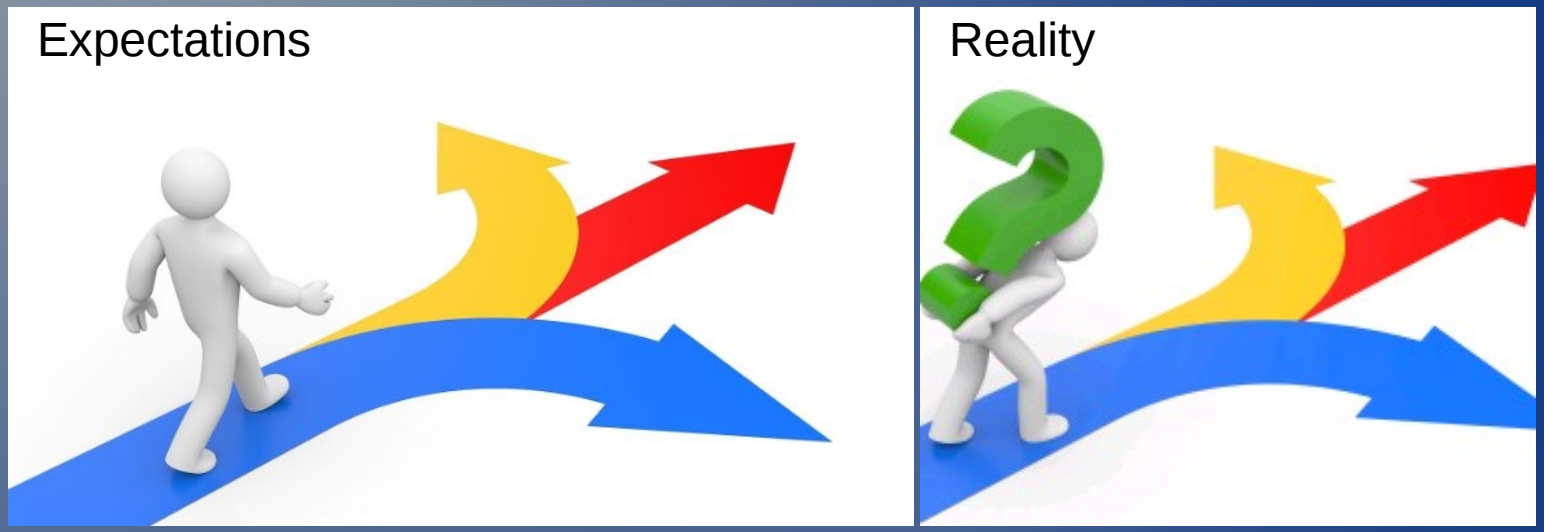
The Evolutionary Pathways of Dwarf Galaxies

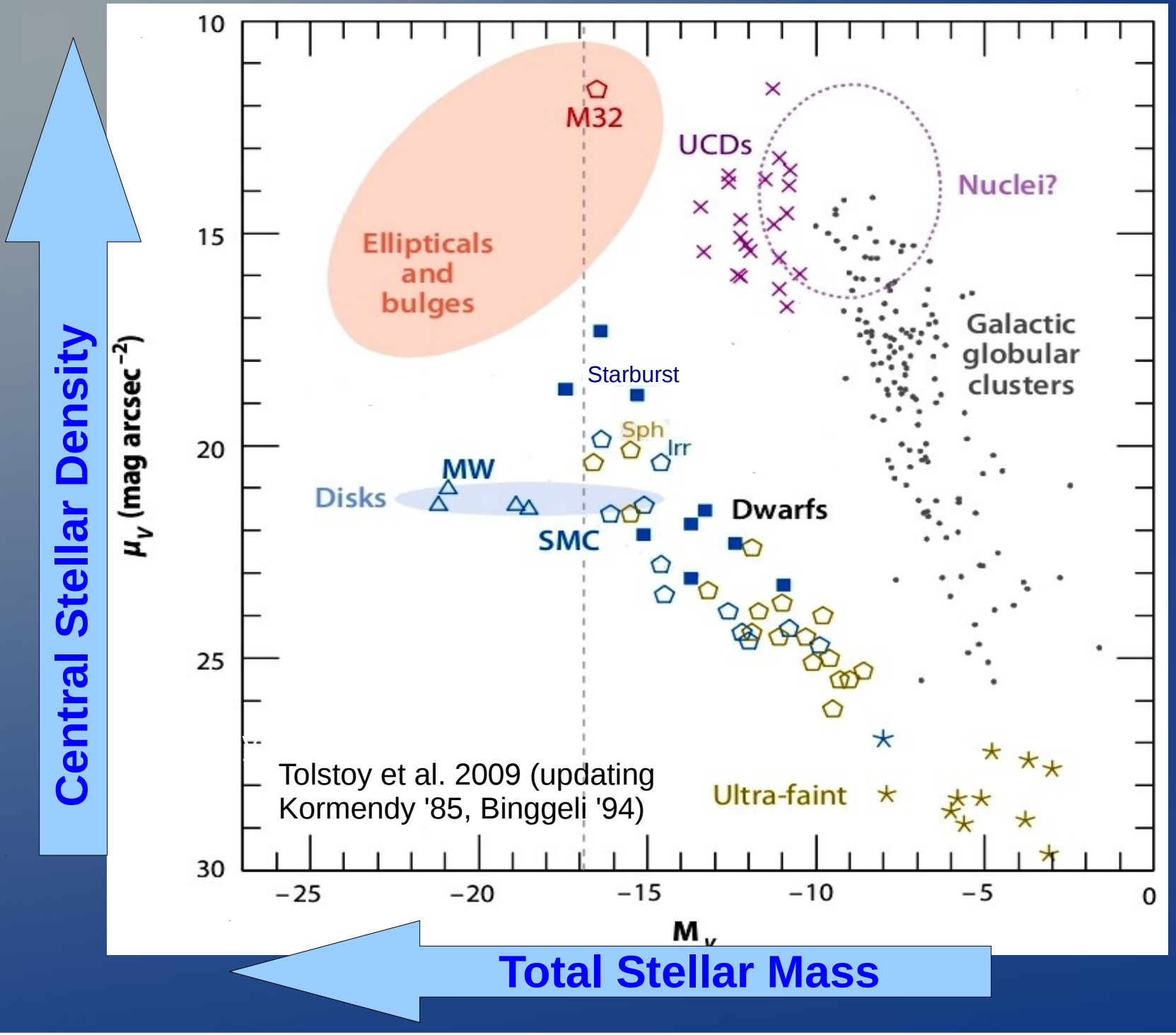


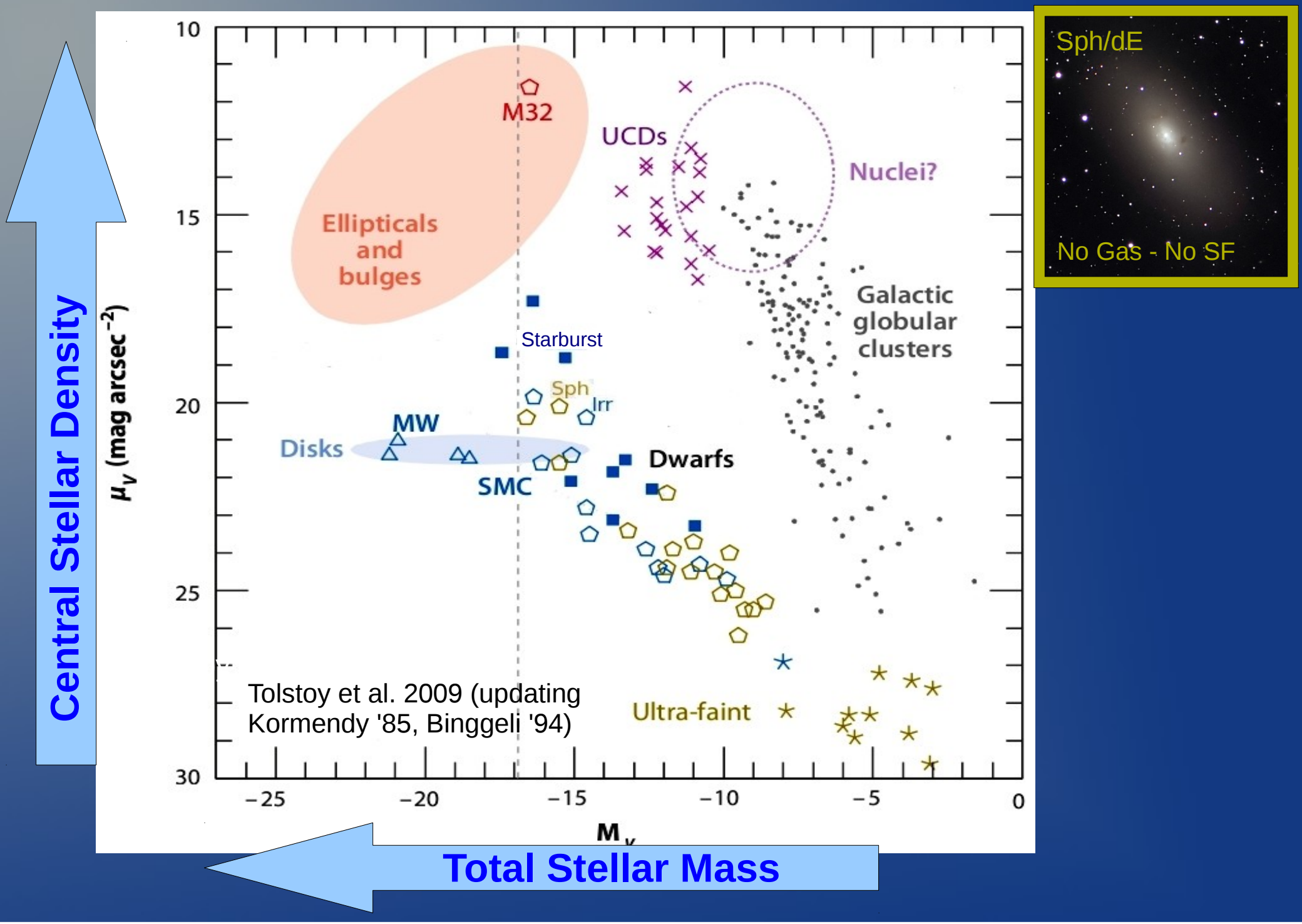
Federico Lelli

Astronomy Department, Case Western Reserve University,

Cleveland, Ohio

Main Collaborators: Marc Verheijen, Filippo Fraternali, Renzo Sancisi, Stacy McGaugh, Kristen McQuinn, Evan Skillman, Pierre-Alain Duc, Elias Brinks, Ute Lisenfeld & more


