OBSERVATIONAL STUDIES OF THE STELLAR HALO OF THE ANDROMEDA GALAXY USING SUBARU TELESCOPE

Abundance and Kinematic Broadening (AKB) PROJECT

Mikito Tanaka (Tohoku University) @Subaru UM, 2012/02/29

Looking back on my contributions to Subaru community (this past year)

- Education

  Producing Subaru's proposal in a lecture is very useful and very helpful for the undergraduate students. Because they can learn how interesting but how tough the career of academic researchers is as well as improve their English skill, astronomical knowledge and social skills. I applied the system to my lecture for the 3rd undergraduate students for the first time. I organized a student team with 6 members. They collaboratively found the most current astronomical issues by themselves and now they're preparing Subaru's proposal by themselves. To manage the lecture, I used some important communication skills such as team management, facilitation and coaching.

  → 「君天×もしドラ」みたいな雰囲気です.

- Astronomy

My Hope to Anonymous Referees & TAC members.
When you see their proposal, could you please read it more carefully and feed back to them more educational and more constructive comments?

Agenda

- Previous Studies (PAST)
  -CFHT/MegaCam, HST/ACS, Subaru/Suprime-Cam and Keck/DEIMOS
- Current Issues (PRESENT)
  -Contaminations
- Solutions (FUTURE)
  -Observational plans of HSC and PFS

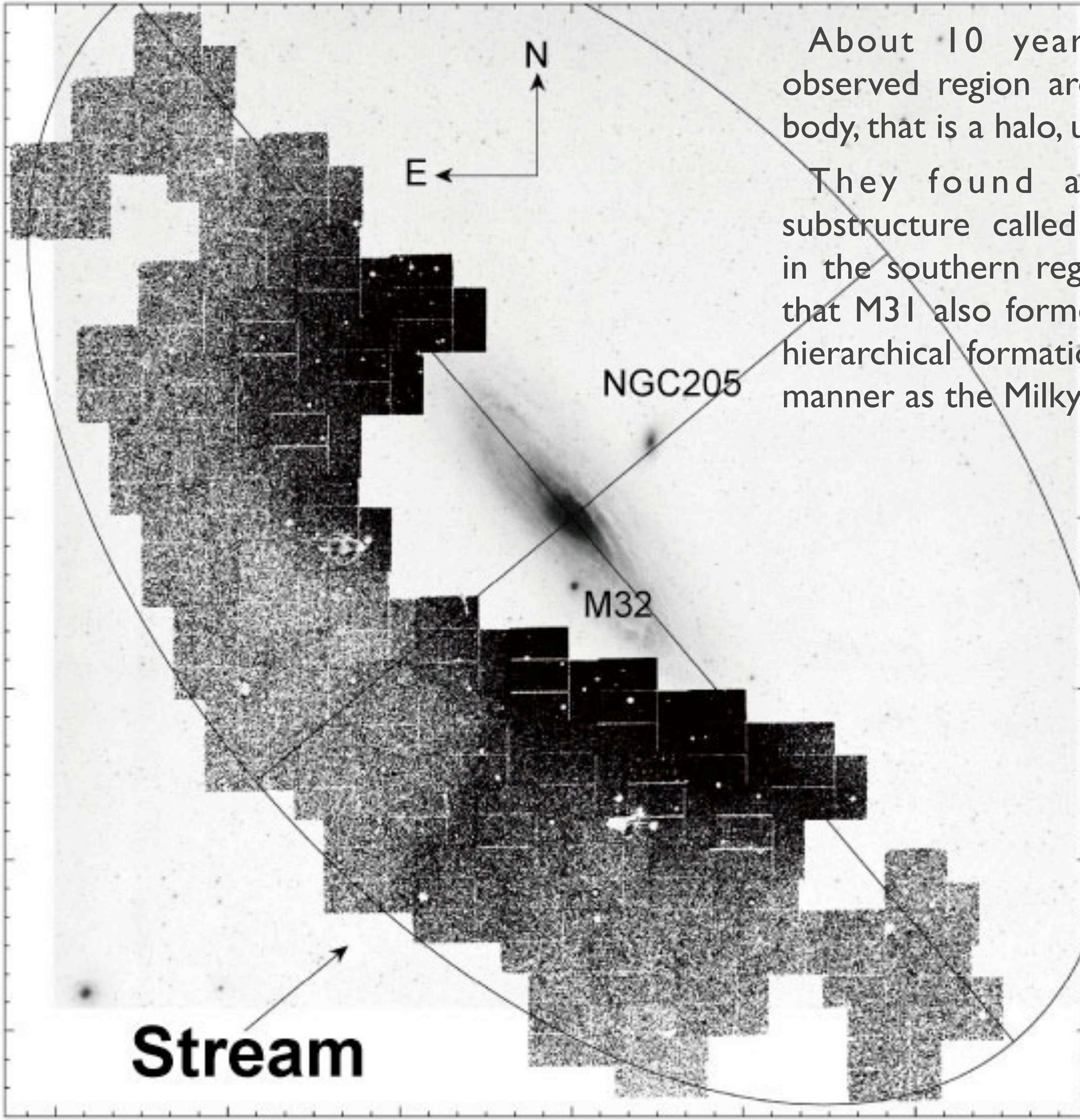
PREVIOUS STUDIES OF THE ANDROMEDA HALO

-CFHT/MegaCam (Ibata+01, Ibata+07, McConnachie+09, Richardson+11)

-HST/ACS (Brown+03)

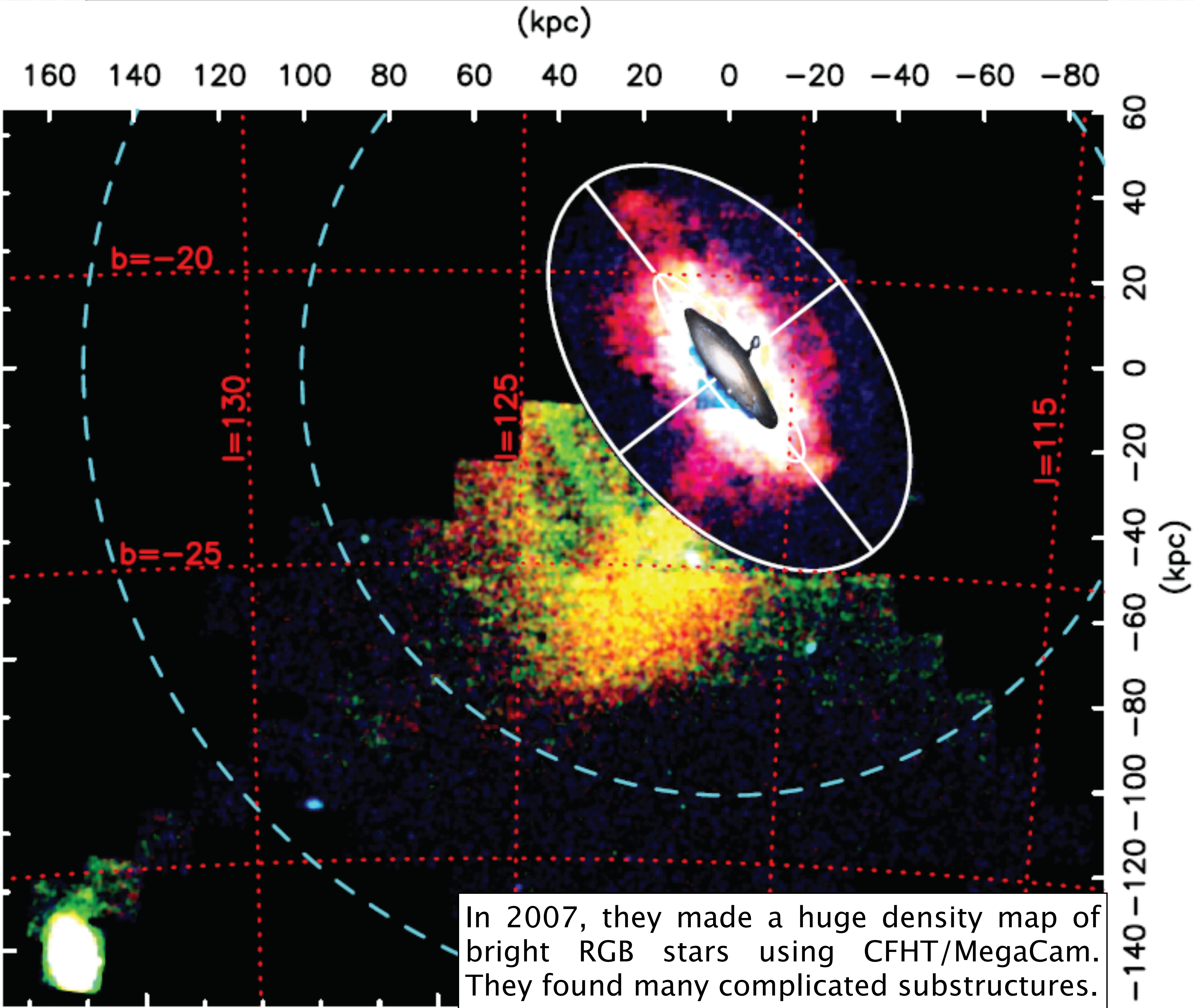
-Subaru/Suprime-Cam (Tanaka+10)

-Keck/DEIMOS (Kalirai+06, Fardal+12)

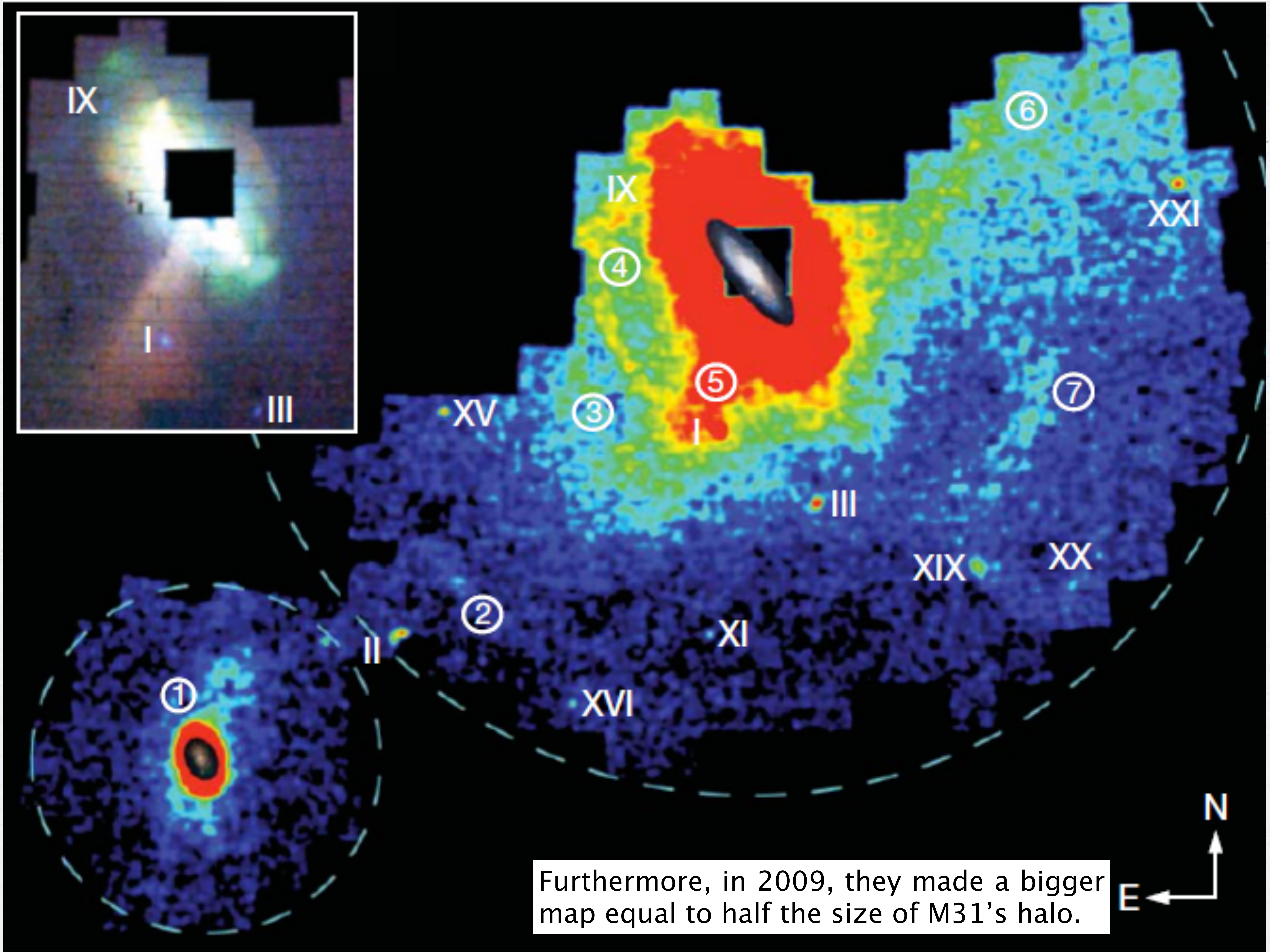


About 10 years ago, Ibata observed region around the main body, that is a halo, using INT.

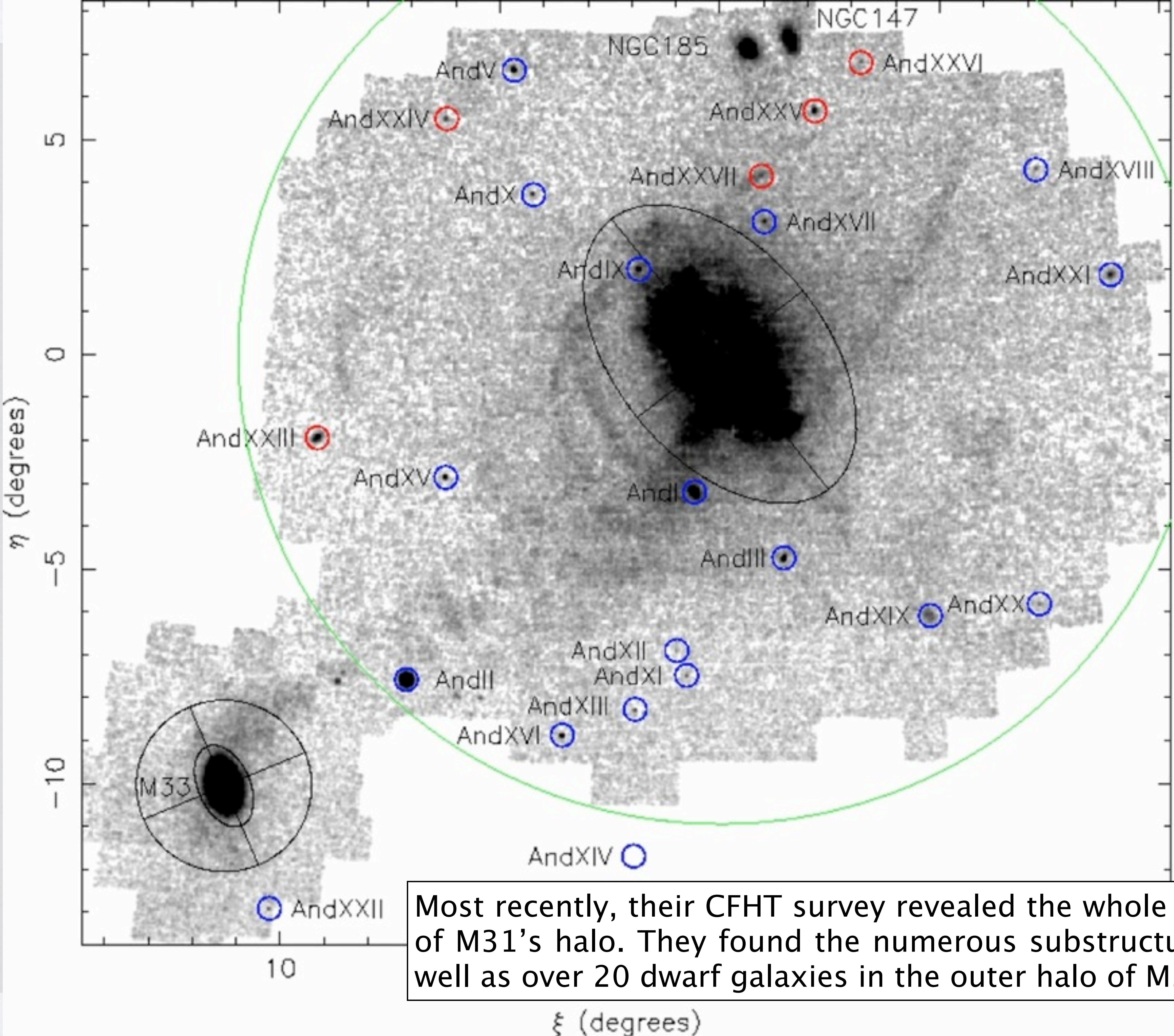
They found a prominent substructure called Giant Stream in the southern region. It suggests that M31 also formed through the hierarchical formation in the same manner as the Milky Way.



