

LOFAR family meeting  
Olsztyn, 2023

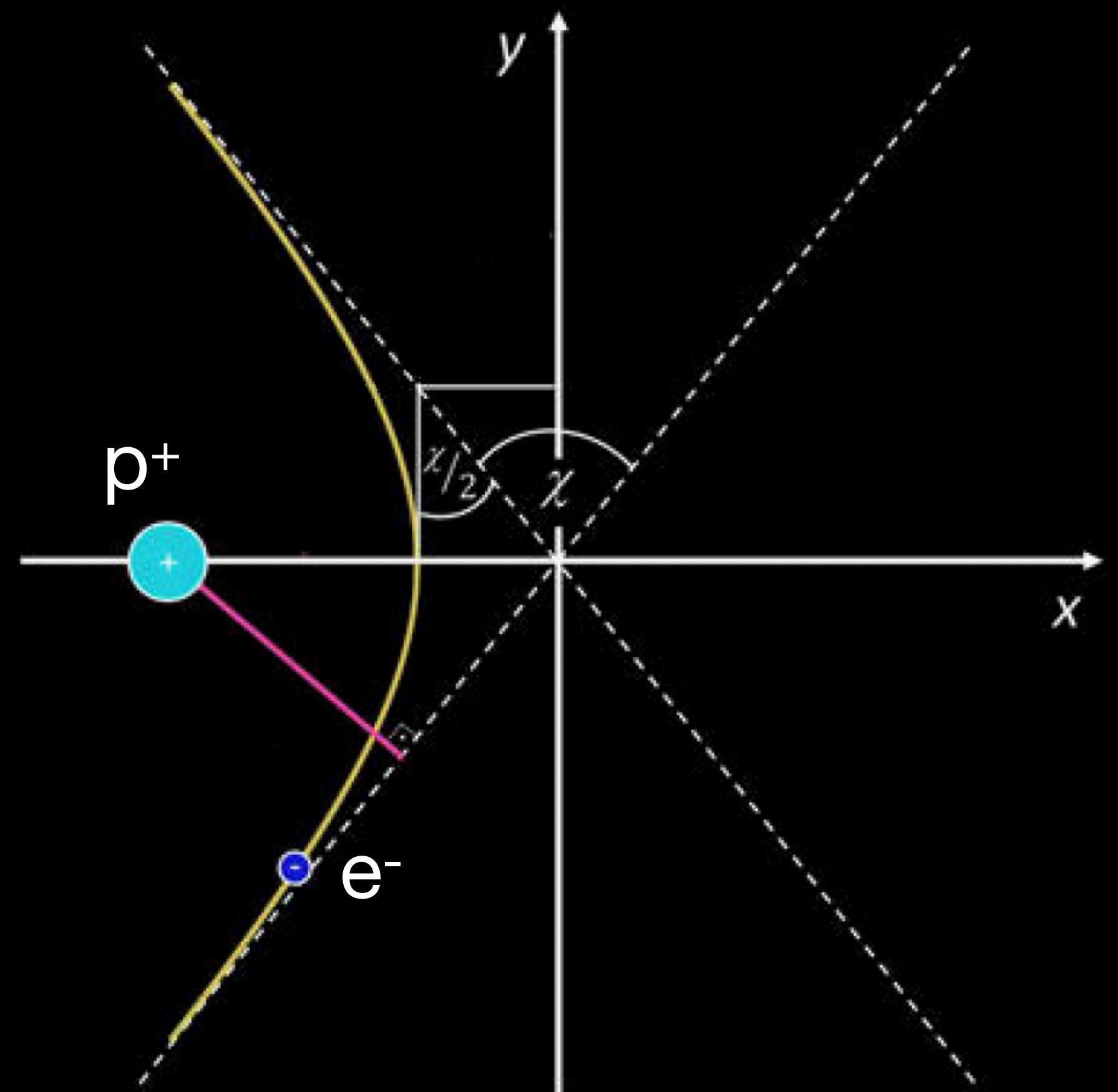
# Spectral turnover at low radio frequencies in HII regions of nearby galaxies

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Volker Heesen, Francesco de Gasperin, Marcus Brüggen, Henrik Edler, Thomas Pasini

# Introduction - free-free emission

- Free electrons and protons in HII regions



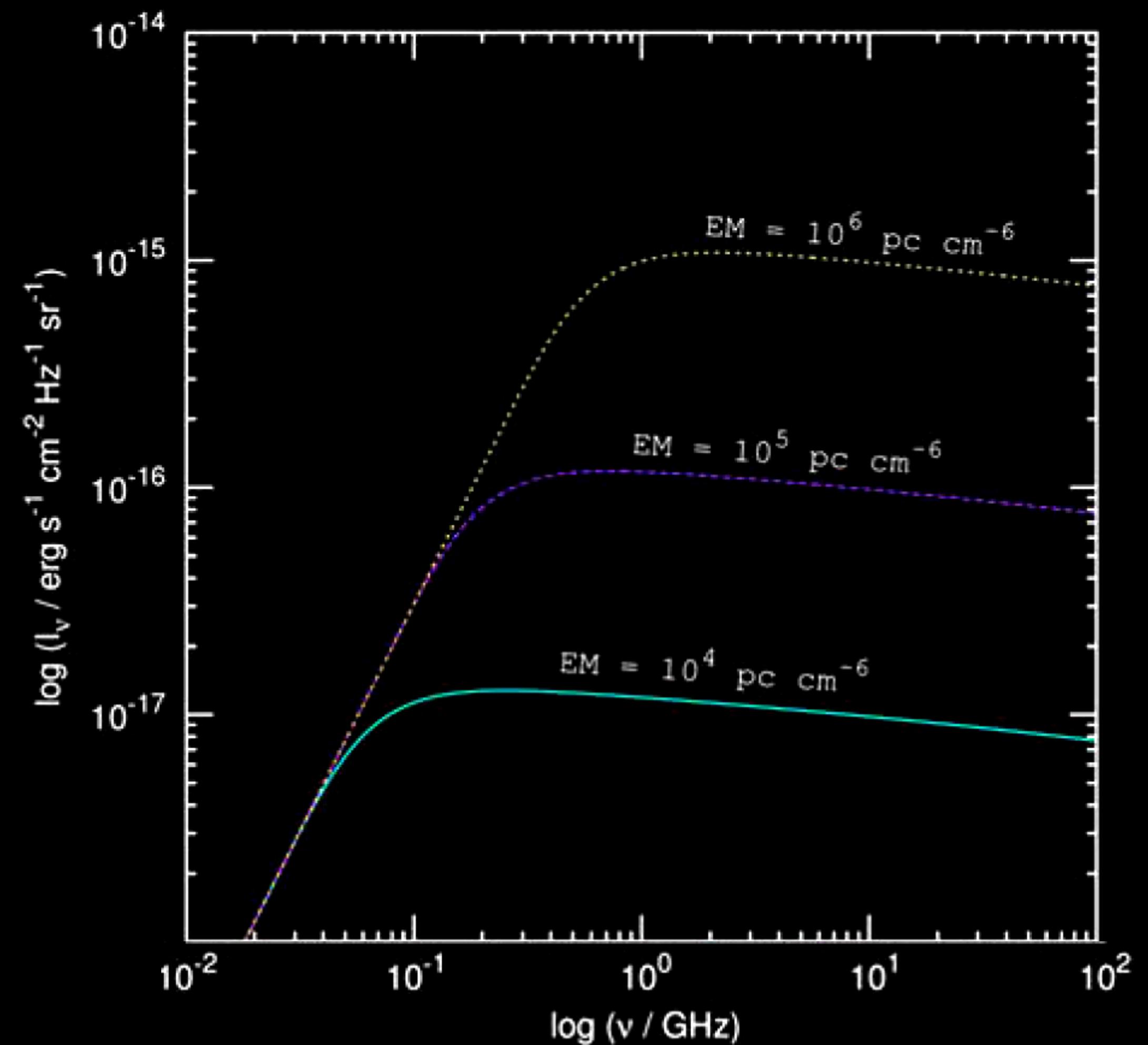
Credit: Figure - Klein and Fletcher, 2015, Background - NASA, ESA, S. Beckwith (STScI), The Hubble Heritage Team (STScI/AURA)

# Introduction - free-free spectrum

Optically thick

$$\tau_\nu \gg 1$$

$$I_\nu \sim \nu^2$$



Optically thin

$$\tau_\nu \ll 1$$

$$I_\nu \sim \nu^{-0.1}$$

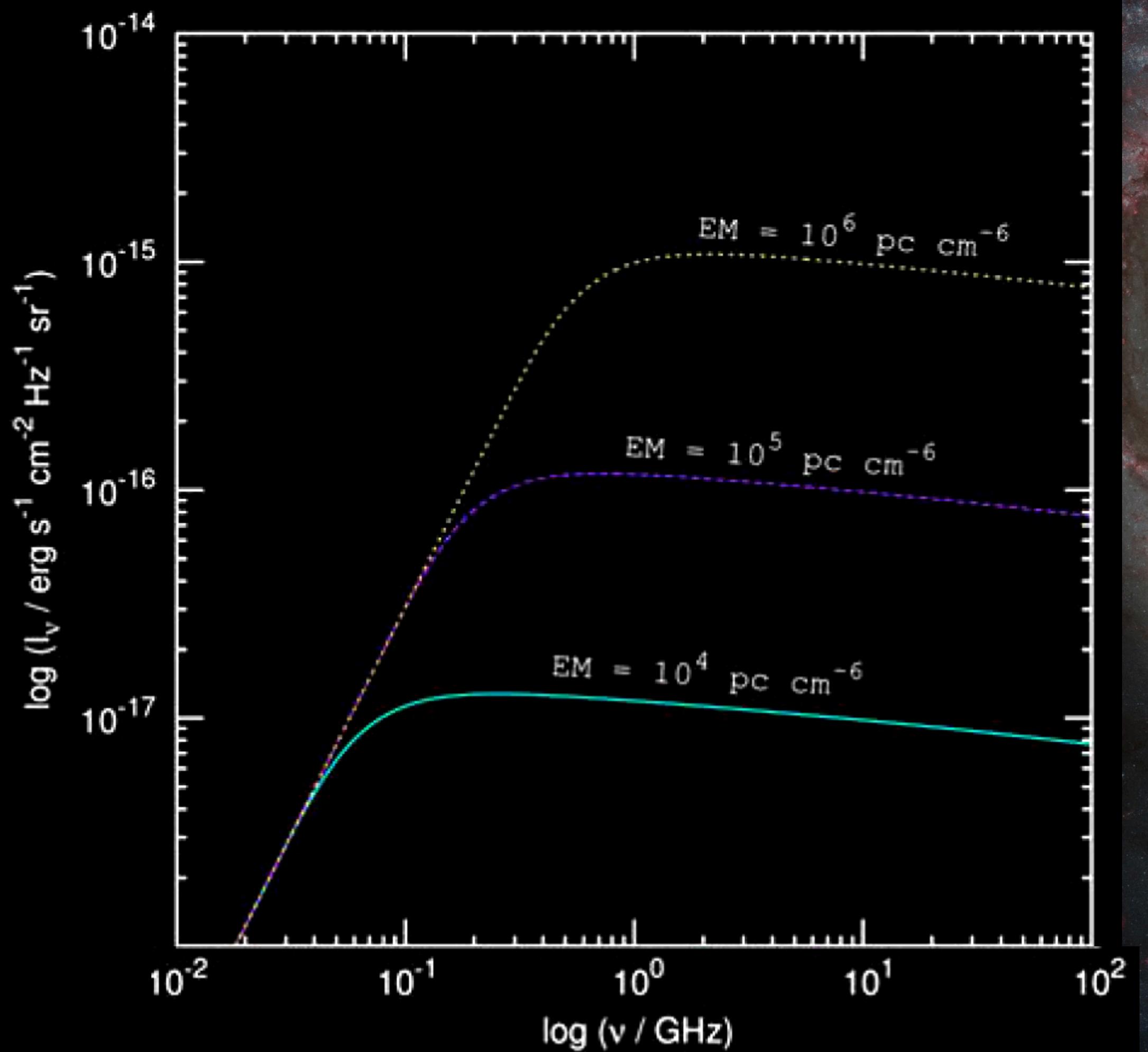
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# Introduction - free-free spectrum

