

# RESOLVING SMALL-SCALE METALLICITY FLUCTUATIONS FROM LOCAL GALAXIES TO COSMIC NOON

Benjamin Metha (he/him) | February 09, 2023



# METALLICITY MODELS OVER TIME

<1971



NO MODEL

Galaxies are assumed to  
have constant Z

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$\nabla Z$  DISCOVERED

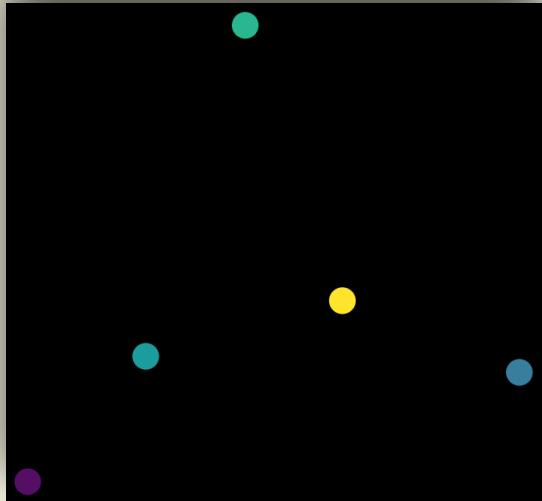
Z found to decrease  
with radius

# METALLICITY DATA OVER TIME

Metal rich



Metal poor



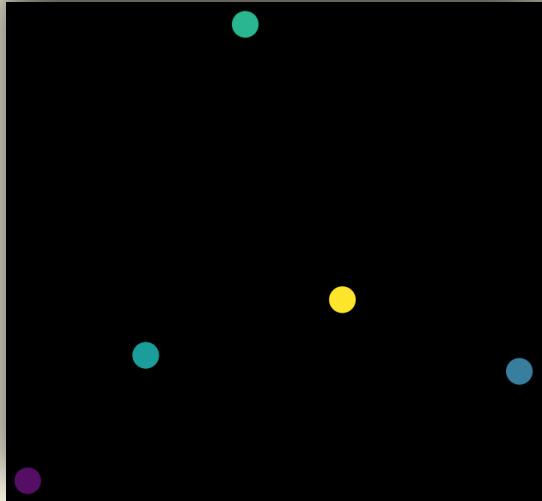
Searle+71: Slit spectroscopy

# METALLICITY DATA OVER TIME

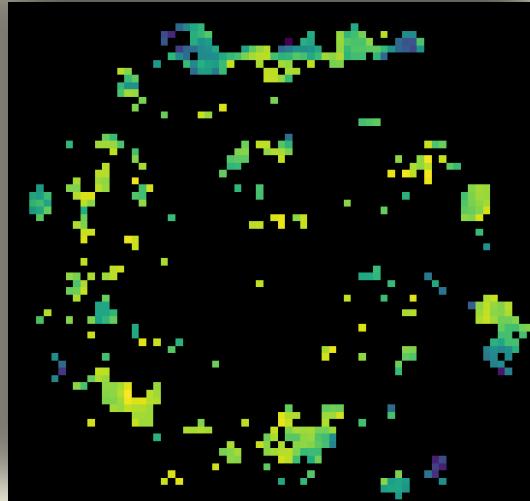
Metal rich



Metal poor



Searle+71: Slit spectroscopy



CALIFA (2012): kpc-scale

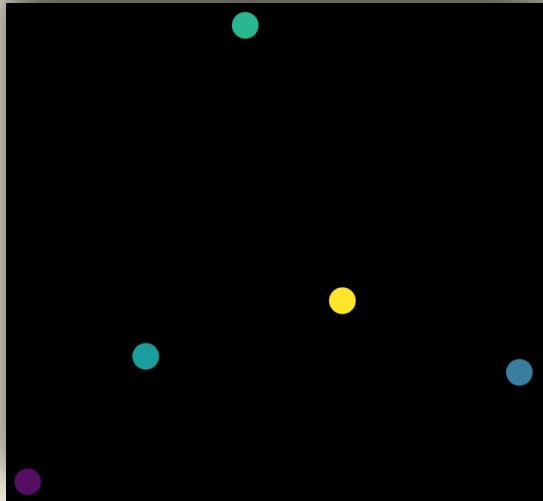
IFU

# METALLICITY DATA OVER TIME

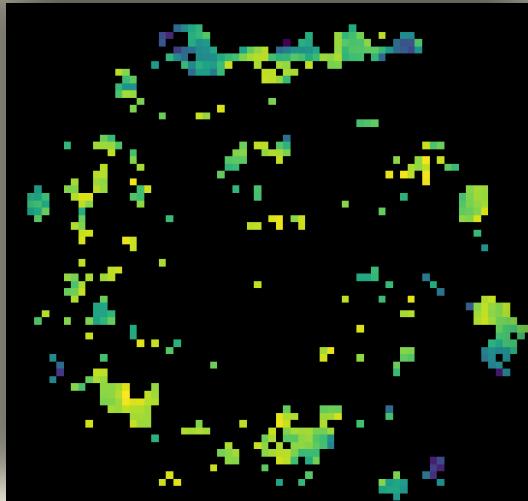
Metal rich



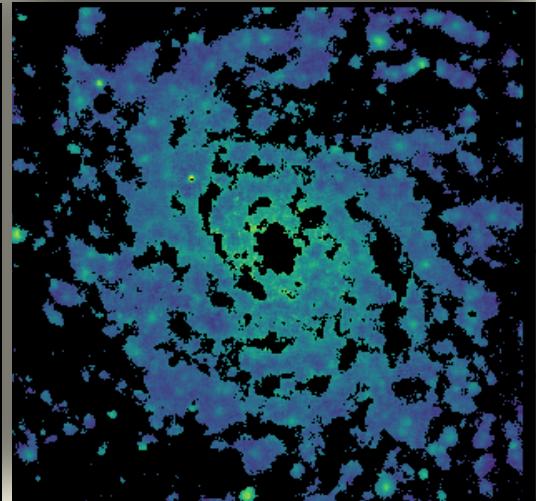
Metal poor



Searle+71: Slit spectroscopy



CALIFA (2012): kpc-scale  
IFU



MUSE (2020):  $\sim 10$  pc  
resolution!

# METALLICITY MODELS OVER TIME

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2021

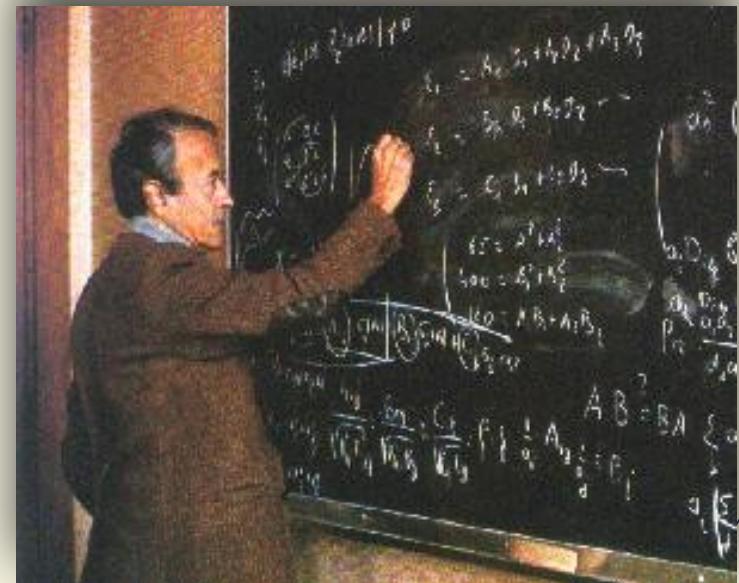


GEOSTATISTICS

A new generation of models for  
a new generation of data

# WHAT IS GEOSTATISTICS?

“GEOSTATISTICS IS THE STUDY OF A **RANDOM PROCESS** THAT VARIES OVER A **SPATIAL DOMAIN** IN A PREDICTABLE WAY”



Georges Matheron. Image credit:  
Centre de Geosciences

# HIERARCHICAL MODELLING

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Process mean:  
accounts for the metallicity gradient

