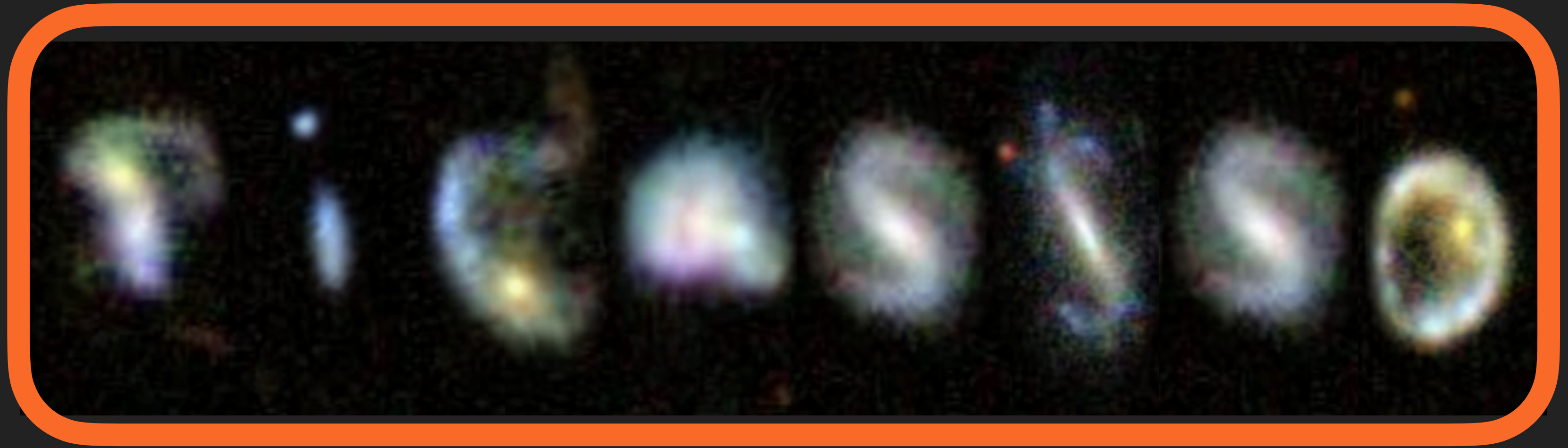
PICASSSO

Visage dans étoile,
Pablo Picasso (1947)

TOBIAS BUCK & STEFFEN WOLF

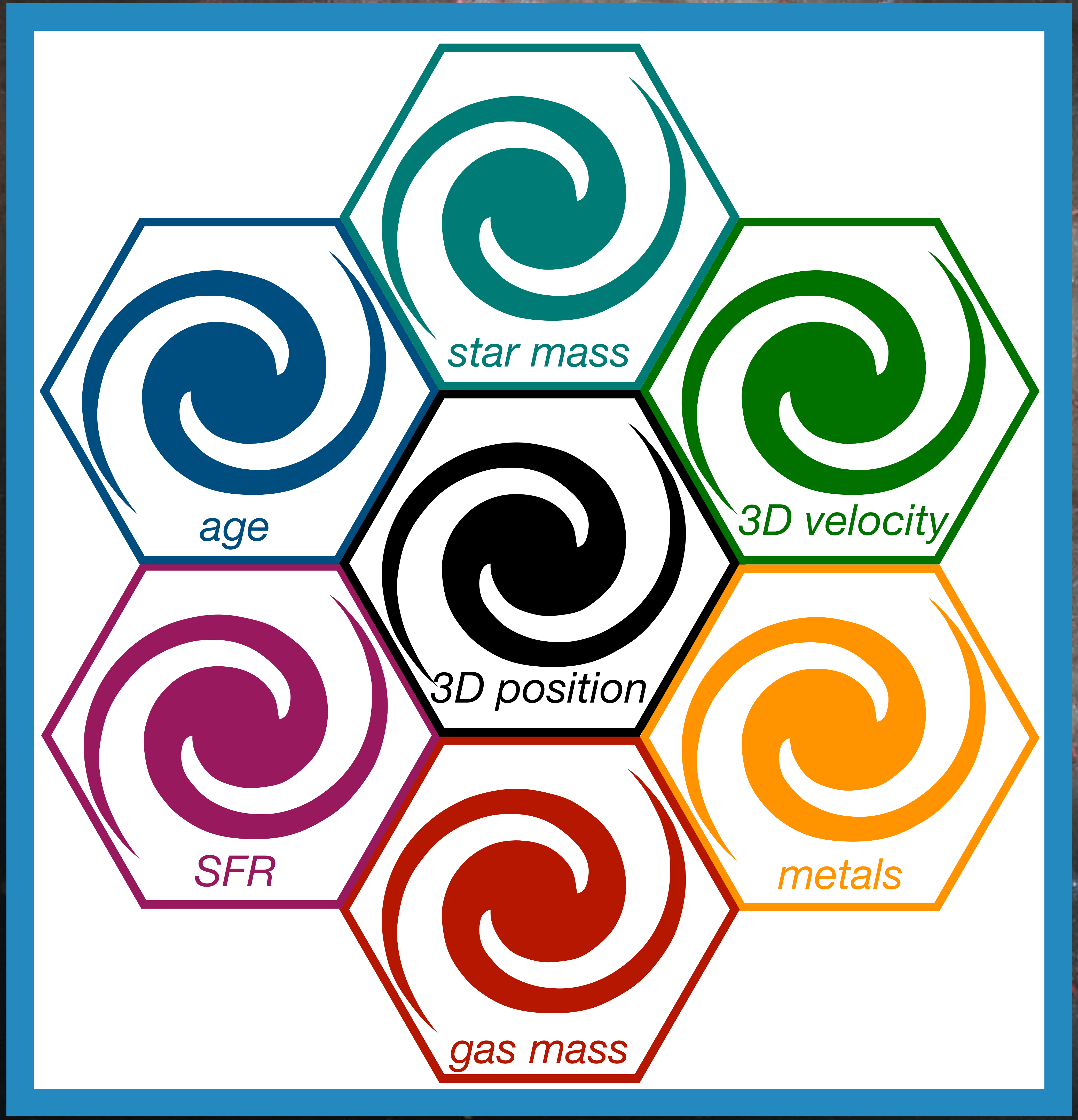


PAINTING INTRINSIC ATTRIBUTES ONTO SDSS OBJECTS

VIRTUAL ANNUAL MEETING OF THE GERMAN ASTRONOMICAL SOCIETY, 23. SEPTEMBER 2020

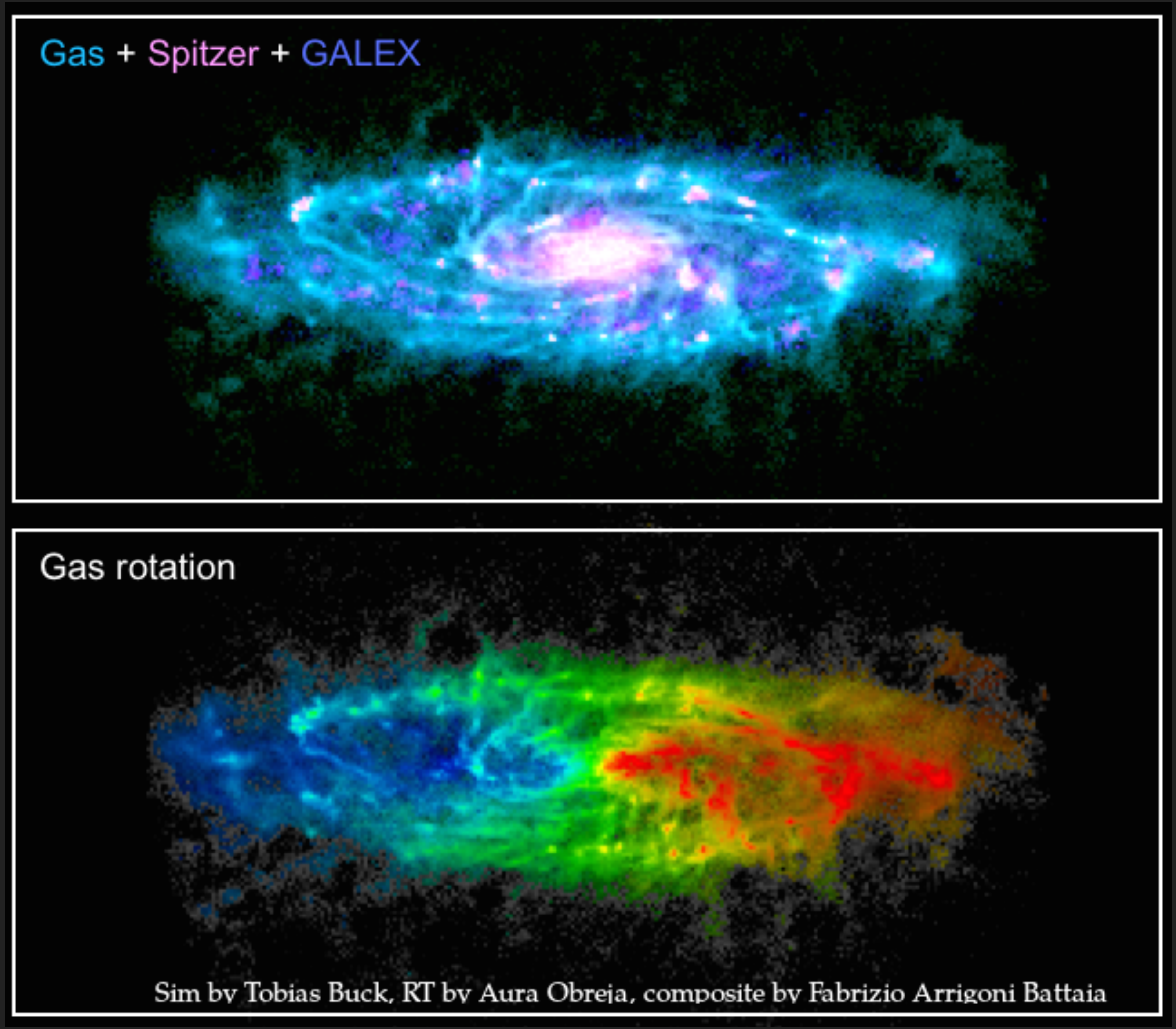
LEIBNIZ-INSTITUT FÜR ASTROPHYSIK POTSDAM (AIP),
tbuck@aip.de

