The relation between GC systems and SMBH in spiral galaxies. The case study of NGC 4258

(Submitted to AAS Journals)

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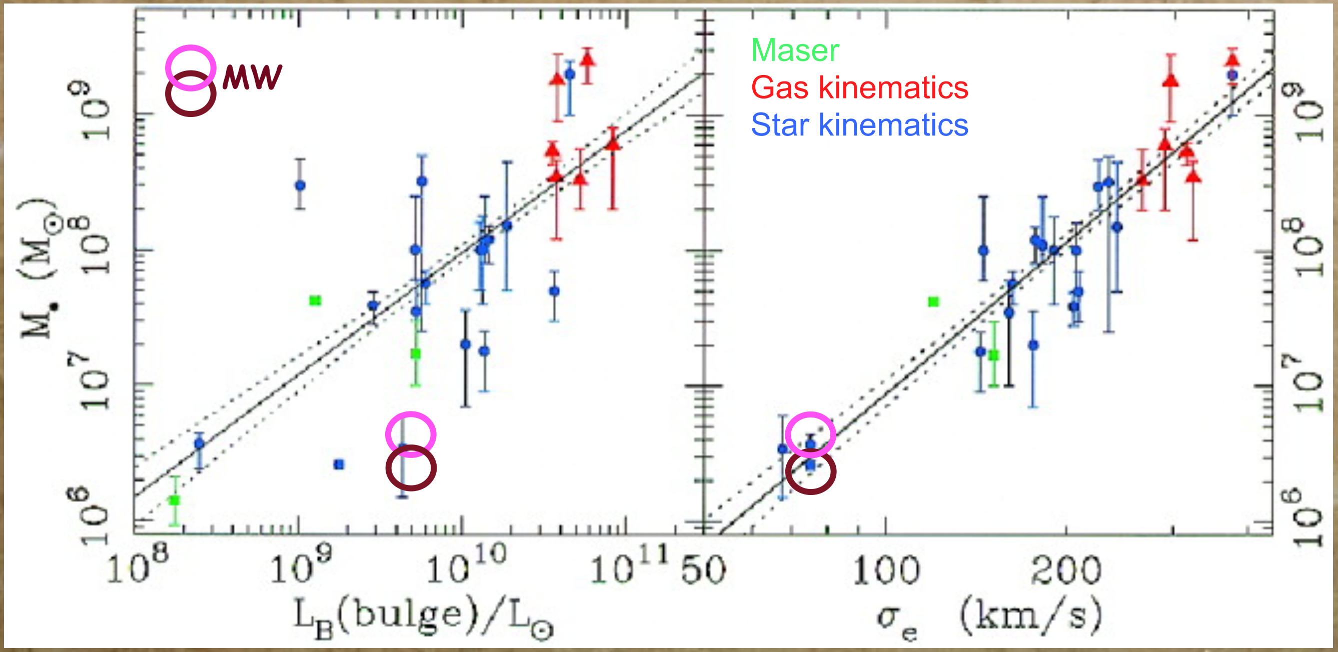
Stellar Aggregates, Bad Honnef, 8 December 2016

Black hole mass scaling relations

σ (Ferrarese & Merritt 2000; Gebhardt et al. 2000; Tremaine et al. 2002; Ferrarese & Ford 2005; Gültekin et al. 2009)

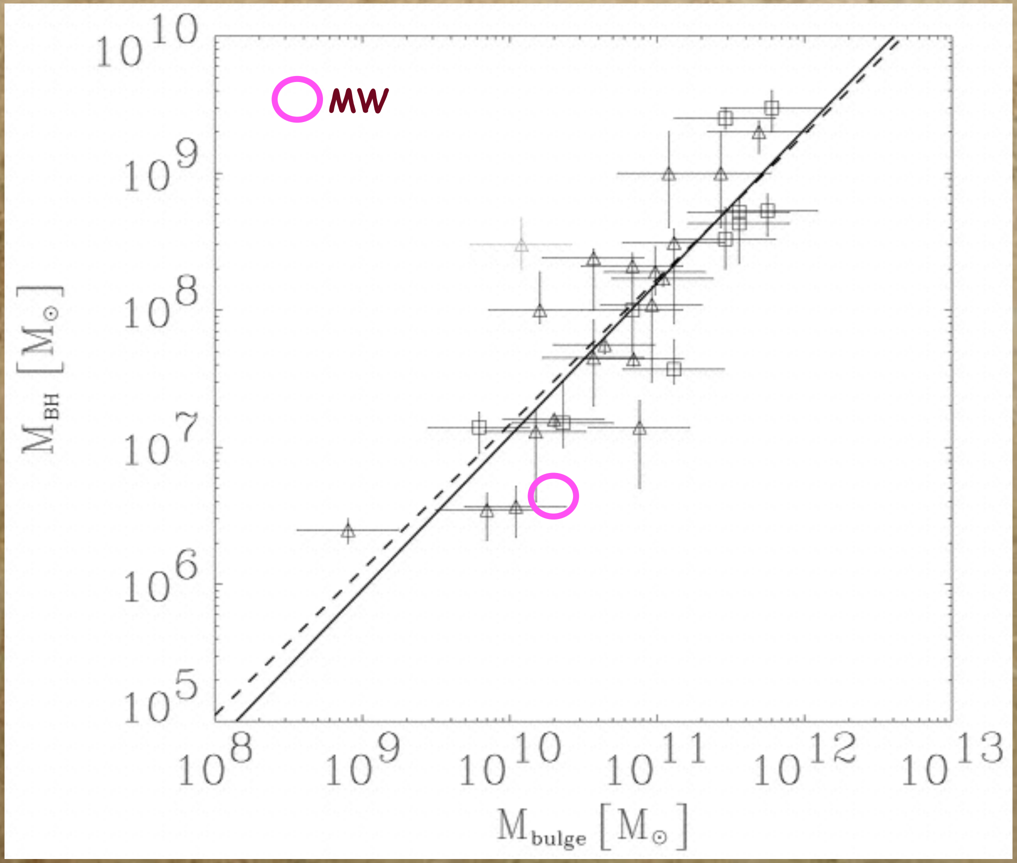
L_{bulge} (Dressler 1989; Kormendy & Richstone 1995; Marconi & Hunt 2003: Graham 2007; Gültekin et al. 2009)



Gebhardt et al. 2000, ApJ, 539, L13

Black hole mass scaling relations

M_{bulge} (Magorrian et al. 1998; Häring & Rix 2004)



