Kinematics and Structure of Dwarf Elliptical Galaxies in the Virgo Cluster

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In collaboration with:

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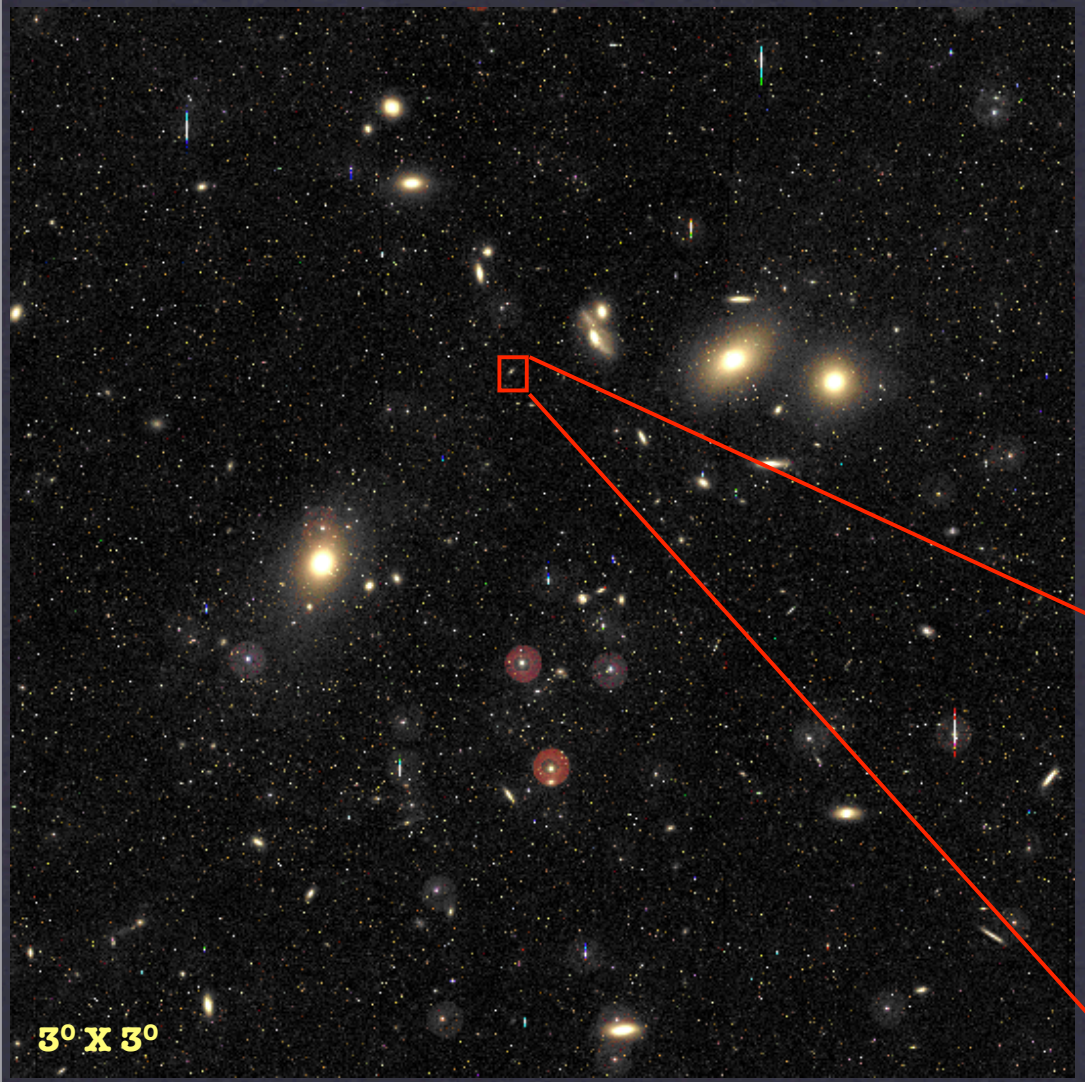
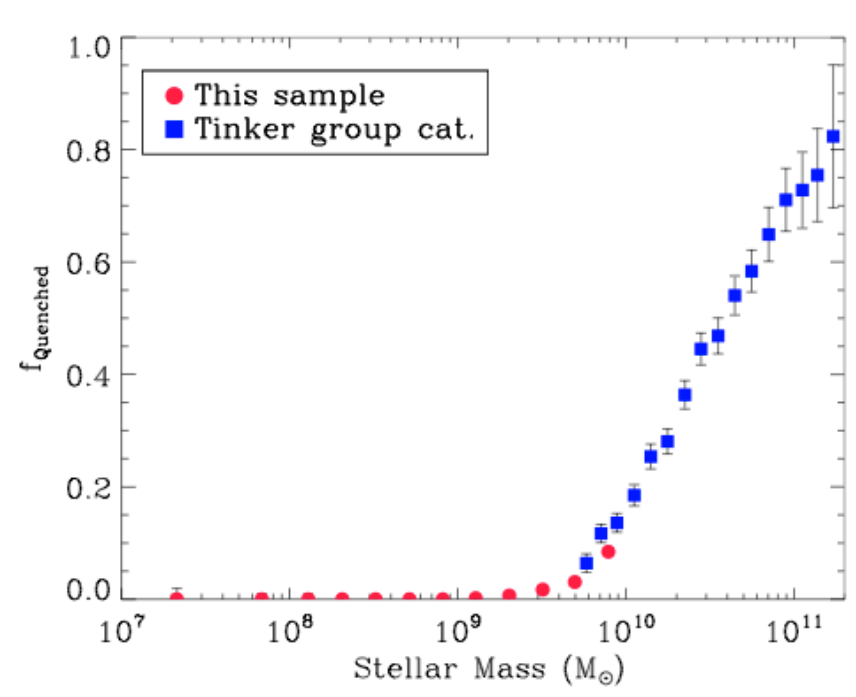
High School Students: Alice Wu & Ajinkya Nene



NGVS IMAGES: FERRARESE+12

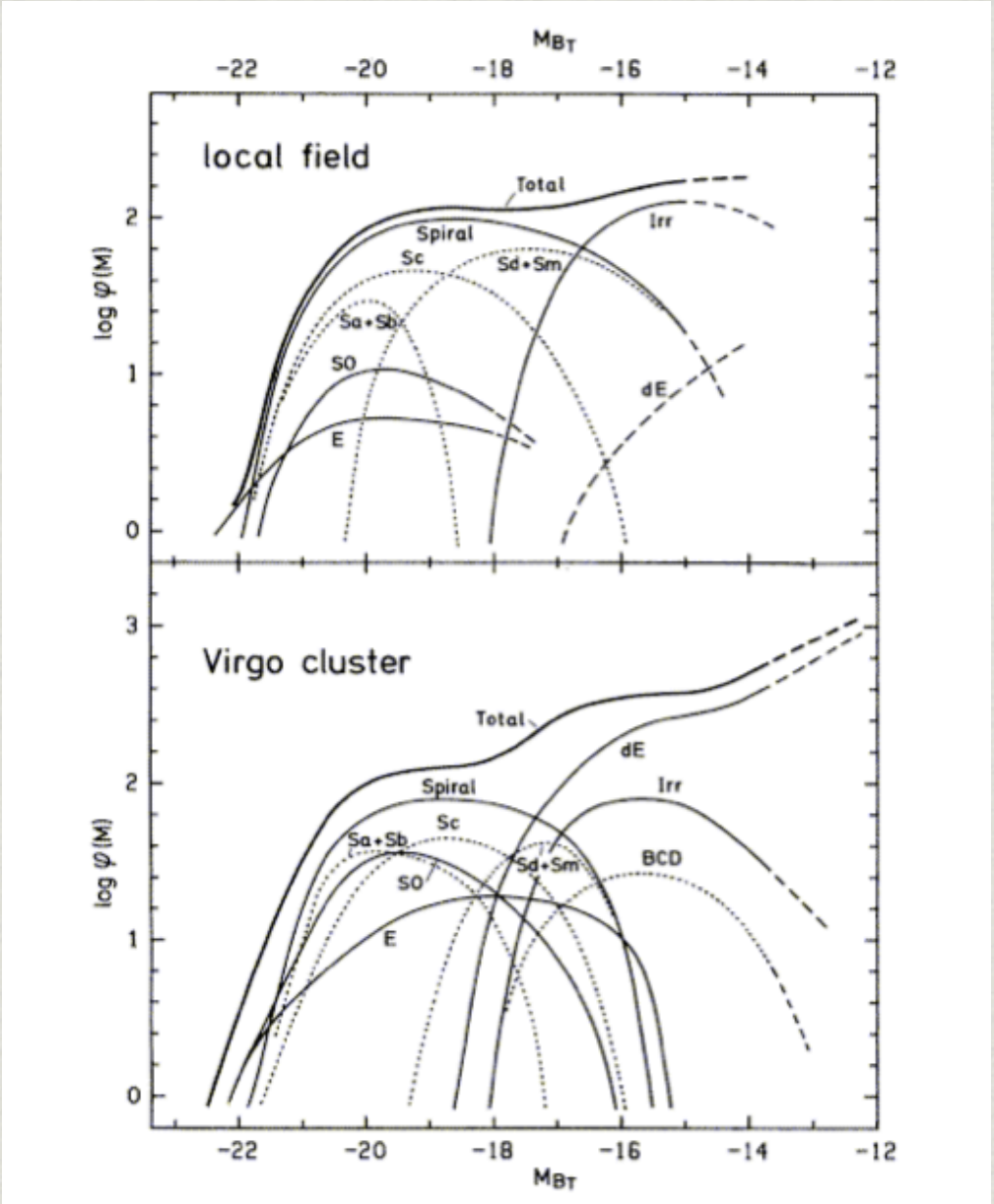
dEs do not exist in isolation

Geha et al. 2012



Dwarf Elliptical Galaxy:

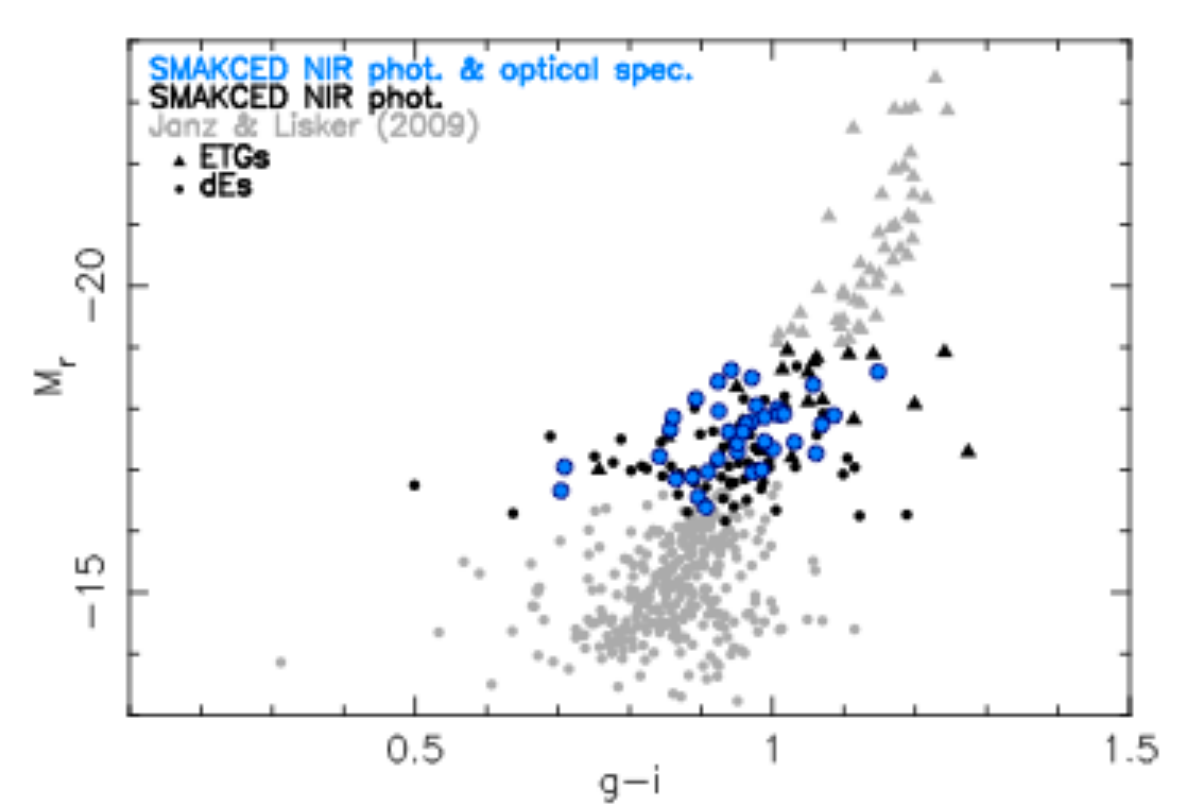
- ☑ $M_B > -18$
- ☑ $\mu_B > 22$ mag arcsec^{-2}



Binggeli et al. 1988

The SMAKCED Survey of Virgo Cluster dEs

SMAKCED (Stellar content, MAss and Kinematics of Cluster Early-type Dwarf galaxies): Long-slit spectroscopy & H-band photometry of 39 dEs in the Virgo cluster (Toloba+2014abc, also H-band photometry of 121 Virgo cluster dEs in Janz+12, Janz+13)

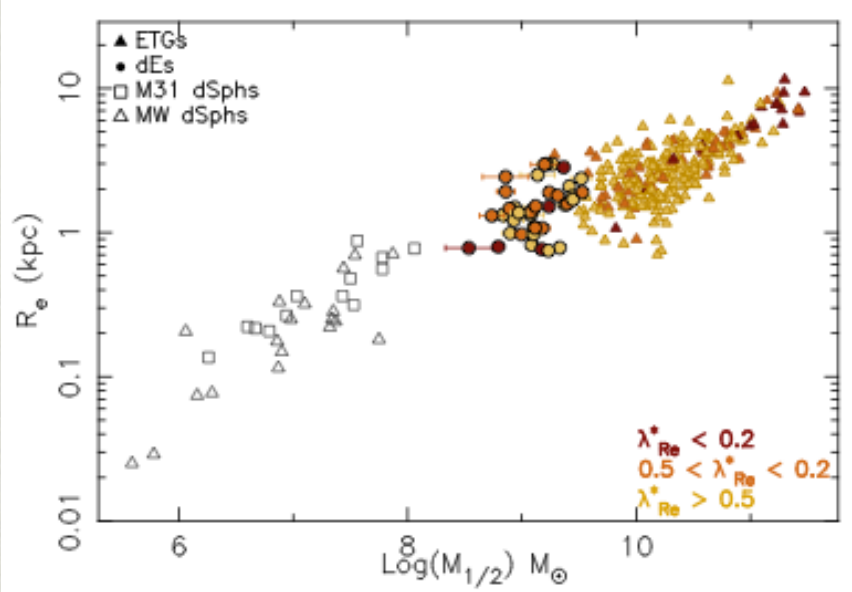


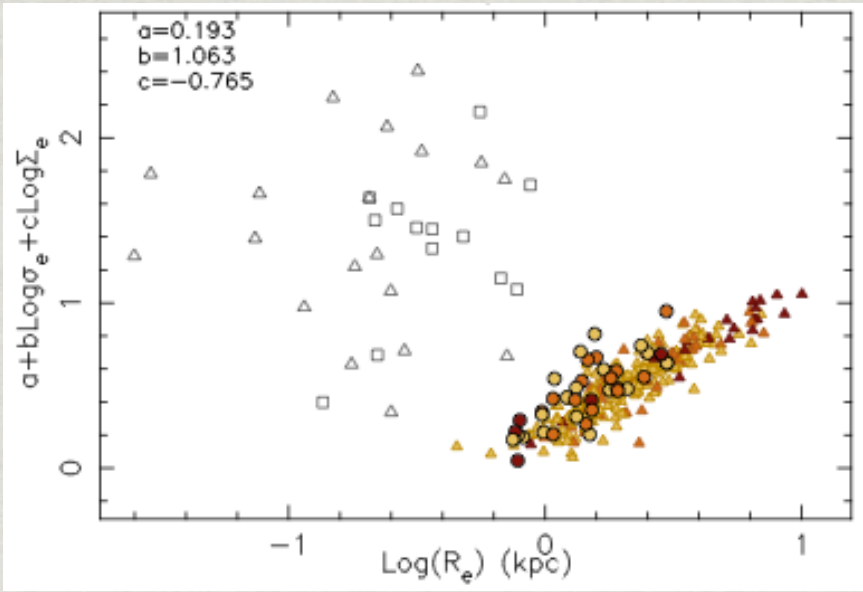
Spectroscopy for a sample of dEs representative in the absolute magnitude range:

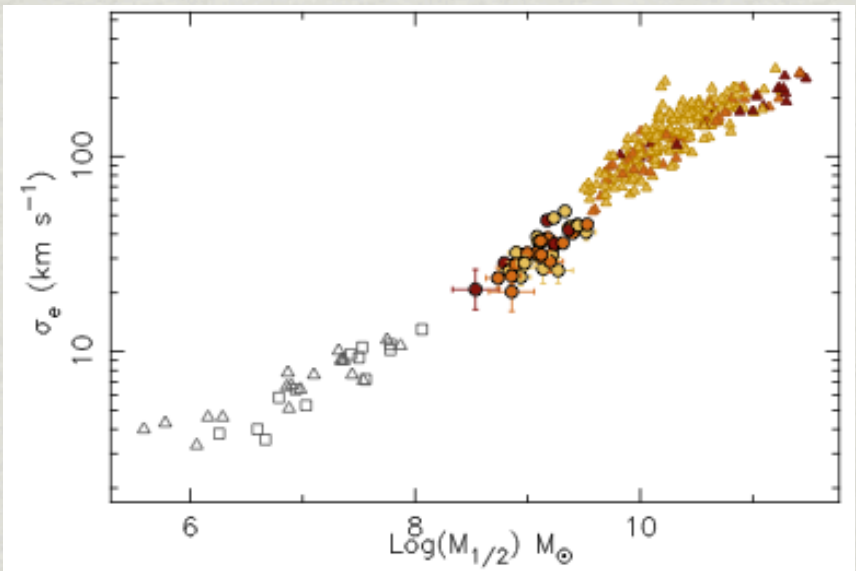
$-19 < Mr < -16$

Toloba+2014b, ApJS submitted

The SMAKCED Survey of Virgo Cluster dEs: Scaling relations







Toloba+2012

Toloba+2014b, ApJS submitted

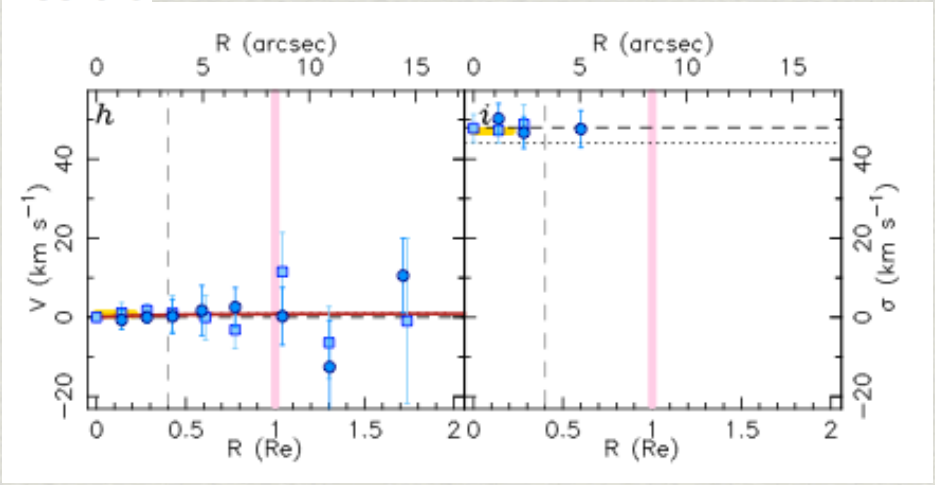
ETGs: ATLAS3D Cappellari+2013, Emsellem+2011

dSphs: Wolf+2010, Tollerud+2012, McConnachie+2012

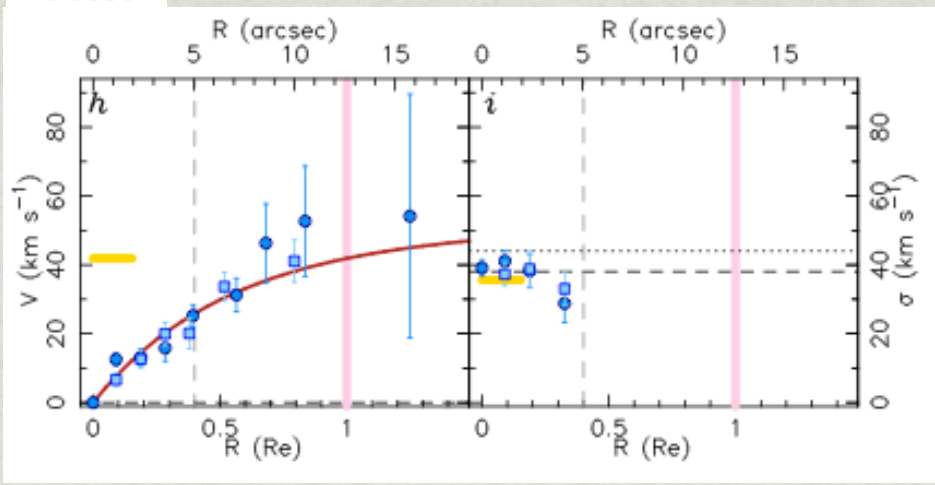
Same trends as Kormendy 2012

Kinematic profiles of Virgo cluster dEs

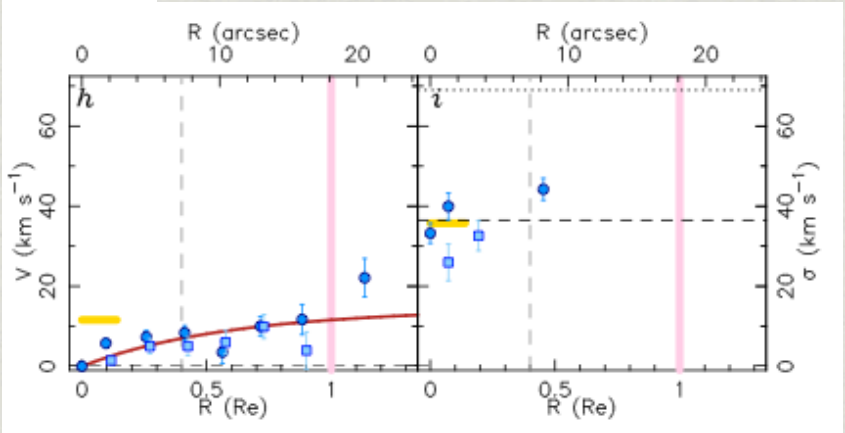
VCC1528

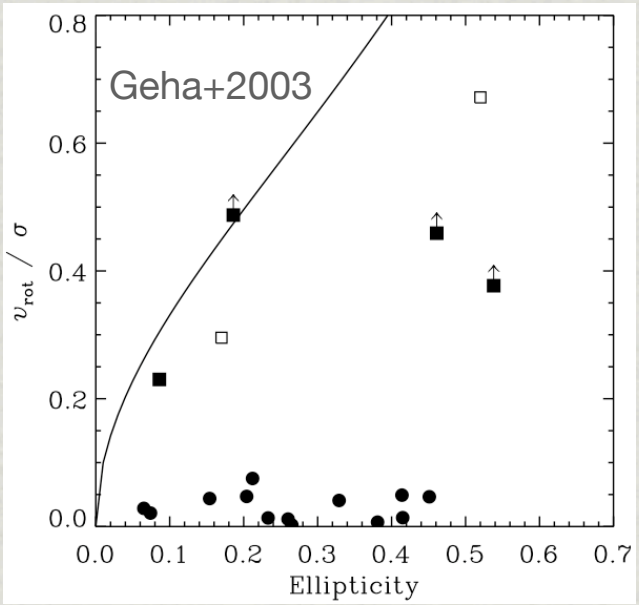


VCC0397



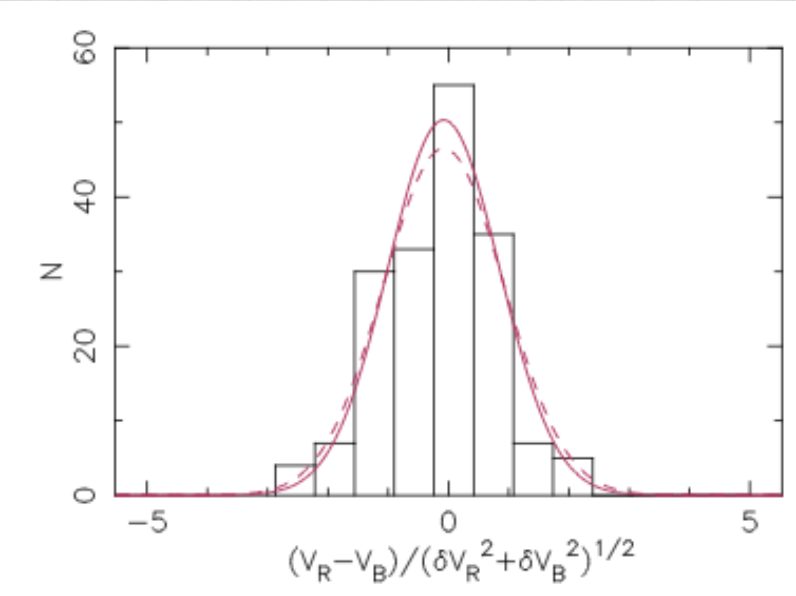
VCC0940

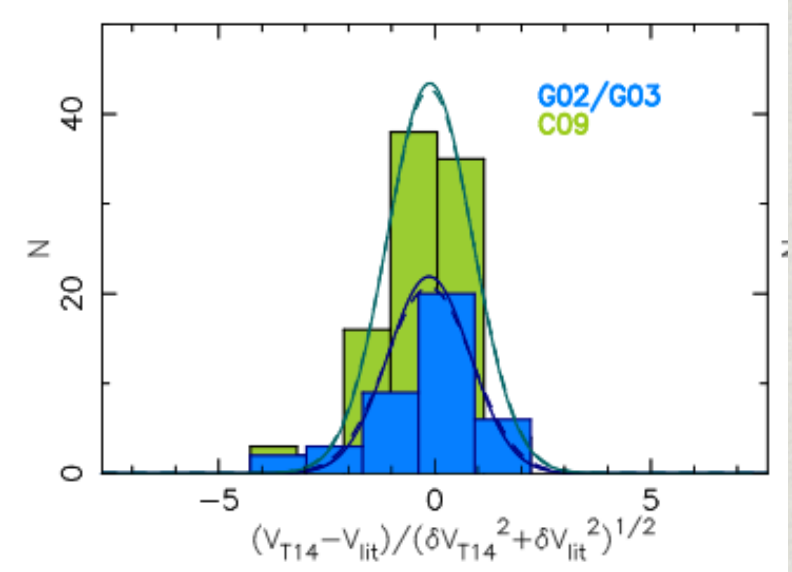




Toloba+2014b, ApJS submitted

Reliability of the velocity uncertainties





3 independent tests:

1.- Compare blue and red setups for dEs observed at the WHT

2.- Compare galaxies in common with Geha+2002 and Geha+2003

3.- Compare galaxies in common with Chilingarian 2009

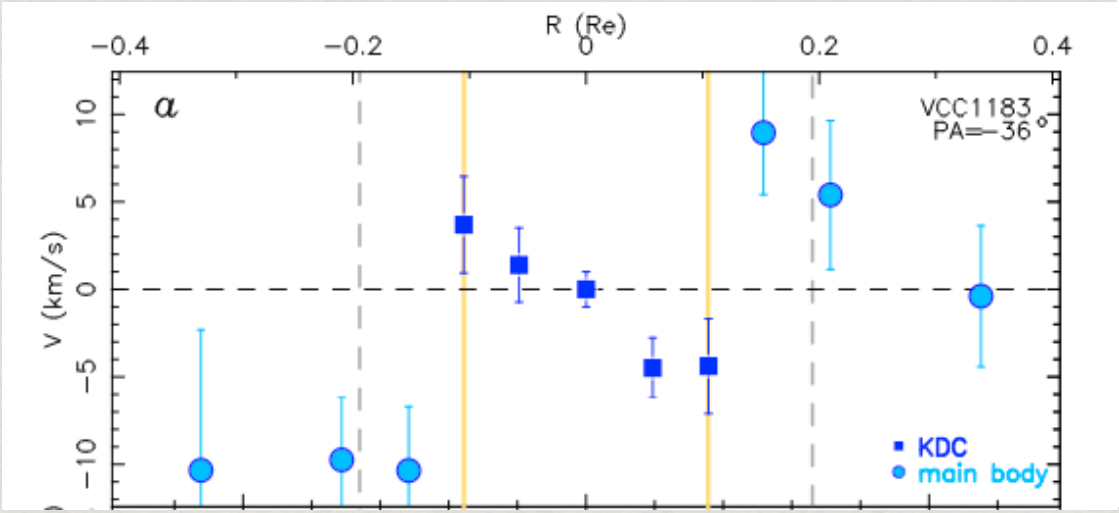
Toloba+2014b, ApJS submitted

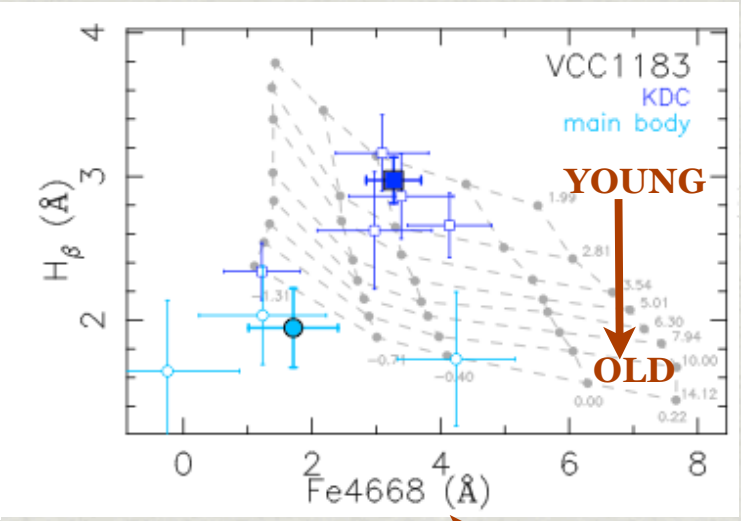
SMAKCED dEs: 2 KDCs Found

2 out of 39 dEs host a Kinematically-Decoupled Core (KDC)

