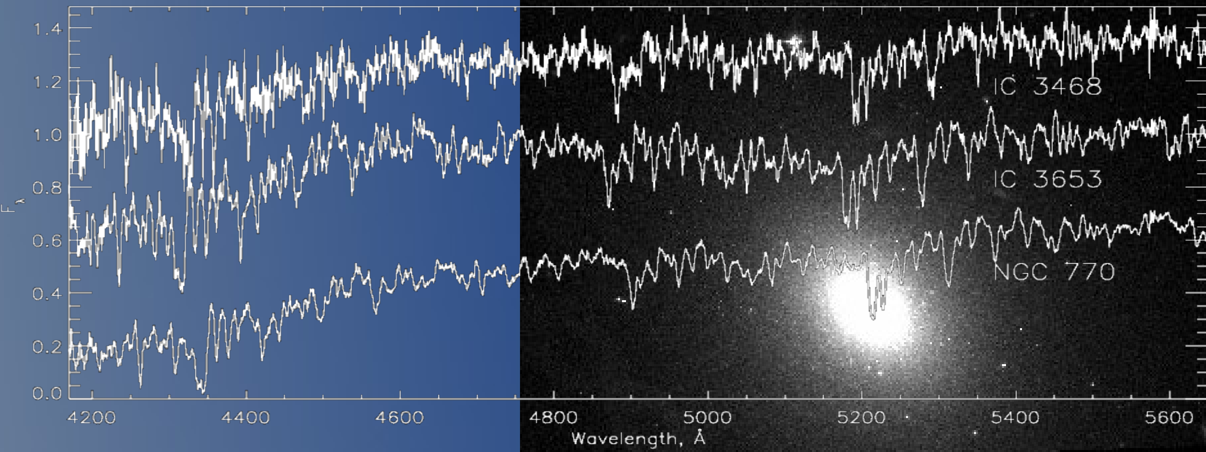


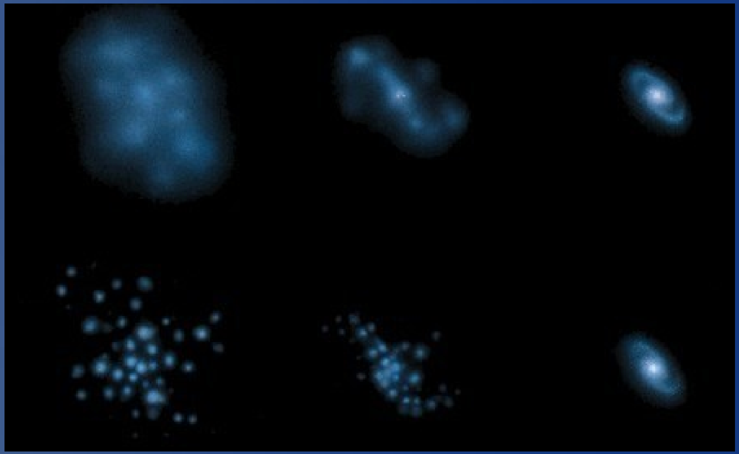
Formation and evolution of early-type dwarf galaxies: what can we learn from their internal kinematics and stellar populations?

Igor Chilingarian
(Observatoire de Paris – LERMA / SAI MSU)

SAO RAS - 2009/09/14

Galaxy Formation and Evolution

- Scenarios of galaxy formation:
  - Monolithic collapse
  - Hierarchical merging



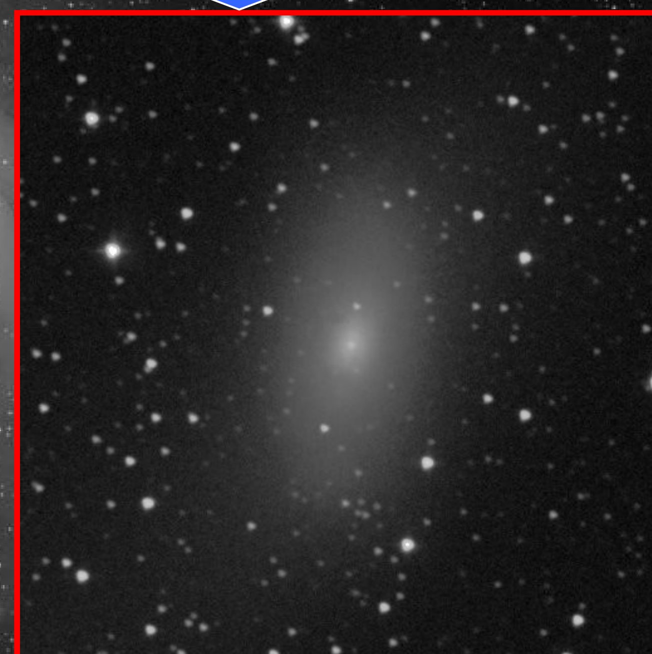
- More recent concept:
  - Downsizing, i.e. stellar growth moving systematically to lower mass galaxies as the Universe expands

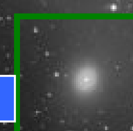
Approaching this challenge by studying nearby galaxies

Dwarf galaxies: historical perspective

M31 satellites (Baade 1944)
- – NGC205: prototypical dE
- – M32: prototypical cE

dE's are the numerically dominant population in the nearby Universe





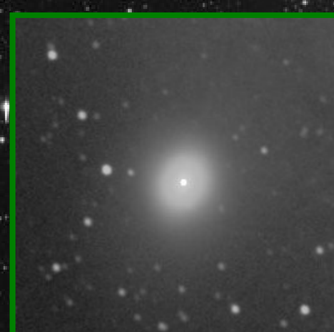
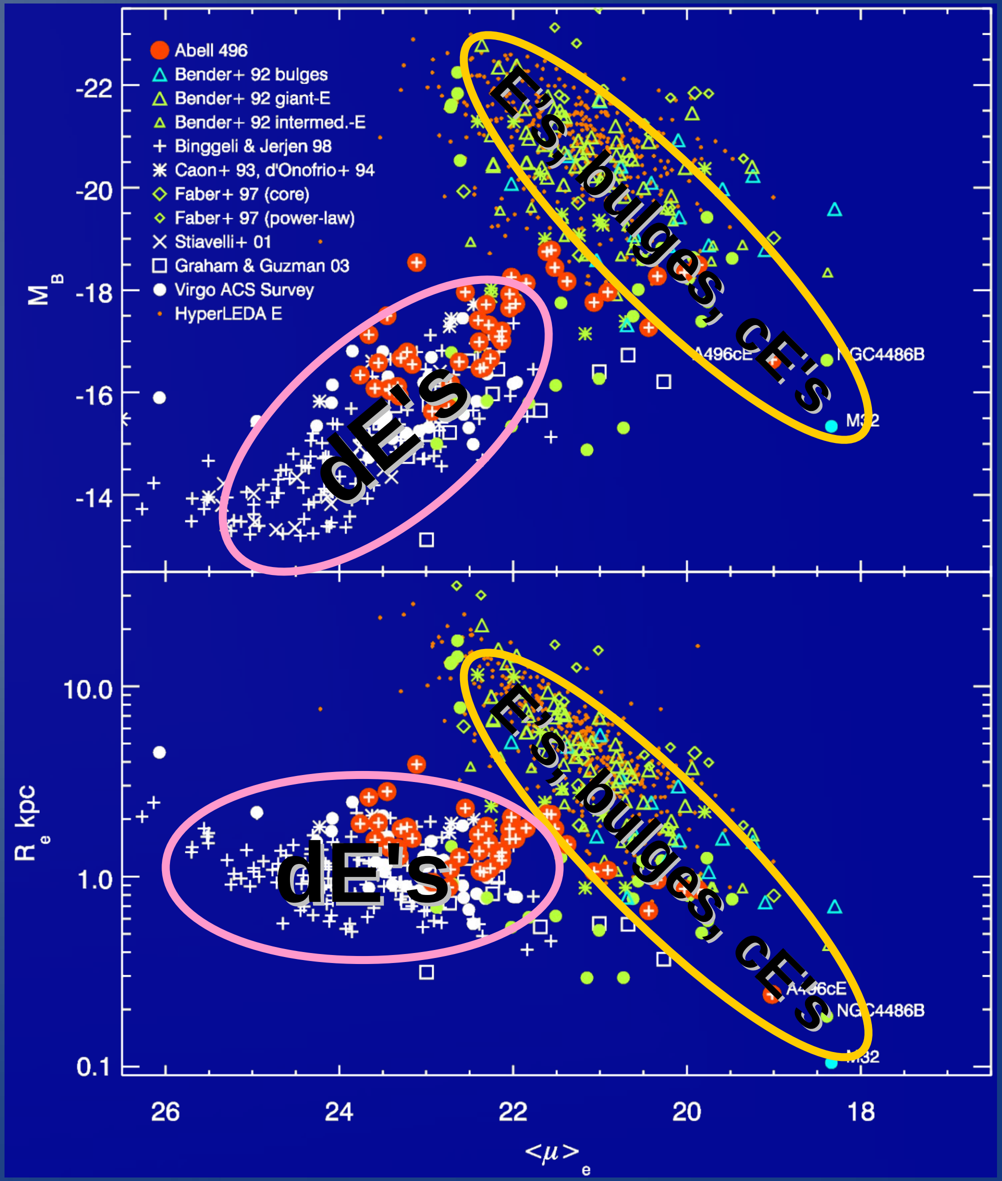


Image credits:

dE: properties, origin, evolution

- Dwarf, elliptical, diffuse
- Structurally different from E
- No ISM, no star formation
- Fine structures in bright dEs
- Often rotationally-supported
- DM fraction ~50%
- t=3..7 Gyr, Z=-0.7..-0.2 dex

