Unveiling spectral view of the M87 radio jet

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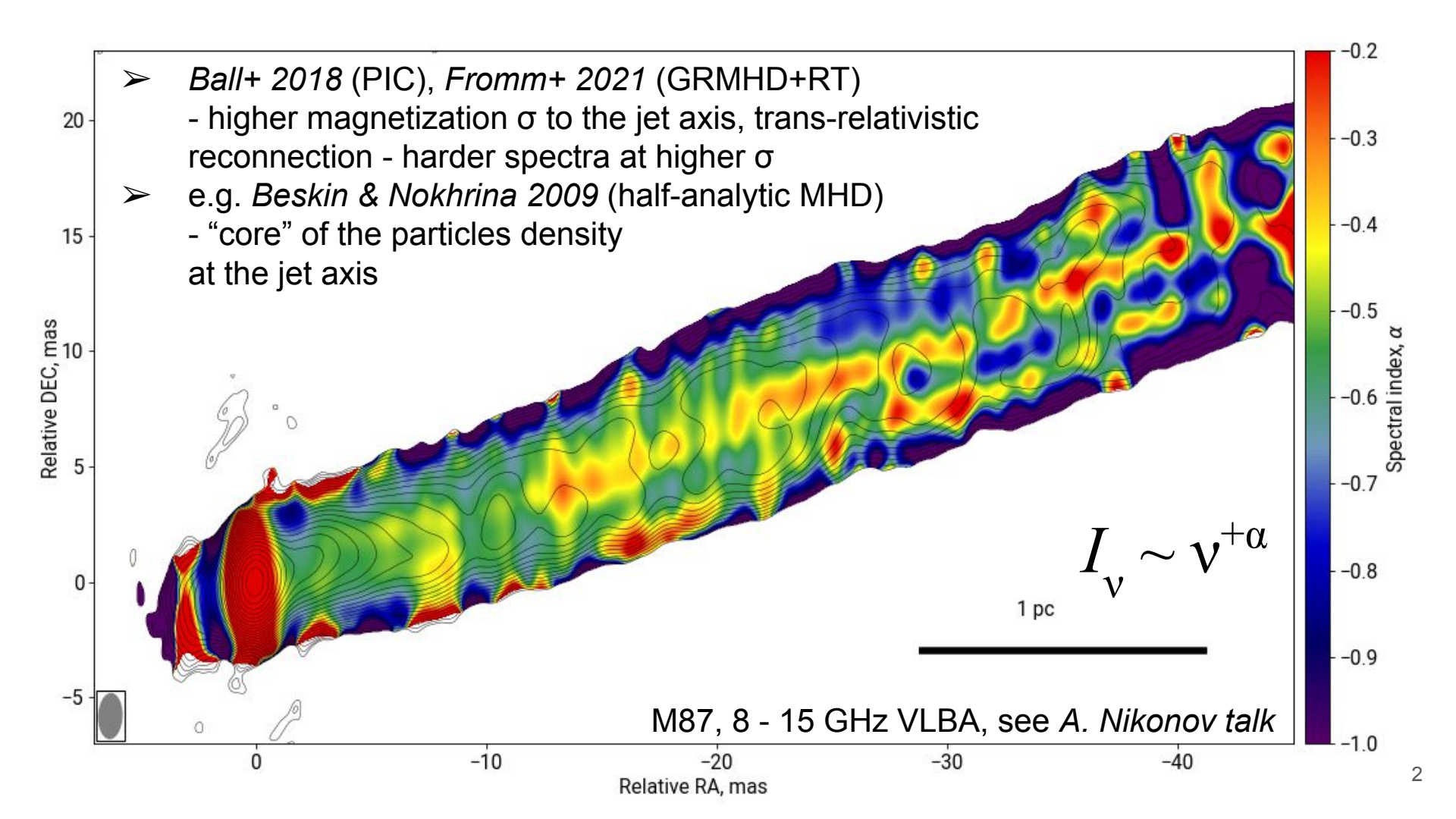
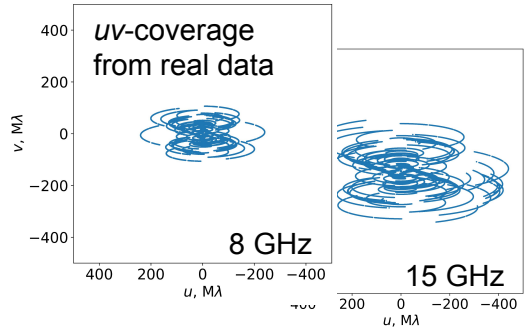
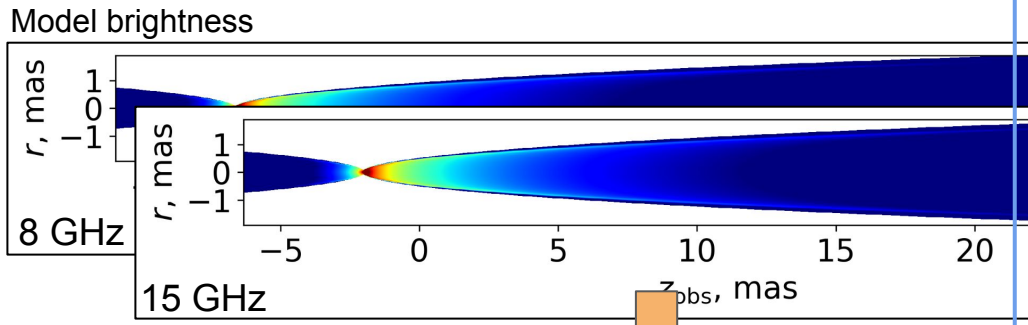
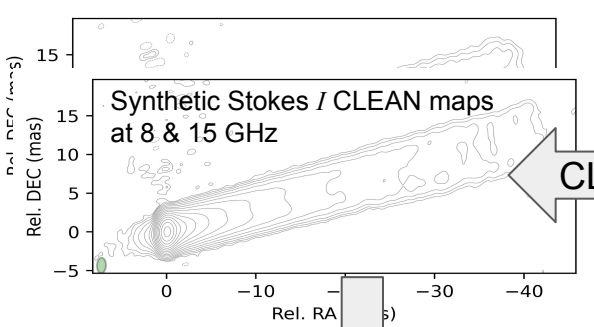

➢ *Ball+ 2018* (PIC), *Fromm+ 2021* (GRMHD+RT)
- higher magnetization σ to the jet axis, trans-relativistic reconnection - harder spectra at higher σ
➢ e.g. *Beskin & Nokhrina 2009* (half-analytic MHD)
- “core” of the particles density at the jet axis
$I_\nu \sim \nu^{+\alpha}$
1 pc
M87, 8 - 15 GHz VLBA, see *A. Nikonov talk*
Relative DEC, mas
Relative RA, mas
Spectral index, α
20
15
10
5
0
−5
0
−10
−20
−30
−40
−0.2
−0.3
−0.4
−0.5
−0.6
−0.7
−0.8
−0.9
−1.0



