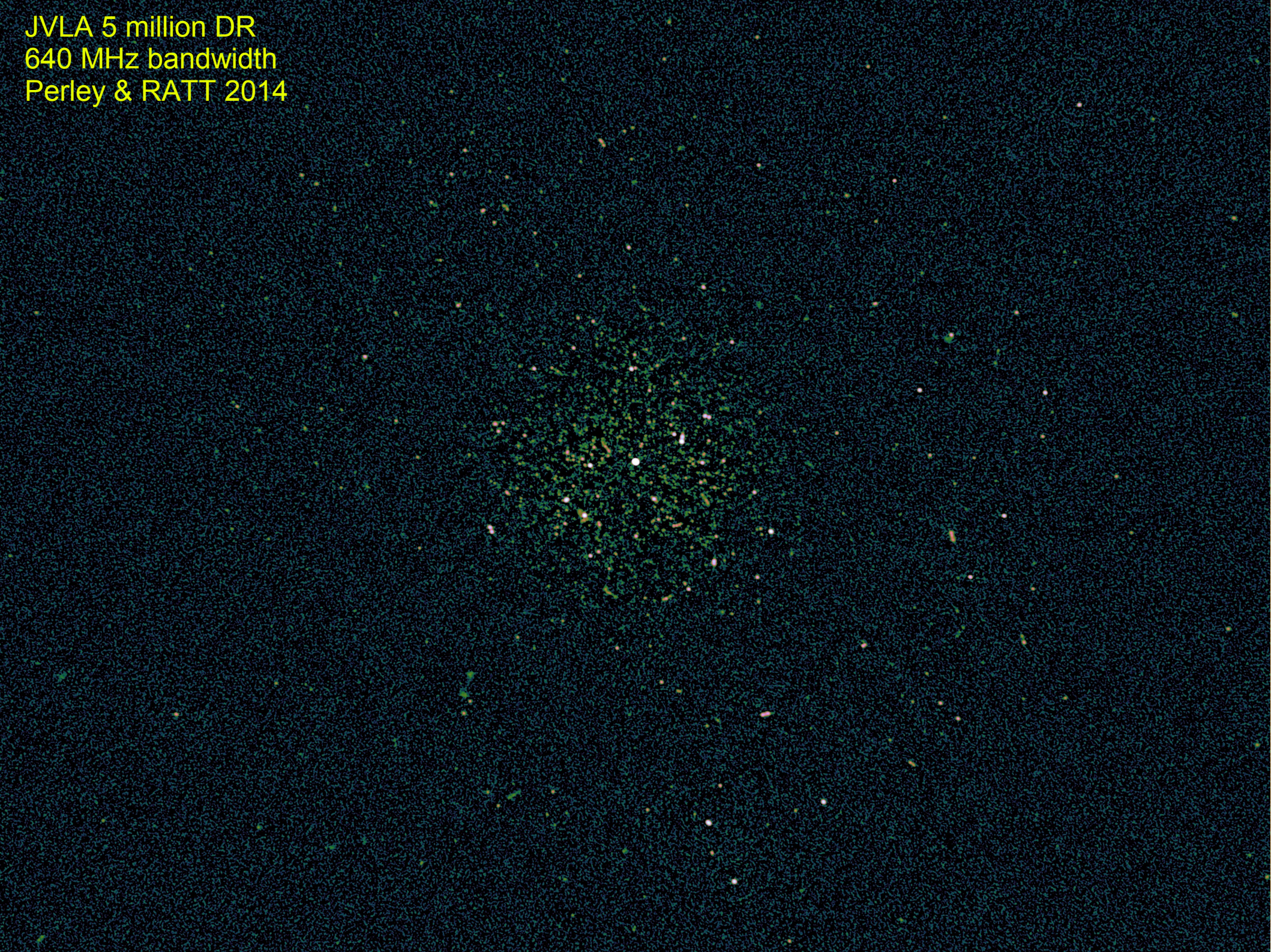
WSRT 1.6 million DR  
160 MHz bandwidth  
de Bruyn & Smirnov 2010



JVLA 3.2 million DR  
192 MHz bandwidth  
Perley & Smirnov 2014



JVLA 5 million DR  
640 MHz bandwidth  
Perley & RATT 2014



# Why Do HDR?

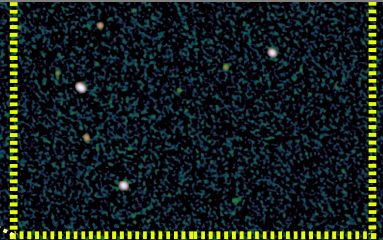
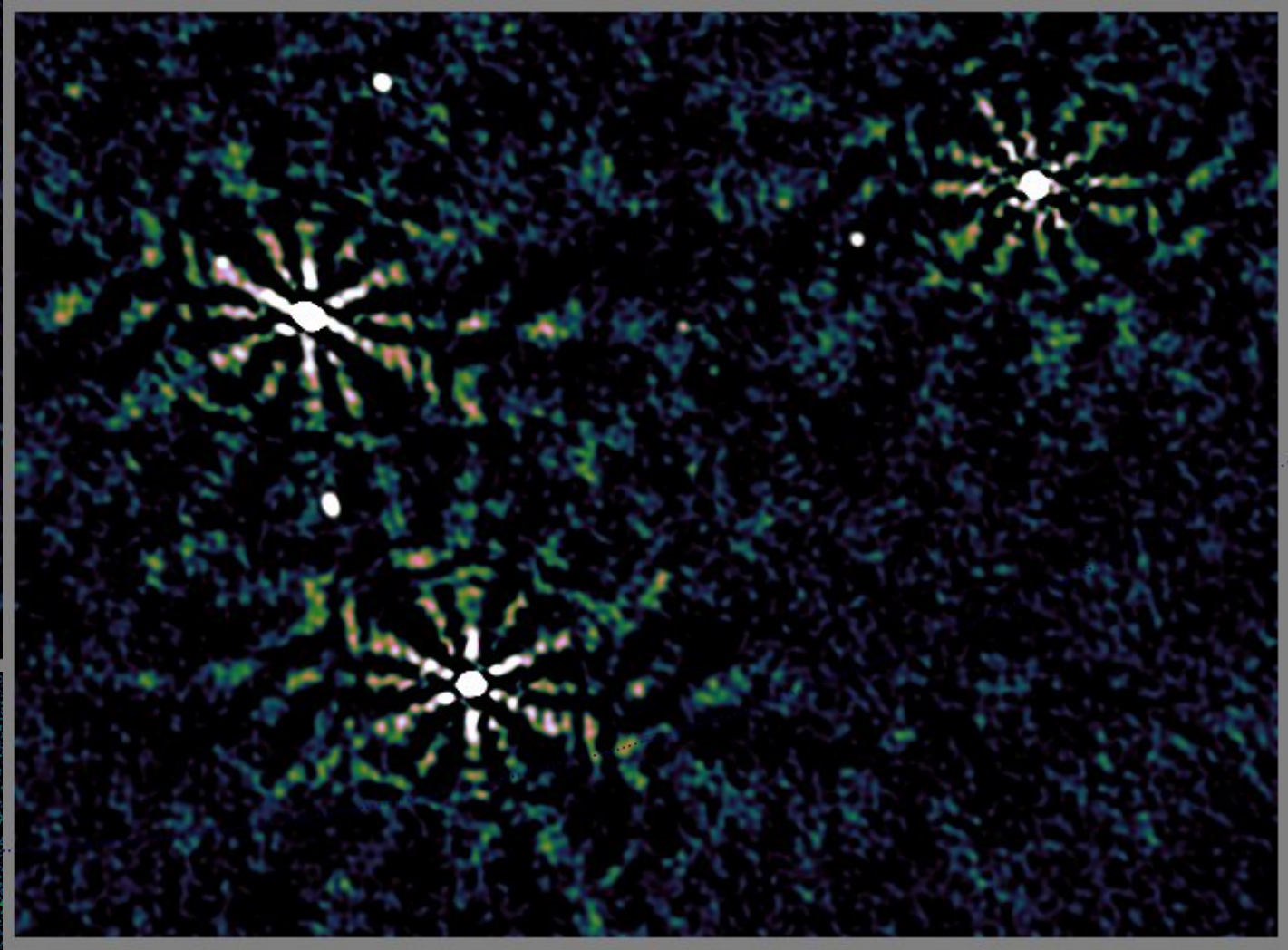
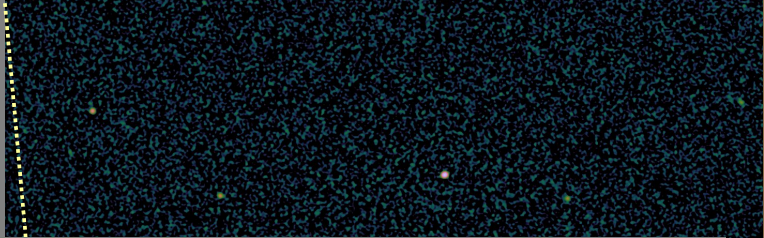
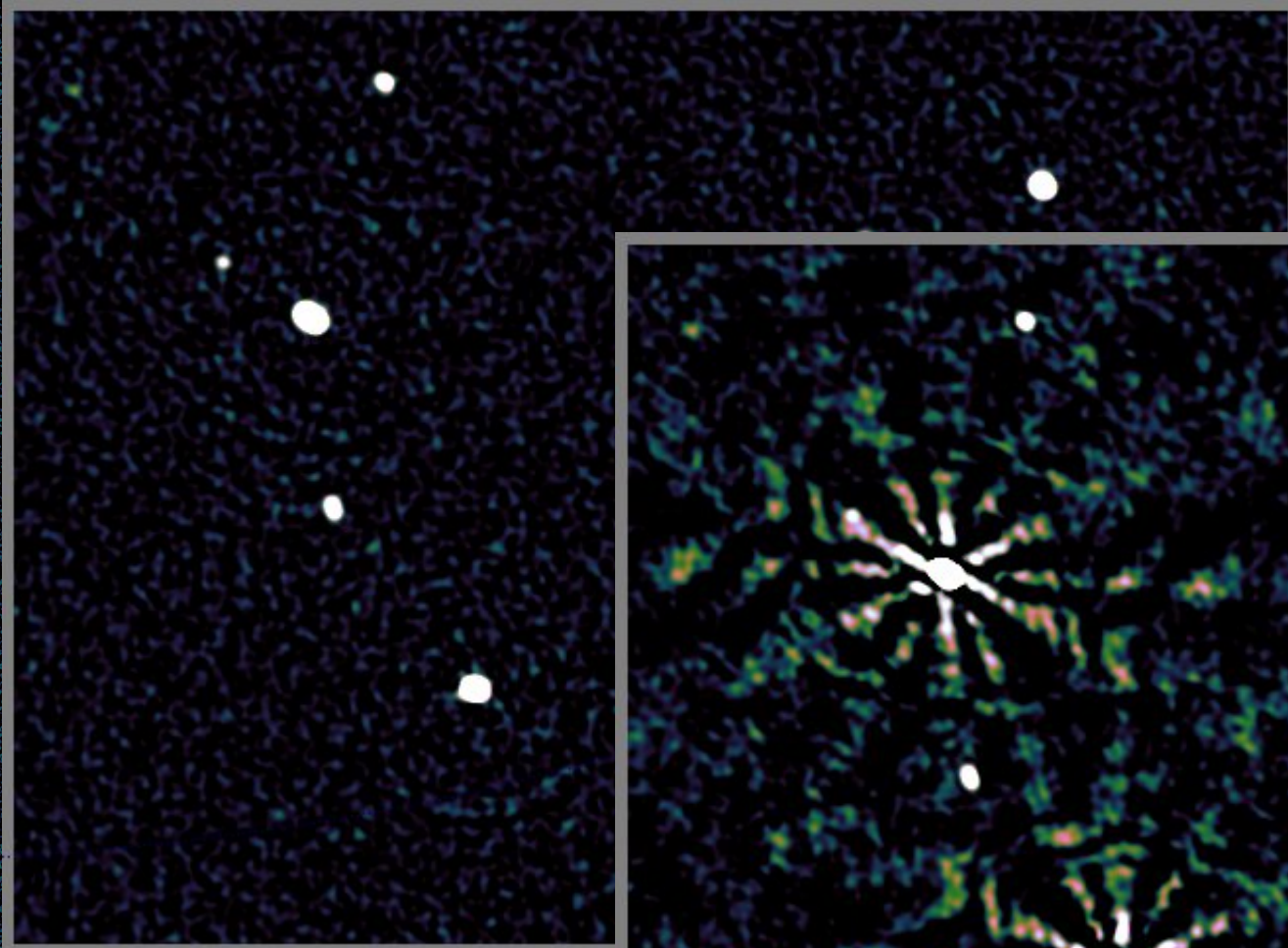
- High-DR imaging has been called various disparaging names
  - (Though primarily by people who can't do HDR)
- “Macho imaging”:
  - Bragging rights, marketing gimmick, etc.
- The trophy wife of radio interferometry:
  - Consumes a disproportionate amount of attention and resources
  - Highly decorative
  - Scientifically useless

