Are most galaxies in the Universe TSTS:Too shy to shine?

R. Giovanelli

UAT Workshop @ AO is grand

Jan 2015

Some statistical tools with paucity of flashy pix[*]:

- The HI mass function which tells us the space density of HI sources for each mass bin;
- The autocorrelation function, which tells us how HI sources cluster (they are the least clustered population in the Universe);
- The stellar mass function, which tells us the space density of galaxies, binned by stellar mass;
- The baryonic mass function, which tells us the space density of galaxies, binned by baryonic mass (stars plus cold gas) ;
- The luminosity function, which tells us the space density of galaxies, binned by their luminosity;
- The rotational velocity (width) function ➔ the space density of galaxies binned by their disks rotational width amplitude.

[*] *like when your dept. Chair asks for classy pix to show the Dean.*

ALFALFA

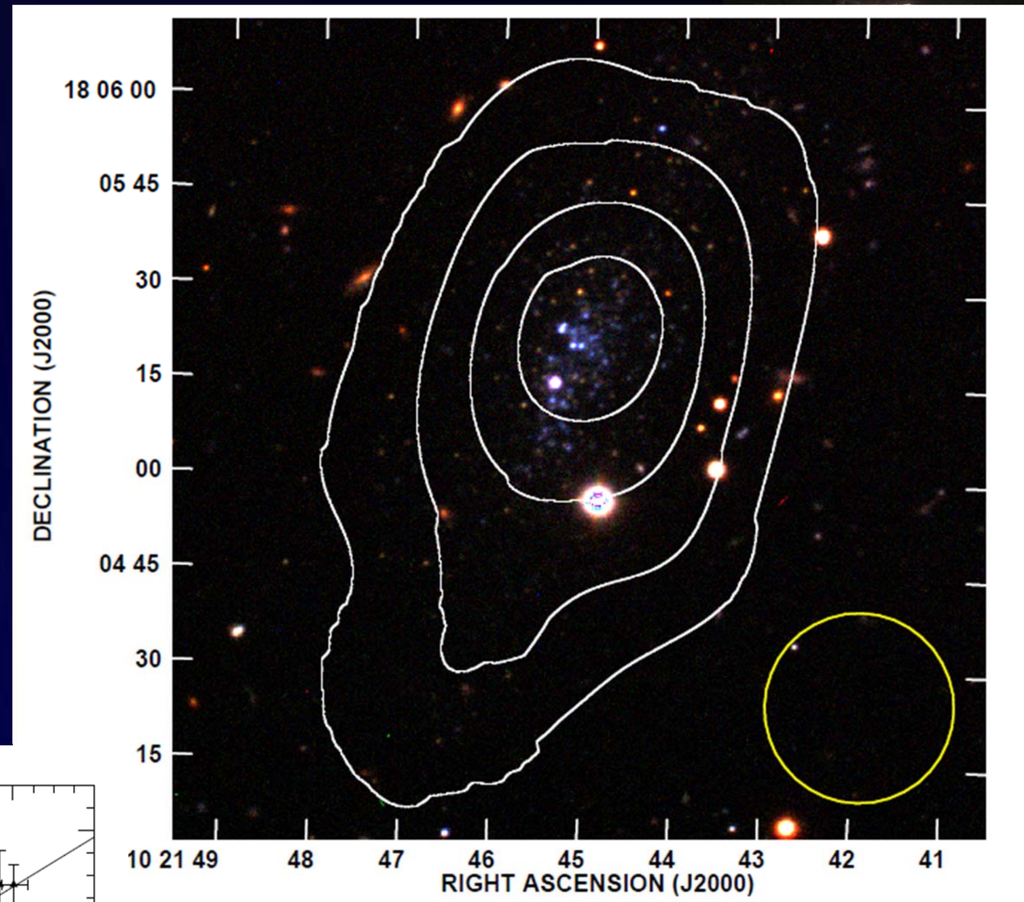
- We have more fun dealing with sources that have no counterpart at other wavelength regimes, beasts that would have not been found, if it were not for ALFALFA.
- We call them (almost) dark: "almost" because, while they may be undetectable on wide field surveys like the DSS2 or SDSS, they can sometimes be seen if much longer exposures are taken than that of those public surveys.
- Today story taps on both the inferences of dry statistics and the fun of almost darks.
- The bottom line will be that perhaps, when we look at the sky, we are missing most of the wannabe galaxies, no matter how big and sensitive our telescope can be.
- I'll try to convince you that perhaps most of the galaxies that DM has set up for us are dormant:

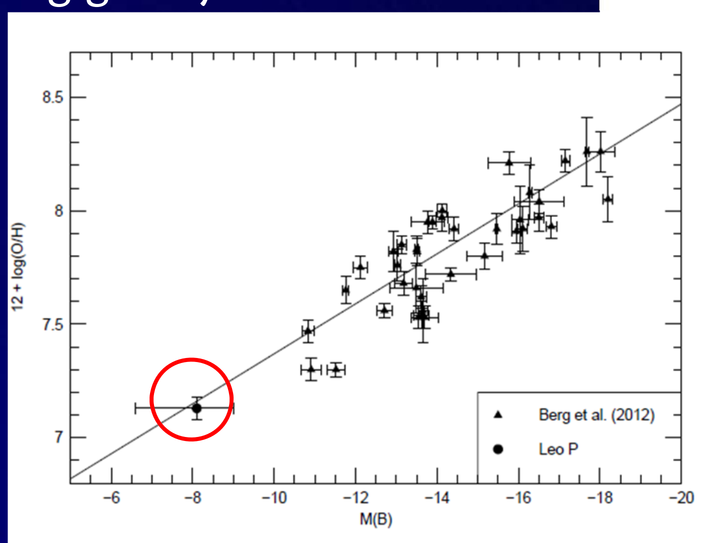
ALFALFA

Leo P

Leocated 1.7 Mpc away
stellar mass 3.7×10^{5} $M_{\odot}$
HI mass 2.5 times as high
HI radius of half a kpc
Dynamical mass: 2.3×10^{7} M_{sun}
within that radius and
$(12+\log(O/H)=7.16\pm0.4)$
making it the lowest metallicity, star forming galaxy in the Local Volume

