The Puzzling Red Halos of Galaxies

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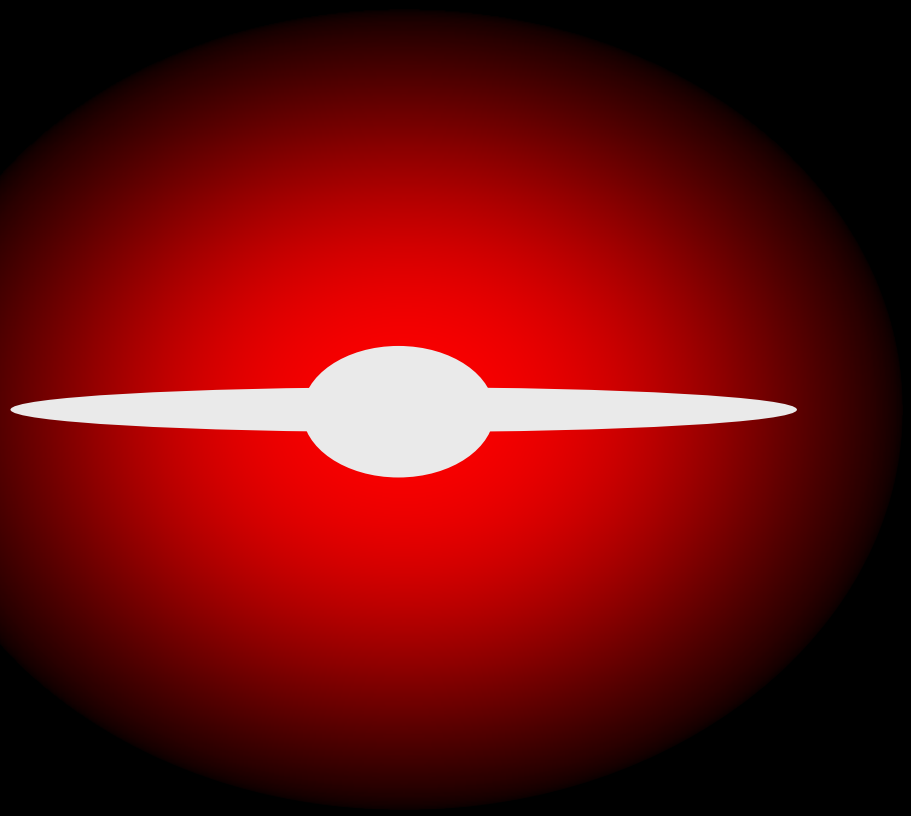
Outline

- Introduction to red halos
- Red halos of disk galaxies
- Red halos of blue compact galaxies
- Red halos as baryonic dark matter
- A red halo around the Milky Way?
- Recent developments

