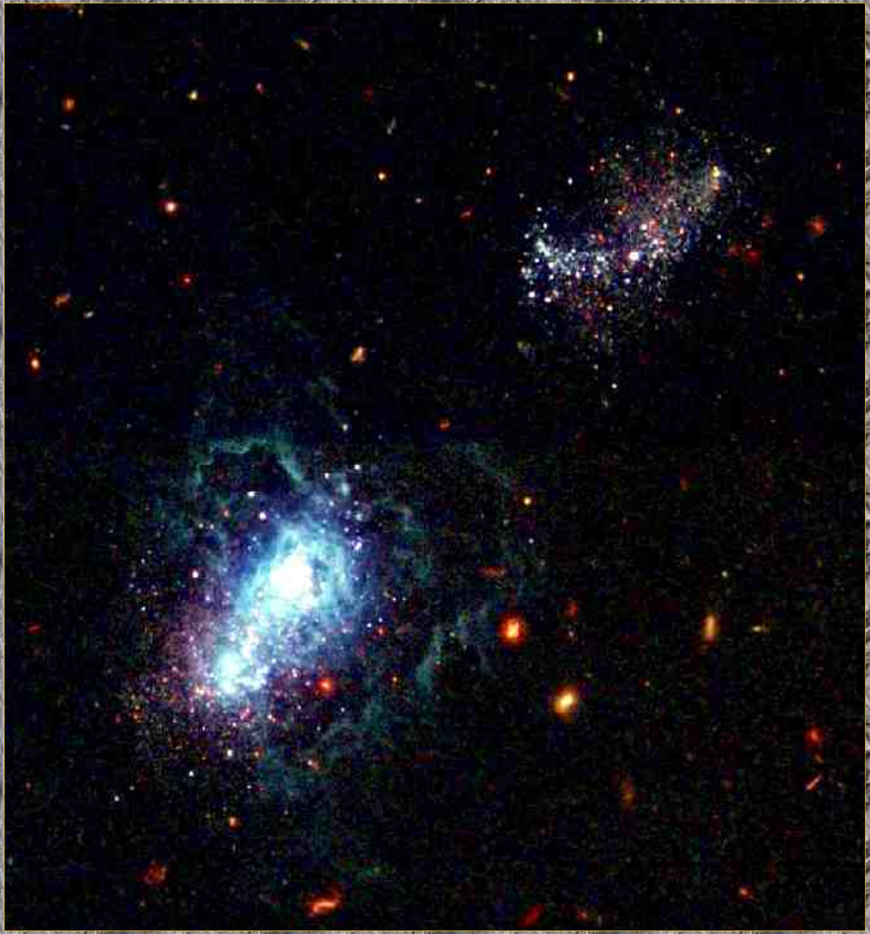

Blue Compact Dwarf Galaxies

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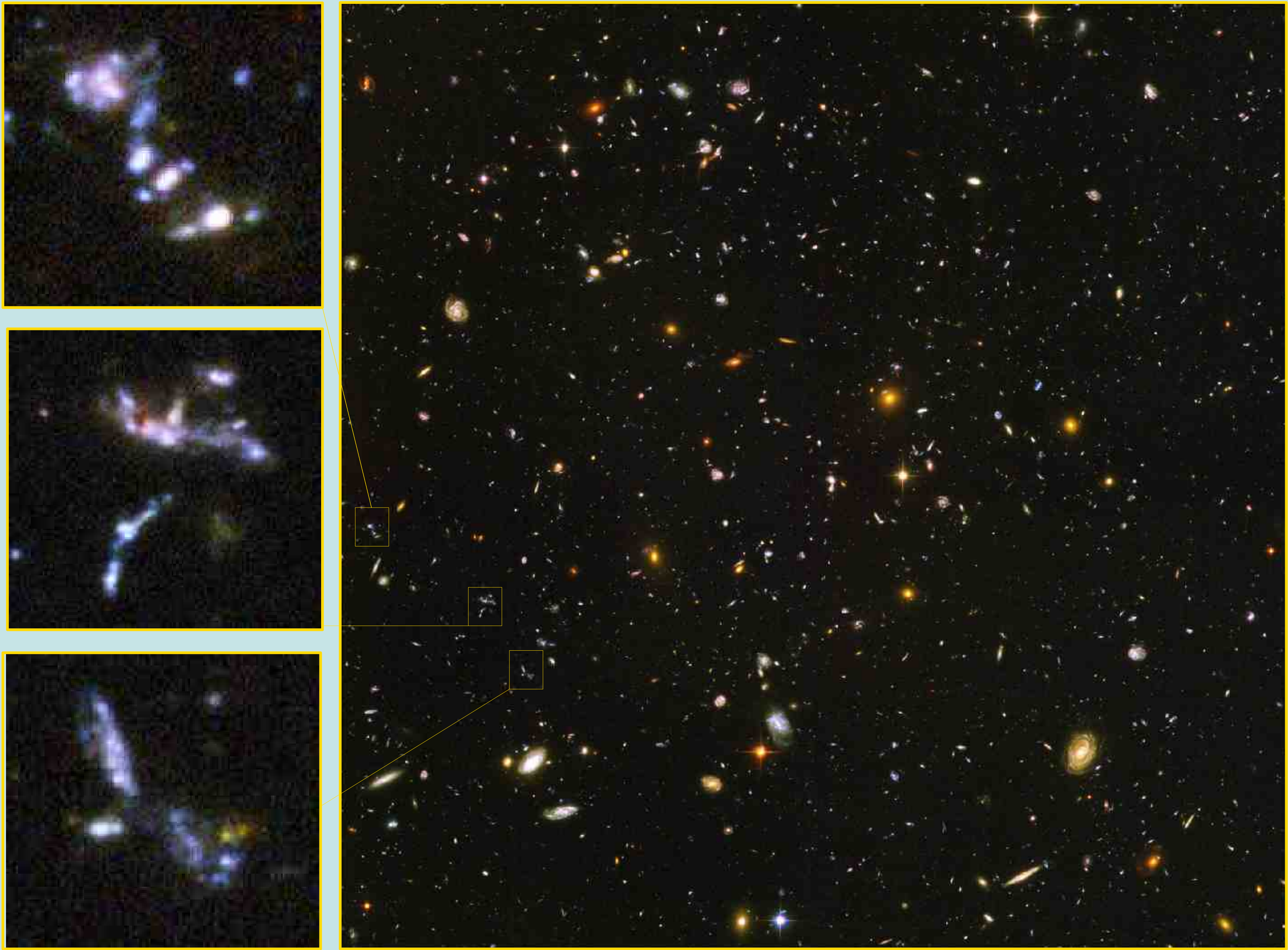
UCM – 5. May 2010

Centro de Astrofísica da Universidade do Porto

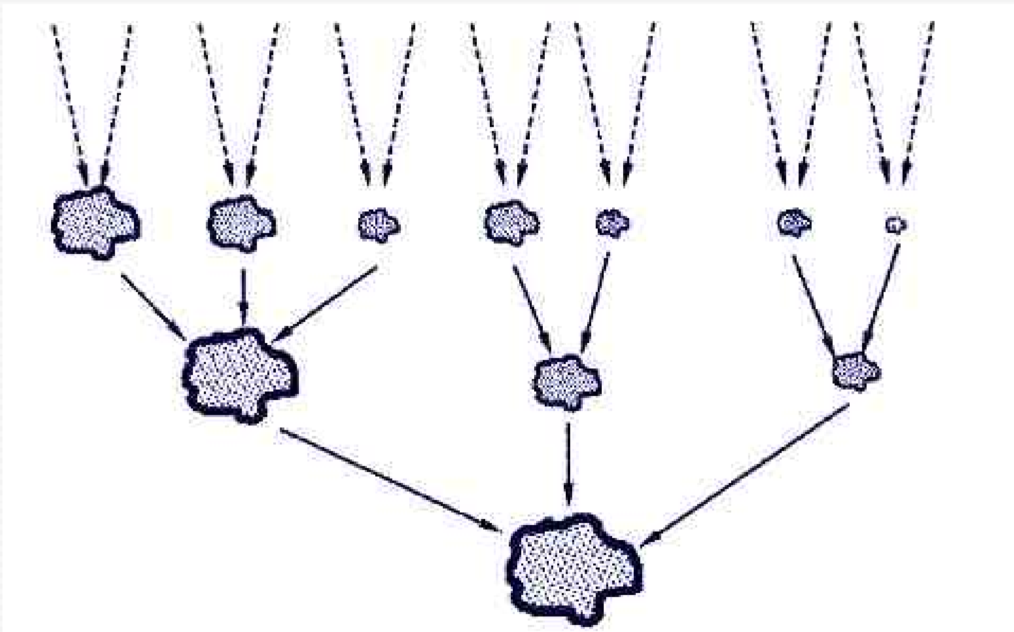
Extragalactic systems in the distant universe

Blue, irregular sub-galactic units in the process of merging



Hierarchical growth of cosmic structures

Formation of massive systems through successive merging of smaller "building blocks"

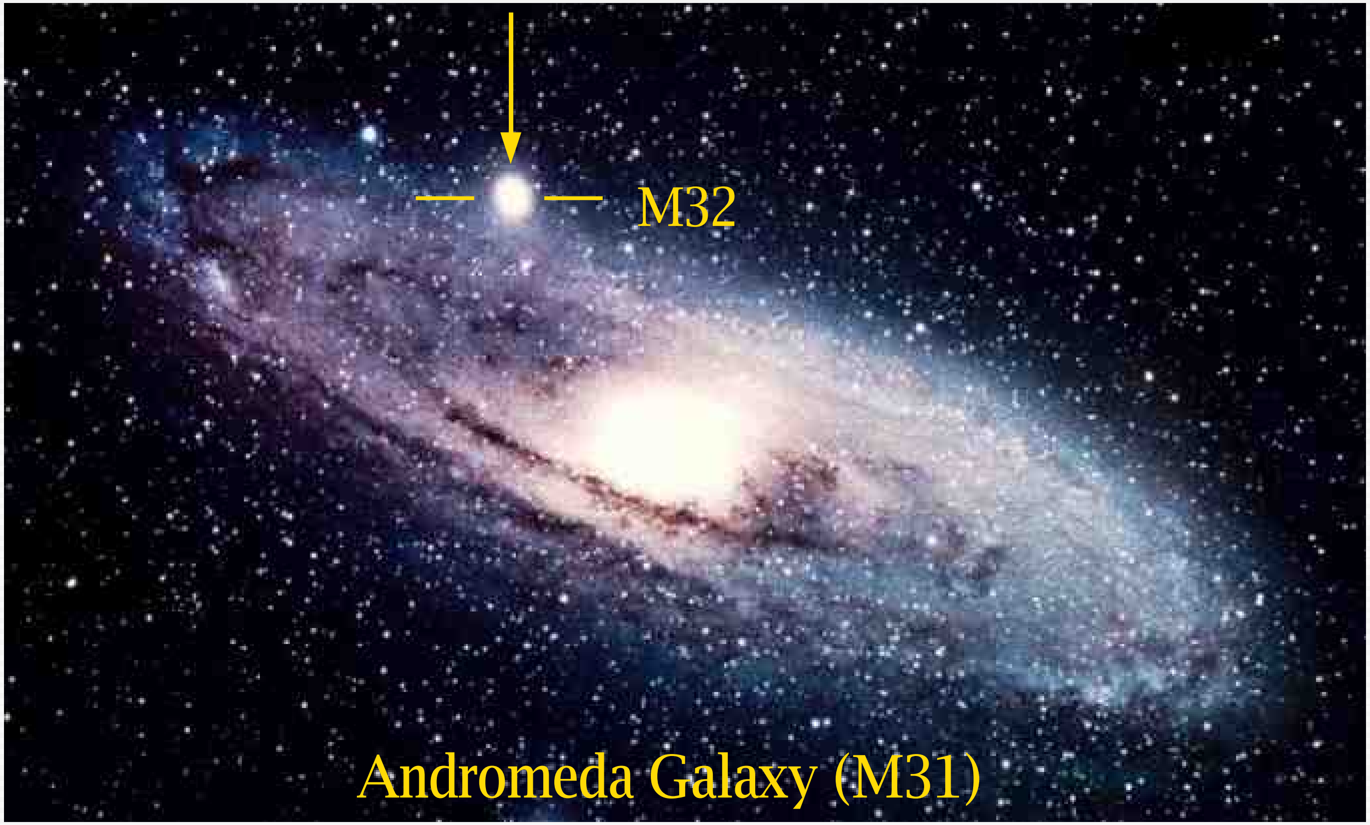


Kauffmann et al. (1993)