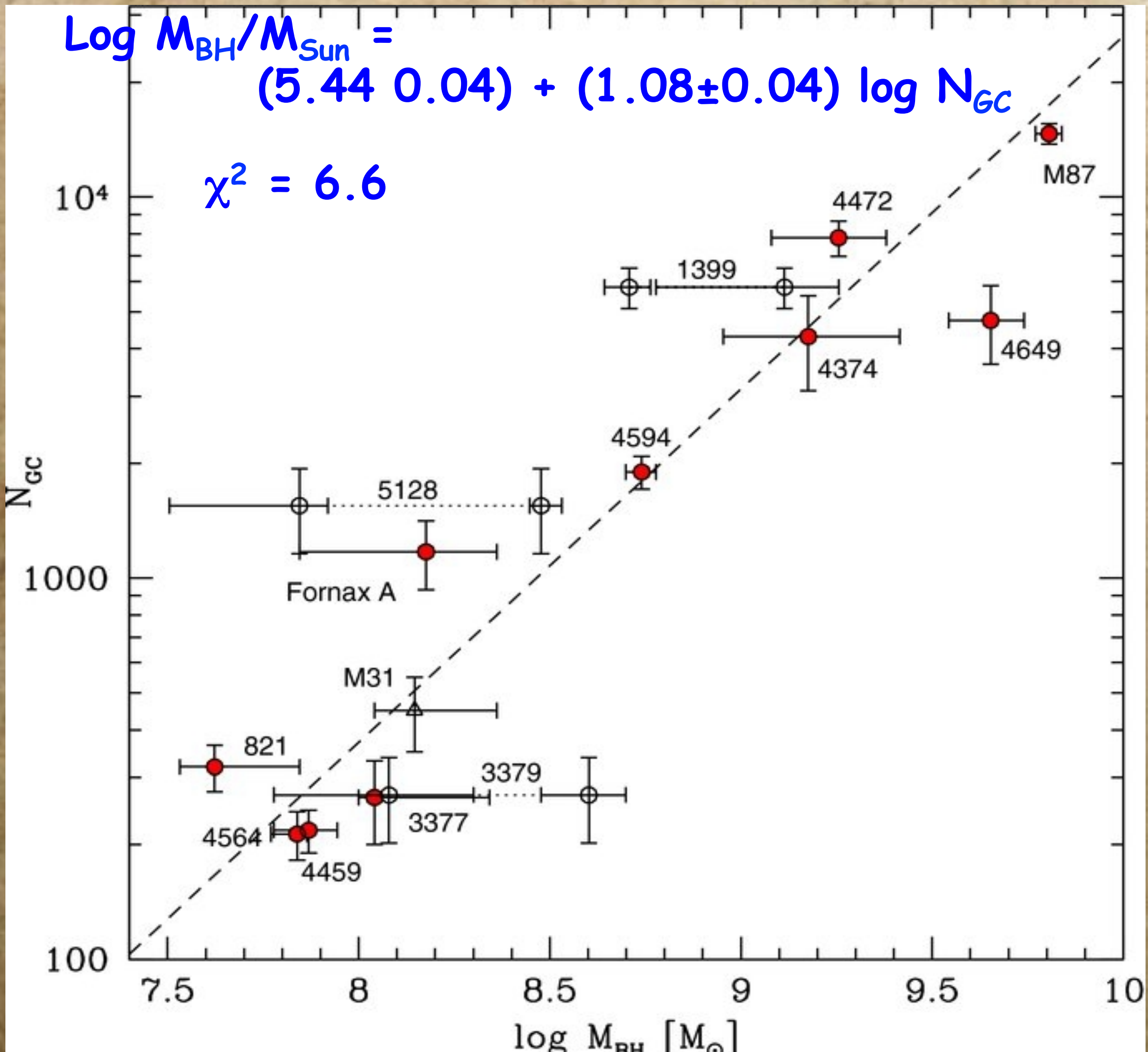
Häring & Rix 2004, ApJ, 604, L89

Correlation between M_{BH} and N_{GC}

$\text{Log } M_{BH}/M_{Sun} =$

$(5.44\ 0.04) + (1.08 \pm 0.04) \log N_{GC}$

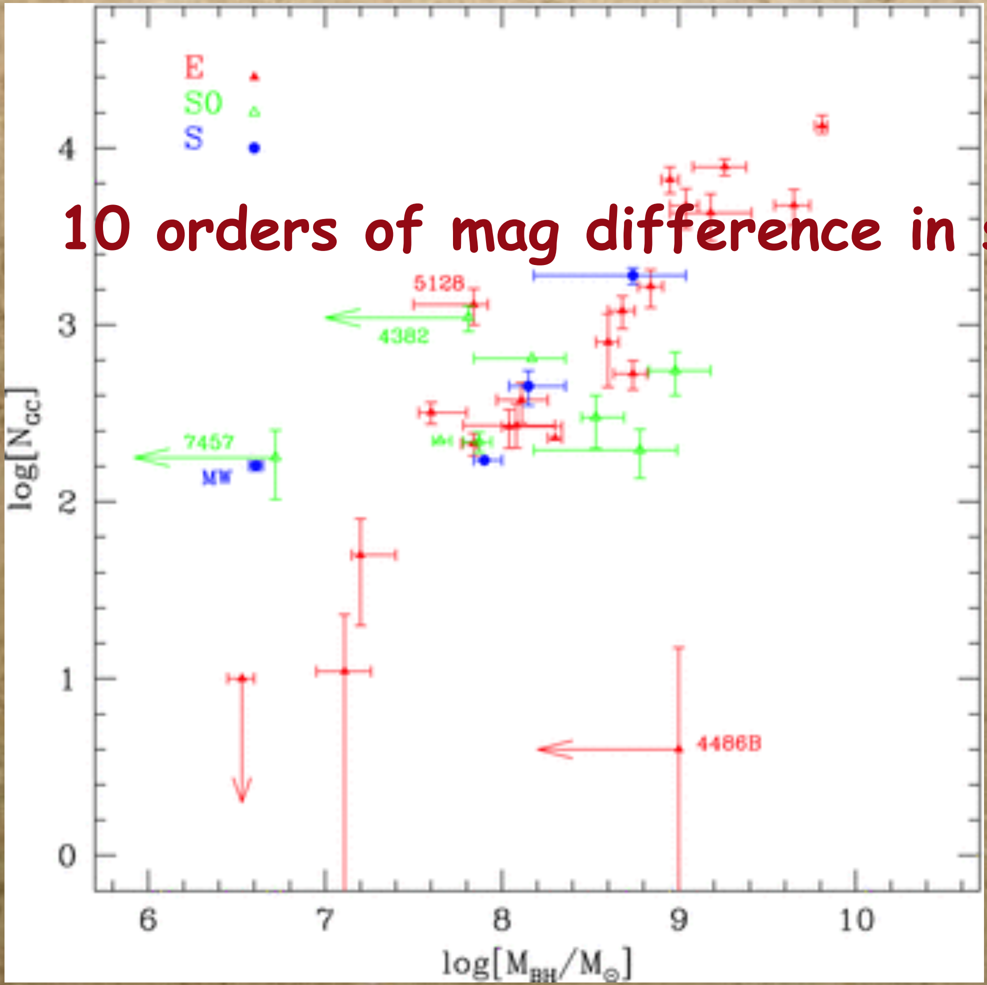
$\chi^2 = 6.6$



Burkert & Tremaine 2010, ApJ, 720, 516

A larger sample

$N_{GC} \propto M_\bullet^{1.02\pm0.10}$, spans 3 orders of mag, tighter than $M_\bullet$ - σ_* relation



10 orders of mag difference in spatial scales!

Harris & Harris 2011, MNRAS, 410, 2347

Clues to BH and galaxy formation

Small scale (BH) linked to large scale (bulge, and beyond?)

Origin of correlation?

Rooted in initial conditions or through galaxy assembly?

Causal?

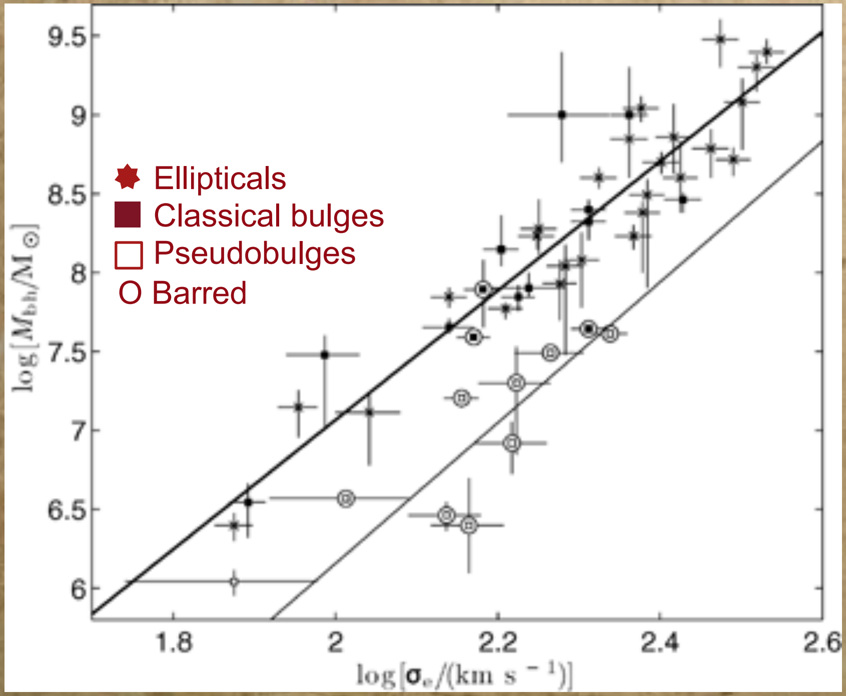
E.g., Star and GC formation driven by AGN jets
(Silk & Rees 1998; Fabian 2012)

BH growth through cannibalization of GCs
(Capuzzo-Dolcetta & collaborators, Gnedin+ 14, Jalili+ 12)

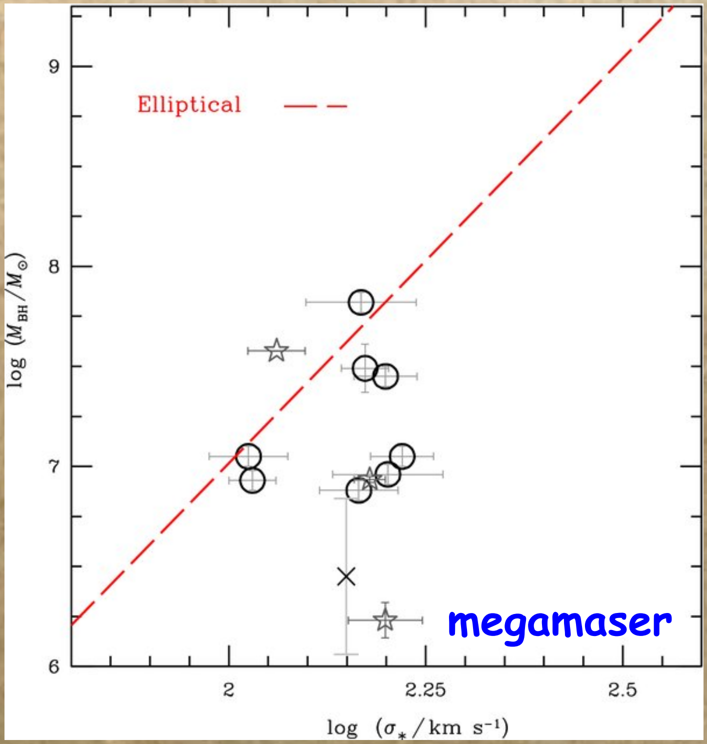
Statistical convergence through hierarchical galaxy formation?
(Peng 2007; Jahnke & Macciò 2011)

Big galaxies have more of everything?

M_{BH} correlations in spirals



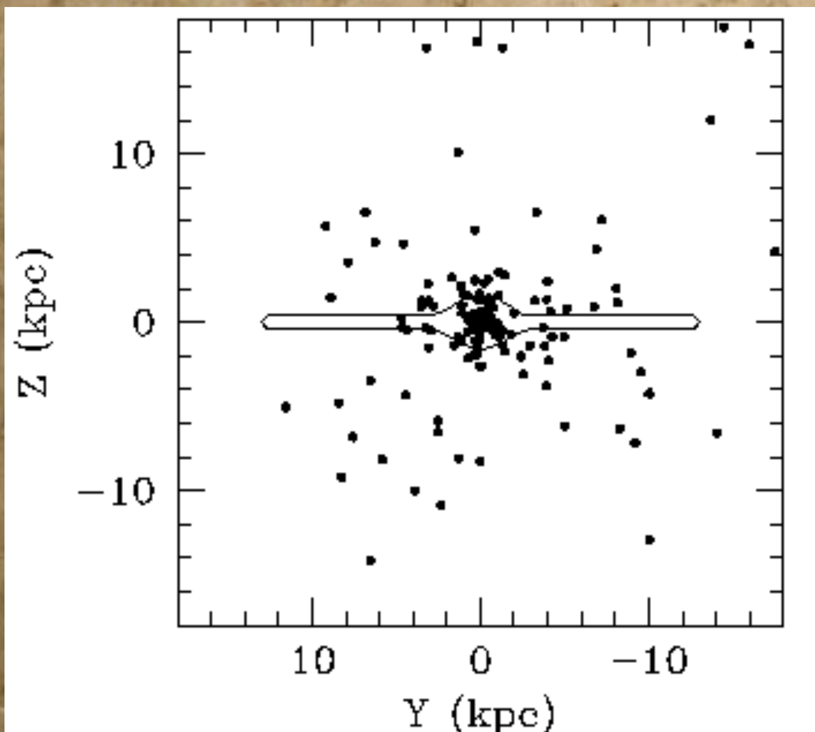
Hu 2008, MNRAS, 386, 2242



Greene et al. 2010, ApJ, 721, 26

Bulge vs. pseudobulge or just small mass (Graham 12a,b; Läsker+ 16)?

M_{BH} vs. N_{GC} in spirals



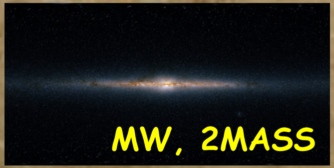
Harris 1996, AJ, 112, 1487

M_{BH} vs. N_{GC} in spirals

Compared to elliptical galaxies, extremely small number of spiral galaxies with N_{GC} or M_{BH} measurements, especially N_{GC}.

➔

Extremely sparse overlapping sample.


