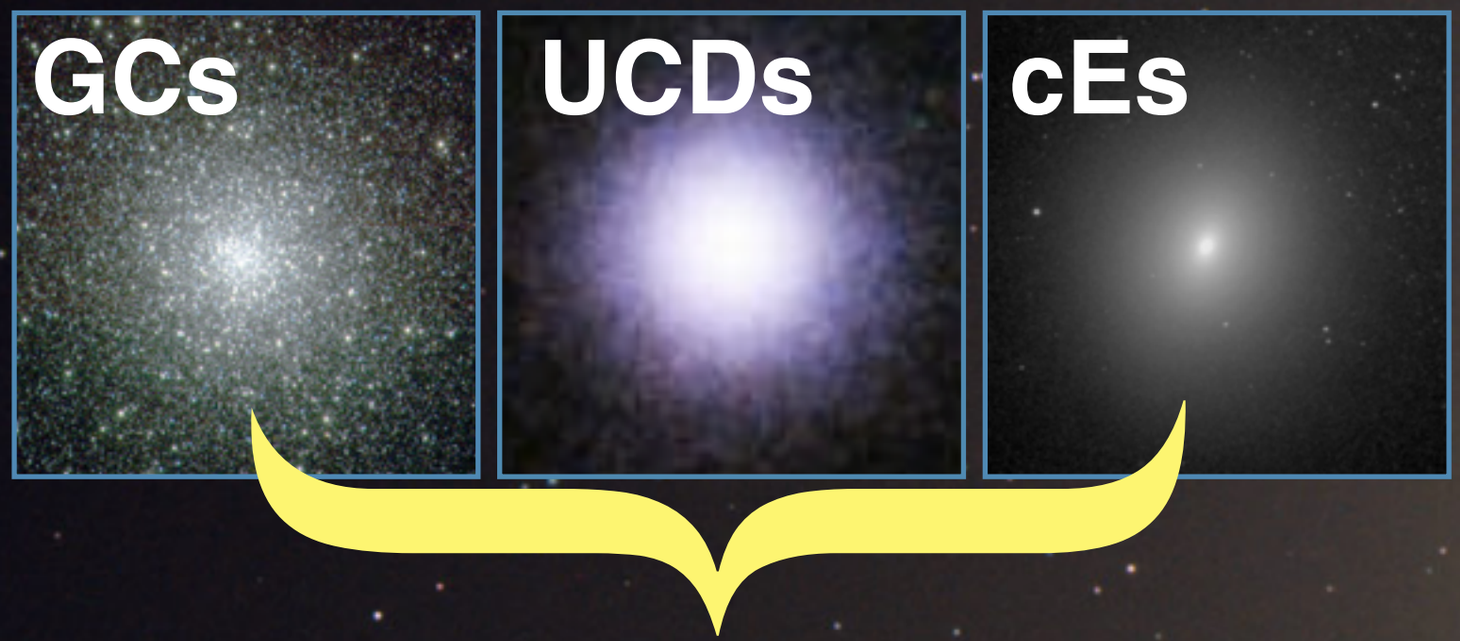
Aiming to Understand Compact Stellar Systems

Mark A. Norris (MPIA)

Sheila Kannappan (UNC), Duncan Forbes (Swinburne), Avon Huxor (ARI Heidelberg), Aaron Romanowsky (SJSC), Favio Faifer (UNLP), Joachim Janz (Swinburne), Jay Strader (MSU) Jean Brodie (UCSC), Claudia Maraston (Portsmouth), Carlos Escudero (UNLP)…

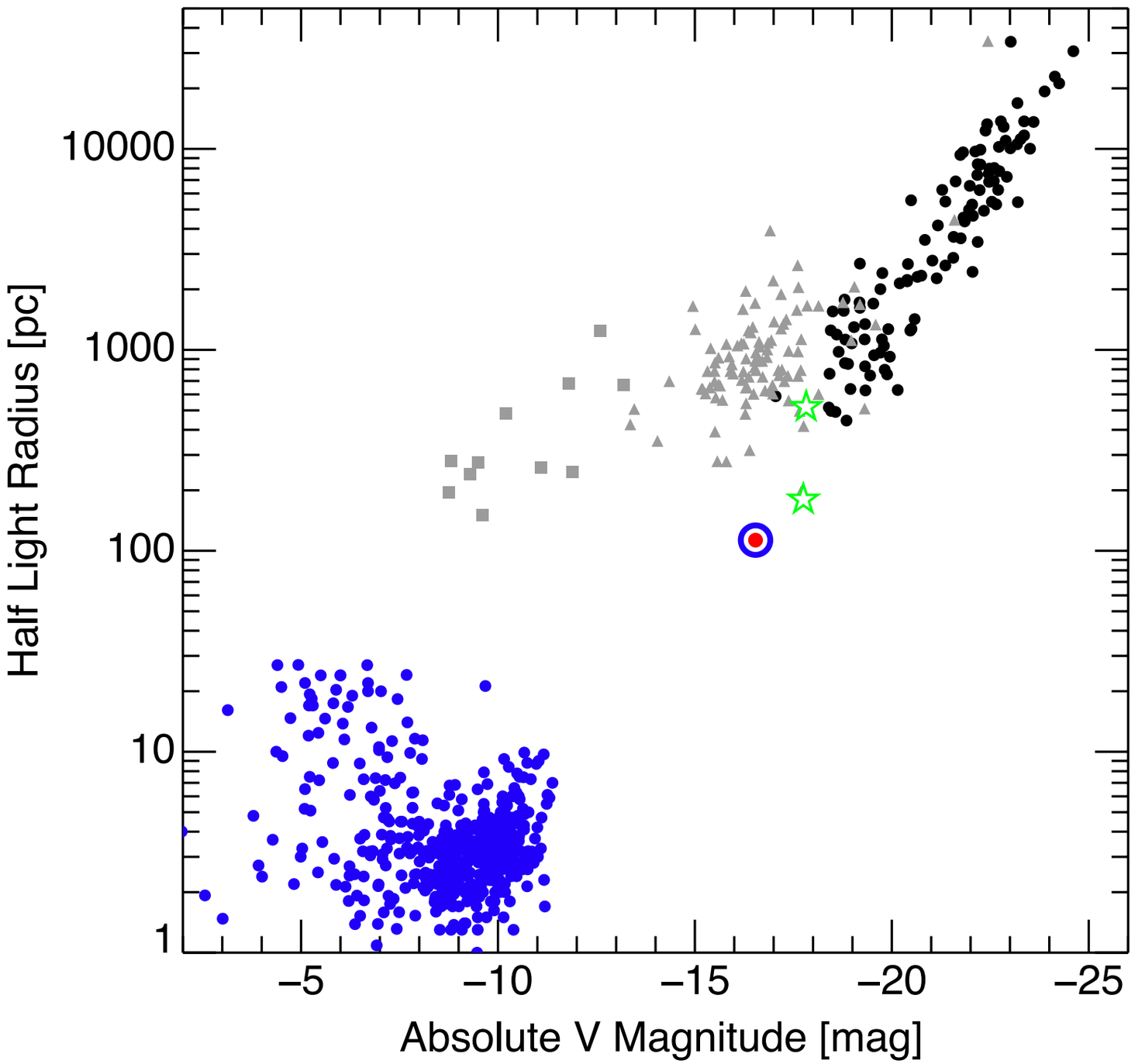
Aiming to Understand Compact Stellar Systems

Mark A. Norris (MPIA)

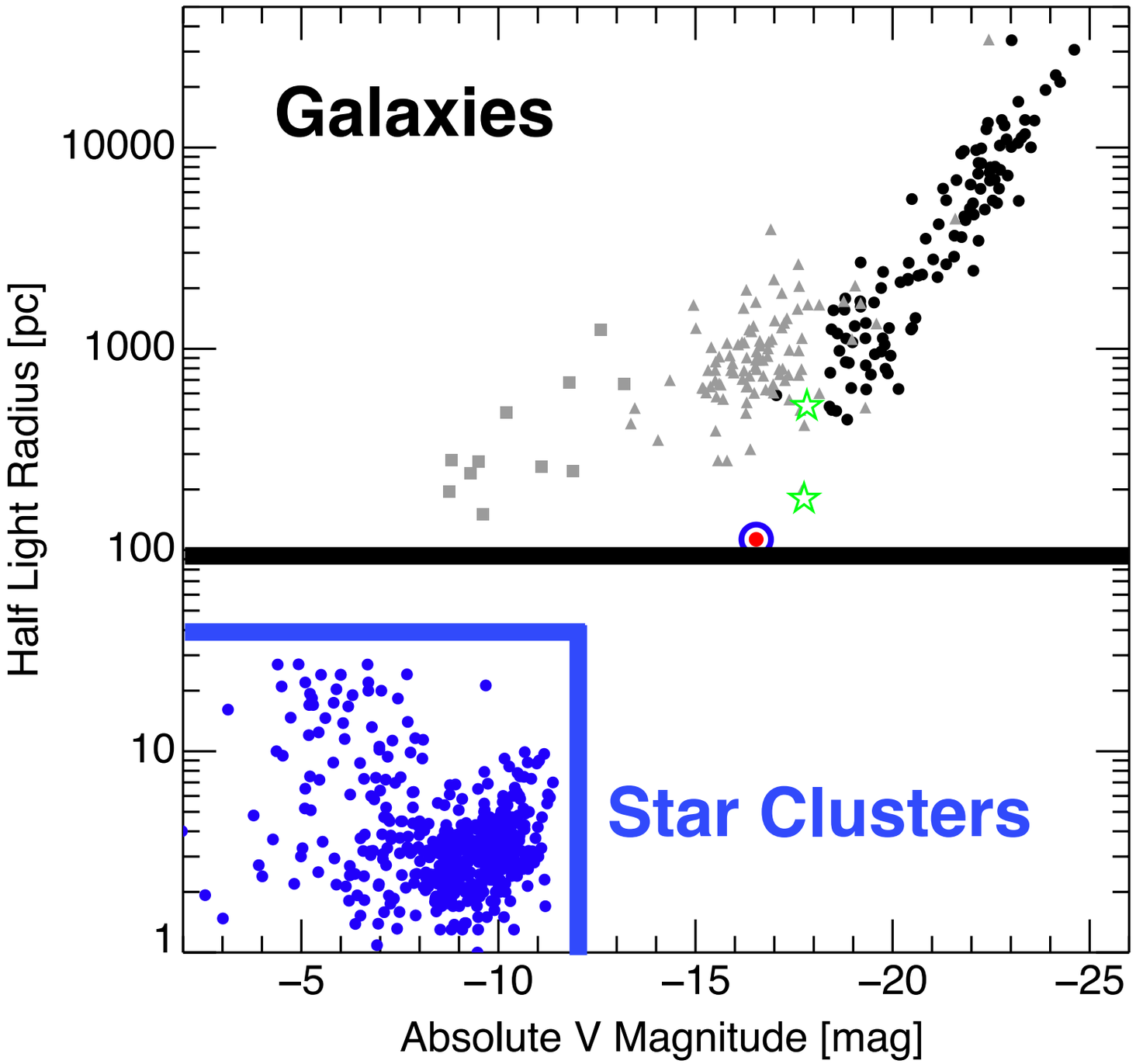


Sheila Kannappan (UNC), Duncan Forbes (Swinburne), Avon Huxor (ARI Heidelberg), Aaron Romanowsky (SJSC), Favio Faifer (UNLP), Joachim Janz (Swinburne), Jay Strader (MSU) Jean Brodie (UCSC), Claudia Maraston (Portsmouth), Carlos Escudero (UNLP)…

Mind the Gap

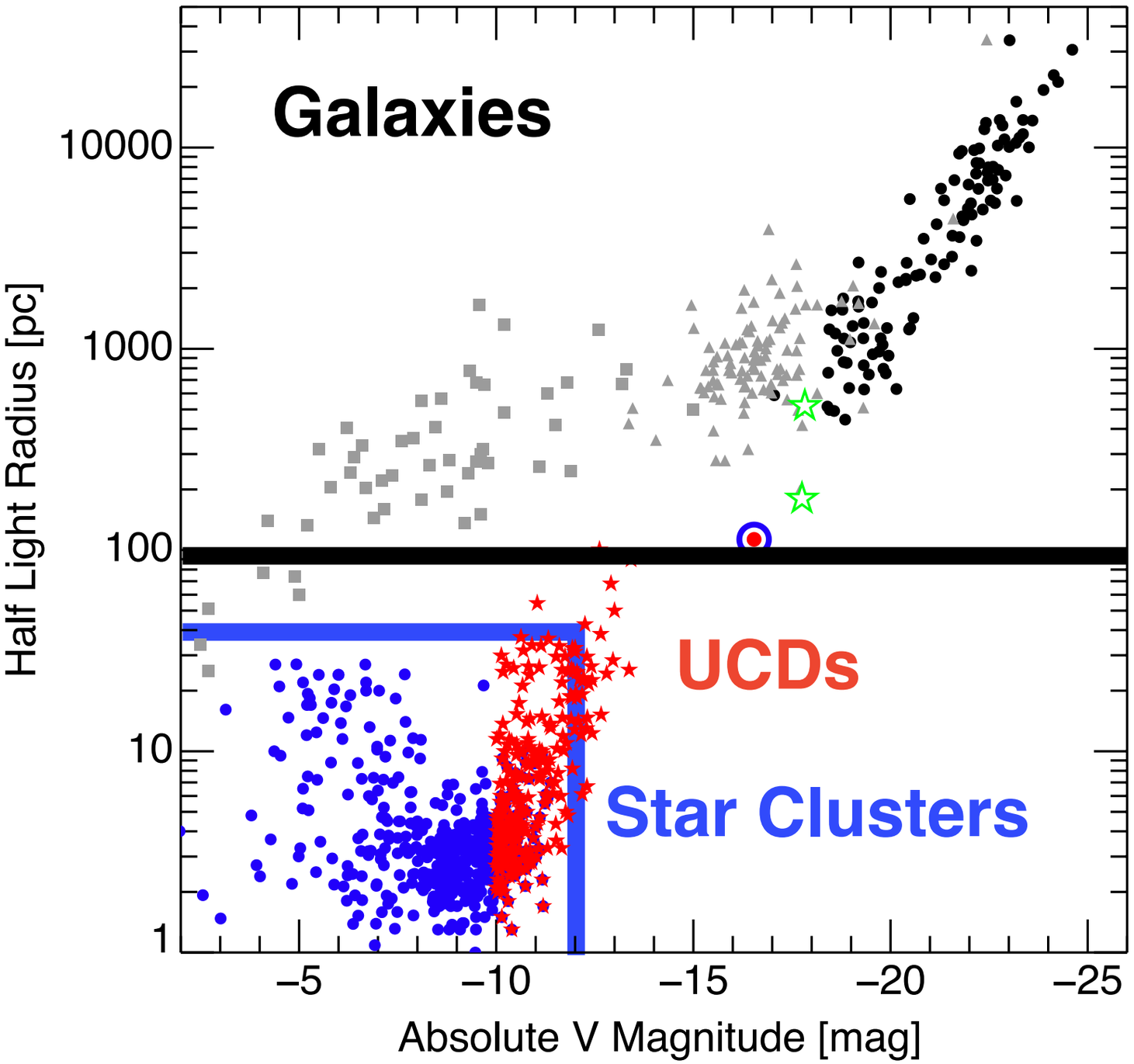

10000
1000
100
10
1
Half Light Radius [pc]
–5
–10
–15
–20
–25
Absolute V Magnitude [mag]

Mind the Gap



Originally thought that stellar systems come in two forms - star clusters and galaxies.

