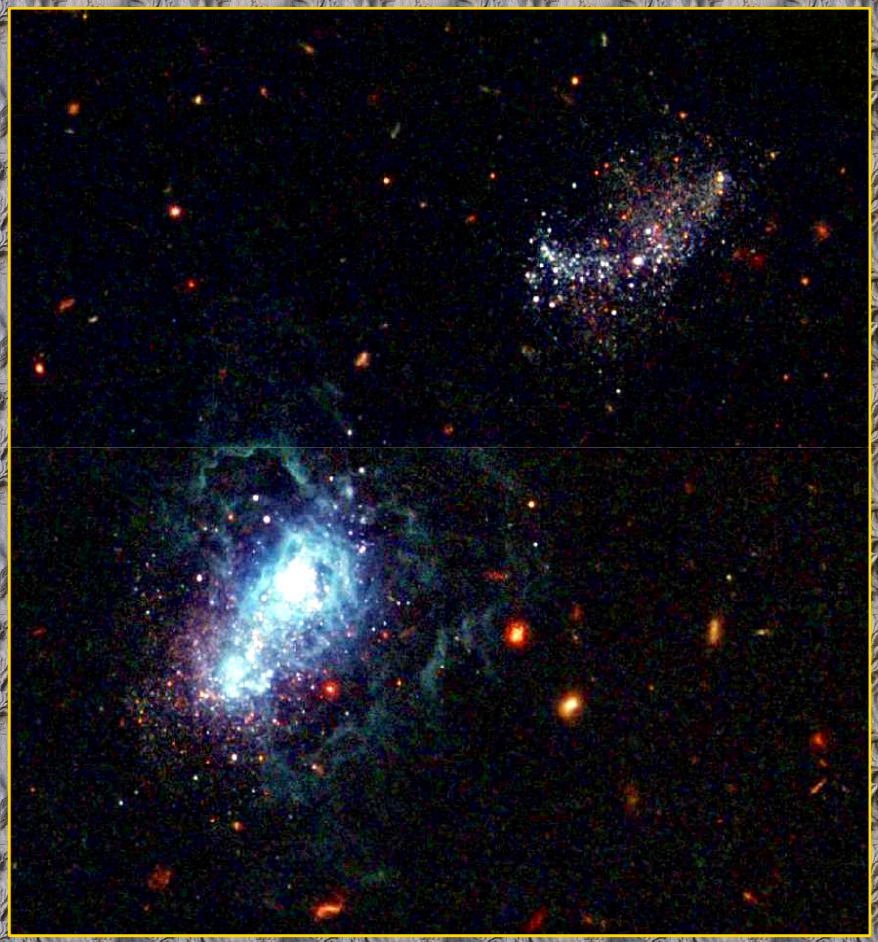


Morphological and photometric properties of extremely metal-deficient Blue Compact Dwarf Galaxies

P. Papaderos

1.03.2007

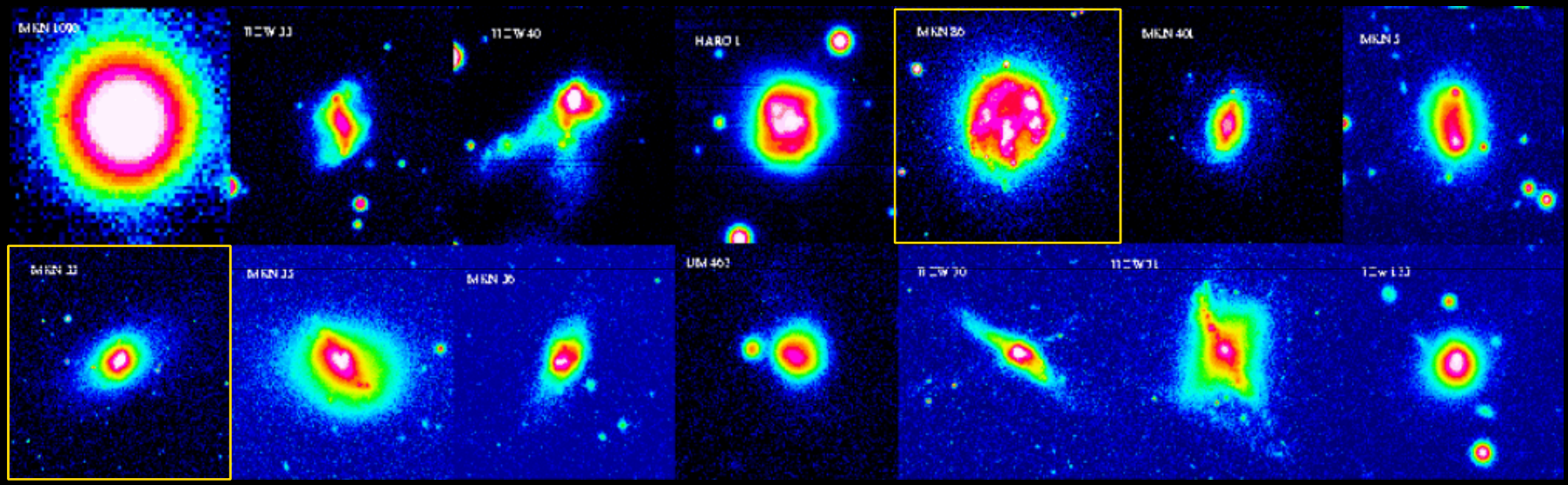


Outline

I. Old dwarf starburst galaxies in the local Universe:
Blue **C**ompact **D**warf Galaxies (**BCD**s)
- general properties
- the star-forming component
- open questions

II. Young galaxy candidates in the local Universe:
E**x**tremely metal-deficient **BCD**s: **XBCDs**

I. Blue Compact Dwarf (BCD) galaxies: a mixed bag

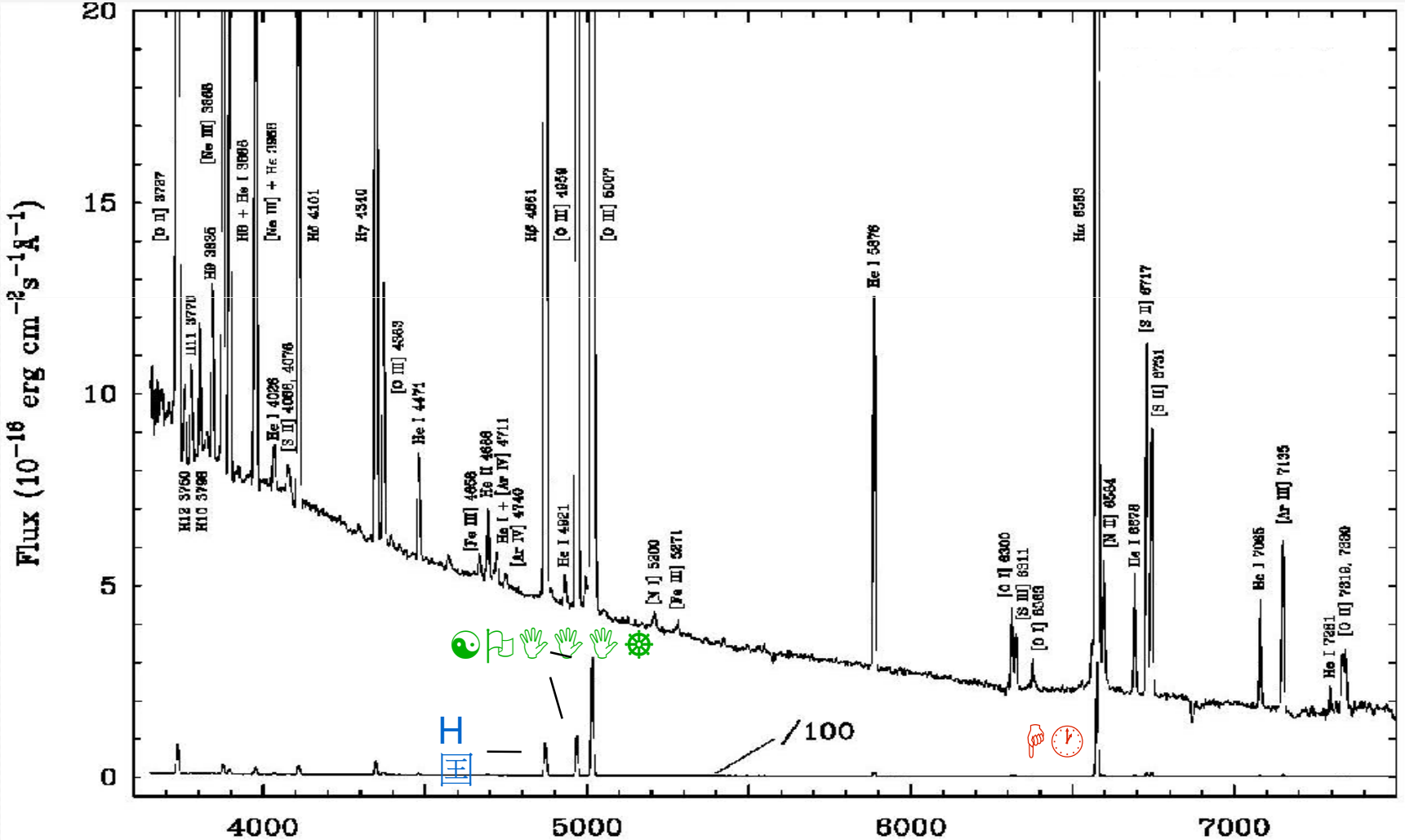


Cairos et al. (2001)

- dwarf galaxies ($10^7 \leq L/L_\odot \leq 10^9$, $M_T \sim 10^8$ ... a few 10^9 $M_\odot$)
- gas-rich: $M_{gas}/M_T(R_{Ho}) = 0.3\text{-}0.8$
- intense star-forming activity within a “compact” region with <1 kpc in diameter; starburst contributes > ½ of optical luminosity
- evolved low-surface brightness (LSB) host galaxy in most (>95%) BCDs
- *luminous* companions are very rare
- ⑦🗁🖃🖹 of BCDs have *dwarf* companions within ~200 kpc



BCDs: spectroscopic properties and star-forming activity



Thuan et al. (1999), Papaderos et al. (2006)

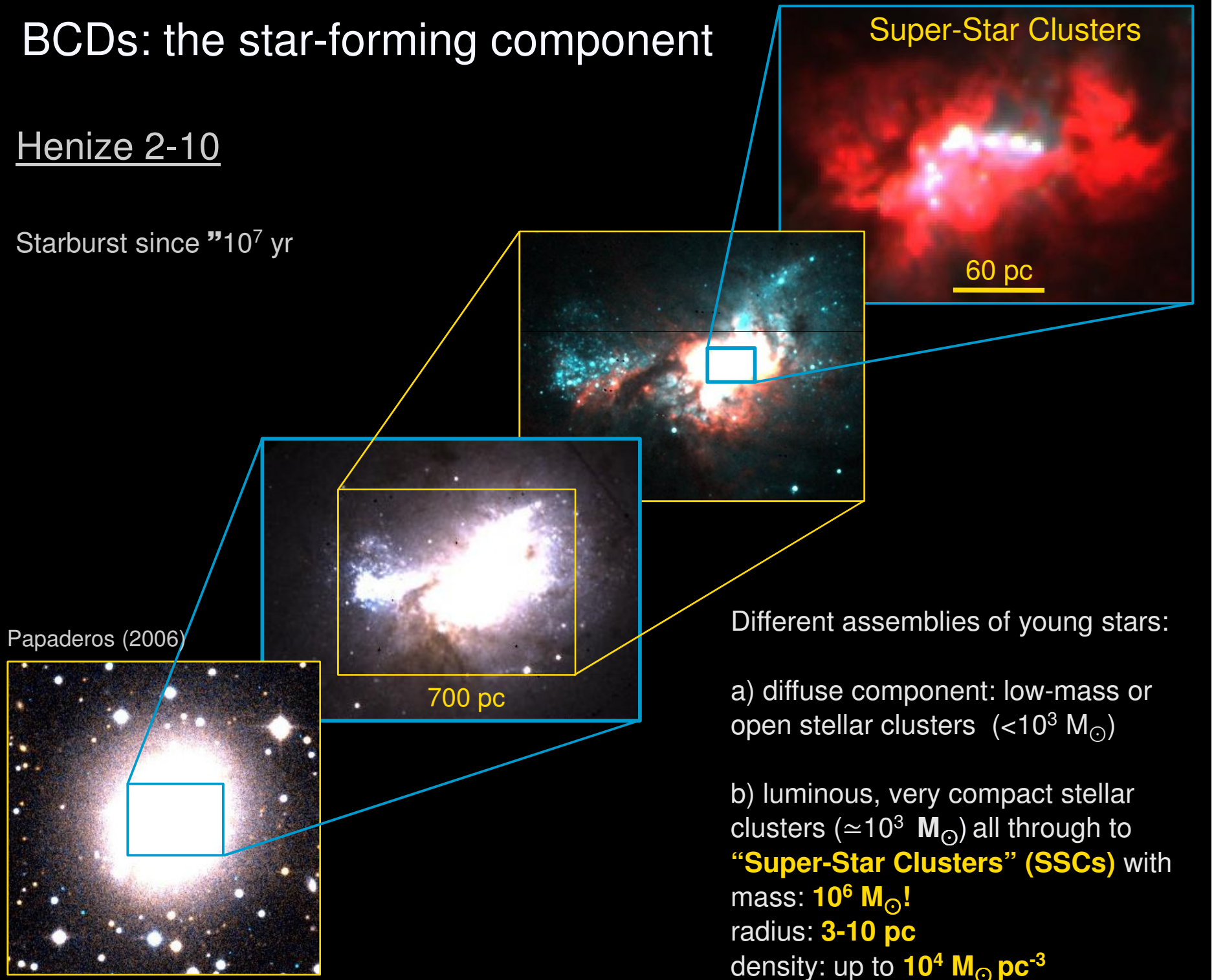


- narrow emission lines superposed on blue stellar continuum
- **S**tar **F**ormation **H**istory: starbursts + low-level star formation
- broad metallicity distribution peaking at 12+log(O/H)”7.9
- low dust content

