Thesis defence

Friday 11:00

Promotors:

Marc Verheijen

Filippo Fraternali

In collaboration with:

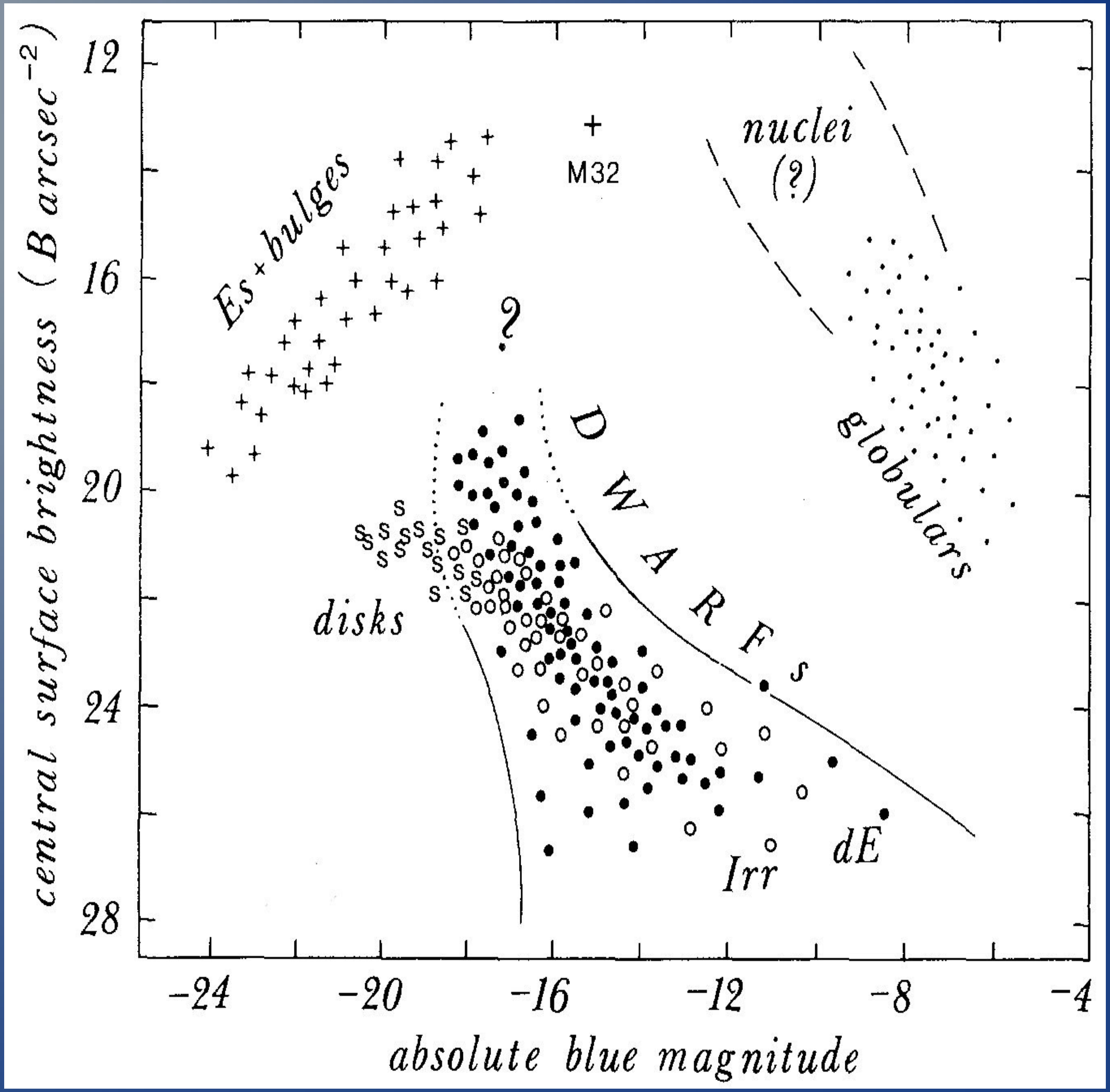
Renzo Sancisi

Outline:

- Introduction on (starbursting) dwarfs (Chap. 1)
- I. Large-scale HI morphology (Chaps. 2 and 6)
- II. Internal dynamics (Chaps. 2, 3 and 4)
- III. Evolution of dwarf galaxies (Chaps. 3 and 5)
- IV. A scaling relation for disk galaxies (Chap. 7)
- Conclusions (Chap. 8)

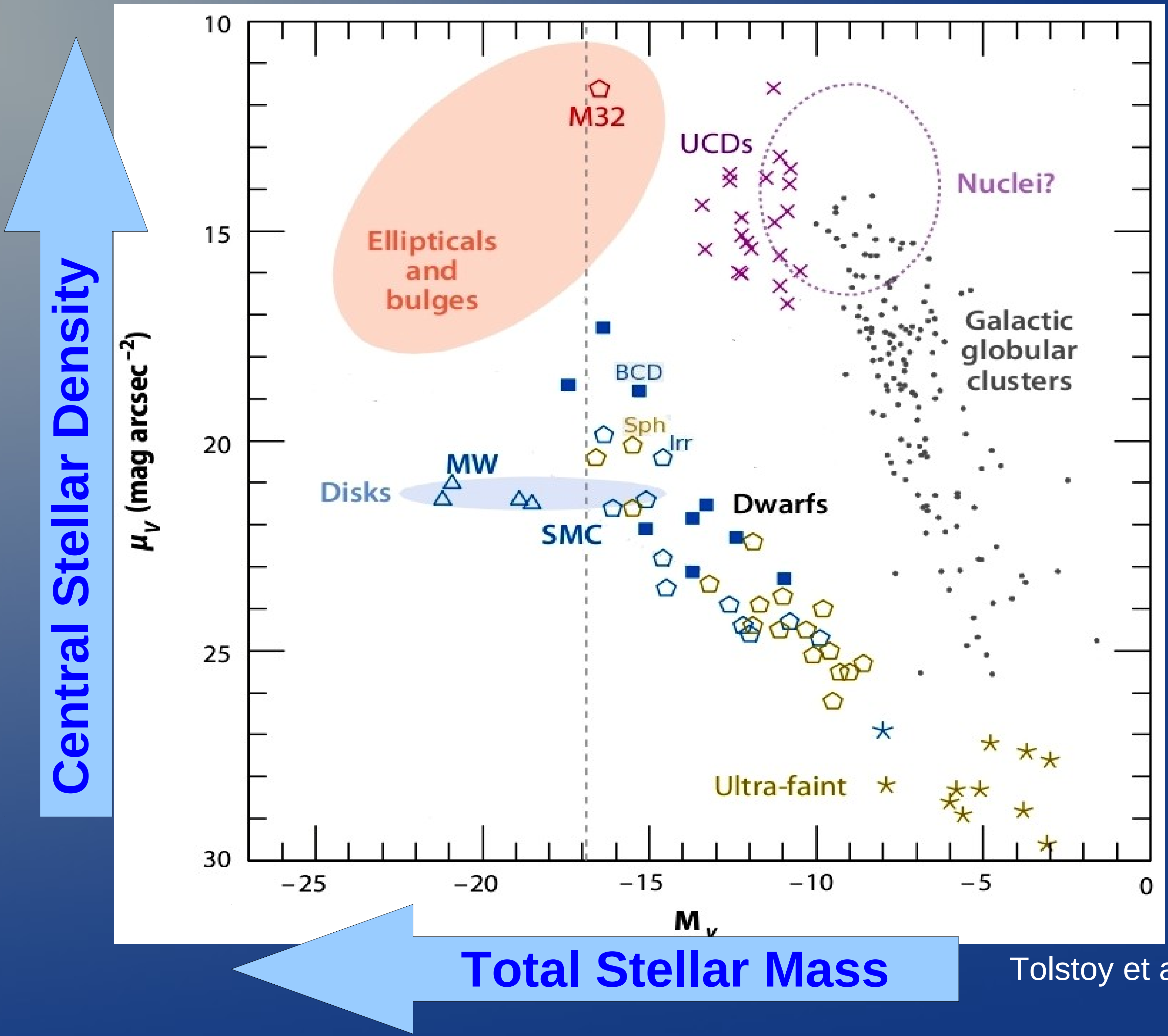
Introduction

Central Stellar Density

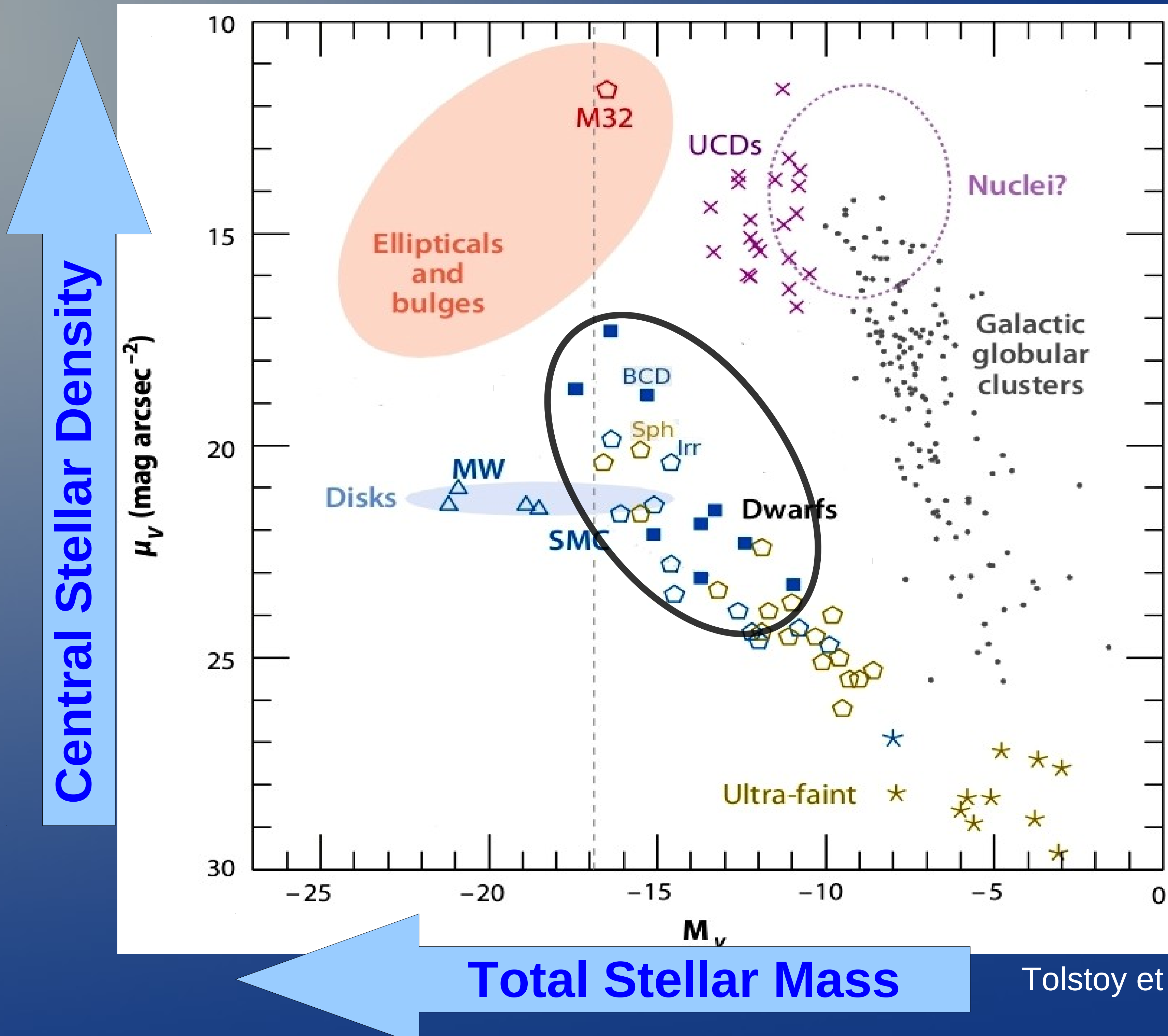


Binggeli (1994)

Total Stellar Mass



Tolstoy et al. (2009)



Tolstoy et al. (2009)

Spheroidals | Irregulars | Starburst dwarfs

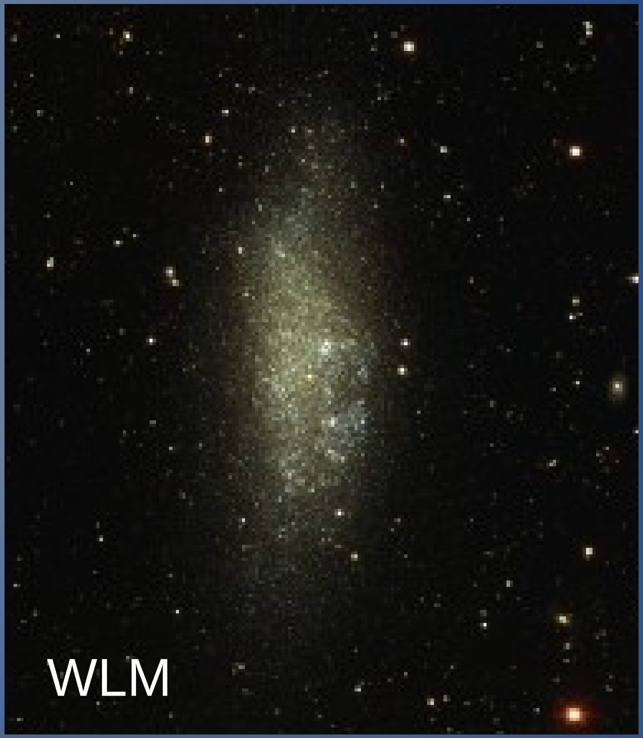
Spheroidals

- no recent SF
- close to spirals *or* in galaxy cluster

Other names:

dEs, early-type dwarfs

Irregulars



- relatively-low SF
- isolated, groups, *or* outskirts of clusters

Other names:

Im, Sm, late-type dwarfs

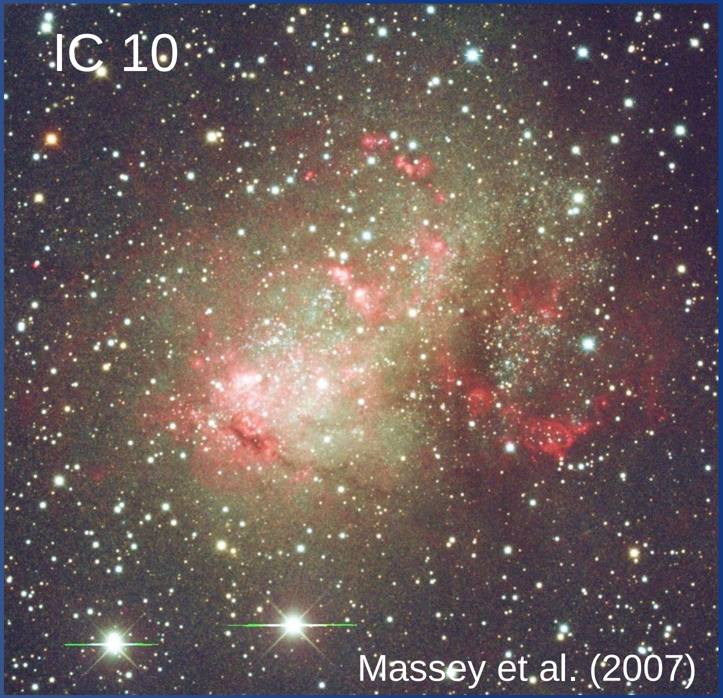
Starburst dwarfs

- strong bursts of SF
- isolated, groups, *or* outskirts of clusters

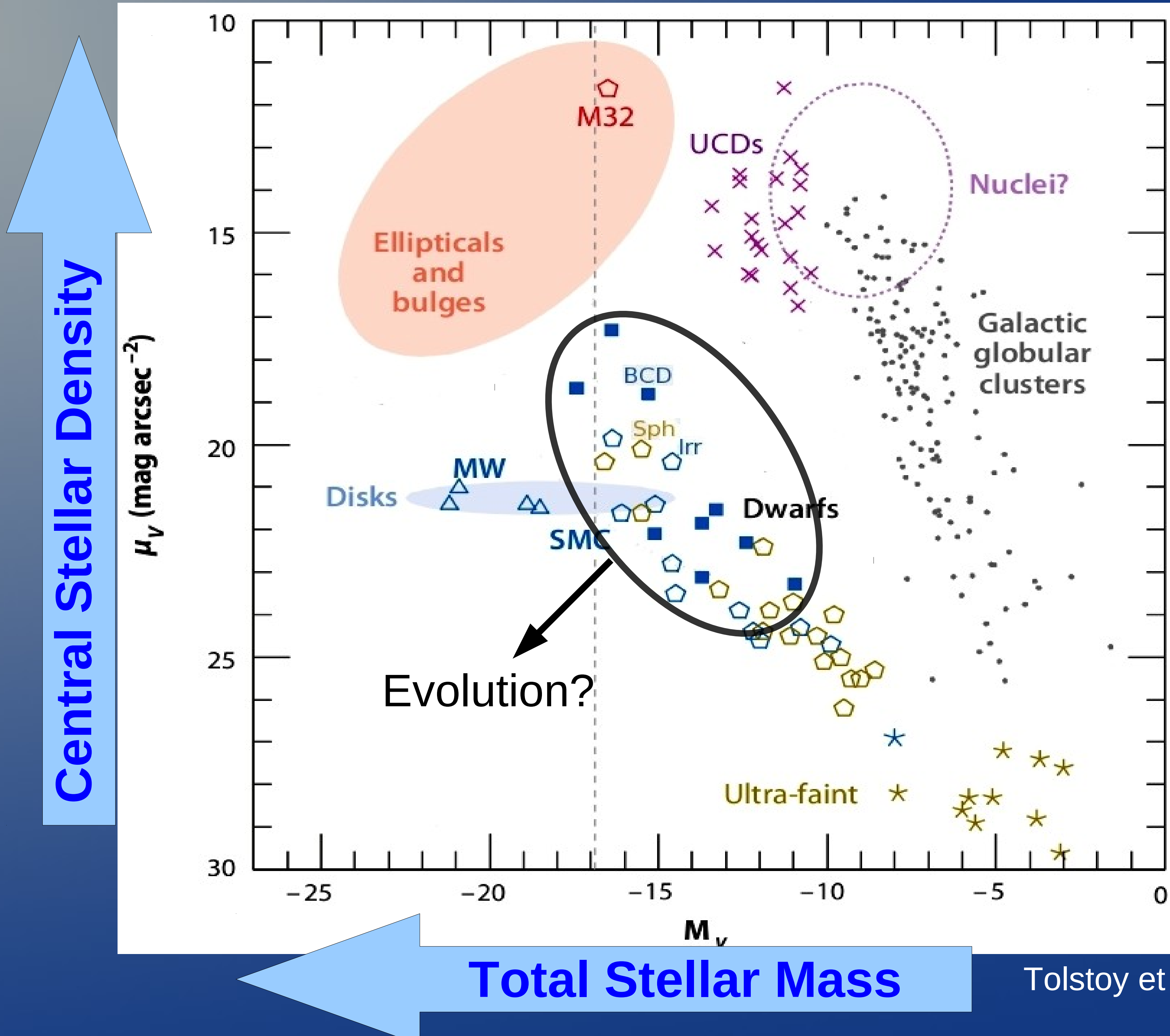
Other names:

HII galaxies, BCDs

BCDs = Starbursting Dwarfs



- **Blue** (young massive stars)
- **Compact** (small scale-length, high surf. bright.)
- **Dwarf** ($M_* \sim 10^7 - 10^9\ M_\odot$)



Tolstoy et al. (2009)

BCDs in a cosmological context

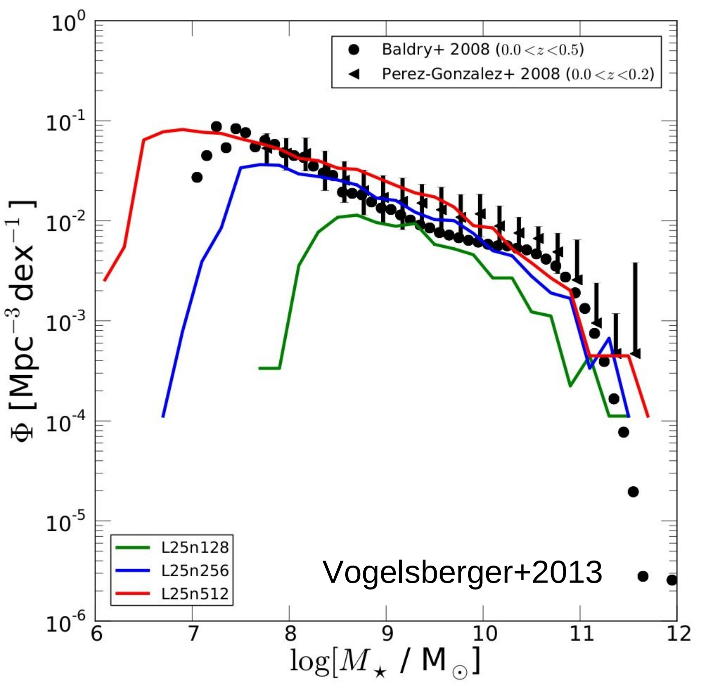
Stellar feedback is invoked to solve several problems...

