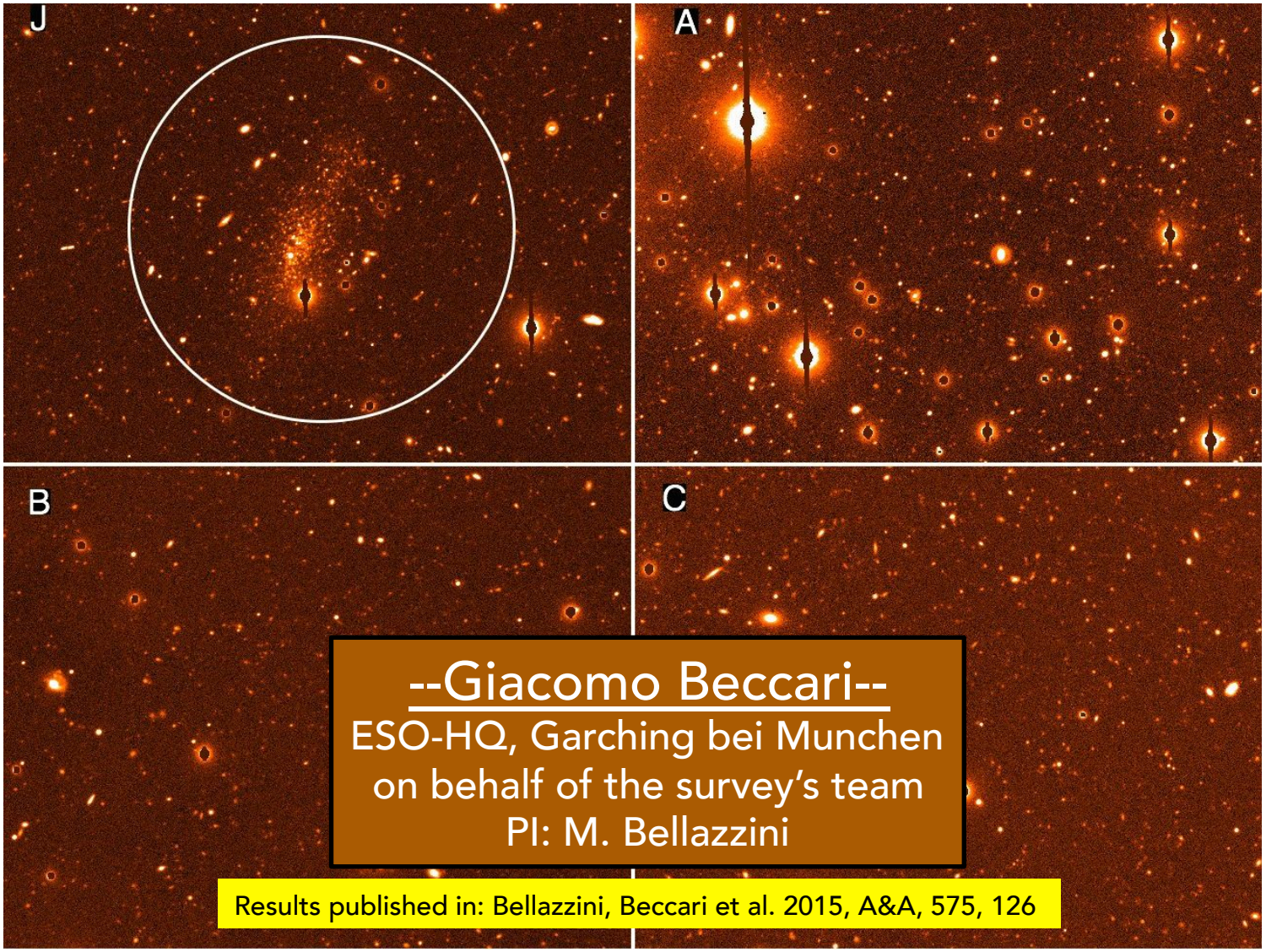
The StEllar Counterparts of COmpact high velocity clouds (SECCO) survey

-Photos of ghosts-

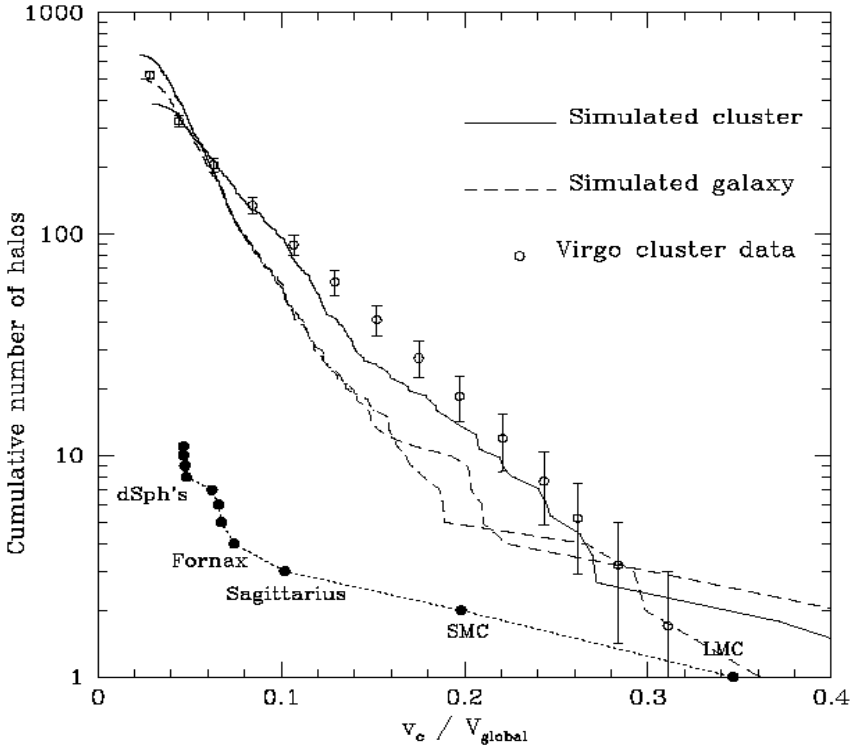


--Giacomo Beccari--
ESO-HQ, Garching bei Munchen
on behalf of the survey's team
PI: M. Bellazzini

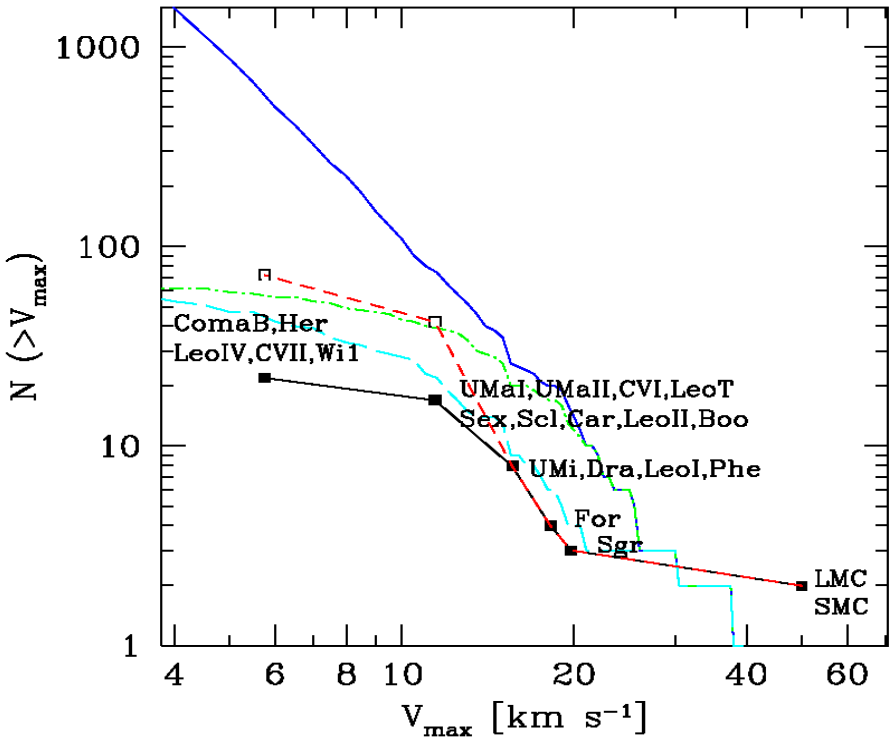
Results published in: Bellazzini, Beccari et al. 2015, A&A, 575, 126

A premise: the "missing satellites" problem (still a problem?)

Moore et al. 1999



Madau et al. 2008



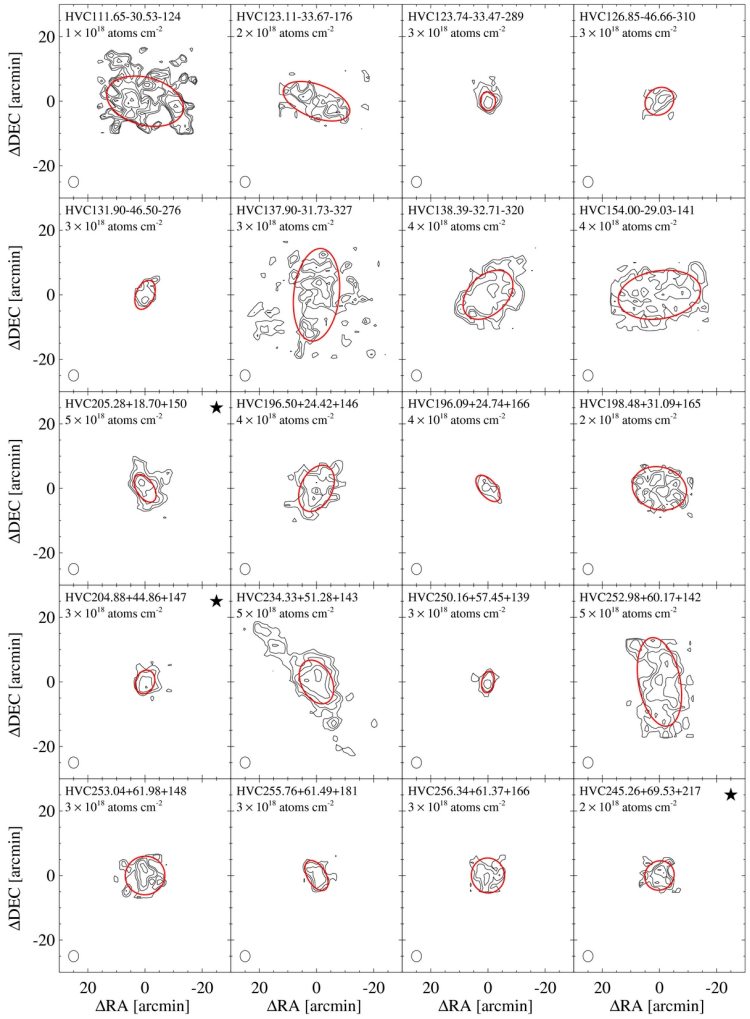
…apparent lack of low mass galaxies compared to the numbers predicted by the numerical simulations

Improvement: Observational → modern wide-field surveys (e.g. SDSS)

Theoretical → baryonic physics (e.g. Koposov et al. 2009, ApJ, 696, 2179)

Interesting alternative: searching for low-mass compact HI clouds.

ALFALFA: Adams et al. 2013 selected 59 UCHVCs which are of interest as speculative minihalo candidates.



UCHVCs = candidate gas-rich and star-poor dwarfs in the range 0.5 Mpc ≤ D ≤ 2.0 Mpc

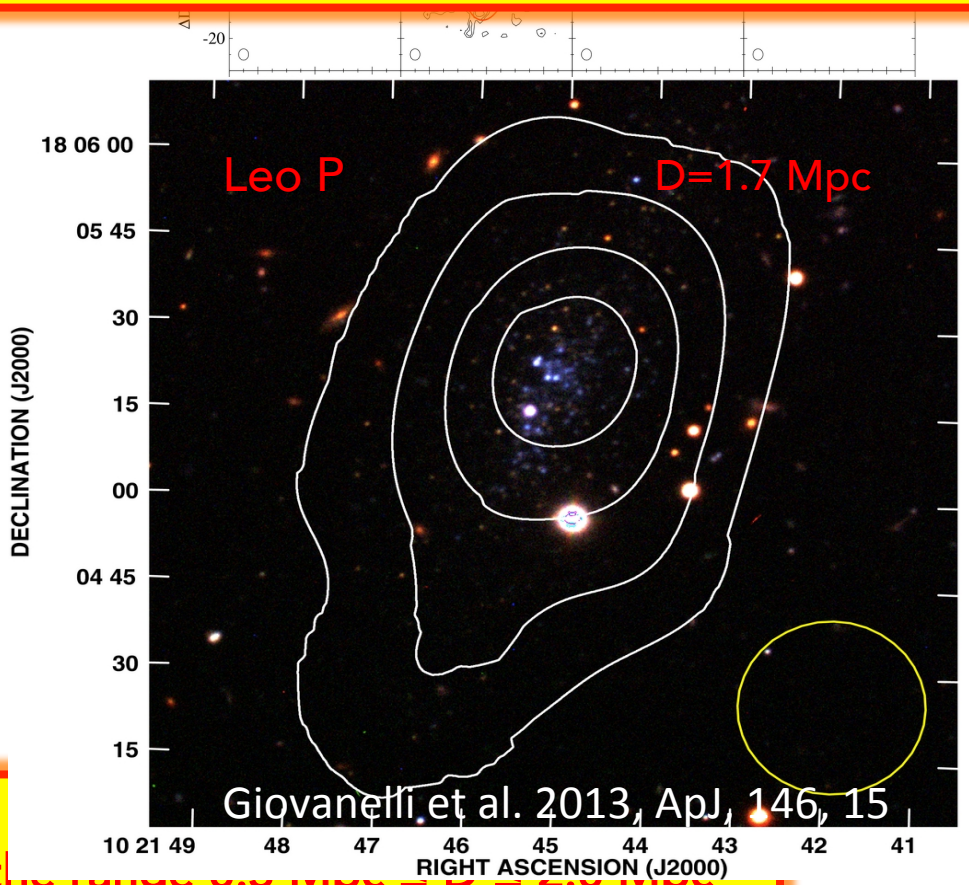
Saul et al. 2012 selected 27 candidates from GALFA-HI

The GALFA- HI and ALFALFA surveys provide a new opportunity for discovering Local Volume galaxies within ~10 Mpc

Finding out a stellar component is crucial:

1. **To confirm the galaxian nature of the things**

2. **To get their DISTANCE. Without a distance estimate you will never know the actual physical properties of the system**

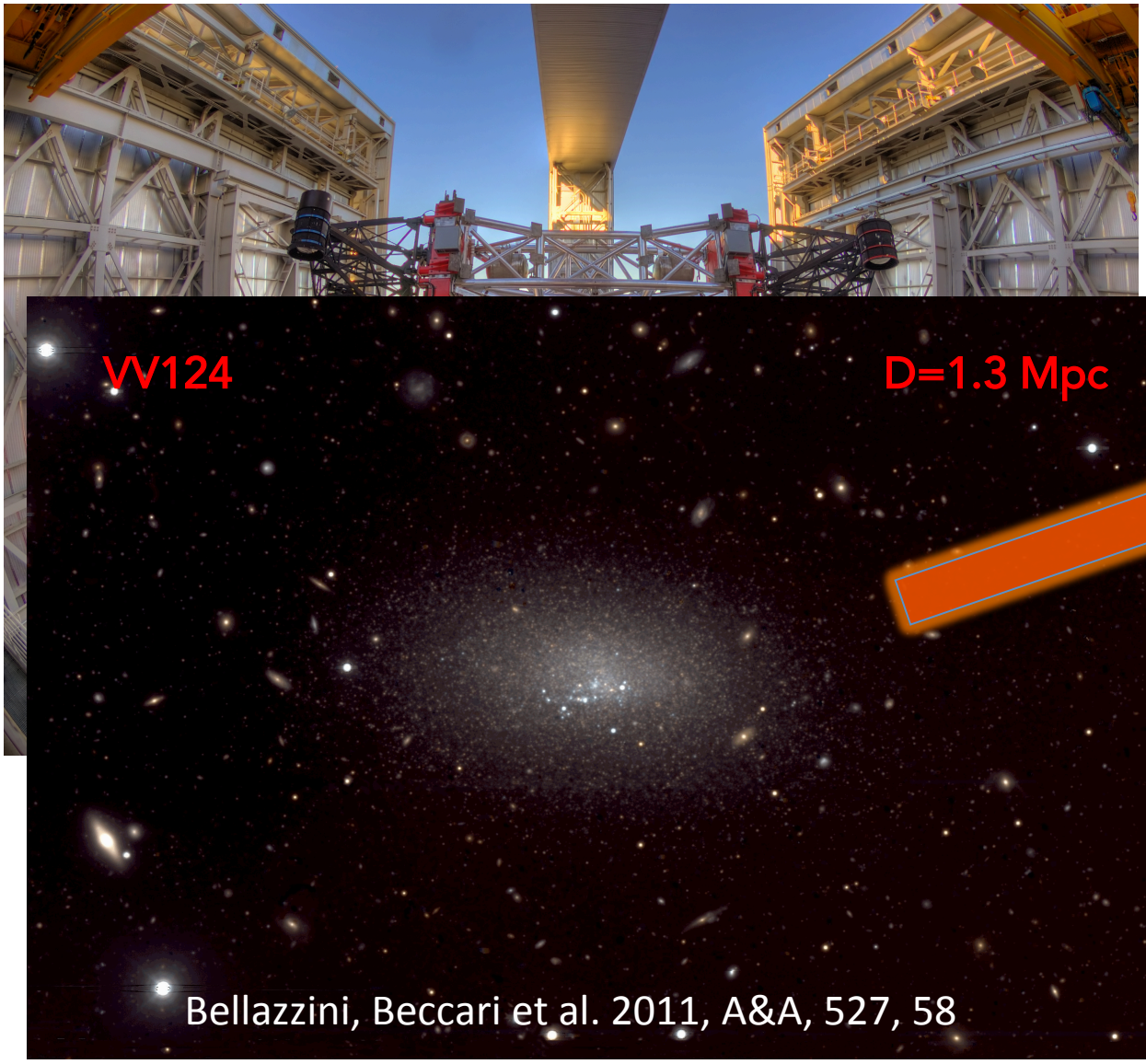


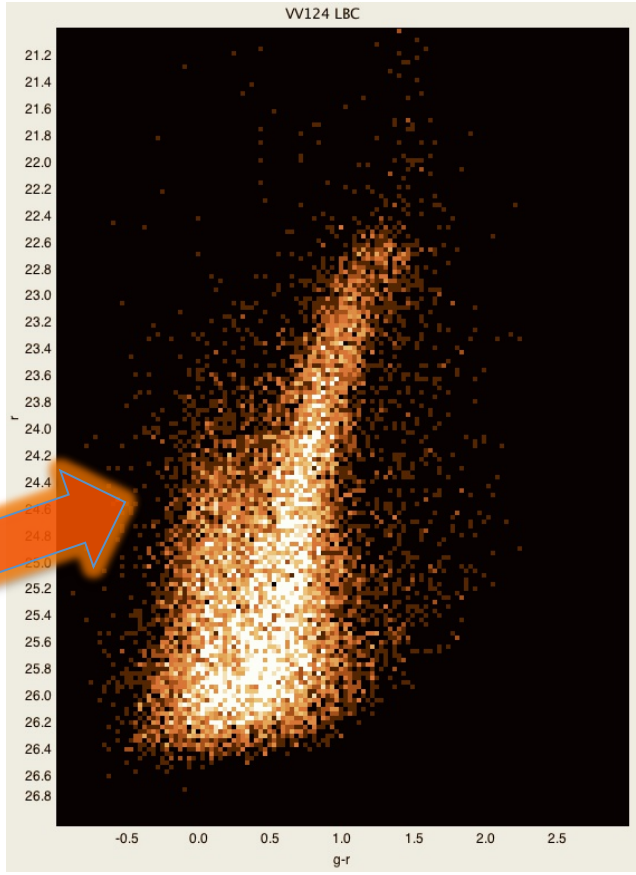
UCHVCs = dwarfs in t

Saul et al. 2012 selected 27 candidates from GALFA-HI

So, let's try: the SECCO survey searching for StEllar Counterparts of COmpact high velocity clouds

