2-Phase Assembly of Galaxies and their GC Systems

Study
Astrophysics of
Globular
clusters in
Extragalactc
Systems

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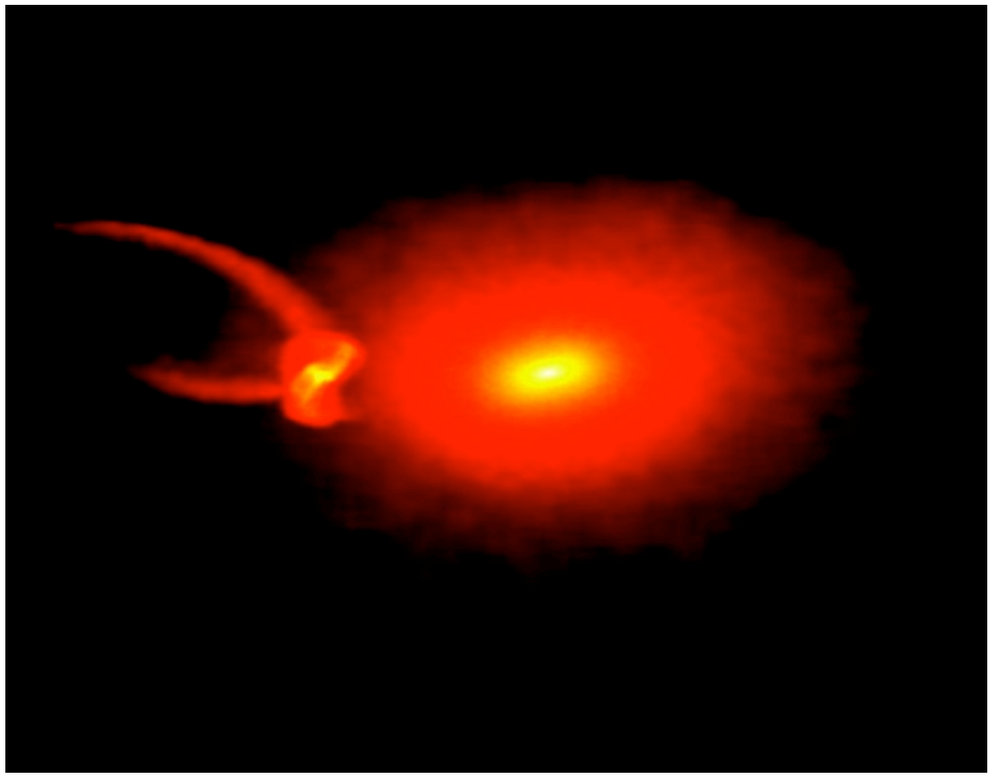
Chris Usher

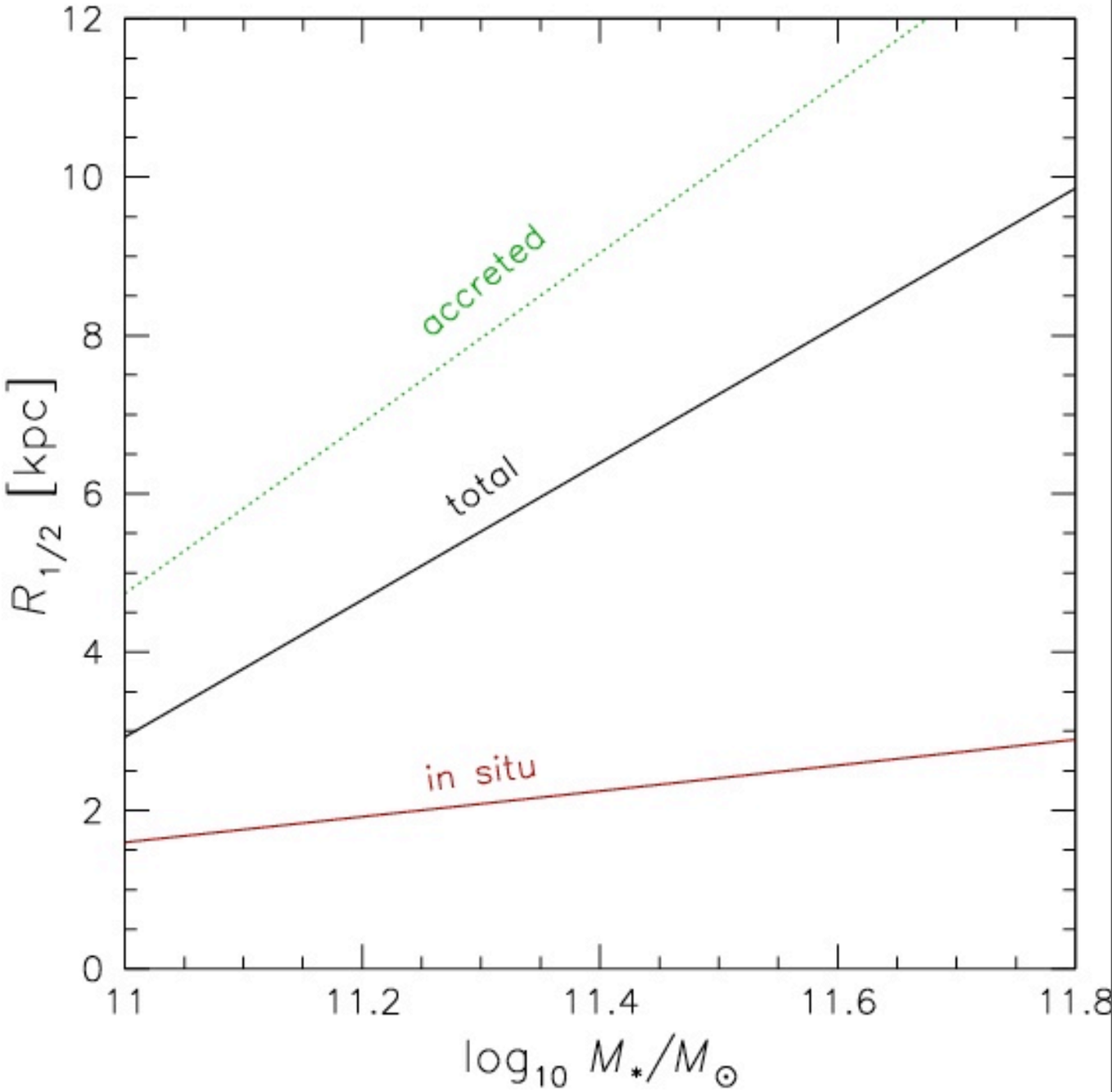
SAGES

Two-phase early-type galaxy formation

- Motivated by observations of strong size-redshift evolution



Half-light radius (z=0) versus mass
(after Oser+2010)



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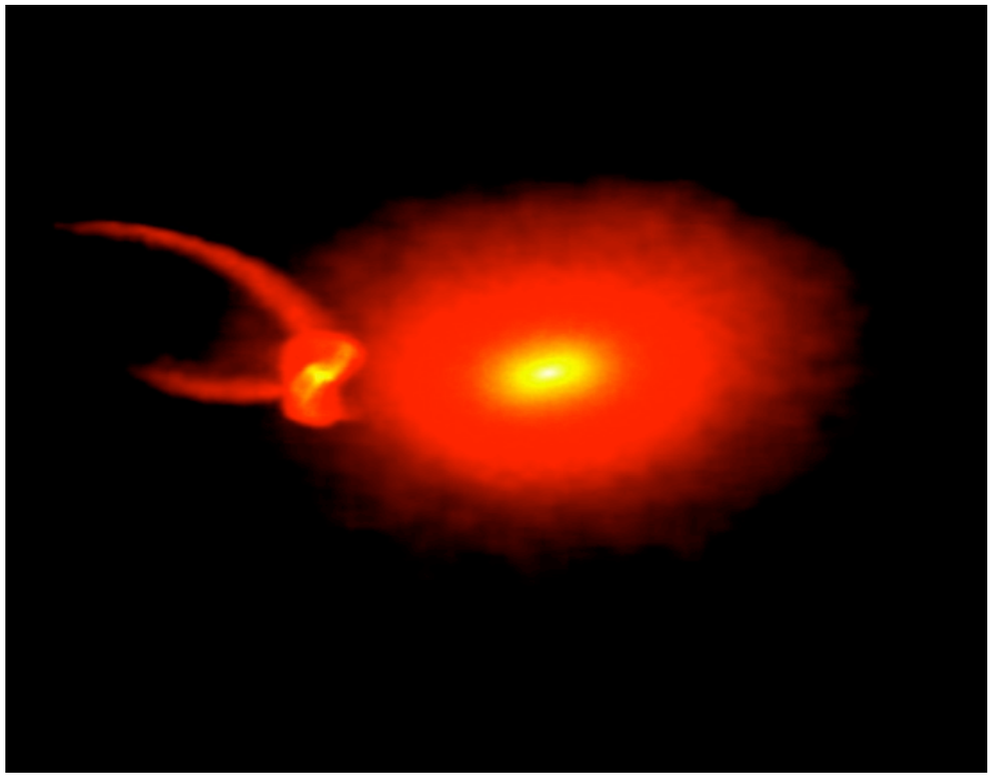

- Only ~10% of stars formed in major merger starbursts, *even in bulges*

  (SAMs: Parry et al 09,
  High z IR obs: Hopkins & Hernquist10)