- number density of low-mass galaxies (e.g. Kauffmann+1993, Vogelsberger+2013)

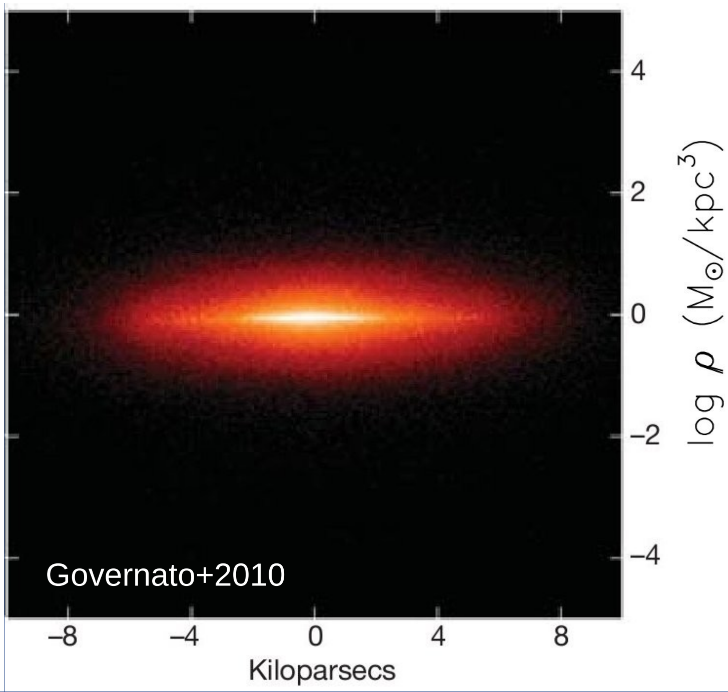
- existence of bulgeless galaxies (e.g. Governato+2010, Brook+2011)

- cusp-core problem (e.g. Navarro+1996, Oh+2011, Governato+2012)

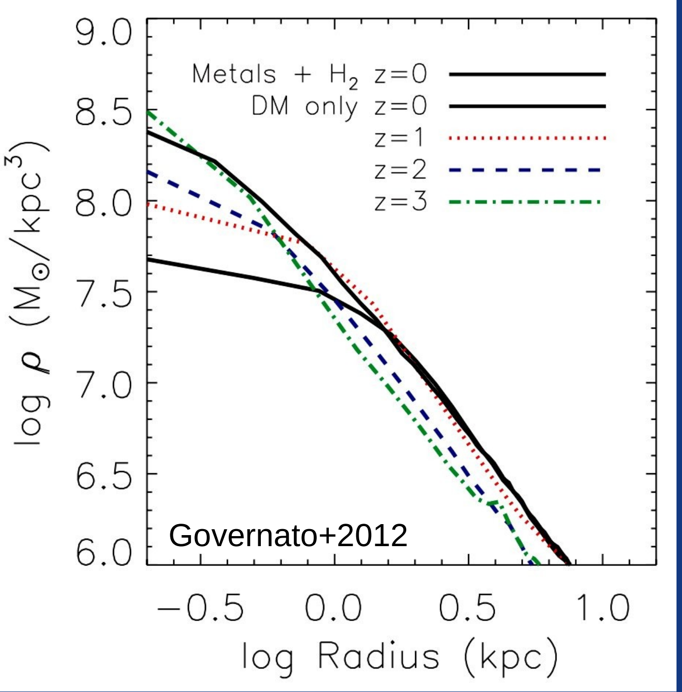
Galaxy Stellar-Mass Function



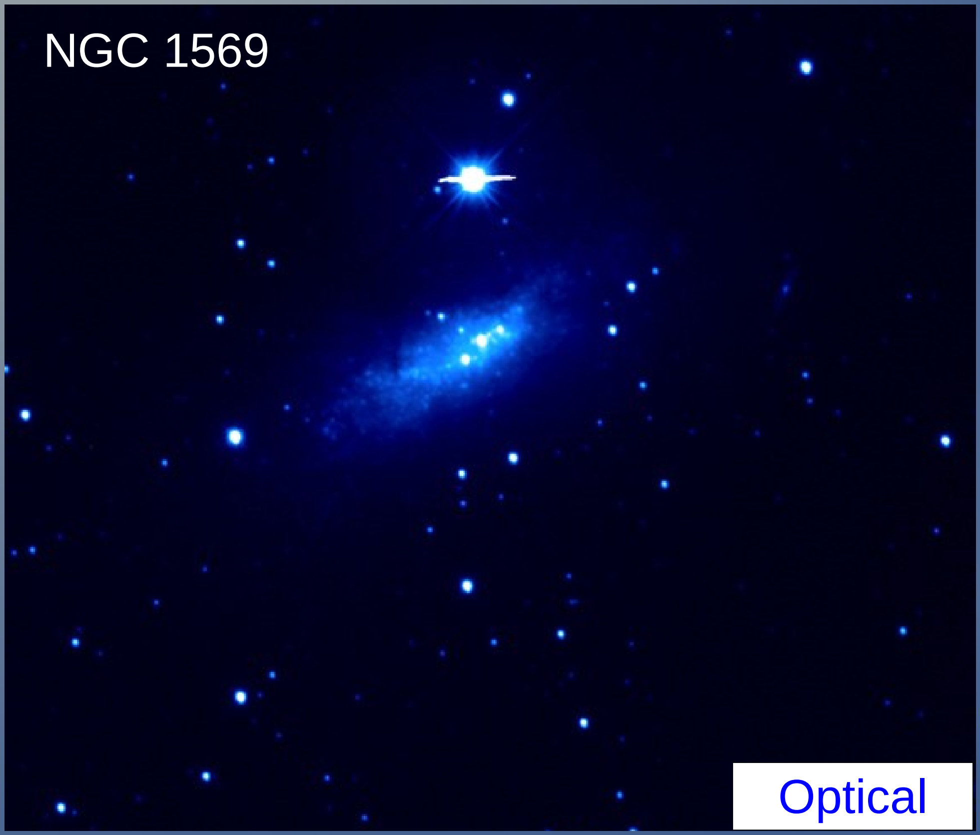
Simulated Dwarf Galaxy

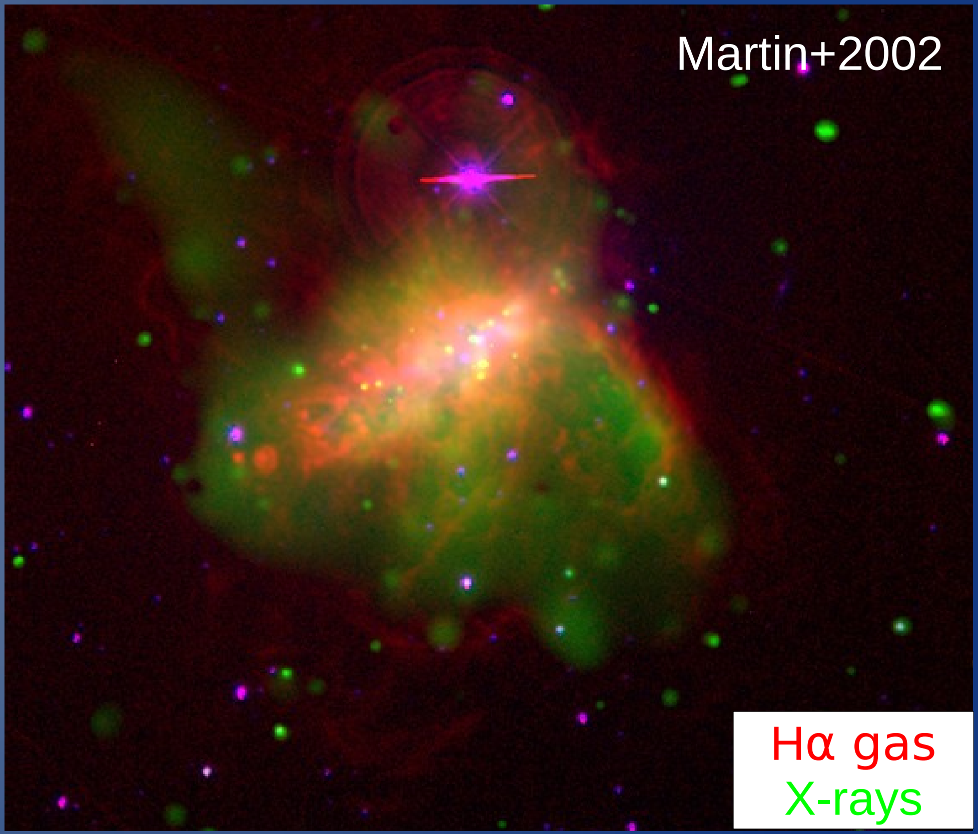


DM density profile



Stellar Feedback in BCDs



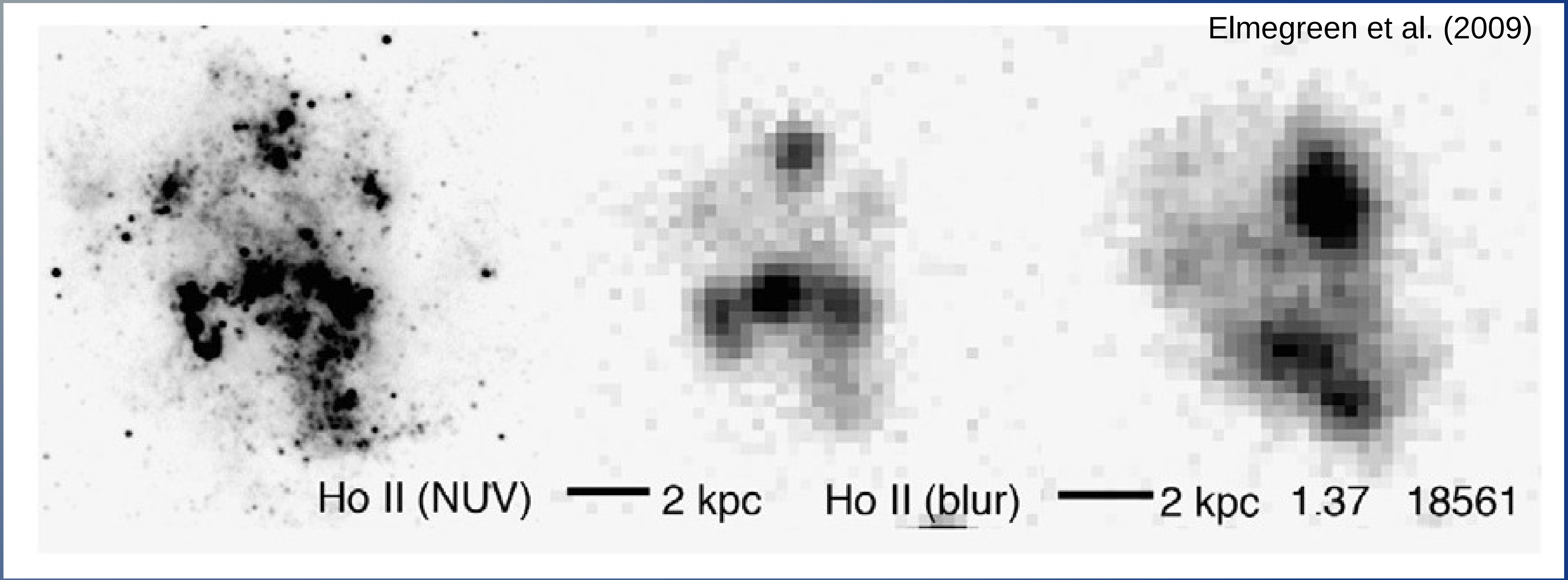


- Velocity of the ionized gas does *not* exceed V_{esc}

  (e.g. Martin 1996, 1998; Schwartz & Martin 2004; van Eymeren+2009, 2010)

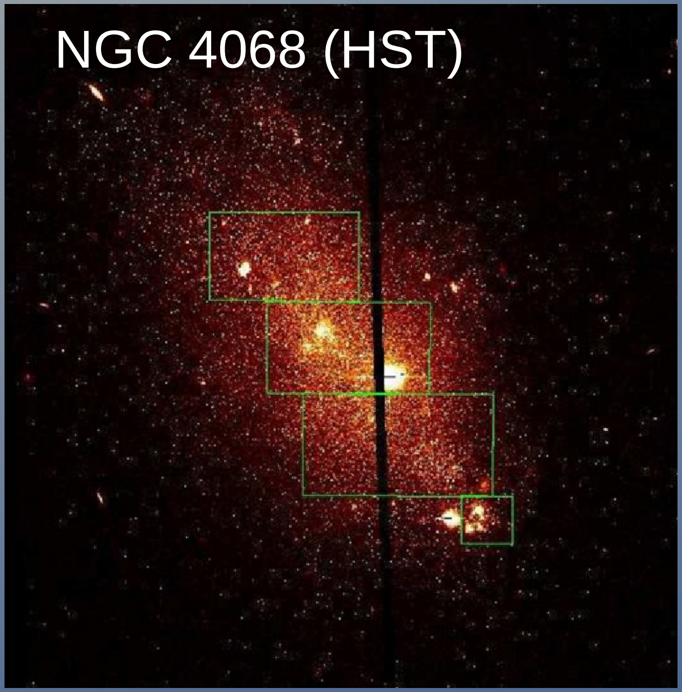
- Mass of the hot gas ~1% M_{HI} (e.g. Ott+2005)

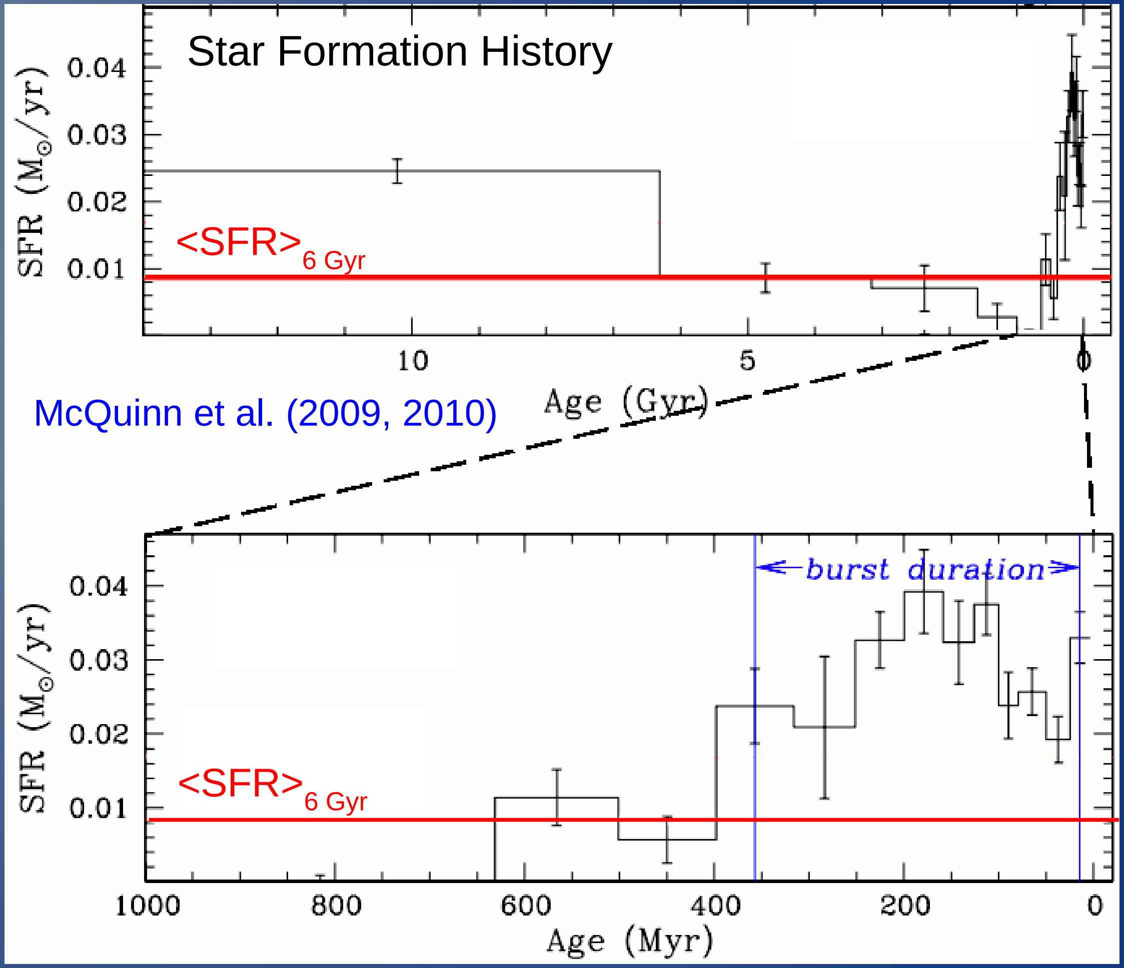
BCDs ~ high-z galaxies ?

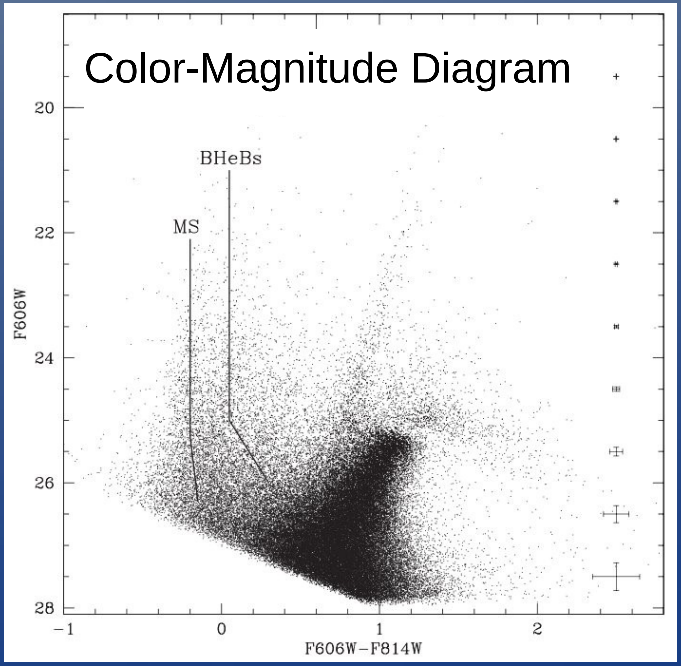


- clumpy morphologies
- high gas fractions ($M_{gas}/M_{*} > 1$)
- low metallicities ($0.2 < Z/Z_{\odot} < 0.02$)
- turbulent gaseous disks ($V_{rot}/\sigma_V < 5\text{-}6$)

Stellar populations of BCDs





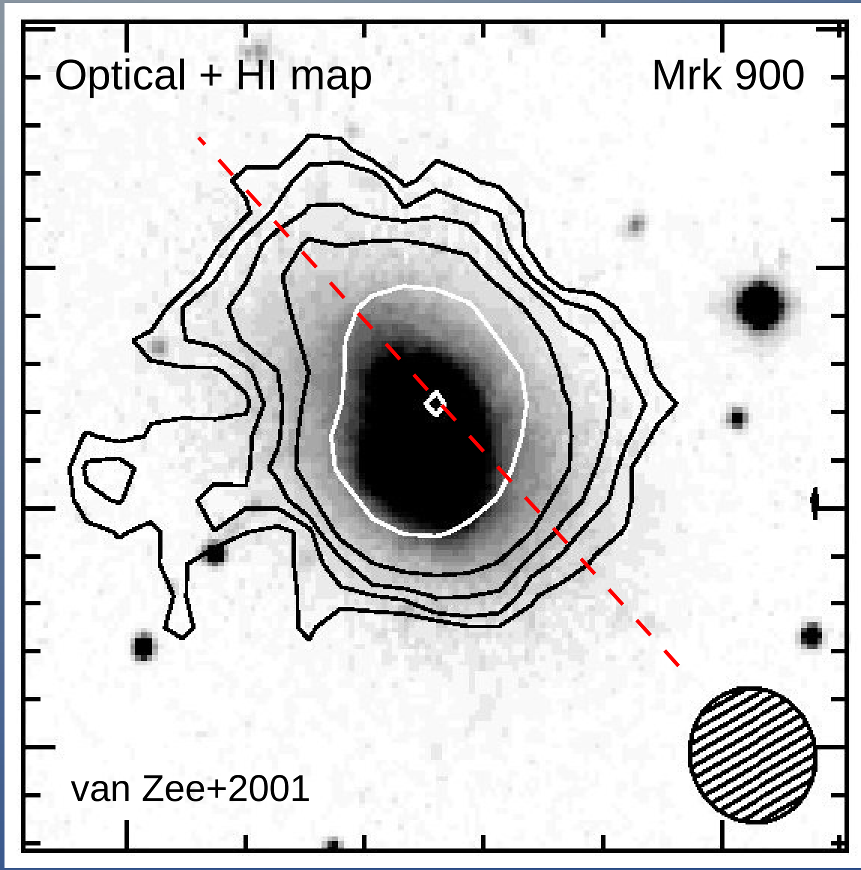


The SFH provides:

- starburst timescales
- energies from SN & stellar winds
- mass in young & old stars

HI properties of BCDs

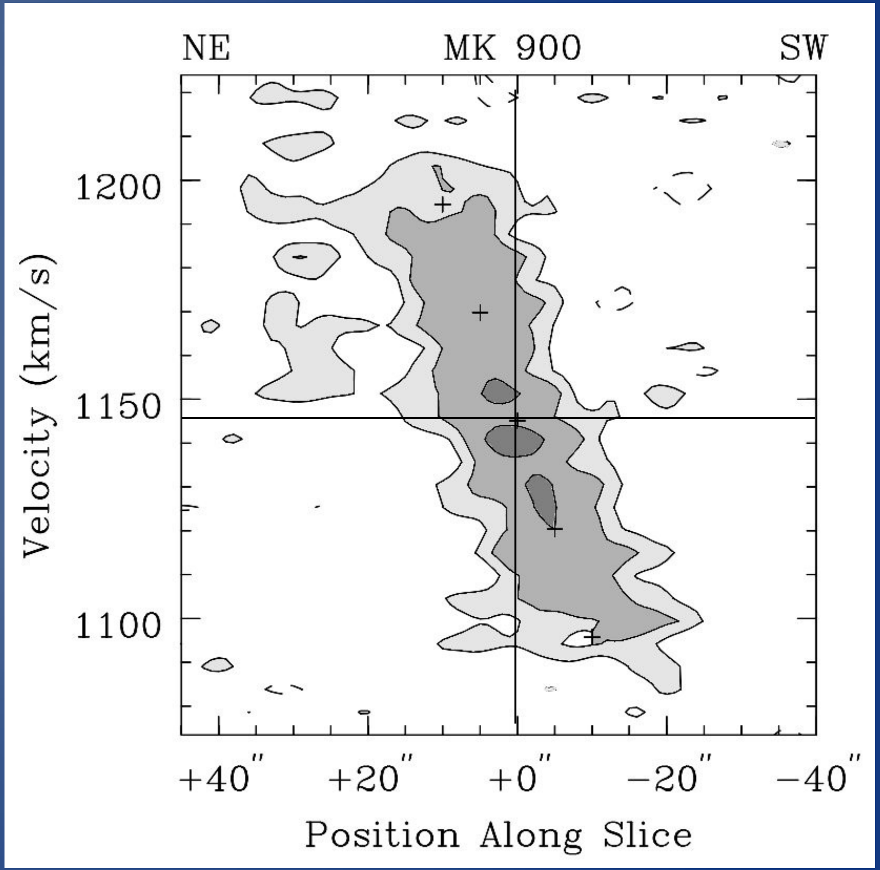
Strong HI Concentration



Central HI densities 2-3 higher than Irrs

(e.g. Taylor+1994, van Zee+1998, vanZee+2001, Simpson & Gottesman 2000, Most+2013)

Steep Velocity Gradients



Fast rotation? Inflows/outflows?

(e.g. Meurer+1996, Meurer+1998, van Zee+2001, Thuan+2004, Elson+2010, Elson+2012)

Questions:

- What triggers the starburst?

  (external *vs* internal mechanisms)

- What are the progenitors/descendants?

  (evolution from/to Irrs and Sphs; role of stellar feedback)

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- What triggers the starburst?

  (external *vs* internal mechanisms)

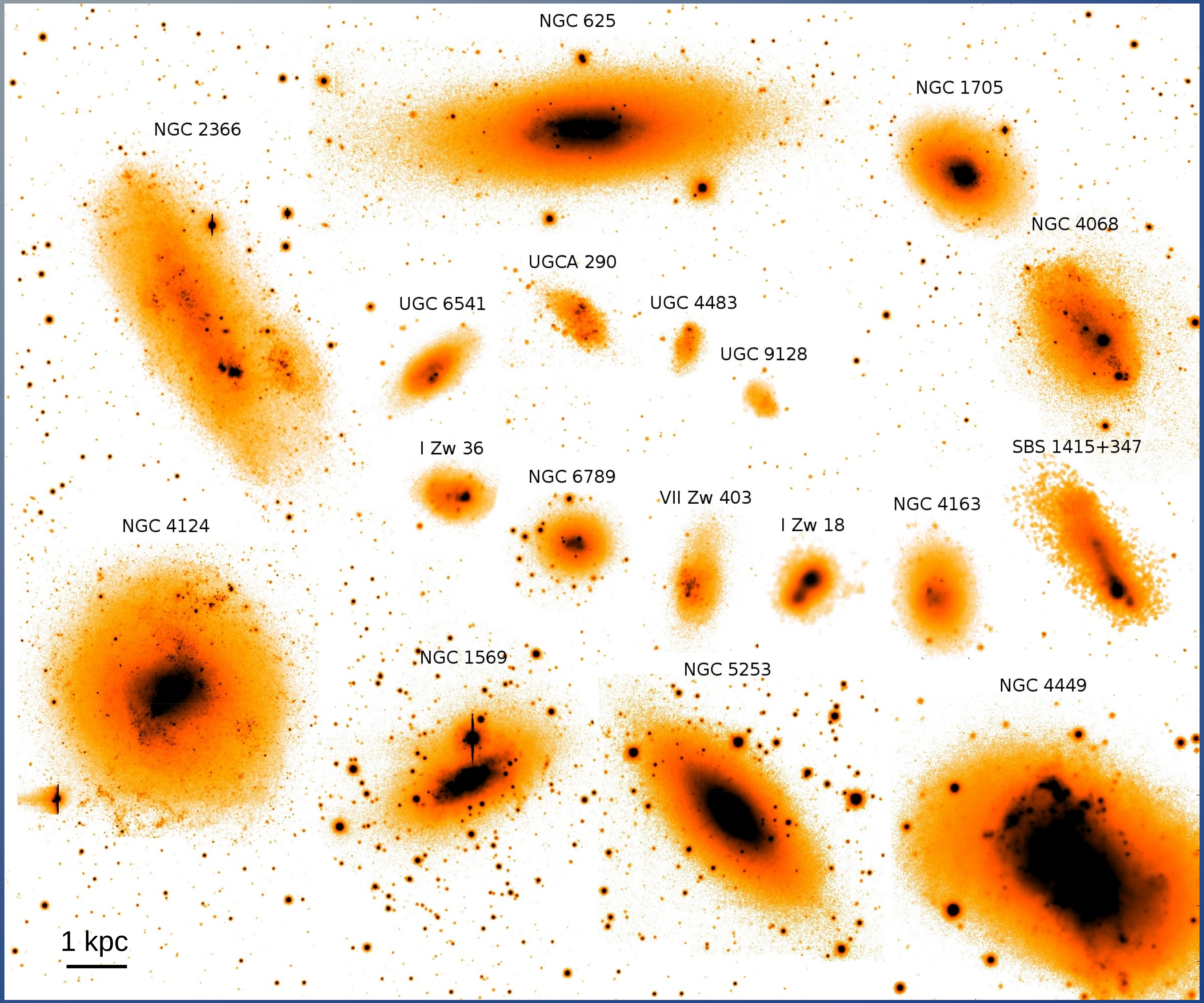
- What are the progenitors/descendants?