MW, 2MASS


M31, Wikipedia


M81, Ken Crawford


El Sombrero, Wikipedia


N253, VISTA, ESO

NGC 4258:
the archaetypical megamaser galaxy

X-ray: NASA/CXC/Caltech/P.Ogle et al.;
Optical: NASA/STSci; IR: NASA/JPL-Caltech;
Radio: NSF/NRAO/VLA

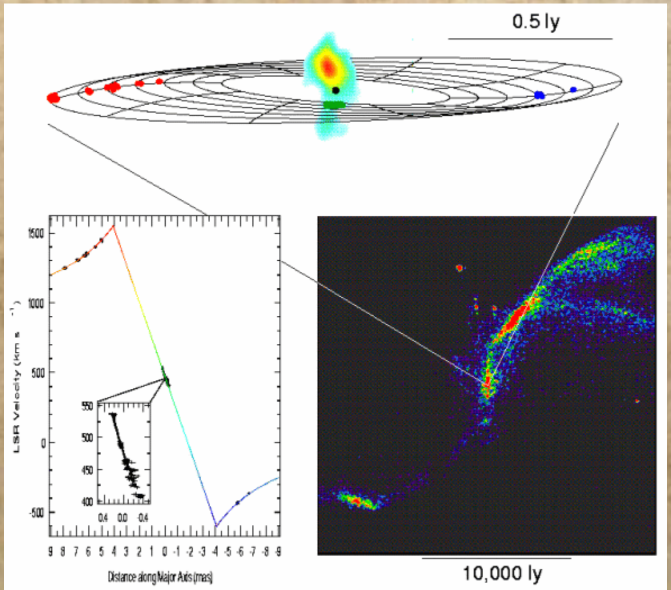


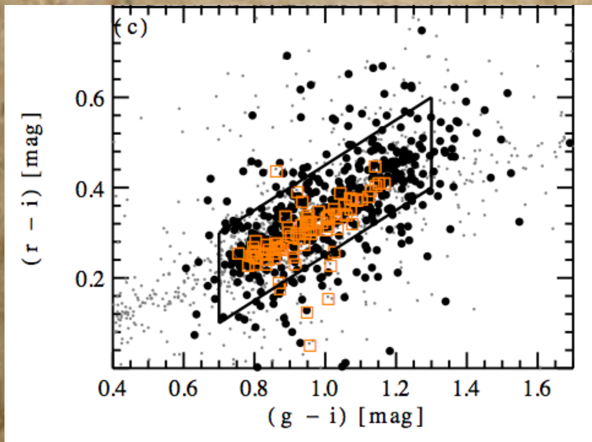
Image courtesy of NRAO/AUI

Distance: 7.60± 0.17± 0.15 Mpc Humphreys+ 13

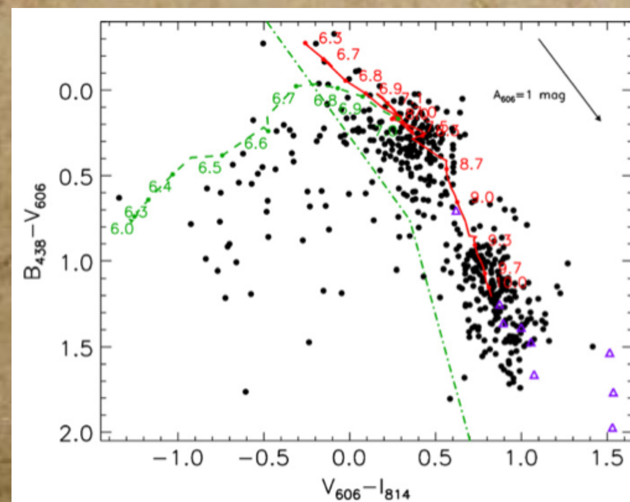
$M_\bullet$: $(4.00\pm0.09)\times 10^7\ M_\odot$, the most precise extragalactic $M_\bullet$ measurement

In spite of megamaser disk, a classical bulge.

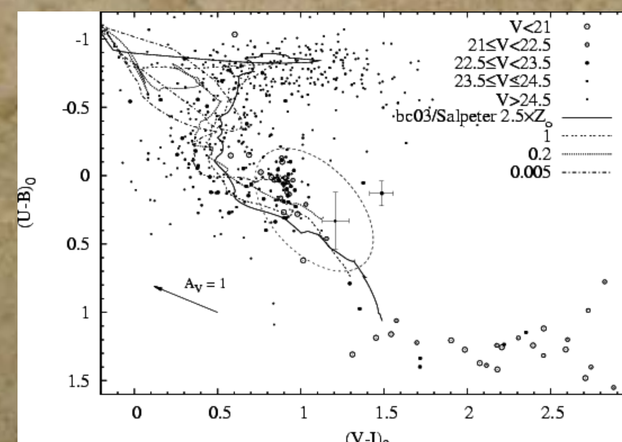
Color-color diagrams as diagnostic tools



