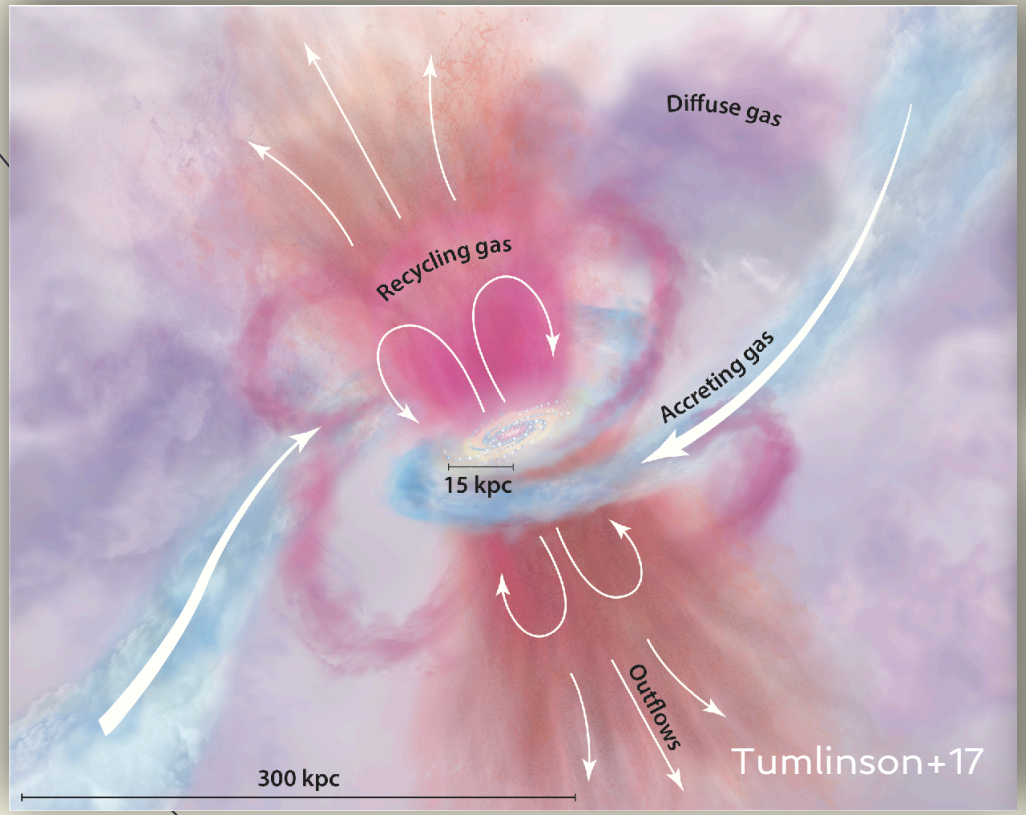
GEOSTATISTICS OF GALAXIES — MAKING THE MOST OF METALLICITY MAPS

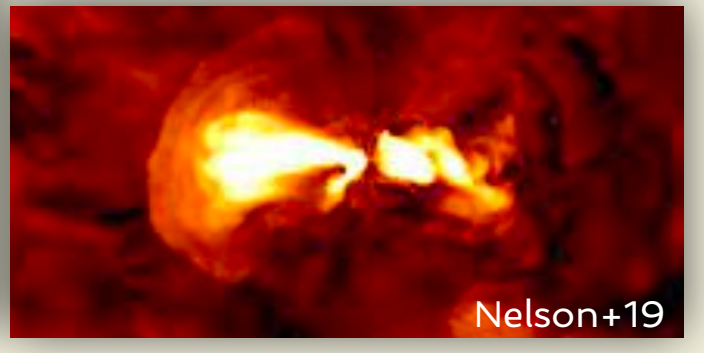
Benjamin Metha (he/him) | December 14, 2023

GALAXIES ARE 3D AND COMPLICATED



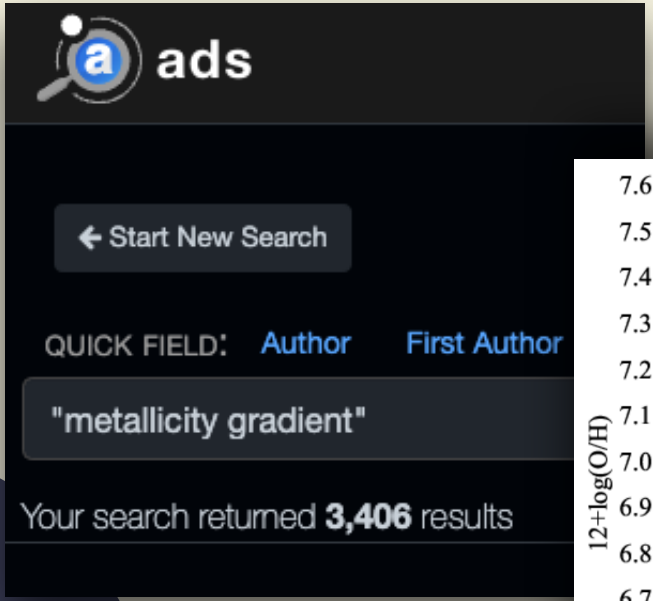
Inflows/outflows

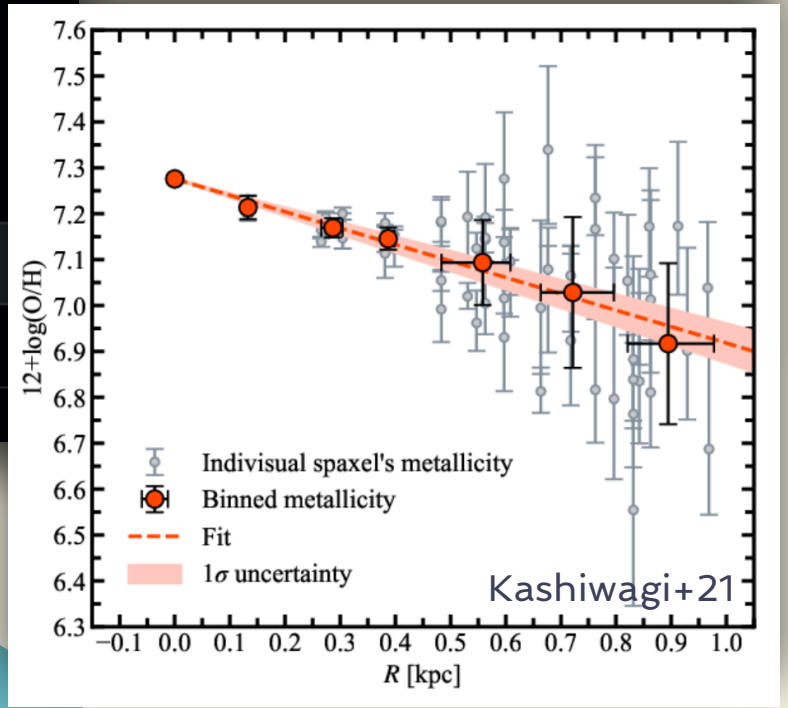
Mergers

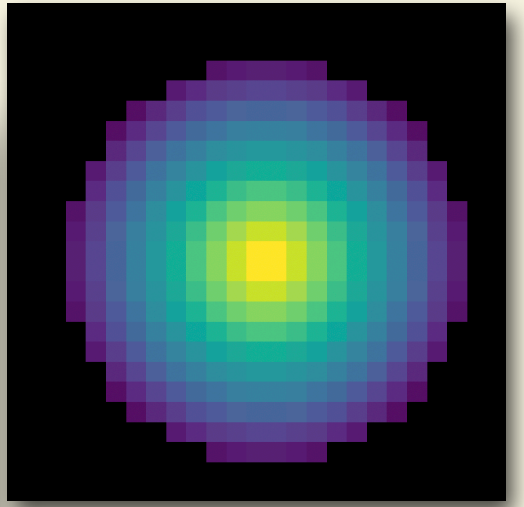


Feedback/Turbulence

OUR MODELS ARE 1D AND SIMPLE







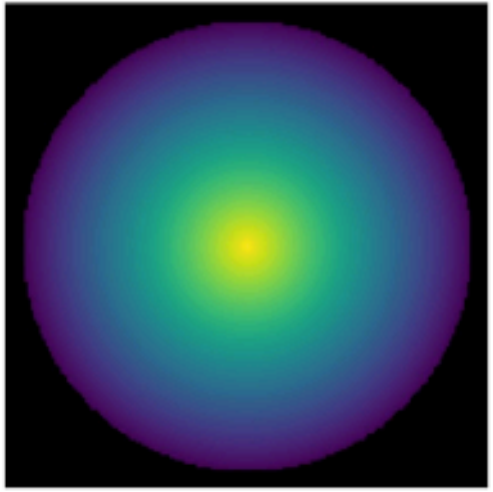
=> inside-out

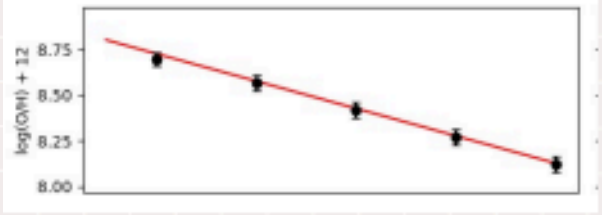
galaxy formation

The Metallicity Gradient can't distinguish...

a smooth, linear profile

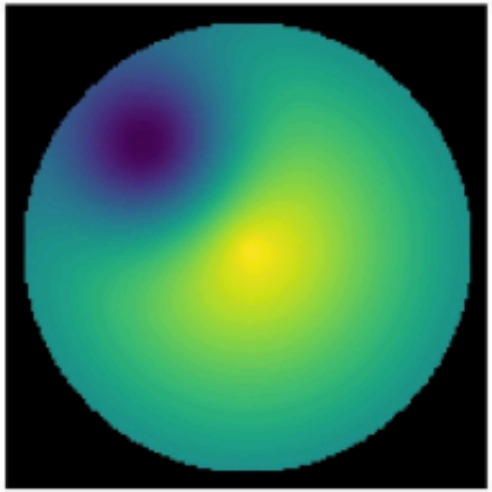
indicative of secular evolution and inside-out star formation

