Extragalactic research with the Virtual Observatory

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Introduction

- The Virtual Observatory is a realisation of the e-Science concept in astronomy.
- **Data archives** and **software tools** interoperating using a set of peer-reviewed standards and technologies developed by the IVOA form a powerful *virtual environment* aimed at facilitating astronomical research and increasing scientific output of data

What does it really mean???

- **to increase N_{paper}/Gb**

WWW and VO: similarities

- W3C
  - HTML/XHTML
  - Javascript specs
- Resources:
  - web-sites
  - portals/directories
  - web-services
- Tools:
  - browsers
    - Firefox
    - IE
  - command-line
  - specialised
    - Picasa
    - Google Earth

- IVOA
  - VOTable
  - all other standards
- Resources:
  - registries
  - data archives / CAS
  - web-services
- Tools:
  - data browsers
    - VODesktop
    - Aladin
    - Topcat
  - command-line
  - specialised
    - Euro3D client

What is already accomplished

- On the IVOA side:
  - a comprehensive set of standards, although still a lot to work on
- On the application developers side:
  - a heterogeneous set of tools from very general to very specialised
- On the data/service providers side:
  - many data collections and archives at wavelength domains from gamma to radio, although some major players are still out of the game
  - first services providing access to models
  - online data analysis services start to appear

What about science?

- Quite a long break (3 years) after the first paper by Padovani et al.
- New results appeared in 2007-2008
  - Caballero et al.
  - Solano et al.
  - Richards et al.
  - *Check IVOA Newsletter for a complete listing*
- At present, the VO-enabled research is mostly data mining
  - Is it already possible to go beyond???

YES, of course! - see examples

Demos and Science Cases

4 parts

1. Data discovery using VO tools and services
2. Search for cE galaxies in the nearby Universe
3. Optical/NIR colours of nearby galaxies
4. The GalMer database – simulations of galaxy mergers in the Virtual Observatory

#1: simple demo (data mining)

- Displaying FLAMES/Giraffe multi-object spectroscopy datasets with VO tools.
- Finding ultra-compact dwarf galaxies with existing archival HST images
  - Mieske et al. (2008) had 8 objects without HST observations, at least it was stated like this
  - Using HST footprint from HLA and a reduced FLAMES/Giraffe dataset to check for existing archival data (Aladin / VO-Paris Euro3D Client)
- Demo (pre-recorded):
  http://sn.sai.msu.ru/~chil/vo_demo/demo_giraffe3d_UCD.html

Advanced science cases

#2: Compact elliptical galaxies

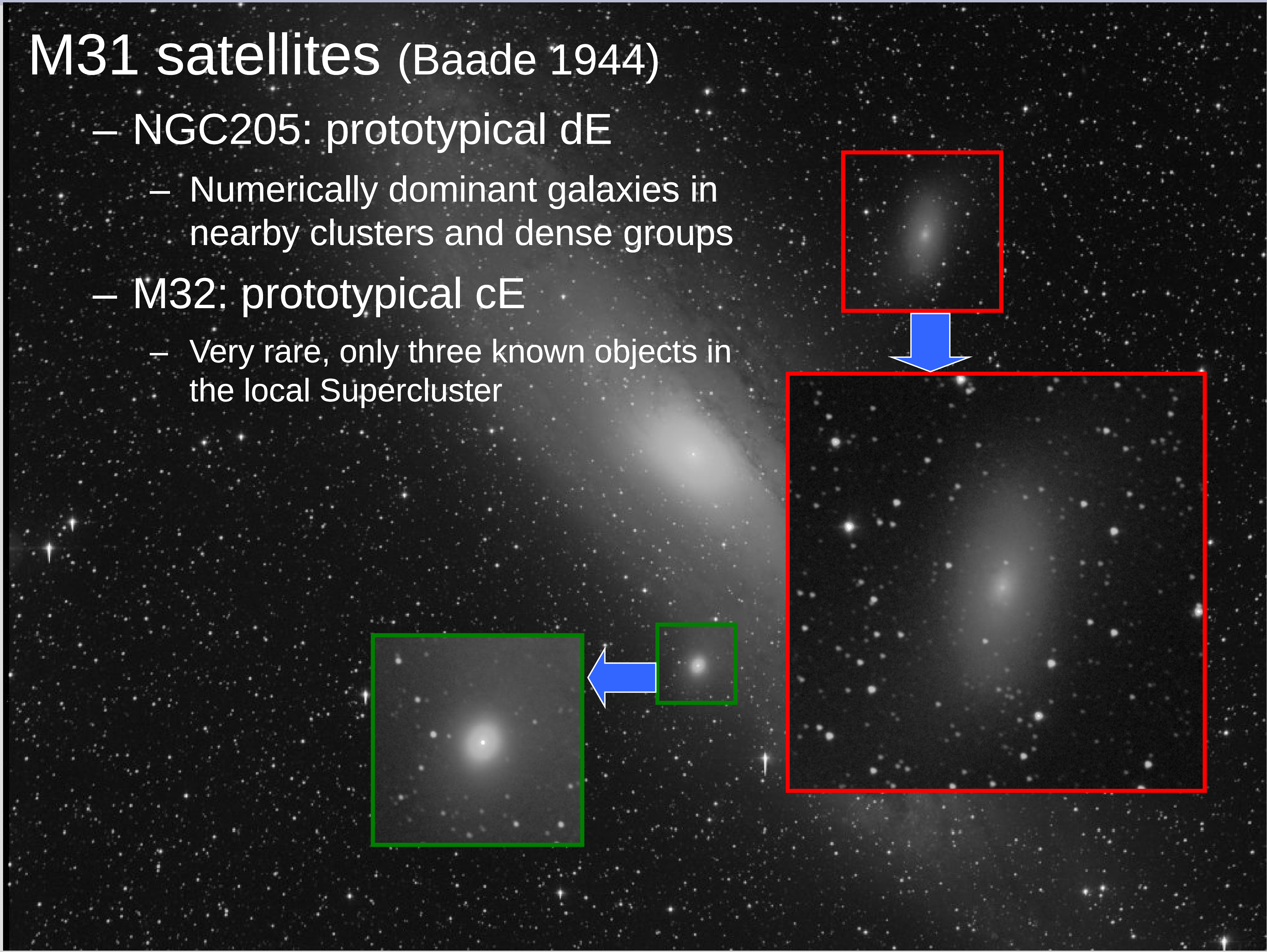
#3: Optical/NIR galaxy colours

#4: GalMer – simulations of galaxy mergers

Nearby dwarf galaxies

M31 satellites (Baade 1944)

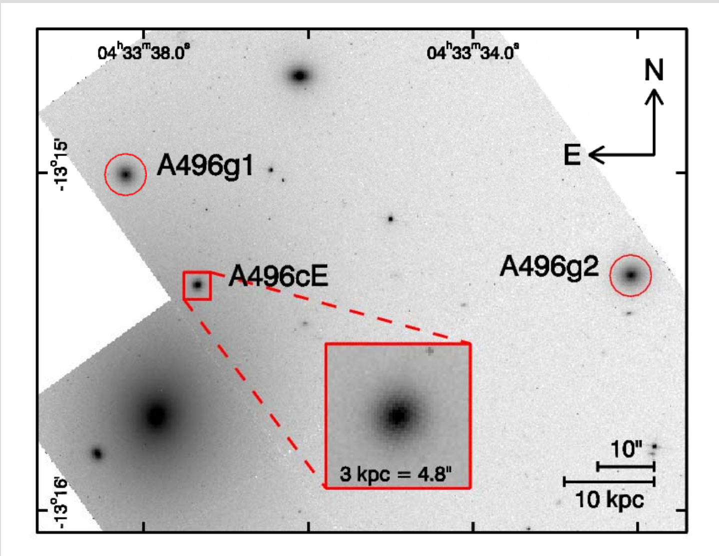
- NGC205: prototypical dE
  - Numerically dominant galaxies in nearby clusters and dense groups
- M32: prototypical cE
  - Very rare, only three known objects in the local Supercluster