time	Age of the Universe (Gyr)	Redshift z
	2.1	3
	3.2	2
	5.7	1
↓	13.6	0

Compact low-mass starburst galaxies in the distant Universe

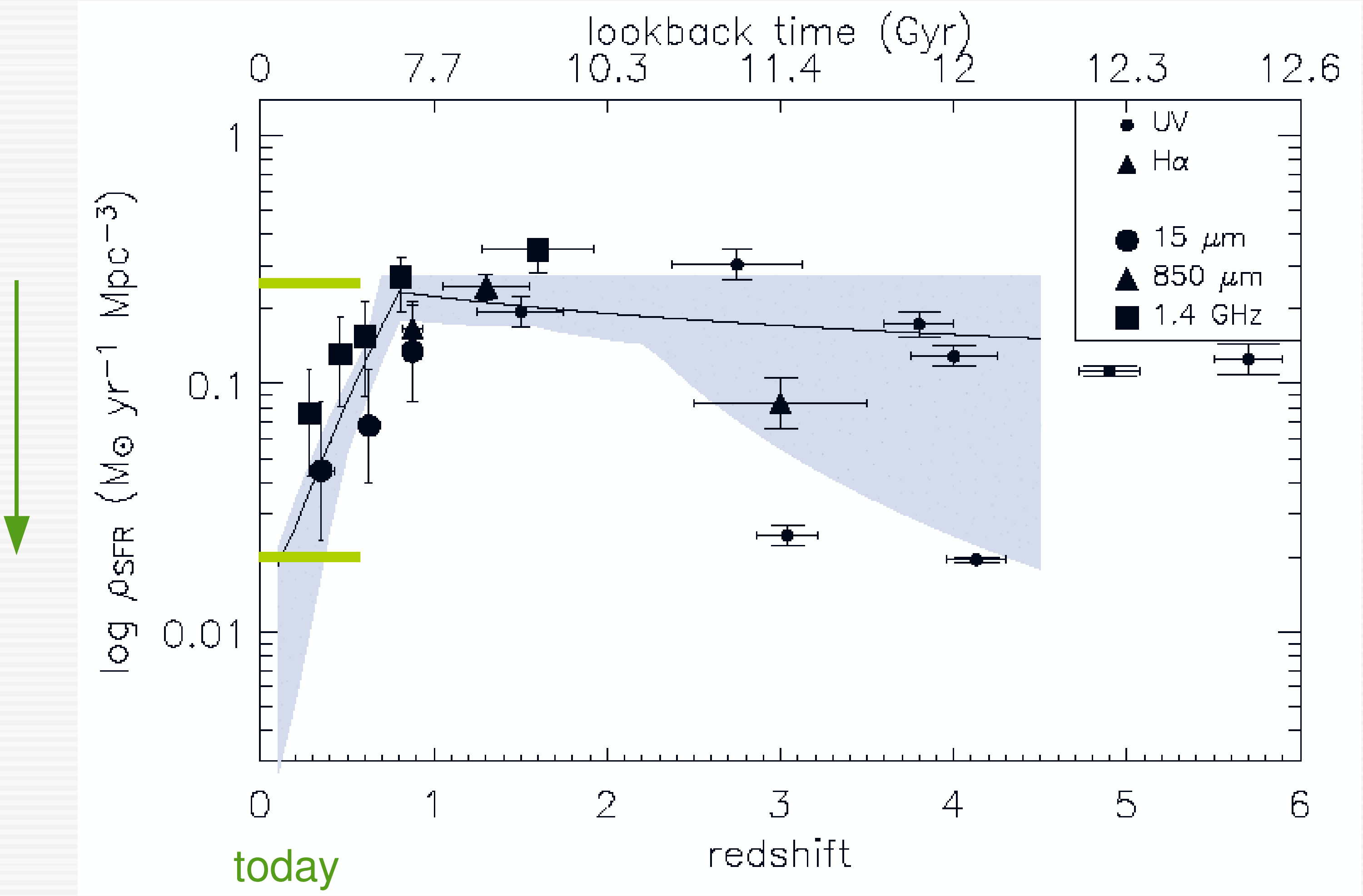
- compact narrow emission line galaxies – **CNELGs**
- luminous blue compact galaxies – **LBCGs**



- diameter: 2 … 5 kpc (Milky Way $\simeq$ 30 kpc)
- mass: 1/10 … 1/100 of the mass of the Milky Way
- irregular morphology
- blue colours → intense galaxy-wide star forming activity

1 kpc = 3.1×10^{19} m

Evolution of the cosmic star formation density



Elbaz et al. (2004)

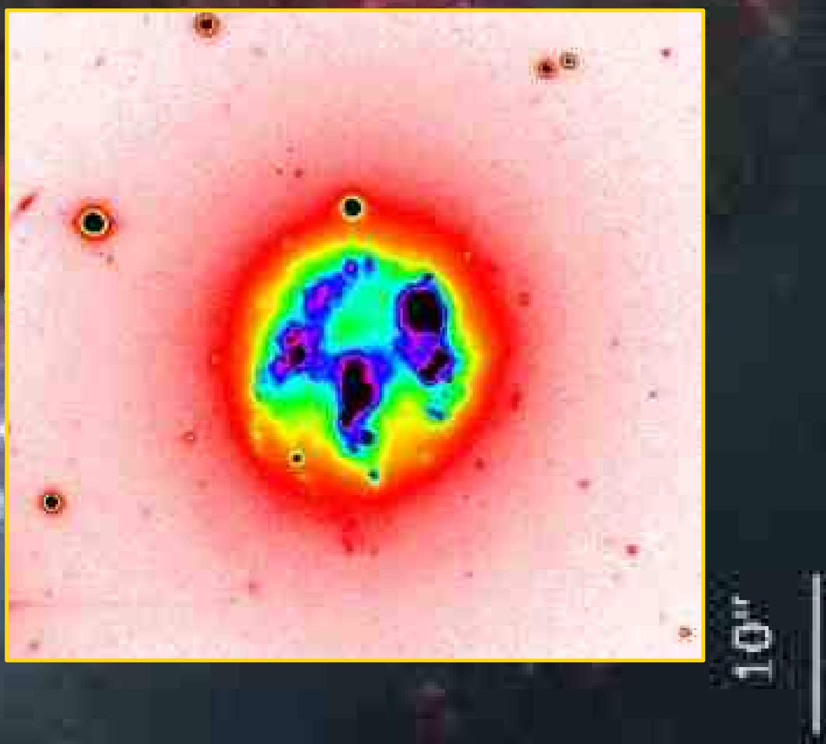
- From z=1 to z=0 (today) the cosmic star formation density has decreased by an order of magnitude.
- Normal galaxies underwent the major phase of their formation several Gyr ago.
- Starburst galaxies are rare in the local volume

Starbursts are rare in the nearby universe

However, they can be studied in spatial detail in

i) interacting/merging galaxies

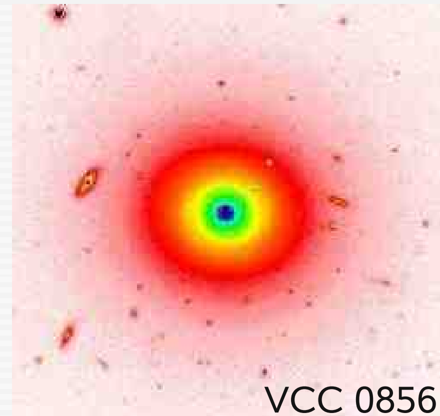
ii) blue compact dwarf (BCD) galaxies



Dwarf Galaxies in the nearby Universe

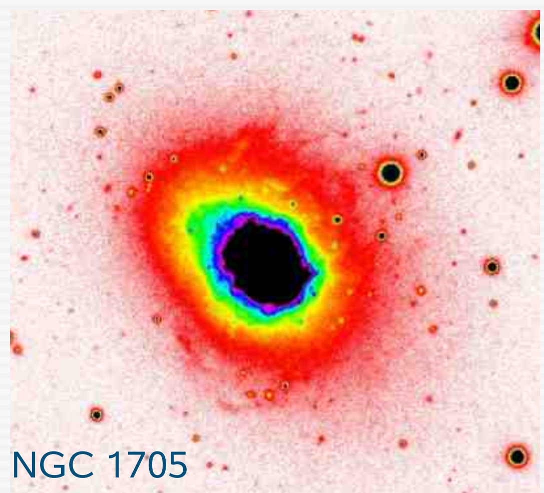
gas content ↑
oxygen abundance ↓
color: rel. blue

Dwarf Irregular (dI)



Dwarf Elliptical (dE)

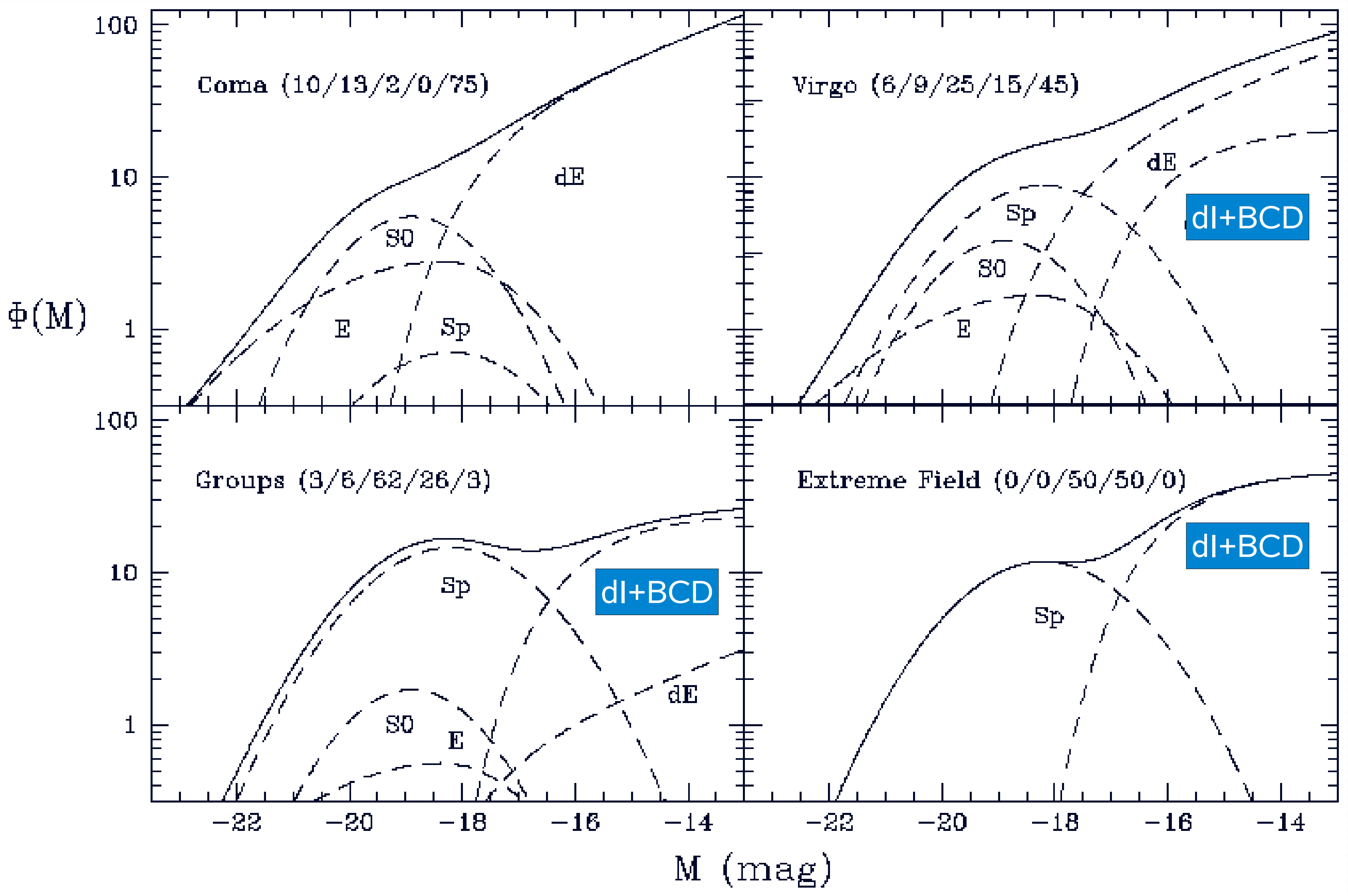
gas content ↓
metallicity ↑
color: red



Blue Compact Dwarf (BCD)

gas content ↑
oxygen abundance ↓
color: blue

Dwarf Galaxies dominate the galaxy population both in clusters in the field.



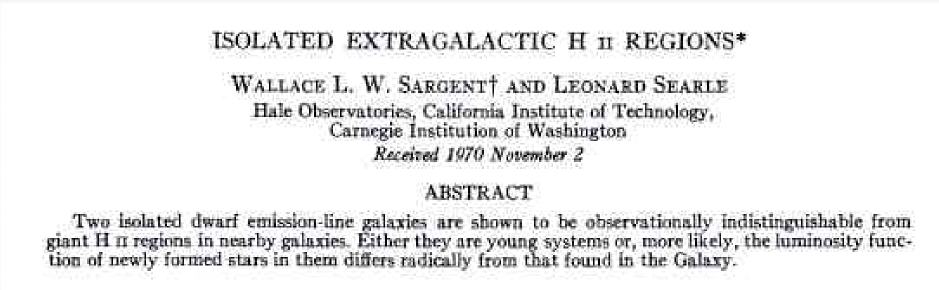
Jerjen et al. (1998)

However the morphological distribution of dwarf galaxies depends on their environment.

Why to study BCDs?

