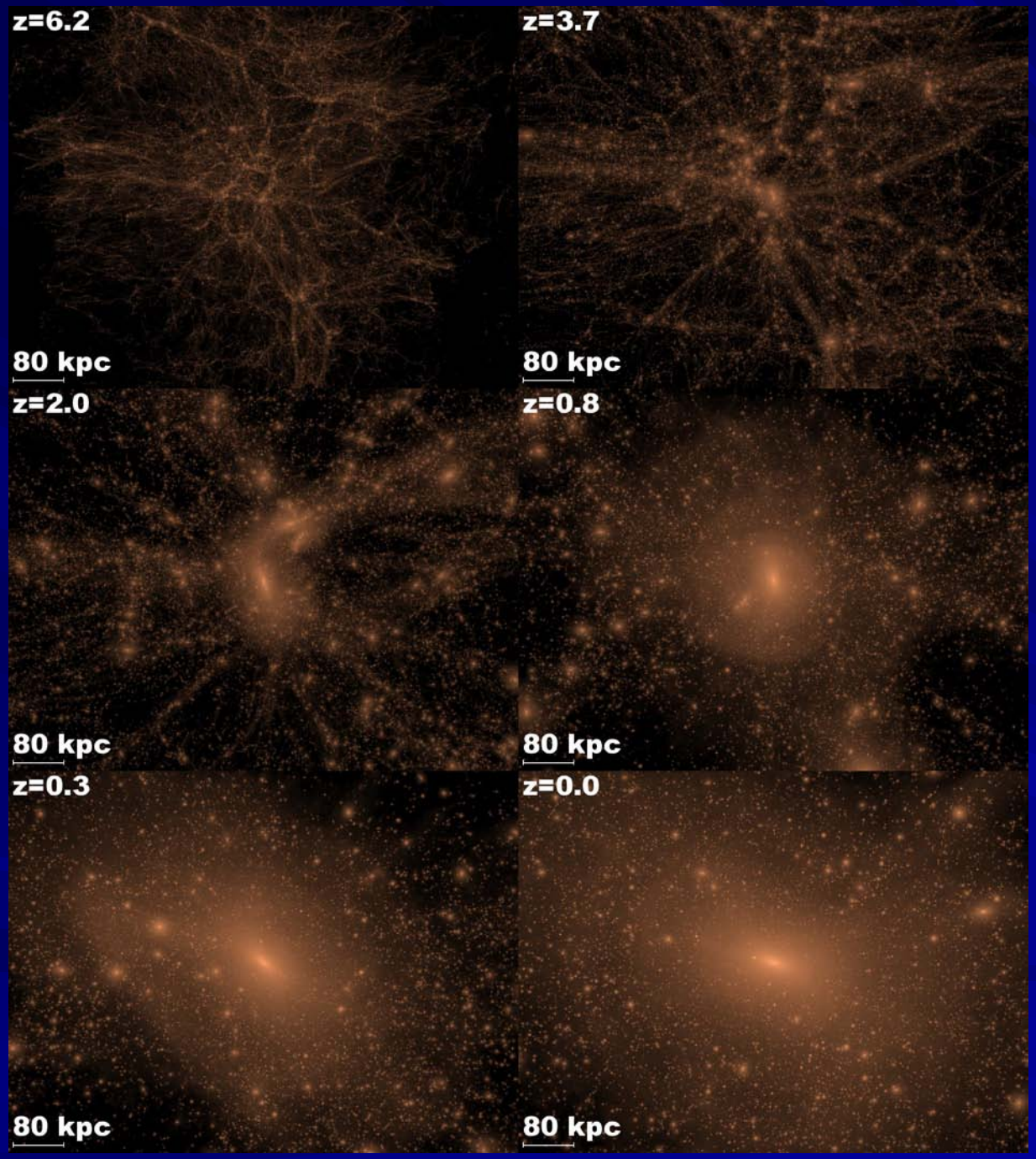
近傍宇宙論
~ Mapping old stellar populations of Local Group galaxies ~

千葉柾司
(東北大学)



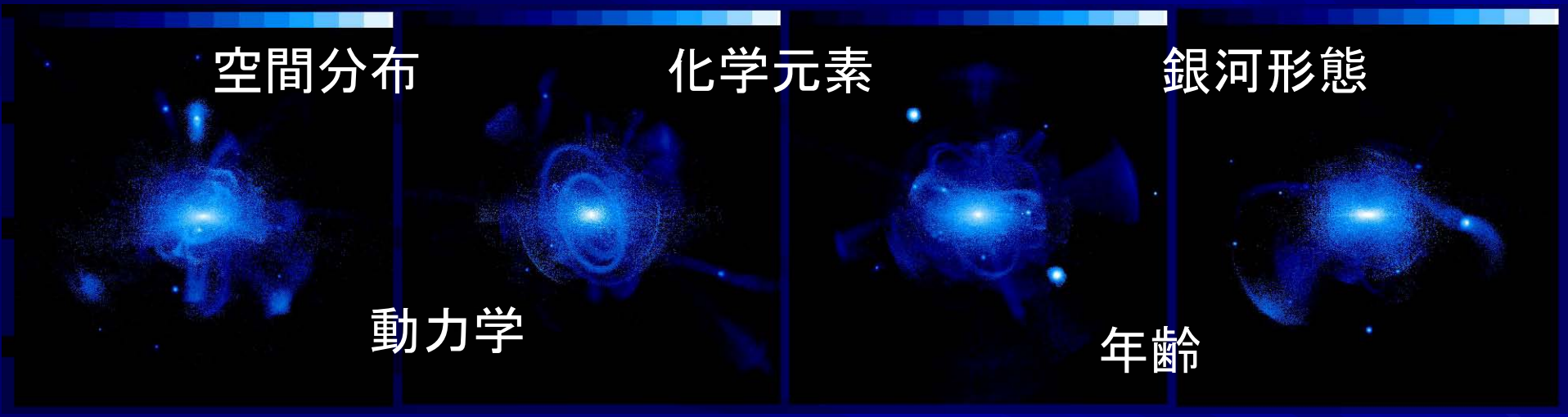
ΛCDM

- ✓宇宙の大構造
- ✓銀河の形成進化
- ✓銀河の動力学
- ✓銀河の形態

Diemand+

恒星系(ハロー)の分布

Bullock & Johnston 2005



- 階層的合体を伴う銀河形成過程
- 暗黒物質の動力学構造

銀河形成の痕跡:恒星分離に基づく銀河形成史

恒星分離に基づく銀河形成史

- Photometry：
  - ✓等級、色 (→ 色-等級図)、空間分布
- Spectroscopy：
  - ✓[Fe/H], V_{rad} (→化学動力学)
  - ✓化学元素パターン (→ 星形成・化学進化)
- Astrometry：
  - ✓固有運動、距離 (→ 6次元位相空間分布)

Subaru/HSC

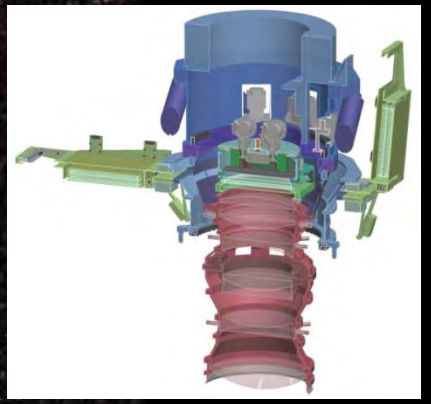
Subaru/PFS

Gaia

動力学構造、星形成、化学進化の情報

⇒ 銀河の形成と進化

HSC



Wide-field FoV is essential for mapping stars

超広視野の重要性

M33

アンドロメダ ハローの大きさ

By Raja

HSCによる大規模サーベイ

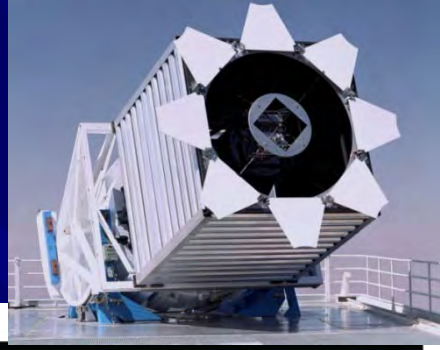
目的:　銀河系ならびにアンドロメダ銀河の
形成史と暗黒物質の詳細な分布を明らかにする

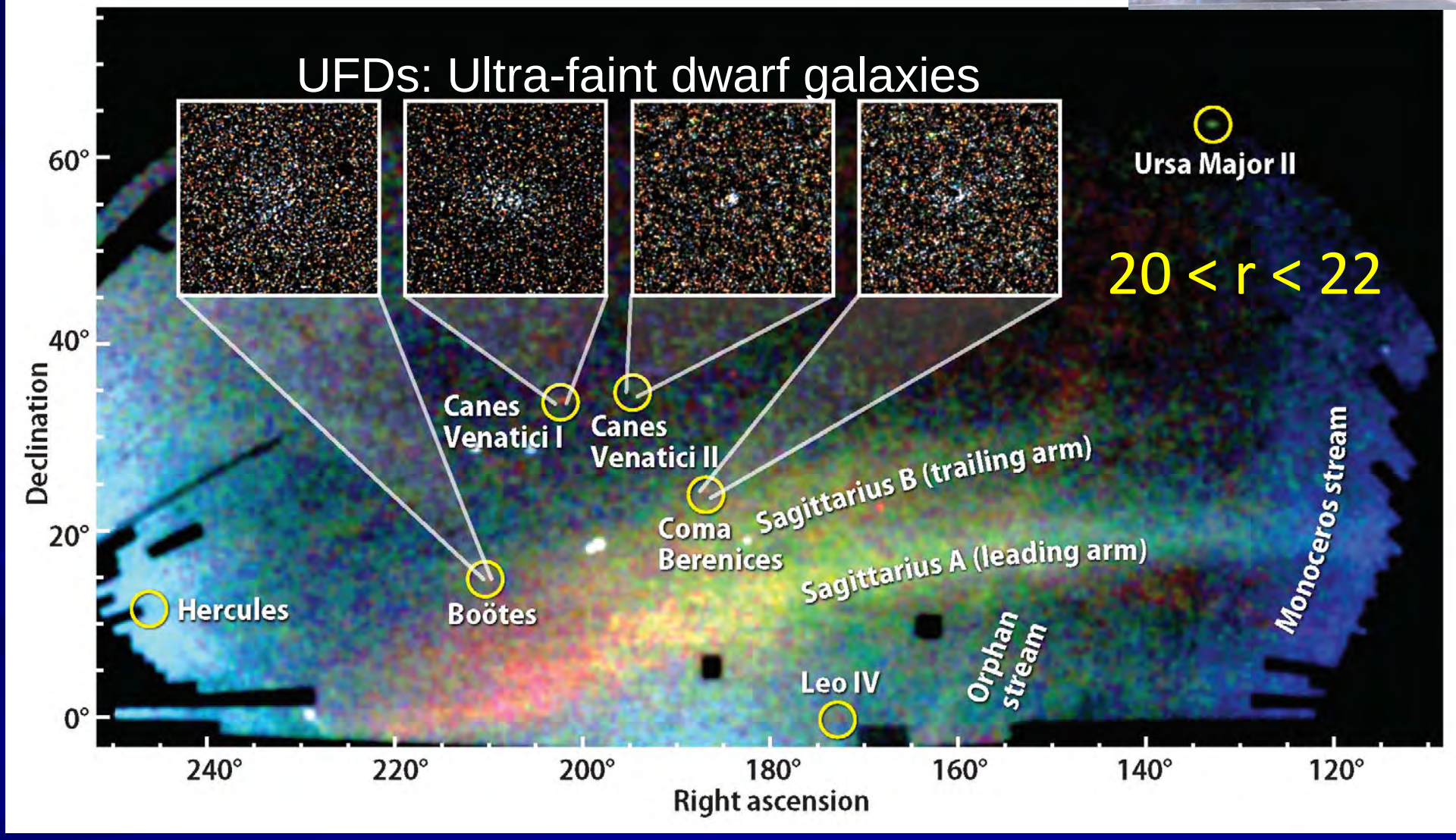
1. 銀河系ハローのサーベイ:
　　新しい矮小銀河と恒星ストリームの探査
2. アンドロメダハローのサーベイ:
　　真の恒星系ハロー構造の導出