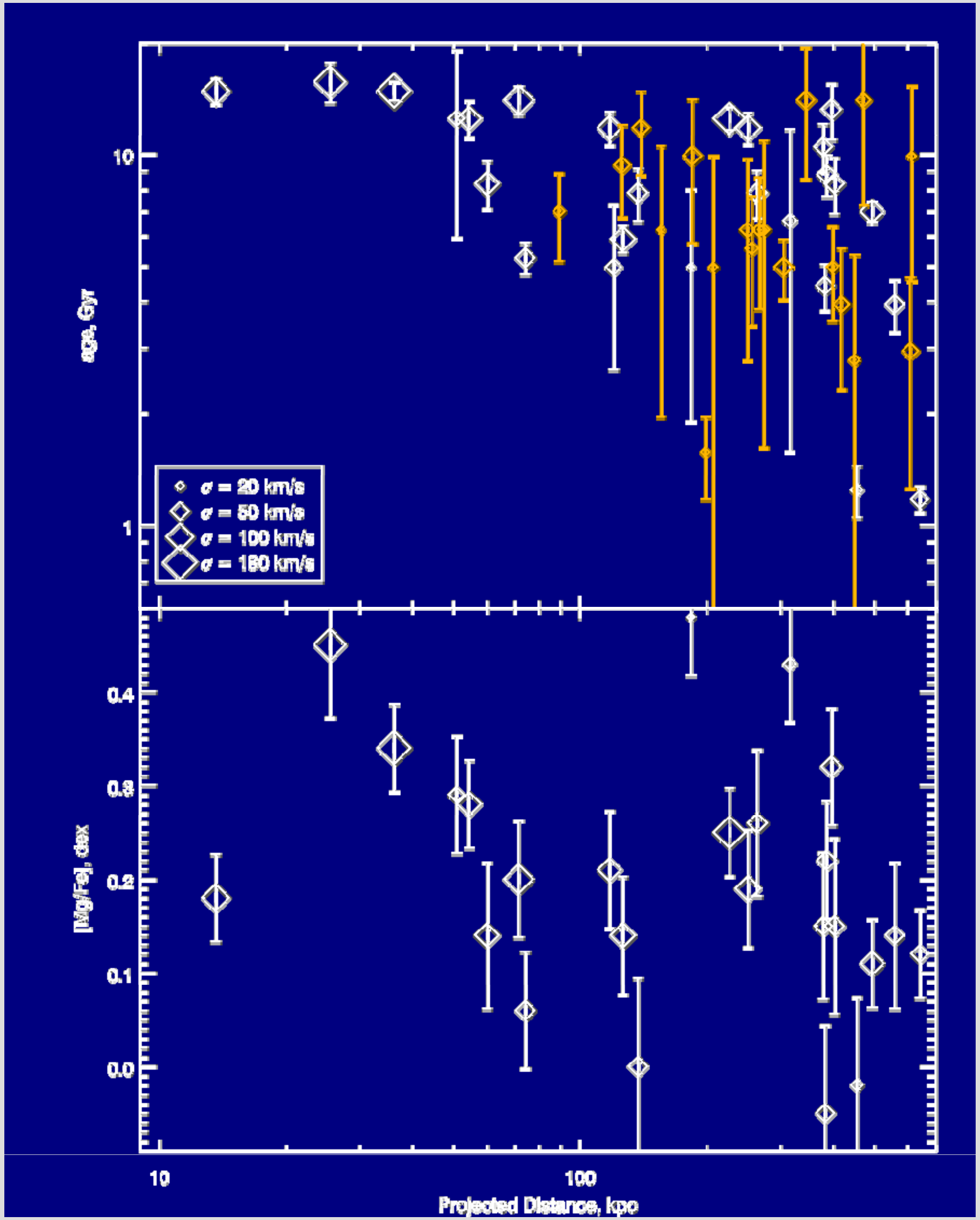


#2: tidally stripped galaxies

Motivation:
Segregation of young galaxies in cluster centres

High [α/Fe] ratios, metallicities and velocity dispersions for 5 low-luminosity galaxies in the the Abell 496 core (Chilingarian+08), one of them is a newly discovered cE (M32-like) galaxy (6-th known in the Universe). Stellar populations suggest massive progenitors.





#2: Search for cE galaxies

- cE galaxies are very small and compact, therefore they become unresolved from ground already at 50 Mpc
- If we expect about one cE per galaxy cluster, we need to increase the volume of the Universe in order to cover many clusters
- Using HST we can go till 200 Mpc thanks to its superior image quality, thus increasing the volume of Universe searched
- Using the Virtual Observatory to find and confirm candidate cE galaxies

#2: Search for cE galaxies

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 in 3 clusters observed with SCORPIO-MultiSlit.

Spectroscopic follow-up (observations + VO)

#2: Analysing the spectra

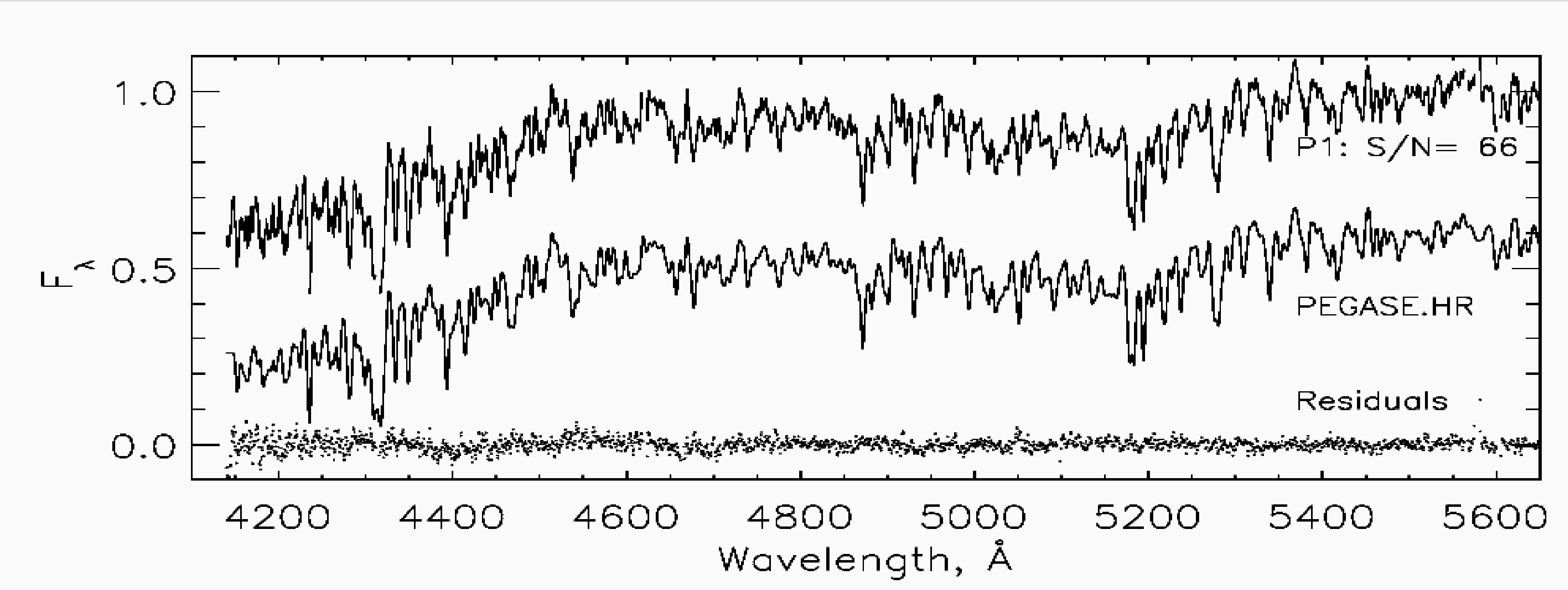
Full Spectral Fitting (*NBursts*) Chilingarian et al. (2007, proc IAUS241)