  (evolution from/to Irrs and Sphs; role of stellar feedback)

My Ph.D. thesis:

- HI study of a "large" sample of 18 BCDs
- Detailed modelling of the HI kinematics
- Combine dynamics & SFHs (from HST studies)

Sample of 18 BCDs (resolved into single stars by HST)

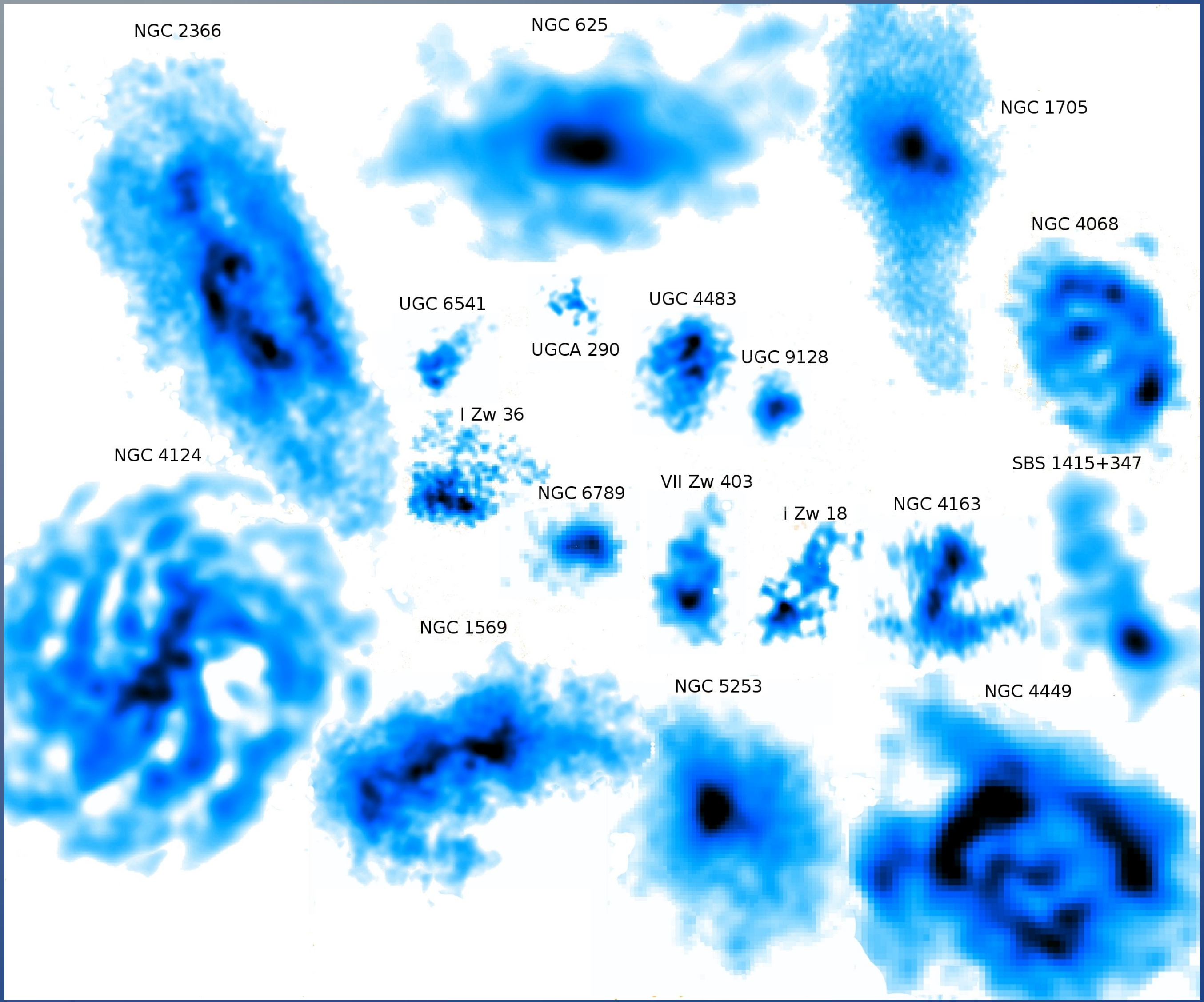


HST studies:

- Galaxy Distance
- Star Formation History:
  - starburst timescales
  - mass young & old stars

$M_* \sim 10^7 - 10^9\ M_\odot$ $R_{opt} \sim 0.5 - 5$ kpc

Sample of 18 BCDs (resolved into single stars by HST)



HST studies:

- Galaxy Distance
- Star Formation History:
  - starburst timescales
  - mass young & old stars

21-cm line obs (VLA, WSRT, ATCA):

- HI distribution
- HI kinematics

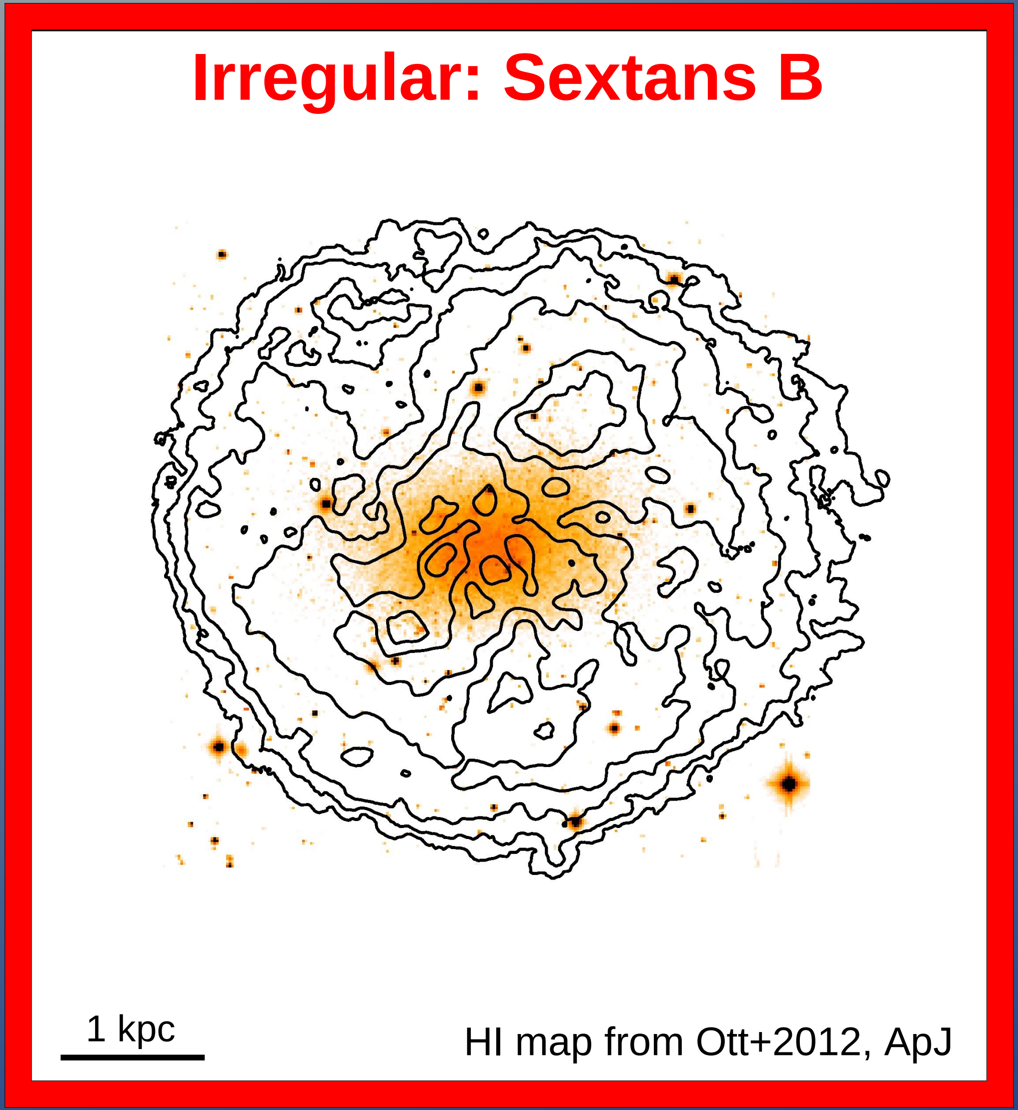
$M_* \sim 10^7 - 10^9\ M_\odot$ $R_{opt} \sim 0.5 - 5$ kpc

I. Large-scale HI morphology:

clues to the starburst trigger

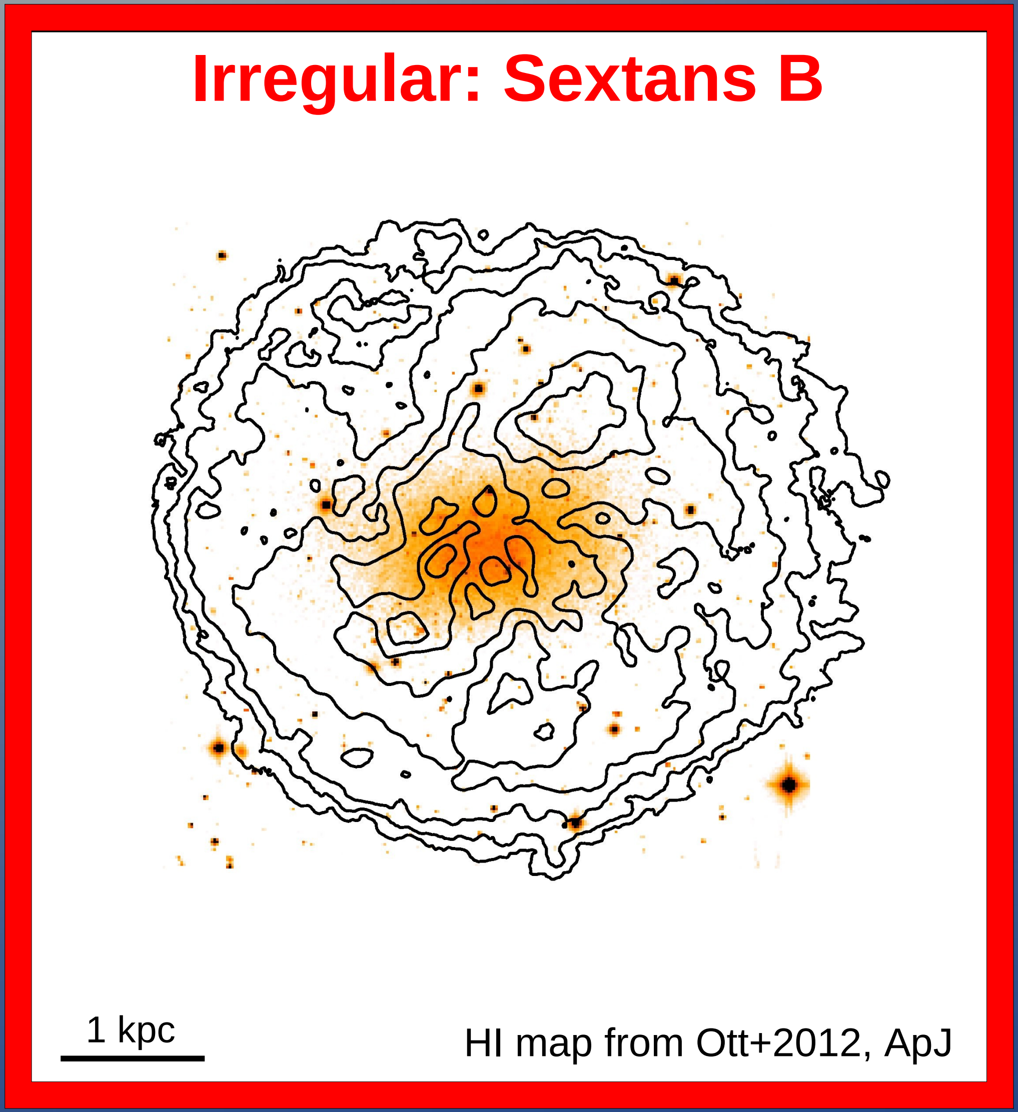
(Chapters 2 and 6)

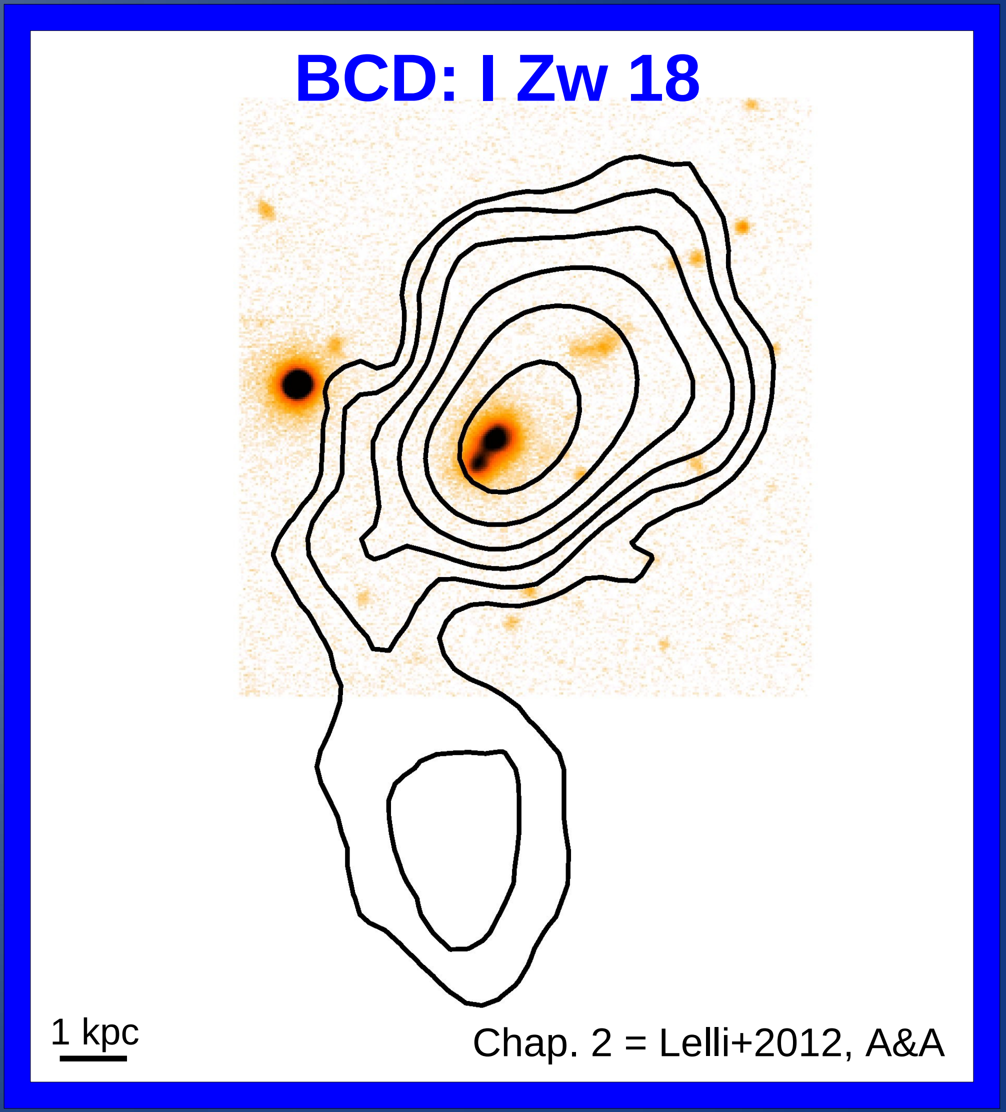
Large-scale HI distribution



Lowest HI contour = 5 x 10^{19} cm^{-2}

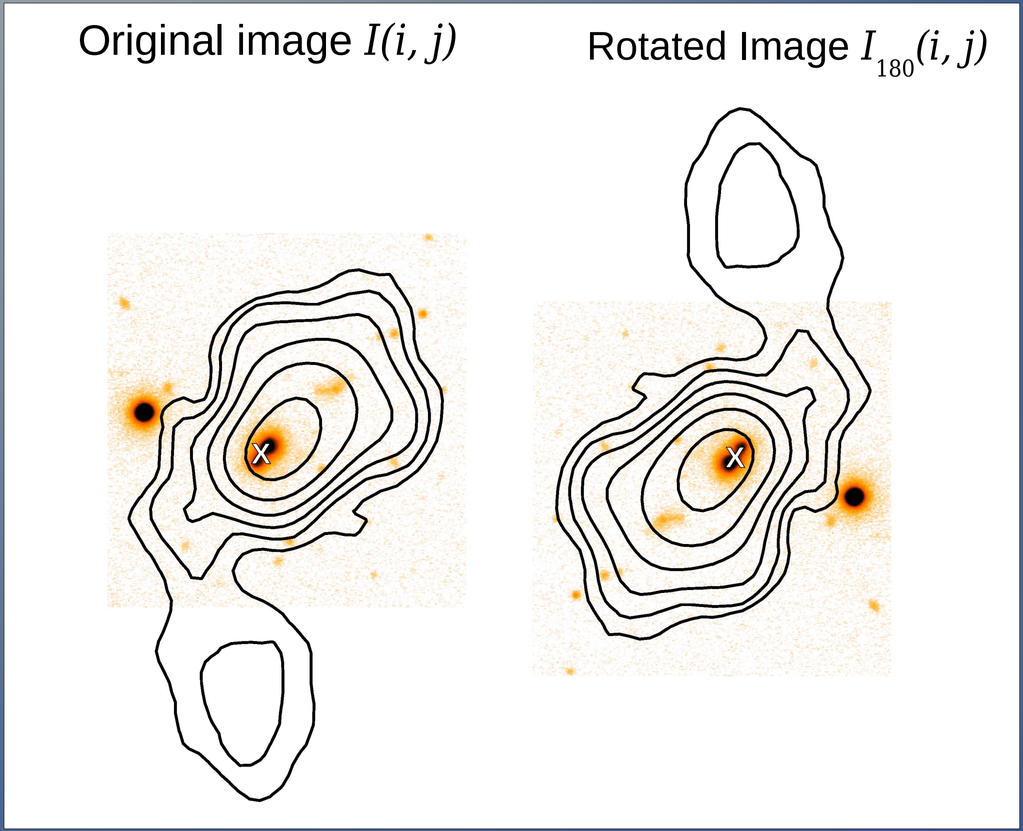
Large-scale HI distribution





Lowest HI contour = 5×10^{19} cm^{-2}

Quantifying the HI Asymmetry



Standard A parameter

(e.g. Conselice 2003, Holwerda+2011)

$$A = \frac{\sum_{i,j} |I(i,j) - I_{180^\circ}(i,j)|}{\sum_{i,j} |I(i,j)|}$$

Our A parameter (Chapter 6)

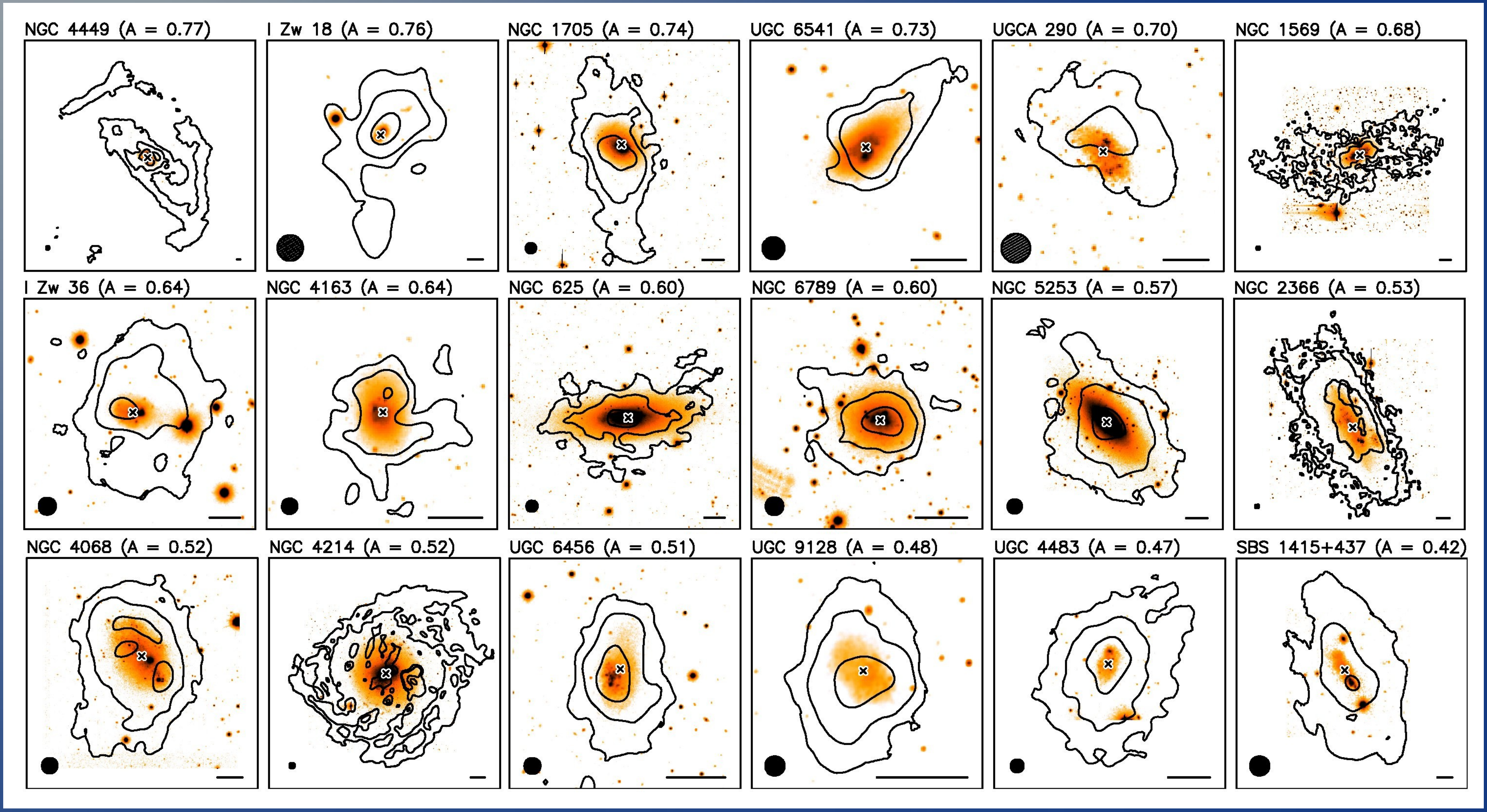
$$A = \frac{1}{N} \sum_{i,j}^{N} \frac{|I(i,j) - I_{180^\circ}(i,j)|}{|I(i,j) + I_{180^\circ}(i,j)|}$$

Good for outer regions!