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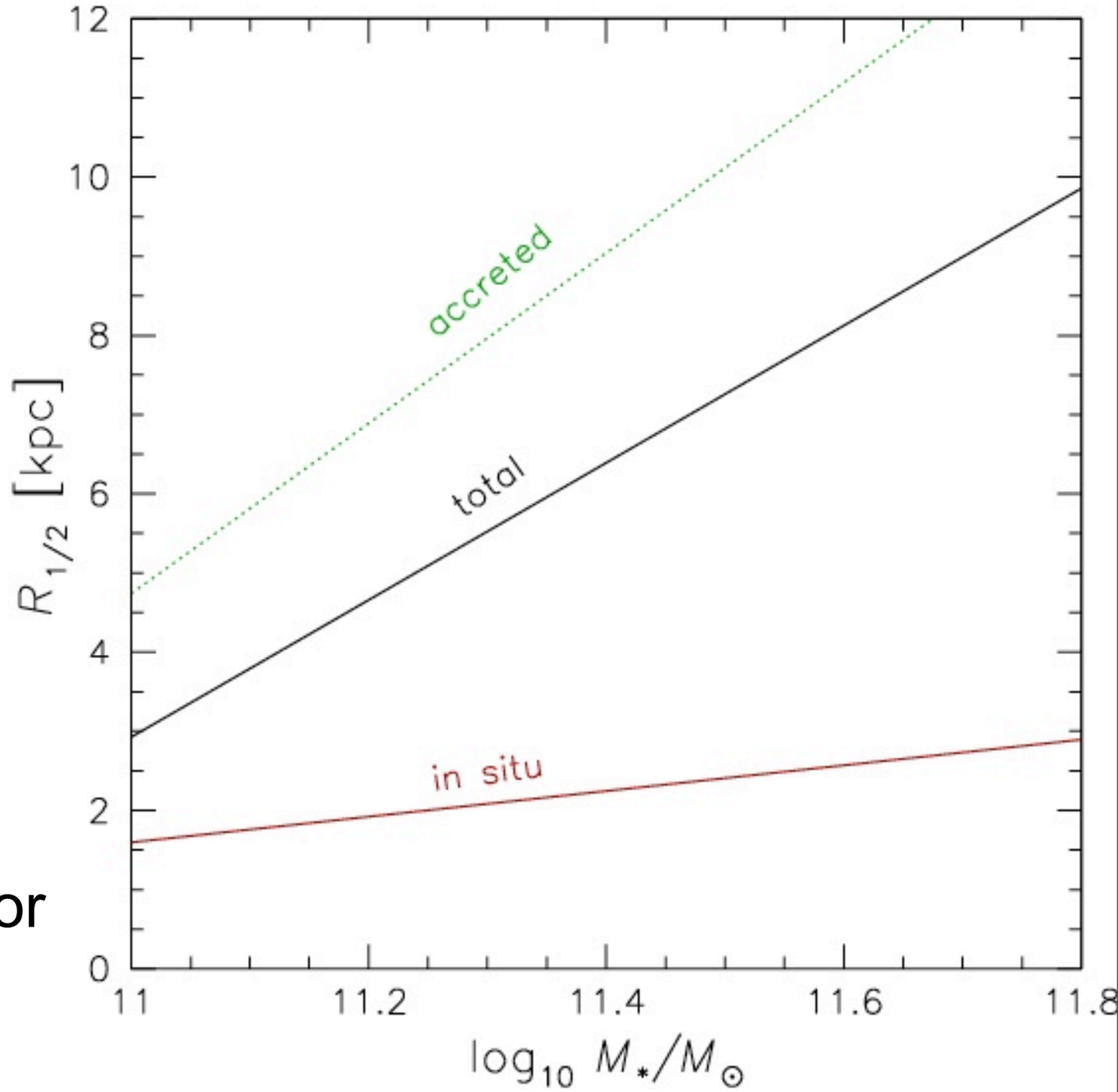


The SLUGGS Survey

SAGES Legacy Unifying Globulars and Galaxies Survey

26 nearby early-type galaxies; range of properties (M, env, ...)

Photometry (Subaru) and spectroscopy (Keck)

Globular clusters to ~10 r_{eff}

Field stars to ~ 3 r_{eff}

Spectroscopic Mapping of Early-type Galaxies to their Outer Limits

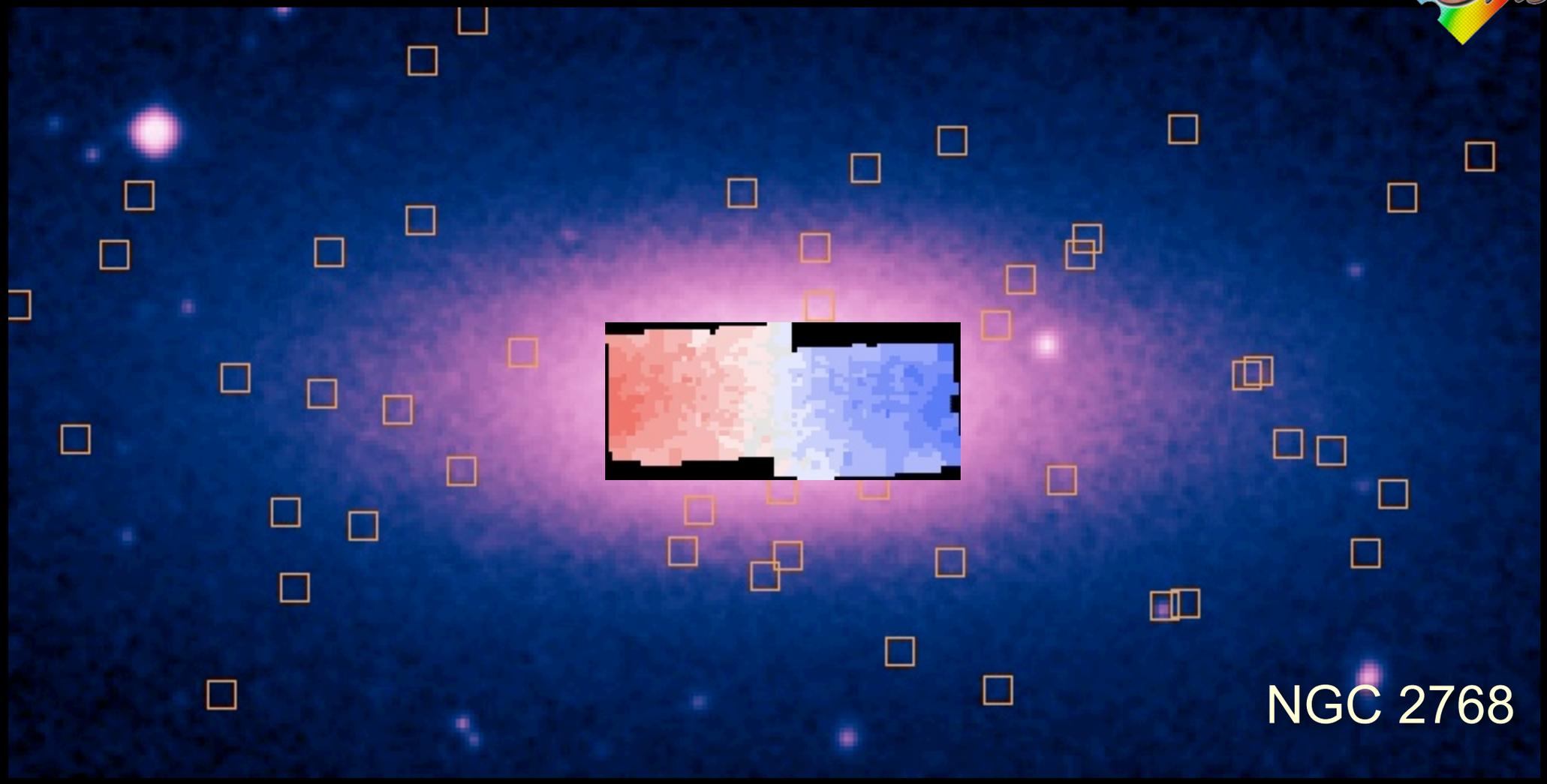
Wide field 2-D stellar kinematics with Keck

Use extra slit light from DEIMOS GC spectra to probe galaxy kinematics and metallicities to ~3 R_{eff} *(psuedo IFU)*