Pota+ 15



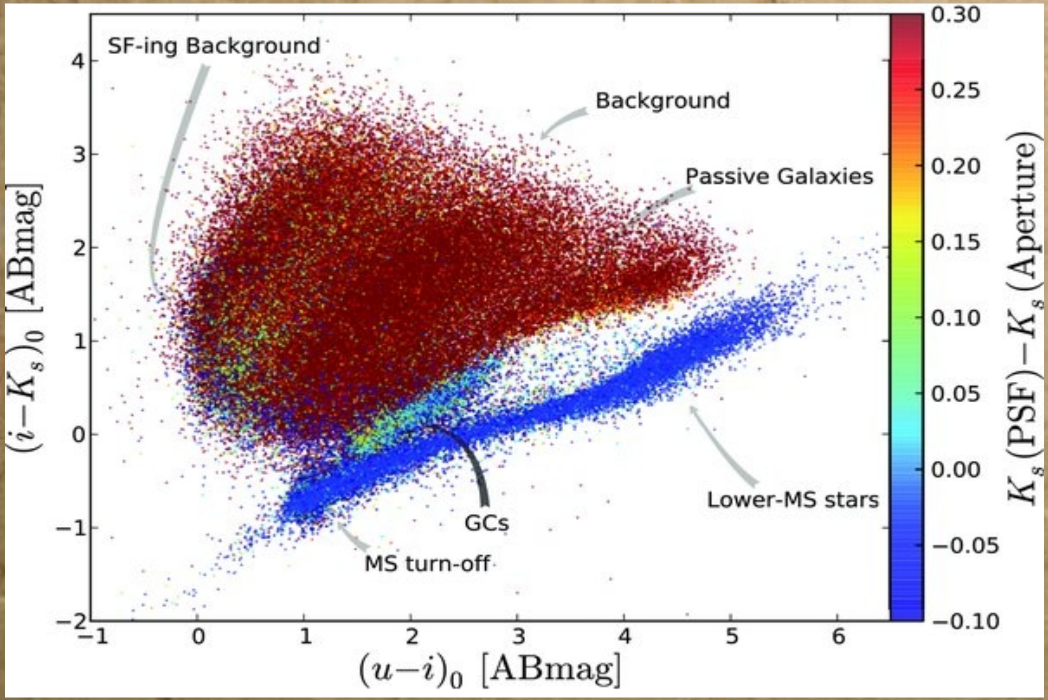
Fedotov+ 11

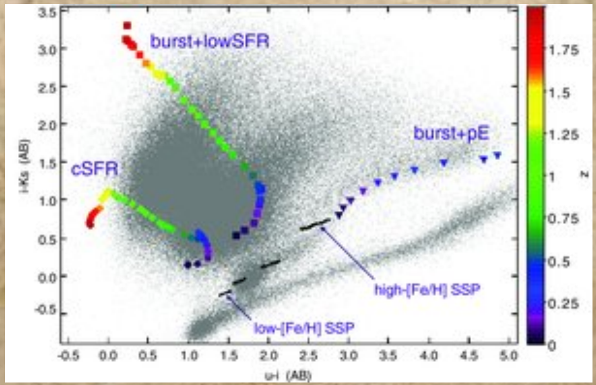


Georgiev+ 06

The (u'-i') vs. (i'-K_s) GC selection technique

M87, CFHT

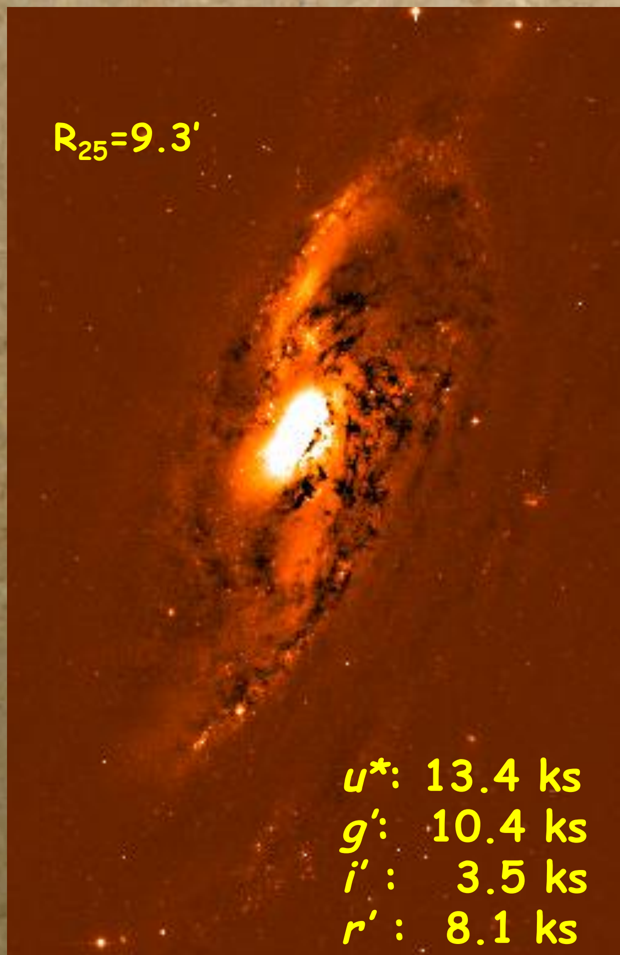




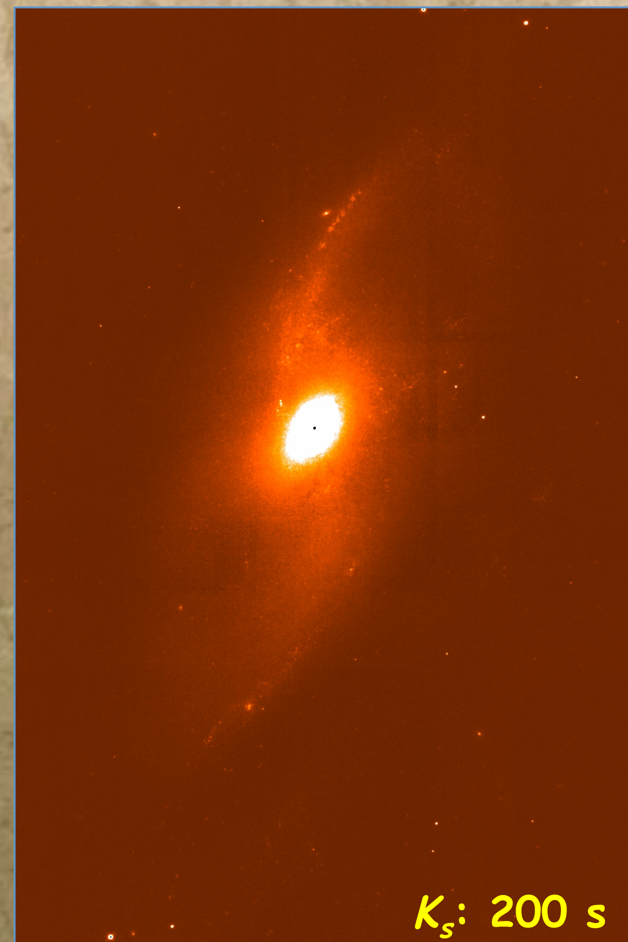
Muñoz+ 14

NGC 4258, CFHT data

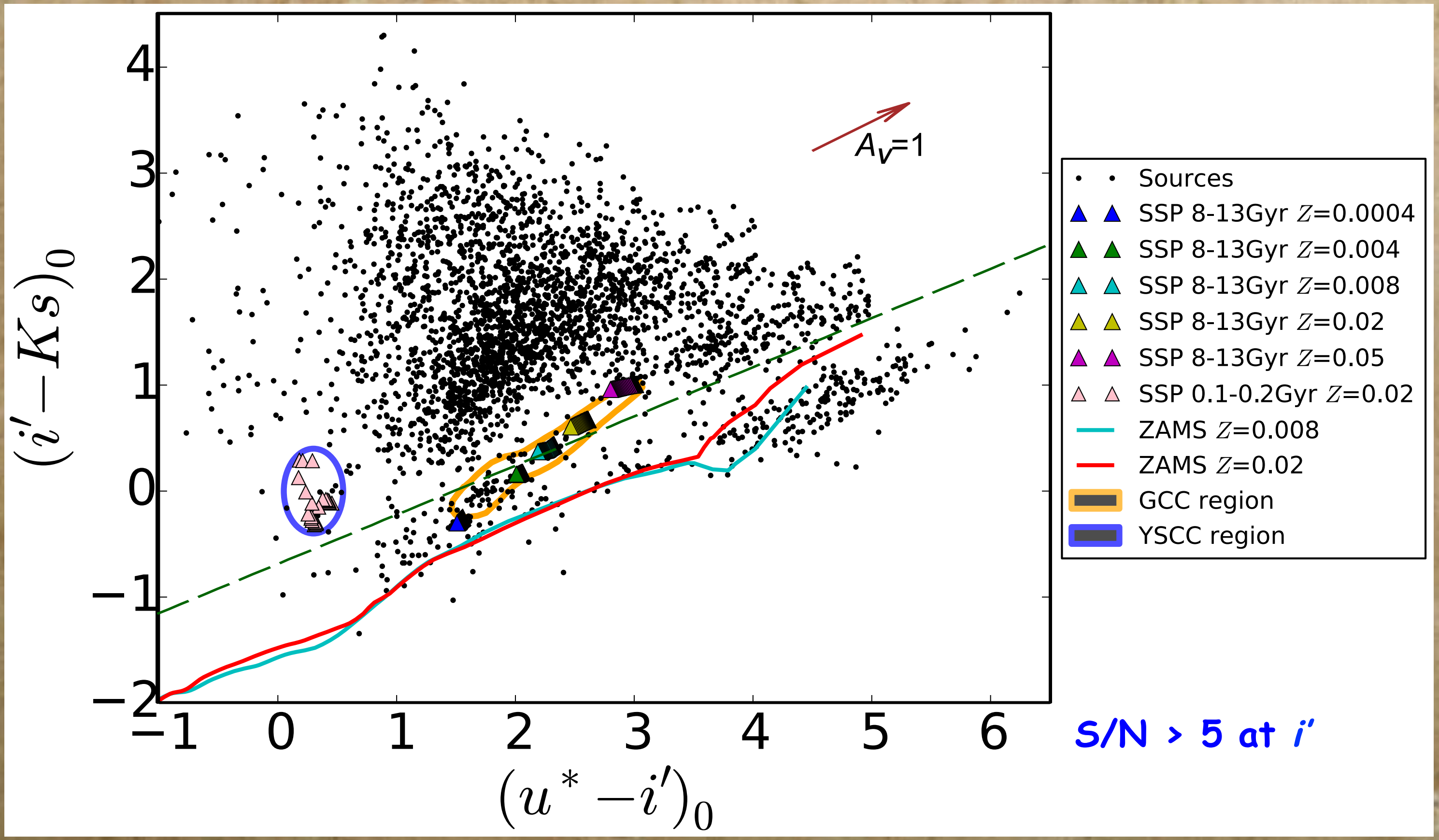
MegaCam archival *u**,*g*′,*i*′,*r*′
FOV = ~1° x 1°
1 pixel = 0.186″ ≈ 6.9 pc



WIRCam, K_s
FOV = 21′ x 21′
1 pixel = 0.307″ ≈ 11.4 pc



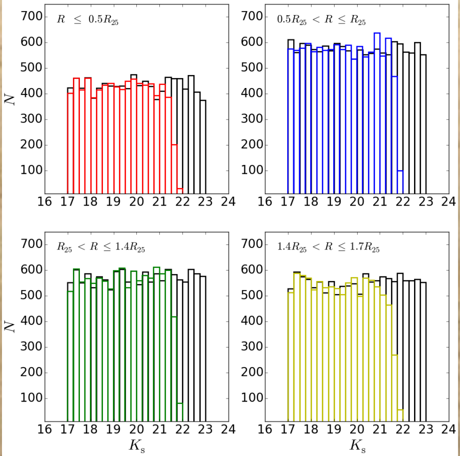
(u'-i') vs. (i'-K_s) -$u'i'K_s$- diagram of NGC 4258

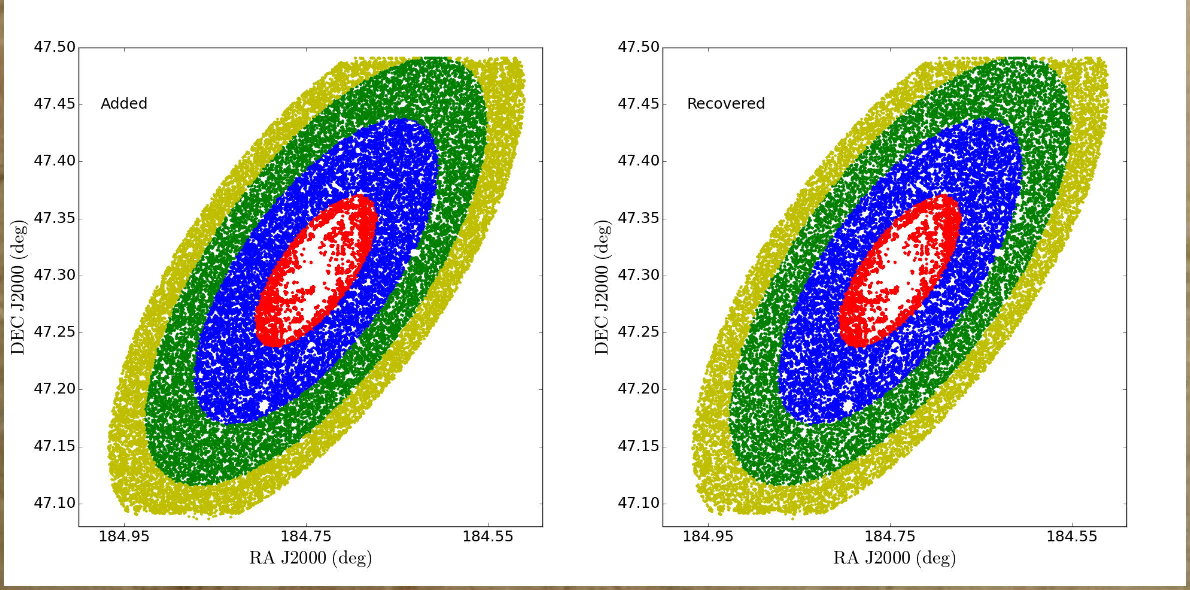


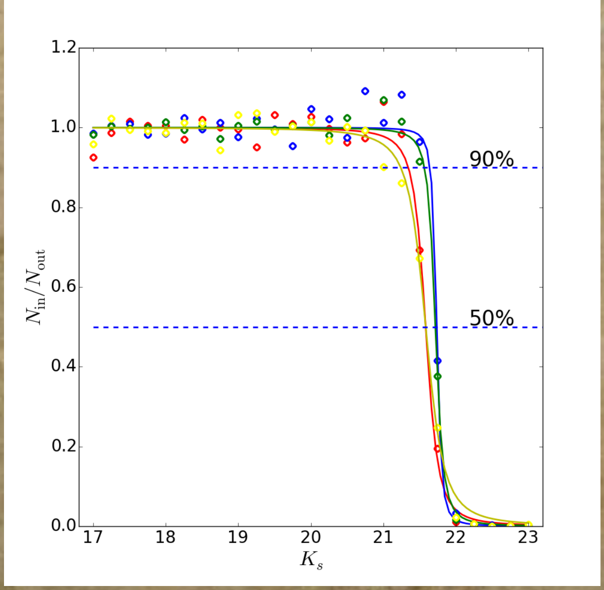
S/N > 5 at i'

Completeness tests (at K_s)

