Stellar kinematics of the Phoenix Dwarf Galaxy

S. Zaggia

INAF - OA Padova

E.V. Held (OAPD)

Y. Momany (ESO/OAPD)

L. Rizzi (JAC - HAWAII)

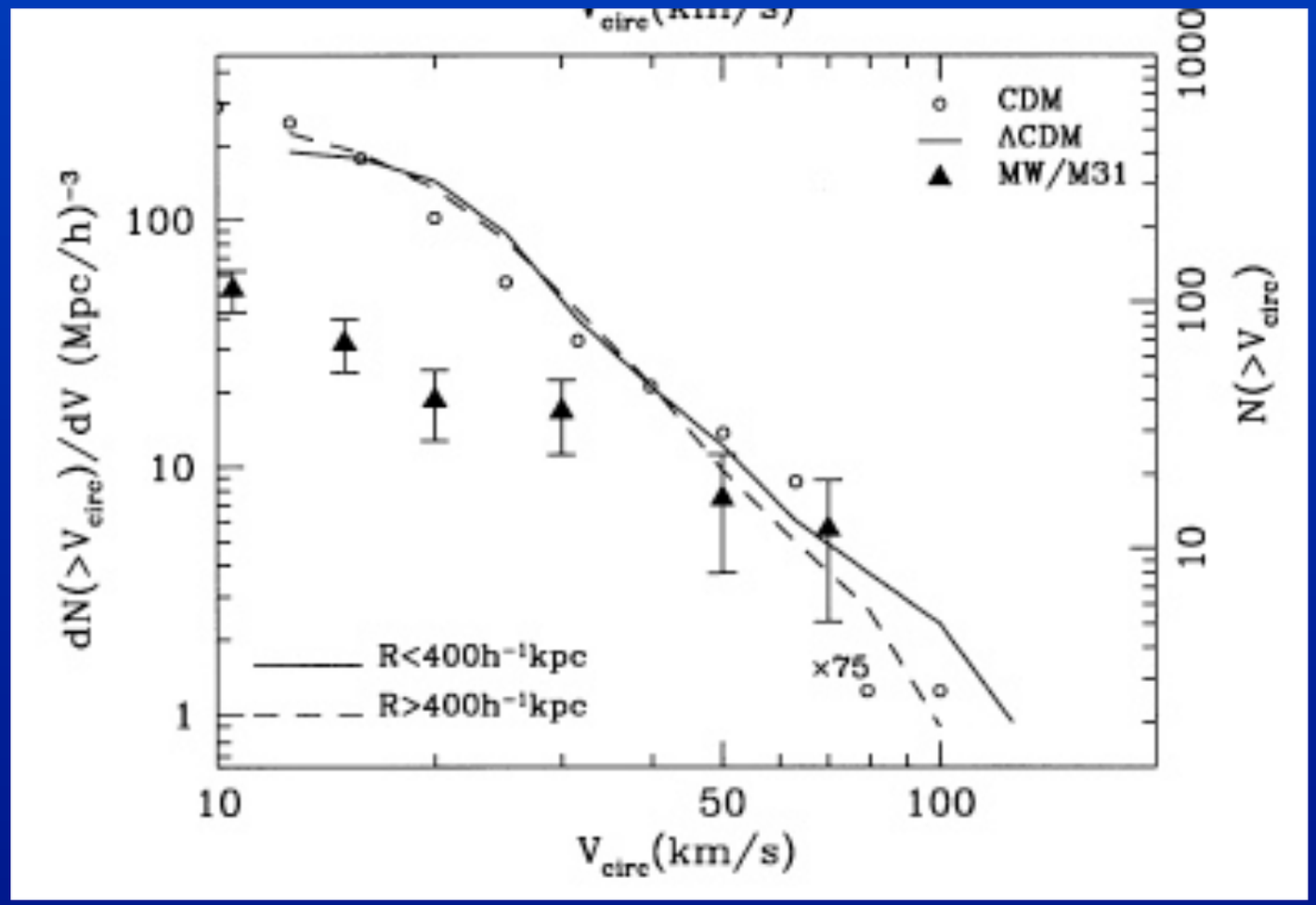
I. Saviane (ESO)

Importance of Dwarf Galaxies

According to the hierarchical clustering scenario, galaxies are assembled from small debris.

Dwarfs are believed to be highly dark matter (DM) dominated, with mass-to-light ratios of ~ 10^{1-3}

Cosmological models predict that our Galaxy should have at least an order of magnitude more dark matter haloes than actually found in dwarf galaxies form.



From Klypin et al 1999

Why is Phoenix interesting?

Why is Phoenix interesting?

The Phoenix galaxy is an excellent candidate for studying the internal kinematics in isolated low-luminosity dwarfs.

Why is Phoenix interesting?

The Phoenix galaxy is an excellent candidate for studying the internal kinematics in isolated low-luminosity dwarfs.

- It is a star-forming (transition) dwarf spheroidal whose stellar populations have been recently studied (Hidalgo+ 2009; Saviane+ 2009).

Why is Phoenix interesting?

The Phoenix galaxy is an excellent candidate for studying the internal kinematics in isolated low-luminosity dwarfs.

- It is a star-forming (transition) dwarf spheroidal whose stellar populations have been recently studied (Hidalgo+ 2009; Saviane+ 2009).
- It is located at about ≈415 Kpc from the Sun, well beyond the outskirts of the Milky Way halo, in an isolated environment of the Local Group.

Why is Phoenix interesting?

The Phoenix galaxy is an excellent candidate for studying the internal kinematics in isolated low-luminosity dwarfs.

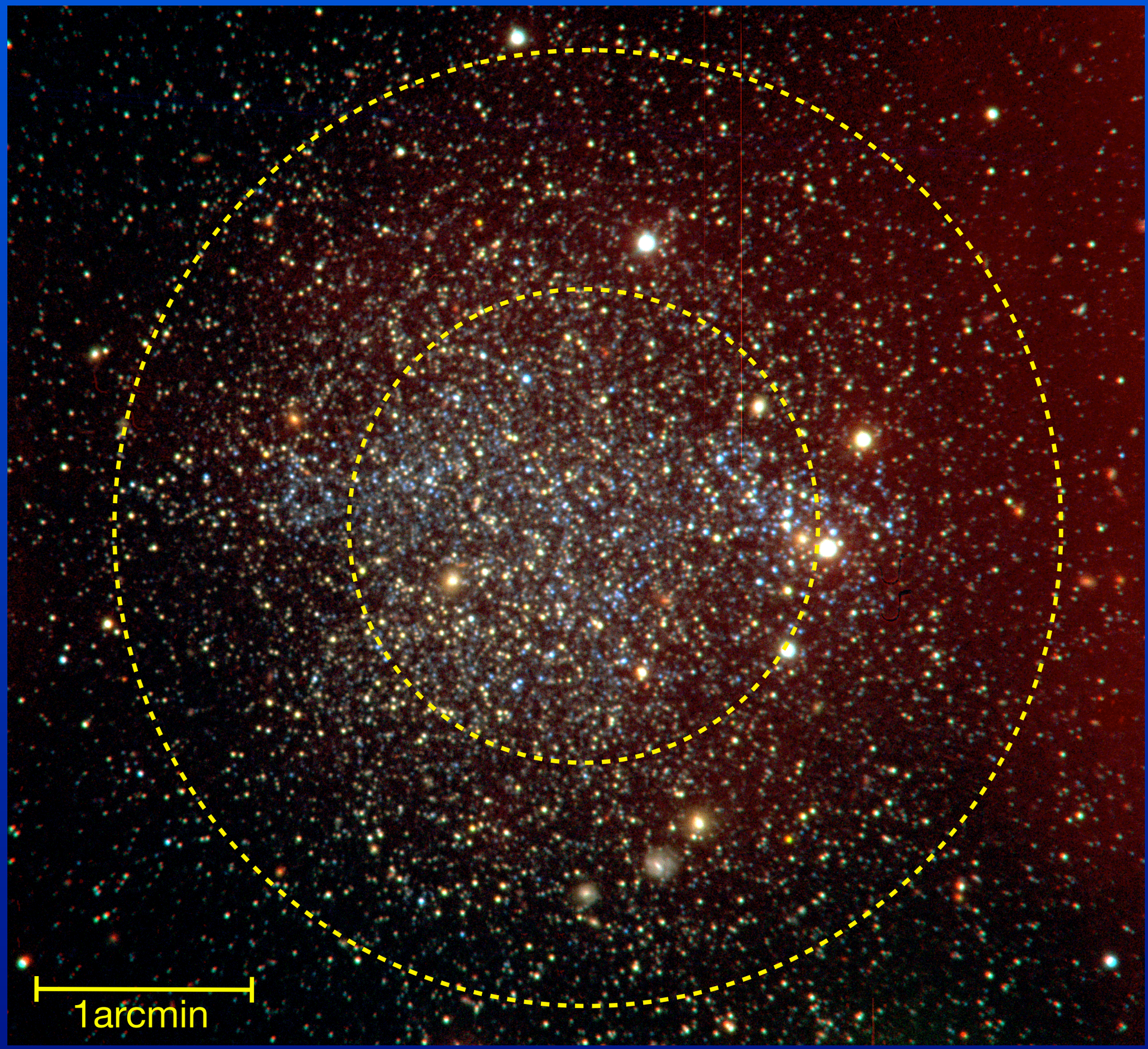
- It is a star-forming (transition) dwarf spheroidal whose stellar populations have been recently studied (Hidalgo+ 2009; Saviane+ 2009).
- It is located at about ≈415 Kpc from the Sun, well beyond the outskirts of the Milky Way halo, in an isolated environment of the Local Group.
- Tidal interaction with either the Milky Way or M31 can be safely ruled out.

Why is Phoenix interesting?

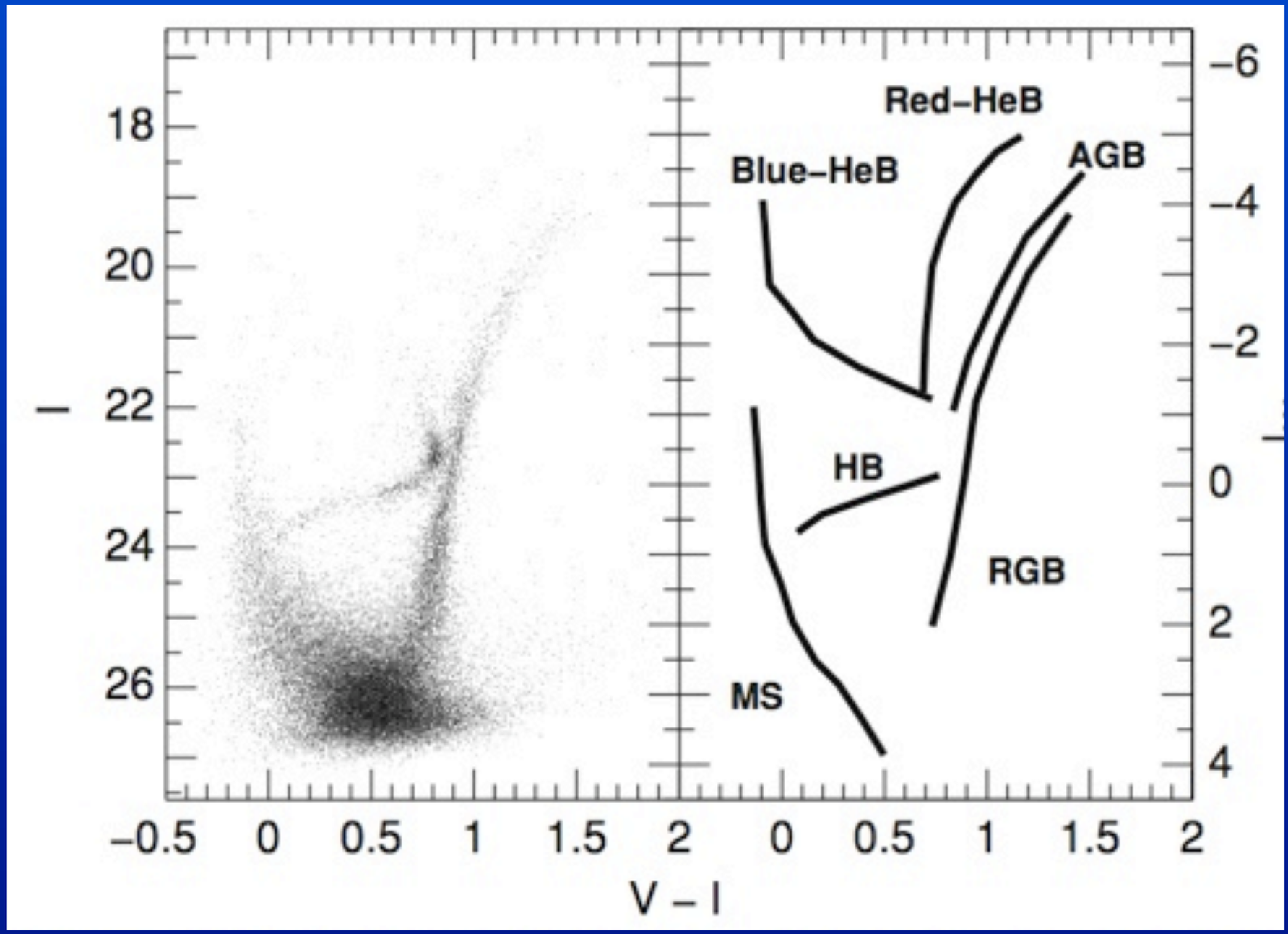
The Phoenix galaxy is an excellent candidate for studying the internal kinematics in isolated low-luminosity dwarfs.

- It is a star-forming (transition) dwarf spheroidal whose stellar populations have been recently studied (Hidalgo+ 2009; Saviane+ 2009).
- It is located at about ≈415 Kpc from the Sun, well beyond the outskirts of the Milky Way halo, in an isolated environment of the Local Group.
- Tidal interaction with either the Milky Way or M31 can be safely ruled out.

Therefore, its internal velocity dispersion cannot be inflated by interaction mechanisms such as tidal heating. The measured dispersion directly leads to measuring its central mass-to-light ratio. A high vs. low mass-to-light ratio would directly point to the presence of a large amount of dark matter, or lack thereof.

