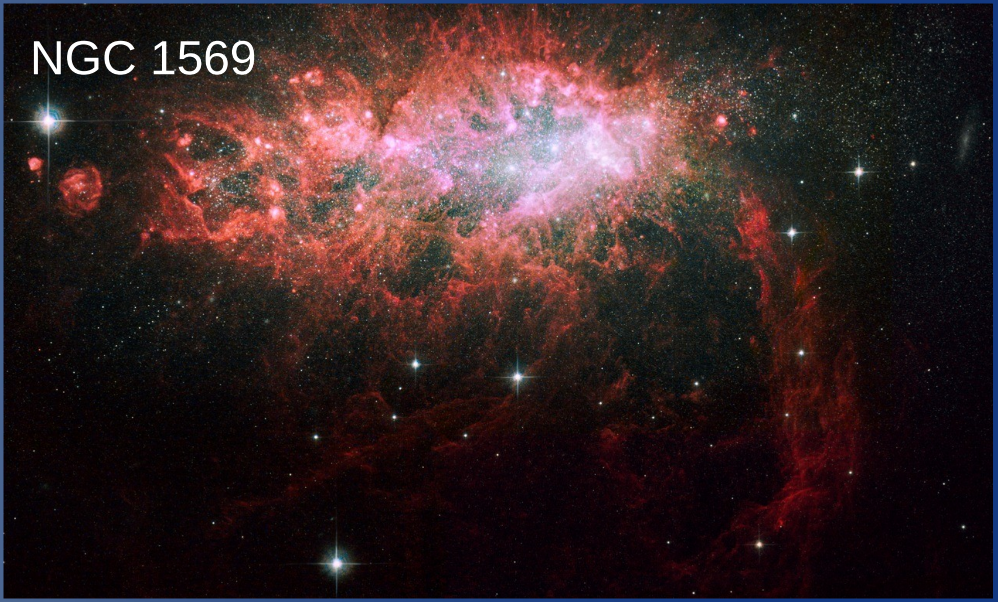
# The Ecosystem of Dwarf Galaxies



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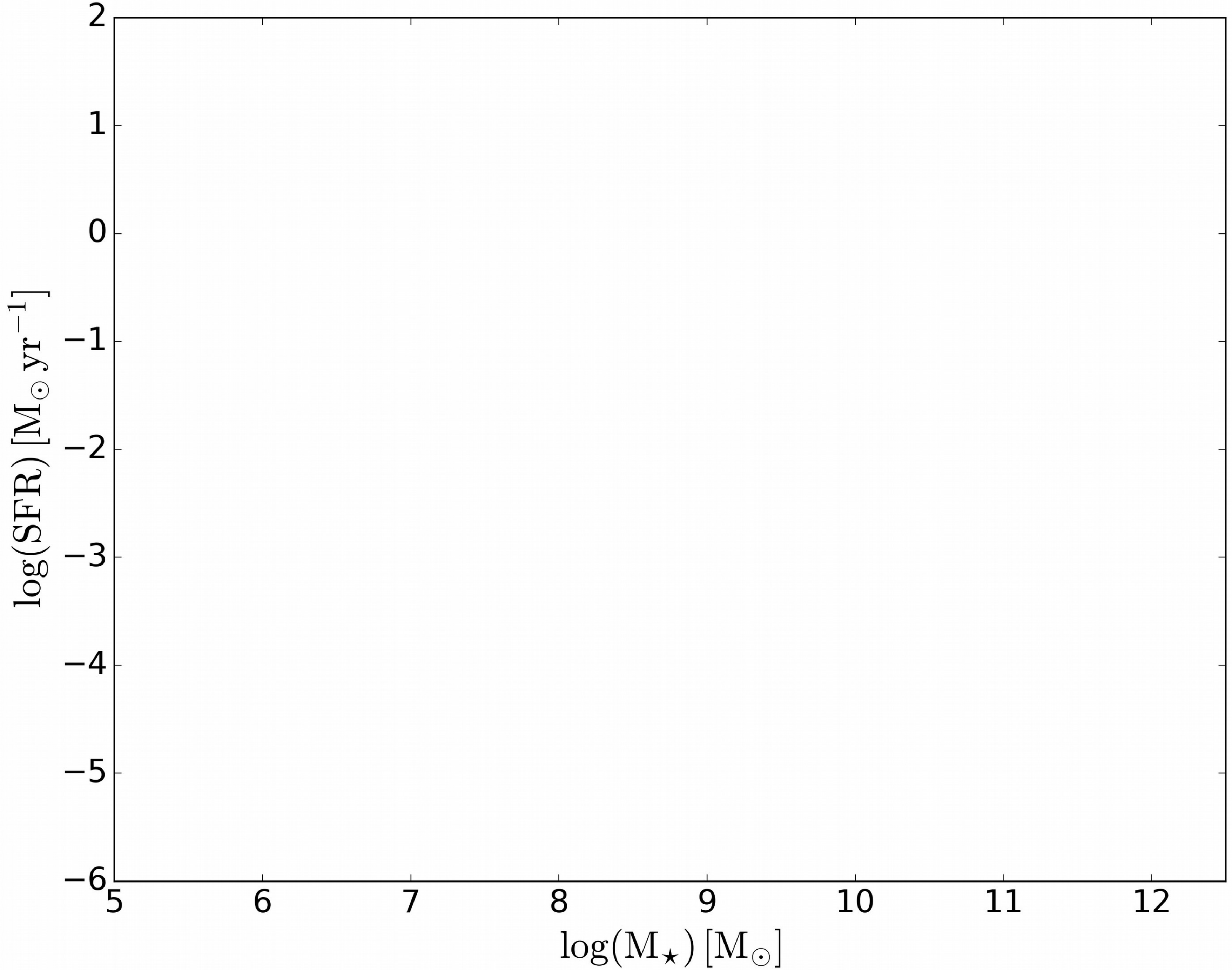
- Giacomo Beccari (ESO - Garching)
- Anna Faye McLeod (Canterbury University)