- Internal mechanisms:
  - collapse + SF feedback
- External mechanisms:
  - ram pressure stripping of S
  - gravitational harassment
- Passive evolution afterwards



Another evolutionary agent and what we can do about all this

- Tidal interactions are believed to be responsible for:
  - creation of strange galaxies such as M32
  - formation of super-starclusters in mergers
  - tidal dwarf galaxies
  - ultra-compact dwarfs (one of the scenarios)
- To understand all this we apply full spectral fitting to the observational data and study:
  - **Internal kinematics**: mass distribution, tracing violent events
  - **Stellar population**: a fossil record of a star formation history

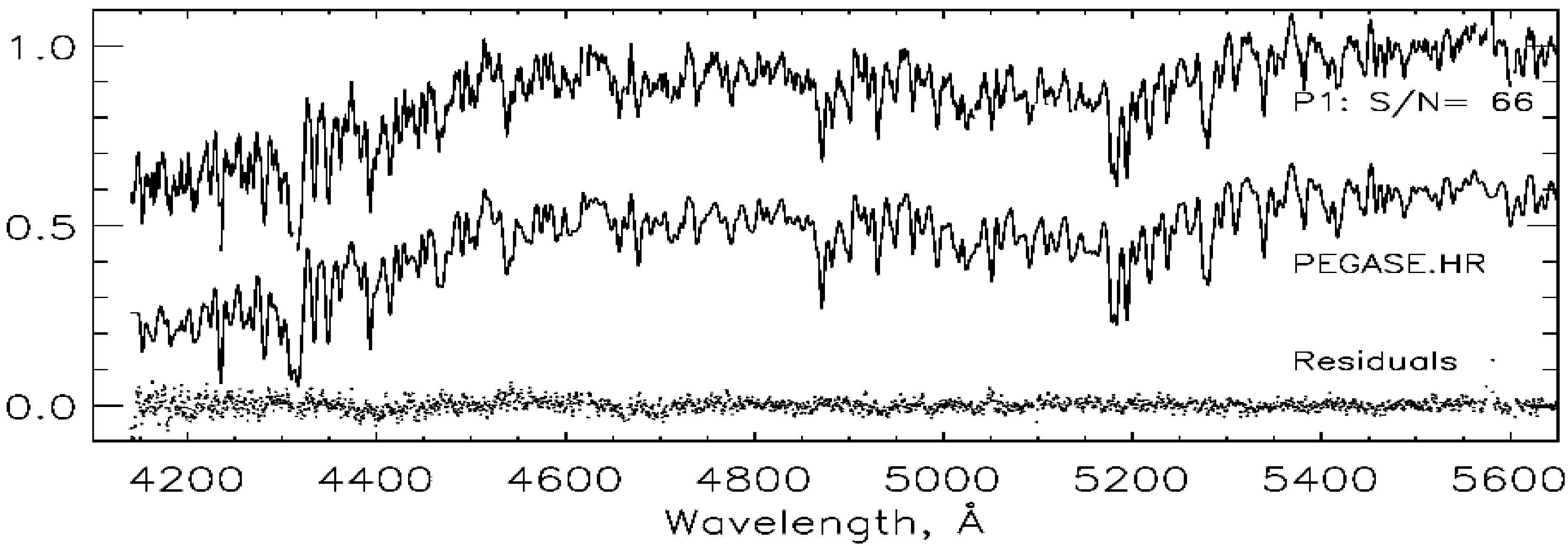
Full Spectral Fitting (*Nbursts*) Chilingarian et al. (2007, proc IAUS241)

Classical Approach:

- Internal kinematics:
  - Cross-correlation
  - Fourier-based techniques
  - Spectral fitting (pixel space)
- Stellar populations: Lick indices

Our Approach:

- Internal kinematics and stellar populations simultaneously from full spectral fitting (PEGASE.HR)
- Avoiding degeneracies, minimizing template mismatch, increasing precision (factor 3-6)



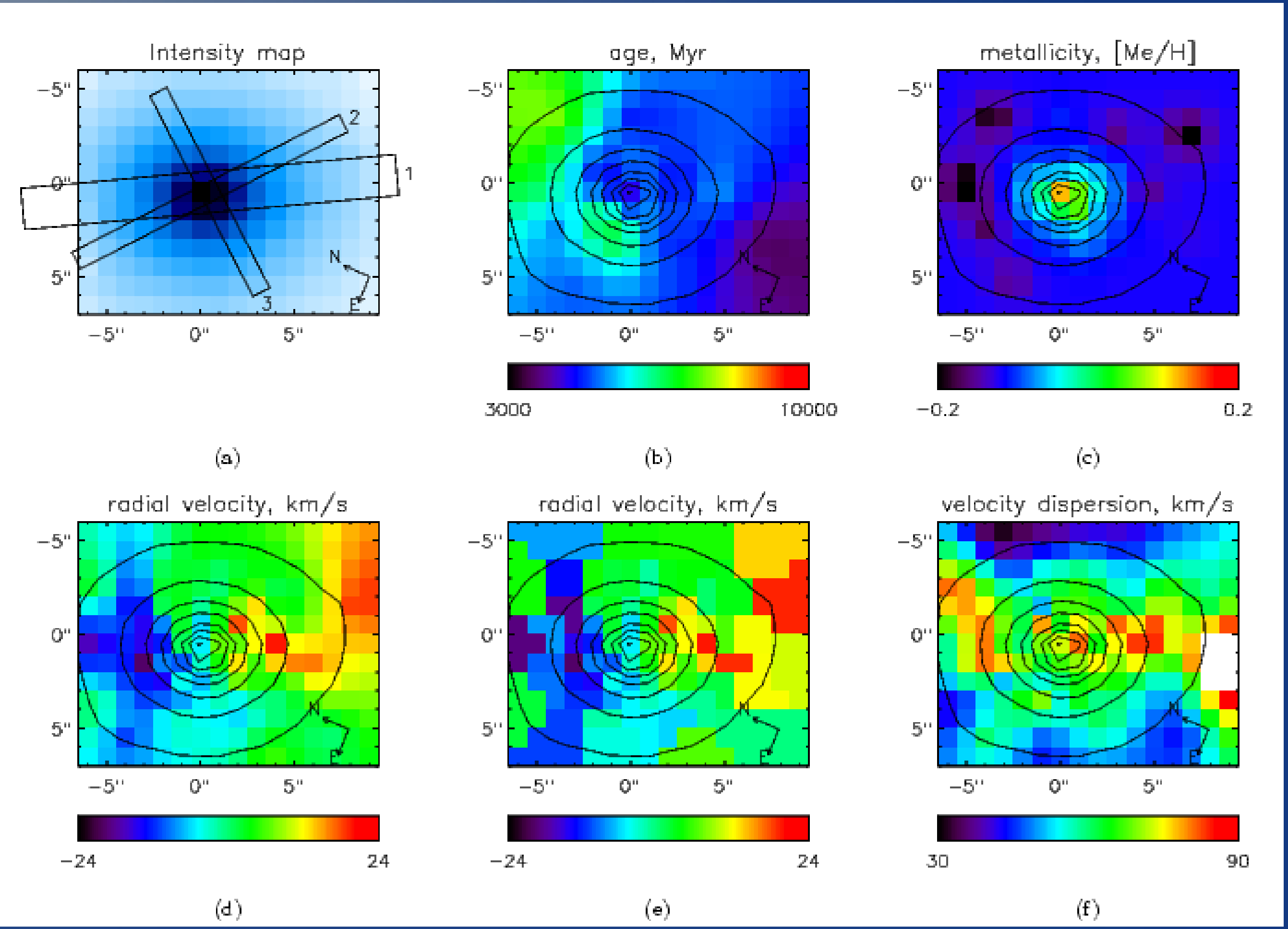
Studies of dE/dS0 Galaxies

- Optical 3D spectroscopy (IFU)
  - MPFS at 6m
  - PMAS at CAHA 3.5m
- Optical multi-object spectroscopy
  - FLAMES/Giraffe at VLT
  - SDSS
- Optical long-slit spectrosopy (archives):
  - Palomar 5m (Van Zee et al. 2004)
  - 1.93m at OHP (Simien & Prugniel 2002)
  - GMOS-S

Virgo dEs: IC 3653 (“bright”)

