A Unified Scenario for the Origin of Spiral and Elliptic Galaxy Structural Scaling Laws

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Laboratório Interinstitucional de e-Astronomia

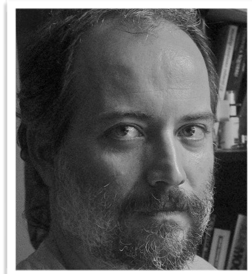
LIneA Webinar - Nov 19, 2020

Collaborators

Julio Navarro

Mario Abadi

José Benavides



Damián Mast

Victoria, Canada

Córdoba, Argentina

Hubble Morphological Classification

Hubble 1926, 1936

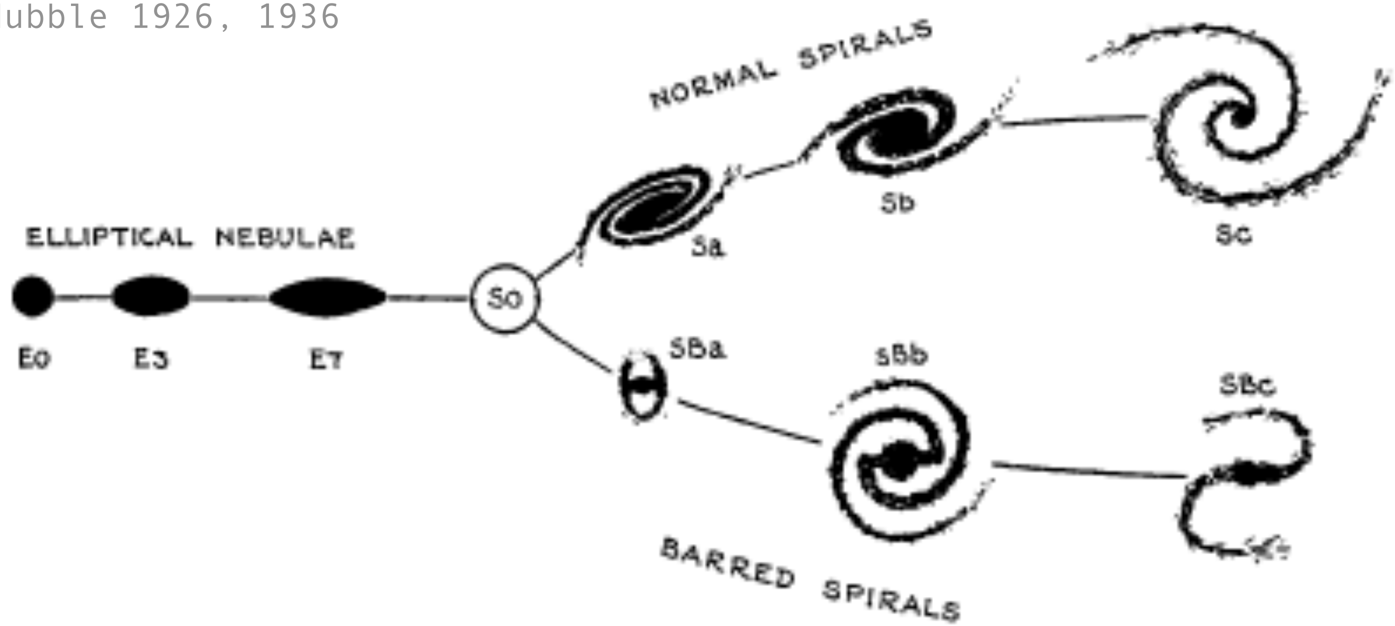
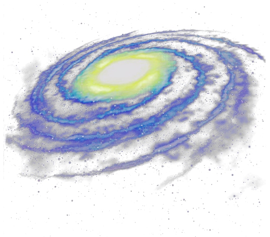
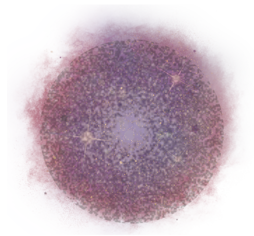
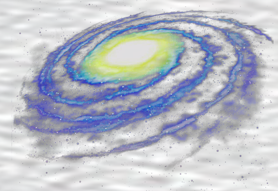


FIG. 1. *The Sequence of Nebular Types.*



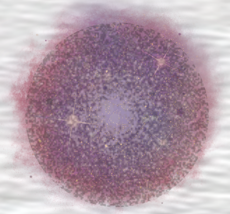
Spirals vs Ellipticals



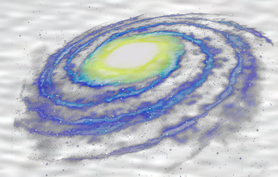


Discoidal

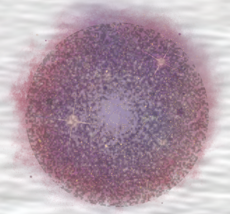
Spirals vs Ellipticals



Spheroidal

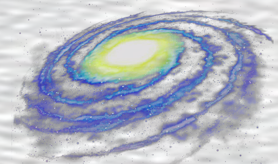


Spirals vs Ellipticals

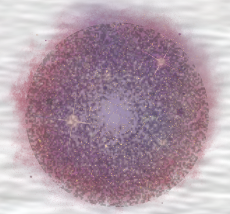


Discoidal
Blue

Spheroidal
Red



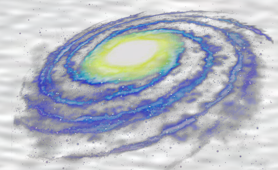
Spirals vs Ellipticals

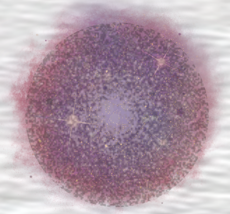


Discoidal
Blue
Structured

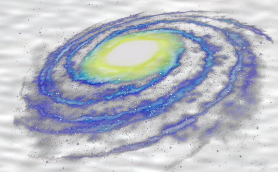
Spheroidal
Red
Smooth

Spirals vs Ellipticals

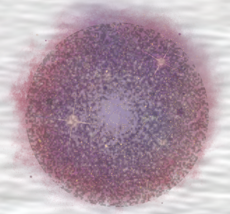




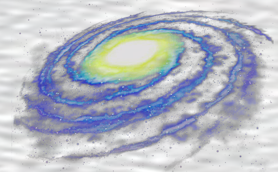
Spirals	Ellipticals
Discoidal	Spheroidal
Blue	Red
Structured	Smooth
Star Forming	Quenched



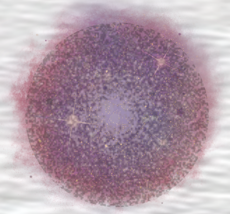
Spirals vs Ellipticals



Discoidal	Spheroidal
Blue	Red
Structured	Smooth
Star Forming	Quenched
Field	Cluster

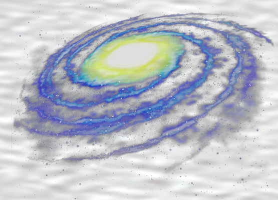


Spirals vs Ellipticals

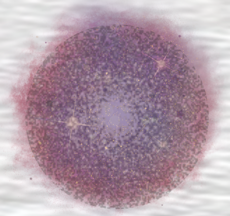


Discoidal
Blue
Structured
Star Forming
Field
Gas Rich

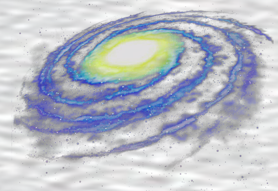
Spheroidal
Red
Smooth
Quenched
Cluster
Gas Poor



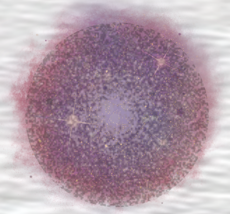
Spirals vs Ellipticals



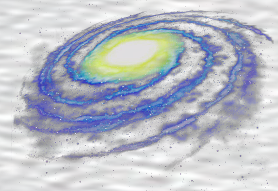
Discoidal	Spheroidal
Blue	Red
Structured	Smooth
Star Forming	Quenched
Field	Cluster
Gas Rich	Gas Poor
Metal Poor	Metal Rich



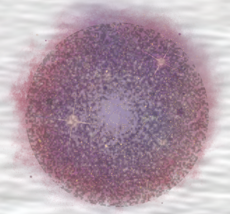
Spirals vs Ellipticals



Discoidal	Spheroidal
Blue	Red
Structured	Smooth
Star Forming	Quenched
Field	Cluster
Gas Rich	Gas Poor
Metal Poor	Metal Rich
Young	Old

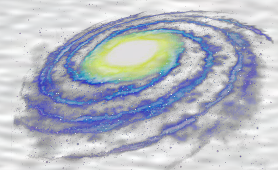


Spirals vs Ellipticals

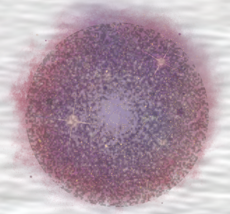


Discoidal
Blue
Structured
Star Forming
Field
Gas Rich
Metal Poor
Young
Collapse

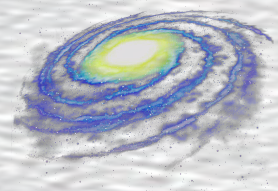
Spheroidal
Red
Smooth
Quenched
Cluster
Gas Poor
Metal Rich
Old
Merge



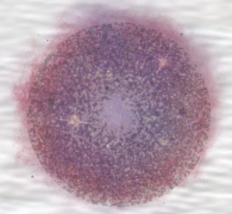
Spirals vs Ellipticals



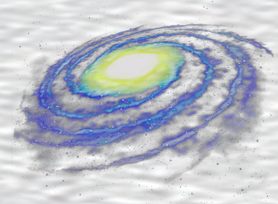
Discoidal	Spheroidal
Blue	Red
Structured	Smooth
Star Forming	Quenched
Field	Cluster
Gas Rich	Gas Poor
Metal Poor	Metal Rich
Young	Old
Collapse	Merge
Exponential	Power law



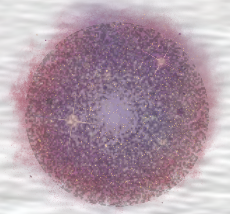
Spirals vs Ellipticals



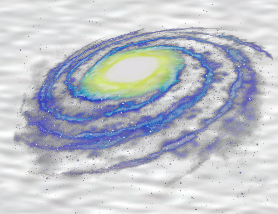
Discoidal	Spheroidal
Blue	Red
Structured	Smooth
Star Forming	Quenched
Field	Cluster
Gas Rich	Gas Poor
Metal Poor	Metal Rich
Young	Old
Collapse	Merge
Exponential	Power law
Rotational	Dispersion



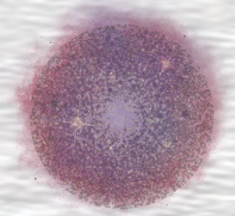
Spirals vs Ellipticals



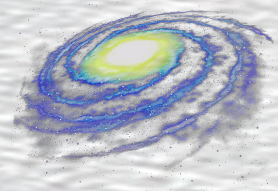
Discoidal	Spheroidal
Blue	Red
Structured	Smooth
Star Forming	Quenched
Field	Cluster
Gas Rich	Gas Poor
Metal Poor	Metal Rich
Young	Old
Collapse	Merge
Exponential	Power law
Rotational	Dispersion
Low mass end	High mass end



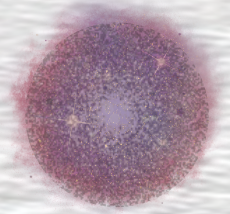
Spirals vs Ellipticals



Discoidal	Spheroidal
Blue	Red
Structured	Smooth
Star Forming	Quenched
Field	Cluster
Gas Rich	Gas Poor
Metal Poor	Metal Rich
Young	Old
Collapse	Merge
Exponential	Power law
Rotational	Dispersion
Low mass end	High mass end
Extended	Compact



Spirals vs Ellipticals



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Blue	Red
Structured	Smooth
Star Forming	Quenched
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Gas Rich	Gas Poor
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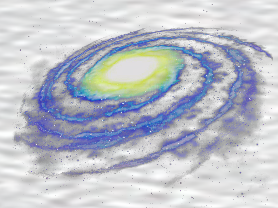
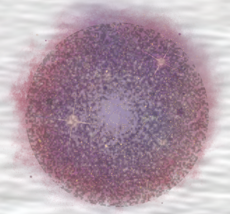
Young	Old
Collapse	Merge
Exponential	Power law
Rotational	Dispersion
Low mass end	High mass end
Extended	Compact
Tully-Fisher	Faber-Jackson



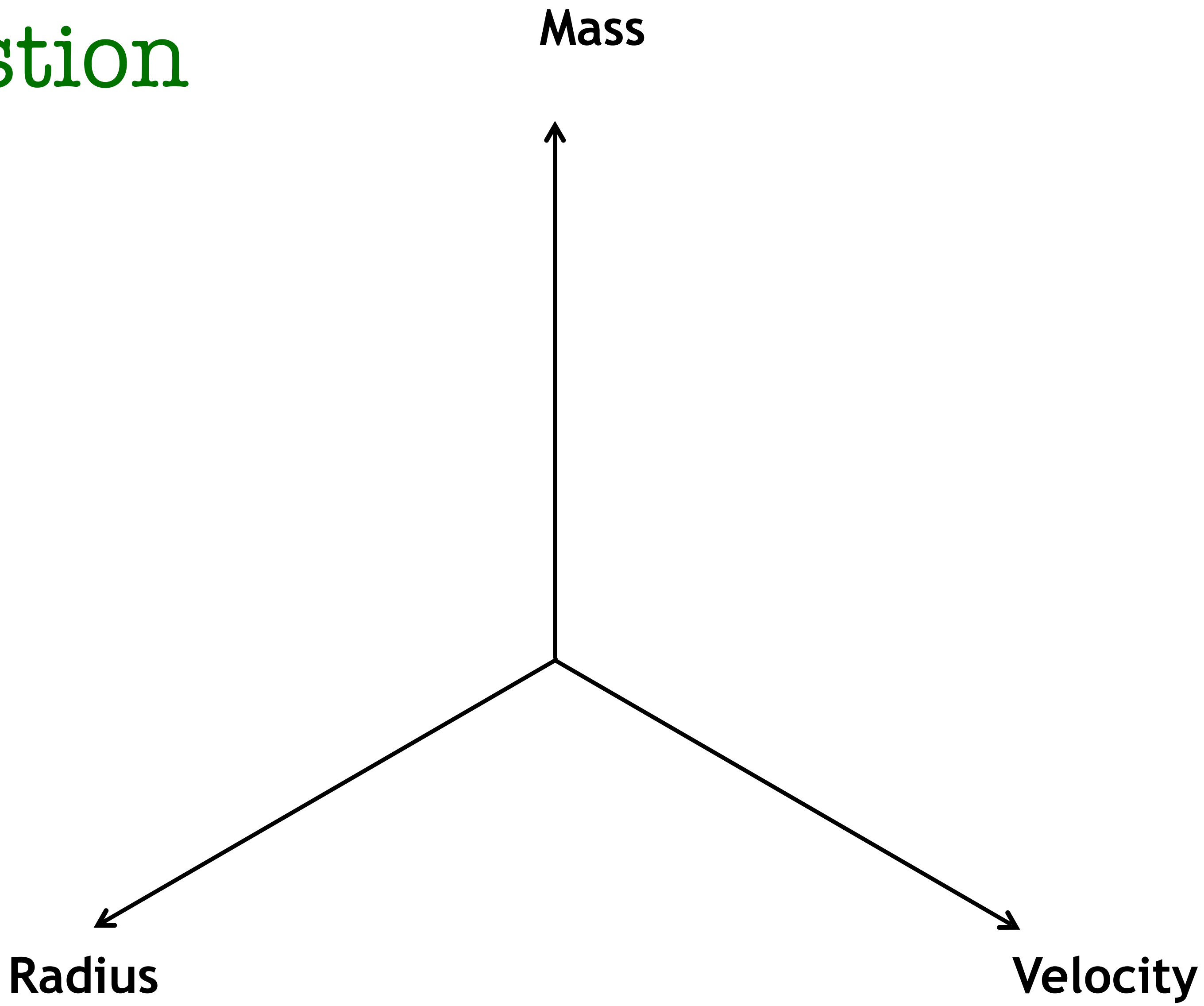
Spirals vs Ellipticals



Discoidal	Spheroidal
Blue	Red
Structured	Smooth
Star Forming	Quenched
Field	Cluster
Gas Rich	Gas Poor
Metal Poor	Metal Rich
Young	Old
Collapse	Merge
Exponential	Power law
Rotational	Dispersion
Low mass end	High mass end
Extended	Compact
Tully-Fisher	Faber-Jackson

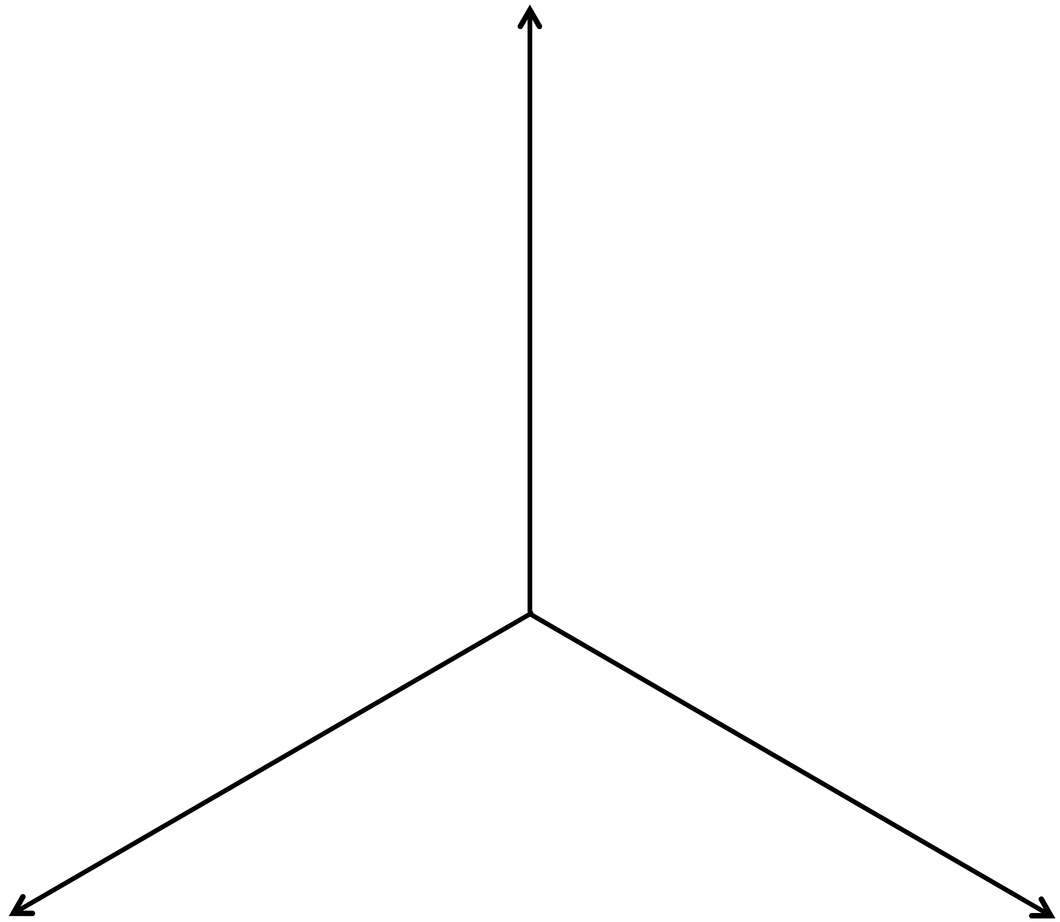
Key Question

Why spiral and ellipticals obey **different** scaling laws?



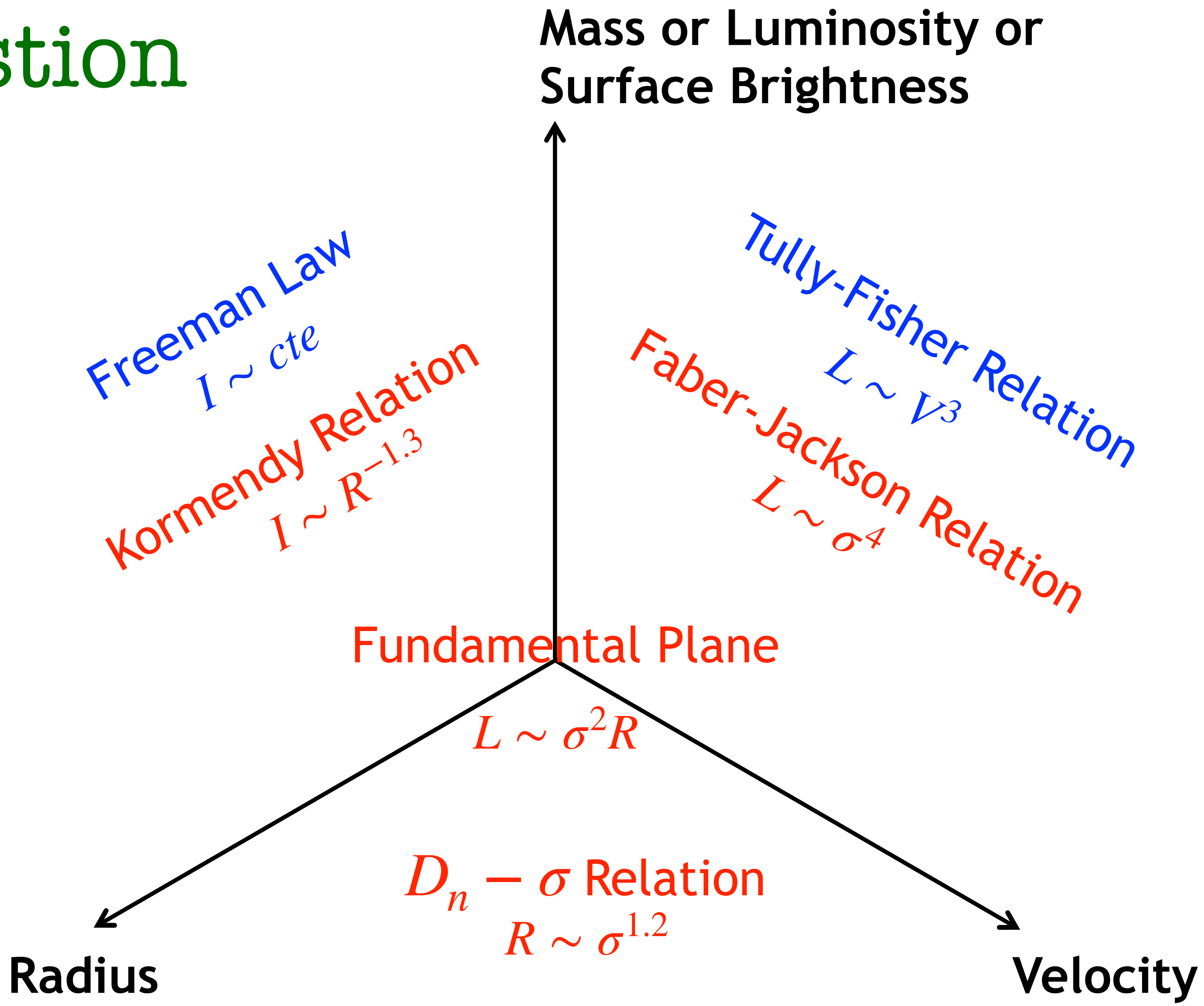
Key Question

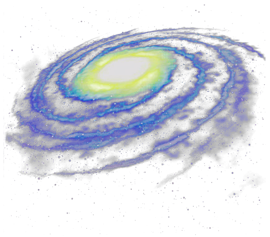
Why spiral and ellipticals obey **different** scaling laws?



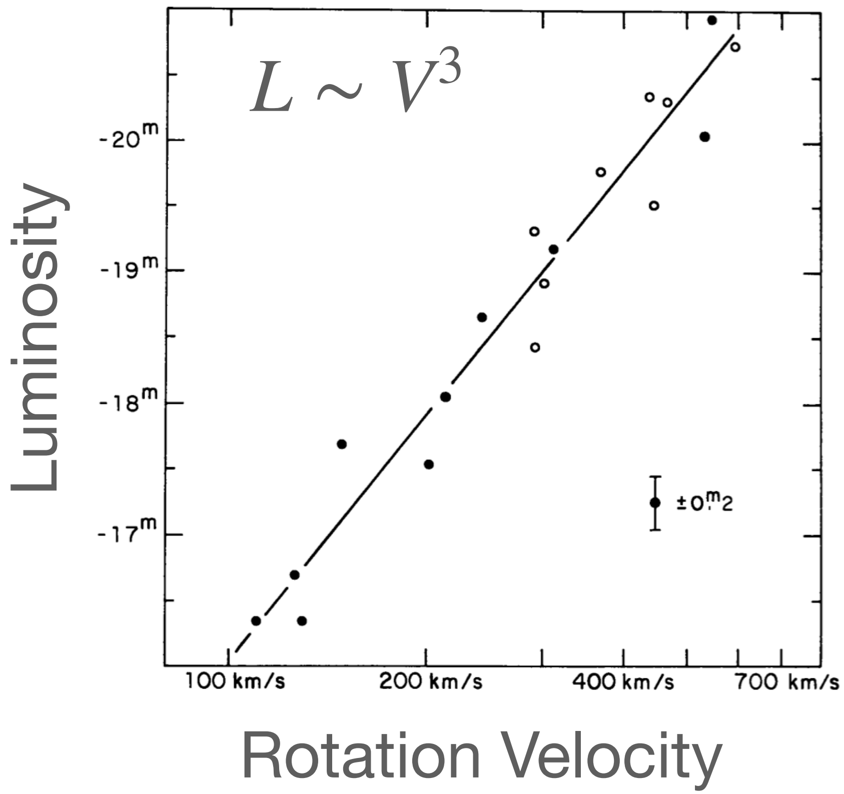
Key Question

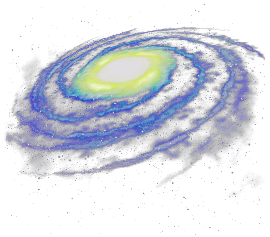
Why spiral and ellipticals obey **different** scaling laws?