For all galaxies:

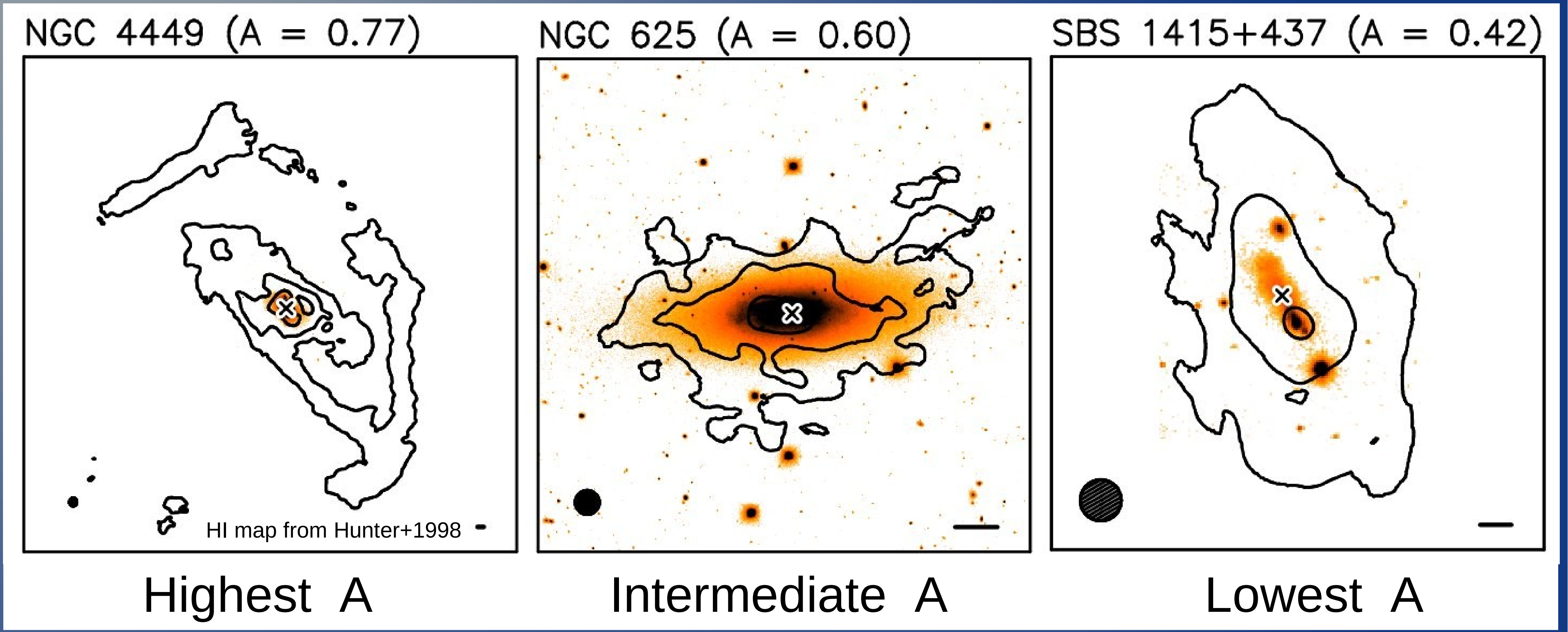
- uniform column density sensitivity
- similar linear resolution (in kpc)

Asymmetry parameter for BCDs



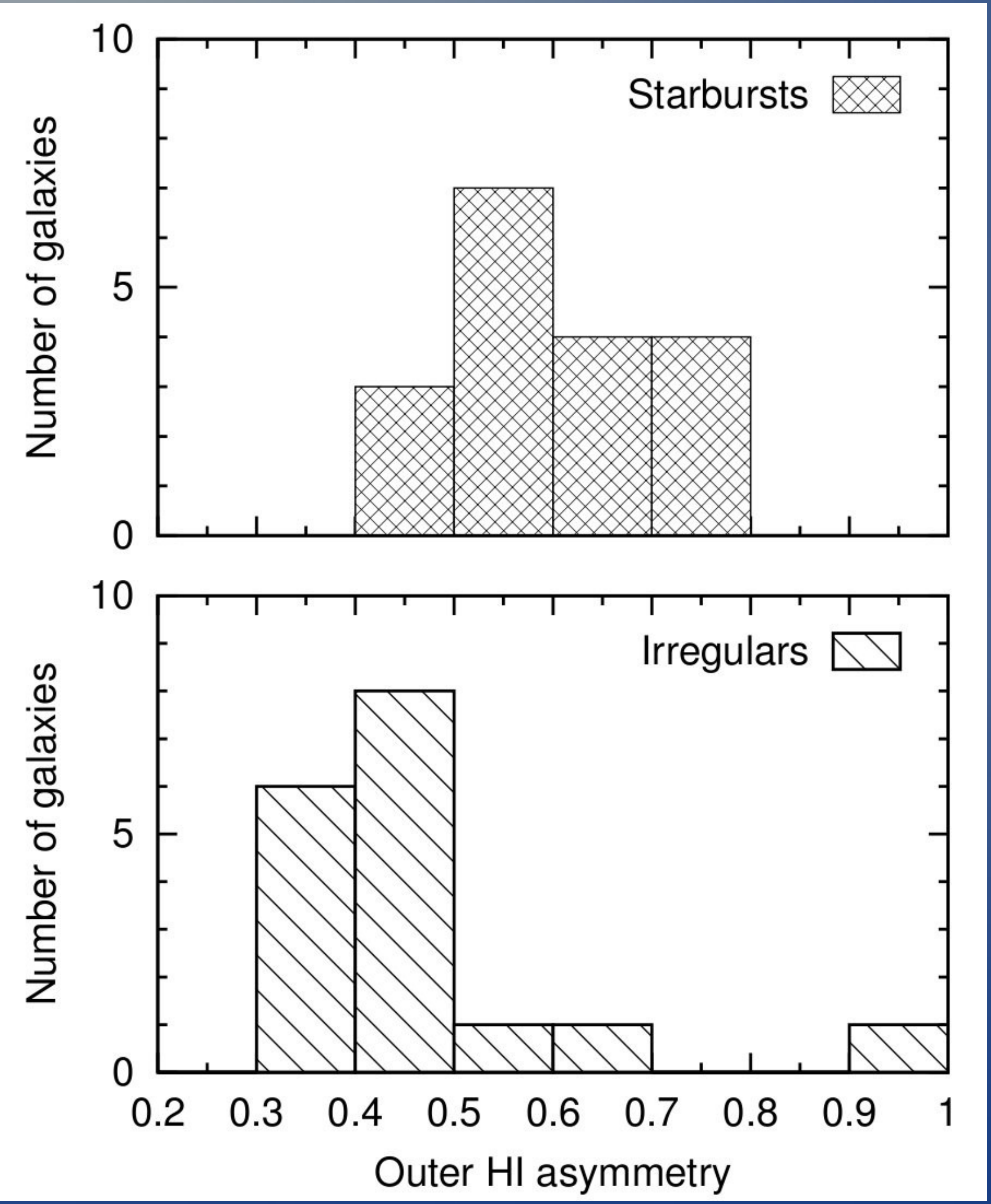
HI contours = 1, 4, 16 x 10^{20} cm^{-2}

Asymmetry parameter: examples



HI contours = 1, 4, 16 x 10^{20} cm^{-2}

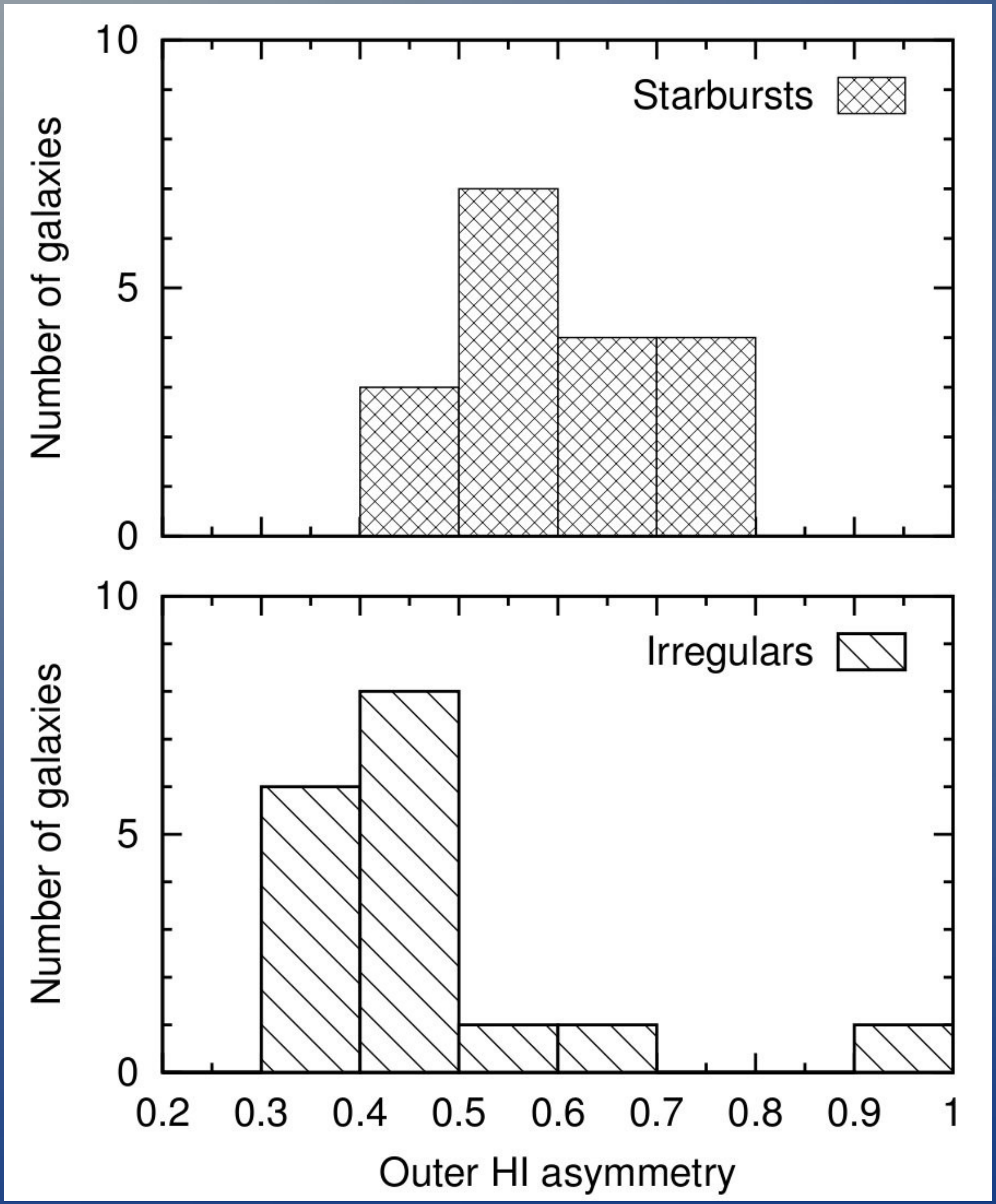
HI Asymmetry: BCDs *vs* Irrs



BCDs have more asymmetric large-scale HI distributions than Irrs

Irregulars from the VLA-ANGST survey (Ott et al. 2012)

HI Asymmetry: BCDs *vs* Irrs



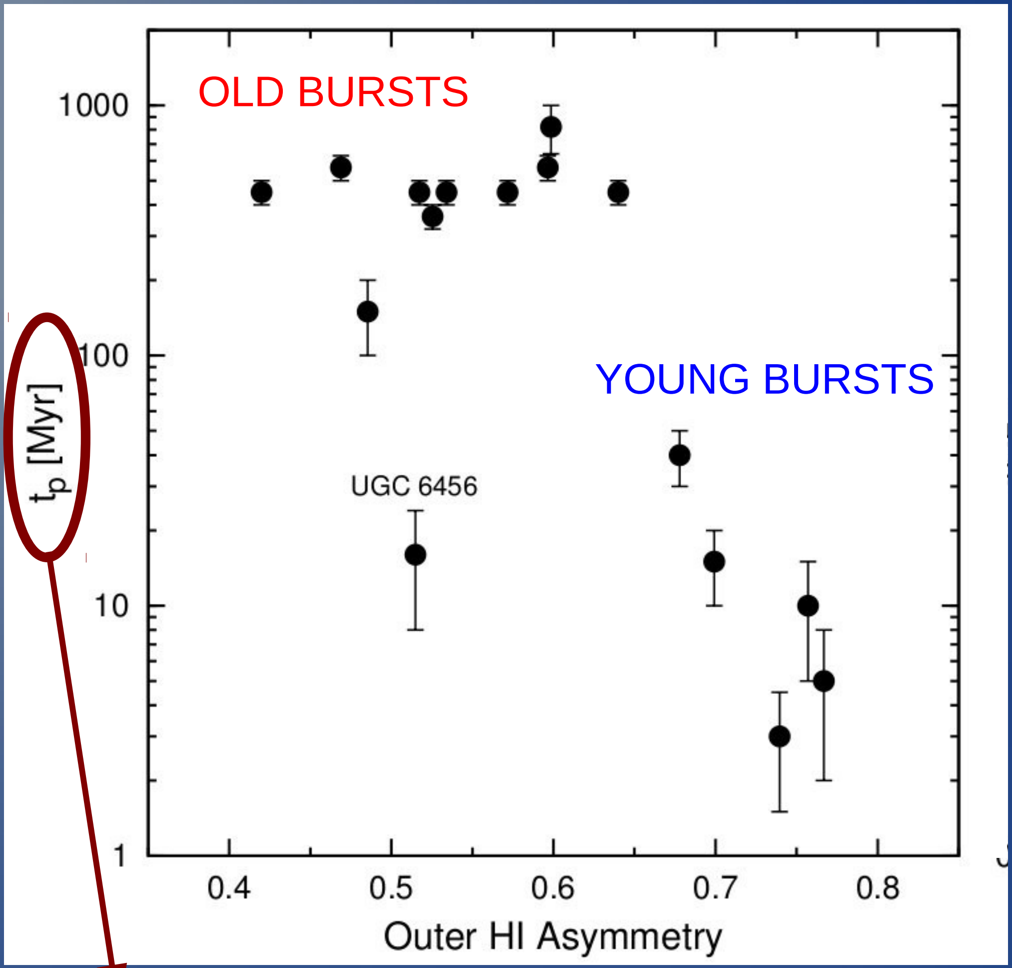
BCDs have more asymmetric large-scale HI distributions than Irrs

External mechanisms triggered the starburst:

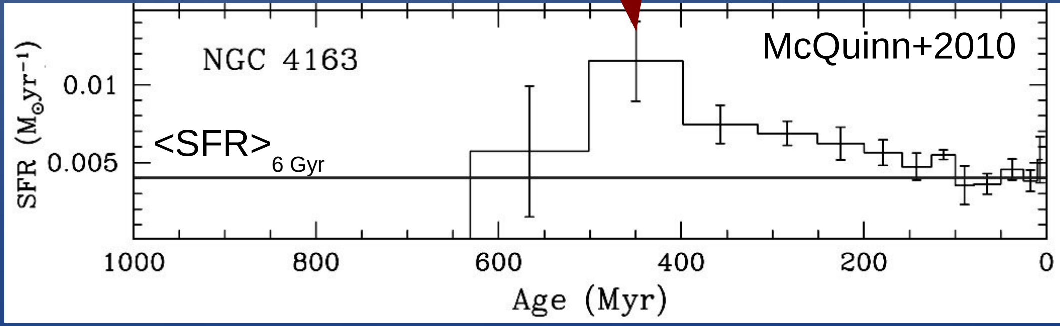
- Interactions/mergers?
- Cold gas accretion?

Irregulars from the VLA-ANGST survey (Ott et al. 2012)

HI Asymmetry *vs* starburst "age"



Star-Formation History:



Message I

Starburst triggered by external mechanism:

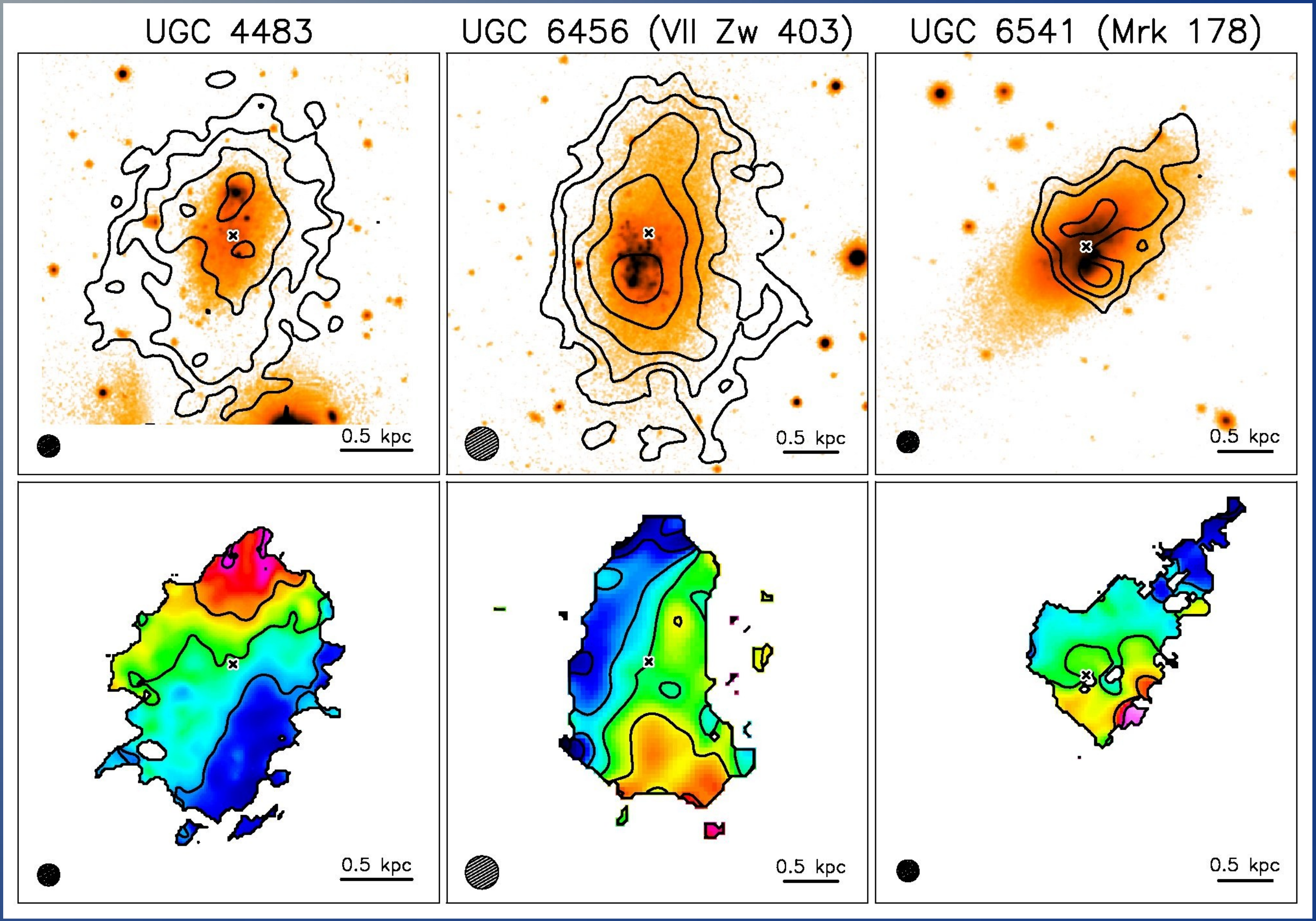
- interactions/mergers between Irrs?
- cold gas accretion from the IGM?

II. Internal Dynamics of BCDs:

distribution of baryons & dark matter

(Chapters 2, 3 and 4)

Gas kinematics of BCDs

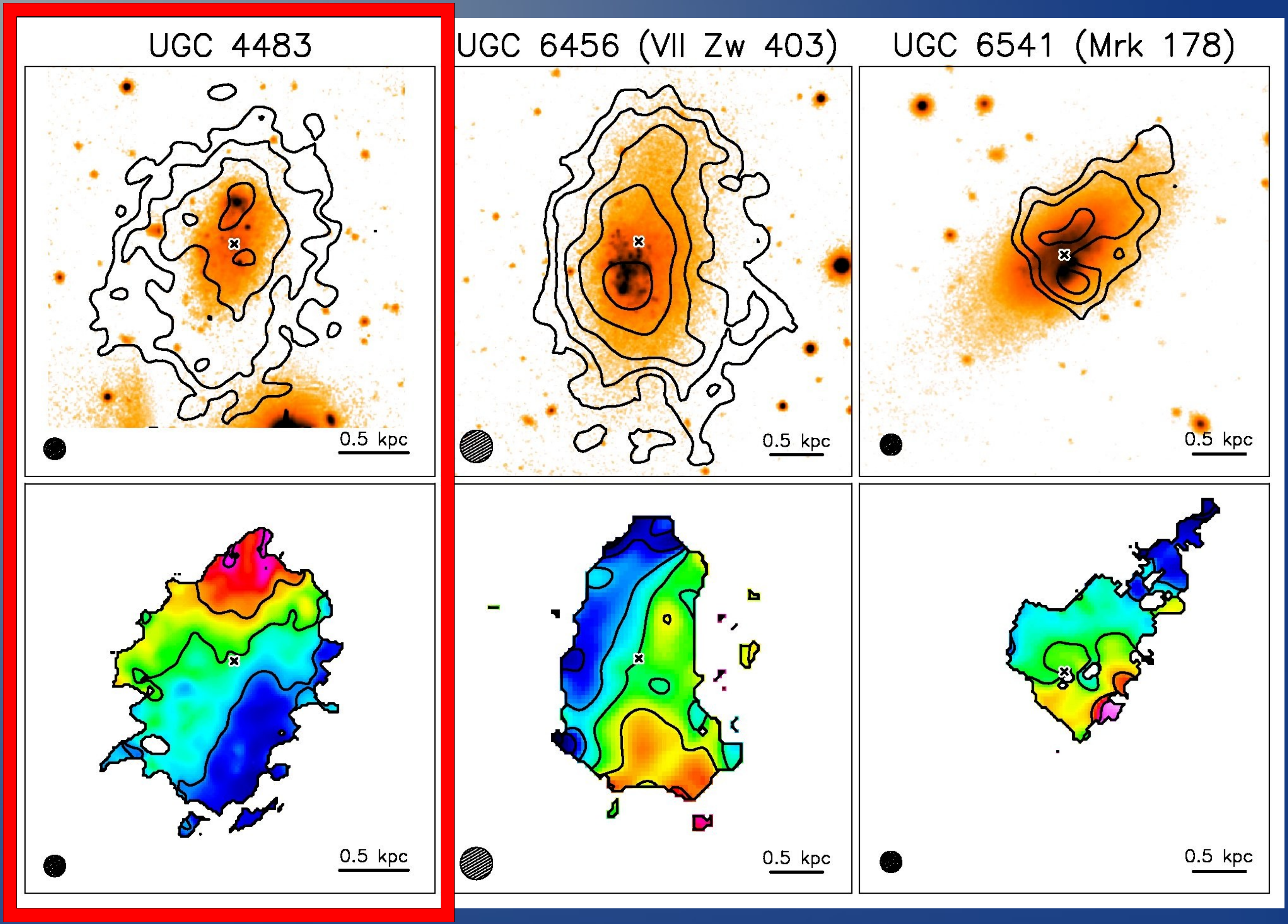


~50%
rotating HI disk

~40%
kin. disturbed HI disk

~10%
unsettled HI distr.

Gas kinematics of BCDs



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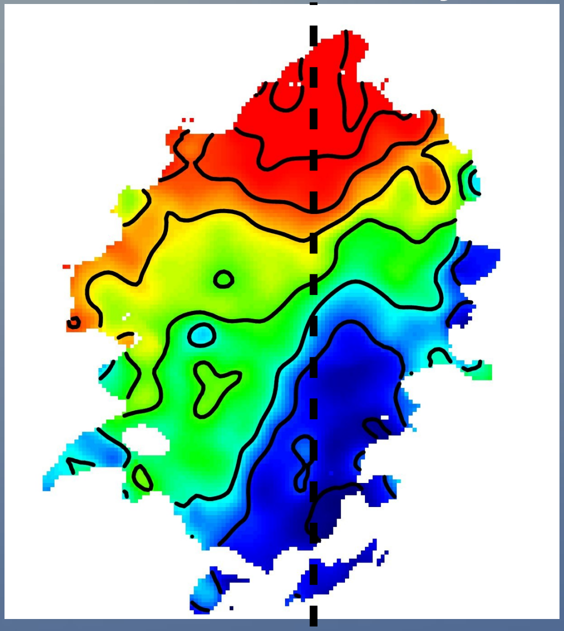
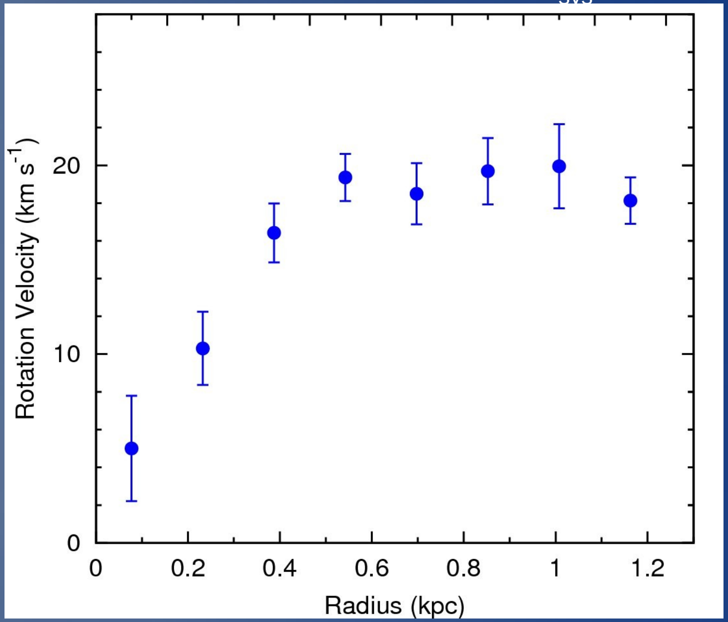
Derivation of the rotation curve

2D fit to the Velocity Field



Rotation curve (+ center, V_{sys}, PA, incl.)



