Themes

testing hypotheses?
initial conditions?
equilibrium?
families vs friends?

This has been a stimulating meeting, with a well-balanced program

Organisation has been excellent

Thanks from all of us to the organisers

Especially

Mark (neigh) and Steffen

Rational debate leading to progress??

Natural philosophy

leading to

Experimental philosophy

“the astronomers” mosaic
Pompeii

What is an answer?

- No set of experiments can ever establish the `truth` of any theory. Even if theory T predicts outcome O, and O is found, T *is not* proven. If O were outlandish, but seen, many assume T is likely. It remains unproven. Supporting T is the fallacy of ``affirmation of the consequent``.

Only if O is not found is anything new learned.

Typically, in astrophysics,
we do not have a theory, in this sense, to test

CONTRARIA SUNT COMPLEMENTA*

``It is wrong to think that the task of physics is to find out how Nature is. Physics concerns what we say about Nature``

*OPPOSITES ARE COMPLEMENTARY

The prime requirement of a model is that ``it is expected to work`` (von Neumann).

In practise, we adopt a `paradigm’, and develop it. It may be strange, or self-contradictory, as wave-particle duality:

To be useful, it must be based on established physical processes, and testable.

Examples include weather forecasts and climate models. Weather forecasts are often inaccurate, but never wrong. Climate models may be right or wrong: they deliver testable predictions, which must match data, or they are discarded.

Steady state cosmology is an example of a good model – just wrong.

OPPOSITES ARE COMPLEMENTARY

Can we ``test`` galaxy formation models?
There is no *ab initio* model of star formation. There is no *ab initio* model of galaxy formation. Galaxy evolution is complex.

Is `right` or `wrong` a relevant concept?

Galaxy formation models function by starting with the simplest `structure`, which is a simple approximation to a `cosmological context`, aka vanilla scale-free ΛCDM.

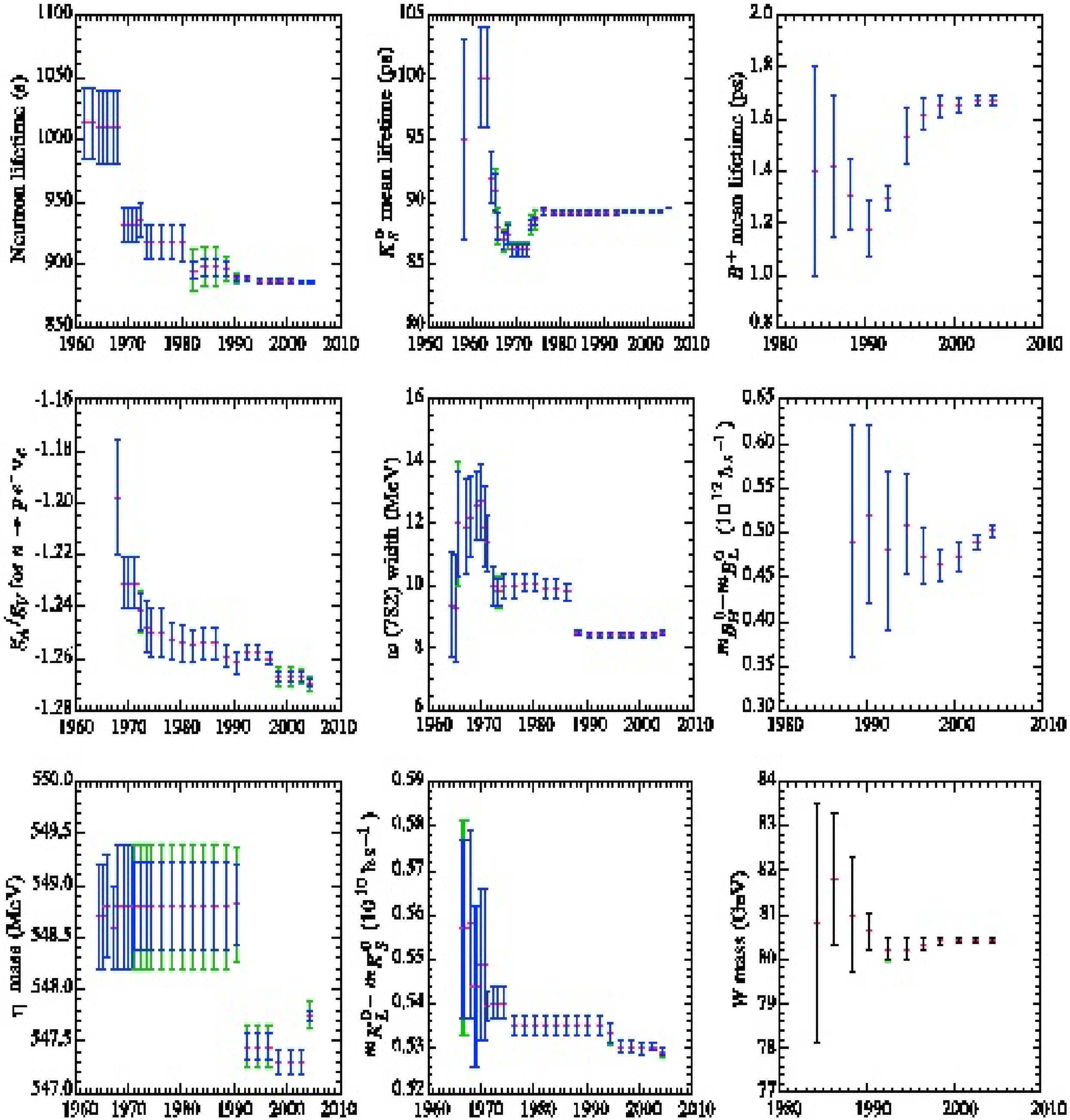
Iterative complexity, aka `physics’, or `feedback`, is added to approximate Nature, driven by new observations. This must eventually provide excellent reproduction of all observed results. And perhaps some new extensions?

It is an enormously powerful and impressive methodology, which is invaluable to test hypotheses..
Is this a theory? Is any prediction provably unique and testable? Or is it an excellent tool? Is it (just) saving the appearances?

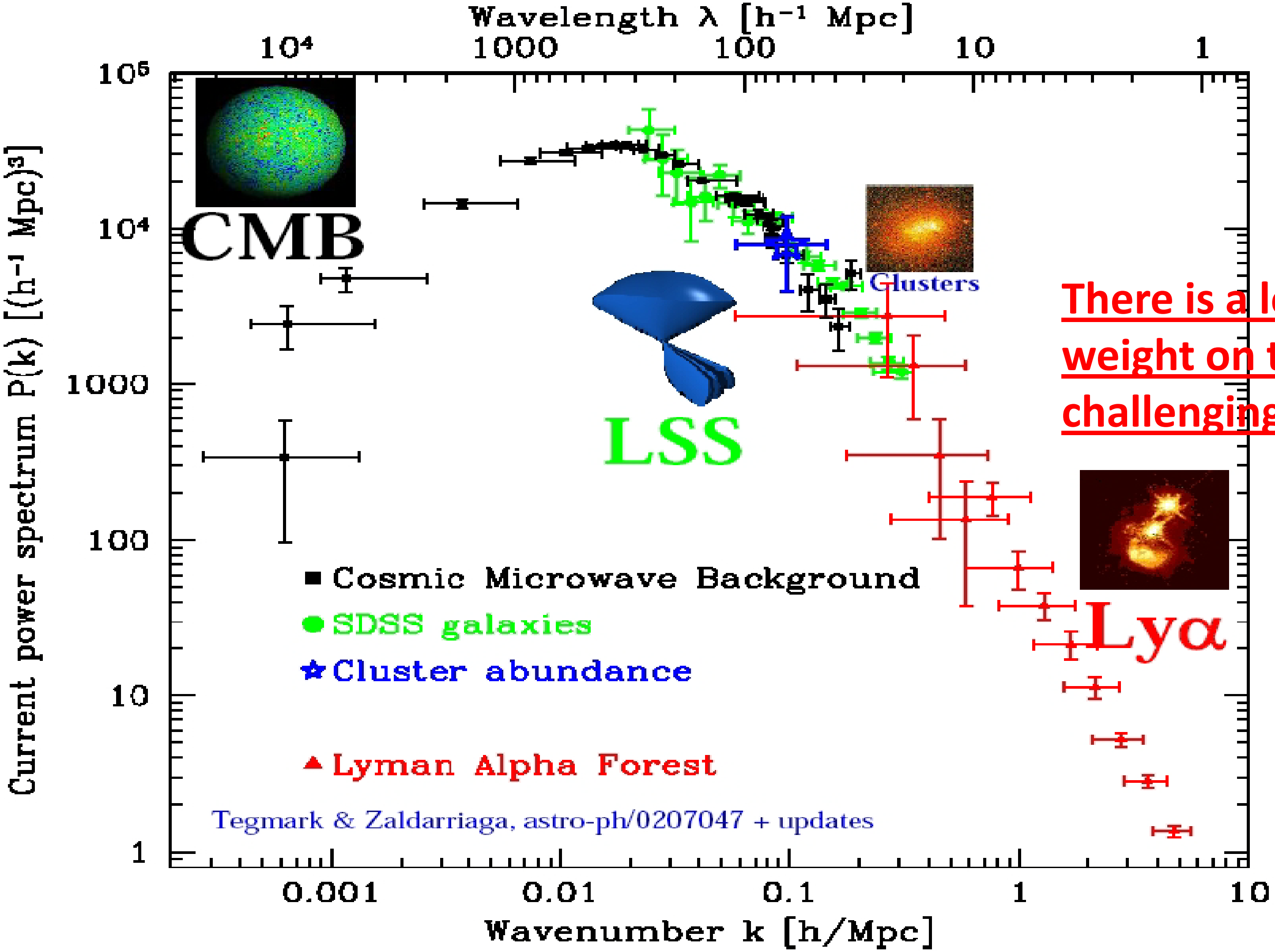
Scientific progress requires these tools are used to investigate wide parameter space: eg disproving HDM models was magnificent progress