# HIERARCHICAL MODELLING

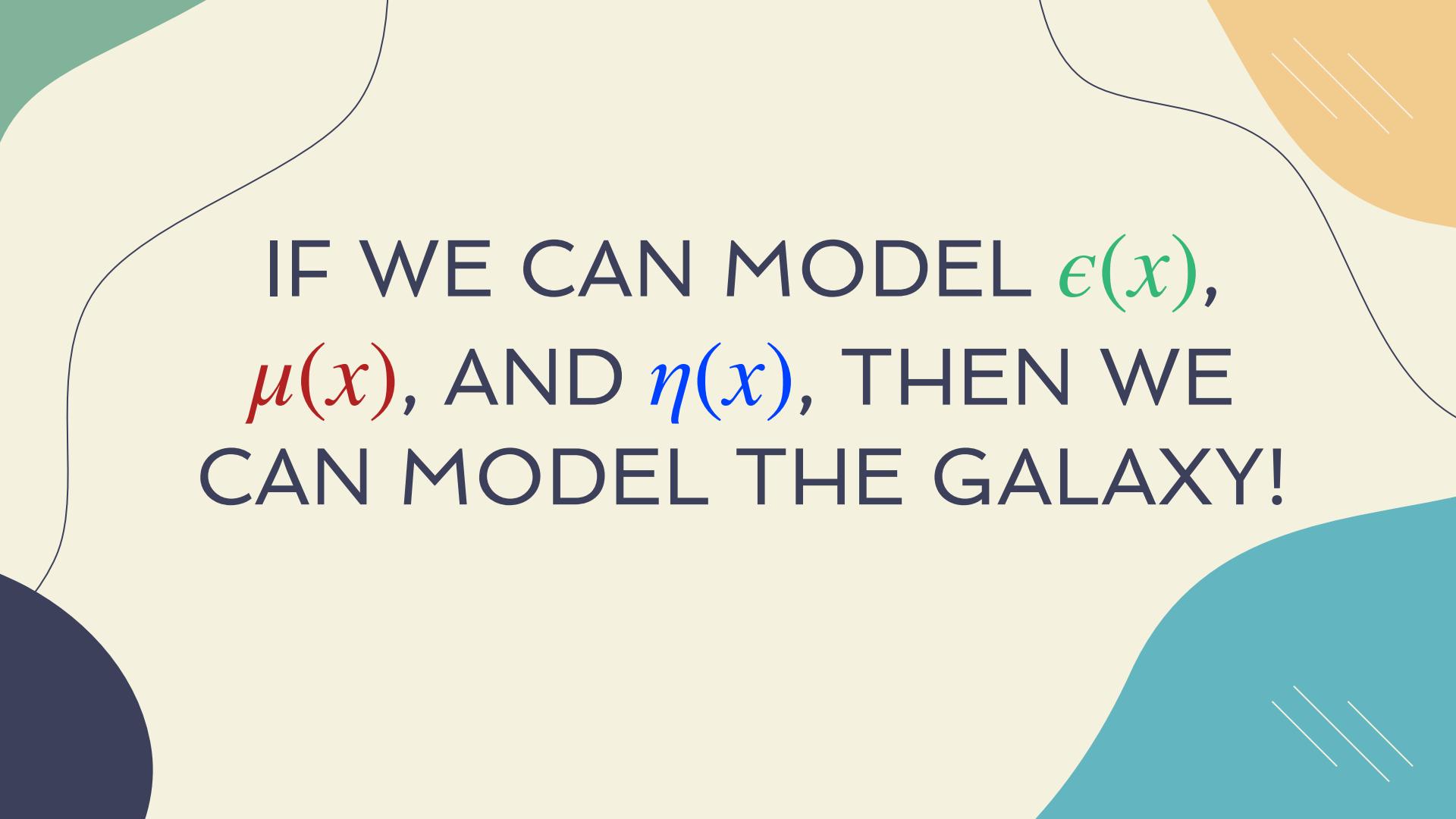
$$Z_{obs}(x) = Z_{true}(x) + \epsilon(x)$$

Observation error:  
known from telescope properties

$$Z_{true}(x) = \mu(x) + \eta(x)$$

Process mean:  
accounts for the metallicity gradient

Random fluctuations:  
spatially-correlated deviations



IF WE CAN MODEL  $\epsilon(x)$ ,  
 $\mu(x)$ , AND  $\eta(x)$ , THEN WE  
CAN MODEL THE GALAXY!

# SEPARATING SMALL FEATURES FROM NOISE

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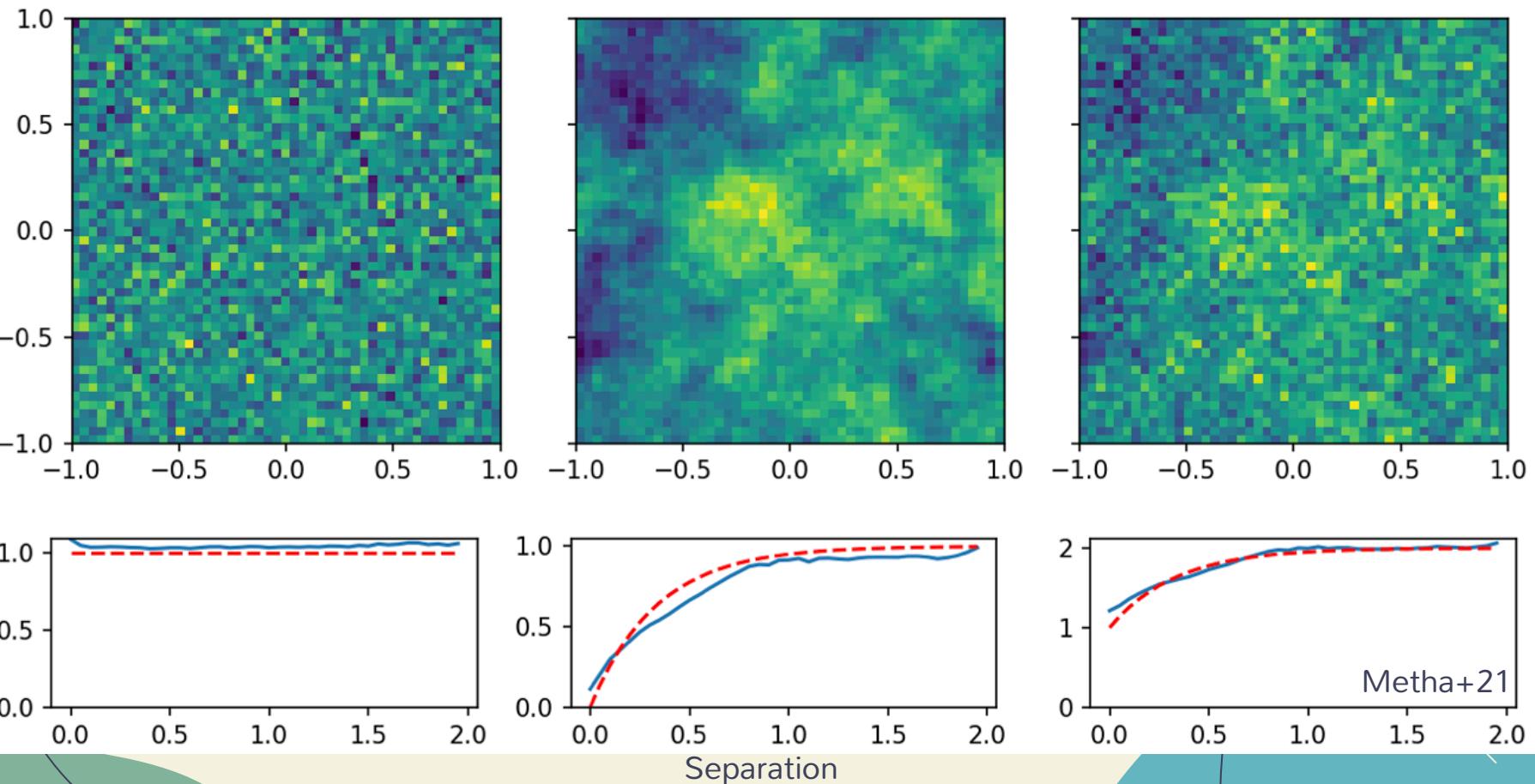
A **semivariogram** shows how the **variance between data points** depends on their **distance**.