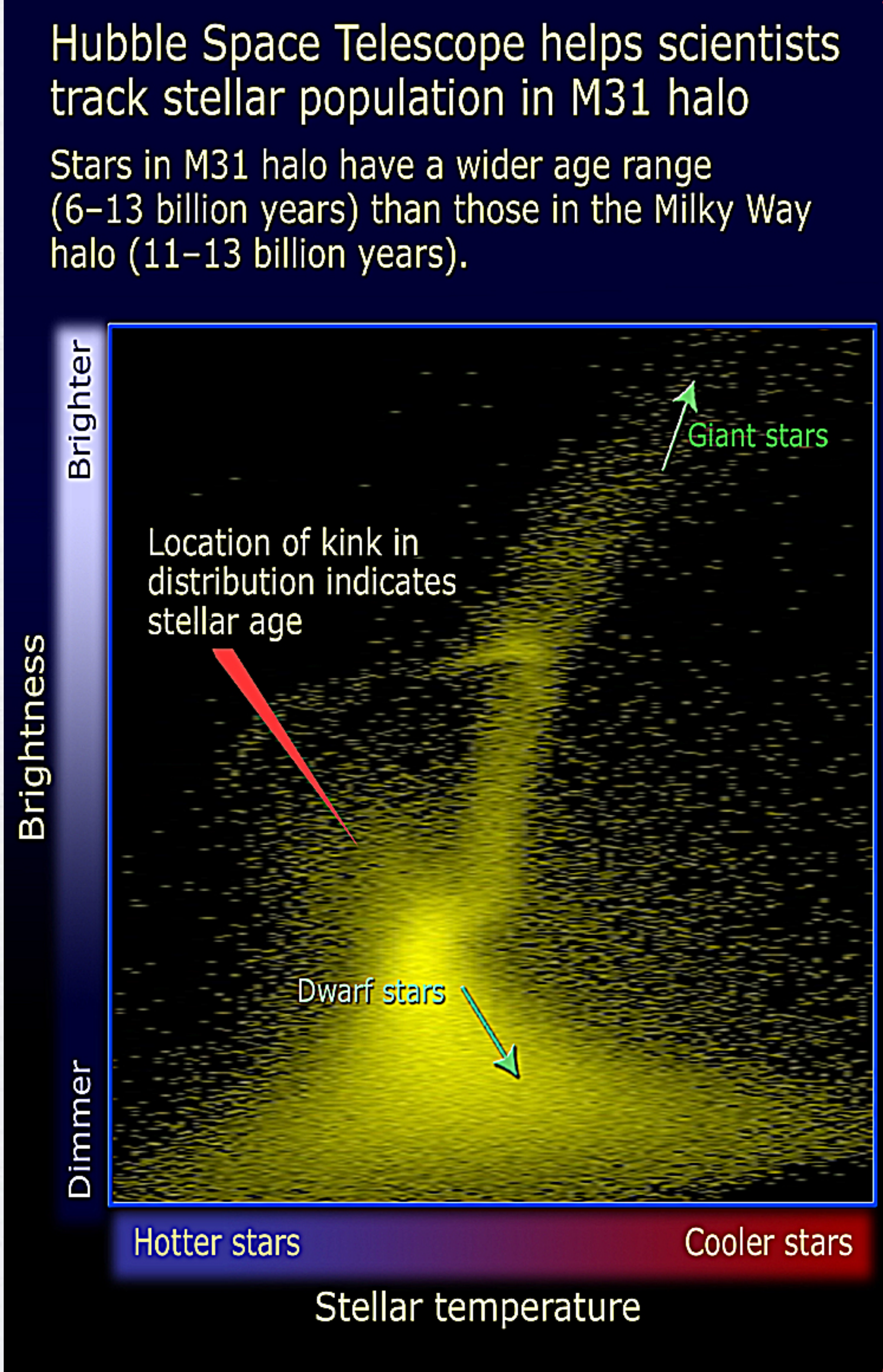
In 2007, they made a huge density map of bright RGB stars using CFHT/MegaCam. They found many complicated substructures.

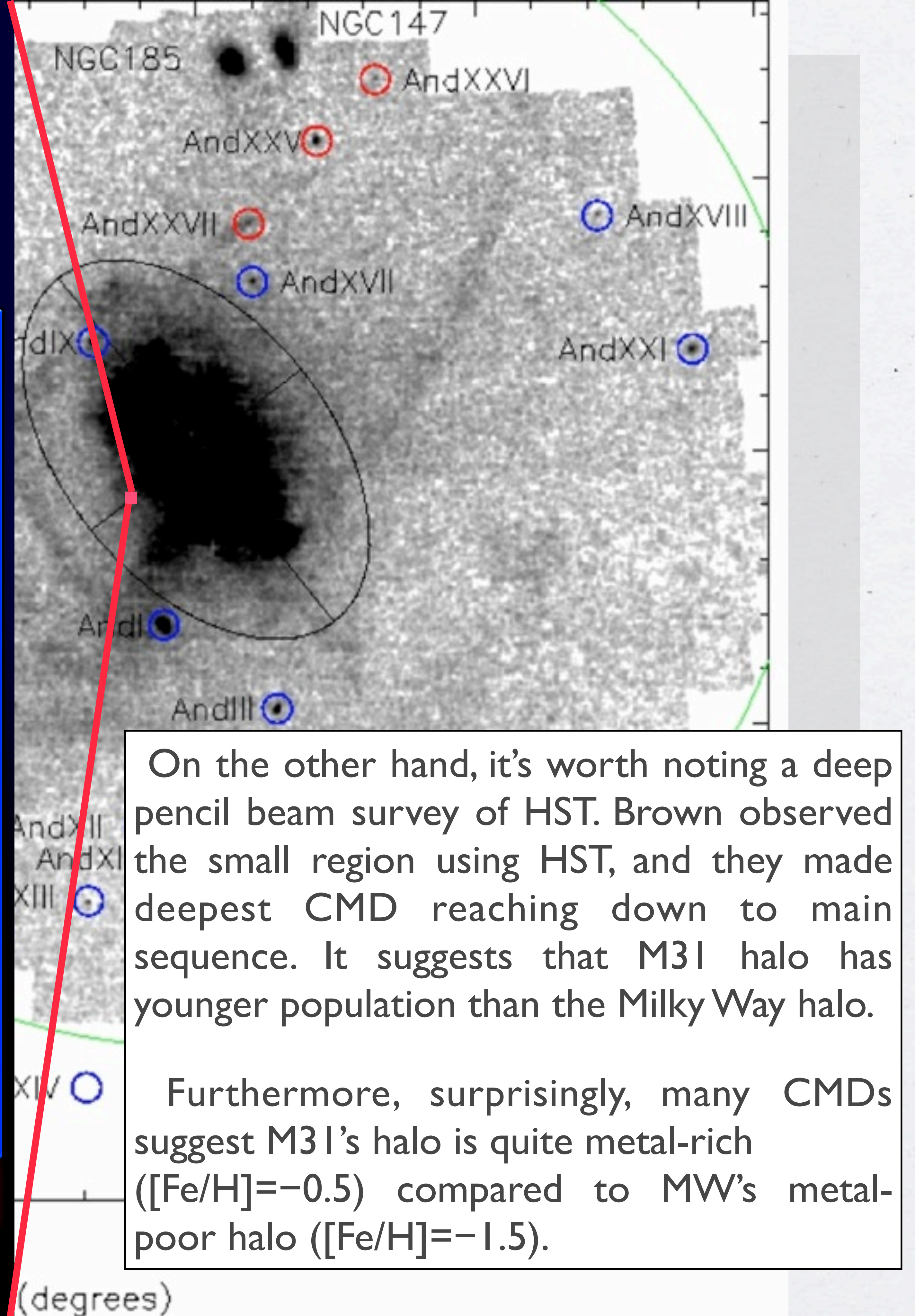


Furthermore, in 2009, they made a bigger map equal to half the size of M31's halo.



Most recently, their CFHT survey revealed the whole region of M31's halo. They found the numerous substructures as well as over 20 dwarf galaxies in the outer halo of M31.





On the other hand, it's worth noting a deep pencil beam survey of HST. Brown observed the small region using HST, and they made deepest CMD reaching down to main sequence. It suggests that M31 halo has younger population than the Milky Way halo.

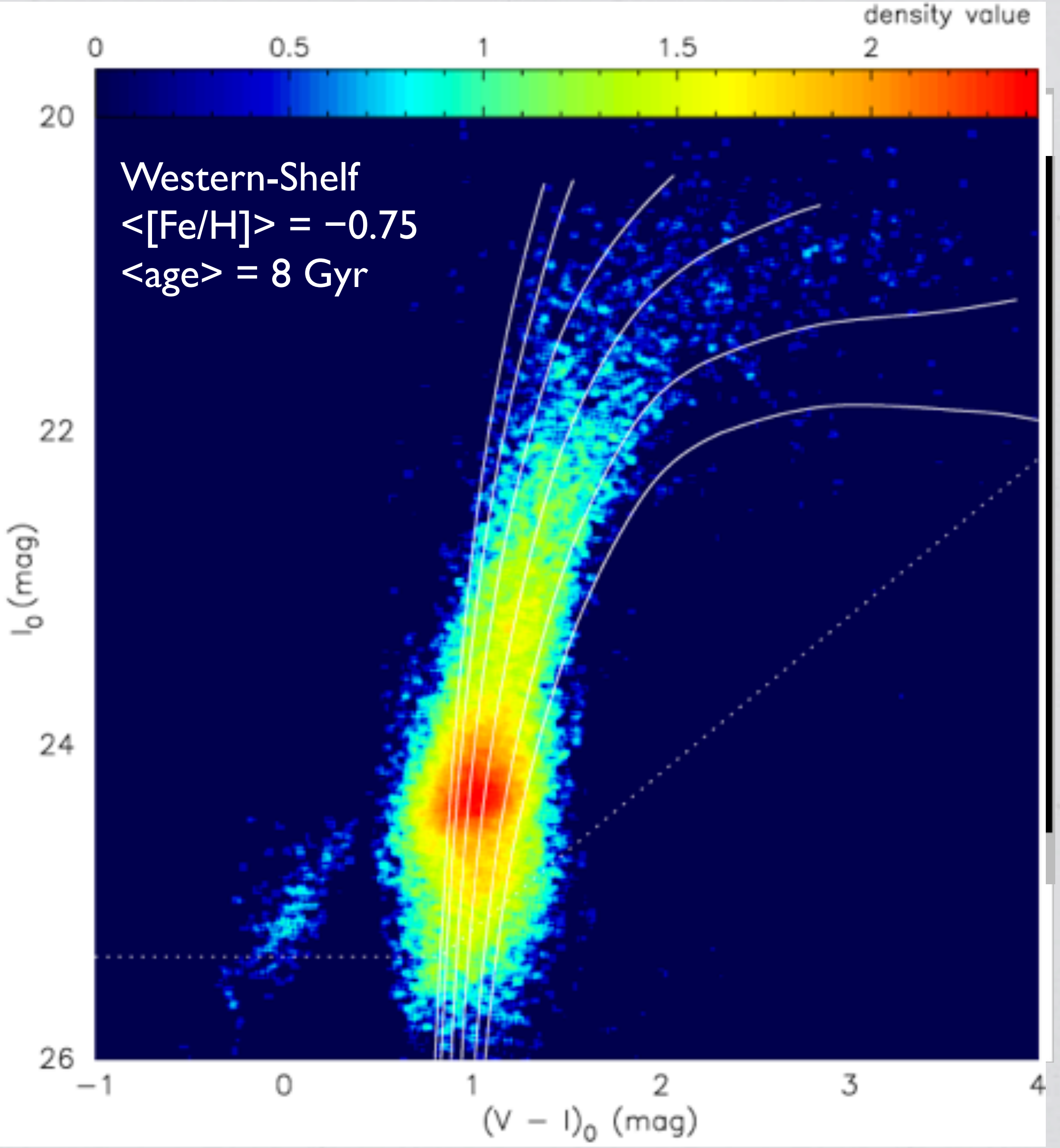
Furthermore, surprisingly, many CMDs suggest M31's halo is quite metal-rich ([Fe/H]=−0.5) compared to MW's metal-poor halo ([Fe/H]=−1.5).

Subaru/Suprime-Cam

We explored northern part of M31's outer halo using Subaru/Suprime-Cam for the first time in the world before CFHT/MegaCam conducted and found some faint substructures.

We confirmed one of the substructures, Stream SW, as a kinematically cold component using Keck/DEIMOS spectroscopy.

Furthermore, taking advantage of capabilities of Subaru and Suprime-Cam, we determined metallicity and age of inner dense substructures from deep CMDs reaching to Red Clump.

