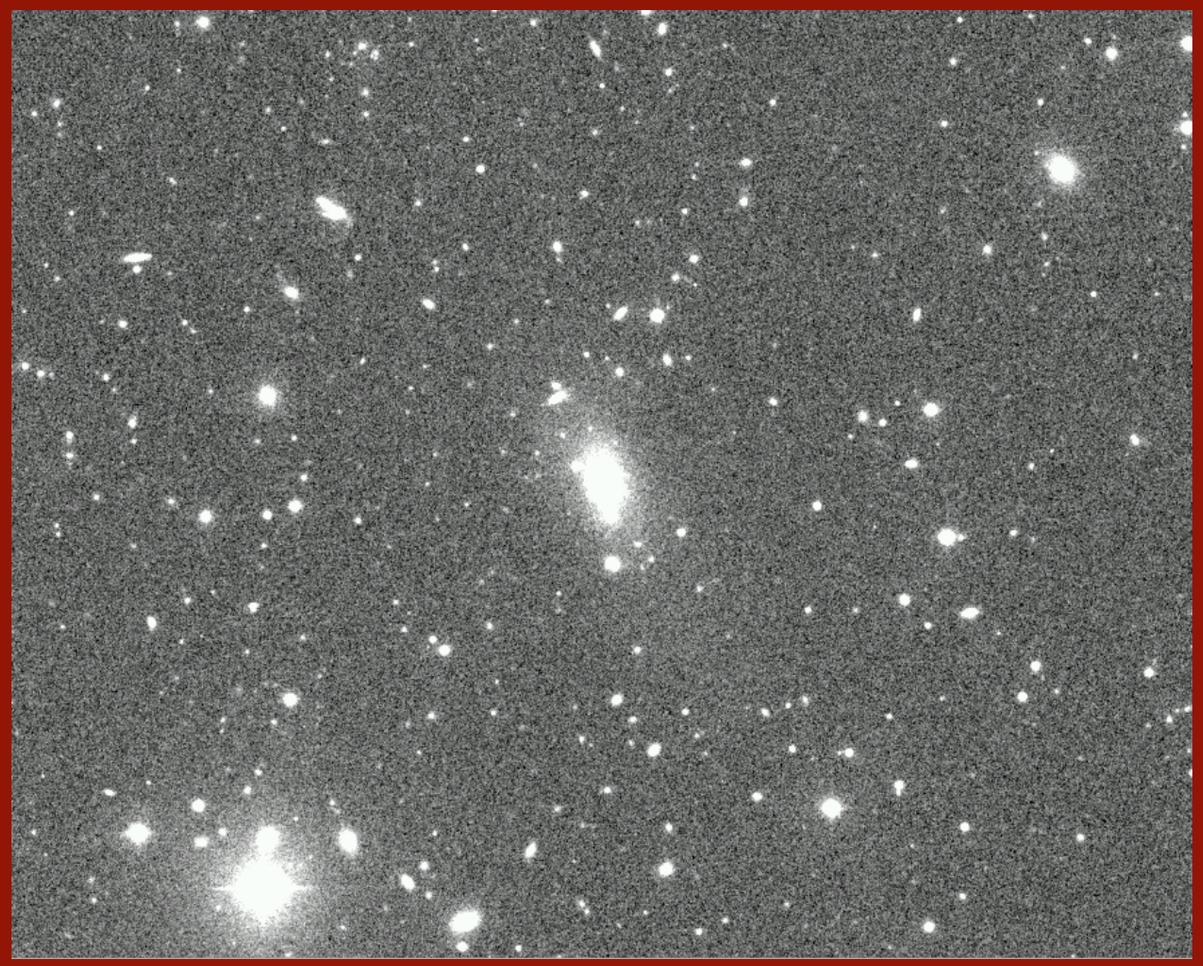
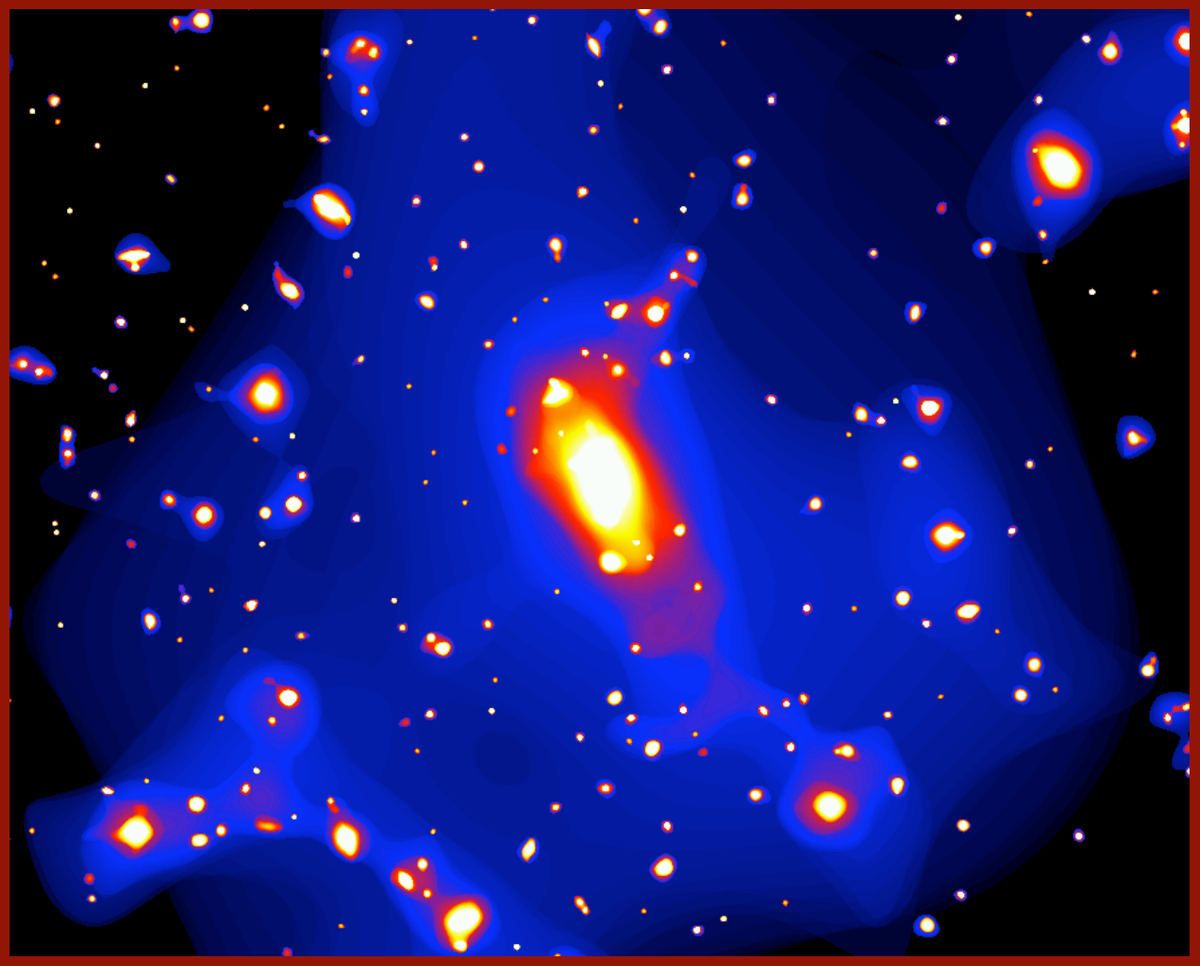
A Census of Baryons in Groups and Clusters

A. Zabludoff (Arizona), D. Zaritsky (Arizona), A. Gonzalez (Florida),
S. Sivanandam (Arizona), D. Kelson (OCIW)





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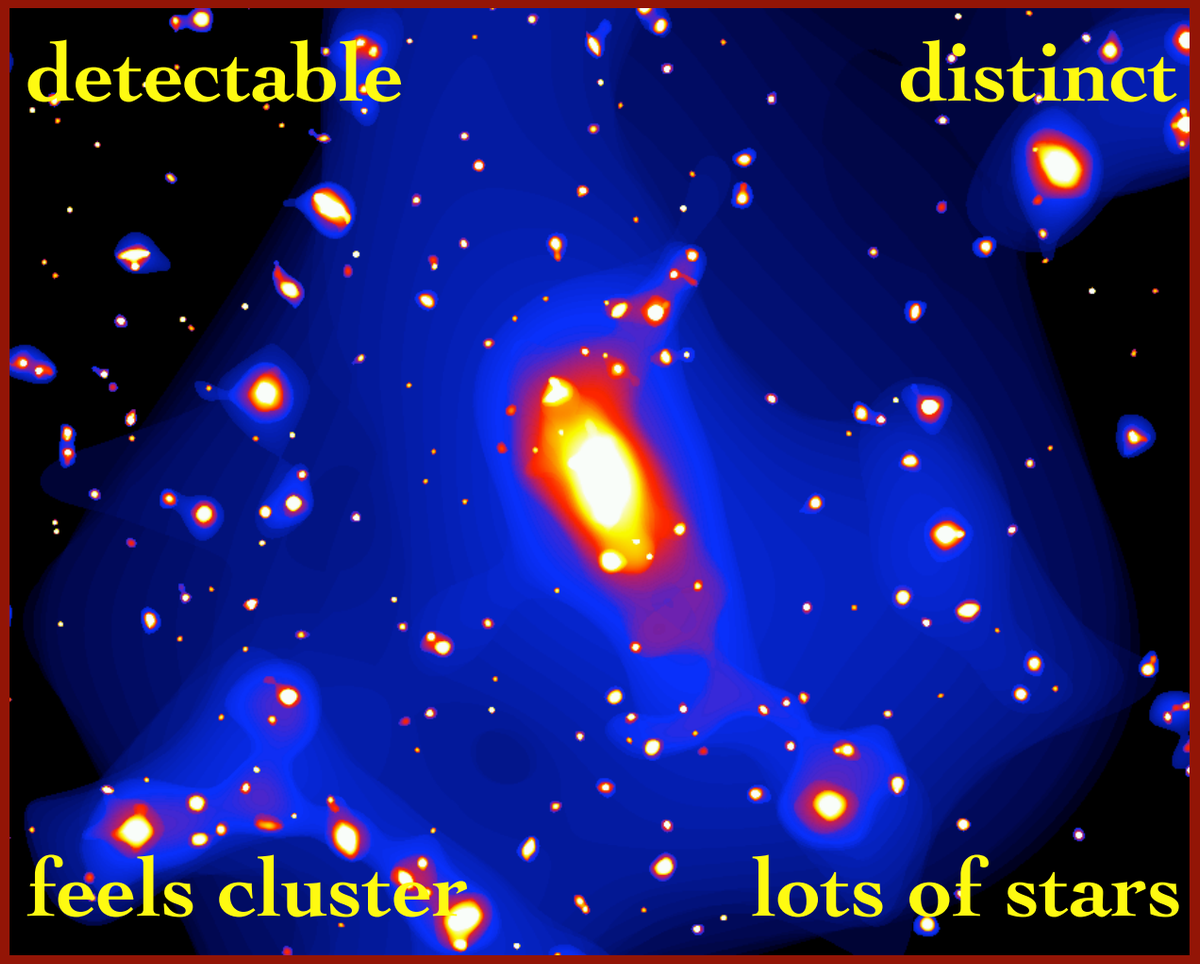


Baryons and Structure Evolution

relationships among baryons, dark matter timely

galactic structure due to baryon packing, star formation efficiency (Zaritsky's colloquium!)

clusters are baryon sinks, ~Universal baryon fraction

cosmology: 1) stars & gas ---> cluster mass ---> number density & spatial distribution, 2) mass fraction in cluster baryons ---> small-scale CMB anisotropies ---> power spectrum normalization, 3) baryon fraction(z) ---> dark energy (!)

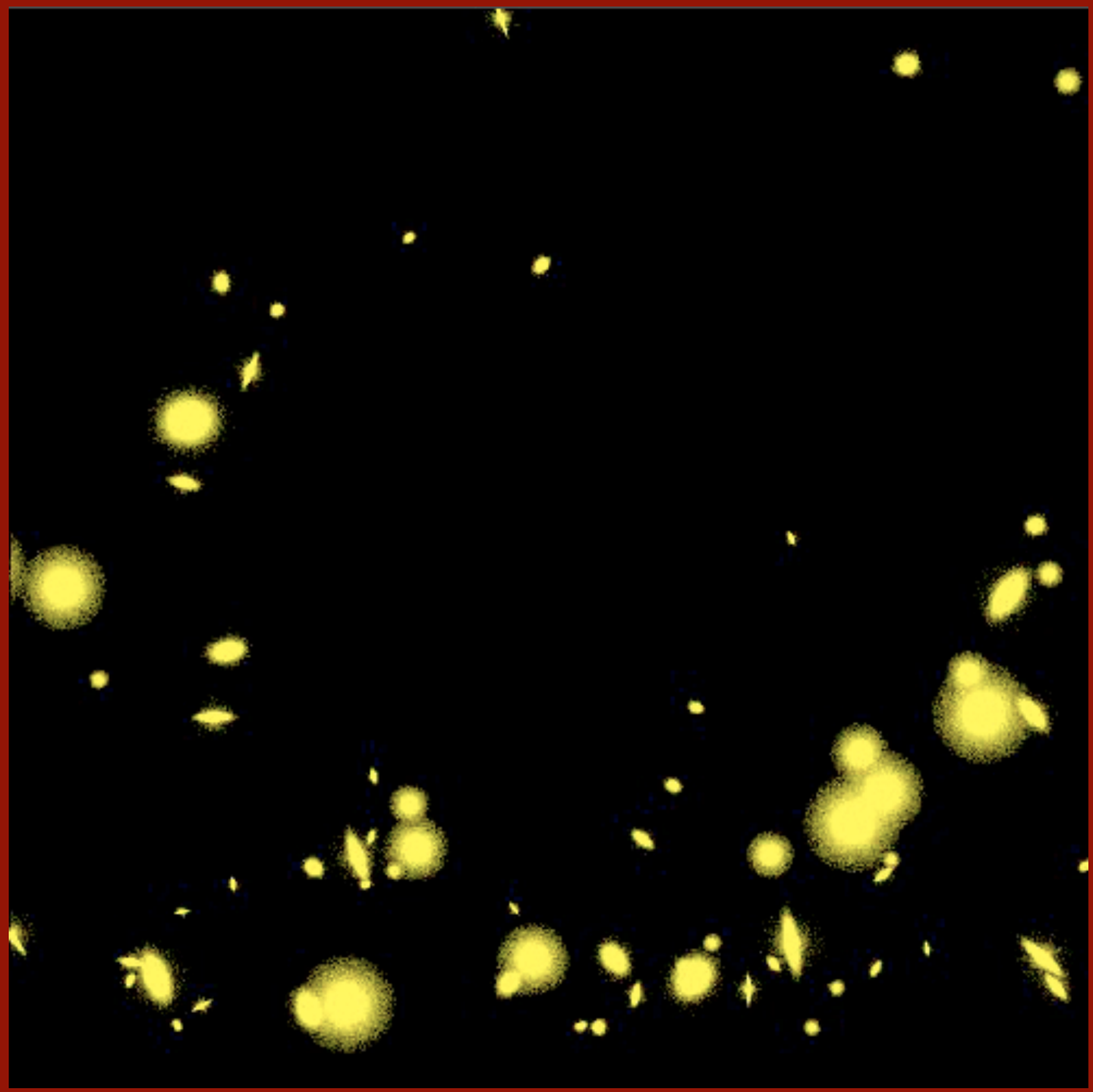
galaxy evolution: efficiencies of star formation, feedback, enrichment

Intracluster Stars and Structure Evolution

intracluster stars hard to count, but significant

trace potential, enrich cluster gas, solve missing baryons, constrain star formation efficiency

arise in groups?



C. Mihos & C. McBride

Intracluster Stars and Structure Evolution

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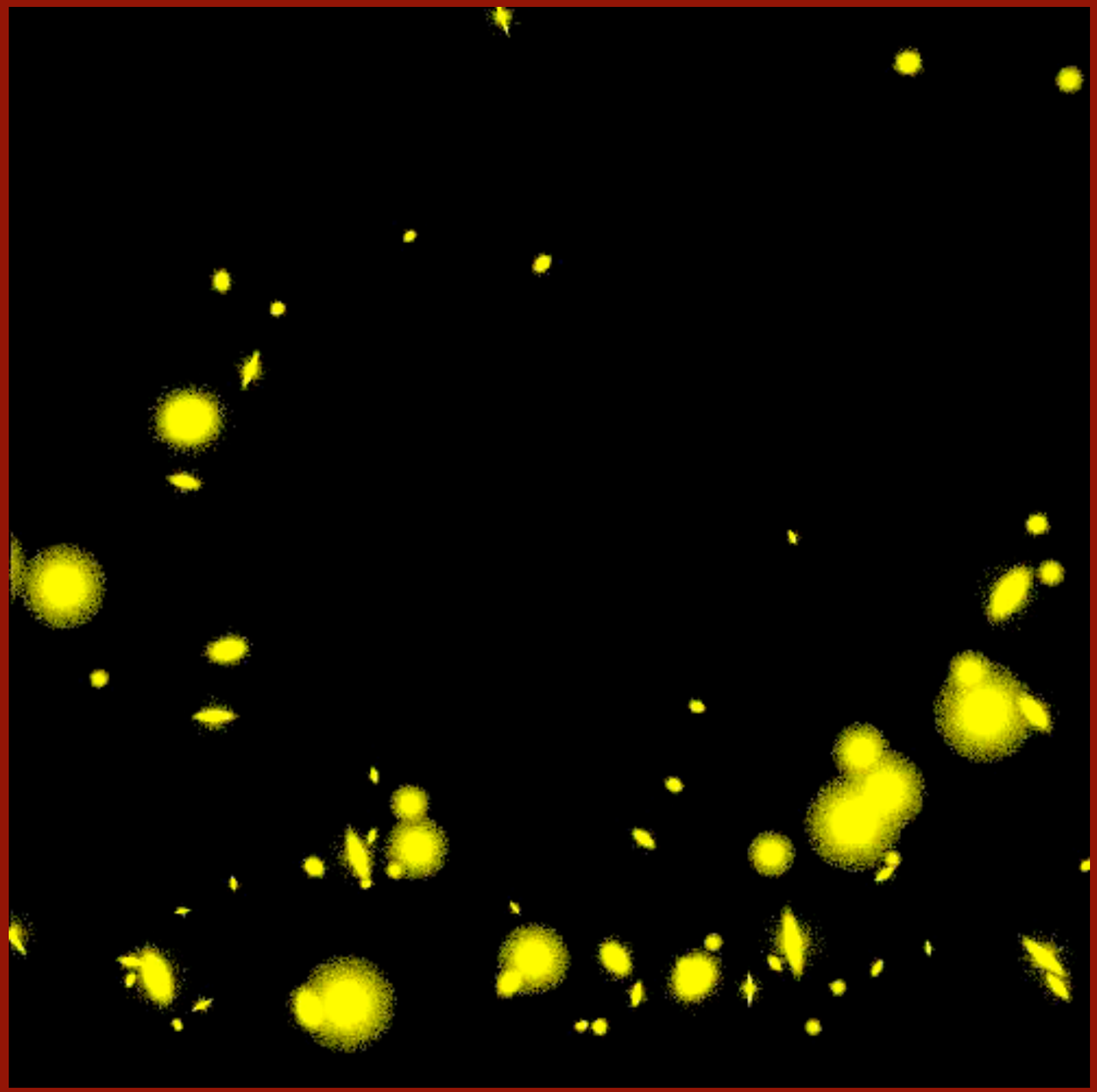


C. Mihos & C. McBride

Detection of Intracluster Starlight

uniform data: drift scans in Gunn-I for 24 clusters, groups at z = 0.03-0.13

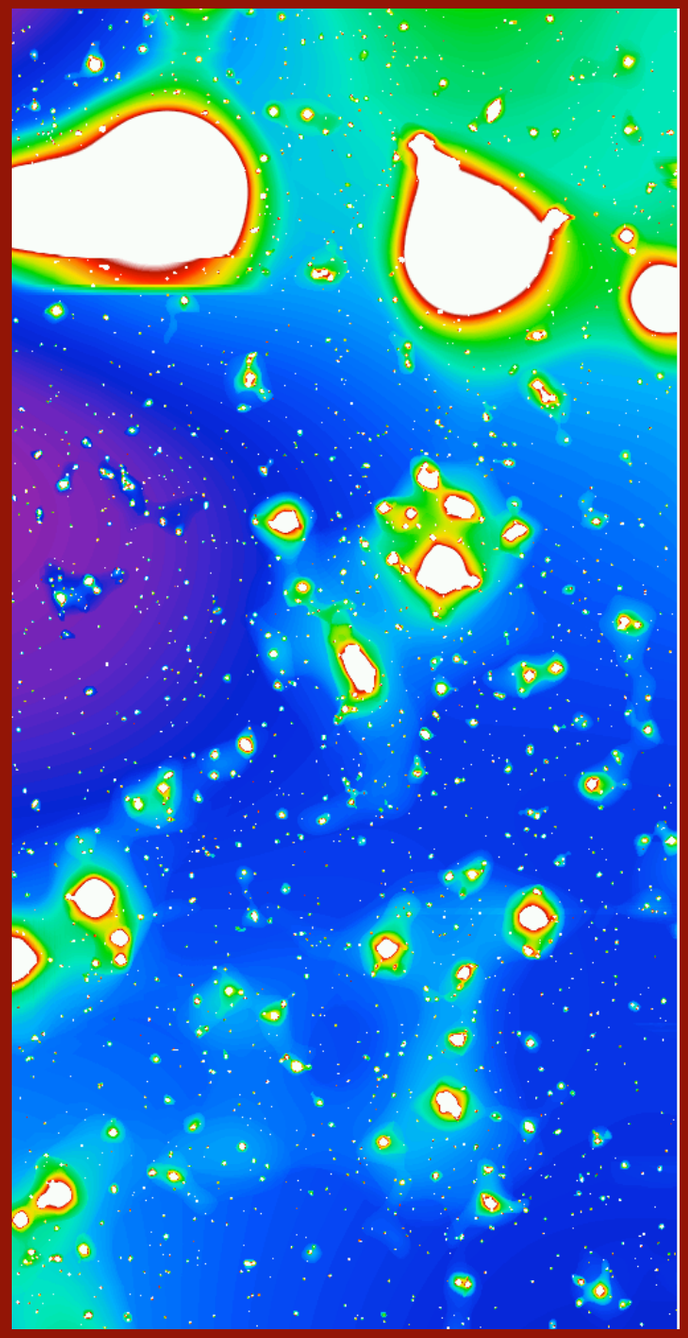
optimized reduction: removal of stars, galaxies, saturated stars, sky gradients >> intracluster stellar component

2-D modeling: convolution with PSF, multiple components, model/data masking (GALFIT; Peng et al. 2002)

goal: robust profiles to 300 kpc (~26 mag/sq")

Detection of Intracluster Starlight (cont.)