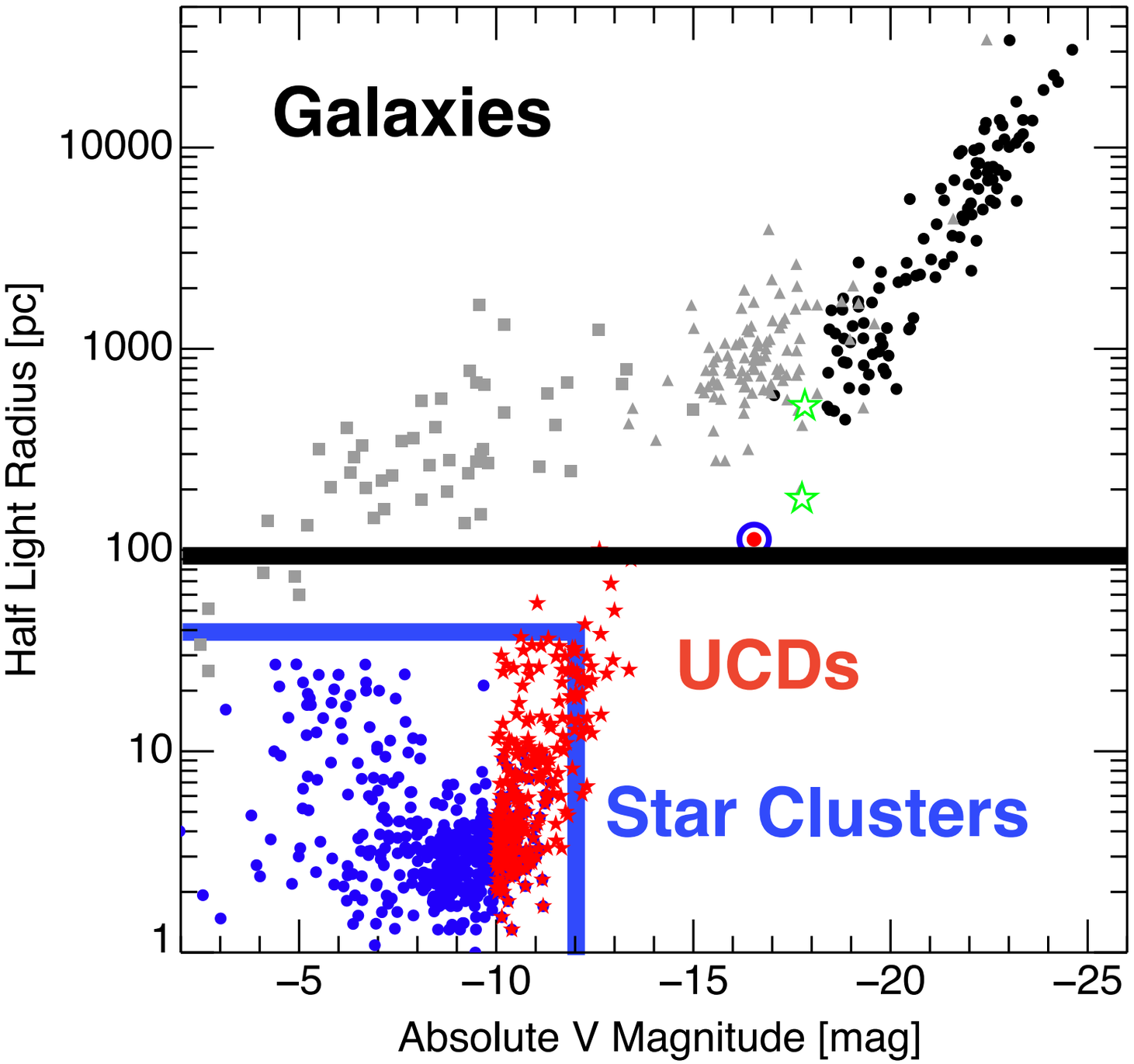
Mind the Gap



Originally thought that stellar systems come in two forms - star clusters and galaxies.

Then UCDs were discovered (Hilker et al. 1999, Drinkwater et al. 2000) that seemed to transition between star clusters and galaxies.

Mind the Gap



Originally thought that stellar systems come in two forms - star clusters and galaxies.

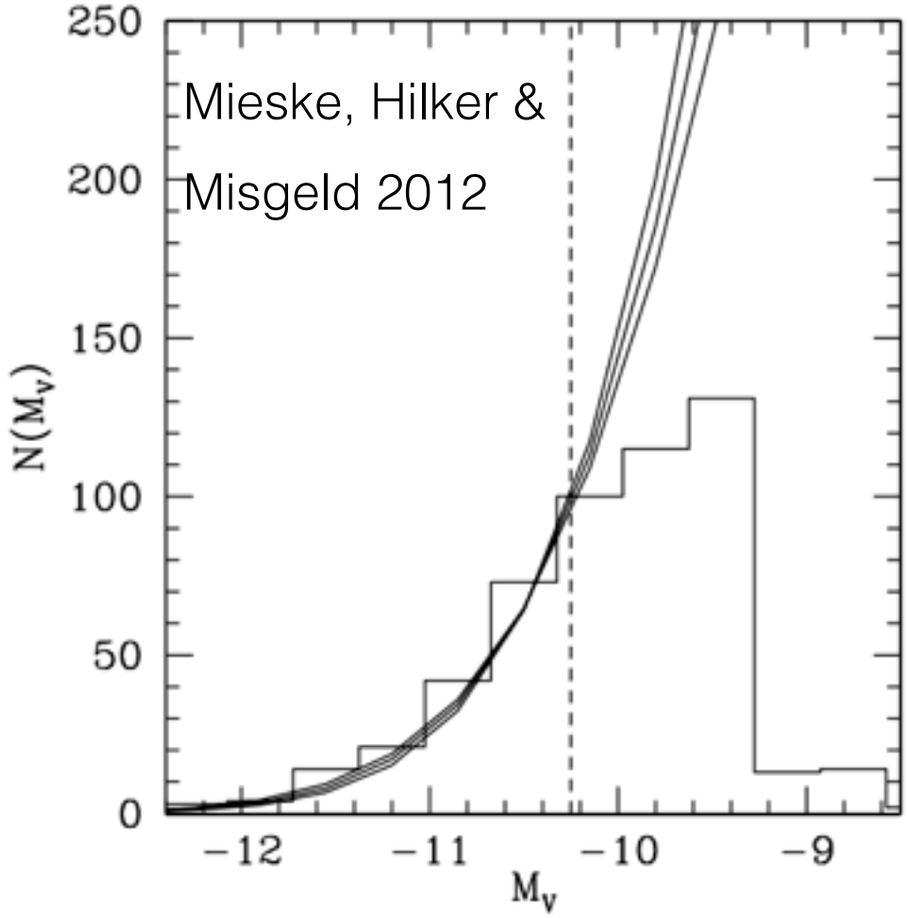
Then UCDs were discovered (Hilker et al. 1999, Drinkwater et al. 2000) that seemed to transition between star clusters and galaxies.

A big argument ensued over whether UCDs were star clusters, or the nuclei of galaxies that had been tidally stripped.

Mind the Gap

The specific frequency of UCDs is very close to that expected if they are massive GCs:

Hilker 2009
Norris & Kannappan 2011
Mieske, Hilker, & Misgeld 2012
Pfeffer et al. 2014



Mind the Gap

The specific frequency of UCDs is very close to that expected if they are massive GCs:

Hilker 2009
Norris & Kannappan 2011
Mieske, Hilker, & Misgeld 2012
Pfeffer et al. 2014

Young massive star clusters with UCD properties are observed:

NGC 7252 - W3: Maraston et al. 2004

Mind the Gap

The specific frequency of UCDs is very close to that expected if they are massive GCs:

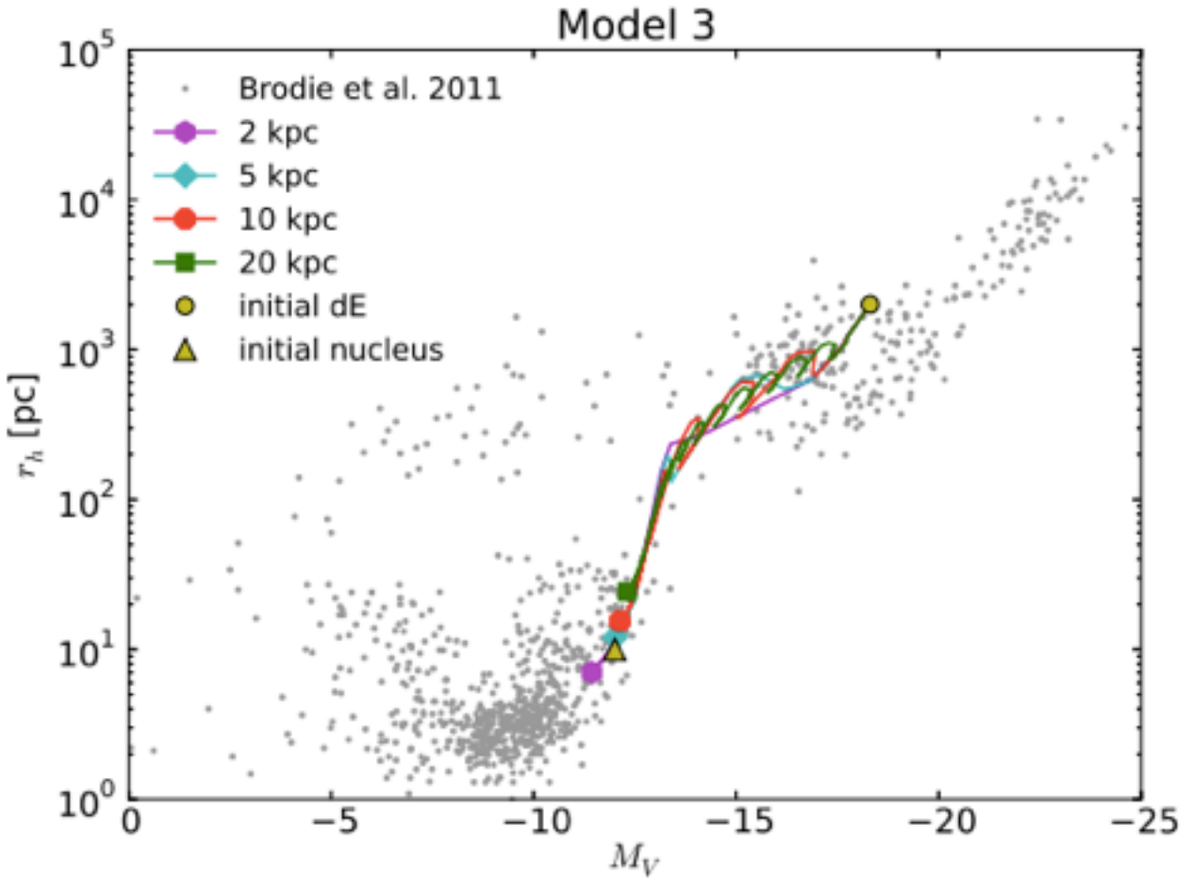
Hilker 2009
Norris & Kannappan 2011
Mieske, Hilker, & Misgeld 2012
Pfeffer et al. 2014

Young massive star clusters with UCD properties are observed:

NGC 7252 - W3: Maraston et al. 2004

Simulations seem to show that tidal stripping of galaxies can produce UCD-like objects:

Bekki et al. 2003
Pfeffer et al. 2013/2014 (and Michaels talk)



Mind the Gap

The specific frequency of UCDs is very close to that expected if they are massive GCs:

Hilker 2009
Norris & Kannappan 2011
Mieske, Hilker, & Misgeld 2012
Pfeffer et al. 2014

Young massive star clusters with UCD properties are observed:

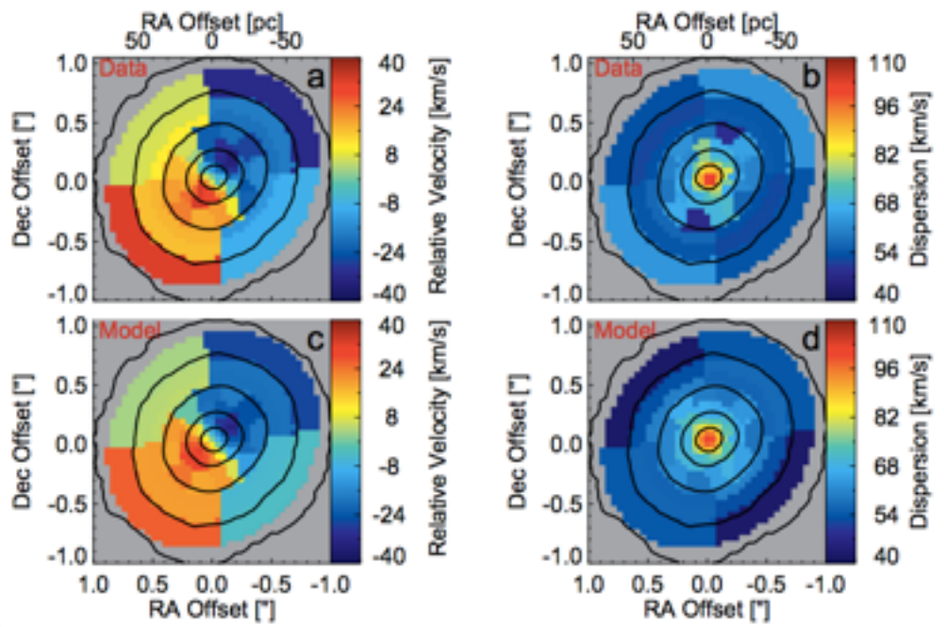
NGC 7252 - W3: Maraston et al. 2004

Simulations seem to show that tidal stripping of galaxies can produce UCD-like objects:

Bekki et al. 2003
Pfeffer et al. 2013/2014 (and Michaels talk)

Plus several incontrovertibly stripped objects exist:

NGC 4546-UCD1: Norris & Kannappan 2011
M60-UCD1: Seth et al. 2014 (and Anils talk)



Mind the Gap

The specific frequency of UCDs is very close to that expected if they are massive GCs:

Hilker 2009
Norris & Kannappan 2011
Mieske, Hilker, & M[illegible]
Pfeffer et al. 2014

Simulations seem to show that tidal stripping of galaxies can produce UCD-like objects:

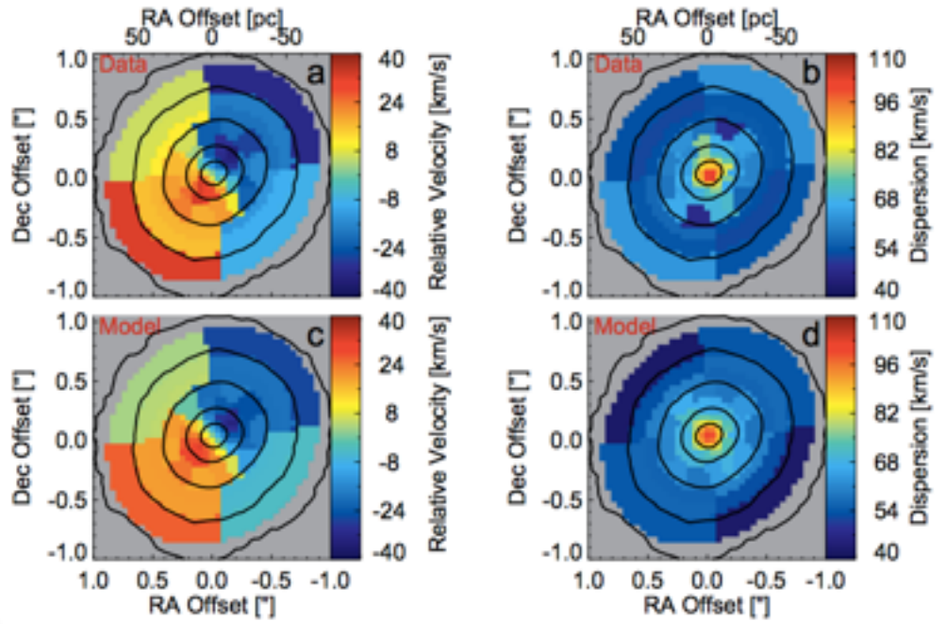
Bekki et al. 2003
Pfeffer et al. 2013/2014 (and Michaels talk)

UCDs are a "mixed bag" (Hilker 2006)

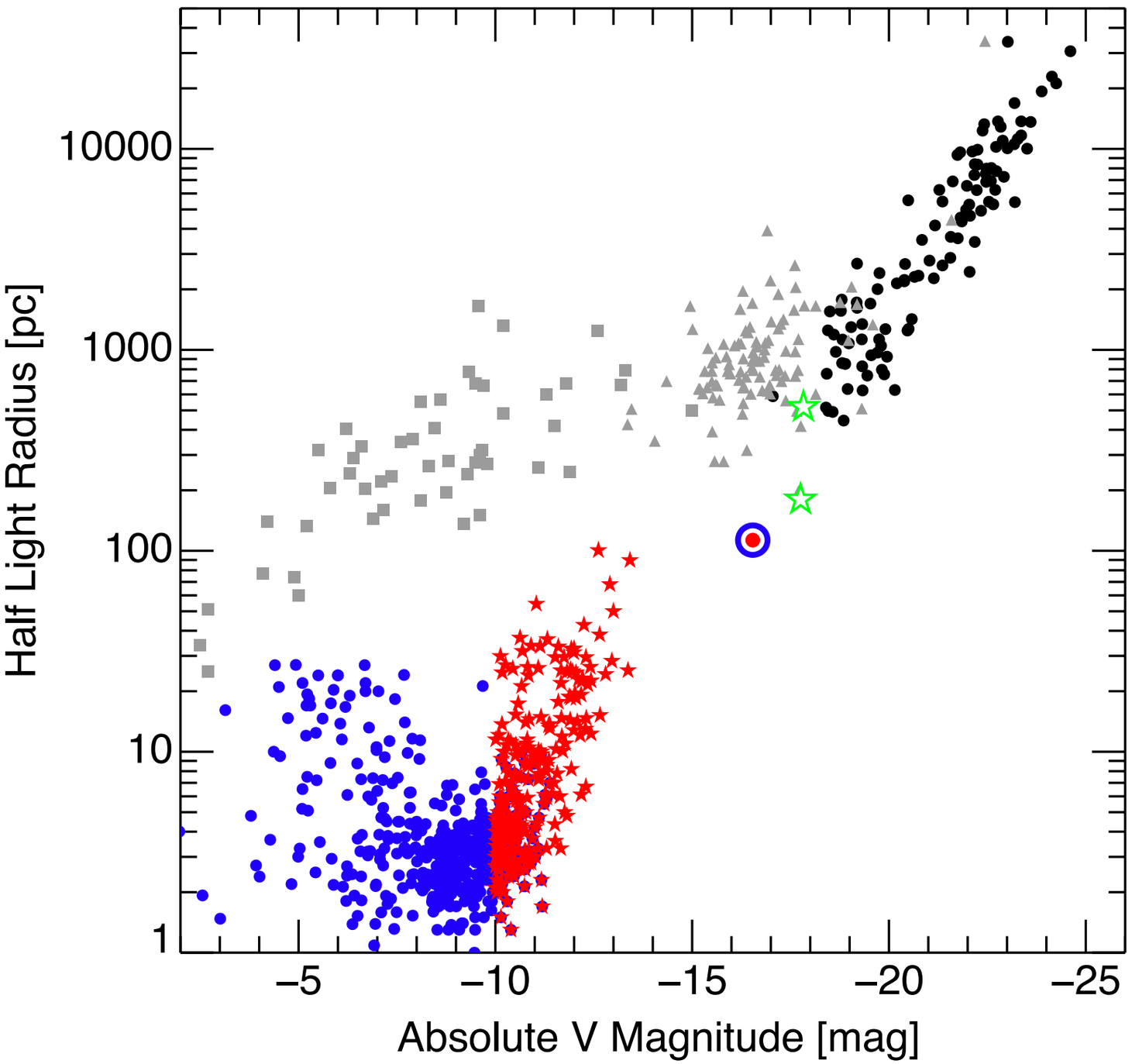
Young massive s[illegible]stripped objects
properties are obse[illegible]annappan 2011