# SEPARATING SMALL FEATURES FROM NOISE

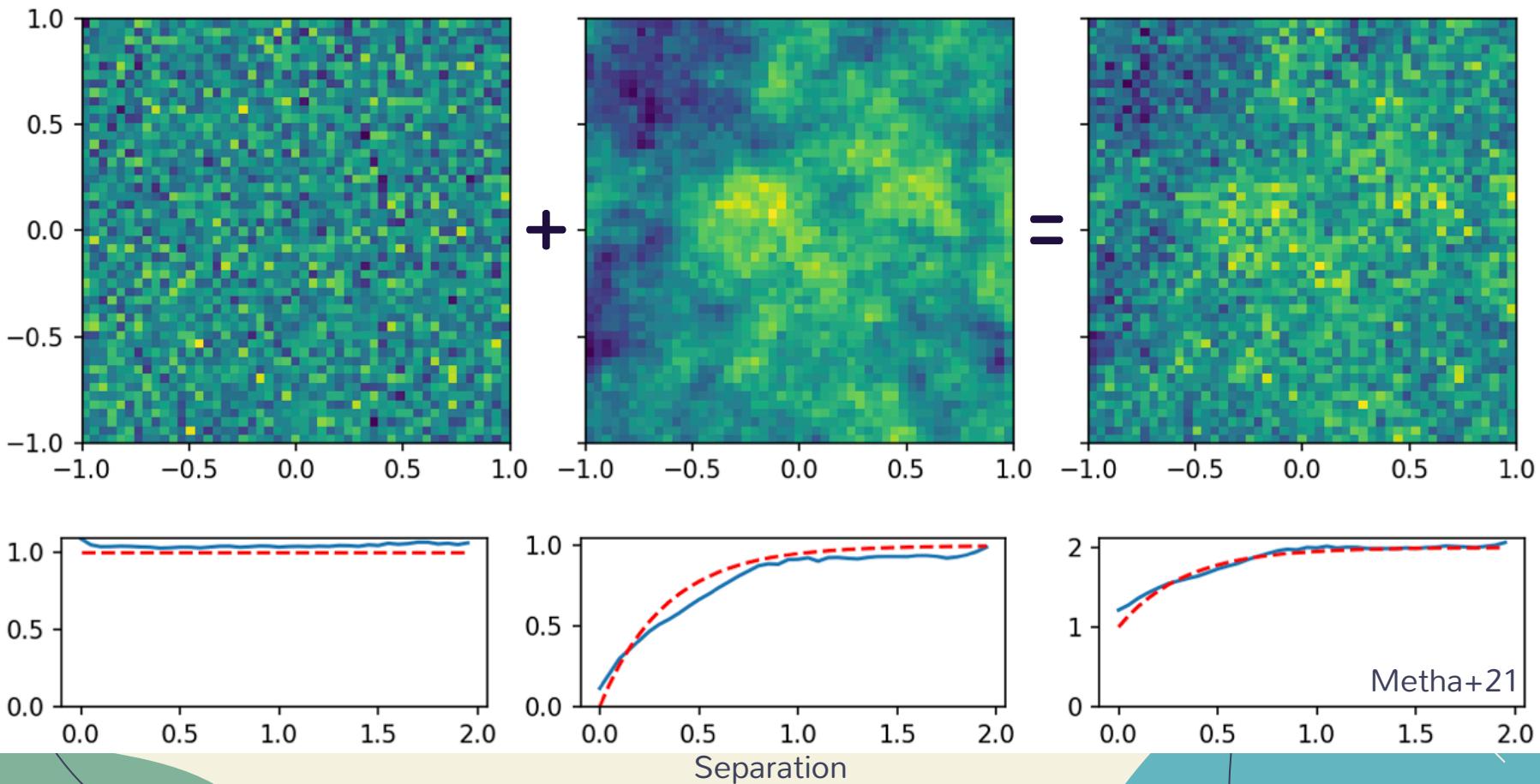
A **semivariogram** shows how the **variance between data points** depends on their **distance**.

This lets us distinguish **spatially correlated** and **uncorrelated** sources of scatter around  $\mu(x)$ .

