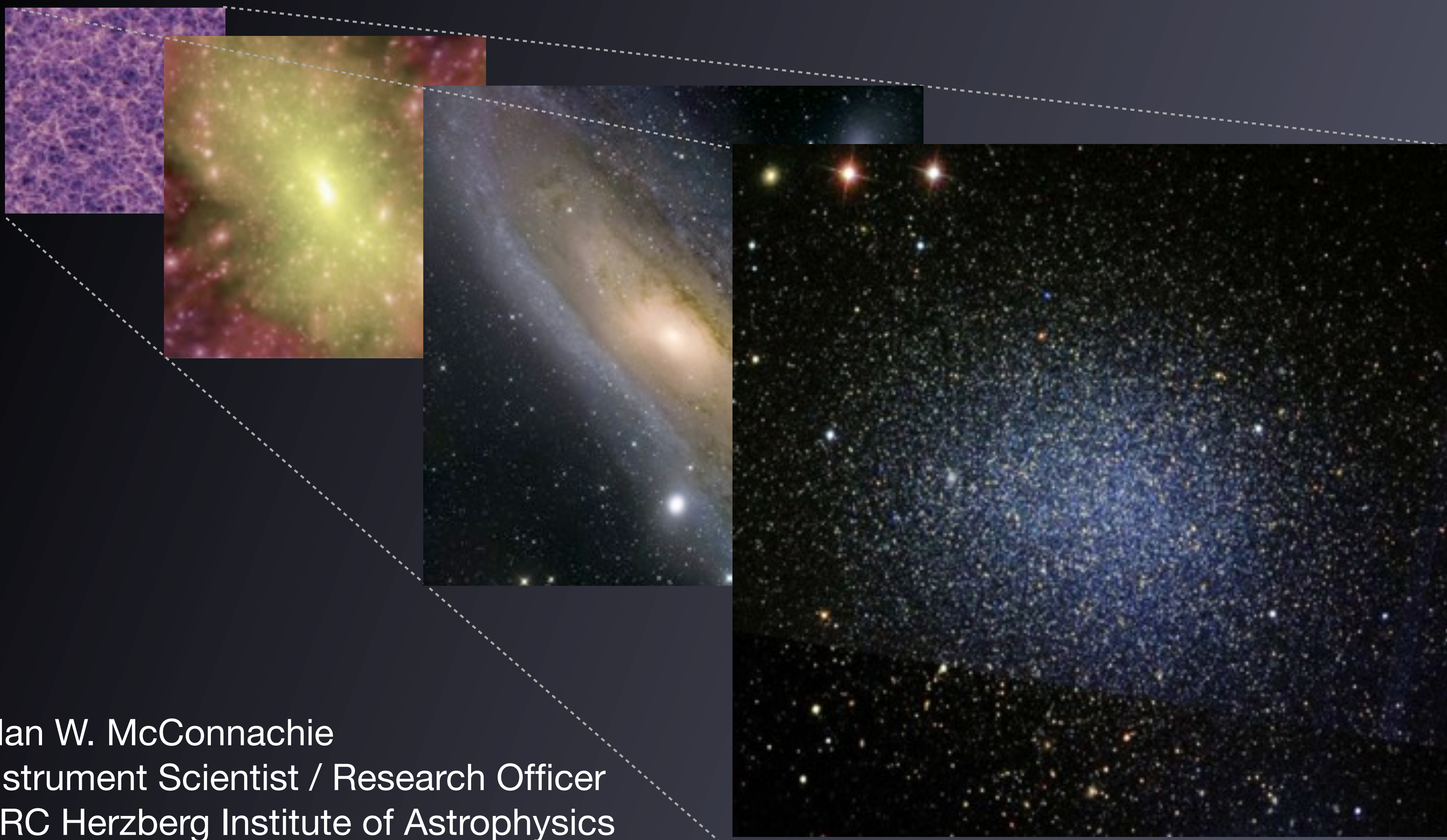
GLAO Workshop, Sapporo, June 14 2013

The Milky Way’s neighbours observed with GLAO



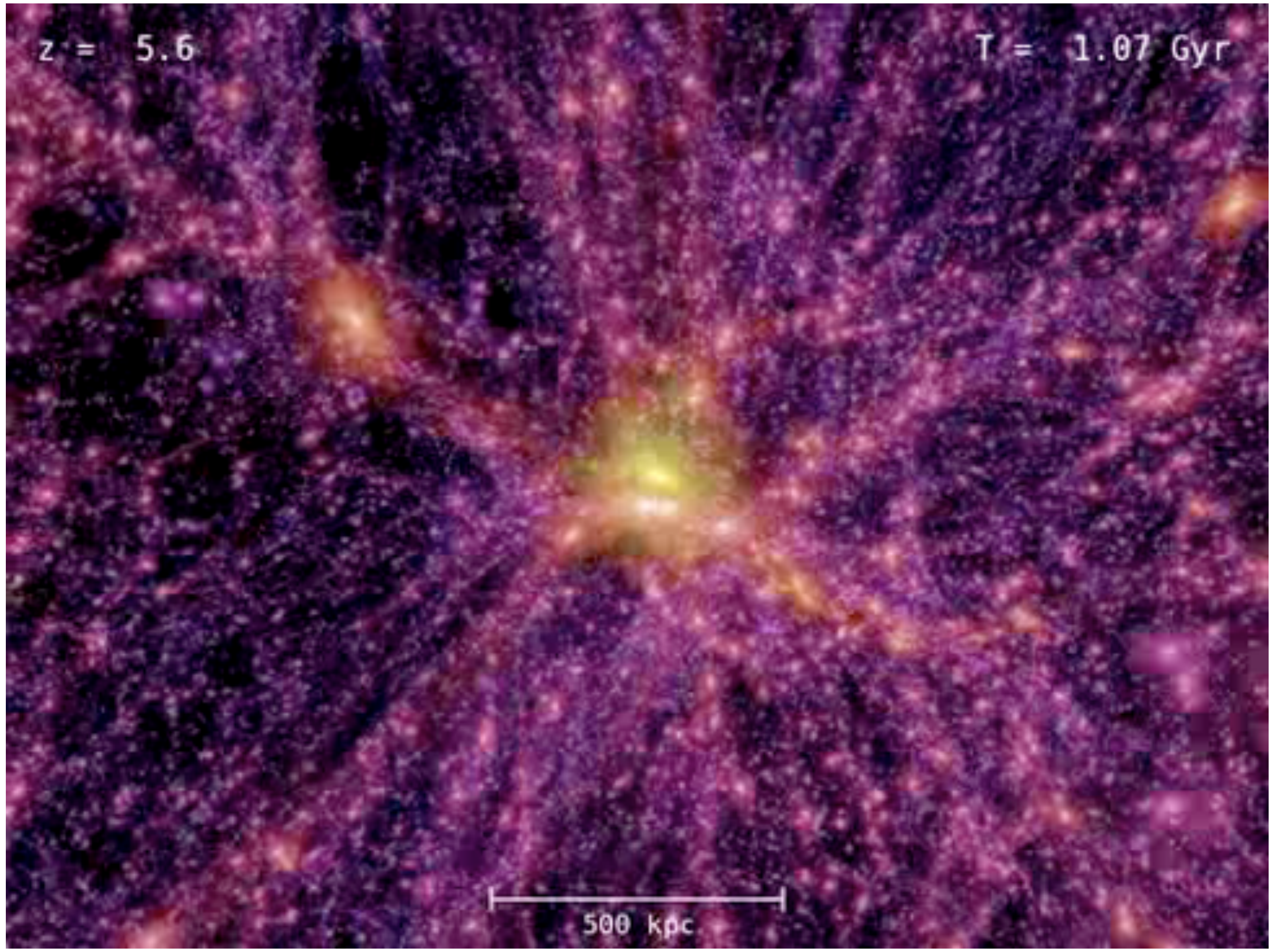
Alan W. McConnachie
Instrument Scientist / Research Officer
NRC Herzberg Institute of Astrophysics

This talk

- Motivation: the nearest galaxies and resolved stellar populations in a cosmological context
- Example science programs
- Random thoughts and the wider context
- See talks by Masashi Chiba and Kim Venn for more discussion of the Milky Way and its globular clusters

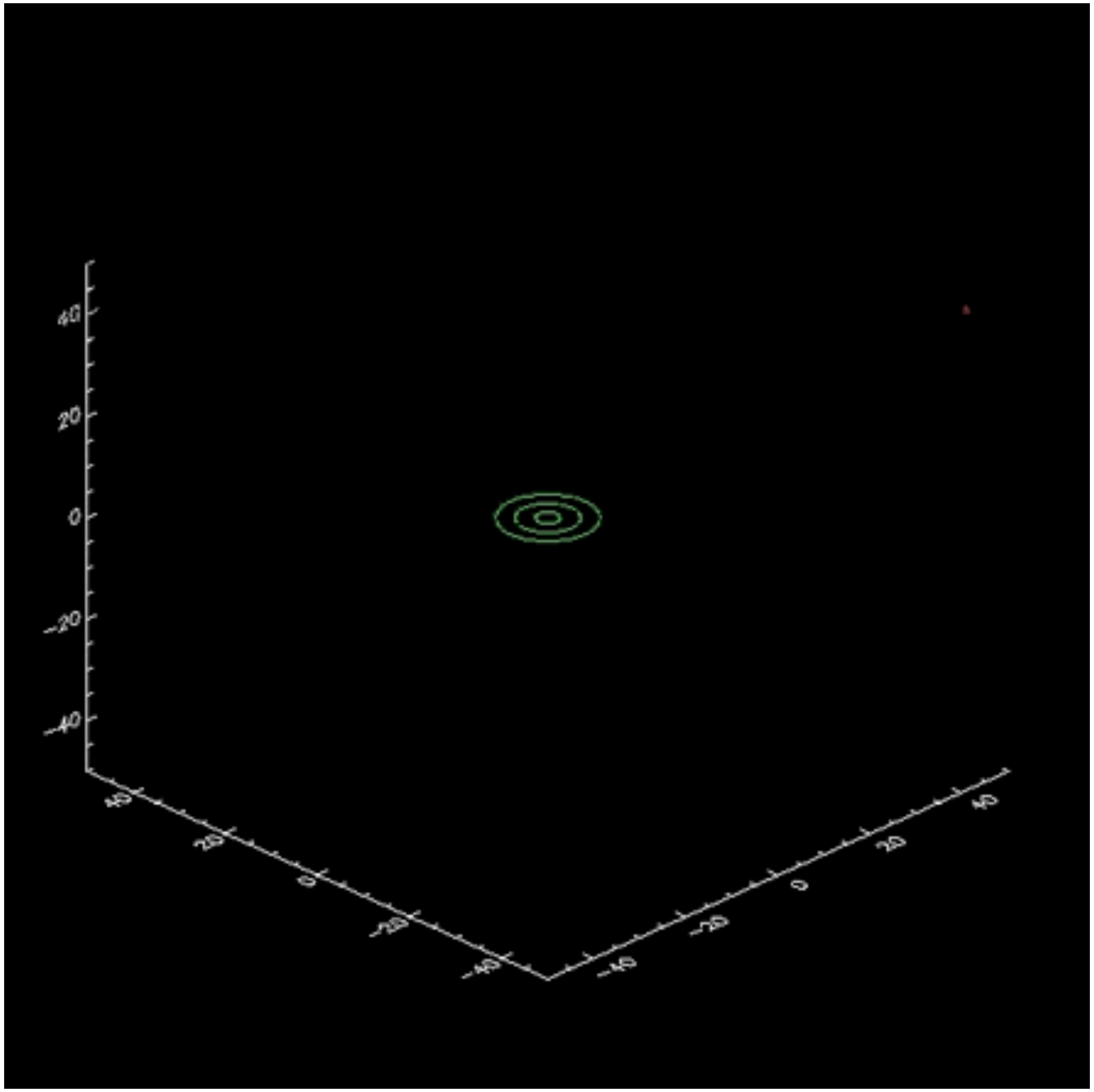
Cosmology on Galaxy scales

- Cosmology (structure formation) on large scales reasonably well modelled within a Lambda Cold Dark Matter paradigm
- Predicts that typical L*-ish galaxy halos should be surrounded by many (>1000s) of low mass sub-halos
- Long dynamical and stellar evolutionary timescales ---> stellar populations (including dwarf galaxies, stellar streams and stellar halos) contain "fossils" of the hierarchical formation of galaxies



Aquarius simulation, Springel *et al.* (2009)

Structure formation and the formation of the MW



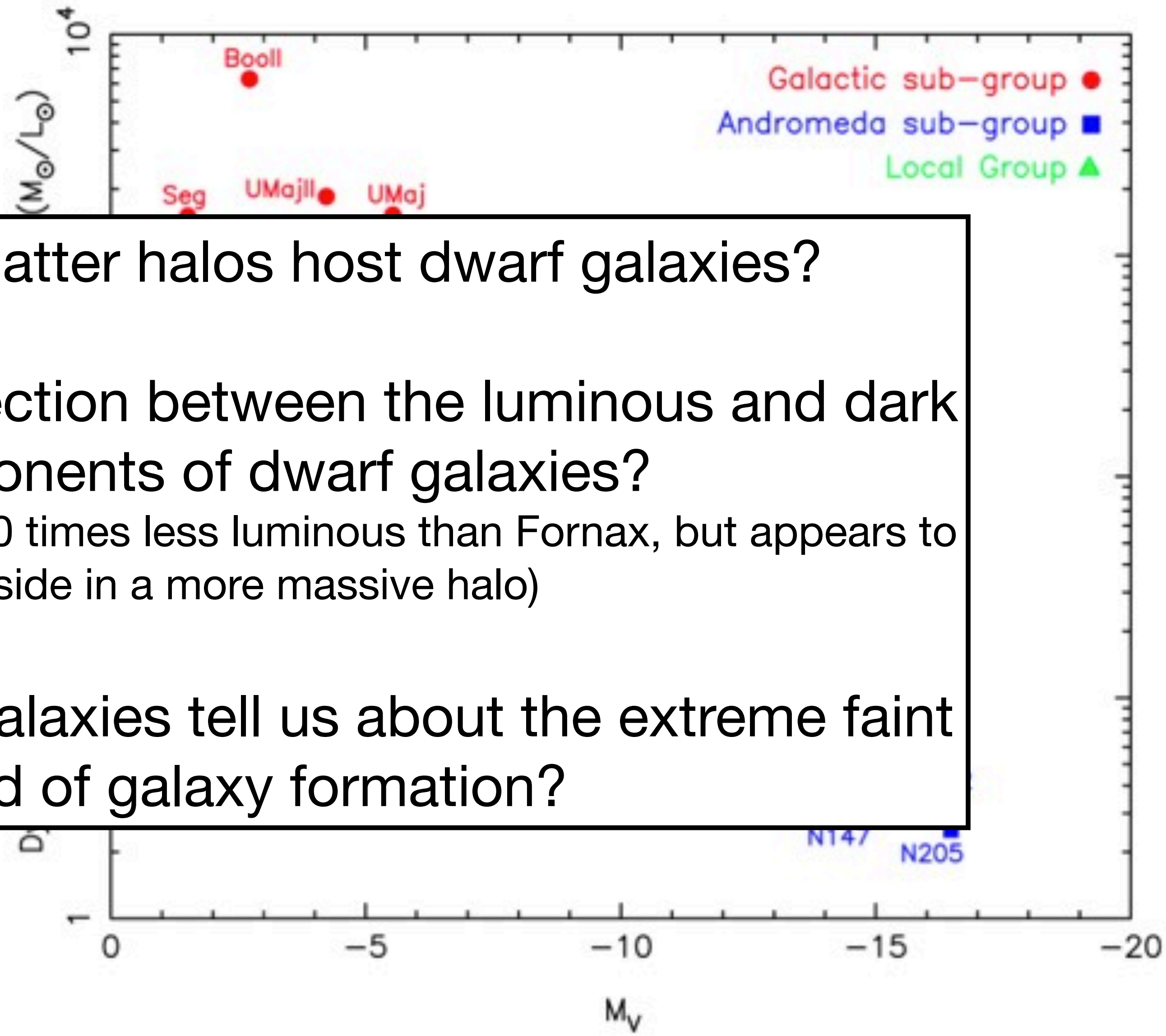
- MW-type haloes expected to accrete many dwarf-mass haloes, some of which will contain baryons (stars)
- Fossil remnants remain at z=0. *Very* faint.

