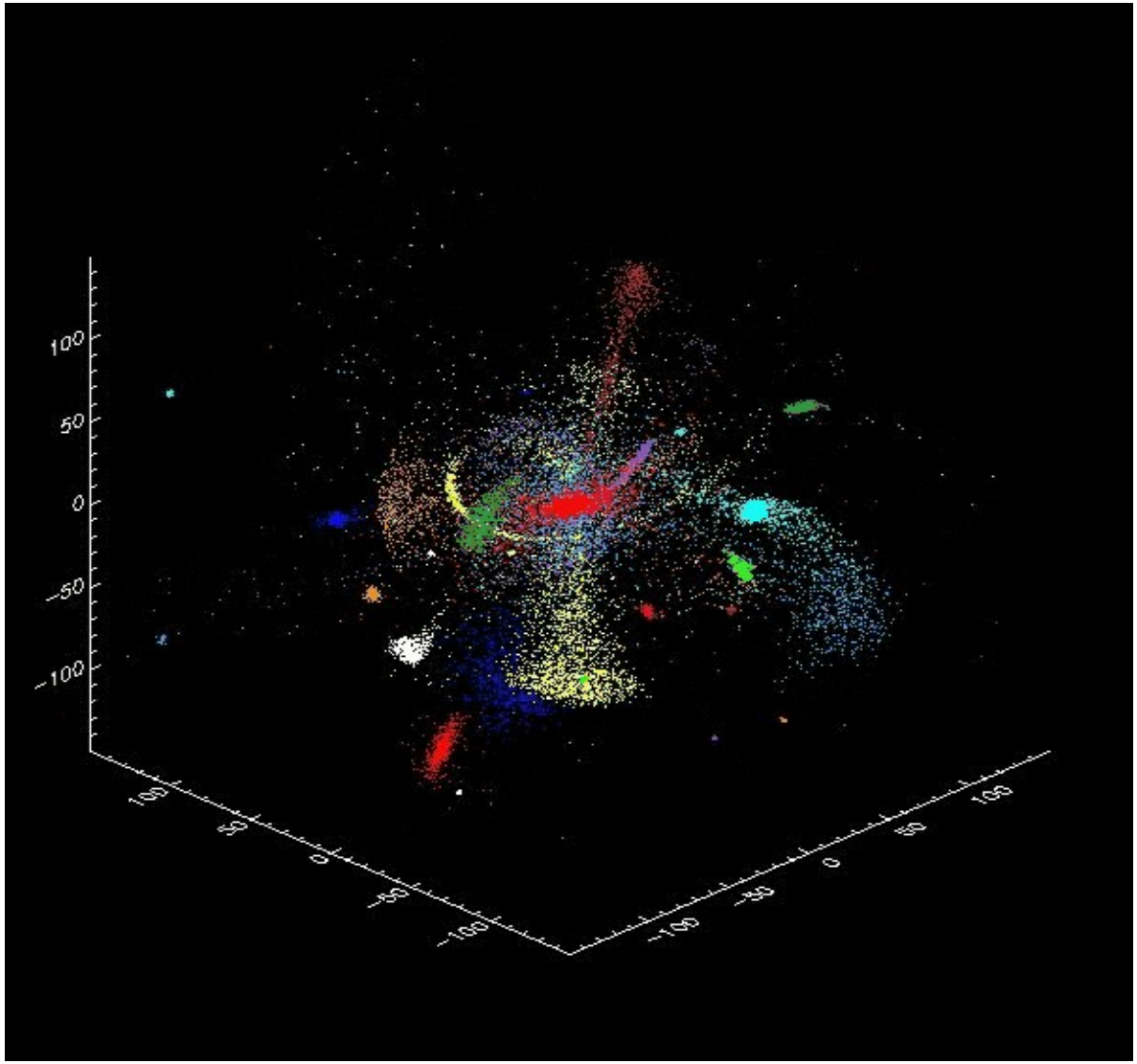
The outskirts of spirals beyond the Local Group

The Milky Way analogue NGC 891

M. Mouhcine (Liverpool John Moores Univ.)

R. Ibata (Strasbourg), M. Rejkuba(ESO)

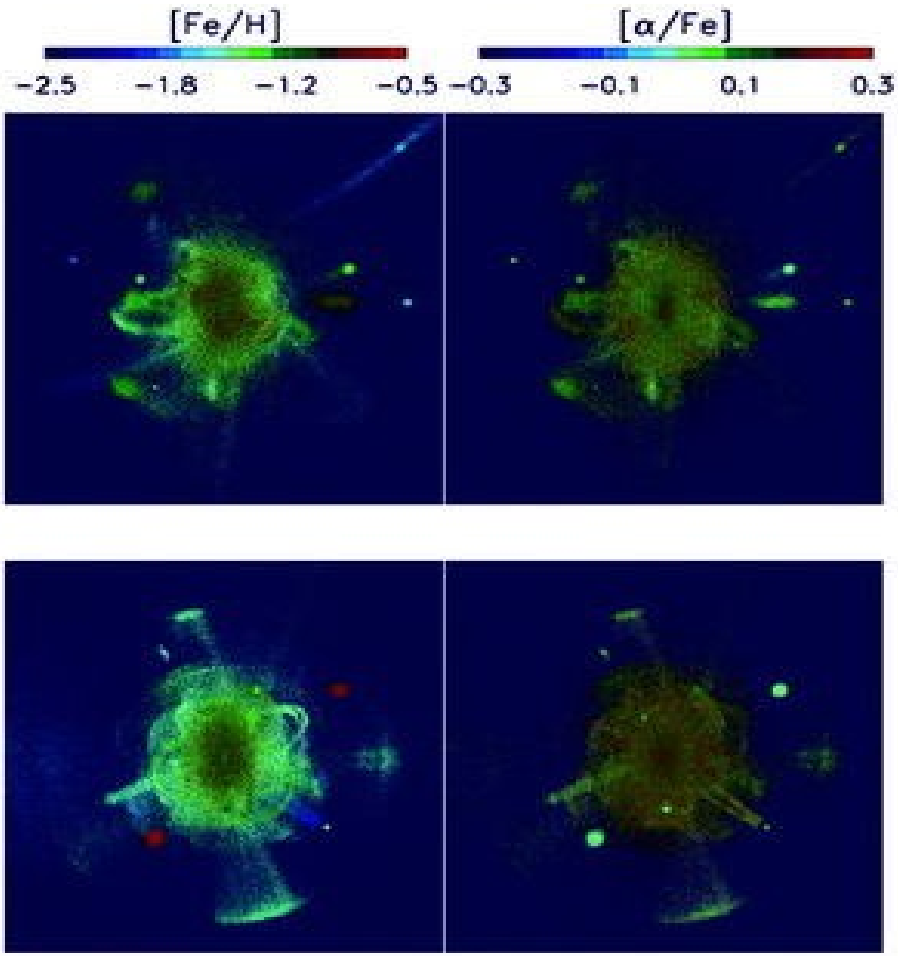
Hierarchical galaxy halo formation



At least a hundred satellite size dark matter halos accreted

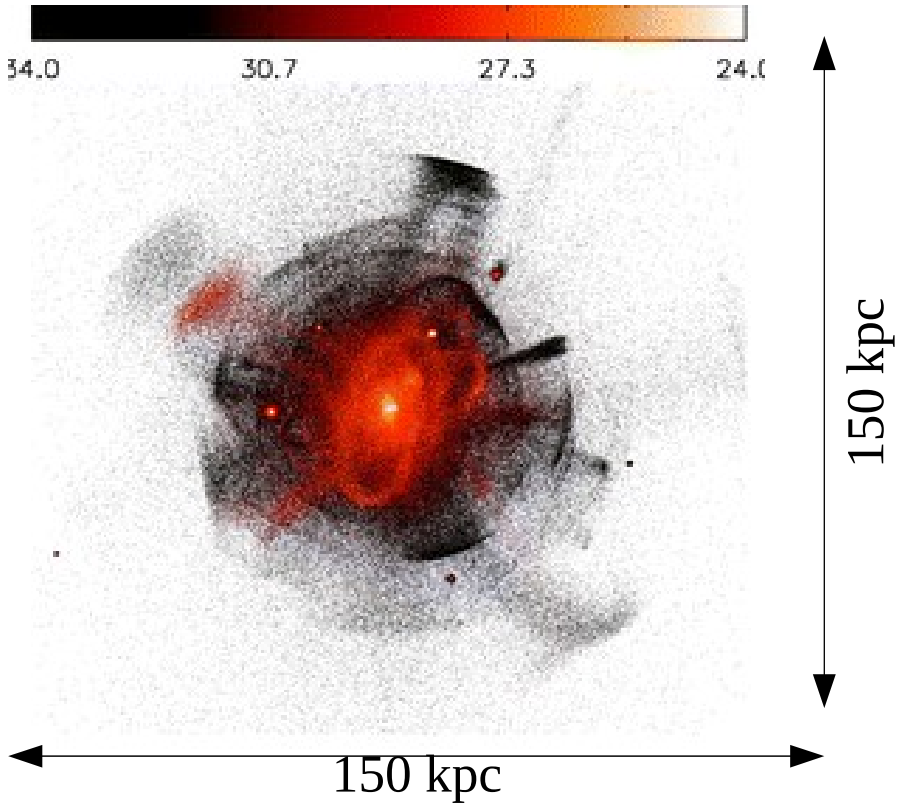
Johnston et al. (1996); Helmi & White (1999);
Bullock & Johnston (2005); Renda et al. (2006); Johnston et al. (2008) ...

Halo shape & substructures



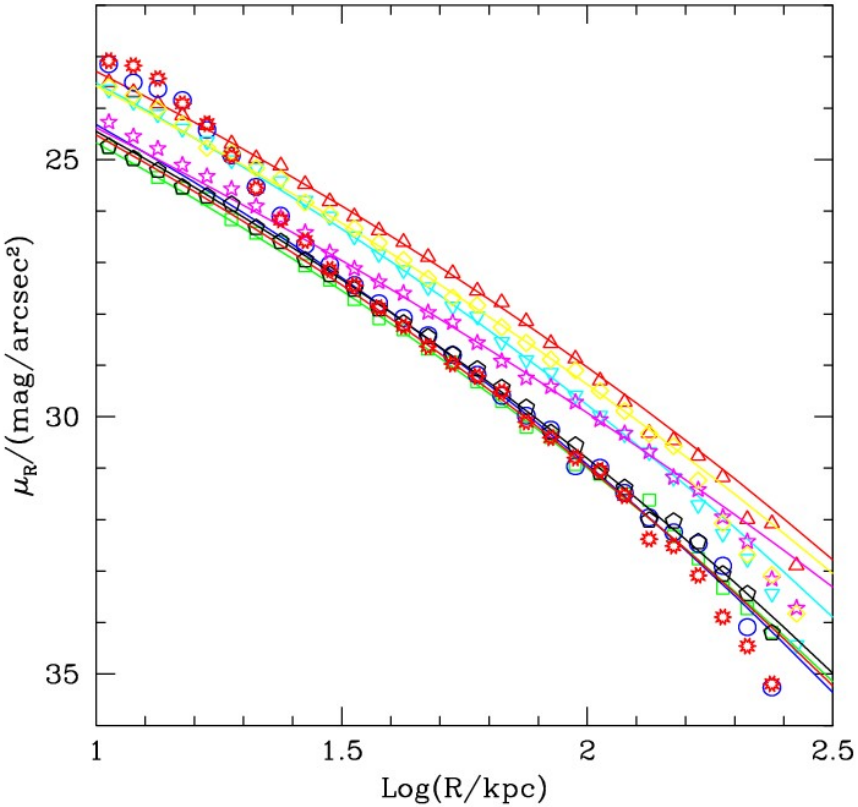
Font et al. (2006)

- Substructures both in stellar spatial distribution and metallicity

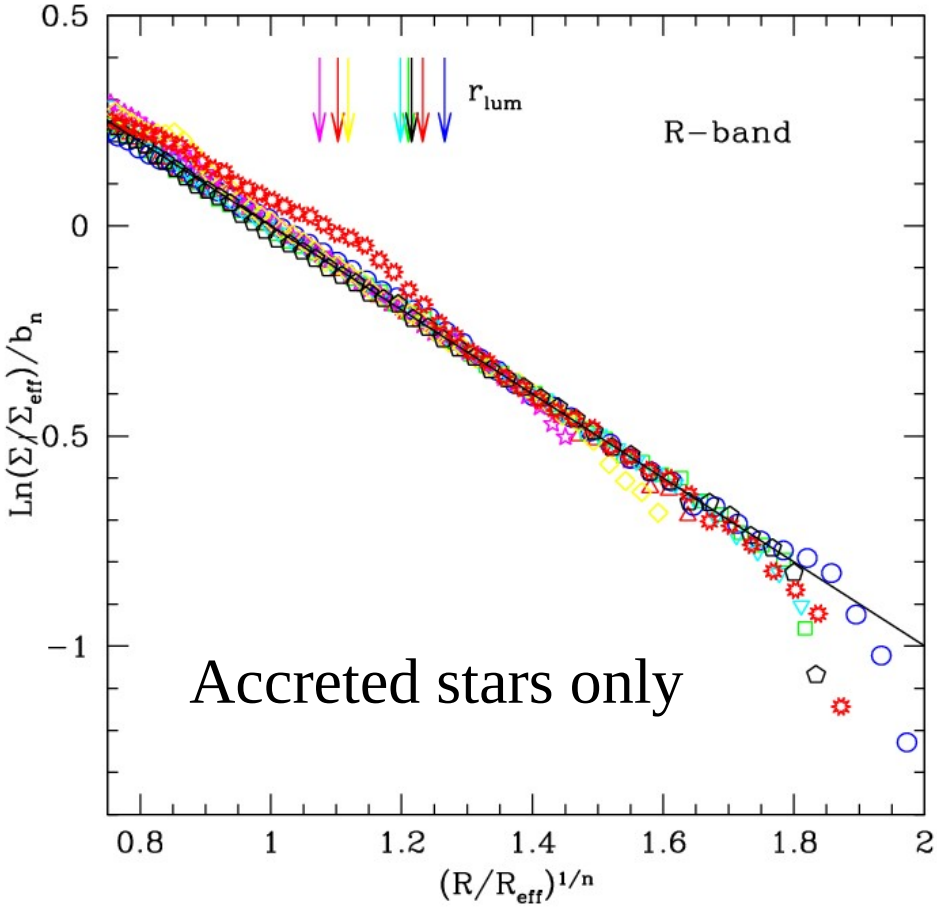


Halo shape

Abadi et al. (2006)

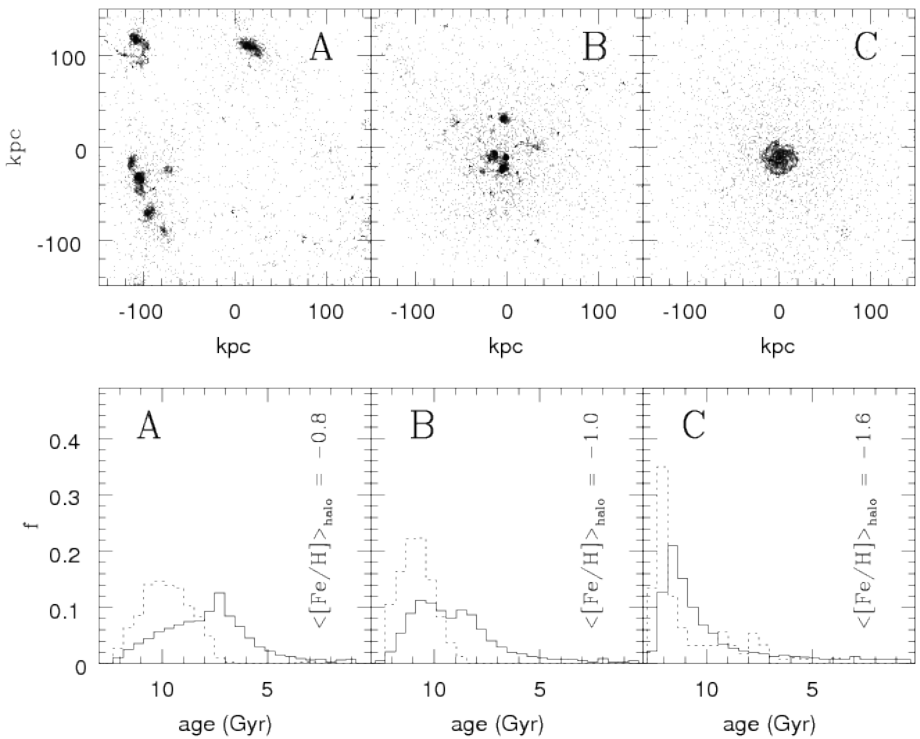


A Sersic prof le is a natural result for collisionless merging;



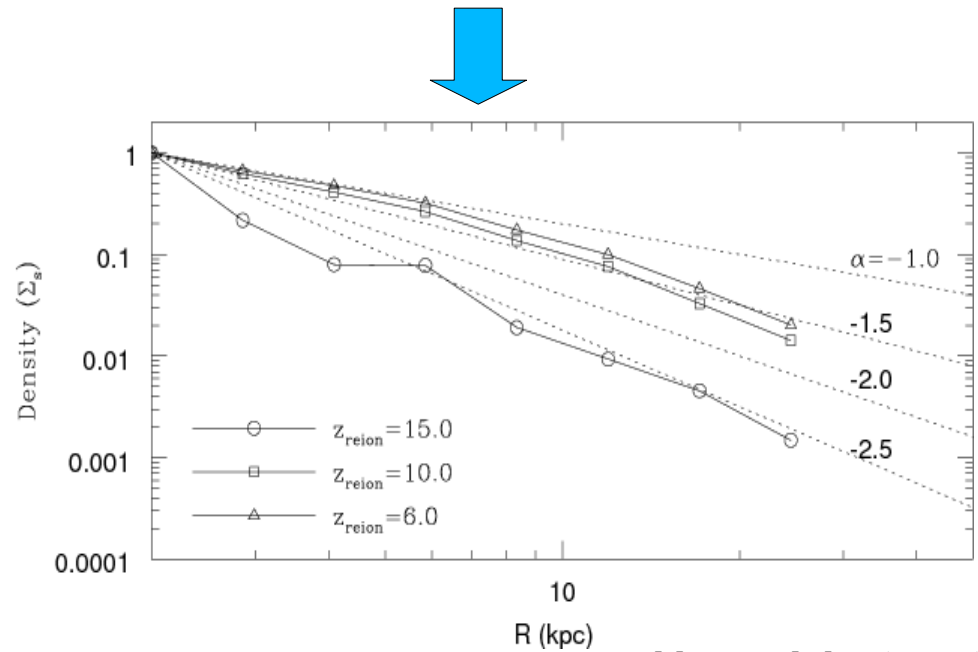
The effects of accretion history

Renda et al. (2006)



The age distribution of halo stars
Reflects the accretion history

The shape of the halo depends on the accretion history;



Bekki & Chiba (2005)

Previous halo observations

- The Milky Way (and M31) have played a pivotal role in studies of the faint outskirts of spirals over the decades.

- Large scale mapping of the properties of the Galaxy stellar populations (SEGUE; RAVE; Pan-STARRS; APOGEE; GAIA, ...)

- The existing observations of the outskirts of spirals beyond the Local Group comprise a sparse archive.

How typical are the Galaxy outer regions?