- Emission measure

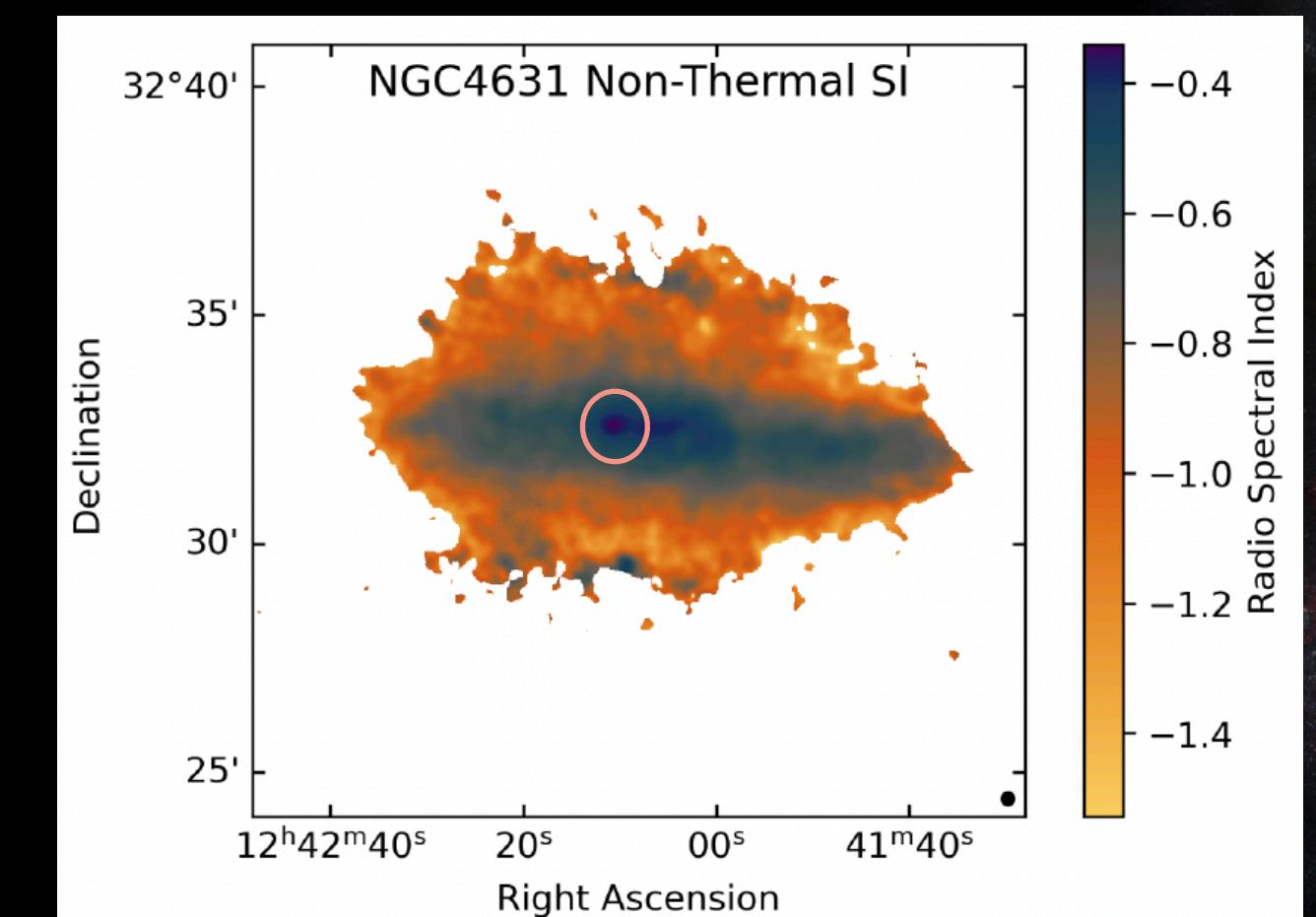
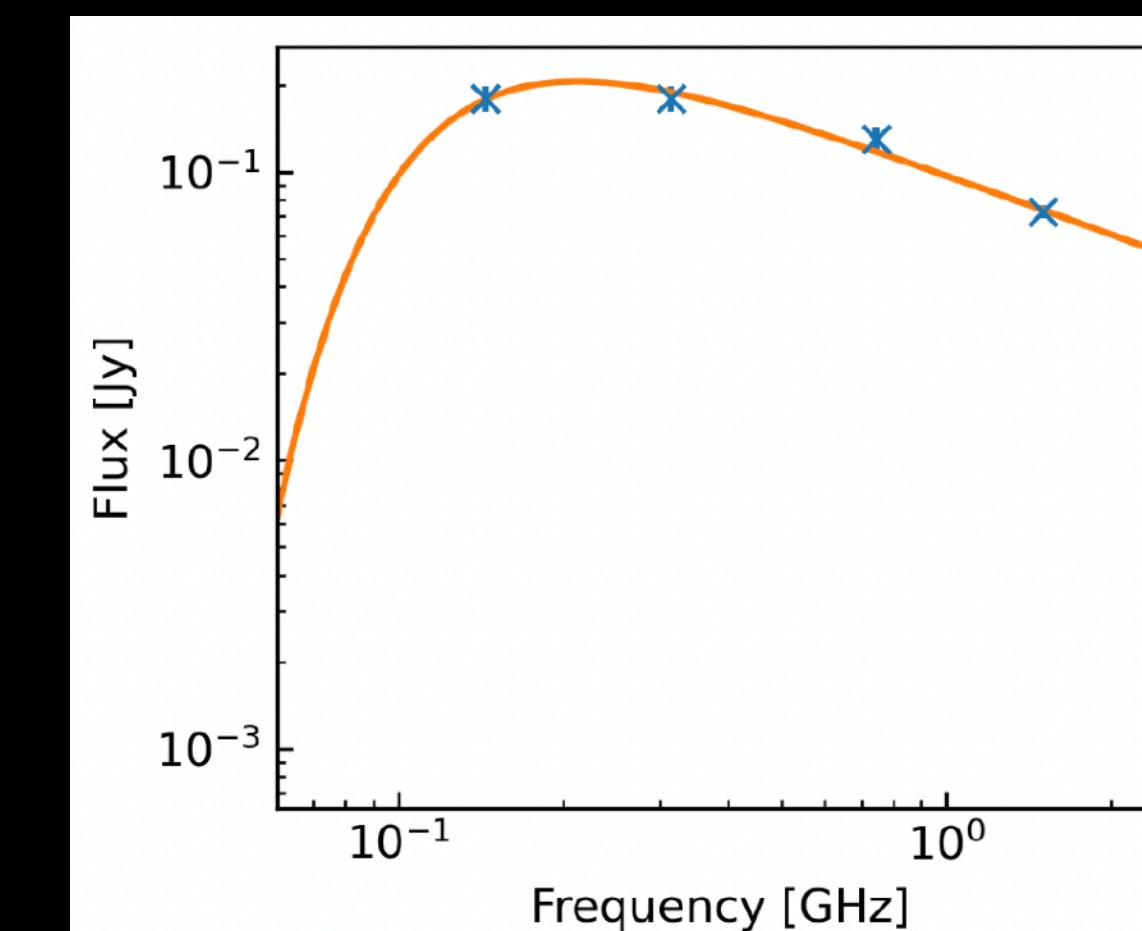
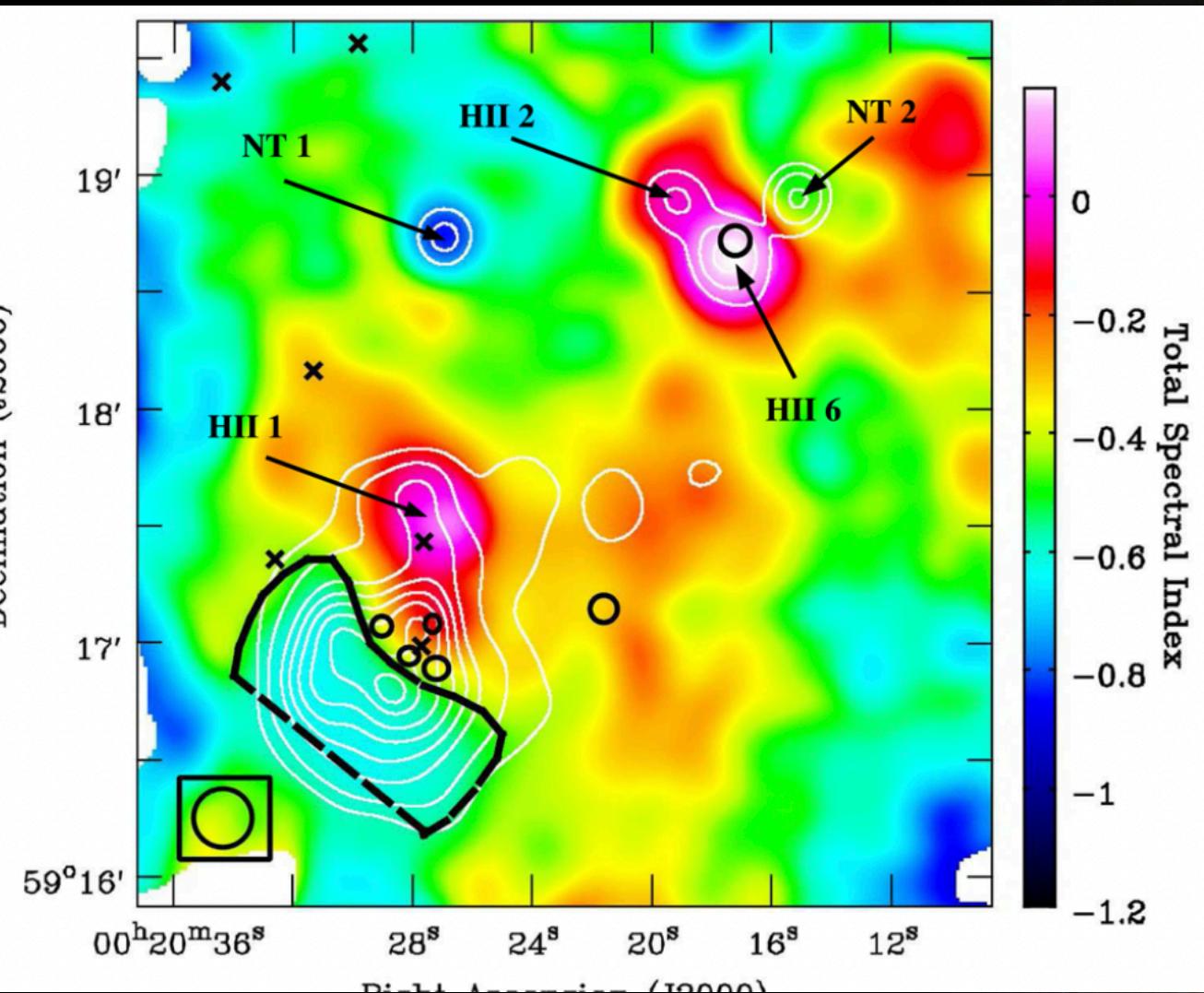
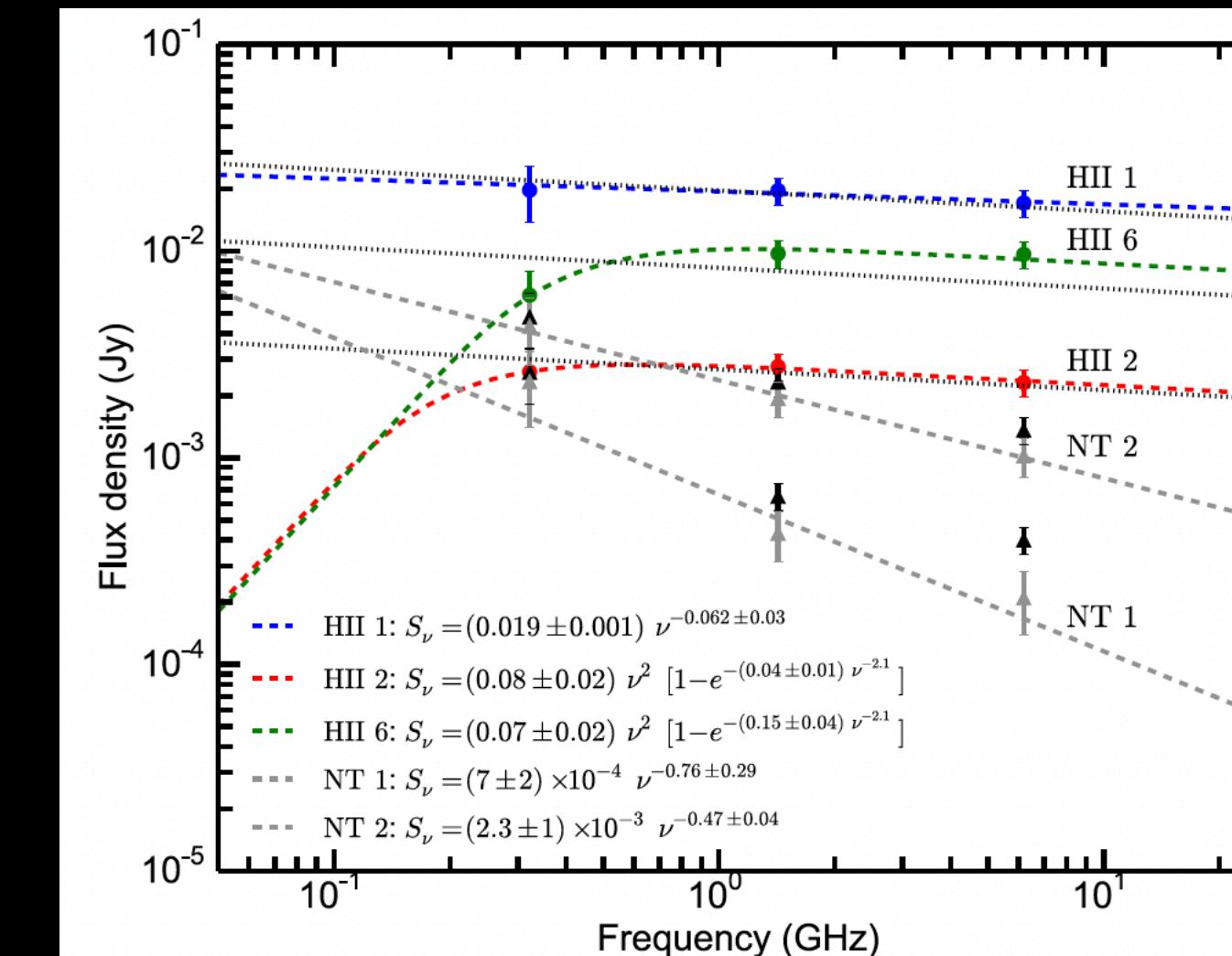
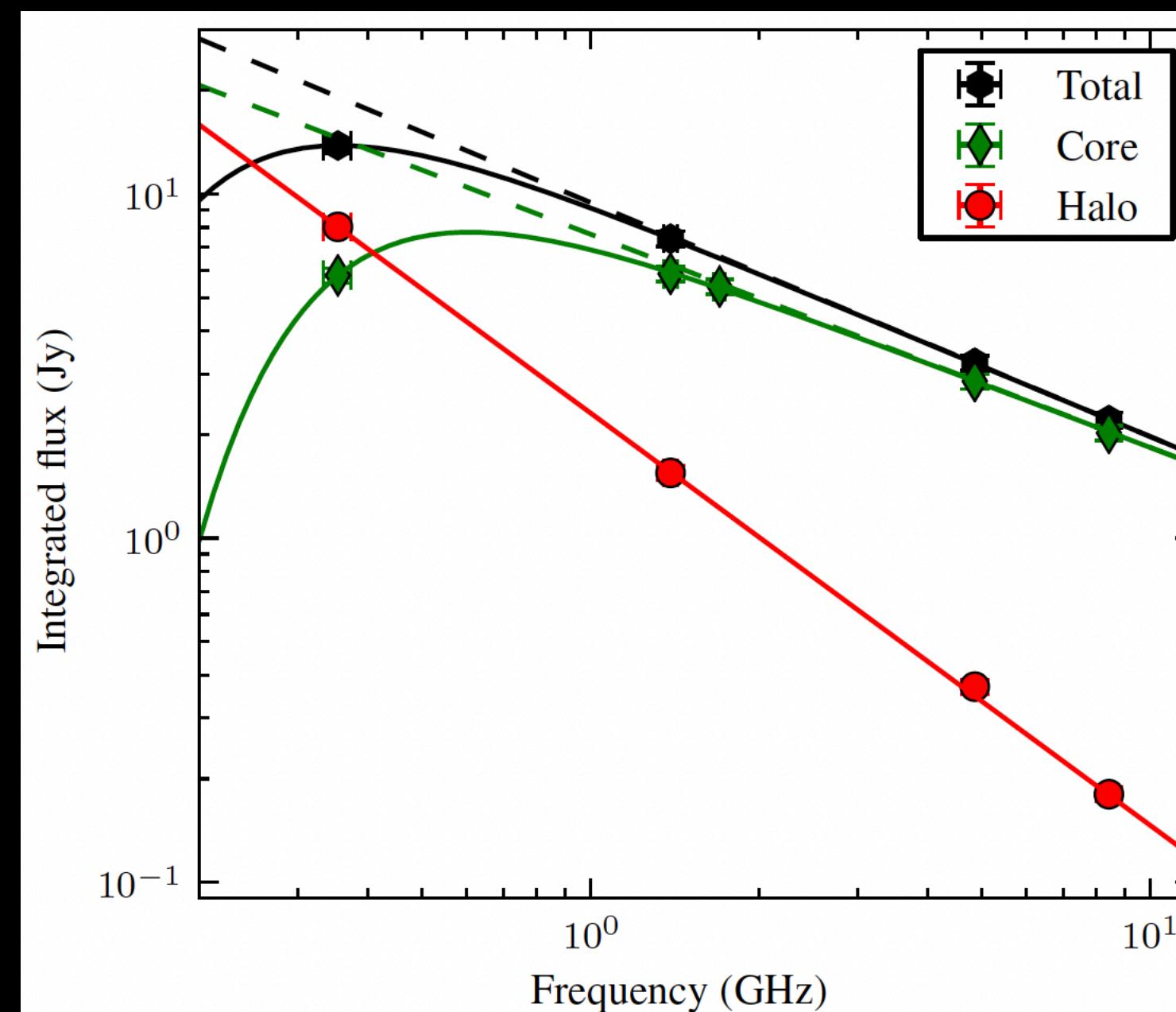
$$EM = \int_0^{s_0} n_e^2 ds$$