derive physical parameters



FULL FORWARD MODELLING: HYDRO SIMS

simulation



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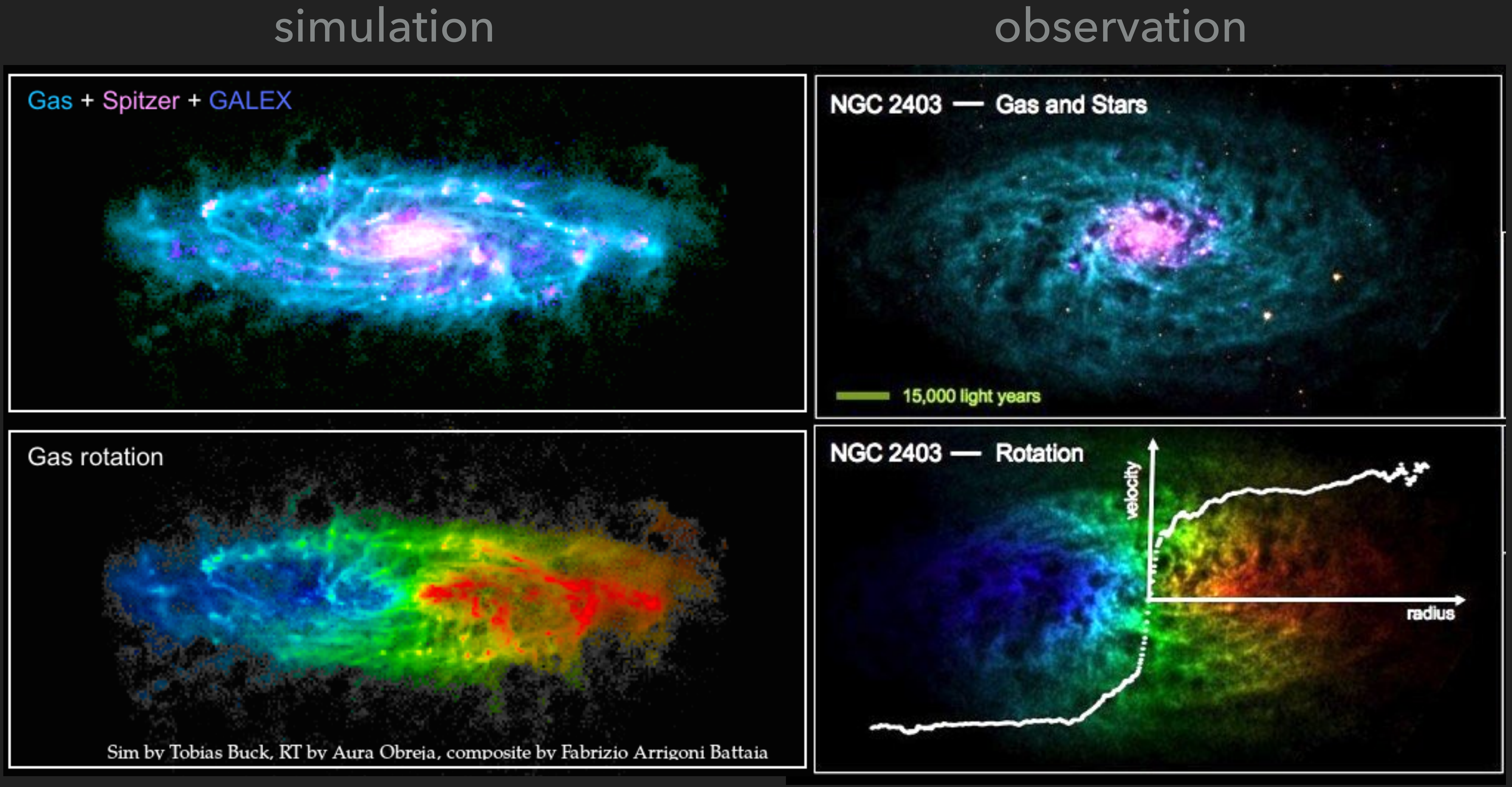
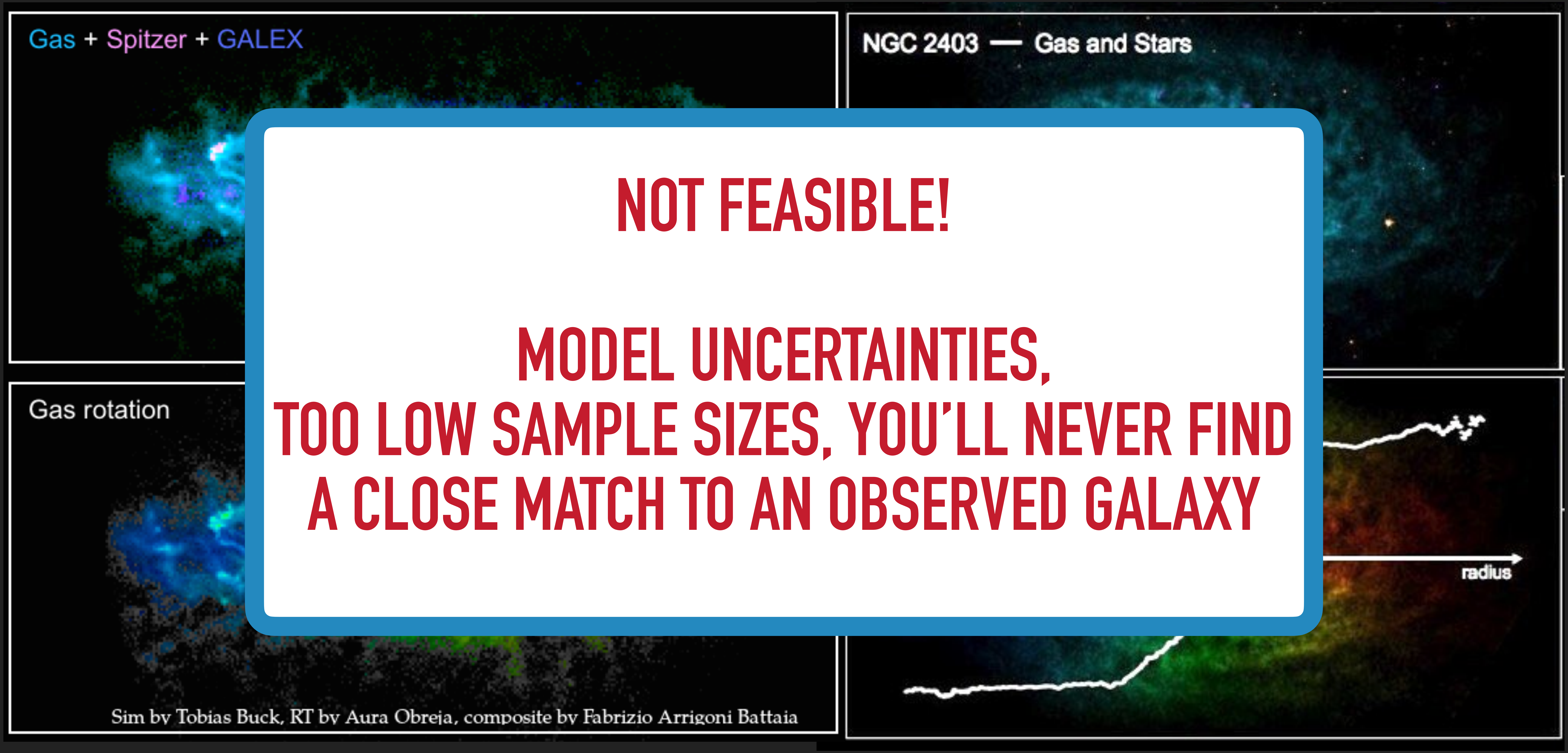


FULL FORWARD MODELLING: HYDRO SIMS

simulation

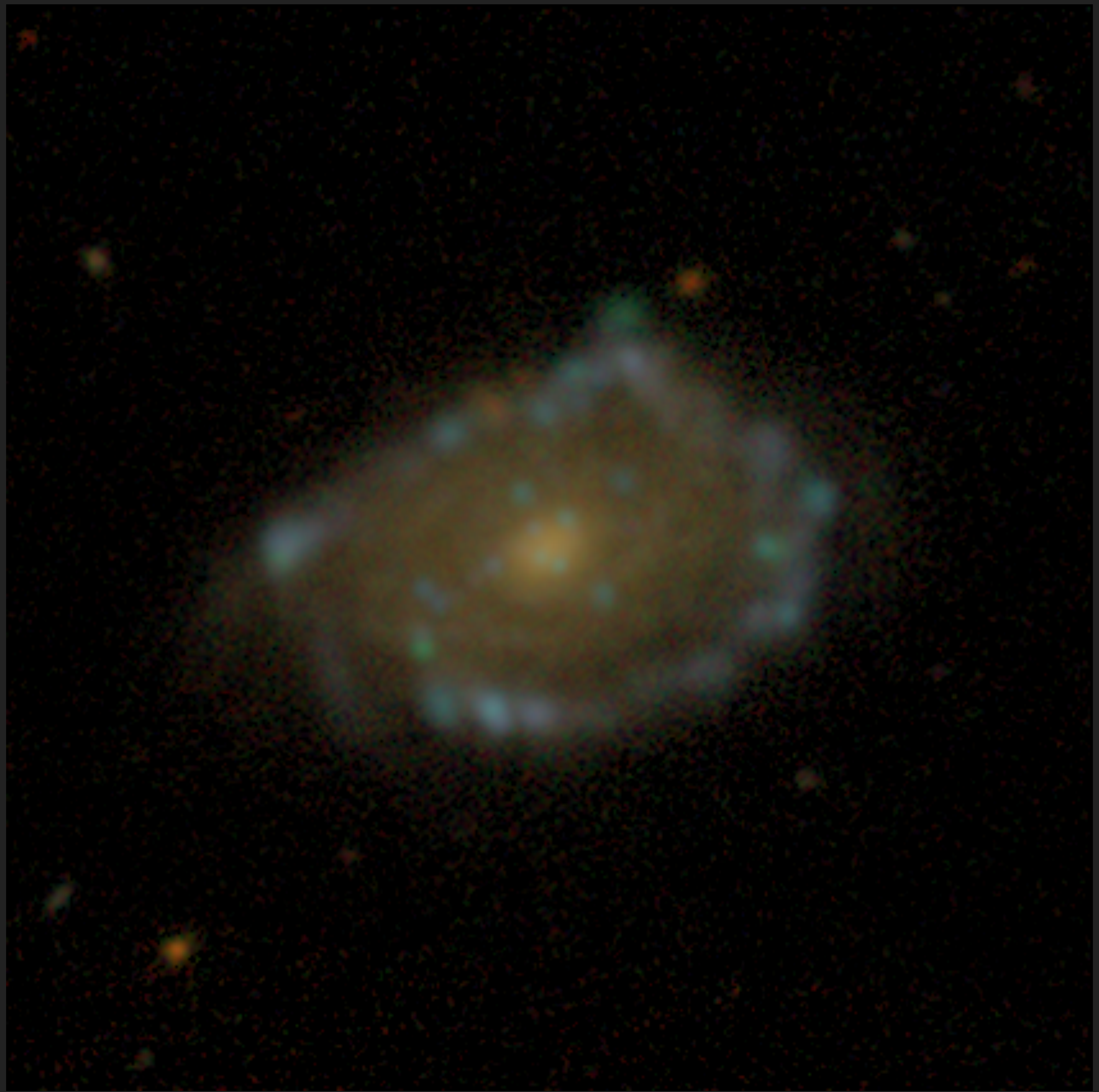
observation



NOT FEASIBLE!