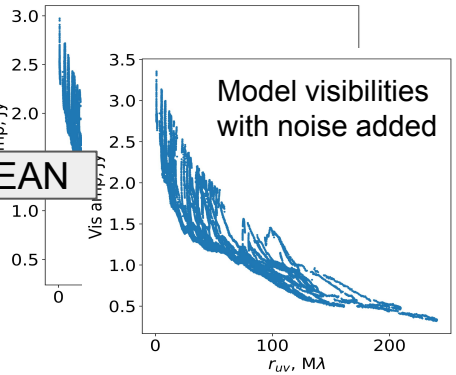
FT

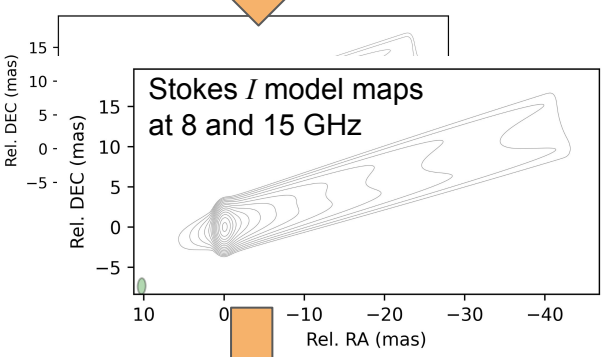


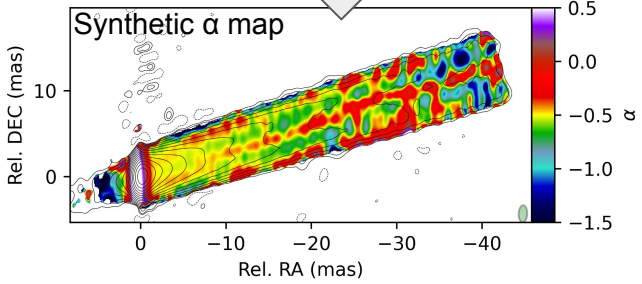
Beam convolution



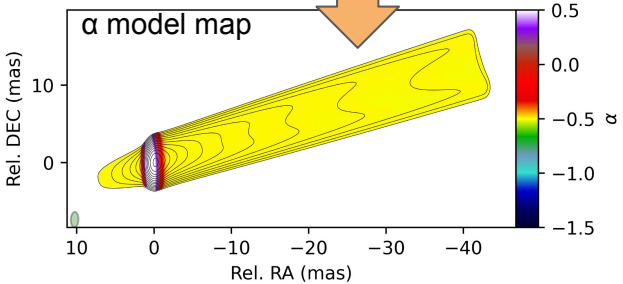
CLEAN

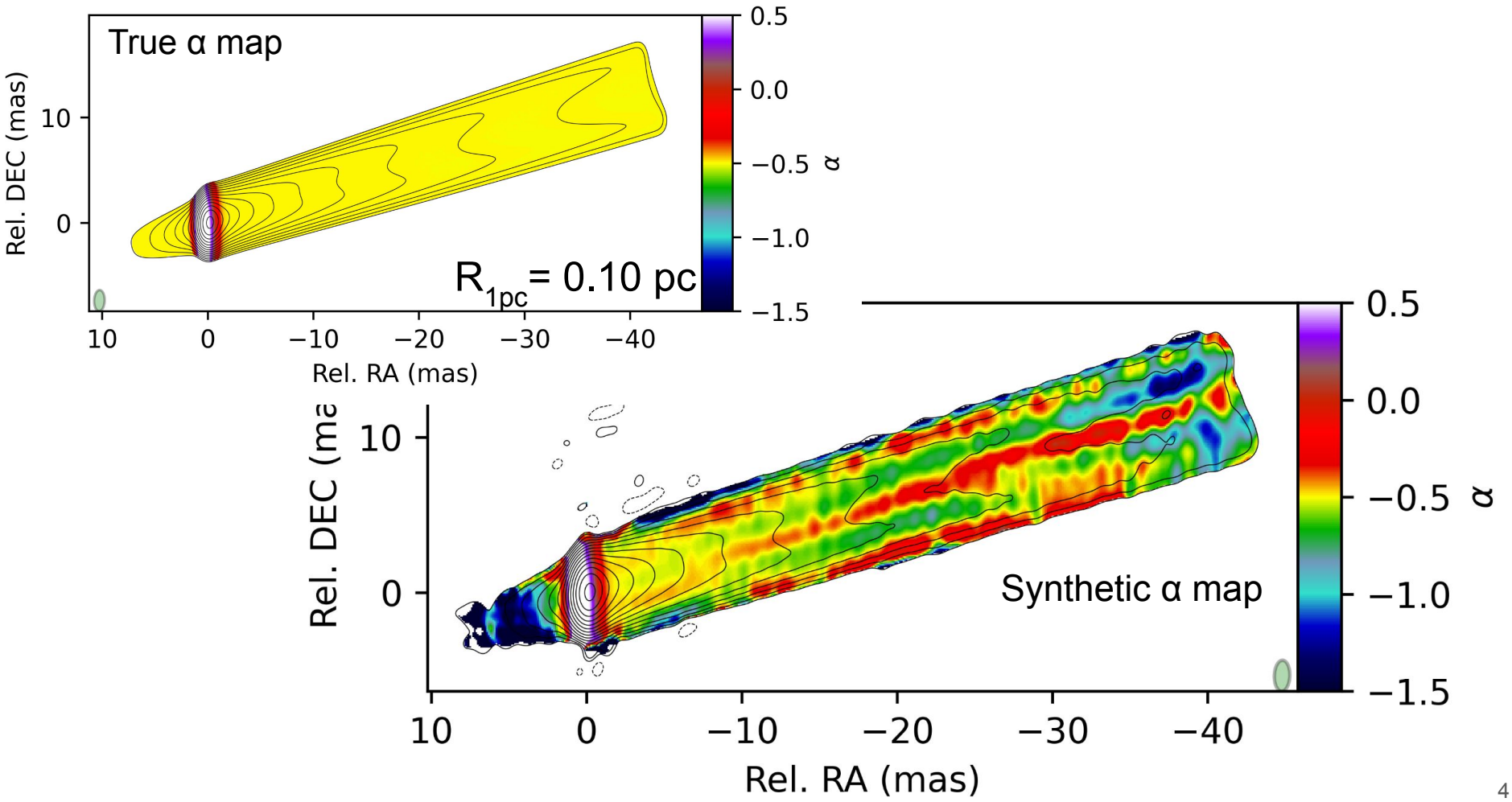






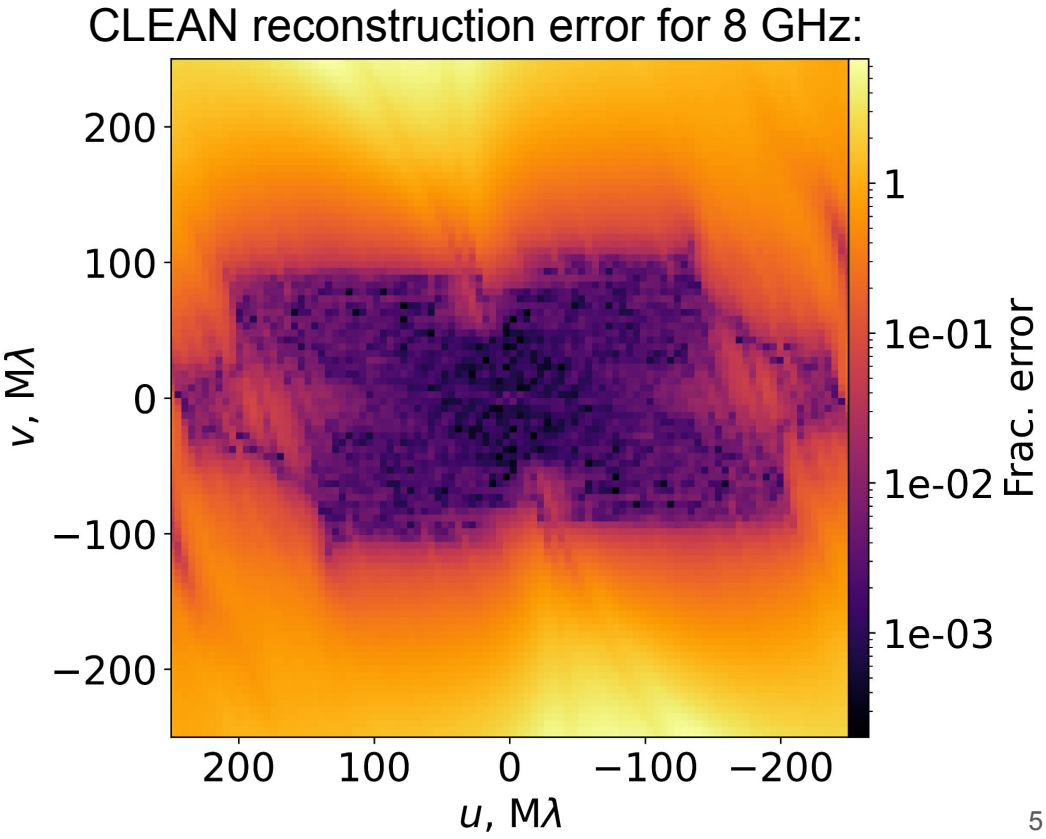
Compare




True α map
R_{1pc} = 0.10 pc
Rel. DEC (mas)
Rel. RA (mas)
α
Synthetic α map

Bias origin: I_{15GHz} or I_{8GHz}?

- α ~ log(I_{15GHz} / I_{8GHz})
- It turns out that:
  Bias(α) ~ - Bias(I_{8GHz})