HSCサーベイプラン

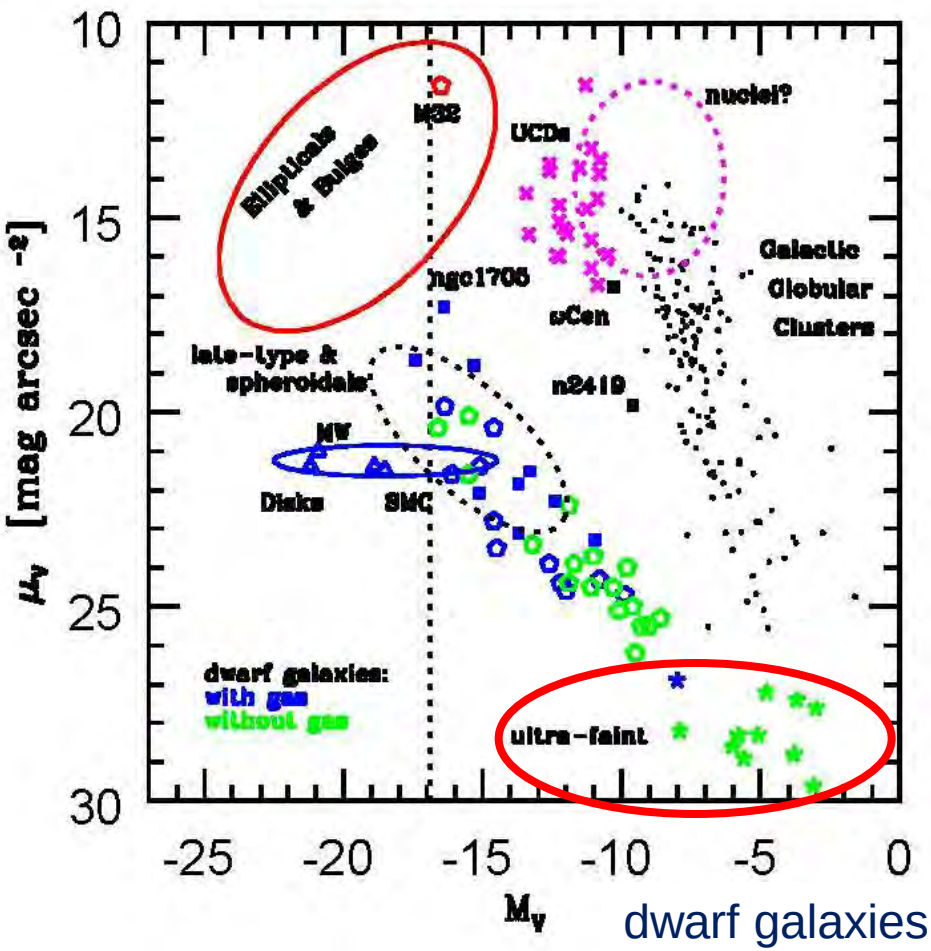
- 銀河系ハローサーベイ
  - (g, r, i), < 26 mag (~3 mag deeper than SDSS)
  - ~1500 deg^2, fully utilizing weak-lensing survey data
  - Obtain color-magnitude diagram for old MS + RGB stars in the outer halo (r = 30 – 250 kpc)
  - Discovery of new ultra-faint dSphs and halo stellar streams
- アンドロメダハローサーベイ
  - Use NB515 filter (CW: 5145 A, BW: 80 A)
  - Separate bright RGB stars (g < 22.5) in the outskirts of the halos from short (g, r, i) + NB515 imaging
  - NB515 is fully optimized for z=3 BAO as well (Matsuda+)
  - The survey will be a PI-led project

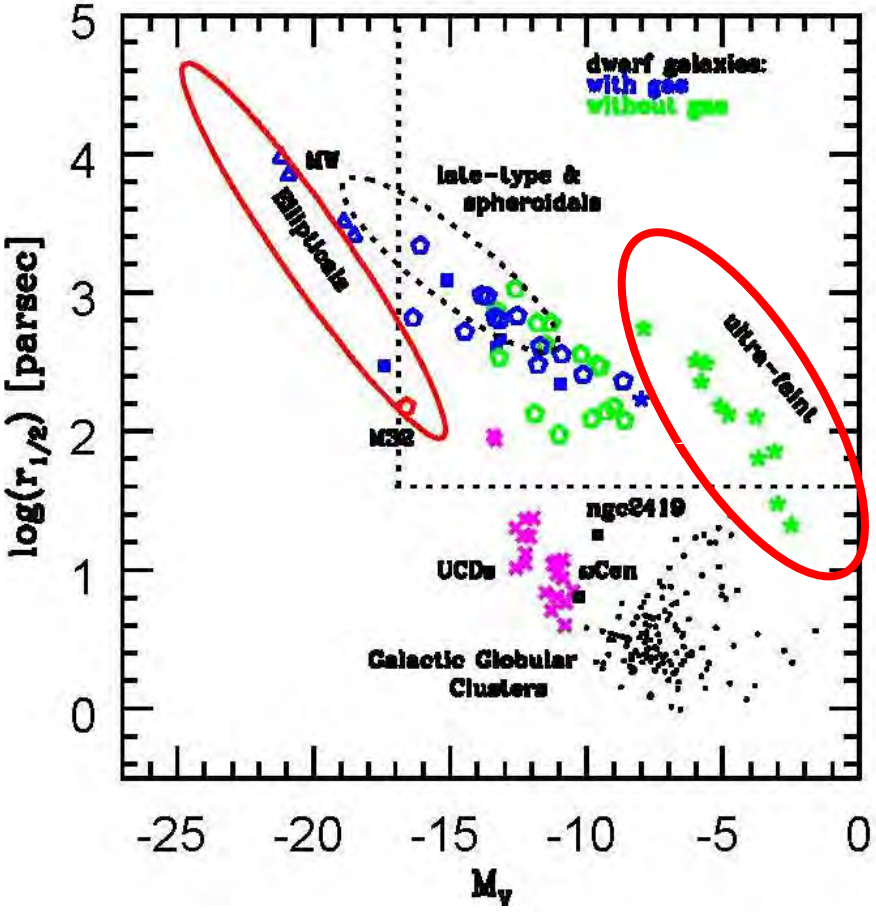
SDSSによる新しい矮小銀河とハローサブ構造の発見





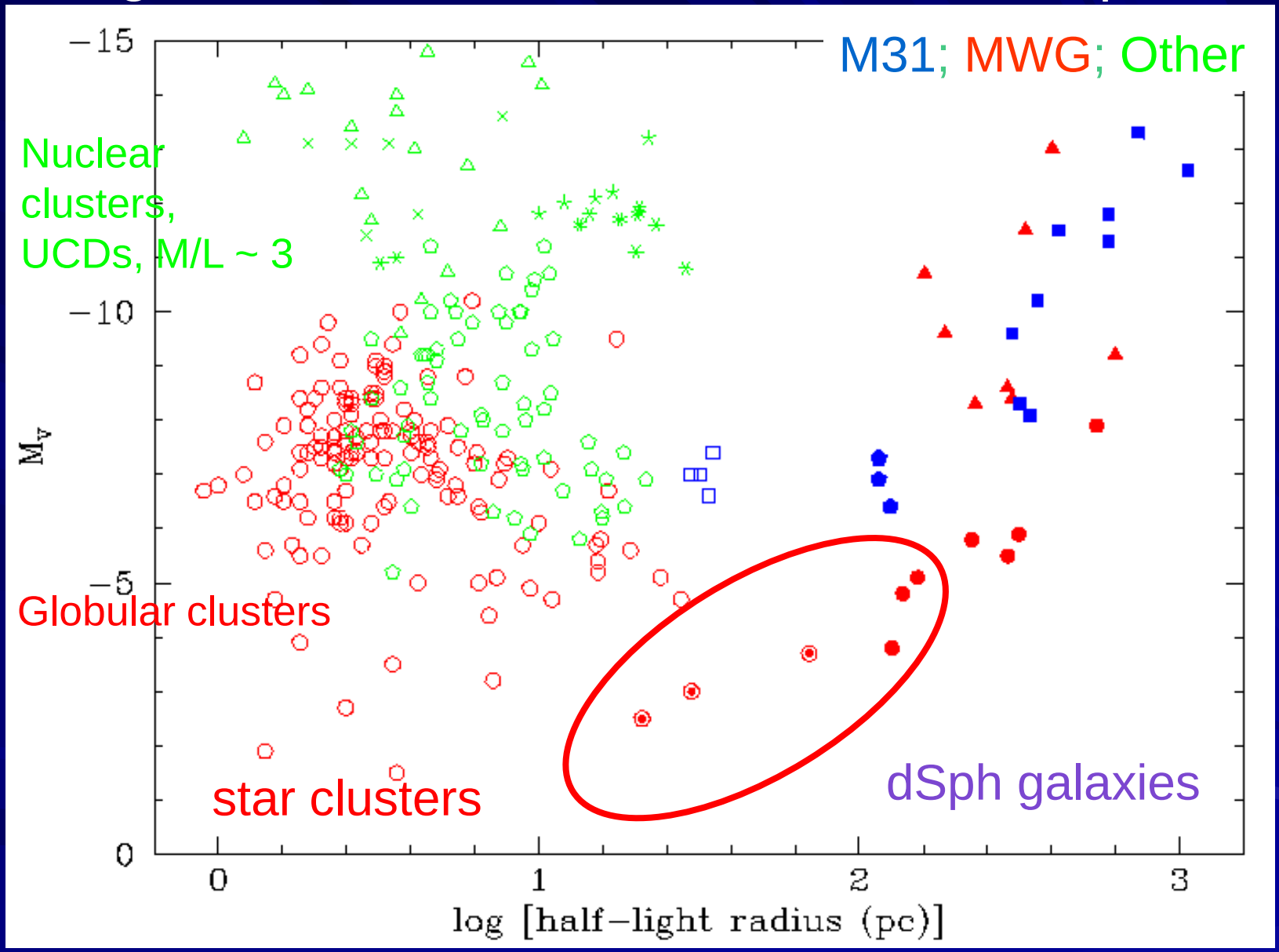
Structures of various types of galaxies
(Tolstoy+09, ARAA, 47, 371)





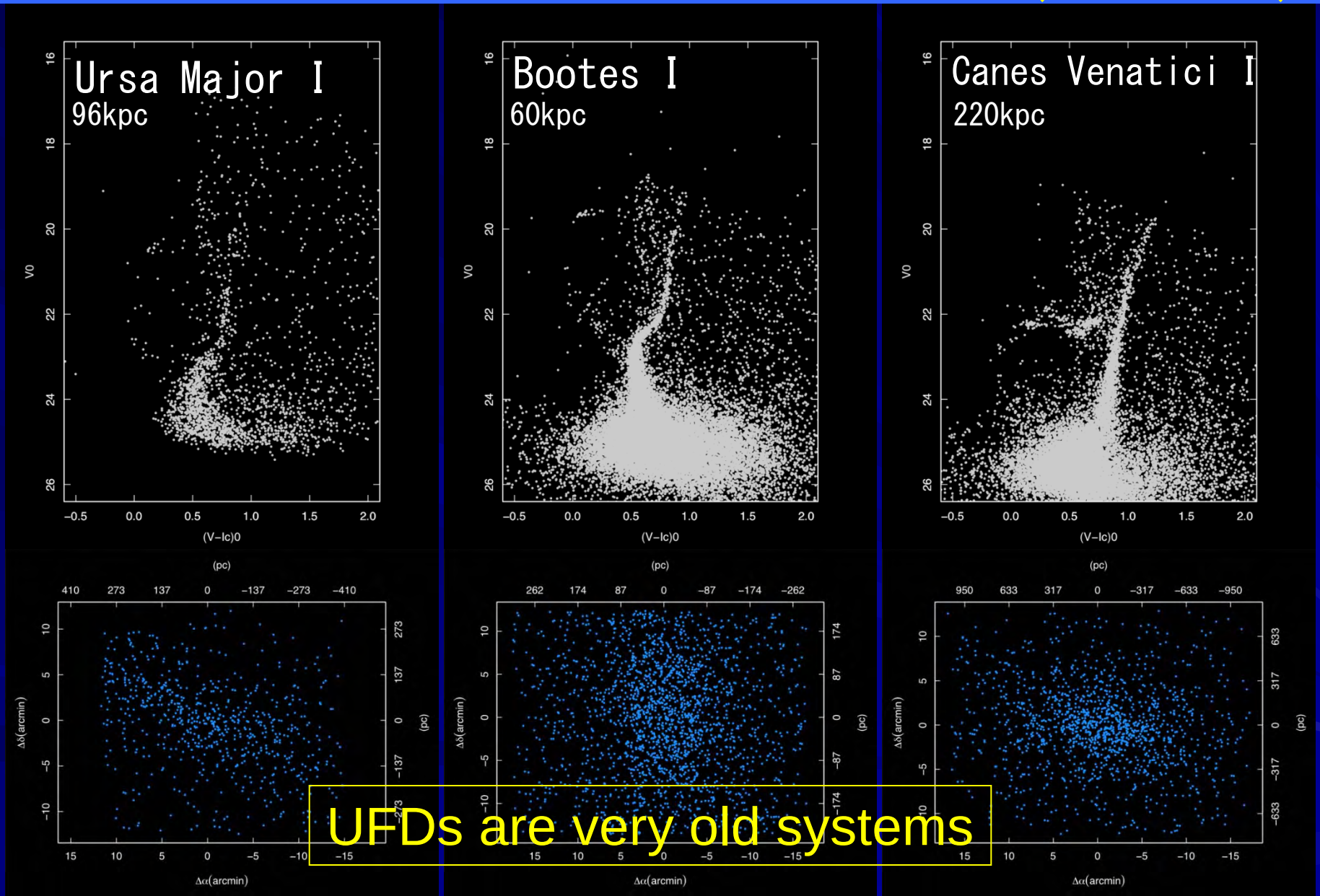
dwarf galaxies:
Mv > -17 and more spatially extended than globular clusters
with gas: dIrr, without gas: dSph