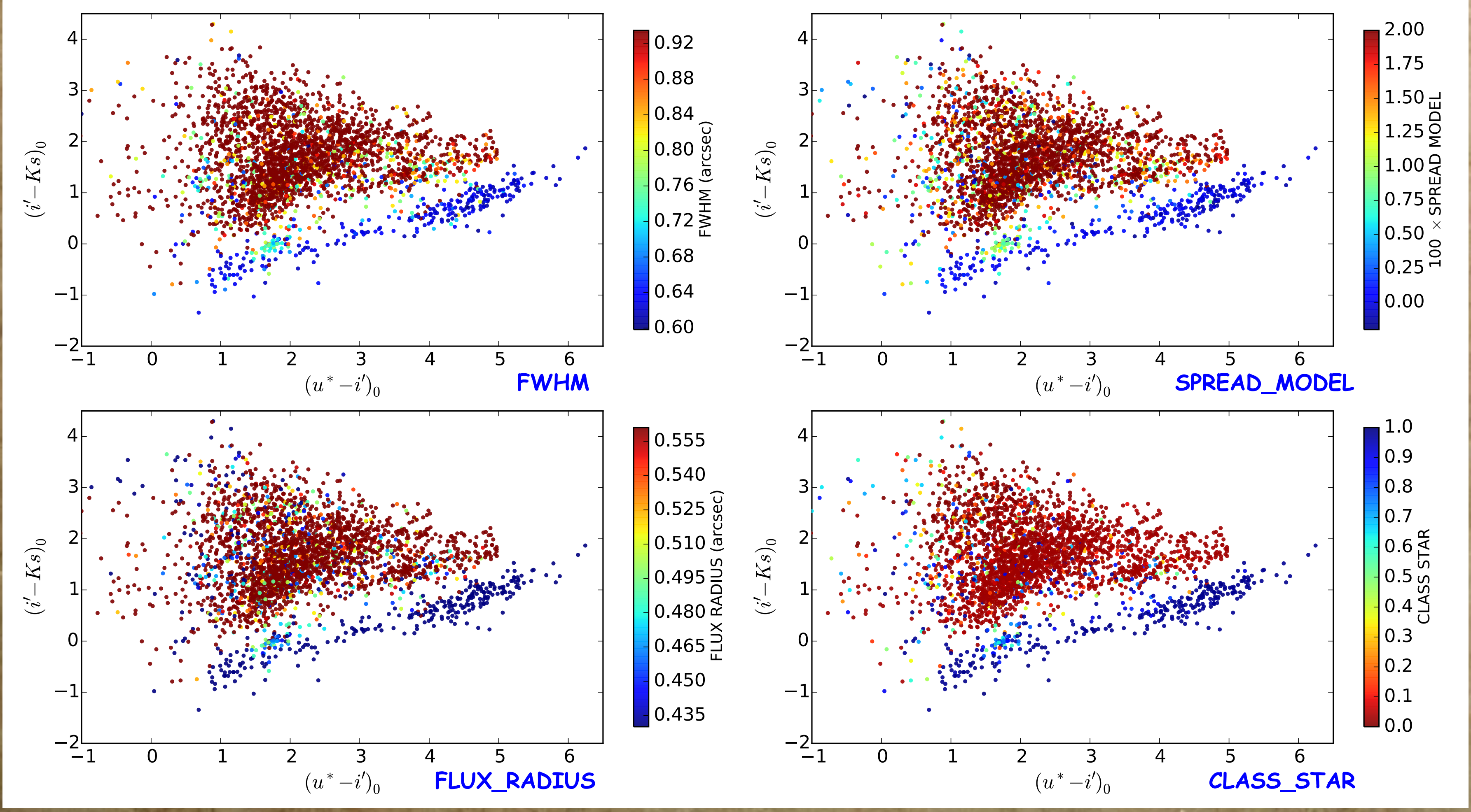
320,000 sources
non-overlapping
scaled by 1/area



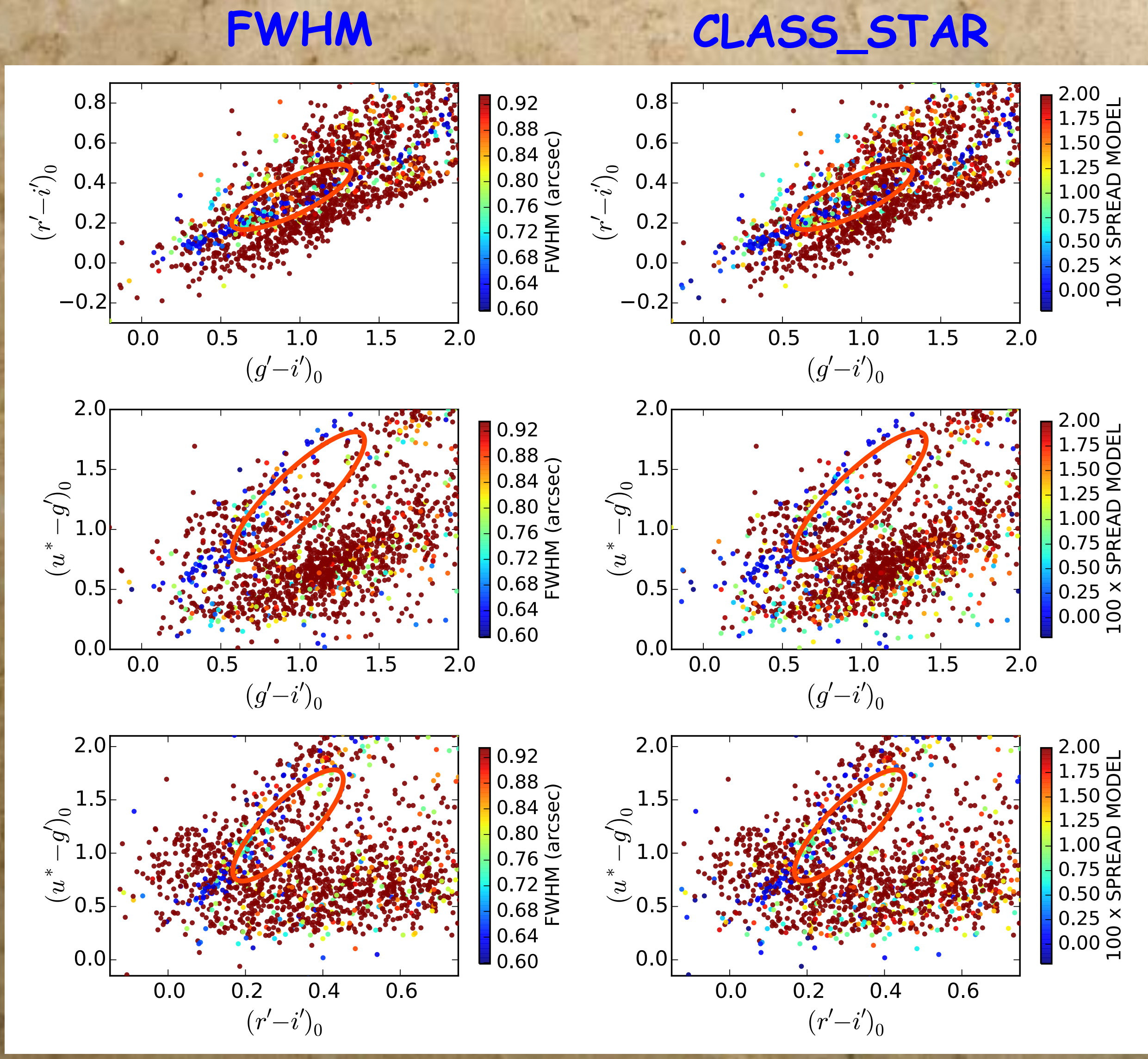




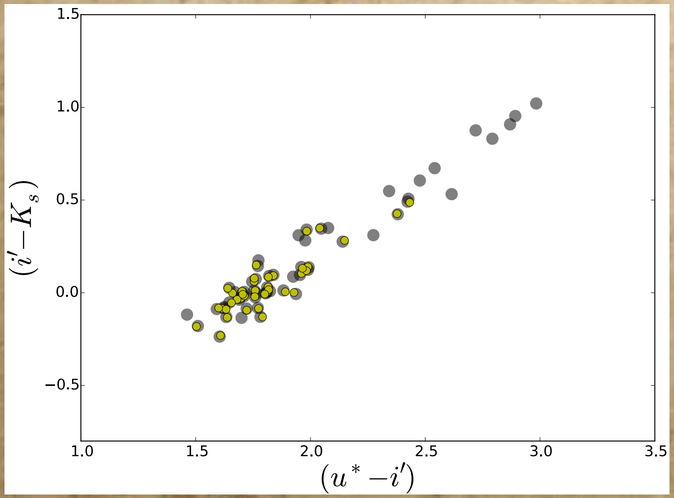
Light concentration parameters (at *i'*)



Alternative color-color diagrams, light concentration parameters (at *i'*)



Final sample



39 objects

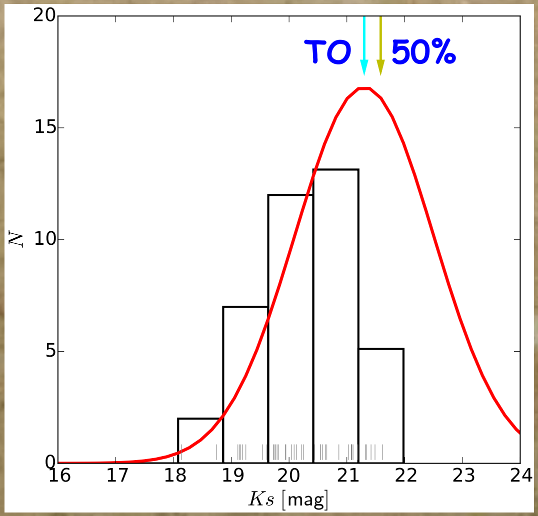
SPREAD_MODEL ≲ 0.017

FWHM ≲ 0.84"

r_e ≲ 6 pc

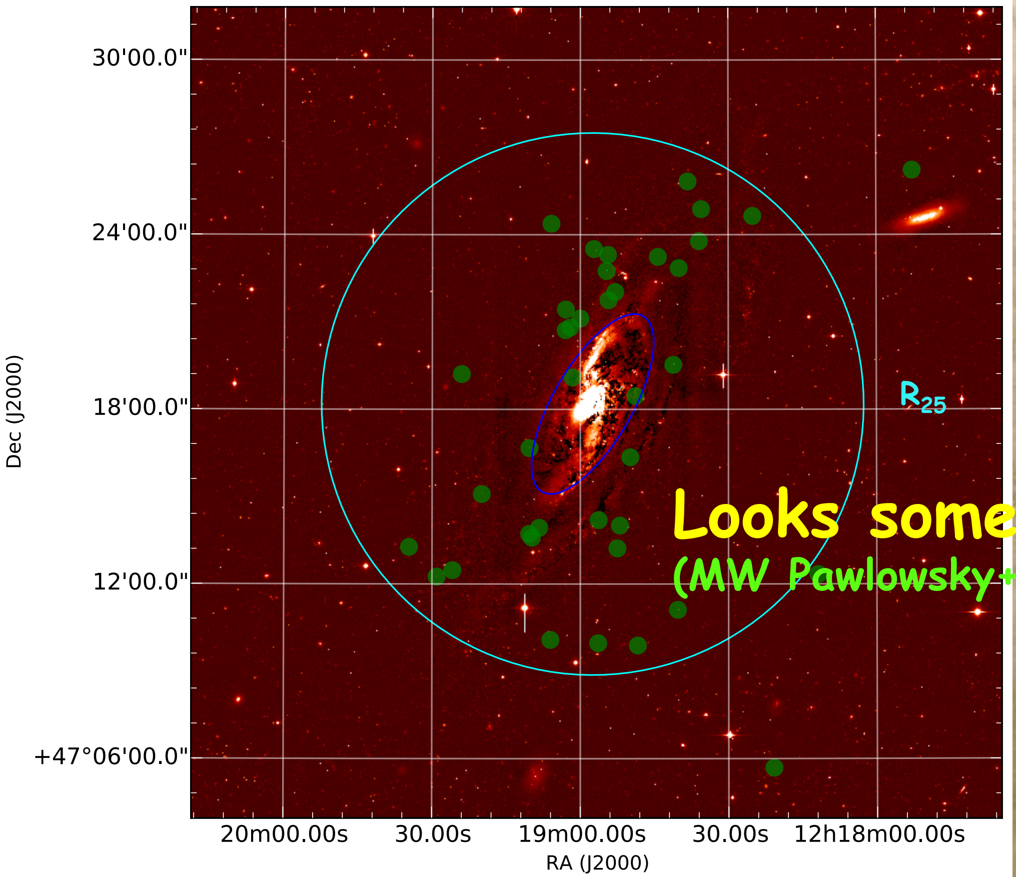
Further eliminated 4 objects,1 too red in other colors, especially in (r' – i'), and 3 for which re fit did not converge (1 probably the nucleous of a dwarf galaxy).