Norris+'08; Proctor+'08; Foster+'09, 2010; Arnold+'10

SLUGGS

SAURON



"SKiMS": Stellar Kinematics with Multiple Slits

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SLUGGS

SMEAGOL

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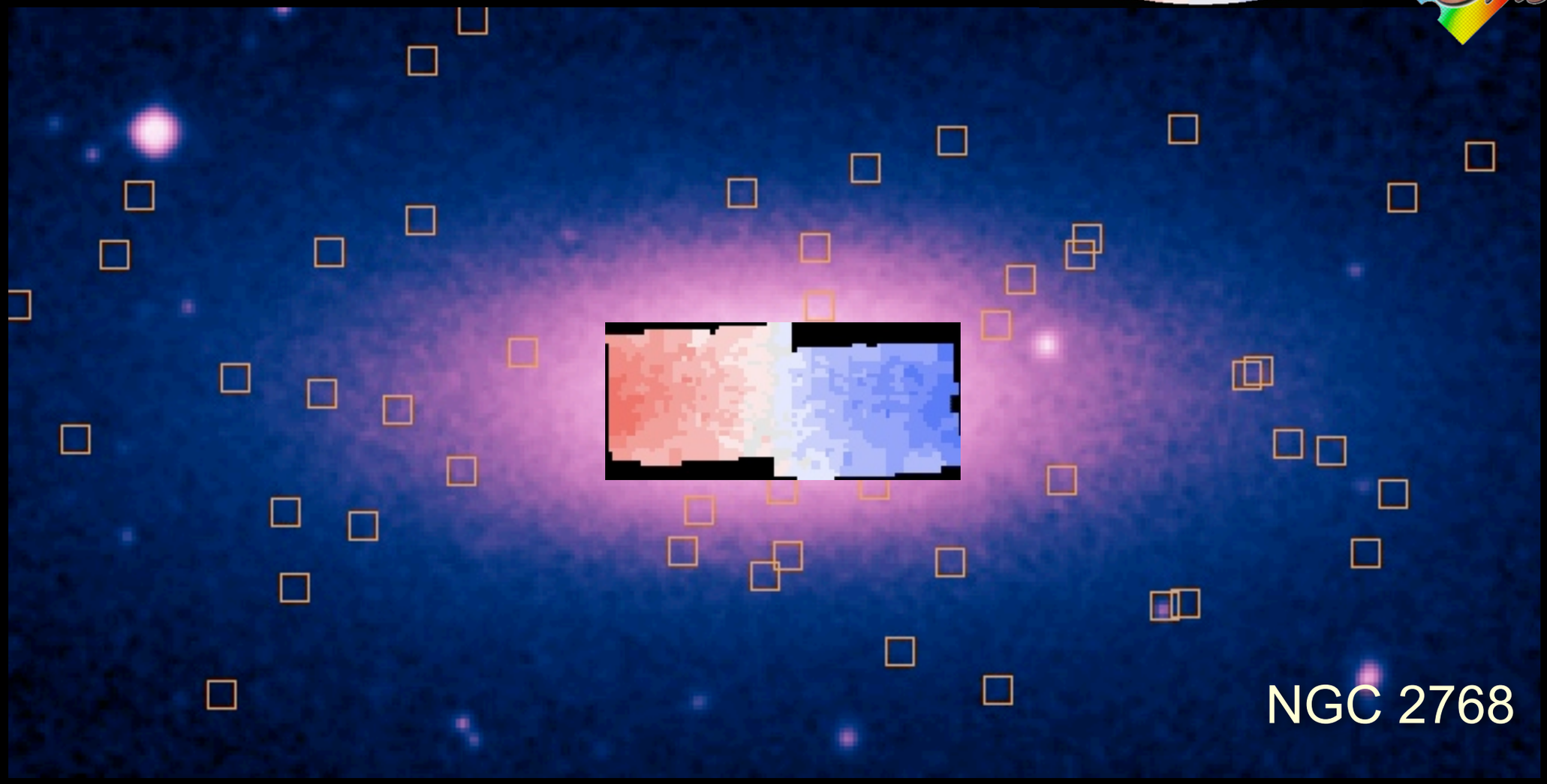

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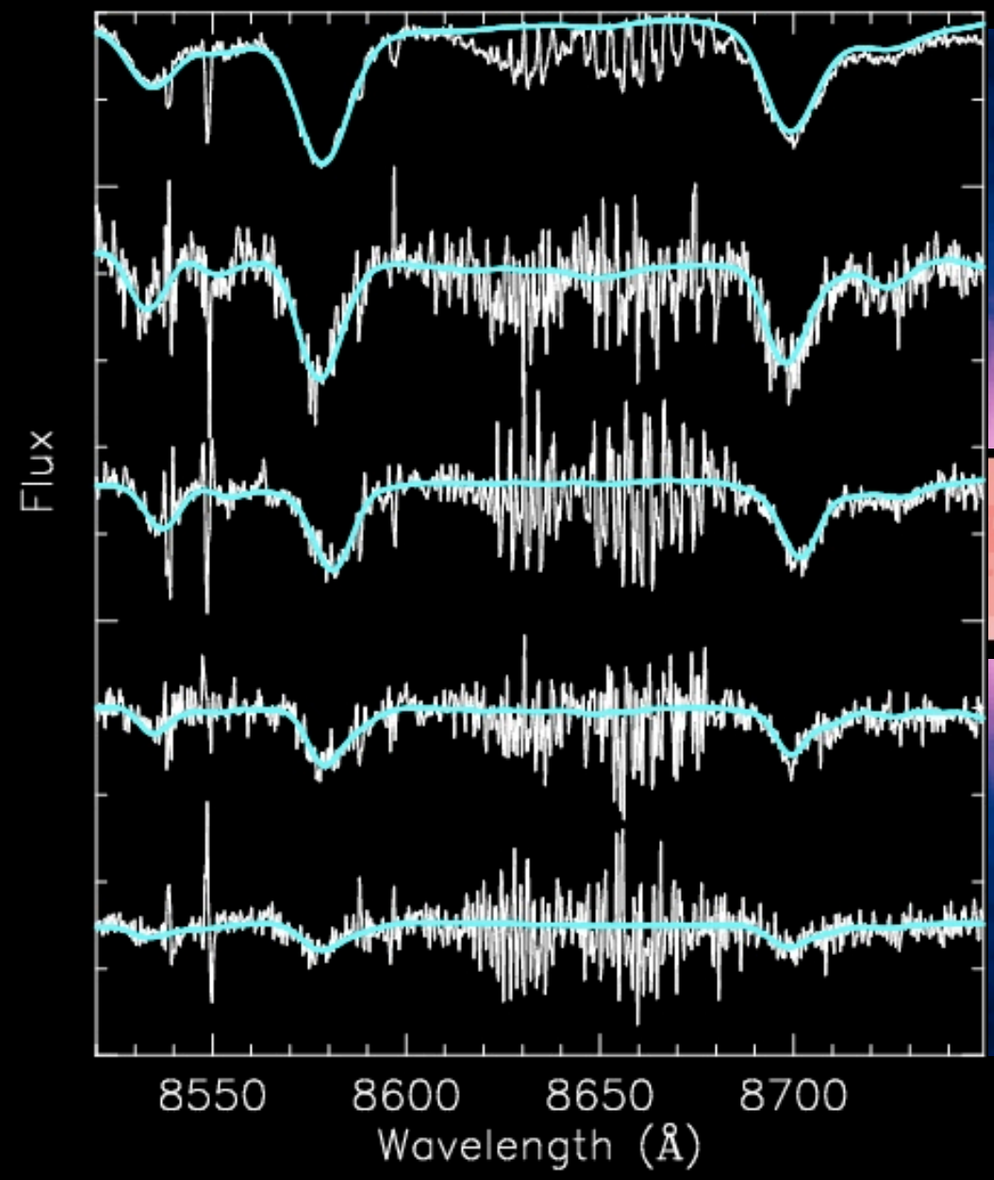
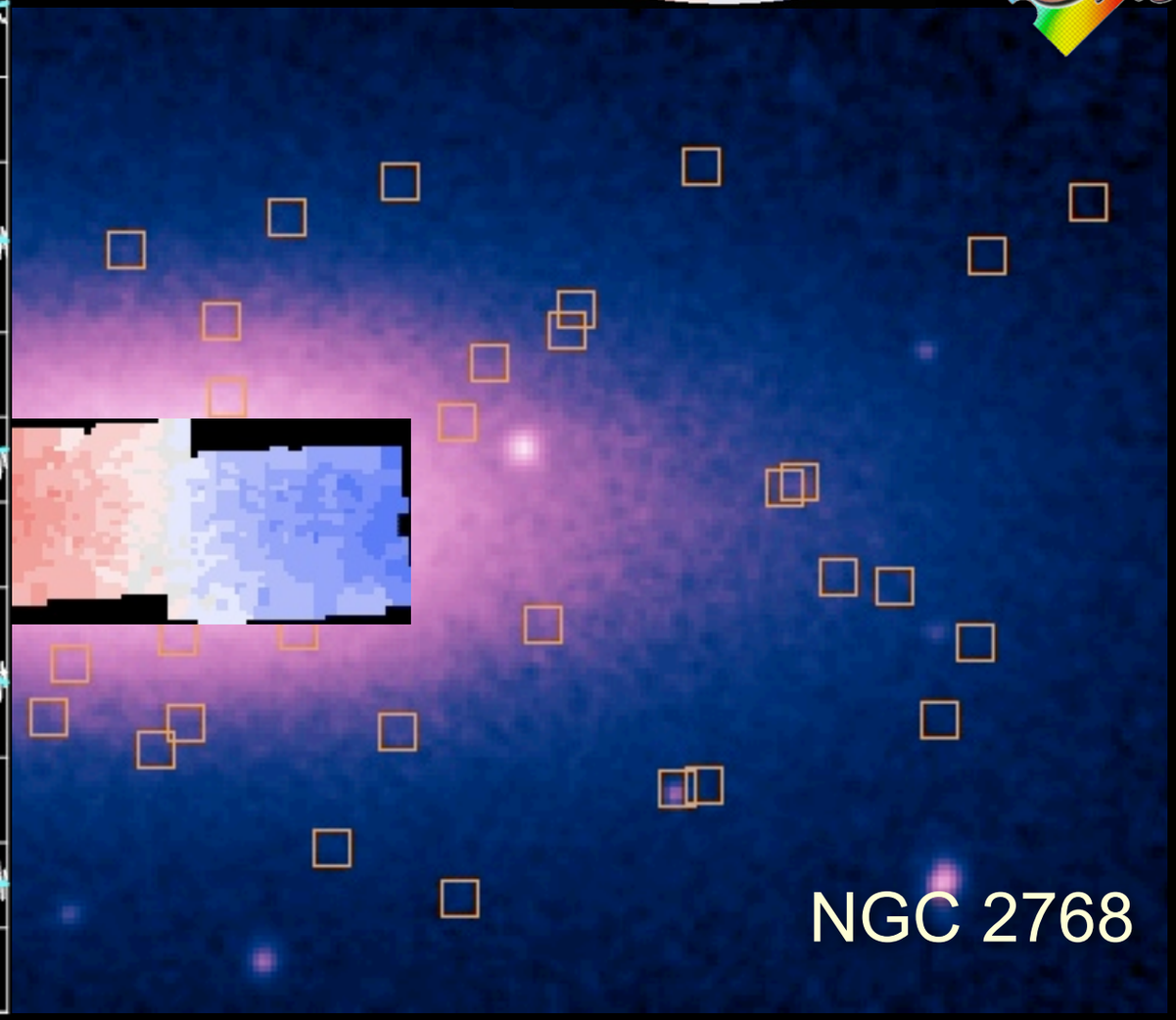
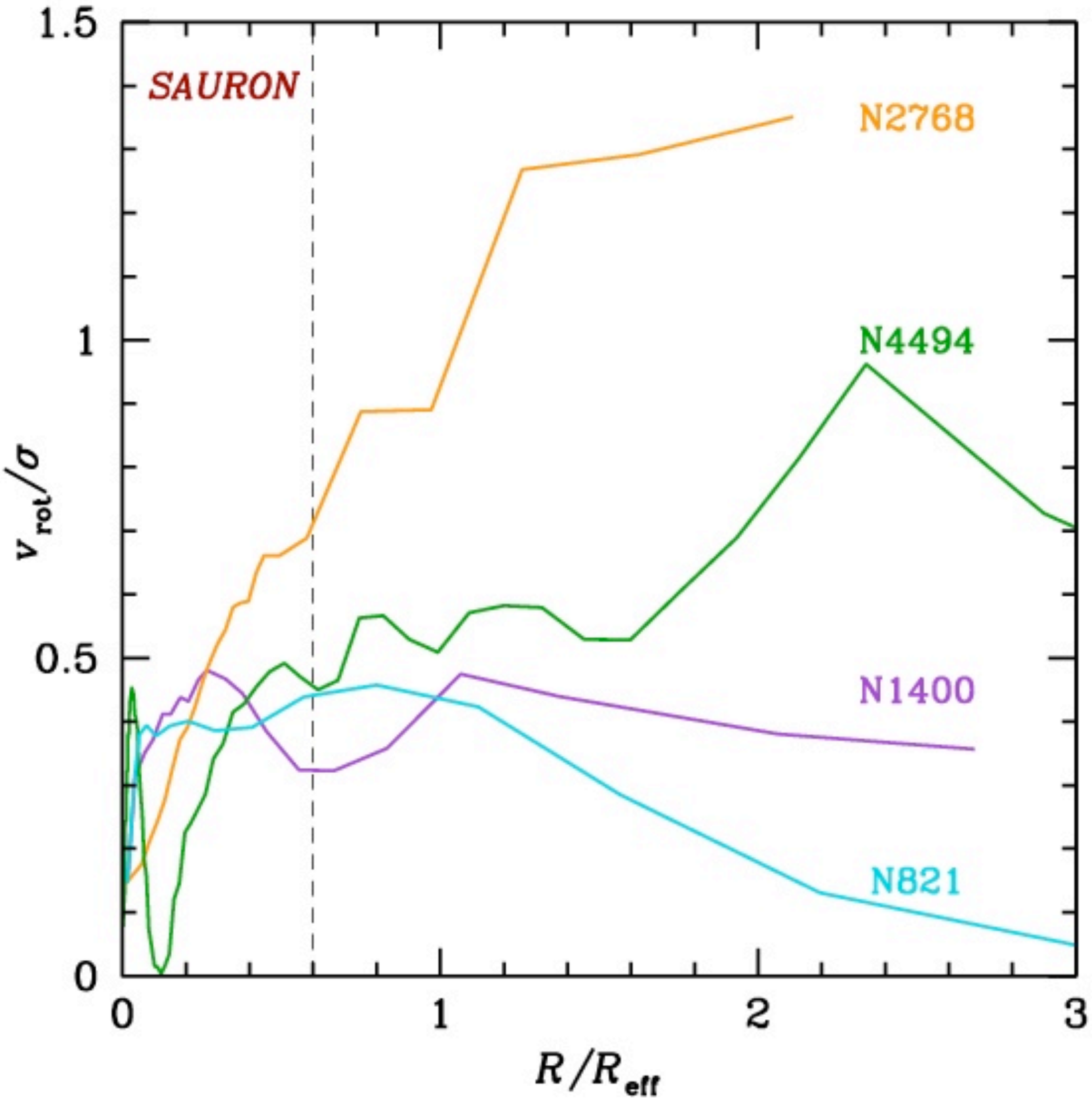