Mapping the outskirts of spirals beyond the Local Group

The Panoramic Landscape of Spiral Galaxies (PLANS)

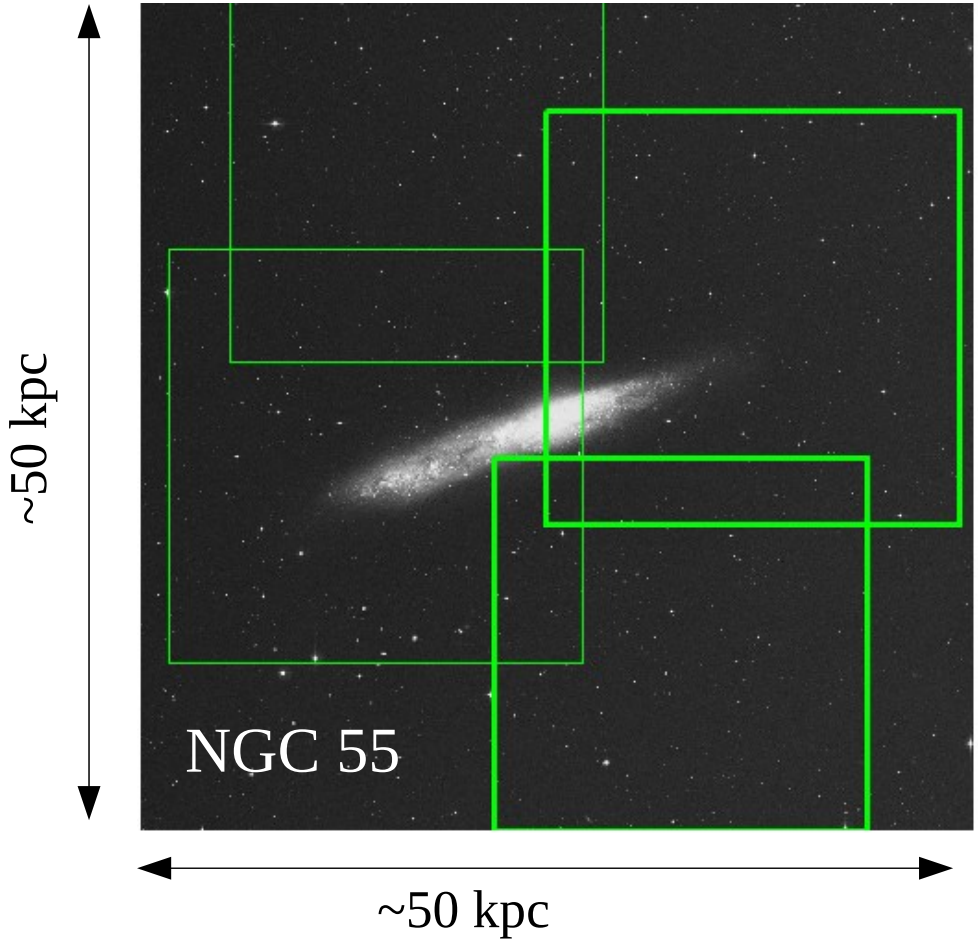
The core team: M. Mouhcine, R. Ibata, M. Rejkuba

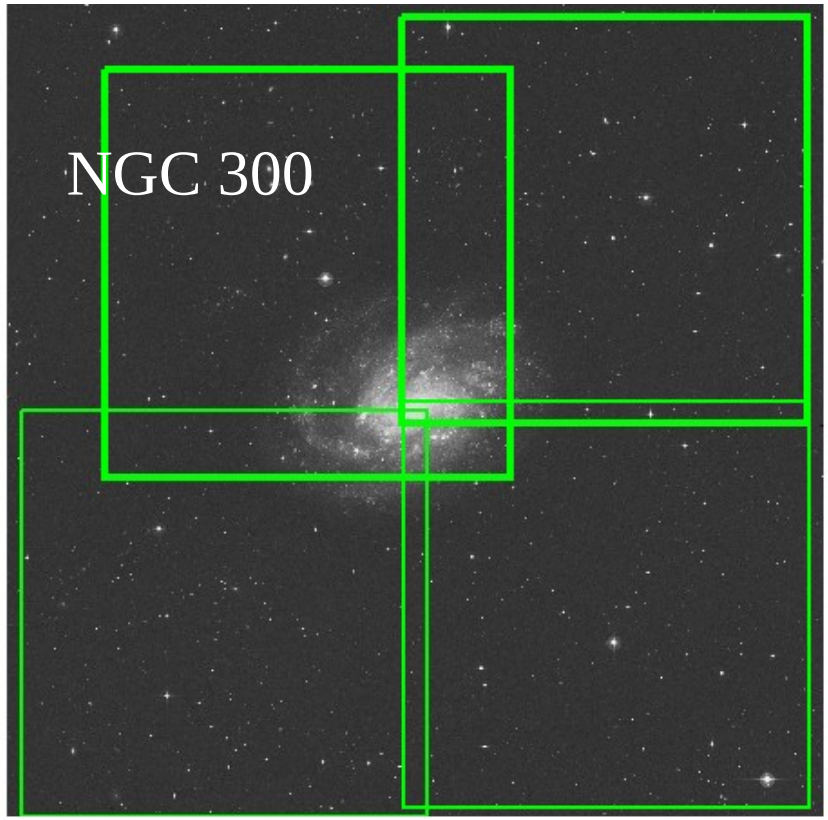
Resolving the upper 2-3 magnitudes of red giant branches of spirals with (i) D < 10 Mpc and (ii) i>60 deg.

10 galaxies: Morph. = [Sa-Sd]; Circular Velocity = [80-225] km/s

The f rst systematic inventory of the stellar content of the extremely faint outskirts of spirals beyond the Local Group

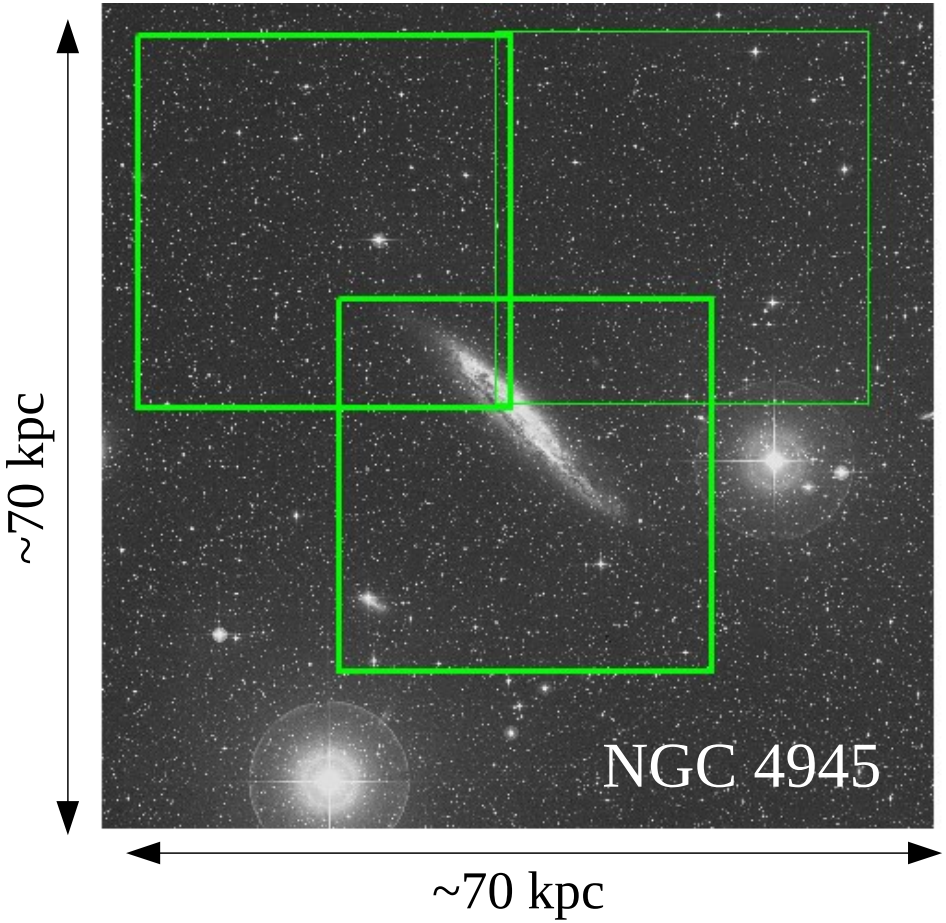
Galaxies at ~2 Mpc (Ex.)

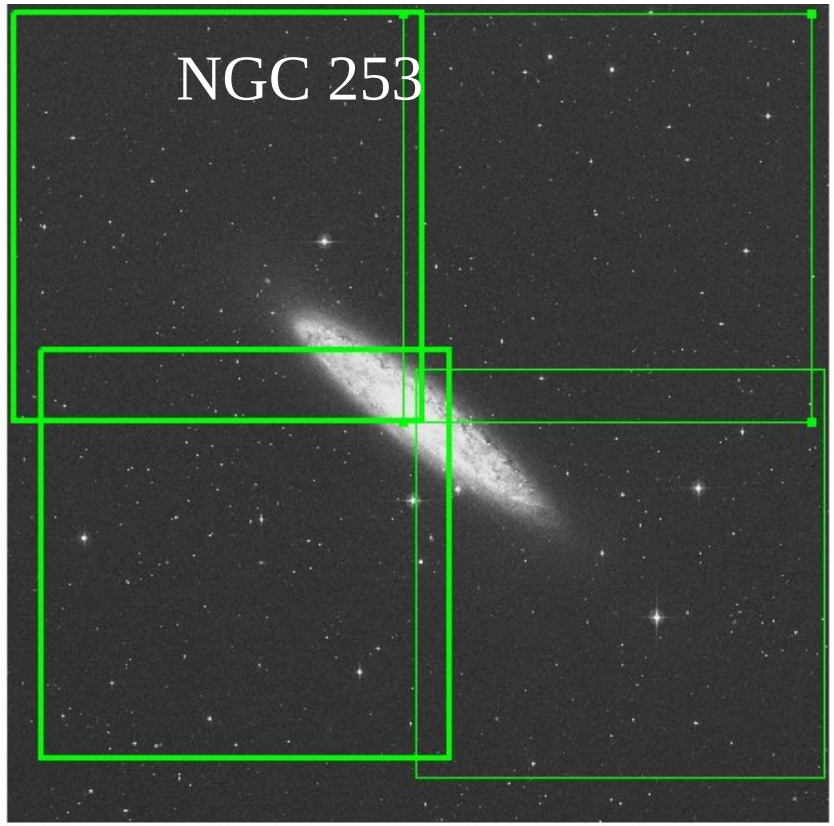




Requirement: S/N=7 @ I~[26.3-26.6] & V~[27.3-27.6]

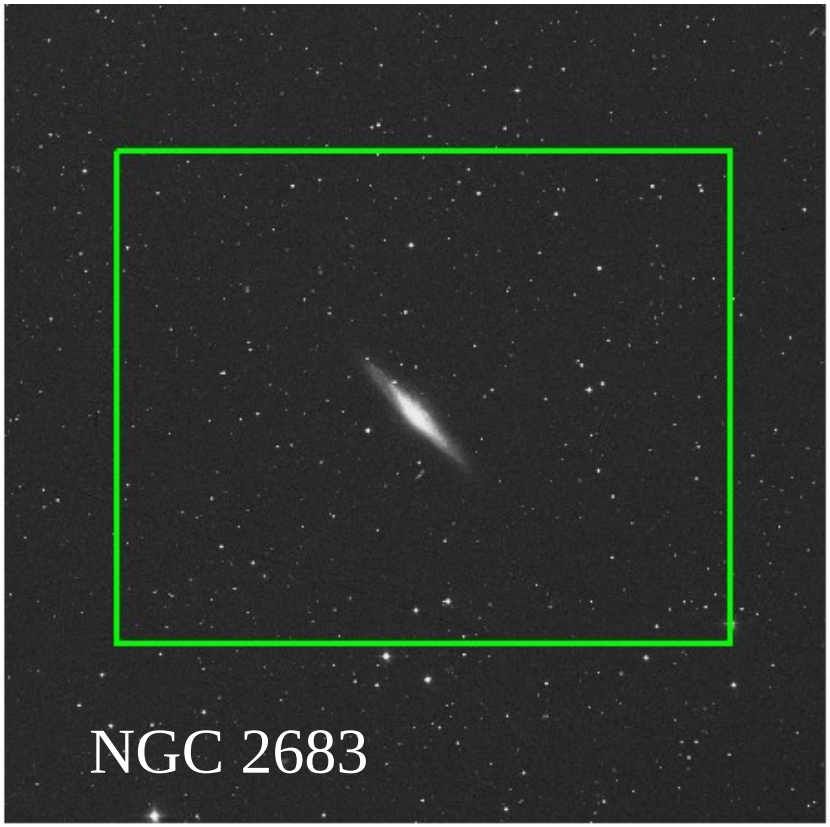
Galaxies at ~4 Mpc (Ex.)

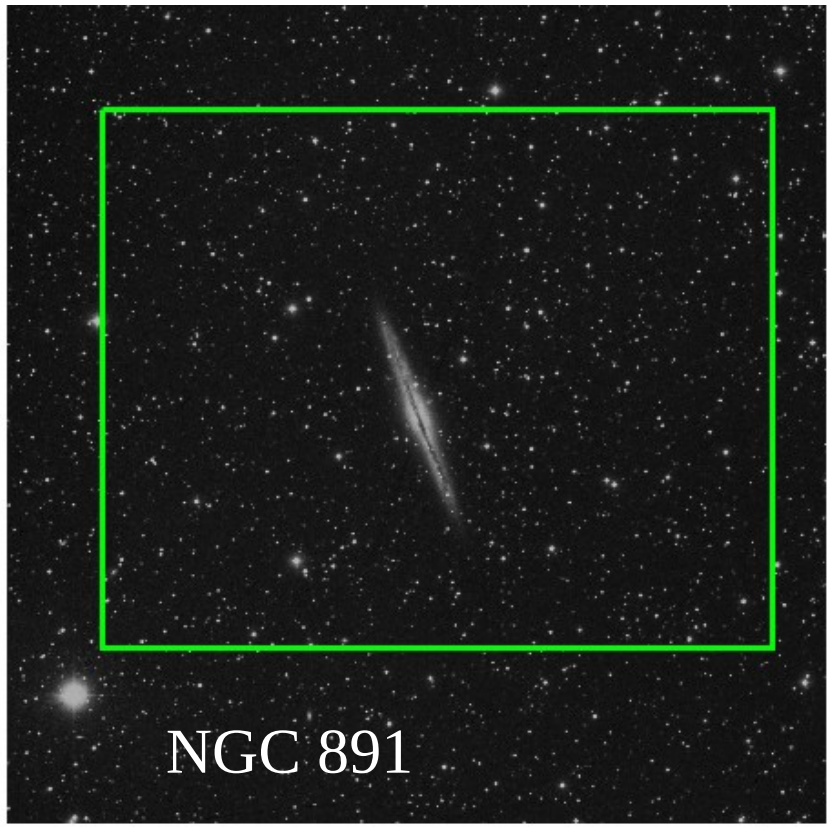




Requirement: S/N=7 @ I~[26.7-27.1] & V~[27.6-28.1]

Galaxies at 8-10 Mpc





~160 kpc

~160 kpc

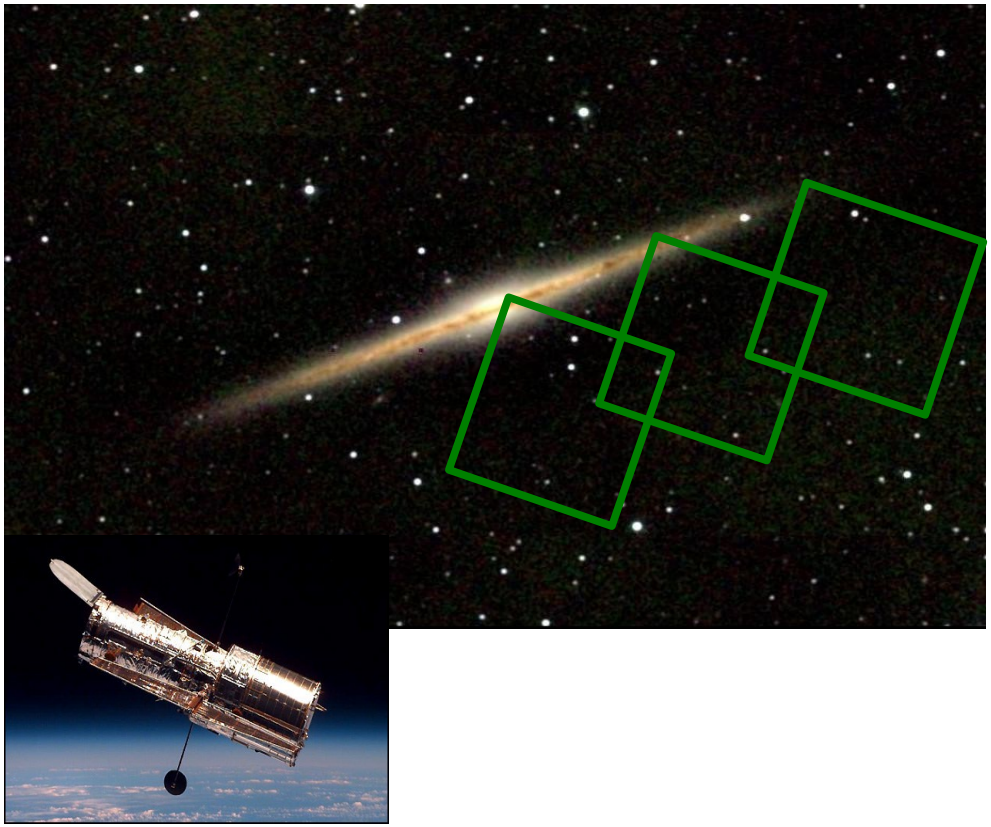
Requirement: S/N=7 @ I~[27.8-28.2] & V~[29.-29.7]

What can be done with the survey?