- $\in$ to the dwarf galaxy population – which dominates galaxy population
- They are the most active types of dwarf galaxies → allow to study the origin and implications of starburst activity in relatively simple systems (i.e. no density waves) with properties similar to those in distant low-masss protogalactic units
- … more arguments to come …

First spectroscopic surveys and dedicated studies



ISOLATED EXTRAGALACTIC H II REGIONS*

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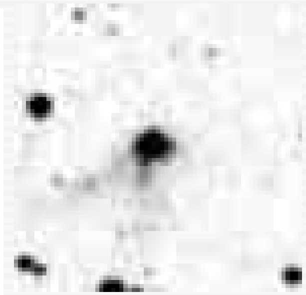
Carnegie Institution of Washington
Received 1970 November 2

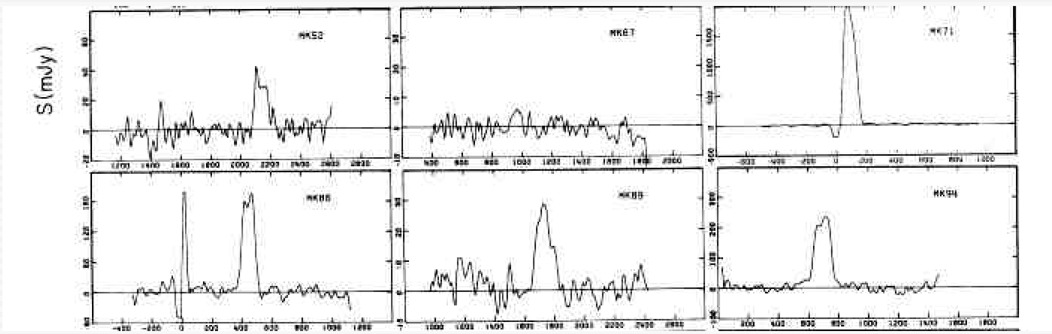
ABSTRACT

Two isolated dwarf emission-line galaxies are shown to be observationally indistinguishable from giant H II regions in nearby galaxies. Either they are young systems or, more likely, the luminosity function of newly formed stars in them differs radically from that found in the Galaxy.



Sargent & Searle (1970)

- Narrow permitted and forbidden emission lines (Extragalactic HII regions)
- Strongly subsolar gas-phase metallicity



Thuan & Martin (1981)

- Introduction of the term BCD
- Determination of the HI mass through single-dish radio observations

Terlevich et al. (1981): Spectrophotometric studies
Loose & Thuan (1986) : Morphological classification scheme
O'Connell et al (1987) : Spectral synthesis models
Salzer et al. (1989) : Spectroscopic classification

Spectroscopic surveys

PARTIAL LIST OF PREVIOUS SCHMIDT/OBJECTIVE-PRISM SURVEYS

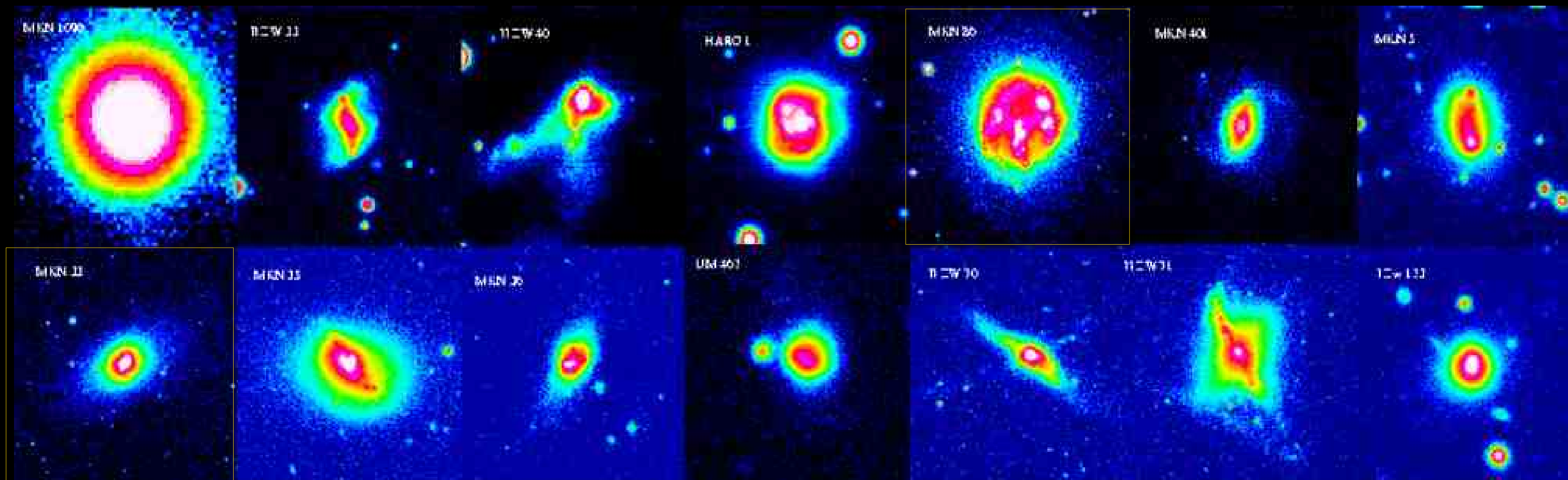
Survey Name (1)	Type[a] (2)	Area (deg^2) (3)	Number of Objects (4)	Density (deg^{-2}) (5)	Completeness[b] Limit (m_B) (6)	Ref. (7)
Haro	C	Lots	~40	Small	??	1
Kiso	C	5100	8162	1.60	16.0	2
Montreal.........	C	4400	469	0.11	14.8	3
Markarian	UV	15000	1500	0.10	15.2	4
Tololo............	L	1225	201	0.16	...	5
UM	L	667	349	0.52	(16.9)	6
Wasilewski	L	825	96	0.18	(15.2)	7
POX	L	82	23	0.28	(16.0)	8
ESO—Hα........	L	400	113	0.28	...	9
UCM............	L	471	263	0.56	(~16.5)	10
Hamburg	L	1248	196	0.16	...	11
Marseille.........	L	46.5	92	1.98	(~16.0)	12
Case	UV+L	1440	1551	0.94	16.0	13
SBS..............	UV+L	~990	~1300	1.31	(~17.0)	14
KISS—red	L	62.2	1128	18.14	(18.1)	15
KISS—blue......	L	116.6	223	1.91	(18.2)	15

[a] (C) Color selected; (UV) UV-excess selected; (L) line selected.

[b] Values in parentheses are median apparent magnitudes for that survey, not a completeness limit.

REFERENCES.—(1) Haro 1956; (2) Takase & Miyauchi-Isobe 1983; (3) Coziol et al. 1993, 1997; (4) Markarian 1967, Markarian et al. 1981; (5) Smith 1975, Smith et al. 1976; (6) MacAlpine et al. 1977, MacAlpine & Williams 1981; (7) Wasilewski 1983; (8) Kunth, Sargent, & Kowal 1981; (9) Wamsteker et al. 1985; (10) Zamorano et al. 1994, 1996; (11) Popescu et al. 1996; (12) Surace & Comte 1998; (13) Pesch & Sanduleak 1983, Stephenson et al. 1992; (14) Markarian et al. 1983, Markarian & Stepanian 1983, Stepanian 1994; (15) this paper, Salzer et al. 2000a, 2000b.

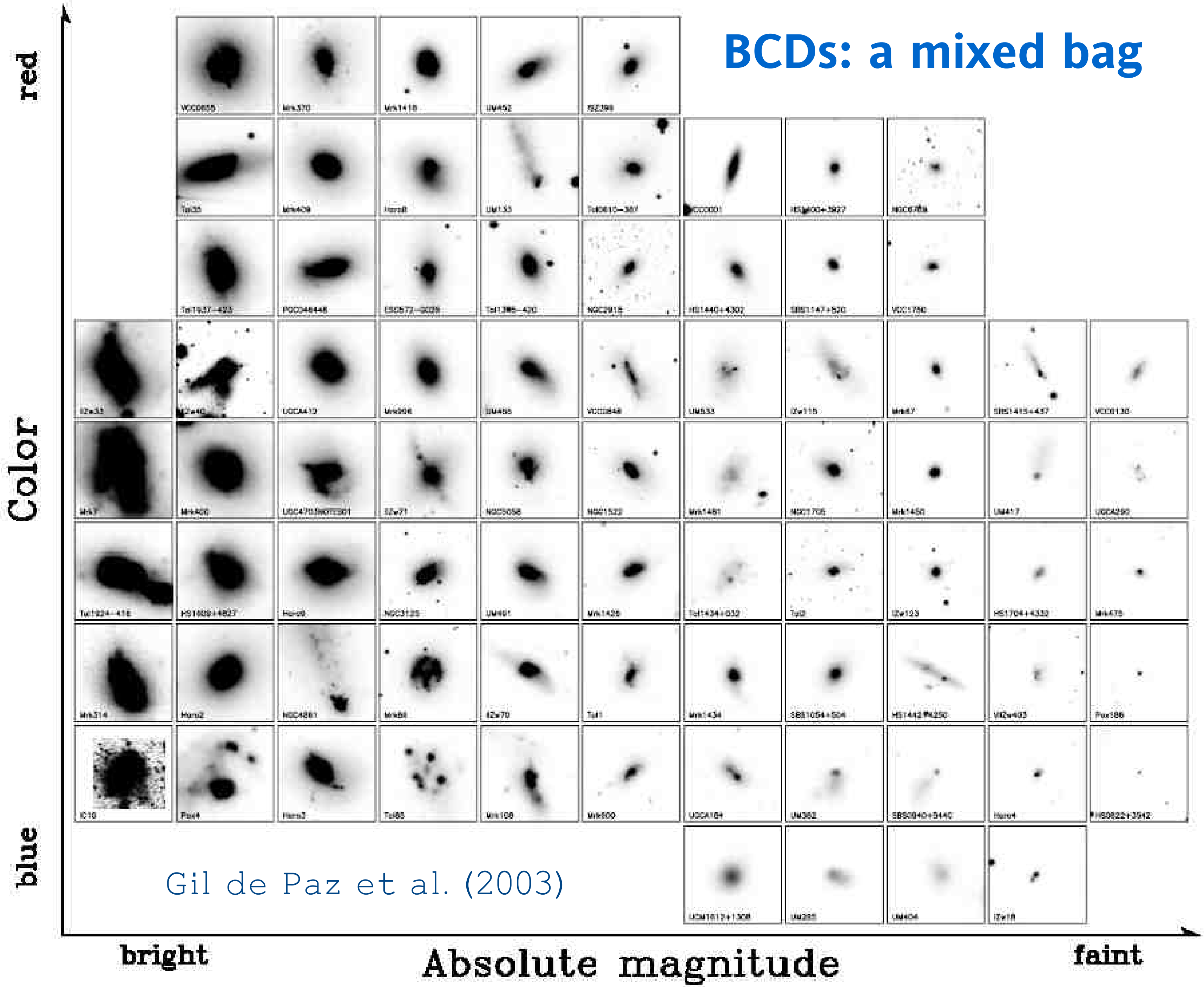
Blue Compact Dwarf (BCD) galaxies: a mixed bag



Cairos et al. (2001)

- dwarf galaxies ($10^7 \leq L/L_\odot \leq 10^9$, $M_B > -18$ mag; $M_T \sim 10^8$ ... a few 10^9 $M_\odot$)
- intense star-forming activity; spatial scale $\simeq 1$ kpc
- evolved low-surface brightness host galaxy in most (>95%) BCDs
- very few BCDs are strongly interacting/merging systems

BCDs: a mixed bag



Gil de Paz et al. (2003)

$10^7 \leq L/L_\odot \leq 10^9$, $M_B > -18$ mag; $M_T \sim 10^8$ ... a few $10^9\ M_\odot$