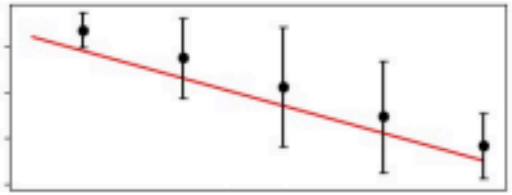




large-scale structure

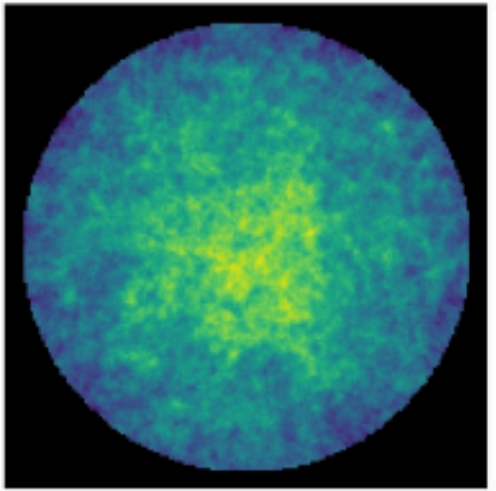
indicative of e.g. recent minor mergers, or extreme outflows

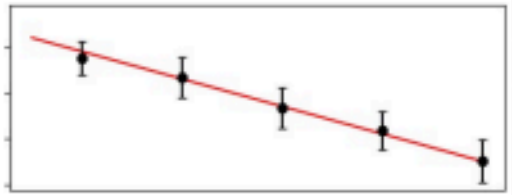




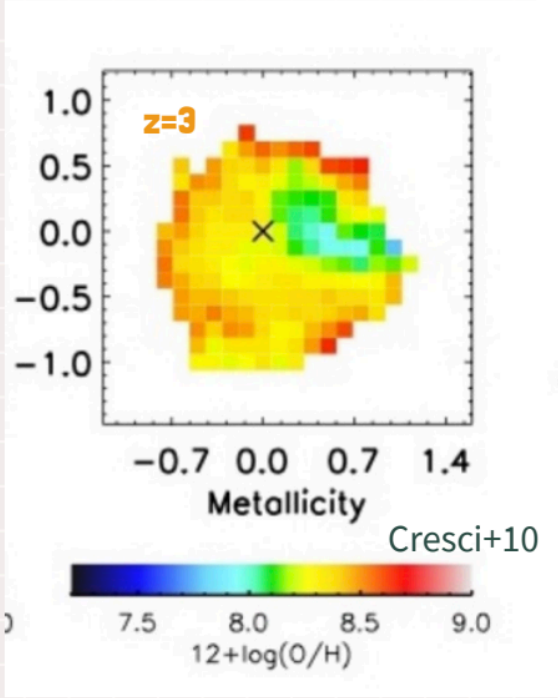
small-scale substructure

indicative of inefficient mixing, constraining SNe-driven feedback

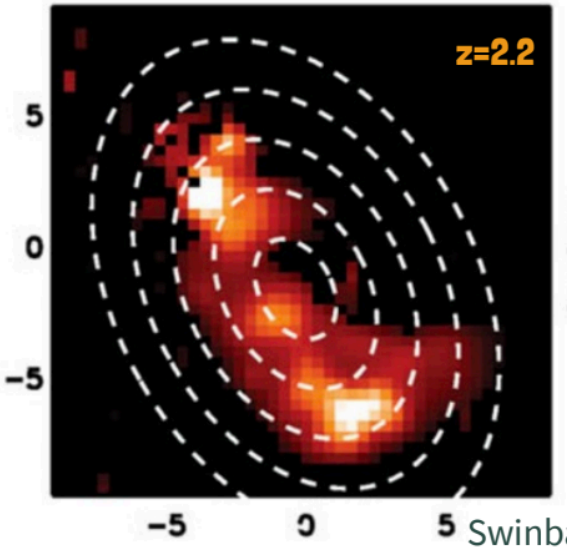




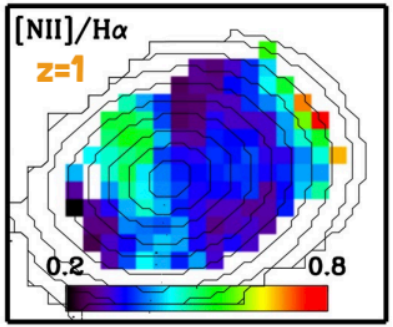
Galaxies at cosmic noon aren't smooth!



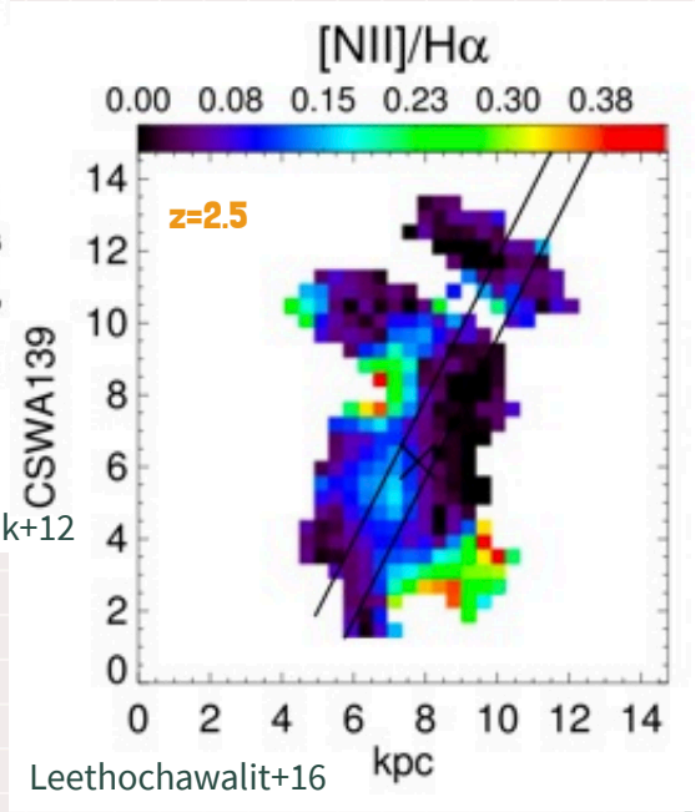
Cresci+10



Swinbank+12



Wuyts+16



Leethochawalit+16

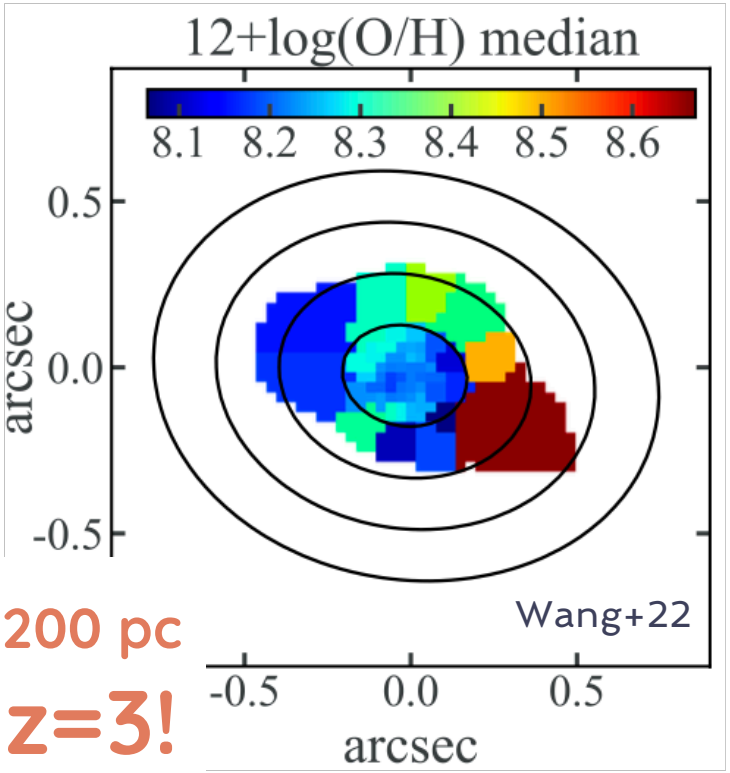
JWST-GLASS IS INCREDIBLE

JWST SENSITIVITY

NIRISS can do 65 mas resolved spectroscopy on $m_{AB} < 24$ targets!

GRAVITATIONAL LENSING

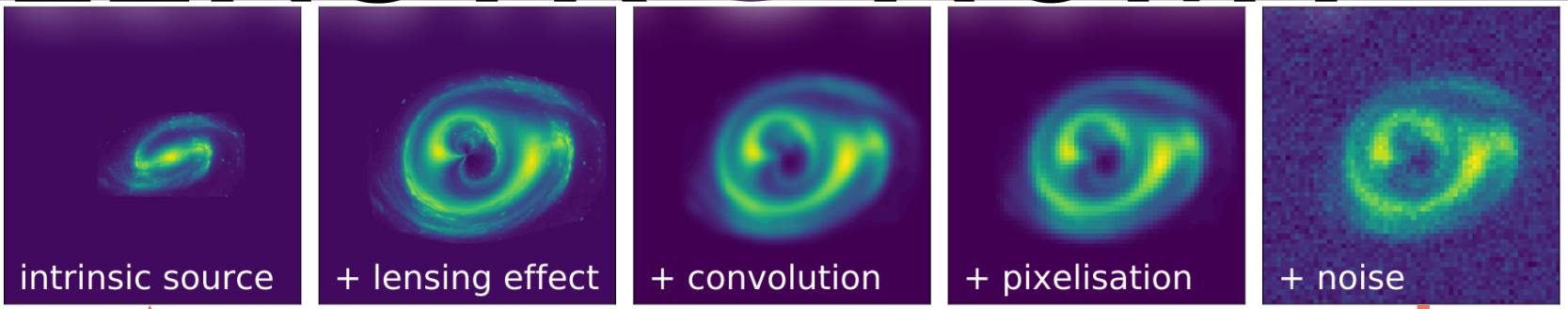
Magnification improves resolution and sensitivity.