Central Stellar Density
Total Stellar Mass
μ_V (mag arcsec^{-2})
M_V
10
15
20
25
30
−25
−20
−15
−10
−5
0
M32
UCDs
Nuclei?
Ellipticals and bulges
Galactic globular clusters
Starburst
Sph
Irr
MW
Disks
SMC
Dwarfs
Ultra-faint
Tolstoy et al. 2009 (updating Kormendy '85, Binggeli '94)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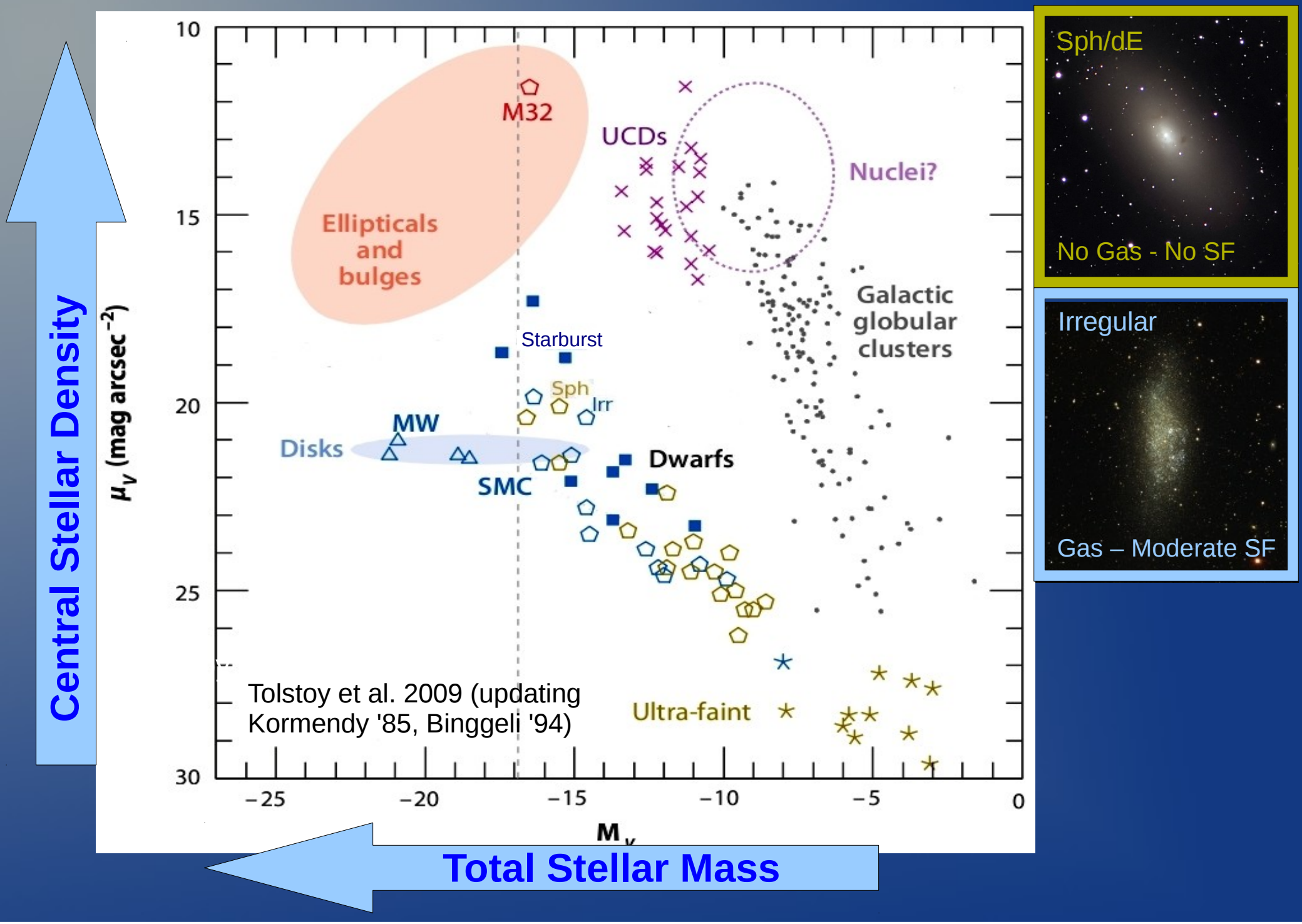
Sph/dE
No Gas - No SF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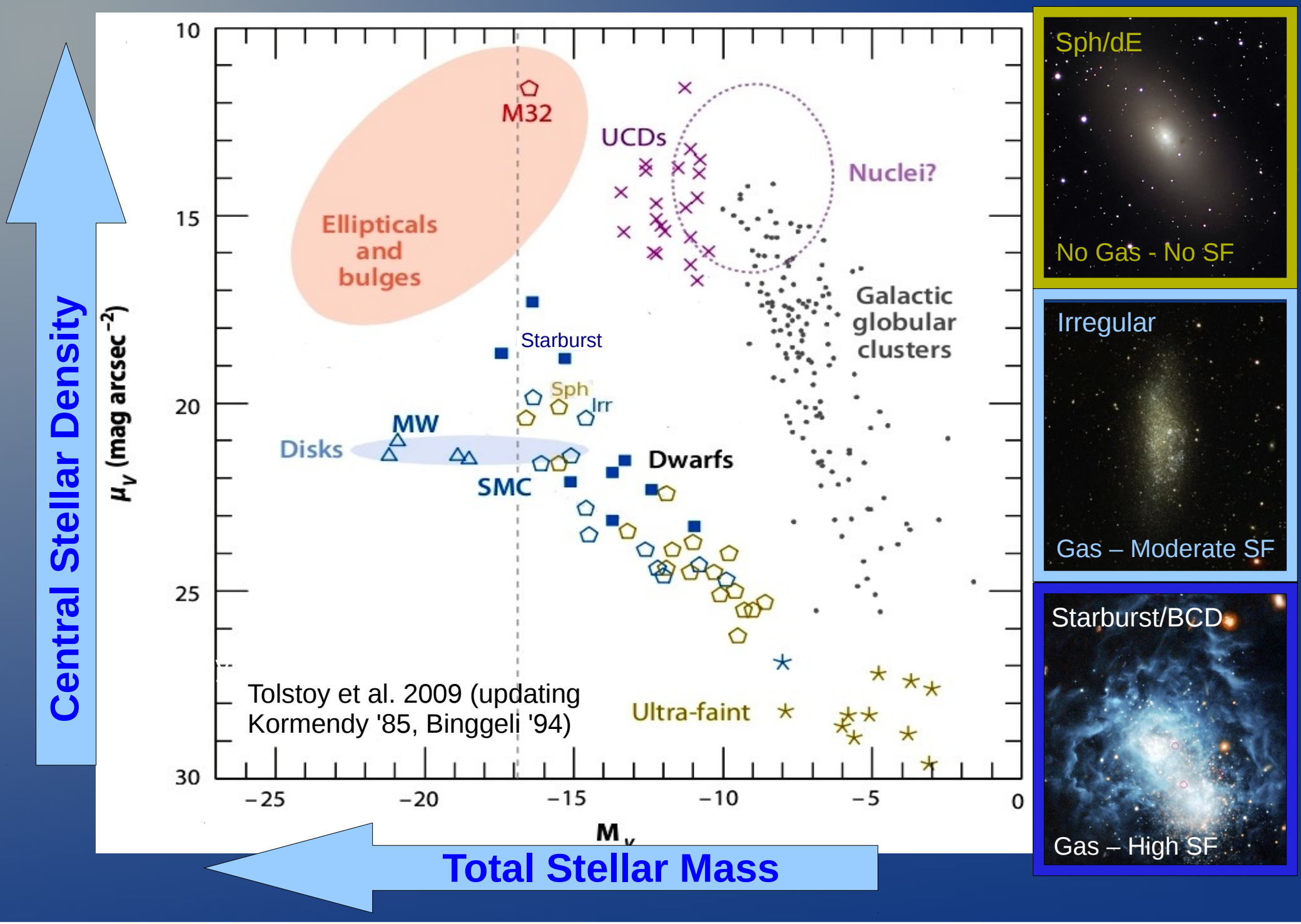
No Gas - No SF
Irregular
Gas – Moderate SF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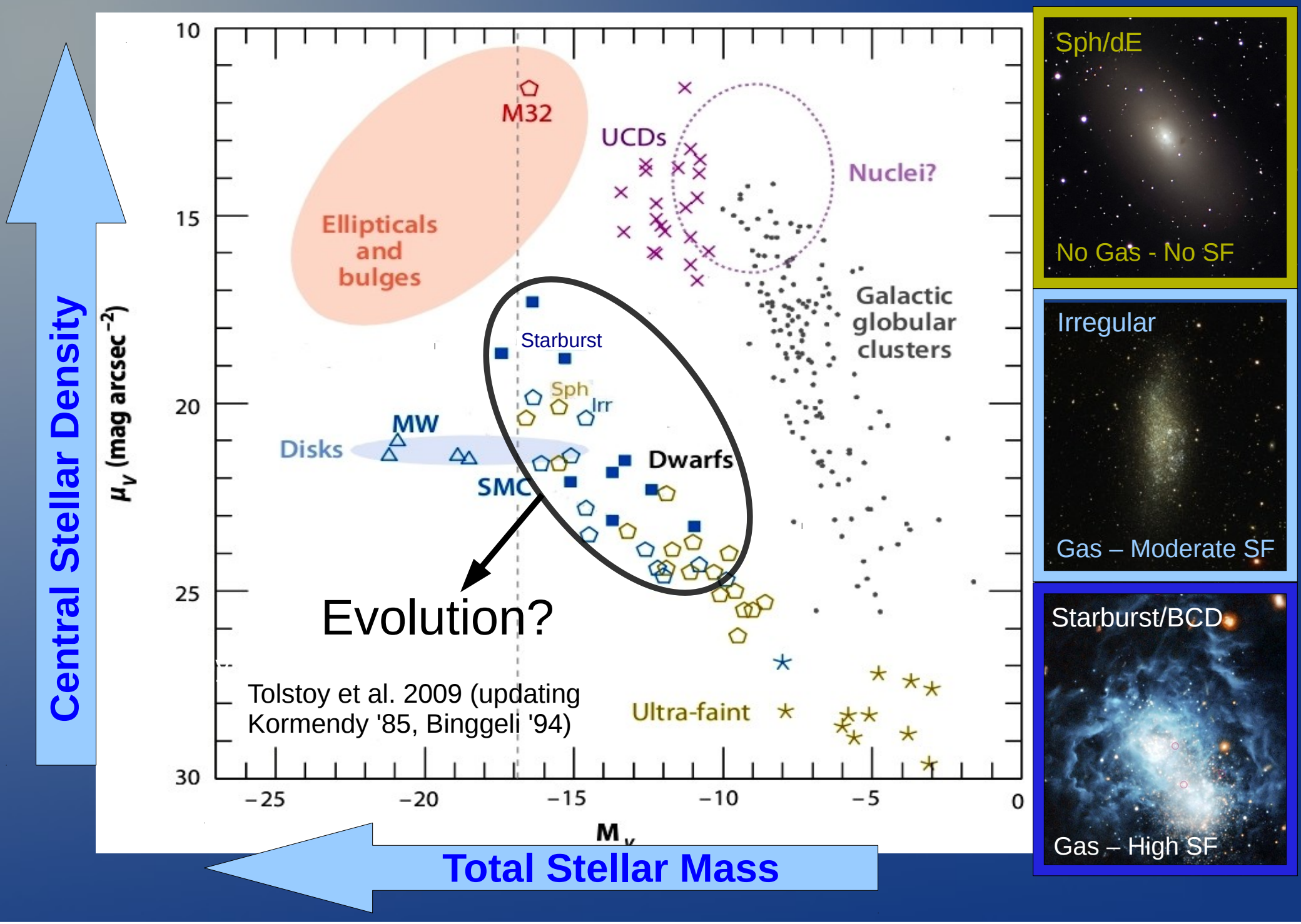
Sph/dE
No Gas - No SF
Irregular
Gas – Moderate SF
Starburst/BCD
Gas – High SF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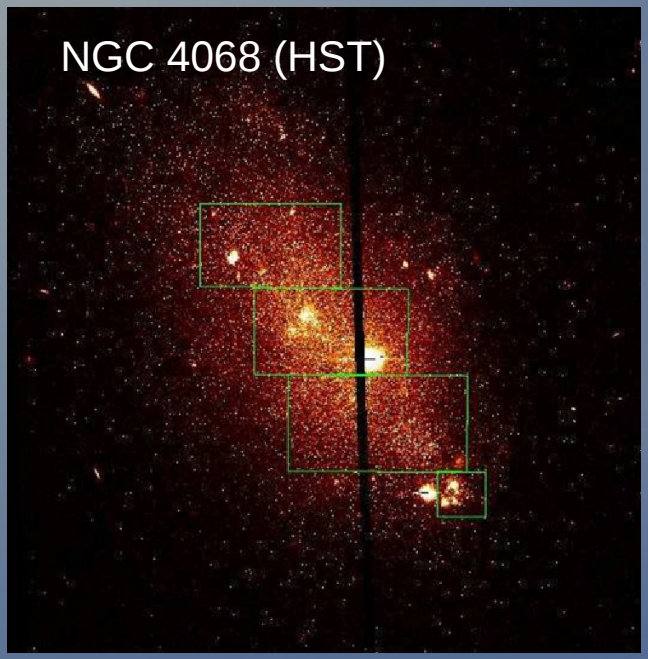
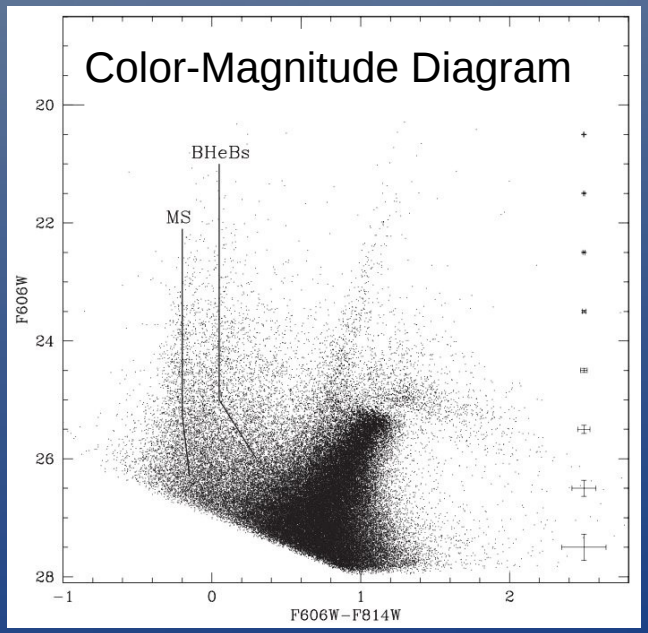
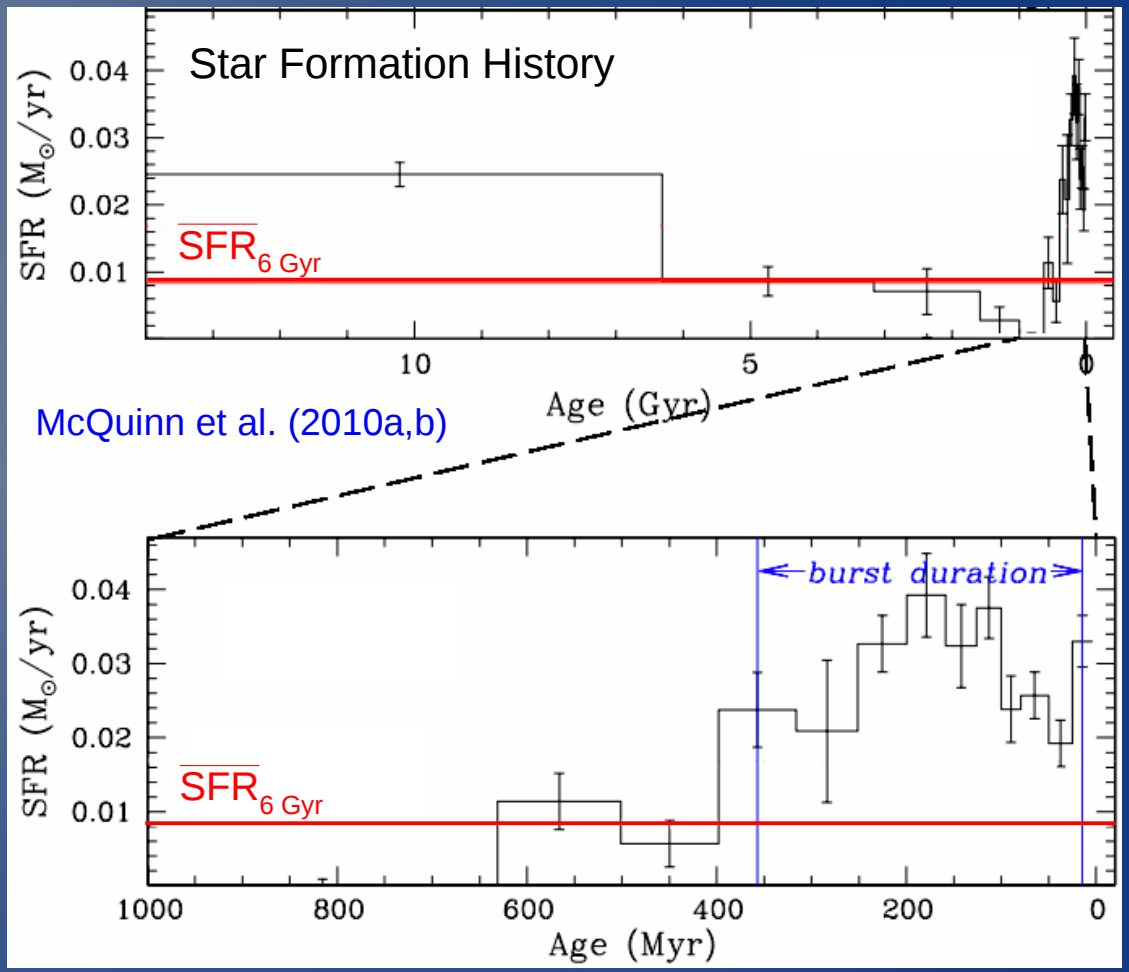
SF Properties of Starburst Dwarfs