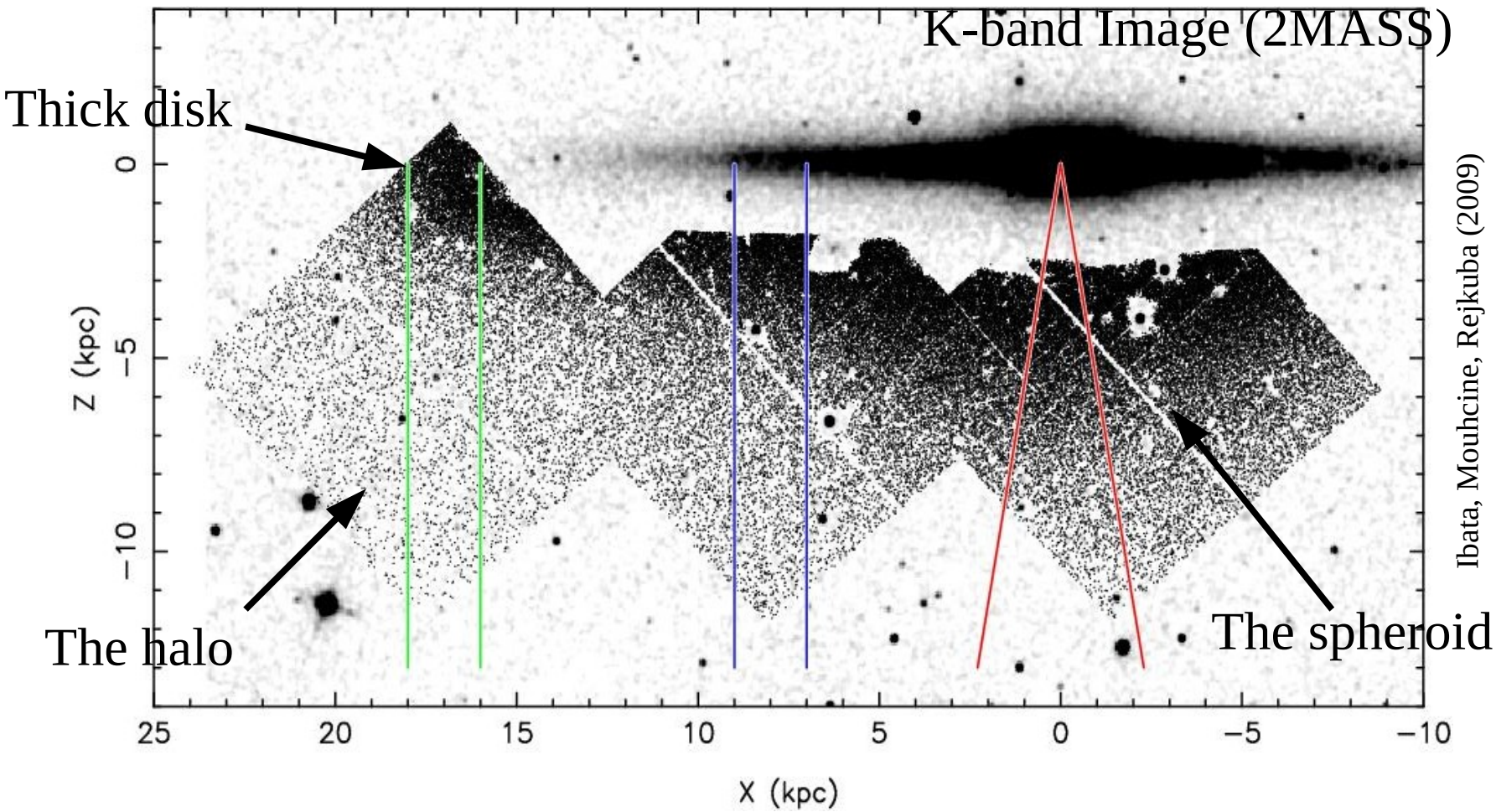
- Disk truncations (e.g. are disks still forming today?)
- Bulge/Halo connection (e.g. the formation of the spheroid)
- Halo structure and substructures (e.g. are they consistent with predictions?)
- Structure of dark matter halos (e.g. dark matter halo f attening)
- Halo metallicities (e.g. the properties of the progenitors)
- The population of satellites (e.g. luminosity function, stellar populations, ...)
- Globular cluster systems (e.g. luminosity function, kinematics, ...)

Mapping the outskirts of spirals beyond the Local Group

NGC 891 vs. The Galaxy

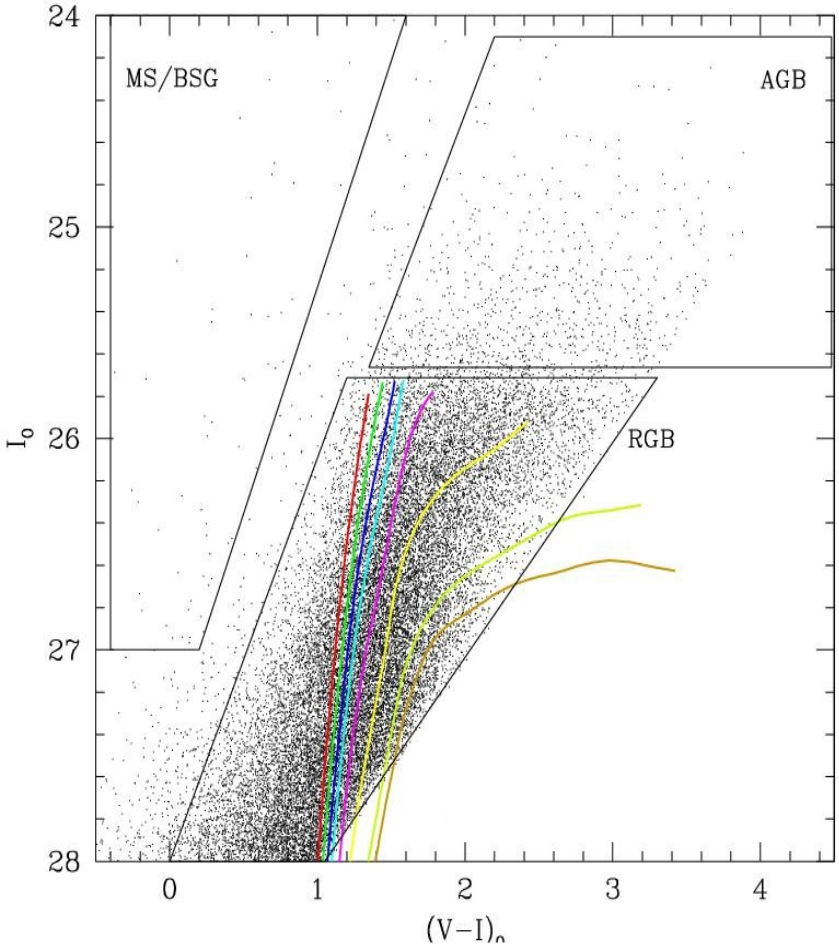


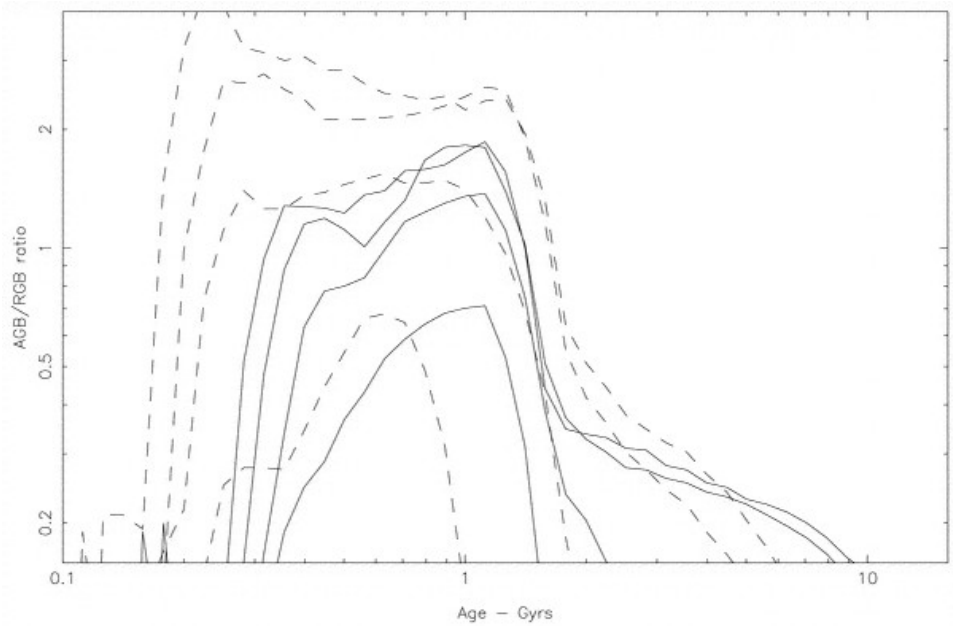
RGB density map



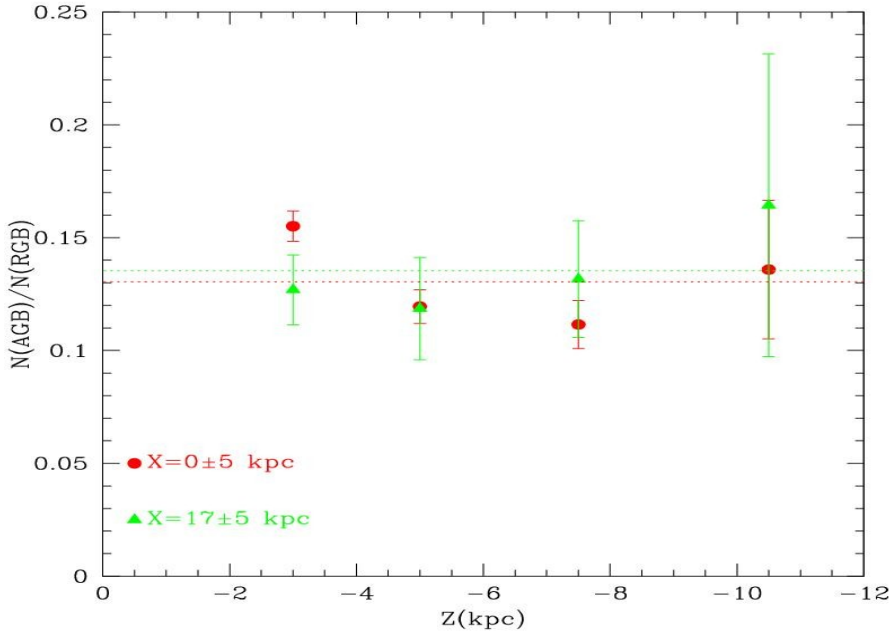
Ibata, Mouhcine, Rejkuba (2009)

Metallicities



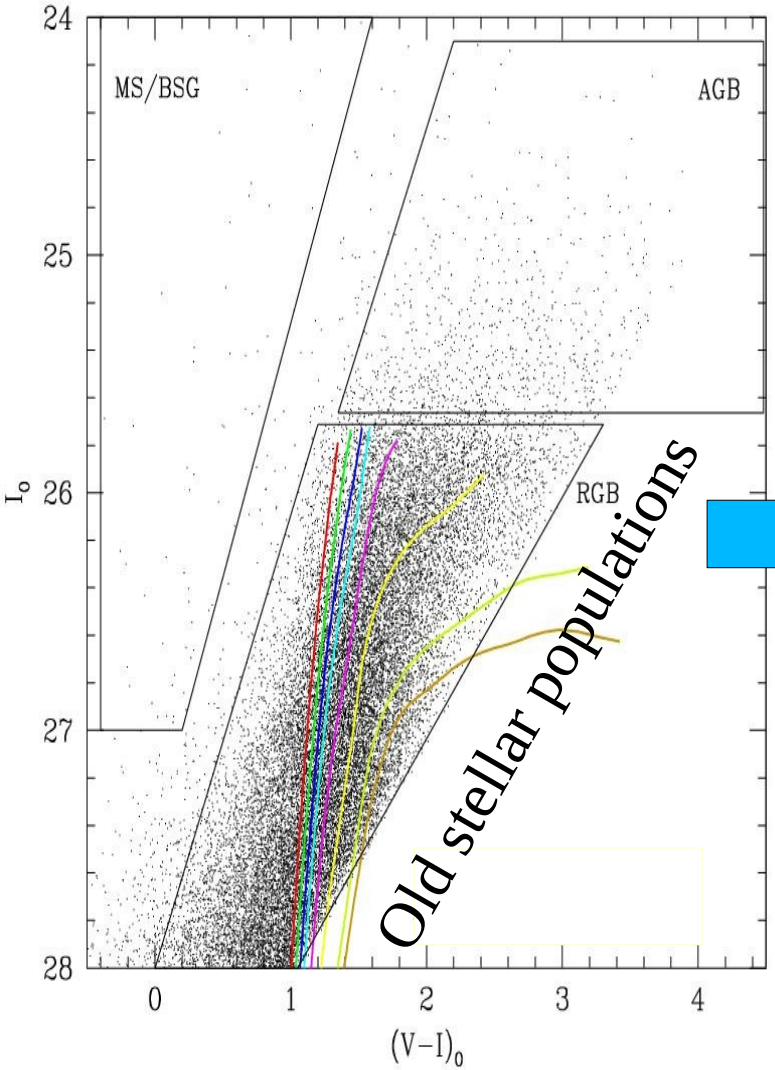


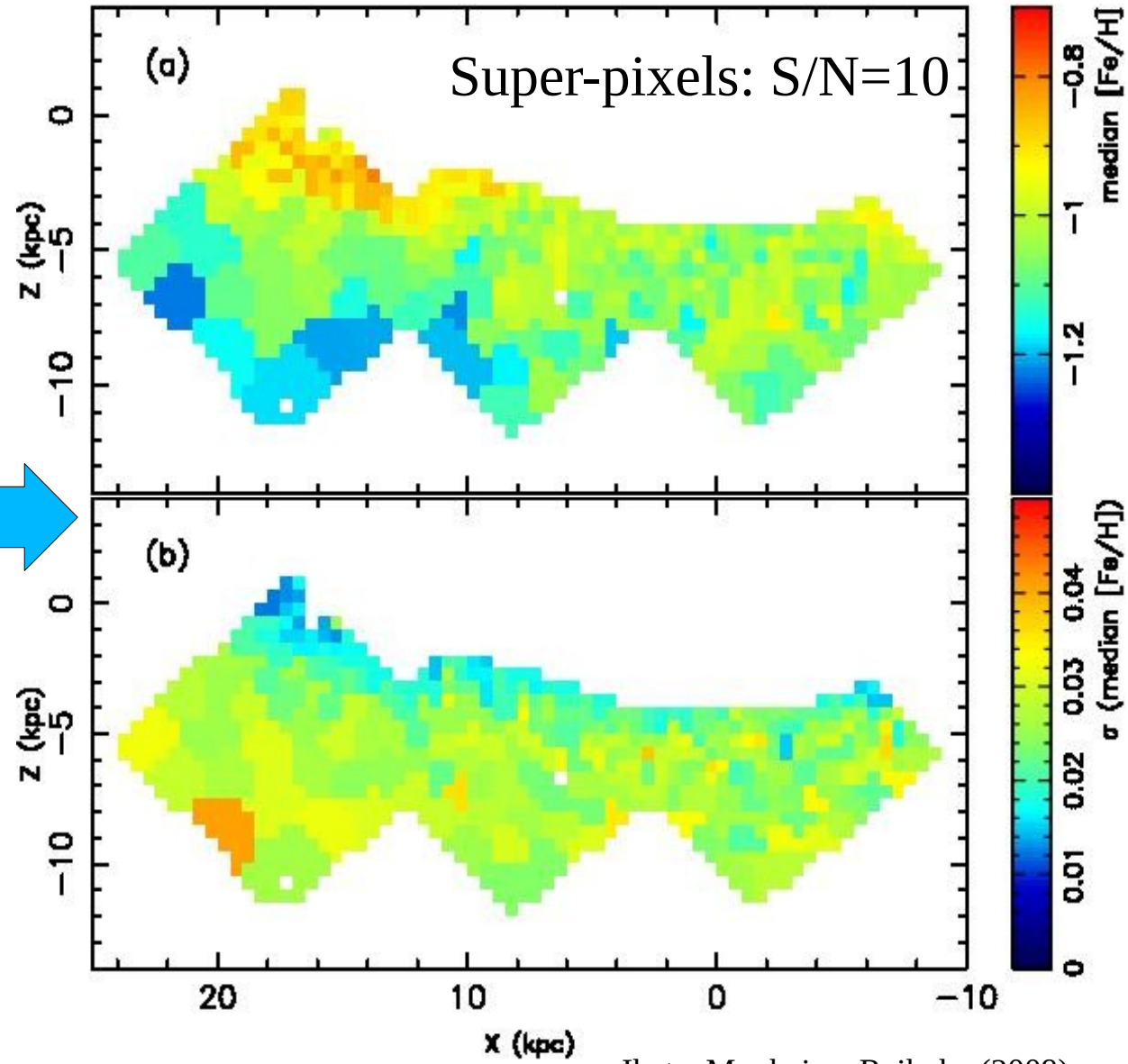
Mould (2005)



- No young stars;
- The AGB content is consistent with an old population;
- No age gradient;

