ASTR 505 – Fall 2014

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www.astro.uvic.ca/~sara/A505.html

- Scope and structure of the course
- Project overview
- Assessment and grading

Course purpose: A practical course in galaxy research, based on data mining techniques.

Course structure: 6 weeks of lectures and literature discussion, followed by an independent research project.

Lecture structure: weekly (up to) 1.5-2 hours of lecture, followed by literature discussions for (up to) 1 hour.

Course objectives:

- Learn about galaxies!
- Learn about current research in galaxies through literature discussions.
- Learn practical research skills (presentations, science writing, logging your research)
- Learn technical skills (programming, visualization, database management, multi-variate analysis)
- Write a report which could lead to a paper or get a thesis started!

The details (weeks 1-6): Friday 9am-12pm

Sept 5: Sara Ellison - Intro to large surveys and projects.
Sept 12: Luc Simard – mysql and databases.
Sept 19: Luc Simard – photometric properties of galaxies.
Sept 26: Hossein Teimoorinia – Practical application of artificial neural networks in astronomy
Oct 3: Asa Bluck – data manipulation and visualization.
Oct 10: Sara Ellison – Spectroscopic properties of galaxies.

Lecture attendance is compulsory – if you need to be absent, consult with the lecturer, and let me know.

Literature discussions: Take place in the last hour of each lecture. Papers posted to website. Make sure you read and prepare for participating in the discussion (10% of grade)! Preparation can be done as a group.

The details (week 7+): Friday 11:15am-12:30pm

Once projects are underway, the format changes, and most of your time should be spent on projects. I strongly recommend you keep a journal.

The lecture becomes a "group meeting"

Each week, every student will present a short (5-10 min) update on his/her project in the last week. We will all discuss/ brainstorm/problem solve and provide feedback and ideas.

In addition, you should meet/skype with your project supervisor at least once per week.

Projects/supervisors

- The clustering of satellites around active galaxies: do mergers trigger black hole accretion? Sara
- How do galaxy mergers affect the Fundamental Metallicity Relation? Sara
- Does nuclear activity affect triggered star formation in galaxy mergers? Sara
- The galaxy size-mass relation for mergers. Dave Patton (Trent)
- Disk shapes and sizes. Luc Simard (HIA)
- HI gas consumption in different environments. Sara

Or your own idea!!

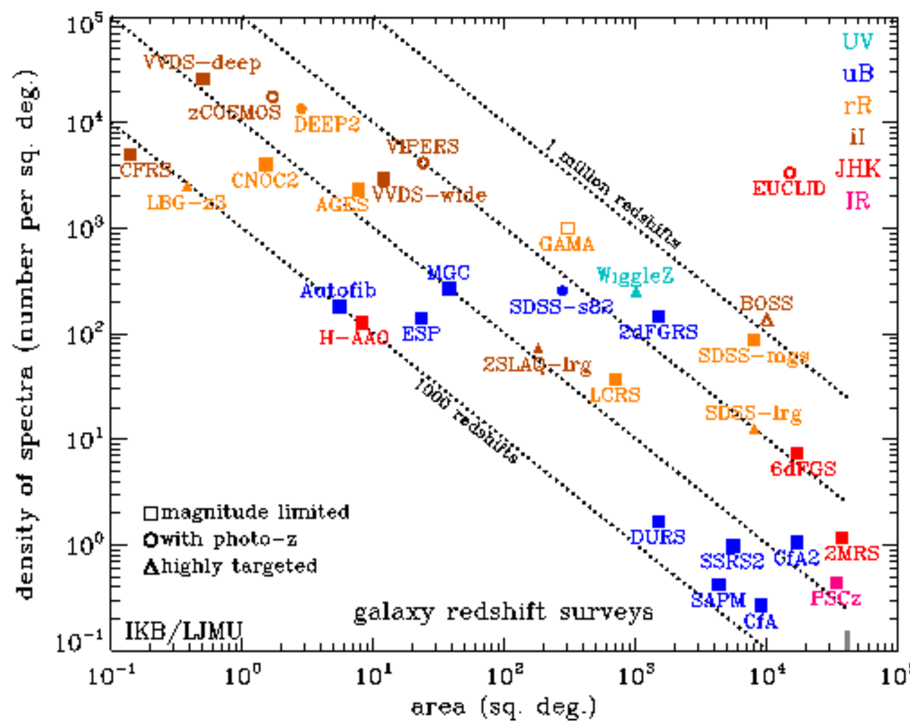
Assessment

- 10% Contributions to weekly paper discussions
- 10% Contributions to weekly project updates
- 20% project presentation (15 minutes)
- 60% Final project write-up

We are in the era of large surveys!!

Some technical considerations:

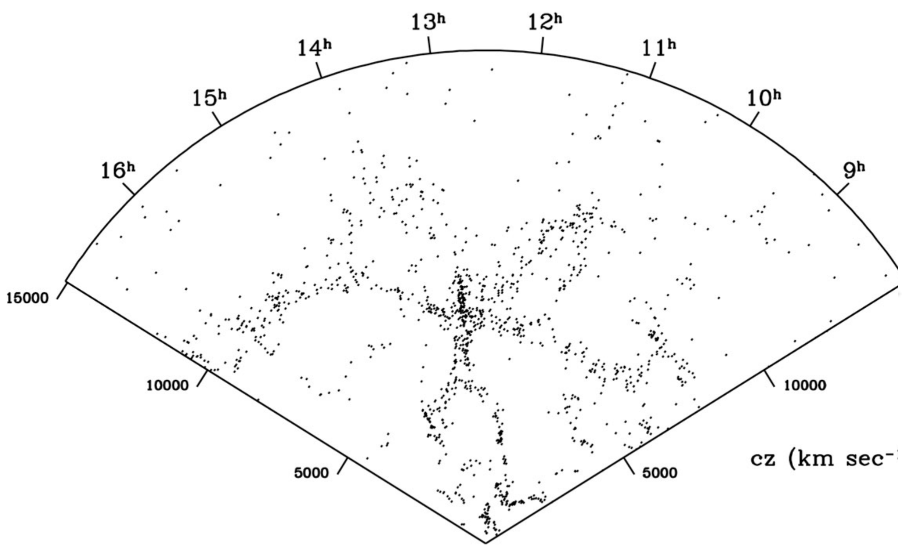
- Single object, masks, fibres: Long slit for CfA, masks for CFHT, fibres for SDSS
- Blind versus targetted/ selection, e.g. ALFALFA vs GASS
- Dedicated telescopes (APO, LSST)
- Depth vs area; bright vs faint



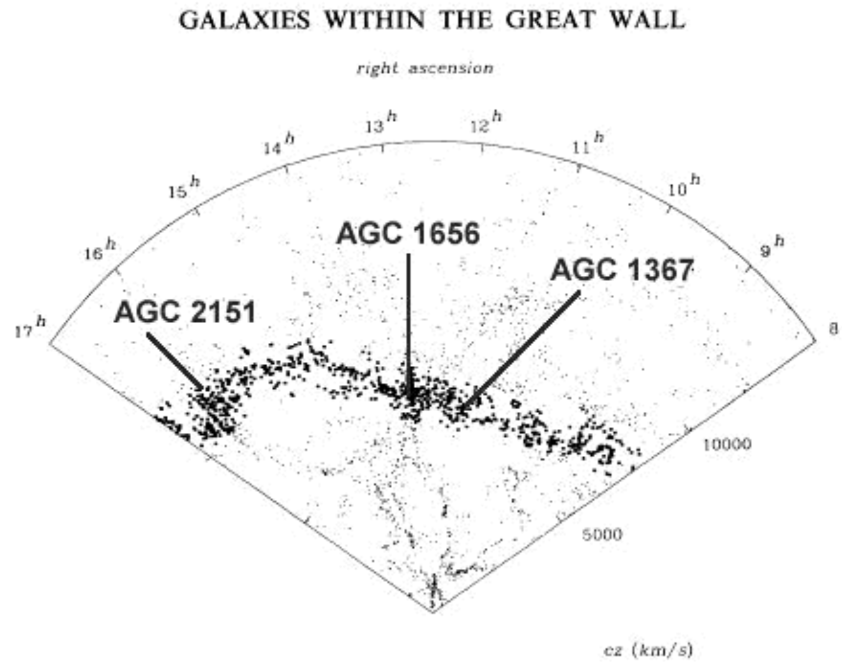
http://www.astro.ljmu.ac.uk/~ikb/research/galaxy-redshift-surveys.html

Some key discoveries by large surveys: z<1

CfA redshift survey (Davis et al. 1982, Huchra et al. 1983) 2400 galaxies, z<0.1 and CfA2 (Falco et al. 1999) 18,000 galaxies.



1100 galaxies in
De Lapparent et al. (1986)

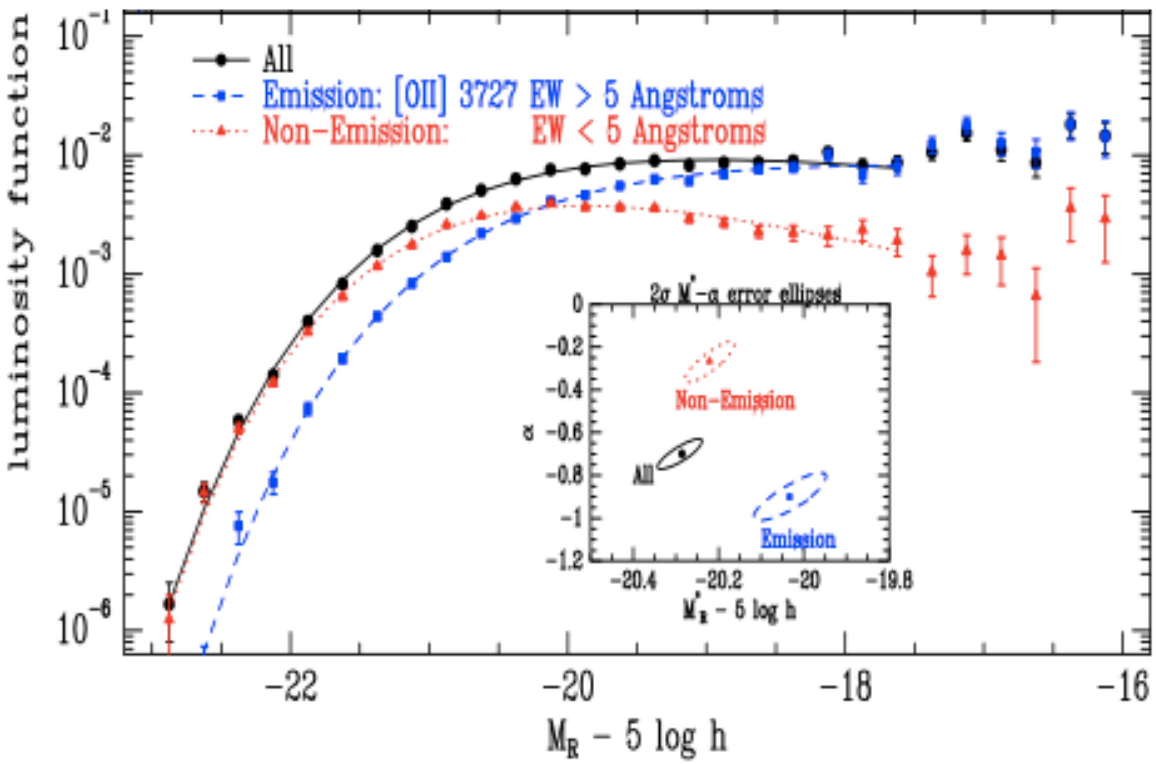


Great wall:
Geller & Huchra (1989)

