Konstantinos Kovlakas
Journal Club, 2019/12/20

Pillepich+2019

First results from the TNG50 simulation:
the evolution of stellar and gaseous disks across cosmic time

FORTH
INSTITUTE OF ASTROPHYSICS

Background

- **Structural morphology** of galaxies is dictated by kinematics of stars, gas and dark matter.

  Affected by accretion of cosmic gas, star formation, galaxy mergers and interactions, feedback from star-formation or SMBHs, gas outflows/recycling

- **Disk-like** morphology is associated with kinematics: **rotation**

- Different levels of **star formation** ↔ **morphology**

Current issues from observations

- At z ~ 2, large star-forming galaxies are gas-rich rotating disks, **but** exhibit larger contribution of **random gas motion**

- Many star-forming galaxies at z ~ 1.5 are **elongated**

- Are galaxy **disks settled** with time
  i.e. increasing in rotational velocity and declining in velocity dispersion?

- Do galaxy **disks settle faster** for higher mass galaxies?

Can we reproduce the properties of galaxies at z = 0,
having a **complete theory** of galaxy formation?

Limitations of previous studies

- Until now large simulations (e.g. *Illustris300/100, EAGLE*) **do not** have high resolution.

  They only show connection between SFR, M and morphology, avoiding the **intrinsic three-dimensional shape**.

- Zoom-in simulations (e.g. *Eris, Auriga*) with high resolution, study few objects, i.e. **representative** classes.

- What about a simulation with high resolution & sample size?

What is TNG50 and why care?

- It is a cosmological **gravo-MHD** simulation of **galaxy formation**, trying to answer the aforementioned questions
- Tracks properties of **thousands** of galaxies across cosmic history
- High **resolution** that probes the 3D structure of galaxies
- **Diversity**: isolated galaxies, interacting galaxies, mergers, clusters
- **IA members** are already, or planning, or may want to use data from the TNG simulations

Astronomy & Astrophysics manuscript no. aanda
December 19, 2019

Turnaround radius of galaxy clusters in N-body simulations

Giorgos Korkidis,[1,2,⋆], Vasiliki Pavlidou[1,2,⋆⋆], Konstantinos Tassis,[1,2], Evangelia Ntormousi[1,2], Theodore N. Tomaras[1], Konstantinos Kovlakas[1,2]

Monthly Notices of the ROYAL ASTRONOMICAL SOCIETY

MNRAS **490,** 3196–3233 (2019) doi:10.1093/mnras/stz2338
Advance Access publication 2019 September 9

First results from the TNG50 simulation: the evolution of stellar and gaseous discs across cosmic time

Annalisa Pillepich,[1★] Dylan Nelson,[2] Volker Springel,[2] Rüdiger Pakmor,[2] Paul Torrey,[3] Rainer Weinberger,[4] Mark Vogelsberger,[5] Federico Marinacci,[5,6] Shy Genel,[7] Arjen van der Wel[1,8] and Lars Hernquist[4]

[1]*Max-Planck-Institut für Astronomie, Königstuhl 17, D-69117 Heidelberg, Germany*
[2]*Max-Planck-Institut für Astrophysik, Karl-Schwarzschild-Str 1, D-85741 Garching, Germany*
[3]*Department of Physics, University of Florida, 2001 Museum Rd., Gainesville, FL 32611, USA*
[4]*Harvard–Smithsonian Center for Astrophysics, 60 Garden Street, Cambridge, MA 02138, USA*
[5]*Kavli Institute for Astrophysics and Space Research, Massachusetts Institute of Technology, Cambridge, MA 02139, USA*
[6]*Department of Physics and Astronomy, University of Bologna, via Gobetti 93/2, I-40129 Bologna, Italy*
[7]*Center for Computational Astrophysics, Flatiron Institute, 162 Fifth Avenue, New York, NY 10010, USA*
[8]*Sterrenkundig Observatorium, Universiteit Gent, Krijgslaan 281 S9, B-9000 Gent, Belgium*

The article and our focus

Purpose

- Structural and kinematical evolution of star-forming galaxies at $0 < z < 6$
- Sizes, disk heights, 3D shapes, rotational vs dispersion-supported motion
- Predictions for *Ha* and stellar-light tracers