- Stacy McGaugh (Case Western Reserve)
- James Schombert (University of Oregon)
- Evan Skillman (University of Minnesota)
- Kristen McQuinn (University of Texas)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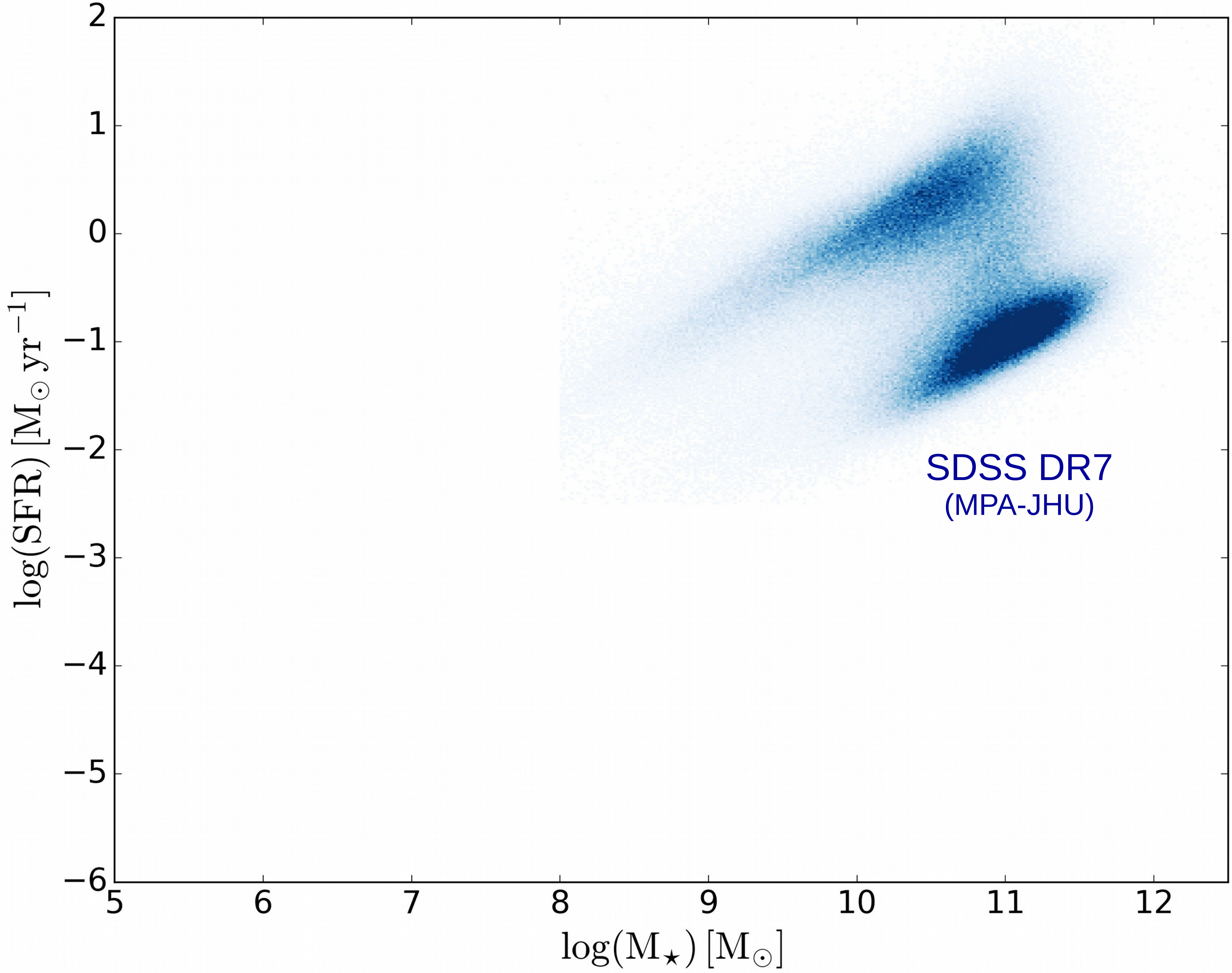