We have a great machine for finding out feeble counterparts: **LBC@LBT**





r≃ 26.5 with 2×300s exposures per filter

So, let's try: the SECCO survey
searching for StEllar Counterparts of COmpact high velocity clouds

TARGETS: 17 Most Isolated Sample (A13) +
the 8 most compact among the A13 UCHVCs+
Leo P (reference case) = 26

EXPs: 2×300s g_{SDSS} 2×300s r_{SDSS}

- 84% of the images comply with requirements (FWHM≤ 1.2″)
  54% of the images have FWHM≤1.0″
  only 3% have FWHM≥1.5″

Field	CHVC	RA_{J2000} [deg]	Dec_{J2000} [deg]	$a \times b$ [arcmin]	$\langle E(B-V) \rangle$ [mag]	$\sigma_{E(B-V)}$ [mag]	$r_{90}{}^{a}$ [mag]	Notes
A	HVC205.28+18.70+150*	116.4995833	+14.9769444	10 × 6	0.029	0.004	26.48	
B	HVC204.88+44.86+147*	142.5550000	+24.2047222	8 × 6	0.021	0.001	26.37	
C	HVC277.25+65.14-140*	182.3333333	+4.3916667	7 × 4	0.015	0.002	26.31	
D	HVC274.68+74.70-123*	185.4779167	+13.4694444	5 × 4	0.048	0.004	26.26	Vis. cand. D1
E	HVC351.17+58.56+214*	215.8383333	+4.5769444	7 × 5	0.024	0.001	26.20	
F	HVC356.81+58.51+148*	217.9950000	+6.5888889	6 × 5	0.024	0.001	26.11	
G	HVC 13.59+54.52+169*	226.8458333	+11.5488889	10 × 5	0.033	0.001	26.38	
H	HVC 13.60+54.23+179*	227.1016667	+11.4061111	15 × 7	0.035	0.003	25.63	
I	HVC 13.63+53.78+222*	227.5025000	+11.1908333	9 × 6	0.038	0.003	25.59	
J	Leo P	155.4379167	+18.0880556	3 × 1.6[b]	0.025	0.008	26.43	
K	HVC196.09+24.74+166	119.0616667	+25.1500000	10 × 5	0.059	0.008	26.35	
L	HVC245.26+69.53+217*	175.0337500	+15.1122222	10 × 9	0.026	0.001	26.27	
M	HVC298.95+68.17+270*	191.3741667	+5.3397222	16 × 9	0.019	0.002	25.98	
N	HVC326.91+65.25+316*	202.6825000	+4.2272222	12 × 10	0.025	0.001	25.76	
O	HVC 28.09+71.86-144*	212.7420833	+24.2011111	15 × 9	0.019	0.002	25.99	
P	HVC353.41+61.07+257*	214.9525000	+7.1875000	13 × 9	0.027	0.002	26.20	
Q	HVC352.45+59.06+263*	215.9904167	+5.3944444	16 × 11	0.024	0.002	26.16	Overd. Q1
R	HVC 5.58+52.07+163*	226.1720833	+6.2163889	11 × 10	0.036	0.007	26.35	
S	HVC 27.86+38.25+124*	246.1808333	+12.7366667	11 × 9	0.053	0.009	25.76	
T	HVC330.13+73.07+132	200.6733333	+11.8752778	6 × 3	0.027	0.005	25.91	
U	HVC250.16+57.45+139	167.3741667	+5.4336111	7 × 4	0.045	0.009	26.32	
V	HVC324.03+75.51+135	198.1762500	+13.5127778	7 × 5	0.020	0.006	25.64	
W	HVC28.07+43.42+150	241.3858333	+14.9888889	10 × 5	0.035	0.006	25.86	
X	HVC290.19+70.86+204	188.6675000	+8.4022222	10 × 6	0.019	0.005	25.73	
Y	HVC255.76+61.49+181	172.2316667	+6.4247222	11 × 6	0.036	0.003	26.36	
Z	HVC26.01+45.52+161	238.7812500	+14.4913889	8 × 6	0.032	0.001	25.89	

homepage publications data **people**

SECCO Survey

searching for StEllar Counterparts of COmpact high velocity clouds

People

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Matteo Correnti (Space Telescope Science Institute, USA)
Rodrigo Ibata (Observatoire astronomique de Strasbourg, Université de Strasbourg, CNRS, France)
Nicolas Martin (Observatoire astronomique de Strasbourg, Université de Strasbourg, CNRS, France / Max-Planck-Institut für Astronomie, Germany)
Vincenzo Testa (INAF - Osservatorio Astronomico di Roma, Italy)

Other collaborators:

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Acknowledgments:

We acknowledge the support from the LBT-Italian Coordination Facility for the execution of observations, data distribution and reduction.

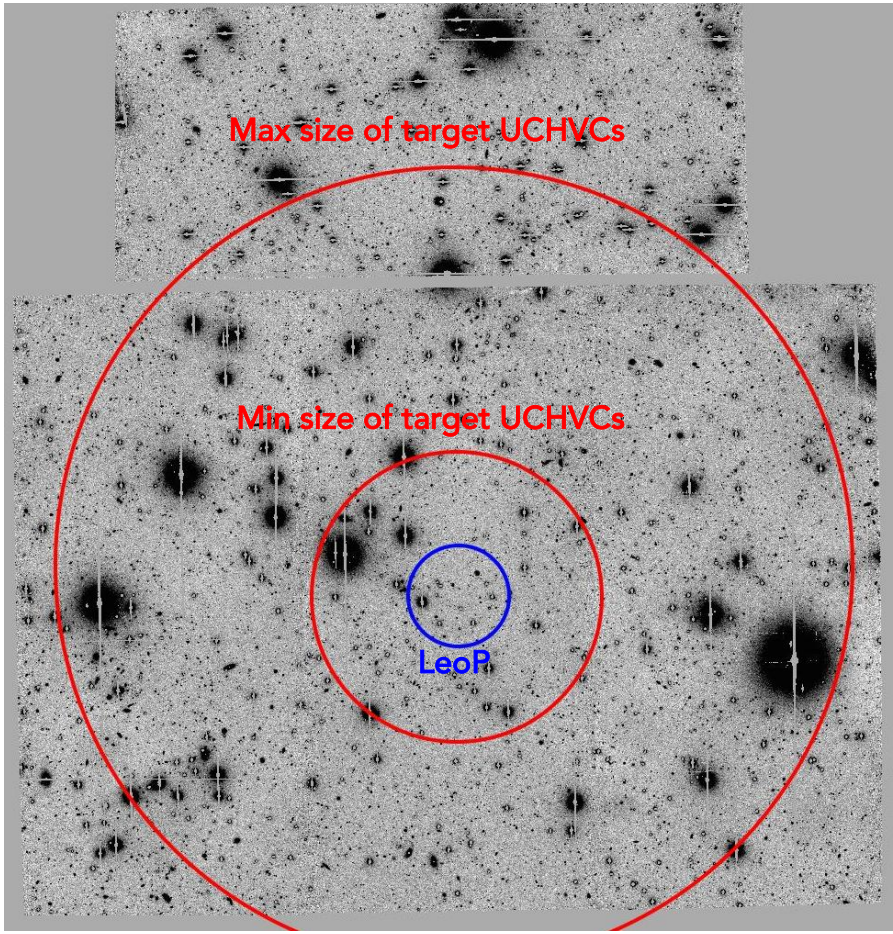
SECCO made use of the CataPack suite of codes. CataPack was developed by Paolo Montegriffo at INAF - Osservatorio astronomico di Bologna.

the SECCO survey: basic characteristics & observations

-The aim-

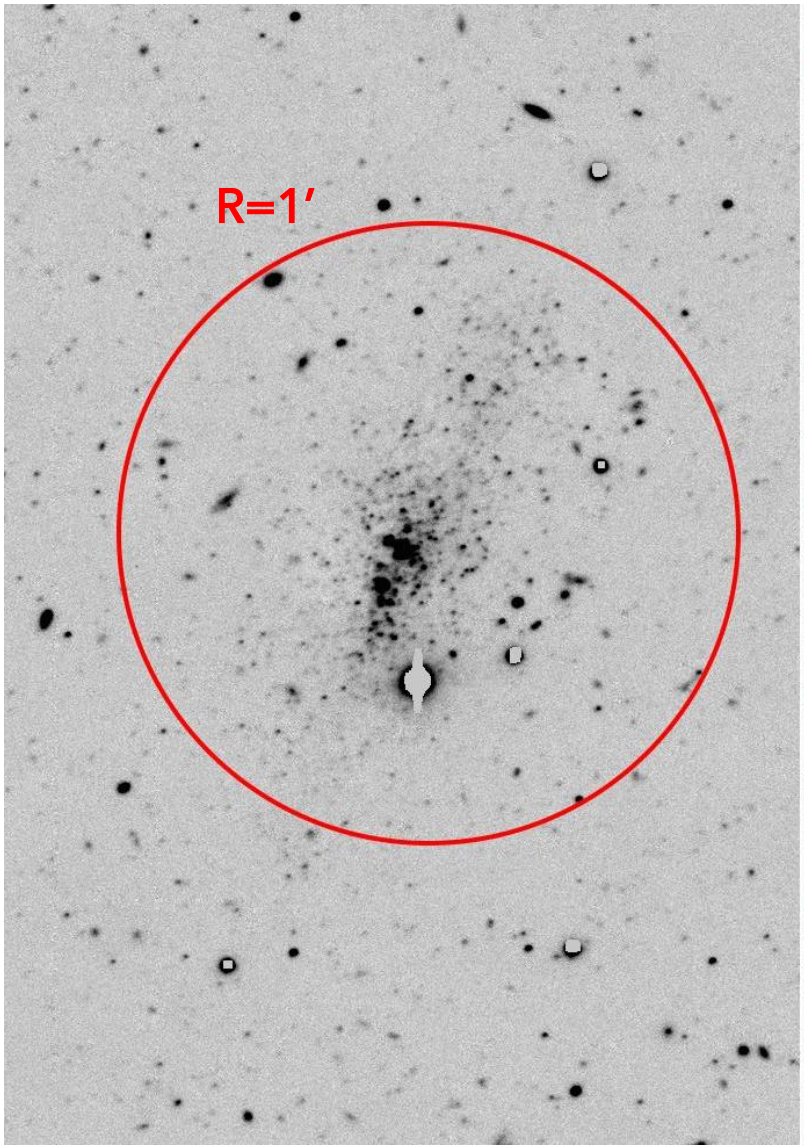
-find out any stellar system that can be associated with the targeted UCHVCs: SECCO images are 4 mag deeper Than SDSS

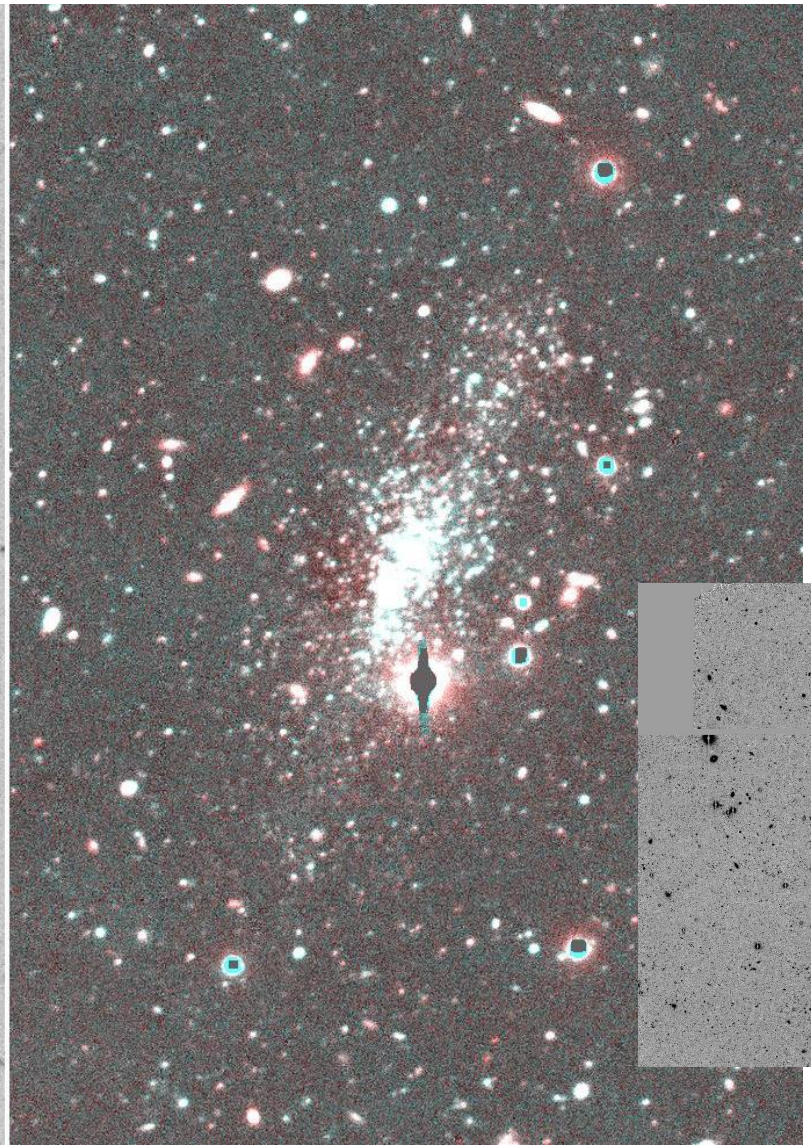
-We want to quantify non-detections, i.e. constrain the sensitivity space of our survey by means of synthetic dwarf galaxies

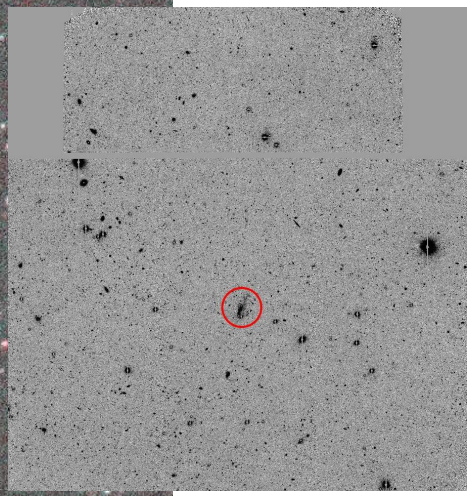


the SECCO survey. STEP0: visual inspection

Leo P: our “standard candle”





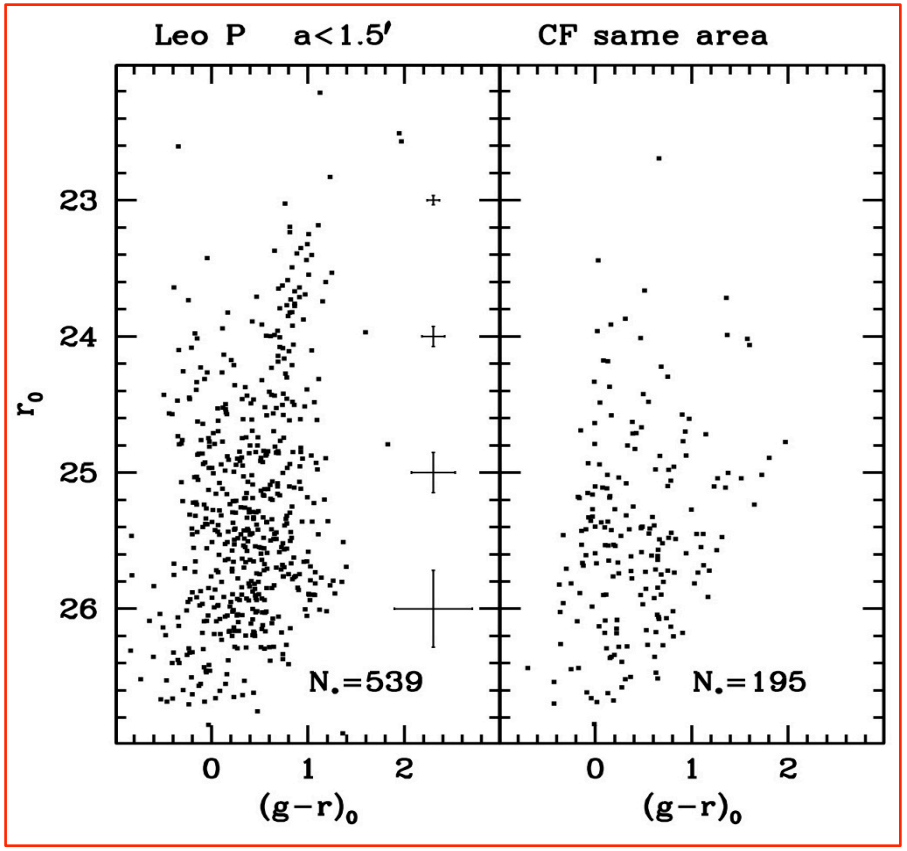


You can’t miss anything barely similar to Leo P in our images

the SECCO survey. STEP1: color magnitude diagrams and density maps

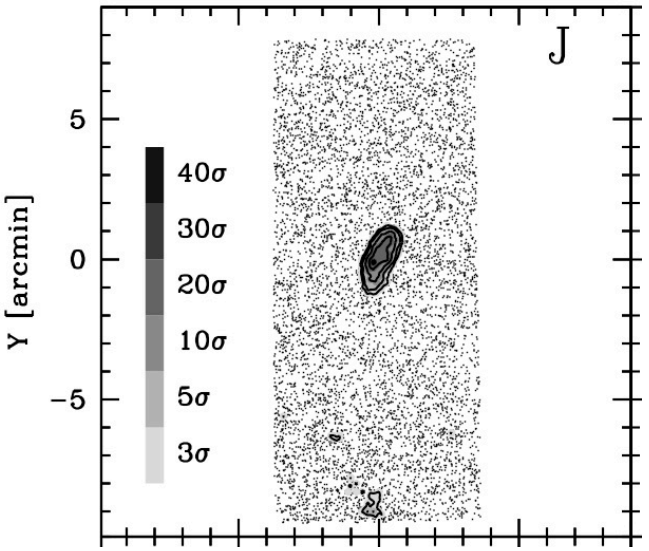
Leo P: our "standard candle"