Spatial distribution of BCDs

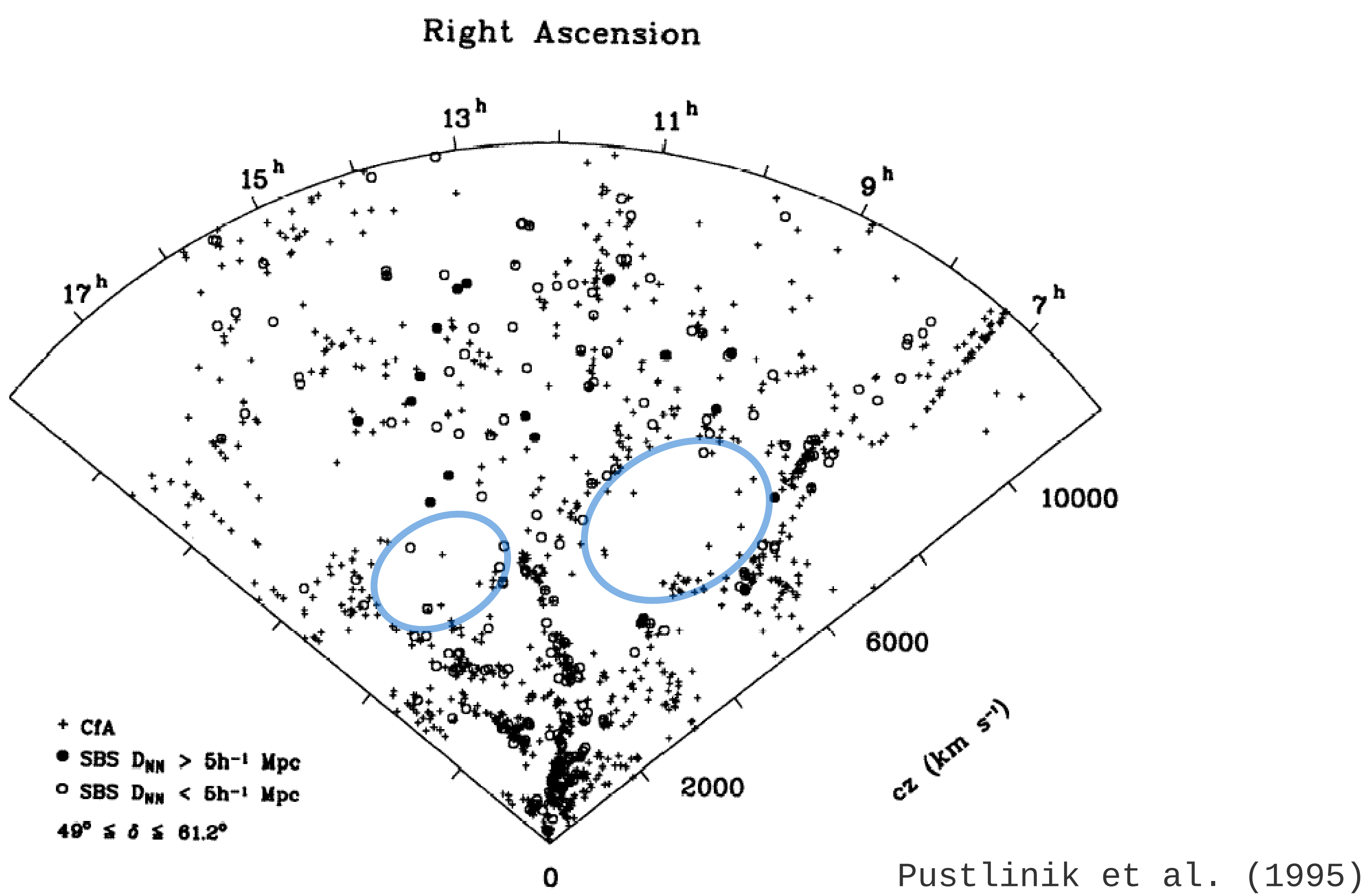
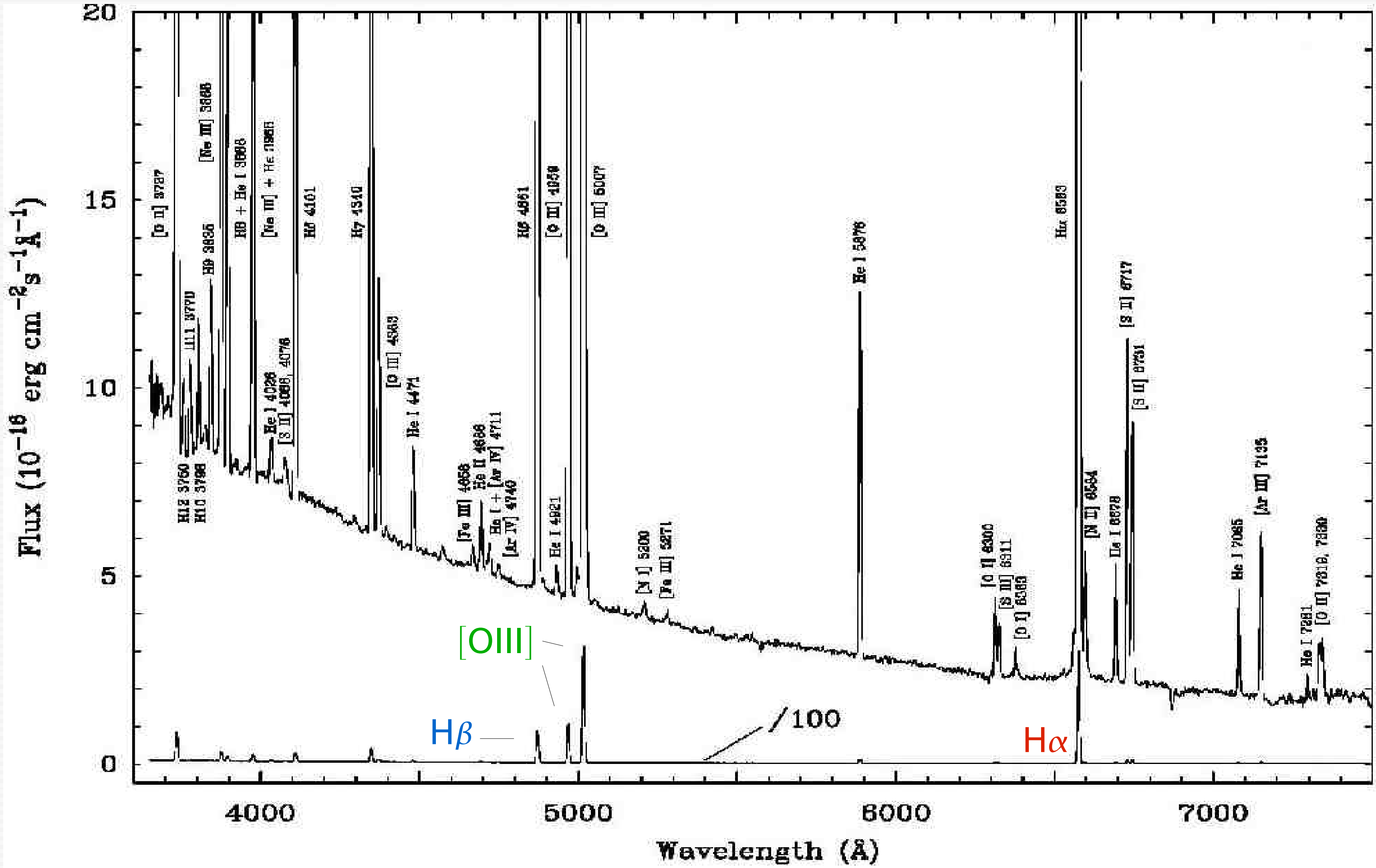


FIG. 2.—Heliocentric velocity vs. right ascension wedge diagram for the SBS zone ($49° \leq \delta \leq 61.2°$). Bright CfA galaxies are shown as crosses, SBS BCGs without a bright neighbor within 5 h^{-1} Mpc are shown as filled circles, and SBS BCGs with a bright neighbor within 5 h^{-1} Mpc are shown as open circles.

- BCDs are relatively evenly distributed in space (i.e. contrary to dwarf ellipticals, they are not concentrated in galaxy clusters)
- Typical distance to normal galaxies: $\simeq$ 5 Mpc (e.g. Pustlinik et al. 1995)
- However, about ½ of BCDs have a close (100 Kpc) dwarf companion

  ➜ weakly interacting systems (e.g. Noeske et al. 2001, Pustilnik et al. 2001)

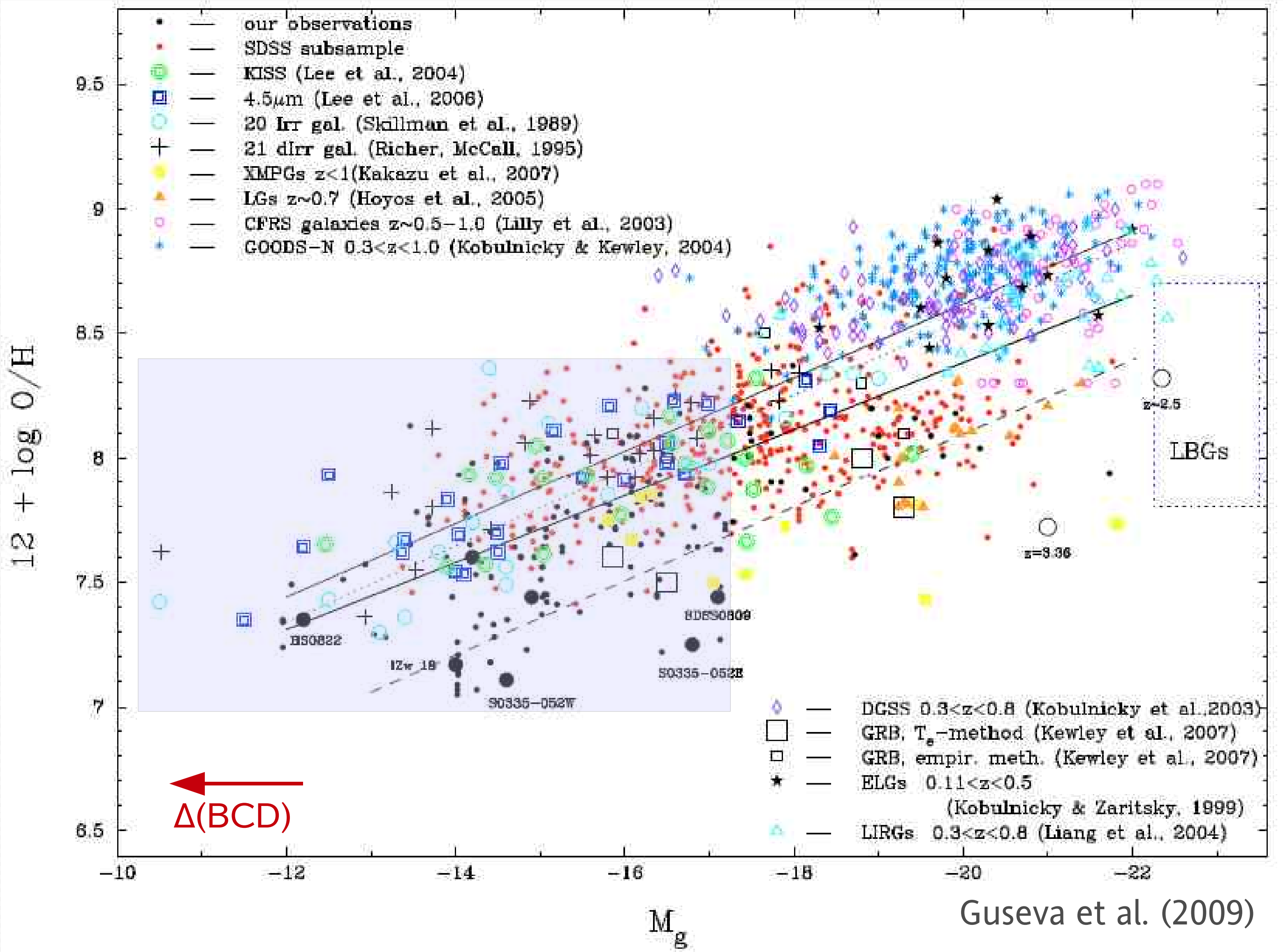
BCDs: spectroscopic properties



Thuan et al. (1999)

- narrow emission lines superposed on blue stellar continuum
- metal-poor (gas-phase metallicity $7.0 \leq 12+\log(O/H) \leq 8.4$, equivalent to ~1/40 … 1/2 solar); <Z>~8.0
- low dust content t (typically $A_V \leq 0.5$ mag, even in the star-forming component)

BCDs and other emission-line galaxies along the luminosity-metallicity (L-Z) relation



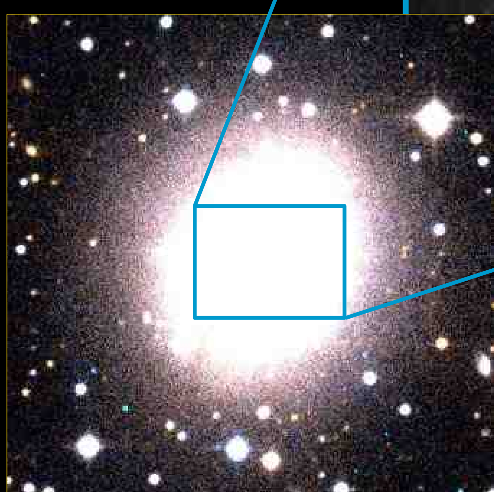
Guseva et al. (2009)

- Estimated fading after the termination of the starburst ~0.75-1.5 B mag

BCDs: the star-forming component

Henize 2-10

Starburst age ~10^7 yr
(Papaderos & Fricke 1998)



Young Stellar Clusters (YSCs):

a) low-mass ($M \simeq 10^3\ M_\odot$) YSCs

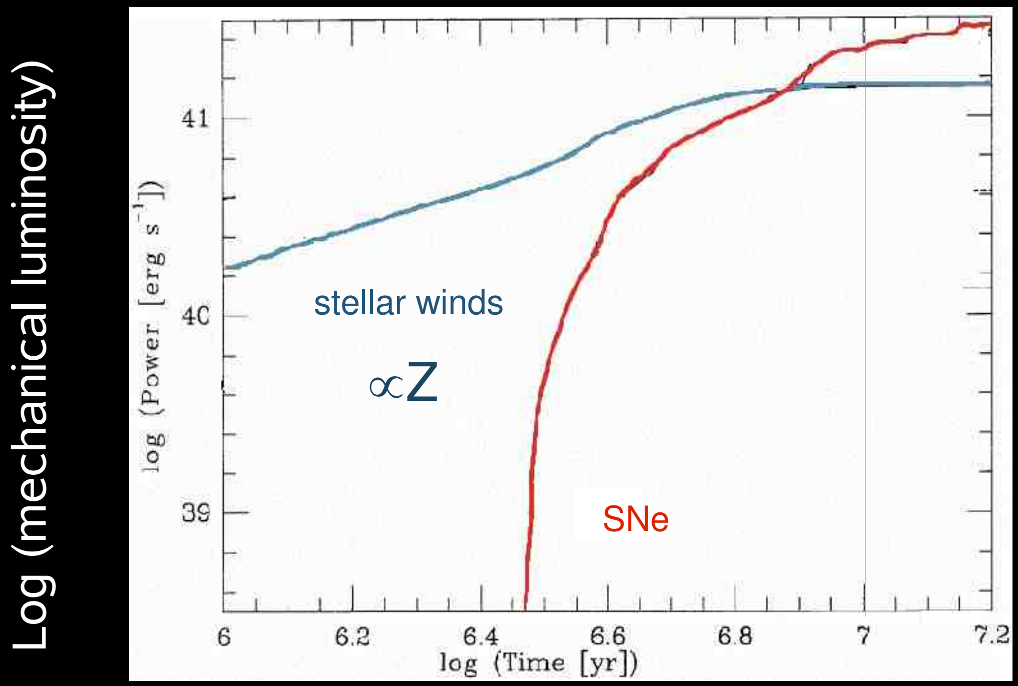
b) more massive ($\simeq 10^4$ **$M_\odot$**) YSCs or even **"Super-Star Clusters" (SSCs)**