Consistency does not imply correctness

particle data properties vs time



LCDM: impressive consistency over five orders in length scale



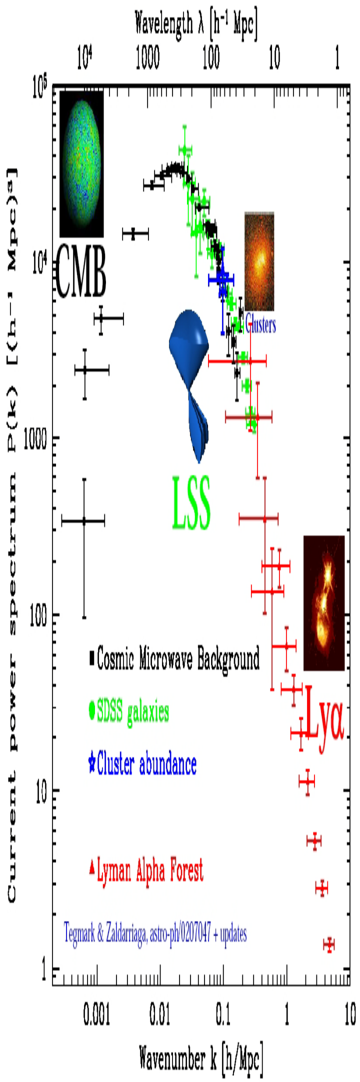
There is a lot of weight on these challenging results

Impressive consistency over five orders in length scale

95 out of 100 orders leaves lots of discovery space

There are 60+ orders of magnitude here, smoothed by inflation?

Searches for non-Gaussianity are standard cosmology

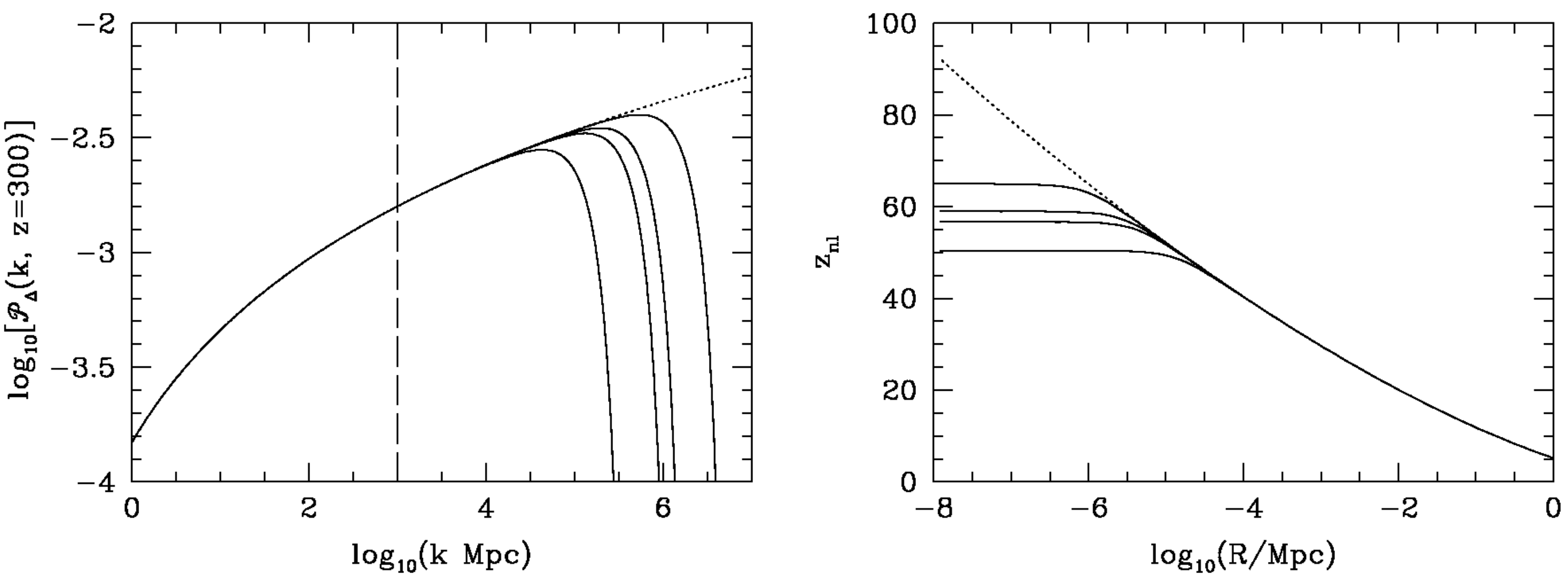


14 orders here to smallest bound systems – solar radius

37 orders to particle scales: electron radius

Are there plausible predictions to test?

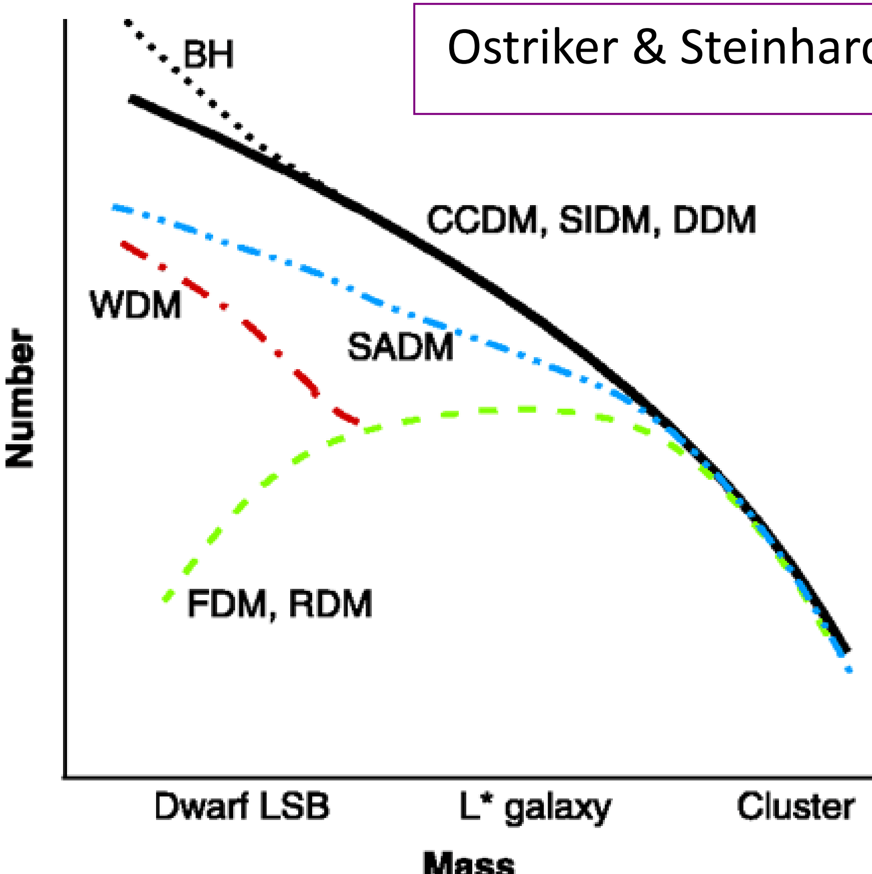
Linear power spectrum at z ~ 300, showing influence of WIMP microphysics:
Physical scales of interest correspond to smallest galaxies
Anticipated DM effects on scales of parsec up ➔ first systems



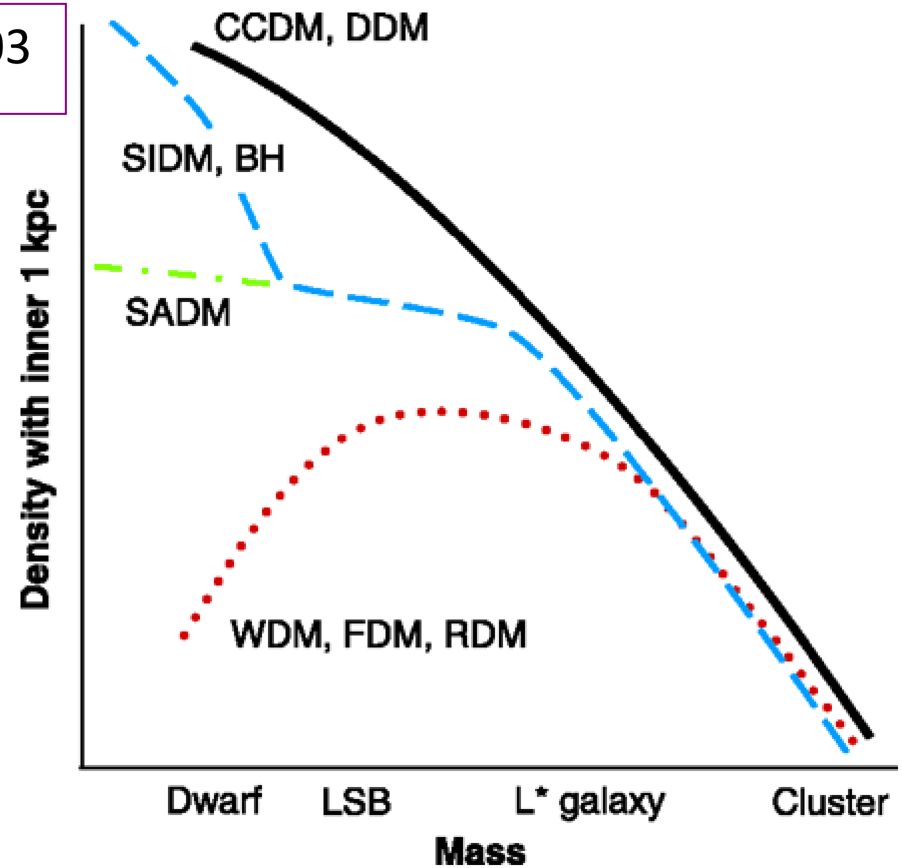
Green, Hofmann & Schwarz 2005

ΛCDM cosmology extremely successful on large scales. Galaxies are the scales on which one must see the nature of dark matter & galaxy formation astrophysics