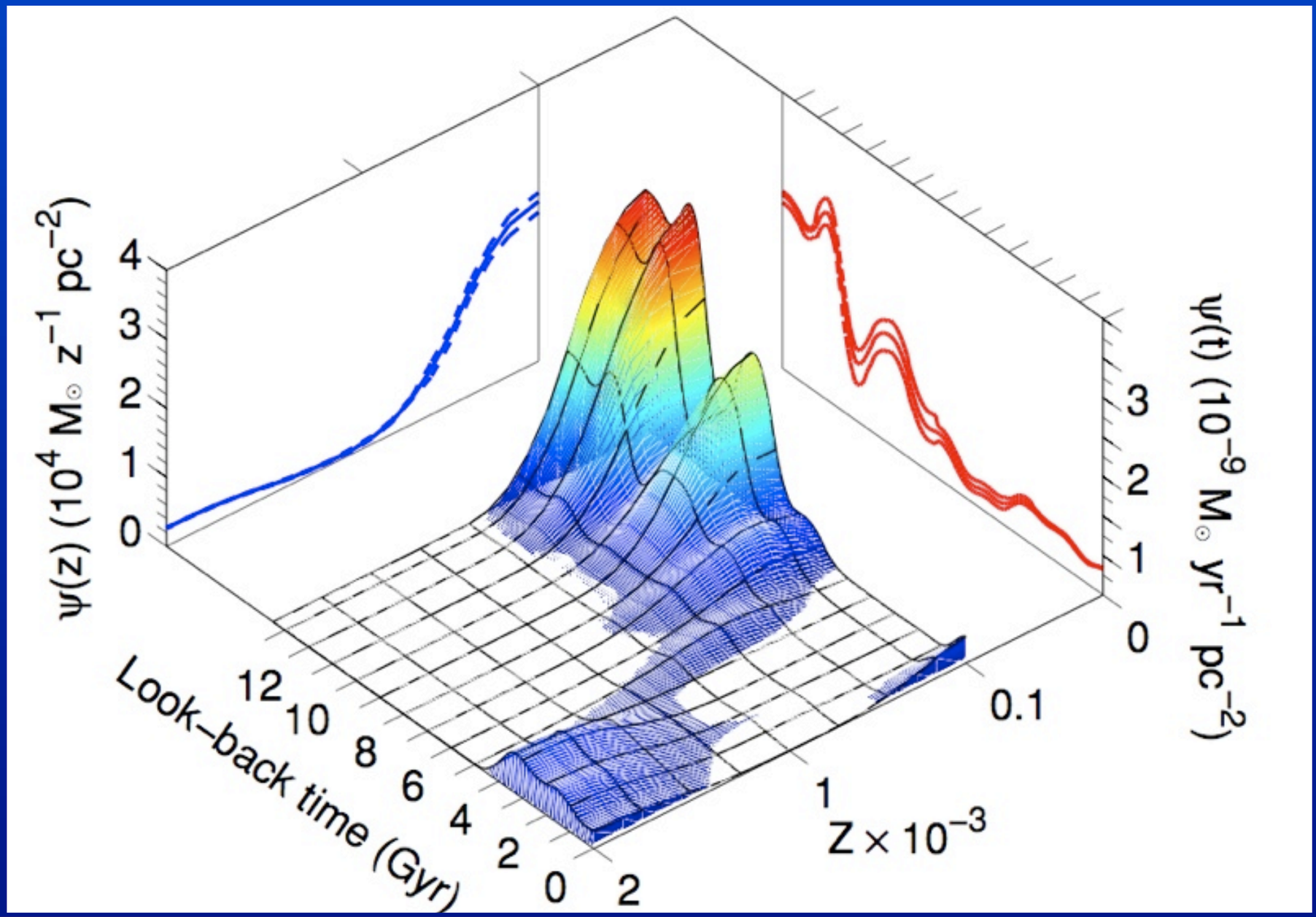

1arcmin

Hidalgo et al 2009

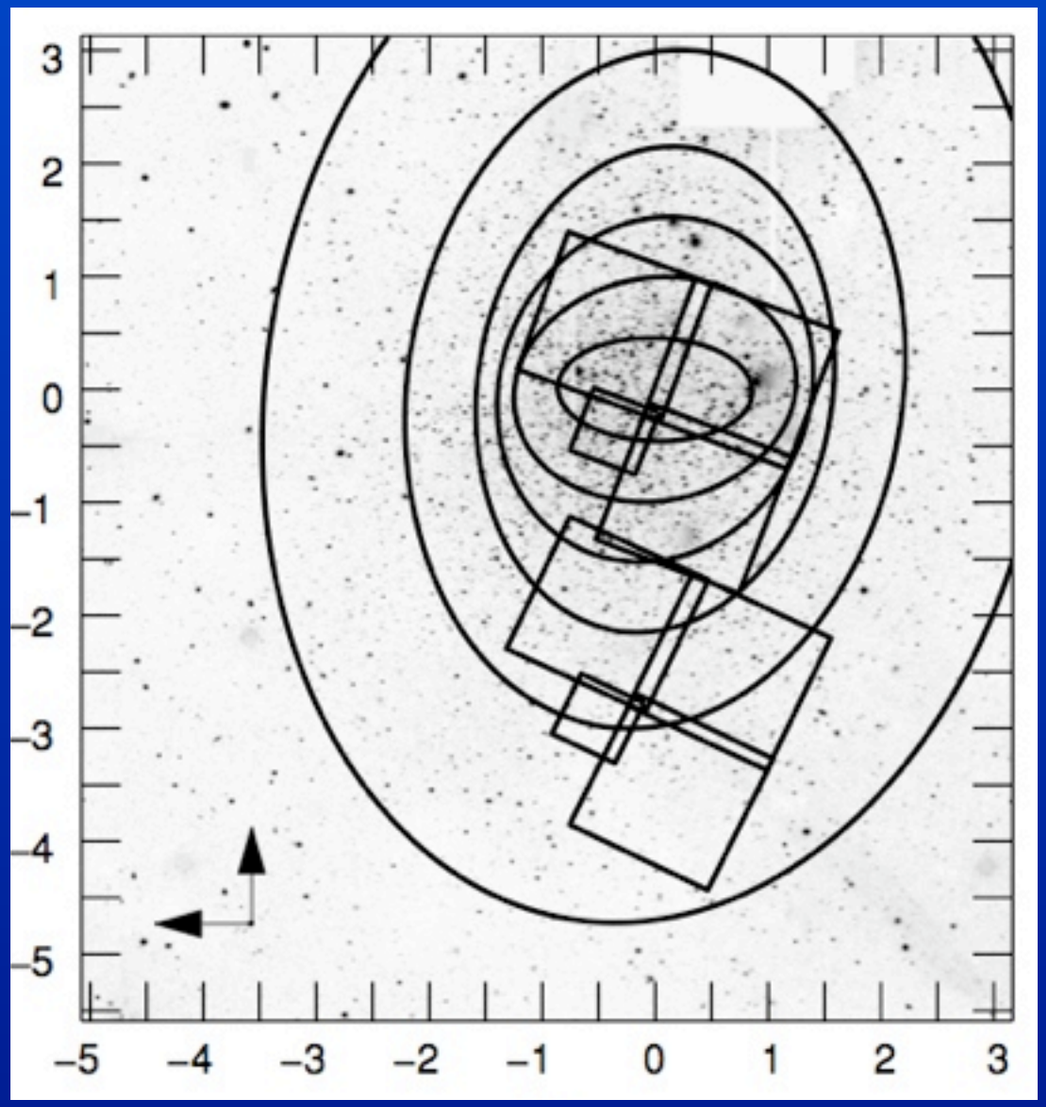


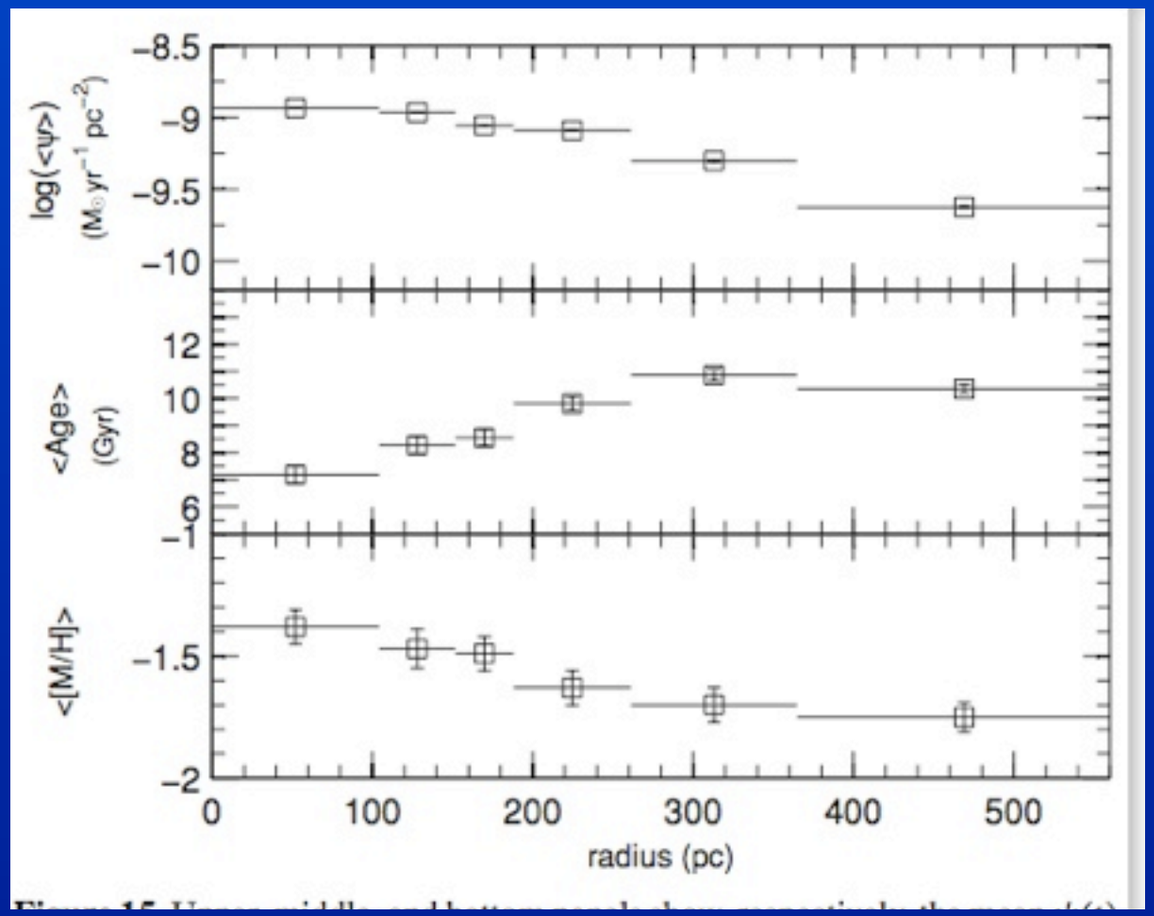
Hidalgo et al 2009

- 50% of all star formation before 10.5 Gyr ago.
- 35% more up to 6 Gyr ago



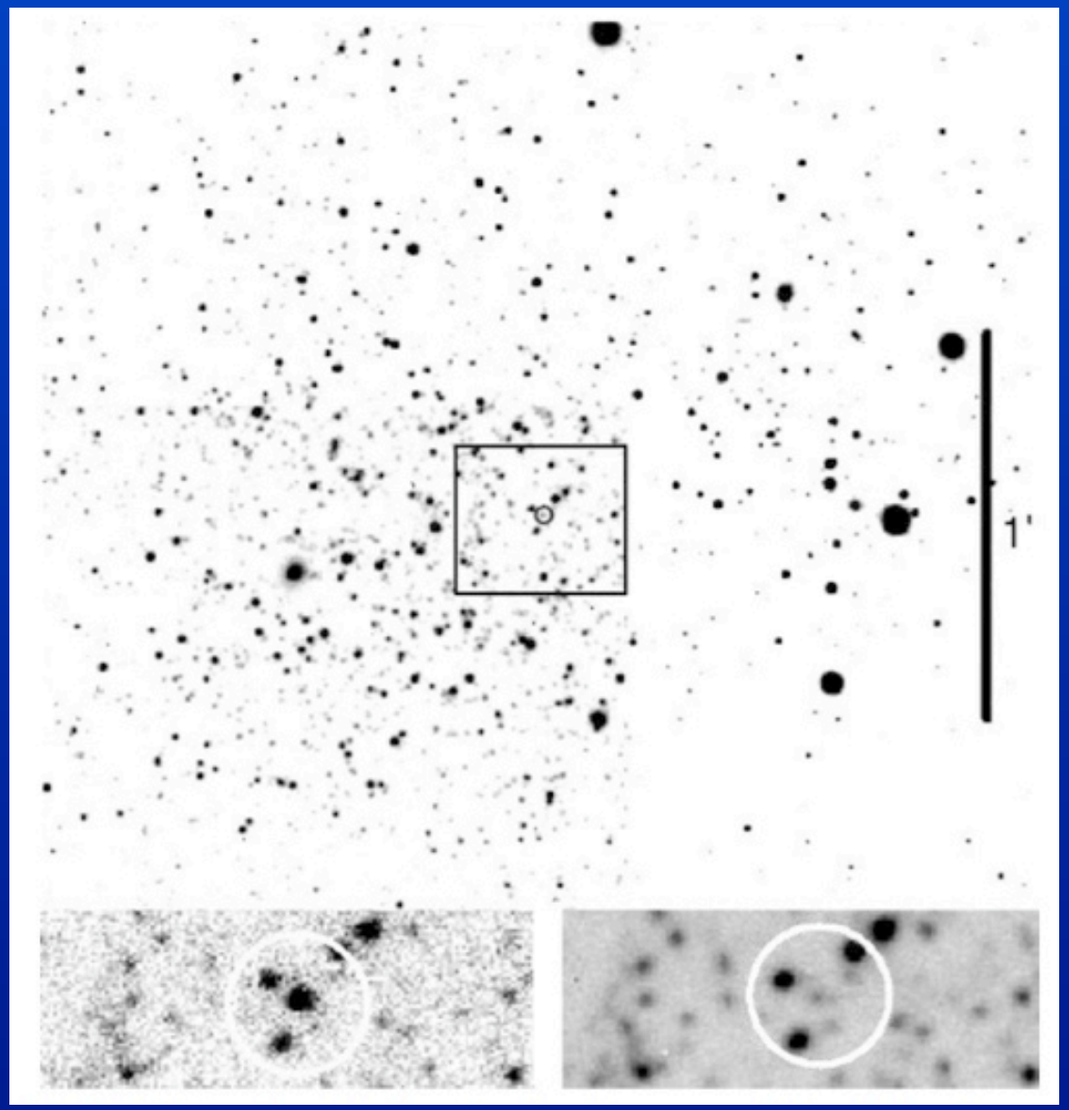
Hidalgo et al 2009

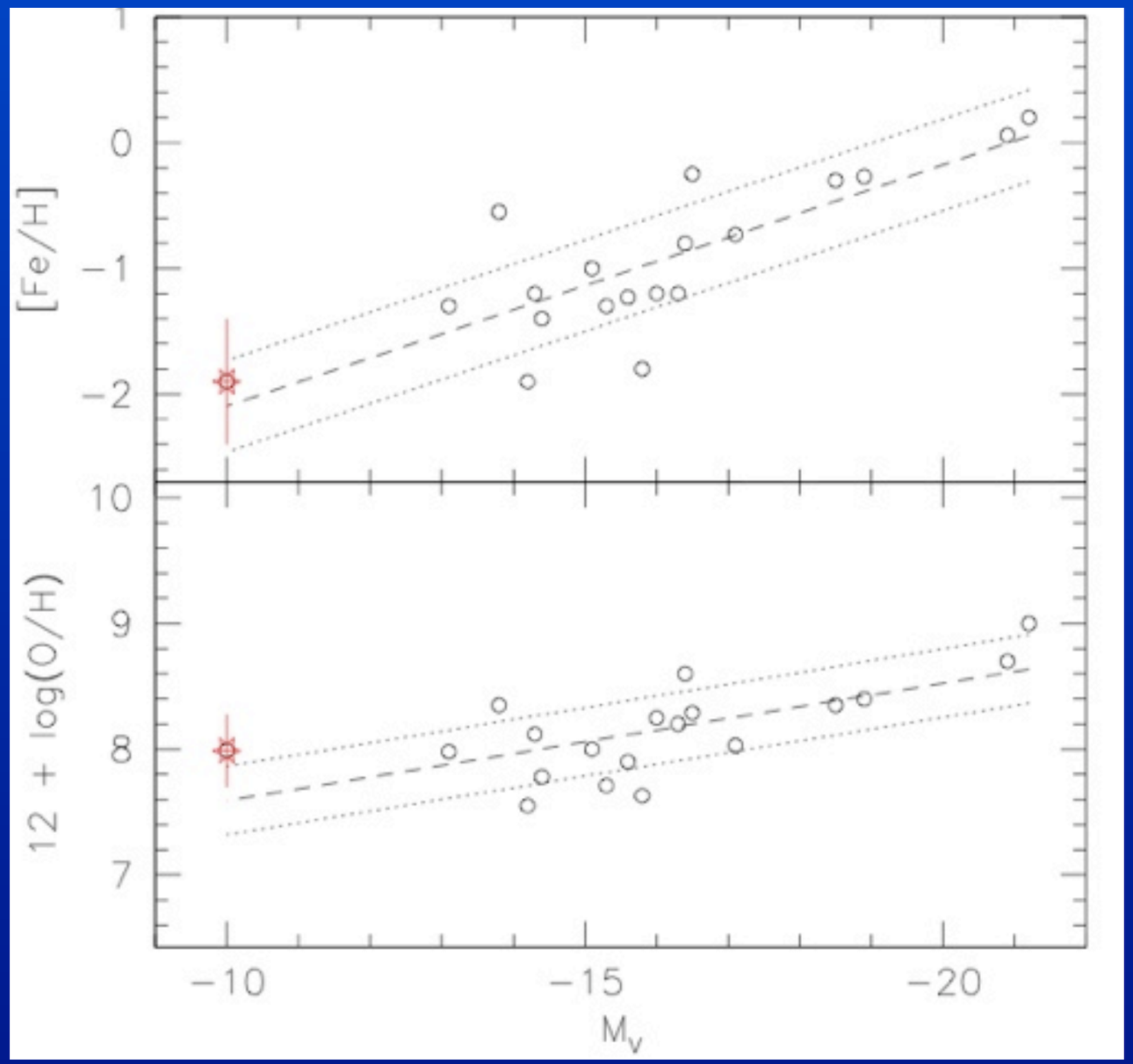




Saviane et al 2009 (Bennu)

- First PNe in Phoenix allowing a direct measure of metallicity





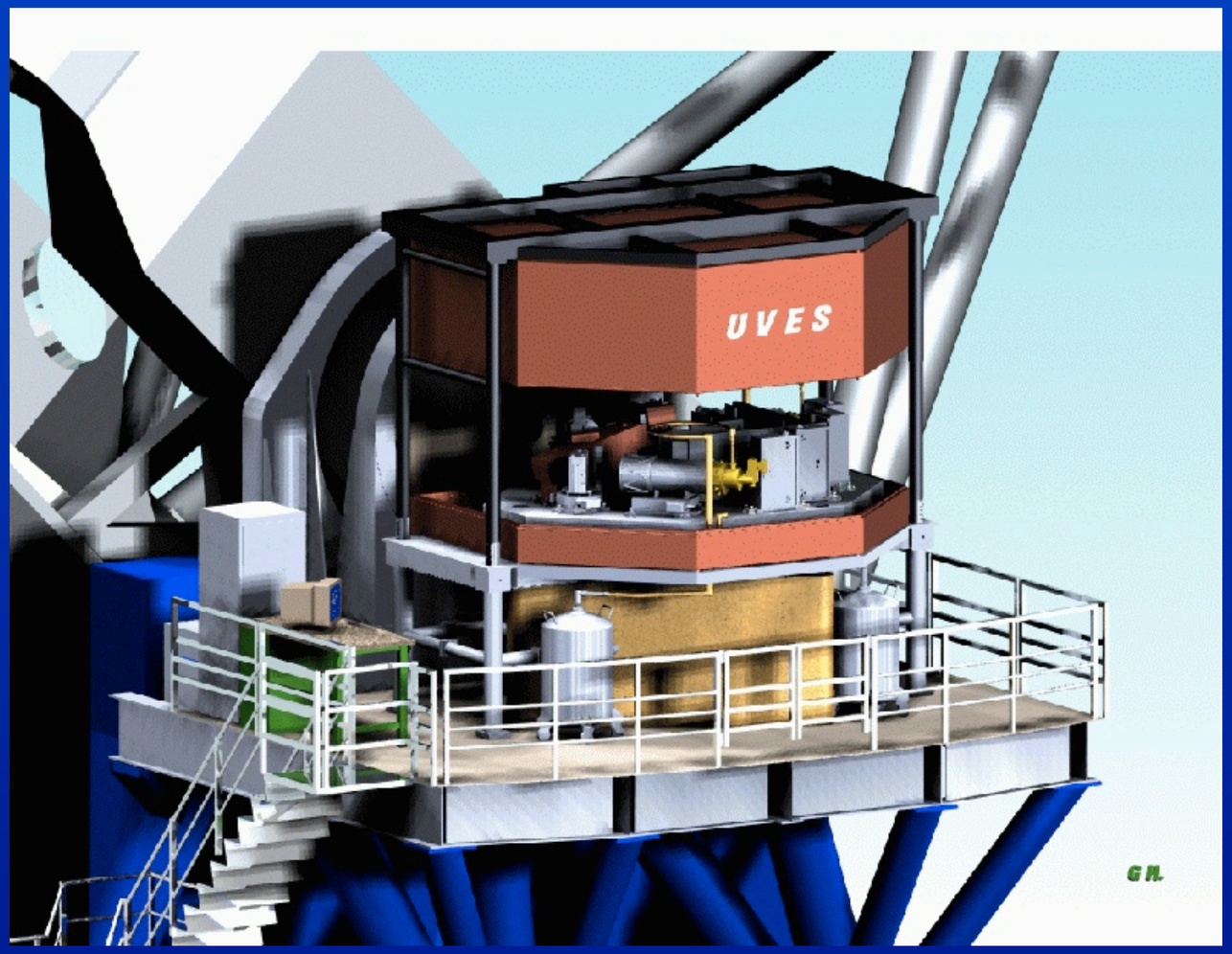
UVES @ VLT

The set of UVES data comes from 2 nights run performed in 2001.