DAOPHOT PSF fitting

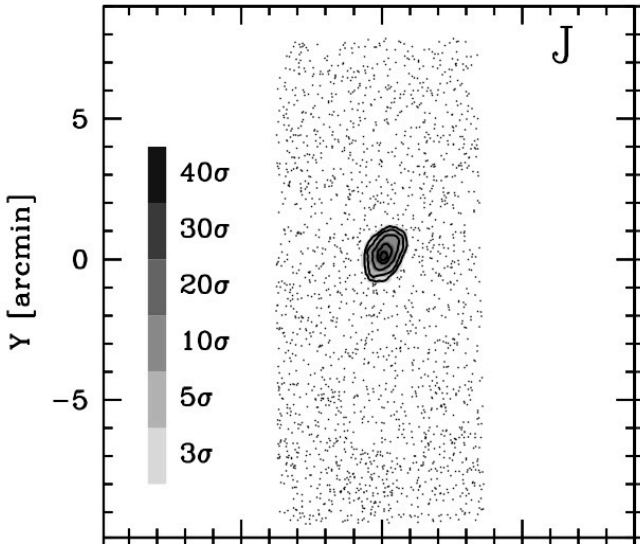


M_V=-9.4 D=1.7 Mpc

All selected sources

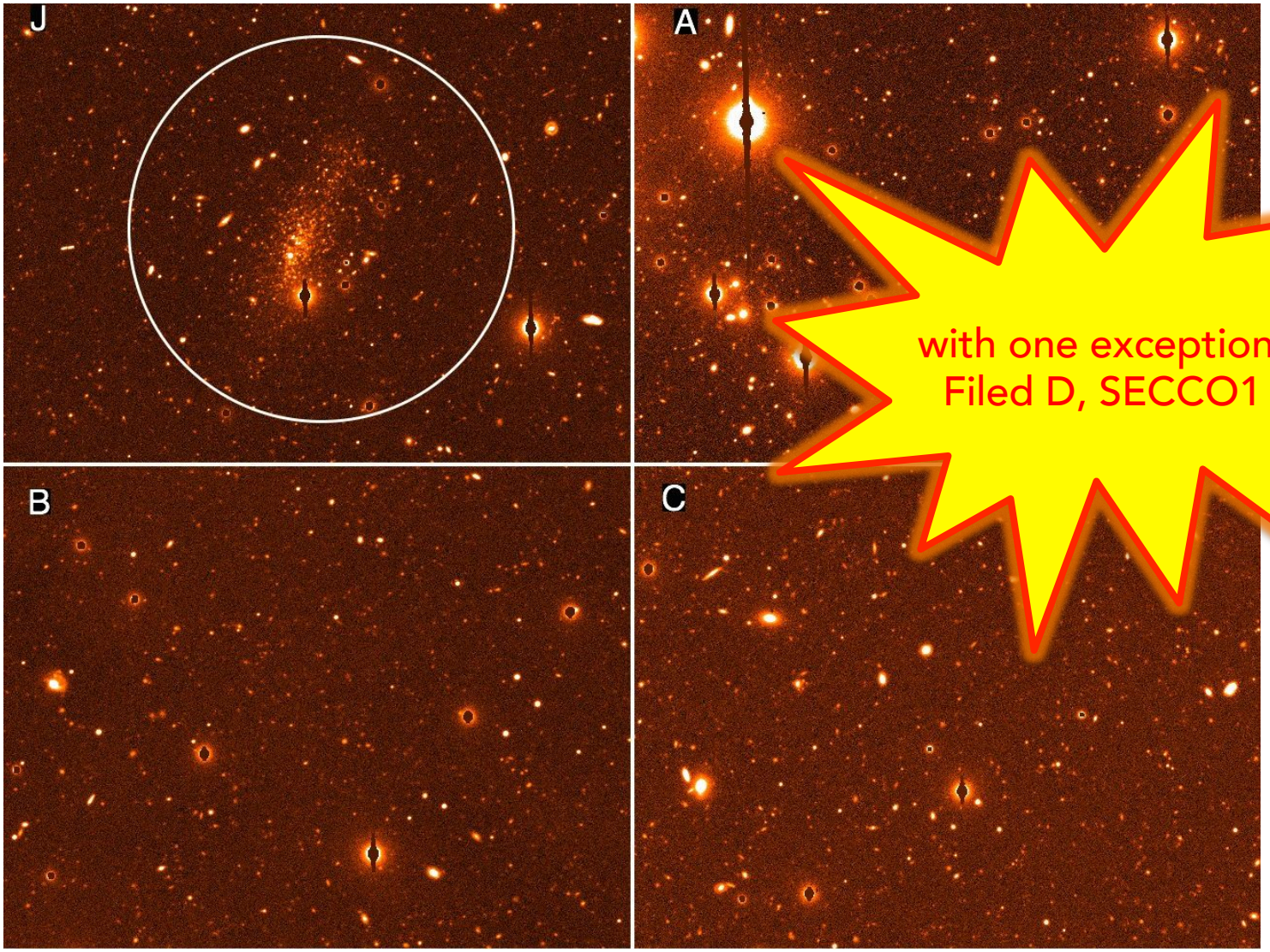


Only selected sources with r<25.0



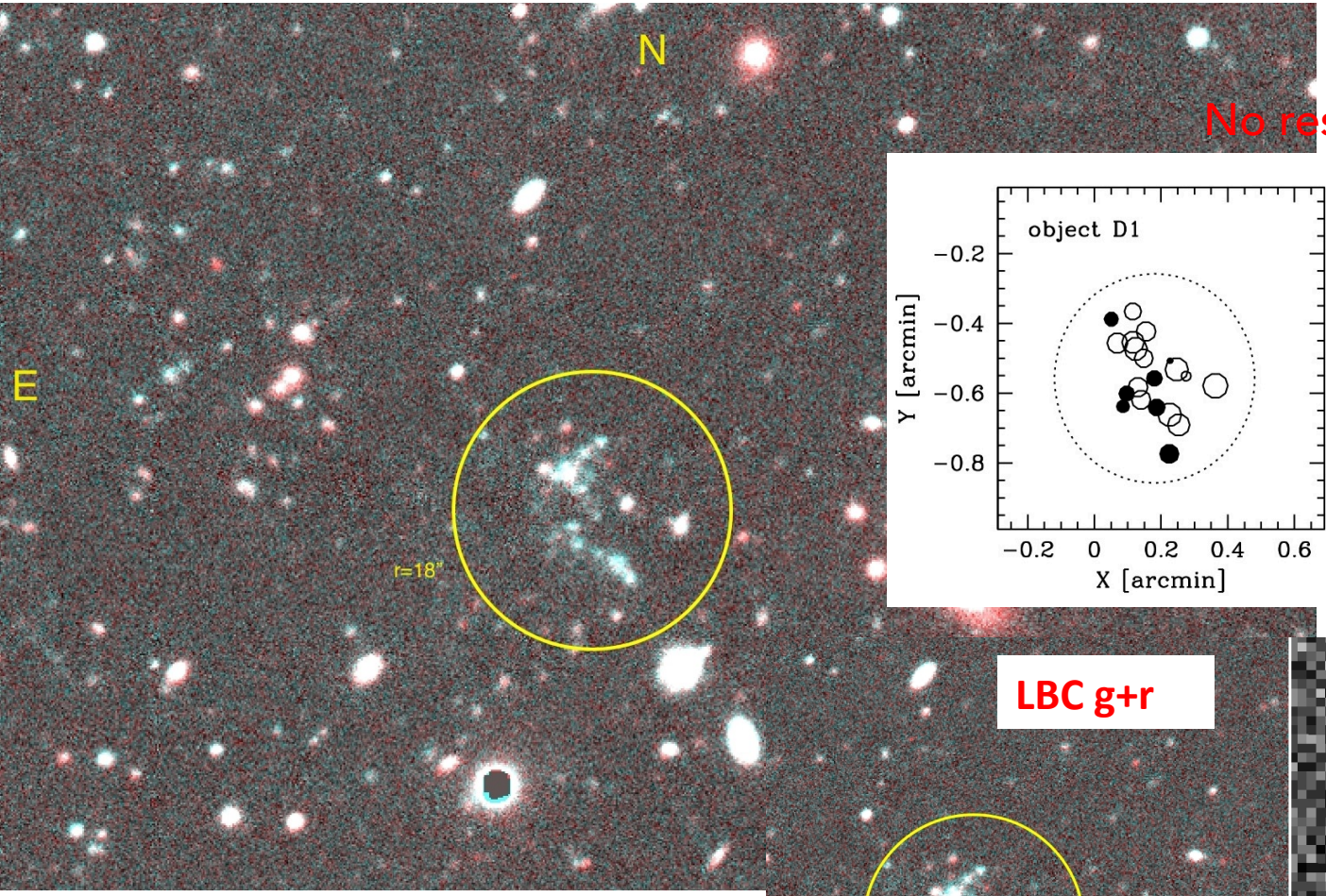
Leo P is detected at >20 σ in r27 maps
and at >30 σ in r25 maps

the SECCO survey. STEP0: photos of ghosts

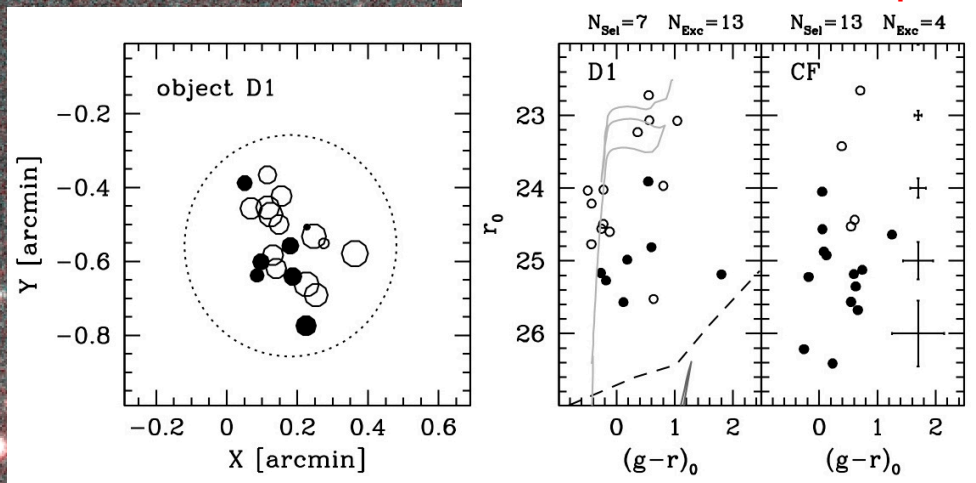


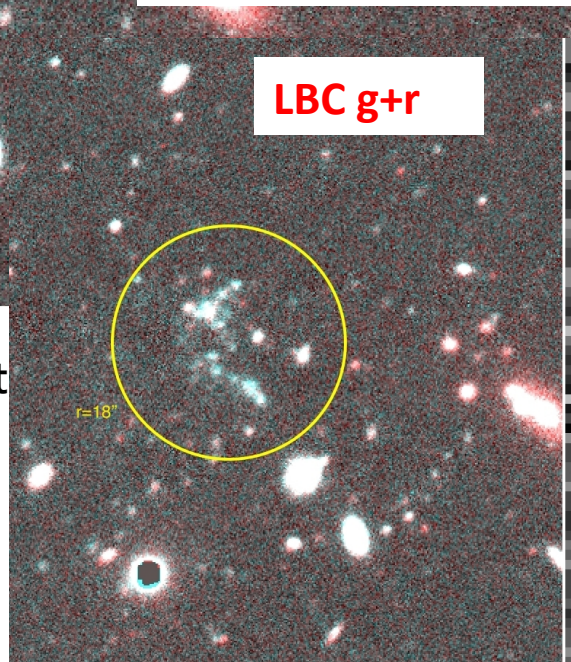
Inspection of all the stacked images:
We do not find anything “as obvious as” Leo P

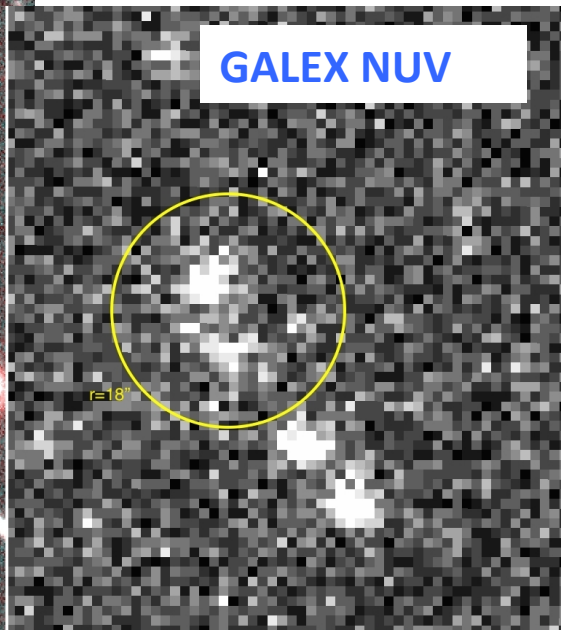
Our STEP0 candidate: Field D: UCHVC (HVC274.68+74.70-123)



No resolved RGB: D>3 Mpc







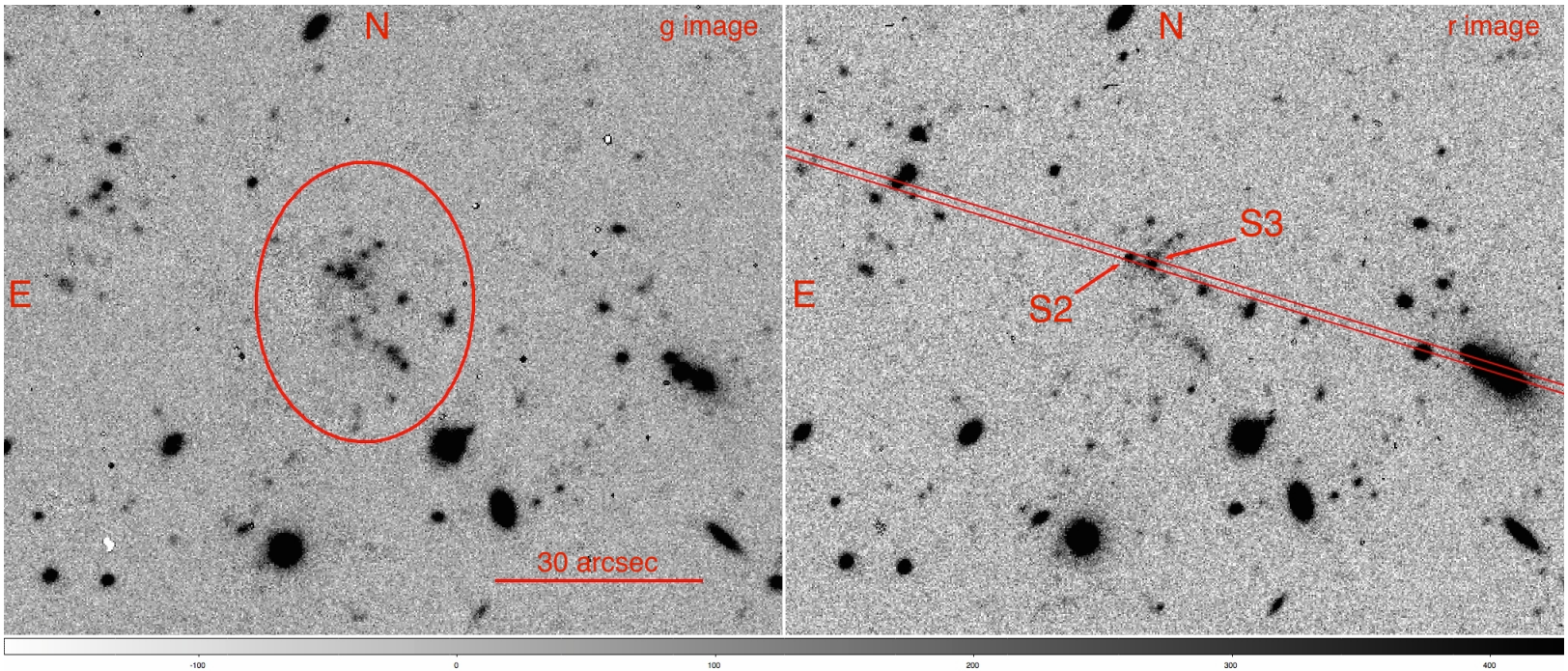
Is it a star-forming dwarf or a distant compact group of galaxies?

Real star forming regions: detected by GALEX

the SECCO survey. Back to our STEP0 candidate. Spectroscopic follow-up

3.5h DDT with
MODS@LBT

5000A< λ <10000A
R ~ 1100



the SECCO survey. Back to our STEP0 candidate. Spectroscopic follow-up

What is this thing? A star-forming low-surface-brightness dwarf galaxy at D>3 Mpc: SECCO 1

For a wide range of distances it fits into the

Nearly rest-fr

group of gala

ed here:

Heliocentric V

S3A = -80 ± 40 km/s

S3B = -200 ±

Compatible w

Associated UC

V_r = -128 ± 6

Association is

Confirmed:-140±12 km/s by Sand et al. 2015

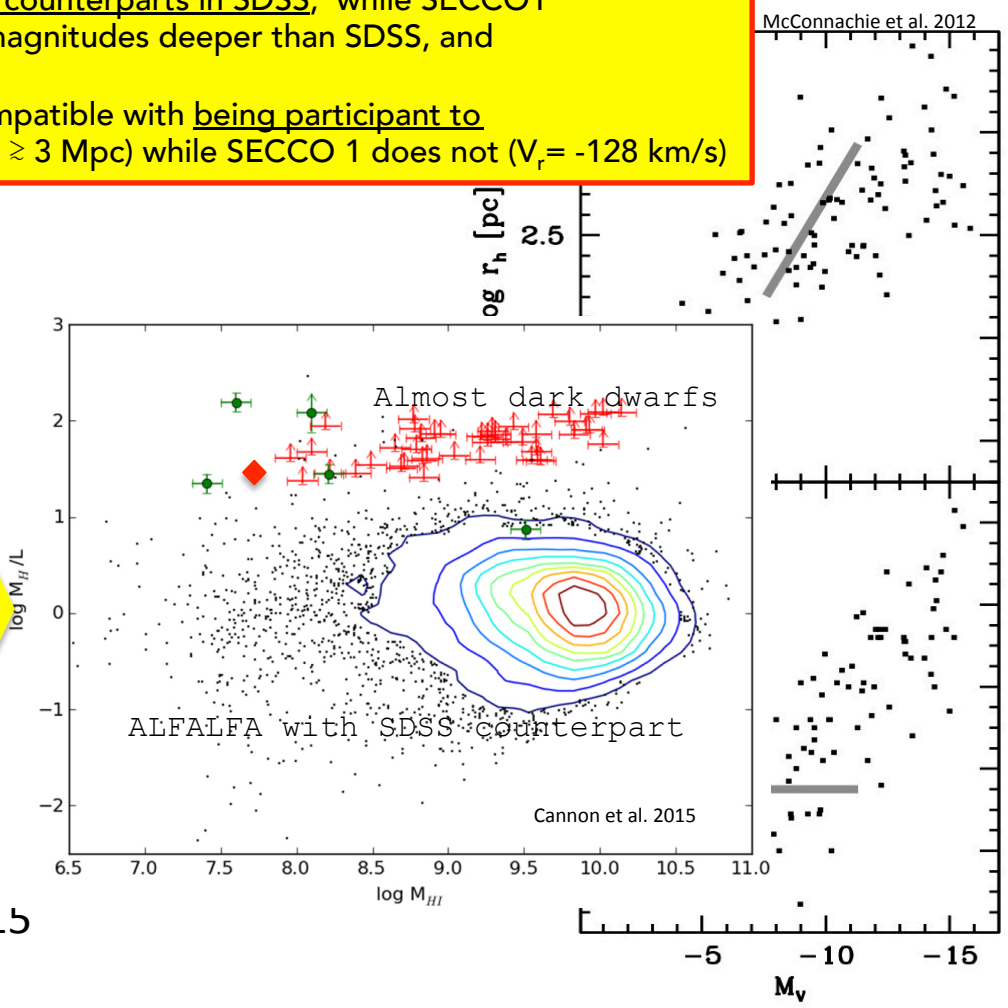
Analogous to SHIELD galaxies? Extremely Low-mass Dwarfs (Cannon+12)