M60-UCD1: Seth et al. 2014 (and Anils talk)

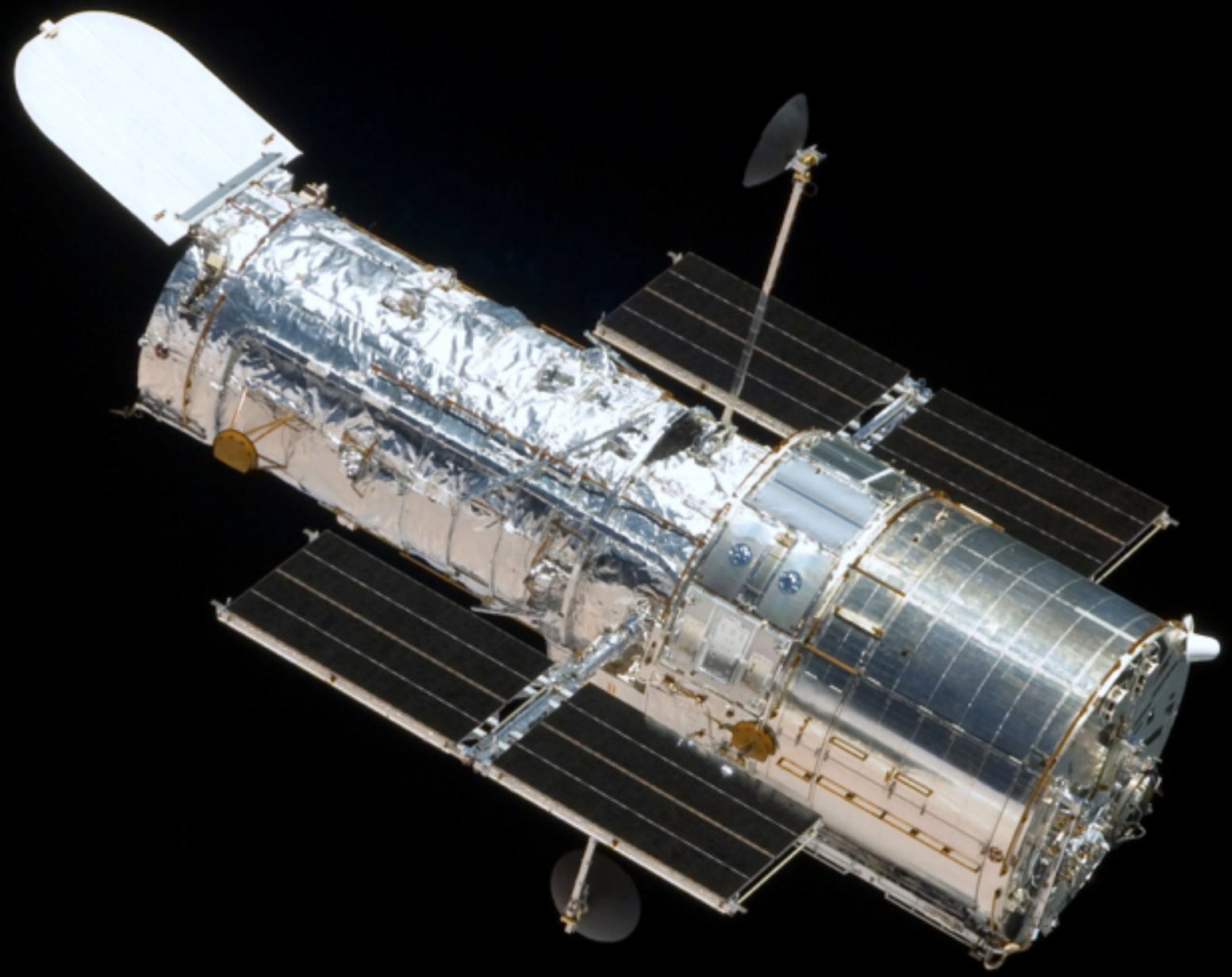
NGC 7252 - W3: Maraston et al. 2004



Mind the Gap


10000
1000
100
10
1
Half Light Radius [pc]
−5
−10
−15
−20
−25
Absolute V Magnitude [mag]

Bridging the Gap

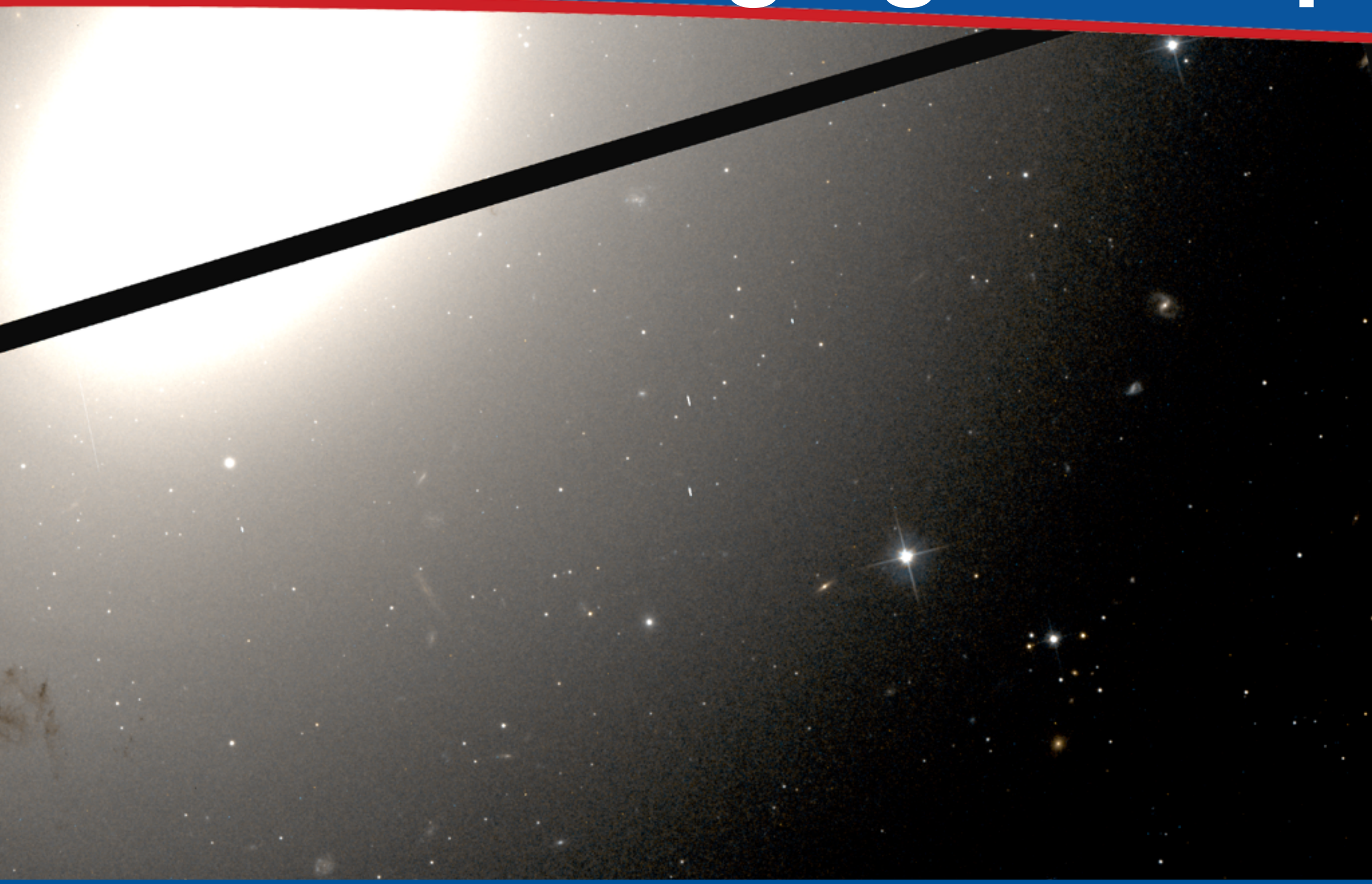


Used HST imaging to select resolved objects near to larger galaxies.

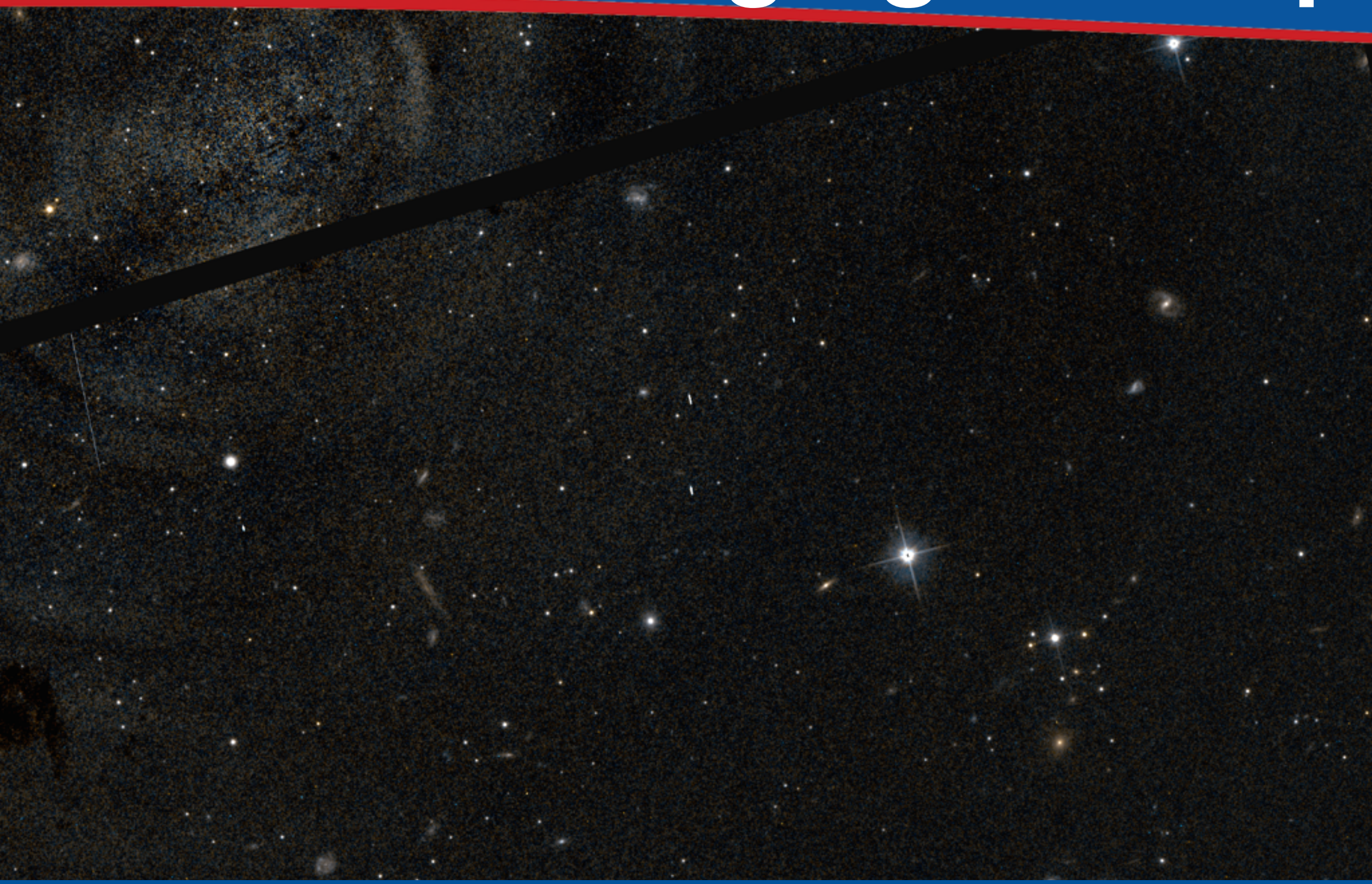
If their implied size (assuming physical co-location) puts them on the mass-size plot for GCs, UCDs or cEs, get a spectrum.

~ 59/60 are bona-fide compact stellar systems.