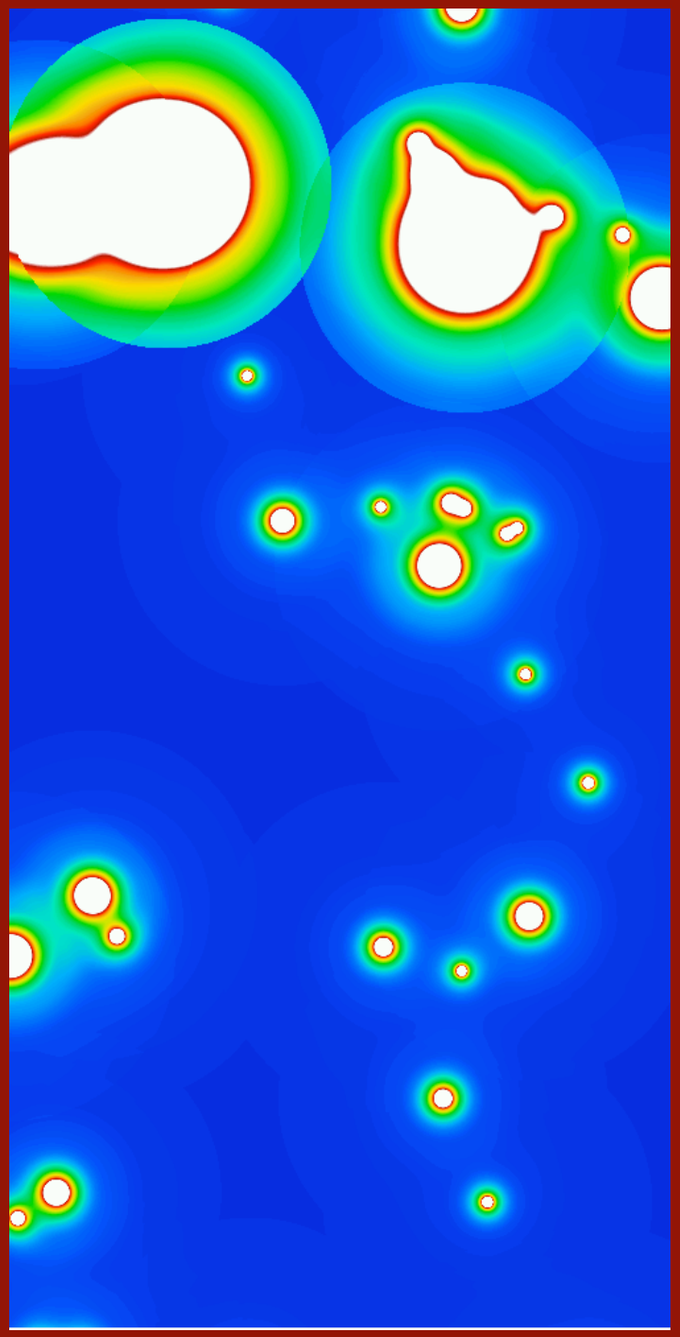
first-pass sky removal



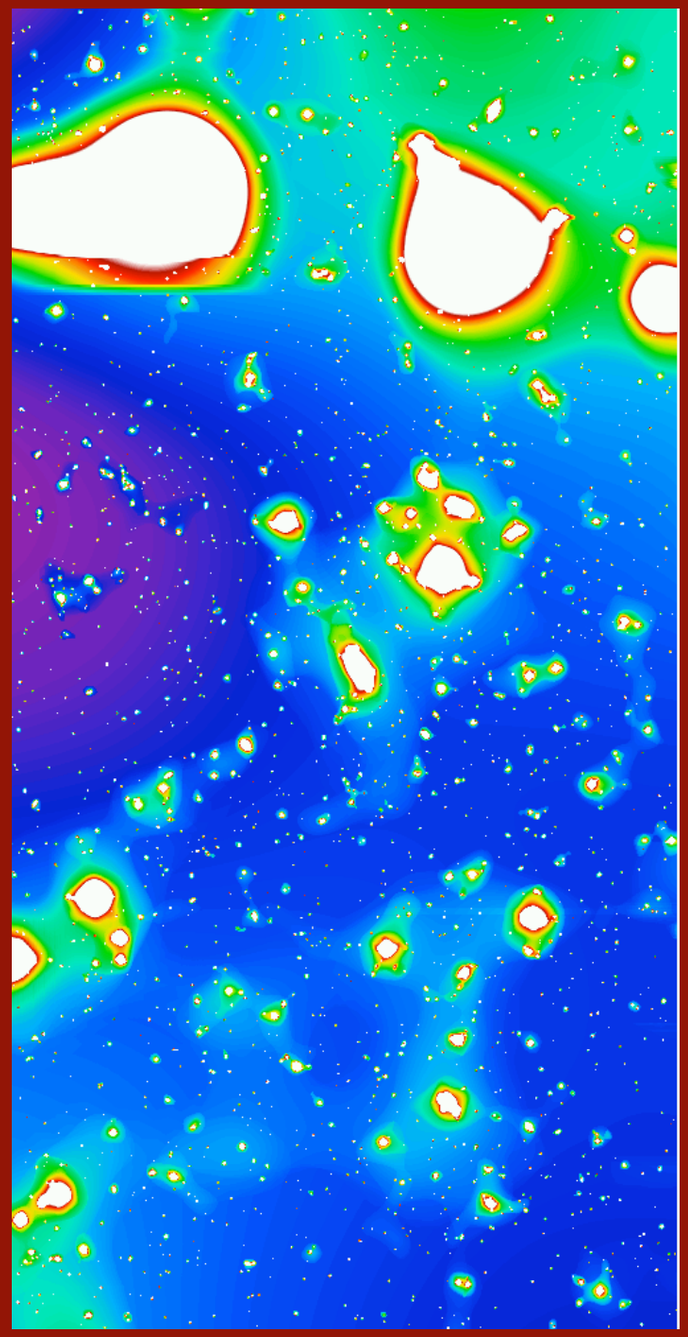
smoothed image

co-add image

Detection of Intracluster Starlight (cont.)



star map

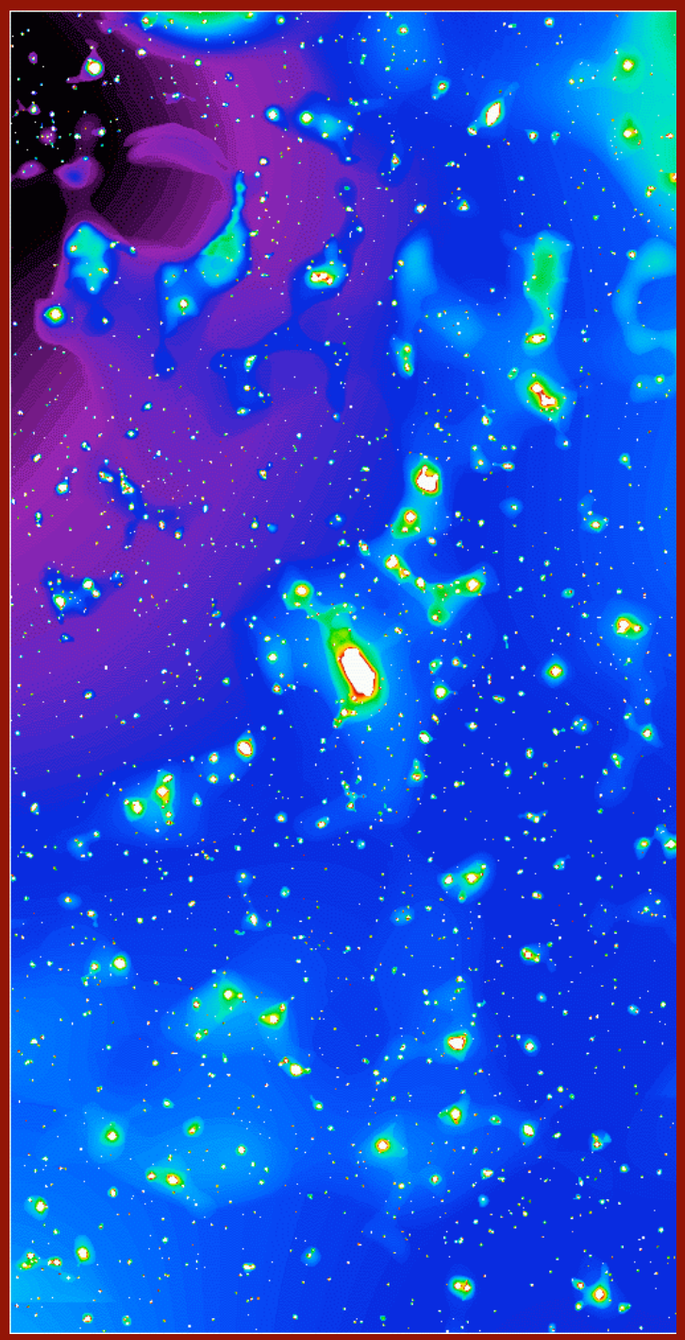


smoothed image

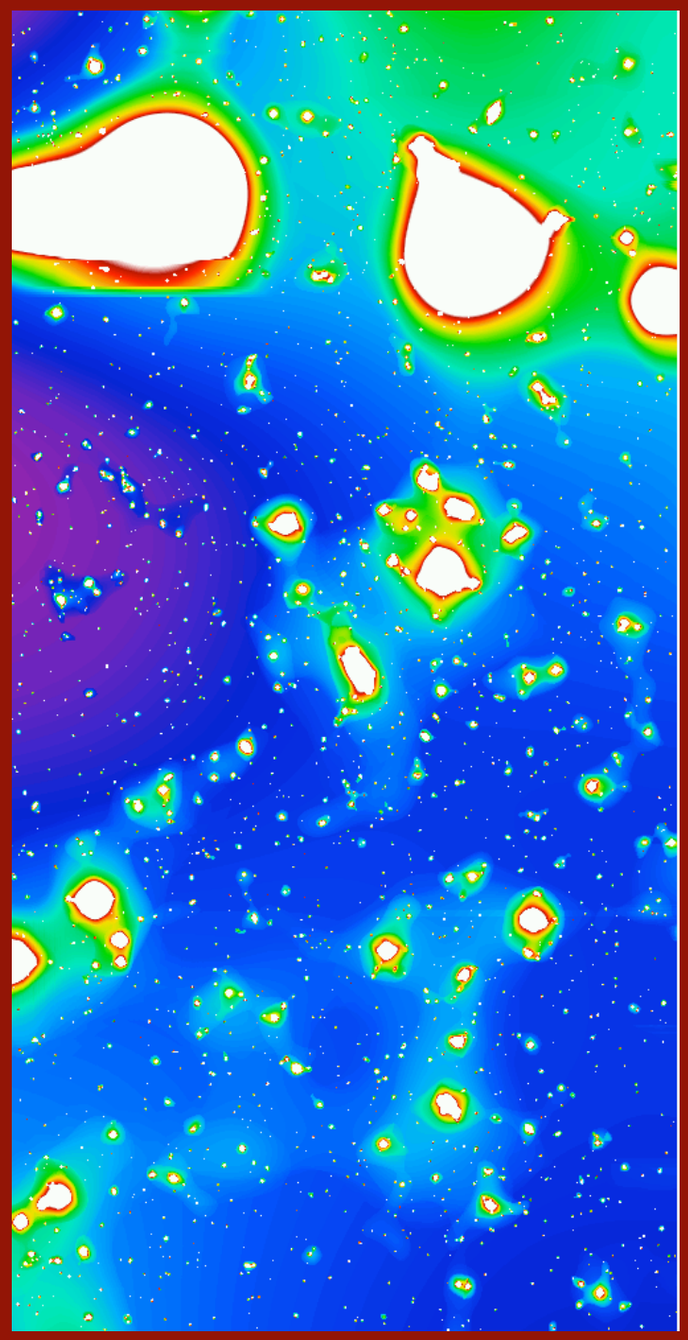
co-add image

fit saturated stars

Detection of Intracluster Starlight (cont.)



subtracted image



smoothed image

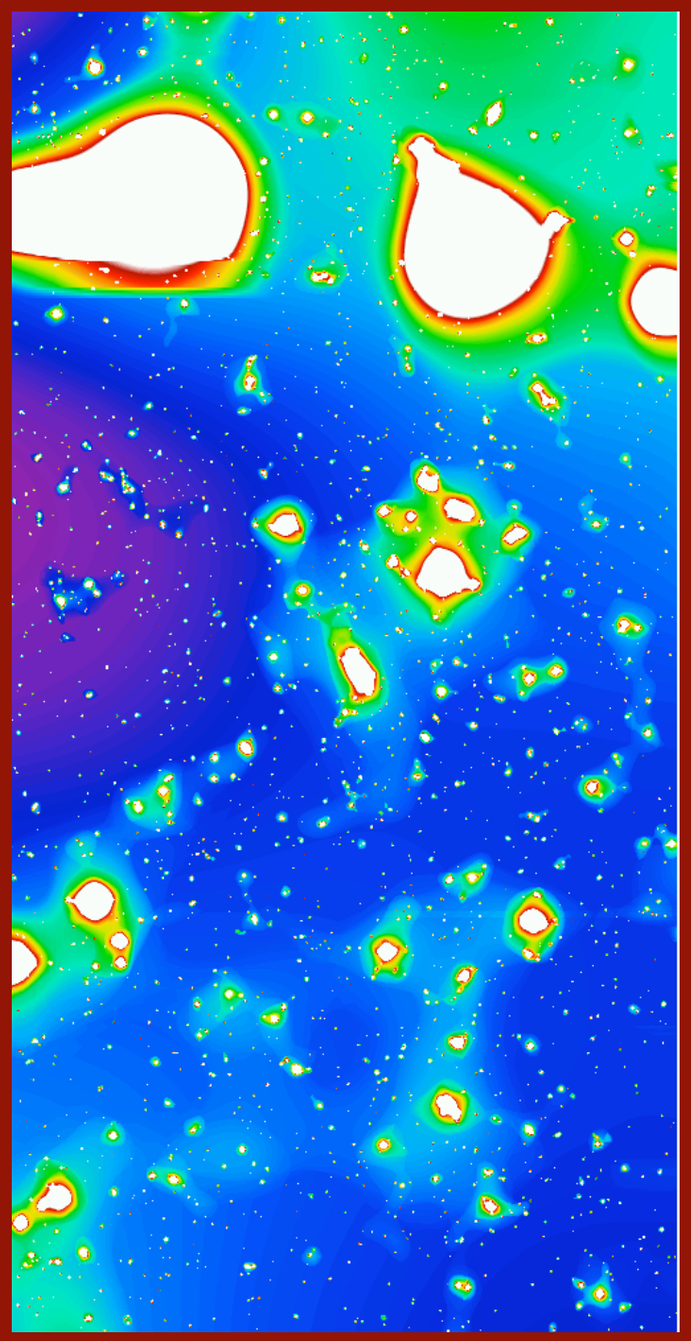
co-add image

fit saturated stars

subtract PSFs

Detection of Intracluster Starlight (cont.)

background image



smoothed image

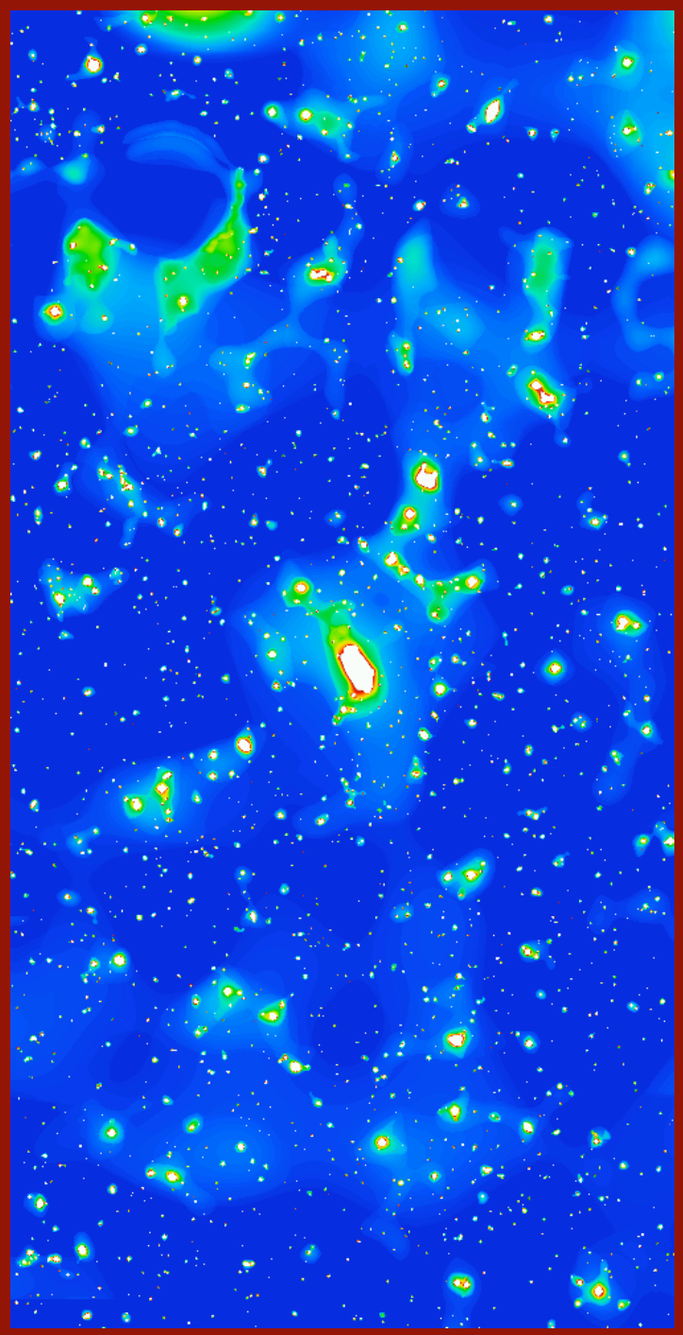
co-add image

fit saturated stars

subtract PSFs

fit large-scale sky gradients

Detection of Intracluster Starlight (cont.)