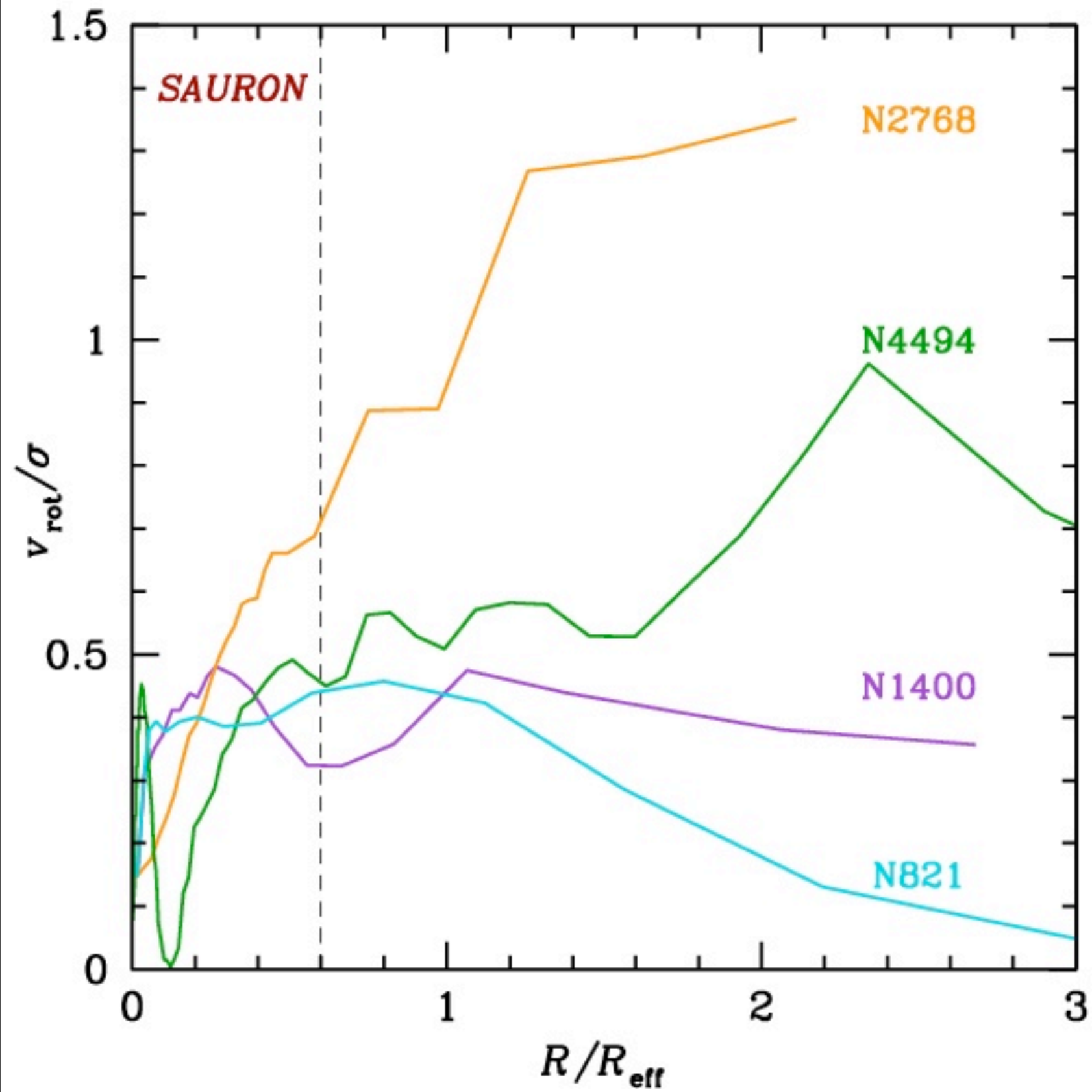
"SKiMS": Stellar Kinematics with Multiple Slits