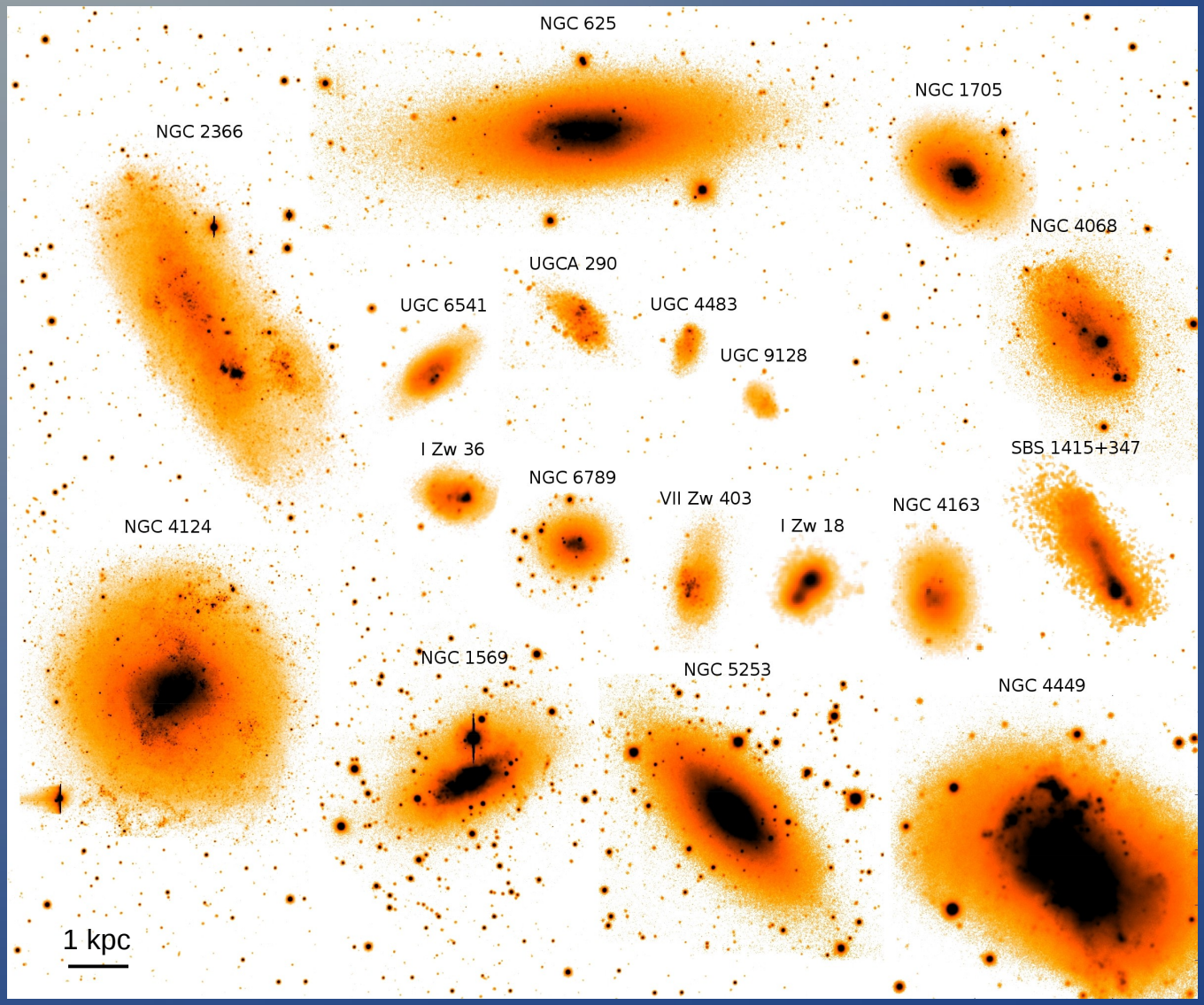






- b = $SFR(t_{peak})/ \overline{SFR}_{6\ Gyr}$ ~ 3-10
- Starburst timescales (few 100 Myr)
- E from SN & stellar winds (~10^{56} ergs)

Sample of 18 Starburst Dwarfs



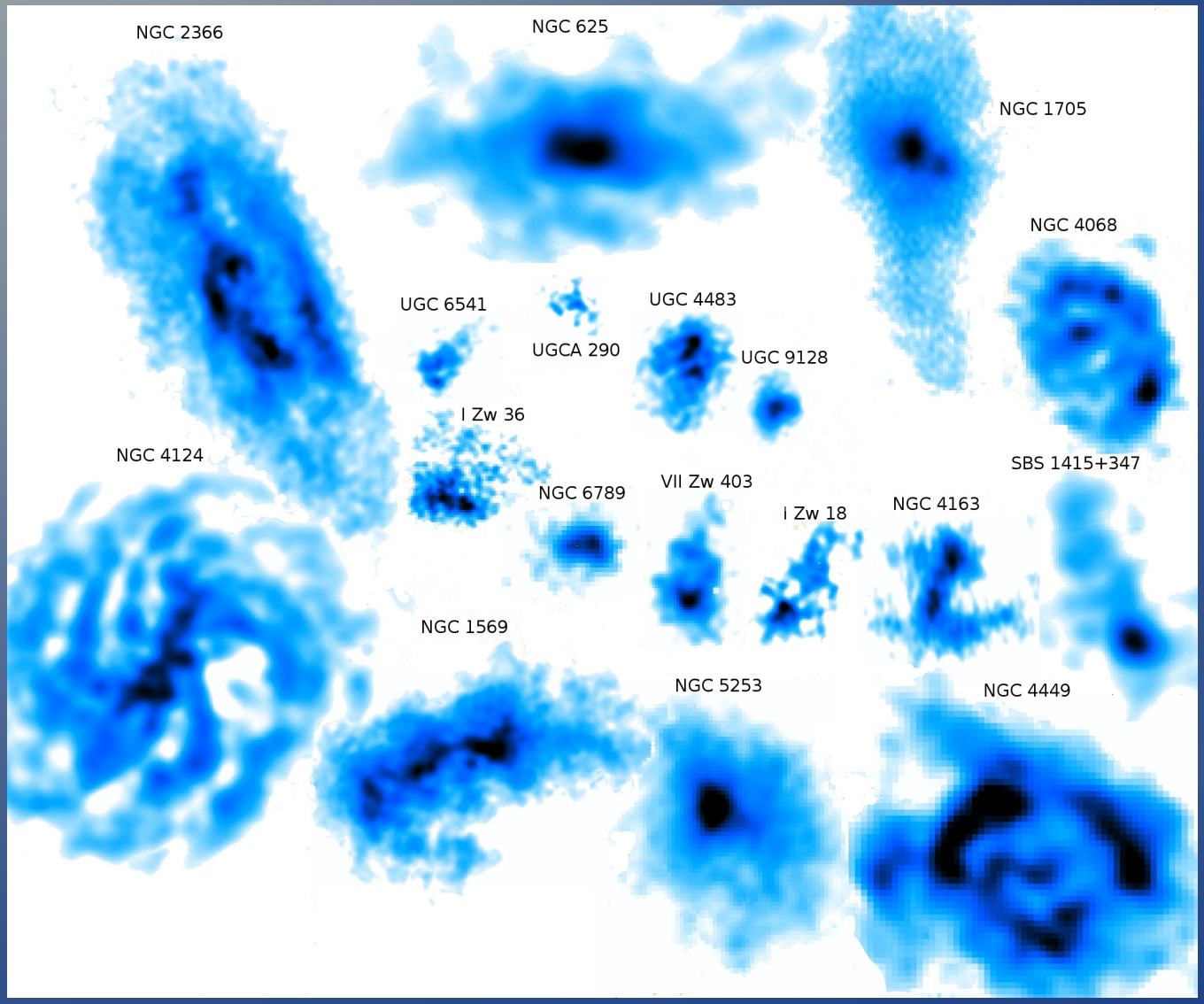
Resolved into single stars by HST obs:

- Distance ≃ 2-10 Mpc
- Star Formation History
- $b = SFR(t_{peak})/\overline{SFR} \geq 3$

Lelli et al. (2012a,b; 2014a,b,c)

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

Sample of 18 Starburst Dwarfs



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- $b = SFR(t_{peak})/\overline{SFR} \geq 3$

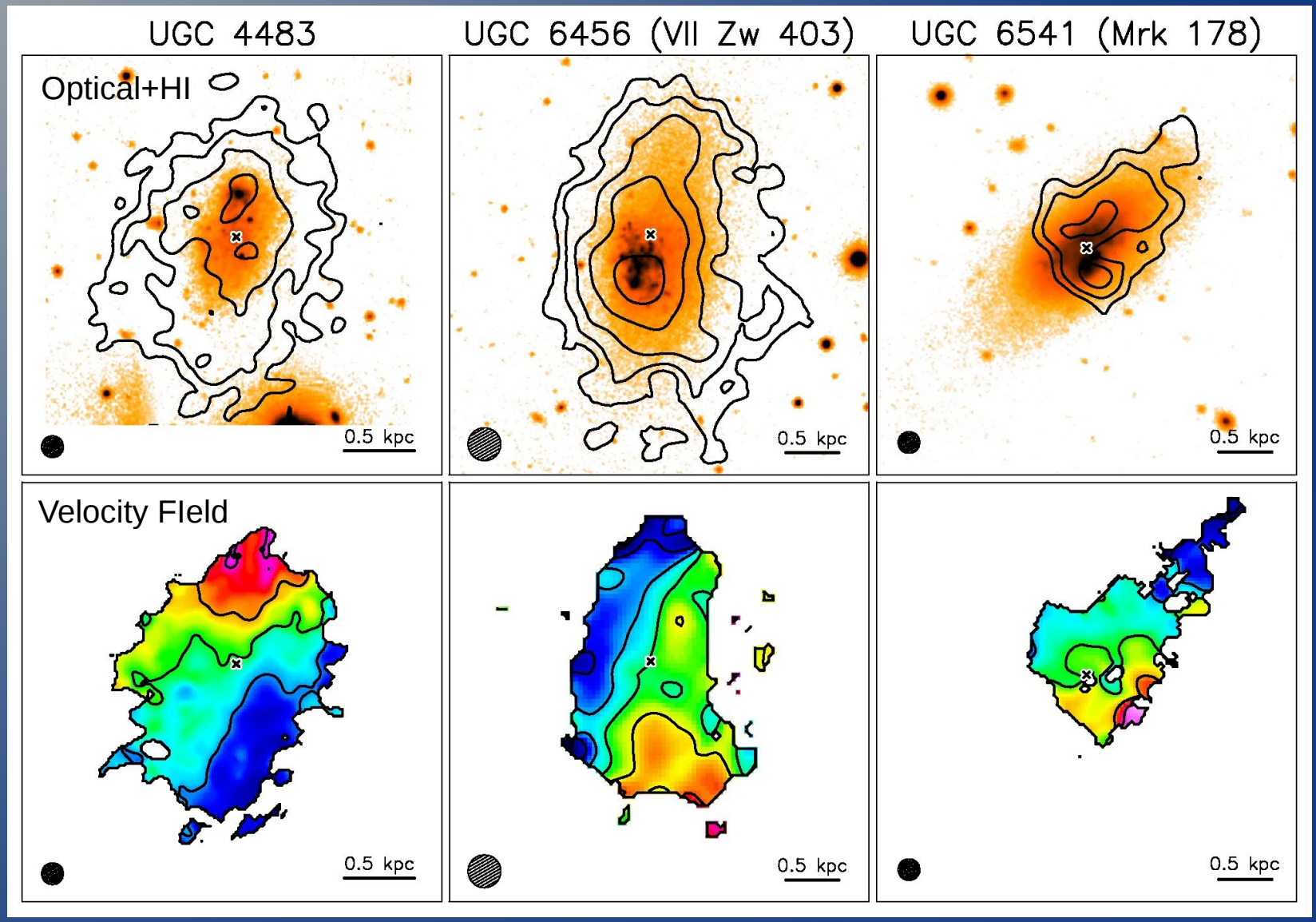
21-cm line obs (VLA, WSRT, ATCA):

- HI distribution
- HI kinematics

Lelli et al. (2012a,b; 2014a,b,c)

