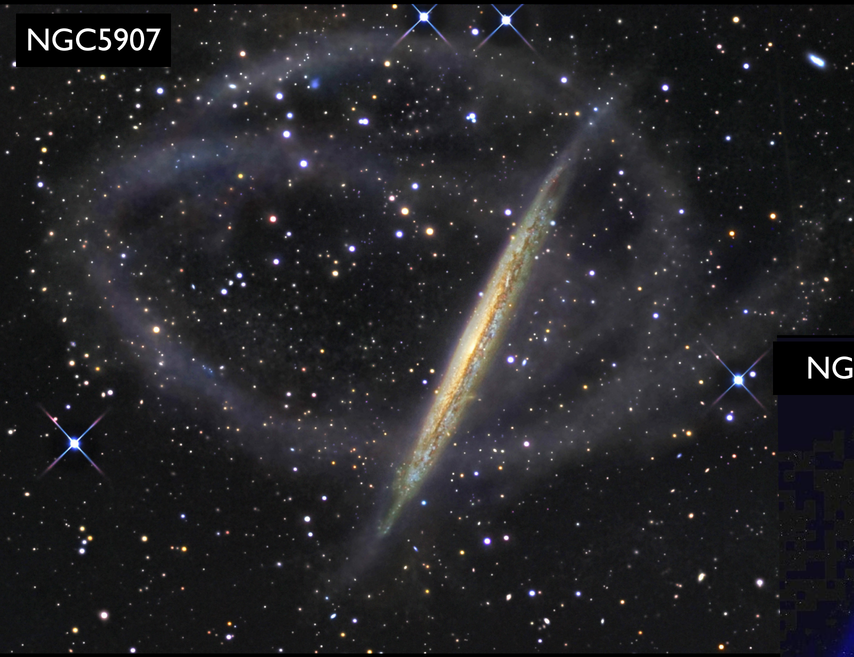
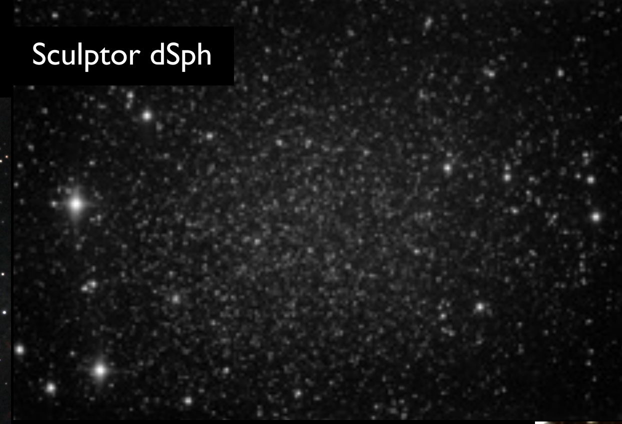
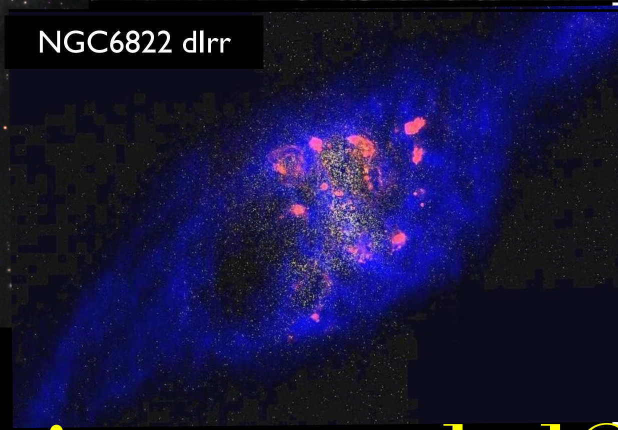


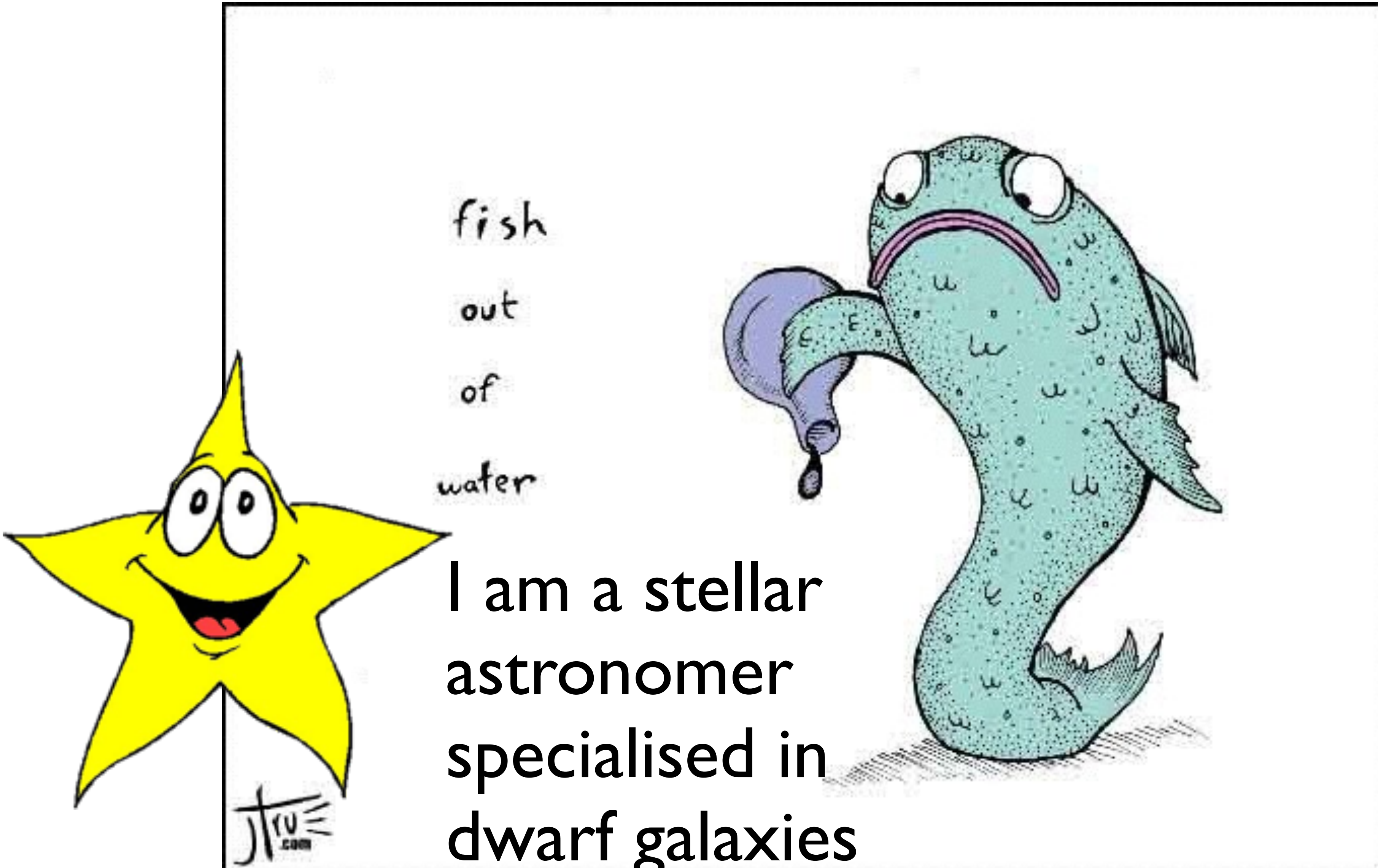




Stellar populations and dSph formation from observational properties

Eline Tolstoy, Kapteyn Astronomical Institute, University of Groningen, NL

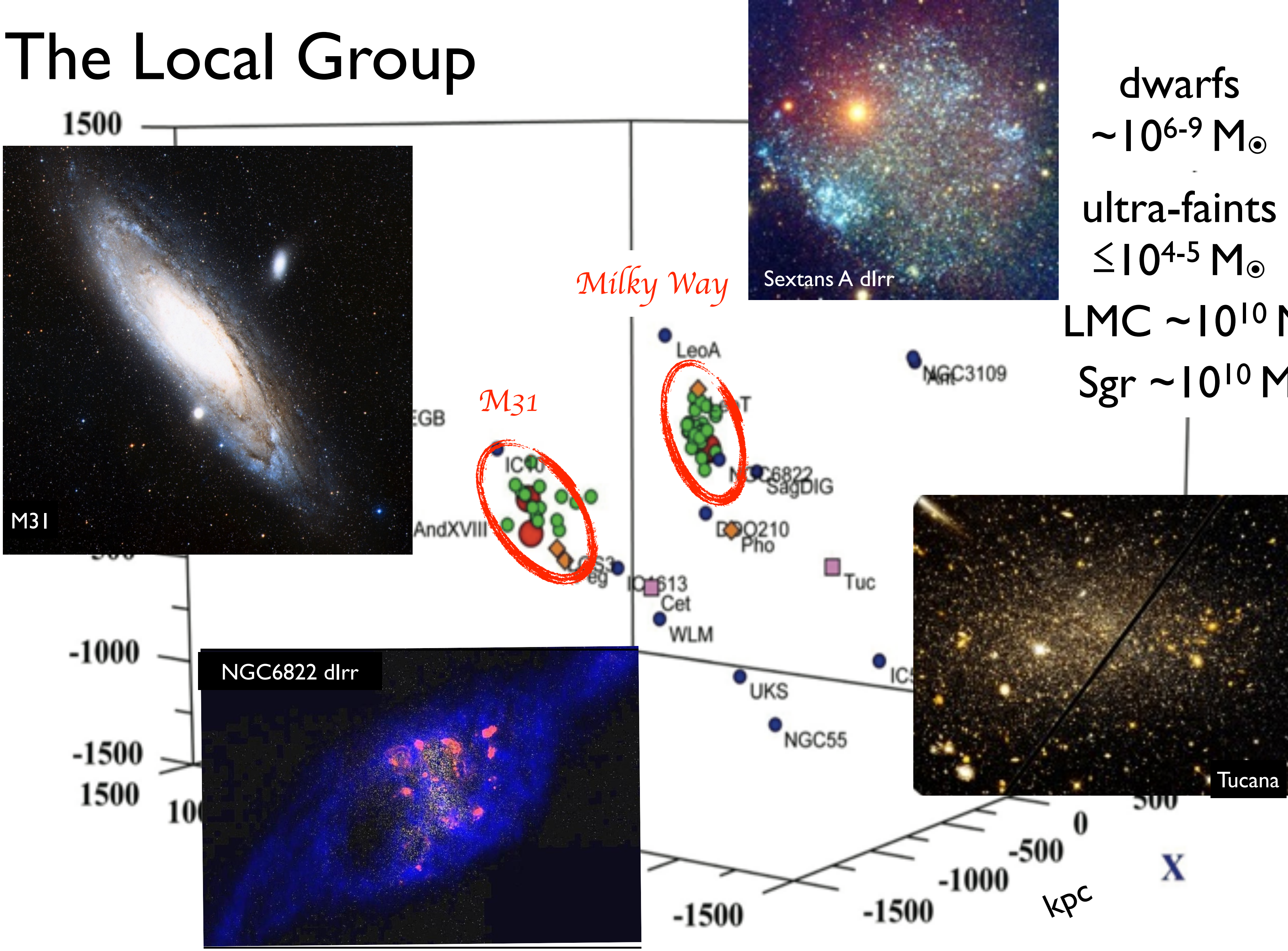
I will only talk about BARYONS….