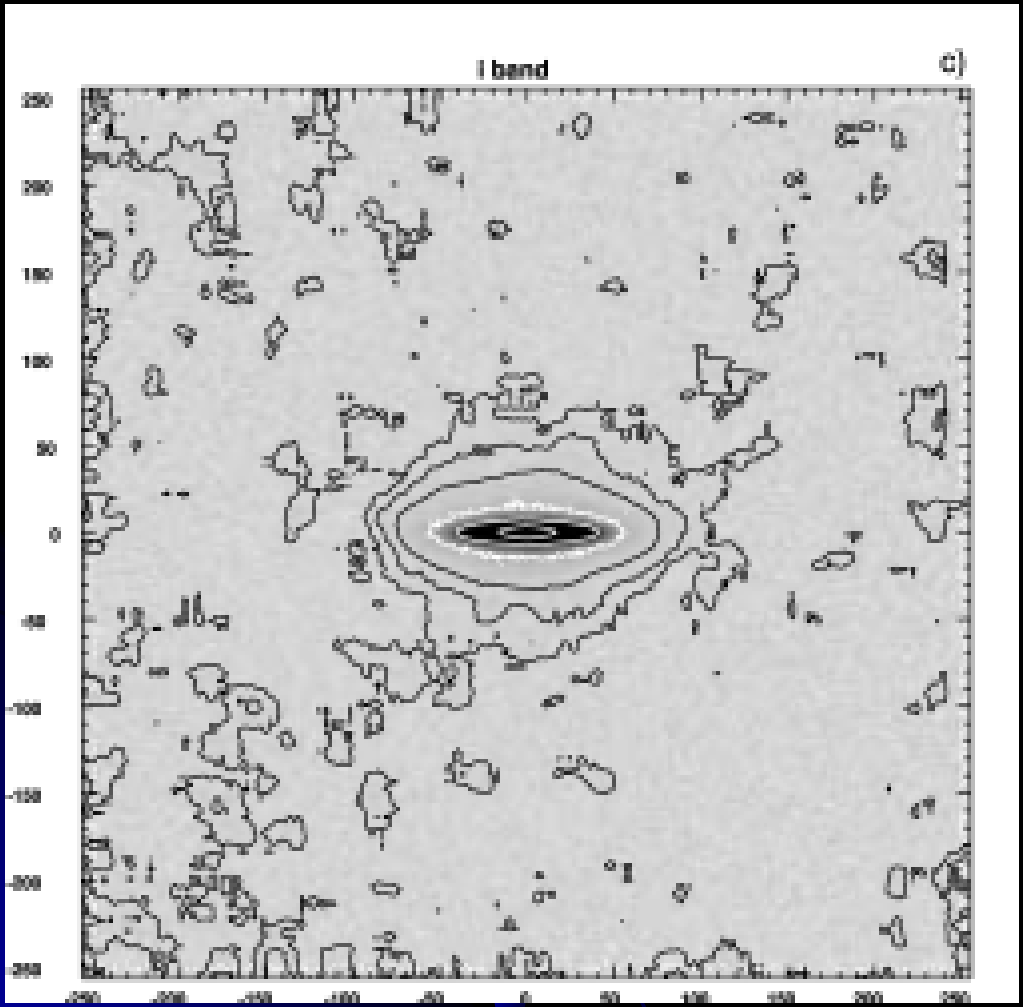
Red halos



Early detections:

- Edge-on disk galaxy NGC 5907 (Sackett et al. 1994, Nature, 370, 441; Rudy et al. 1997, Nature 387, 159)
- cD-galaxy in A 3284 (Molinari et al. 1994, A&A 292, 54)

Halos of Edge-On Disk Galaxies in the SDSS I



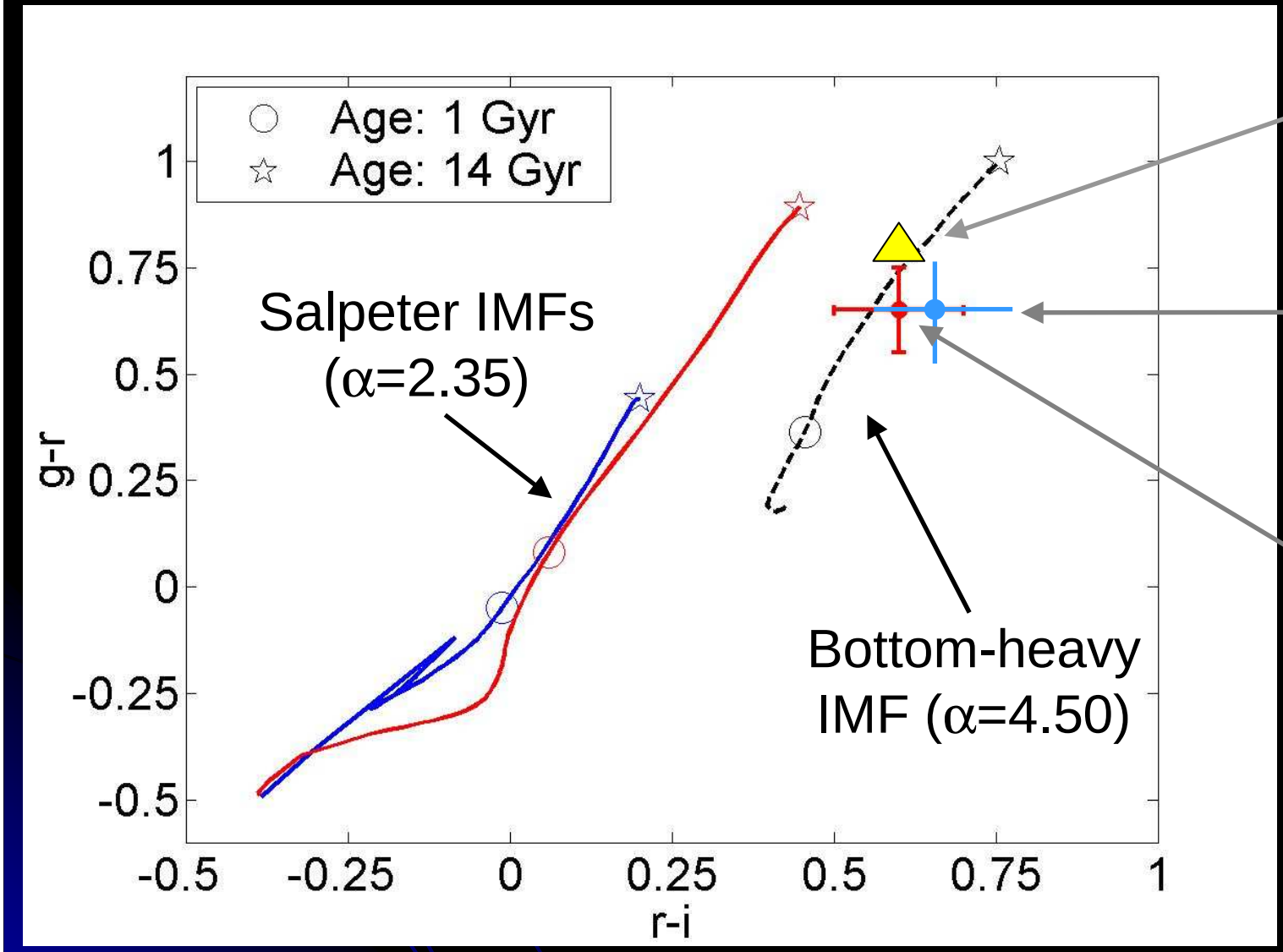
High surface brightness disks
Zibetti et al. (2004, MNRAS, 34, 556)