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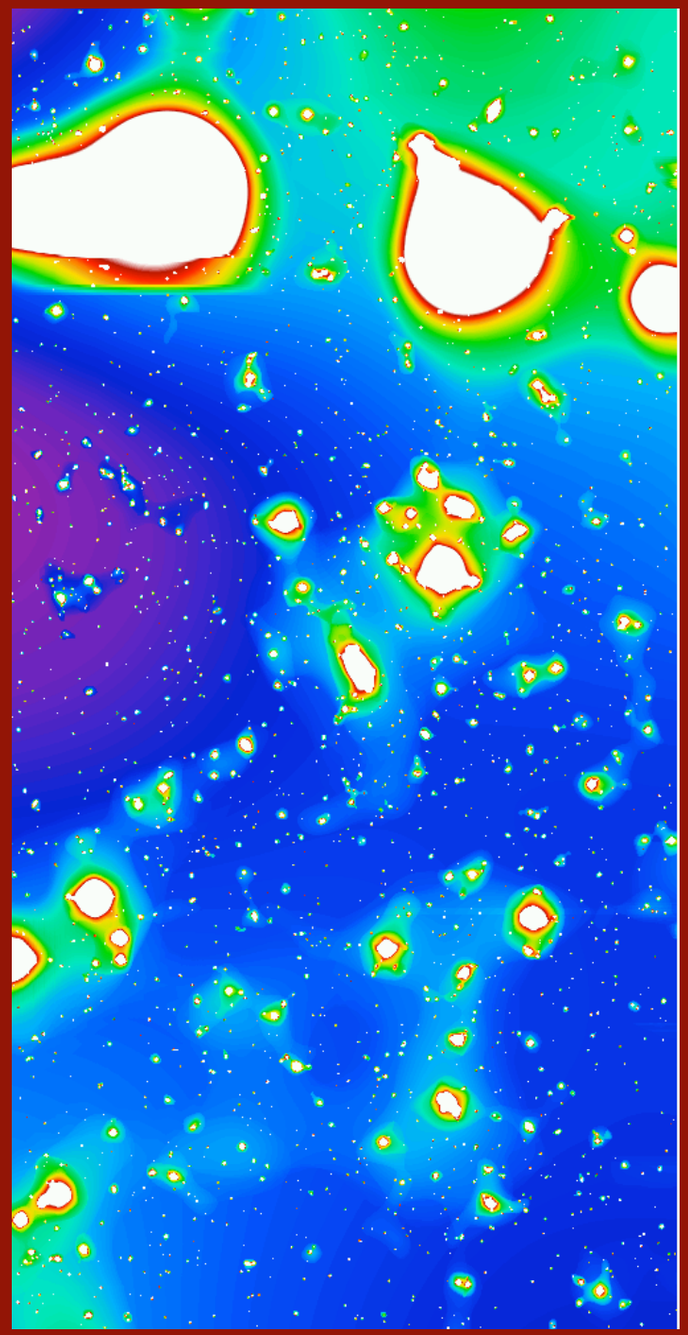

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co-add image

fit saturated stars

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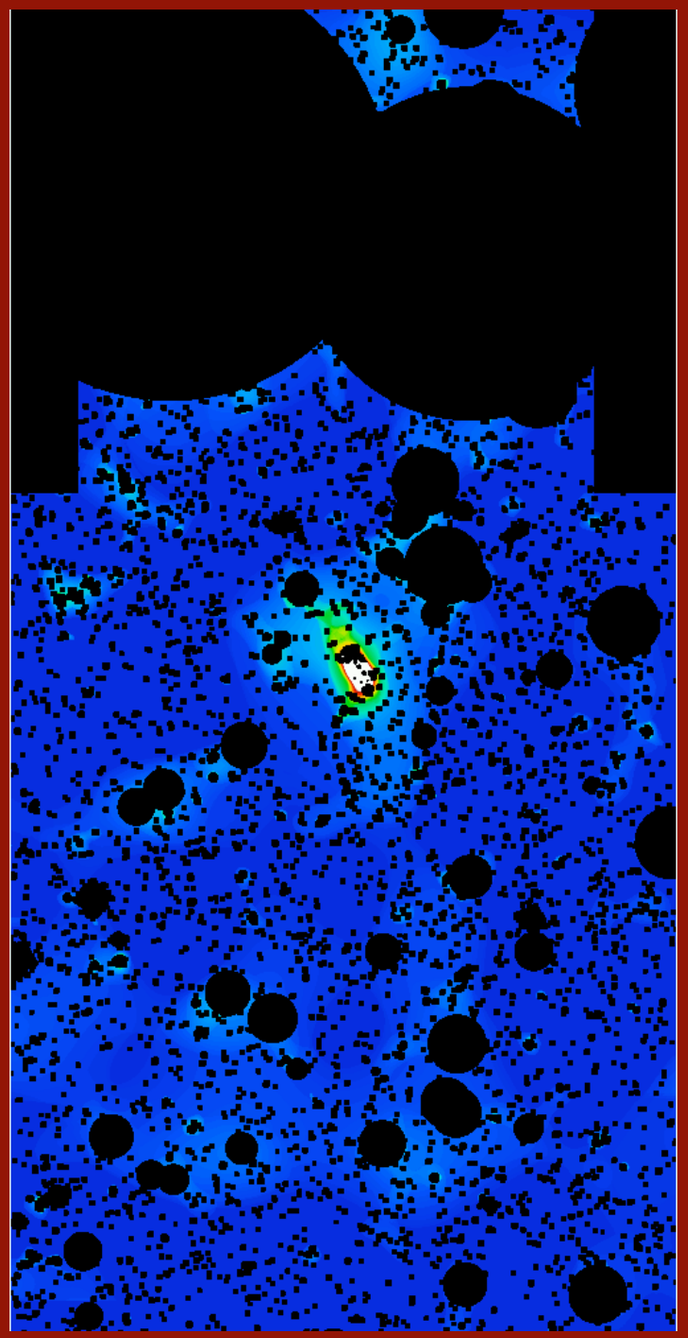
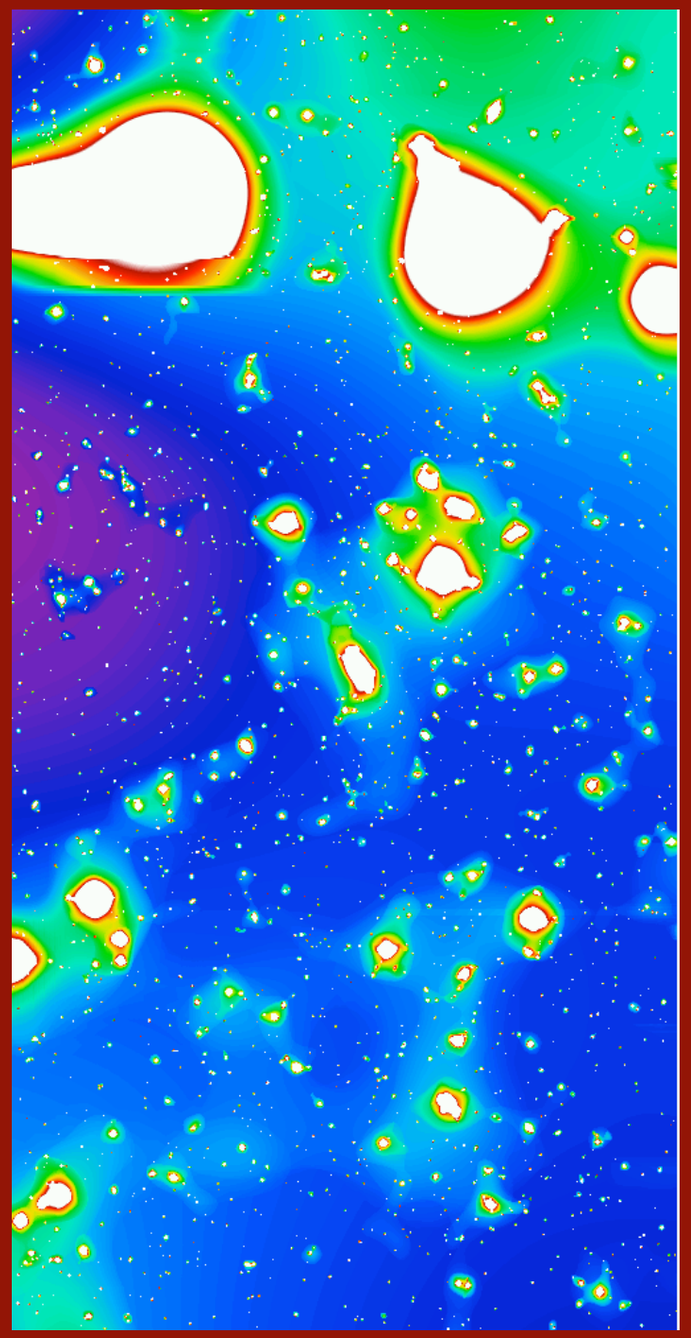
Detection of Intracluster Starlight (cont.)



final masked image



smoothed image

co-add image

fit saturated stars

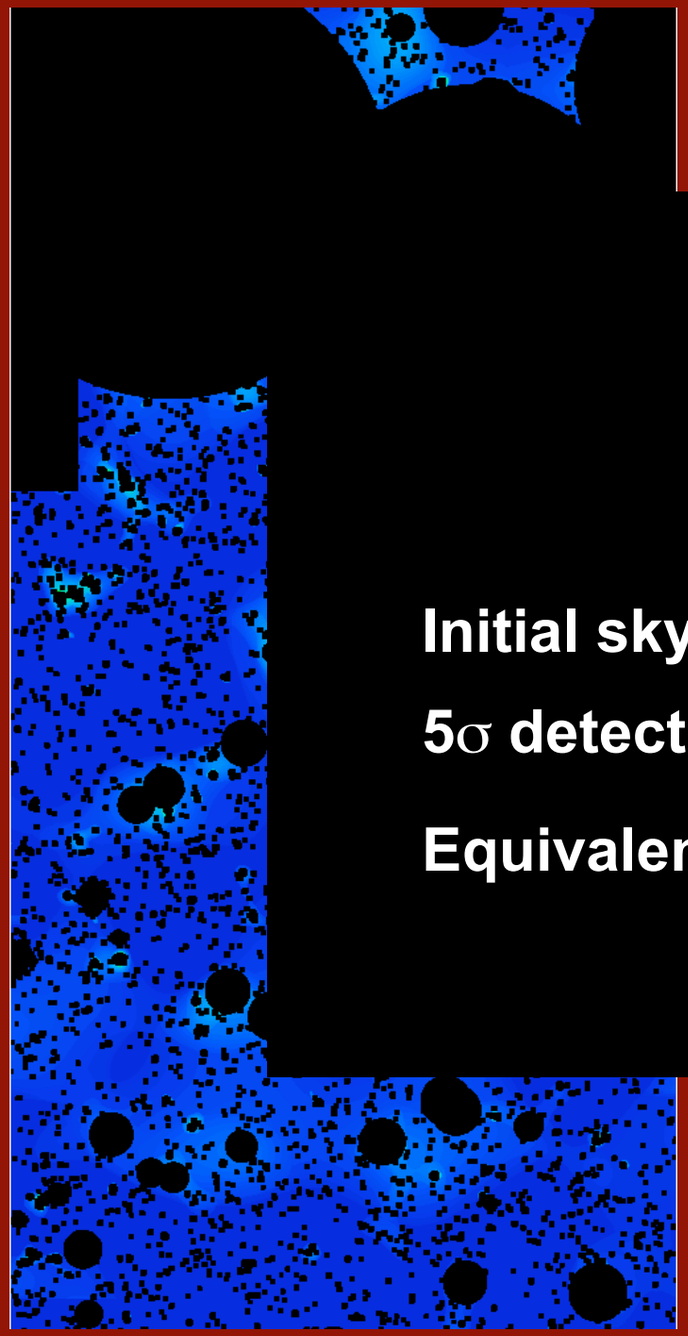
subtract PSFs

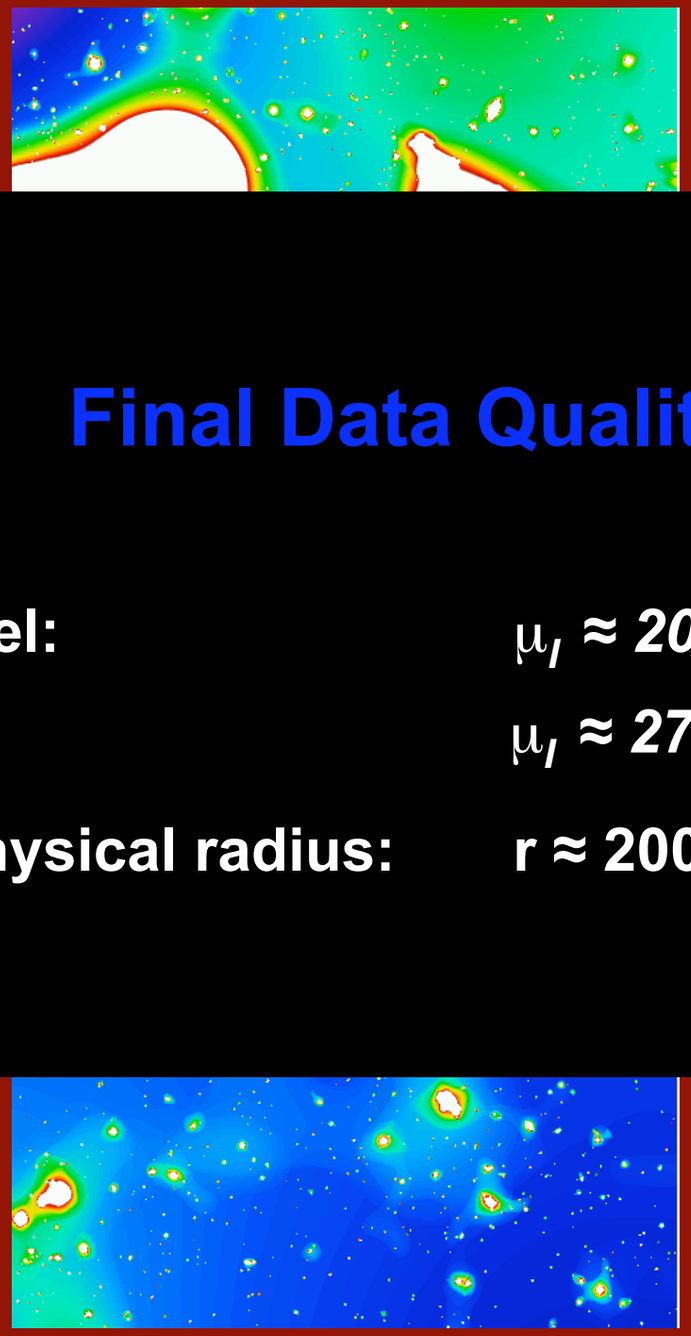
fit large-scale sky gradients

subtract background map

mask objects

Detection of Intracluster Starlight (cont.)





final masked image

smoothed image

co-add image

d stars

SFs

ale sky

background map

mask objects

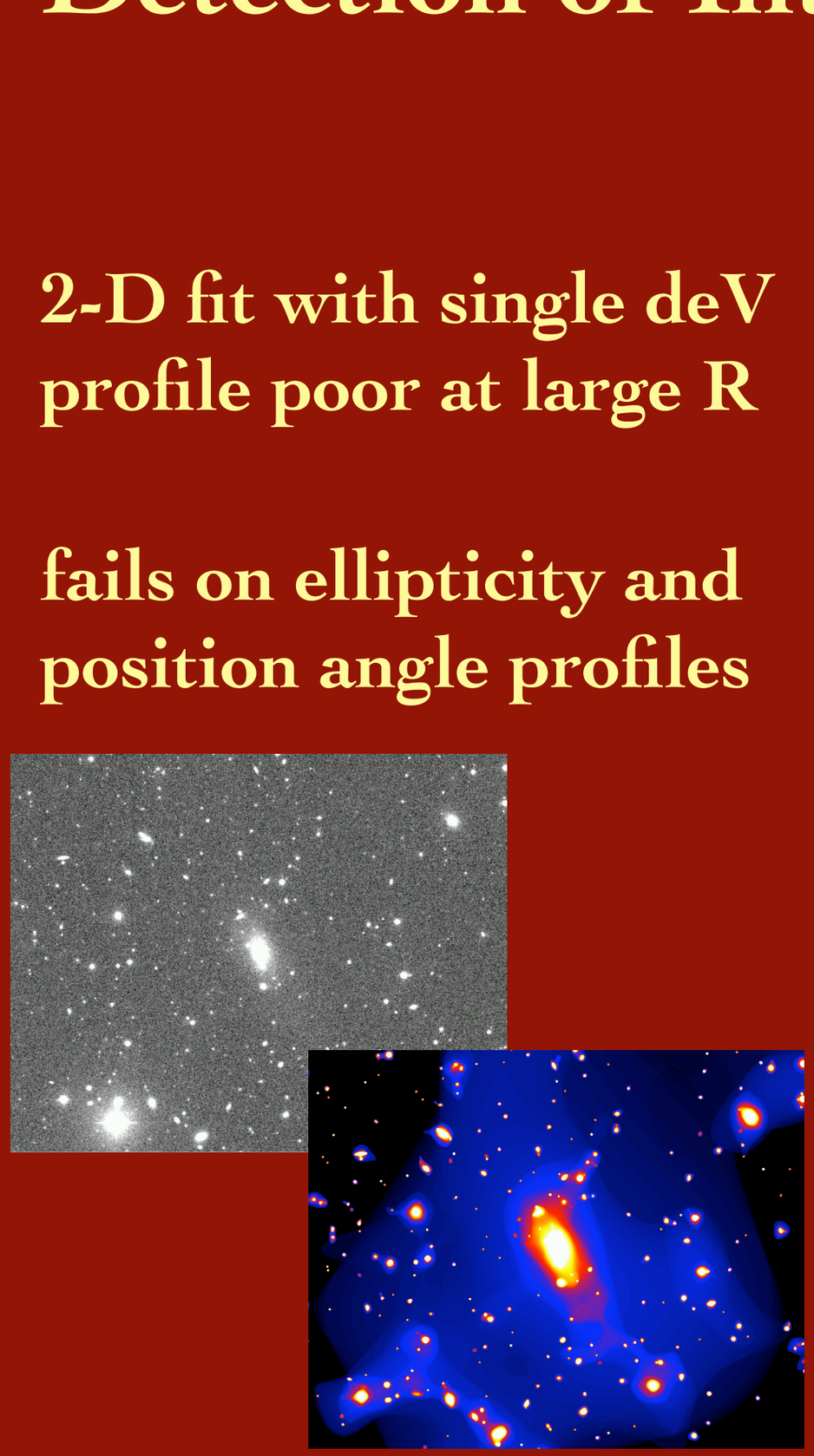
Final Data Quality

Initial sky level:	$\mu_I \approx$ *20 mag/sq"*
5σ detection:	$\mu_I \approx$ *27.5 mag/sq"*
Equivalent physical radius:	**r ≈ 200-600 h_{70}^{-1} kpc**

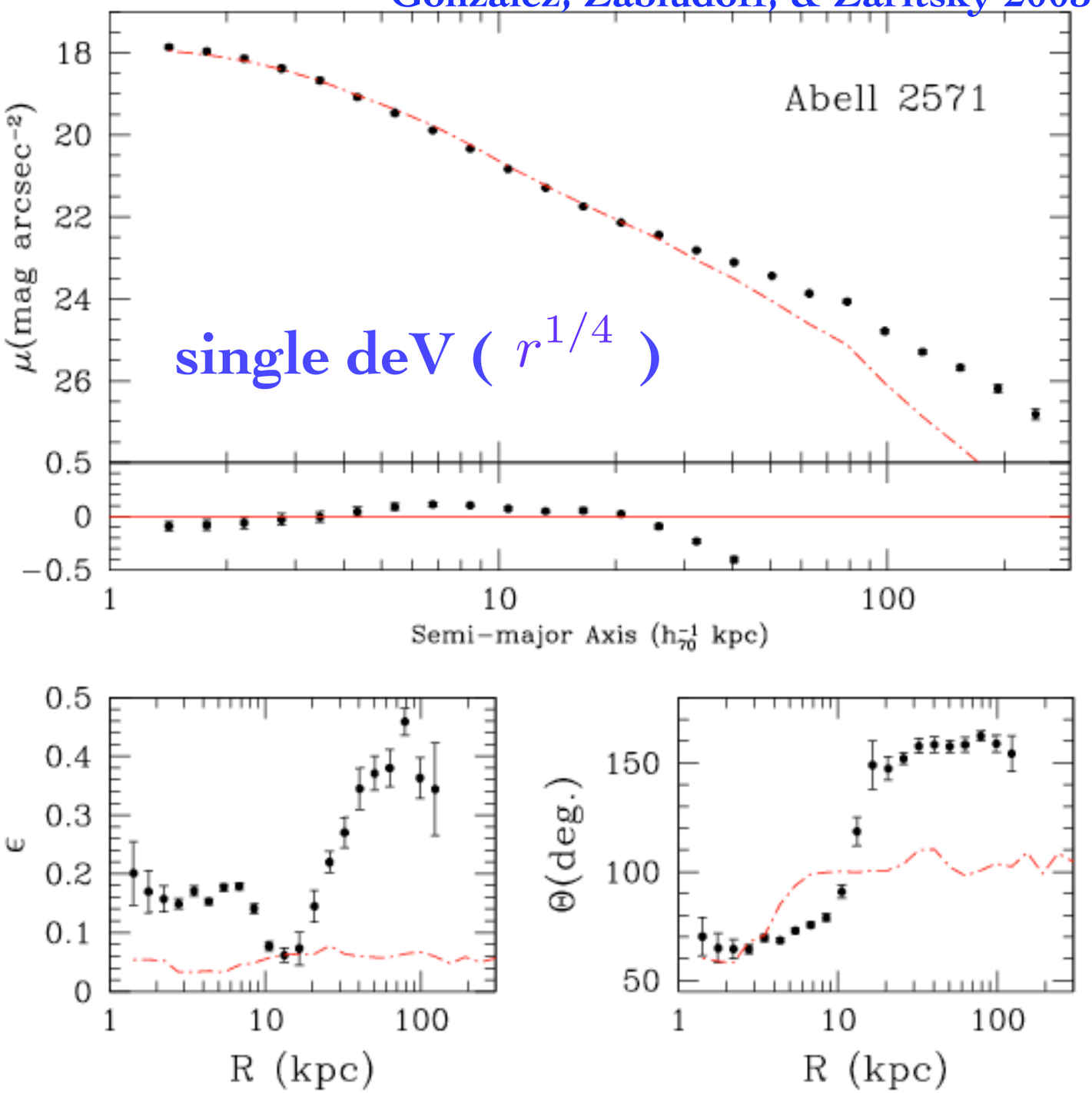
Detection of Intracluster Starlight (cont.)