$\log(\mathrm{SFR})\ [\mathrm{M_\odot\,yr^{-1}}]$
$\log(\mathrm{M_\star})\ [\mathrm{M_\odot}]$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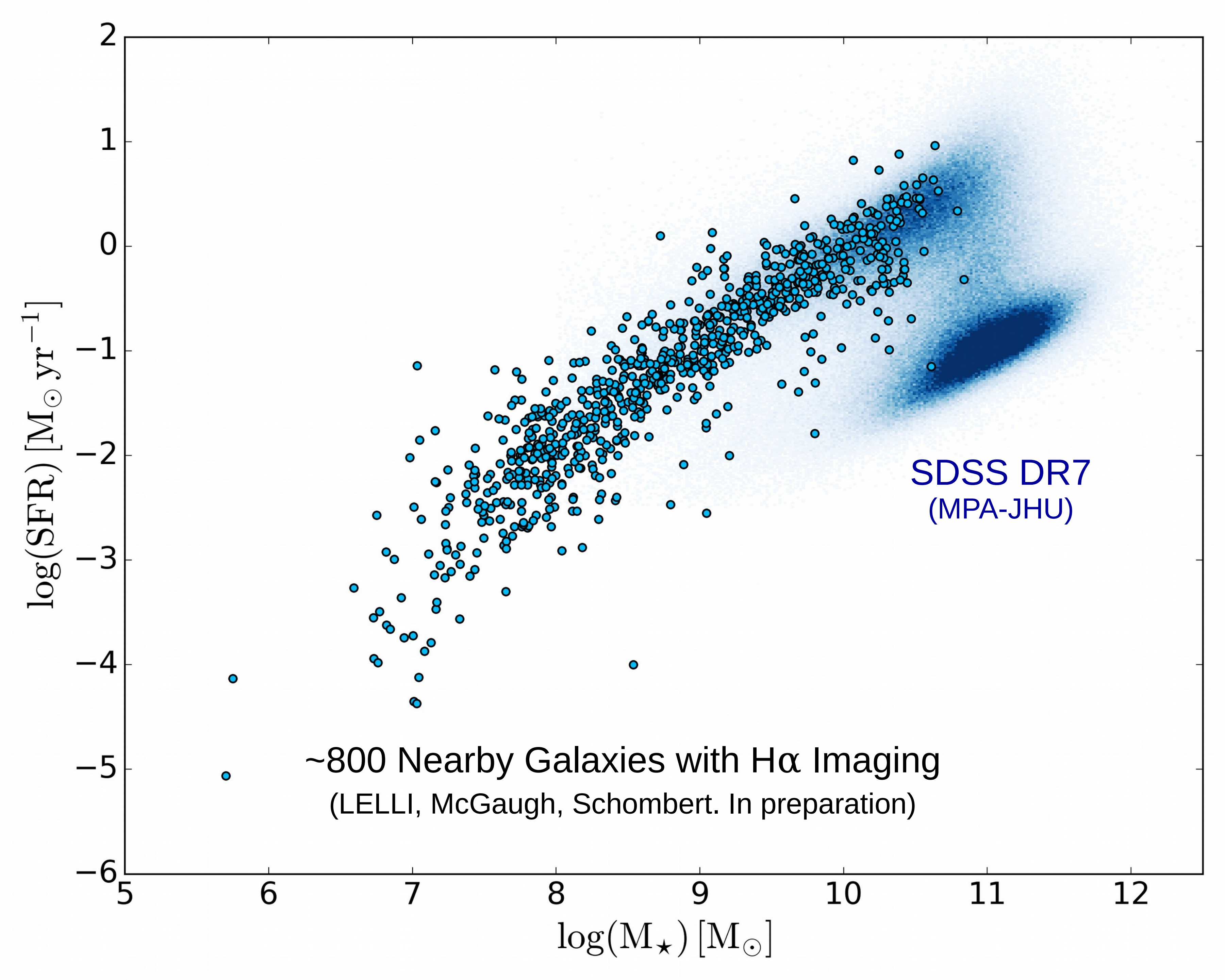
log(SFR) [M⊙ yr⁻¹]
log(M⋆) [M⊙]