Our focus

- Few key, qualitative results
- Science value of the simulation

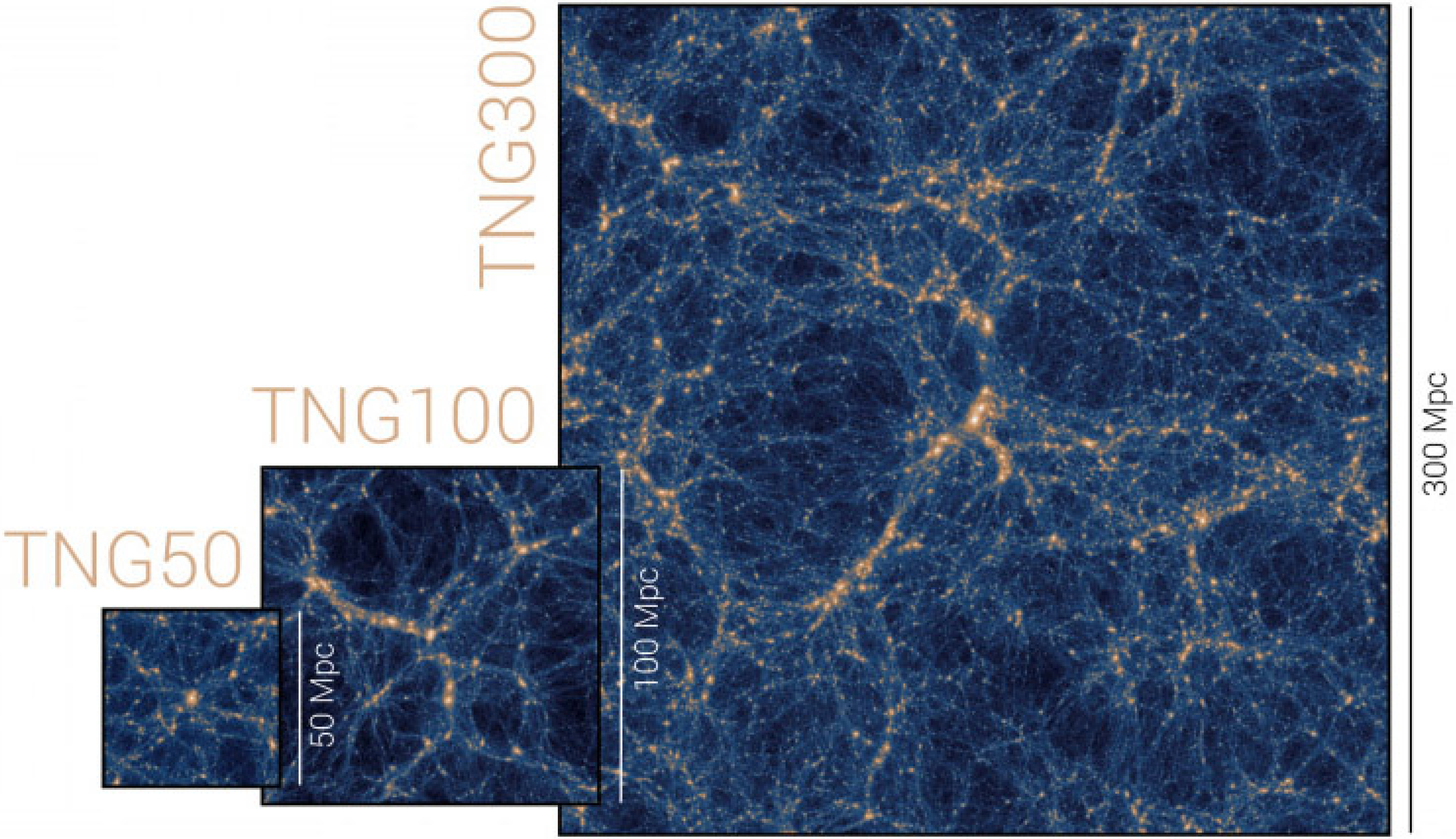
The model

- Planck Collaboration XIII (2016) cosmological parameters
- $(51.7\ \mathrm{cMpc})^3$ volume
- 2 x 2016^3 dark matter particles and gas cells
- **8.5 x 10^4 $M_\odot$** baryonic elements
- Average cell size: **70–140 pc** in star-forming regions (comparable to zoom-in)

- At z=1, **~6500 galaxies** with stellar mass >10^8 $M_\odot$
- At z=0, **~130 galaxies** as massive as MW & one **Virgo-cluster** analogue

- *“Necessarily **simplified** numerical treatment of **star formation** and **feedback** that acts below ~100 pc scales in the ISM”*. Using Springel & Hernquist (2003) model.

The simulation



Analysis

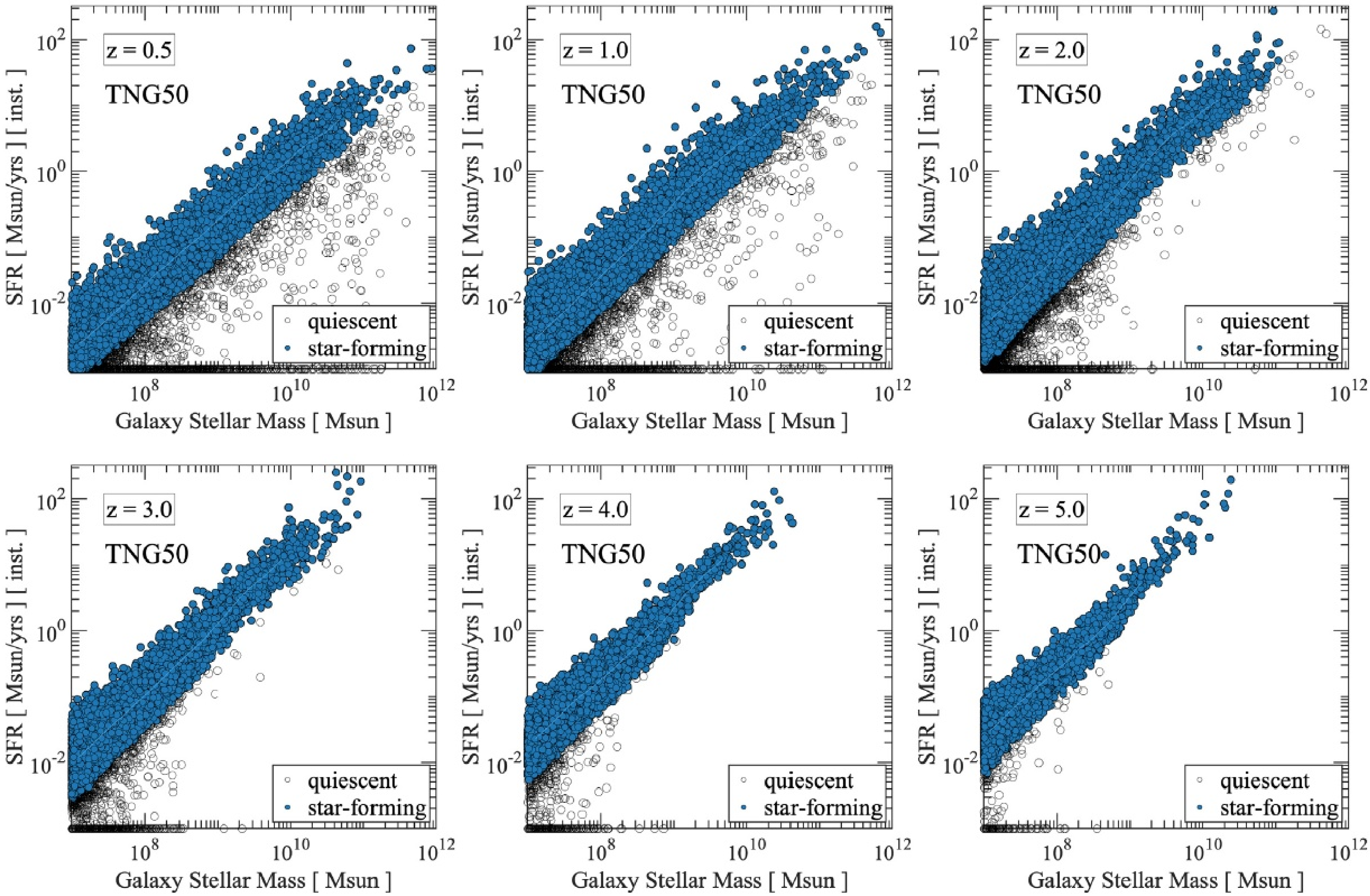
- **Galaxy identification**: haloes, subhaloes, galaxies (central and satellite)
- **Galaxy descriptors**