- Measuring thermal electron density independent on extinction



Credit: Figure - Klein and Fletcher, 2015, Background - NASA, ESA, S. Beckwith (STScI), The Hubble Heritage Team (STScI/AURA)

# Previous work



# Multi-frequency data

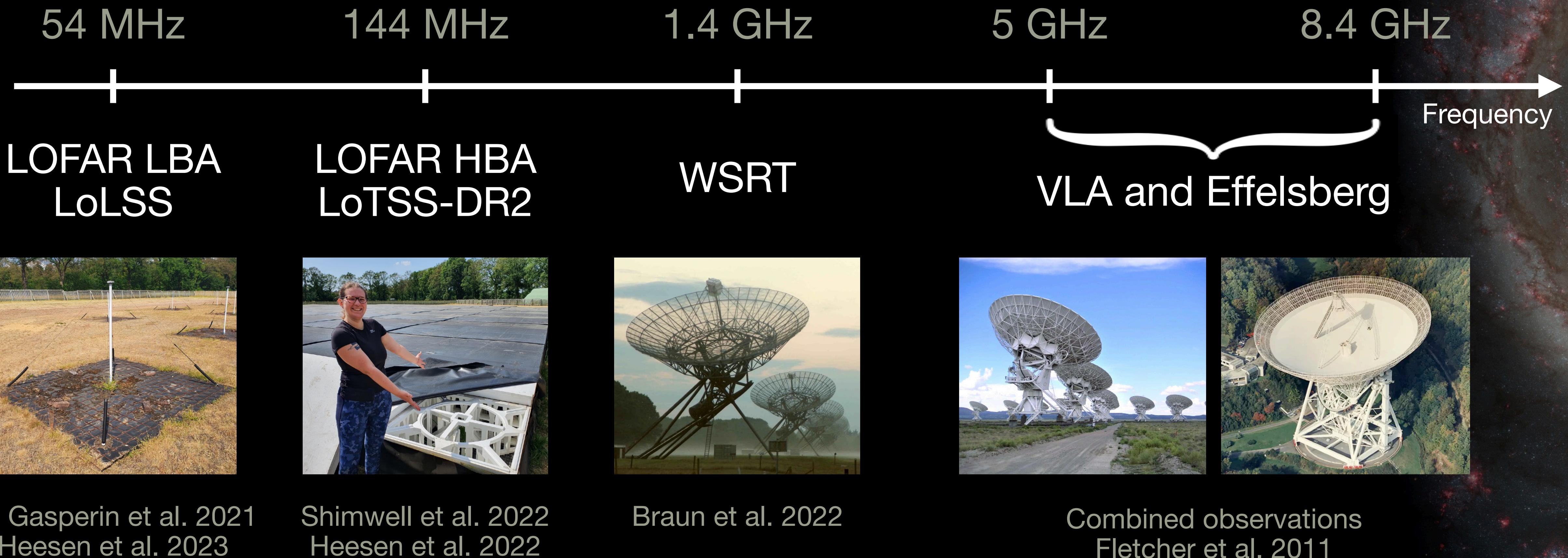


Image credit: Marcote (2016), Wikipedia, MPI for Radio Astronomy

# Whirlpool galaxy (M51, NGC5194)

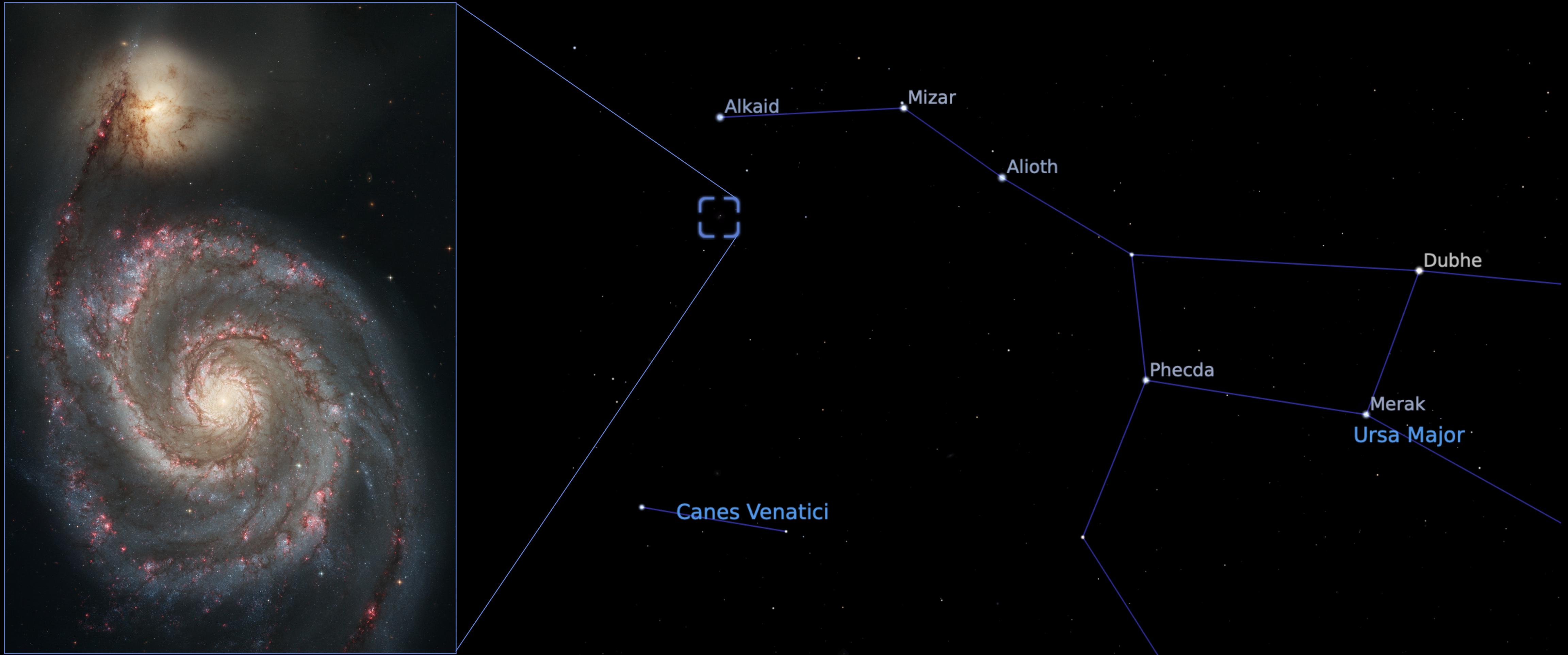


Image credit: NASA, ESA, S. Beckwith (STScI), The Hubble Heritage Team (STScI/AURA) and Stellarium

