Organizing Galaxies

with Ann Zabludoff (Arizona) & Anthony Gonzalez (Florida)

Organizing Galaxies

Are the rules simple or complicated?

Rule : an early type galaxy is formed when a 3:1 or higher merger event happens if the satellite is on an plunging orbit with an impact parameter less than the stellar radius of the primary galaxy and neither galaxy has higher than a 10% gas fraction. Furthermore, the primary galaxy needs to reside in a DM halo that is sufficiently deep to heat up any residual gas and prohibit subsequent accretion of cold gas. If the progenitor primary is an S0 rather than and E, then the merger remnant will remain an S0 if and only if the satellite is at the low mass range (i.e. 3:1), otherwise it will dynamically disturb the disk sufficiently that it will become and E. If the progenitor has more than a 10% gas reservoir, then it will only become an early type galaxy if the merger also fuels the central AGN sufficiently that it the feedback from the AGN is sufficient to quench subsequent star formation. As such, the nature of the environment the galaxy resides in will play an additional role. If the intracluster or intragroup medium is sufficiently dense then it too will help remove the fuel reservoir and quench subsequent star formation. Additionally, early type formation is more likely in environments that provide “harassment”, ram pressure stripping or other unknown processes. Past history is no guarantee of future evolution. Early type formation does not occur where prohibited by law.

Organizing Galaxies

Are the rules simple or complicated?

Can progress be made?

What do the baryons do?

- accretion history (minor vs. merger, prograde/retrograde, radial/tangential, dynamical friction, tidal disruption of satellite,...)
- disk heating
- secular evolution (bulges, psuedobulges)
- outflow/infall of gas/metals
- feedback
- angular momentum redistribution
- magnetic fields
- environment (local/global)
- star formation history (+ IMF, SF threshold, etc.)
- multiphase ISM
- local ionization field (delayed formation)
- multiple dynamical components
- effects of varying metallicity

Organizing Galaxies

Are the rules simple or complicated?

Can progress be made?

What do the baryons do?

What fraction form stars?

How do they settle in DM halos?

