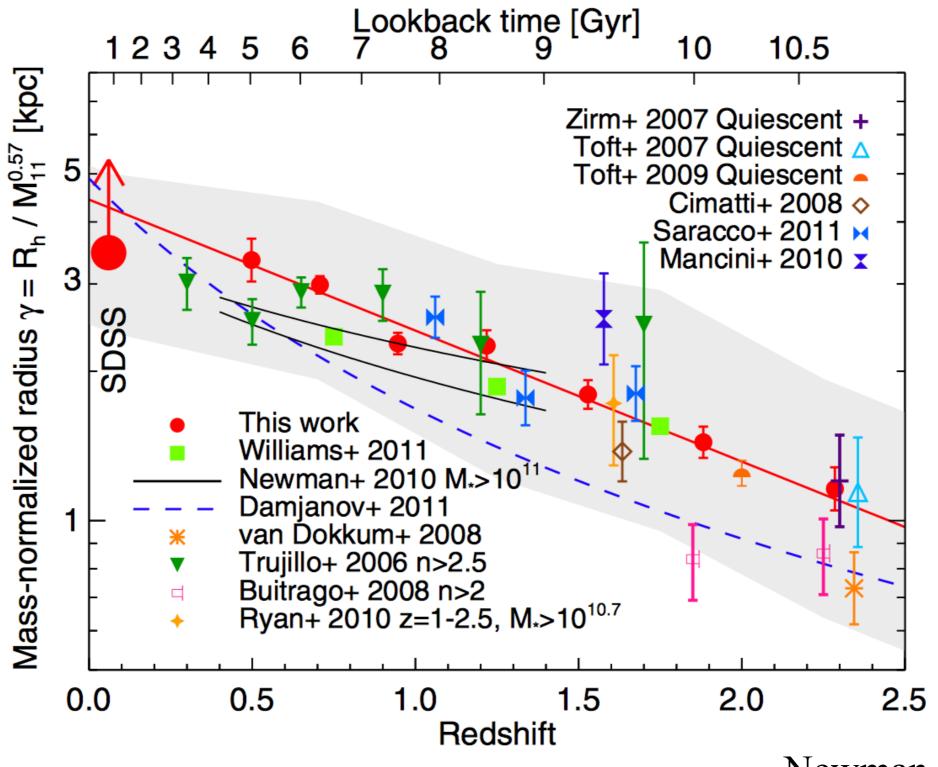# Testing Theories of Size Evolution at $z < 2$

Mike Cooper
UC Irvine

Michael Balogh (Waterloo), Roger Griffith (PSU),
Adam Muzzin (IoA), Jeff Newman (Pitt),
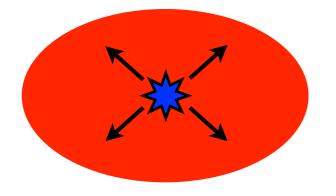Greg Rudnick (KU), Gillian Wilson (UCR)
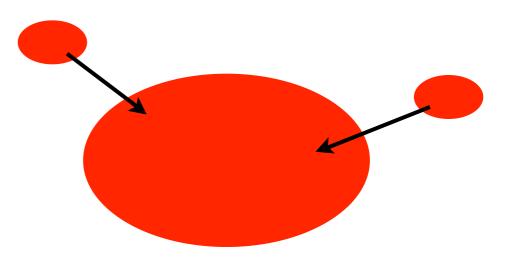
Size Evolution of Ellipticals at z < 2

Newman et al. 2012

Proposed Mechanisms of Size Growth
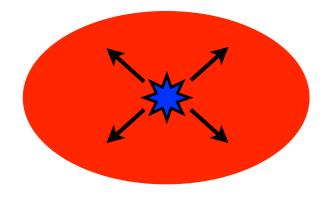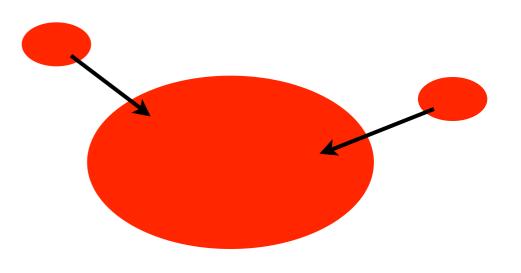
Quasar Feedback

Minor Mergers

e.g. Fan et al. (2008, 2010)
Damjanov et al. (2009)
Hopkins et al. (2010)

e.g. Khochfar & Silk (2006)
Naab et al. (2007)
Bournaud et al. (2007)
Hopkins et al. (2010)