Derivation of the rotation curve

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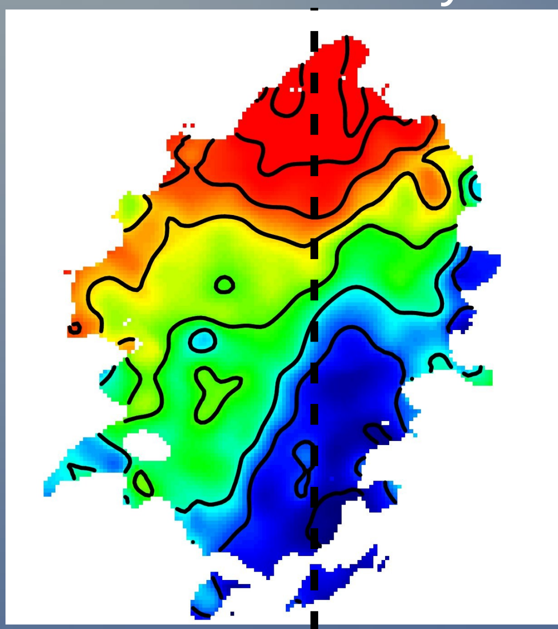
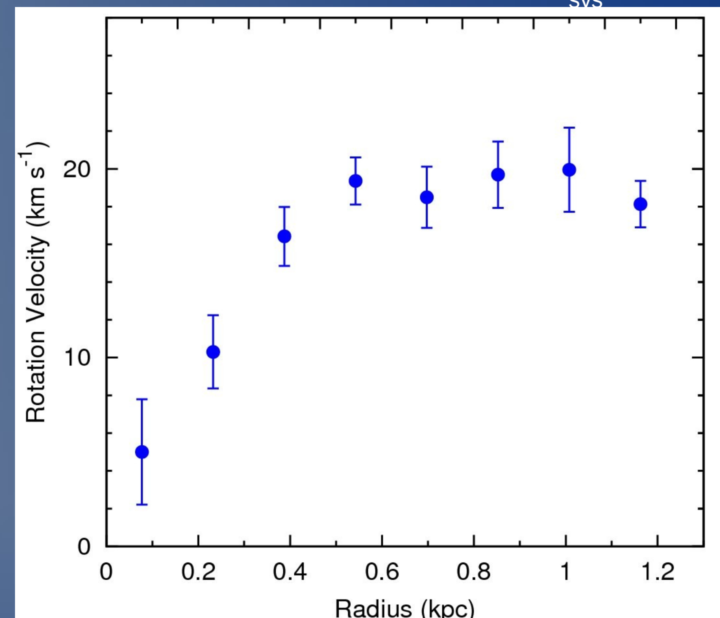
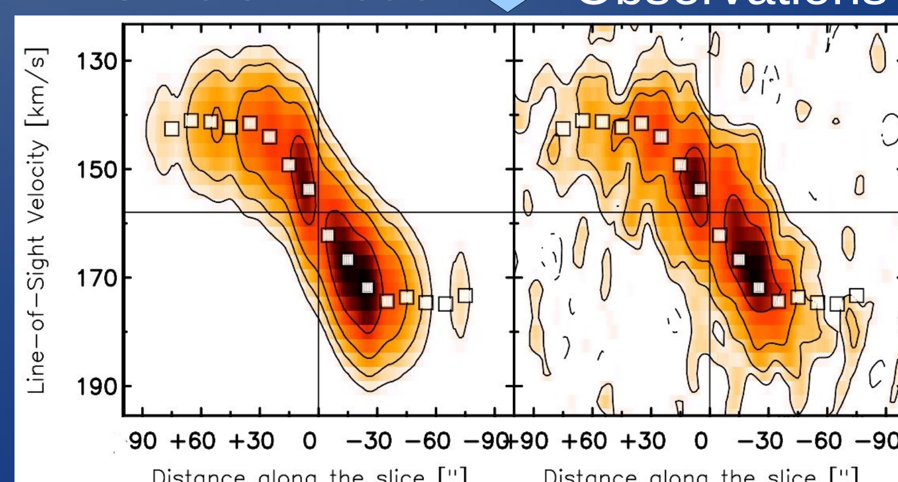


Rotation curve (+ center, V_{sys}, PA, incl.)



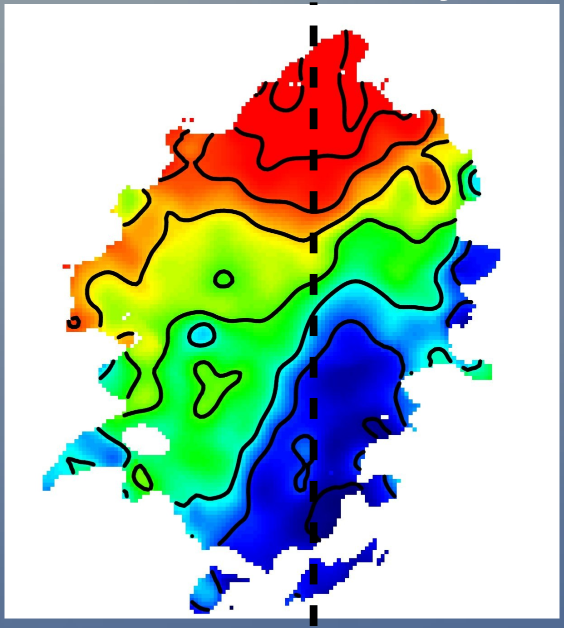
3D disk model

Observations

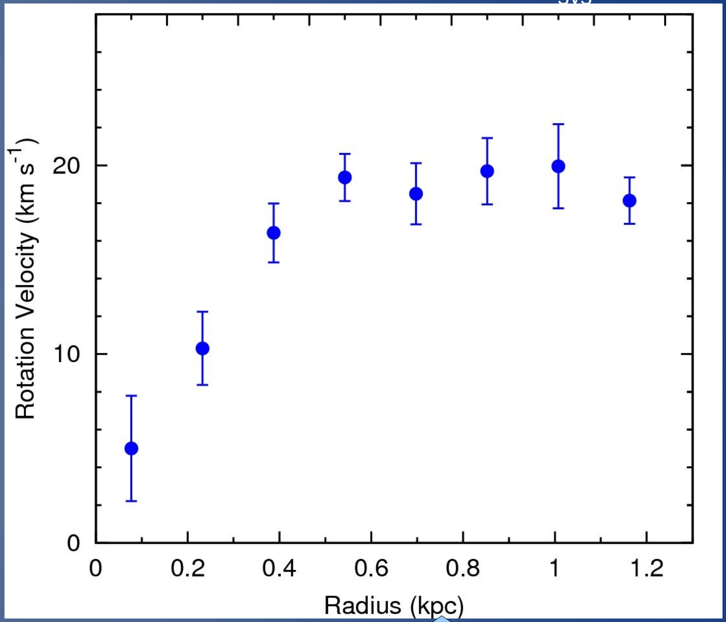


Derivation of the rotation curve

2D fit to the Velocity Field



Rotation curve (+ center, V_{sys}, PA, incl.)

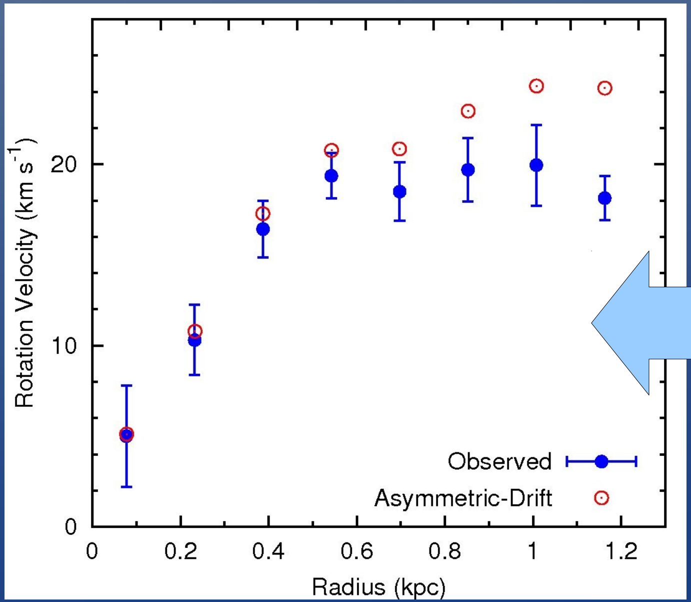


V_{rot} ~ 20 km/s

σ_{HI} ~ 8 km/s

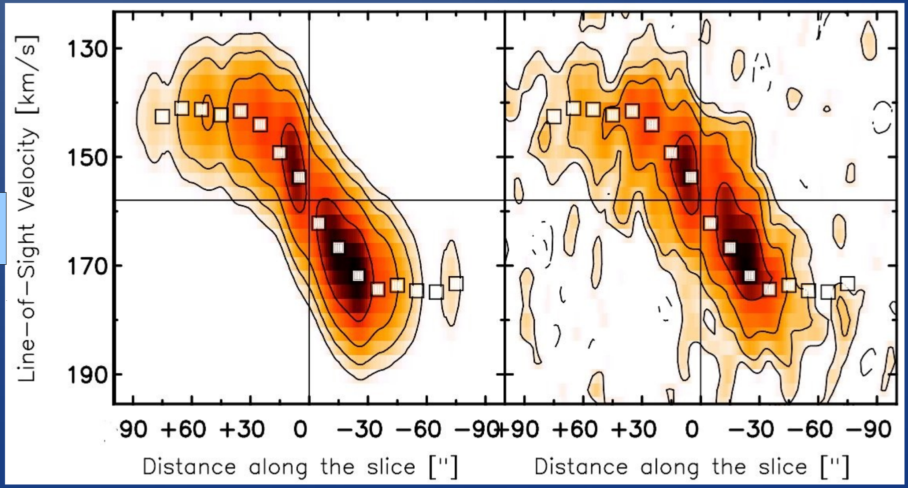
V_{rot}/σ_{HI} ~ 2-3

Correction for pressure-support

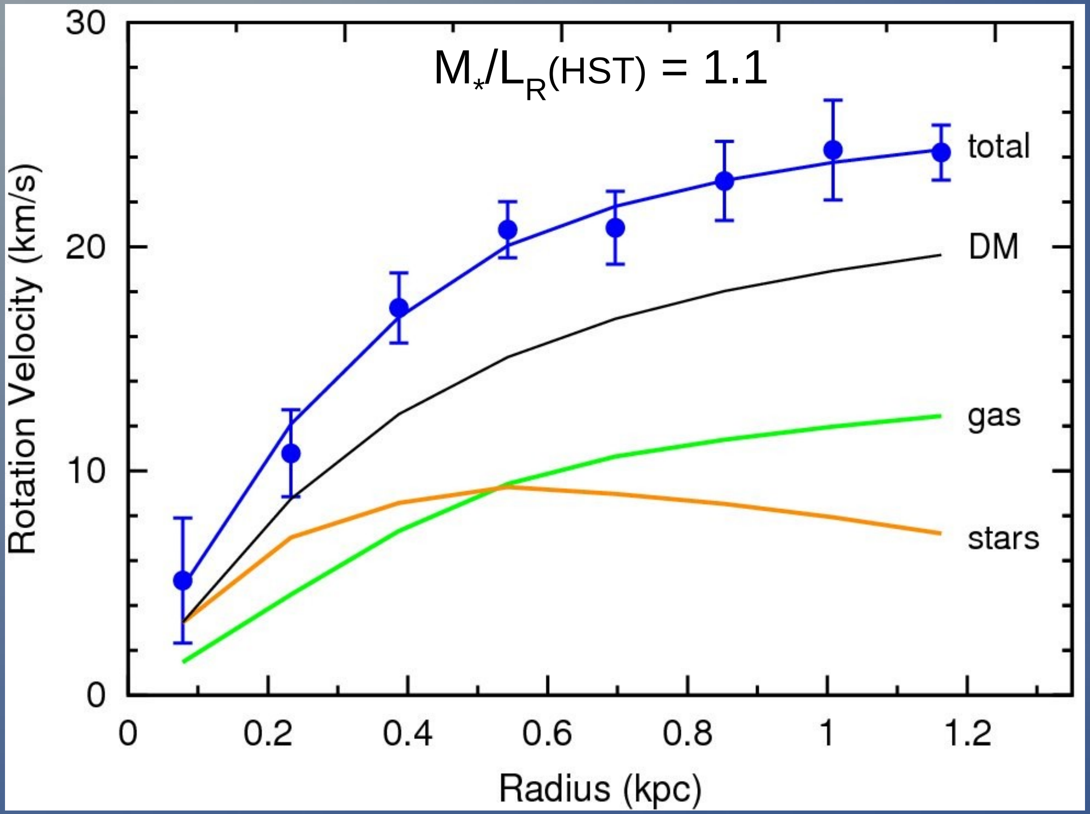


3D disk model

Observations



Mass Model: UGC 4483



Lelli et al. 2012, A&A, 544, 145L

$M_{dyn} = (16 \pm 3) \times 10^7\ M_\odot$

$M_{*(HST)} = (1.0 \pm 0.3) \times 10^7\ M_\odot$

assuming Salpeter IMF (McQuinn+2010)

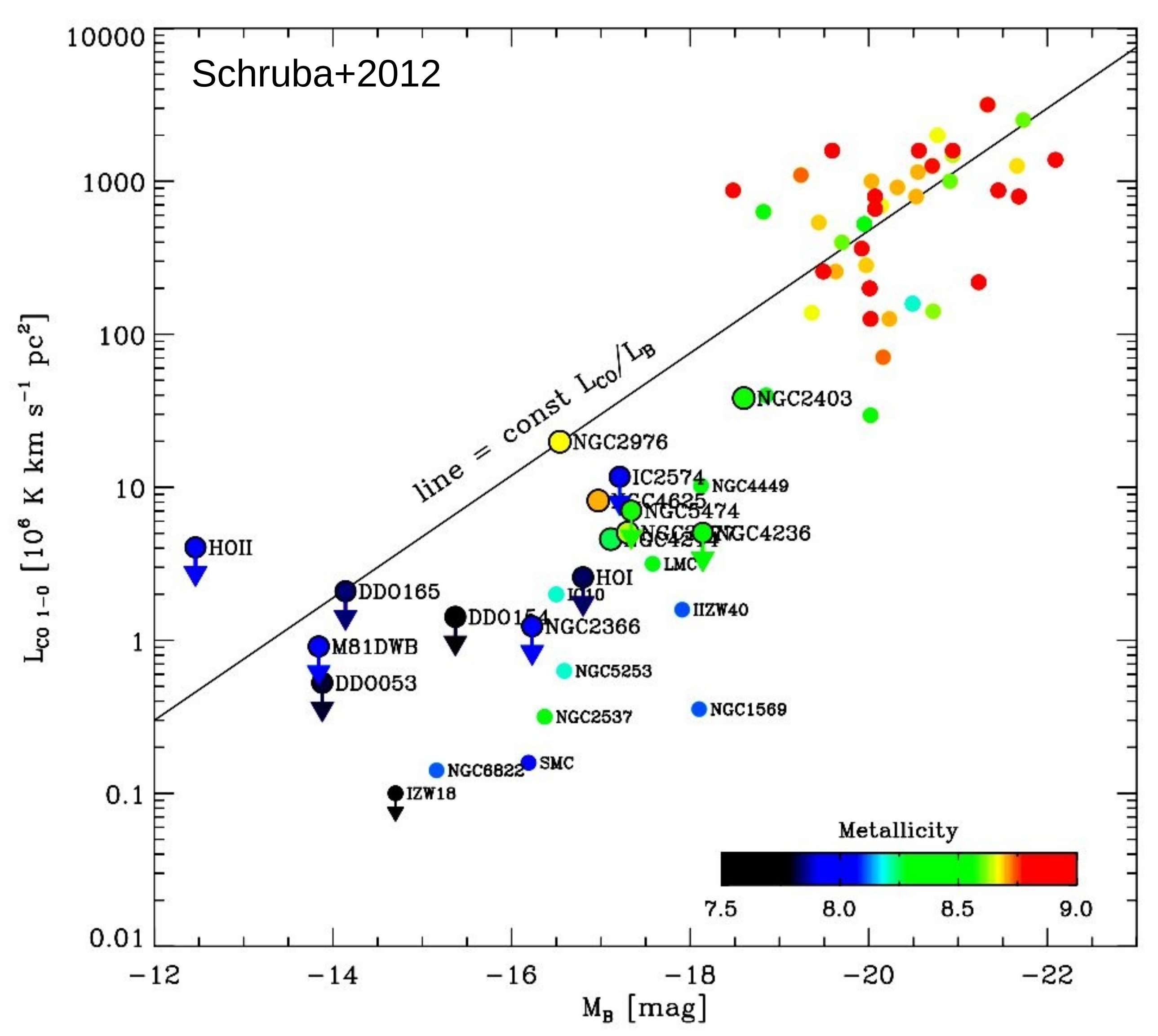
$M_{gas} = (3.3 \pm 0.4) \times 10^7\ M_\odot$

M_*(young) ~ $0.2 \times 10^7\ M_\odot$

M(molecules) ~ ?

At least ~30% of the mass within R_{HI} is baryonic (gas + old stars)

Molecular mass is unknown...



Dwarfs are metal-poor

CO lines undetected

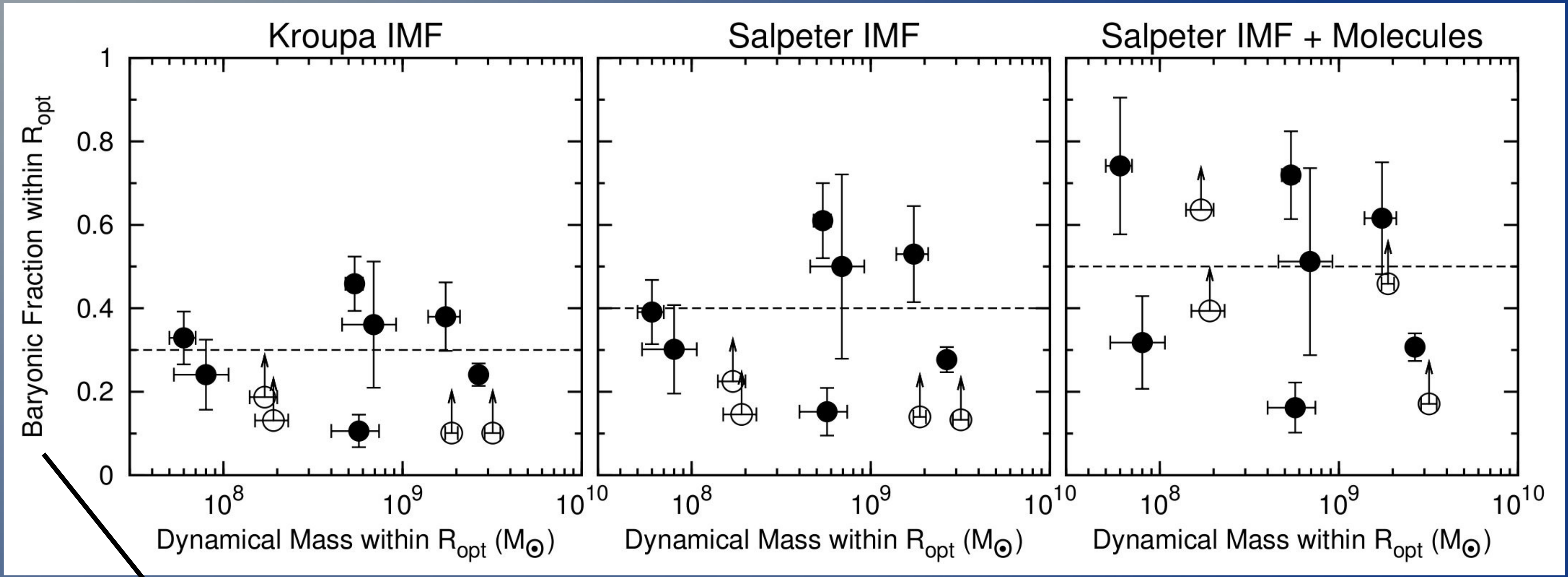
CO-to-H_2 conversion may depend on Z!

Indirect estimate:

$M_{mol}(M_\odot) \sim 2 \times 10^9$ SFR ($M_\odot$/yr)

(e.g. Leroy+2008)

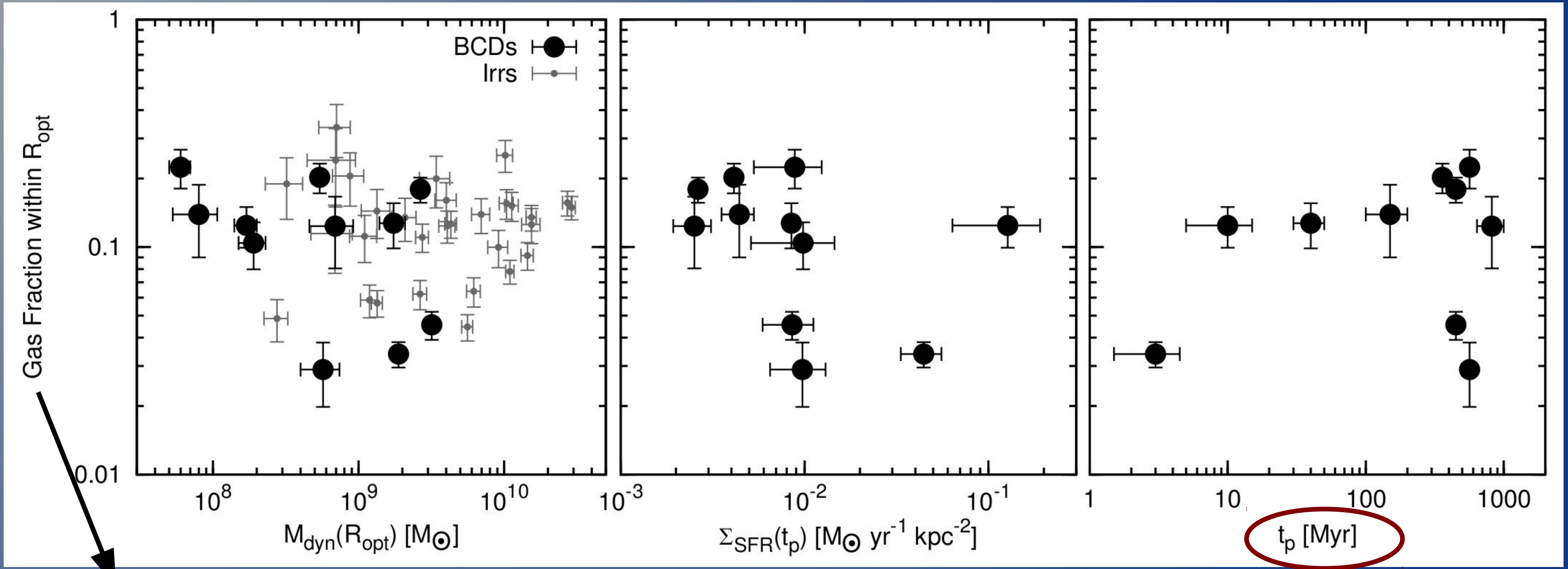
Baryonic Fractions in BCDs



$f_{bar} = M_{bar}/M_{dyn}$ measured within the optical radius

Baryons constitute a relevant fraction of the dynamical mass
(similar to typical Irrs, e.g. Swaters+2011)