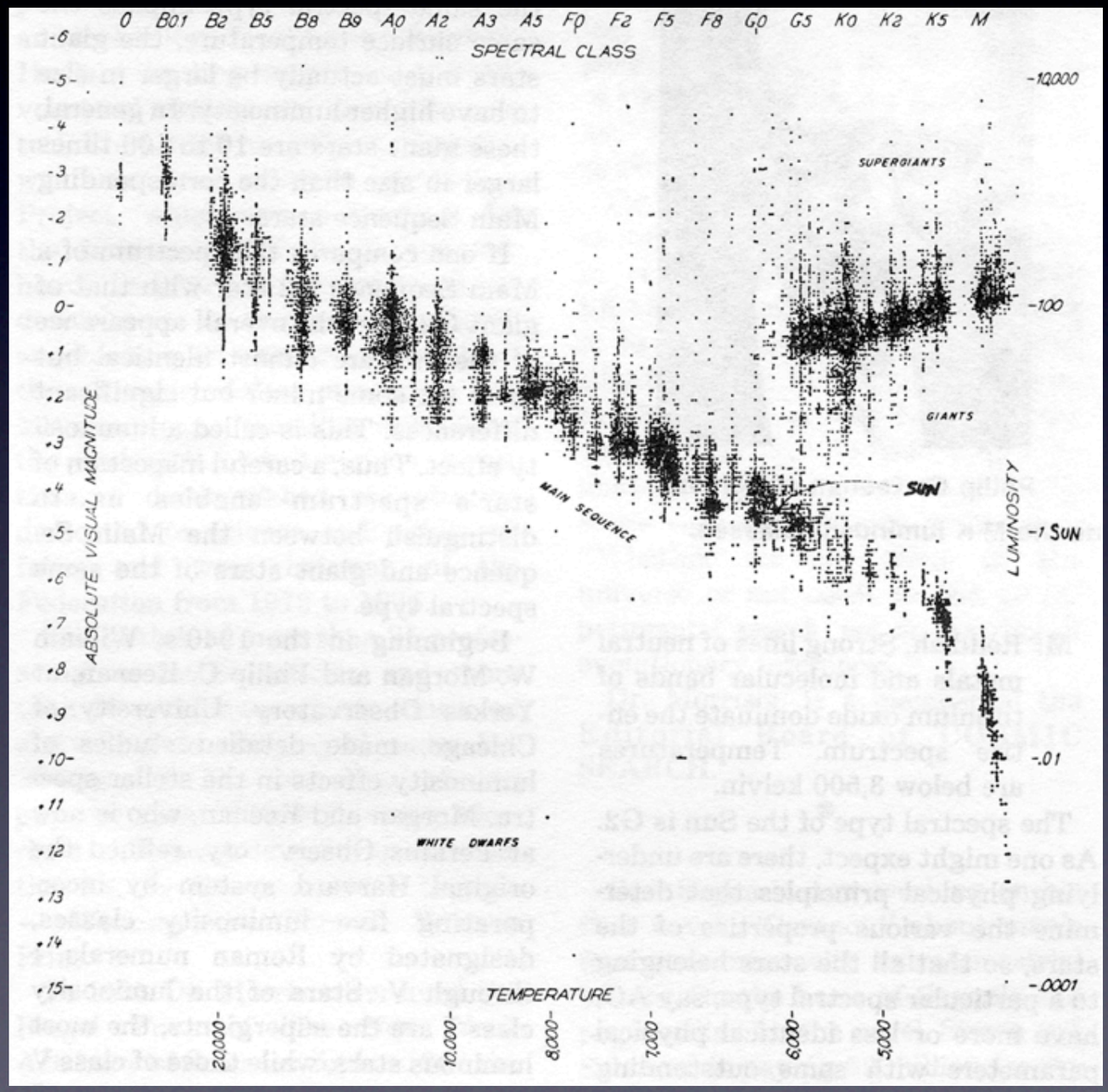
Lessons from Stellar Structure

Equilibria identified

1-D sequence in 2-D space implies one driving parameter

Problem of structure separated from that of formation

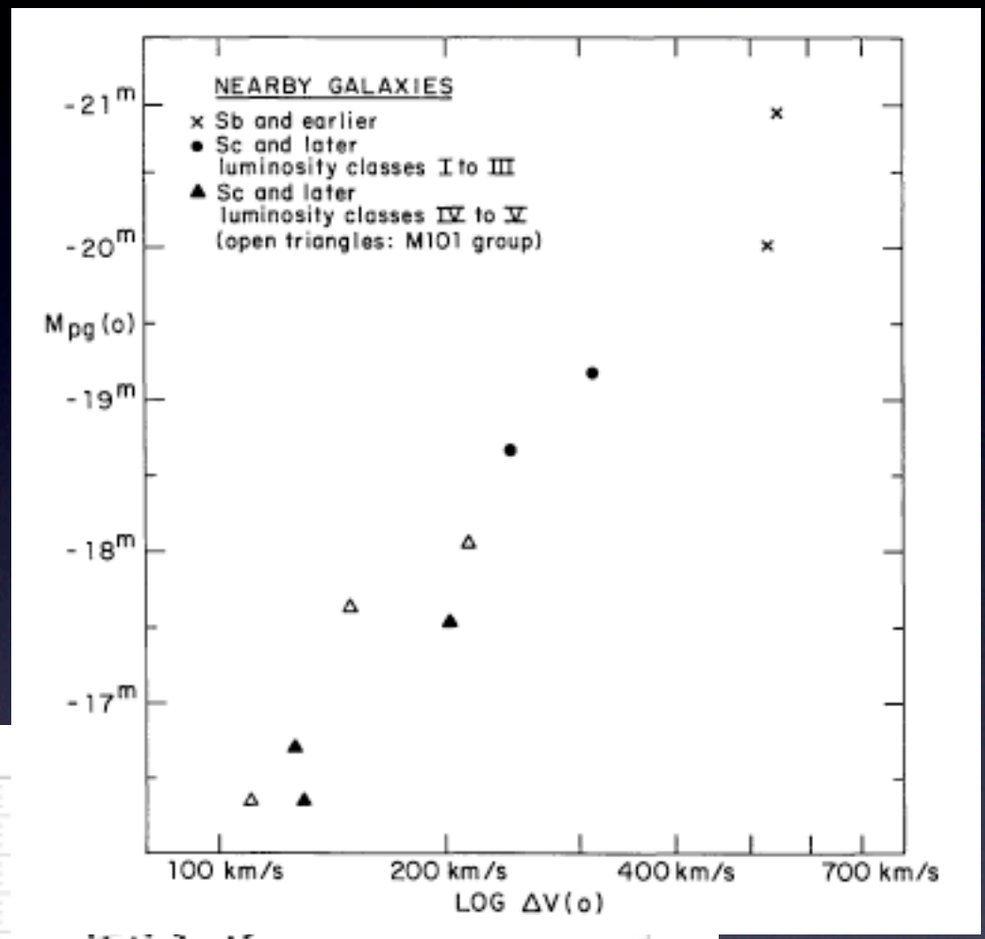
luminosity



spectral type or color

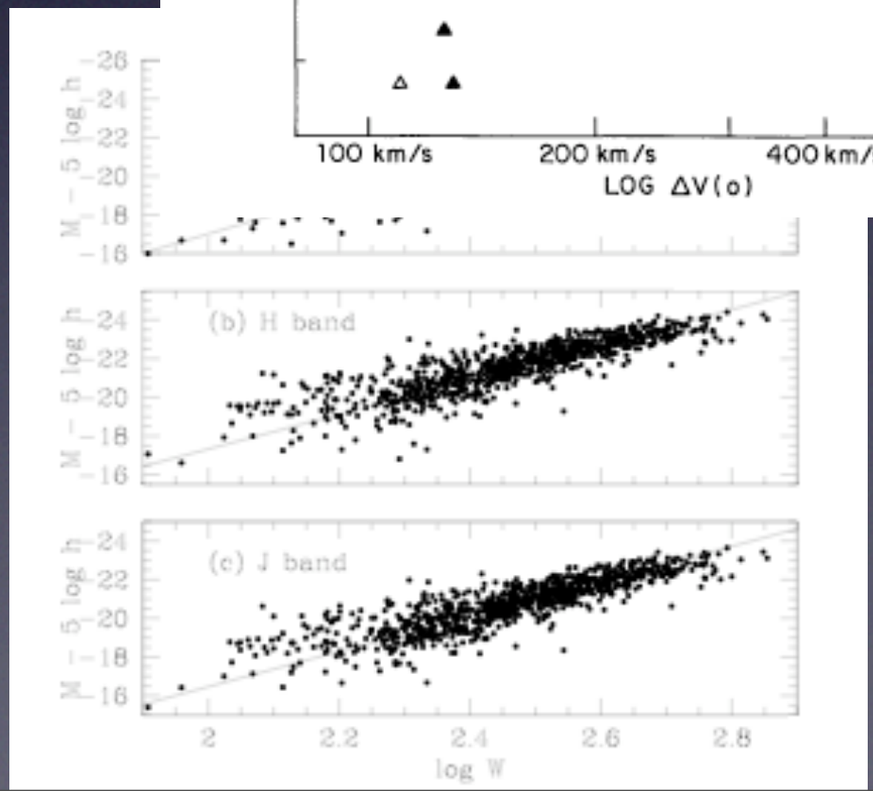
Prospects for Galactic Structure

Tully & Fisher 1977



Tully-Fisher

Masters et al. 2008

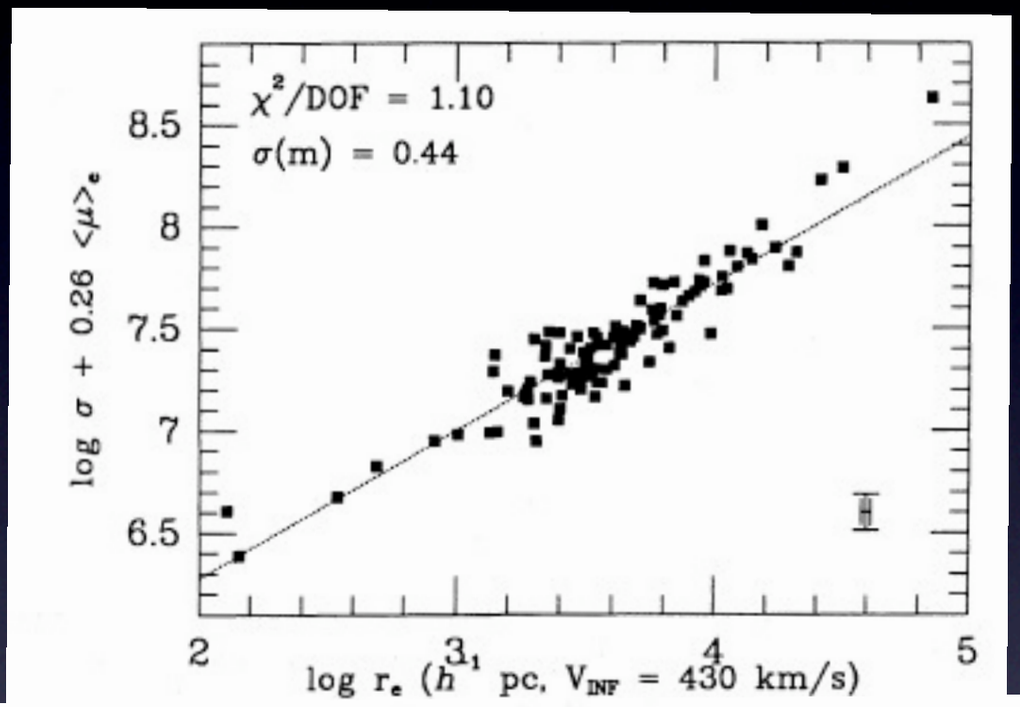


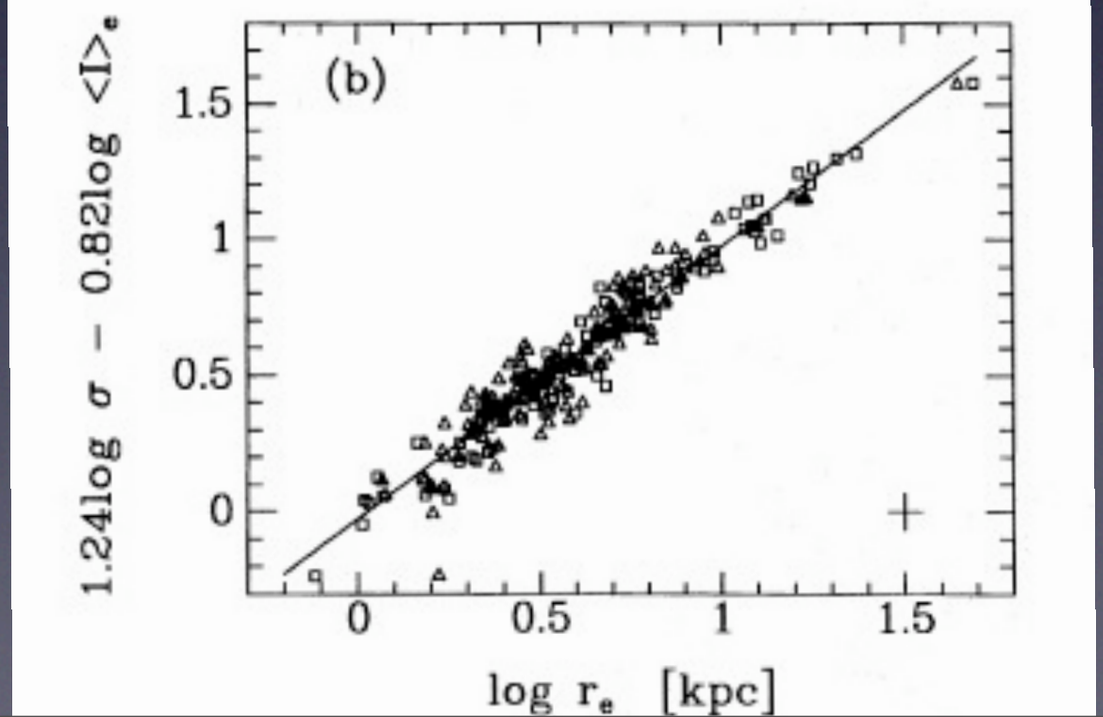
Prospects for Galactic Structure

Djorgovski & Davis (1987)

Fundamental Plane

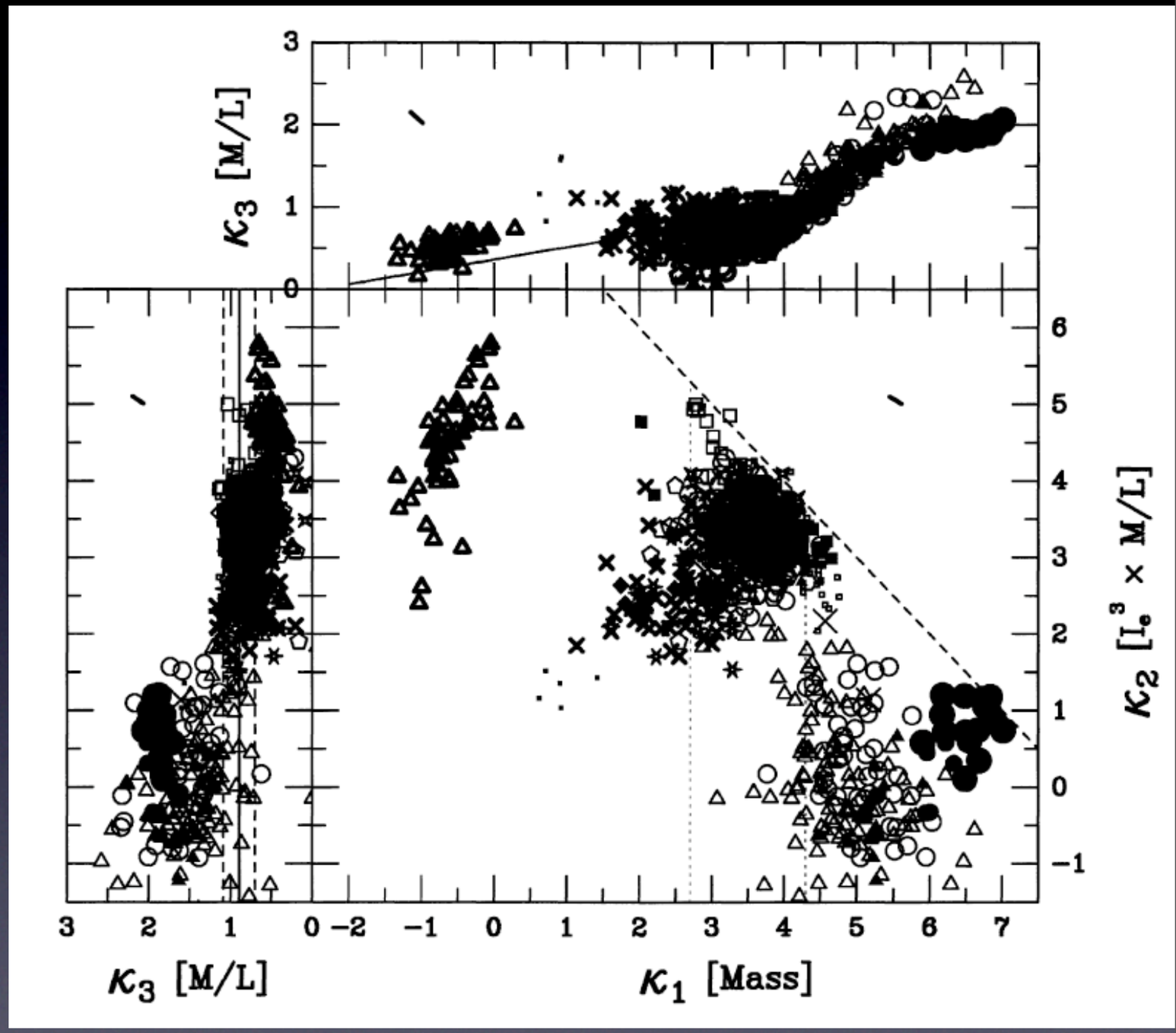
Jørgensen, Franx, Kjœrgaard (1996)





A Grand Unification?

"In reality, there is probably a continuum of fundamental planes, just as we know there is a continuum of Hubble types, but we simplify them here to just three."



Burstein et al. 1997

So where are we?

There appear to simple rules of structure
(at least for certain galaxy types)

Unification lacking (if possible)

Difficult to merge with basic physical model

Back to Basics

$$2T + \Pi + W = 0$$

Tensor Virial Thm

$$2T + \Pi + W = 0$$

Tensor Virial Thm

$$\sum v_i^2 = A_0 v_s^2$$

systemic (bulk) motion

Details of integral (or sum) over all particles absorbed in A_0

$$2T + \Pi + W = 0$$

Tensor Virial Thm

$$\sum v_i^2 = A_1 \sigma^2$$

random motion

Details of integral (or sum) over all particles absorbed in A_1

$$2T + \Pi + W = 0$$

Tensor Virial Thm

$$\sum_{ij} \frac{Gm_j}{r_{ij}} = B\frac{GM}{r_e}$$

potential energy

Details of integral (or sum) over all particles absorbed in B

$$2T + \Pi + W = 0$$

Tensor Virial Thm

$$A_0 v_s^2 + A_1 \sigma^2 = \frac{BGM}{r_e}$$

$$A\left(\frac{v_c^2}{2} + \sigma^2\right) = \frac{BG(\Upsilon_e \pi r_e^2 I_e)}{r_e}$$

$$\uparrow \equiv V^2$$

isotropic, isothermal

$$\log r_e = \log V^2 - \log I_e - \log \Upsilon_e + \log A - \log B + C$$

$$2T + \Pi + W = 0$$ Tensor Virial Thm

$$A_0 v_s^2 + A_1 \sigma^2 = \frac{BGM}{r_e}$$

$$A(\frac{v_c^2}{2} + \sigma^2) = \frac{BG(\Upsilon_e \pi r_e^2 I_e)}{r_e}$$ isotropic, isothermal

$$\uparrow \equiv V^2$$

$$\equiv \Delta$$

$$\log r_e = \log V^2 - \log I_e - (\log \Upsilon_e + \log A - \log B + C)$$

Data

Spheroids:

normal ellipticals (Jørgensen et al. 1996,
SDSS/DR5 NYU-VA, Blanton et al.)

dE's (Matkovic & Guzman 2005, Geha et al. 2003)

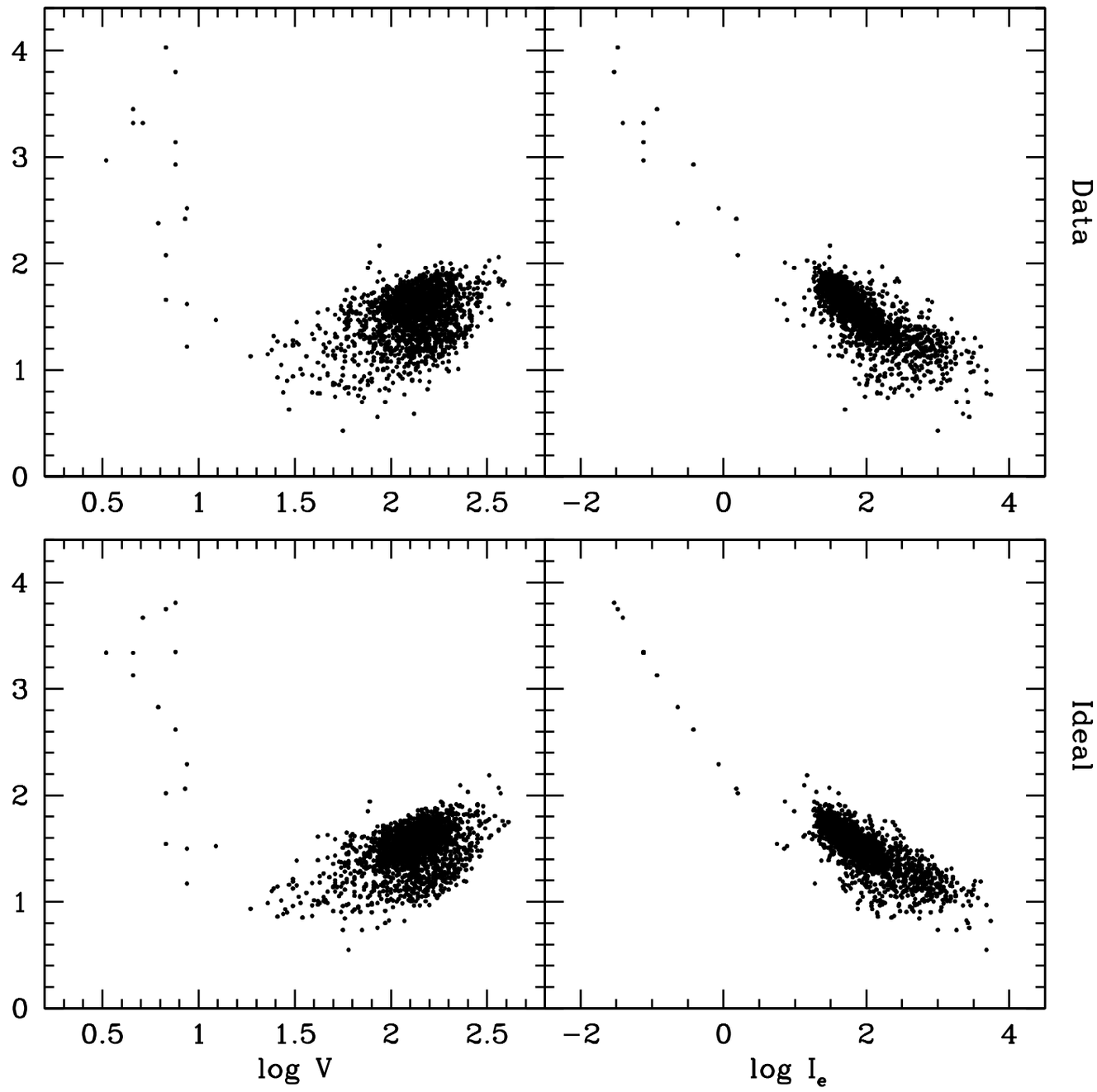
dSphs (Mateo 1998, Simon & Geha 2007)