M_*	:	stellar particles → Chabrier IMF
M_g	:	gas cells
M_{HI}	:	neutral H gas cells
$H\alpha$	:	instantaneous SFR → Kennicutt (1998) scaling relation
V-band	:	light from stellar particles at 0.55 μm

- **Galaxy properties**

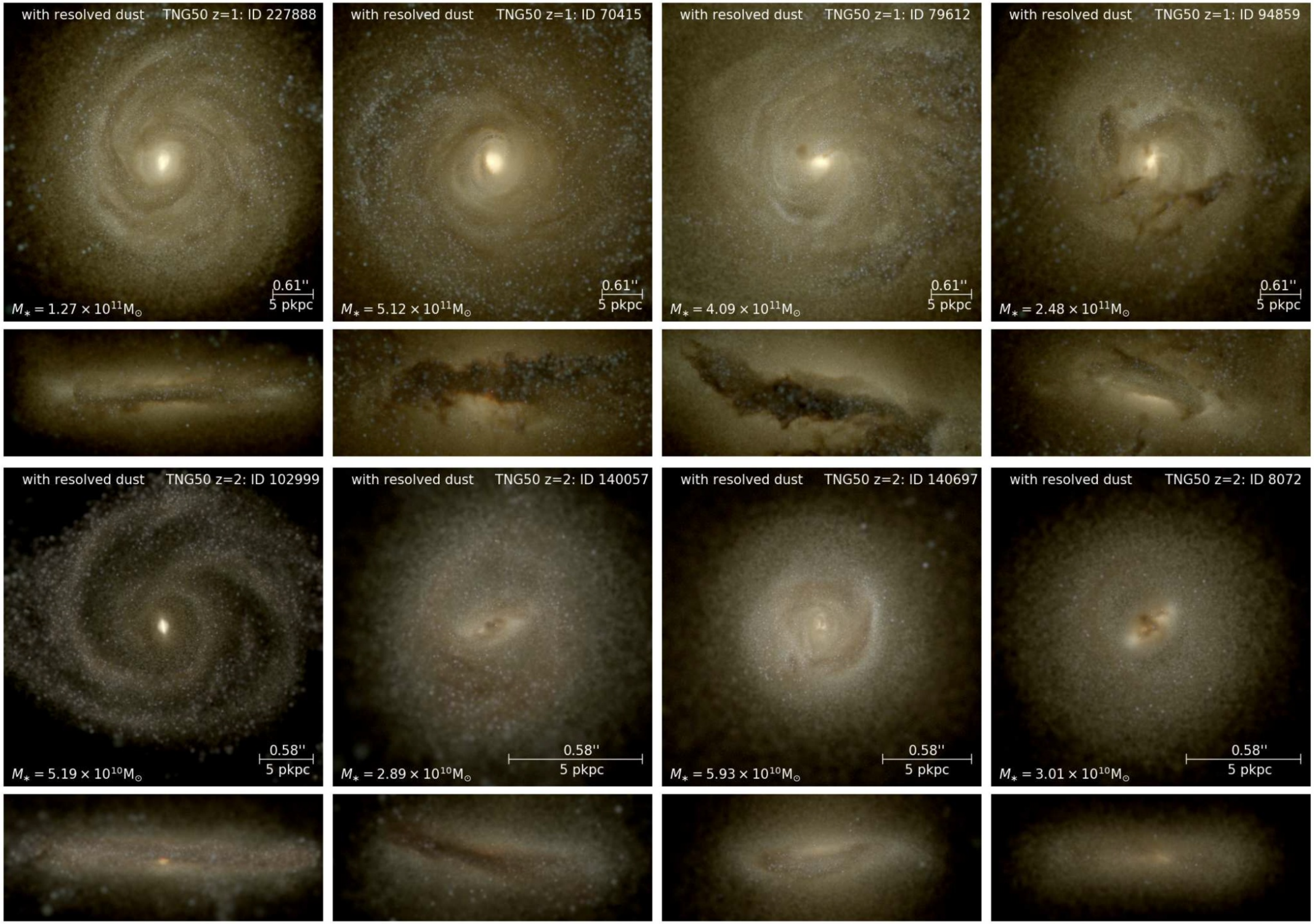
size ($r_{1/2}$)	:	3D stellar/gas half-mass radius / 2D half-light in $V/H\alpha$
disk height ($h_{1/2}$)	:	half-mass or half-light (stars or gas)
shape	:	(i) minor/major axis and (ii) middle/major axis
kinematics	:	velocity dispersion and rotational velocity