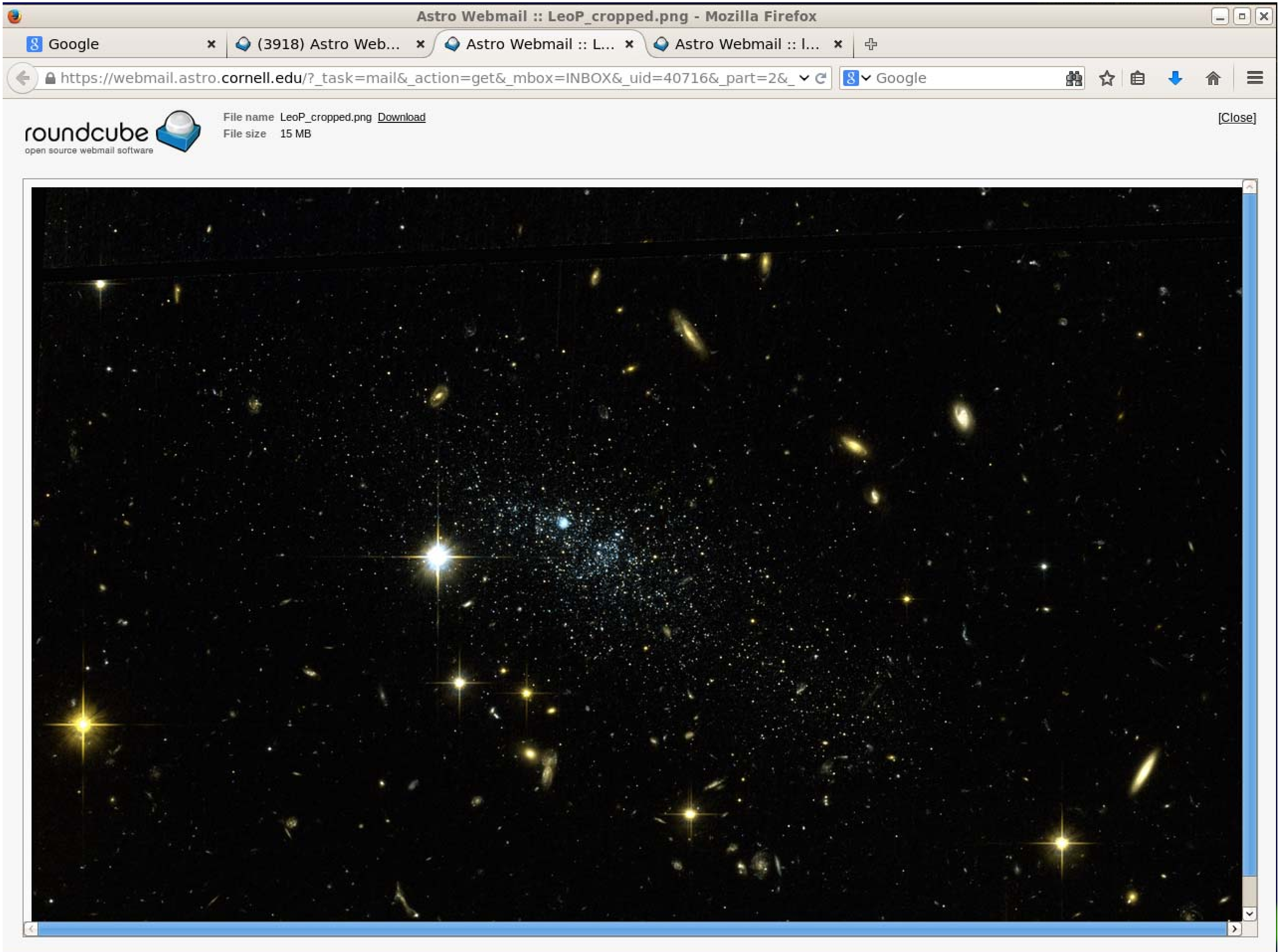
1/50 sol



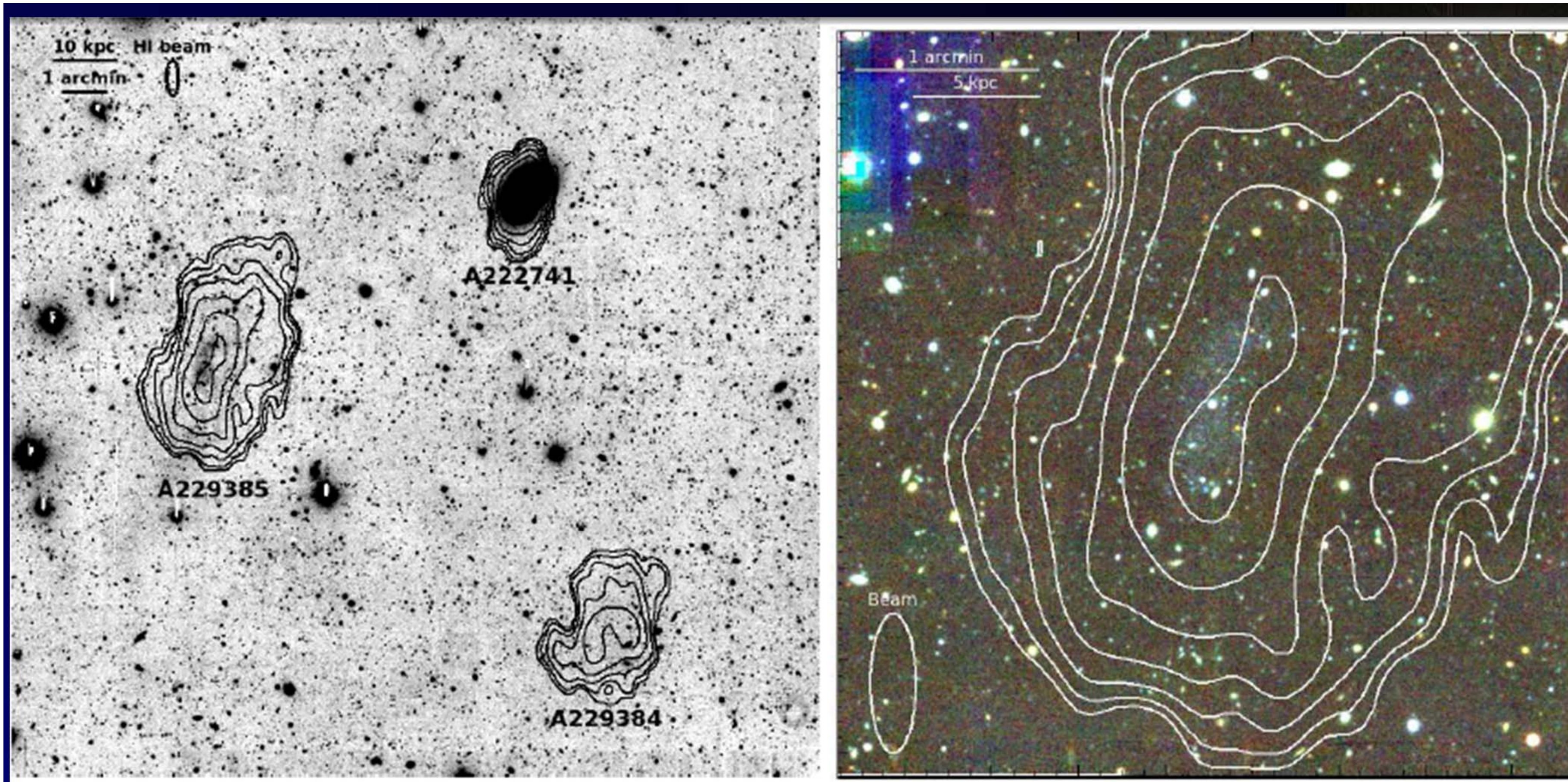


Had it been 2–3 times farther away, it would not have been detected by ALFALFA.

We'd call its DM host a "minihalo".

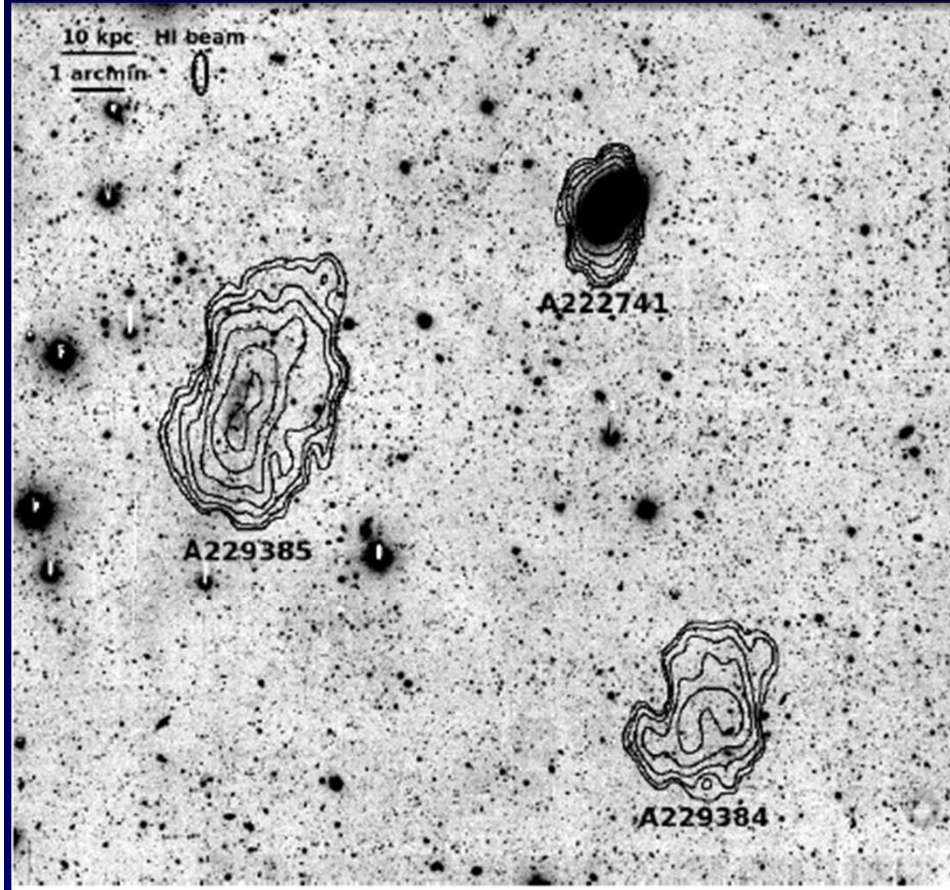


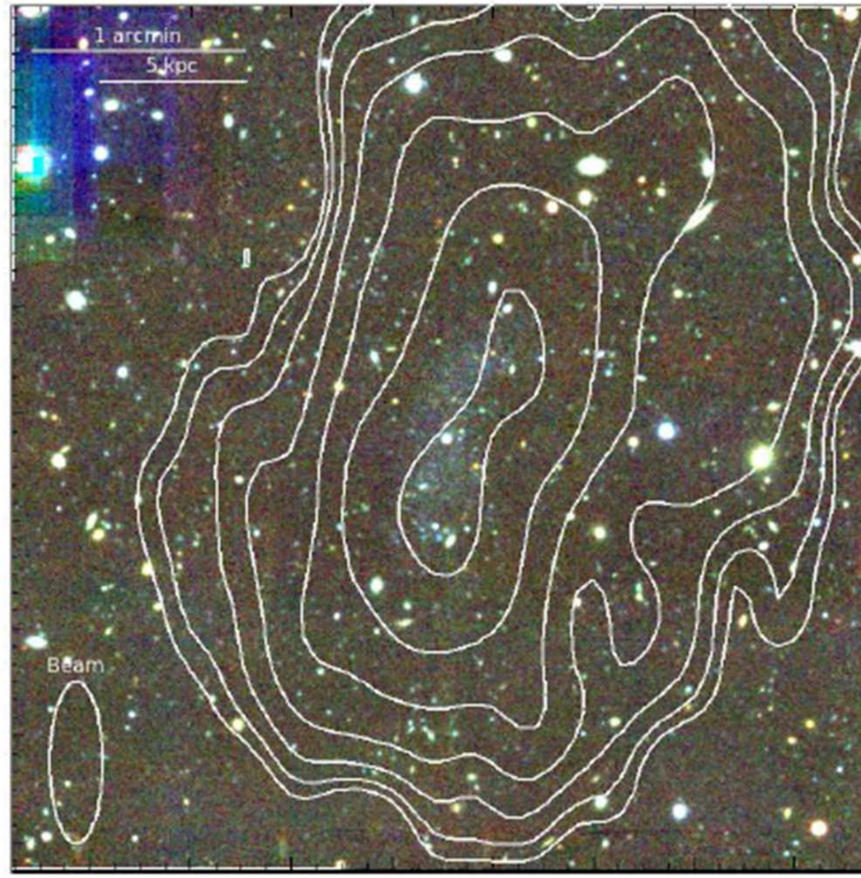
Astro Webmail :: LeoP_cropped.png - Mozilla Firefox
Google
(3918) Astro Web...
Astro Webmail :: L...
Astro Webmail :: l...
https://webmail.astro.cornell.edu/?_task=mail&_action=get&_mbox=INBOX&_uid=40716&_part=2&_
Google
roundcube
open source webmail software
File name LeoP_cropped.png Download
File size 15 MB
[Close]