Classical Approach:

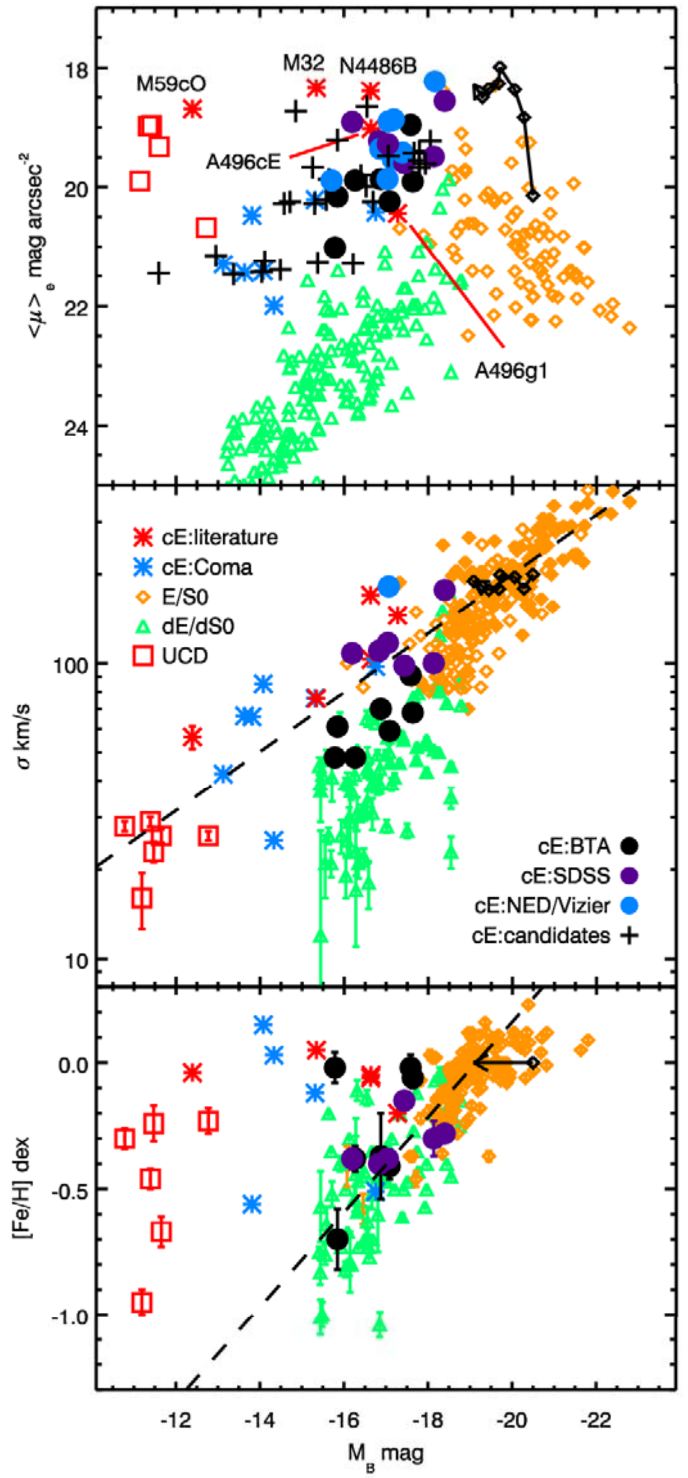
- Internal kinematics:
  - Cross-correlation
  - Fourier-based techniques
  - Spectral fitting (pixel space)
- Stellar populations: Lick indices

Our Approach:

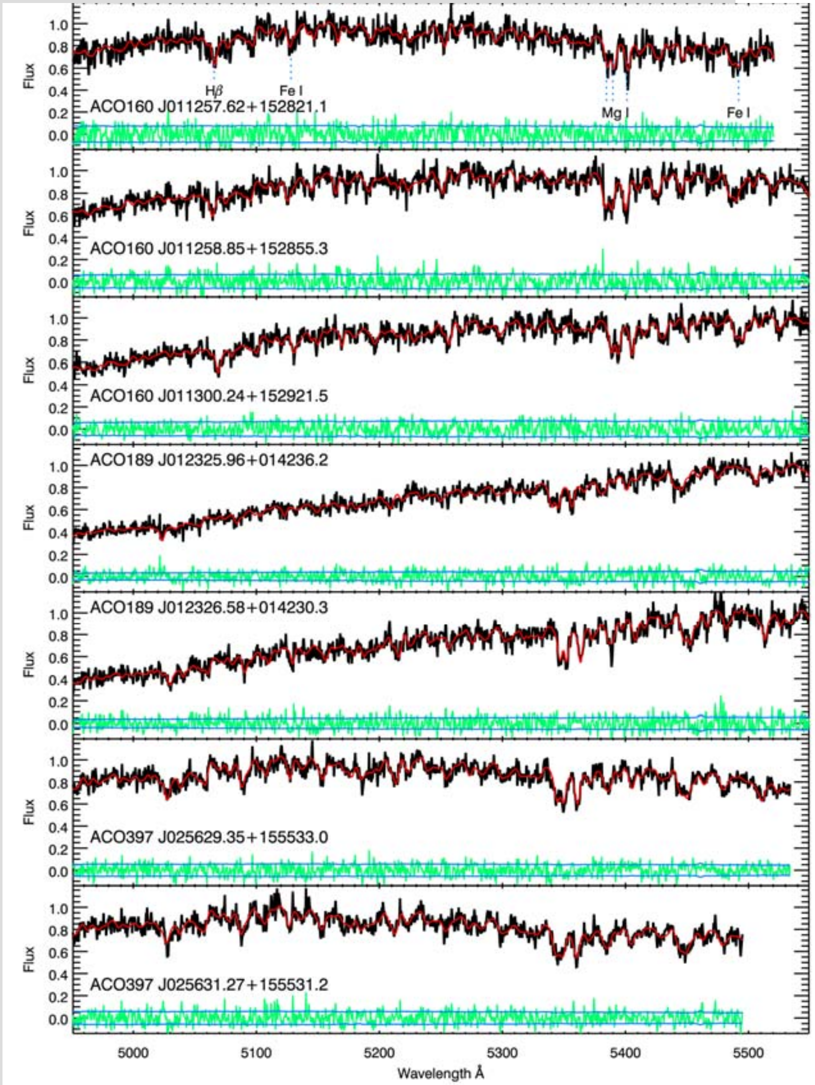
- Internal kinematics and stellar populations simultaneously from full spectral fitting (PEGASE.HR)
- Avoiding degeneracies, minimizing template mismatch, increasing precision (factor 3-6)