Emergence of SFMS and selection of star-forming galaxies with $M_* > 10^7\ M_\odot$



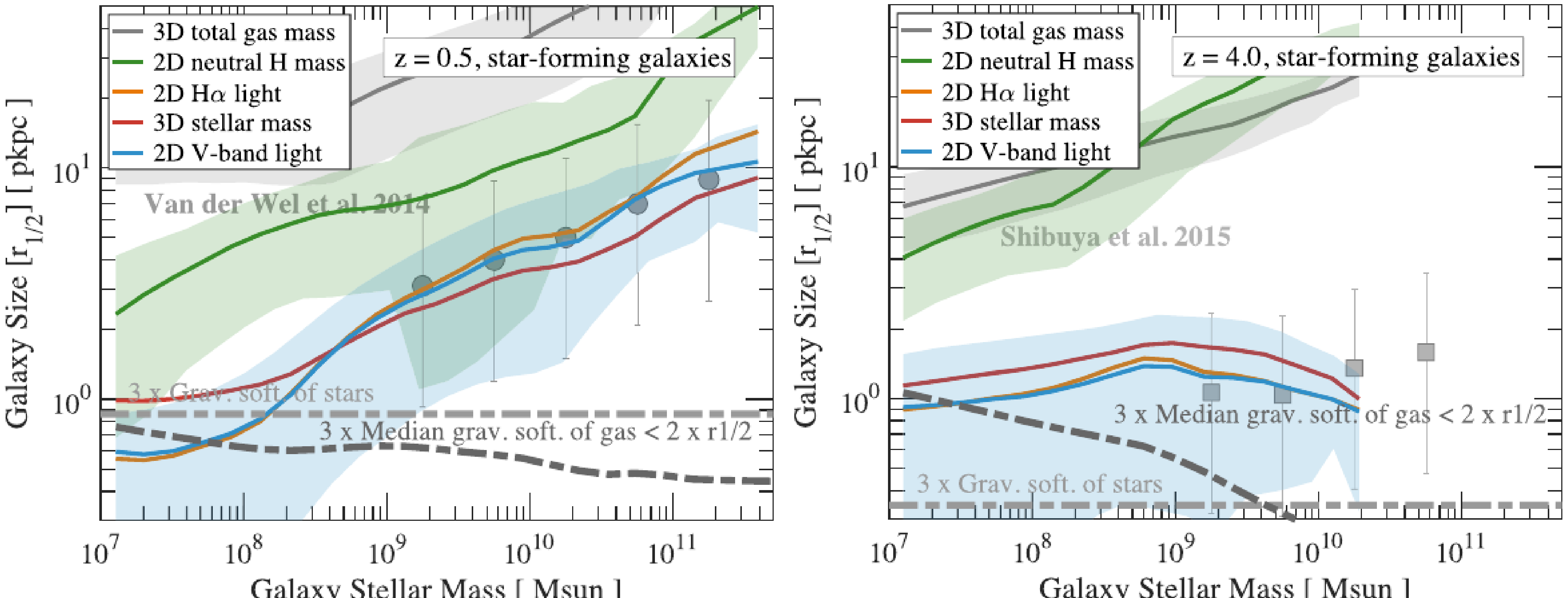
Mock JWST images (from site)