MODEL UNCERTAINTIES,
TOO LOW SAMPLE SIZES, YOU'LL NEVER FIND A CLOSE MATCH TO AN OBSERVED GALAXY

OBSERVATIONS



CLASSIC SDSS ~100.000 GALAXIES

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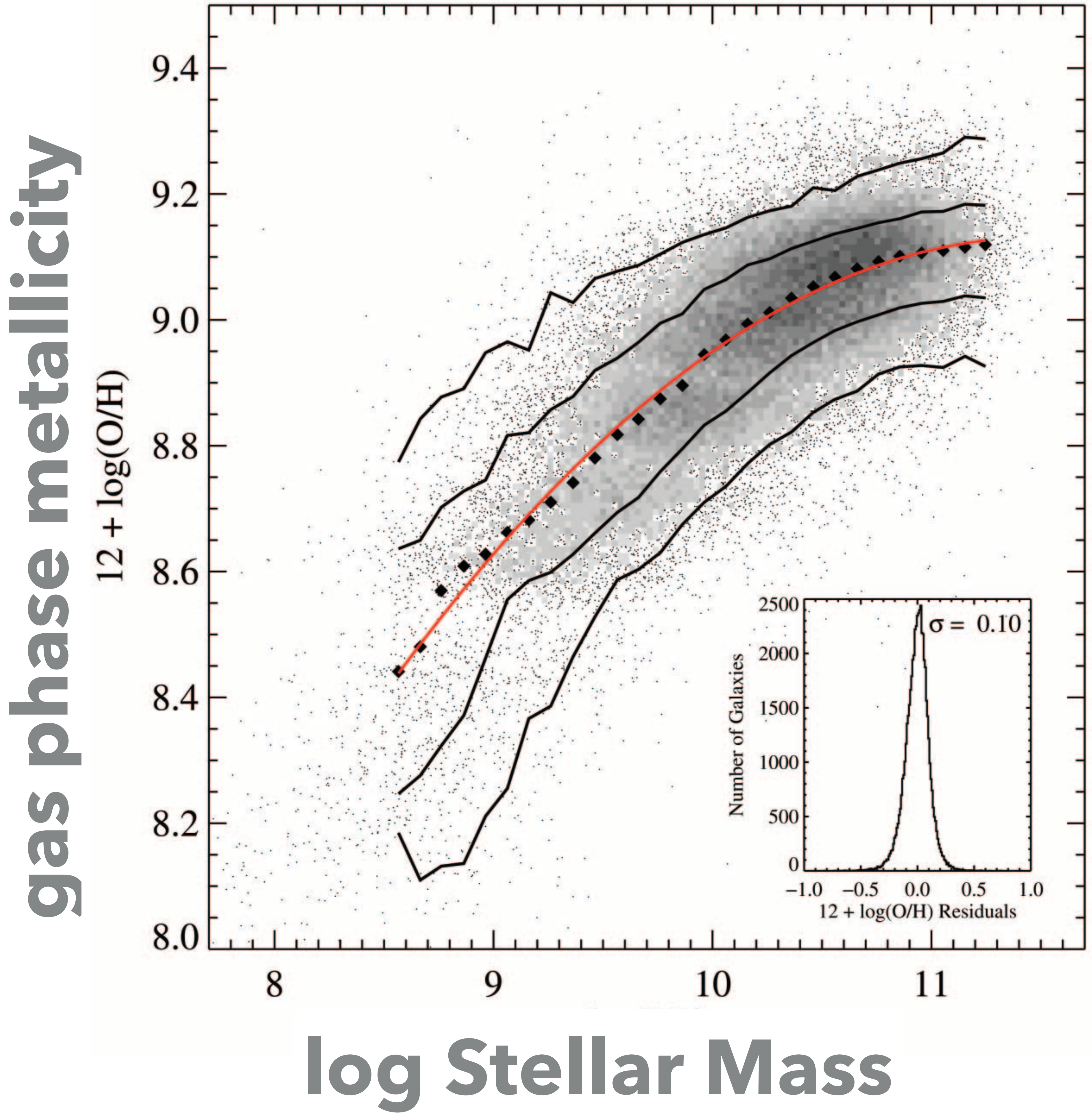
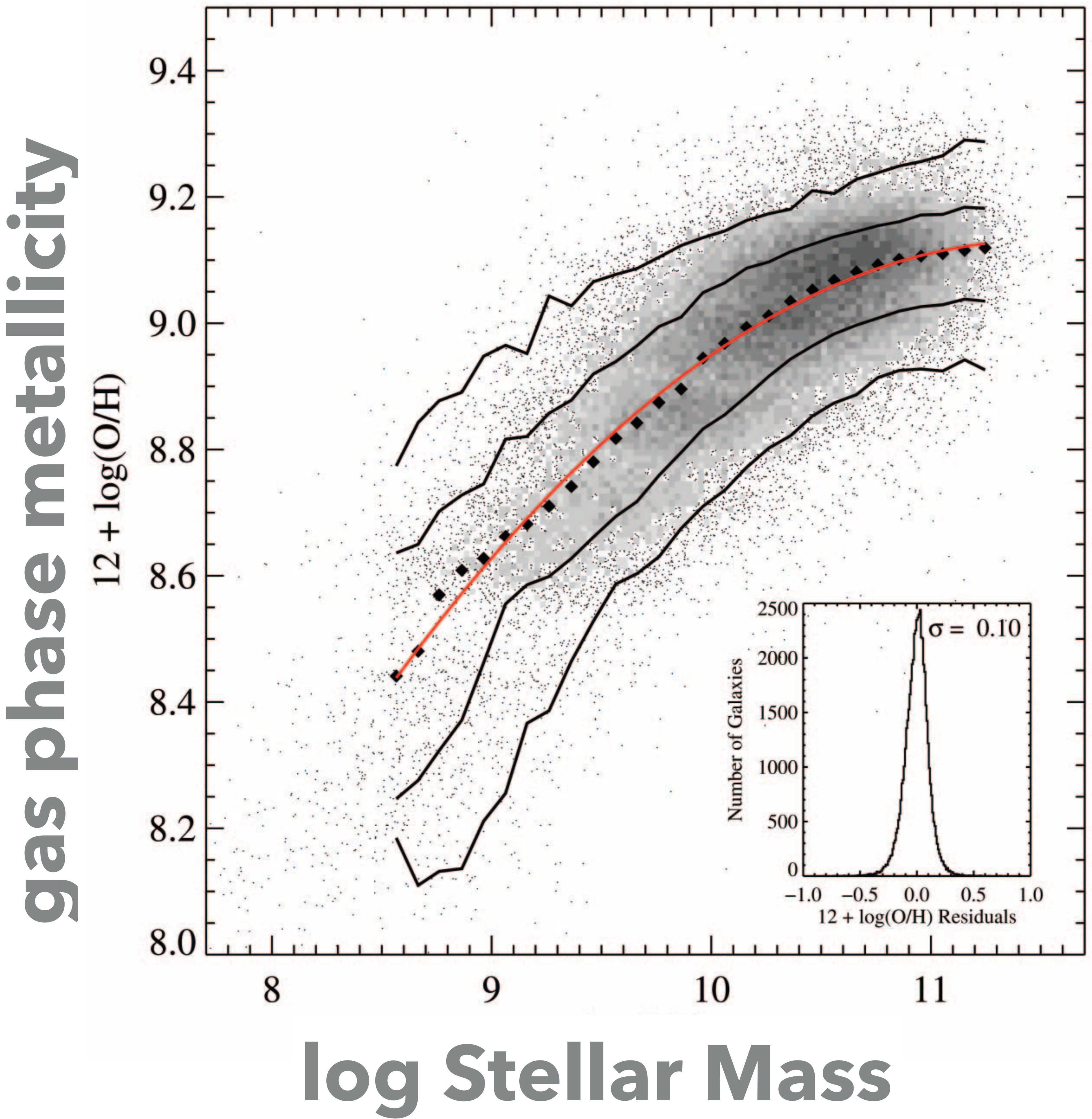
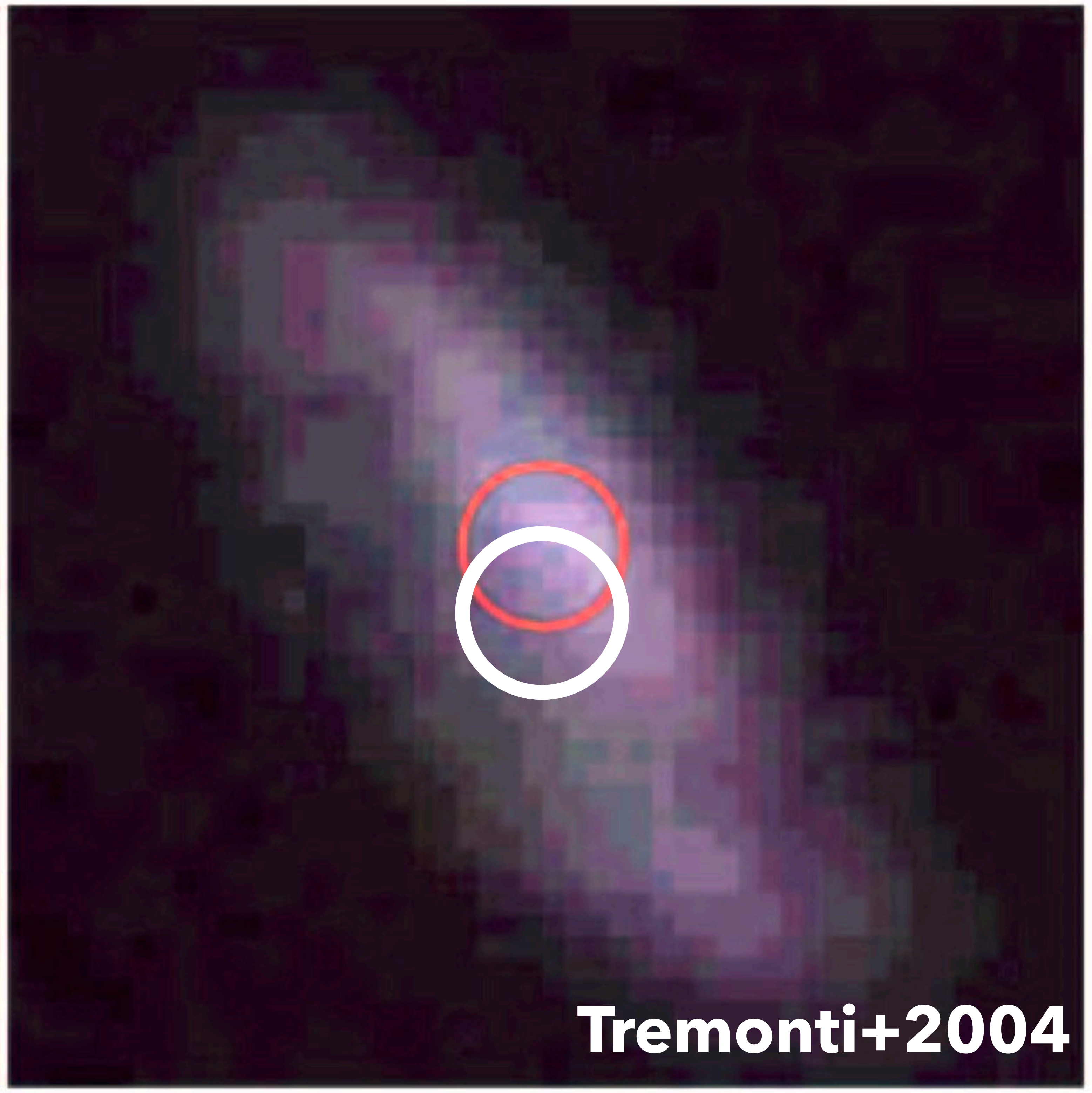


CLASSIC SDSS ~100.000 GALAXIES





SDSS MANGA ~10.000 GALAXIES

EXPENSIVE INTEGRAL FIELD SPECTROSCOPY

OTHER EXAMPLES: SAMI, CALIFA, FORNAX3D, ETC.

LARGE SCALE SURVEYS: CHALLENGE FOR CONVENTIONAL ANALYSIS / MODELLING

PHOTOMETRIC DATA FOR MILLIONS OF GALAXIES,
(EUCLID, LSST, DES, COSMOS, DEEP2, BUT ALSO LEGACY DATA LIKE SDSS)

CLASSICAL ANALYSIS/CLASSIFICATION (VISUAL OR GALAXY ZOO LIKE) NOT FEASIBLE

DATA EXPLORATION BEYOND (SIMPLE) MORPHOLOGICAL CLASSIFICATION

- RESOLVED GALAXY PROPERTIES

HOW MUCH INFORMATION IS ENCODED IN BROAD BAND GALAXY IMAGES?

CAN WE BUILD AN ANALYSIS TOOL WHICH:

- WORKS ON LARGE PHOTOMETRIC DATA SETS
  A. FAST

- IS EASY TO HANDLE
  C. AUTOMATION
  D. GENERALIZATION

➡ FAST, OFF-THE-SHELF TOOL, READY TO USE

MOTIVATION/ROAD MAP

- Proof-of-concept: Does multi-band photometry contain enough information to recover resolved maps of intrinsic properties —> Knowledge transfer from IFU surveys
- Which properties can we recover? Can we do kinematics?
- What do we learn about galaxies? —> Inspect the latent space. How does the machine reconstructs galaxies?
- Can we make the model physically interpretable?
- How can we incorporate such models in future pipelines?
  —> Sampling from latent space to create close analogues to observed galaxies

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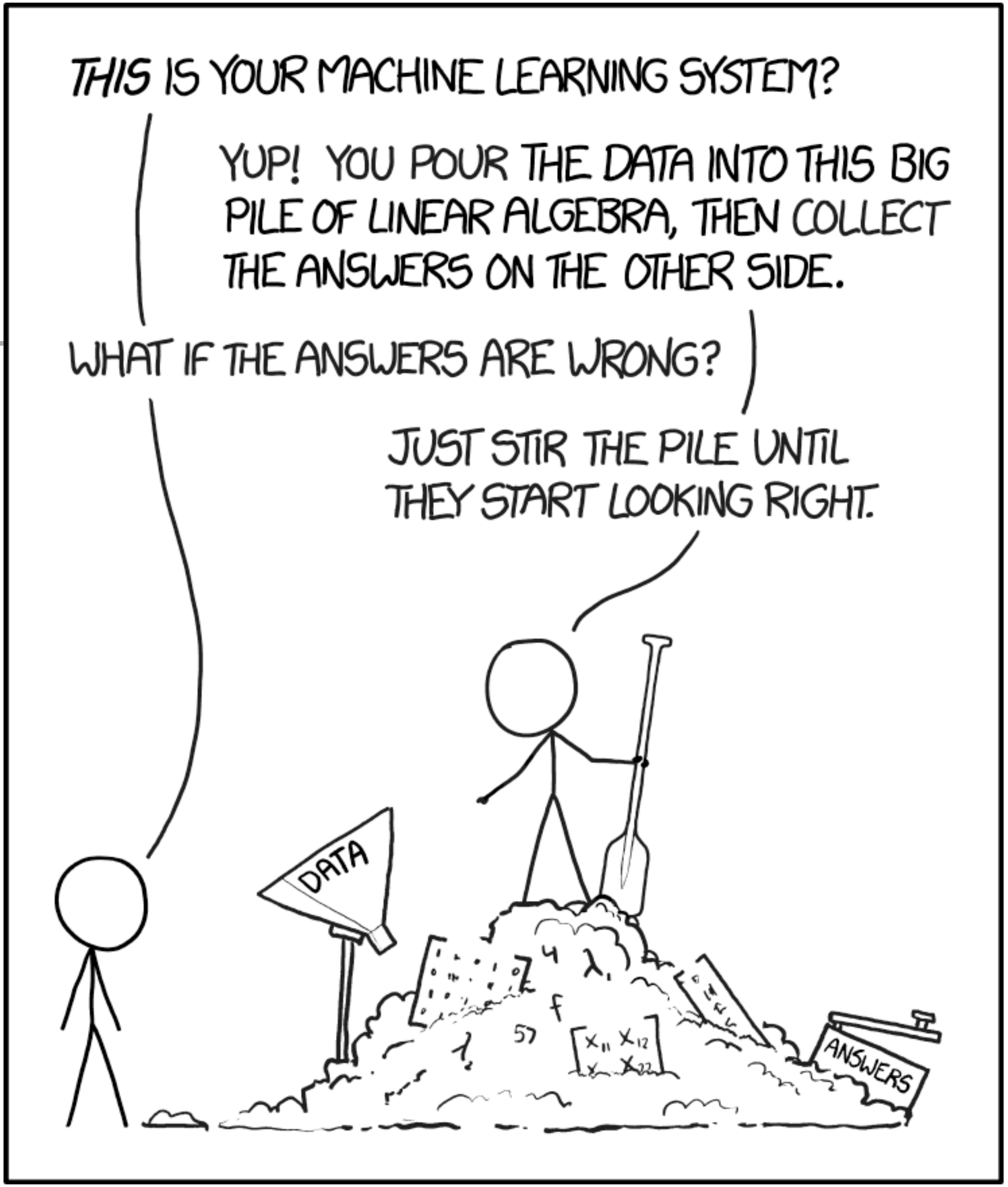
PHOTOMETRY TO PHYSICAL PROPERTIES