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

Inner HI Structure of Starburst Dwarfs

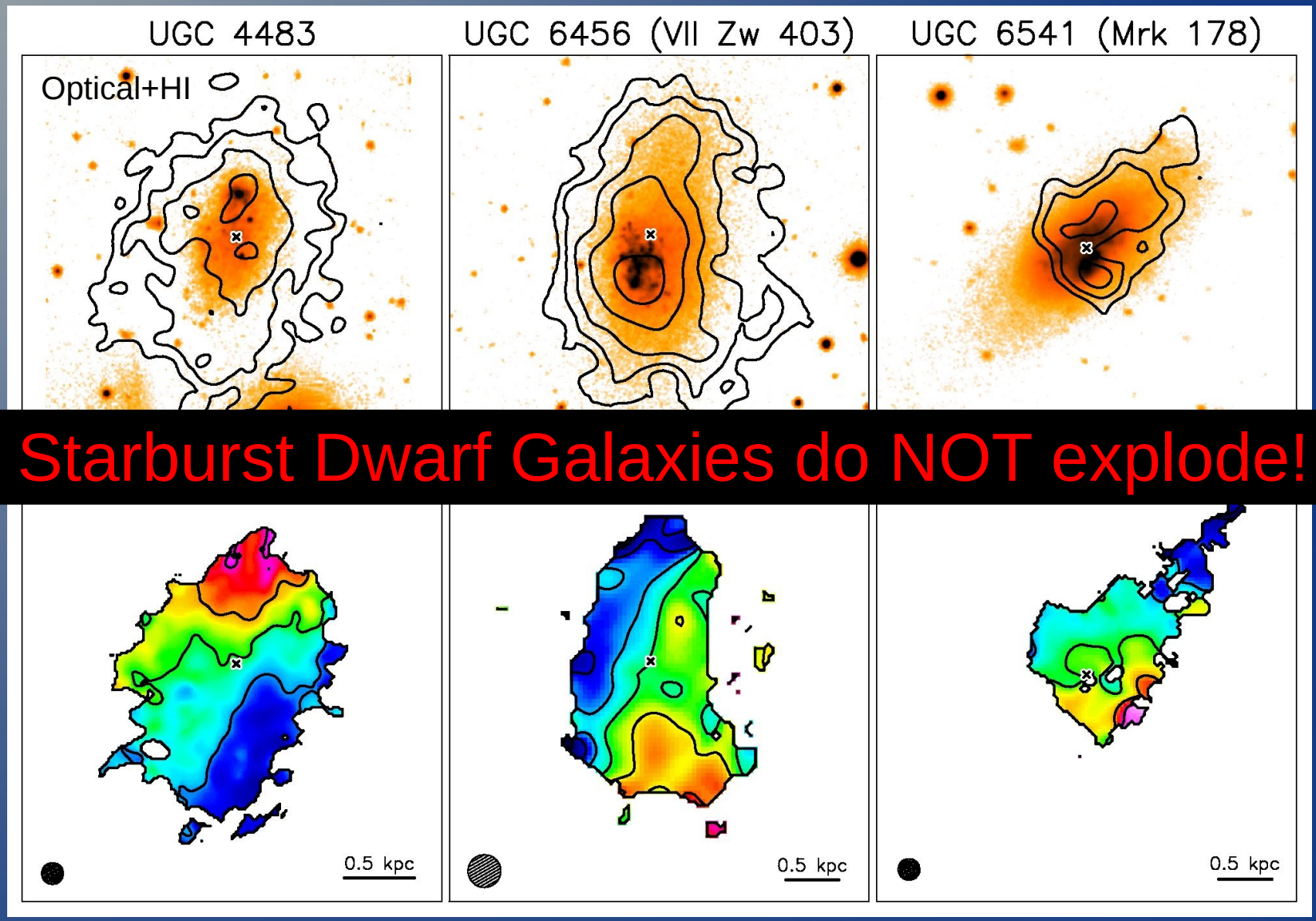


~50%
rotating HI disk

~40%
kin. disturbed HI disk

~10%
unsettled HI distr.

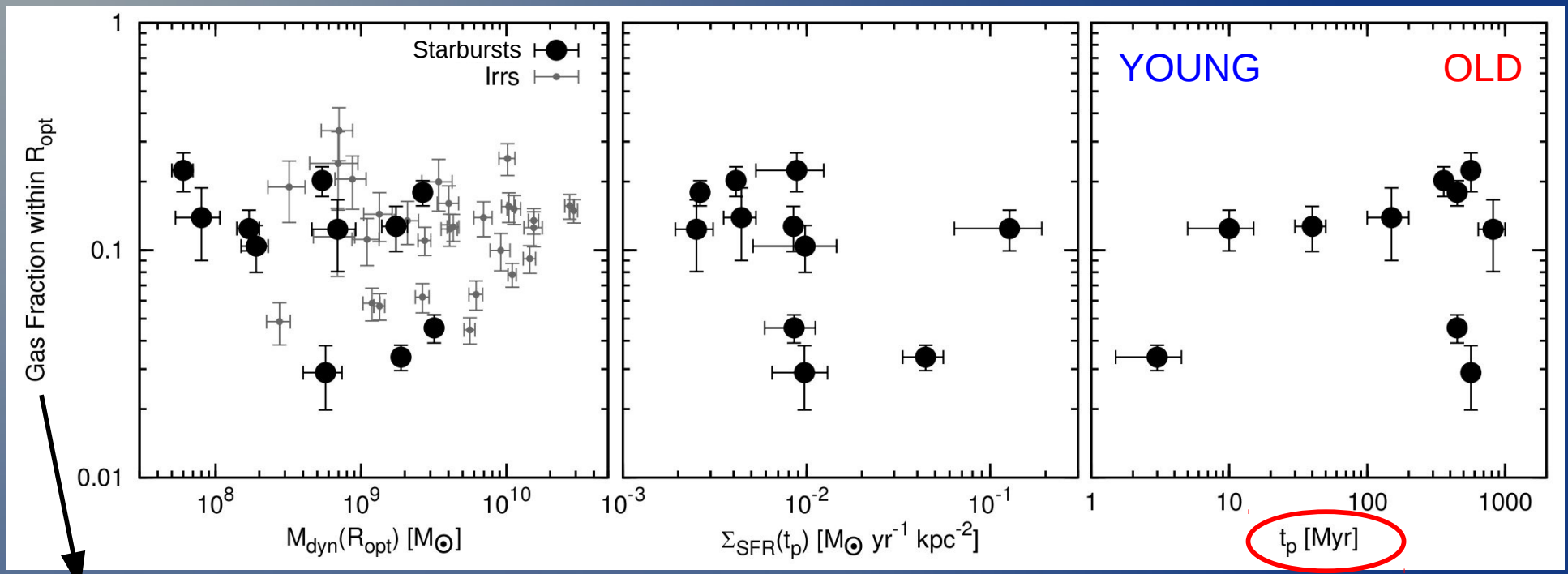
Inner HI Structure of Starburst Dwarfs



Starburst Dwarf Galaxies do NOT explode!

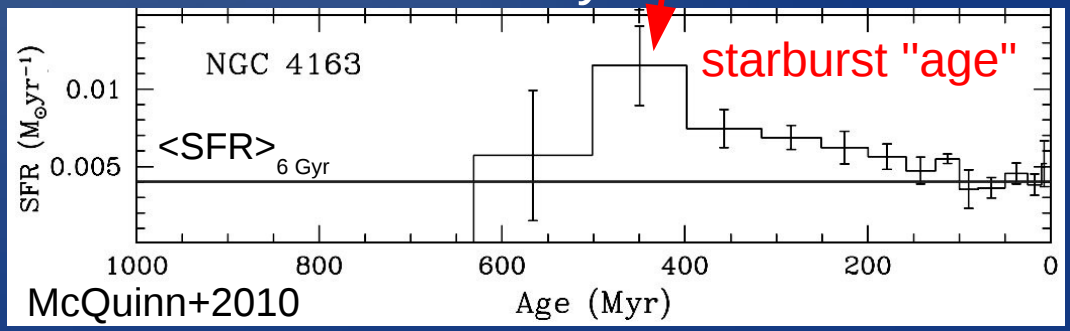
~50%	~40%	~10%
rotating HI disk	kin. disturbed HI disk	unsettled HI distr.

Gas Fractions: Starbursts *vs* Irrs

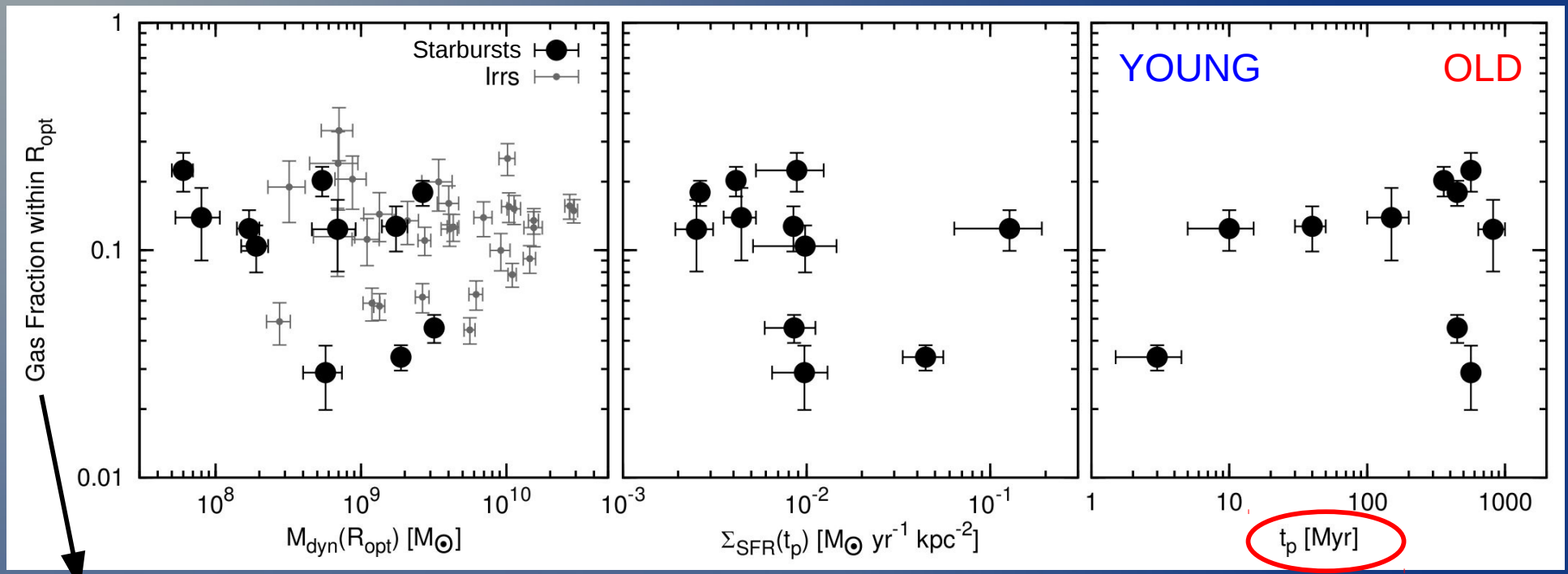


M_{gas}/M_{dyn} within R_{opt} Lelli+2014b, A&A (Irrs from Swaters+2009)

Star-Formation History



Gas Fractions: Starbursts *vs* Irrs

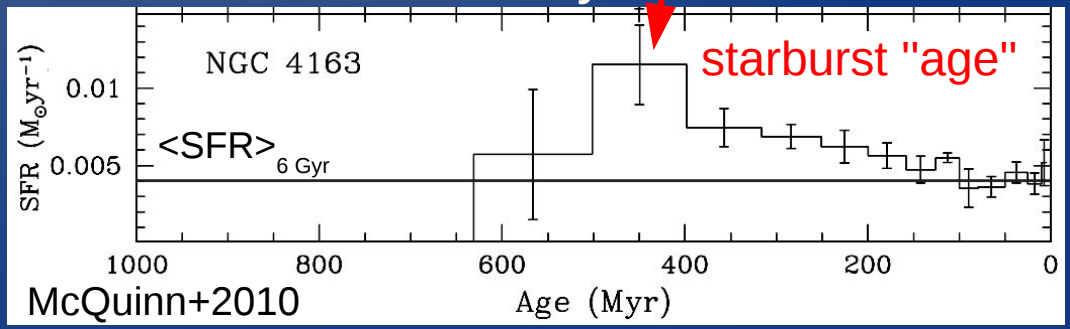


M_{gas}/M_{dyn} within R_{opt} Lelli+2014b, A&A (Irrs from Swaters+2009)

Similar gas fraction as typical Irr:

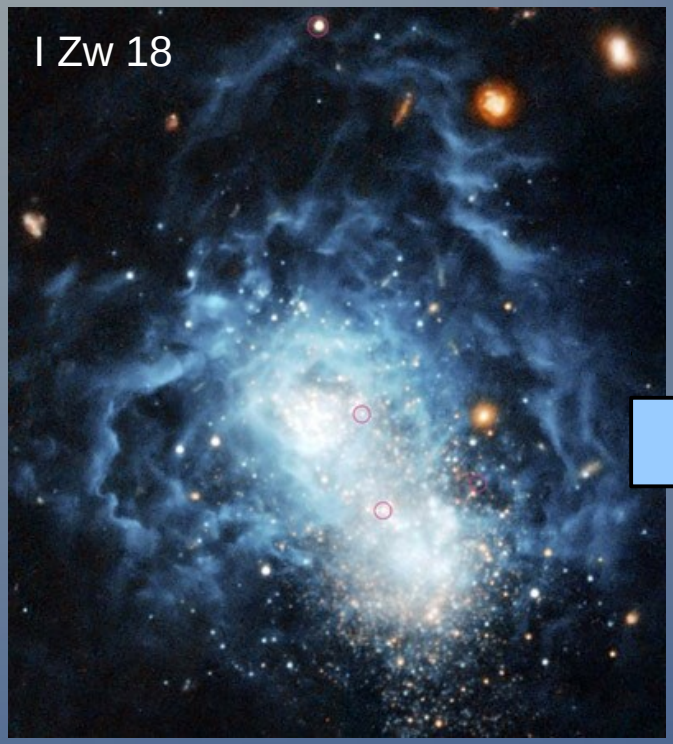
- No evidence for massive outflows
- $t_{dep} = M_{gas}/SFR$ = 3-10 Gyr for BCDs
  = 10-100 Gyr for Irrs

Star-Formation History



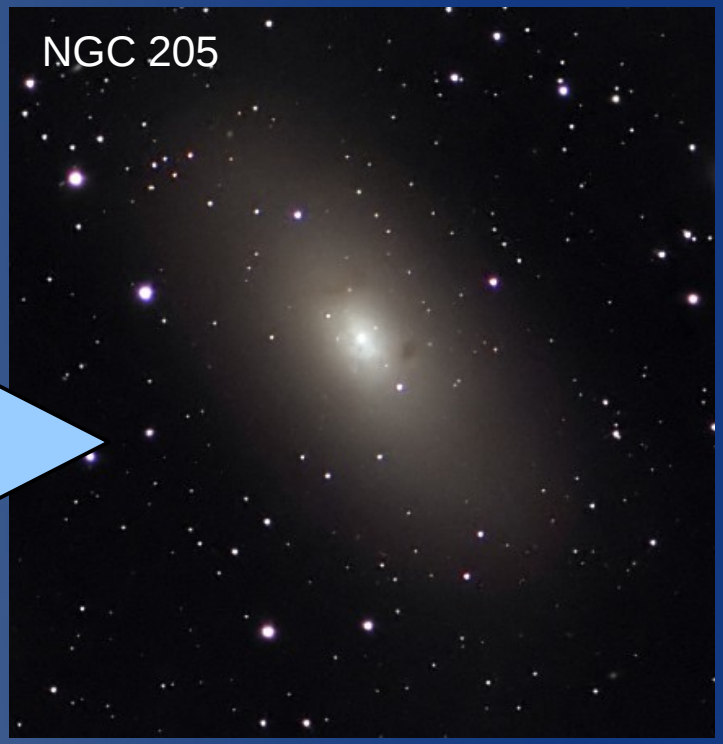
Gas-rich Dwarf

Gas-poor Sph/dE



Internal Processes:

- Starvation/SF
- Stellar Feedback
  (e.g. Dekel & Silk 1986)



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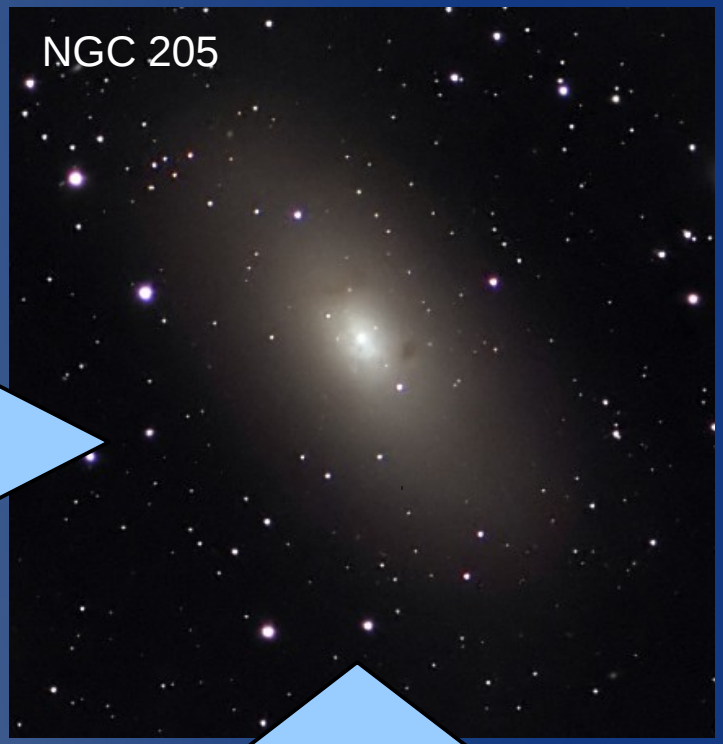
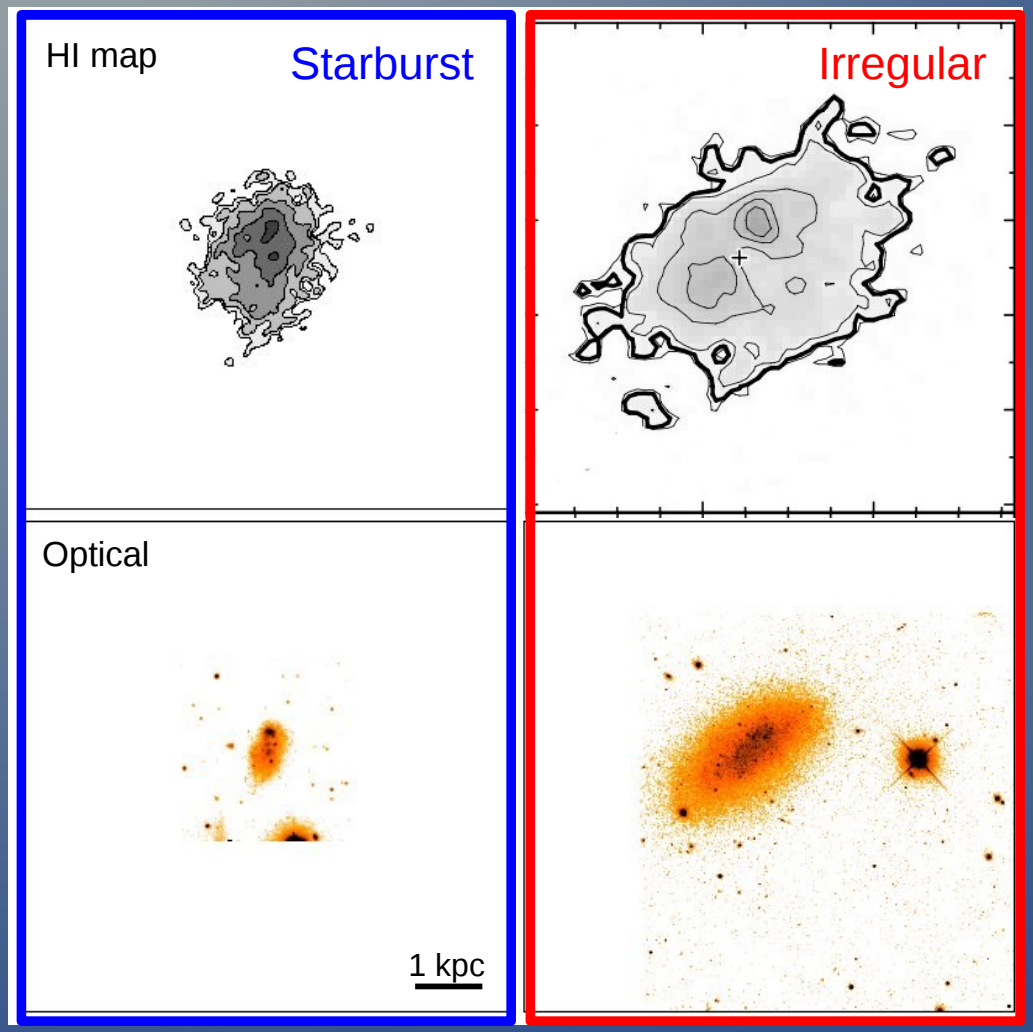
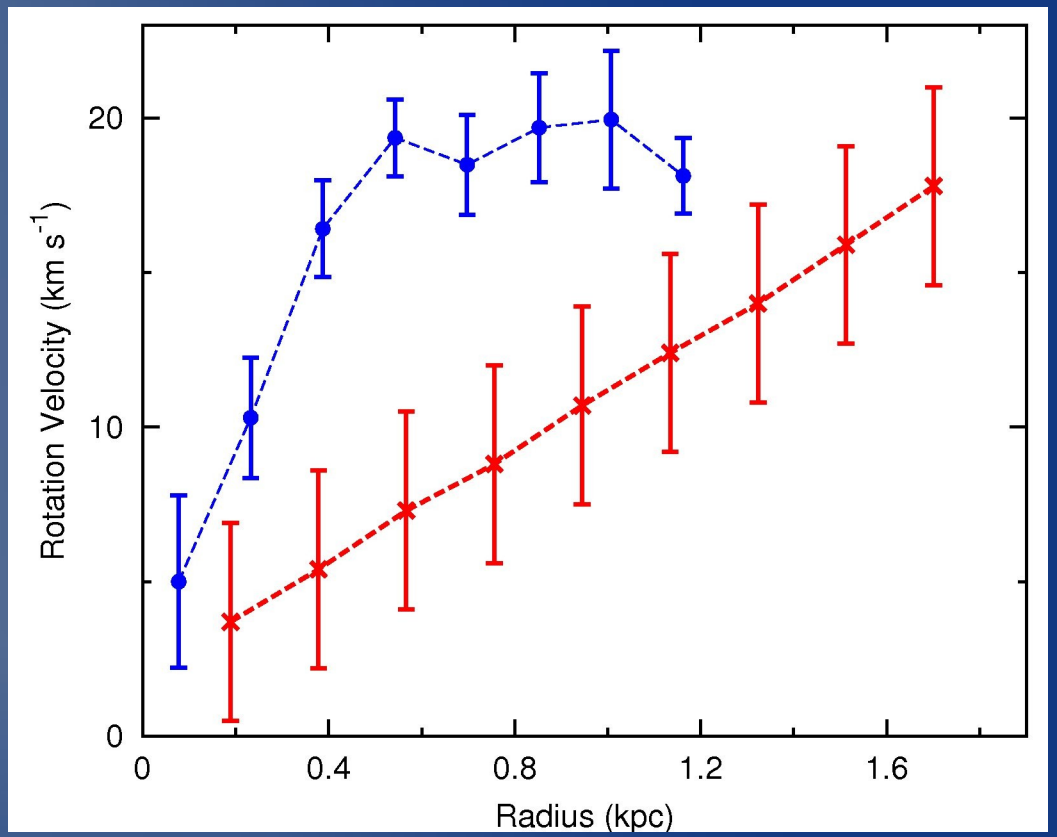


External Processes:

- Ram-Pressure Stripping
  (e.g. Gunn & Gott 1972)
- Galaxy Harassment
  (e.g. Moore+1998)
- Tidal Stirring
  (e.g. Mayer+2006)

Rotation Curves: Starbursts *vs* Irrs



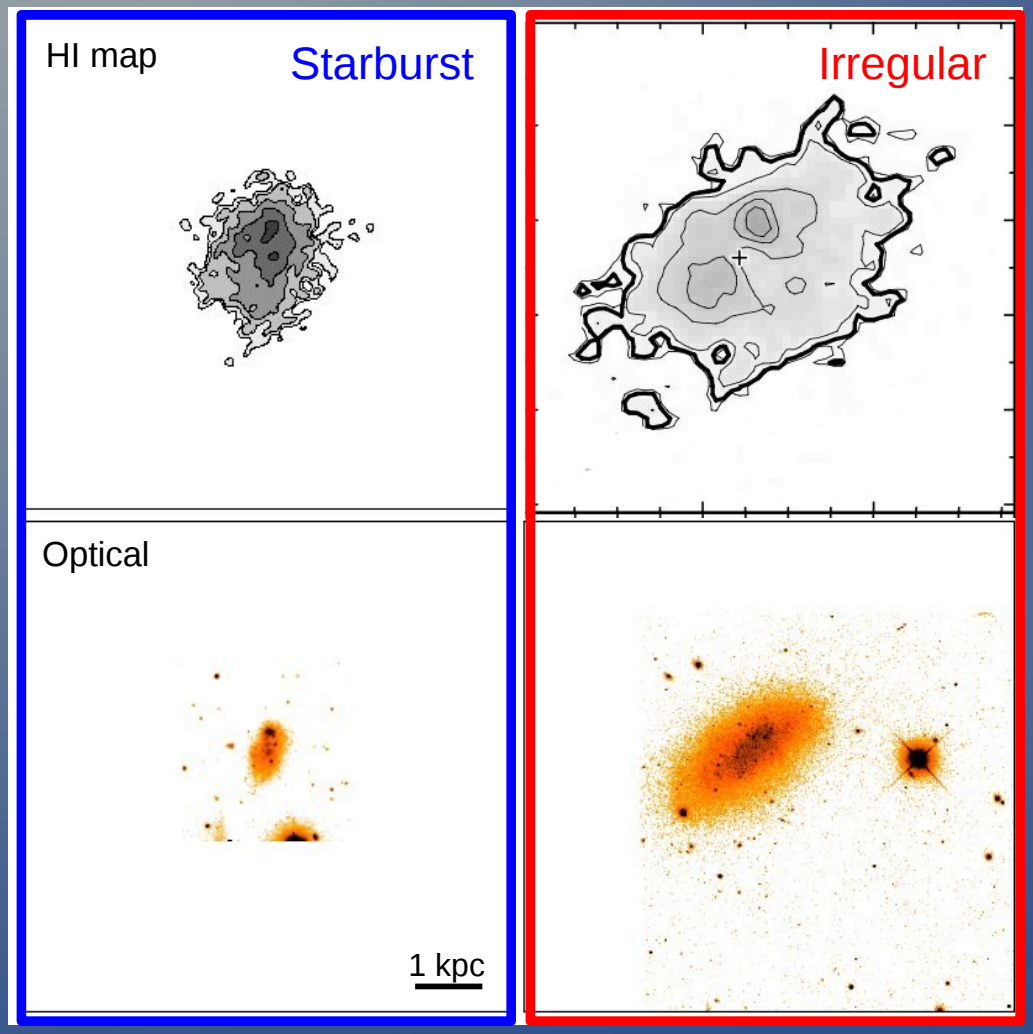


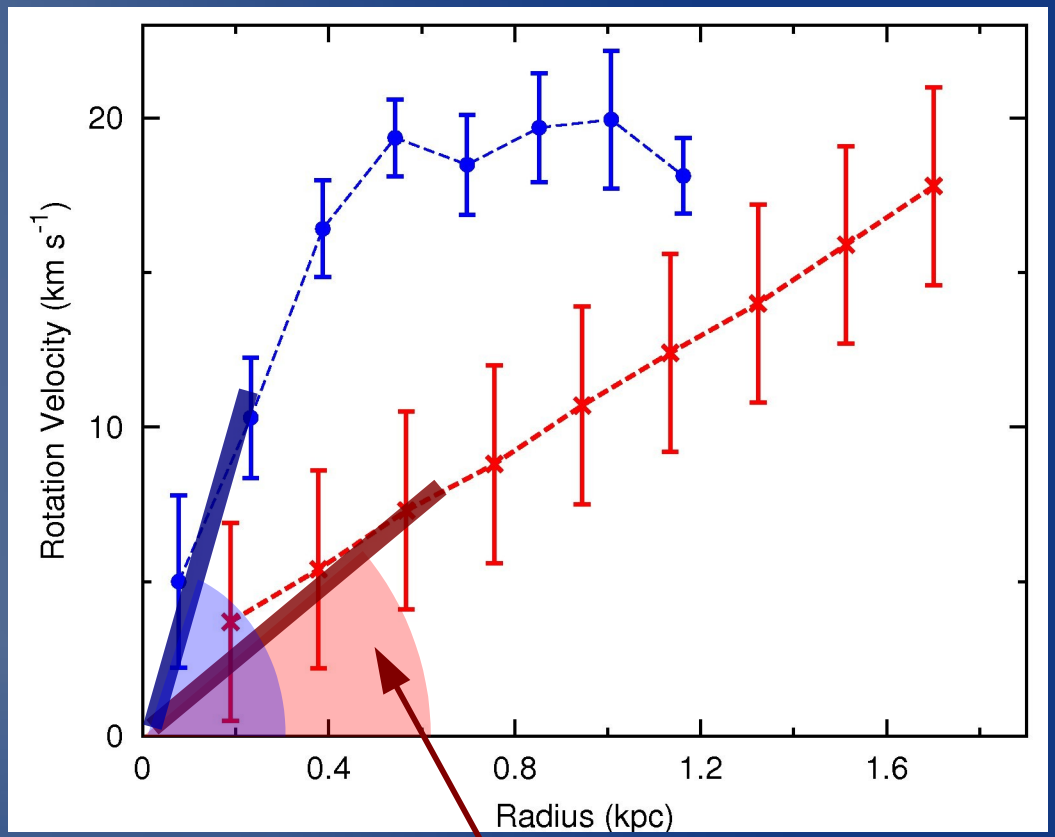
$V_{rot} \simeq 20$ km/s $\rightarrow$ $M_{dyn} \simeq 10^8 M_\odot$