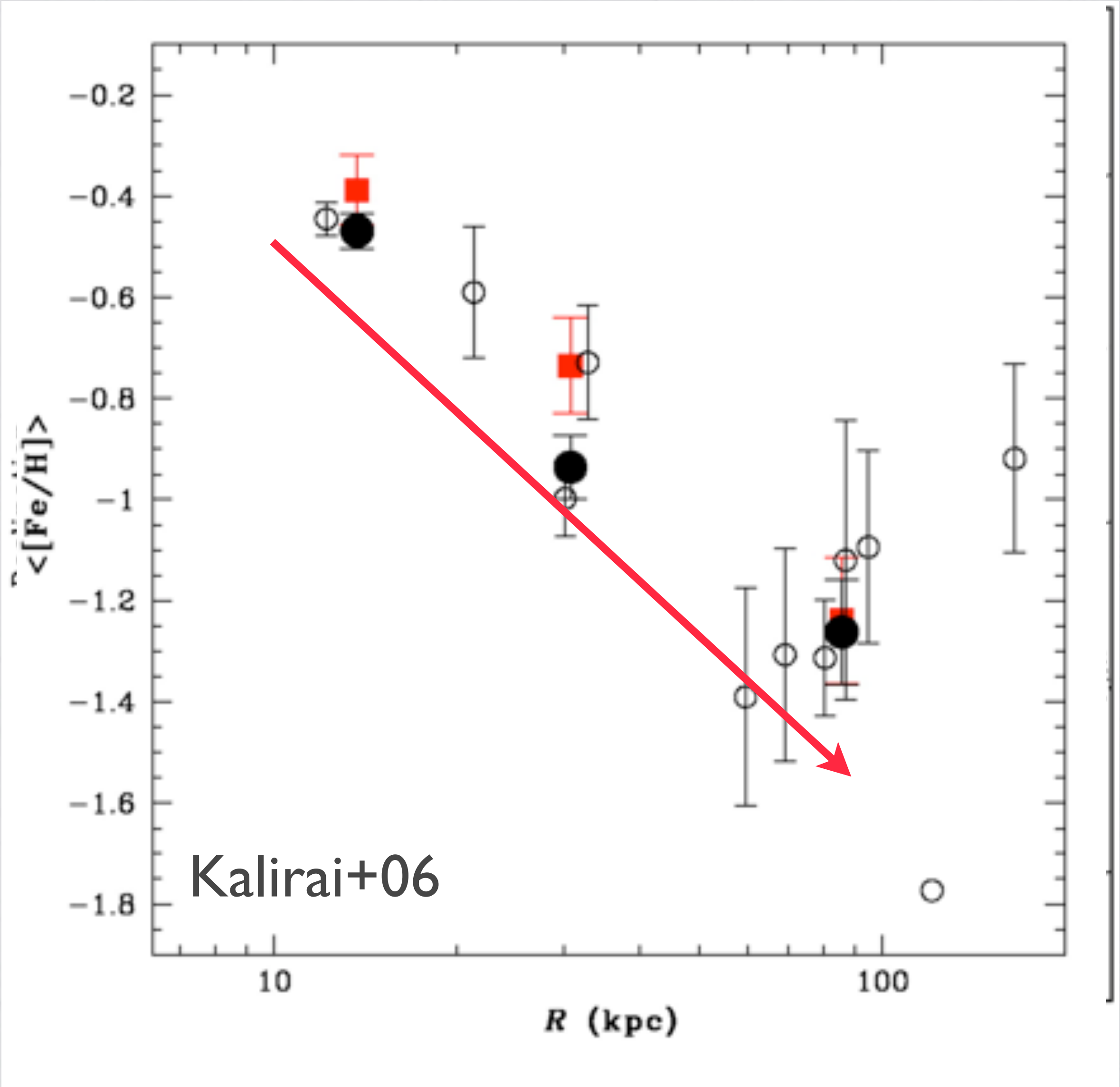


Spectroscopic Studies

On the other hand, it is worth noting spectroscopic observations of M31's halo by Keck/ DEIMOS.

For example, Kalirai+06 found metal-poor stars and the metallicity gradient along the minor axis out to 160 kpc. After that, we confirmed the trend using deep observations of Subaru/Suprime-Cam.

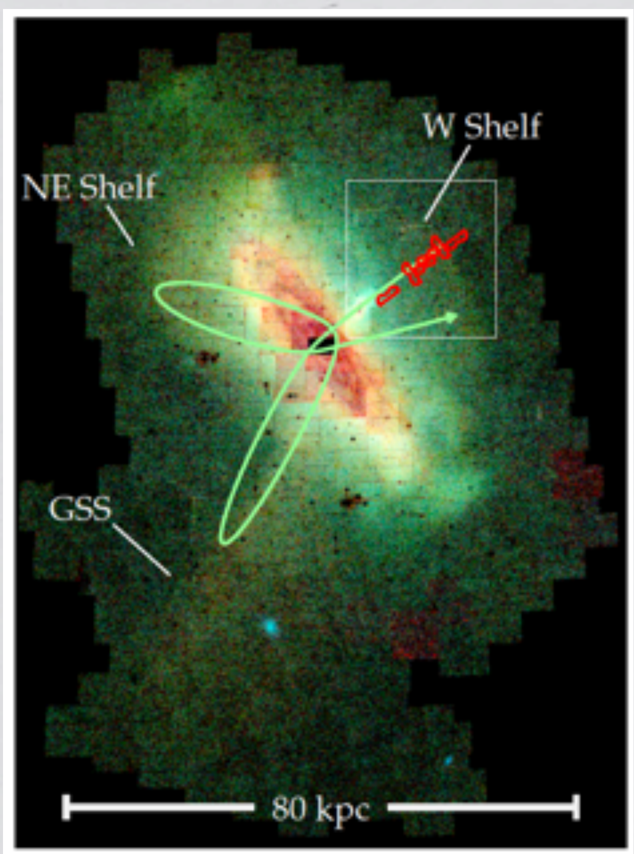
SPLASH: Spectroscopic and Photometric Landscape of Andromeda's Stellar Halo

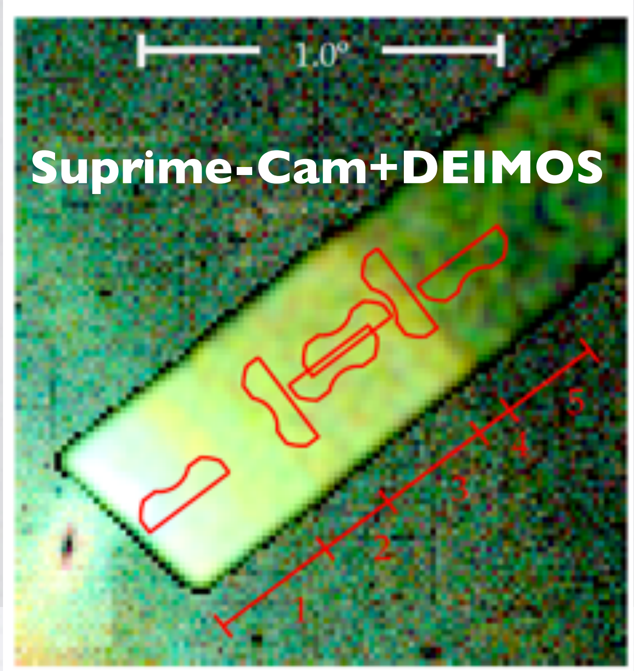


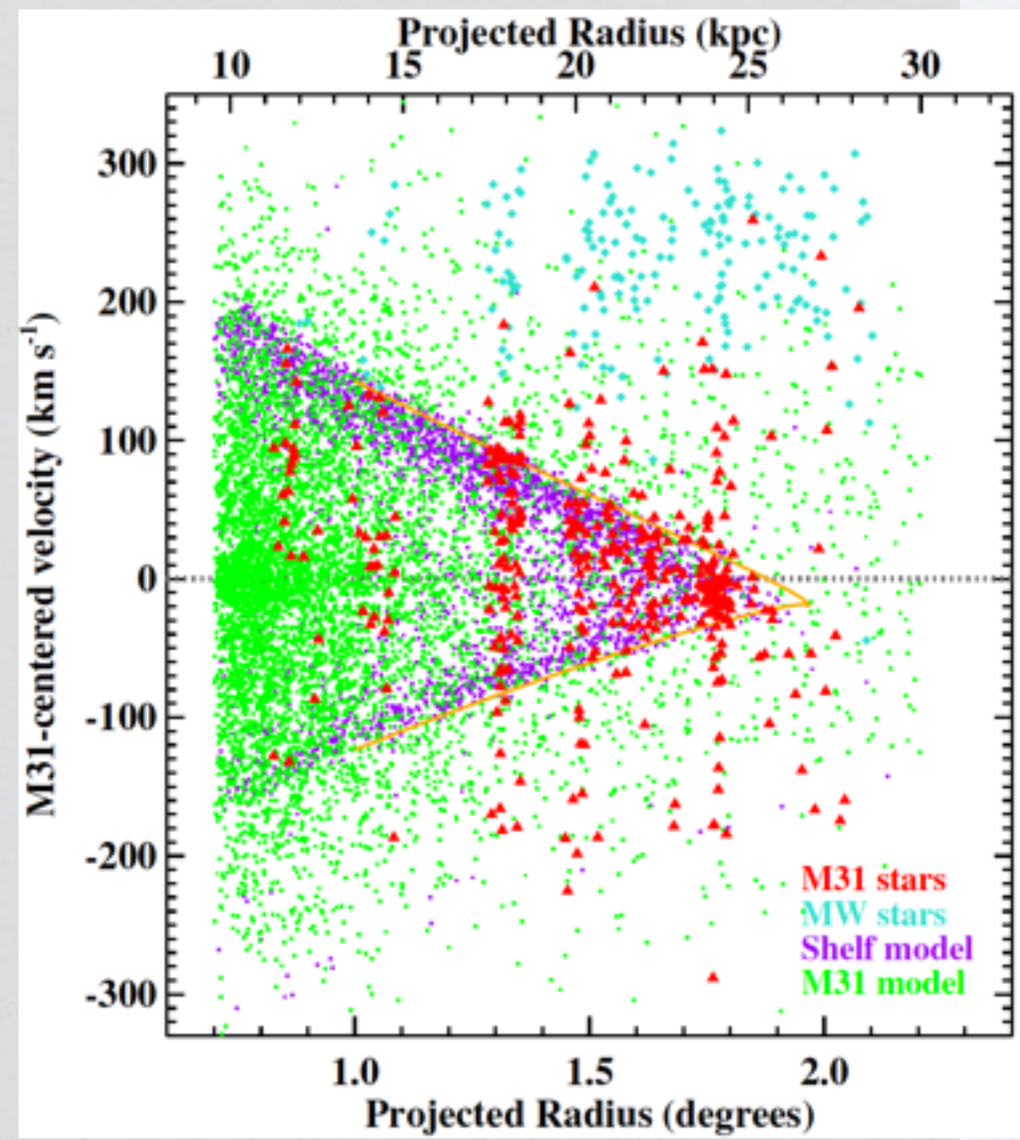
Red rectangles show current DEIMOS fields.

Fardal+12. (incl. Tanaka)

Fardal+12 conducted Keck/DEIMOS spectroscopic observations of W Shelf using our Suprime-Cam samples. We suggest that W-shelf may have the same origin as the Giant Southern Stream. One of the most interesting things in this study is that we more clearly separated stars of substructures with M31's halo stars as well as MW's dwarf stars by comparing N-body simulation to calculate the orbit of the progenitor of Giant Southern Stream and W Shelf. In the right panel, the red points overlapping on simulated purple points suggest stars of W Shelf. On the other hand, the other red points show M31's halo stars.