2-D fit with single deV profile poor at large R

fails on ellipticity and position angle profiles



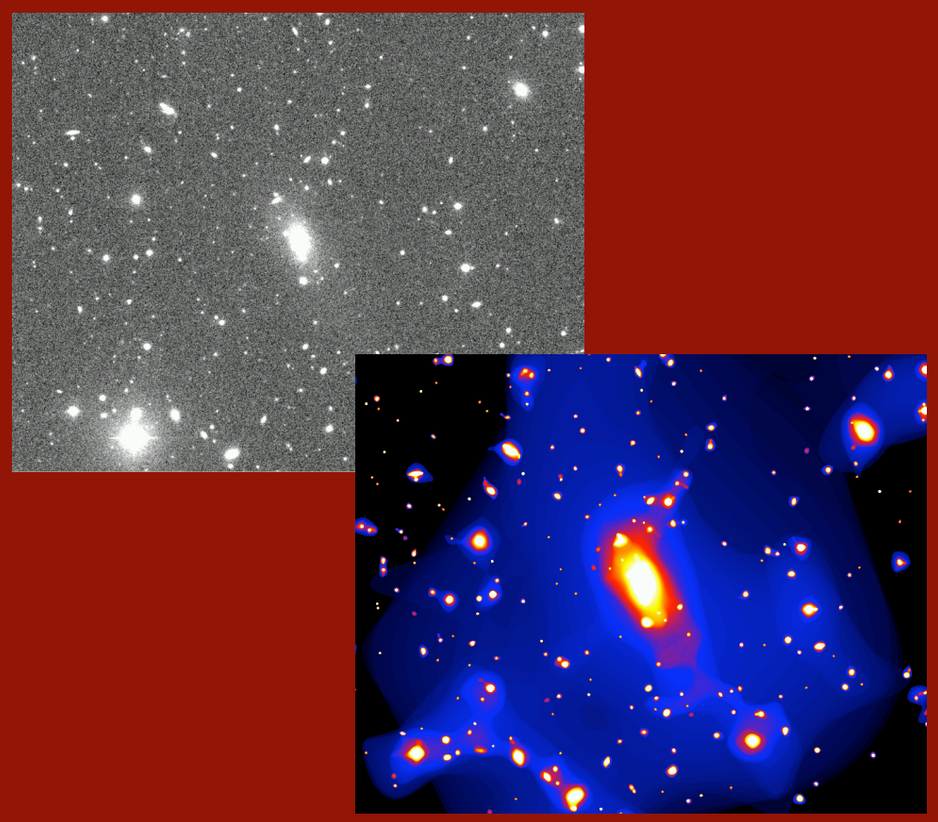
Gonzalez, Zabludoff, & Zaritsky 2005



Detection of Intracluster Starlight (cont.)

2-D fit with single Sersic profile better

fails on ellipticity and position angle profiles



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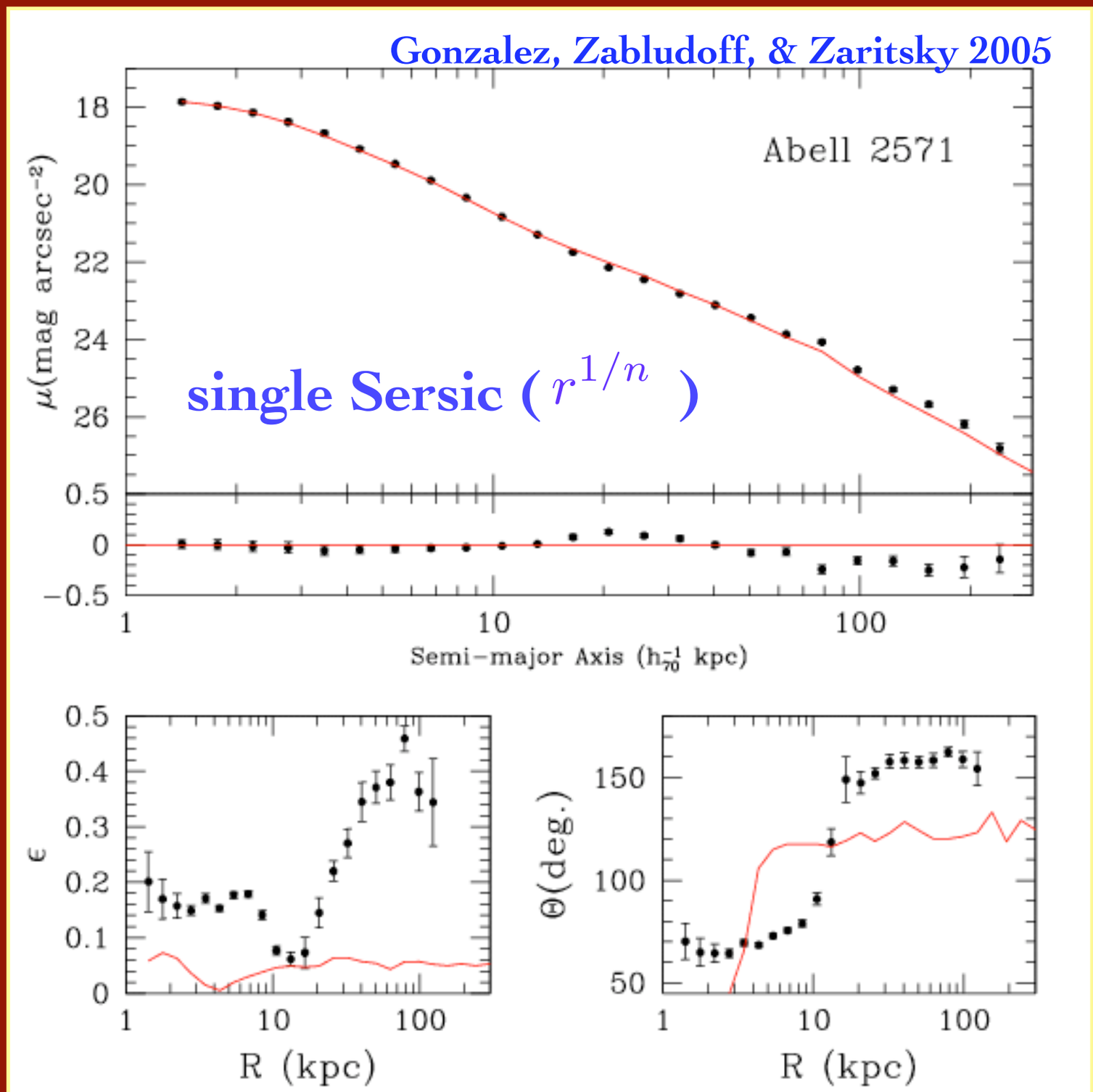
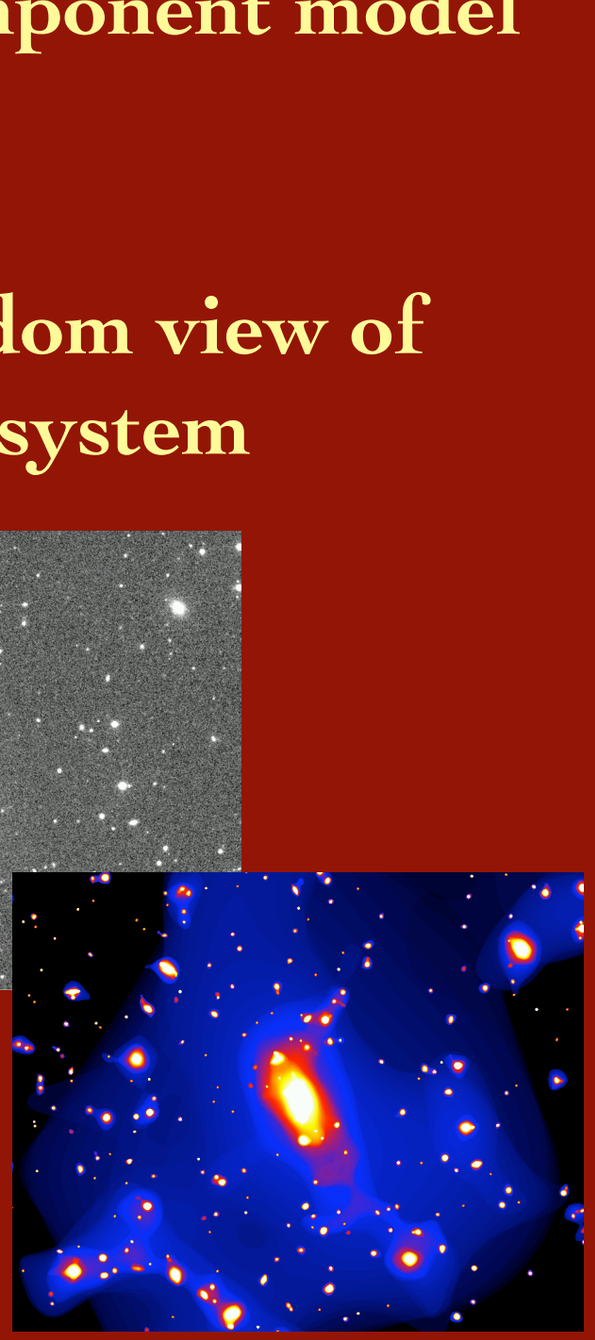


Detection of Intracluster Starlight (cont.)

two component model best fit

not random view of triaxial system



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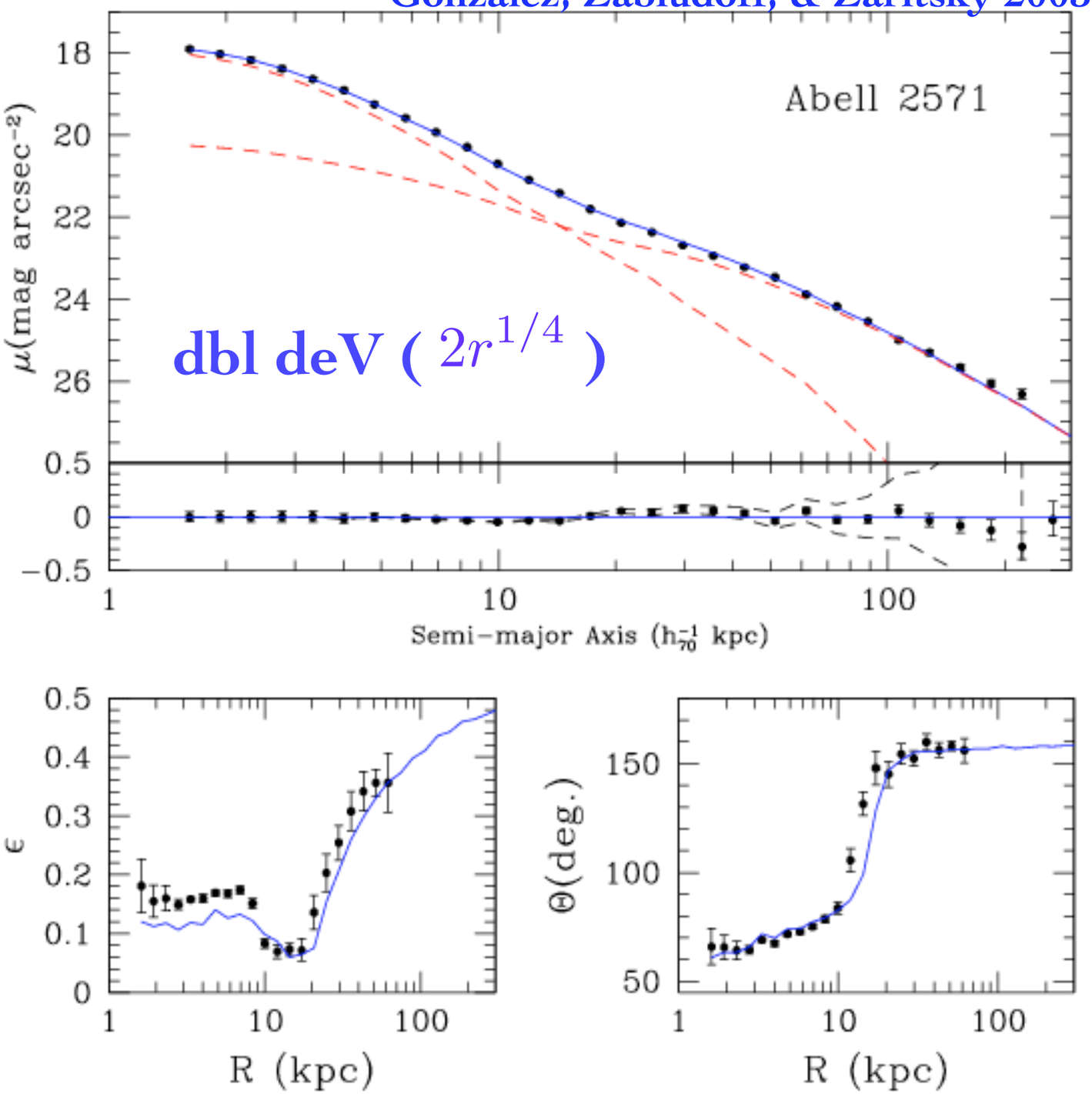
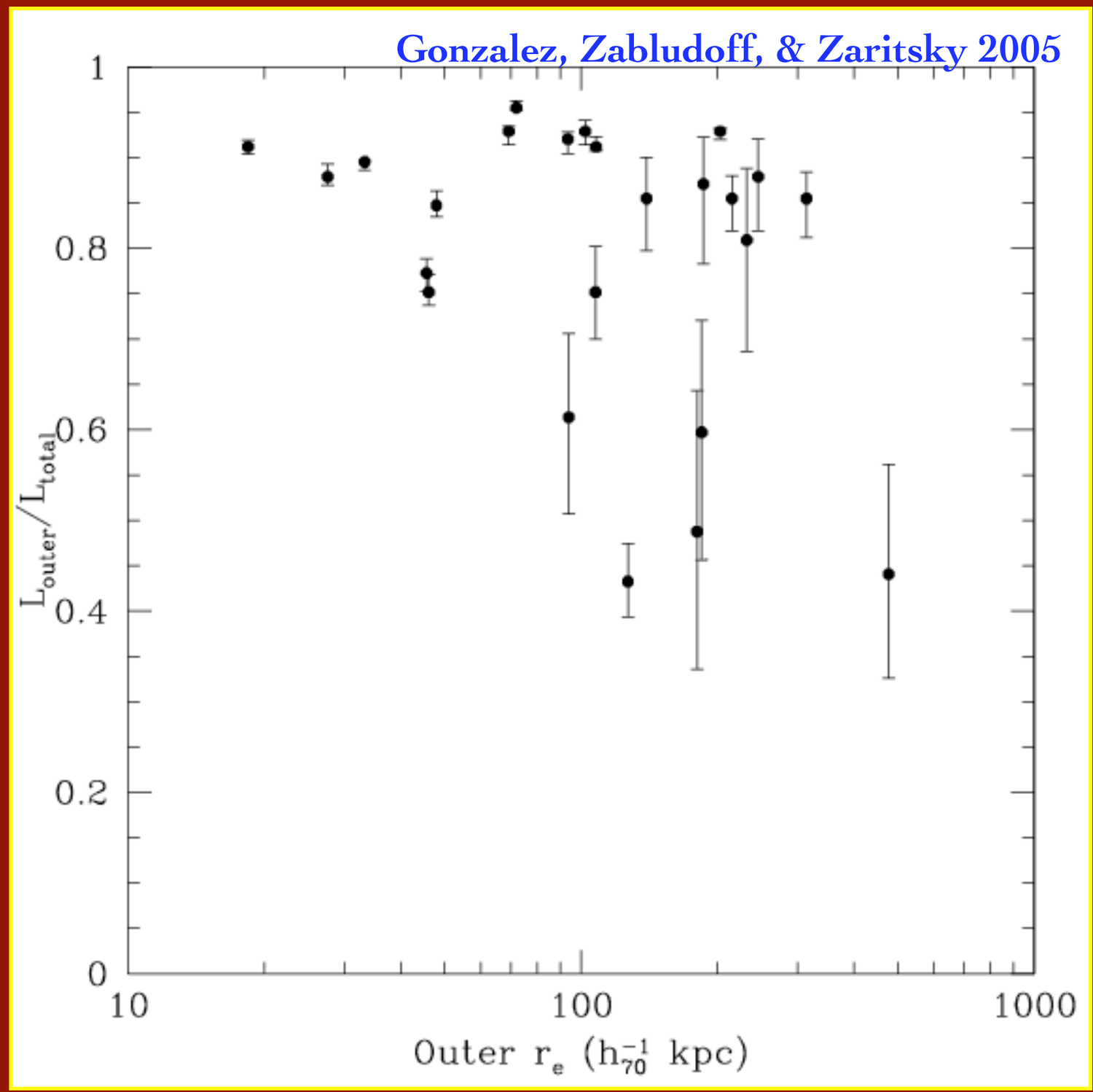