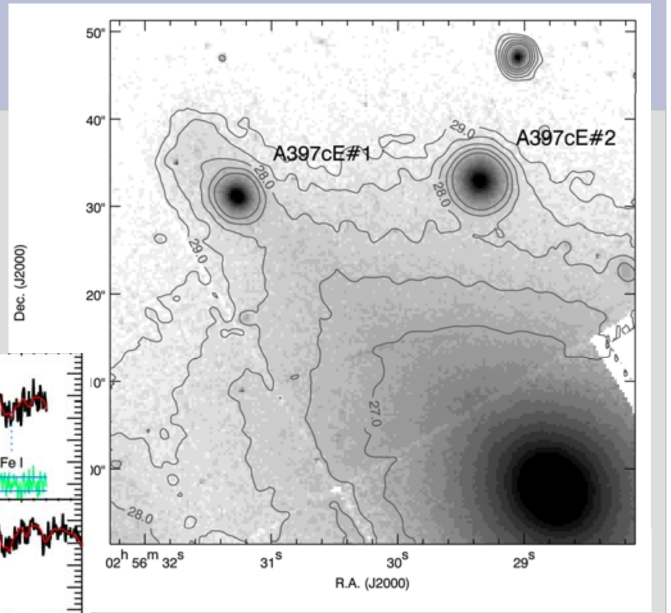
#2: New cEs



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



ACO160 J011257.62+152821.1
Hβ
Fe I
Mg I
Fe I
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



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

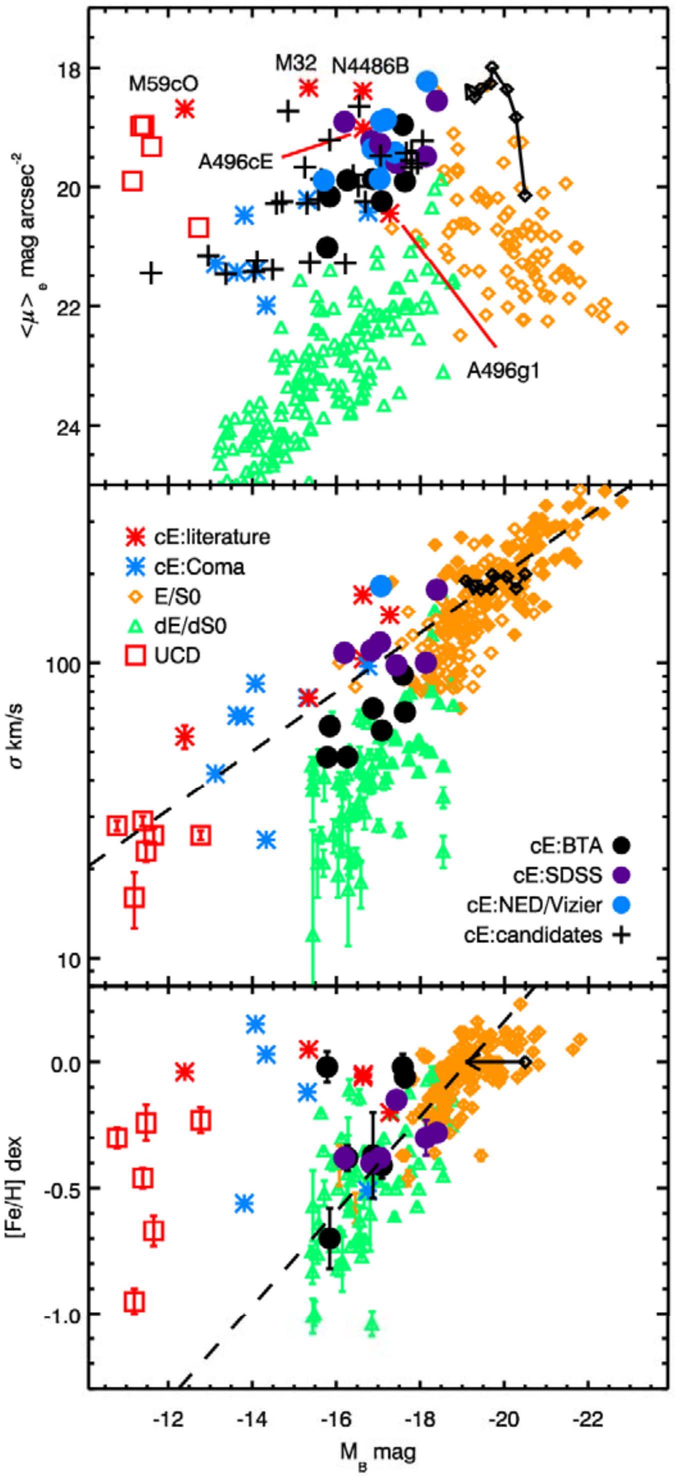
#2: observational properties of cEs

- 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)

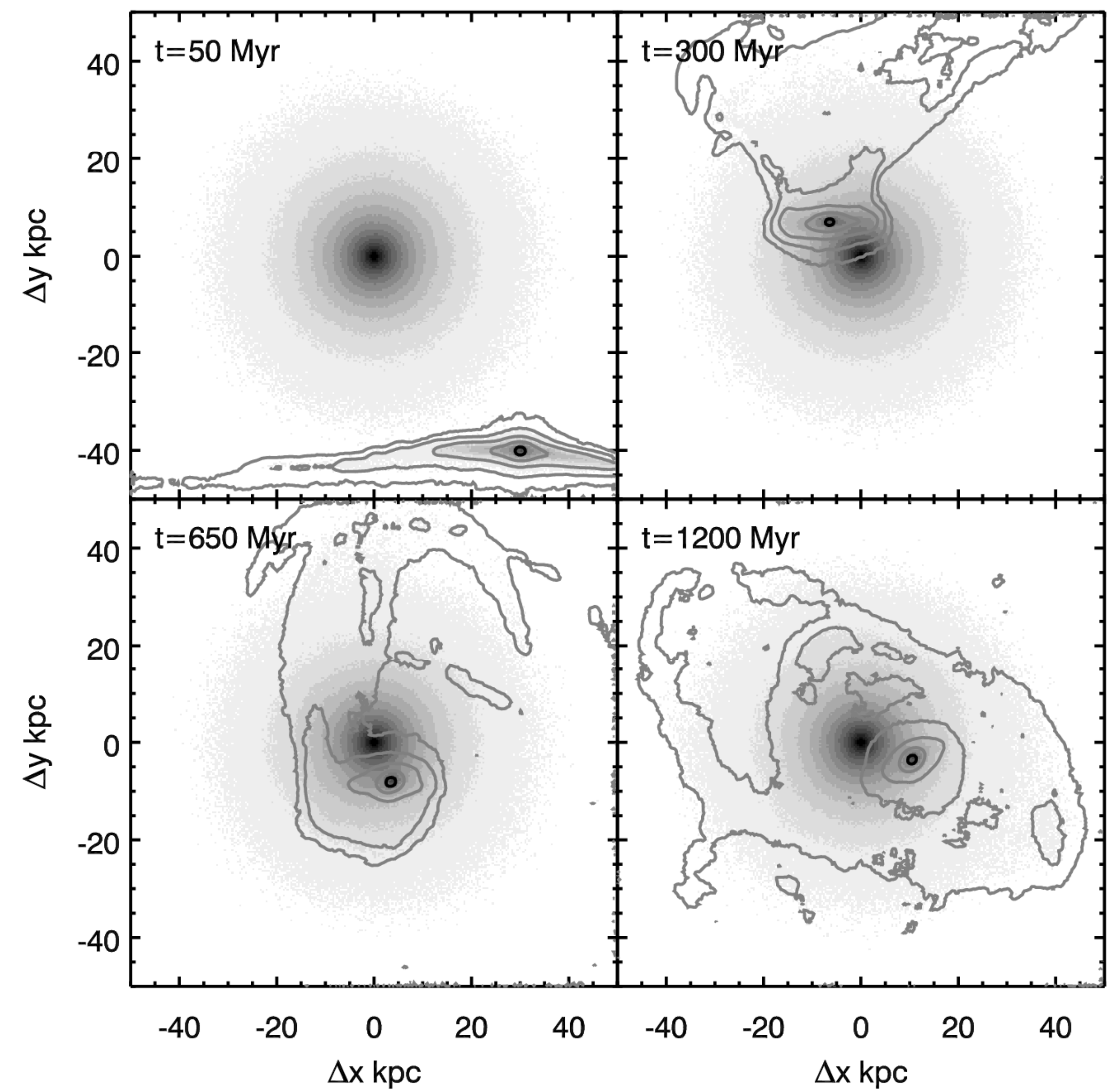
Formation scenario: tidal stripping of intermediate-luminosity S0s

Why are they rare? Probably because of the very narrow range of input parameters, short lifetime. Need to run numerical simuations.