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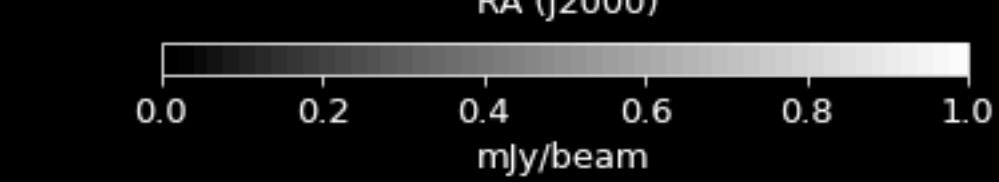
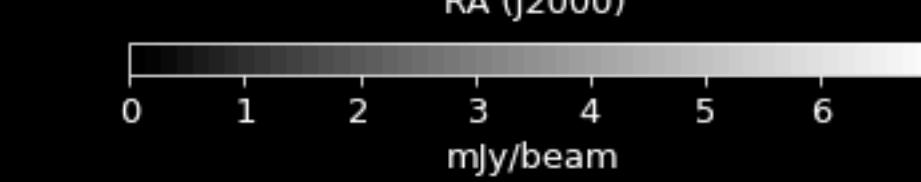
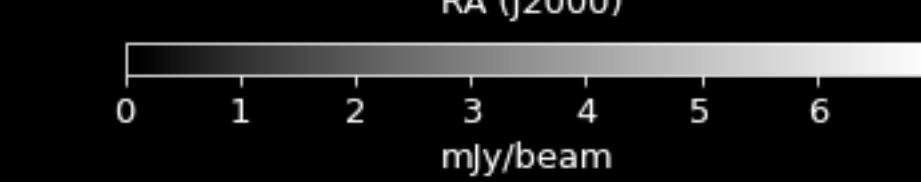
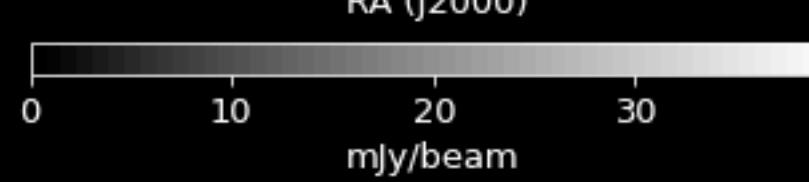
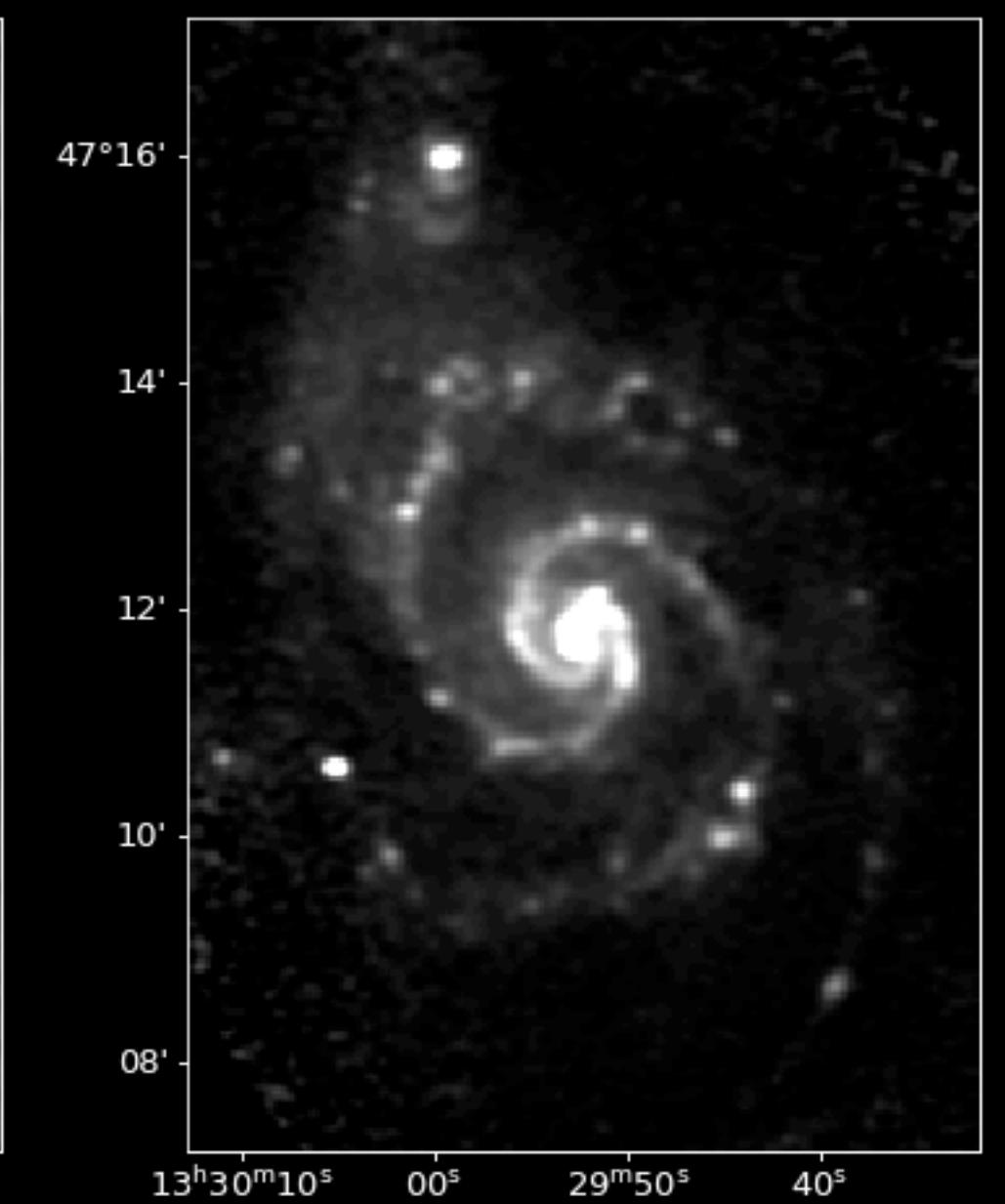
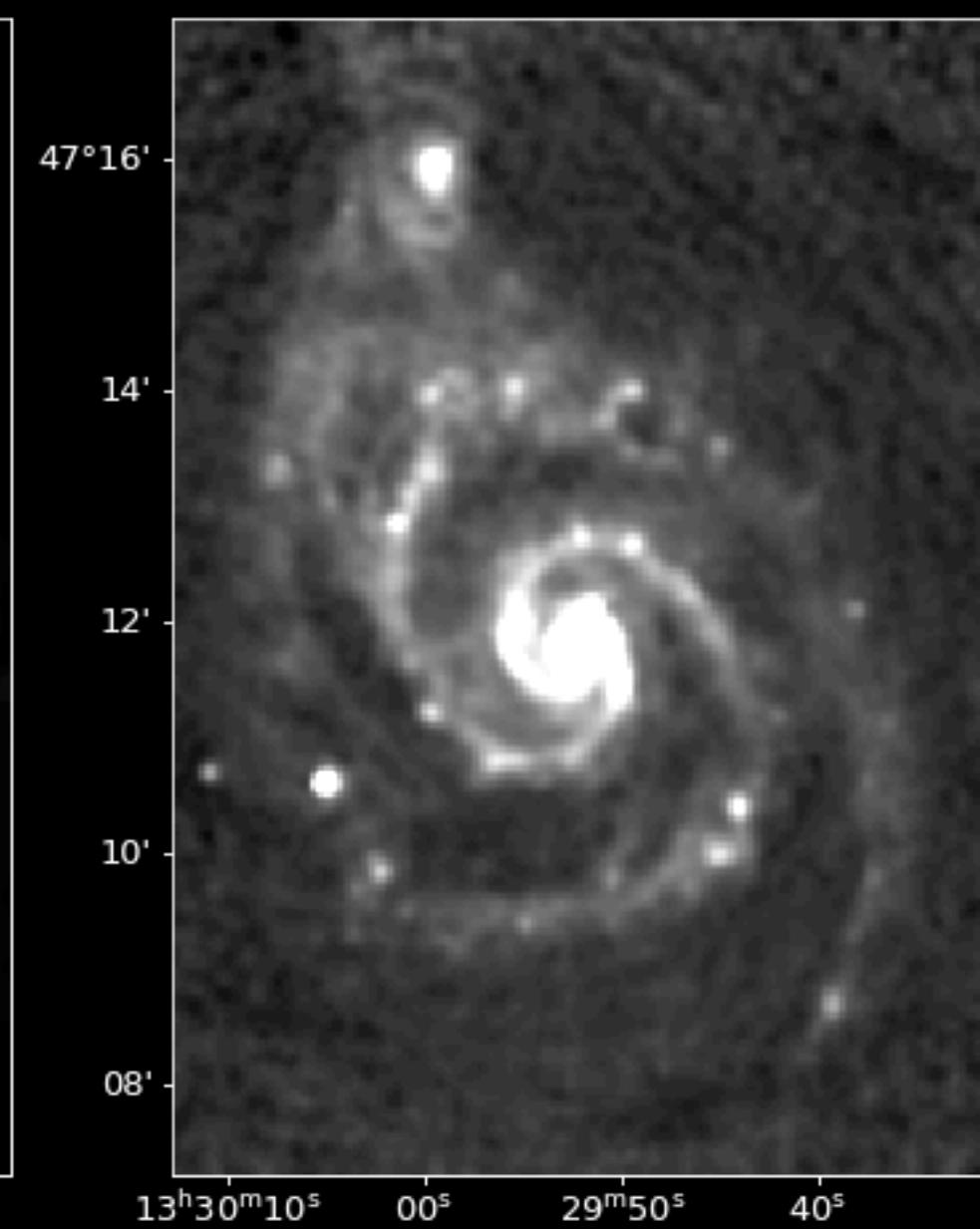
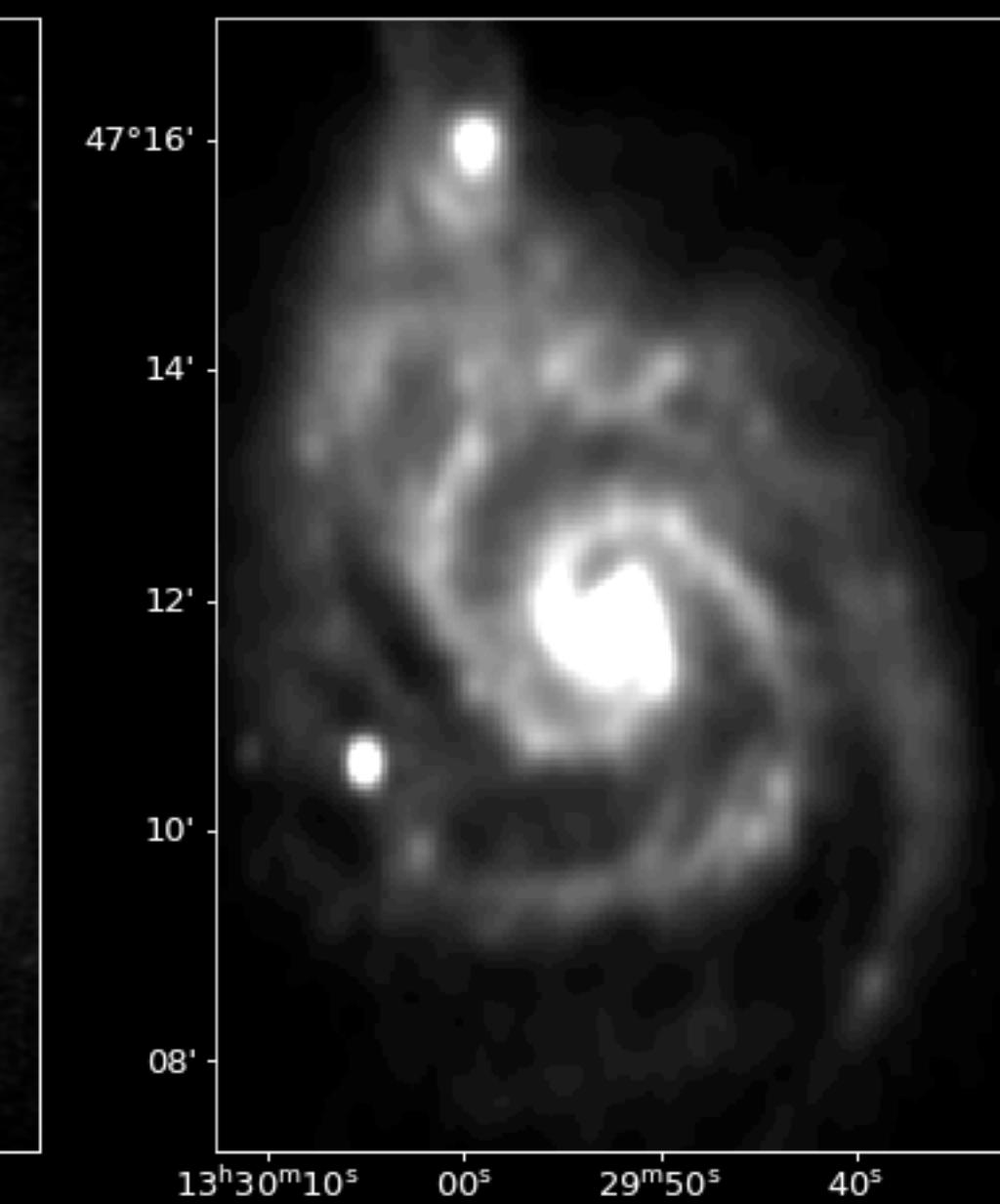
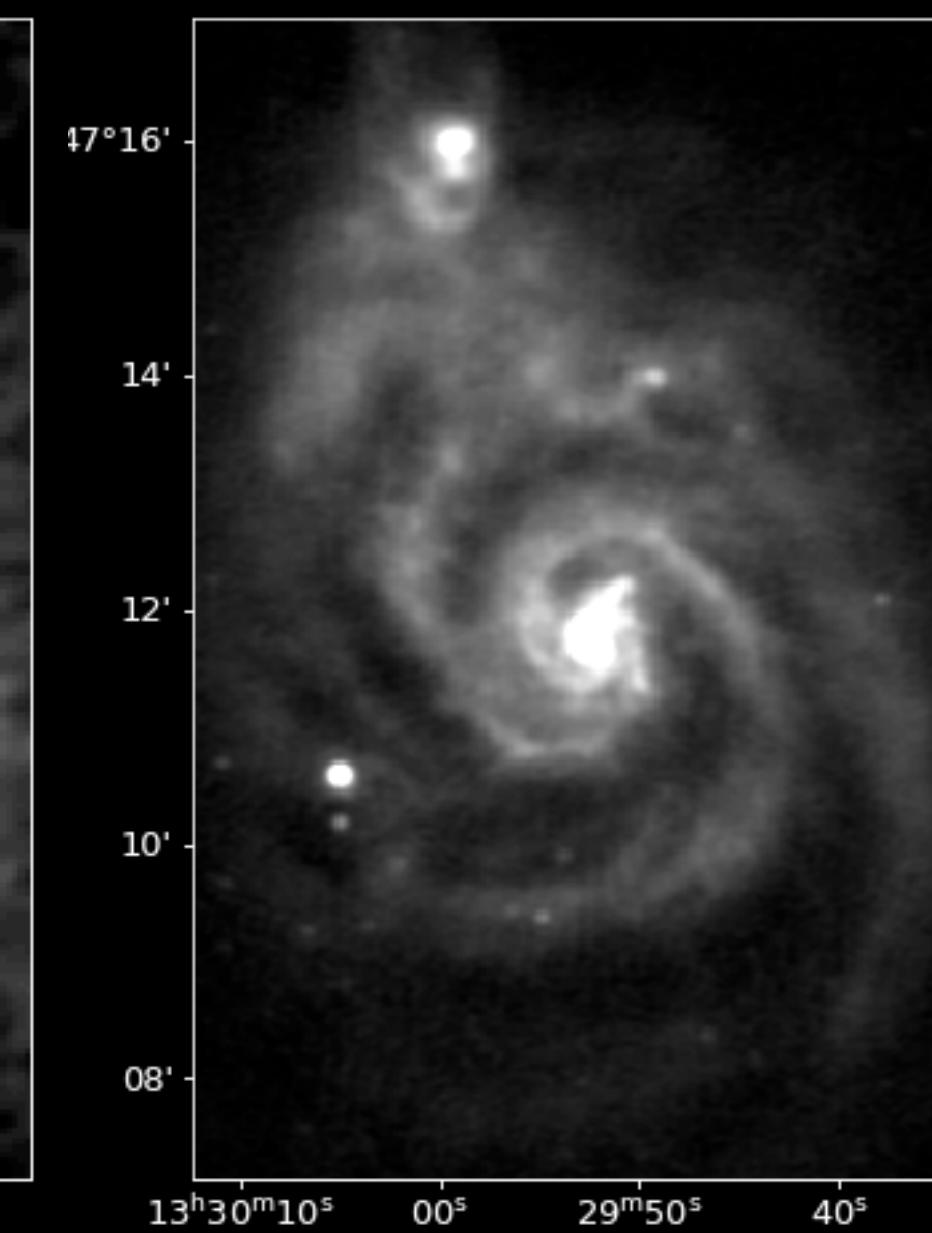
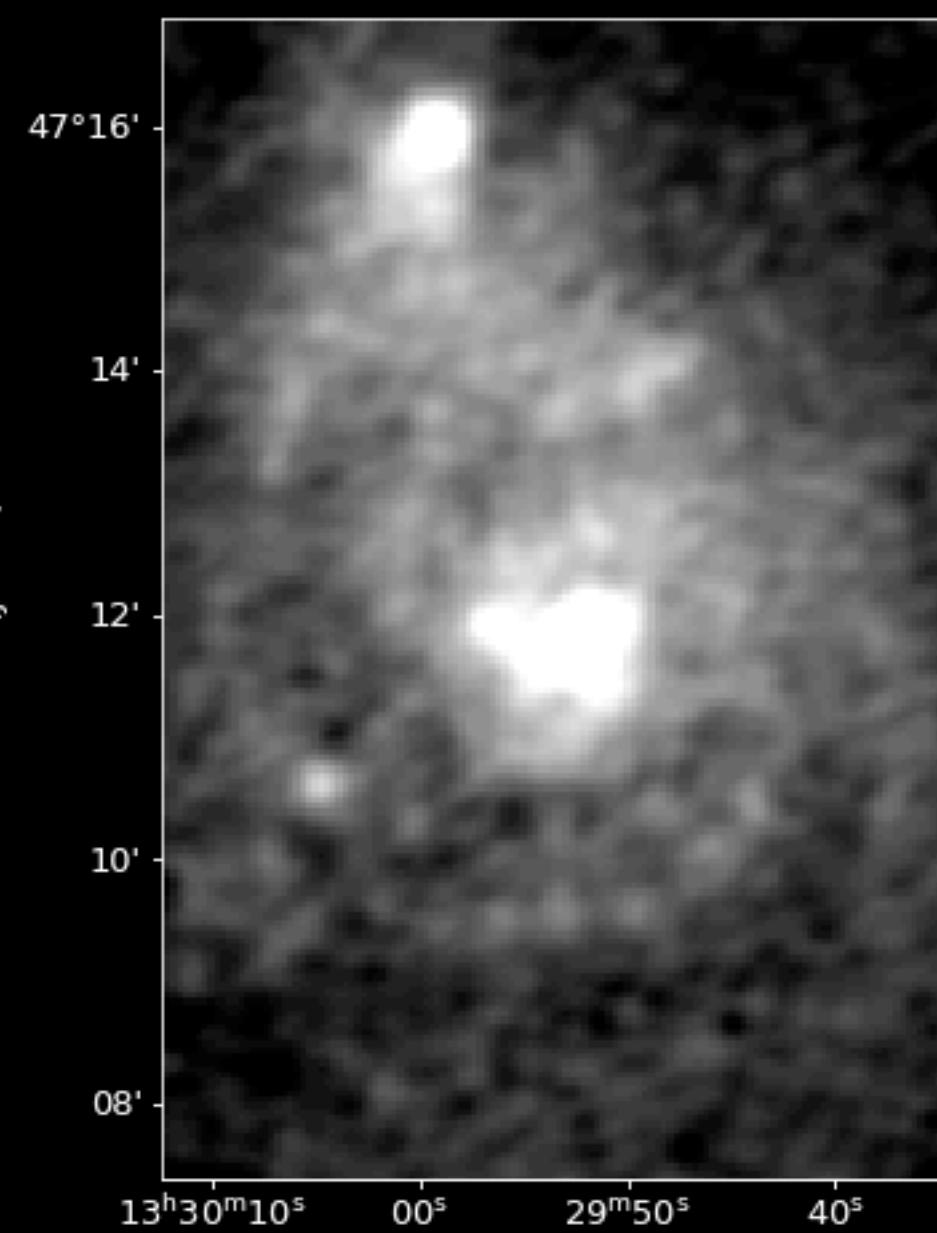
54 MHz