I am a stellar astronomer specialised in dwarf galaxies

The Local Group

The Local Group



dwarfs $\sim 10^{6\text{-}9}\ M_\odot$

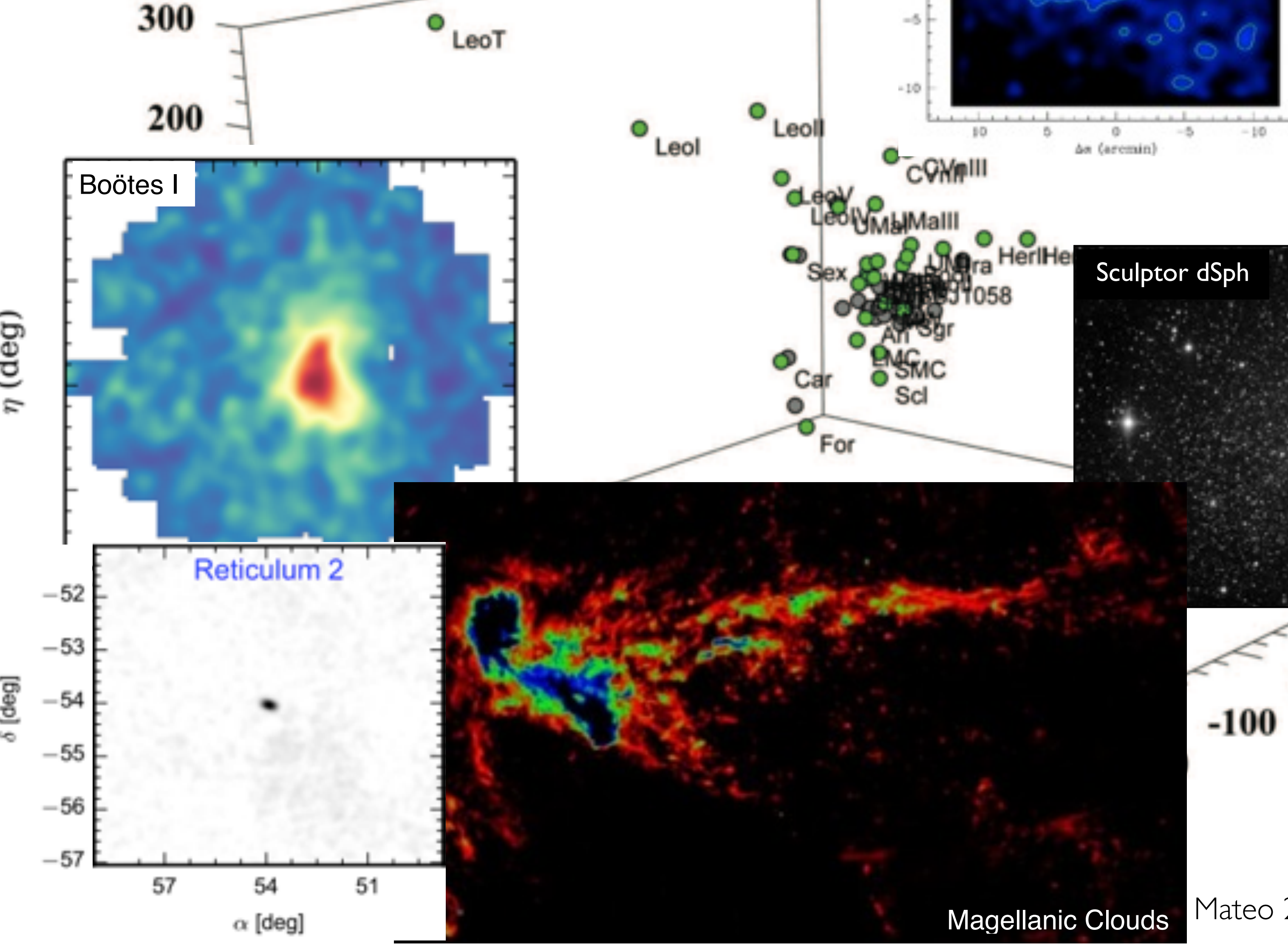
ultra-faints $\lesssim 10^{4\text{-}5}\ M_\odot$

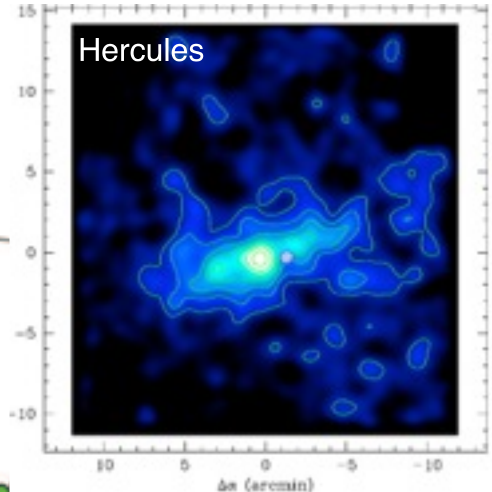
LMC $\sim 10^{10}\ M_\odot$

Sgr $\sim 10^{10}\ M_\odot$

Mateo 2008, MPA/ESO/MPE/USM Joint Conference

Milky Way - Halo





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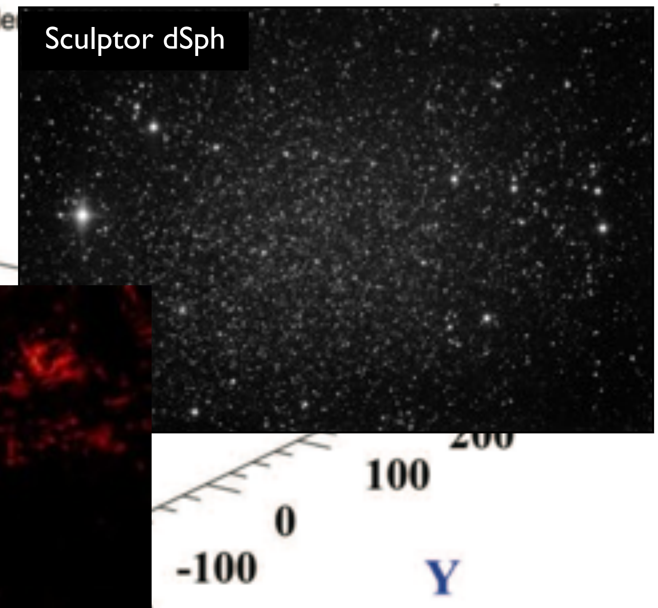
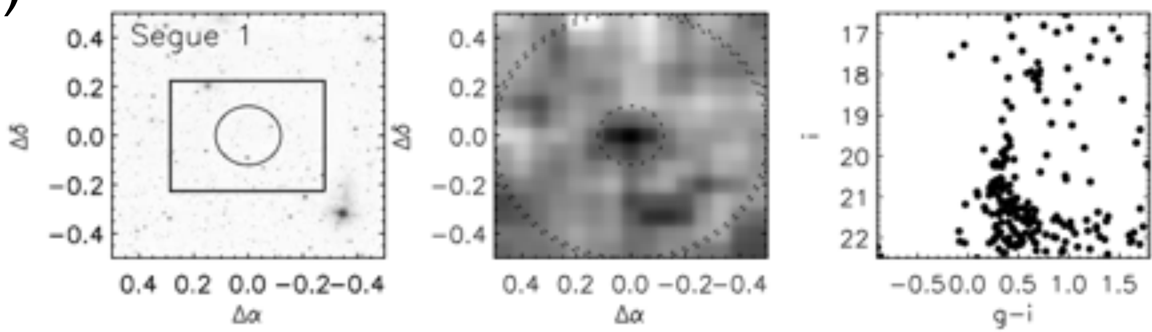
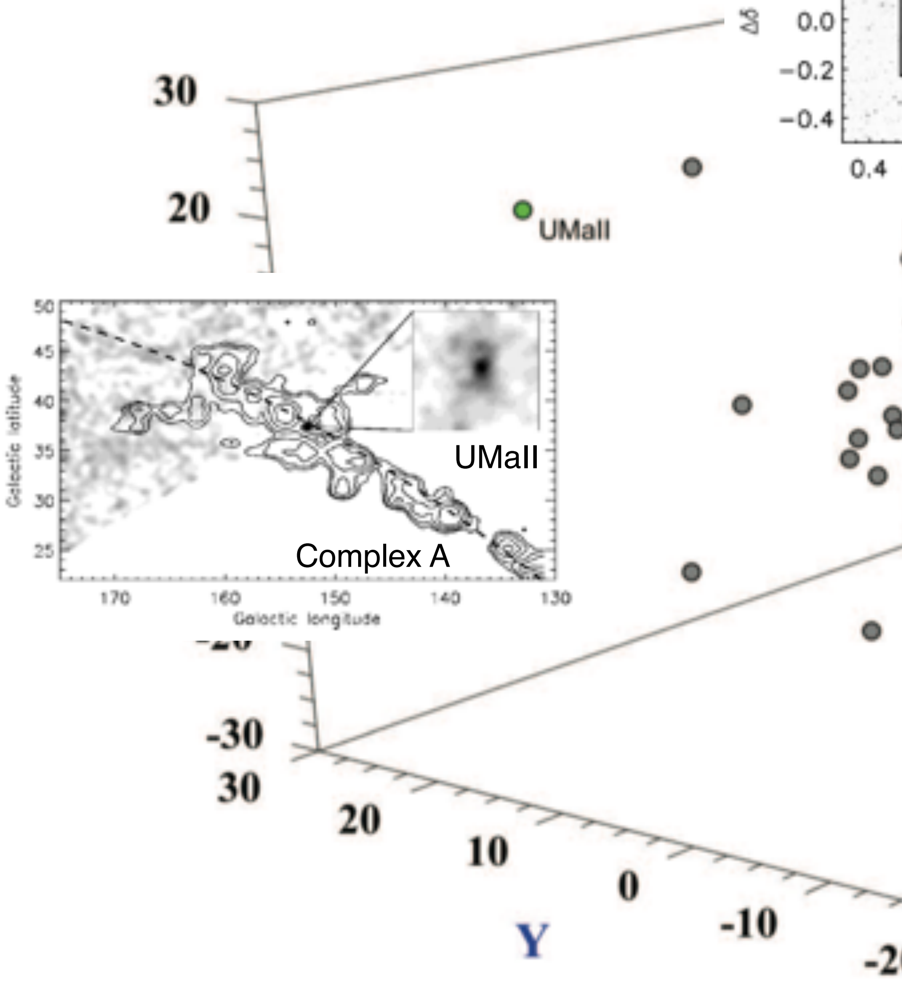


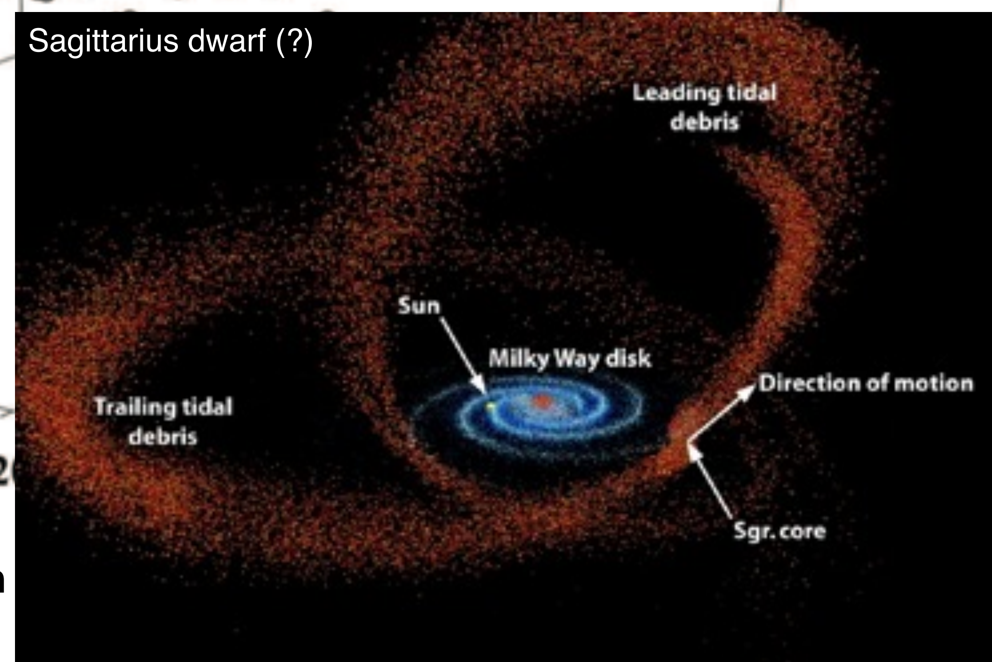
Mateo 2008, Garching workshop

Globular Clusters

(and a few ultra-faints)