Lelli et al. (2012a, b; 2014a, b)

See also Meurer+1998; van Zee+2001

Rotation Curves: Starbursts *vs* Irrs





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See also Meurer+1998; van Zee+2001

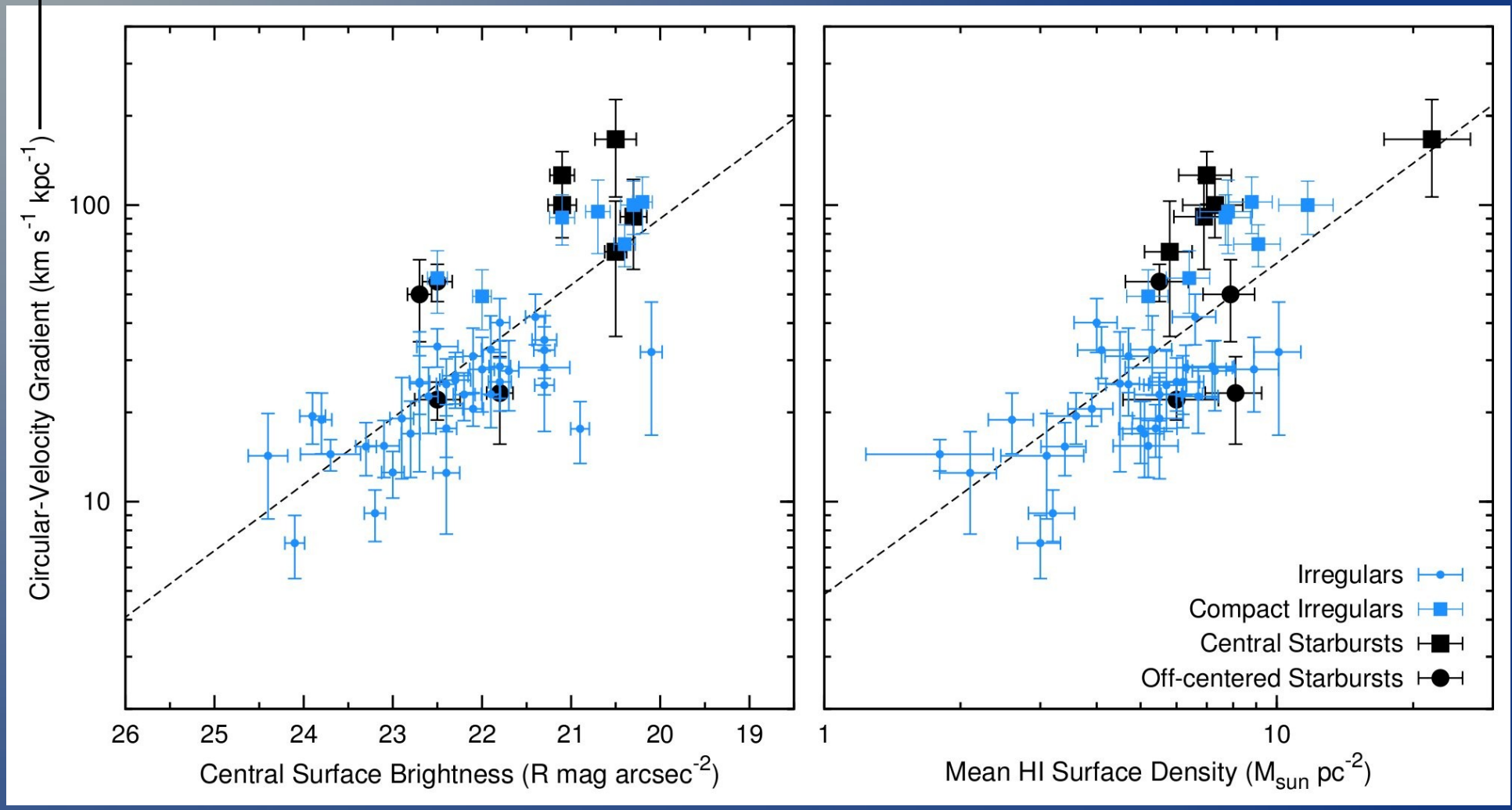
$$dV/dR \simeq V(R_d)/R_d \propto \sqrt{\rho_0}$$

ρ_0 = central dynamical mass density

(baryons and dark matter)

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

Starbursts *vs* Irrs



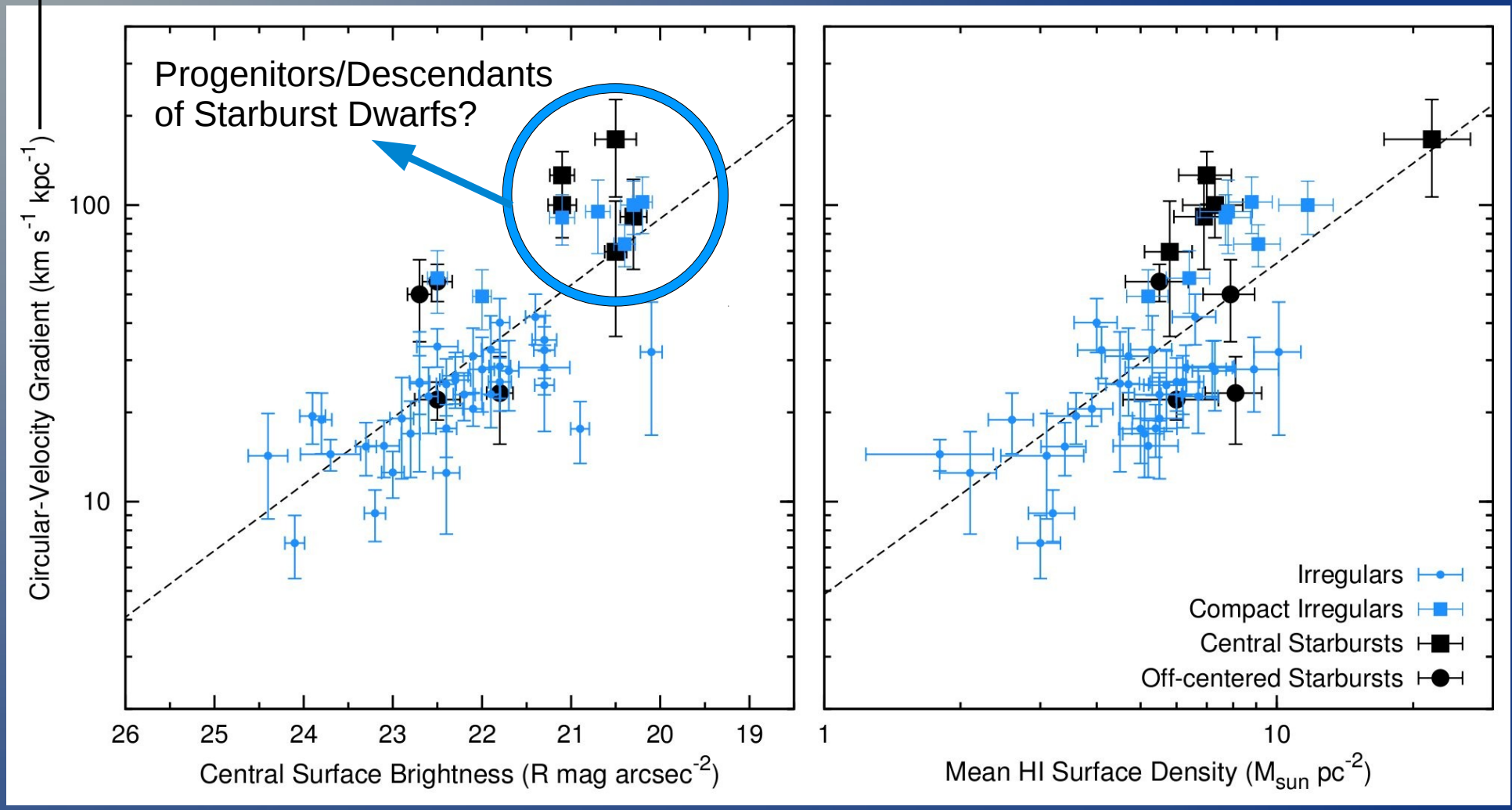
Link: Star Formation – inner potential well

Lelli et al. (2014a), A&A

Irrs from Swaters et al. (2009)

Starbursts *vs* Irrs

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



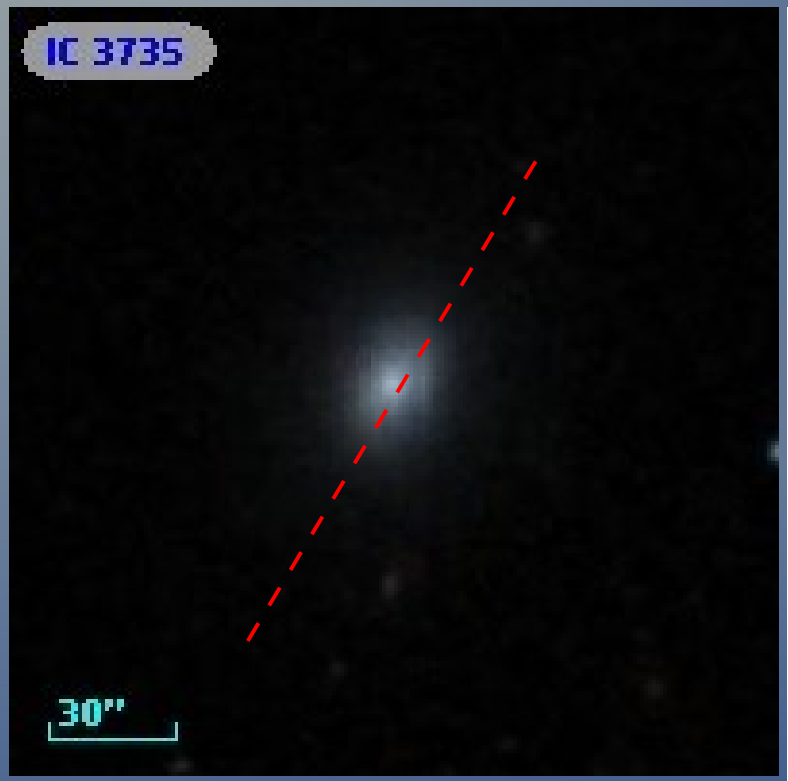
Link: Star Formation – inner potential well

Compact Irrs = similar ρ_0 as starbursts

Lelli et al. (2014a), A&A

Irrs from Swaters et al. (2009)

Rotating Sph/dE in the Virgo Cluster



Optical Spectroscopy:

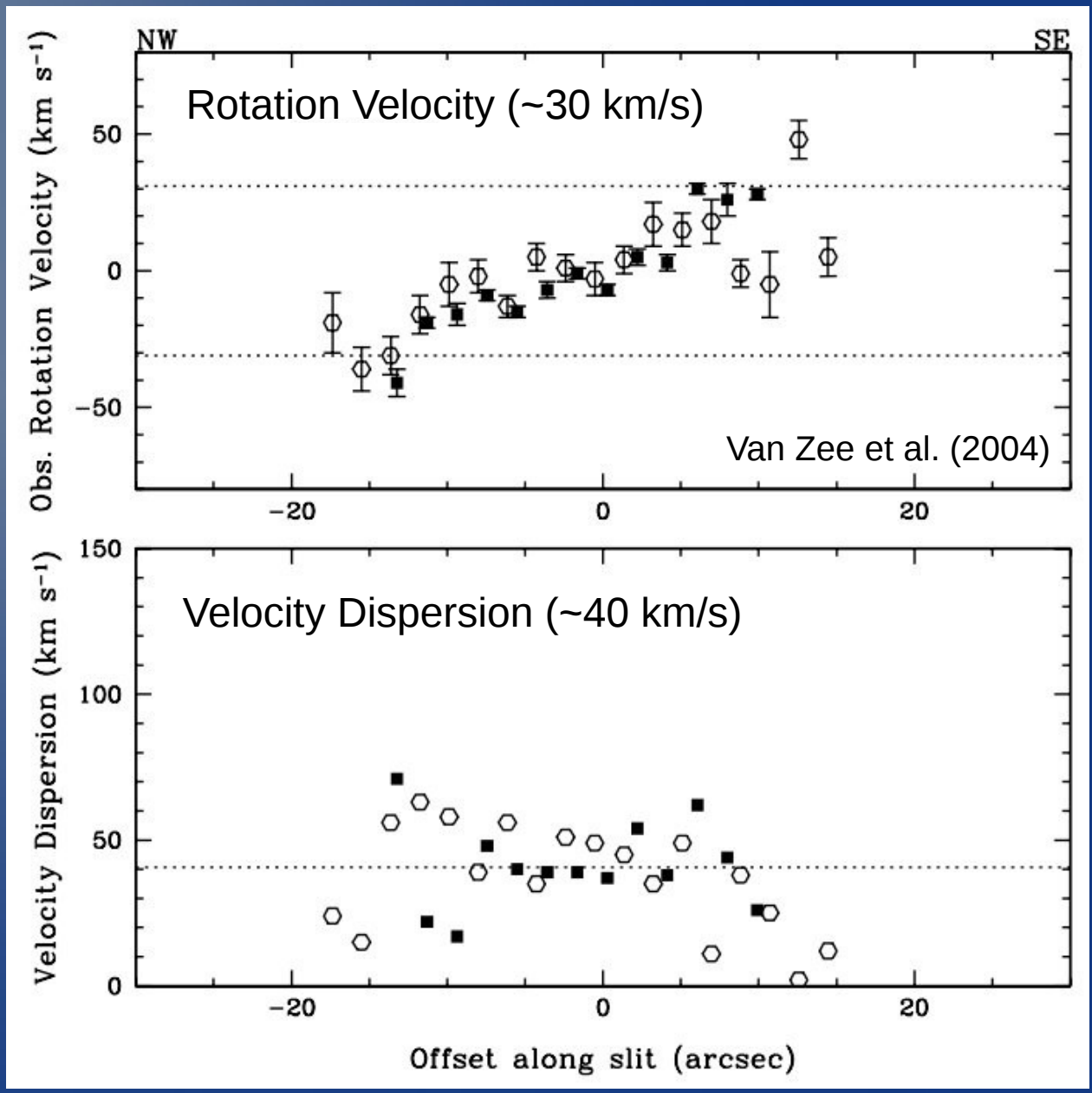
Geha et al. (2002, 2003)

van Zee et al. (2004)