LUKE's SPECIAL: WSRT HI column density contours superimposed on an optical image of a field containing several ALFALFA sources. The optical image is a composite of three 45-min exposures in three filters (*g*, *r* and *i*) made with the pODI camera at the 3.5m WIYN telescope (Janowieki *et al.*2014, in preparation). Three HI sources are clearly detected. The strongest is an undisturbed background spiral (CGCG 129-006 = AGC 222741) at *cz*=1884 km s−1. The others are at *cz* ~1320 km s−1 and have no SDSS counterparts.

ALFALFA





A 4′ ×4′ blow up centered on AGC 229385, showing a faint, blue optical counterpart coincident with the HI source; blue, star forming. AGC 229384 has no optical counterpart.

Table 1 Properties of AGC 229384 and AGC 229385 at $D_{Mpc} = 25$

	$\log M_{HI}$ $M_\odot$	R_{HI} kpc	cz km s^{-1}	W_{50} km s^{-1}	M_g mag	$g-r$ mag	M_{HI}/L_g $M_\odot/L_\odot$	$\log M_{dyn}$ $M_\odot$
AGC 229384	8.3	7	1310	27	>-12.9	...	>14	8.5
AGC 229385	8.8	14	1348	34	-12.8	-0.09	44	9.0

ALFALFA

Galaxies form through the collapse and subsequent accretion of baryonic material onto dynamically dominant dark mater (DM) halos. At $z = 0$, the baryonic component of the cosmic matter–energy budget is 4.9%, while that of DM is 26.8%, so $\Omega_b/\Omega_{matter} \simeq 0.15$.

The stellar mass function exhibits a shallow power law slope of about -1.3.

However, the ΛCDM prediction for the low end of the halo mass function is a steeper power law of index -1.8.

➔The stellar mass of a galaxy is thus not a fixed fraction of the host halo mass.