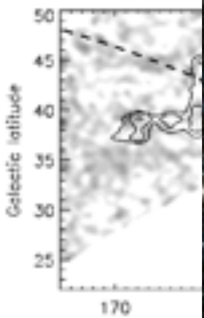
~140 globular clusters, 65% <8kpc from

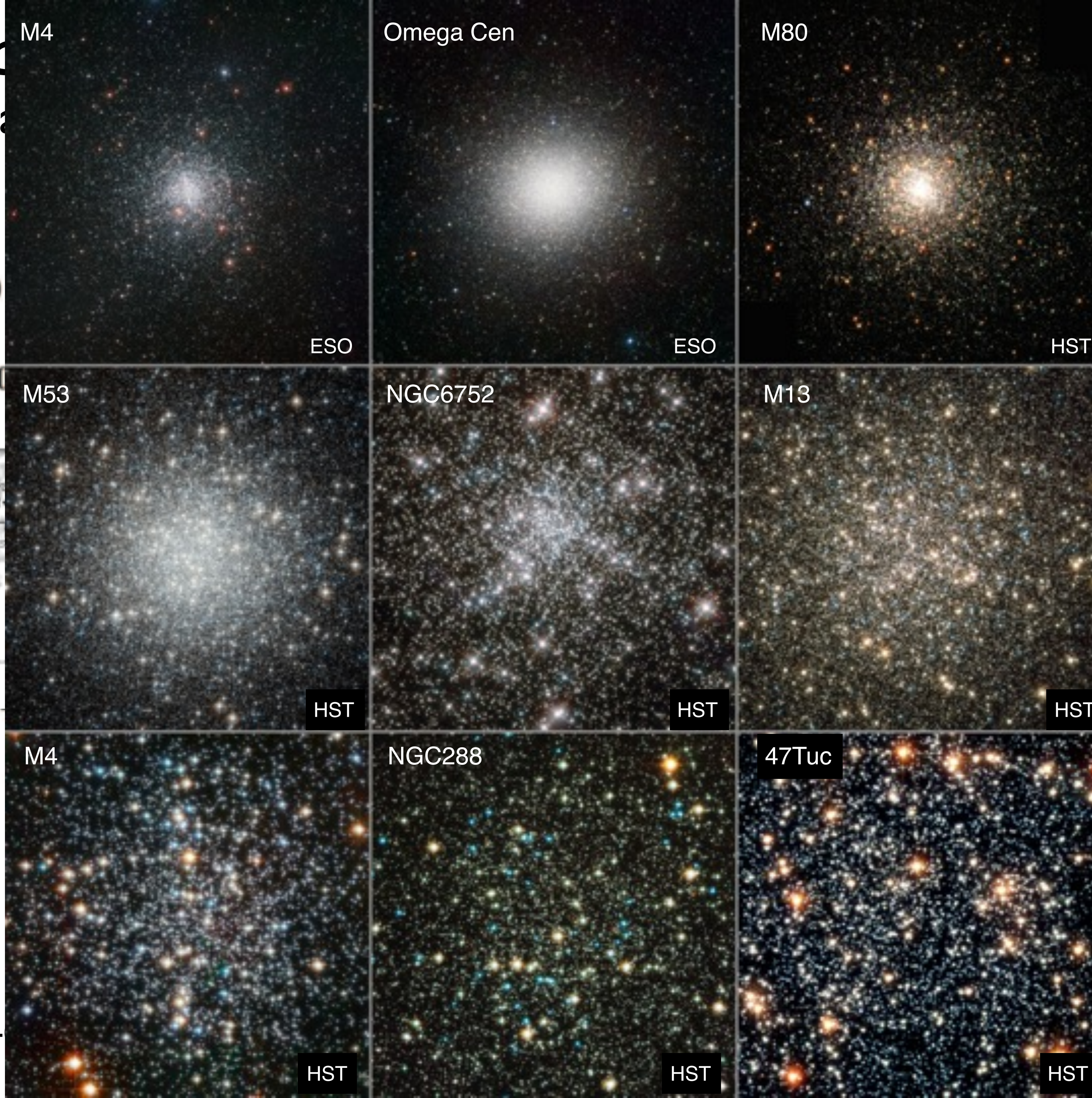
Glob

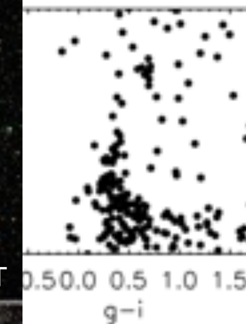
(a

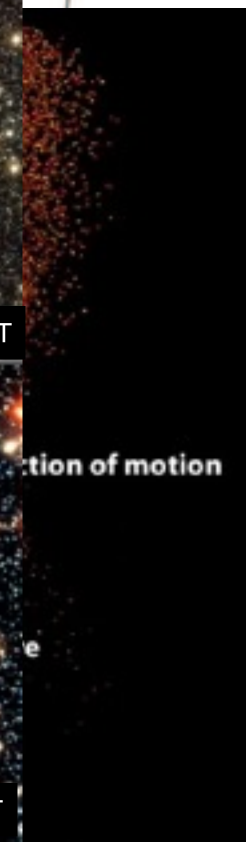
30

20









~14

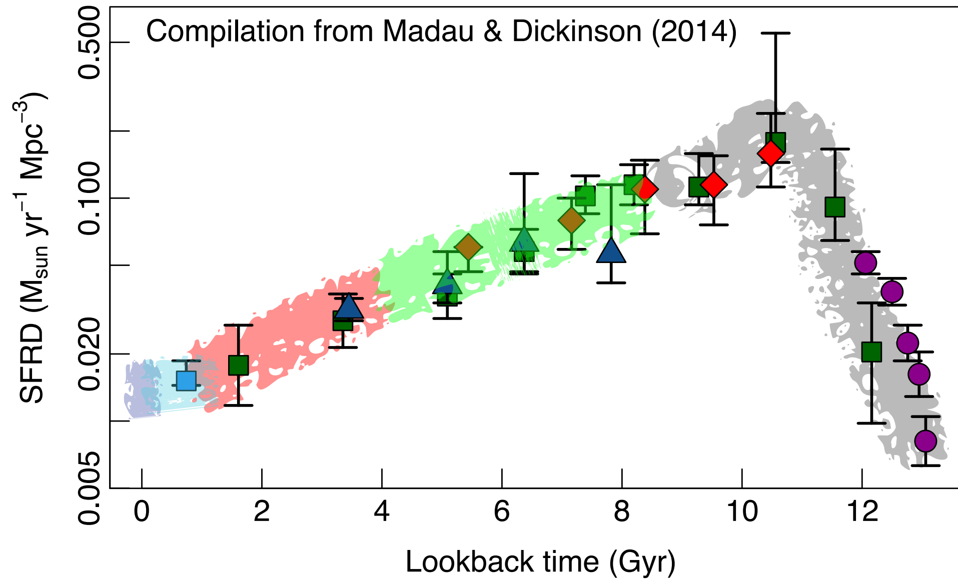
Resolved Stellar Populations

Resolved Stellar Systems

Observations/Simulation of Omega Centauri
credit: NASA, ESA & J. Anderson (STScI)

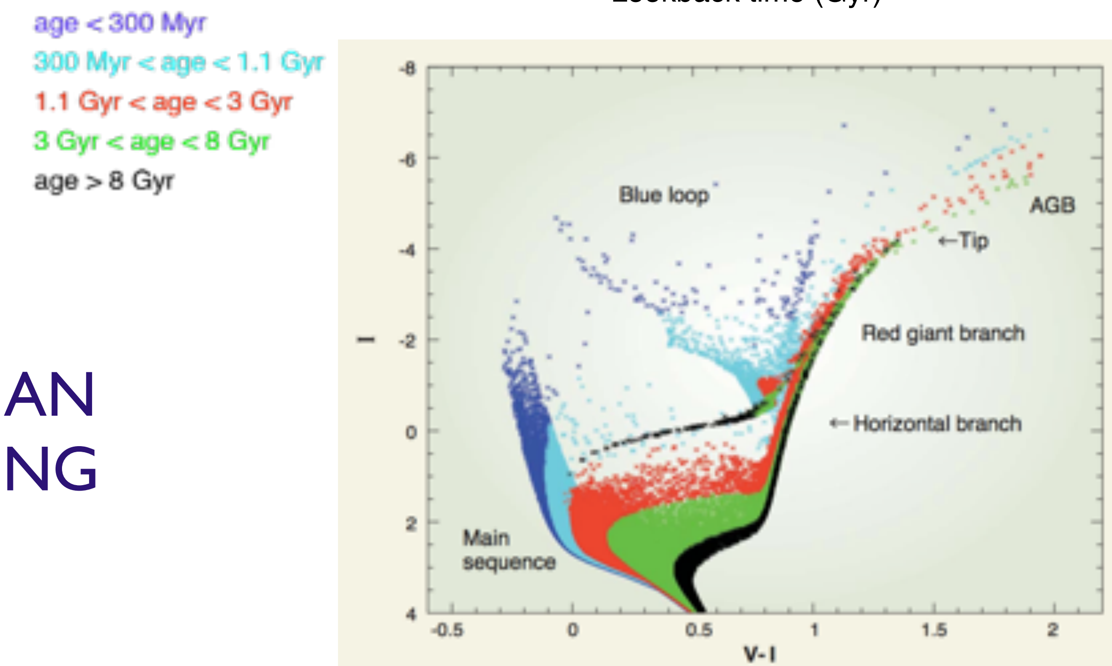
Resolved Stellar Populations: Star Formation Histories

Stars as living fossils



mass		lifetime
120M⊙	O3 star	~ 2.5Myr
12M⊙	B0 star	~ 16 Myr
2.5M⊙	B9 star	~ 600 Myr
1.25M⊙	F5 star	~ 5 Gyr
1M⊙	G8 star	~10 Gyr
0.8M⊙	K2 star	~25 Gyr
0.5M⊙	M0 star	~100 Gyr

increasing numbers: IMF

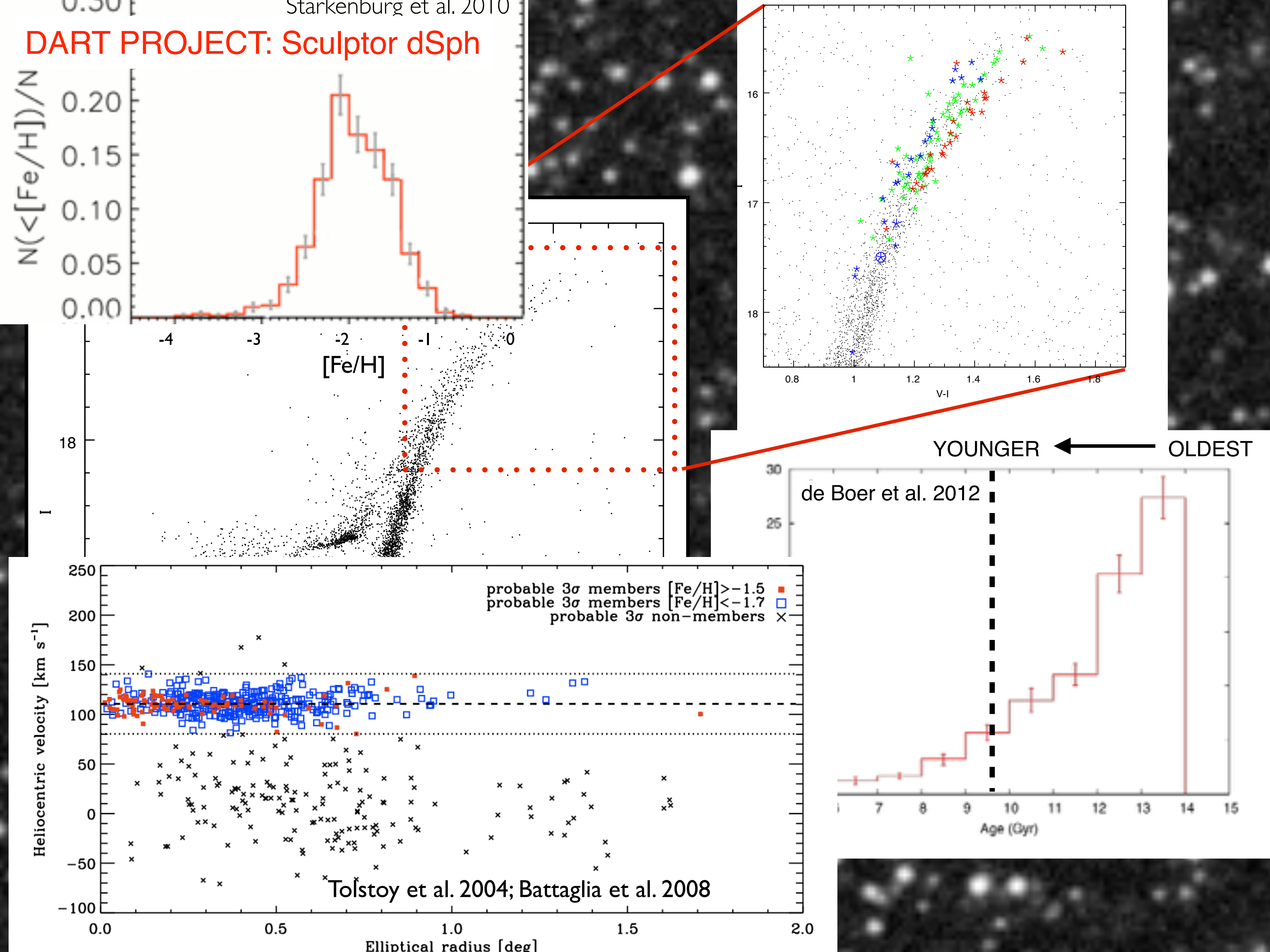


LOW MASS STARS CAN LIVE A VERY VERY LONG TIME

Resolved Stellar Populations:

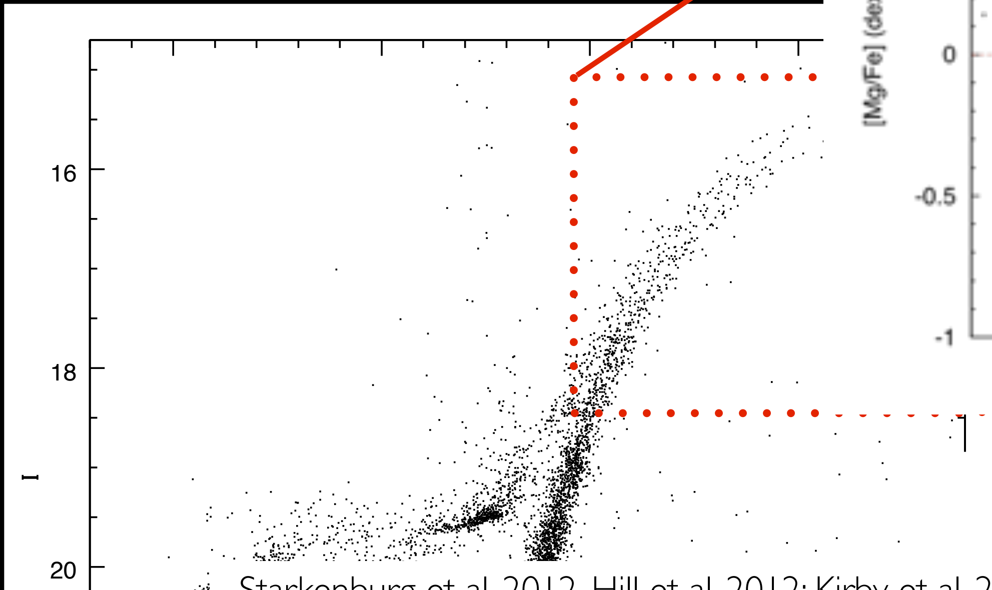
Star and Metal Formation Histories

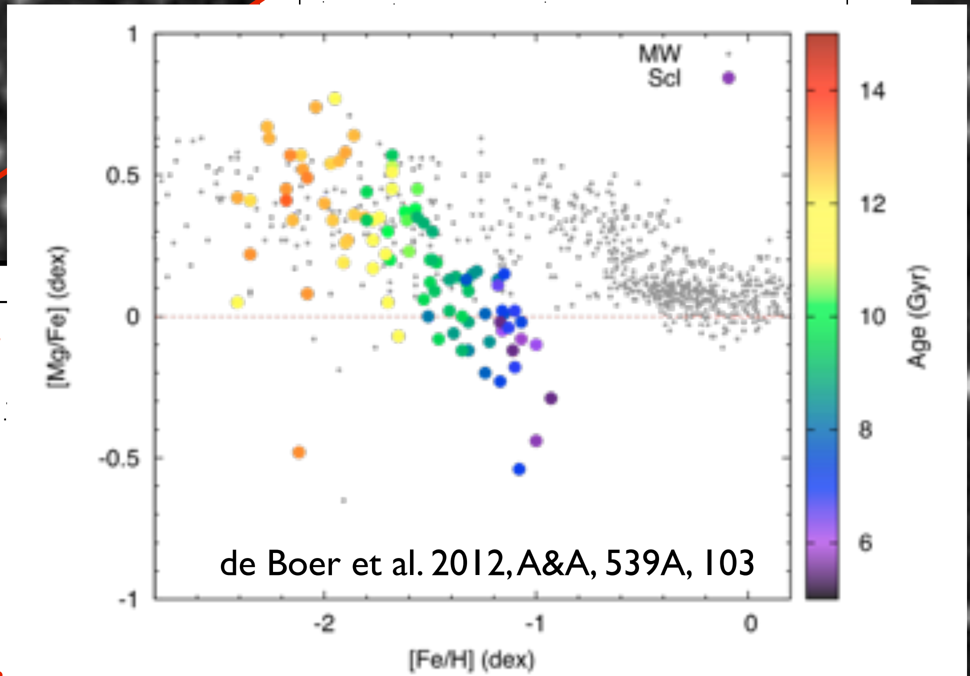
Sculptor dSph



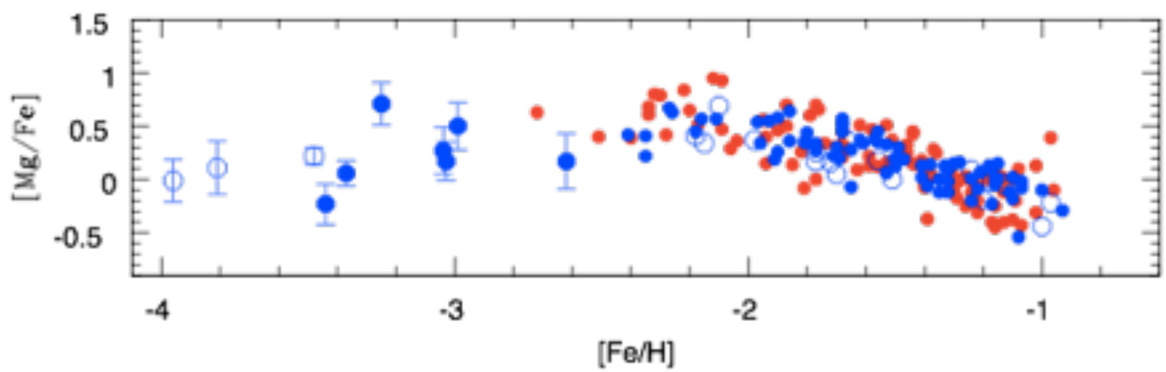
DART PROJECT: Sculptor dSph
Starkenburg et al. 2010
N(<[Fe/H]))/N
0.20
0.15
0.10
0.05
0.00
-4
-3
-2
-1
0
[Fe/H]
18
I
16
17
18
0.8
1
1.2
1.4
1.6
1.8
V-I
YOUNGER
OLDEST
de Boer et al. 2012
30
25
7
8
9
10
11
12
13
14
15
Age (Gyr)
probable 3σ members [Fe/H]>−1.5
probable 3σ members [Fe/H]<−1.7
probable 3σ non−members
Heliocentric velocity [km s⁻¹]
250
200
150
100
50
0
−50
−100
0.0
0.5
1.0
1.5
2.0
Elliptical radius [deg]
Tolstoy et al. 2004; Battaglia et al. 2008

