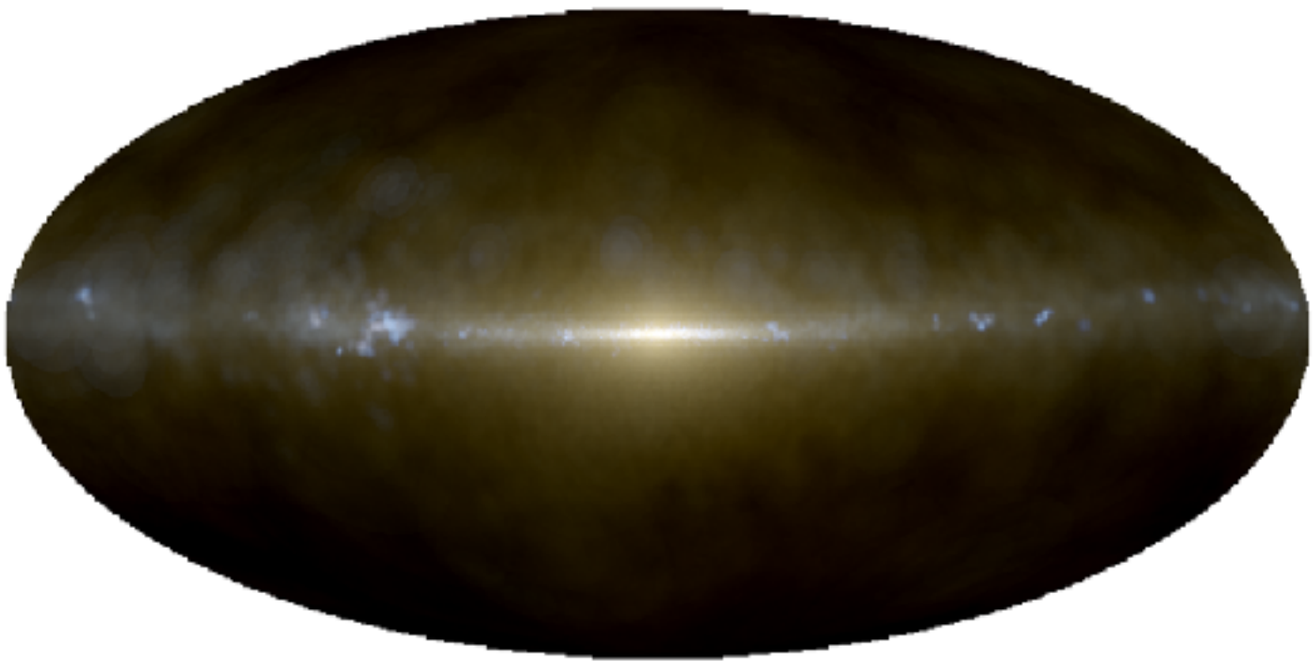
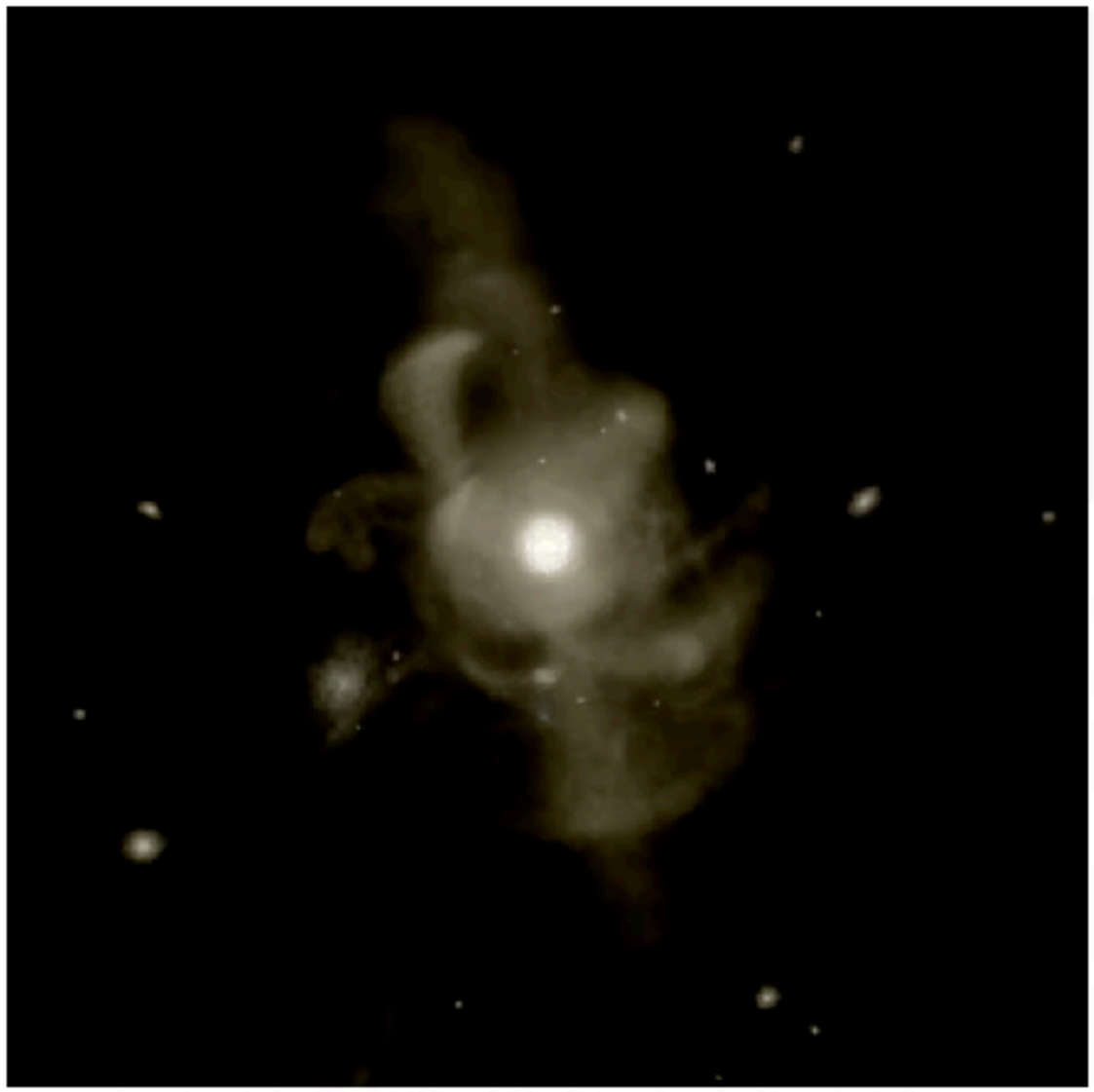
NIHAO-UHD: High-resolution Simulations of Milky Way mass galaxies

IAU S334 Potsdam 13th of July

Tobias Buck

Andrea V. Macciò, Melissa Ness, Aura Obreja, Aaron A. Dutton, Hans-Walter Rix





Animation by T. Buck (MPIA, NYUAD) based on NIHAO simulations

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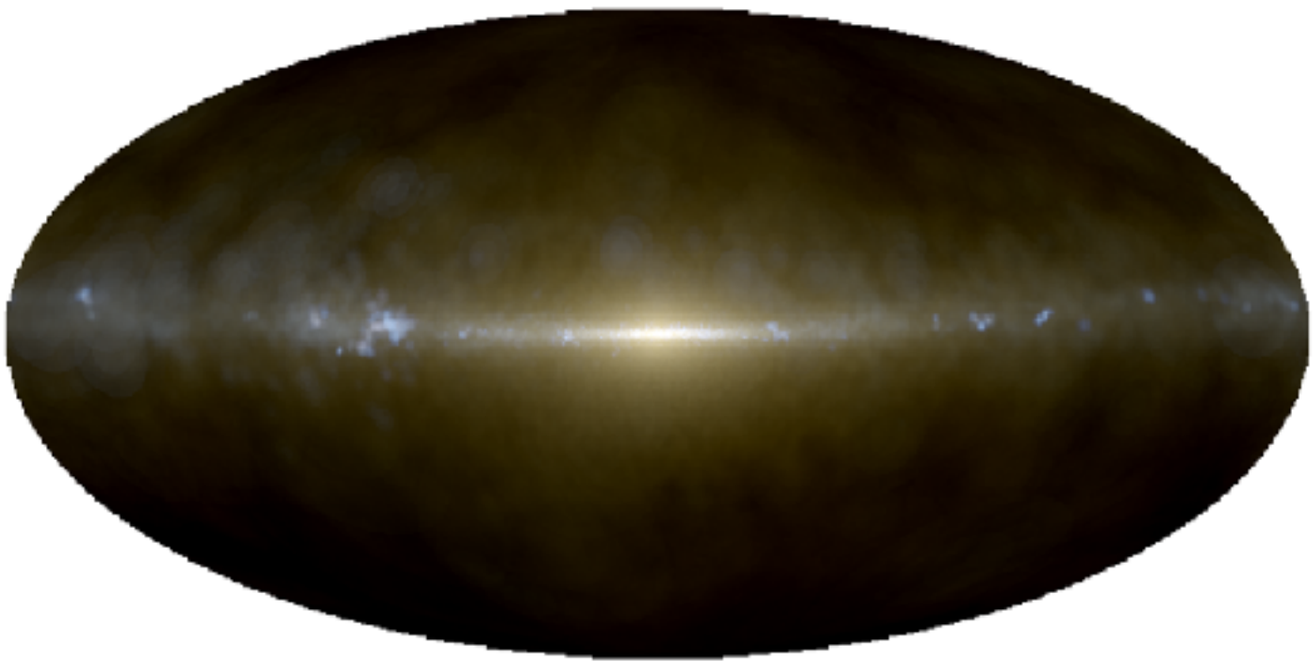

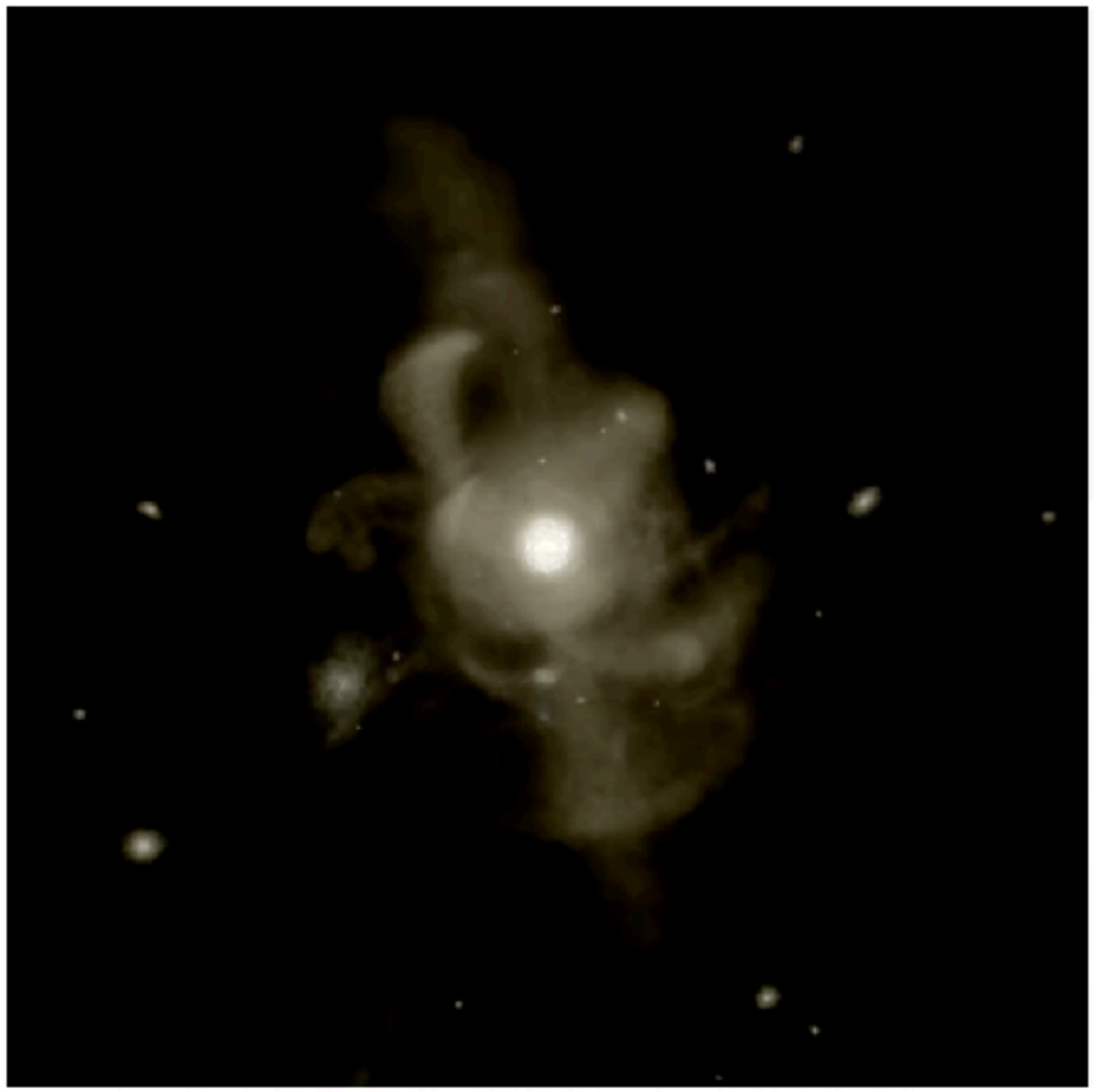

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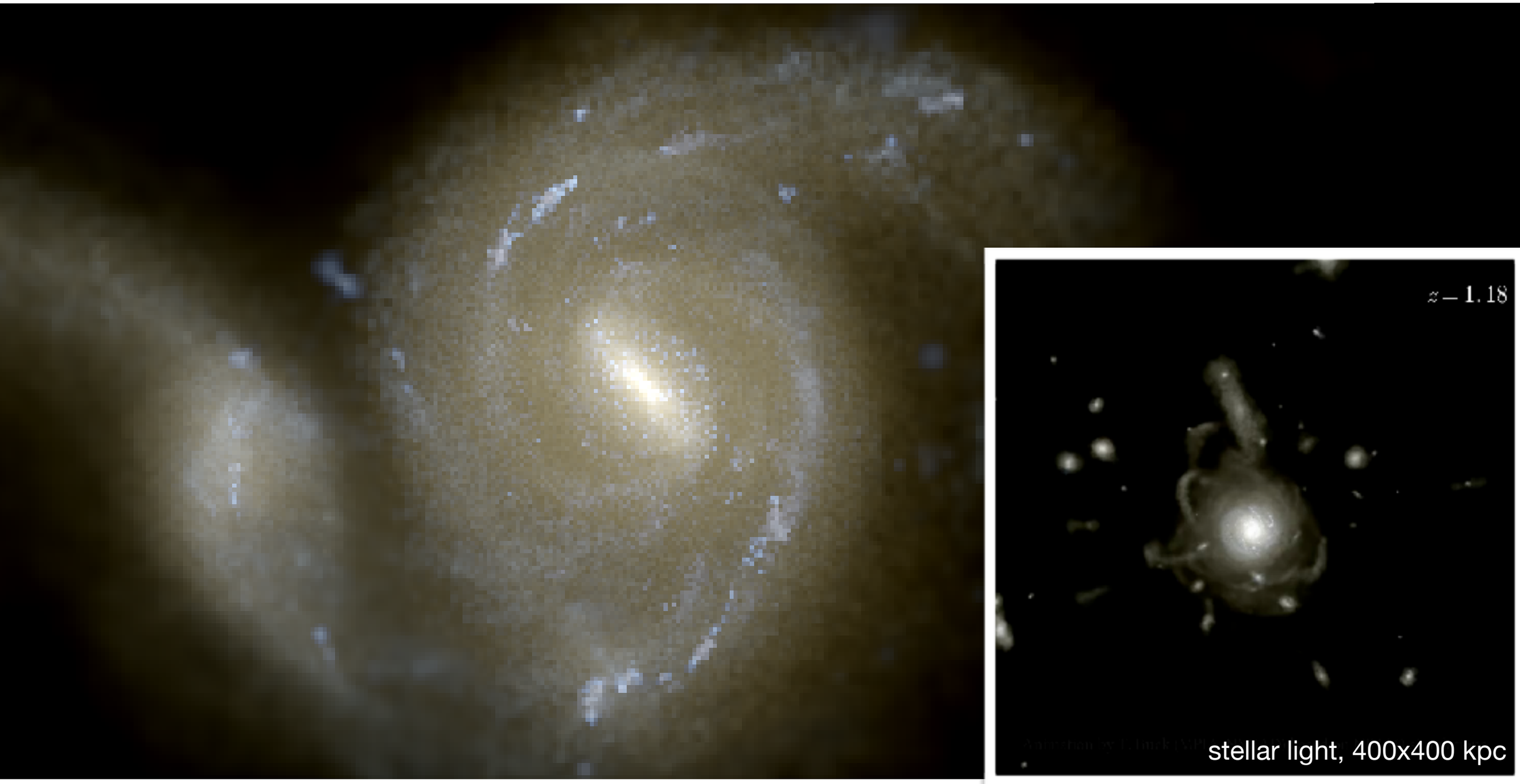
Why doing high-resolution cosmological simulations?



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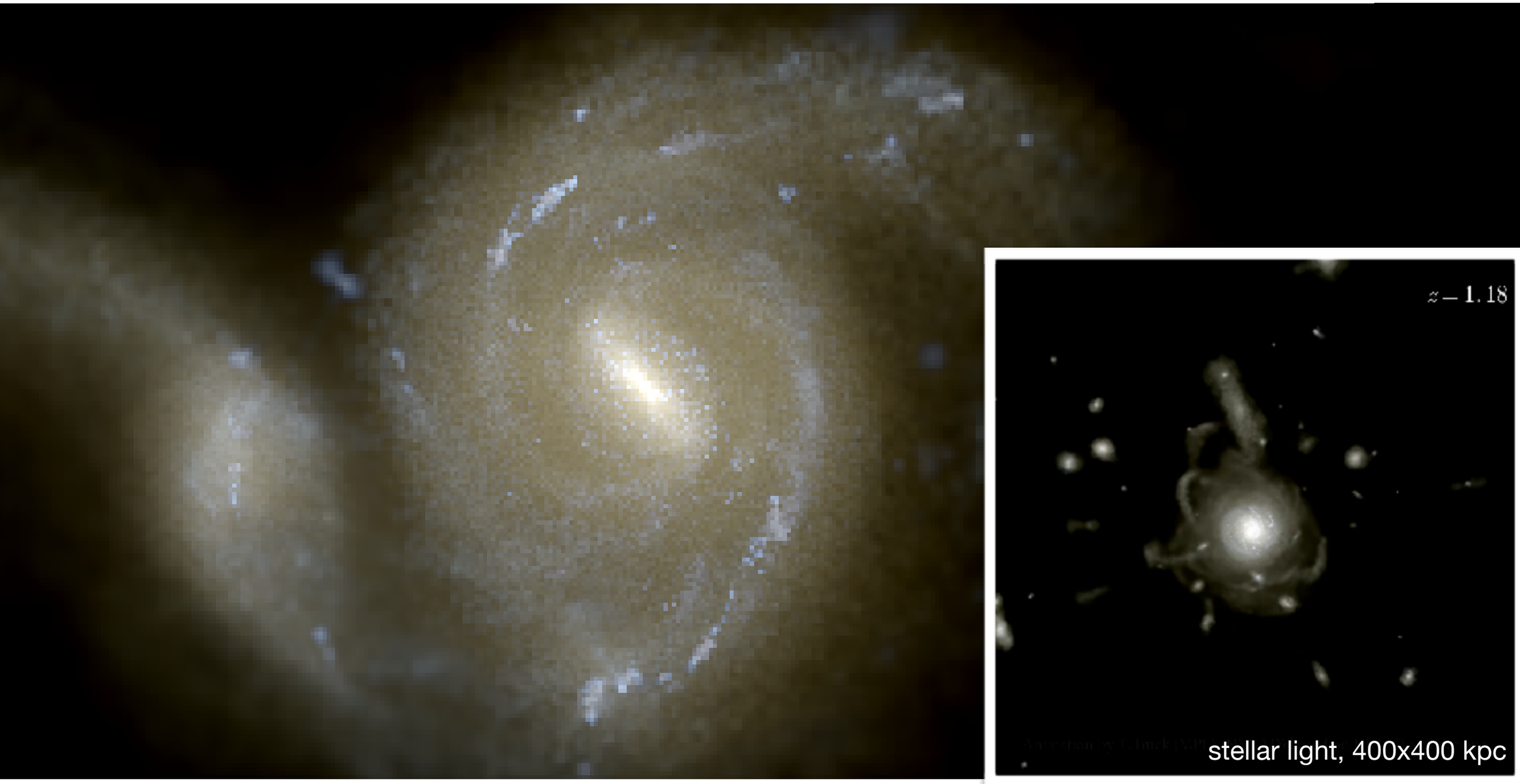

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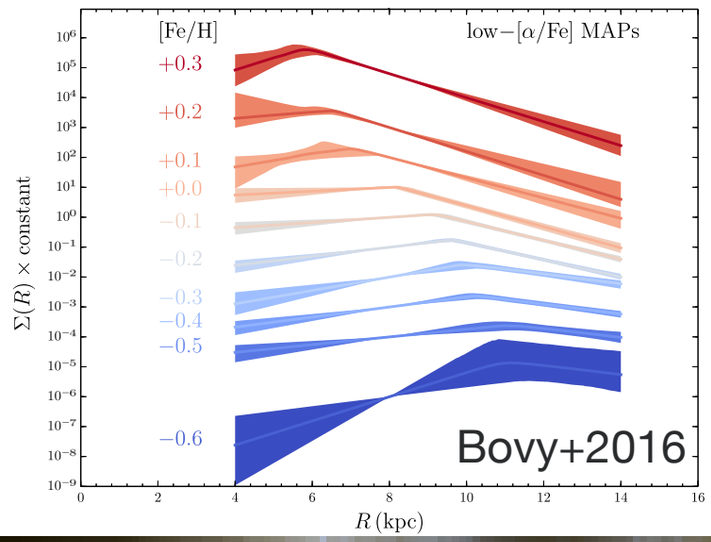
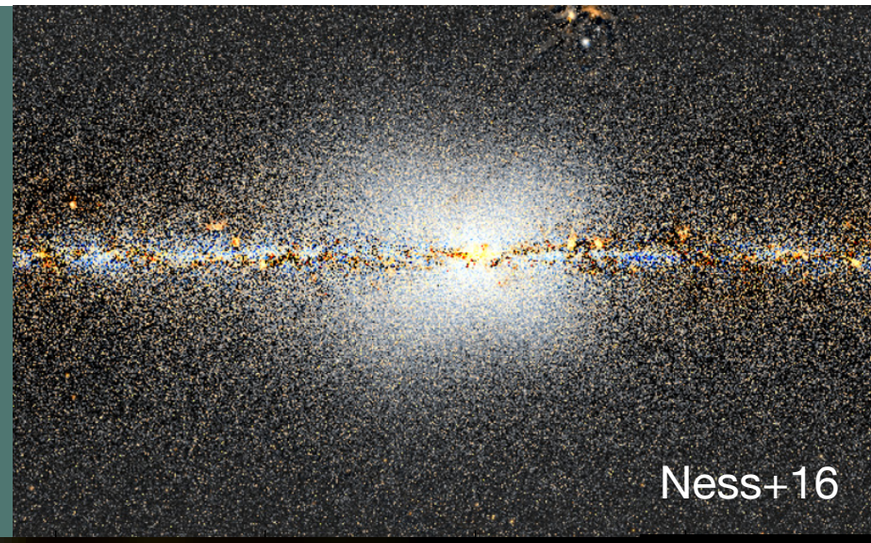
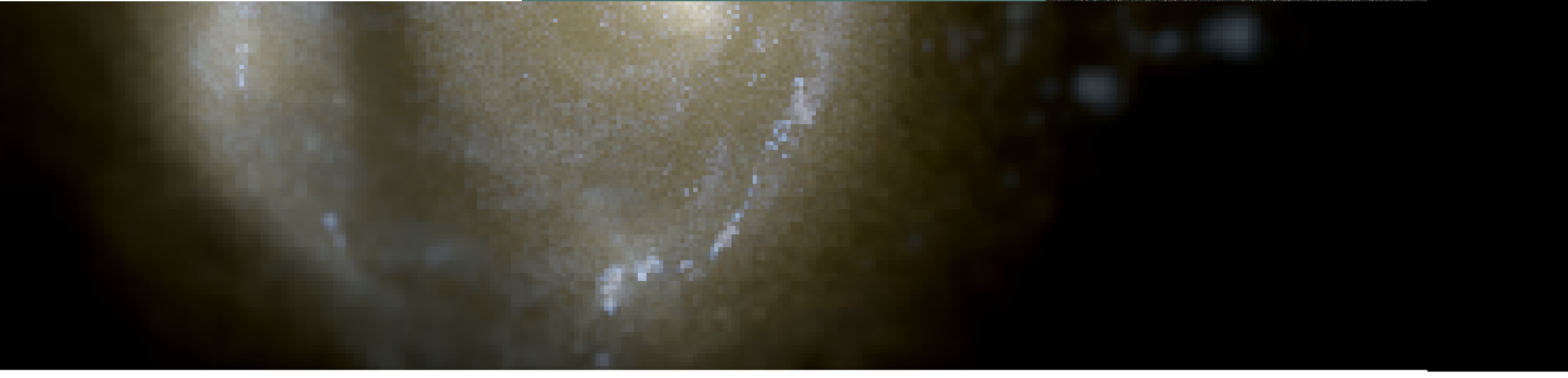