- CLEAN reconstruction error at 15 GHz is downweighted by the convolution with common beam of 8 GHz.
- Consistent with CLEAN reconstruction study by *Briggs 1995*.



Bias origin: $I_{15\mathrm{GHz}}$ or $I_{8\mathrm{GHz}}$?

- $\alpha \sim \log(I_{15\mathrm{GHz}} / I_{8\mathrm{GHz}})$
- It turns out that:
  $\mathrm{Bias}(\alpha) \sim -\ \mathrm{Bias}(I_{8\mathrm{GHz}})$
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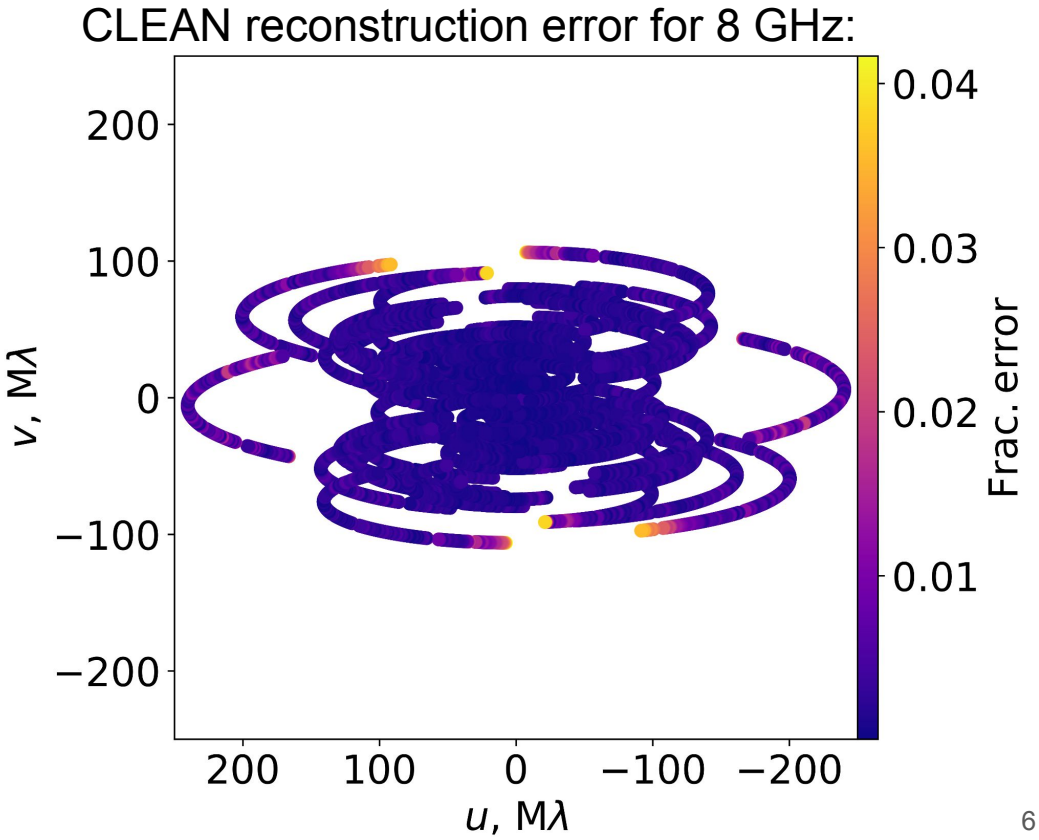
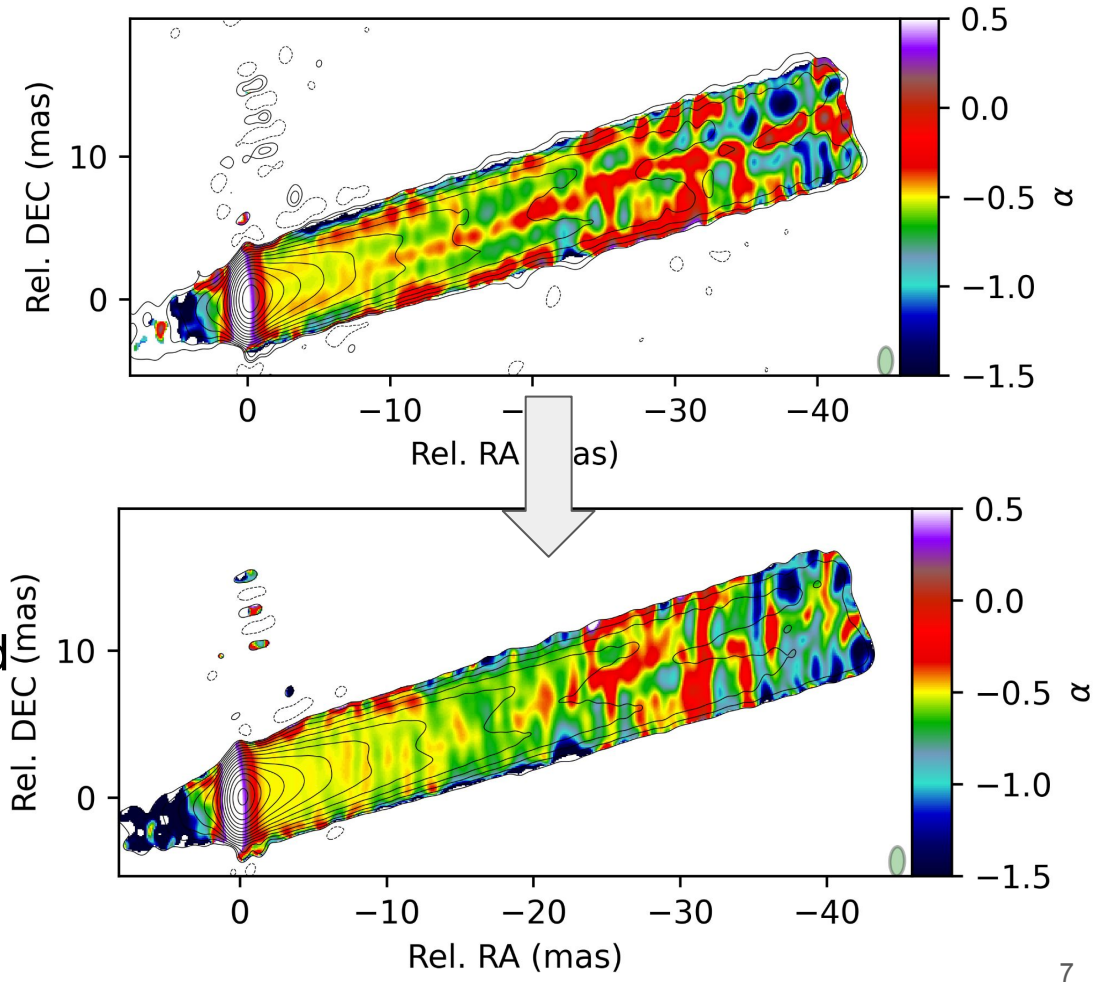