Bridging the Gap

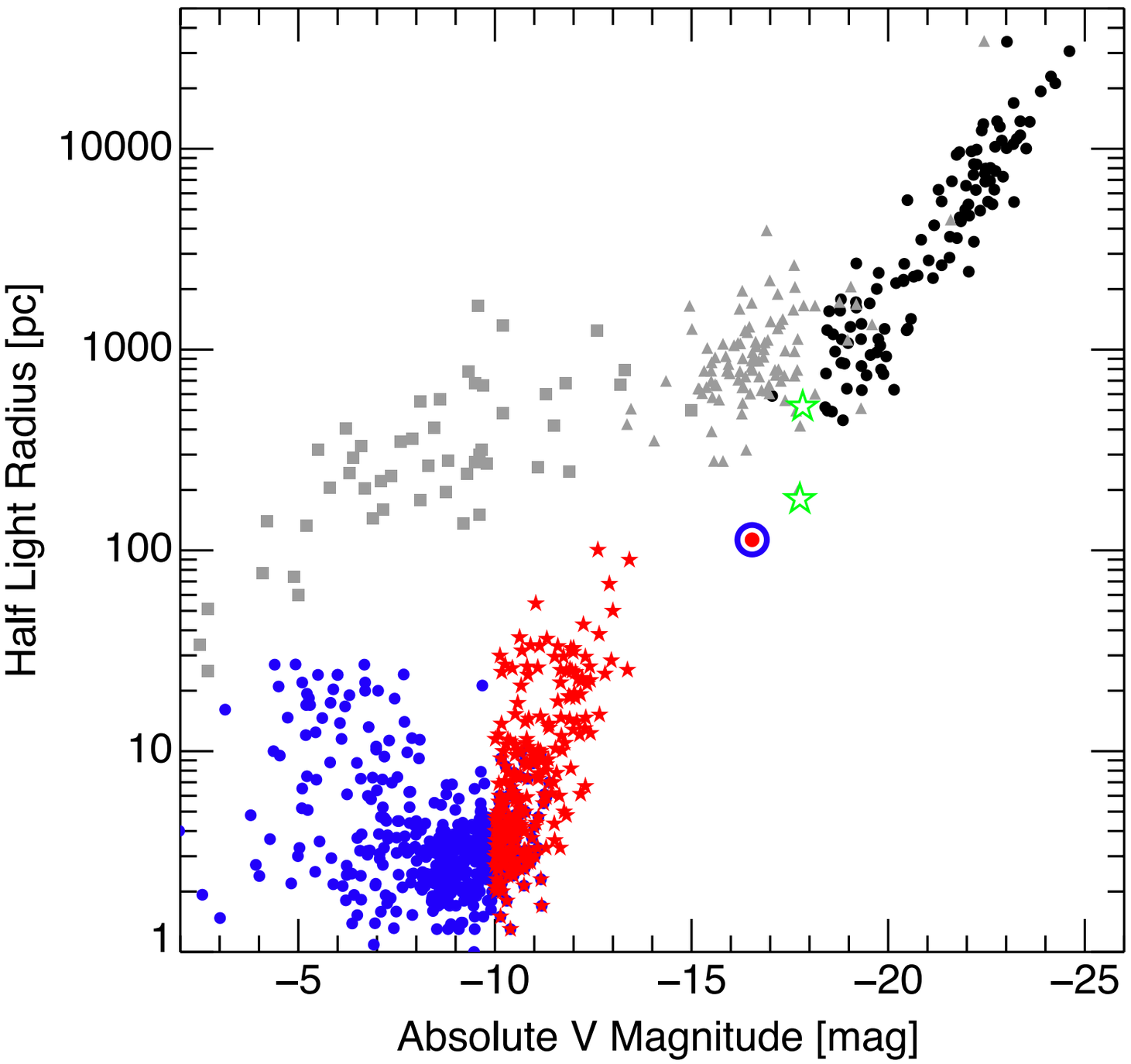


Bridging the Gap

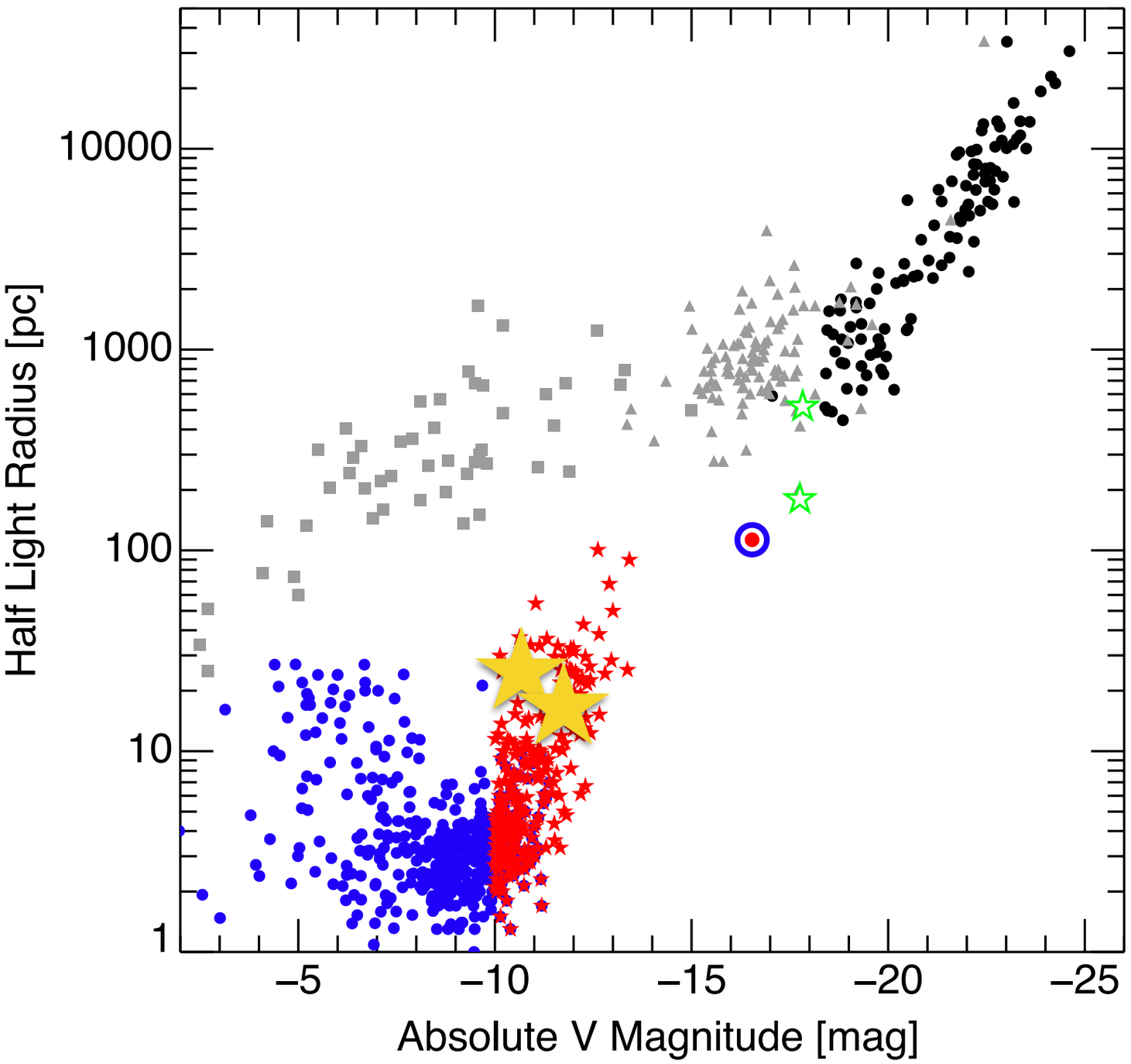


Bridging the Gap

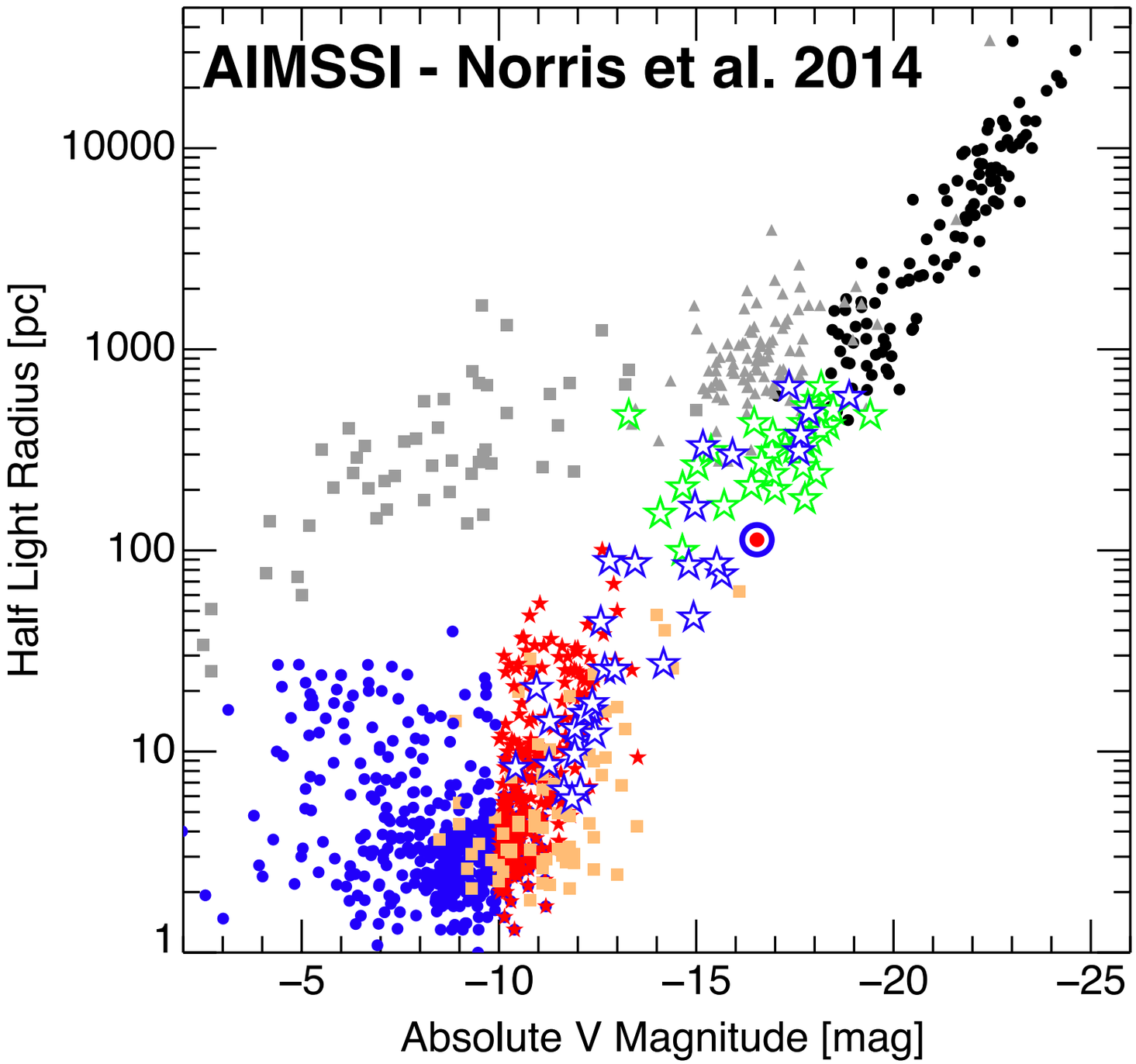
Bridging the Gap



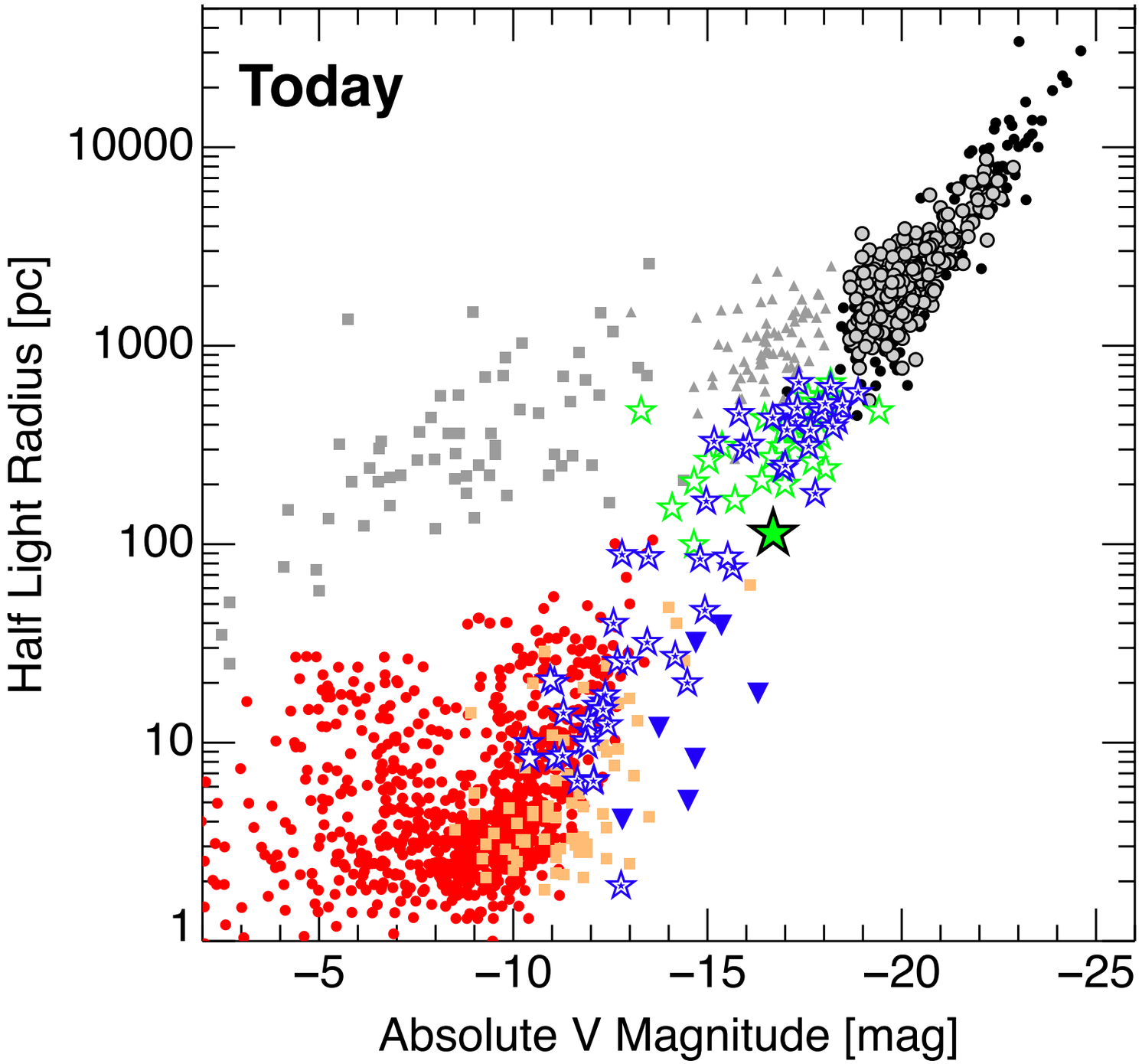
Bridging the Gap



Bridging the Gap



Bridging the Gap

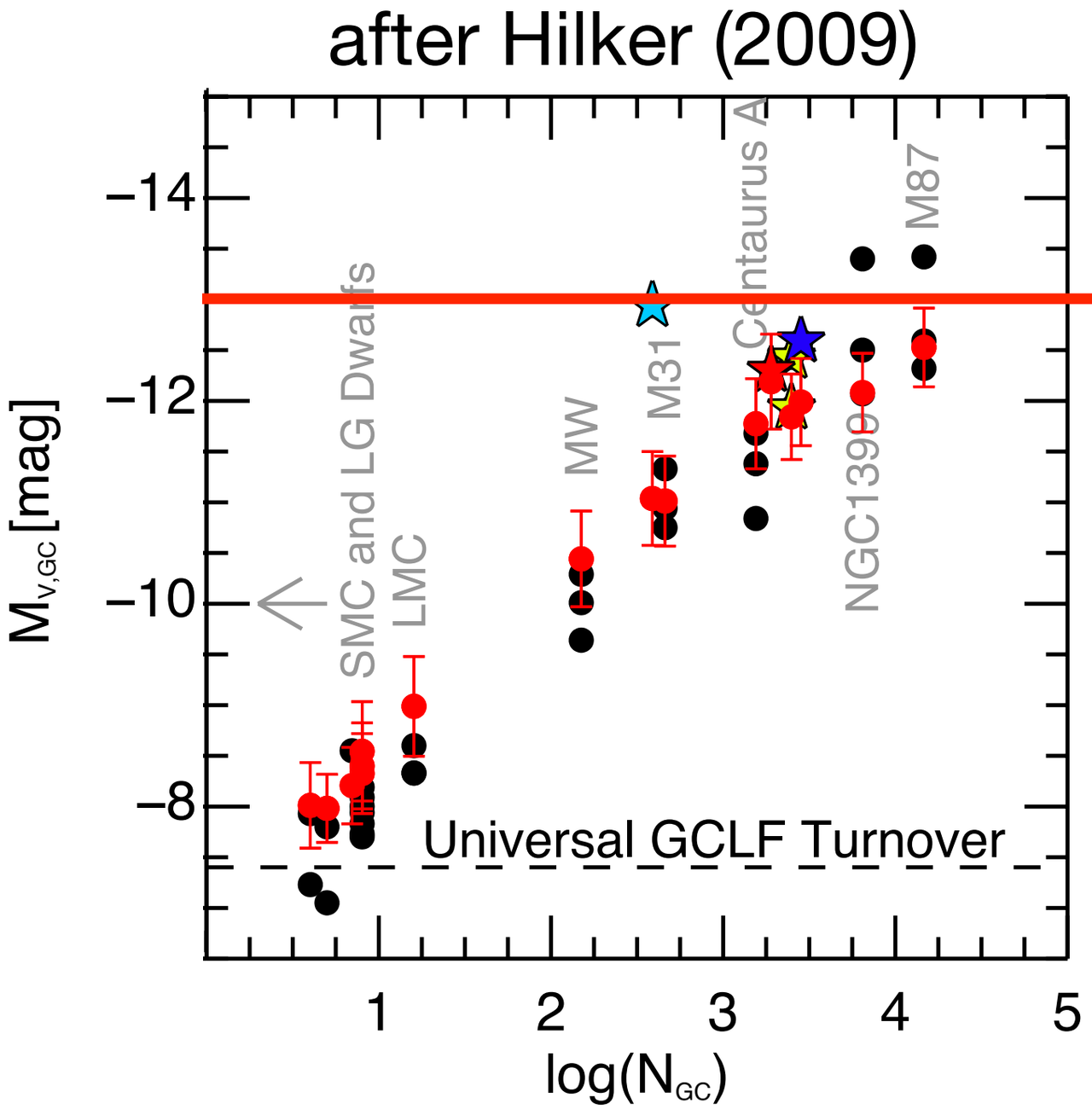


Have now completely filled the gap between GCs and galaxies.

Seems to be a common scaling relation from 10^6 to 10^{13} $M_\odot$ for dynamically hot stellar systems.

Are there any regions where we can be confident about what is a star cluster and what is a stripped nucleus?

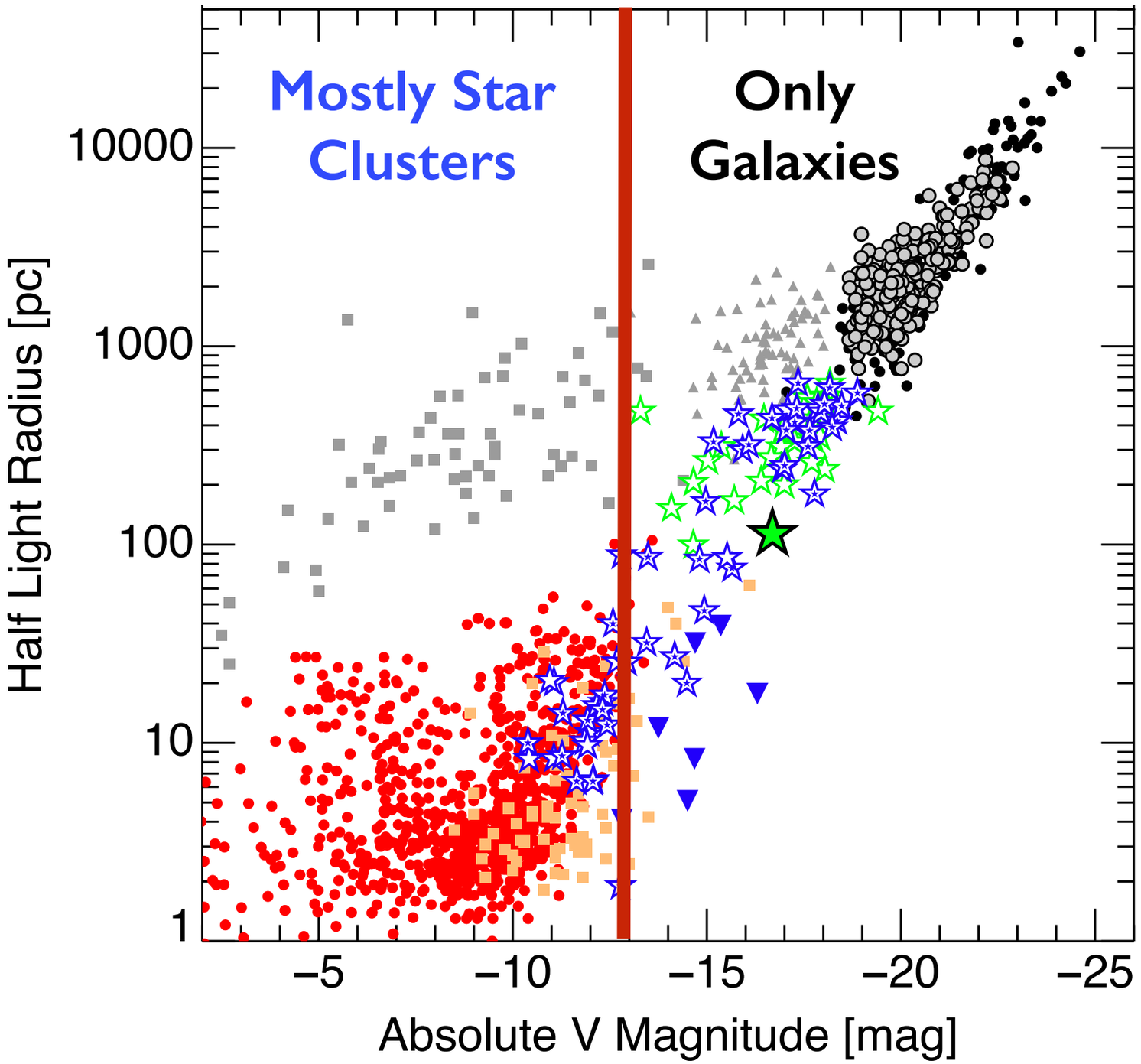
The Most Massive Star Cluster?