METHOD:
DEEP LEARNING



SIMILAR APPLICATIONS

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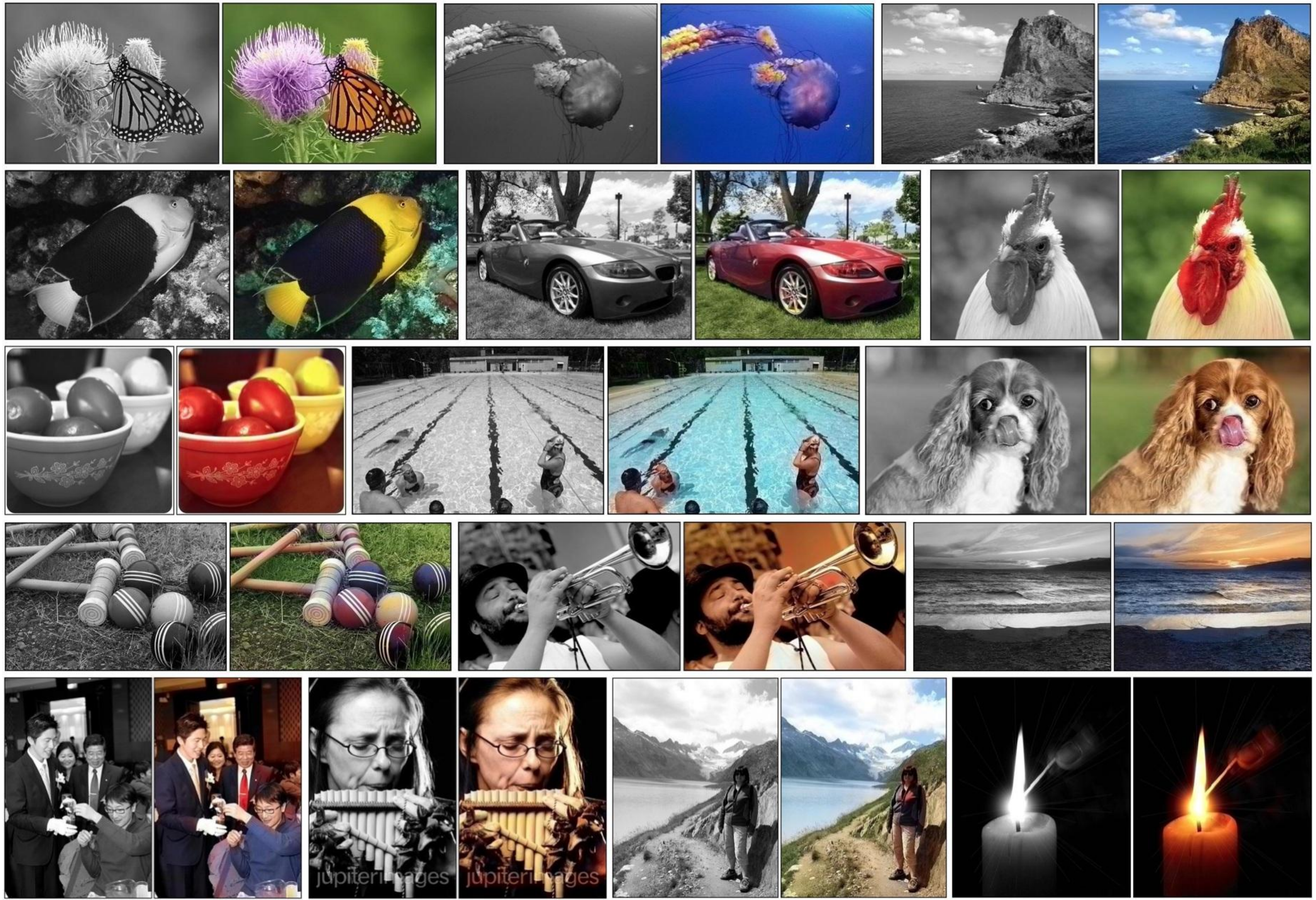

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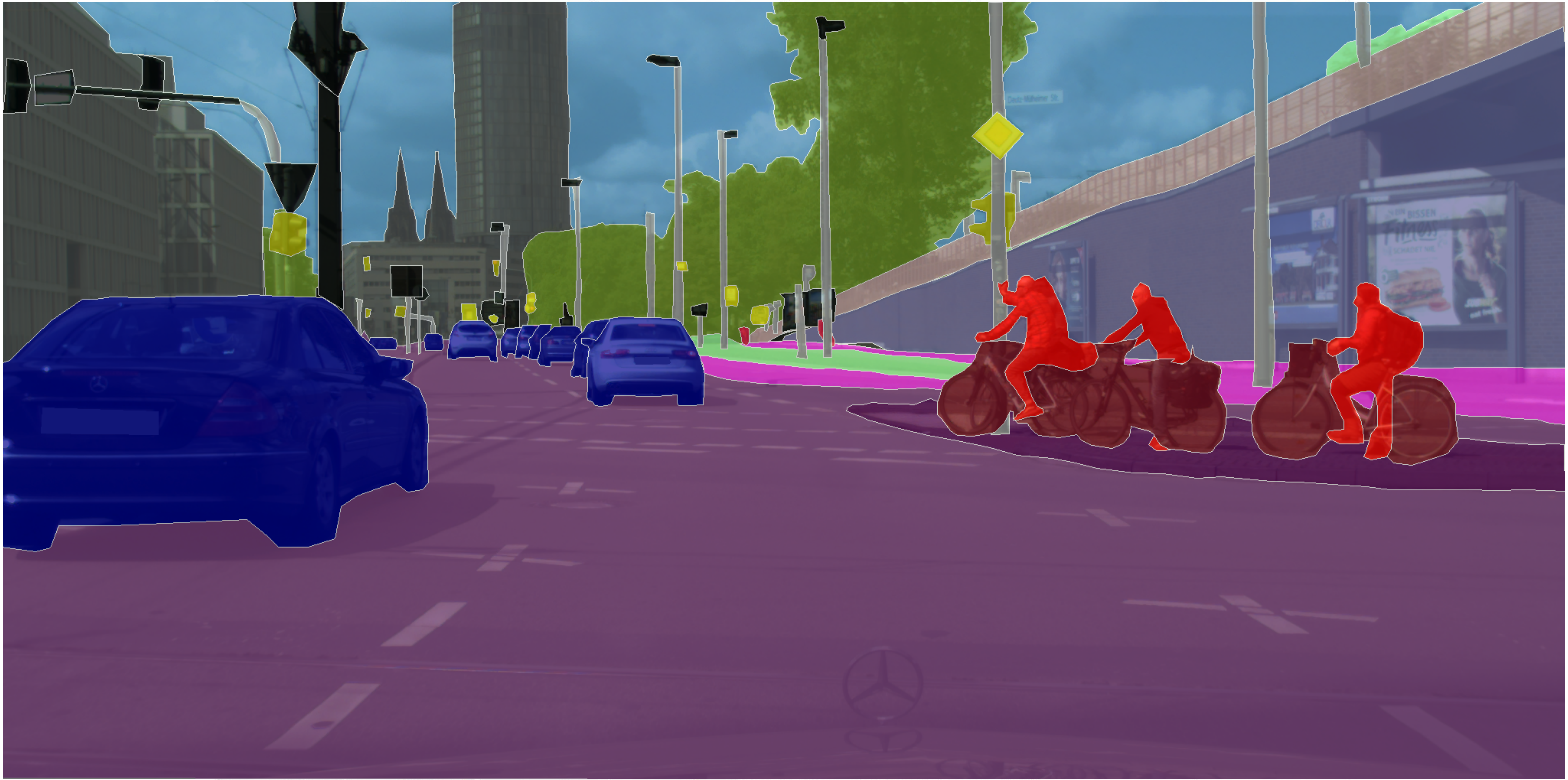

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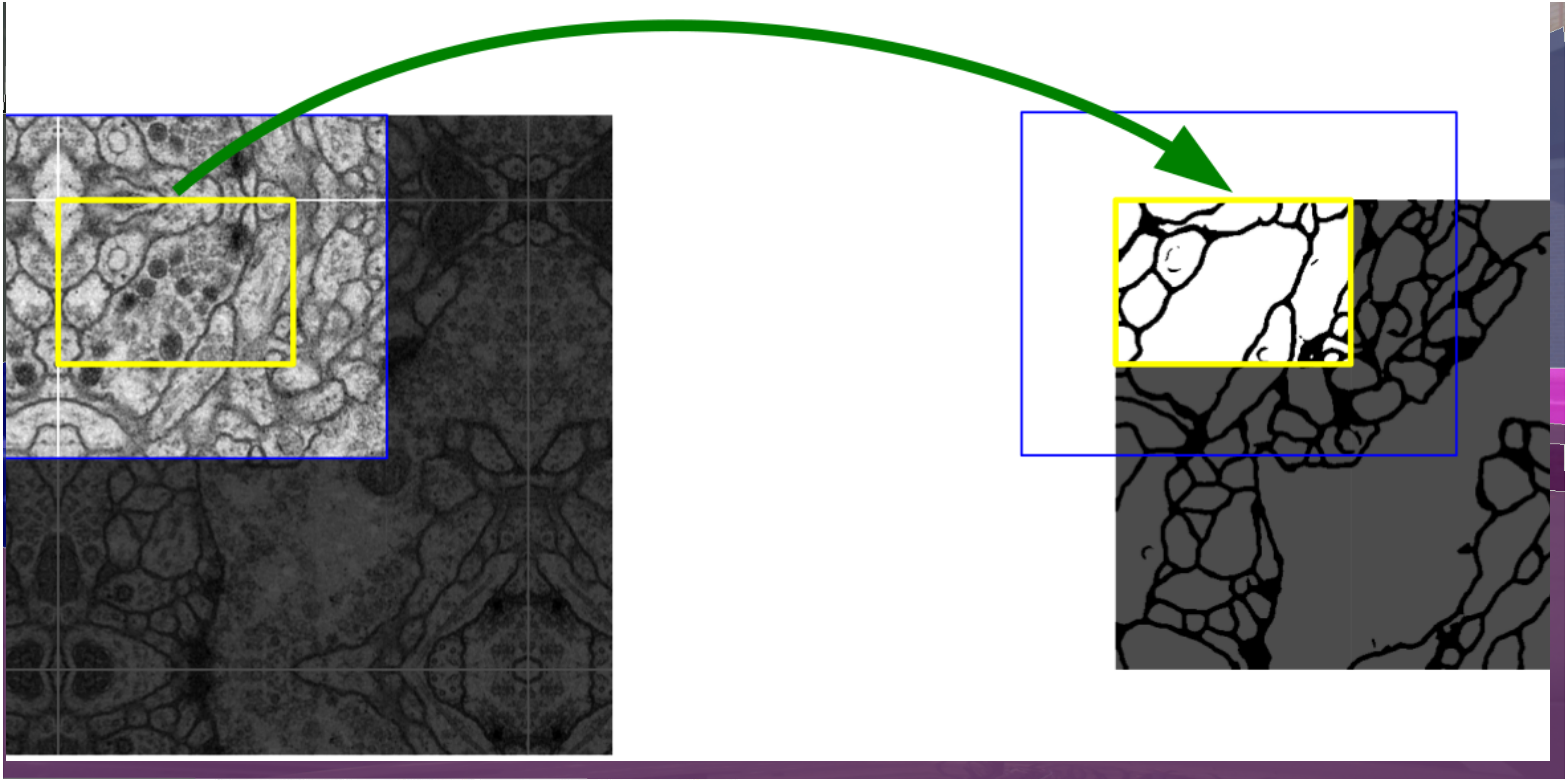