Proposed Mechanisms of Size Growth

Quasar Feedback

Minor Mergers

QSOs cluster like
Blue Galaxies

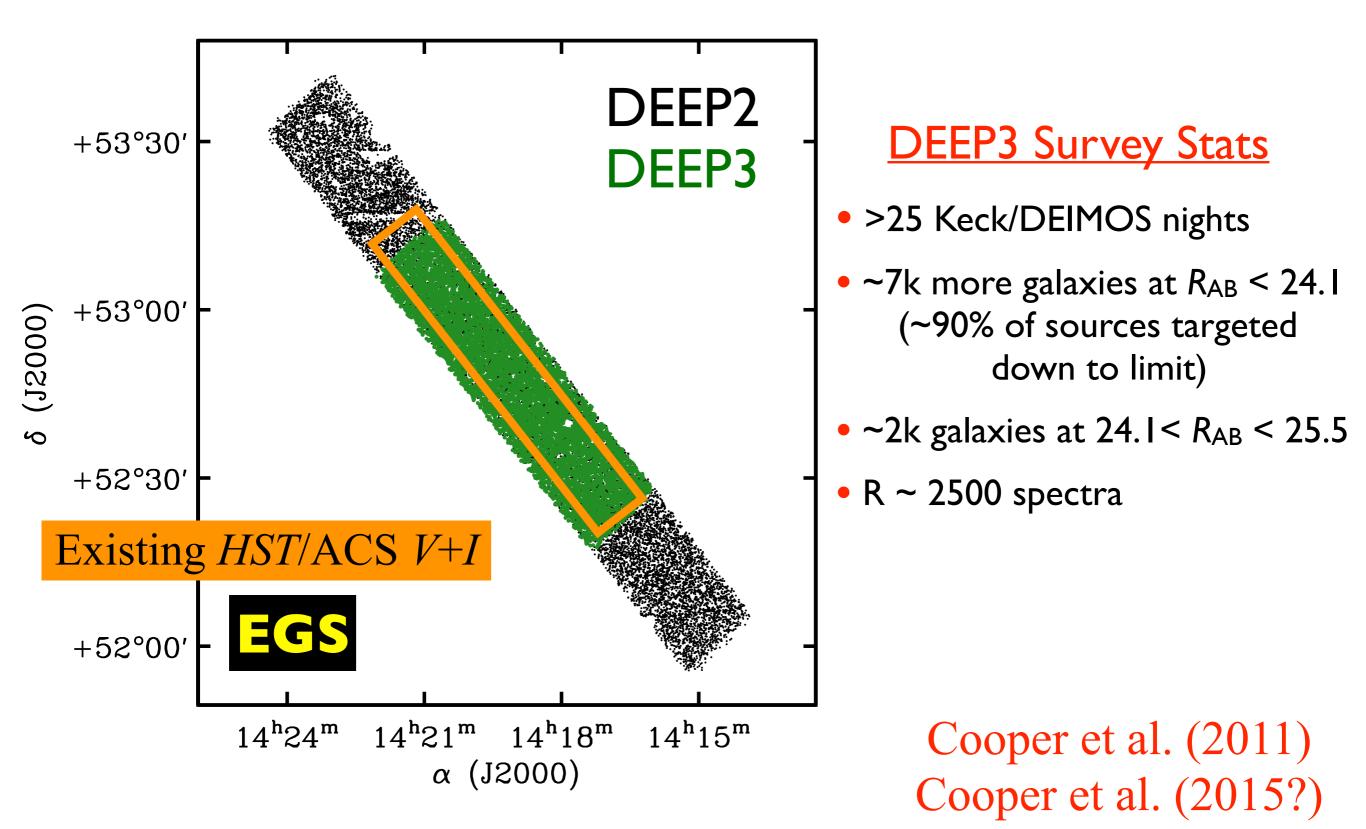(i.e. lower-density environs
than red galaxies, Coil et al. 2007)

Favored in High-Density
Environments

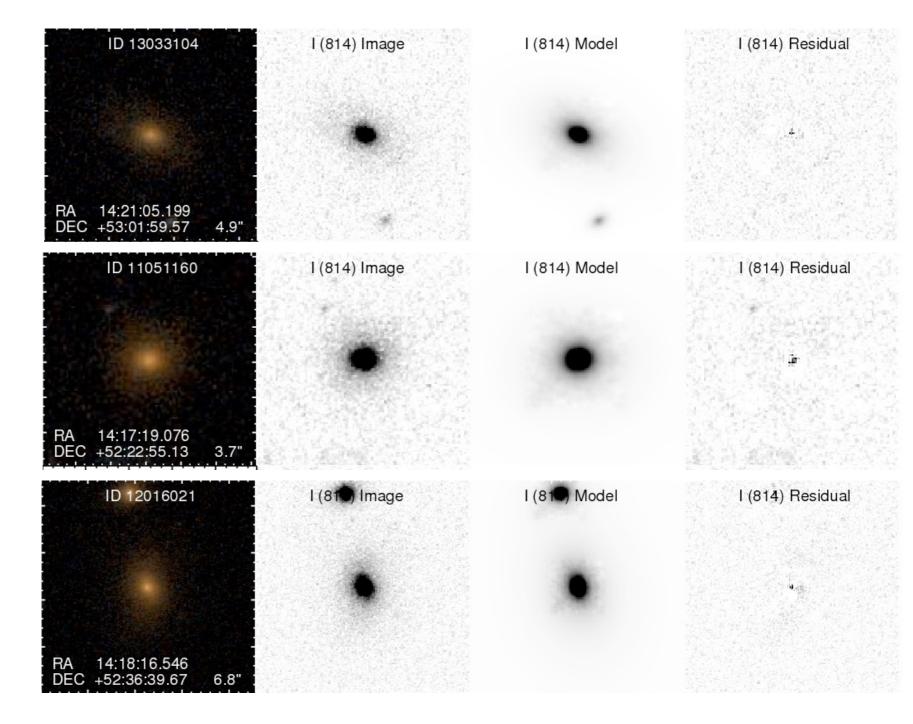(e.g. Lin et al. 2010; Lotz et al. 2013;
McIntosh et al. 2008)

To study the variation in early-type sizes with environment, we need…

[0] study early-types at $z \sim 1$, catching growth in the act.

[1] high-resolution imaging (i.e. *HST*/ACS or WFC3)

[2] either an extensive spectroscopic z survey
-or- deep multi-band imaging for very good photo-z

[3] both of these over a wide enough area,
so as to establish a large sample.
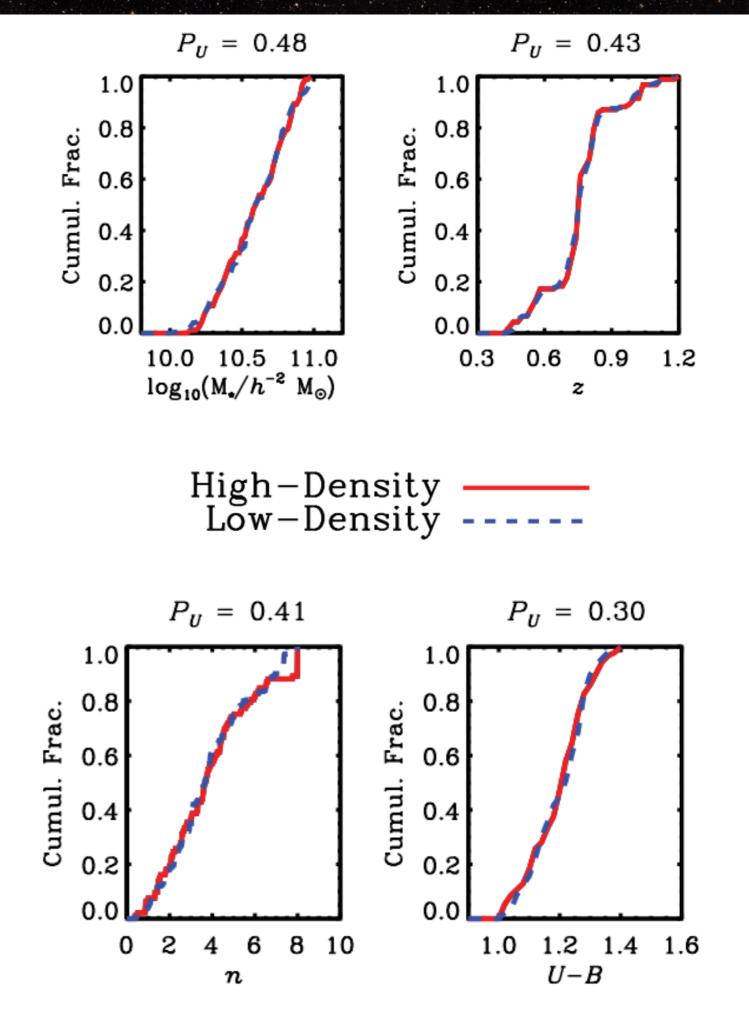
DEEP3: DEEPer than DEEP2