https://www.cfa.harvard.edu/~dfabricant/huchra/zcat/

Some key discoveries by large surveys: z<1

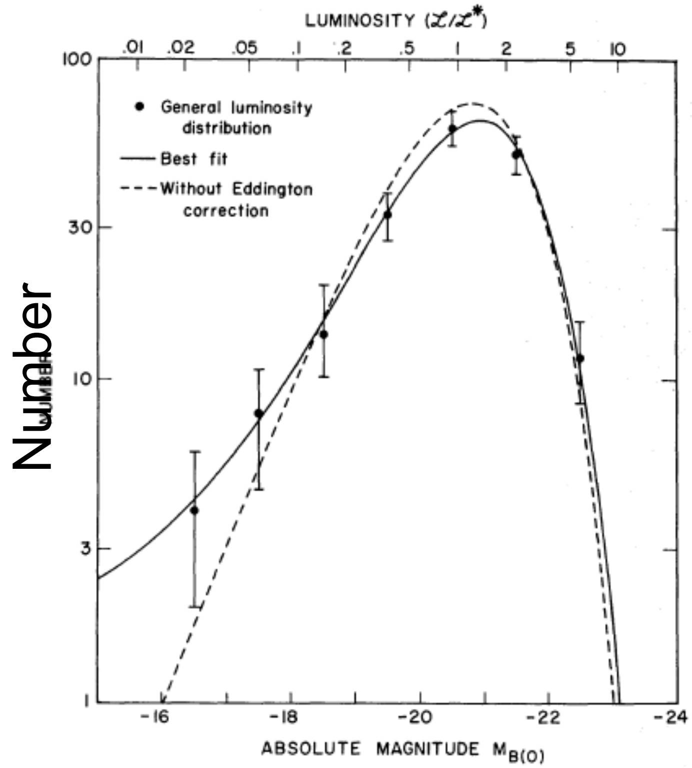
The Las Campanas Redshift Survey (Schectman et al. 1996), 26,000 redshifts at z~0.1 with 2.5-m DuPont.

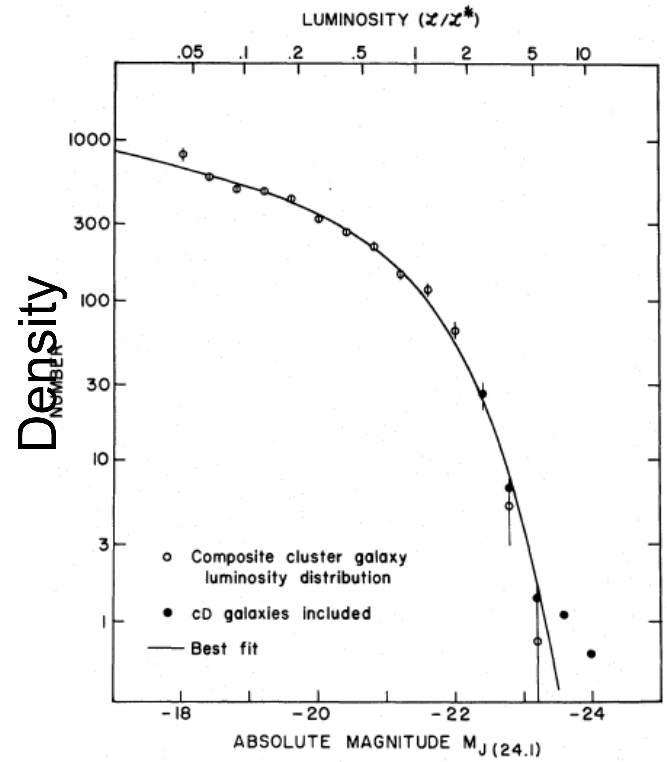


Emission line galaxies dominate faint end slope: Lin et al. (1996)

What is this “luminosity function”?

The luminosity function (LF) describes the space density of galaxies per unit luminosity as a function of luminosity.





Schechter 1976

$$\phi(L)dL = \phi^{\star}(L/L^{\star})^{\alpha} exp(-L/L^{\star}) d(L/L^{\star})$$

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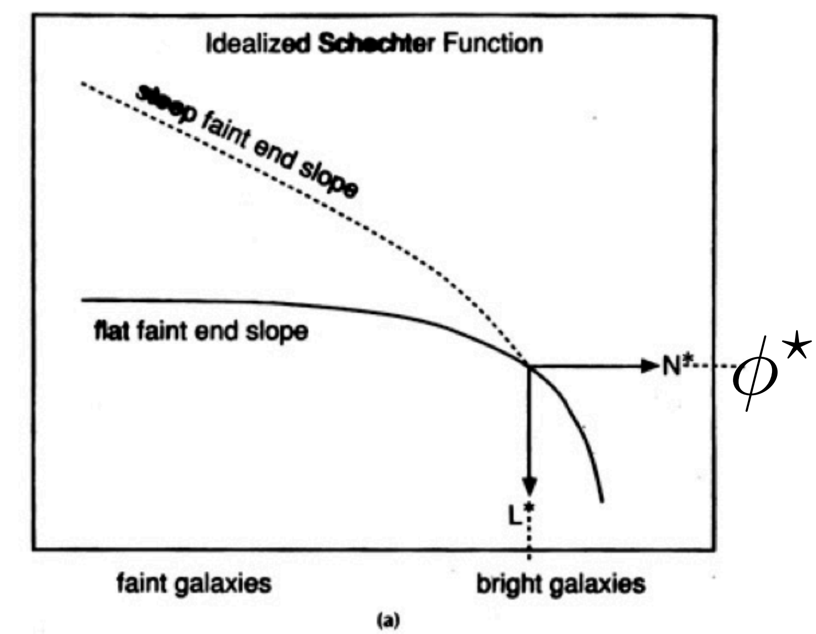
Schechter 1976 $$\phi(L)dL = \phi^{\star}(L/L^{\star})^{\alpha} exp(-L/L^{\star})d(L/L^{\star})$$

L^* = Luminosity that separates high and low luminosity parts (the “knee”)

At low L ($L<L^*$) galaxies follow a power law (brighter galaxies are rarer: $\phi \propto L^{\alpha}$

At high L ($L>L^*$) it is exponential and defines a fall-off (very bright galaxies are very rare: $\phi \propto e^{-L}$

Normalization at L^* set by $\phi^{\star}$



https://www.astro.virginia.edu/class/whittle/astr553/Topic04/Lecture_4.html

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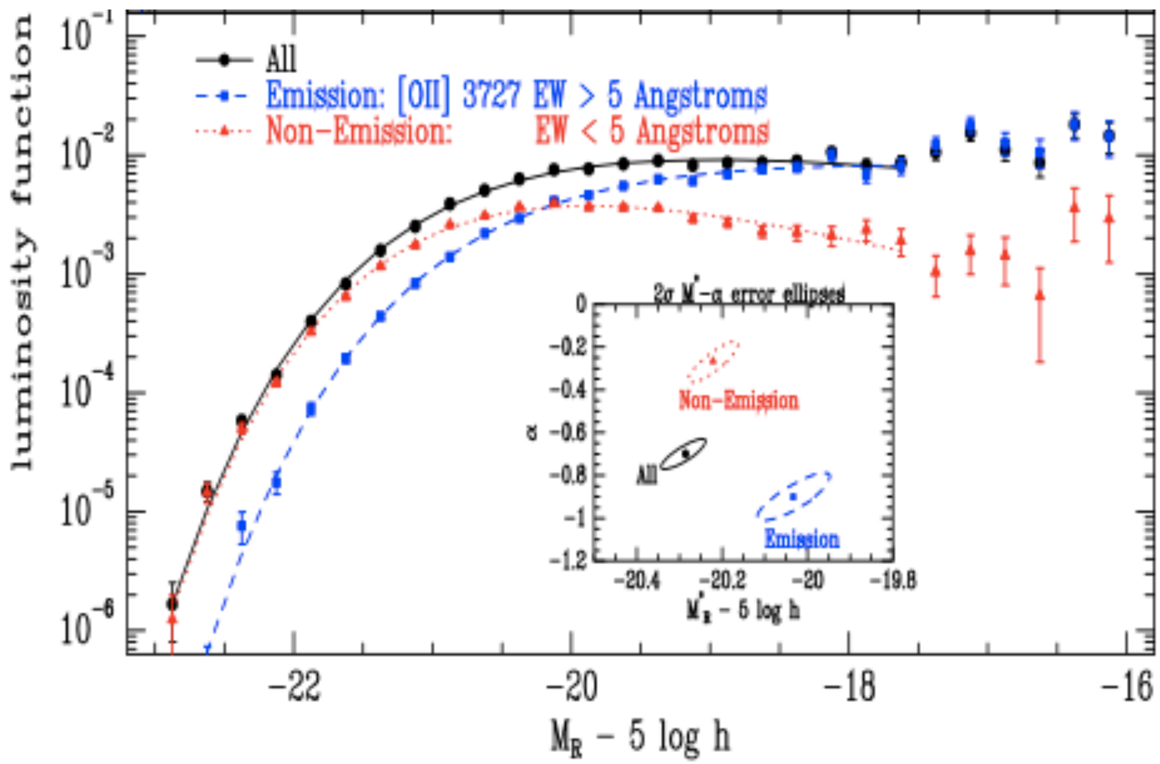
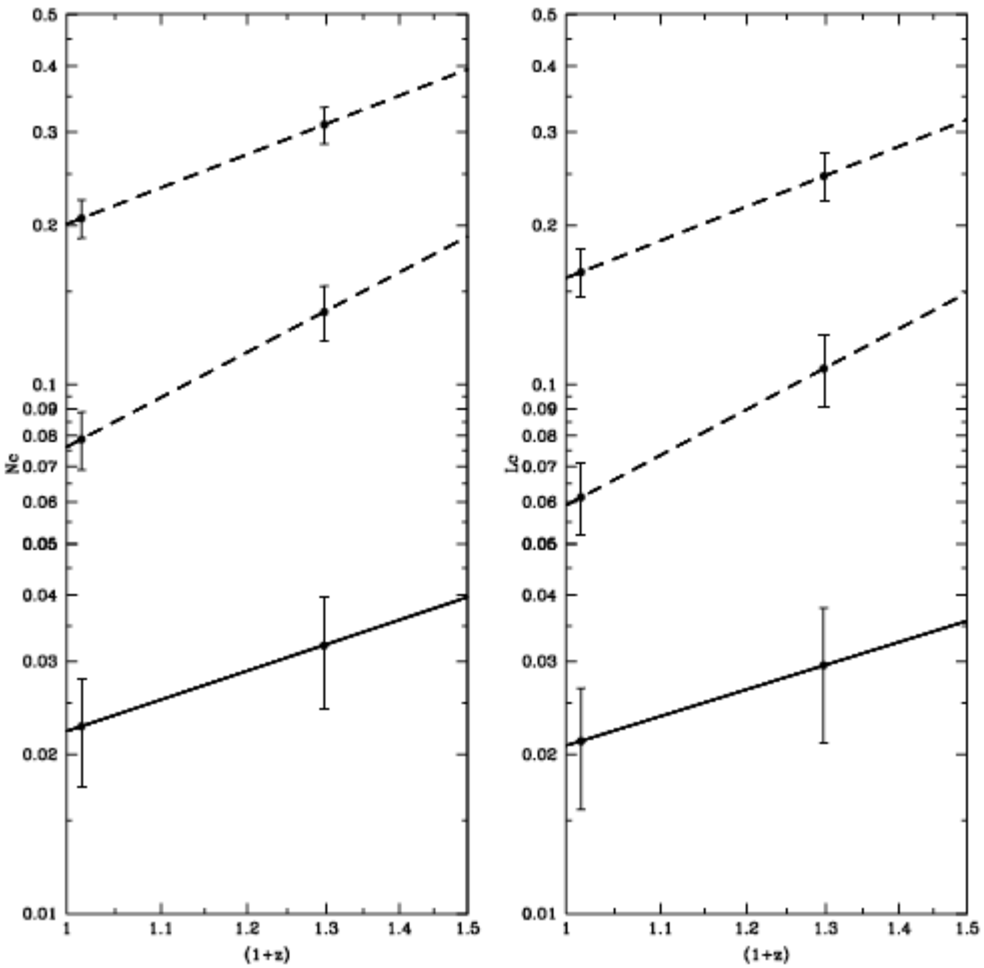