# Why Do HDR

- We do DR to show that we can do DR
  - i.e. that we can understand and control every little finicky subtlety of the instrument well enough to get to **X** million
- Every major gain in DR has come on the back of some crucial advance in calibration tools or techniques
  - Which will presumably become bread-and-butter stuff for future deep surveys
- Primary beam is the usual villain of the piece
  - Going from 3M to 5M has been a PB story







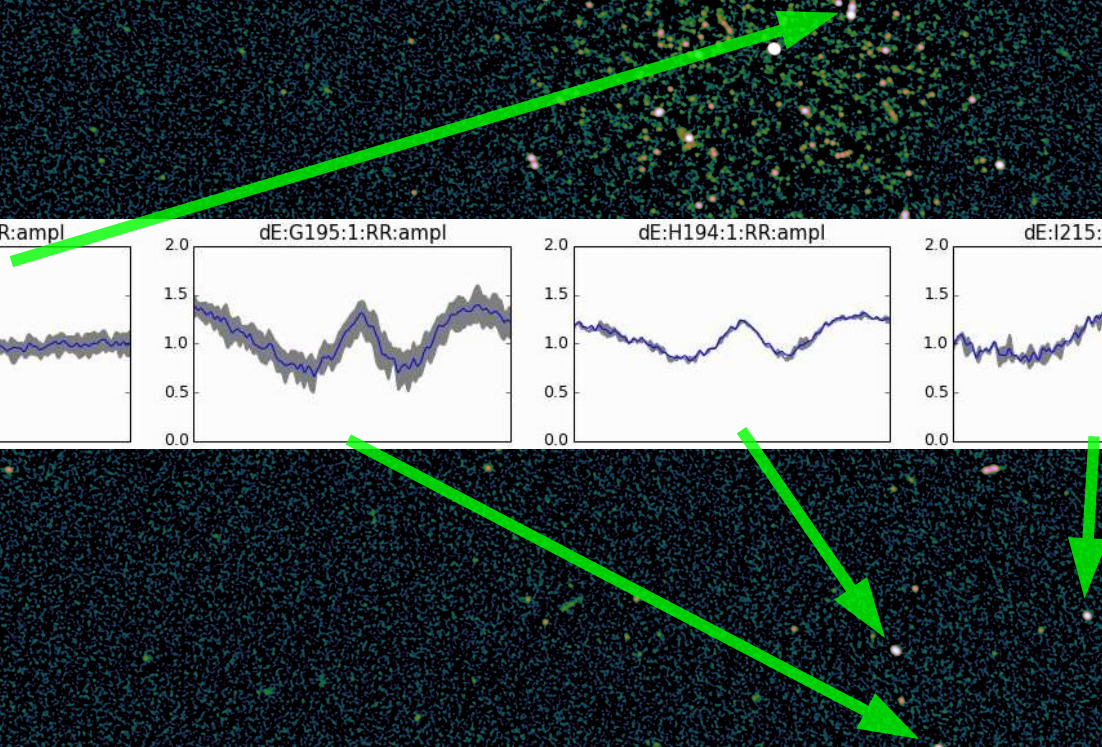
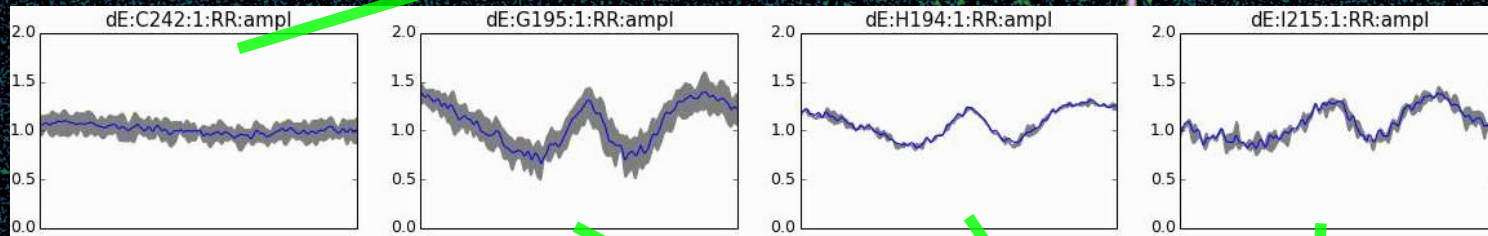
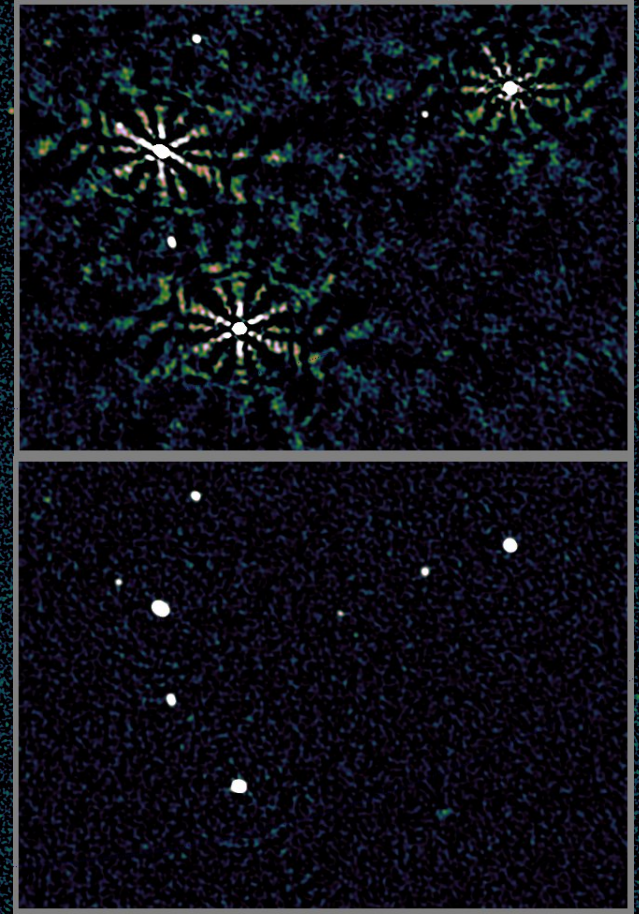
# Differential Gains (2009)

$$\mathbf{V}_{pq} = \overbrace{\mathbf{G}_p}^{\text{gain \& bandpass}} \underbrace{\left( \sum_s \overbrace{\Delta \mathbf{E}_p^{(s)}}^{\text{differential gain}} \overbrace{\mathbf{E}_p^{(s)}}^{\text{beam}} \overbrace{\mathbf{X}_{pq}}^{\text{source coherency}} \mathbf{E}_q^{(s)H} \Delta \mathbf{E}_q^{(s)H} \right)}_{\text{sum over sources}} \mathbf{G}_q^H$$

- Phenomenological, solvable term capturing all DD effects towards a particular source
- Varies slower than normal (direction-independent) gain

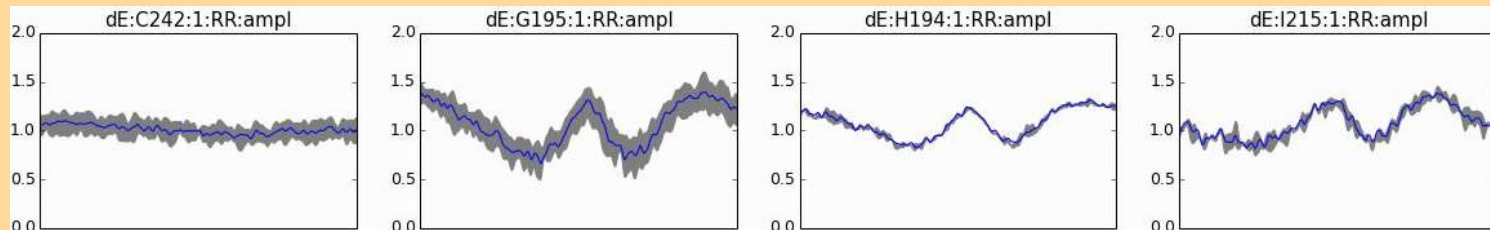


Example differential gain solutions for JVLA (2014 image)  
Dominated by primary beam rotation