DEEP2
DEEP3

δ (J2000)

+53°30′
+53°00′
+52°30′
+52°00′

Existing *HST*/ACS *V+I*

EGS

14ʰ24ᵐ 14ʰ21ᵐ 14ʰ18ᵐ 14ʰ15ᵐ
α (J2000)

DEEP3 Survey Stats

- >25 Keck/DEIMOS nights

- ~7k more galaxies at $R_{AB} < 24.1$ (~90% of sources targeted down to limit)

- ~2k galaxies at $24.1 < R_{AB} < 25.5$

- R ~ 2500 spectra

Cooper et al. (2011)
Cooper et al. (2015?)

DEEP2+DEEP3 in the EGS:

- red galaxies at
  $0.4 < z < 1.2$
  $10.3 < \log(M_\star) < 11.3$

- sizes from ACS-GC
  Griffith et al. (2012)
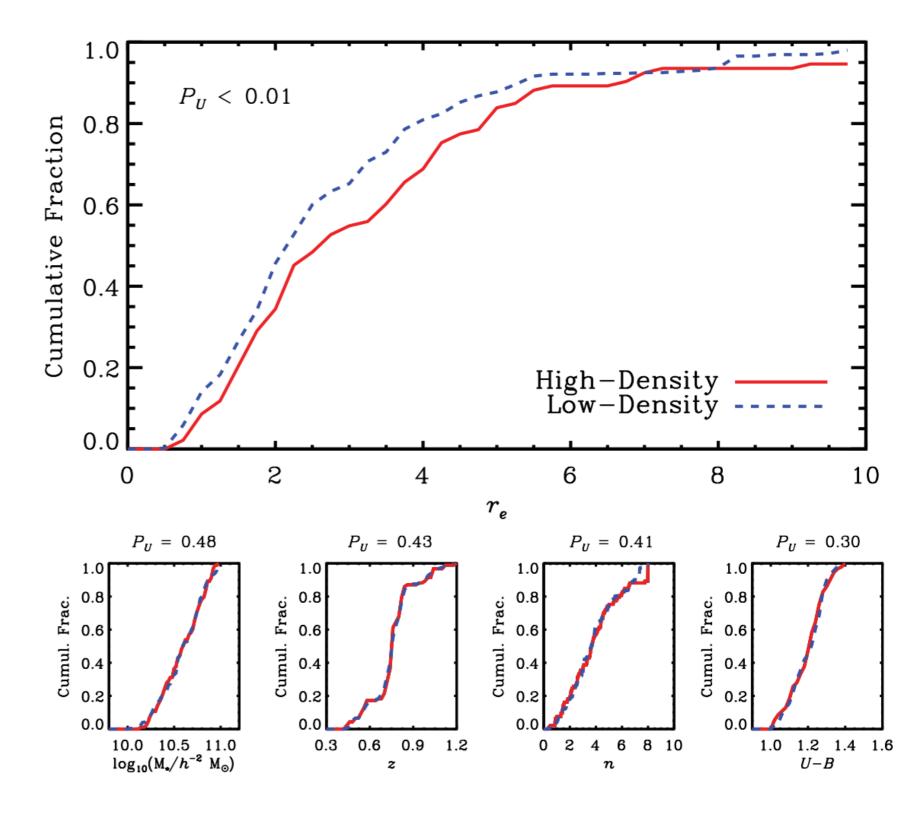
Size-Environme

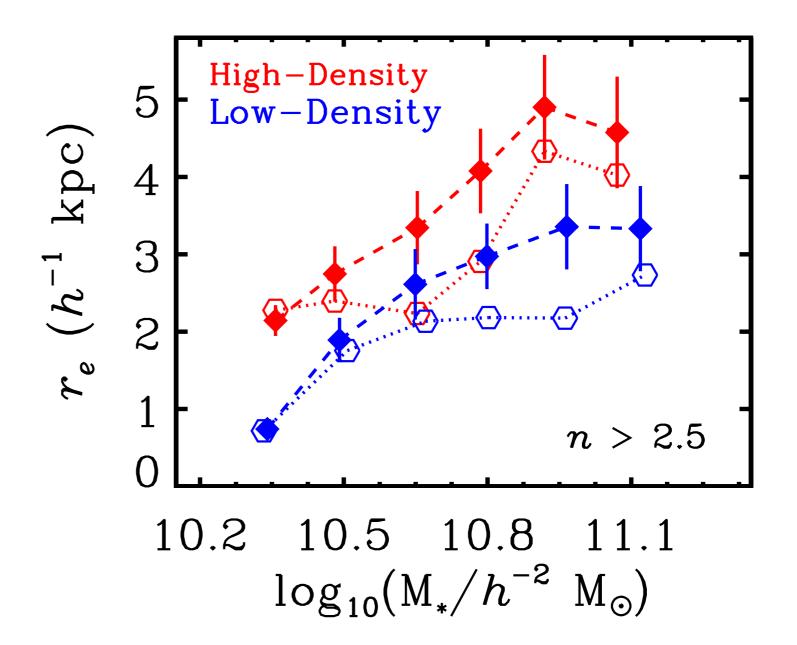DEEP2+DEEP3 in the EGS:

- red galaxies at
    0.4 < z < 1.2
    10.3 < log(M$_\star$) < 11.3

- sizes from ACS-GC
    Griffith et al. (2012)

- low- and high-density
  samples matched in z,
  M$_\star$, *n*, and *U-B*

DEEP2+DEEP3 in the EGS:

- red galaxies at
  - 0.4 < z < 1.2
  - $10.3 < \log(M_\star) < 11.3$

- sizes from ACS-GC
  - Griffith et al. (2012)

- low- and high-density samples matched in z, $M_\star$, *n*, and *U-B*

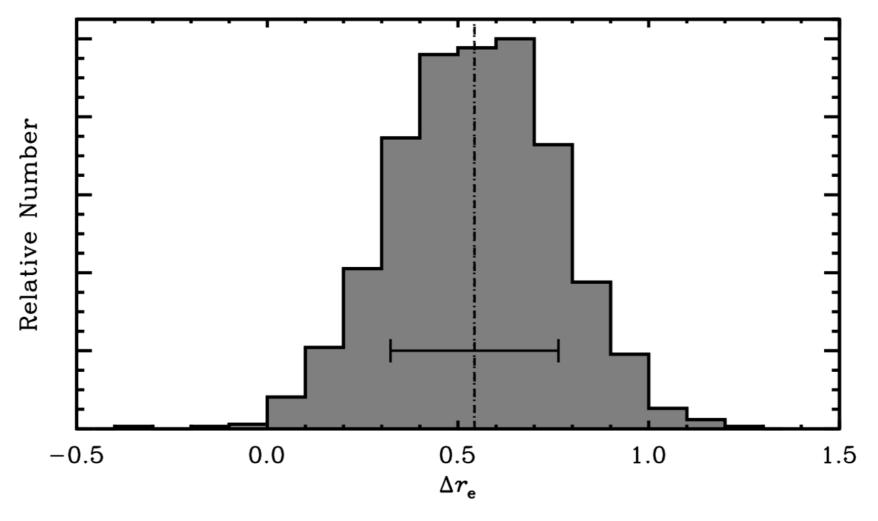**DEEP2+DEEP3 in the EGS:**

- red galaxies at
  $0.4 < z < 1.2$
  $10.3 < \log(M_\star) < 11.3$

- sizes from ACS-GC
  Griffith et al. (2012)

- low- and high-density
  samples matched in z,
  $M_\star$, n, and U-B

DEEP2+DEEP3 in the EGS:

Cooper et al. 2012

- red galaxies at
  0.4 < z < 1.2
  10.3 < log($M_\star$) < 11.3

- sizes from ACS-GC
  Griffith et al. (2012)

- low- and high-density
  samples matched in z,
  $M_\star$, *n*, and *U-B*

size difference (*h*$^{-1}$ physical kpc)
high- minus low-density

▸ ellipticals in high-density
regions are ~0.7 kpc (or 25%)
larger galaxies at z ~ 1.

Papovich et al. 2012

Sizes for
< 20 "cluster"
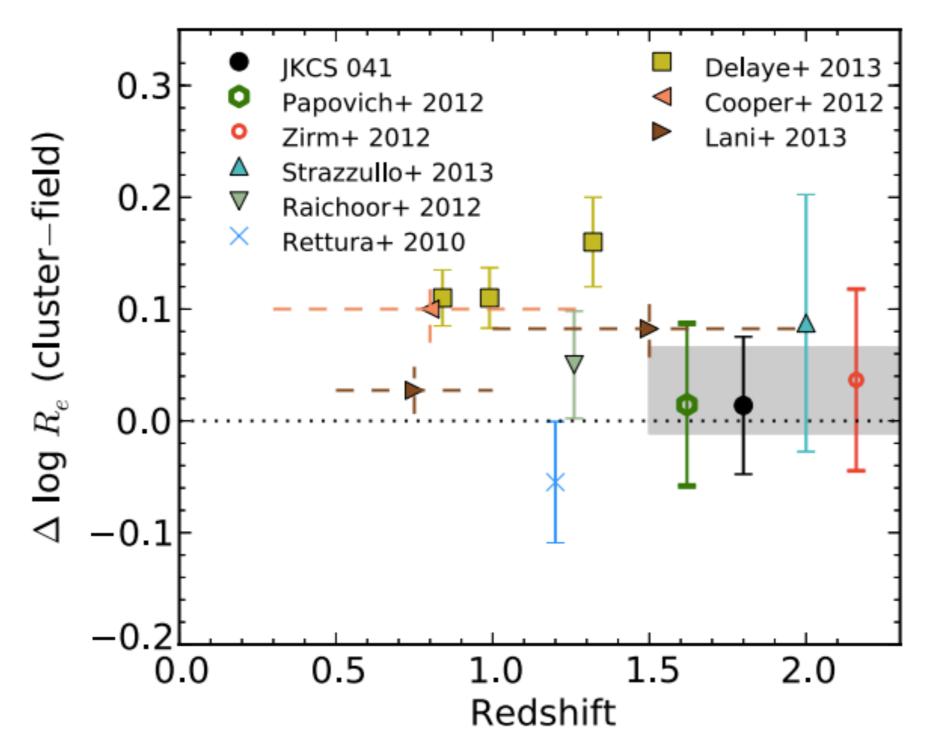ellipticals at
z ~ 1.6

See also results
from Lani,
Delaye, Zirm,
Newman, etc.