Light distribution of star clusters and dSph



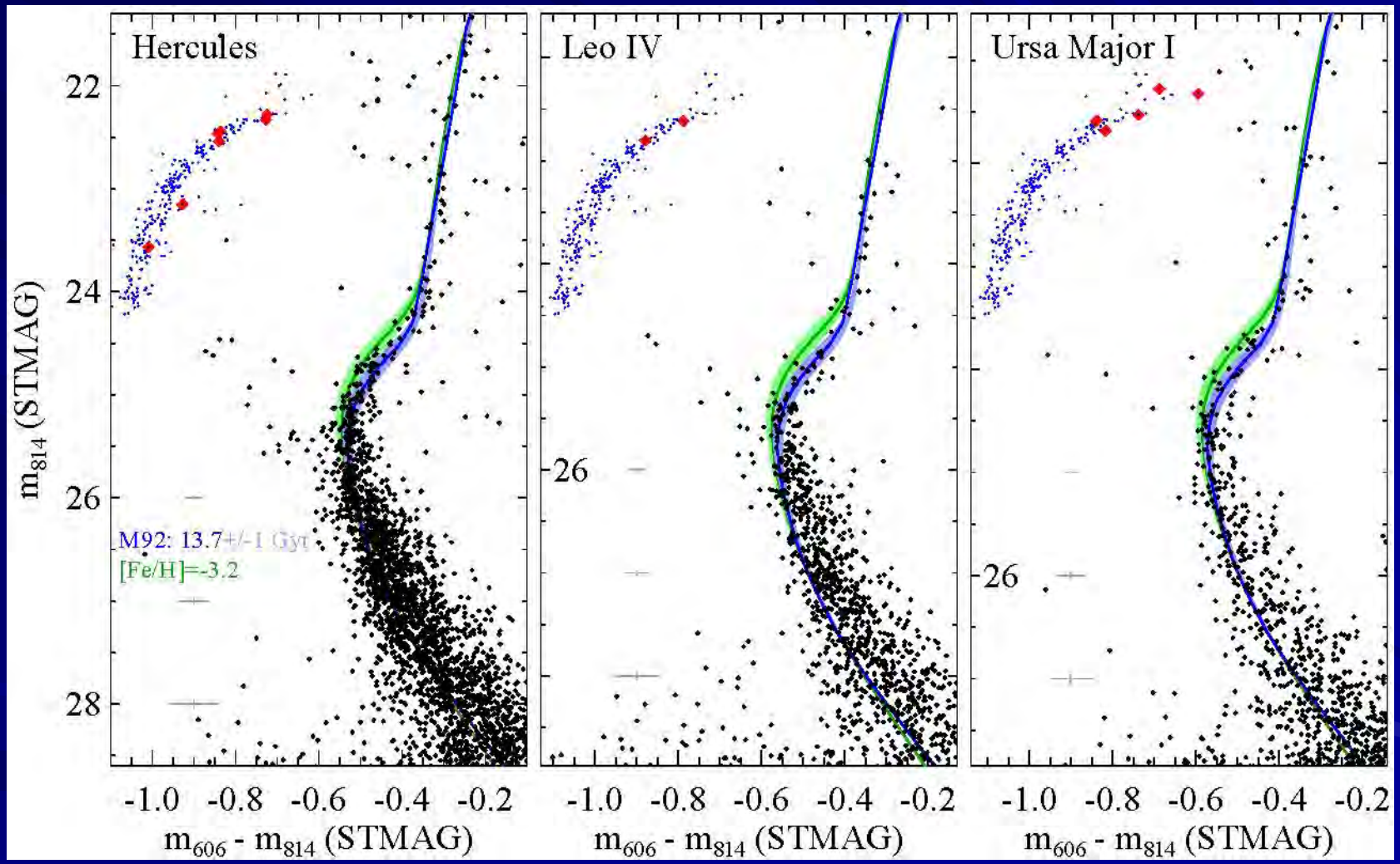
Gilmore, Wilkinson, Wyse et al 2007 ApJ 663 948

UFDs by Suprime-Cam (Okamoto+2008)



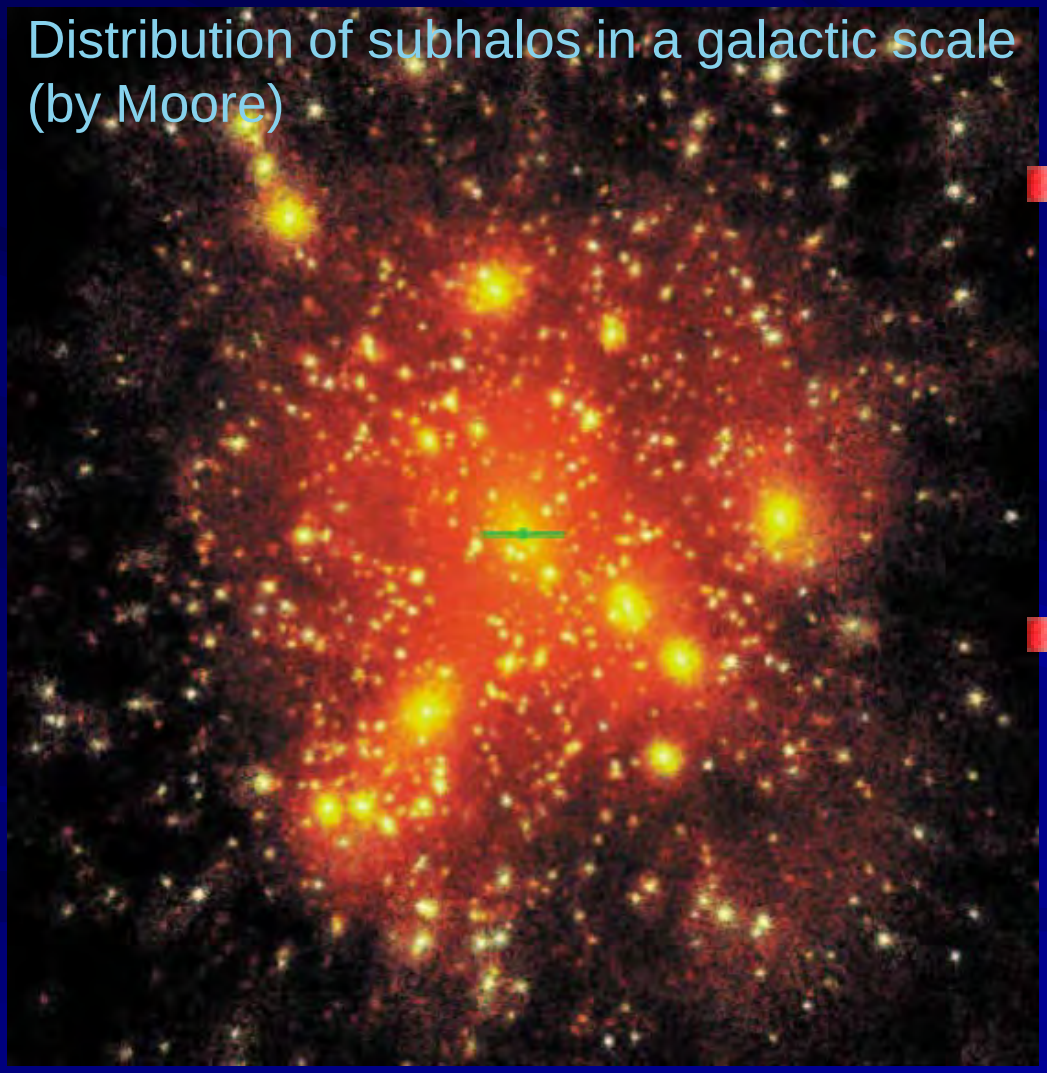
UFDs are very old systems (as old as M92)

HST results by Brown+2012



Synchronization of SF truncation within ~1 Gyr ?

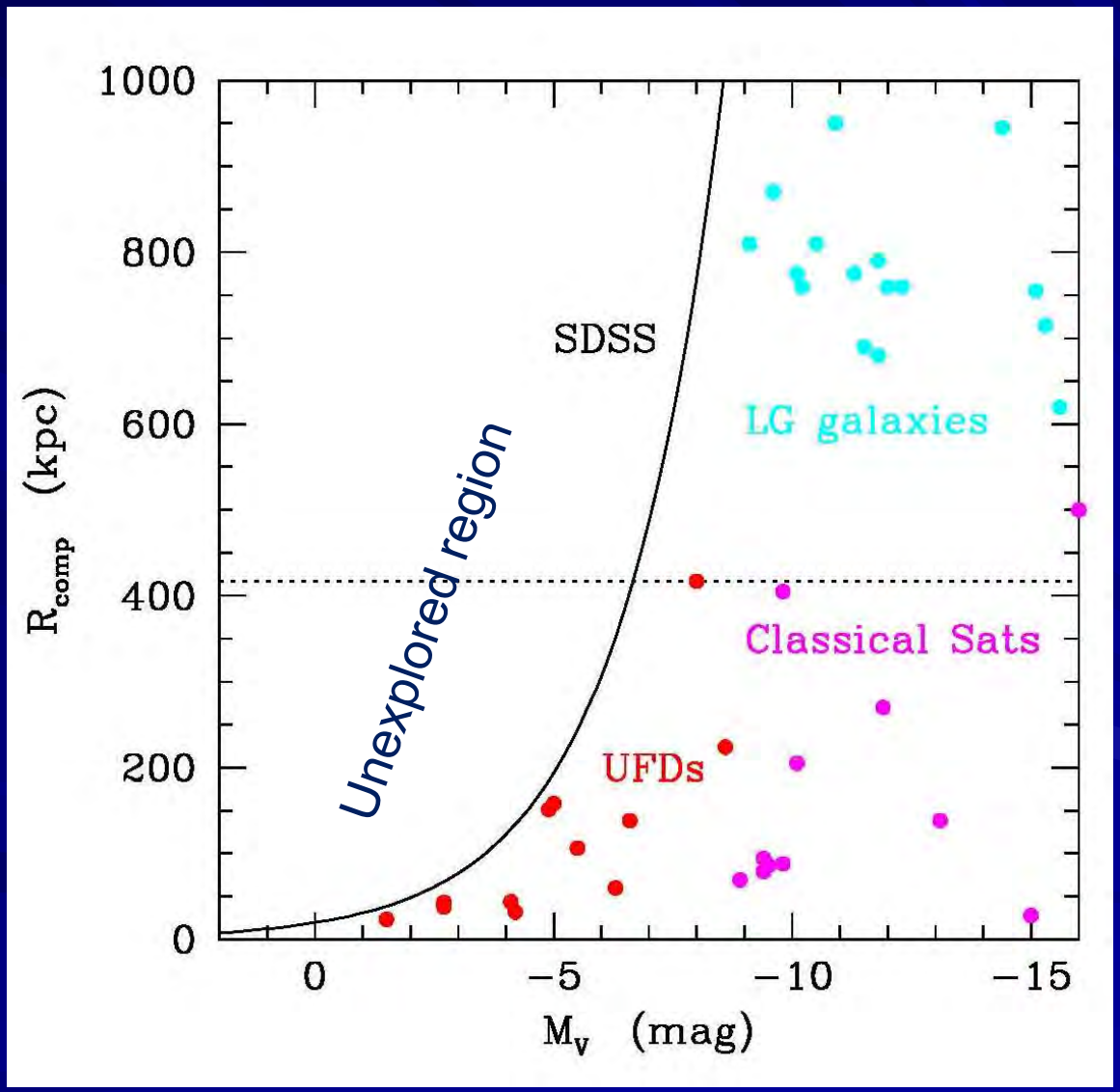
ミッシングサテライト問題？

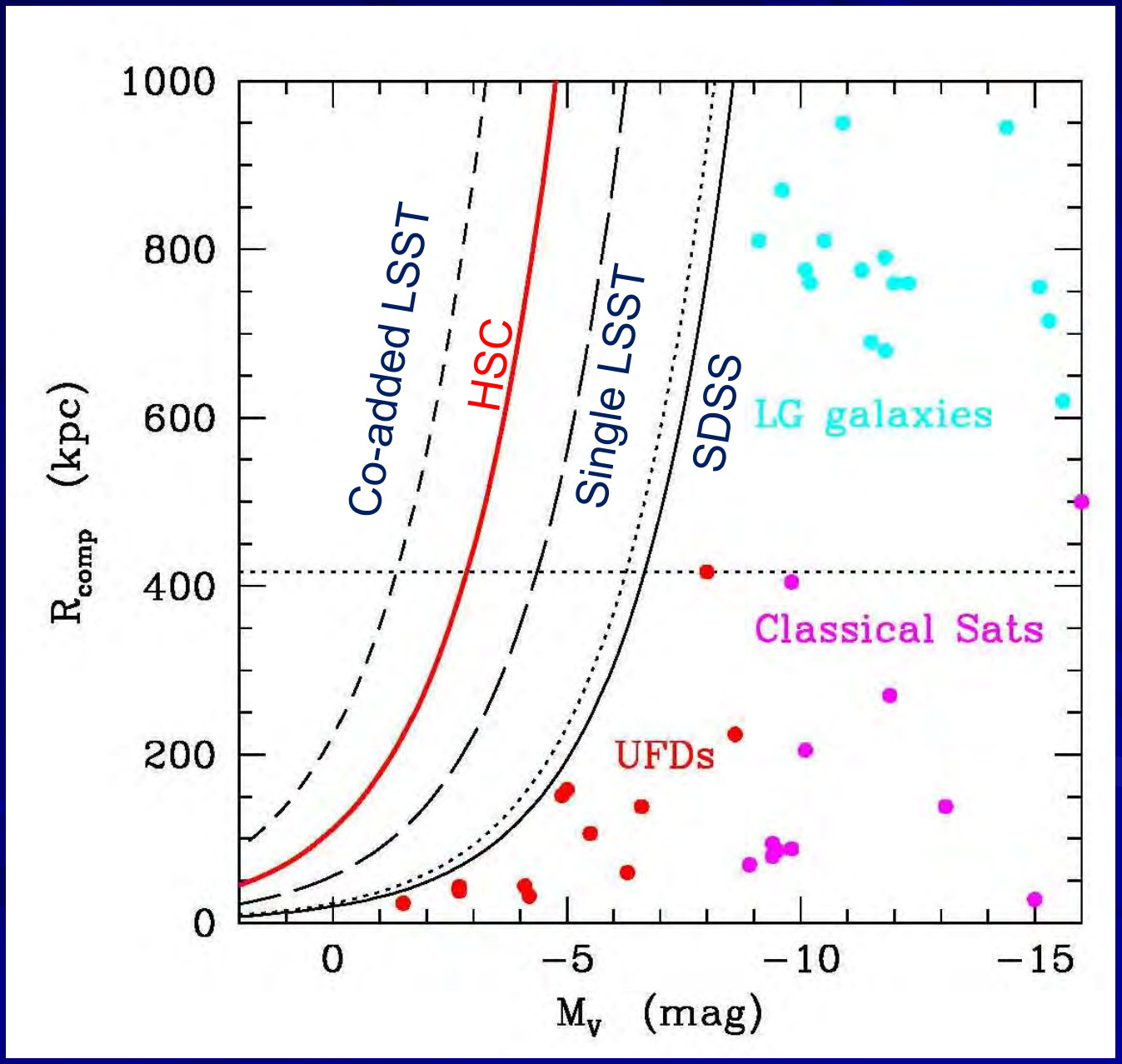


- 銀河系伴銀河の数はサブハローの数に比べて圧倒的に少ない
  - SDSSによって見つかった暗い矮小銀河を含めても20数個程度
- 一方、我々は矮小銀河の多くをまだ観測できていない
  - SDSSは全天の一部のみ観測
  - 遠くて暗い矮小銀河の見落とし
  - 暗い表面輝度の銀河の見落とし