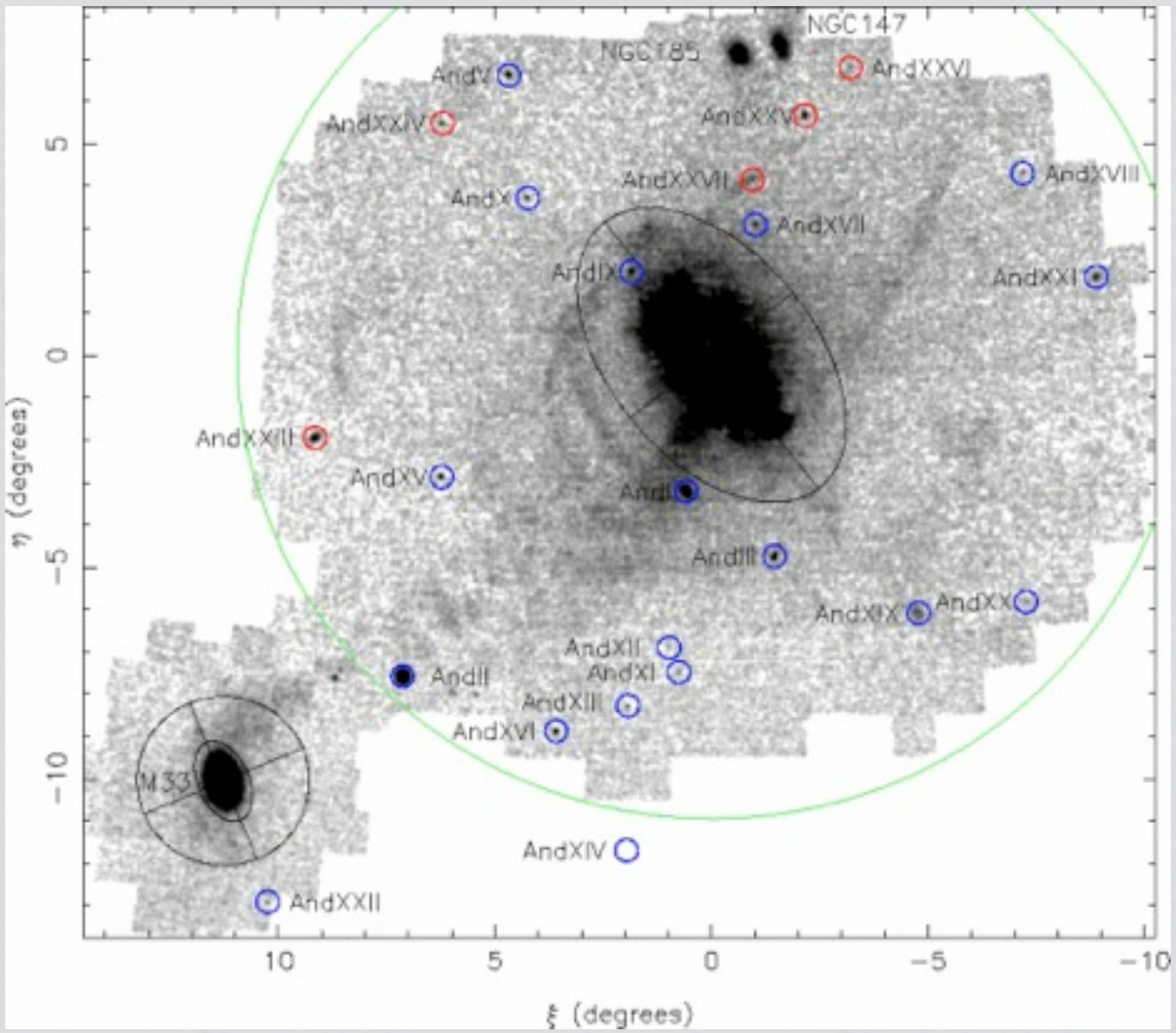


CURRENT ISSUES

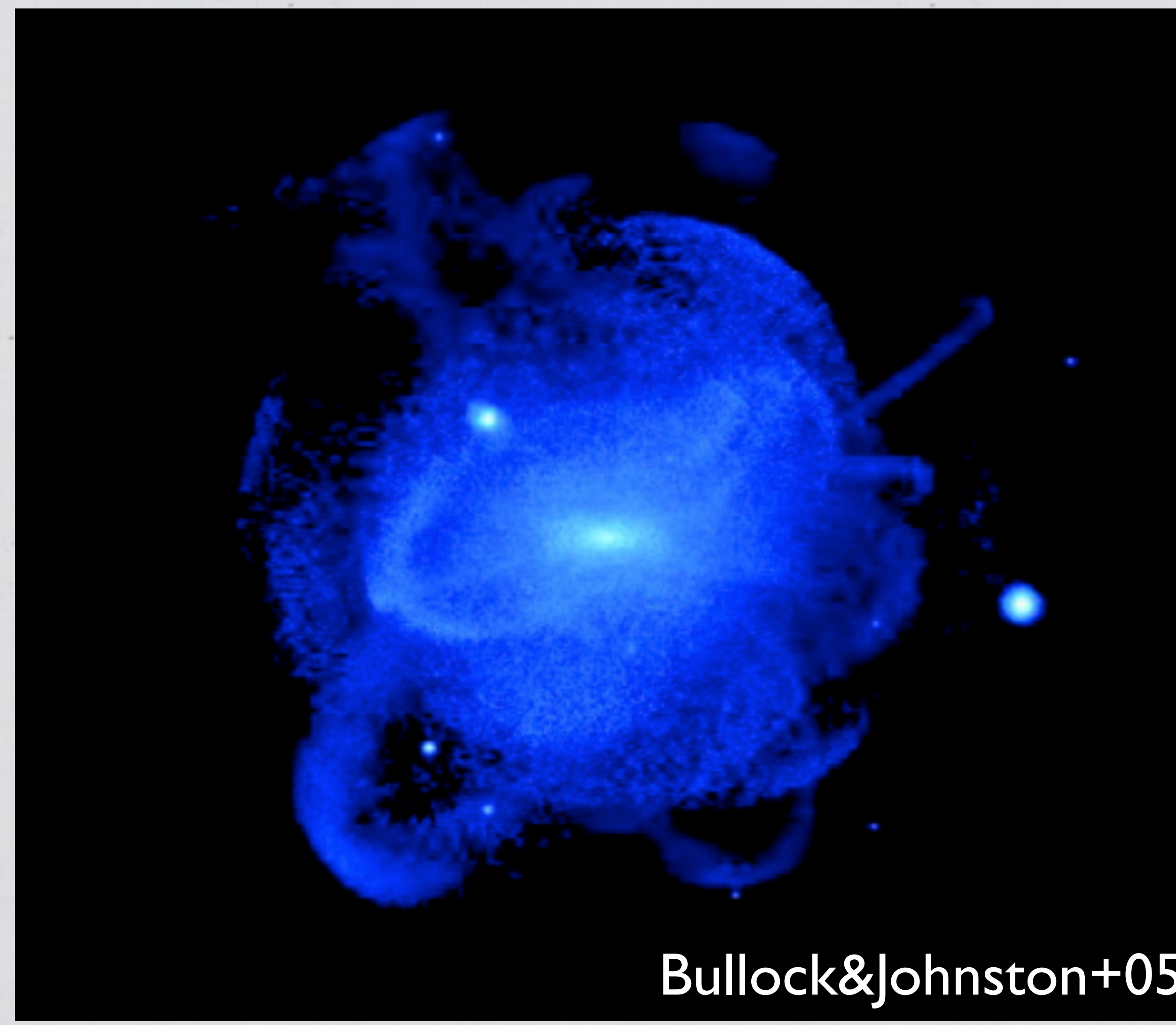
Observations about M31's halo have been dramatically advancing for the last decade. Some of people may say that they largely understood structure and formation of M31's halo. But, one thing we can surely say is that M31 has been forming through hierarchical merging events of many dwarf galaxies. We don't know well about origins of the substructures and the classical halo. From now, exploring M31's halo to discuss about a general formation history of galaxies is the most realistic approach and become more and more important, because M31 is the easiest object to investigate its fine structure using current and upcoming telescopes and instruments. So, we'd like to summarize the most significant problem we have to solve in the next decade.

Inconsistency between observations and simulations.

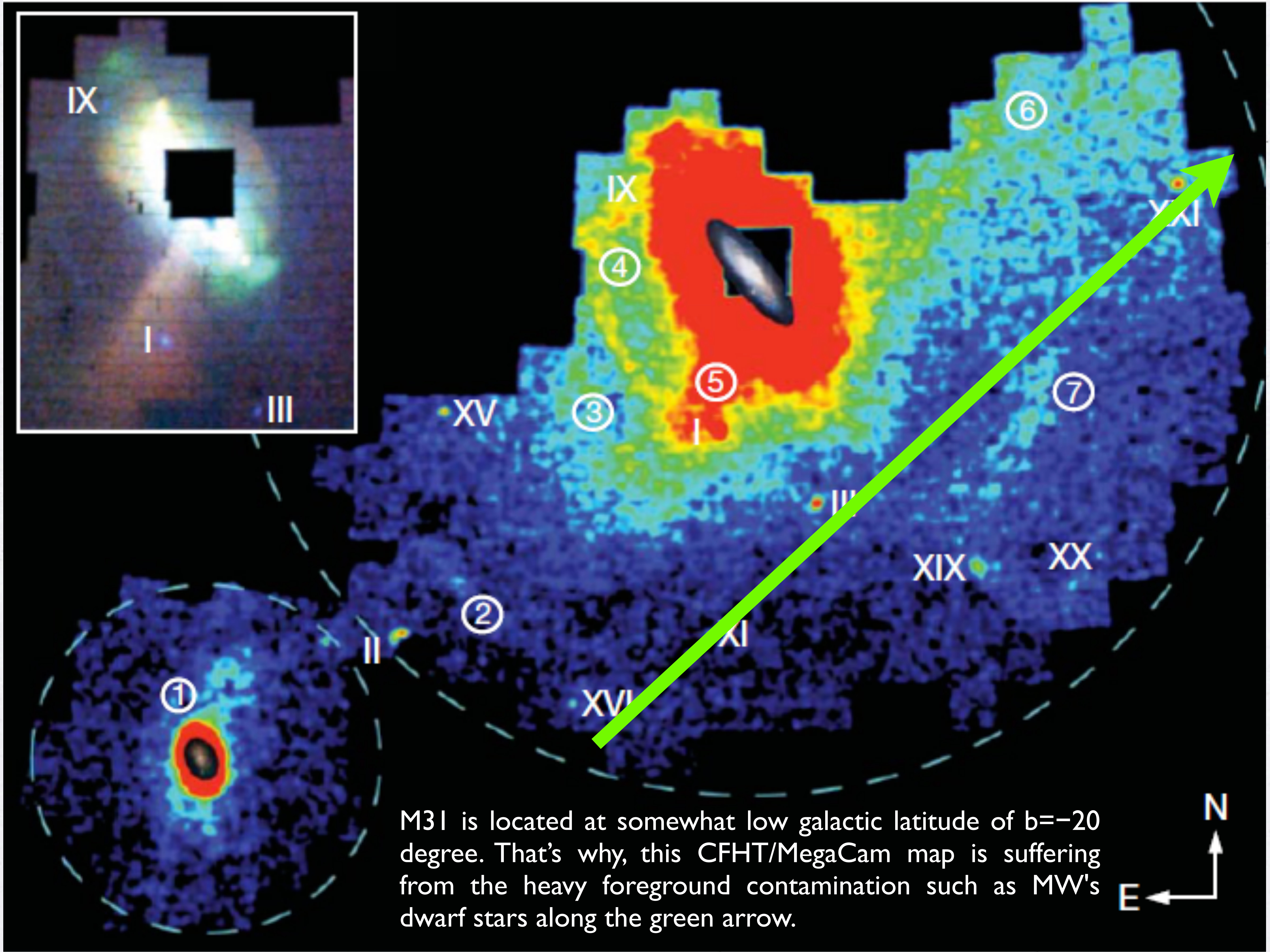
Observation



Simulation



Apparently, CFHT/MegaCam's map lacks about 10 times as many substructures as the numerical simulation.

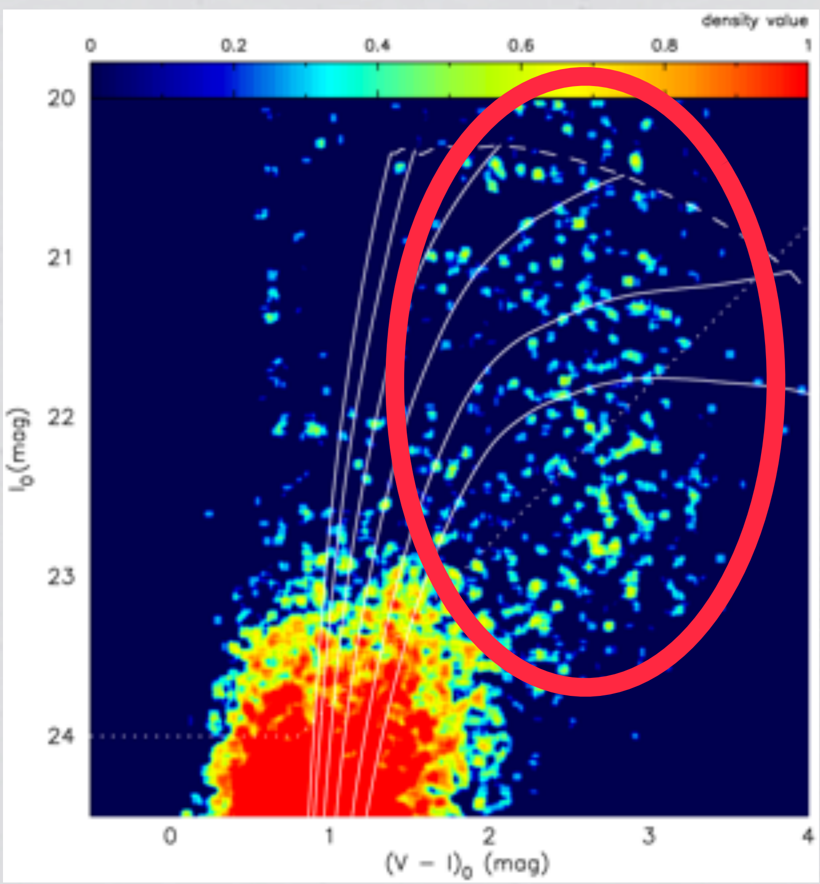


M31 is located at somewhat low galactic latitude of b=−20 degree. That's why, this CFHT/MegaCam map is suffering from the heavy foreground contamination such as MW's dwarf stars along the green arrow.

Contamination (MW dwarf stars)

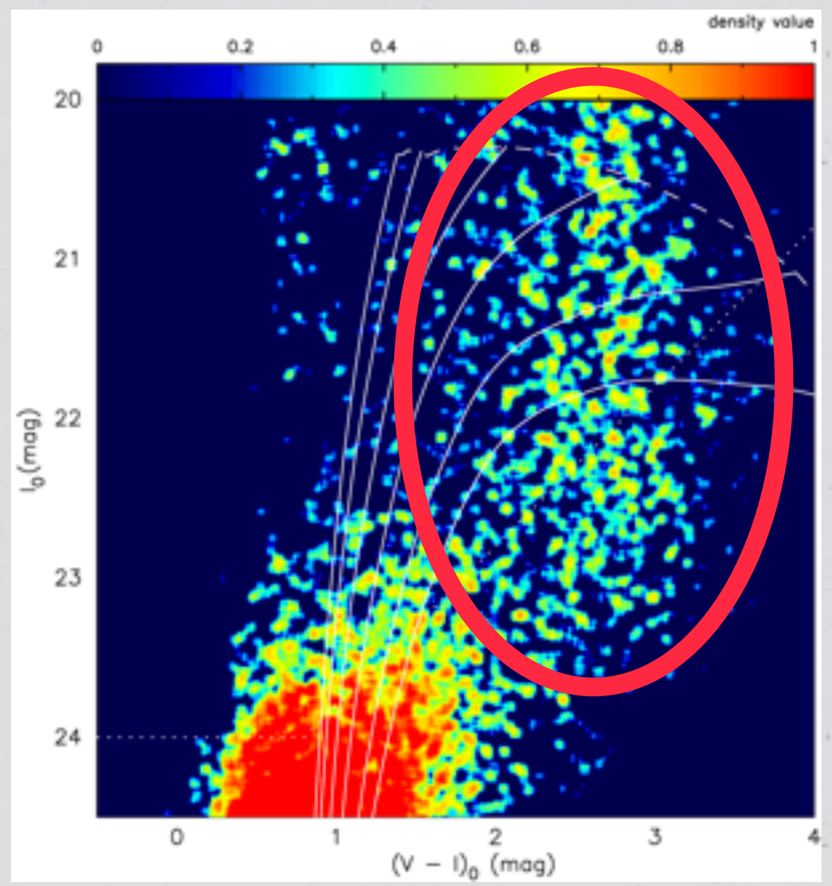
Tanaka+10

b=−25°



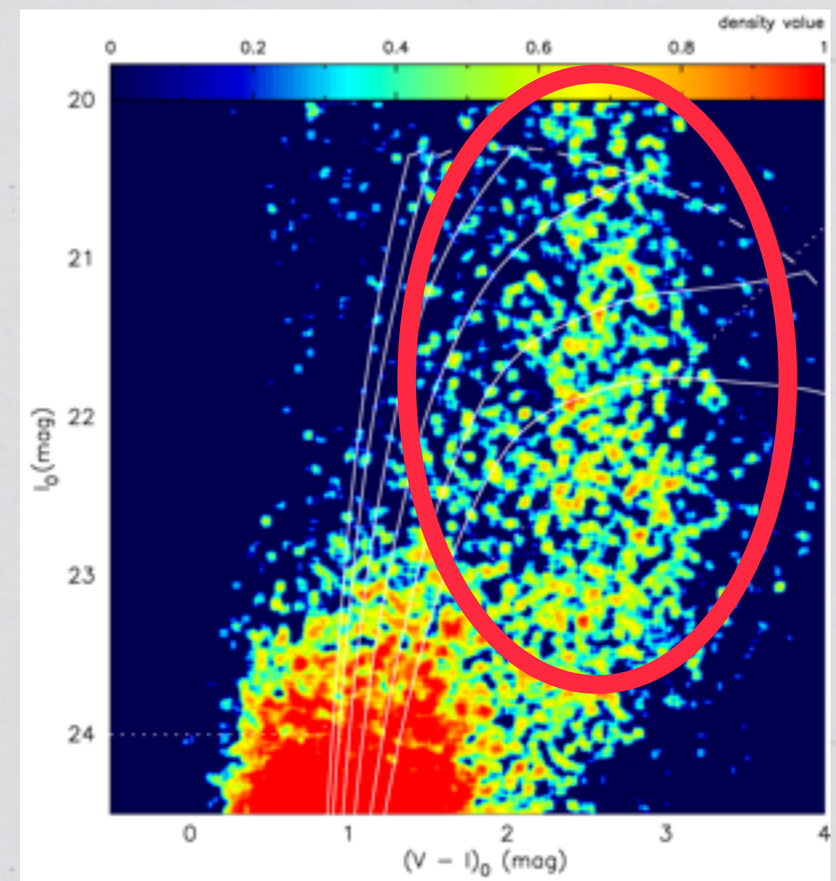
SE@90kpc

b=−21°



M31's center

b=−17°



NW@90kpc

You can make sure of the fact from these CMDs in the control field. There are dwarf stars in these red circles. It looks like that the number gradually increases with decreasing galactic latitude.