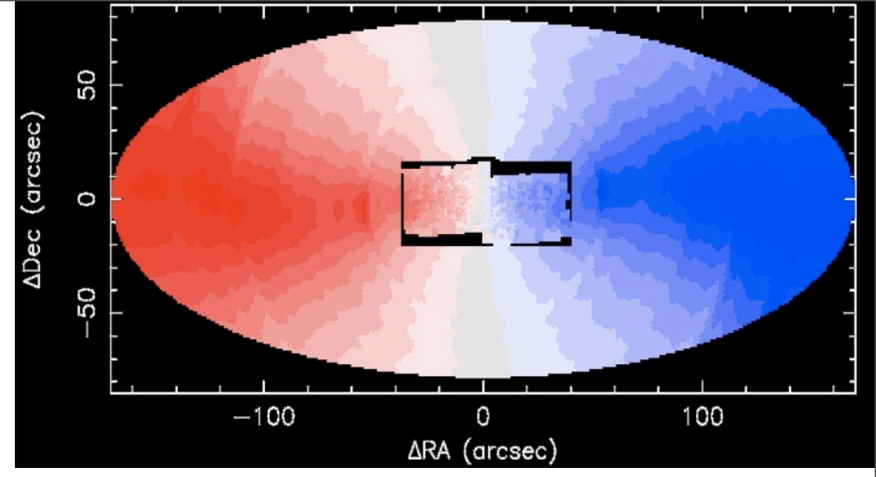
Galaxy Kinematic Profiles



Inner profiles do not predict large radius behavior

Galaxy Kinematic Profiles

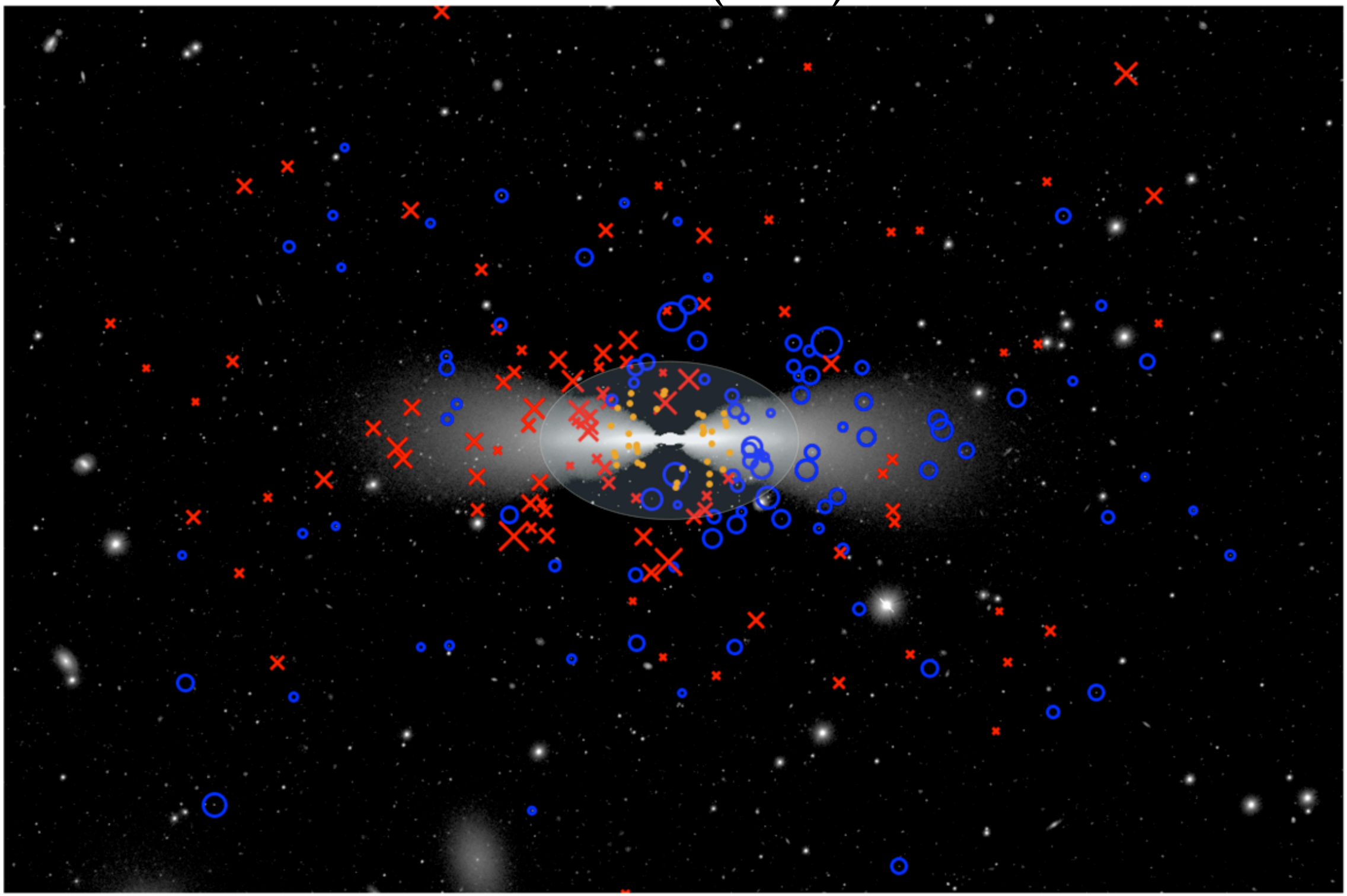




Inner profiles do not predict large radius behavior

NGC 3115

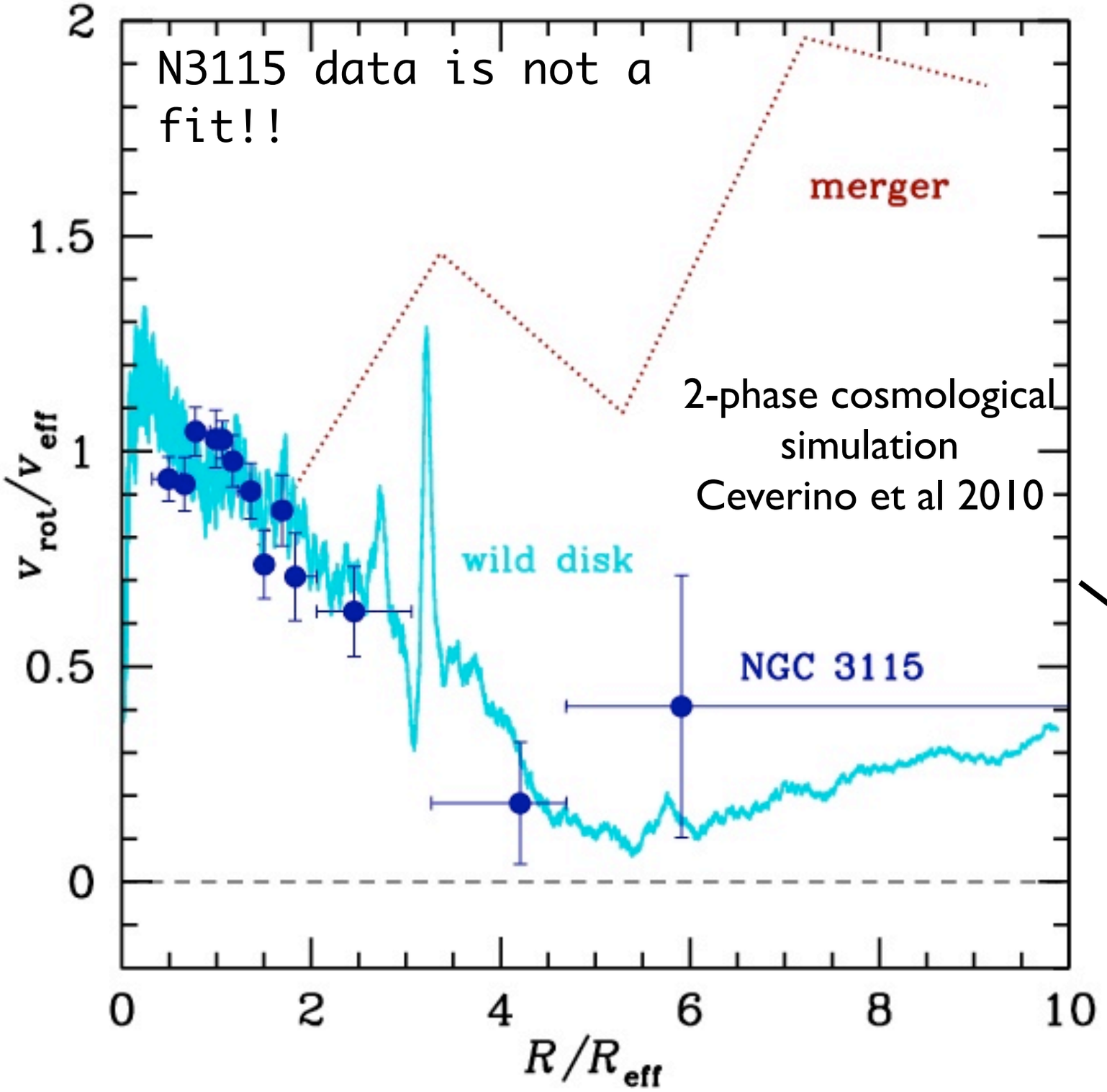
Arnold et al (2011)