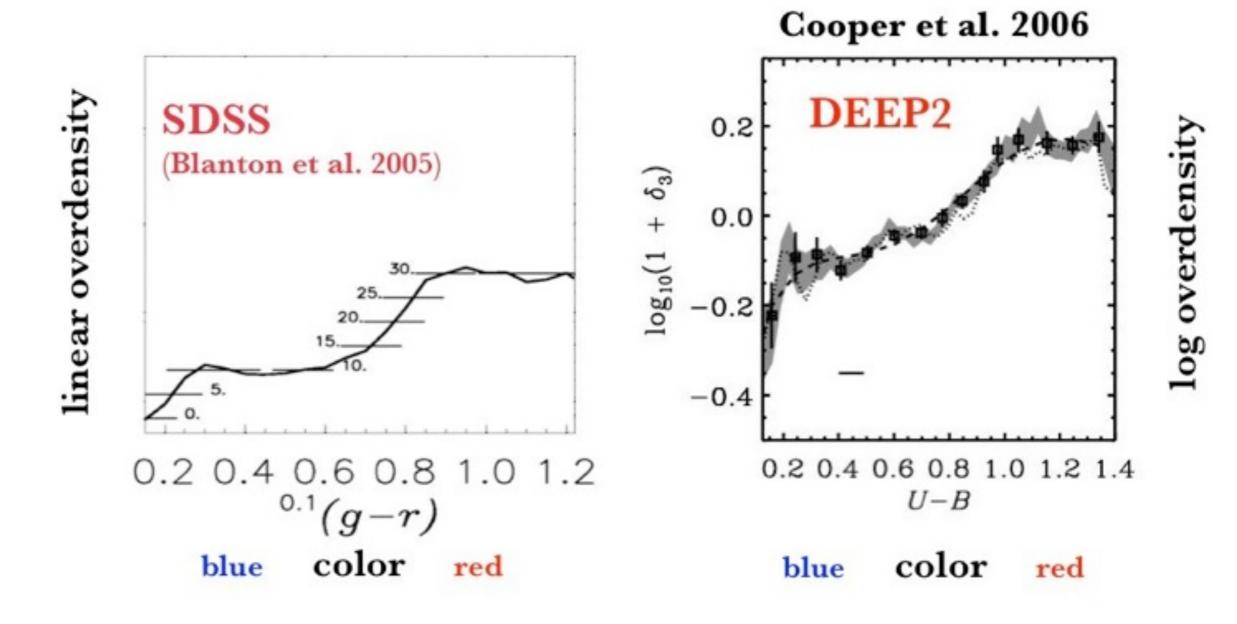# A muddled picture at high z...
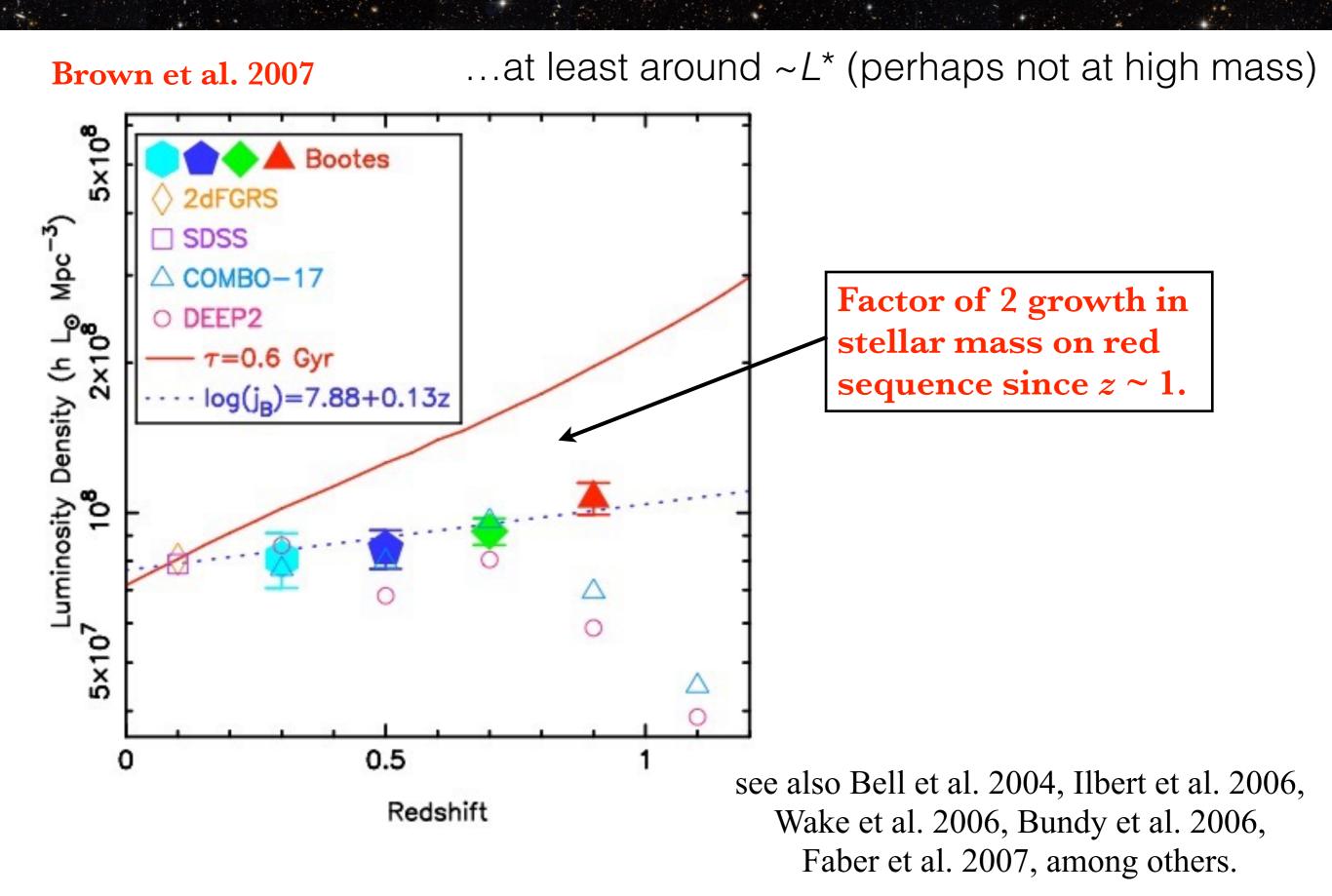
Newman et al. (2014)