$M \simeq 10^{5-6}$ **$M_\odot$**
R_{eff} : **3-10 pc**
$\rho_\star$: **10^4 $M_\odot$ pc^{-3}**

Henize 2-10: Hα supershells and large-scale gas outflows

a)

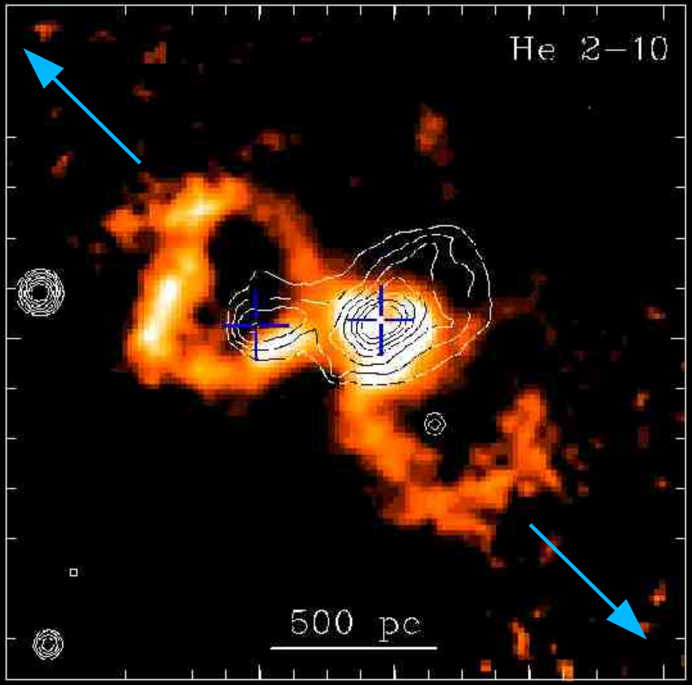
Leitherer et al. (1992)



Log (time)

b)

Papaderos & Fricke (1998)

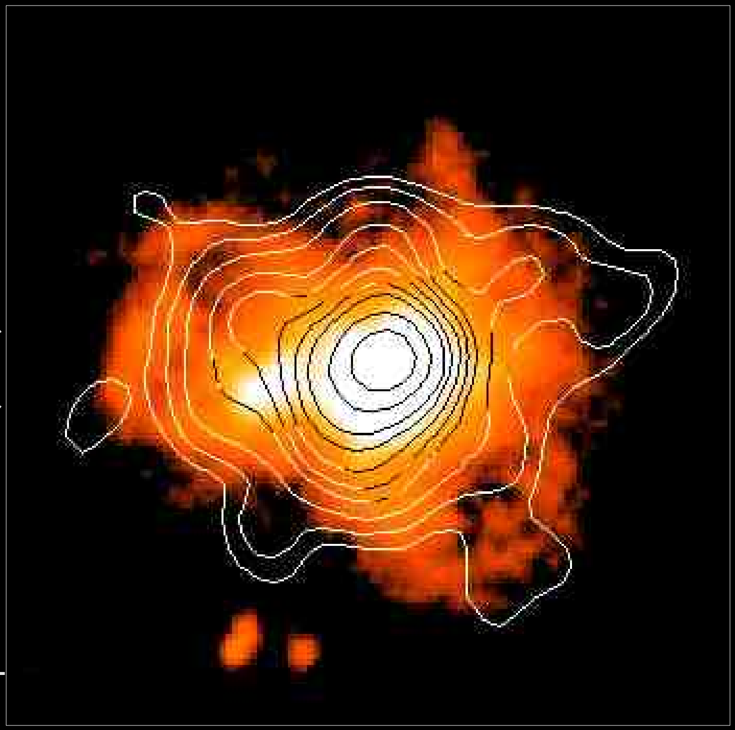


Hα equivalent width map

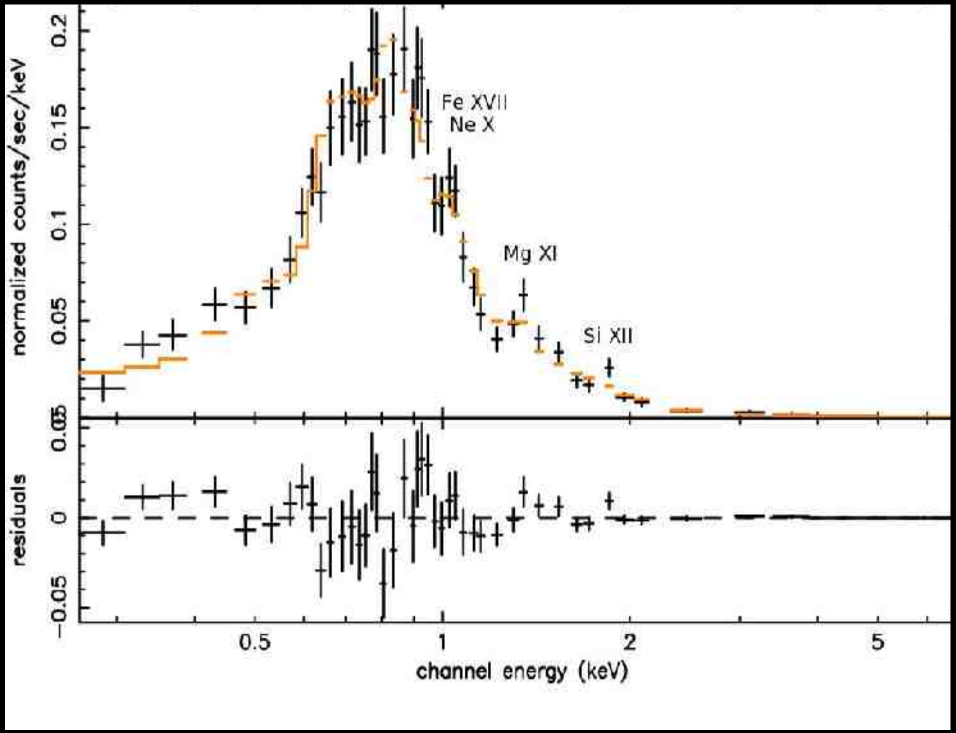
a) mechanical luminosity for a Star Formation Rate of 1 $M_{\odot}$ yr^{-1} as a function of time
Luminosity Power at t=10^7 yr : 4×10^{41} erg s^{-1}
(total energy injected into the ISM: 4.5×10^{55} erg)

b) observations: gigantic bipolar outflow of hot and metal-enriched gas from the starburst component, expanding with velocities of ~300 km s^{-1} into the ambient interstellar medium.

Henize 2-10: extended X-ray emission



X-ray contours (ROSAT HRI) overlaid with a continuum-subtracted Hα map.



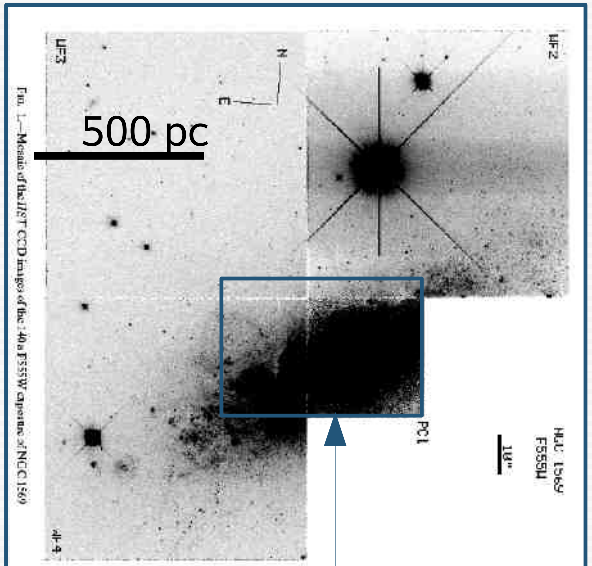
XMM-Newton X-ray spectrum (0.25-6 keV)

Hot (10^7 K) X-ray emitting gas:

- Expansion into the ambient ISM and ejection into the halo (and possibly beyond): **galactic winds**
- Chemical enrichment of the interstellar and intergalactic medium.

BCDs: starburst-driven mass ejection into halo

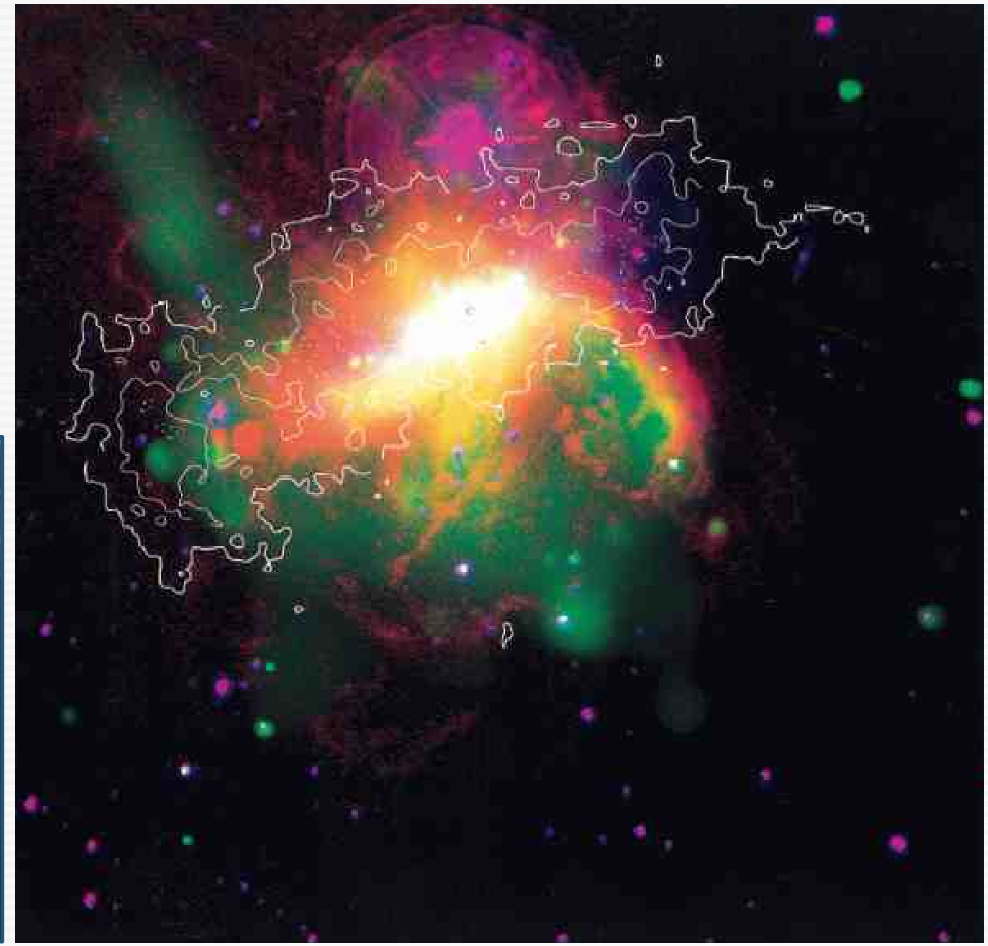
NGC 1569



Hunter et al. (2000)

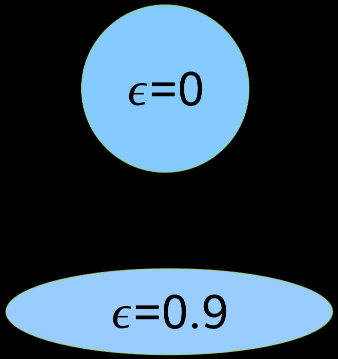
Super-Star Clusters

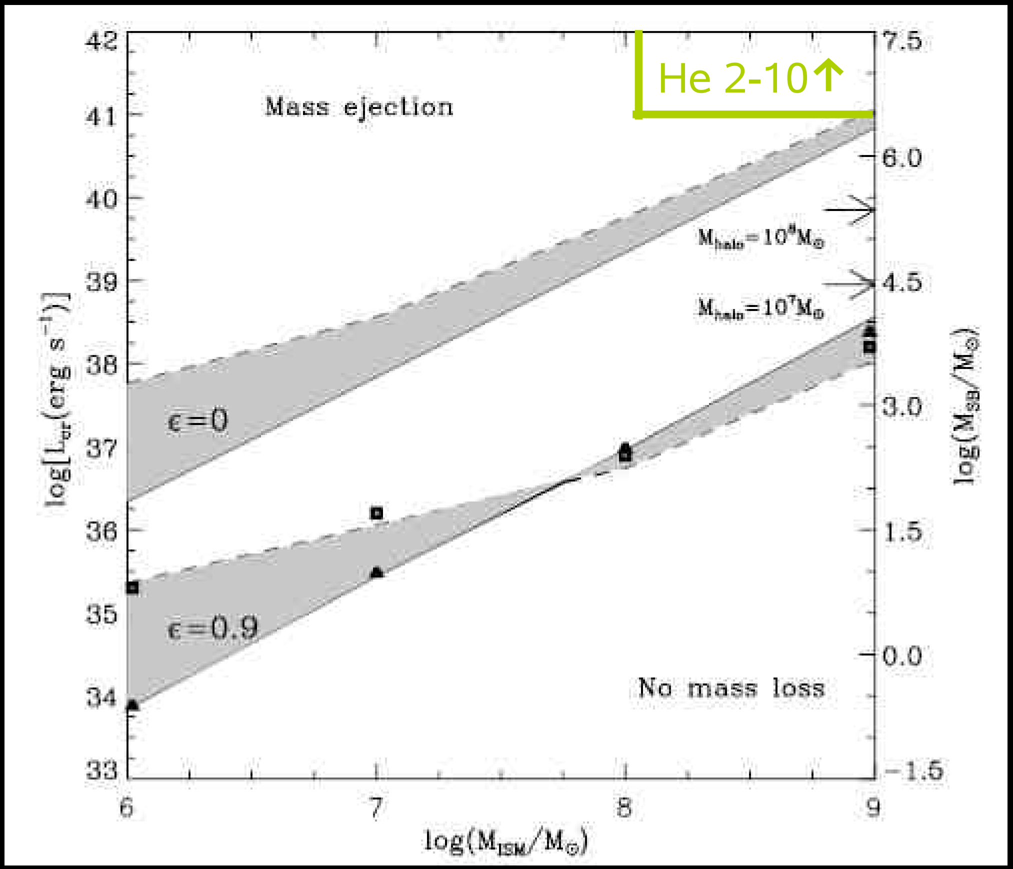
Martin et al. (2001)



HI   Hα   X-ray

Does starburst activity in BCDs lead to galactic winds?