using Monte Carlo radiative transfer post-processing



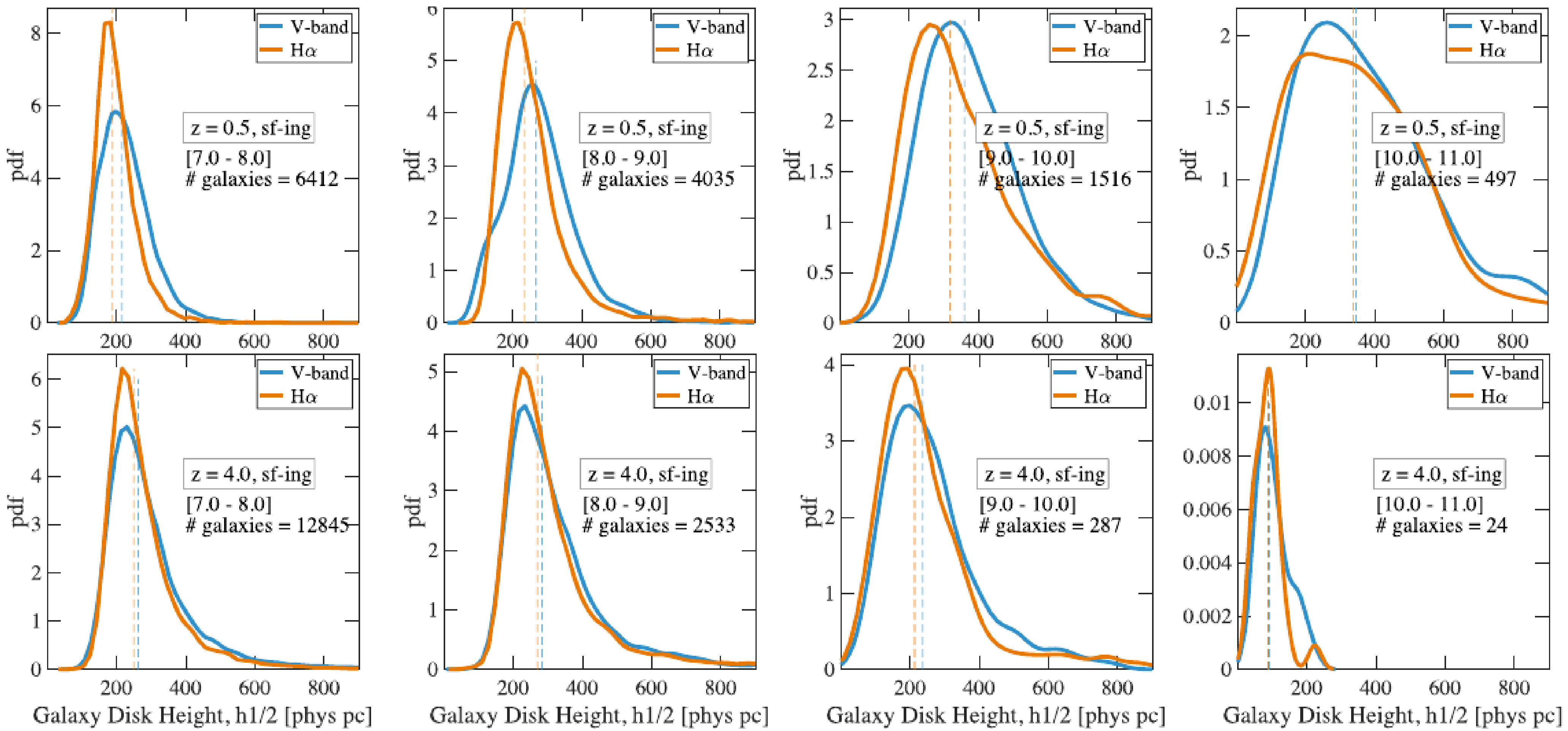
Results: extent of different components

- *V* and *Hα* trace each other within a factor of ~2
- *Hα* > stars at recent times for massive galaxies: mergers



Results: disk heights

- Heights increase with M_* at $z \sim 0.5$, non-monotonic relation after $z \sim 1$
- *Hα*: thinner