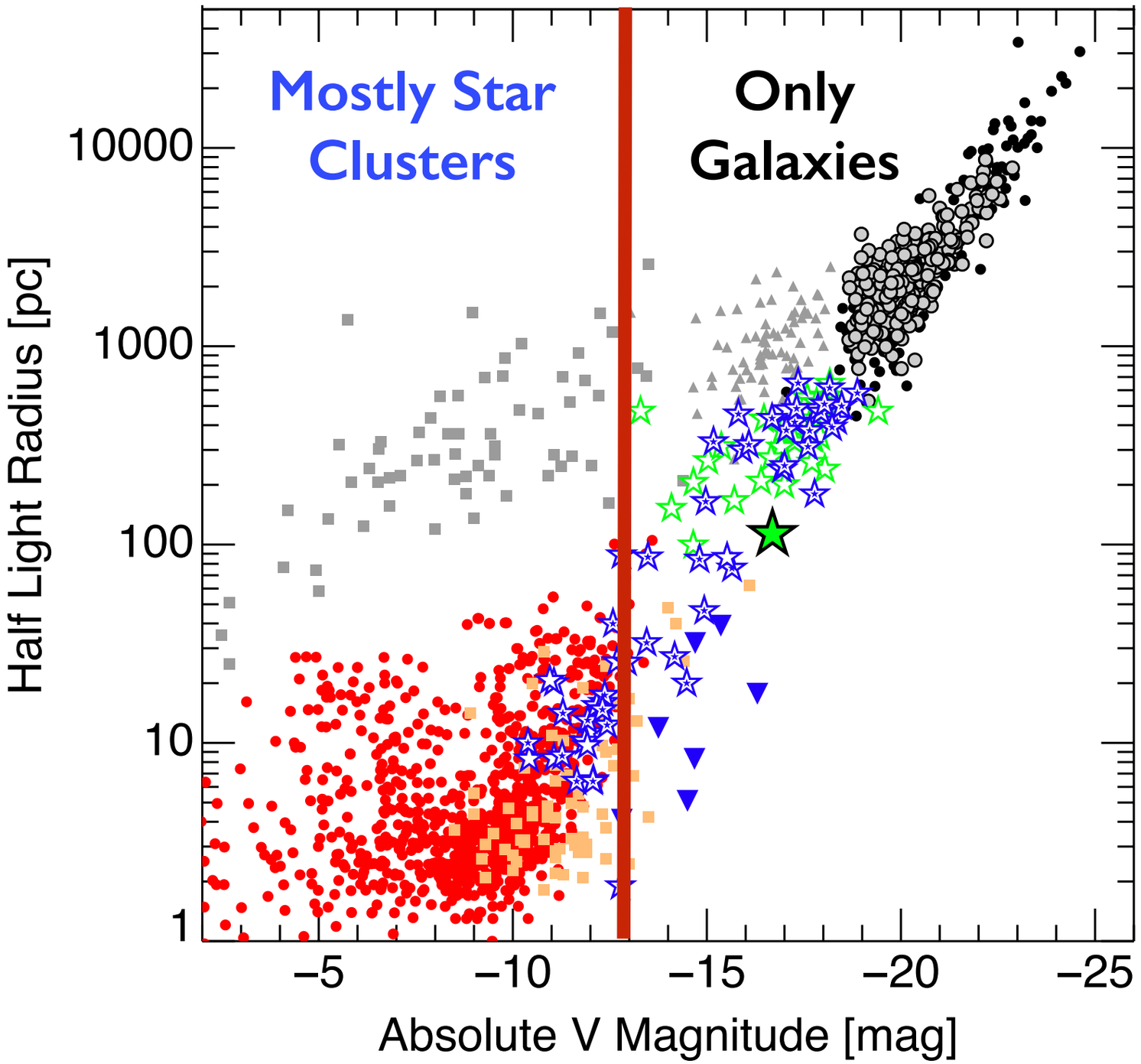
In Norris & Kannappan 2011 Extrapolation of the GCLF indicates upper mass limit for star clusters (however they form) of M_V ~ -13, or 7 x 10^7 Msun.

See also talk by Oleg Gnedin, and Harris et al. 2014 for a similar conclusion.

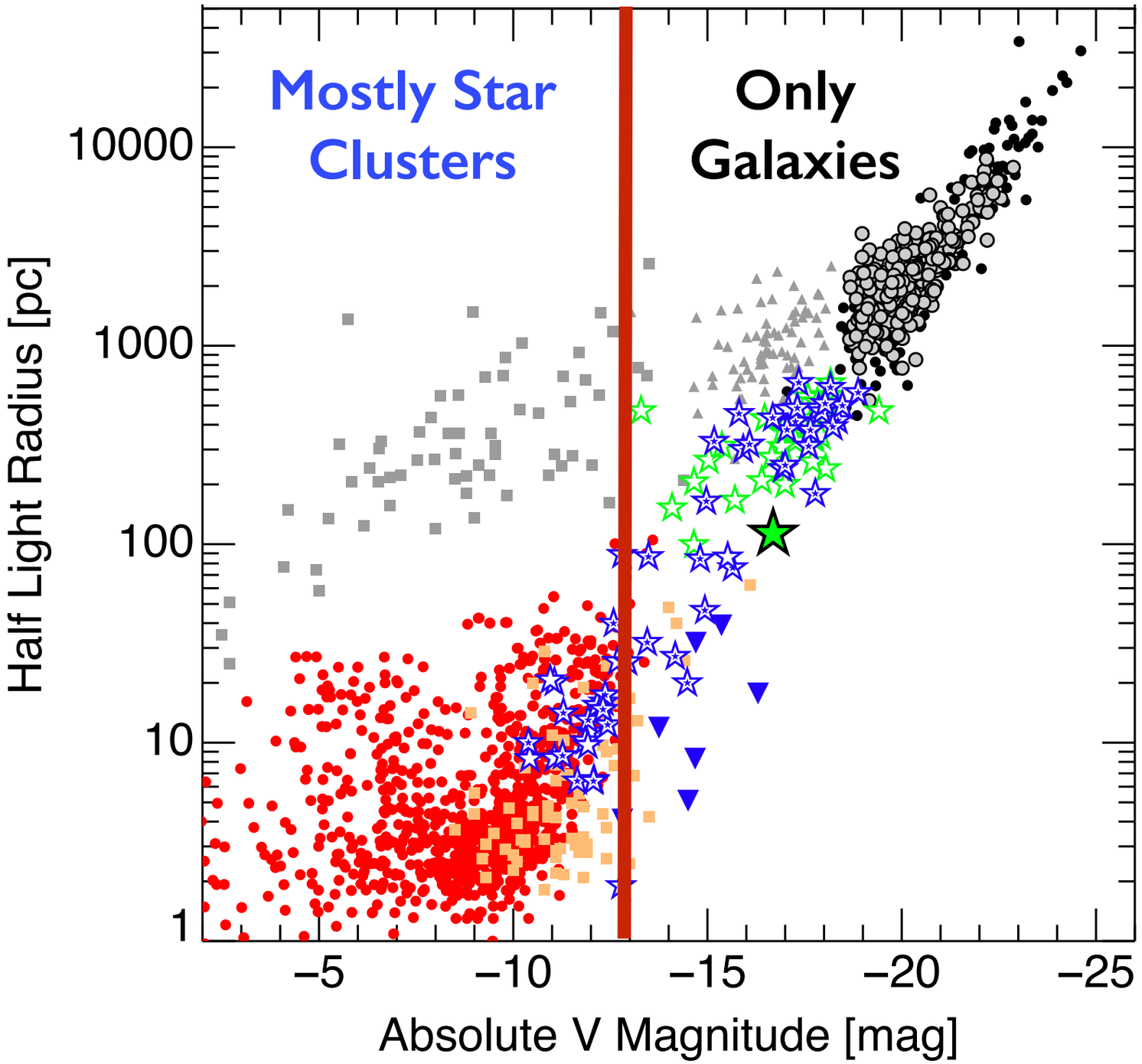
Separating the Wheat from the Chaff



Unmixing the Bag



Unmixing the Bag

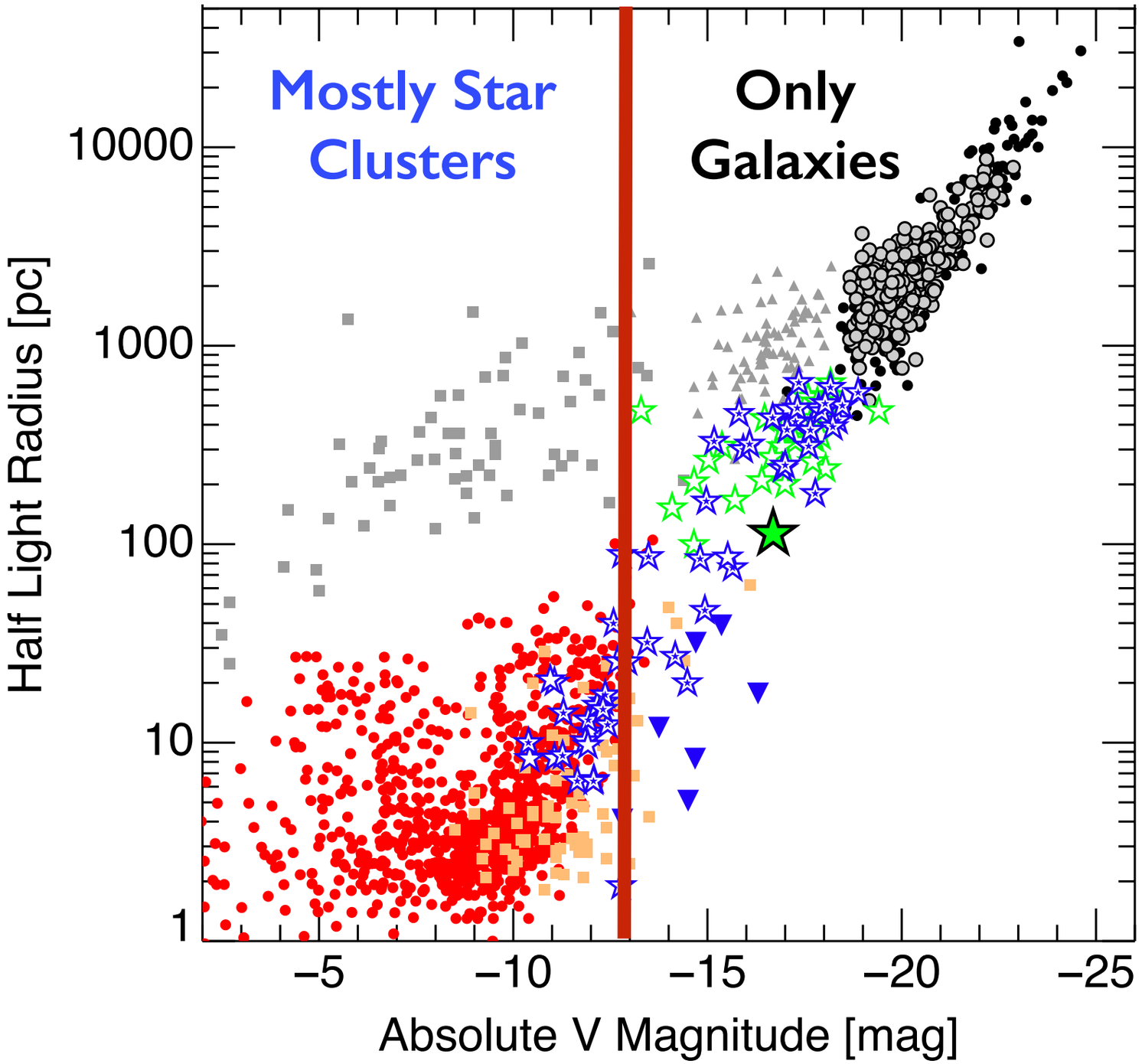


But how to separate star clusters and ex-nuclei below this limit?

Two methods:

Kinematics (see talks by Duncan Forbes and Anil Seth) and AIMSSII (Forbes et al. 2014) and Seth et al. 2014

Unmixing the Bag



But how to separate star clusters and ex-nuclei below this limit?

Two methods:

Kinematics (see talks by Duncan Forbes and Anil Seth) and AIMSSII (Forbes et al. 2014) and Seth et al. 2014