Observed photometric properties of Galactic satellites (SDSS)

Tollerud +08



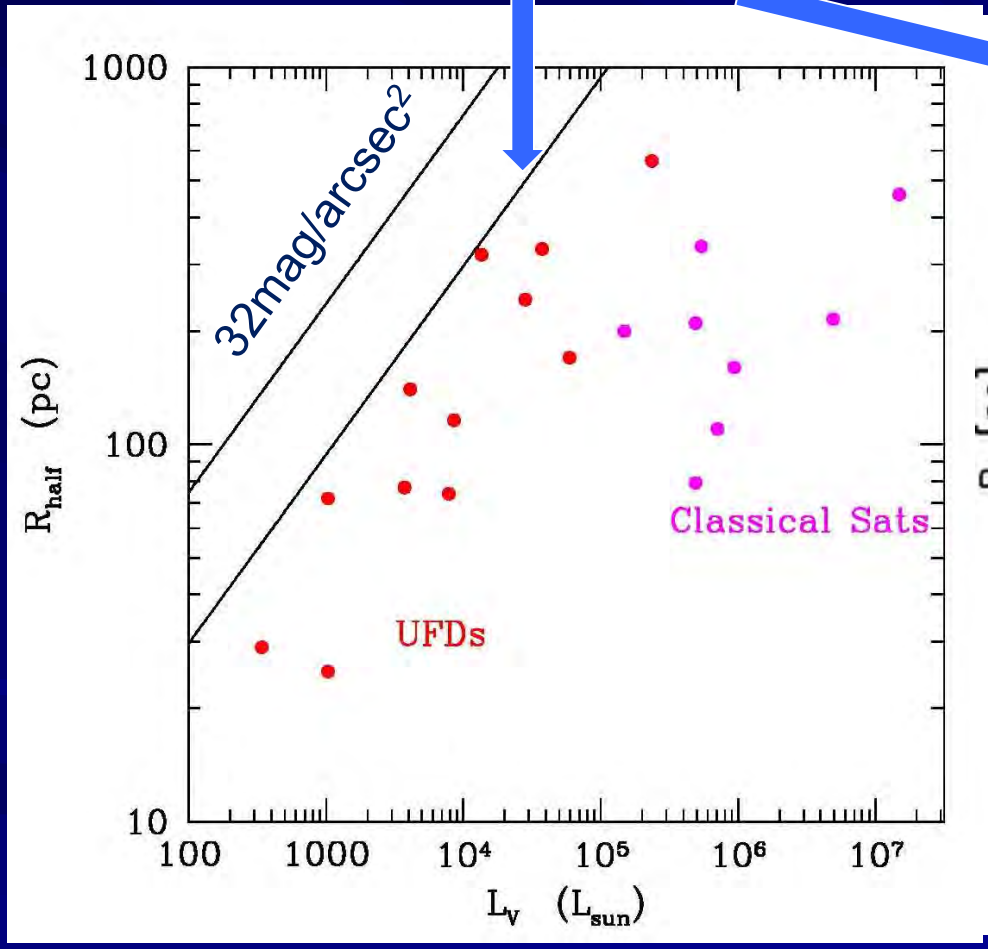


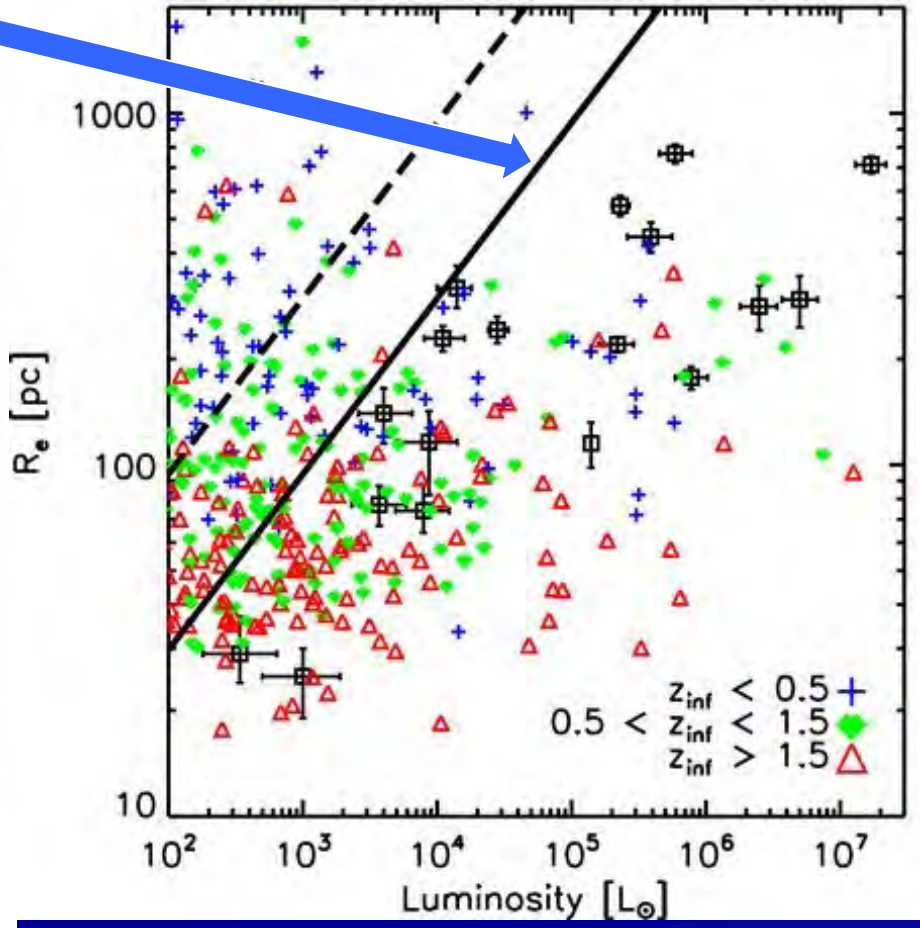
Single LSST:
r_{lim} = 24.5
Co-added LSST:
r_{lim} =27.5
Subaru/HSC
(wide-f. survey):
r_{lim}~26

隠された矮小銀河：表面輝度のリミット

SDSS (μ<30mag/arcsec^2)

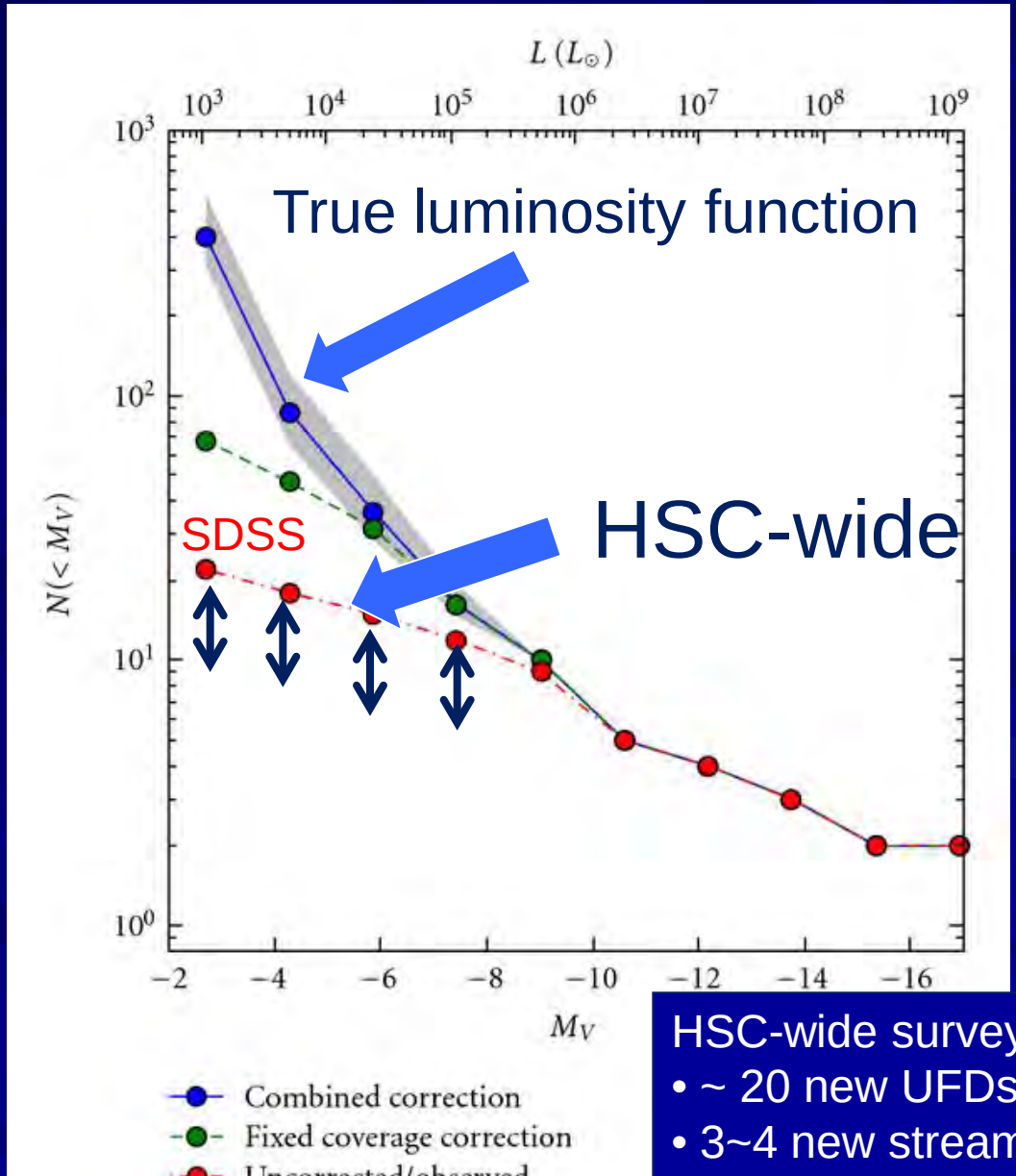
銀河形成モデル





(Bullock+2010)