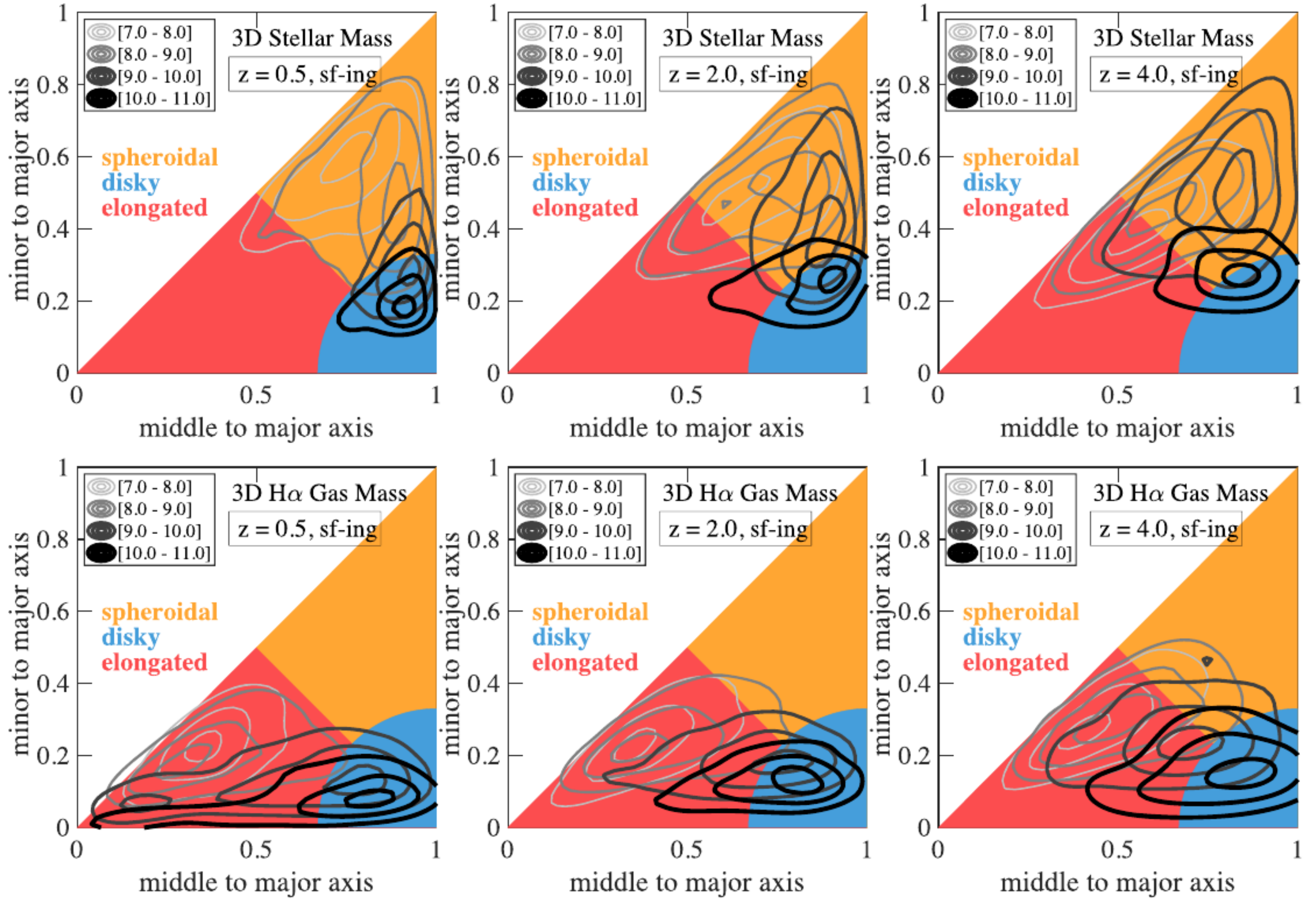
Results: 3D shapes

Observed

- Disky for <z and >*M**
- Elongated for >z and <*M**

Novelty

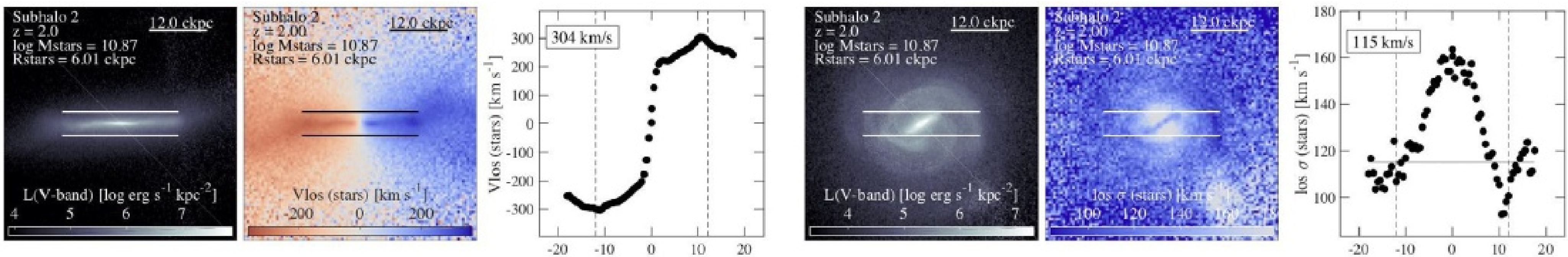
- *Hα* shape is mostly disky or elongated



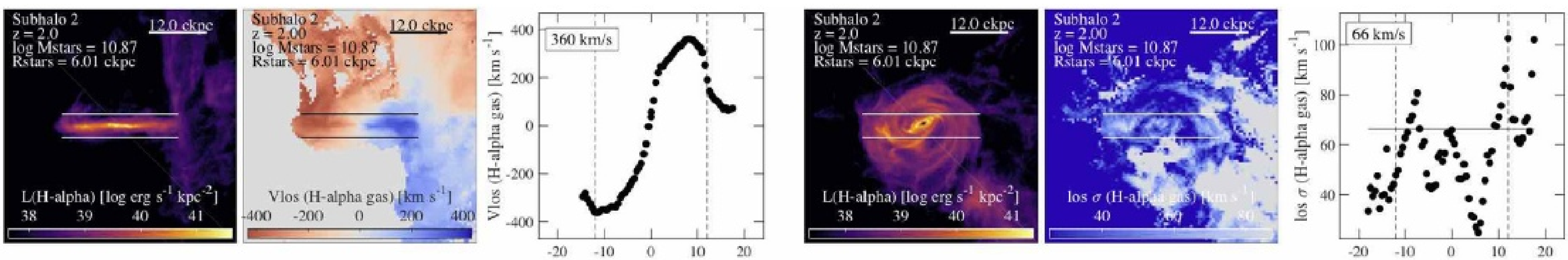
Results: kinematical maps

- Edge on: rotational velocity | Face on: velocity dispersion
- Stellar (top): they find bulges, bars, etc. *Hα* (bottom): enhanced **complexity**

V



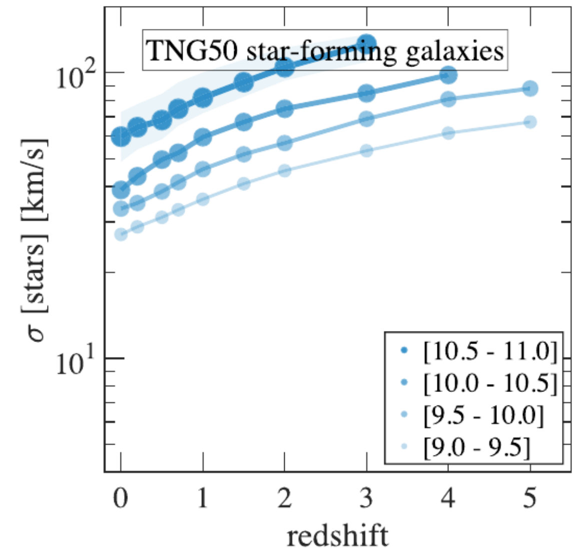
Hα

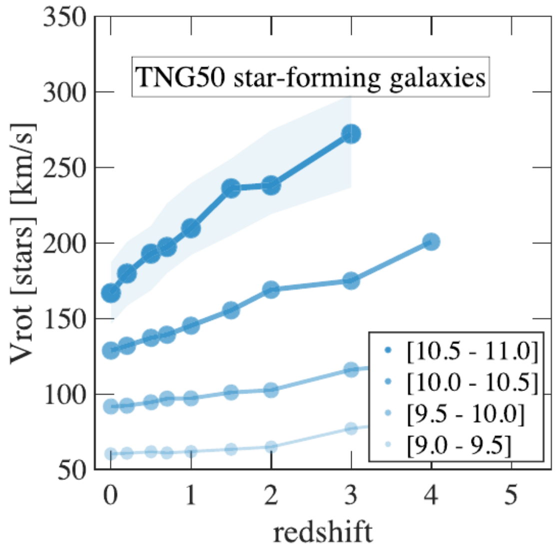


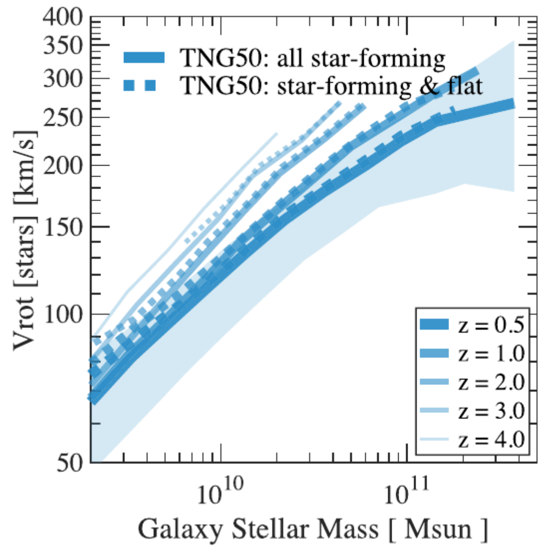
Results: V_{rot} and σ measures for galaxies (figures for stellar mass only)