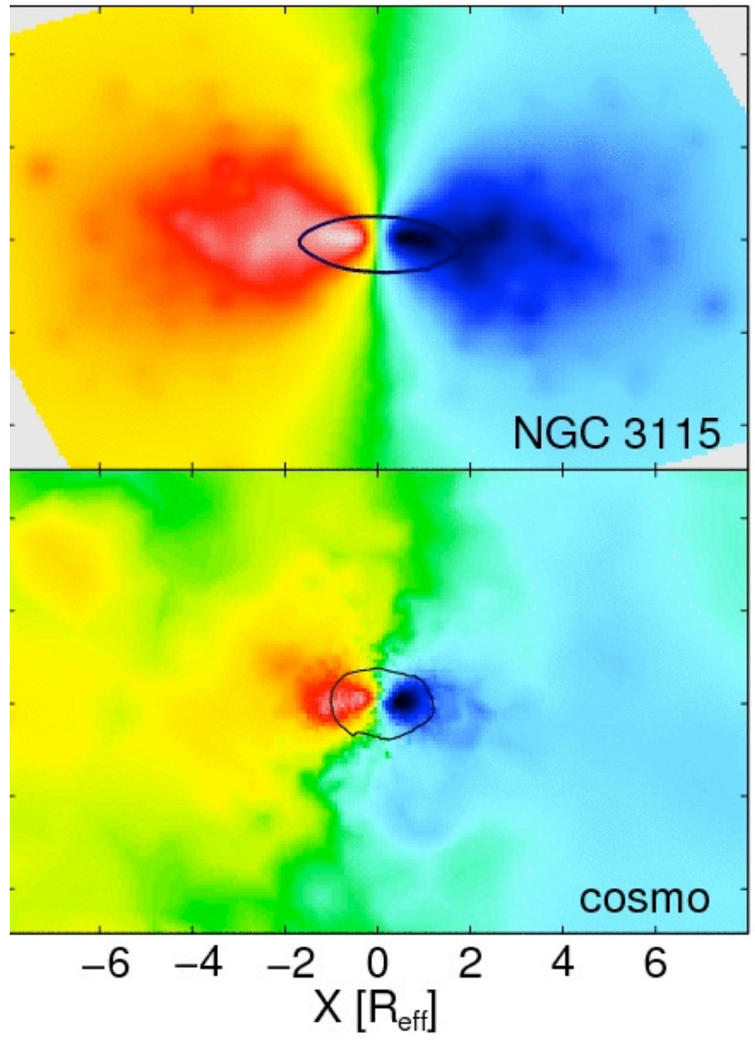


Disky elliptical/S0 at ~10 Mpc

GC velocities from Keck+

Arnold et al 2011





Inner regions heated disk material

Outer regions accreted

Need large radii data to test generic merger predictions

Two-component galaxies can ***in principle***
be produced by major mergers

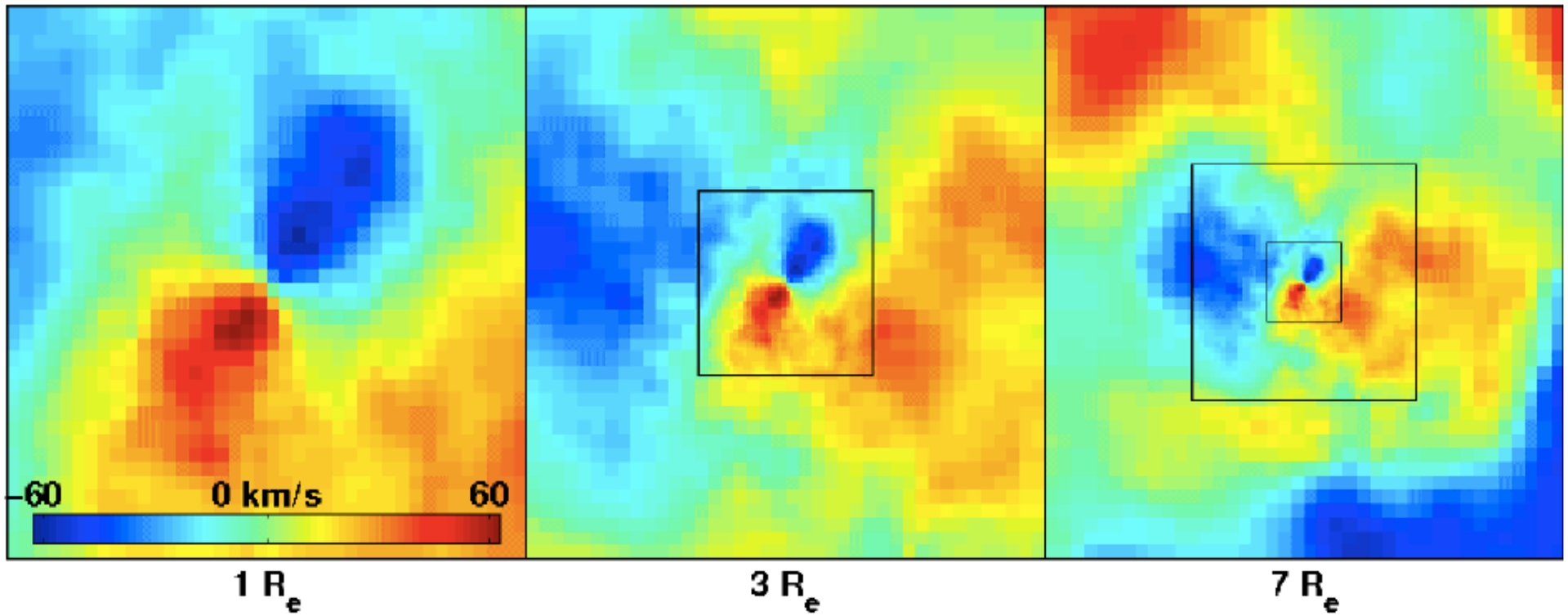
BUT

Low-angular momentum 1:1 merger needed for low halo rotation

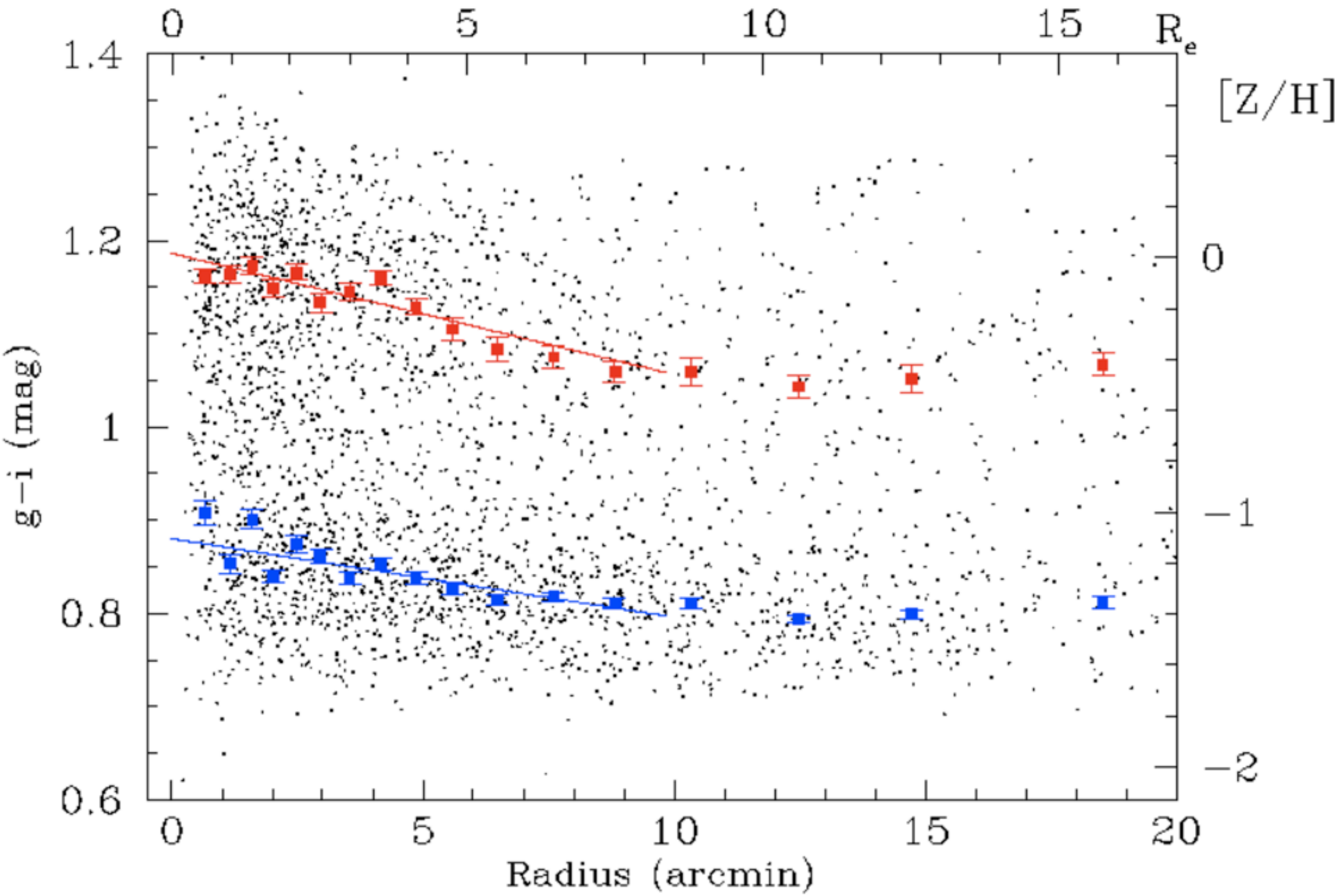
- Rare
- Predicts kinematic twist - not so far seen