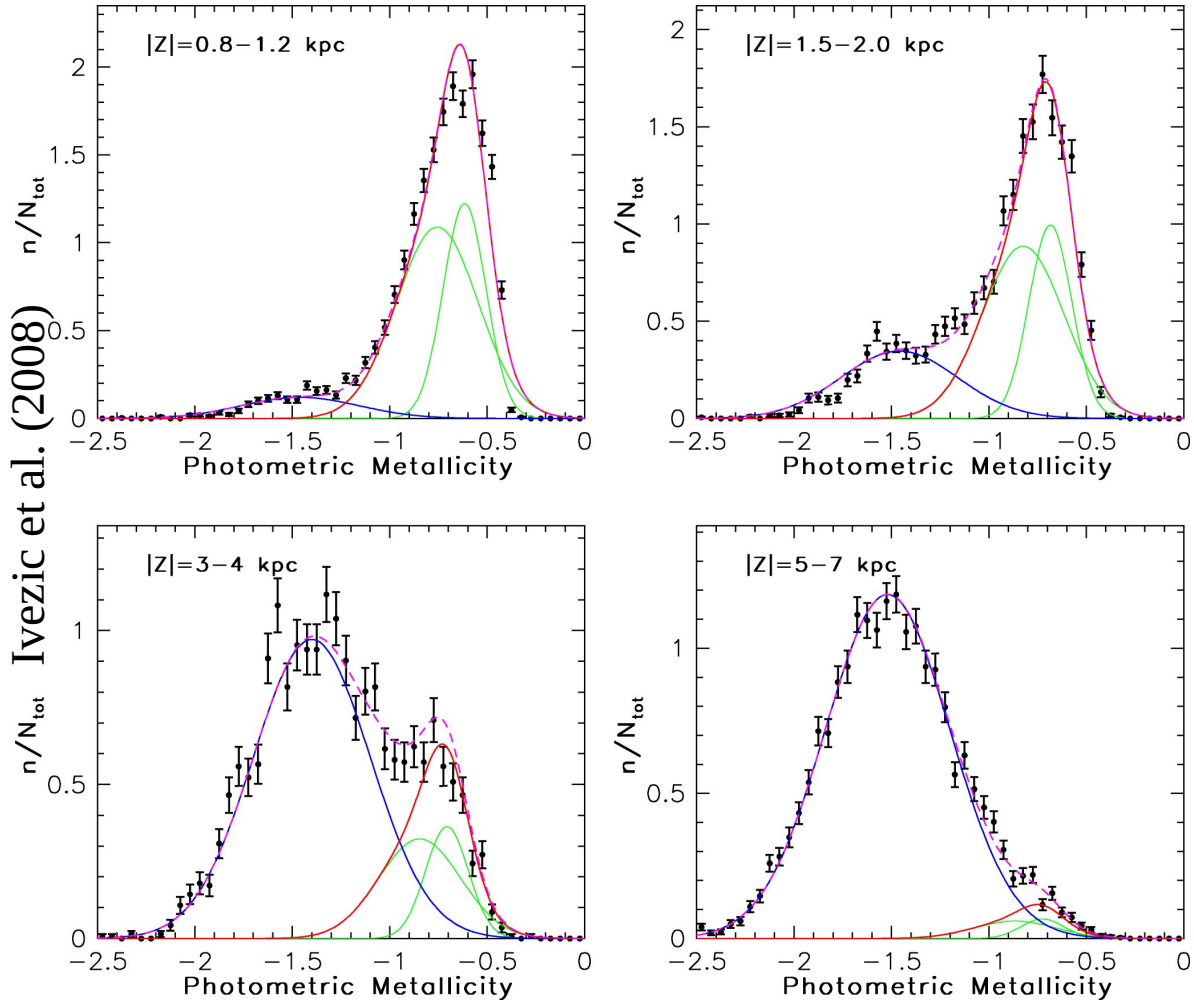
Metallicities





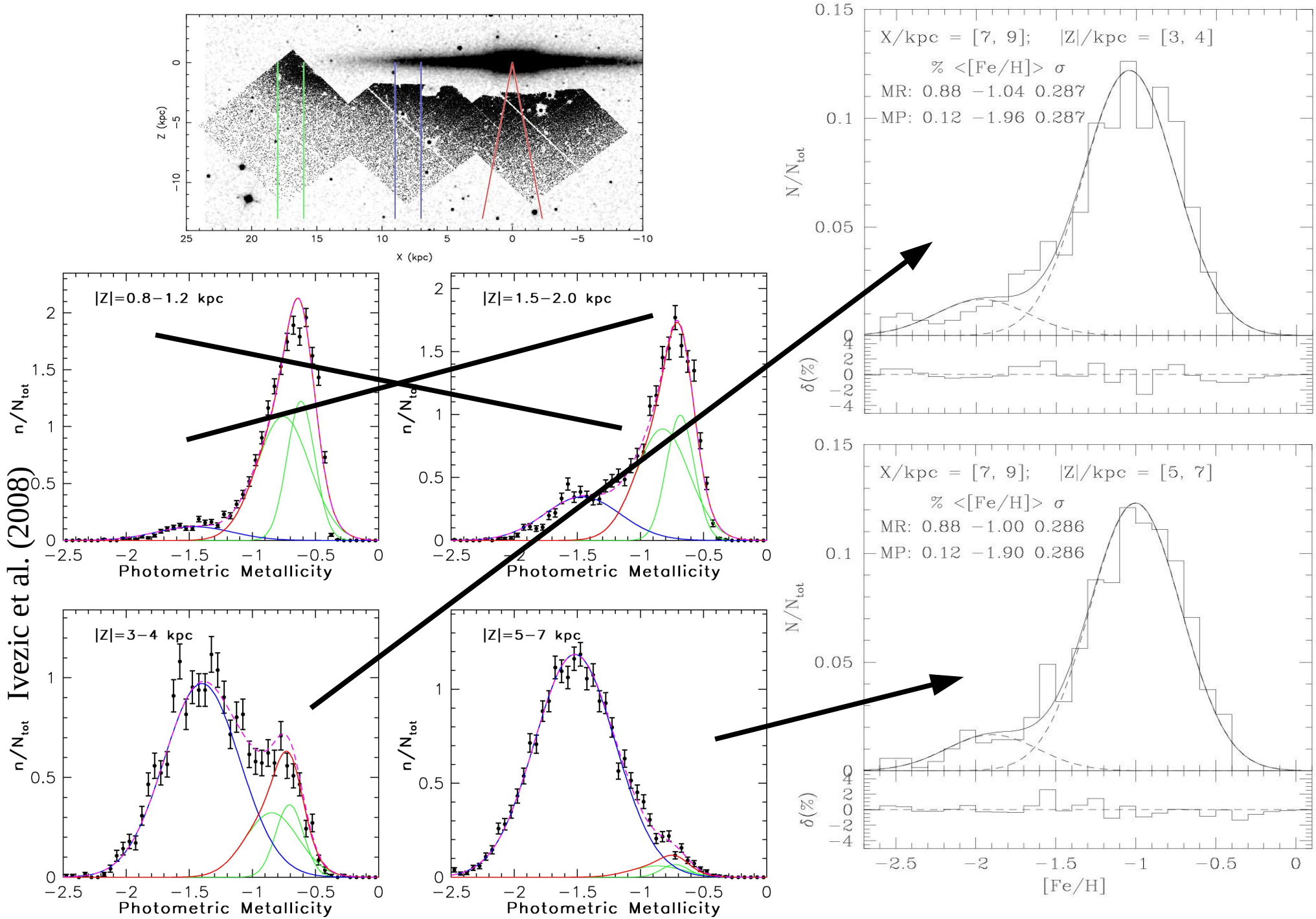
Ibata, Mouhcine, Rejkuba (2009)
Rejkuba, Mouhcine, Ibata (2009)

The extra-planar populations: the solar neighbourhood



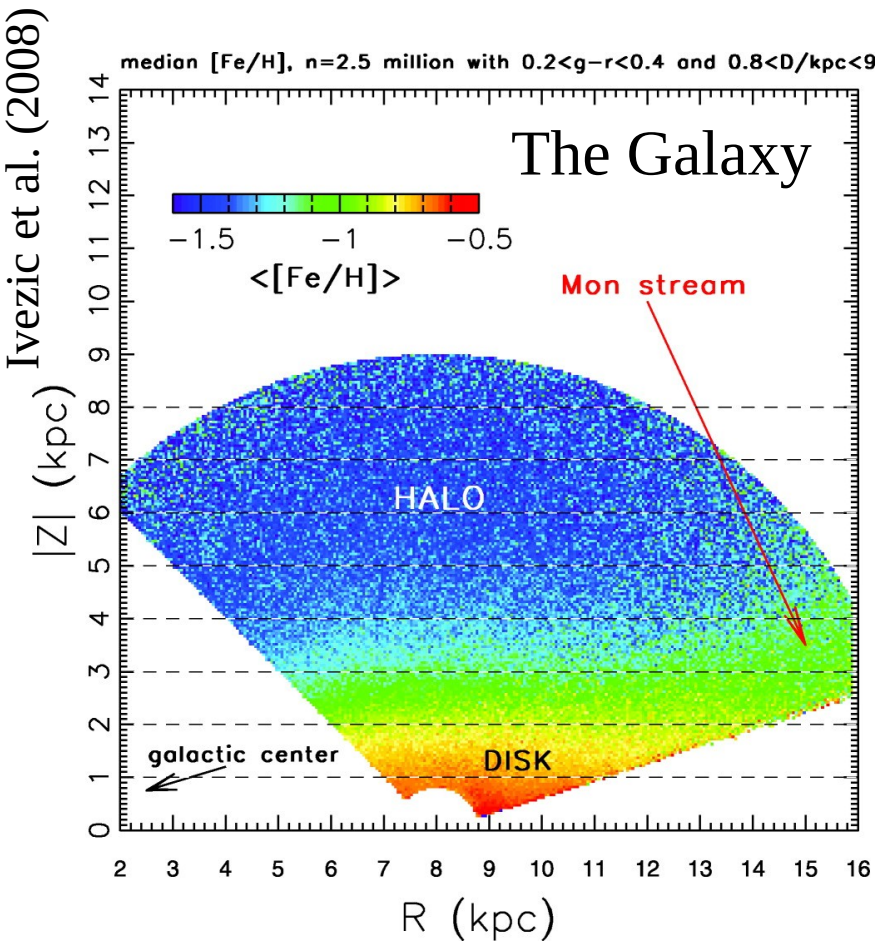
Ivezic et al. (2008)

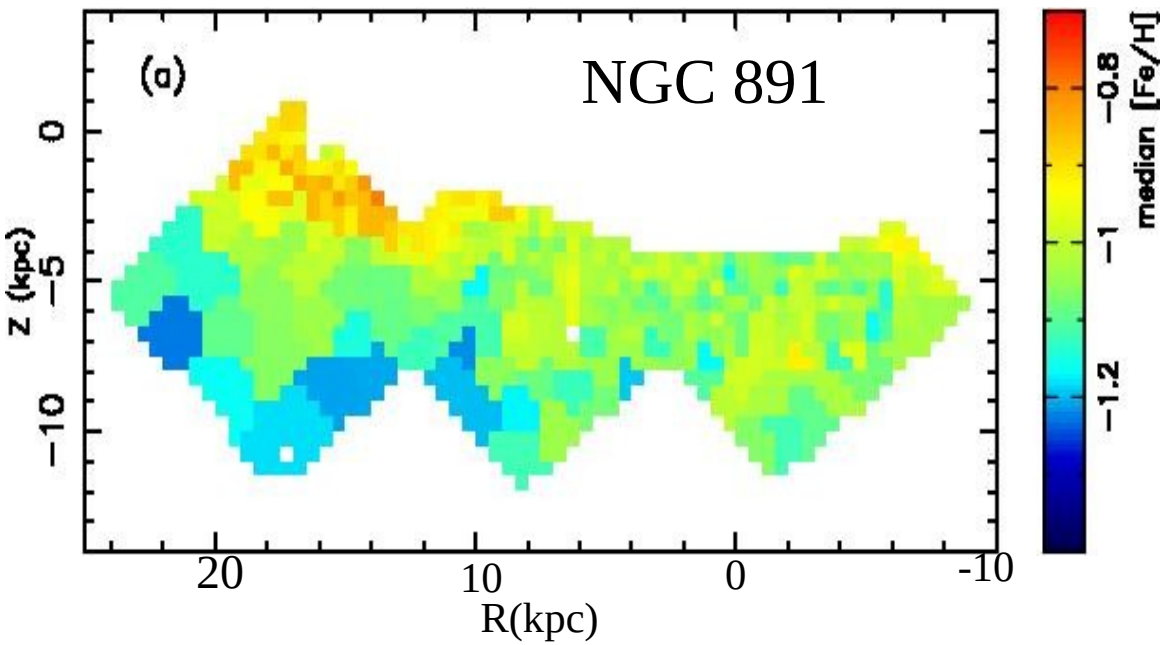
The extra-planar populations: the solar neighbourhood



Ivezic et al. (2008)

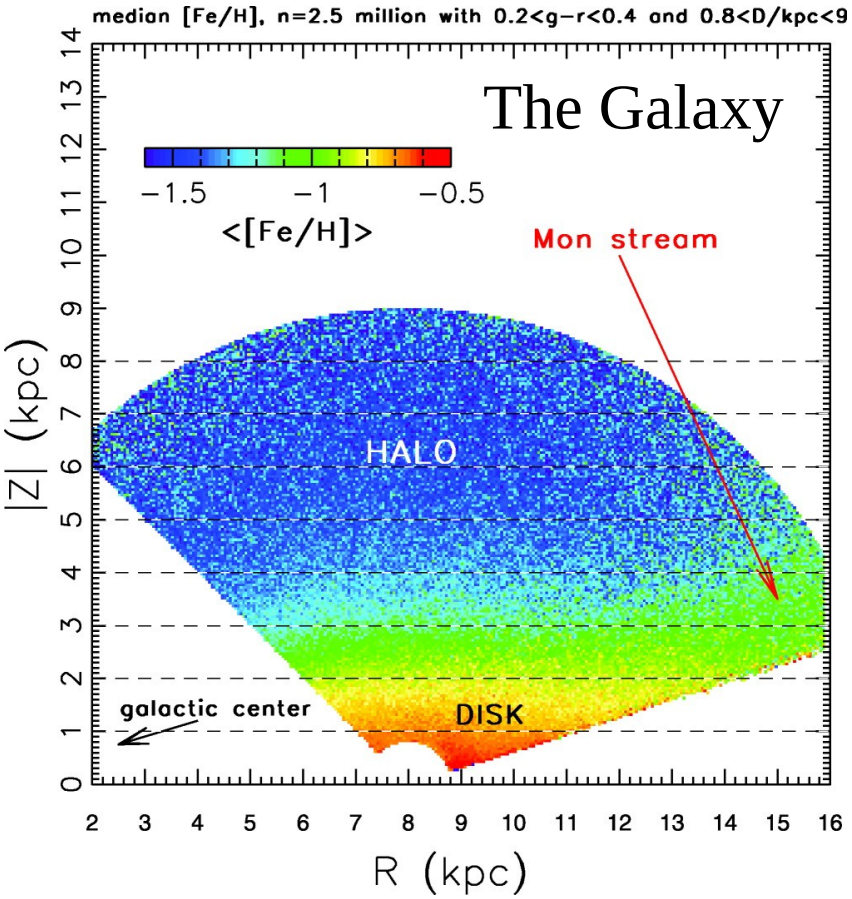
The two-dimensional metallicity distribution

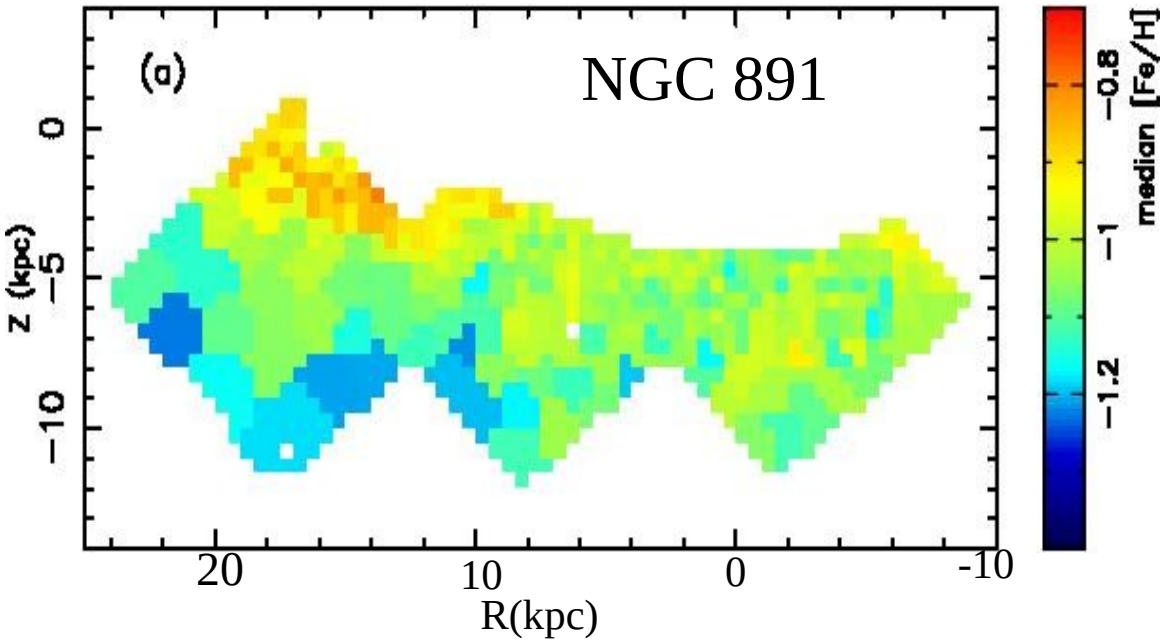




NGC 891 inner halo appears to be more chemically enriched than its Galactic counterpart

The two-dimensional metallicity distribution

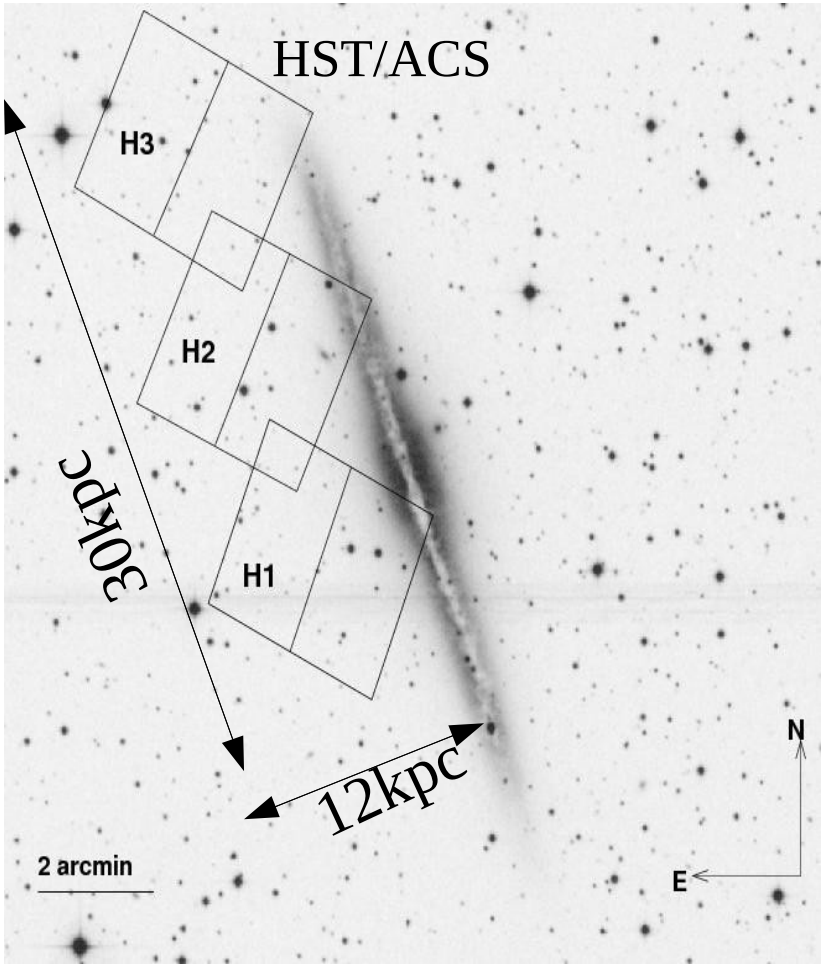


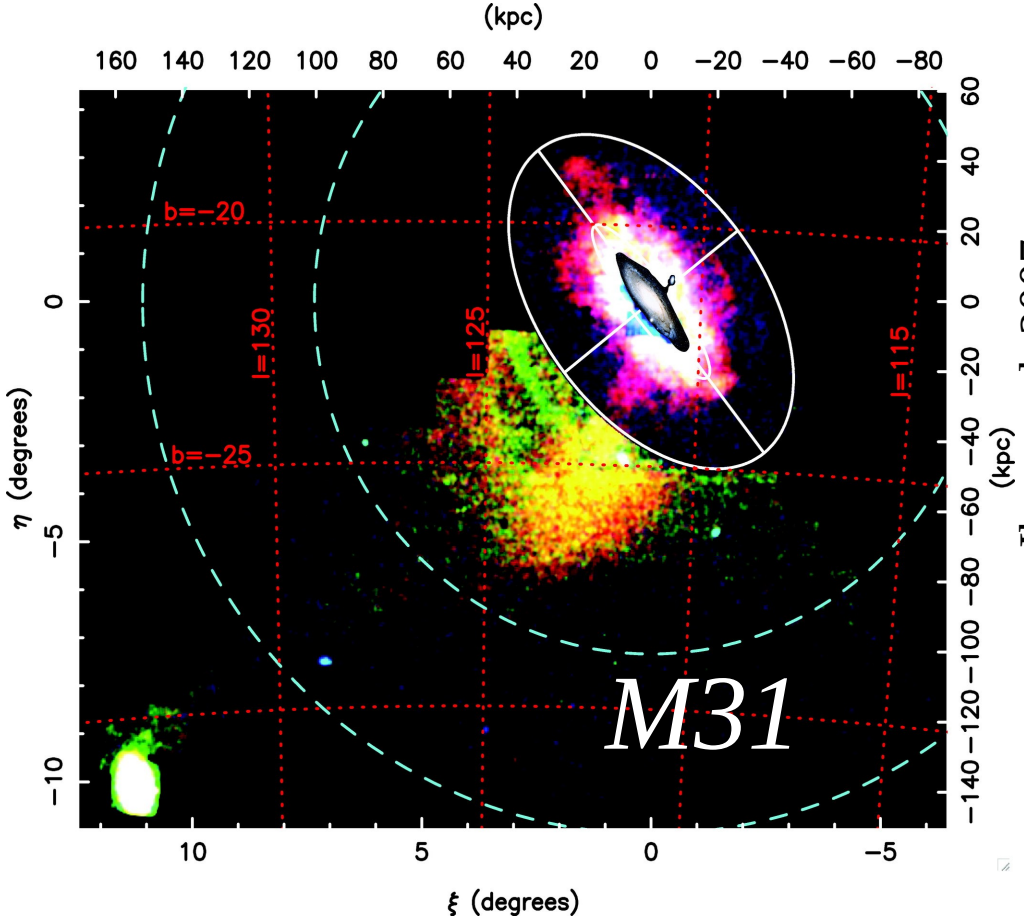


NGC 891 inner halo appears to be more chemically enriched than its Galactic counterpart