Bias correction

- I_{8GHz} is biased, while I_{15GHz}- not
- Can't correct I_{8GHz} directly
- But we can introduce the similar bias into I_{15GHz}! => α ~ log(I_{15GHz}/I_{8GHz}) would be unbiased



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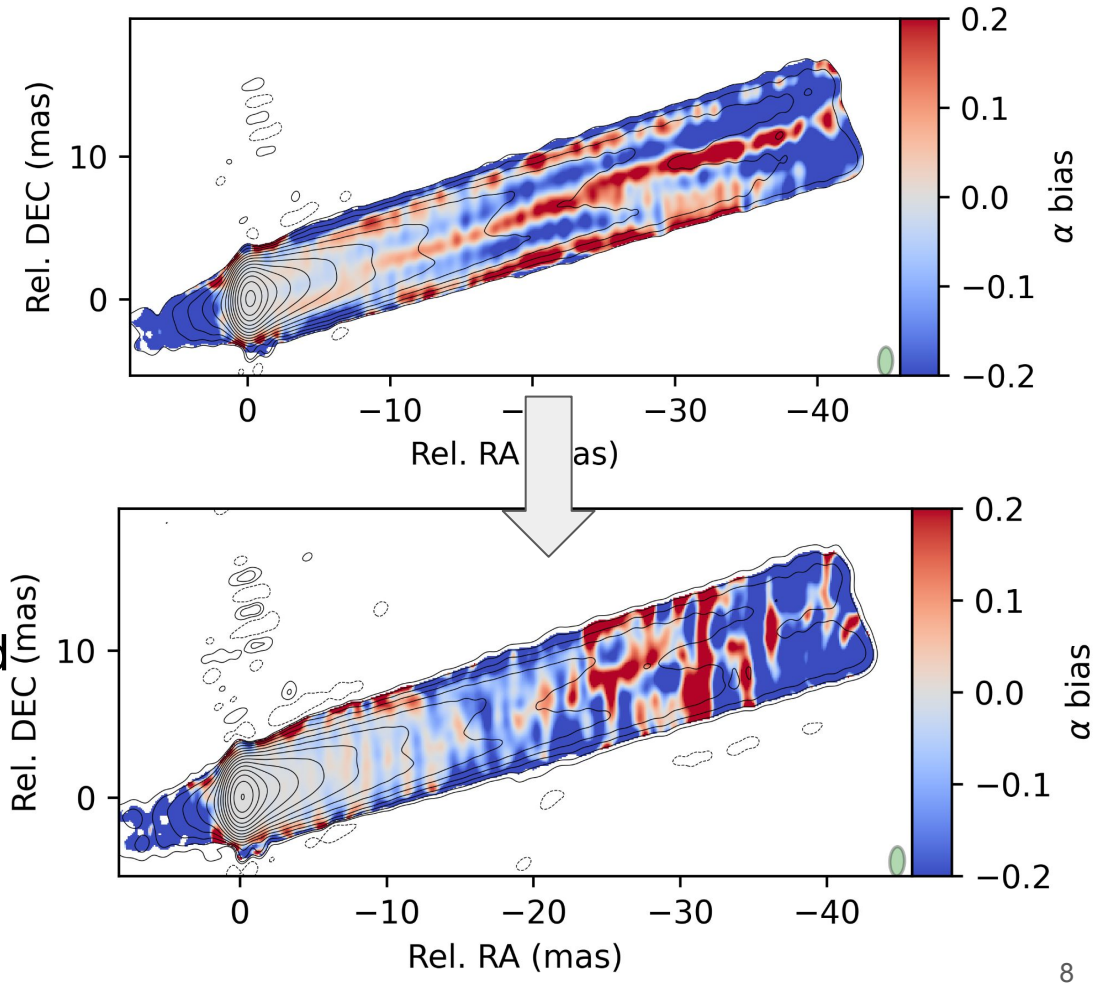
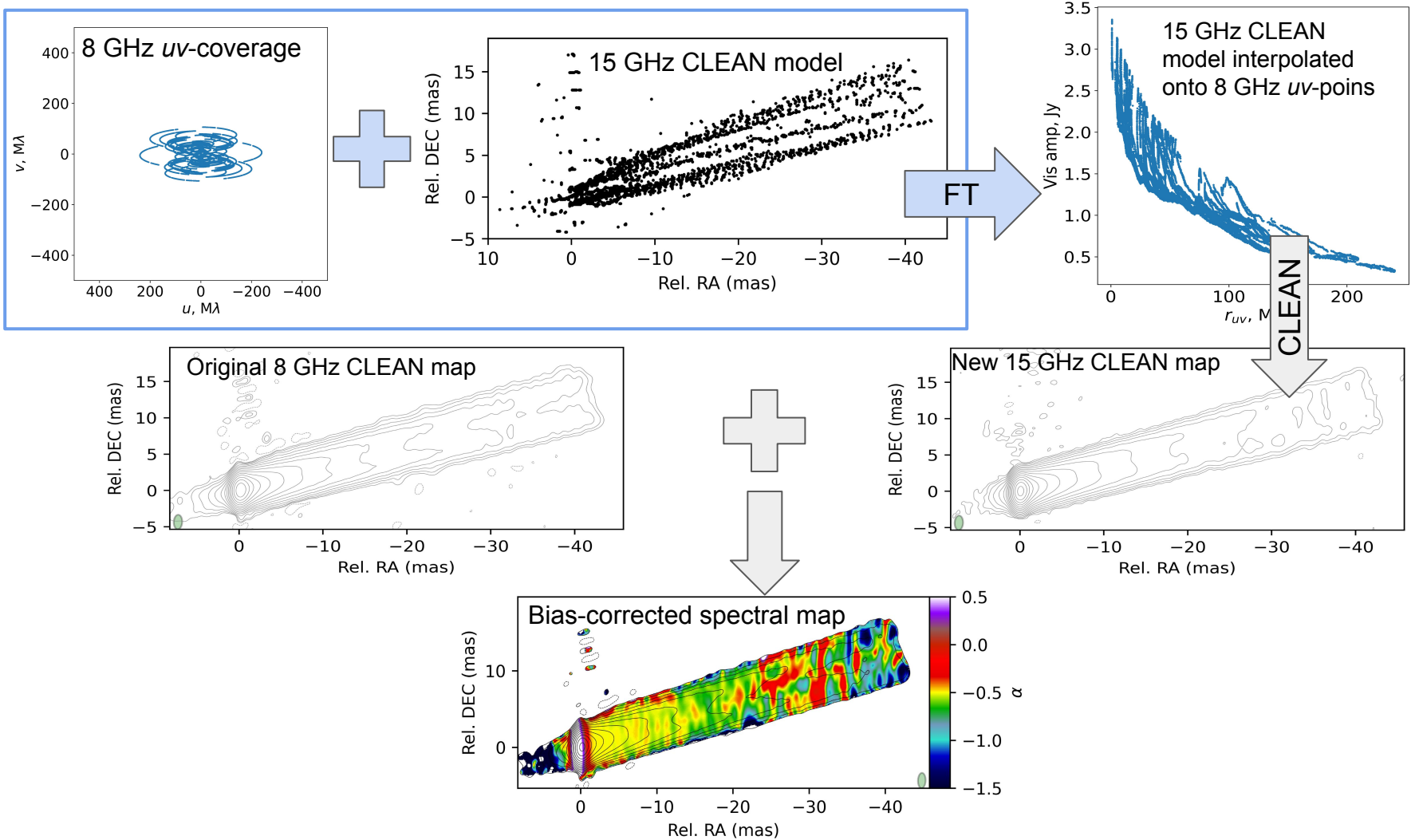
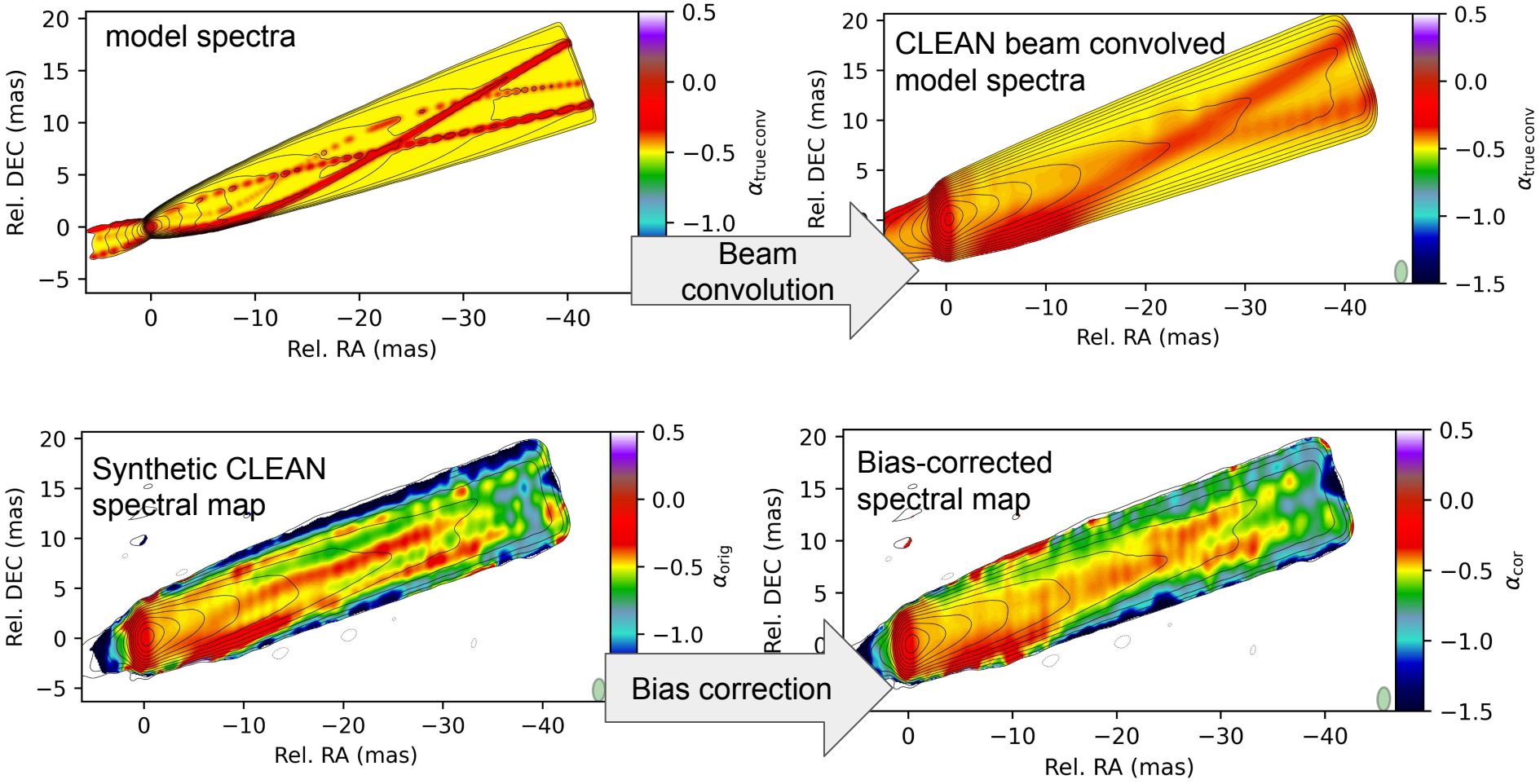
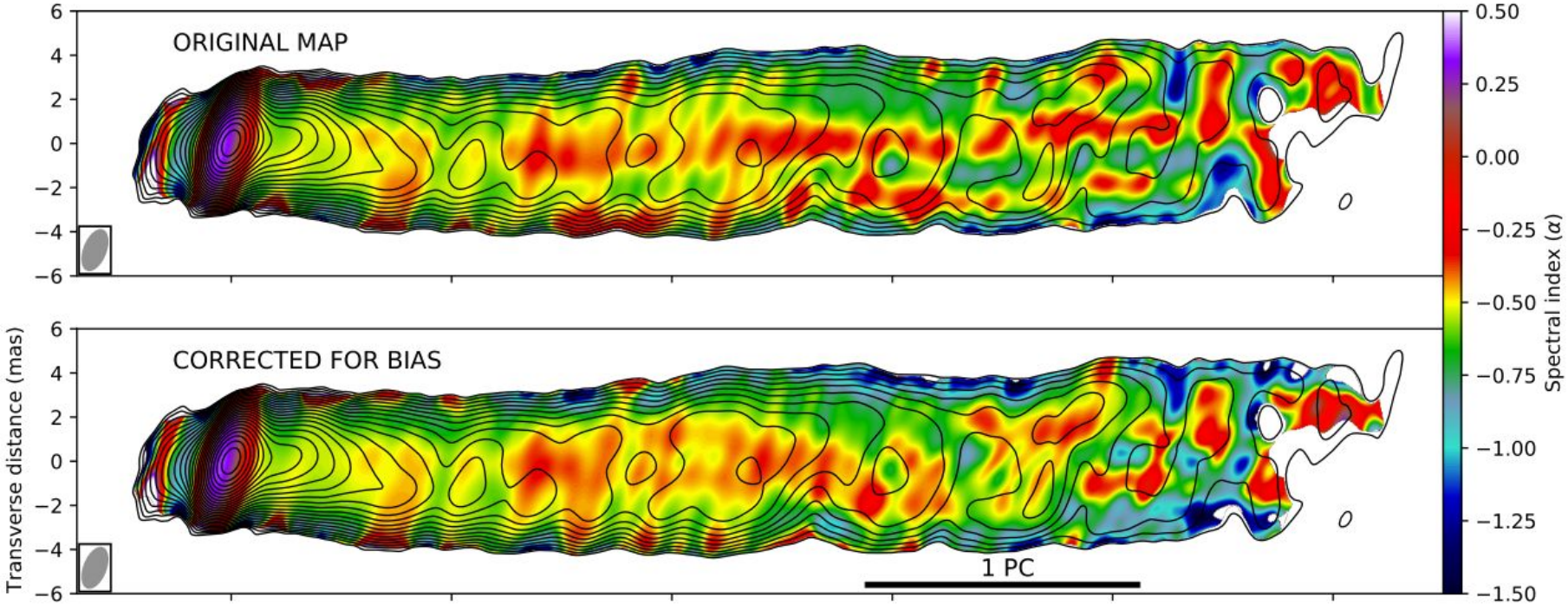