# Downside To Diffgains

- A solvable term absorbs all differences w.r.t. starting model, whether they come from sky or instrument
- Makes for beautiful maps
- ...by destroying astrophysical information!
- Think of diffgains as representing everything we **don't yet** understand about the instrument

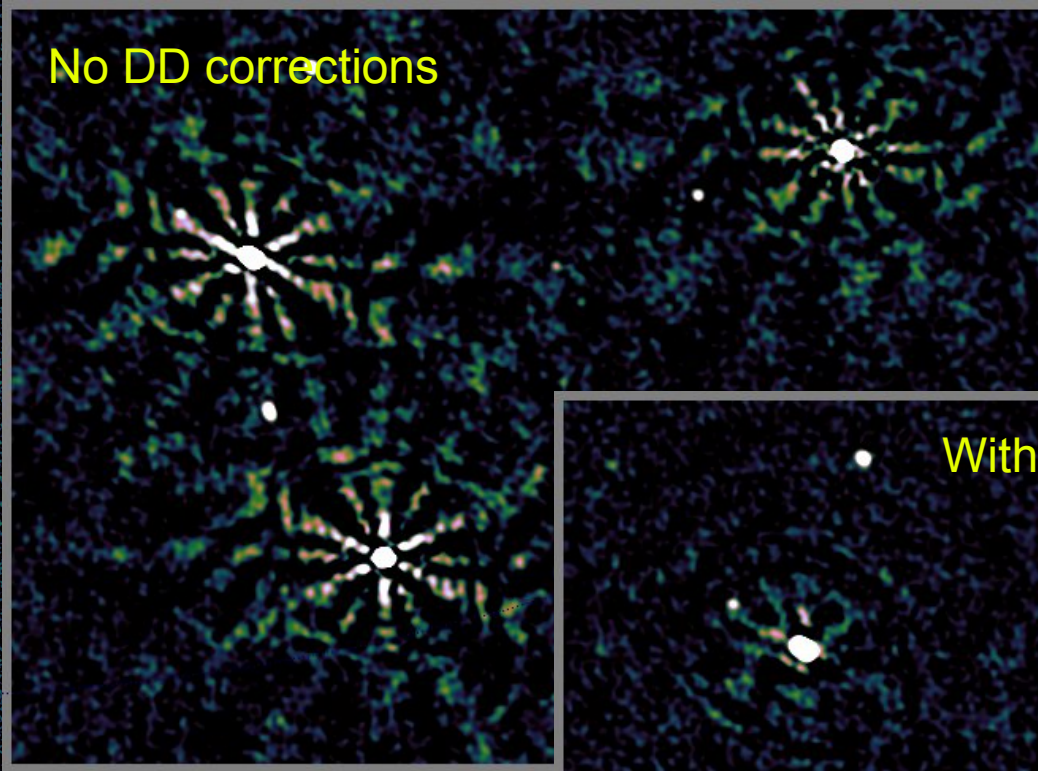


# Modelling The Primary Beam

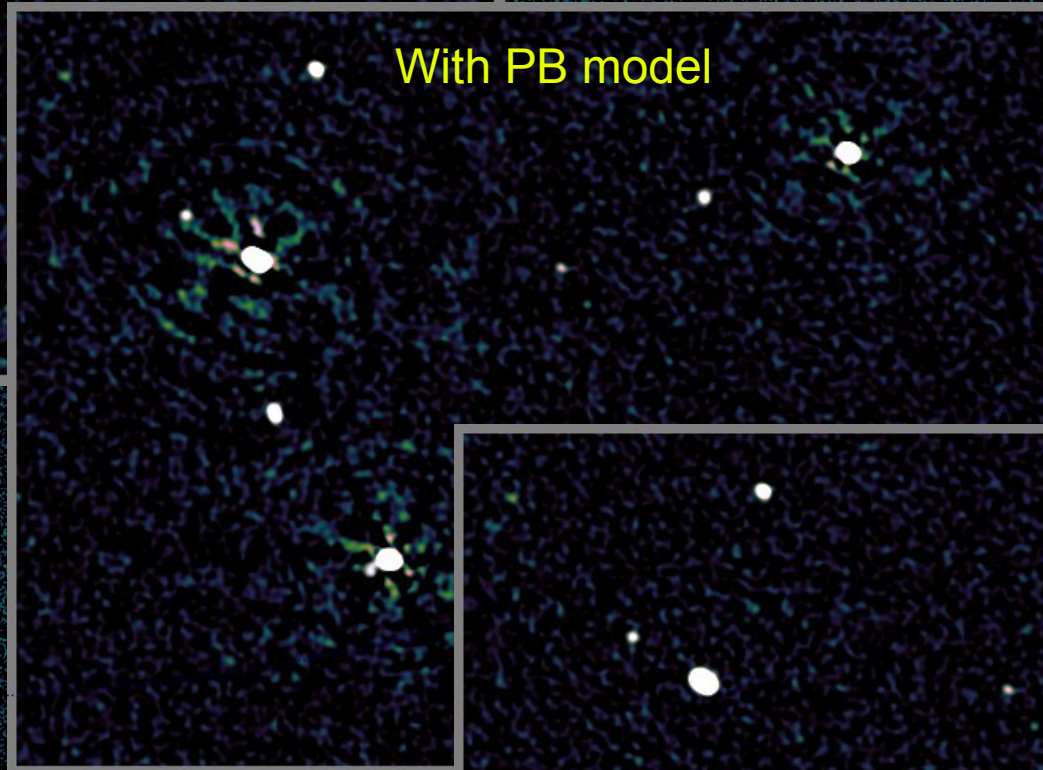
- Cassbeam (Walter Brisken, NRAO) is a ray-tracing primary beam simulator
- Why not put the pattern into the selfcal loop?
  - “Radio interferometry is death by a million papercuts” (after G. de Bruyn)
- A-projection/CASA does something similar – in conference talks. In practice, the current public release is useless.
- Alternative: component model in MeqTrees



No DD corrections



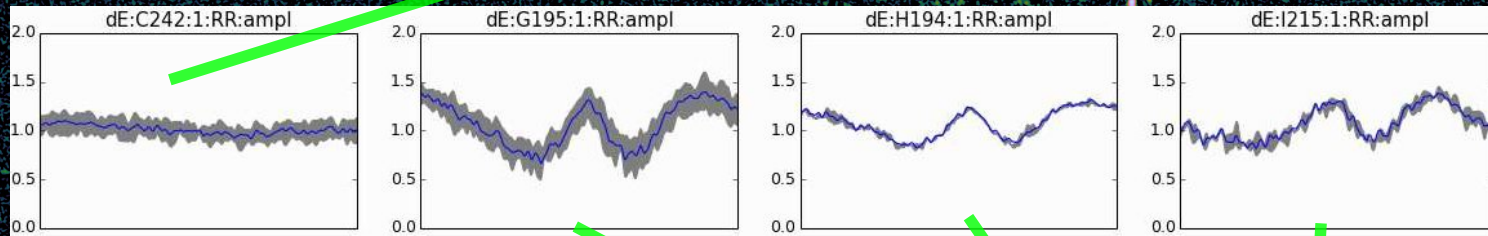
With PB model



With PB + diffgains – still needed!

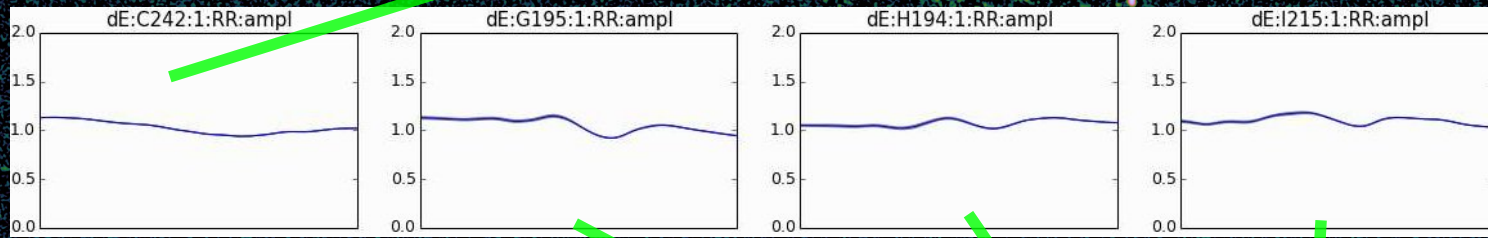


Example differential gain solutions for JVLA (2014 image)  
Dominated by primary beam rotation