Toloba+2014a

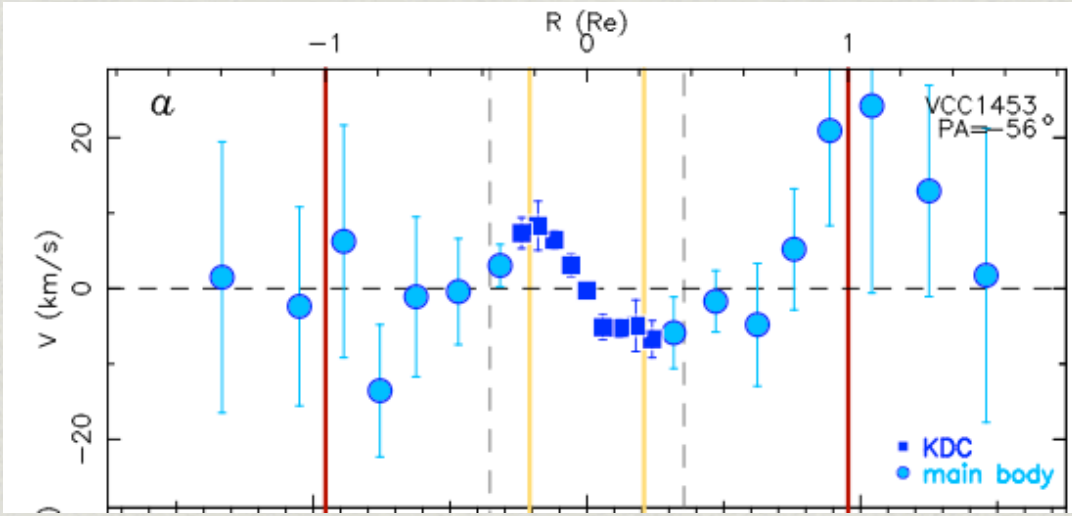
VCC1183

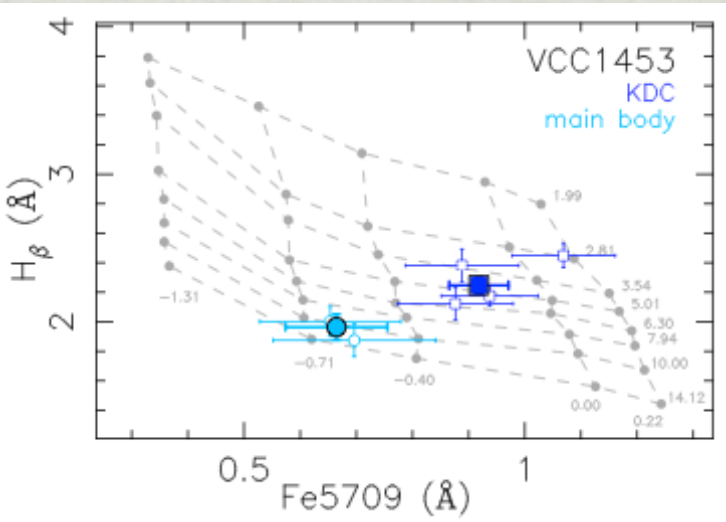




METAL-POOR → METAL-RICH

VCC1453





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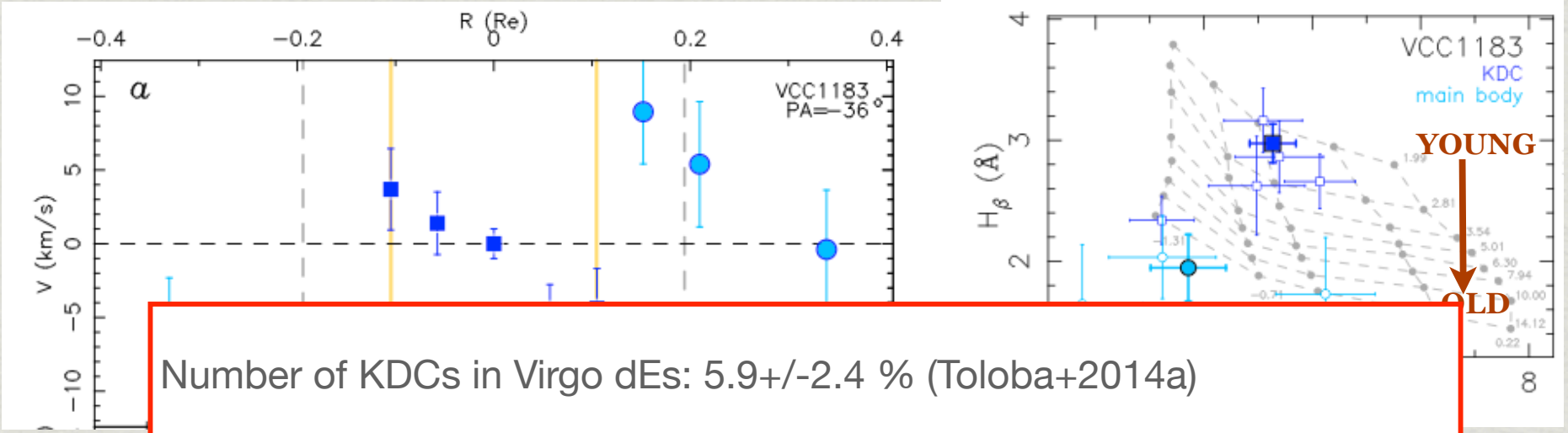
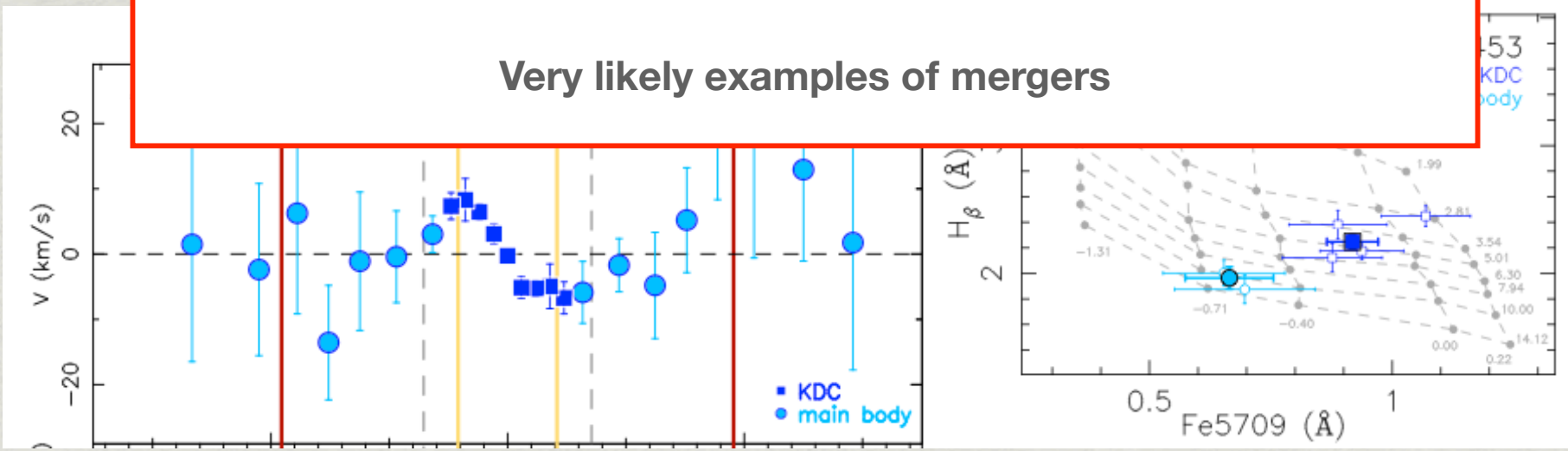


Number of KDCs in Virgo dEs: 5.9+/-2.4 % (Toloba+2014a)

Number of KDCs in ETGs (ATLAS3D): 8.1+/-1.8 % (Krajnovic+2011)

Very likely examples of mergers



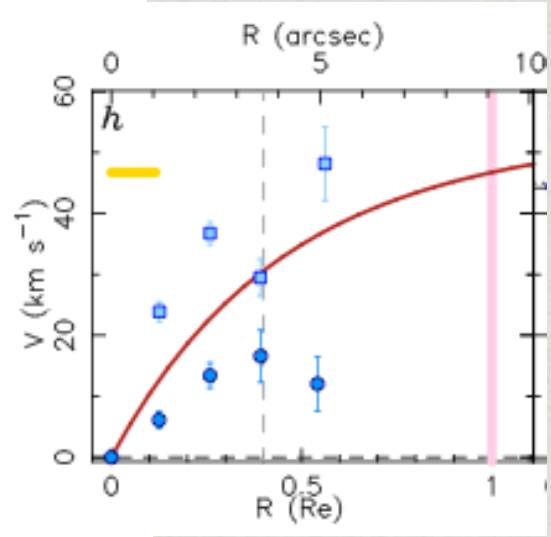
Asymmetric rotation curves

Amplitude asymmetry: AA

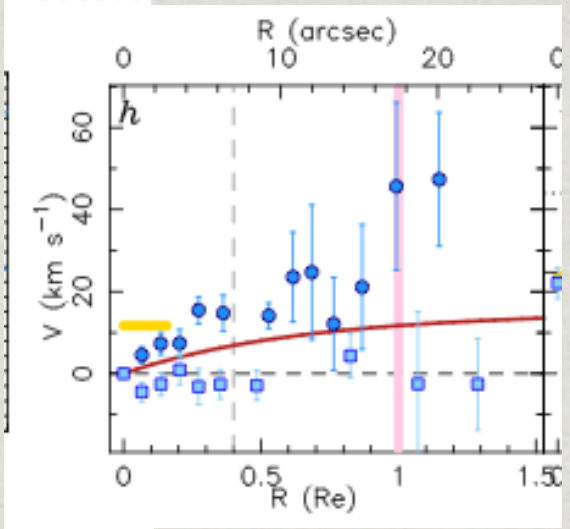
$$S_{AA} = \frac{|\langle \Delta V_{app} \rangle - \langle \Delta V_{rec} \rangle|}{\sqrt{\delta \langle V_{app} \rangle^2 + \delta \langle V_{rec} \rangle^2}}$$