Bullock & Johnston (2005)

Are the dwarf galaxies in massive sub-haloes?

•Walker et al. and Wolf et al. demonstrate that the de
betwe
velocit
minim

•M_{dyn}

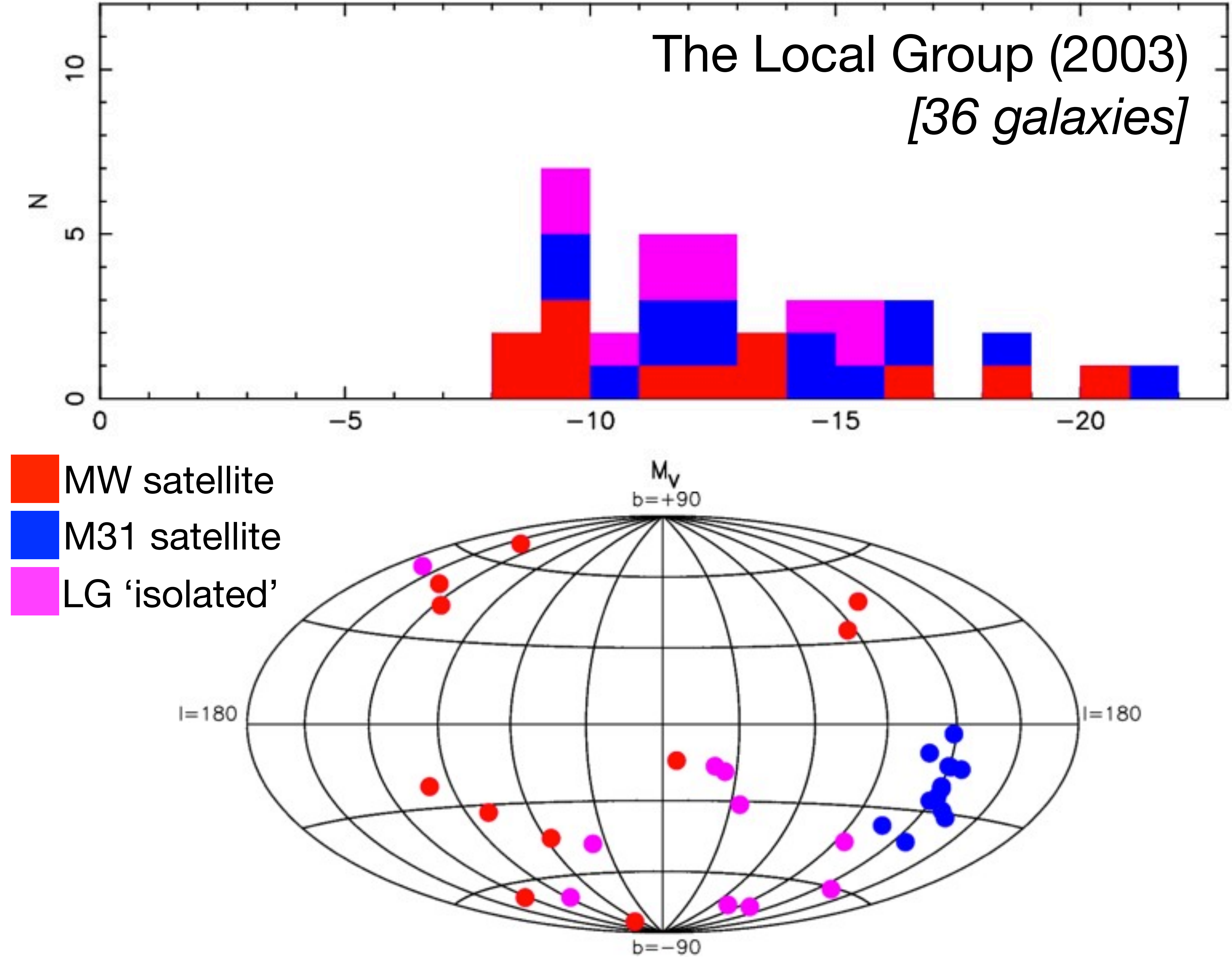


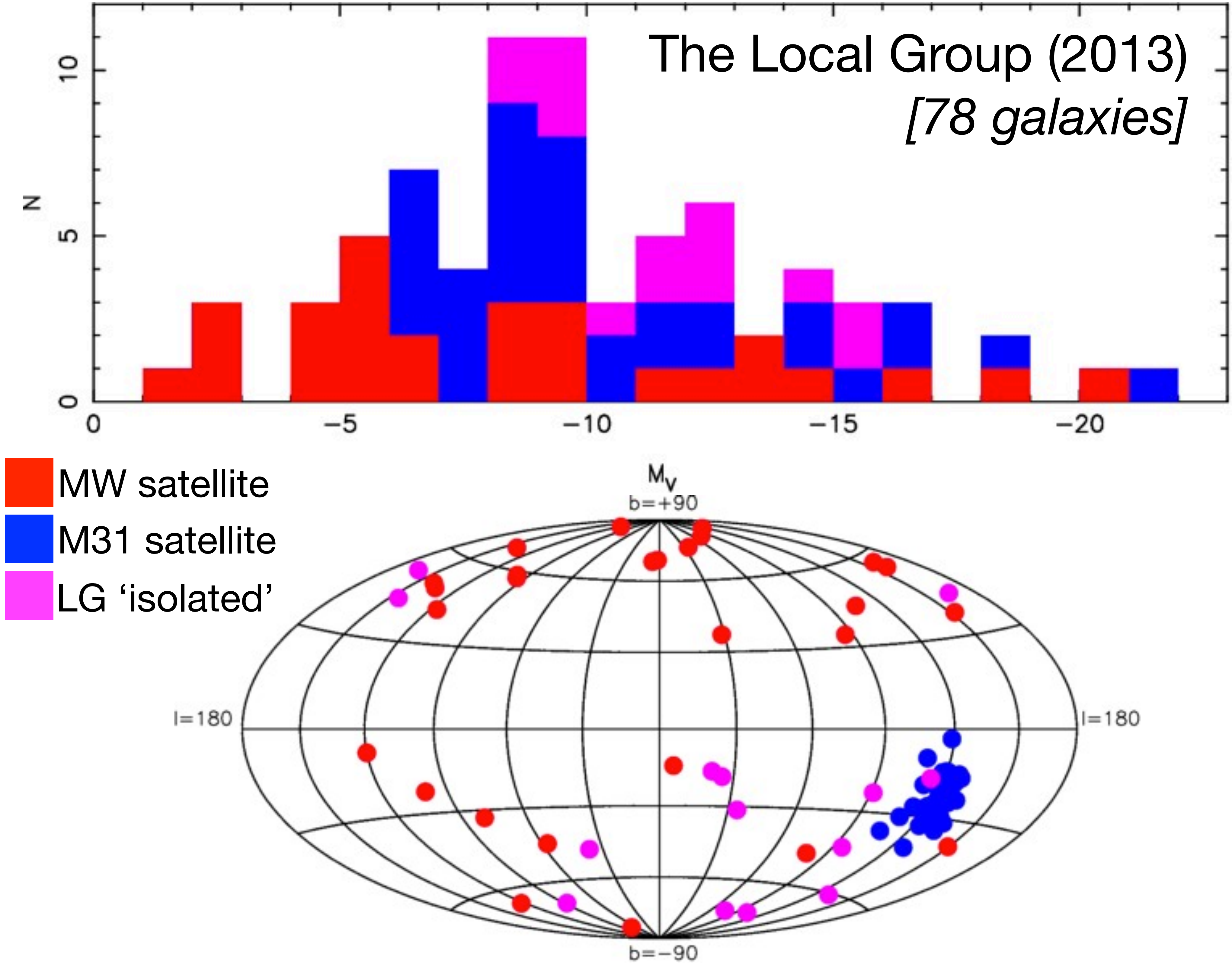
What dark matter halos host dwarf galaxies?

What is the connection between the luminous and dark components of dwarf galaxies?

(e.g., Draco is about 100 times less luminous than Fornax, but appears to reside in a more massive halo)

What can dwarf galaxies tell us about the extreme faint end of galaxy formation?


The Local Group (2003)
[36 galaxies]
N
0
5
10
0
−5
−10
−15
−20
M_V
MW satellite
M31 satellite
LG ‘isolated’
b=+90
b=−90
l=180
l=180



The Local Group (2013)
[78 galaxies]
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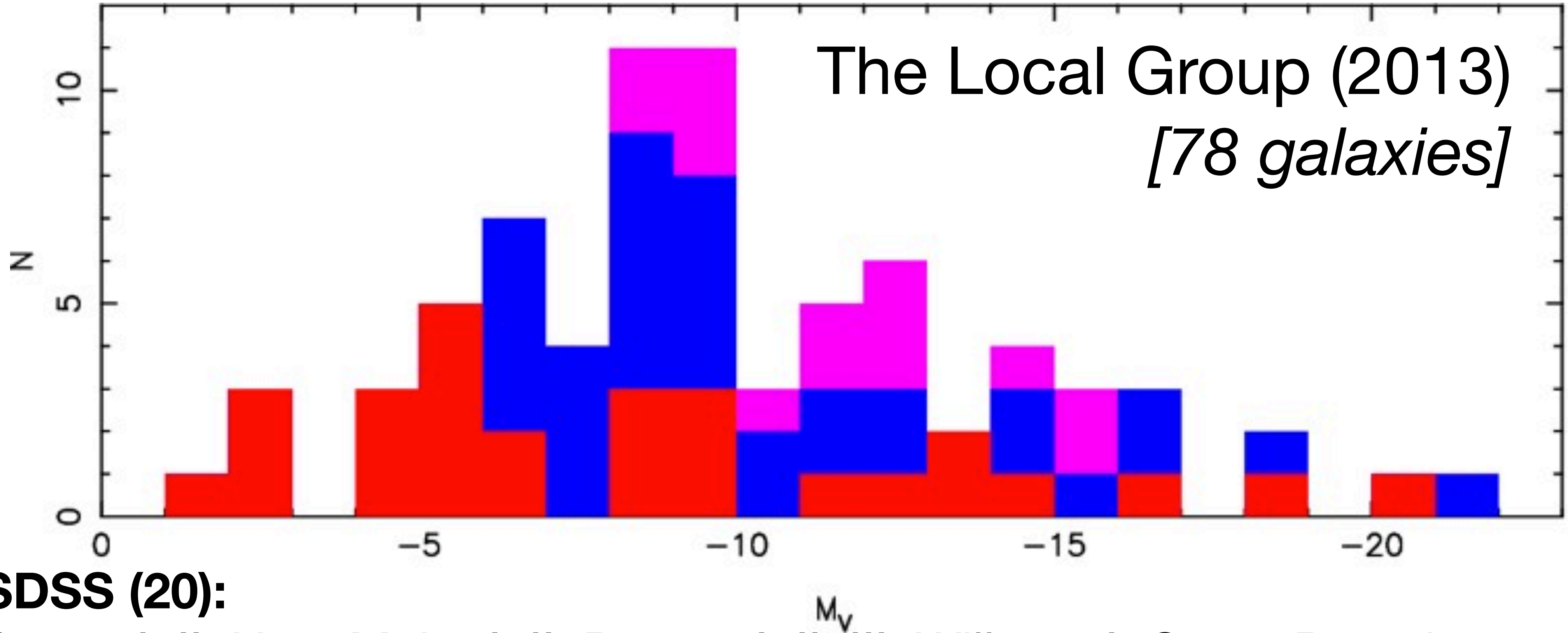


SDSS (20):

Segue I, II, Ursa Major I, II, Bootes I, II, III, Willman I, Coma Berenices, Hercules, Leo IV, V, Leo T, Canes Venatici I, II, Pisces II, Andromeda IX, X, XXVIII, XXIX

PAndAS (17):

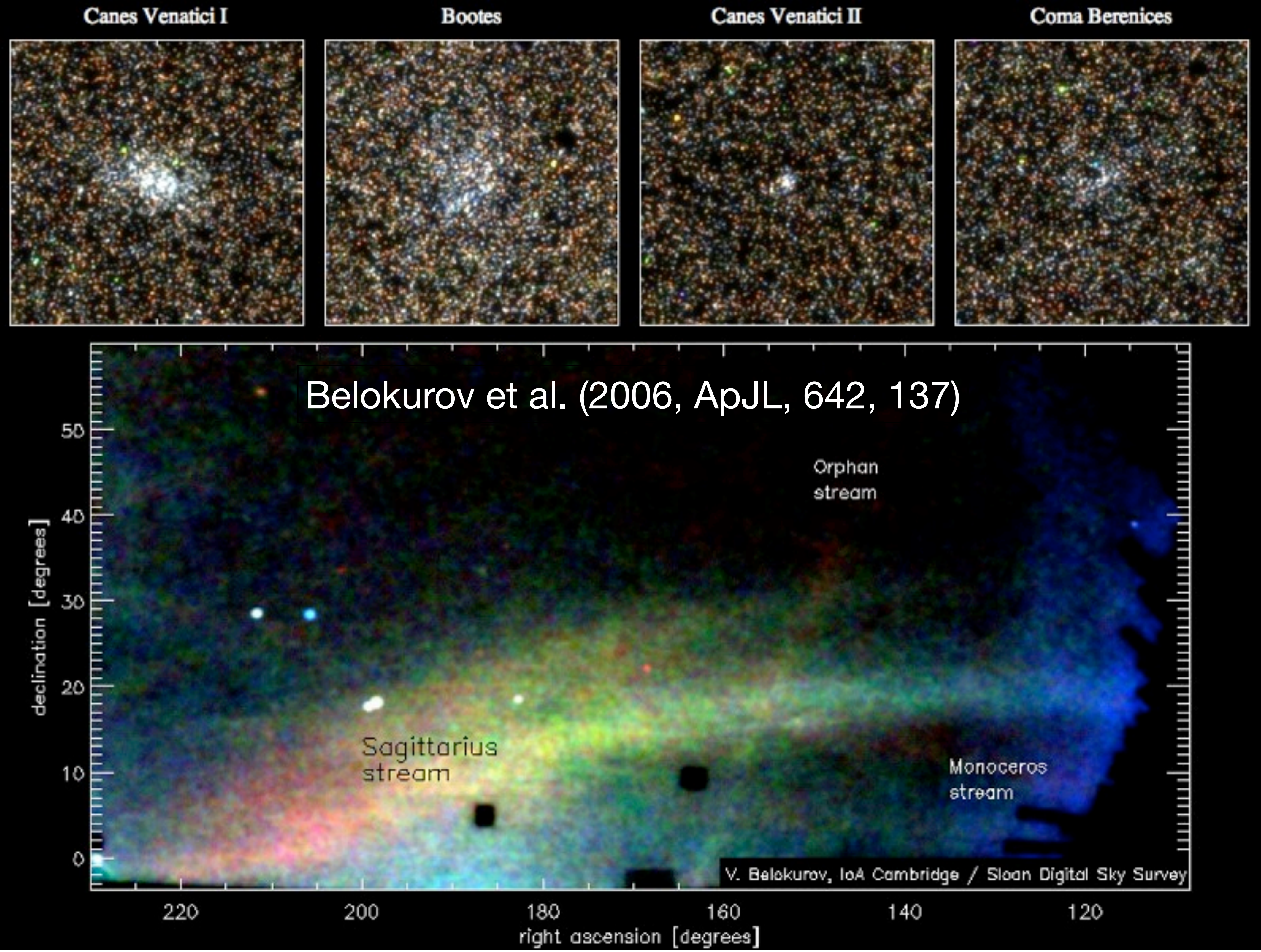
Andromeda XI, XII, XIII, XV, XVI, XVII, XVIII, XIX, XX, XXI (Tri I), XXII, XXIII, XXIV, XXV, XVI, XXVII, *XXX (Cass II)*