BCDs: the star-forming component

Henize 2-10

Starburst since "10^7 yr



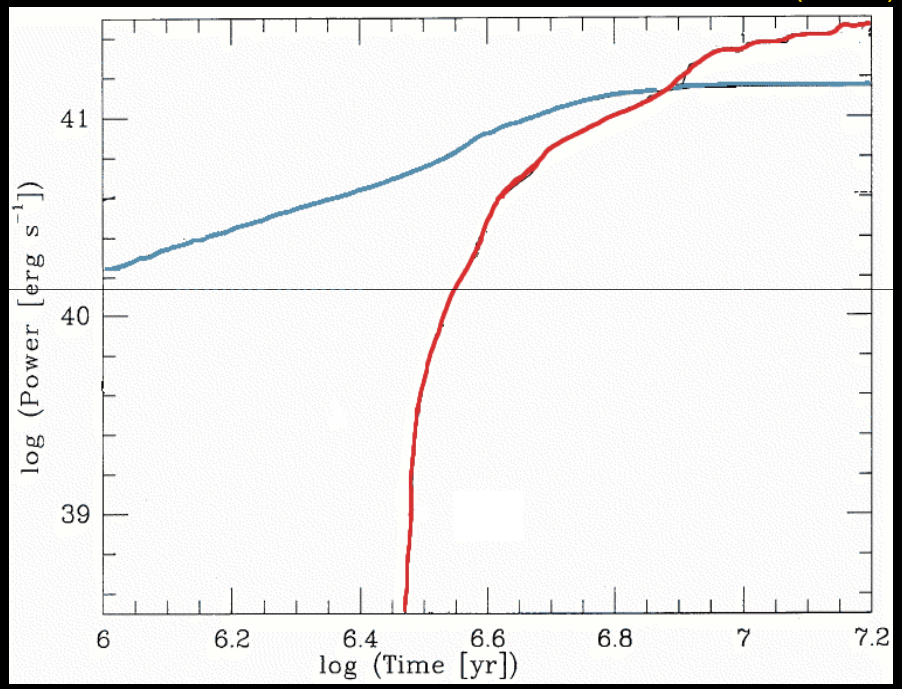
Different assemblies of young stars:

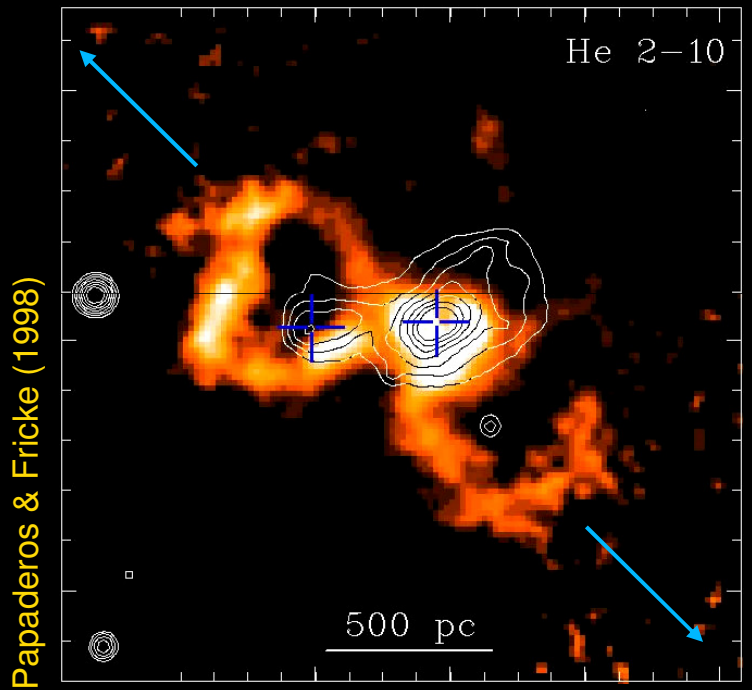
a) diffuse component: low-mass or open stellar clusters ($<10^3$ $M_\odot$)

b) luminous, very compact stellar clusters ($\simeq 10^3$ $\mathbf{M_\odot}$) all through to **"Super-Star Clusters" (SSCs)** with mass: **10^6 $M_\odot$!**
radius: **3-10 pc**
density: up to **10^4 $M_\odot$ pc^{-3}**

Henize 2-10: H⍵ supershells and large-scale gas outflows

Leitherer et al. (1992)





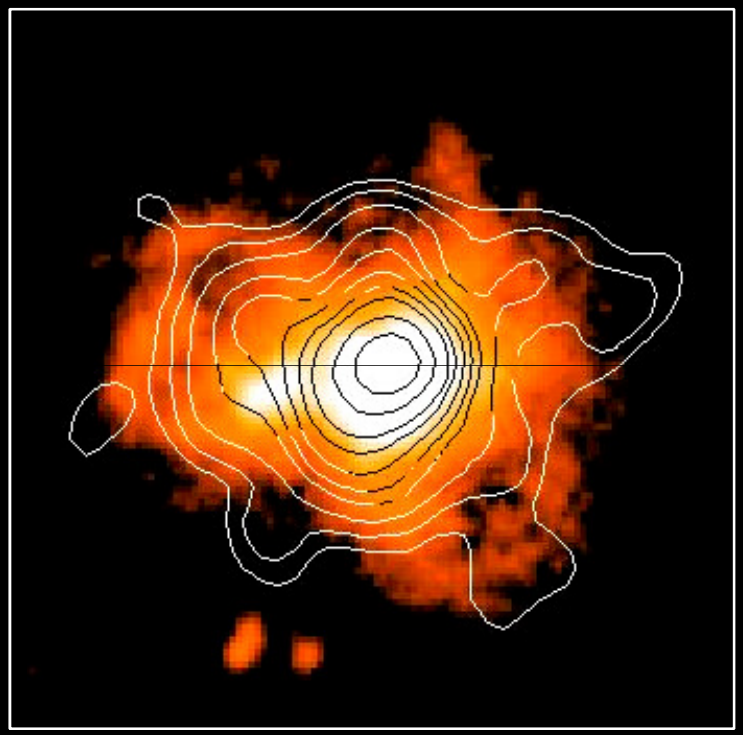
H⍵ equivalent width map

- for a **S**tar **F**ormation **R**ate SFR = 1 $M_\odot$ yr^{-1}
  the total energy injected into the ISM at t=10 Myr is >10^{55} erg

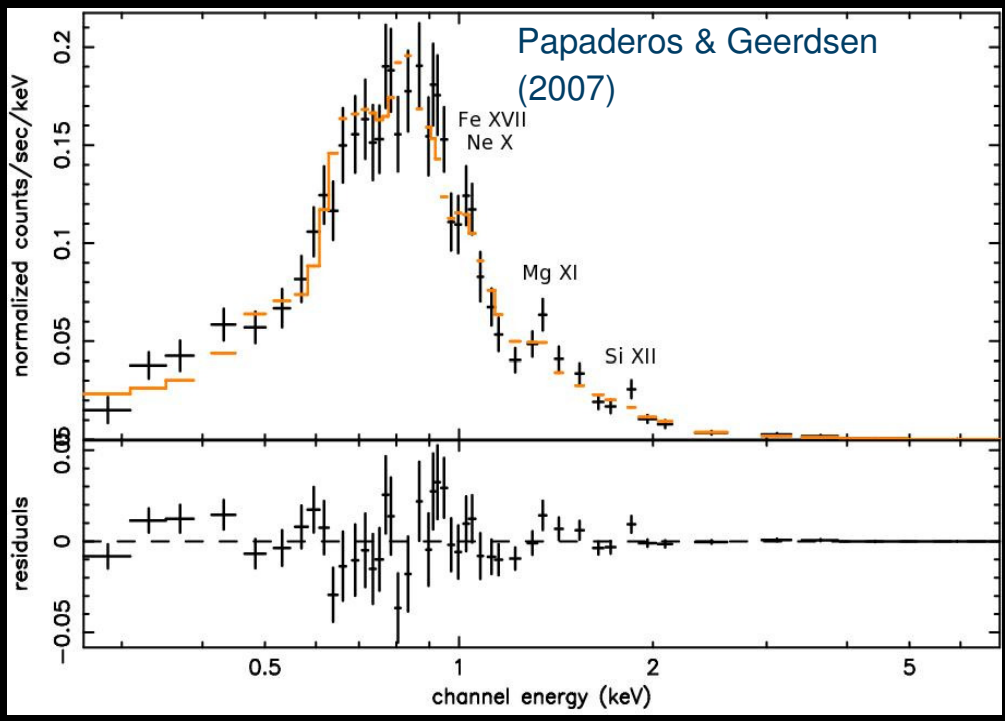
- Gigantic bipolar outflow of hot and metal-enriched gas from the starburst component, expanding with velocities of ~300 km s^{-1}
  (Papaderos & Fricke 1998, Mendez & Esteban 1999, Johnson et al. 2000).



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 (several 10^6 K) X-ray emitting gas:

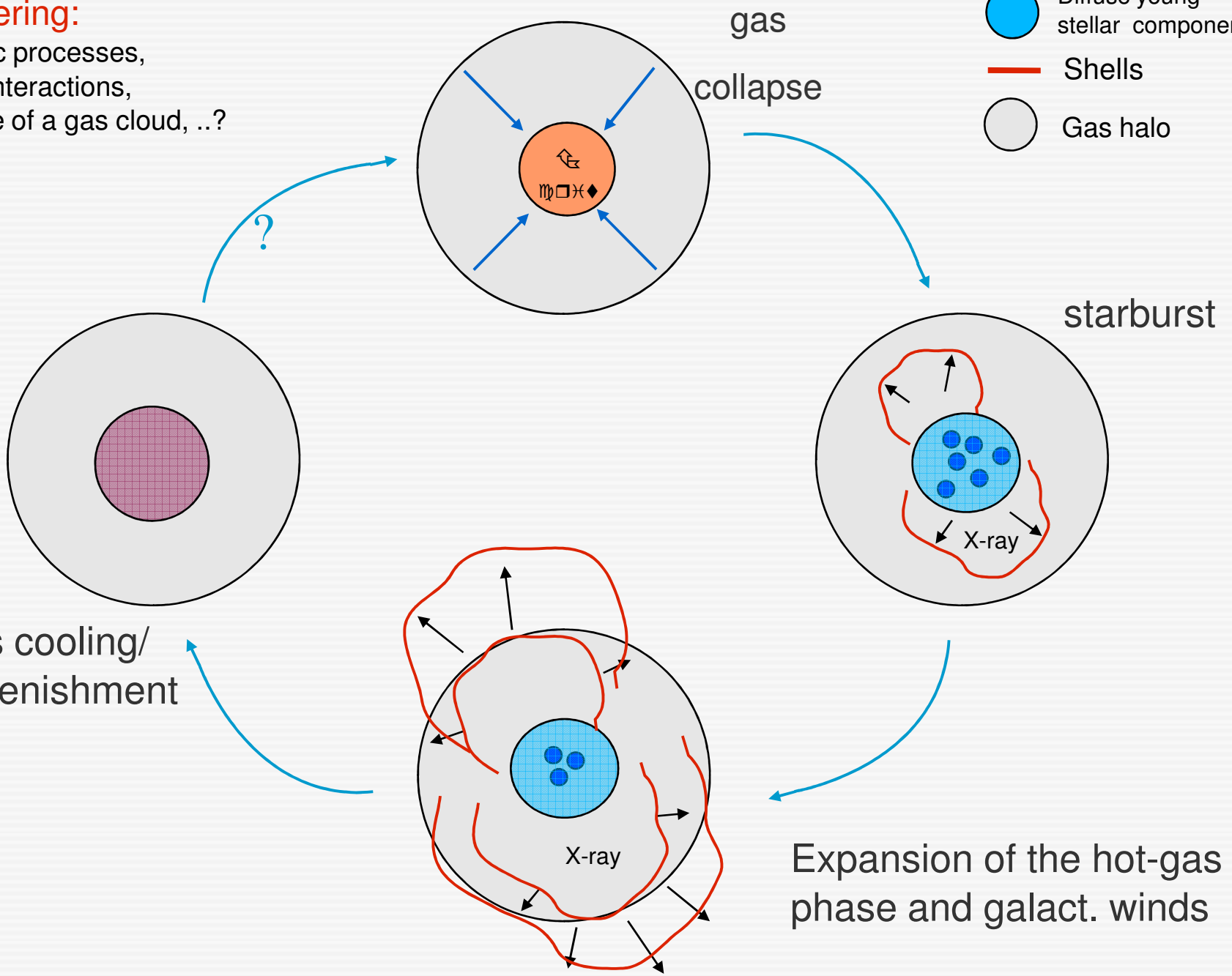
- Expansion into the ambient **Inter**stellar **M**edium (ISM) ISM and ejection into the halo and possibly beyond ❼ **galactic winds**
- Chemical enrichment of the interstellar and intergalactic medium



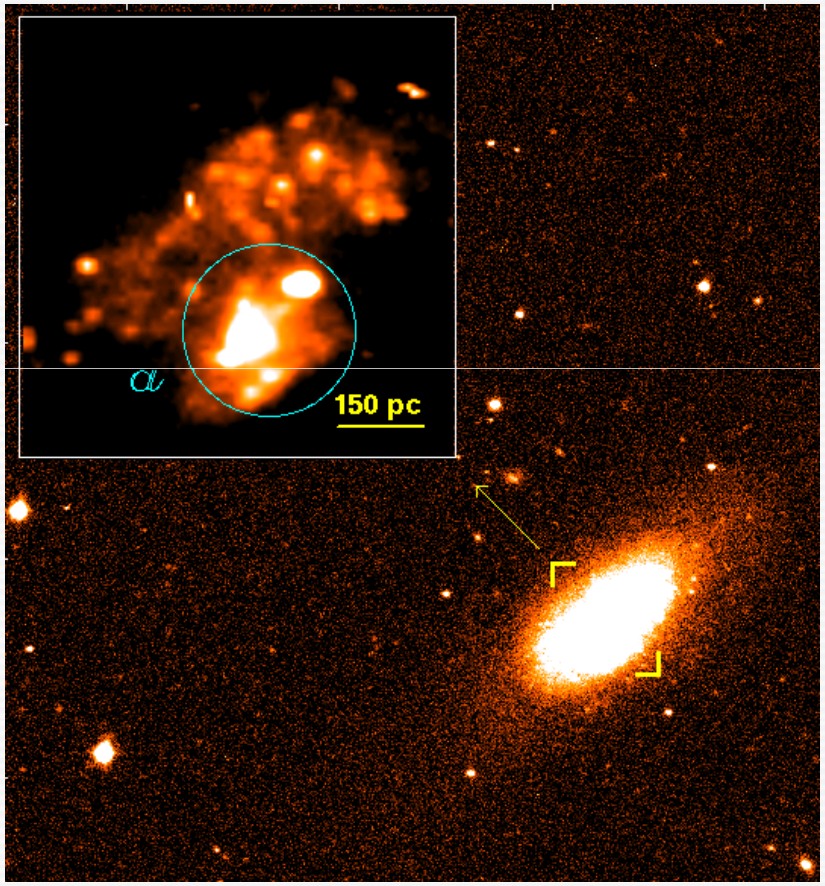


Chronology of a starburst in a BCD (?)