Questions from observation

- structure of the disc
- the Galactic center
- structure of satellites





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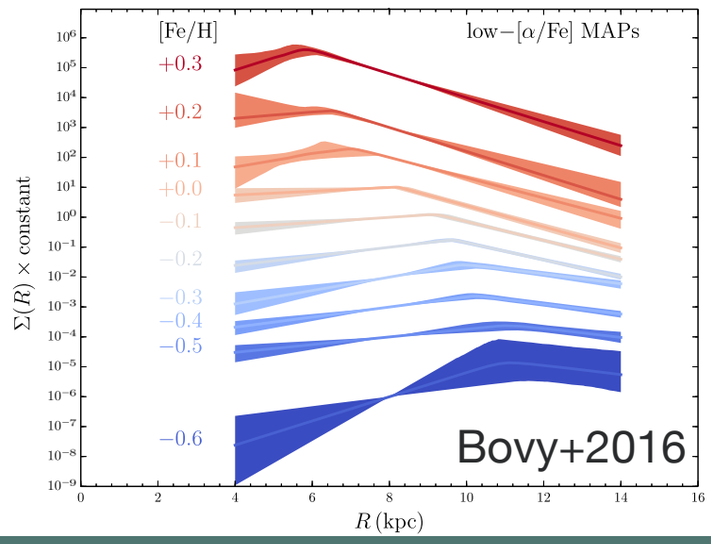

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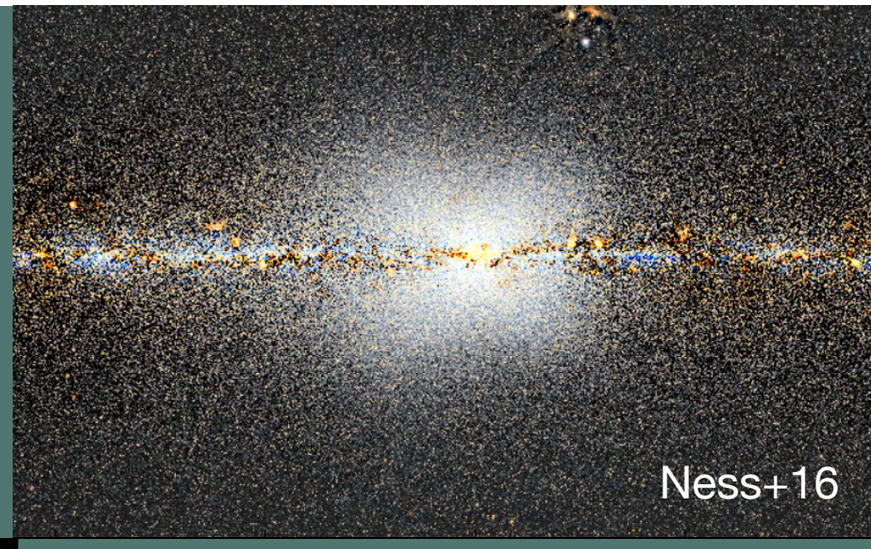
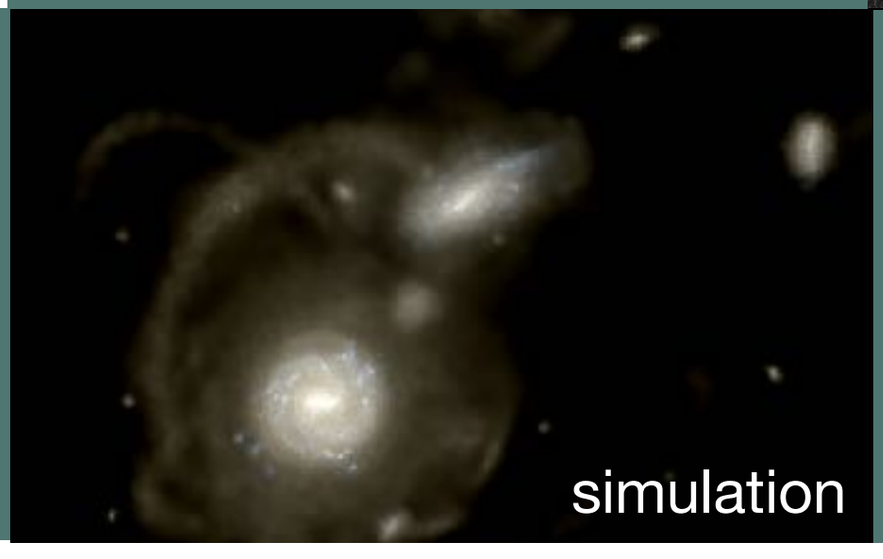


Why cosmological simulations

- realistic environment
- realistic growth history



Why high resolution simulations

- resolve disc scale-height
- resolve the satellites
- resolve the Galactic center

Simulation Recipe

1

smoothed particle hydrodynamics

GASOLINE2.1

Wadsley+2004, Keller+2014

2

gas cooling

via hydrogen, helium and various metal lines and Compton cooling

gas heating

via Photoionisation from the UV background

Shen+2010

3

self consistent star formation from cold dense gas

Stinson+2006

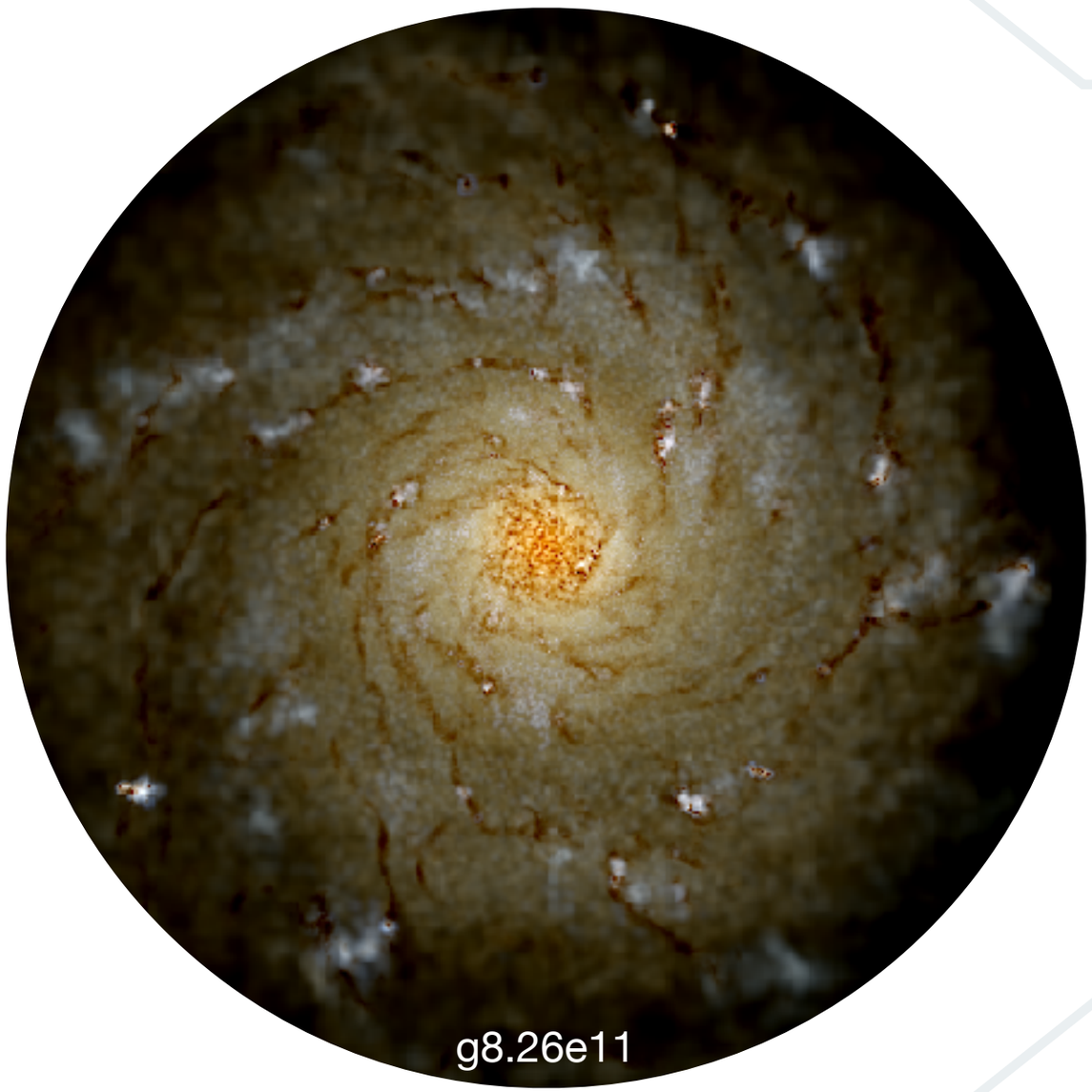
4

early stellar feedback and SN feedback (energy + metals)

Stinson+2013

The Set of Simulations

6 Zoom-in simulations of Milky-Way mass galaxies

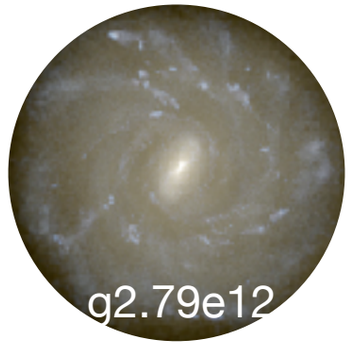


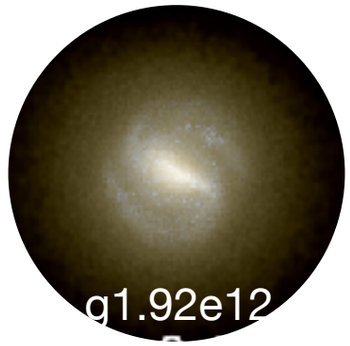
Initial conditions from the NIHAO project (Wang+2015) but a factor of 8-16 increase in mass resolution

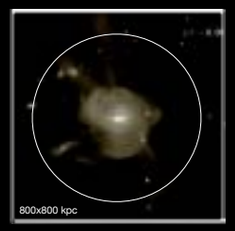
Final galaxy masses:
7.5 x $10^{11} M_\odot$ to 2.8 x $10^{12} M_\odot$

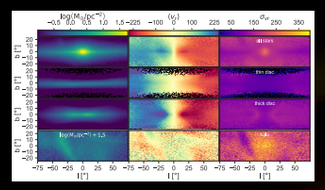
Gravitational softening and particle masses:

- dark matter: 400 pc, 1.5 x $10^5 M_\odot$
- gas: 180 pc, 2.8 x $10^4 M_\odot$
- stars: 180 pc, 9300 $M_\odot$





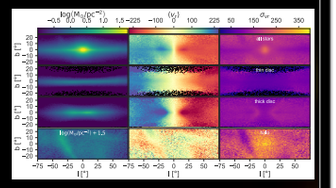




RESULTS AND SCIENCE CASES

SCIENCE WITH NIHAO-UHD:

- SATELLITES AND DWARFS
- DISC STRUCTURE
- MILKY WAY BULGE



WITH

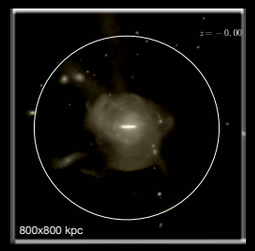
- SAT
  DWA
- DISC
- MILI

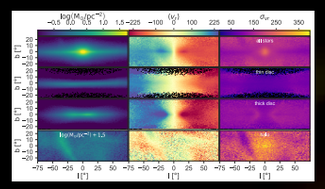
$z = -0.00$

800x800 kpc

ND

ES





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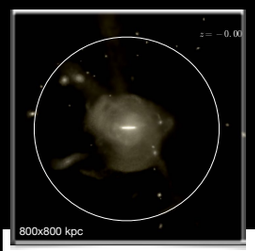
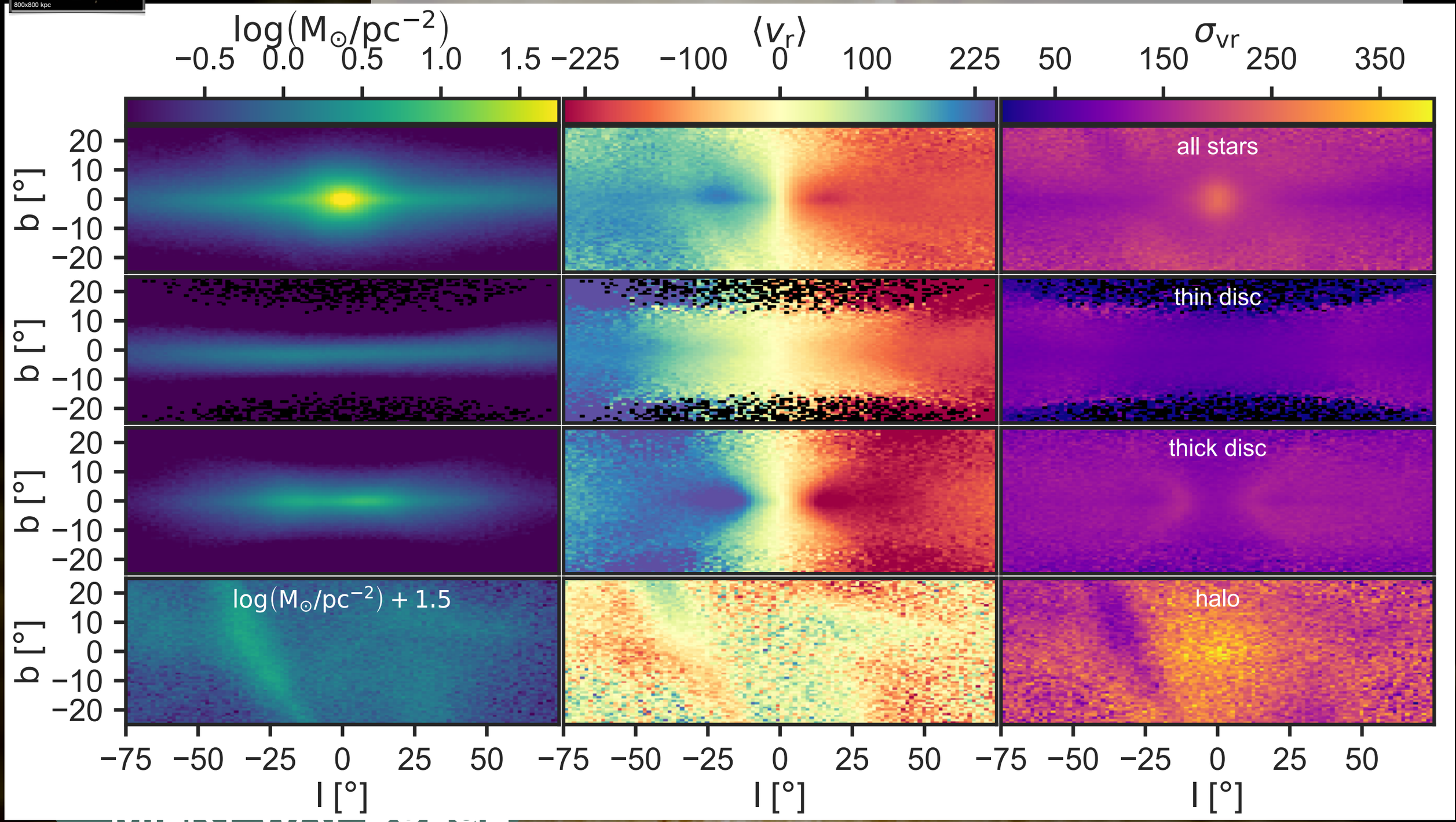
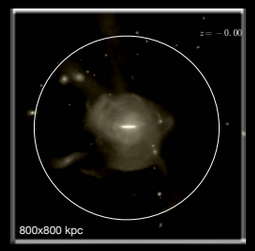
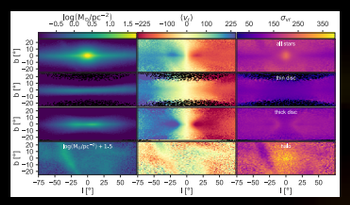

800x800 kpc


log(M⊙/pc⁻²)
−0.5 0.0 0.5 1.0 1.5
⟨v_r⟩
−225 −100 0 100 225
σ_vr
50 150 250 350
all stars
thin disc
thick disc
halo
log(M⊙/pc⁻²) + 1.5
b [°]
20 10 0 −10 −20
l [°]
−75 −50 −25 0 25 50





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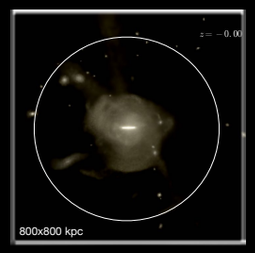
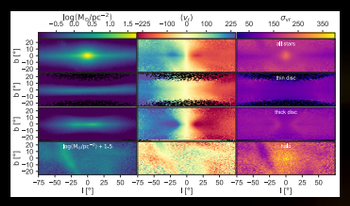




RESULTS AND SCIENCE CASES

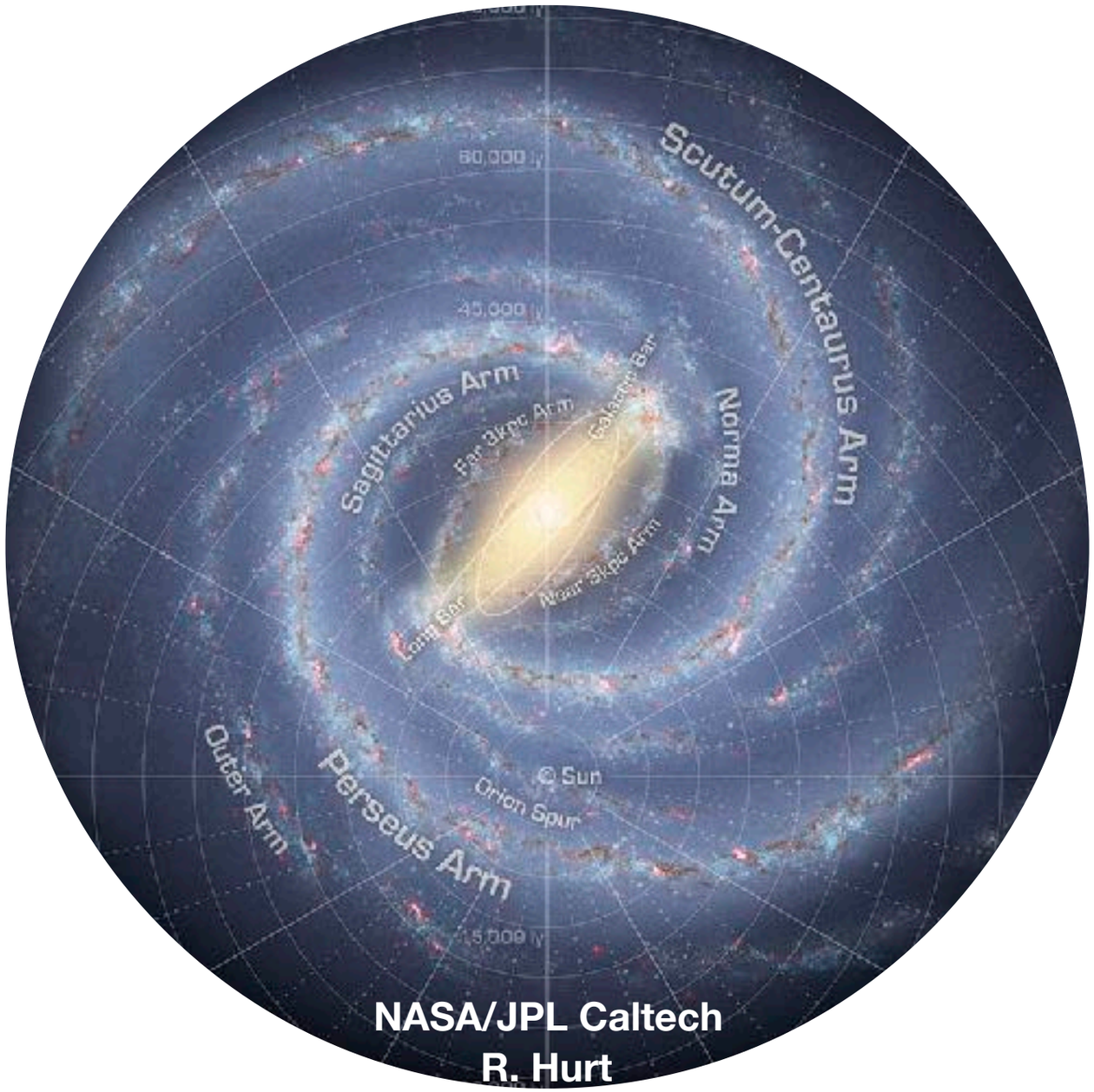
SCIENCE WITH NIHAO-UHD:

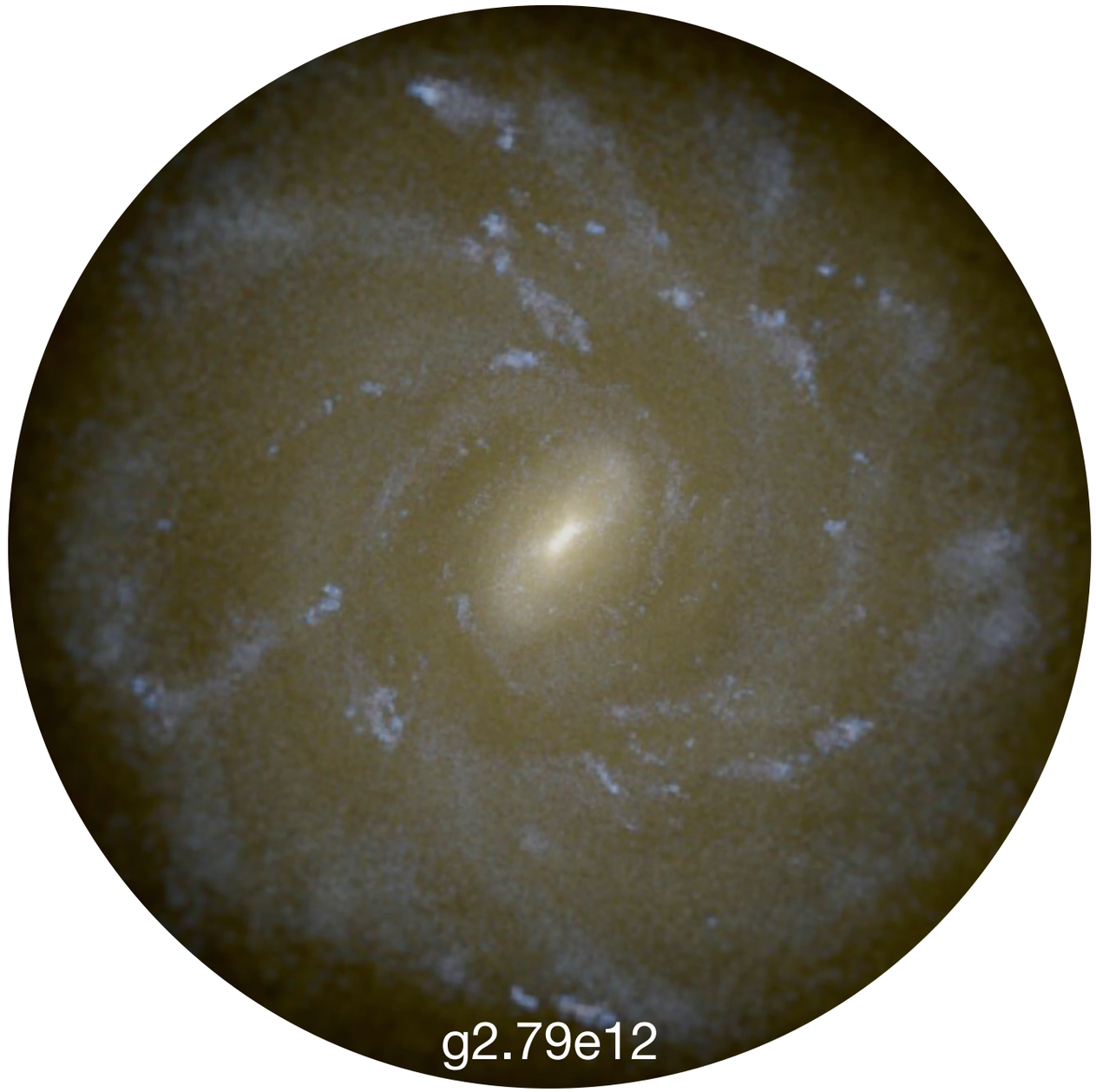
- SATELLITES AND DWARFS
- DISC STRUCTURE
- MILKY WAY BULGE

see also Poster: 20 (Fragkoudi et al.), 32 (Han et al.), 46 (Kunder et al.), 50 (Lee et al.), 85 (Ciambur et al.)