17 stars observed (few multiple spectra)

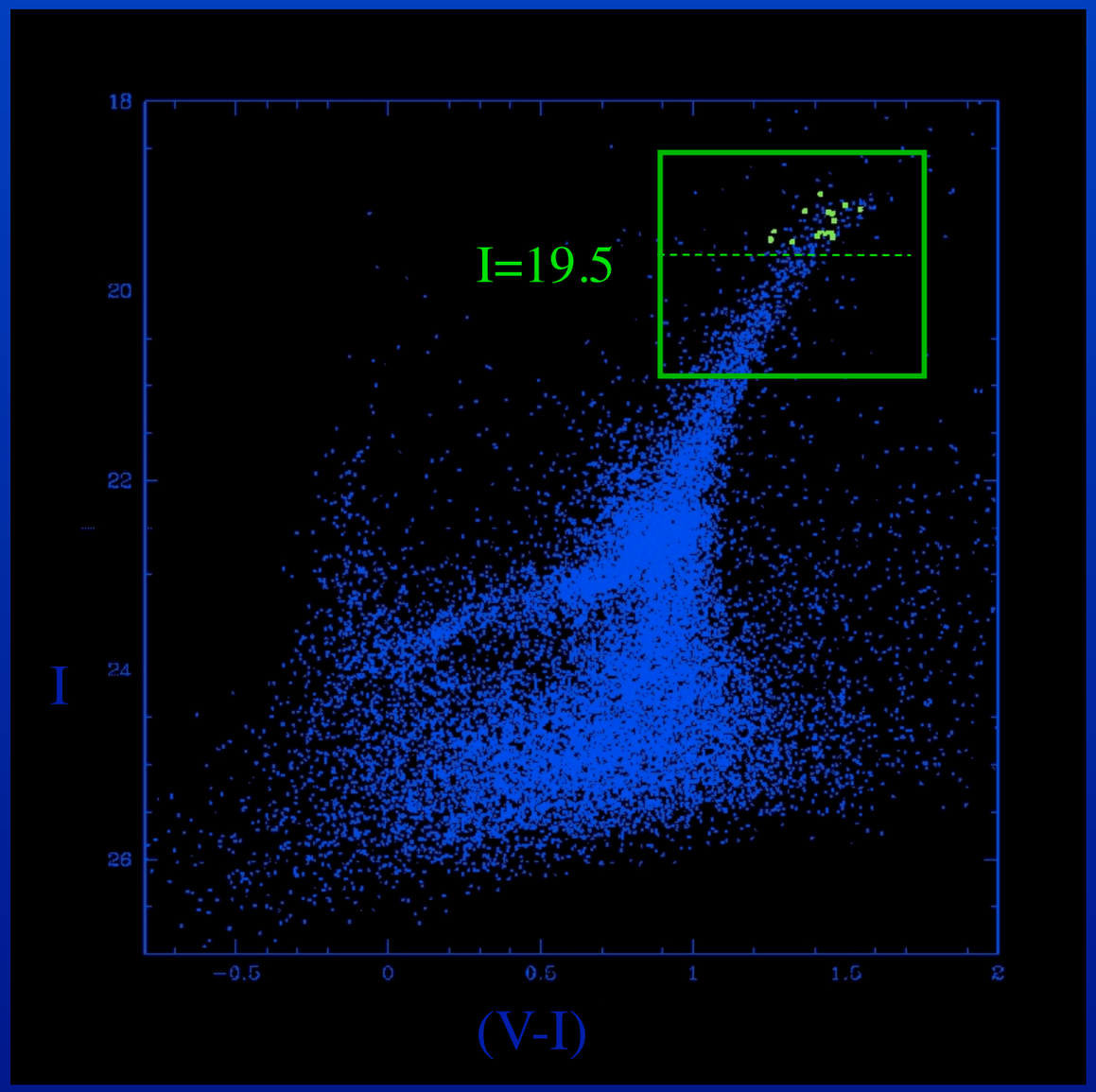
UVES set-up of the observations:

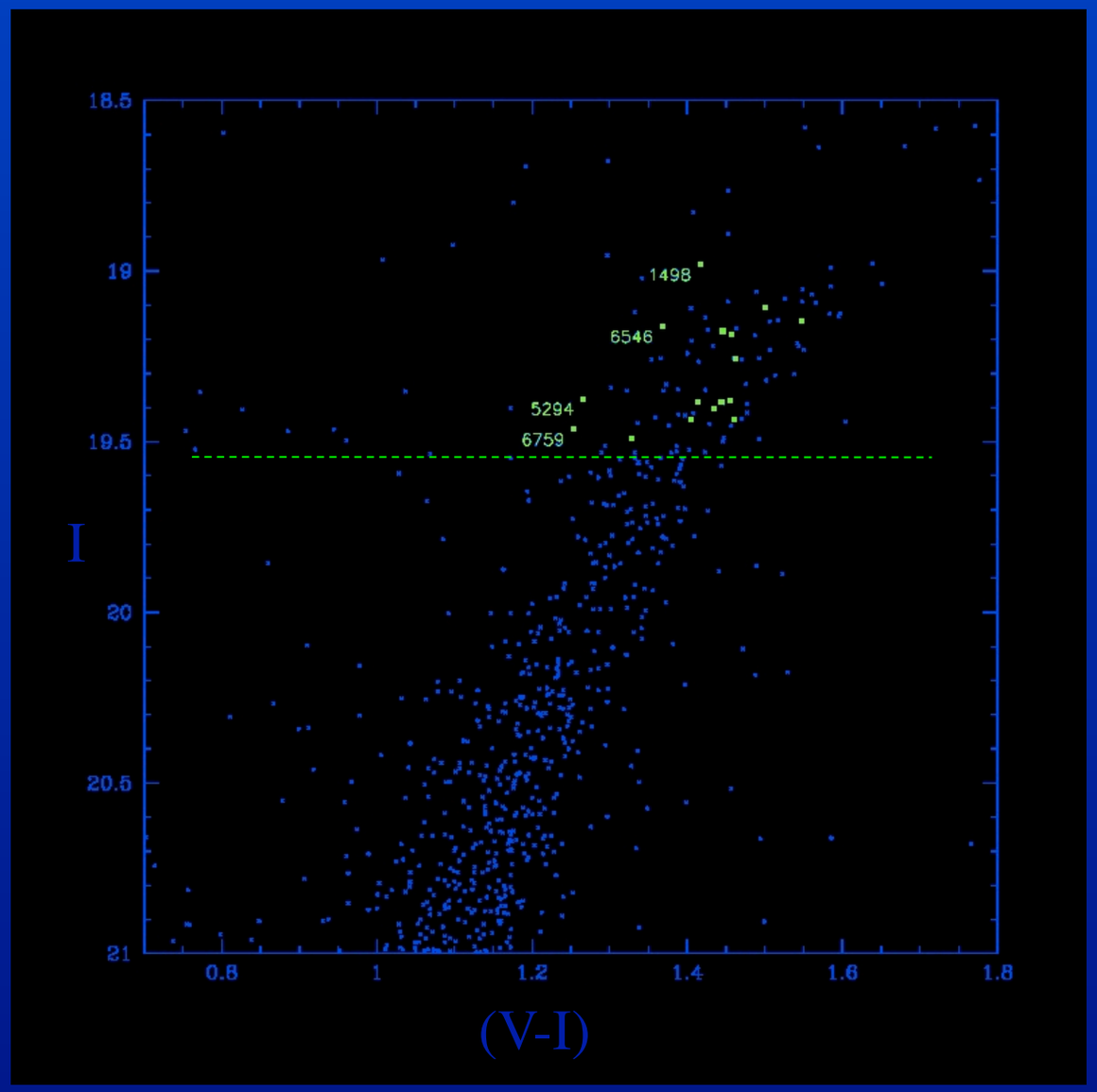
- UVES Red-Arm
- λ center 5800Å
- λ range 4500÷6600Å
- Slit width 1.2 arcsec
- Resolving power 40000
- Exposure time 1800÷5100s
- Observed S/N 10÷30

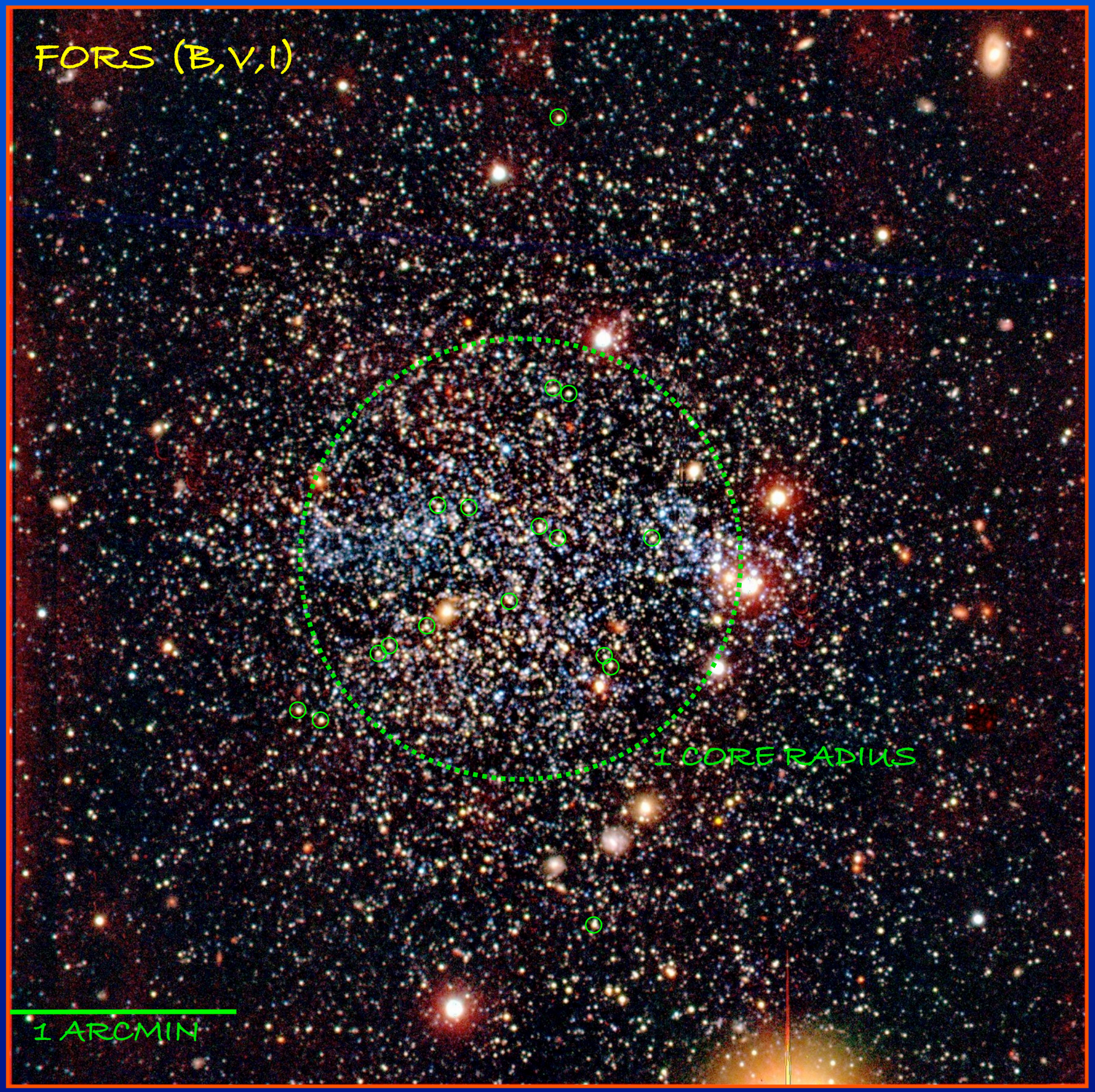


UVES target stars

A total of 17 objects were observed after a careful selection along the RGB sequence in the center (r<150”) of the galaxy. The magnitude limit was set to I=19.5, about V≈21.0.






FORS (B,V,I)
1 CORE RADIUS
1 ARCMIN

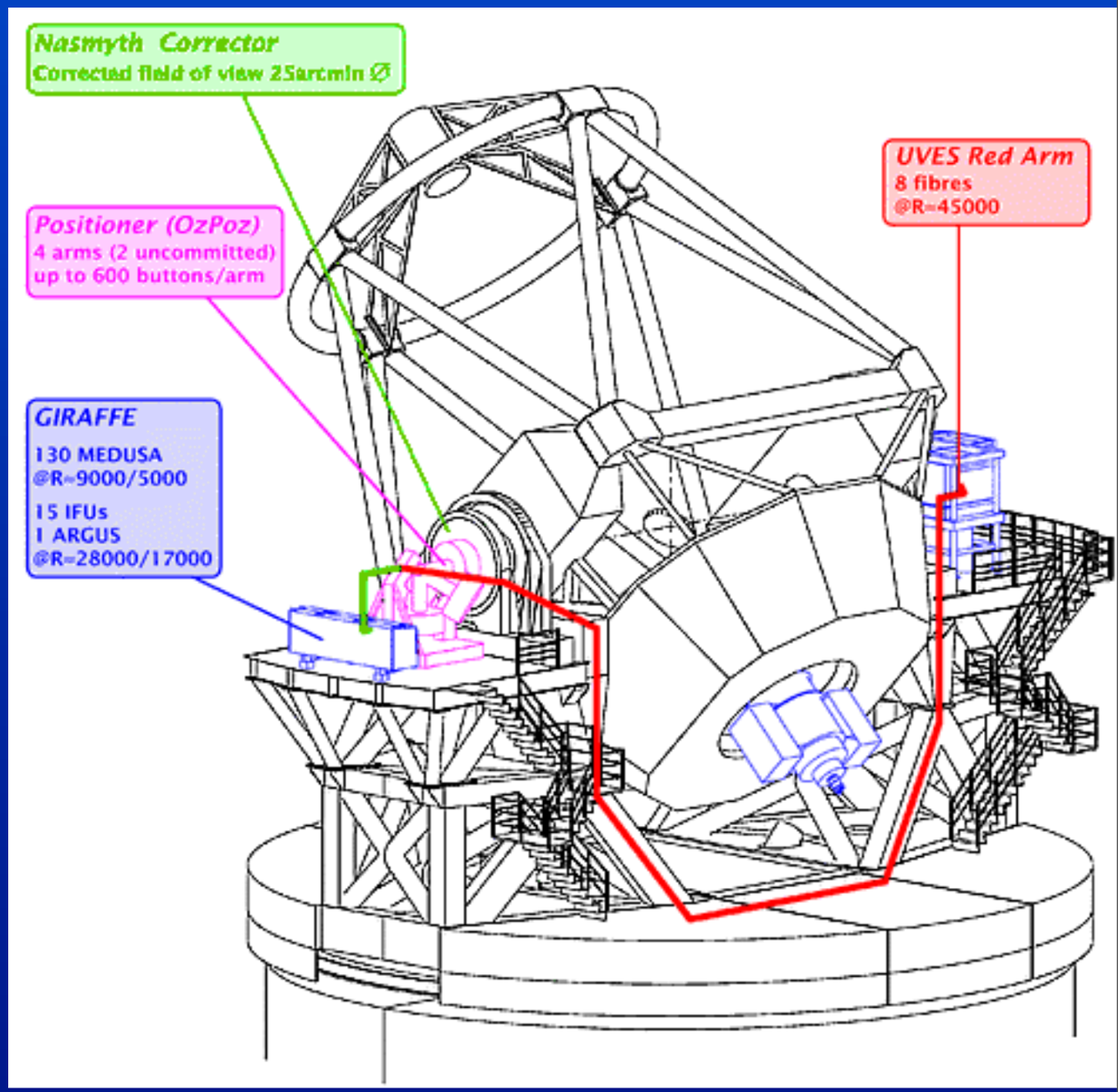
FLAMES @VLT

The set of FLAMES data comes from a run performed in 2004.

85 stars were observed

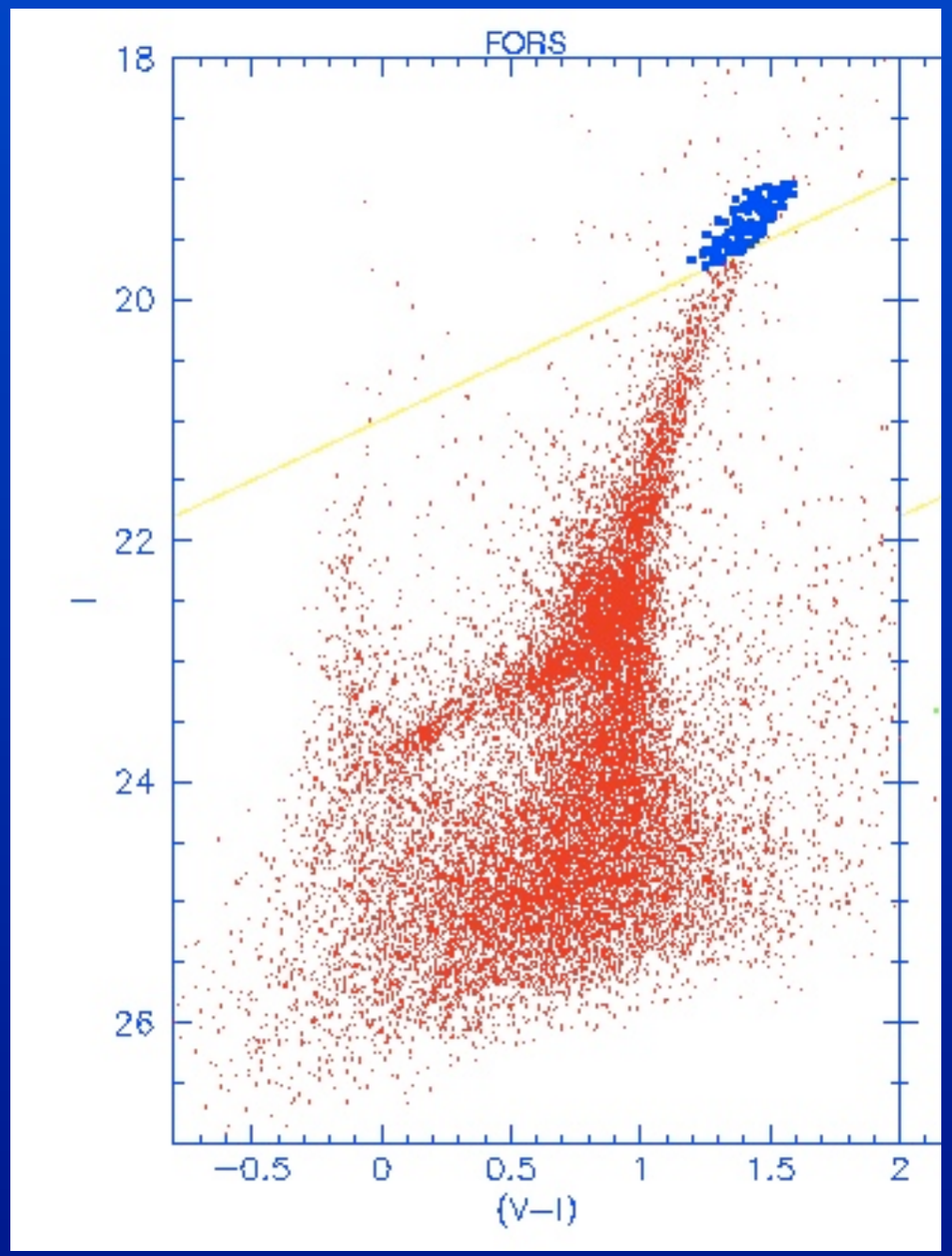
GIRAFFE set-up of the observations:

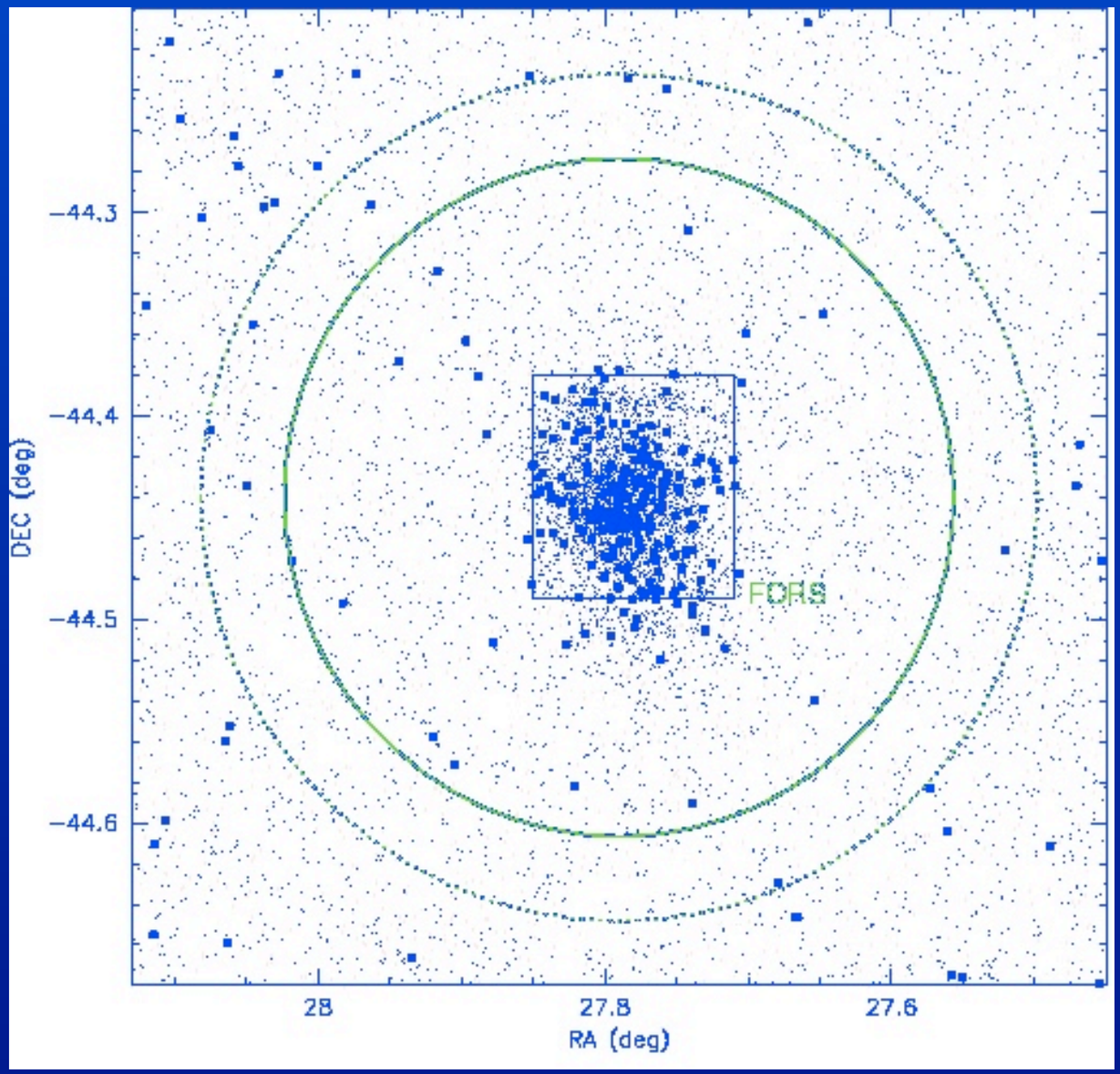
- HR14 (H-alpha) set up
- λ center 6500Å
- λ range 6400÷6600Å
- Fiber diameter 1.2 arcsec
- Resolving power 10000
- Exposure time 4x2800s
- Observed S/N 5÷20



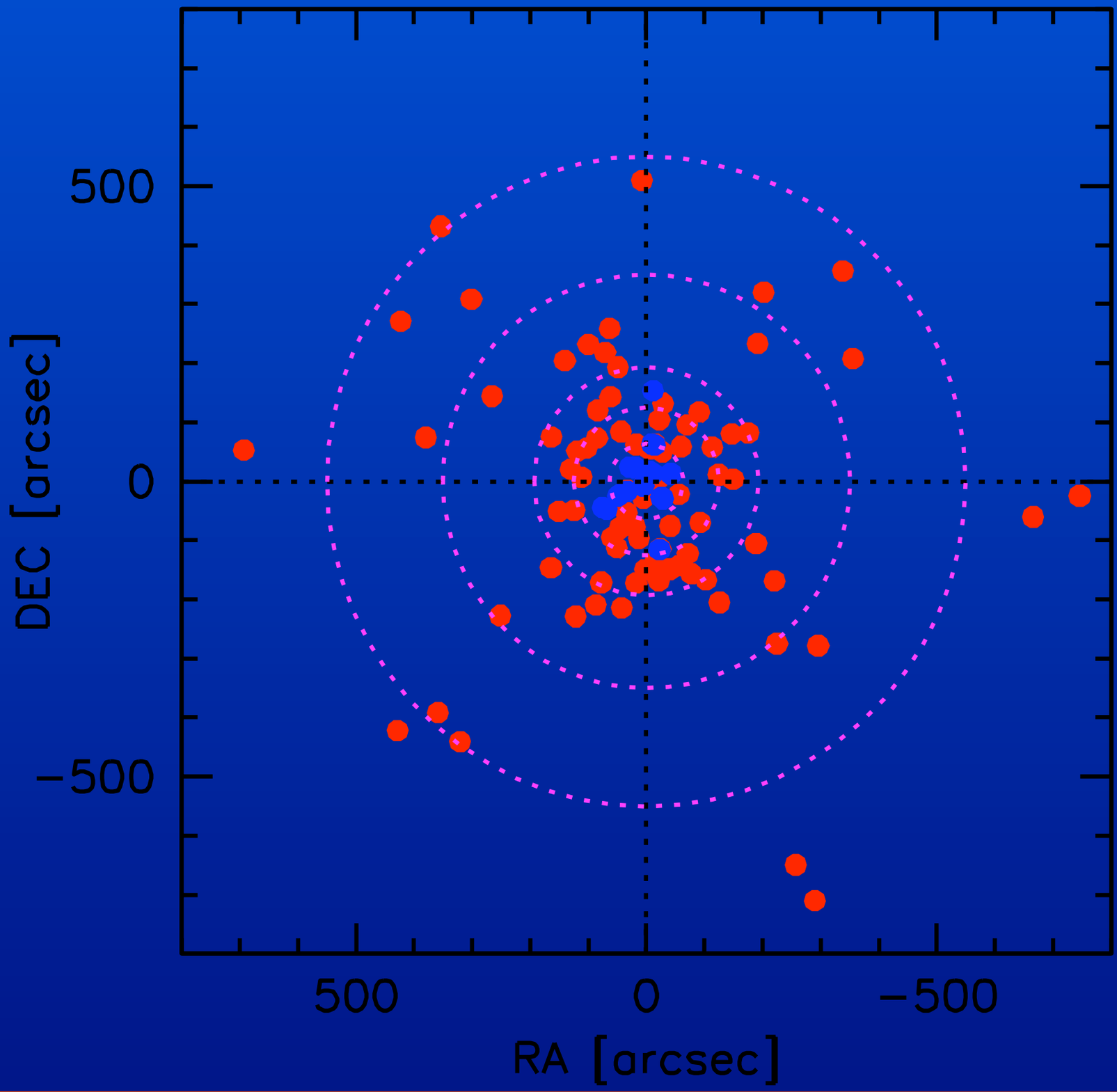
FLAMES target stars

A total of 85 objects were selected extending down to 1 mag along the RGB and out to r~500” of the galaxy. The magnitude limit was set to I=19.8, about V≈21.2. We repeated part of UVES targets testing for variability.

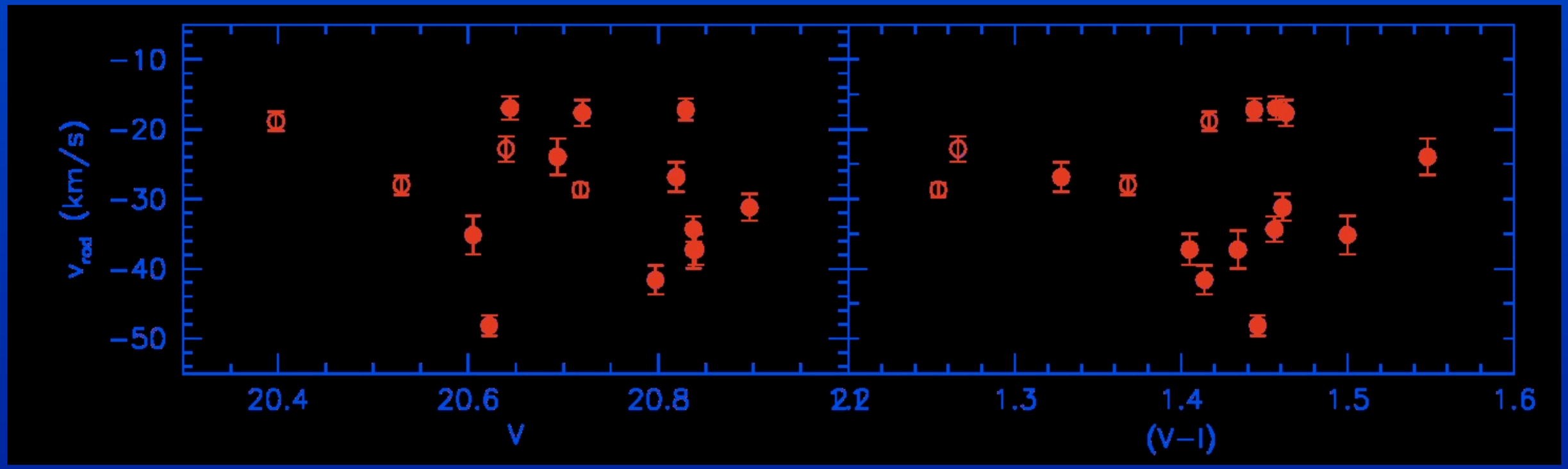




UVES+FLAMES



UVES 17 stars vrad



The systemic velocity of Phoenix

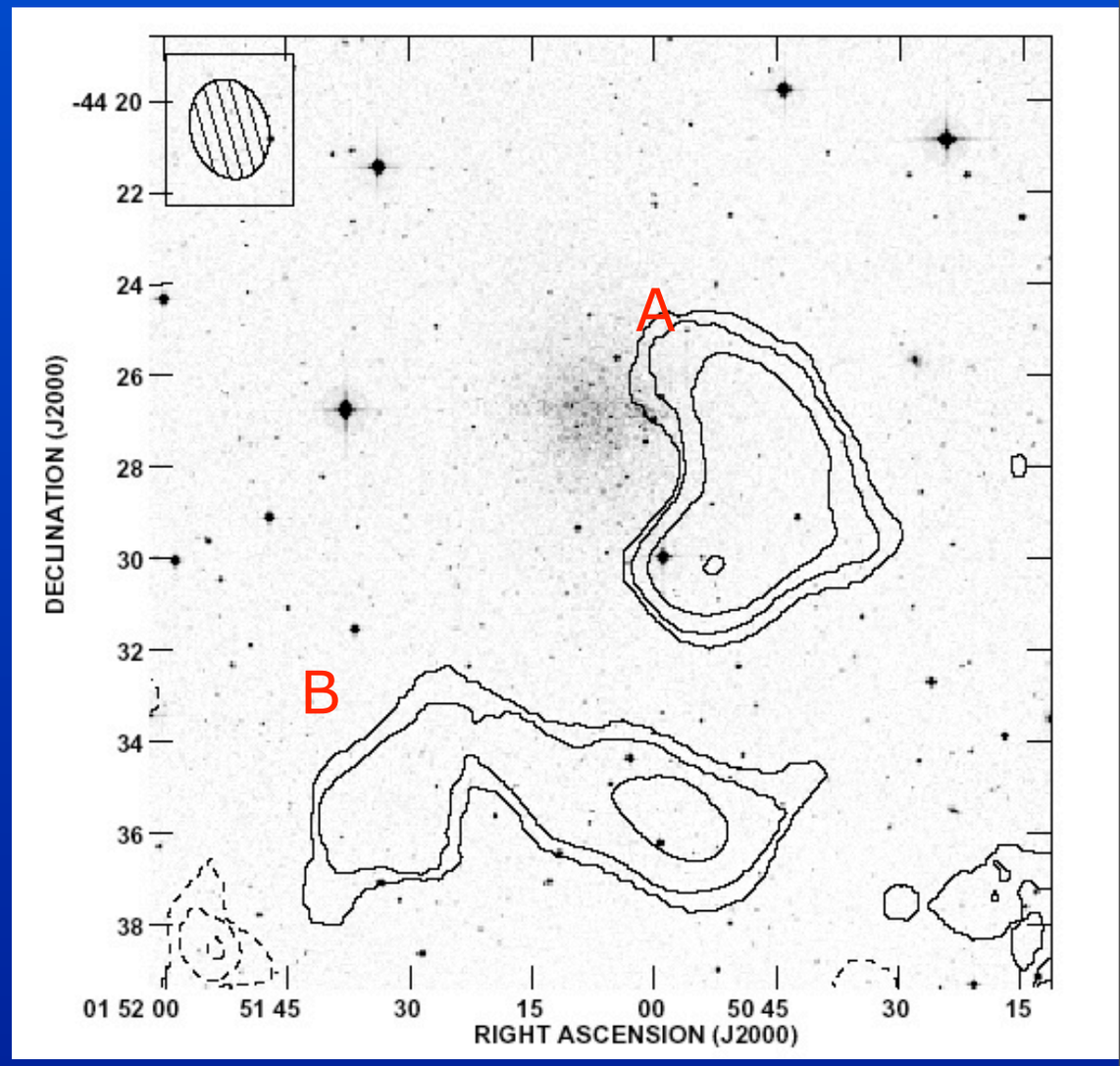
The UVES Phoenix mean radial velocity is:

$<V_r>$= -29.1 ± 2.0 kms^{-1}

This value confirms a physical connection with the HI cloud "A" detected nearby the galaxy by Young and Lo (1997), which mean radial velocity is -23 kms^{-1}.

The value is in good agreement with Irwin and Tolstoy who found a mean radial velocity of -13±9 kms^{-1} from FORS data.

Finally, our precise radial velocity definitely rule out the value of Gallart+ (2001) of -52±6 kms^{-1}.



The systemic velocity of Phoenix

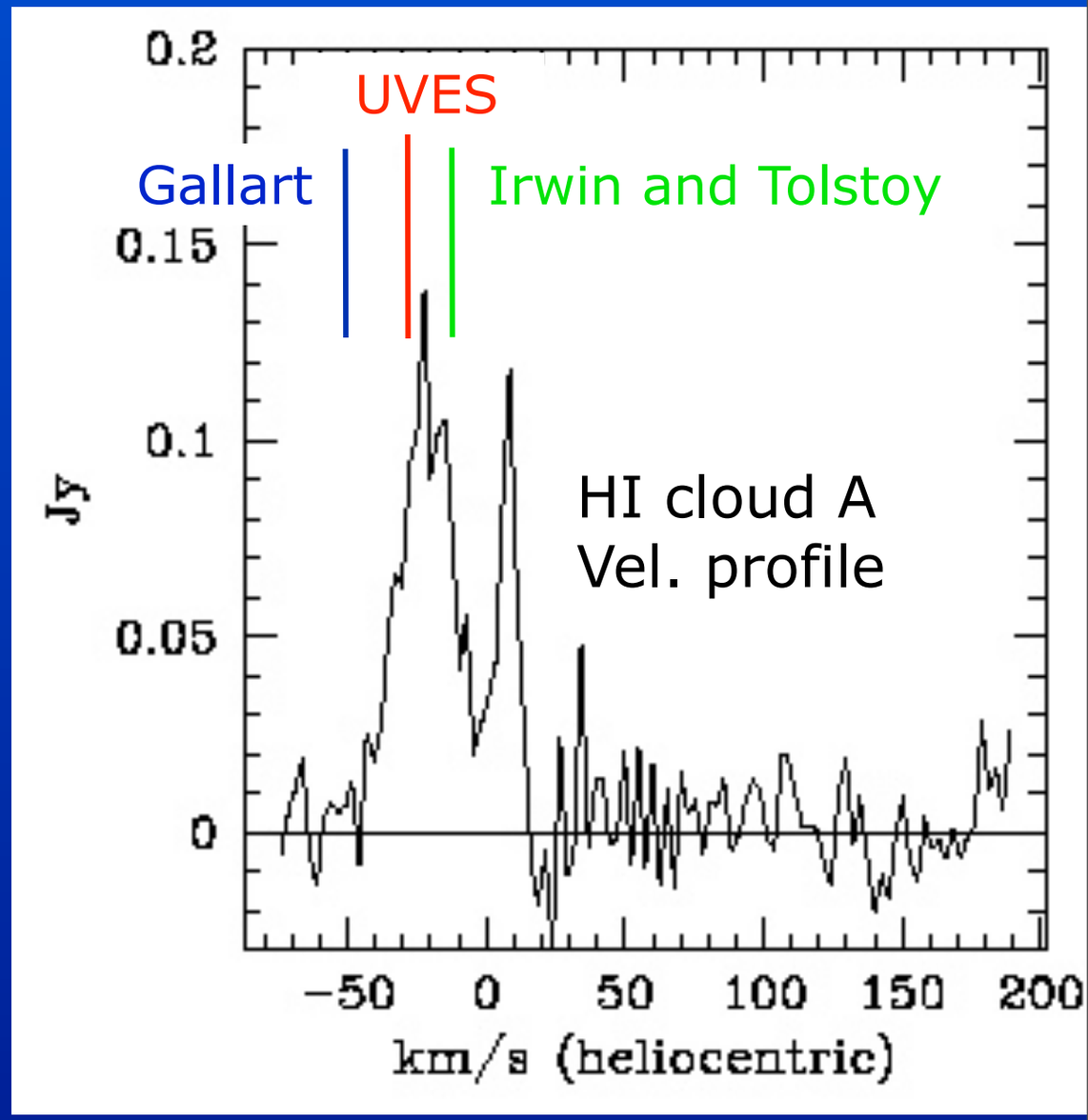
The UVES Phoenix mean radial velocity is:

$<V_r>$= -29.1 ± 2.0 kms^{-1}

This value confirms a physical connection with the HI cloud "A" detected nearby the galaxy by Young and Lo (1997), which mean radial velocity is -23 kms^{-1}.

The value is in good agreement with Irwin and Tolstoy who found a mean radial velocity of -13±9 kms^{-1} from FORS data.

Finally, our precise radial velocity definitely rule out the value of Gallart+ (2001) of -52±6 kms^{-1}.