GCLF



TO = 21.3 mag
σ = 1.2 mag

Spatial distribution

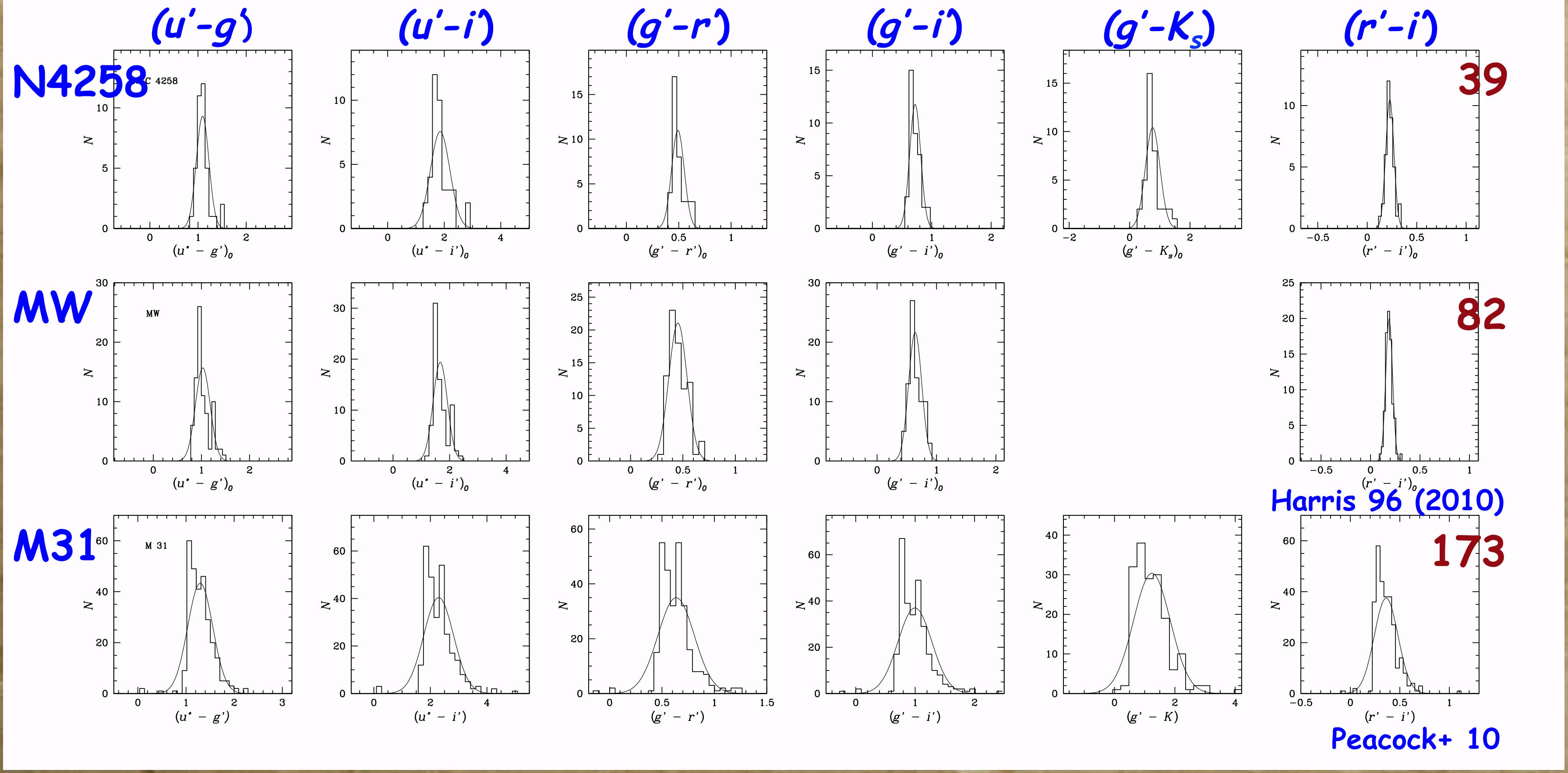


Looks somewhat disky!

(MW Pawlowsky+; M31 Ibata+)

KS test could not rule out with high significance system drawn from uniform distribution of ϕ, but need spectroscopy!

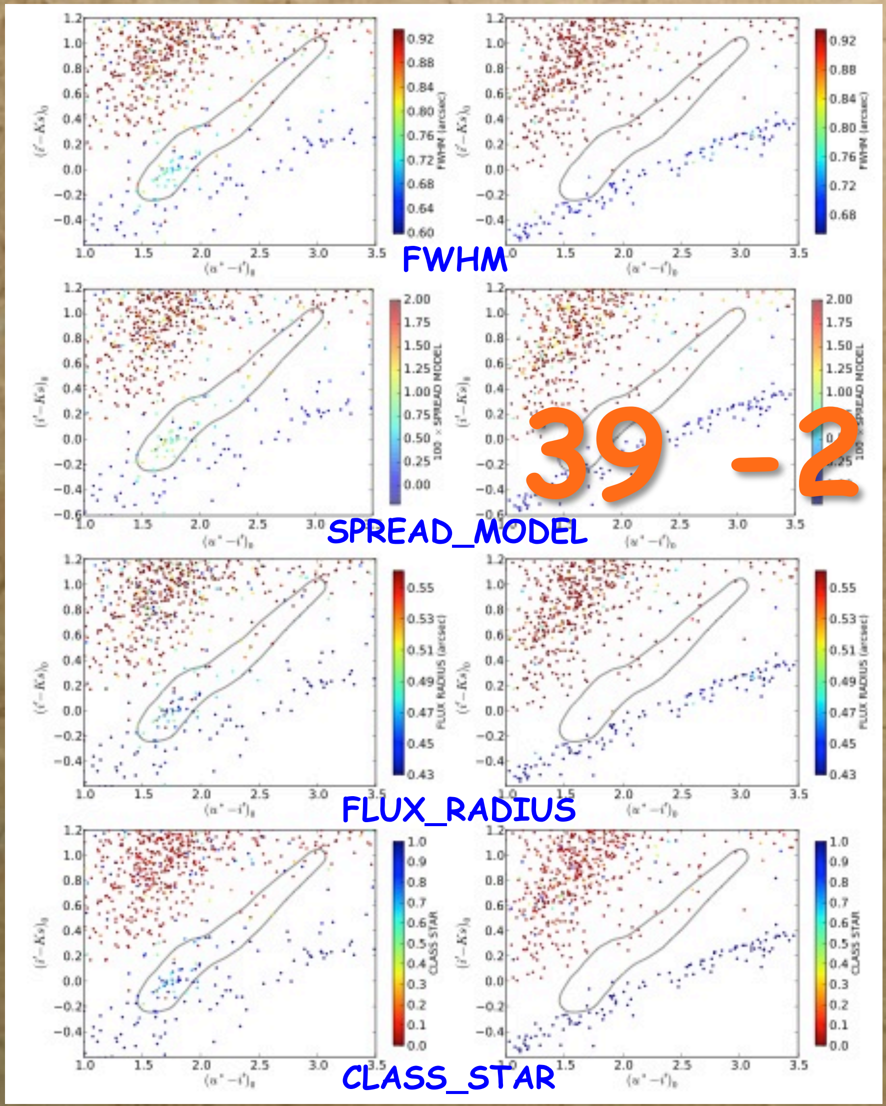
Color distributions



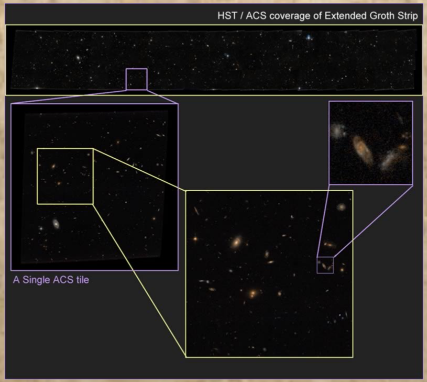
Same if we just take brighter than LFTO for MW and M31