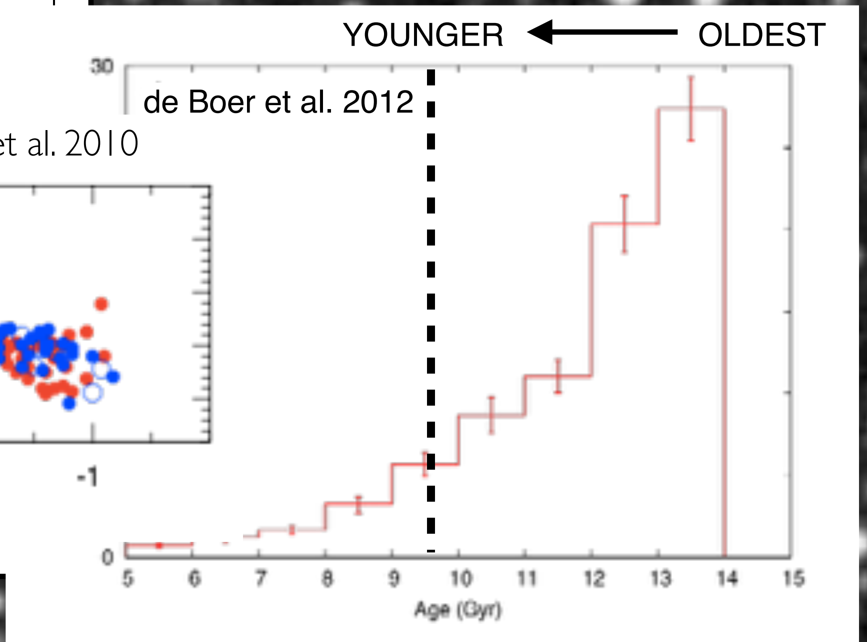
DART PROJECT: Sculptor dSph





Starkenburg et al. 2012, Hill et al. 2012; Kirby et al. 2010

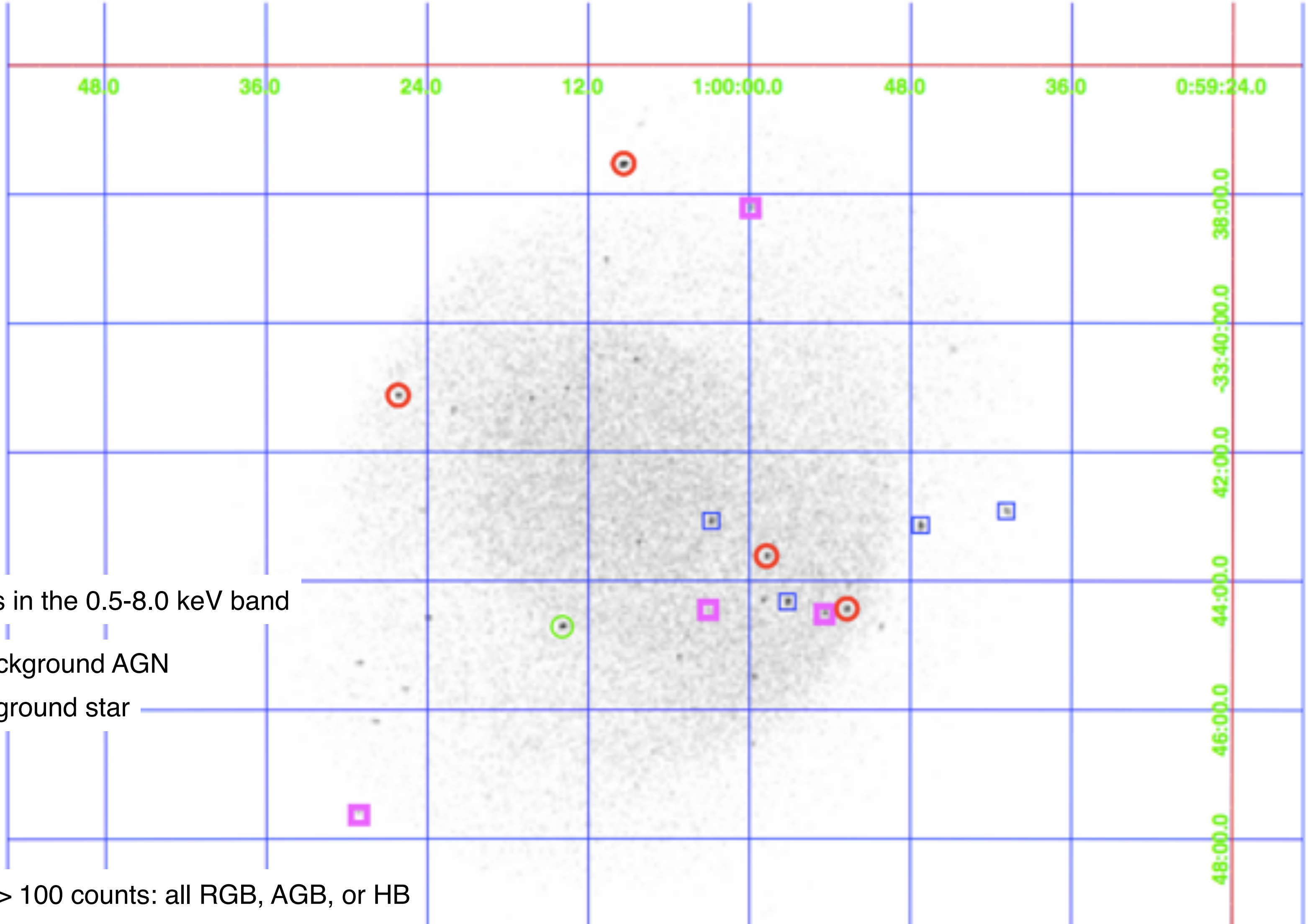




Sculptor dSph in X-rays

deep CHANDRA imaging

21 exposures of 6-kiloseconds each



74 sources in the 0.5-8.0 keV band

~50 background AGN

~1 foreground star

9 sources > 100 counts: all RGB, AGB, or HB

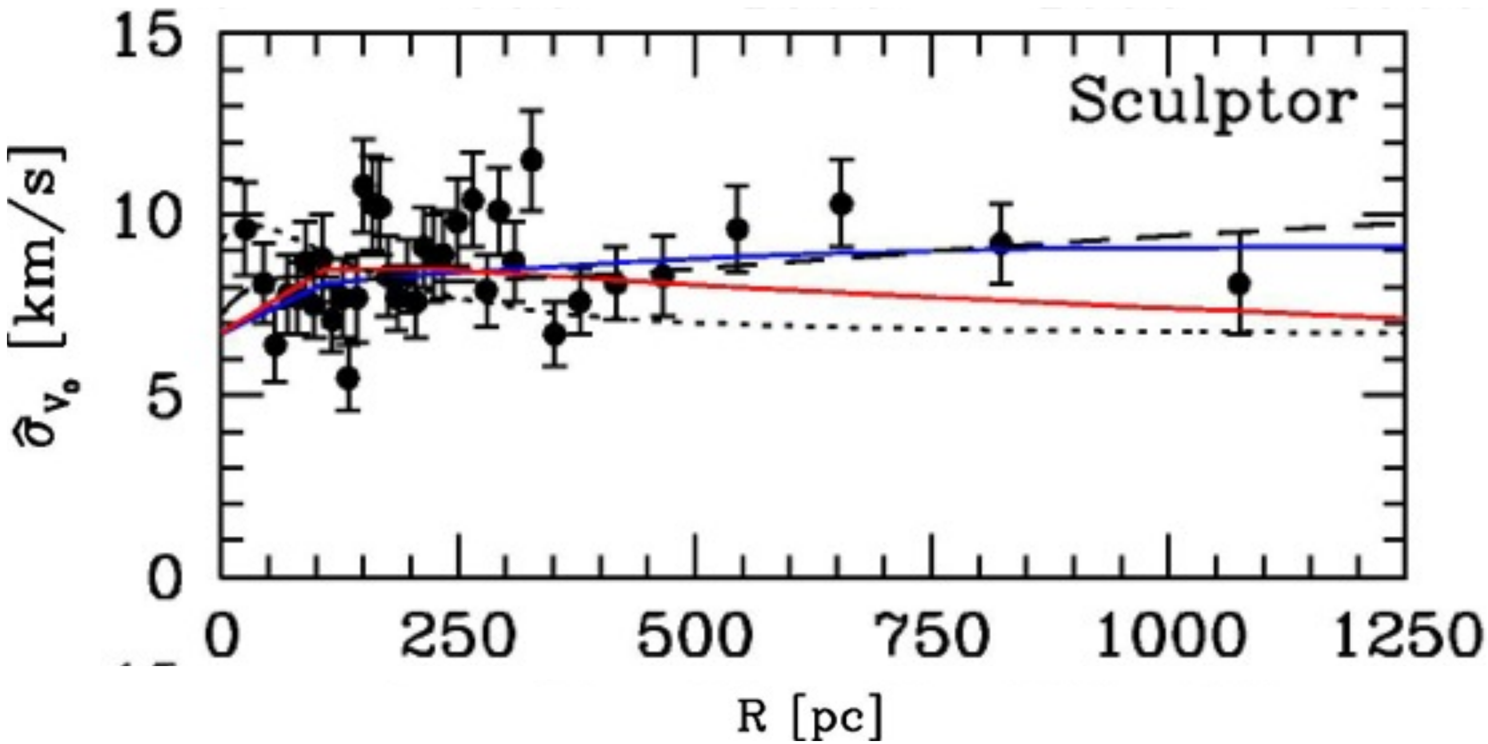
~5 XRBs in Scl (low duty cycle)

no sign of a (central) BH

Maccarone et al. 2005 MNRAS

Sculptor dSph

isothermal, power-law, NFW and cored halos



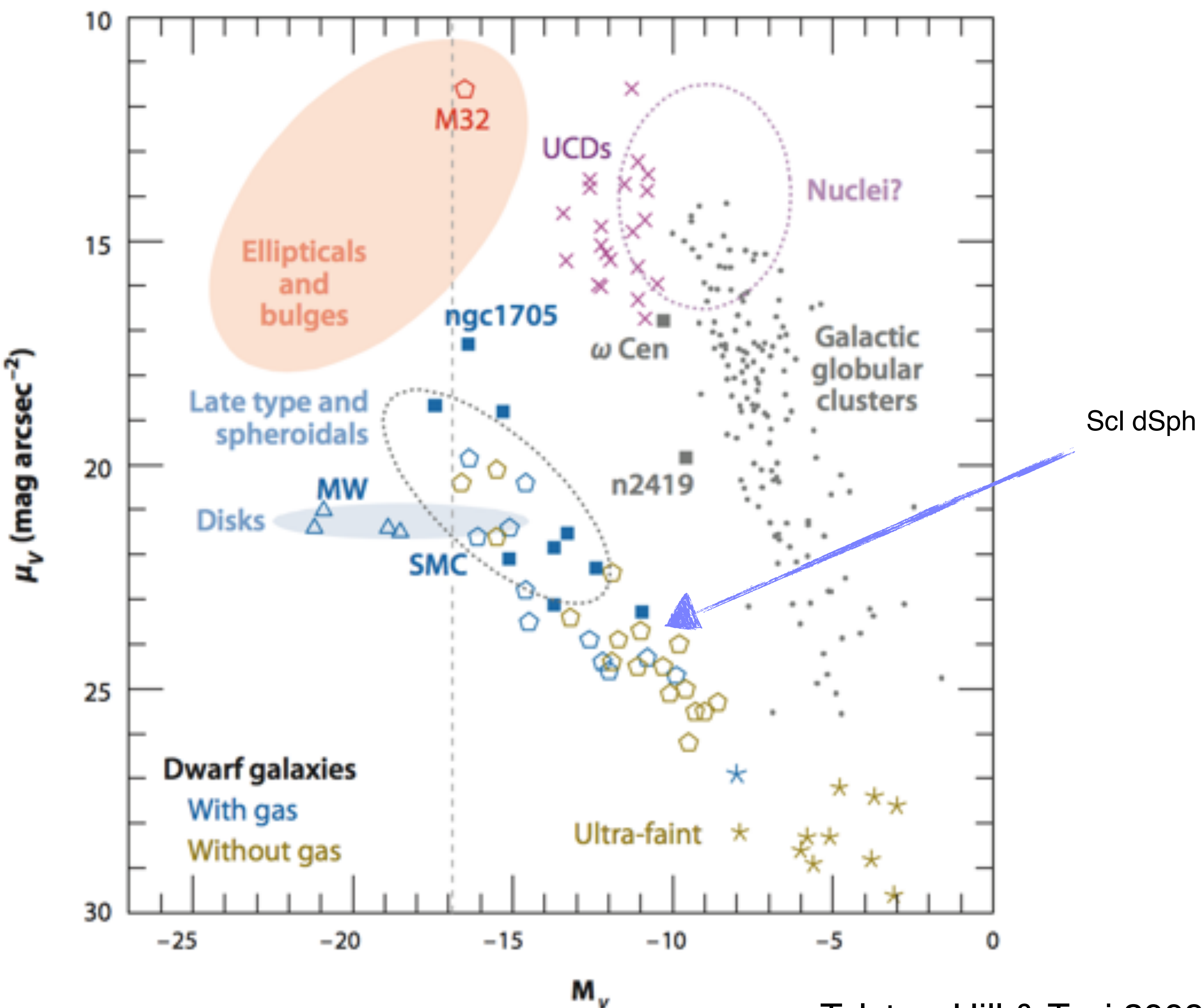
despite all this information… still don't know for sure form of halo profile

Walker et al. 2009 ApJ

Resolved Stellar Populations:

Global properties of stellar systems

Global Properties: luminosity & size



Tolstoy, Hill & Tosi 2009 ARAA

Resolved Stellar Populations:

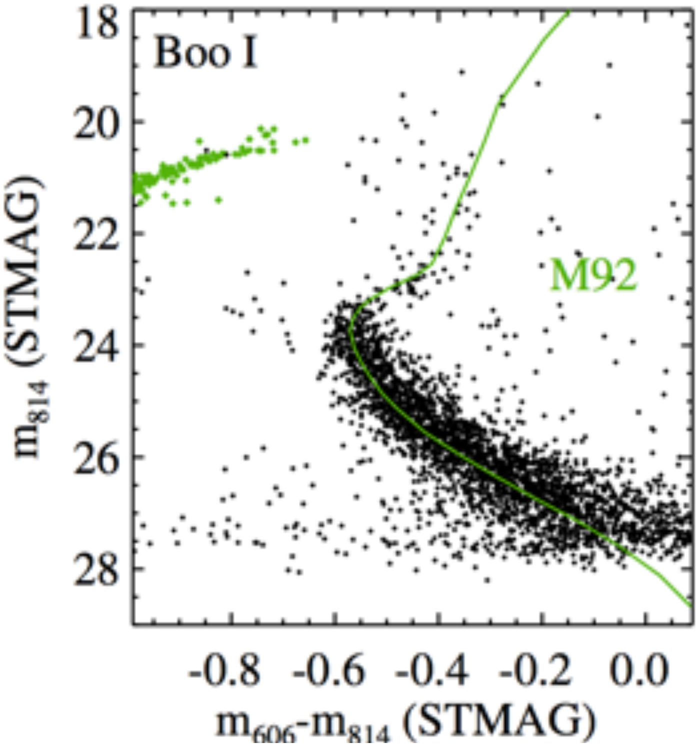
very low (stellar) mass systems

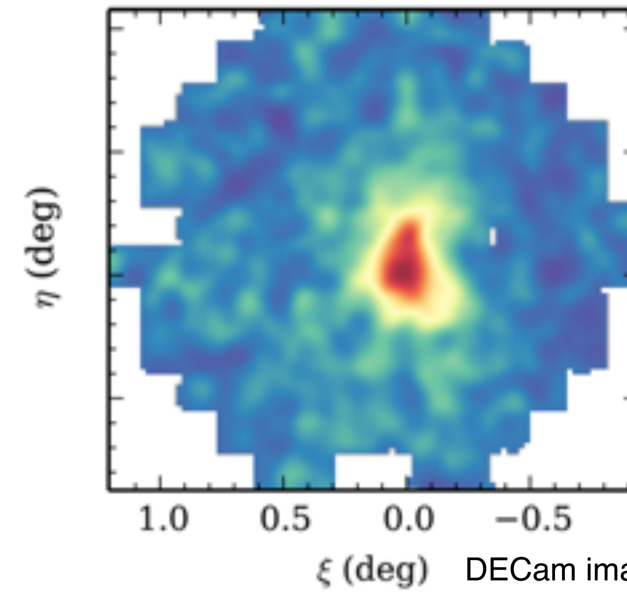
Bootes I

$M_V \sim -6.3$

60kpc

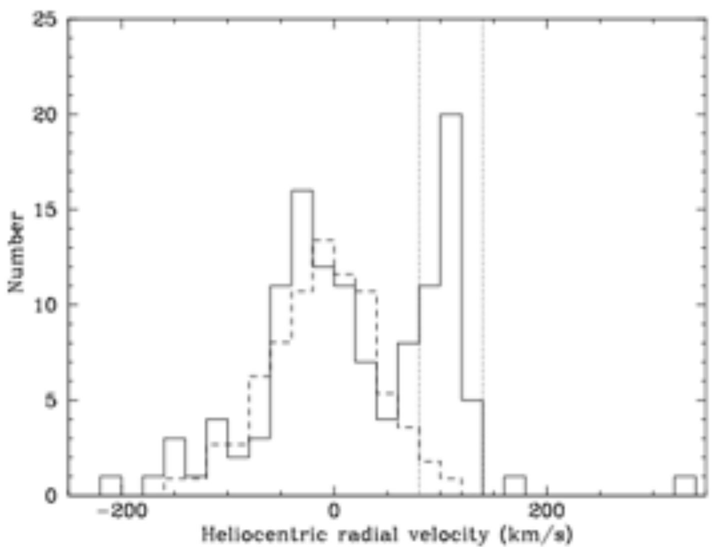
ACS survey
Brown et al. 2014

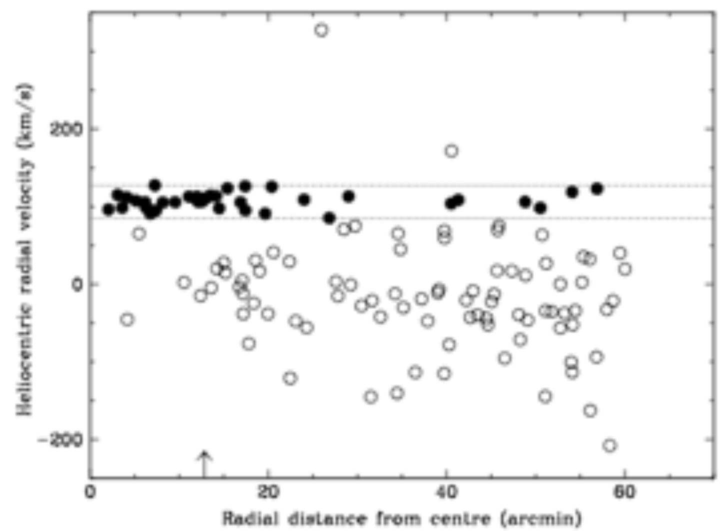




DECam imaging
Roderick et al. 2016

Norris et al. 2010

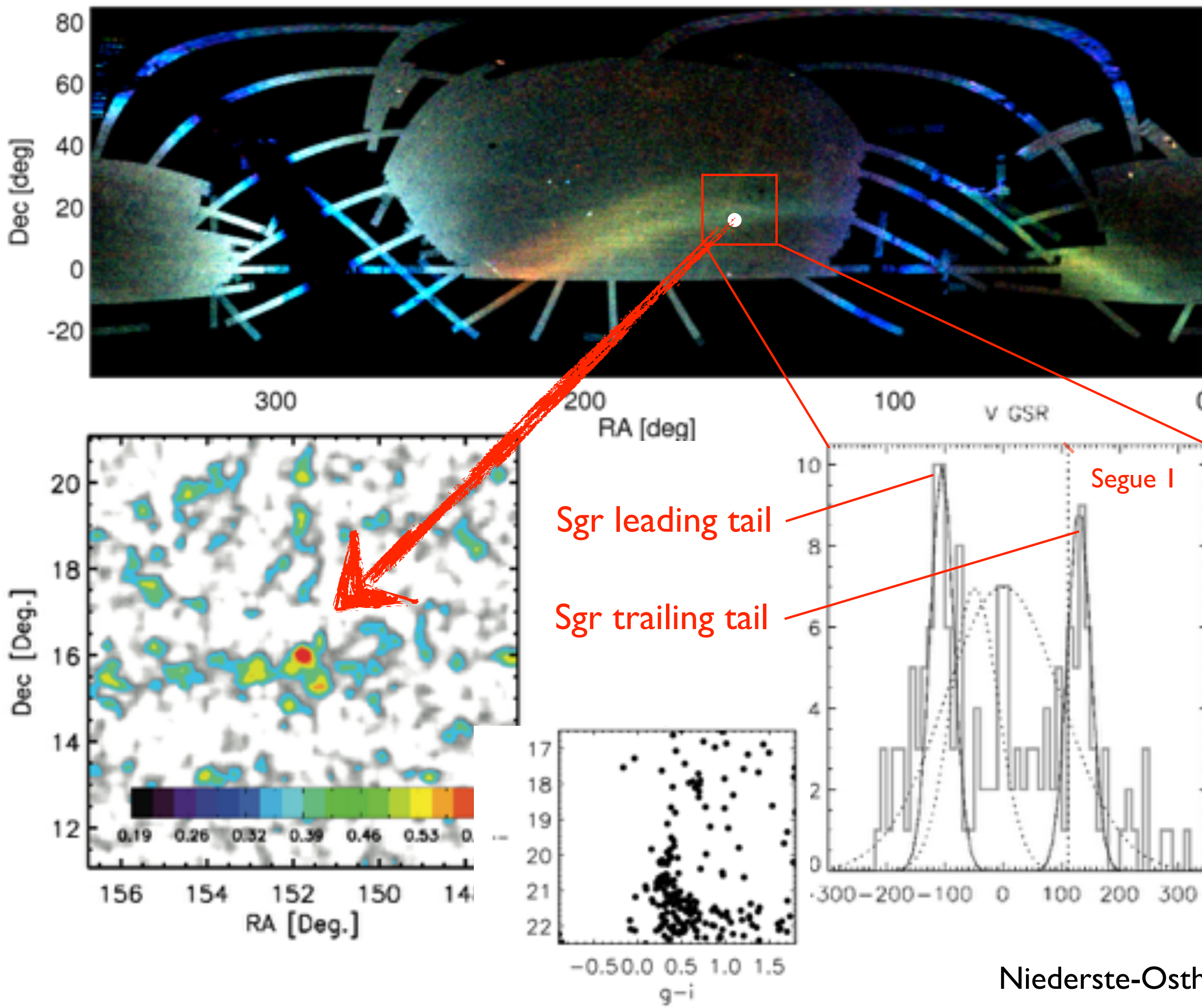




Segue 1

$M_V \sim -1.5$

23kpc



Niederste-Ostholt et al, 2009

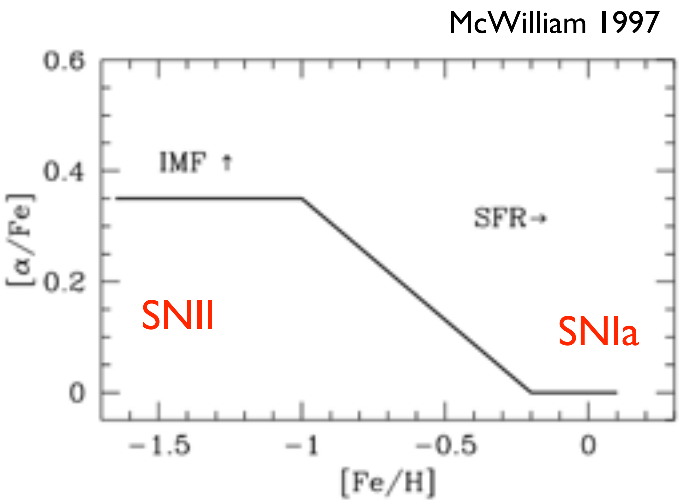
Resolved Stellar Populations:

Chemical Abundances:
detailed record of star formation

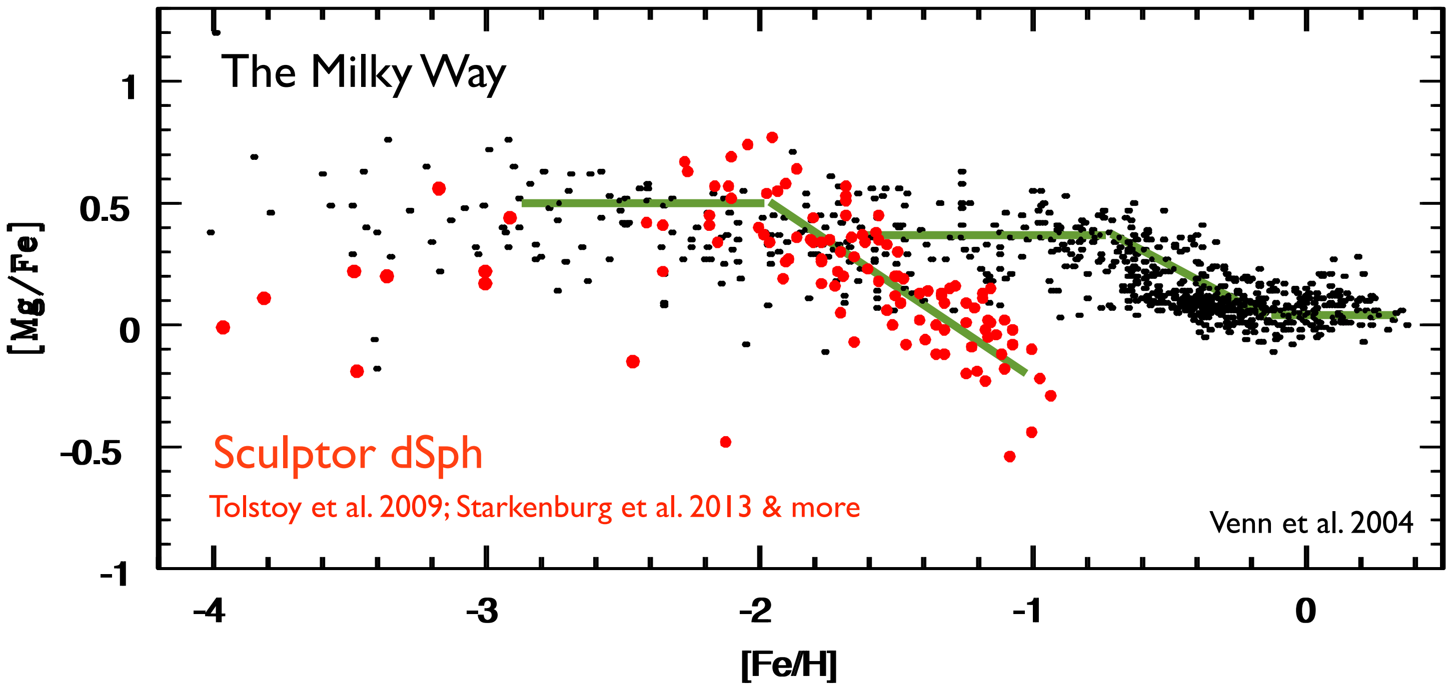
Alpha-Elements

"The Knee"

can only make halo out of existing dSph galaxies at very early times



FLAMES DART project

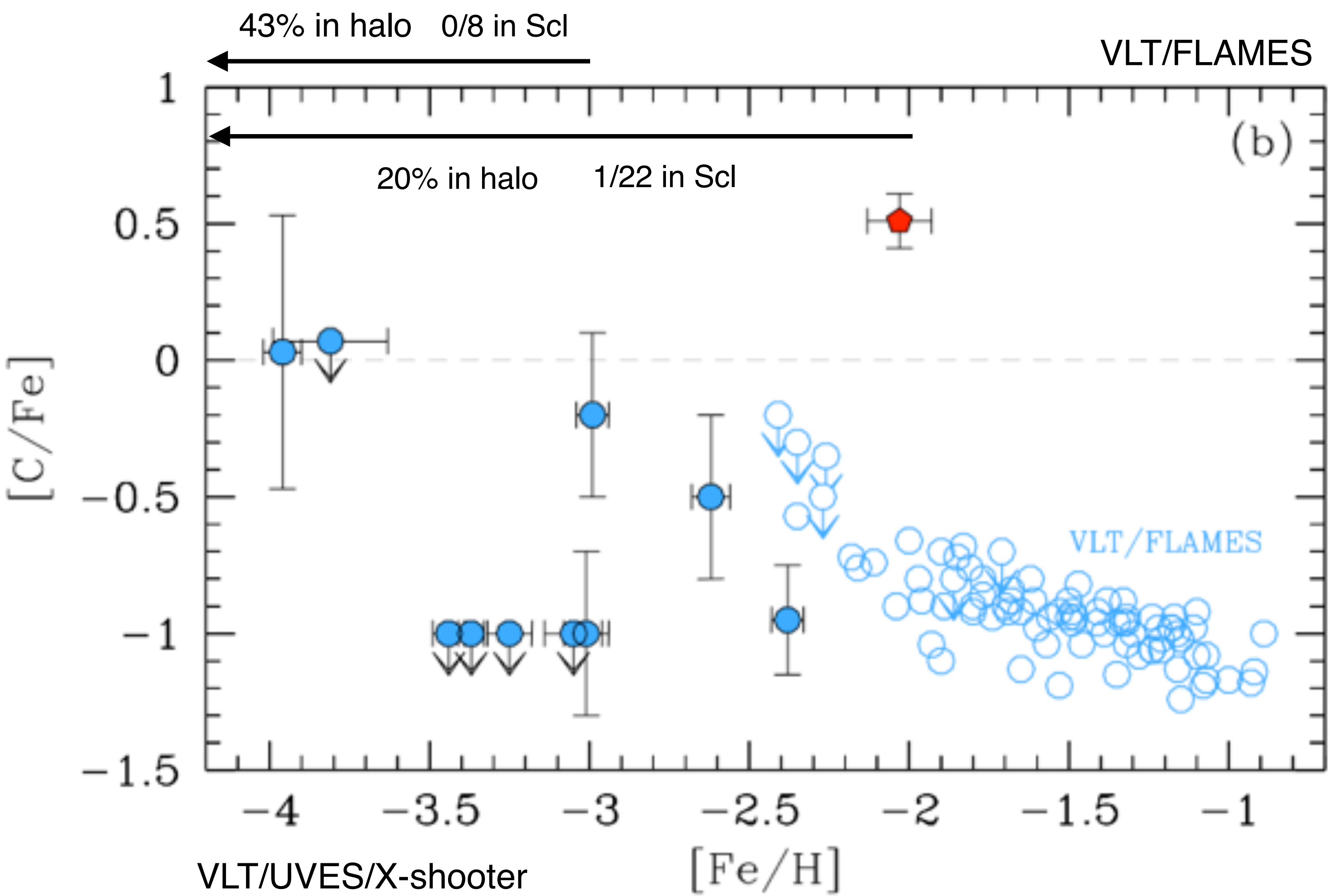


Fe Mg, Si, Ti, Ca

alpha-elements

SNIa start to contribute to the chemical enrichment of the Sculptor dSph galaxy 1-2 Gyr after star formation began

The First CEMP-no star in Sculptor.