UCD (Mieske et al. 2007)

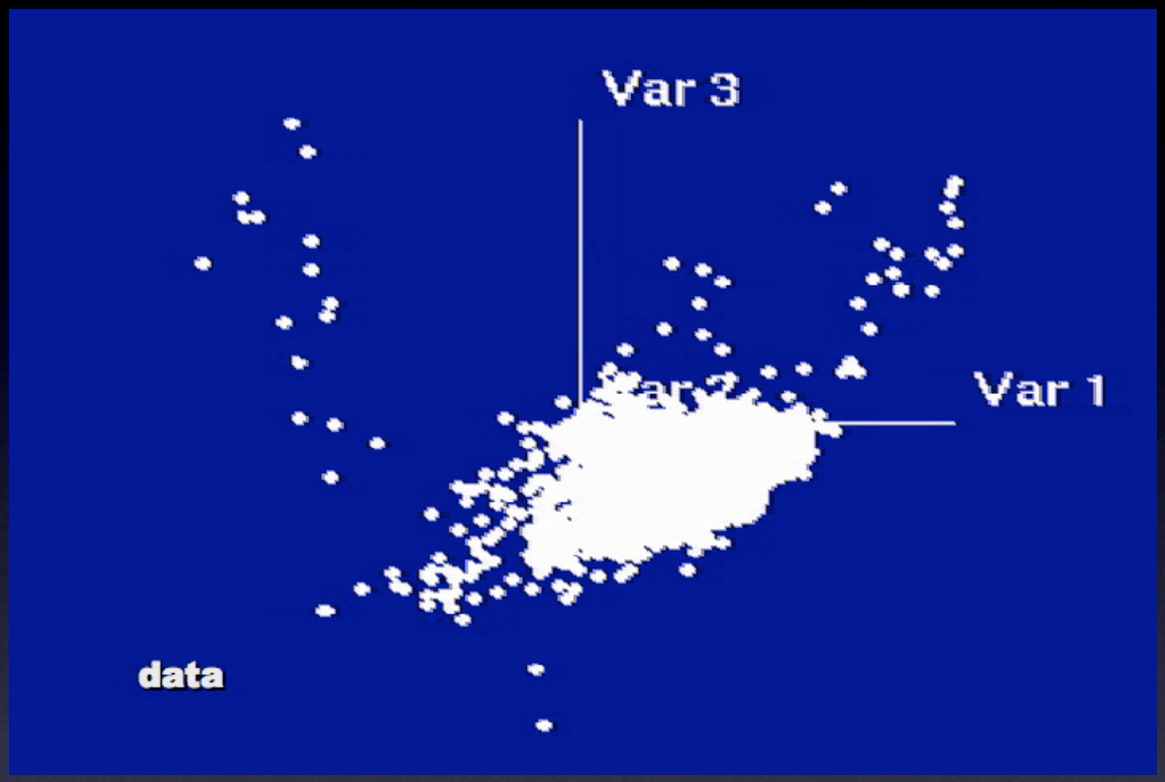
Disks:

HI rotation (Springob et al. 2007)

optical rot. curves (Pizagno et al. 2007 (SDSS),
Courteau et al. 2007)