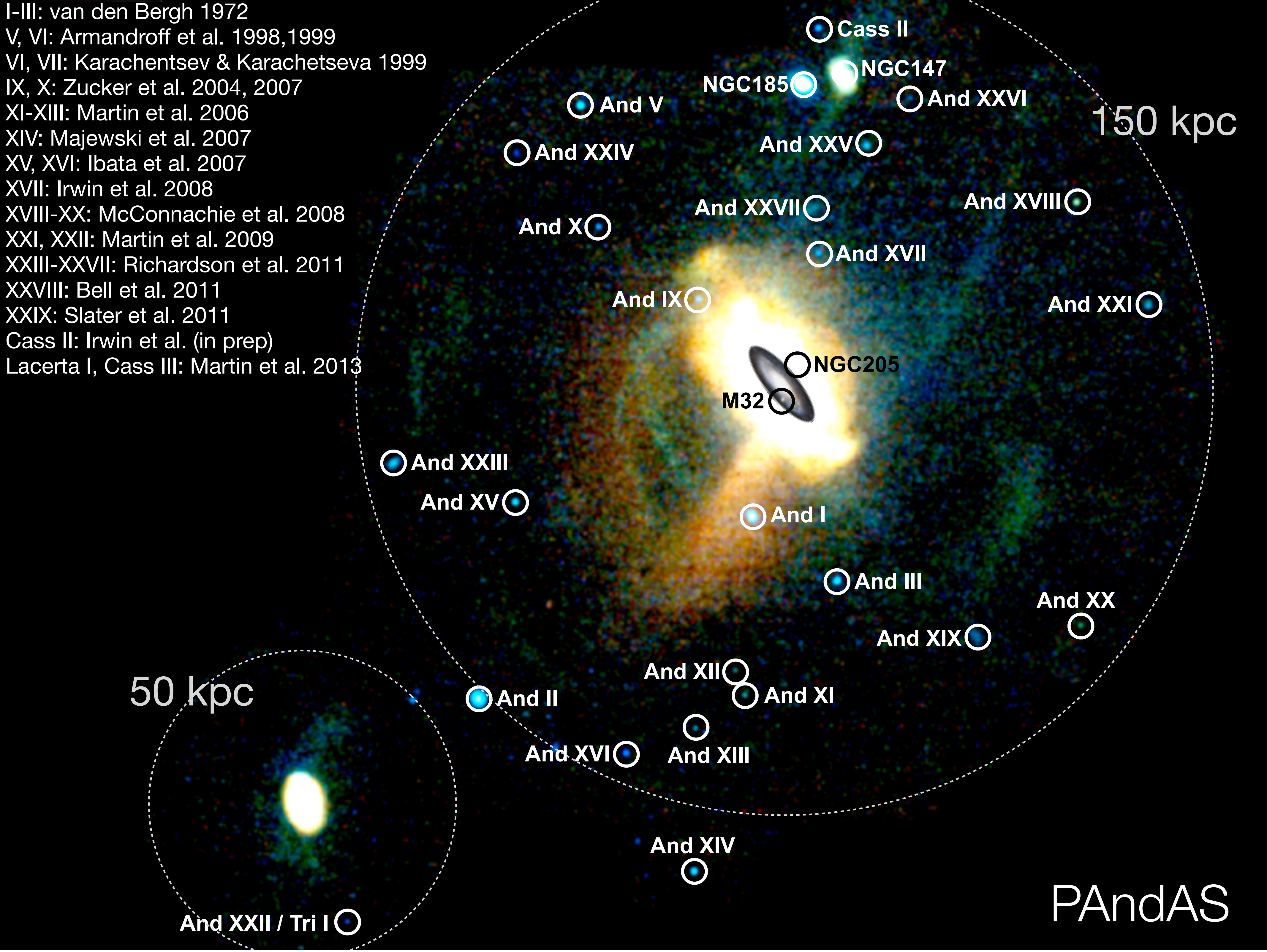
PanSTARRS I (2):

Lacerta I (And XXXI), Casseopeia III (And XXXII)

Others (3):

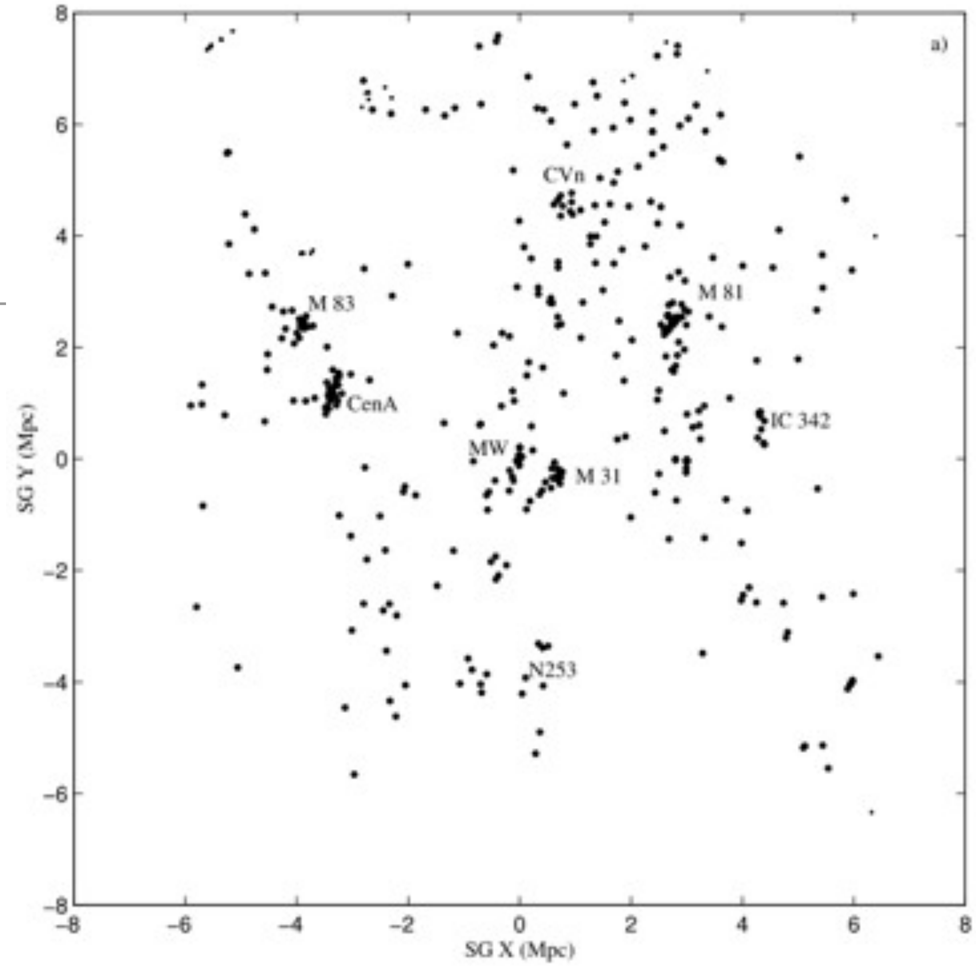
Canis Major [controversial], UGC4879 [new distance], And XIV [Majewski]

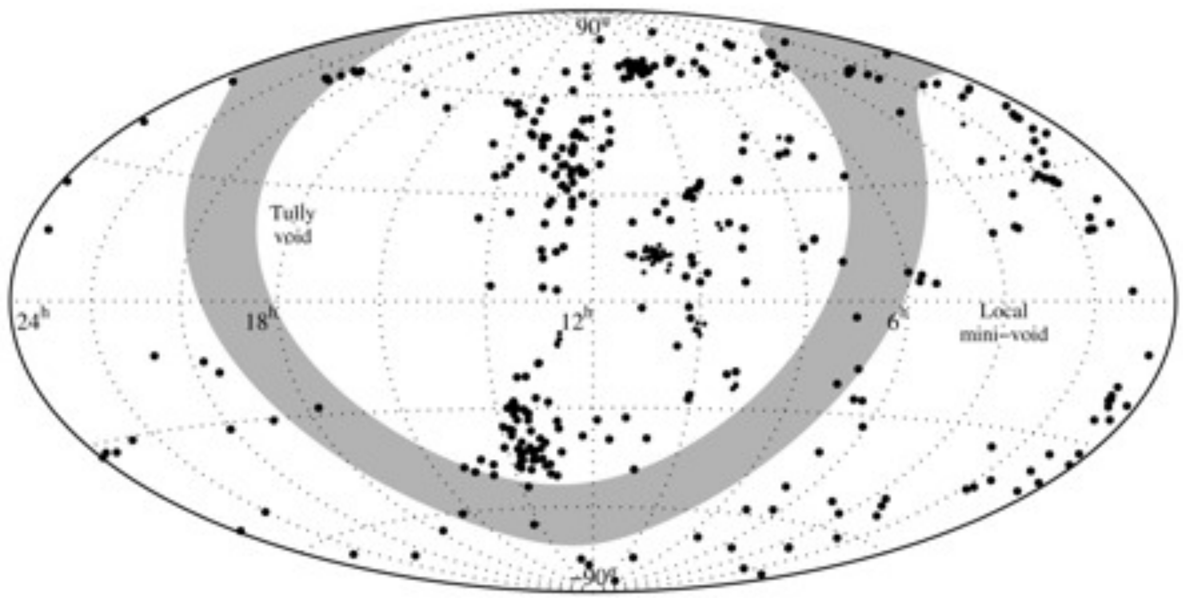

Canes Venatici I
Bootes
Canes Venatici II
Coma Berenices
Belokurov et al. (2006, ApJL, 642, 137)
Orphan
stream
Sagittarius
stream
Monoceros
stream
V. Belokurov, IoA Cambridge / Sloan Digital Sky Survey
declination [degrees]
right ascension [degrees]
0
10
20
30
40
50
220
200
180
160
140
120


I-III: van den Bergh 1972
V, VI: Armandroff et al. 1998,1999
VI, VII: Karachentsev & Karachetseva 1999
IX, X: Zucker et al. 2004, 2007
XI-XIII: Martin et al. 2006
XIV: Majewski et al. 2007
XV, XVI: Ibata et al. 2007
XVII: Irwin et al. 2008
XVIII-XX: McConnachie et al. 2008
XXI, XXII: Martin et al. 2009
XXIII-XXVII: Richardson et al. 2011
XXVIII: Bell et al. 2011
XXIX: Slater et al. 2011
Cass II: Irwin et al. (in prep)
Lacerta I, Cass III: Martin et al. 2013
Cass II
NGC147
NGC185
And XXVI
And V
150 kpc
And XXIV
And XXV
And XXVII
And XVIII
And X
And XVII
And IX
And XXI
NGC205
M32
And XXIII
And XV
And I
And III
And XX
And XIX
And XII
And XI
50 kpc
And II
And XVI
And XIII
And XIV
PAndAS
And XXII / Tri I

The Local Volume

- 106 galaxies within 3Mpc of the Sun, overwhelming majority are dwarf galaxies
  - 28 members of the MW subgroup
  - 36 members of M31 subgroup
  - 14 other Local Group members
  - 28 nearby neighbours
- 450 - 500 galaxies within 10Mpc
- Virgo Cluster at ~15Mpc

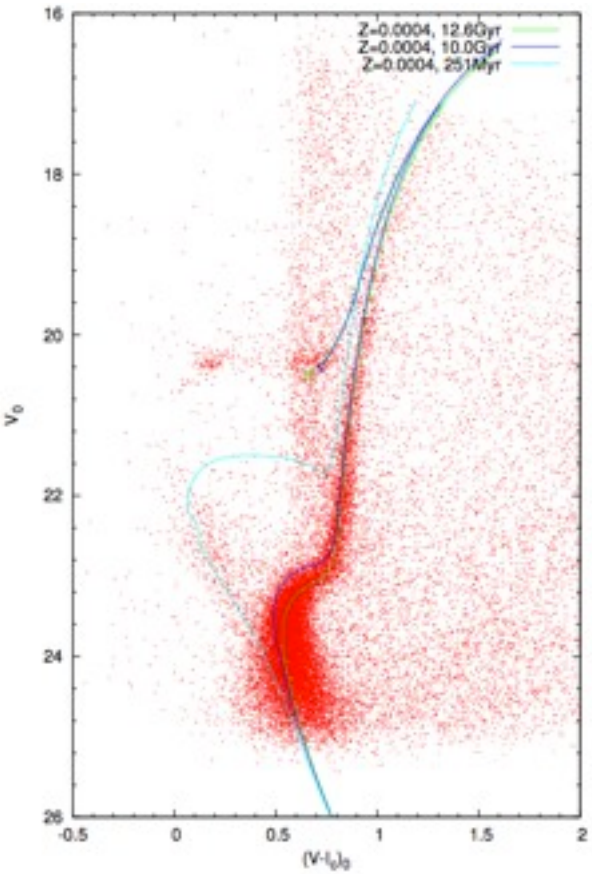


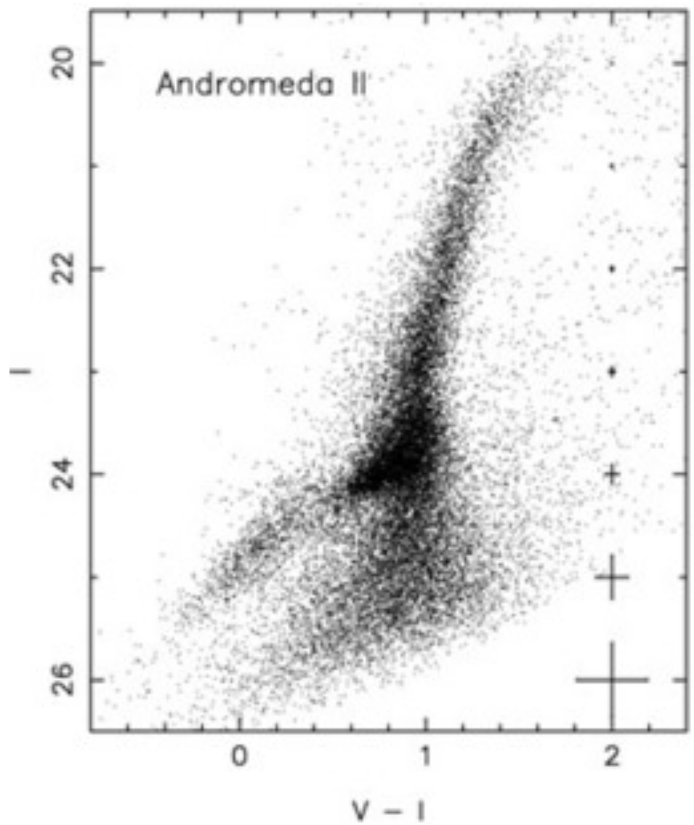


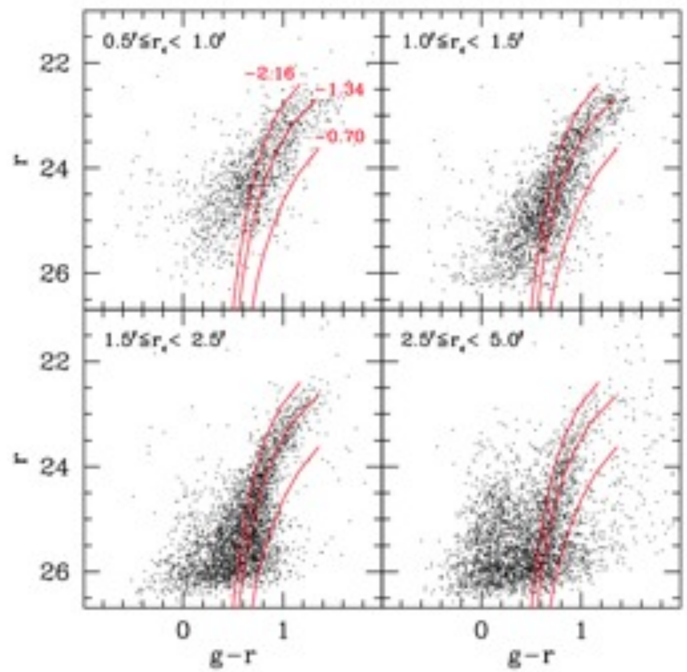
Friday, June 14, 2013

Resolved stellar populations in the coming decades

- Key diagnostic plots are color-magnitude diagrams (observational equivalent of Hertzsprung-Russell diagrams)
- From the ground, can obtain useful CMDs out to D~ few Mpc **IN UNCROWDED REGIONS**