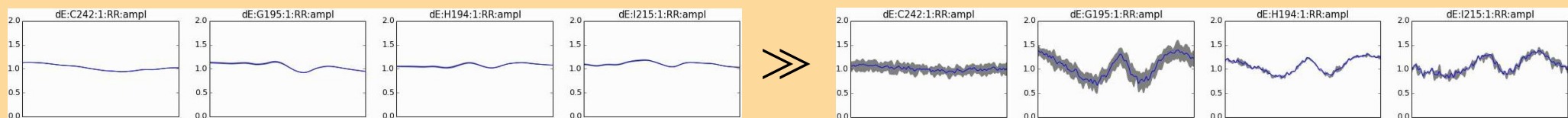


# Example differential gain solutions for JVLA (2015 image) Dominated by pointing error and PB pattern differences



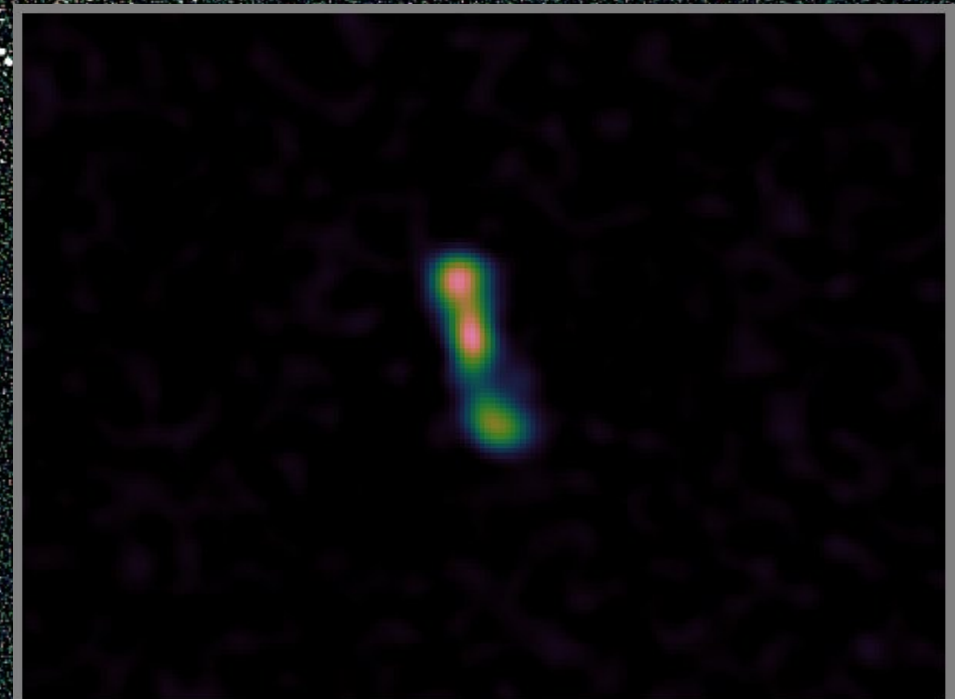
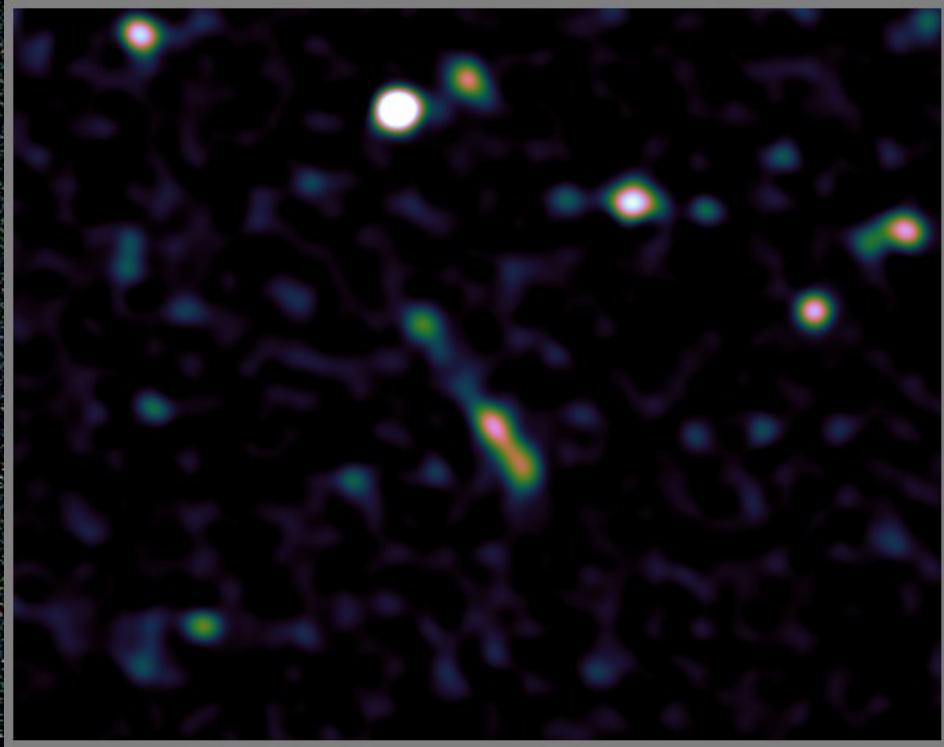
# Platonic Ideal Of Calibration

- Results of calibration:
  - Sky model, i.e. catalog of sky sources with their intrinsic properties (flux, spectrum, shape)
  - Best-fitting instrumental model
  - Noise-like residual map
- Differential gains: smooth and close to unity

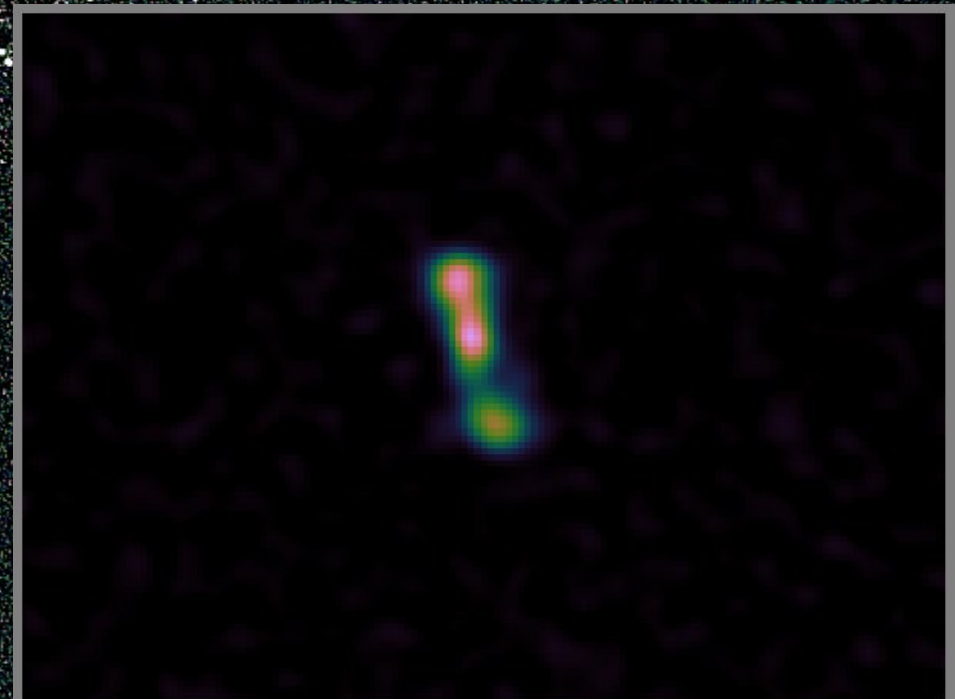
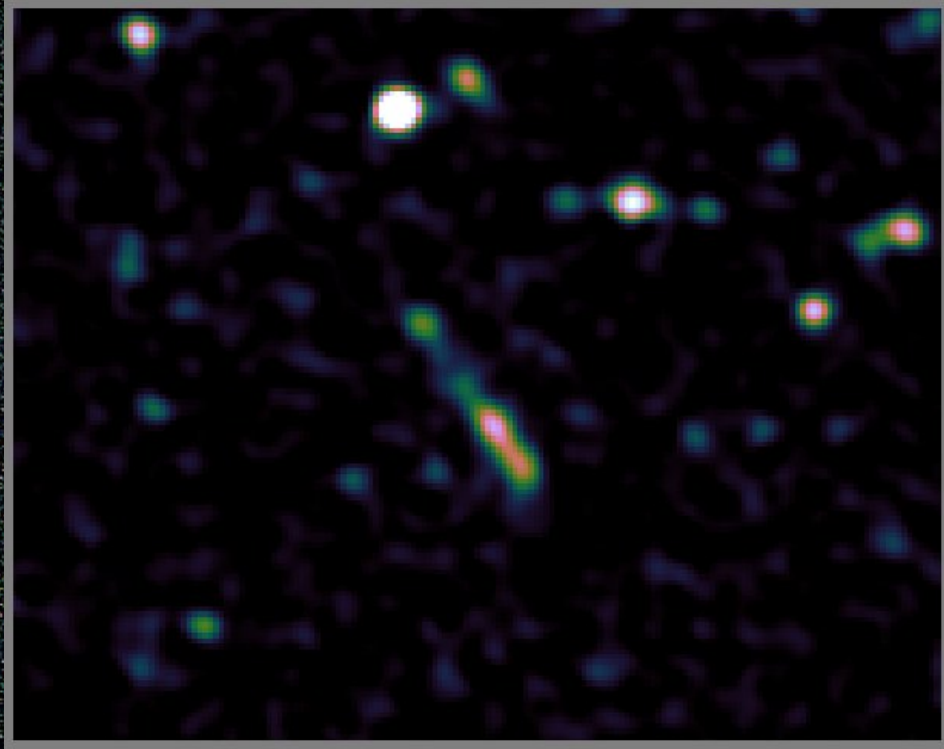