Ostriker & Steinhardt 03



Galaxy mass function depends on DM type



Inner DM mass density depends on the type(s) of DM

Progress in science

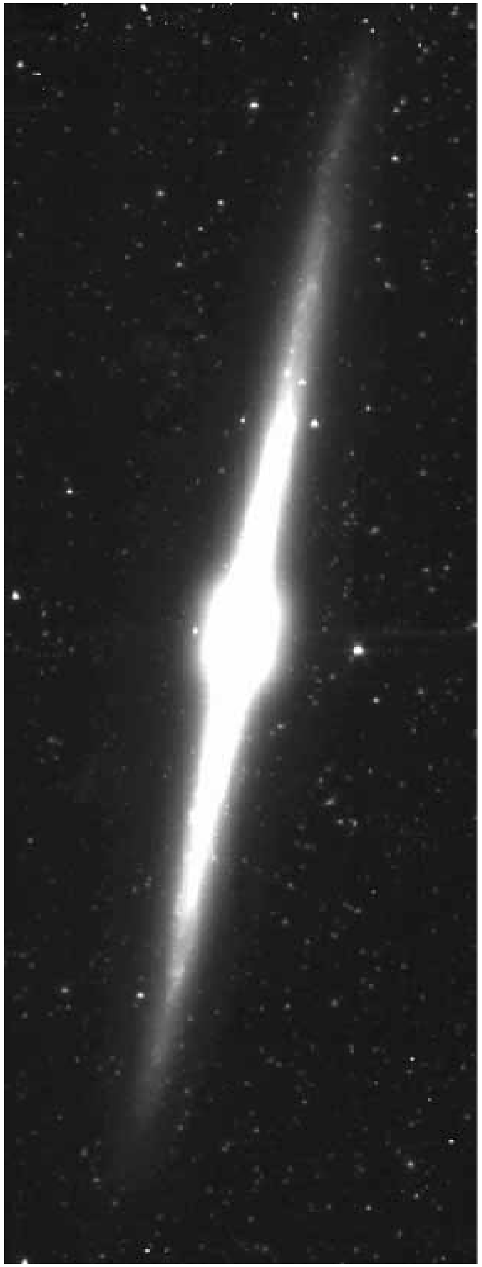
- T here are many manifest limitations in current galaxy formation theory, inside the LCDM paradigm
- There are many aspects of LCDM which are excellent descriptors of nature
- We progress by stressing the failures
- Not by abandoning the fundamentals.
- Fundamental change requires much bigger problems – eg, dark energy – or much more fundamental theories –
- MOND is a limited ad hoc possibility in some special cases. MOND cannot reproduce the successes of LCDM, and go further.
- It is not an alternative to LCDM.
- Personally, I suspect the way forward is to think more carefully about the C in LCDM. In an LHC environment.

-- the Galaxy-scale context

On galaxy scales ΛCDM `predictions' are much less successful than on large scales: `satellite problem', `overcooling problem', `old disk problem', top-down, etc etc.
No-one has yet built a realistic Milky Way

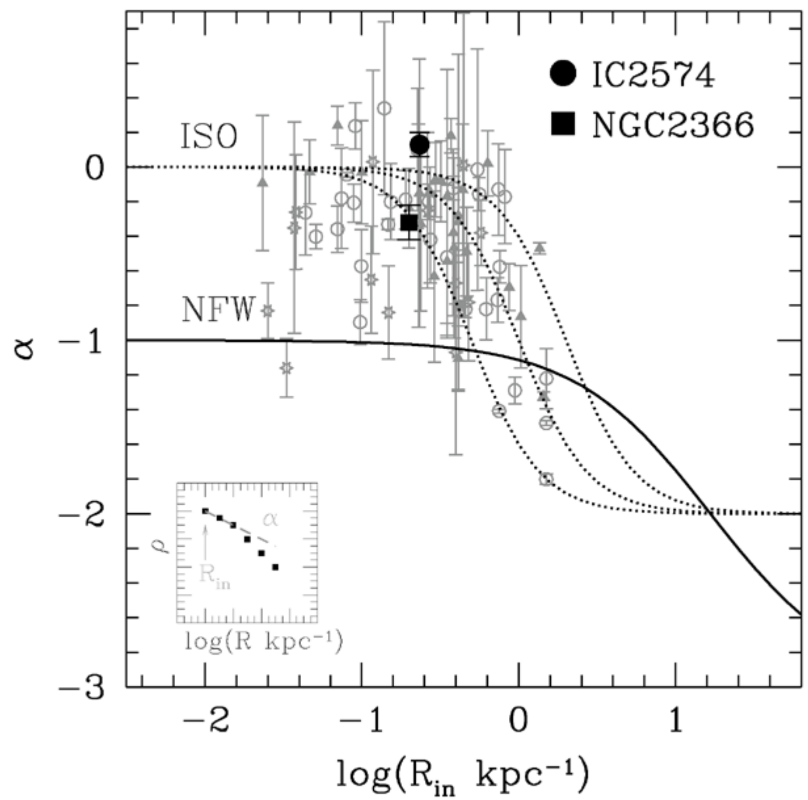
The MWG challenge is not rare: large old disk galaxies with no bulge are common. 95% of `MWG galaxies' have a major merger in ΛCDM in the last 10Gyr – which destroys disks.

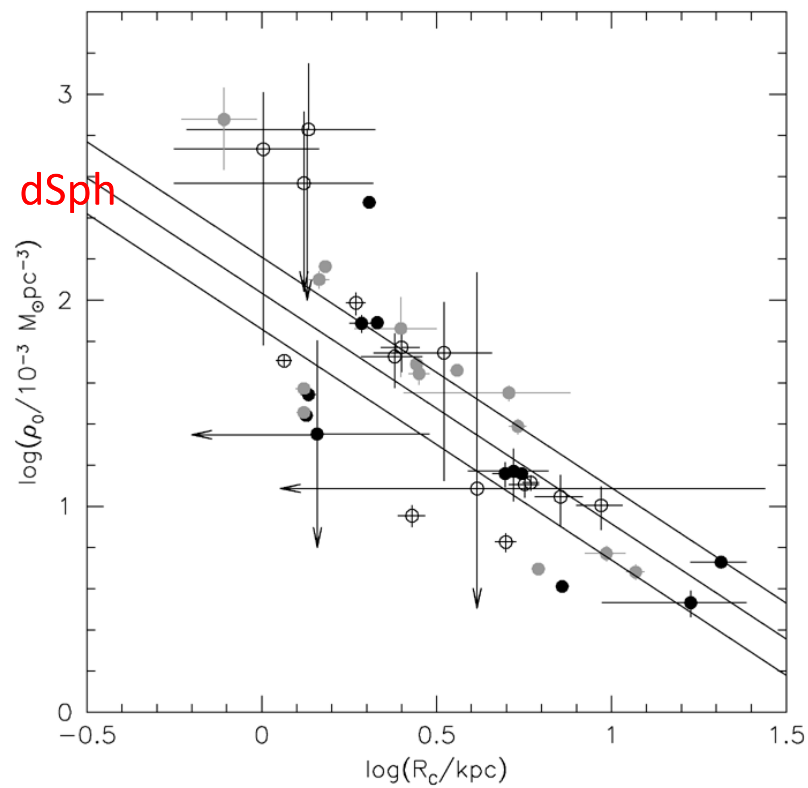
cf Kormendy & Kennicutt ARAA 2004; Kormendy: arXiv:0708.2104; Stewart etal 2008 ApJ 683 597 "Our results raise serious concerns about the survival of thin-disk-dominated galaxies within the current paradigm for galaxy formation in a ΛCDM universe."



[It is no coincidence that Baade's populations do not include bulges]

cusps are a generic CDM expectation none has yet been found. Why?