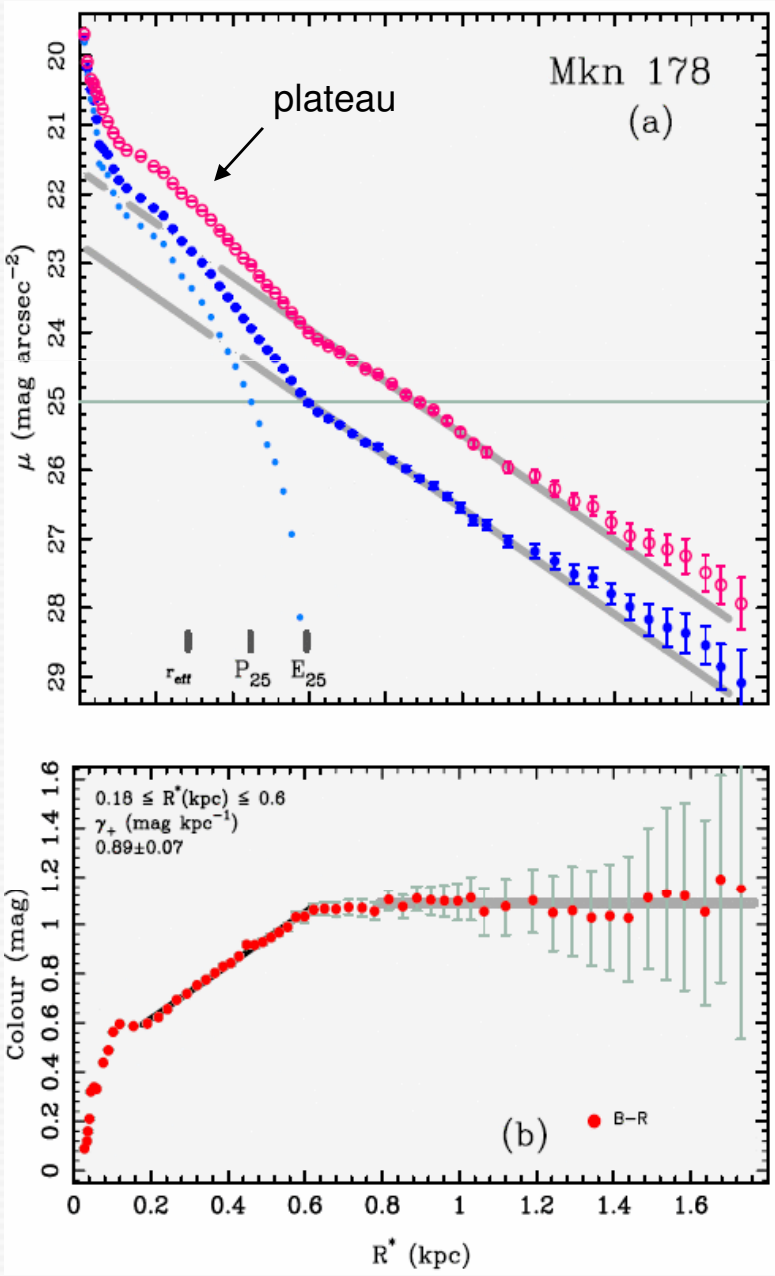
Triggering:
intrinsic processes,
weak interactions,
capture of a gas cloud, ..?



BCDs: photometric structure



Papaderos et al. (1996, 2002)

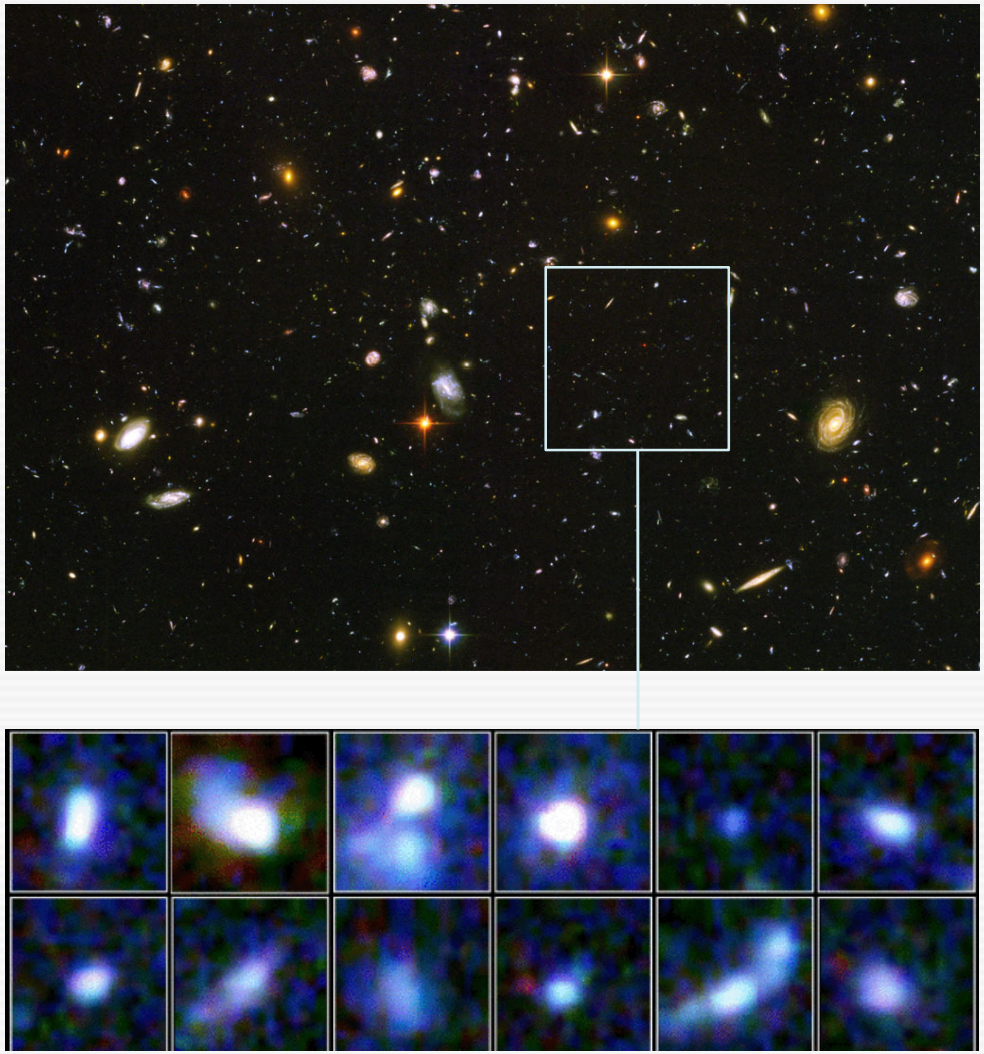


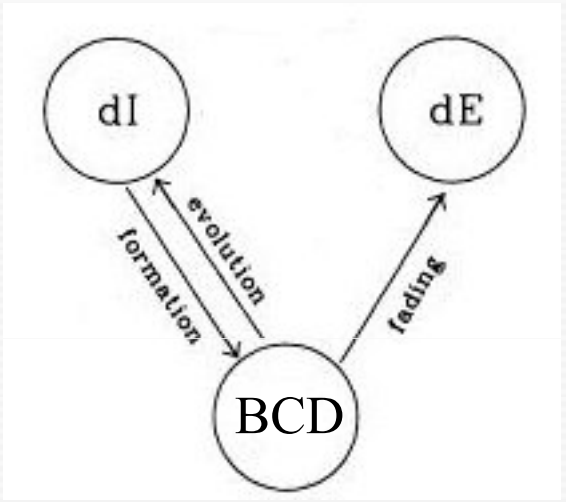
- A single fitting law (e.g. Sersic) cannot fit the surface brightness profiles (SBPs) of BCDs
- SBP decomposition in (at least) two components:
  a **young** star-forming component and
  an **old(er)** host galaxy
- Large colour gradients within the star-forming component ($R \leq P_{25}$) are typical for BCDs



Morphological and Photometric Properties of Extremely Metal-Deficient Blue Compact Dwarf Galaxies

Questions



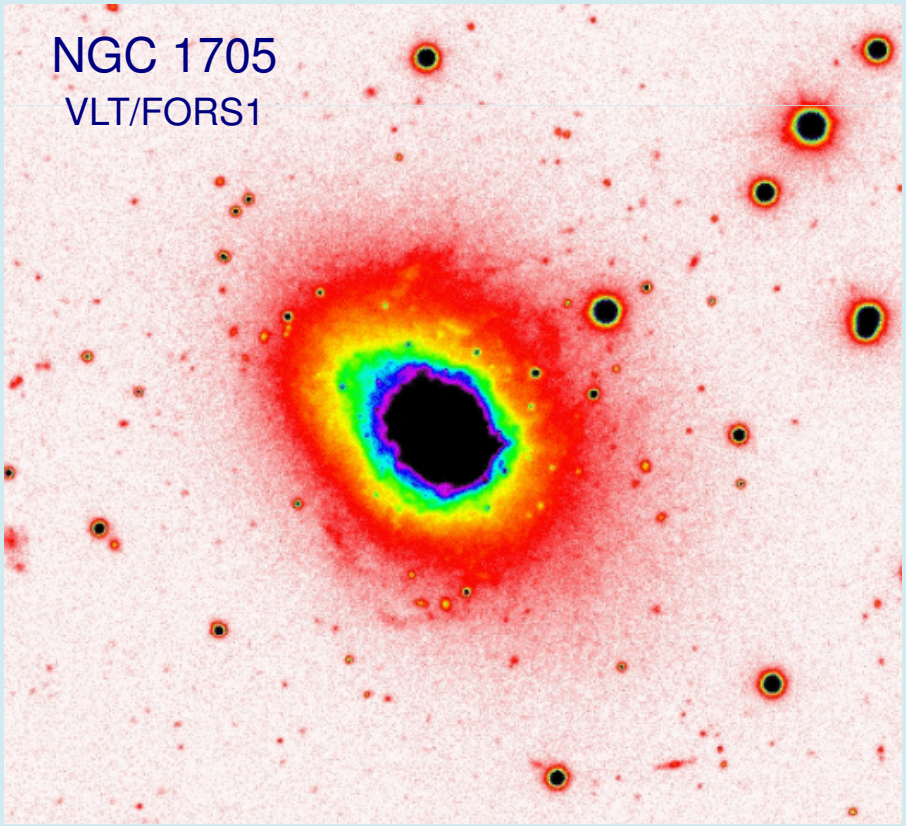




- Starburst: physical origin, feedback processes and self-regulation
- Evolutionary pathways of low-mass starburst galaxies in the early Universe
- Evolutionary links between BCDs and other types of dwarf galaxies in the local universe (dwarf irregulars dIs and dwarf ellipticals dEs)



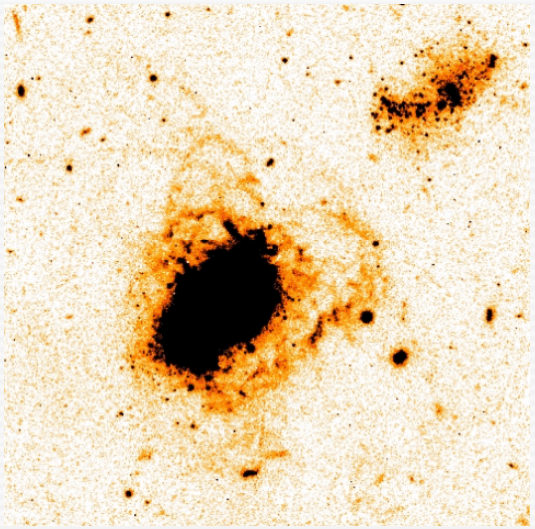
The overwhelming majority of BCDs possess an evolved host galaxy



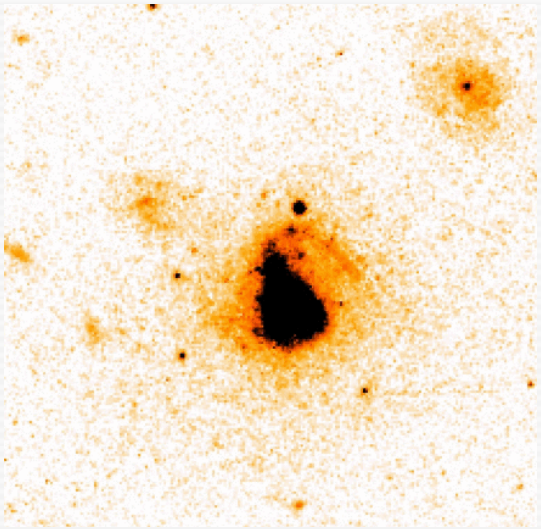
There are very few exceptions!

II. Extremely metal-deficient **BCD**s: **XBCD**s

Young galaxy candidates in the local universe?

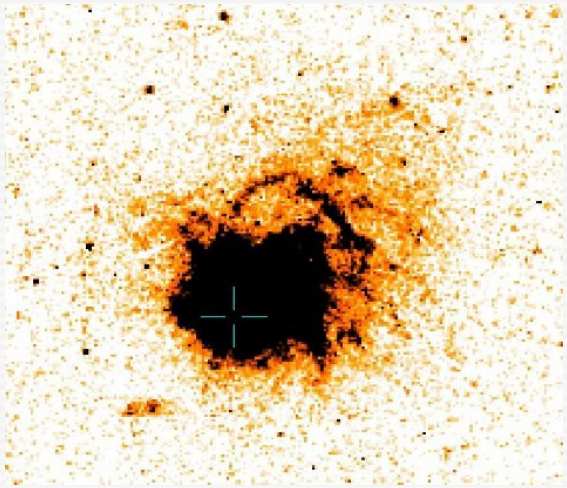


Papaderos et al. (2002)

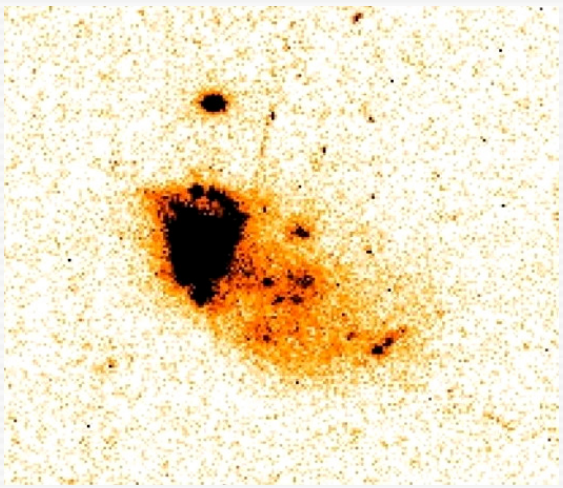


Guseva, Papaderos, Izotov et al. (2004)