#2: New cEs



Simulations of tidal stripping



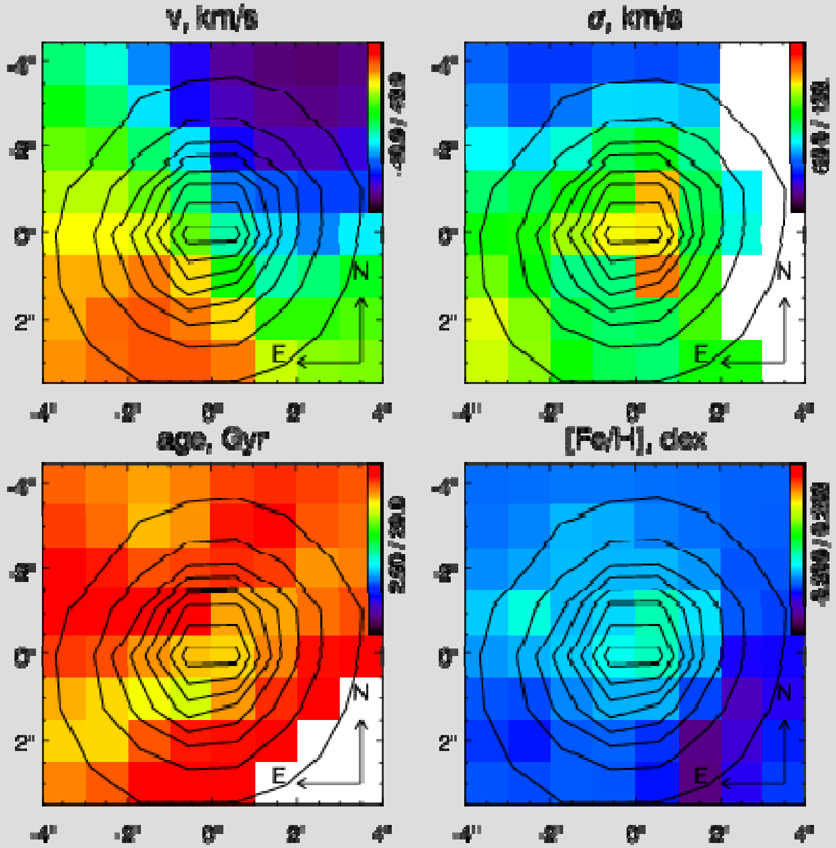
#2: Main result

- The class of cE galaxies was converted from “unique” into “common under certain environmental conditions”
- Evidences are given for an importance of tidal stripping of stellar discs of lenticular galaxies as a way to form “compactish” ellipticals
- The first study made with VO, then followed-up with a large telescope and reproduced by dedicated numerical simulations: a new model of astrophysical research, which can be adopted in other disciplines where experimental data are put into public domain
- **Great promotion of the VO concept: paper in Science (2009, v.326, p.1379)**

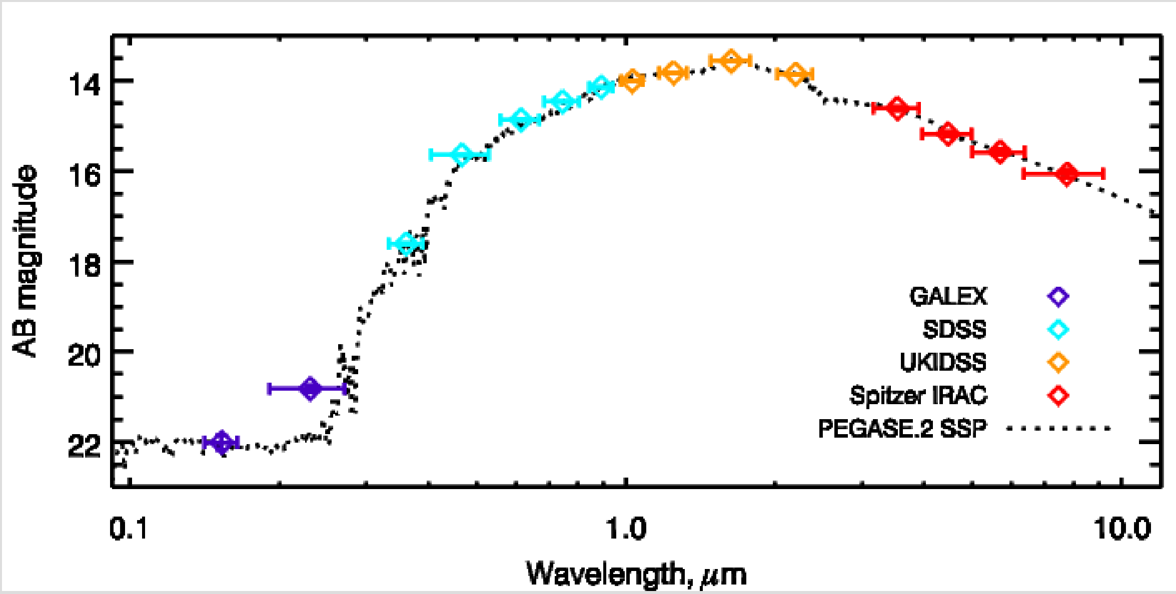
#2 Follow-up: cEs in groups

Testing the workflow with galaxy group data. The first obvious sanity check: the NGC5846 group.

- The workflow detects two (!) objects:
  - NGC5846A (a well-known cE, one of the prototypes)
  - SDSSJ150634.27+013331.6 – the second cE in the group
    - Observed with PMAS IFU at CalarAlto 3.5m



FUV-to-IR SED from VO and archives



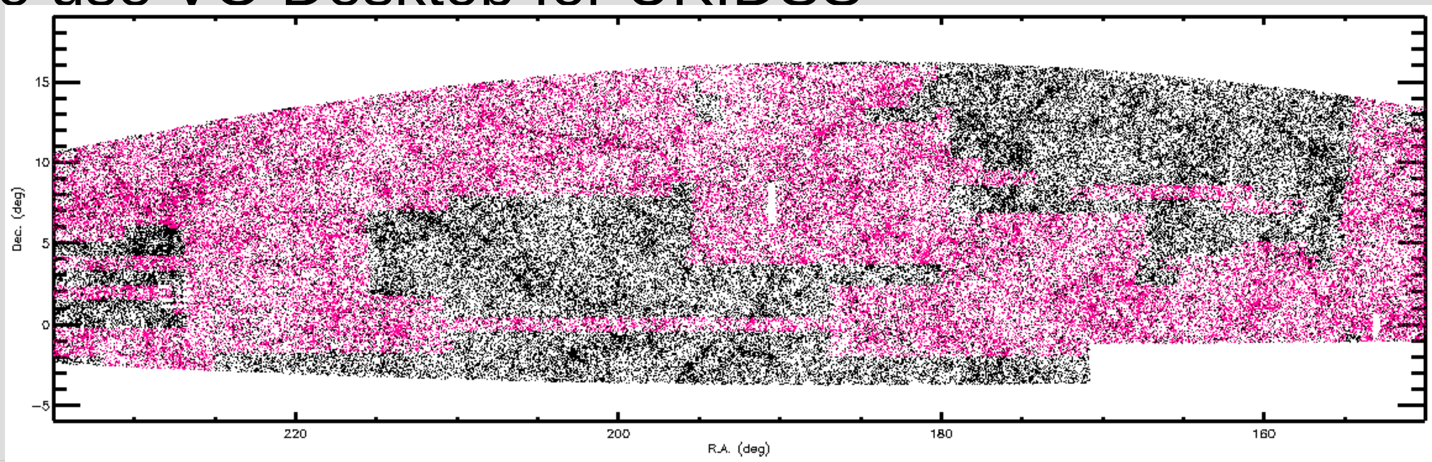
Chilingarian & Bergond 2010 (MNRAS Letters)