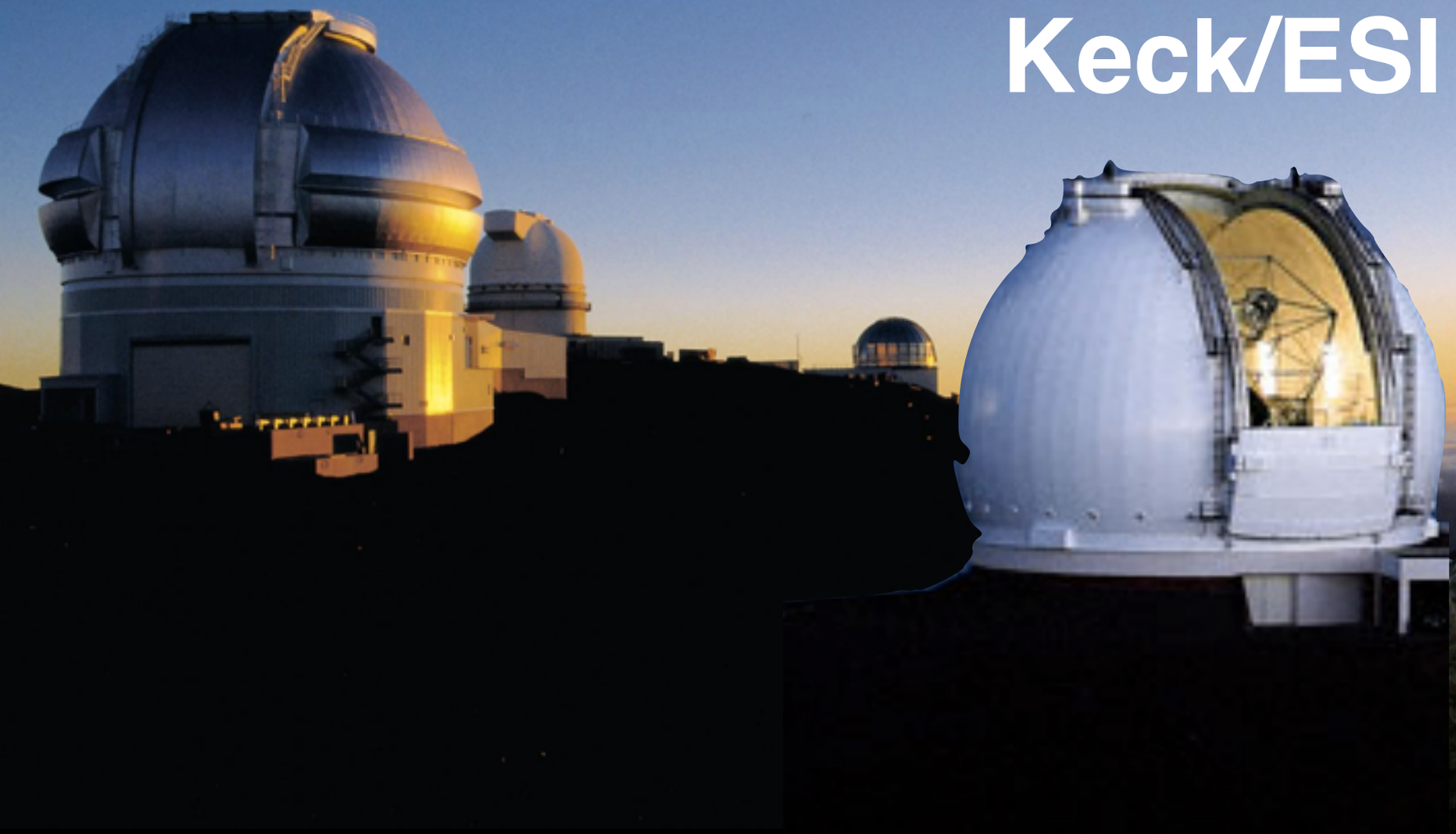
Stellar Populations

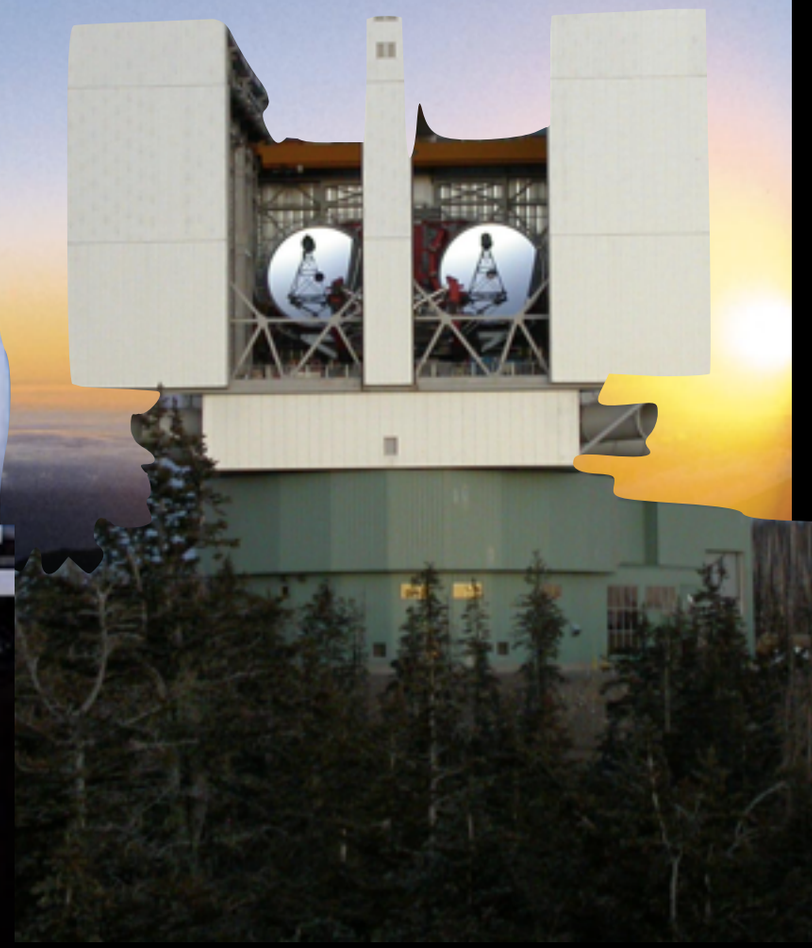
Unmixing the Bag

Gemini/GMOS

LBT/MODS

Keck/ESI





Unmixing the Bag

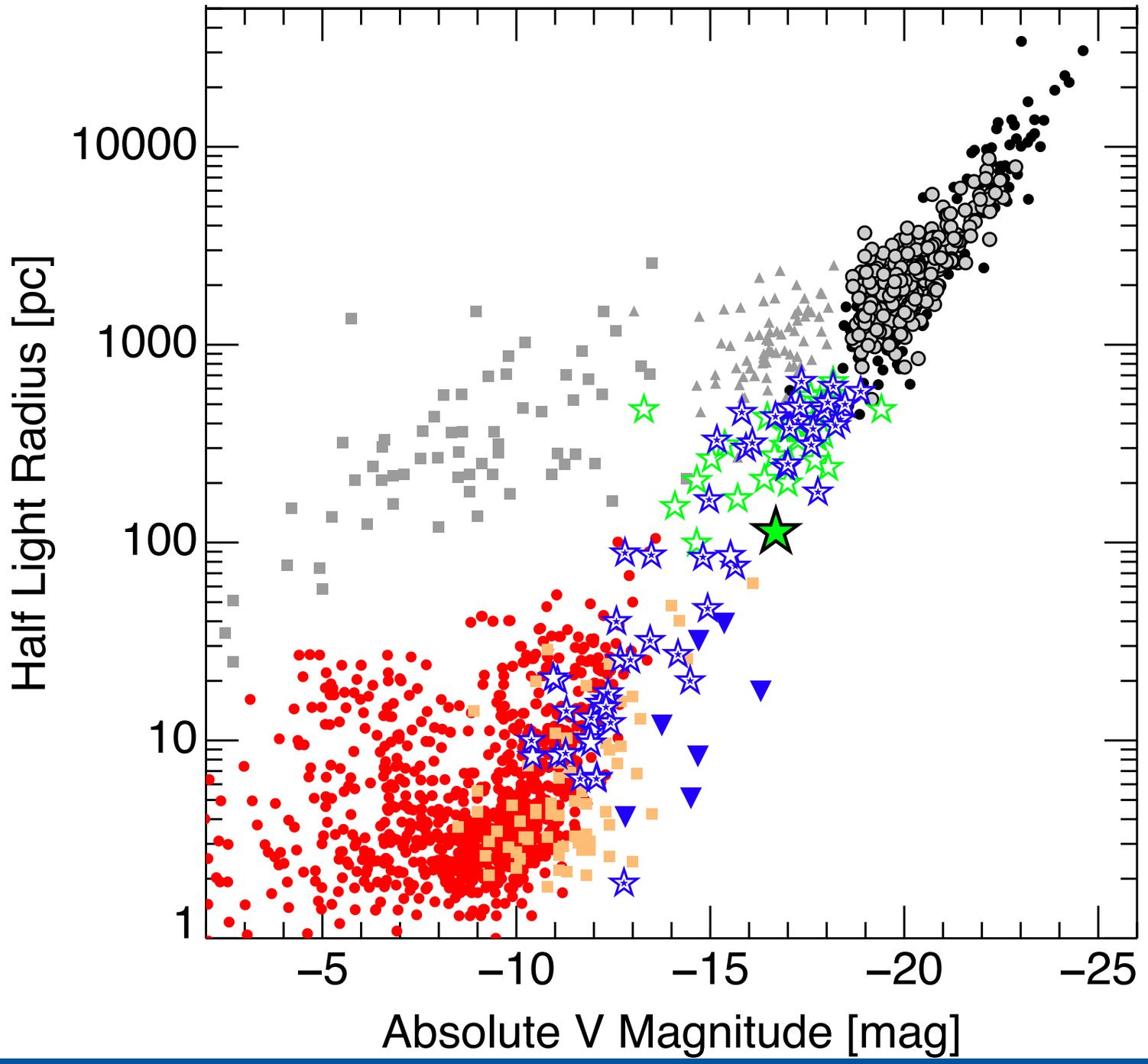
Gemini/GMOS

LBT/MODS

Keck/ESI

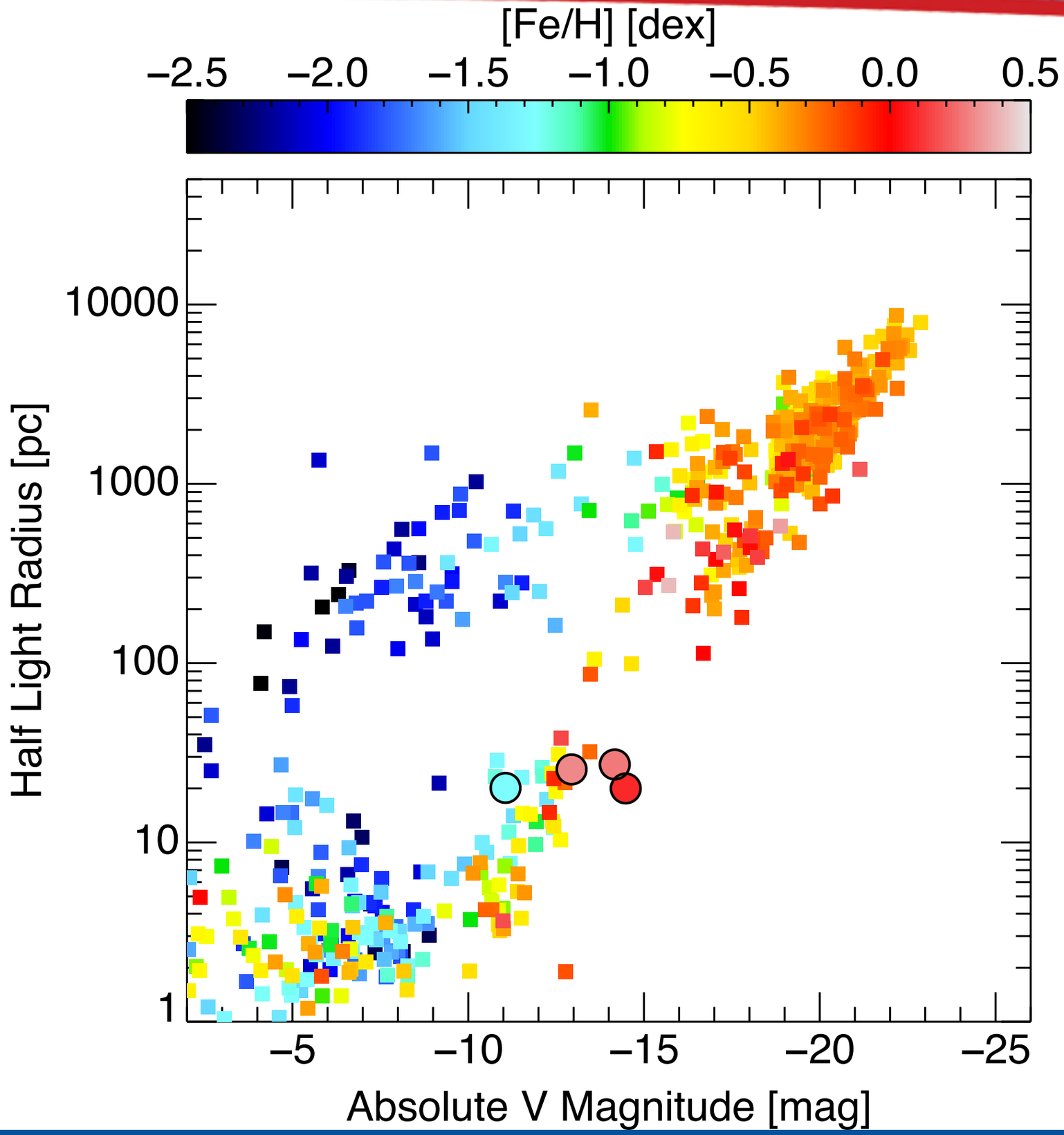
VLT/XShooter?

Unmixing the Bag



High S/N spectra for several dozen compact stellar systems.

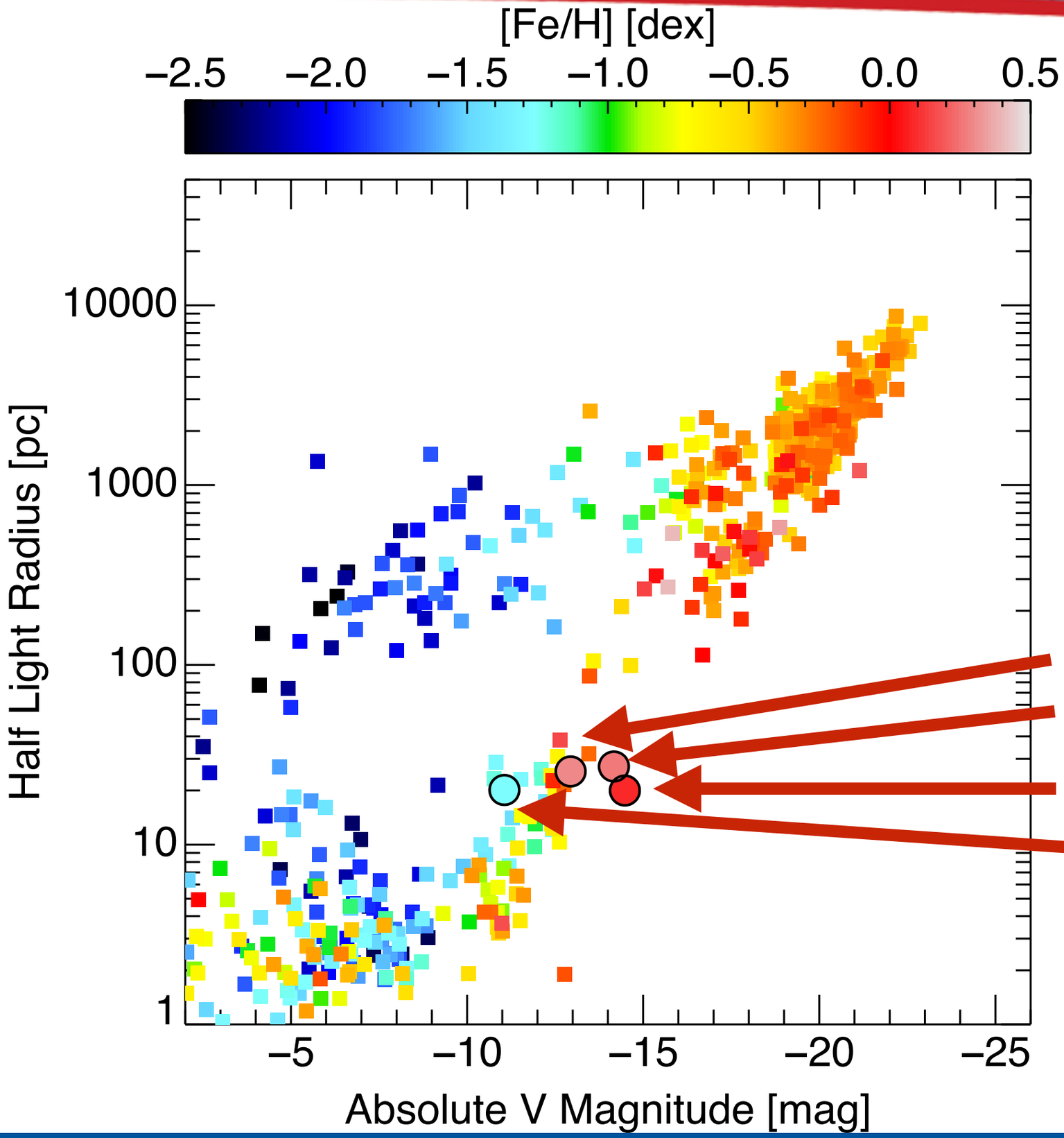
Unmixing the Bag



High S/N spectra for several dozen compact stellar systems.

Known stripped nuclei generally show extremely high metallicities.

Unmixing the Bag

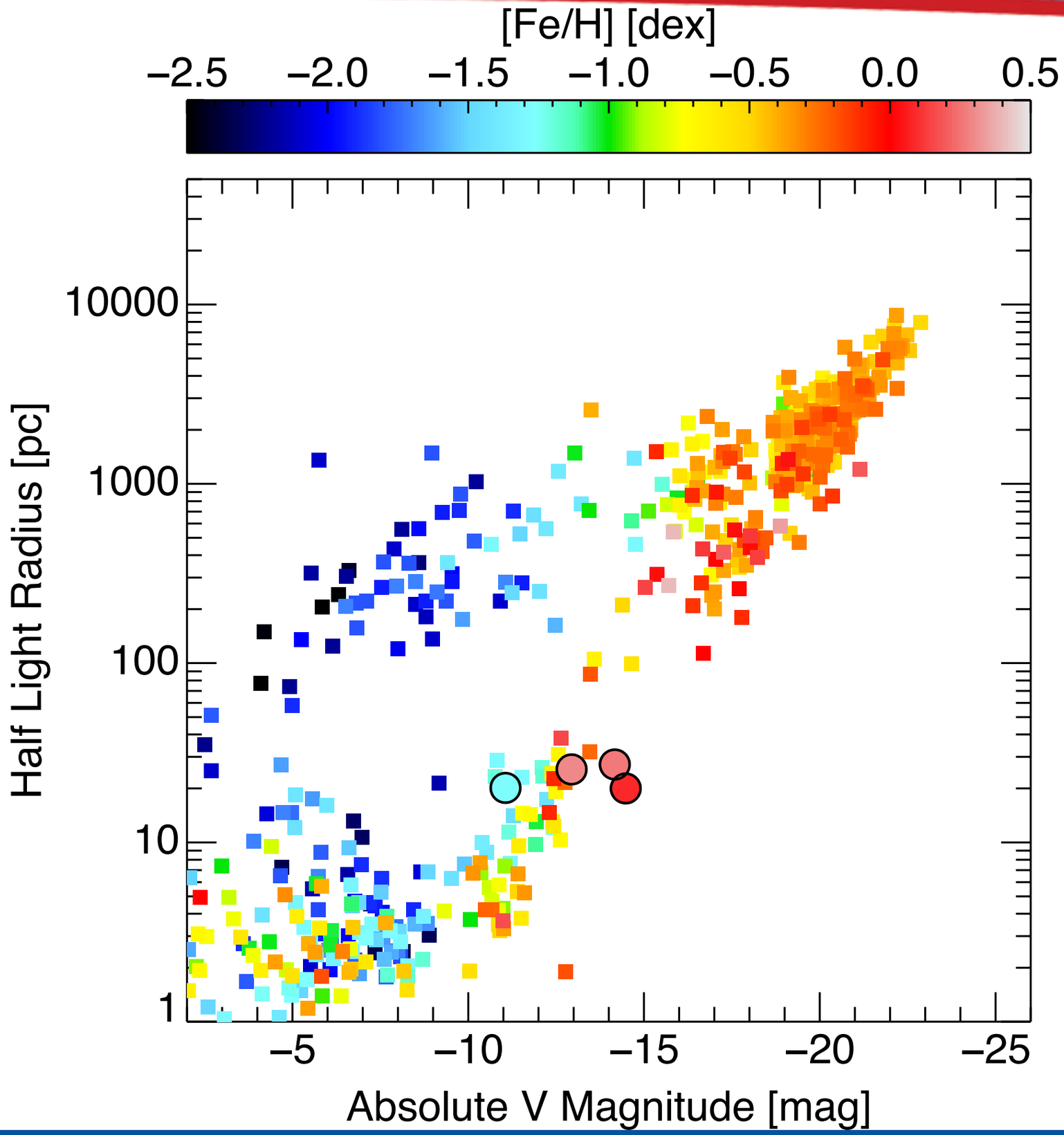


High S/N spectra for several dozen compact stellar systems.