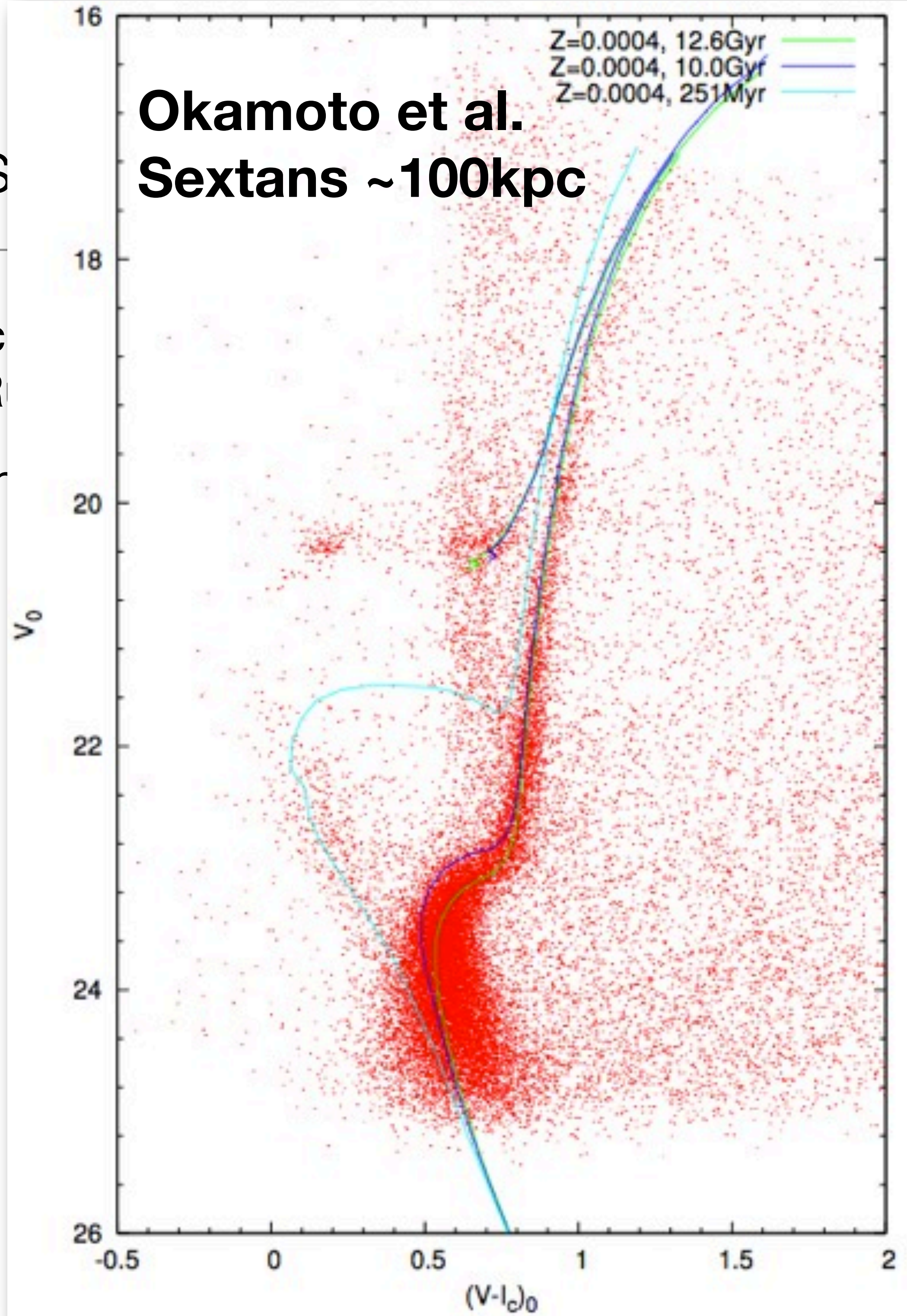


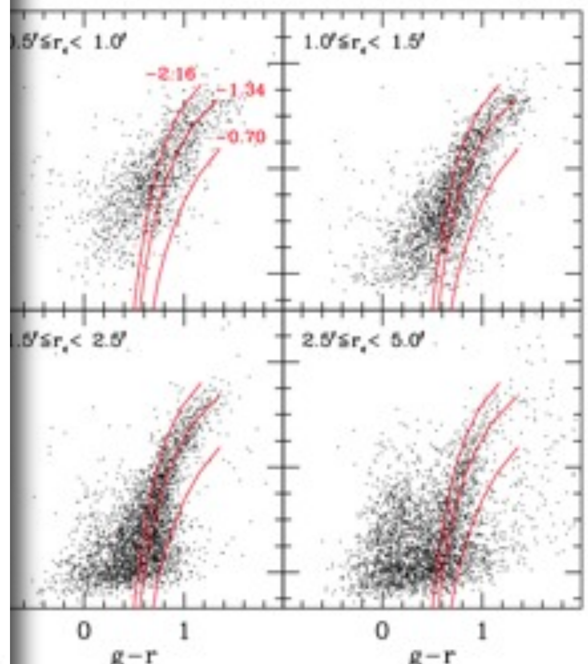




Resolved s ng decades

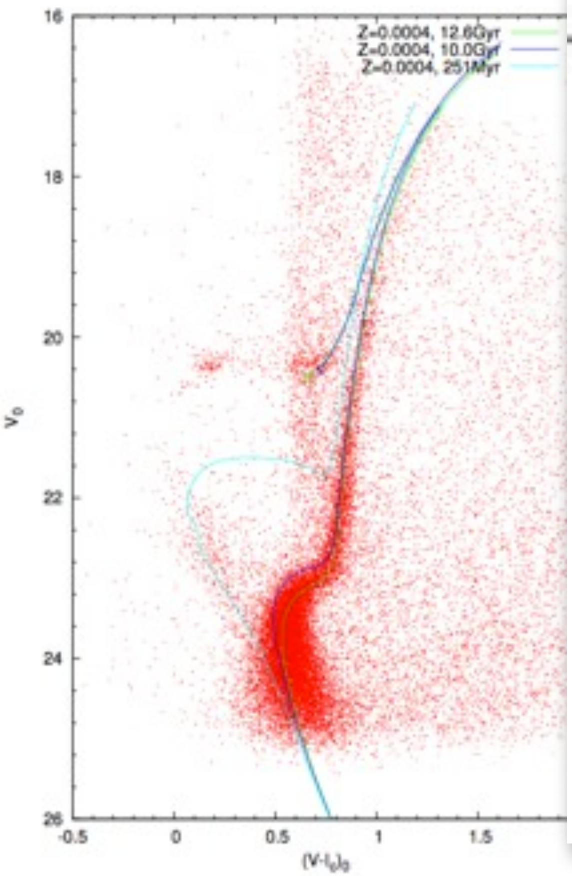
- Key diagnostic ational equivalent of Hertzsprung-R
- From the grour pc **IN UNCROWDED REGIONS**

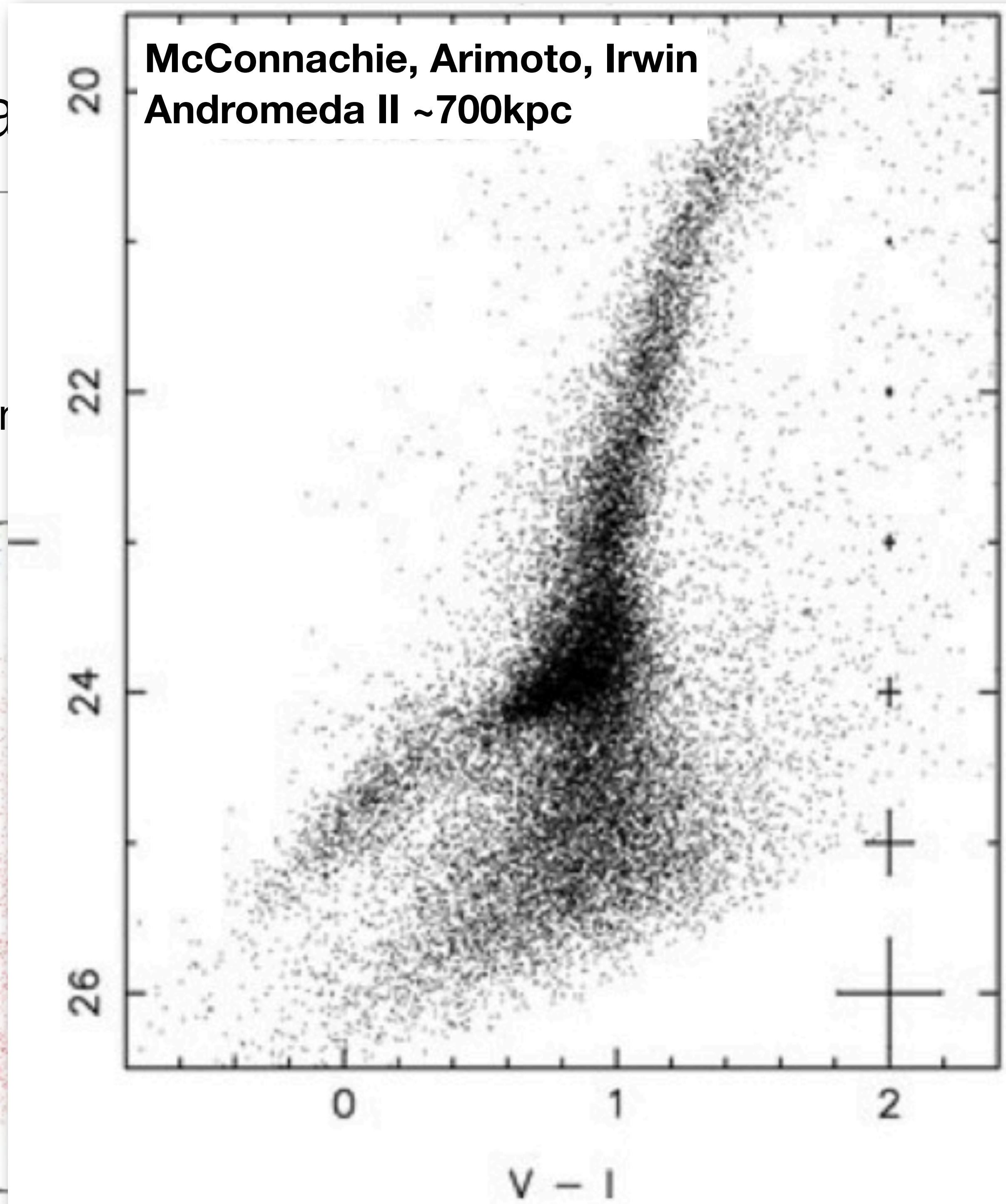


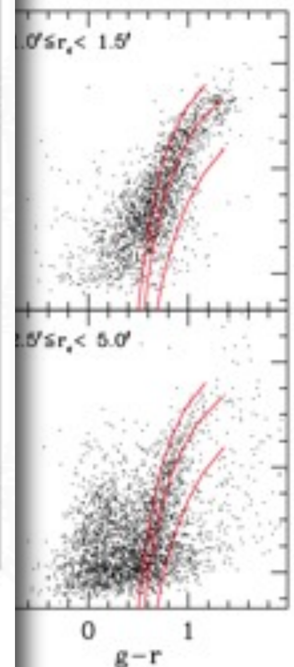


Resolved stella ... des

- Key diagnostic plots ... alent of Hertzsprung-Russell
- From the ground, car ... OWDED **REGIONS**

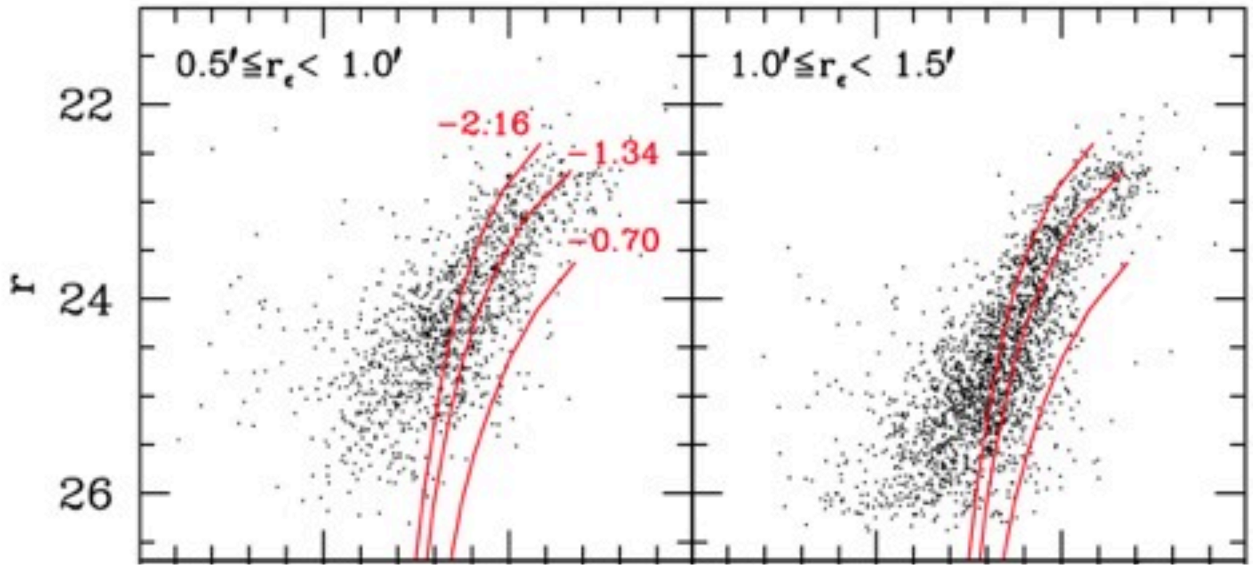




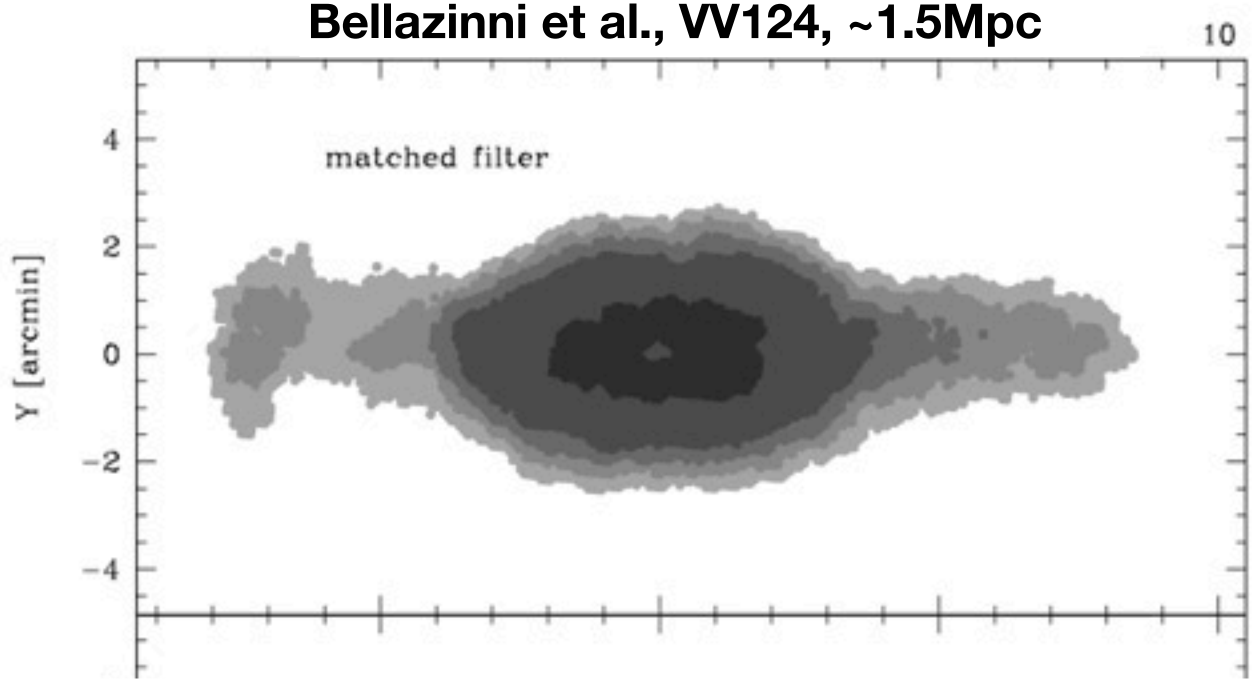


The importance of wide fields

- Stellar populations probe **ages, metallicities, structures, dynamical histories, environments...**
- Crowding/confusion limited. Need wide fields ---> GLAO ideal for wide field, confusion limited observations!!
- **JWST, TMT will provide pointed deep observations over small fields. Subaru should concentrate on GLOBAL NOT LOCAL picture of galaxy evolution**