Properties of Intracluster Starlight: Luminosity, Orientation, Size, Ellipticity

80-90% of light of two components



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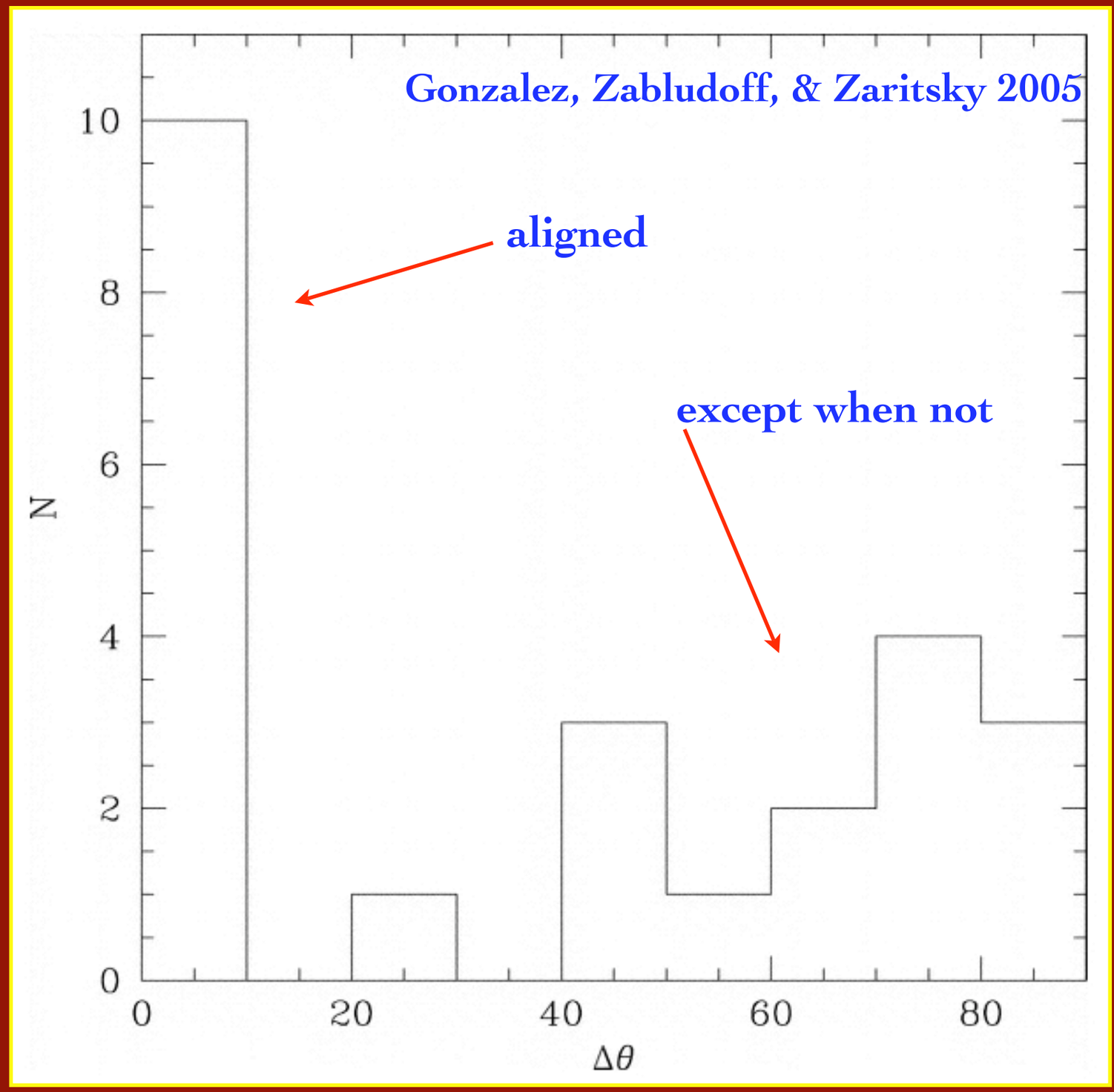
aligned within 10 deg ~40% of time



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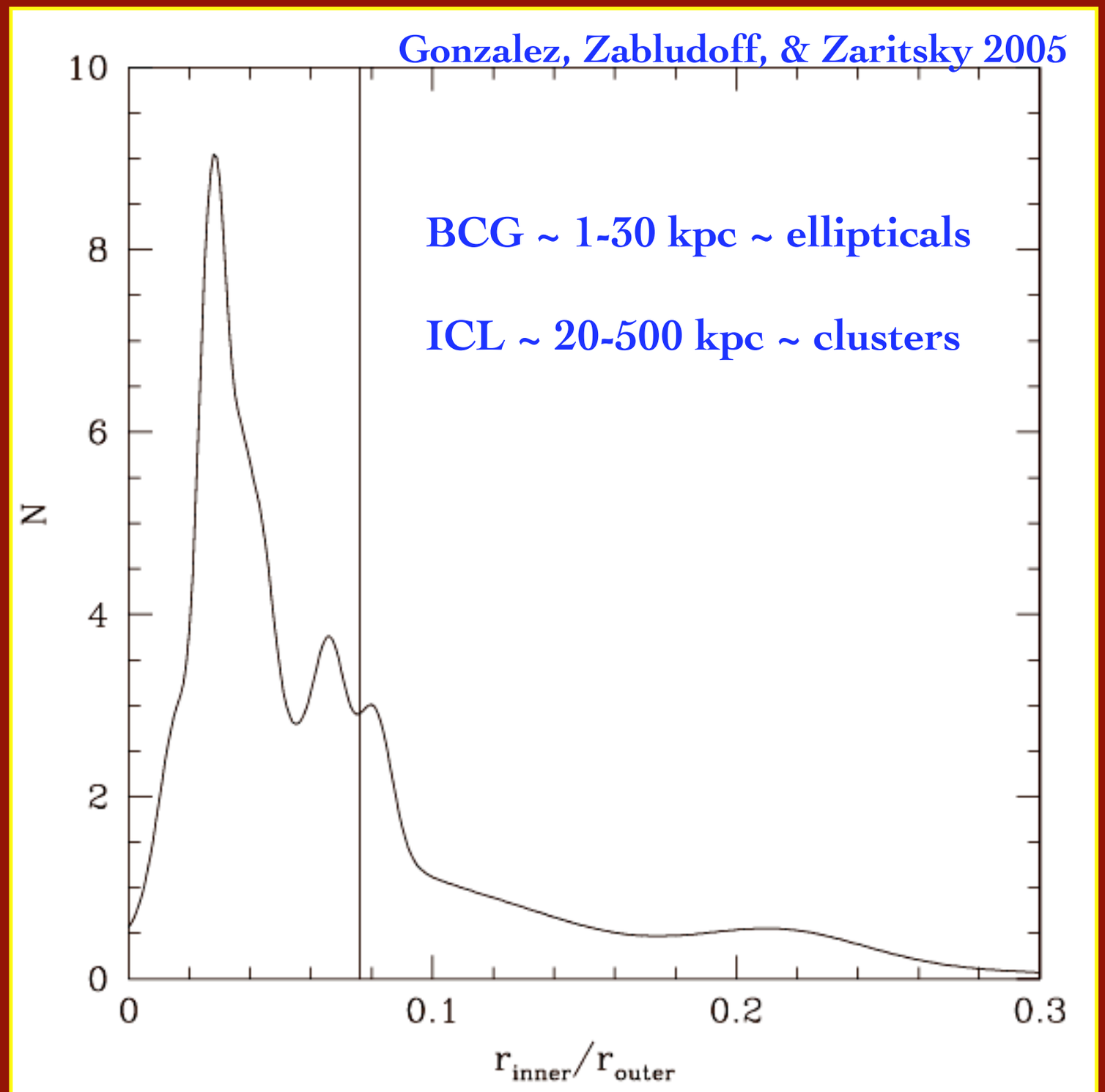
10-40x brightest cluster galaxy (BCG), ~cluster halo



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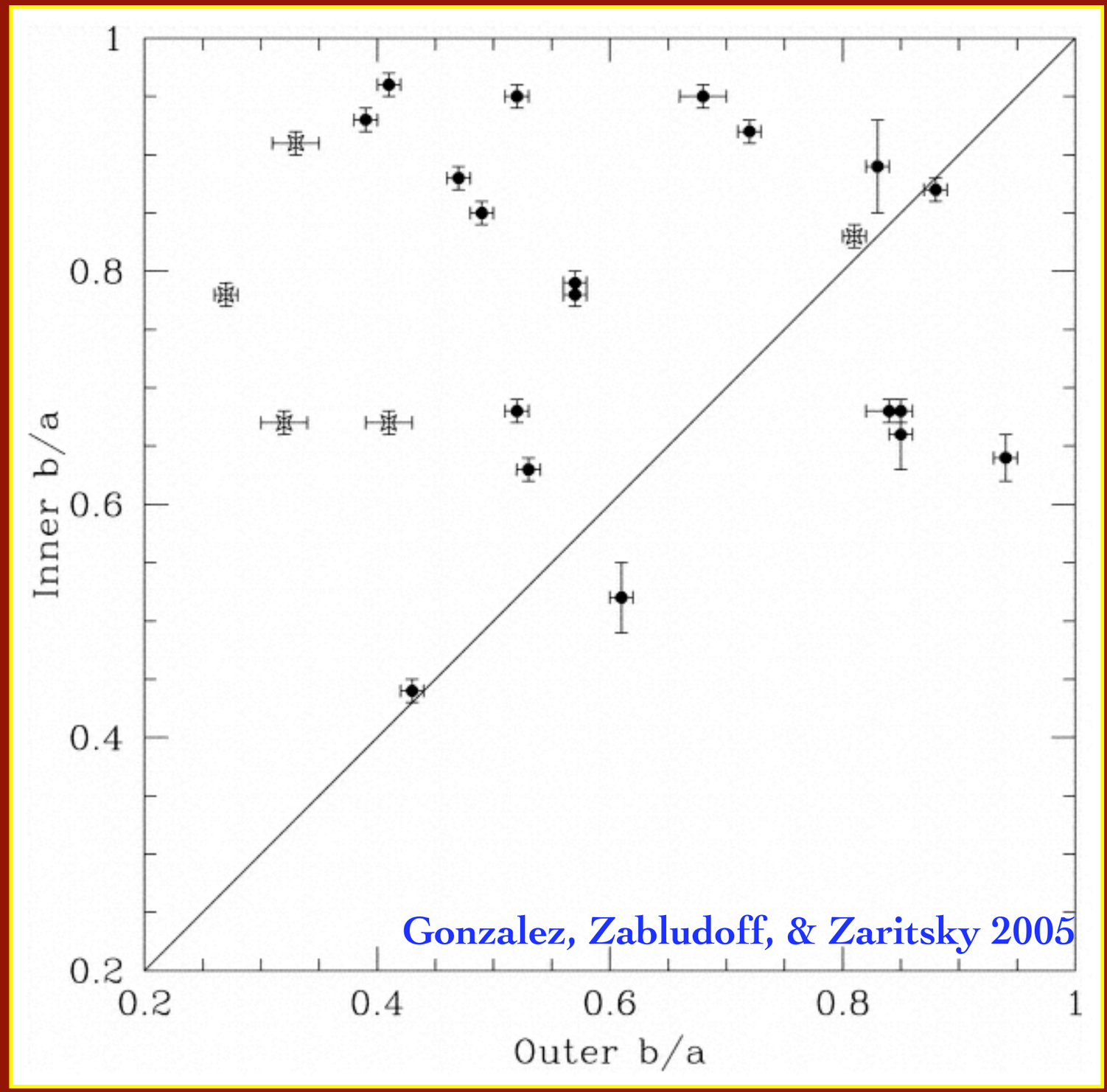
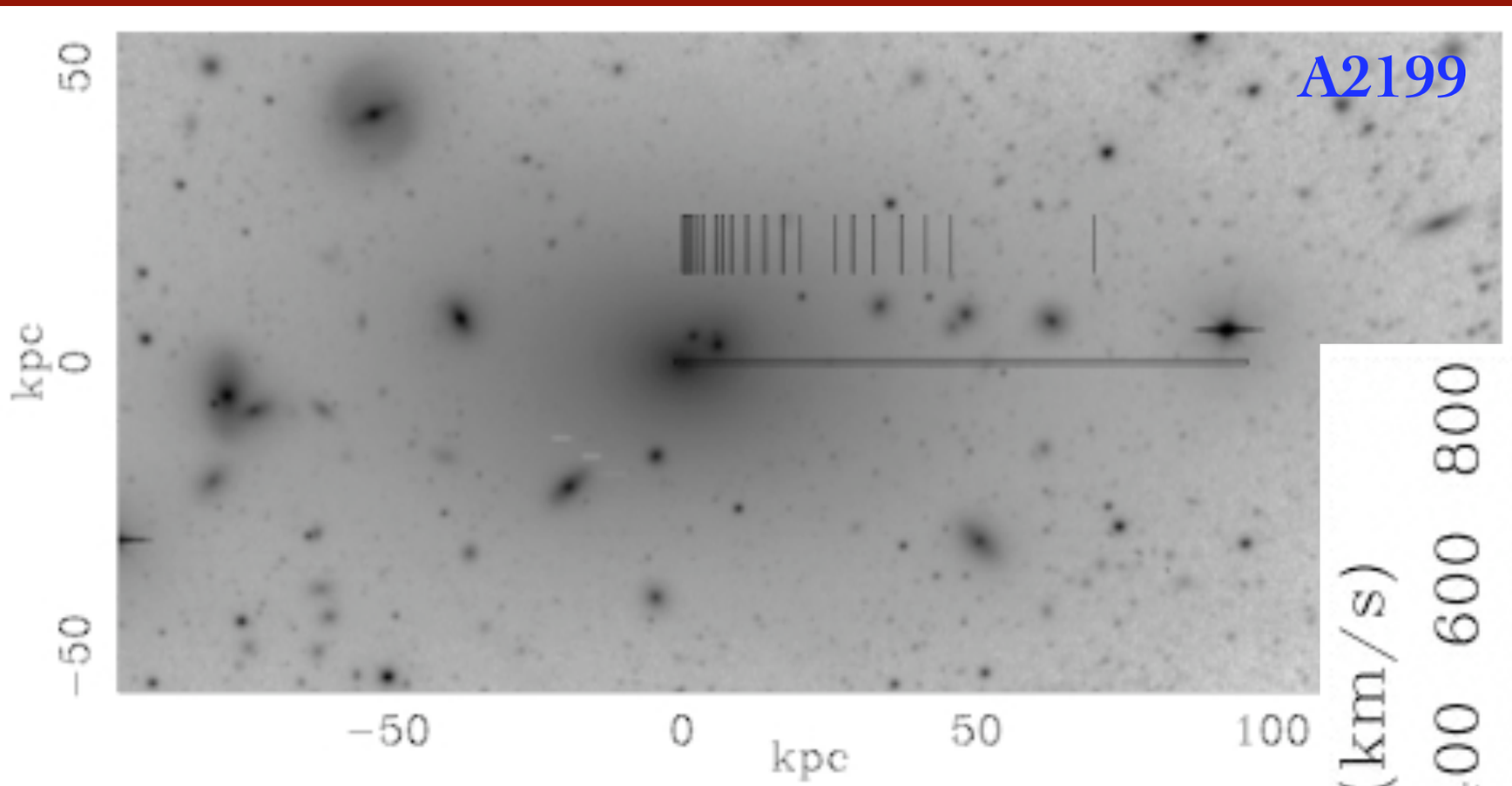
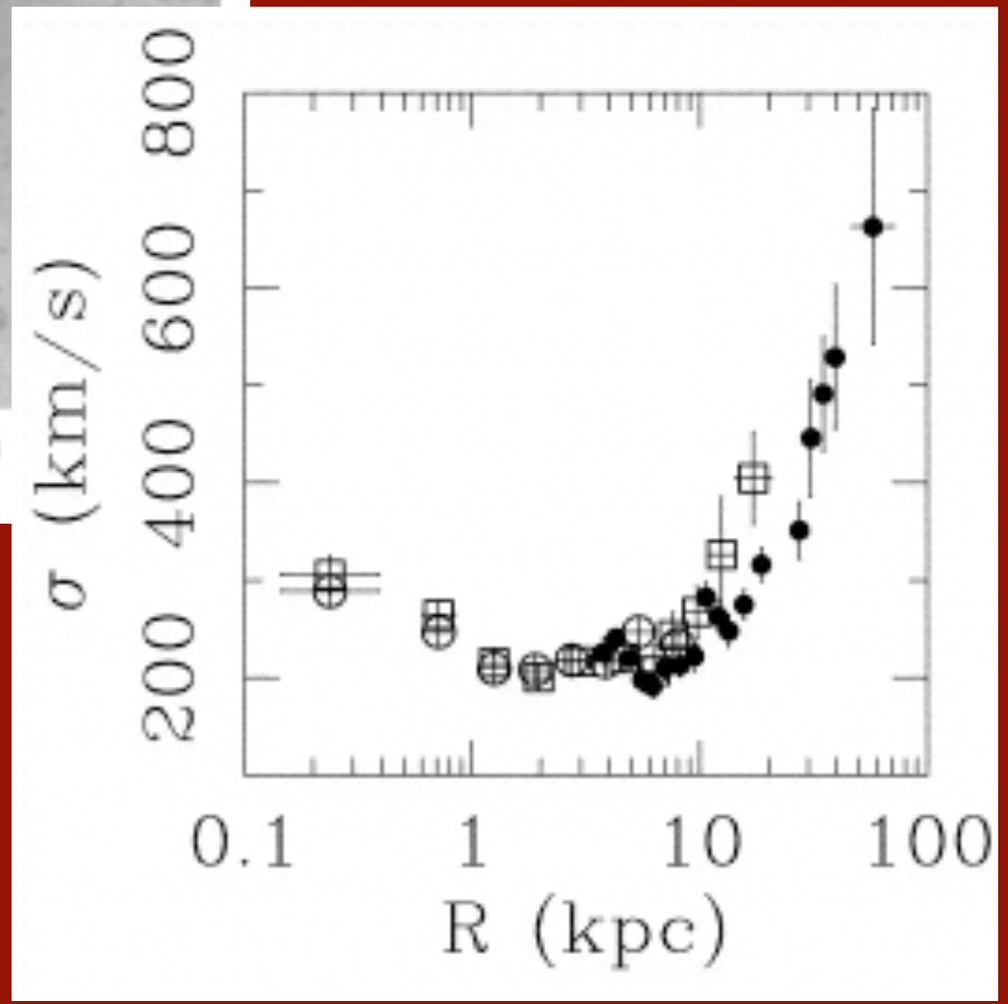
flatter than BCG, like cluster galaxies



Properties of Intracluster Starlight: Mass Profiles



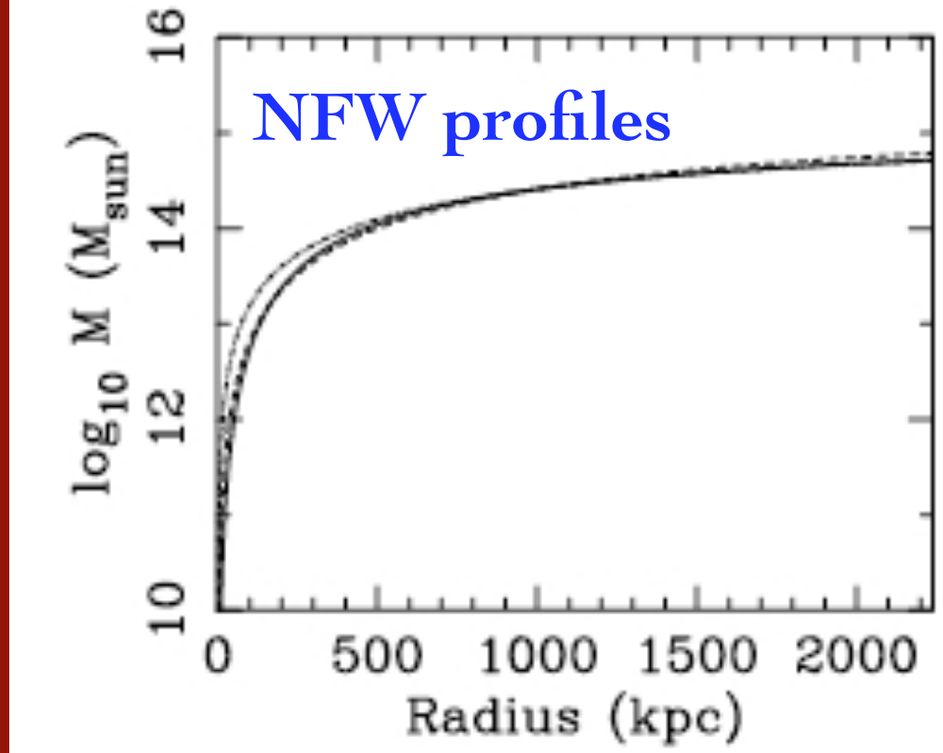
Kelson et al. 2002

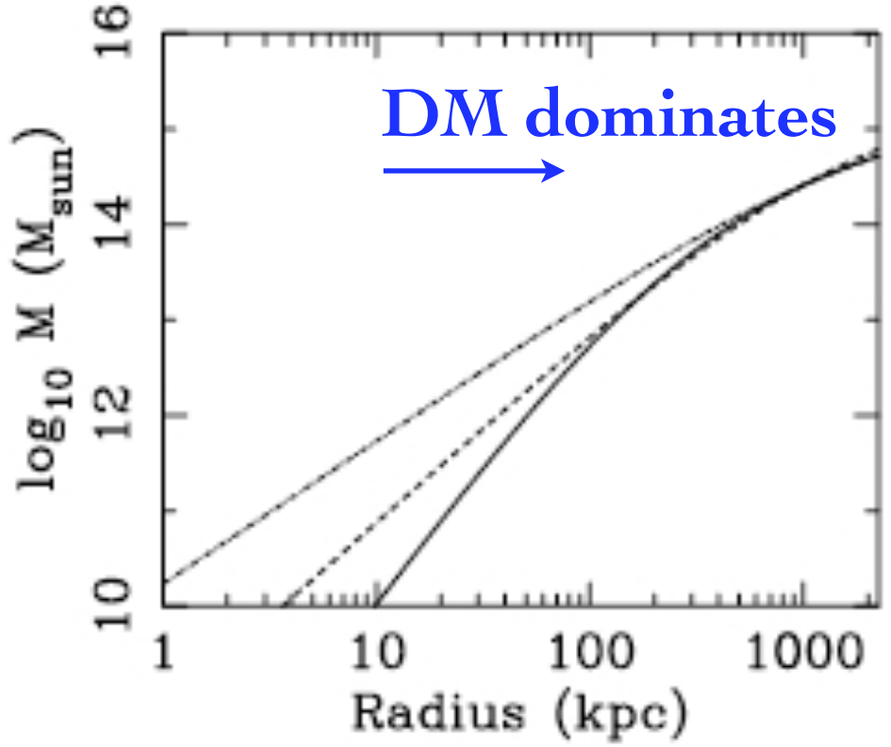


velocity dispersion rises

stars trace galaxy, then cluster potential

Properties of Intracluster Starlight: Mass Profiles (cont.)