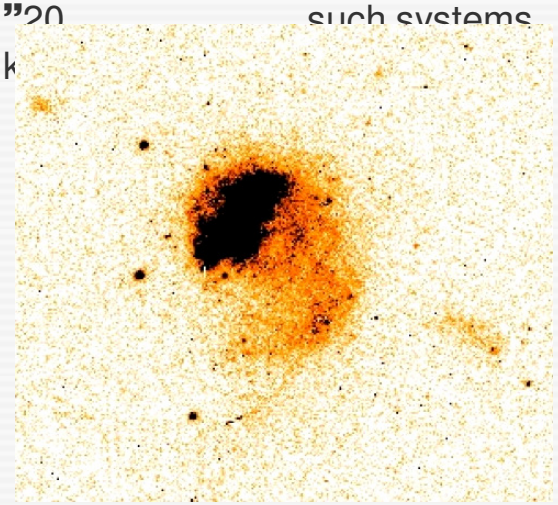
- no evidence for an old host galaxy
- irregular morphology and intense star-forming activity
- extremely metal-deficient ($Z_{\odot}/60 \leq Z \leq Z_{\odot}/20$)
- extremely rare (<1% of the BCD-population; until recently only ”20 such systems k



Thuan et al. (1997),
Papaderos et al. (1998)



Fricke, Izotov & Papaderos (2001)
Papaderos et al. (2006)



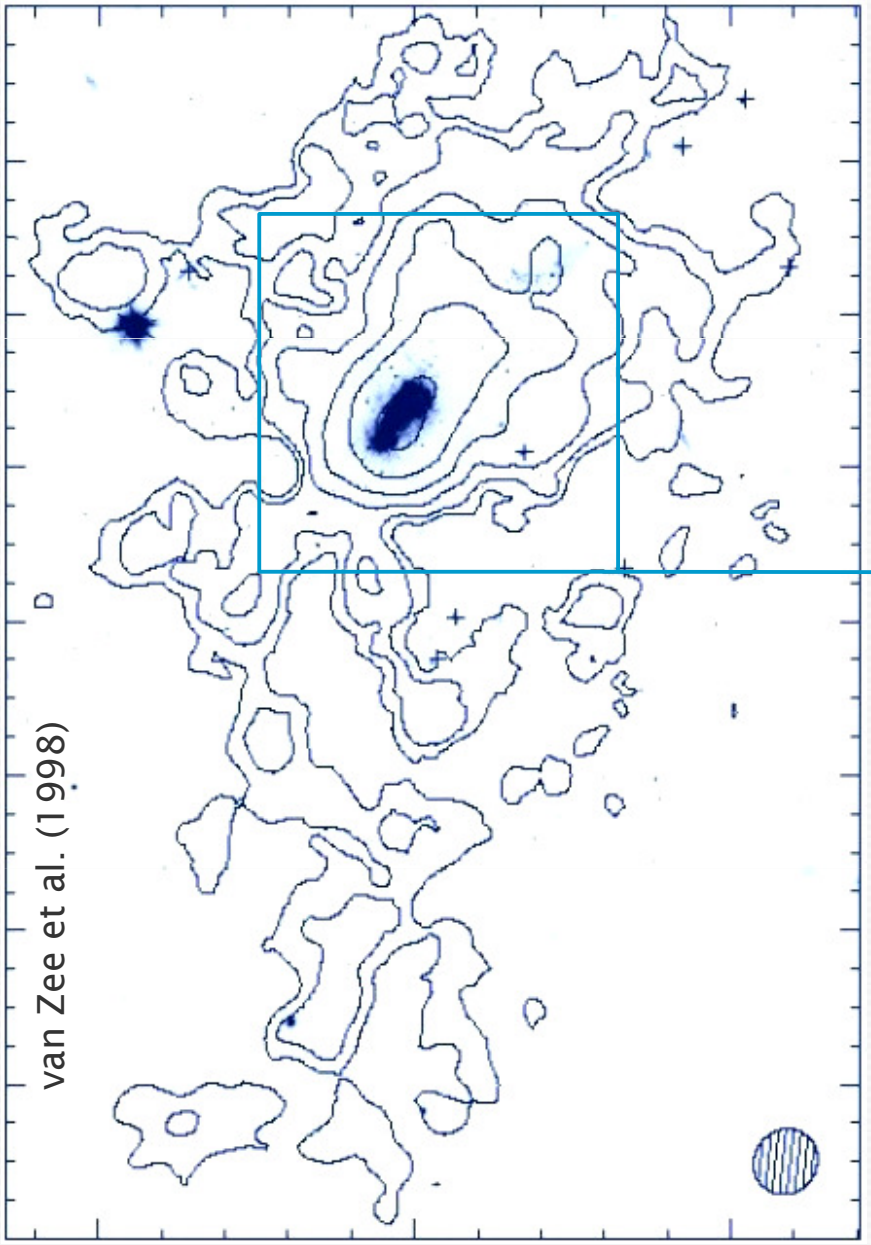
Papaderos et al. (1999,2007)

Why are we interested in XBCDs?

- Star formation and feedback processes under chemical conditions similar to those in primeval galaxies
  - gas collapse characteristics and star formation at low metallicity
  - properties of massive low-metallicity stars
  - cooling efficiency of the hot, X-ray emitting plasma
- Determination of the primordial ^{4}He abundance
- Dynamical build-up and early chemical and spectrophotometric evolution of low-mass galaxies
  - dynamical processes (e.g. monolithic collapse, inside-out; timescales)
  - metallicity gradients
  - observational constraints to numerical simulations of dwarf galaxy formation



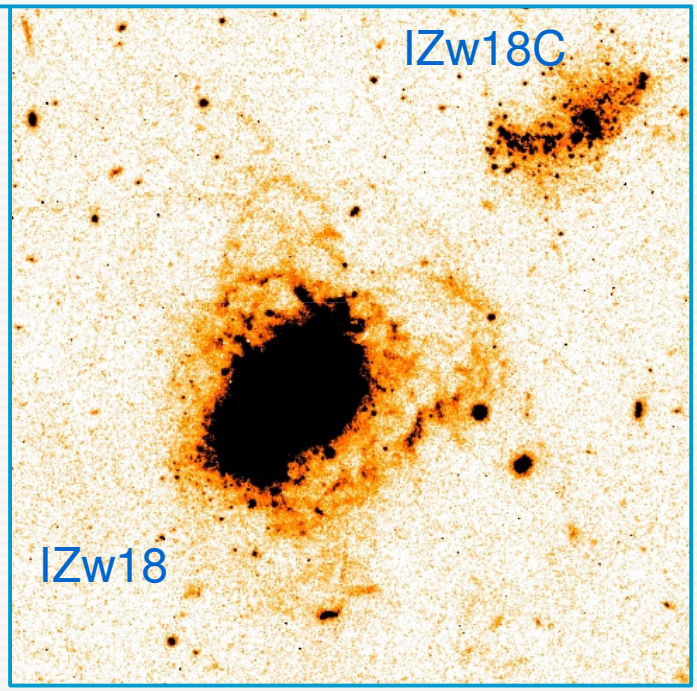
I Zw 18 – the prototypical XBCD ($Z=Z_{\odot}/50$, D=15 Mpc)



21cm VLA map



Fritz Zwicky (1898-1974)

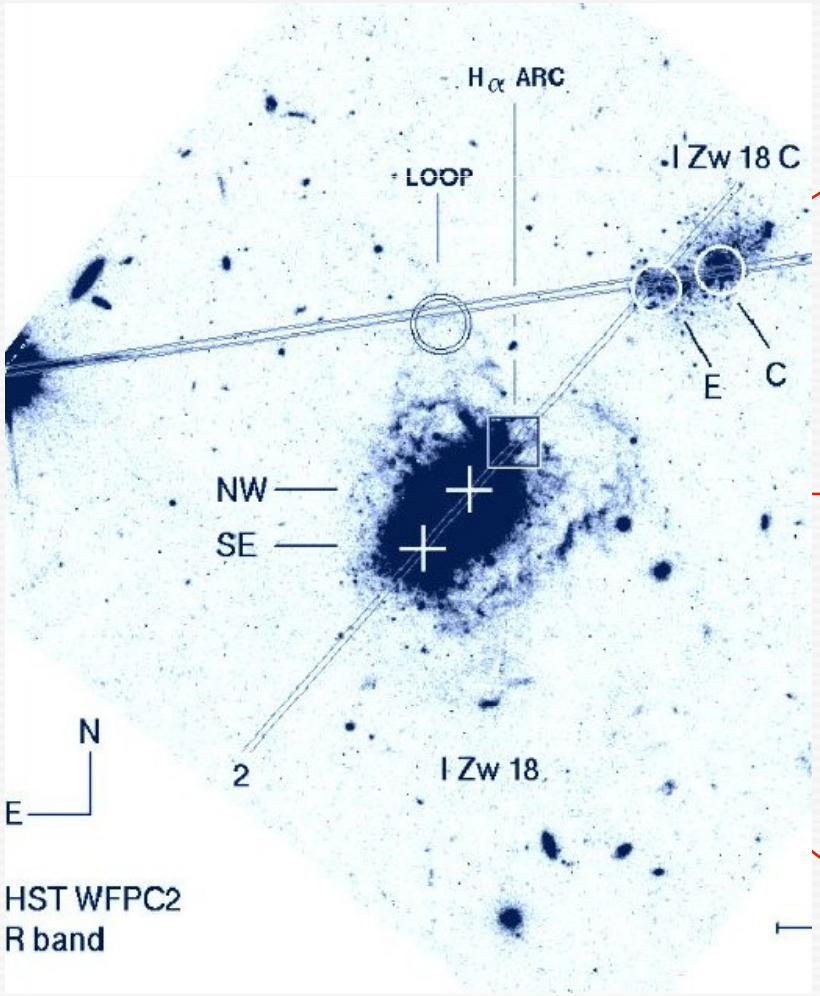


Optical HST exposure

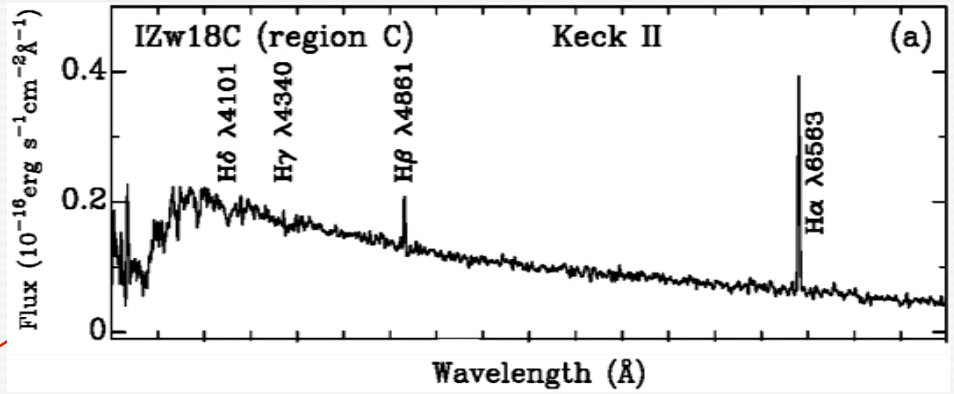


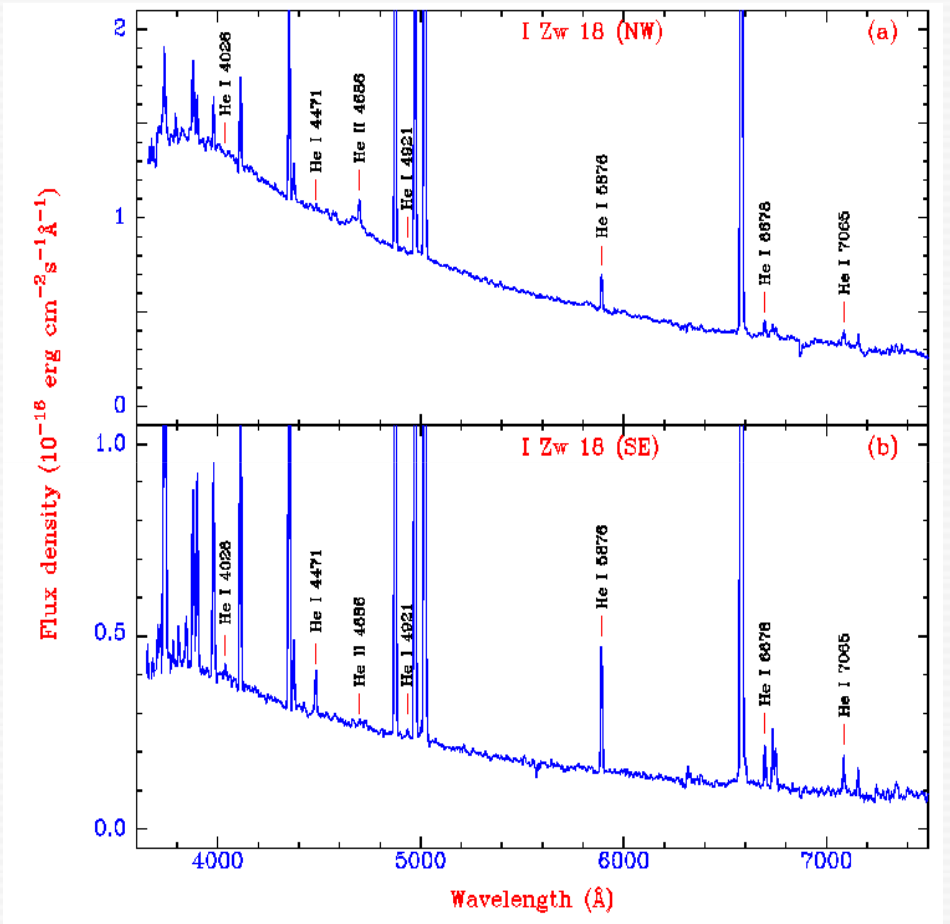
Morphological and Photometric Properties of Extremely Metal-Deficient Blue Compact Dwarf Galaxies