SDSS DR7
(MPA-JHU)



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log(SFR) [M⊙ yr−1]
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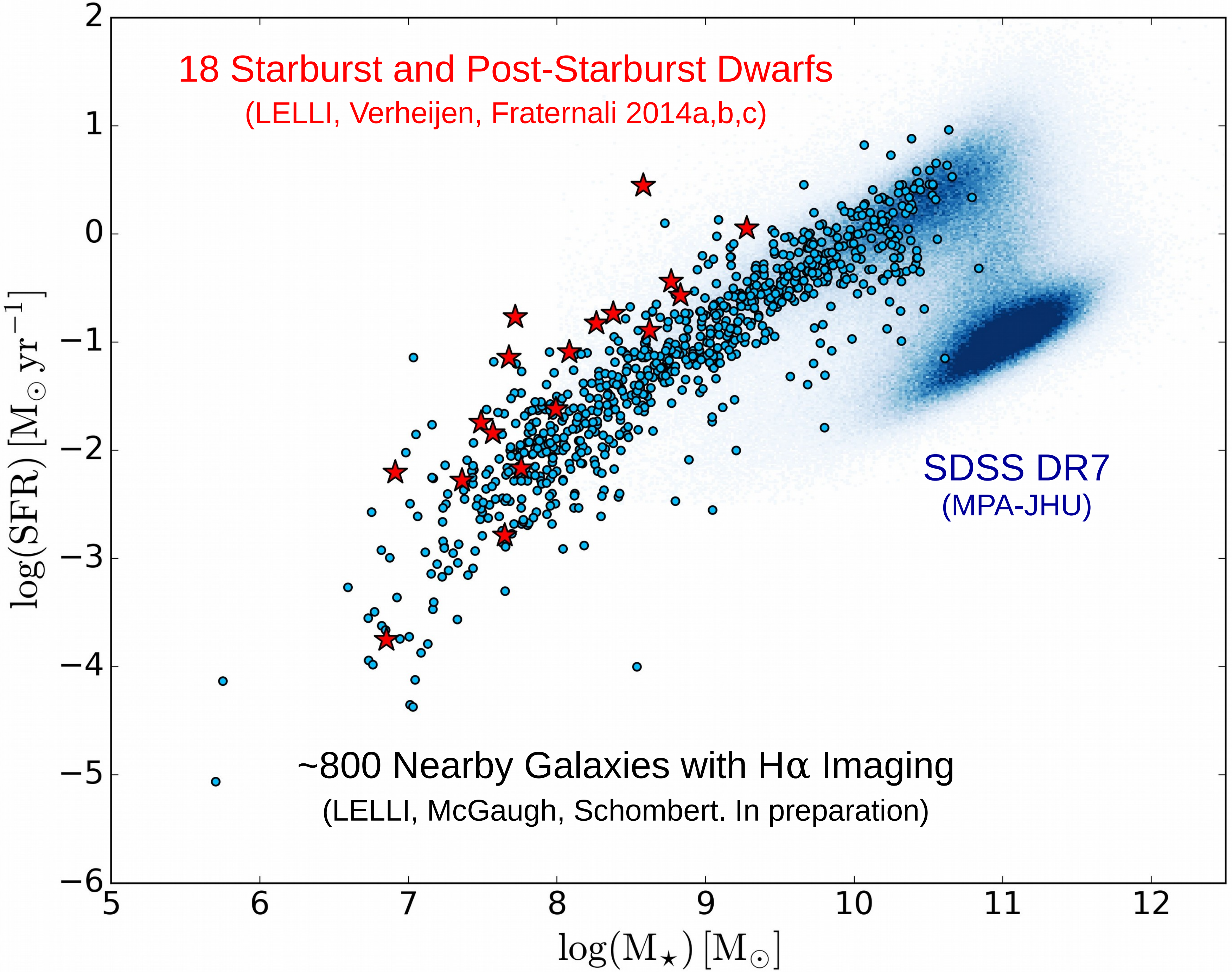
SDSS DR7
(MPA-JHU)
~800 Nearby Galaxies with Hα Imaging