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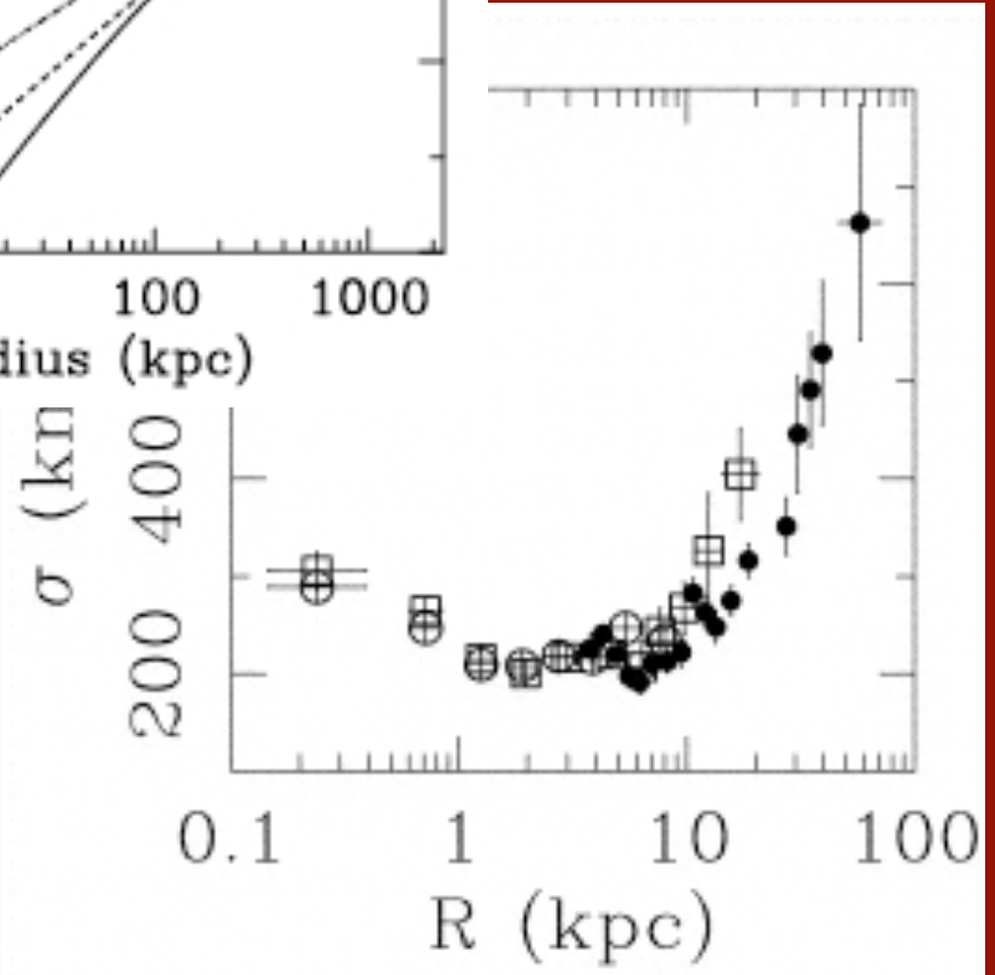
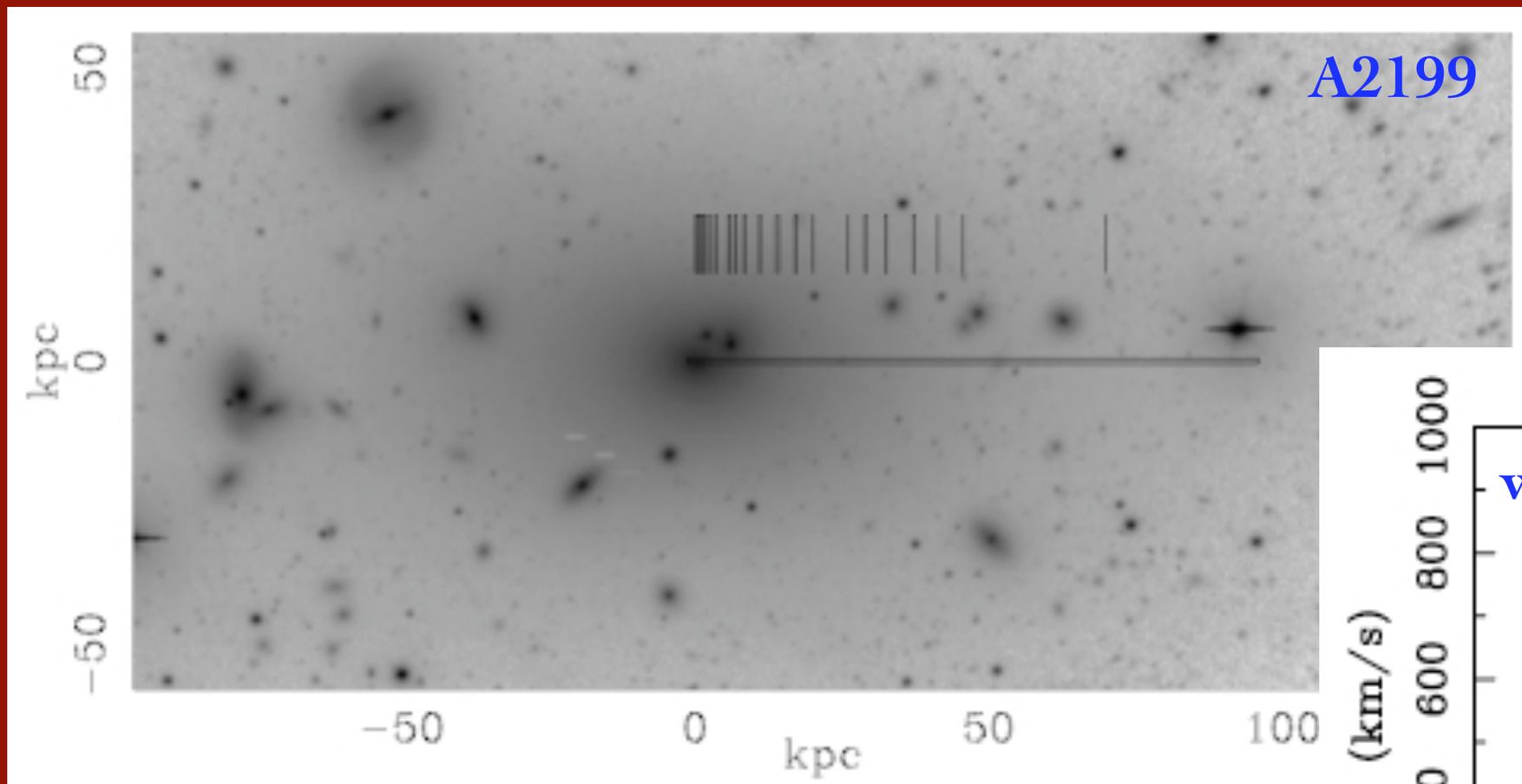


tracers within critical 100 kpc

distinguish among mass profiles

Properties of Intracluster Starlight: Mass Profiles (cont.)



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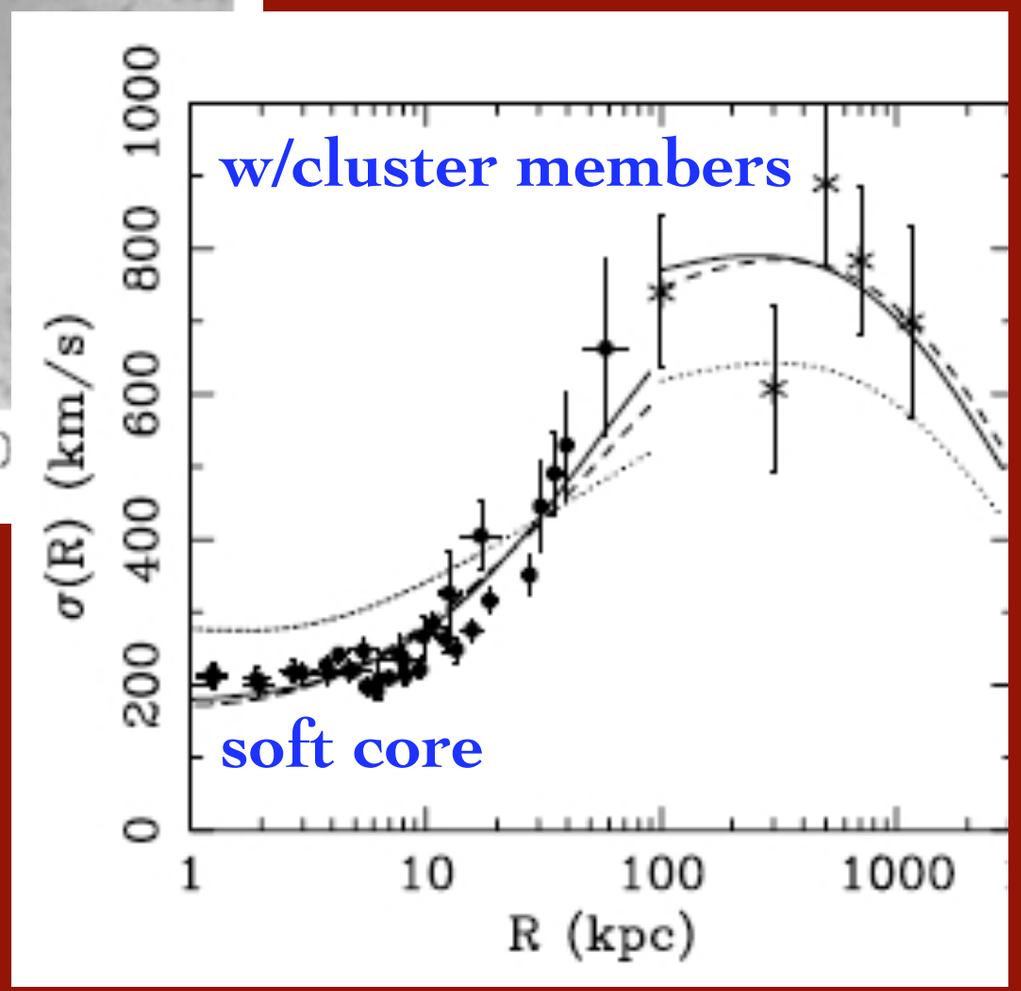
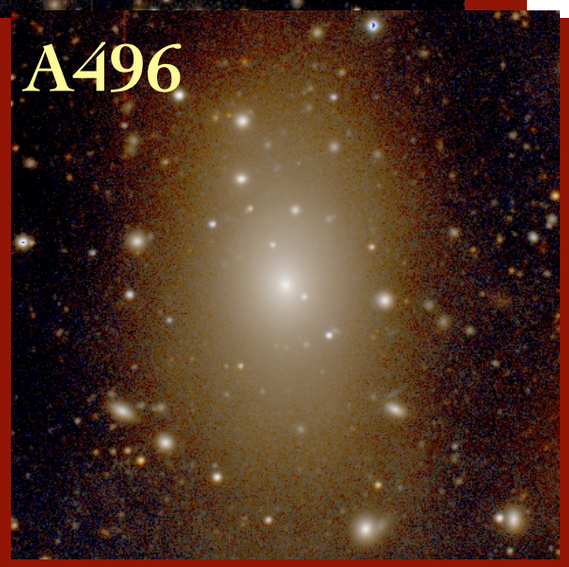


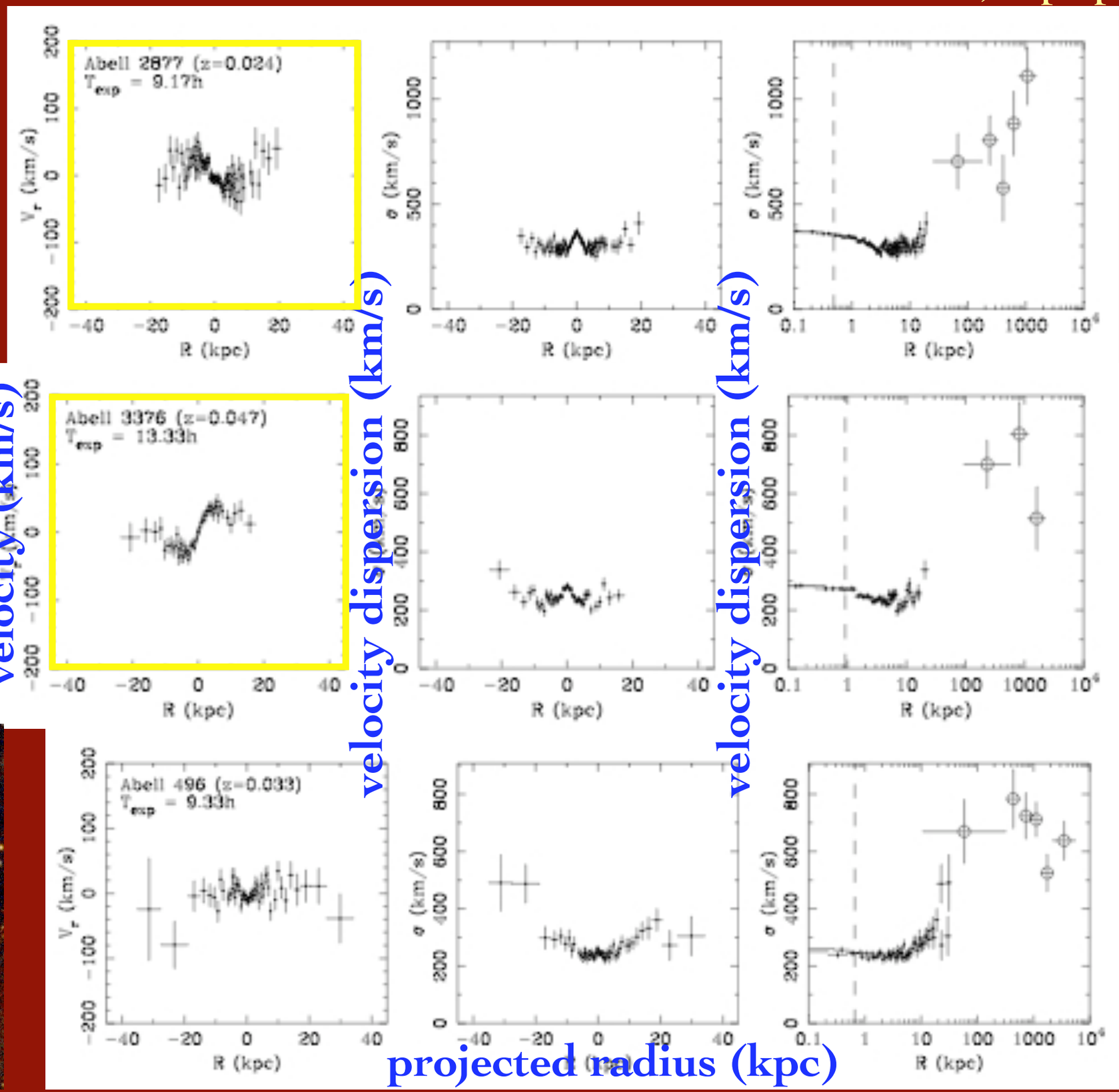
isotropy, M/L ==> soft core like
X-ray, strong lensing, not like sims

but what is scatter?

Mass Profiles (cont.)

Kelson et al., in prep.





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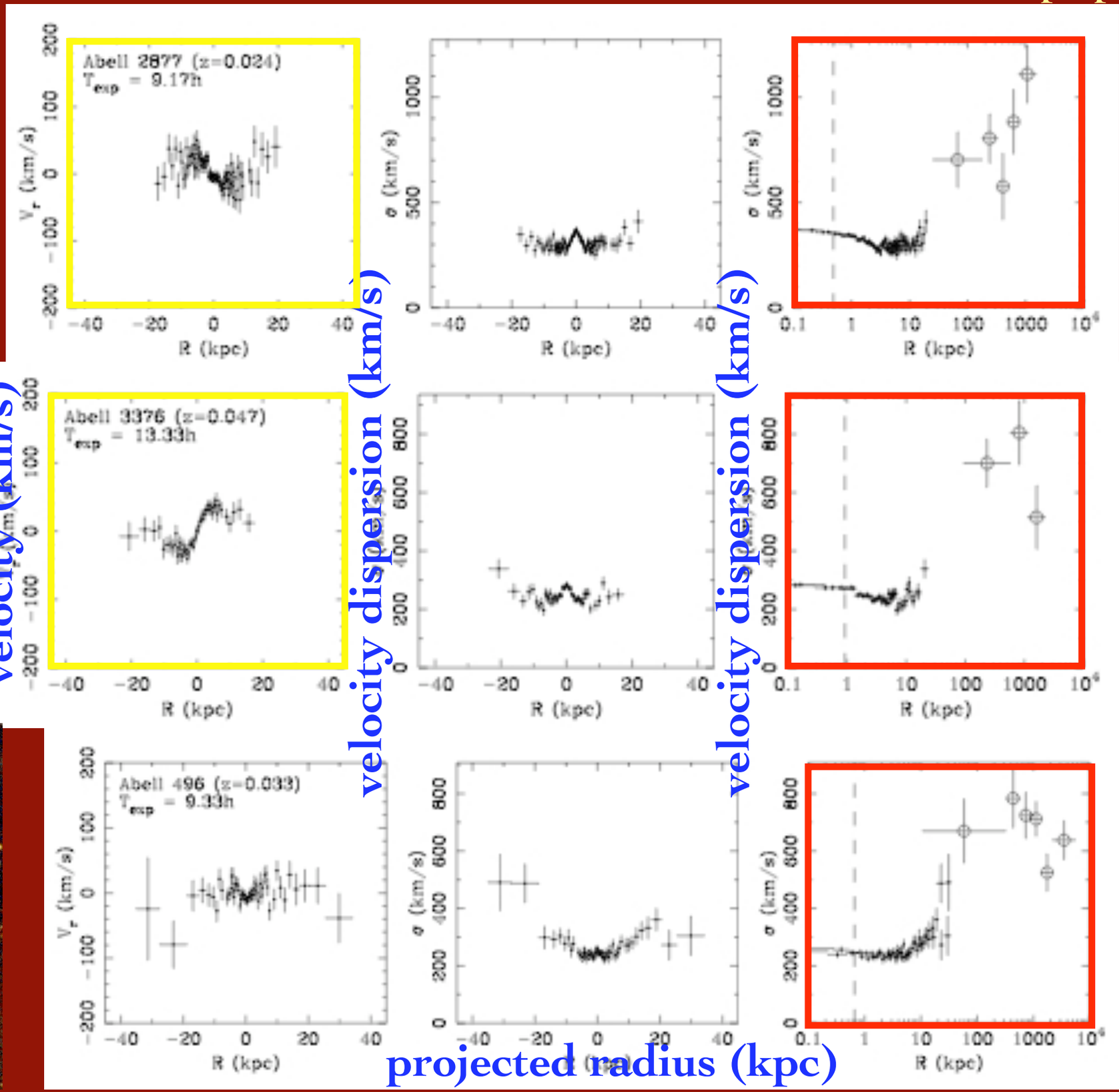