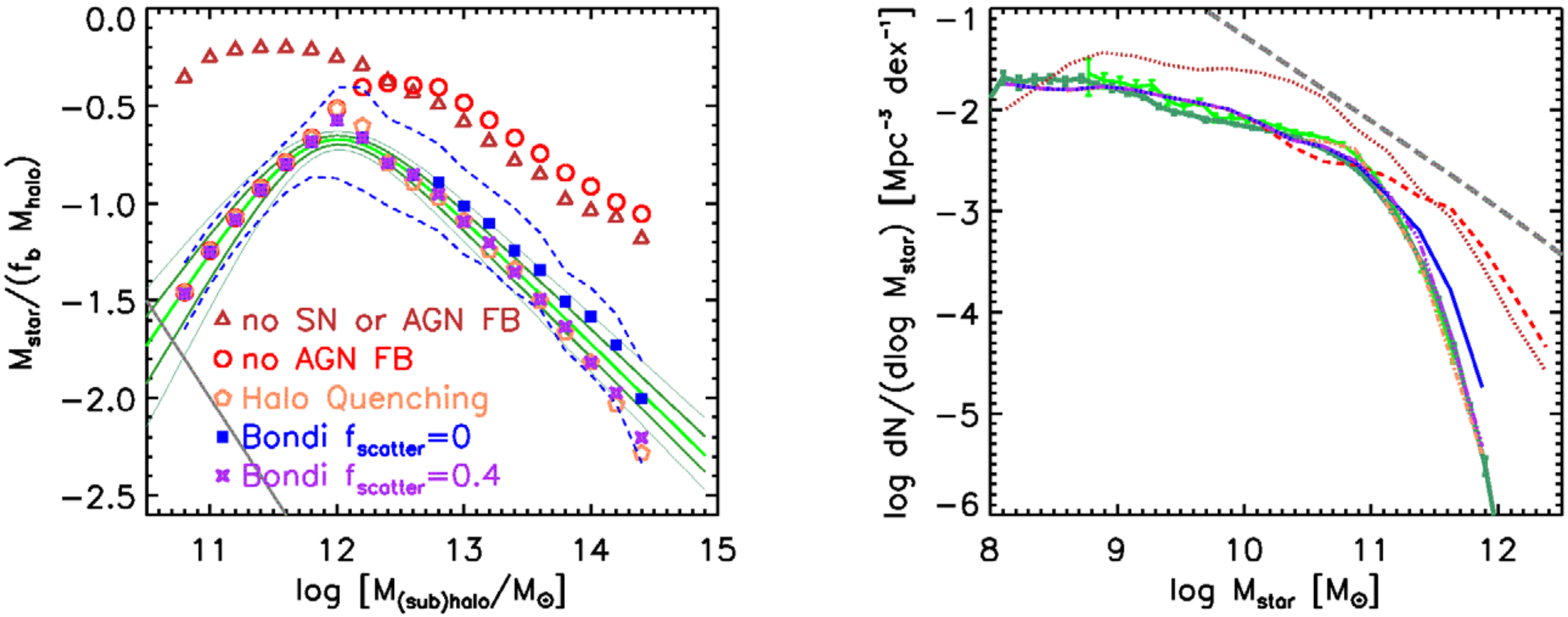




Oh etal; de Blok etal AJ 2008 v136 2761; 2648. `Things` HI/Spitzer/Galex survey –

Various ‘feedback’ recipes/satellite challenges

Somerville et al 08



Right panel: Mass function of CDM halos is dashed grey line, observed galaxy luminosity function given by green symbols -- need ‘feedback’ at both faint and bright ends to populate halos with stars of correct total luminosity
High-mass AGN link motivated by Mbh-bulge relation
There is no hint of small-scale feedback physics: SNe???

Knowing if the M_bh vs bulge sigma relation continues to low masses is clearly important for this modelling.
We await a clear answer!

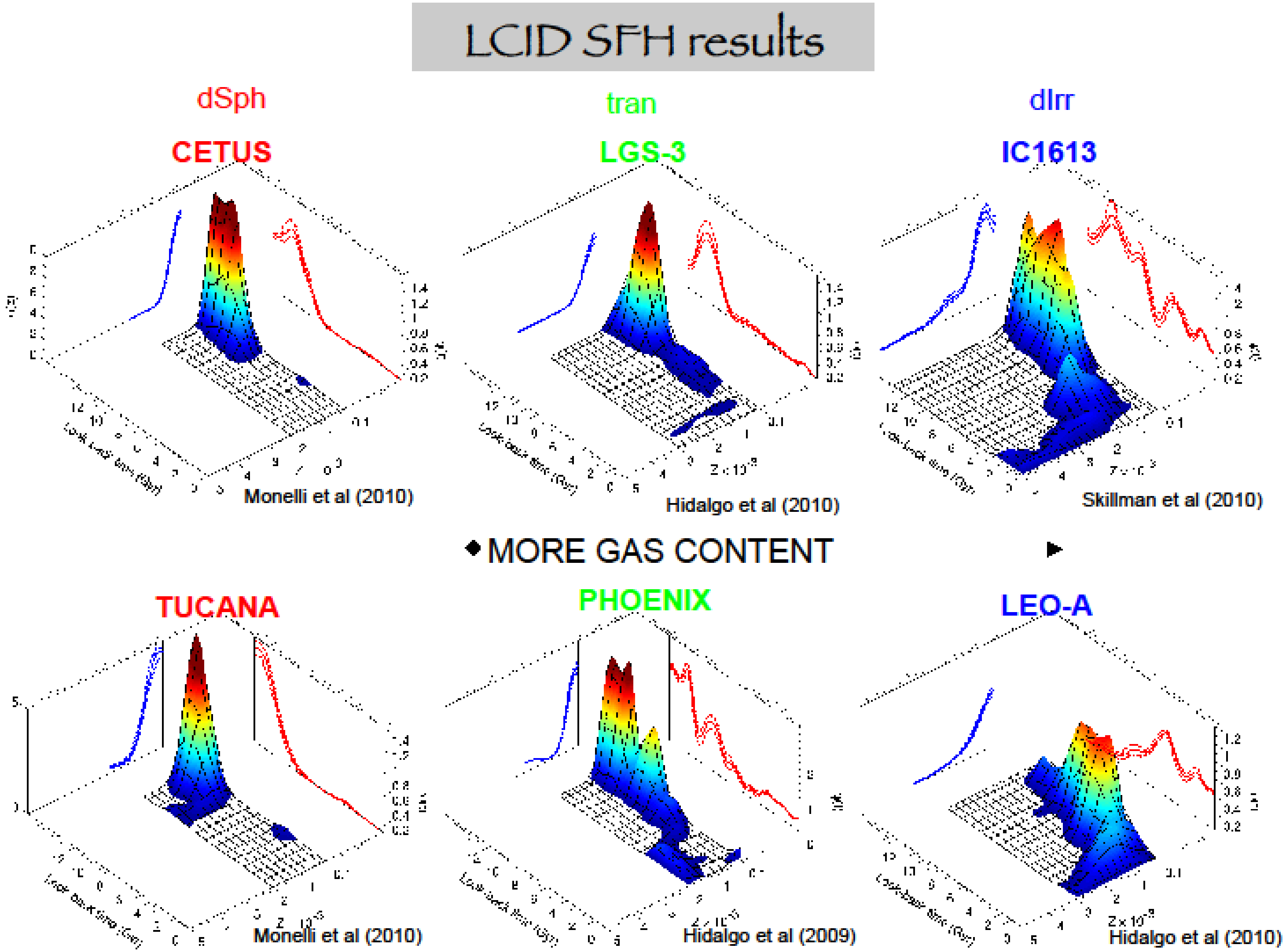
UCD/Nuclear star clusters

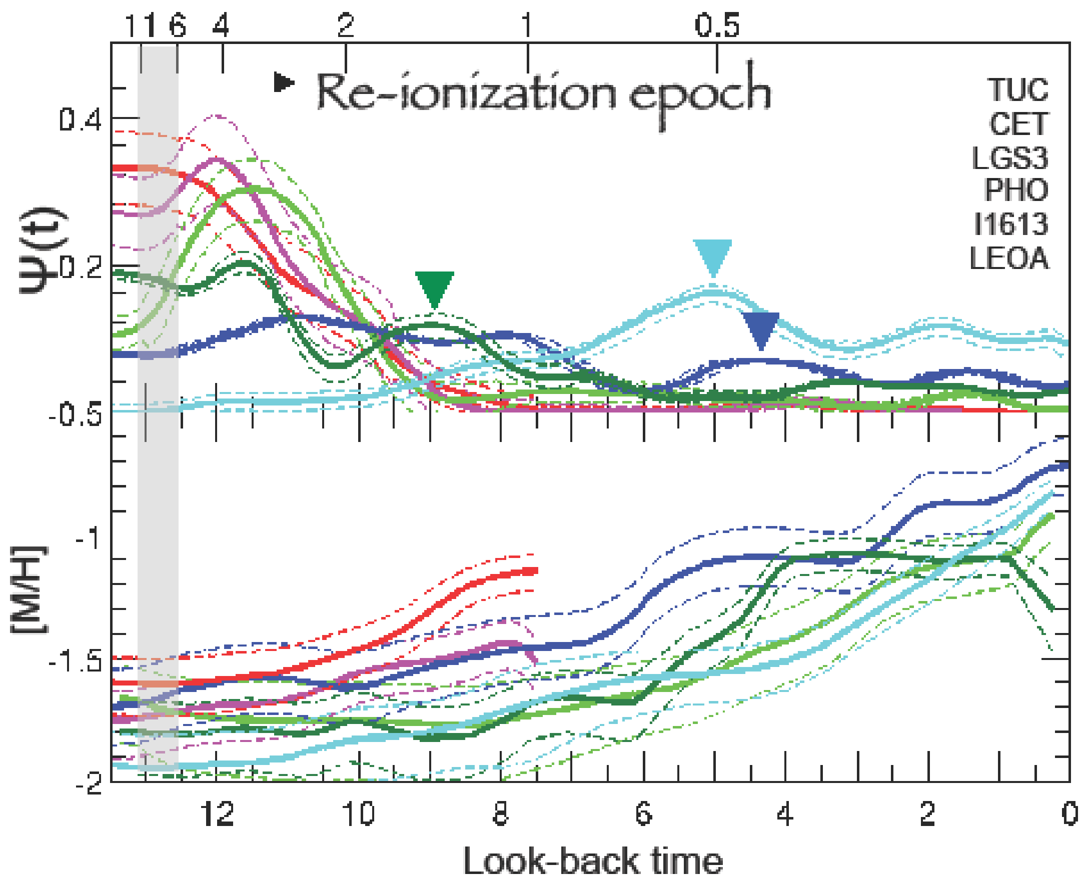
- BH/AGN feedback apparently doesn't limit nuclear star cluster formation...
- SMBH correlate with bulges, but NOT with DM (V_c) or disks
- (Kormendy etal Nat 469 374 2011)

- How does AGN feedback operate "at a distance" through the nuclear star cluster?
- How does one form dense nuclear star clusters (formation continuing today in MWG) ?
- Is an extreme environment essential to form extreme clusters?   UCDs?
- Are those star clusters similar to other star clusters?