1:1 Wet Merger Simulation

Hoffman et al. 2010



NGC 1407 GC metallicity profile

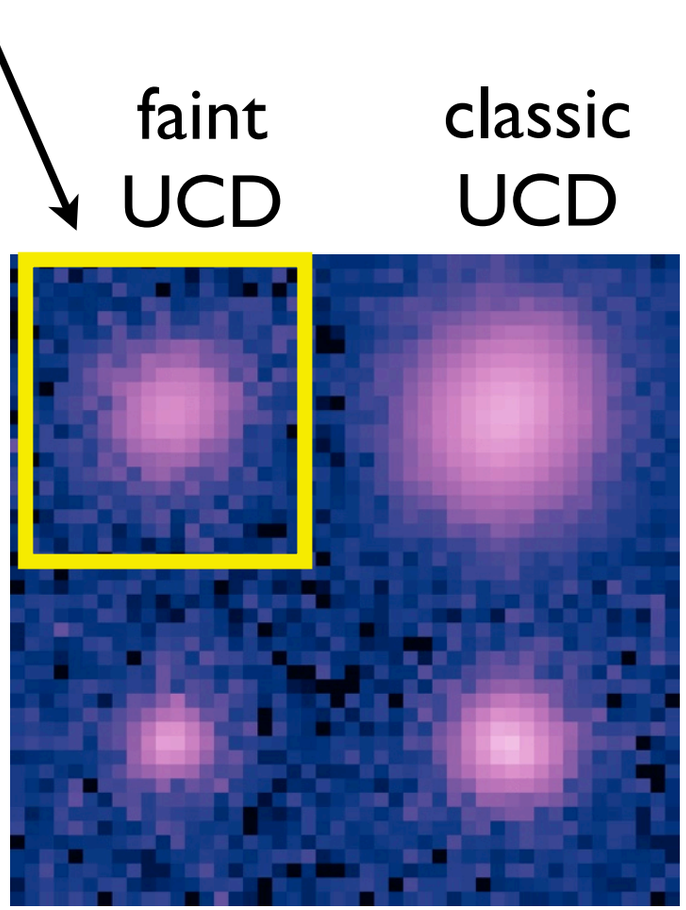


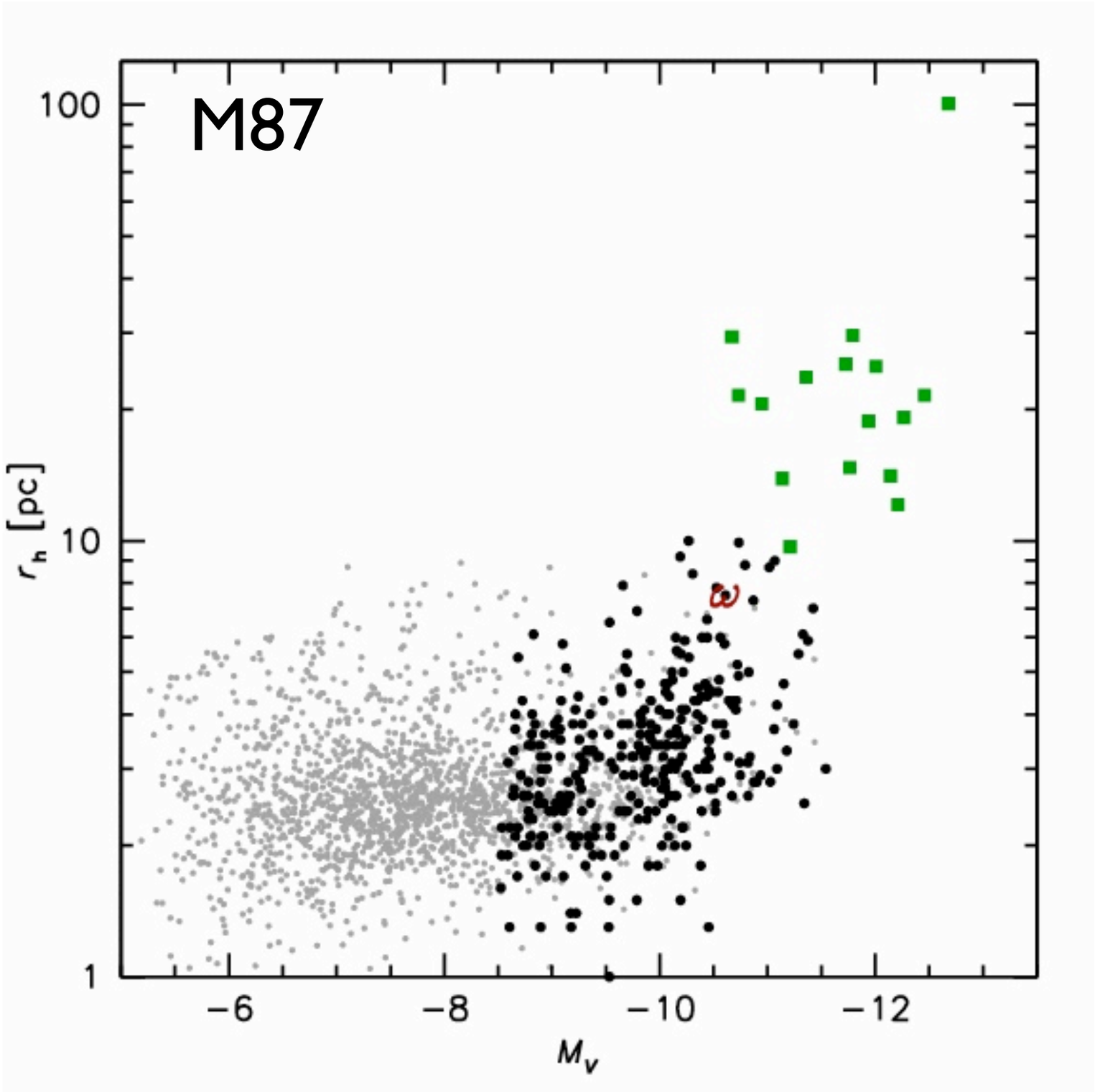
Forbes et al 2011

The Relationships between Compact Stellar Systems: A Fresh View of UCDs in M87

Brodie et al 2011

New area of parameter space





The Relationships between Compact Stellar Systems: A Fresh View of UCDs in M87

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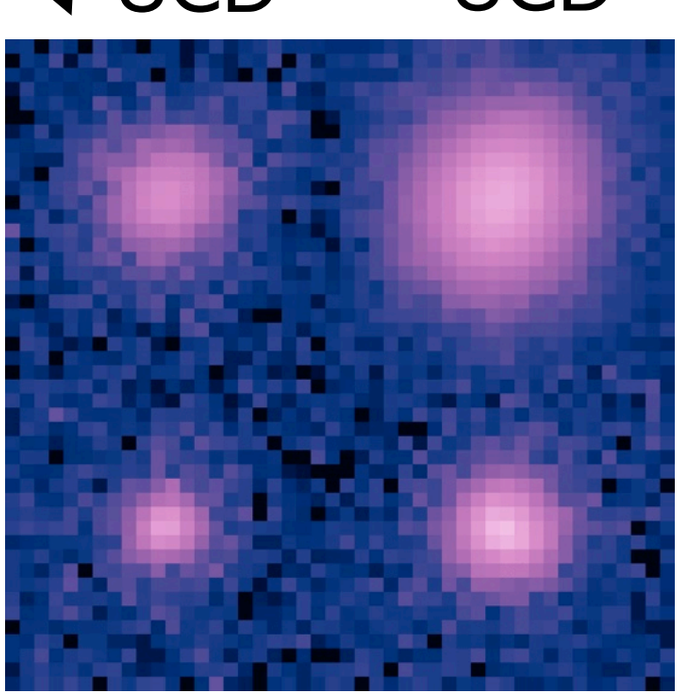
New area of parameter space