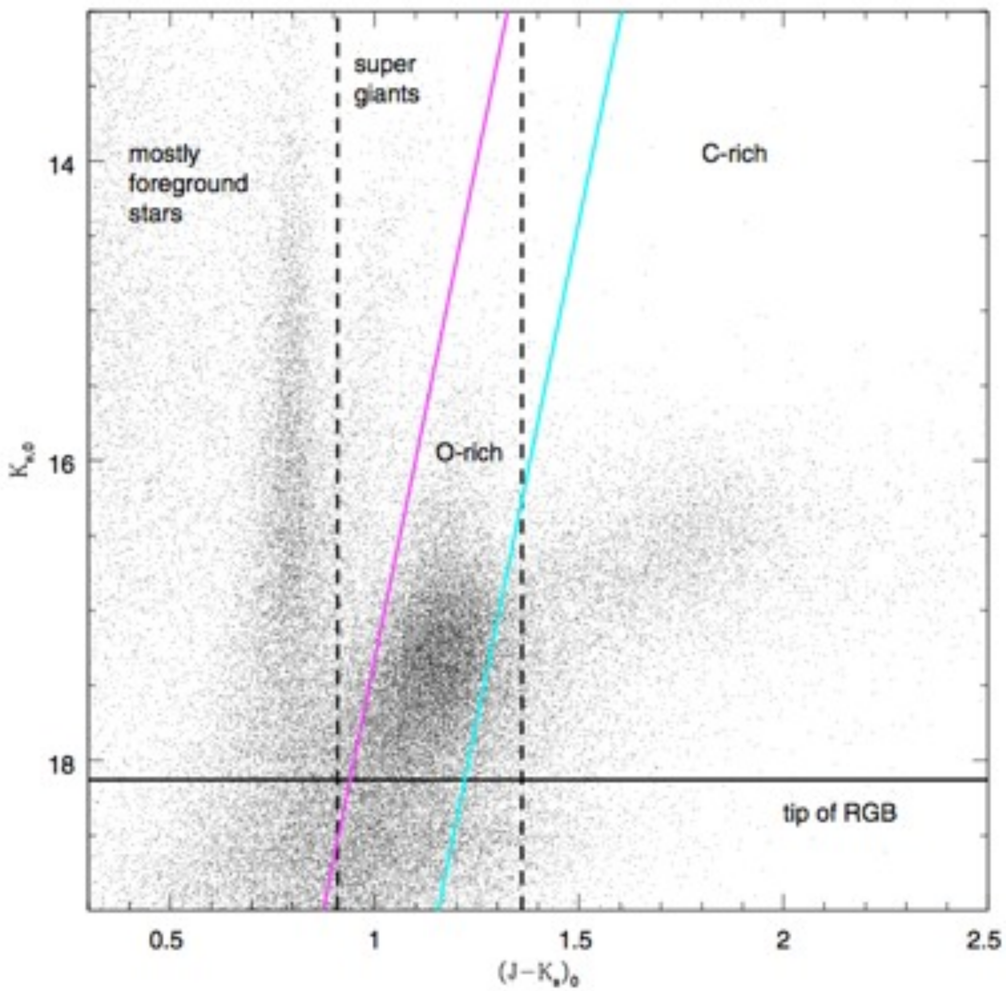


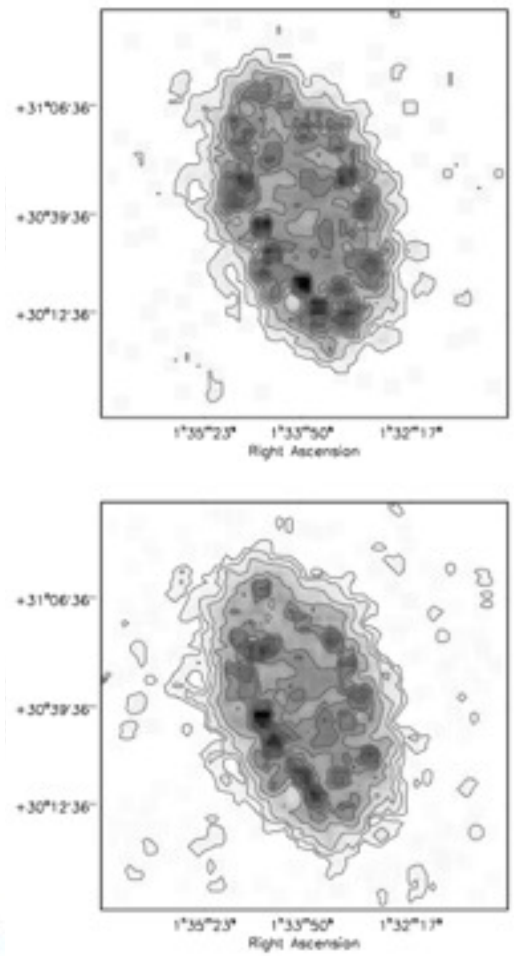
Bellazinni et al., VV124, ~1.5Mpc



The near-IR

Cioni et al, M33, ~800kpc

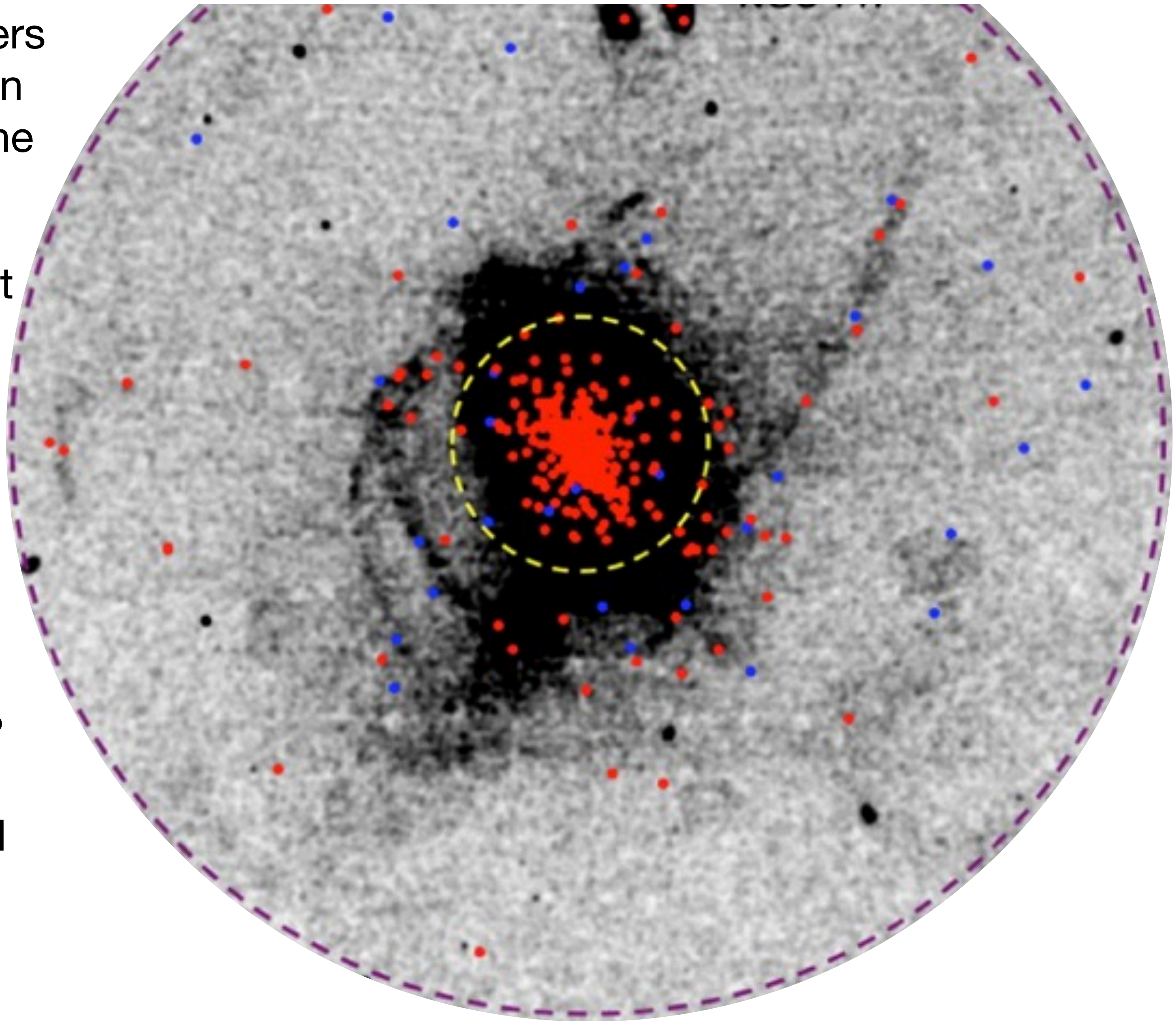




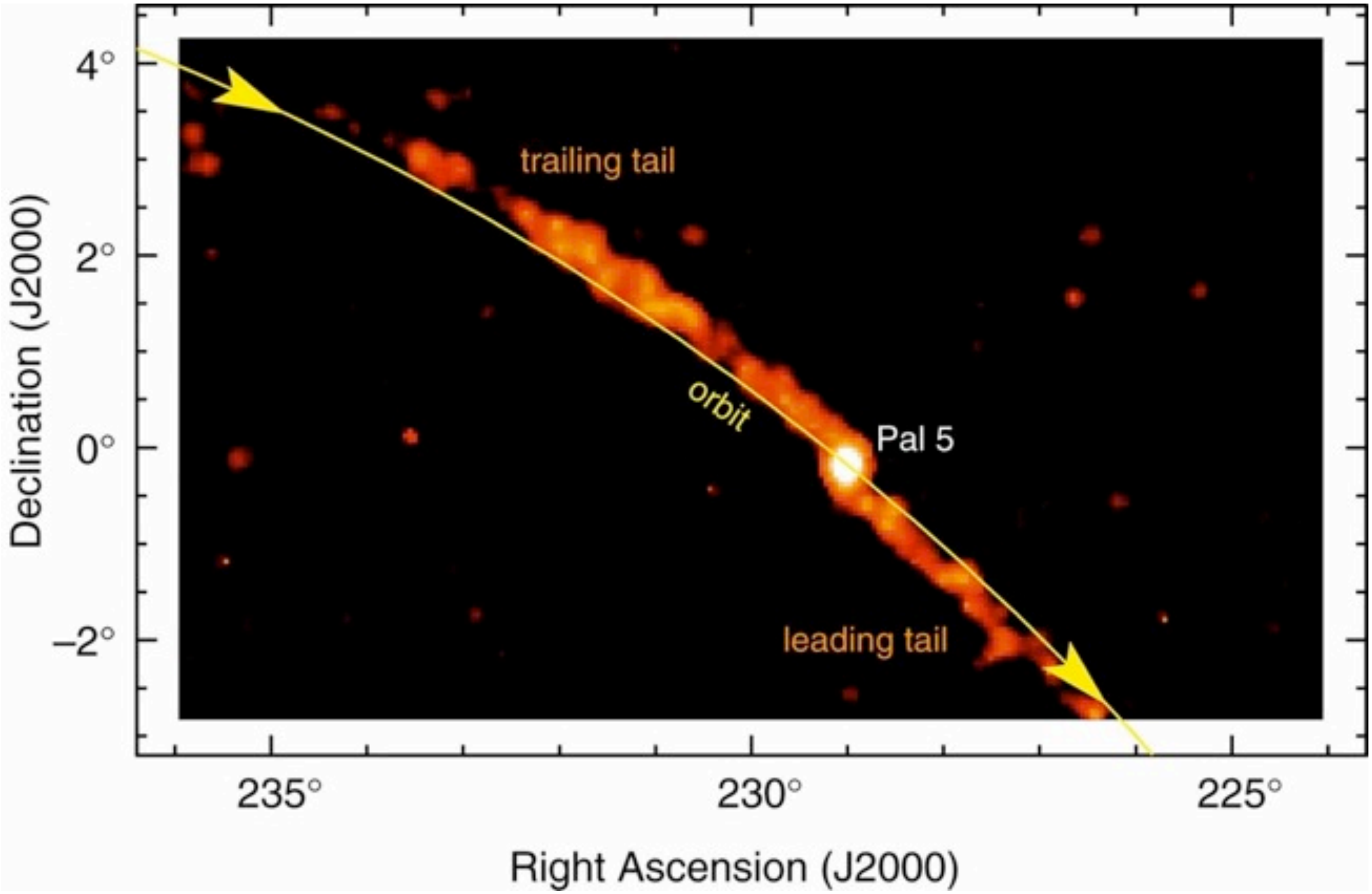
- Bright NIR dominated by RGB, AGB stars --> tracers of intermediate/old-ages
- AGB stars represent a challenge to stellar evolution due to role of stellar mass loss
- RGB stars ubiquitous in all galaxies

Exemplar Science Case I: M31 and its halo clusters

- Only some globular clusters at the distance of M31 can be barely resolved from the ground
- HST/ACS ideal instrument for obtaining deep (subgiant) CMDs
- Some GCs in M31 clearly associated with stellar streams and halo substructure
- Do GCs show disruption? Can we trace their orbit? Are halo stars contributed by GCs or just dwarf galaxies?