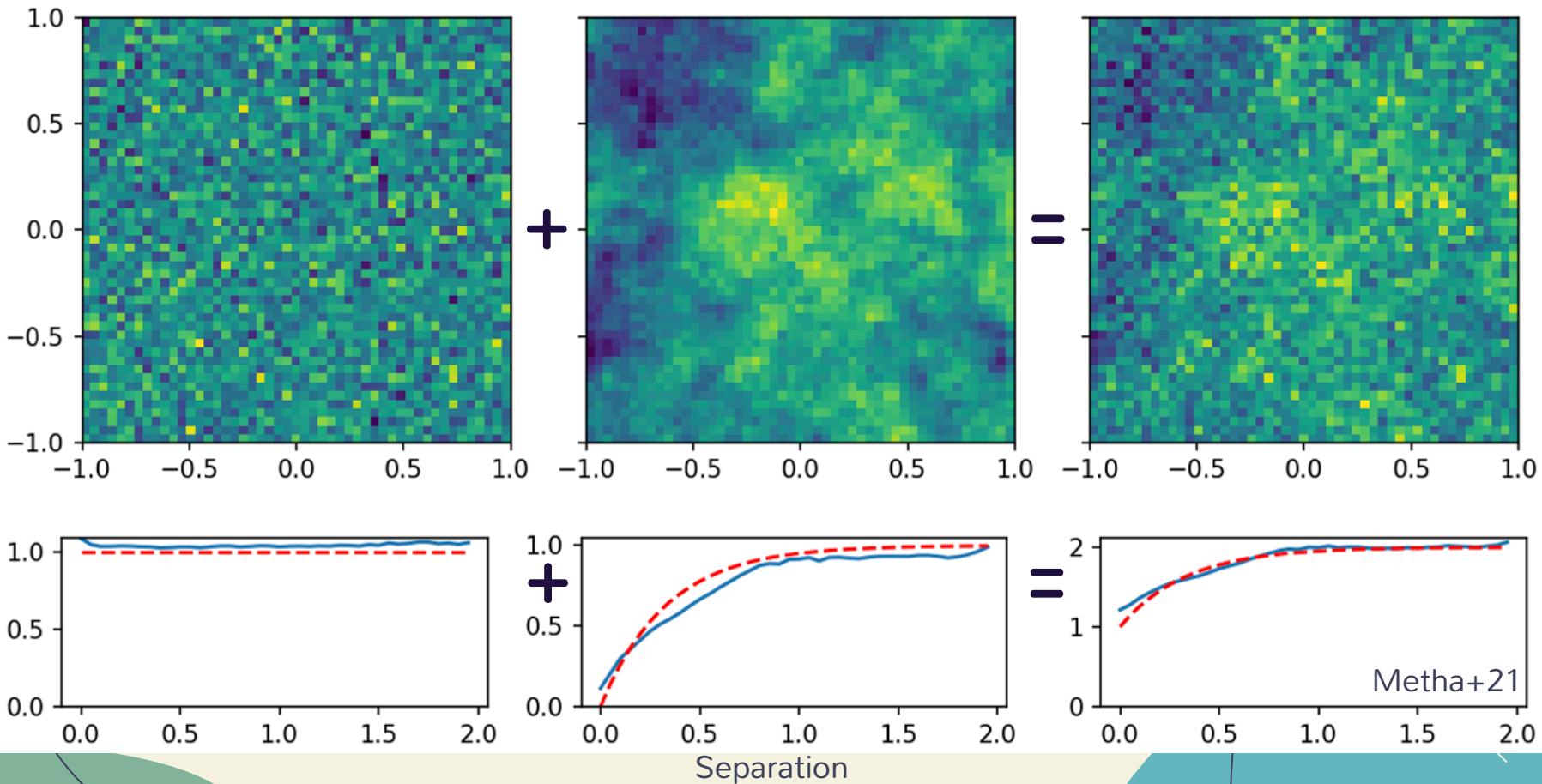
# A WORKED EXAMPLE



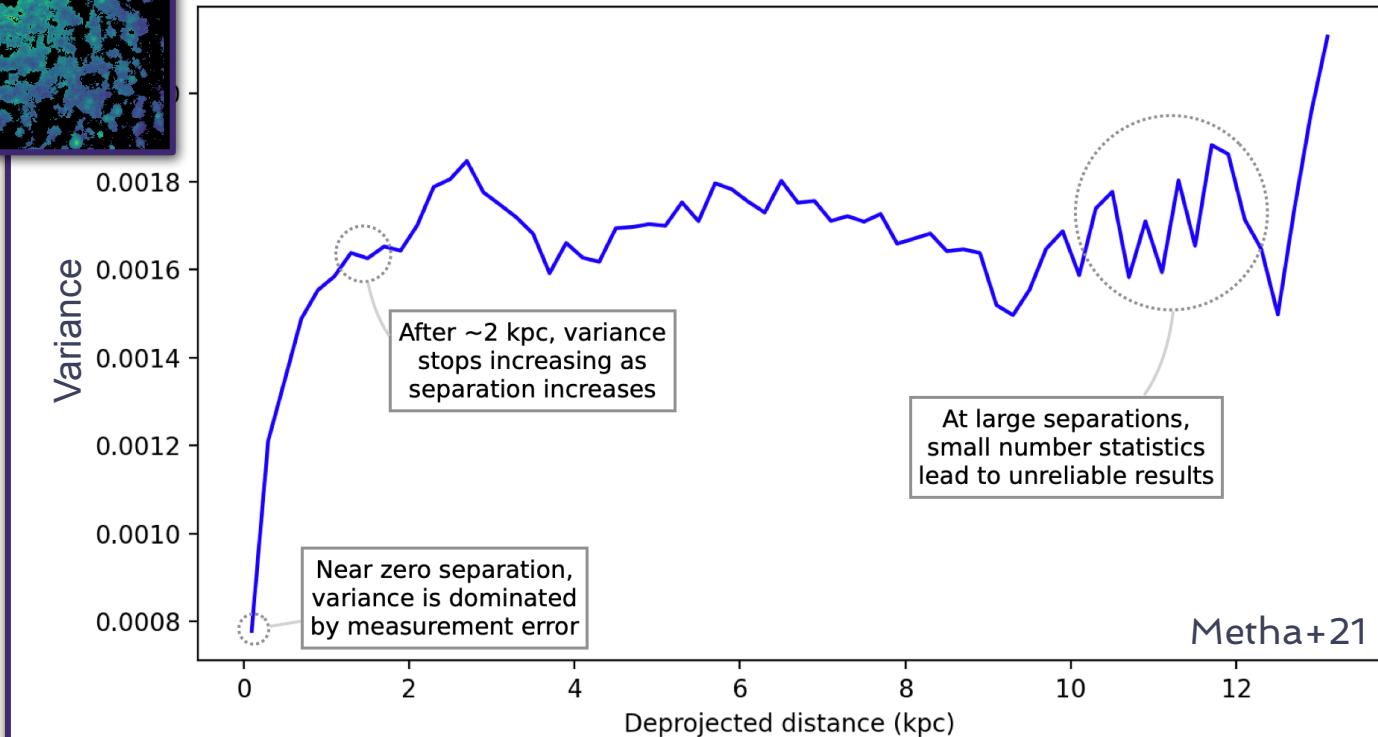
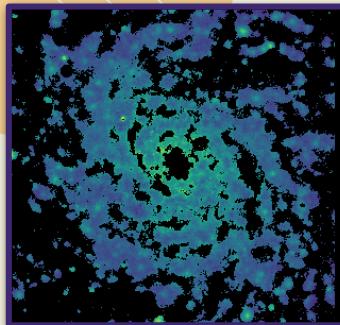
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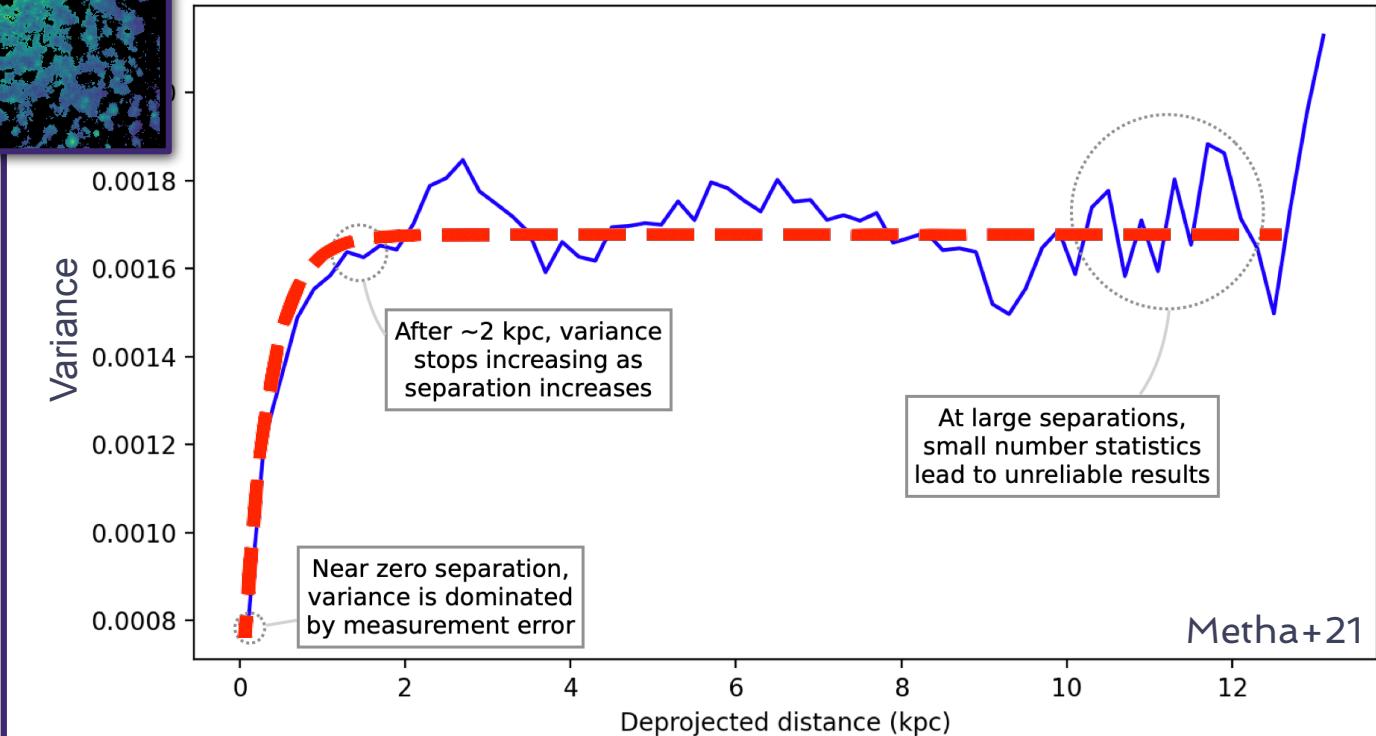
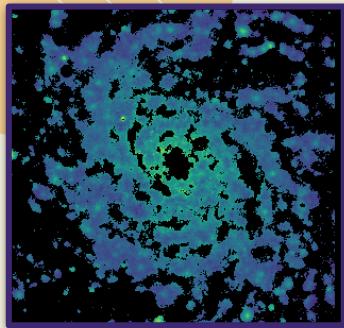
# A WORKED EXAMPLE