Starkenburg et al. 2013 A&A, 549, A88
Tafelmeyer et al. 2010 A&A, 524, A58

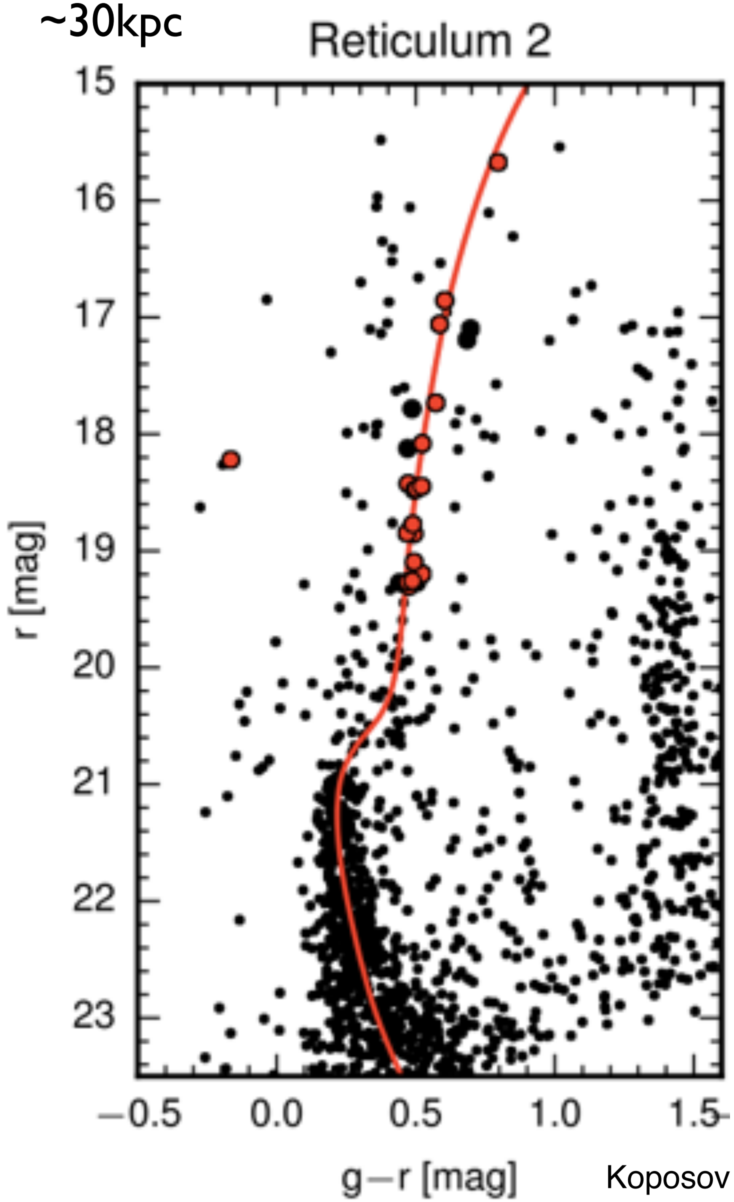
Skúladóttir et al. 2015, A&A, 574, A129

FLAMES DART project

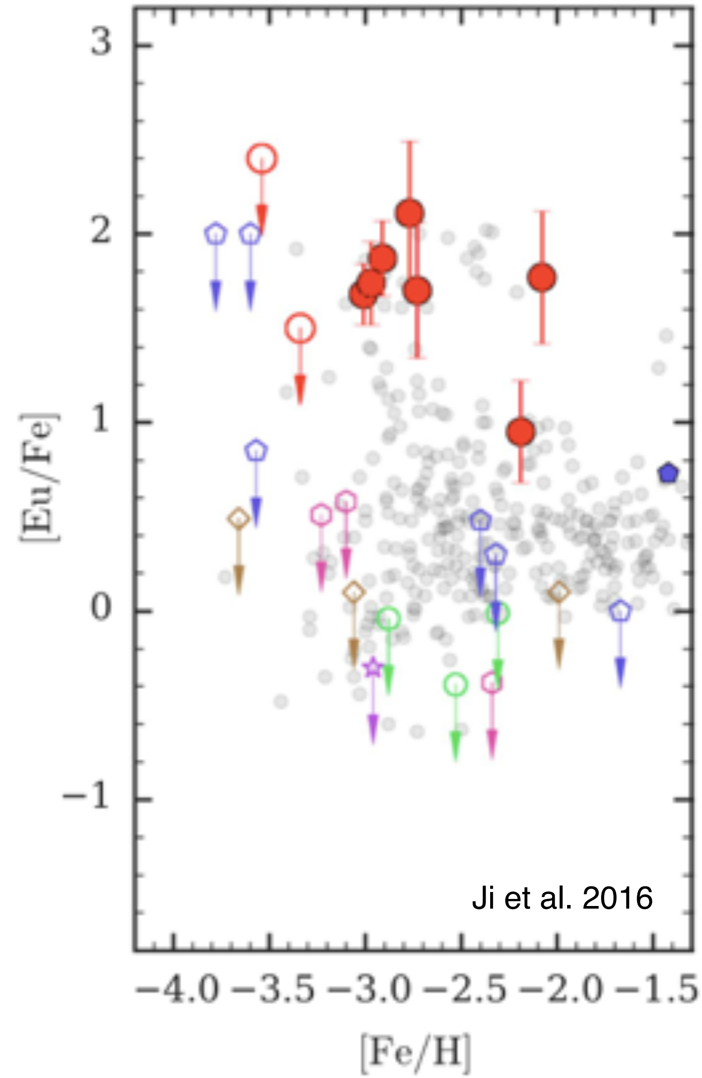
Ret II dwarf galaxy

M_V ~ -2.7

~30kpc



Koposov et al. 2015b



Neutron capture elements

The low Ba, high [Mg/Ca] an [Co/Cr] in Hercules stars (Koch et al. 2013) and also in other ultra-faints

The high Eu in Rec II stars (Ji et al. 2016a,b) - r-process rich galaxy

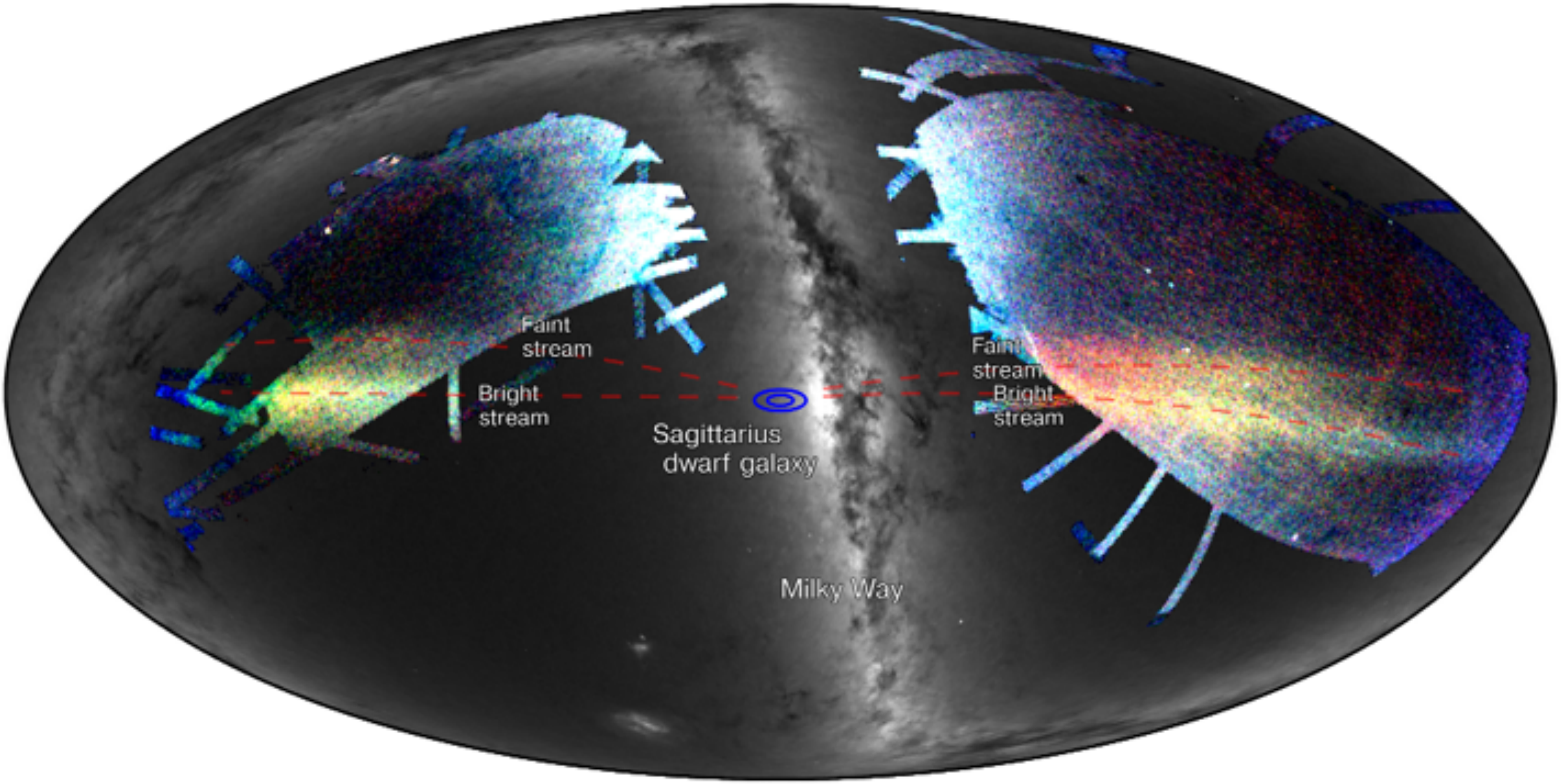
These suggest high mass SNII, higher than for dSph

Did these stars form in a larger system that was destroyed?

e.g., Sagittarius or LMC/SMC systems?

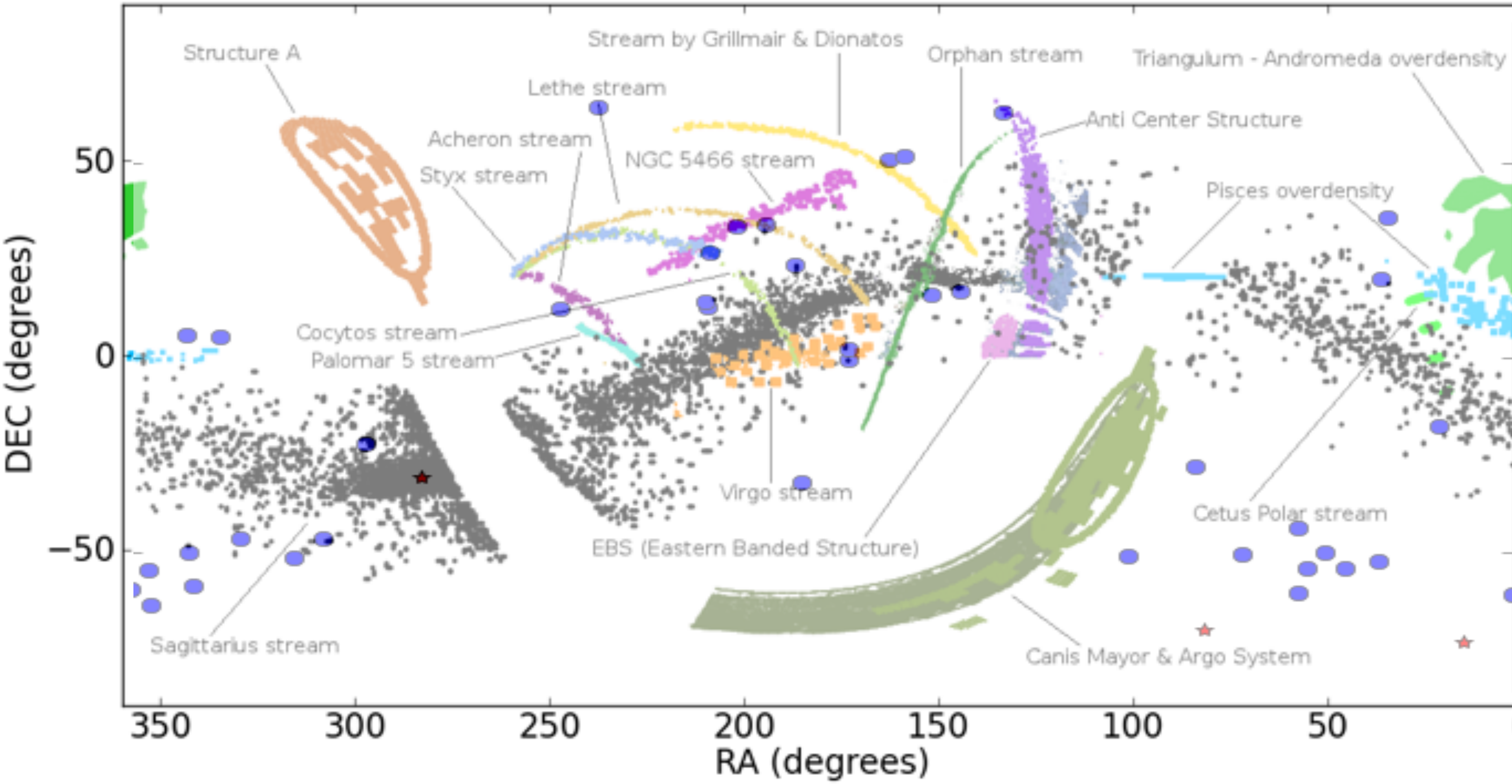
The environment of the Milky Way halo: stellar streams