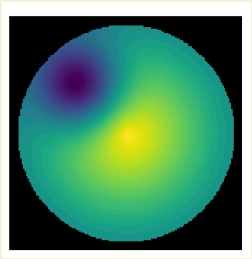
WHAT DO WE DO NOW?

METALLICITY MODELLING IN:

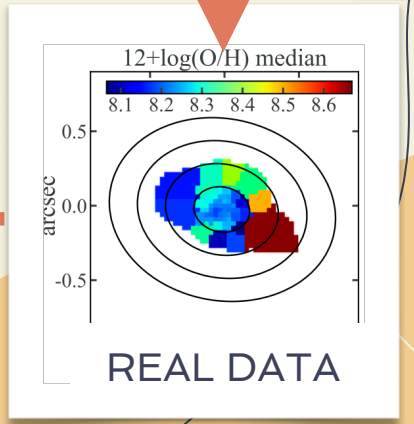
LENSTRONOMY



SUBMITTED!

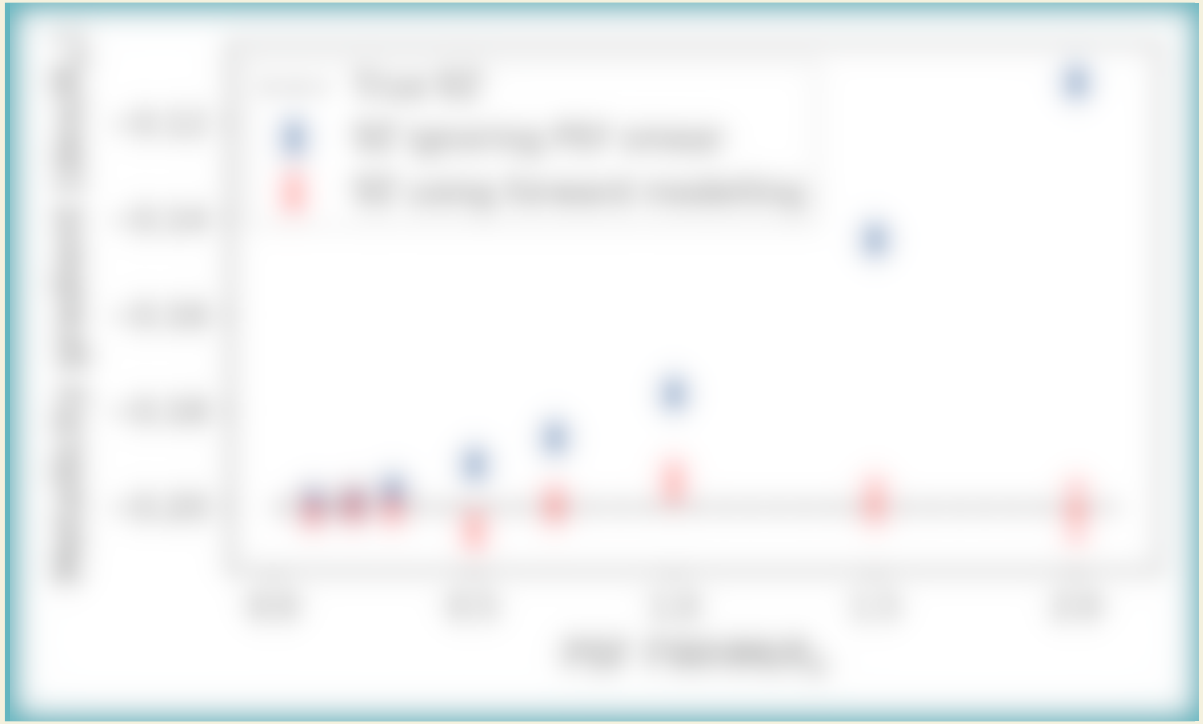


MODELS WITH
2D STRUCTURE

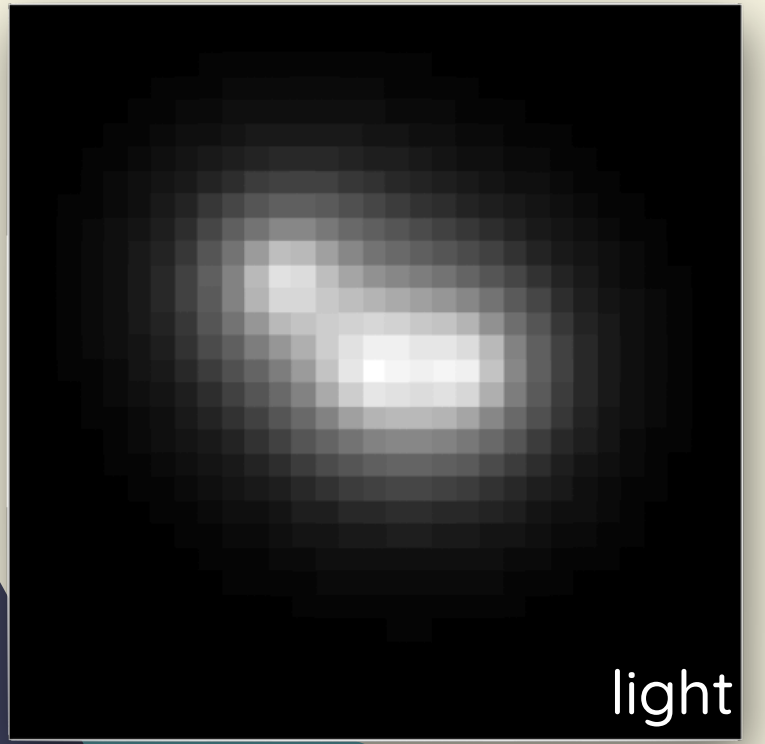


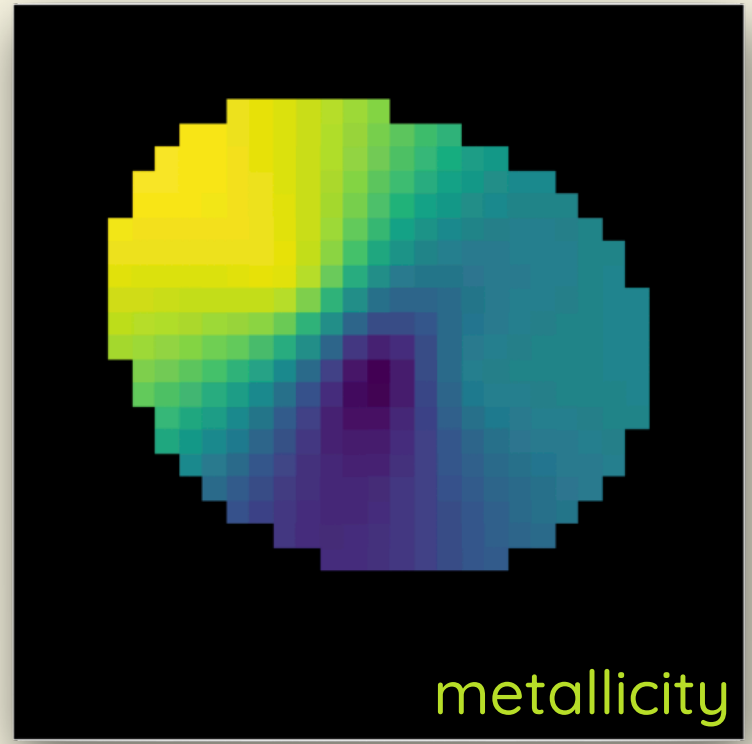
REAL DATA

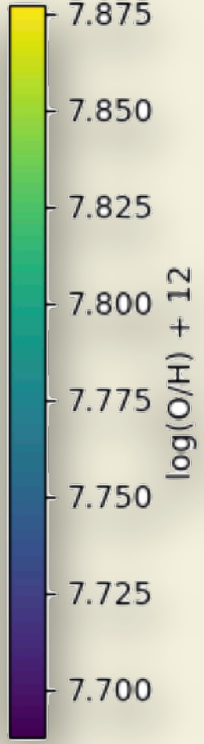
CORRECTIONS FOR PSF SMEAR



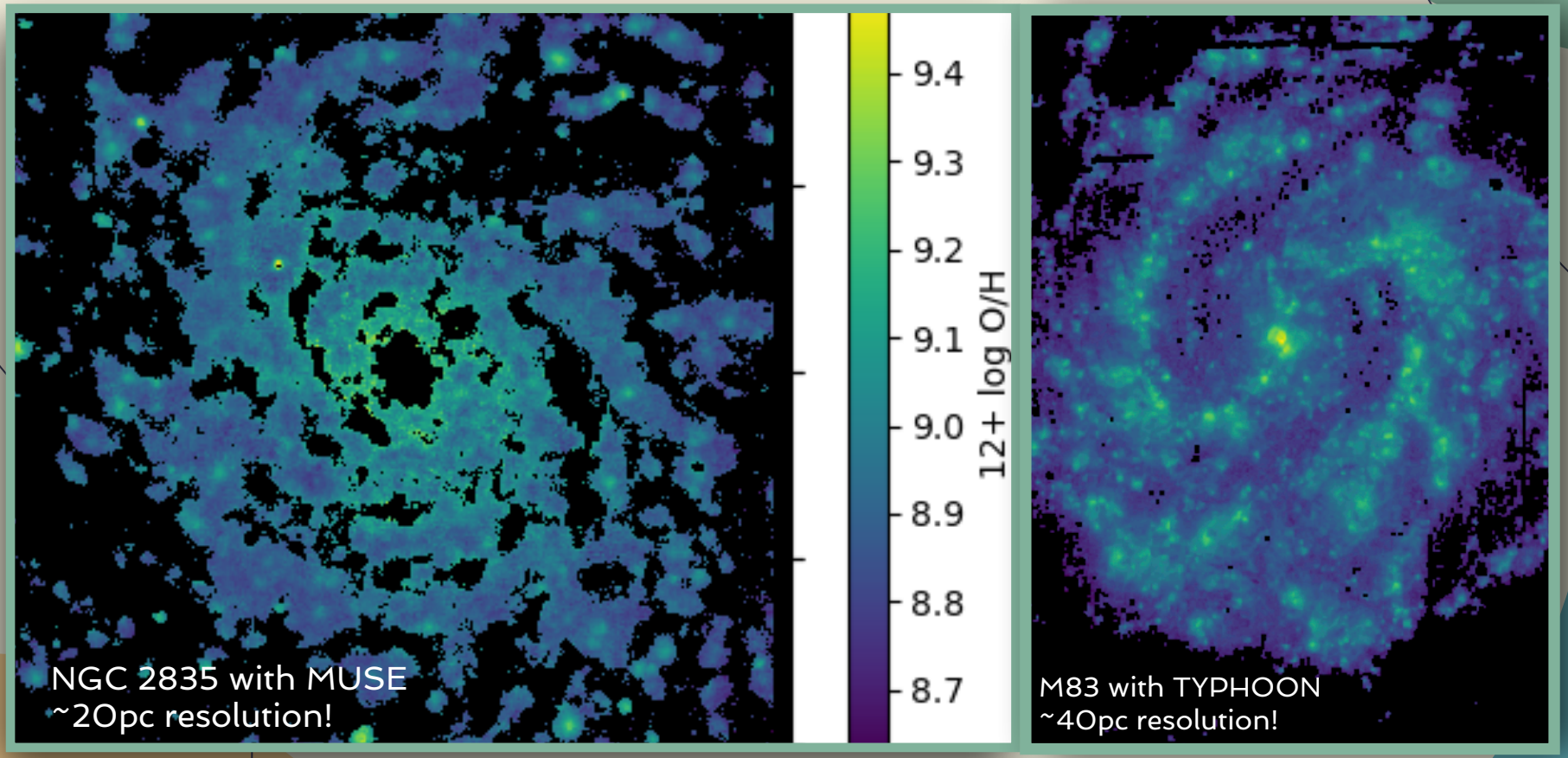
FITTING MORE FLEXIBLE MODELS





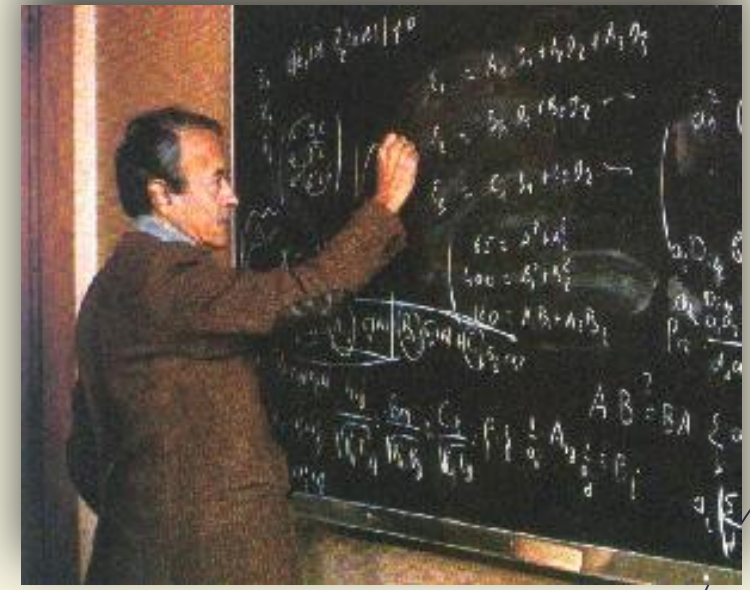


LOCAL DATA LOOKS EVEN COOLER



CAN WE DO EVEN BETTER?

"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

Observation error:
known from telescope properties

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

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

Process mean:
accounts for the metallicity gradient

Random fluctuations:
spatially-correlated deviations

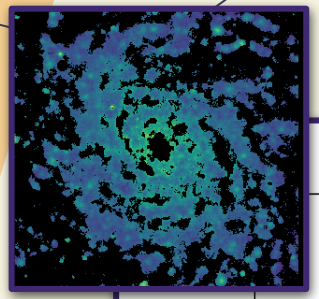
IF WE CAN MODEL $\epsilon(x)$, $\mu(x)$, AND $\eta(x)$, THEN WE CAN MODEL THE GALAXY!

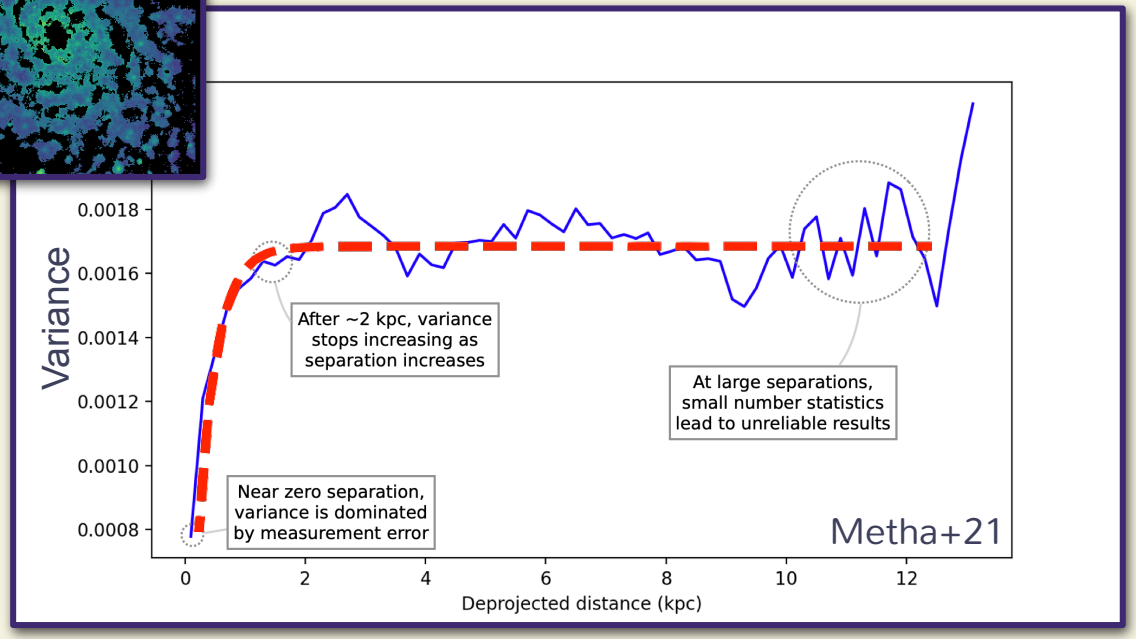
TESTING AN ANALYTICAL MODEL

Krumholz & Ting (2018)

- Stochastic partial differential equations
- Assumptions:
  - Constant, uniform star formation
  - **Linear diffusion**
  - No stellar winds
- Predictions:
  - Spatial correlation of metallicity