- What are/were/will be UCDs?

More feedback –
Consider initial conditions – do we know them anywhere?





Reionization seems to have not stopped star formation in any of these galaxies.

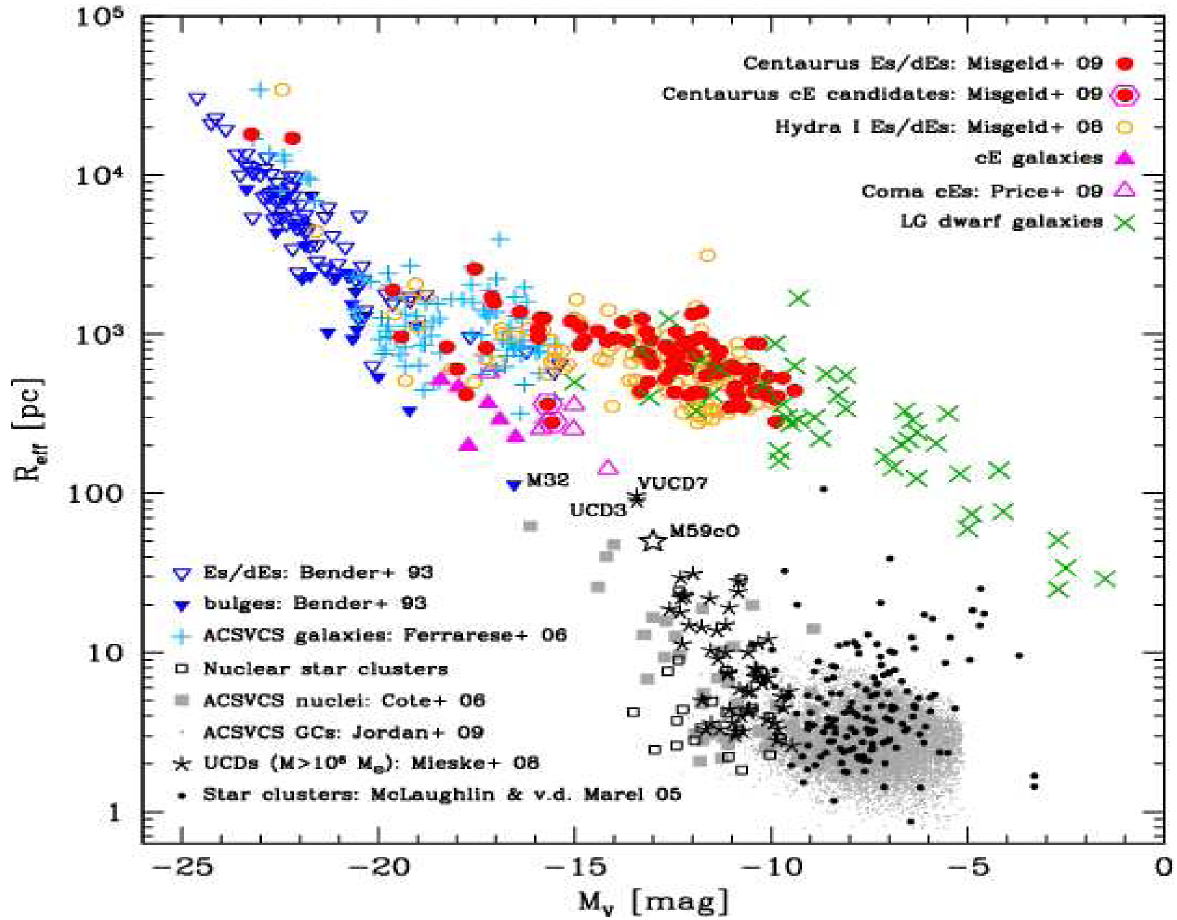
Phoenix, LeoA, and IC1613 had a medium-to-high star formation rate clearly when the universe was fully reionized.

What about the dSph and LGS3?

Why assume star formation is triggered by orbital peri-centre?
Kennicutt relation says just need surface density. Cooling is enough, shocks a bonus?