Emission line galaxies dominate faint end slope: Lin et al. (1996)

Some key discoveries by large surveys: z<1

The CNOC2 survey, (Yee et al. 2000) 6,000 redshifts with CFHT MOS z<0.7



Merger rate evolves like $(1+z)^{2.3}$ and ~15% of galaxies have had a major merger since z~1

Patton et al. (2002)

Some key discoveries by large surveys: z<1

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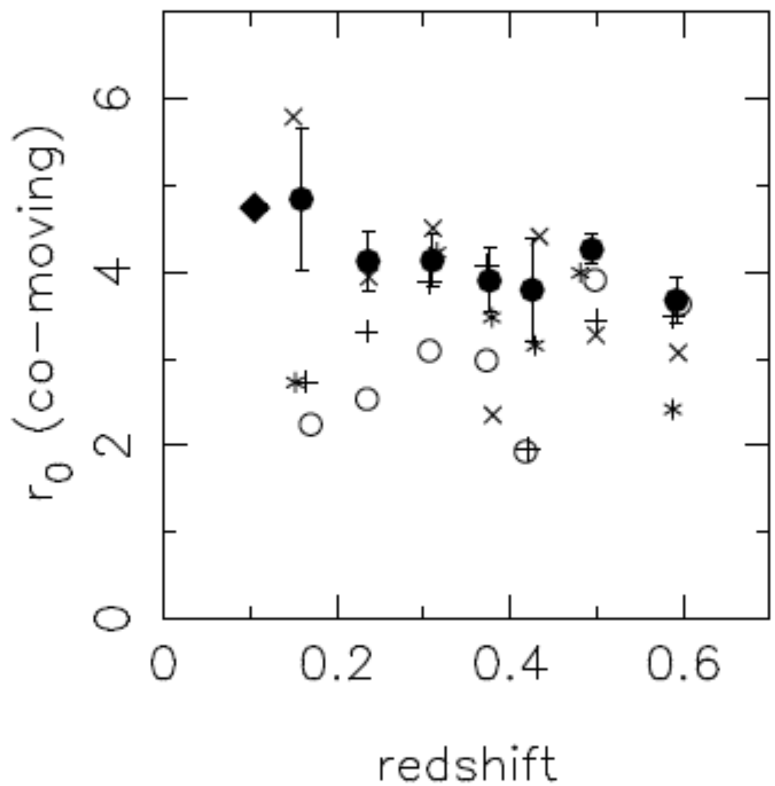


Clustering of galaxies does not significantly evolve with redshift (up to z~0.6)

Carlberg et al. (2000)

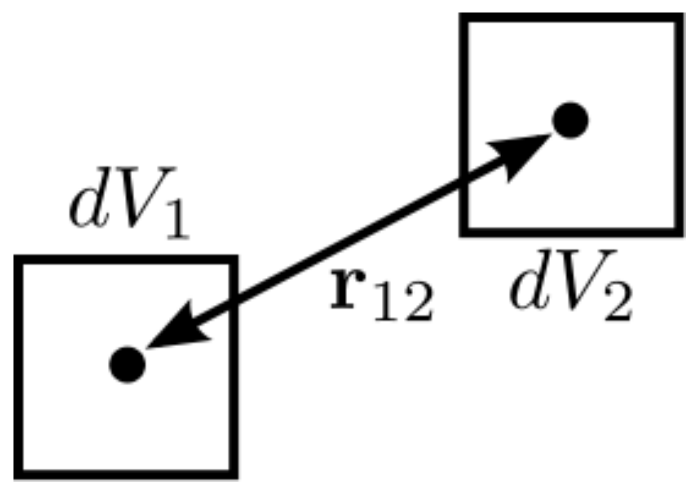
The two point correlation function, ξ(r)

The two-point correlation function describes the excess probability of clustering.

For two small volumes, ΔV_1 and ΔV_2 and an average galaxy density of *n* galaxies per Mpc^3,:

Probability of finding a galaxy in volume 1:
$\Delta P_1 = n\Delta V_1$

Probability of having a galaxy in volume 1
 and another in volume 2,
for randomly distributed galaxies:
$\Delta P_{12} = n^2 \Delta V_1 \Delta V_2$



The two point correlation function, $\xi(r)$

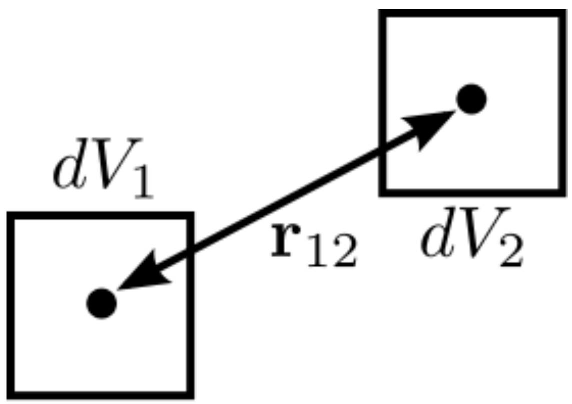
But galaxies are not randomly distributed!

Probability of also having a galaxy in volume 2, at distance r_{12} depends on how clustered the galaxies are. Joint probability of galaxy in V1 and V2:
$\Delta P = n^2 [1+\xi(r_{12})] \Delta V_1 \Delta V_2$

$\xi(r)$ is the correlation function and expresses the excess probability as a function of r. On scales <10 Mpc it takes the form $\xi(r) \sim (r/r_0)^{-\gamma}$.
If $\xi(r) > 0$, galaxies are clustered. If $\xi(r) < 0$ they avoid each other.

When $r < r_0$ (the correlation length) the probability of finding a galaxy within r of another is larger than random.

$\gamma \sim 1.8$ and $r_0 \sim 5$ Mpc (~6 Mpc for ellipticals which are more strongly cluster) .



Also commonly defined are:
P(k) – the power spectrum, Fourier transform of $\xi(r)$
W(θ) – angular correlation function

Some key discoveries by large surveys: z<1

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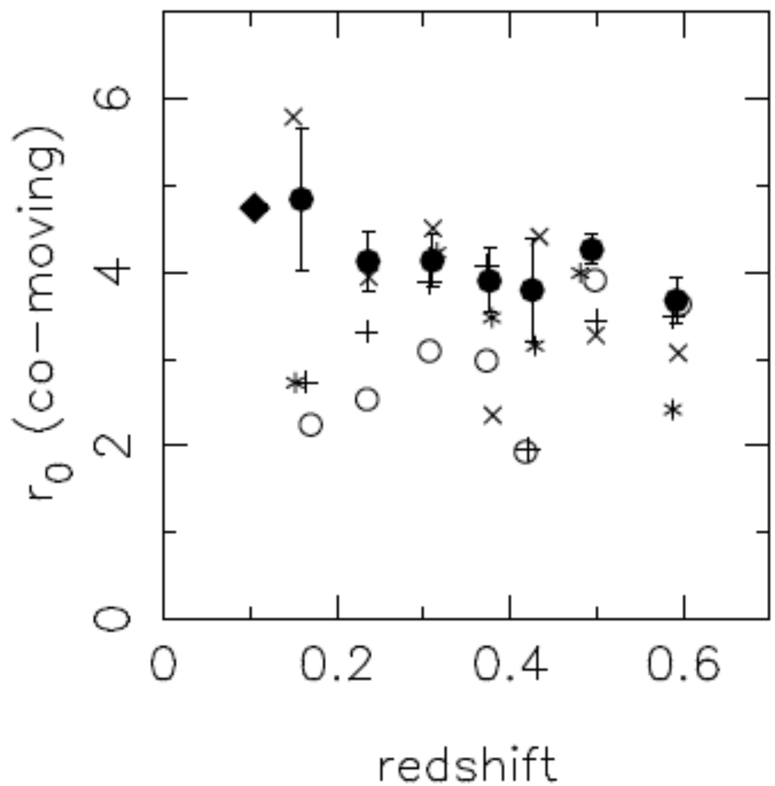


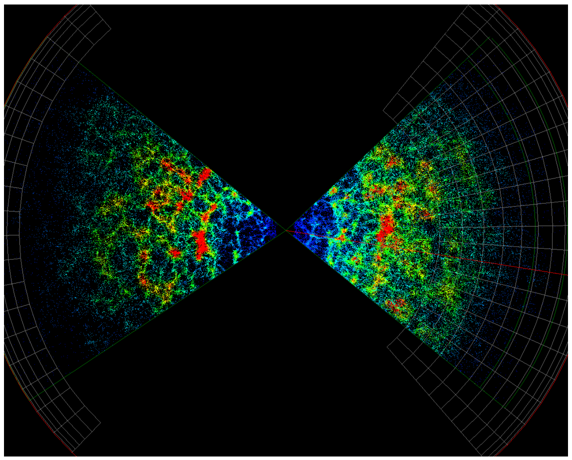
Clustering of galaxies does not significantly evolve with redshift (up to z~0.6)

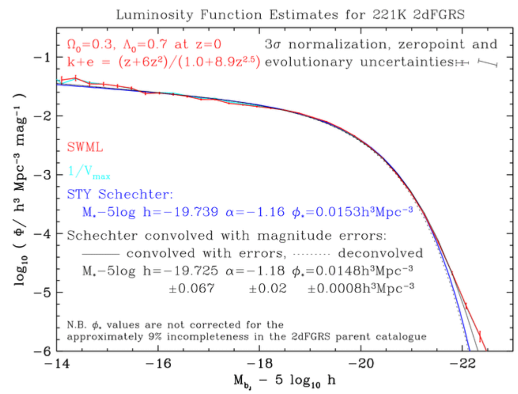
Carlberg et al. (2000)

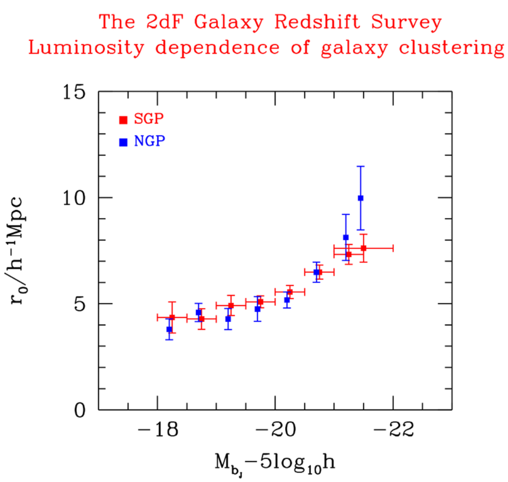
Up until 2000, surveys limited to a few tens of thousands of galaxies.