The Galactic Center

The Milky Way is a barred spiral galaxy





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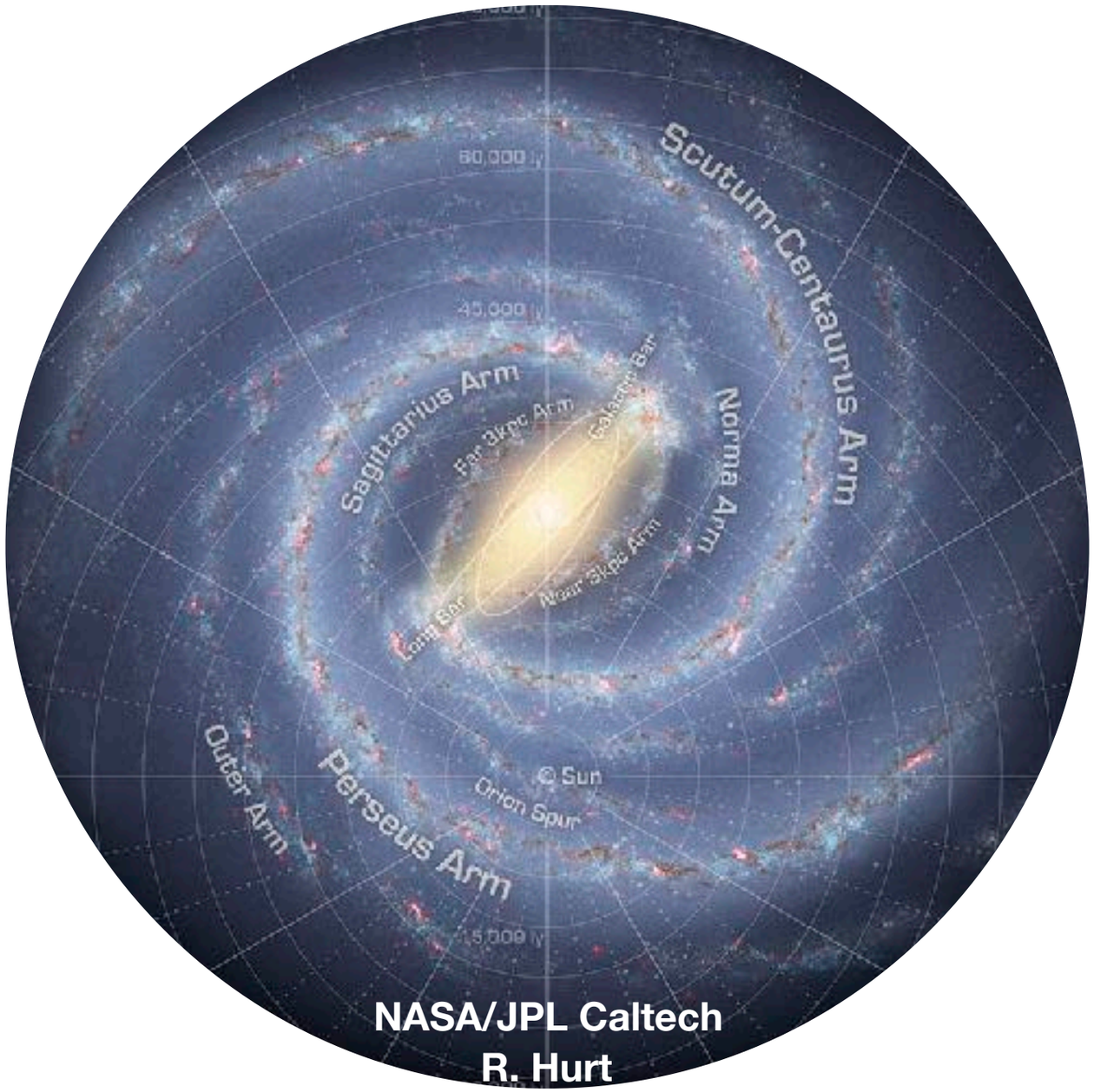
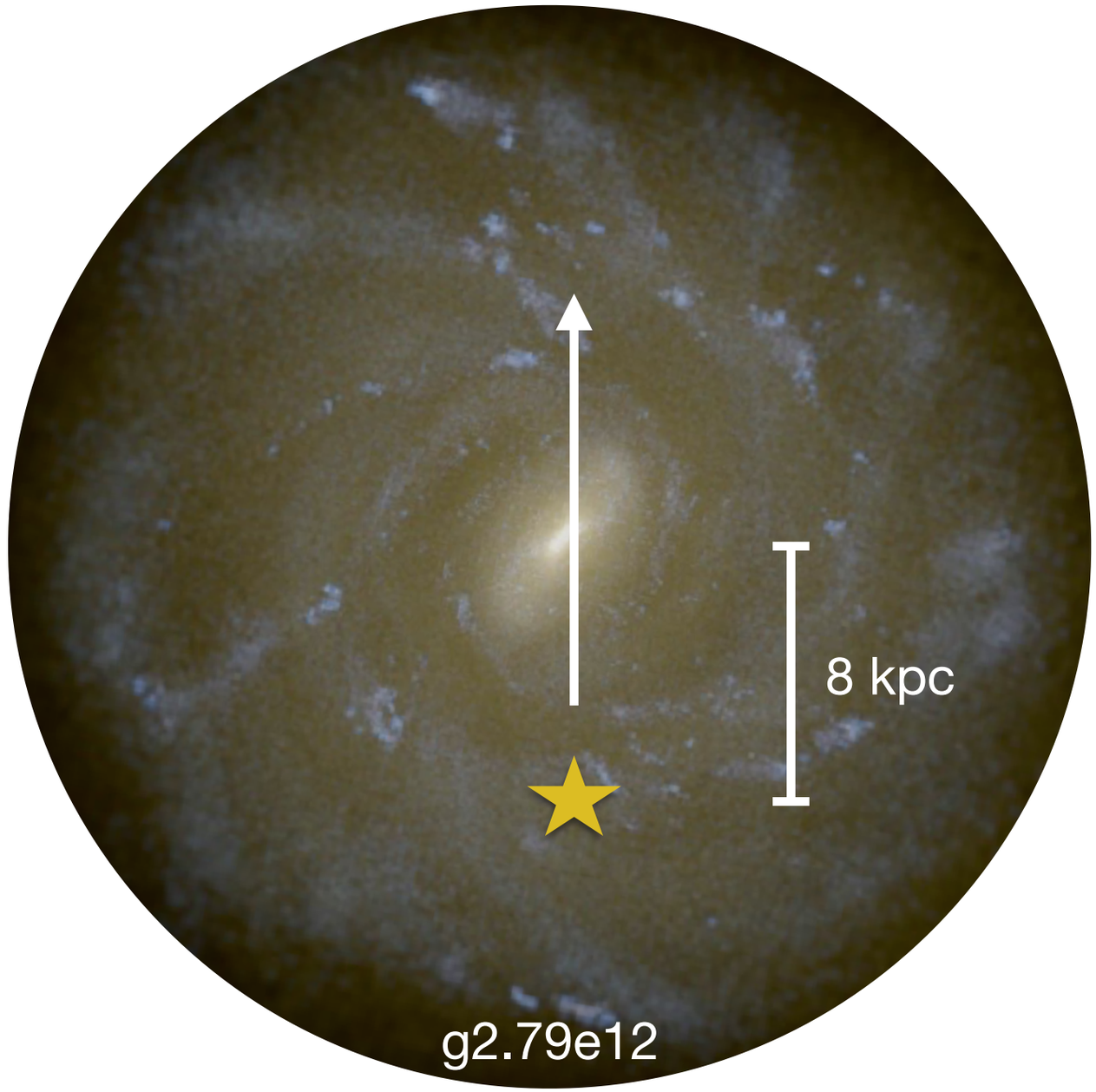
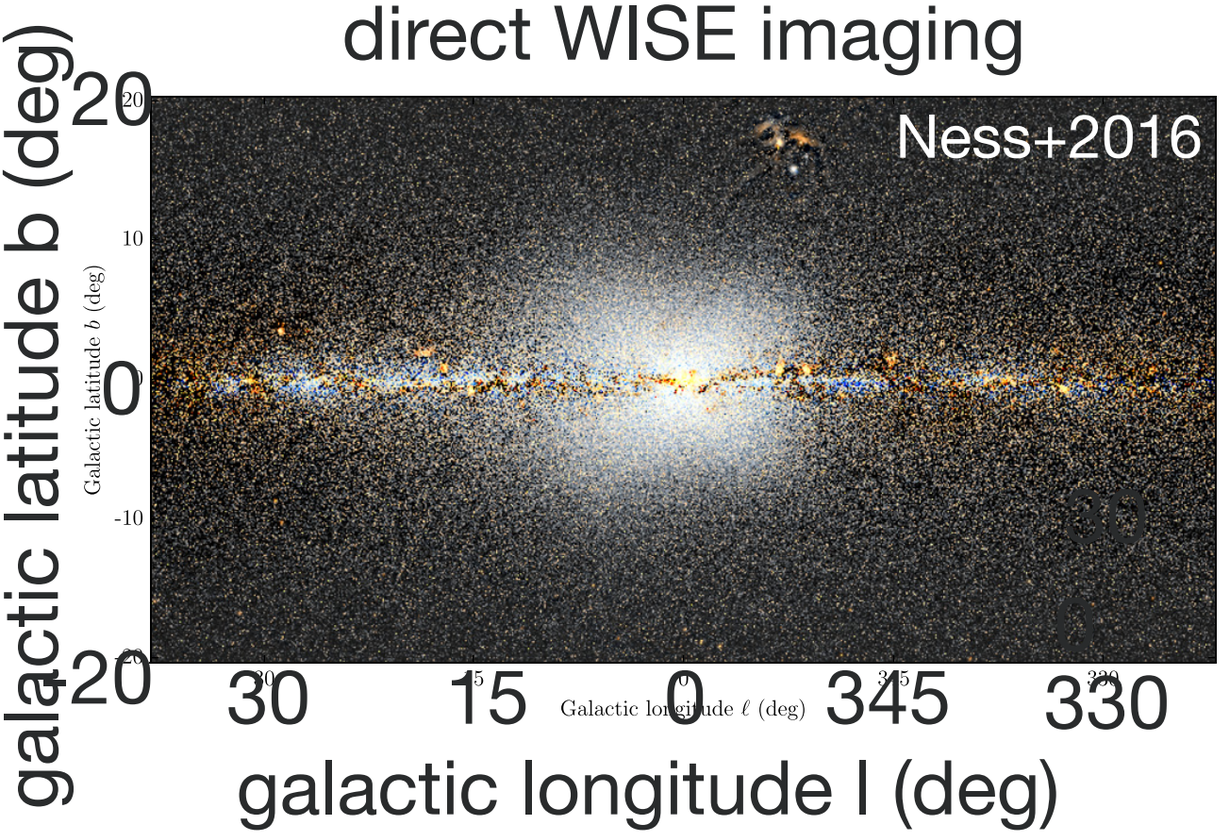




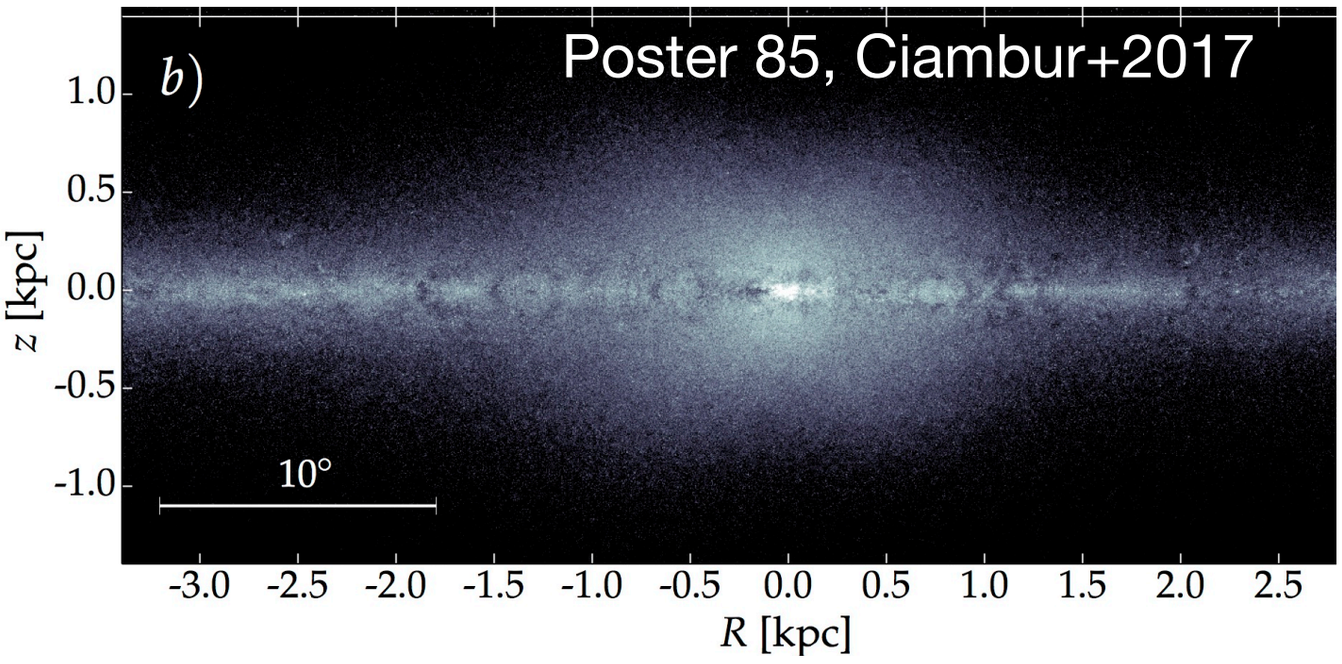
The Galactic Center

Observations vs. Simulations

direct WISE imaging



WISE 3.4 ym



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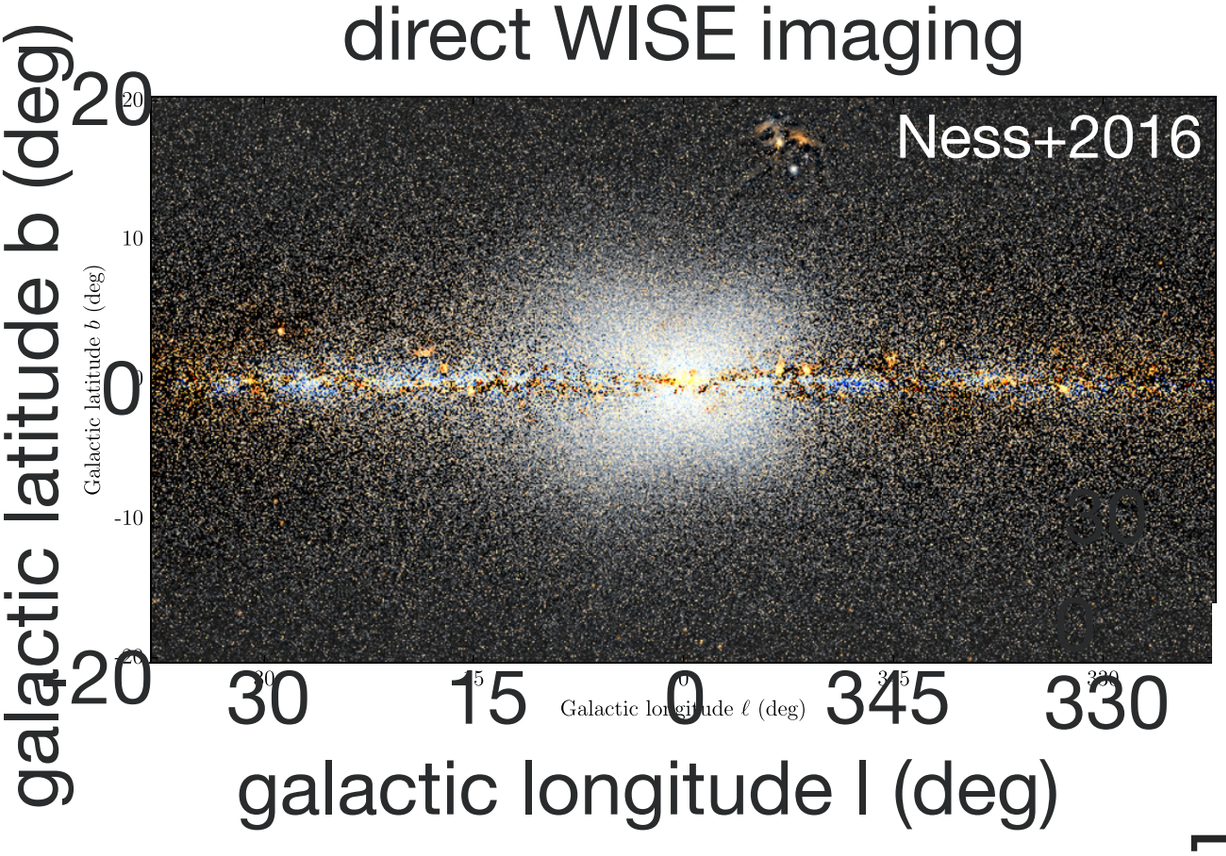

WISE 3.4 ym

but see also Poster:
32 (Han et al.) and 50 (Lee et al.)

The Galactic Center

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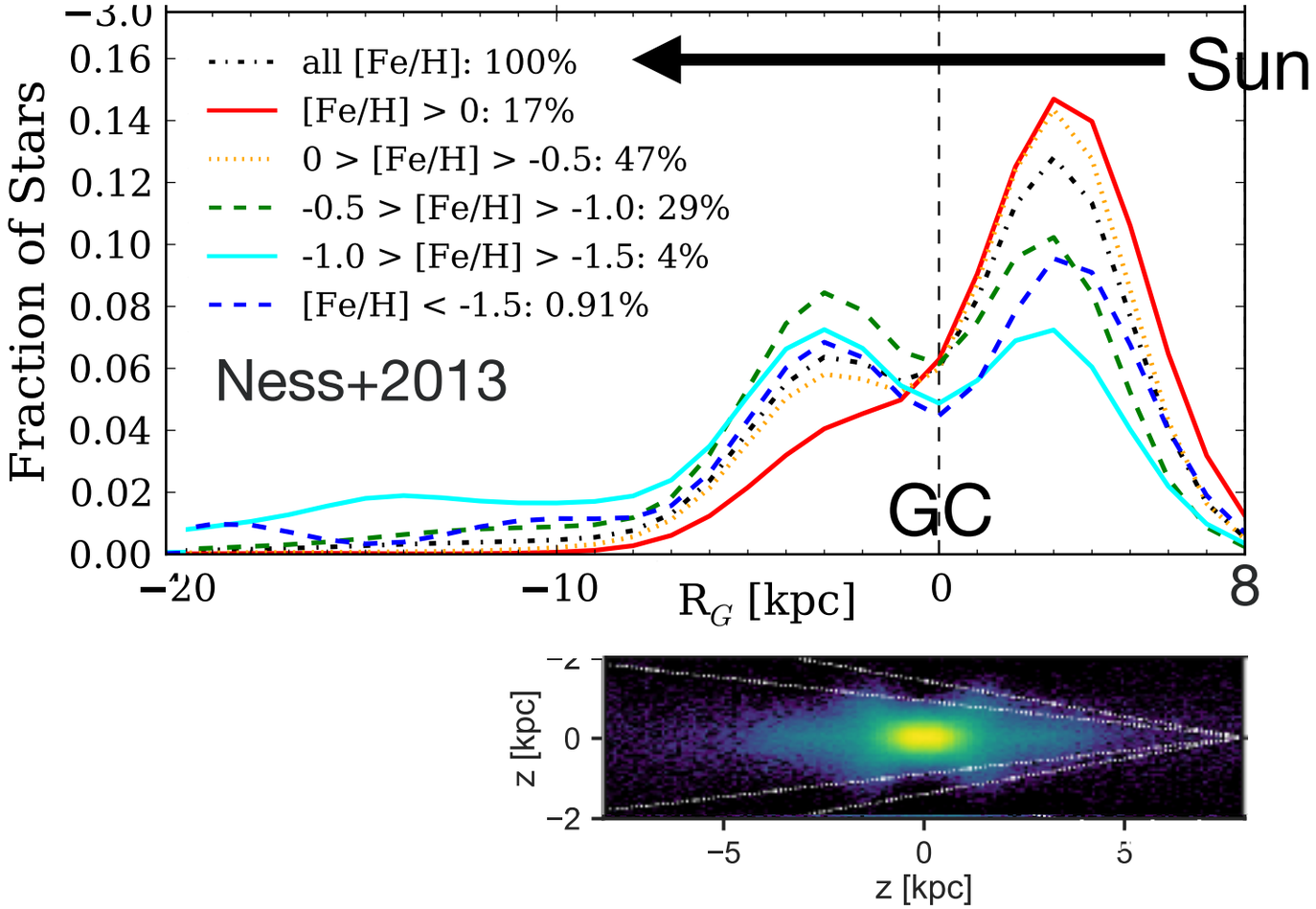
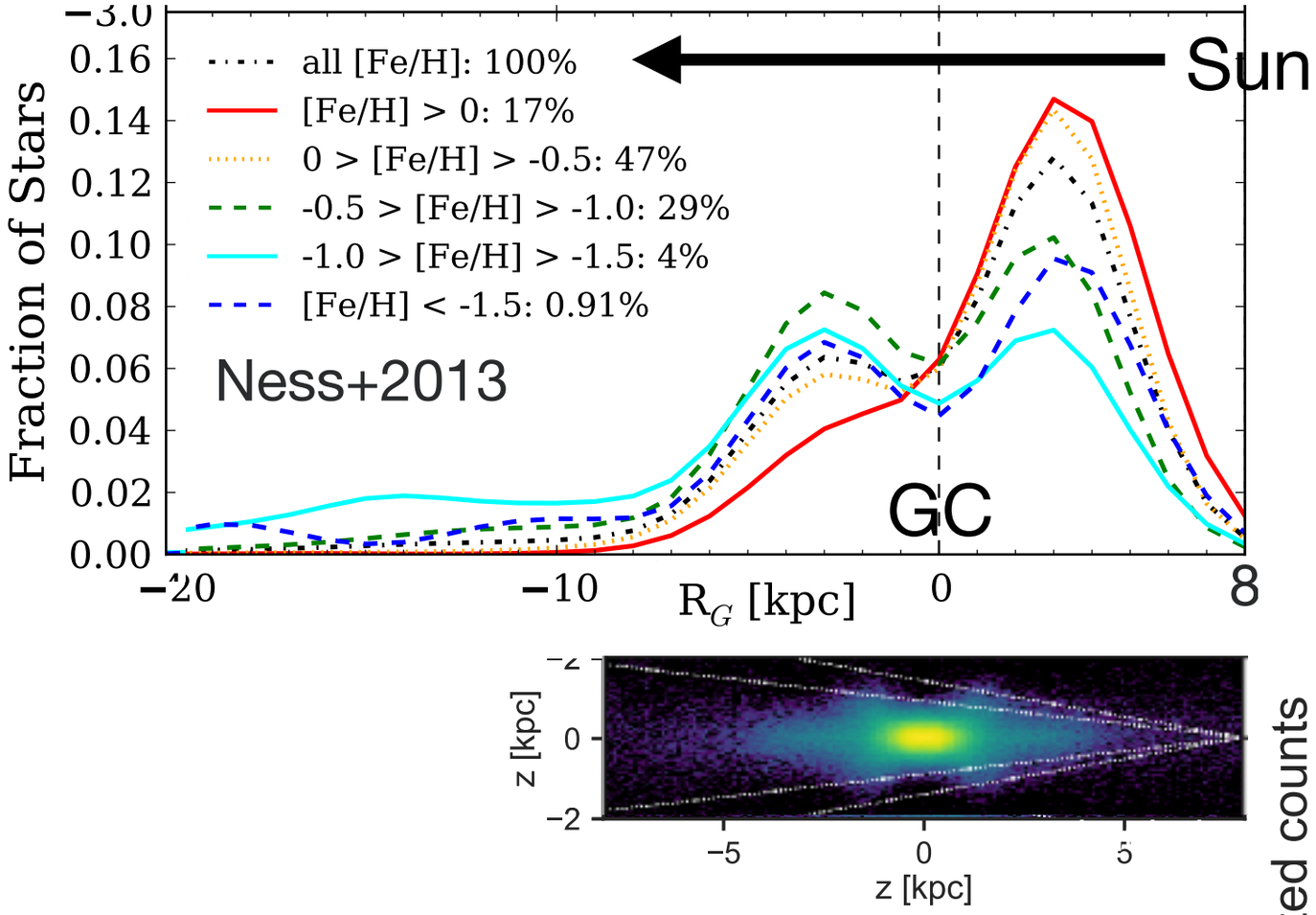