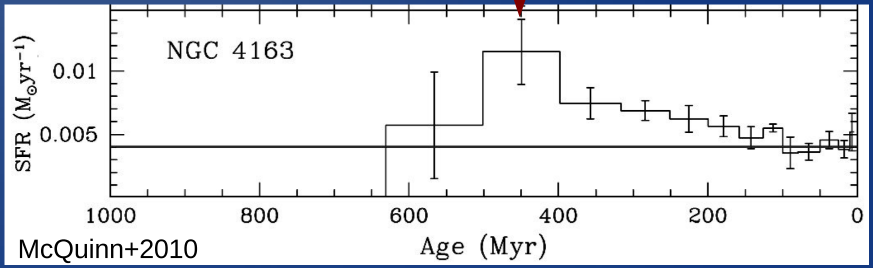
Atomic Gas Fractions



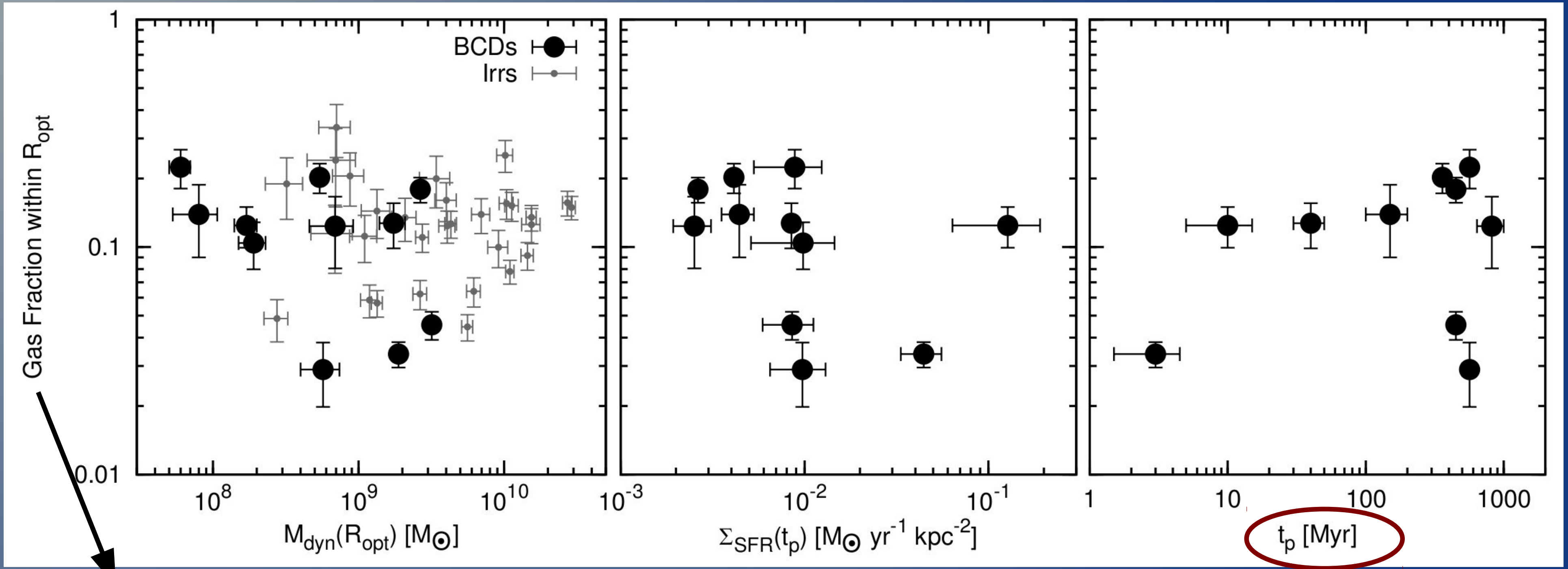
$f_{gas} = M_{HI}/M_{dyn}$ measured within R_{opt} (Irrs from Swaters+2009)

Similar f_{gas} as typical Irrs

Star Formation History



Atomic Gas Fractions

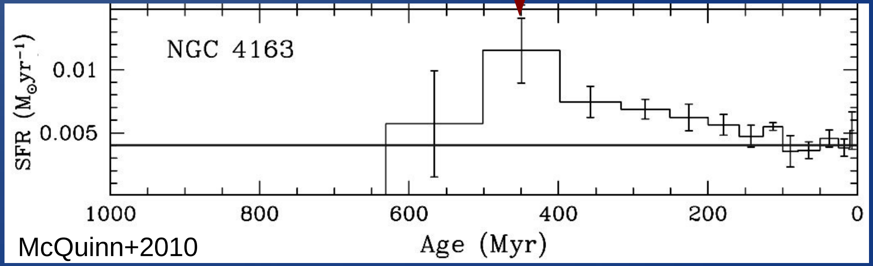


$f_{gas} = M_{HI}/M_{dyn}$ measured within R_{opt} (Irrs from Swaters+2009)

Similar f_{gas} as typical Irrs

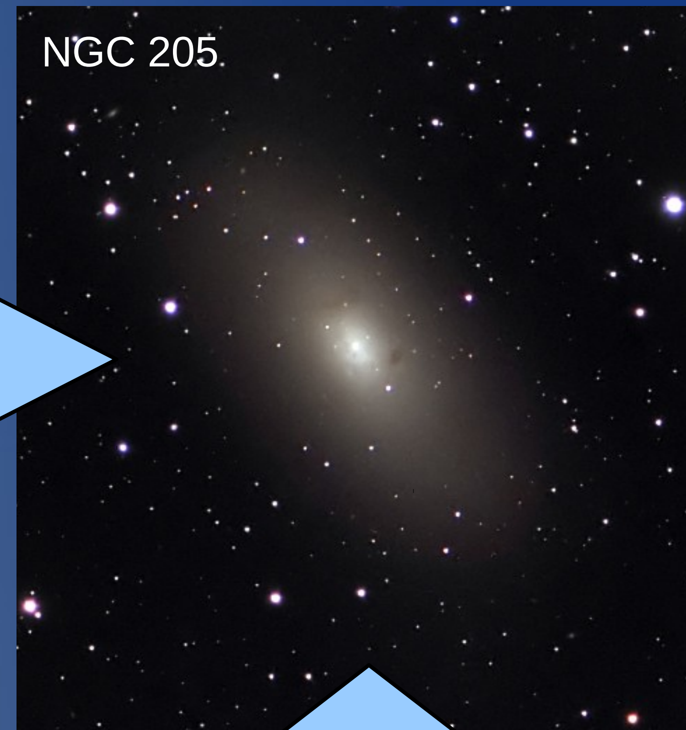
No evidence for <u>massive</u> outflows!

Star Formation History



Starburst dwarfs

Gas-poor Sphs



Gas Outflows

External mechanisms:

- ram-pressure stripping
  (e.g. Gunn&Gott 1972)
- galaxy harassment
  (e.g. Moore+1998)
- tidal stirring
  (e.g. Mayer+2006)

Message II

BCDs & Irrs have similar baryonic & gas fract.

↓

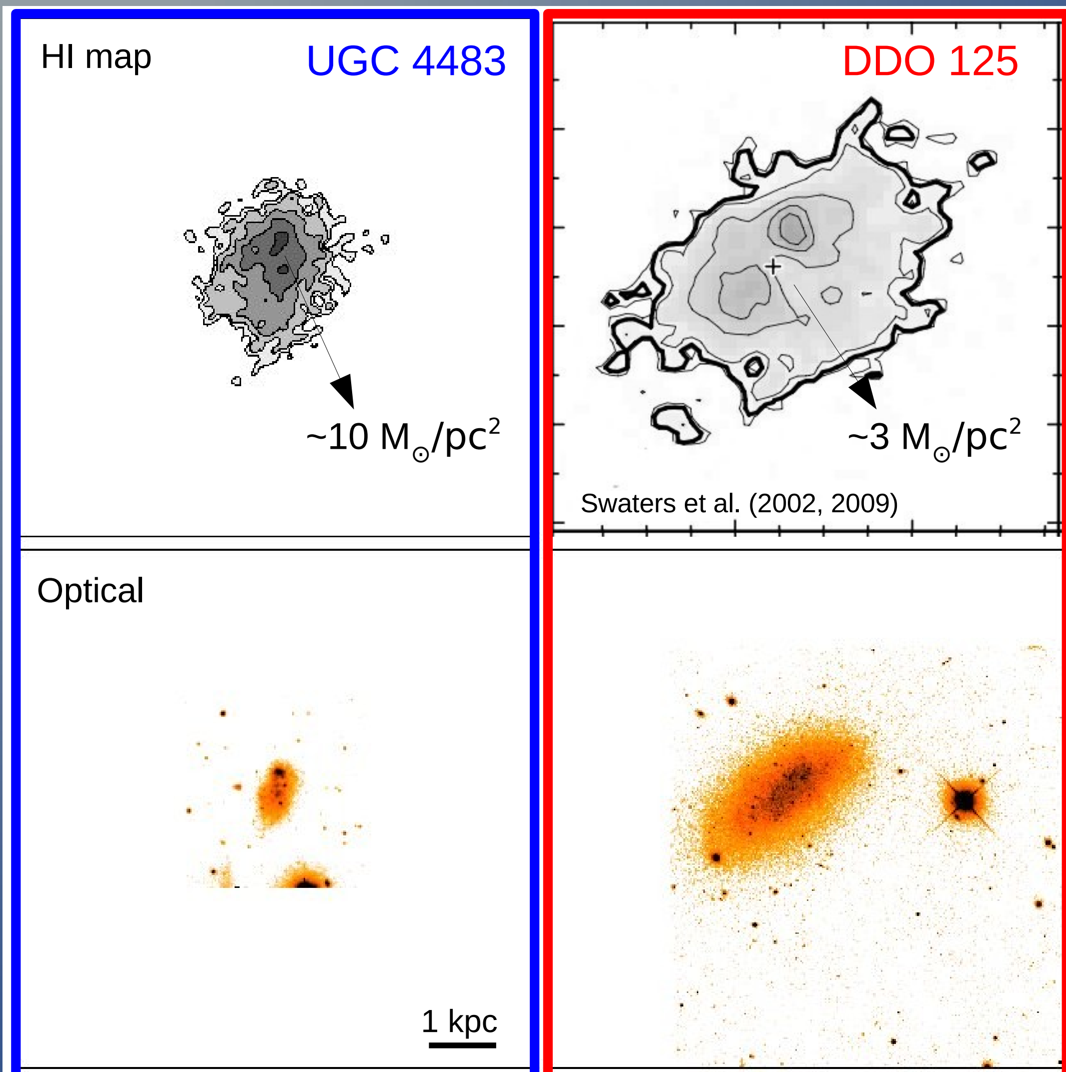
The starburst does not blow away the ISM.

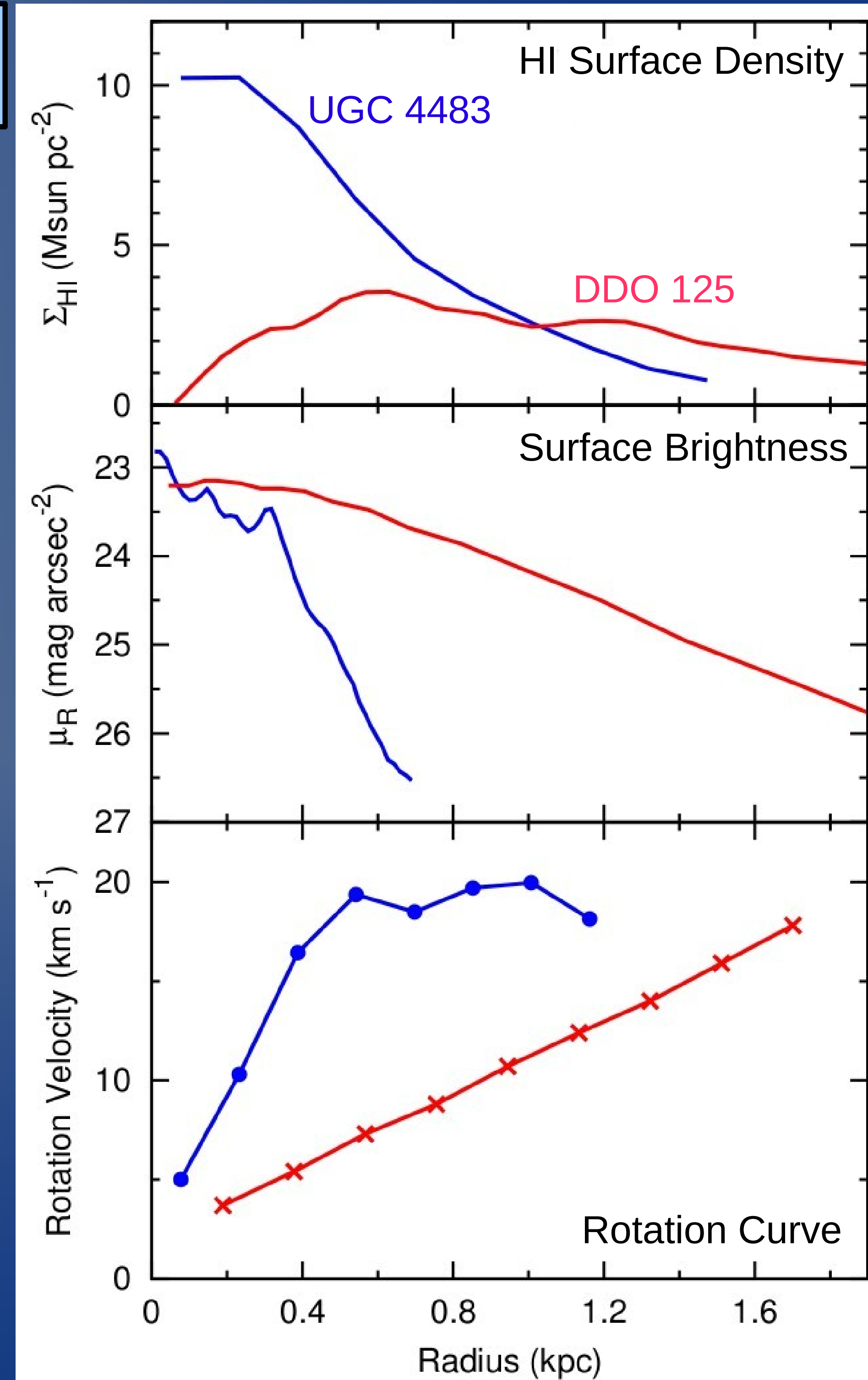
III. Evolution of dwarf galaxies:

linking dynamics & star formation

(Chapter 5 = Lelli et al. accepted!)

Starburst *vs* **Irregular**

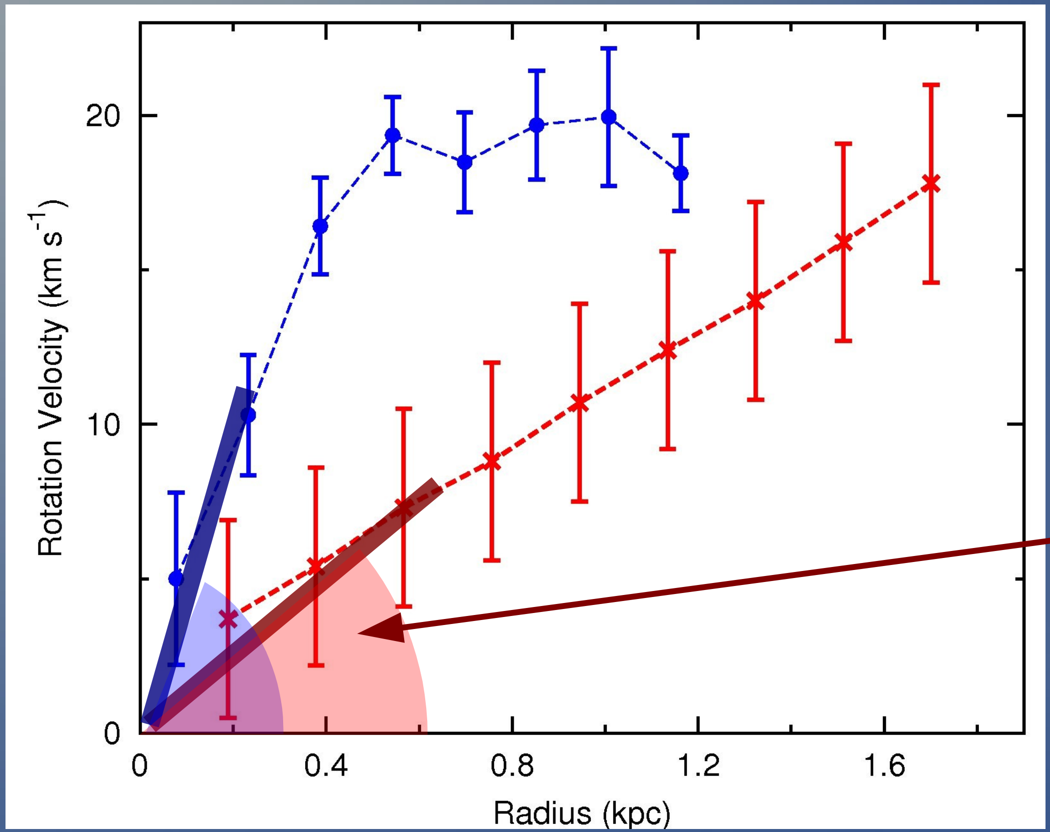




$M_{dyn} \sim 1\text{-}2 \times 10^8 \, M_\odot$

Chap 3 = Lelli et al. 2012, A&A, 544

Inner Circular-Velocity Gradient



$$\lim_{R \to 0} \frac{dV_{\rm circ}(R)}{dR} \propto \sqrt{\rho_0}$$

ρ_0 = central dynamical mass density

For a bulgeless disk galaxy:

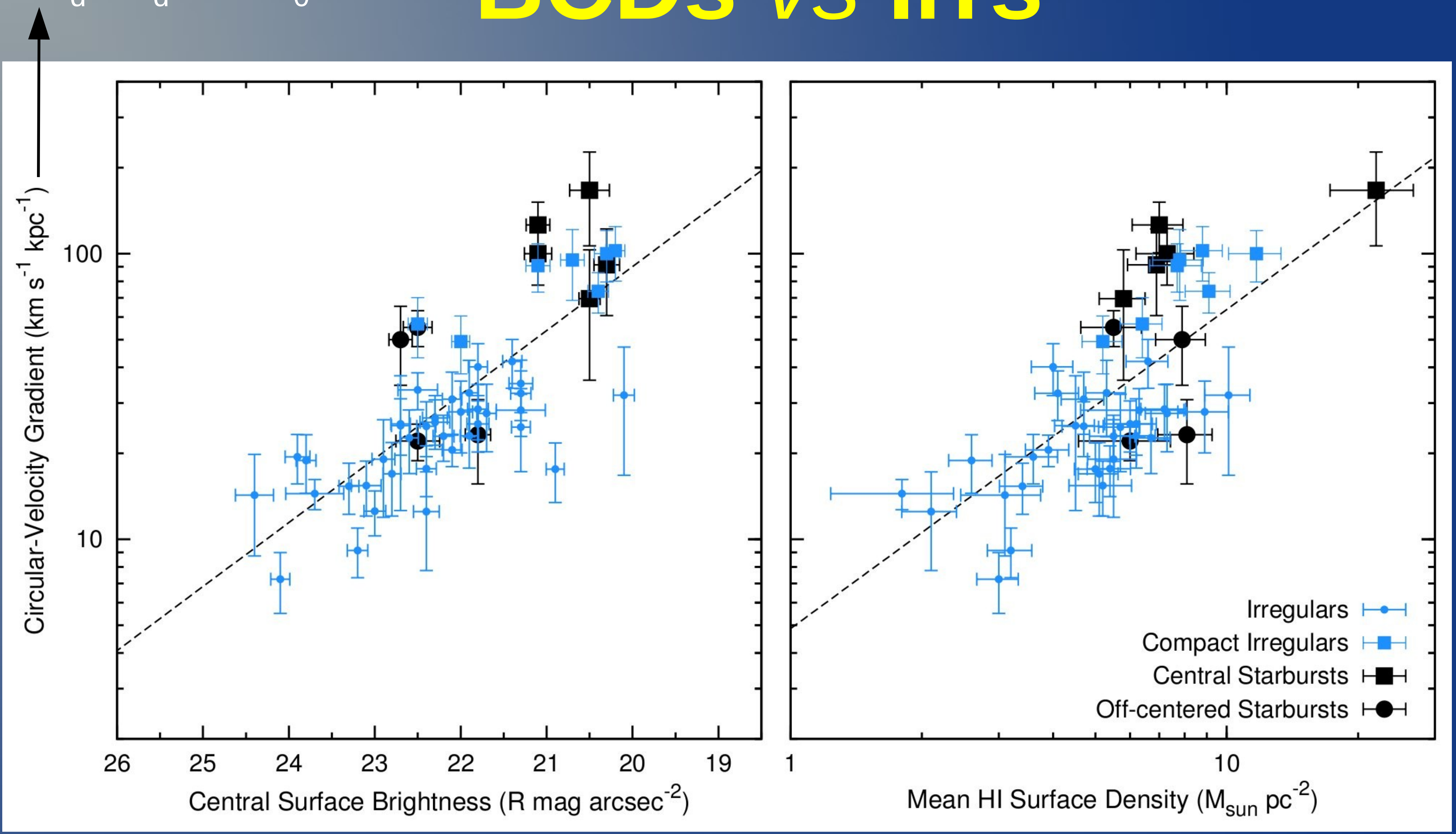
$dV/dR \sim V(R_d)/R_d$

R_d = disk scale length

- Measure the inner shape of the potential well
- Equal to the angular speed along the solid-body part

BCDs *vs* Irrs

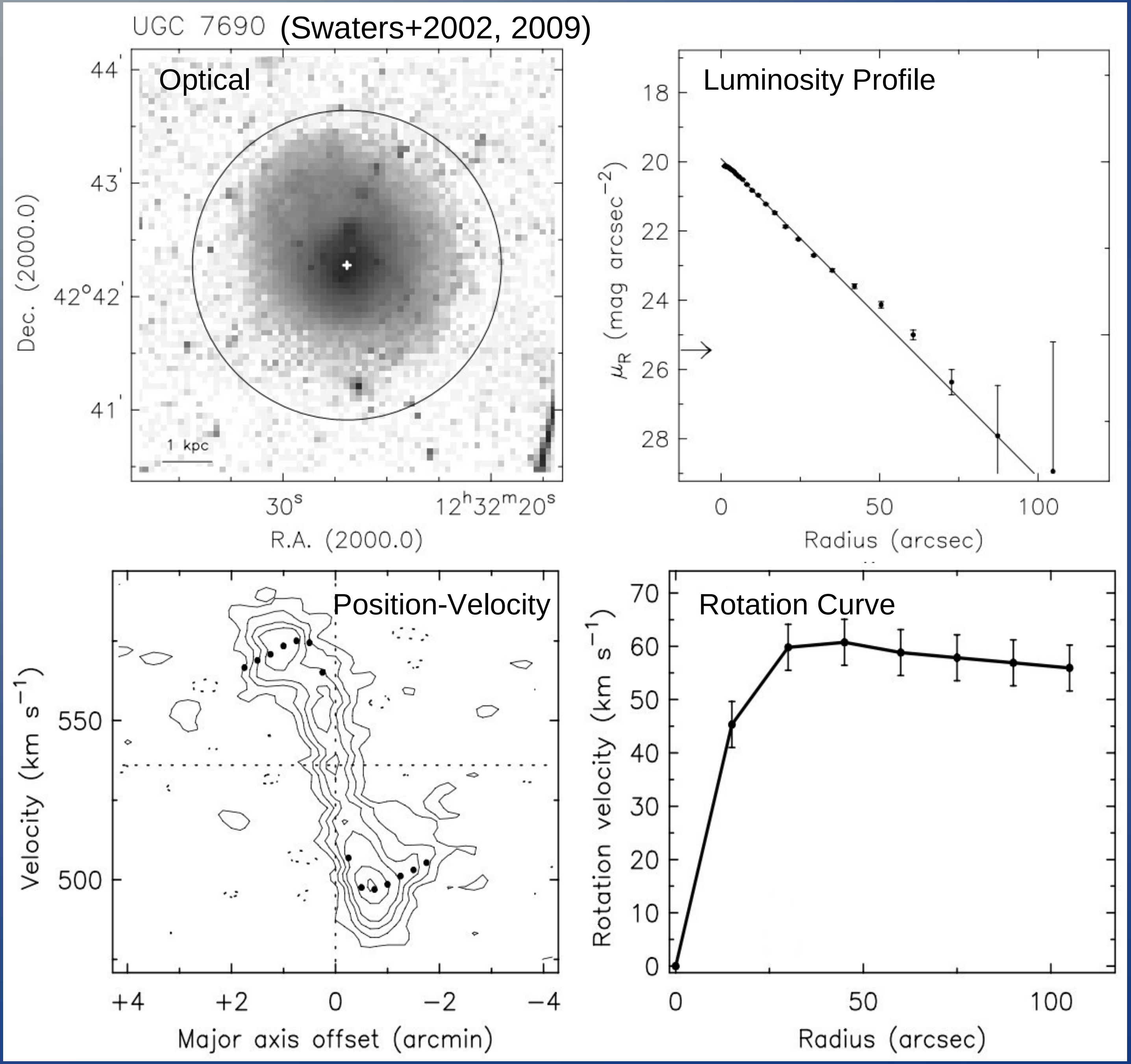
$V(R_d)/R_d \propto \sqrt{\rho_0}$



Compact Irrs = similar ρ_0 as BCDs

Irrs from Swaters+2009

Descendants of BCDs?