Some key discoveries by large surveys: z<1

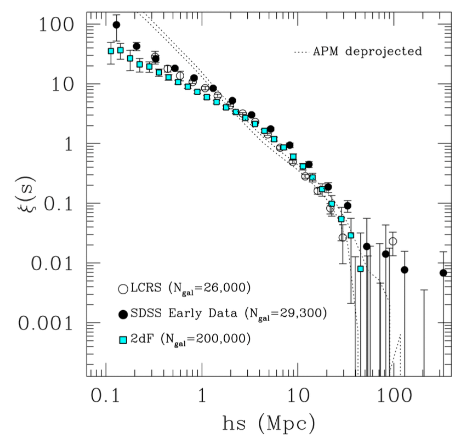
2dF galaxy survey (Colless et al. 2003) 220,000 z~0.1 galaxies with AAT.







Norberg et al. (the 2dFGRS team) 2001, astro-ph/0105500



Statistics nailed galaxy parameters!

Some key discoveries by large surveys: z<1

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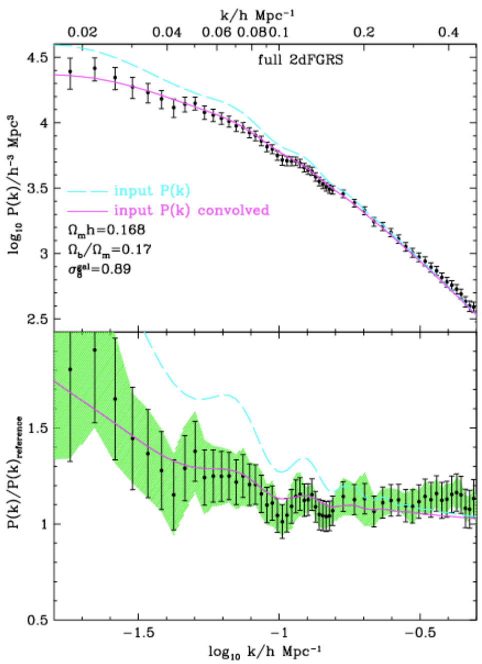
Cosmology with galaxy surveys! E.g. Percival et al (2001), Cole et al. (2005)



Measurements of the matter power spectrum can constrain cosmological parameters, such as Ω_M and Ω_{lambda}.

This field is known as Baryon Acoustic Oscillations (BAO)

http://www.astro.uvic.ca/~jwillis/teaching/astr405/astr405_lecture6.pdf
http://astro.berkeley.edu/~mwhite/bao/
http://en.wikipedia.org/wiki/Baryon_acoustic_oscillations

A very brief cosmology review!

The expansion of the universe as a function of z is expressed with the scale factor

$$a(t) = d(t)/d_0 = (1+z(t))^{-1}$$

The Hubble parameter is then defined as

$$H(t) \equiv \frac{\dot{a}}{a}$$

The density of various components can be expressed as a function of the critical density

$$\rho_c = \frac{3H^2}{8\pi G}$$

$$\Omega_x \equiv \frac{\rho_x}{\rho_c} = \frac{8\pi G \rho_x}{3H^2}$$

The Friedmann equation can be re-written in terms of densities

$$H^2(a) = \left(\frac{\dot{a}}{a}\right)^2 = H_0^2 \left[\Omega_m a^{-3} + \Omega_r a^{-4} + \Omega_k a^{-2} + \Omega_\Lambda a^{-3(1+w)}\right]$$

I.e. the rate of expansion is governed by cosmological parameters.

H(z) can be inferred from “standard rulers”.

By measuring the subtended angle $\Delta\theta$ and known length scale $\Delta\chi$ we map the angular diameter distance as a function of z:

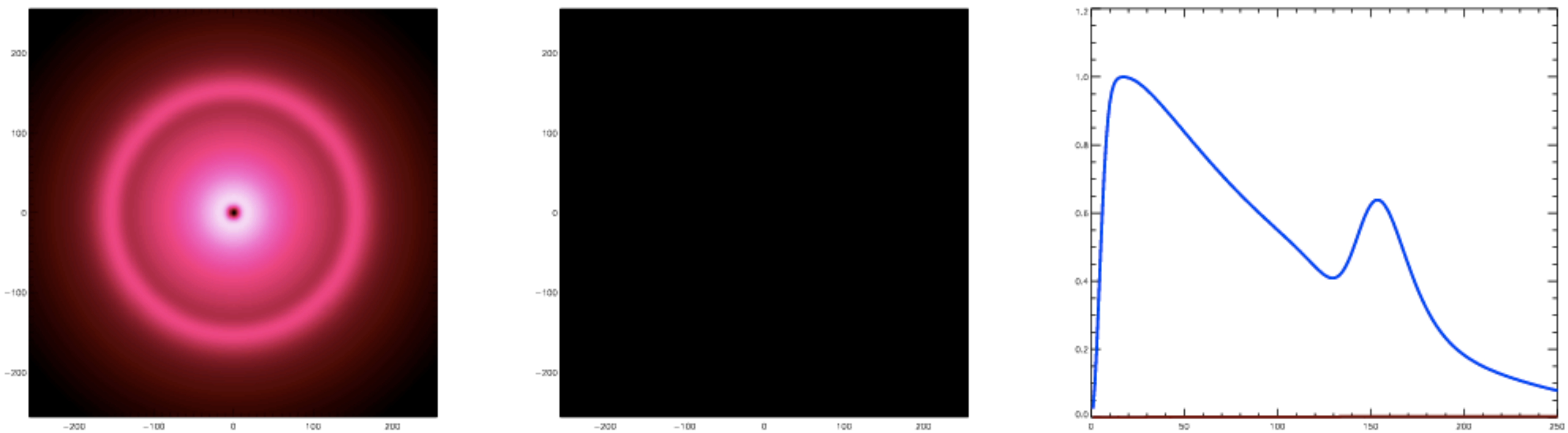
$$\Delta\theta = \frac{\Delta\chi}{d_A(z)}$$

$$d_A(z) \propto \int_0^z \frac{dz'}{H(z')}$$

The redshift interval is measured from the data and hence H(z) can be determined

$$c\Delta z = H(z)\Delta\chi$$

Consider an initial perturbation in the primordial plasma (free protons and electrons, plus photons). Perturbations travel together until recombination, after which the baryons stall (leaving a shell at the sound horizon) and photons free stream.

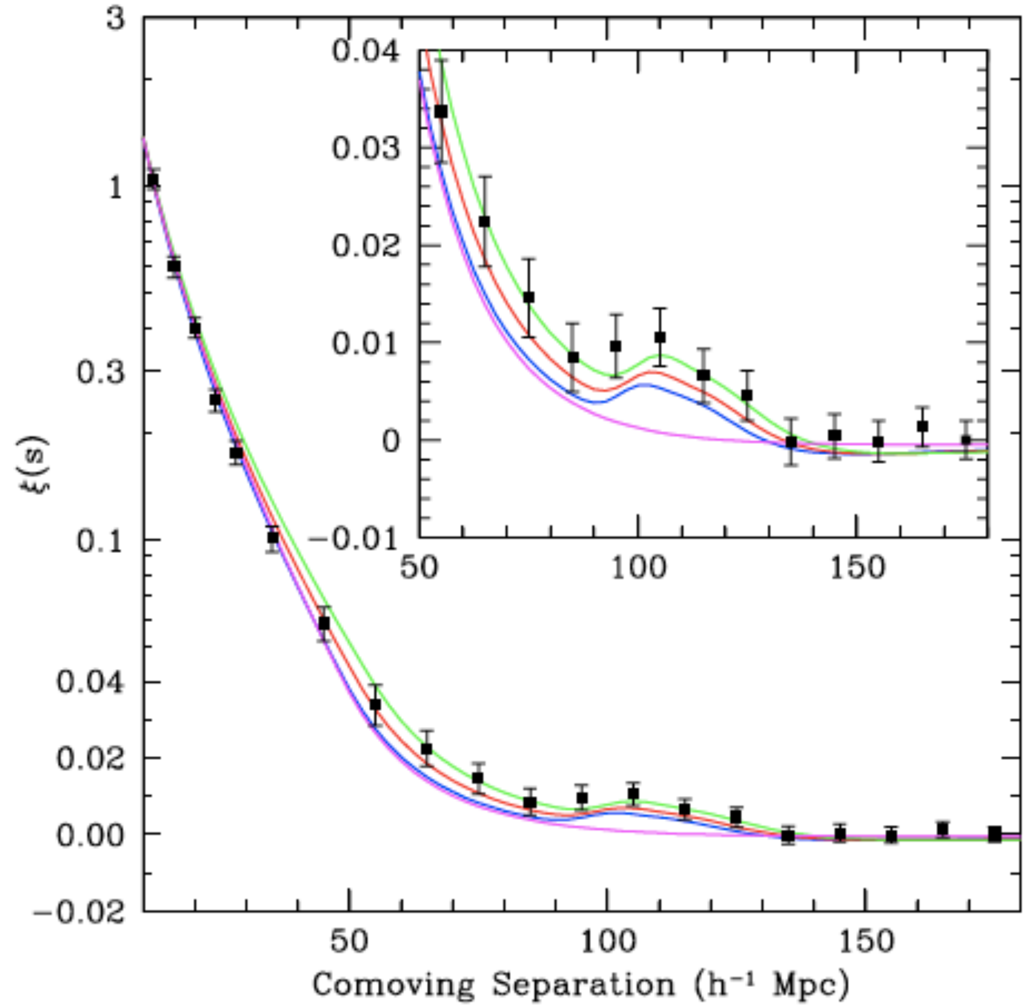


Baryons

Photons

Baryons fall back in under gravity. Galaxies form at overdensities at centres of these ripples and at sound horizon (~100 Mpc).