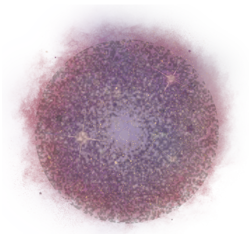


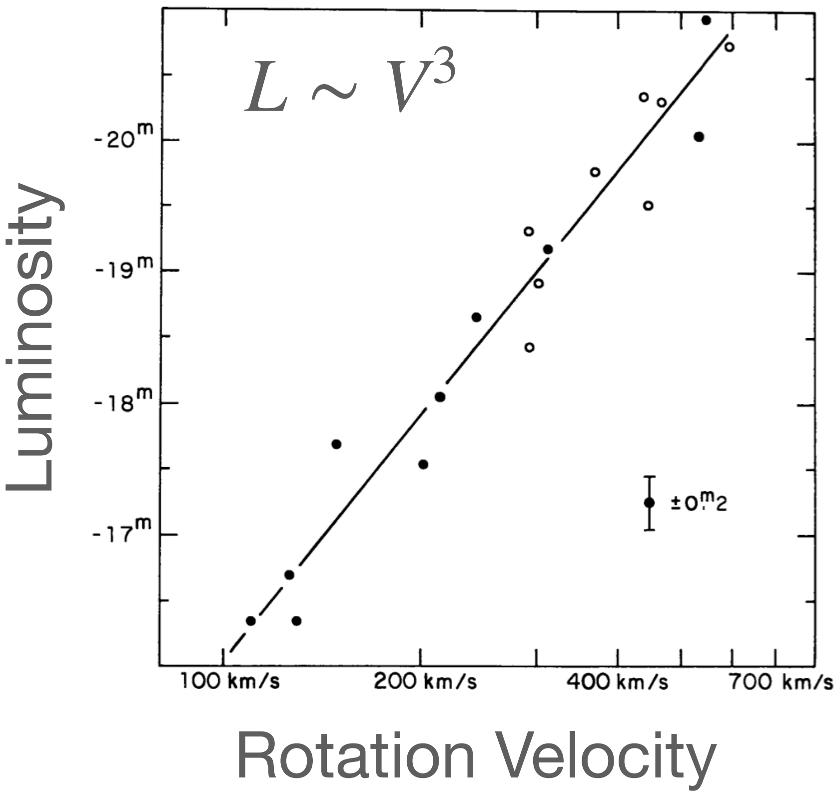
Tully-Fisher 1977

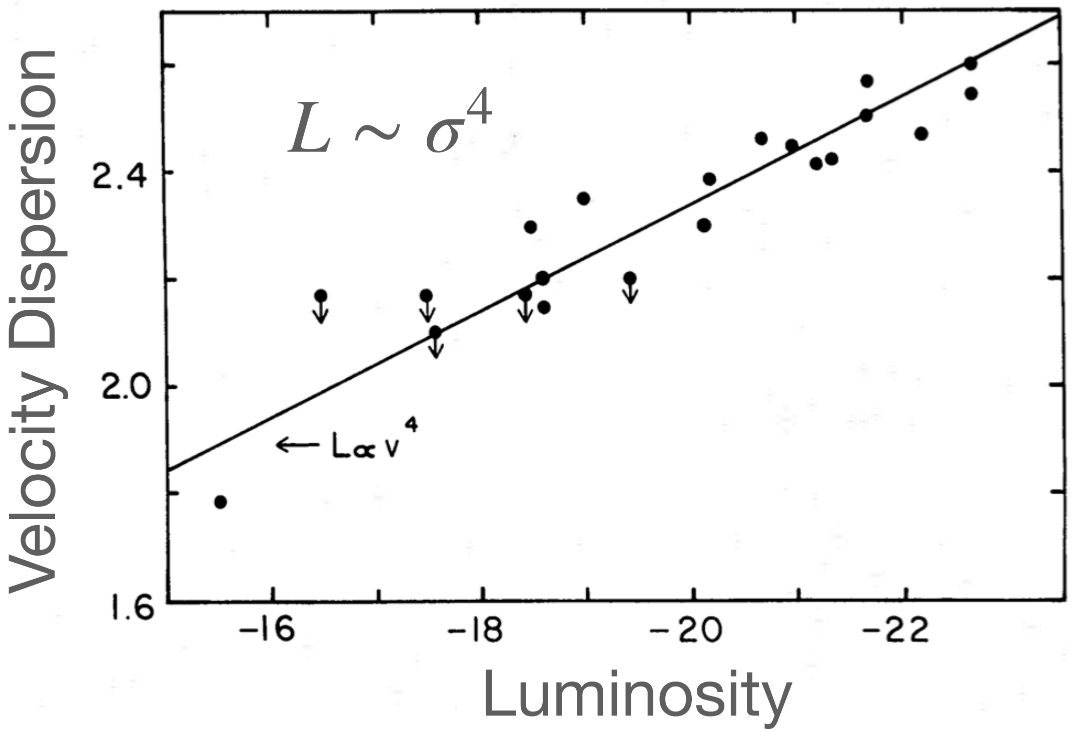




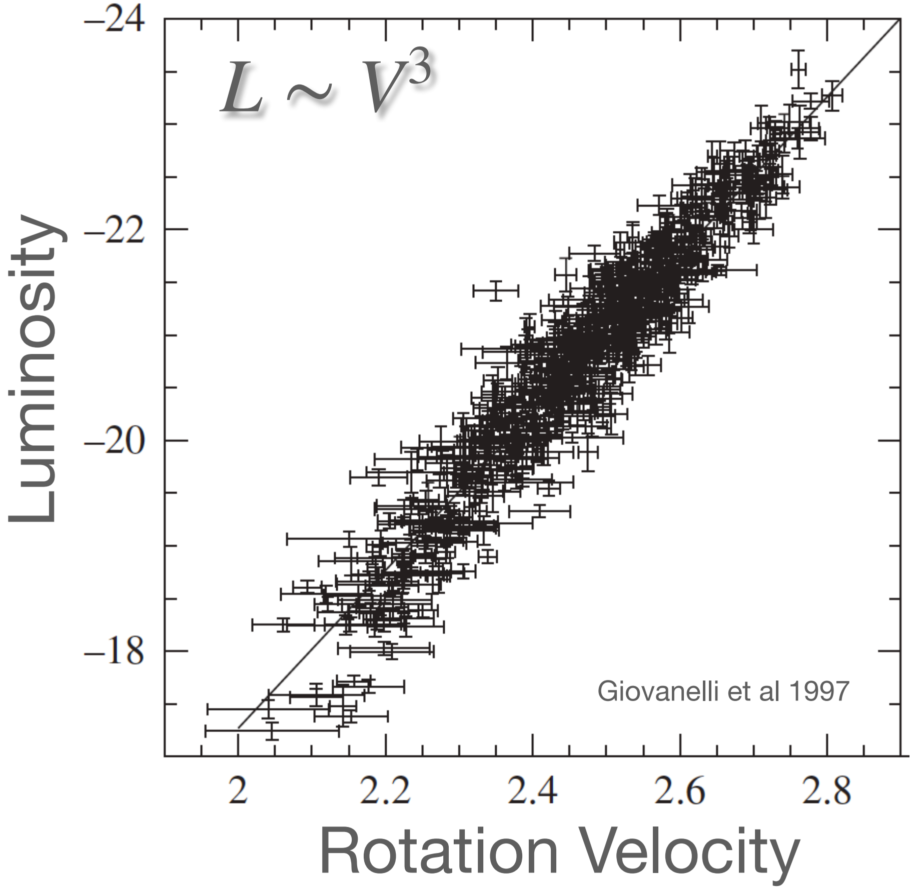
Tully-Fisher 1977 and Faber-Jackson 1976



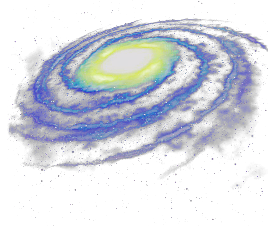


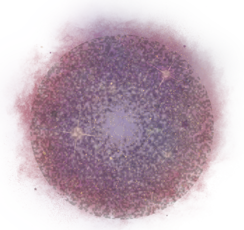


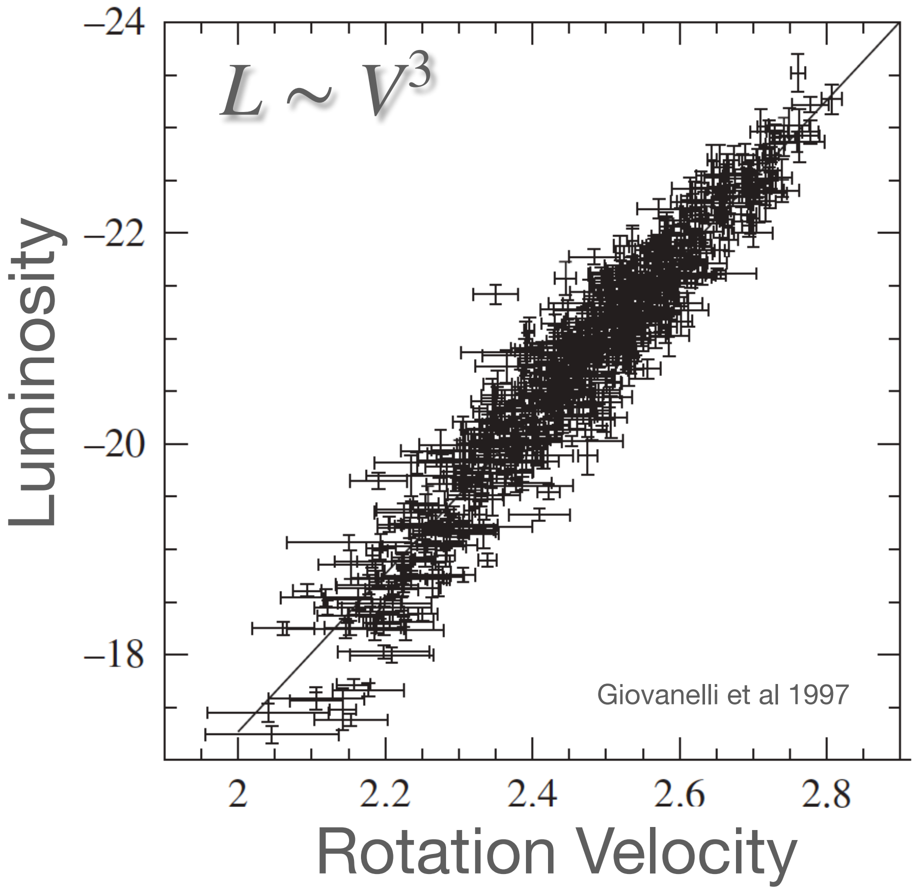
Spiral & Elliptical Scaling Relations

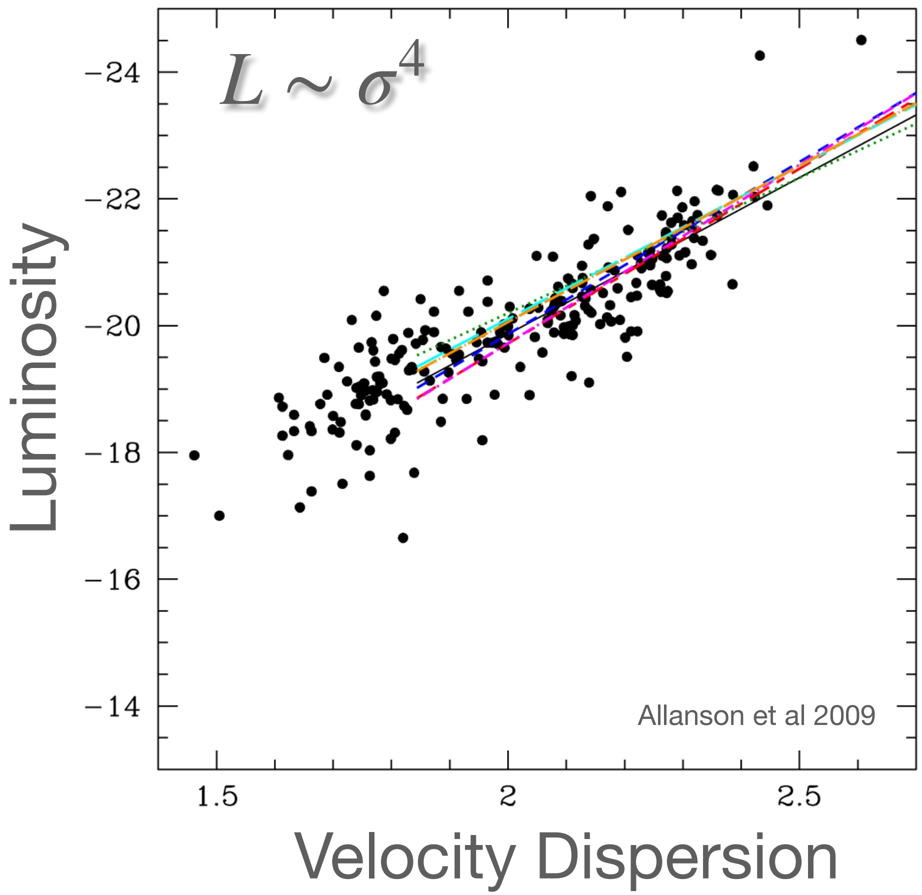


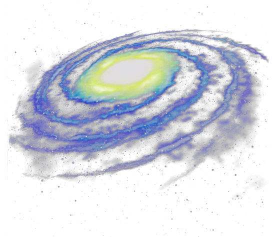
Spiral & Elliptical Scaling Relations



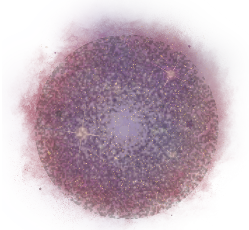


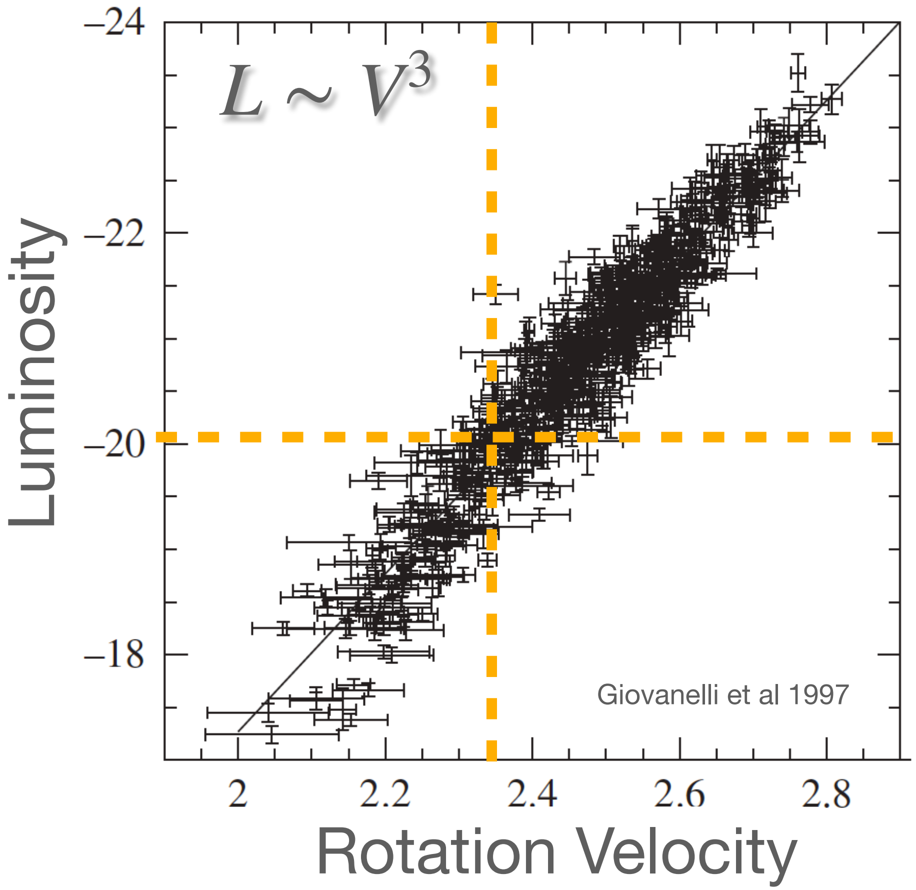


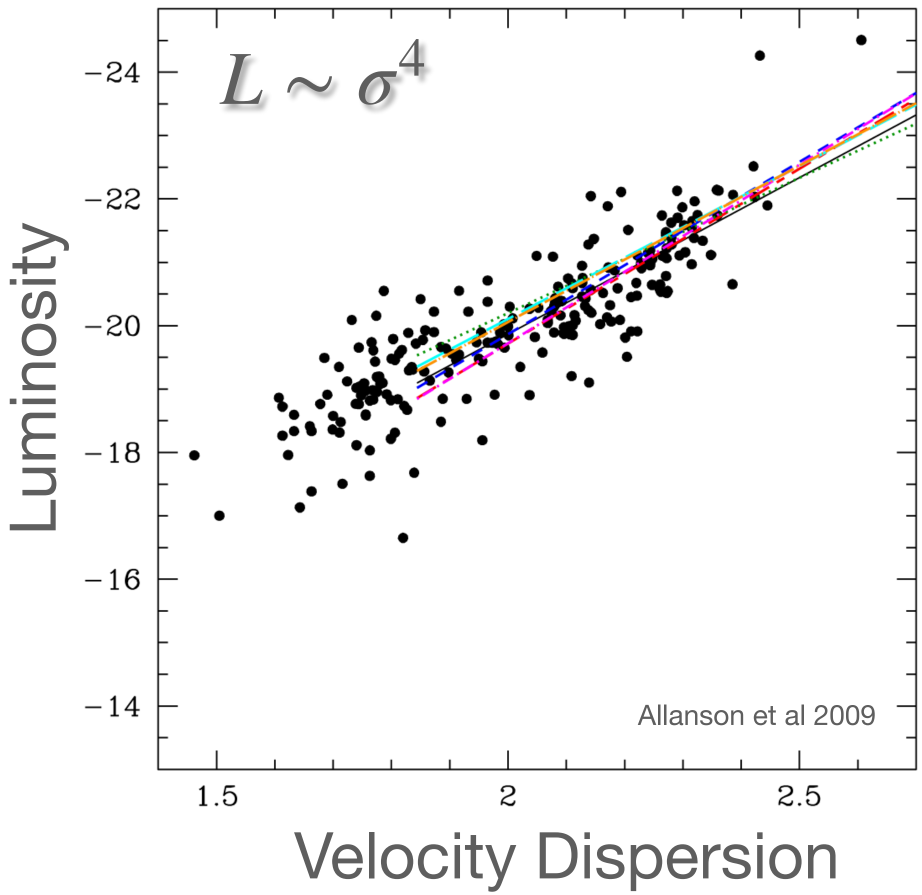


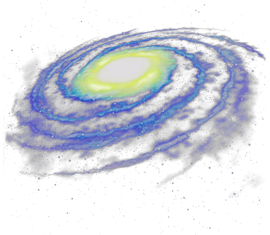


Spiral & Elliptical Scaling Relations

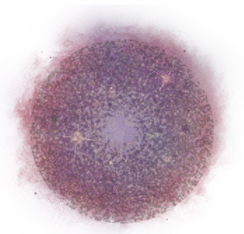


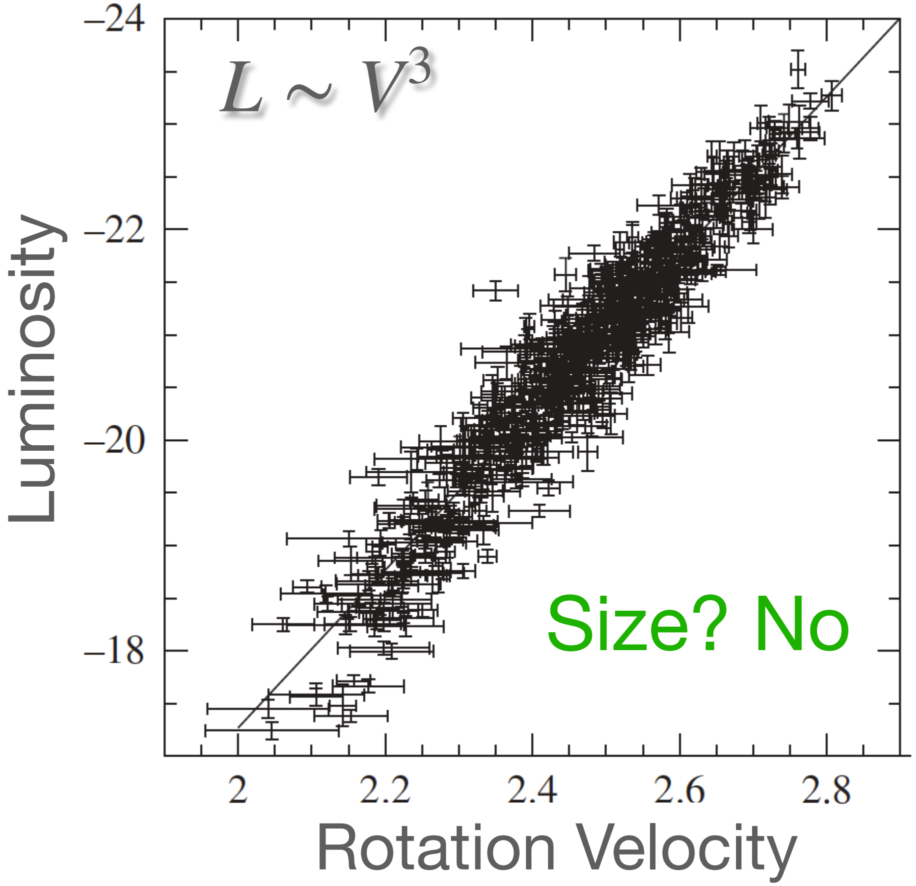


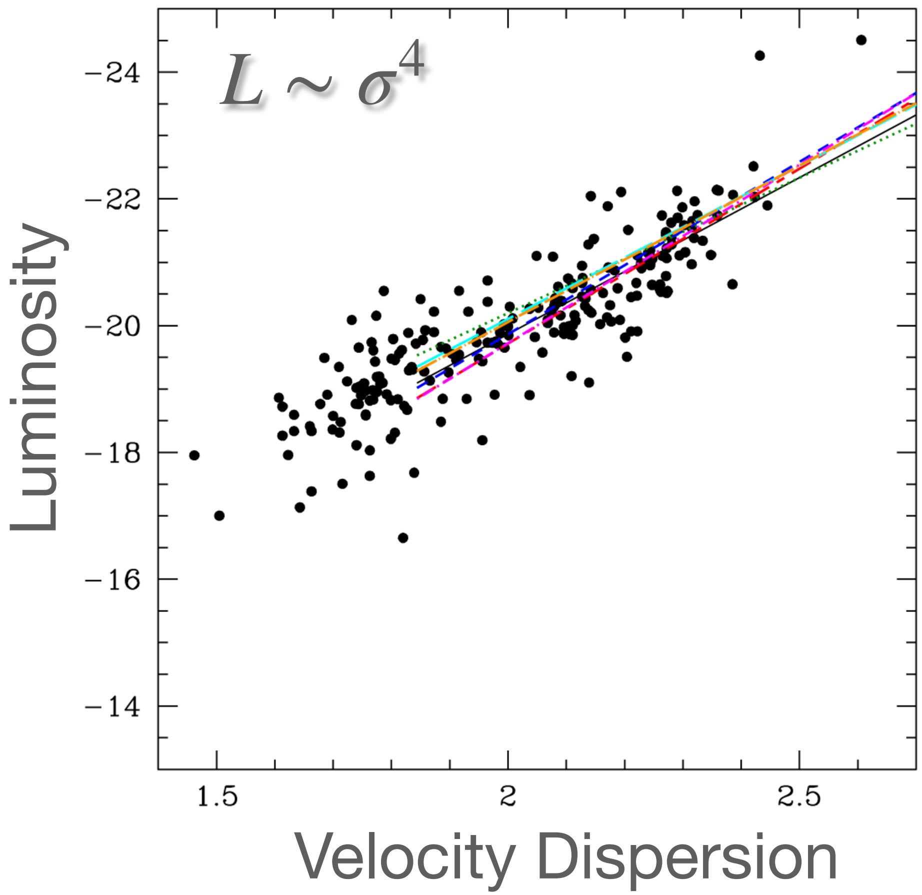




Spiral & Elliptical Scaling Relations







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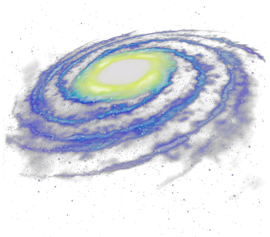

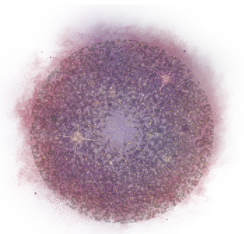

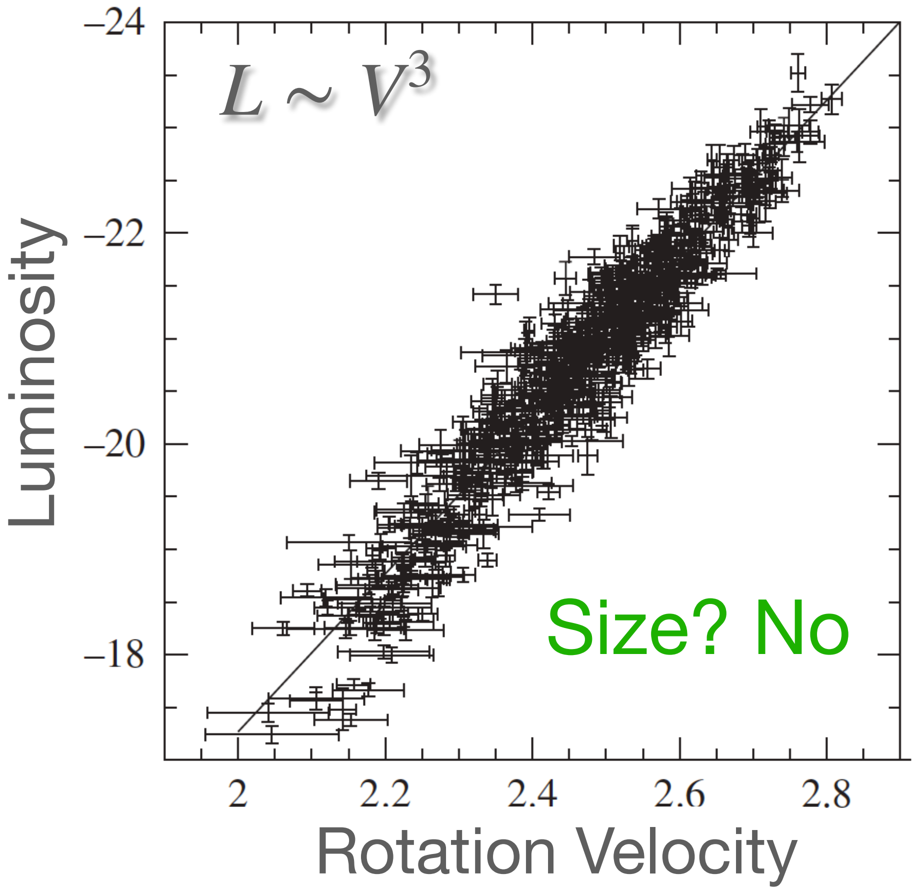

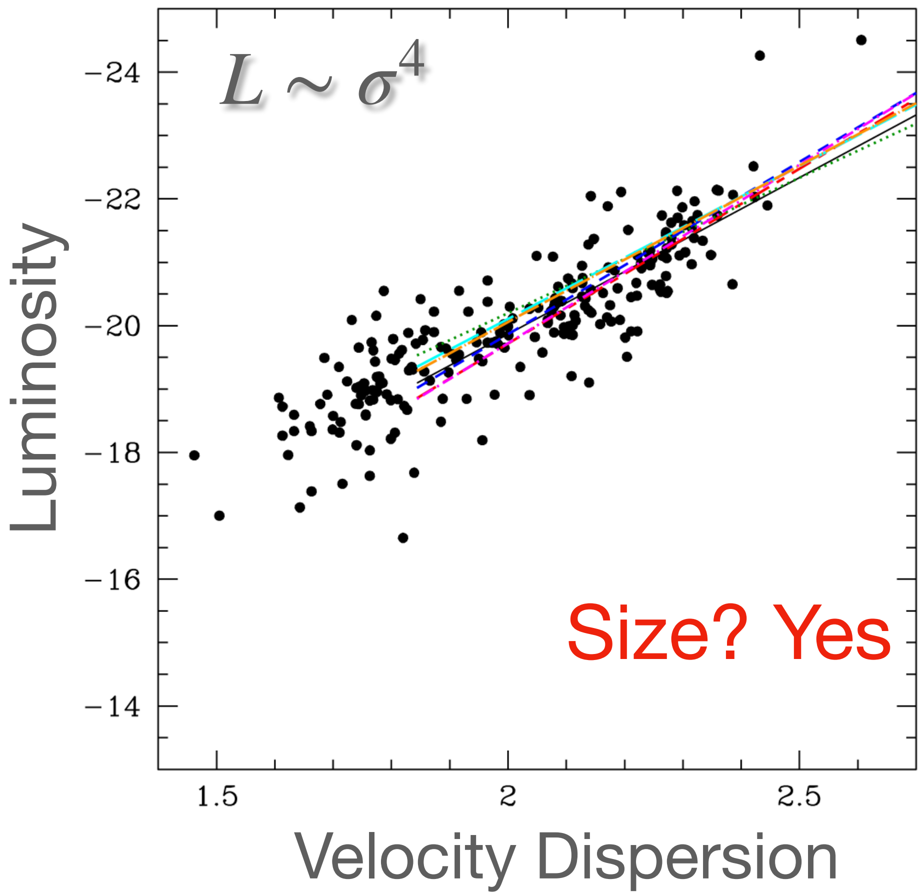

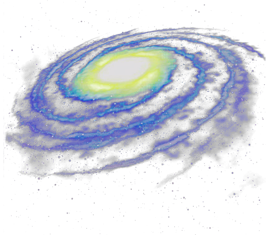

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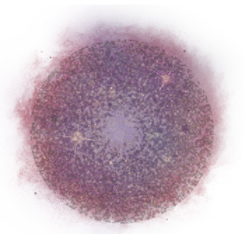
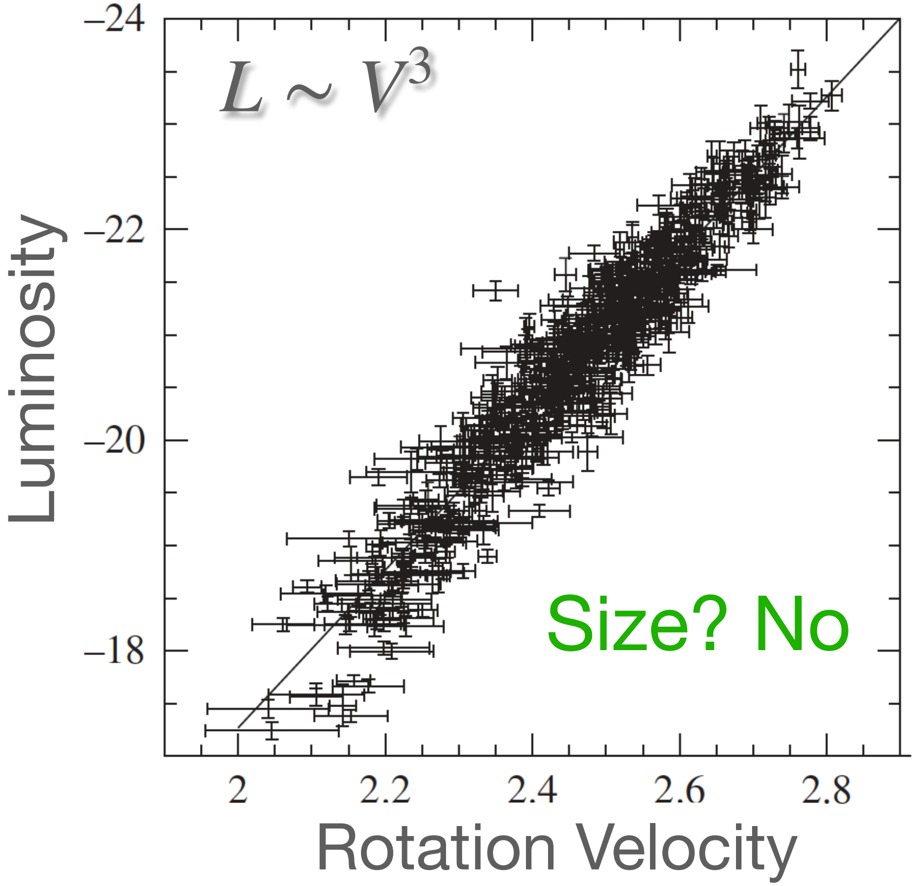
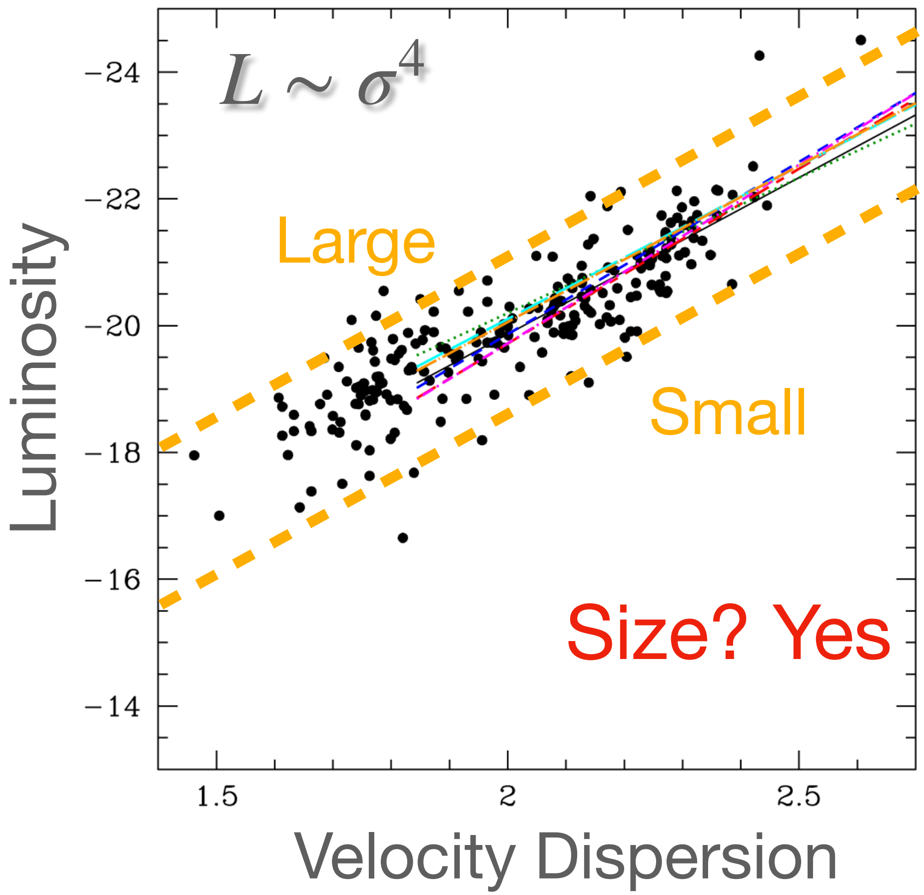
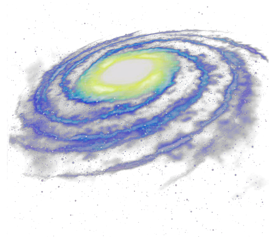
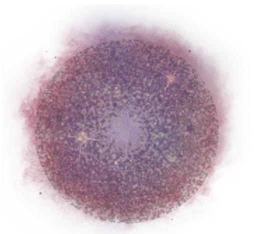