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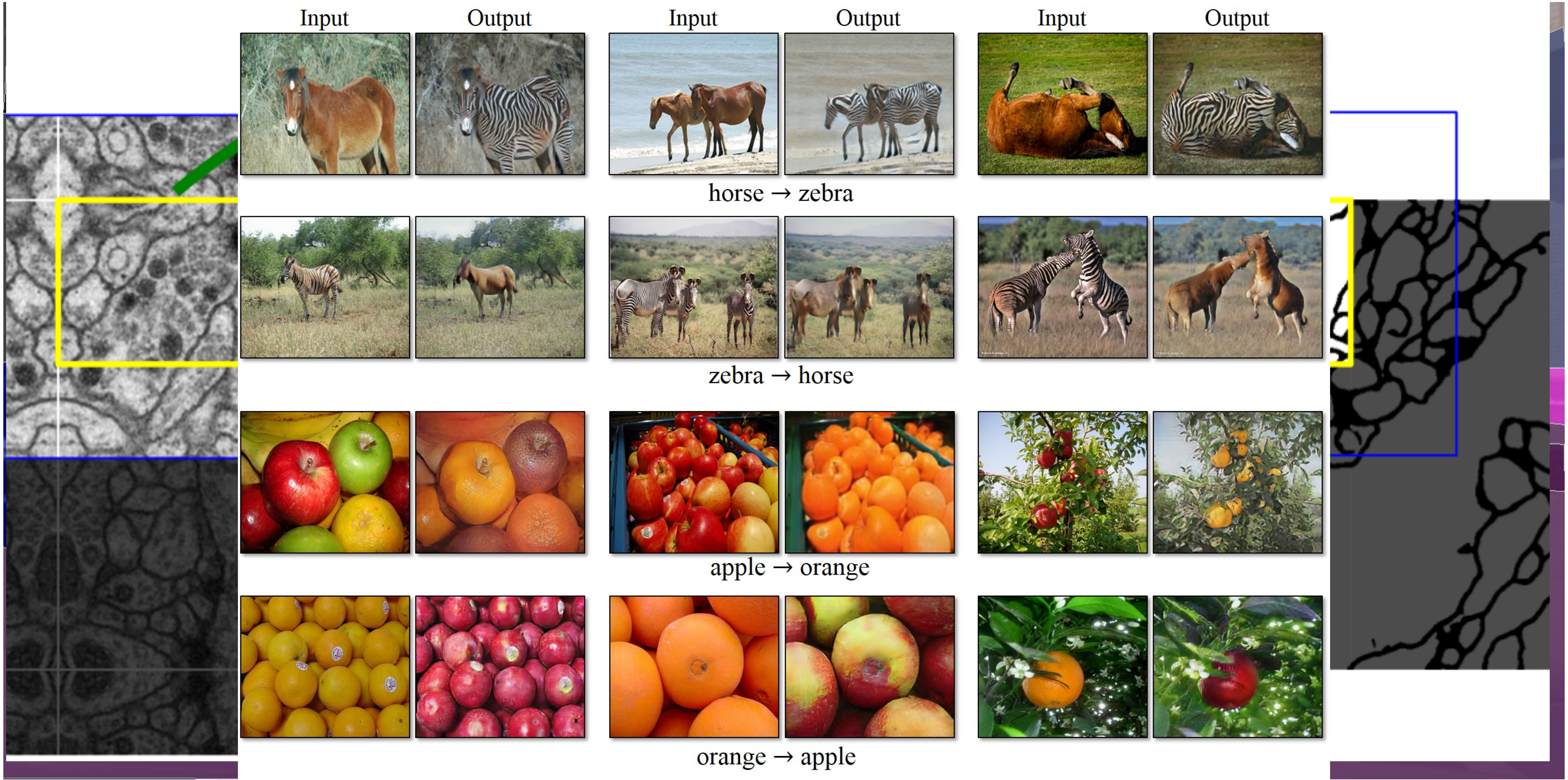

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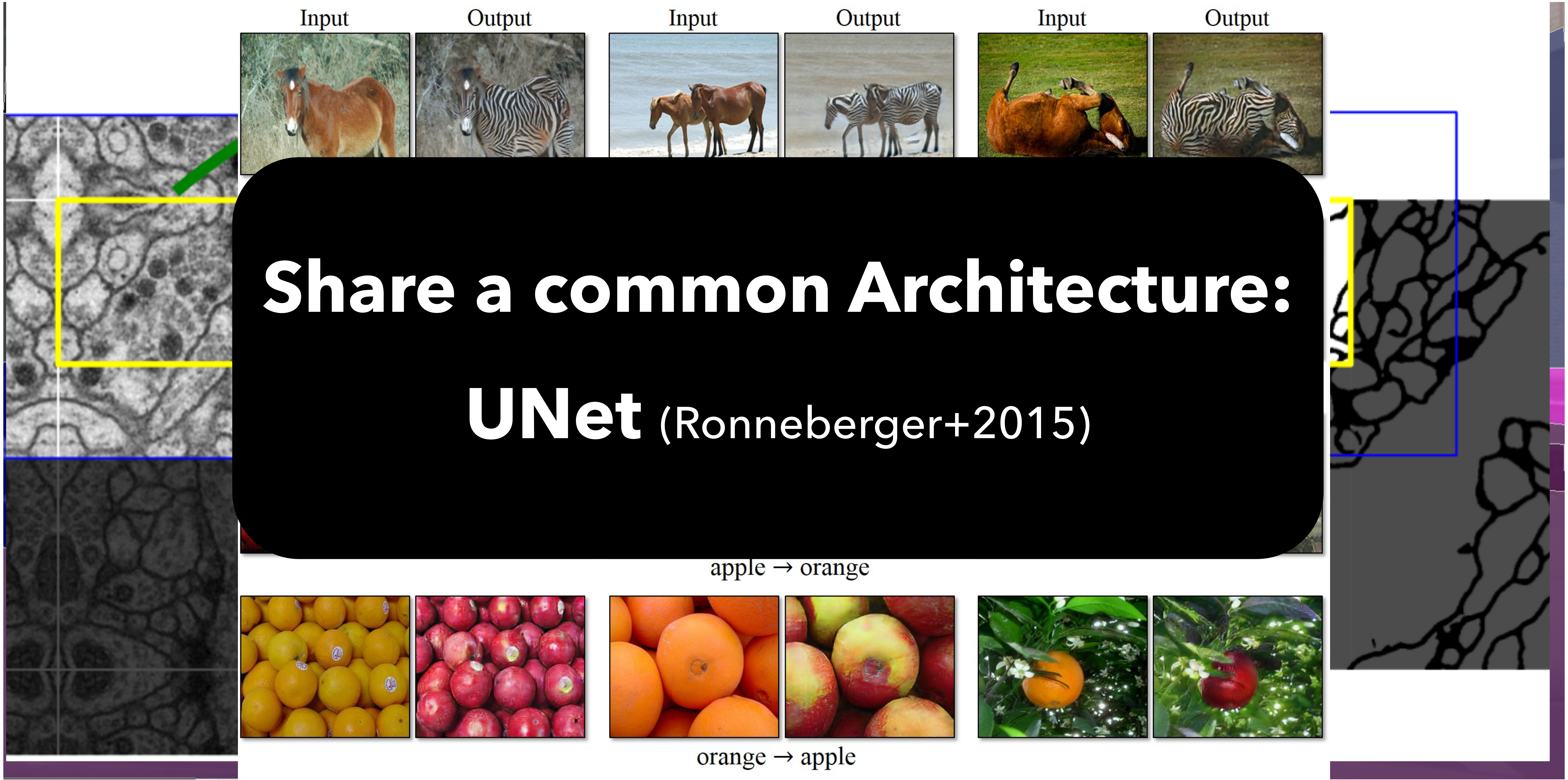

Share a common Architecture:

UNet (Ronneberger+2015)

U-NET ARCHITECTURE: PIX2PIX (CONDITIONAL GAN)

Isola+ CVPR 2017

WHAT IS DIFFERENT WHEN PREDICTING PHYSICAL PROPERTIES

- Almost all CNNs are classifiers: $Y \in \{0, 1\}^N$
- Here $Y \in \mathbb{R}^N$ with multiple orders of magnitude

1. Predict log(Y)
2. Quantized Regression [Güler et al. *CVPR* 2017]

Bins $B = \{-14, -12, \dots, 0, 2\}$

quantiles $q \in [0,1]^{|B|-1}$

residuals $r \in [0,1]^{|B|-1}$

$$f_\theta(x) = \sum_{i=0}^{|B|-2} q_i \left(B_i + r_i \left(B_{i+1} - B_i \right) \right)$$