M_B = -16.8	σ = 70 km/s	[Fe/H] = 0.0	Age =5 Gy

- Embedded disc
- Metal-rich nucleus
- Intermediate age



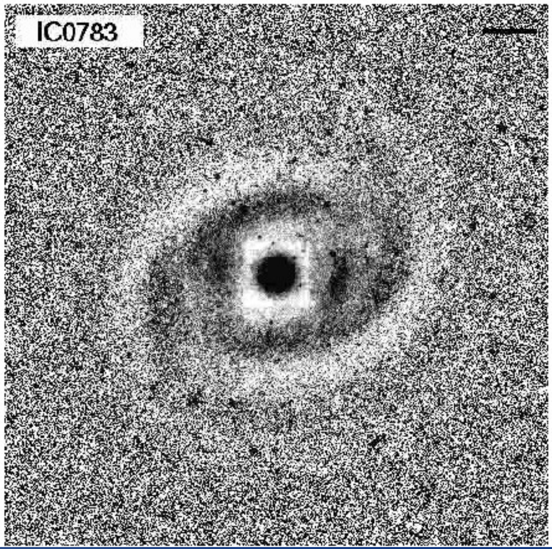
Chilingarian et al., 2007, MNRAS

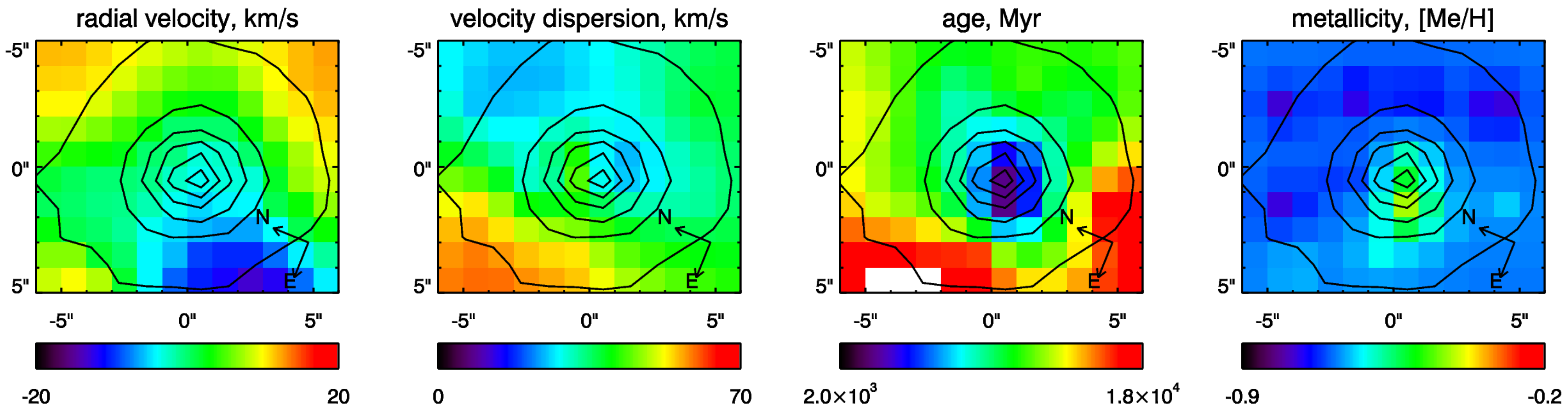
Chilingarian et al., 2007, AstL

Virgo dEs: IC 783 (“spiral”)

M_B = -16.3	σ = 30 km/s		
age_{cnt}=3.3 Gyr	$[Fe/H]_{cnt}$=-0.35	age_{out}=13 Gyr	$[Fe/H]_{out}$=-0.8

- Rotation in the inner region
- **Young nucleus (3 Gyr)**
- Low metallicity
- Two consequent crossing of the cluster centre?

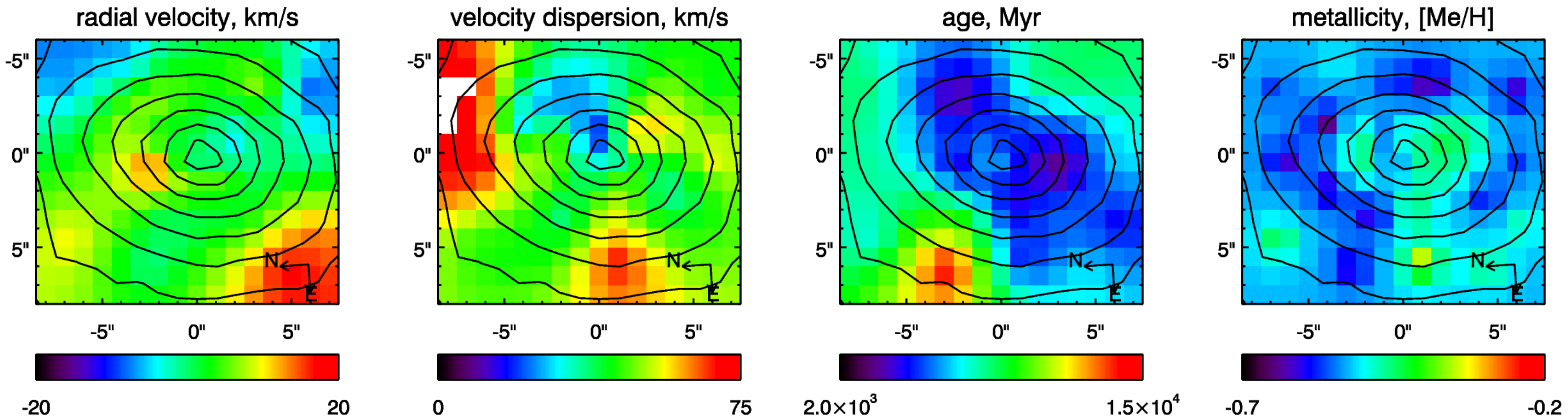




Virgo dEs: IC 3468 (“barred”)

M_B = -16.7	σ = 40 km/s		
age_{cnt}=5.3 Gyr	$[Fe/H]_{cnt}$=-0.4	age_{out}=8.6 Gyr	$[Fe/H]_{out}$=-0.6

- Kinematical axis is turned by 35-40 degrees off the photometric one. HST images reveal faint warped structure, corresponding to this orientation
- Young extended embedded structure (disc)
- Velocity dispersion map shows a dip, corresponding to this “disc” (“bar” according to Barazza et al. 2002)

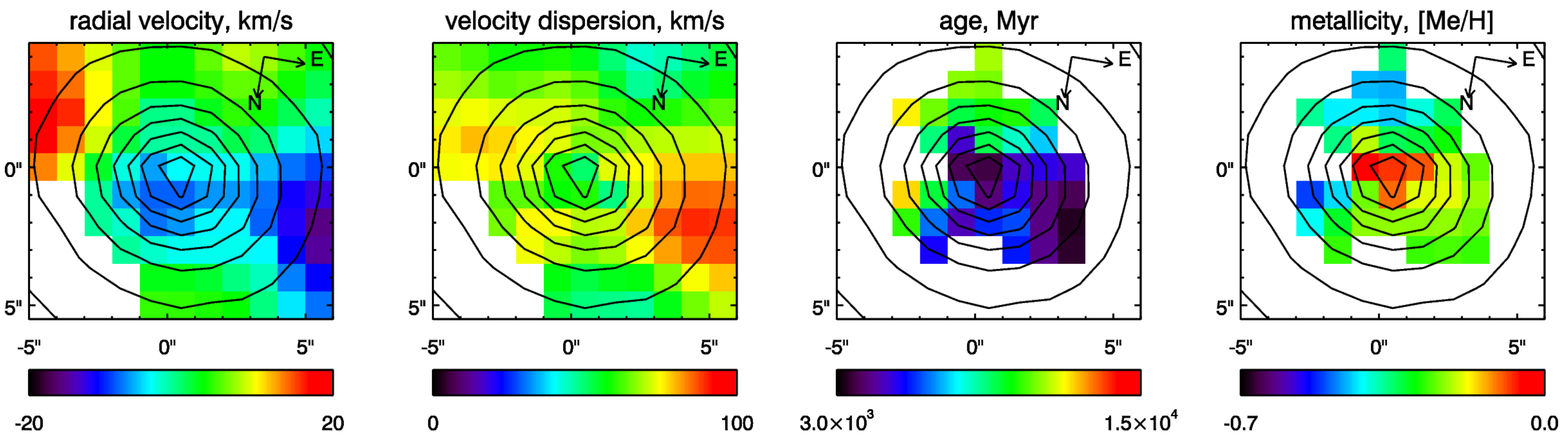


Chilingarian et al., 2007, AstL

Virgo dEs: IC 3509 (“classical”)

M_B = -16.2	σ = 50 km/s		
age_{cnt}=4.1 Gyr	$[Fe/H]_{cnt}$=-0.0	age_{out}=7.8 Gyr	$[Fe/H]_{out}$=-0.4

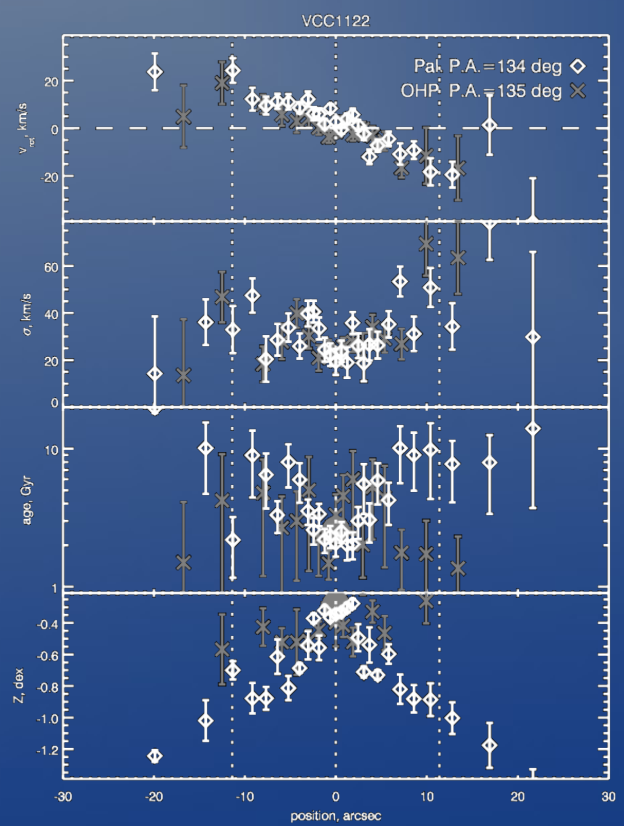
- Was chosen as a “prototypical” dE: without bar, disc, spirals
- Rotation along two perpendicular directions. Kinematical appearance looks very similarly to giant E NGC4365, where it was explained as a projection of orbits in a 3-axial potential (without need for embedded structure)
- Rather young (4 Gyr) metal-rich ([Fe/H]=0) nucleus