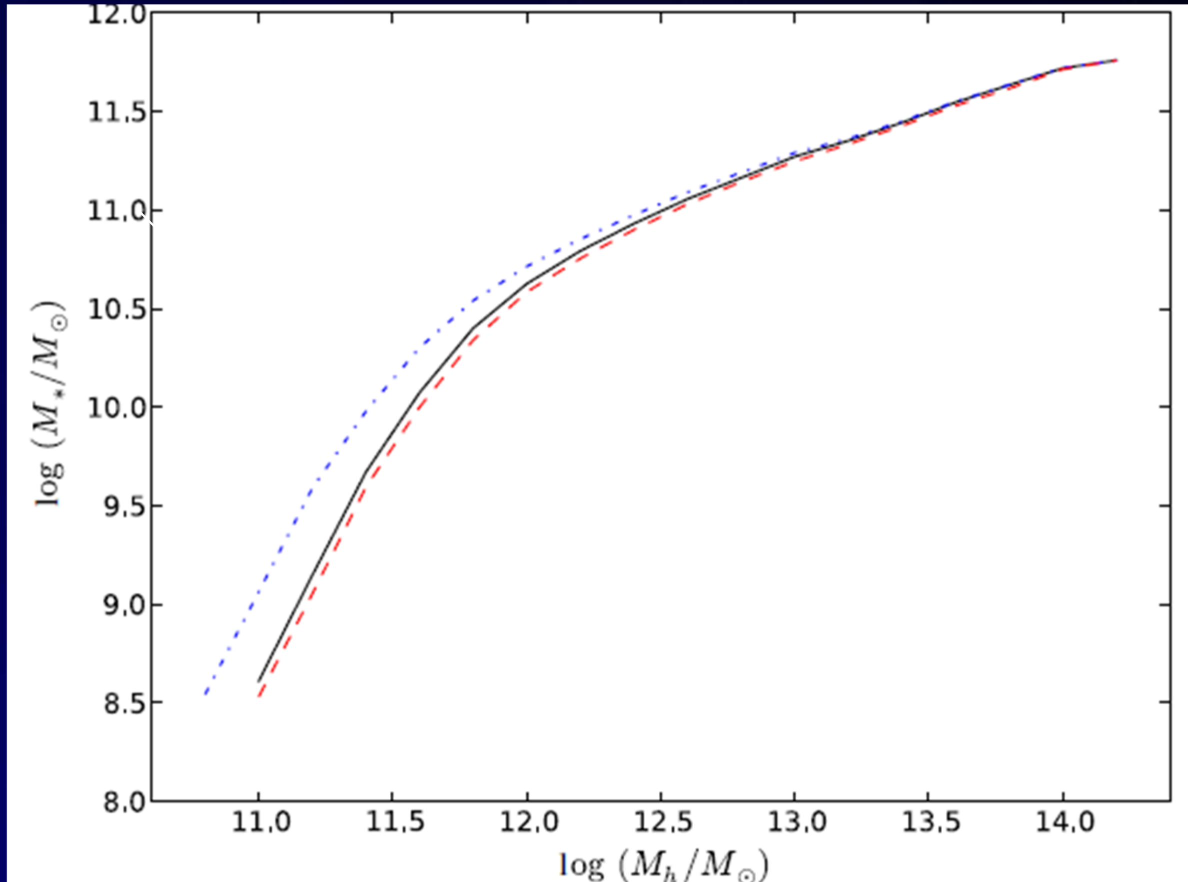
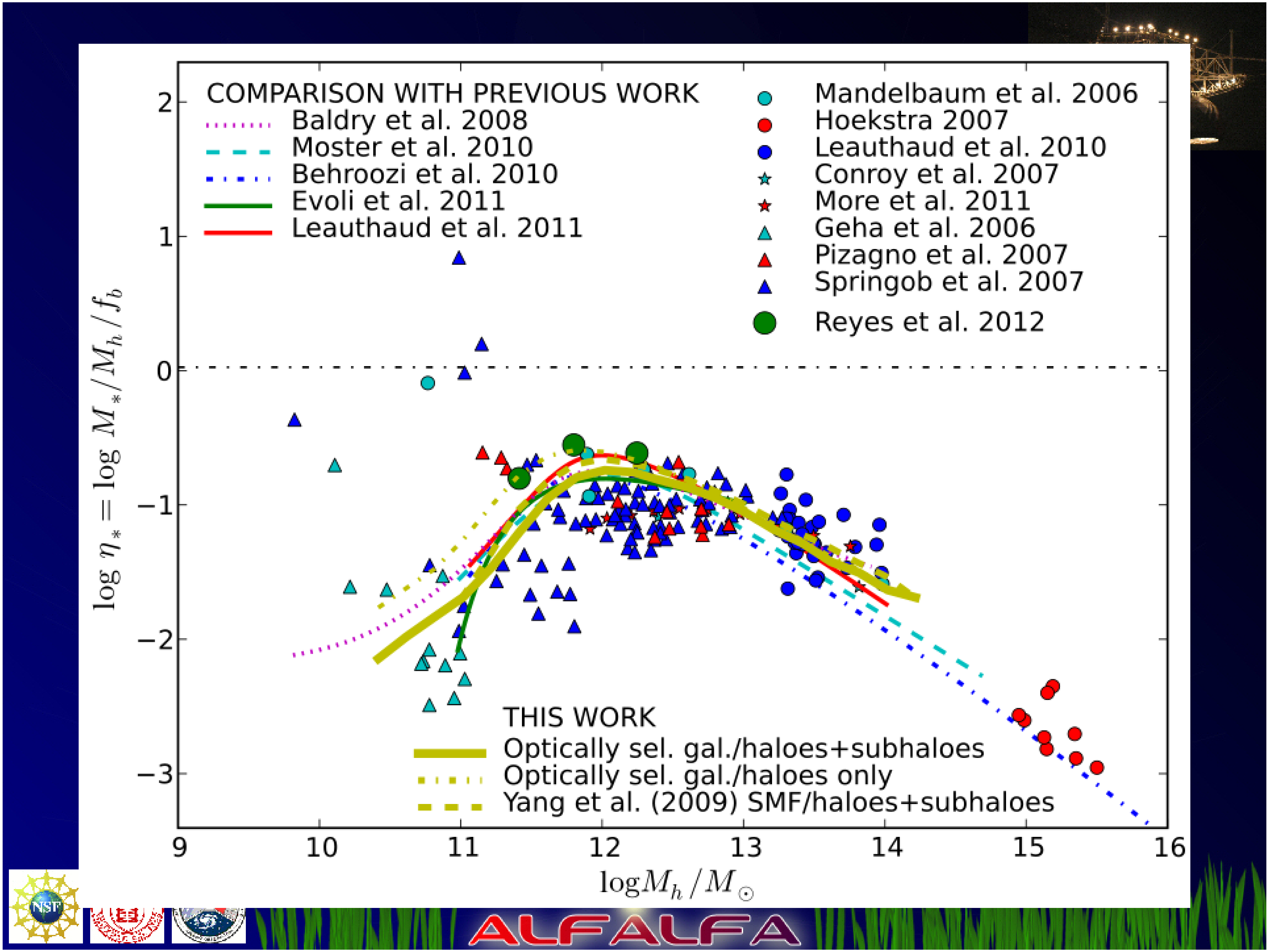


Figure 14. Effects of the choice of stellar and halo mass functions on the M_*–M_h relation. The black solid line shows the M_*–M_h relation obtained by matching the stellar mass function of central galaxies to the mass function of halos excluding subhalos. This matching should reproduce the "true" relation for central galaxies. The blue dot-dashed line is the relation obtained by matching the total galaxy stellar mass function, including central and satellite galaxies, to the mass function of halos excluding subhalos. The red dashed line is the