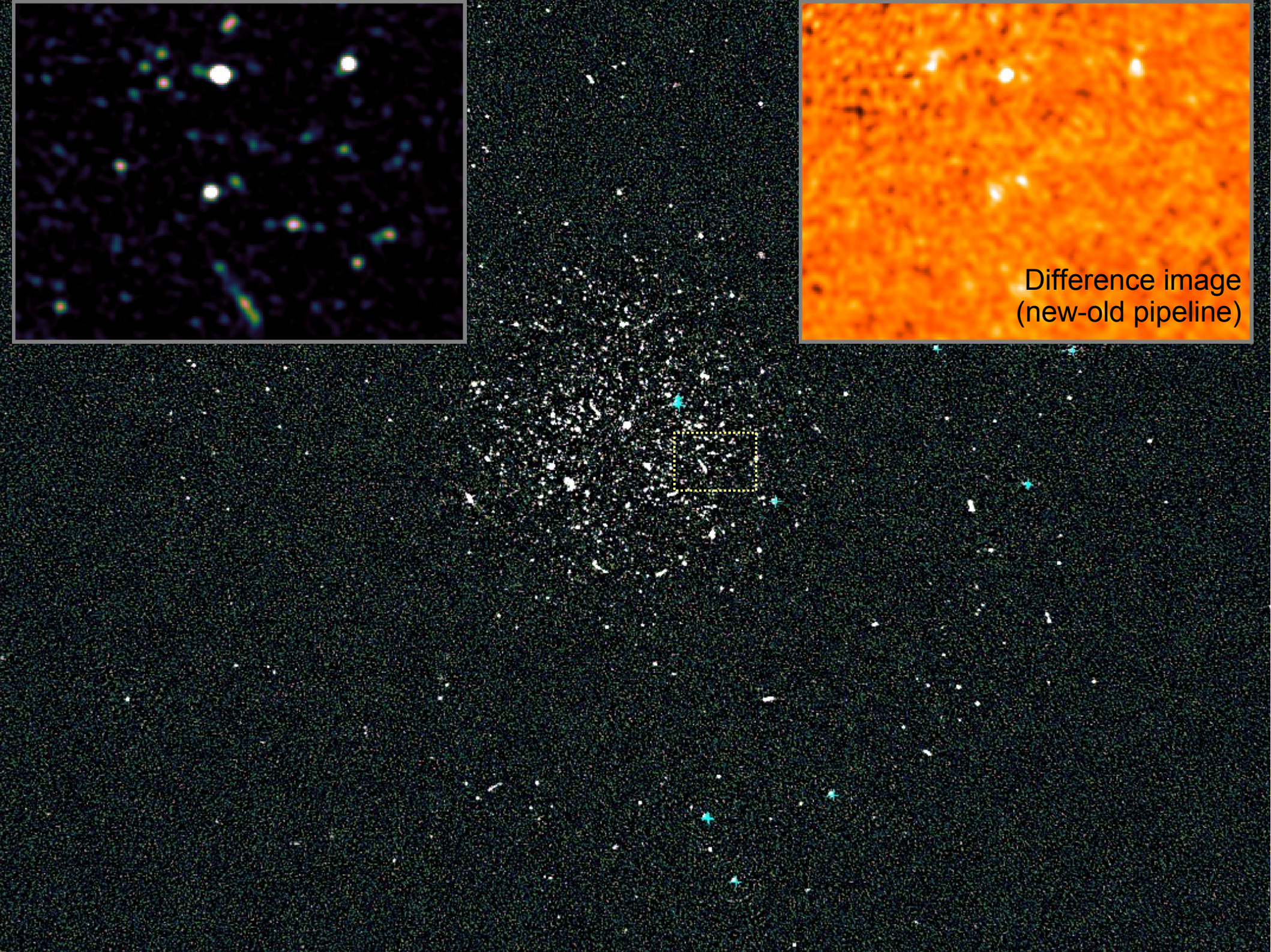
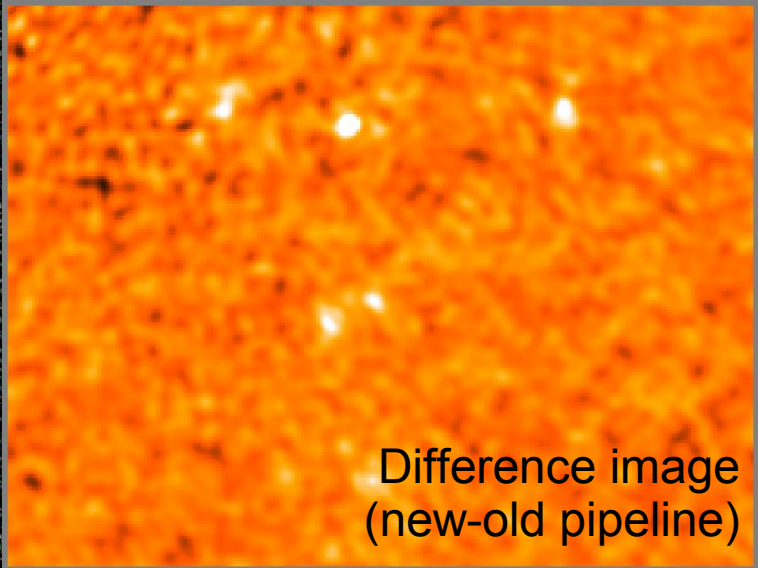
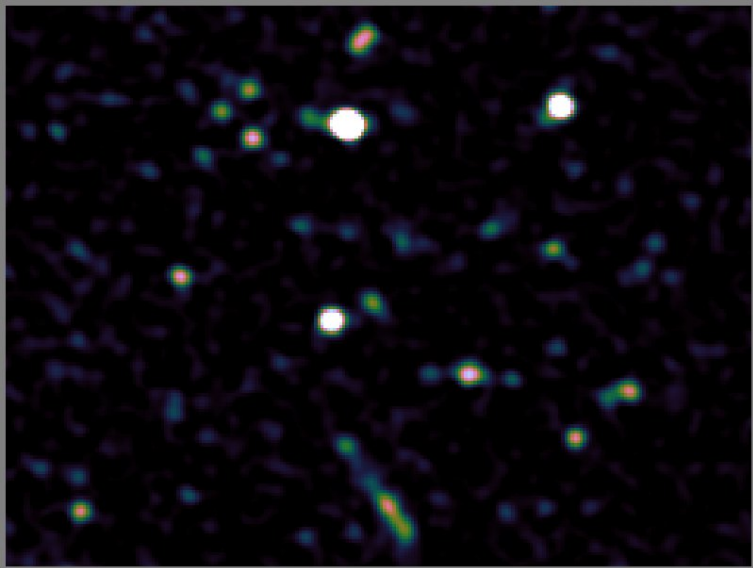
- Fewer degrees of freedom
- Consequently, less source suppression

192 MHz band,  
old pipeline (dE only)



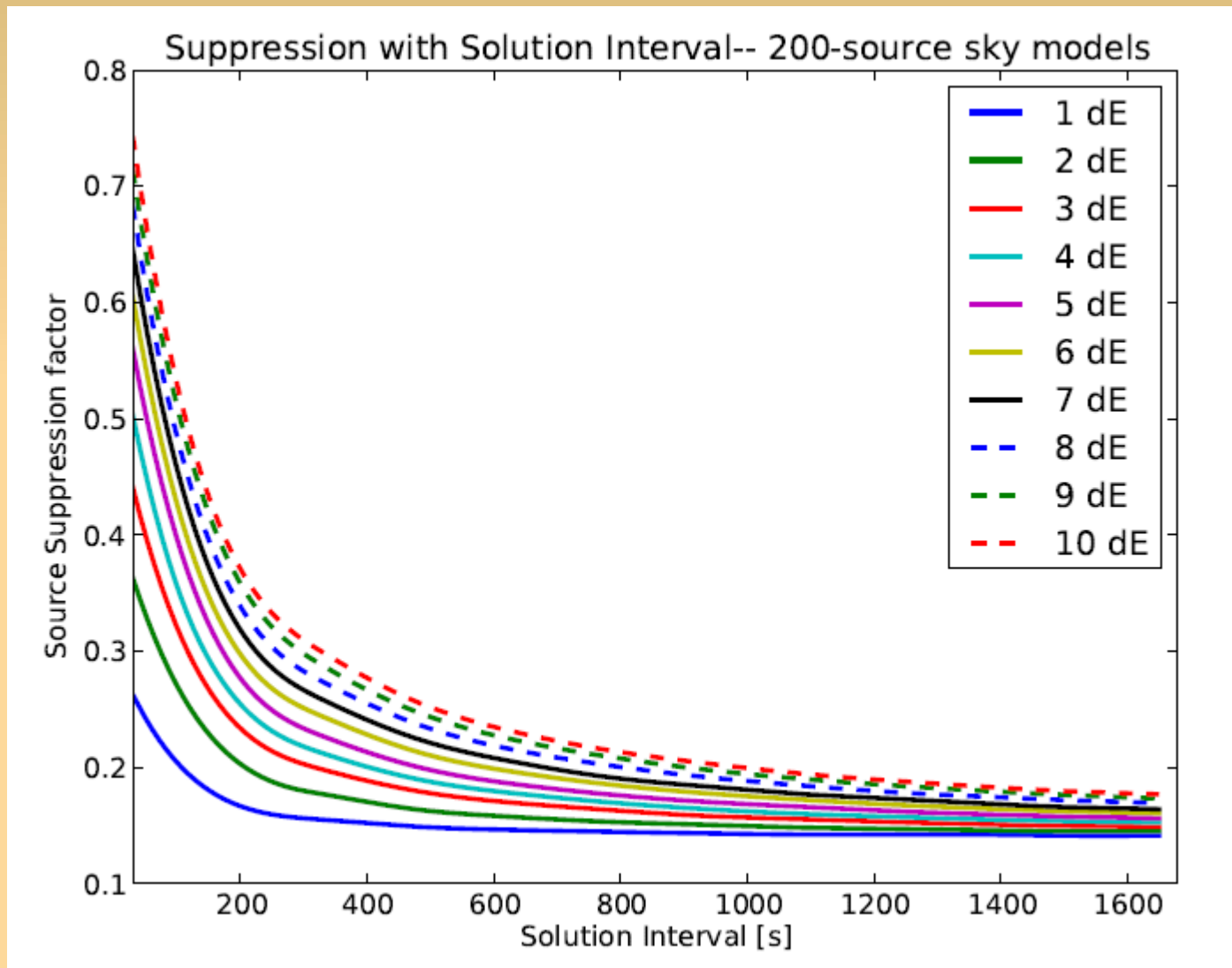
192 MHz band,  
new pipeline (PB+dE)





# Source Suppresion

(Nunhokee 2015, MSc thesis)



# Diffgains Are Dangerous

- Clean maps are addictive...
- ...but diffgains are dangerous and should be used sparingly
- 5M map has a **factor of ~60 fewer** degrees of freedom in the diffgains (compared to 2014 3M map)
- How many do you need?
  - Enough to meet your science goals
  - Simulations can help (ask Sphe)