144 MHz

1.37 GHz

4.85 GHz

8.35 GHz



# Convolved to 17arcsec

54 MHz

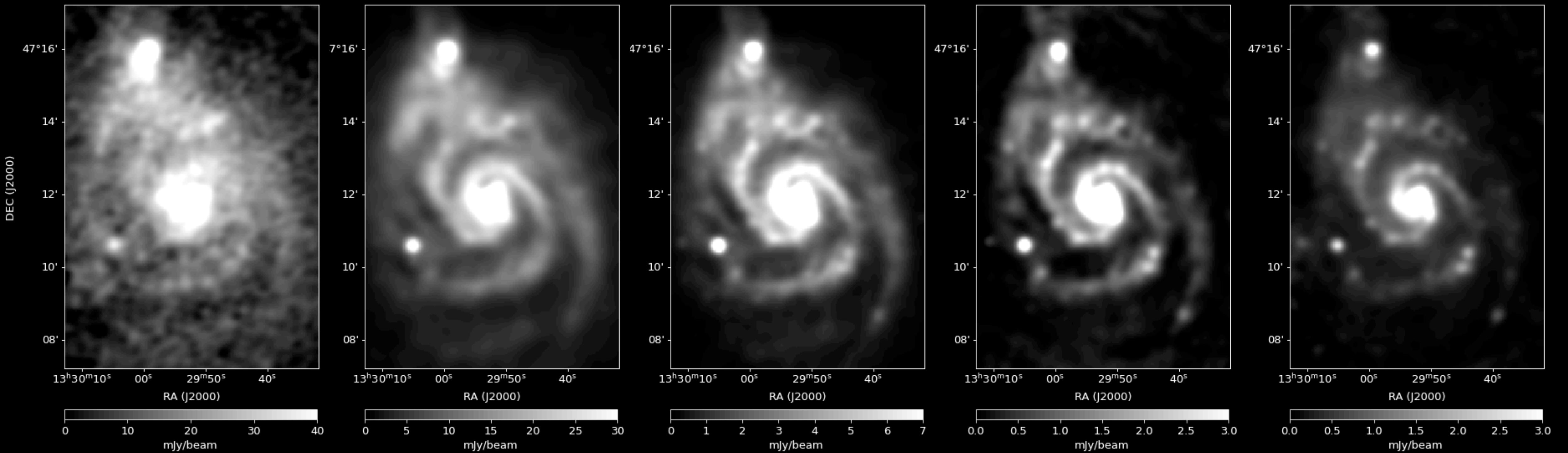
144 MHz

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4.85 GHz

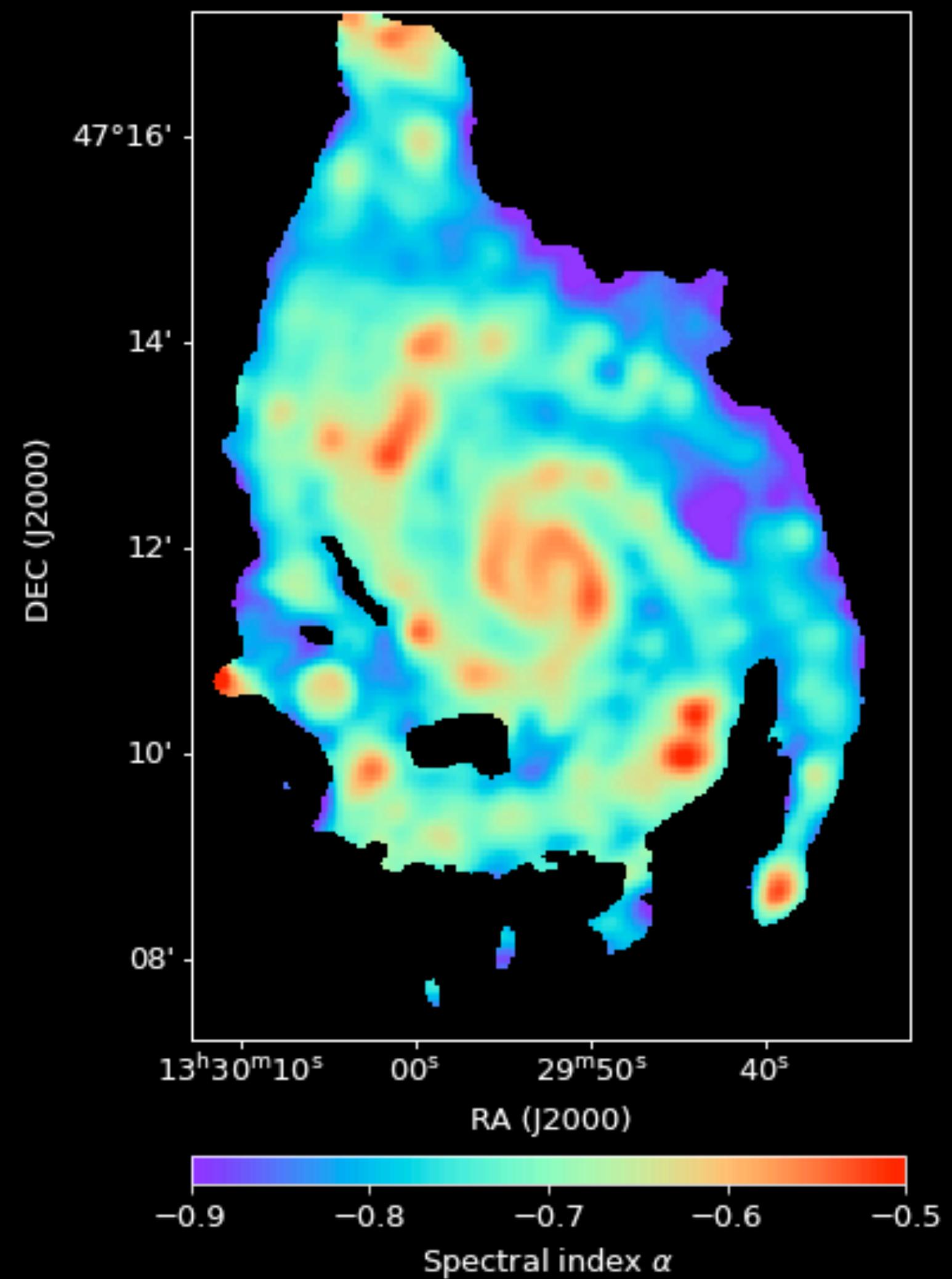
8.35 GHz

Frequency



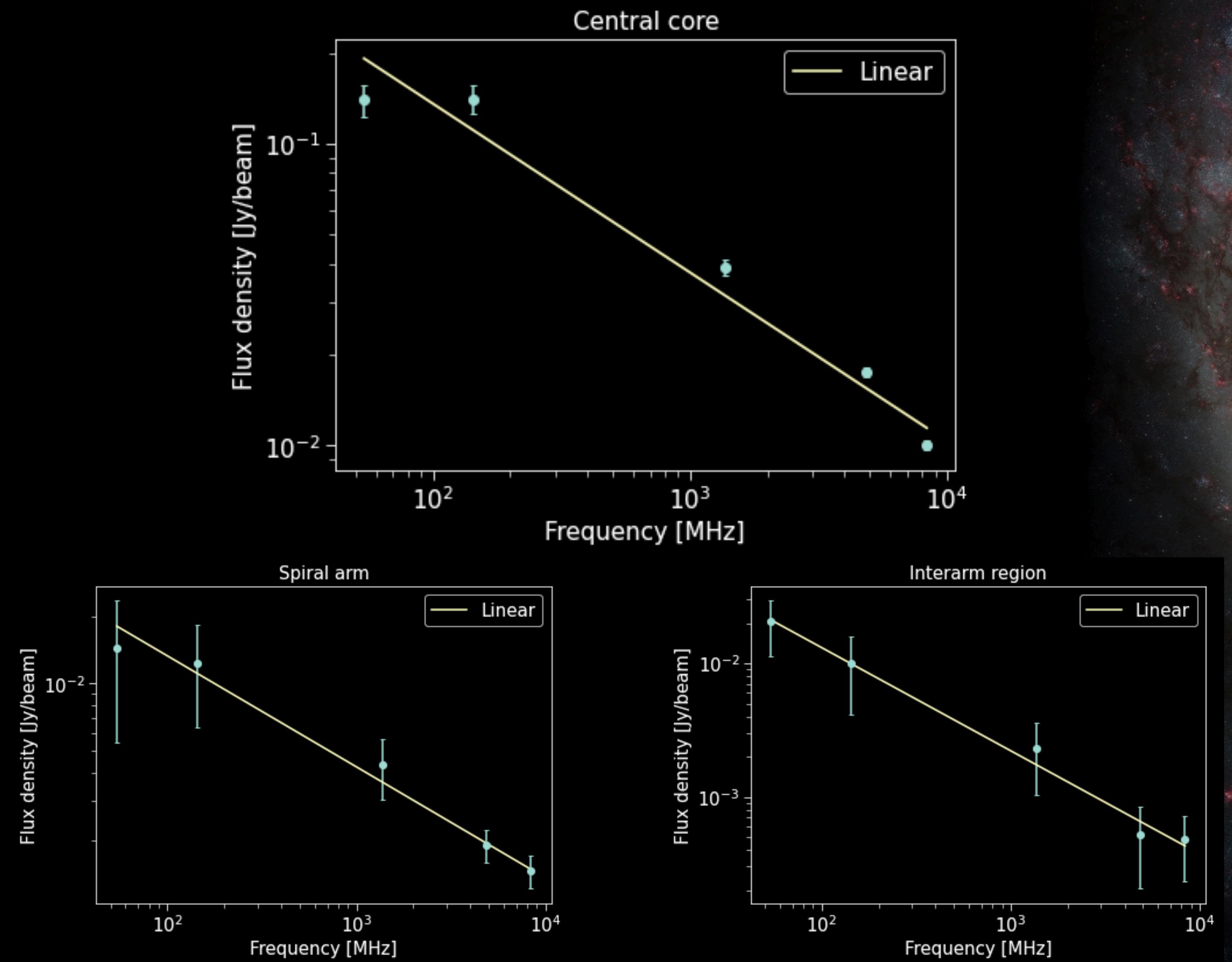
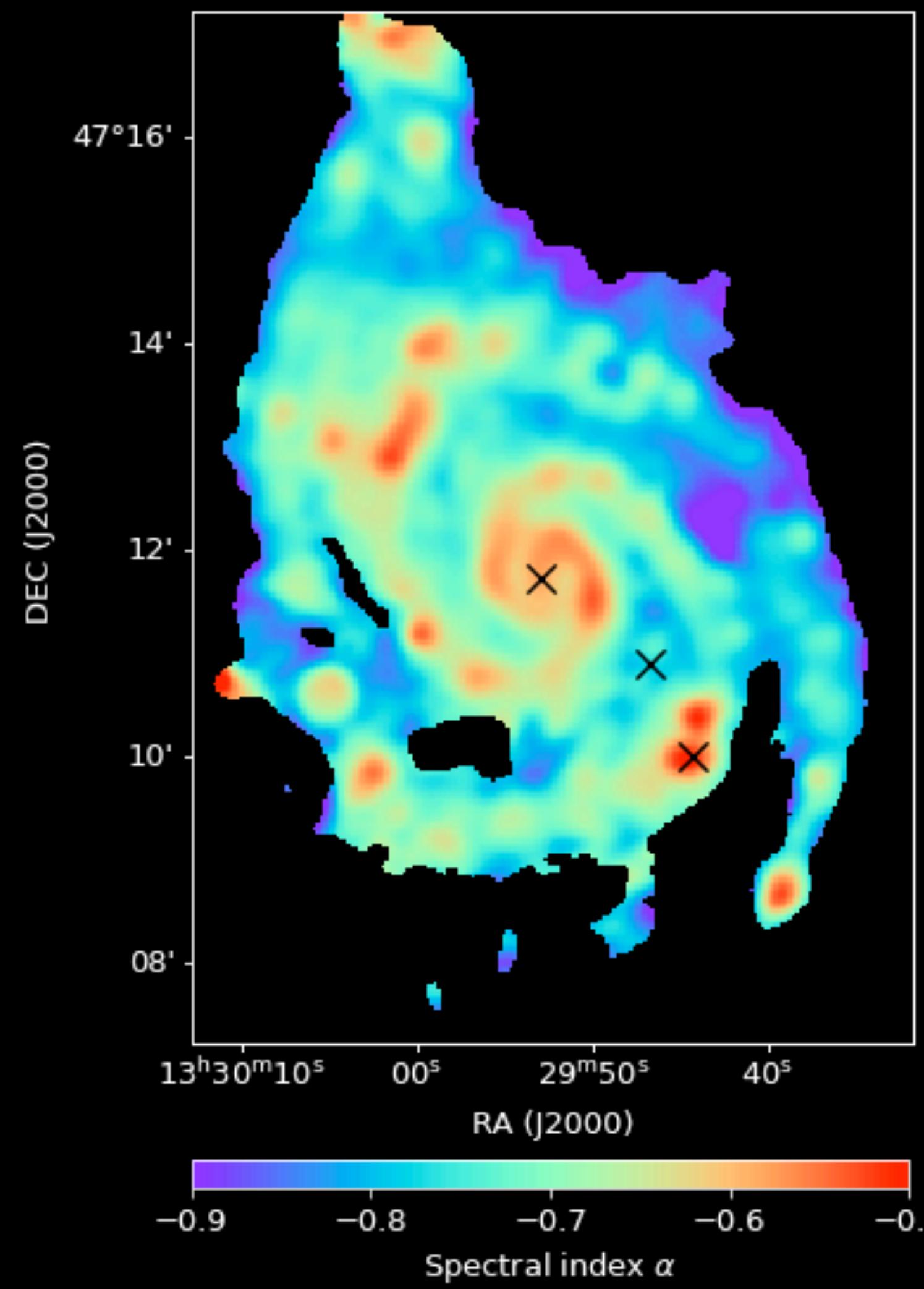
# Spectral index