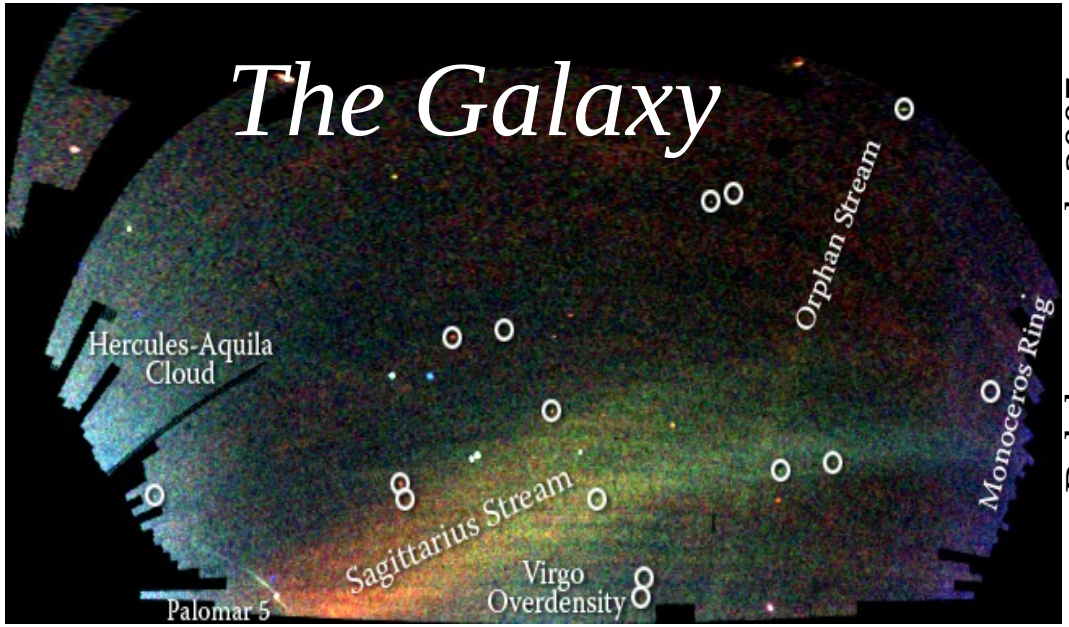
Different accretion histories of the (twin) galaxies

A panoramic view is needed



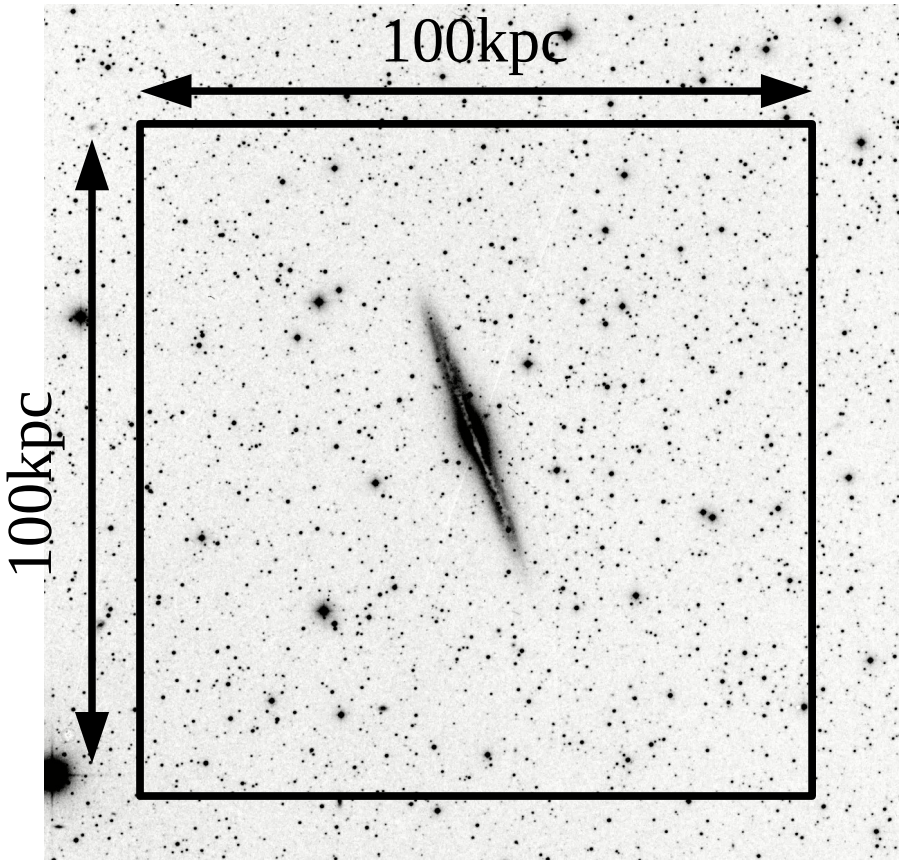


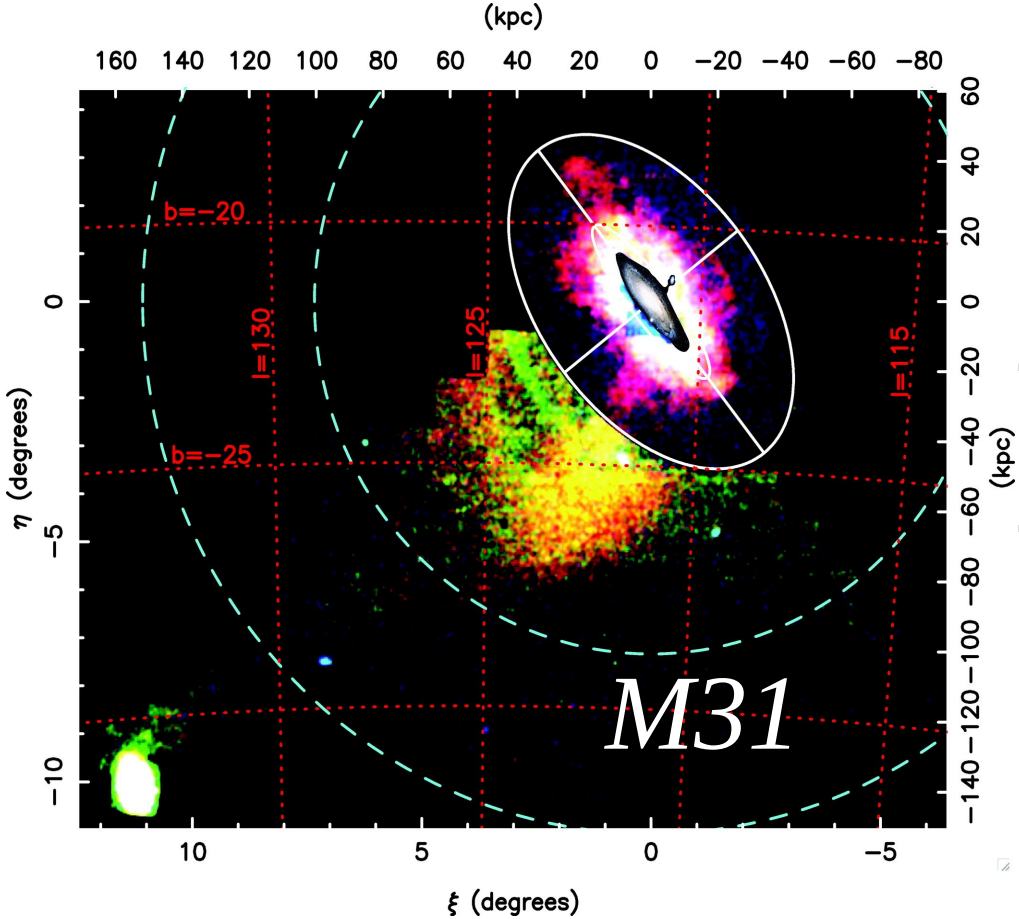
Ibata et al. 2007



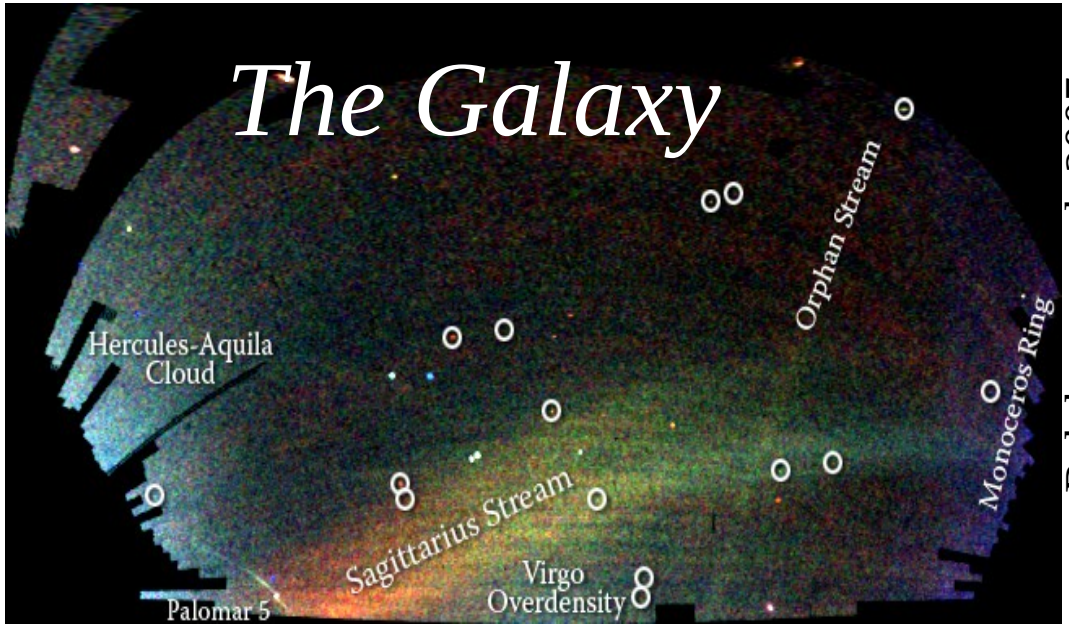
Belokurov et al. 2007

Subaru/Supreme-Cam



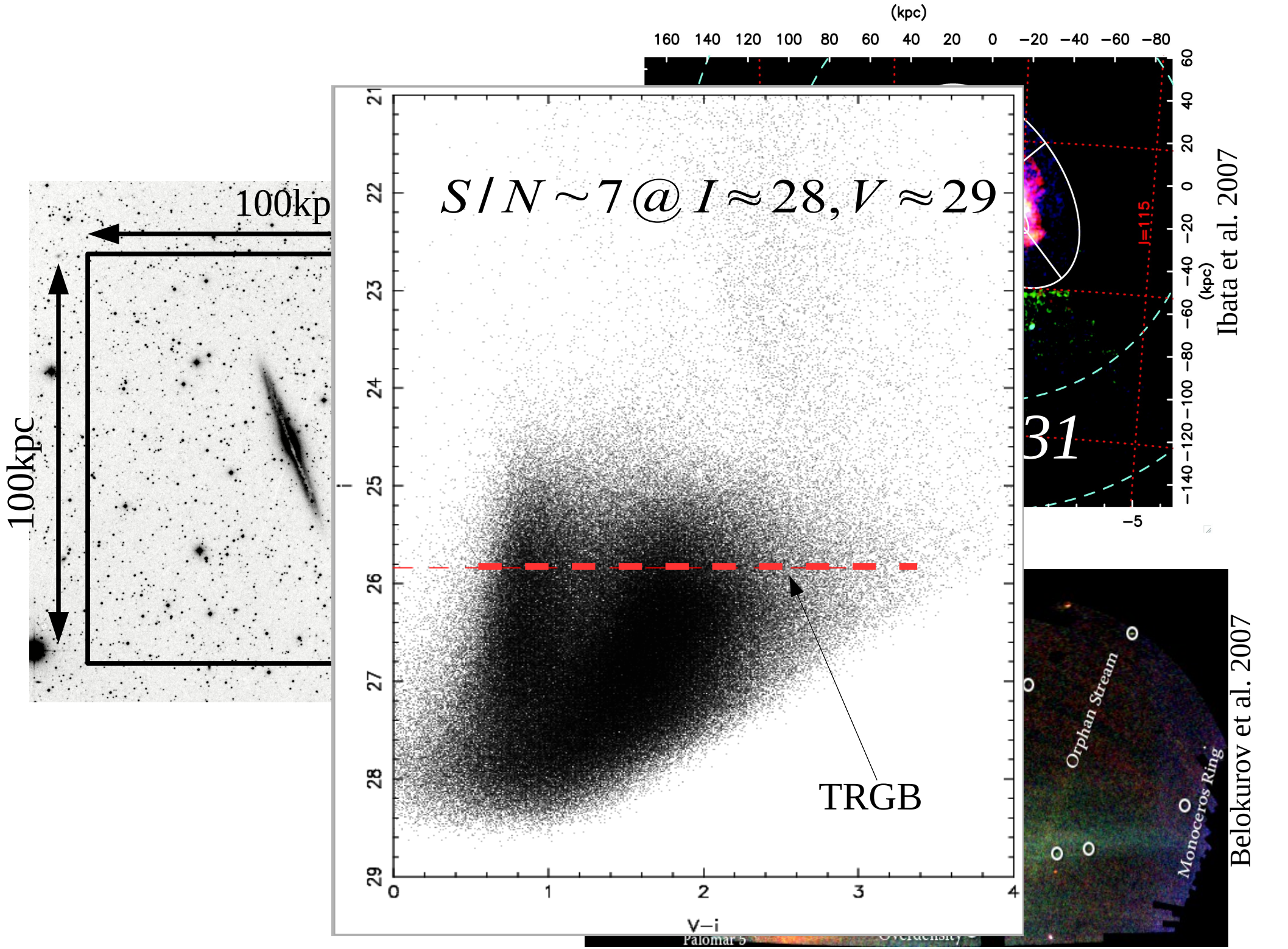


Ibata et al. 2007

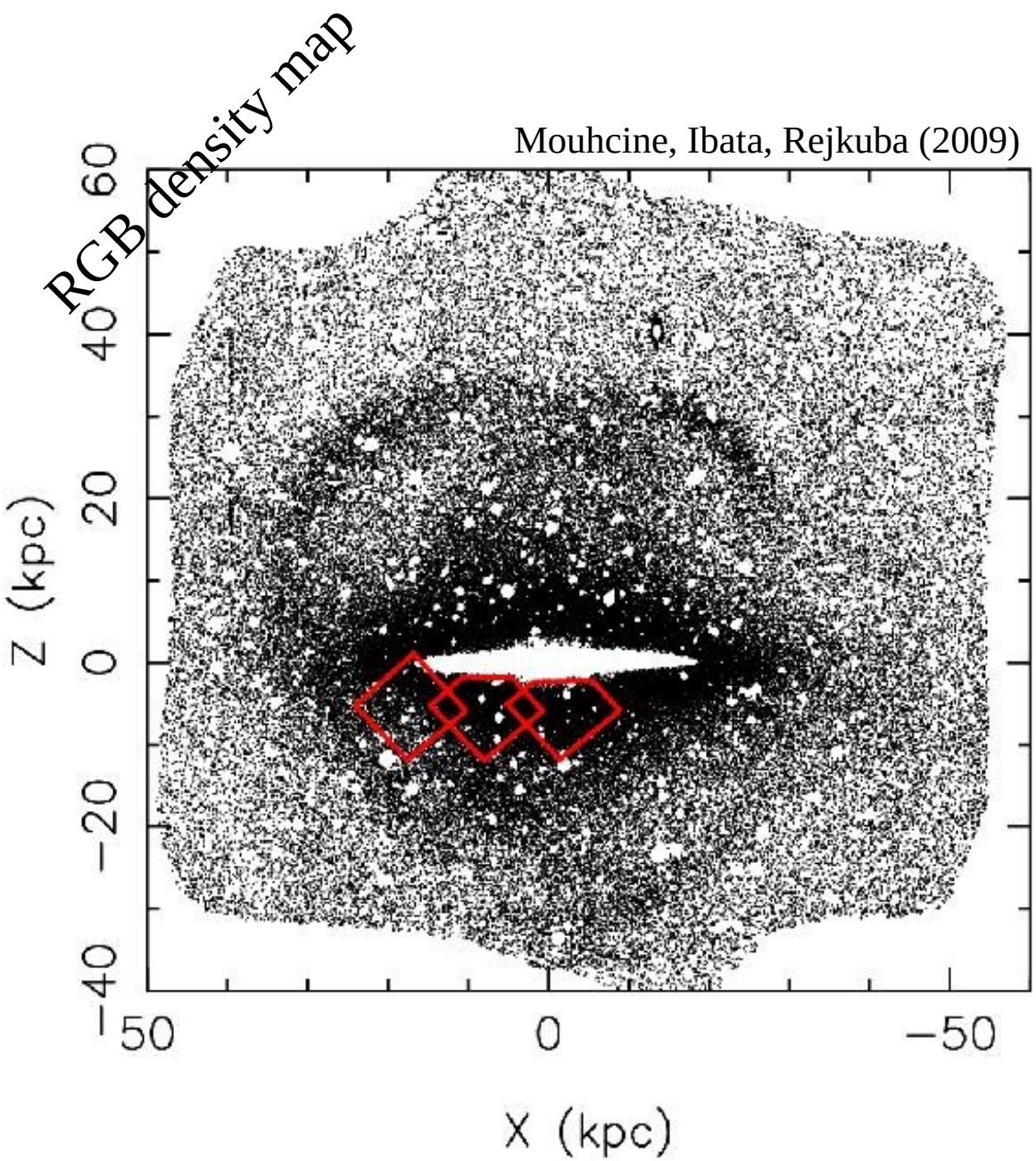


Belokurov et al. 2007

The first panoramic coverage of a Milky Way-like galaxy beyond the Local Group


100kp
100kpc
$S/N \sim 7 @ I \approx 28, V \approx 29$
TRGB
i
V−i
(kpc)
J=115
Ibata et al. 2007
Orphan Stream
Monoceros Ring
Belokurov et al. 2007
Palomar 5