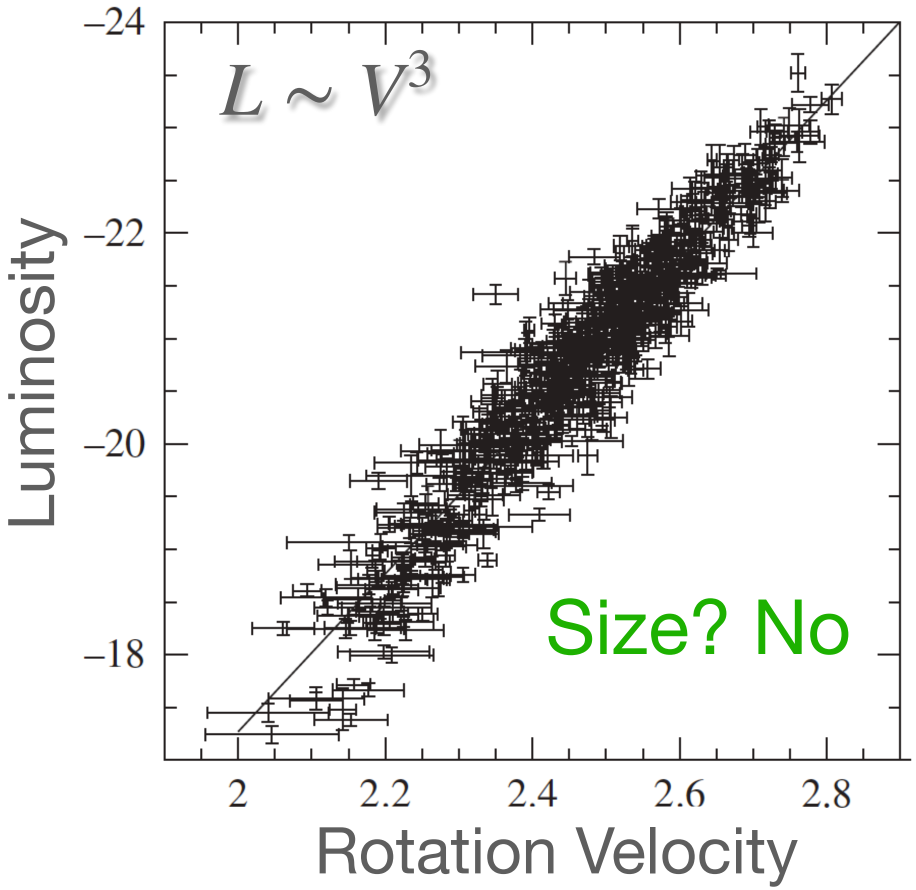


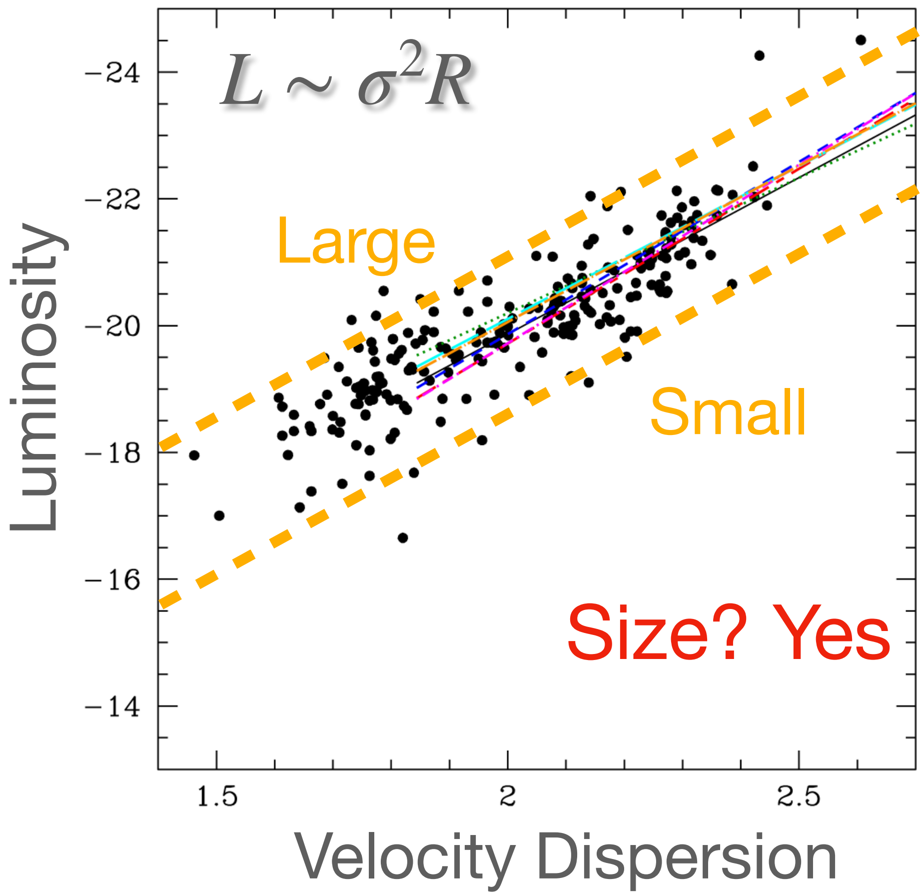


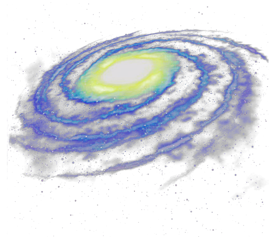


Spiral & Elliptical Scaling Relations

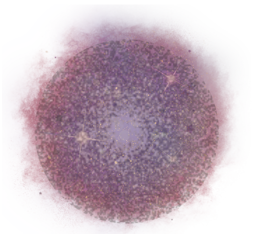


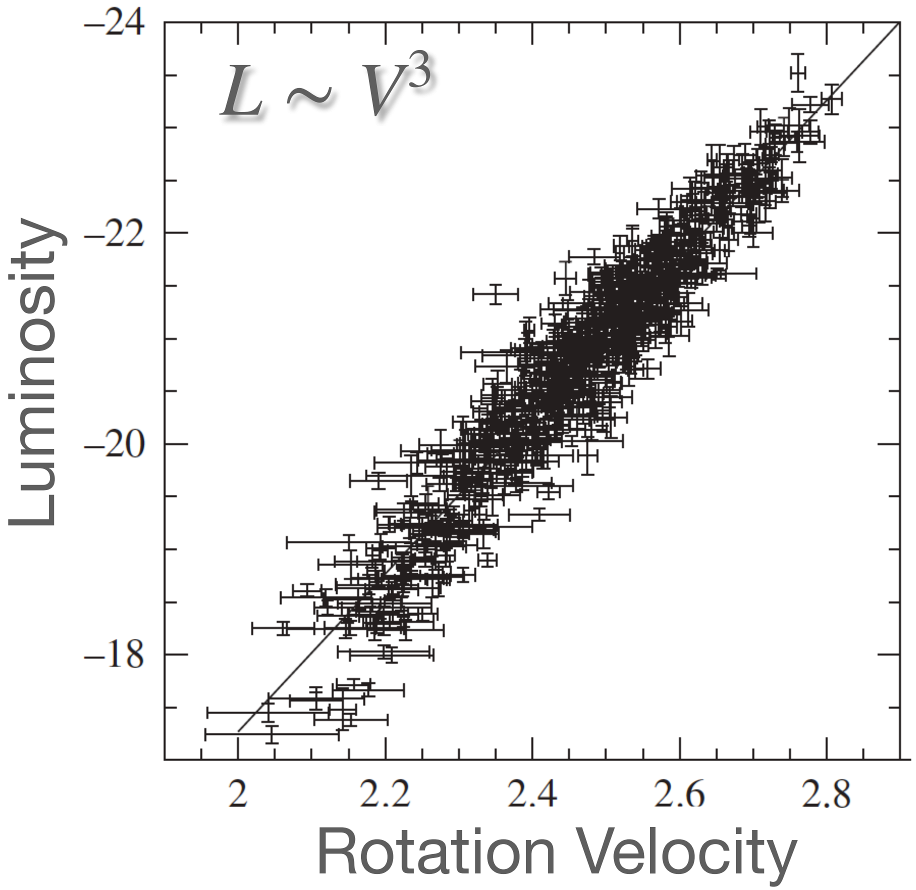


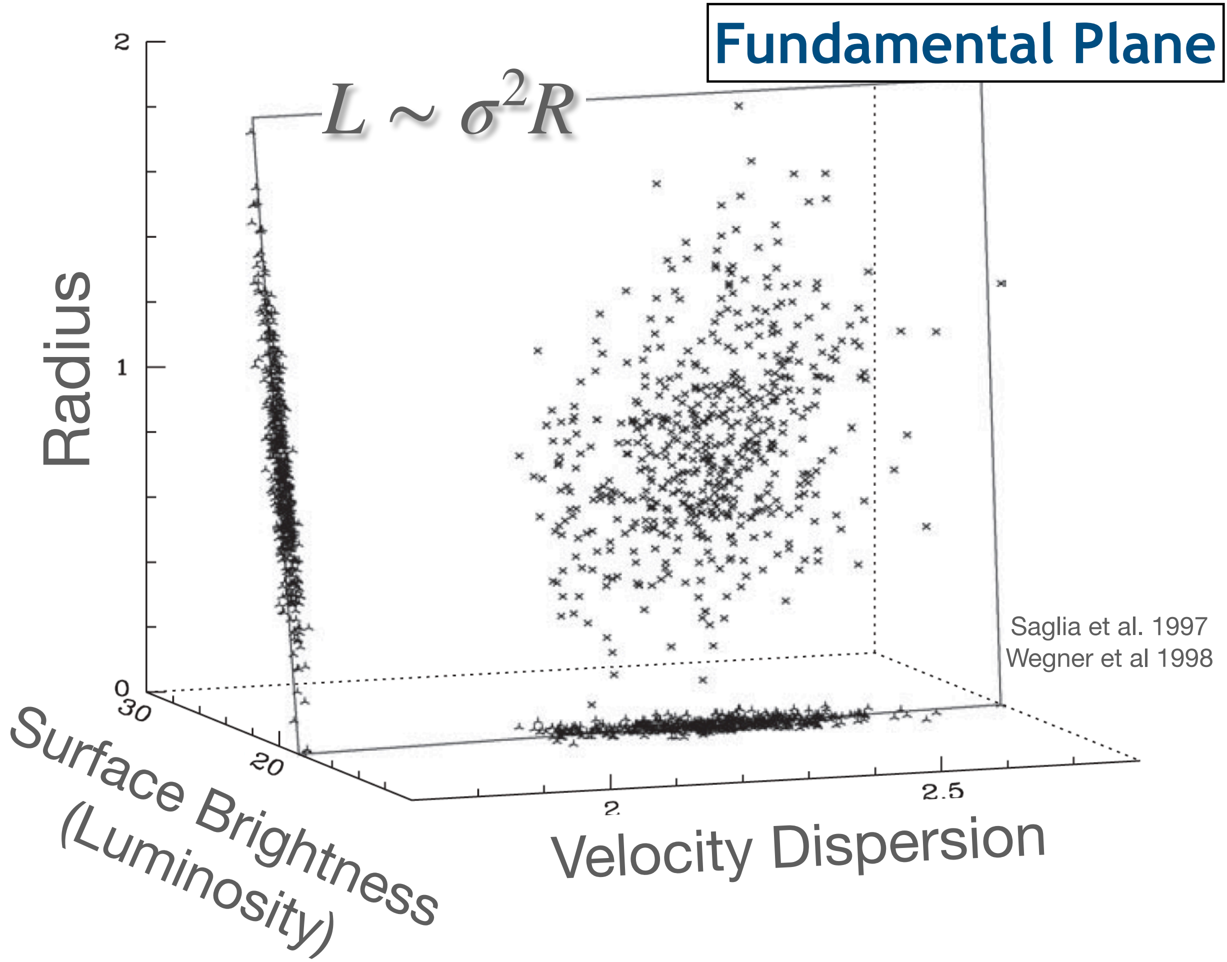


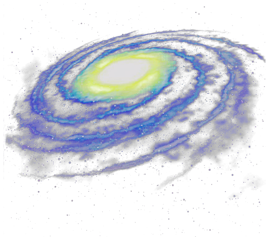


Spiral & Elliptical Scaling Relations

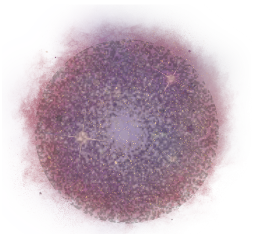


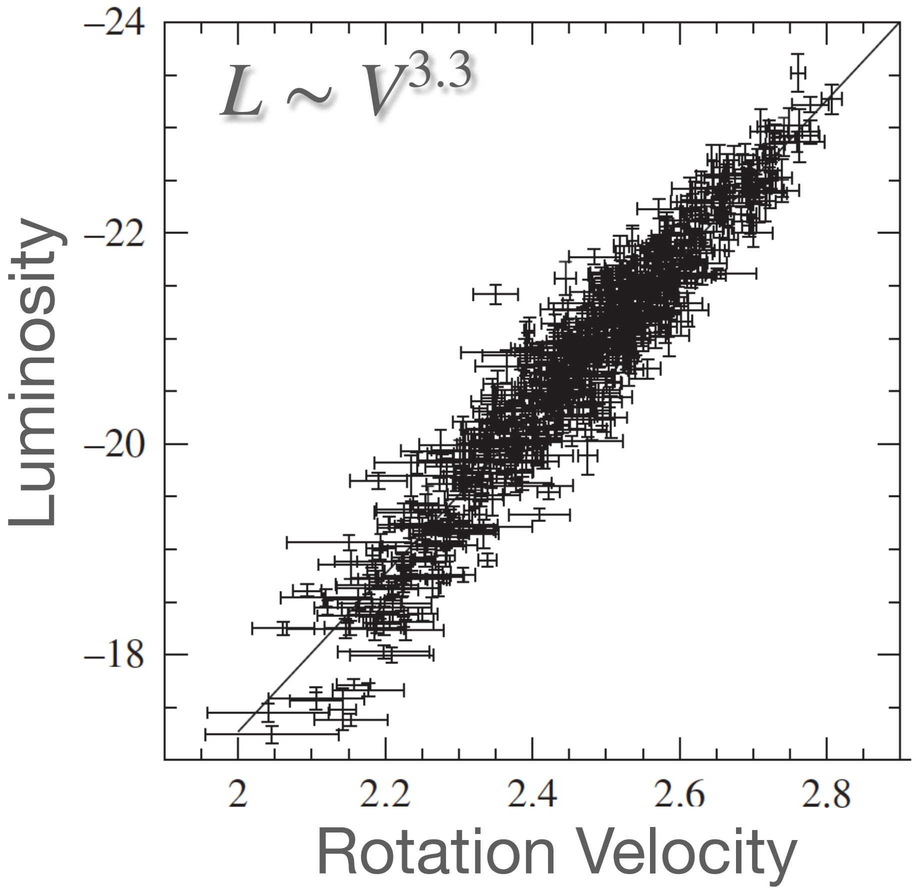


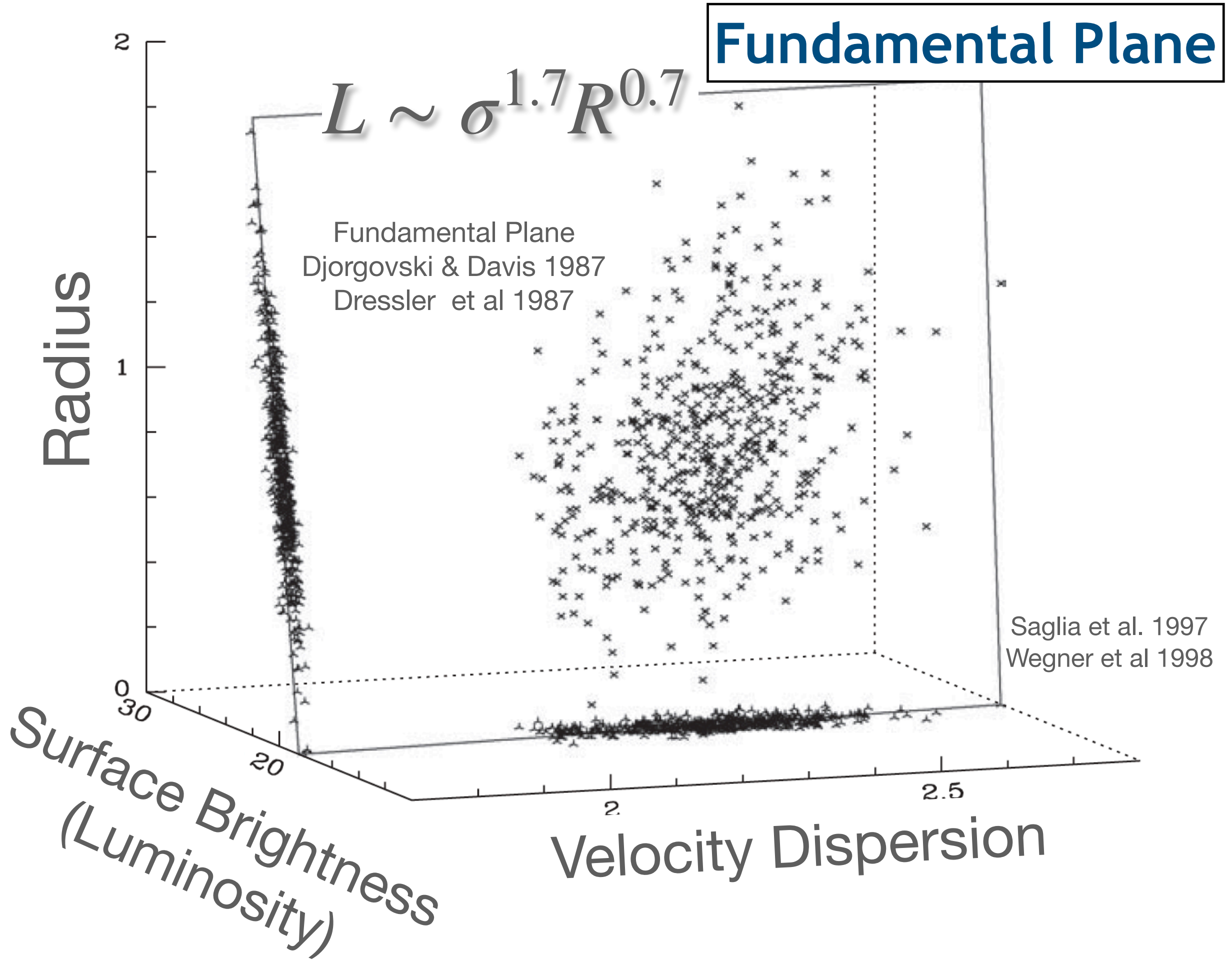




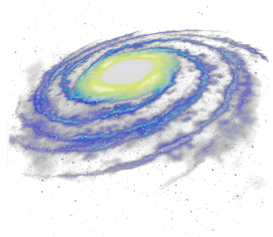
Spiral & Elliptical Scaling Relations

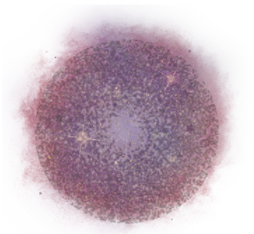


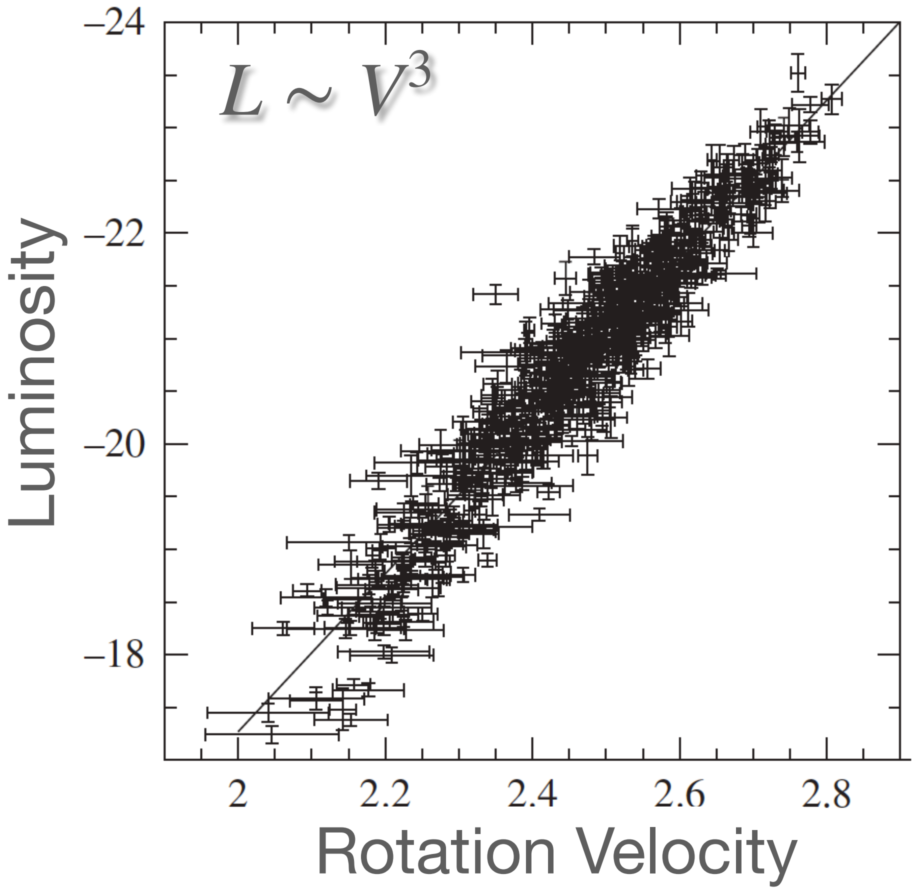


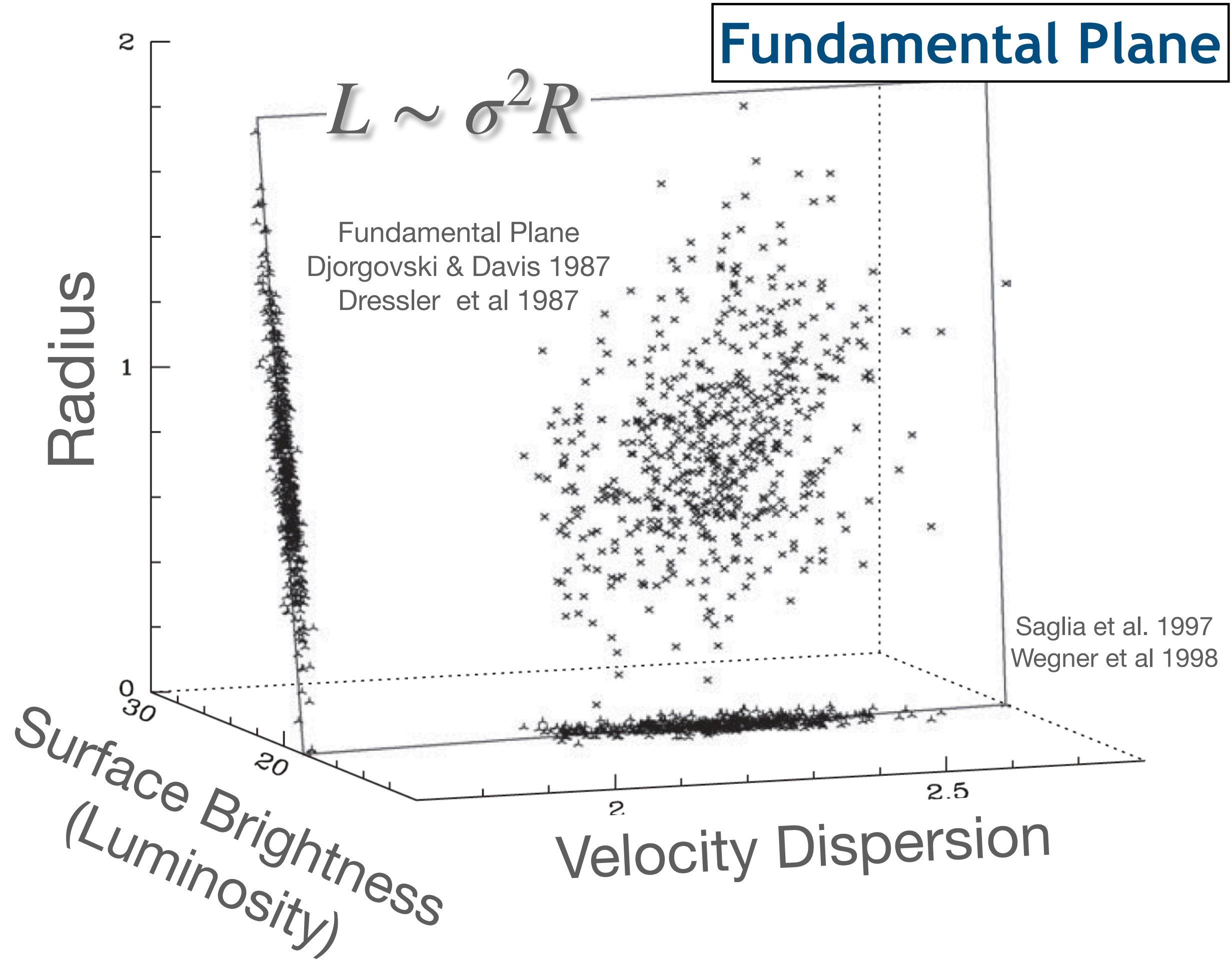


Spiral & Elliptical Scaling Relations

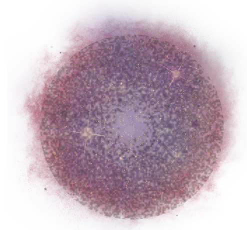






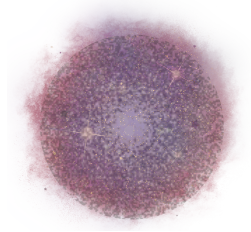


System in Equilibrium
2T+W=0



Virial theorem $\sigma^2 = \frac{GM}{R}$

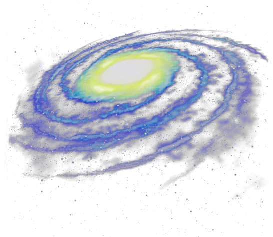
System in Equilibrium
2T+W=0



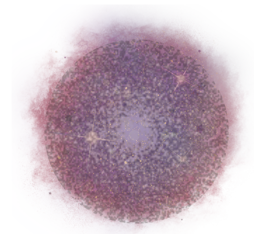
Virial theorem $\sigma^2 = \frac{GM}{R}$

=

Fundamental Plane $M = \frac{\sigma^2 R}{G}$



System in Equilibrium
2T+W=0

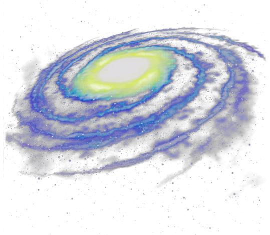


Virial theorem $V^2 = \frac{GM}{R}$

Virial theorem $\sigma^2 = \frac{GM}{R}$

=

Fundamental Plane $M = \frac{\sigma^2 R}{G}$



System in Equilibrium
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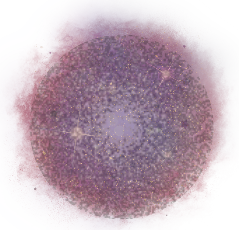