sub-structure in Milky Way halo: Sagittarius



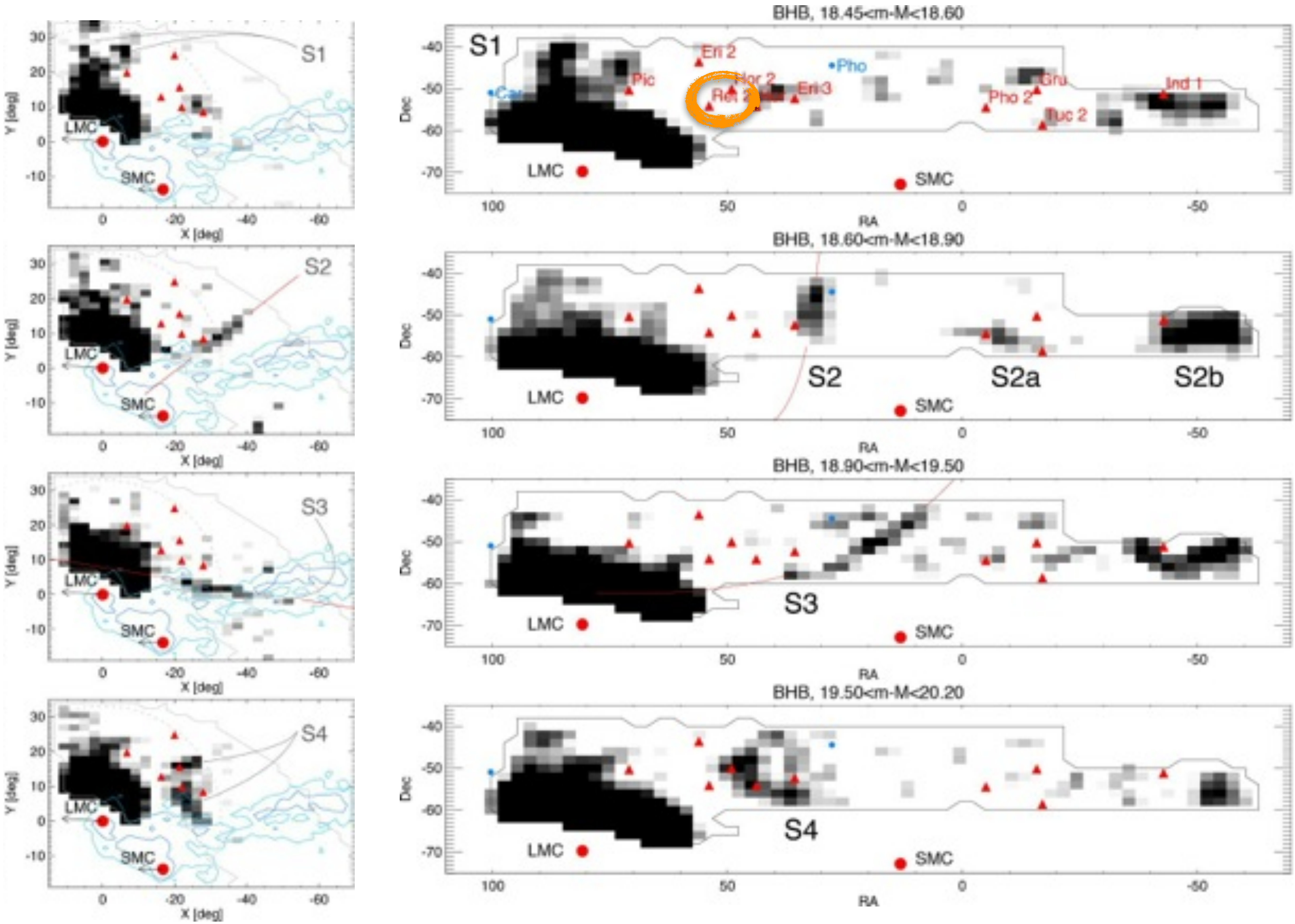
credit: S. Koposov and the SDSS-III collaboration

sub-structure in Milky Way halo: not only Sagittarius



compilation by Berenice Pila Diez

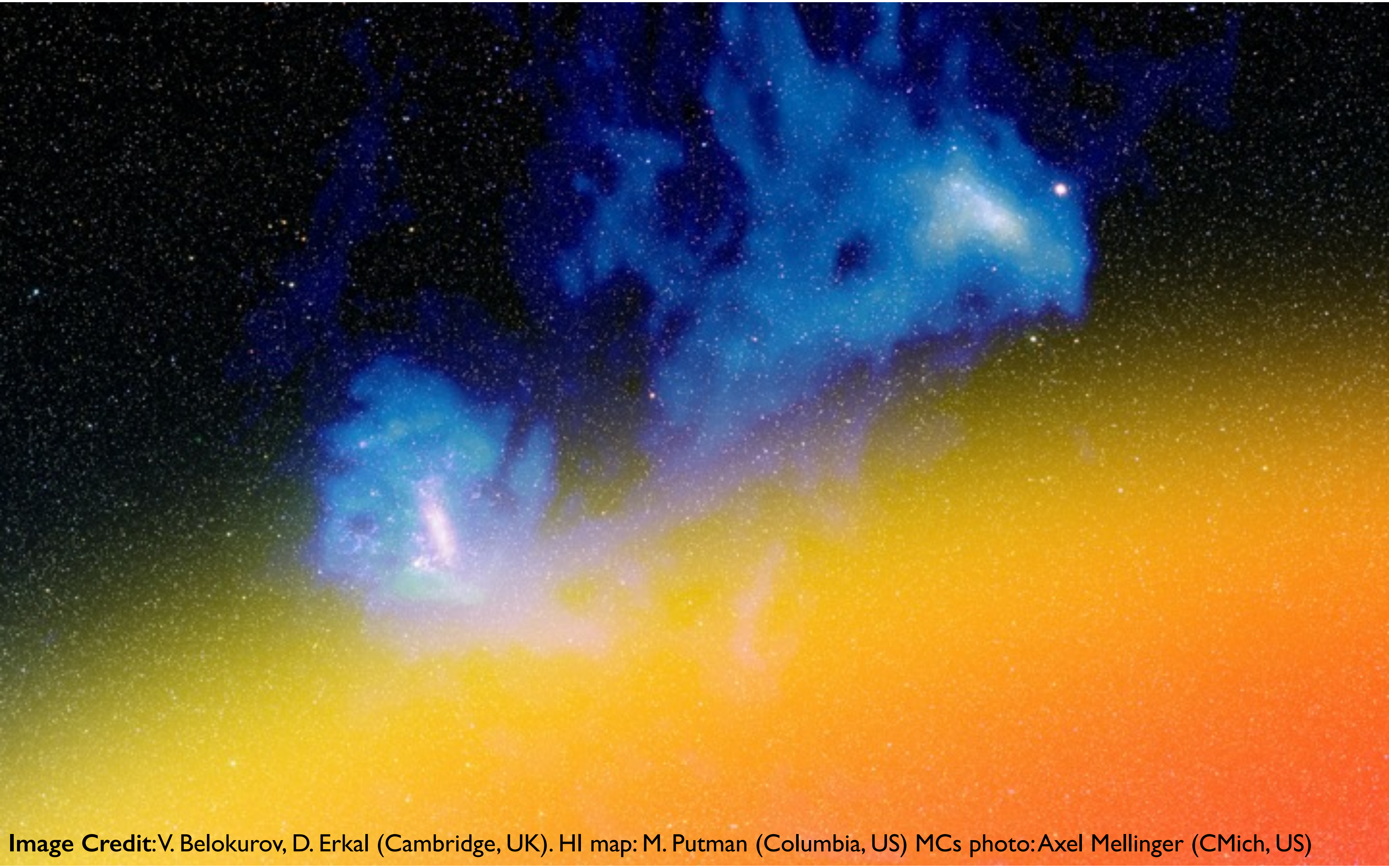
Stellar streams around the Magellanic Clouds



Belokurov & Koposov 2016 MNRAS, 456, 602

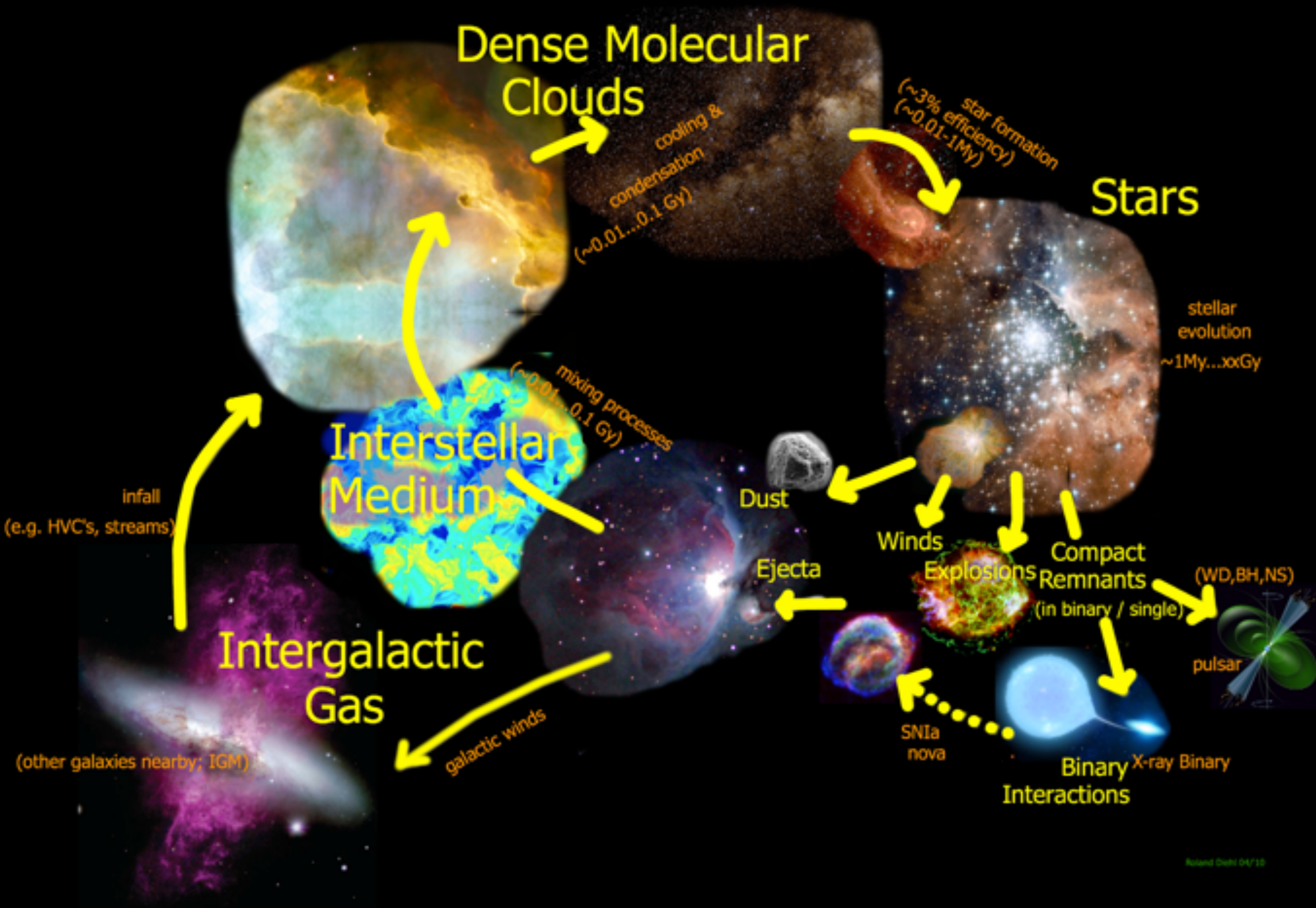
The environment of the Milky Way halo: hot corona

HI gas around the Magellanic Clouds



Gatto et al. 2013 MNRAS, 433, 2749 $n_{\rm cor} \sim 3 \times 10^{-4}\,{\rm cm}^{-3}$ Belokurov et al. 2017 MNRAS, 466, 4711

Galaxy evolution is complex, even for small galaxies



Dense Molecular Clouds
cooling & condensation (~0.01...0.1 Gy)
star formation (~3% efficiency) (~0.01-1My)
Stars
stellar evolution ~1My...xxGy
Dust
Winds
Explosions
Compact Remnants (in binary / single)
(WD,BH,NS)
pulsar
Ejecta
SNIa nova
Binary Interactions
X-ray Binary
Interstellar Medium
mixing processes (~0.01...0.1 Gy)
galactic winds
Intergalactic Gas
(other galaxies nearby; IGM)
infall (e.g. HVC's, streams)

Dwarf Spheroidals useful for indirect dark matter detections because….

(i) gravitational dynamics indicate DM-dominated

NOT SURE: need to select carefully

(ii) typically moderate or high Galactic latitudes thus low diffuse gamma-ray foregrounds

effect of streams?

(iii) lack of unambiguously discernible astrophysical gamma-ray emission

NOT BRIGHT: but LMXBs exist; effect of streams of gas & stars?

(iv) relatively small uncertainties on the DM profile.

NOT SURE: need to select carefully

Dwarf galaxies have complex evolutionary histories *quite different from the Milky Way*

They live in an active environment: Milky Halo, which is clumpy and contains hot diffuse gas

Baring et al. 2016 Phys.Rev.D

Make catalogues of detections!

It is interesting to see how many stellar sources may radiate at X-ray and beyond!