But (a) all SHIELD dwarfs have visible counterparts in SDSS, while SECCO1 is barely visible in our images, 4 full magnitudes deeper than SDSS, and

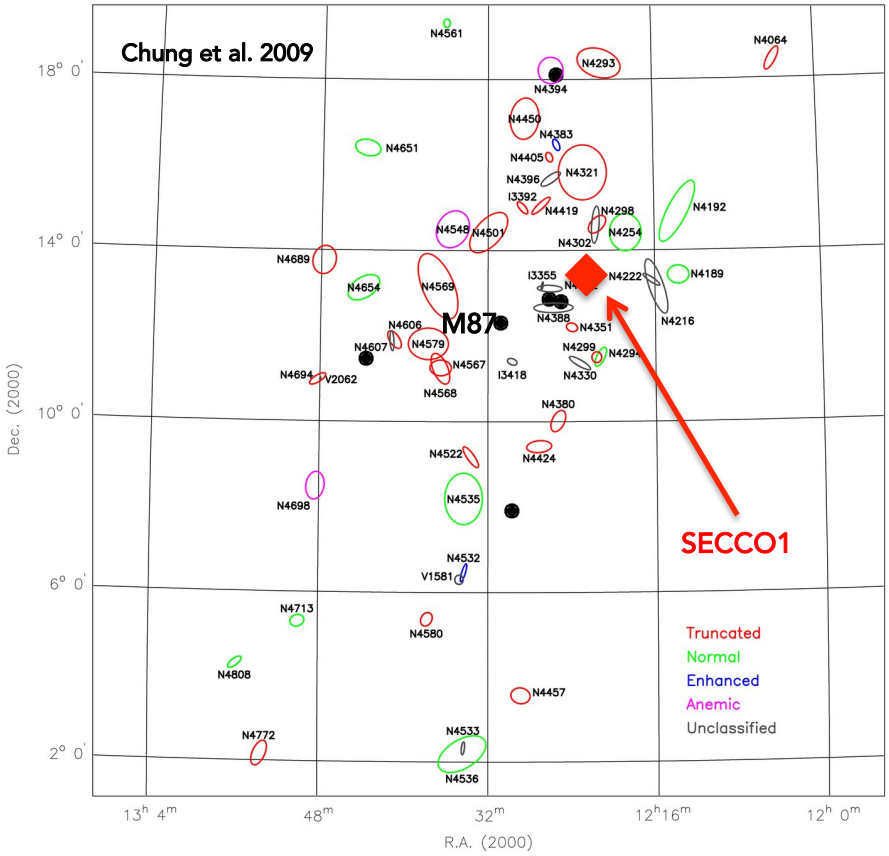
(b) SHIELD dwarfs have velocities compatible with being participant to the Hubble flow ($V_r \gtrsim$ +150 km/s for D $\gtrsim$ 3 Mpc) while SECCO 1 does not (V_r= -128 km/s)

Independently of the Assumed distance
$M_{HI}/L_v \approx 20$
Much larger than Local dwarfs and SHIELD dwarfs

A nearly STARLESS DWARF



the SECCO survey. SECCO 1: a dwarf galaxy in Virgo?



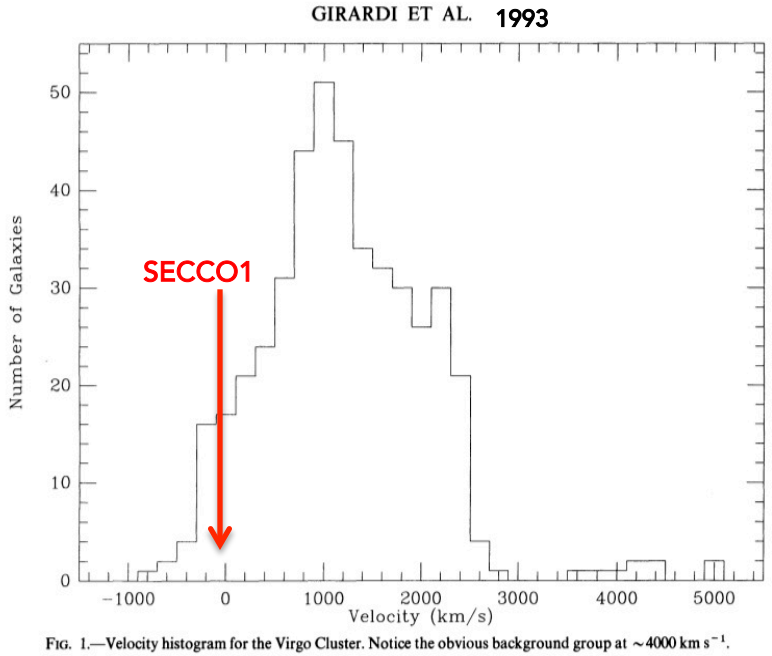
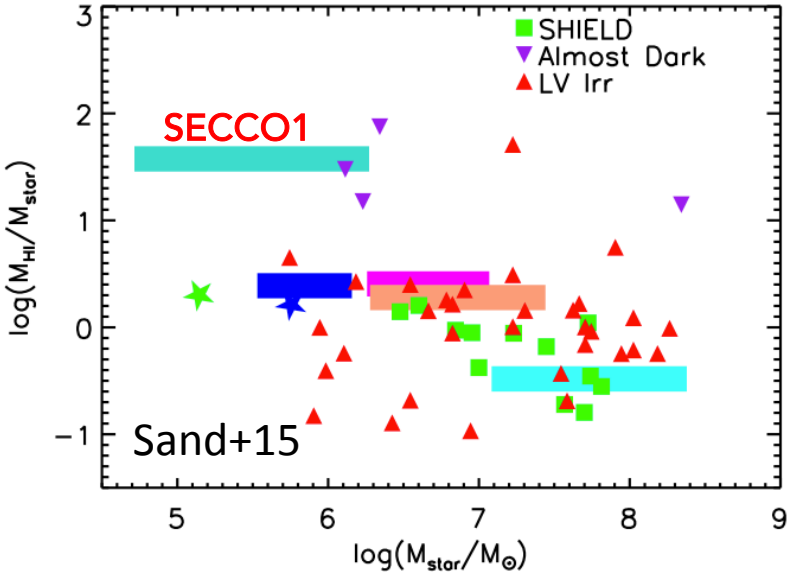


FIG. 1.—Velocity histogram for the Virgo Cluster. Notice the obvious background group at ~4000 km s^{-1}.



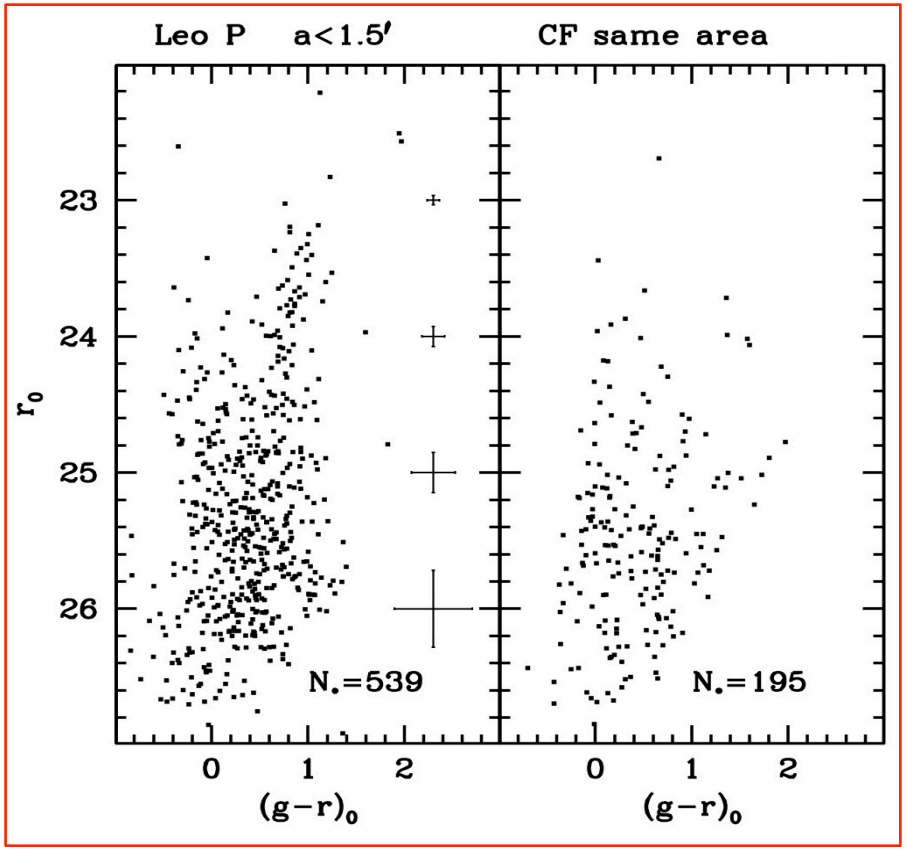
Projected at less than 3 deg from M87 and velocity fully compatible with the distribution of the Virgo cluster. A natural explanation for the negative velocity ($V_r \gtrsim$ -128 km/s)

@ Virgo: SFR = 6.1×10^{-6} $M_\odot$/yr
f_b ~ 0.046 (typical of dwarfs, ~1/3 of the cosmic mean)

the SECCO survey. STEP1: color magnitude diagrams and density maps

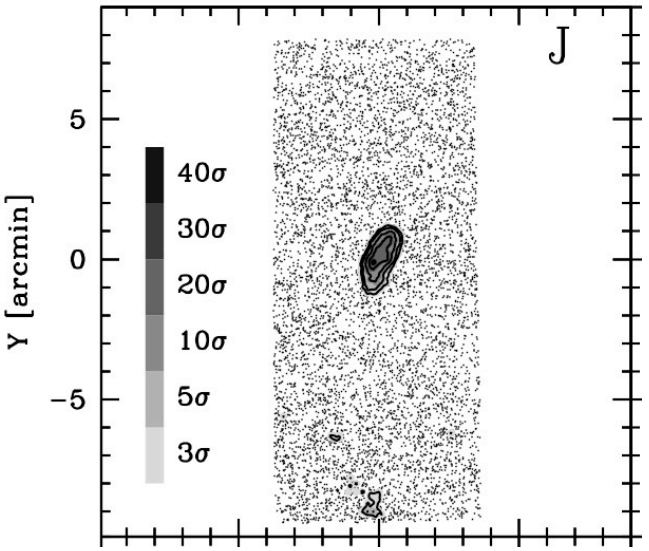
Leo P: our "standard candle"

DAOPHOT PSF fitting



M_V=-9.4 D=1.7 Mpc

All selected sources



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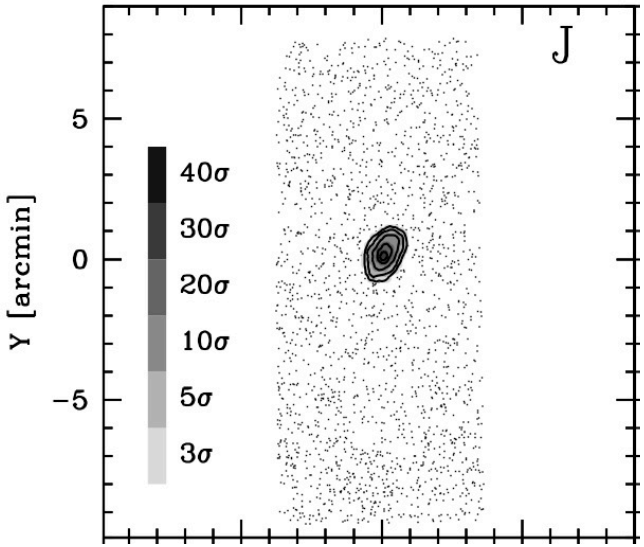
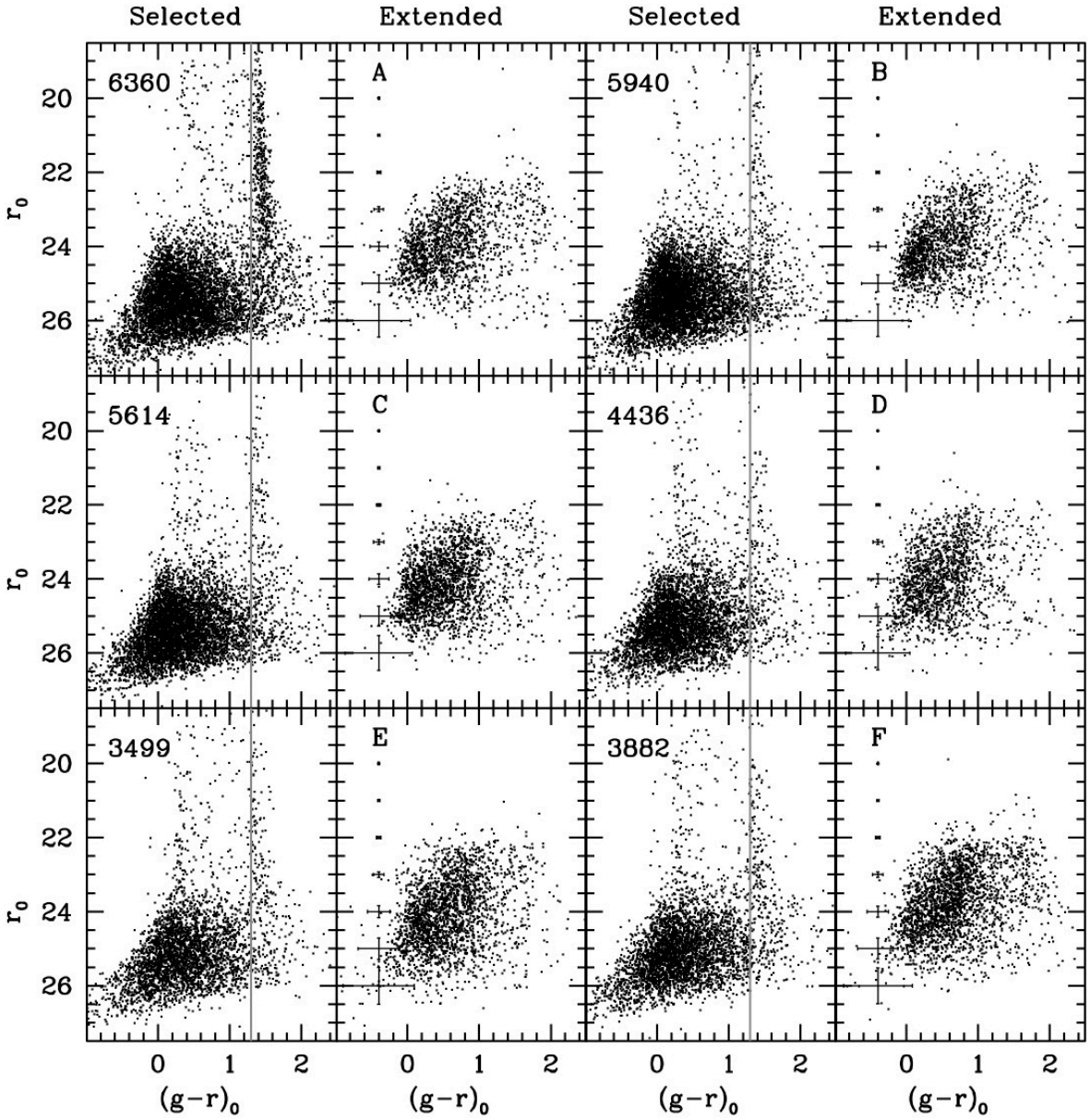
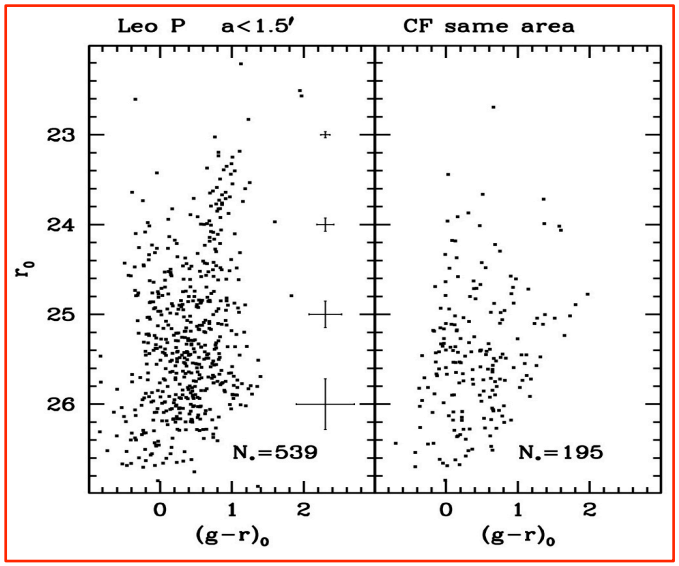


Leo P is detected at >20 σ in r27 maps
and at >30 σ in r25 maps

the SECCO survey. STEP1: color magnitude diagrams



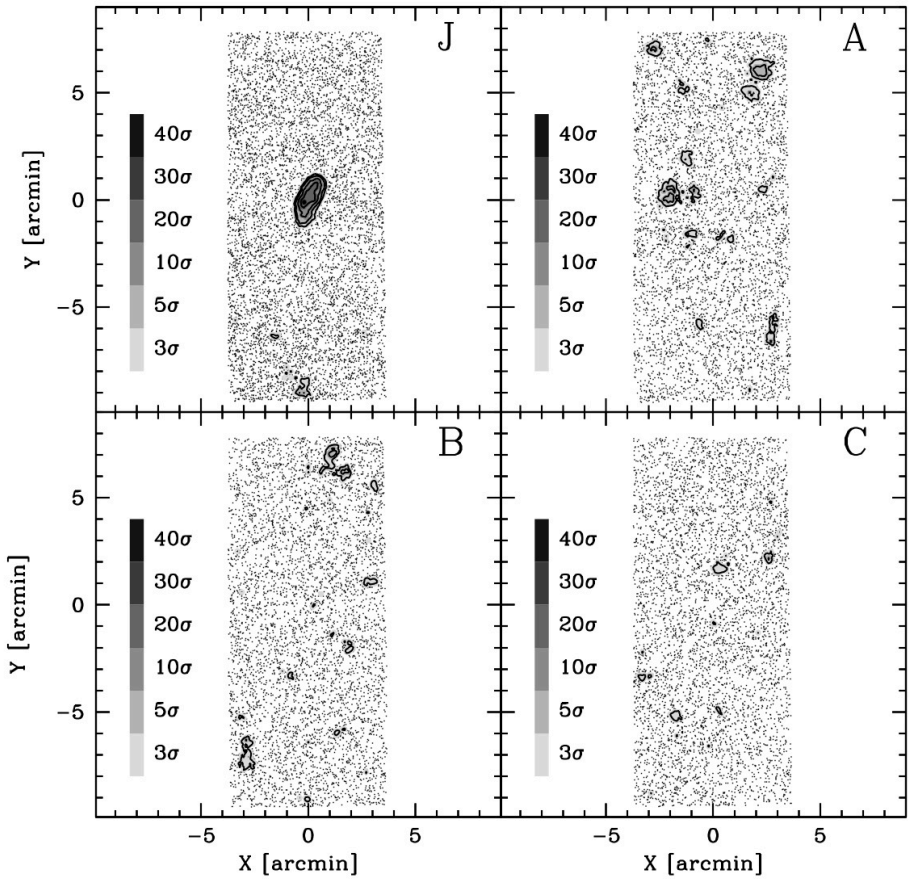
1- local M dwarfs at (g-r)0=1.5
2-Sparser Halo MS-TO (g-r)=0.4