33% (13/39) of the SMAKCED dEs have AA

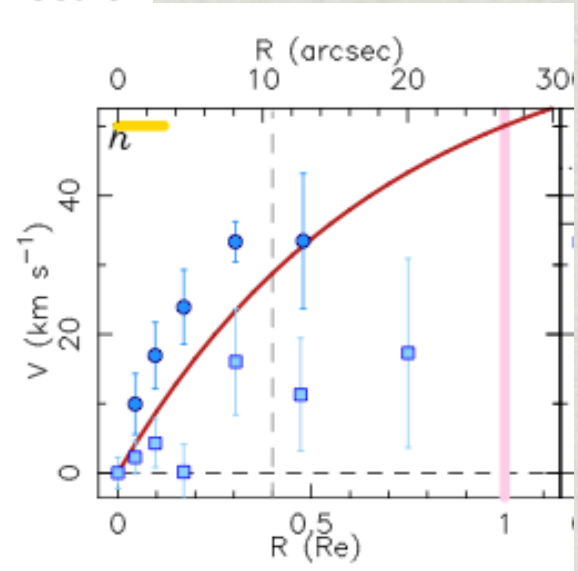
VCC1947



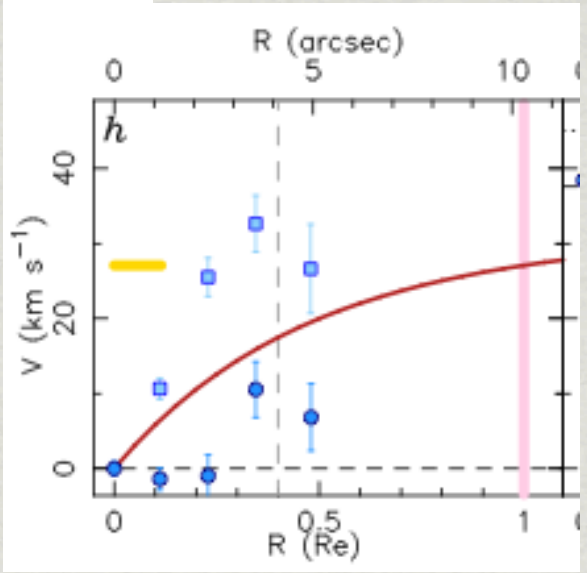
VCC0308



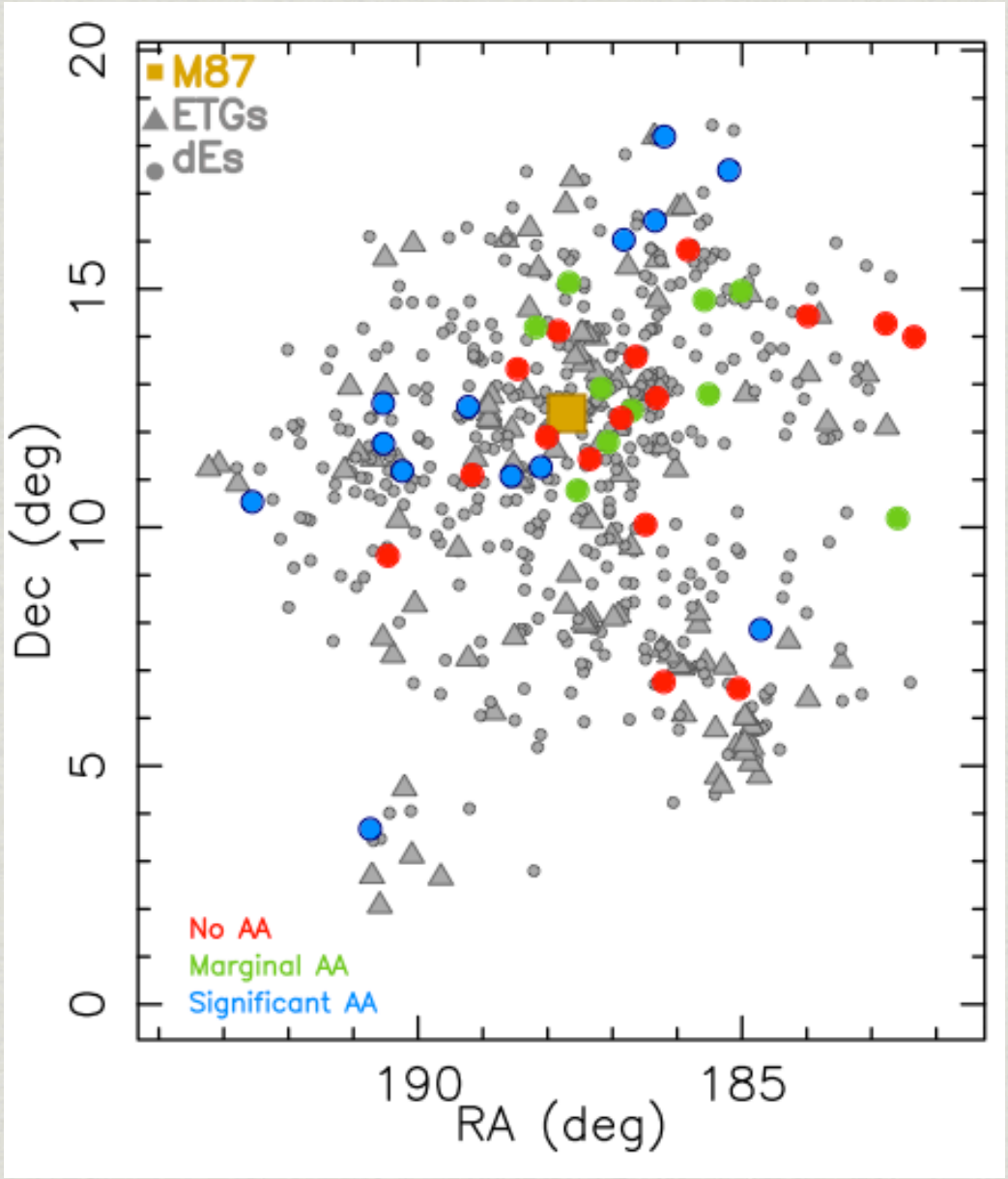
VCC0437



VCC0990

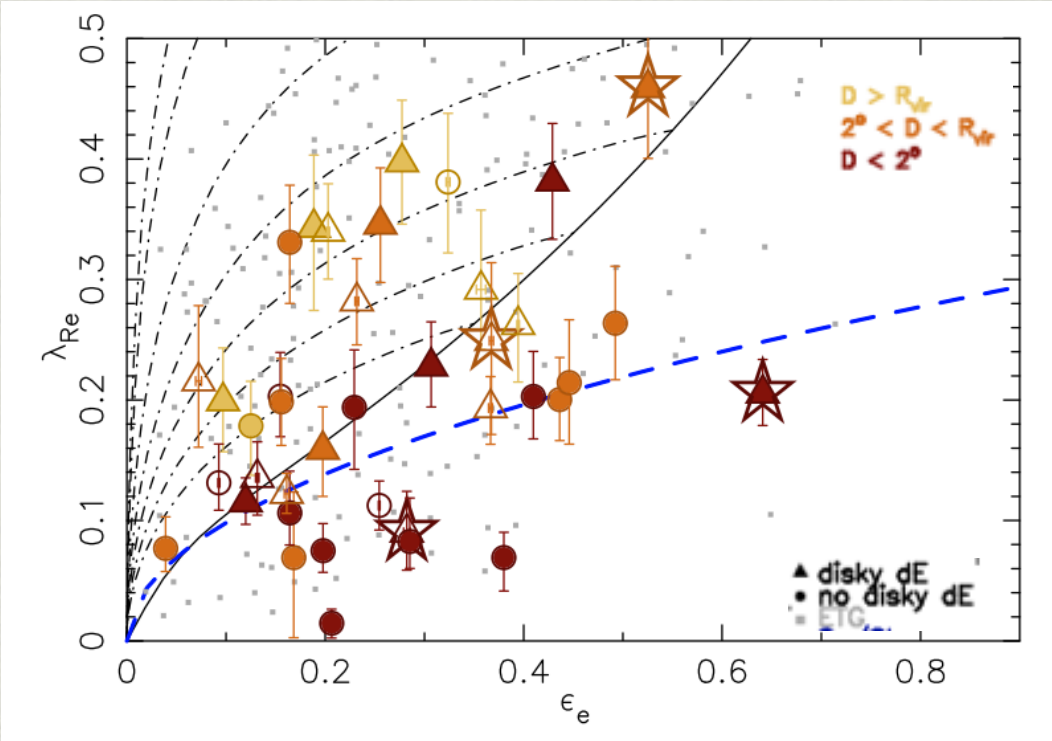


Amplitude Asymmetry: distribution within the cluster



Toloba et al. in prep.

Global kinematics: lambdaR parameter



☑ Many slow rotating dEs (different nature of slow rotating ETGs)

☑ disky dE: $<\lambda_{Re}>=0.25+/-0.02$

☑ no disky dE: $<\lambda_{Re}>=0.16+/-0.02$

☑ Correlation with distance to M87:

Spearman test: 99.92% confidence

Pearson test: 99.97% confidence

Results already hinted in Toloba+2009

dE disky/no disky classification: Lisker+2006a,b, Lisker+2007

ETGs: ATLAS3D Emsellen+2011

Why slow rotators are either very massive of dwarfs?

$$\lambda_R = \frac{\sum_{i=1}^{N} F_i R_i |V_i|}{\sum_{i=1}^{N} F_i R_i \sqrt{V_i^2 + \sigma_i^2}}$$ Emsellem+2007,2011

Toloba+2014c

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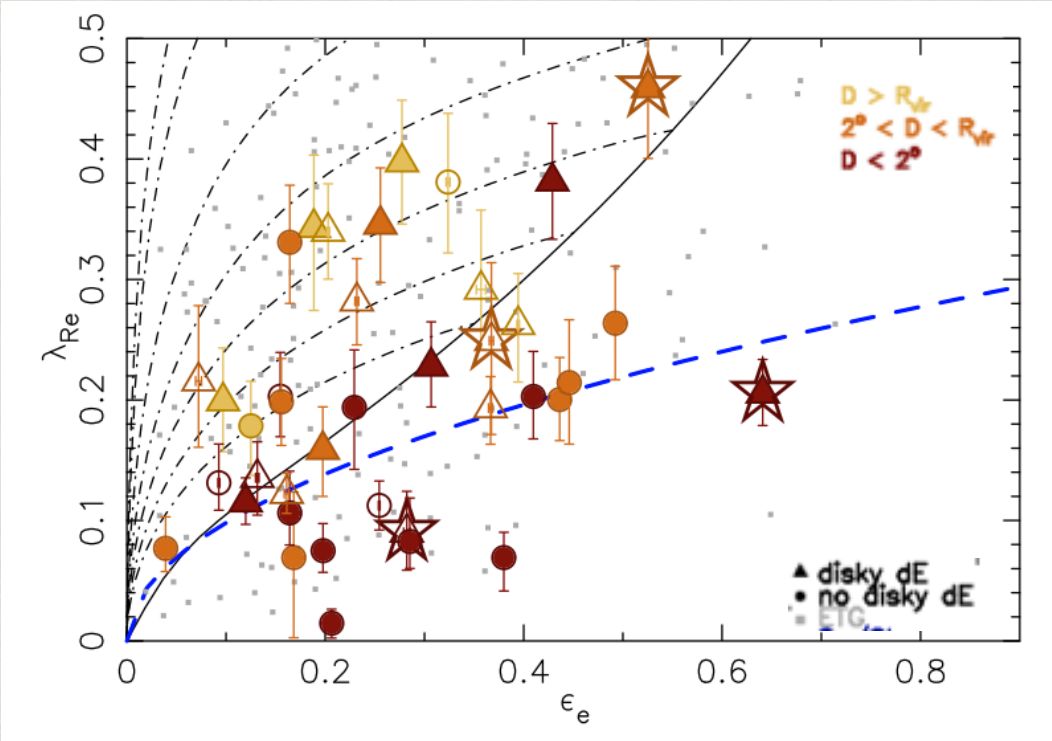