ALFALFA

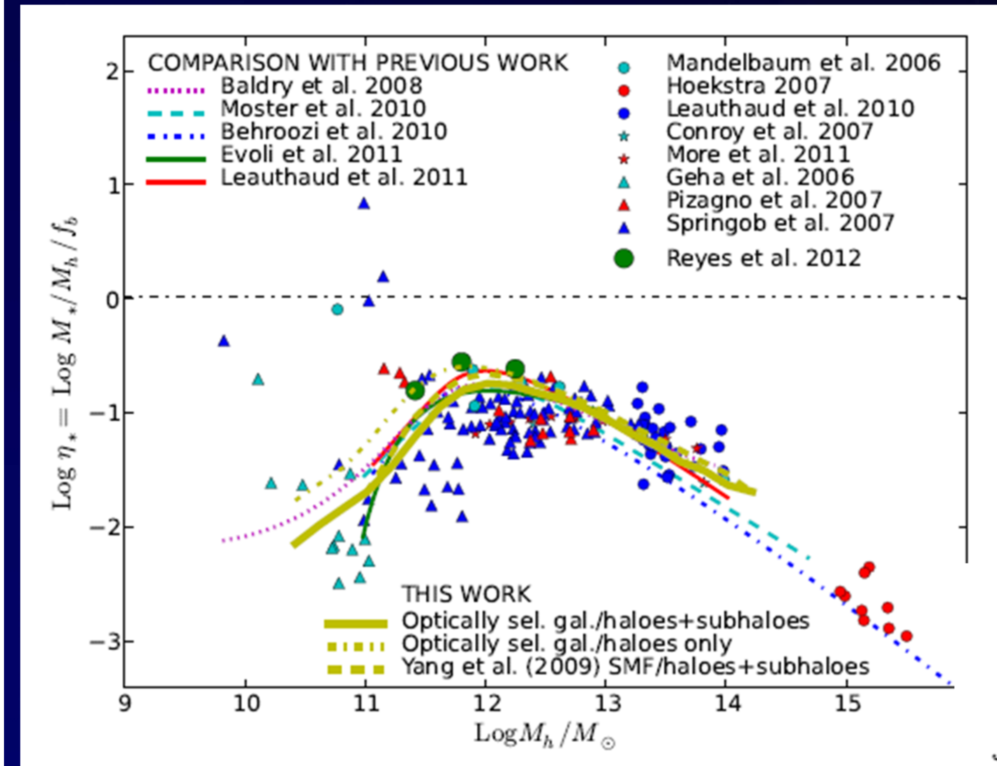
Abundance Matching



COMPARISON WITH PREVIOUS WORK
Baldry et al. 2008
Moster et al. 2010
Behroozi et al. 2010
Evoli et al. 2011
Leauthaud et al. 2011
Mandelbaum et al. 2006
Hoekstra 2007
Leauthaud et al. 2010
Conroy et al. 2007
More et al. 2011
Geha et al. 2006
Pizagno et al. 2007
Springob et al. 2007
Reyes et al. 2012
THIS WORK
Optically sel. gal./haloes+subhaloes
Optically sel. gal./haloes only
Yang et al. (2009) SMF/haloes+subhaloes
$\log \eta_* = \log M_* / M_h / f_b$
$\log M_h / M_\odot$
ALFALFA
NSF

Baryonic Mass Function Papastergis+ (2012)

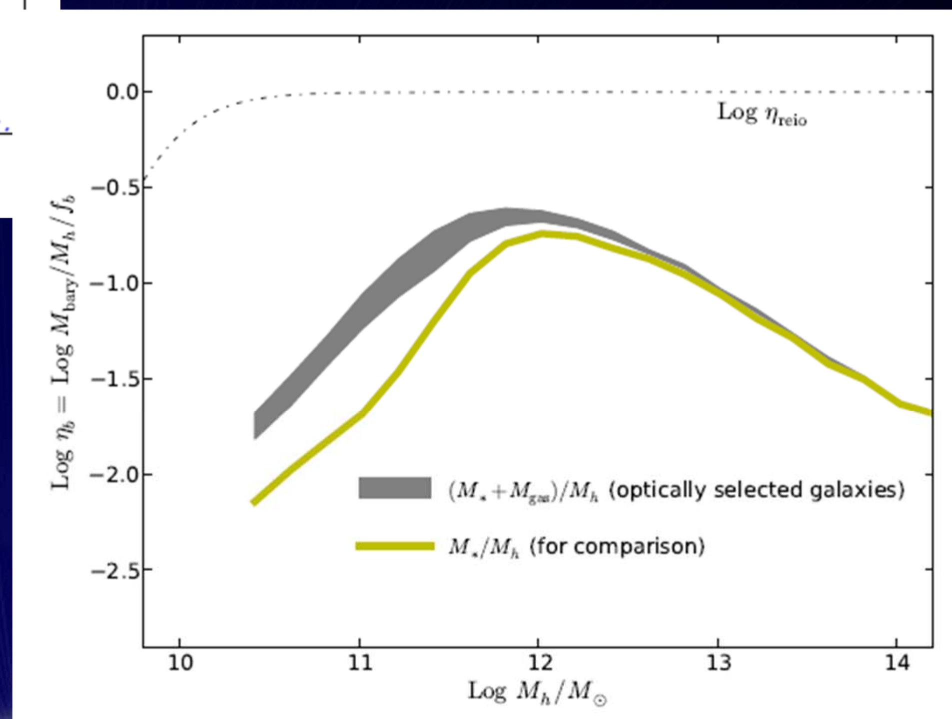
wk lensing constraint



log ($M^*/f_b\ M_{halo}$) vs. log M_{halo} ^

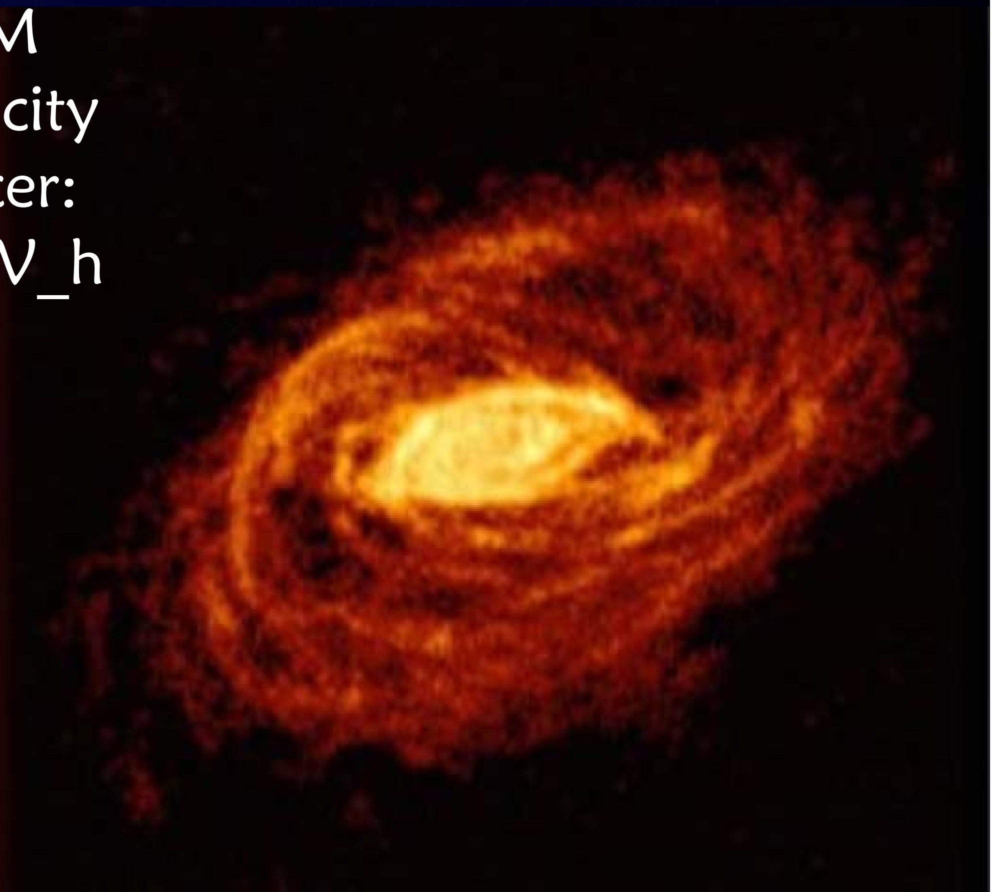
log ($M_{bar}/f_b\ M_{halo}$) vs. log M_{halo} ➔