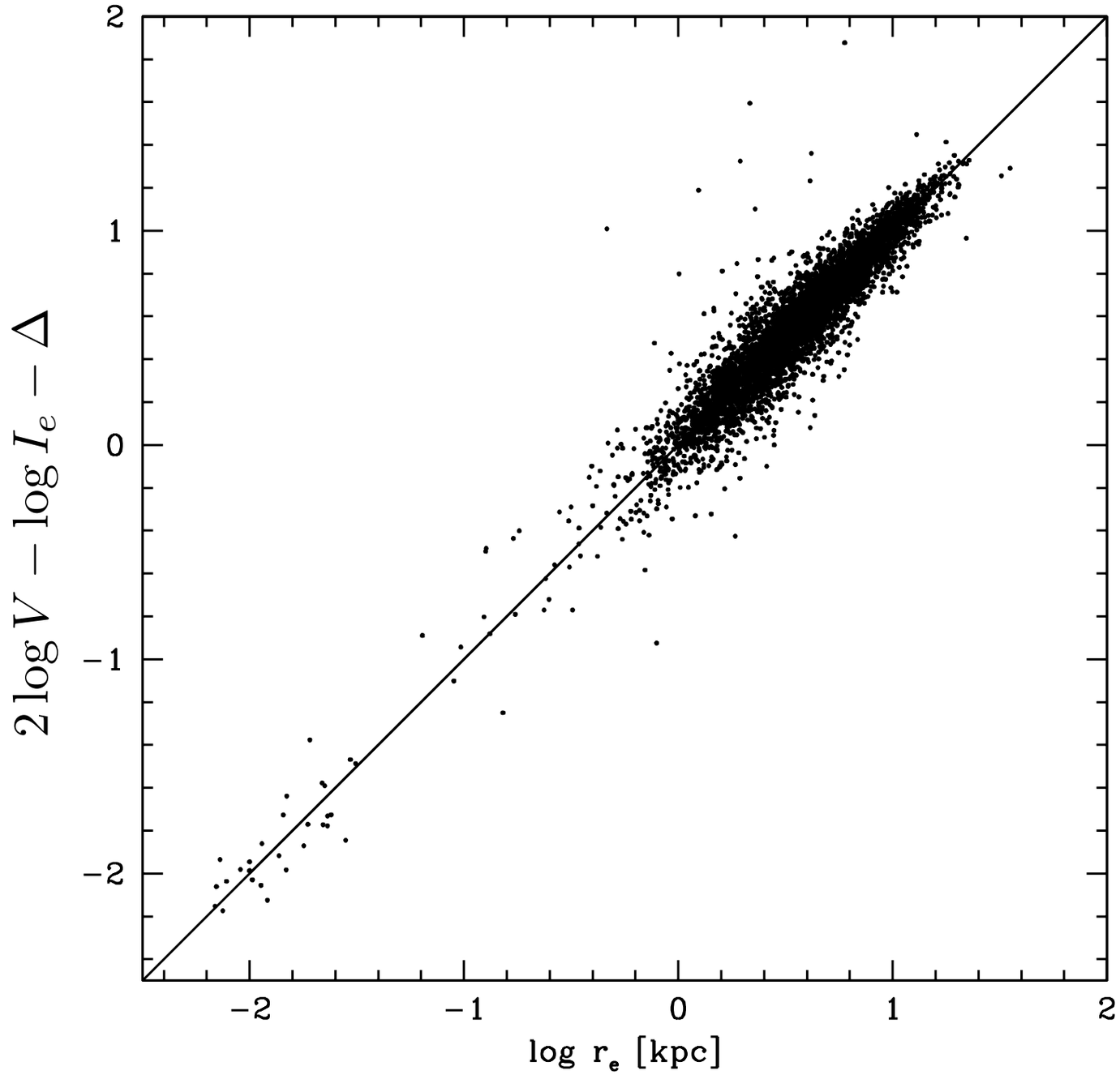
log V log I_e

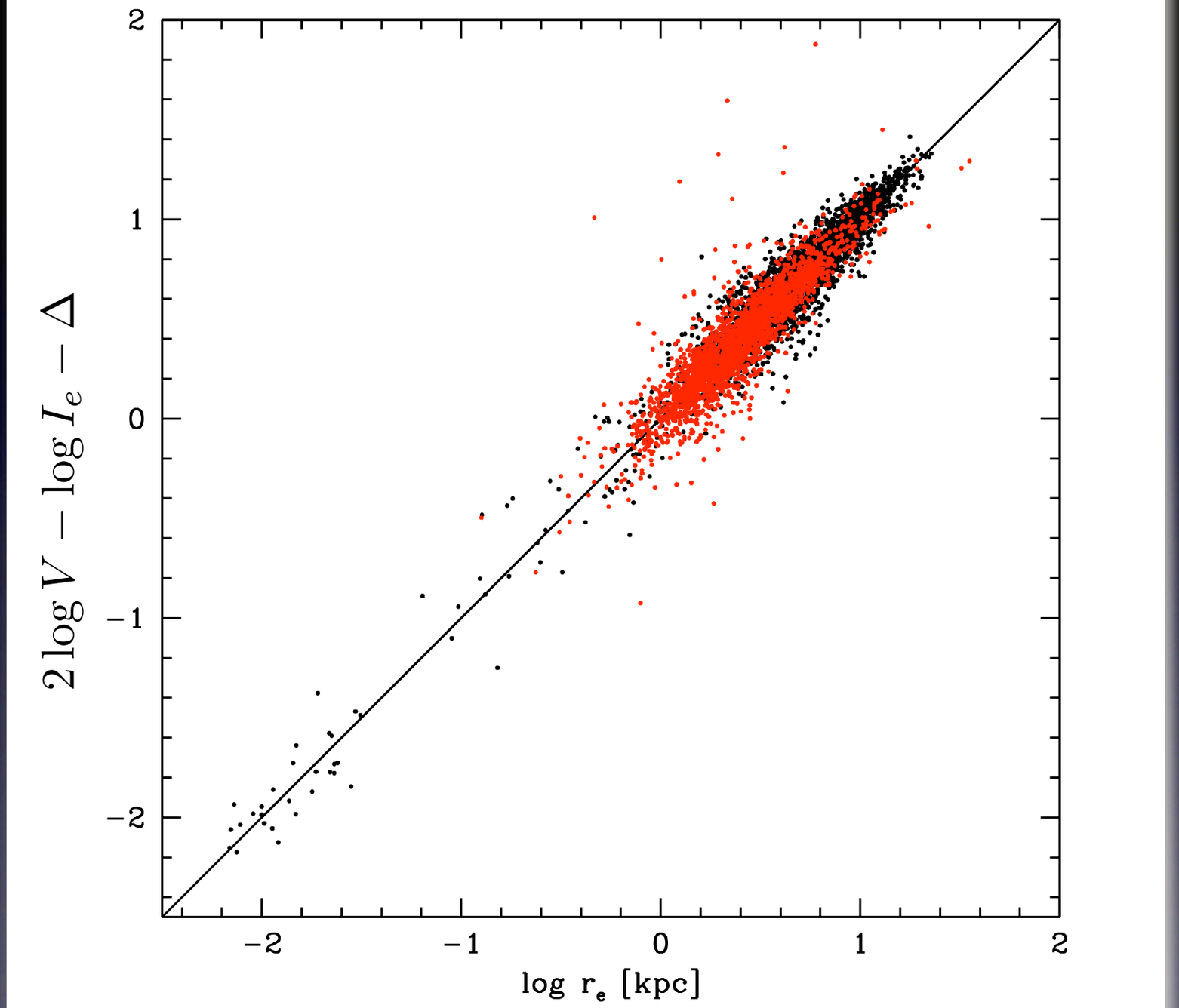


Var 1 = V

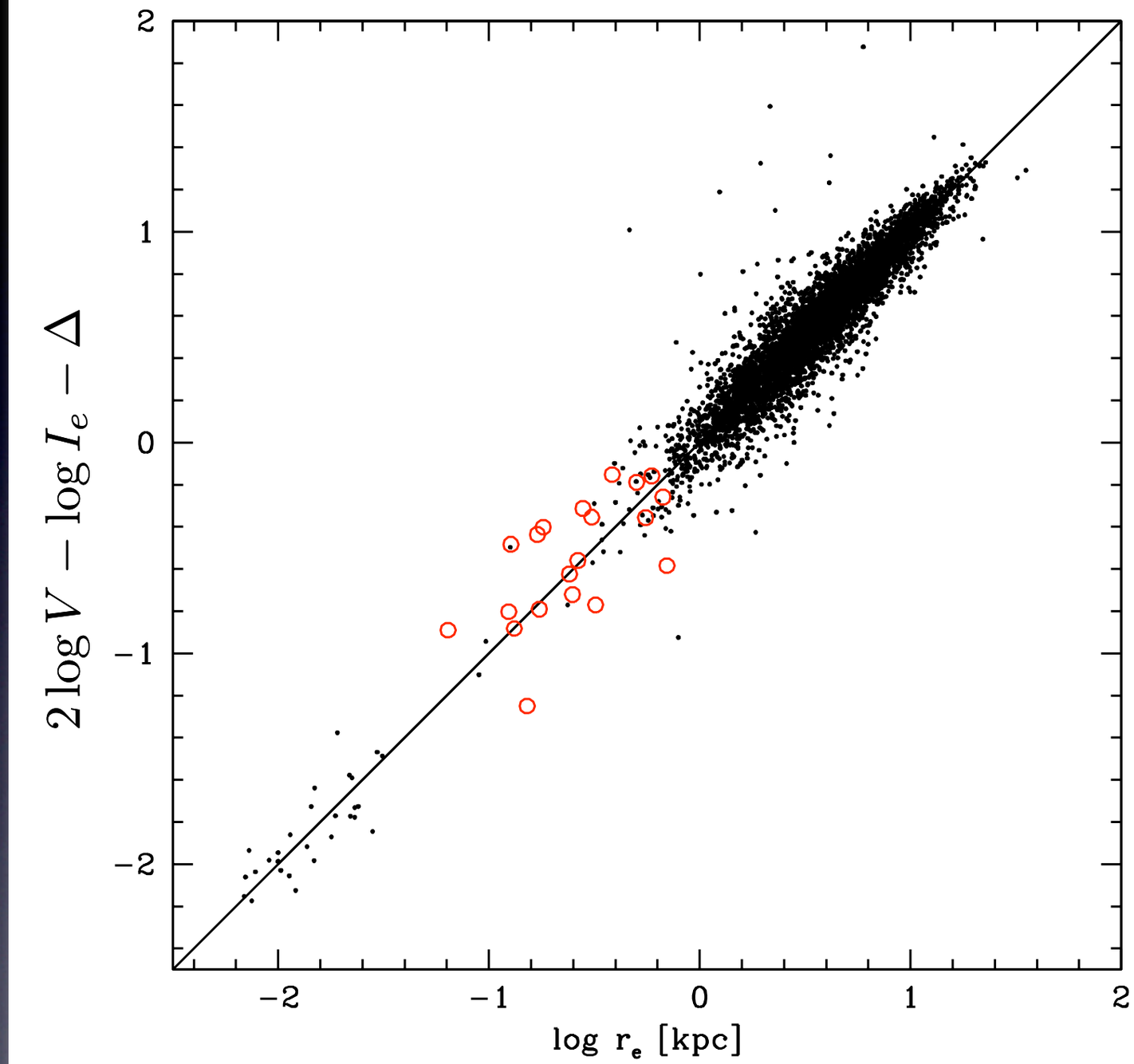
Var 2 = I_e

Var 3 = Δ

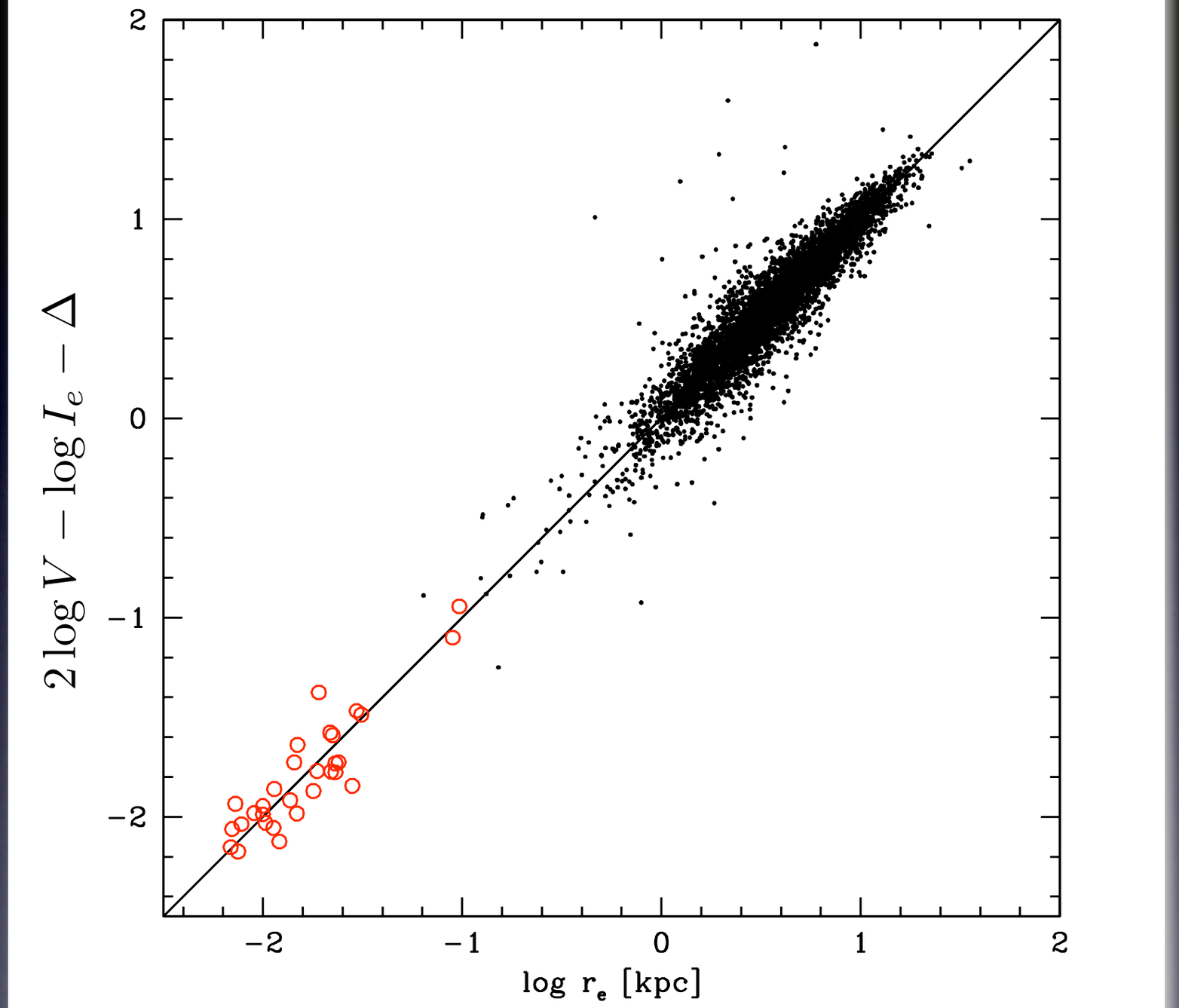

2
1
0
−1
−2
−2
−1
0
1
2
$2\log V - \log I_e - \Delta$
log r_e [kpc]



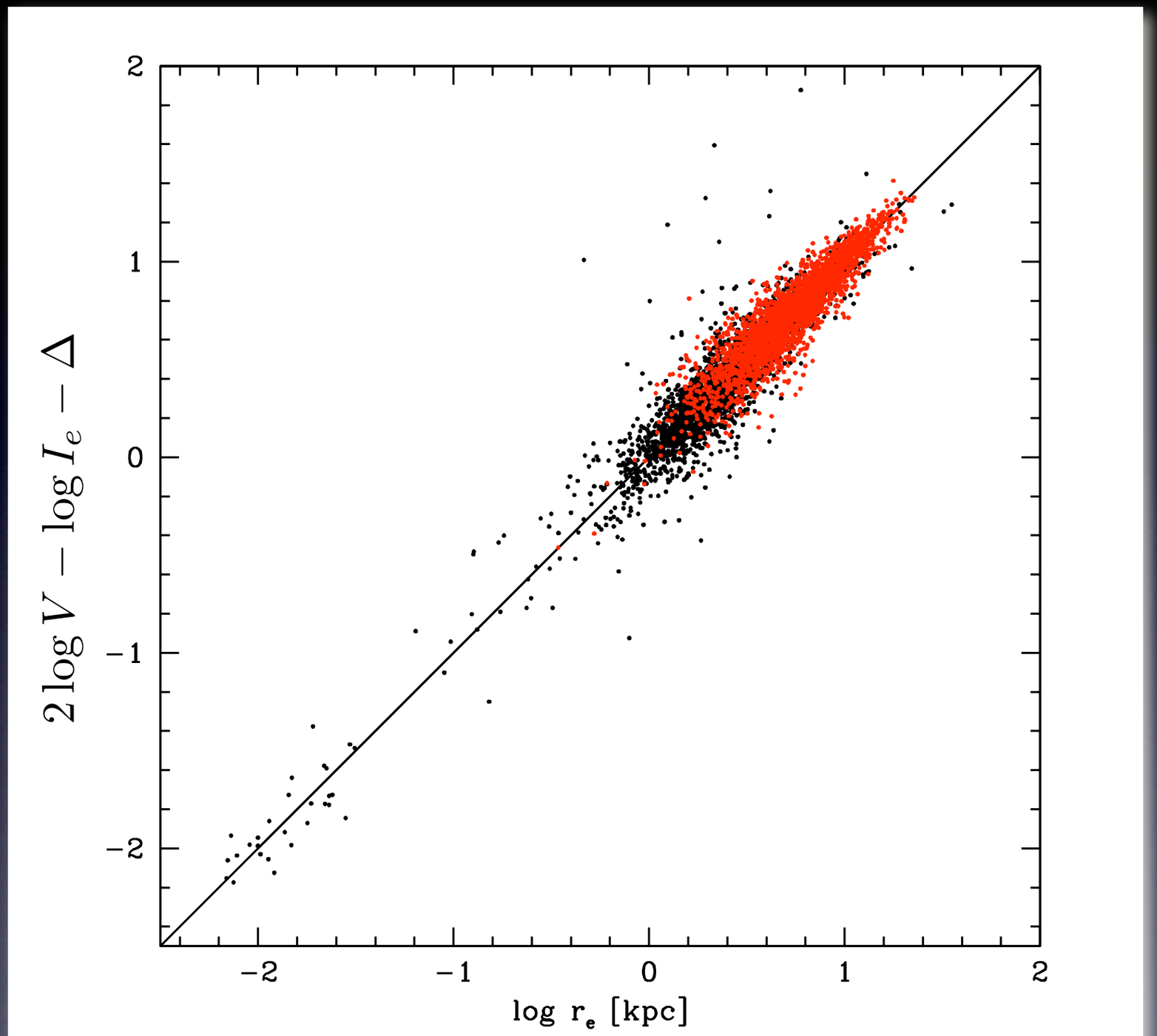
Ellipticals



dwarf Spheroidals



Ultracompact dwarfs



Spirals

So where are we?

I. All types of galaxies satisfy

$$\log r_e = \log V^2 - \log I_e - \Delta$$

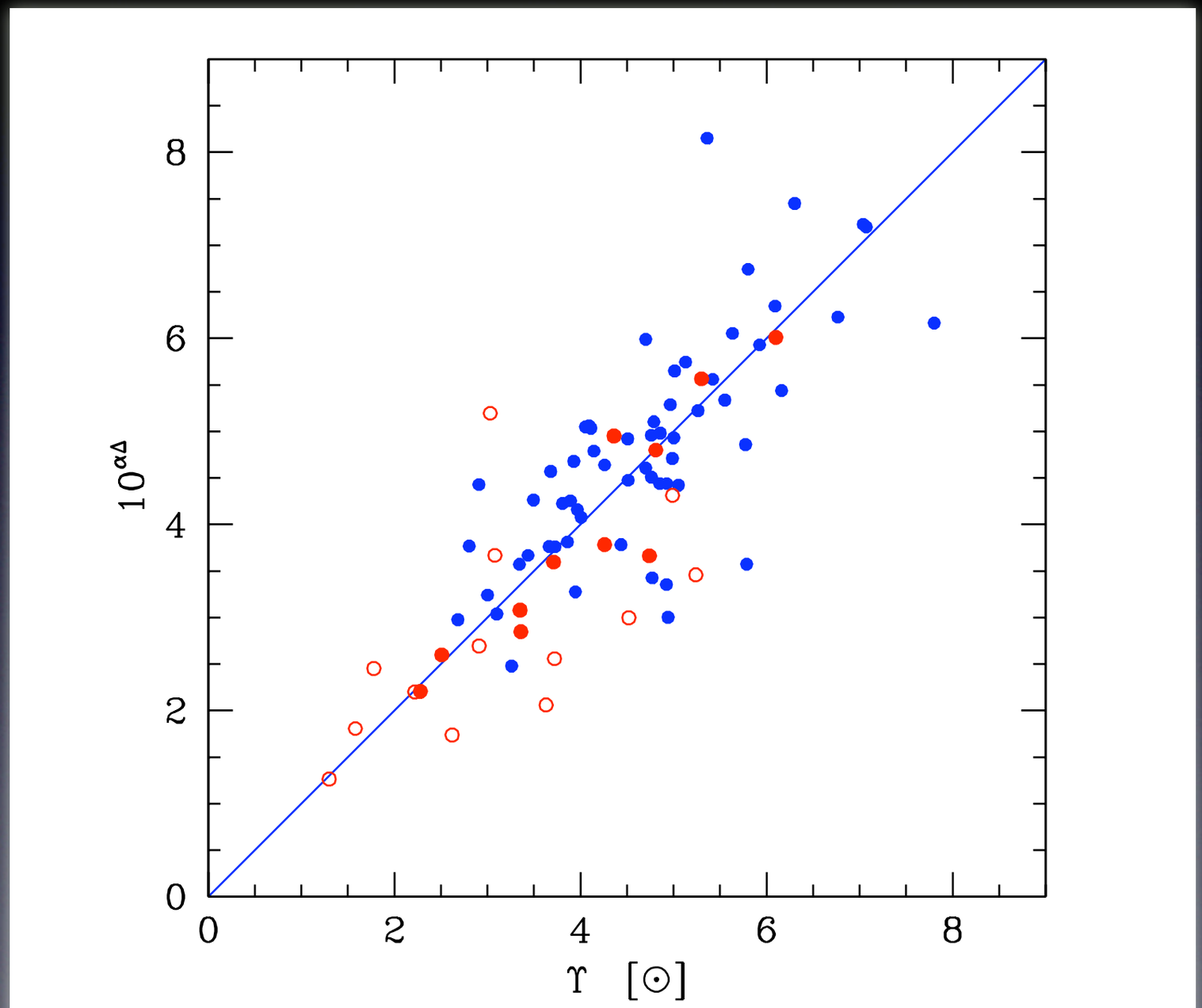
II. Δ is a function of V and I_e

III. Galaxies fall on a 2-D sequence in a 3-D space, therefore two parameters are the principal drivers of their equilibrium structure

Where do we need to go?