Known stripped nuclei generally show extremely high metallicities.

NGC 4546-UCD1
M60-UCD1
UCDX
S999

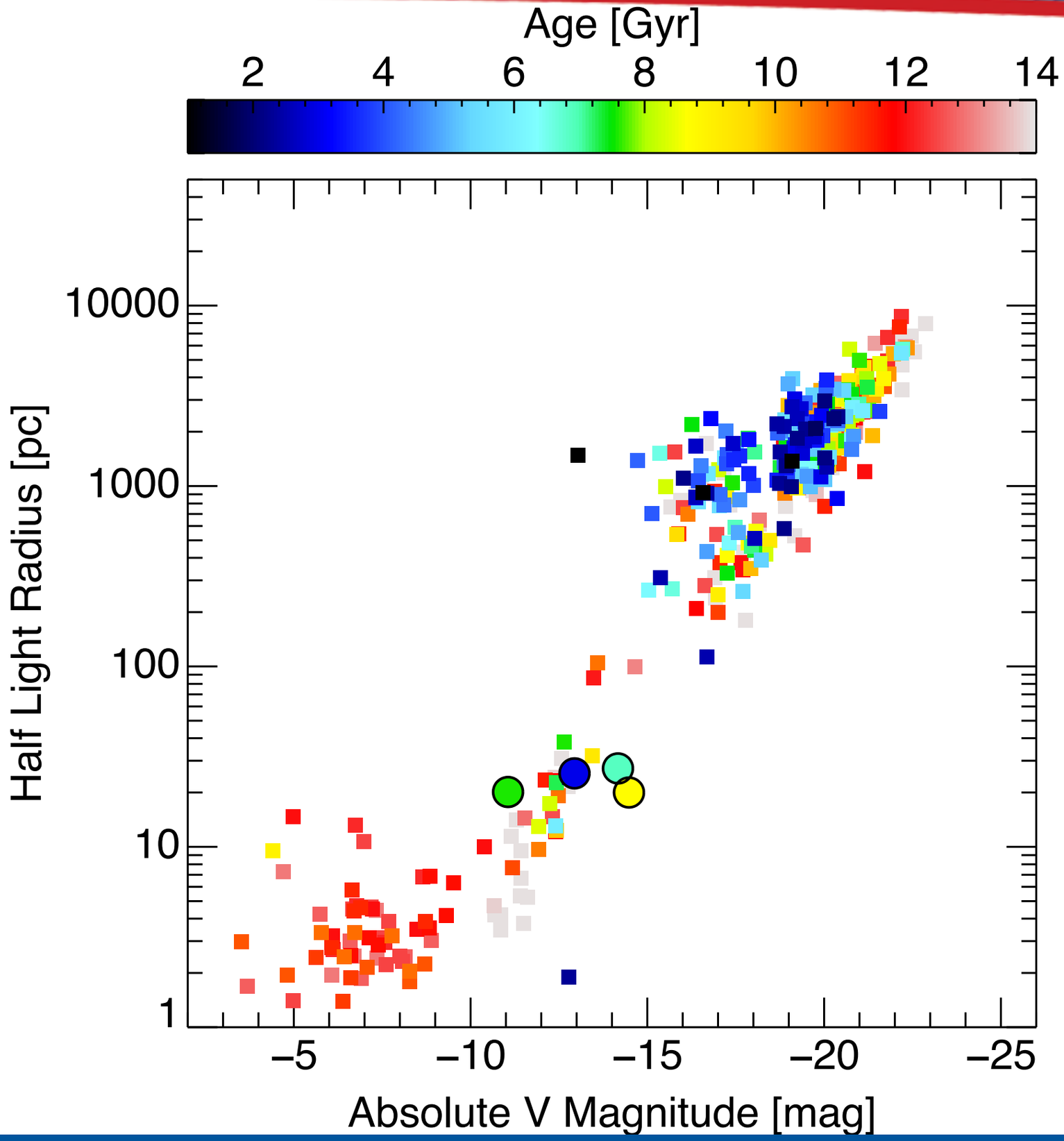
Unmixing the Bag



High S/N spectra for several dozen compact stellar systems.

Known stripped nuclei generally show extremely high metallicities.

Unmixing the Bag



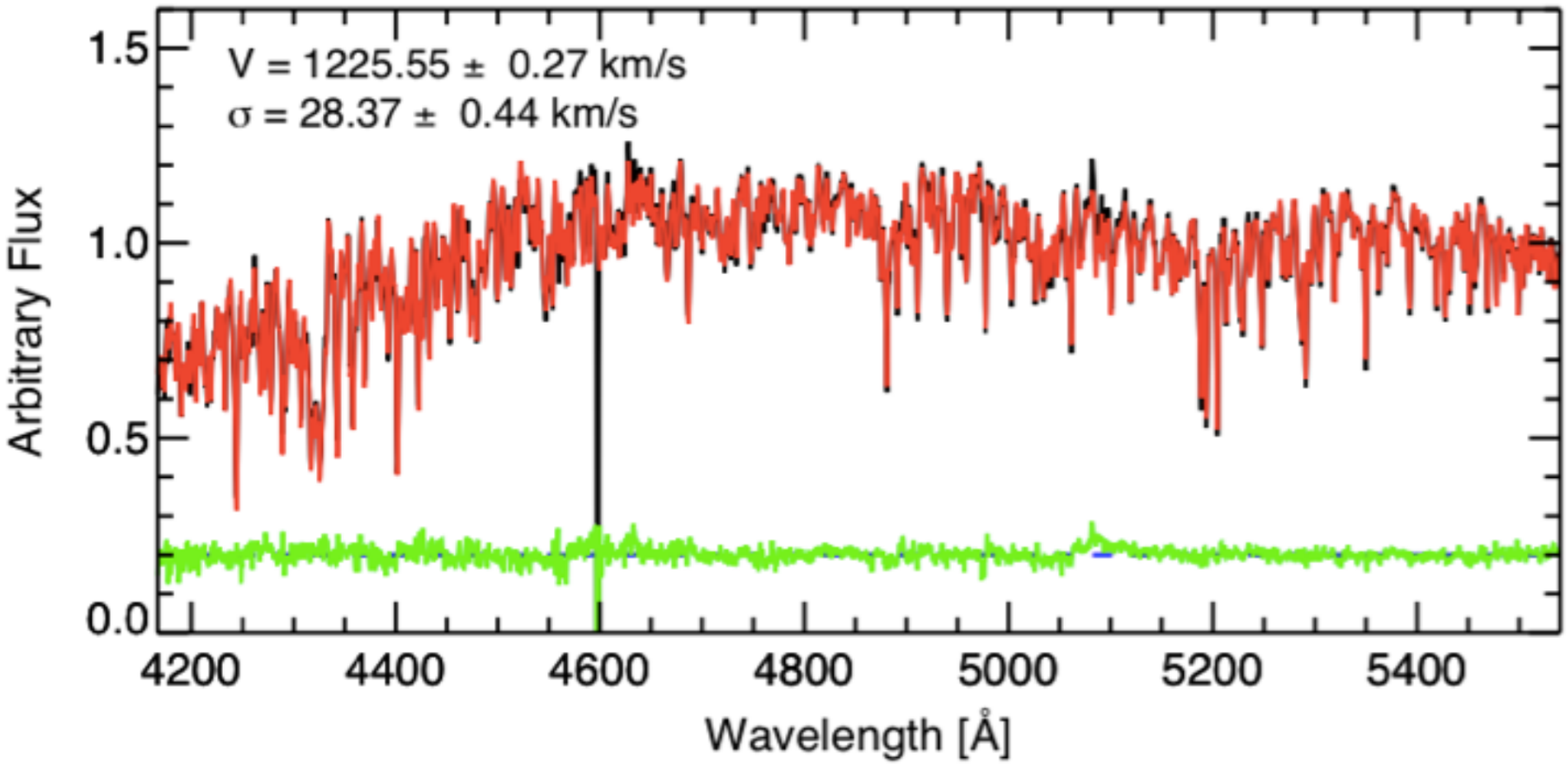
High S/N spectra for several dozen compact stellar systems.

Known stripped nuclei generally show extremely high metallicities.

They are also younger than most GCs.

(AIMSSIII: Janz et al. in prep).

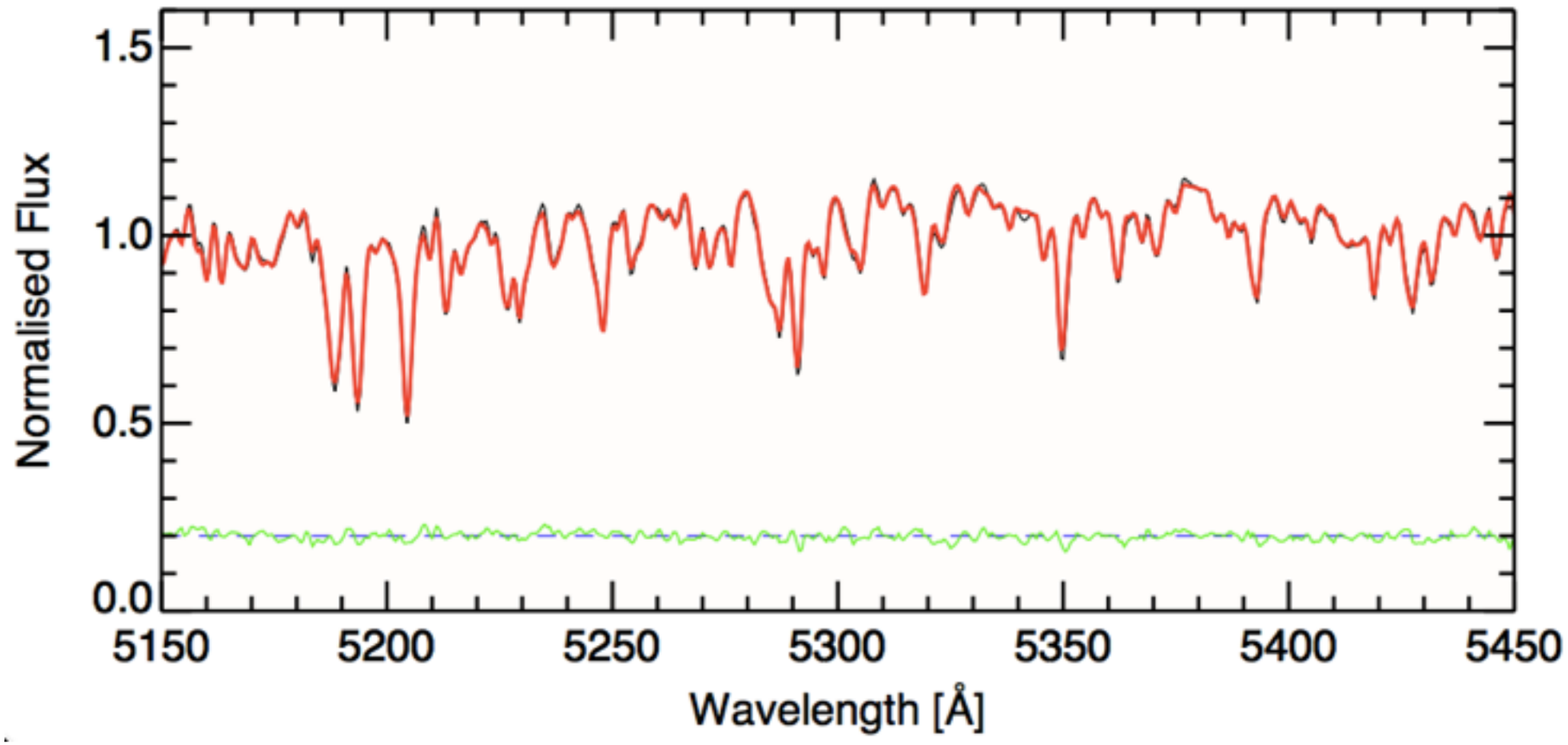
Unweaving the Rainbow



Where S/N is high enough can use full spectral fitting to determine SFH. Use ppxf with the latest Vazdekis/MIUSCAT models with [Z/H] up to +0.4.

GCs form in rapid bursts, NSCs can have very extended star formation histories (e.g. Seth et al. 2006, Georgiev et al. 2014).

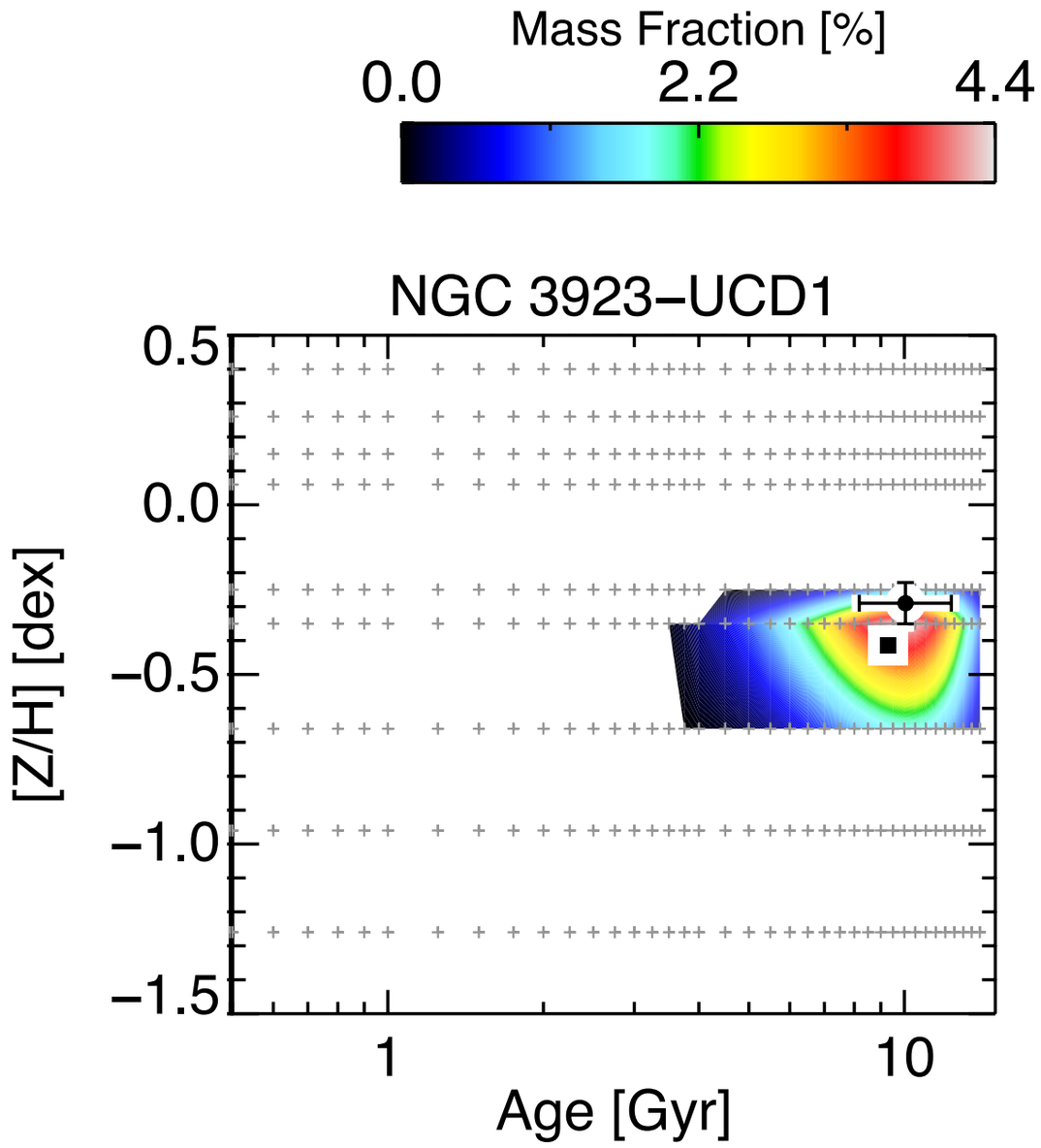
Unweaving the Rainbow



Where S/N is high enough can use full spectral fitting to determine SFH. Use ppxf with the latest Vazdekis/MIUSCAT models with [Z/H] up to +0.4.