8 GHz uv-coverage
v, Mλ
u, Mλ
15 GHz CLEAN model
Rel. DEC (mas)
Rel. RA (mas)
FT
15 GHz CLEAN
model interpolated
onto 8 GHz uv-poins
Vis amp, Jy
CLEAN
Original 8 GHz CLEAN map
New 15 GHz CLEAN map
Bias-corrected spectral map
α


model spectra
CLEAN beam convolved
model spectra
Beam
convolution
Synthetic CLEAN
spectral map
Bias-corrected
spectral map
Bias correction
Rel. DEC (mas)
Rel. RA (mas)
$\alpha_{\rm true\,conv}$
$\alpha_{\rm orig}$
$\alpha_{\rm cor}$

see *A. Nikonov talk*

Bias correction for real 8-15 GHz data



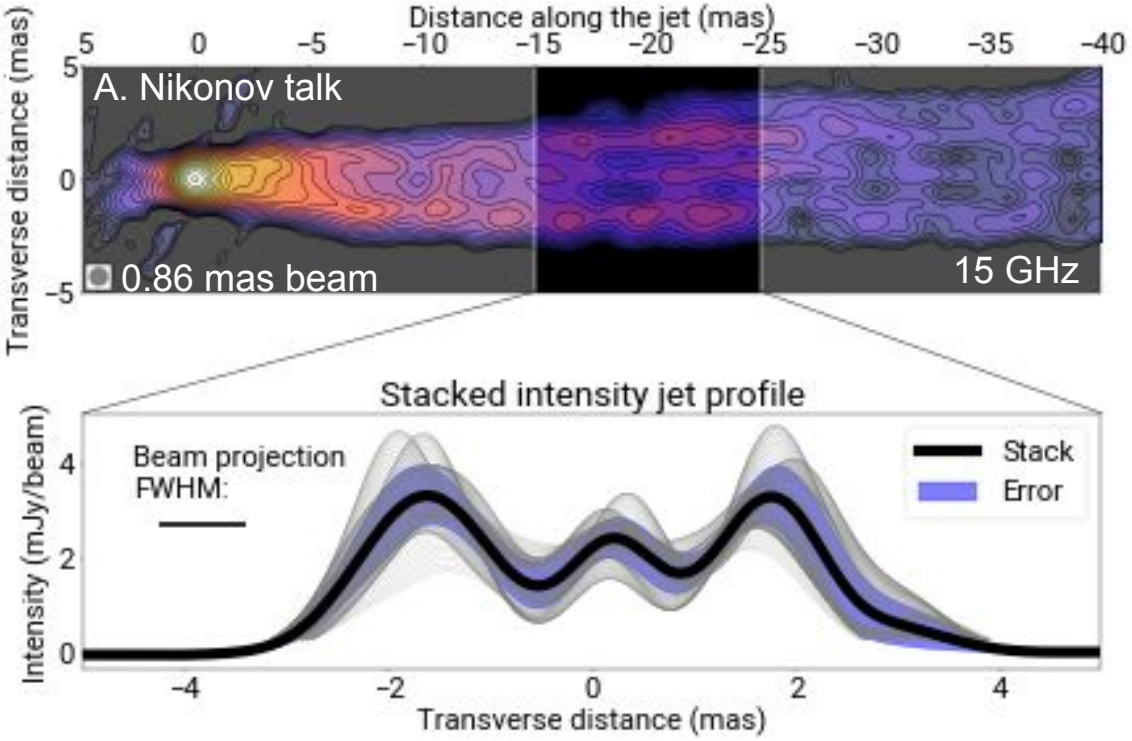
Inner ridgeline?

Observed earlier:

- *Hada 2016*, 15 GHz, VLBA+Y1
- *Asada+ 2016*, 1.4 - 5 GHz, VSOP
- *Kim+ 2018*, 86 GHz, GMVA

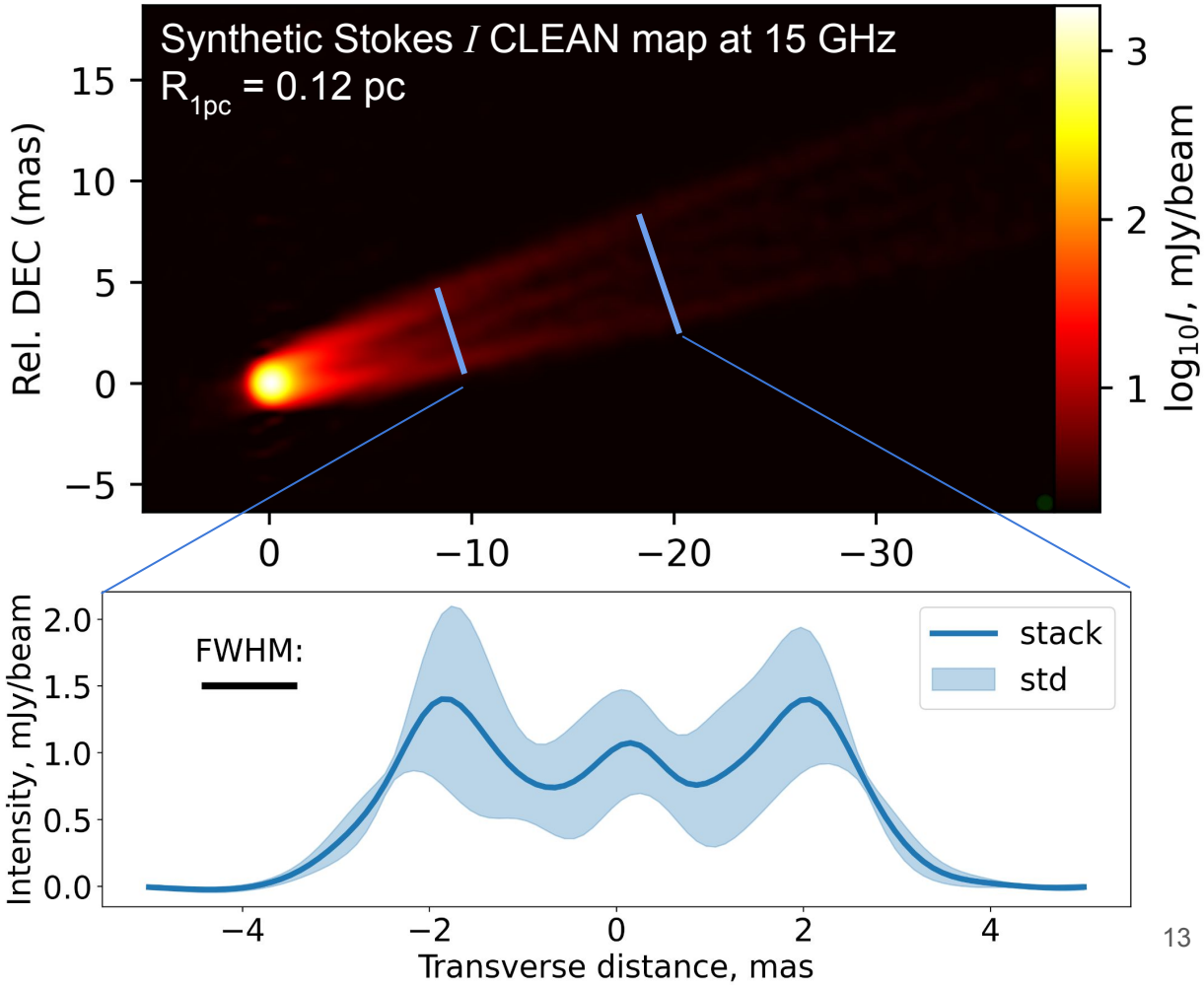
Possible explanations:

- synchro cooling or Doppler de-boosting? (*Asada+ 2016*)
- EM drift velocity (*Ogihara+ 2019*)



Inner ridgeline?

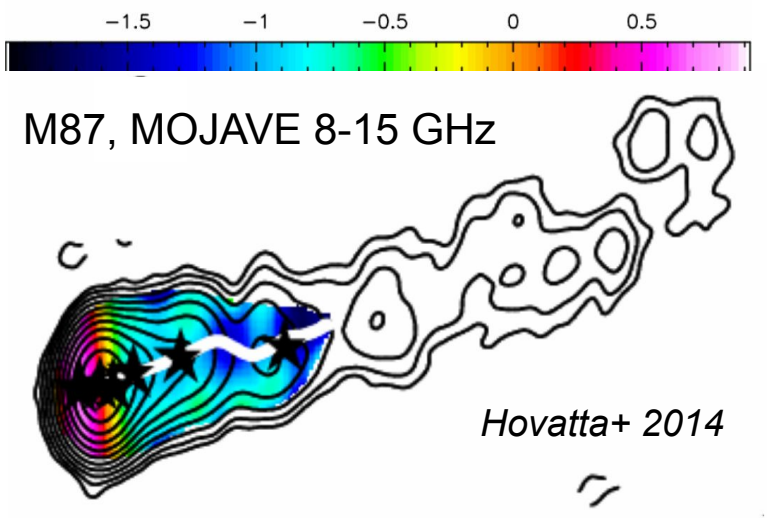
- Apparent in the CLEAN image of the intrinsically edge brightened model
- Increases with smaller convolving beams



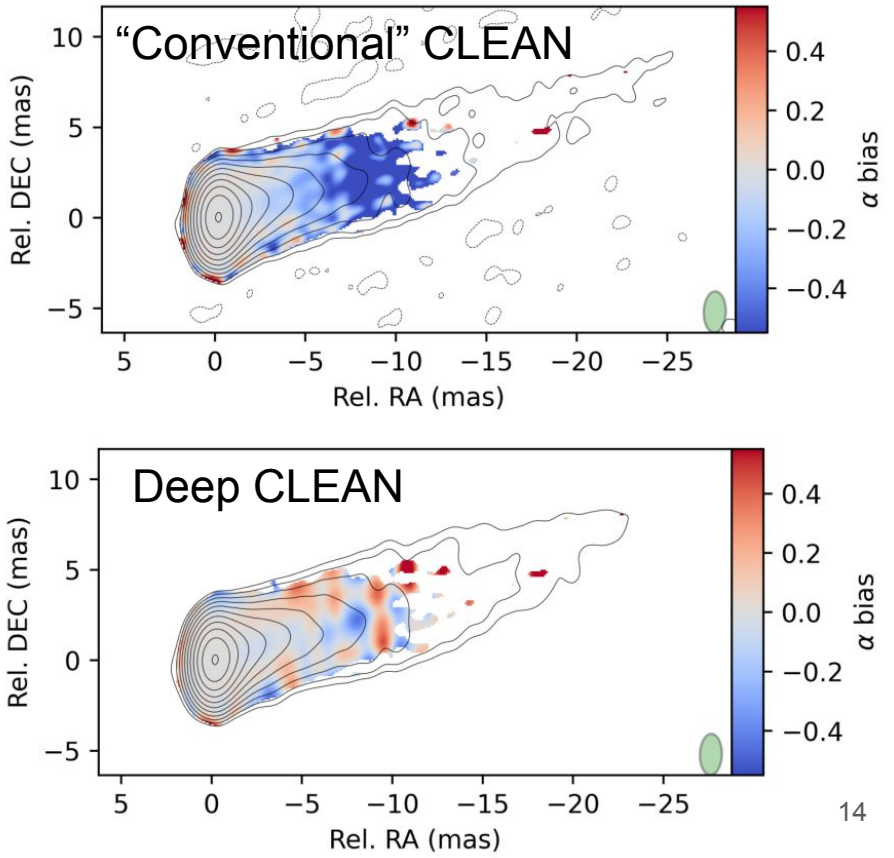
Spectral steepening along a jet?

Pushkarev & Kovalev 2012: 2-8 GHz,
370 sources, median steepening $\Delta\alpha = 0.05$ mas^{-1}

Hovatta+ 2014: 4 freqs. at 8-15 GHz,
191 sources, median $\Delta\alpha_{jet} = 0.4$-0.5