PROOF OF CONCEPT: ILLUSTRIS DATA

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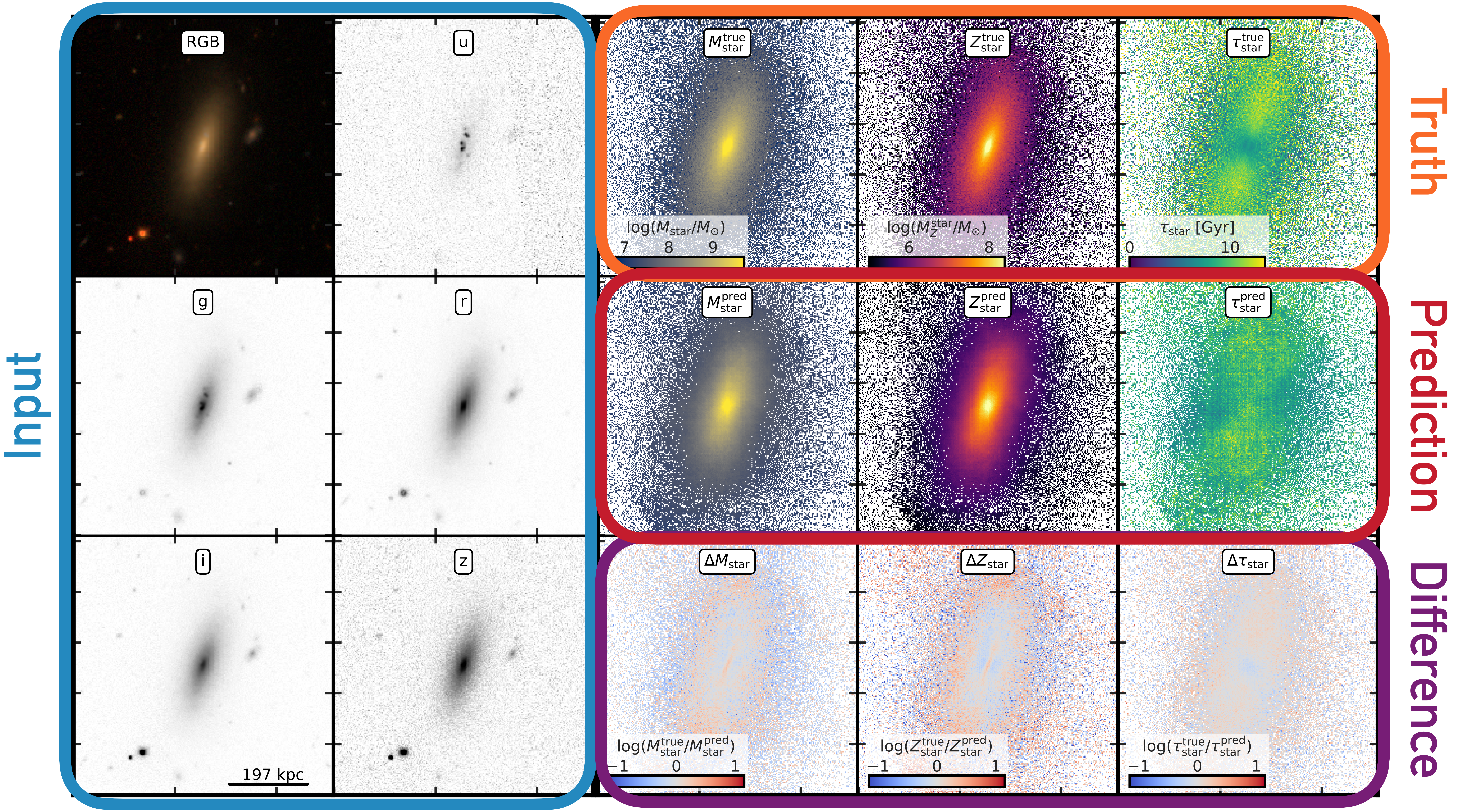
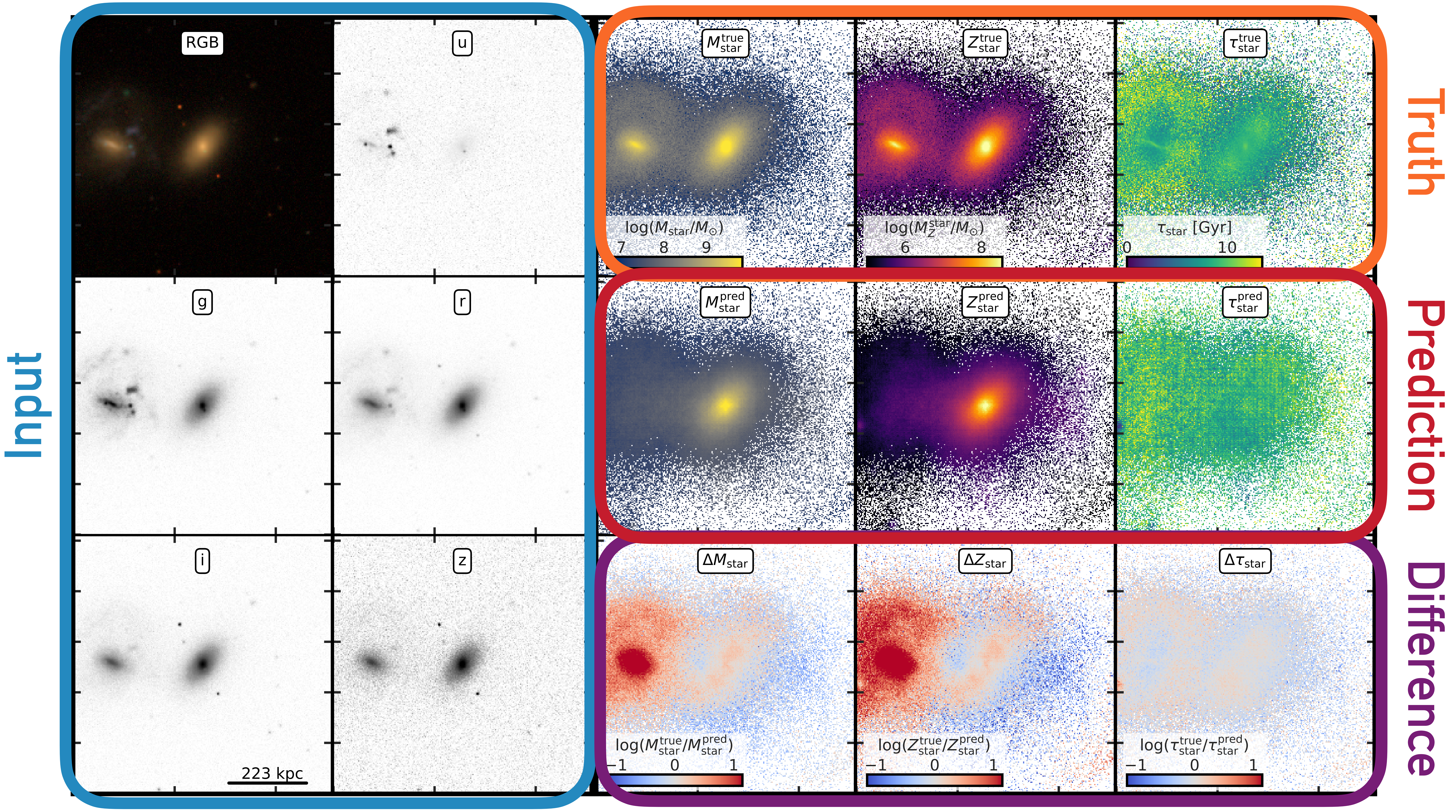
- SDSS MOCK IMAGES 256X256 PIXELS TORREY+2014, SNYDER+2015
- RADIATIVE TRANSFER, BACKGROUND STARS, PSF, NOISE, SURFACE BRIGHTNESS CUT
- PHYSICAL PROPERTIES ON SAME SCALE

RESULTS


THE DATA CLEARLY PROVES THAT—
ARE YOU INDIANA JONES?
BECAUSE YOU'VE GOT A LOT OF ARTIFACTS THERE, AND I'M PRETTY SURE YOU DIDN'T HANDLE THEM RIGHT.

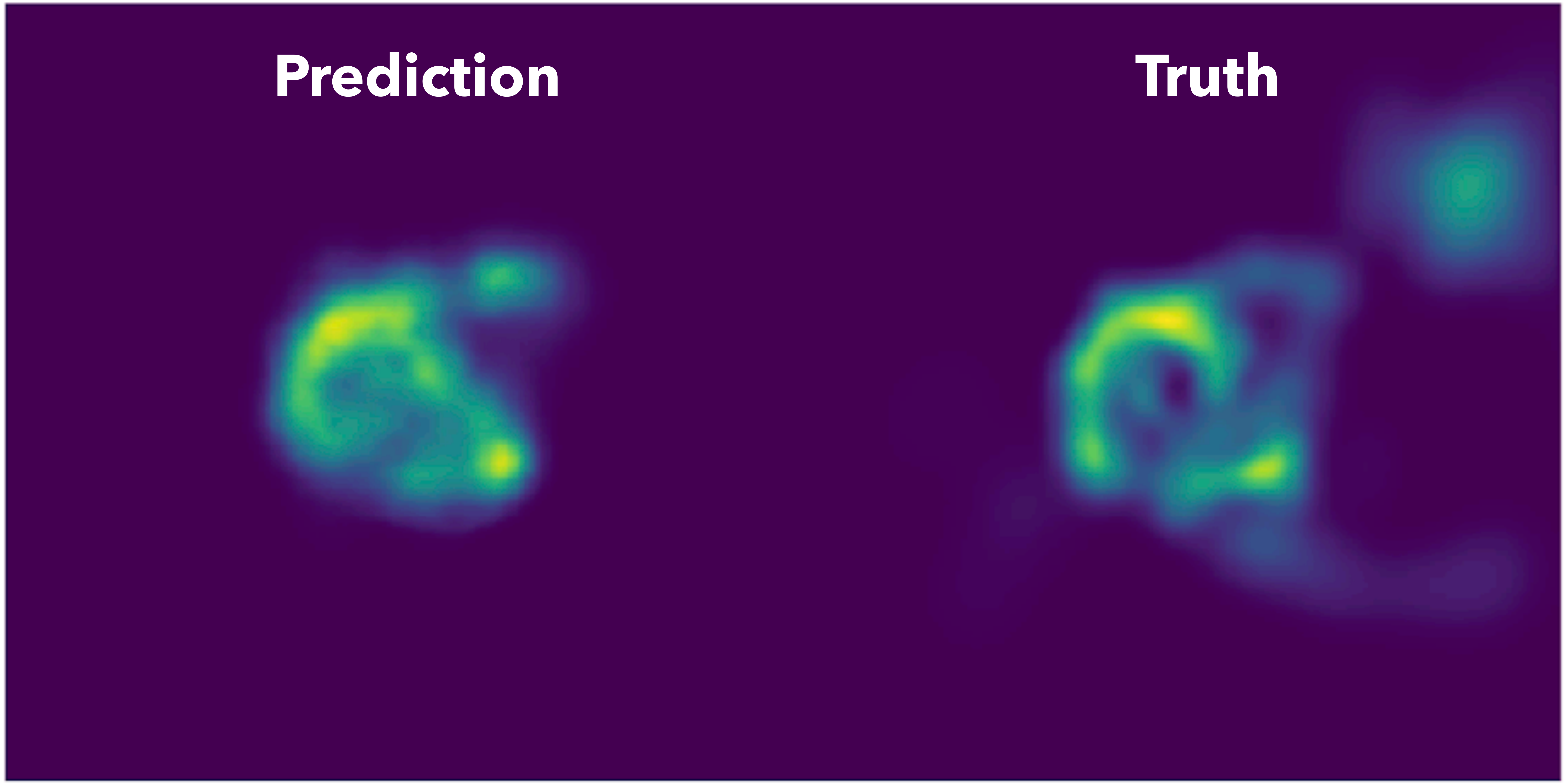


Input
RGB
u
g
r
i
z
197 kpc
Truth
$M_{\rm star}^{\rm true}$
$Z_{\rm star}^{\rm true}$
$\tau_{\rm star}^{\rm true}$
$\log(M_{\rm star}/M_\odot)$
7 8 9
$\log(M_Z^{\rm star}/M_\odot)$
6 8
$\tau_{\rm star}$ [Gyr]
0 10
Prediction
$M_{\rm star}^{\rm pred}$
$Z_{\rm star}^{\rm pred}$
$\tau_{\rm star}^{\rm pred}$
Difference
$\Delta M_{\rm star}$
$\Delta Z_{\rm star}$
$\Delta \tau_{\rm star}$
$\log(M_{\rm star}^{\rm true}/M_{\rm star}^{\rm pred})$
−1 0 1
$\log(Z_{\rm star}^{\rm true}/Z_{\rm star}^{\rm pred})$
−1 0 1
$\log(\tau_{\rm star}^{\rm true}/\tau_{\rm star}^{\rm pred})$
−1 0 1

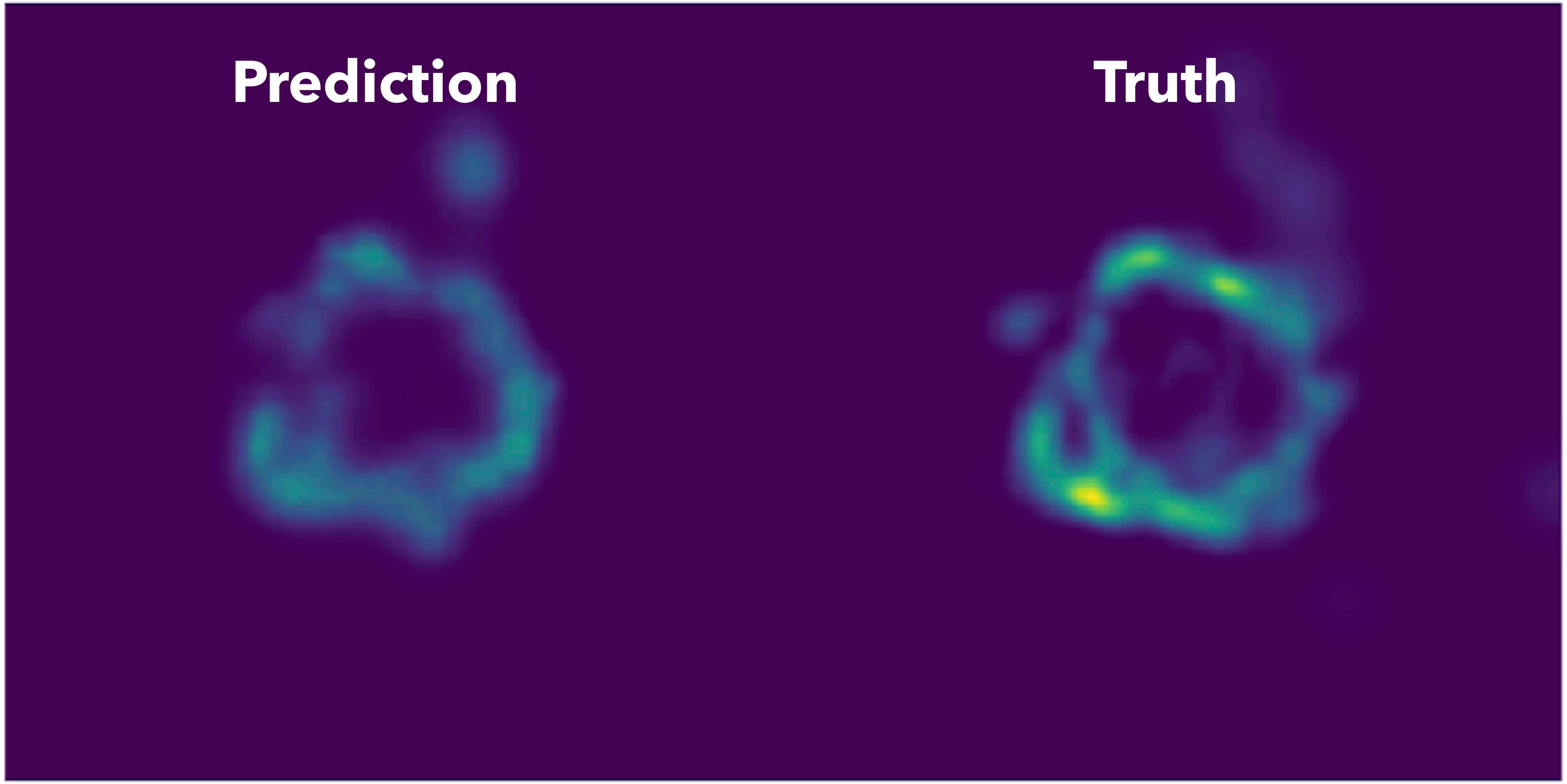


Input
RGB
u
g
r
i
z
223 kpc
Truth
Prediction
Difference
$M_{\rm star}^{\rm true}$
$Z_{\rm star}^{\rm true}$
$\tau_{\rm star}^{\rm true}$
$\log(M_{\rm star}/M_\odot)$
7 8 9
$\log(M_Z^{\rm star}/M_\odot)$
6 8
$\tau_{\rm star}$ [Gyr]
0 10
$M_{\rm star}^{\rm pred}$
$Z_{\rm star}^{\rm pred}$
$\tau_{\rm star}^{\rm pred}$
$\Delta M_{\rm star}$
$\Delta Z_{\rm star}$
$\Delta \tau_{\rm star}$
$\log(M_{\rm star}^{\rm true}/M_{\rm star}^{\rm pred})$
−1 0 1
$\log(Z_{\rm star}^{\rm true}/Z_{\rm star}^{\rm pred})$
−1 0 1
$\log(\tau_{\rm star}^{\rm true}/\tau_{\rm star}^{\rm pred})$
−1 0 1