# ON REAL DATA

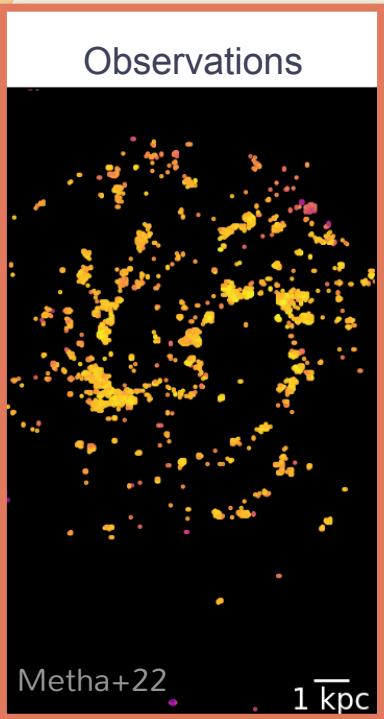


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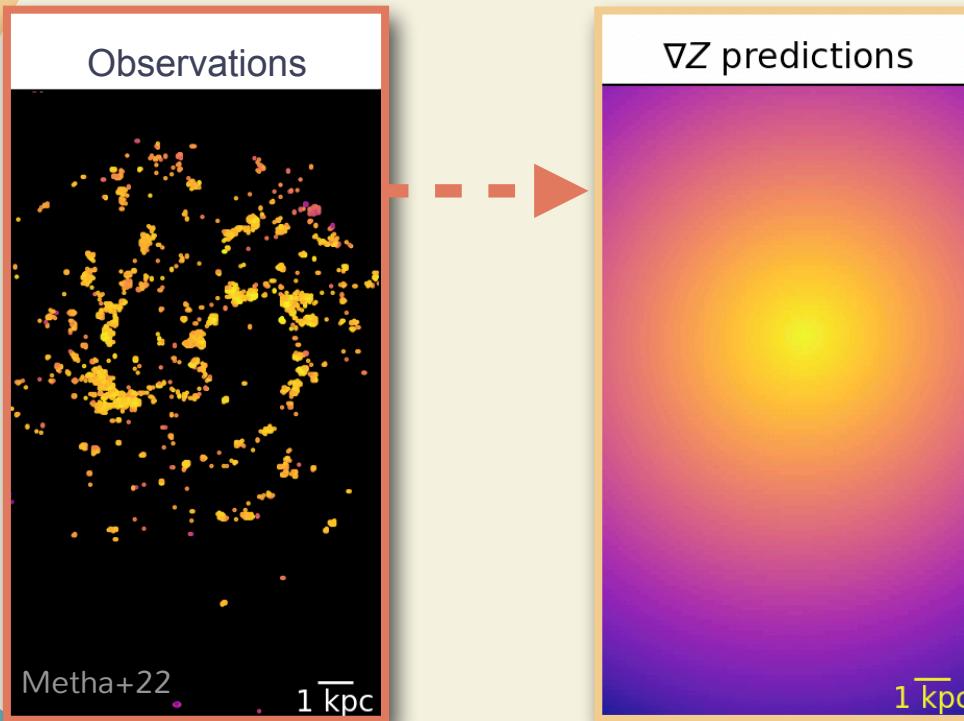
# ARE GEOSTATISTICAL MODELS BETTER?

# GEOSTATISTIC MODELS → MORE DETAILS

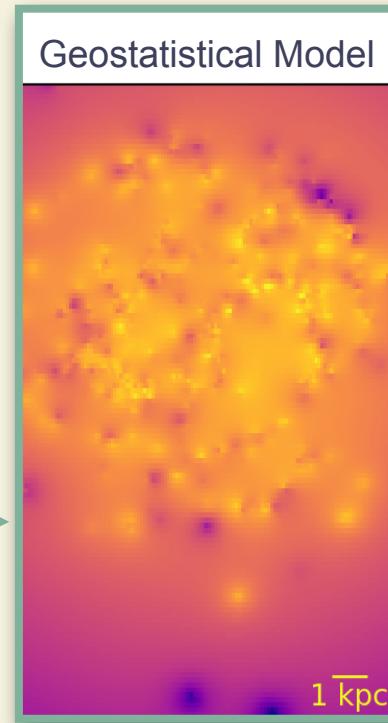
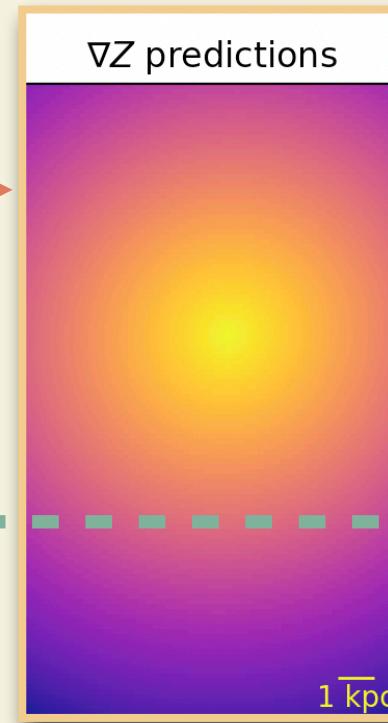
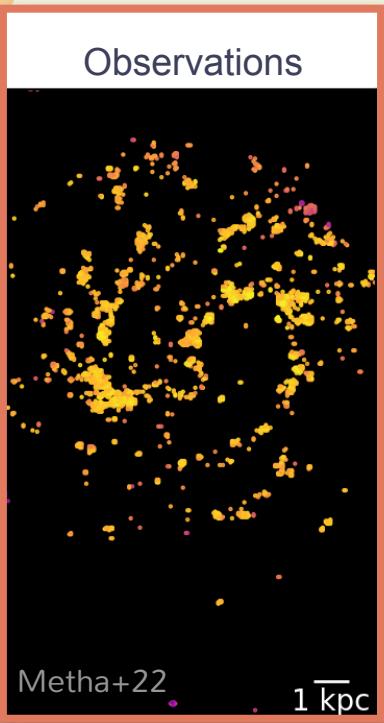
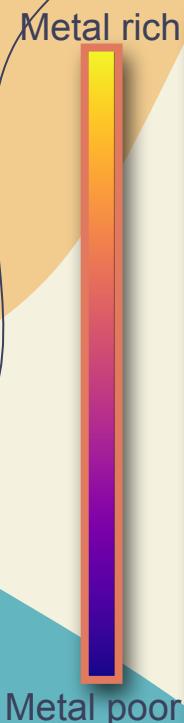


# GEOSTATISTIC MODELS → MORE DETAILS

Metal rich  
  
Metal poor

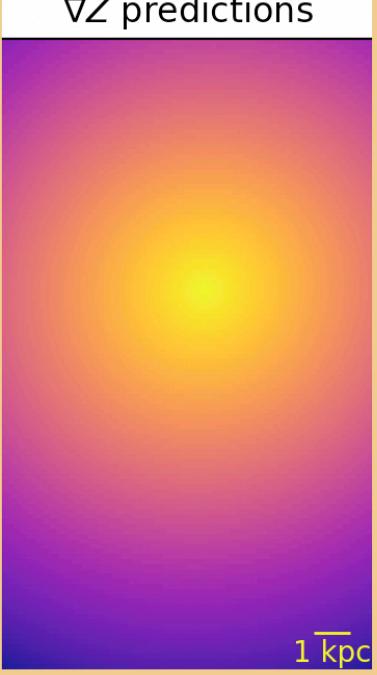


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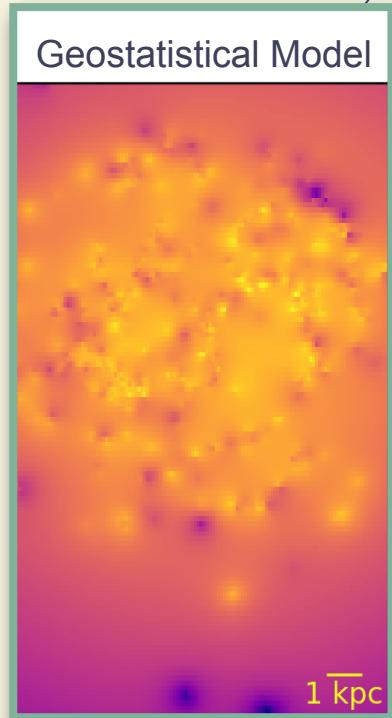