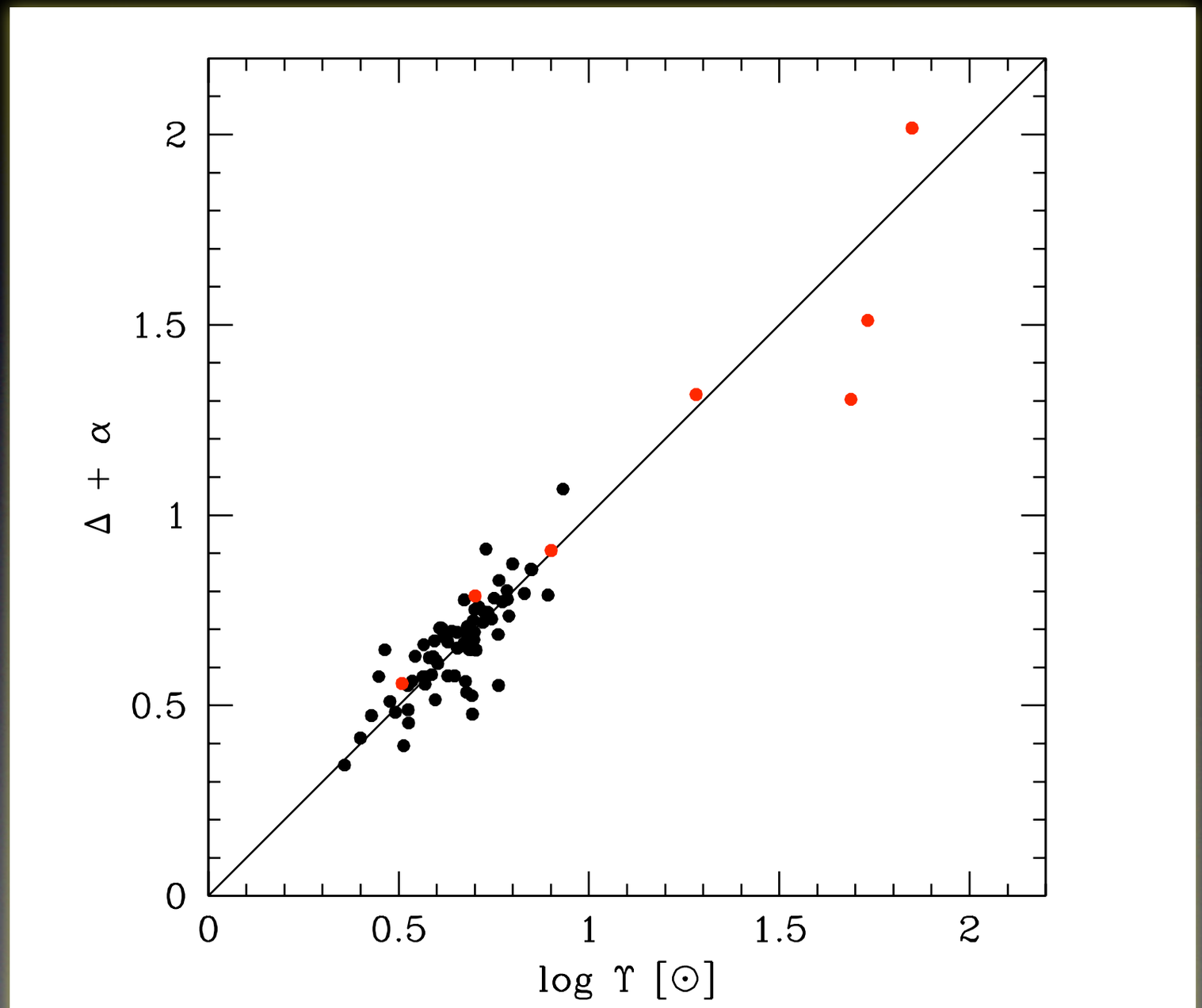
What is Δ ?

$$\Delta = \log \Upsilon_e - \log A + \log B - C$$



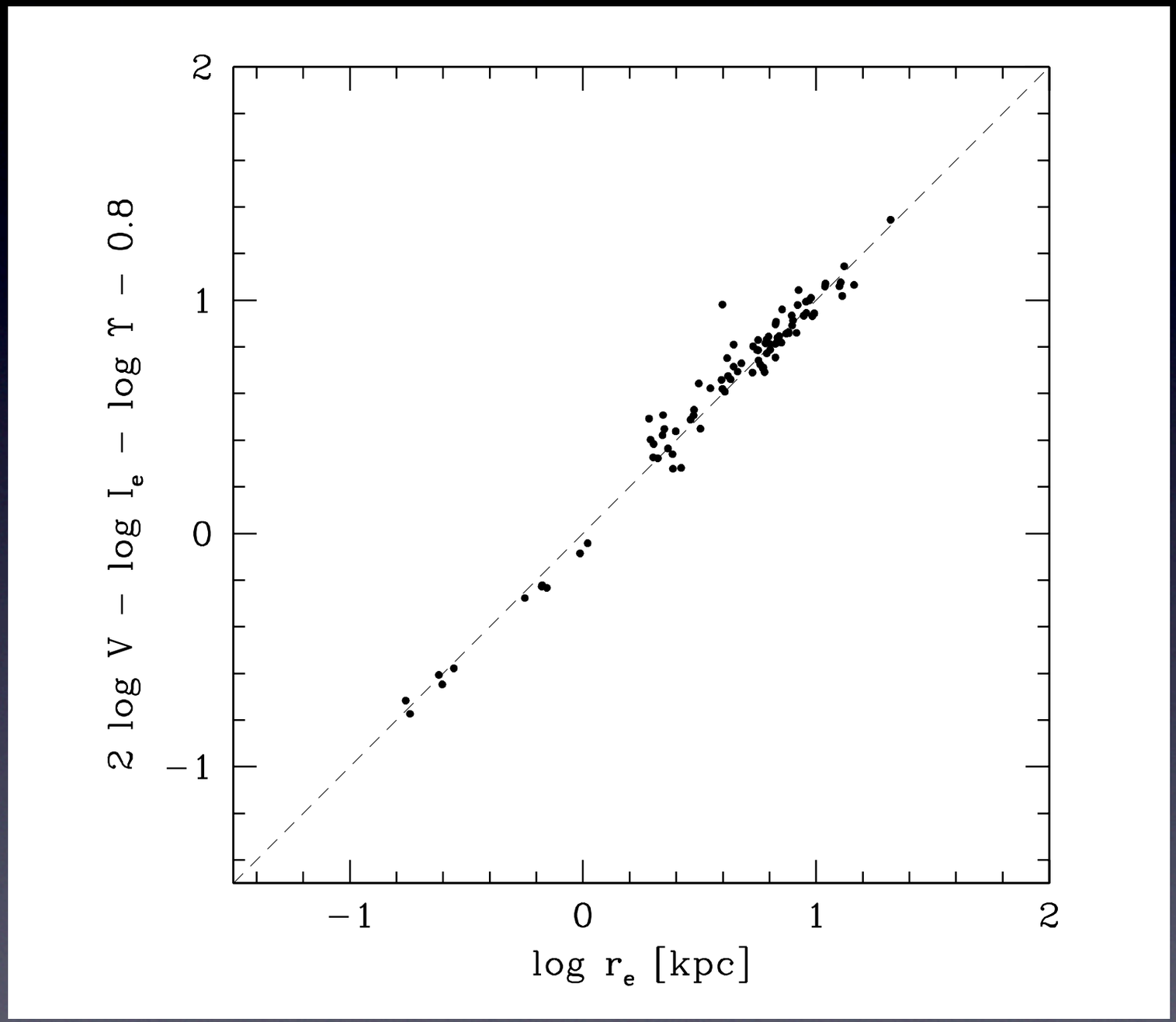
compare to Cappellari et al. 2006,2007 & Bolton et al. 2008