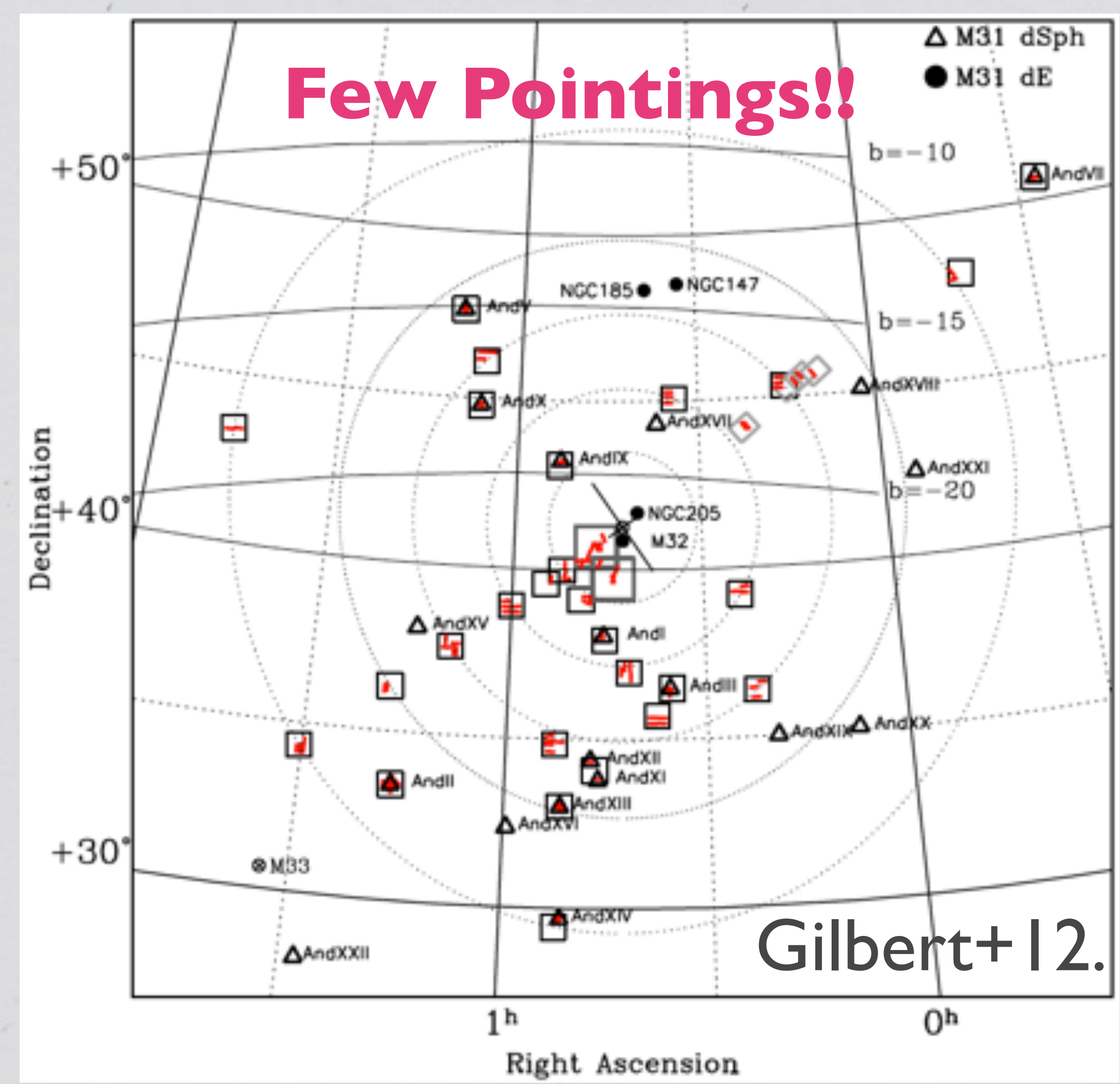
Gilbert+12. (incl. Tanaka)

Here, we introduce one example which suffers from the contaminations and another trouble.

Gilbert+12 (including Tanaka and Chiba) spectroscopically identified the existence of M31's population out to a projected radius of 180 kpc (farthest!!). On the other hand, we cannot kinematically detect substructures which Tanaka+10 detected as Stream E and F, although Stream F was also clearly detected by CFHT/MegaCam survey of Richardson +11. The inconsistency could be due to such heavy contaminations.

Furthermore, current spectroscopic sample is very small, as you can see DEIMOS fields in the right panel. That's why, exploring the remote outer region of M31's halo is still quite limited.

SPLASH: Spectroscopic and Photometric Landscape of Andromeda's Stellar Halo



Red rectangles show current DEIMOS fields.

Issue

* Due to such contaminations and small spectroscopic sample, our understanding of the density distribution in the outer region of M31 is not enough, even if accounting the number of stars is the easiest way. Even more difficulty we cannot determine distributions of fundamental properties such as metallicity and age which are important clue to study history of M31's halo. If we determine global distributions of these parameters, we need deep and particular wider observations. However, no one can do so using current instruments. How should we do?

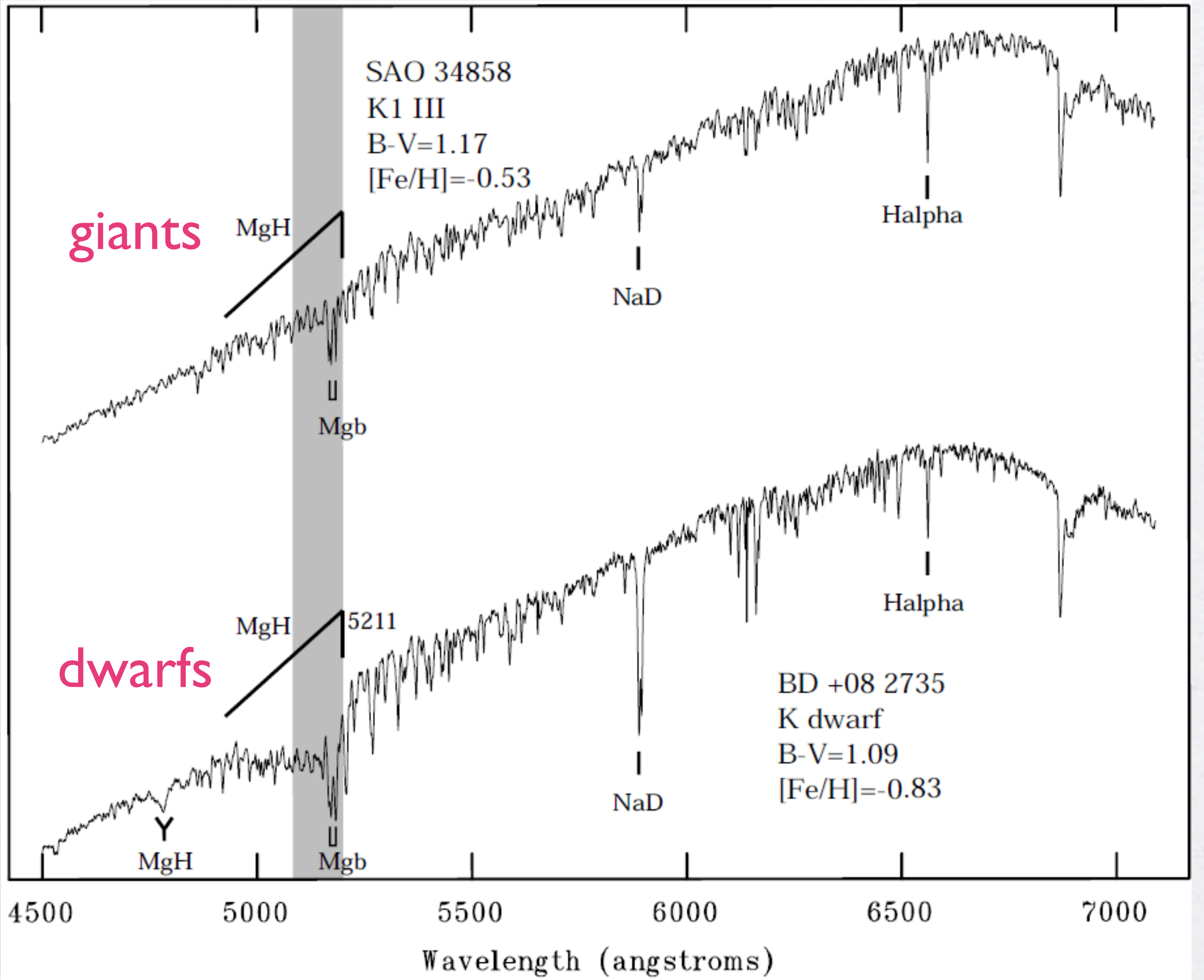
SOLUTION

In order to solve these complicated issues, we propose observations of M31's stellar halo using Hyper Suprime-Cam (HSC) and Prime Focus Spectrograph (PFS), which are next generation instruments installed on Subaru telescope.

How to segregate M31's red giants from MW dwarf stars.

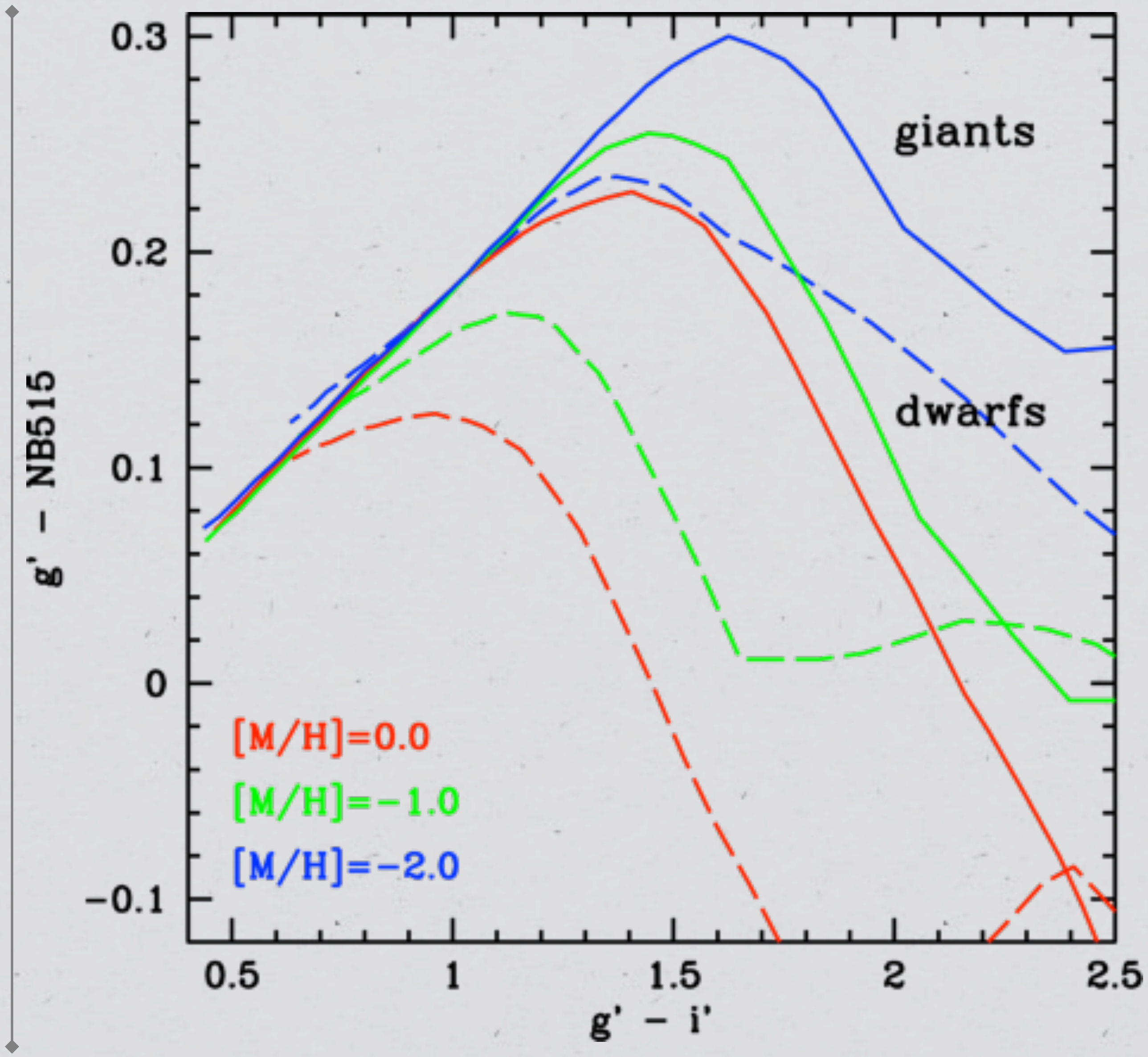
- In order to take clean sample of M31's halo, we take advantage of the difference of Mg absorption line between giants and dwarfs.

Majewski+00.



How to segregate M31's red giants from MW dwarf stars.

* Narrow band filter, NB515, enables us to quantitatively evaluate such difference on the right color-color diagram. You can see red giants well separate from dwarf stars at low metallicity range. We ordered NB515 filter for HSC last year. So, we'll be able to use it soon. (PI:Chiba)

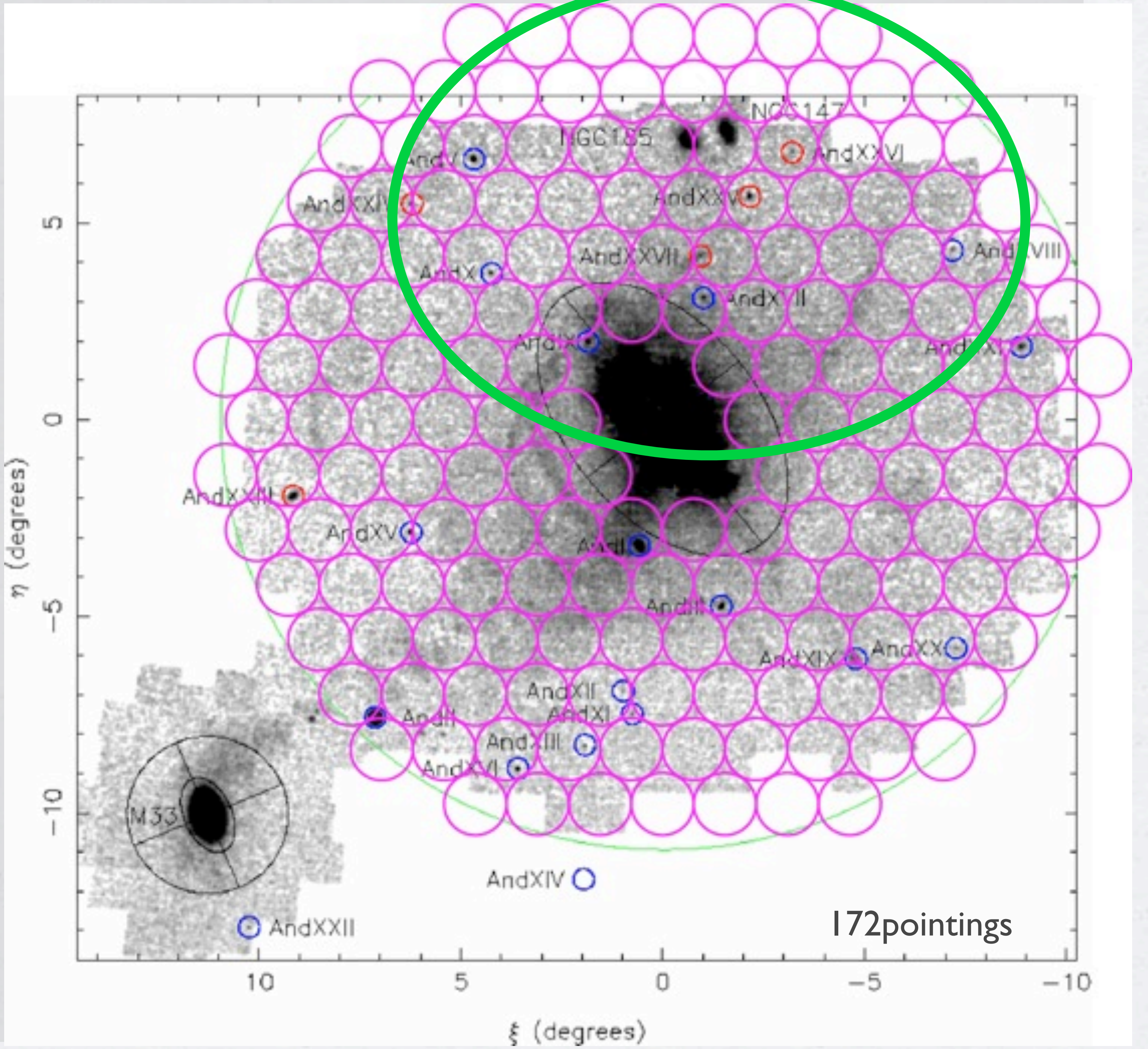


Color-color diagram we calculated for HSC survey according to Majewski+00.