Chilingarian et al. (2007, 2009)

Toloba et al. (2011, 2012, 2014)

Rys et al. (2013, 2014)



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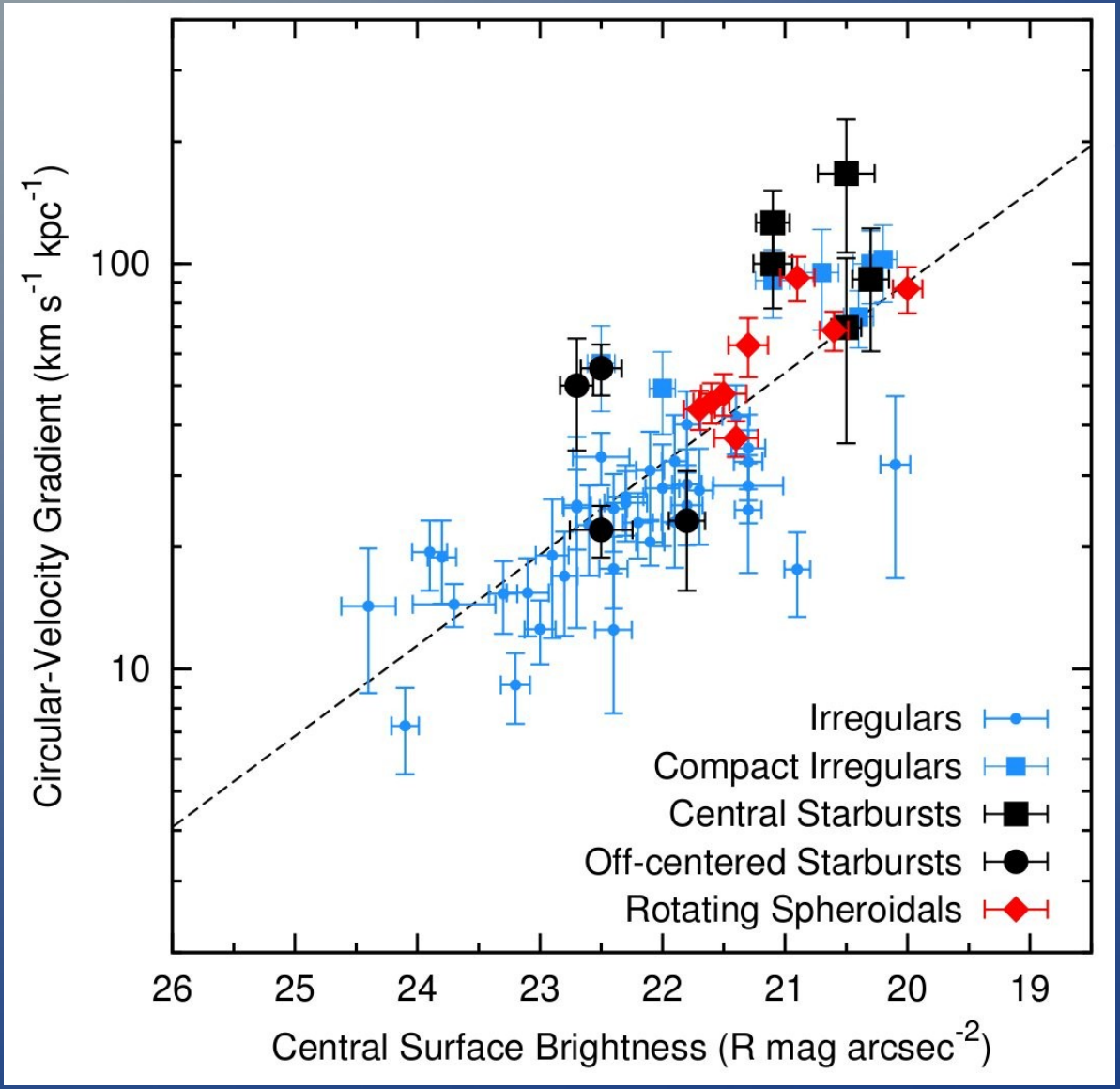

Lelli et al. (2014a), A&A

dEs from van Zee et al. (2004)

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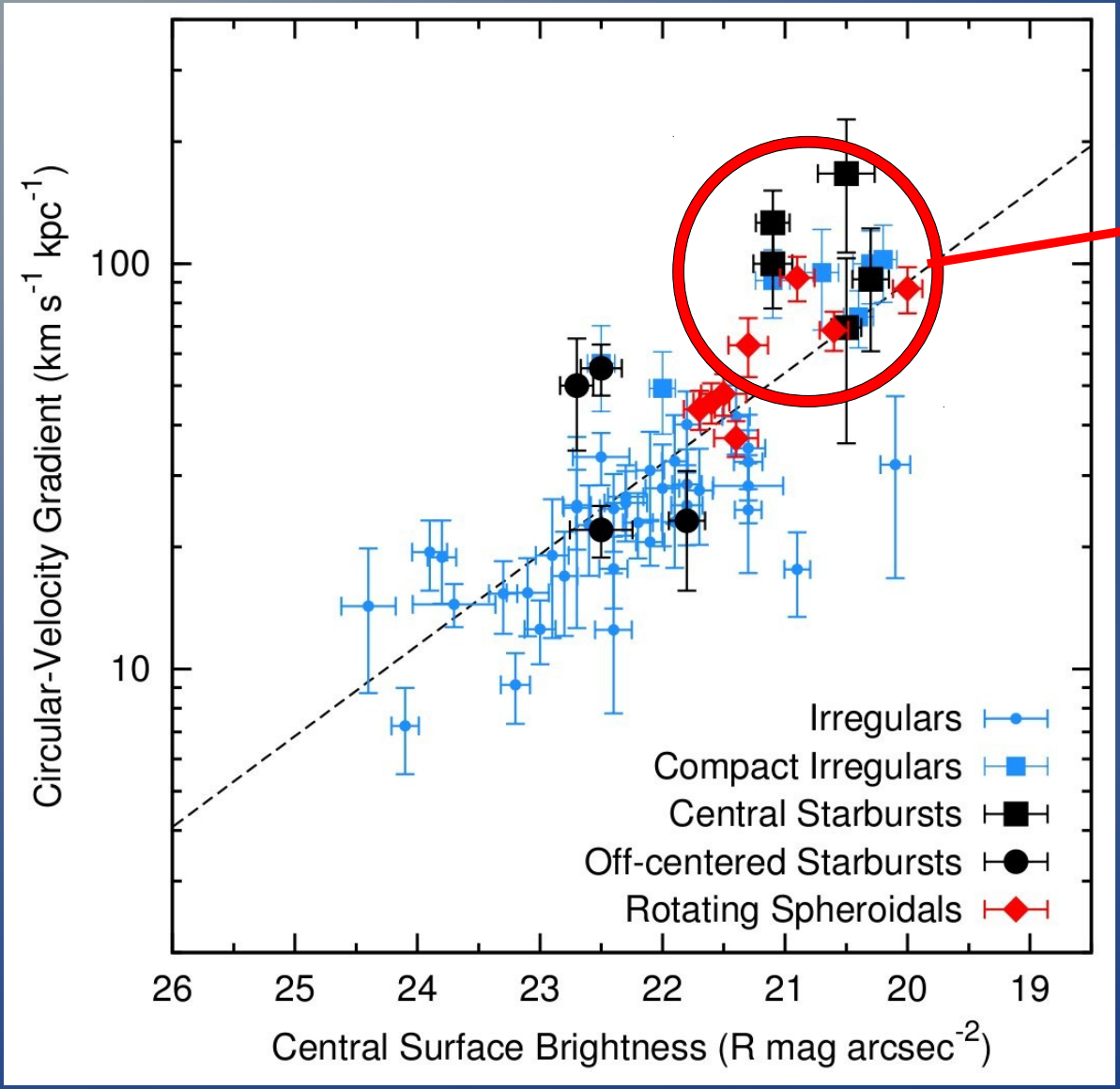


Descendants of Compact Dwarfs!

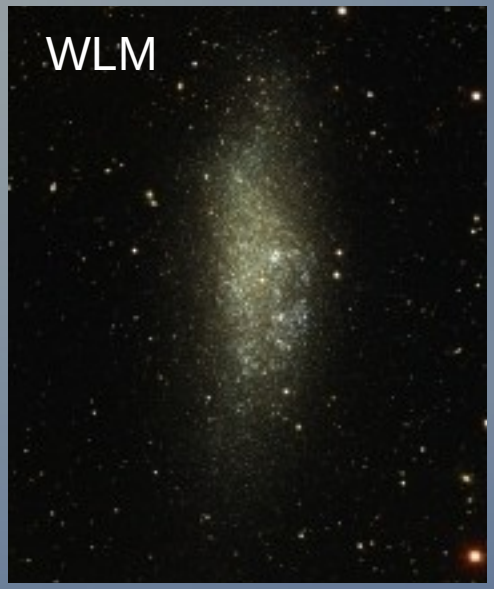
Not of typical Irrs!?

Providing that some external mechanism removes the gas.

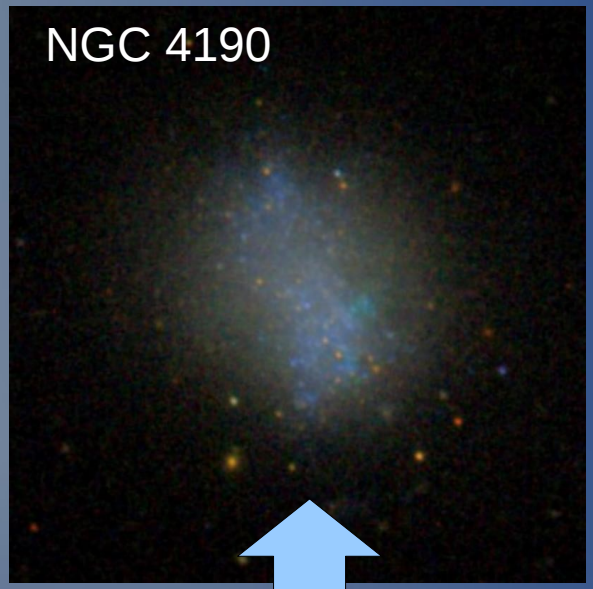
Lelli et al. (2014a), A&A

dEs from van Zee et al. (2004)