The X-shaped structure of the MW bulge is revealed by the split in red clump star counts

The Galactic Center

Observations vs. Simulations



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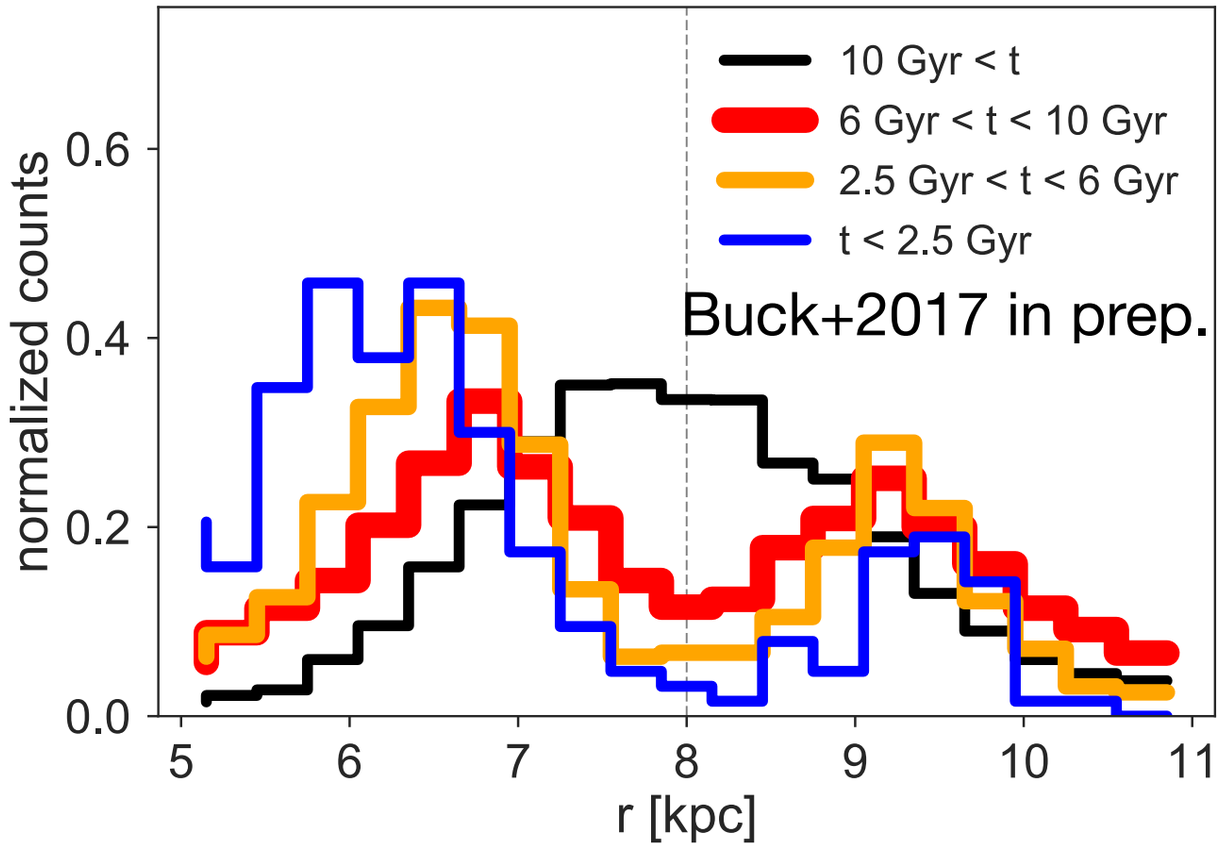
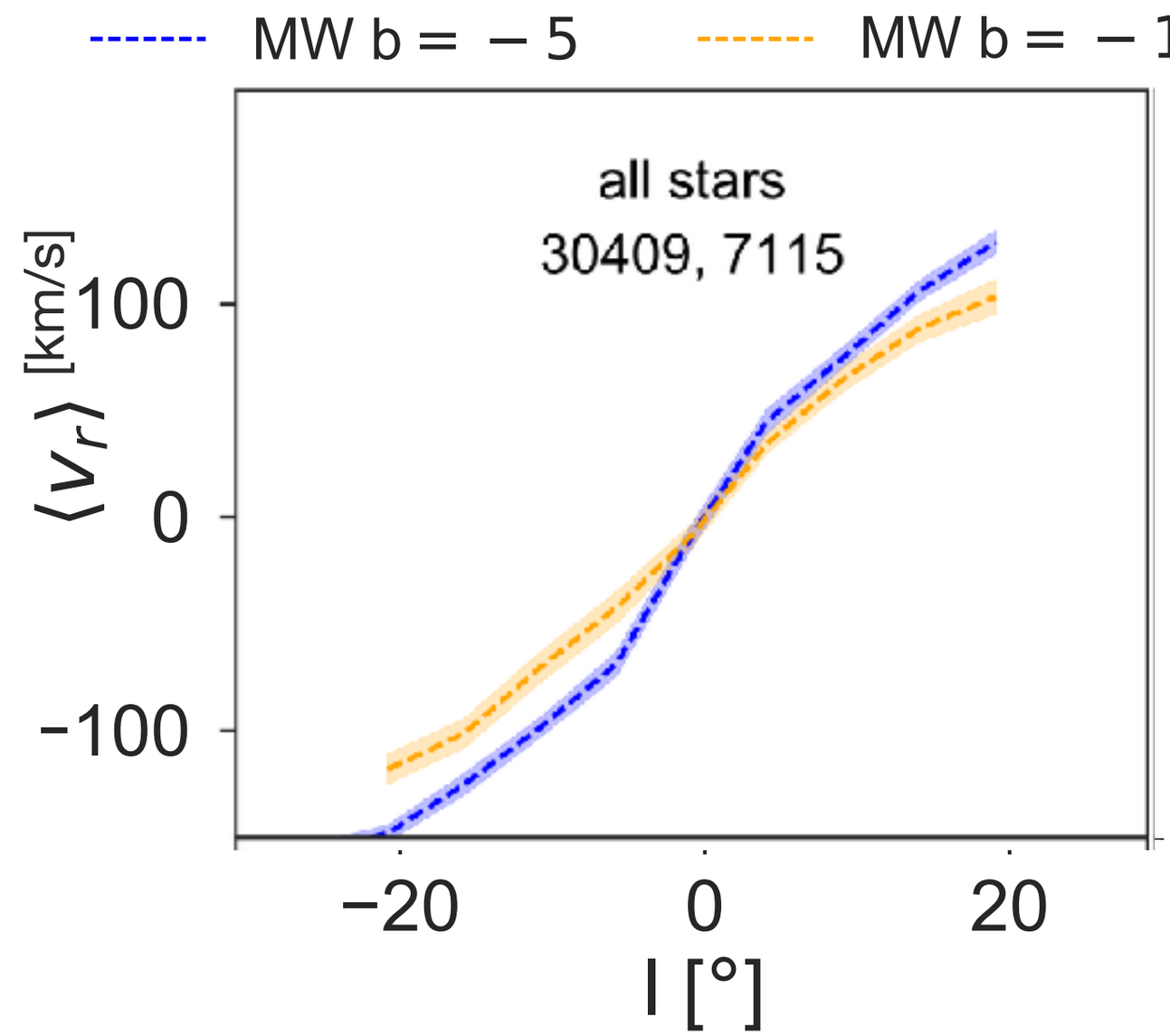


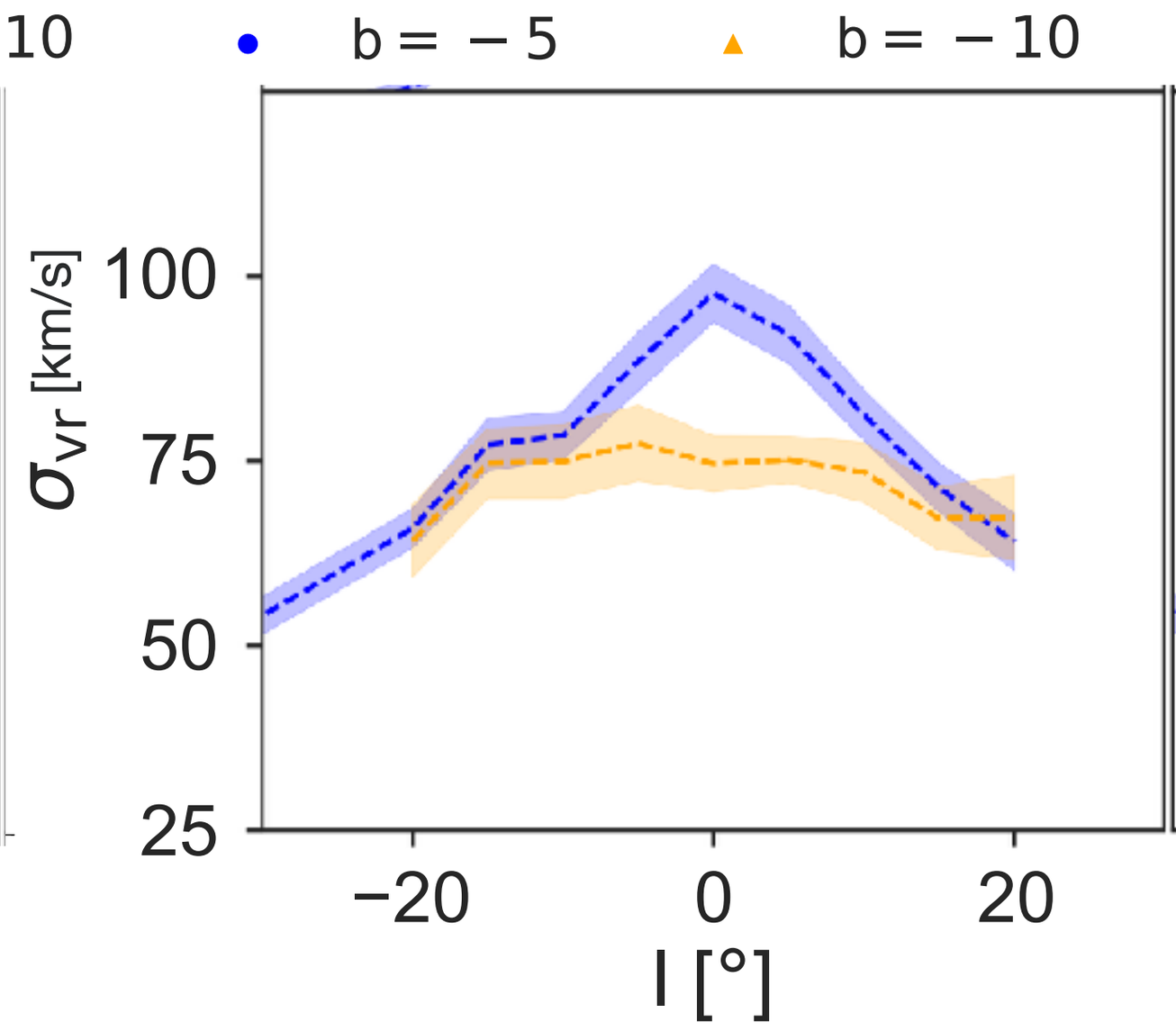
The Galactic Center

Observations vs. Simulations

rotation profile

dispersion profile





Simulations from Buck+2017in prep.
Milky Way observations from ARGOSS (Ness+2013)

The Galactic Center

Observations vs. Simulations

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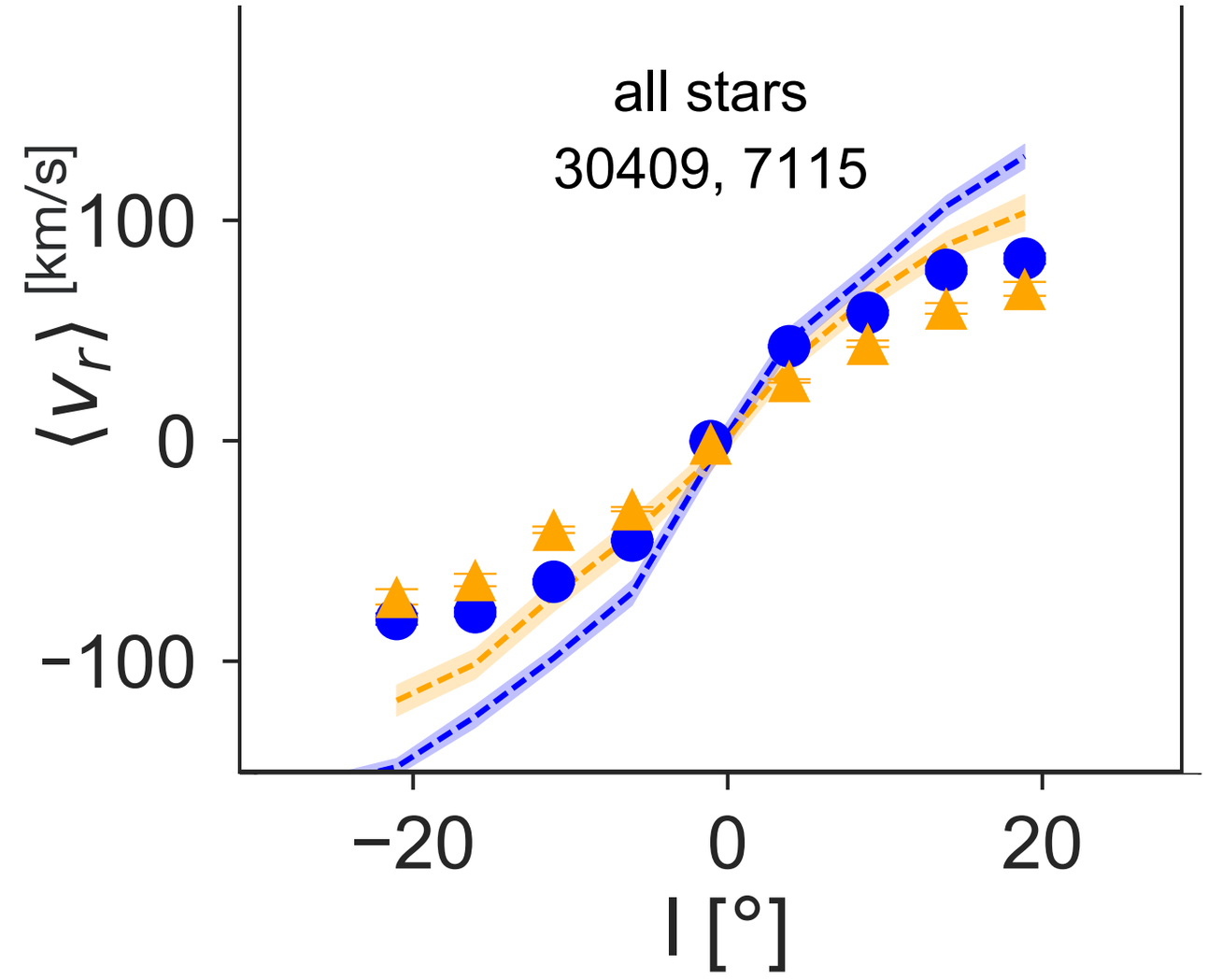
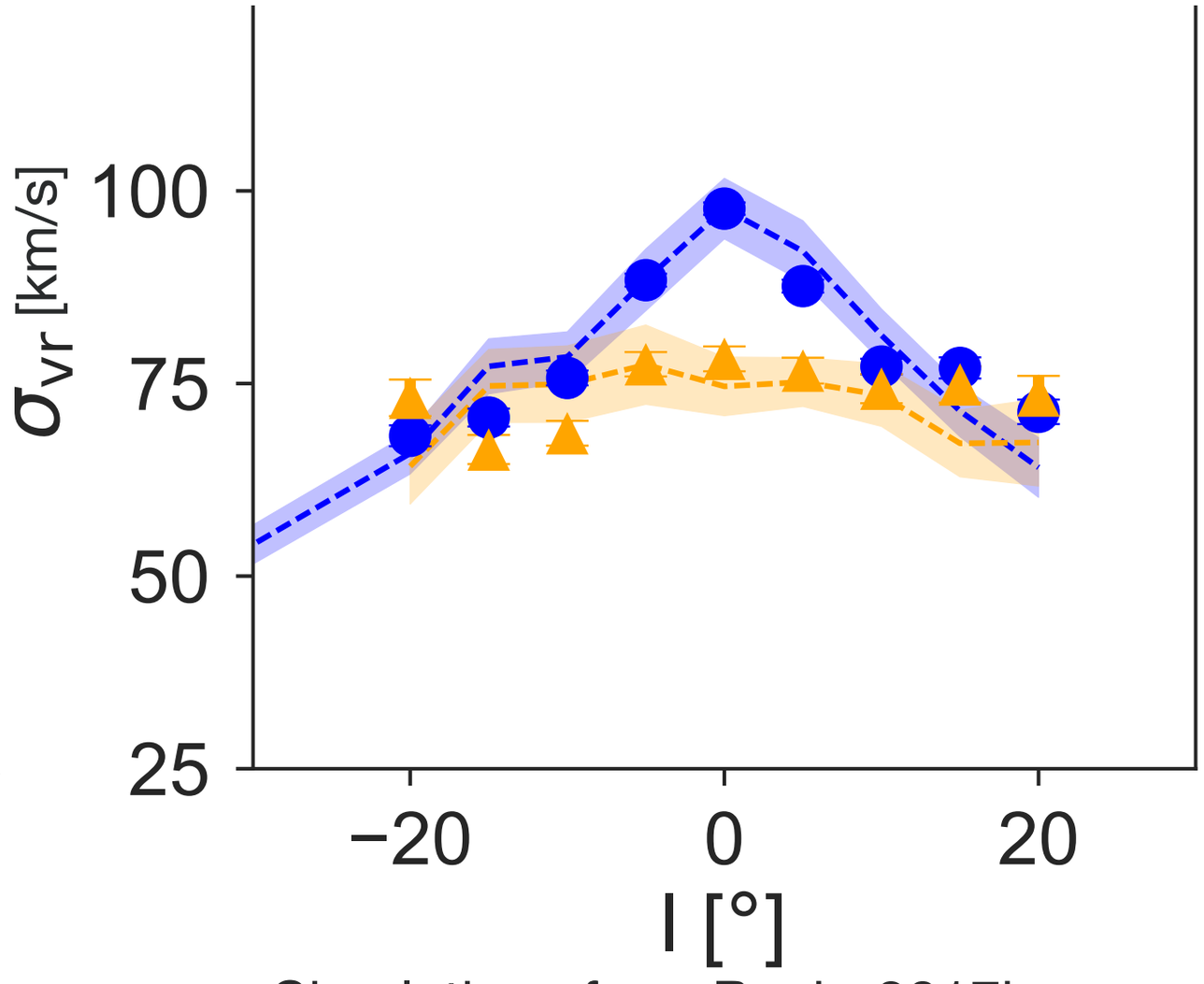
dispersion profile