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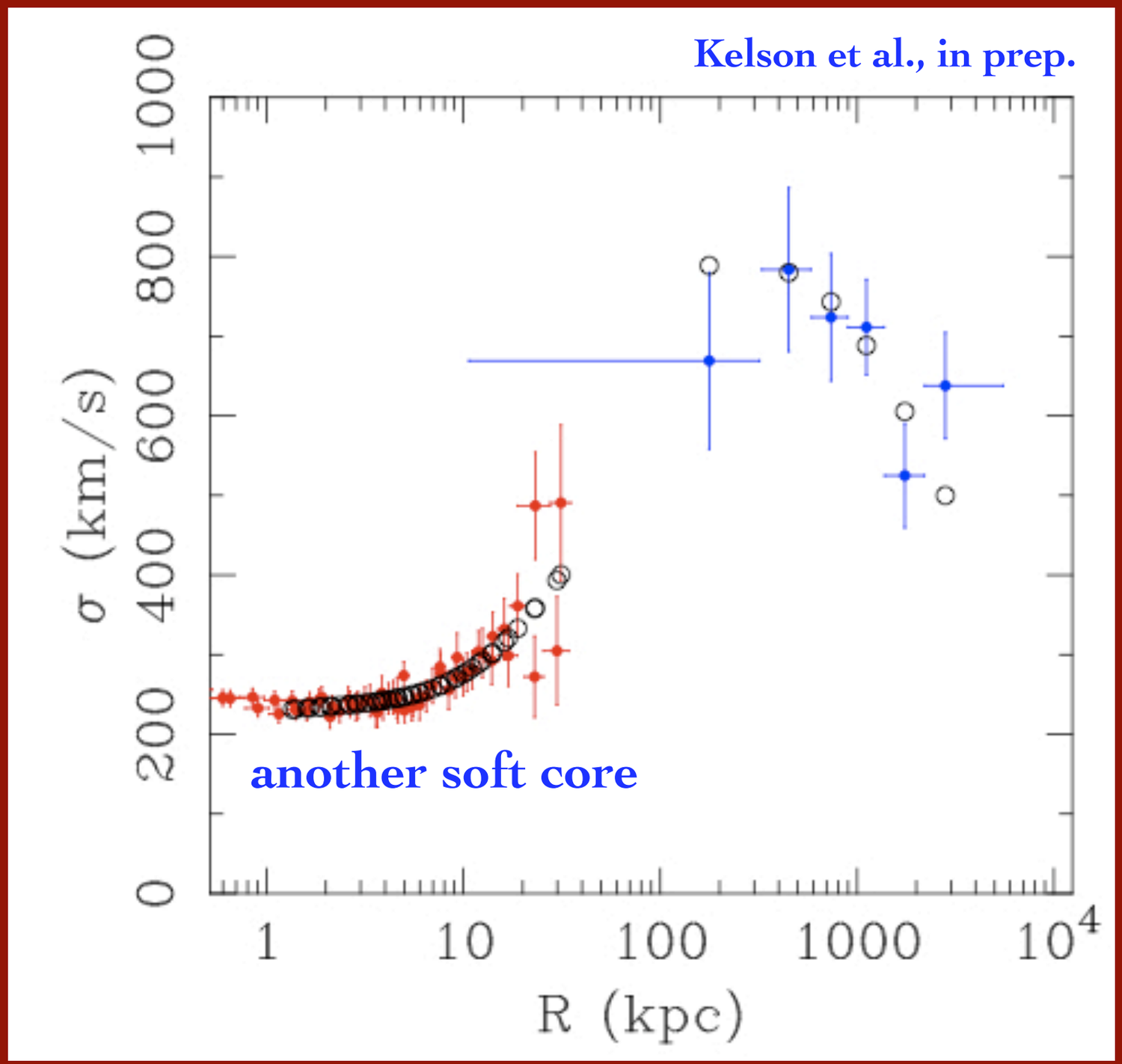


projected radius (kpc)

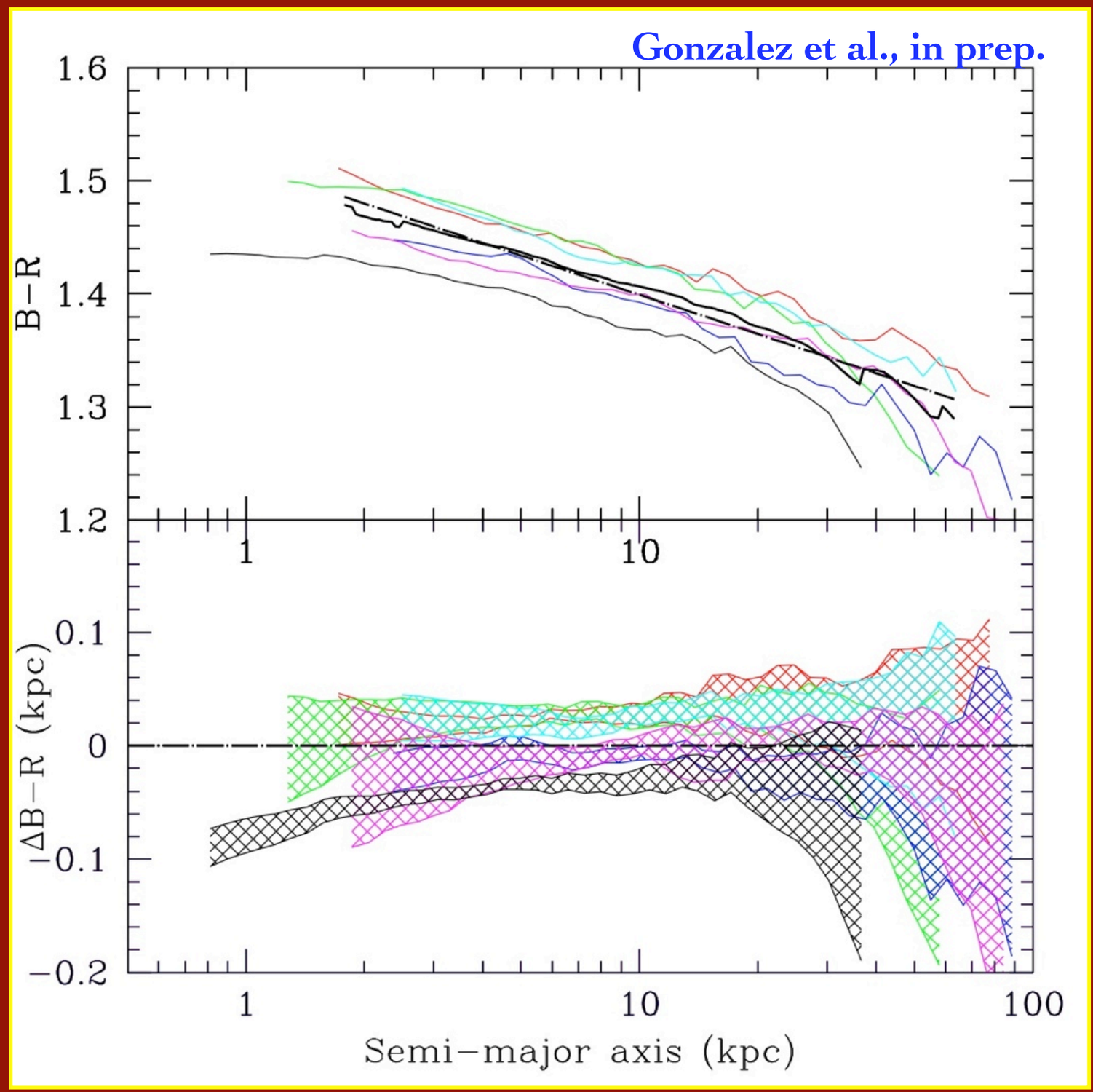
Properties of Intracluster Starlight: Color Gradients

gradients smooth, same over mass range ==> dynamically relaxed

colors also like old population

suggest metal-poor progenitors

early formation, not much recent growth?



Properties of Intracluster Starlight: Summary

distinct, ubiquitous

80-90% of two components (40% of all light within r_{500})

aligned with BCG, but exceptions

10-40x bigger than BCG, ~cluster halo

more elliptical than BCG, ~cluster members

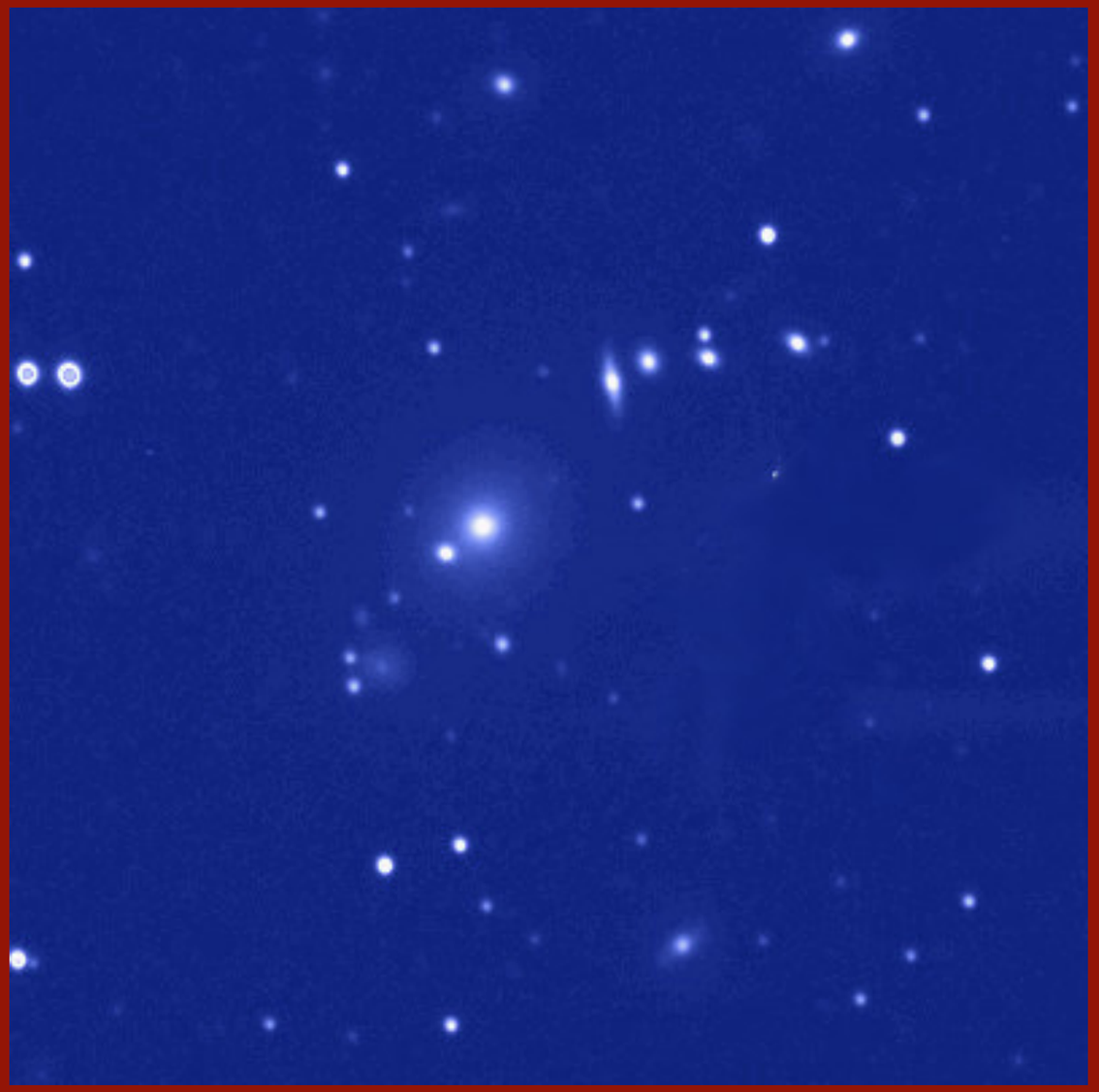
responds to cluster potential (dispersion rises)

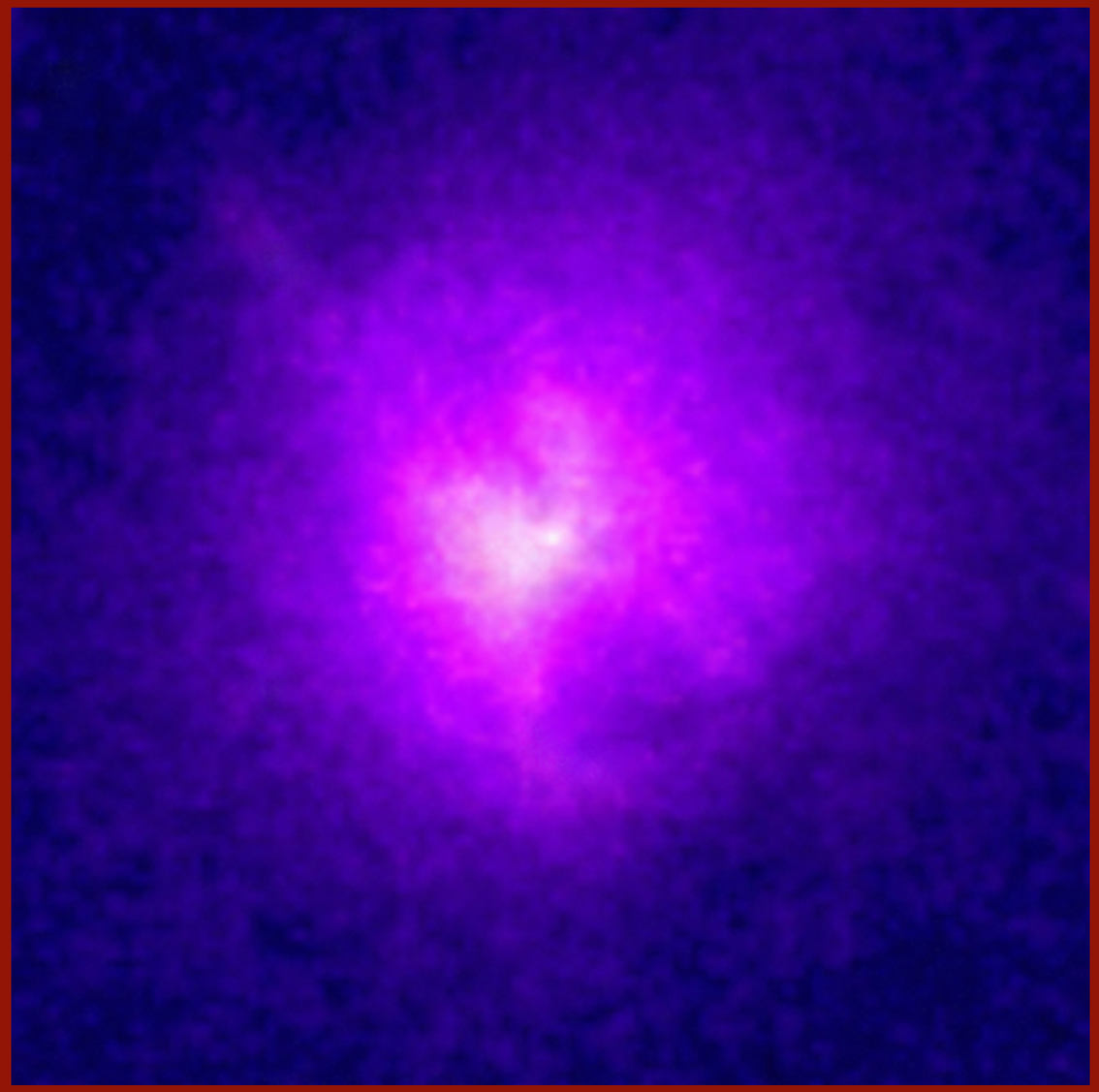
dynamically-relaxed, old stars, metal-poor progenitors ==> formed early, growth slowed

Enrichment of Intracluster Medium

[Fe/H] ~ 0.3 solar hard via galactic winds,

but intracluster stars deposit all their metals

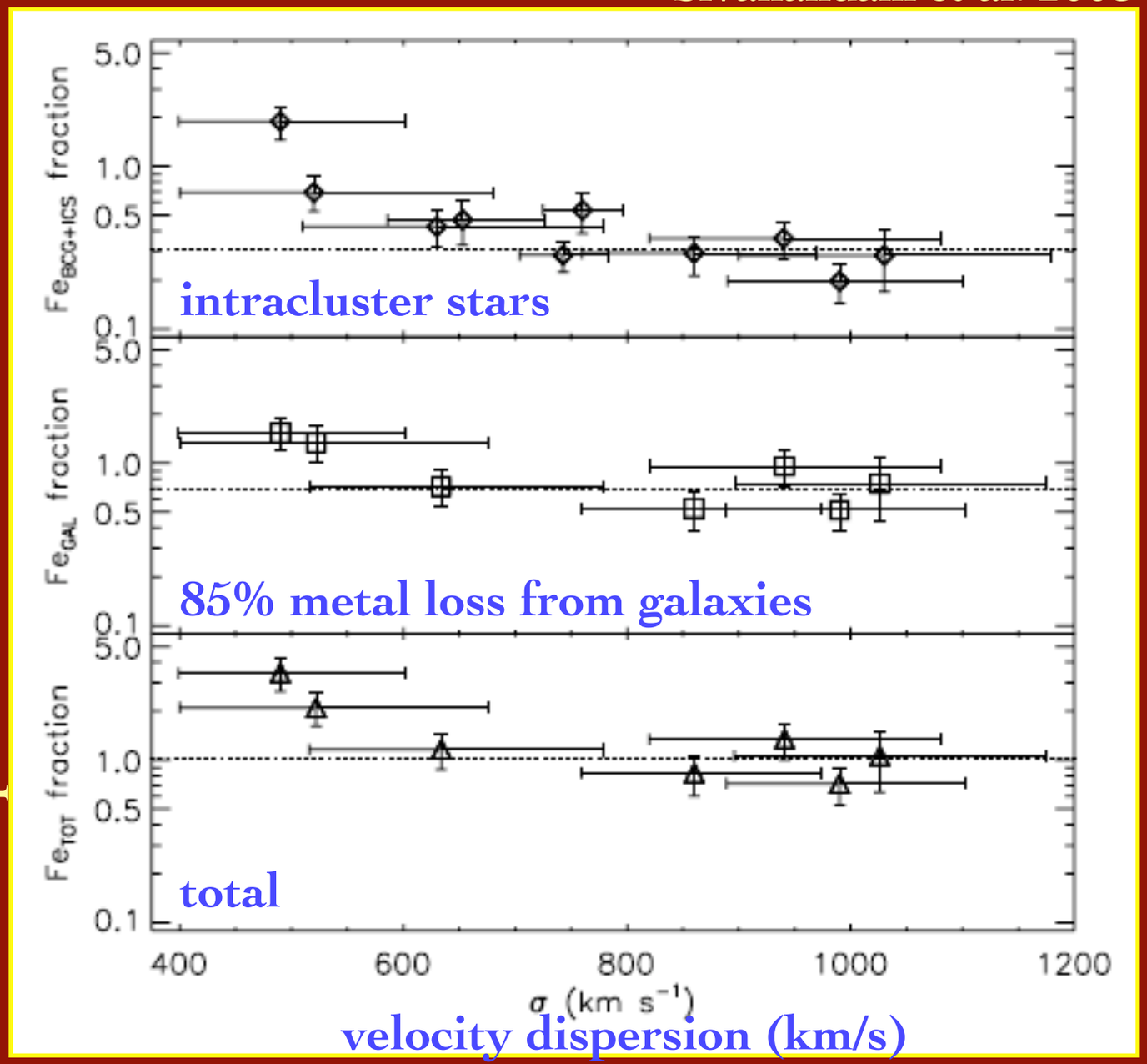




evolve old population (= L_{ICL}), SNe and Fe at z, integrate over z

Enrichment of Intracluster Medium (cont.)