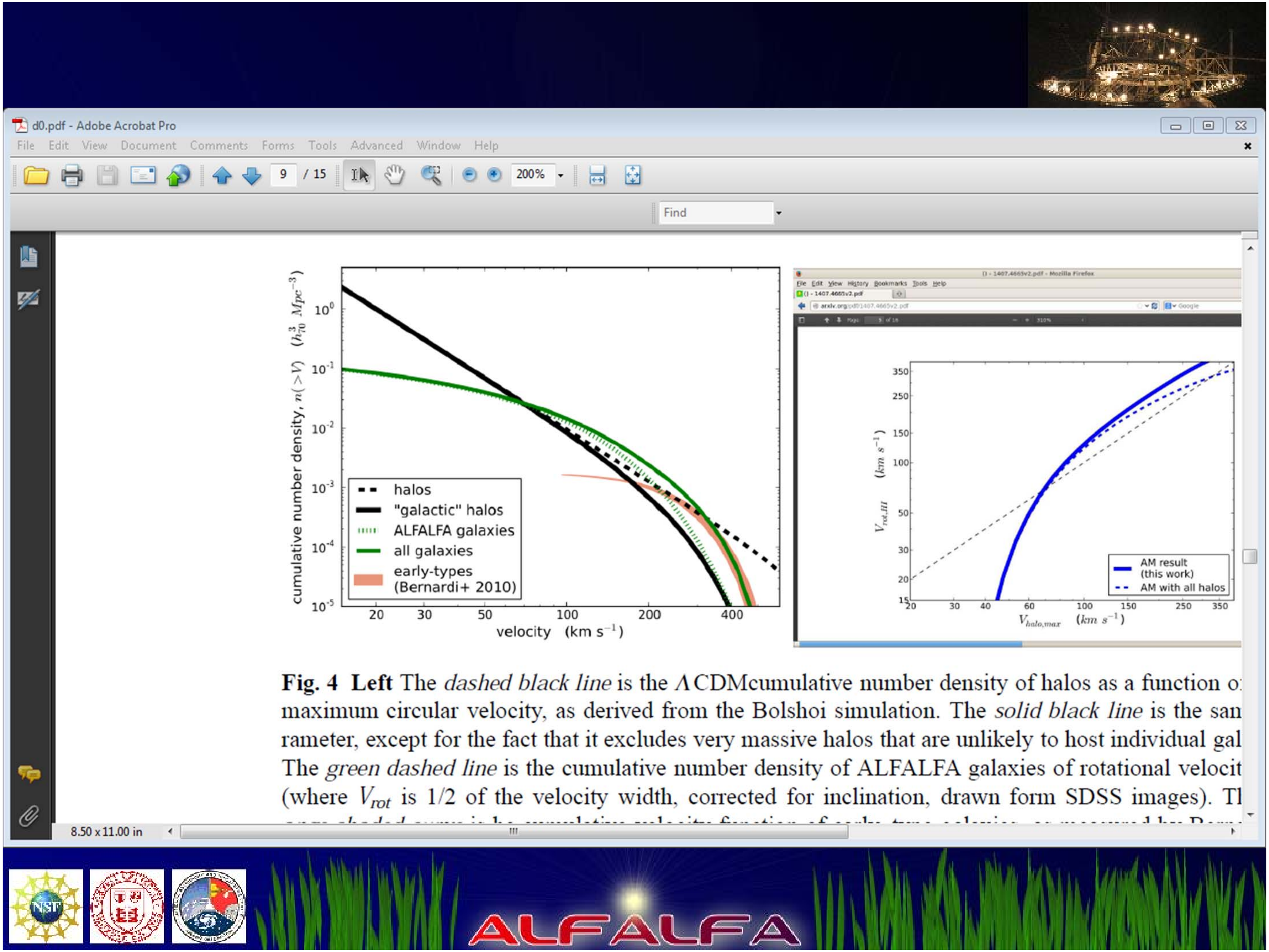
Observed baryon mass



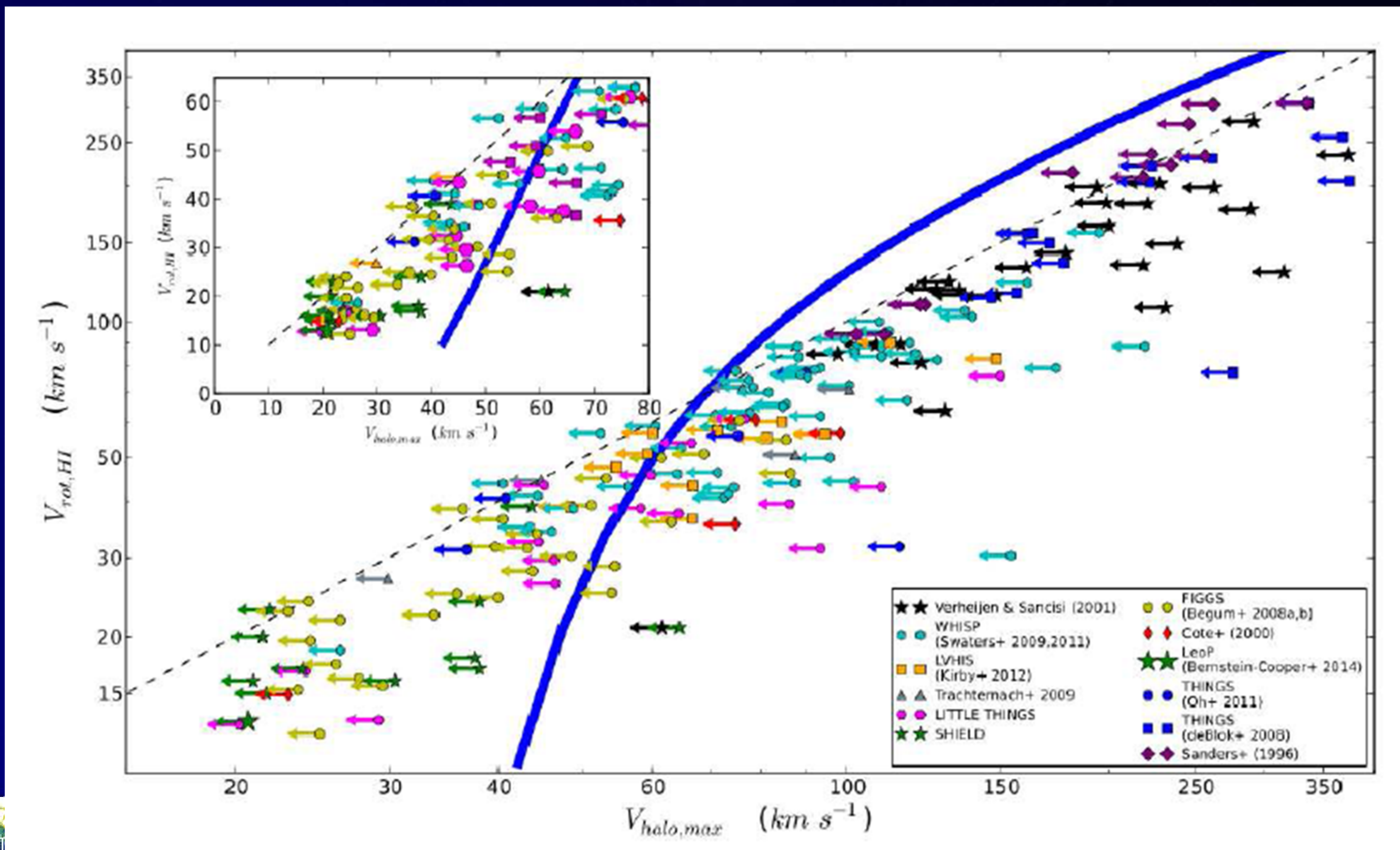
ALFALFA

A good reason to use HI line velocity width as the closest baryonic parameter to the DM halo V_max: it samples velocity field farther out than any tracer:
➔ Abundance match W and V_h




d0.pdf - Adobe Acrobat Pro
File Edit View Document Comments Forms Tools Advanced Window Help
9 / 15
200%
Find
cumulative number density, $n(>V)$ $(h_{70}^3\ Mpc^{-3})$
velocity (km s^{-1})
halos
"galactic" halos
ALFALFA galaxies
all galaxies
early-types
(Bernardi+ 2010)
$V_{rot,HI}$ $(km\ s^{-1})$
$V_{halo,max}$ $(km\ s^{-1})$
AM result
(this work)
AM with all halos
Fig. 4 Left The *dashed black line* is the ΛCDMcumulative number density of halos as a function o
maximum circular velocity, as derived from the Bolshoi simulation. The *solid black line* is the san
rameter, except for the fact that it excludes very massive halos that are unlikely to host individual gal
The *green dashed line* is the cumulative number density of ALFALFA galaxies of rotational velocit
(where V_{rot} is 1/2 of the velocity width, corrected for inclination, drawn form SDSS images). Tl
8.50 x 11.00 in
ALFALFA

Abundance Matching requires that all galaxies have DM halos with V_halo to the right of the blue line: e.g. a dwarf galaxy with V_rot=15 km/s would have a DM halo with V_halo > 40 km/s



ALFALFA

Abundance Matching and halos extracted from a DM-only simulation lead to unrealistic results.

There are two ways to "forcing" ΛCDM + Abundance Matching to avoid the embarassment presented in the previous slide, i.e. having small galaxies with $V_{rot} \sim 12$ km/s stuck in a halo with $V_h=40$ km/s, rather than one much less massive, as in the case of Leo P. One way is to count many more low mass (slow rotators), perhaps with a barely detectable, old stellar population. The other is having LCDM simulations that include DM and baryonic physics, capable of "uncounting" many low mass halos that turn dark because of their inability to retain their baryons after re-ionization, their inability to accrete IGM gas and to form stars for very long periods of quiescence.

Connecting statistically galaxies with their halos by using the technique of AM appears incompatible with observational data.