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The Galactic Center

Observations vs. Simulations

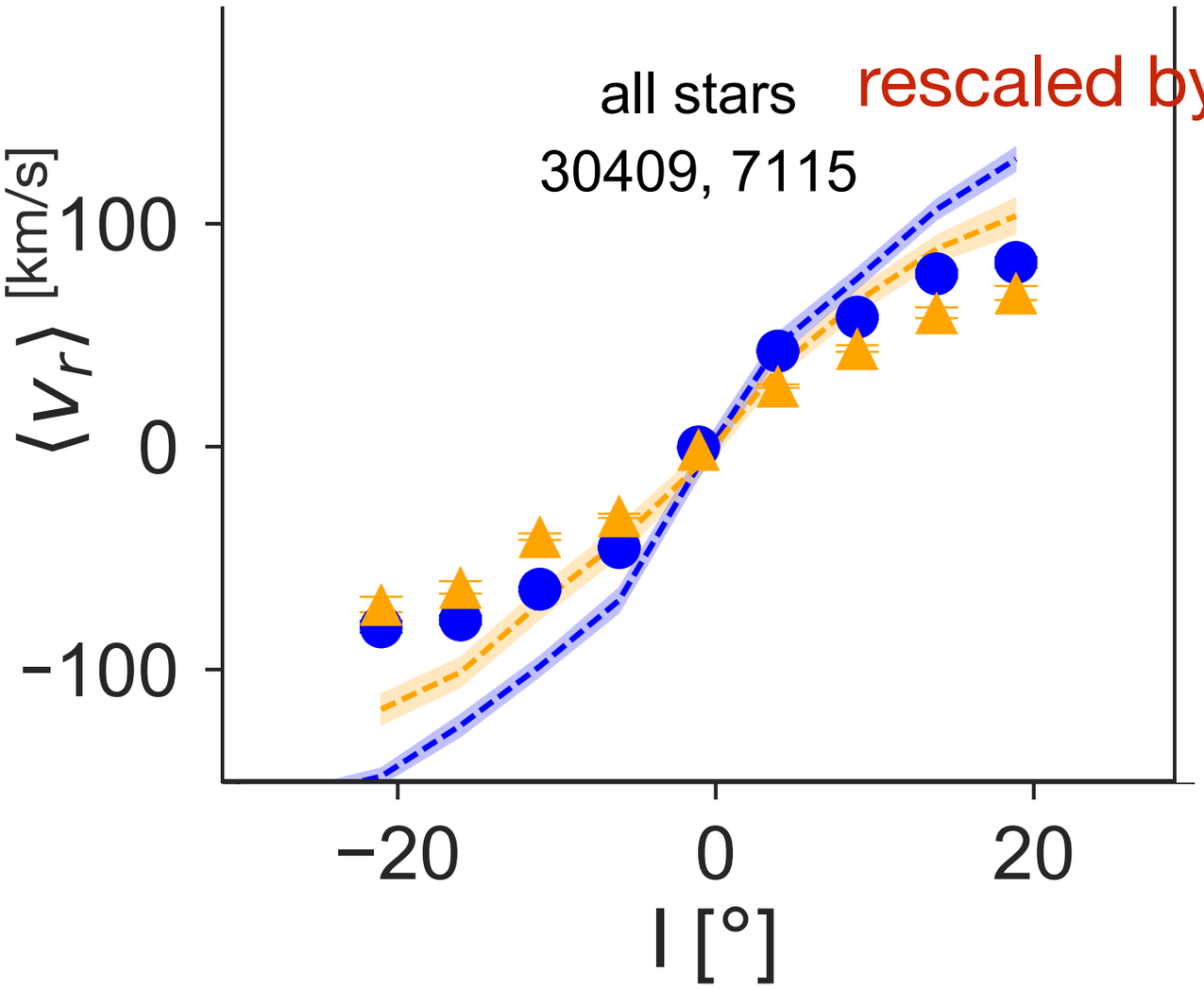
rotation profile

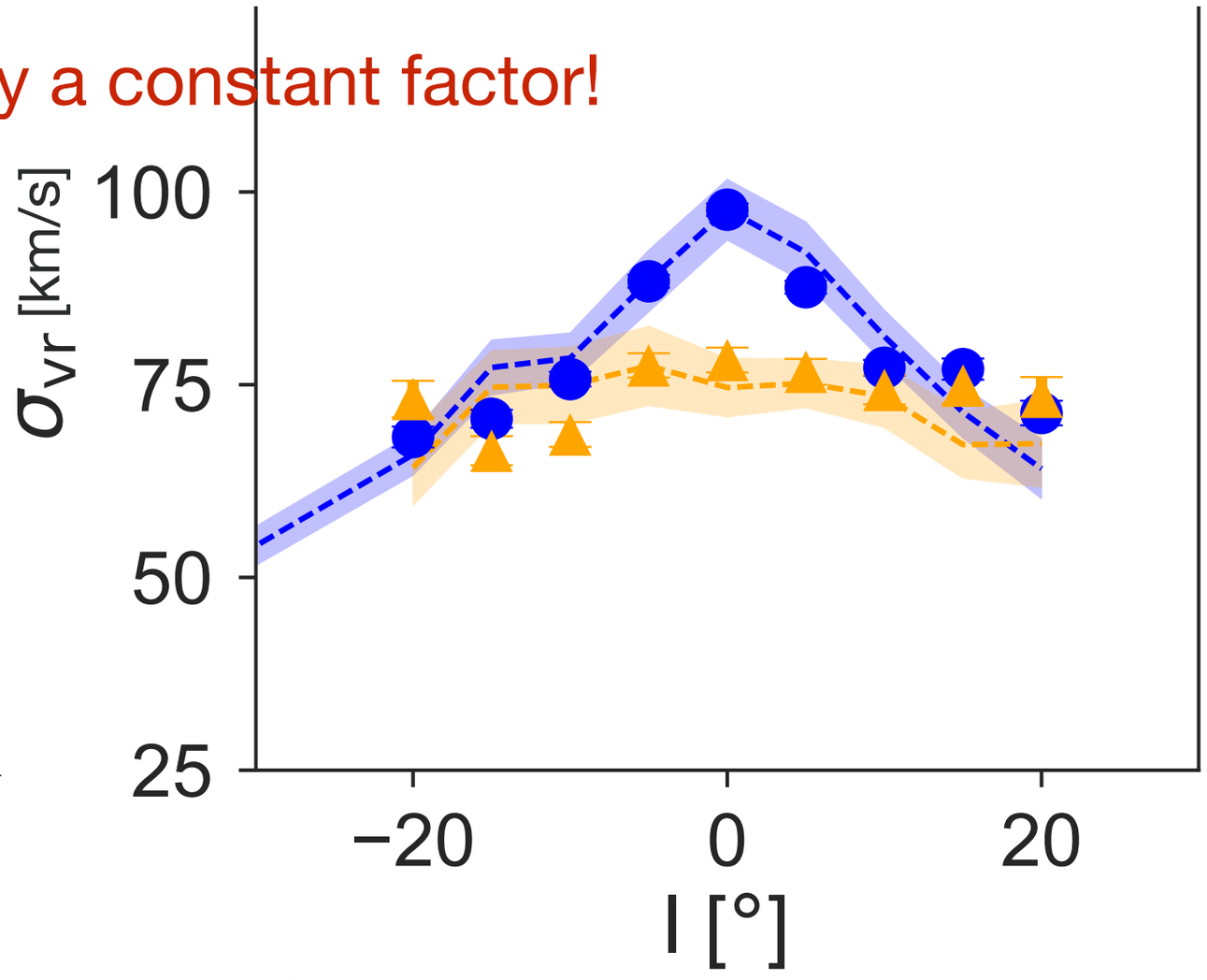
dispersion profile

MW b = −5 MW b = −10 b = −5 b = −10

all stars
30409, 7115

rescaled by a constant factor!





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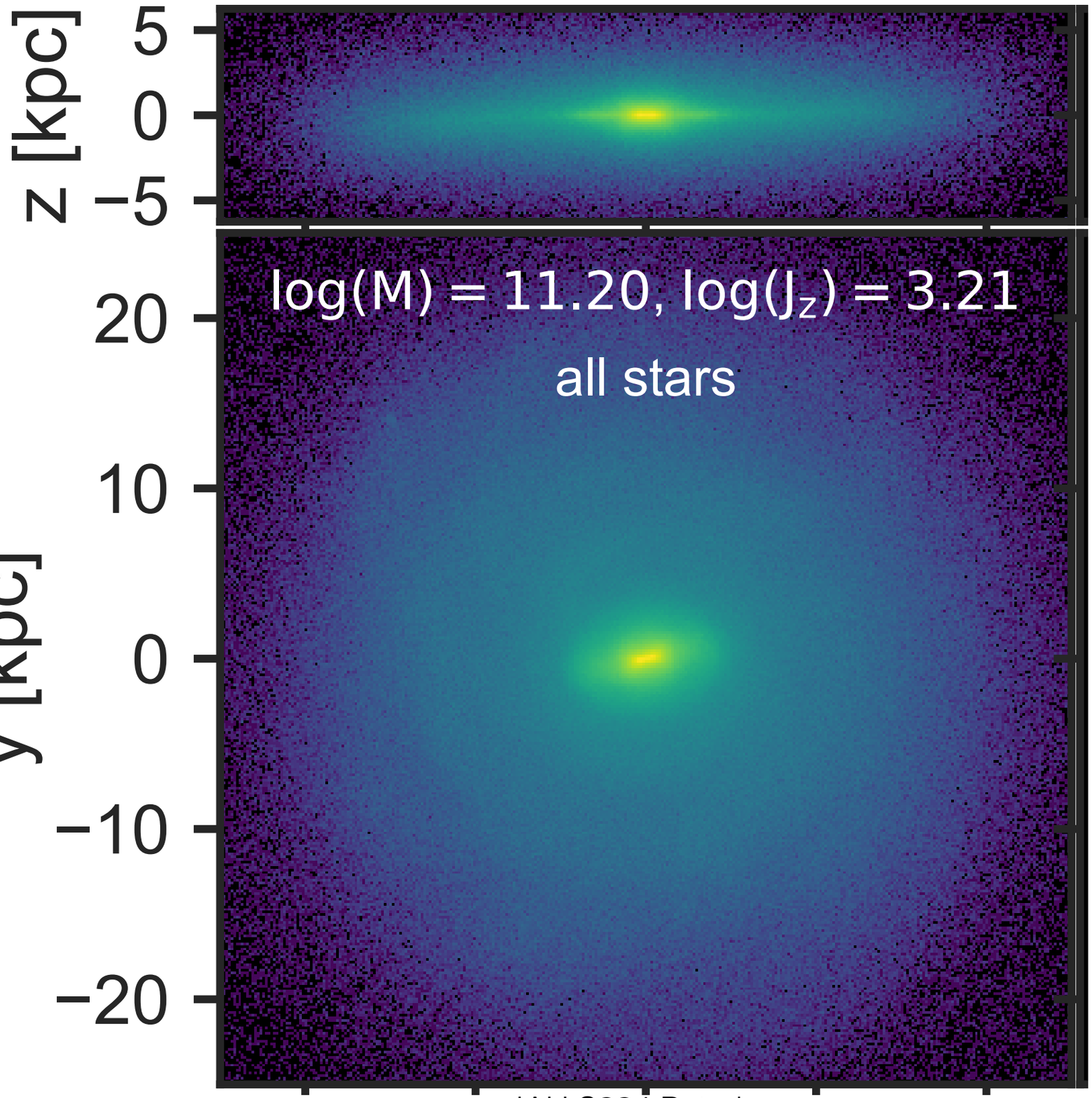
The Galaxy in Kinematic Components



6D phase space kinematic decomposition:

decomposition of the galaxy by using gaussian mixture models and the parameter set (jz /jc , jp /jc , e) as from Obreja+2016

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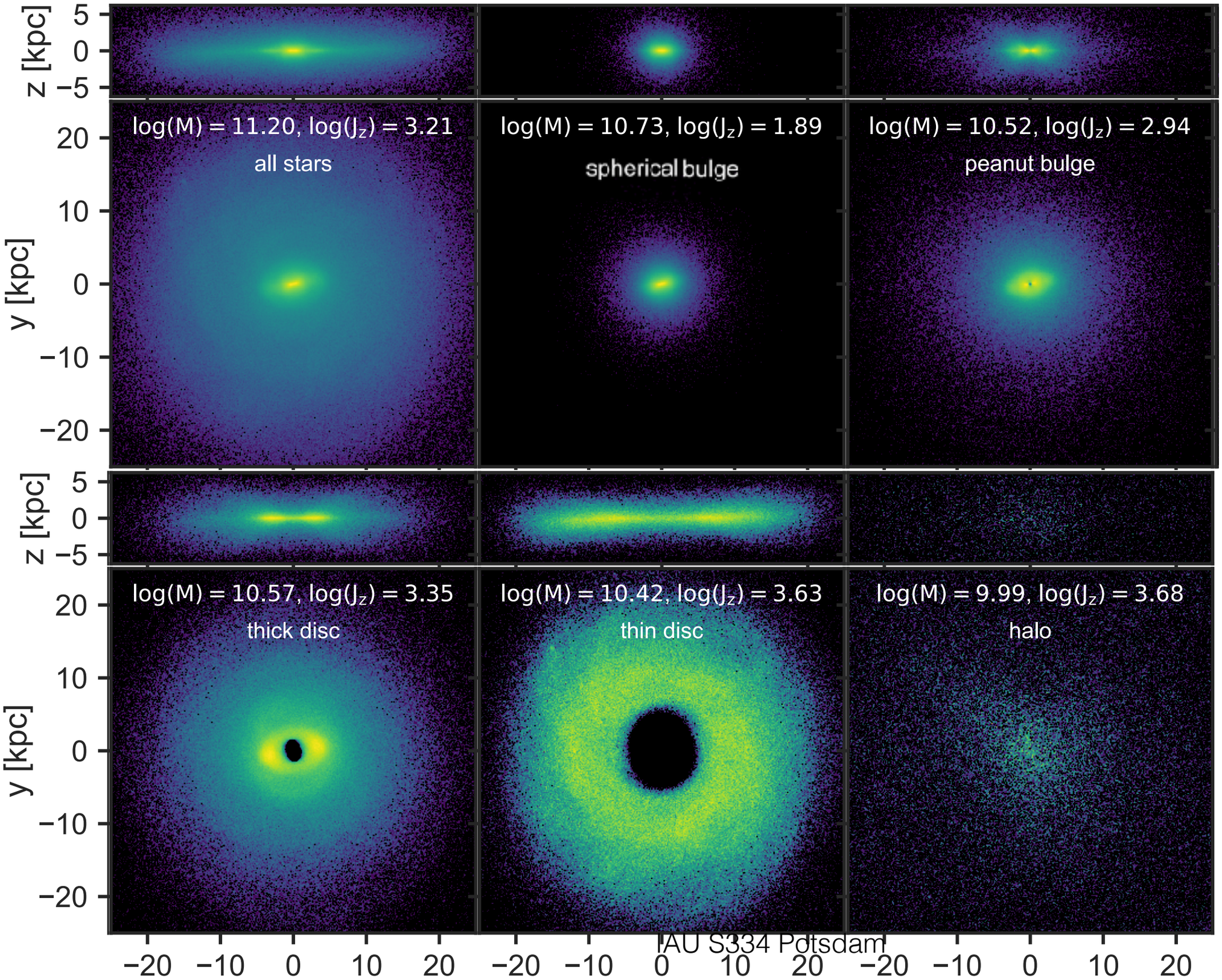

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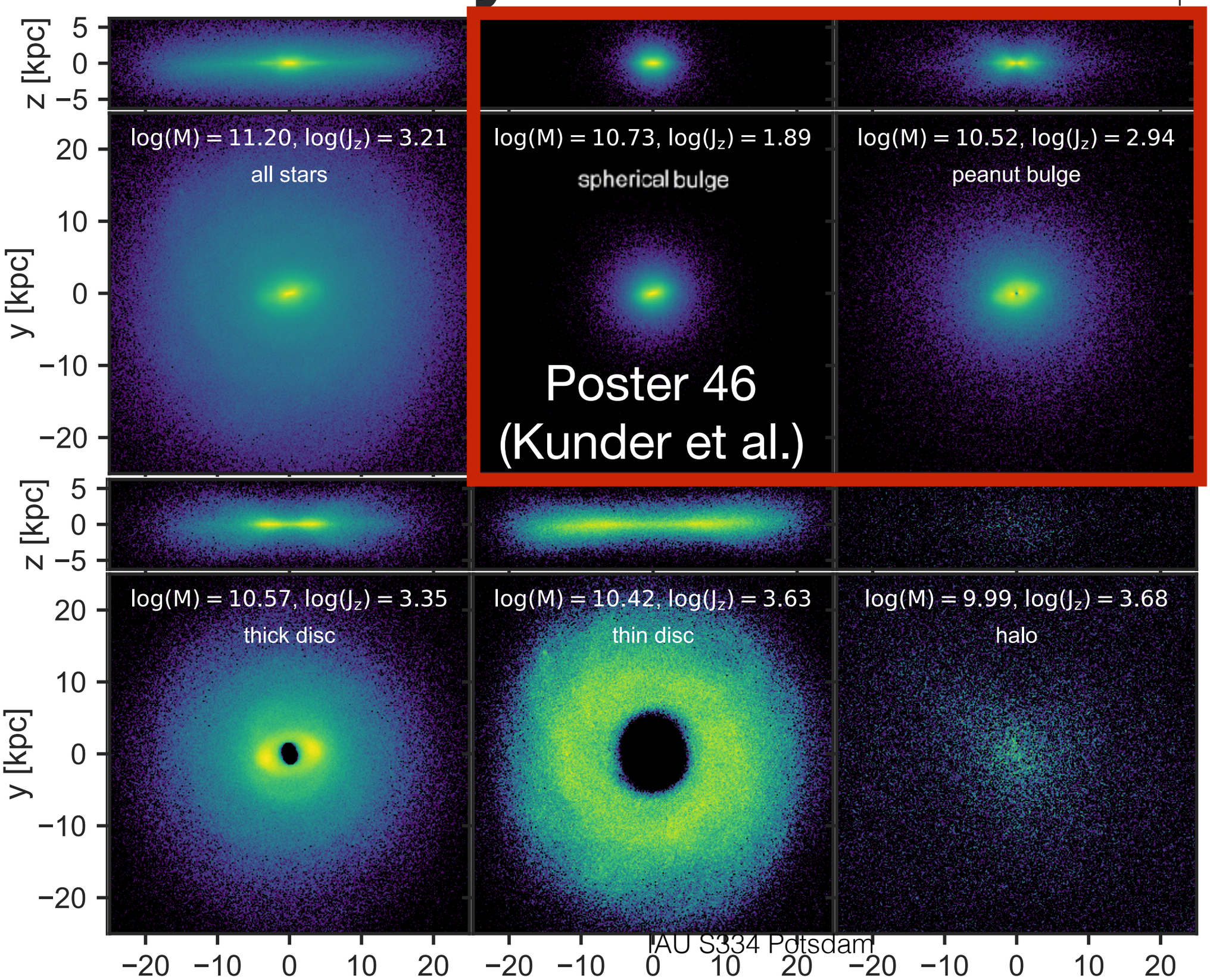


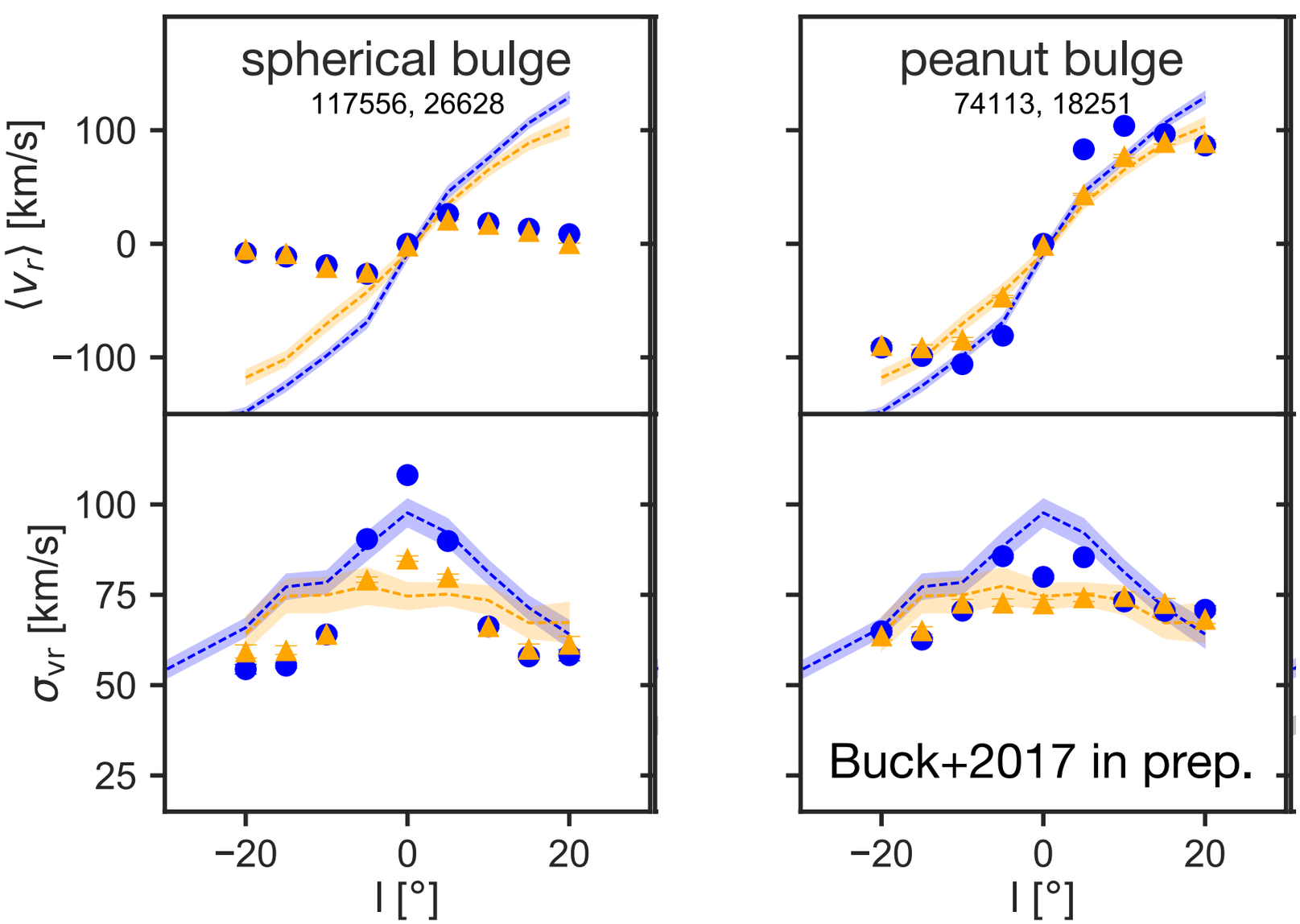
Poster 46
(Kunder et al.)

6D phase space kinematic decomposition:

decomposition of the galaxy by using gaussian mixture models and the parameter set (jz /jc , jp /jc , e) as from Obreja+2016