Virial theorem $$V^2 = \frac{GM}{R}$$

Virial theorem $$\sigma^2 = \frac{GM}{R}$$

+

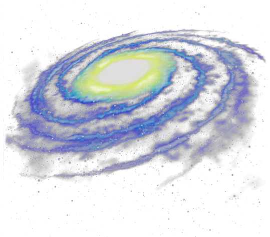
Integrated density constant

$$\rho = \Delta\rho_c$$

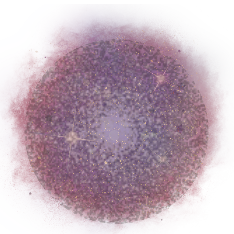
$$\frac{3M}{4\pi R^3} = \Delta\frac{3H^2}{8\pi G}$$

=

Fundamental Plane $$M = \frac{\sigma^2 R}{G}$$



System in Equilibrium
2T+W=0



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+

Integrated density constant

$$\rho = \Delta \rho_c$$

$$\frac{3M}{4\pi R^3} = \Delta \frac{3H^2}{8\pi G}$$

=

Tully Fisher $M = \sqrt{\frac{2}{\Delta}} \frac{V^3}{GH}$

=

Fundamental Plane $M = \frac{\sigma^2 R}{G}$

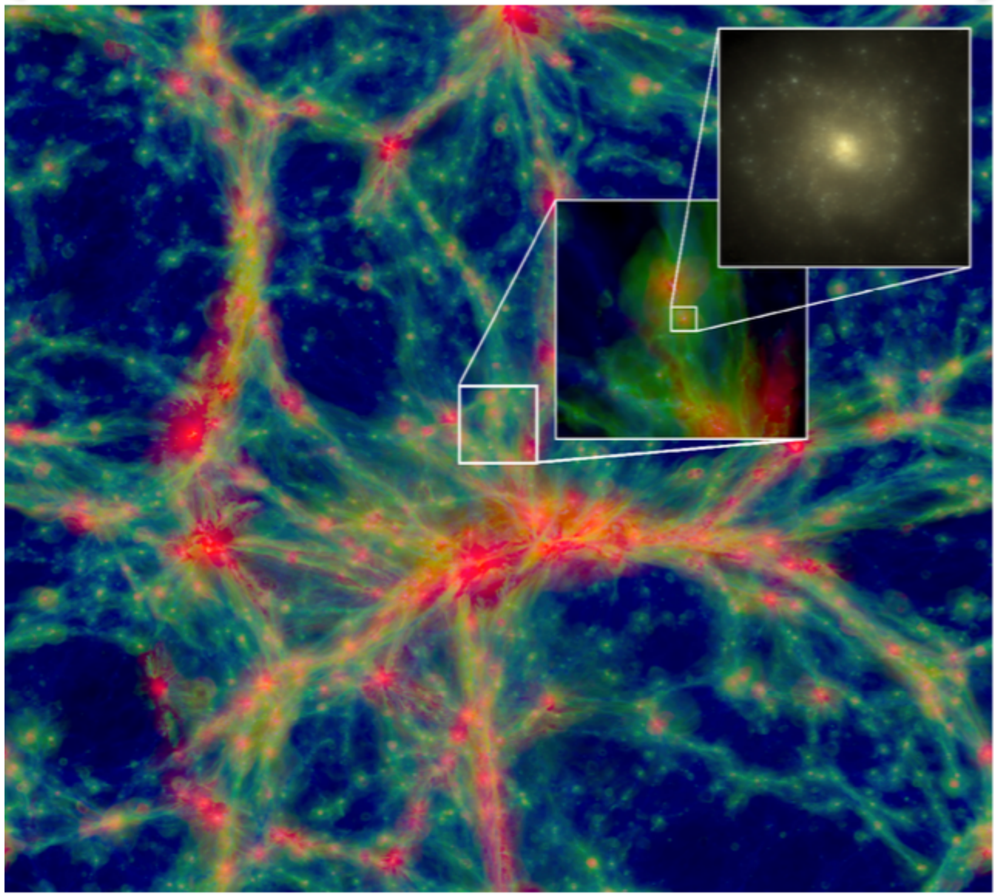
Cosmological Numerical Simulations

EAGLE Cosmological Simulations

Physical Process

- Gravity
- Hydrodynamics
- Radiative cooling
- Star formation
- Feedback SN
- Feedback AGN
- Metallicity

100 Mpc (Gas)



60 kpc (Stars)
$M_{stellar} = 3 \times 10^{10} M_{\odot}$

Particles:
Gas, stars and dark matter

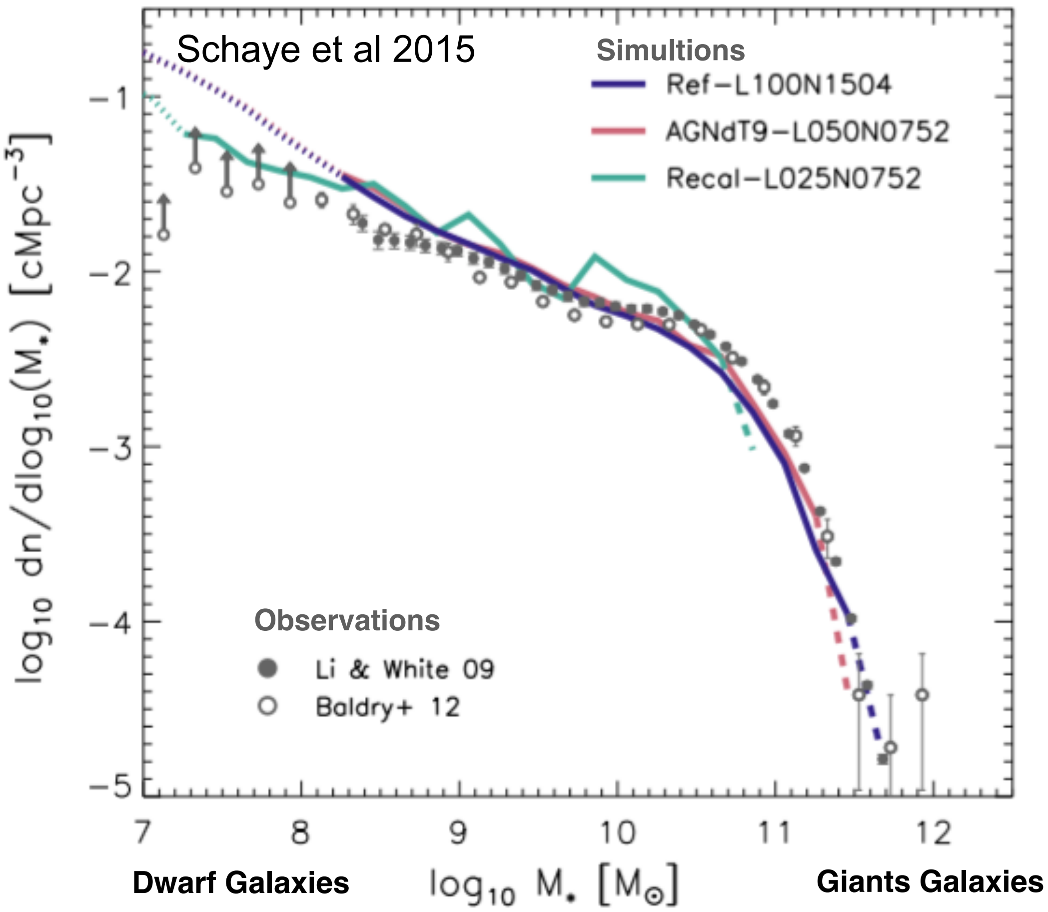
Code:
GADGET-3 Springel et al 2005

Cosmological Parameters:
ΛCDM model Plank et al 2014

Particle Mass:
$M_{gas} = 1.81 \times 10^{6} M_{\odot}$
$M_{dark} = 9.70 \times 10^{6} M_{\odot}$

Schaye et al 2015

Stellar Mass Function



The galaxy stellar mass function at z = 0.1 for the EAGLE simulations compared to observations.

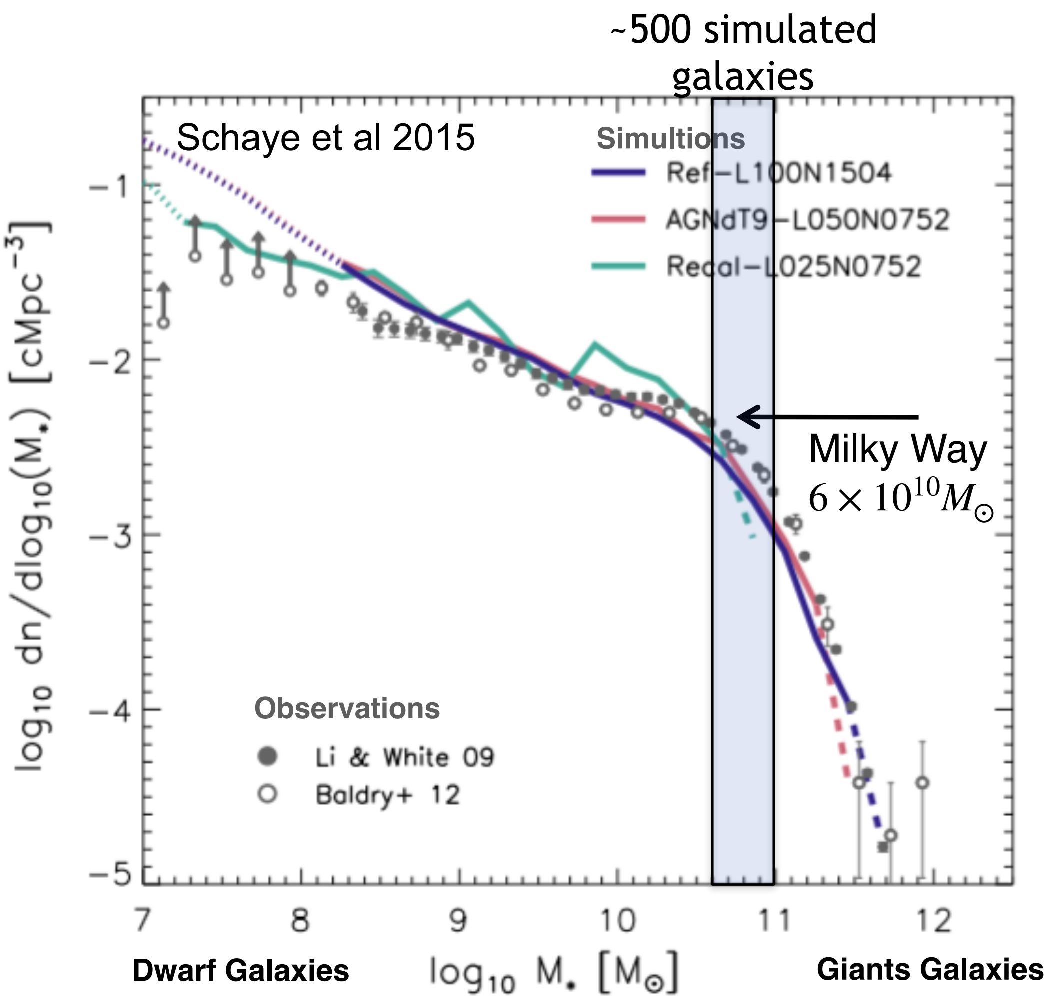
The galaxy number density agrees with the data to <~ 0.2 dex.

High-mass end fewer than 10 objects per (0.2 dex) stellar mass bin.

Low-mass end stellar mass falls below 100 baryonic particles.

GAMA survey (z < 0.06; Baldry et al. 2012)
SDSS (z ~ 0.07; Li & White 2009).

Stellar Mass Function



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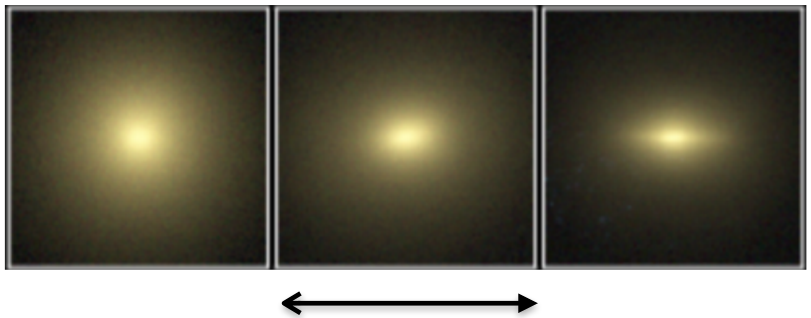
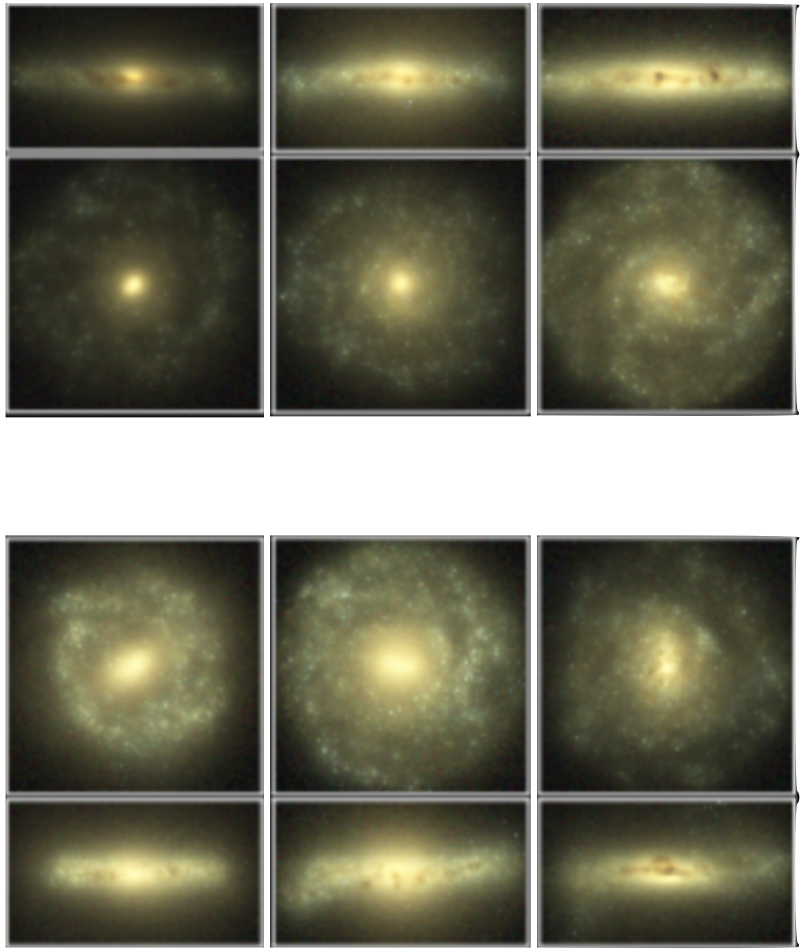
EAGLE Morphological Classification



60 kpc (Stars)

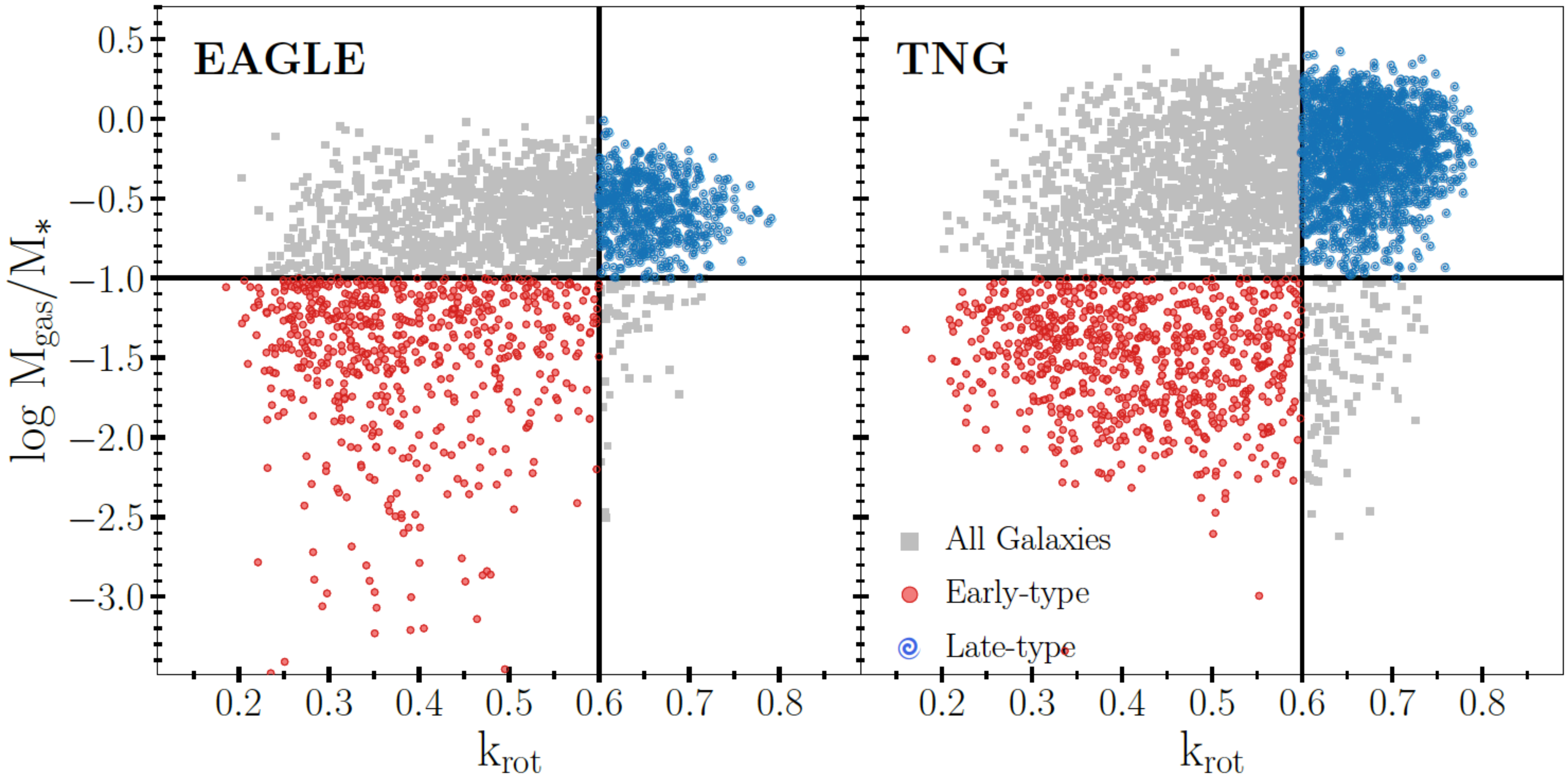
$M_{stellar} = 5 - 6 \times 10^{10} M_{\odot}$

Normal Spirals

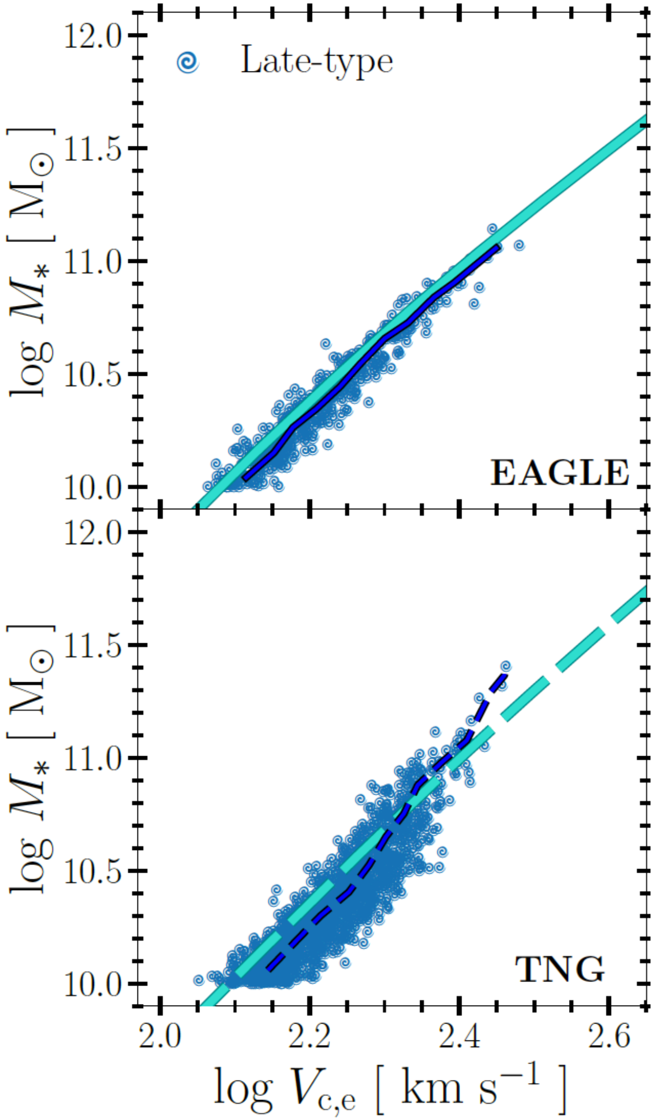


Barred Spirals

Spiral & Elliptical Classification



Simulated Scaling Relations



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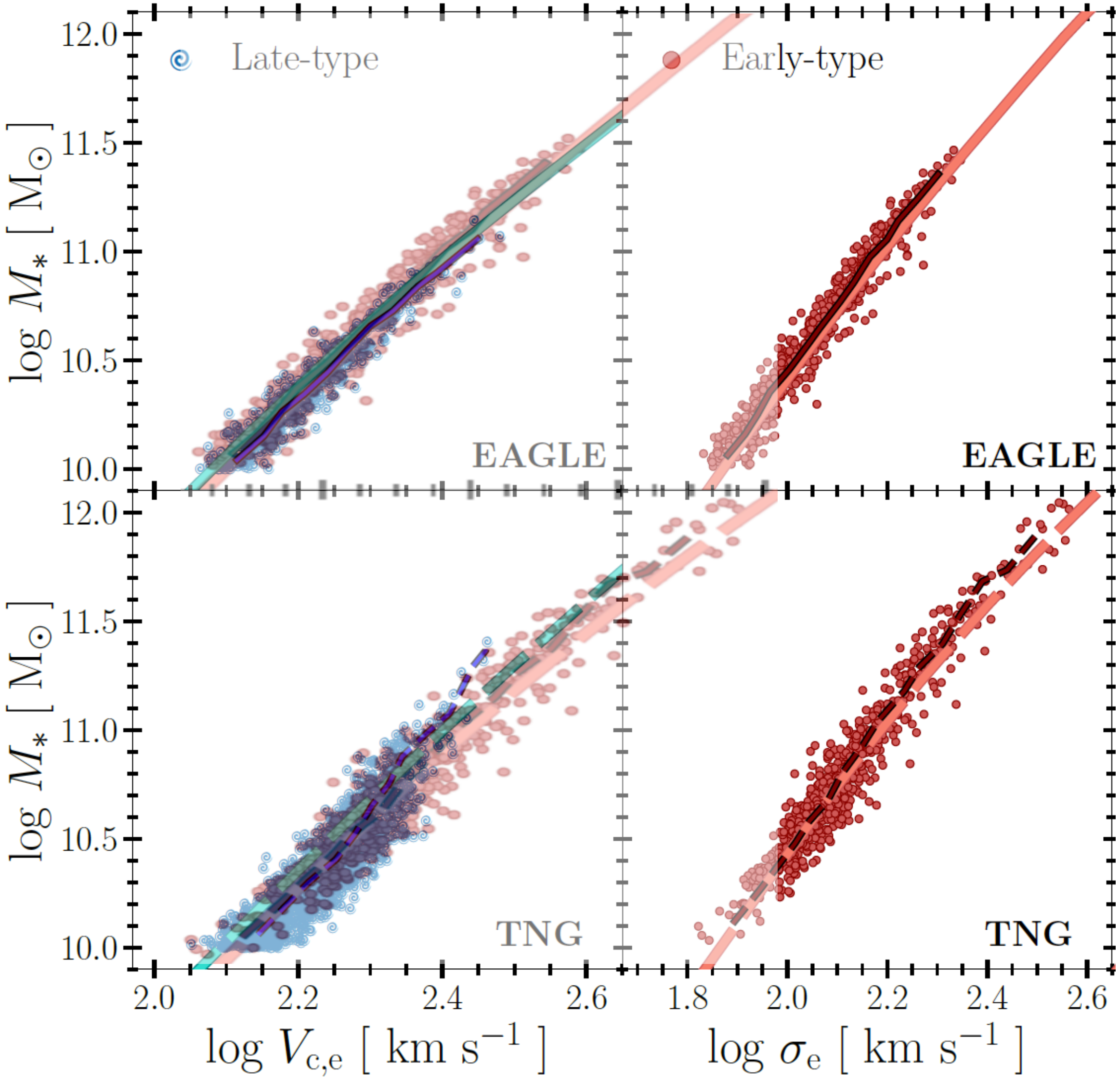
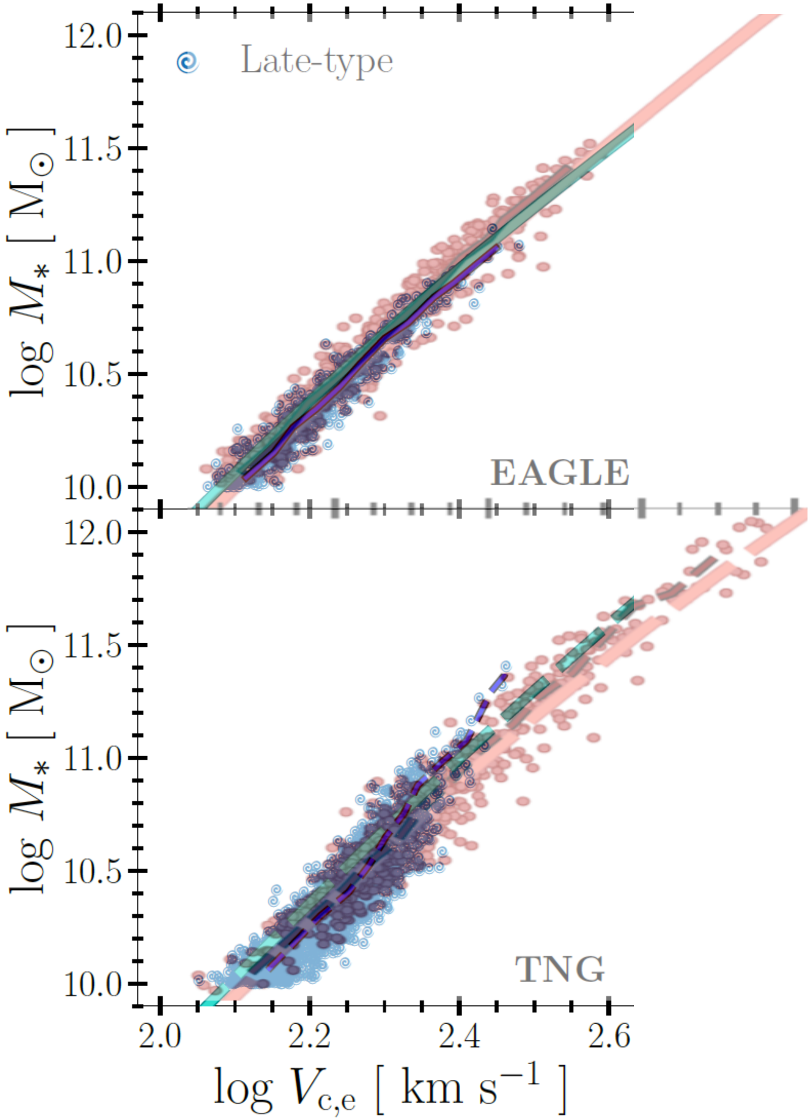
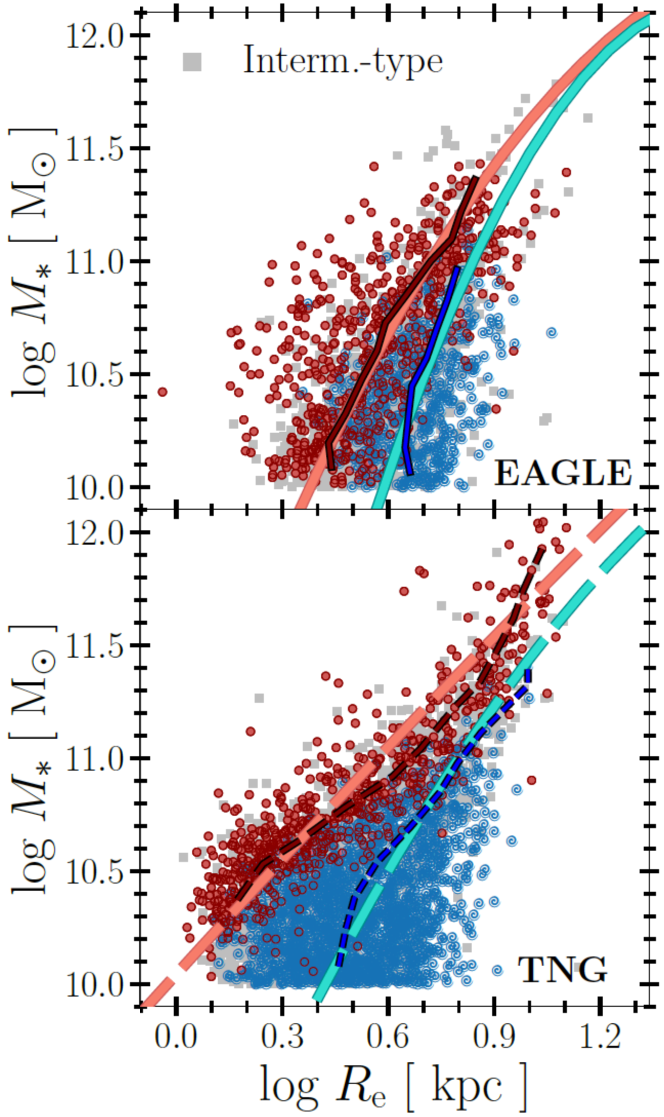
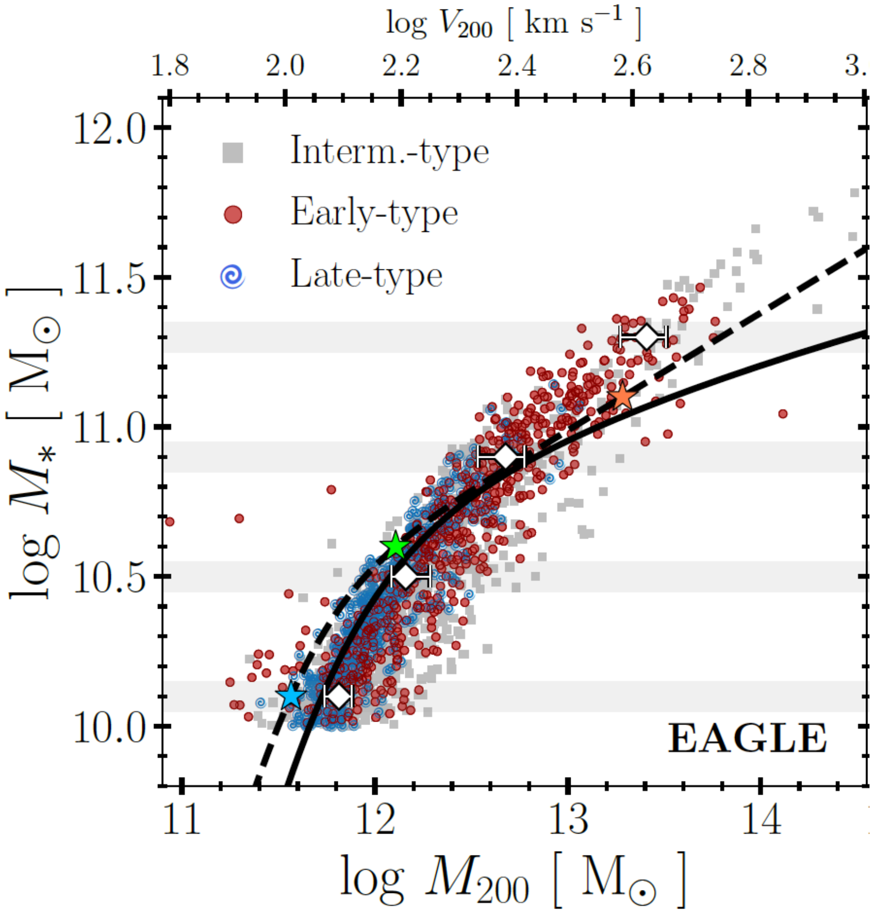