UVES: Rotation

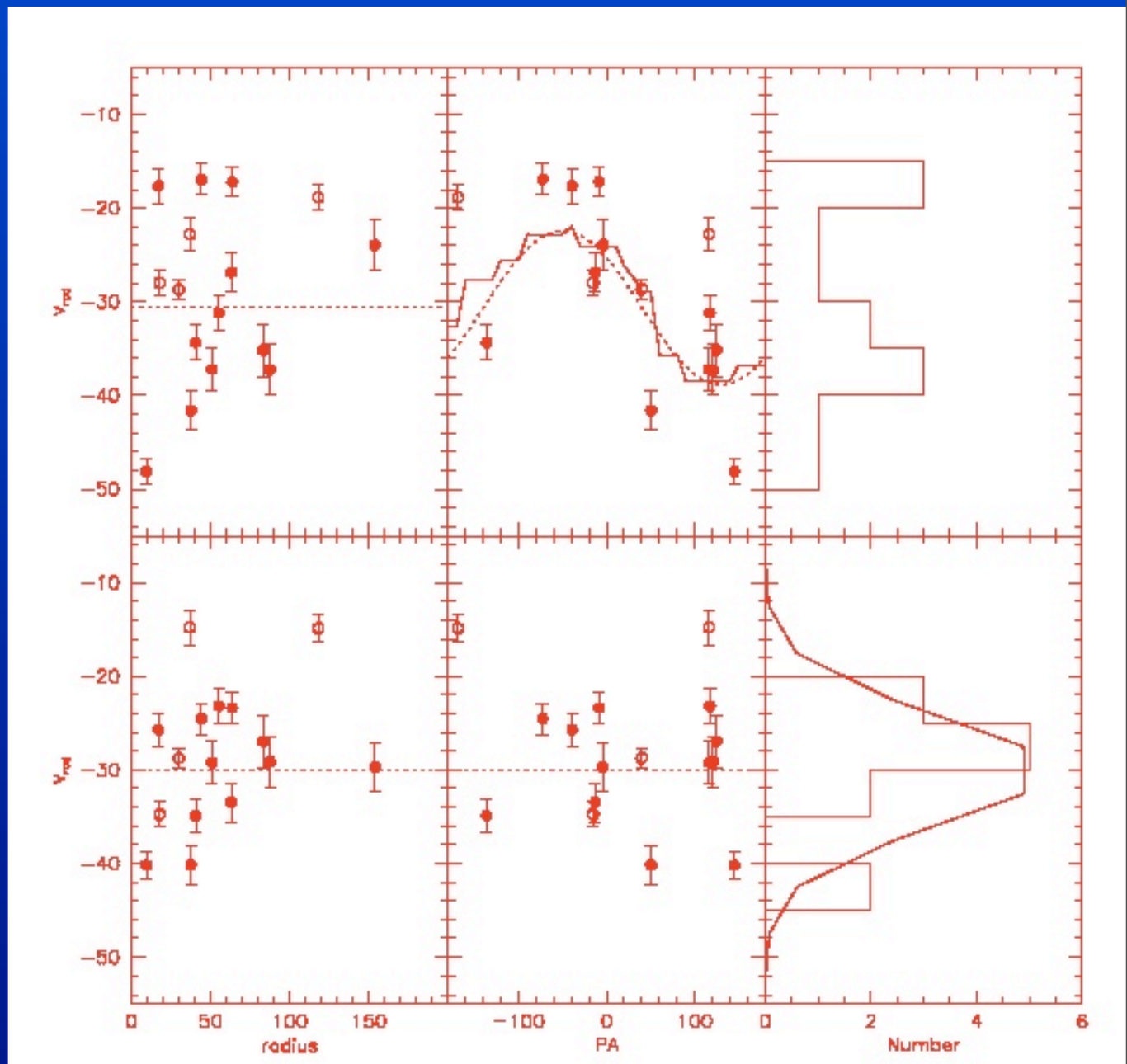
The galaxy shows a clear rotational component. Montecarlo experiments showed a chance of ≤1.7% to obtain such a rotation curve with a similar sample of objects. The Position Angle (PA) is coincident with the major axis of Phoenix (next slides).

Original data.
The solid body rotation fitted to the data gives:

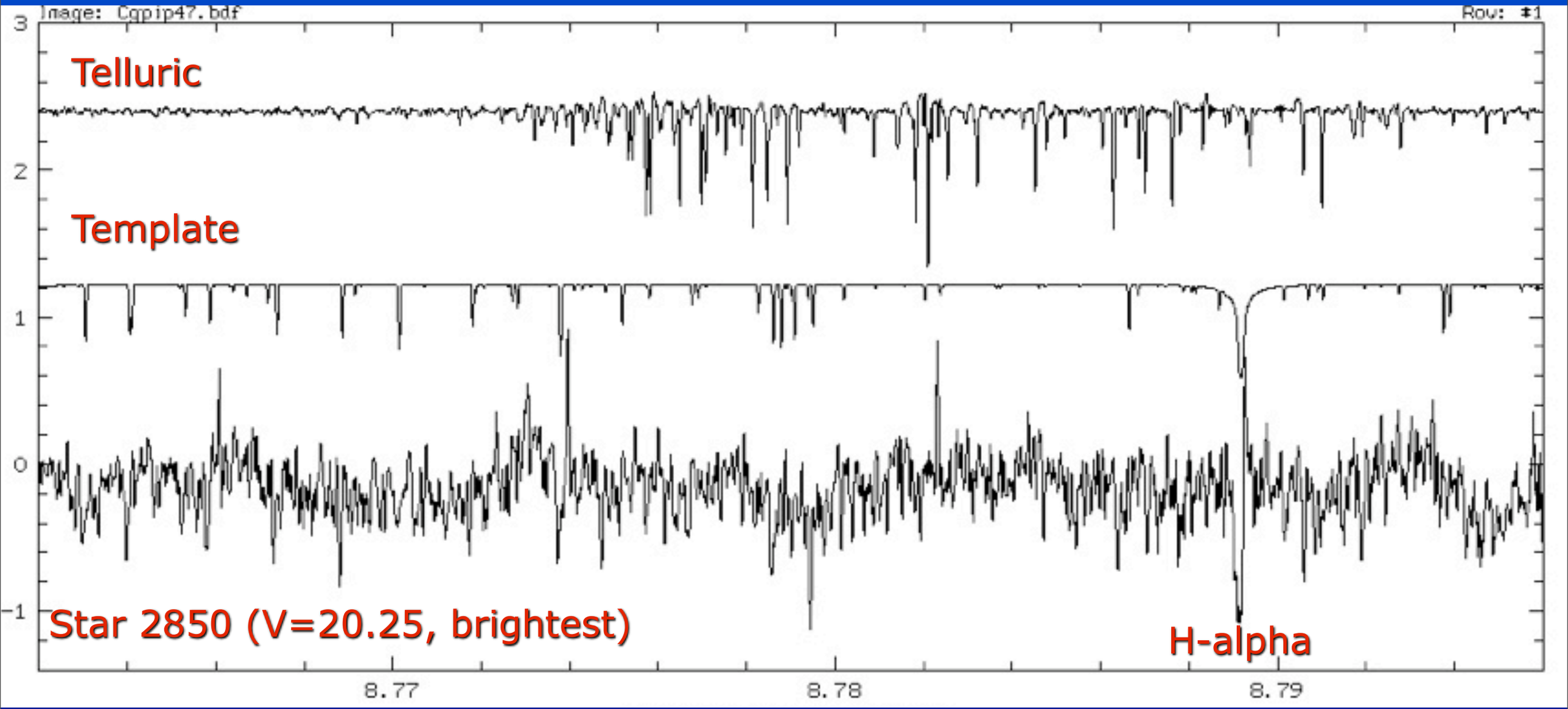
V_{rot}=6.2 ±2.0 kms^{-1}

Max at PA=-50°

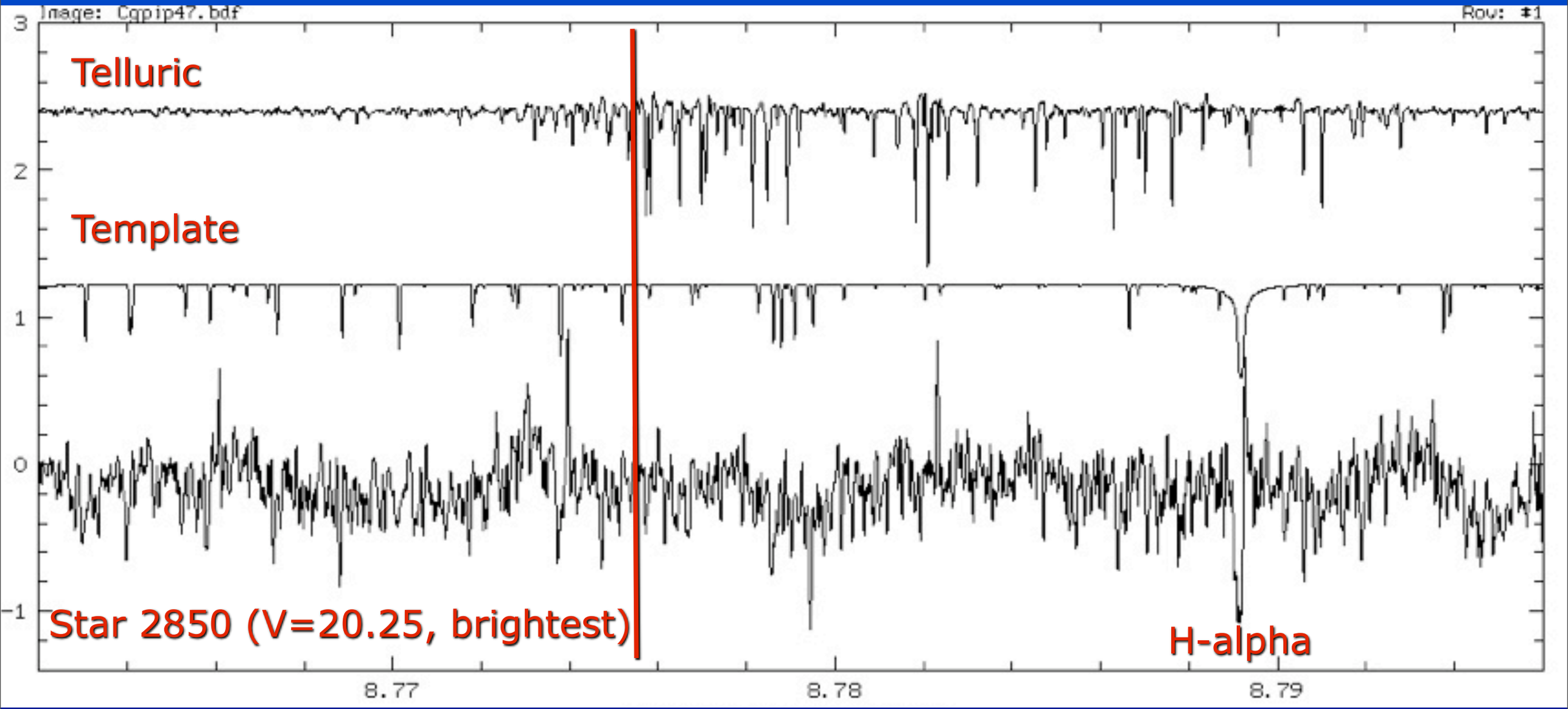
Corrected data.
The above rotation curve has been subtracted to the data. The distribution of radial velocities is gaussian.