Low surface brightness disks
Bergvall et al. (2008, in prep.)

Red halos detected at
$\mu_g \geq 28$ mag arcsec^{-2}

Note: This is $\geq$ 300 times fainter than the sky flux!

Halos of Edge-On Disk Galaxies in the SDSS II



Halo of NGC 5907

Bergvall et al. (2008) halo

Zibetti et al. (2004) halo

$$\frac{dN}{dM} \propto M^{-\alpha}$$

A bottom-heavy IMF with α=4.50 explains the observations (Zackrisson et al. 2006, ApJ, 650, 812)

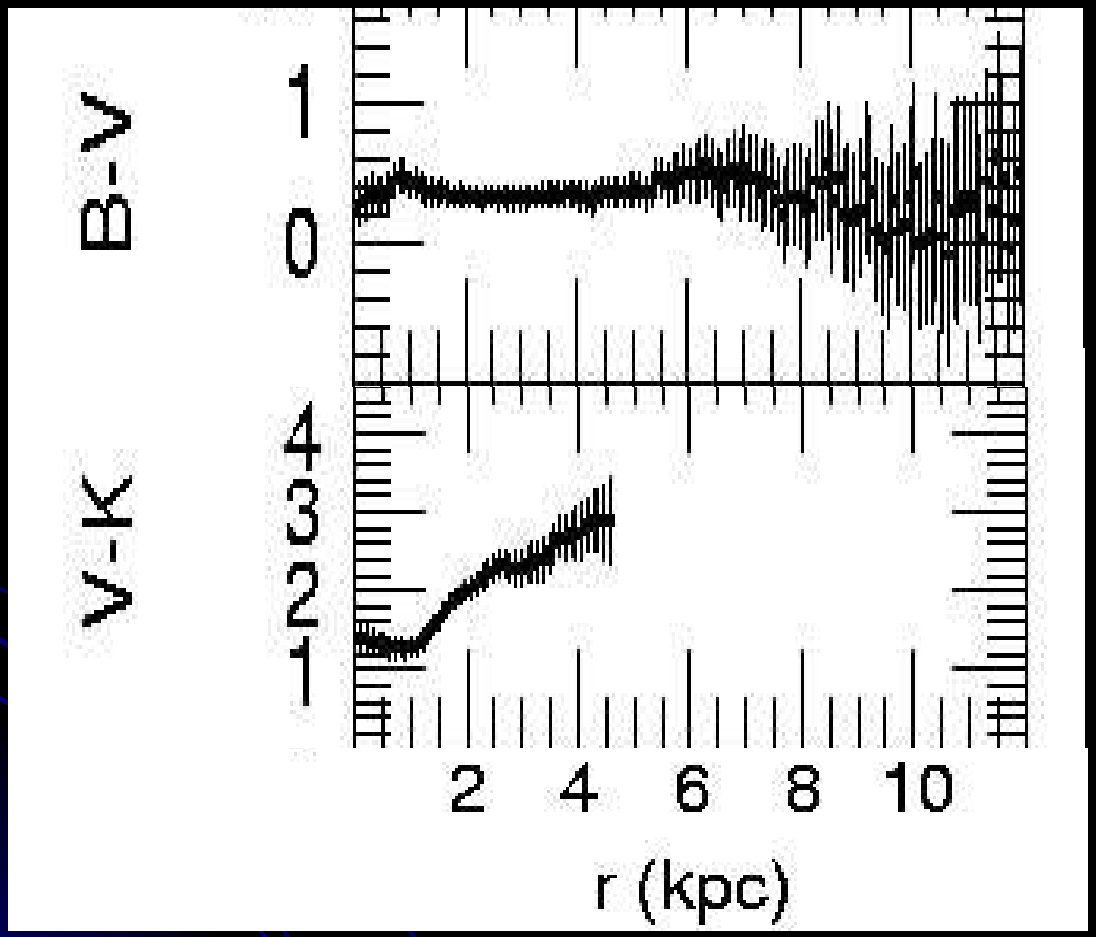
Blue Compact Galaxies (BCGs)