I Zw 18 – the prototypical XBCD

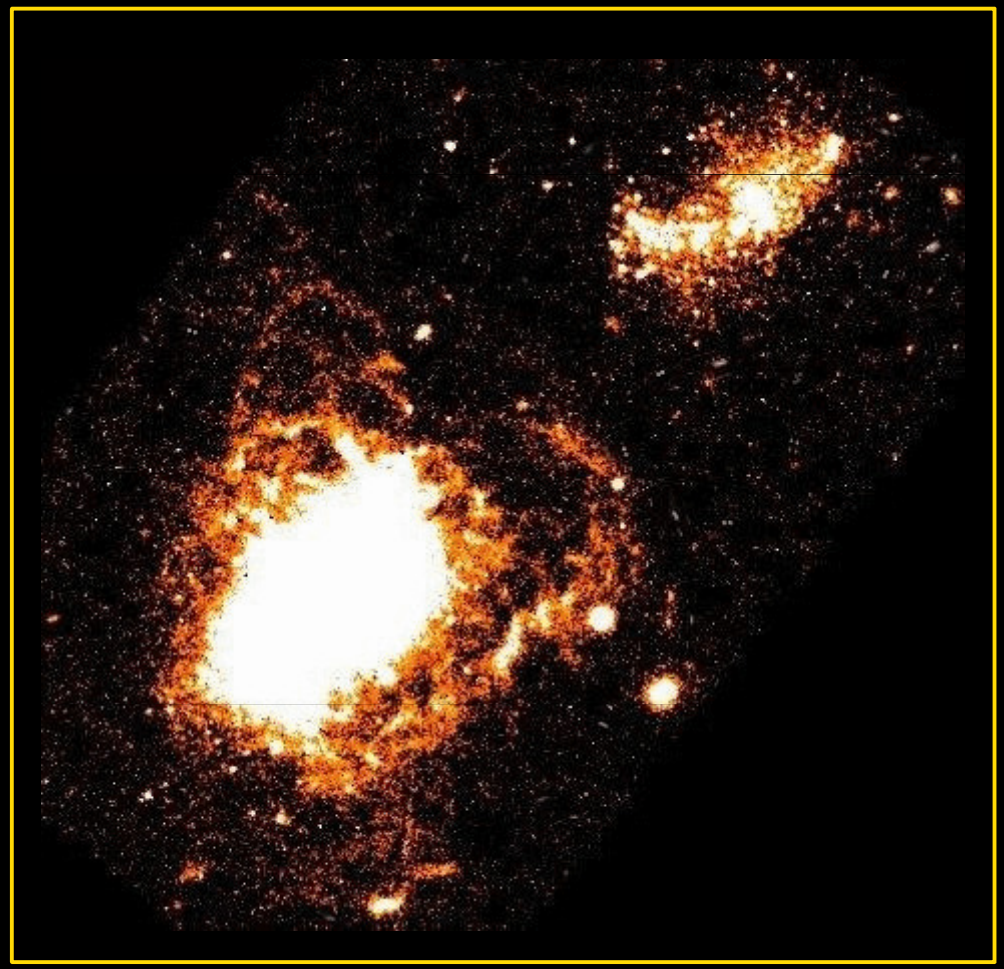


Izotov et al. (2001), Papaderos et al. (2001, 2002)





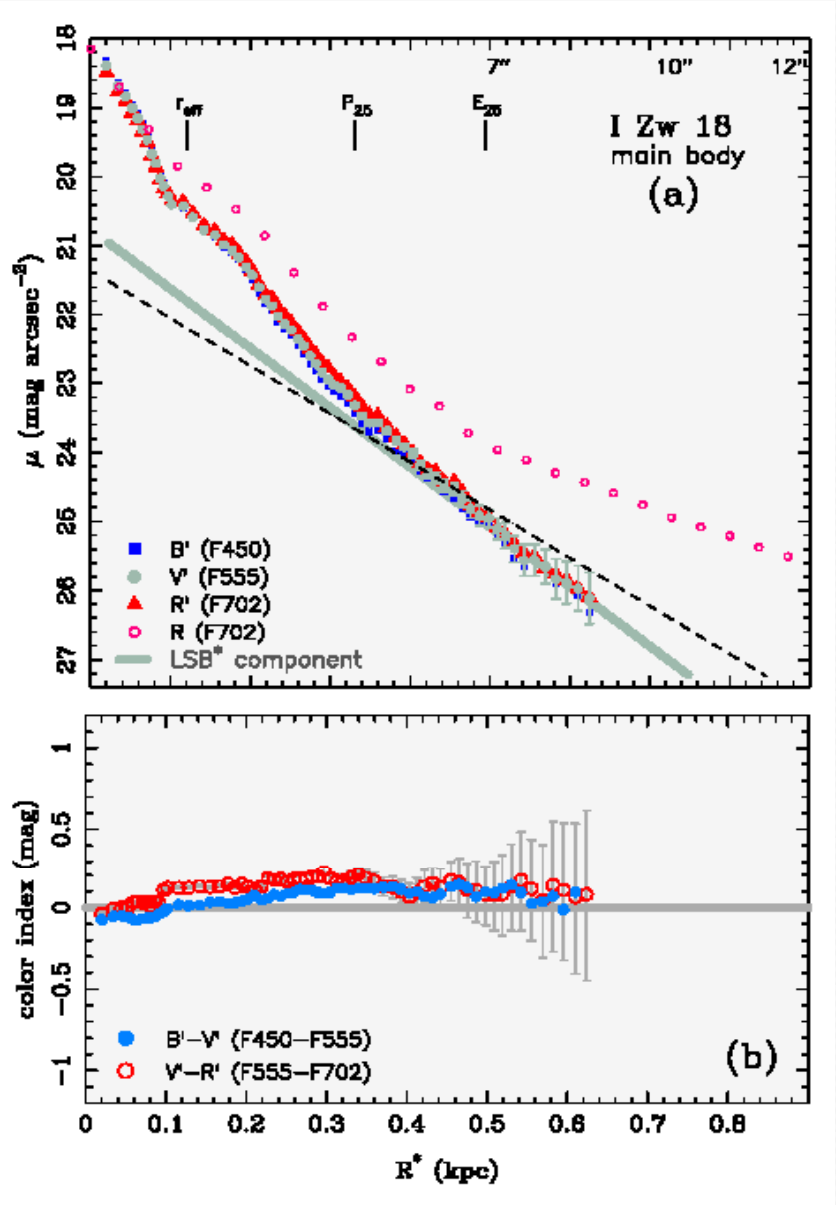
I Zw 18: a dwarf galaxy forming within an extended halo of ionized gas



Papaderos et al. (2001, 2002)



Zw 18: a dwarf galaxy forming within an extended halo of ionized gas



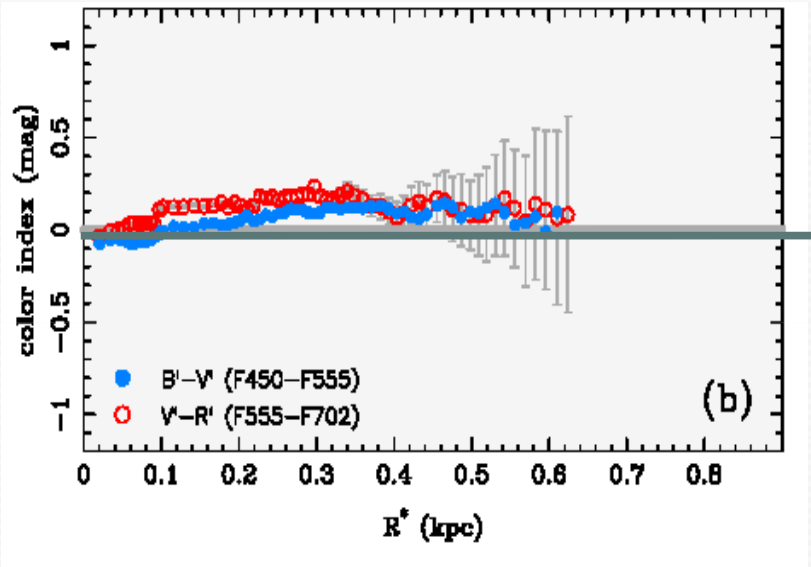
Papaderos et al. (2002)

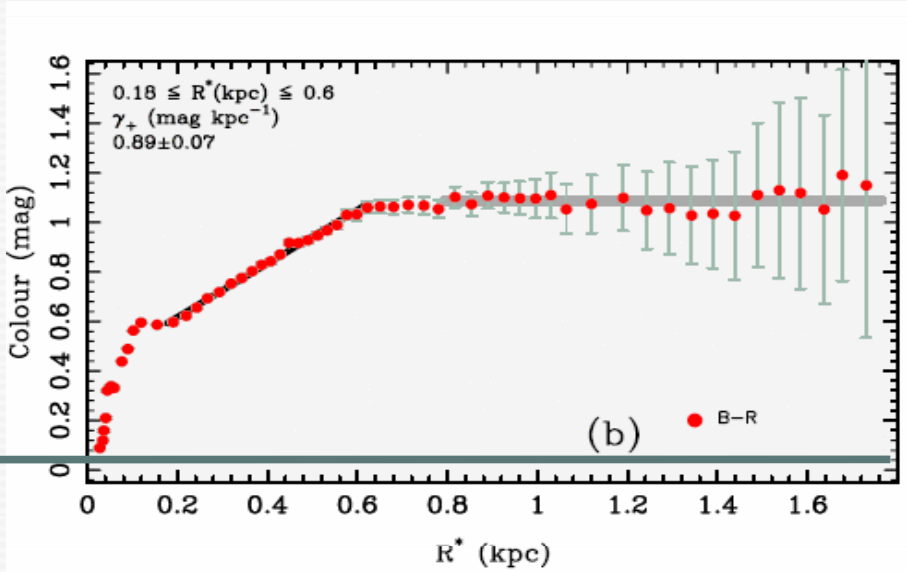
- I Zw 18 main body: compact host galaxy, immersed within a more extended halo of ionized gas
- The Hβ line contributes ~40% of the total R-band emission of IZw18's main body
- The host galaxy of I Zw 18 shows an exponential profile,
- ... very blue (V-I=0.-0.3) colors and no color gradients
- Estimated galaxy age[1]: 0.5 Gyr

[1]: age of the dynamically dominant fraction of the stellar component, assuming a standard IMF and a SFH approximated by an exponentially decreasing SFR with

I Zw 18: comparison with an old BCD

Color profile of the stellar component of I Zw 18





Color profile of the old BCD Mkn 178

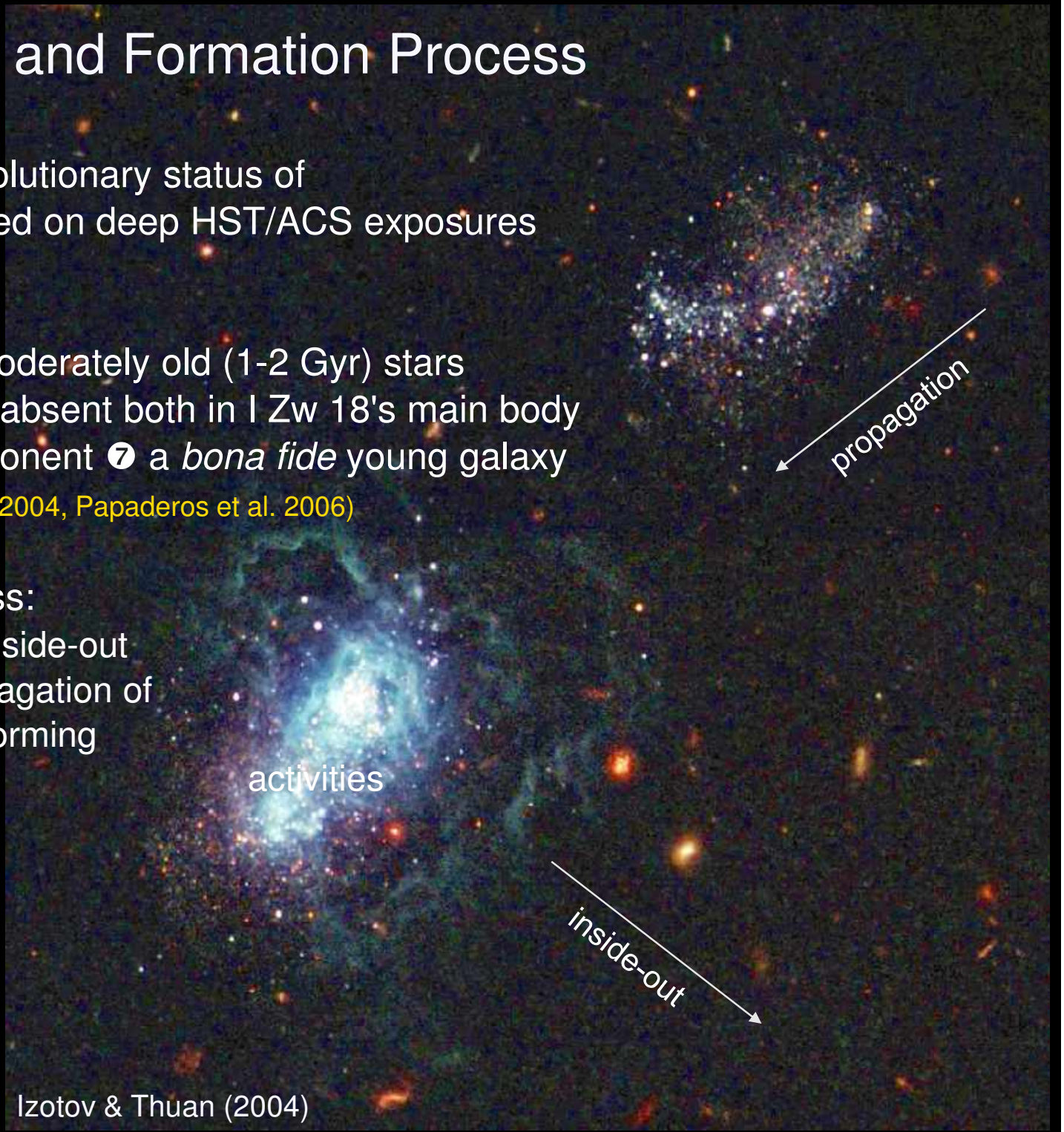


I Zw 18: Age and Formation Process

- Studies of the evolutionary status of I Zw 18 based on deep HST/ACS exposures
  (Izotov & Thuan 2004)

- Candidates for moderately old (1-2 Gyr) stars are virtually absent both in I Zw 18's main body and C component ❼ a *bona fide* young galaxy
  (Izotov & Thuan 2004, Papaderos et al. 2006)