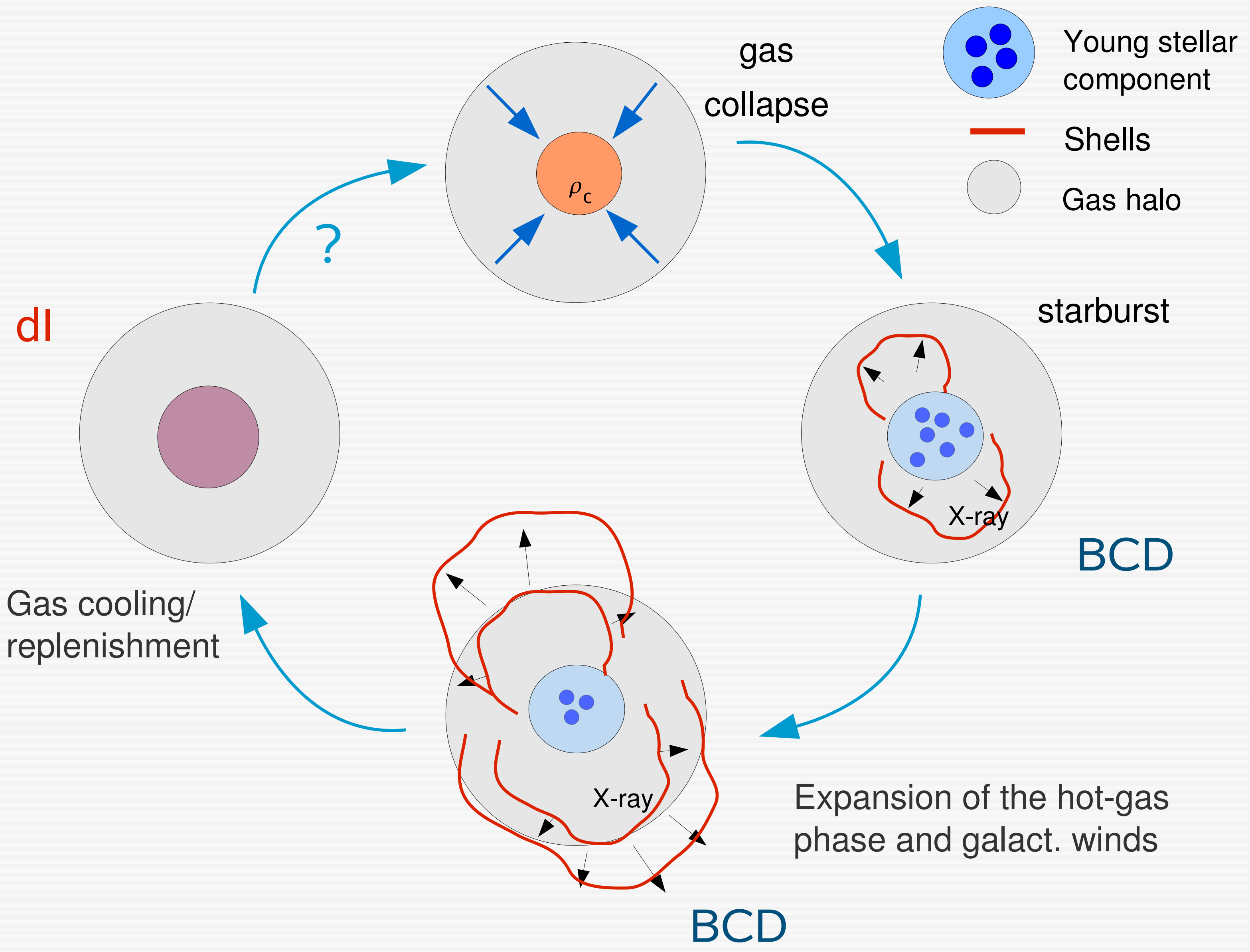


Silich & Tenorio-Tagle (2001)

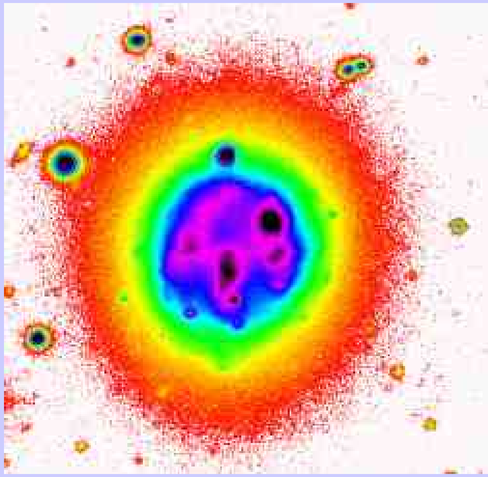
Several semi-analytic models:

de Young & Gallagher (1990), de Young & Heckman (1994), Silich & Tenorio-Tagle (2001)

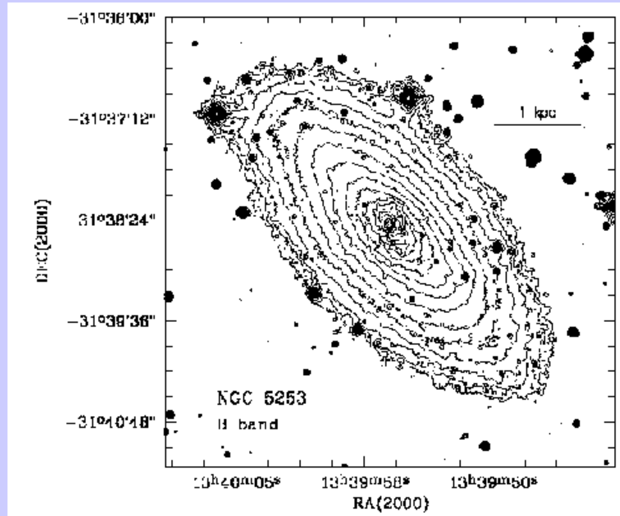
Chronology of a starburst in a dI/BCD



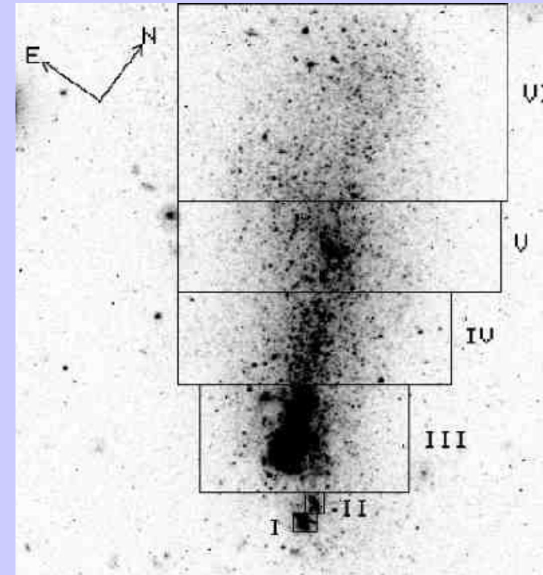
The BCD classification scheme by Loose & Thuan (1986)



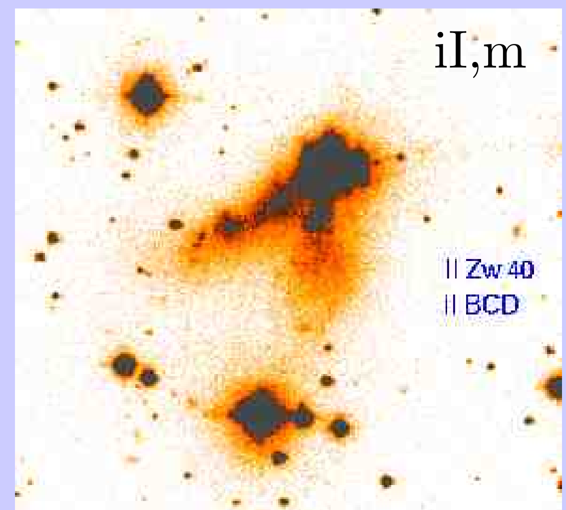
irregular elliptical (iE)
70%



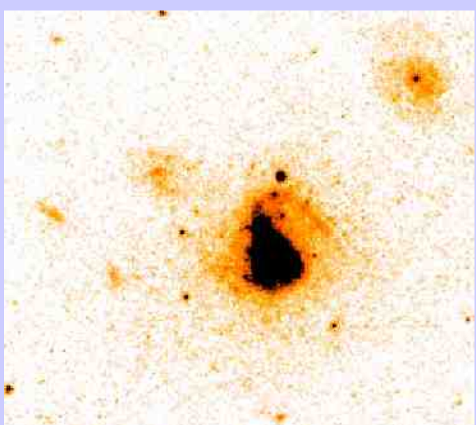
nuclear elliptical (nE)
20%



cometary iI



irregular irregular (iI)
~10%



Irregular 0 (i0)
≤5%

- Discovery of a host galaxy underlying the star-forming component
- Definition of four main morphological classes (iE, nE, iI and i0)

The (spectroscopic) classification scheme by Salzer et al. (1989)

TABLE 3
AVERAGE PHYSICAL PARAMETERS

ELG Type	$B-V_{corr}$	V_0 (km s^{-1})	M_B	D (kpc)	W(O III) (Å)
Seyfert 1	0.71	24778	−21.43	34.7	36.2
Seyfert 2	0.77	10966	−20.08	21.1	51.3
Starburst nucleus	0.63	14508	−20.07	20.1	21.3
Dwarf amorphous nuclear starburst	0.59	7005	−18.38	9.4	21.0
H II hotspot	0.43	10435	−18.43	9.3	193.1
Dwarf H II hotspot	0.43	5241	−16.56	3.8	238.8
Sargent-Searle	0.27	2549	−14.08	1.6	1090.5
Giant irregular	0.48	13425	−19.88	21.9	138.3
Magellanic irregular	0.40	2677	−16.48	5.9	646.8
Interacting pair	0.48	8344	−18.42	13.5	82.4

- Galaxies with a spectrum similar to that of an HII region
- Sample: mainly the University of Michigan (UM) survey
- BCDs ∈ HII galaxies of type DANS, HIIH, DHIIH and SS

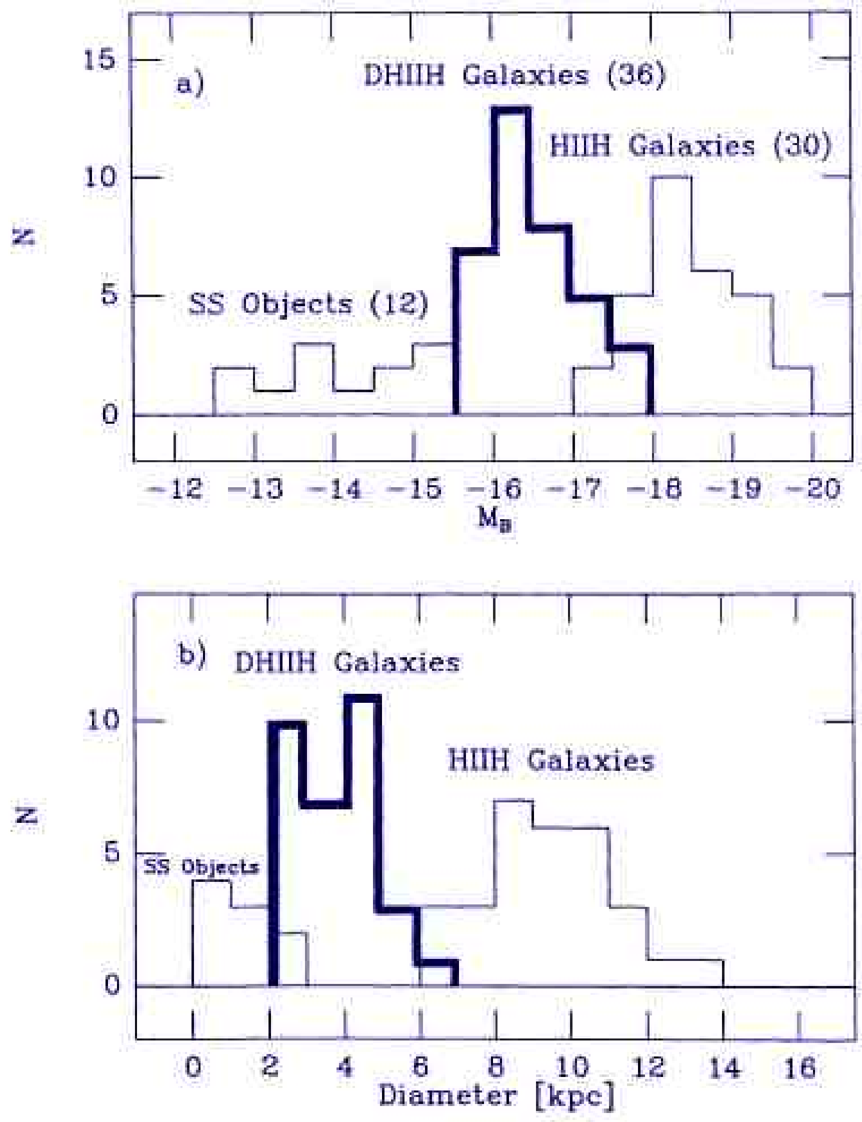


FIG. 9.—Physical parameters for the H II hotspot, dwarf H II hotspot, and Sargent-Searle galaxies. The two diagrams show the distributions of (*a*) absolute magnitudes and (*b*) diameters.