FLAMES spectra

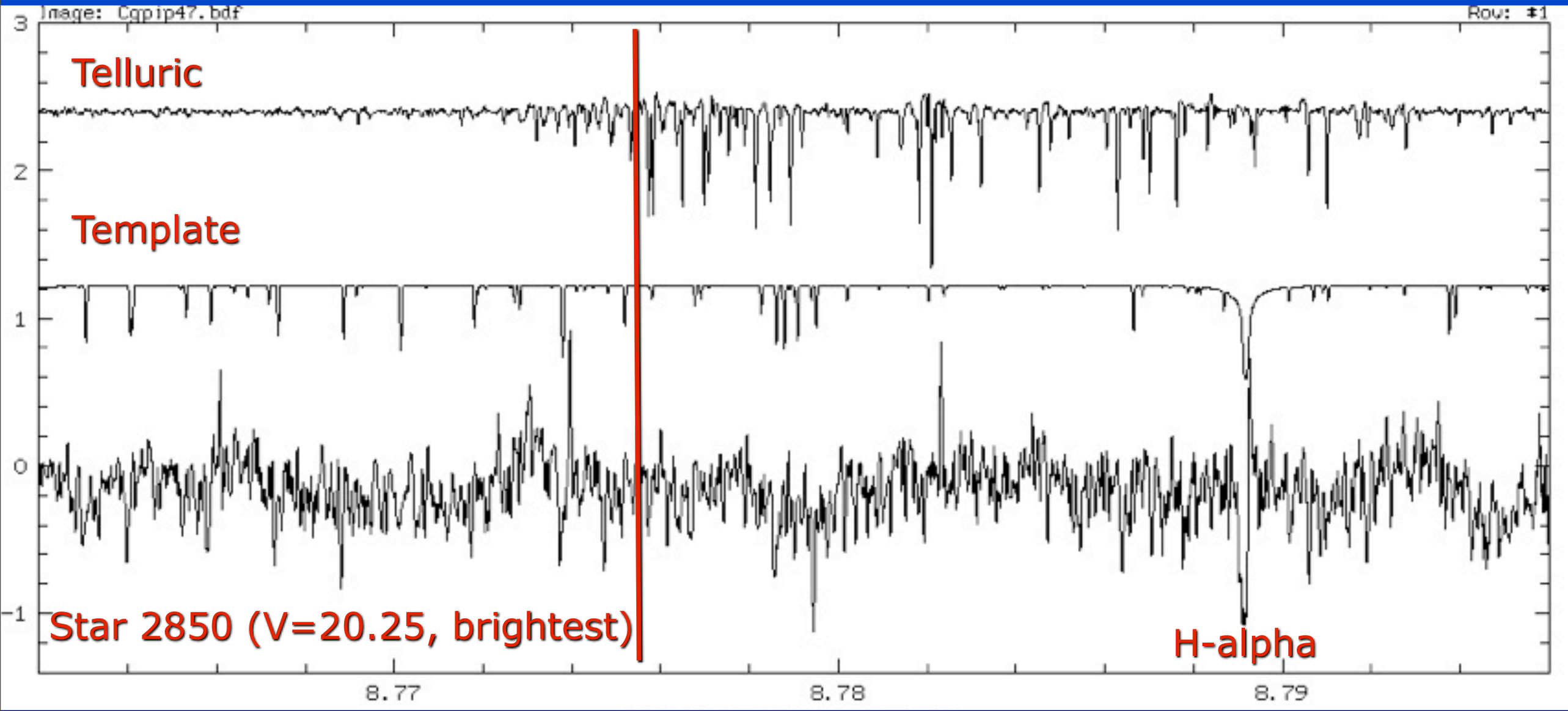


FLAMES spectra



FLAMES spectra

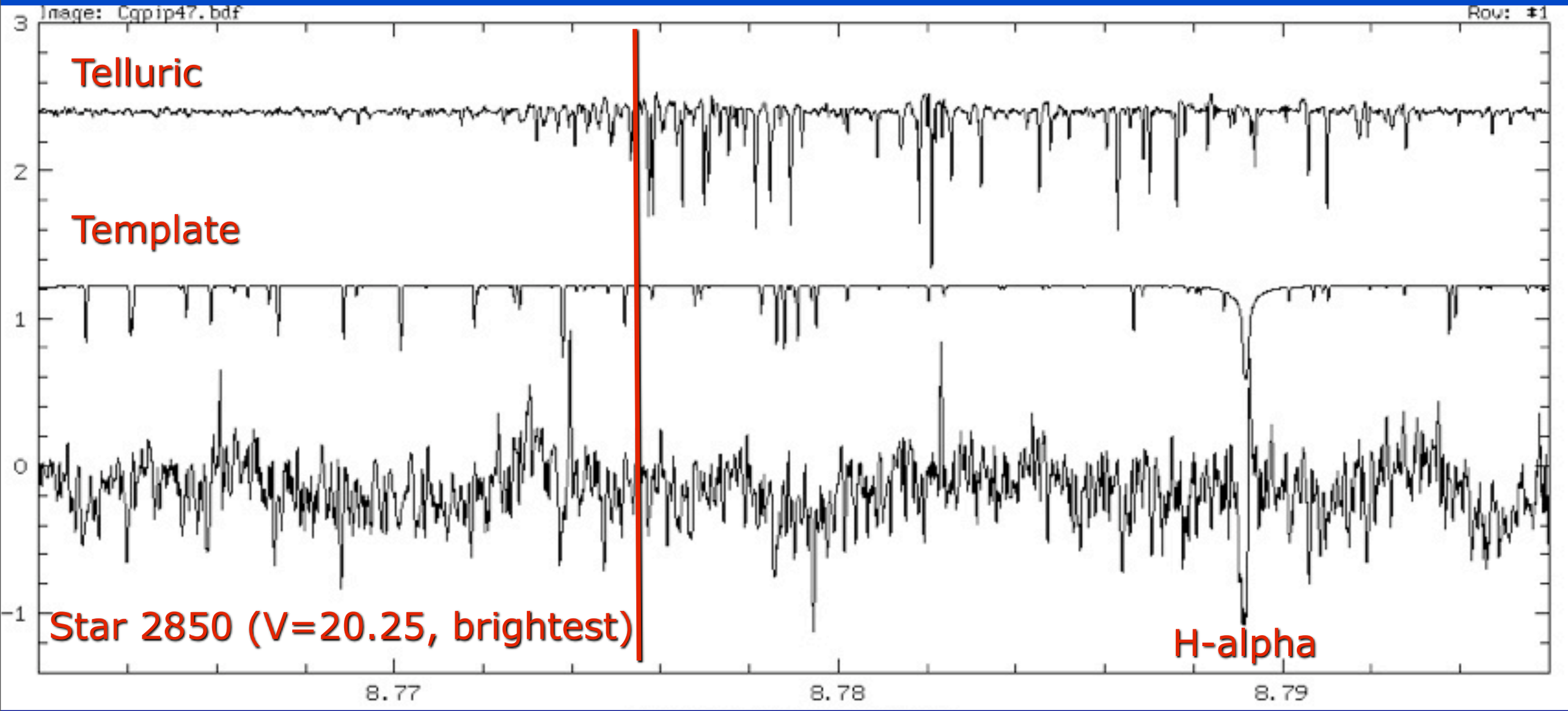
No Telluric



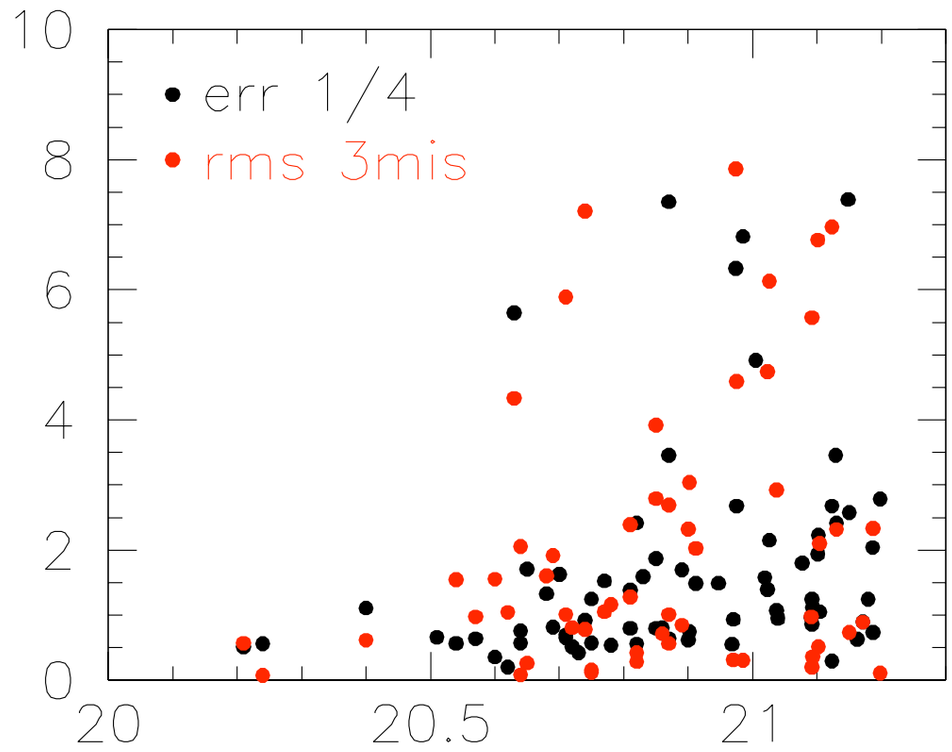
FLAMES spectra

No Telluric

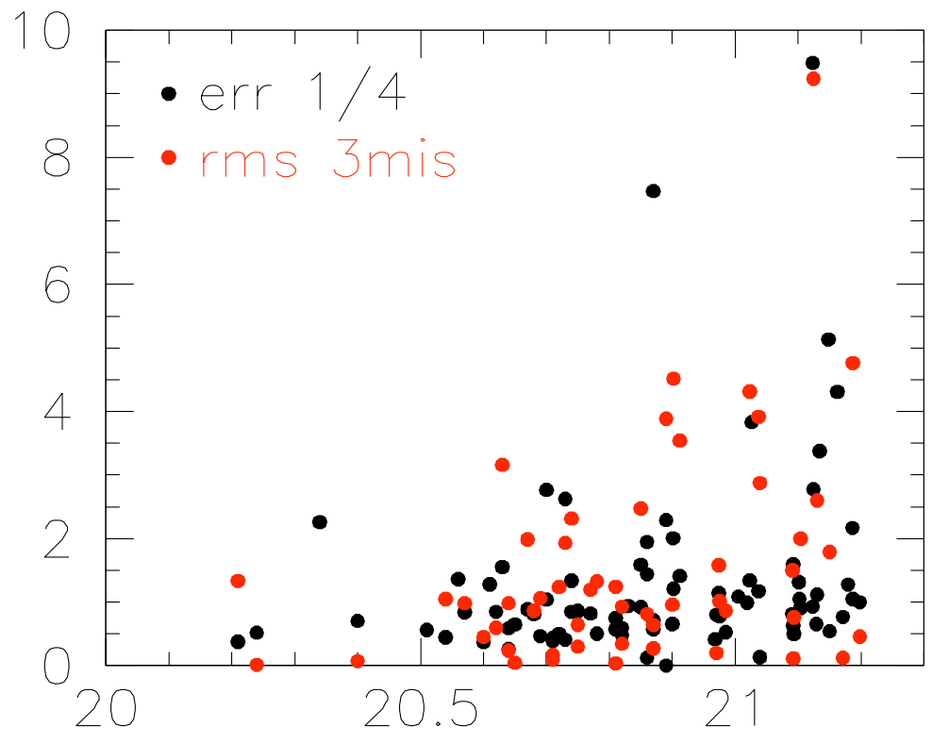
H-alpha



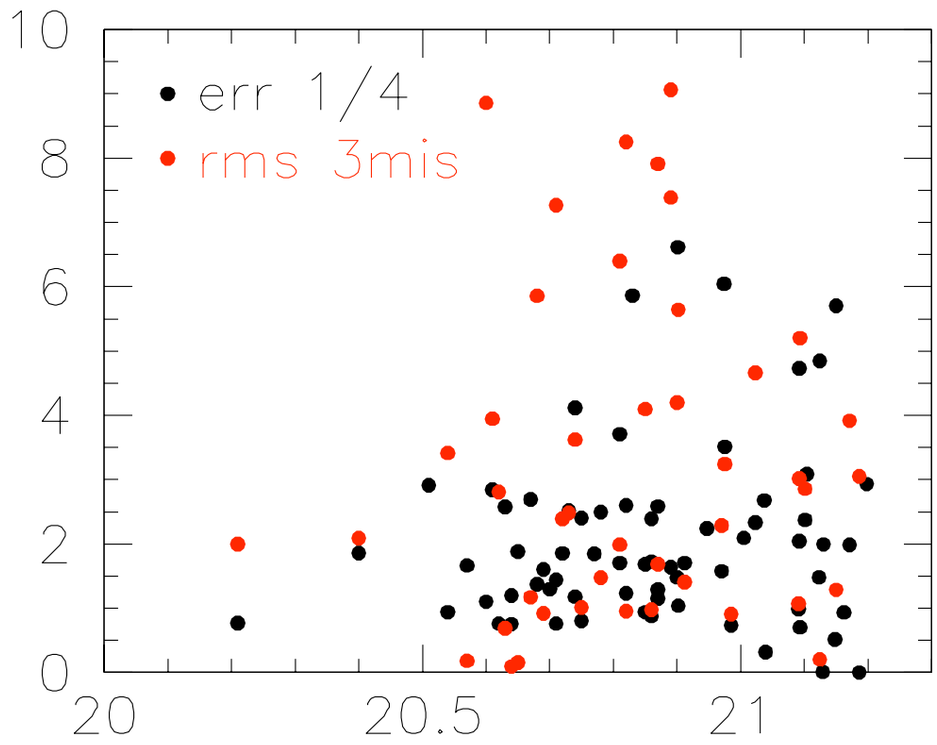
Whole spectrum



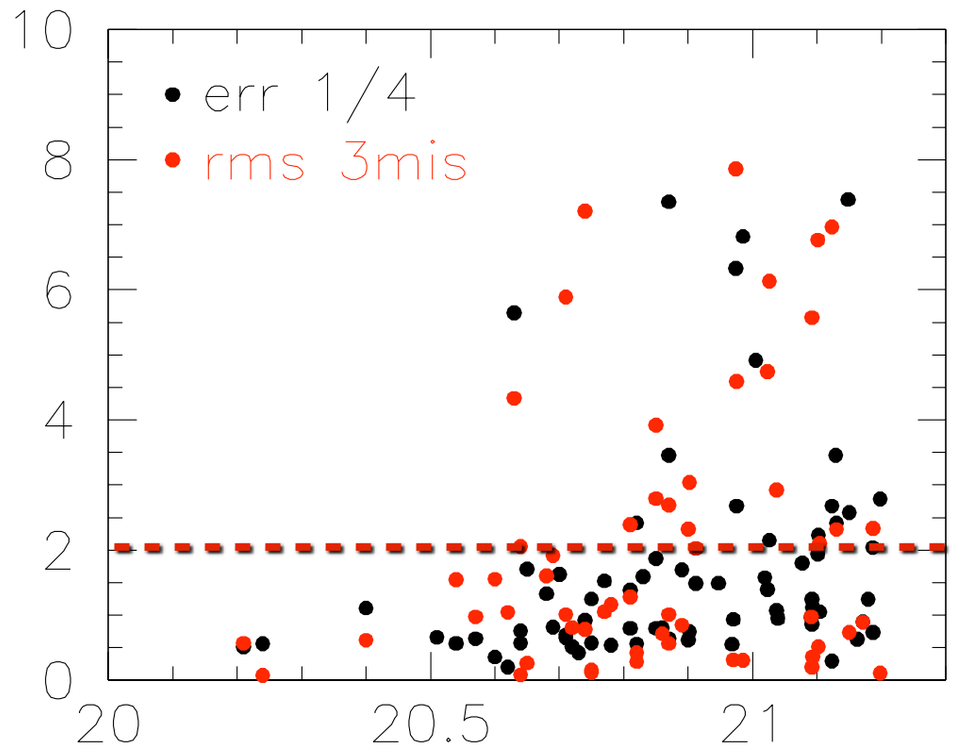
No Telluric



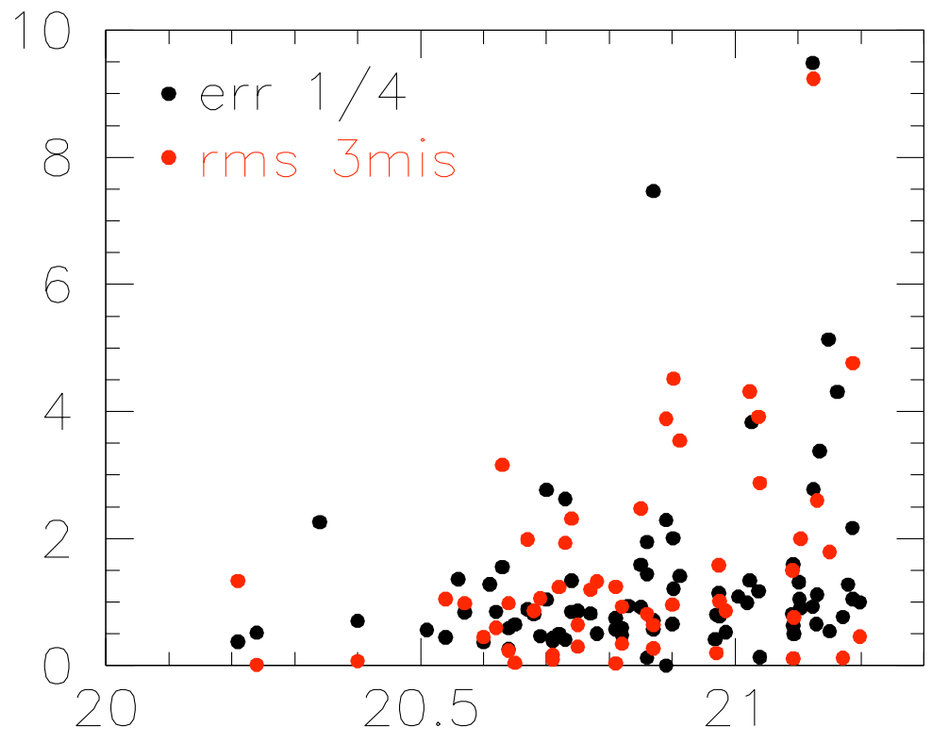
H-alpha



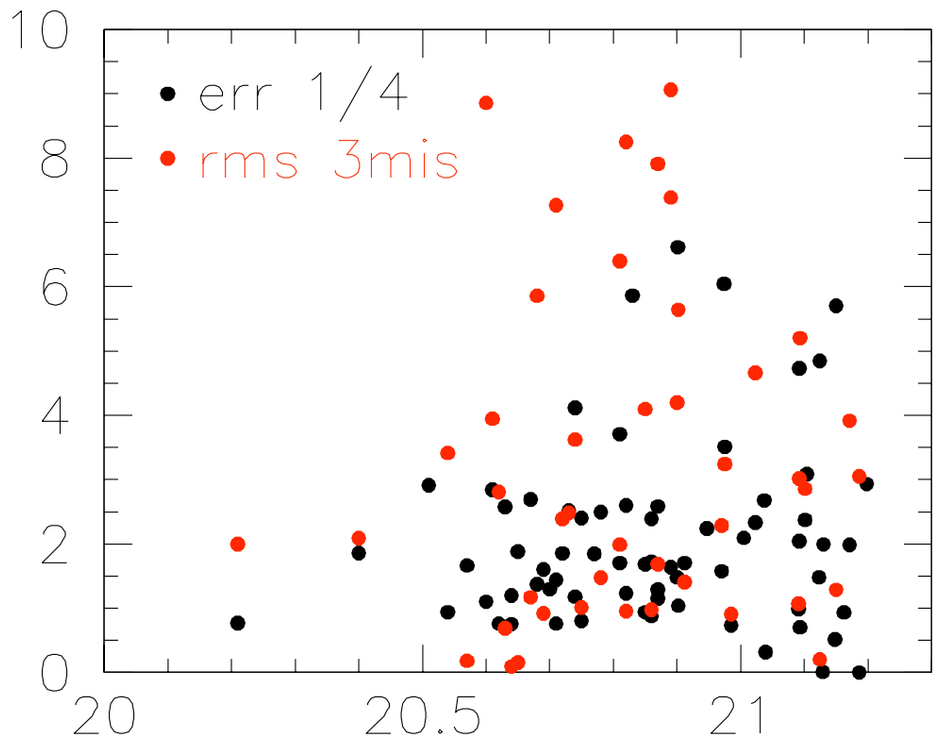
Whole spectrum



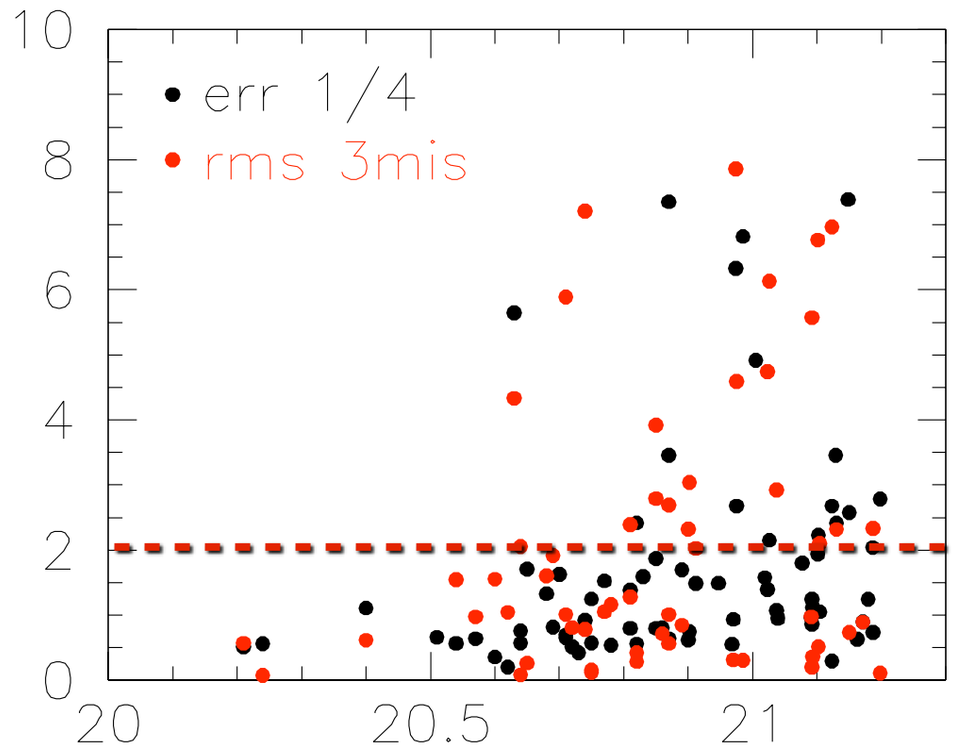
No Telluric



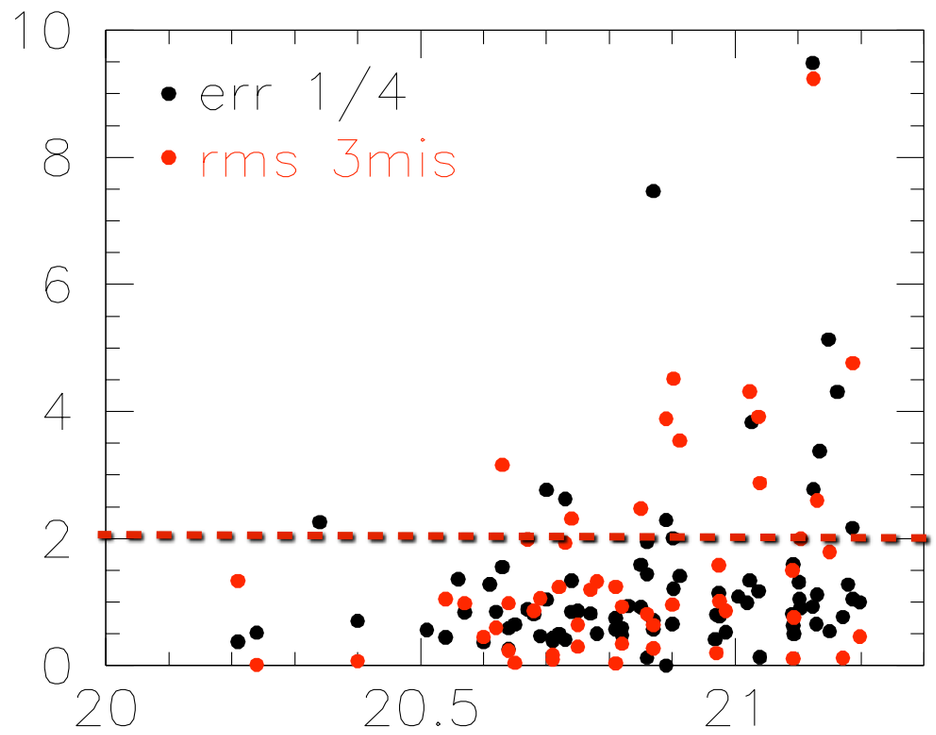
H-alpha



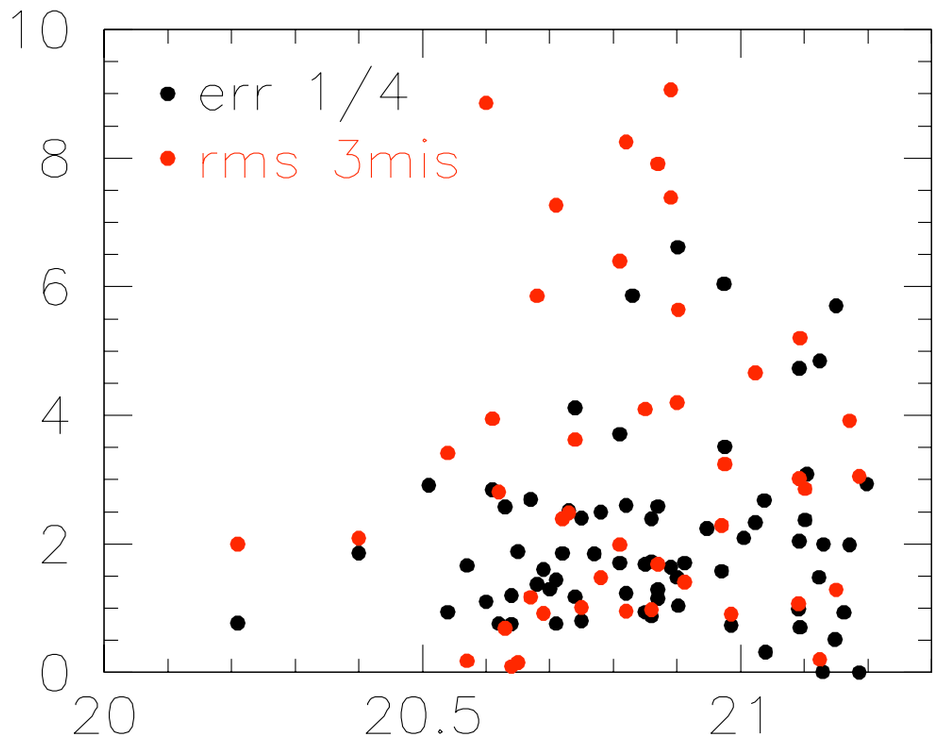
Whole spectrum



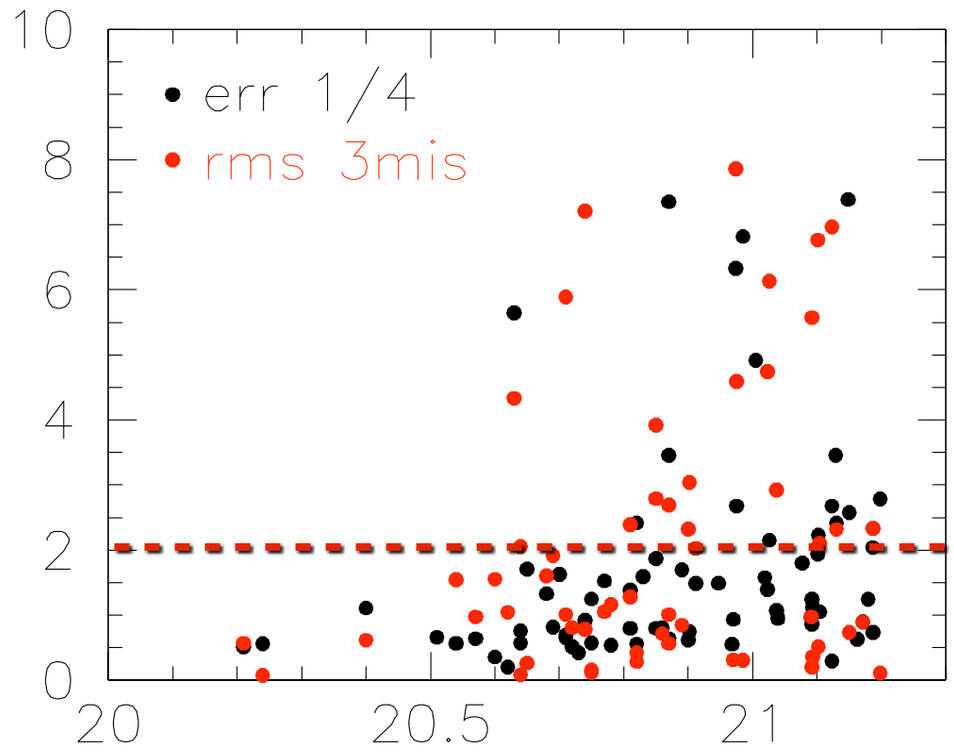
No Telluric



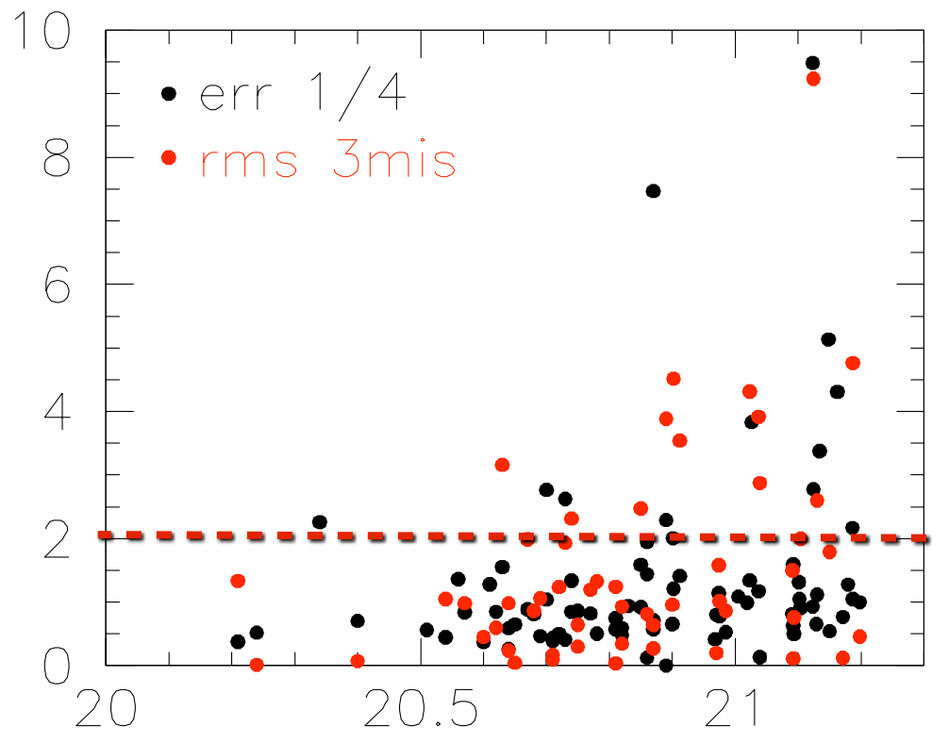
H-alpha



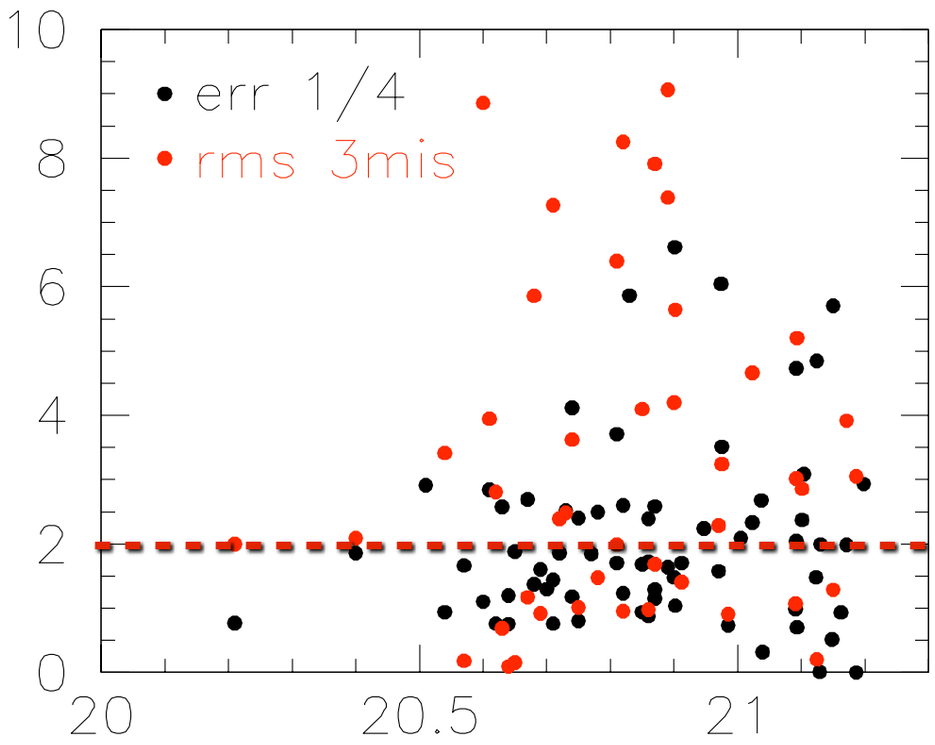
Whole spectrum



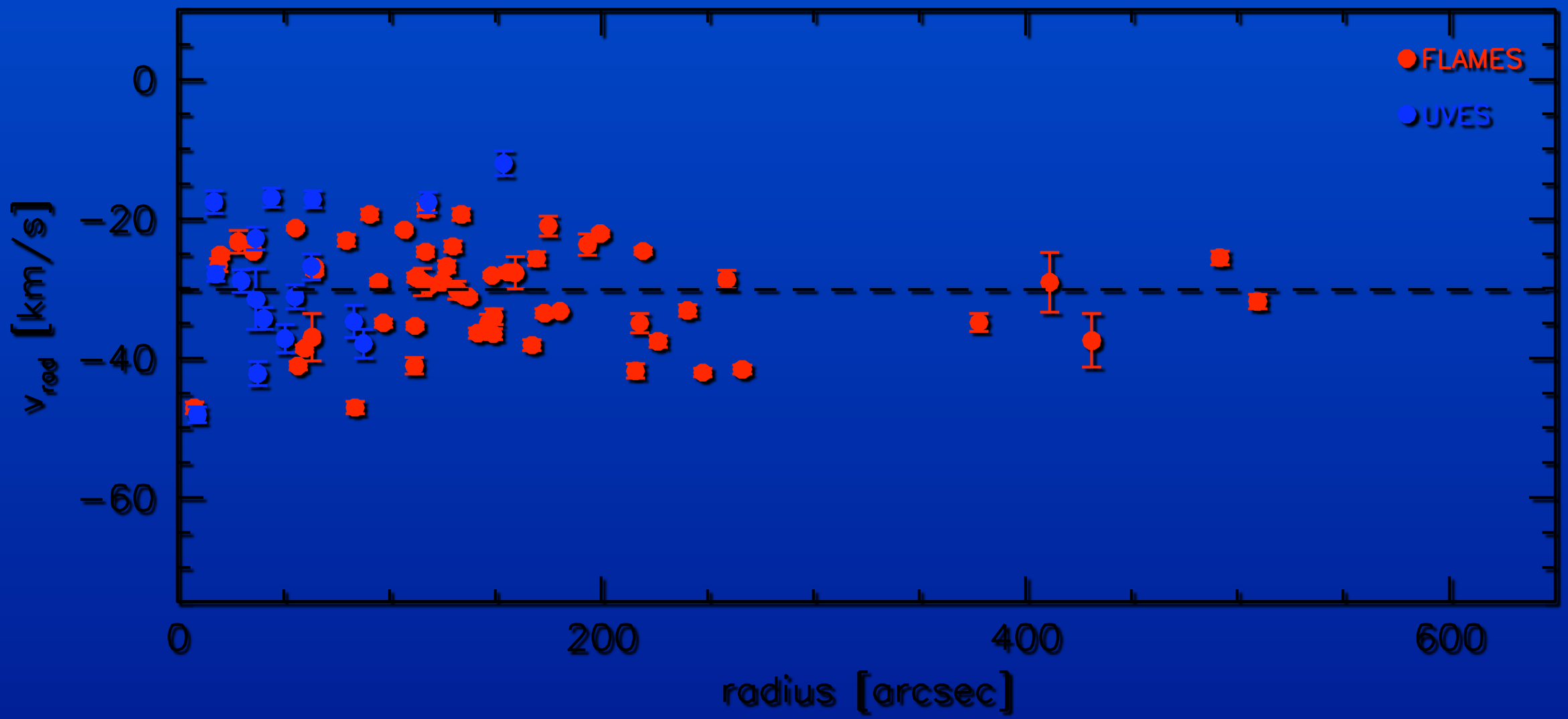
No Telluric



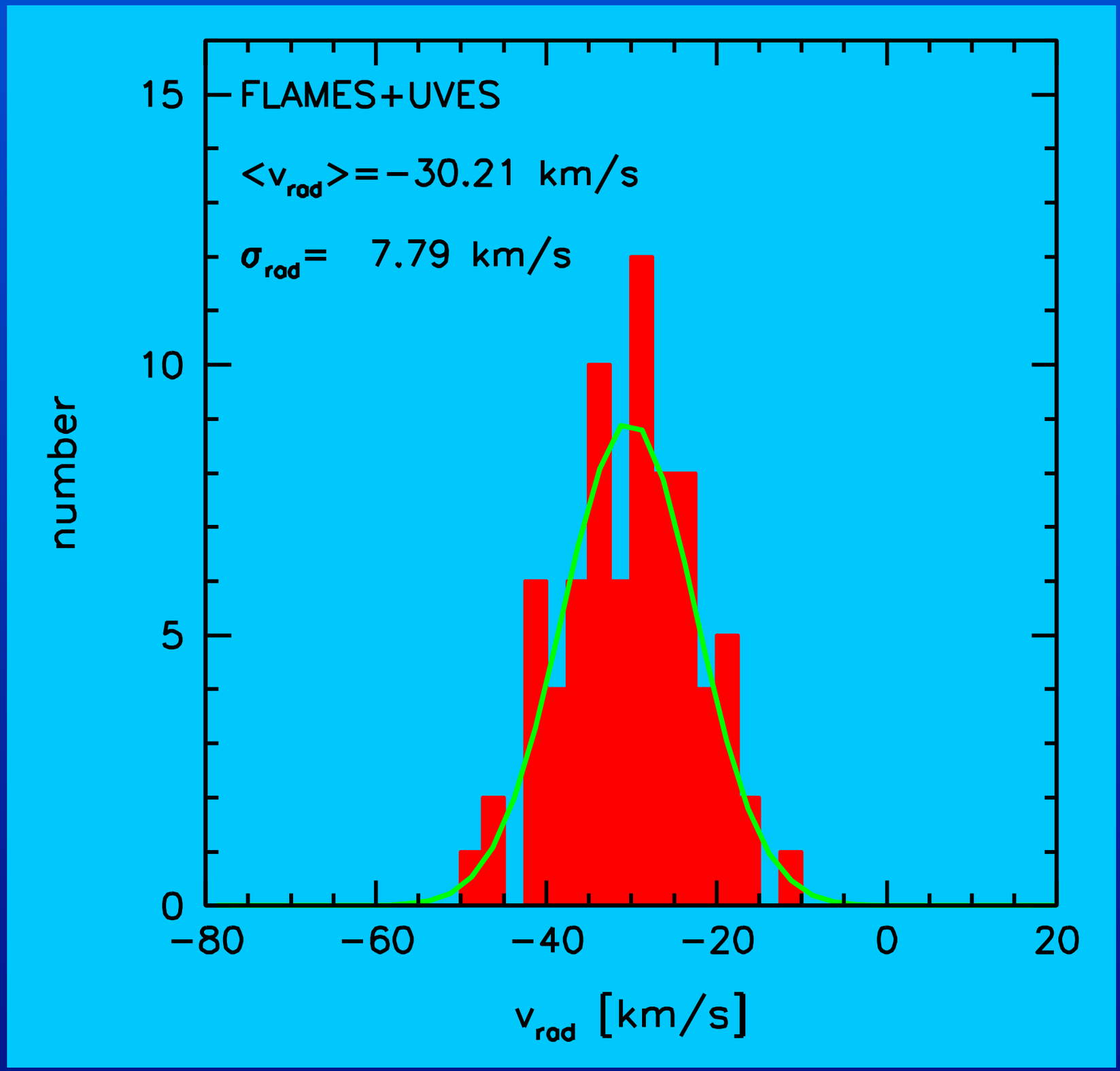
H-alpha



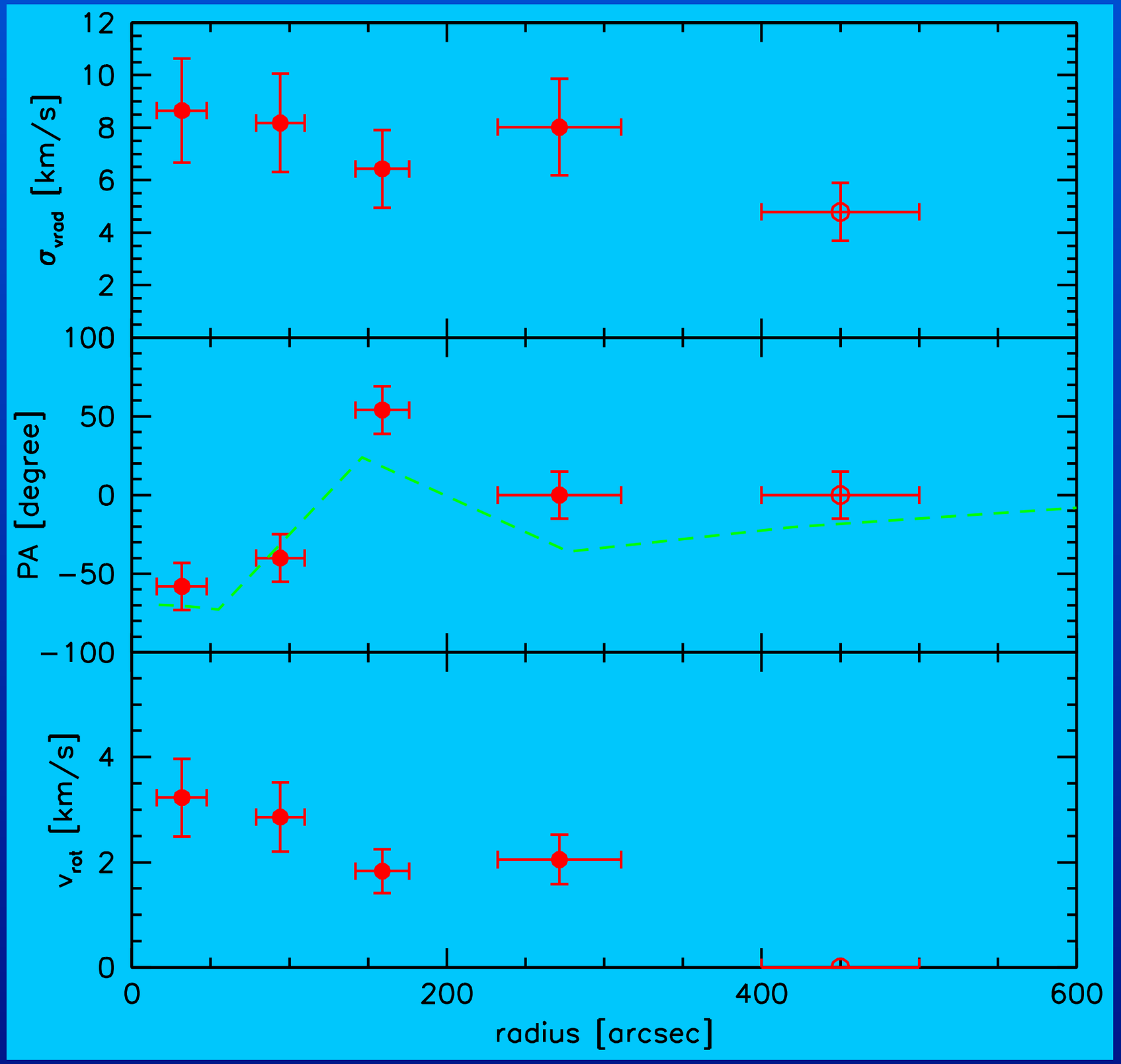
UVES+FLAMES



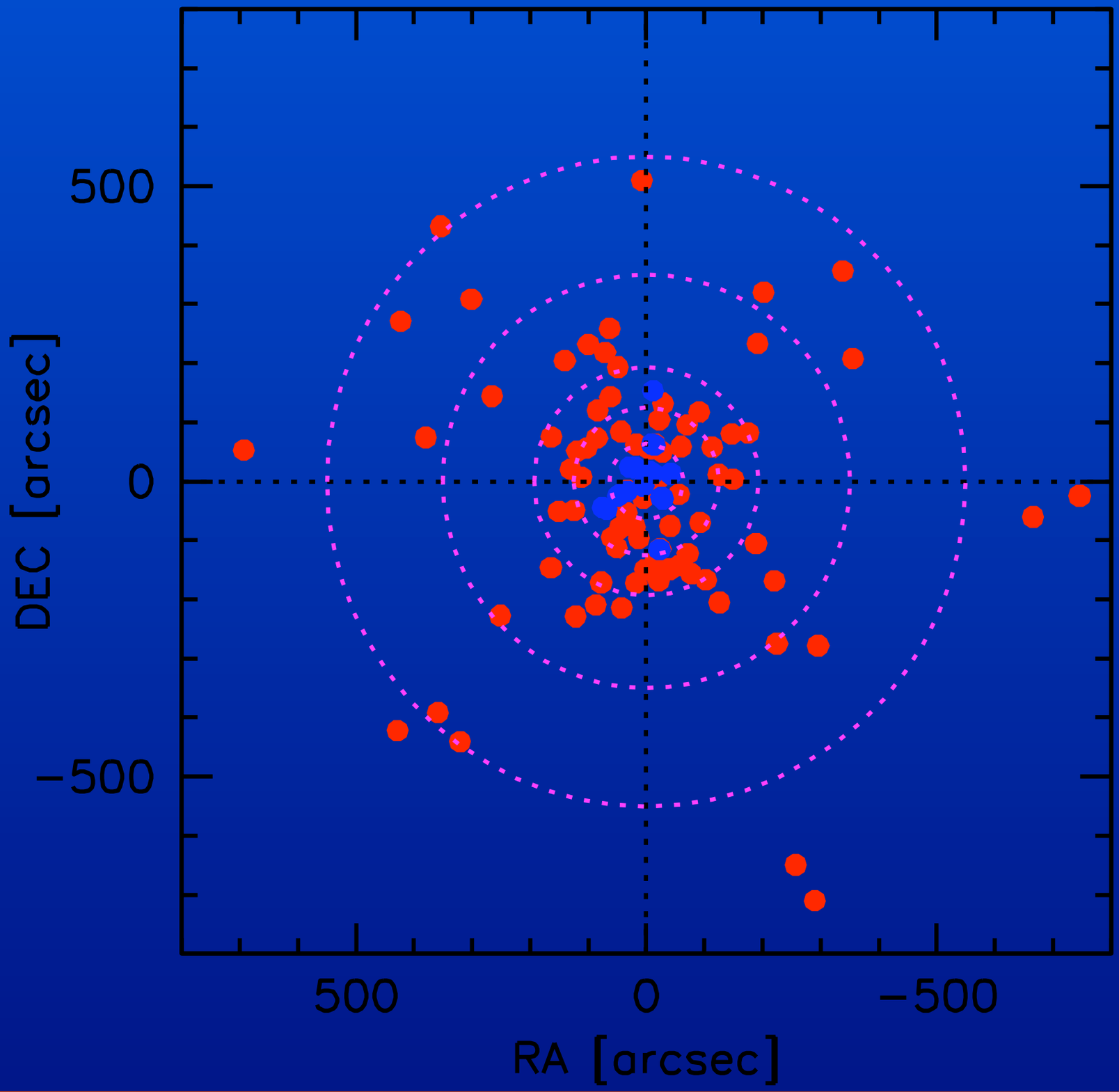
UVES+FLAMES


FLAMES+UVES
<v_rad>=−30.21 km/s
σ_rad= 7.79 km/s
number
15
10
5
0
−80
−60
−40
−20
0
20
v_rad [km/s]

Radial profiles



UVES+FLAMES



The radial density profile

The FORS and CTIO star counts have also been used to build an extended radial density profile and

bi-dimensional surface map.

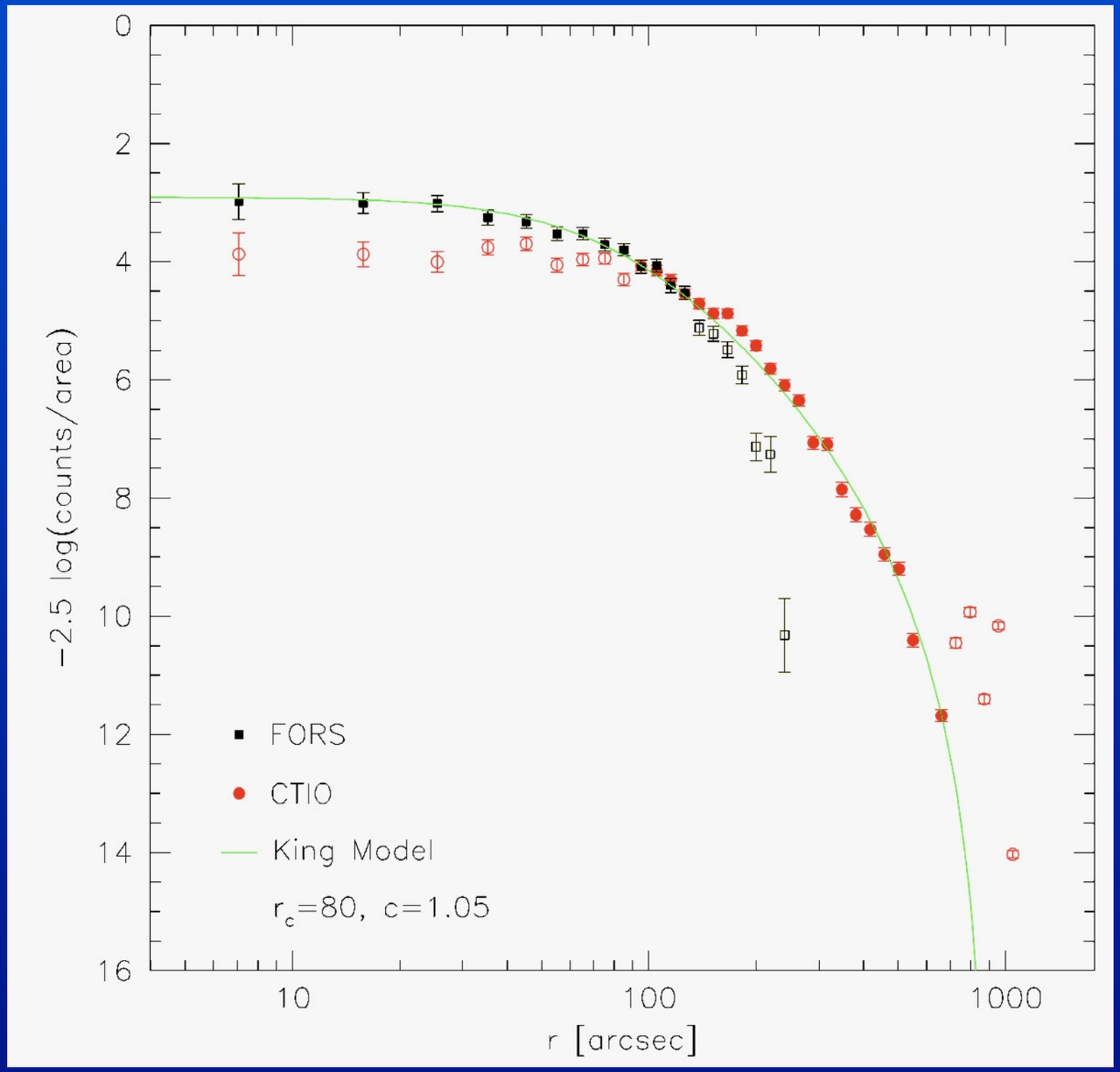
The profile has been fitted with an isotropic King-Michie model with the following parameters:

r_c=80” (0.16 kpc)

r_t≈900” (1.83 kpc)

c=1.05

No extended halo stars have been detected, at least with the available data.



The Mass

Using the velocity dispersion profile and the radial density profile, using formula (11) of Walker+ (09) the total mass of Phoenix is:

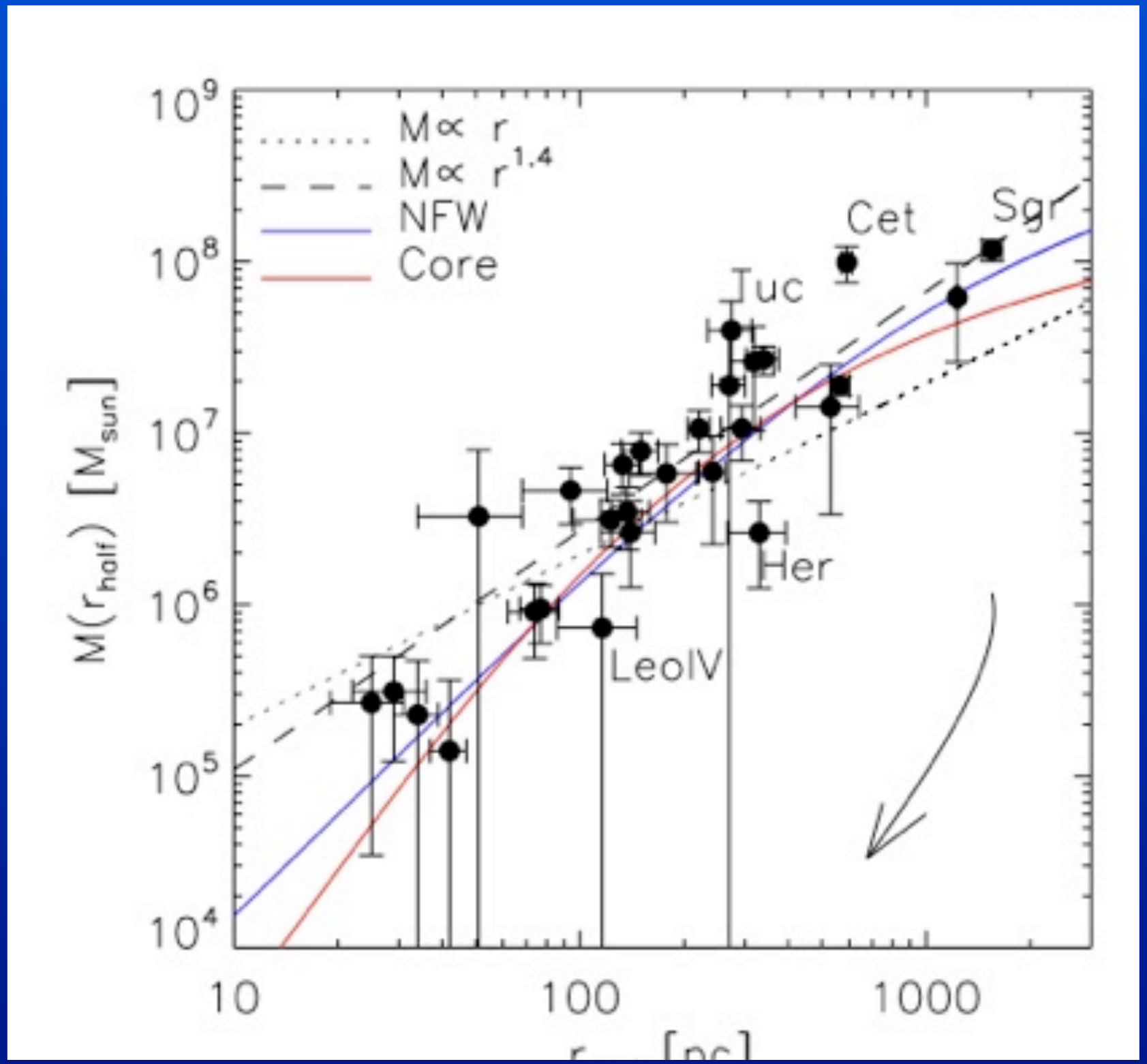