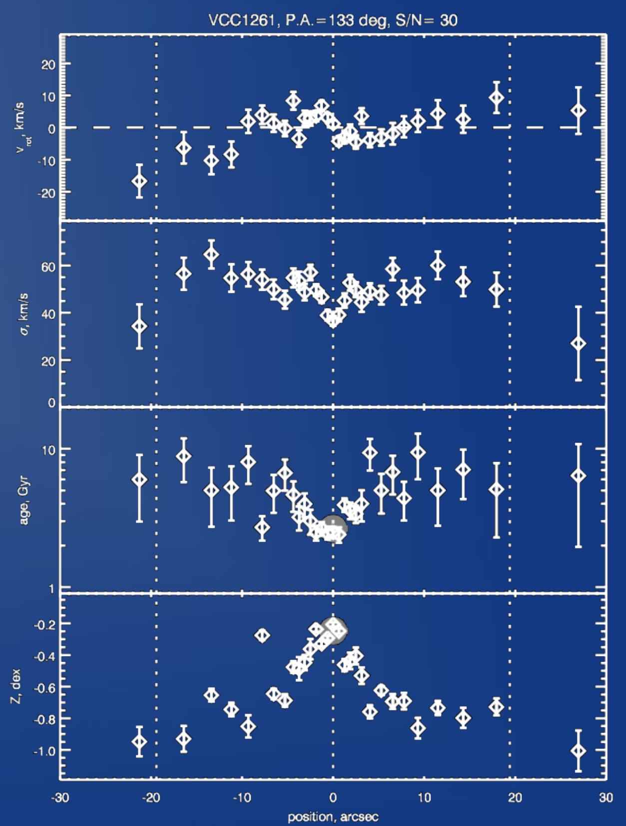


Chilingarian, 2009, MNRAS

Virgo dEs: long-slit archival data

- 31 galaxies from Palomar 5m and OHP
- Many evolutionary decoupled nuclei
- 4 new KDCs (VCC917,1036,1122,1261)
- σ-drops



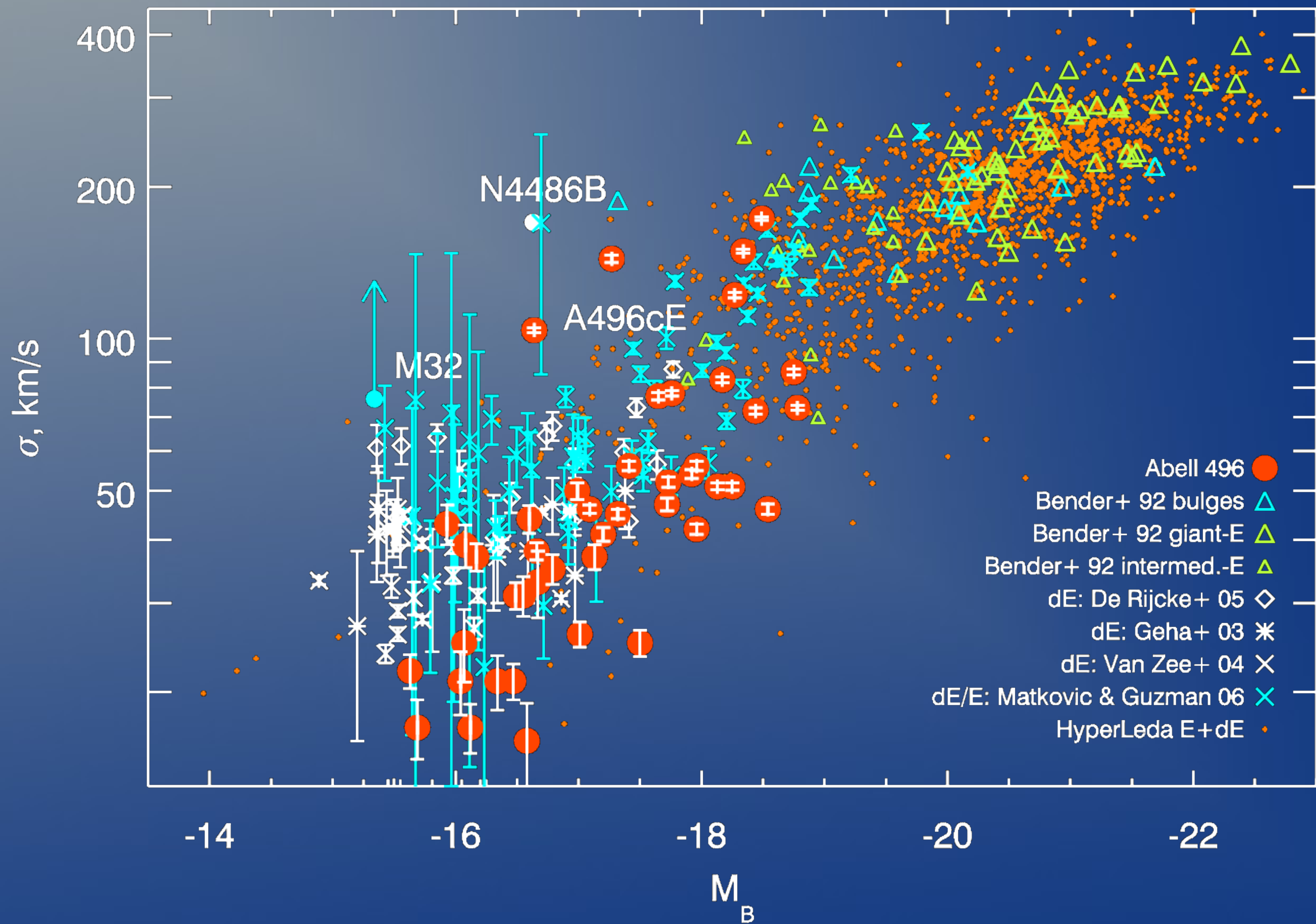


dE/dS0 galaxies in Abell 496 (131 Mpc)

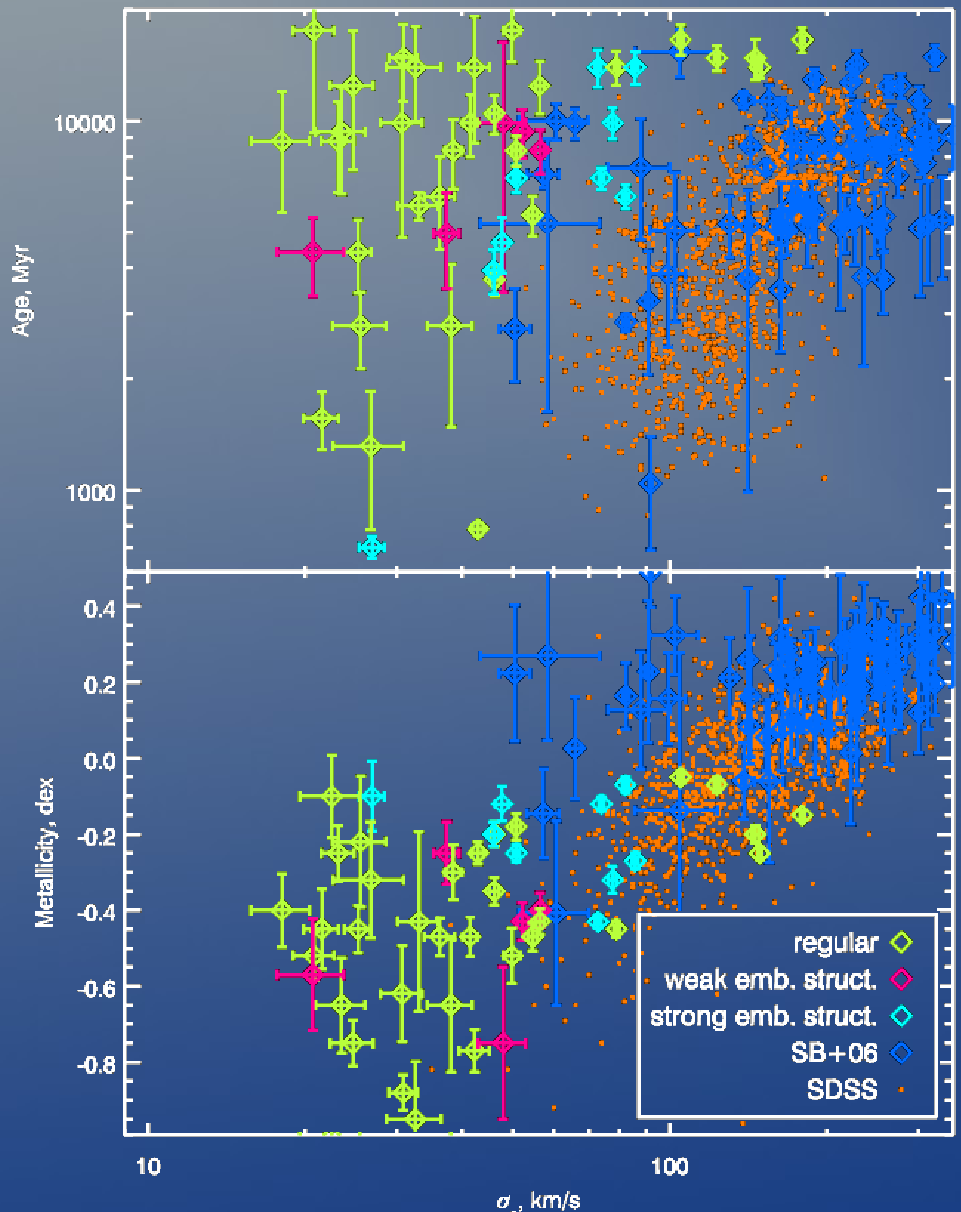
(Chilingarian et al., 2008, A&A)

- Data:
  - Imagery (u*, g’, r’, i’) using MegaCam @ CFHT
  - Spectroscopy: 3 fields with VLT FLAMES/Giraffe
- 110 spectra. 48 cluster members (46 sufficient S/N ratio):
  - 36 dEs/dS0s, 2 SBs, 10 low-luminosity E/S0/Sa
  - Accurate internal kinematics ⇨ scaling relations
  - [Mg/Fe] abundance ratios by measuring Lick indices
  - Estimations of age and metallicity for the luminosity-weighted population (single starburst)
    - Mapping relations between stellar populations and velocity dispersions in the low-σ regime
- Colour maps for 48 galaxies
- Unsharp masking for 48 galaxies