$$S_\nu = S_0 \nu^\alpha$$

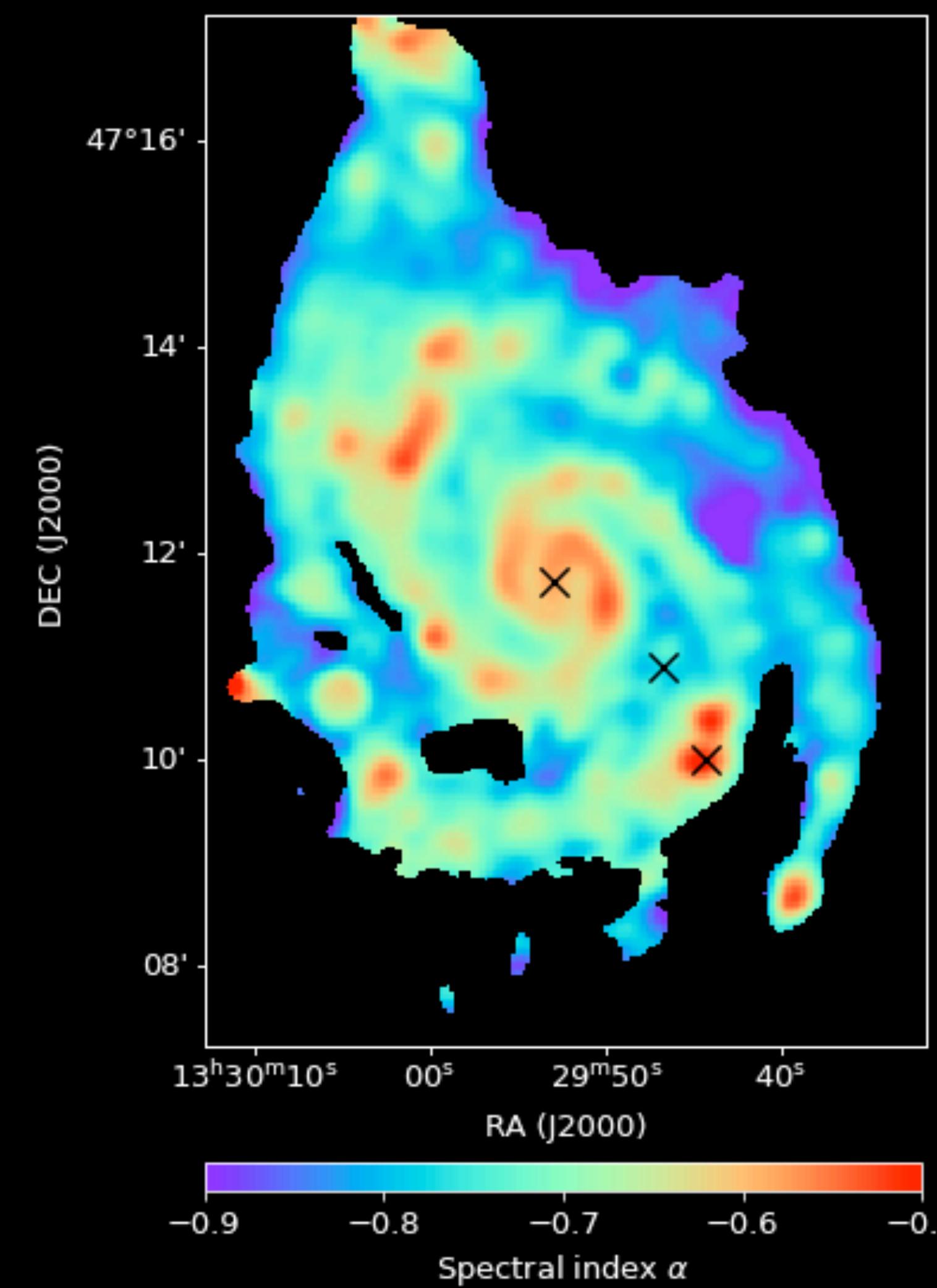


# Spectral index

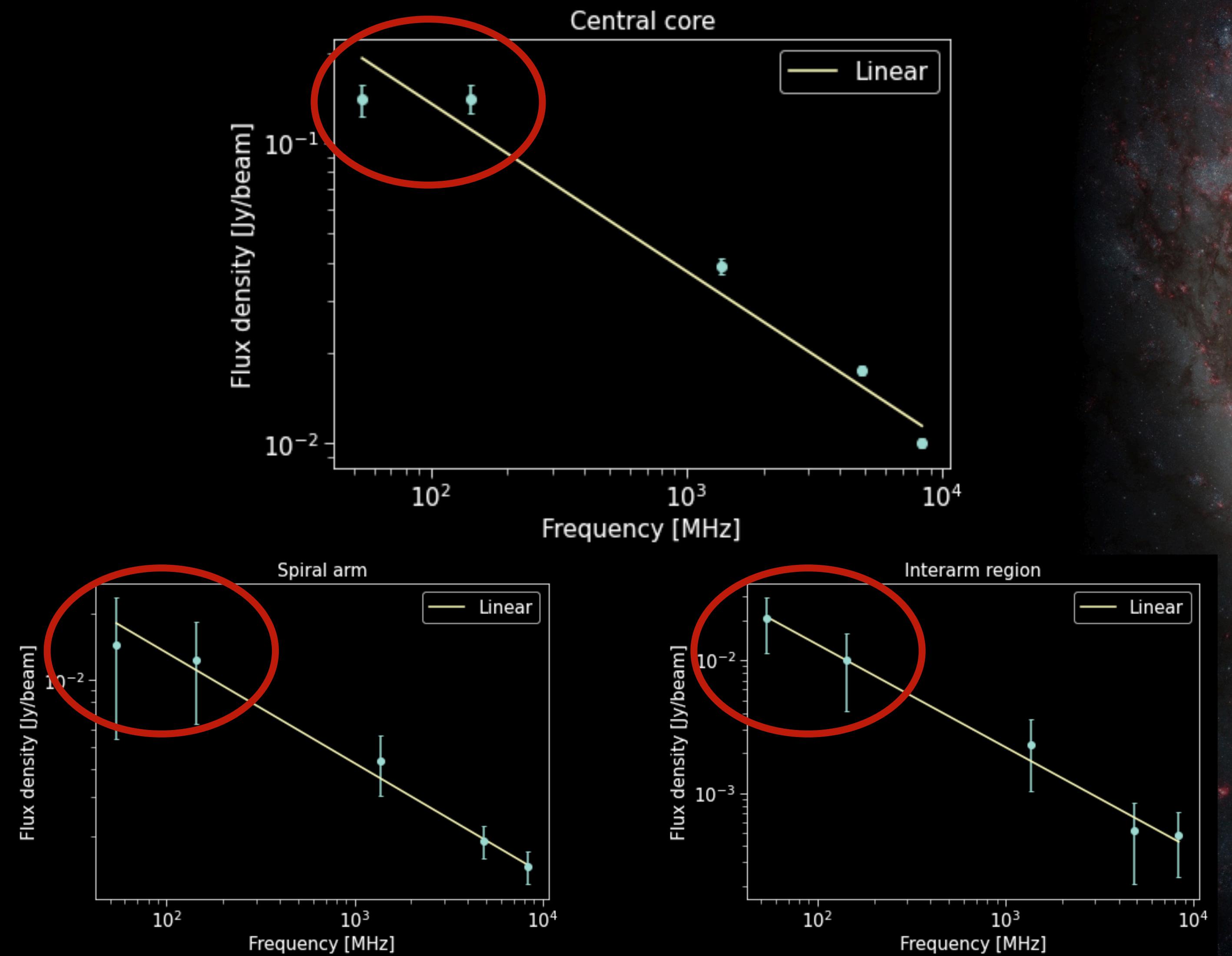
$$S_\nu = S_0 \nu^\alpha$$



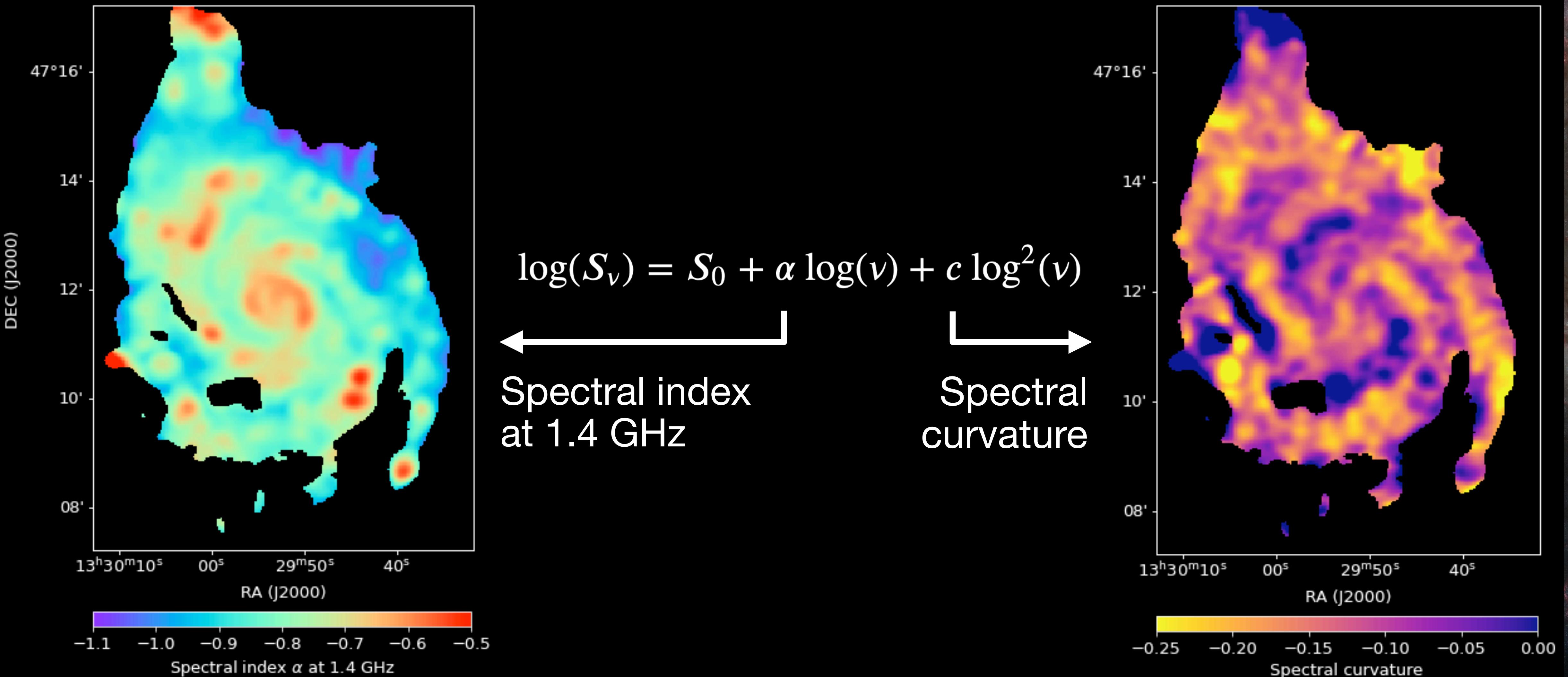
# Spectral index



$$S_\nu = S_0 \nu^\alpha$$

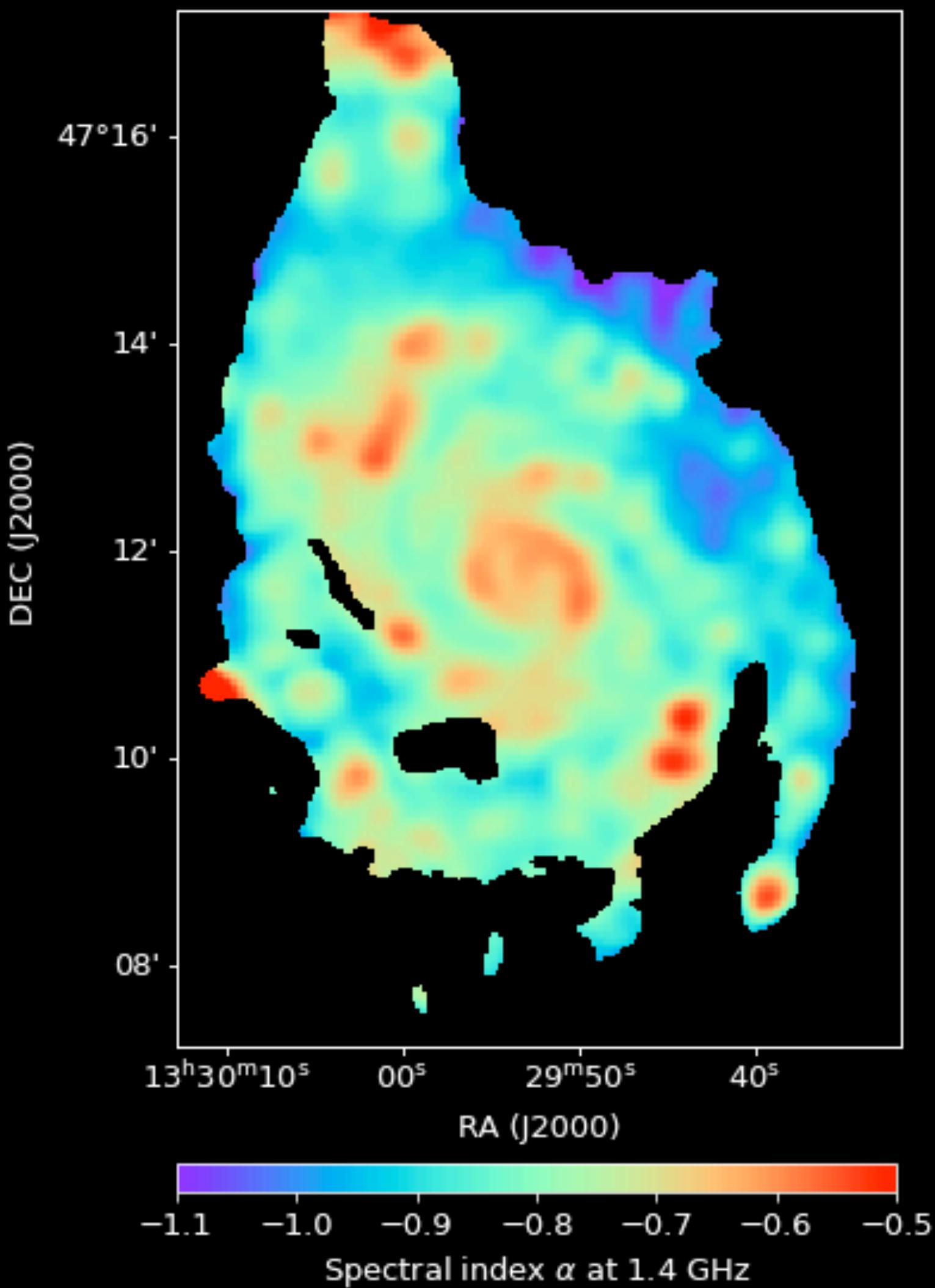