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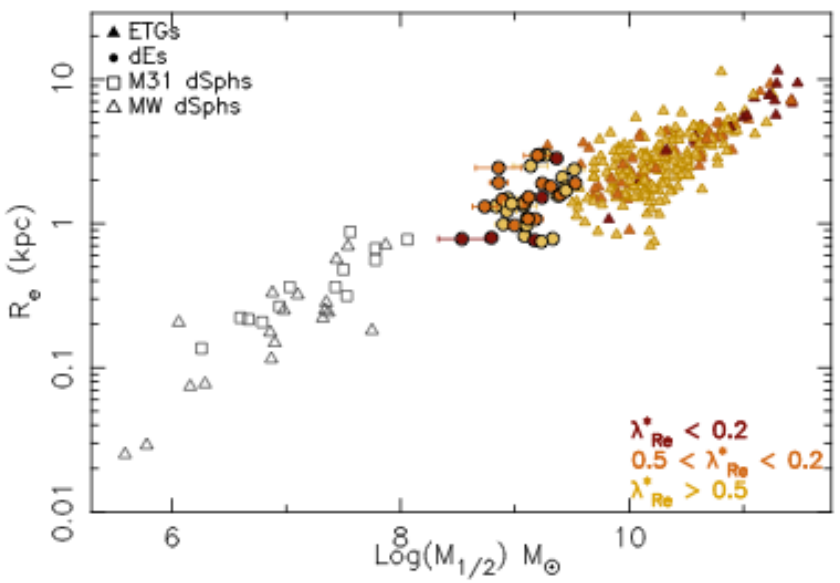

dE disky/no disky classification: Lisker+2006a,b, Lisker+200

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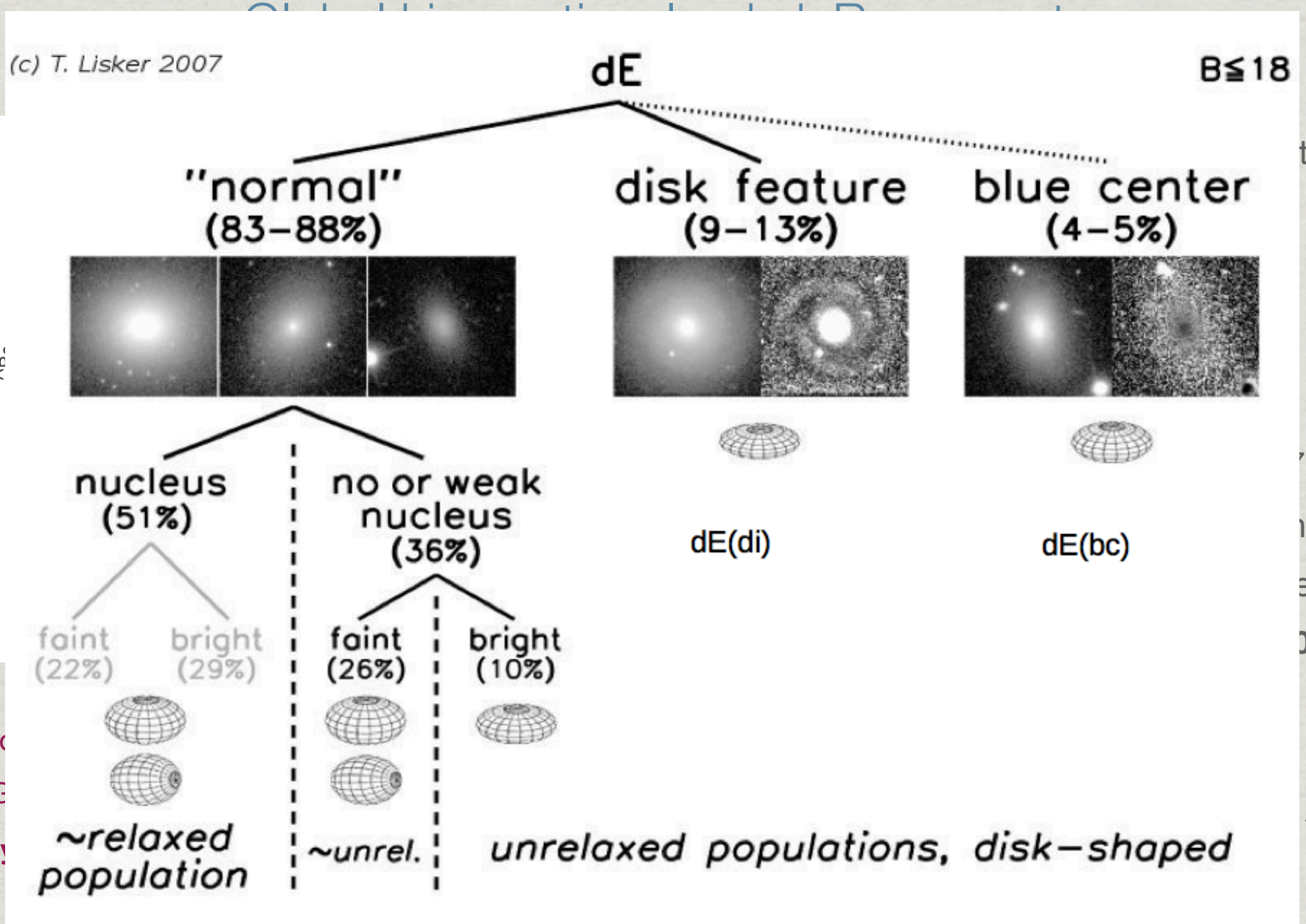

Toloba+2014c

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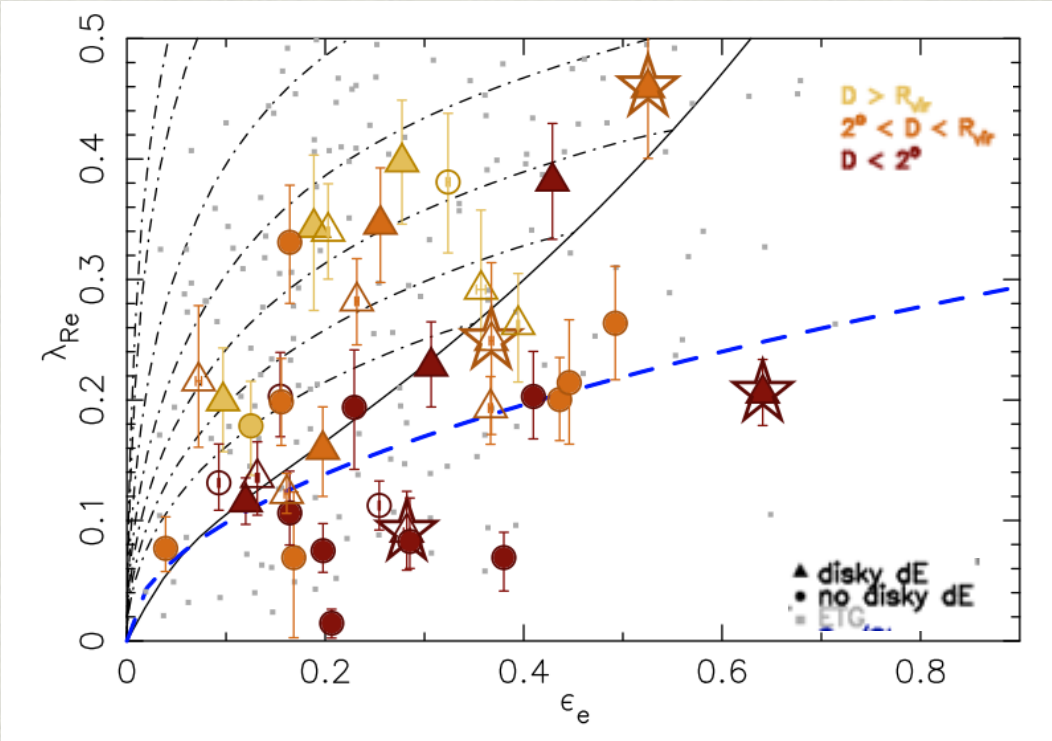

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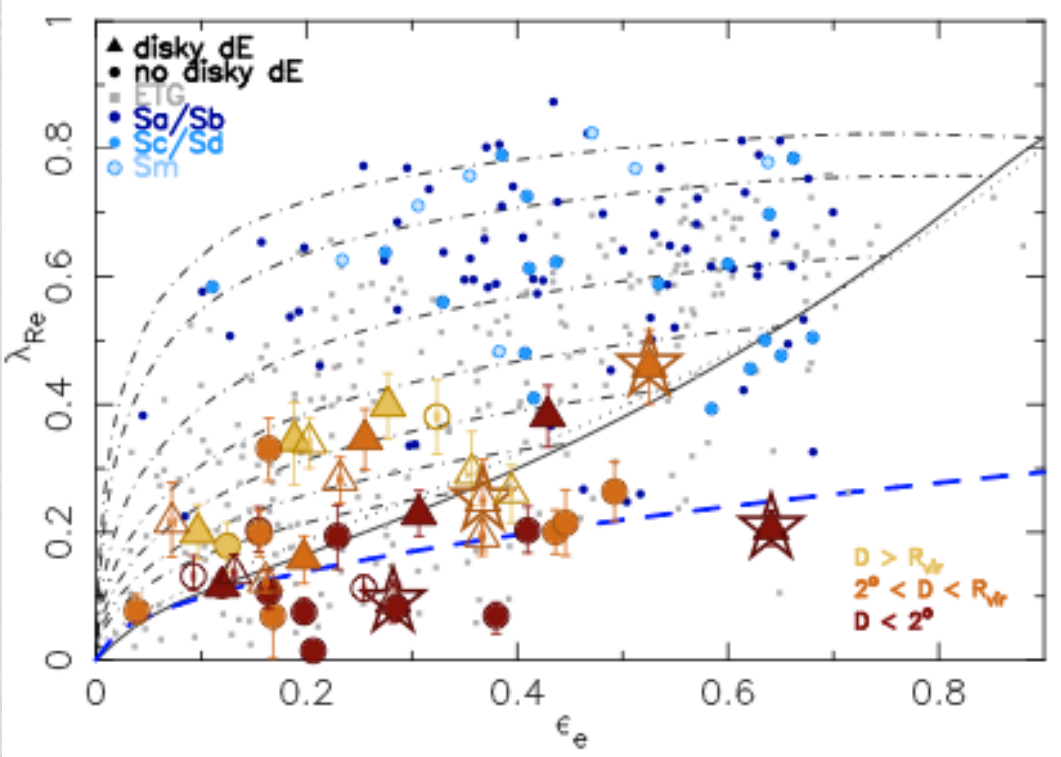

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Sa/Sb/Sc/Sd: CALIFA Falcon-Barroso in prep.