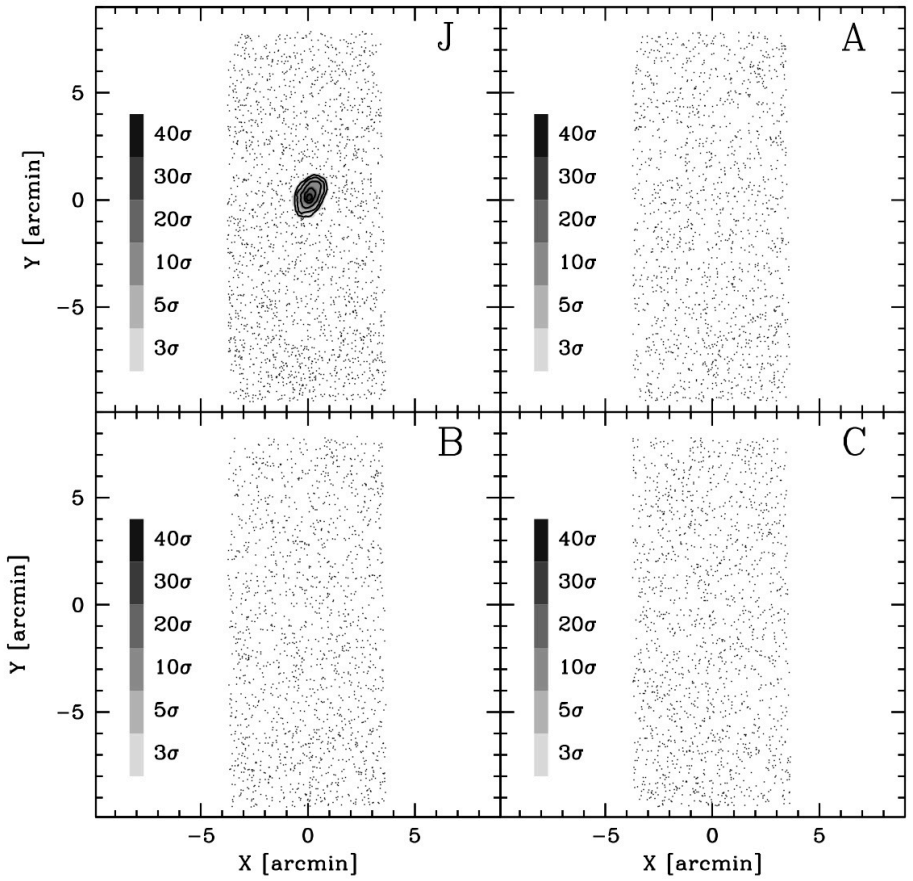
M_v=-9.4 D=1.7 Mpc

the SECCO survey. STEP1: density maps

All selected sources



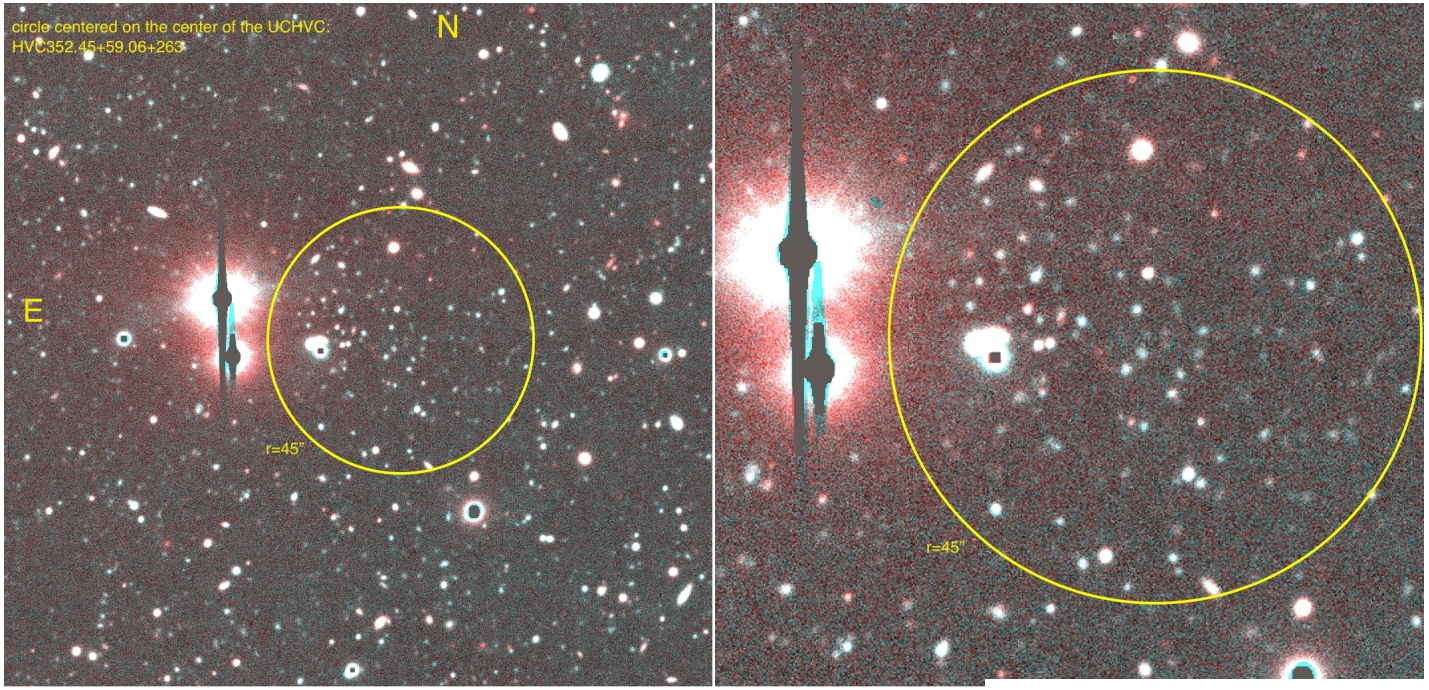
Only selected sources with r<25.0

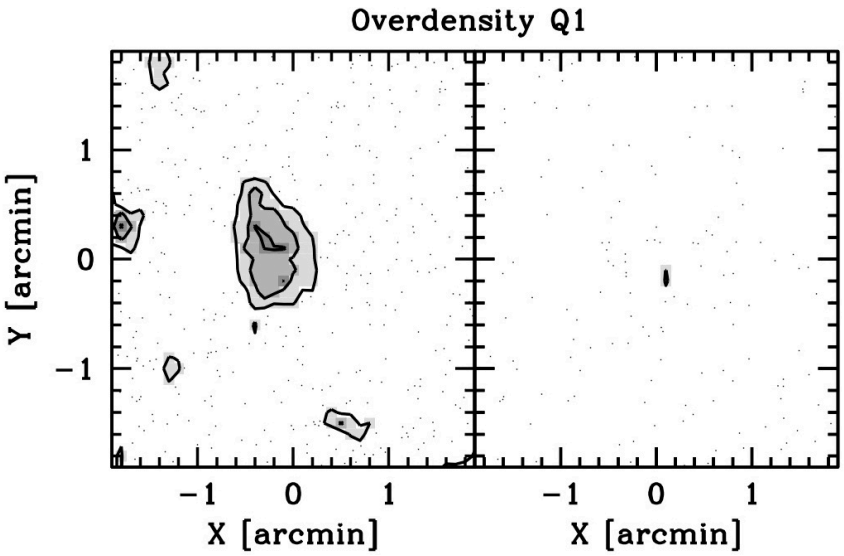


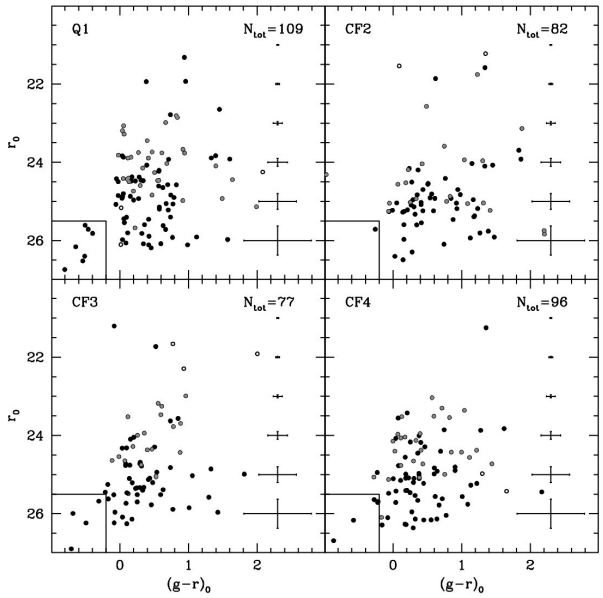
Nothing is detected at >5 σ in r27 maps (except for LeoP) and at >3 σ in r25 maps (one exception)

We had a close look to all the 3-5 σ overdensities in r27 maps: no potentilly resolved stellar systems

the SECCO survey. STEP1: overdensity Q1







the SECCO survey. STEP1: assessing the sensitivity of density maps

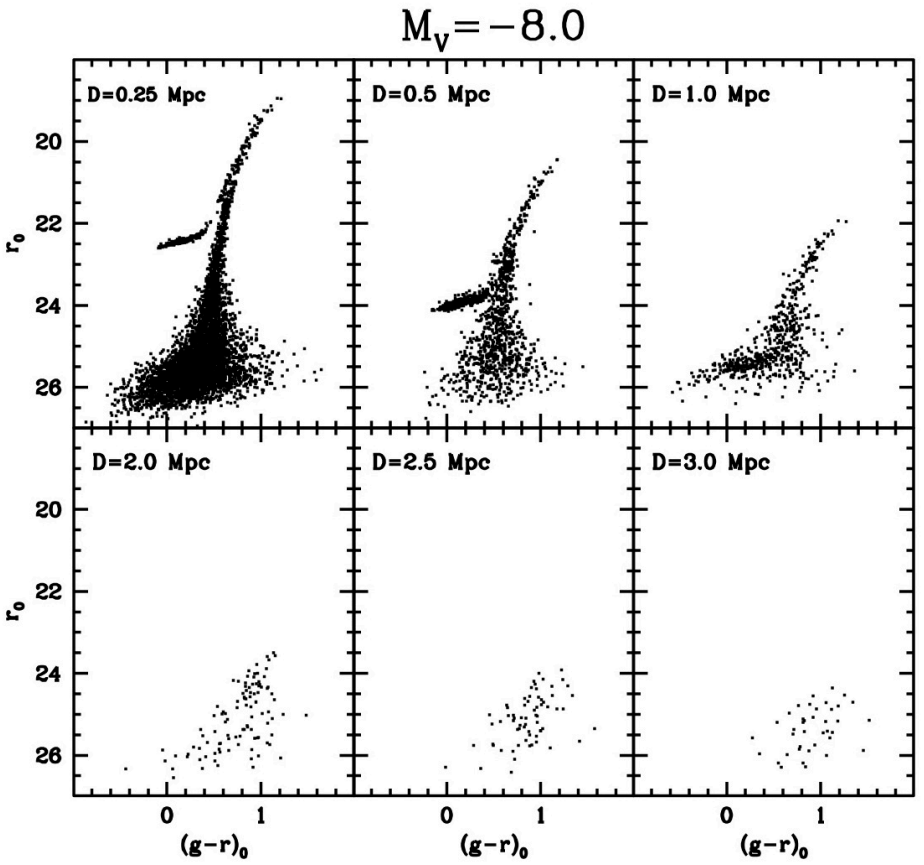
-Take a synthetic population of stars with a given integrated $M_{v,}$ Kroupa IMF, down to H-burning limit, with a given age and metallicity distribution. In the present case <[Fe/H]>=-1.8 and $\sigma_{[Fe/H]}$=0.1 and exponentially declining SFR with τ =0.5 Gyr, starting 13 Gyr ago.

-Shift all the magnitudes to a given distance and reddening.

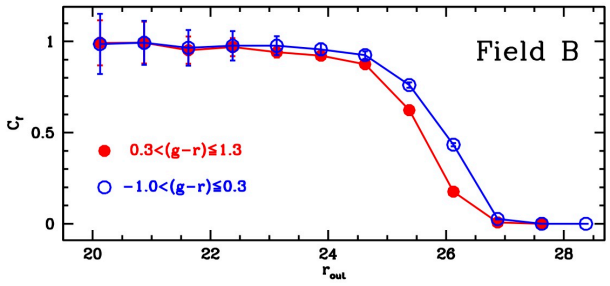
- Apply all the effects of observations: incompleteness and photometric errors from extensive artificial stars experiments.

- Associate to each survived star a position (X_{pc}, Y_{pc}) extracted from an exponential profile of given R_h. Convert into (X_{arcmin}, Y_{arcmin}) according to the adopted distance.

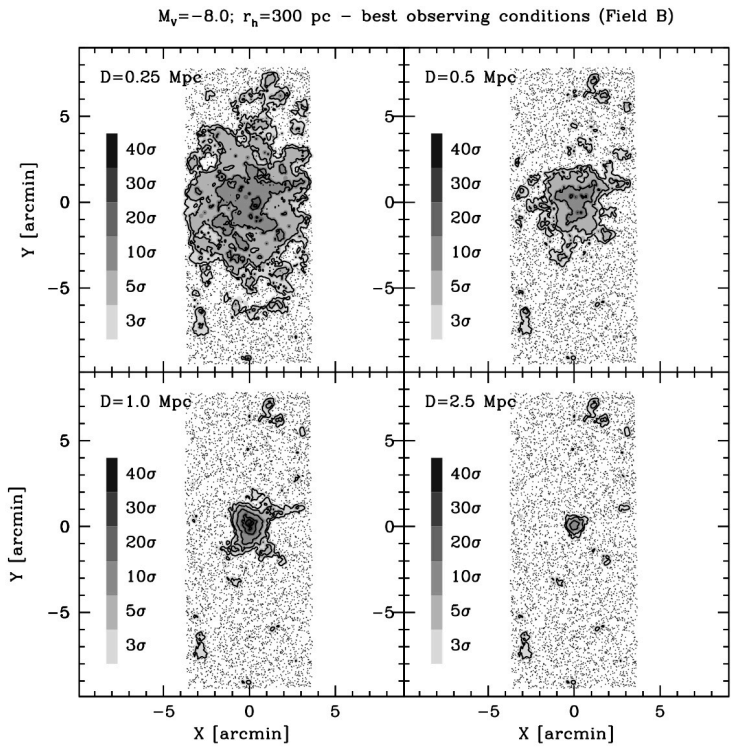
-Insert the points into the original Daophot Catalog, apply all the selections and recompute the density map:
is the galaxy detected?

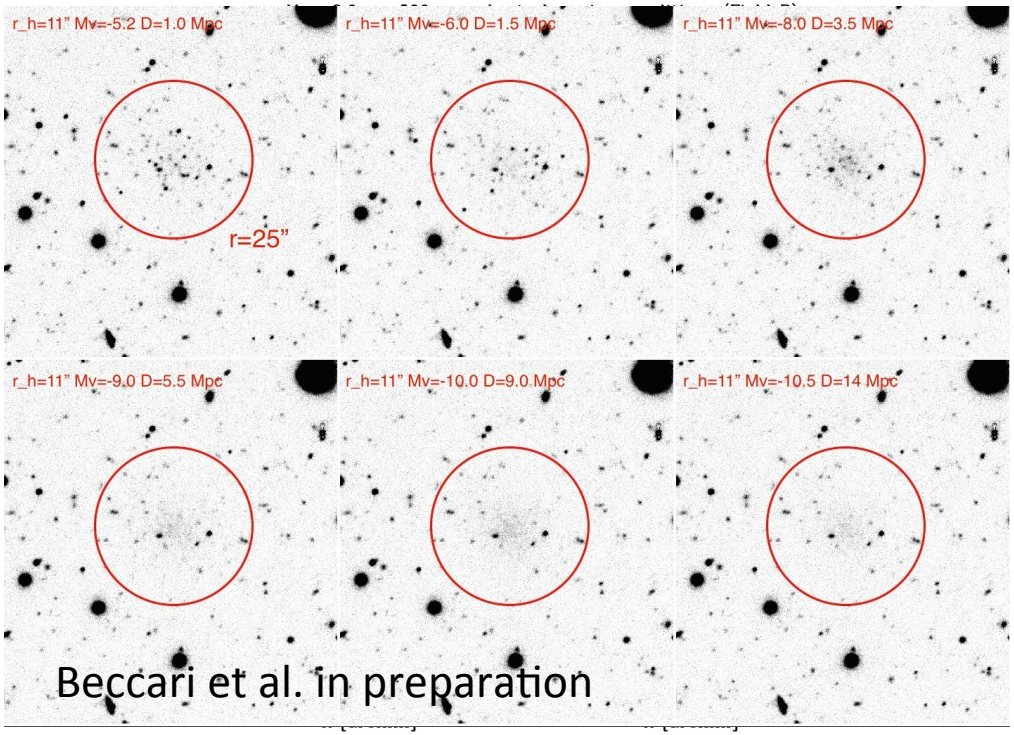


Field B:
representative of the
40% best quality fields



the SECCO survey. STEP1: sensitivity of density maps – best quality fields





Conclusions:

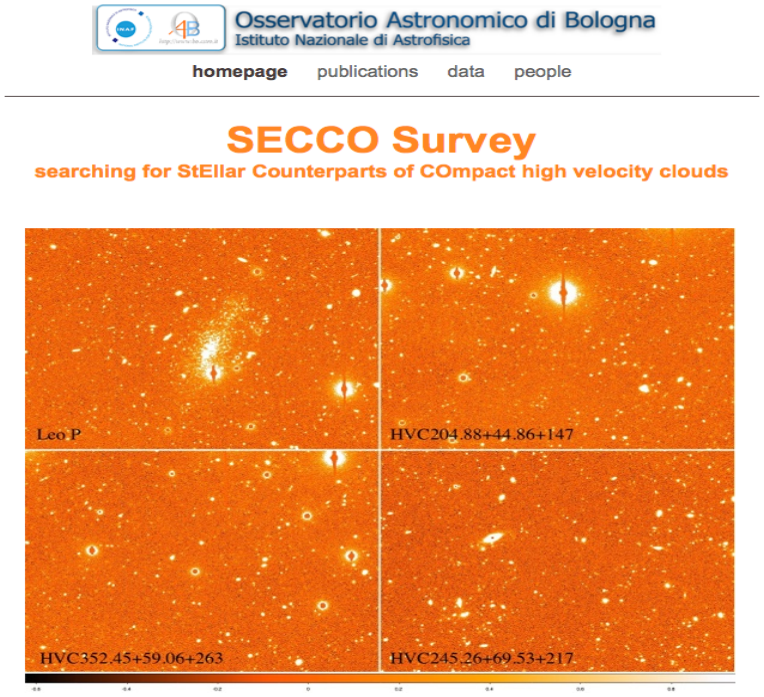
1. we would have detected any dwarf with $R_h \leq$ 300 pc and $M_V \leq$ -8.0 lying within 1.5 Mpc from us

2. In the 40% best quality fields we would have detected any dwarf with $R_h \leq$ 500 pc and $M_V \leq$ -8.0 lying within 2.5 Mpc from us

Summary

We inspected 25 UCHVCs from A13 (0.25Mpc<D<2.0Mpc)

- No “obvious” detection like LeoP
- 2 possible low SB candidates (one visual inspection and one over-density)
- SECCO1 may be a very low luminosity, low SB member of the Virgo cluster? HST needed!!
- Any galaxy with *r*h < 300(500) pc and M_V < 8.0, lying within 1.5 (1.0) Mpc, would have appeared as a 5σ over-density in our density maps
- we would have detected any galaxy with *r*h<500 pc and M_V <8.0 out to *D*=2.5Mpc



http://www.bo.astro.it/secco

the SECCO survey. STEP1: quantitative results from the first systematic survey

In the meanwhile, what's going on in the literature?