Salzer et al. (1989)

The BCD vs. HII classification scheme

nE+iE
irregular elliptical

iI; iI,C
irregular-irregular
cometary iI

i0
irregular-0

Loose & Thuan (1986)

\+

\-

Luminosity
Size

SBN
Starburst nucleus

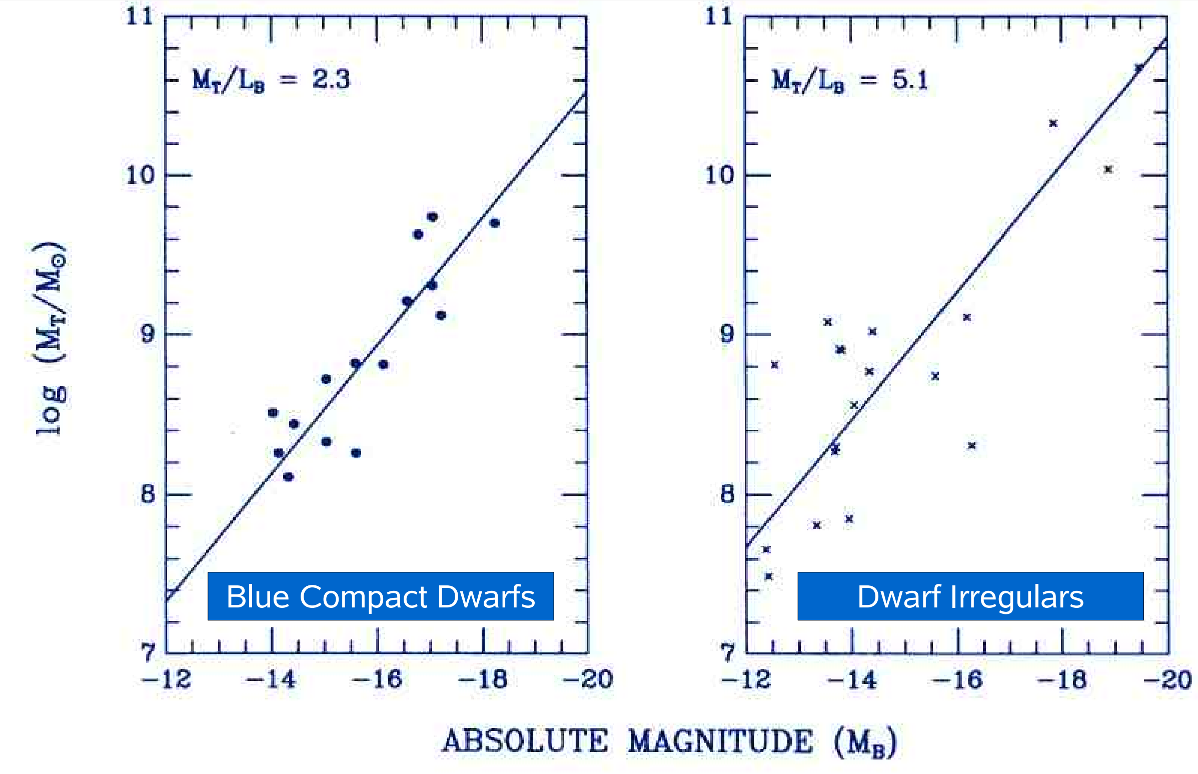
DANS
dwarf amorphous
nuclear starburst

DHIIH
Dwarf HII hotspot

SS
Sargent & Searle

Salzer et al. (1989)

The gas content of BCDs

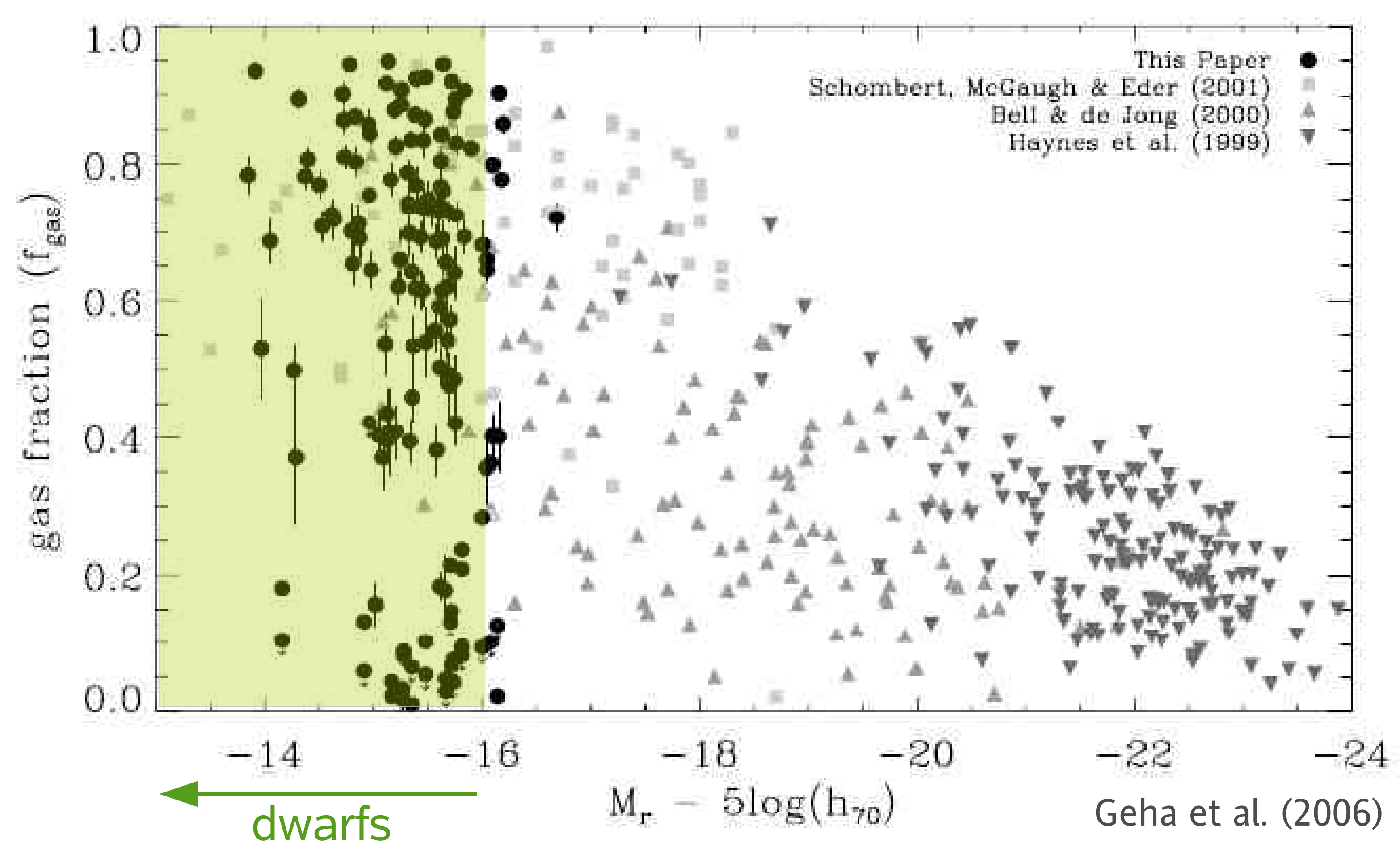


Staveley-Smith et al. (1992)

- Gas (hydrogen+helium) contributes between 40% and 95% of the mass of BCDs
- Ratio between (virial) mass and B band luminosity in BCDs **M_T/L_B=2.3** (½ of that for dIs)
- → BCDs could have not sustained their current SFR over the Hubble time (otherwise they would have consumed their gas reservoir)

Gas fraction as a function of absolute magnitude

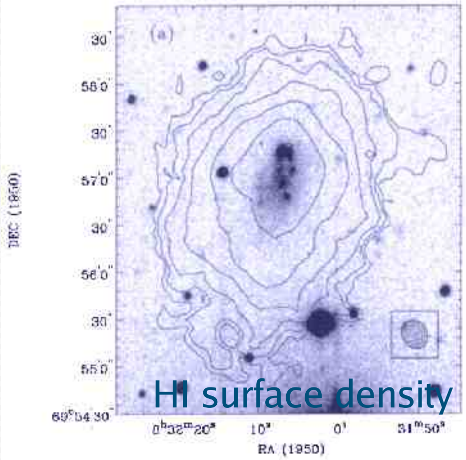
typically M(HI+He)/M(⁎+gas) > 0.4

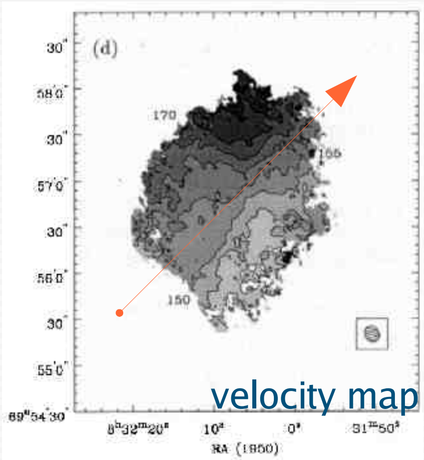


Geha et al. (2006)

BCDs: HI distribution and kinematics

UGC 4483

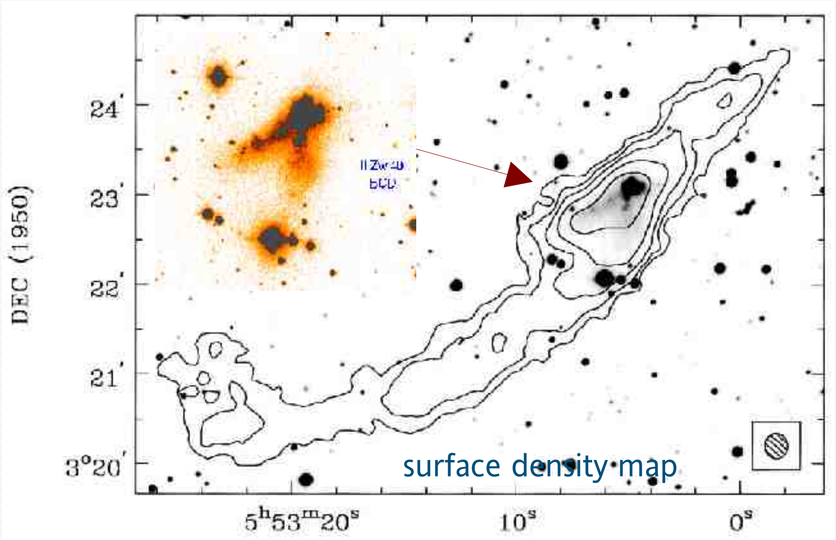


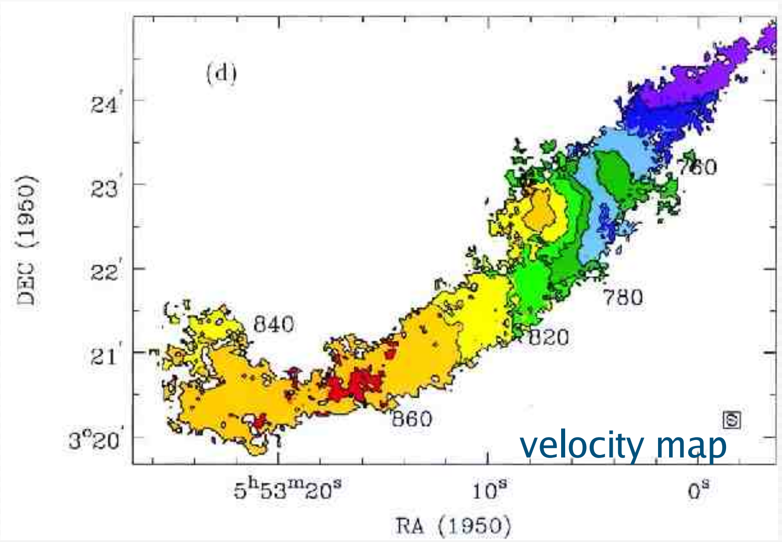


NGC 2915

van Zee et al. (1998)