Sm: Adams+2014

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Toloba+2014c

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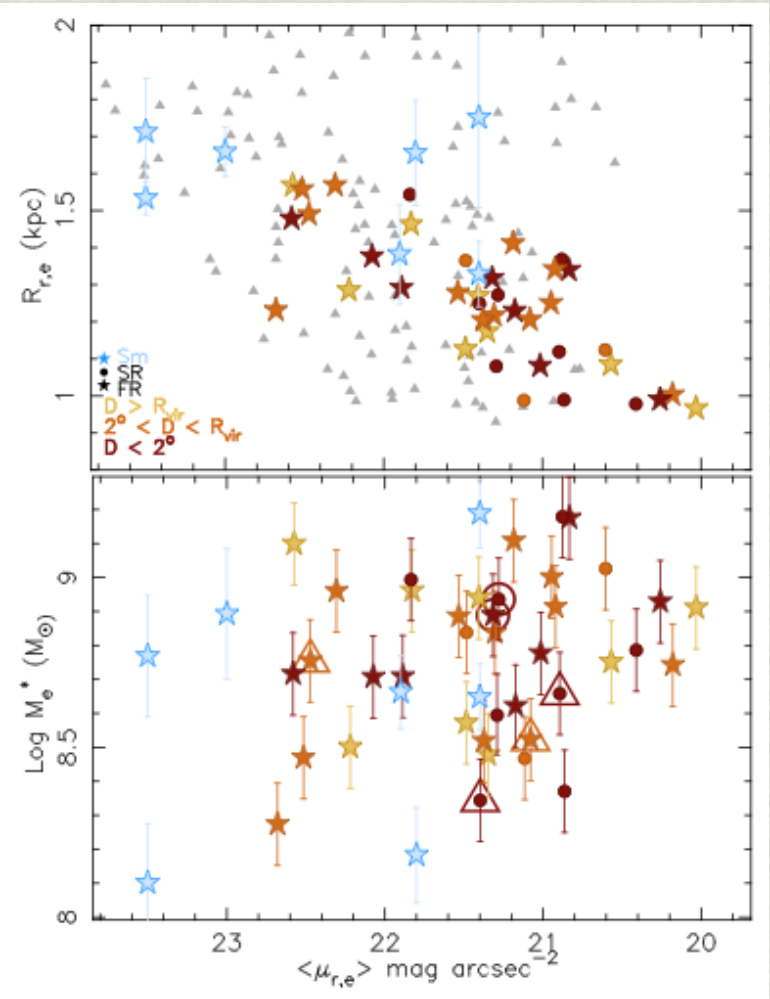
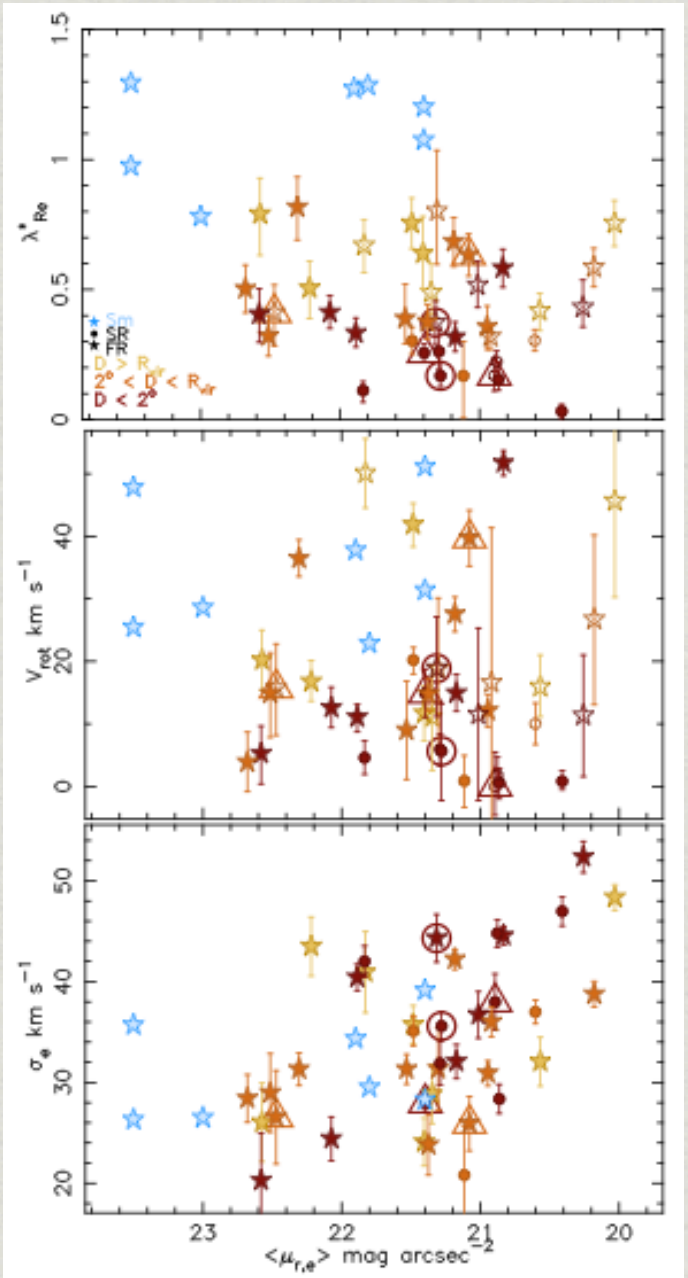
Comparison with low luminosity late-type galaxies



stellar kinematics of dEs and the low-luminosity late-type Sm galaxies from Adams+2014



Toloba+2014c

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Summary & Implications for dE Formation

☑ 2 KDCs found in Virgo cluster dEs VCC1183 & VCC1453 (Toloba+2014a)

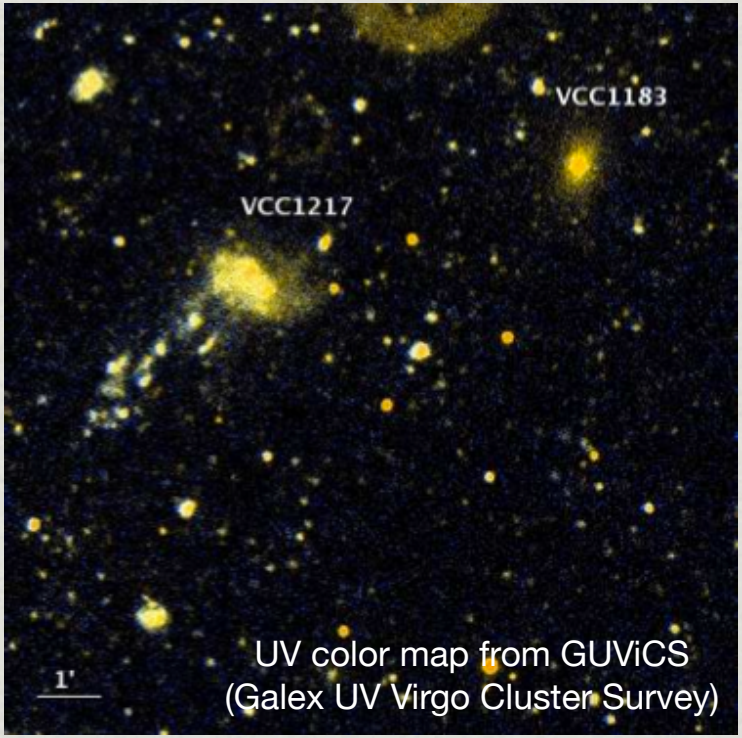
☑ 33+/-8% (13/39) have asymmetric rotation curves (Toloba+2014b, Toloba+in prep.)

☑ 11 slow rotators (5 of them non-rotators), 28 fast rotators (Toloba+2014c)

☑ lambdaR correlates with the clustercentric distance: slow rotators in the central 2deg, the fastest rotators beyond the virial radius (Toloba+2014c)

☑ 4 dEs with emission partially filling in the Balmer absorption lines (Toloba+2014b)

☑ 2<Age<14 Gyr, -1.3<[M/H]<0.0 => $(M/L)_{stars,H}$ = 0.73+/-0.19 => DM fraction ~40% (in agreement with Toloba+2011,2012, Rys+2014)



UV color map from GUViCS
(Galex UV Virgo Cluster Survey)

FORMATION SCENARIOS

- **Transformed low luminosity late-type galaxies**: ram pressure stripping, harassment.
- **Dwarf-dwarf merger** more important than previously thought (e.g. de Lucia+2006 vs. Deason +2014): not possible inside the Virgo cluster => **some dEs such as KDCs formed while dwarfs were in a group that subsequently fell into the Virgo cluster.**