HSC Survey of M31's Halo

* Total Area: 304 sq. degree
* Exp. time, Filter and Sensitivity:
  60s (g'), 30s (i') and 1000s (NB515)
  @S/N=10, seeing=0.7"

This is our ambitious HSC survey design covering the whole area of M31's halo.
At a first step, we'll target bright RGB stars using three filters. We need about 30 nights if a whole area survey is permitted.
But, we'll realistically focus on important northern parts of M31 that it's more difficult for CFHT to observe.
When we detect interesting structures, we'll follow up them by deeper and multi-band photometries to separate M31's stars from unresolved background galaxies.
After the HSC survey, we'll get numerous spectroscopic targets. Therefore, PFS is required for further follow-up studies.



PFS Survey Design of M31's Outer Halo.

This is PFS survey design we're planning now (PI:Chiba). It'll be included into Subaru's strategic project if possible. We're planning wide-field spectroscopic survey along M31's minor axis. PFS will measure RVs and [Fe/H] for M31's stars, based on Ca II triplet. After the first result will be made, we'll extend survey area to a whole region of M31's halo.

- Required Observation -

★Spectral mode: Low (with a broad wavelength range) @V < 21.5

★Area: 66 sq. degree (= 50 pointings)

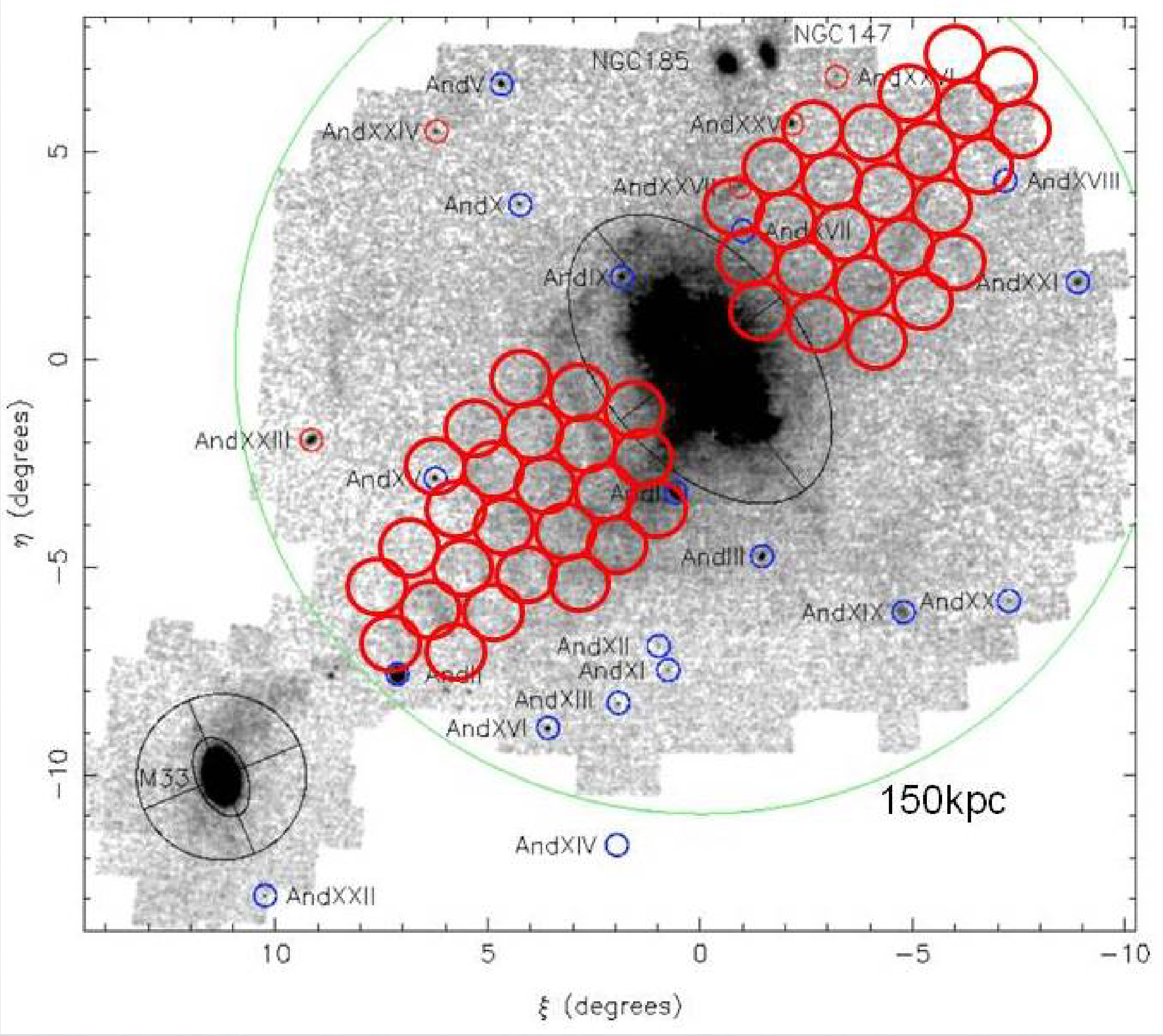
- We can get over hundreds of M31's RGB stars in each pointing.

★Exp. Time: 5 h / pointing

- Total: about 30 nights.

★Sensitivity:

S/N = 20 at λ=5000Å for stars with V=21.5 mag.

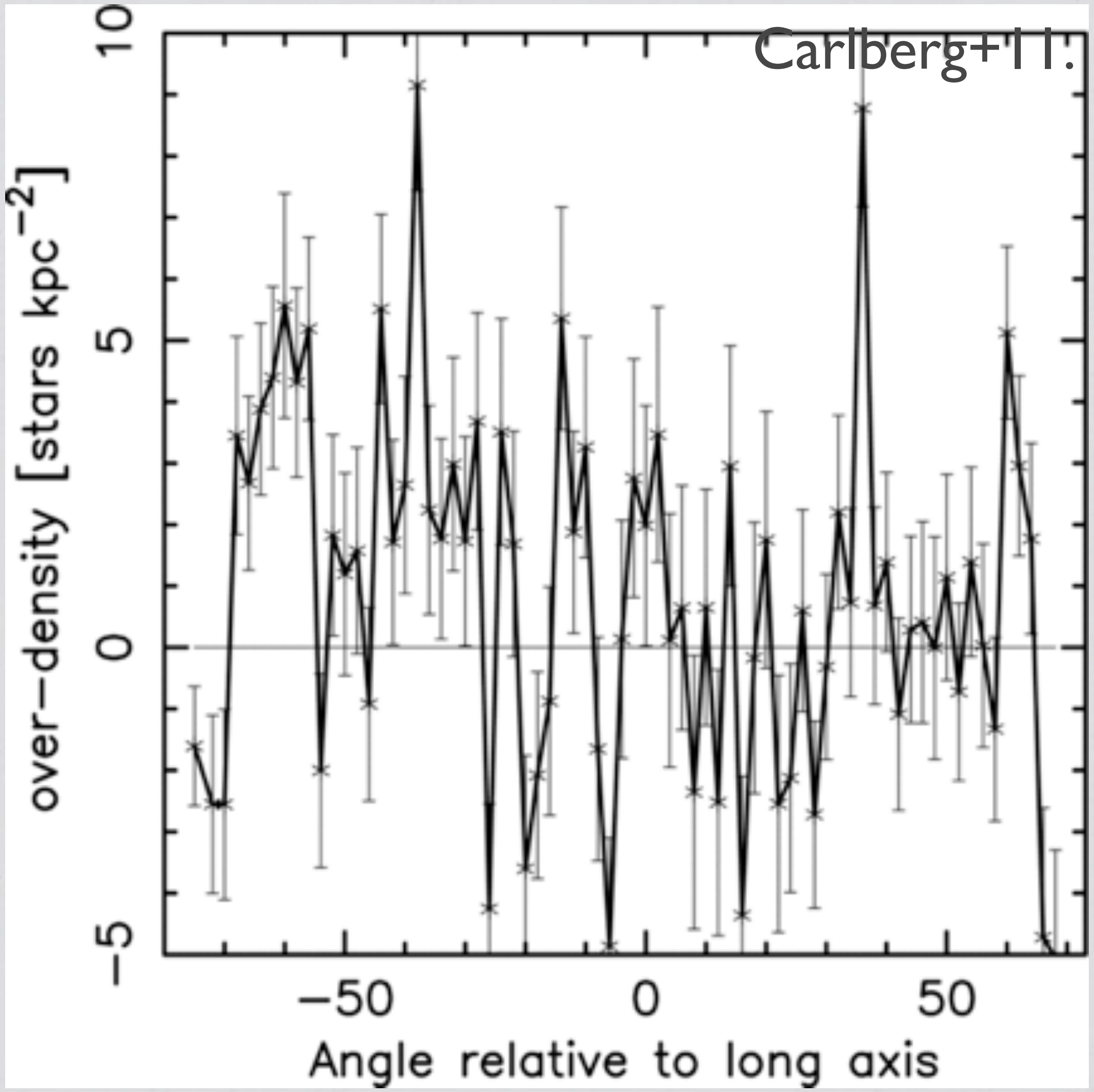


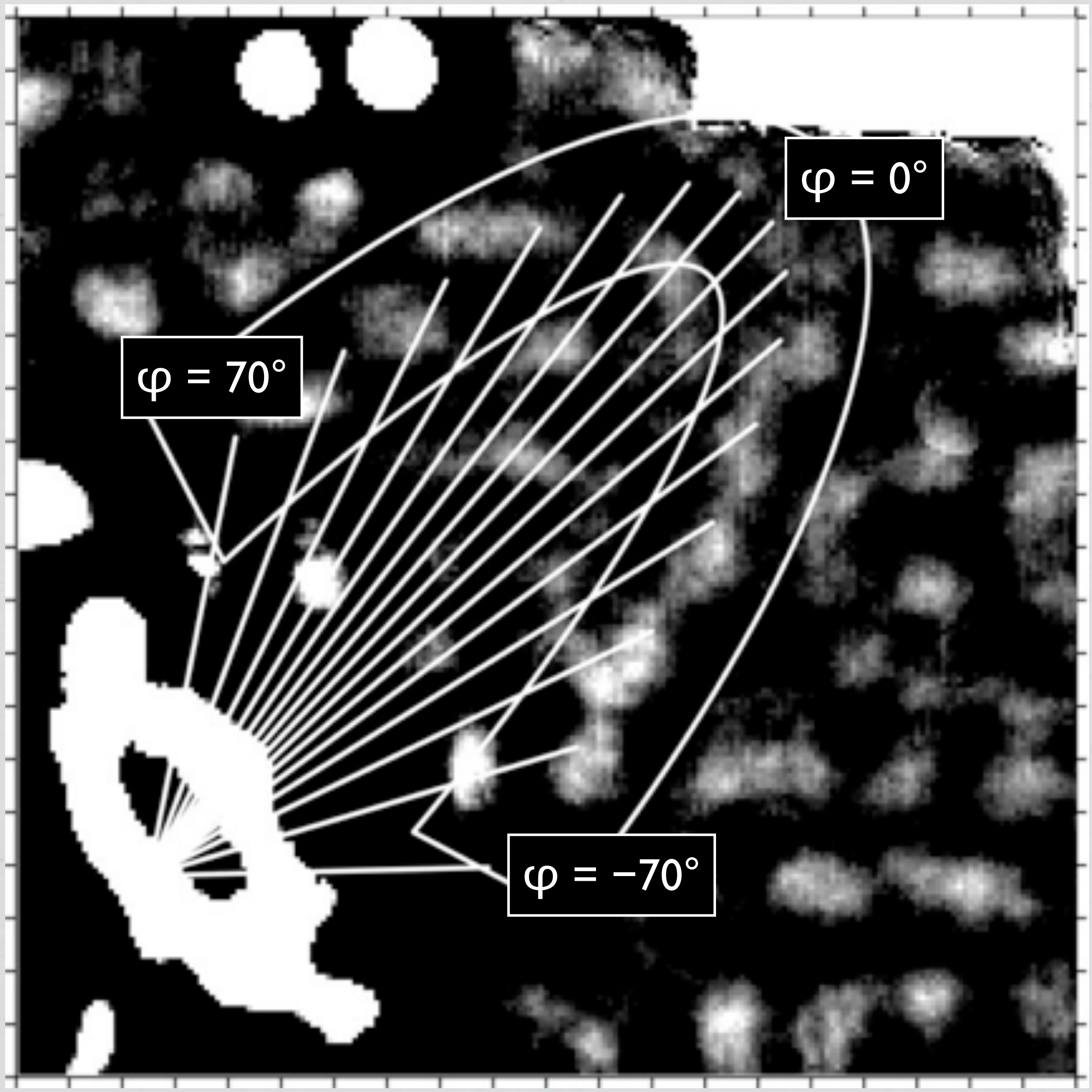
Expected Scientific Results

Based on numerous genuine stars free from contaminations we're going to detect by HSC and PFS, we can verify λCDM cosmology and more restrict the formation and chemo-dynamical evolution of outer halos. Finally, let's mention particular two importance of identifying genuine stars in M31's outer halo.

- To investigate how many dark matter sub-halos M31's halo consists of.
- To constrain structure and formation of a vast M31's halo (substructures + classical smooth halo) based on its genuine RGB stars.

Test ground for the presence of dark sub-halos.



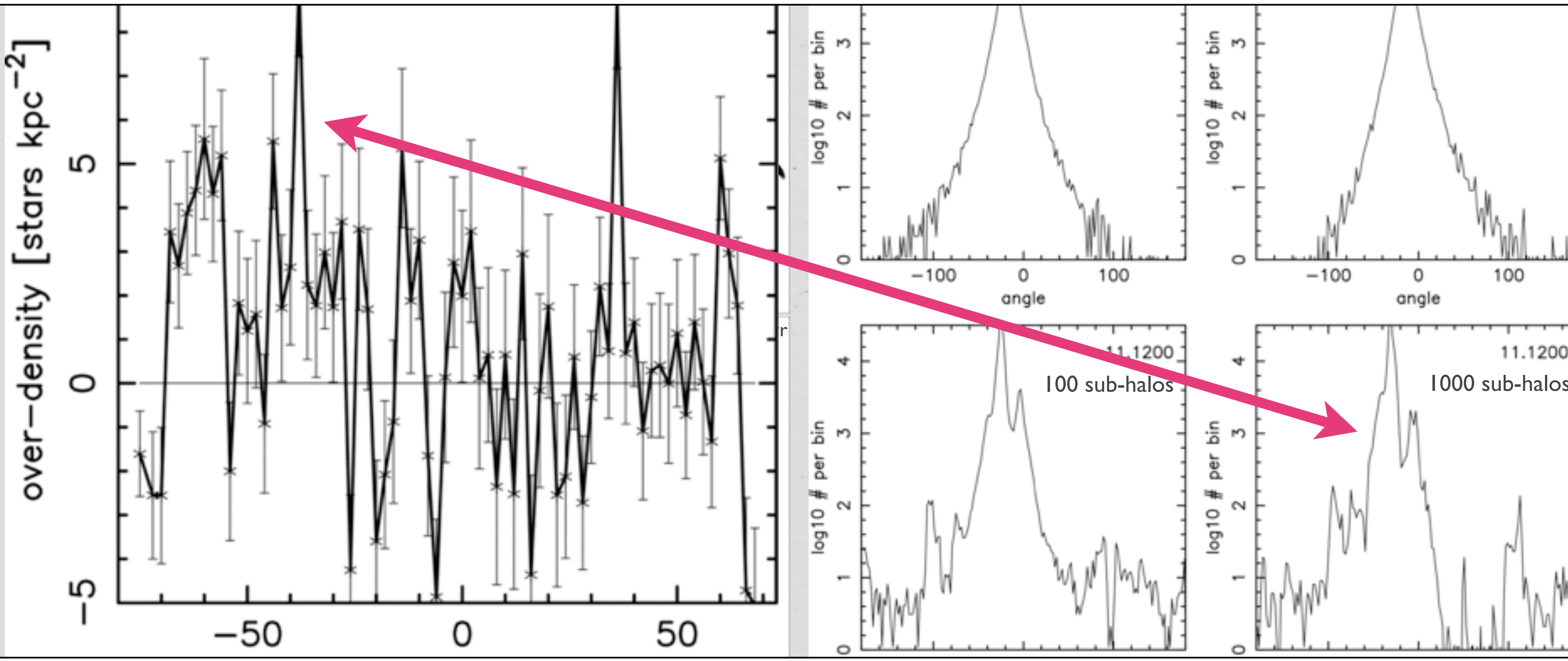


This is a north western map of M31's halo, including NW stream. It looks like a long stellar stream is in left hand panel. I'll show you density distribution along the NW stream. Angle, φ, is defined like the right hand panel. It looks like there are some density variations along the stream.