DR ~ 100 000

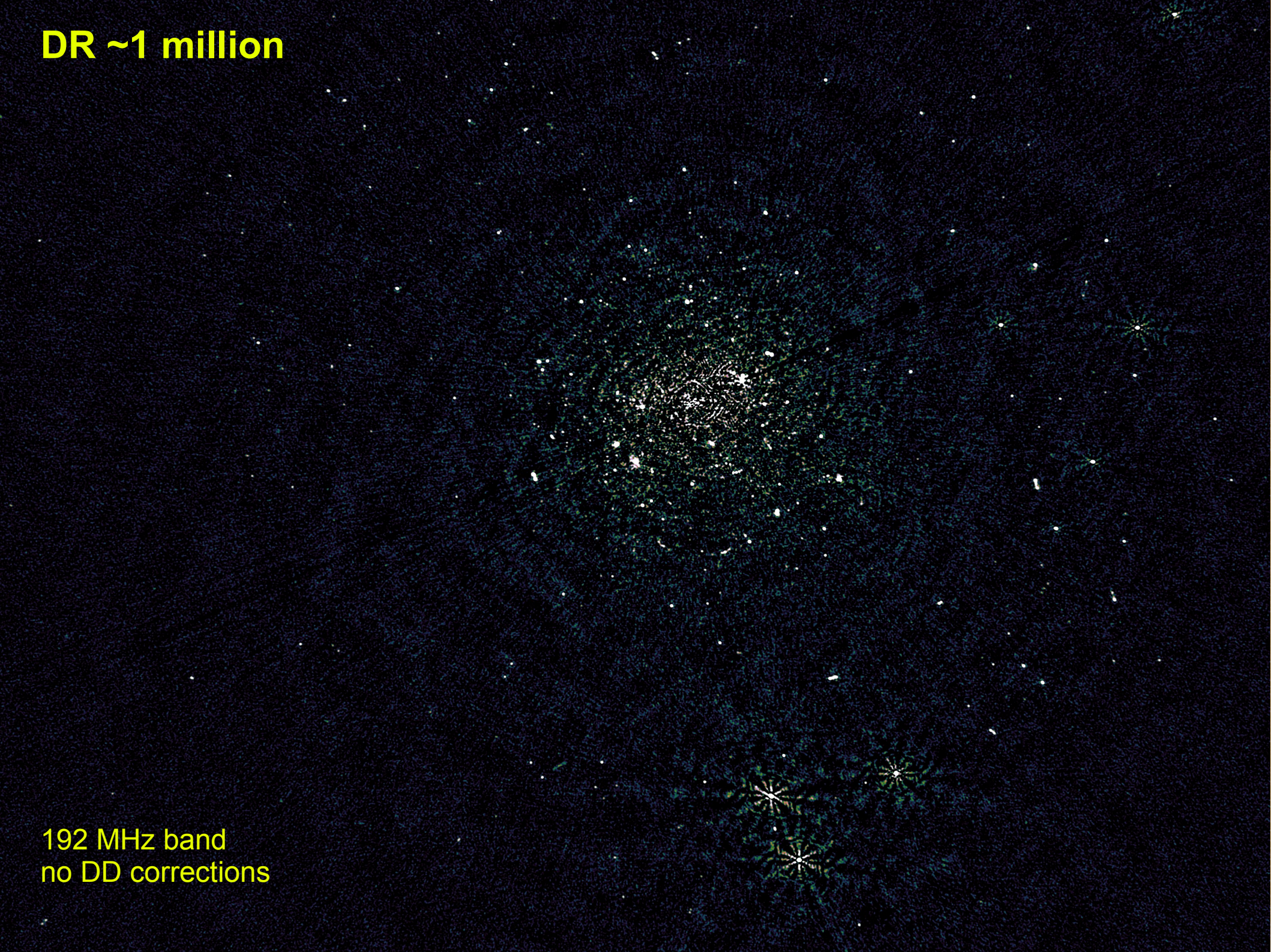
192 MHz band  
no DD corrections





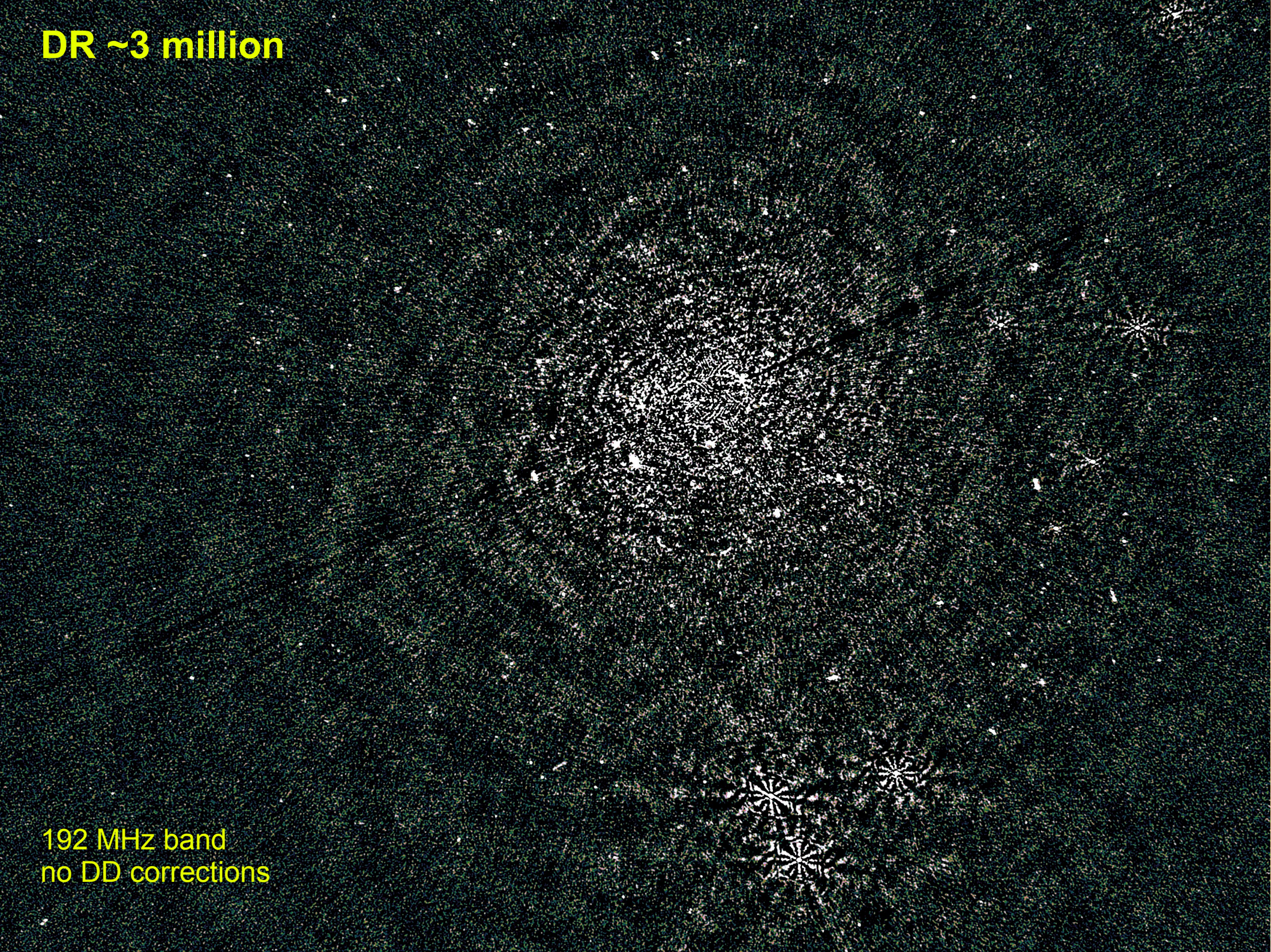
DR ~1 million

192 MHz band  
no DD corrections



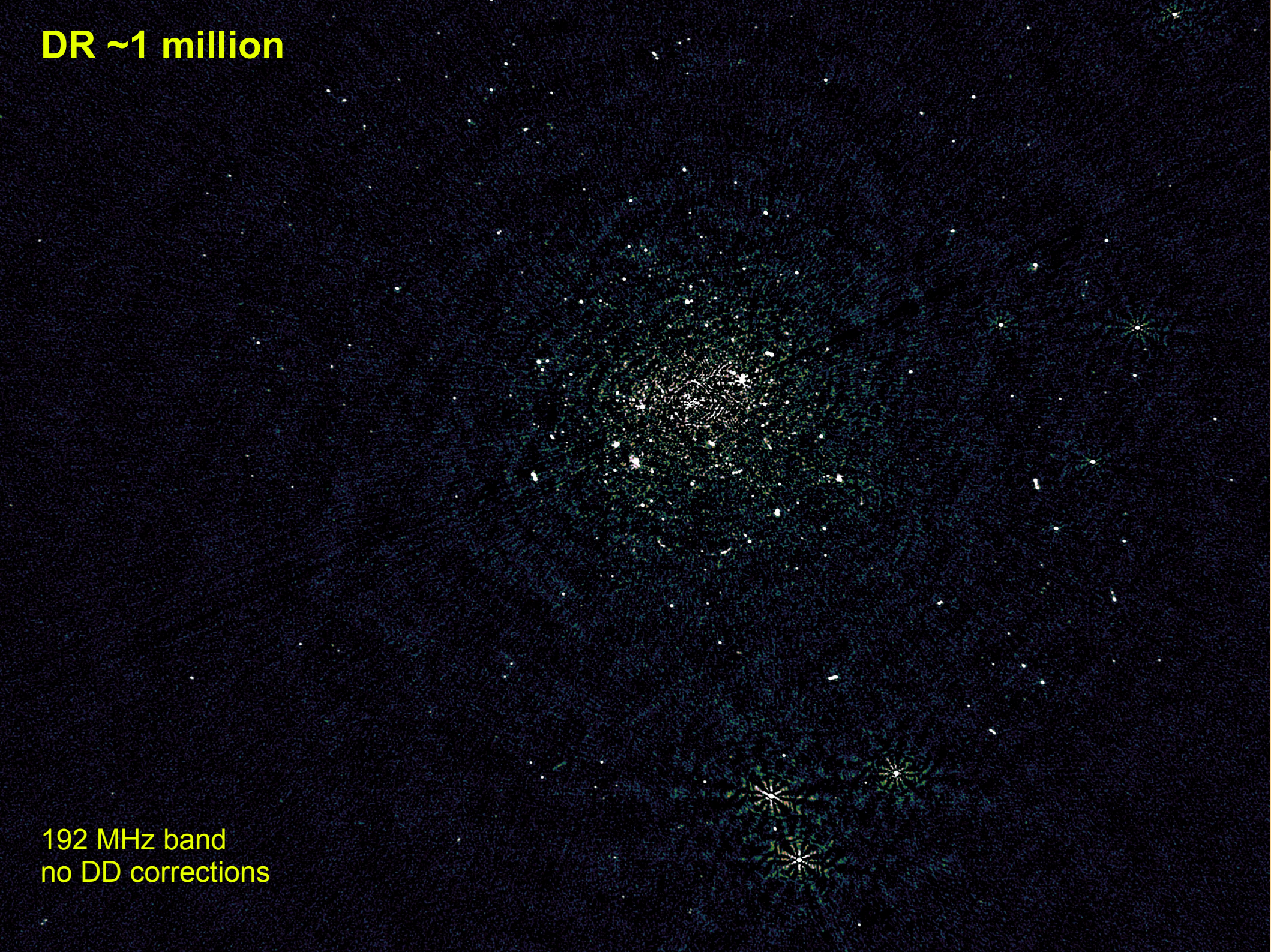
DR ~3 million

192 MHz band  
no DD corrections



DR ~1 million

192 MHz band  
no DD corrections



**DR ~1 million**

**192 MHz band  
primary beam corrected, no diffgains**



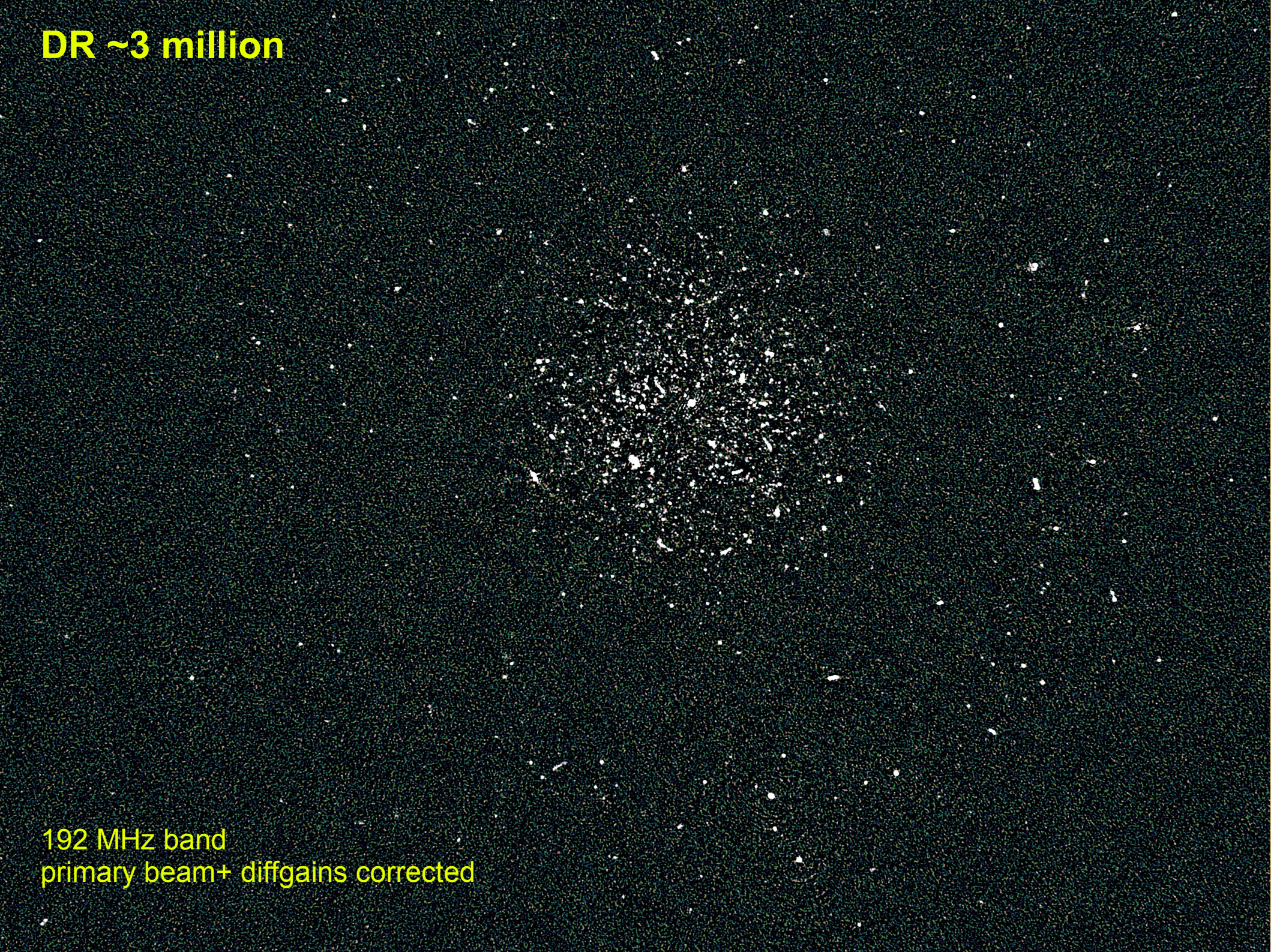