#3: optical/NIR galaxy colours

- Goal: studying optical/NIR colours of nearby galaxies and connecting them to the stellar populations
  - NIR magnitudes are much less sensitive to the stellar population age compared to the optical, therefore they are good stellar mass indicators (although not perfect)
  - extinction effects are smaller in NIR
  - spectroscopic ages and metallicities are important additional bricks of information
- Use VO data mining technologies

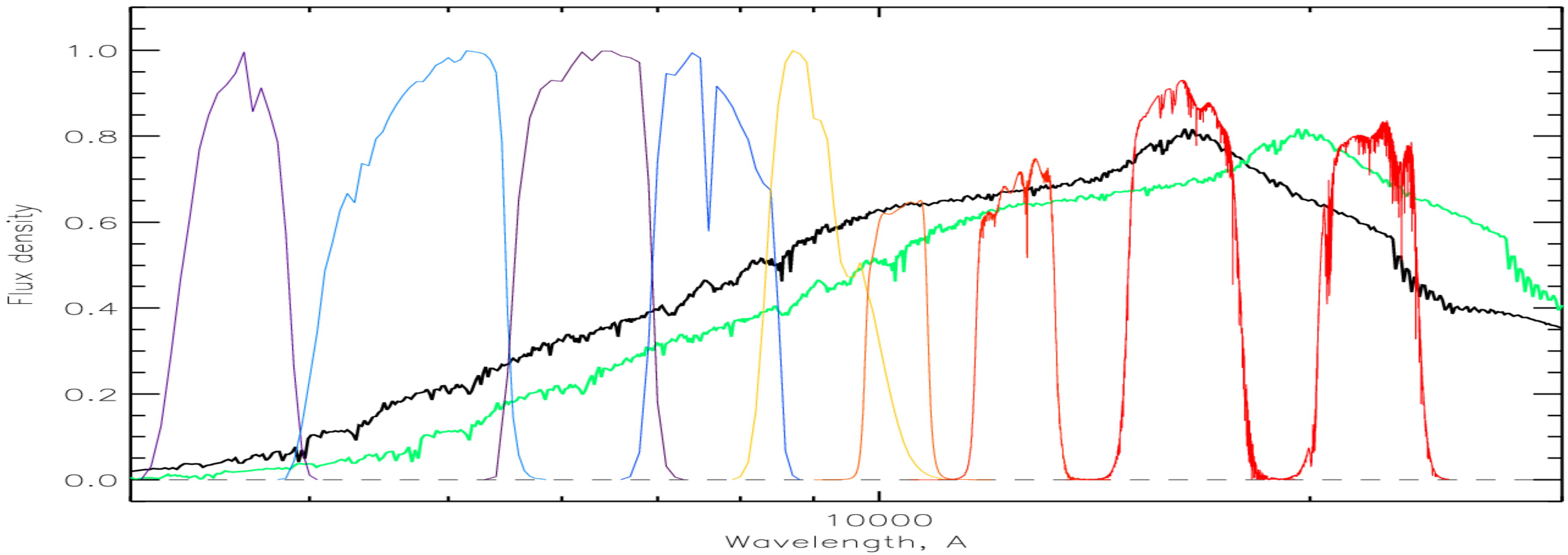
#3: optical/NIR galaxy colours

- Resources used:
  - SDSS DR7 catalogues and spectra
  - UKIDSS DR5 Large Area Survey catalogue
- Techniques:
  - positional cross-match (VO-possible)
  - stellar population modelling using PEGASE2/PEGASE.HR (VO-possible)
  - *NBursts* spectral fitting (non-VO)
- Tools:
  - Topcat/STILTS to join and merge the tables (just to simplify the life)
  - script-based access to SDSS
  - *possible* to use VO Desktop for UKIDSS