(LELLI, McGaugh, Schombert. In preparation)



18 Starburst and Post-Starburst Dwarfs
(LELLI, Verheijen, Fraternali 2014a,b,c)
SDSS DR7
(MPA-JHU)
~800 Nearby Galaxies with Hα Imaging
(LELLI, McGaugh, Schombert. In preparation)
log(SFR) [M⊙ yr⁻¹]
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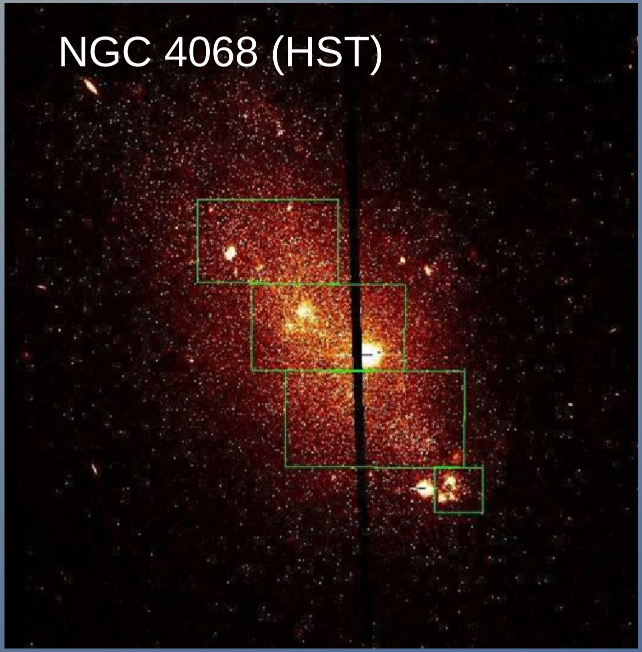
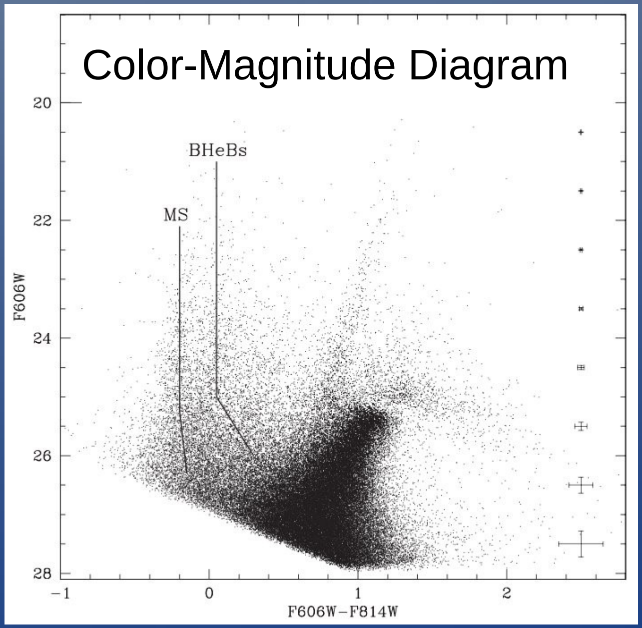
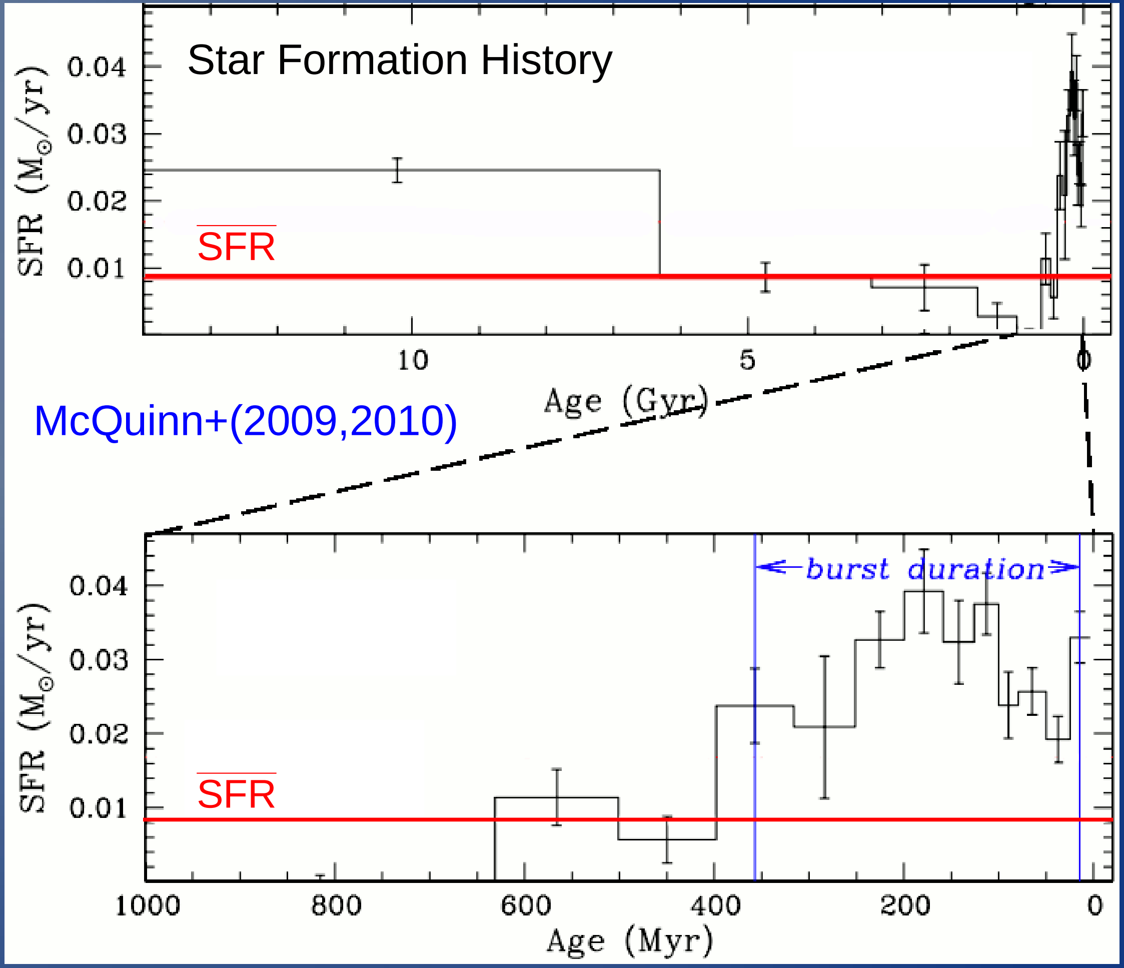
# SF Histories of Starburst Dwarfs

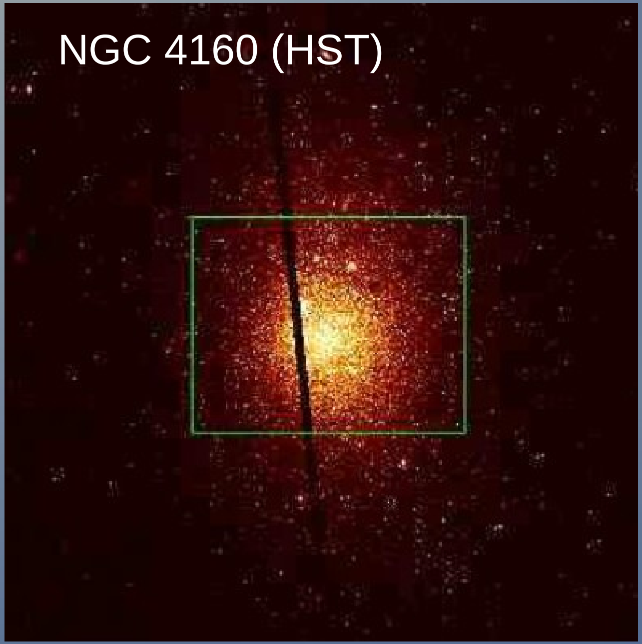