Nature dislikes making (equilibrium) systems with size 30pc to 100pc

Equilibrium is important:
eg M32 would not be recognised by its mother

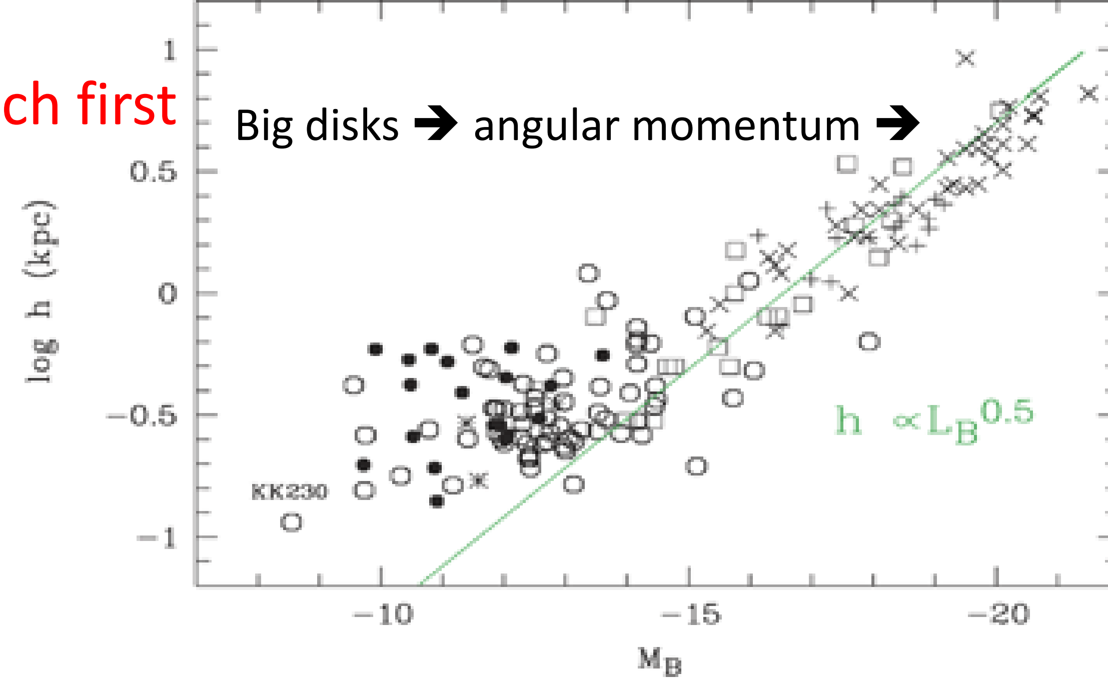


Look at the galaxy branch first

galaxies break from
the luminosity-size scaling
relation at dSph
luminosities

Sharina etal 2008
MN 384 1544

Big disks ➔ angular momentum ➔

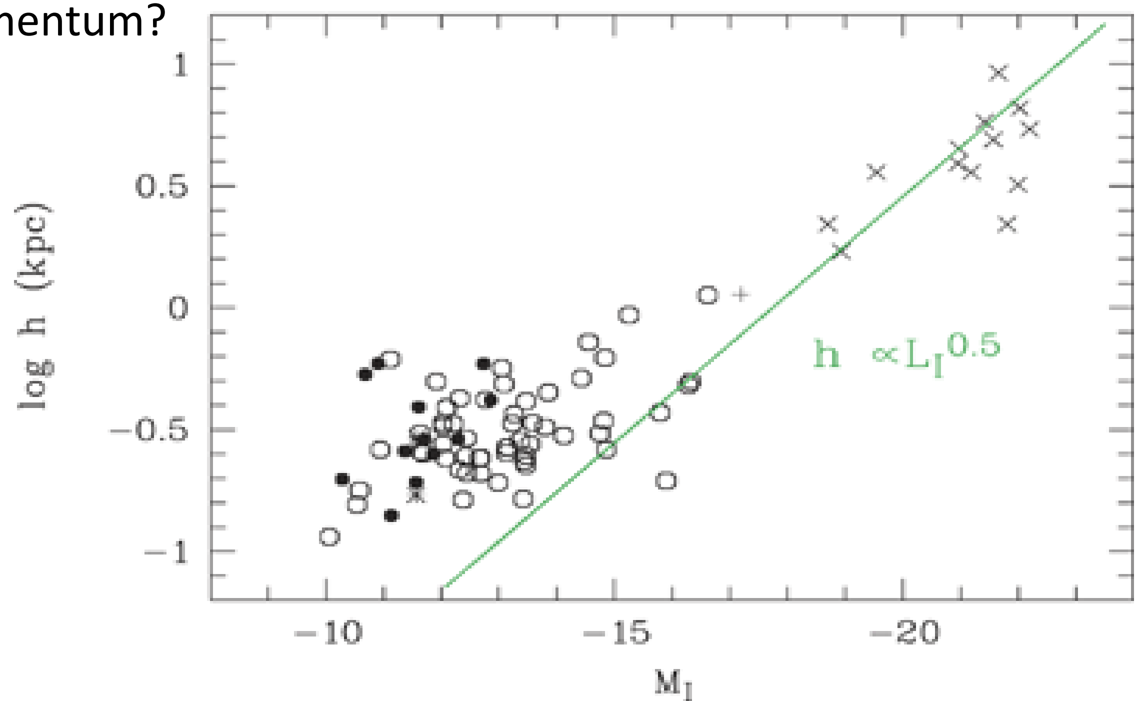


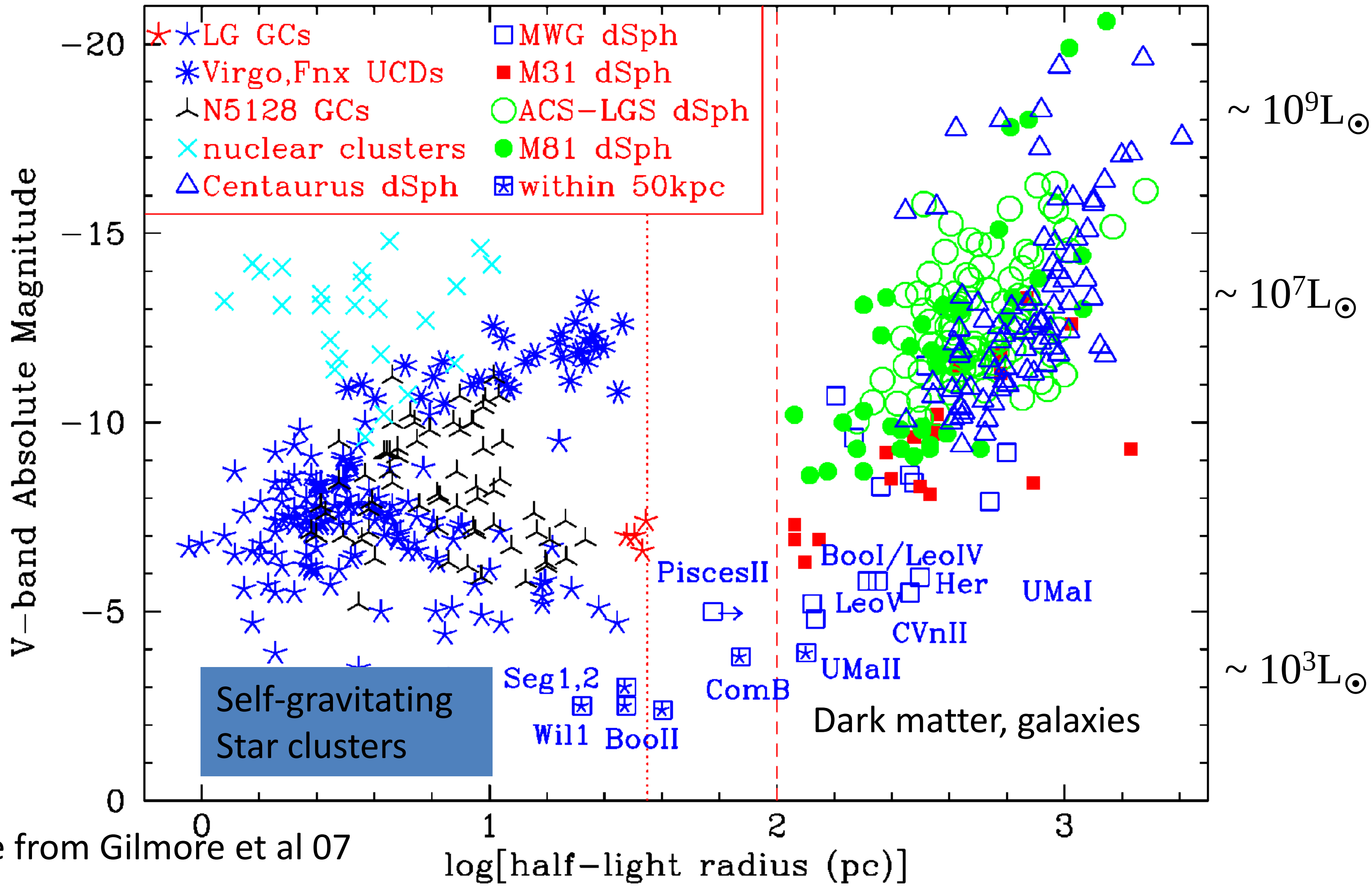
Is this scale set by angular momentum?
[dSph do not rotate..]

Or a scale in the potential?

Challenge: no model
predictions on these scales

Feedback, overcooling....



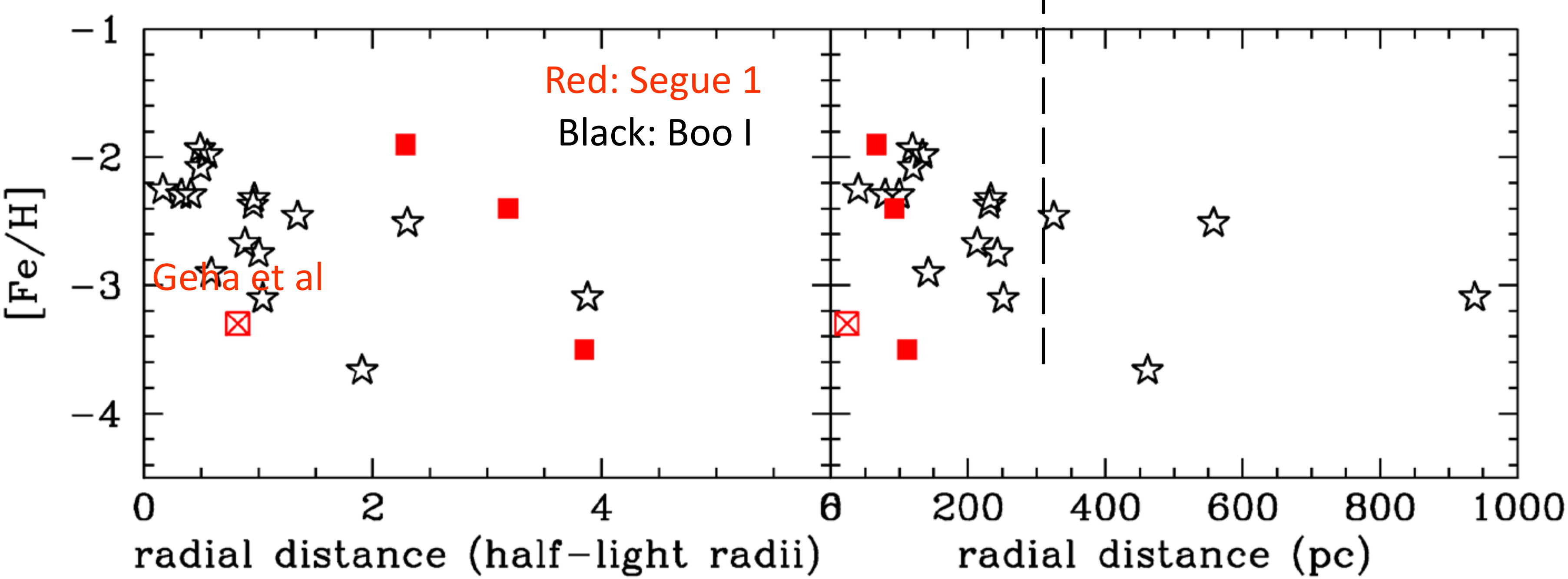


Update from Gilmore et al 07

All new data confirm a size gap for -12<M<-5,
Perhaps extending significantly brighter ?? Or tidal junk??
fainter objects deep in tides??

Norris, GG,RW et al 2010
Wide-area spectroscopy

Tides, tides?, tides!, tides??....



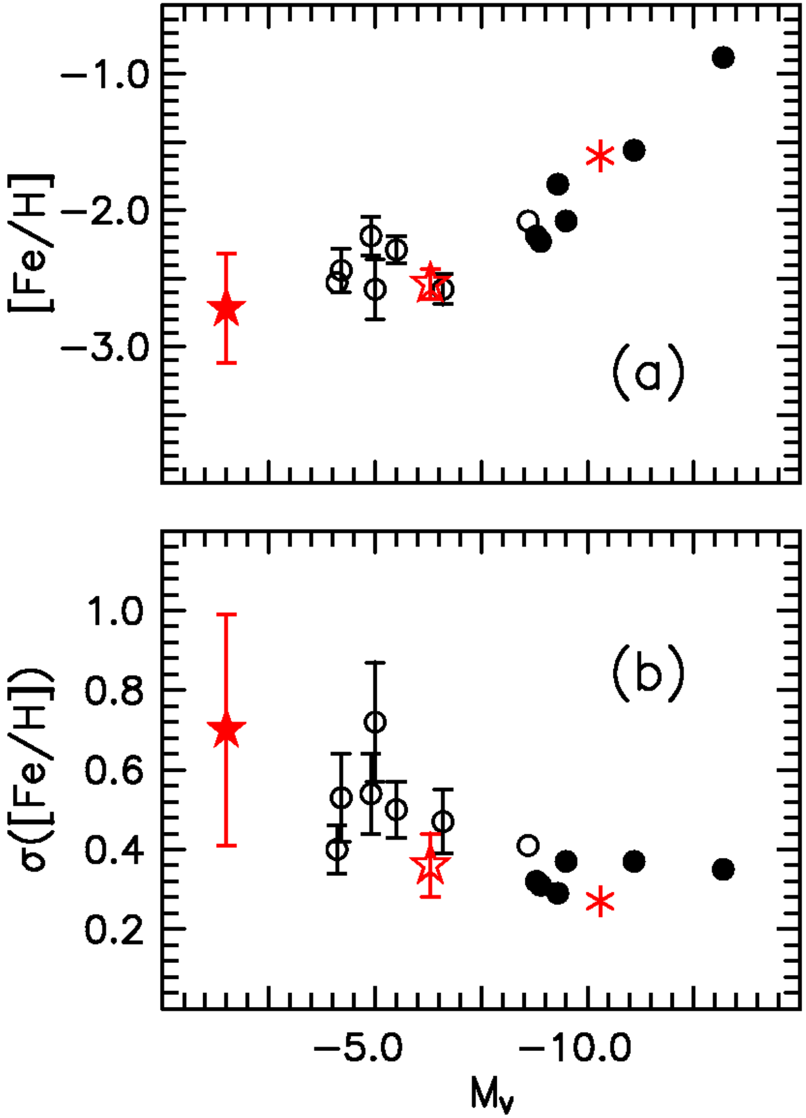
- Members well beyond the nominal half-light radius in both
- Stars more iron-poor than -3 dex exist in both
  - Both systems show a large spread in iron
  - *Implies dark halo for self-enrichment (cf Simon et al 2010)*
  - Caveat: Segue 1 in complex part of Galaxy: higher metallicity stars?