HSC-wide survey で期待される矮小銀河数



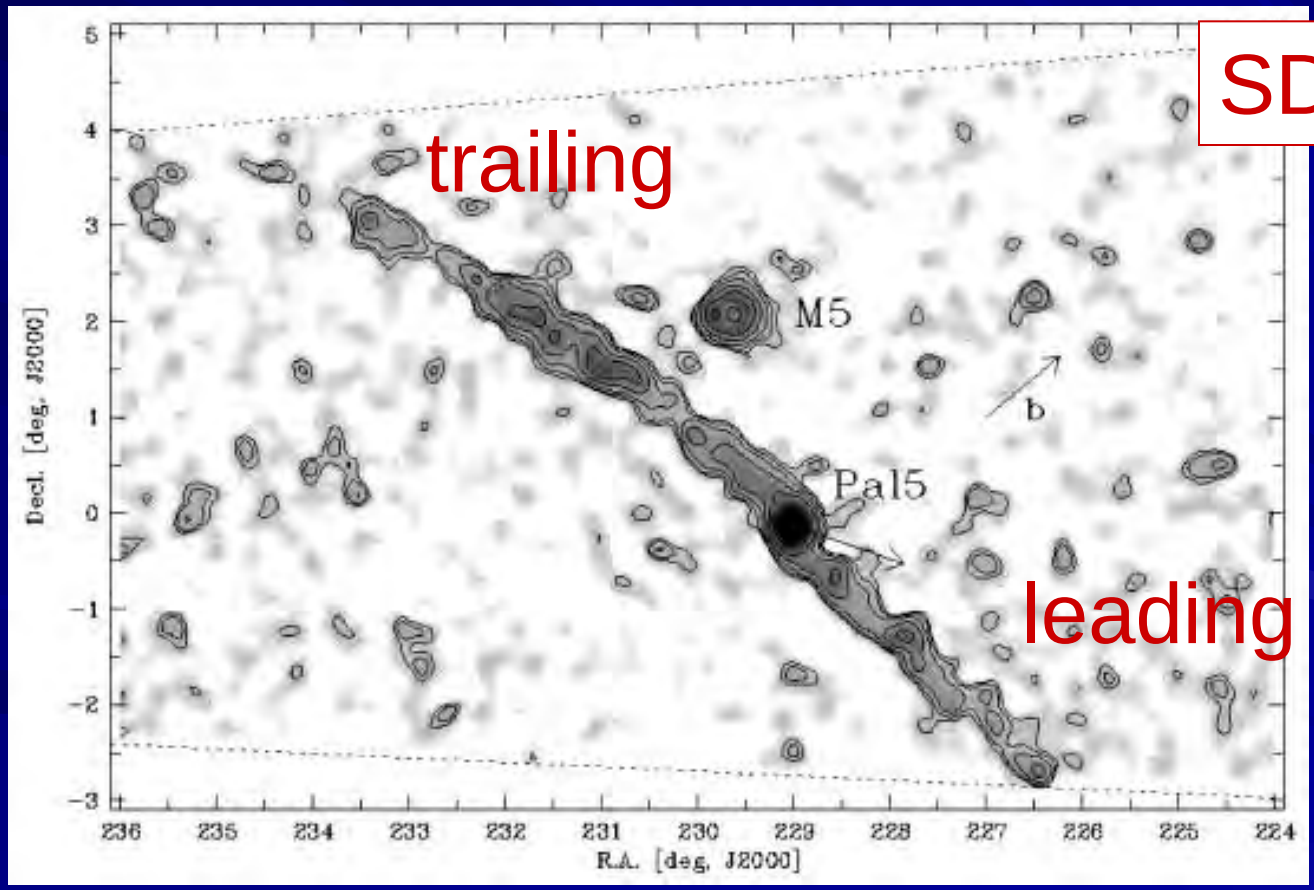
N=9~17
@M_V=-3

N~20
@M_V<-3

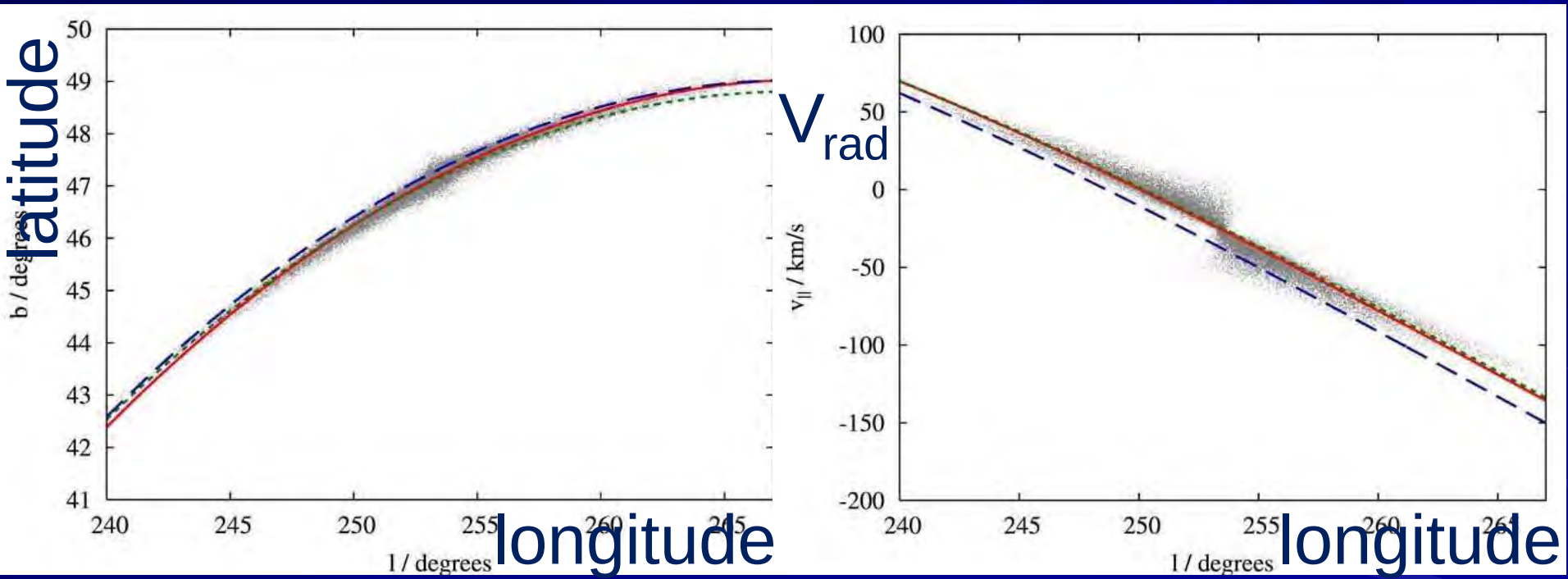
HSC-wide survey over ~1,500 deg^2
- ~ 20 new UFDs @ Mv<-3
- 3~4 new streams with μ_{lim}~34 mag/□”

Mapping the Galactic potential using stellar streams

Palomer 5: tidally elongated GC
over 10 deg @ d=25kpc (Odenkirchen+ 2003)



様々なストリームを組み合わせた
銀河系ポテンシャルと質量分布決定



Eyre & Binney 2009

広い領域に渡るストリーム分布
と視線速度分布が必要

HSCサーベイプラン

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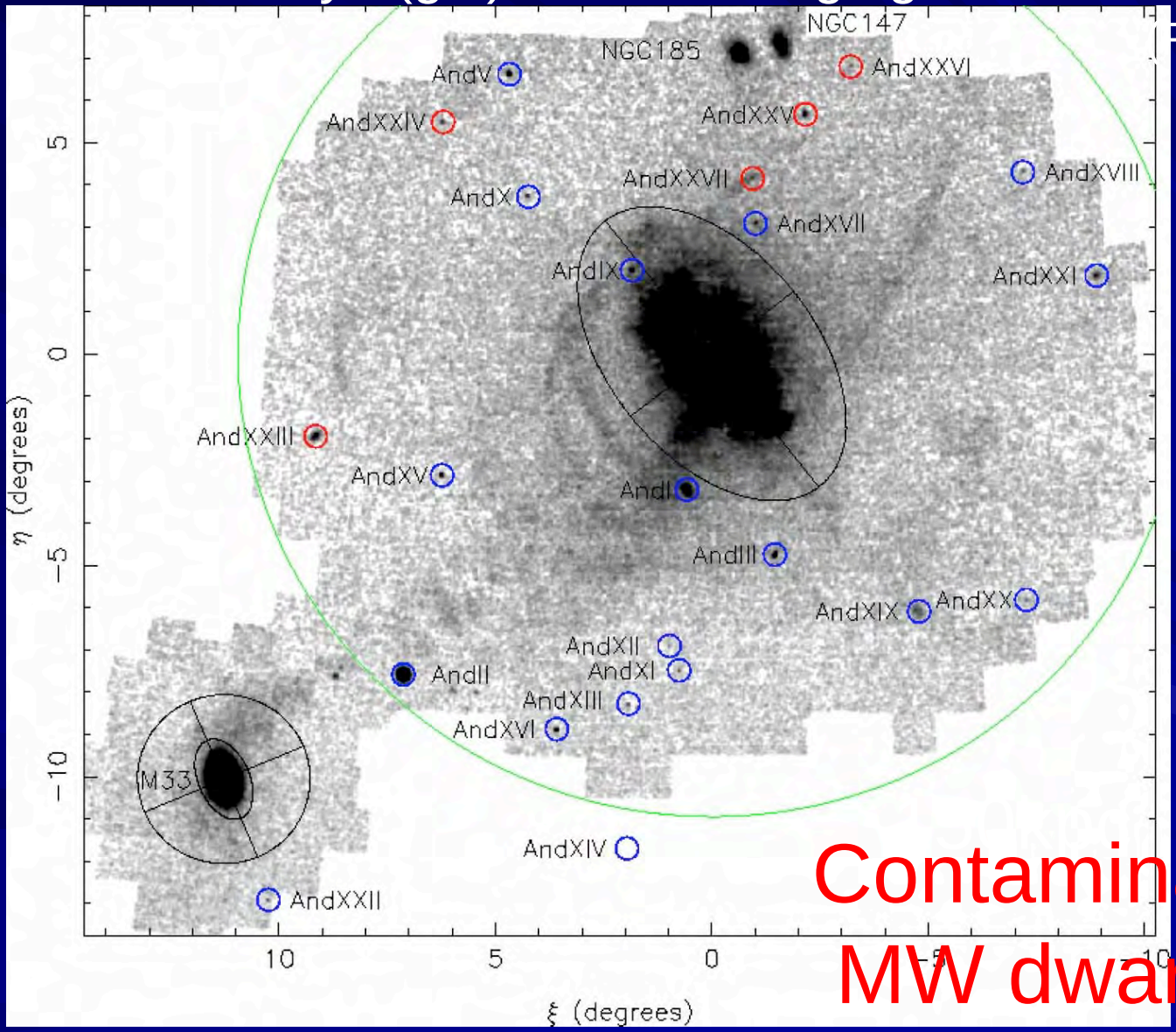
  - NB515 is fully optimized for z=3 BAO as well (Matsuda+)
  - The survey will be a PI-led project

Tracing assembly history: M31 halo

PAndAS survey: (g, i) 2-color imaging with CFHT

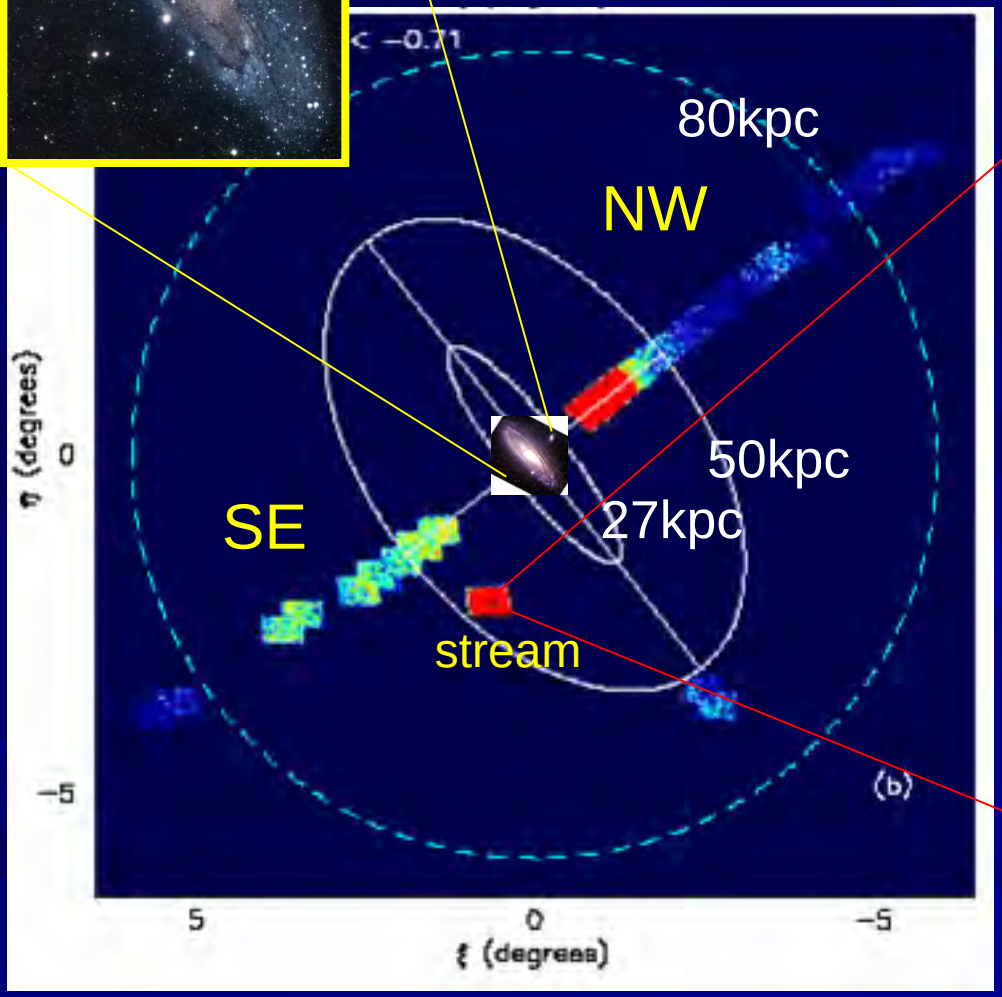


(Richardson+11)