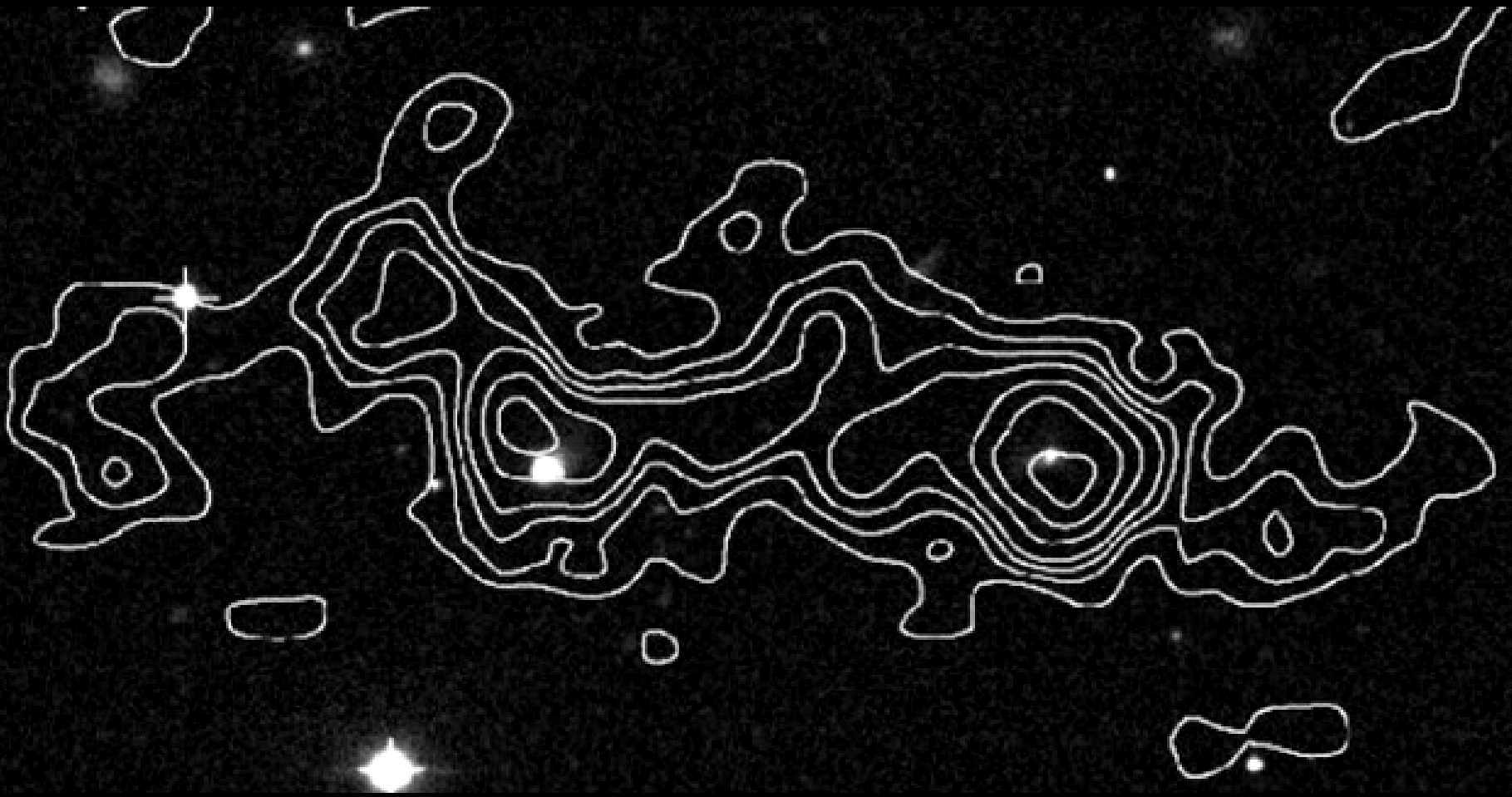
- Formation Process:
  main body: inside-out
  IZw18C: propagation of star forming activities



Izotov & Thuan (2004)



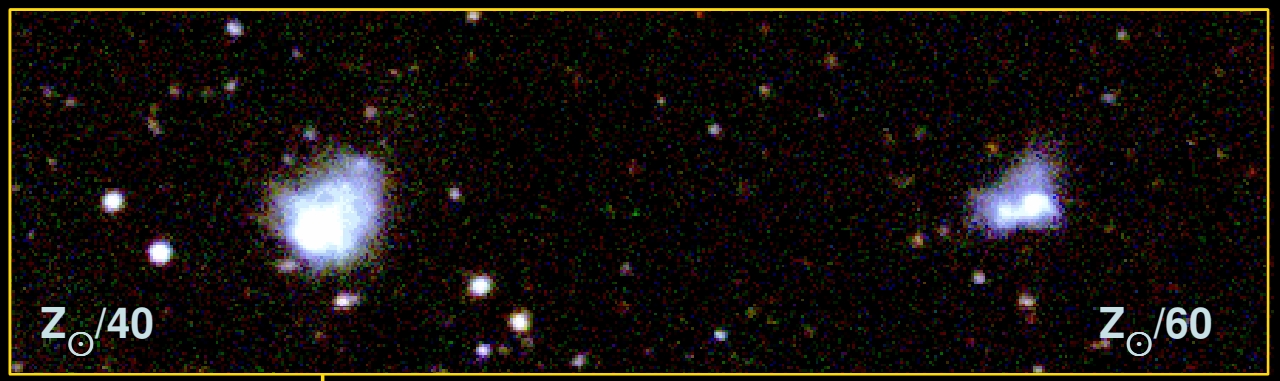
The pair of XBCDs SBS 0335-052 E&W



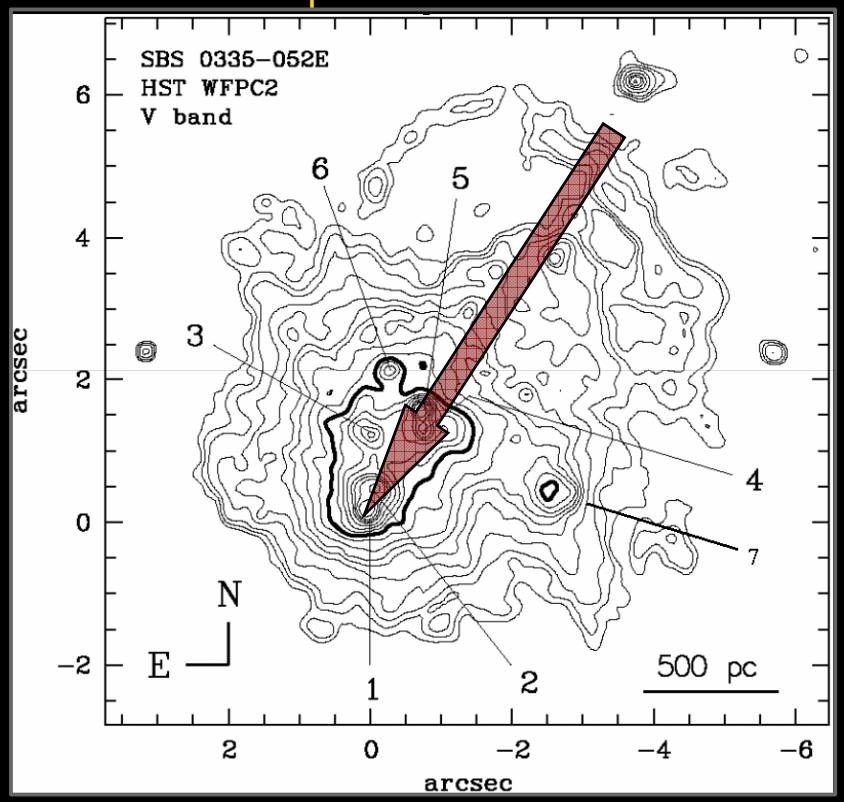


SBS 0335-052: HI cloud with a projected size of 70×20 kpc and a mass of ~10^9 $M_\odot$ (Pustilnik et al. 2001)

The pair of XBCDs SBS 0335-052 E&W



ESO 3.5m NTT
Papaderos et al. (2006b)



Papaderos et al. (1998)

SBS 0335-052 (D=54.3 Mpc)
M_V = -17 mag/-15 mag for E&W, resp.

SBS 0335-052 E

- No detectable old host galaxy ($M_* \sim 10^7 M_\odot$; age < 1 Gyr)
- Study of the color and spatial distribution of several stellar clusters using HST data

→

galaxy is forming in a propagating mode from northwest to southeast

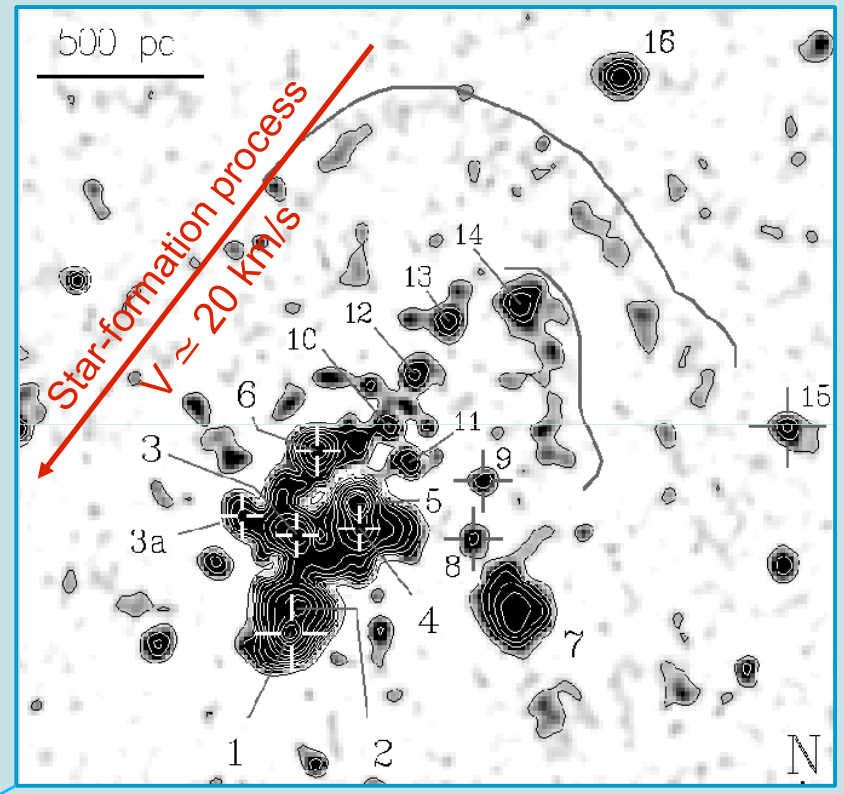


Formation process of SBS 0335-052E

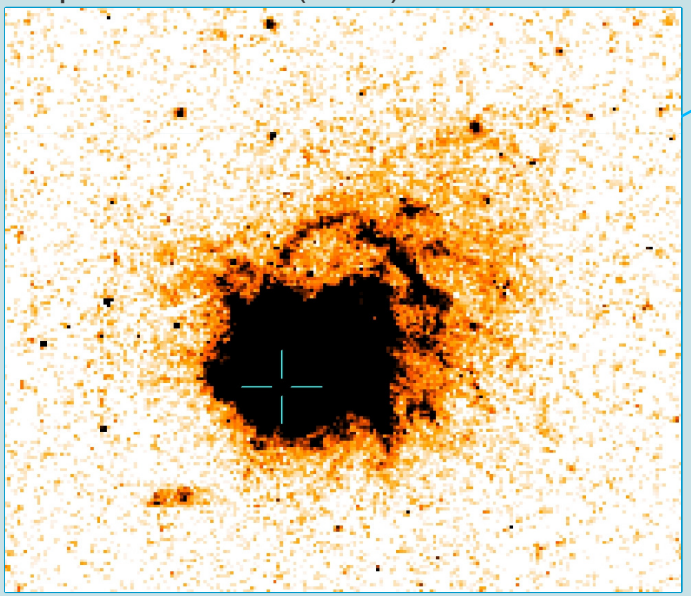
- Application of a flux-conserving unsharp masking technique (Papaderos 1998) led to the detection of several faint clusters in NW direction.

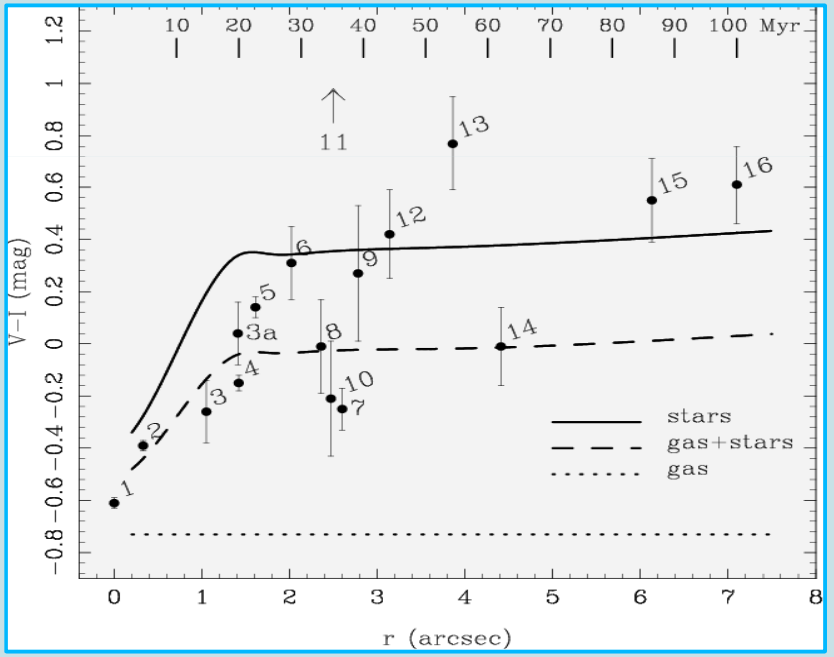
- Color (i.e. age) gradient along the major axis of SBS 0335-052, with the older stellar clusters being located towards the NW direction.

- From the age of individual clusters one can estimate the propagation velocity of star-forming activities from NW towards SE to 10-20 km s^{-1}.