Kinematics of the Bulge Components

Rotation and Dispersion profiles for classical and peanut bulge components



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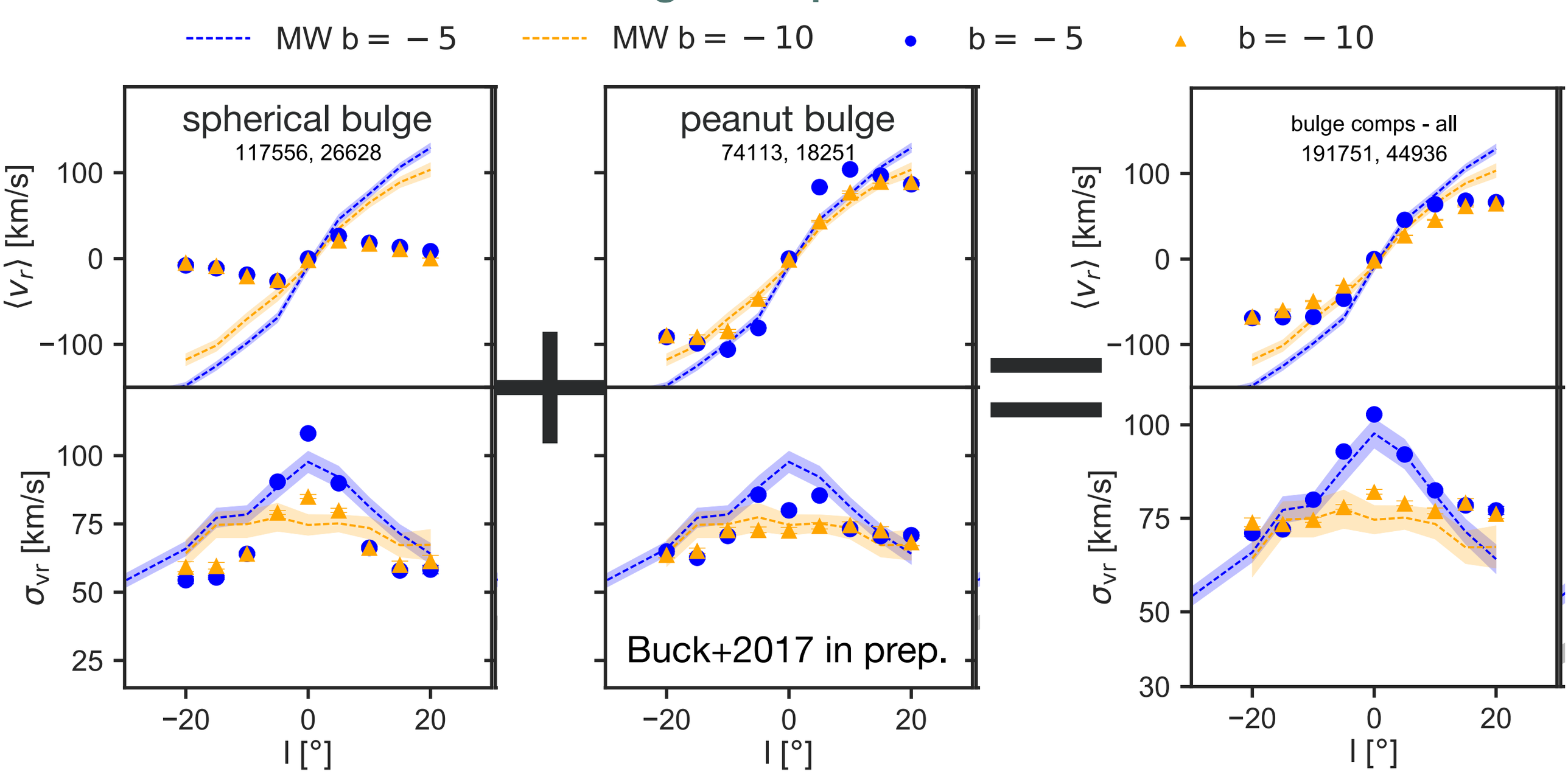
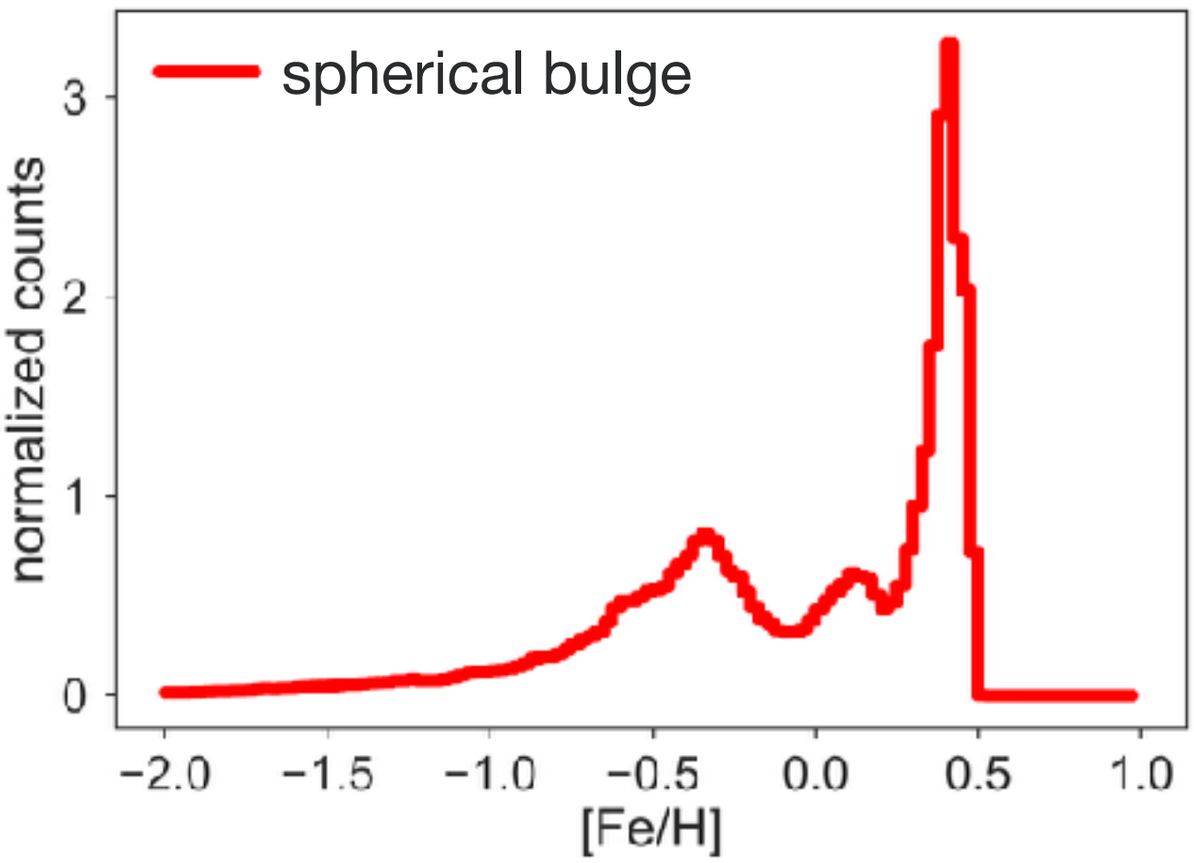
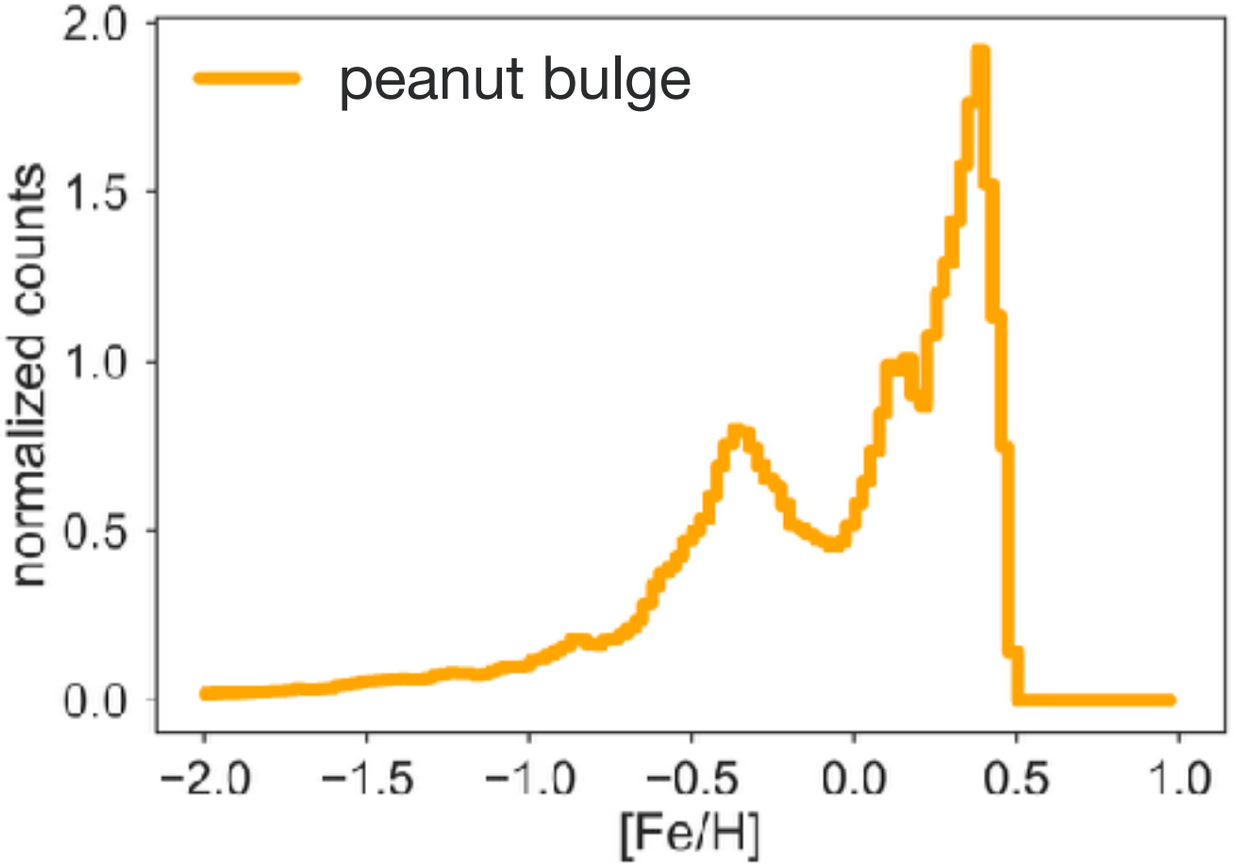


Metallicities of the Bulge Populations

the bulge components show distinct metallicity sub-components





Buck+2017 in prep.

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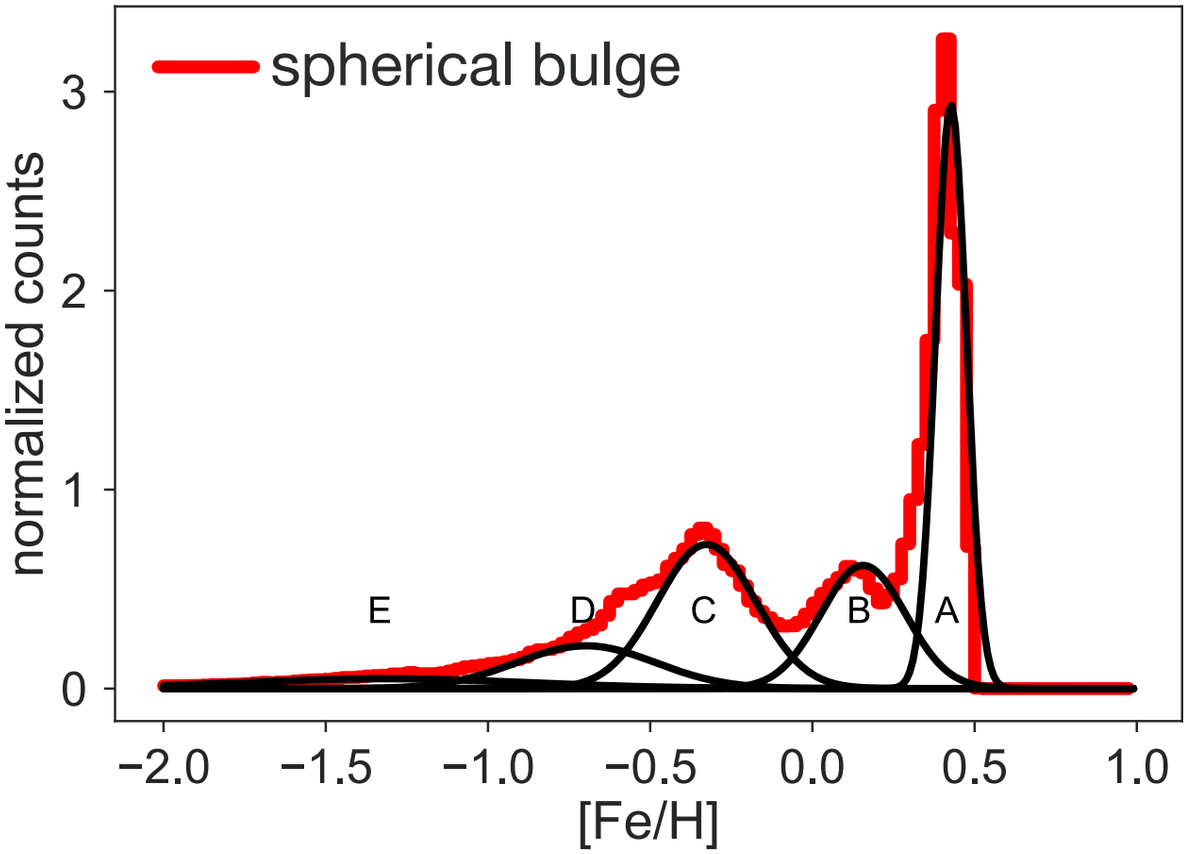
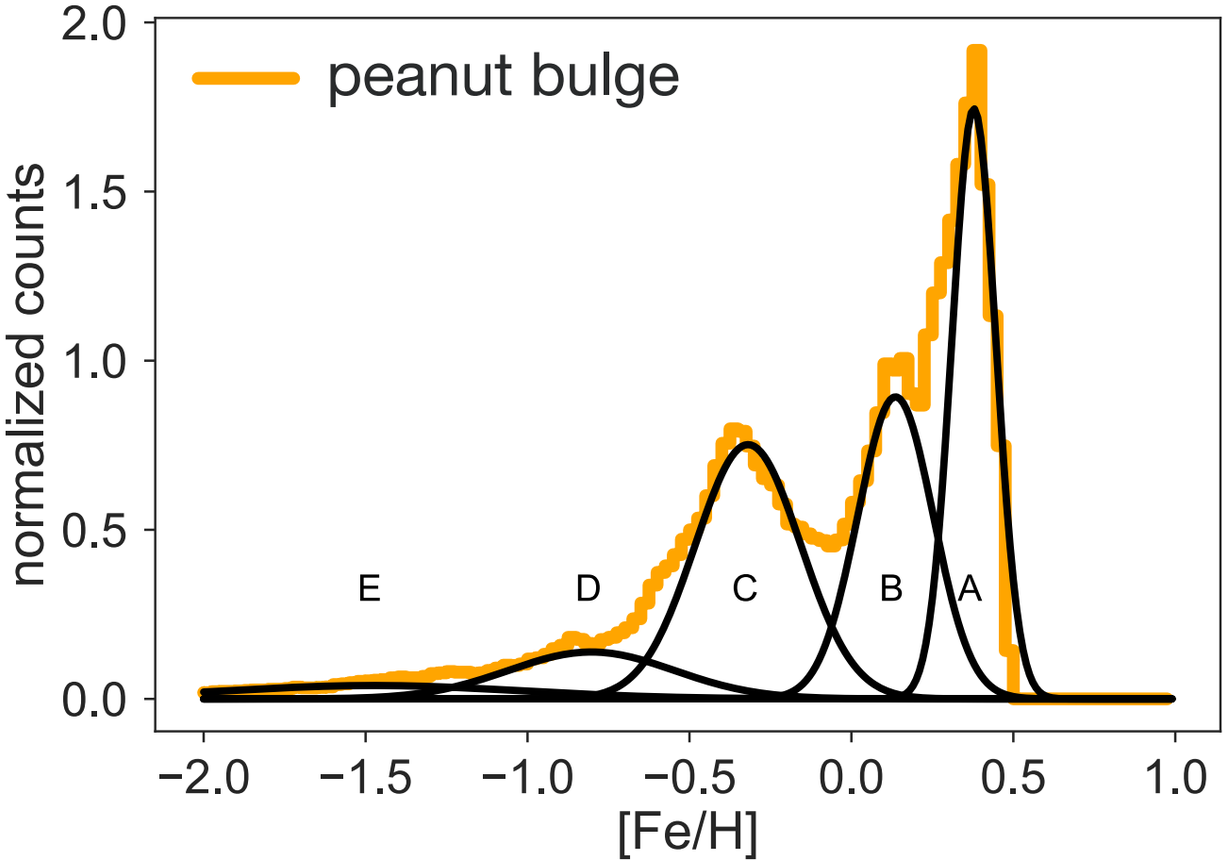
the bulge components show distinct metallicity sub-components

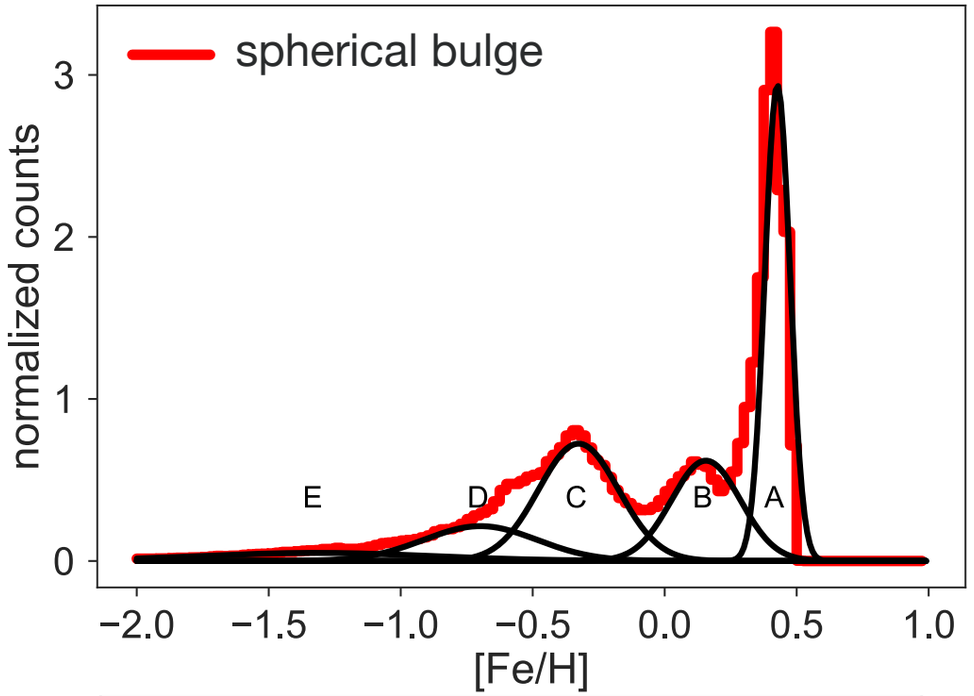


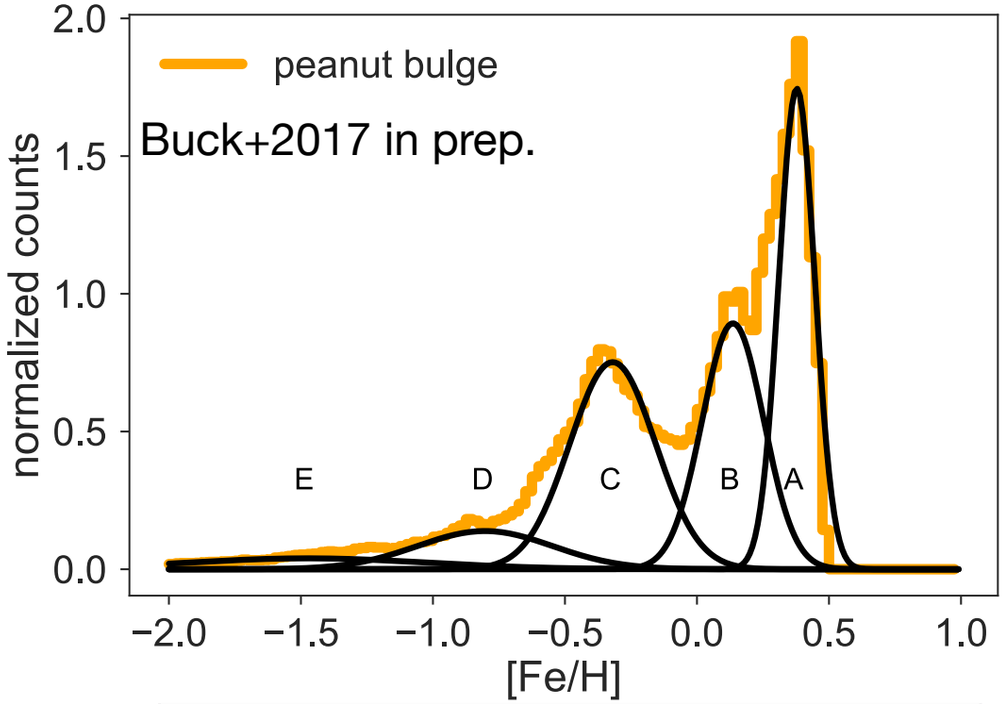


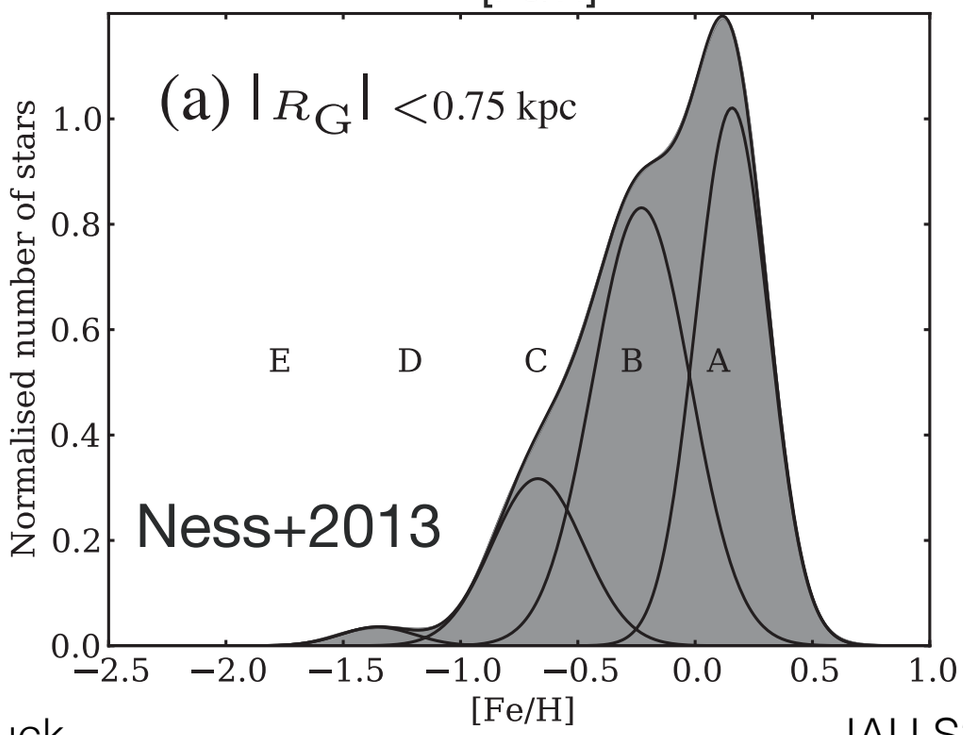
Buck+2017 in prep.