$$M(r_{half})=9.7\pm2.3 \times 10^6 M_{solar}$$

Using the literature value of the total luminosity of Phoenix

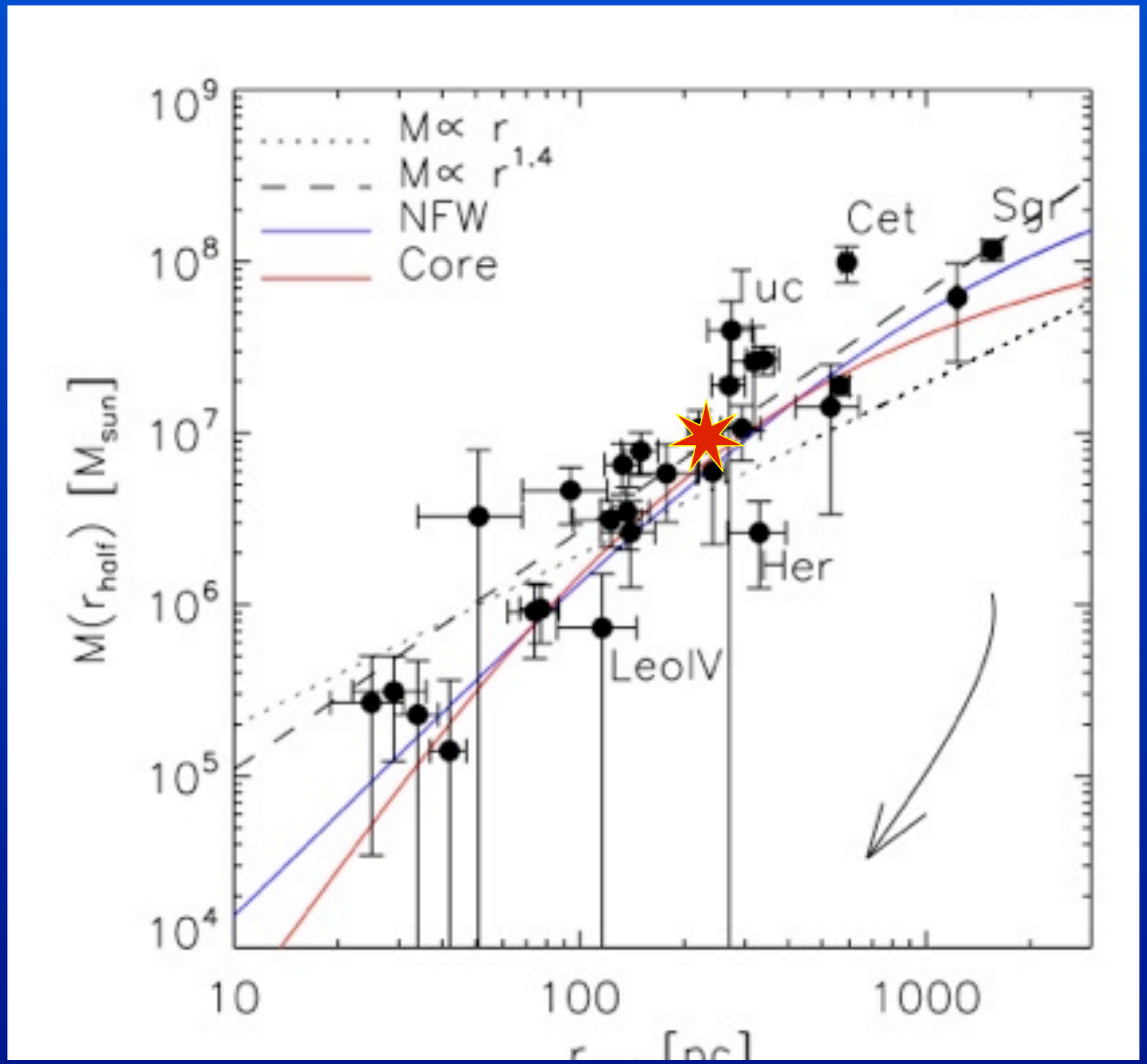
V=-10.1 the M/L is:

$$M/L=10.7$$

Walker plot


10^9
10^8
10^7
10^6
10^5
10^4
$M(r_{half})$ [M_{sun}]
M∝ r
M∝ r$^{1.4}$
NFW
Core
Cet
Sgr
Tuc
Her
LeoIV
10
100
1000

Walker plot


10^9
10^8
10^7
10^6
10^5
10^4
$M(r_{half})$ [M_{sun}]
M∝ r
M∝ r$^{1.4}$
NFW
Core
Cet
Sgr
Tuc
Her
LeoIV
10
100
1000

Summary and Conclusions

Summary and Conclusions

We have presented a first study on the dynamics of the Phoenix dwarf galaxy, an isolated member of the Local Group, based on precise radial velocity measurements obtained from the UVES spectrograph.

Summary and Conclusions

We have presented a first study on the dynamics of the Phoenix dwarf galaxy, an isolated member of the Local Group, based on precise radial velocity measurements obtained from the UVES spectrograph.

The main results of this study are the following:

Summary and Conclusions

We have presented a first study on the dynamics of the Phoenix dwarf galaxy, an isolated member of the Local Group, based on precise radial velocity measurements obtained from the UVES spectrograph.

The main results of this study are the following:

Summary and Conclusions

We have presented a first study on the dynamics of the Phoenix dwarf galaxy, an isolated member of the Local Group, based on precise radial velocity measurements obtained from the UVES spectrograph.

The main results of this study are the following:

- Definitive confirm of a physical connection of the HI cloud detected in the vicinity of Phoenix by Young and Lo (1997).

Summary and Conclusions