**DR ~3 million**

**192 MHz band  
primary beam corrected, no diffgains**



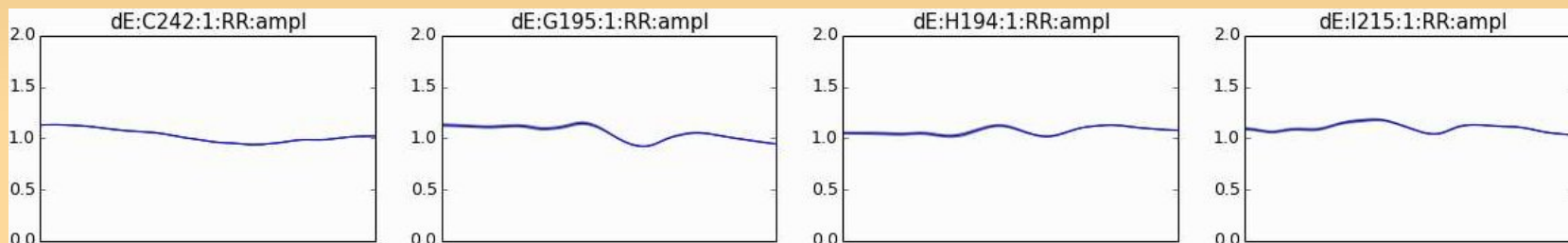
DR ~3 million

192 MHz band  
primary beam+ diffgains corrected



# Onwards And Upwards

- Remember: diffgain solutions represent the remaining instrumental effects that we haven't dealt with



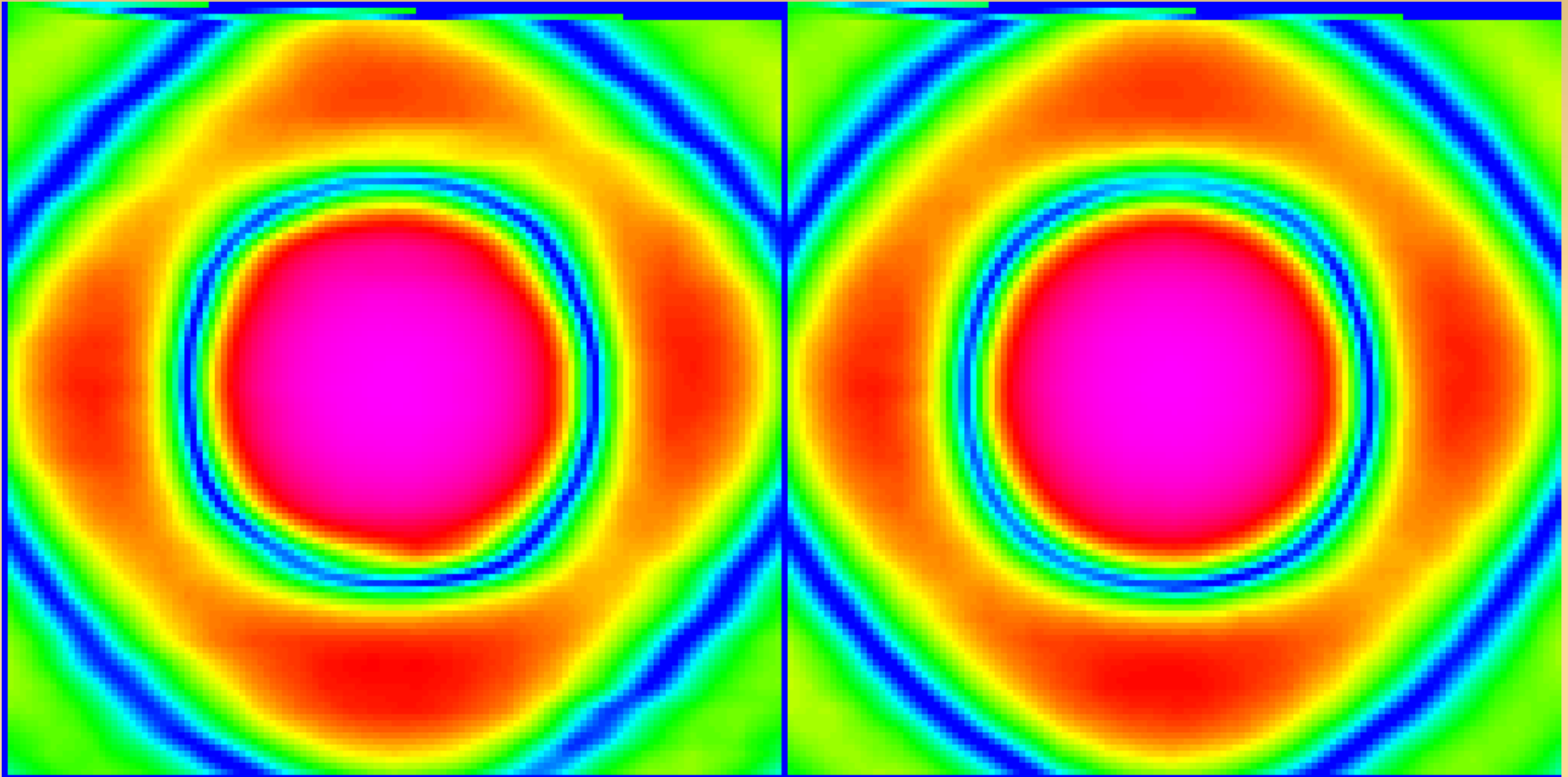
- What don't we deal with yet?
  - Differences w.r.t. model
  - Differences dish-to-dish
  - Pointing error