Test ground for the presence of dark sub-halos.

Carlberg+11.

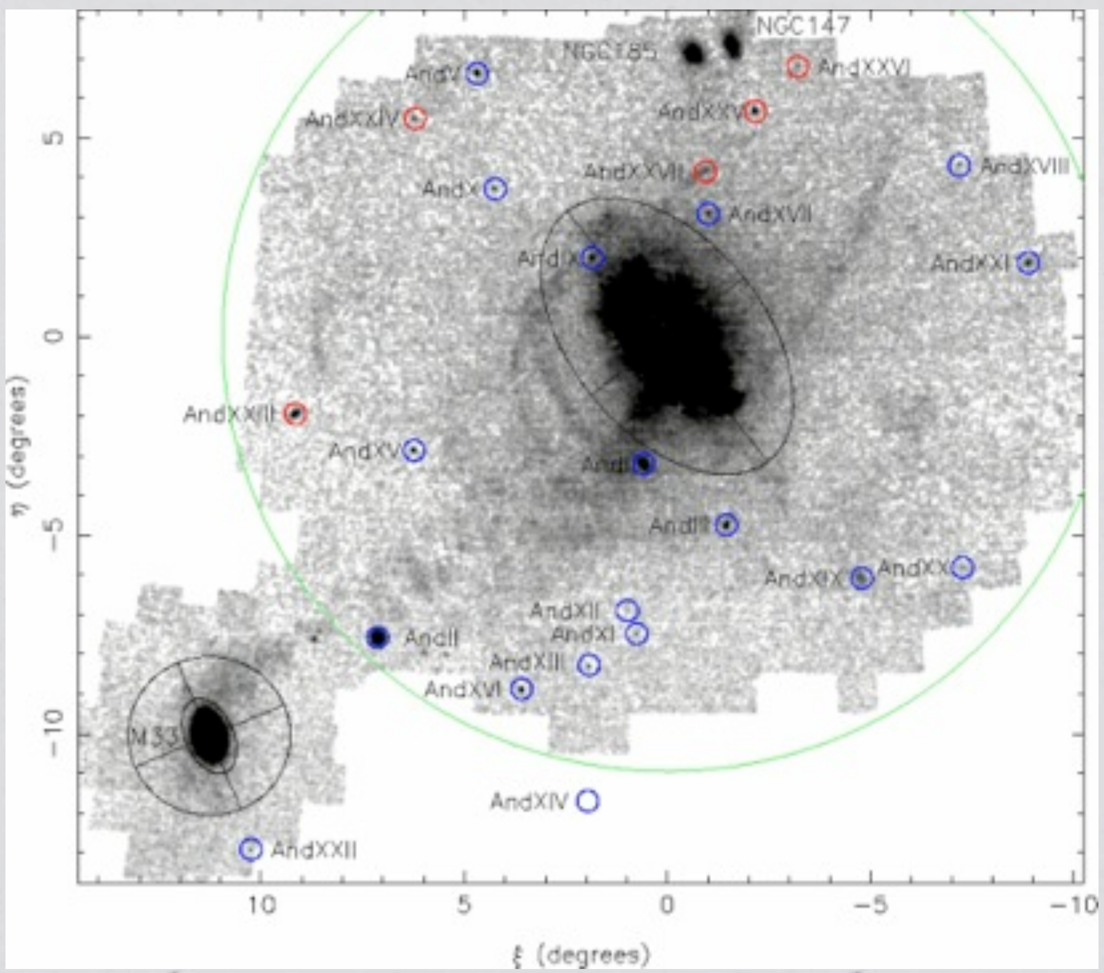
Are the thousands of dark matter sub-halos present in M31's dark halo?



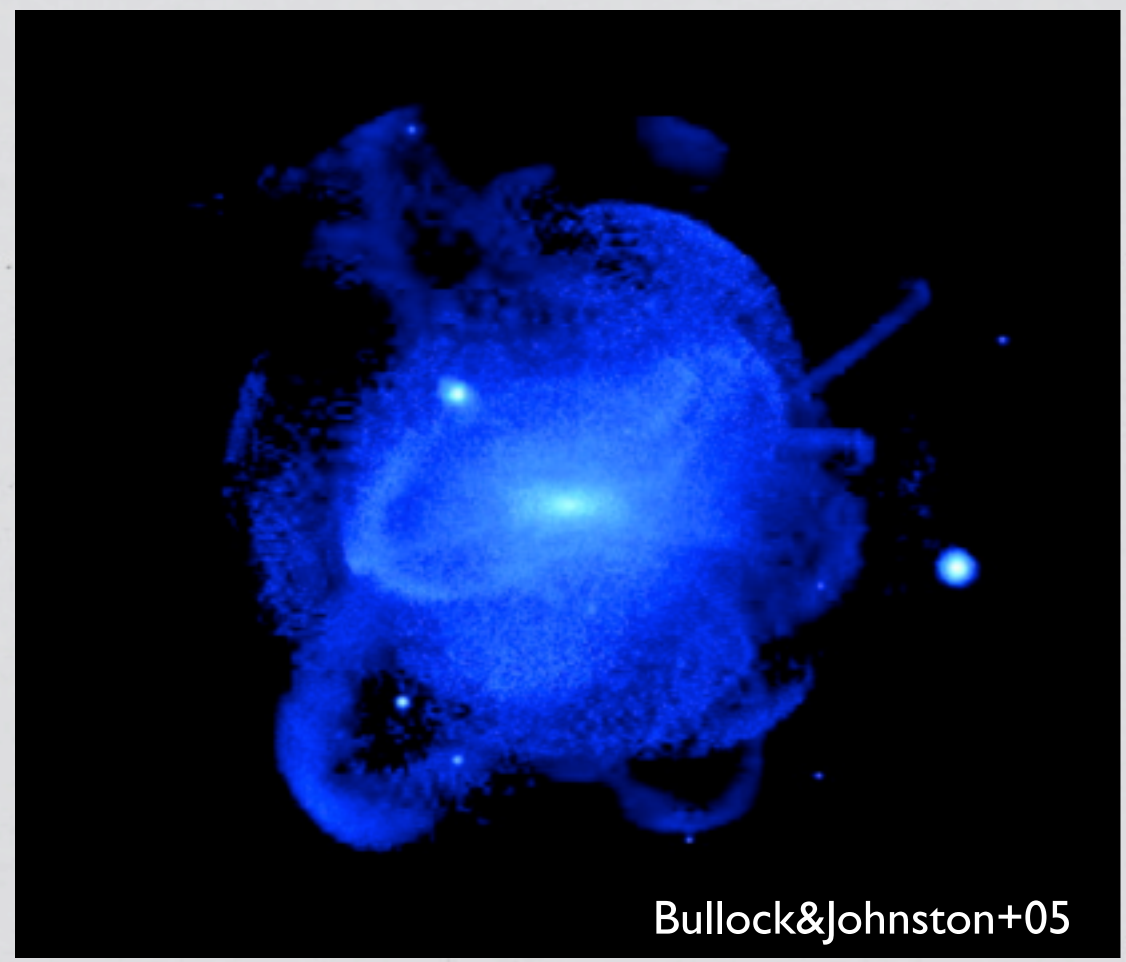
Actually, we cannot definitely answer it yet. Because, it looks like this observational result is quite noisy due to the heavy contaminations. So, we need HSC and PFS observations in order to test the presence of dark matter sub-halos through more precise identifications of M31's stars.

To trace a vast M31's halo (substructures + classical smooth halo) based on its genuine RGB stars.

Observation

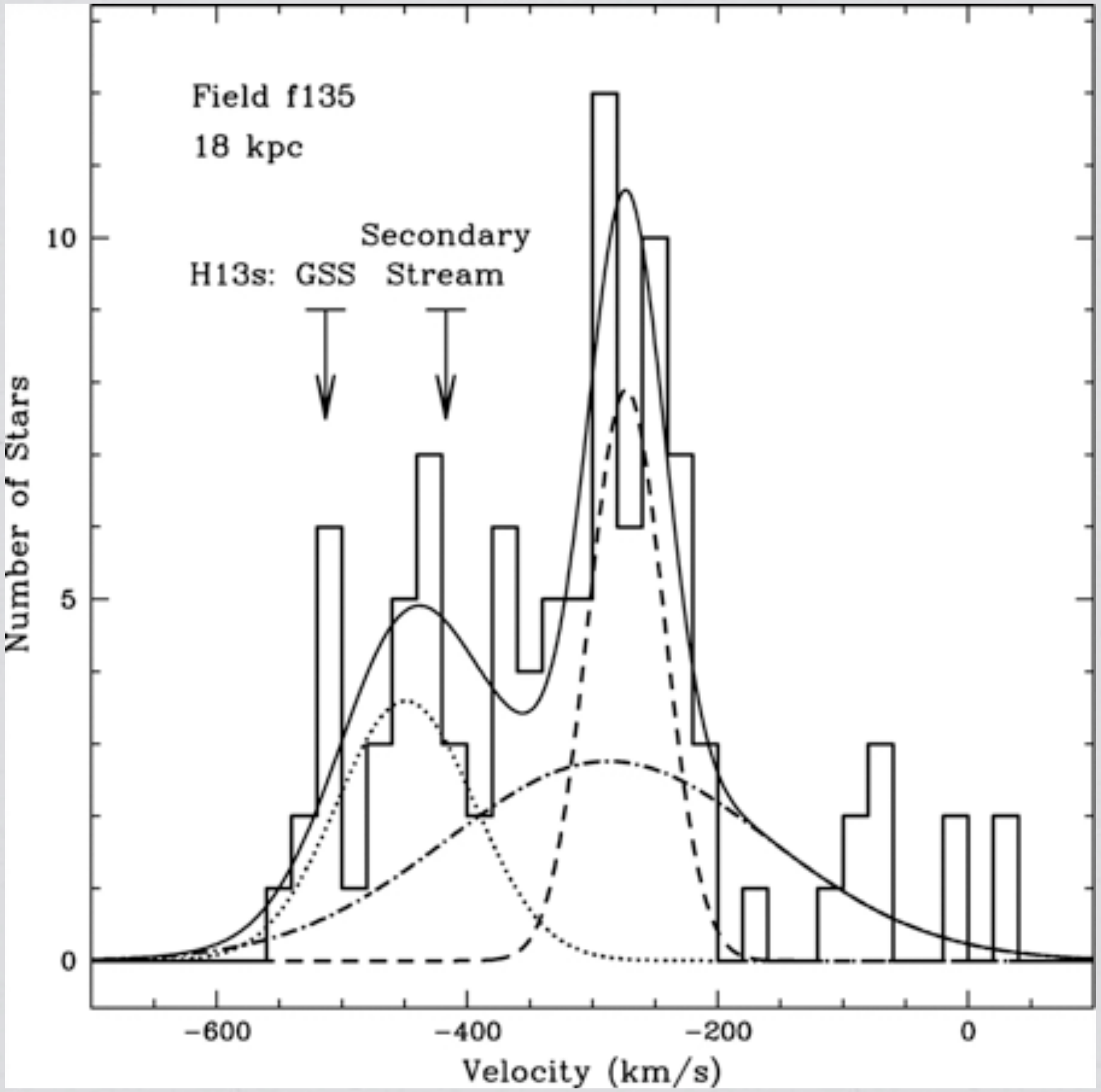


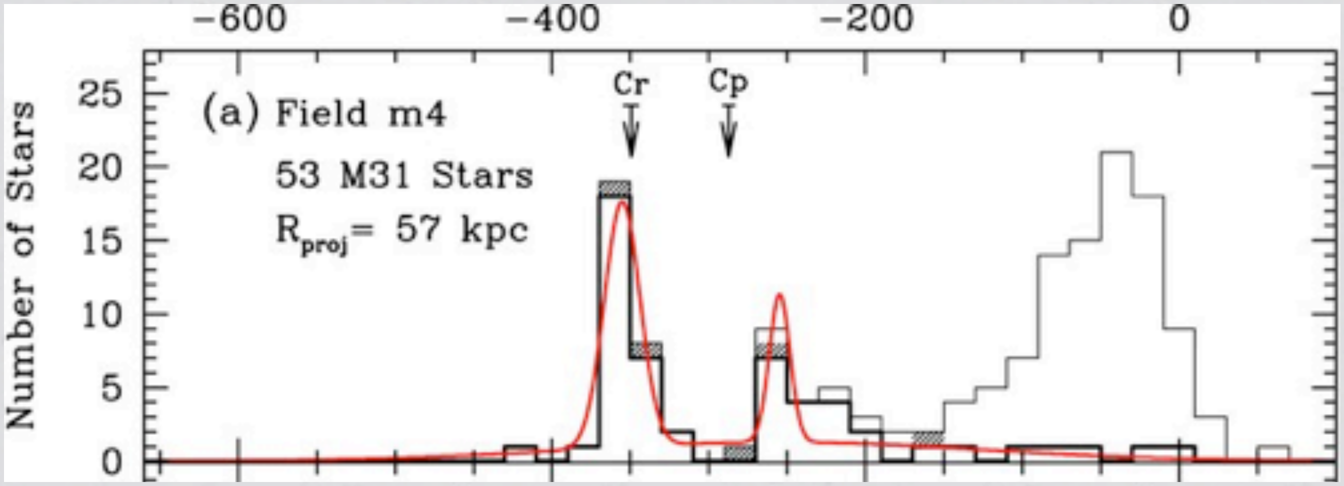
Simulation



Tracing M31's genuine stars by HSC and PFS will resolve the inconsistency between observations and simulations we previously mentioned, that is, the observational result lacks about 10 times as many substructures as the numerical simulations.