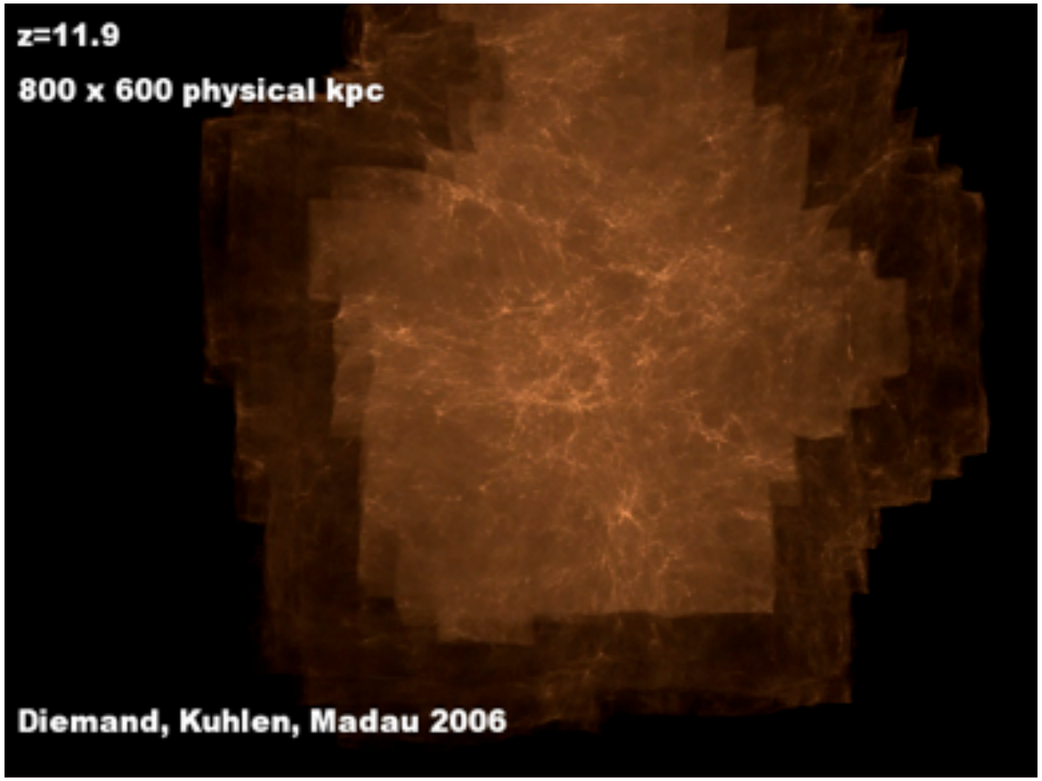


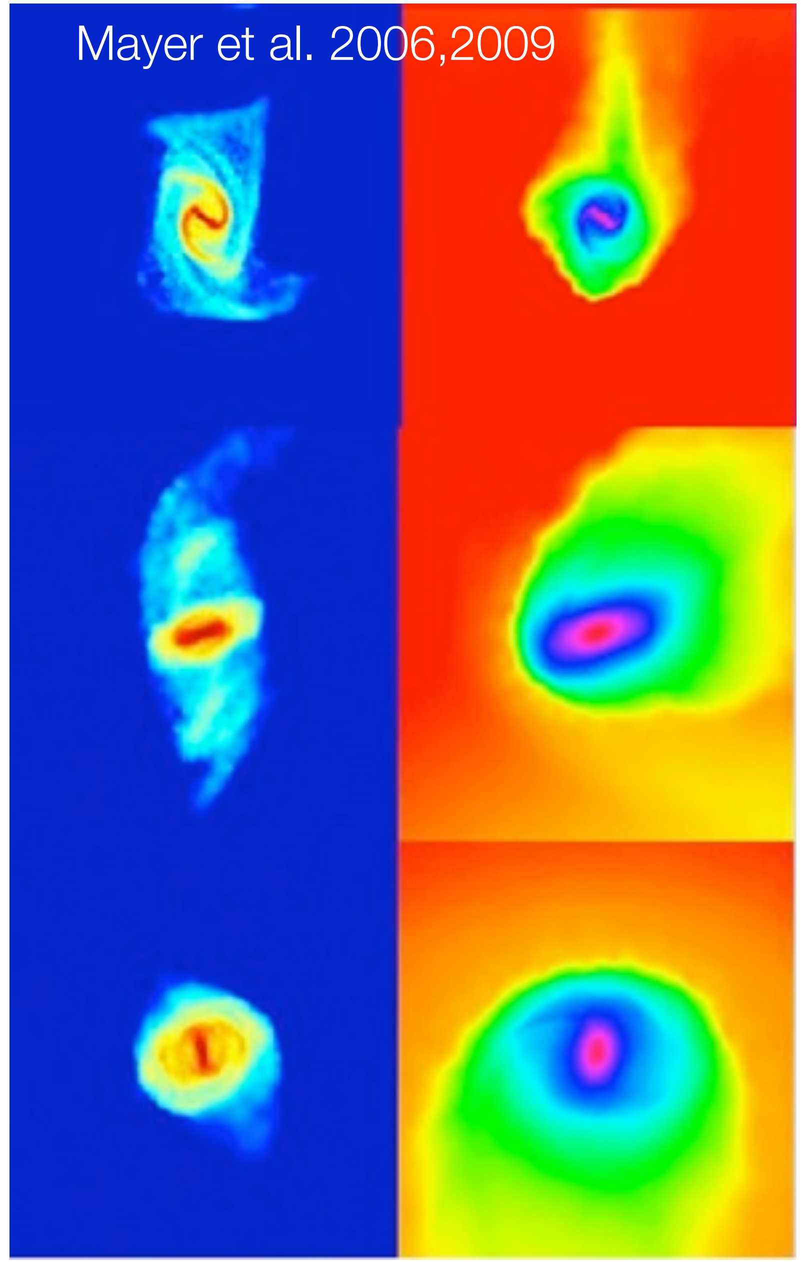
M31 and its halo clusters



- Difficult to determine if any of the GCs show tidal debris cf. Pal 5

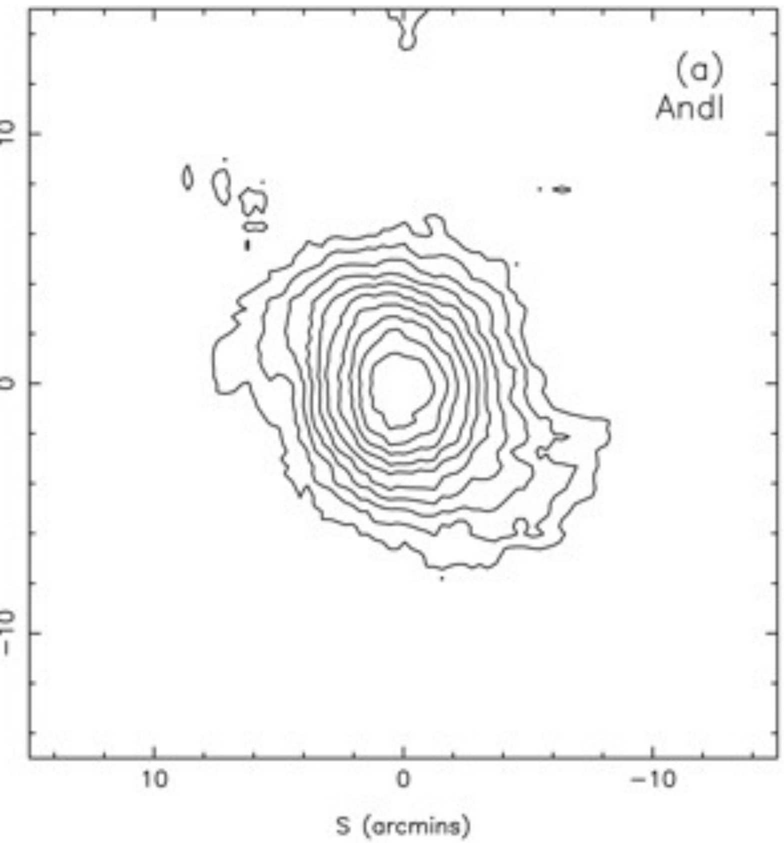
Exemplar Science Case II:
The limits of galaxy formation: isolated dwarfs in the nearby Universe

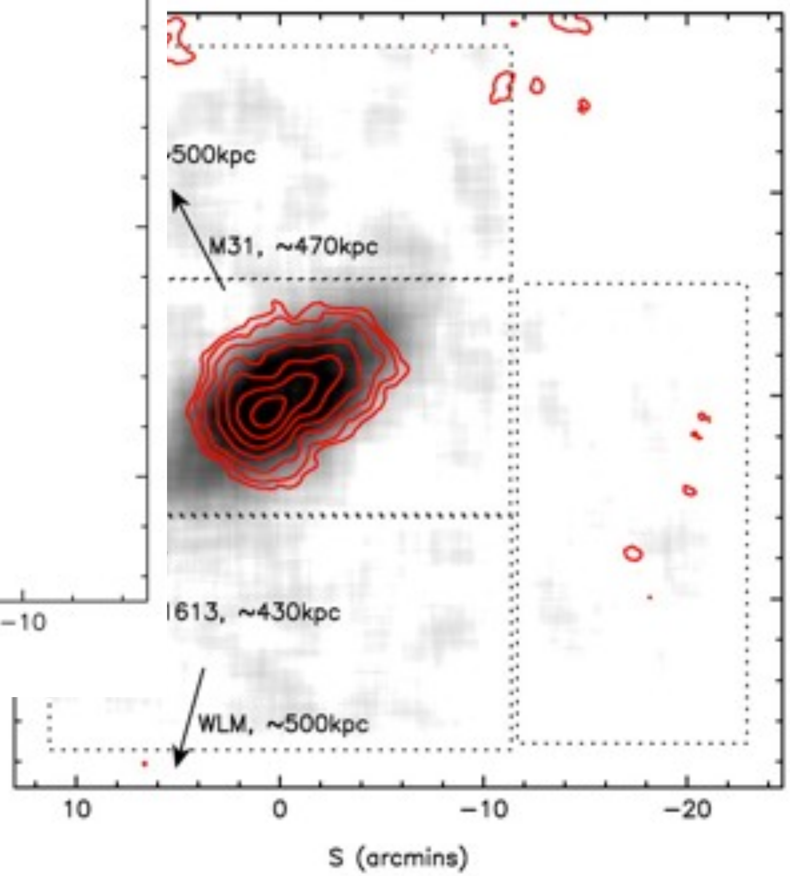


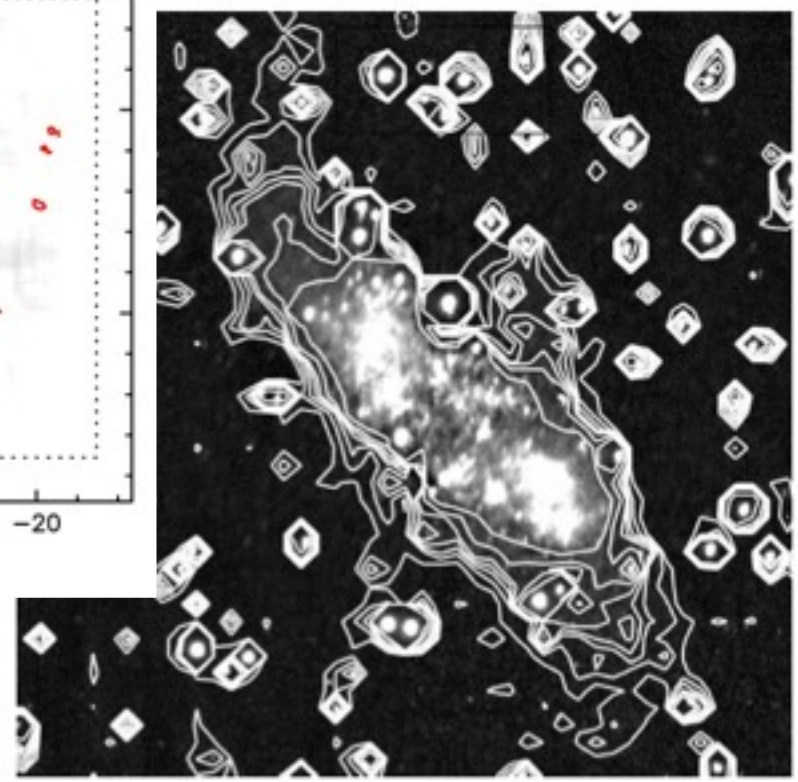


- **How do small mass halos evolve in the absence of strong environmental mechanisms?**
- Isolated dwarf: tidal disruption, ram pressure stripping, interaction-induced star formation (etc) likely minimal
  - **14 isolated members of the Local Group**
  - **28 nearby neighbours beyond turnaround radius**
- Half-light radii ~0.5 <-> ~few arcmins