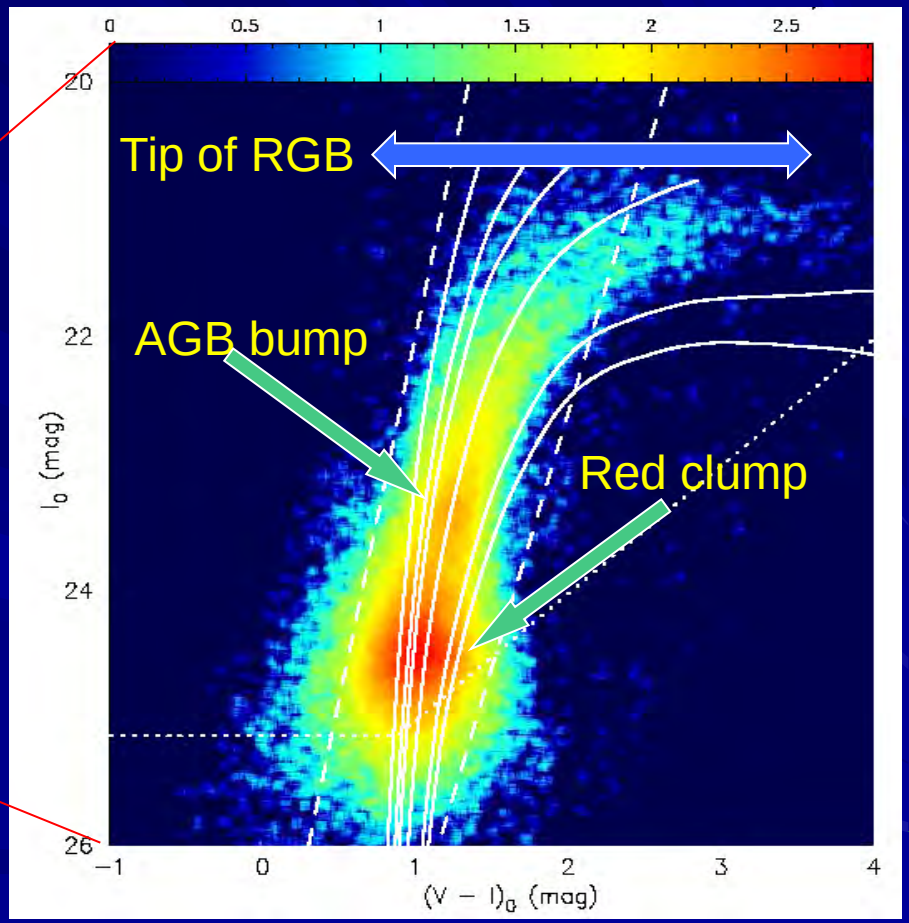
RGB with i<23.5

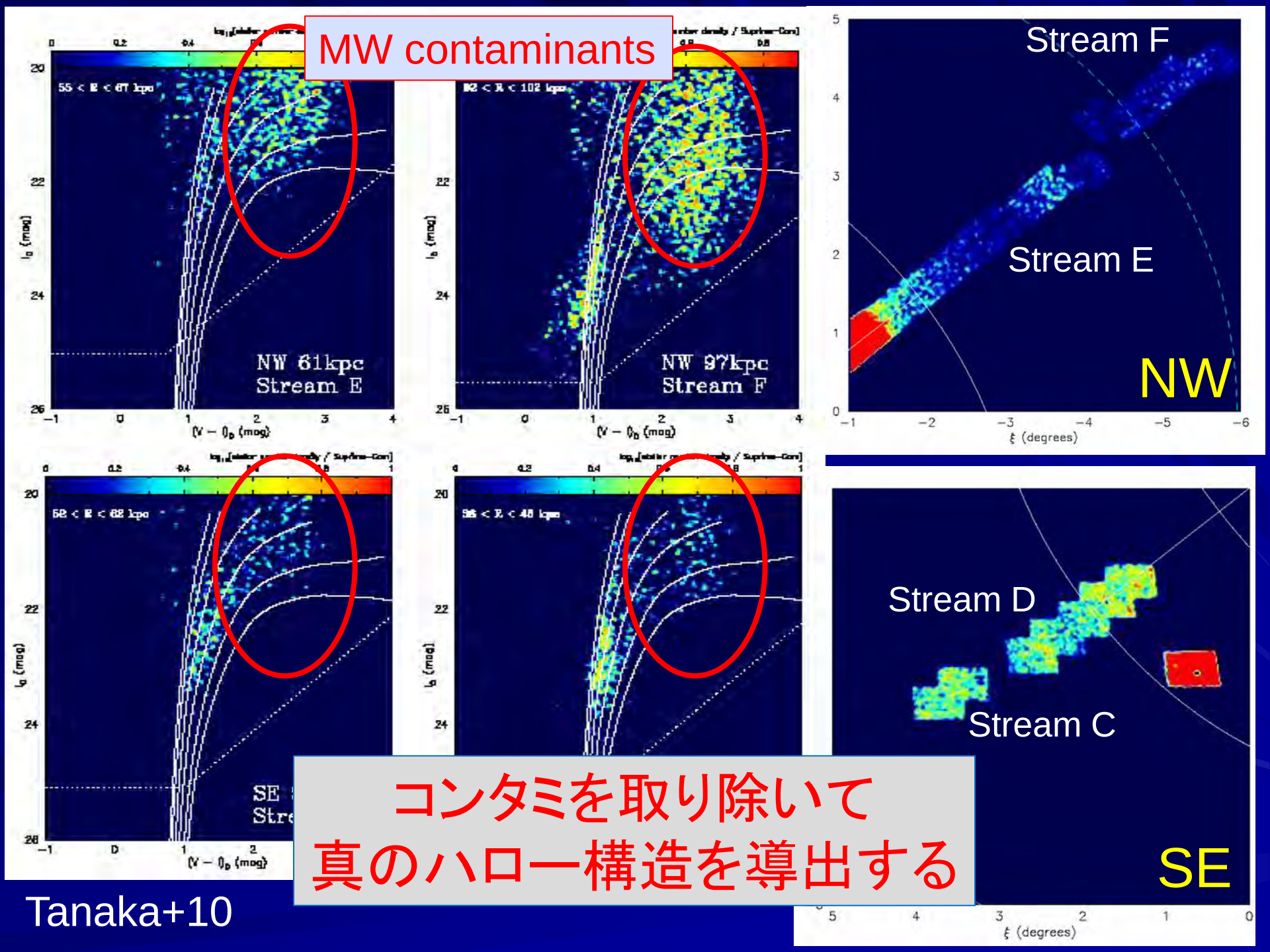
Contamination by MW dwarf stars

Structure of the M31 halo
(Tanaka+ 10)



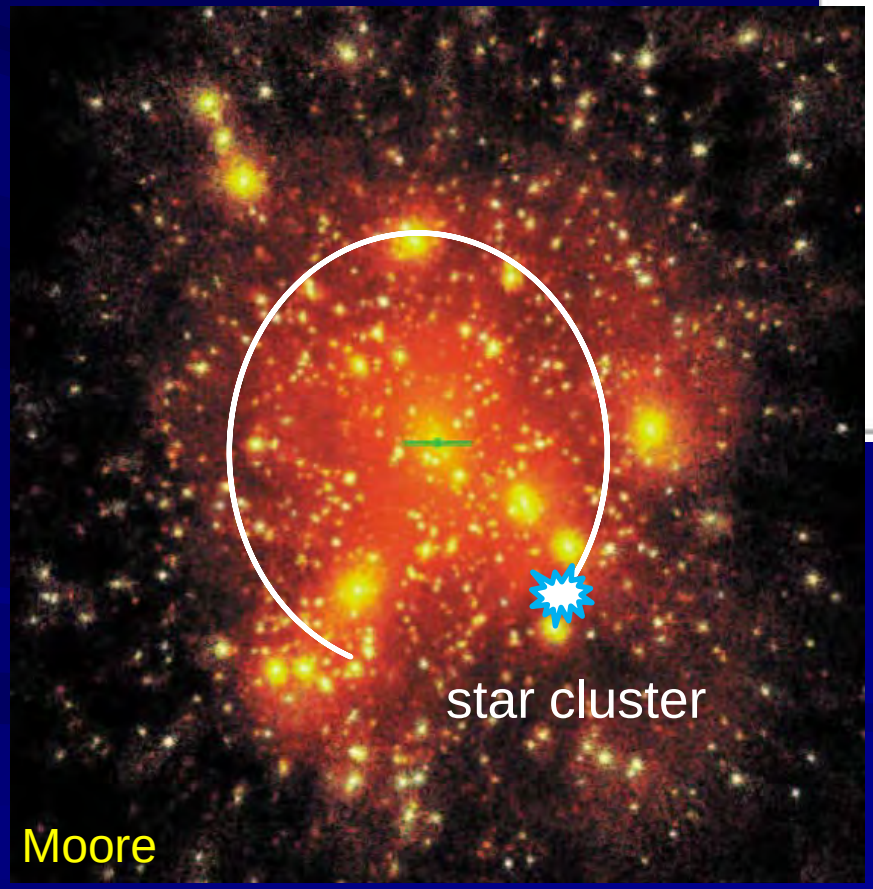
Stream field

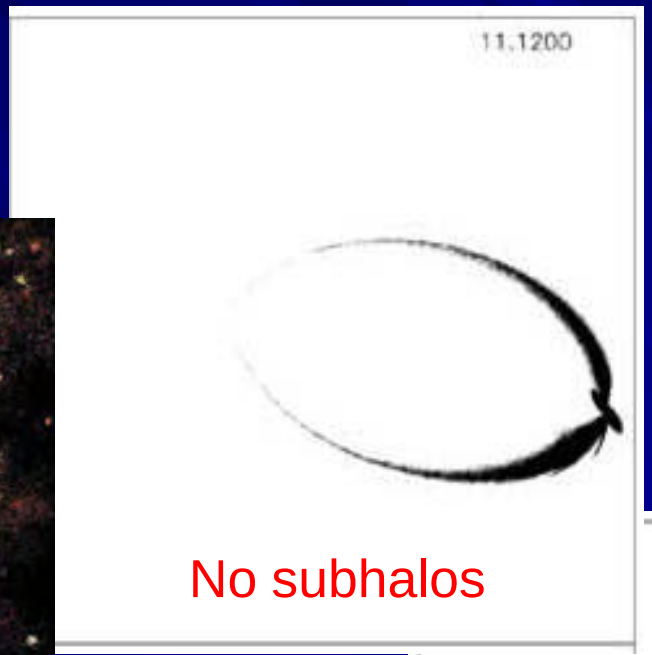



MW contaminants
NW 61kpc
Stream E
NW 97kpc
Stream F
Stream F
Stream E
NW
Stream D
Stream C
SE
コンタミを取り除いて
真のハロー構造を導出する
Tanaka+10

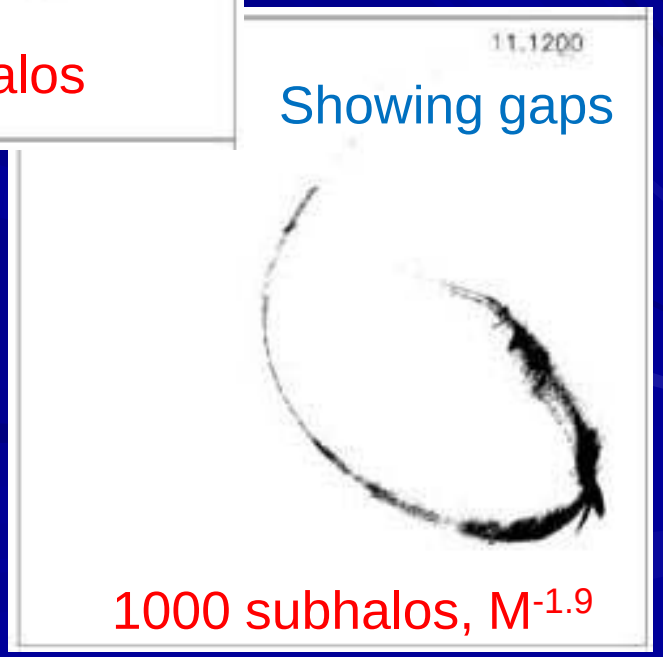
Are there many CDM subhalos in a galaxy-sized halo? (Carlberg 2011)

CDM halo in a galaxy

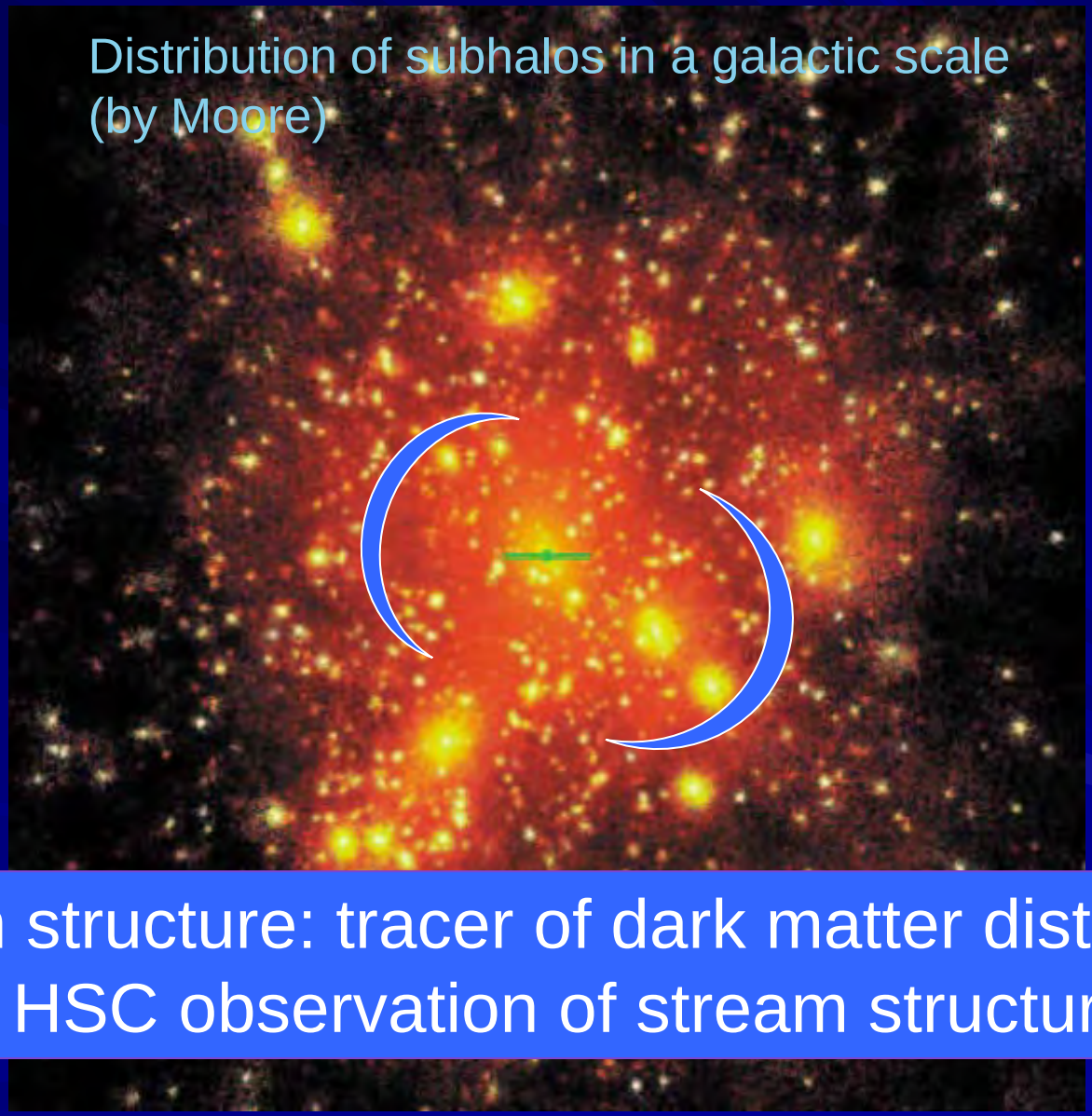




dynamical effects on stellar stream ($M_{star}=10^6 M_{sun}$



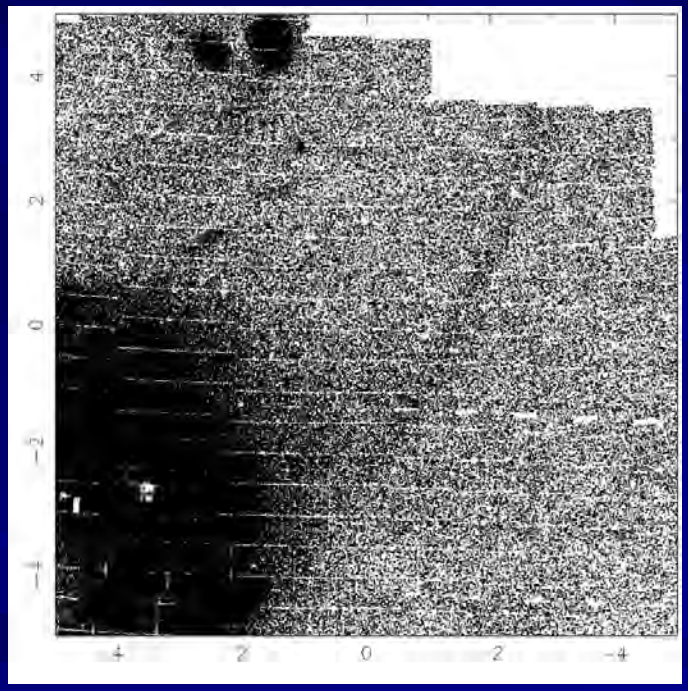
（数年前に作ったスライドから）
A key for the missing satellite problem