Chemical abundances: dispersion (self enrichment)

is evidence for early massive halos in extreme low luminosity systems

Simon & Geha; Kirby etal, ...

Norris, GG et al 2010a



Mean iron abundance of member stars against total luminosity of host system: clear trend, hard to maintain if significant tidal stripping of host ➔ are any of the dSph tidally stripped?
➔ Interesting? since cusps survive, but cores don't in simulations.

Segue 1 (filled red star) based on only 4 stars – caution!

Dispersion in metallicity increases as luminosity decreases – consistent with inhomogeneous stochastic enrichment in low-mass halos, gentle feedback:
Highly variable SFR models predict high element **ratio** scatter

Equilibrium dynamics

M<r

- Illingworth 1976
- ....
- Mateo 1990s
- Strigari, Walker, Mamon, Wolf...

M=L?

- Mateo etal 1990s
- Wilkinson etal 2002
- Koch etal
- Lokas
- Many more

M(r)

- MB, BE, FD, RJ....
- Eddington, Jeans, Fricke, Chandrasekhar, Miyamoto, Nagai, Toomre, Lynden-Bell, Dehnen, deZeeuw, Evans, Kent &Gunn, Merrifield & Kent, Kuijken & Gilmore, Wilkinson & KEG, Wu & Tremaine, Lokas.....

Hundreds of others

➔ Show half-light radius is a robust parameter

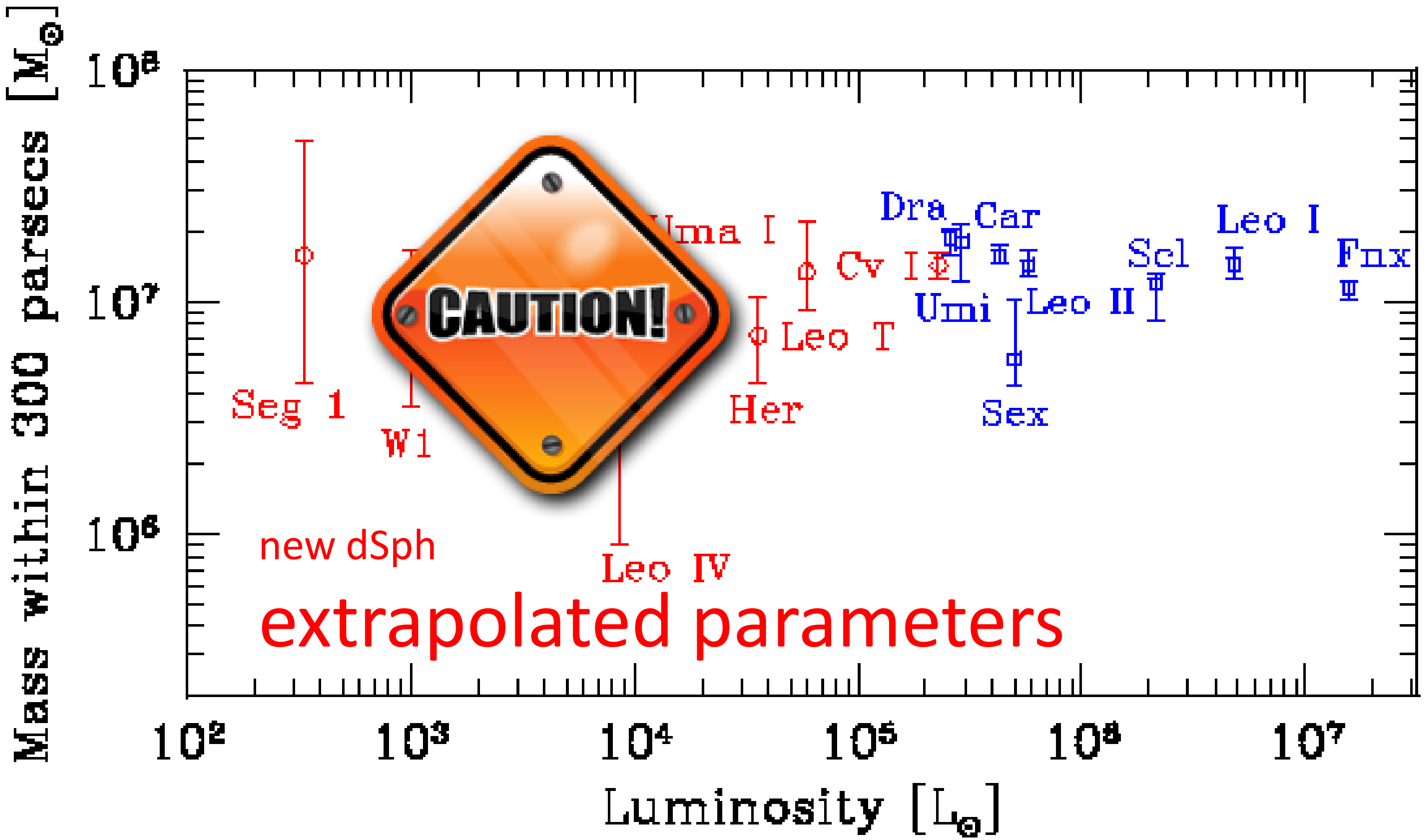
Plus proxy methods based on internal abundance dispersion

Compress kinematics to an enclosed mass in a metric size:

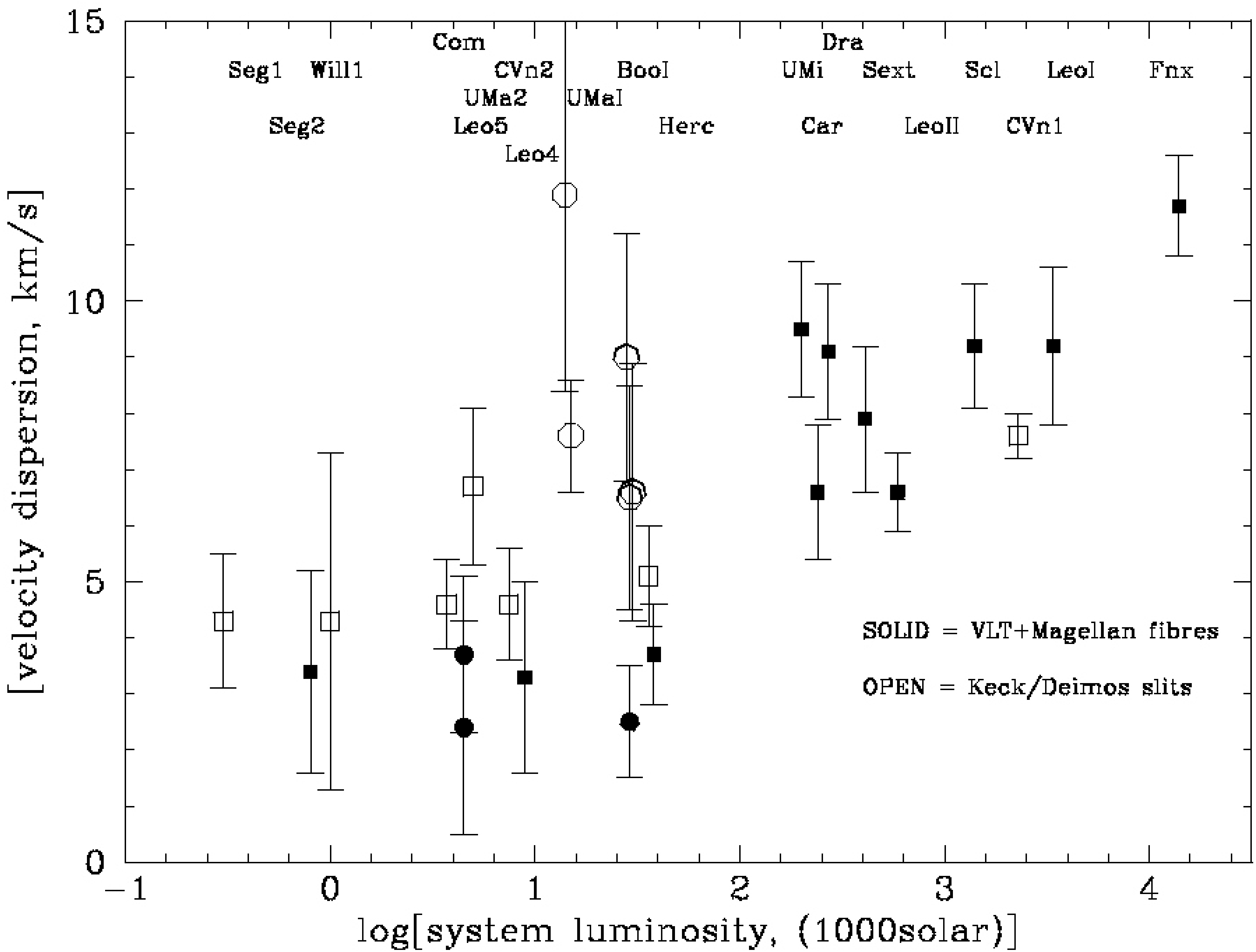
Concept valid only when constrained by luminosity data

– M300 mixes data and model.

Better is the object-specific half-light scale



Strigari etal Nature 454 1096 2008; idea: Mateo 1992



15
10
5
0
−1
0
1
2
3
4
[velocity dispersion, km/s]
log[system luminosity, (1000solar)]
Com
Dra
Seg1
Will1
CVn2
BooI
UMi
Sext
Scl
LeoI
Fnx
UMa2
UMaI
Seg2
Leo5
Herc
Car
LeoII
CVn1
Leo4
SOLID = VLT+Magellan fibres
OPEN = Keck/Deimos slits

Imperfect data!!