# GEOSTATISTIC MODELS → BETTER PREDICTIONS

$\nabla Z$  predictions

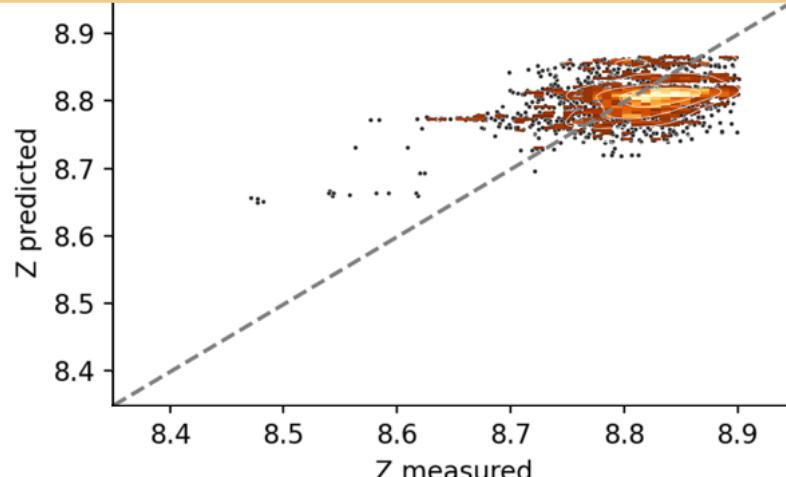


Geostatistical Model

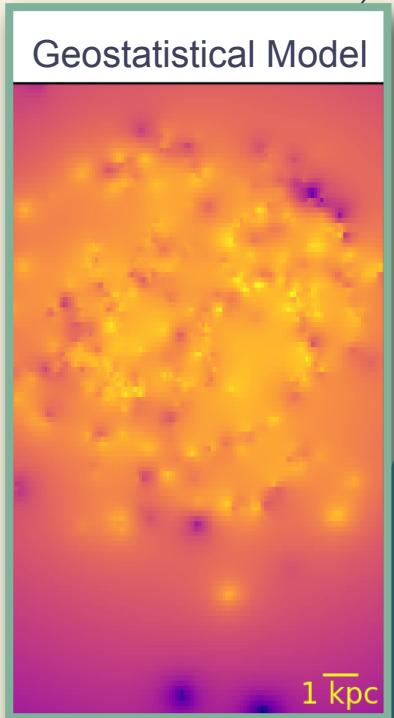


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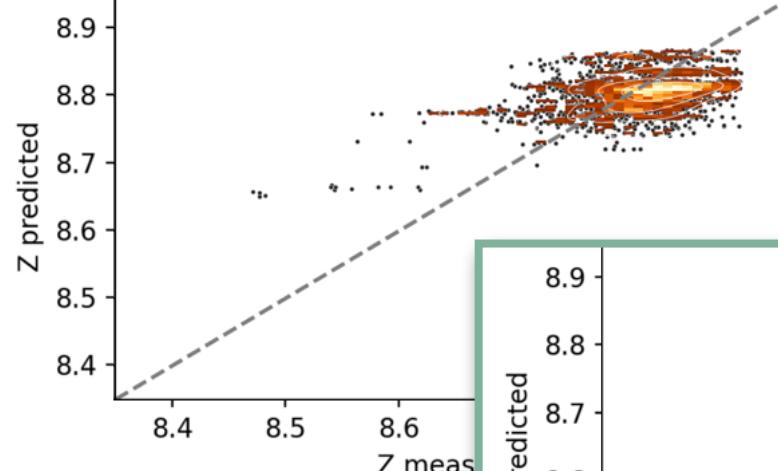
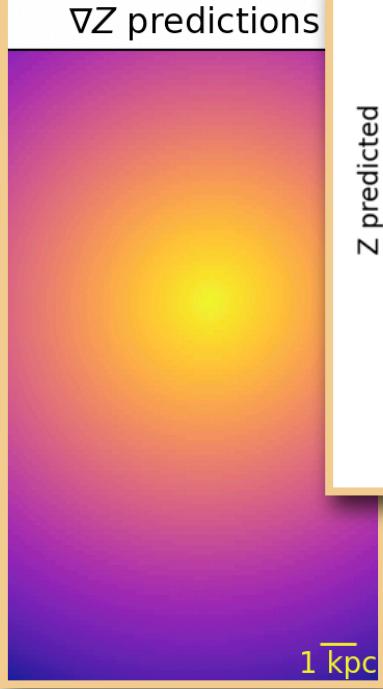


Geostatistical Model

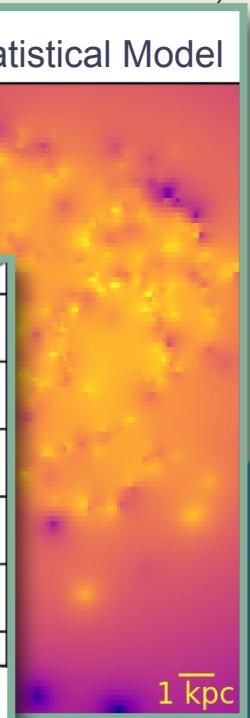
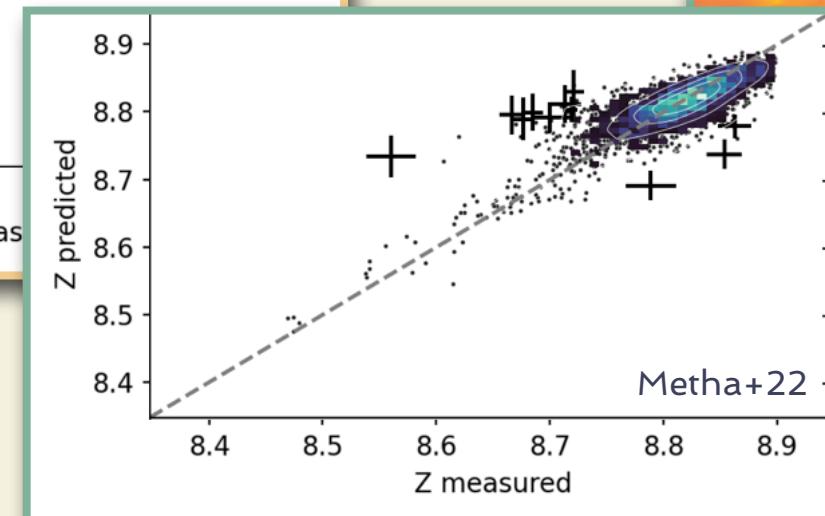


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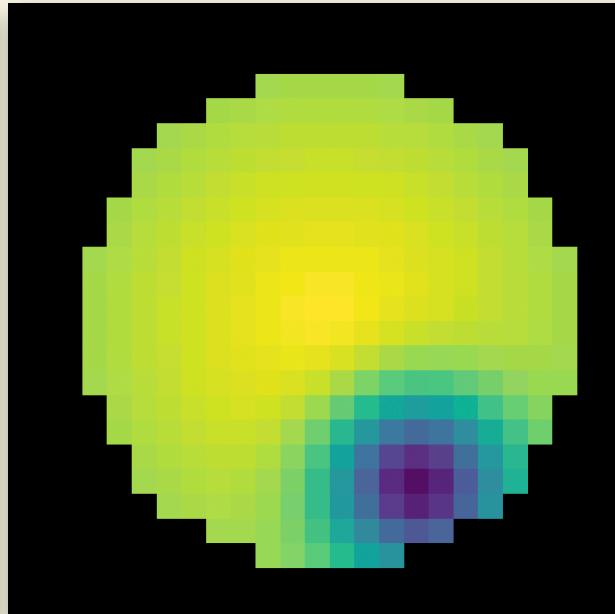
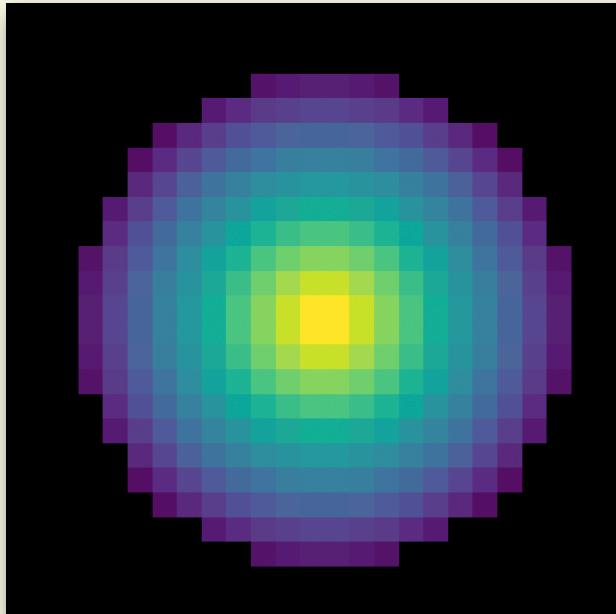
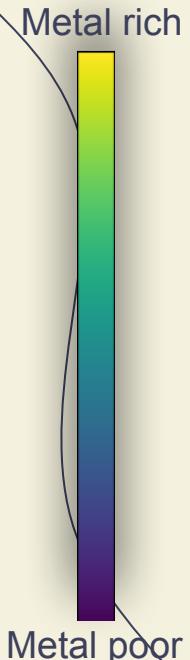


Geostatistical Model



# GEOSTATISTIC MODELS → HIGH-Z SCIENCE

Does gas accrete smoothly or in clumps?



Are feedback processes in high redshift galaxies the same as in low redshift galaxies?

Do “clumpy” galaxies have clumpy metallicity profiles?

Does the ISM of galaxies become more or less homogeneous with time?

These questions cannot be answered with a metallicity gradient!