$$\Delta = \log \Upsilon_e - \log A + \log B - C$$

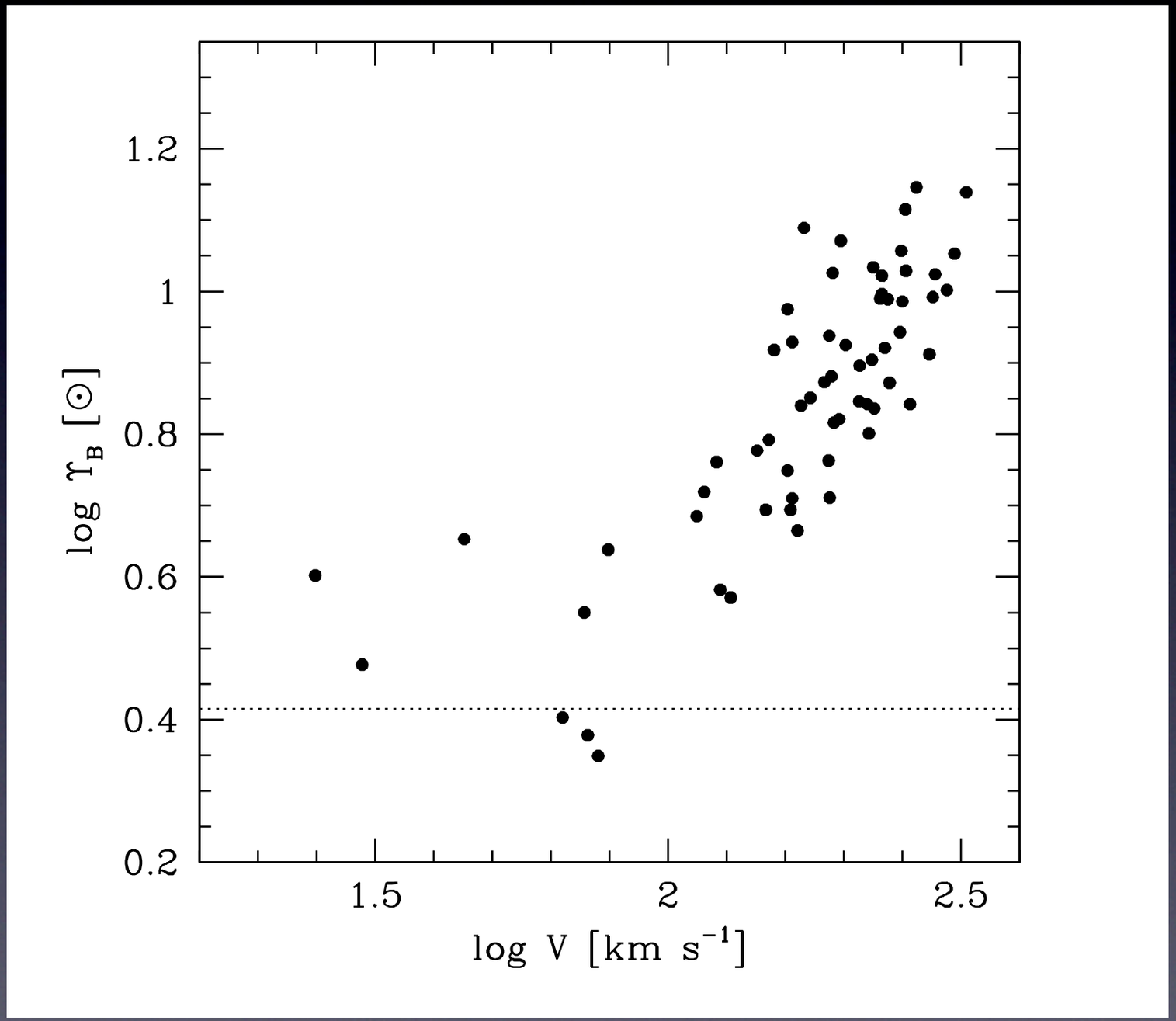


add Walker et al. (2007) dSphs

Galaxies with independently measured Υ_e

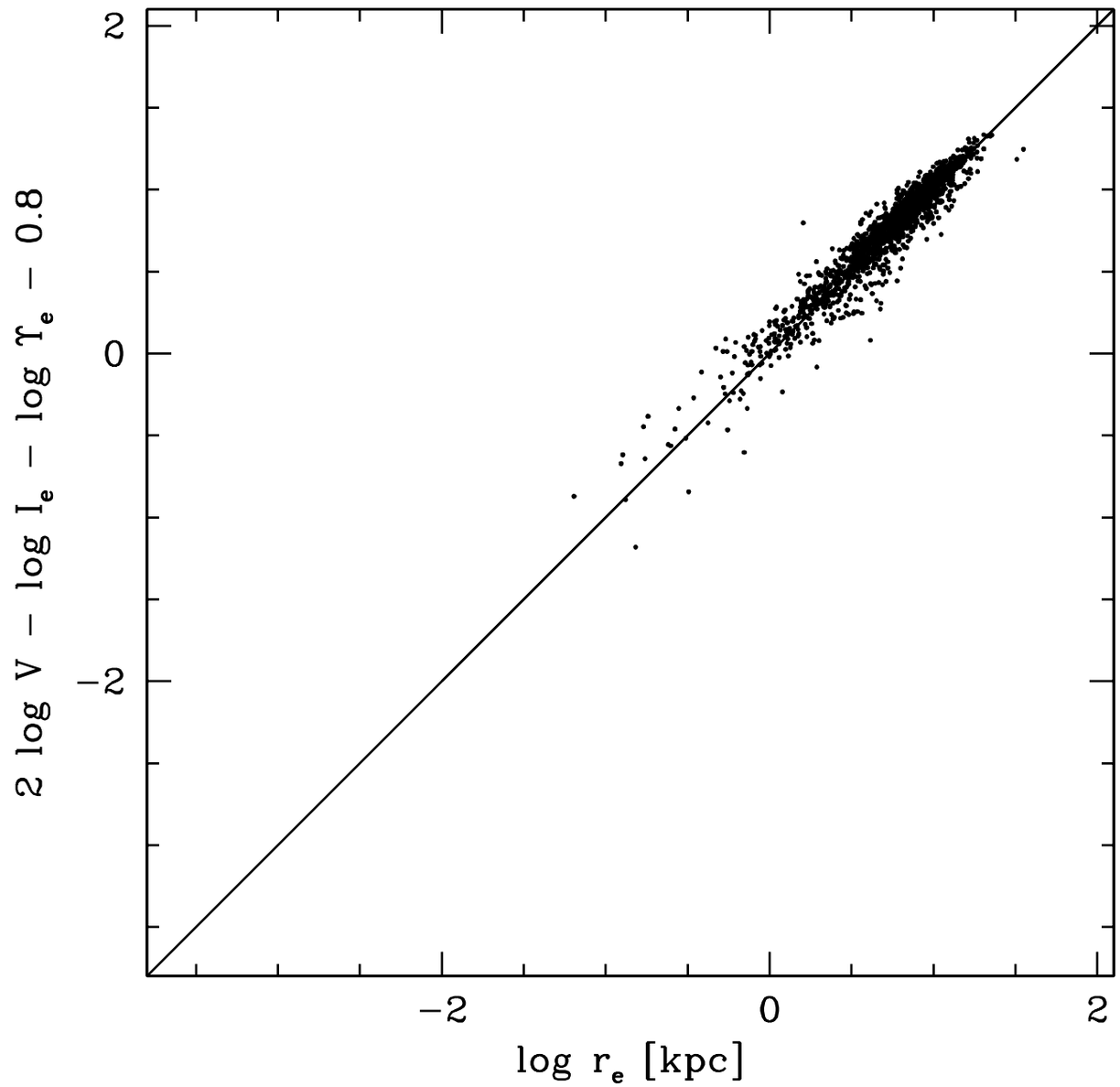


Why the Fundamental Plane must fail



nearby galaxies with Jeans modeling

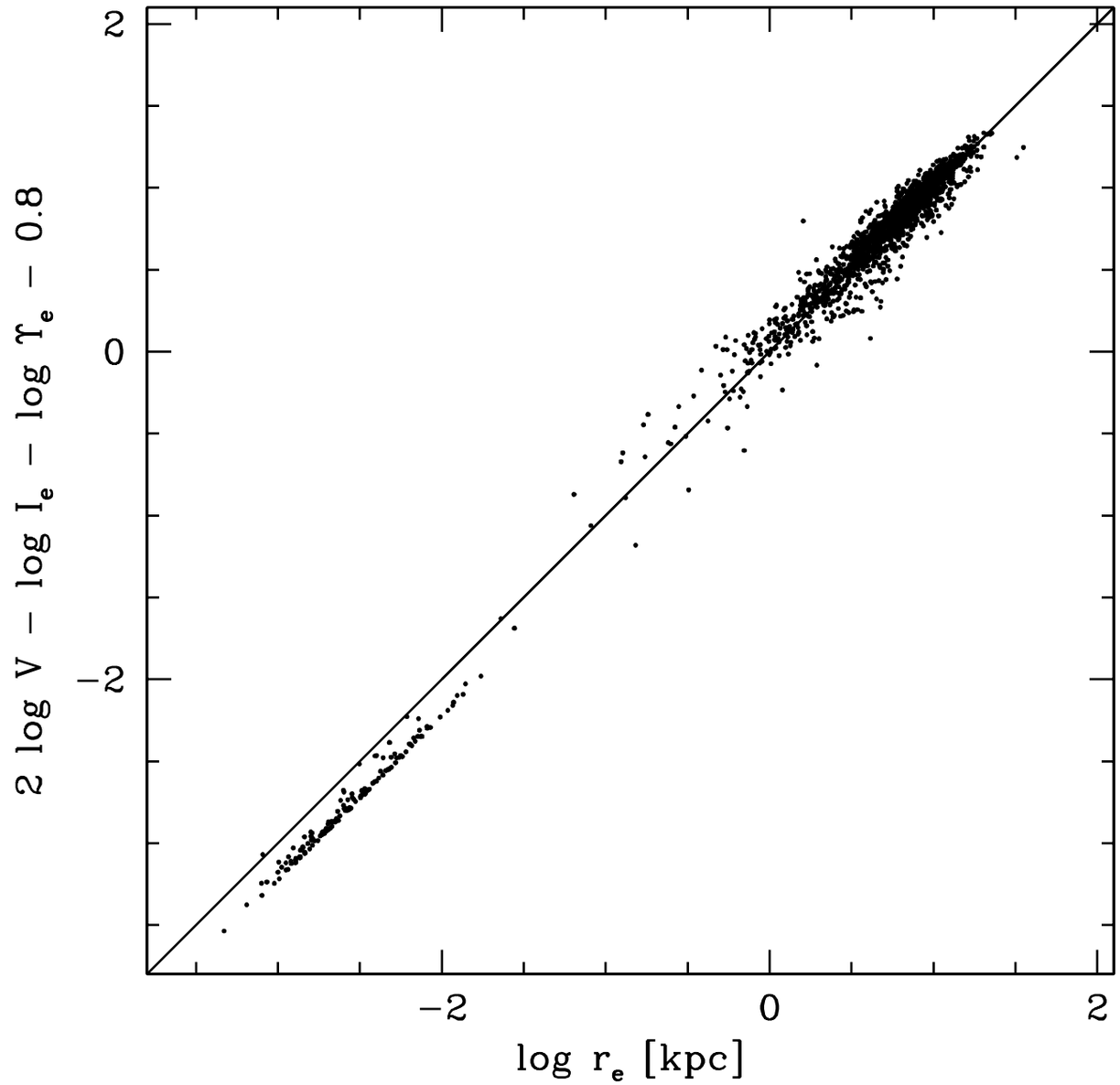
galaxies - UCDs



galaxies - UCDs

+ LG globulars

(McLaughlin & van der Marel ‘05)



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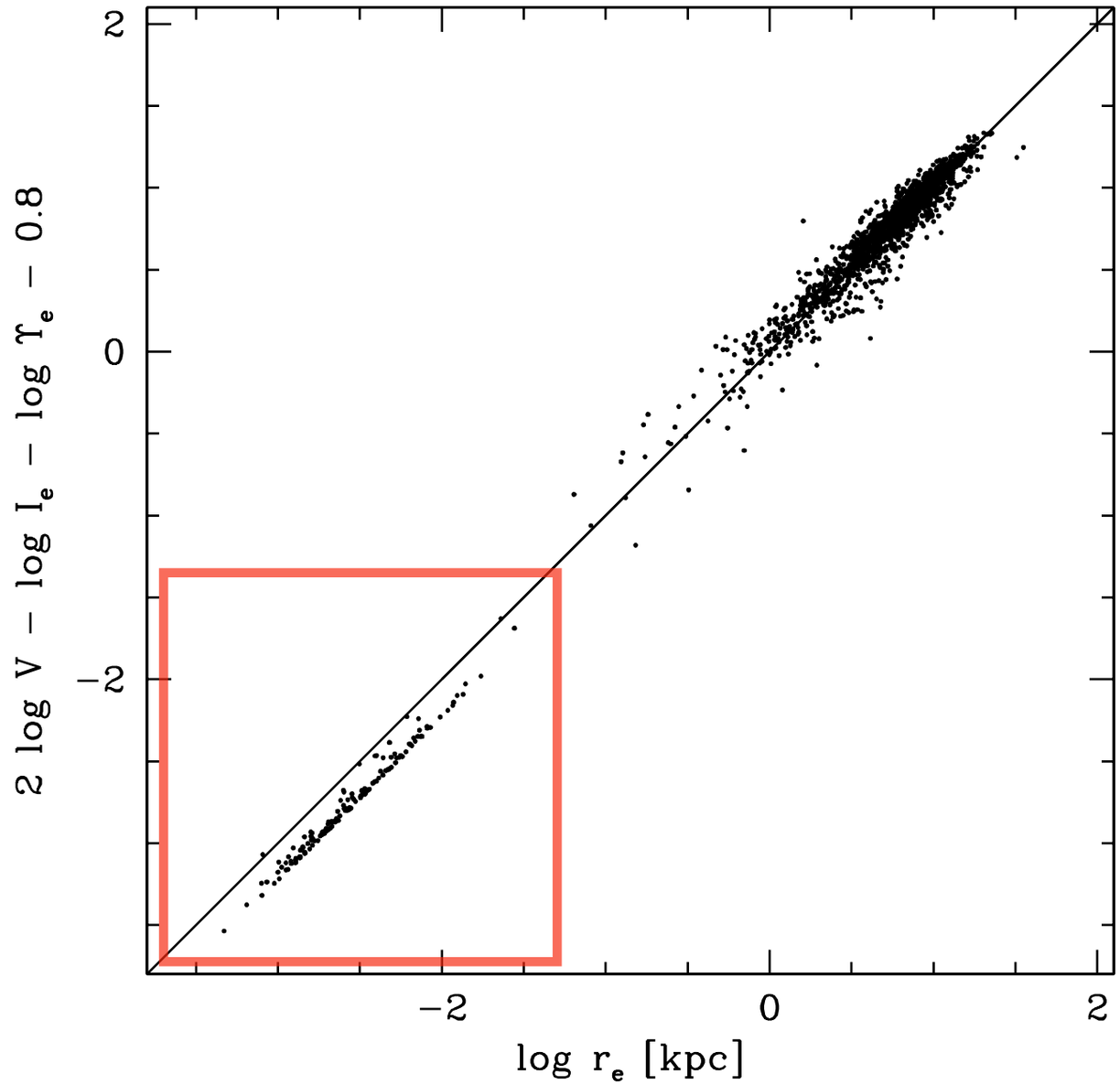

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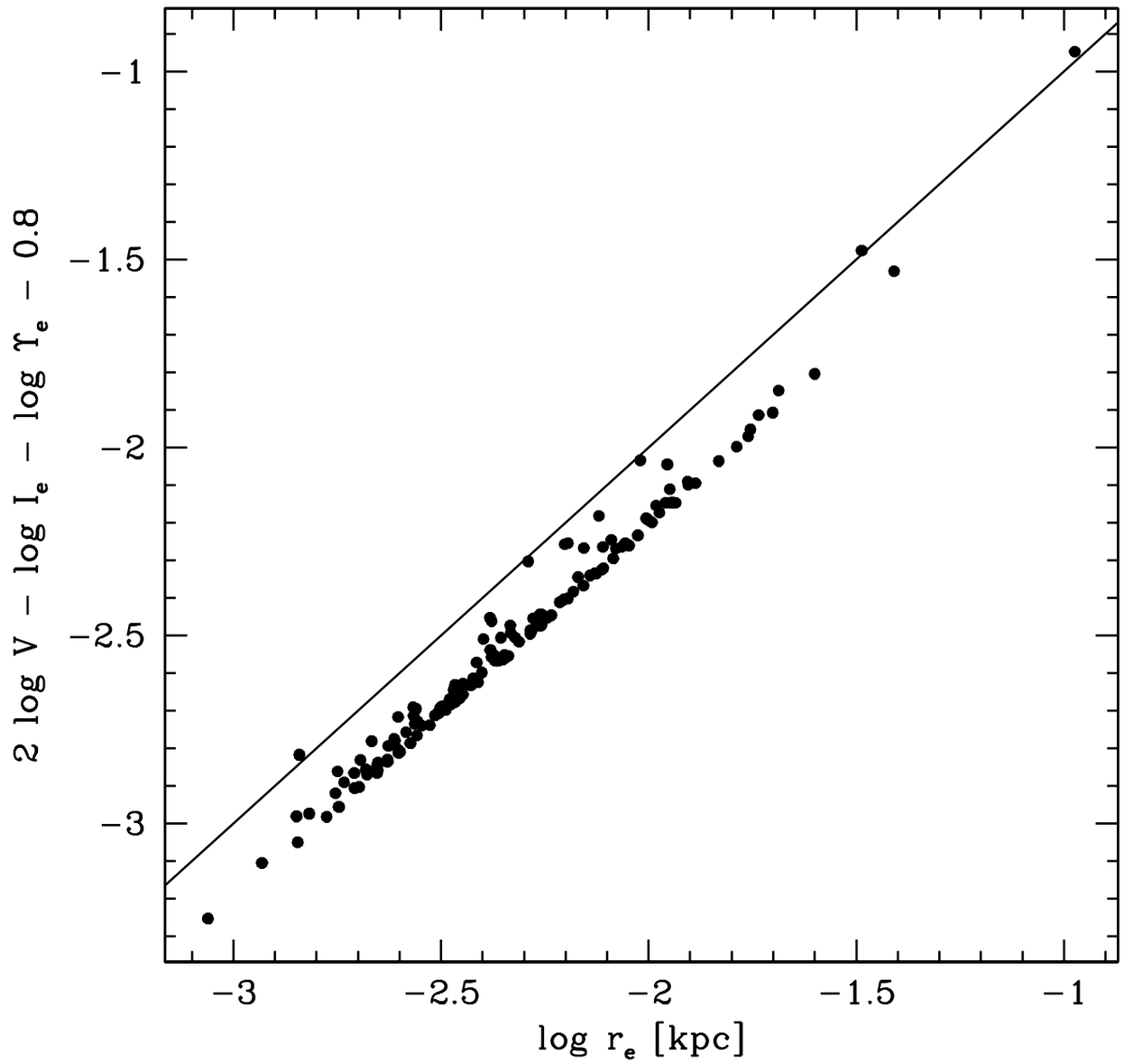