Simulated Scaling Relations

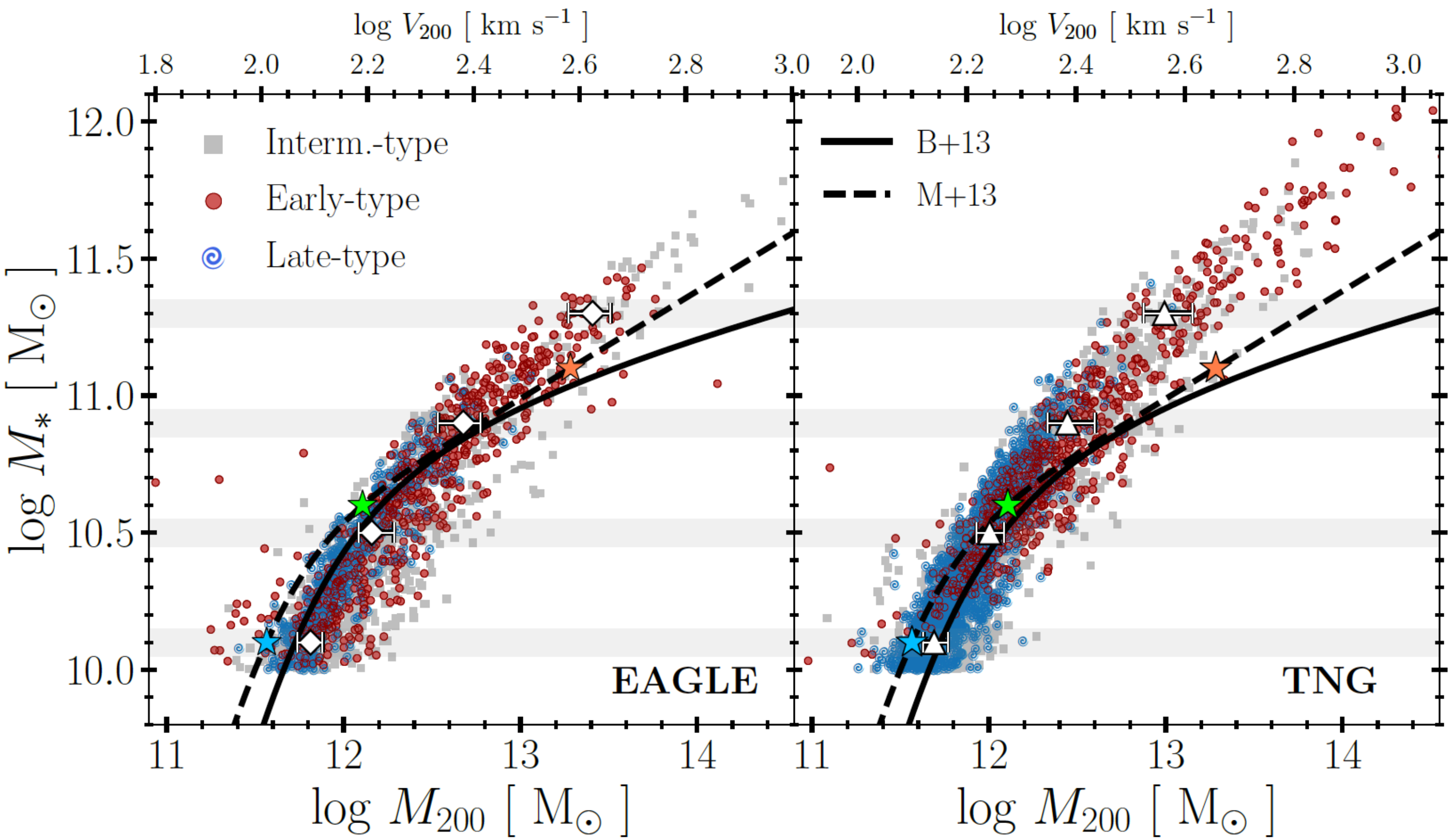




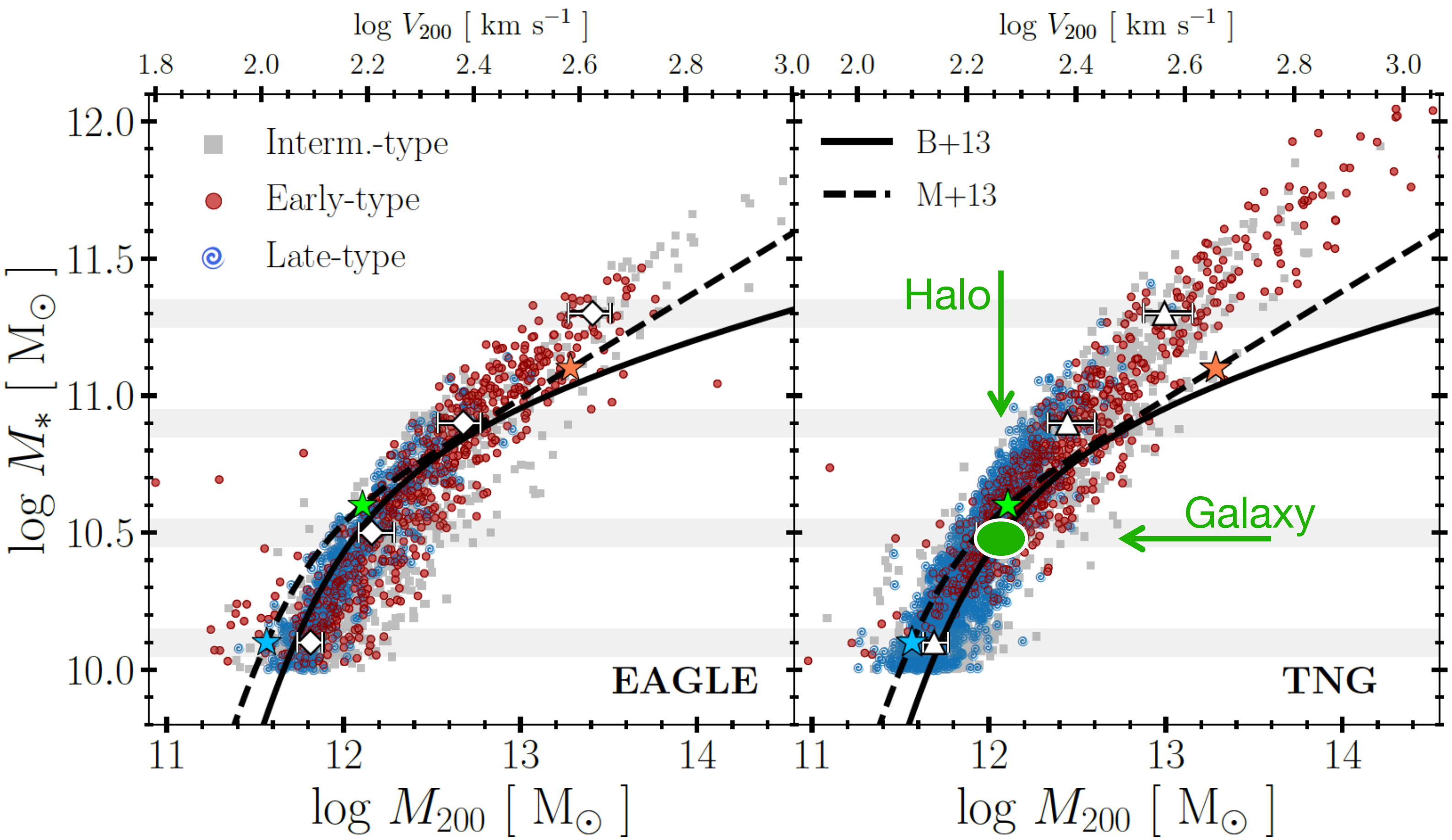
Stellar Halo Mass Relation



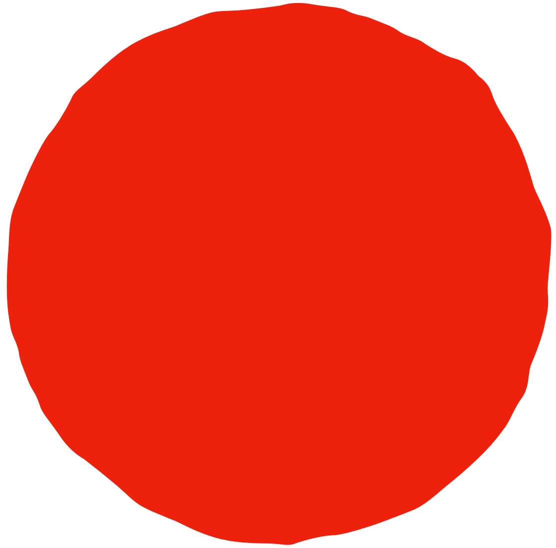
Stellar Halo Mass Relation



Stellar Halo Mass Relation



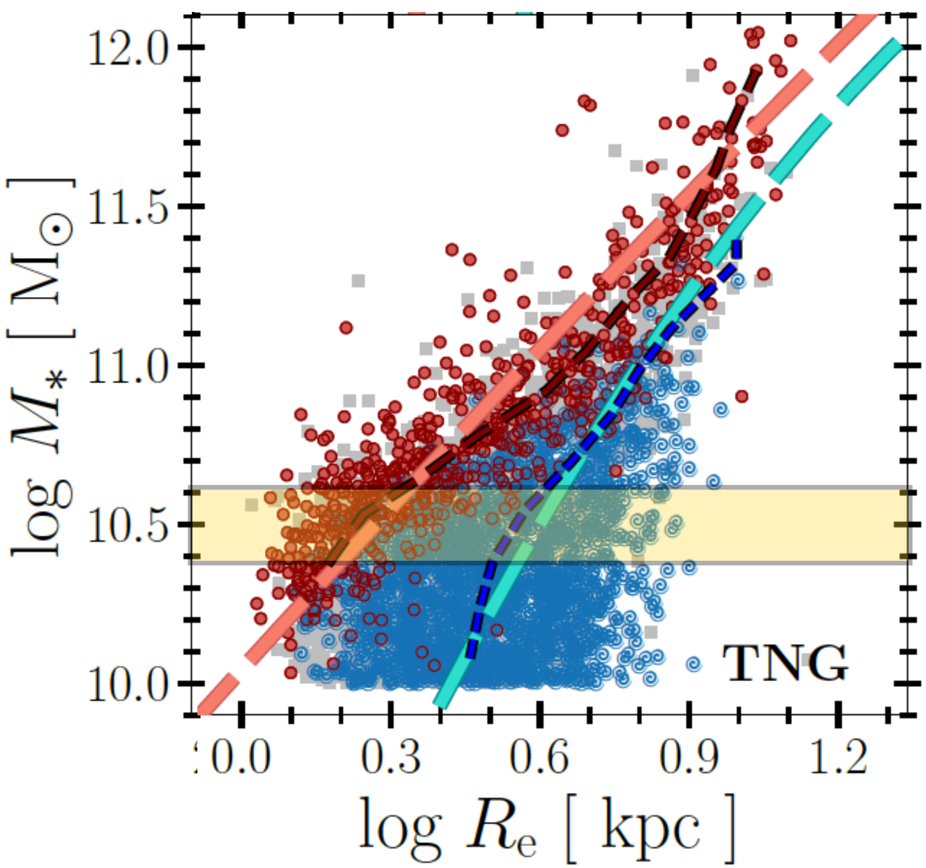
Theoretical Model

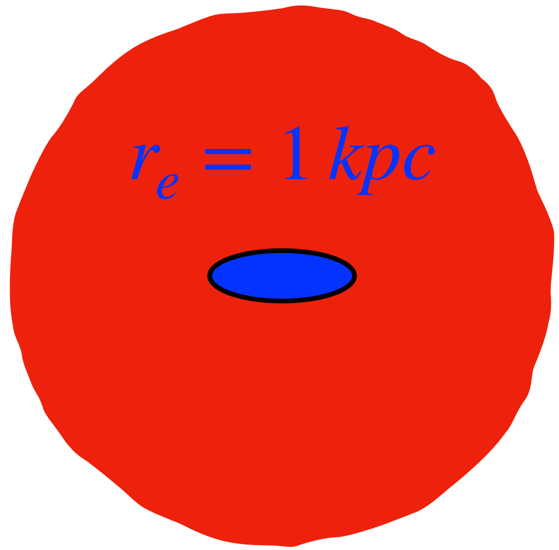


Dark matter halo

$10^{12}M_\odot$

Theoretical Model

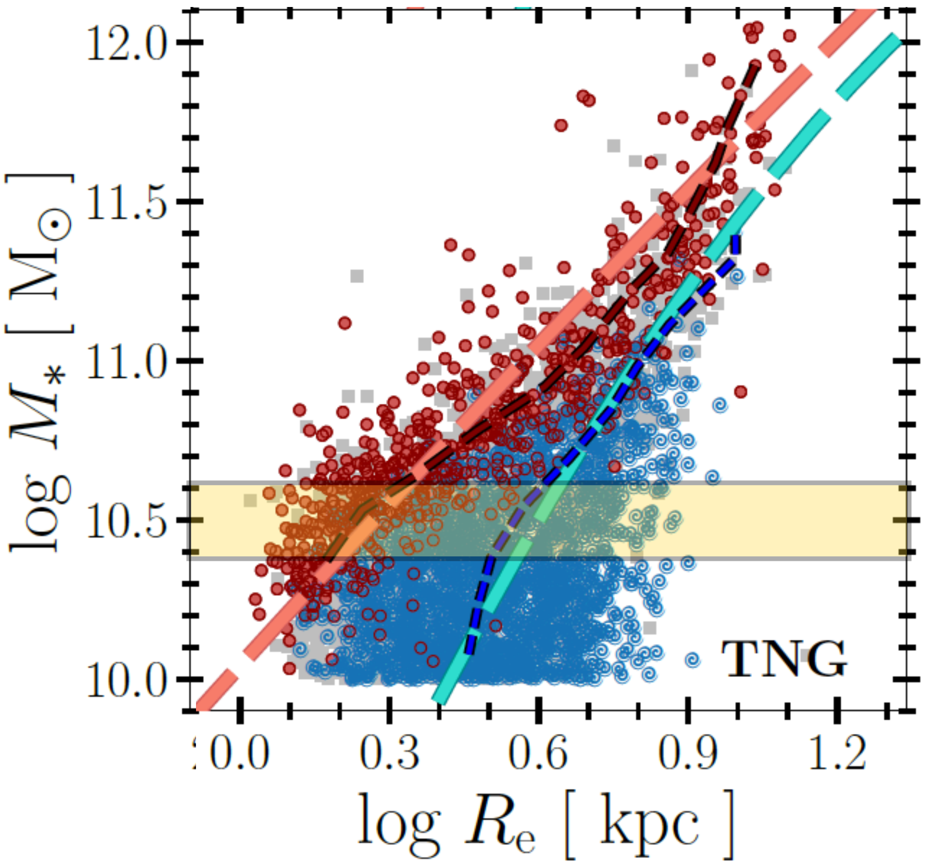


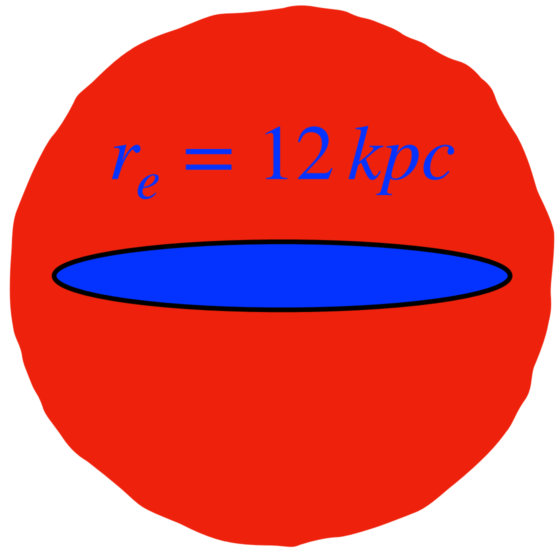


Dark matter halo
$10^{12} M_\odot$

COMPACT Galaxy
$10^{10.5} M_\odot$

Theoretical Model

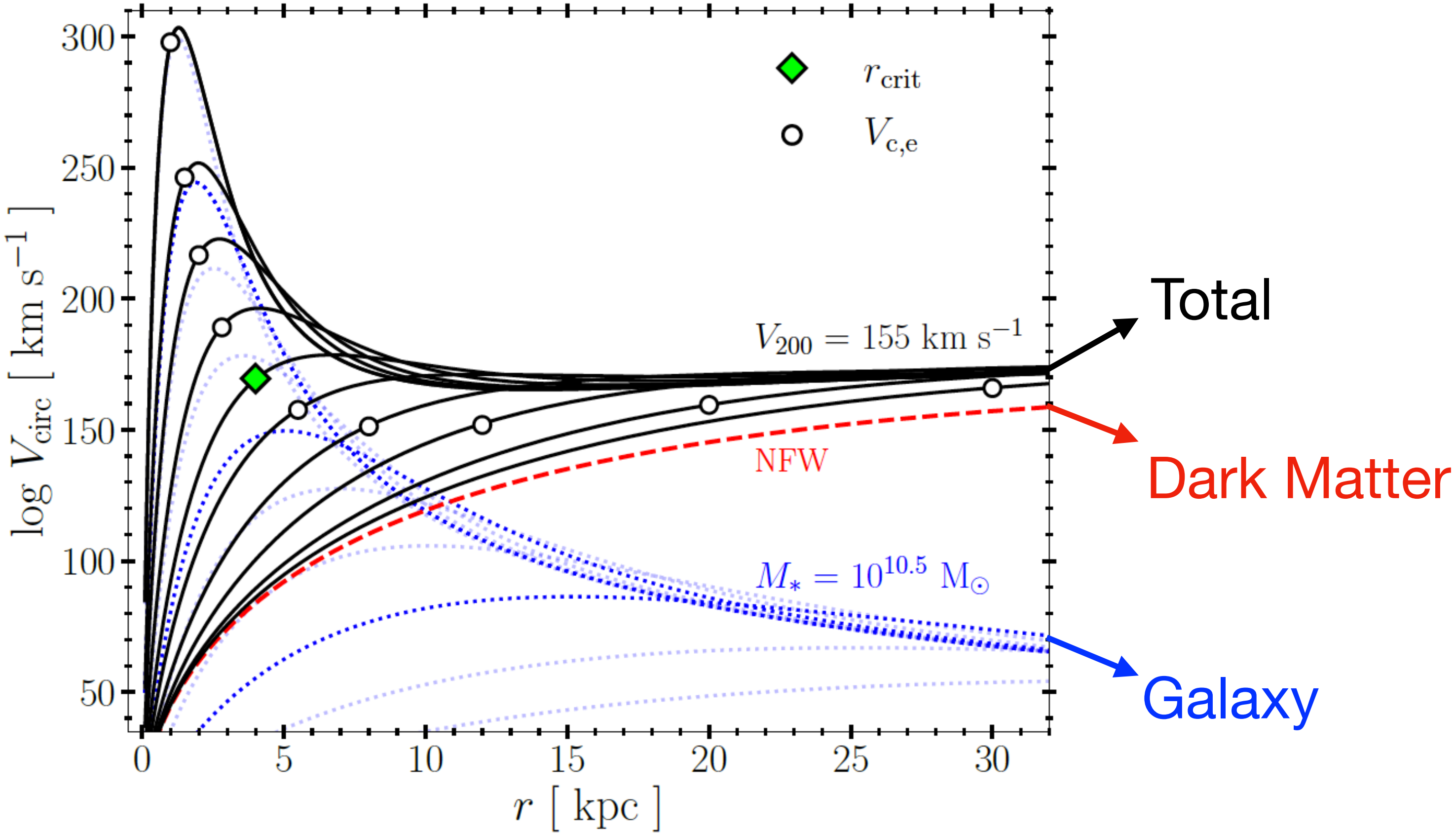


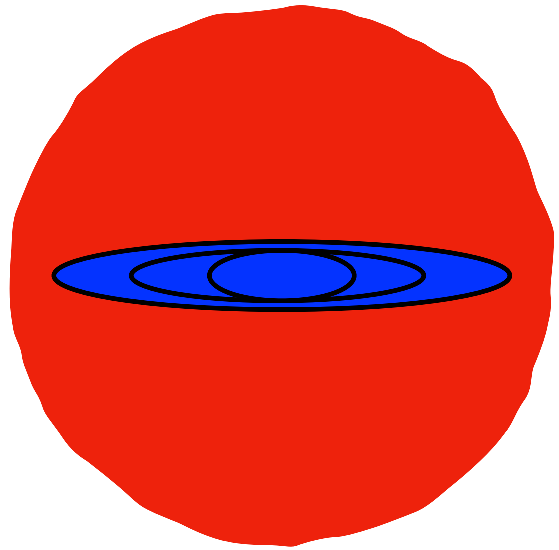


Dark matter halo
$10^{12} M_\odot$

EXTENDED Galaxy
$10^{10.5} M_\odot$

Theoretical Model





Dark matter halo

$10^{12} M_\odot$

Galaxy

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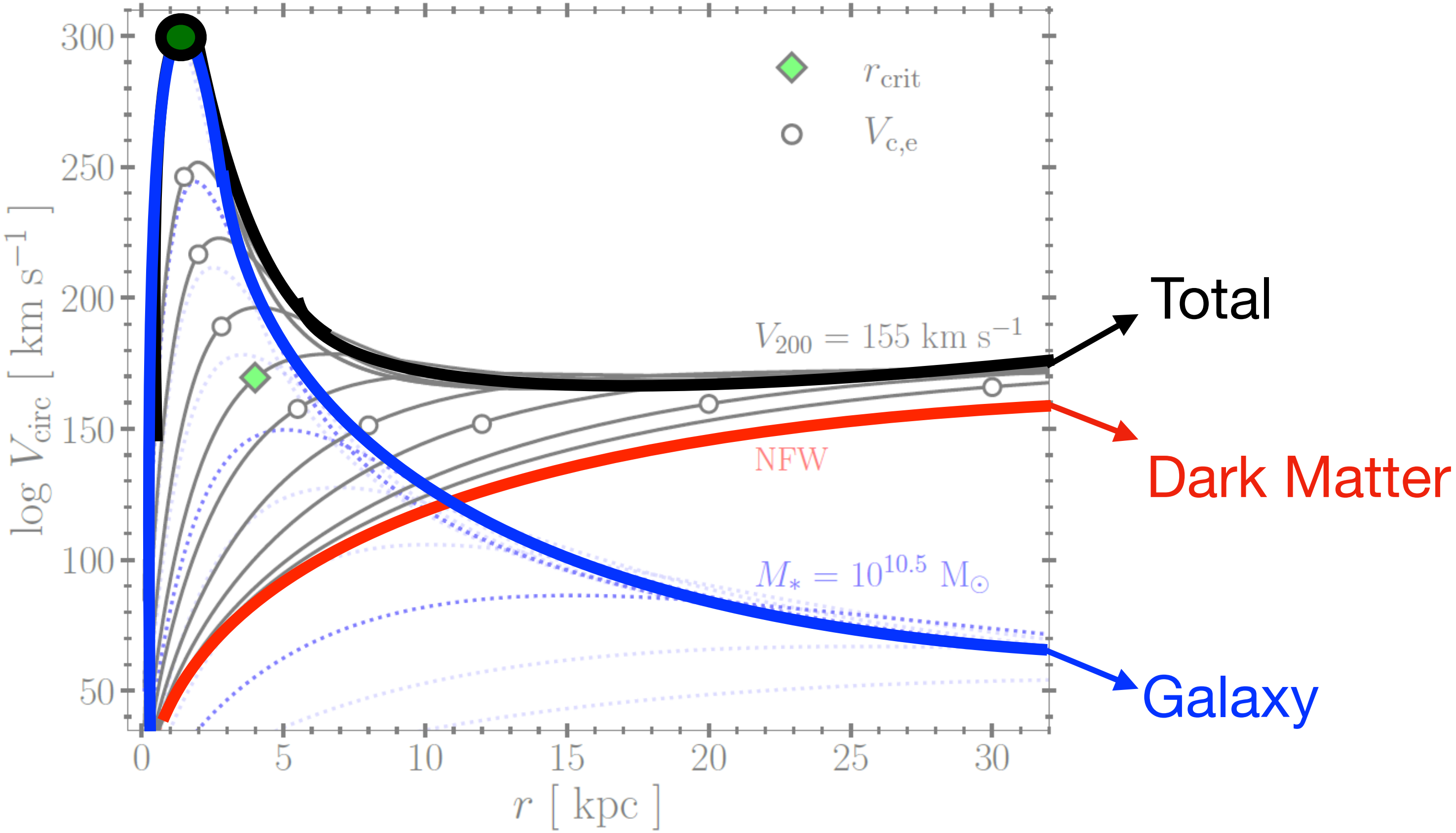
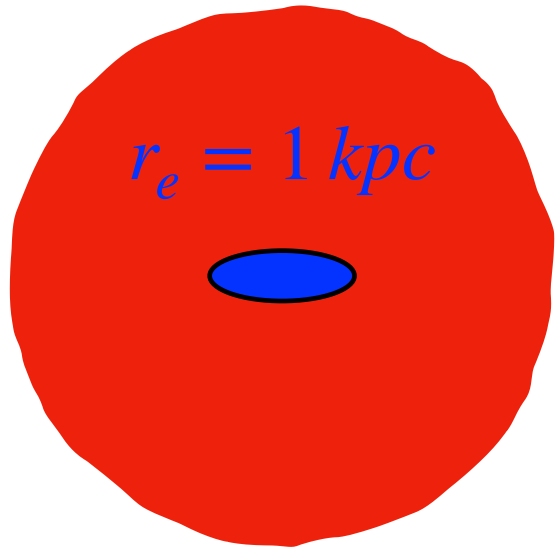
Theoretical Model