# CHALLENGES AT HIGH REDSHIFT

LOW SURFACE  
BRIGHTNESS



COARSE  
RESOLUTION

PSF-  
SMEARING



# JWST-GLASS IS INCREDIBLE



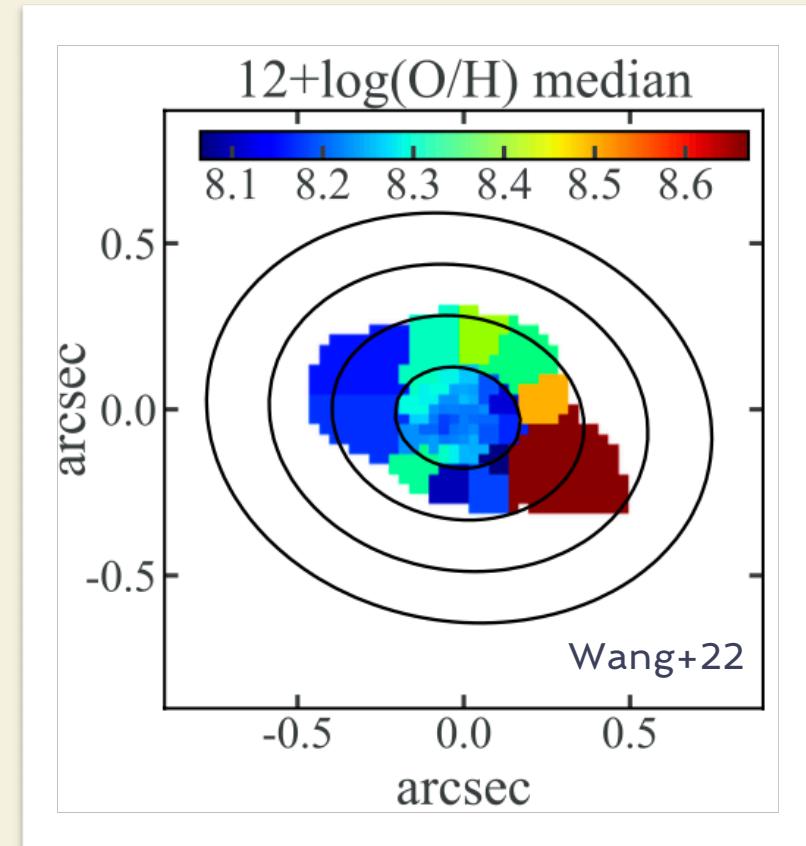
## JWST SENSITIVITY

NIRISS can do resolved spectroscopy on  $m_{AB} < 24$  targets!



## GRAVITATIONAL LENSING

Magnification improves resolution and sensitivity.

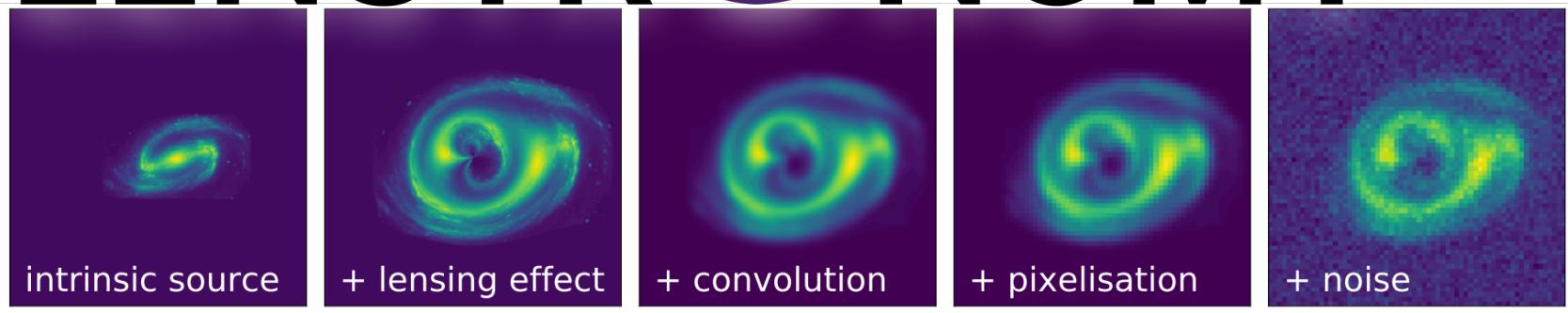


FORWARD MODELLING

**LENSTR****NOMY**

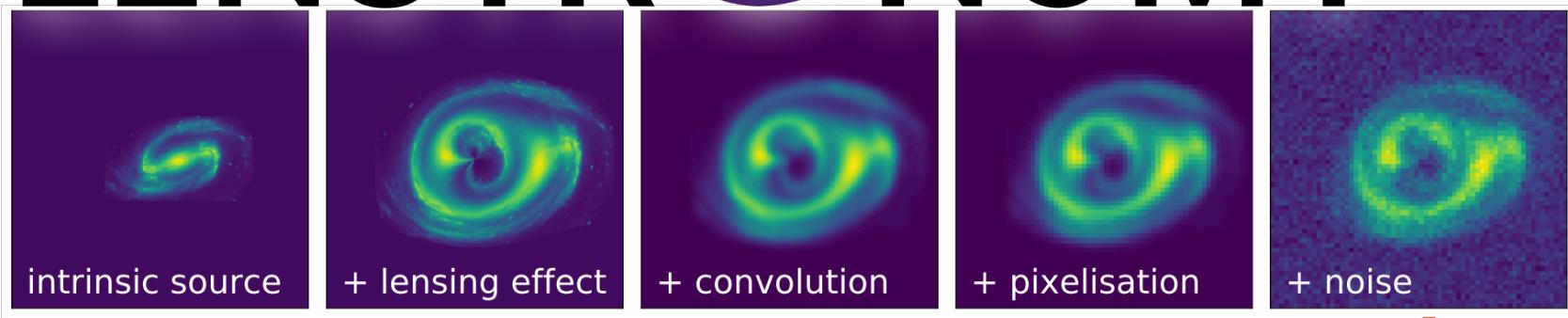
# FORWARD MODELLING

# LENSTR<sup>ON</sup>OMY



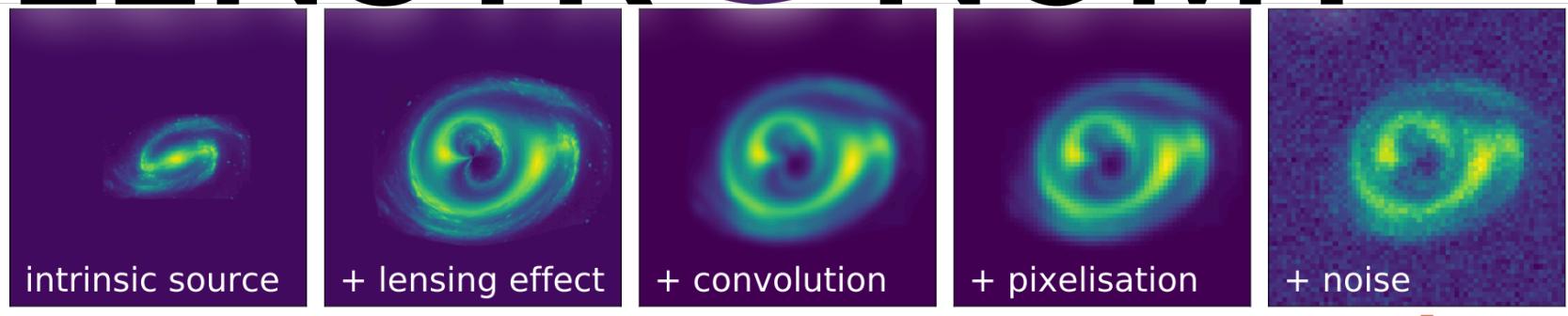
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# LENSTR<sup>ON</sup>OMY