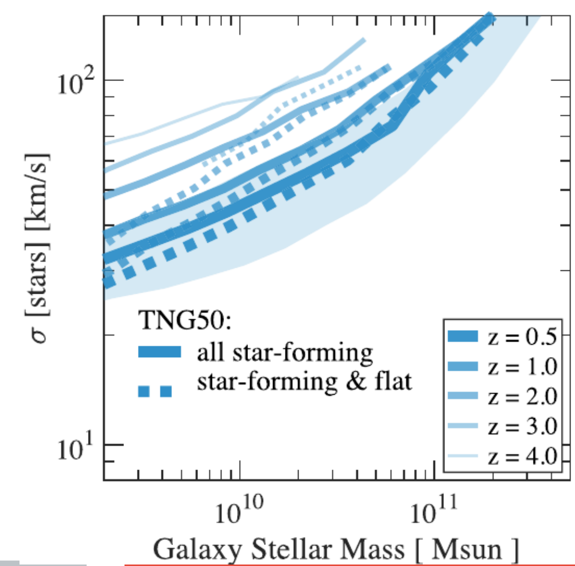
- V_{rot}: mean vel. in bins of 0.5 ckpc → absolute maximum
- σ : vel. disp. in bins of 0.5 ckpc → mean at $1<r/r_{1/2}<2$

- V_{rot} & σ decrease with time at fixed M_*. Weaker *z*-trends for V_{rot}
- V_{rot} is stronger function of stellar mass than σ
- At all redshifts, V_{rot} >> *Hα*



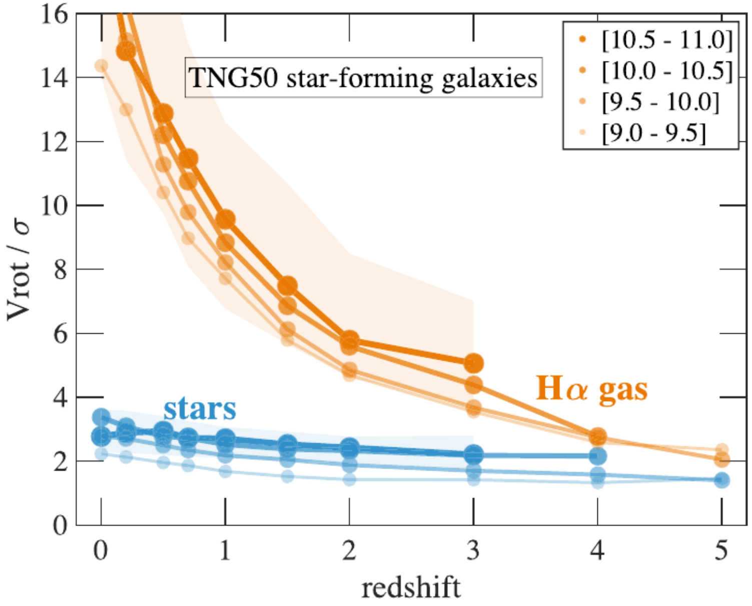






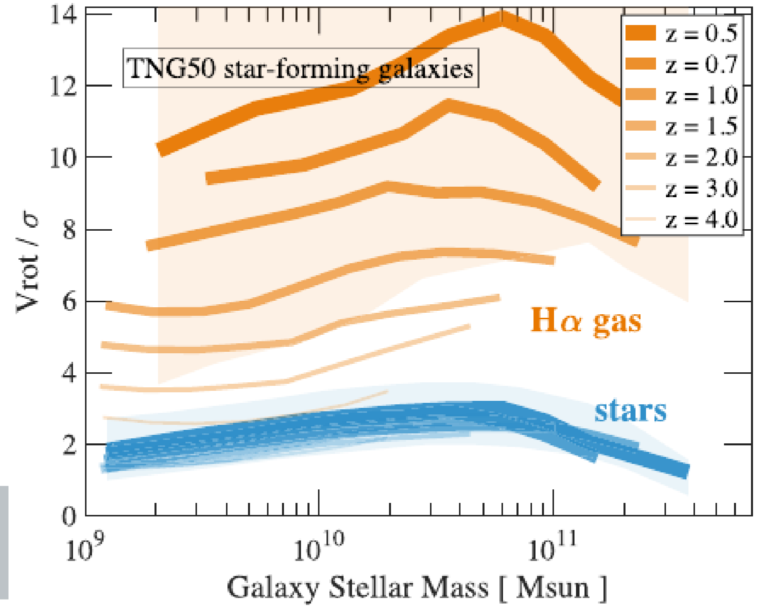
Results: order vs. disordered motion, aka V_{rot} / σ

- Dense gas has larger V_{rot}/σ at all z and M_*
- Stellar V_{rot}/σ does not evolve much with time
- At higher masses the ratio declines, possibly due to merger activity increasing σ
- Flatter galaxies have higher ratio (no fig.)