The sound horizon is a standard ruler

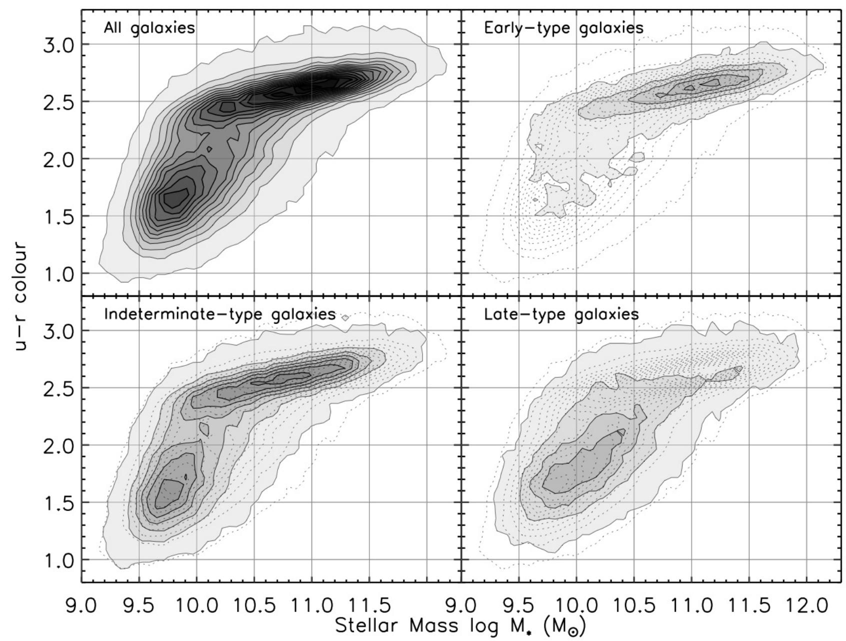


Correlation function of SDSS LRGs from Eisenstein et al. (2005)
Other important BAO surveys include wiggleZ and BOSS

Some key discoveries by large surveys: z<1

Sloan Digital Sky Survey (Strauss et al. 2002) 700,000 galaxies at z<0.2 (plus 100,000 LRGs out to z~0.5). Totally public, rather than team.

Beyond LFs and clustering: Detailed properties of galaxies



Galaxy bimodality e.g. Strateva et al. (2001)

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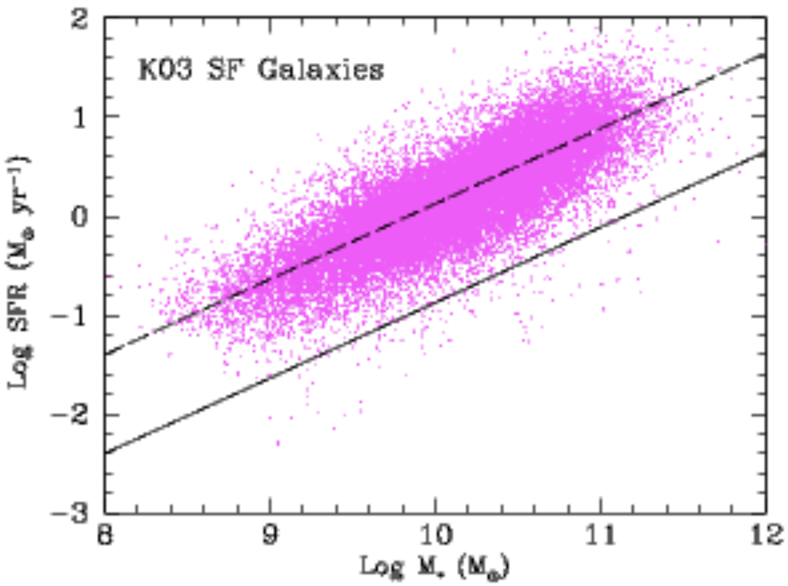

Star formation "main sequence" e.g. Brinchmann et al. (2004)

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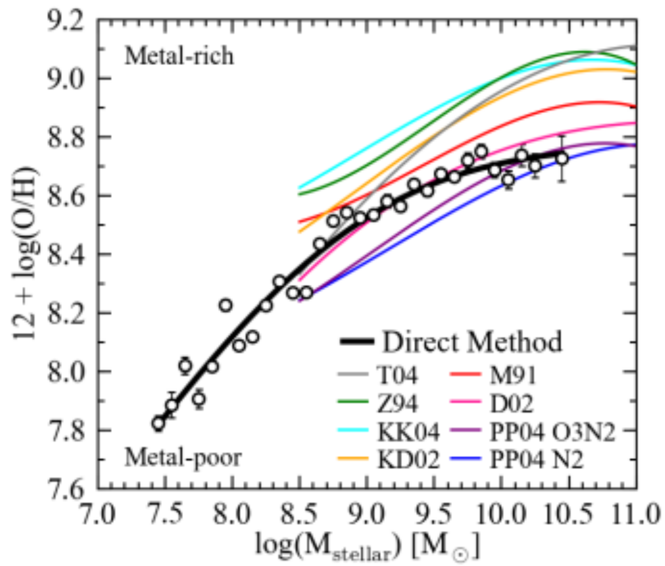
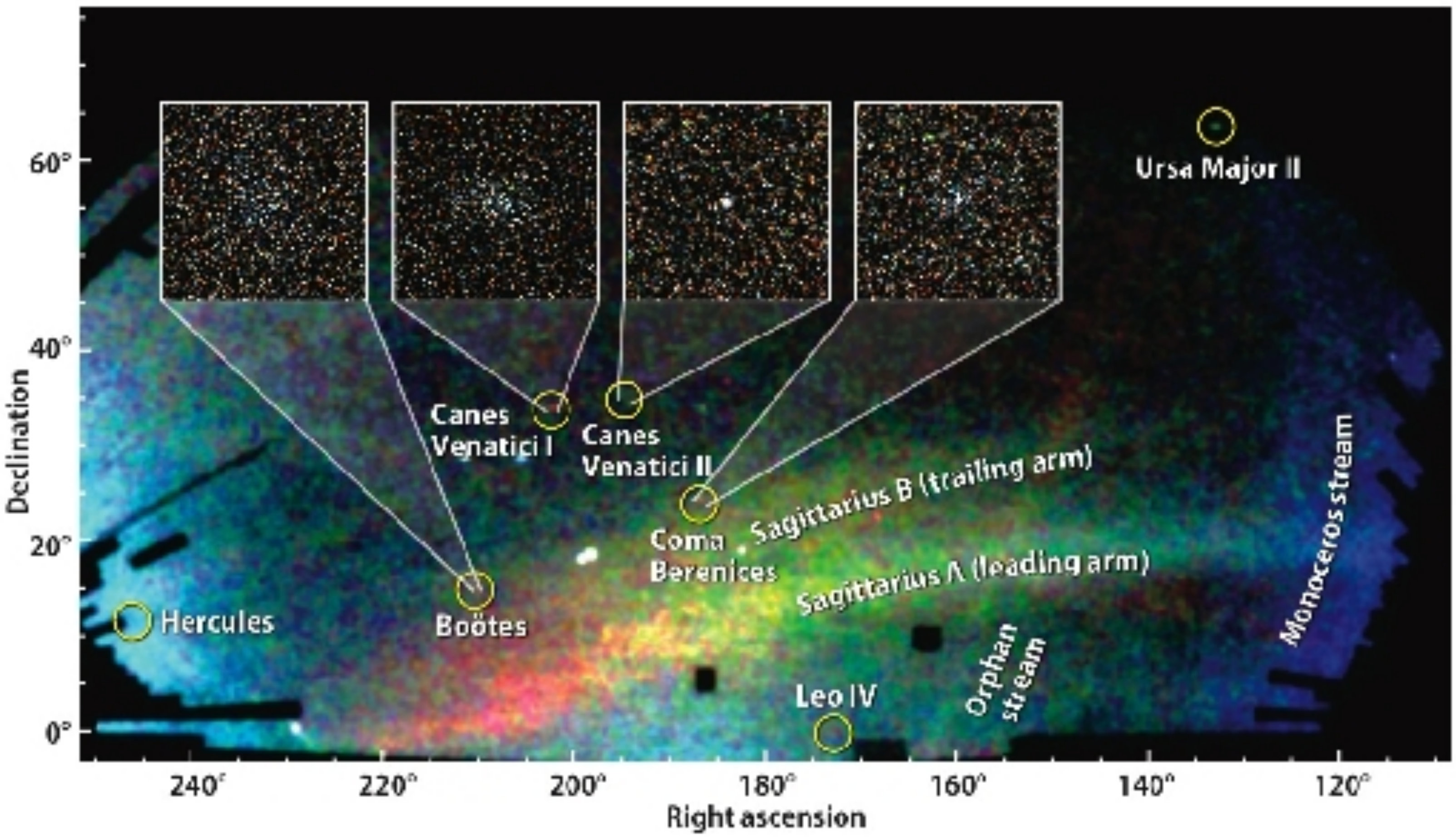


Mass metallicity relation, e.g. Tremonti et al. (2004)

Discoveries about our own Galaxy with SEGUE



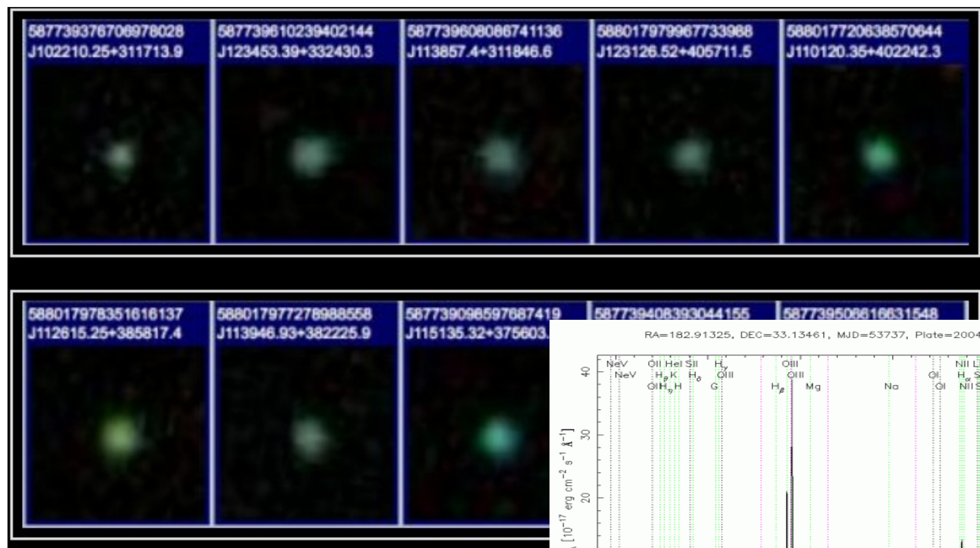
Many follow-up SDSS surveys: http://en.wikipedia.org/wiki/Sloan_Digital_Sky_Survey

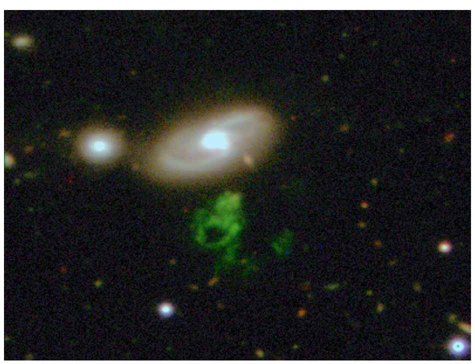
Citizen Science explosion!