For example, galaxies with V_{rot} = 15 km/s are expected by AM to be hosted by halos with V_h > 40 km/s, and yet the observations indicate that such galaxies are embedded in much less massive halos.

Leo P has a Vrot ~11 km/s and a mass within the HI radius of 2×10^7 M_{sun}; AM requires it to be hosted by a halo of ~40 km/s → $M_h \sim 10^{10}$ M_{sun}

If the halo mass were to increase linearly with radius, the inferred halo radius would be 500XR_{HI}, i.e.

500x0.5 =250 kpc → ~ the R_{vir} of the MW!!!

… so people have been looking for alternatives to LCDM + Abundance Matching, e.g. Warm rather than Cold DM, which would suppress the formation of low mass halos (which would save the day but bring headaches tomorrow).

There is however a simpler way to look at things…

ALFALFA

Consider the following:

- Field dwarf galaxies (objects of stellar mass 10^7 to 10^9 M_{sun}) with no ongoing star formation are extremely rare: fewer than 0.06% (Geha, Blanton & Tinker+12). ``Field'' is defined as farther than 1.5 Mpc from a massive galaxy.
- The history of star formation of field dwarf galaxies is episodic, with bursts of activity between long periods of quiescence (Tolstoy, Hill & Tosi+09).
- The typical duration of starburst events is 200-400 Myr (McQuinn+2009).
- Halos of mass $< 10^{10}$ M_{sun} ($V_h < 50$ \km/s) are unable to retain most of their baryons after re-ionization and to accrete fresh ones from the IGM after re-ionization (Hoeft +06). However they may be able to do so at later epochs, especially in low density environments (Ricotti +09).

ALFALFA

- Between star formation episodes field dwarf galaxies can be dark, their optical and HI emissions being quenched. For them, detection would be restricted to that of the faint light of old stars formed before re-ionization.
- Galaxies in halos with $M_h > 10^{10}$ M_{sun} would not be dramatically affected by re-ionization, but in the measure by which baryonic feedback processes may be able to alter the structure of DM halos, their initial configuration may be falsified.
- The counting of dwarf galaxies is thus likely affected by the ``Cheshire Cat'' effect postulated by Salpeter & Hoffman (1995): between bursts of star formation, they fail to be counted.

Hence they are TSTS: too shy to shine

ALFALFA