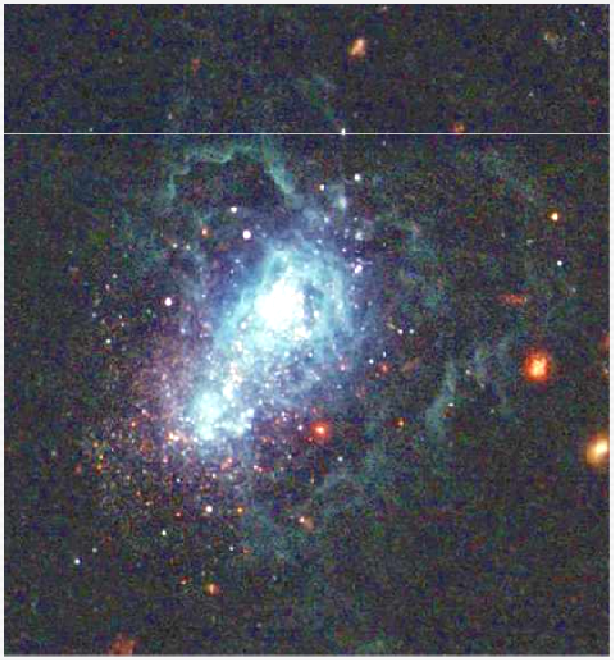
Papaderos et al. (1998)



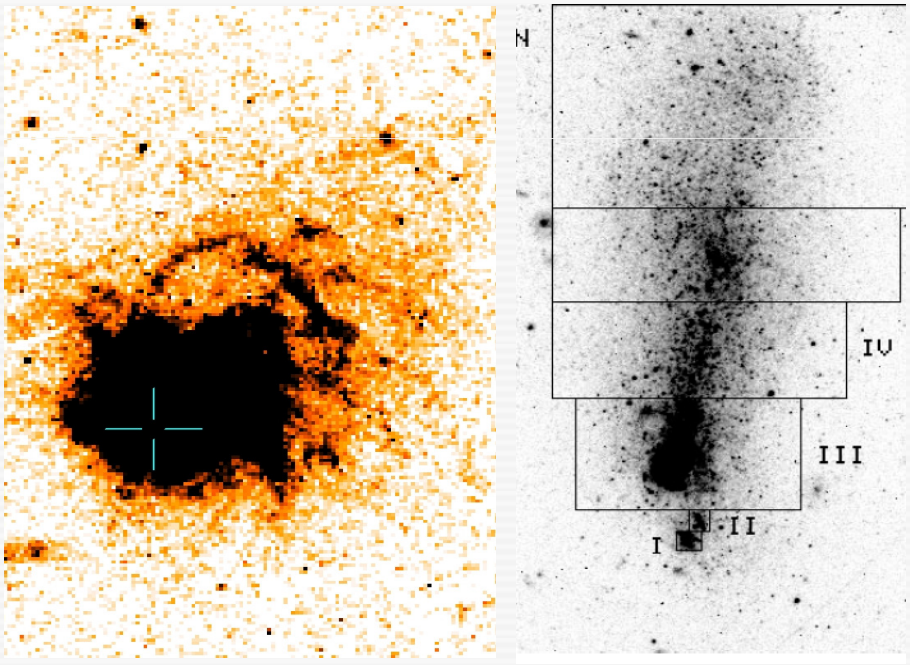




XBCDs: laboratories to study the formation of low-mass galaxies



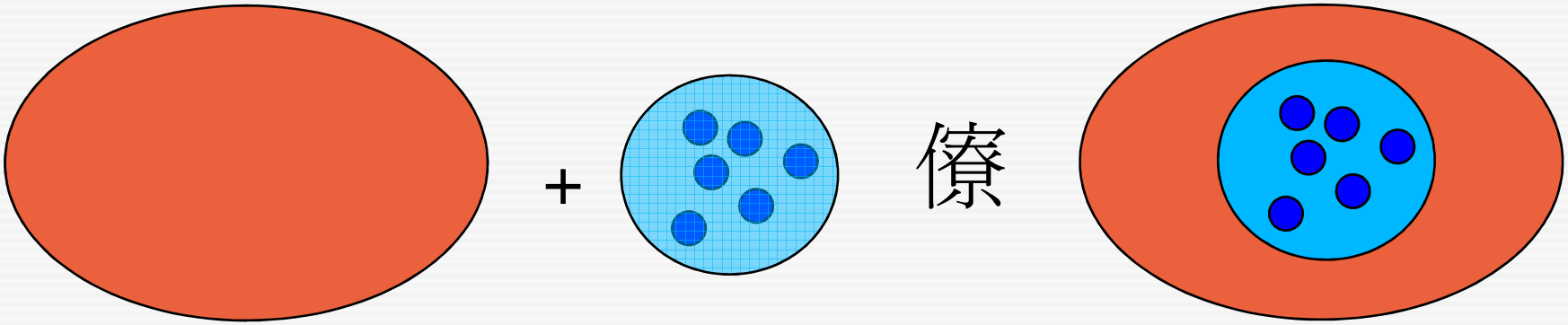
inside-out



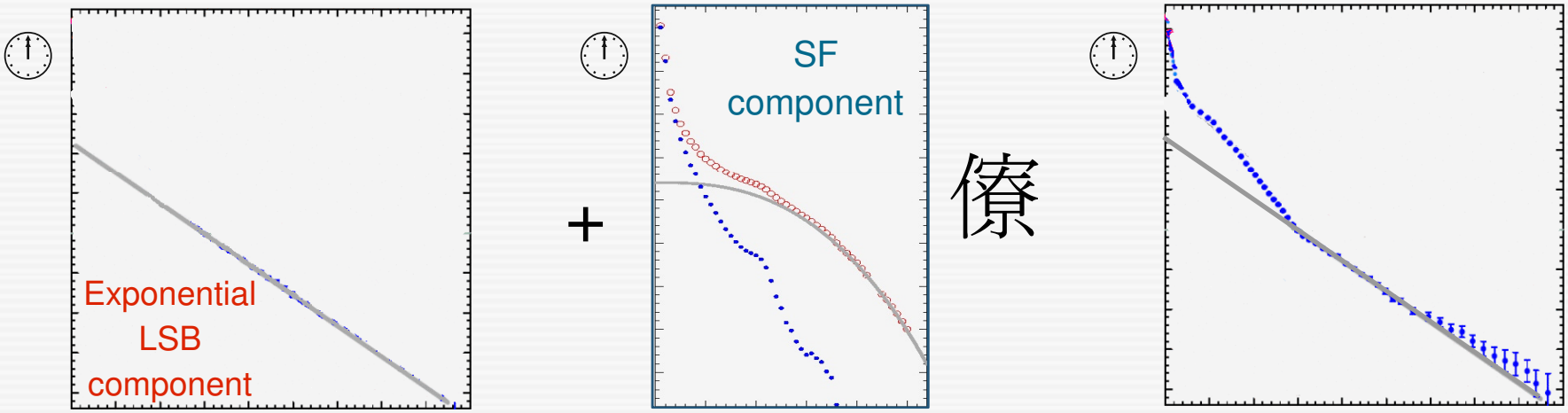
Propagating star formation
and outwards diffusion of stars



Structural properties of the host galaxy of XBCDs



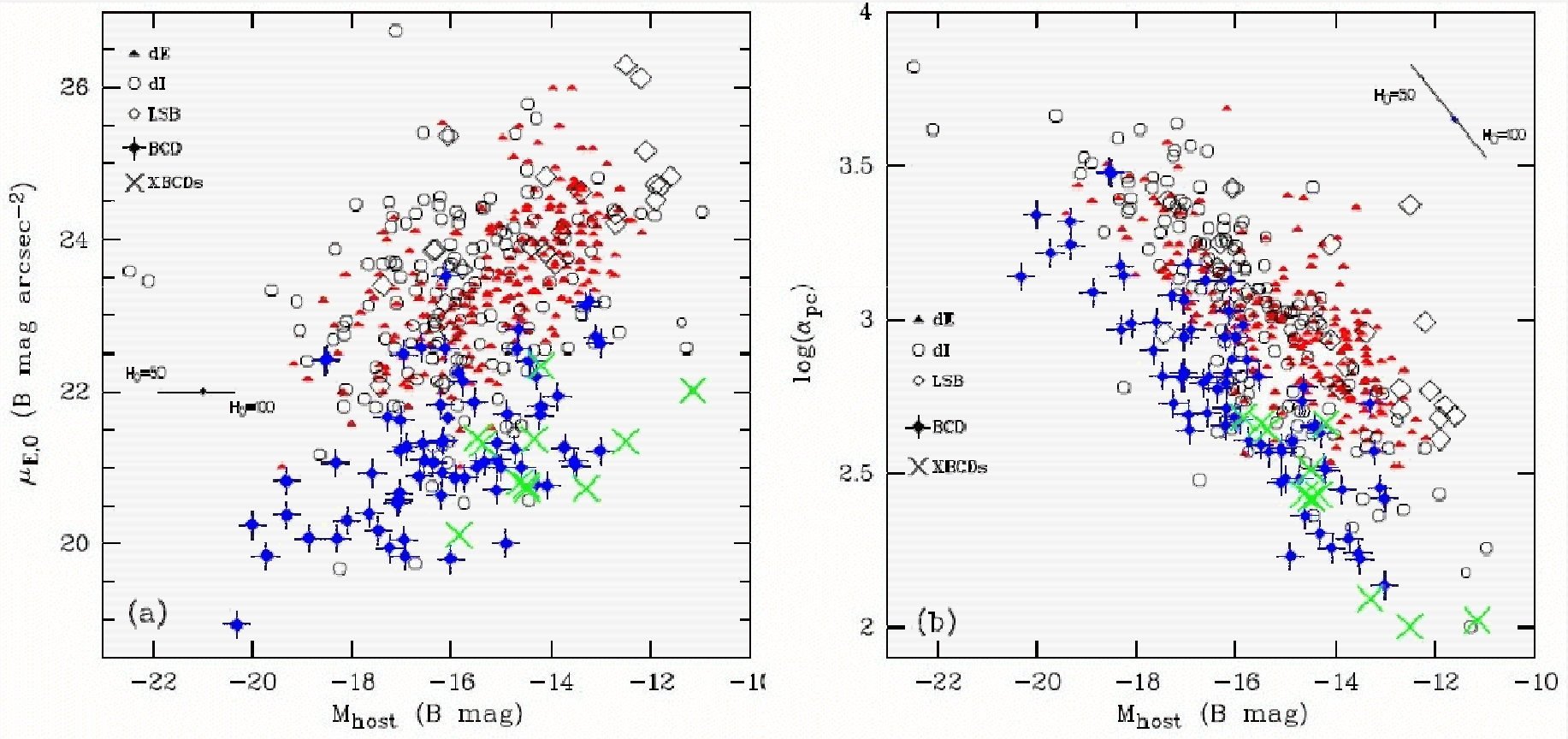
Host Galaxy + Starburst 僚 BCD



Radius (R*) + Radius (R*) 僚 Radius (R*)



Structural properties of the host galaxy of XBCDs

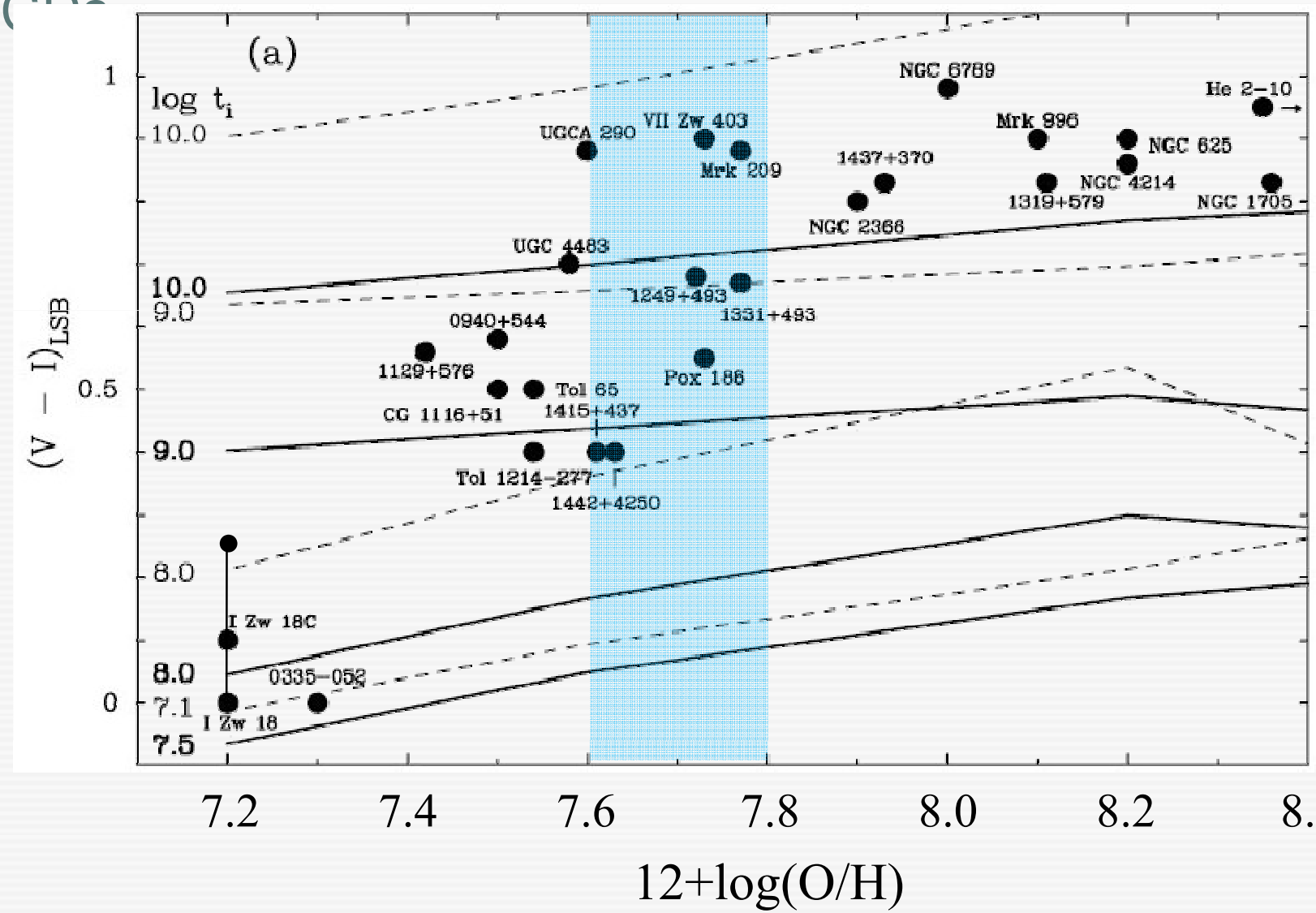


- The host galaxy of XBCDs can be approximated in its outer parts ($R^{\square}$ ⑦ 3 囡)

  by an exponential fitting law

- (the few photometrically studied) XBCDs do not significantly differ from evolved BCDs with respect to the structural properties ($\textcircled{1}_{E,0}$, 囡) of

Gas-phase metallicity vs. color of the host galaxy in XBCDs

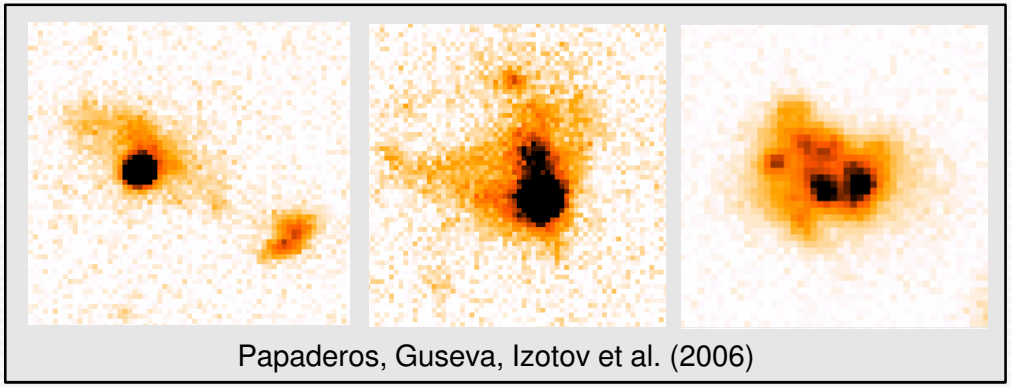


Guseva et al. (2003)

- 12+log(O/H)>7.8: no relation between metallicity and color of the host galaxy
- 12+log(O/H)>7.6: (...) possible trend that cannot be explained