# Holography: Antennas 5 & 28, LL (1 to 2 GHz)

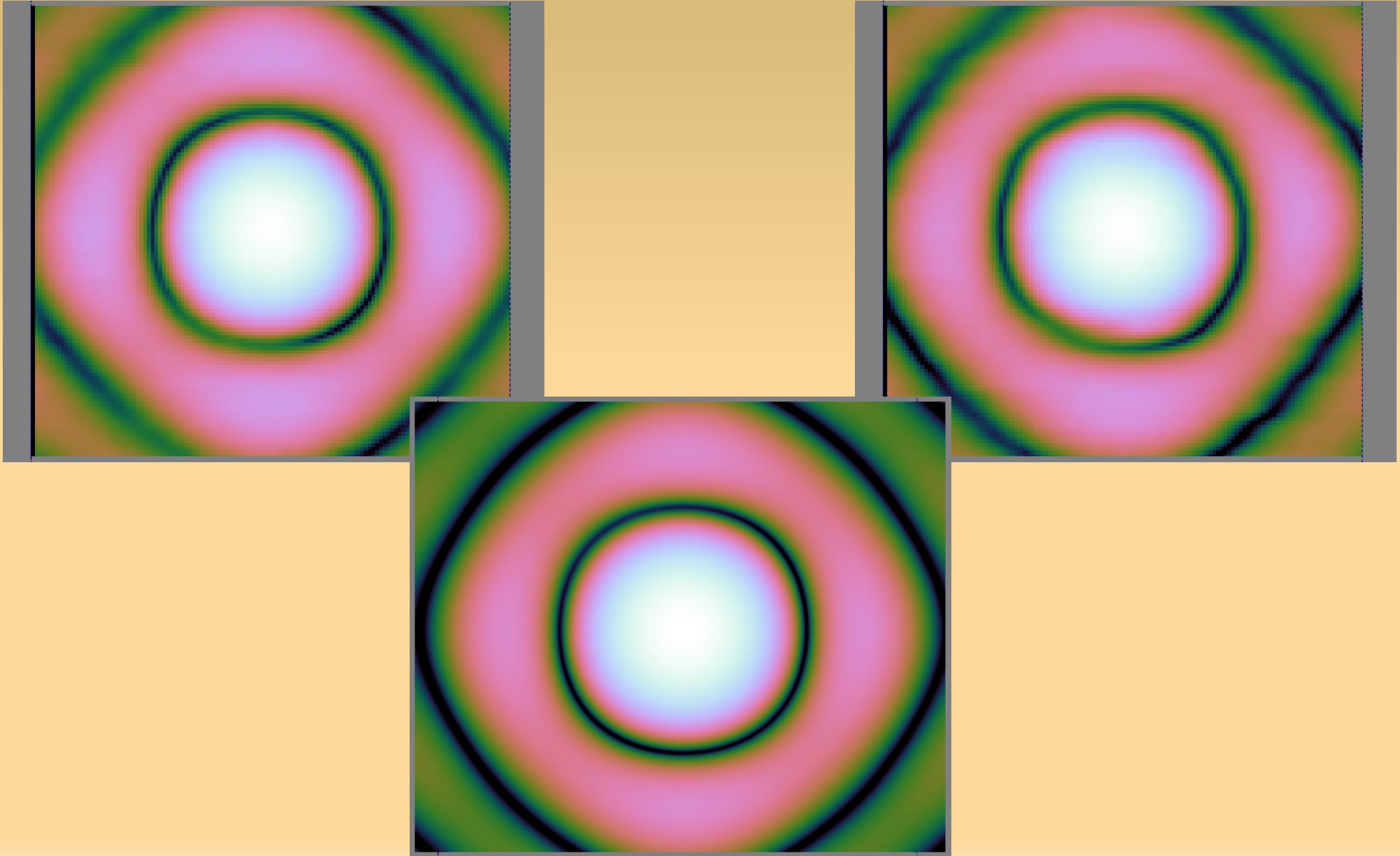




# Spot The Difference



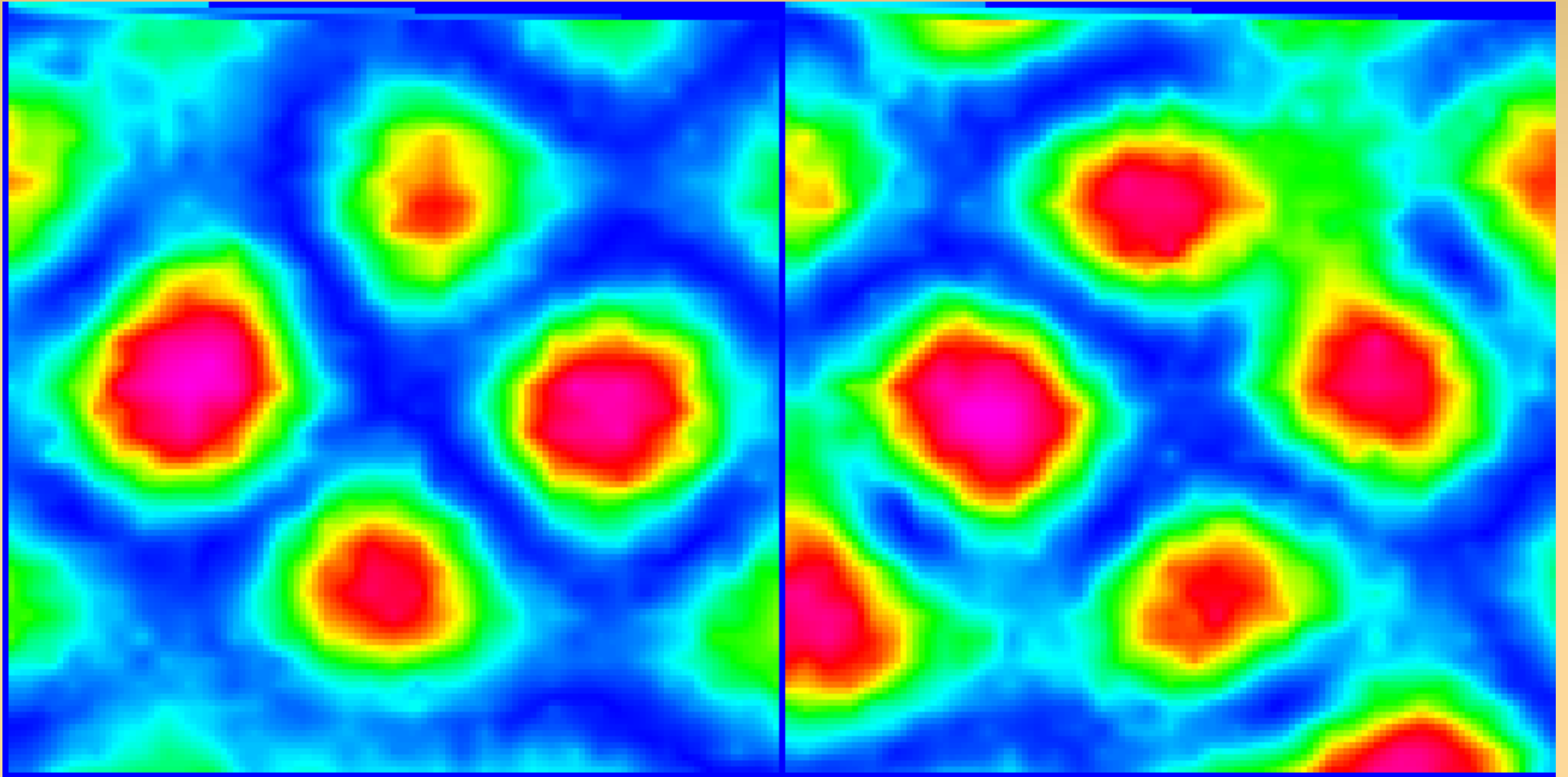
# Spot The Difference I



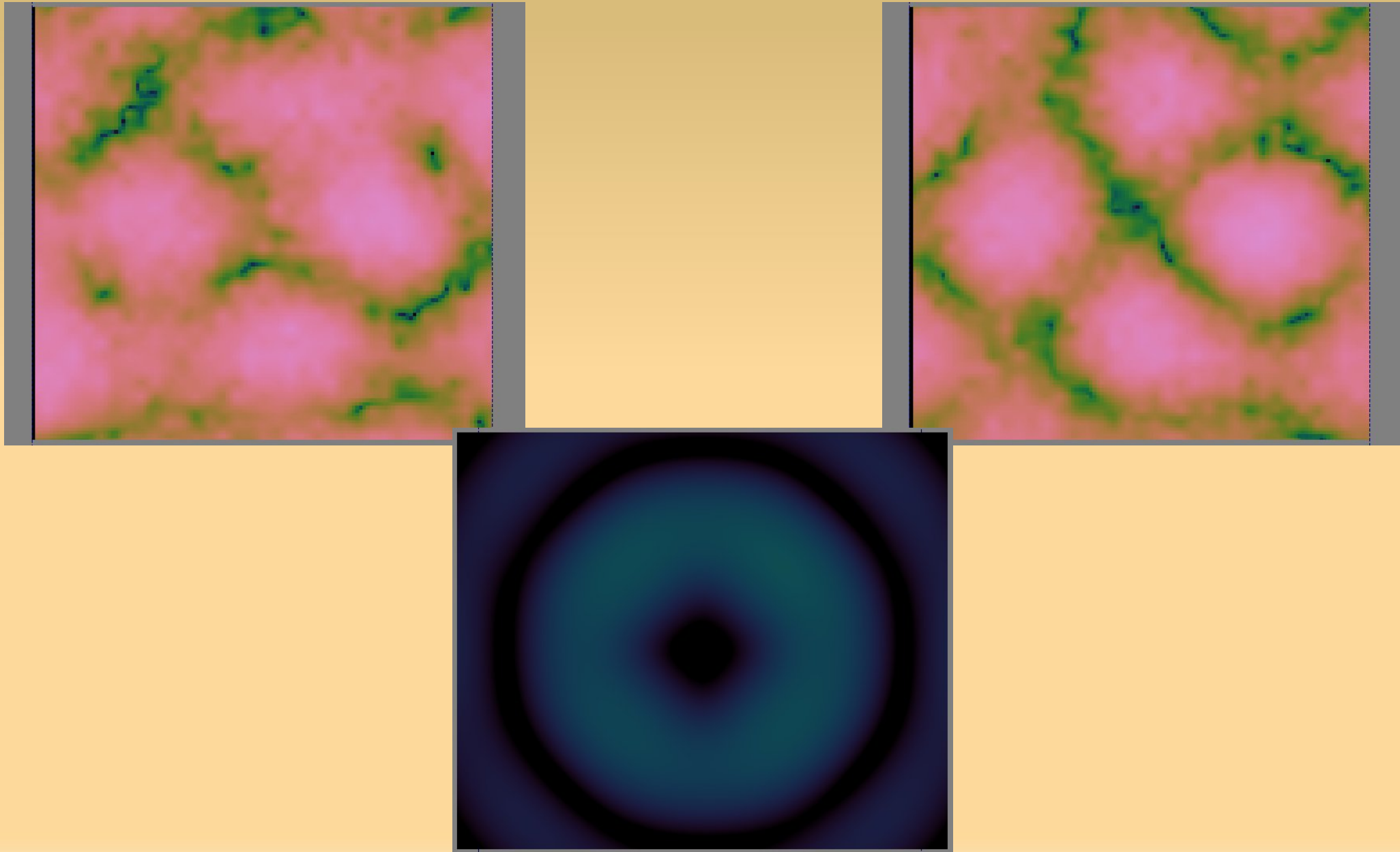
# Holography: Antennas 5 & 28, LR (1 to 2 GHz)



# Sport The Difference II



# Spot The Difference II





*"A highbrow is the kind of person who looks at a sausage  
and thinks of Picasso."  
- Alan Patrick Herbert, MP (Oxford)*