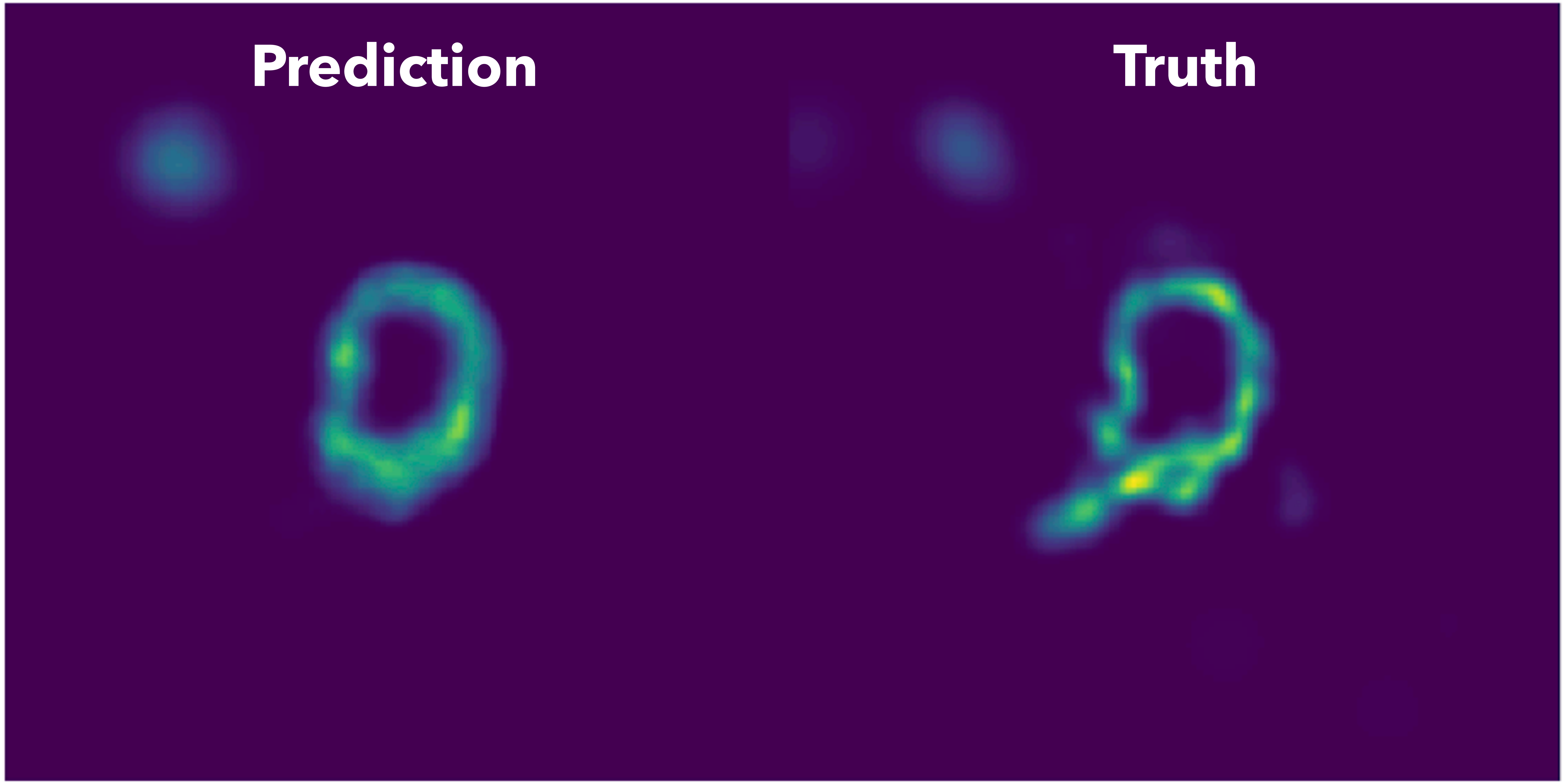
COMPARING TRUE AND PREDICTED SFR – 100TH QUANT.



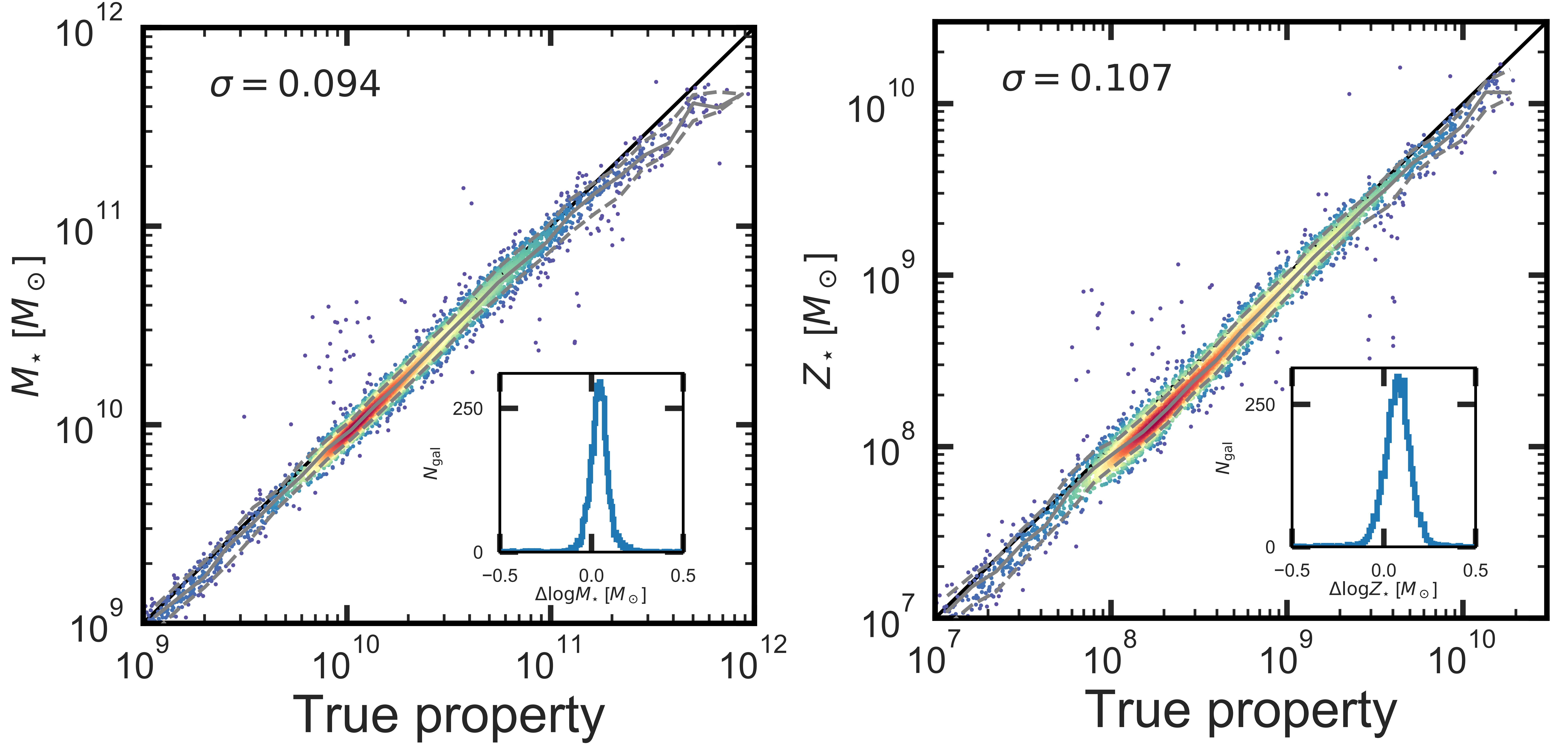
COMPARING TRUE AND PREDICTED SFR – 70TH QUANT.



COMPARING TRUE AND PREDICTED SFR – 40TH QUANT.