SEMIVARIOGRAMS REVEAL SUBSTRUCTURE



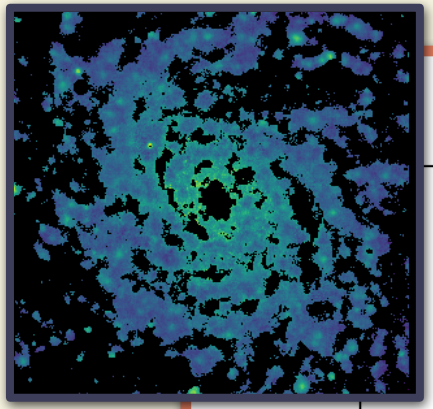


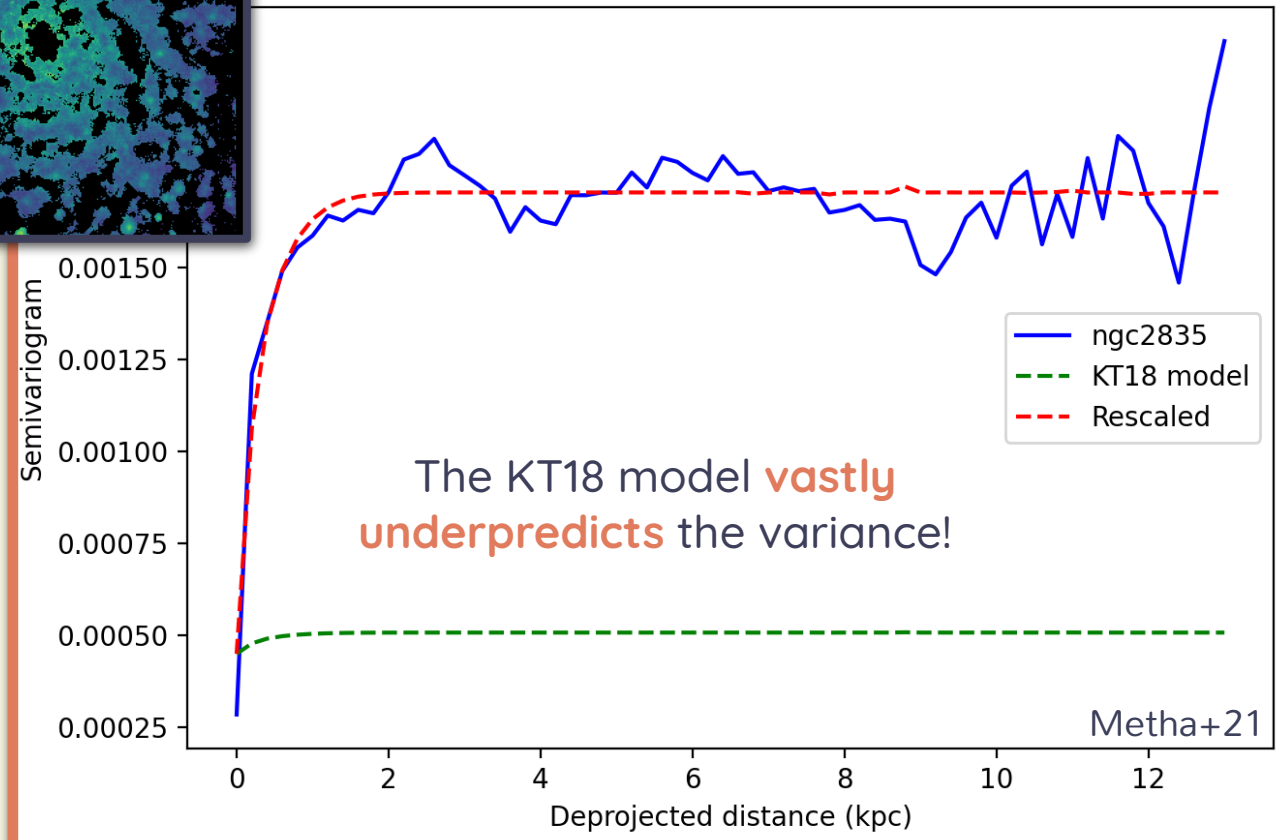
WORKS ON BAD DATA

Naturally separates structures from uncorrelated noise.

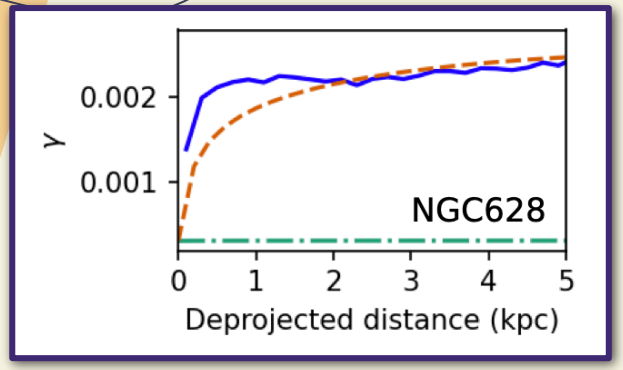
HIGHLY INFORMATIVE

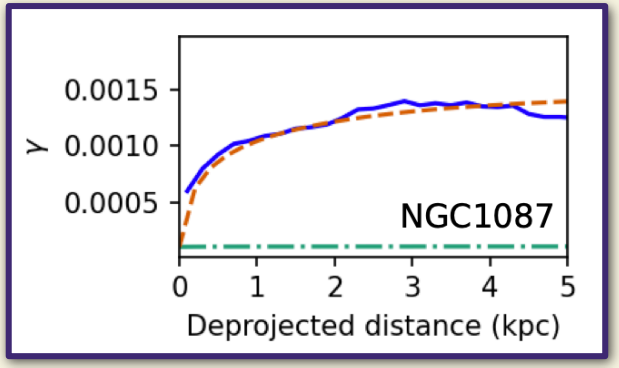
Shows covariance structure, like a power spectrum.

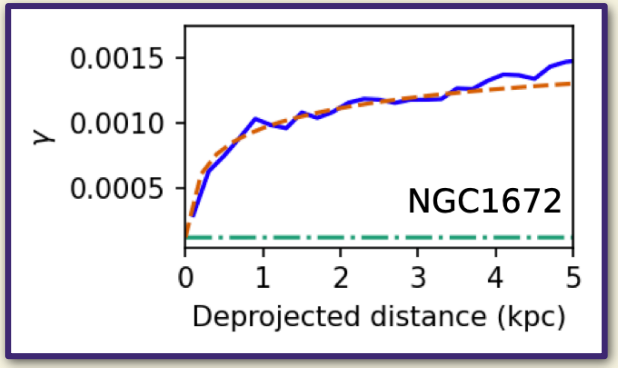


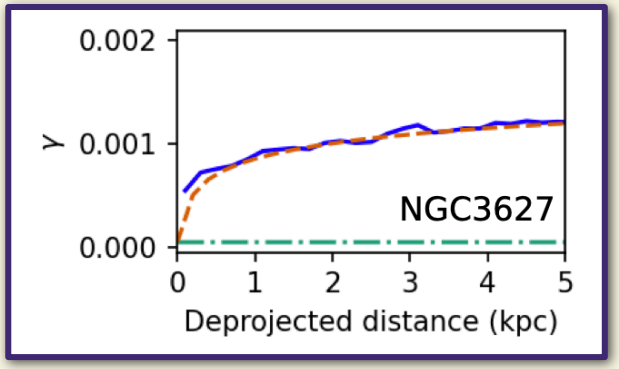

Semivariogram
0.00150
0.00125
0.00100
0.00075
0.00050
0.00025
0
2
4
6
8
10
12
Deprojected distance (kpc)
ngc2835
KT18 model
Rescaled
The KT18 model vastly underpredicts the variance!
Metha+21