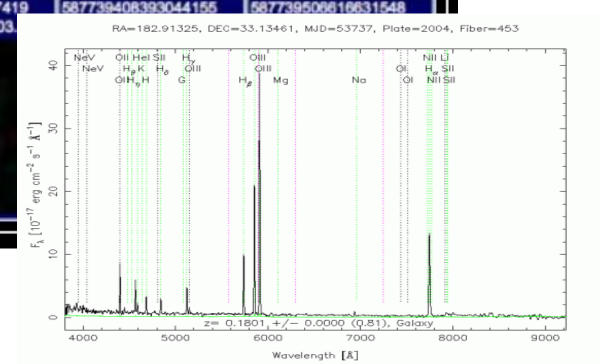
GZ1: 1 million galaxies, 100,000 volunteers, 40 million classifications!

Visual classifications help find the unusual.

Galaxy mergers, Hanny's voorwerp and green peas!

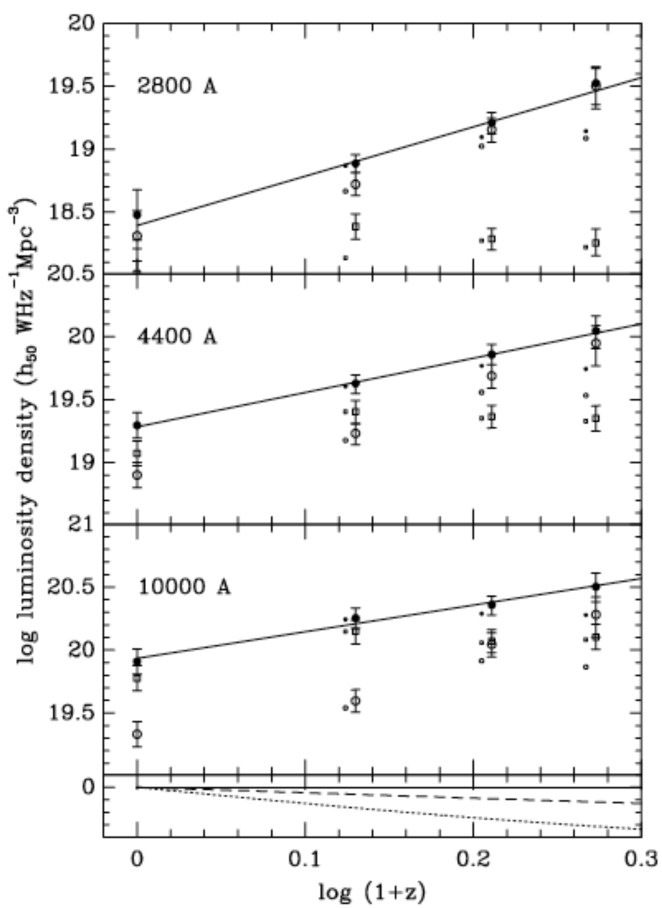




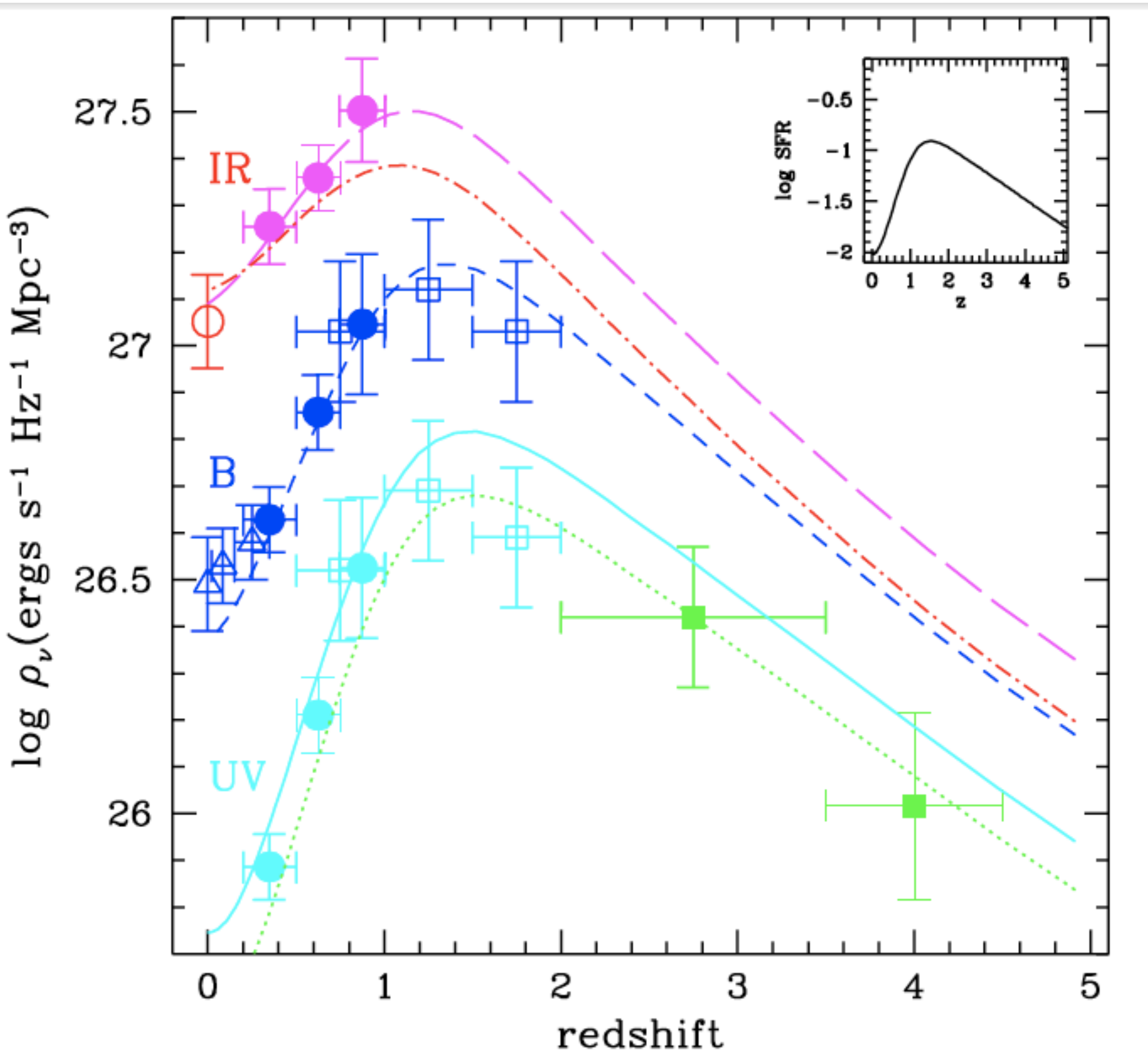


Some key discoveries by large surveys: high z

The Canada-France Redshift Survey (Lilly et al. 1995), 700 redshifts at z<1.2 with CFHT



Lilly et al (1996) - evolution in galaxy luminosity density. Pre-cursor to the “Madau plot” of SFR evolution.

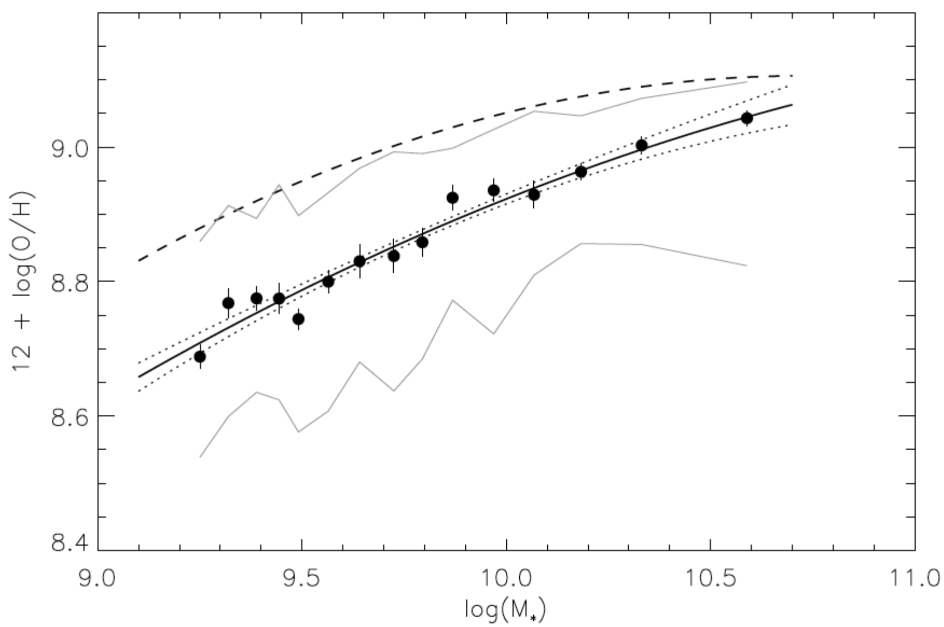


Madau et al. (1998)

Some key discoveries by large surveys: high z

DEEP2 (Davis et al. 2003) 60,000 galaxies with Keck z~1.2

More than just a redshift survey: Designed to be able to compare properties of z~1 galaxies with SDSS. Large sample of spectroscopically derived quantities e.g. O/H and SFR.



Mass-metallicity relation, Zahid et al. (2010)