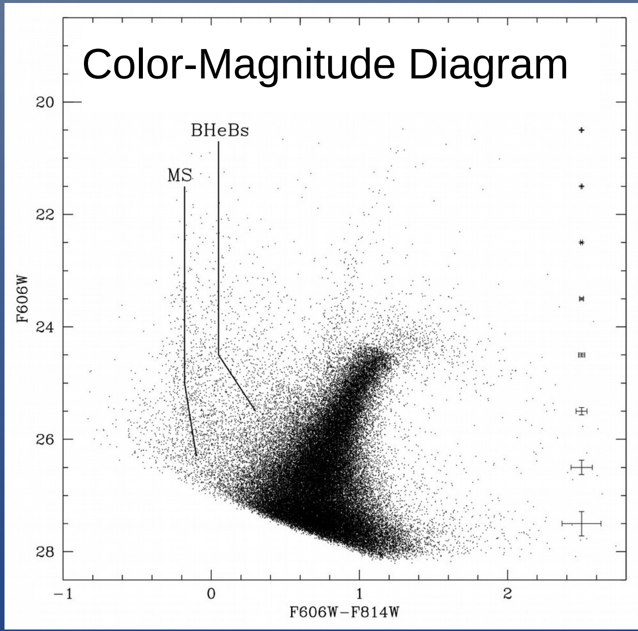



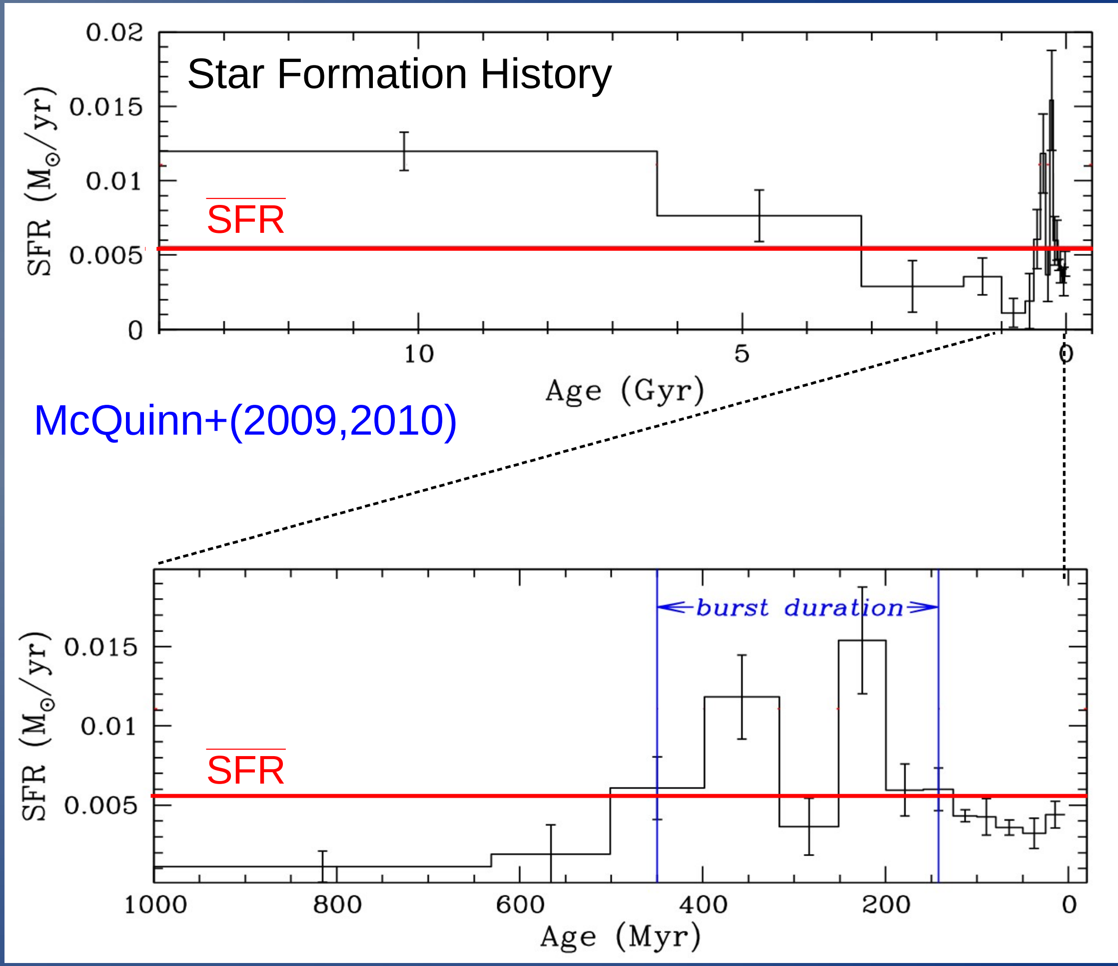




- Strength: $b = SFR(t_{peak}) / \overline{SFR}$ ~ 3-10
- Burst Duration: ~few 100 Myr
- Burst Energy: ~$10^{56}$ ergs