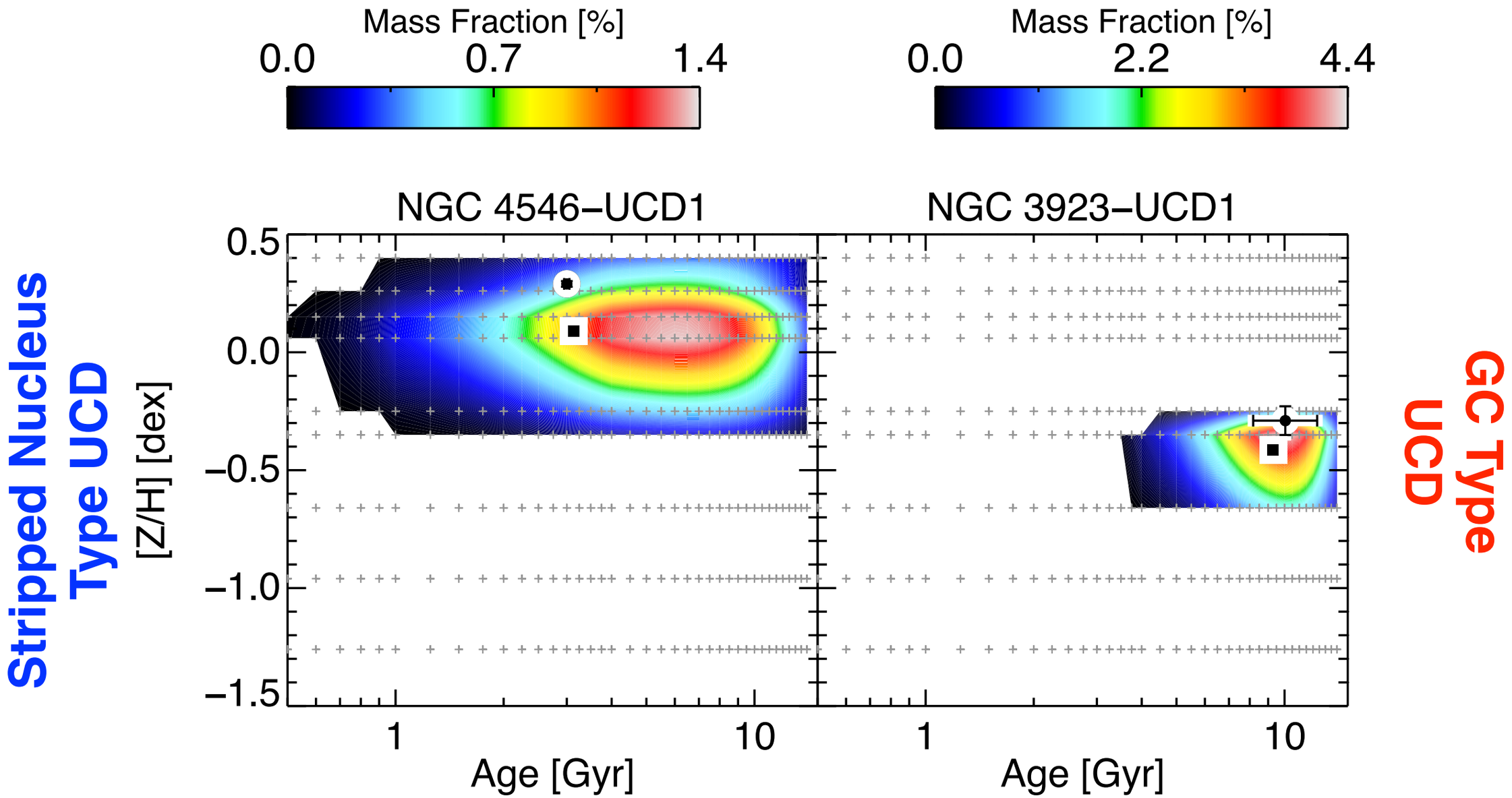
GCs form in rapid bursts, NSCs can have very extended star formation histories (e.g. Seth et al. 2006, Georgiev et al. 2014).

Unweaving the Rainbow



Norris et al. 2015, submitted and AIMSSIV - Norris et al. (in prep)

Unweaving the Rainbow



Norris et al. 2015, submitted and AIMSSIV - Norris et al. (in prep)

Conclusions

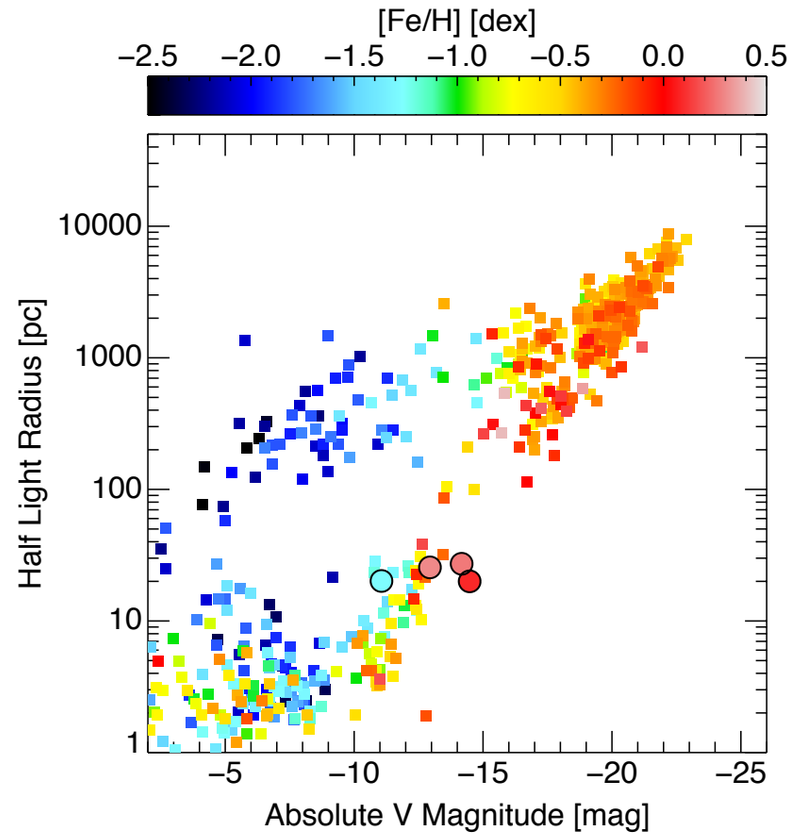
UCDs come in two flavours - Massive GC and stripped nucleus/bulge.

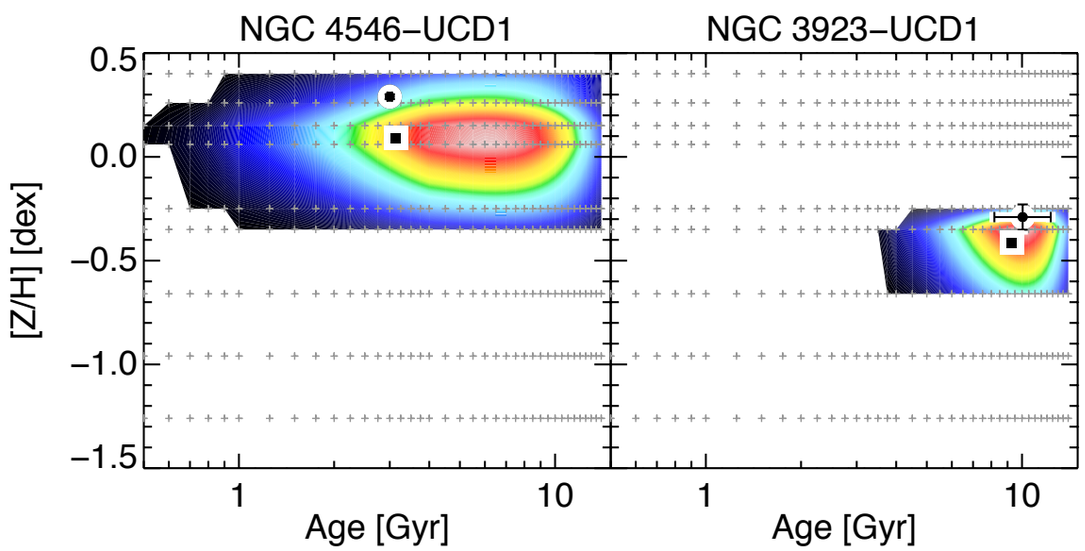
Above ~7x10^7 M_{sun} UCDs/cEs are stripped nuclei.

Stellar populations can be used to separate them.

Stripped nuclei are generally extremely metal rich, and younger than typical GCs.

The temporally resolved star formation history holds even greater promise for decoding how these objects form.





Some Shameless Advertising

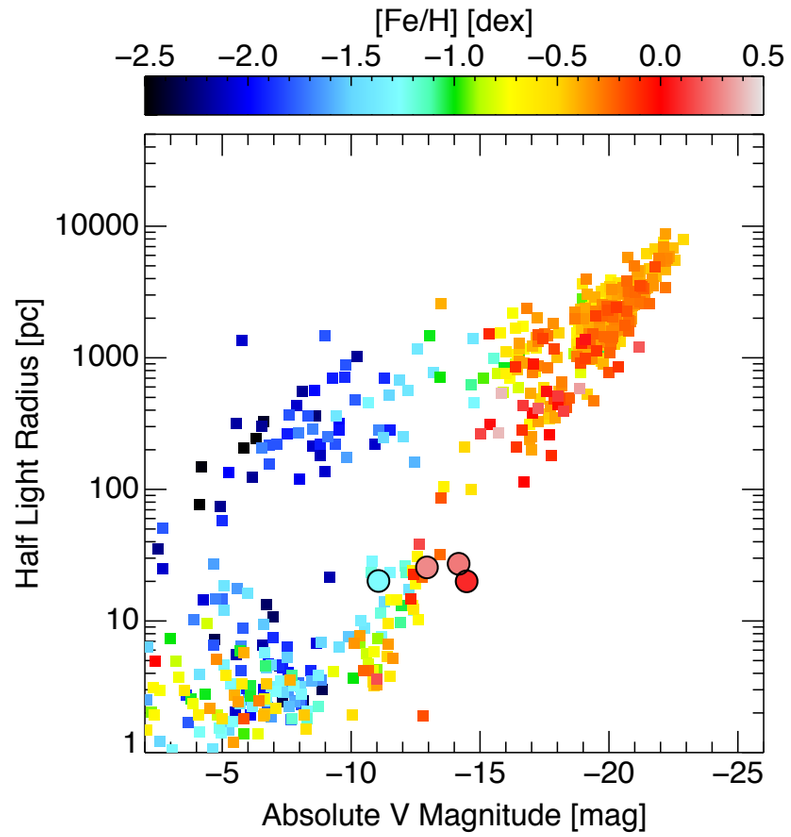
AIMSS I - Survey design/dense UCDs
Norris et al. 2014

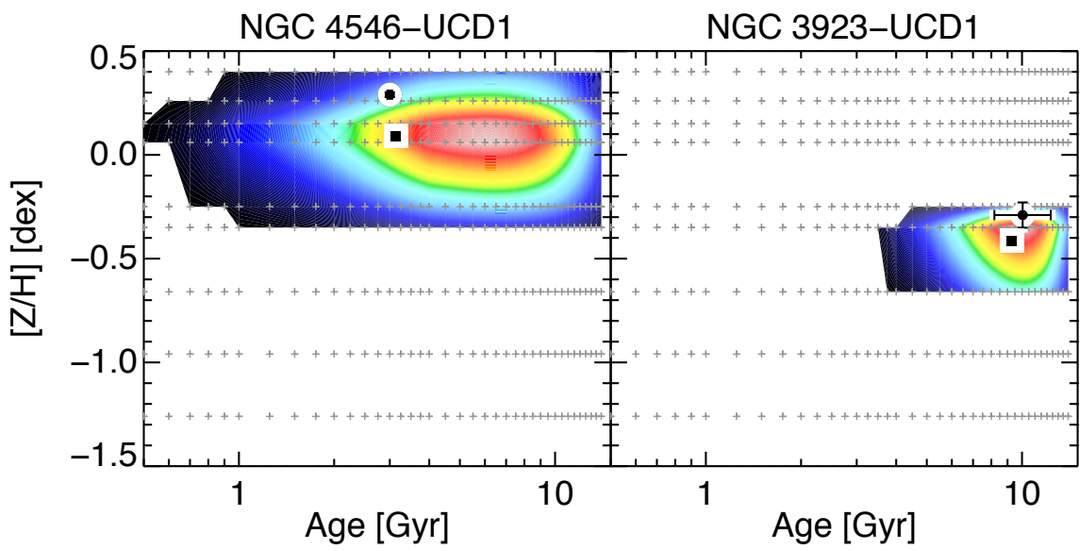
AIMSS II - Internal dynamics of GCs/UCDs/cEs
Forbes et al. 2014

AIMSS III - Integrated stellar populations of CSSs
Janz et al. in prep

AIMSS IV - The SFHs of CSSs
Norris et al. in prep

New data release of entire catalog > 1000 objects, with redshifts, photometry, sizes, masses, internal dynamics and stellar populations to be released alongside Janz et al. in prep





Identifying Stripped Nuclei

Does it have a big black hole?

Is it younger than the typical GC?

Is is extremely metal rich, more metal rich than typical GCs?

Does it have an extended star formation history?

Does it have CN consistent with galaxies - Frank talk?

Identifying Stripped Nuclei

Does it have a big black hole?

Is it younger than the typical GC?

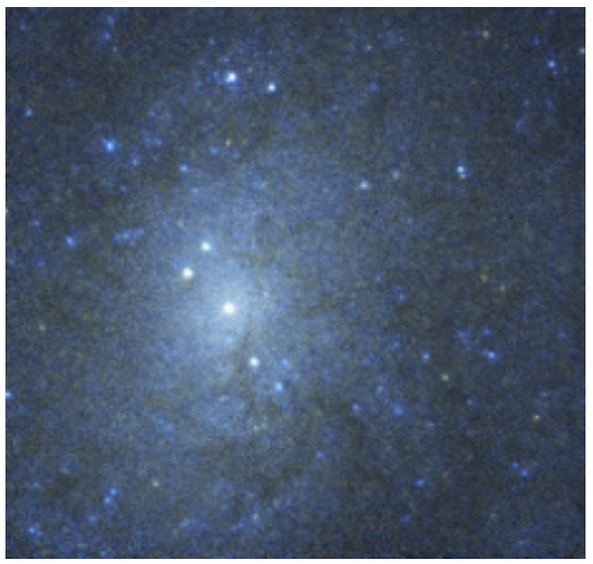
Is is extremely metal rich, more metal rich than typical GCs?

Does it have an extended star formation history?

Does it have CN consistent with galaxies - Frank talk?

If it looks like a duck, swims like a duck and quacks like a duck, its a nuclear star cluster.

=

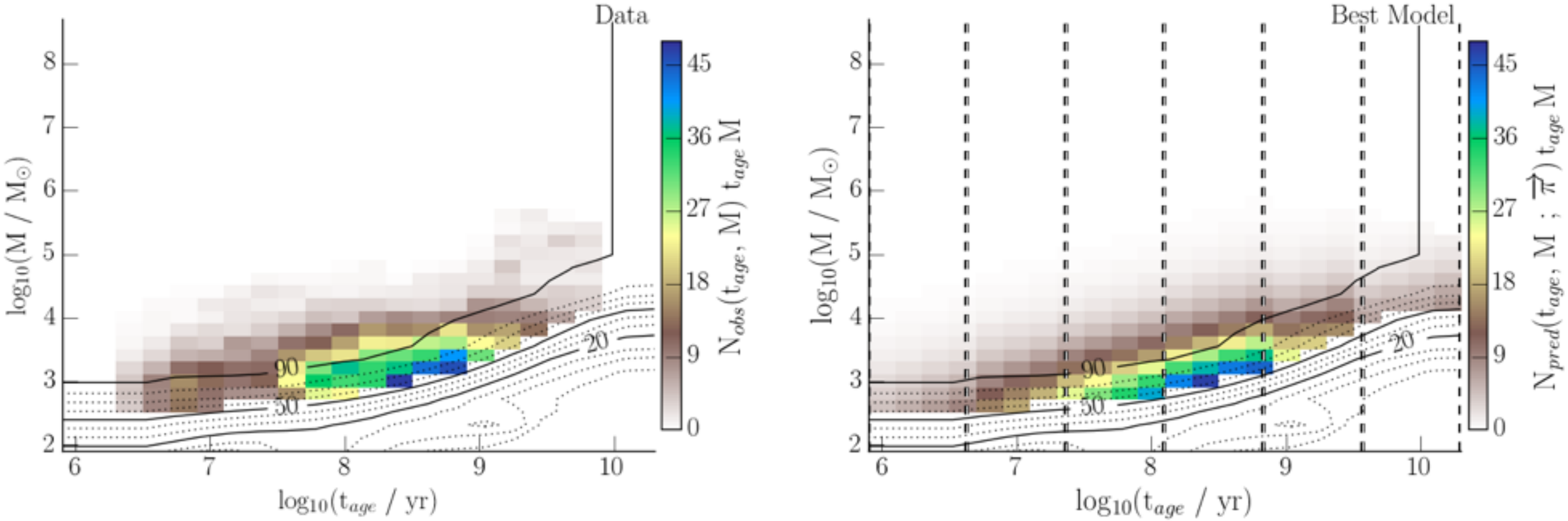


The Most Massive Star Cluster?

The most massive YMC is NGC 7252-W3 with

$8\ (\pm 2) \times 10^7\ M_{sun}$

The Most Massive Star Cluster?



Fouesneau+(in prep) find maximum star cluster mass of 5×10^7 M_{sun} using data from the PHAT survey.