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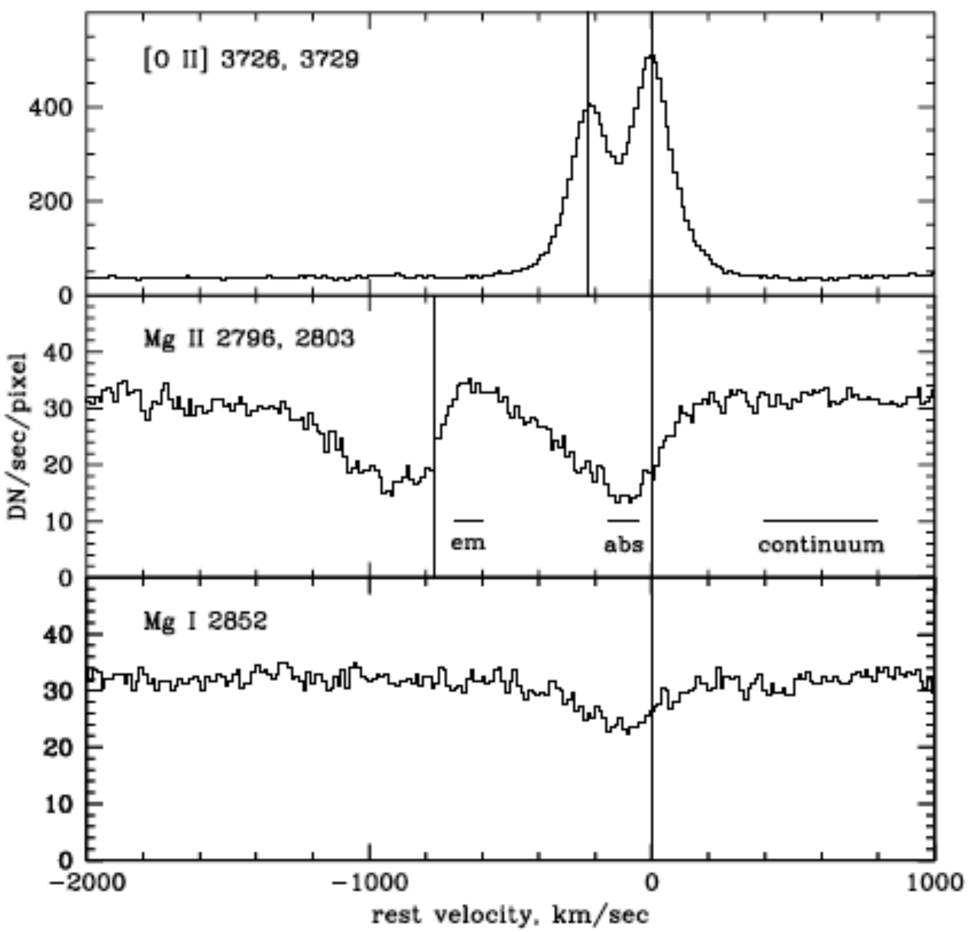
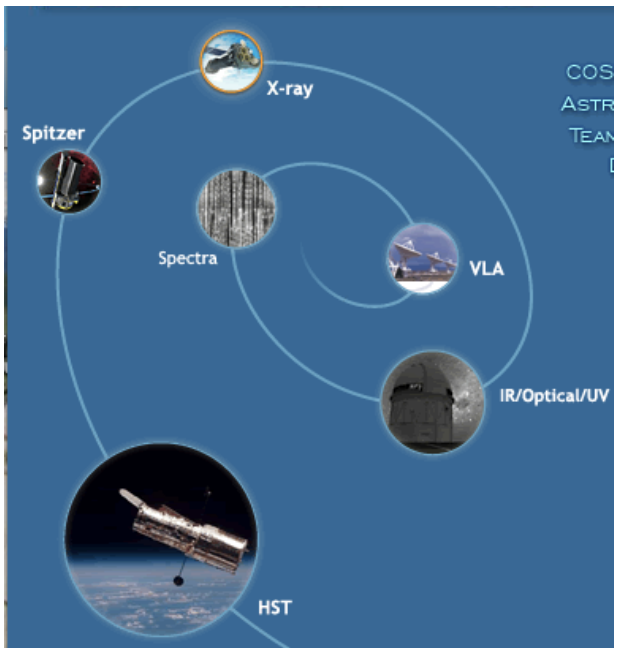


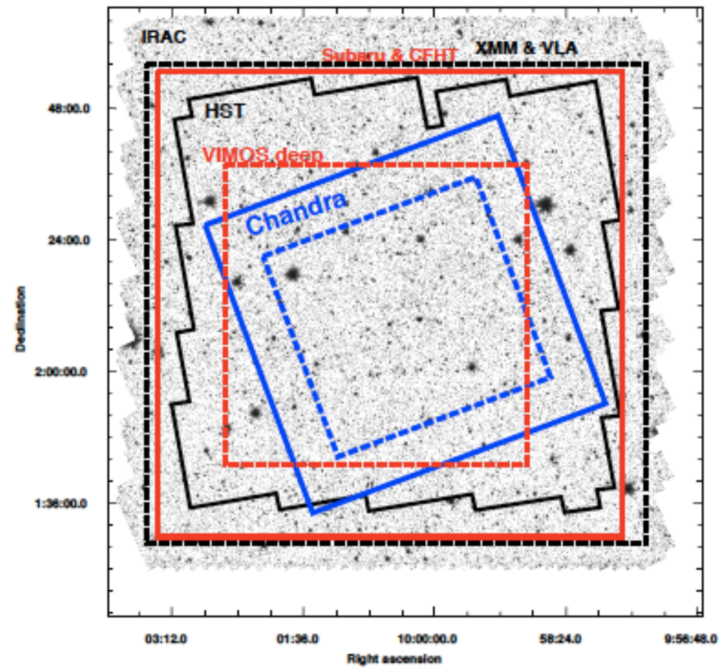
Stacked spectra showed first evidence of outflows in z~1 galaxies. Independent AGN or morphology.

Weiner et al. 2009

Some key discoveries by large surveys: high z

zCOSMOS (Lilly et al. 2007) with VLT. 20,000 at z~1, and 10,000 galaxies at z~2.

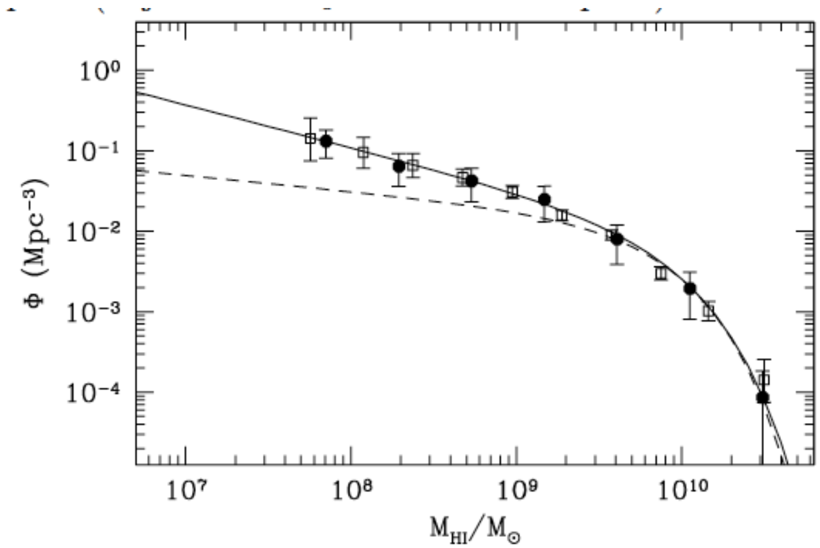




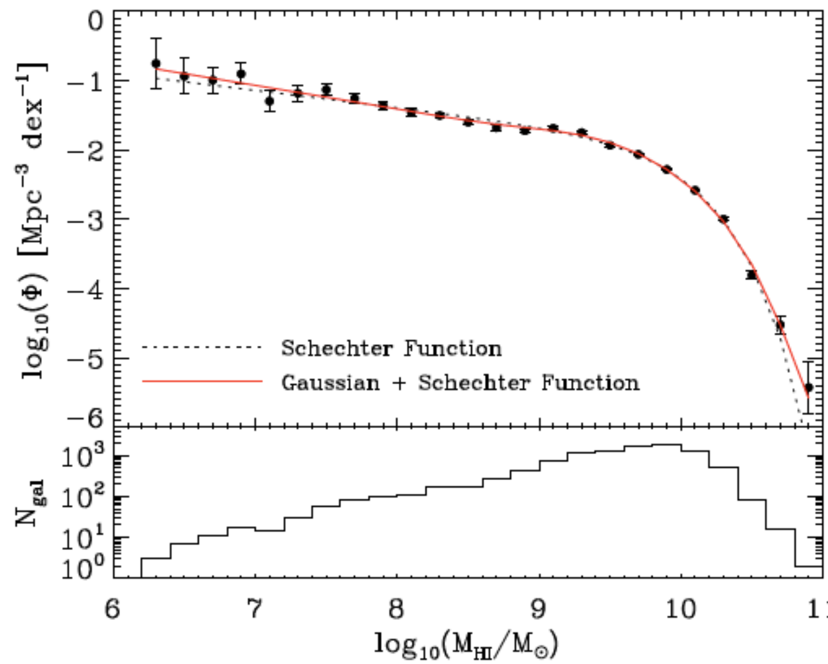
COSMOS: 2 degree field with ACS over 640 orbits. The first deep, high z, multiwavelength galaxy survey.

Multiwavelength surveys

ALFALFA: HI 21cm survey with Arecibo (Giovanell et al. 2005), ~30,000 gals at z<0.06.



Rosenberg & Schneider (2002) with ADBS (HIPASS Zwaan et al. (1997) in dashed. α_{ADBS} = -1.53, α_{HIPASS} = -1.2.



Martin et al. 2010 α= -1.33

Multiwavelength surveys

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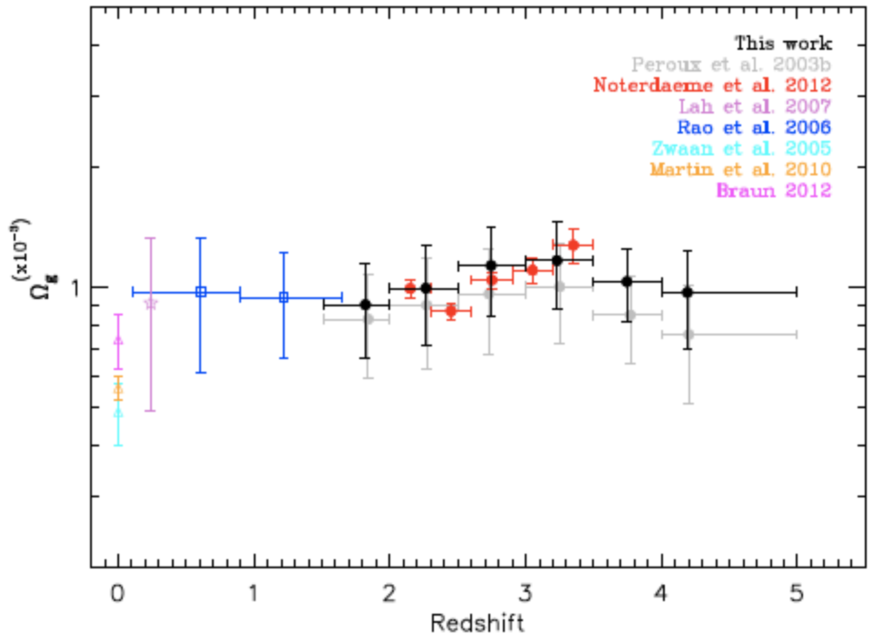
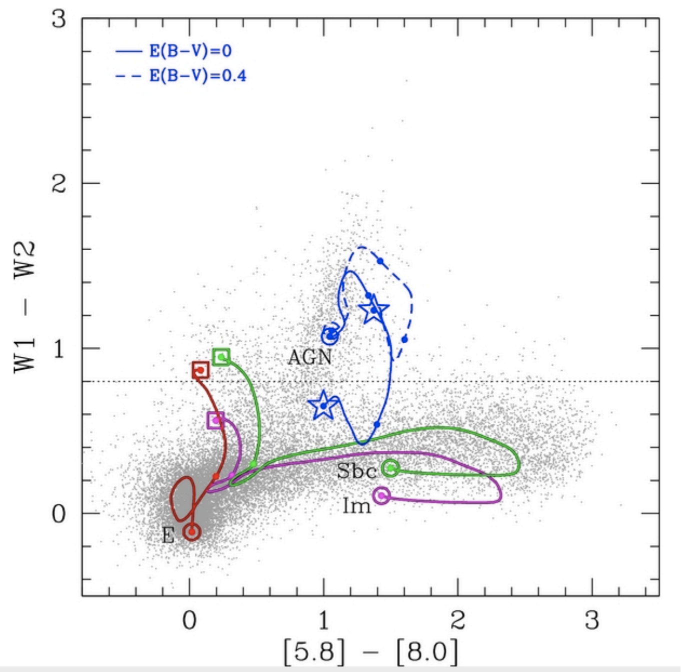


Important zero point for for cosmological measurements of Ω_{gas}

Multiwavelength surveys

Wide-field IR Survey explorer (WISE). Mid-IR NASA small mission, all sky survey, 0.4-m mirror. Decommissioned in 2011.