A panoramic view of NGC 891

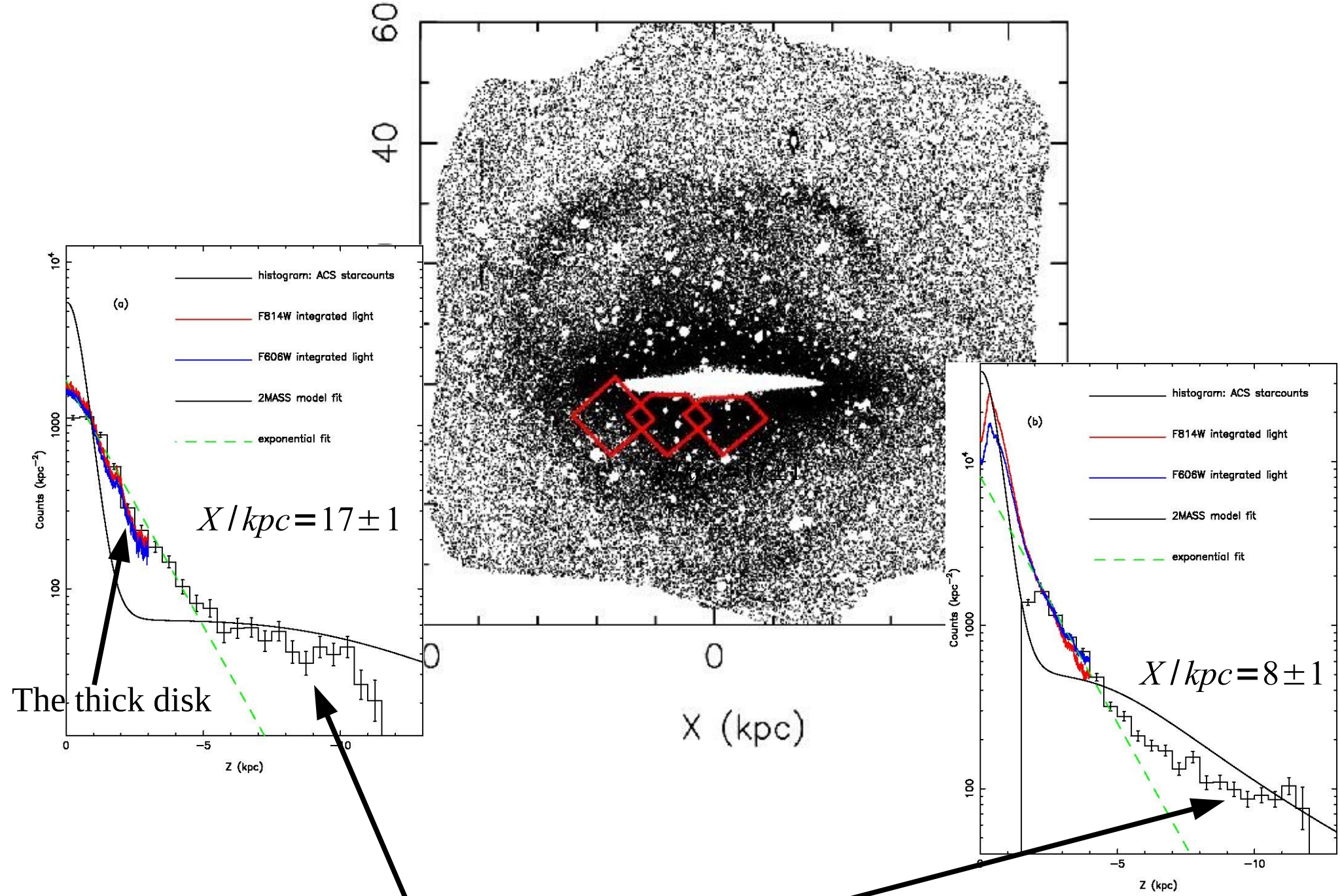


- A giant stellar stream is detected (the f rst to be resolved beyond the LG)

- The galaxy outskirts are dominated by numerous stellar substructures

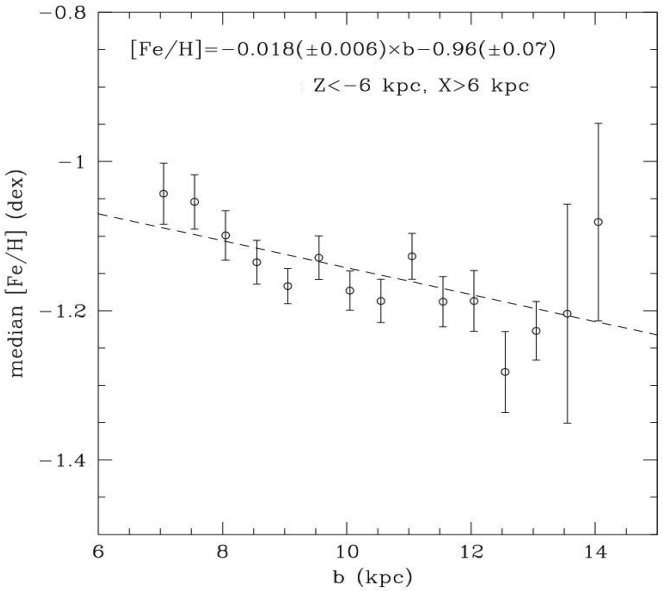
- The detection of a vast, f at, and thick structure surrounding the galaxy (q~0.3 [NGC891] vs. q~0.7 [MW]):

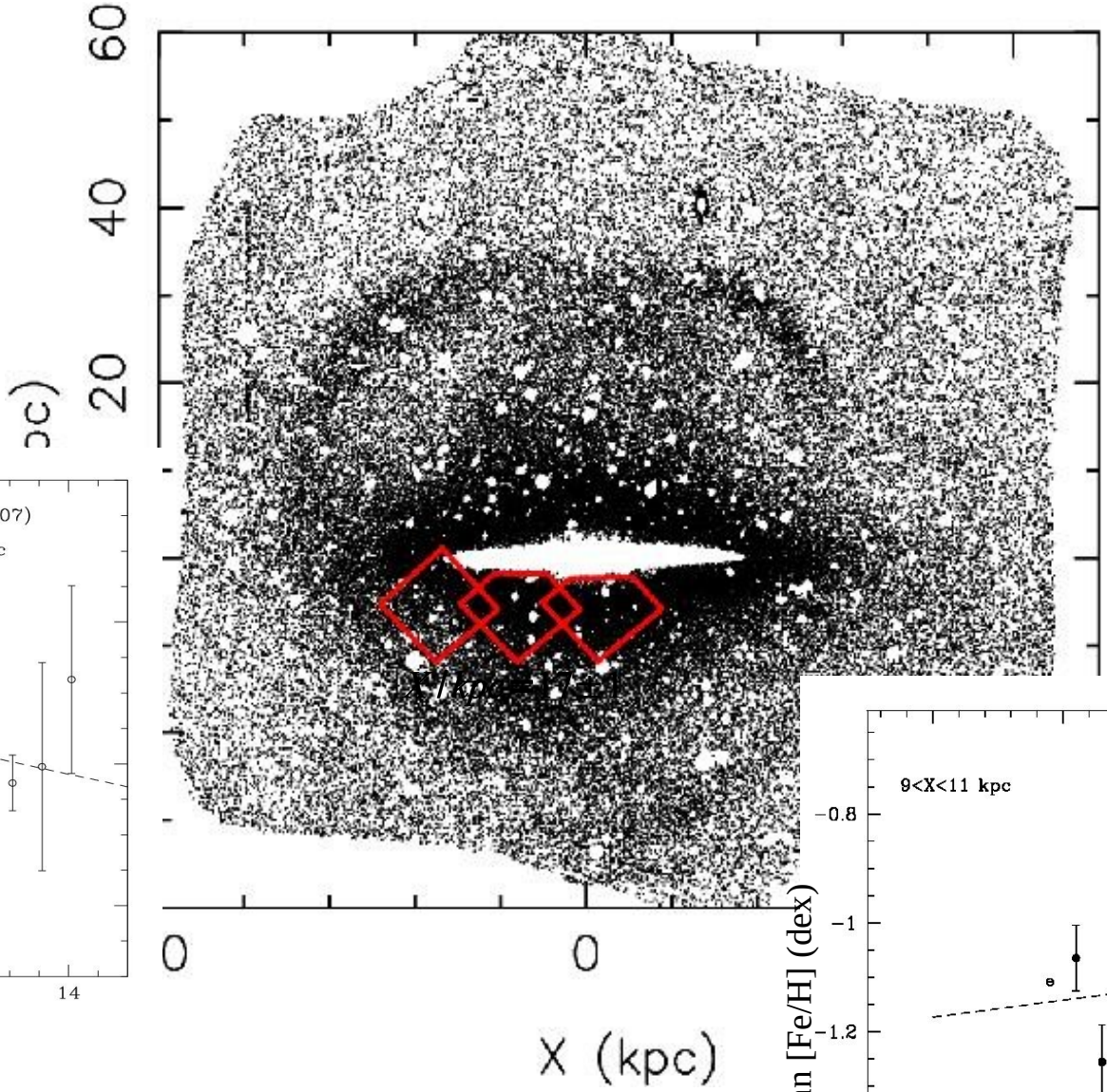
    - An extension of the thick disk?
    - A new component?



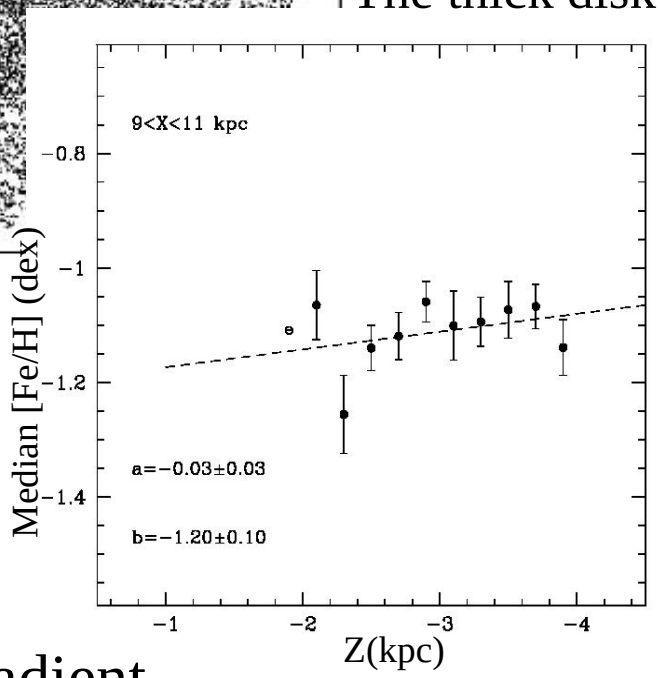
The presence of an extended component beyond $|Z| \sim 5$kpc

The envelope



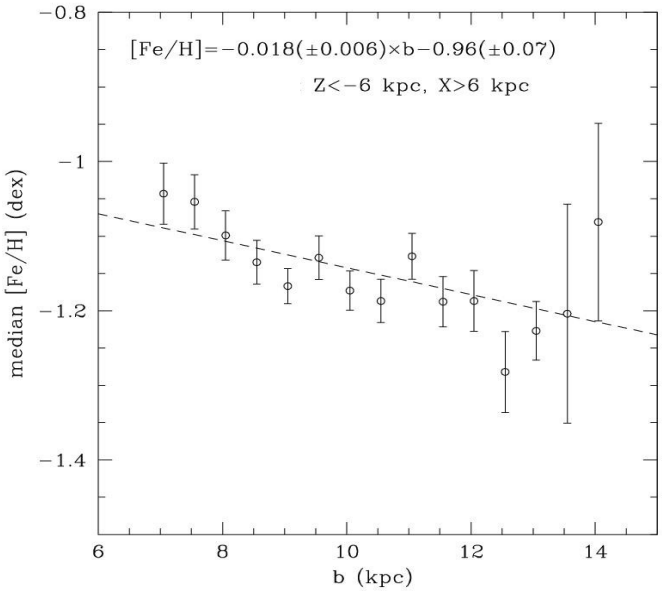


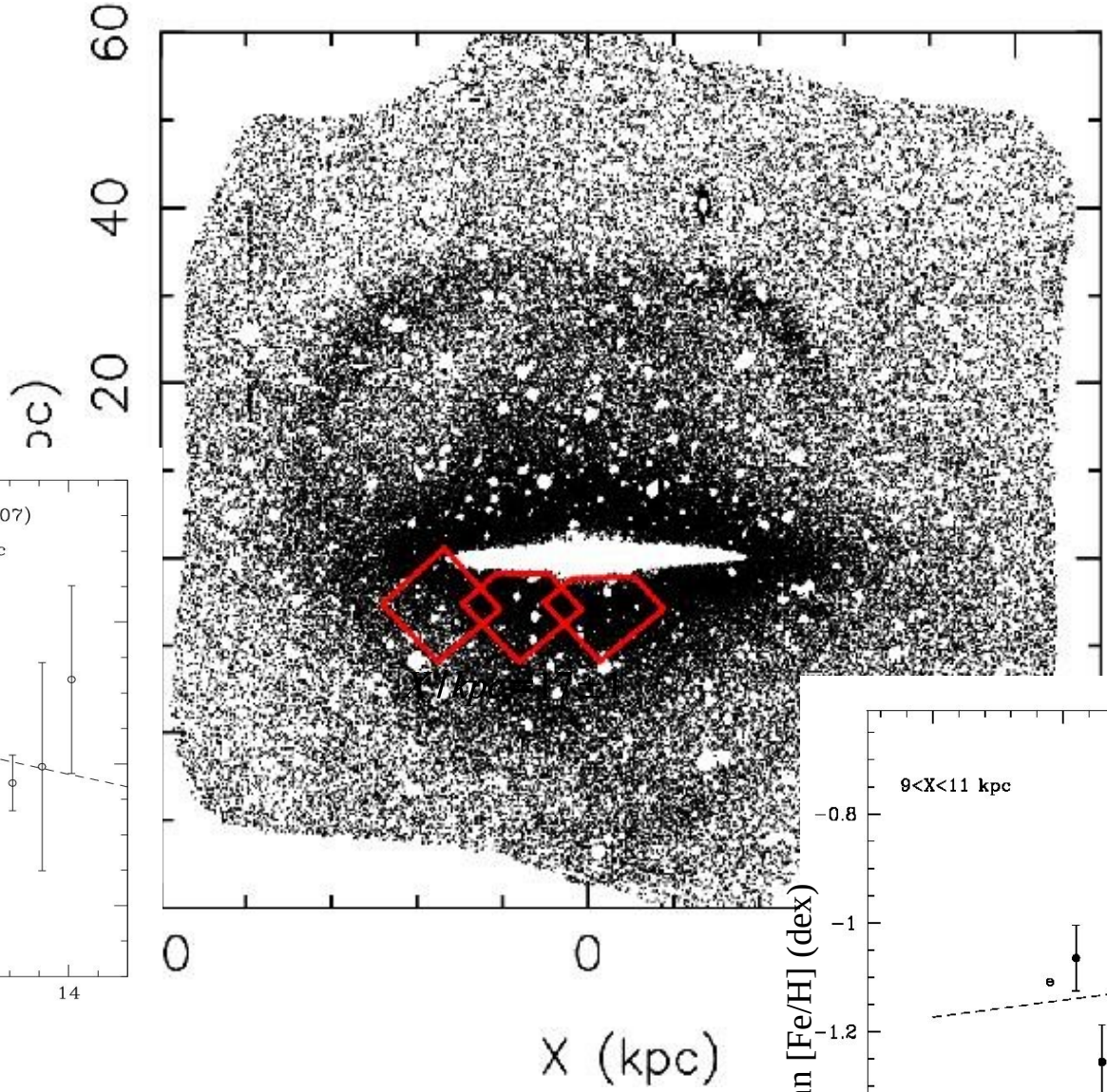
The thick disk



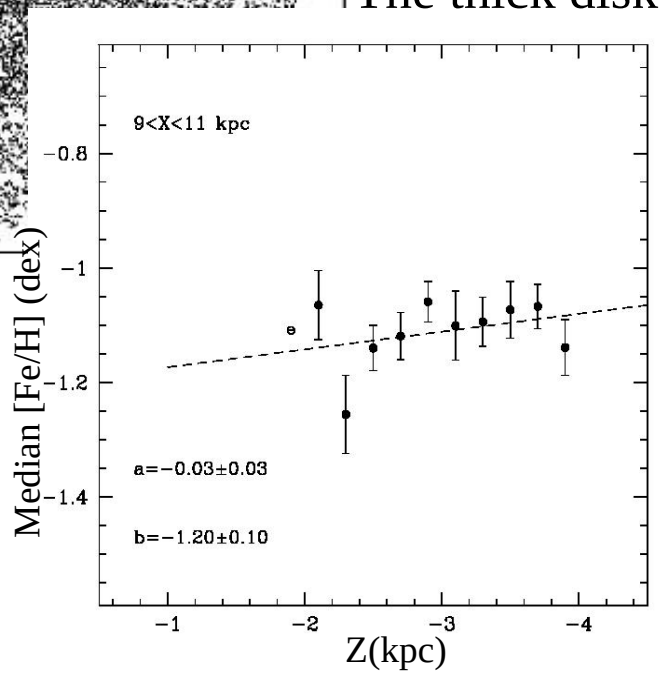
The stellar envelope exhibits a (mild) metallicity gradient

The envelope



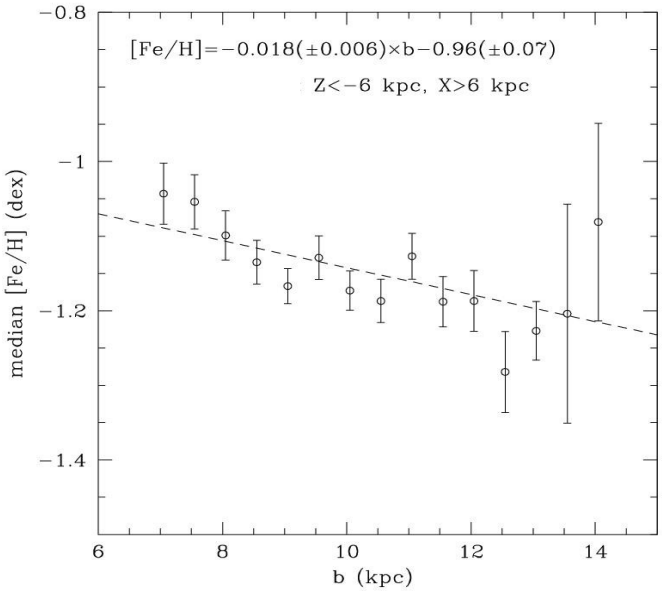


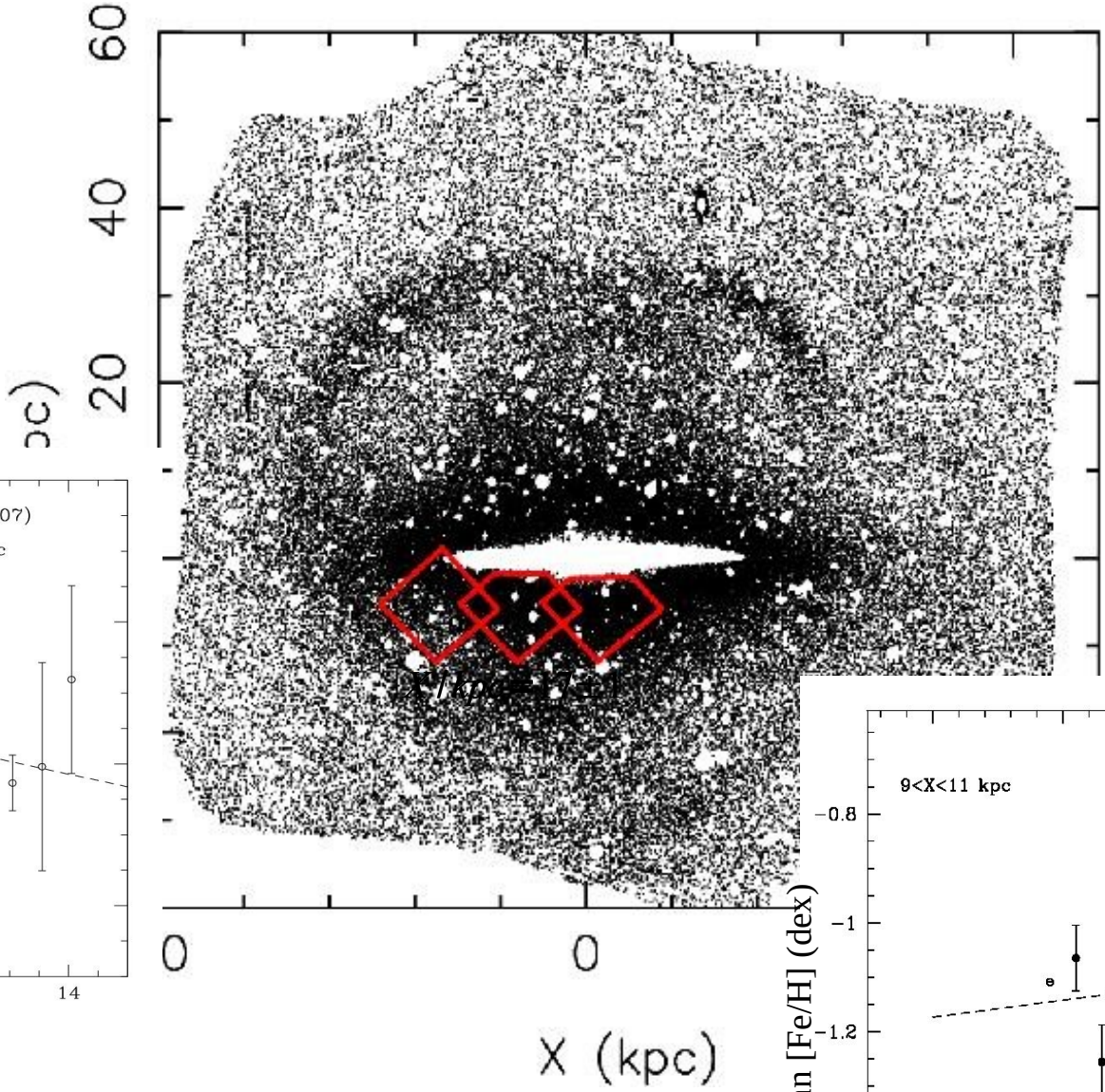
The thick disk



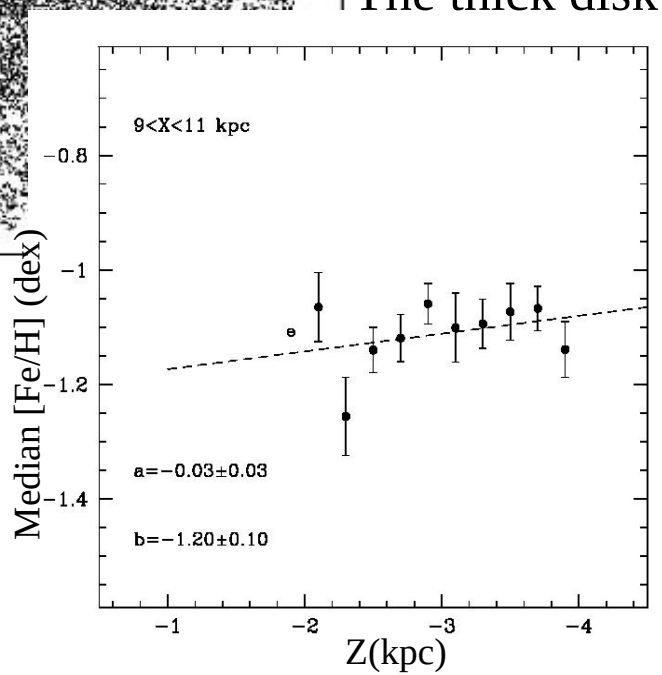
The stellar envelope is not an extension of the thick disk