Faber-Jackson Relation



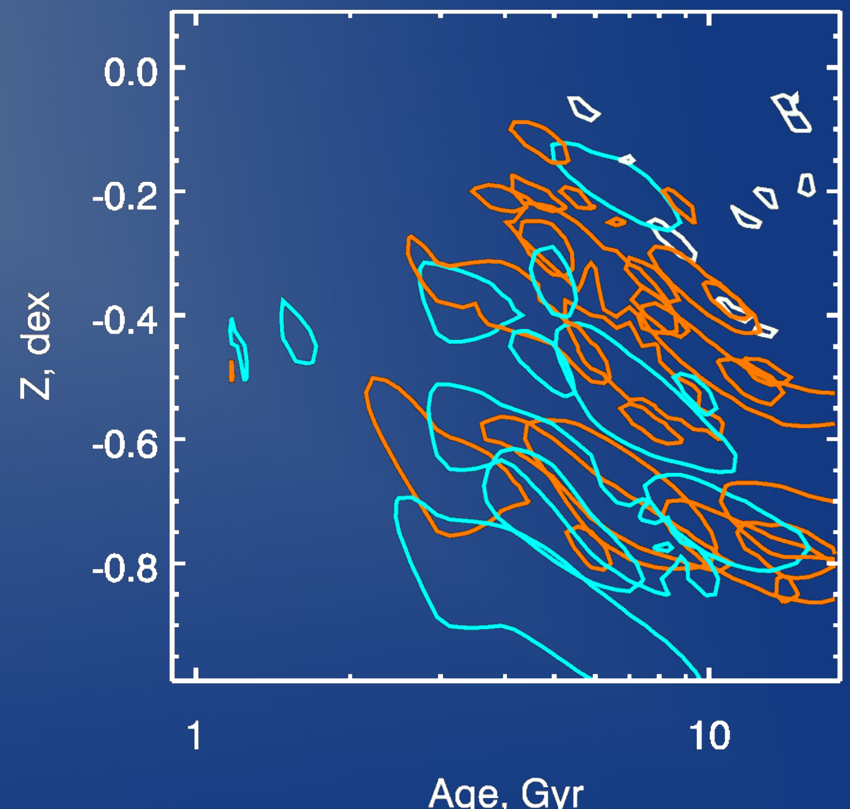
Stellar Populations: age, [Fe/H]



What we see:

- Strong correlation in [Fe/H]-σ
- Much less clear on the age-σ plot

Age-metallicity degeneracy??? NO!



Summary for dE galaxies

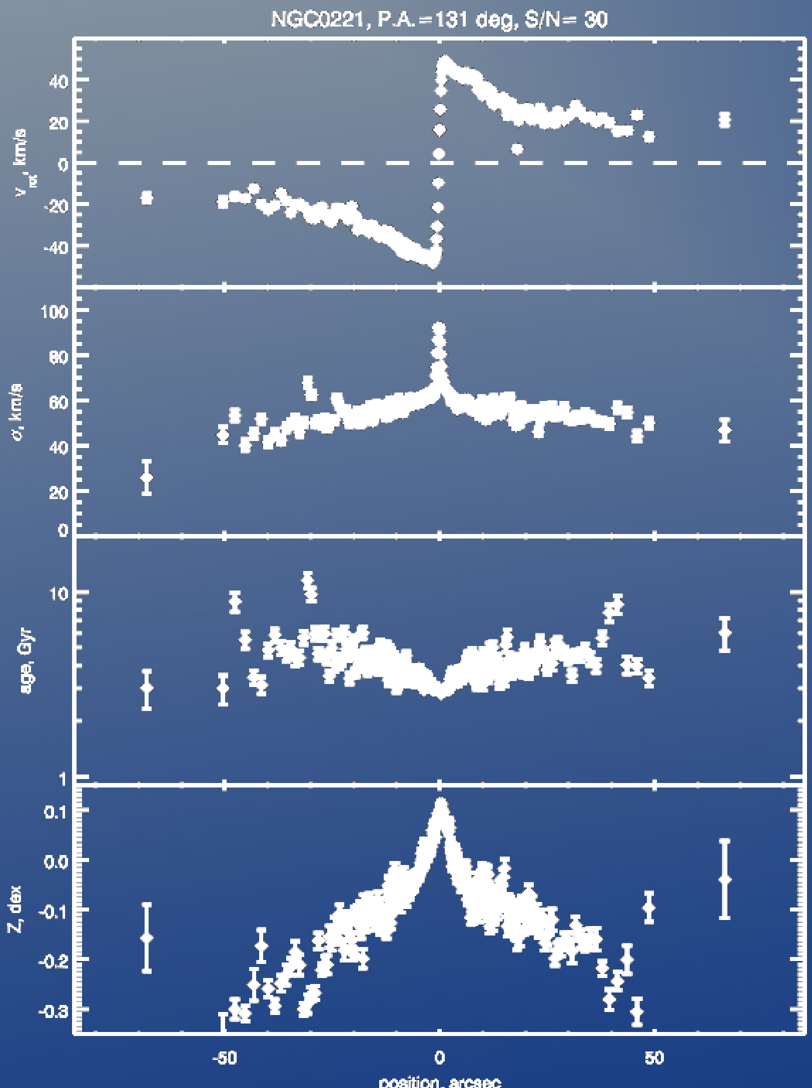
- Embedded discs – early type progenitors
- Ubiquitous evolutionary decoupled cores
- [Mg/Fe]=0, therefore the starburst events in dE/dS0 galaxies must have lasted at least 1-2 Gyr to explain observed iron enrichment
- Only brighter galaxies exhibit embedded structures
- Many galaxies exhibit red and blue nuclei
- Wide range of ages, but mostly intermediate

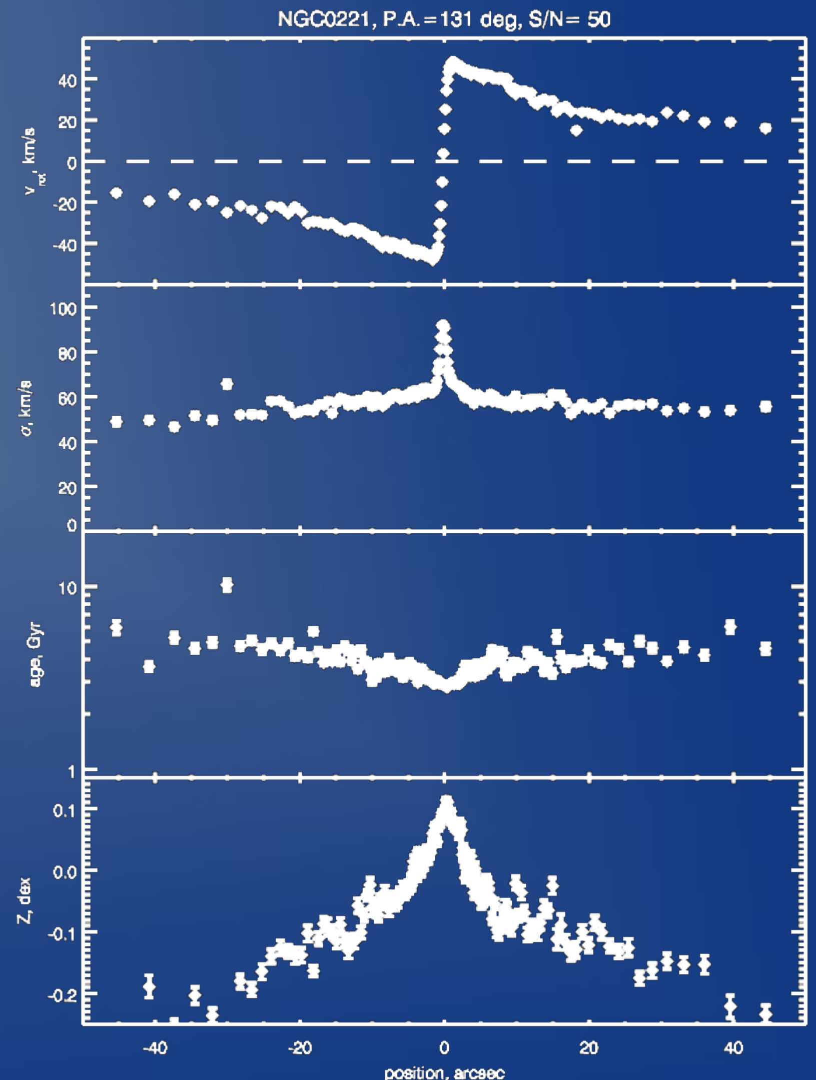
Main conclusion: "external" channel of dE formation (ram pressure stripping + harassment) is the most important mechanism, while SN winds (though required to explain mass-[Fe/H] relation) fail to reproduce observed α-enrichment.