faint UCD

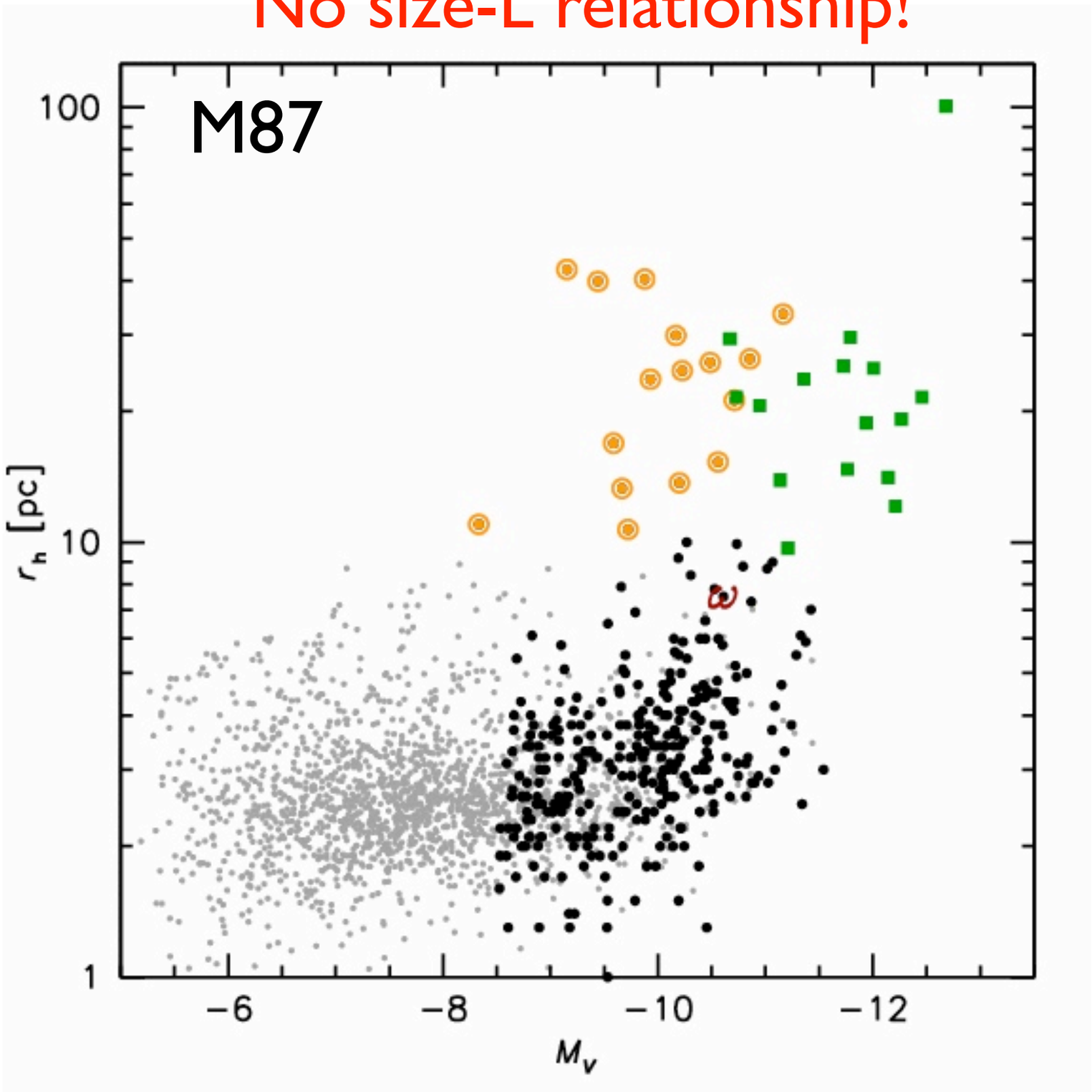
classic UCD



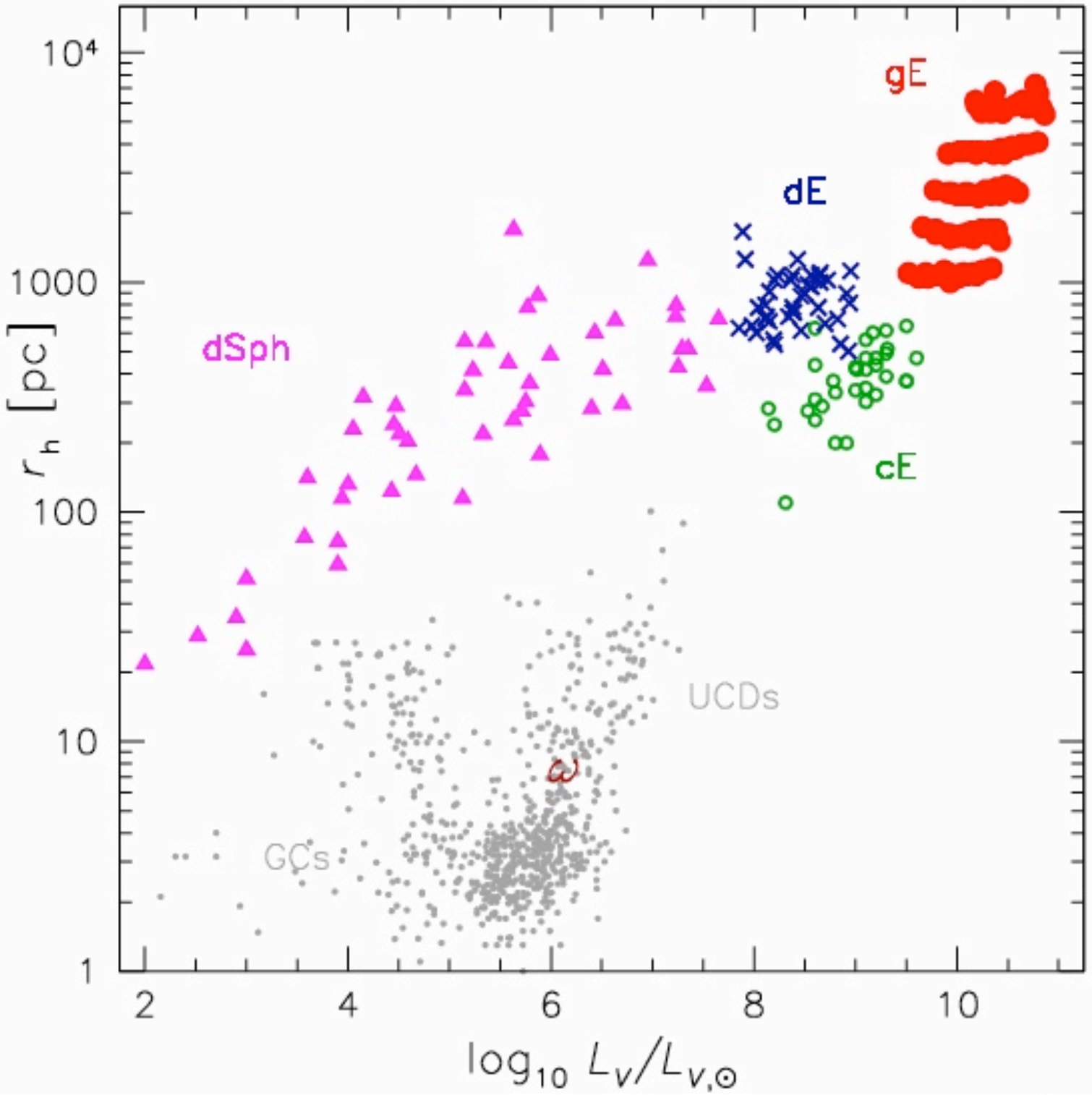
faint compact GC

bright compact "UCD"

No size-L relationship!



The Everything Plot



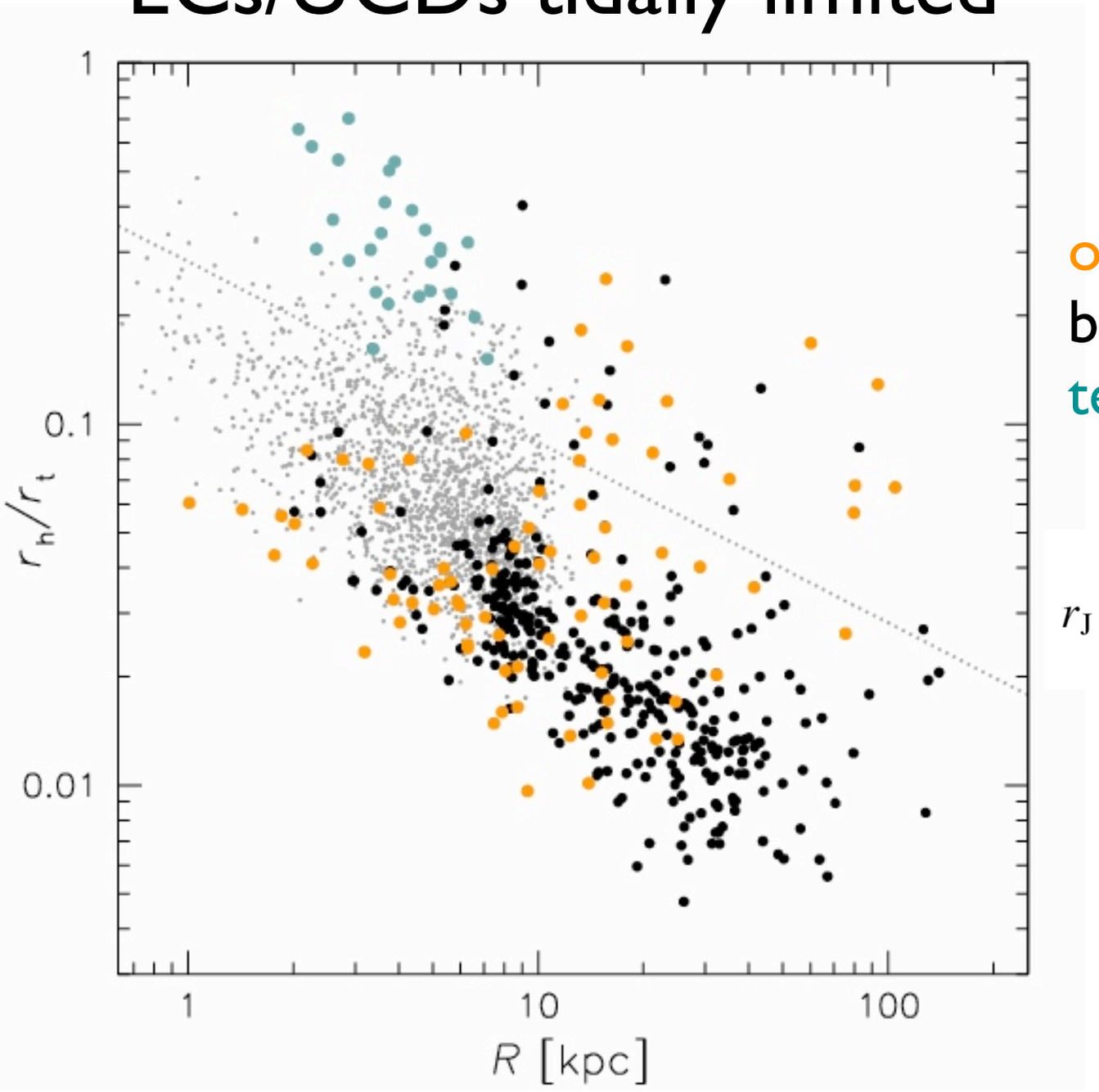
UCDs bright end of a continuous EC sequence
Gap between galaxies and star clusters

2 formation channels for star clusters?

GCs *form* as compact objects
ECs form with a range of radii that are tidally limited (van den Bergh '96; Da Costa et al '09; Baumgardt et al '10)

Only distance-confirmed objects

Two populations of Star Clusters
ECs/UCDs tidally limited



orange=MW
black=M87
teal=Faint Fuzzies

$$r_J = \left(\frac{G\,M_c}{2\,V_G^2}\right)^{1/3} R_{GC}^{2/3}$$

UCDs in M87 have the same size as MW ECs when rescaled by the tidal radius even though they have *very different* mass scales - 3 orders of magnitude!!!

Prediction: ECs should have a strong size-mass relation at a given R

SUMMARY

Tests of 2-phase galaxy assembly

26 nearby early-type galaxies
SLUGGS survey: Globular clusters to ~10 r eff
SMEAGOL survey: Field stars to ~ 3 r eff

Inner profiles =/=> large radius behavior - wide field observations essential
Evidence for 2 components
Examples in: NGC 3115 GC and stellar kinematics
NGC 1407 Metallicity gradients

Difficult to produce rapid inner + low outer rotation with major mergers
Cosmological simulations of "wild disks" + accretion preferred

UCDs in M87

Faint UCDs discovered in M87
Need spectra and accurate sizes to define UCD samples
No size-luminosity relation
UCDs bright end of a continuous EC sequence

2 formation channels for star clusters?
GCs form as compact objects
ECs form with a range of radii that are tidally limited
Prediction: ECs should have a strong size-mass relation at a given R