The envelope





The thick disk



The stellar envelope is not an extension of the thick disk

A previously undetected galaxy morphological component

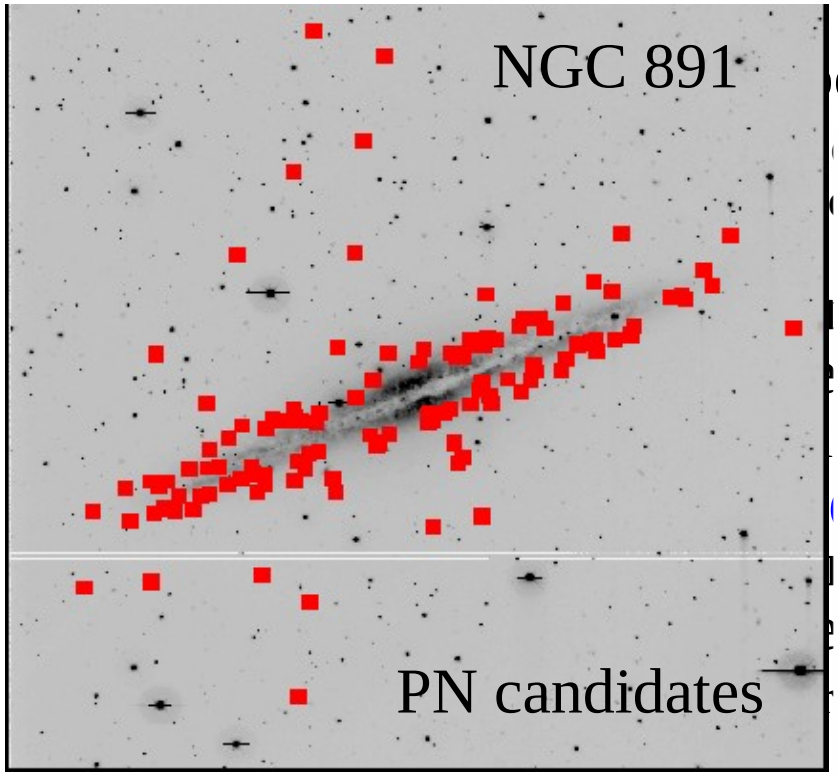
Open questions: A case for ELT observations

- A detailed kinematic portrait of the super-thick structure
  - the formation mechanism of extended disks
  - the inner/outer disk connection

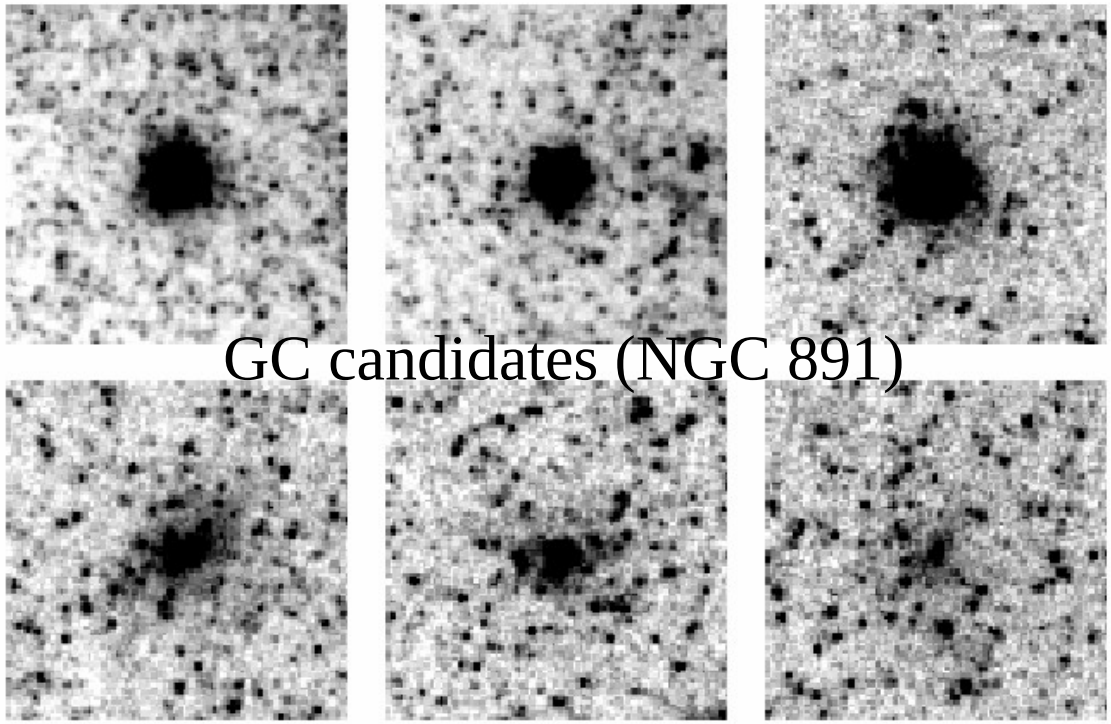
- is there a metallicity-kinematic-morphology relation for stellar populations in the outer regions of spirals?
  - is the kinematically hot metal-poor halo a generic feature of spirals?

- is there (chemical/kinematical) differences between the diffuse stellar halo and localised substructures?
  - How representative the present-day substructures of previously disrupted systems?

Open questions: A case for ELT observations

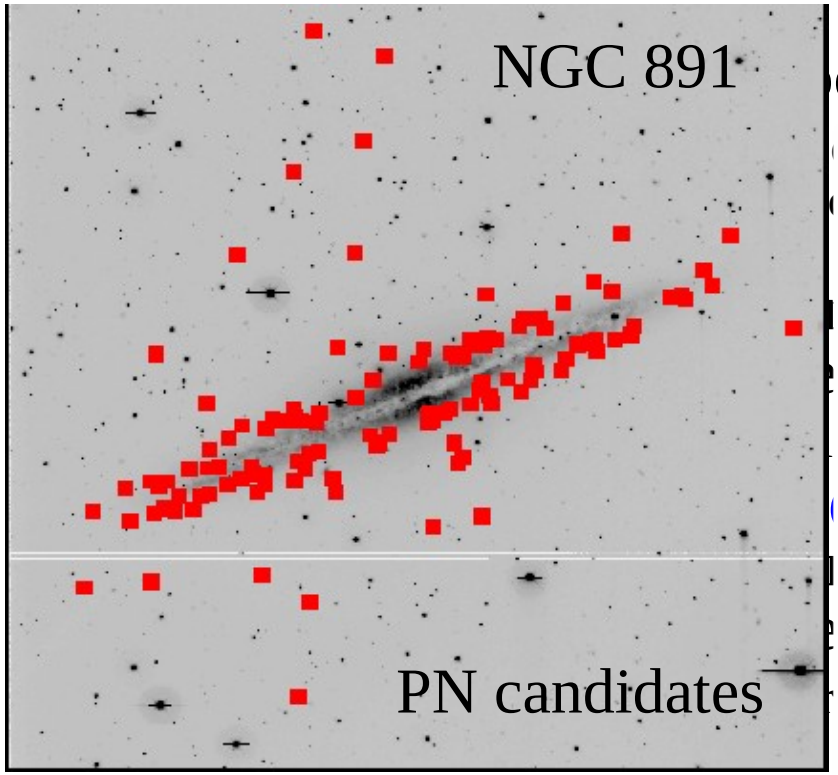


ortrait of the super-thick envelope

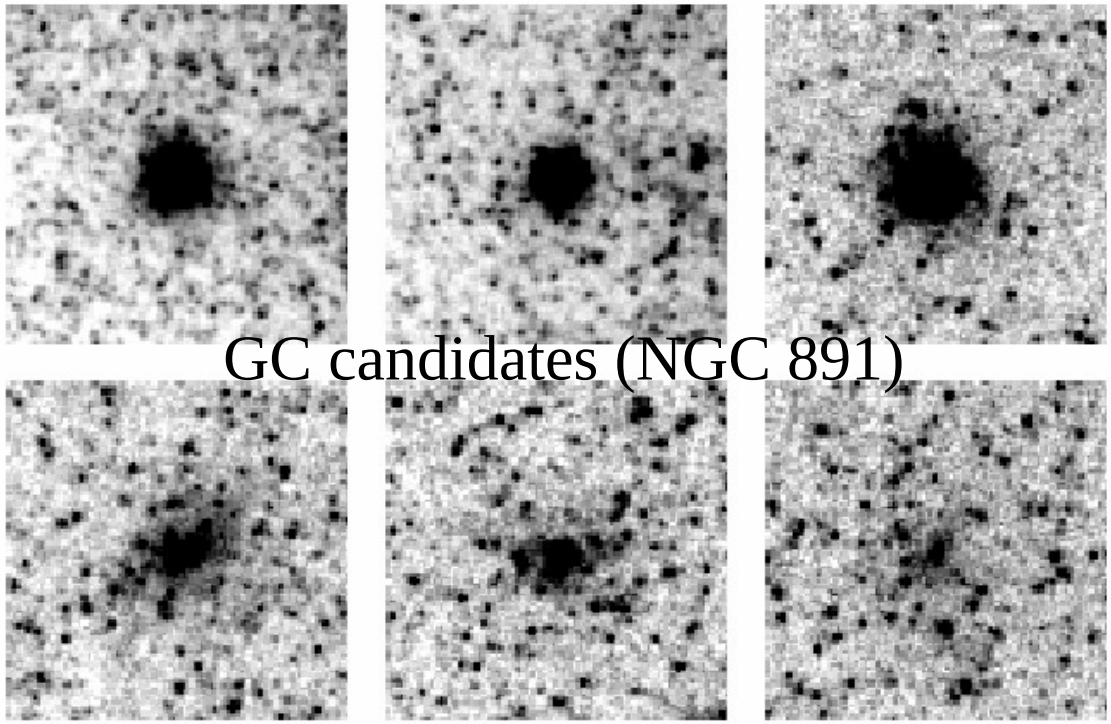


The samples of PNs/GCs are small to deliver the required data-set

Open questions: A case for ELT observations

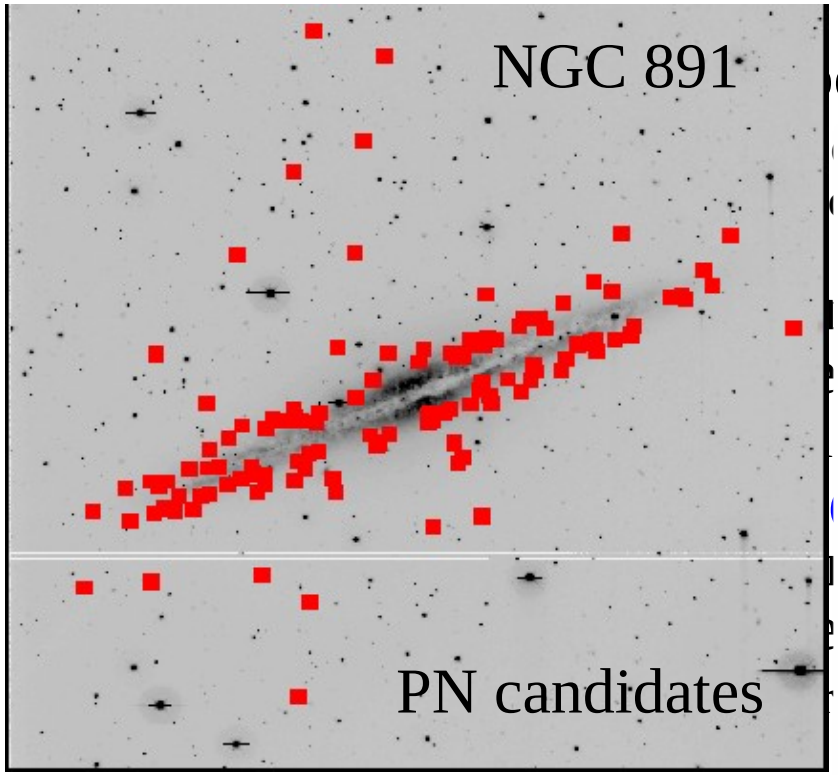


ortrait of the super-thick envelope

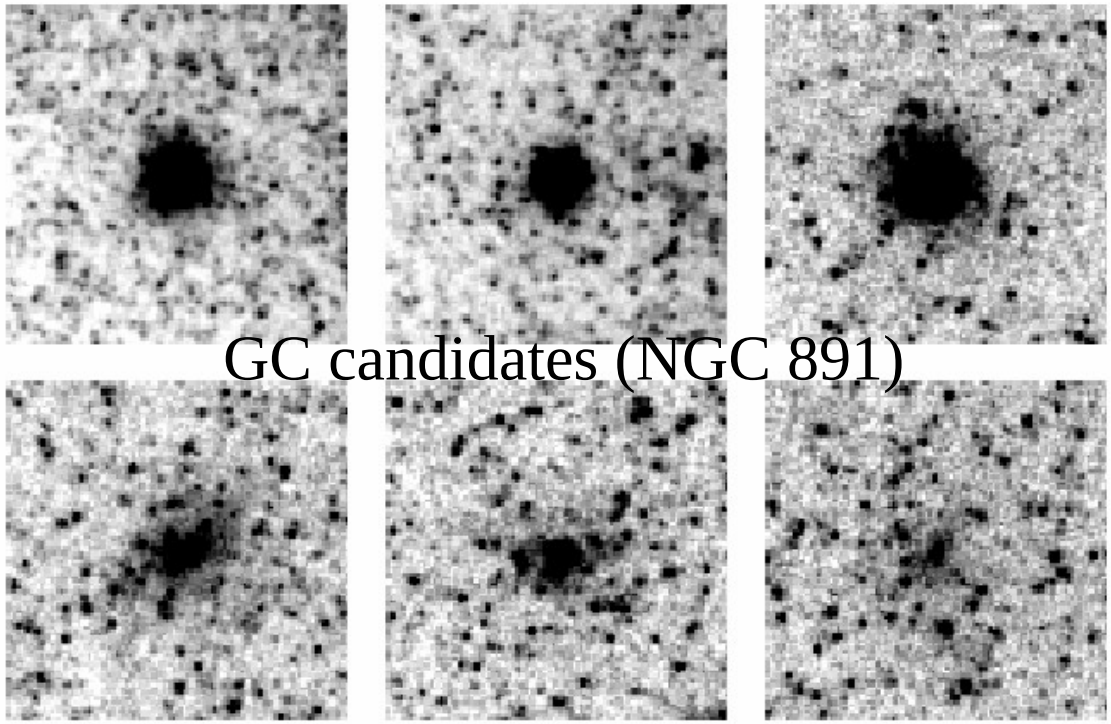


Extensive spectroscopic surveys of RGB stars in the outskirts of spirals are needed

Open questions: A case for ELT observations



ortrait of the super-thick envelope



Extensive spectroscopic surveys of RGB stars in the outskirts of spirals are needed

E-ELT observations

Summary & Conclusions

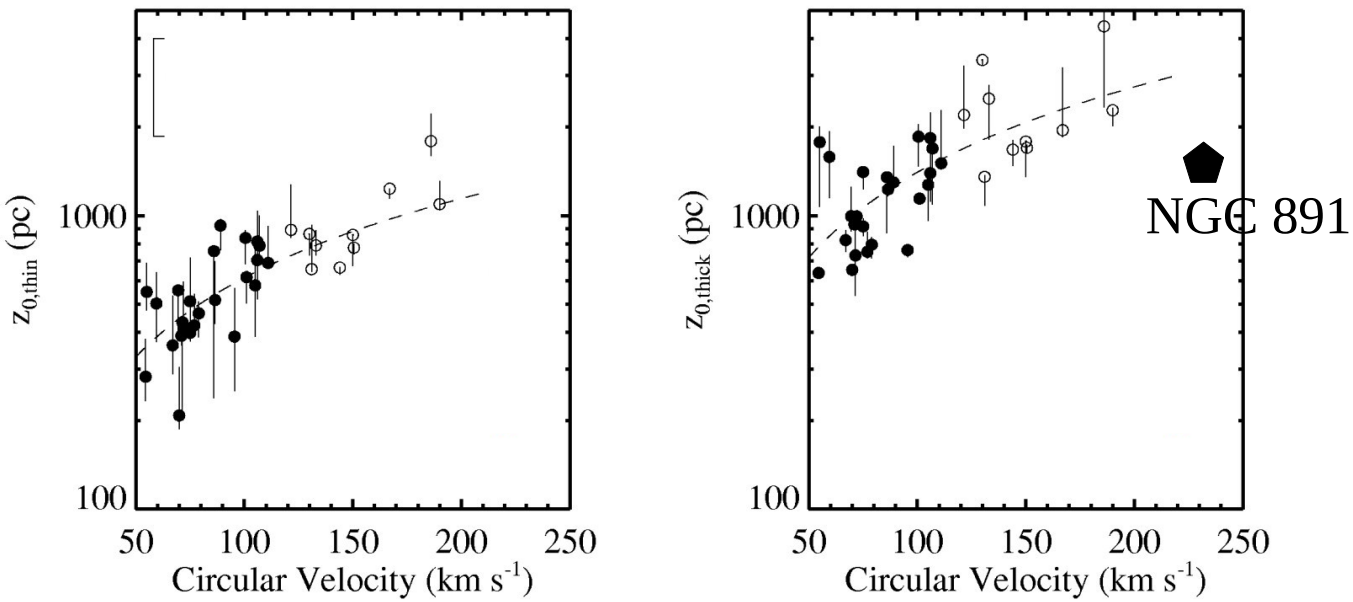
- NGC 891 extra-planar stellar populations are more chemically enriched than their Galactic counterparts;