Decontamination, a direct approach: the Extended Groth Strip

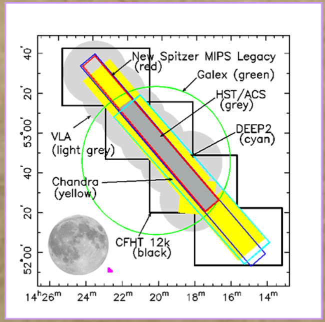
N4258 GROTH

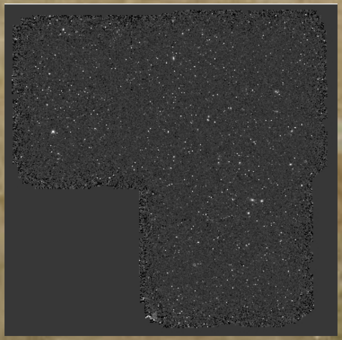


39 -2 = 37



aegis.ucolick.org



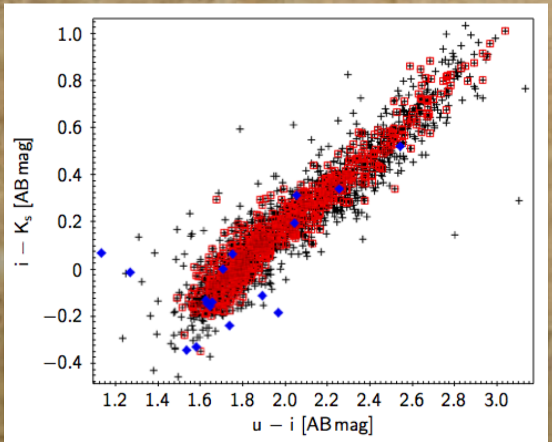


CFHT, K_s, Davis+ 07

Decontamination

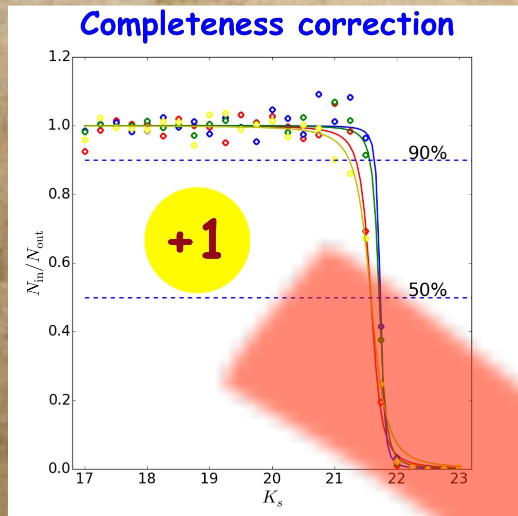
Conservatively, 2 contaminants (~5%), i.e., 37 objects

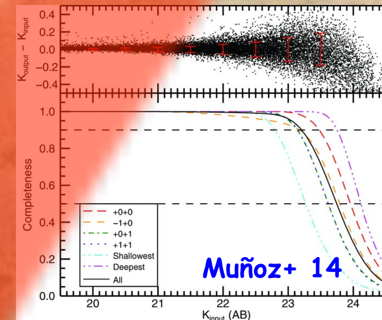
Consistent with Powalka+ 16 for M87

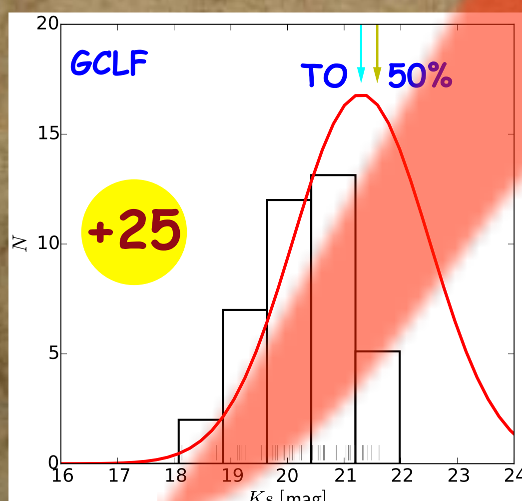


Black: detections
Red: spectroscopically confirmed
Blue: spurious

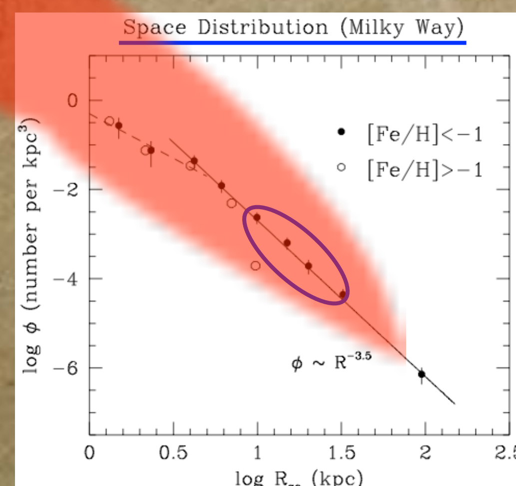
Total number of clusters, N_{GC}





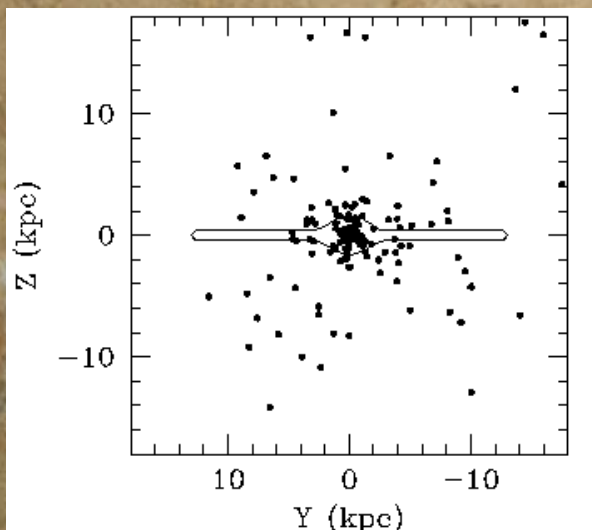


http://www.physics.mcmaster.ca/
Fac_Harris/Harris_SaasFee.pdf

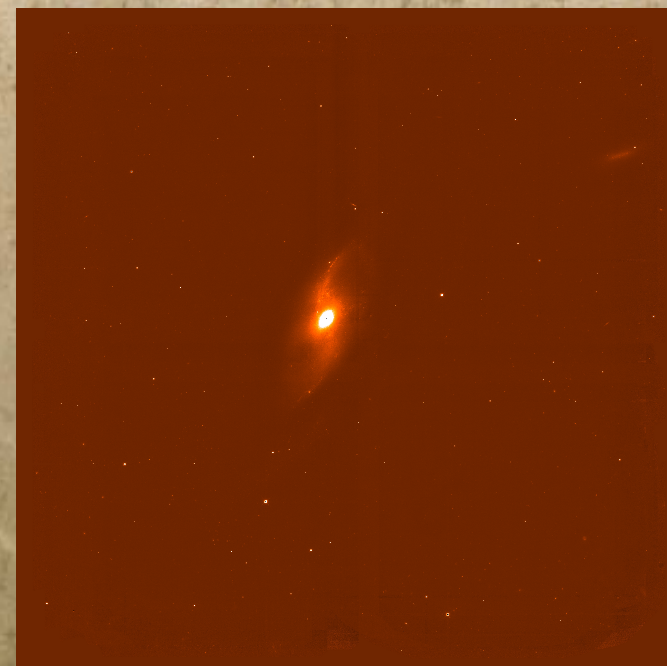


Project MW GC system as viewed if in NGC 4258

(e.g., Kissler-Patig+ 1999, AJ, 118, 197)



Harris 1996, AJ, 112, 1487



$N_{GC}(N4258) = N_{GC}(MilkyWay) \times N_{obs}/N_{FOV}$

i=67°
P.A. 150°

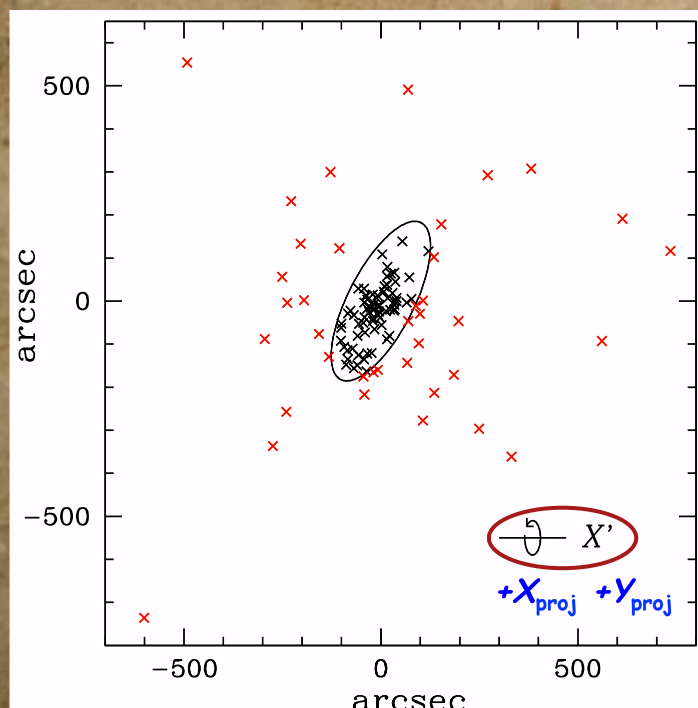
Possible orientations

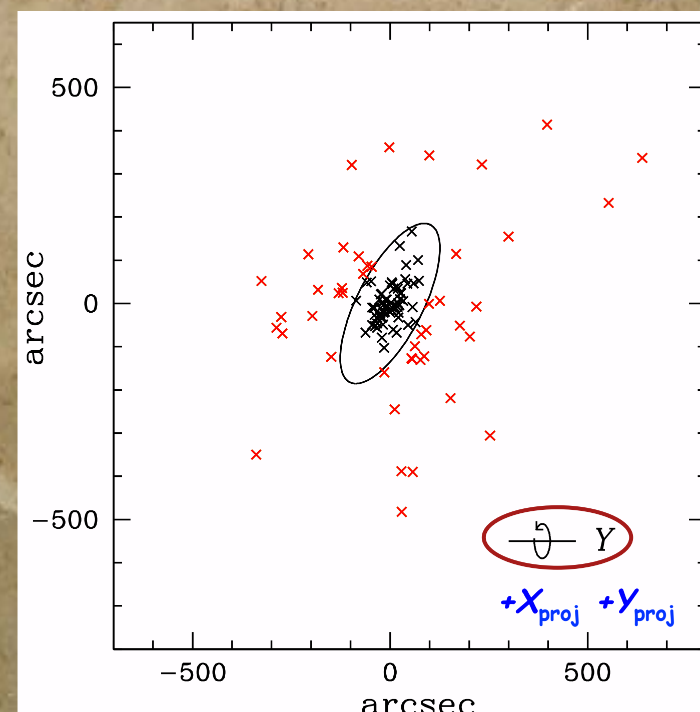
Edge-on, 4: *+Y +Z, -Y +Z, -Y -Z, +Y -Z*

NGC 4258, 8:

Rotation around *X'*: $+X_{proj}$ $+Y_{proj}$, $+X_{proj}$ $-Y_{proj}$, $-X_{proj}$ $+Y_{proj}$, $-X_{proj}$ $-Y_{proj}$

Rotation around *Y* : $+X_{proj}$ $+Y_{proj}$, $+X_{proj}$ $-Y_{proj}$, $-X_{proj}$ $+Y_{proj}$, $-X_{proj}$ $-Y_{proj}$





N_{GC} and S_N

$N_{GC} = N_{GC}(\text{MilkyWay}) \times N_{obs}/N_{FOV}$

N_{GC}(MilkyWay) = 160±10 (Harris et al. 2014)