# FORWARD MODELLING

# LENSTR<sup>o</sup>NOMY



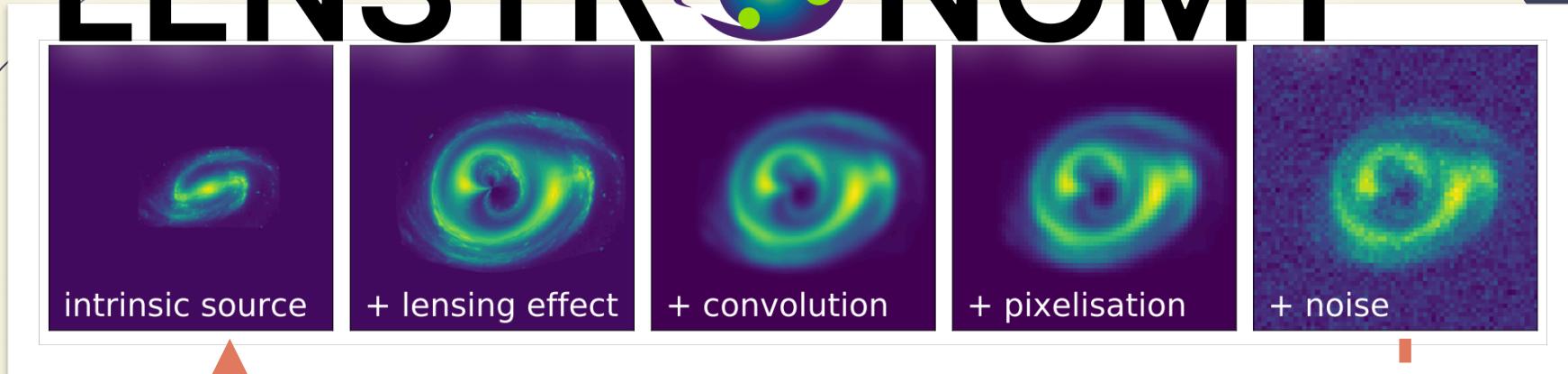
BETTER  
MODELS



REAL  
DATA

# FORWARD MODELLING

# LENSTR<sup>o</sup>NOMY



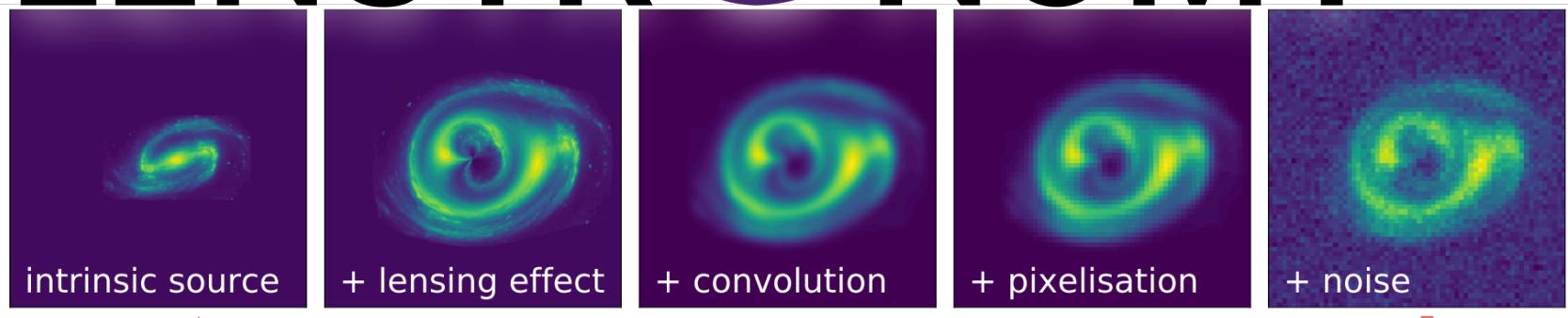
BETTER  
MODELS



REAL  
DATA

# FORWARD MODELLING

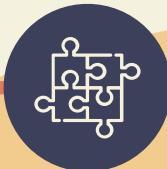
# LENSTRONOMY



UNDER CONSTRUCTION!



BETTER  
MODELS



REAL  
DATA

# PATHWAYS TO HIGH REDSHIFT

LOW SURFACE  
BRIGHTNESS



COARSE  
RESOLUTION

PSF-  
SMEARING



# PATHWAYS TO HIGH REDSHIFT

~~LOW SURFACE  
BRIGHTNESS~~  
~~JWST~~



COARSE  
RESOLUTION

PSF-  
SMEARING



# PATHWAYS TO HIGH REDSHIFT

~~LOW SURFACE  
BRIGHTNESS~~  
JWST



~~COARSE  
RESOLUTION~~  
GRAVITATIONAL  
LENSING

PSF-  
SMEARING



# PATHWAYS TO HIGH REDSHIFT

~~LOW SURFACE  
BRIGHTNESS~~  
JWST

~~PSF-  
SMEARING~~  
FORWARD  
MODELLING



~~COARSE  
RESOLUTION~~  
GRAVITATIONAL  
LENSING

# THANKS!

DO YOU HAVE ANY QUESTIONS?

[methab@student.unimelb.edu.au](mailto:methab@student.unimelb.edu.au)

CREDITS: This presentation template based on a template by Slidesgo, and includes icons by Flaticon and The Noun Project

# WHY NOT A POWER SPECTRUM?

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A **Fourier analysis** will give the same information as a semivariogram if the following assumptions are met:

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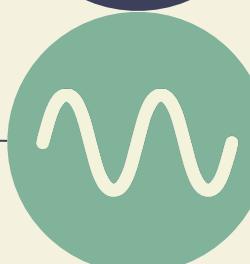
A **Fourier analysis** will give the same information as a semivariogram if the following assumptions are met:

NO MISSING  
DATA



HOMOSKED-  
ASTICITY

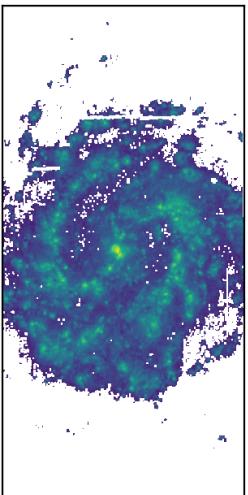
PERIODIC  
SIGNALS



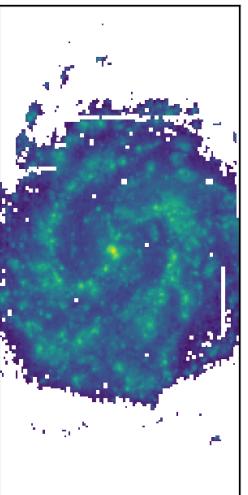
NO EDGES

# RESOLUTION LIMITS

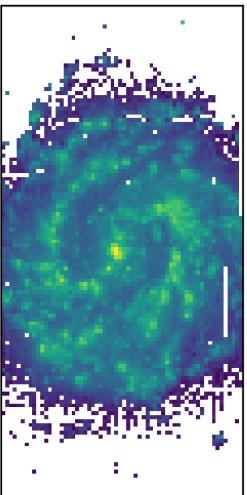
Native resolution



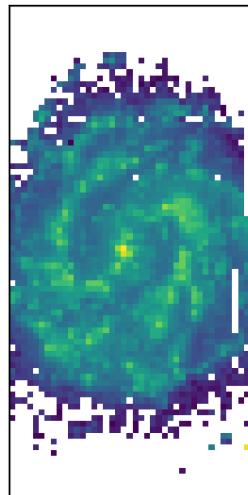
75pc ( $f=2$ )



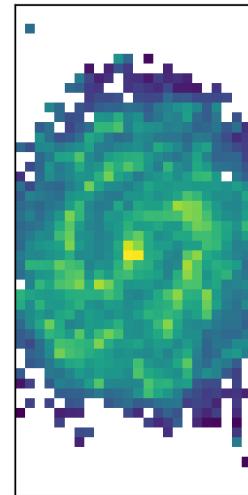
150pc ( $f=4$ )



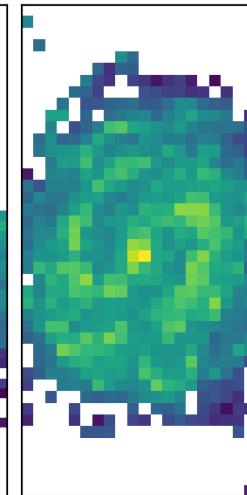
225pc ( $f=6$ )



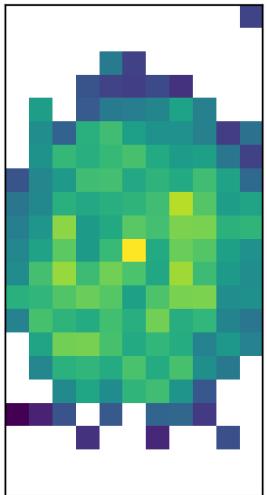
373pc ( $f=10$ )



448pc ( $f=12$ )



895pc ( $f=24$ )



MUSE quality



CALIFA/SAMI/  
MANGA quality

# RESOLUTION LIMITS