Compact Irrs

Photometry:

HSB exponential

μ_0 ~ 20 R mag asec^{-2}

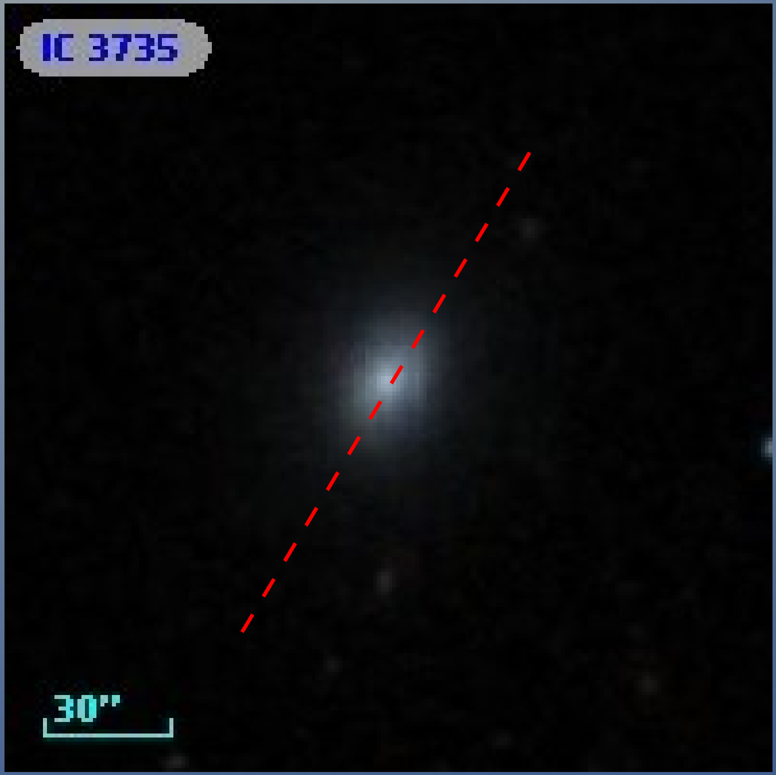
R_d ~ 400 pc

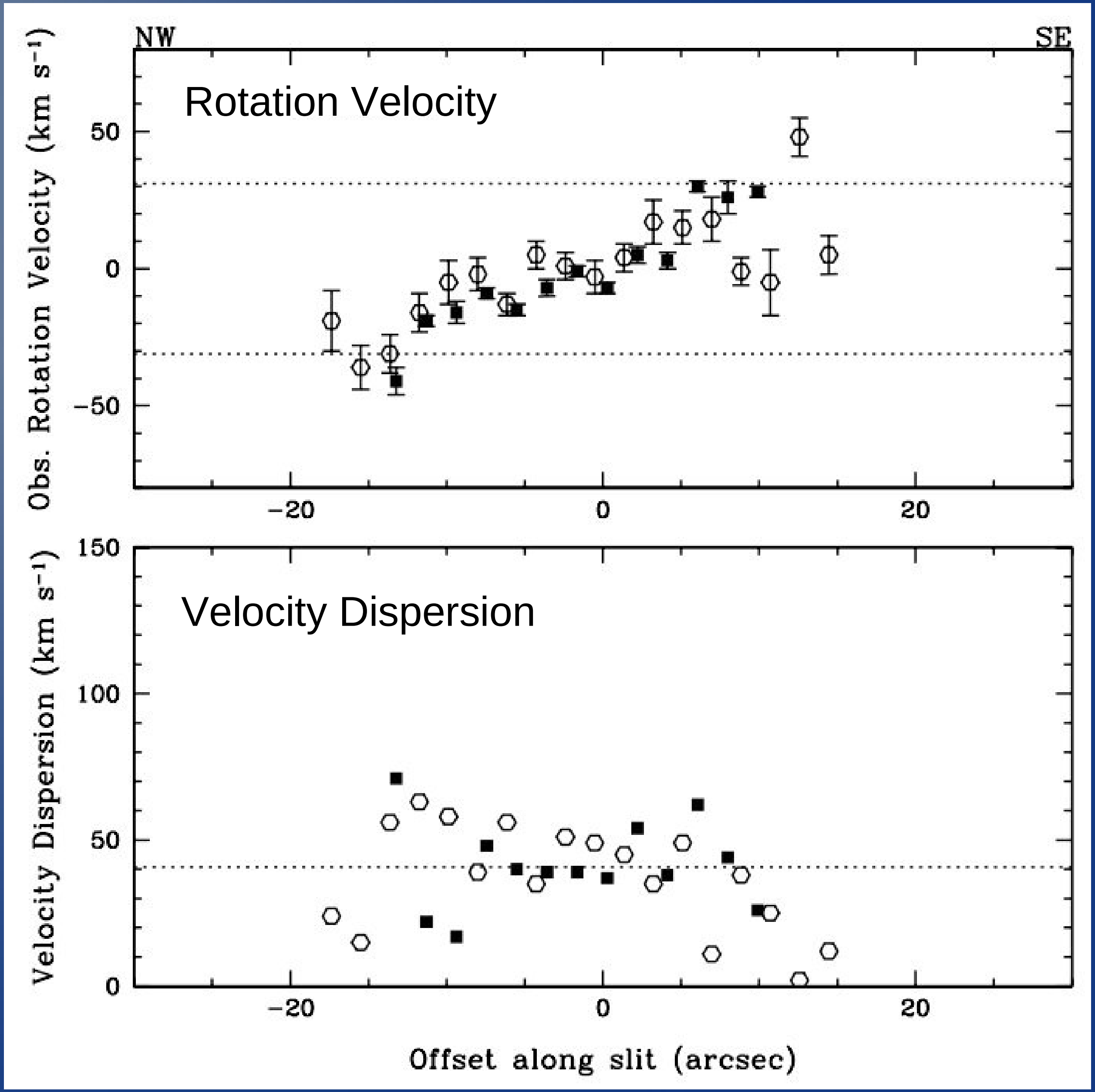
HI kinematics:

Steeply-rising

rotation curve!

Rotating Sphs in Virgo Cluster



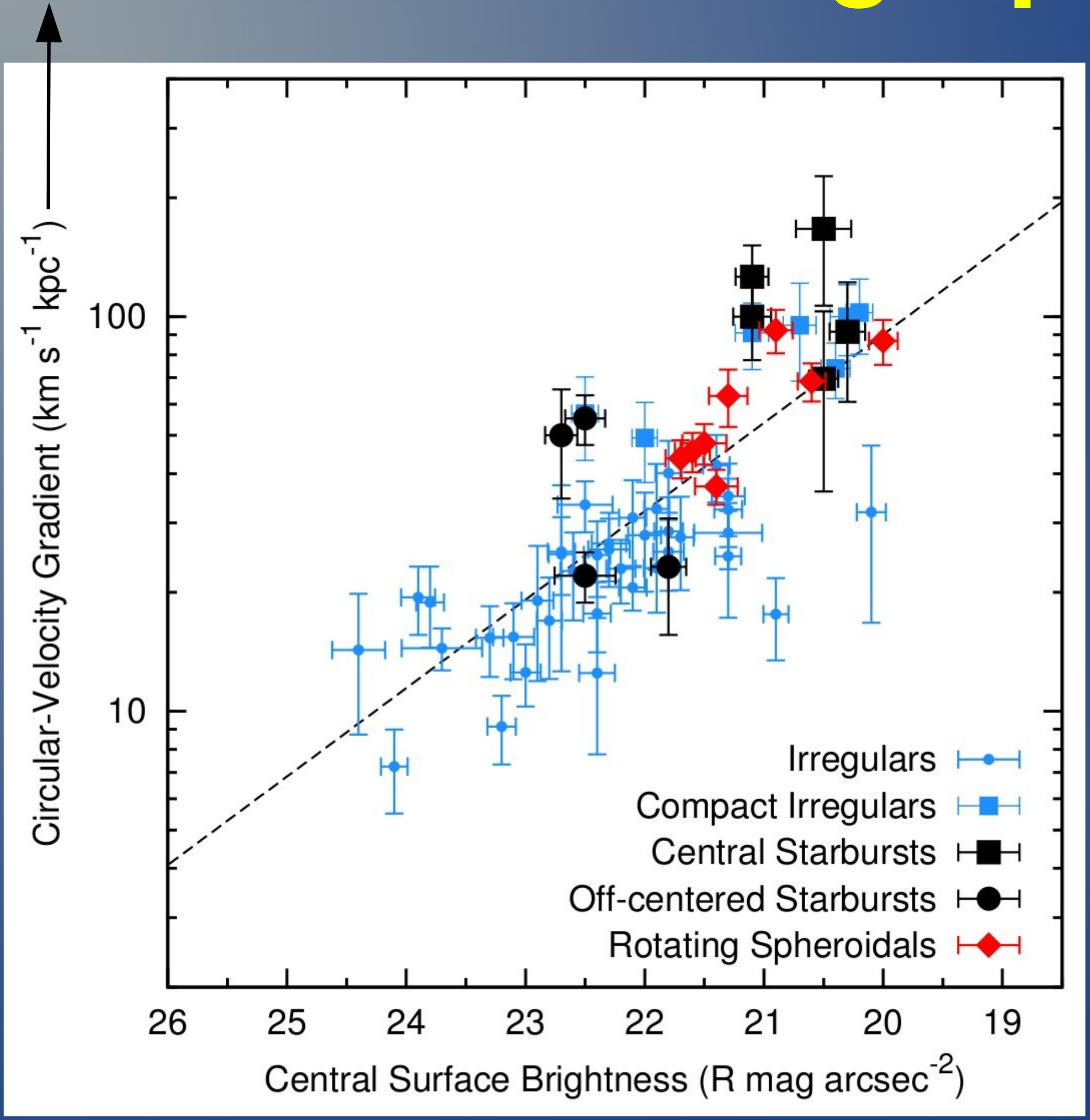


Optical Spectroscopy:

e.g. van Zee et al. (2004)

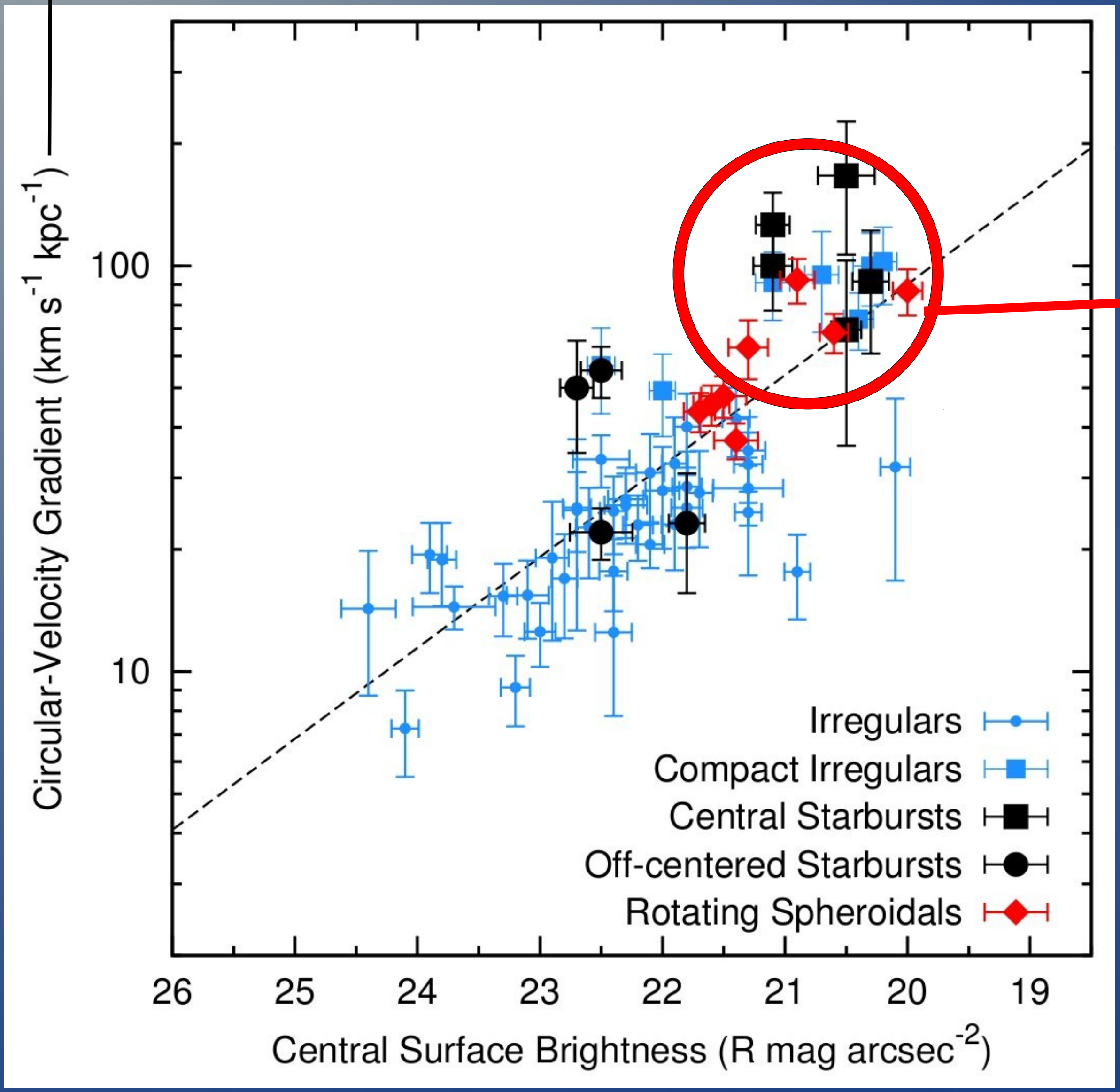
Rotating Sphs

$V(R_d)/R_d \propto \sqrt{\rho_0}$



Rotating Sphs

$V(R_d)/R_d \propto \sqrt{\rho_0}$



Descendants of BCDs?

Providing that some external mechanism removes the gas.

Message III

BCDs are different from typical Irrs:

⇒ strong central concentration of mass

Link: star-formation & inner potential well

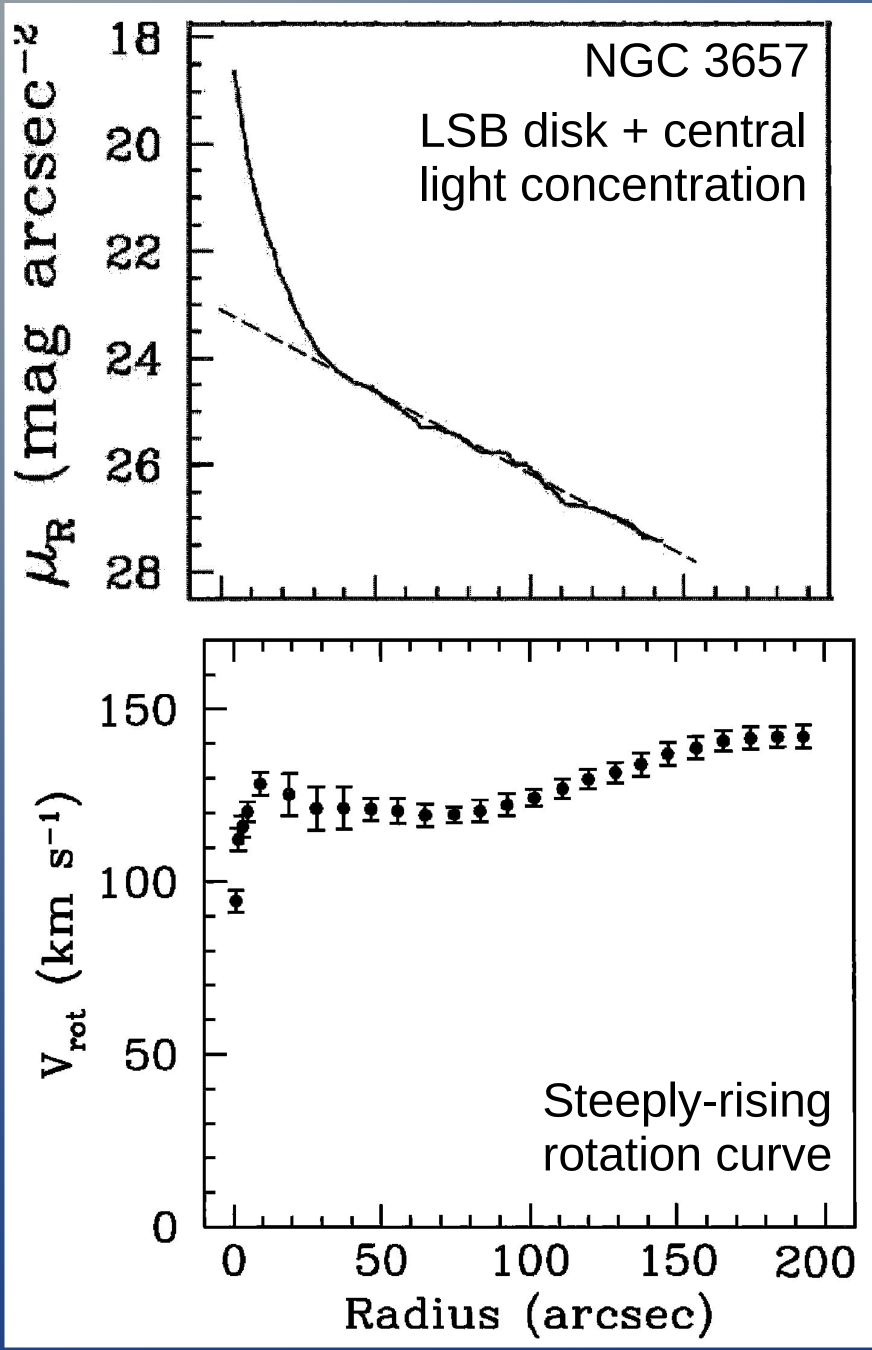
Evolution: compact Irrs & rotating Sphs

IV. A scaling-relation for disk galaxies:

linking baryonic & dynamical mass density

(Chapter 7 = Lelli et al. 2013, MNRAS: letters)

The visible – dark matter coupling

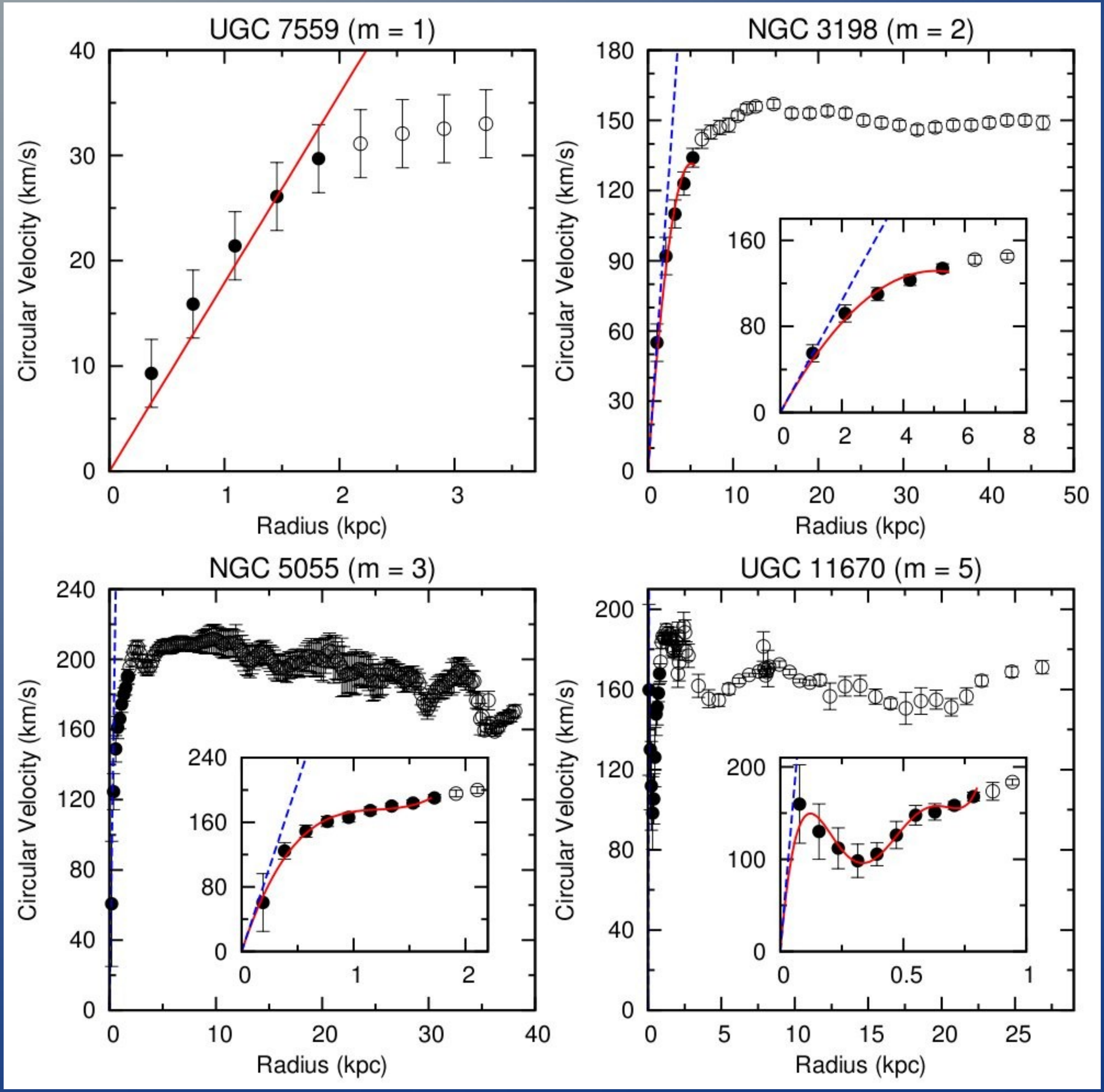


Renzo's Rule:

"For any feature in the luminosity profile there is a corresponding feature in the rotation curve and vice versa."