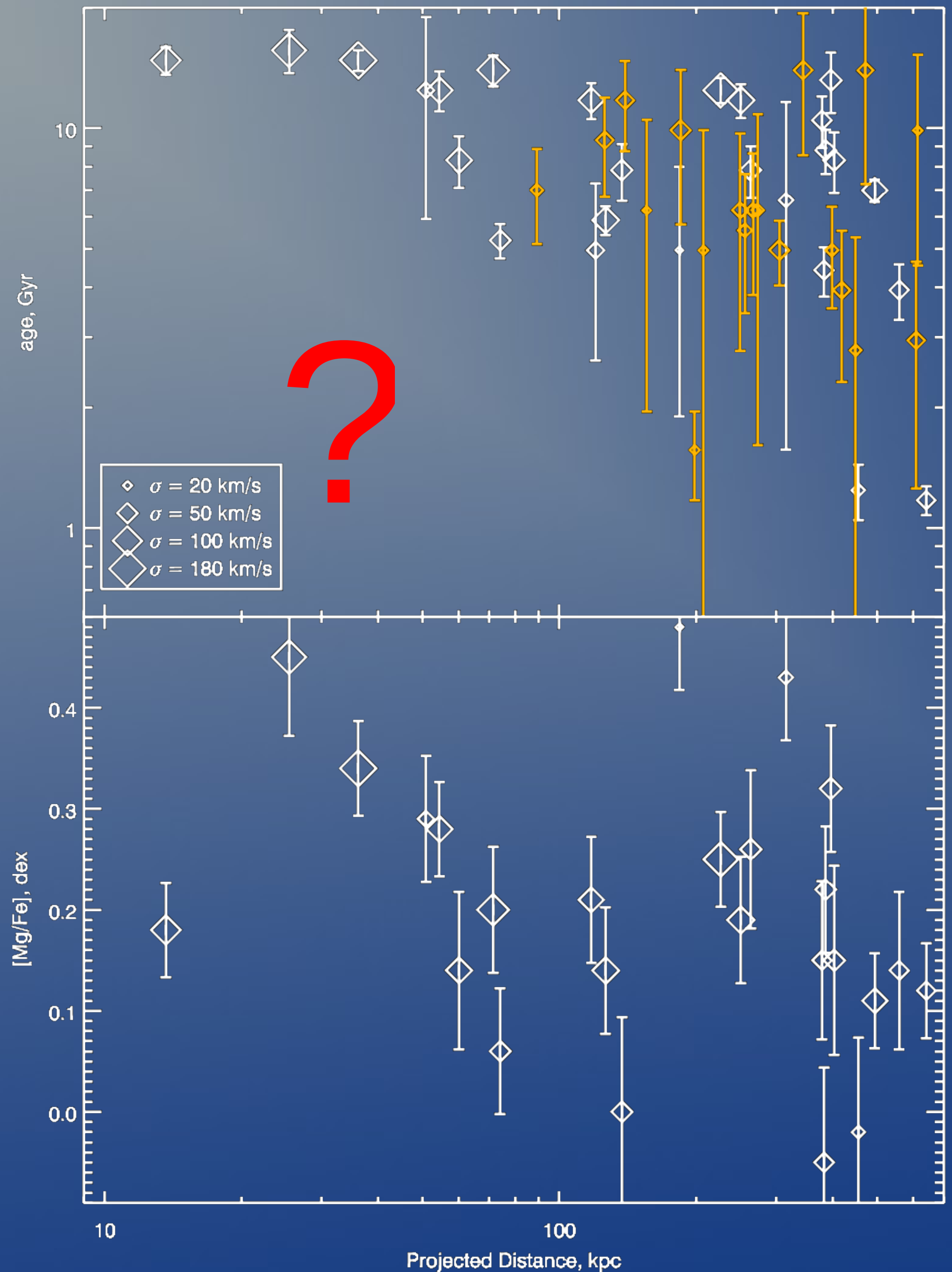
DOWNSIZING???

Compact elliptical galaxies

M32 the prototype: a story different than dE





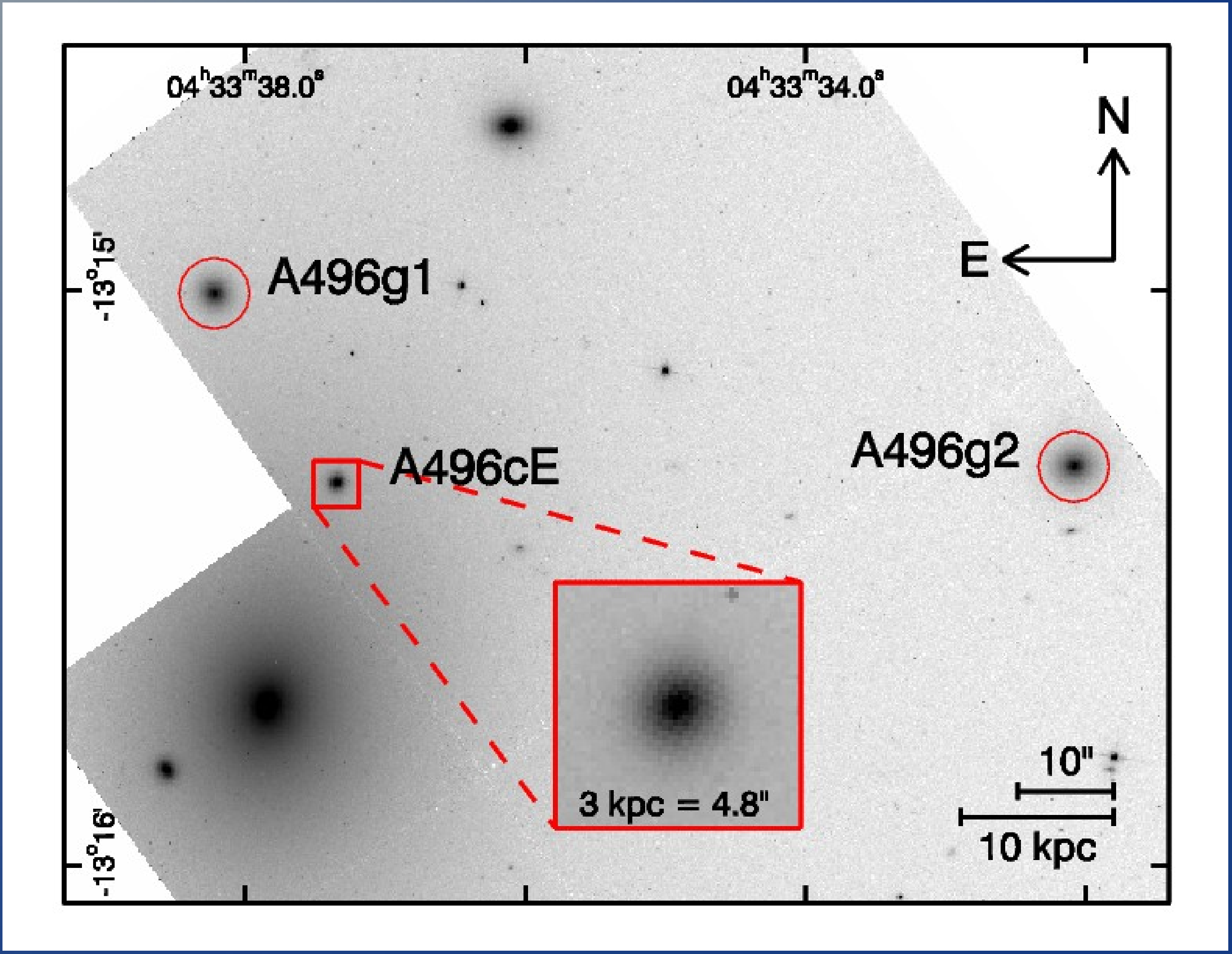


Segregation of young galaxies in clusters

High [α/Fe] ratios and high velocity dispersions for 5 low-luminosity galaxies in the the Abell 496 core, one of them is a newly discovered cE (M32-like) galaxy (6-th known in the Universe)