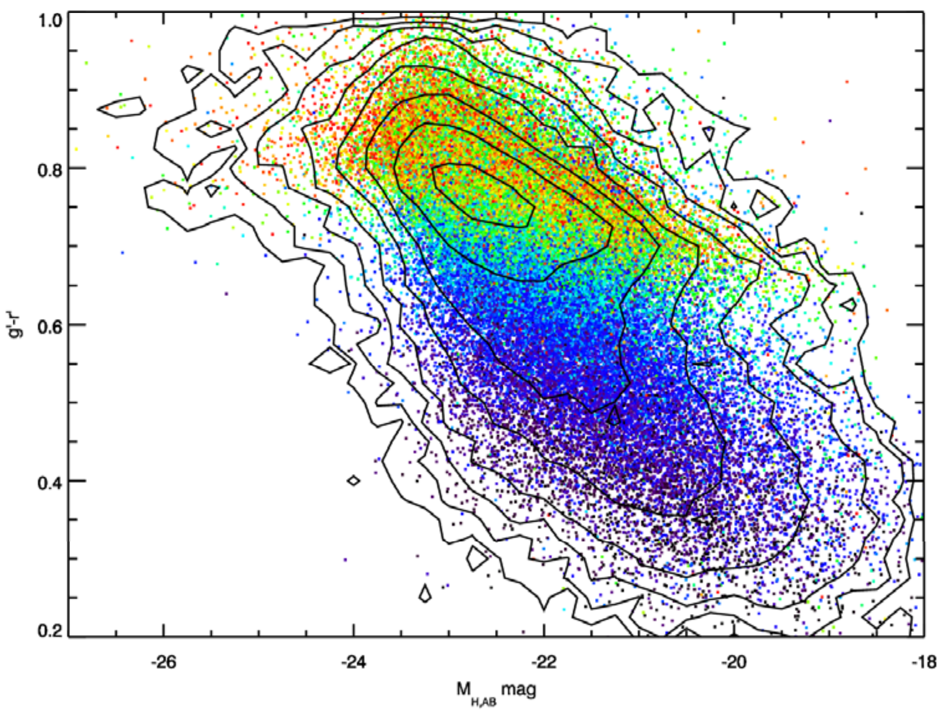
#3: Issues

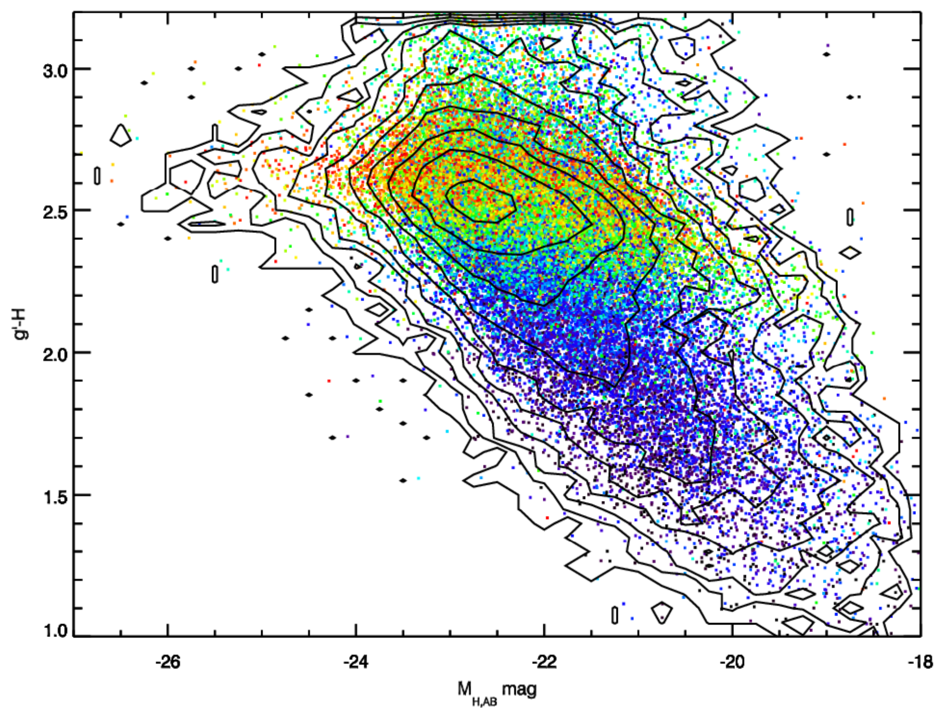
- Aperture effects: Petrosian radii in SDSS and UKIDSS are sometimes very different
  - Solution: using aperture magnitudes for colours + SDSS r' to renormalize the SED
- K-corrections: controversial information is given in literature
  - Solution: compute them ourselves



#3: Results (preliminary)

- New K-correction computation technique (Chilingarian et al., MNRAS in press, arXiv:1002.2360)
- In the optical-NIR colours (e.g. g-H) the blue cloud starts to overlap the red sequence – extinction effects, since galaxies show intermediate stellar population younger than of red sequence objects: important effects of the AGB phase of stellar evolution on global galaxy colours
- Bright tail of the red sequence: how and when do LRGs grow?





#4: GalMer Database

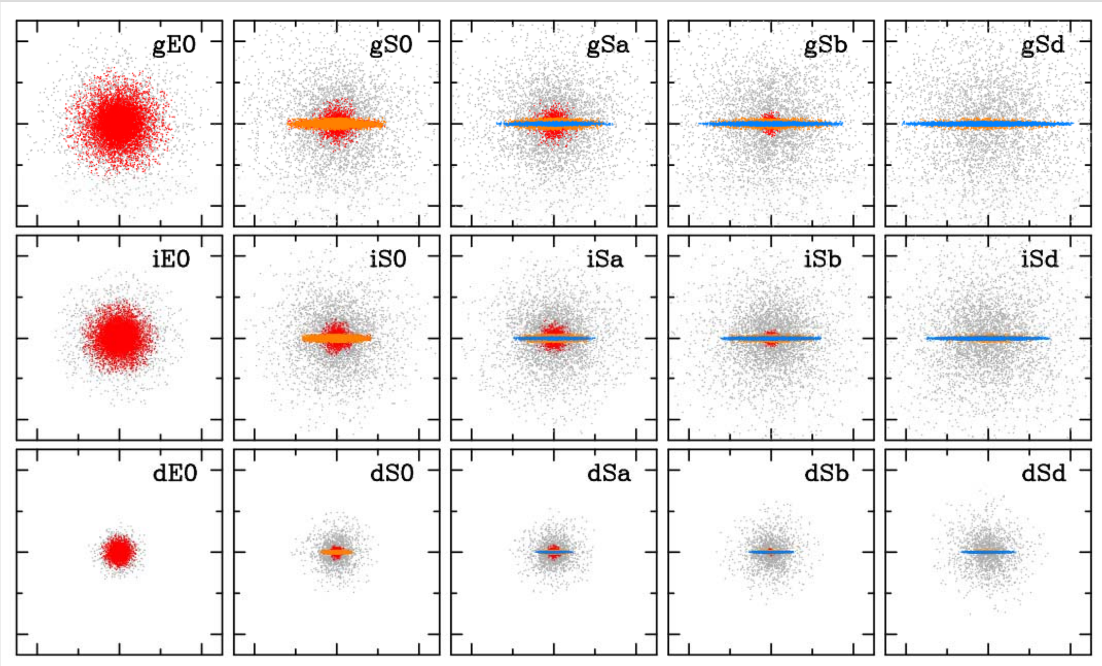
Science Case

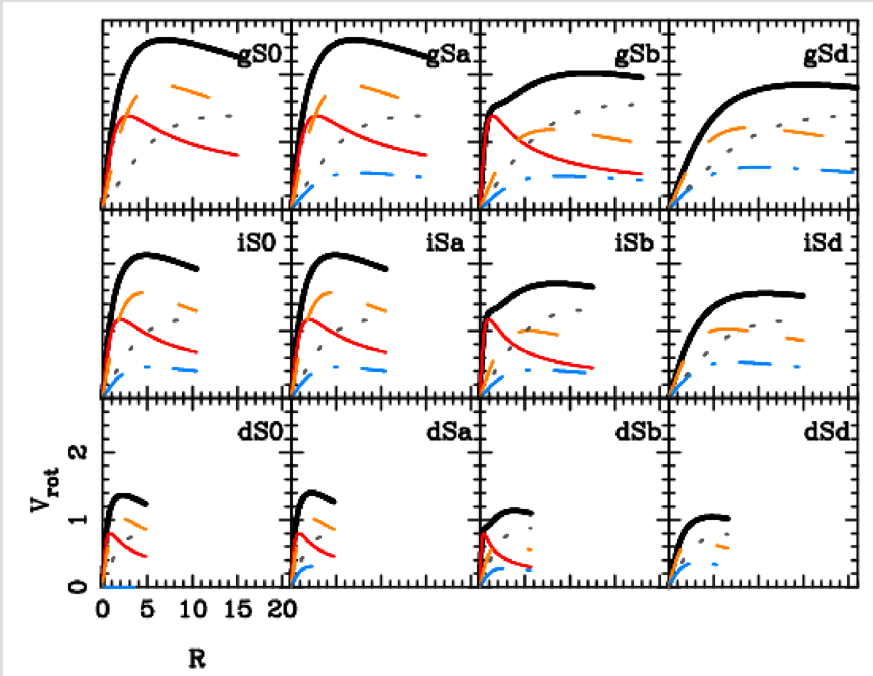
- Simulations of major and minor mergers of galaxies: statistical approach
- Statistical studies of SFR and SFE changes, metal enrichment, kinematics and dynamics of merger remnants, comparison with observations
- Compromise between the diversity of initial conditions and spatial resolution, i.e. details of undelying physics (0.2 – 0.3 kpc)

#4: GalMer Database

Simulations:

- Tree-SPH code (Semelin & Combes 02)
- 3 types of particles: hybrid, star, DM
- Simulations till 3-3.5 Gyr
- Snapshots every 50 Myr
- 2 galaxies (E0, S0, Sa, Sbc, Sd): 240k points
- 3 mass ratios: 1:1, 1:2, 1:10





#4: GalMer Database

Data

- We trace the following properties:
  - x, y, z, vx, vy, vz, mass (all types of particles)
  - average metallicity (hybrid and star particles)
  - metal enrichment history and star formation history (hybrid parcles)
- FITS binary tables to store the snapshot data (12Mb per snapshot) + FITS tables to store SFH and CEH for hybrid particles (200Mb)
- 50 to 70 snapshots for ~1000 simulations
- Total volume ~1Tb available data as of now
- PostgreSQL with native XML support is used to store the Characterisation DM metadata
- Retrieval of integrated SFH using “stored procedure” (pl/pgSQL)