(Sancisi 2004)

Circular-velocity gradient for spirals



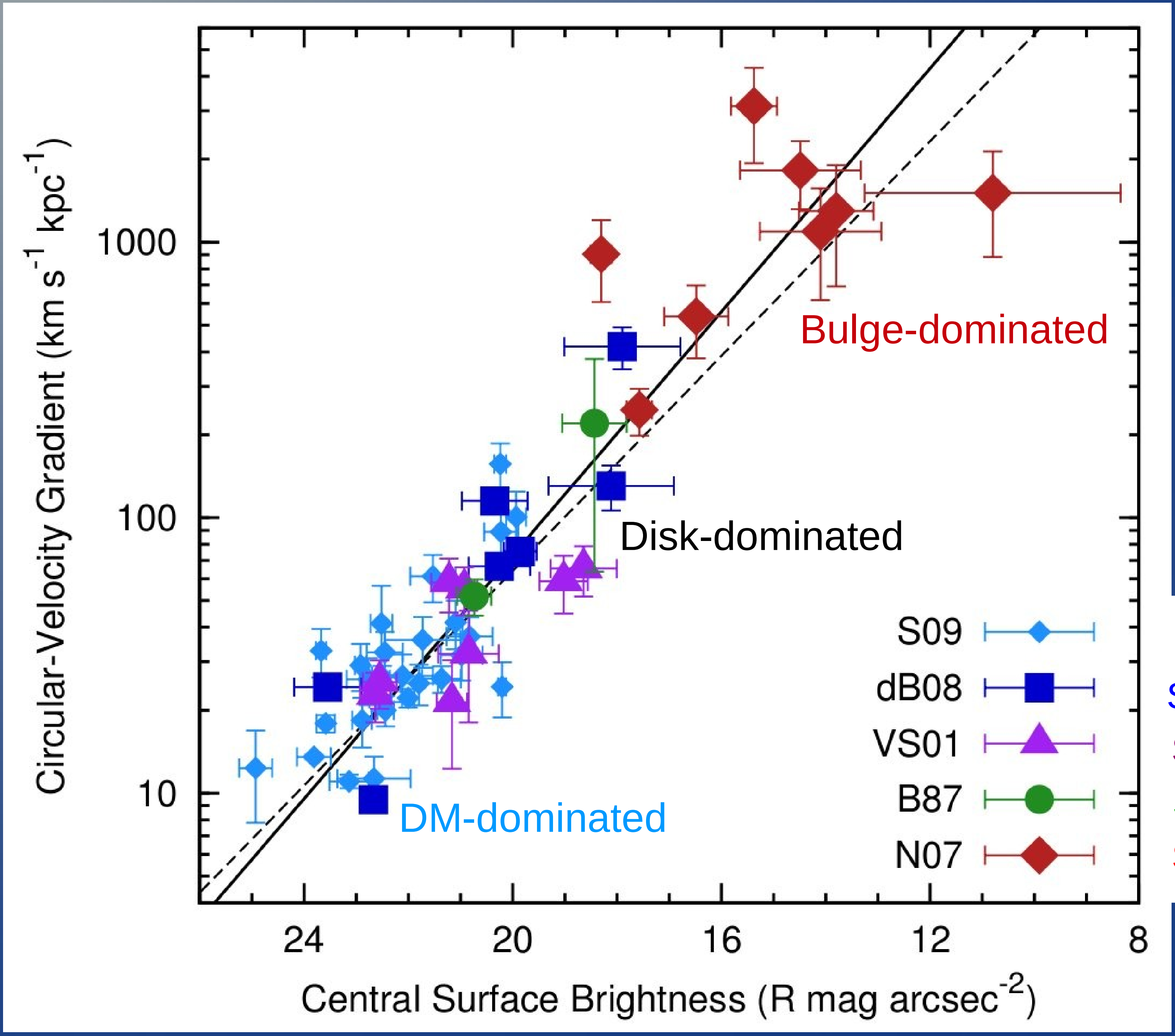
$$V(R) = \sum_{n=1}^{m} a_n \times R^n$$

$$a_1 = \lim_{R \to 0} dV/dR.$$

5 Galaxy Samples:

- Noordermeer 06: S0 – Sa
- de Blok+2008: Sab – Irr
- Begeman 1987: Sb – Sc
- Verheijen 1997: Sb – Irr
- Swaters 1999: Sd – Irr

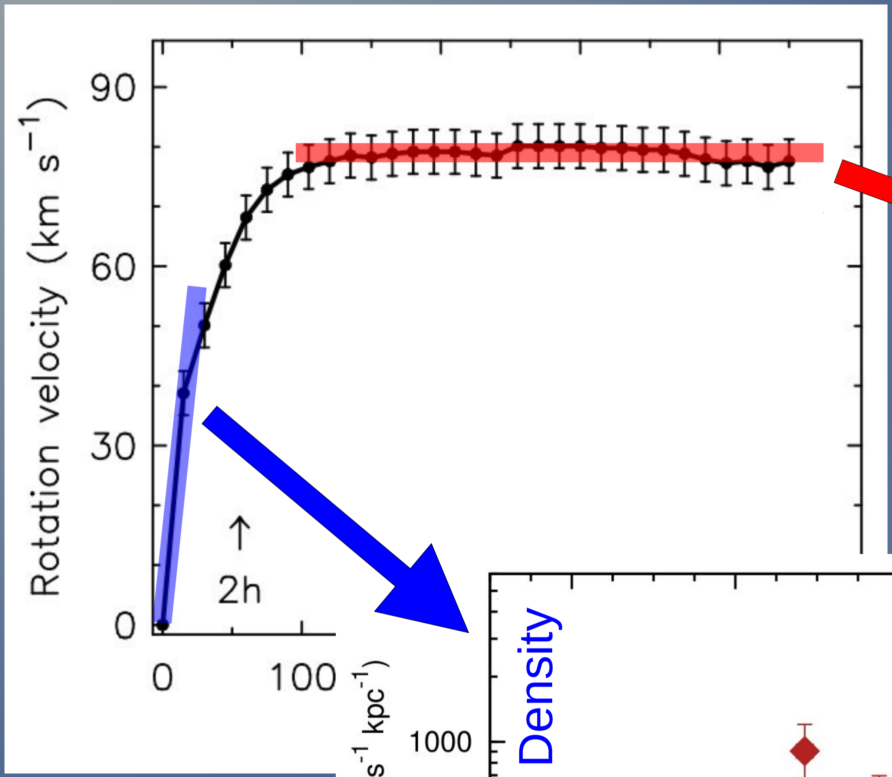
Velocity gradient *vs* central SB



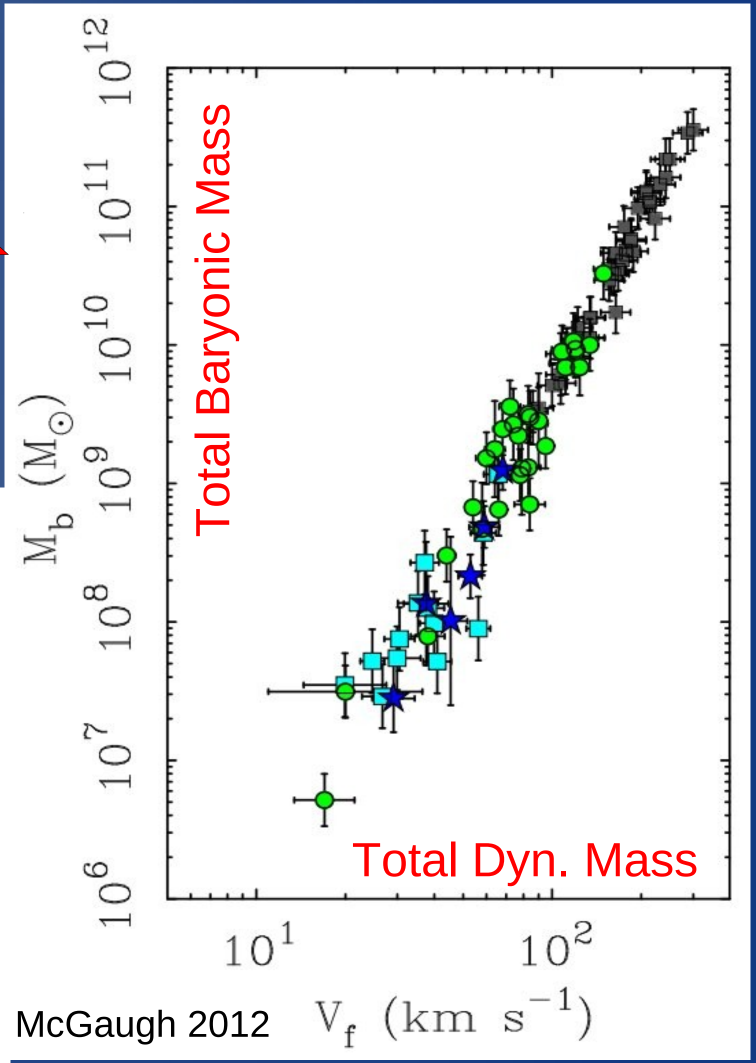
Sd – Irr
Sab – Irr
Sb – Irr
Sb – Sc
S0 – Sa

Lelli et al. 2013, MNRAS: letters

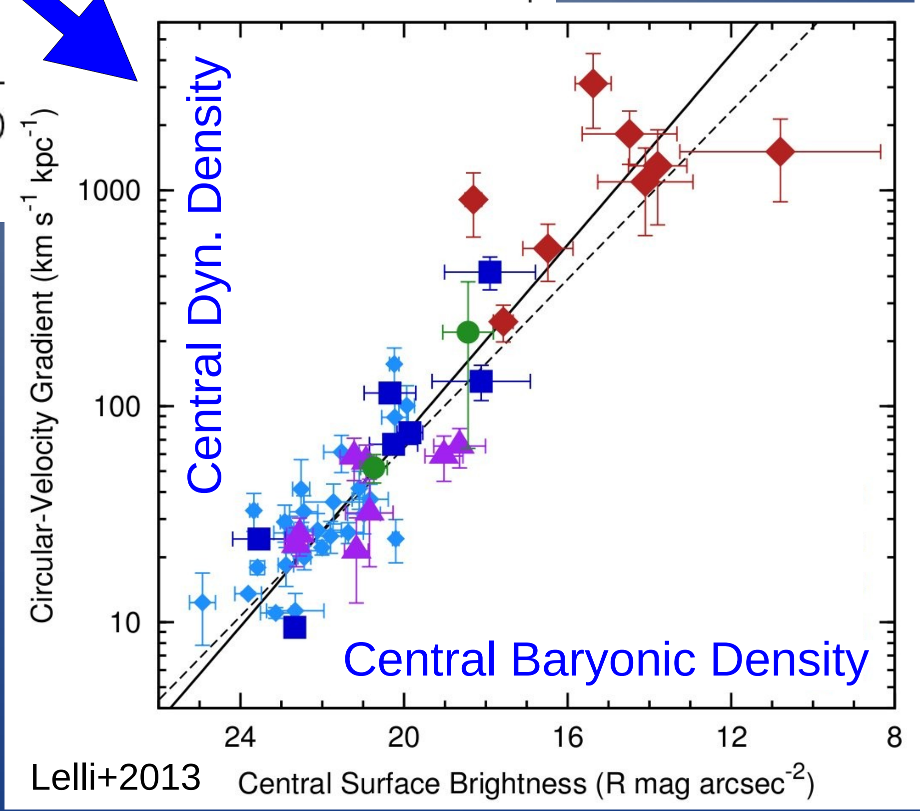
Scaling Relations for Rotating Galaxies



Baryonic TF relation



McGaugh 2012



Lelli+2013

Message IV

Baryonic density ⟷ dynamical mass density

...even in galaxies that should be DM-dominated!

Conclusions

- Starburst is triggered by external mechanisms

  - Interactions/mergers? Cold gas accretion?

- BCDs and Irrs have similar baryonic & gas fract.

  - No evidence for massive outflows

- BCDs have a strong central mass concentration

  - starburst <--> inner potential well

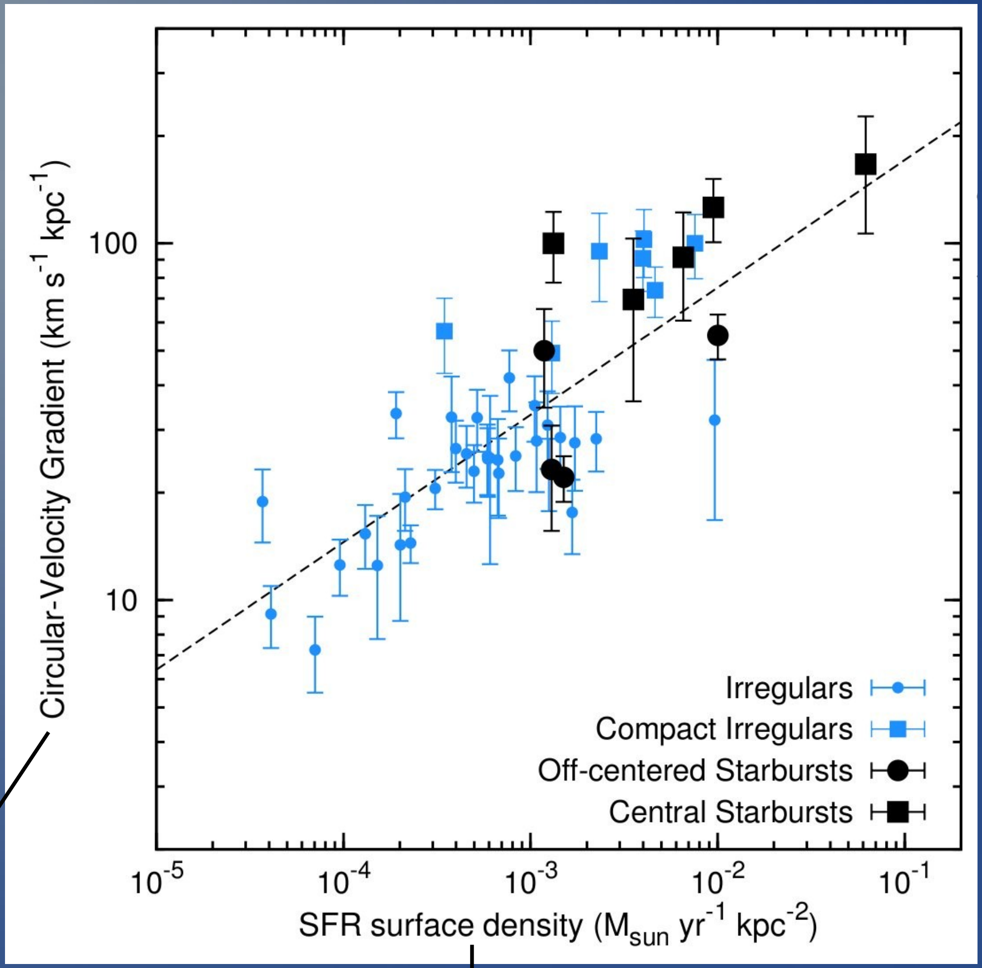
  - BCDs <--> compact Irrs & rotating Sphs

- Scaling relation: velocity gradient *vs* central SB

  - Dynamical mass density <--> Baryonic density

More Slides

Link: Star Formation – Dynamics



$V(R_d)/R_d \propto \sqrt{\rho_0}$

$SFR(H\alpha)/(\pi\ R_{opt}^{\ 2})$

Hα fluxes from Kennicutt+2008

Theoretical Interpretation

Expected relation:

$$\log[d_R V(0)] = -0.2\,\mu_0 + 0.5\log\left(\alpha G \frac{M_*/L}{z_0\, f_{\mathrm{bar},0}}\right).$$

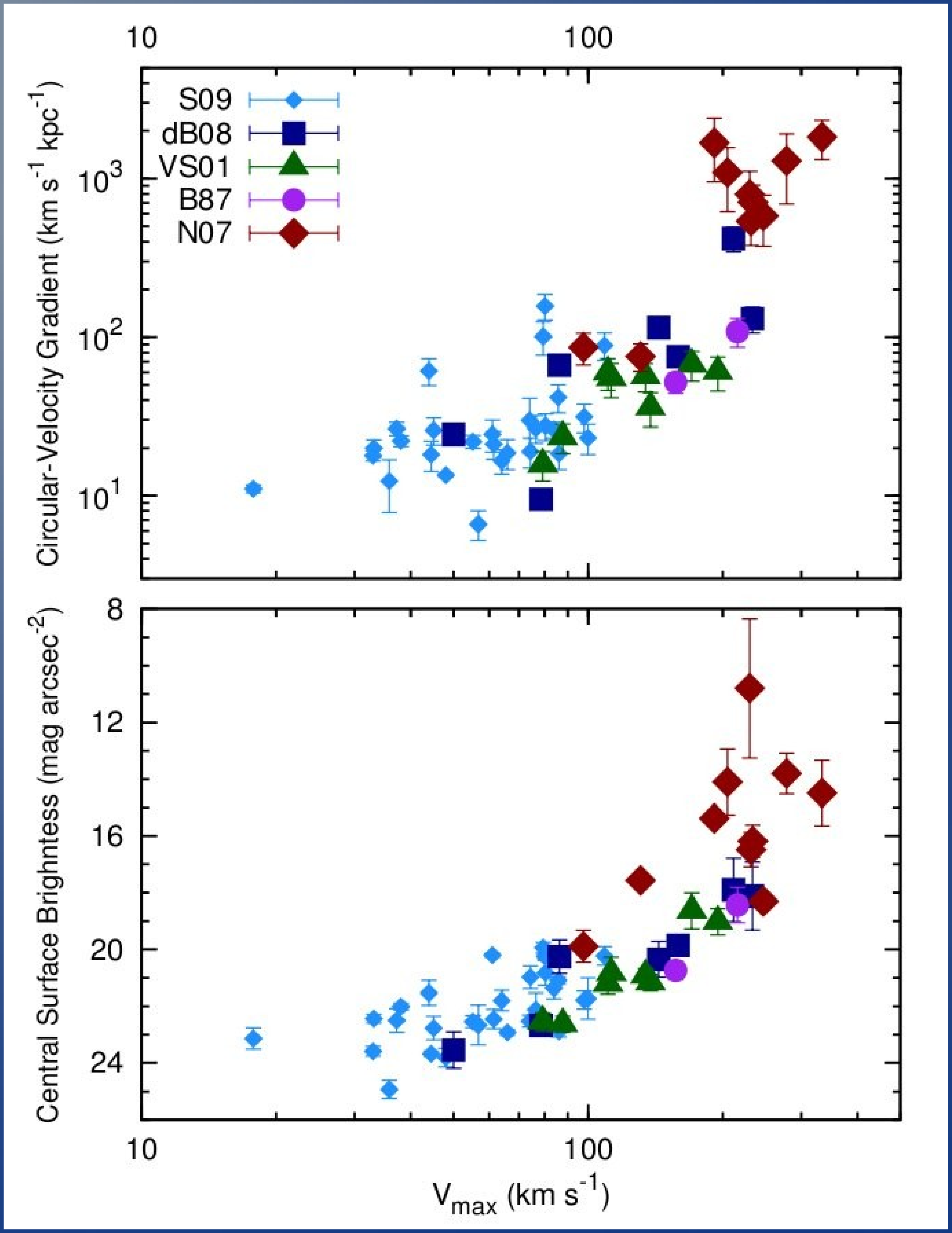
Observed relation:

$$\log[d_R V(0)] = (-0.205 \pm 0.023)\,\mu_0 + (5.91 \pm 0.52).$$

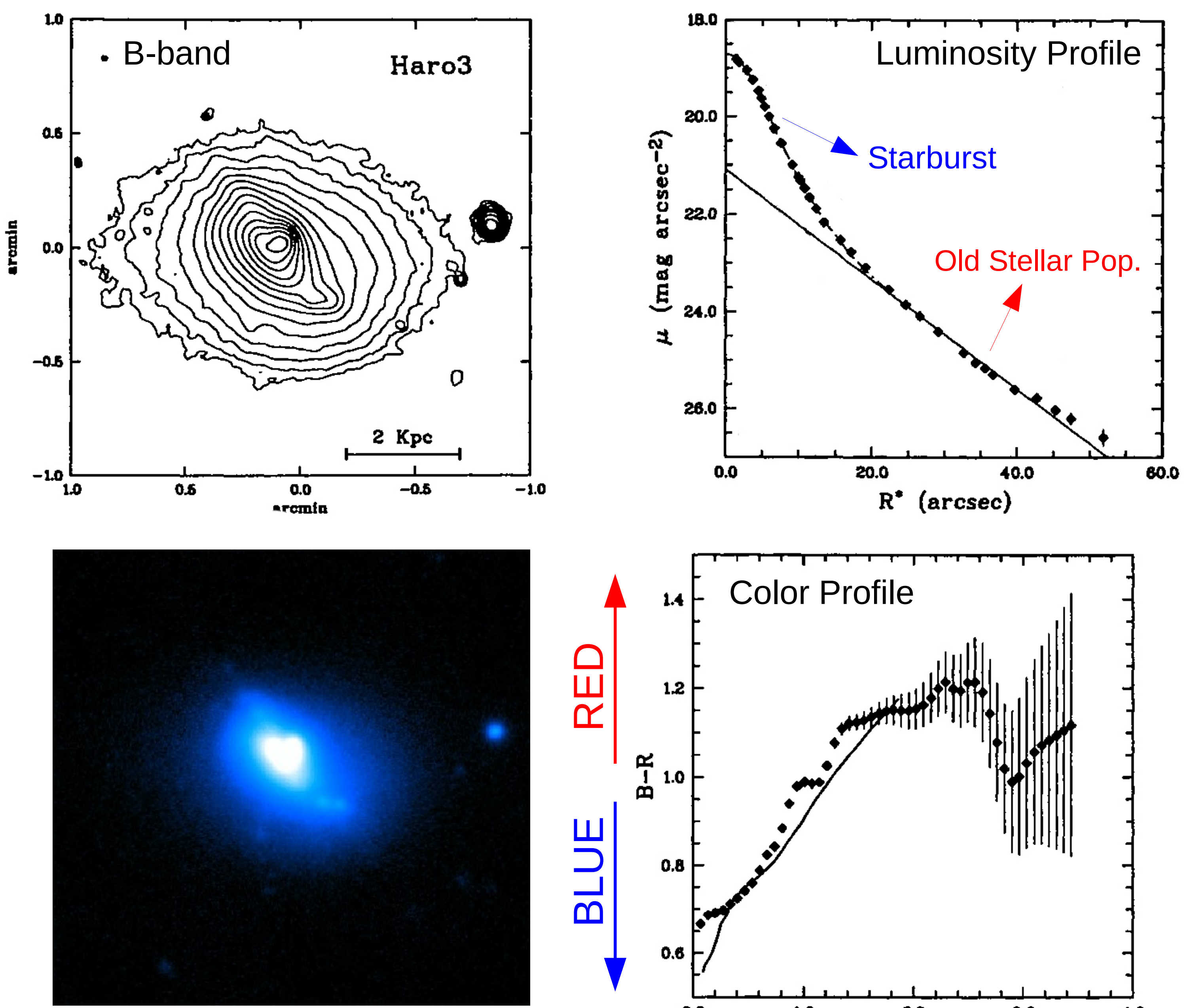
If slope = -0.2, puzzling fine-tuning between:

- geometrical parameters (α, z_0)
- stellar populations (M_*/L)
- dark matter content ($f_{\mathrm{bar,\,0}}$)

Velocity Gradient *vs* Vmax

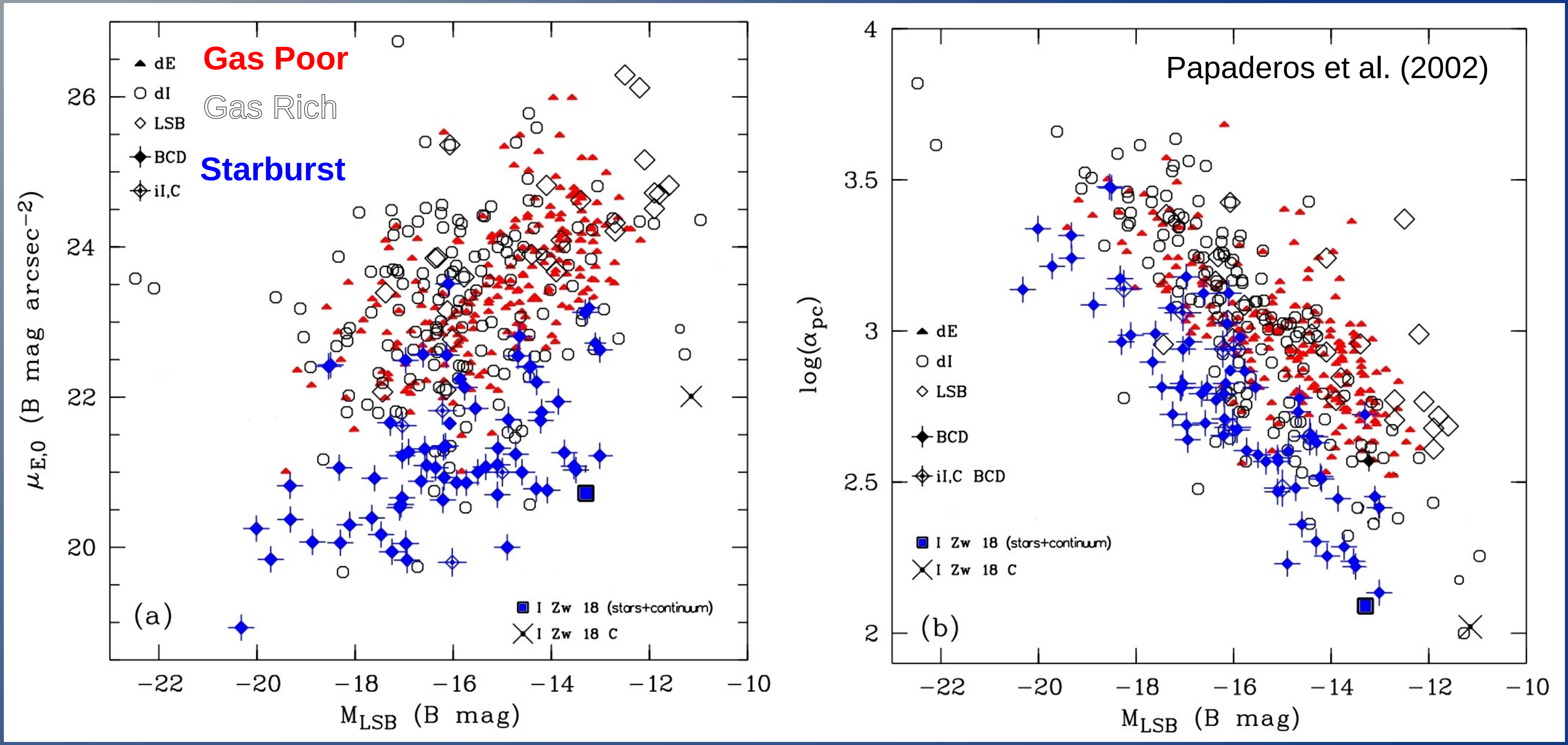


Optical Structure of BCDs



Papaderos et al. (1996)

Optical Structure of BCDs



Old component of BCDs: $\mu_0 \sim 21.5$ mag asec^{-2} (Freeman value)

Papaderos et al. (1996, 2002); Salzer & Norton (1999); Cairos et al. (2001); Gil de Paz & Madore (2005); Amorin et al. (2009).