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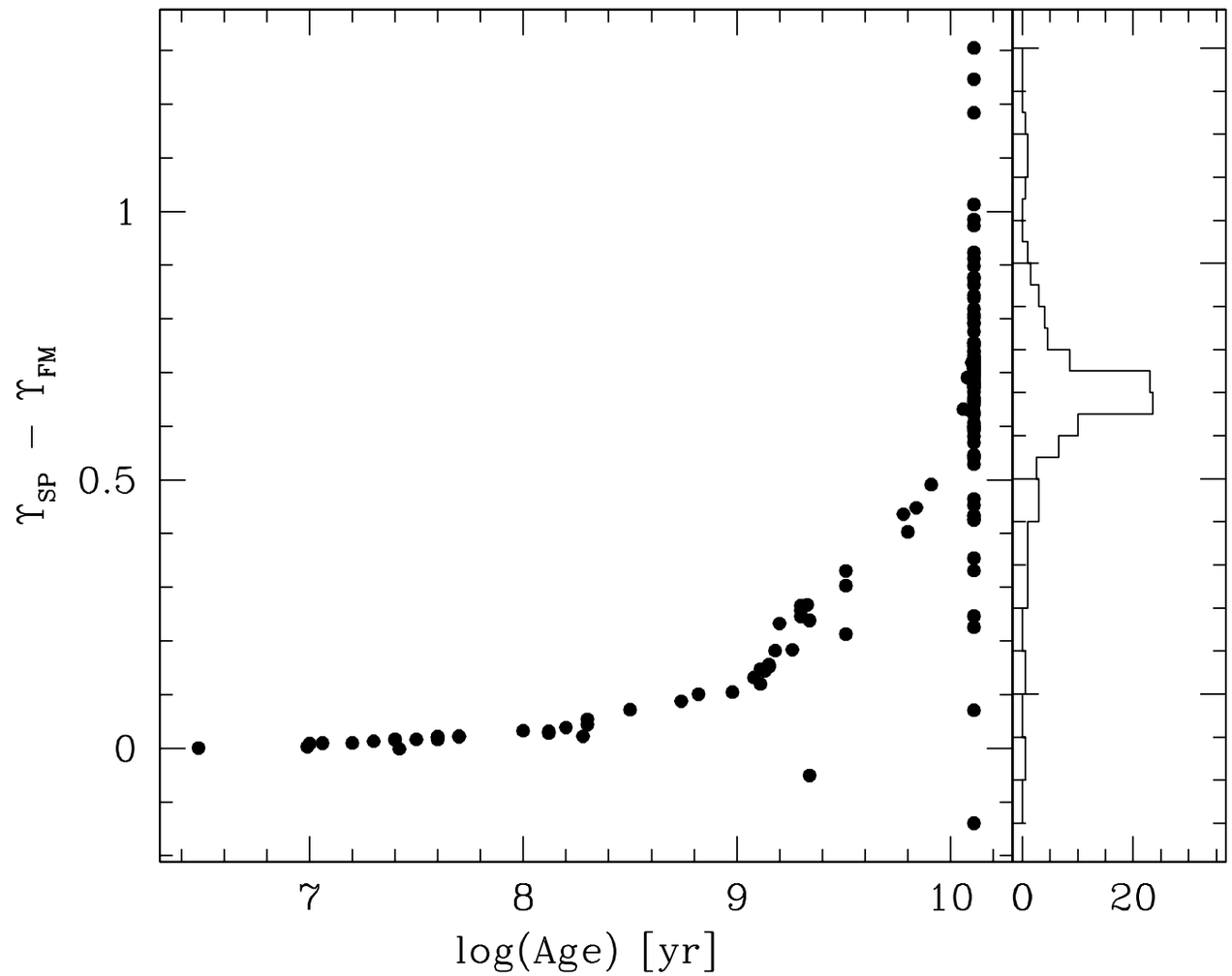

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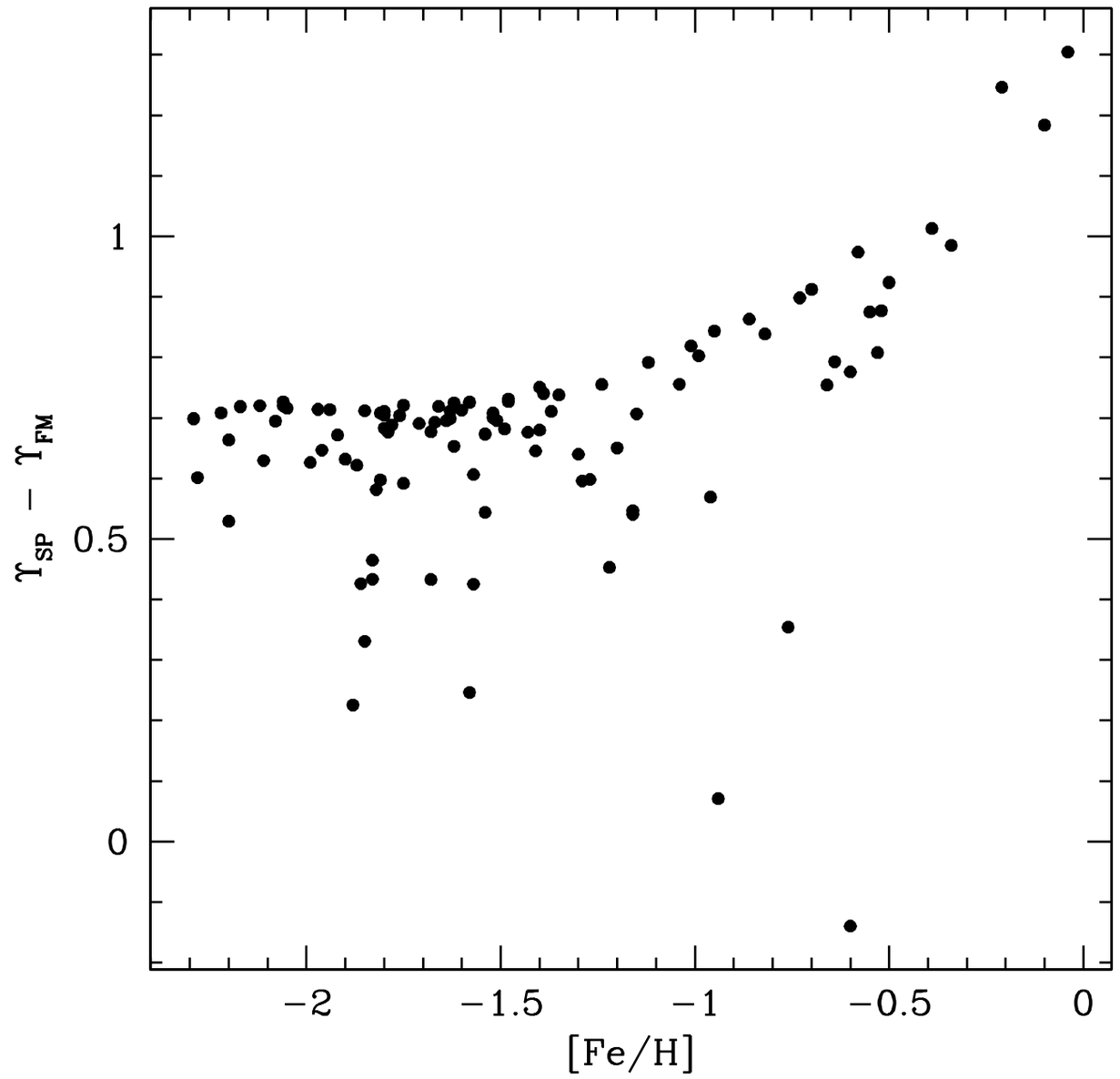
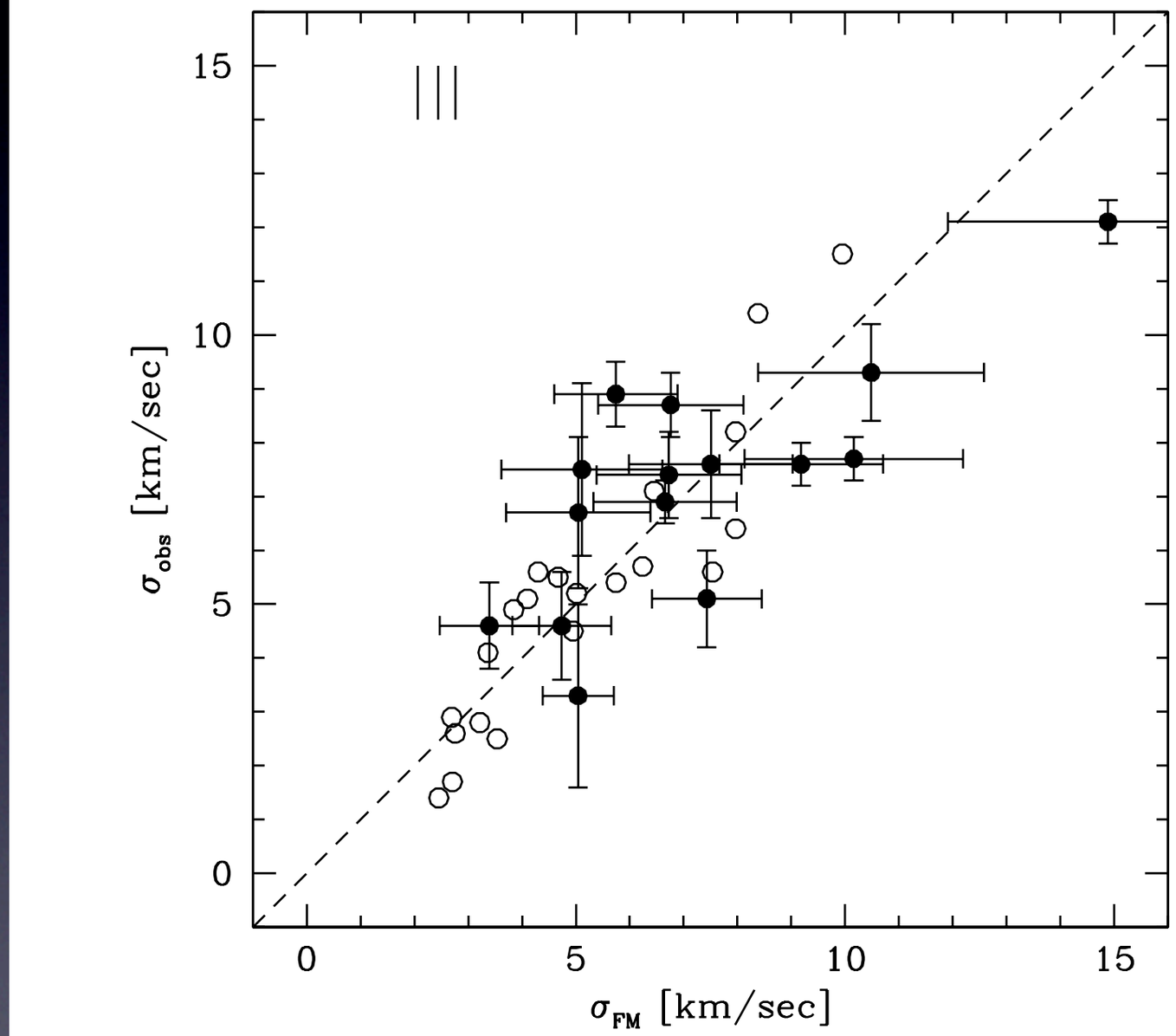