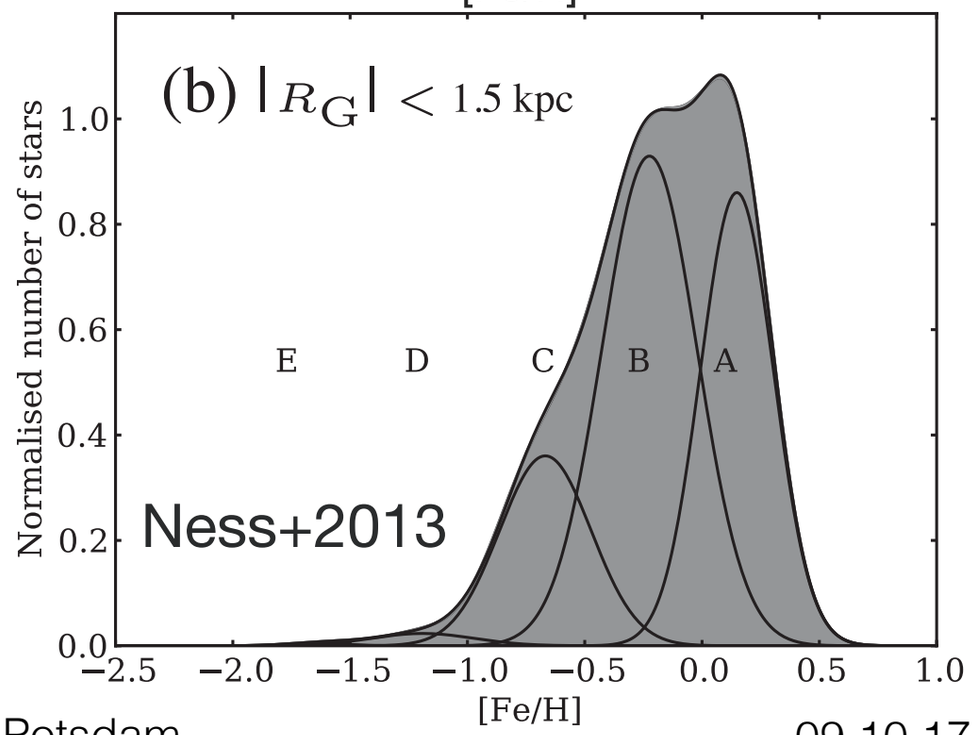
Metallicities of the Bulge Populations

the bulge components show distinct metallicity sub-components

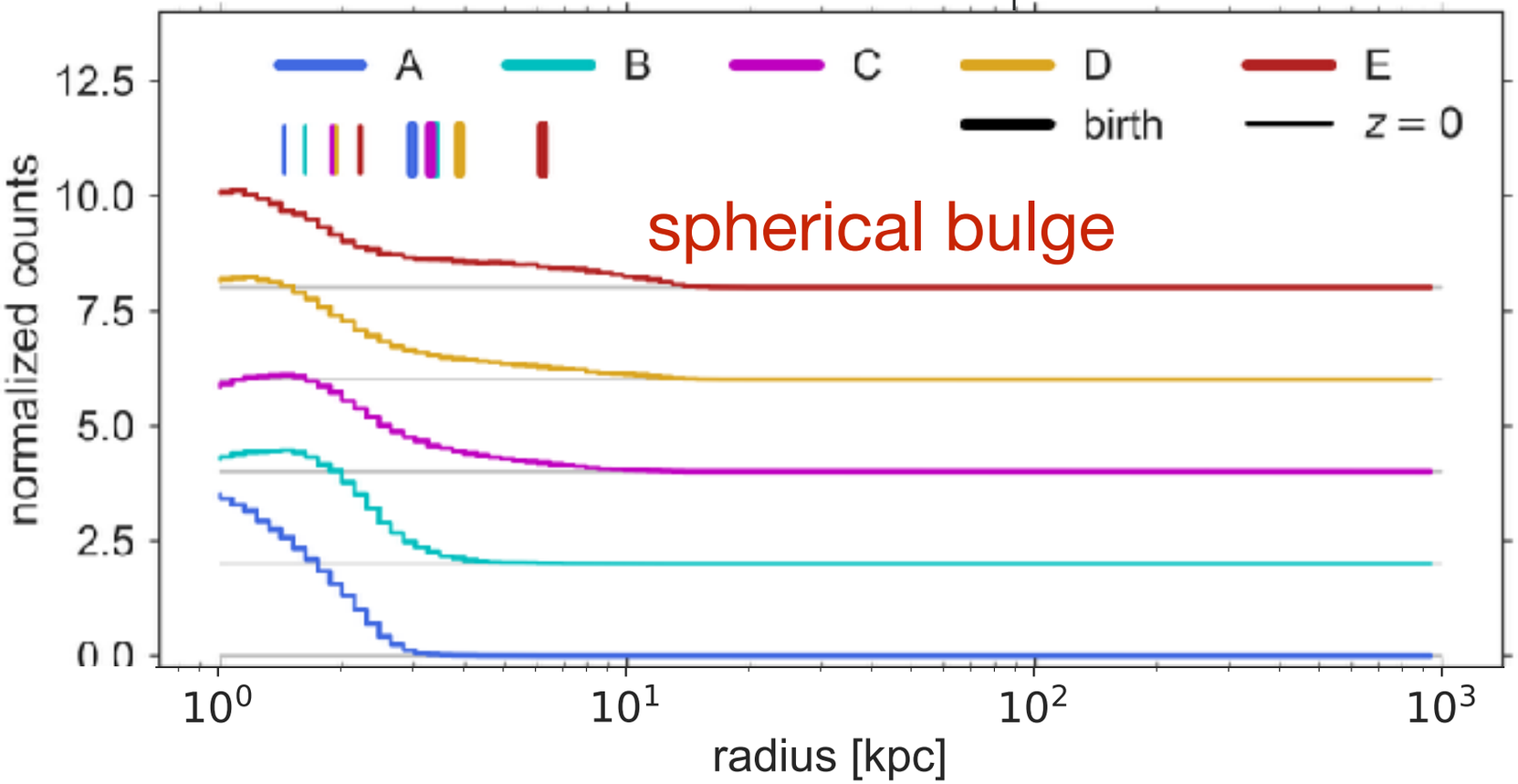






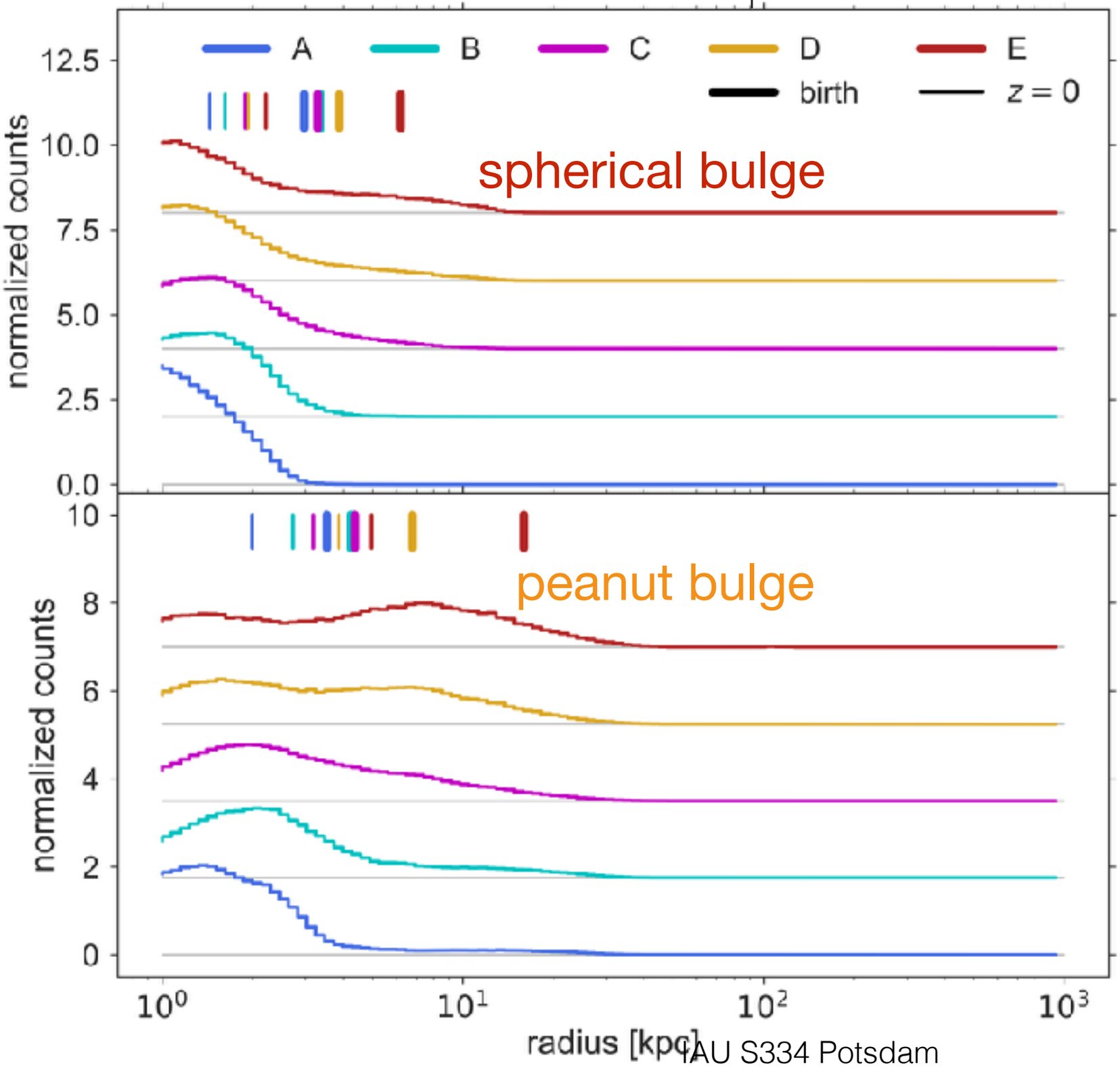


Present Day Position of the Bulge Components



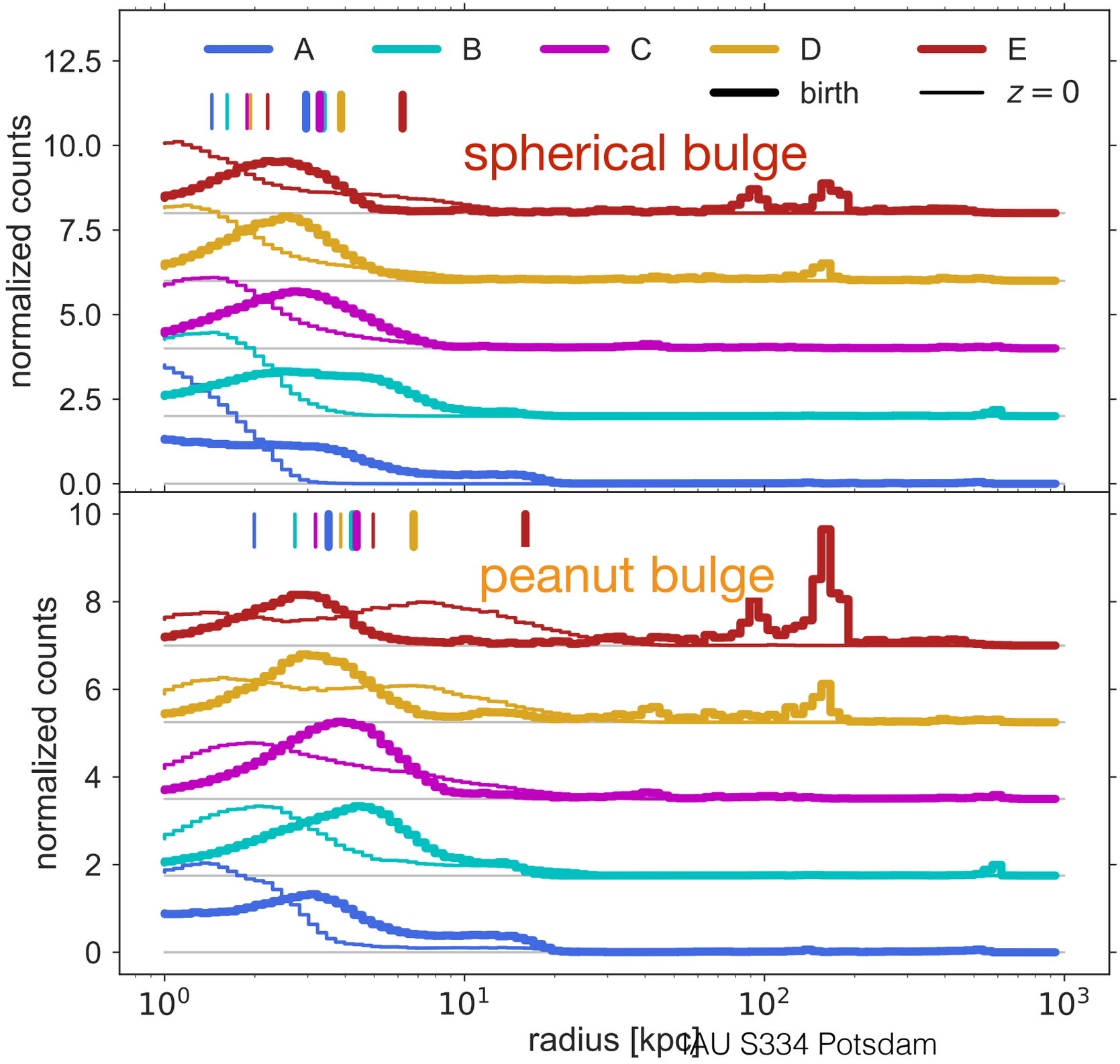
Buck+2017 in prep.

Present Day Position of the Bulge Components



Buck+2017 in prep.

Birth Position of the Bulge Components



equal birth positions
but very different
present day positions!

secular evolution
by the bar scatters
stars to vastly
different orbits!

see also Poster 20
(Fragkoudi et al.)

Buck+2017 in prep.

Conclusions to Go

NIHAO-UHD:

- reproduces key features of the MW
- contribute new insights into the formation and evolution of the MW
- the simulated bulge has a complex sub-structure shaped by secular evolution

If you like to see your favourite Milky Way plot for my galaxies… write me: **buck@mpia.de**

Extra Material

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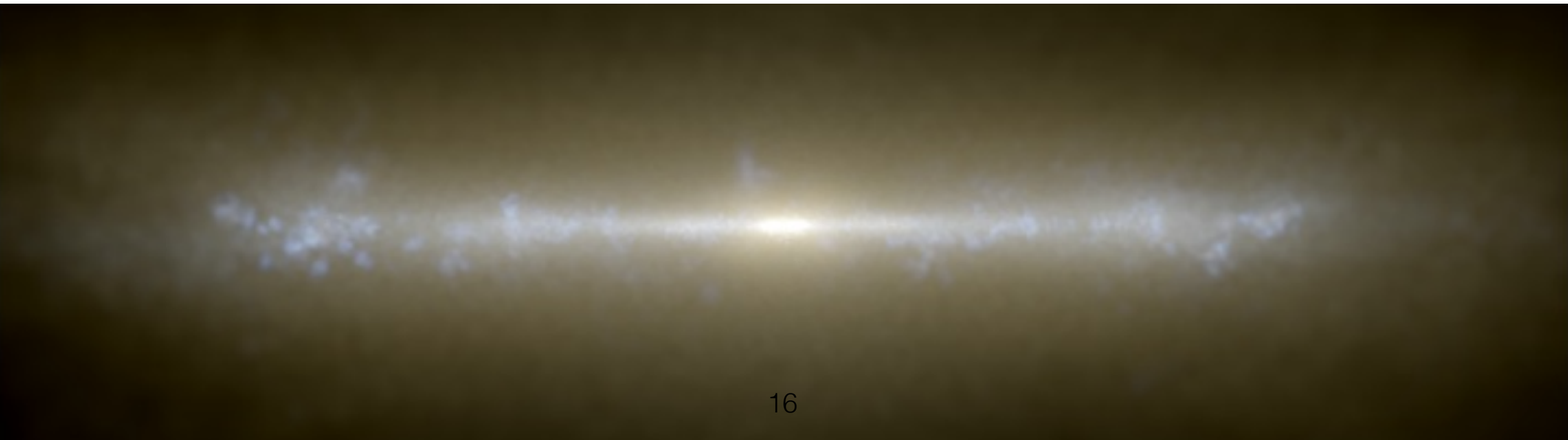
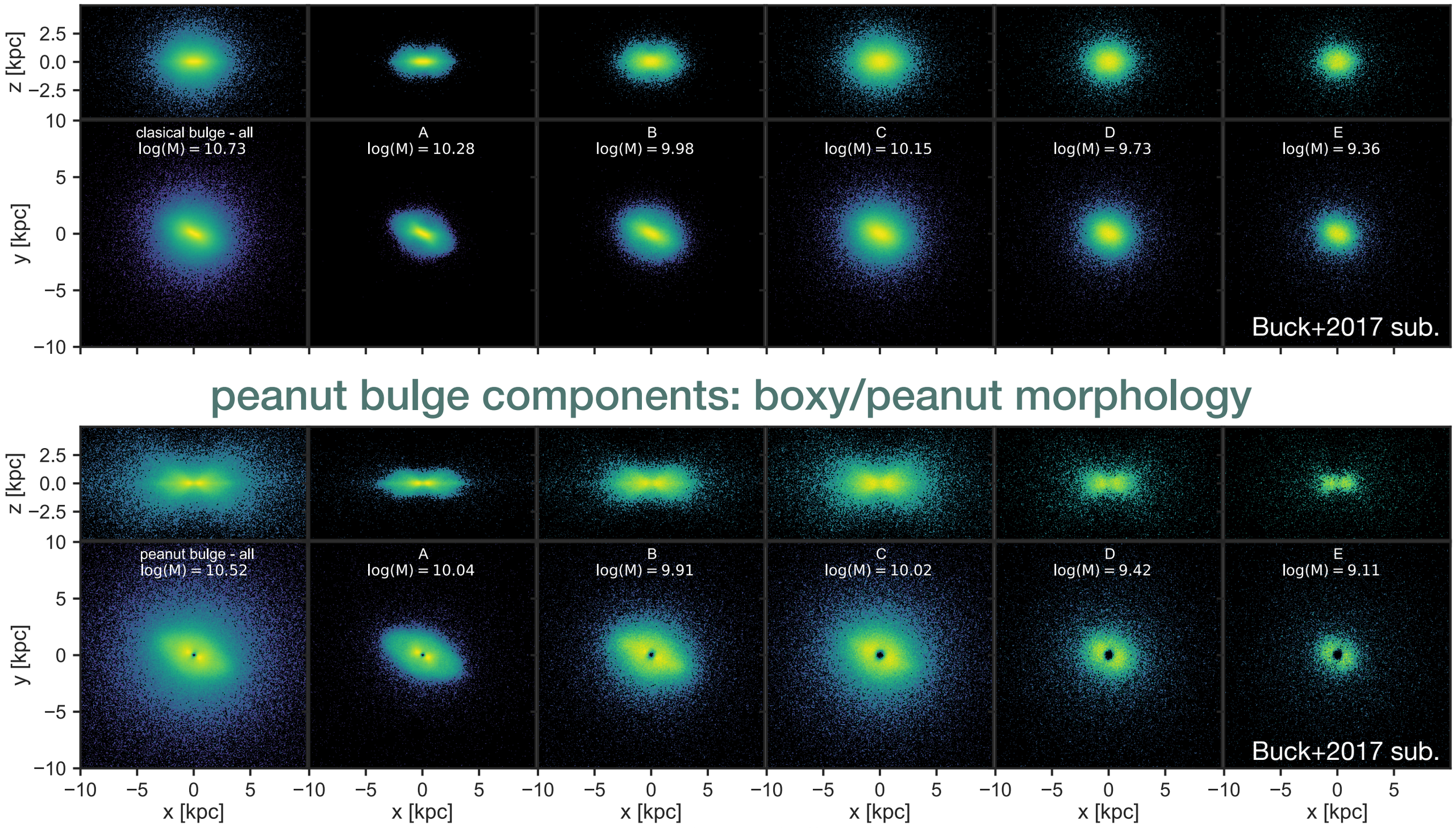