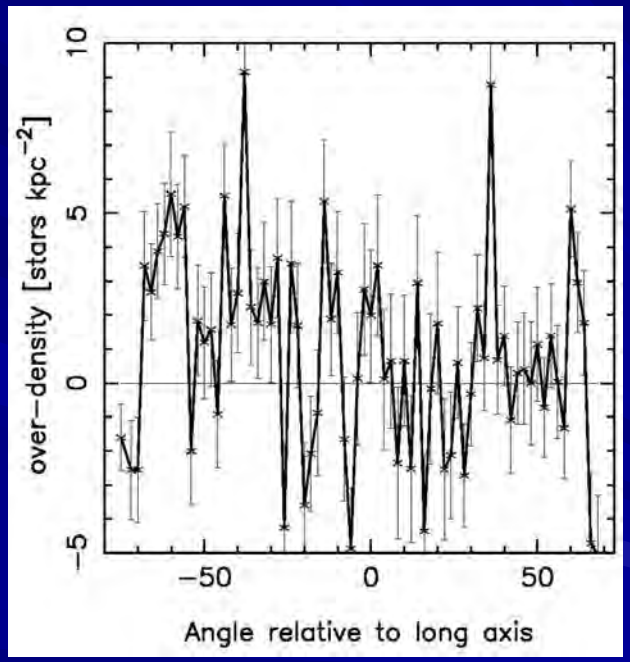
Stream structure: tracer of dark matter distribution
⇒ HSC observation of stream structure !

Are there many CDM subhalos in a galaxy-sized halo? (Carlberg 2011)

NW stream in M31
(Richardson+ 2011)



Non-uniform density distribution
(~12 gaps⇒consistent with CDM?)



- Careful subtraction of foreground stars
- More theoretical analysis

Stellar halos in M31/M33

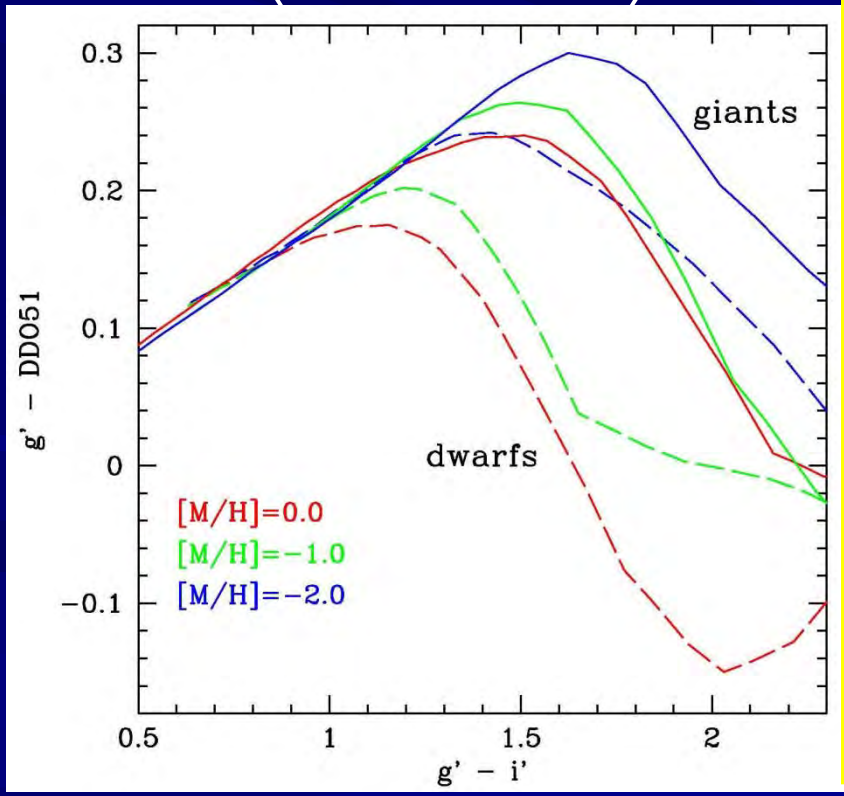
using (DDO51-type) NB515 filter

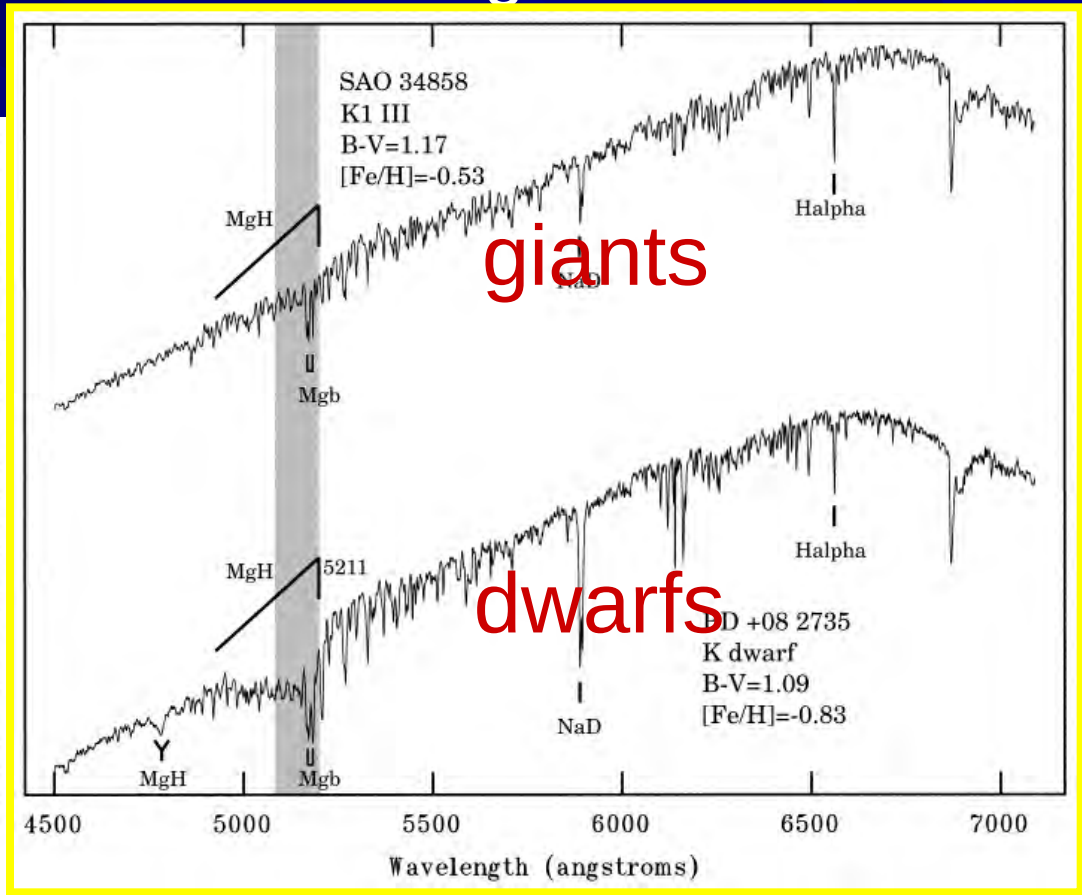
CW: 5145 A, FWHM: 80 A

To separate RGBs in M31/M33 from Galactic dwarfs

+ optimized for BAO science using z=3 LAEs

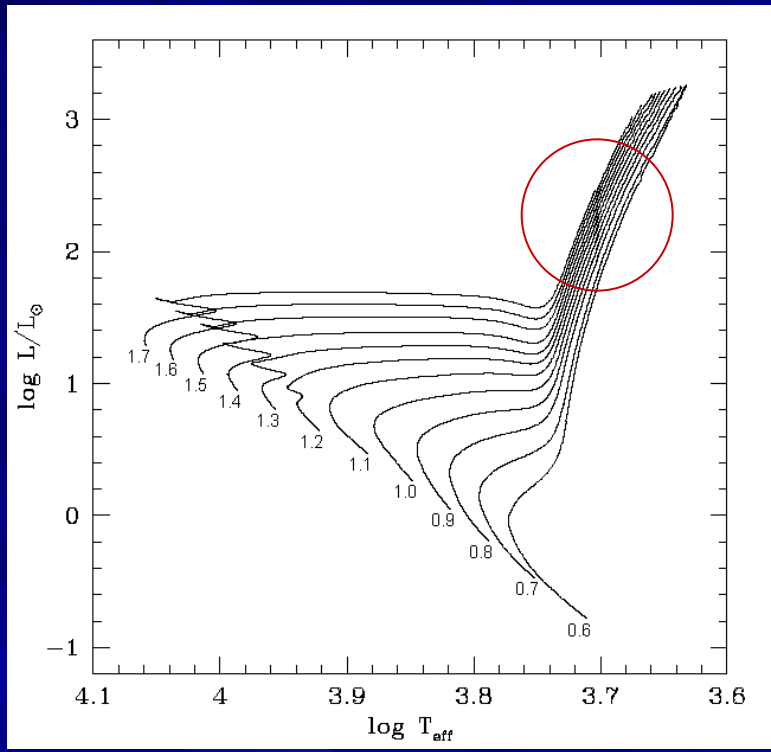
Feasibility for LG science
(with M.Tanaka)





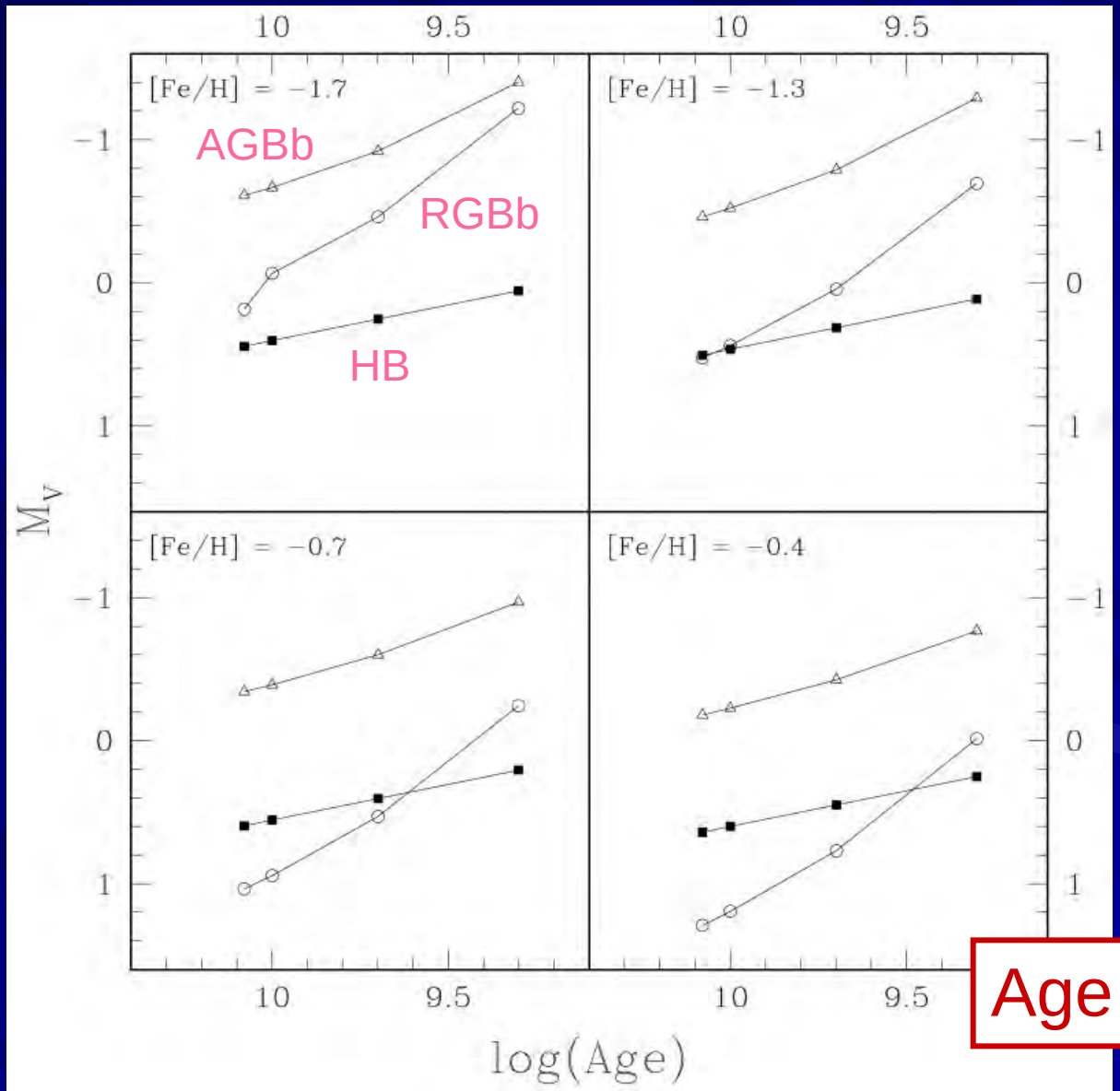
Important features in CM diagram

- RGB bump (RGBb)
  - Evolutionary pause when the H-burning shell crosses a discontinuity left by the convective envelope
- Tip of RGB (TRGB)
  - He-burning ignition through the He flash
  - Nearly constant I-band mag ⇒ standard candle
  - 843±48kpc, 855±48kpc ＞ D=770kpc
- Red Clump (RC)
  - Clustered feature of red HB (He core-burning) stars being metal-rich / young age
- AGB bump (AGBb)
  - Clustered feature of AGB stars at the beginning of He shell-burning evolution