Typical LSB Irr



Compact HSB Irr

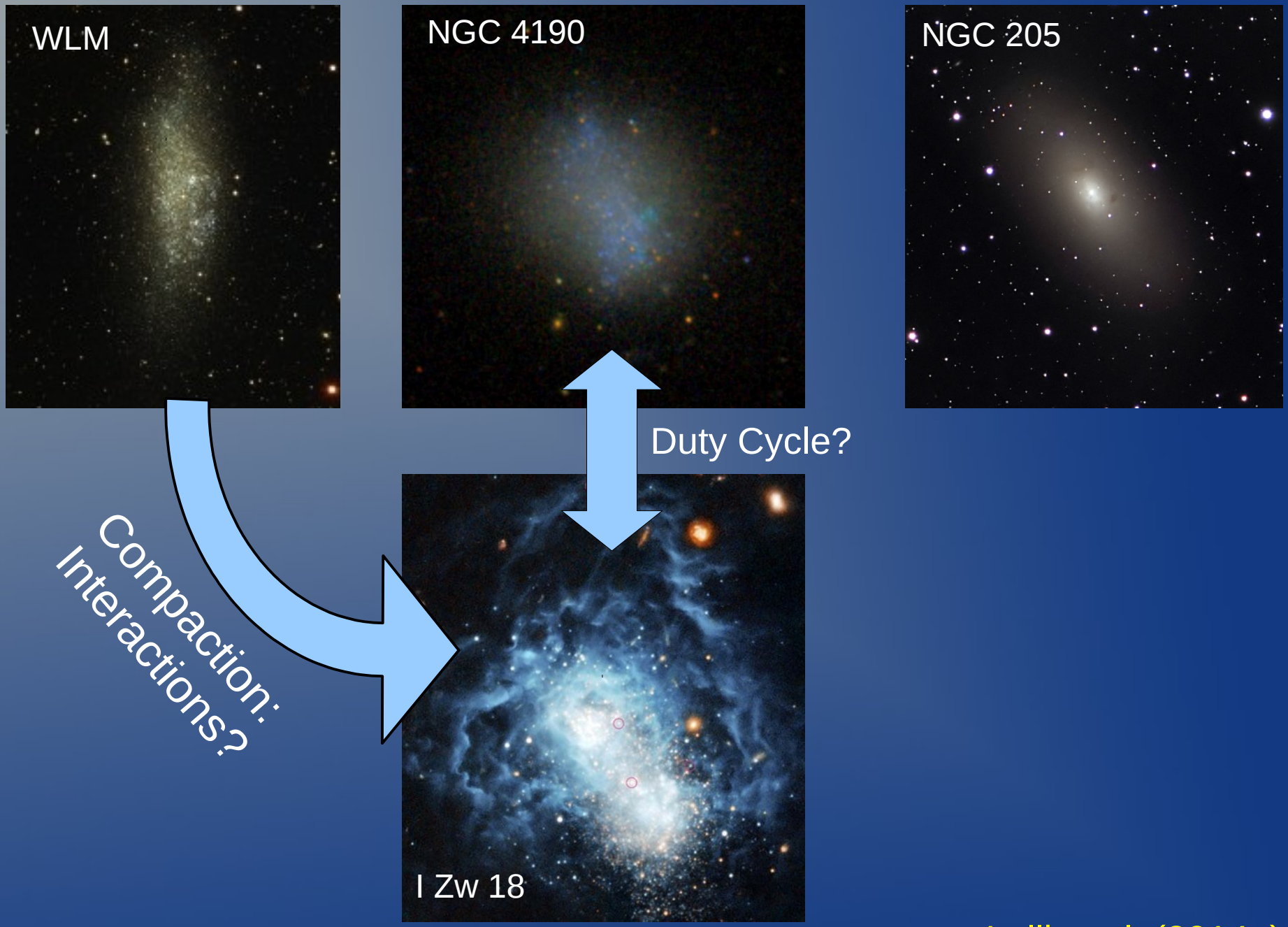


"Rotating" Sph/dE

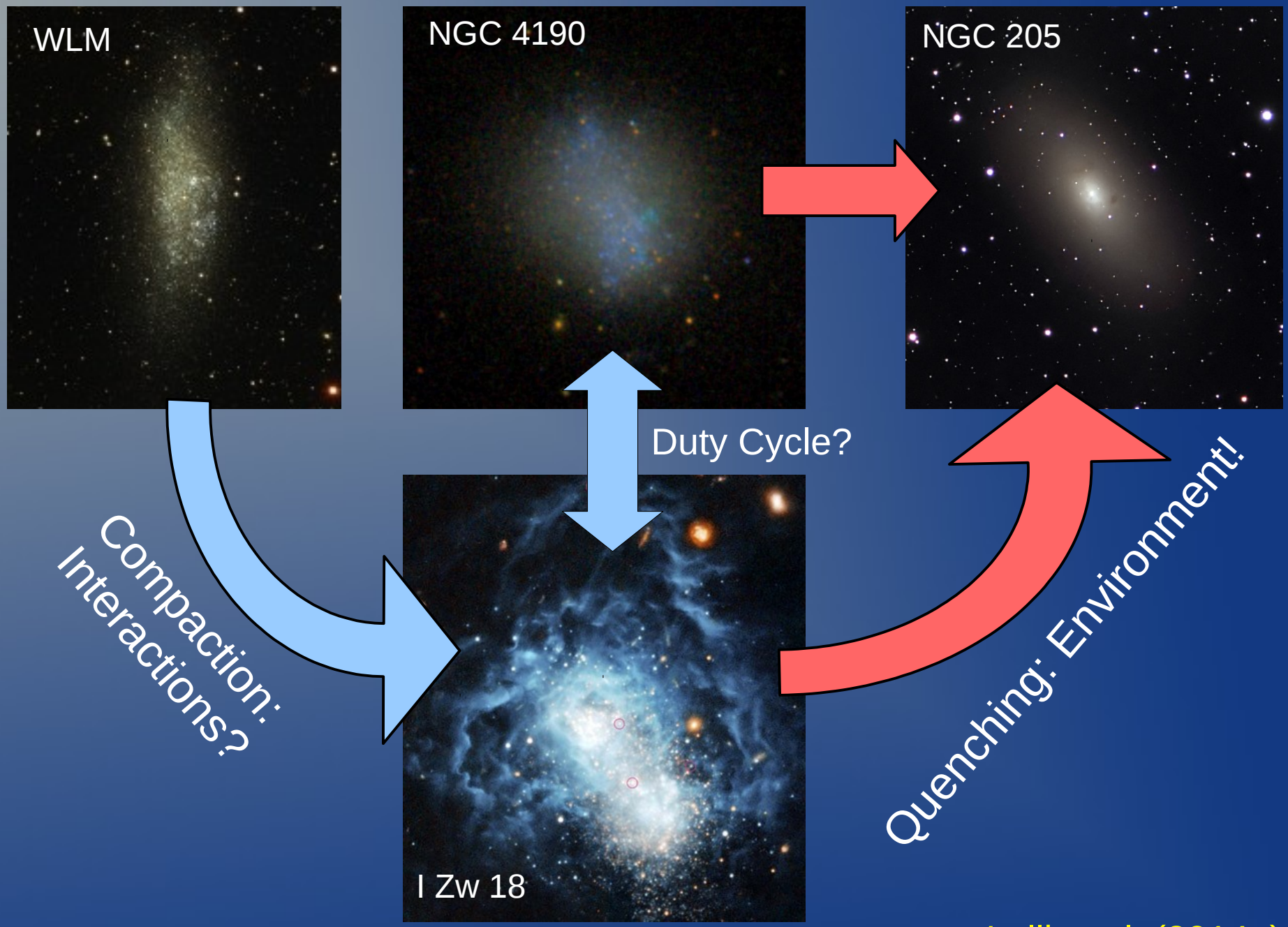
Duty Cycle?

Starburst (~5%?)

Lelli et al. (2014a), A&A



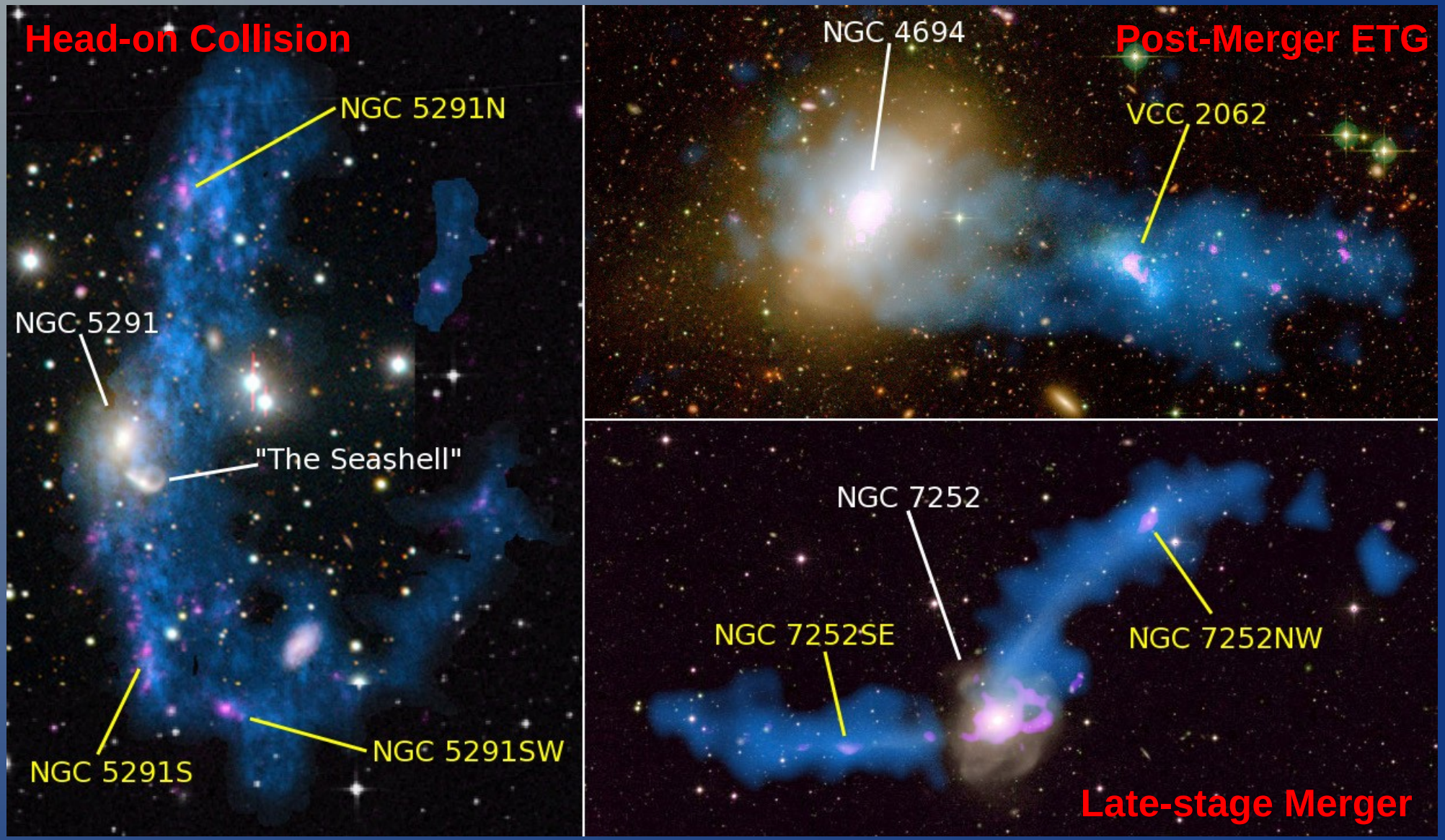
Lelli et al. (2014a), A&A



Lelli et al. (2014a), A&A

OK, just two more slides...

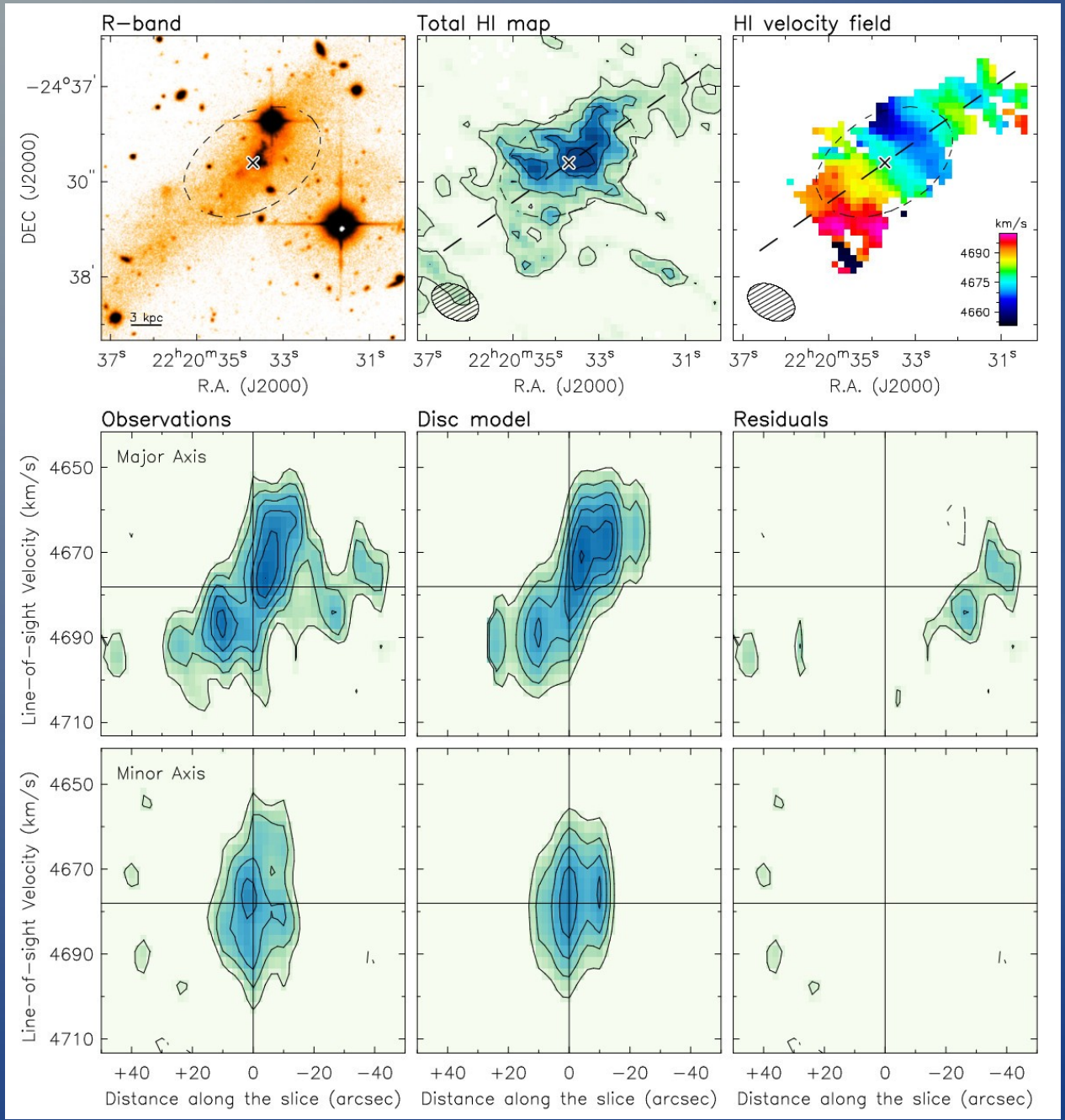
Forming Dwarf Galaxies at z=0



Blue = HI (VLA)
Pink = FUV (GALEX)

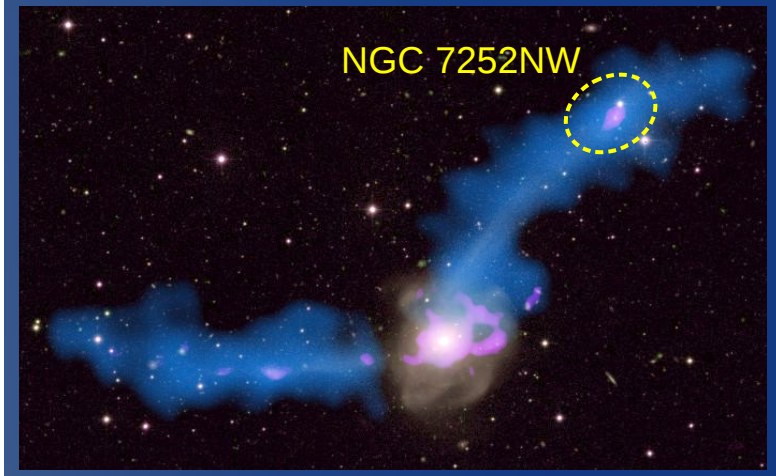
Yellow = Tidal Dwarf Galaxies
Lelli, Duc, Brinks et al. (2015), A&A

Disk Models for Tidal Dwarf Galaxies



Lelli et al. (2015), A&A:

- High-Res. VLA data
- 3D kinematical model



V_{rot} ~ 20 km/s

R_{HI} ~ 8 kpc

M_{gas}/M_{*} ~ 8!!

Conclusions on Dwarf Galaxies:

- Starbursts show NO evidence for massive outflows

  Irr/Starburst --> Sph/dE: only with external mechanisms

- Starbursts have high central mass concentrations

  Starburst/BCD <--> Compact Irr or Rotating Sph/dE

- Tidal Dwarfs can form during Major Mergers at z=0

  Possible links with "normal" dwarfs to be understood!