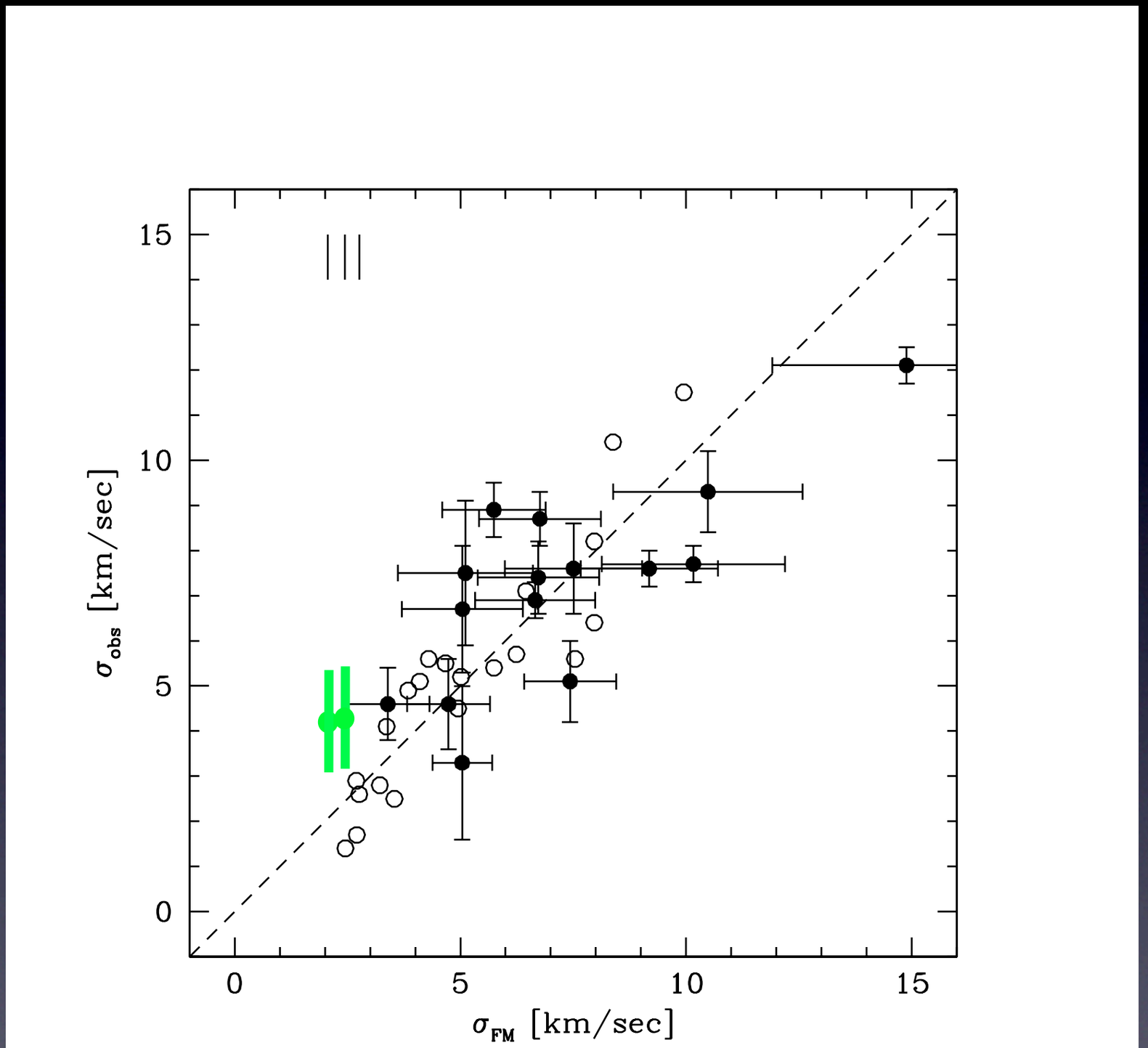
Bootes II
Segue I
Willman I



Bootes II
Segue I
Willman I

Geha et al. 2008
Segue I

Martin et al. 2007
Willman I



So where are we?

IV. Virial Thm + Υ_e describes the gross structure of all stellar systems

V. Scatter constrains models of physical processes

Where do we need to go?

What two parameters drive Υ_e for galaxies?

Where do we need to go?

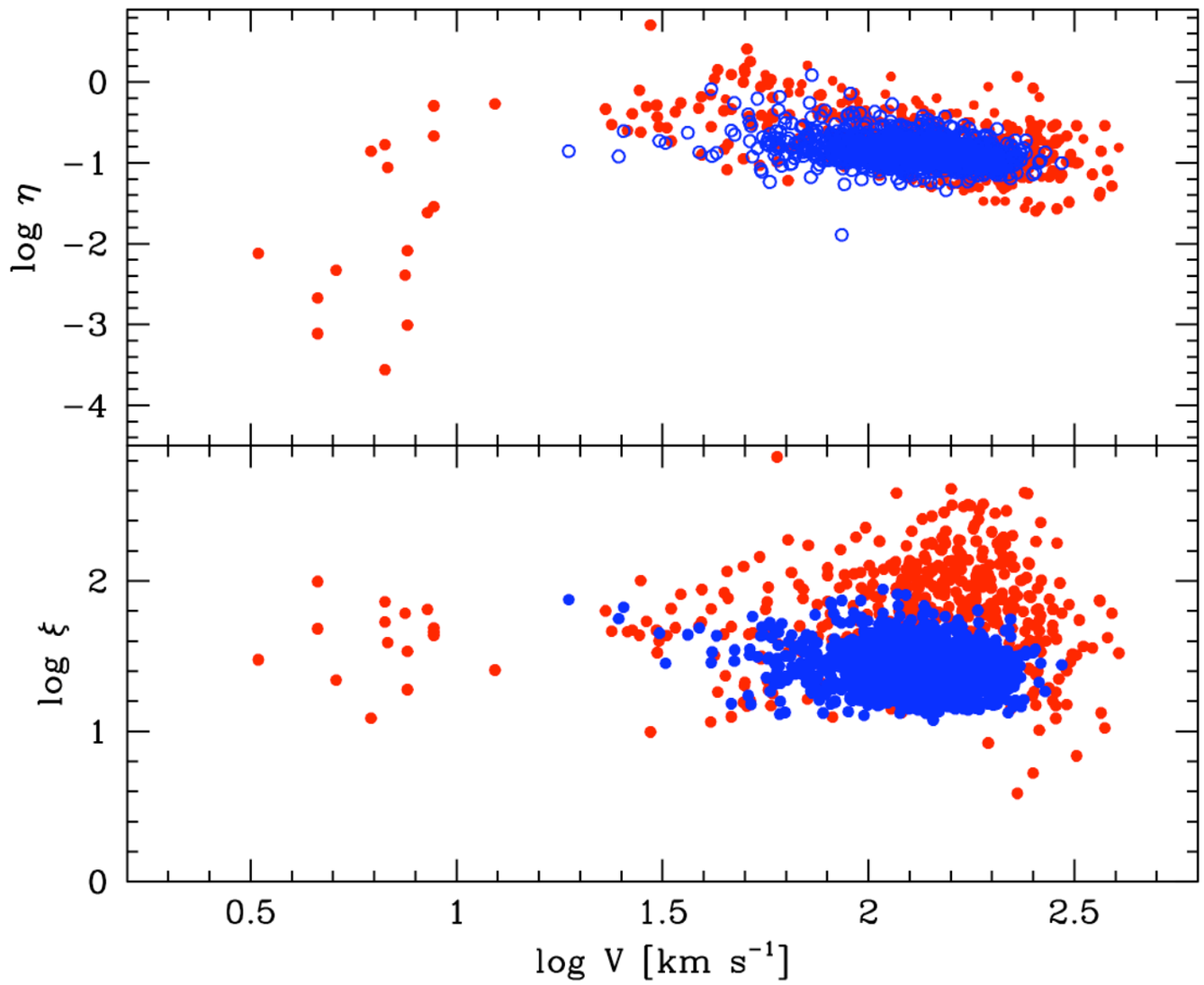
What two parameters drive Υ_e for galaxies?

the efficiency with which baryons are turned to stars, η

how concentrated those stars in the DM halo, $\xi(\equiv R_{200}/r_e)$

Efficiency

Packing



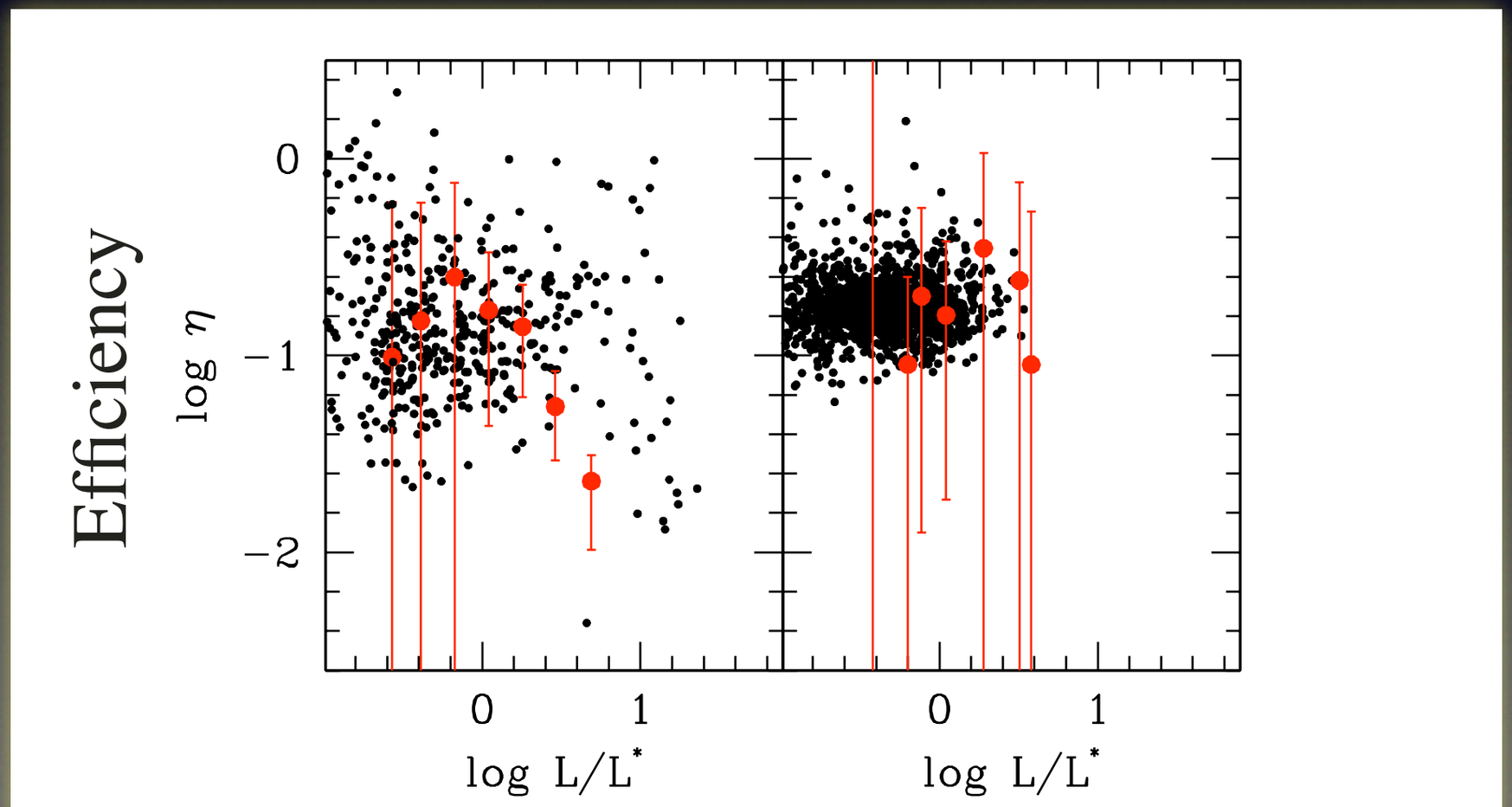
efficiency

$$\eta = K\frac{L}{V^3}$$

packing

$$\xi = J\frac{V}{r_e}$$

$$\log\xi + \log\eta = -\log\Upsilon_e + C$$



(comparison to Mandelbaum et al. 2006)

So where are we?

VI. Scaling relations can be used to populate halos

VII. Answer relative question about SF efficiency & baryon packing

VIII. Provide absolute numbers

(eg. for MW-like, $\eta = 0.14 \pm 0.05$)

Where do we need to go?

What two fundamental parameters drive Υ_e for galaxies?

Where do we need to go?

What two fundamental parameters drive Υ_e for galaxies?

mass & angular momentum?

Where do we need to go?

What two fundamental parameters drive Υ_e for galaxies?

Examine the “face-on” manifold

Obtain true distribution of galaxies on manifold

Organizing Galaxies

Summary

All galaxies on 2-D surface $\longrightarrow$ two driving parameters

a “go proof” for galactic structure?

Organizing Galaxies

Summary

All galaxies on 2-D surface ⟶ two driving parameters

a “go proof” for galactic structure?

Virial Thm. + M/L ⟶ all galaxy formation “physics” in M/L

higher-level physics can’t break M/L behavior

Organizing Galaxies

Summary

All galaxies on 2-D surface ⟶ two driving parameters

a "go proof" for galactic structure?

Virial Thm. + M/L ⟶ all galaxy formation "physics" in M/L

higher-level physics can't break M/L behavior

SF efficiency & packing ⟶ mass & angular momentum?