ESO 338-04
(HST)

Deep surface photometry in this region reveals host (or halo!)

Red halos of blue compact galaxies

Red halos typically detected at μ_B = 26—27 mag arcsec^{-2}



Bergvall & Östlin
2002, A&A 390, 891

The same bottom-heavy IMF explains the colours
of these halos as well (Zackrisson et al. 2006, ApJ, 650, 812)

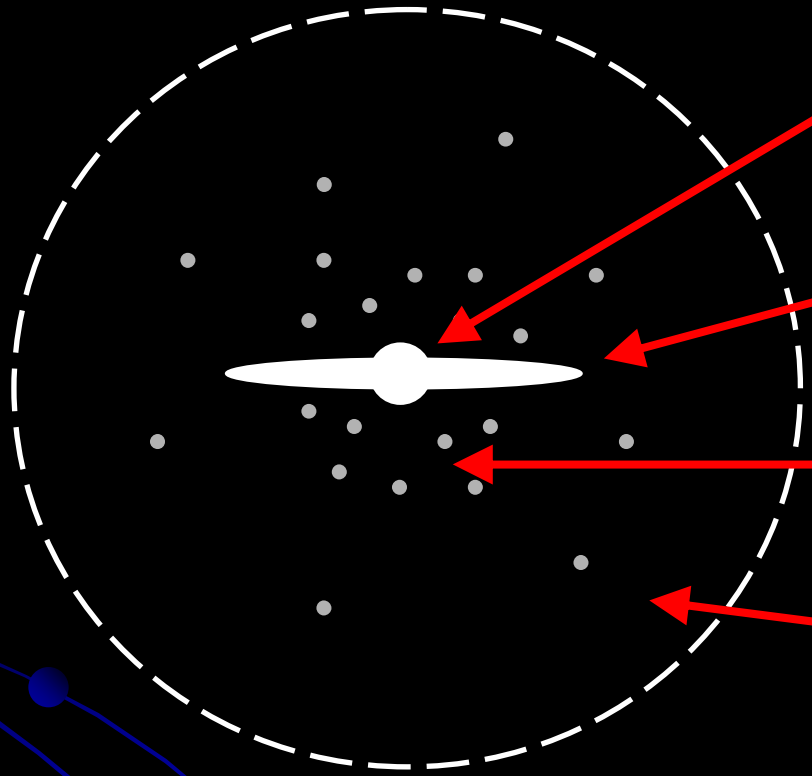
Red halos as baryonic dark matter

- Red halos dominated by low-mass stars common to very different types of galaxies
- Mass-to-light ratio:

  M/L > 40 $\rightarrow$ Effectively baryonic dark matter
- Could contribute substantially to the baryon budget of galaxies
- But note: Non-baryonic CDM still required in the dark halo