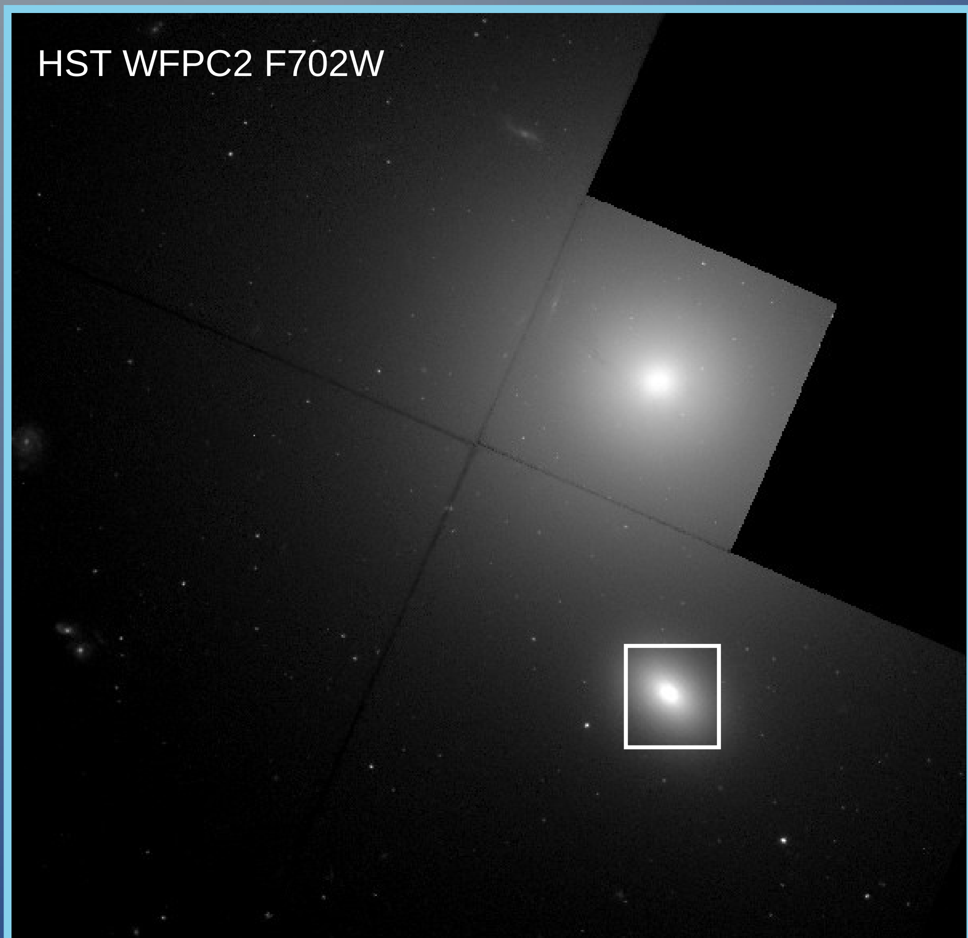
cE galaxy in Abell 496

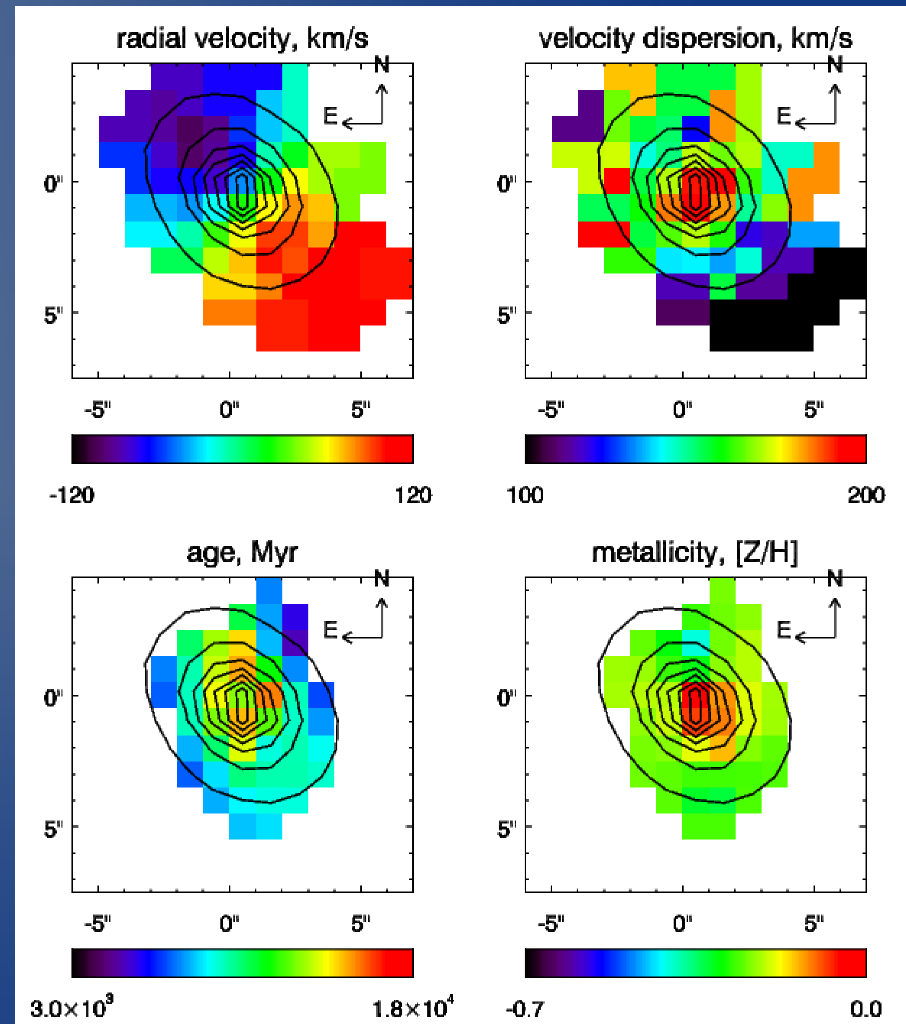
Chilingarian et al. 2007 (A&A Letters)



NGC 5846A (PMAS Calar-Alto 3.5m)

M_B = -19.5	σ = 190 km/s	[Fe/H] = -0.0	Age = 12 Gy





Search for cE galaxies

(Chilingarian et al. 2009, Science, submitted)

Exploiting power of the Virtual Observatory

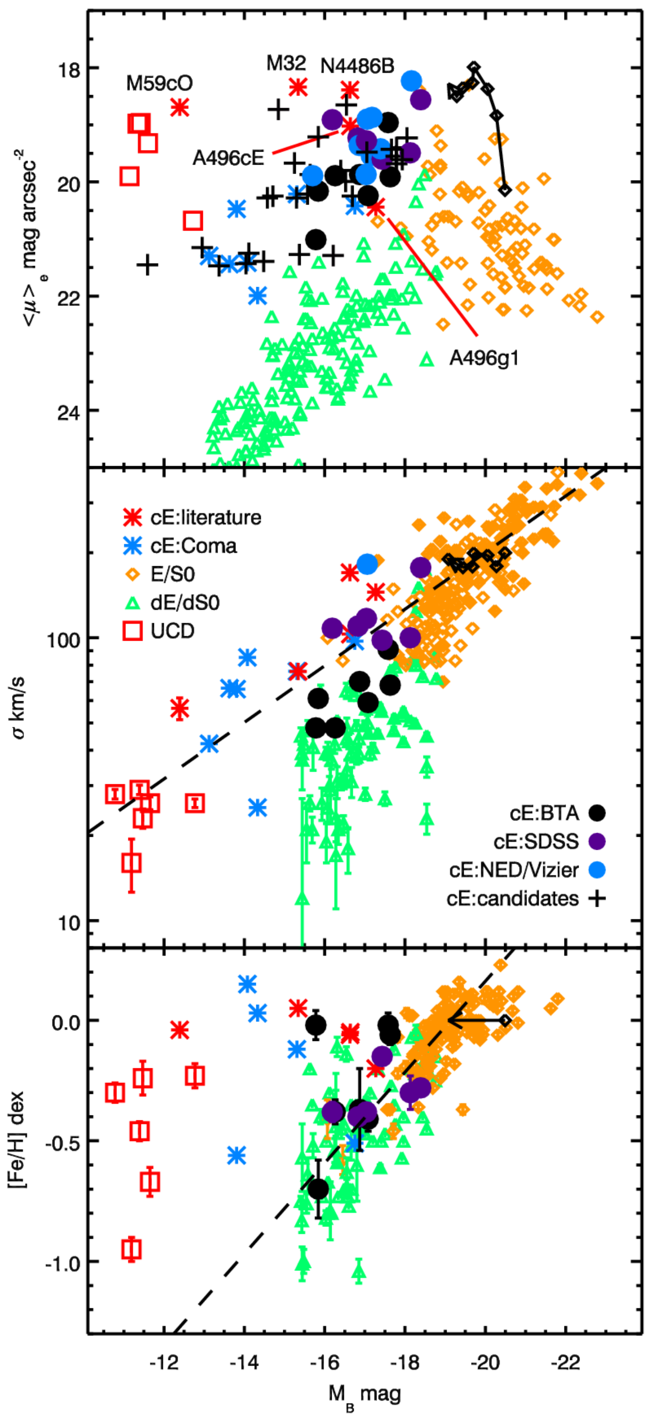
VO workflow includes:

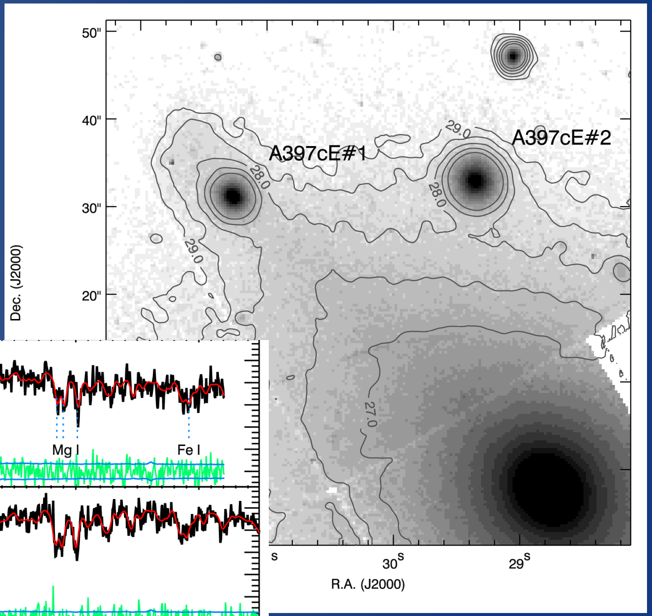
- **querying NED to retrieve a list of Abell clusters having z<0.055;**
- **querying HST WFPC2 at HLA (fully-reduced direct images) using IVOA Simple Image Access Protocol (SIAP);**
- **running SExtractor service on these images;**
- **selecting extended objects having effective radii below 0.7 kpc and B-band mean effective surface brightness higher than 20 mag/arcsec^2;**
- **querying NED to check if there are published redshifts for the selected objects.**