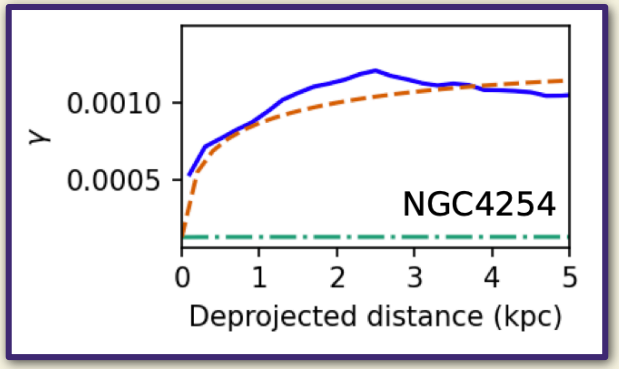
FOR 6 OTHER GALAXIES

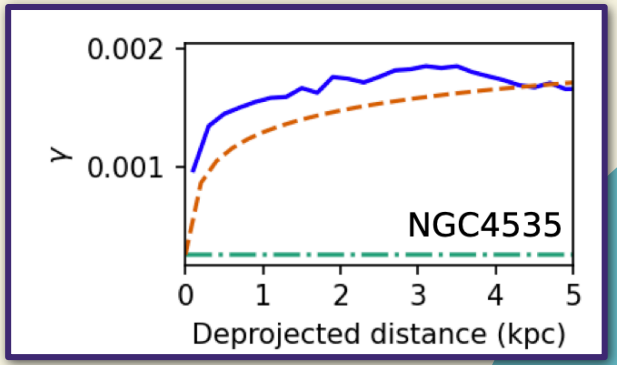








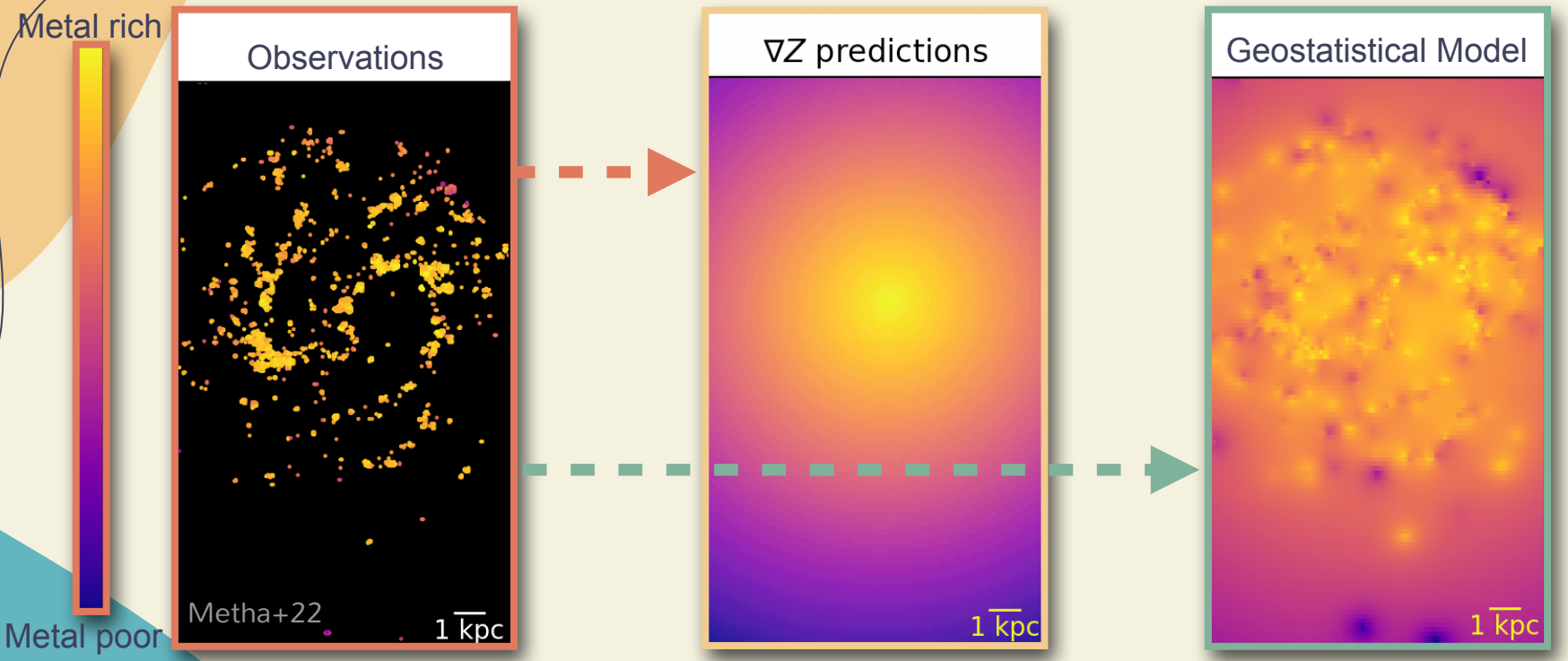




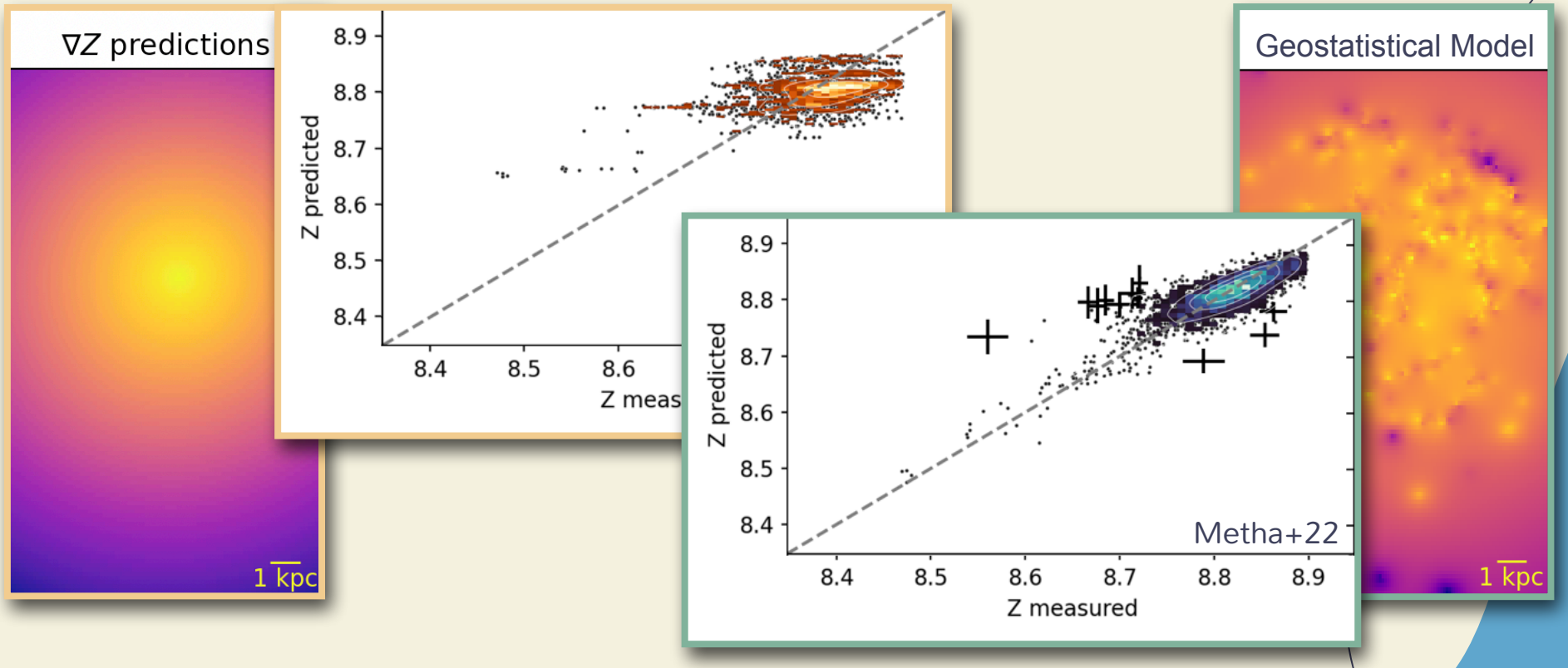
Empirical Semivariogram
KT18 model
Rescaled KT18 model

GALAXIES AREN'T VERY WELL MIXED!