Zackrisson et al. (2007, arXiv: 0708.0762)

The Milky Way



Milky Way Bulge
$M \sim 2 \times 10^{10}\ M_{solar}$

Milky Way disk(s)
$\sim 6 \times 10^{10}\ M_{solar}$

Stellar halo
$M \sim 10^{9}$ Msolar

Dark halo
$M \sim 10^{12}$ Msolar

Crain et al. (2007) & WMAP 5-yr results →
Baryonic mass $\sim 15 \times 10^{10}\ M_{solar}$ expected within R_{vir}
Only $\sim 8 \times 10^{10}\ M_{solar}$ identified →
We are missing a few times $10^{10}\ M_{solar}$ of baryonic material!

Estimating the Mass of the Red Halo

Assume power-law density profile for the red halo:

$$n(x,y,z) = n_{\rm sun}\left(\frac{x^2+y^2+(z/q)^2}{R_0^2}\right)^{-\beta/2}$$

Adopt structural properties derived by Zibetti et al. (2004):

$$\beta \approx 3 \quad q \approx 0.6$$

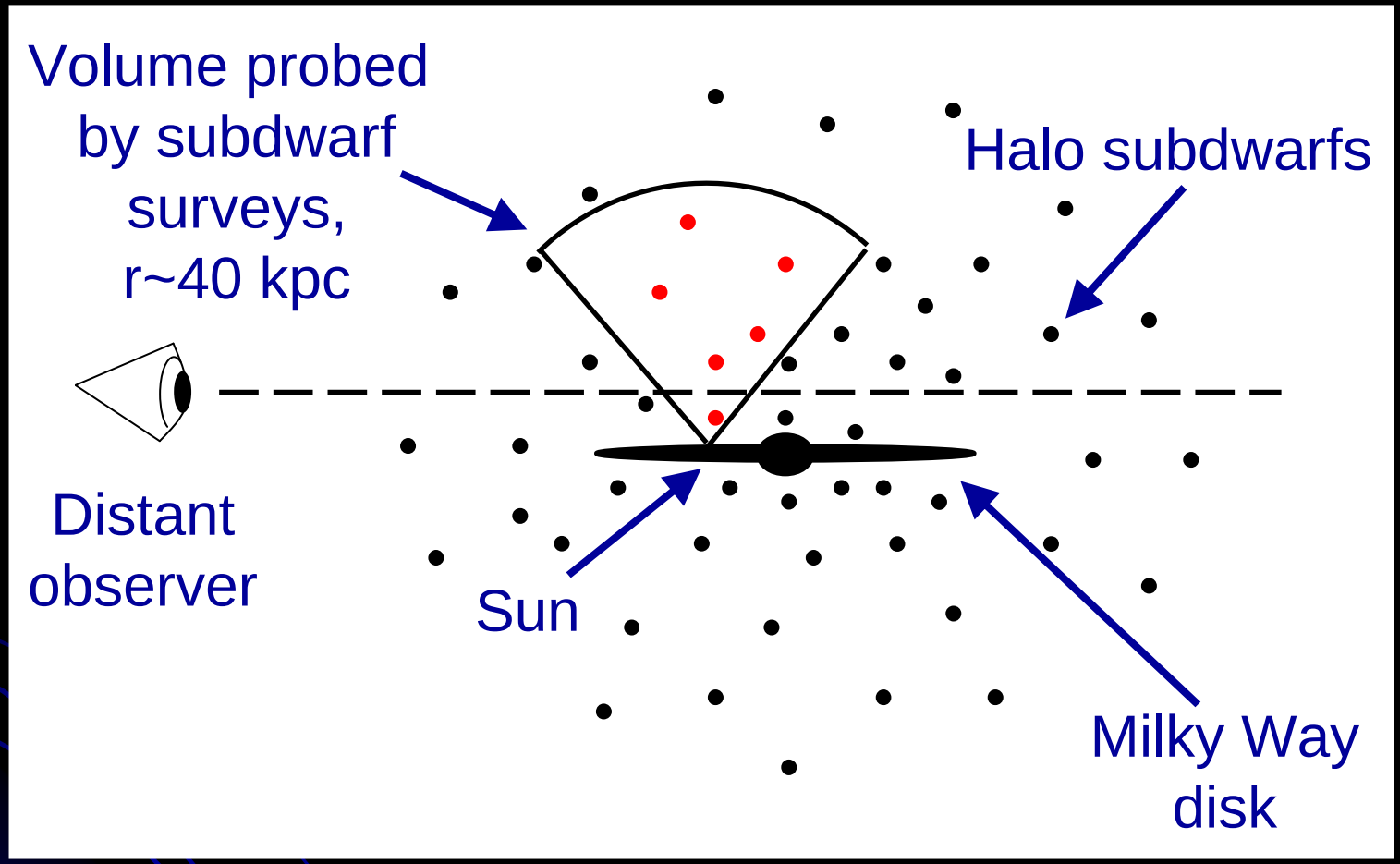
$$\mu_i \approx 26.7 \text{ mag arcsec}^{-2} \text{ at } R_{\rm proj} \approx 5 \text{ kpc}$$