Complementary selection for AGN. Can make a simple WISE colour cut, e.g. W1-W2>0.8.

Assef et al. (2010, 2013).

Also studied rocky solar system objects and cool stars
http://wise.ssl.berkeley.edu/mission.html

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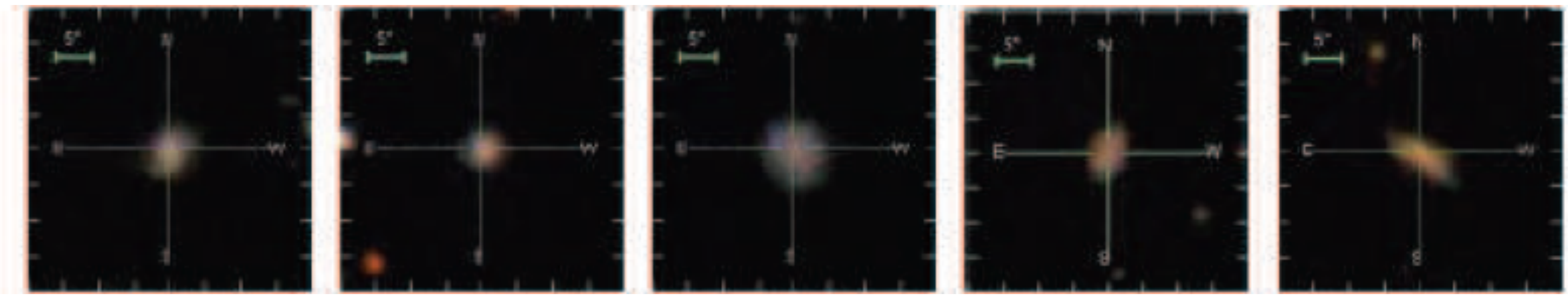
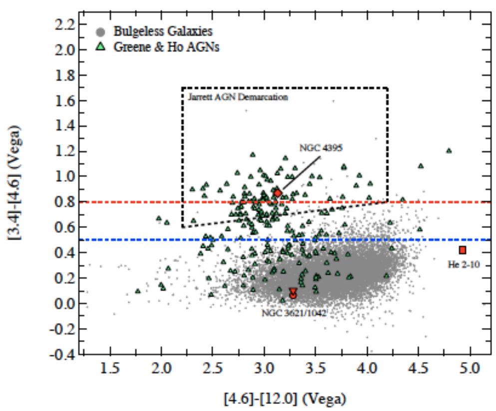


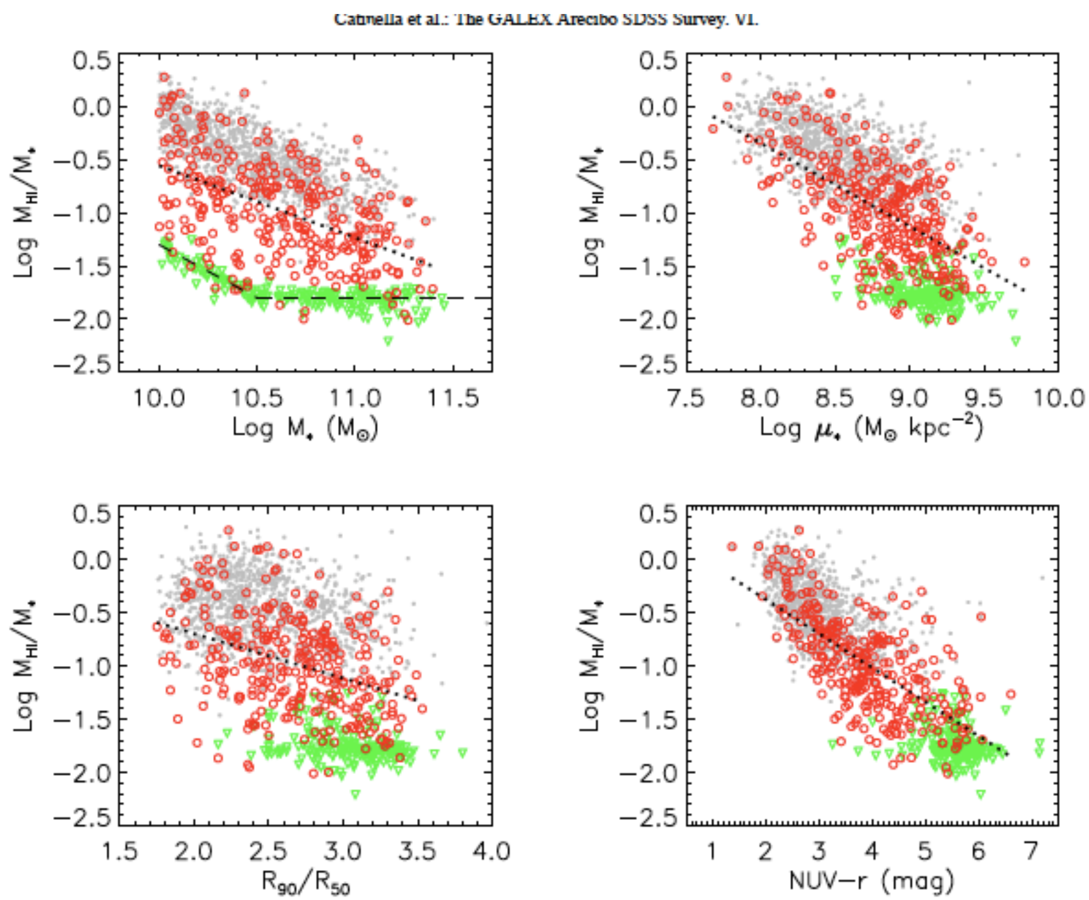


Discovery of population mid-IR selected "bulgeless" AGN.

Satyapal et al. (2014).

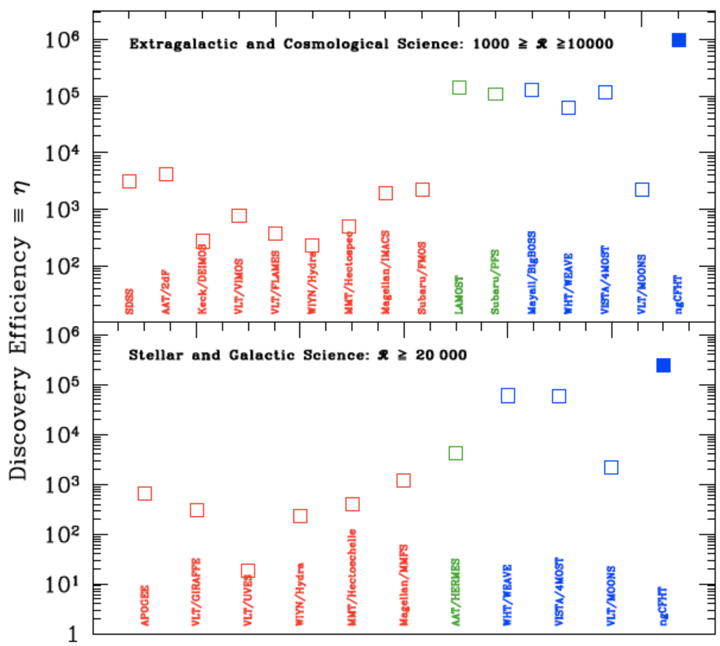
Multiwavelength surveys

Galaxy evolution explorer (GALEX), NASA “small” explorer, all sky UV survey, 0.5-m telescope. Now decommissioned (2012). GALEX Arecibo SDSS Survey (GASS), e.g. Catinella et al 2012.



The future of large surveys

Mauna Kea Spectroscopic Explorer (MSE): 10-m telescope using old CFHT support building and pier. 1.5 deg^2 field, 3200 galaxies per shot at medium-high resolution. Project office just opened (but not fully funded yet).



$$\eta \equiv D_{\rm M1}^2 \Omega N_{\rm mos} f / IQ^2.$$

Discovery efficiency η is function of mirror size (D), number of objects per field (N_{MOS}), fractional time available for survey (f) and image quality (IQ).

http://www.cfht.hawaii.edu/en/news/MSE/

The future of large surveys

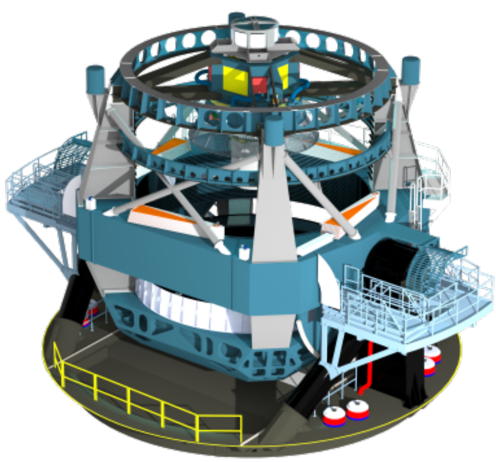
Large Synoptic Survey Telescope (LSST): dedicated 8.4-m telescope to be built on Cerro Pachon (Chile, near Gemini). 10 deg^2 field of view!! Total survey: 30,000 deg^2 in 5 filters (no spectra).

"10,000 square degrees of sky to be covered using pairs of 15-second exposures twice per night every three nights on average, with typical 5σ depth for point sources of r ~ 24.5 (AB)." Ivezic et al. (2014) LSST overview paper http://www.lsst.org/files/docs/LSSToverview.pdf

LSST 2014 CONSTRUCTION START

Main science drivers for LSST, whose strategy is deep, wide, fast:

- Probing dark energy and dark matter: weak lensing studies and SN
- An inventory of the solar system: In December 2005, the U.S. Congress directed76 NASA to implement a NEO survey that would catalog 90% of NEOs with diameters larger than 140 meters by 2020.
- Exploring the transient sky: (micro-)lensing events, supernovae, exoplanets, AGN monitoring, variable stars, GRBs.
- Mapping the Milky Way: streams, stellar populations, RR lyrae



Our database and getting an account

Unix machine “llaima” hosts “sdss” database accessed by mysql.

Llaima access for netlink ID “student” via netlink passwd:
ssh student@llaima1p.mysql.uvic.ca

Accessing database with mysql passwd:
mysql –u student -p --socket=/m1/LLAIMA1P/mysql.sock

Test commands in mysql:
use sdss;
show tables;
describe dr7_uberuber;
select count(*) from dr7_uberuber;
select count(*) from dr7_uberuber where z_spec >0.2;
select total_mass_med from dr7_uberuber limit 10;