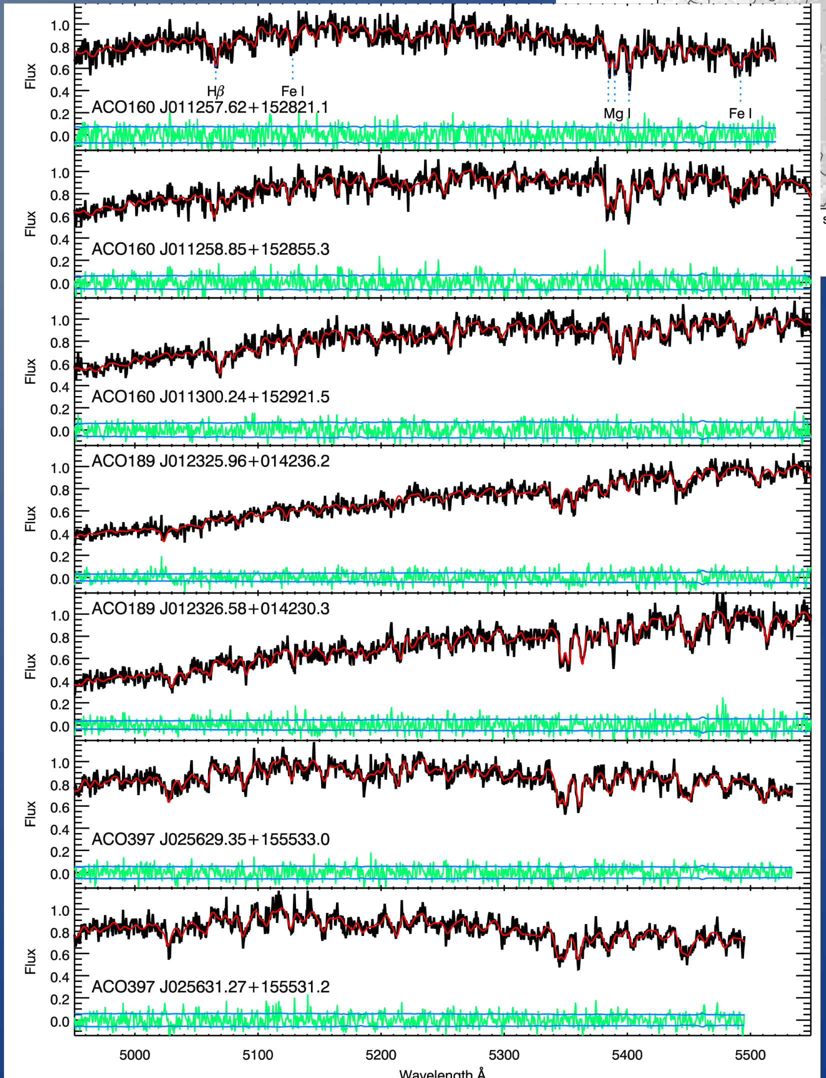
RESULTS:

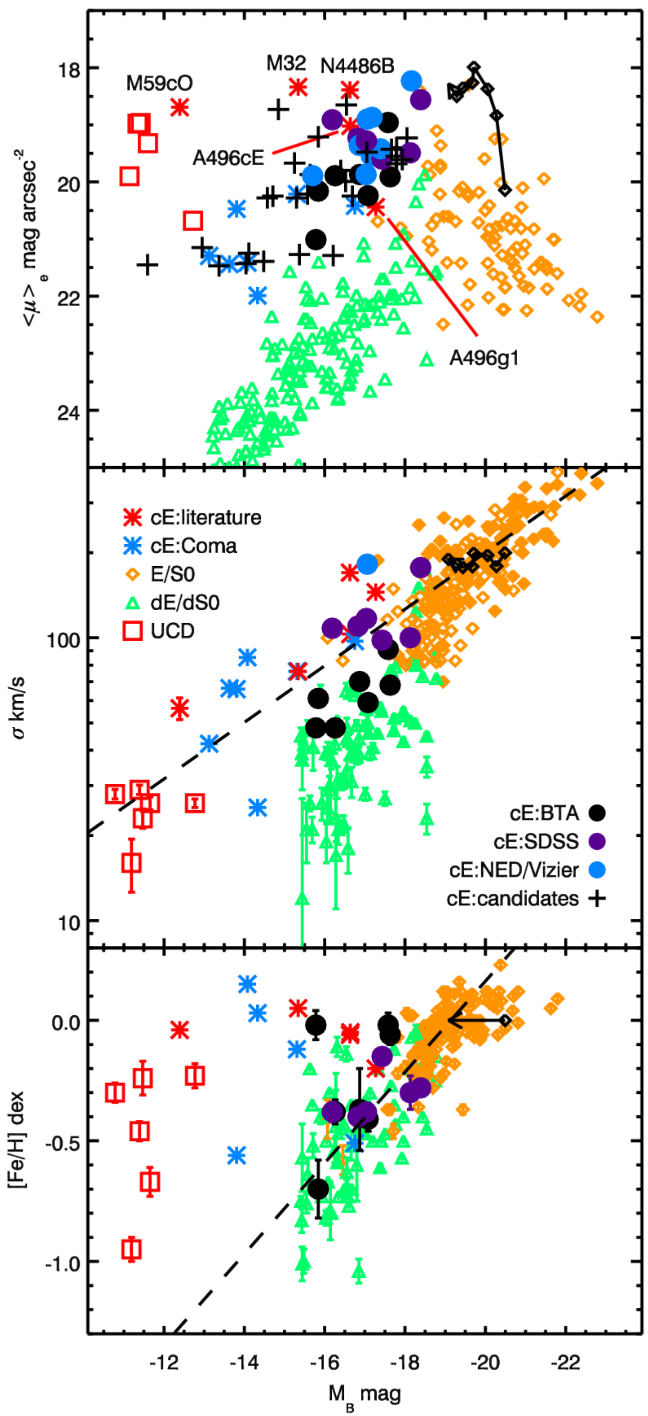
- 55 candidates in 23 Abell clusters;
- 14 galaxies immediately confirmed from literature and or SDSS;
- 7 fainter galaxies confirmed with SCORPIO-MultiSlit.

New cEs

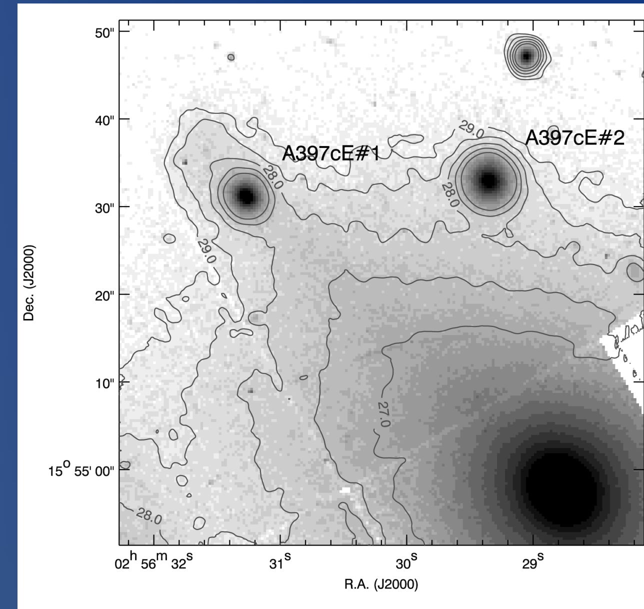

M59cO
M32
N4486B
A496cE
A496g1
cE:literature
cE:Coma
E/S0
dE/dS0
UCD
cE:BTA
cE:SDSS
cE:NED/Vizier
cE:candidates
<μ>e mag arcsec⁻²
σ km/s
[Fe/H] dex
M_B mag


A397cE#1
A397cE#2
Dec. (J2000)
R.A. (J2000)

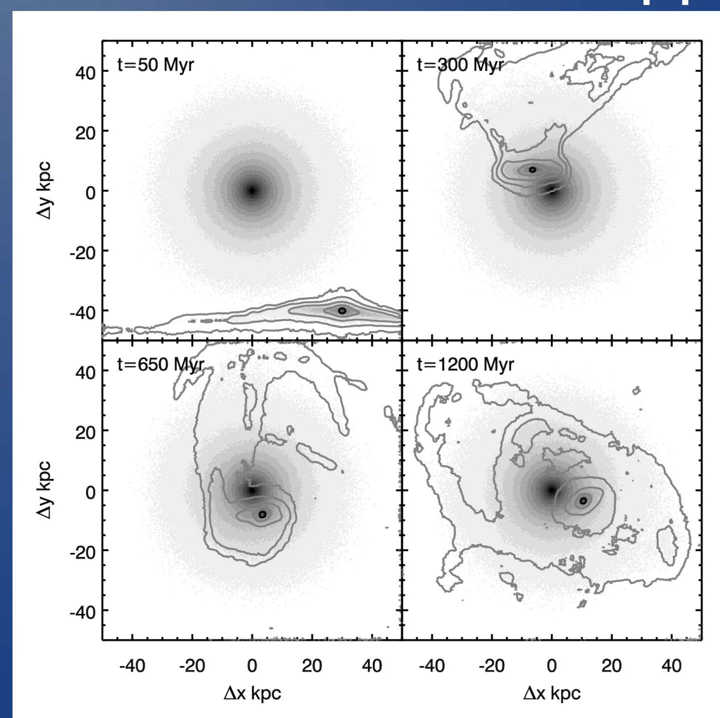

Hβ
Fe I
Mg I
Fe I
ACO160 J011257.62+152821.1
ACO160 J011258.85+152855.3
ACO160 J011300.24+152921.5
ACO189 J012325.96+014236.2
ACO189 J012326.58+014230.3
ACO397 J025629.35+155533.0
ACO397 J025631.27+155531.2
Flux
Wavelength Å



New cEs



Simulations of tidal stripping



cE galaxies: observational properties

- Very high metallicities for their dwarf luminosities
- Old ages (comparable to the age of the Universe)
- Supersolar [Mg/Fe] (except M32, which is quite special)
- High velocity dispersions
- Peaked velocity dispersion fields (for nearby cEs) proving existence of central Bhs
- Rotation (for nearby cEs)
- Two-component brightness profiles (for most of them)

Formation scenario: tidal stripping of intermediate-luminosity S0s

Why are they rare? Probably because of the very narrow range of input parameters, short lifetime

Summary

- dEs and cE's have similar luminosities, but their properties and evolutionary scenarii are absolutely different
- dEs originate from low-massive disk galaxies that have lost their gas due to ram pressure stripping and gravitational harassement
- cEs are remnants of more massive objects being tidally stripped by the cluster cD galaxies. Loss of mass helps them to survive in this environment for Gyrs.

Acknowledgments

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