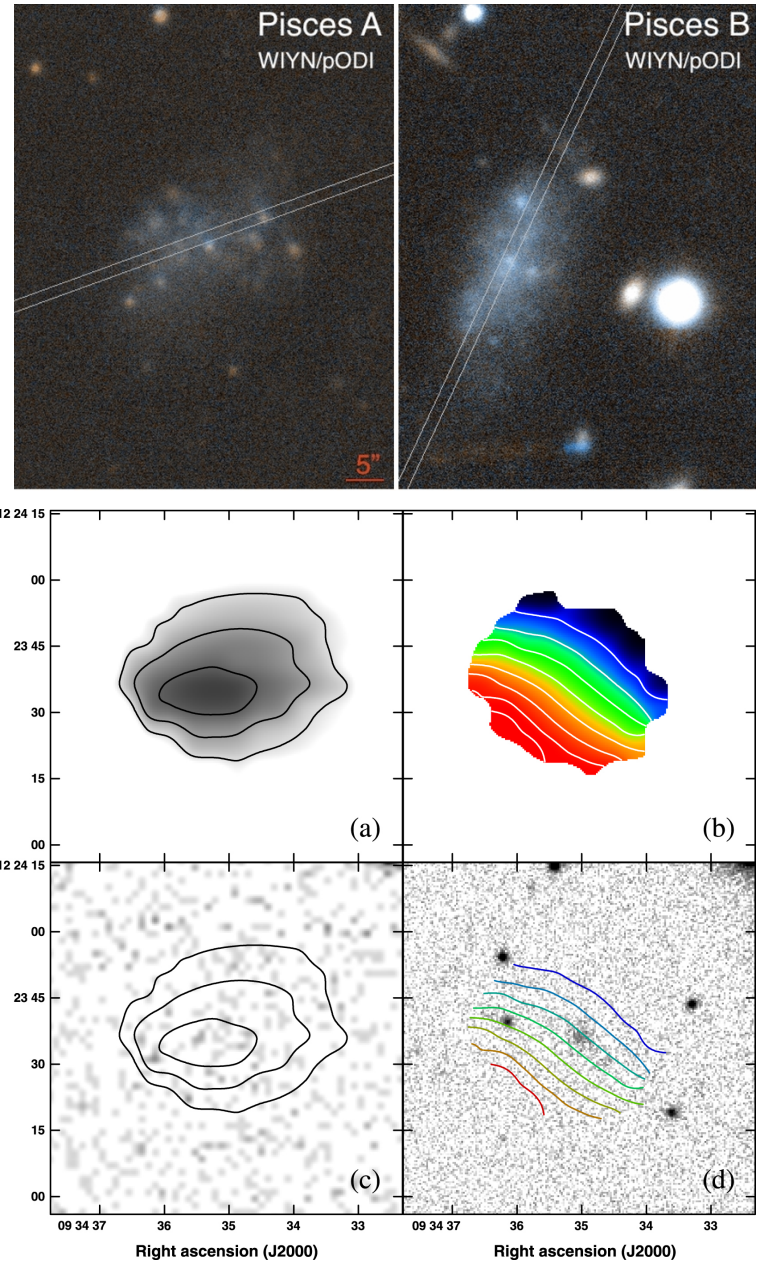
- Tollerud et al. 2015 (GALFA team), looking at the best GALFA candidates found two blue counterparts: spectroscopic confirmation, no distance estimate

- Cannon et al. 2015 (A13 team): VLA observations of 5 ALMOST DARK galaxies, difficult counterparts D_z=10-40 Mpc [ALFALFA HI clouds not comprised in the A13 list]

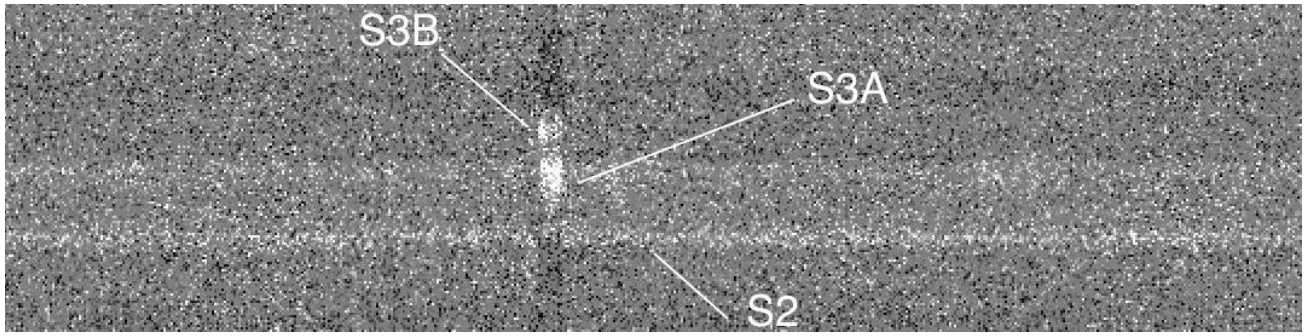
- Completely dark galaxies: Adams et al. 2015; Janowiecki et al. 2015 (A13 team; rotating clouds with no detection of a stellar counterpart) [Niedever et al. 2013, companion to IC10]

- SHIELD project (Cannon et al. 2011): follow up of ALFALFA clouds with faint stellar counterparts visible in the SDSS. LSB, very metal-poor star-forming galaxies

- James et al. 2015: guided by the case of Leo P search the SDSS for overdensities of BLUE stars; found ~100 candidate metal-poor LSB star-forming dwarfs; 12 followed up spectroscopically; D=5-120 Mpc



the SECCO survey. Back to our STEP0 candidate. Spectroscopic follow-up



3.5h DDT with MODS@LBT

5000A< λ <10000A
R ~ 1100

Nearly rest-frame H_α: this is not a group of galaxies

Heliocentric V_r:

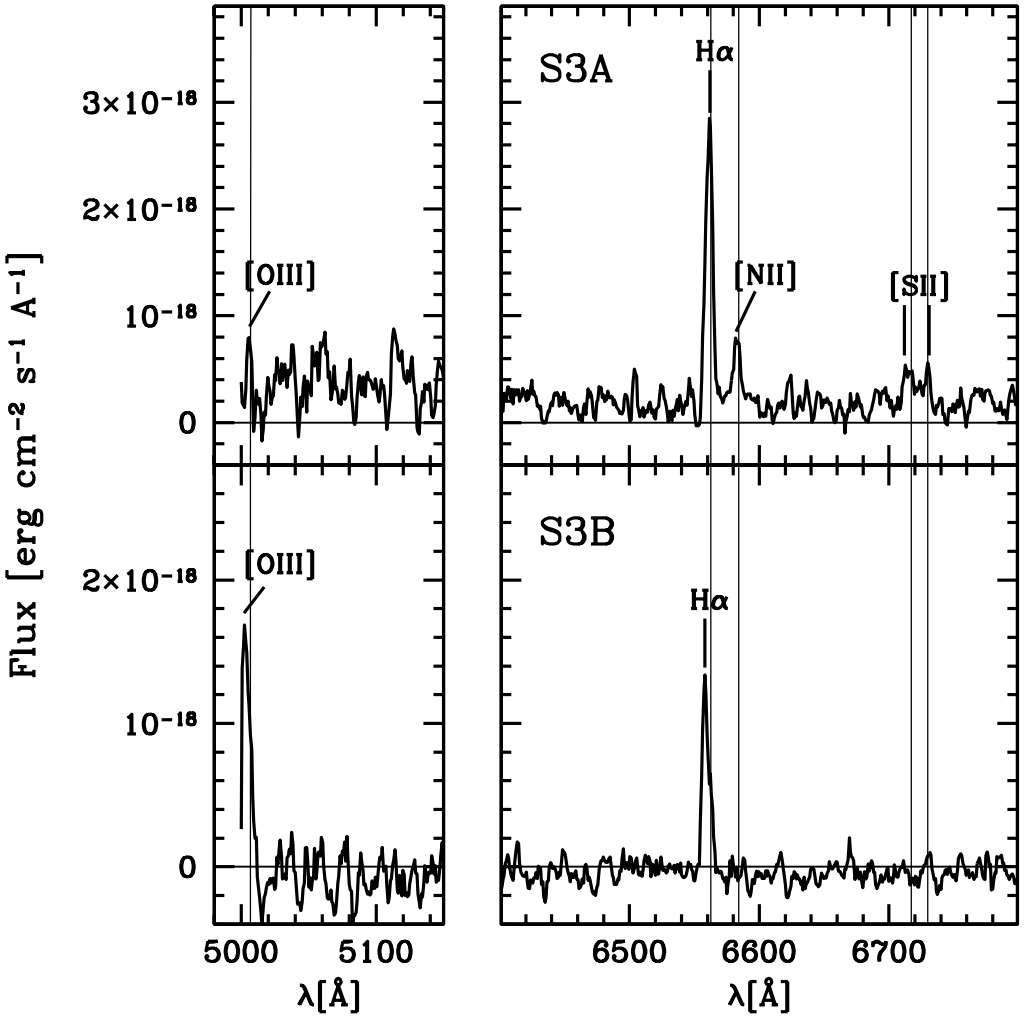
S3A = -80 ± 40 km/s

S3B = -200 ± 100 km/s

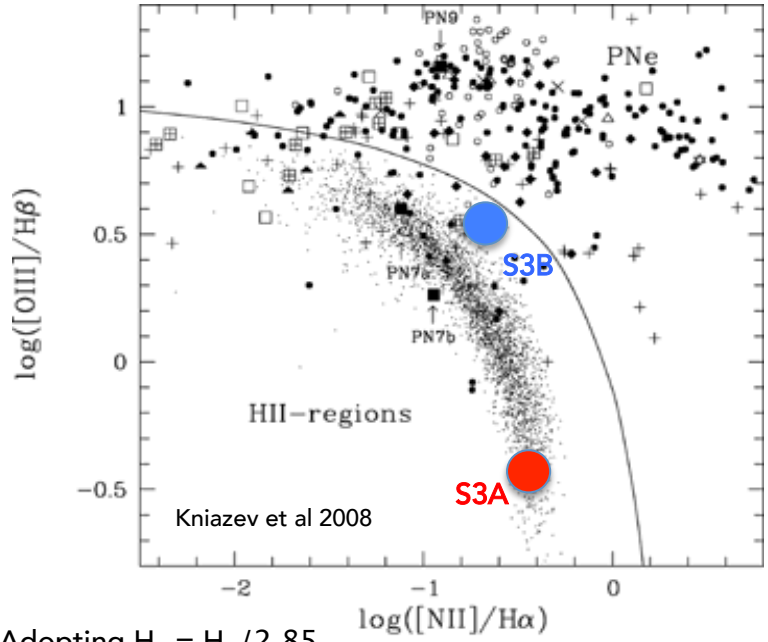
Compatible with the velocity of the Associated UCHVC

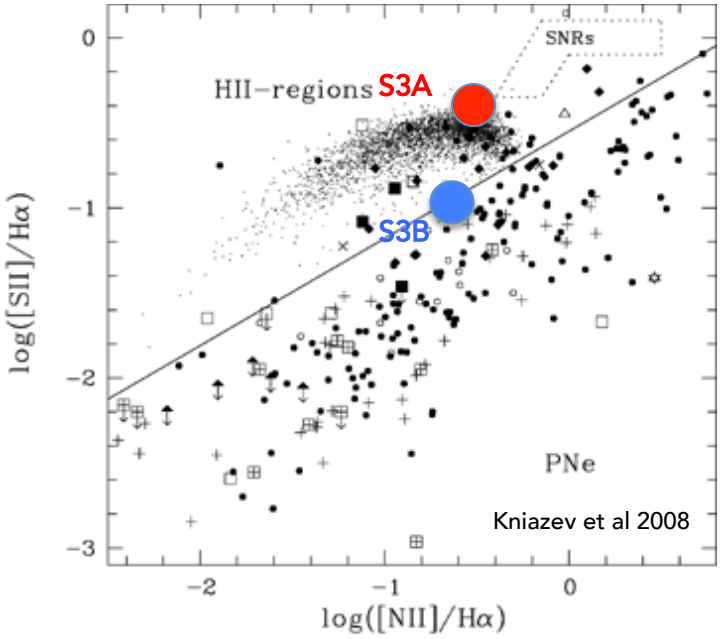
V_r = -128 ± 6 km/s

Association is extremely likely



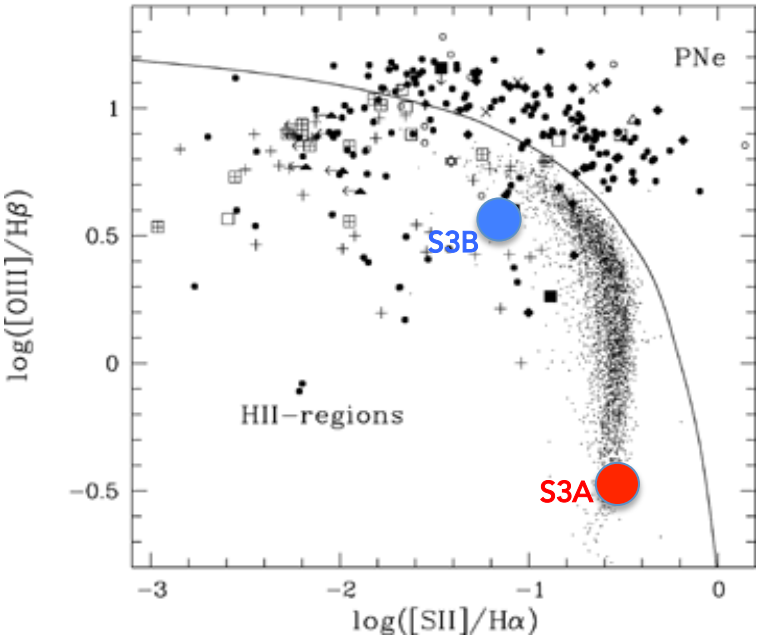
the SECCO survey. Back to our STEP0 candidate. Spectroscopic follow-up

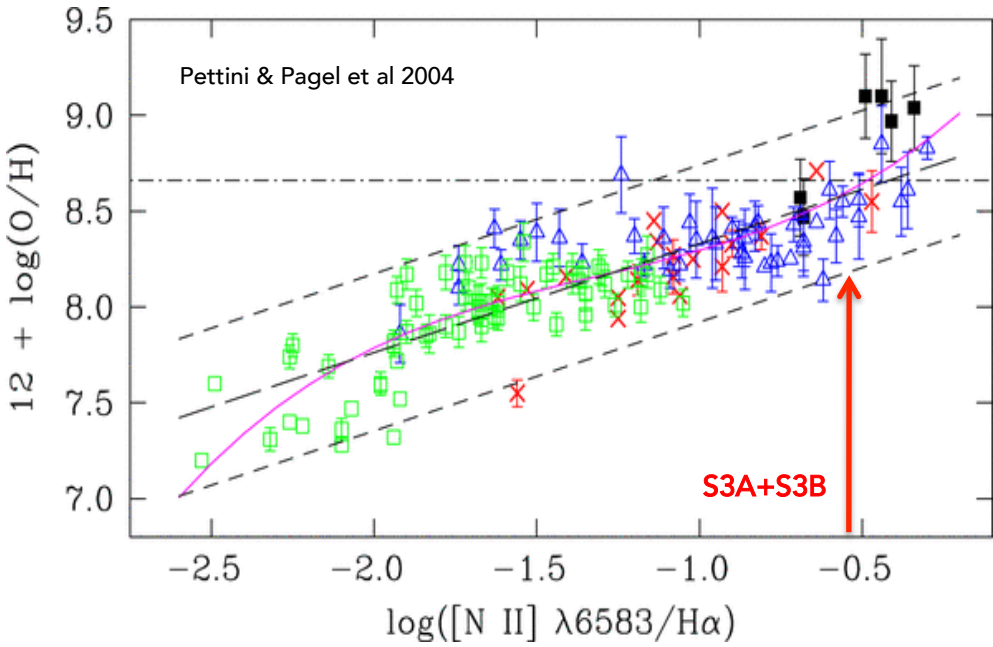




Assuming $T_e=10^4$ K
➔ ρ_e=1100 cm^{-3}

Adopting $H_\beta = H_\alpha/2.85$





the SECCO survey. Star formation within HVC274.68+74.70-123

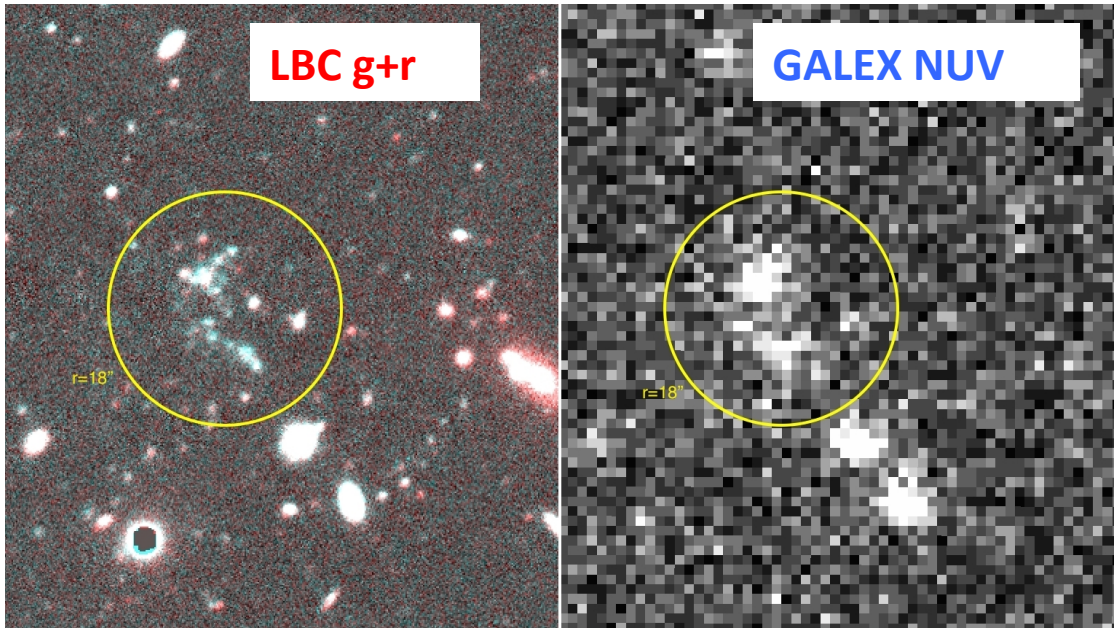
What is this thing?

1. An HII complex in the Milky Way [NO. It should lie in the disc but velocity is incompatible. Angular size constrain the distance to D>100 kpc].

2. An HII complex within an HVC in the MW halo [very unlikely. Large distance, stars never found within MW HVCs; it would be difficult not to call such system a "galaxy"]

3. A few distant blue galaxies superimposed (by chance) to a nearby (D<10 kpc) HVC ionized by hot stars in the MW disc [very unlikely. H_α emission from HVCs has the right [NIII/H_α] ratio but it is extended over arcmin while we do not see additional H_α emission over the 5 arcmin length of the slit. Typical H_α fluxes are a factor of 3–10 smaller than what observed here.]