- Next you’ll be telling me our political leaders are imperfect!!

Assembly & accretion

- Significant (red?) GC production during major (wet) mergers – these build early-type galaxies?
- Significant (blue?) GC accretion during minor (dry) mergers, which disks survive?
- This doesn't explain the origin of blue GCs ... Are they like the LMC clusters?
- MWG blue GC have complex chemistry. Why?
- Do internal GC abundance dispersions require all of a stable history, low SFR and gentle tides?
- NB: luminous GC lack metal-poor stars – they are NOT the central regions of dSph/dE

Globular Cluster & system evolution are we talking about the same things

E. Carretta et al.: Properties of stellar generations in GCs

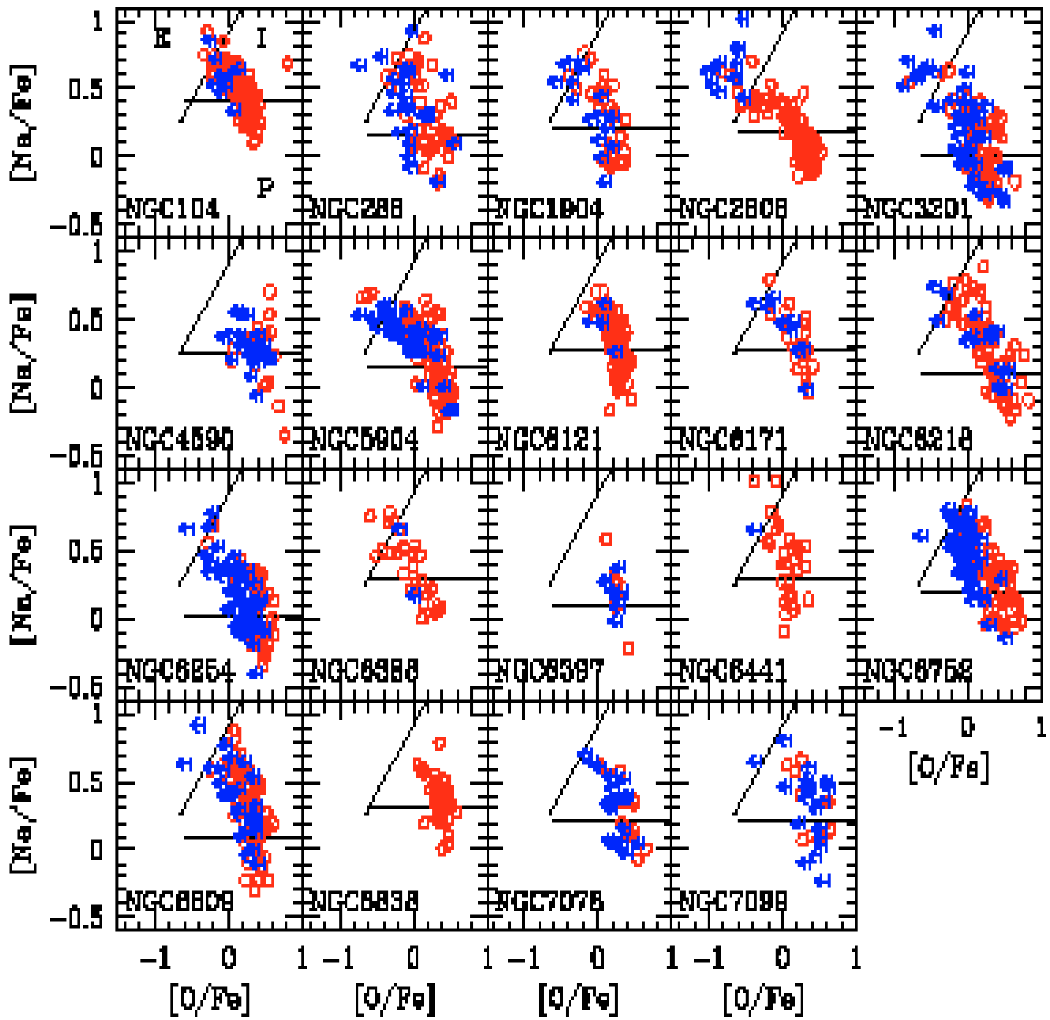
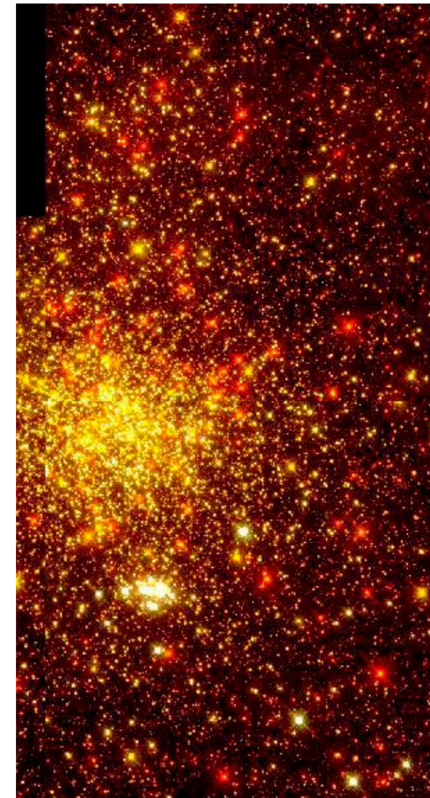
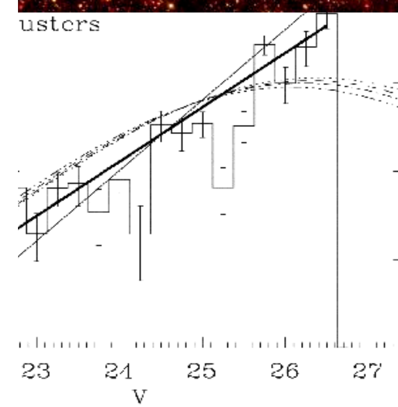


Fig. 1. Summary of the Na-O anticorrelation observed in the 19 GCs of our sample. Arrows indicate upper limits in O abundances. The two lines in each panel separate the primordial component (located in the Na-poor/O-rich region), the Na-rich/O-poor extreme component, and the intermediate component in-between (called P, E, and I, respectively as indicated only in the first panel). See Sect. 2 for details.





Nature dislikes making (equilibrium) systems with size 30pc to 100pc

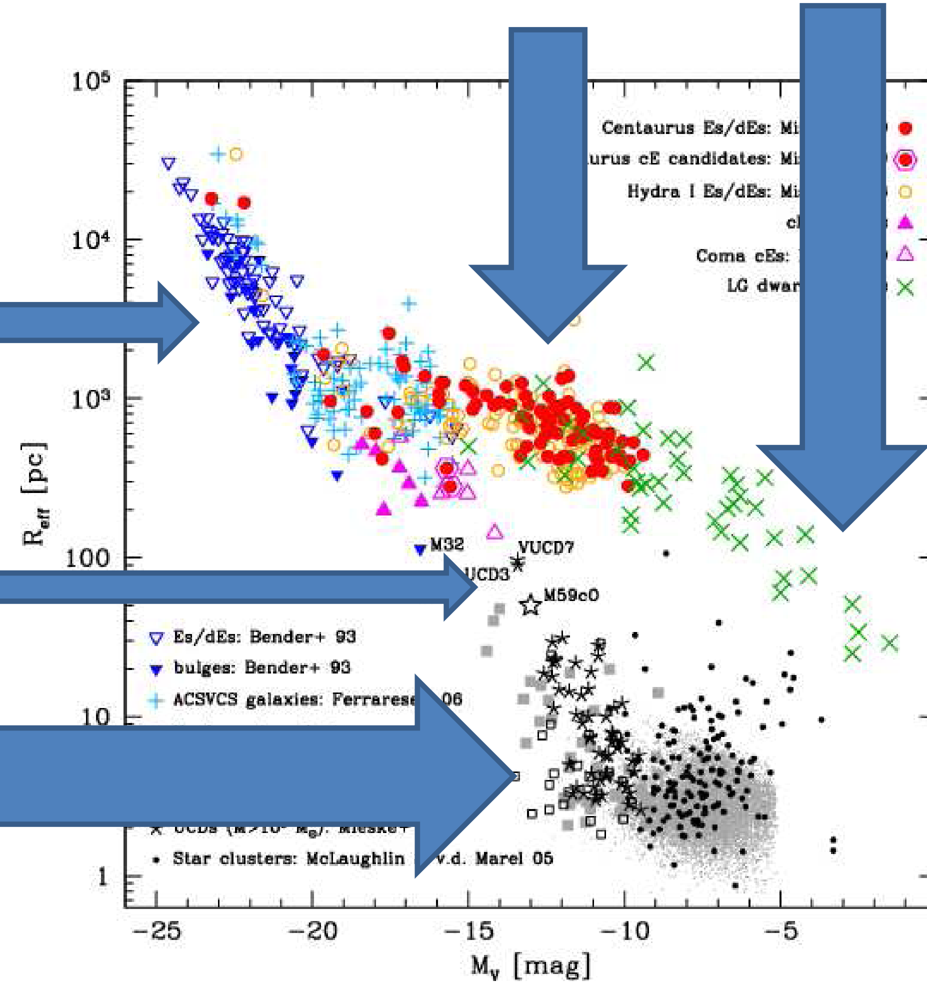
Are there any true equilibrium systems in this range?

Tidal damage???

GALAXIES – baryons in DM halos

The "junkyard"
Tidal debris, stripped,
monsters, dragons...

Star clusters- baryon dominance



Where are we, after a stimulating week?