STELLAR PROPERTIES



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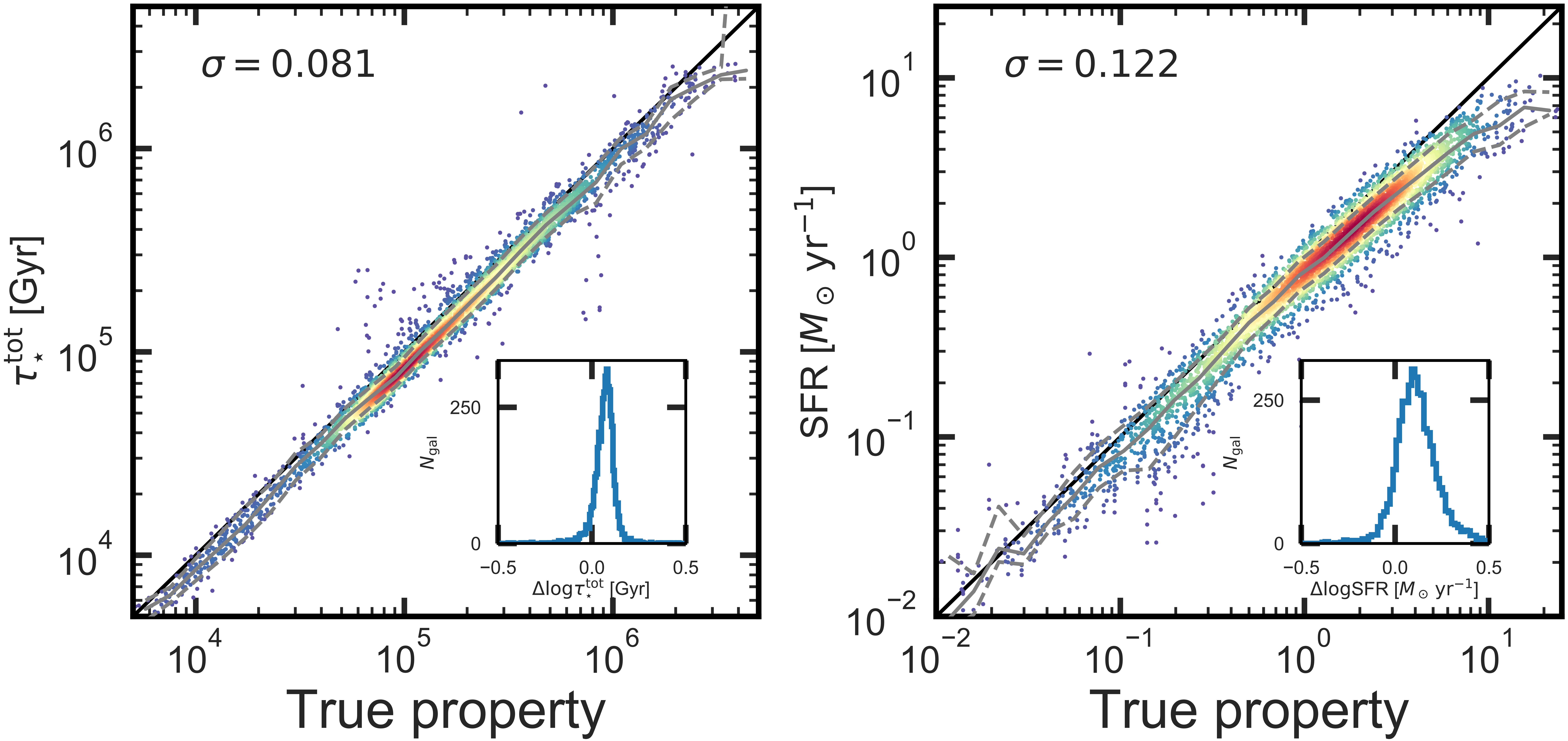
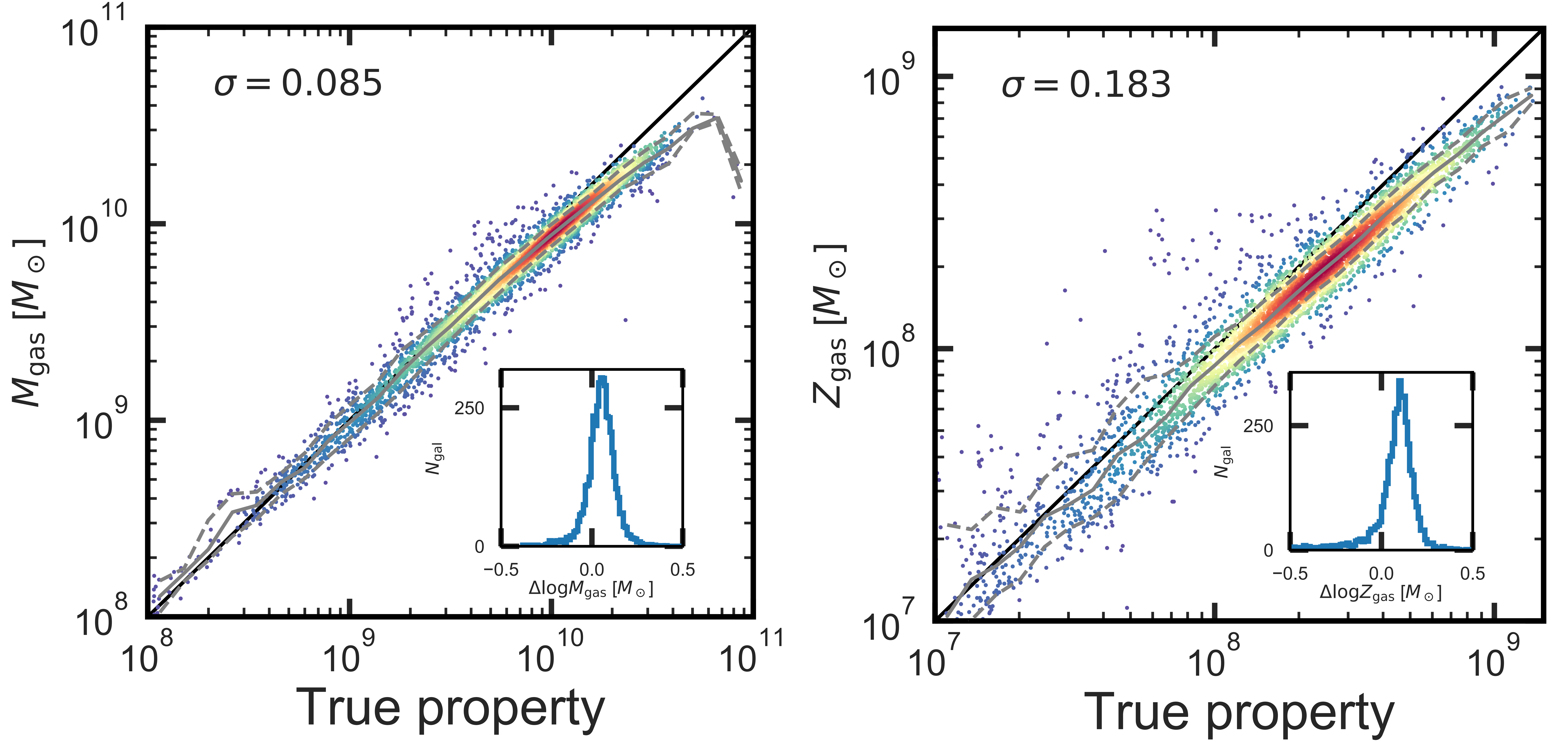
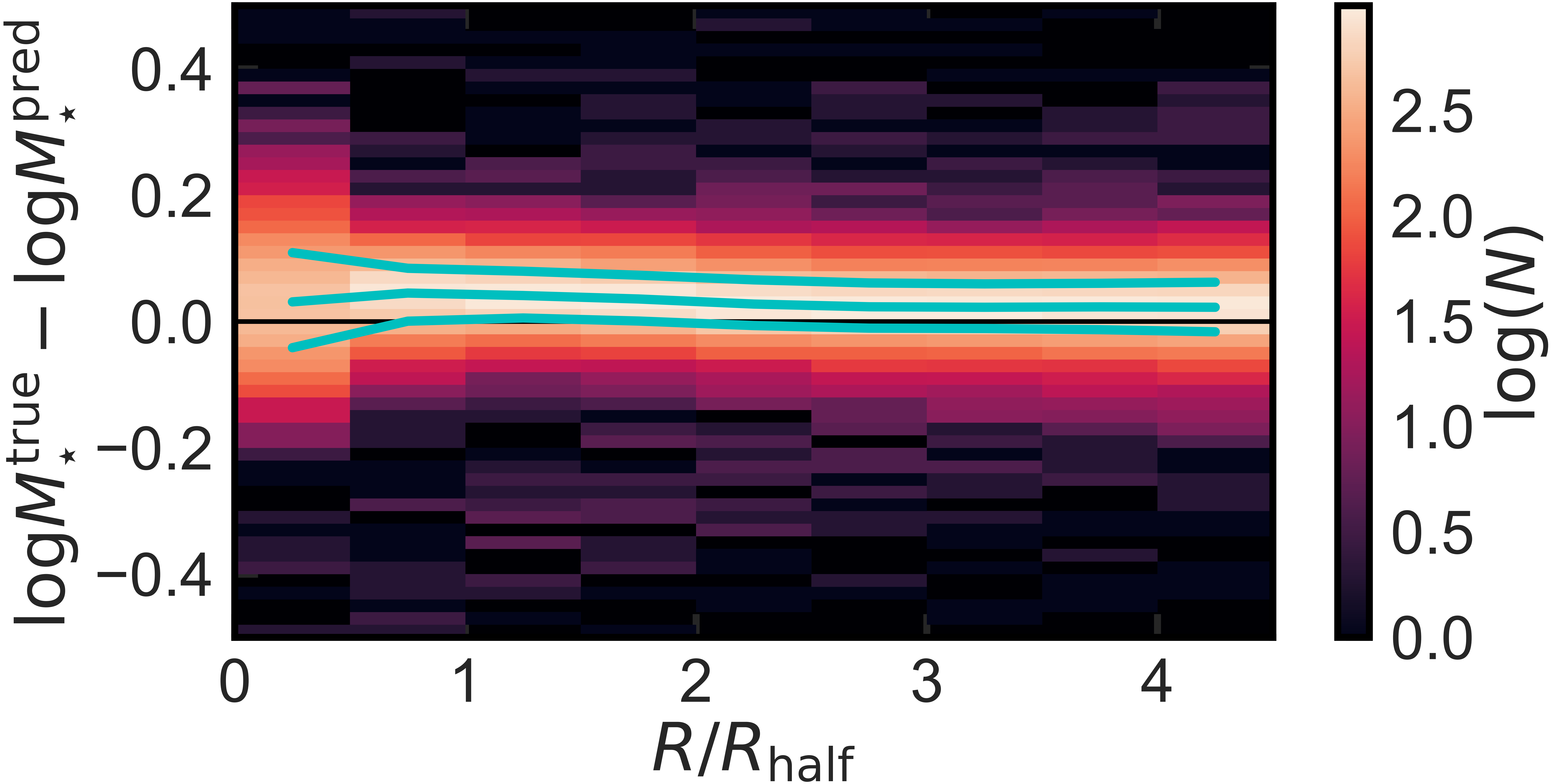


GASEOUS PROPERTIES



RADIAL SYSTEMATICS?



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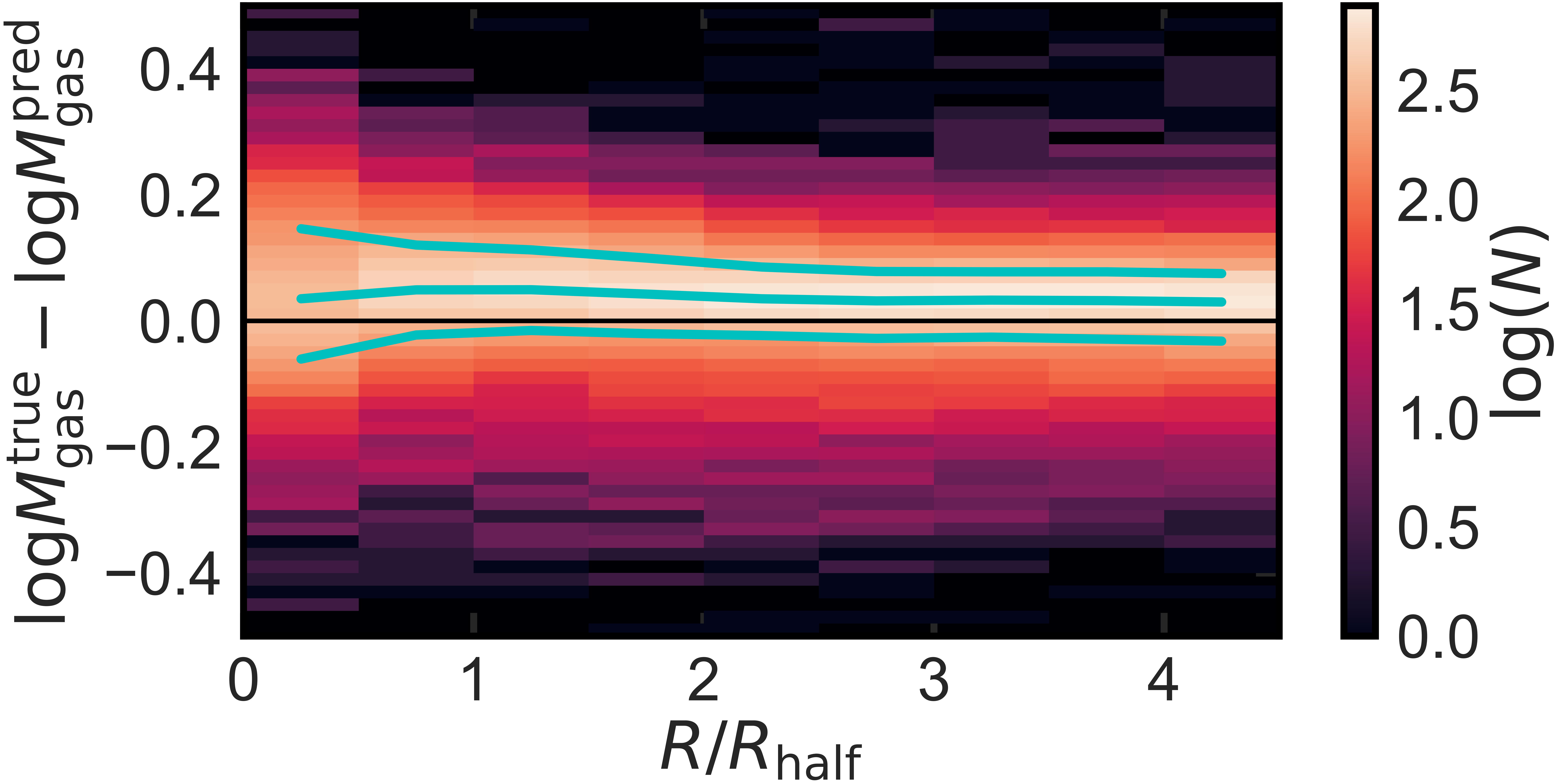

SUMMARY

SDSS (MOCK) *U,G,R,I,Z* IMAGES CONTAIN ENOUGH INFORMATION TO ***PREDICT*** PHYSICAL PROPERTIES OF GALAXIES ON A ***PIXEL-BY-PIXEL*** BASIS

NEXT STEPS: REAL LIFE APPLICATION

USE **PICASSSO** ON REAL SDSS IMAGES WITH SDSS MANGA, SAMI, OR CALIFA AS TRAININGS SAMPLE

NEXT STEPS:

PROOF-OF-CONCEPT WORKS

QUANTIFY WHAT IS LEARNED: MORPHOLOGY OR COLOR?

QUANTIFY DEPENDENCE ON:

- IMAGE RESOLUTION (STABLE AGAINST FACTOR 2/4 LOWER RES)
- TRAINING SET SIZE
- NUMBER OF INPUT BANDS

REAL LIFE APPLICATION: IFU SURVEY DATA (E.G. MANGA)

RELEASE IT AS READY-TO-USE TOOL?