Dark matter halo
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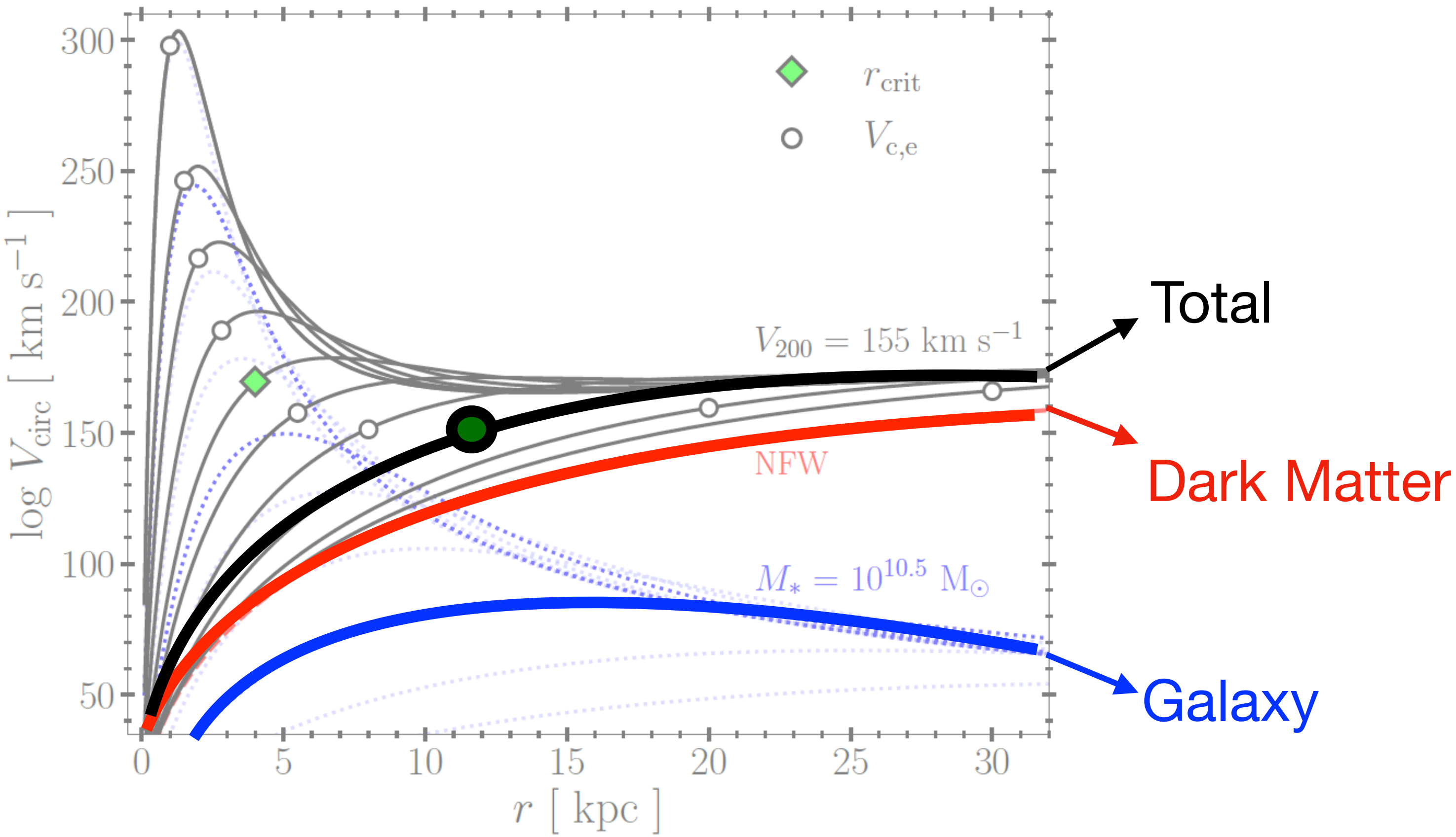
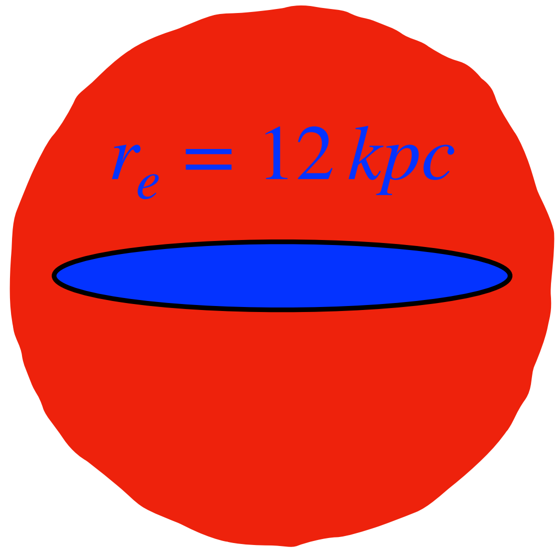
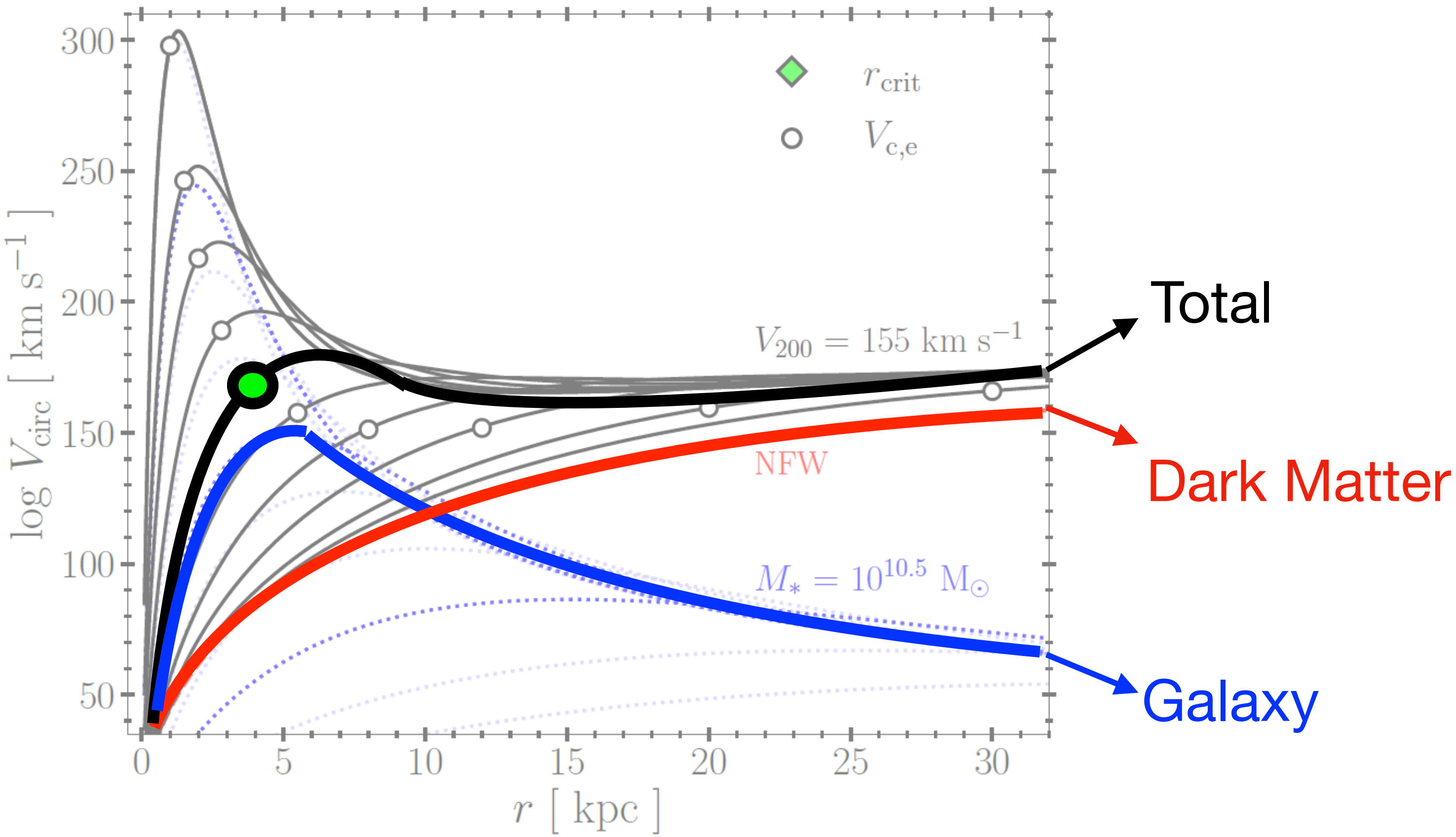


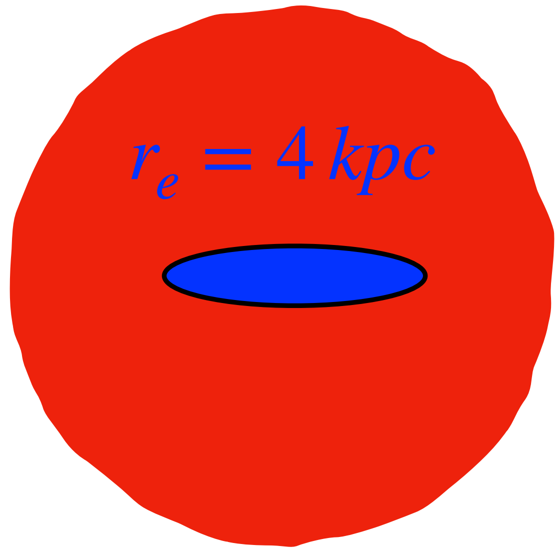


Dark matter halo
$10^{12} M_\odot$

EXTENDED Galaxy
$10^{10.5} M_\odot$

Theoretical Model

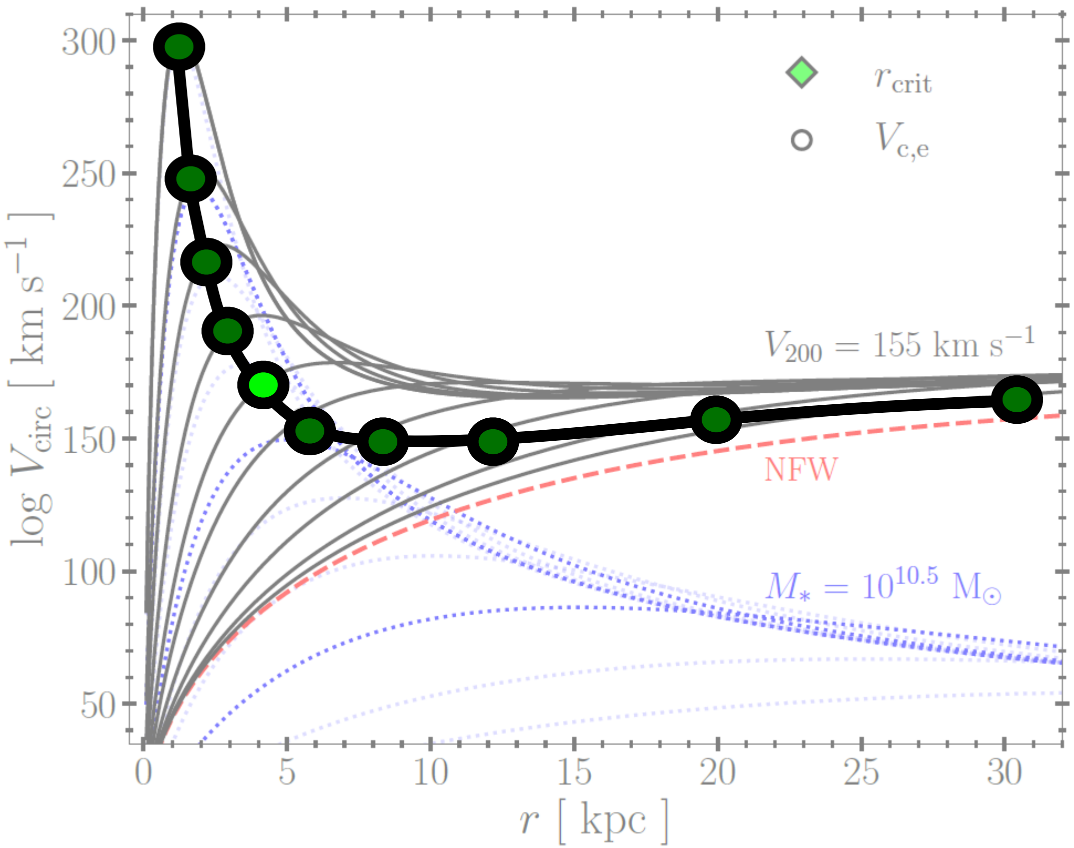


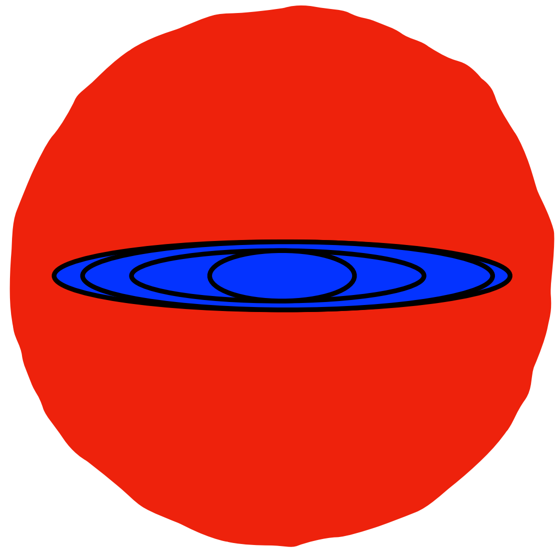


Dark matter halo
$10^{12} M_\odot$

Galaxy
$10^{10.5} M_\odot$

Theoretical Model





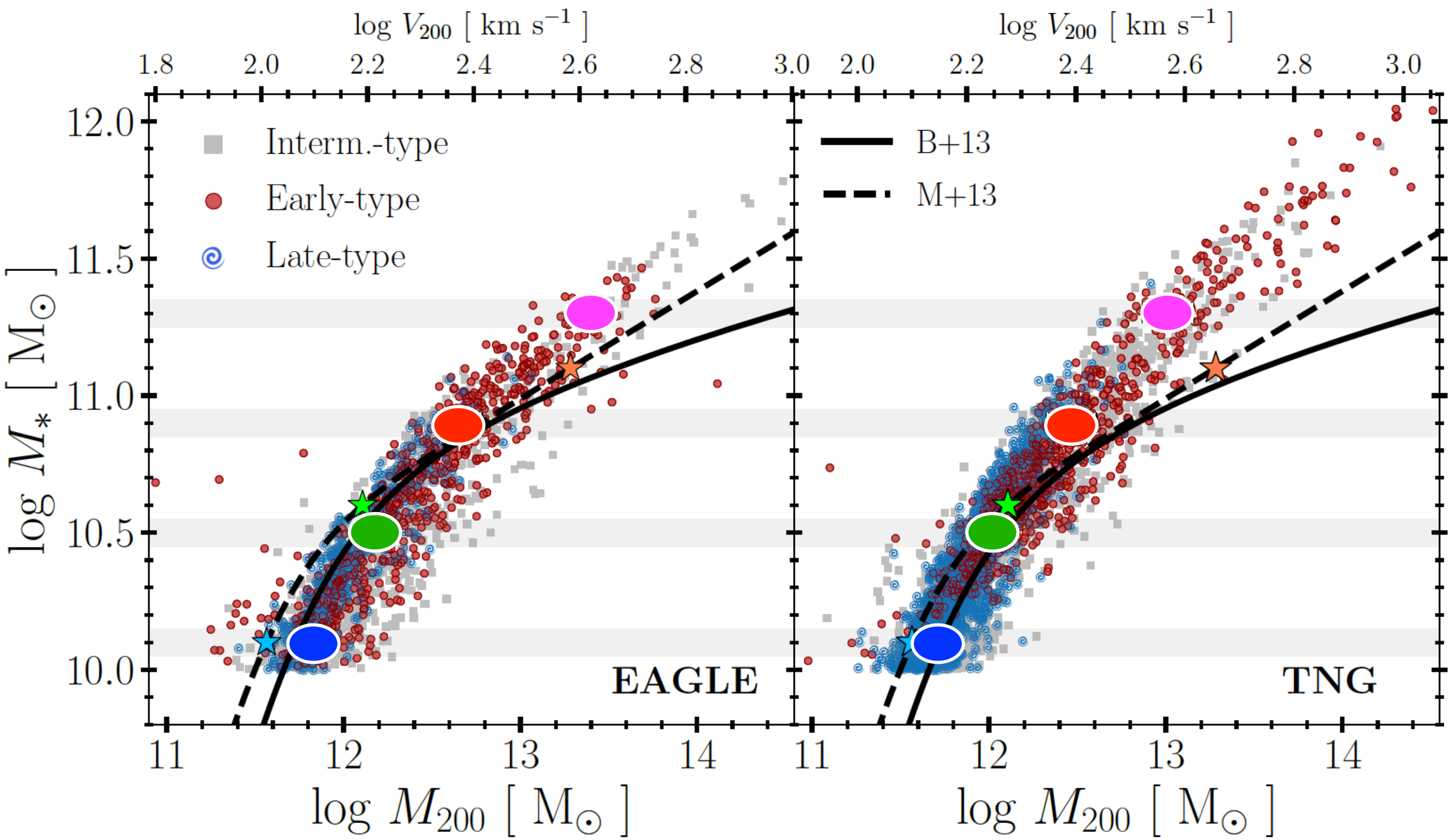
Dark matter halo

$10^{12} M_\odot$

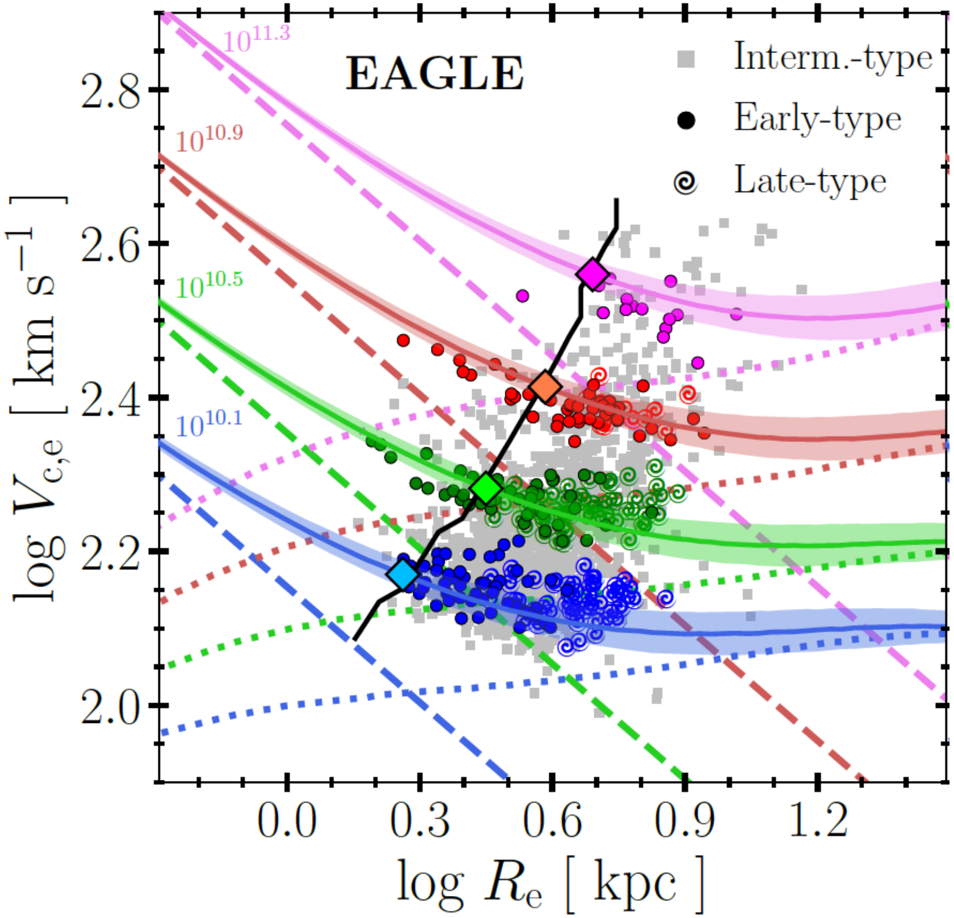
Galaxy

$10^{10.5} M_\odot$

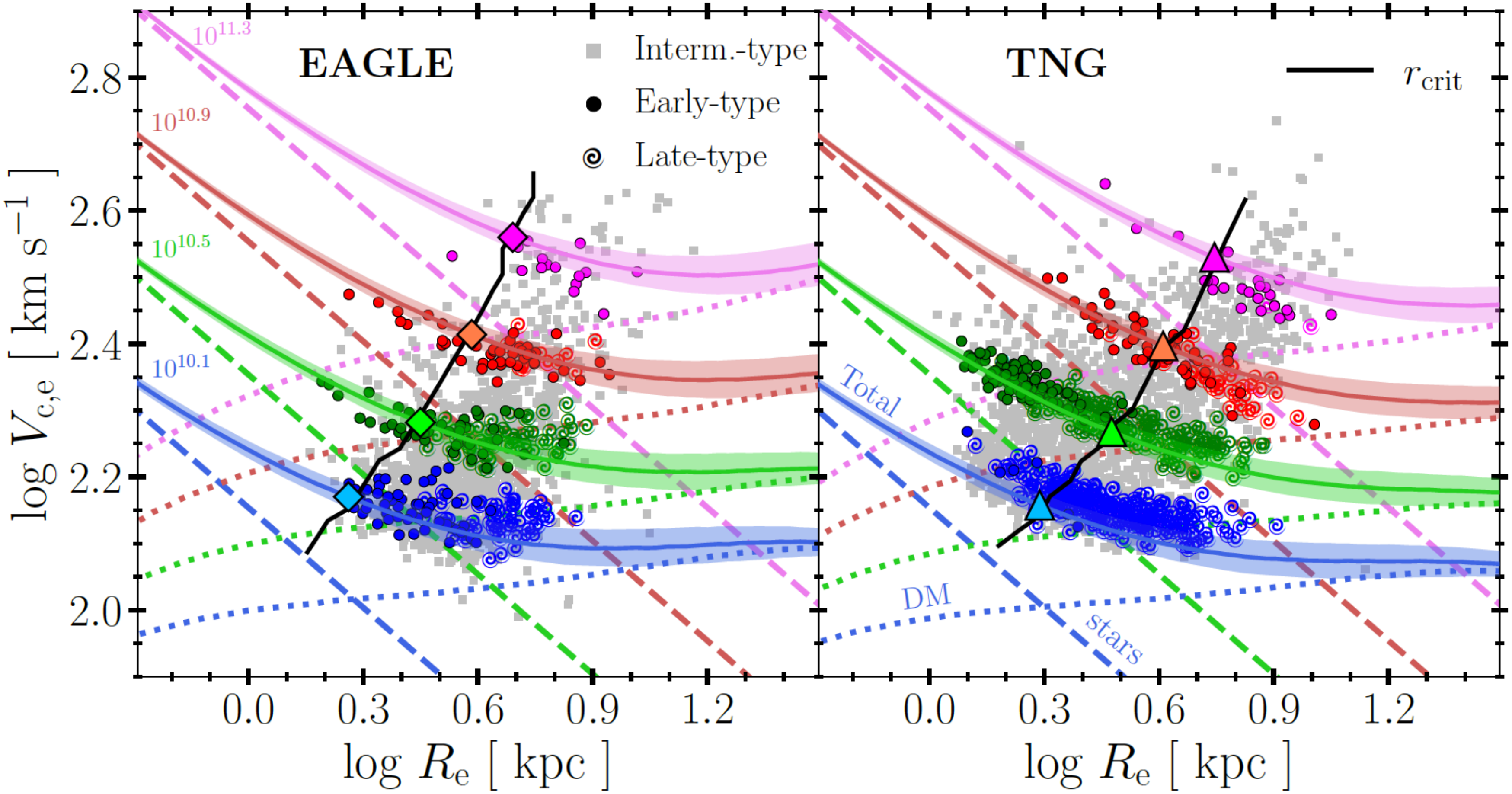
Stellar Halo Mass Relation



Velocity-Radius Relation

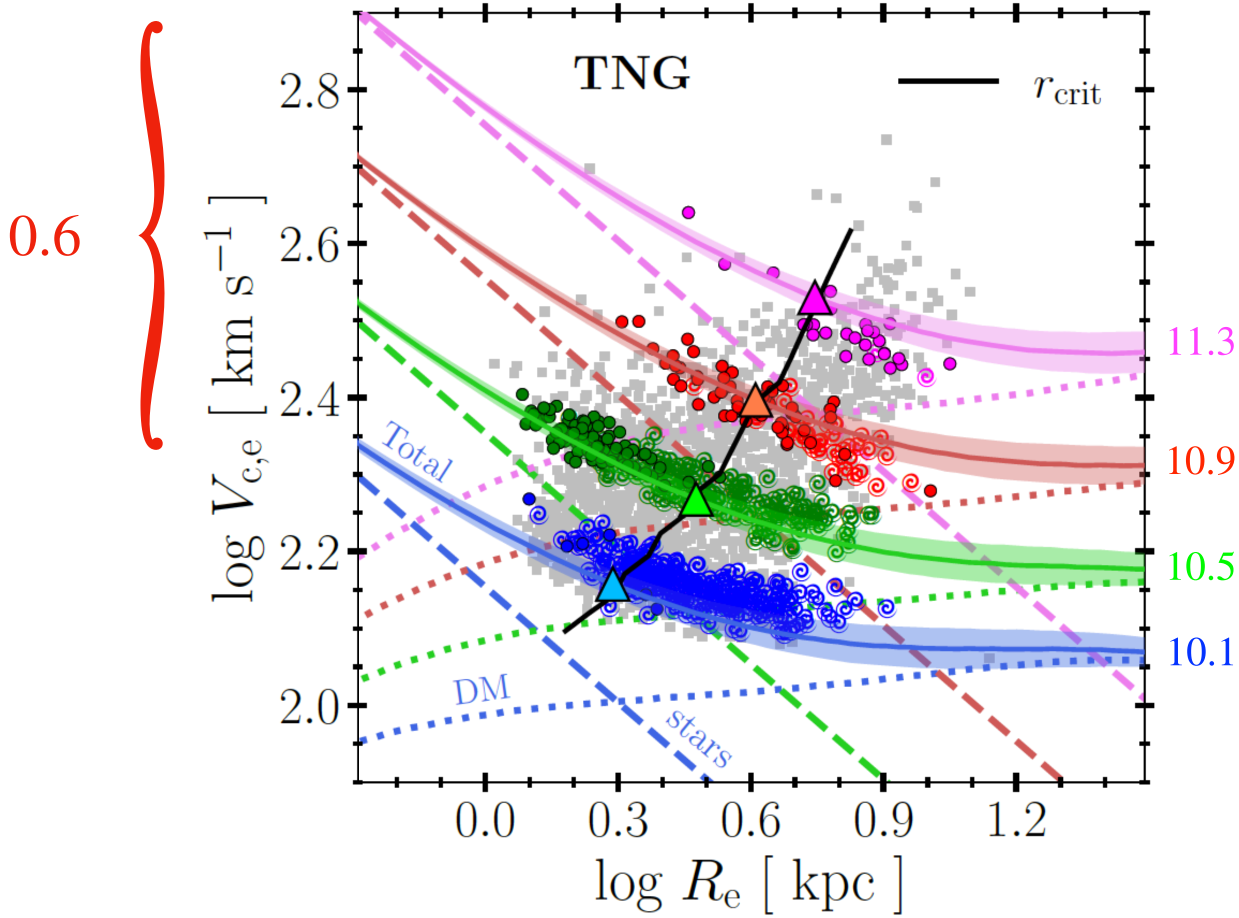


Velocity-Radius Relation



Velocity-Radius Relation

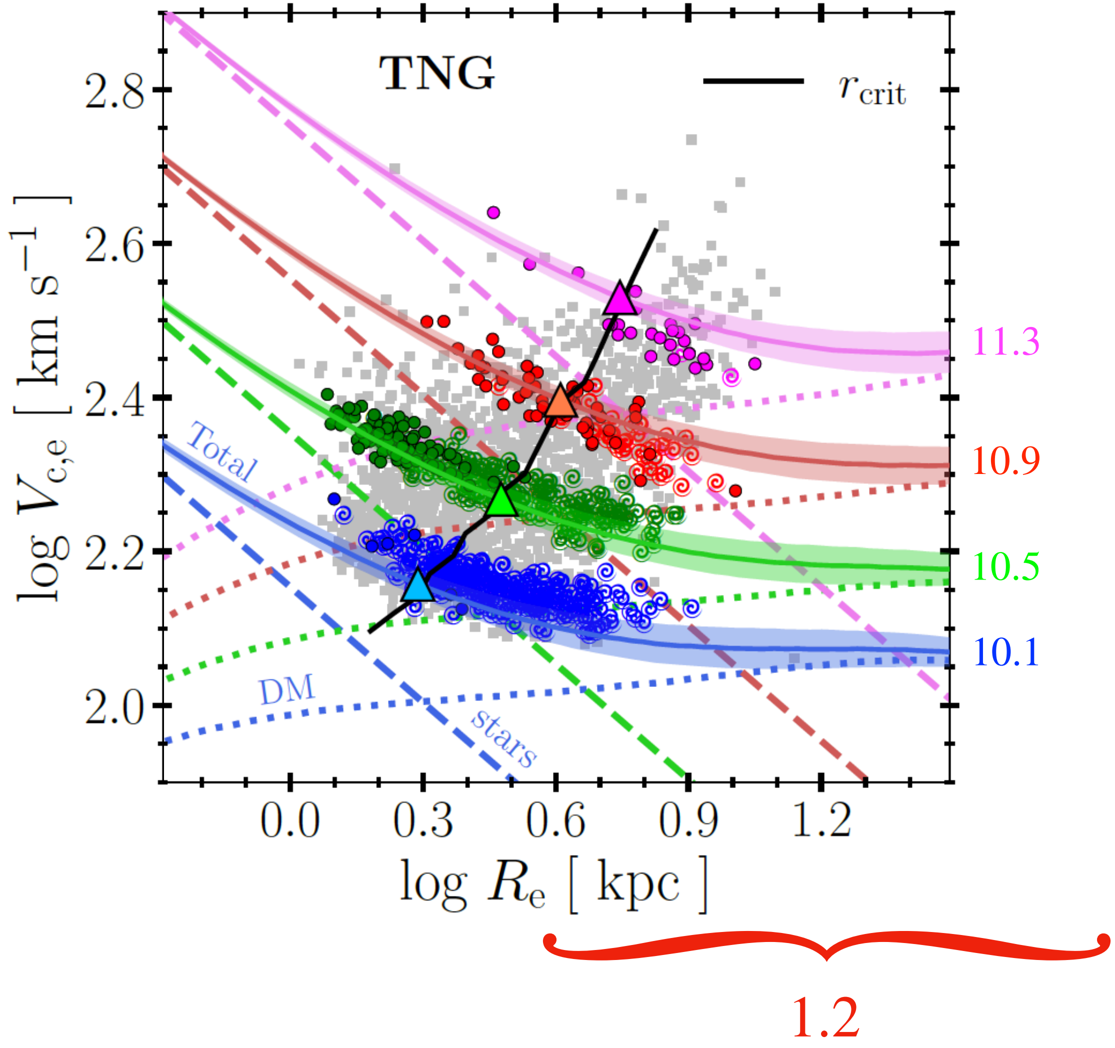
$$\frac{\Delta Log M}{\Delta Log V} \sim \frac{1.2}{0.6} \qquad M \sim V^2$$