# Spectral curvature



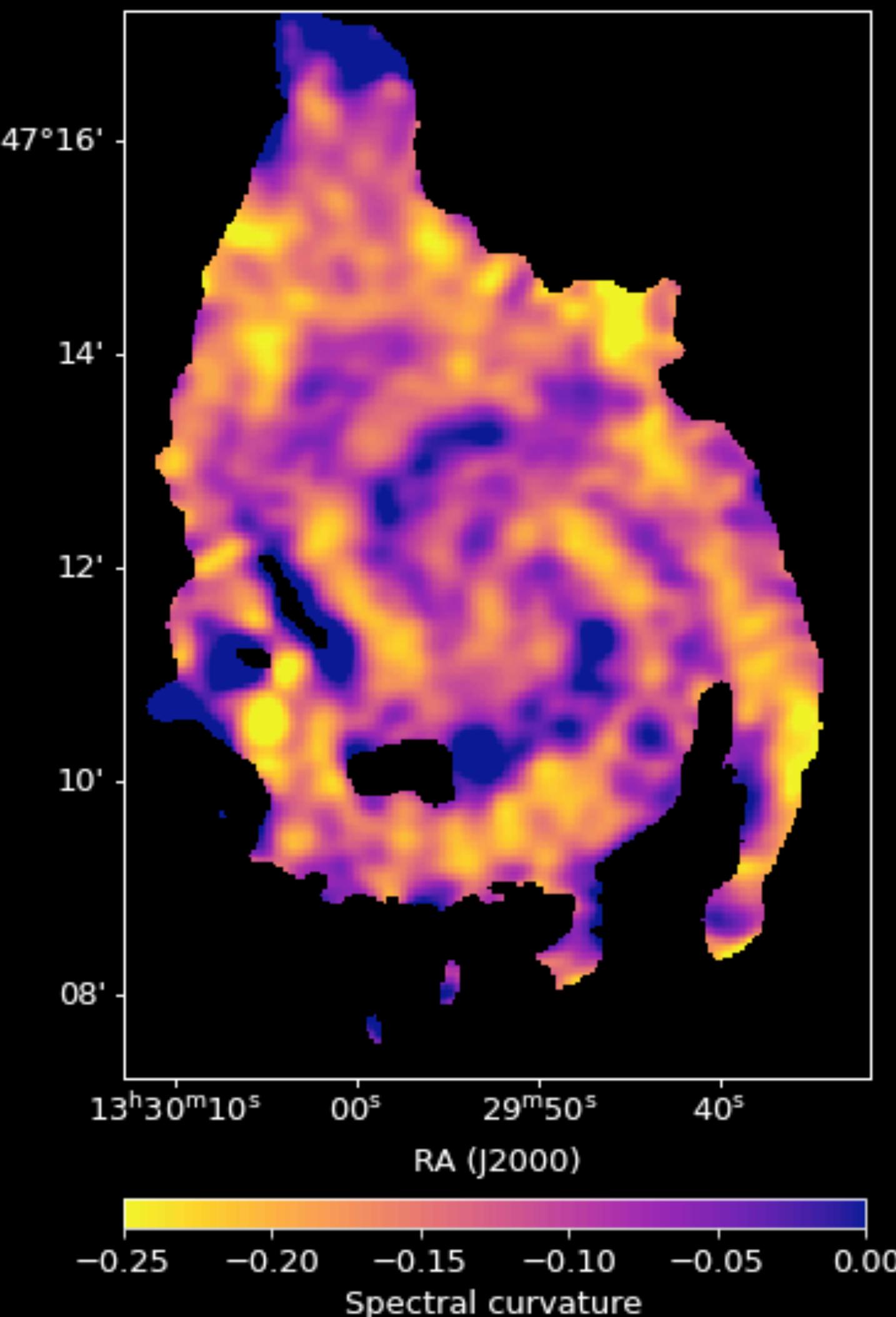
# Spectral curvature

IS IT SIGNIFICANT?

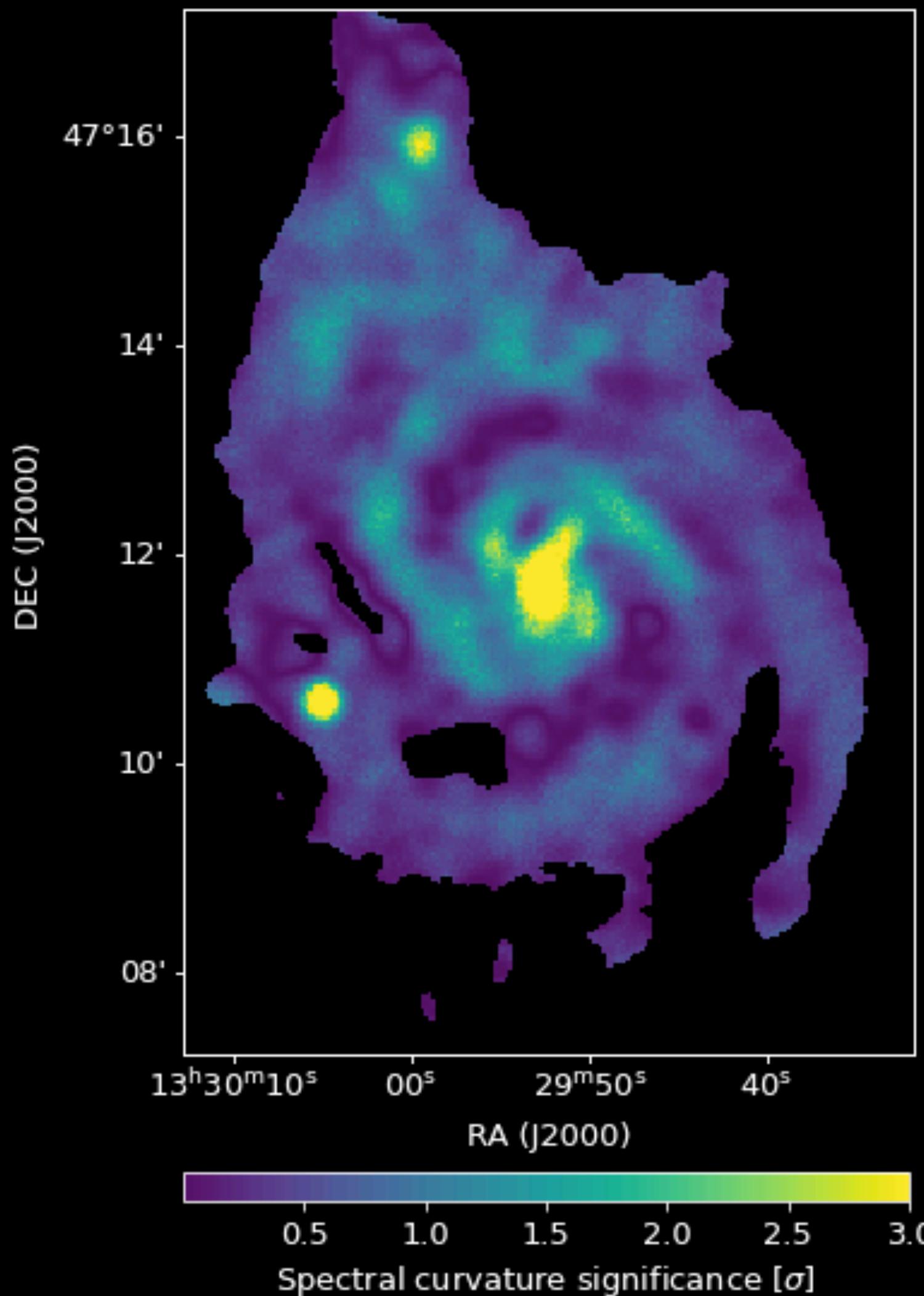


$$\log(S_\nu) = S_0 + \alpha \log(\nu) + c \log^2(\nu)$$

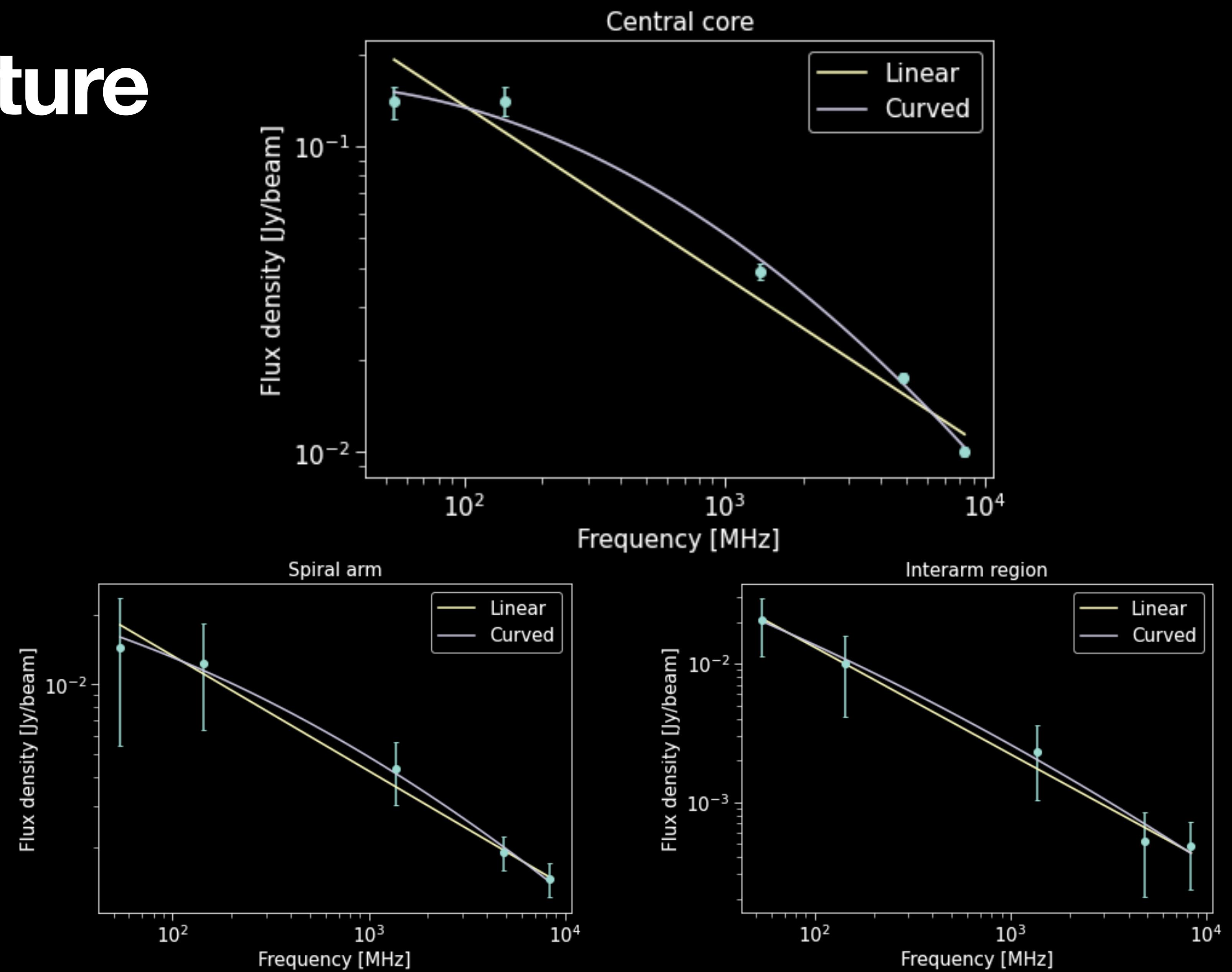
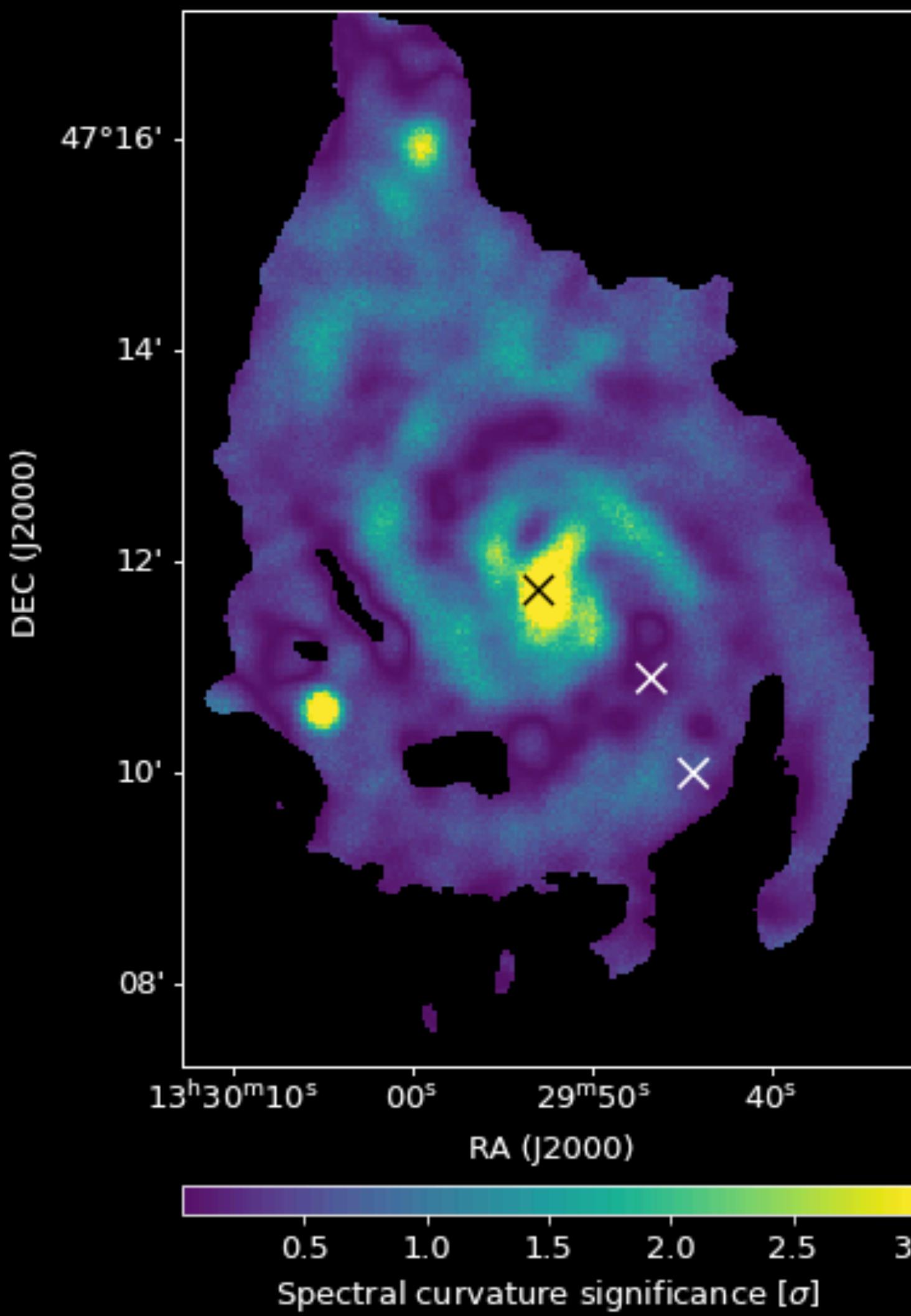
← Spectral index at 1.4 GHz →  
Spectral curvature