Real star forming regions: detected by GALEX



the SECCO survey. Star formation within HVC274.68+74.70-123: a dwarf galaxy?

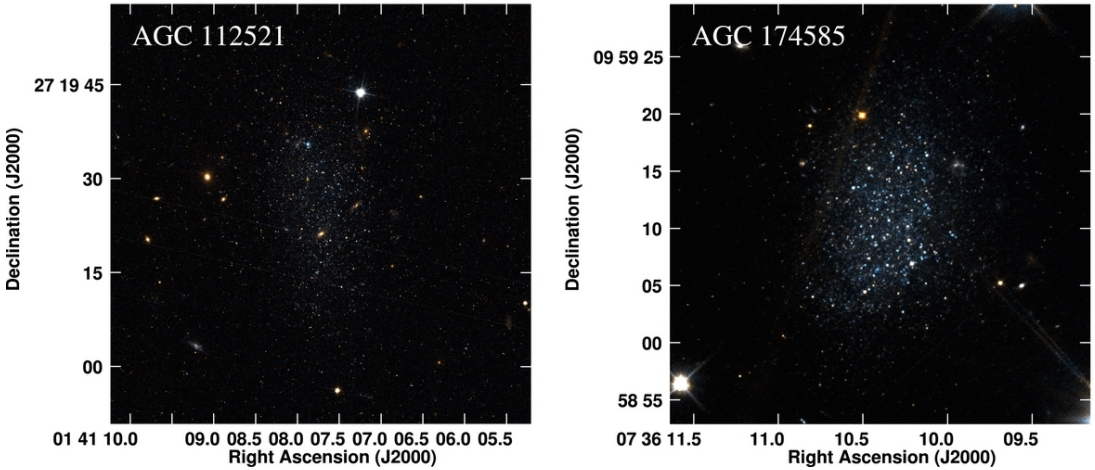
What is this thing?

A star-forming low-surface-brightness dwarf galaxy at D>3 Mpc: SECCO 1

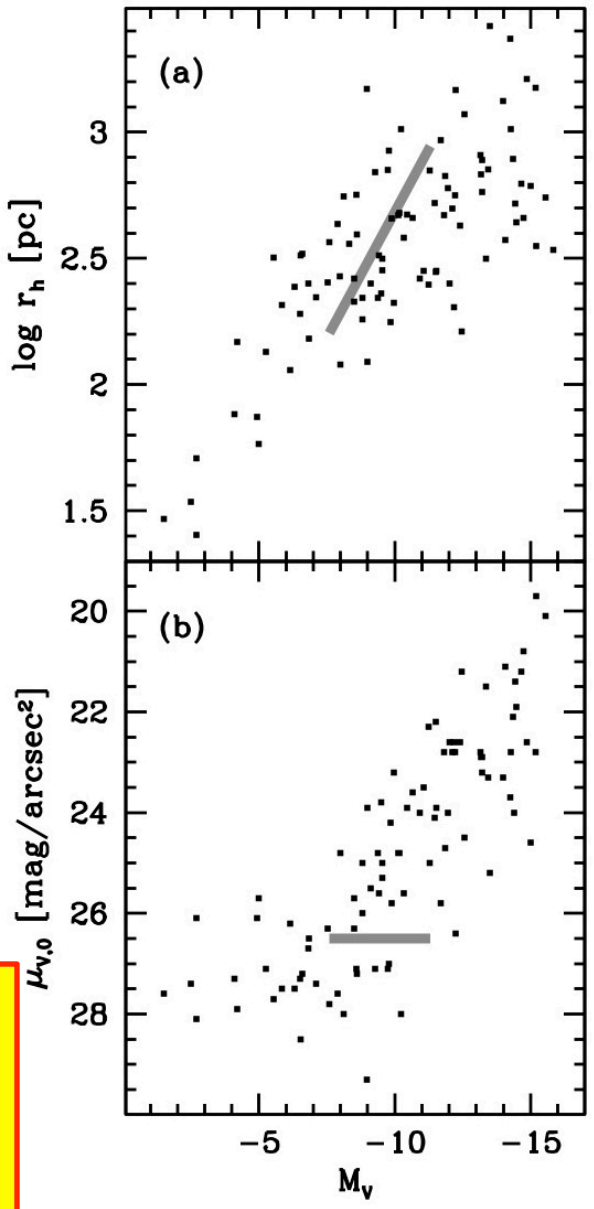
For a wide range of distances it fits into the dwarf scaling relation [range explored here: 3.0 Mpc ≤ D ≤ 16.5 Mpc]

$-7.6 \leq M_V \leq -11.3$ $160\ pc \leq r_h \leq 880\ pc$, $10^{6.3}\ M_\odot \leq M_{HI} \leq 10^{7.8}\ M_\odot$

McQuinn et al. 2014



McConnachie et al. 2012

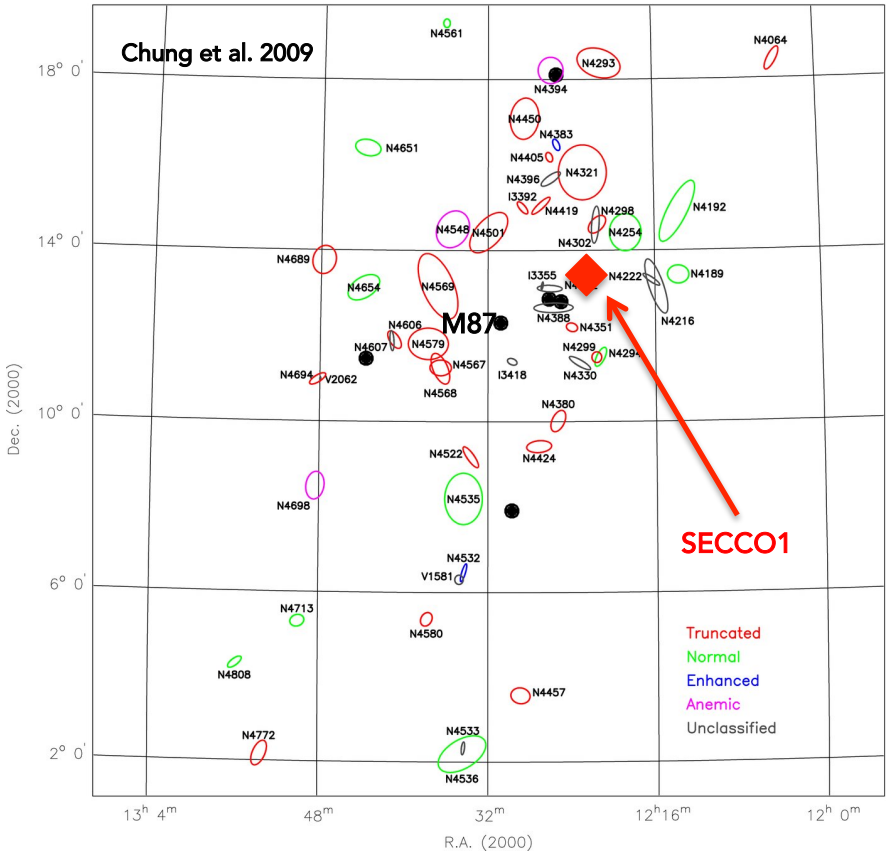


Analogous to SHIELD galaxies?

But (a) all SHIELD dwarfs have visible counterparts in SDSS, while SECCO1 is barely visible in our images, 4 full magnitudes deeper than SDSS, and

(b) SHIELD dwarfs have velocities compatible with being participant to the Hubble flow ($V_r \gtrsim +150$ km/s for $D \gtrsim 3$ Mpc) while SECCO 1 does not ($V_r = -128$ km/s)

the SECCO survey. SECCO 1: a dwarf galaxy in Virgo?



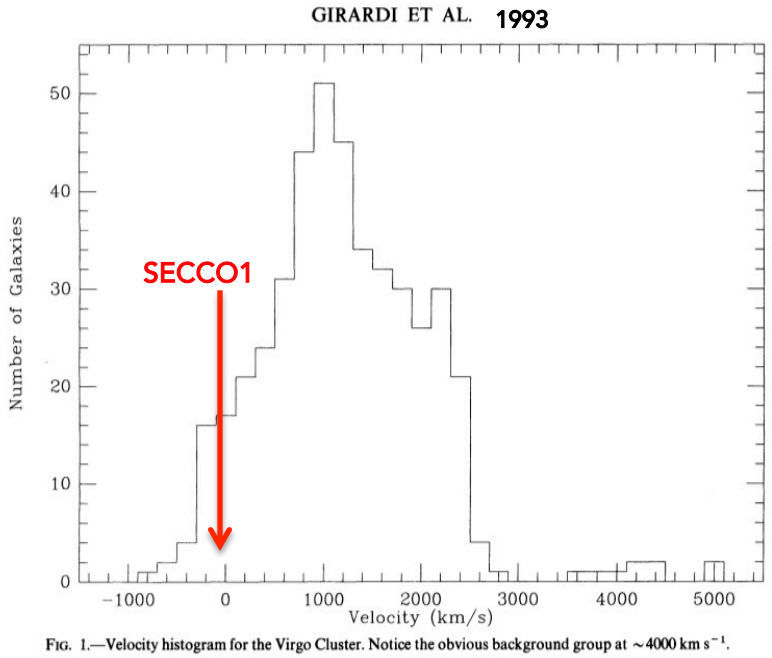
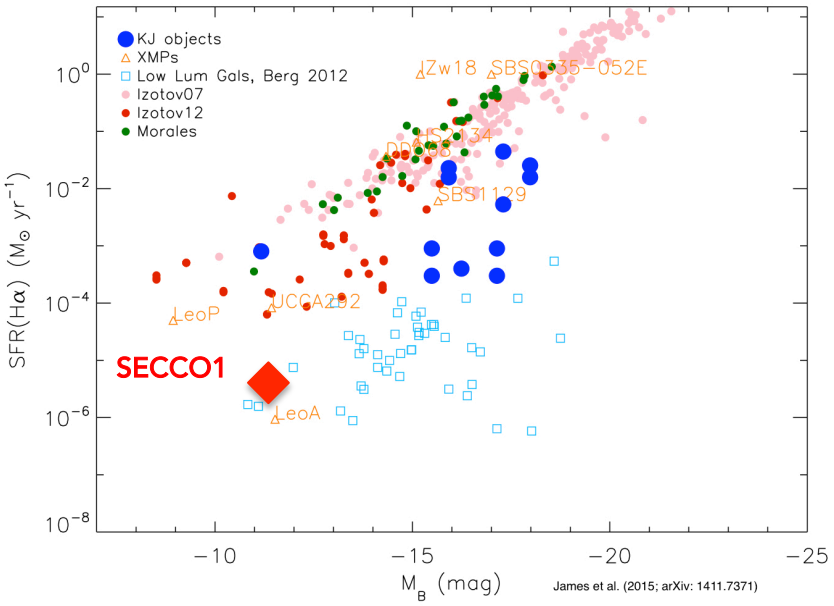


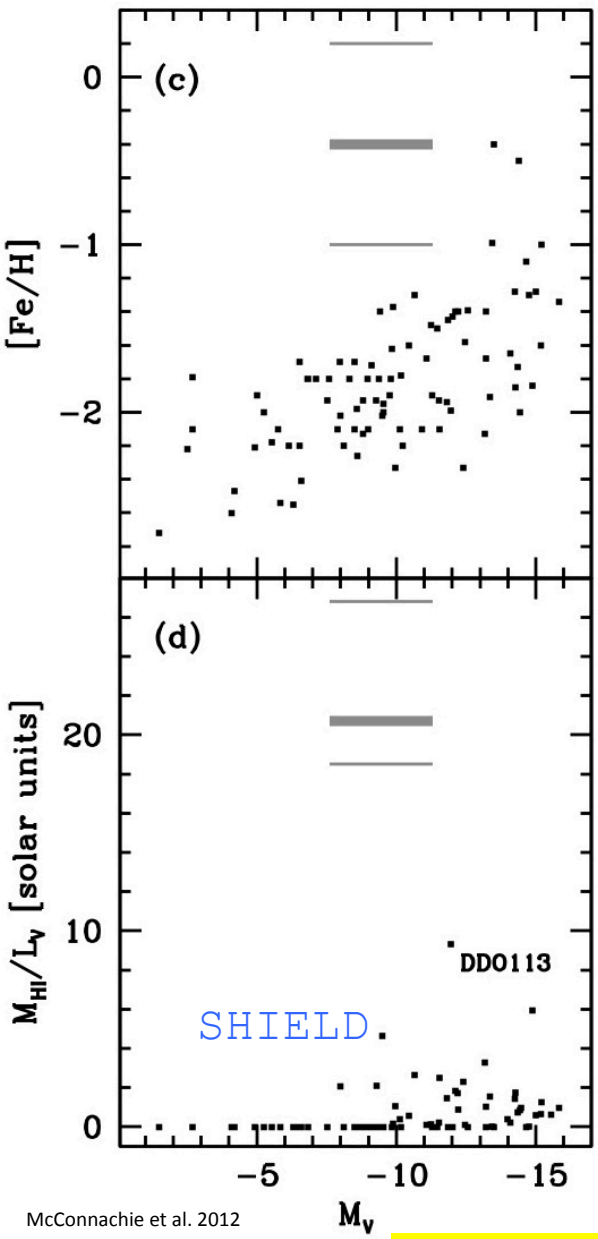
FIG. 1.—Velocity histogram for the Virgo Cluster. Notice the obvious background group at ~4000 km s^{-1}.

Projected at less than 3 deg from M87 and velocity fully compatible with the distribution of the Virgo cluster. A natural explanation for the negative velocity ($V_r \gtrsim$ -128 km/s)

@ Virgo: SFR = 6.1×10^{-6} $M_\odot$/yr
f_b ~ 0.046 (typical of dwarfs, ~1/3 of the cosmic mean)

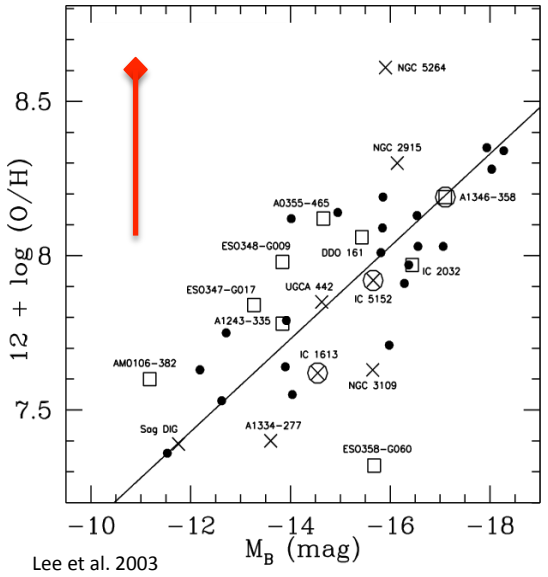


the SECCO survey. SECCO 1: a nearly starless galaxy in Virgo?



McConnachie et al. 2012

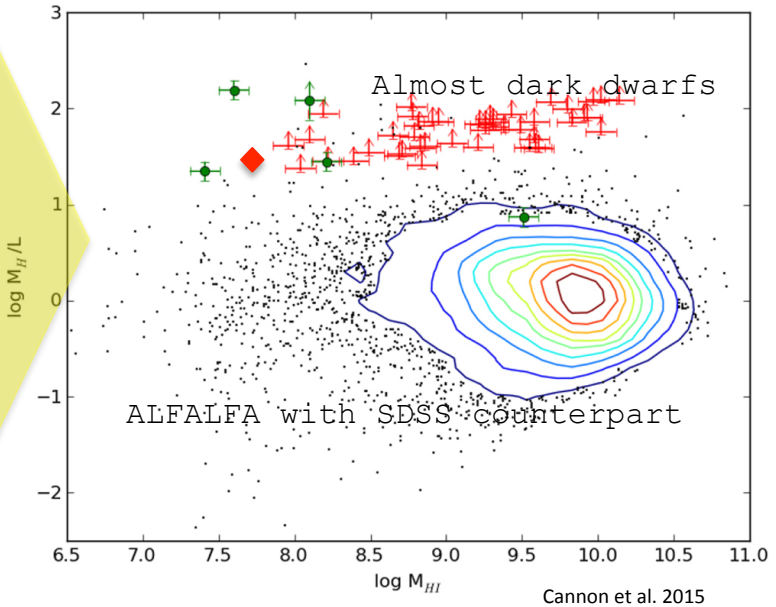
The metallicity - as derived from [NII/H_α] - is too high



Lee et al. 2003

Independently of the Assumed distance
$M_{HI}/L_v \approx 20$
Much larger than Local dwarfs and SHIELD dwarfs

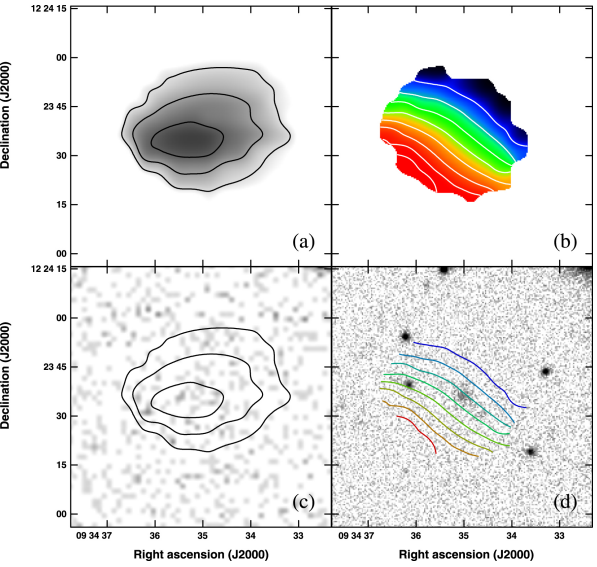
A nearly STARLESS DWARF

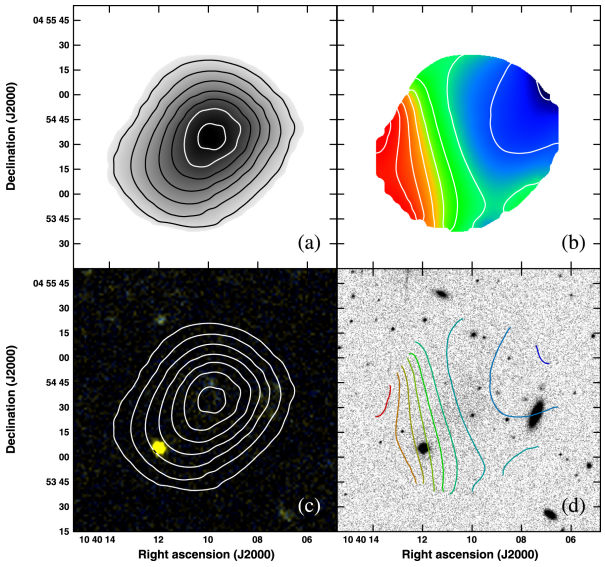


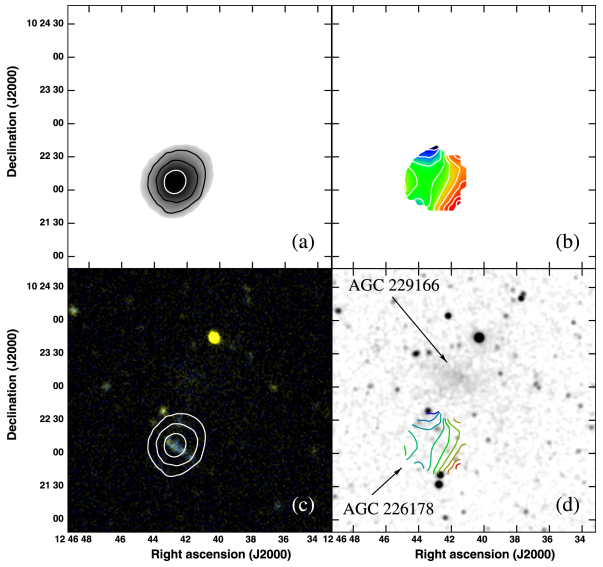
Cannon et al. 2015

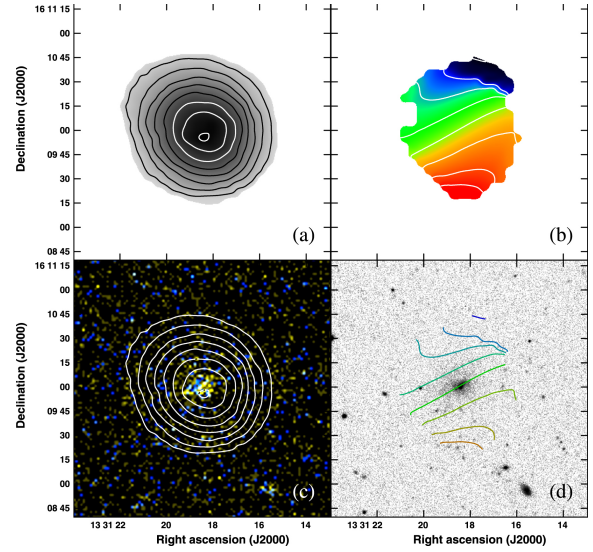
Results published in: Bellazzini et al. 2015, ApJ, 800, L15