Velocity-Radius Relation

$$\frac{\Delta LogM}{\Delta LogV} \sim \frac{1.2}{0.6} \qquad M \sim V^2$$

$$\frac{\Delta LogM}{\Delta LogR} \sim \frac{1.2}{1.2} \qquad M \sim R$$



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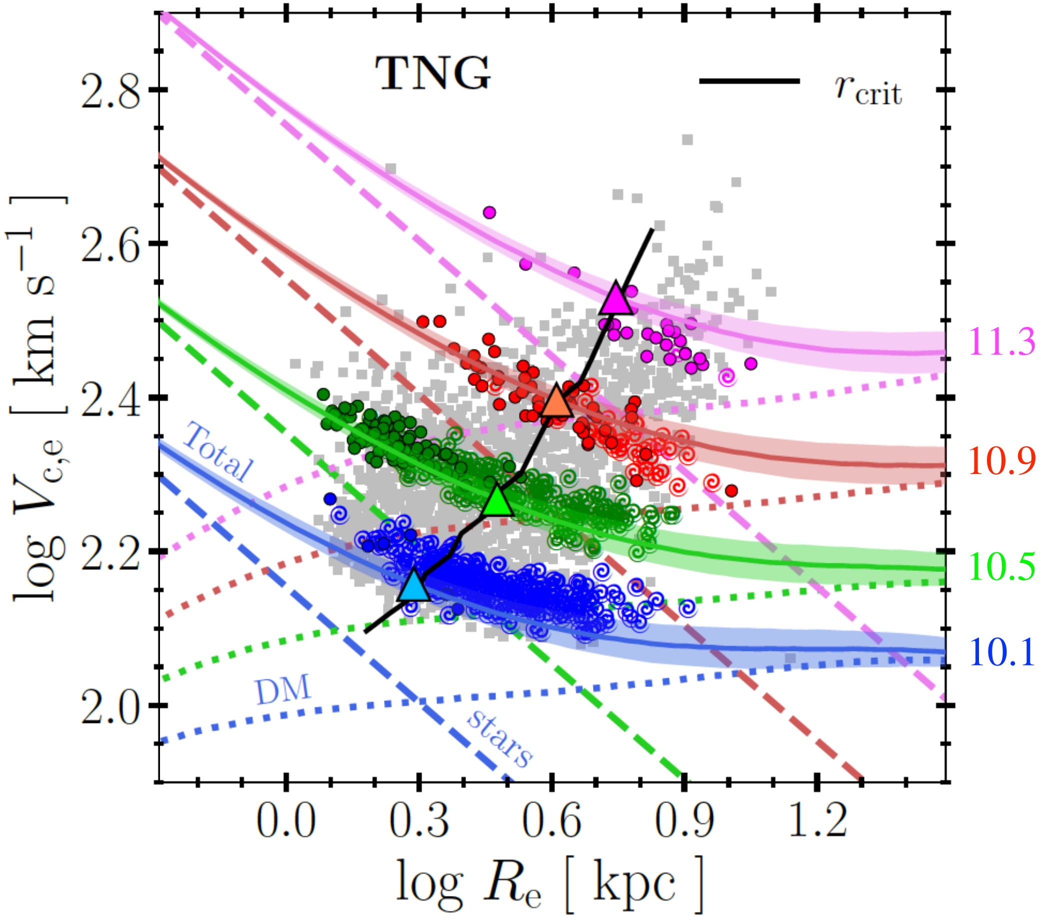
$$\frac{\Delta LogM}{\Delta LogR} \sim \frac{1.2}{1.2} \qquad M \sim R$$

$M \sim V^2 R$ Fundamental Plane



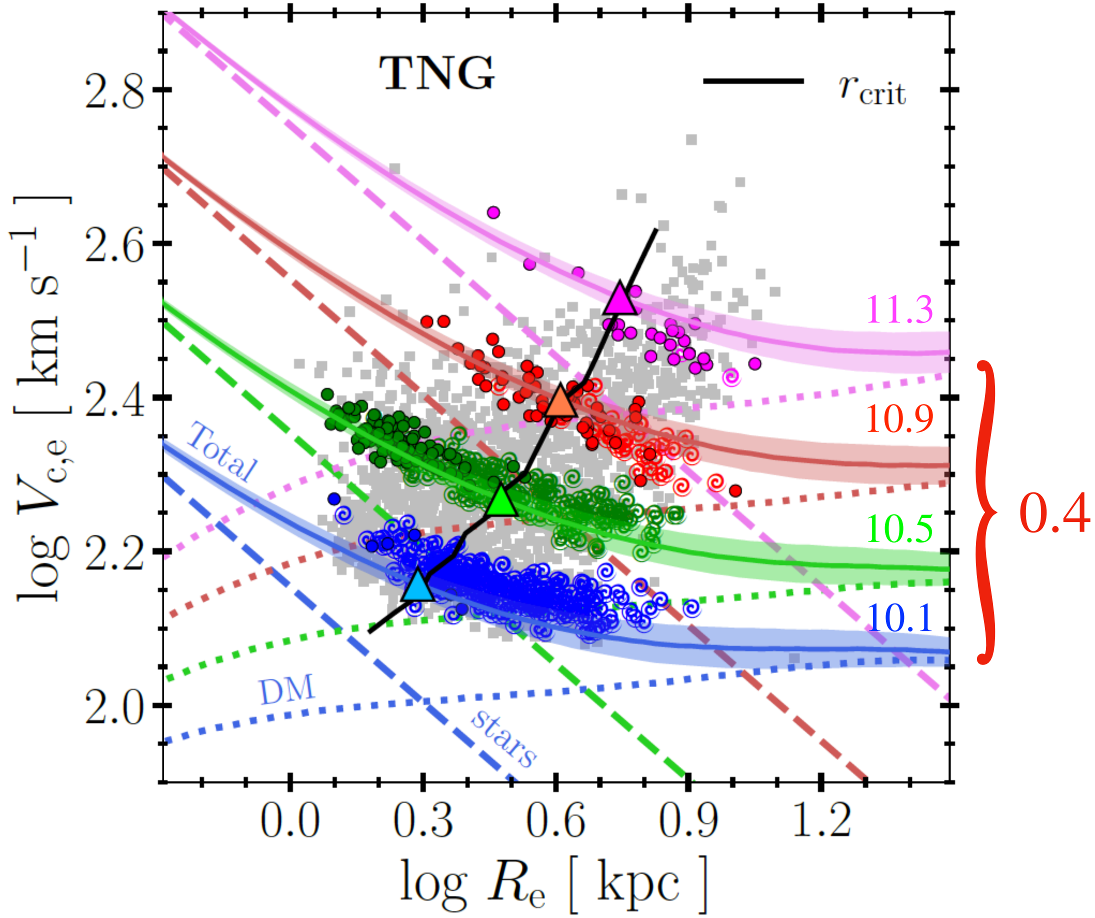
Velocity-Radius Relation

$$\frac{\Delta Log M}{\Delta Log V} \sim \frac{1.2}{0.6} \qquad M \sim V^2$$

$$\frac{\Delta Log M}{\Delta Log R} \sim \frac{1.2}{1.2} \qquad M \sim R$$

$M \sim V^2 R$ Fundamental Plane

$$\frac{\Delta Log M}{\Delta Log V} \sim \frac{1.2}{0.4} \qquad M \sim V^3$$



Velocity-Radius Relation

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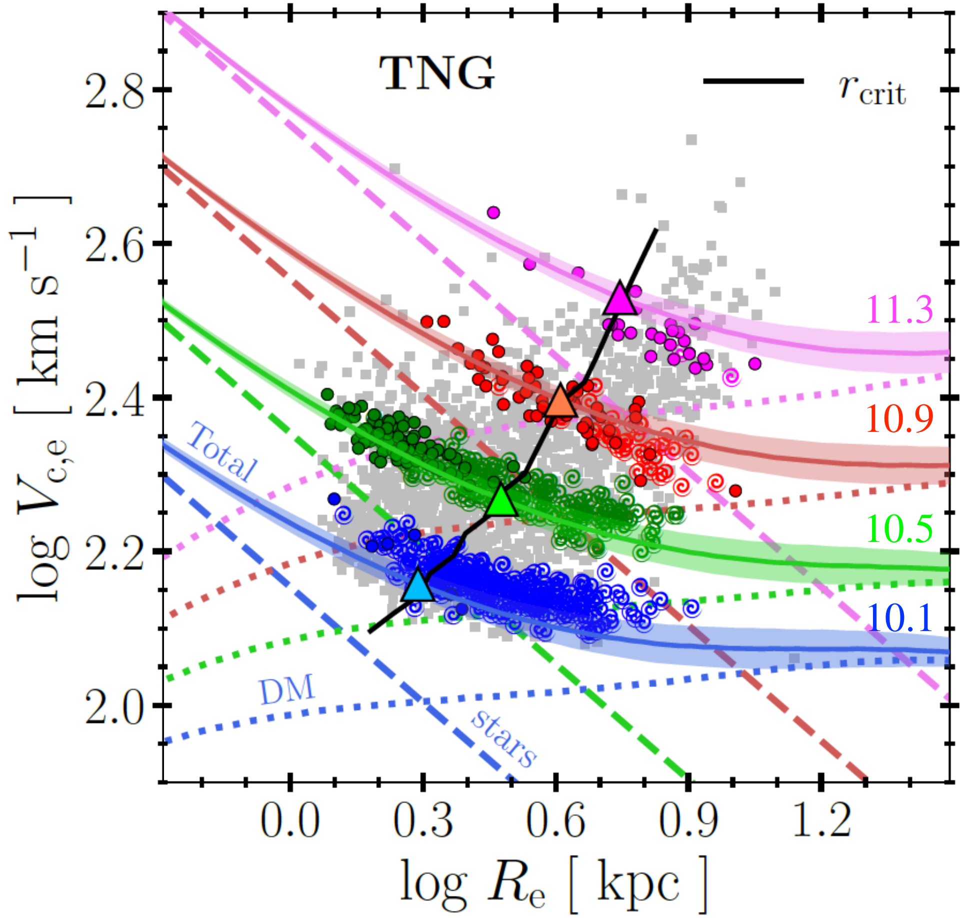
$$\frac{\Delta LogM}{\Delta LogR} \sim \frac{1.2}{1.2} \qquad M \sim R$$

$M \sim V^2 R$ Fundamental Plane

$$\frac{\Delta LogM}{\Delta LogV} \sim \frac{1.2}{0.4} \qquad M \sim V^3$$

$$\frac{\Delta LogM}{\Delta LogR} \sim \frac{1.2}{\infty} \qquad M \sim R^0$$



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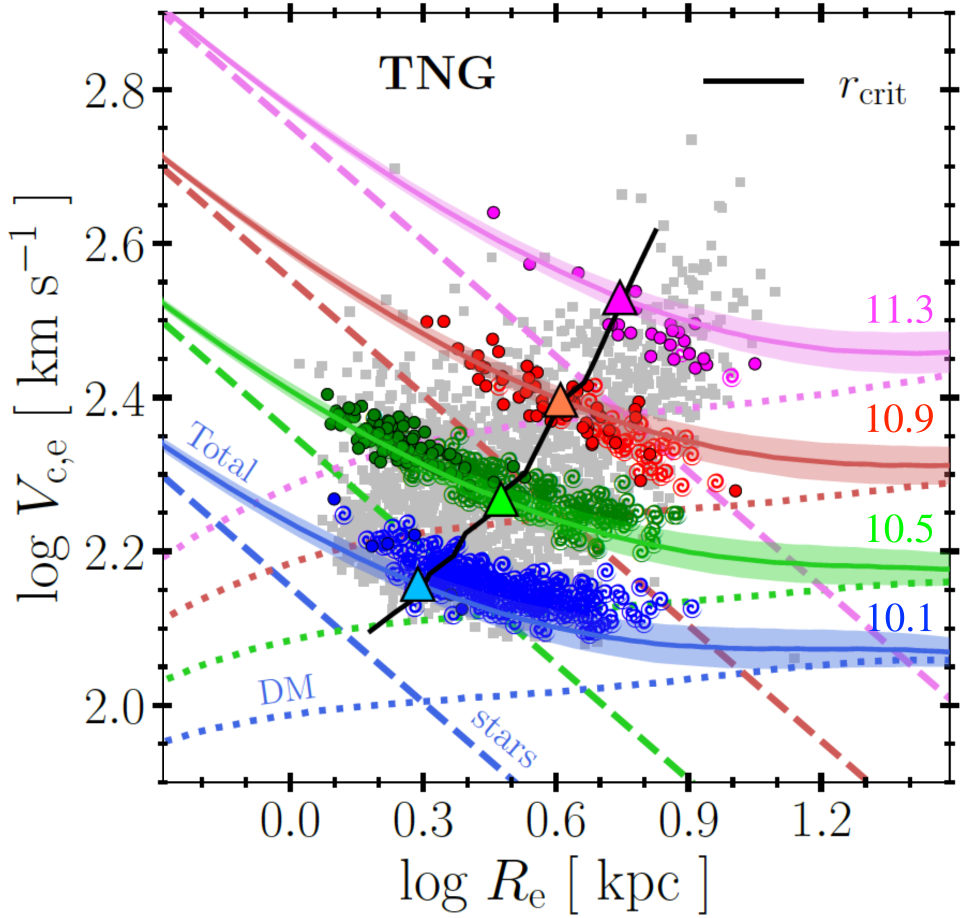
$$\frac{\Delta LogM}{\Delta LogR} \sim \frac{1.2}{1.2} \qquad M \sim R$$

$M \sim V^2 R$ Fundamental Plane

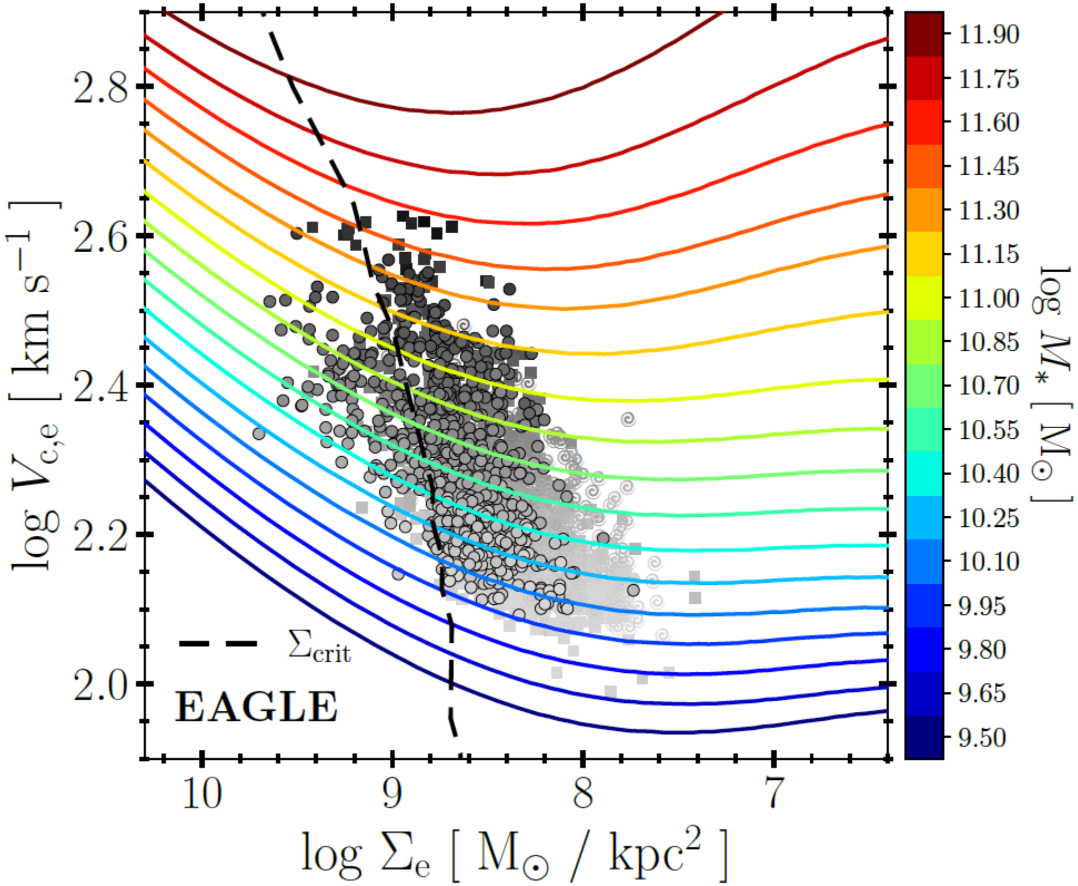
$$\frac{\Delta LogM}{\Delta LogV} \sim \frac{1.2}{0.4} \qquad M \sim V^3$$

$$\frac{\Delta LogM}{\Delta LogR} \sim \frac{1.2}{\infty} \qquad M \sim R^0$$

$M \sim V^3$ Tully-Fisher



Secondary Distance Indicator



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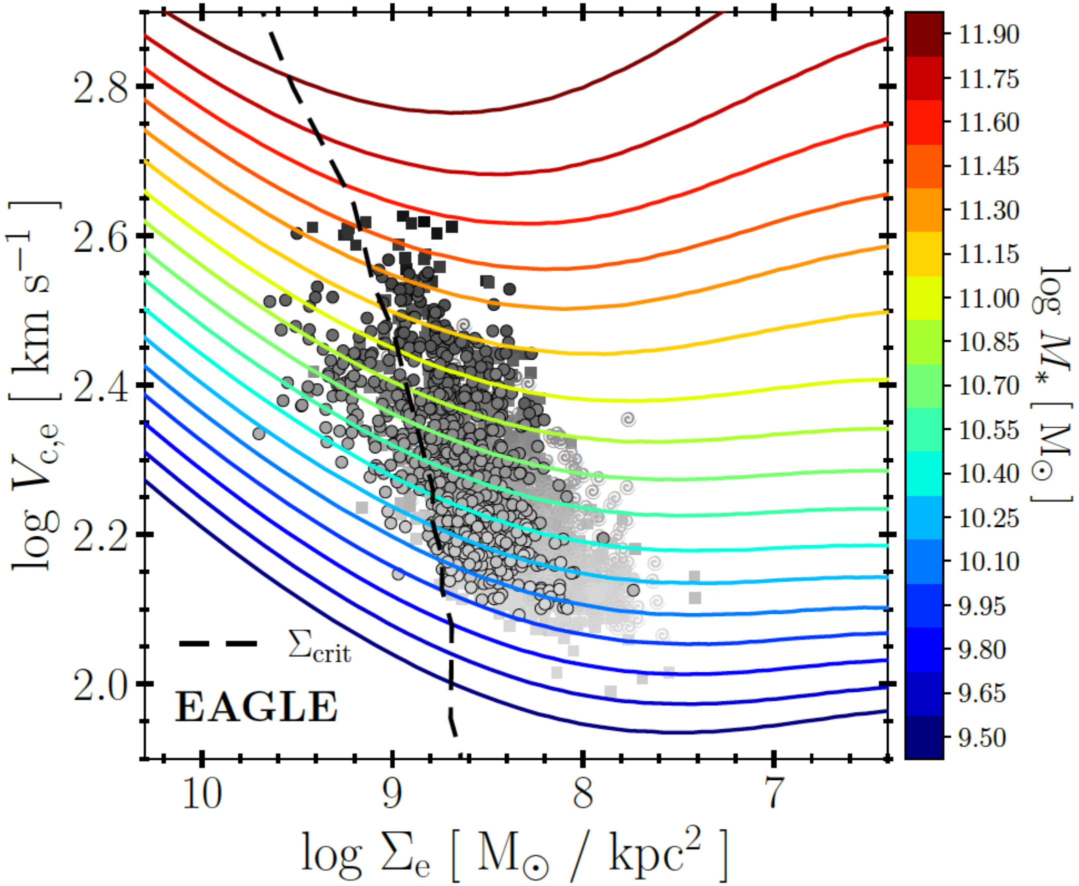
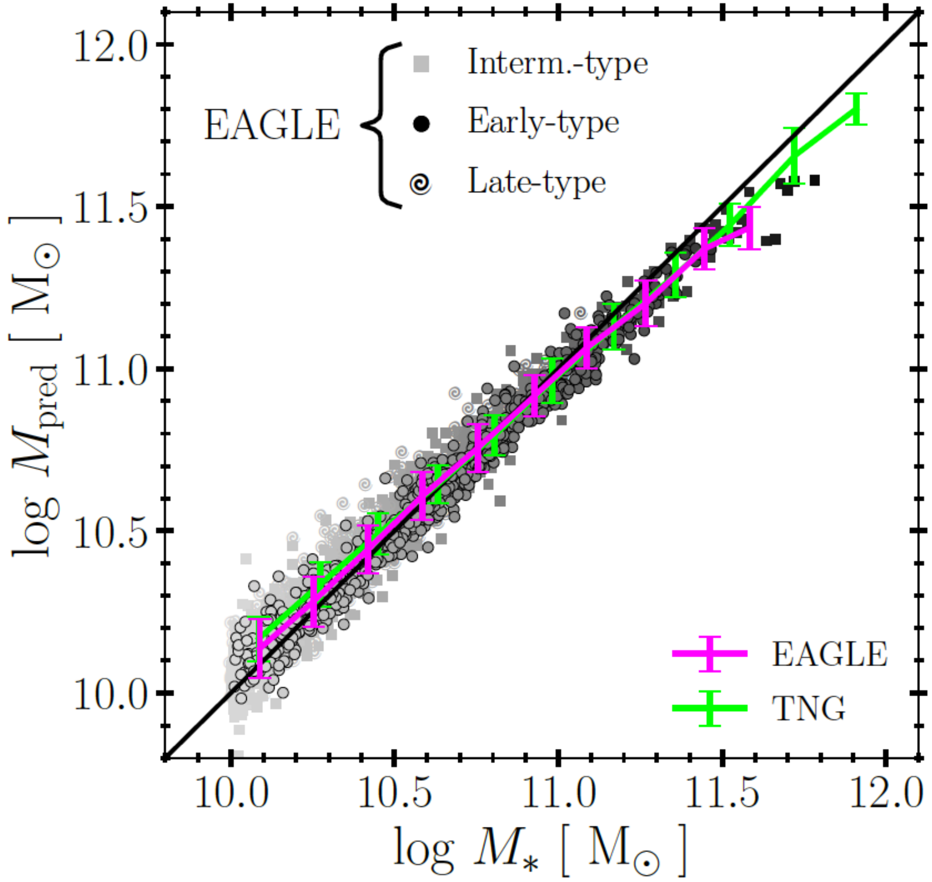
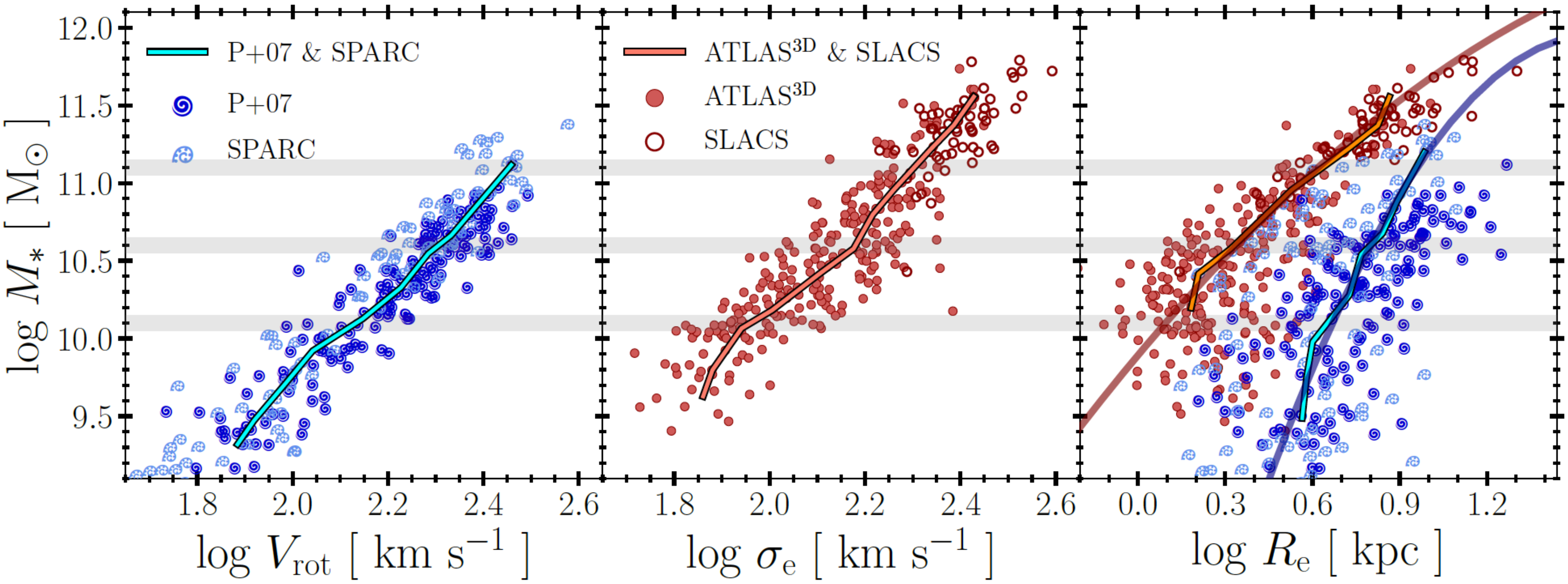
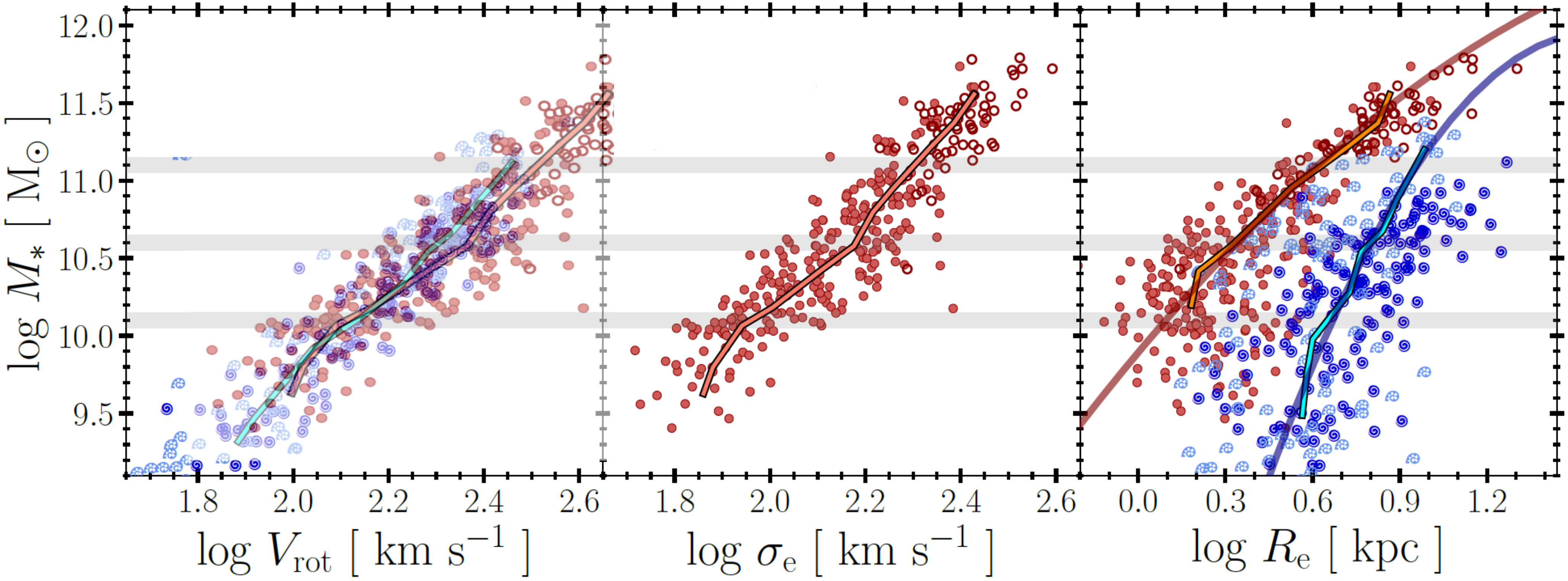