Luminosities of RGBb, RC, & AGBb depend on age.
⇒ age distribution

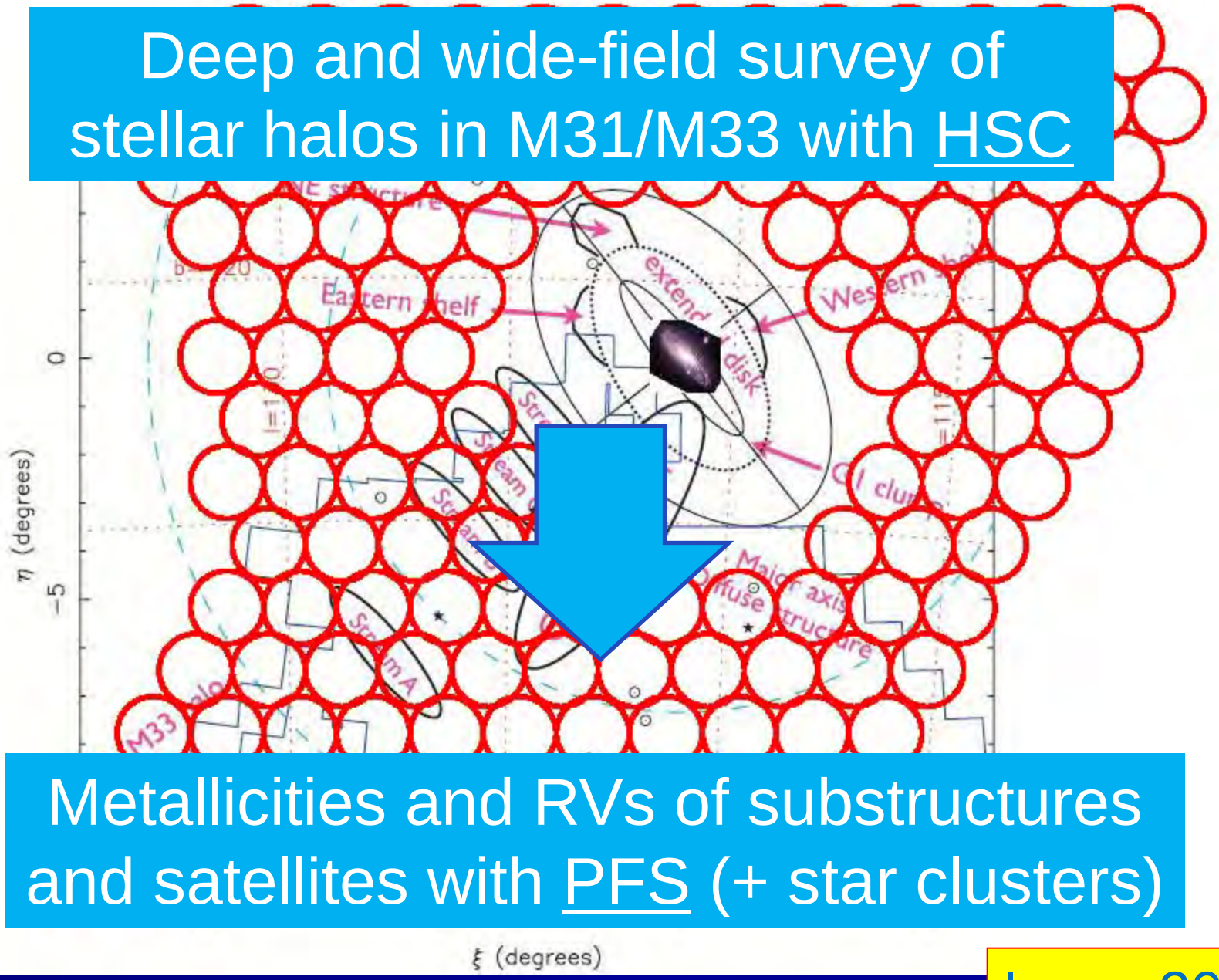
Alves & Sarajedini 1999



Fainter for Z↑M↓

Age indicator

Deep and wide-field survey of stellar halos in M31/M33 with HSC

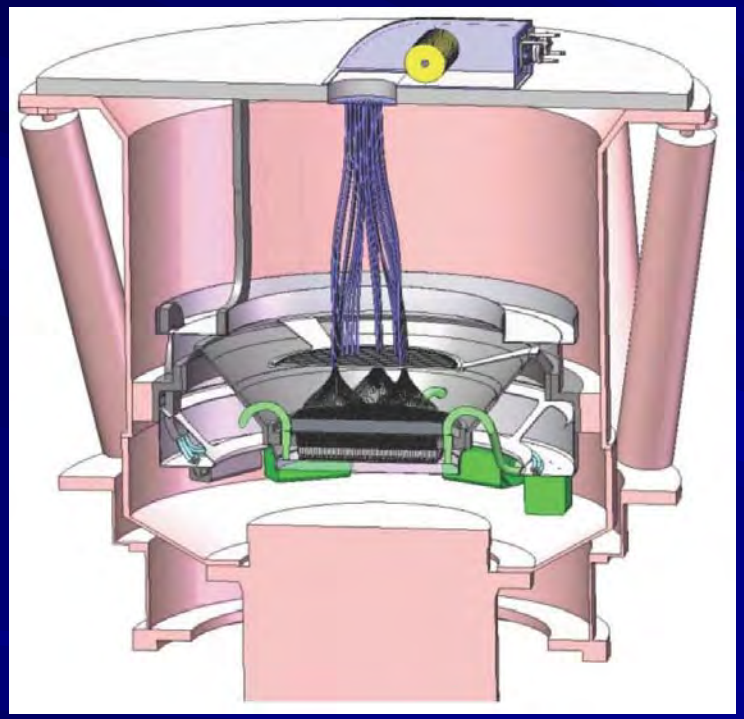


Metallicities and RVs of substructures and satellites with PFS (+ star clusters)

130 HSC pointings

I_{TRGB}=20.5

PFS
(Prime Focus Spectrograph)

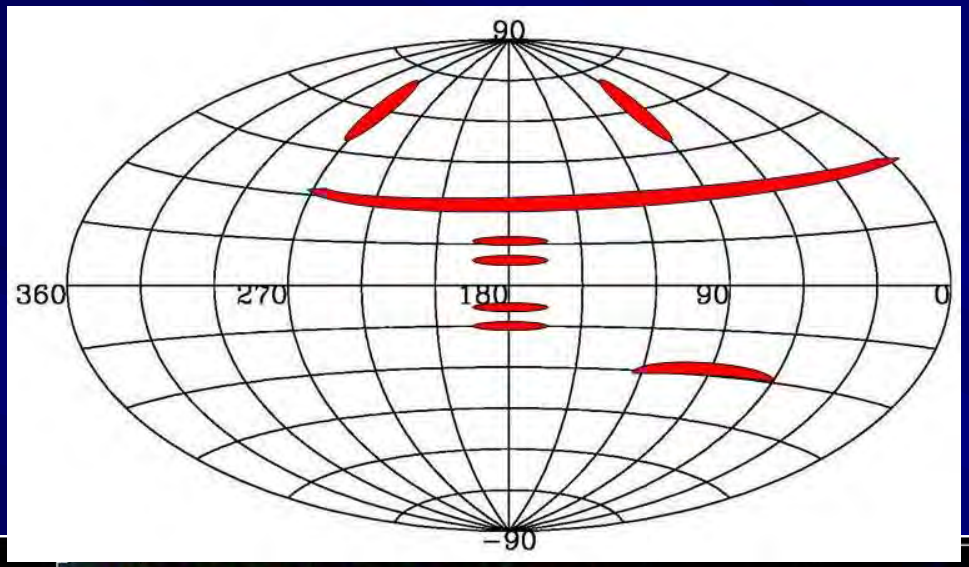


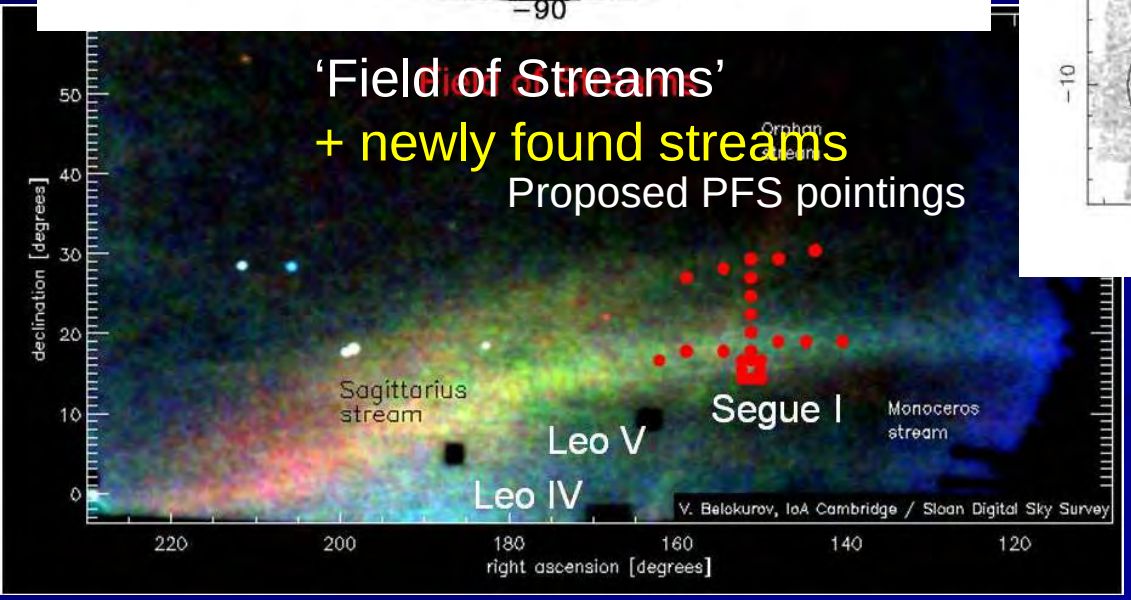
FOV: 1.3 deg in diameter
2400 fiber positioners
λ: 380~1,300 nm
(3 channels: Blue, Red, IR)
R: ~3,000
First light: 2017?

Led by IPMU (U. of Tokyo) + NAOJ/Subaru community
+ Caltech/JPL, Princeton, JHU, LAM, UK, Brazil, Taiwan

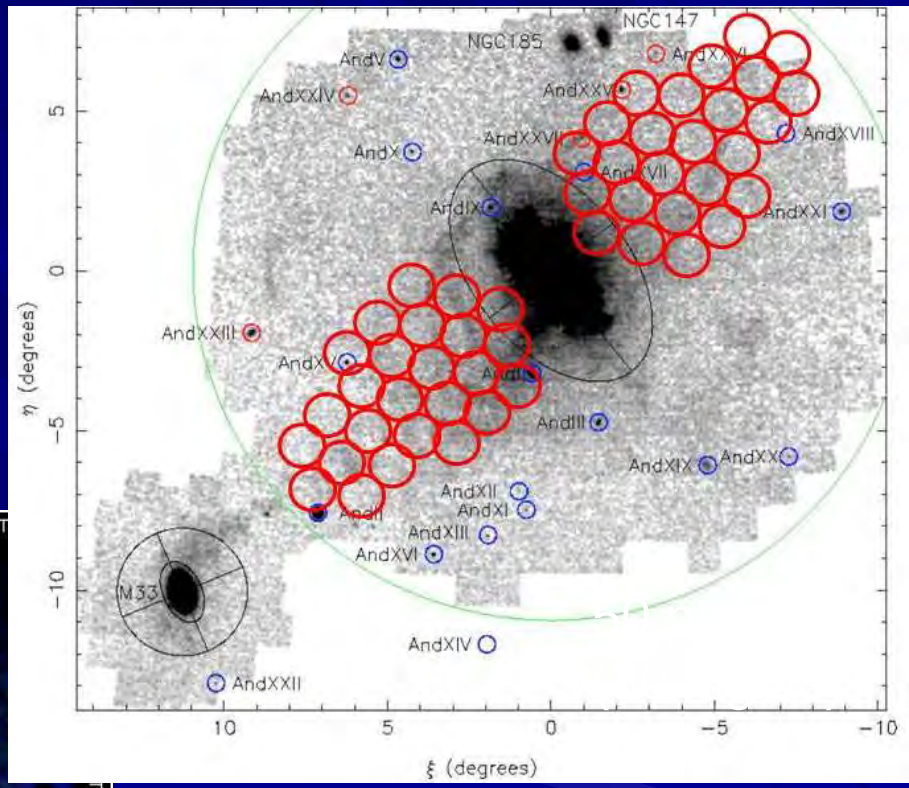
Proposed Survey Fields with PFS

1. The Milky Way





2. M31 halo



Detailed chemodynamics of M31 halo stars:

- Halo substructures
- Global halo structure

HSCによる近傍銀河サーベイ

- 銀河系ハローサーベイ
  - SSPのHSC-wideサーベイにより、新しい矮小銀河とハロー恒星ストリームを多数発見　⇒岡本
- アンドロメダハローサーベイ
  - PI型観測プログラムにより、真のハロー構造とその金属・年齢分布を導出　⇒田中
- PFSによる化学・動力学構造の導出

銀河古成分にみられる銀河形成の痕跡を通して、銀河系とアンドロメダの形成過程の最終解明を行う

END