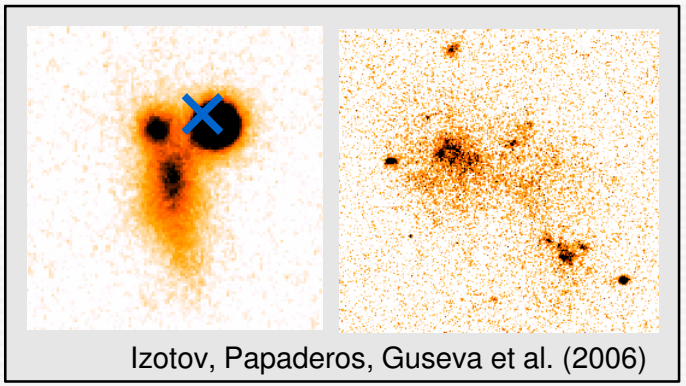
Search for new extremely metal-deficient emission-line galaxies



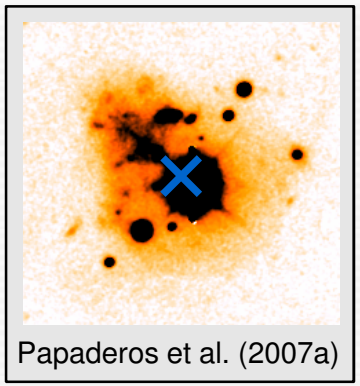
Papaderos, Guseva, Izotov et al. (2006)

Sloan Digital Sky Survey

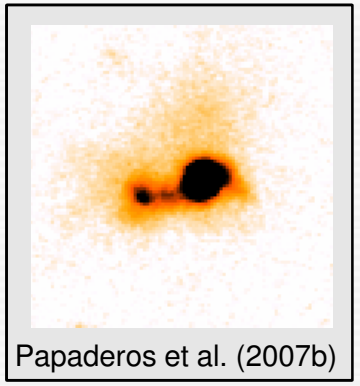
6DF GALAXY SURVEY



Izotov, Papaderos, Guseva et al. (2006)



Papaderos et al. (2007a)



Papaderos et al. (2007b)

- Visual inspection of ”10^6 spectra from SDSS and 6dF
- Extraction of a list of 150 new XBCD candidates and follow-up spectroscopy with the 3.6m ESO telescope at La Silla
- Discovery of **15 (!)** XBCDs



Morphological and Photometric Properties of Extremely Metal-Deficient Blue Compact Dwarf Galaxies



4 observing runs since 2003; continuation of the programme in ESO P79



VLT/FORS2: 4 nights of observing allocated during Period 78 (October 2006 – March 2007)



10m Southern African Large Telescope (SALT): ongoing observations of XBCD candidates (PVP)





Summary

- Some of the extremely metal-deficient ($Z_\odot/60 \leq Z \leq Z_\odot/20$) BCDs (XBCD) in the local Universe are young (i.e. $M_{\star,old}/M_{\star,young} \lesssim 1/5$)

- └ (gas-phase) metallicity – age – morphology relation for XBCDs

- The host of XBCDs does not significantly differ from BCDs in its structural properties → common evolutionary sequence

- XBCDs are important laboratories of observational cosmology (dynamical formation and early chemical evolution of low-mass "galaxy building blocks", properties of metal-poor massive stars, observational constraints to galaxy downsizing scenarios)

- Much coordinated work is needed

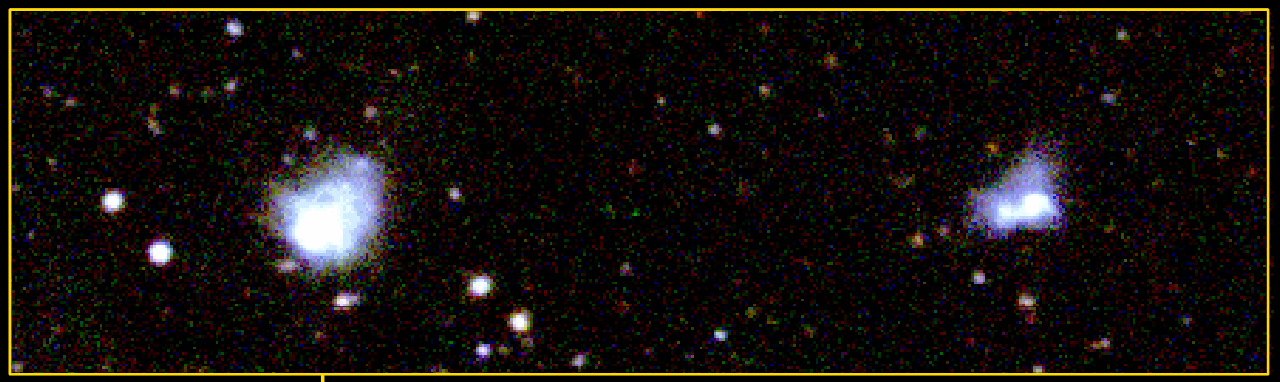
Additional Material

P. Papaderos

Granada 1.3.2007

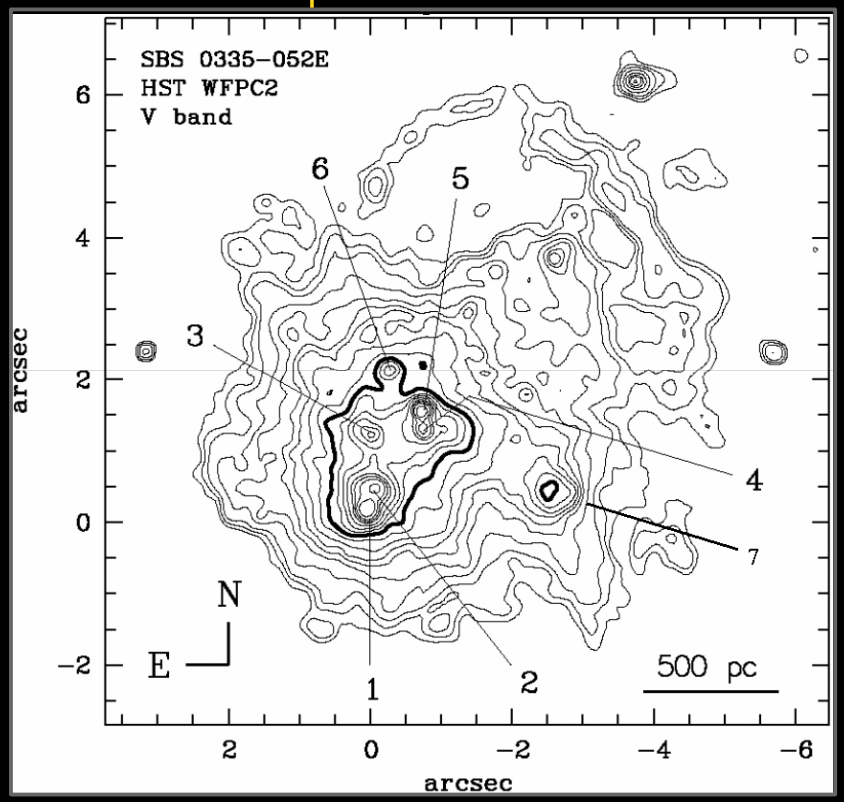
Morphological and Photometric Properties of Extremely Metal-Deficient Blue Compact Dwarf Galaxies

The pair of extremely metal-deficient BCDs SBS 0335-052 E&W



ESO 3.5m NTT
Papaderos et al. (2006b)

Star-formation process
V ≃ 20 km/s



Papaderos et al. (1998)

SBS 0335-052 (D=54.3 Mpc)

M_V = -17 mag/-15 mag for E&W, resp.

SBS 0335-052 E

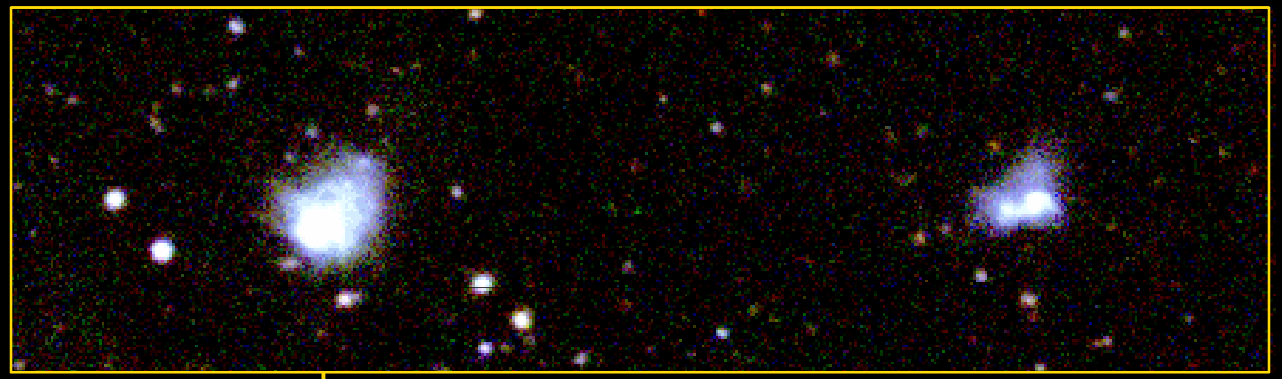
- Several very bright SSCs (-14.9 ≤ MV ≤ -11) at the SE part of the galaxy; supershell expanding towards NW
- Diffuse X-ray emission
- Oxygen abundance 12+log(O/H) between 7.30 ($\simeq Z_\odot/40$ in region 1&2) and 7.20 ($\simeq Z_\odot/50$ in region 7)
- Wolf-Rayet features in region 3
- Strong ionized gas emission: H equivalent width of 370 Å
- No detectable old host galaxy (M_*~10^7 $M_\odot$); age < 1 Gyr

SBS 0335-052 W : $Z_\odot/60$

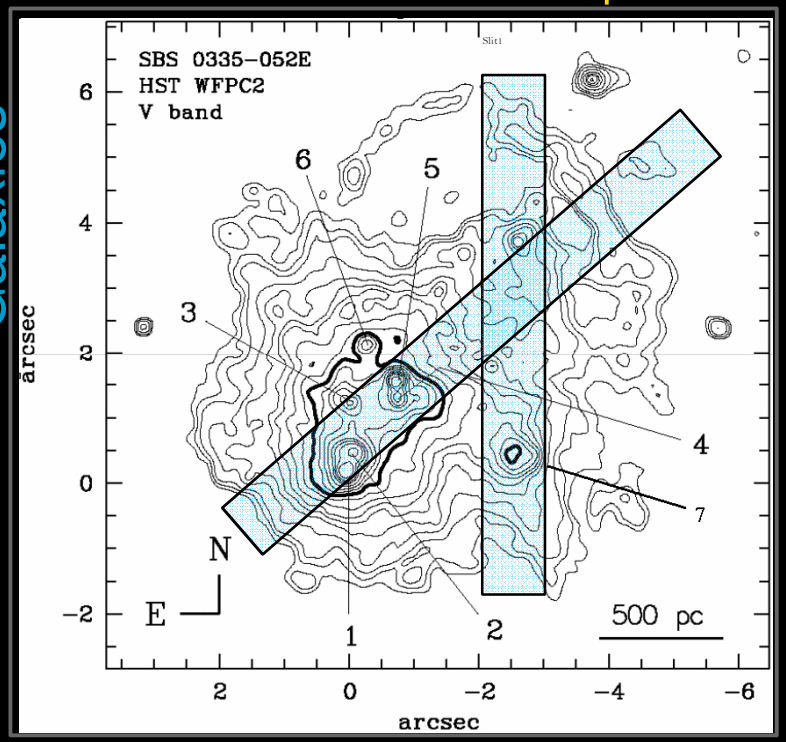
Dissecting Blue Compact Dwarf Galaxies

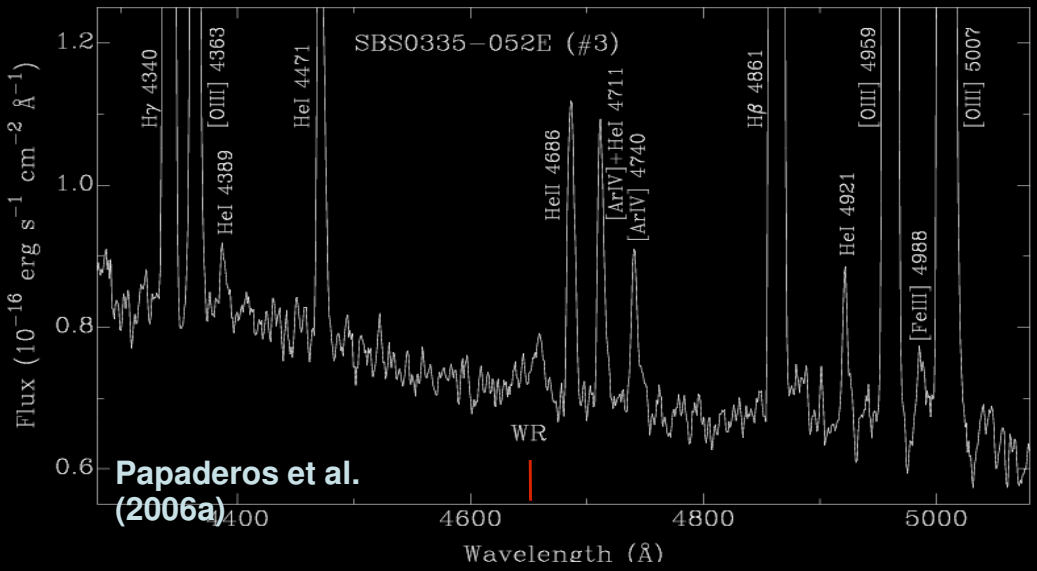
The pair of extremely metal-deficient BCDs SBS 0335-052 E&W

SBS 0335-052E **SBS 0335-052W**



ESO 3.5m NTT
Papaderos et al. (2006b)





The spectrum of cluster #3 (taken under seeing conditions of 0.7" FWHM) reveals a broad emission feature at λ4658 Å This feature is coincident with the [Fe III]λ4658 nebular emission line but its width is much larger than those of other nebular emission lines in the spectrum of cluster #3. We interpret therefore the broad feature as due mainly to the stellar Wolf-Rayet (WR) emission line C IV λ4658, a signature of WC4 stars. This would make SBS 0335-052E the second most metal-deficient galaxy, after I Zw 18 (Izotov et al. 1997, Legrand et al. 1997), in which a WR stellar population has been detected. The total λ4658 flux, corrected for the interstellar extinction C(Hβ) = 0.43 and the contribution of the [Fe III] λ4658 emission line corresponds to a luminosity L(C IV) = 1.1×10^{38} erg s^{-1} or to an equivalent number of WC4 stars N(WC4) = 22 ... 120, depending on adopted luminosity of one WC4 star .

Evolutionary Synthesis

Studies of the evolutionary status of XBCDs