# Spectral curvature significance



# Spectral curvature



# Fitting the free-free absorption model

Synchrotron radiation  
including free–free absorption  
(Adebahr et al. 2013)

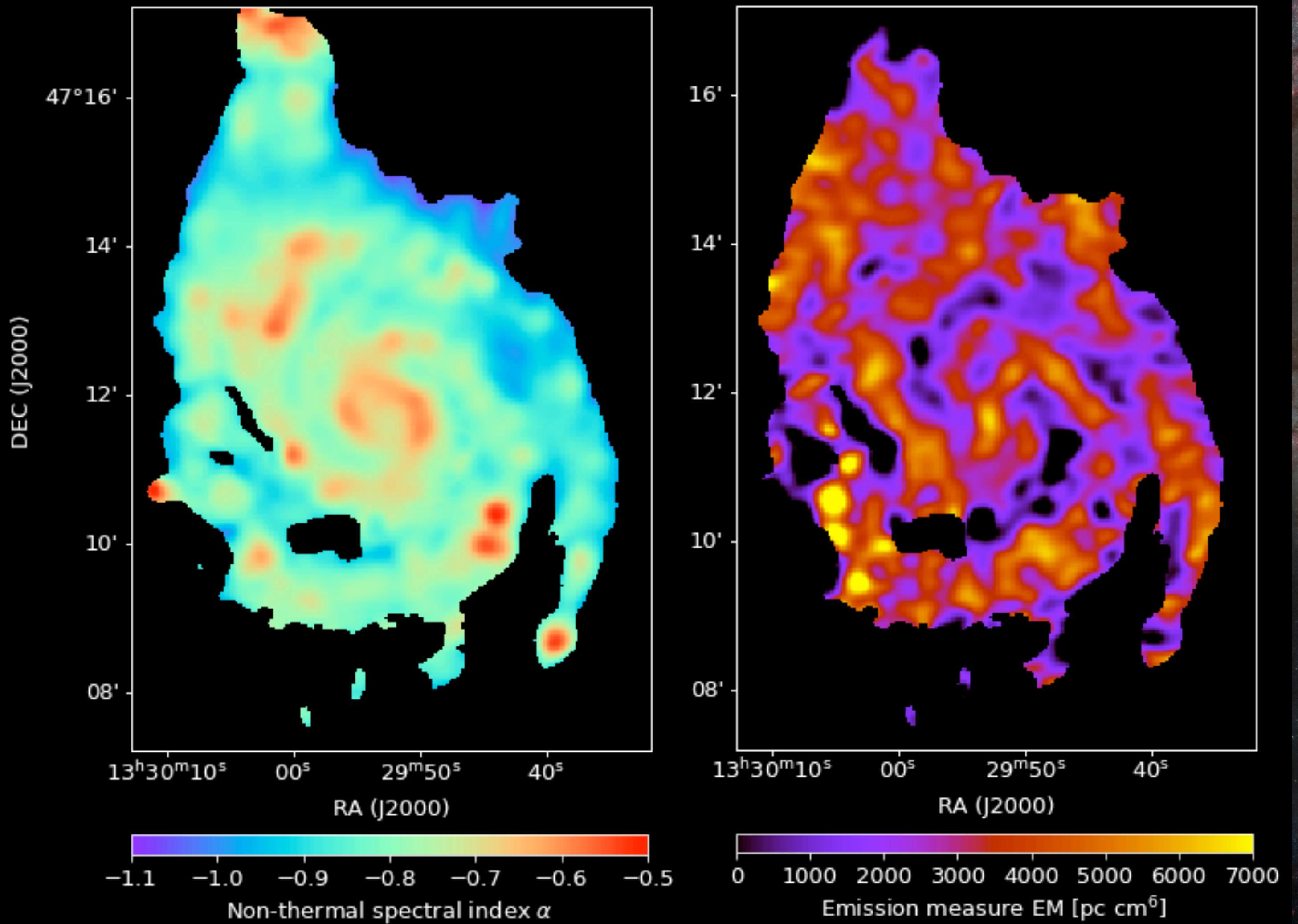
$$S = S_0 \left( \frac{\nu}{\nu_0} \right)^\alpha e^{-\tau}$$

$$\tau = \frac{8.2 \times 10^{-2} \nu^{-2.1} EM}{T_e^{1.35}}$$

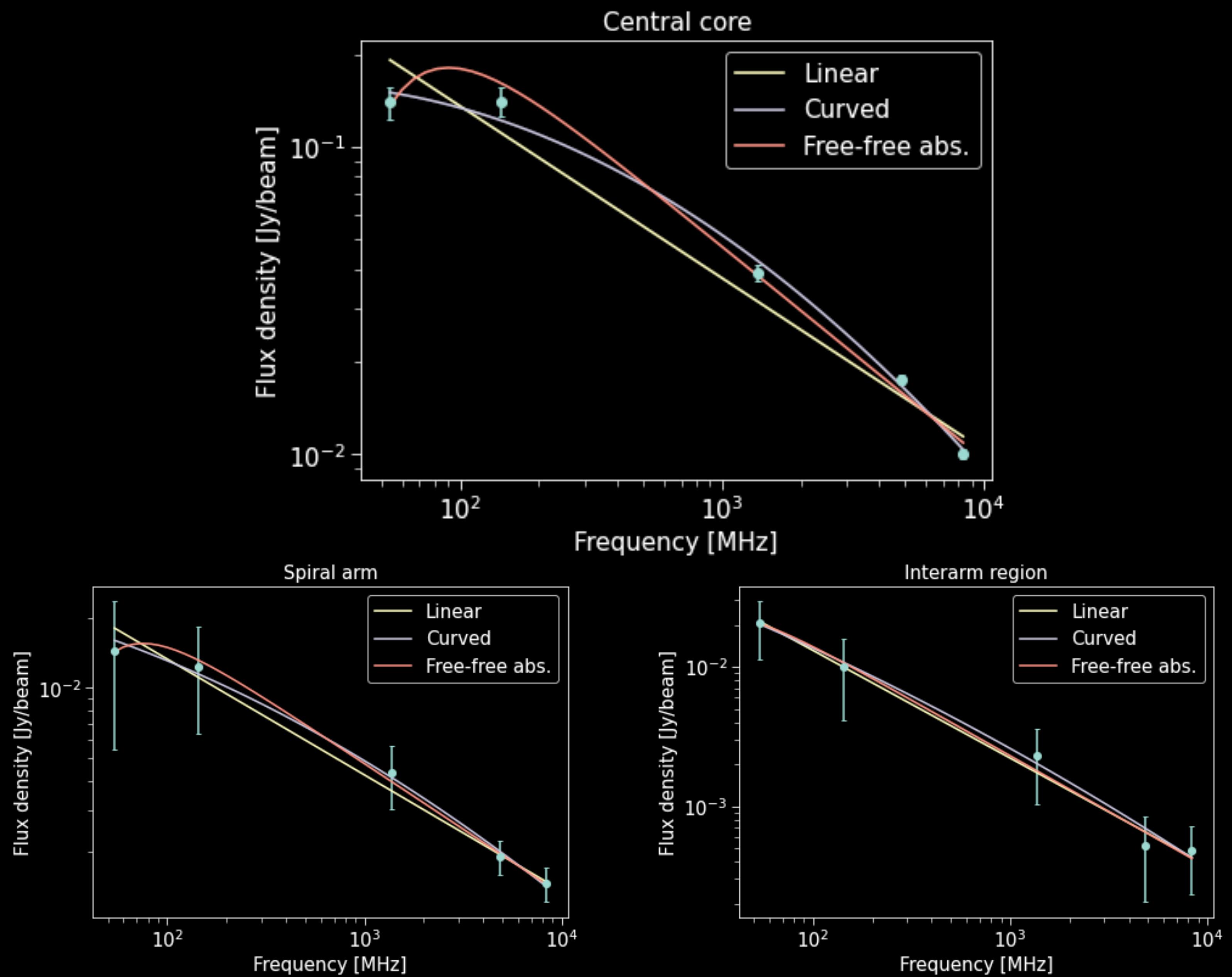
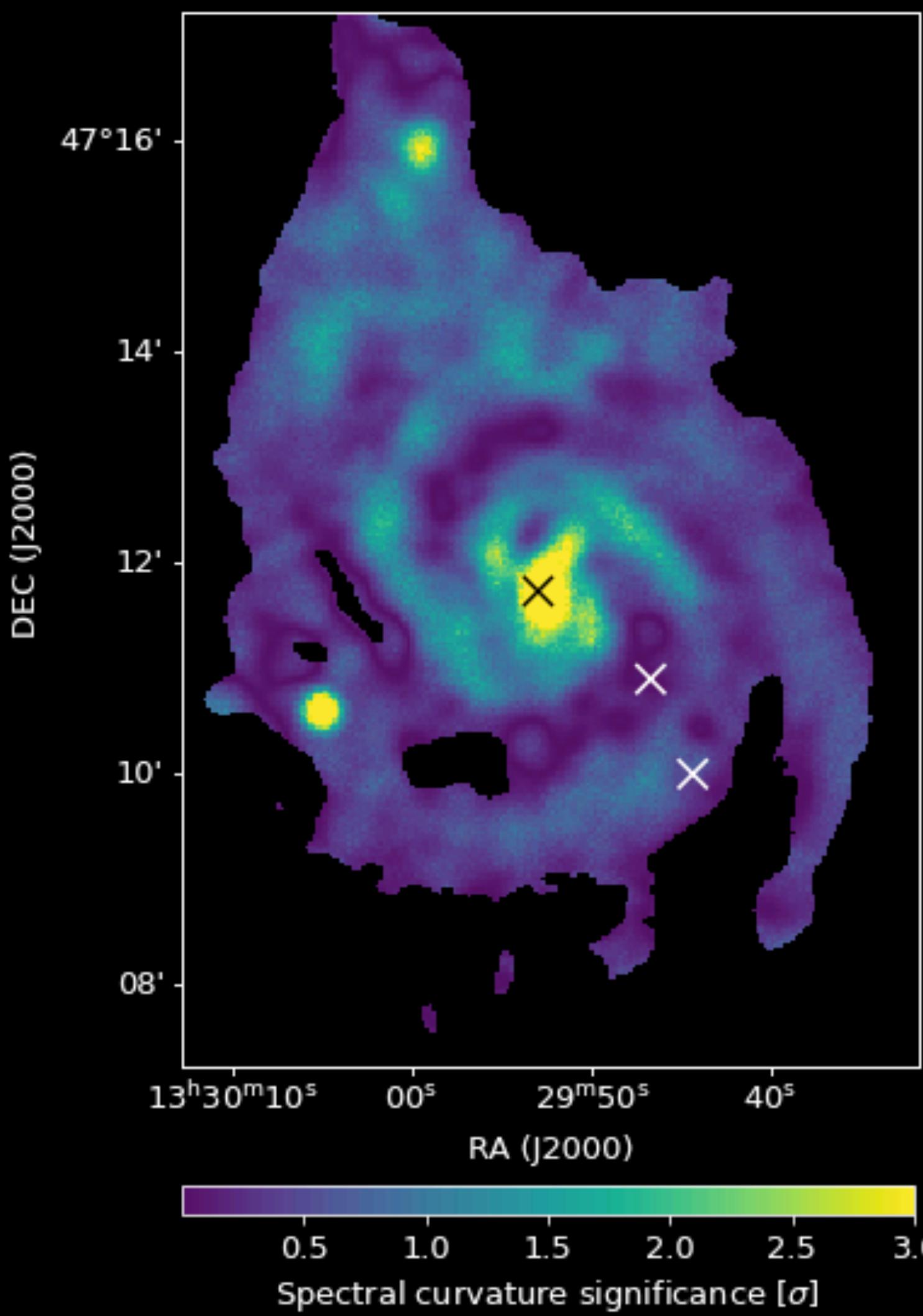
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$$\tau = \frac{8.2 \times 10^{-2} \nu^{-2.1}}{T_e^{1.35}} EM$$



# Spectra



# Summary and conclusion

- Significant spectral curvature in the spiral arms and central region of M51
- Fitting the free-free absorption model to find the emission measure

## Next steps

- Explore different absorption models
- Fit the temperature
- Make the same analysis on other galaxies with LBA data, starting with M101

# Fitting the absorbing screen model

Synchrotron power law with an internal free–free absorbing screen (Tingay & de Kool, 2003 and Kapińska et al. 2017)

$$S_\nu = S_0 \left( \frac{\nu}{\nu_0} \right)^\alpha \left( \frac{1 - e^{-\tau_{\text{ff}}(\nu)}}{\tau_{\text{ff}}(\nu)} \right)$$

$$\tau_{\text{ff}}(\nu) = (\nu / \nu_{\tau=1})^{-2.1}$$