II Zw 40

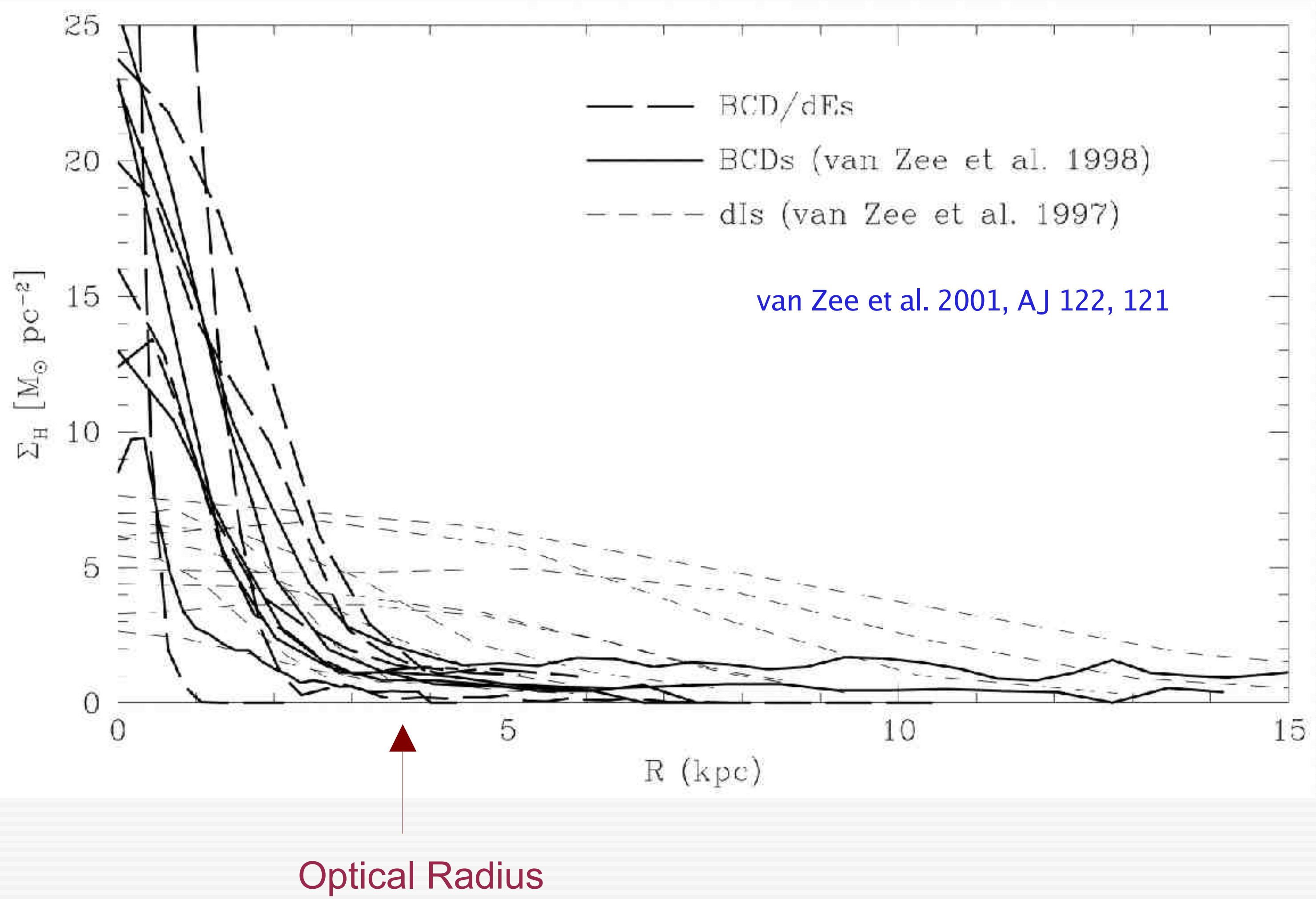




van Zee et al. (1998)

- $M_T/L_B(R_{Ho})$ = 2-6
- HI extent R_{HI} / optical Holmberg radius R_{Ho}: $R_{HI}/(R_{Ho})$ = 3-10
- Dark Matter dominated (unclear whether this is the case within R_{Ho})
- HI gas shows both rotaitonal and turbulent motions

Comparison of the radial HI surface density (Σ_{HI}) distribution in BCDs and dIs

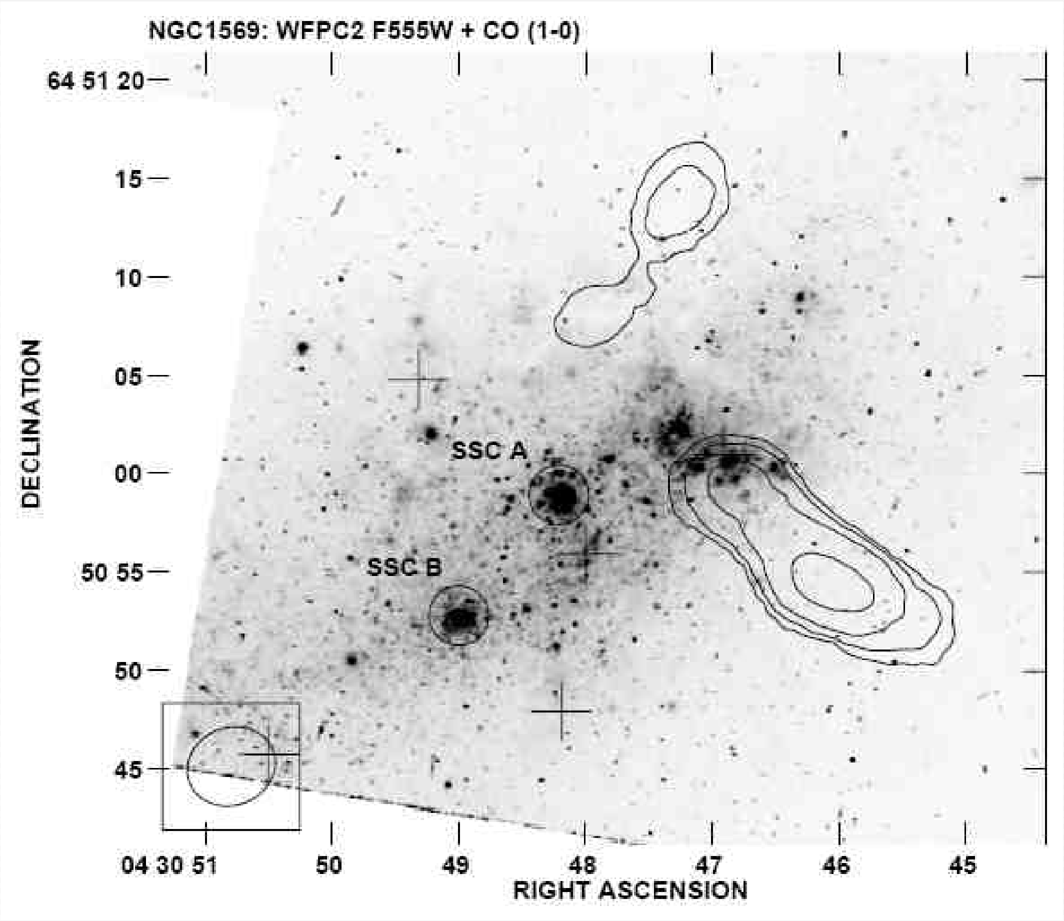


BCDs are more compact than dIs with respect to their HI distribution

$$\Sigma_{HI}(\text{BCDs}) \sim 5 \times \Sigma_{HI}(\text{dIs})$$

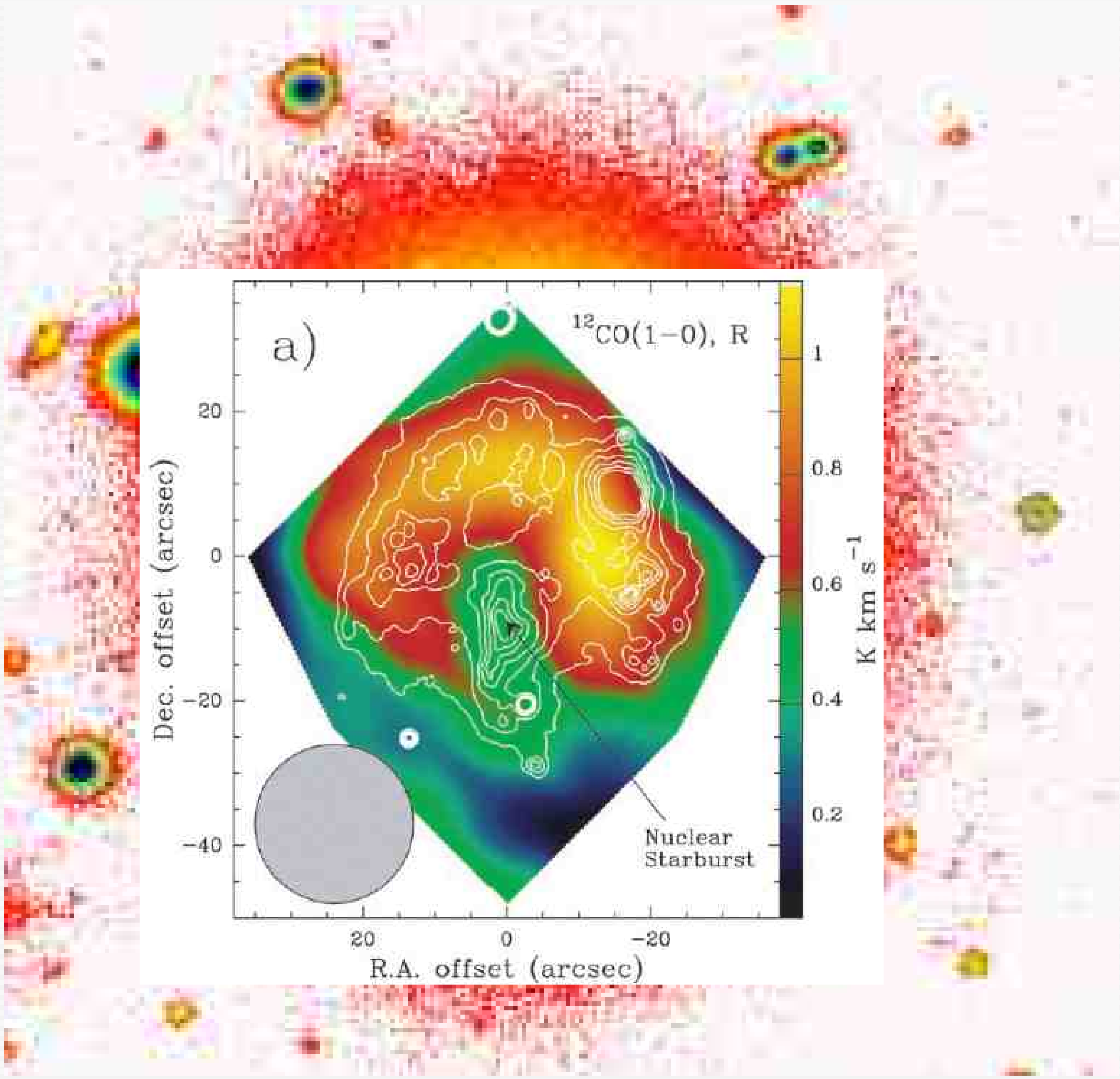
BCDs: molecular hydrogen content and distribution

- Problem: the H_2 gas can not be directly studied at mm wavelengths.
- Solution: observations of the CO molecule (mainly at 2.6 mm) and convertion of the the CO luminosity into H_2 mass.
- But: **a)** the χ factor $^{12}CO/H_2$ depends i.a. on particle density and temperature
  b) as BCDs are metal-poor, they are deficient in C+O
  c) in the presence of intense UV radiation field, molecules are destroyed
- H_2 mass: typically (1...7) $\times$ 10^6 $M_\odot$ ($\equiv$ a few % of the HI mass)



Taylor et al. (1999)

BCDs: molecular hydrogen content and distribution



The horseshoe CO distribution in the BCD Mrk 86

Gil de Paz et al. (2002)

Summary I

- dwarf galaxies: the most common class of extragalactic objects in the Universe
- 3 main types of dwarf galaxies: dwarf ellipticals, dwarf irregulars and Blue Compact Dwarfs (BCDs)
- BCDs undergo intense star-forming activity (starbursts)
- … are not strongly clustered & a few of them in strong gravitational interaction with other gal.
- … gas-rich and metal-poor. They span a wide range in their gas-phase metallicity
- Typical diameter of the starburst component in a BCD: 1 kpc.
- Formation of hundreds of Young Stellar Clusters or even (a few) Super-Star Clusters
- Cyclic starburst phenomenon in BCDs:

  Explanation: Tremendous energetic output through stellar winds and SNe → generation of a hot X-ray gas phase → galactic winds → termination of the starburst
- Two classification schemes for BCD/HII galaxies (morphological & spectroscopic)
- Spectral synthesis models aiming at understanding the Star Formation History of BCDs

  a) evolutionary synthesis (different approaches, e.g. spectrophotometric, closed-box, chemodynamical)

  b) population synthesis