Morphology of the Bulge Components

classical bulge components: more spherically symmetric

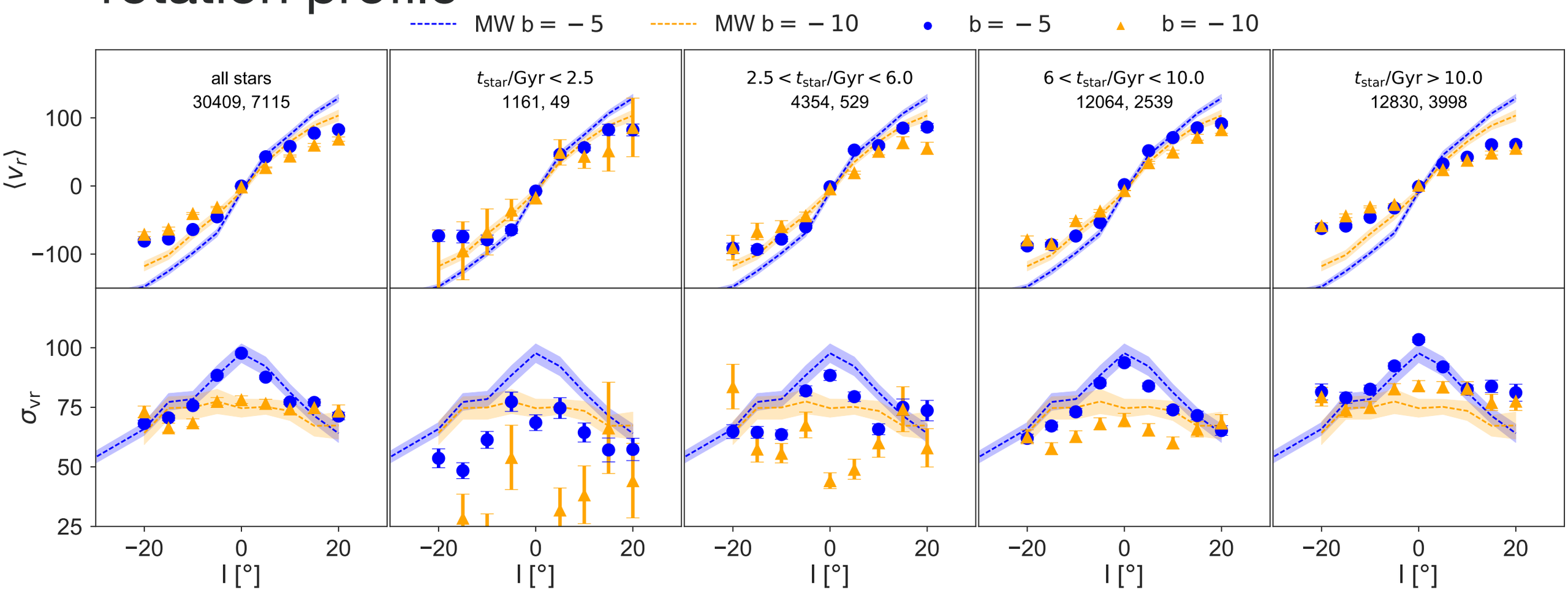


peanut bulge components: boxy/peanut morphology

The Galactic Center in Simulations

The Kinematics

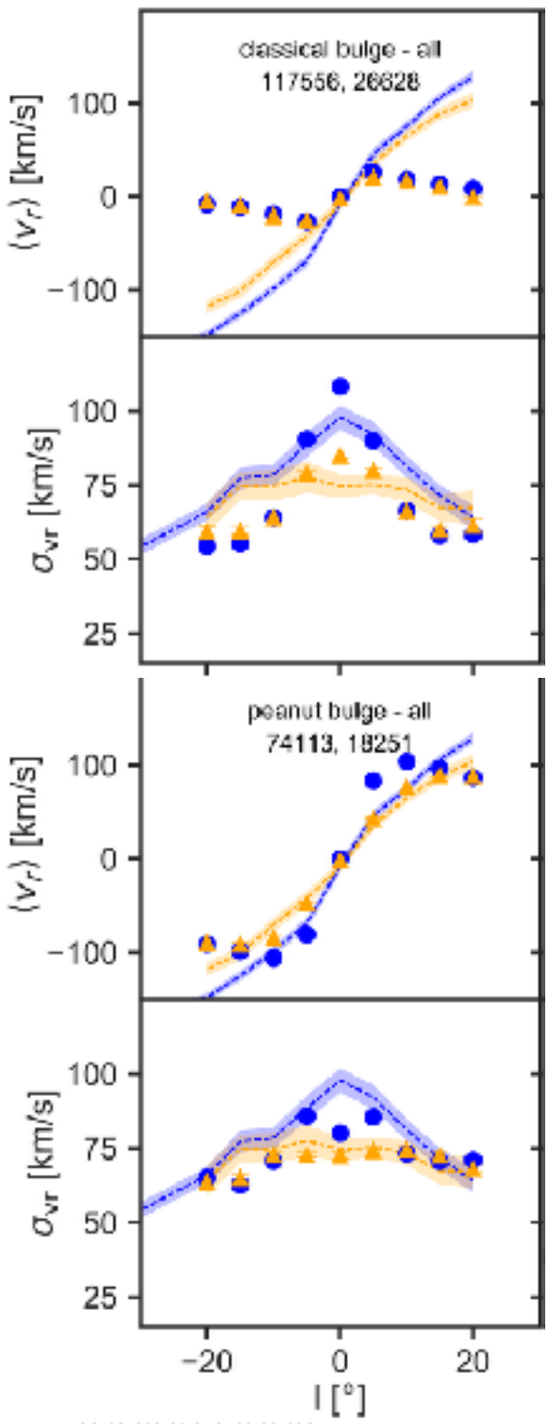
rotation profile



dispersion profile

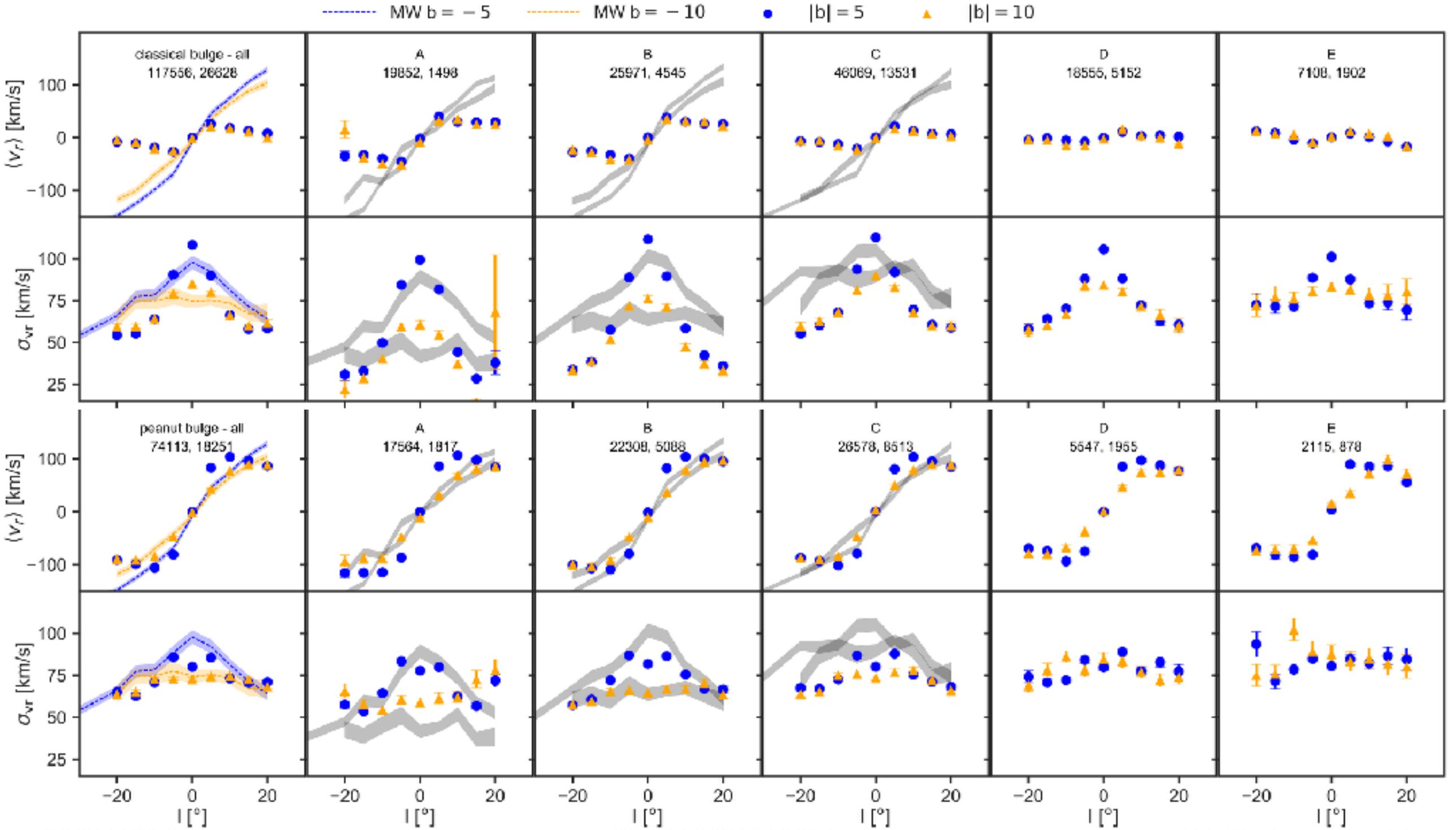
Kinematics of the Bulge Components

decomposition of the metallicity distribution function by



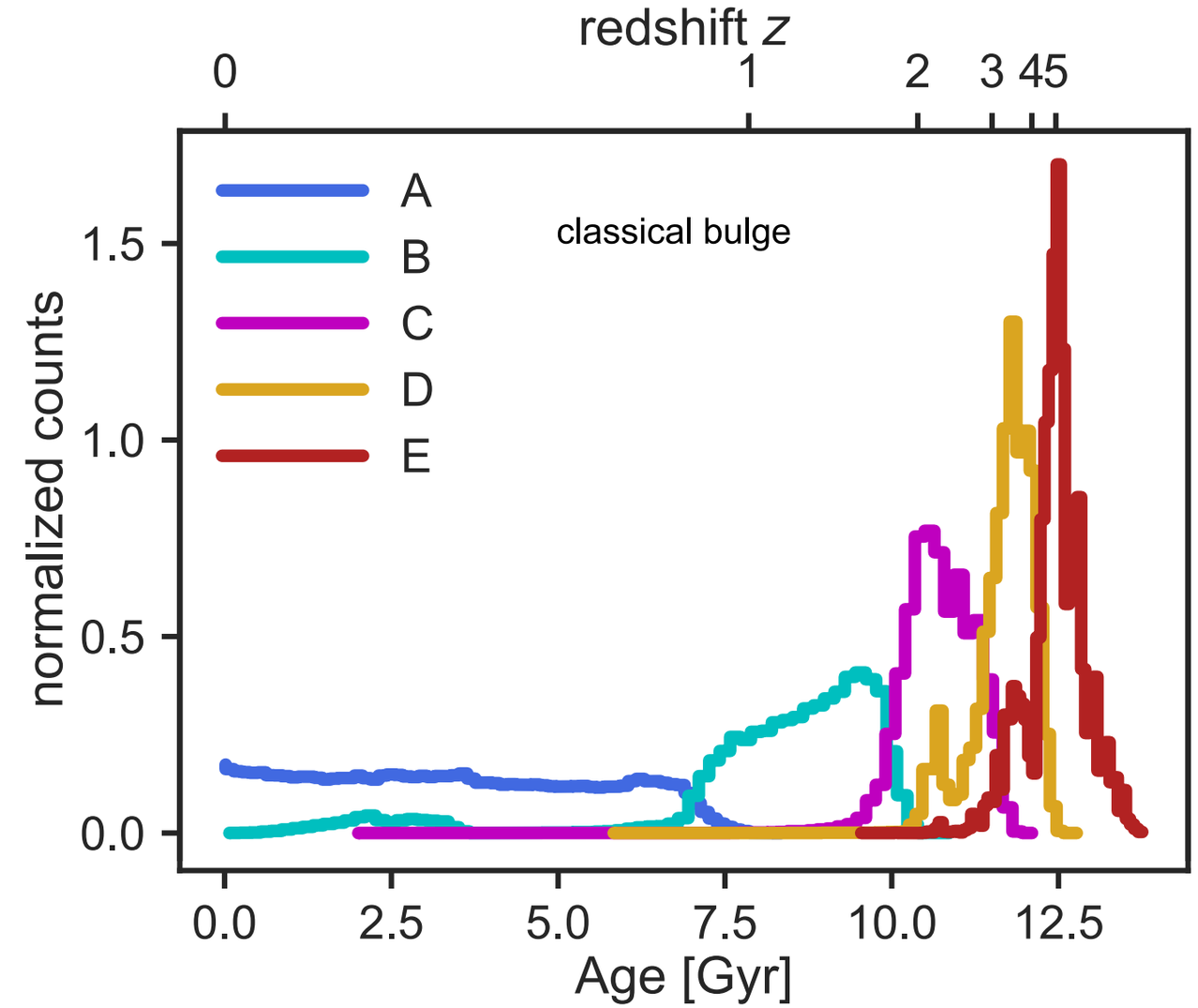
Kinematics of the Bulge Components

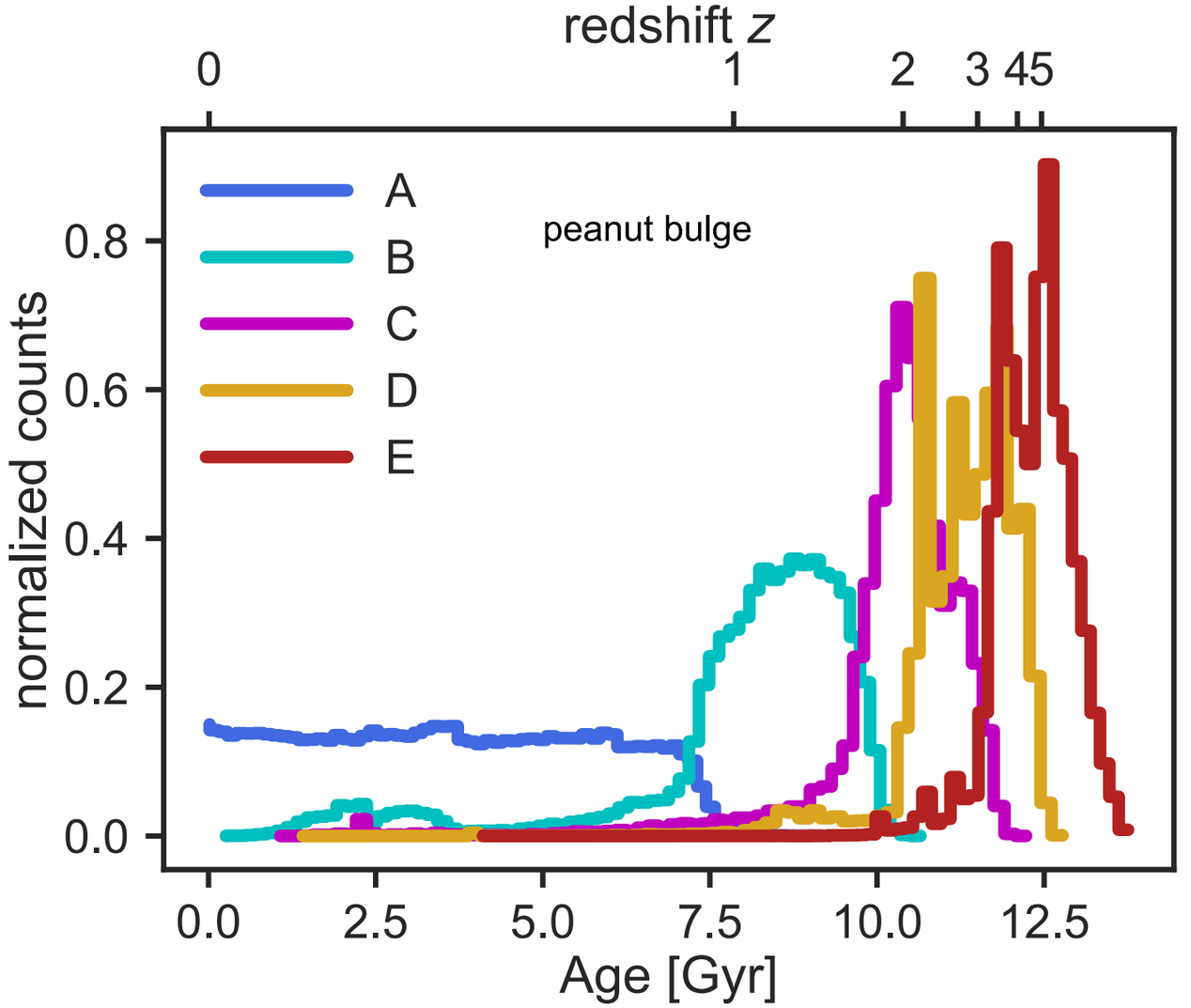
decomposition of the metallicity distribution function by



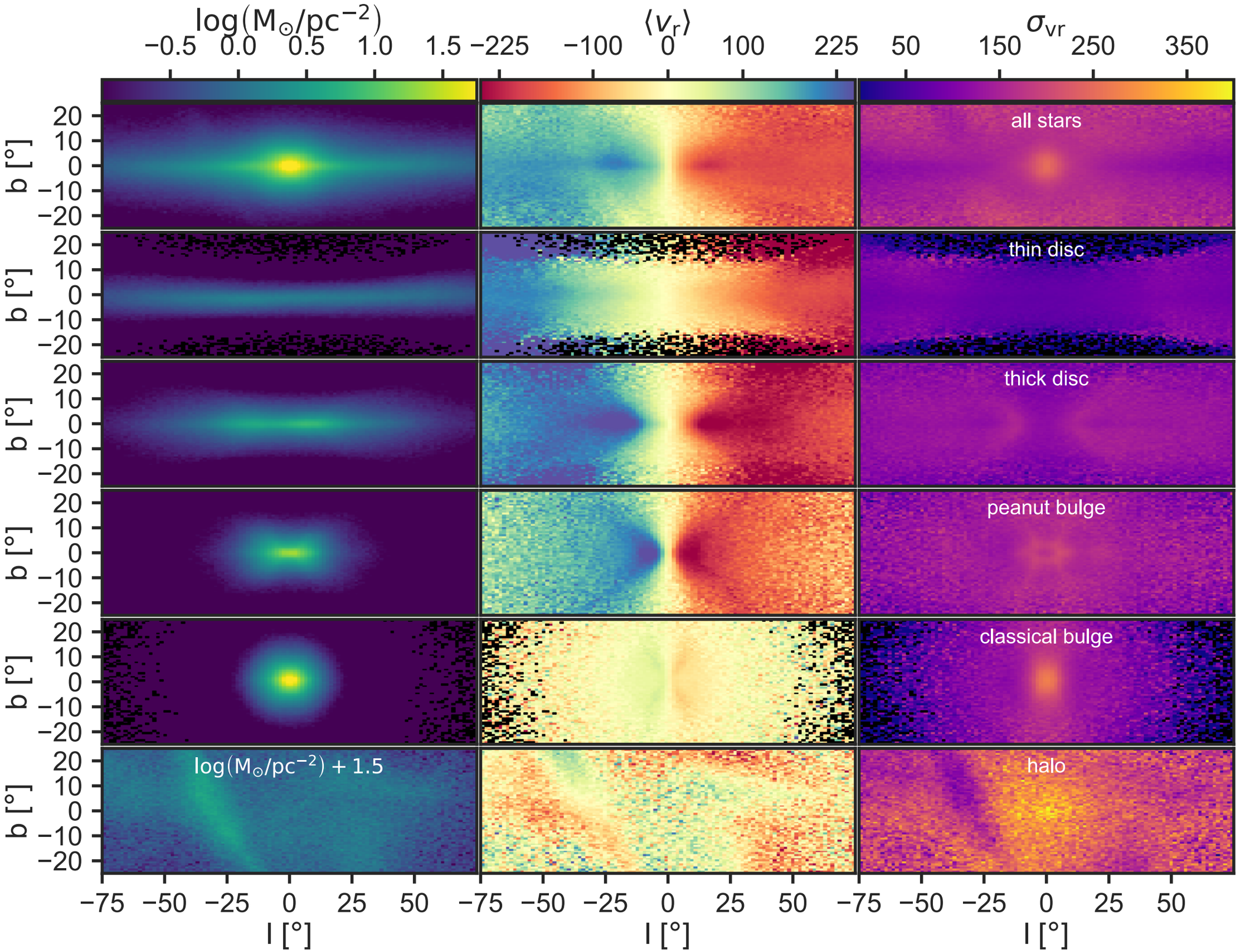
Ages of the Bulge Components

decomposition of the metallicity distribution function by usage of 5 component gaussian mixture model

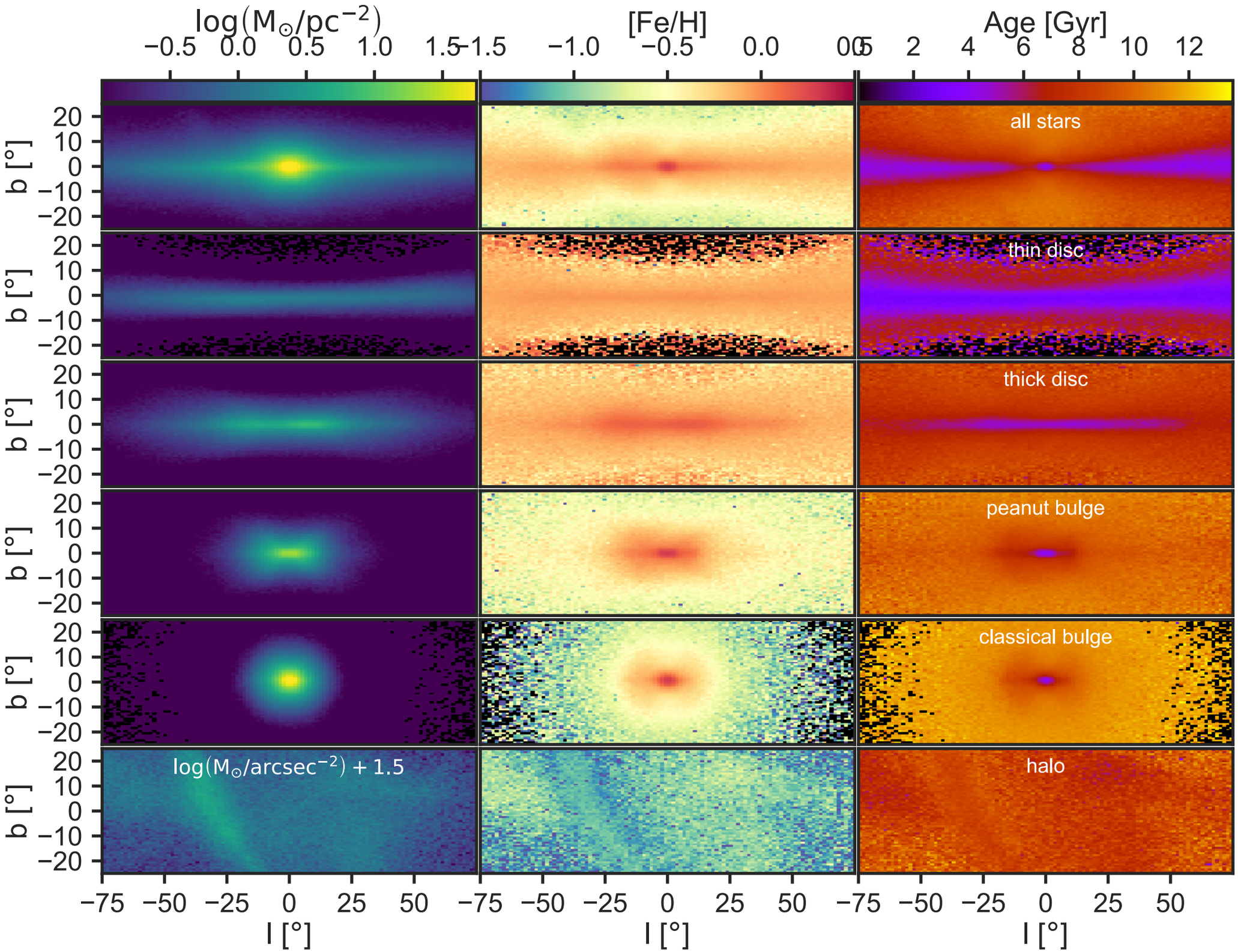




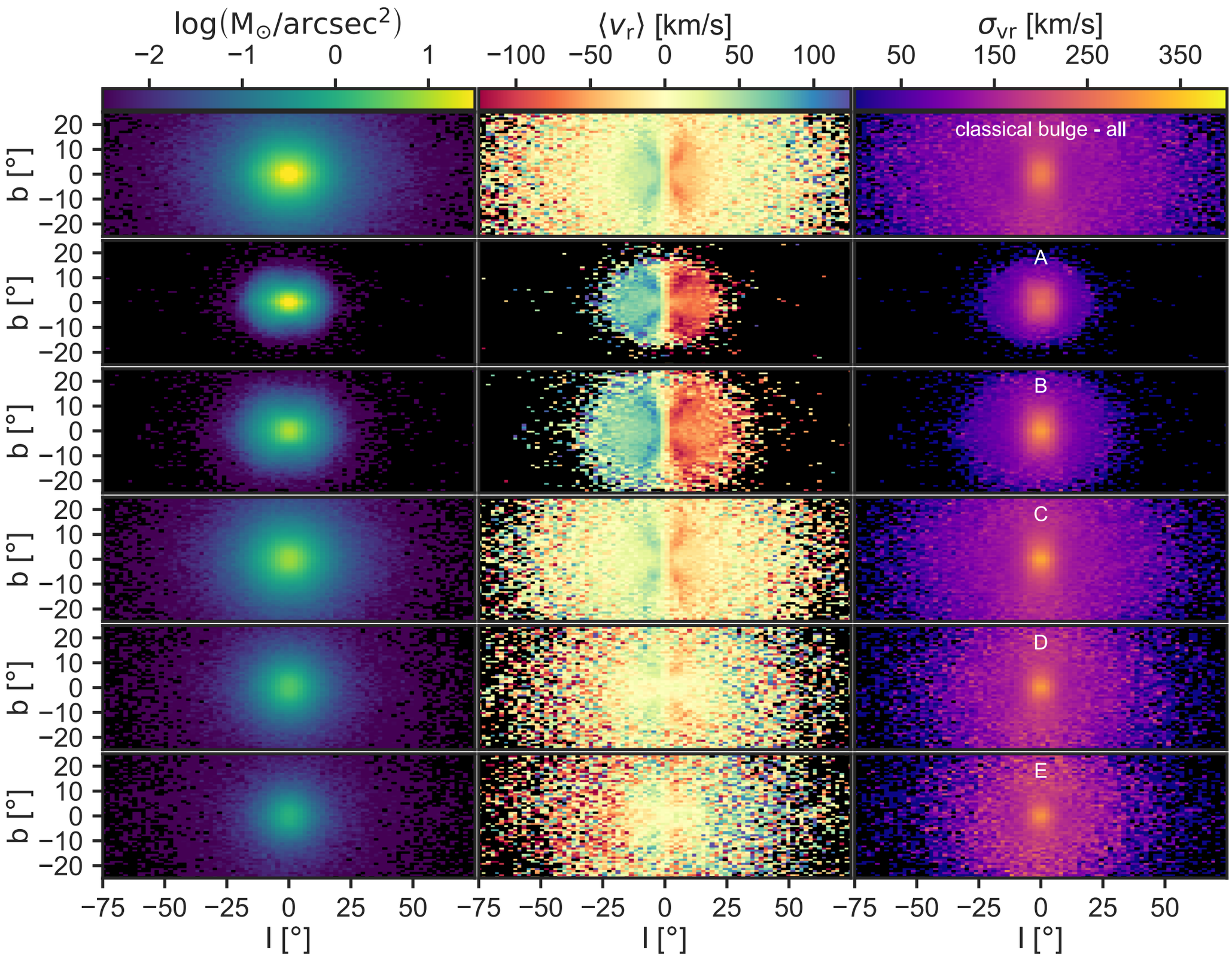
Kinematic Maps in l,b



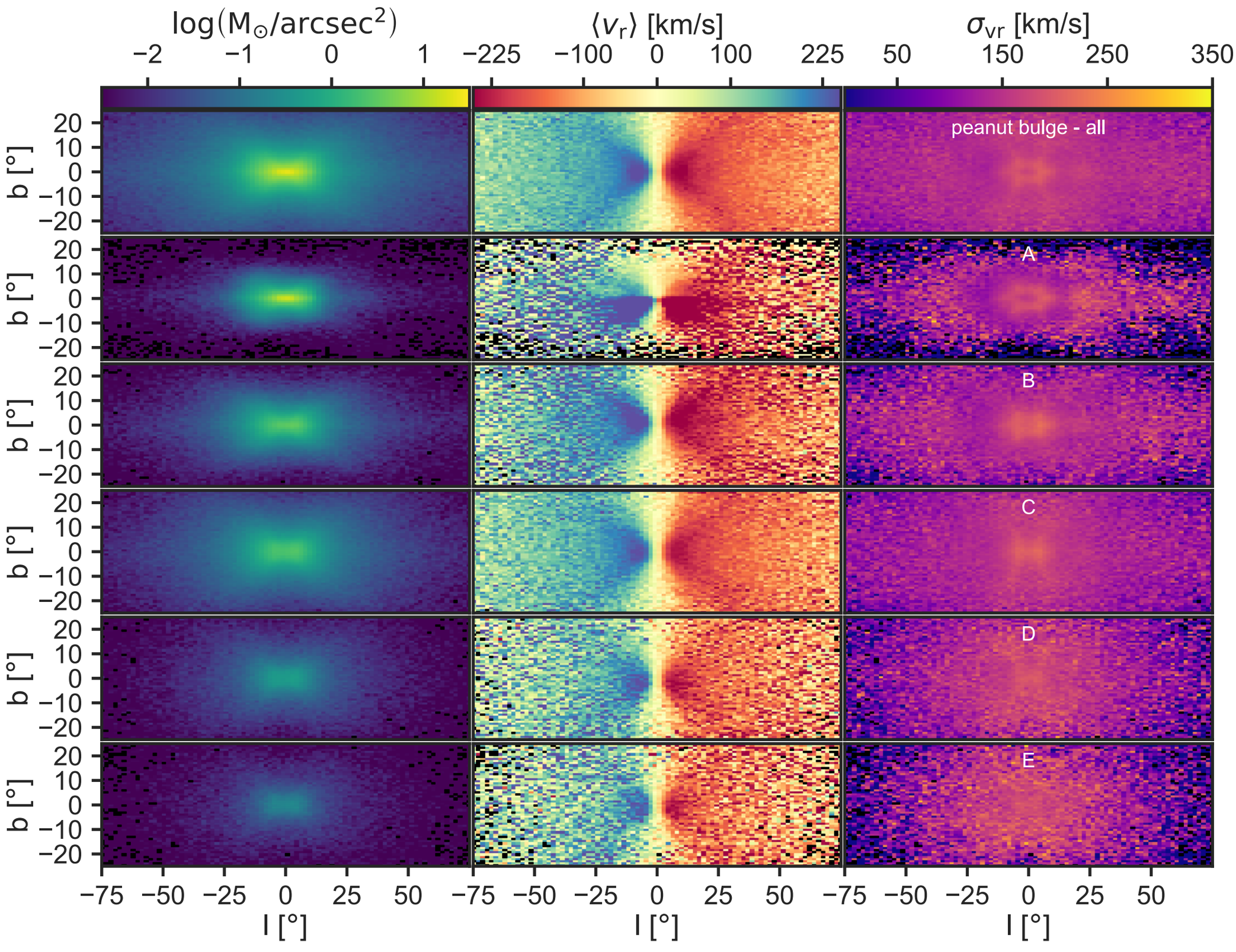
Metallicity Maps in l,b



Kinematic Maps in l,b - classical bulge



Kinematic Maps in l,b - peanut bulge



Environmental Effects on Satellites and Dwarfs