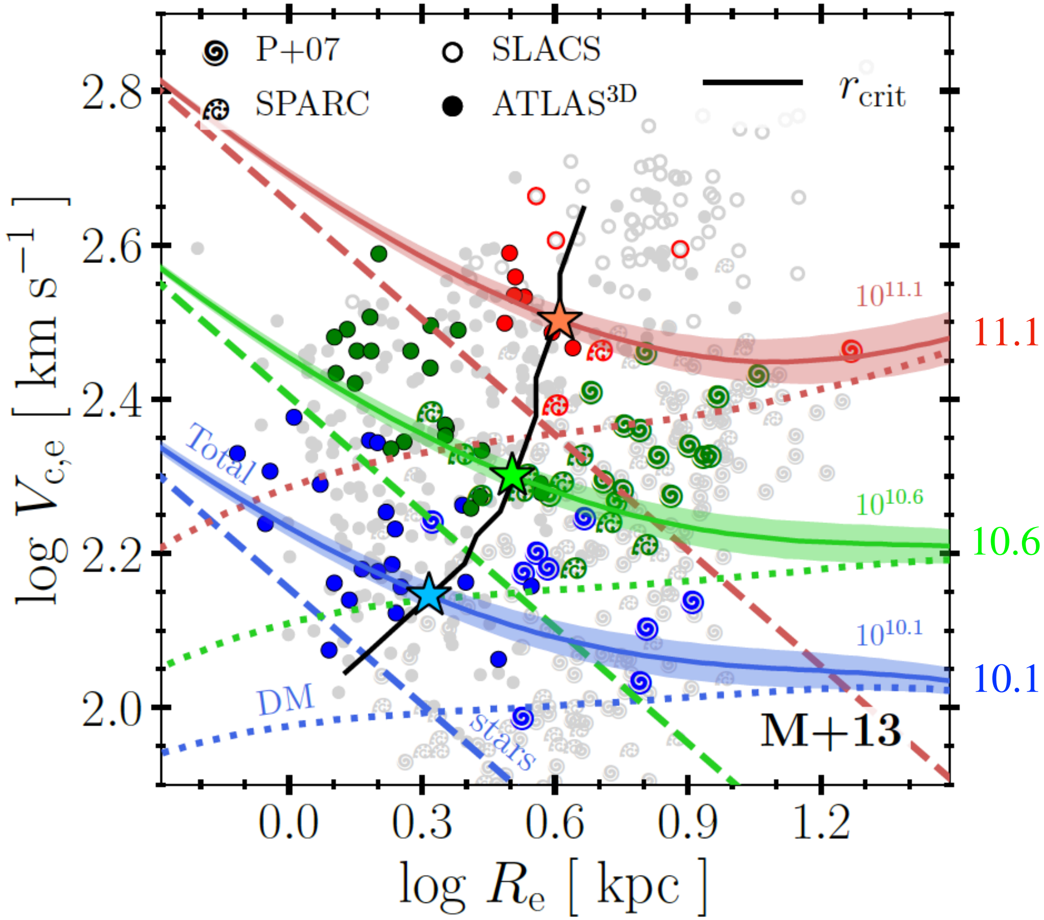
Observed Scaling Relations



Observed Scaling Relations

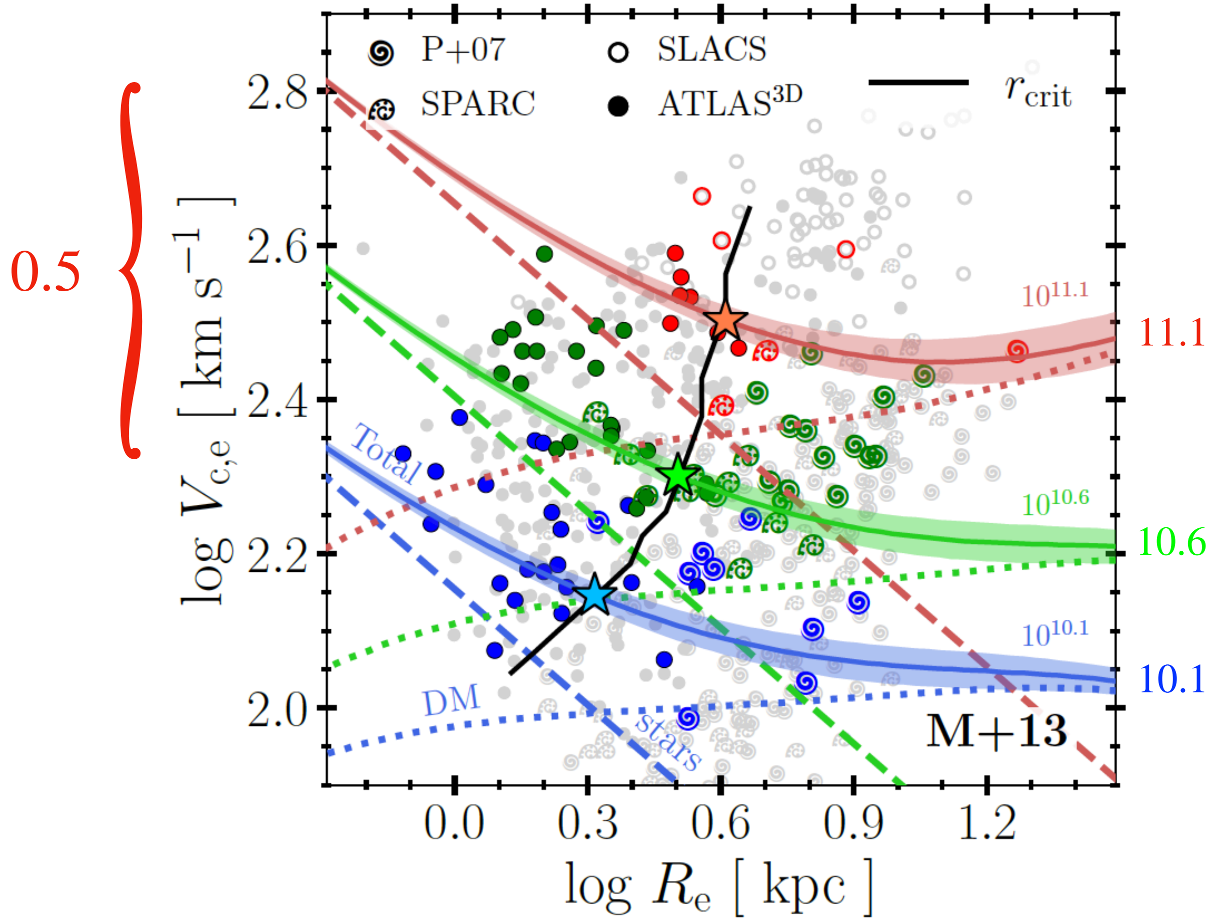


Velocity-Radius Relation



Velocity-Radius Relation

$$\frac{\Delta LogM}{\Delta LogV} \sim \frac{1.0}{0.5} \qquad M \sim V^2$$



Velocity-Radius Relation

$$\frac{\Delta LogM}{\Delta LogV} \sim \frac{1.0}{0.5} \qquad M \sim V^2$$

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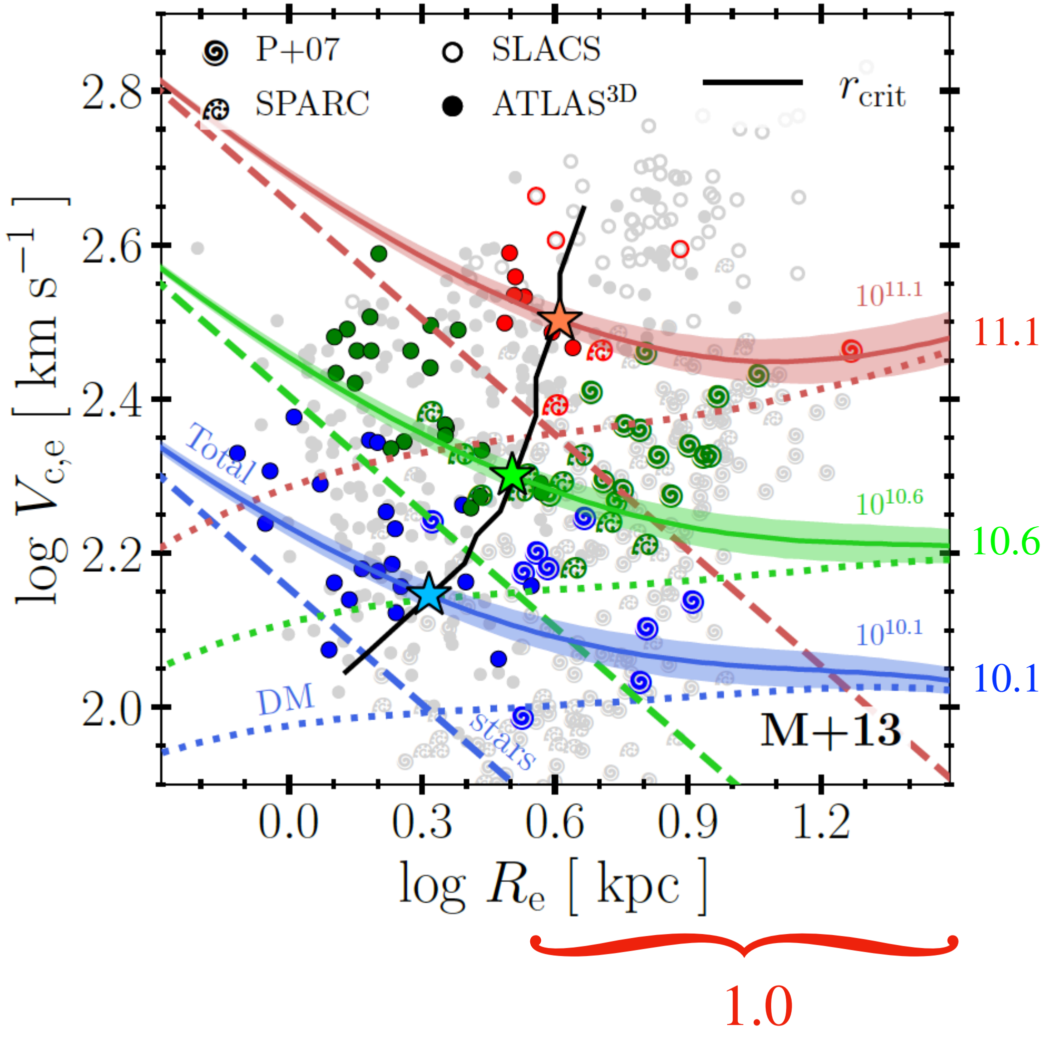

Velocity-Radius Relation

$$\frac{\Delta Log M}{\Delta Log V} \sim \frac{1.0}{0.5} \qquad M \sim V^2$$

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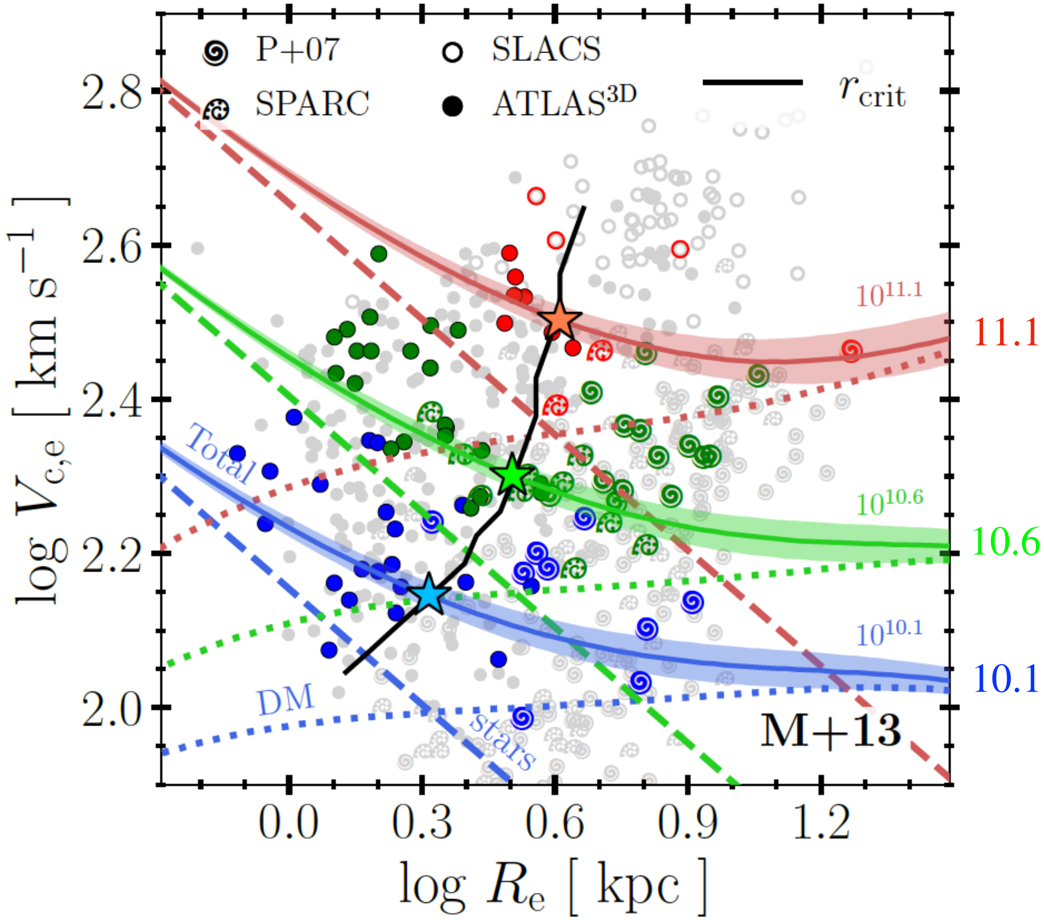
$M \sim V^2 R$ Fundamental Plane



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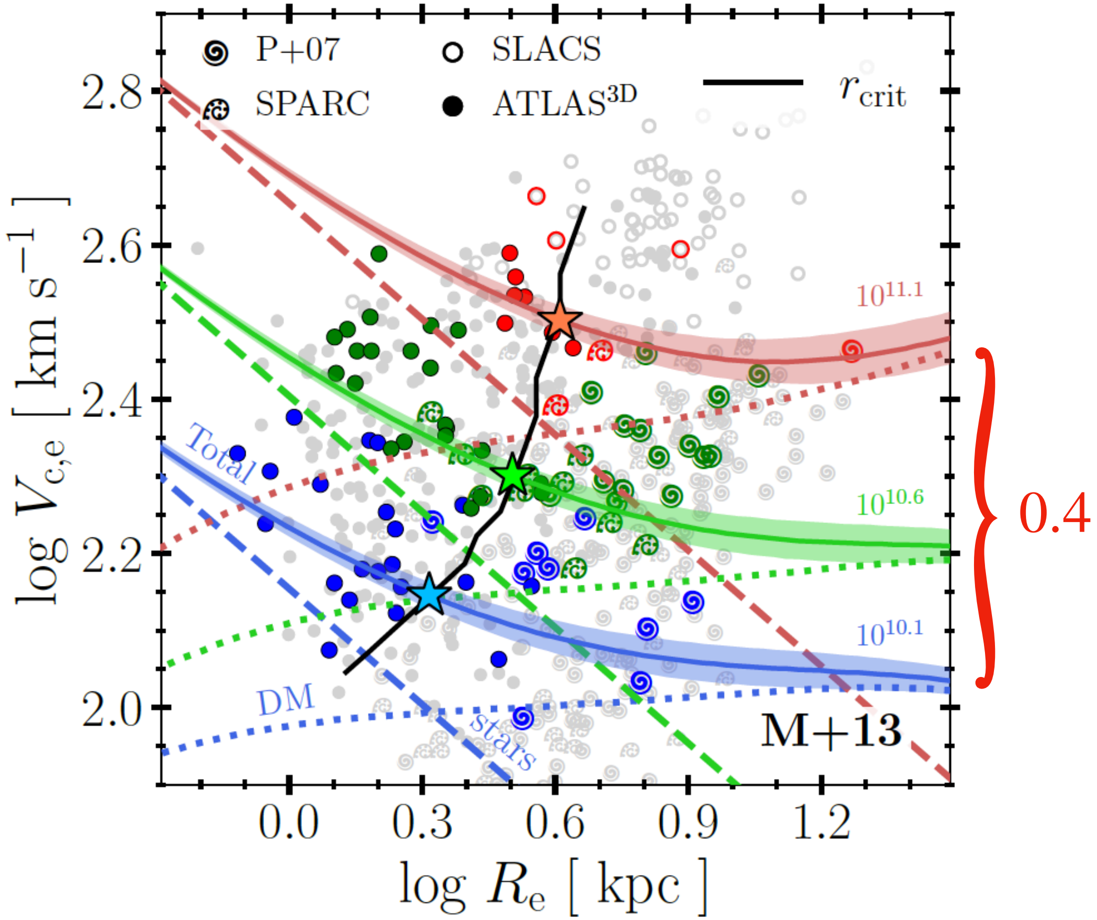
$M \sim V^2 R$ Fundamental Plane

$$\frac{\Delta LogM}{\Delta LogV} \sim \frac{1.0}{0.4} \qquad M \sim V^{2.5}$$



Velocity-Radius Relation

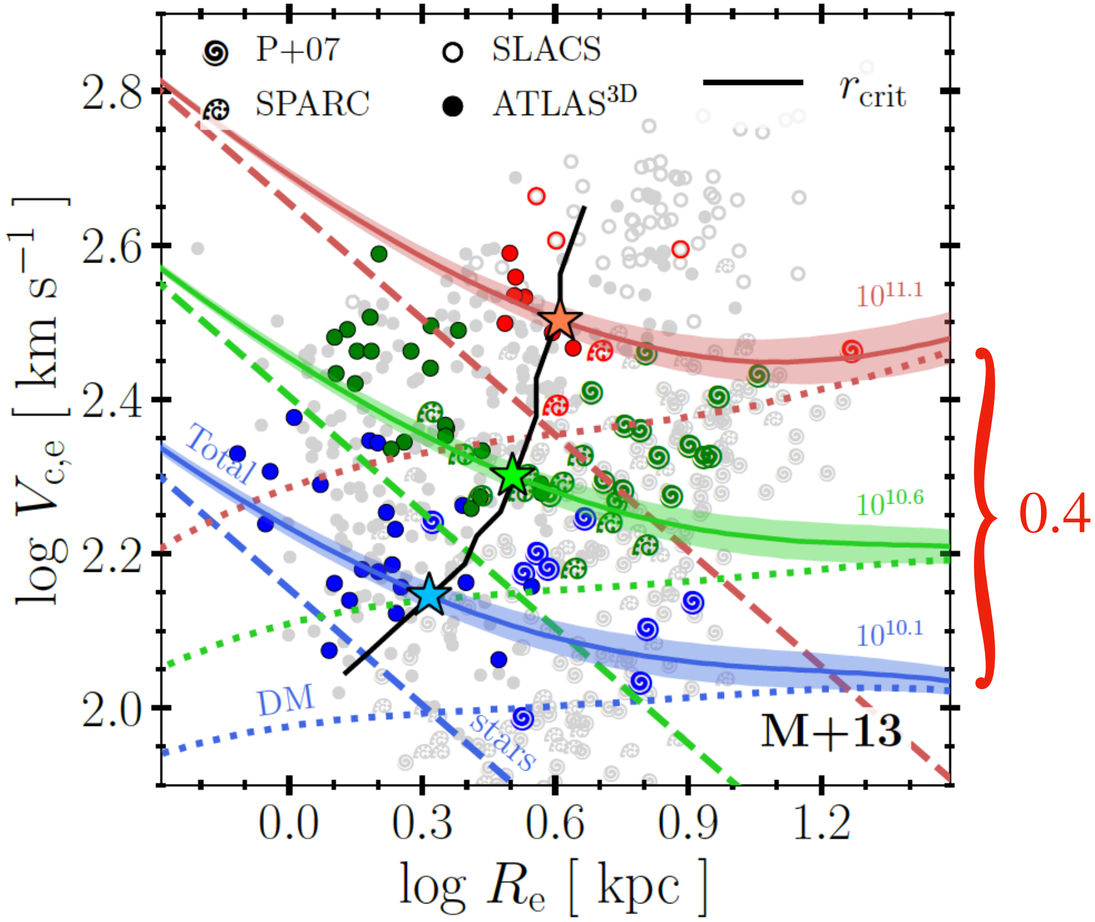
$$\frac{\Delta LogM}{\Delta LogV} \sim \frac{1.0}{0.5} \qquad M \sim V^2$$

$$\frac{\Delta LogM}{\Delta LogR} \sim \frac{1.0}{1.0} \qquad M \sim R$$

$M \sim V^2R$ Fundamental Plane

$$\frac{\Delta LogM}{\Delta LogV} \sim \frac{1.0}{0.4} \qquad M \sim V^{2.5}$$

$$\frac{\Delta LogM}{\Delta LogR} \sim \frac{1.0}{\infty} \qquad M \sim R^0$$



Velocity-Radius Relation

$$\frac{\Delta LogM}{\Delta LogV} \sim \frac{1.0}{0.5} \qquad M \sim V^2$$

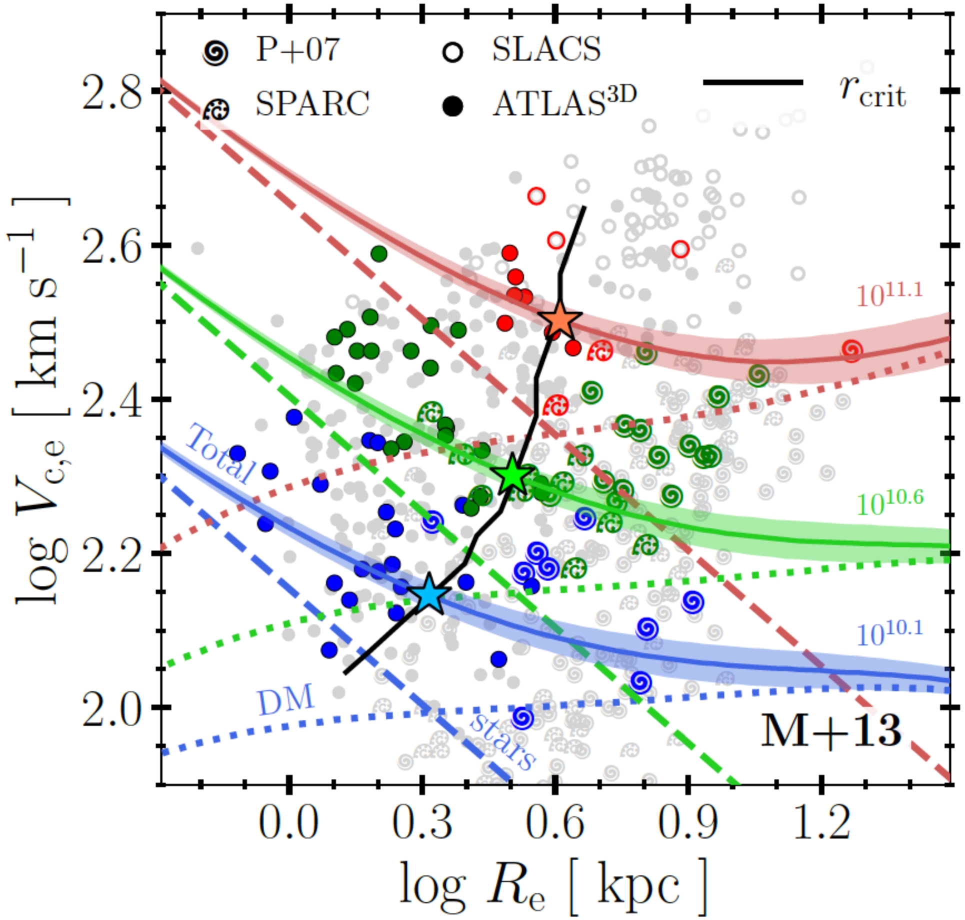
$$\frac{\Delta LogM}{\Delta LogR} \sim \frac{1.0}{1.0} \qquad M \sim R$$

$M \sim V^2 R$ Fundamental Plane

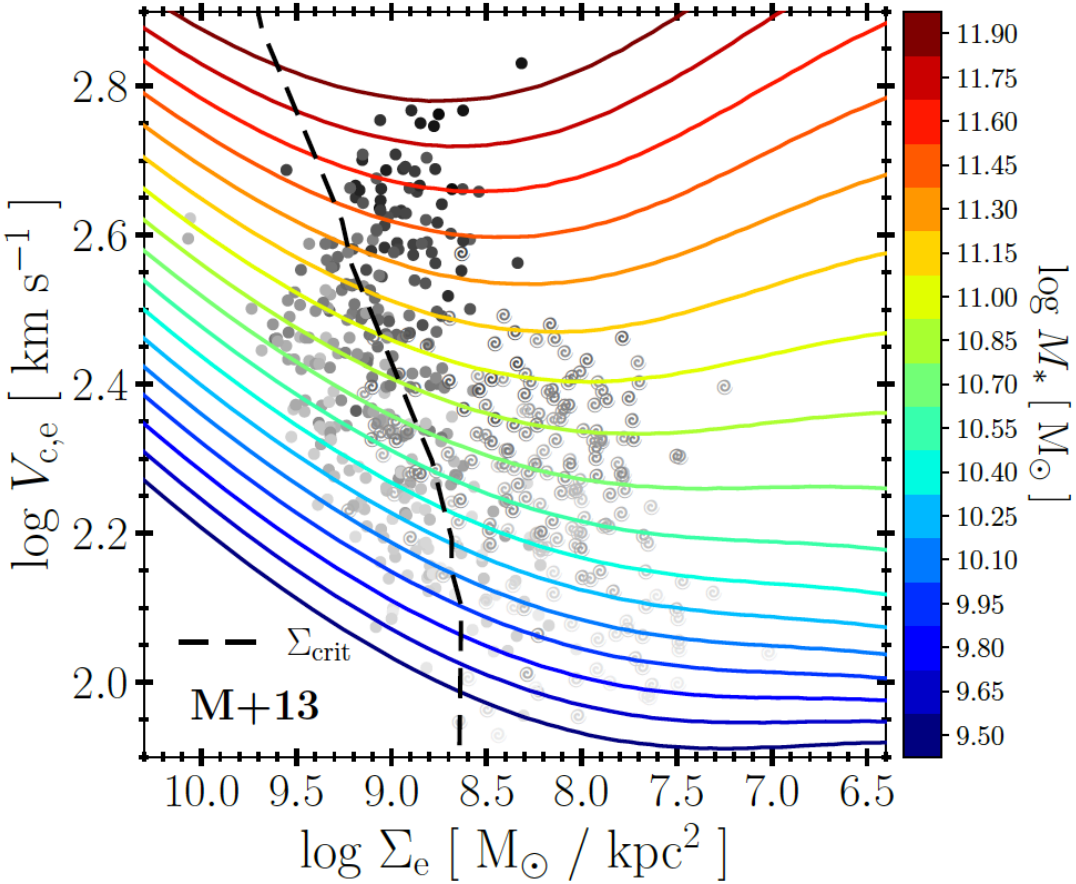
$$\frac{\Delta LogM}{\Delta LogV} \sim \frac{1.0}{0.4} \qquad M \sim V^{2.5}$$

$$\frac{\Delta LogM}{\Delta LogR} \sim \frac{1.0}{\infty} \qquad M \sim R^0$$

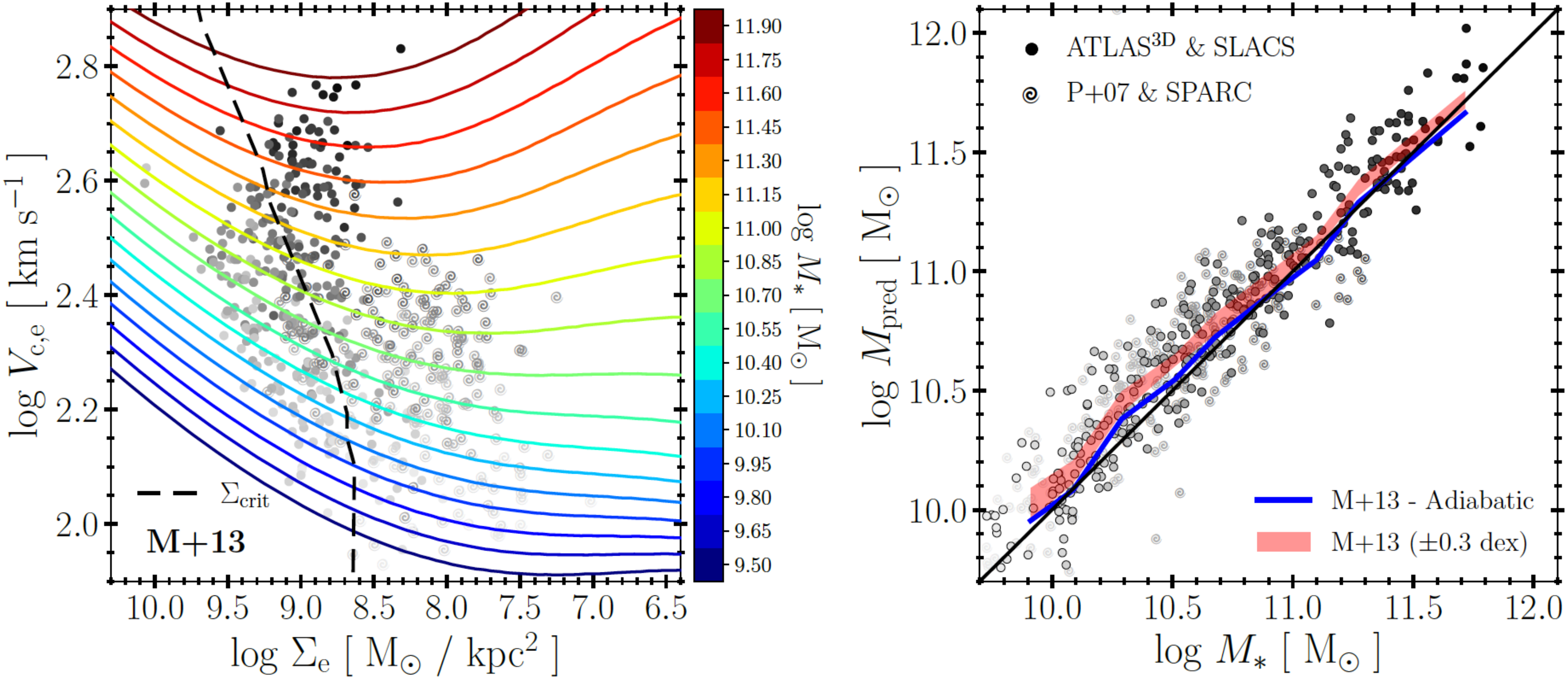
$M \sim V^{2.5}$ Tully-Fisher



Secondary Distance Indicator



Secondary Distance Indicator



Take-home Message

1) Tully-Fisher and Fundamental Plane scaling relations emerge as a consequence of the different dark matter content inside the effective radius

2) A unified distance indicator gives competitive results for all galaxies independent of the morphological type.