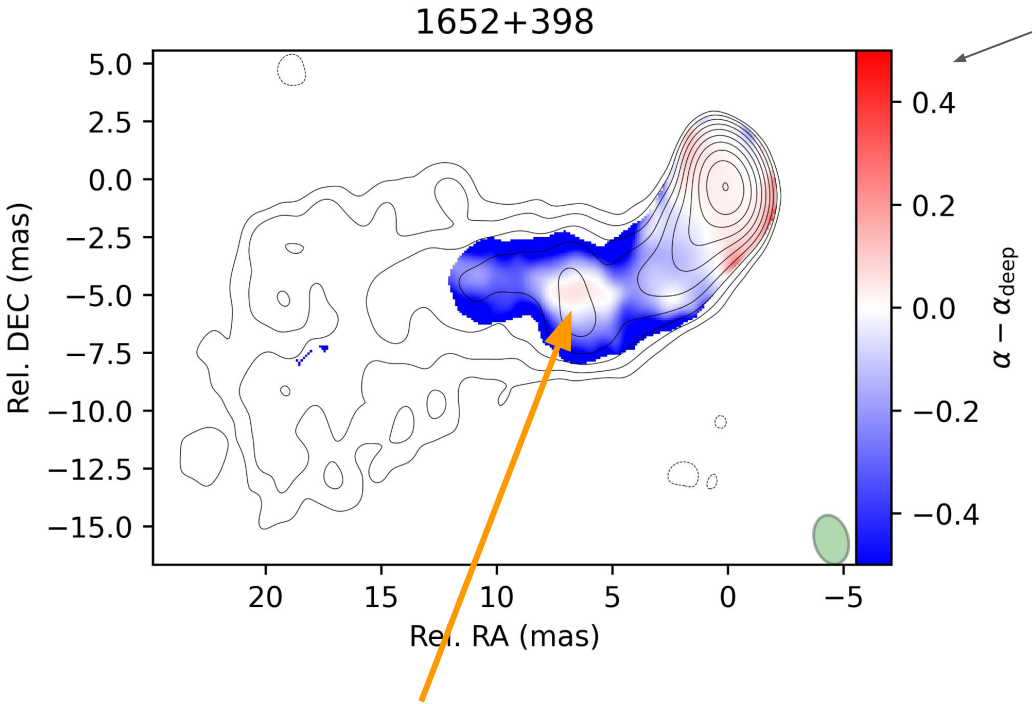


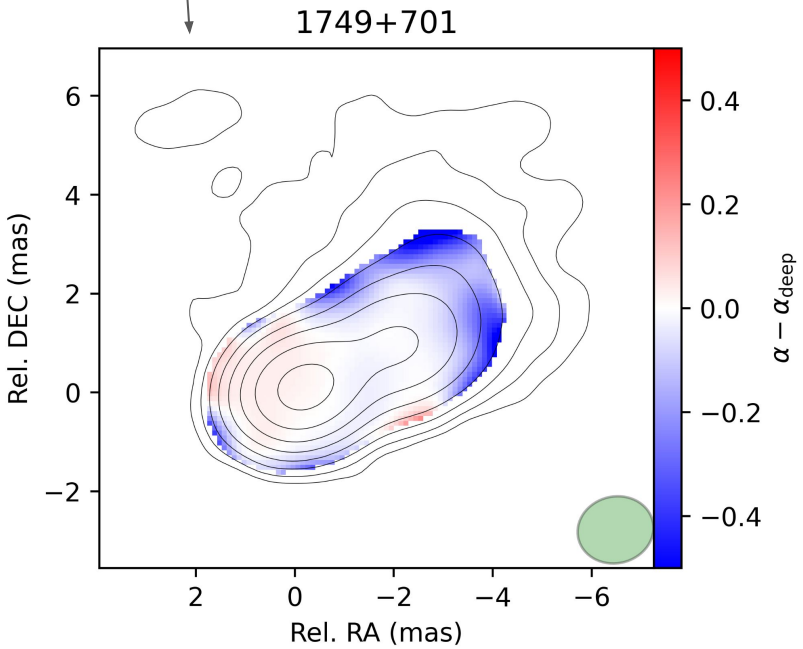
Synthetic images:



Spectral steepening along a jet?

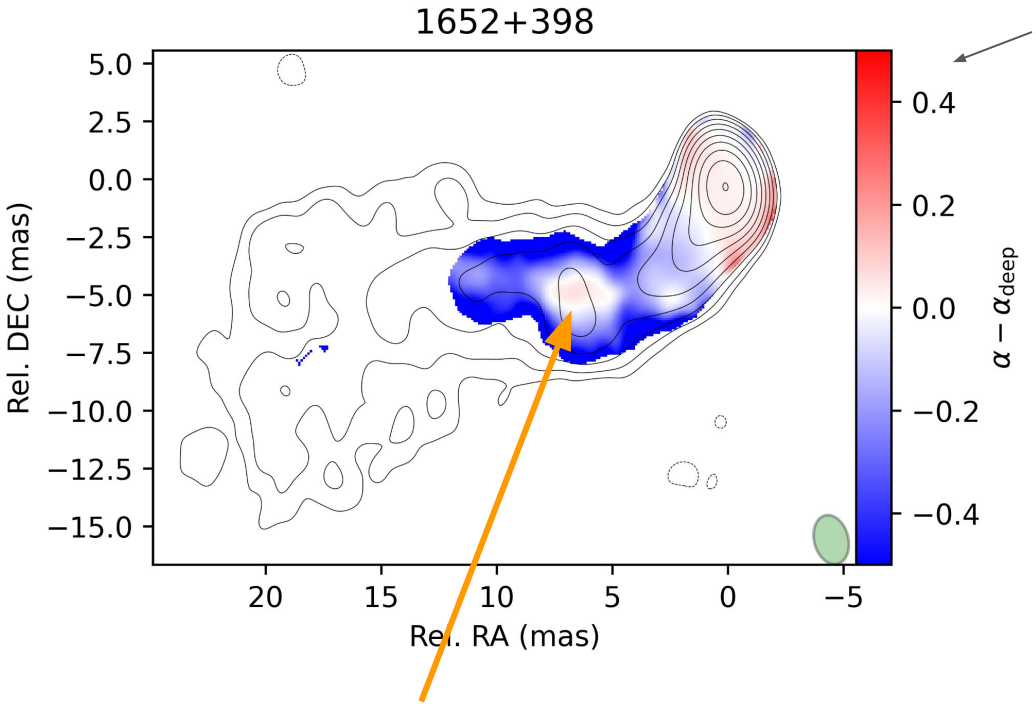
Real MOJAVE 8-15 GHz 4-freqs data.
Difference of spectral index maps made with conventional and deep CLEAN.





Does the observed spectral flattening at components position (*Hovatta+ 2014*) is solely due to the systematics that depends on SNR?

Spectral steepening along a jet?



Real MOJAVE 8-15 GHz 4-freqs data. Difference of spectral index maps made with conventional and deep CLEAN.

- The origin of the bias: residuals of the high frequency CLEAN image.
- The bias increases with increase of the common convolving beam (as opposite to the bias due to CLEAN reconstruction error)

Does the observed spectral flattening at components position (*Hovatta+ 2014*) is solely due to the systematics that depends on SNR?

Summary:

- ➢ Spectral index images of M87 jet are affected by the CLEAN imaging systematics that flattens the spectra in a series of stripes nearly along the jet. The bias is due to the CLEAN reconstruction error and can be compensated using the observed data only. The observed α in M87 jet is more complicated than flattening along a jet axis (*A.Nikonov talk*).
- ➢ Jet inner ridgeline in M87 (if does exist) is affected by the CLEAN systematics.
- ➢ The spectral steepening along a jets is at least partially due to the residual unCLEANed flux in the high-frequency image.

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- ➢ Spectral index images of M87 jet are affected by the CLEAN imaging systematics that flattens the spectra in a series of stripes nearly along the jet. The bias is due to the CLEAN reconstruction error and can be compensated using the observed data only. The observed α in M87 jet is more complicated than flattening along a jet axis (*A.Nikonov talk*).
- ➢ Jet inner ridgeline in M87 (if does exist) is affected by the CLEAN systematics.
- ➢ The spectral steepening along a jets is at least partially due to the residual unCLEANed flux in the high-frequency image.

More details (including Space VLBI) - in *Pashchenko+ subm.*