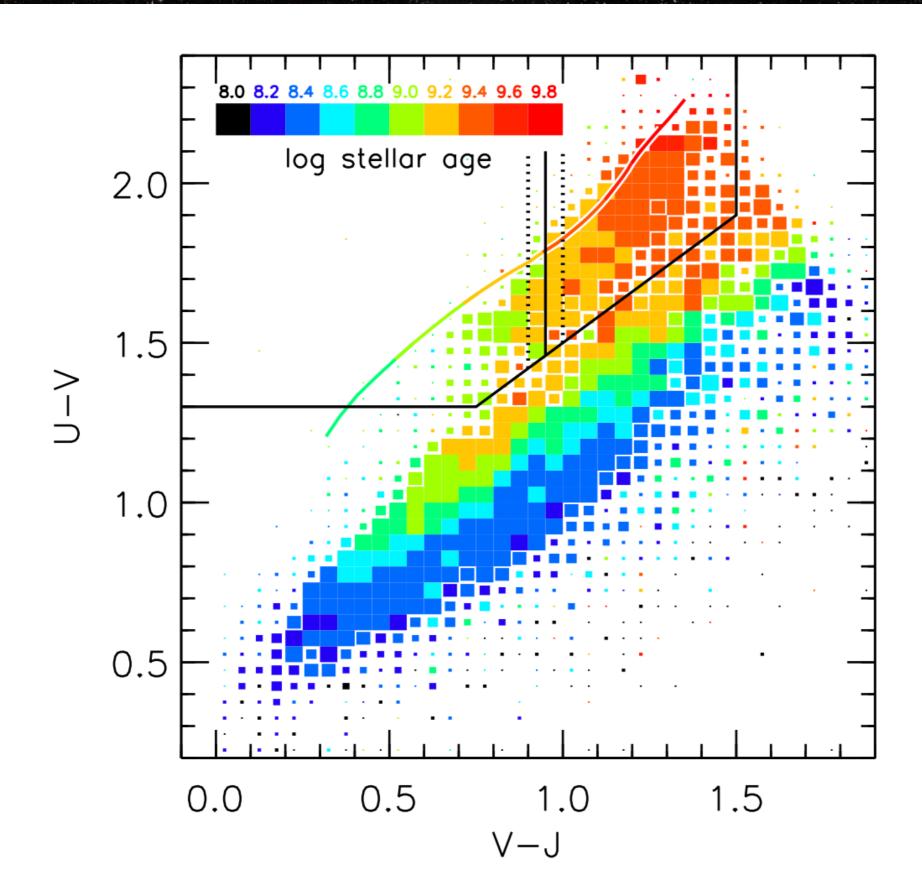But recently-quenched galaxies are also biased towards dense regions.

Cooper et al. 2006

And there are plenty of new early-types...

Brown et al. 2007

...at least around ~*L** (perhaps not at high mass)

Factor of 2 growth in stellar mass on red sequence since $z \sim 1$.

see also Bell et al. 2004, Ilbert et al. 2006, Wake et al. 2006, Bundy et al. 2006, Faber et al. 2007, among others.
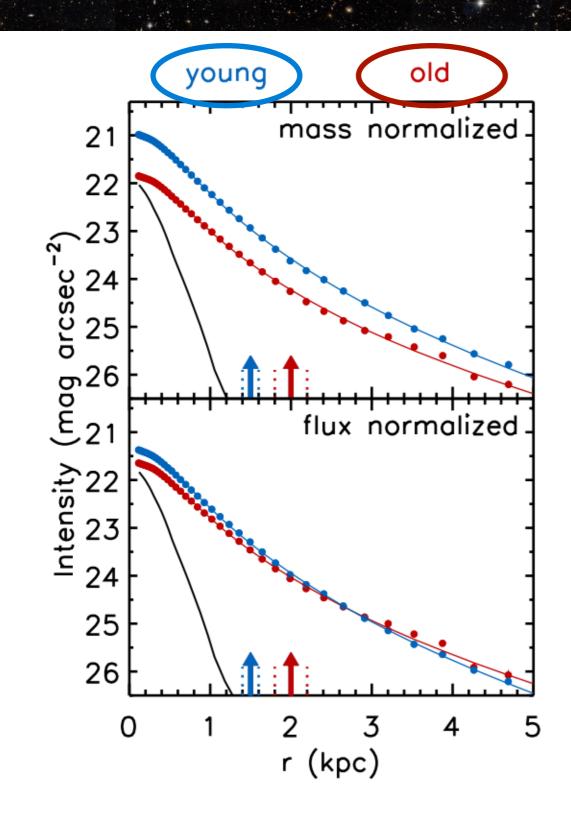
Are younger galaxies larger?

Whitaker et al. (2012)

Ages based on BC03 modeling of NMBS data.
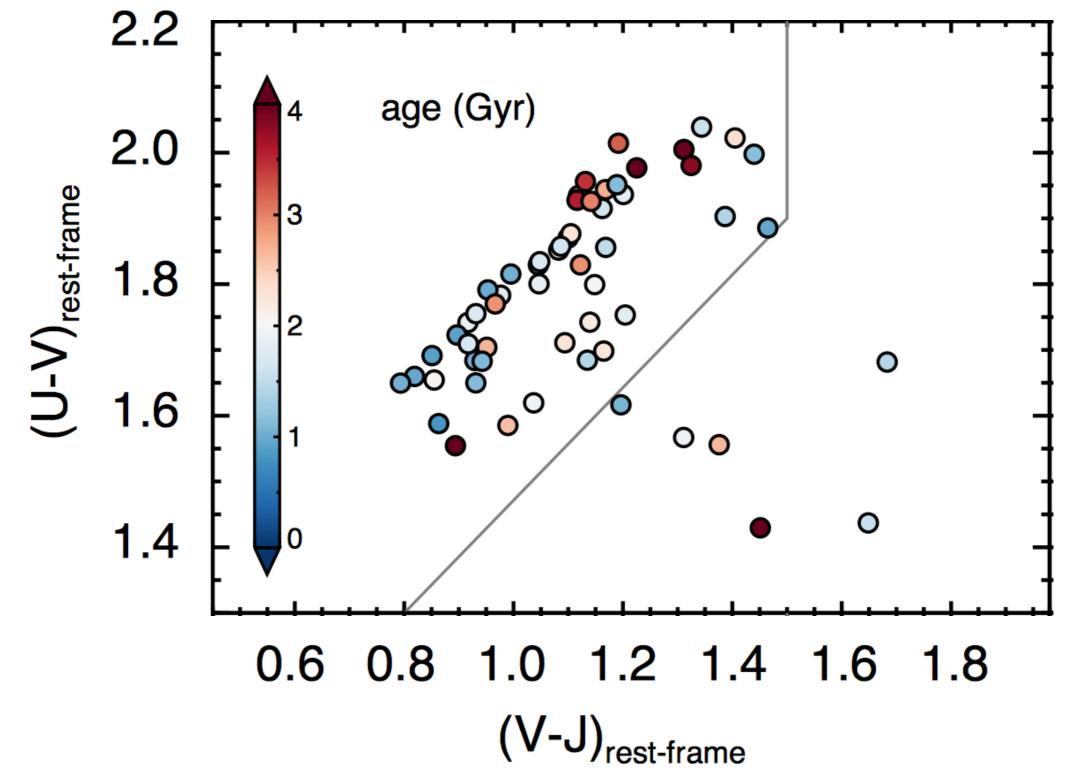
Young Galaxies are More Compact!?