Assume bottom-heavy IMF for the red halo:

$$dN/dM \propto M^{-4.50}$$

$\rightarrow$ A few times 10^{10} M_{solar} within R_{vir}! Great!

But Star Counts Disagree…



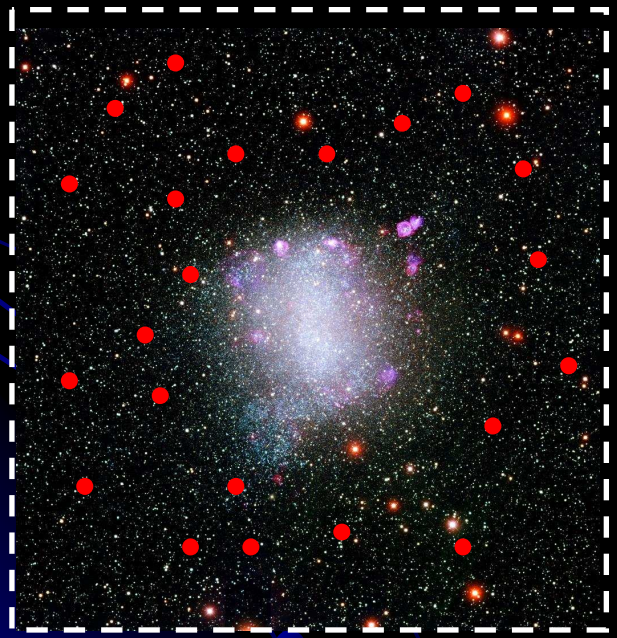
Smooth red halo of low-mass stars *completely ruled out*

→ Red halo stars must be clustered

(Zackrisson & Flynn 2008, in prep.)

Observable Consequences of Clusters of Low-Mass Stars

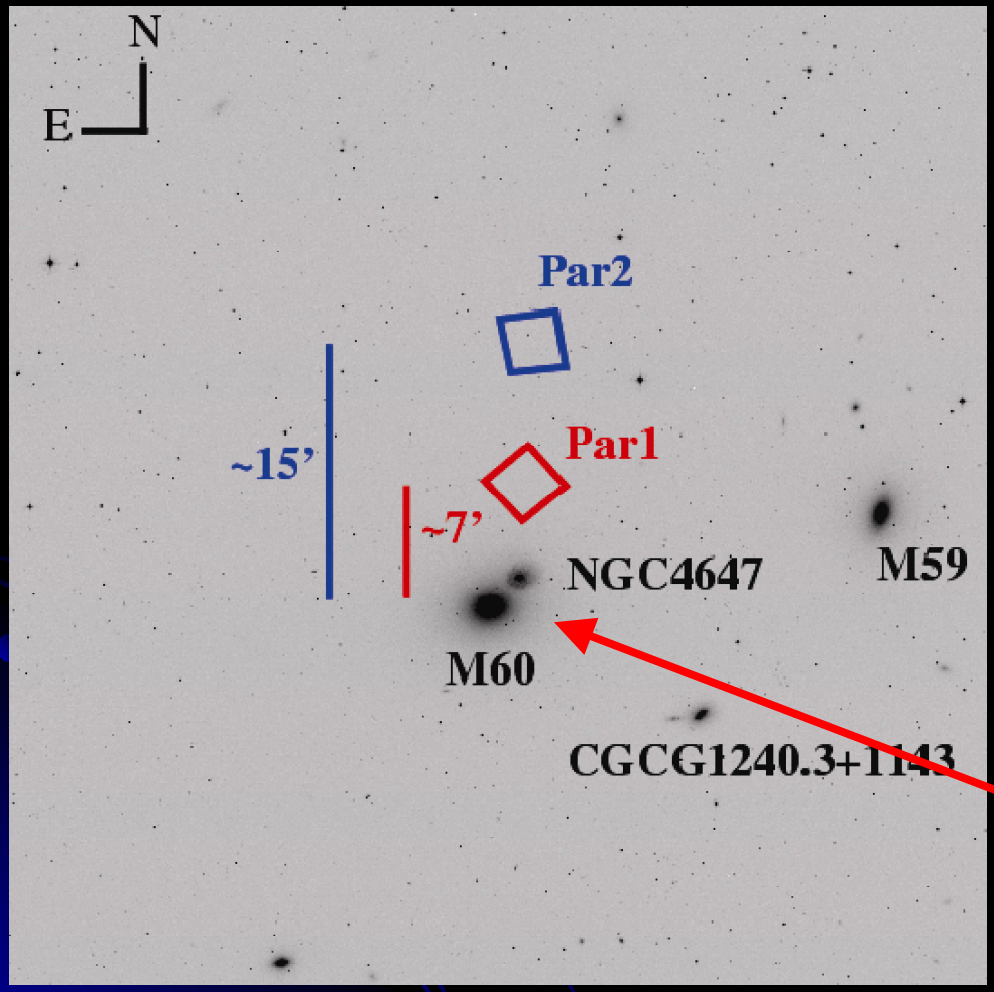
Deep, high-resolution observations of nearby halos should unravel point-sources with luminosities of red giants but very strange colours