Sivanandam et al. 2008

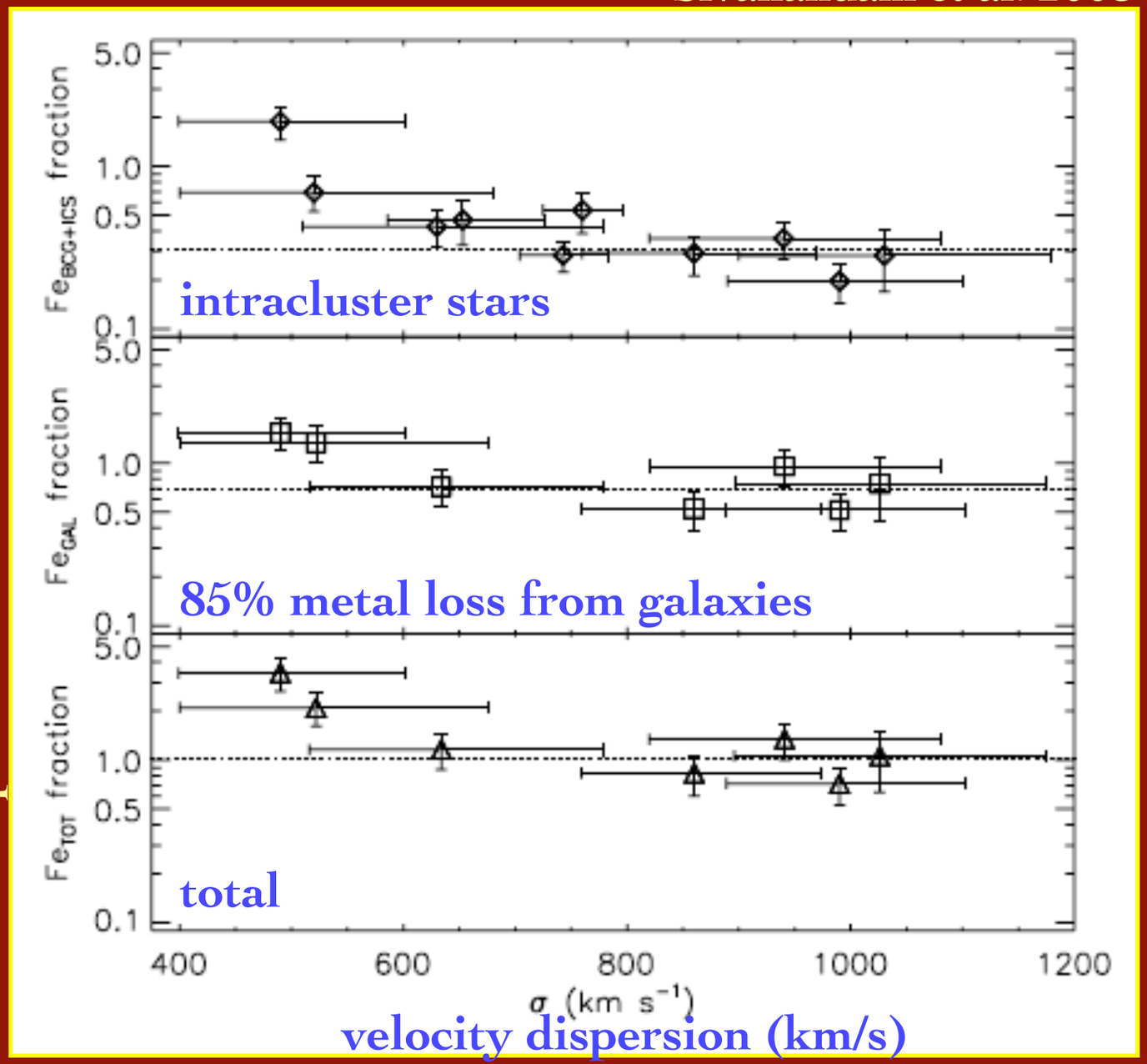


~30% of Fe within r_{500}

need galaxies + intracluster stars, but 85% metal loss?

Enrichment of Intracluster Medium (cont.)

Sivanandam et al. 2008



~30% of Fe within r_{500}

need galaxies + intracluster stars, but 85% metal loss?

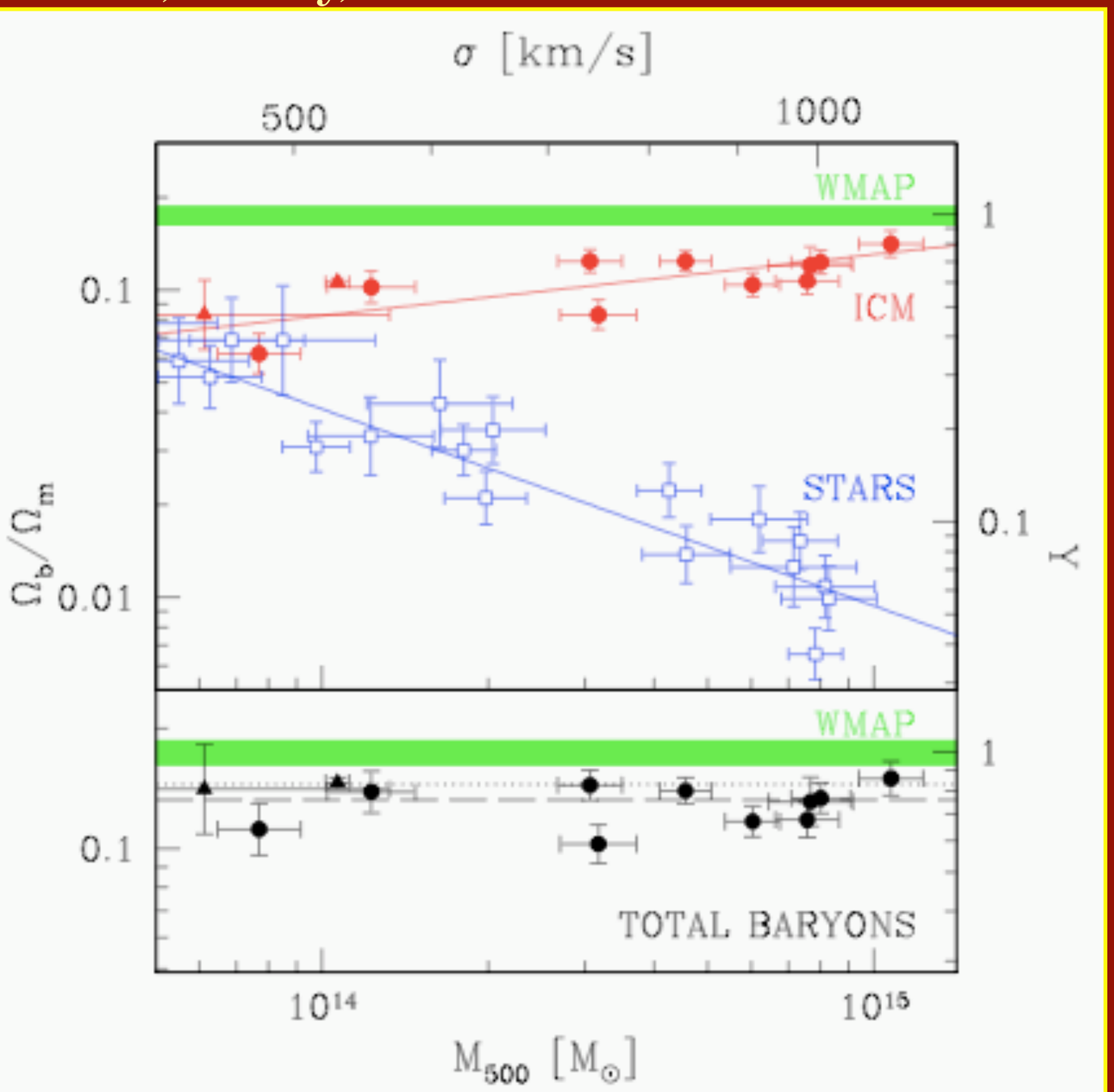
SN Ia rate upper-bound gives 35% metal loss

can now account for all Fe

what about trend? SN Ia rate change with environment?

Baryon Budget of Clusters

Gonzalez, Zaritsky, & Zabludoff 2007



baryon fraction ~ WMAP

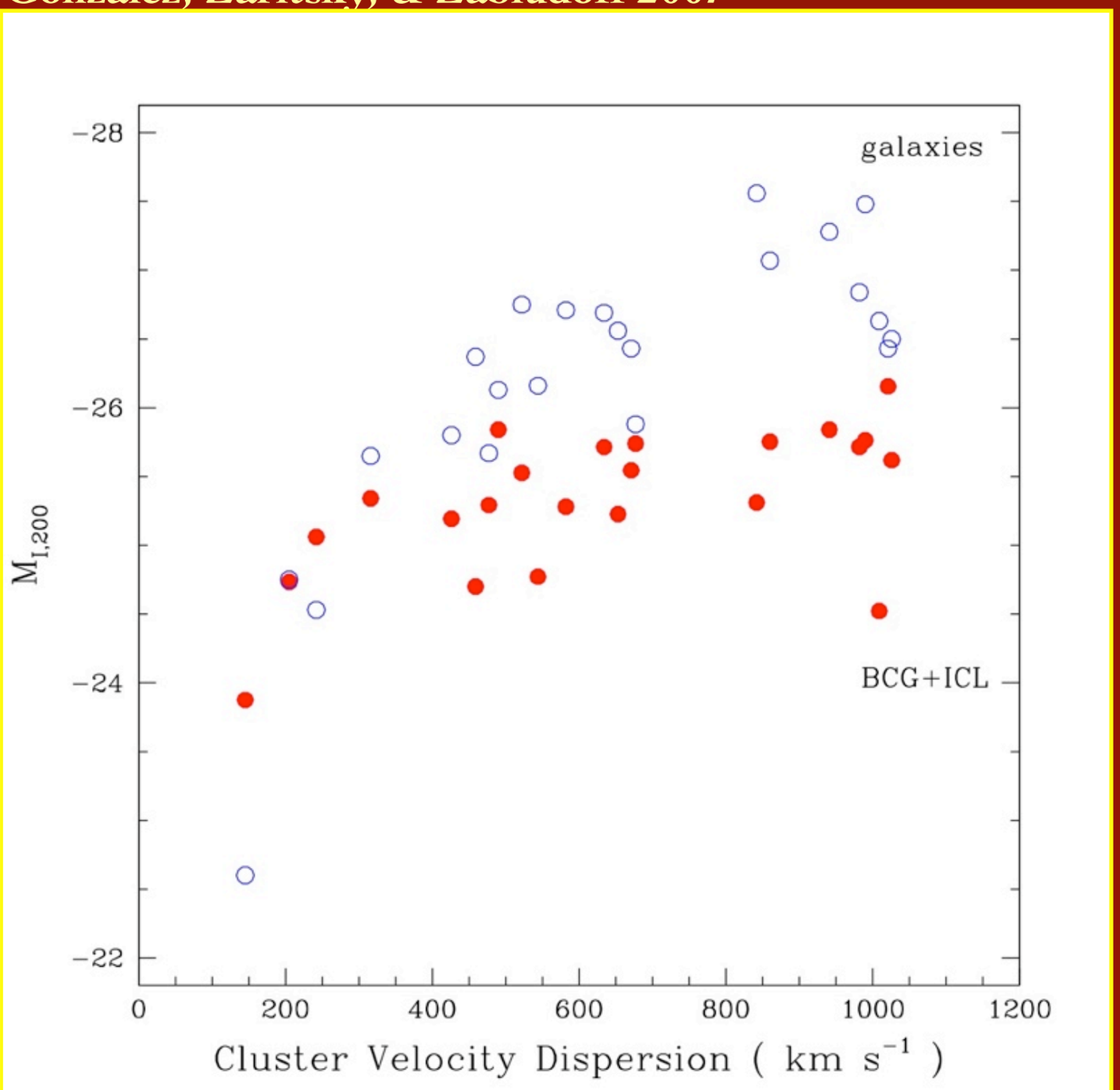
constant from groups to clusters

no undetected component

gas up, stars down ==> star formation efficiency down

Apportionment of Cluster Stellar Baryons

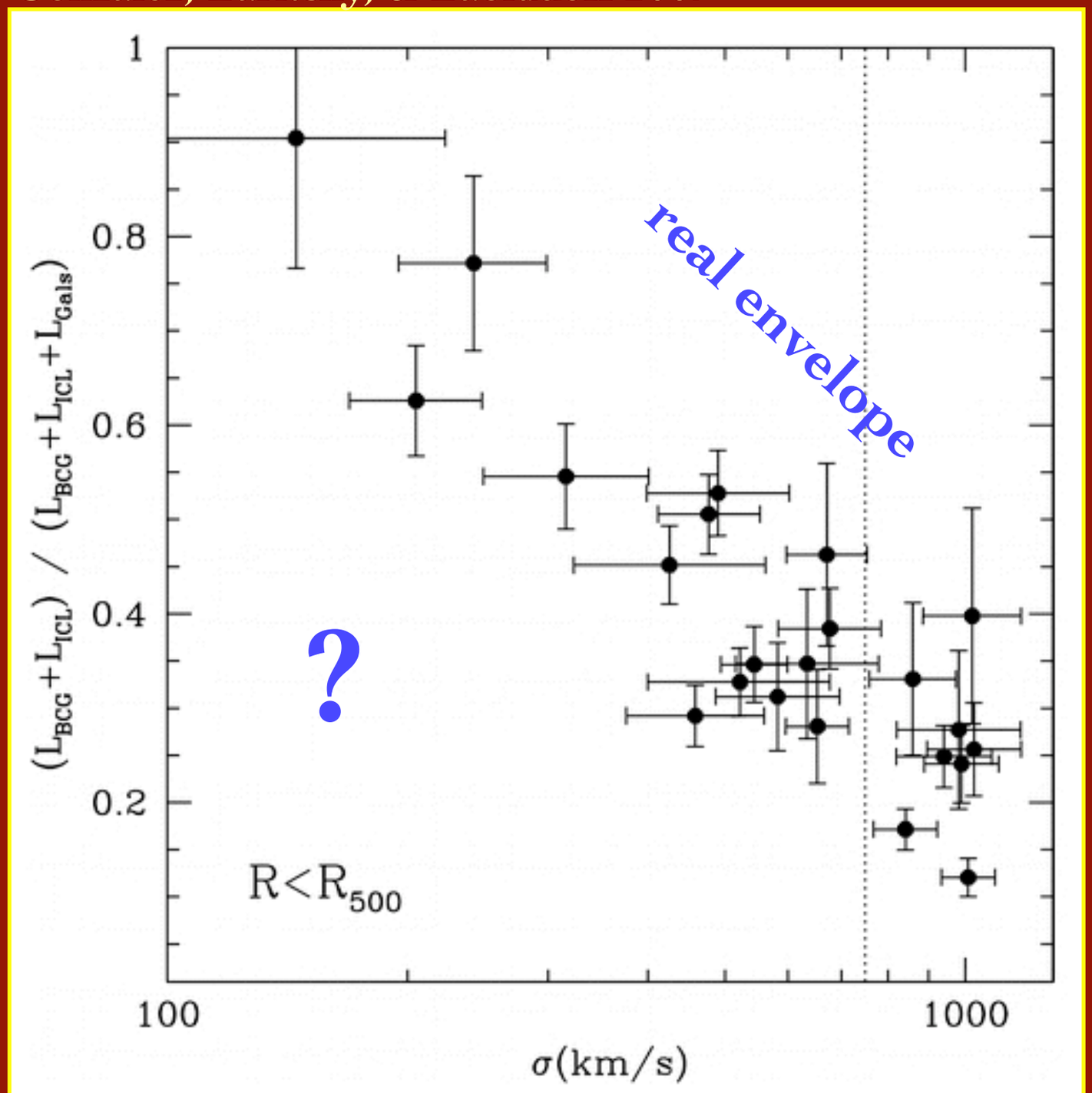
Gonzalez, Zaritsky, & Zabludoff 2007



intracluster stars rise slower than galactic stars

Apportionment of Cluster Stellar Baryons (cont.)

Gonzalez, Zaritsky, & Zabludoff 2007



intracluster stars rise slower than galactic stars

fewer intracluster stars, more galactic stars ==> less efficient stripping?

selection effects?

intracluster stars do not need cluster

Conclusions

intracluster starlight: distinct, significant, tracer of cluster potential, old

intracluster metals: from stars in and out of galaxies

baryon fraction: ~Universe, constant with mass

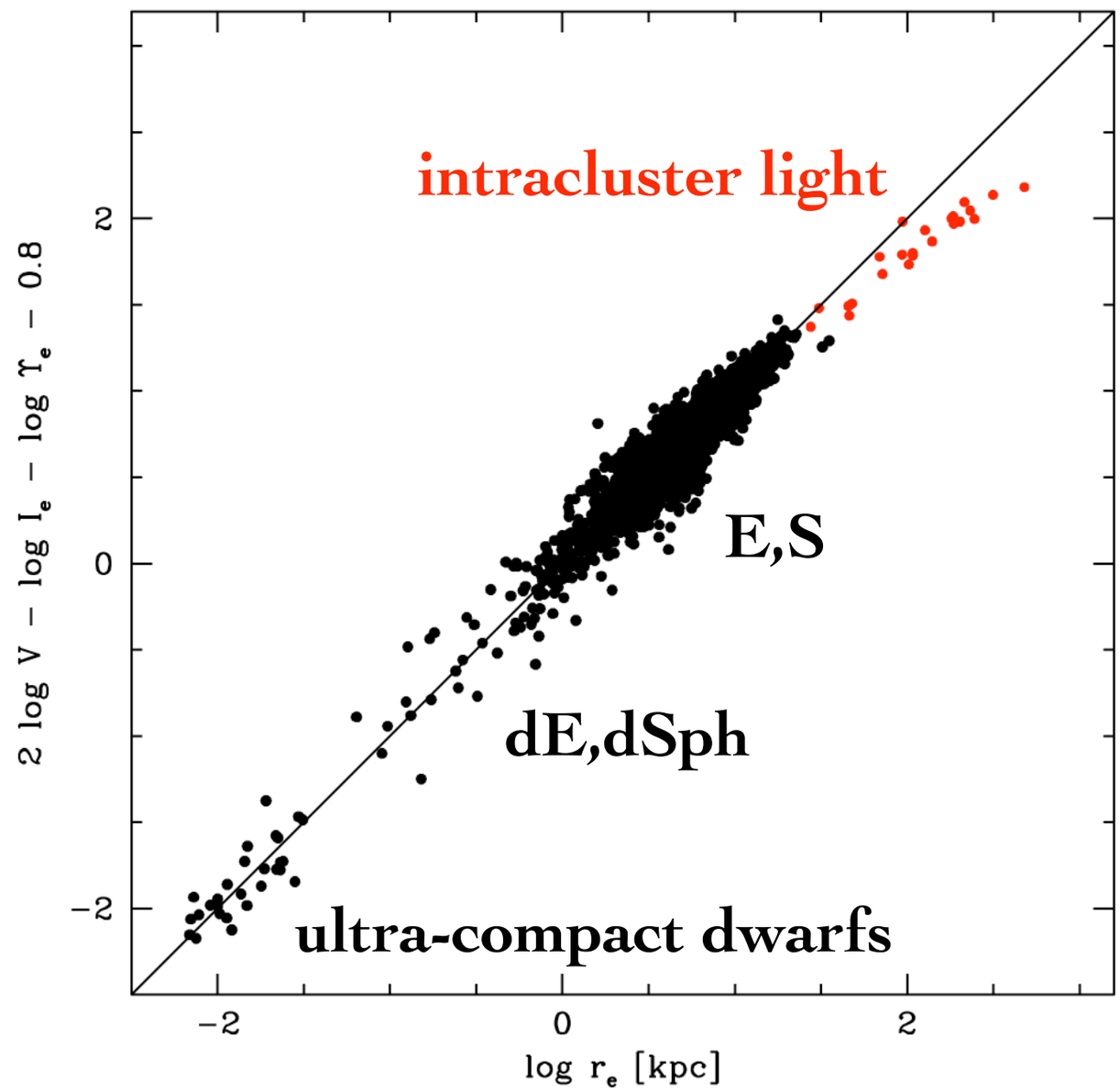
baryon phases: more gas, fewer stars vs. mass (star formation efficiency);

fewer intracluster stars, more galactic stars vs. mass (early formation, growth via stripping stalled)

Properties of Intracluster Starlight: Fundamental Manifold

velocity dispersion profiles rise, do not reach cluster value

AIZ with Gonzalez & Zaritsky



Properties of Intracluster Starlight: Fundamental Manifold

velocity dispersion profiles rise, do not reach cluster value

for cluster velocity dispersion, intracluster stars on F-*M*

==> trace cluster potential

AIZ with Gonzalez & Zaritsky