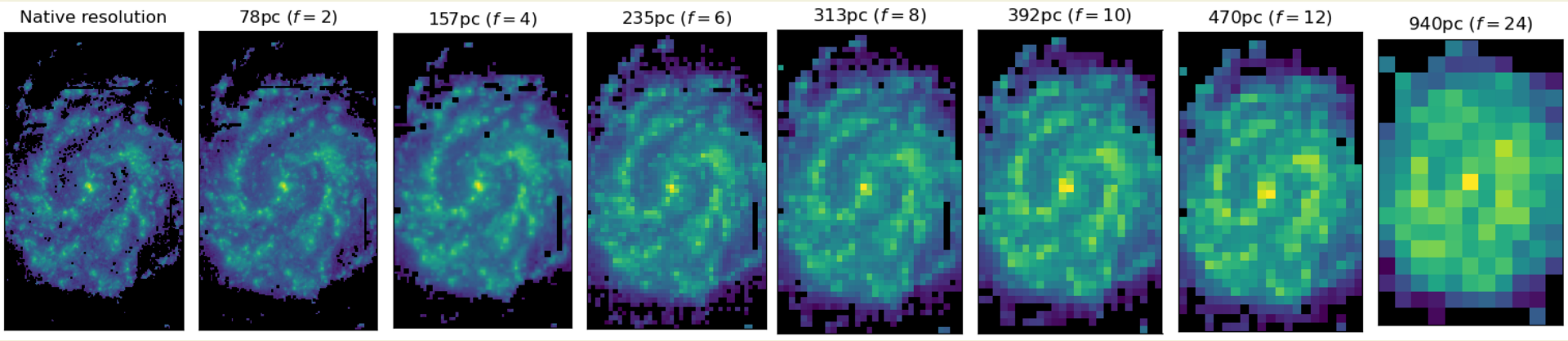
GEOSTATISTIC MODELS → MORE DETAILS



GEOSTATISTIC MODELS → BETTER PREDICTIONS



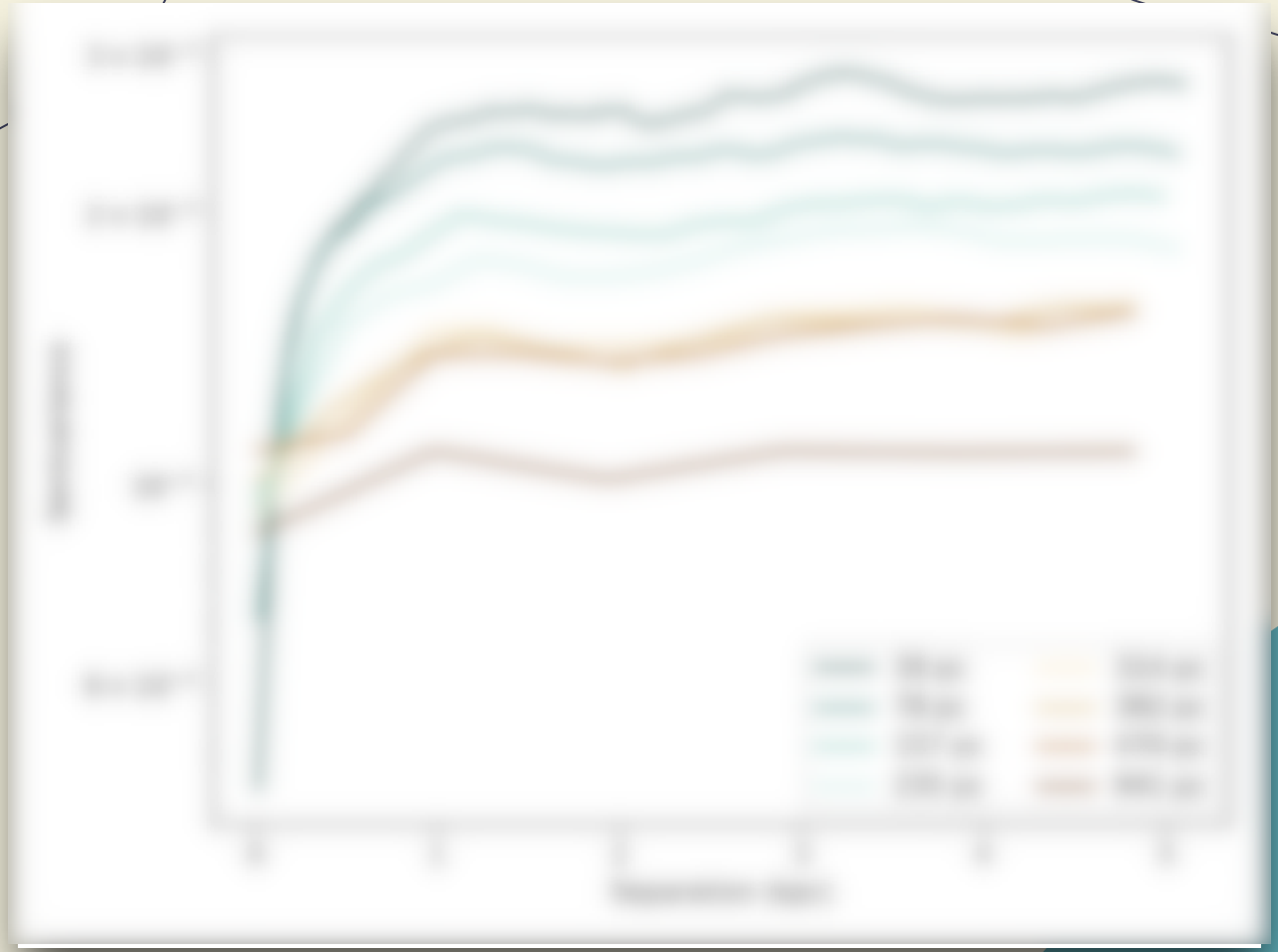
RESOLUTION LIMITS



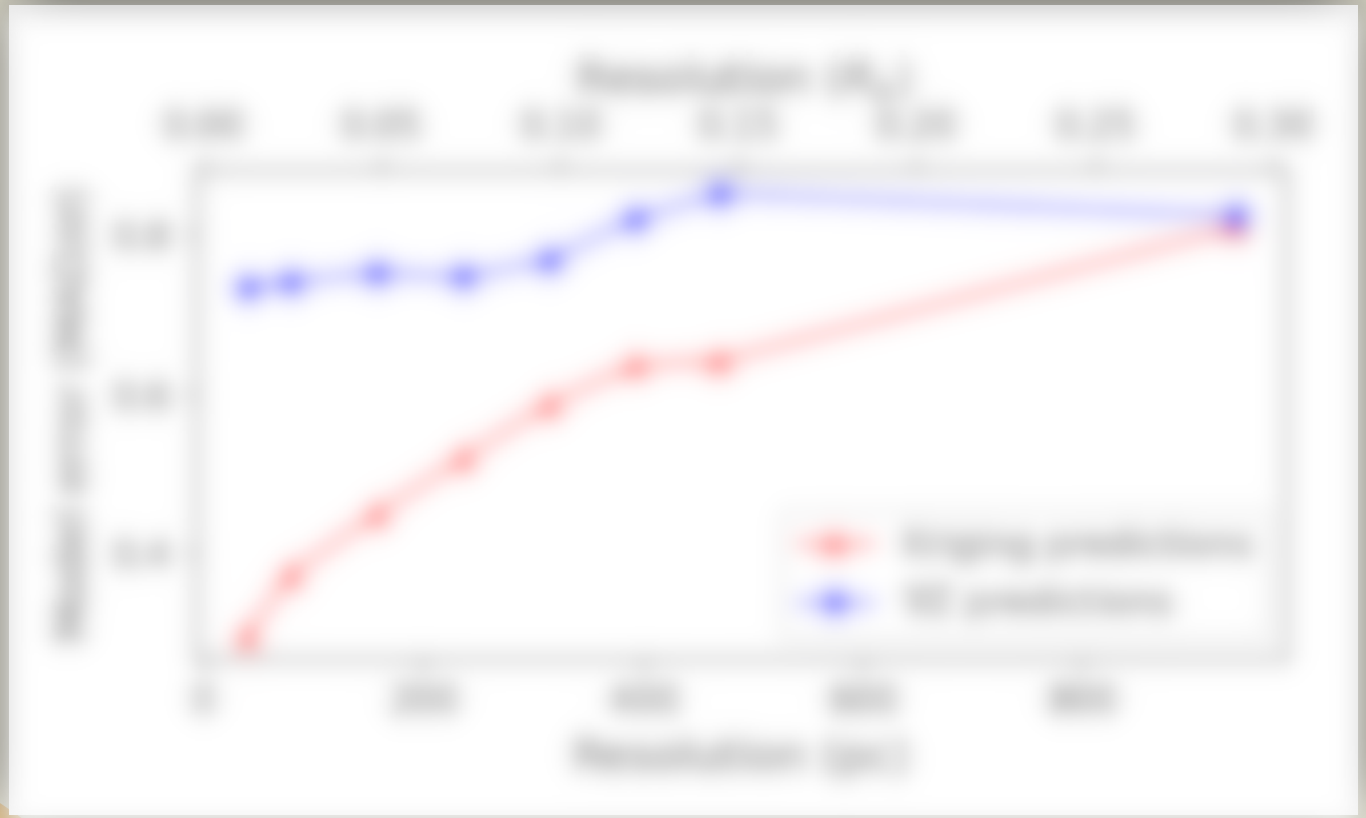
MUSE quality

CALIFA/SAMI/
MANGA quality

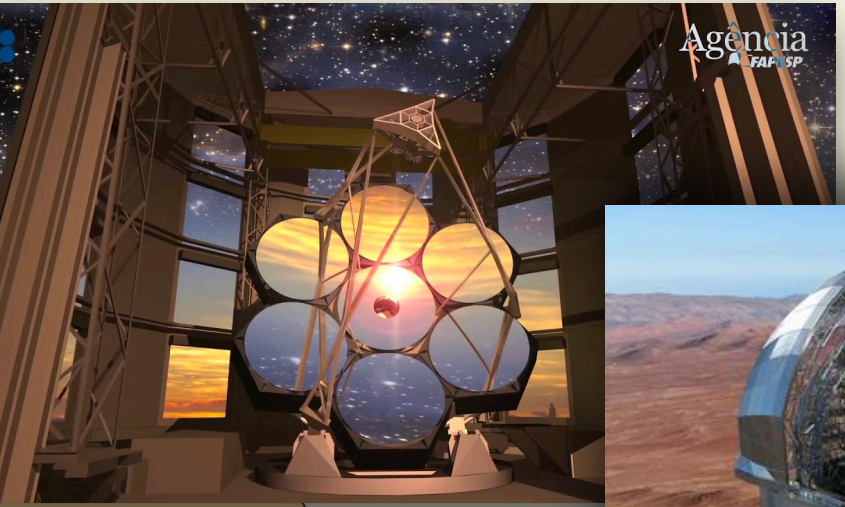
RESOLUTION LIMITS



PREDICTION ACCURACY vs RESOLUTION

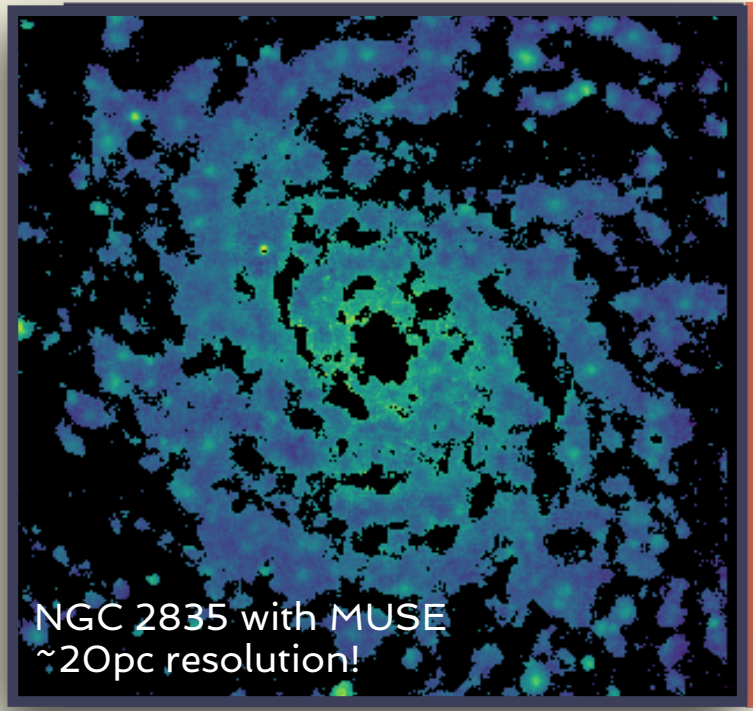


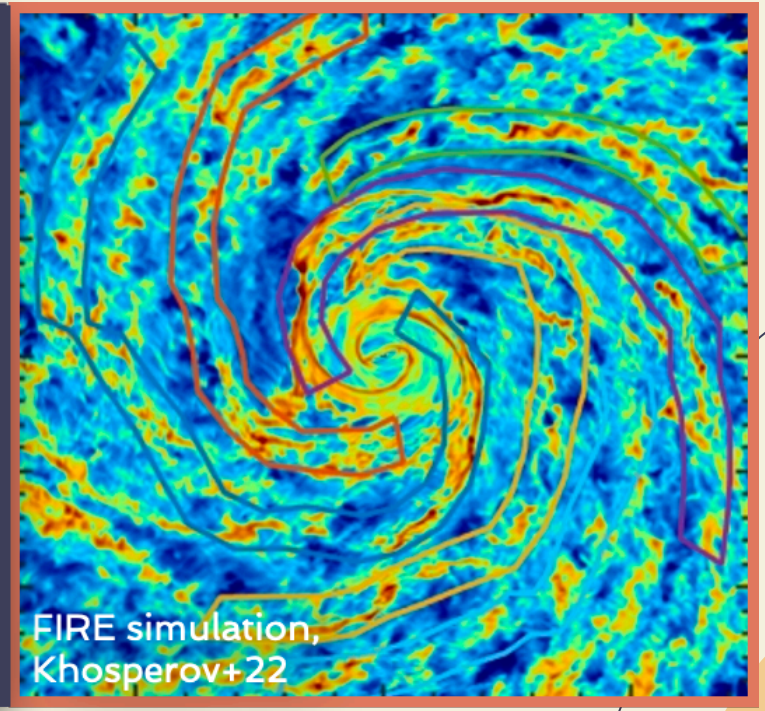
THE ELTs WILL SOLVE ALL MY PROBLEMS



PARSEC RESOLUTION FOR LOCAL GALAXIES

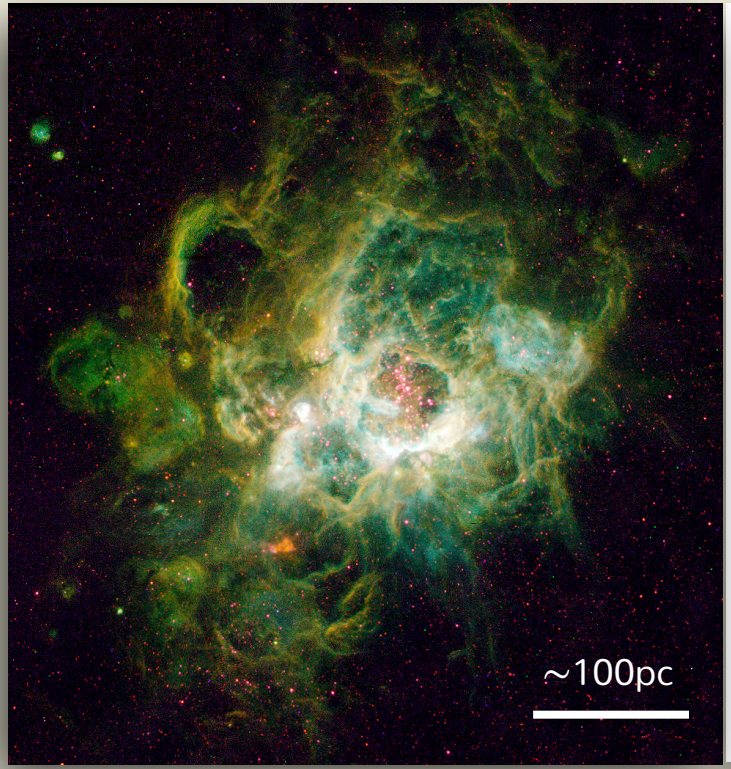
⇒ Direct comparisons to zoom-in simulations like FIRE!

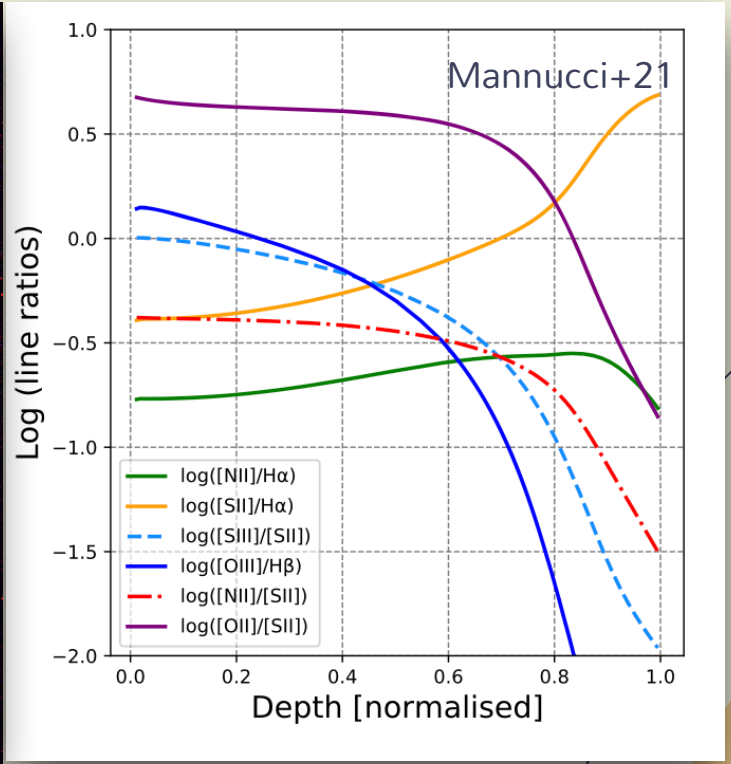