young   old

Younger ellipticals at z ~ 2
are more compact
*(i.e. inconsistent with dilution
due to newly-formed ellipticals
being larger).*

Whitaker et al. (2012)

[but see also Valentinuzzi et al. (2010)]
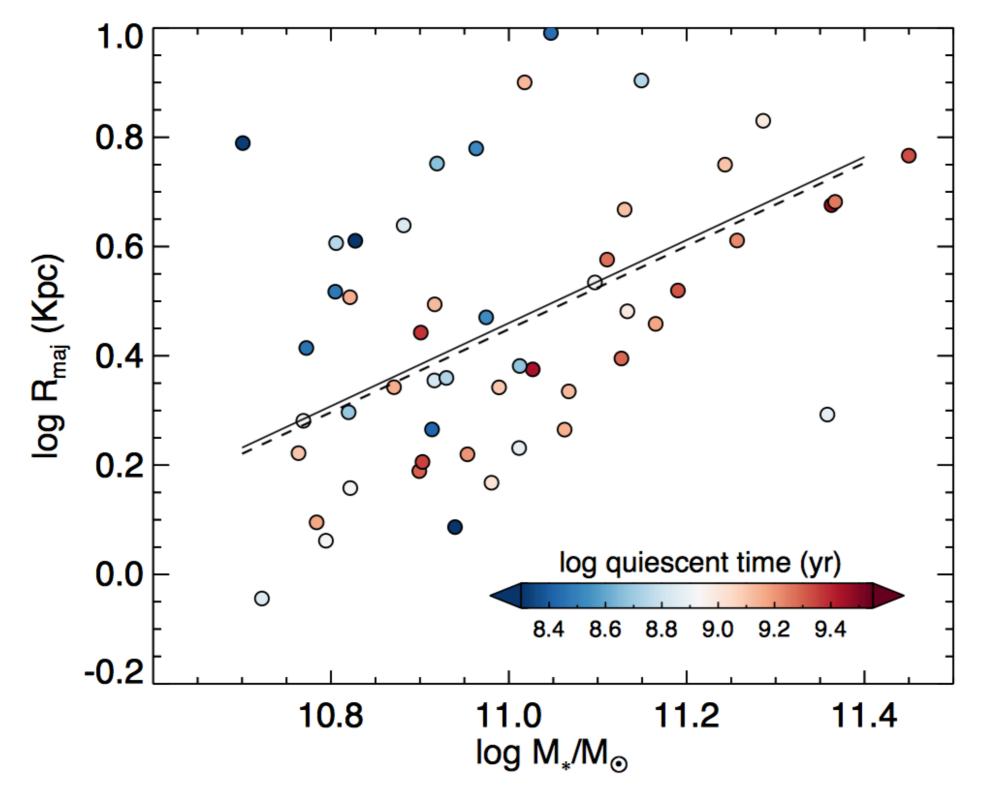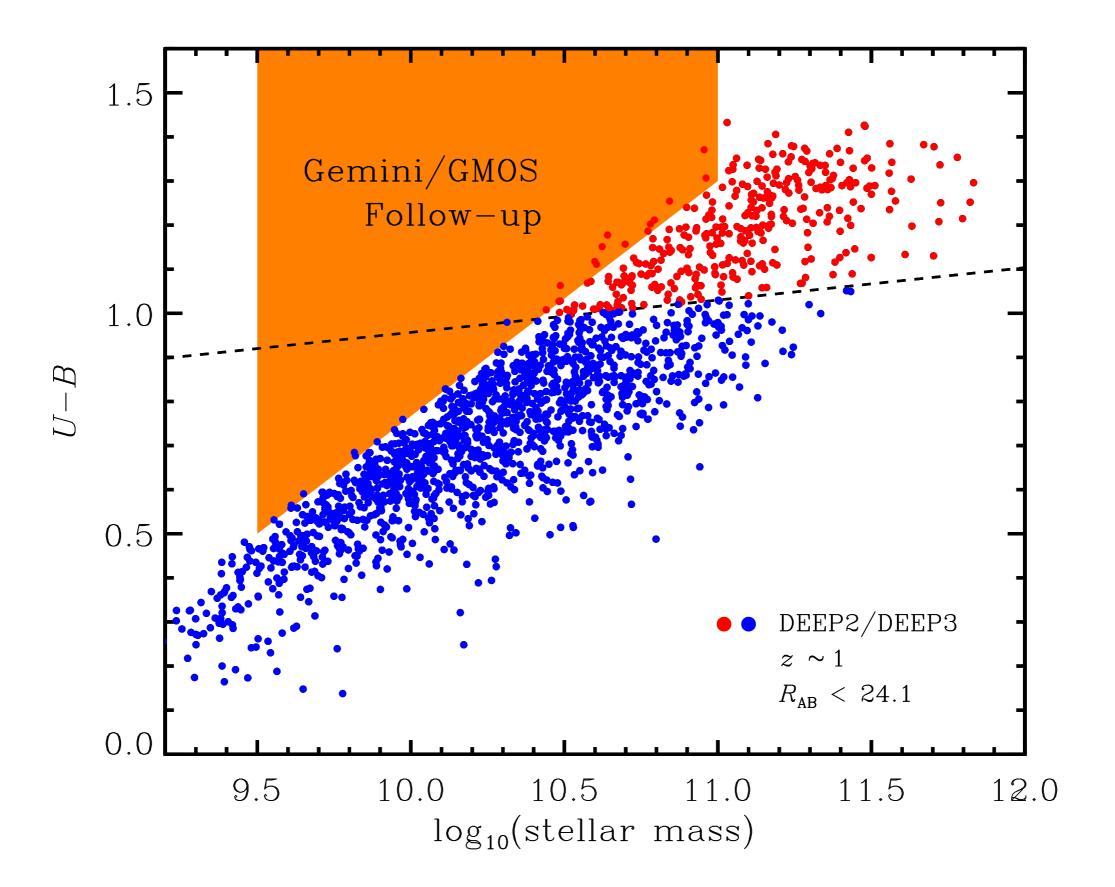
Belli et al. (2014)