- The outer regions of NGC 891 are highly structured;

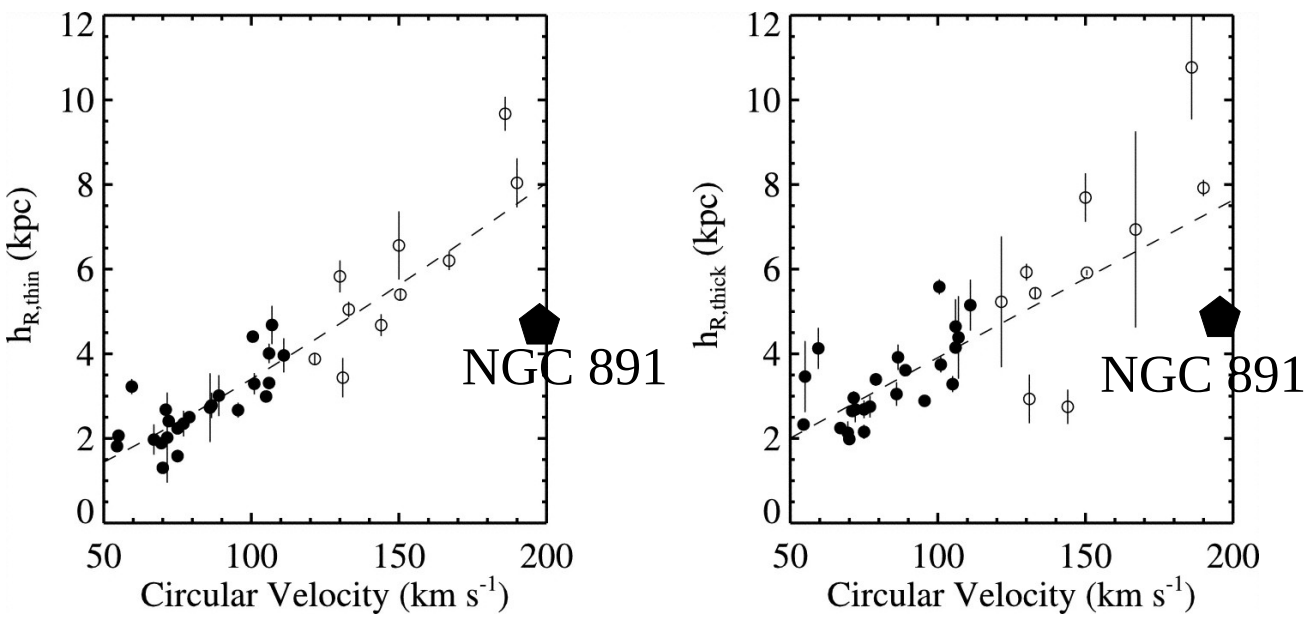
- The def ning components of a spiral are embedded in a previously undetected f at, and super-thick stellar structure;

- The E-ELT instrumentation will open a new era of galactic halo astronomy

Yoachim & Dalcanton (2006)



	MW	NGC 891
$h_R(thin)$	2.6 ± 0.05kpc;	4.19 ± 0.03kpc
$h_z(thick)$	0.9 ± 0.18kpc;	1.44 ± 0.13kpc
$h_R(thick)$	3.6 ± 0.15kpc;	4.81 ± 0.11kpc



MW vs. NGC 891

- similar $h_z(thick)/h_R(thick)$
- comparable $h_R(thin)/h_R(thick)$

Integrated light measurements tend to overestimate the thick disk structural parameters

Panoramic mapping the outskirts of spiral galaxies beyond the Local Group

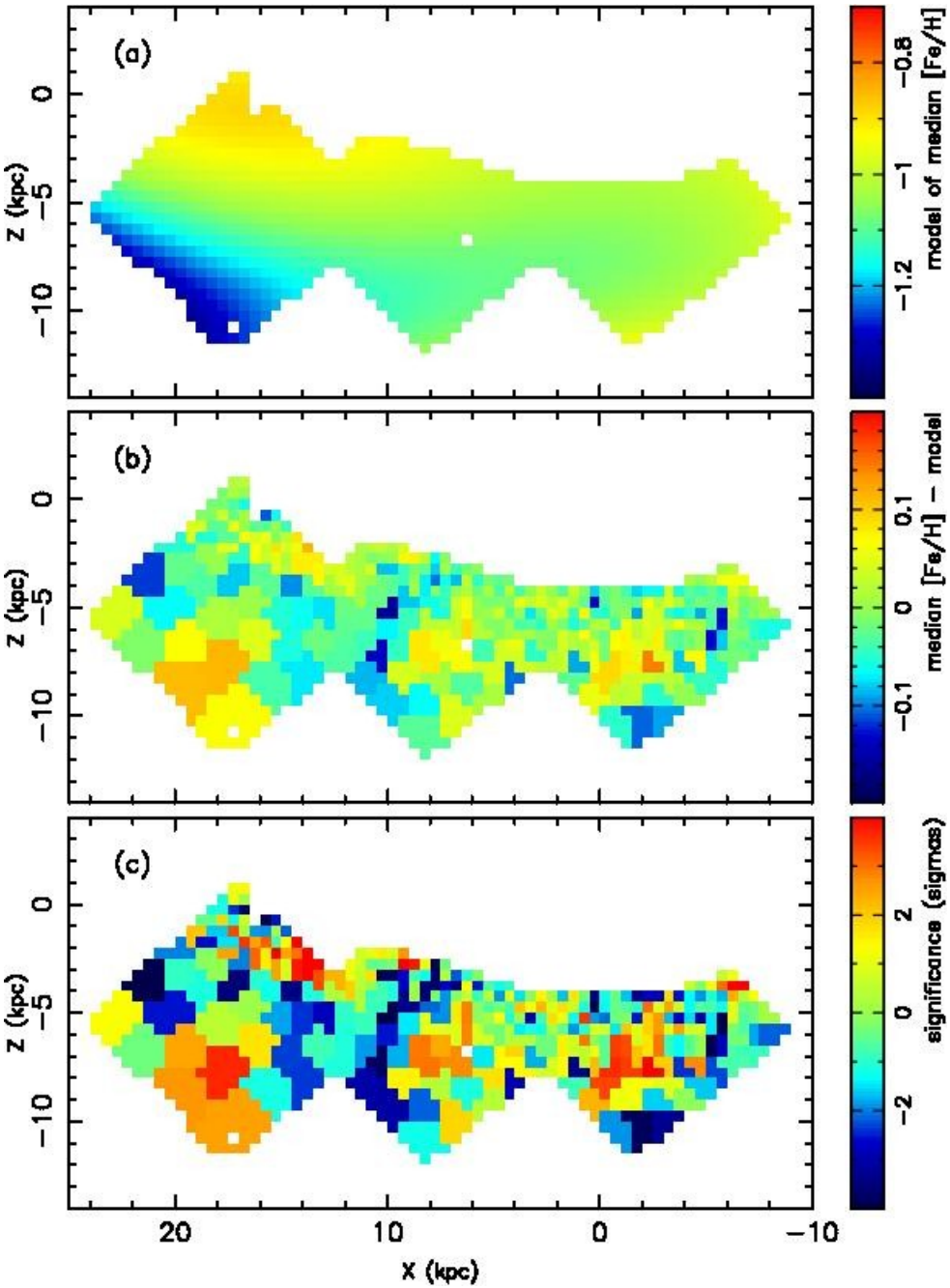
Resolving the upper 2-3 magitudes of red giant branches of spirals with (i) D < 10 Mpc and (ii) i>60 deg.

Morph. Type = [Sa-Sd]; Circular Velocity = [80-220] km/s
Requirement: S/N=7 @ I~[26.2-28.2] & V~[27.2-29.2]

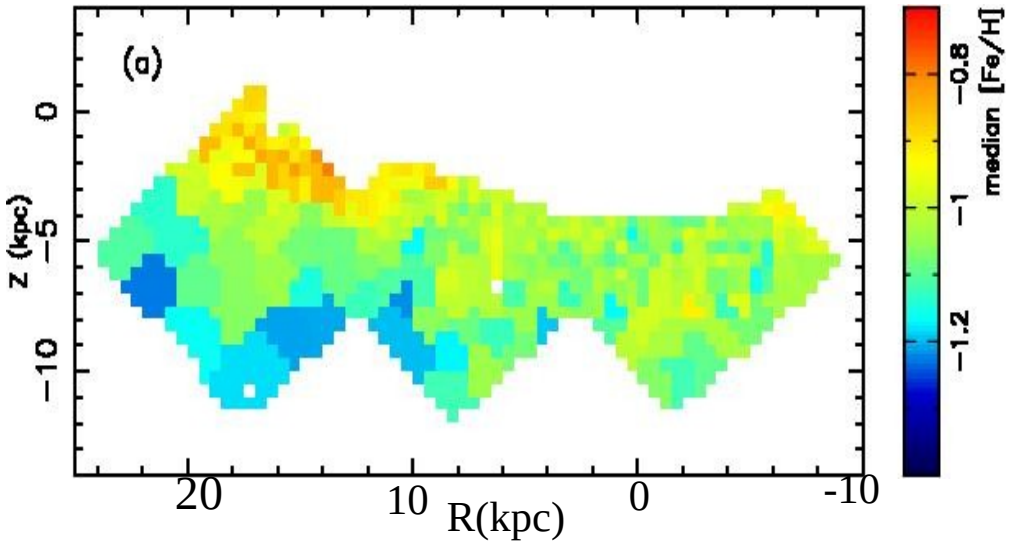
The f rst systematic inventory of the stellar content of the extremely faint outskirts of spirals beyond the Local Group

Quantifying the substructures

Ibata, Mouhcine, Rejkuba (2009)

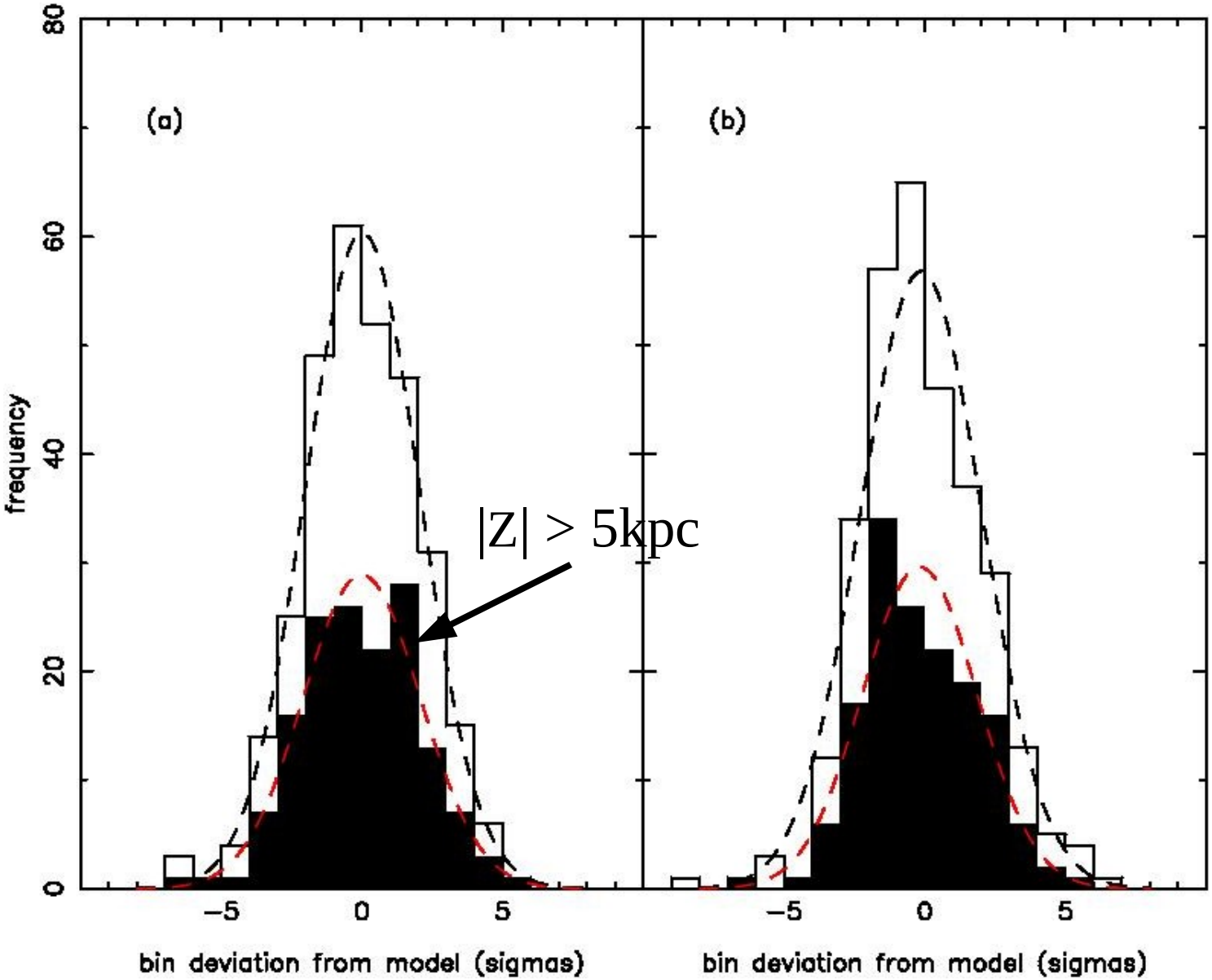


2D polynomial f t



Signif cant variations on the scale of a super-pixel or a few super-pixels

Quantifying the substructures



Highly signif cant local metallicity variation

Quantifying the substructures

$$\sigma/total = \frac{\sqrt{1/n\sum(D_i - M_i)^2 - 1/n\sum(M_i^p - M_i)^2}}{1/n\sum D_i}$$

Bell et al. (2008)

D_i: Observed counts in the pixels

M_i: Model counts in the pixels

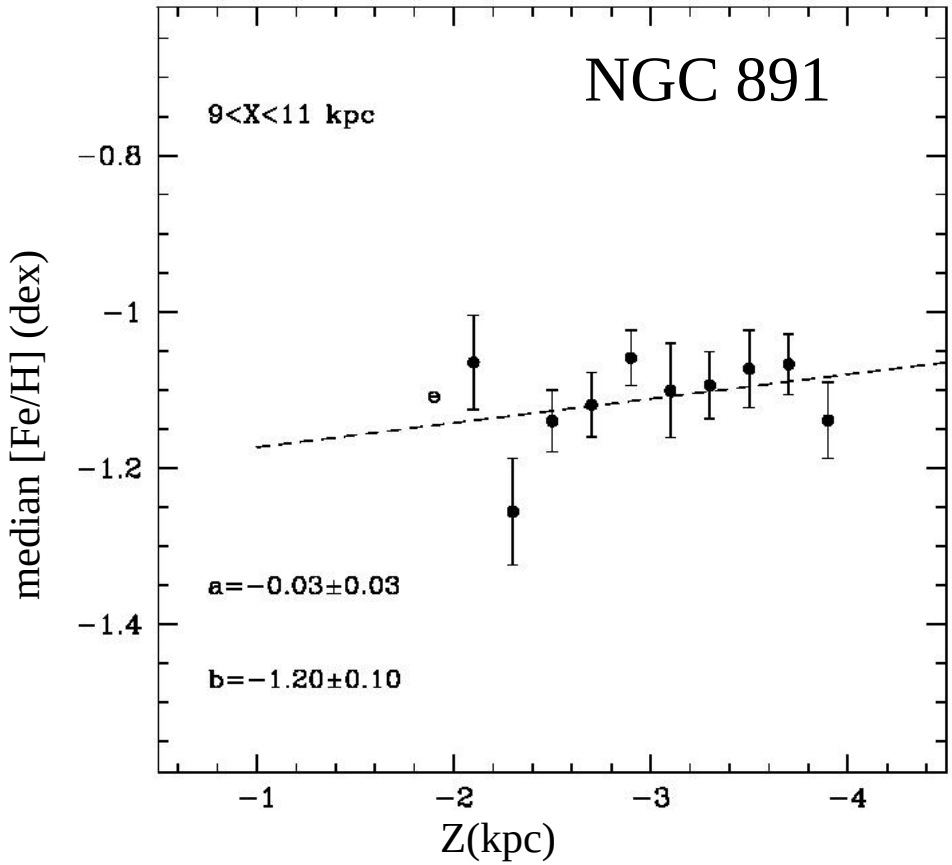
M_i^p: Poisson realisation on the model with mean M_i

$X > 10\text{kpc}, Z < -5\text{kpc}$ $\sigma(NGC891)/total = 0.14; P = 0.8\%$

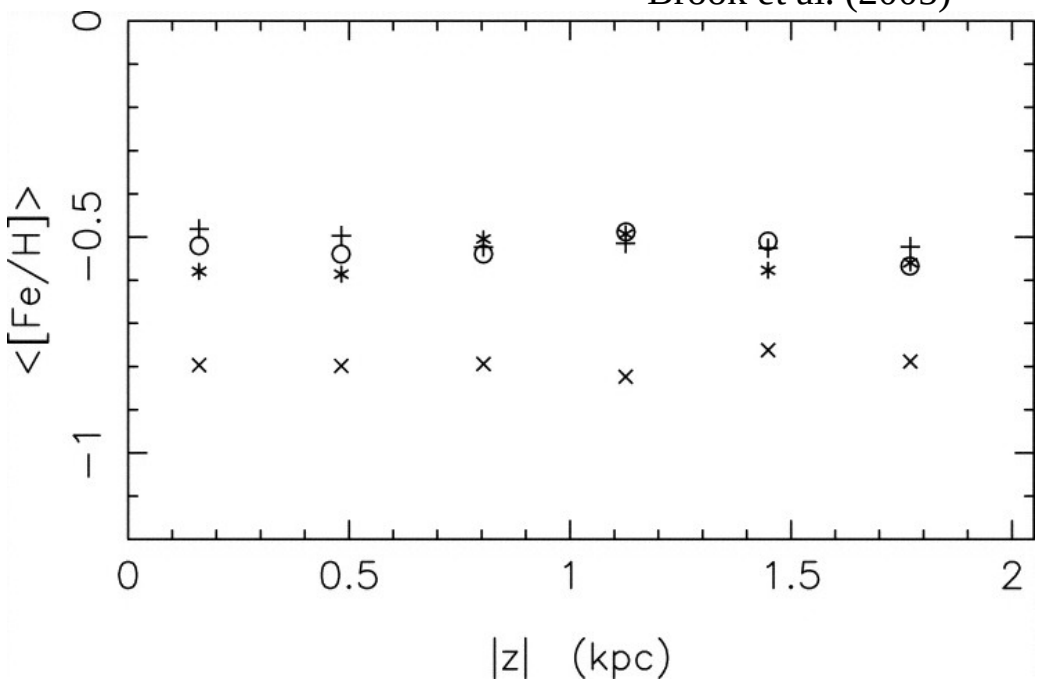
The inner halo of NGC 891 is composed of a large number of incompletely mixed sub-populations

The thick disk

Rejkuba, Mouhcine, Ibata (2009)



Brook et al. (2005)



(i) No metallicity gradient