#4: GalMer Database

WEB Access

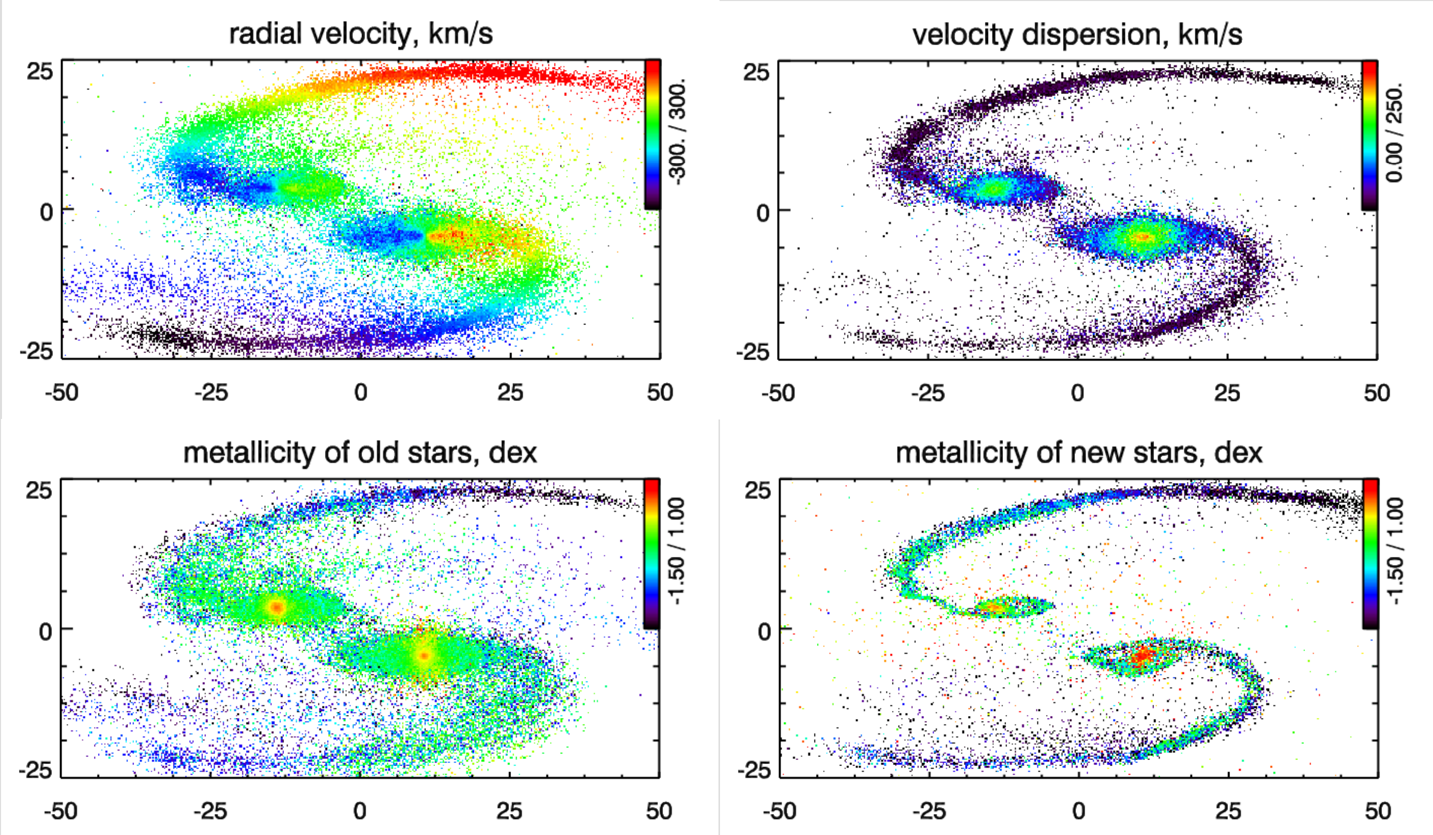
- Simple DB Query interface
  - http://galmer.obspm.fr/
- Direct download of snapshot data (FITS)
- Interaction of the web-interface with dedicated Virtual Observatory tools: TOPCAT, CDS Aladin, ESA VOSpec
- All required software components are installed and started automatically by JavaScript (WebStart) - we are user-friendly :)

Chilingarian et al. A&A in press

#4: GalMer Database

Value-added tools

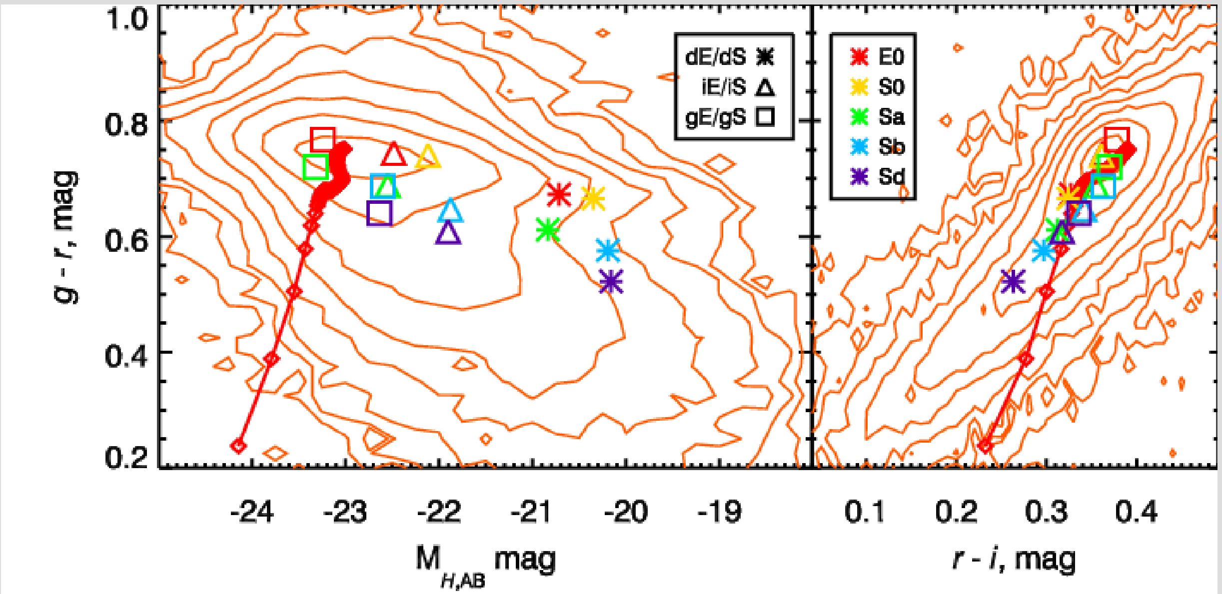
- On-the-fly generation of projected maps for the quantities traced in the simulations
- Spectrophotometric modelling using PEGASE2/PEGASE.HR stellar population models



#4: GalMer Database

Applications

- Galaxy properties from simulations
  - SFR/SFE changes (Di Matteo et al. 2007, 2008a)
  - Creation of old KDCs (Di Matteo et al. 2008b)
  - Reshaping metallicity gradients (Di Matteo et al. 09a)
  - Angular momentum transfer (Di Matteo et al. 09b)
- Synthetic observations: virtual telescope
  - Match between three-component density profiles for NGC6340 and a major merger of spirals (Chilingarian et al. 2009)
  - synthetic images
  - galaxy colours



#4: GalMer Database

Demo...

Summary

- These examples aim at stimulating “usual” (non-VO) astronomers to carry-out VO-enabled research on everyday basis, since it is possible to combine VO and non-VO data discovery and analysis
- A PhD thesis based entirely on the VO and archival data has been defended by Ivan Zolotukhin in Moscow on 1/Oct/2009
- Although minor infrastructural difficulties still exist, it is already possible to carry out VO-enabled research beyond data mining

We foresee a growing amount of VO-powered studies to arrive in near future