SECCO 1: the most clearly resolved, nearest "almost dark" galaxy

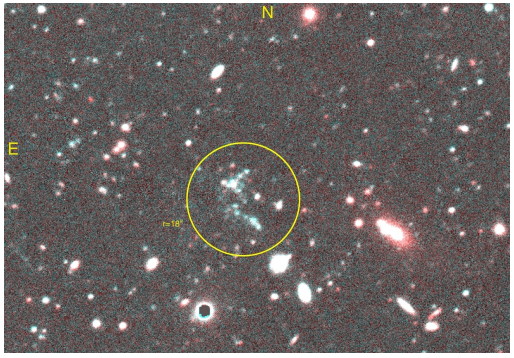


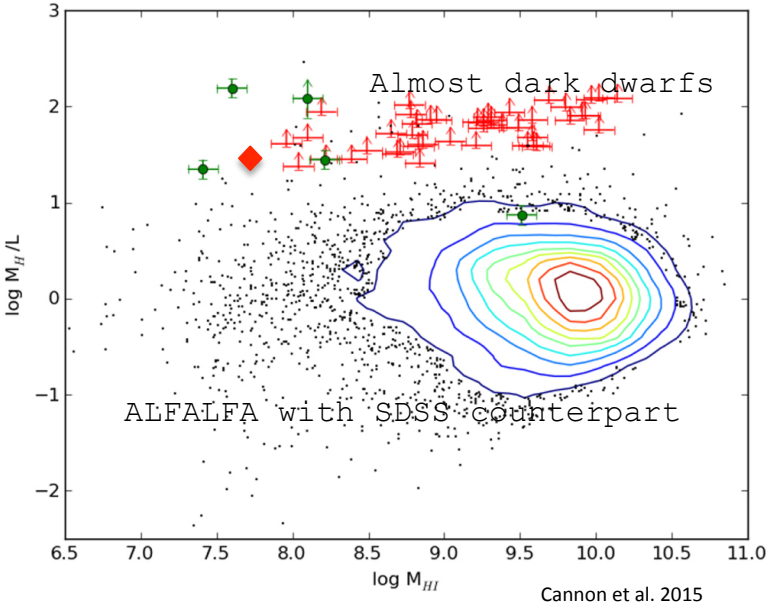






HST can resolve RGB stars in Virgo for such LSB systems: An unique opportunity





Cannon et al. 2015

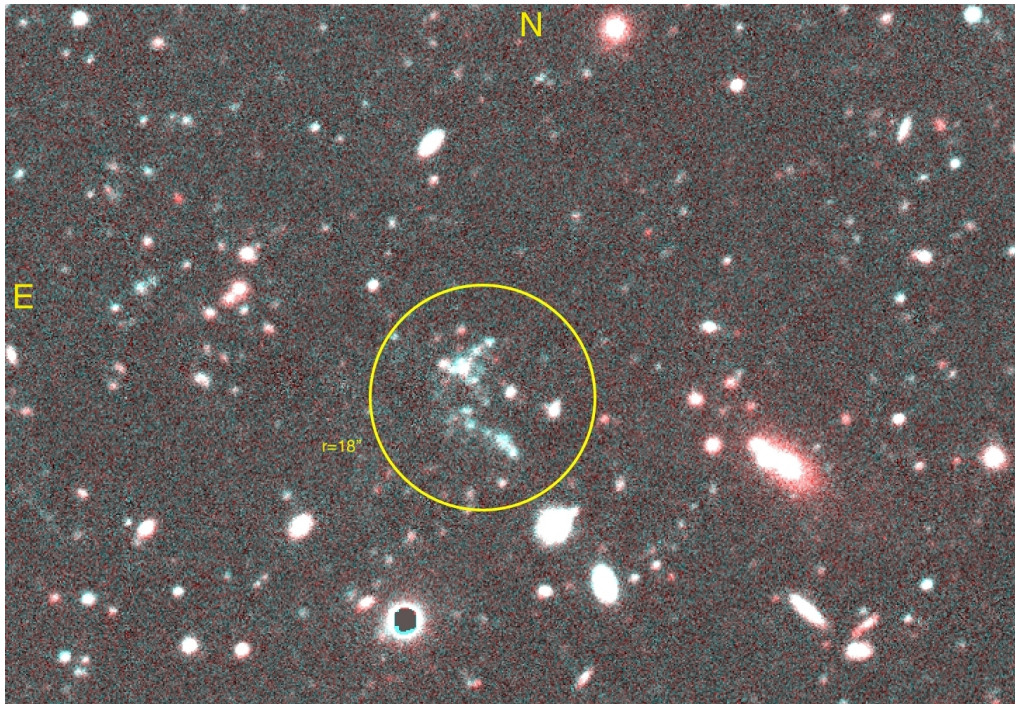
Results published in: Bellazzini et al. 2015, ApJ, 800, L15

the SECCO survey. SECCO 1: next steps

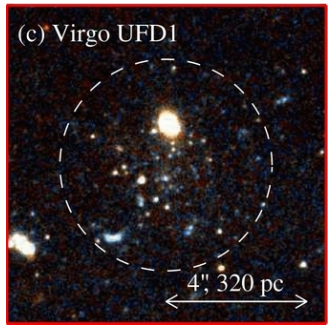
1. On March 22, H_α imaging with DOLORES@TNG: additional HII regions, total H_α fluxes

2. LBT proposal for further Red+Blue arm MODS spectroscopy: observing H_β and other lines; better constraints on velocity, higher S/N

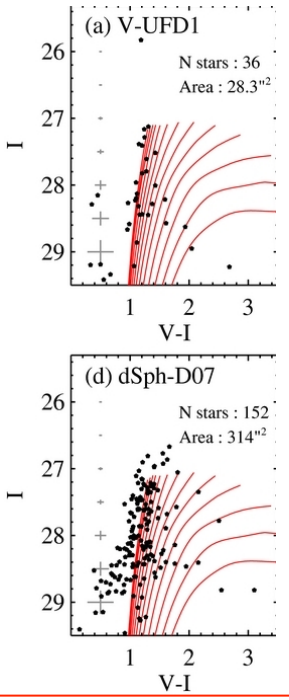
3. HST proposal to resolve RGB if there: final word on the nature of SECCO1 and distance



Example of CMDs of dwarfs in Virgo with HST (Jang & Lee 2014)



ACS image



the SECCO survey. next steps

STEP2 (Sextractor photometry of the entire fields): ongoing

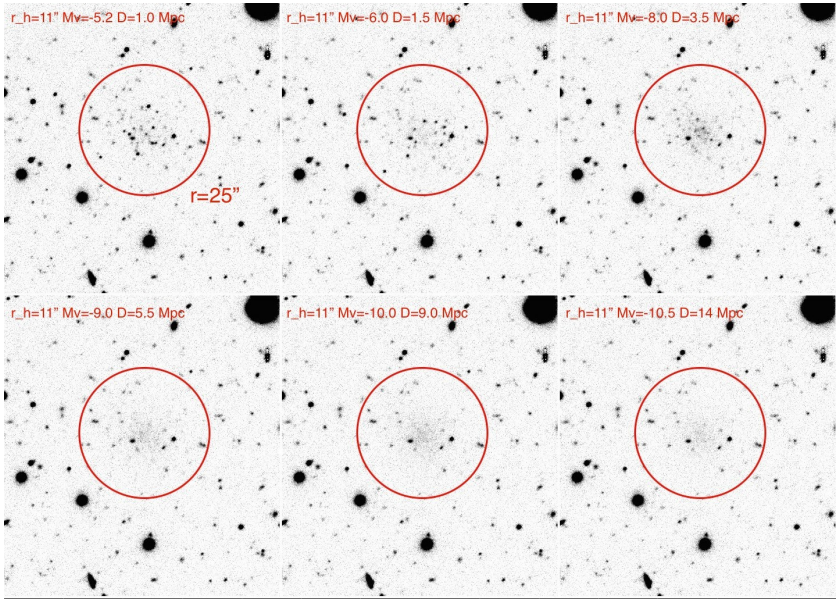
Extensive experiments with artificial galaxy: ongoing in Garching (G. Beccari), to explore the sensitivity of the survey in the (D, M_v, r_h) space

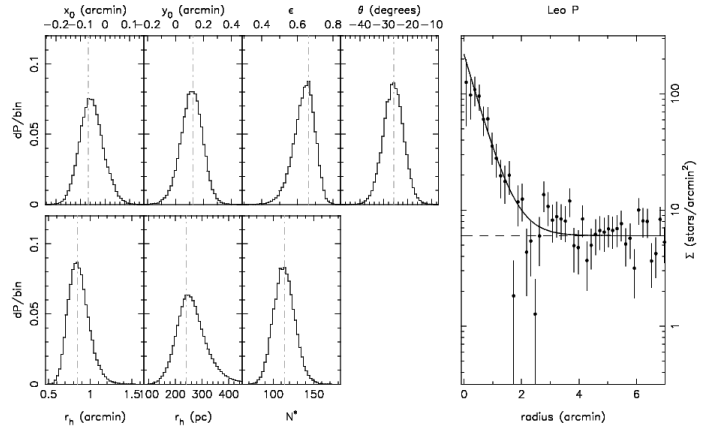
New structural parameters and SFR of Leo P (N. Martin + M. Cignoni): writing paper

Proposal for H_α imaging of overdensity Q1 with OSIRIS@GRANTECAN (G. Battaglia)

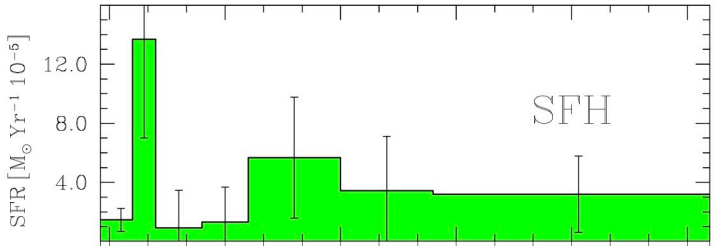
SECCO extension

Ancillary science

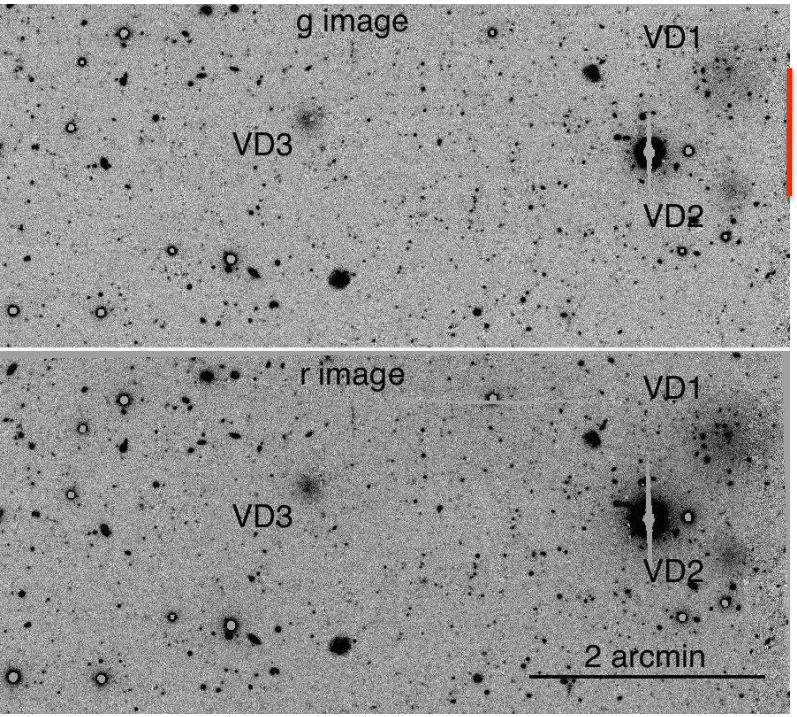


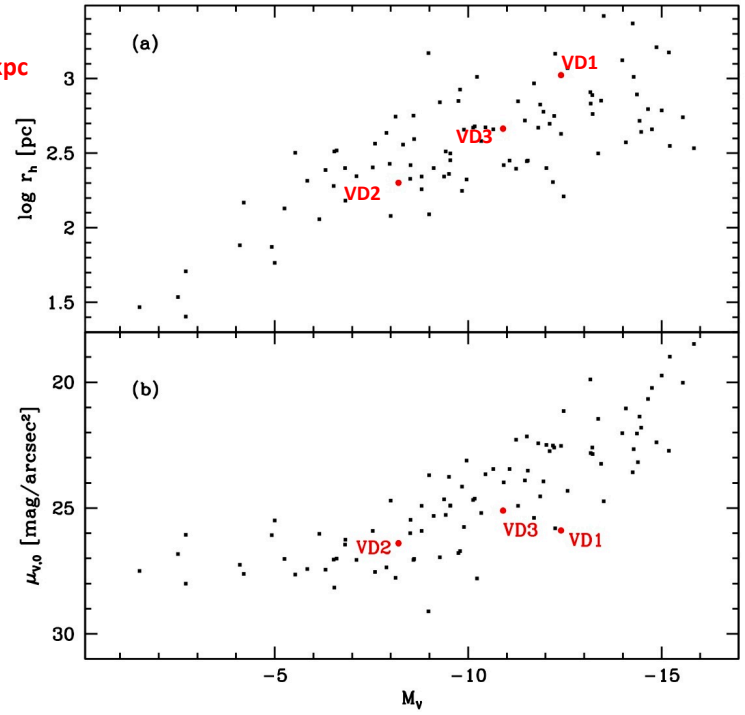


Leo P

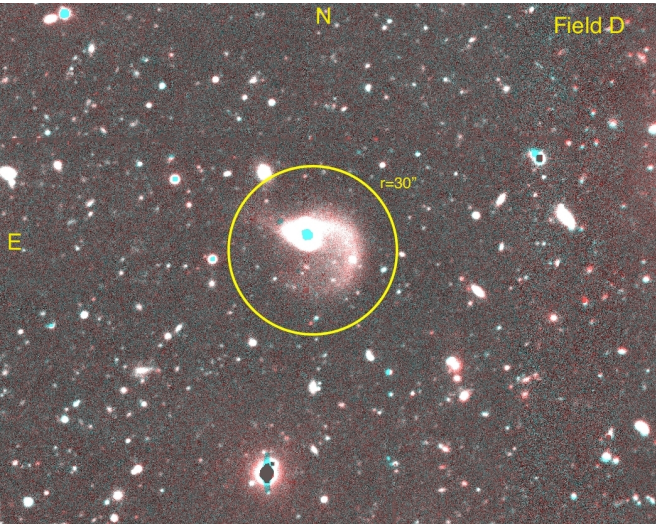


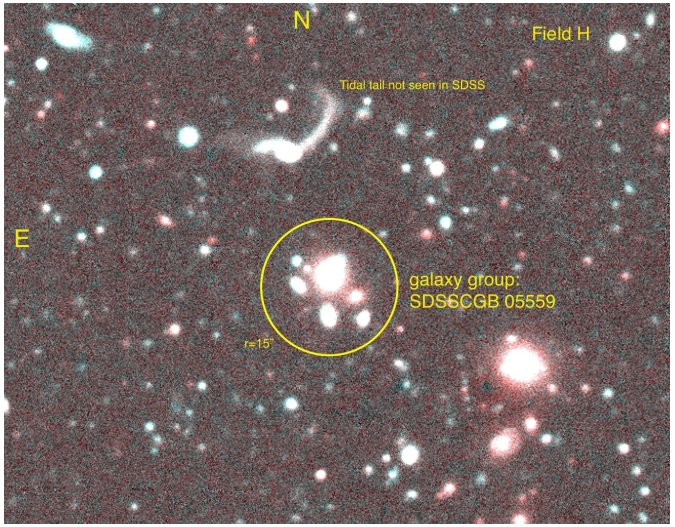
the SECCO survey. Ancillary science: examples





A group of very low SB dwarfs in Virgo





Deep images of:

interacting galaxies

galaxy groups

clusters of galaxies

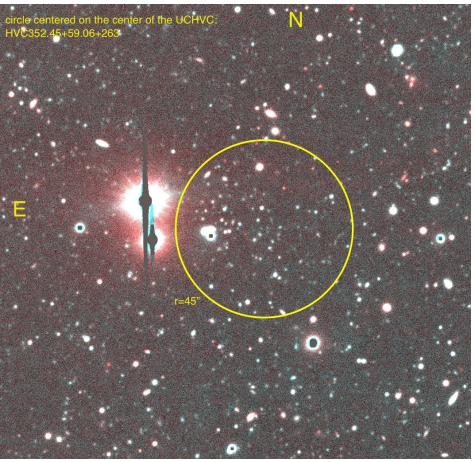
STEP0 will provide basic parameters also for resolved Galaxies: M_{int}, R_h, ellipticity

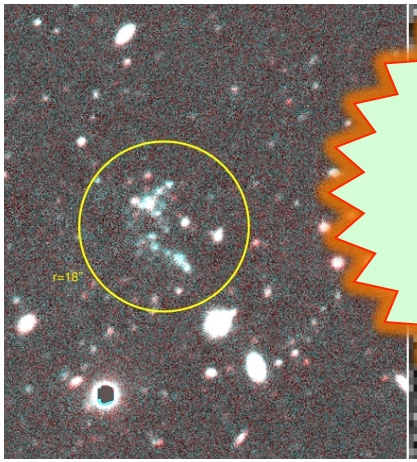
the SECCO survey

We are on the verge of a revolution?
Beginning to find nearly and fully starless dwarf galaxies.
SECCO is our opportunity to play the fascinating game of hunting these **dark butterflies**.

They are cosmological probes and also a window to a new regime of star formation, chemical evolution etc.
A different way of life for baryons.

A PhD thesis has been proposed within SECCO.
There is material also for a couple of *Laurea Magistrale* thesis:
join us! My office is at the first floor.





Thanks!