PARSEC RESOLUTION METALLICITY

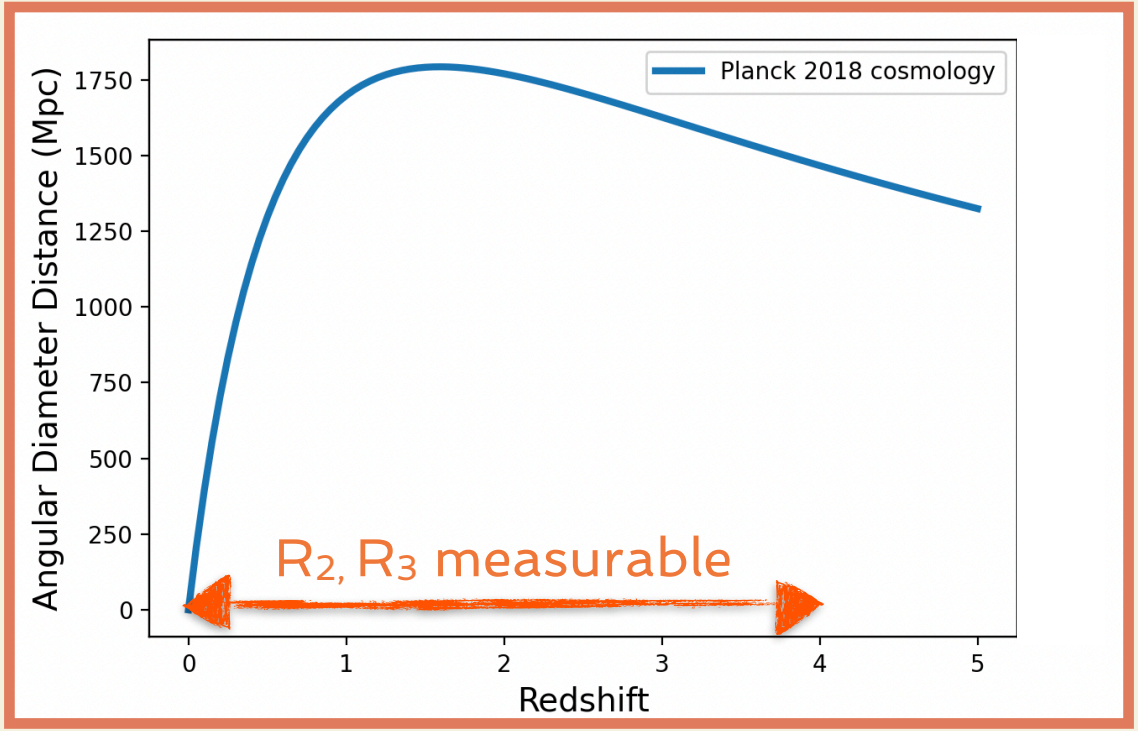
May need new diagnostics.





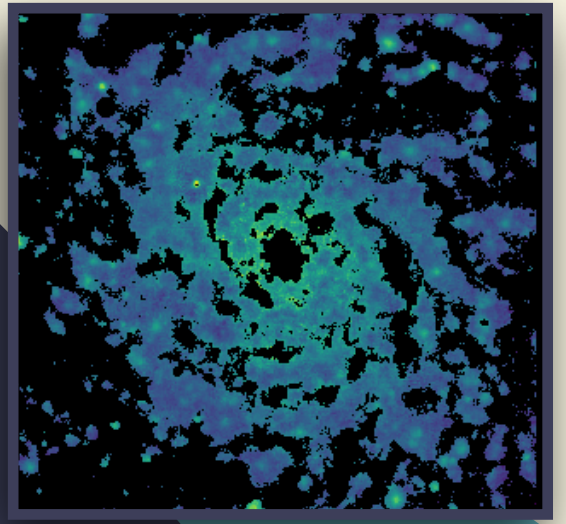
GEOSTATISTICS AT HIGH REDSHIFT!

GMTIFS, HARMONI and IRIS will give **better than 100pc resolution** at **all redshifts.**

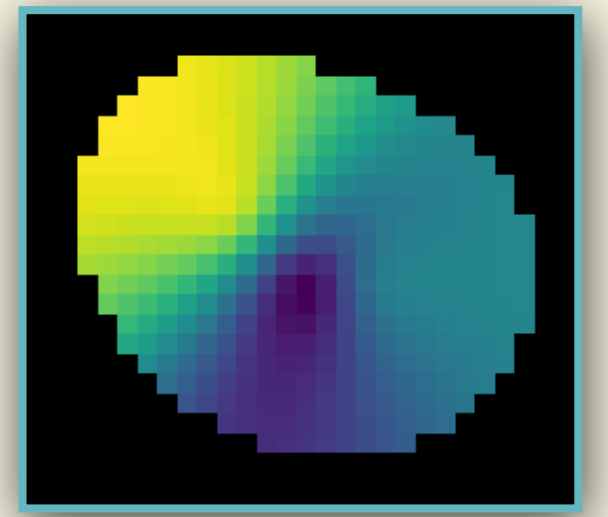


SUMMARY

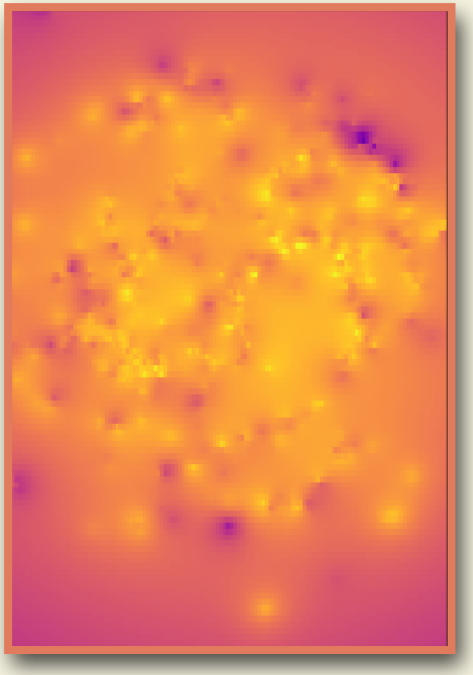
High resolution metallicity maps contain a wealth of information!



Lenstronomy's new module can correct for PSF smear and fit new models to JWST data



Geostatistical methods are ideal for ELTs' data



THANKS!

DO YOU HAVE ANY QUESTIONS?

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