N_{obs} = 39 – 2 = 37

N_{FOV} = 41 ± 5 (average of 8 projections)

=> N_{GC} = 144±31 (statistical error)

Systematics:

Δdistance (± 0.23 Mpc) => ΔN_{GC} = +12/-3
(mainly, limiting mag)

Difference in obscuration wrt MW, assume 25%

=> $N_{GC} = 144 \pm 31^{+38}_{-36}$

N_{GC} and S_N

$S_N = N_{GC} \times 10^{0.4\times[MV+15]} = 0.39 \pm 0.09$ (statistical only)

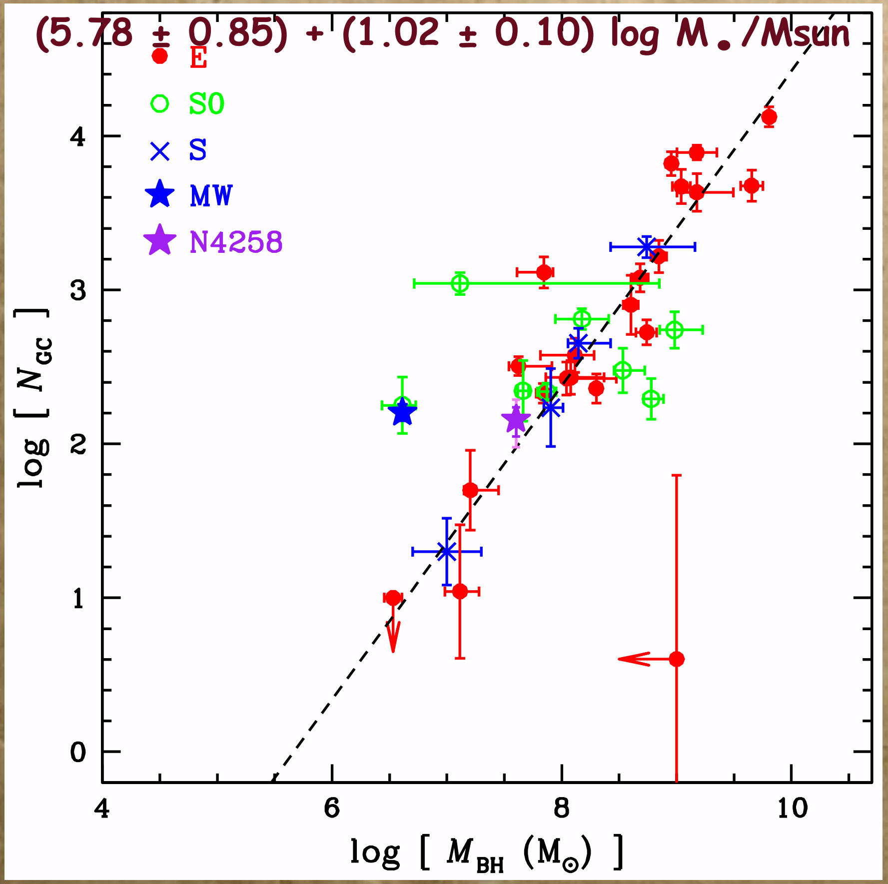
$S_N = 0.39 \pm 0.13$ if Δ obscuration included (Δ distance cancels out)

For comparison, S_N (MW) = 0.5 ± 0.1 (Ashman & Zepf 1998)

N_{GC} and M_{GC} vs. $M_\bullet$

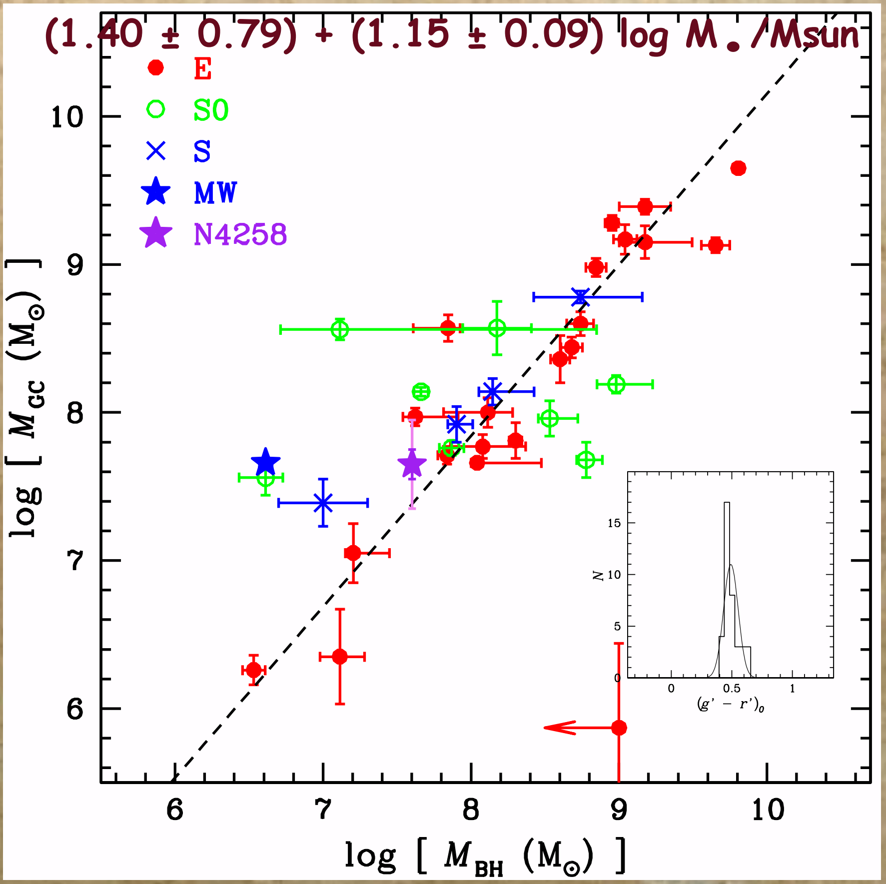
log N_{GC} =

(5.78 ± 0.85) + (1.02 ± 0.10) log $M_\bullet$/Msun



log M_{GC}/Msun =

(1.40 ± 0.79) + (1.15 ± 0.09) log $M_\bullet$/Msun



Potentially much less biased by incompleteness; more than 90% of mass in clusters brighter than 1 mag beyond LFTO.

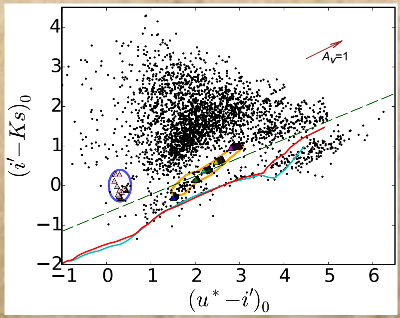
Near future

A spectroscopic study will:

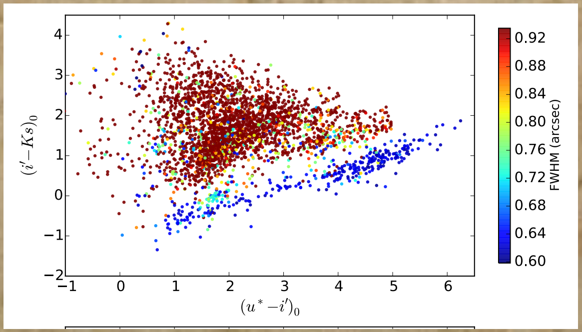
- Further validate procedures of souce detection and selection
- Confirm GCC membership
- Determine kinematics, shape of system (disky?), DM content (or alternative)
- Investigate correlation between GC system velocity dispersion and $M_\bullet$ (Sadoun & Colin 2012)

Conclusions

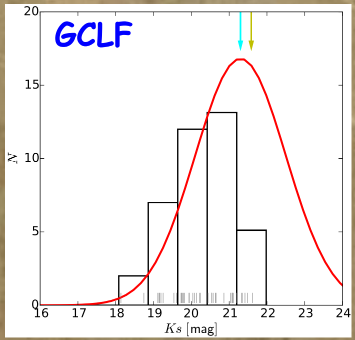
Successfully applied the $u^*i'K_s$ GC selection technique for the first time to a spiral.

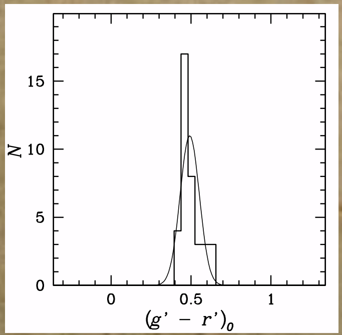


$u^*i'K_s$ diagram + light concentration parameters the most efficient photometric tool to study GC systems; much cheaper than spectroscopy.



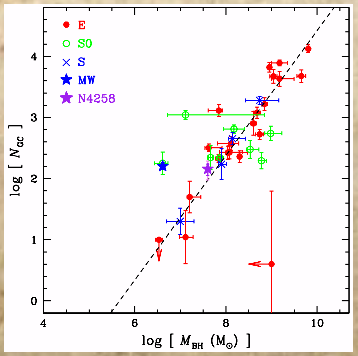
Detected 39 GCCs in NGC 4258. Color distribution consistent with MW and M31 GC systems.

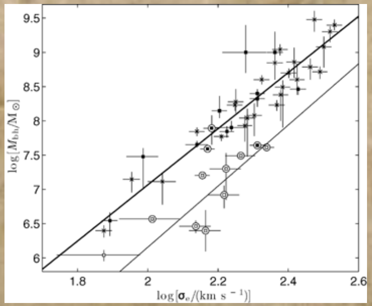




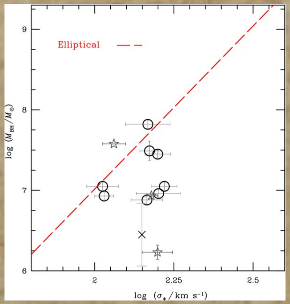
Conclusions

N_{GC} = 144±31, S_N = 0.4±0.1 (random uncertainty only). NGC 4258 falls within 2 σ on the N_{GC} vs. $M_\bullet$ relation for elliptical galaxies. The MW continues to be the only spiral that deviates significantly.

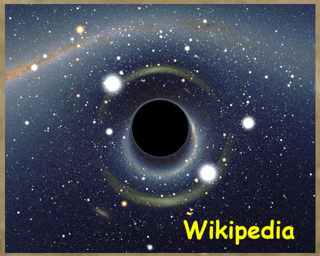




We need a larger sample of low mass galaxies of different morphologies. E.g.,parallel sequence (BH feeding efficiency) or scatter (convergence through merging)?



At the very least, N_{GC} vs. $M_\bullet$ correlation probe of otherwise inaccessible BH masses.



THANKS!