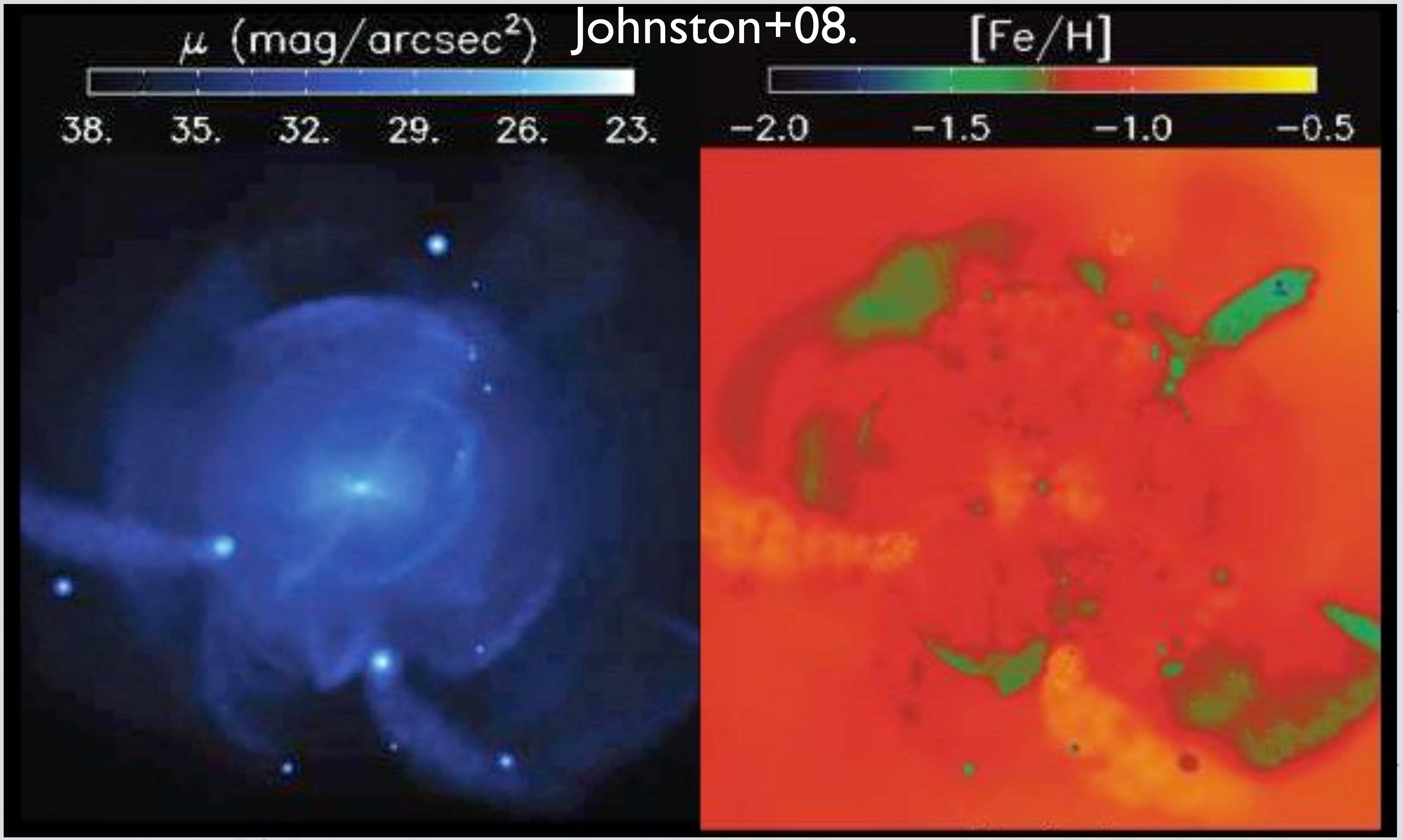
Unknown faint streams are detected as kinematically cold structures





For example, spectroscopic survey enables us to detect fainter substructures because streams are kinematically cold. Actually, our SPLASH group has identified kinematic substructures in M31's halo which previous photometric studies had NOT identified tidal features (Gilbert+07, 09).

Unknown faint streams are detected as abundance space structures

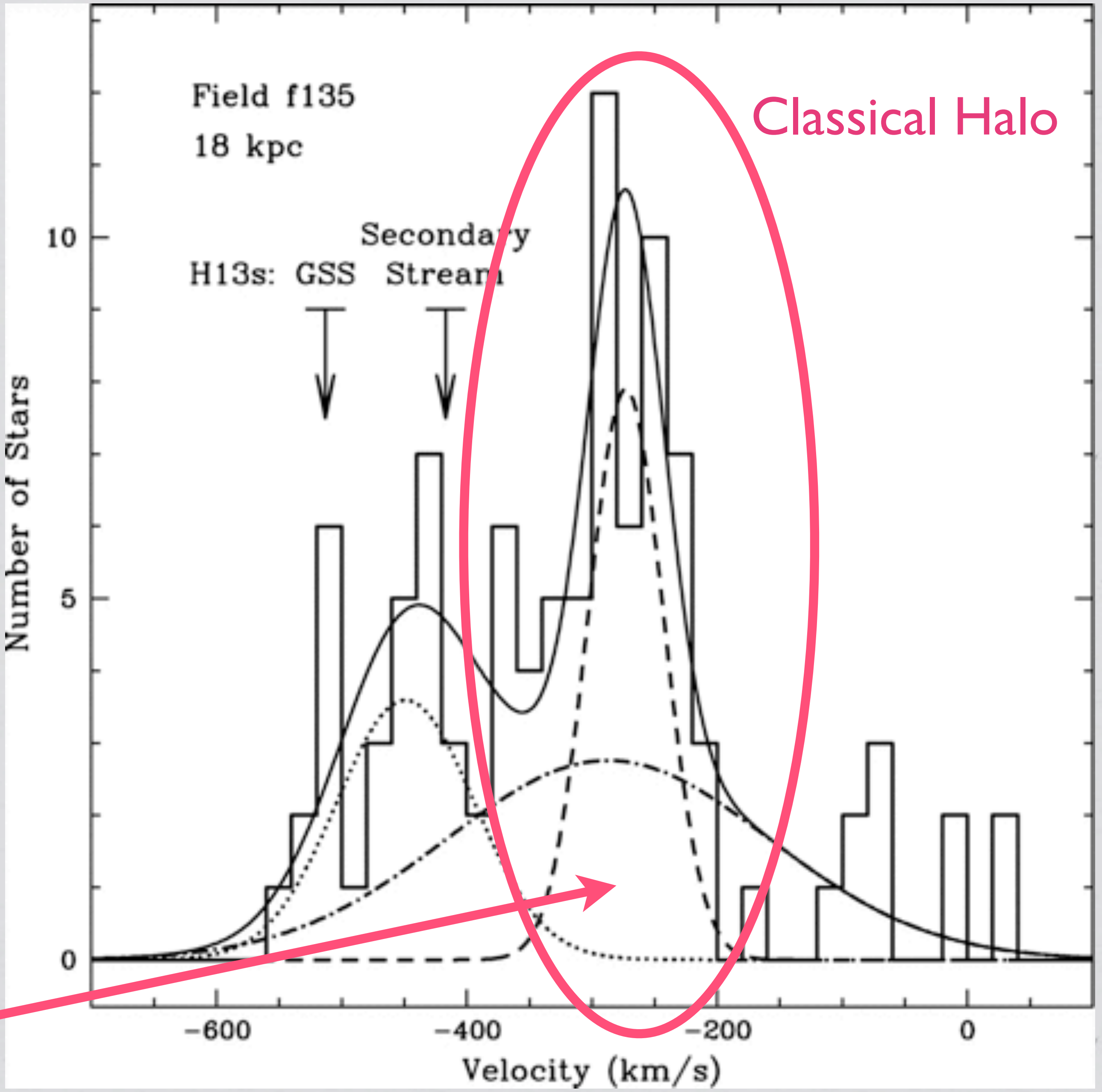


Furthermore, here is the same simulation as Bullock & Johnston+05. It suggests that some substructures are detected in abundance space. But, no one has detected such substructures in M31's halo yet. Therefore, by virtue of the HSC and PFS survey, the number of faint substructures of M31 may increase more and more.

What's M31's classical halo like?

The classical halo means an old spheroidal component which formed in the early universe and has been virialized. Therefore, it seems like its density distribution is kind of smooth. Unfortunately, we don't know M31's classical halo well. Because it's quite difficult to trace it since M31's halo is filled with numerous substructures.

As identifying a substructure as a kinematically cold component from information of radial velocity, we can separate stars of the classical halo from stars of substructures and the other contaminations. The velocity distribution of the classical halo has a broad gaussian centered at about -300 km/s.



What's M31's classical halo like?

We have a lot of issues about M31's classical halo.

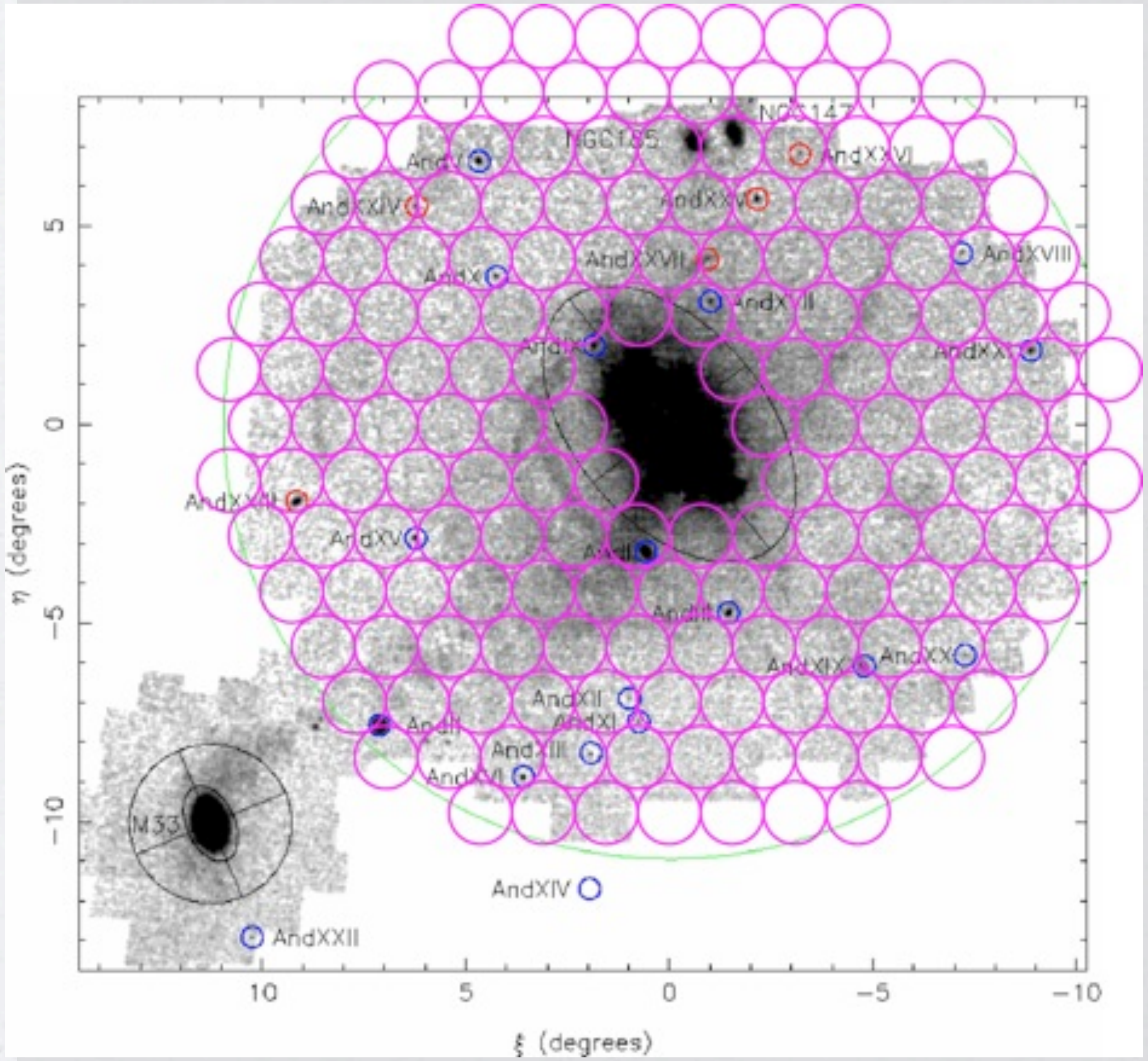
- How many substructures does it have?
- What's the stellar density profile like?
- What's shape?
- How big?
- How much metal?
- Does it have metallicity gradient?
- How old?

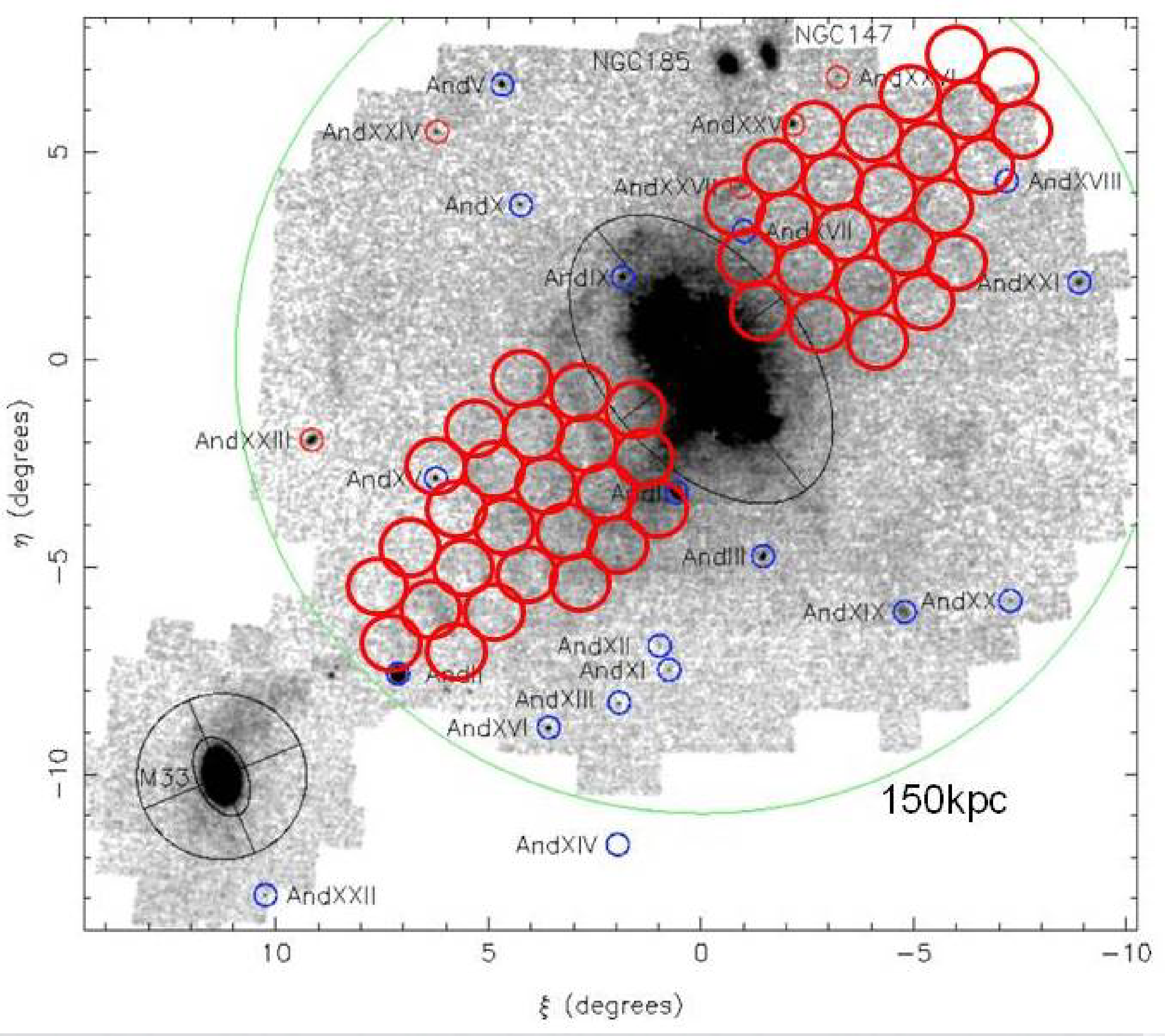
These structural information are really important to understand the formation history of stellar halos.

Thank you for your attention.

HSC (From 2012?)

PFS (From 2017?)





For fully untangling M31's haunted halo, I hope that HSC and PFS will work soon!!

Thank you for your attention.