We have presented a first study on the dynamics of the Phoenix dwarf galaxy, an isolated member of the Local Group, based on precise radial velocity measurements obtained from the UVES spectrograph.

The main results of this study are the following:

- Definitive confirm of a physical connection of the HI cloud detected in the vicinity of Phoenix by Young and Lo (1997).
- Detection of a rotational component in the core of the galaxy compatible with disk dynamics.

Summary and Conclusions

We have presented a first study on the dynamics of the Phoenix dwarf galaxy, an isolated member of the Local Group, based on precise radial velocity measurements obtained from the UVES spectrograph.

The main results of this study are the following:

- Definitive confirm of a physical connection of the HI cloud detected in the vicinity of Phoenix by Young and Lo (1997).
- Detection of a rotational component in the core of the galaxy compatible with disk dynamics.
- Dynamical analysis imply mass of $9.7 \pm 2.3 \times 10^6$ and $M/L = 10.7$

Summary and Conclusions

We have presented a first study on the dynamics of the Phoenix dwarf galaxy, an isolated member of the Local Group, based on precise radial velocity measurements obtained from the UVES spectrograph.

The main results of this study are the following:

- Definitive confirm of a physical connection of the HI cloud detected in the vicinity of Phoenix by Young and Lo (1997).
- Detection of a rotational component in the core of the galaxy compatible with disk dynamics.
- Dynamical analysis imply mass of $9.7 \pm 2.3 \times 10^6$ and $M/L = 10.7$

Finally, given the large distance of Phoenix the velocity dispersion cannot be inflated by interaction mechanisms. Therefore we can safely conclude that its measured central mass-to-light ratio directly point to the presence of dark matter.