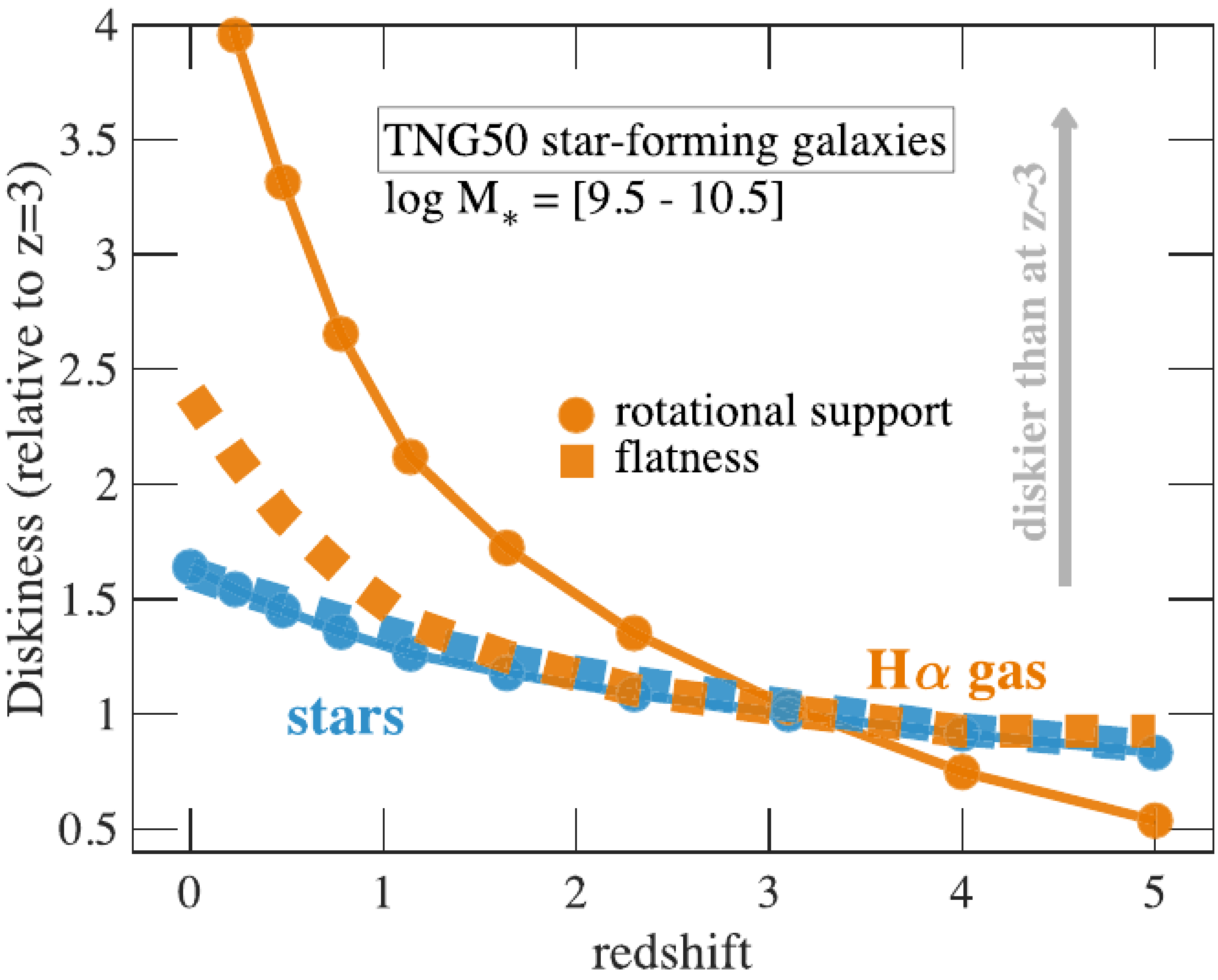
V_{rot}/σ lower for stars, interpreted as vertical, dispersion-supported motion of stars although dispersion fields more coherent (kinamatical maps)

We need better observational diagnostics to capture the chaotic nature of gas kinematics.



Results: settling of disks

- **Solid**: kinematics
- **Dashed**: flatness from 3D shape
- Relative to z = 3 where most galaxies are classified as gaseous disks
- Trends for stars are more coupled than for gas
- A typicall star-forming galaxy has $h_{1/2}/r_{1/2} < 0.1$



Important results

- Star-forming galaxies become disky quickly (observed)
  Disks become more rotationally supported (observed)

- Gas and stellar components: different structural/kinematic behaviours:
  stars have collisionless dynamics while gas is collisional and dissipates energy through radiative cooling

- Smaller galaxies have larger velocity dispersions (observed)

- Rapid drop of velocity dispersion through time.
  - Small scale turbulance in the ISM is **not modelled** and could increase it.
  - Other drivers are modelled (e.g. interactions, gas inflows/outflows):

  in the future they will disentangle them

Closing remarks on simulation

- Structures at lower masses (10^8 at z=0) than previous uniform-volume simulations

- Resolving thinner galaxies (~100 pc) than previous simulations, unaffected by gravitational softening (~300 pc)

- Caveats
  (i) simple treatment of **unresolved ISM**
  (ii) **empirical scaling** between SFR and *Hα*
  (iii) **simplified galactic winds** from SN – ISM interactions

A protocluster at z ~ 1

Two massive galaxy groups in a protocluster.
Large DM haloes (orange), bridge of DM (blue), high-speed gas (white) reveals outflows and ram-pressure & tidal stripping of orbitting satellite galaxies

Backup: gravitational softening

- In N-body simulations, particles may come very close to each other, resulting into infinite forces. The gravitational softening is the trick of choosing a very small value e so that the radius in the potential equation is never zero:

$$\Phi = -\frac{1}{\sqrt{r^2 + e^2}}$$