Mass ~ 10^5 M_{solar} $\rightarrow$ M_I~-4

Typical TRGB luminosity!

M60 – A Rosetta Stone for Red Halos?



Serendipitous discovery of extremely red objects in the halo of M60, while using the HST to search for z~6 galaxies

The colours of these objects do not match any known type of star!

M60
~14 Mpc away

Yan et al. 2008, ApJ, 675, 136

Mundane explanations I

- Nebular emission?

  Photoionization models $\rightarrow$ No!

  Nebular emission would make the halo bluer!

- High metallicities (for BCGs)?

  In conflict with gaseous metallicities and mass estimates $\rightarrow$ Not likely!

- Dust reddening?

  Balmer decrement of BCGs $\rightarrow$ No!

- Dust emission in the K-band?

  ISO observations of BCGs $\rightarrow$ No!

Mundane explanations II

- Spectral synthesis problems?

  BC03, Pegase2, Zackrisson et al. (2001), Maraston (2005), Li & Han (2007) and Marigo et al. (2008) models all confirm that extreme stellar population properties are required.

- Sky subtraction problems?

  Tests with synthetic galaxies $\rightarrow$ No!

  Estimates of surface brightness level of extragalactic background light (Zackrisson & Östlin, in preparation) $\rightarrow$ No!

- Some instrumental effect ?

  Same red excess seen with different telescopes and instruments. No similar red halos seen around stars $\rightarrow$ No!

Ongoing searches

- Observational searches for red halos around:
  - A larger sample of BCGs (PIs Östlin & Zackrisson)

    ~ 45 objects, ~60 nights on NOT 2.5 m
  - Elliptical galaxies (PI Bergvall)

    ~ 15 objects,15 nights on NOT 2.5 m
  - Post-starburst galaxies (PI Zackrisson)

    ~ 15 objects, 5 nights on NOT 2.5m and ESO 3.5m
  - Local Group dwarfs (PI Zackrisson)

    2 nights with ESO 2.2m/WFI

Corroborating evidence for a bottom-heavy IMF

Star counts in the LMC reveal a field IMF with $dN/dM \propto M^{\alpha}$ and $\alpha \approx -5$ to -6 for $M \geq 1$ Msolar

Massey 2002, ApJS, 141, 81
Gouliermis et al. 2006, ApJ, 641, 838

Summary

- Red halos detected through deep surface photometry of galaxies
- Possible explanation: A stellar population dominated by low-mass stars $\rightarrow$ Important consequences for baryonic dark matter!
- Star counts in the Milky Way rule out a smooth red halo of low-mass stars $\rightarrow$ Red halo stars would have to be highly clustered
- Red halo star clusters may be detectable in other nearby galaxies