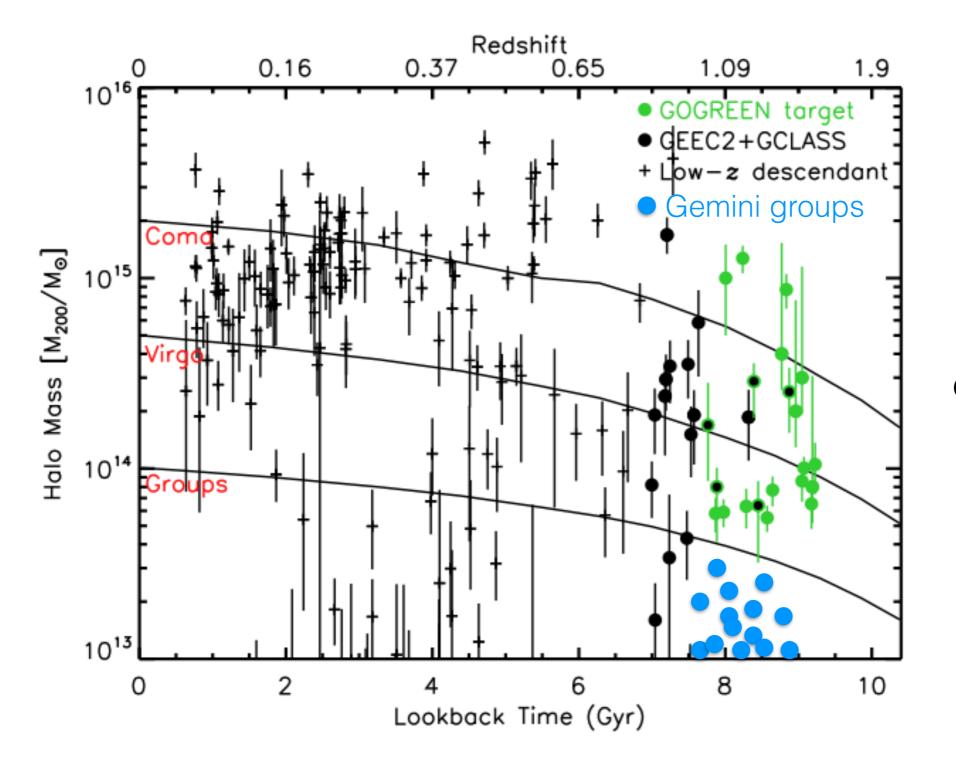# ✦ *Evidence that younger galaxies are larger…*

Belli et al. (2014)

Spectroscopy of passive systems is difficult...

GOGREEN

Gemini Observations of Galaxies in Rich Early Environments
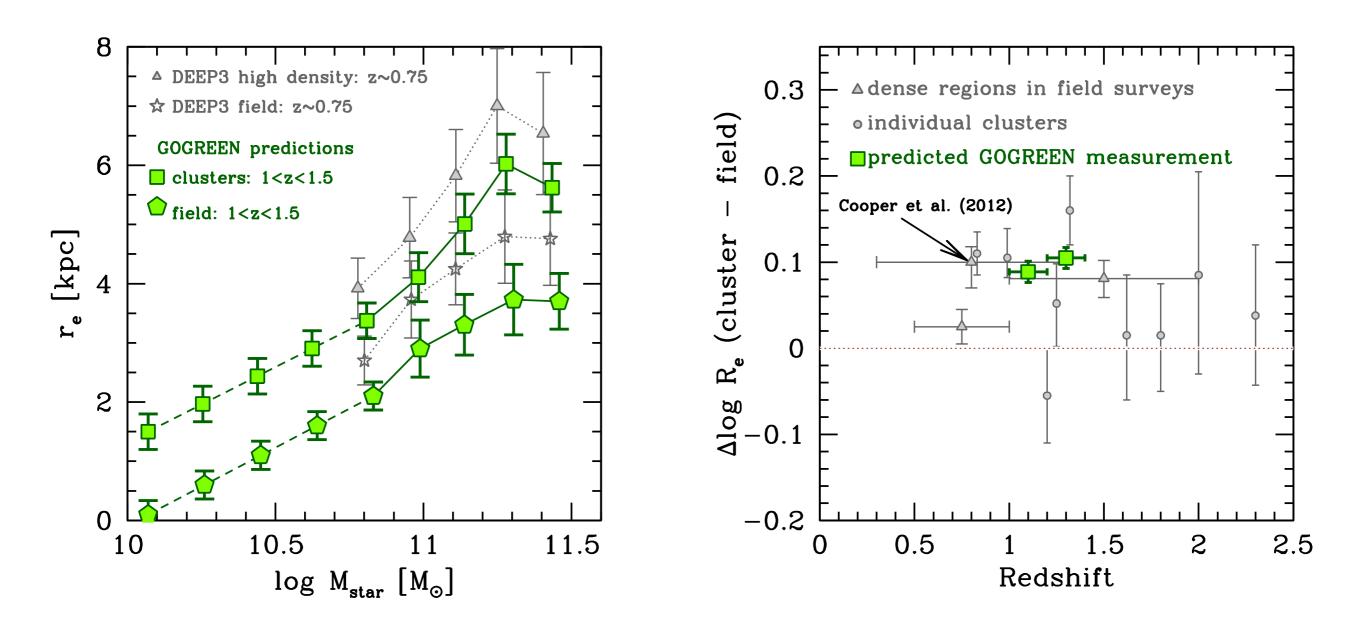

Balogh (PI), Muzzin, Lidman, McGee, Rudnick....

~30 groups and clusters at $1 < z < 1.5$

~40-50 members per system (plus large field samples)

GOGREEN

Gemini Observations of Galaxies in Rich Early Environments

Conclusions

- There is a increasingly clear size-environment correlation at *z* ~ 1.

- Minor mergers and/or progenitor bias could be at play (likely both).

- Why is this environmental dependence gone by z ~ 0?**
   ** — we need to be careful about how we interpret a lack of
      environmental dependence.

- We need bigger samples (including ages) to make progress.
  Plus, more effort in connecting ancestors and descendants
  observationally.
     [CANDELS, GOGREEN, DES, MANGA, LSST+WFIRST, etc.]

Analysis of environment dependence is a useful sanity-check, but is likely
not the best way to proceed. Instead, we need to be using models + the
statistical power of large field samples to address open questions.