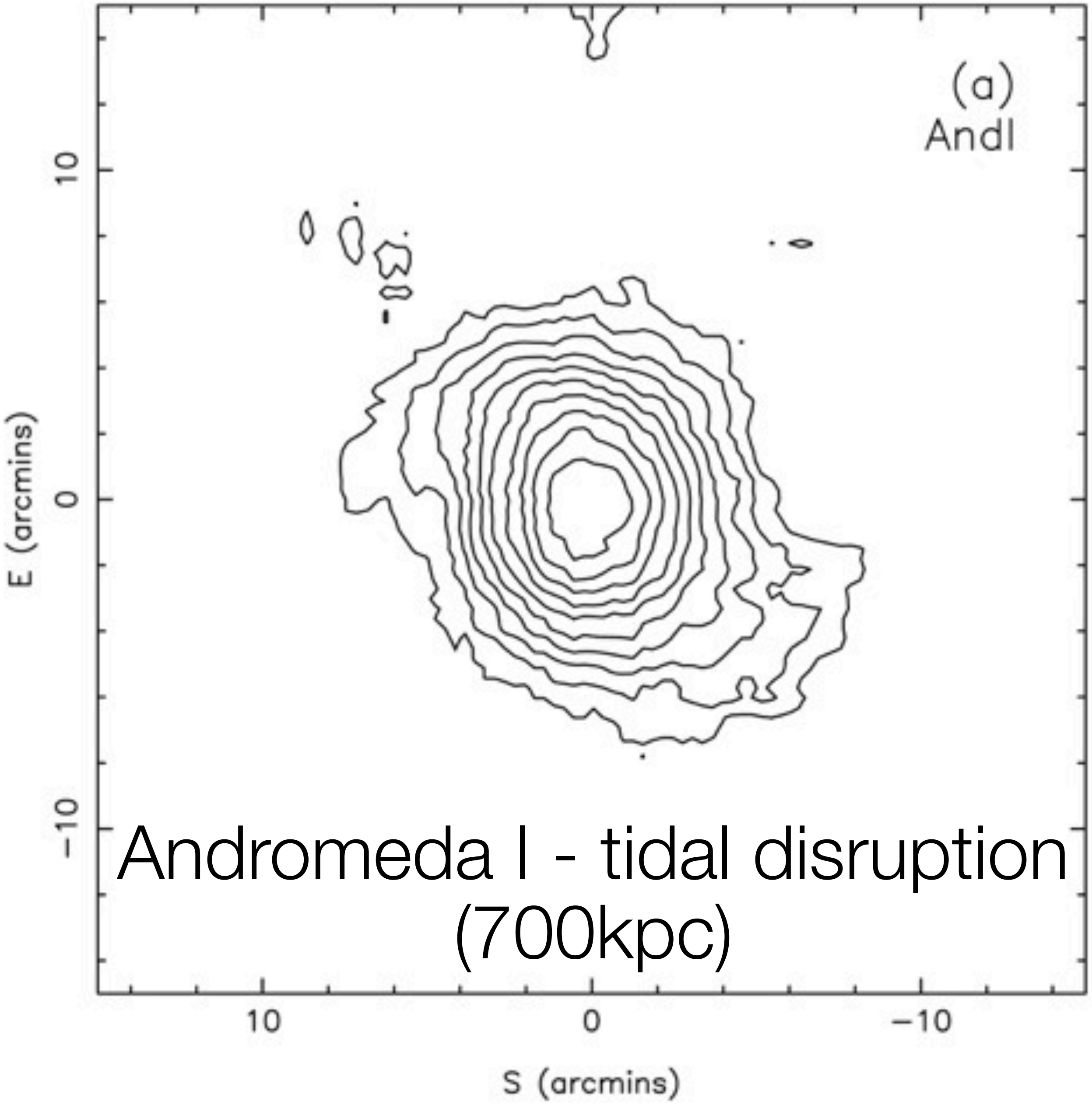
Wide field views of nearby dwarfs

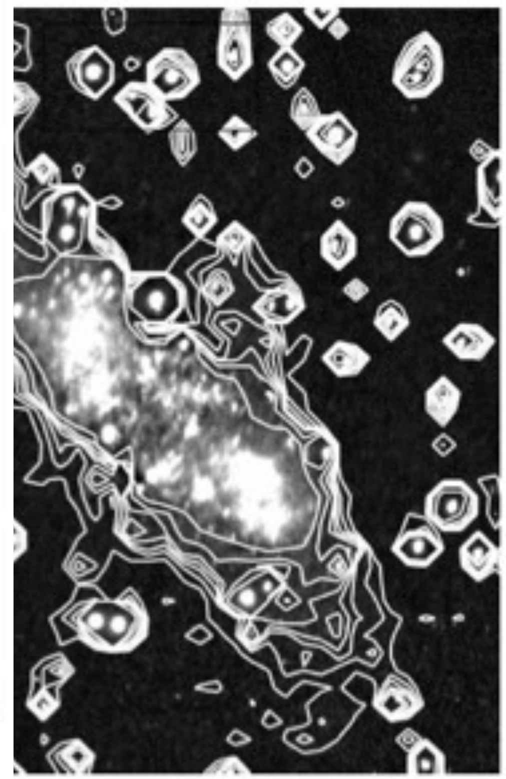






Wide field views of nearby dwarfs

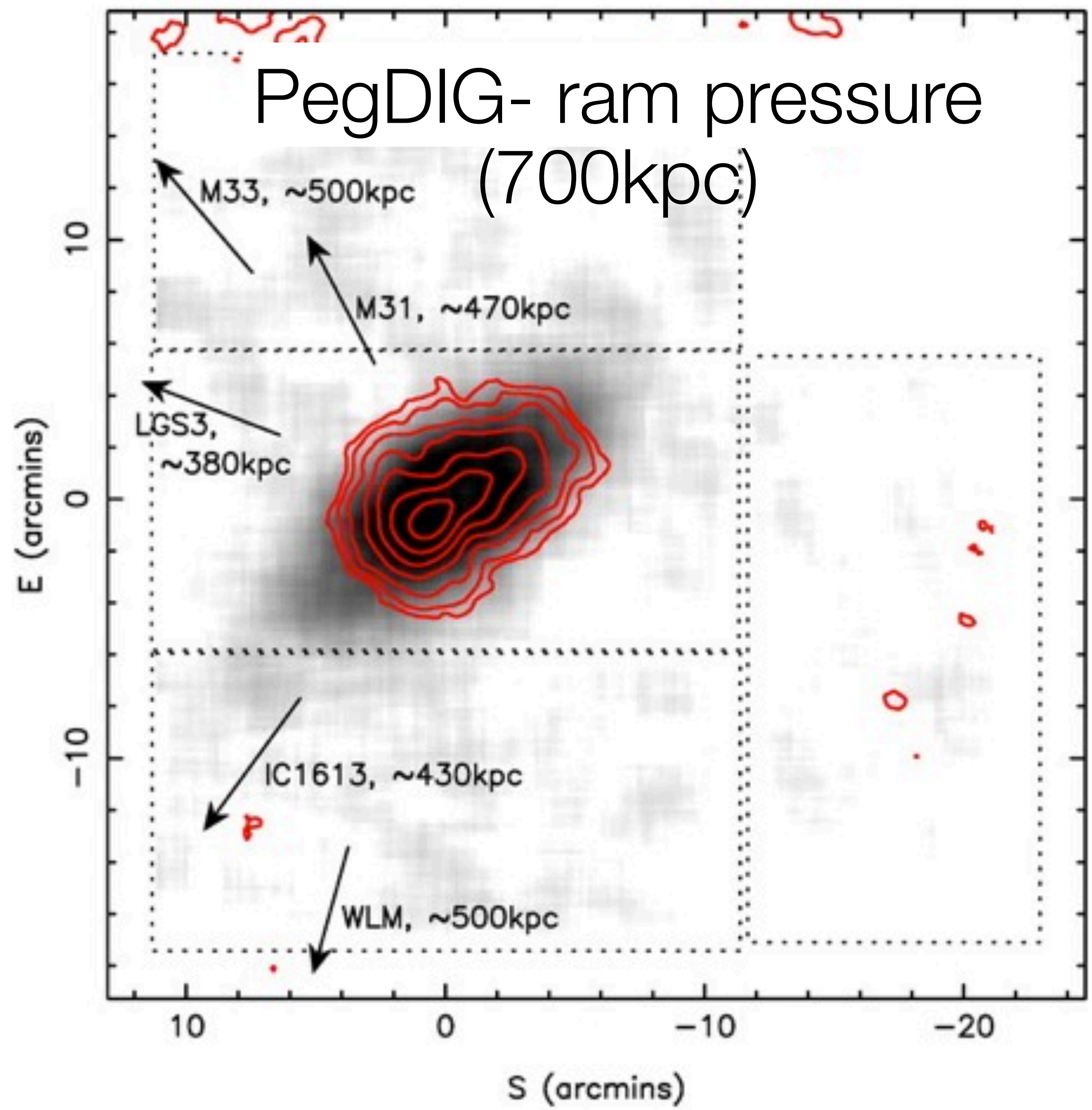


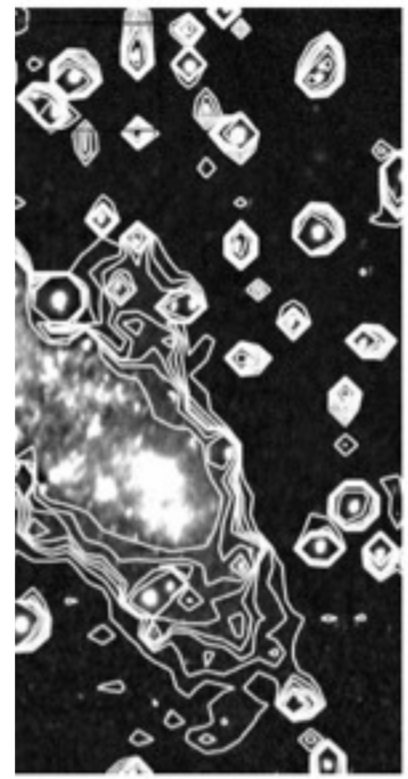


Andromeda I - tidal disruption
(700kpc)

Wide field views of nearby dwarfs

PegDIG- ram pressure
(700kpc)





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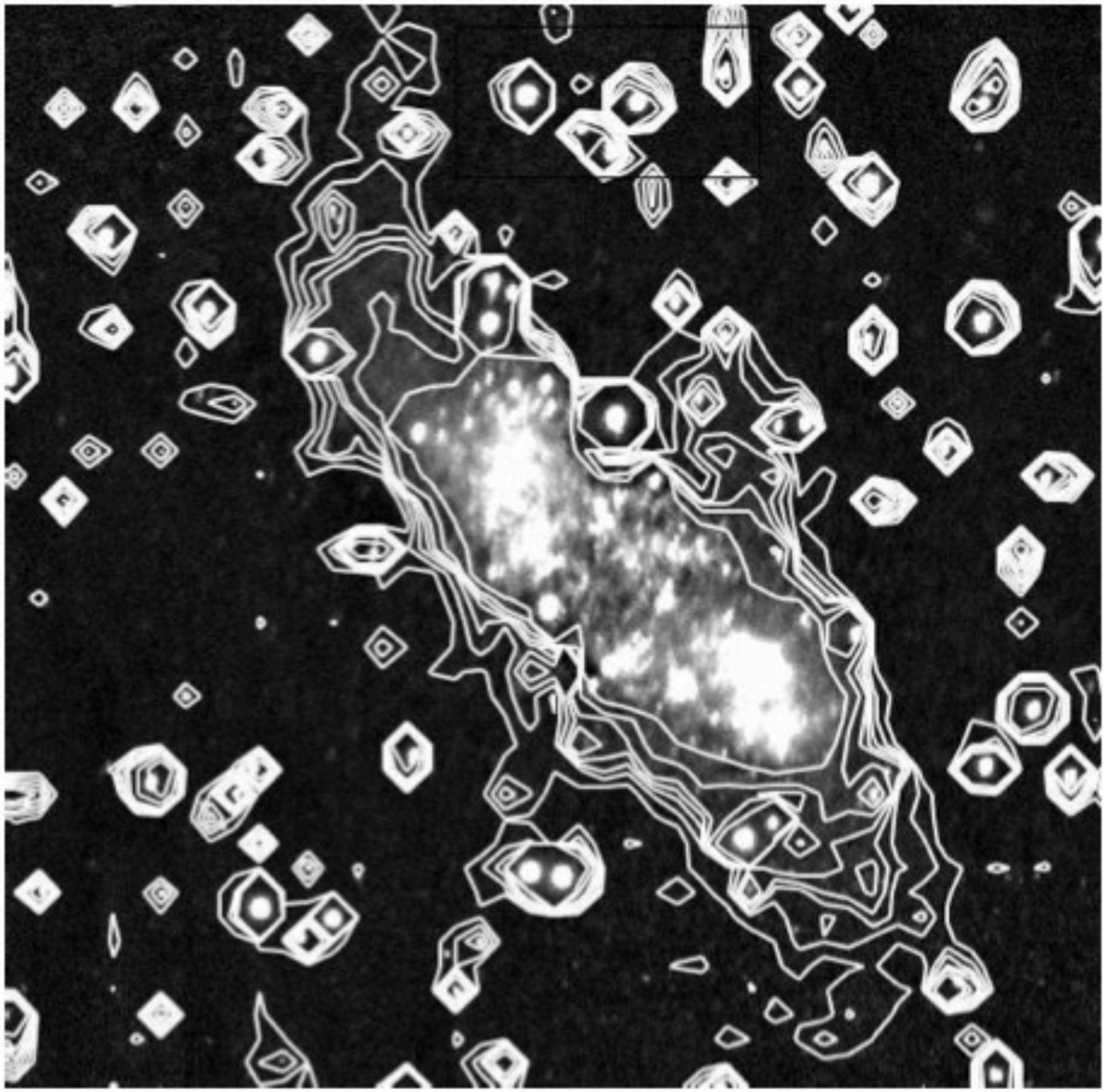


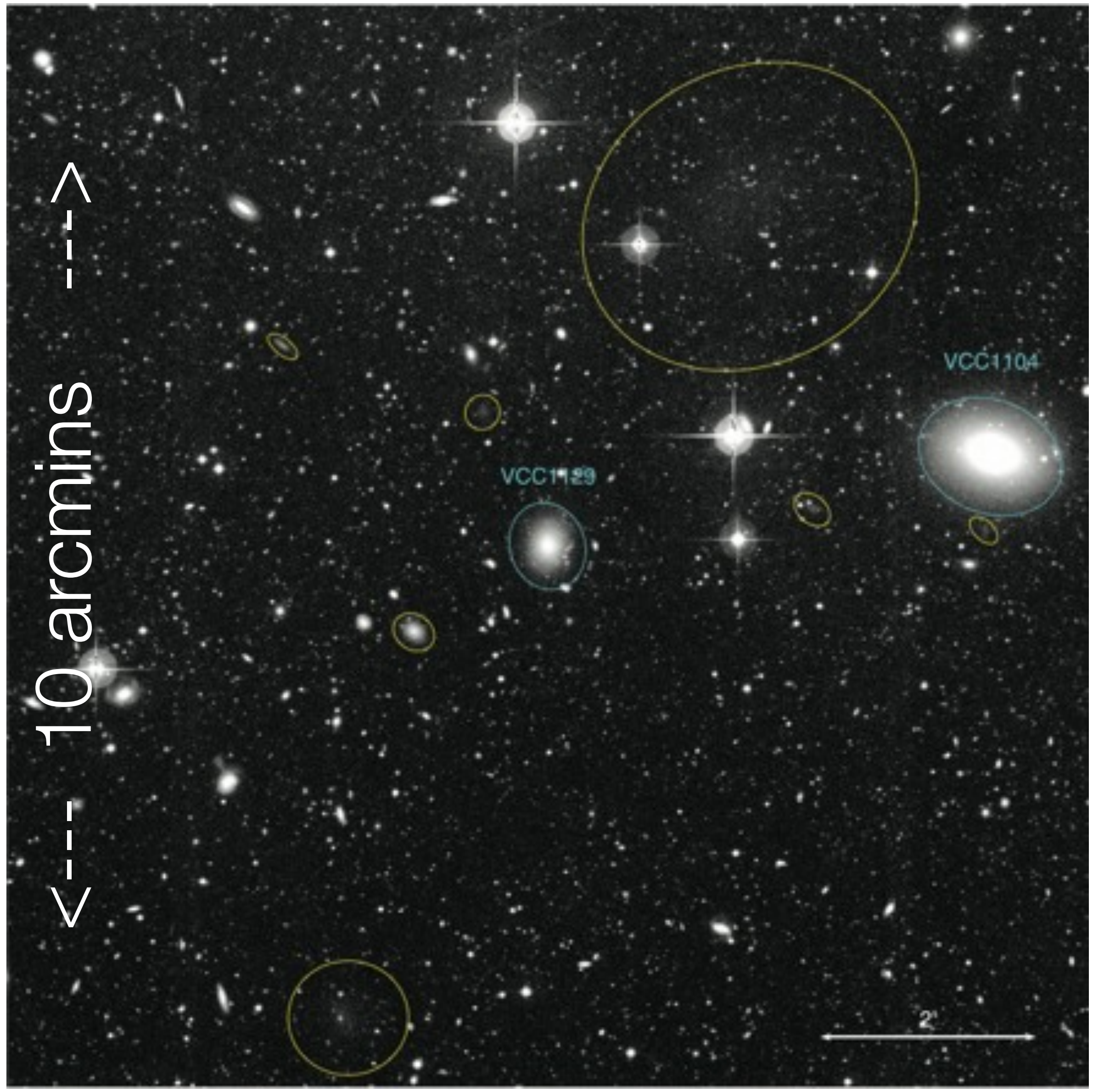
IC3104 (diffuse light only)
(2.2Mpc)

Hints of warping?? GLAO on Subaru will be able to map the extended structure of this galaxy to large radius and low effective SB, and to obtain CMDs for all but the central regions

Only way of understanding galaxy structures (dwarfs, giants, whatever...) at SB>29/30mags/sq.arcsec

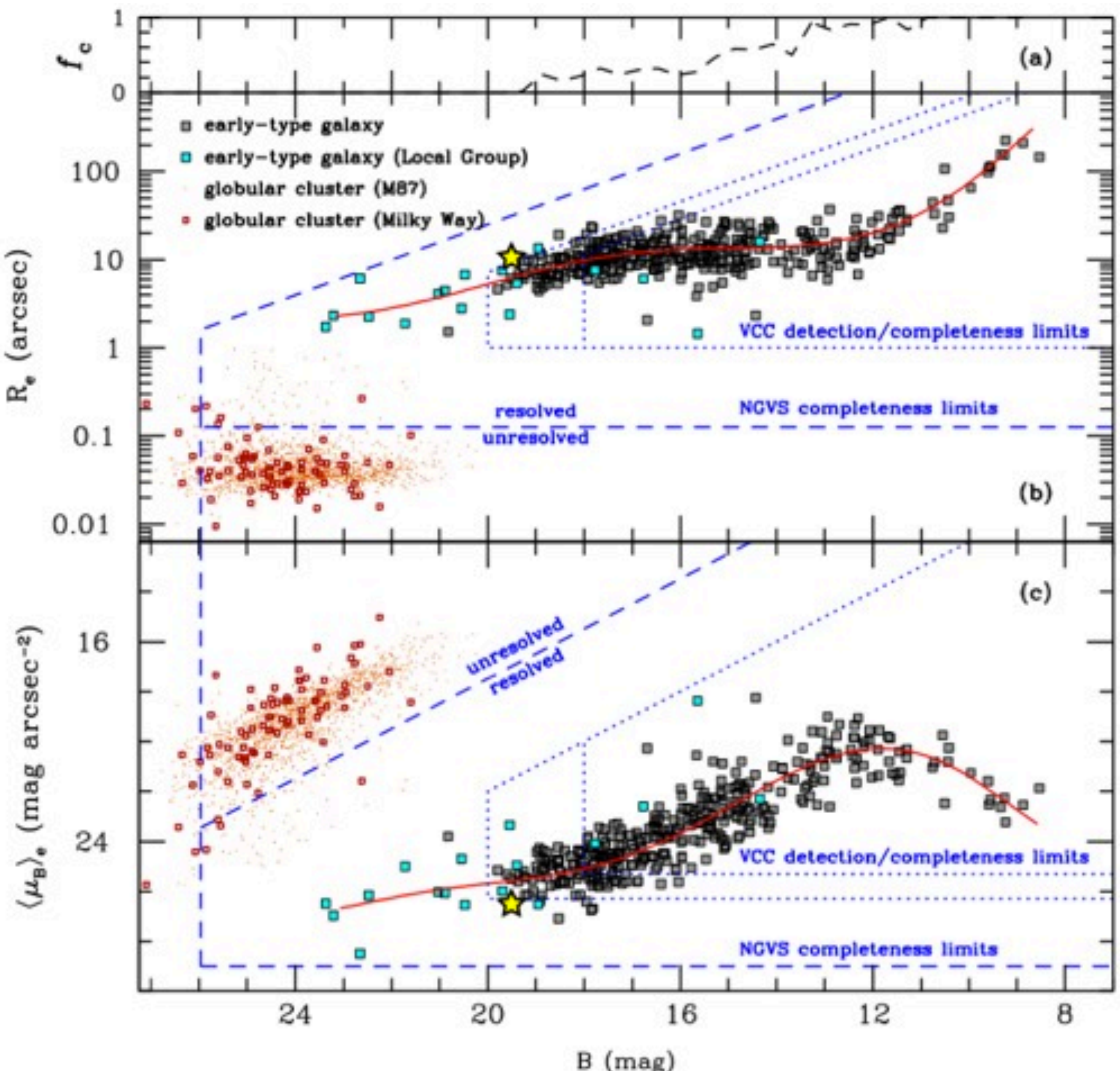
Exemplar Science Case III: Galaxy structures in the Local Volume

- So far, I’ve discussed galaxies in which both Subaru and TMT can resolve stars (albeit to different depths and in different regions)
- One of the main transformations that will occur in with TMT is the ability to resolve stars out to the distance of the Virgo Cluster
- Figure shows 10*10 arcmin cutout from 3.6mCFHT/ MegaCam survey of Virgo (NGVS). Ellipses show locations of various (dwarf) galaxies.



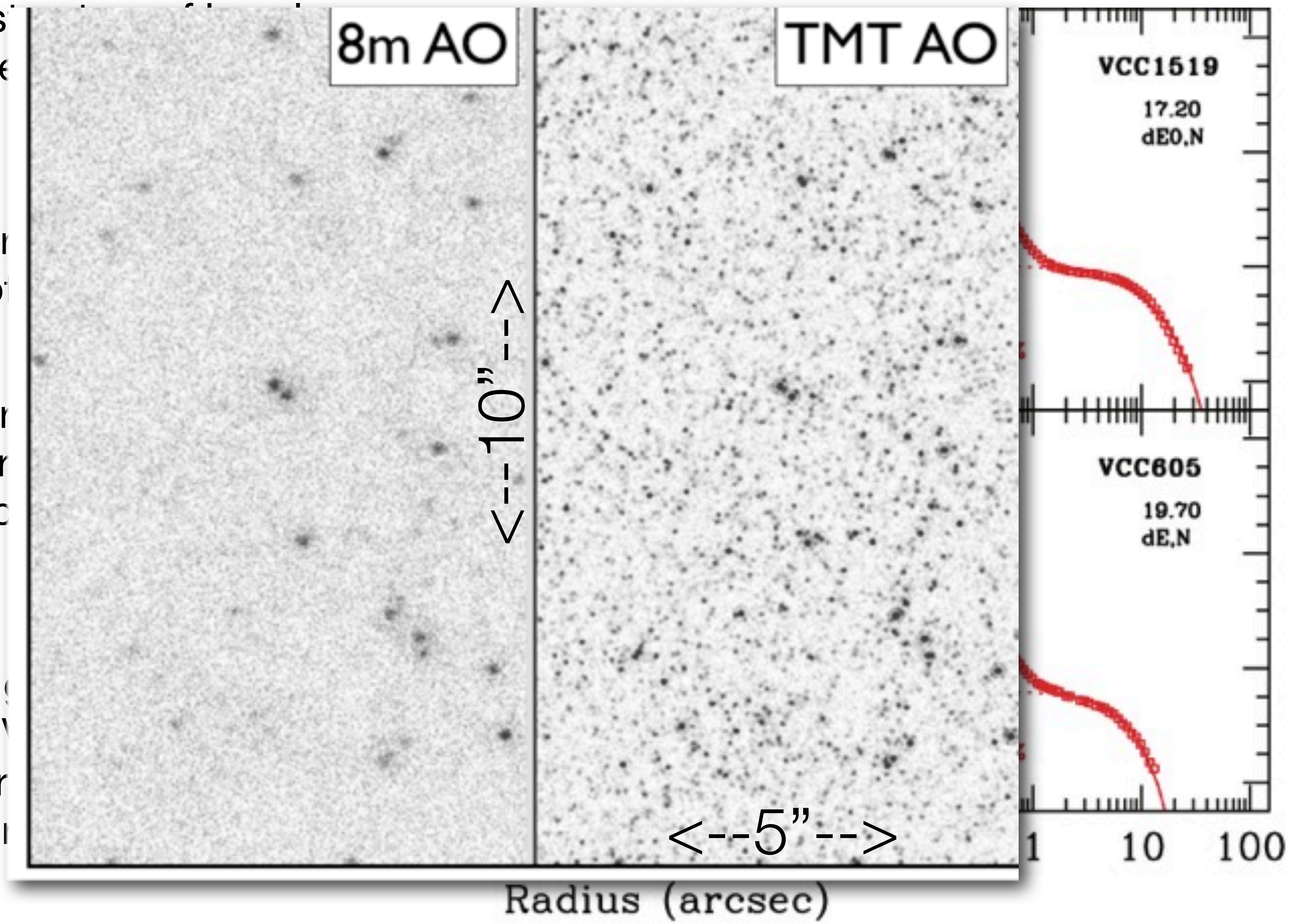
Galaxy structures in the Local Volume: Resolved stellar laboratories for the 2020s

- TMT will bring all galaxies in the Local Volume within reach of resolved stellar population studies
- But with precision studies of their stellar populations possible, how do we provide **precision studies of their environments and structures** to give these studies focus and context
- **Wide field NIR capabilities are essential to motivate and inform TMT resolved stellar populations science**



Local Volume galaxies from pc to kpc scales

- Mapping the s
  Volume galaxie
  scales
- 0.2arcsecs co
  the distance o
- Figure shows r
  from optical gr
  observations o
  natural seeing
- Target (dwarf)
  groups out to
  global structur
  studies of thei



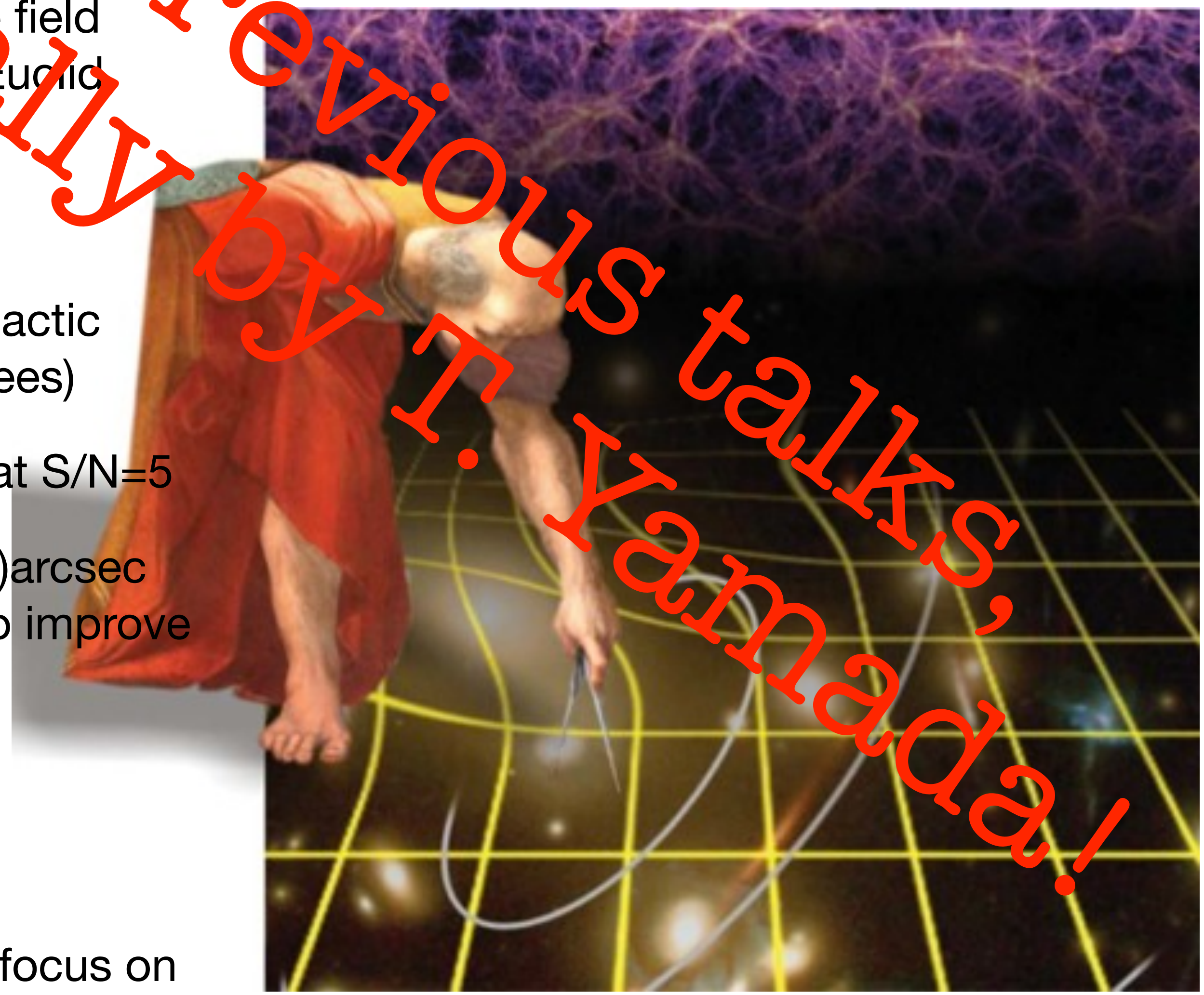
Key Requirements

- Wide FoV: at least of order 10 x 10 arcmins, larger FoV desirable
- **Well characterised, stable (uniform) and well sampled PSF: key for confusion limited observations eg star vs barely-resolved galaxy**
- J,H,K wavelengths best. Longer color baselines preferred due to better sensitivity distinguishing ages, metallicities etc.
- Strong synergies with TMT, JWST: **Global structures + environment vs pointed deep observations**
- Additional new GLAO spectroscopic capabilities not essential: nearest galaxies can already have their brightest stars targeted with existing capabilities (e.g., Keck/DEIMOS, Gemini/GMOS, Subaru/FMOS, HDS) and more important to improve multipexing rather than depth/crowded regions. More distant targets require larger apertures (TMT).

Space-based wide field NIR imaging

See previous talks, especially by T. Yamada!

- Several plans for space-based wide field imaging in the NIR in the future eg Euclid, WISH, WFIRST
- Euclid:
  - All sky survey away from the Galactic plane (15000-20000square degrees)
  - Point source limit of Y=J=H=24 at S/N=5
  - PSF: EA50<0.3(Y), 0.3(J), 0.33(H)arcsec with 0.3arcsec pixels (dithered to improve sampling)
- Conclusions:
  - K band essential
  - GLAO needs to be optimised to focus on faint universe (>24mag)
  - WISH wins, but maybe not for the Local Universe



Aside: Why GLAO?

- *Reason: spatial resolution over a wide field*
  - Criticism: but not as good as space??
  - *Partial* Rebuttal: true, but eventually space missions get cancelled, blow up, or just stop working...(but criticism still stands)

- *Reason: increased sensitivity/efficiency*
  - Criticism: just expose for longer!
  - Rebuttal: doesn't work for confusion limited observations
  - Rebuttal to rebuttal: how often are you working on confusion-limited science over a wide field?
  - (My rebuttal to rebuttal to rebuttal: all the time)

  - New Rebuttal: I'm observing a huge area and so the gain in sensitivity I'm getting make a big difference. Its not practical to do otherwise!
  - Lesson: Large area surveys to serious depths could be important (and, you want to have a large FoV to make this large area survey more practical). But unless you are looking at the Local Universe, planned space-based (imaging) missions will win

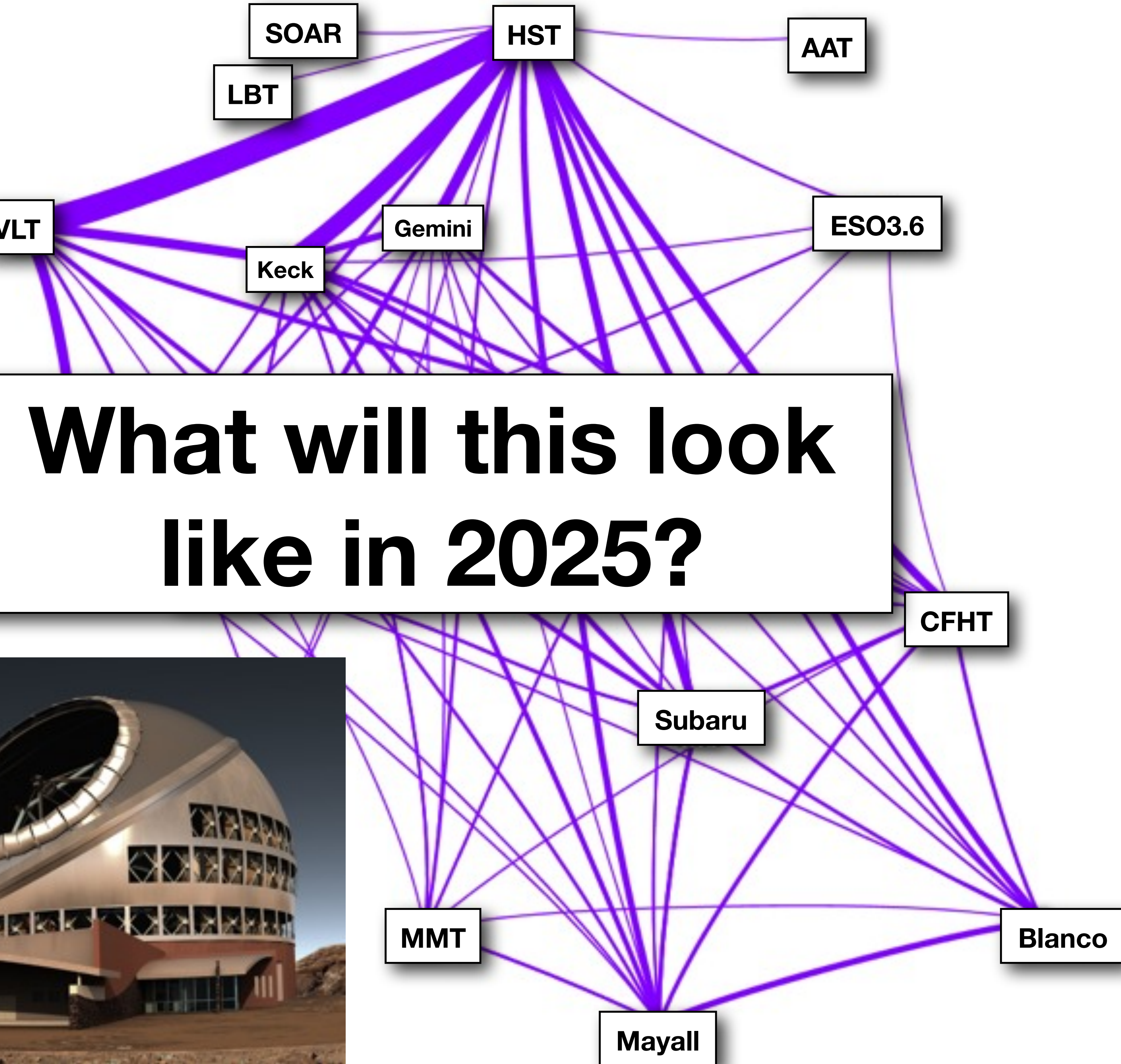
Aside: Why GLAO?

- The reason for GLAO versus space is for a convenient and flexible workhorse capability with a long lifetime
- The reason for GLAO versus seeing limited NIR is **efficiency over a wide field** and **spatial resolution**
  - To ensure efficiency gains are realised, GLAO field must not be small compared to seeing-limited field (e.g., might be better to build a 60*60arcmin seeing-limited FoV than a 10*10arcmin GLAO FoV)
  - To ensure efficiency gains are realised, GLAO operations must have small overheads and have a high fraction of open shutter time (not trivial with laser constellations, planes flying overhead etc). Should be studied carefully!
  - To ensure spatial resolution gains are realised, do not want to undersample PSF, even in great condition (if conditions are great, we want the data to be great!!)
  - (But also be realistic - lots of science using FWHM~0.2arcsec, but half the time the FWHM is bigger than this!!)

Aside: an imager with multiple plate scales

- Two types of imaging science:
  - Finding rare objects: requires very large field of view and care less about sampling (some undersampling is ok)
  - Galaxy morphologies: to understand galaxy (sub)structure, presumably want to have a critically sampled PSF (and if the focus is on faint objects, then surely this is even more important given the S/N might not be very high...?). Half the time the FWHM is better than 0.2!
- For the same detectors, plate scale and FoV are related. Can we have multiple settings? Could make for an interesting instrument...for example...
  - Setting 1: 0.1arcsec/pix = 4 * (6.8’x6.8’) [F/4]
  - Setting 2: 0.05arcsec/pix = 4 * (3.4‘x3.4’) [telephoto F/8]
  - Or put in some zoom lenses to change magnification...
- According to John Pazder (optics) and Vlad Reshetov (mechanics), these types of options are feasible

The OIR Telescope Network 2013



What will this look like in 2025?

SUMMARY

Instrument

Which instrument is essentially important for your science cases?
WF-NIR Imager

What is the optimal plate scale / FoV for your science cases?
Large FoVs (>10*10'). Very important to critically sample PSF (eg star-galaxy classification at faint magnitudes)

Do you need spectroscopic capability?
Not a GLAO/8m version...

Is the Multi-object IFS assisted with GLAO desirable?
Not useful for stellar science

Synergies with other facilities

Does this instrument have competitive (or complementary) capabilities with planned Near-IR space missions such as JWST, Euclid and WISH?
Complimentary to JWST.
Ensure we are complimentary to Euclid!! (K band, deep).

Can you highlight synergies between this instrument and the TMT/How could these observations be used to leverage the TMT capabilities?

Nearby galaxies: Global vs local observations