# SF Histories of Post-Starburst Dwarfs

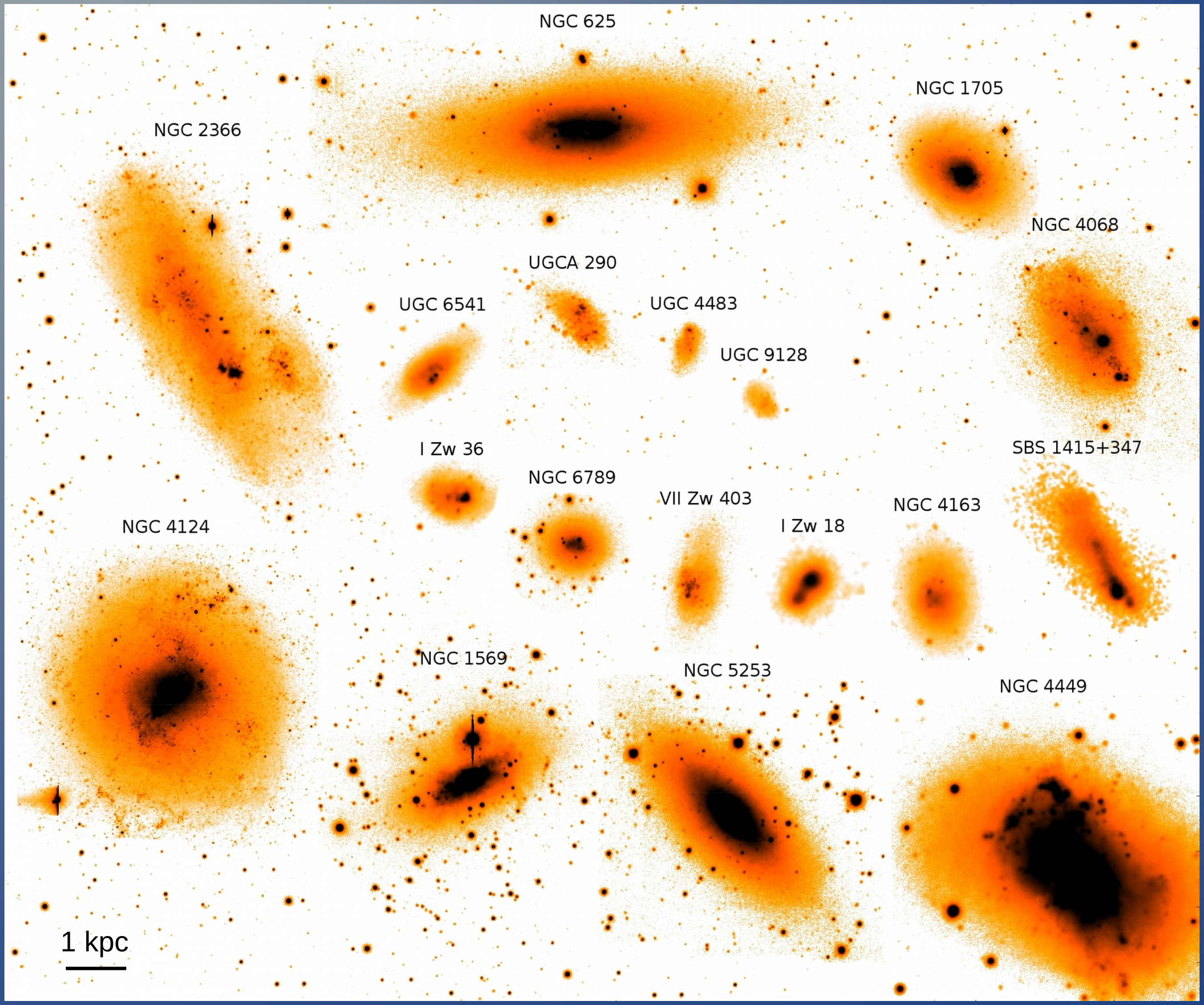



- Strength: $b = SFR(t_{peak}) / \overline{SFR} \sim 3\text{-}10$
- Burst Duration: ~few 100 Myr
- Burst Energy: ~$10^{56}$ ergs

# 18 Starburst & Post-Starburst Dwarfs



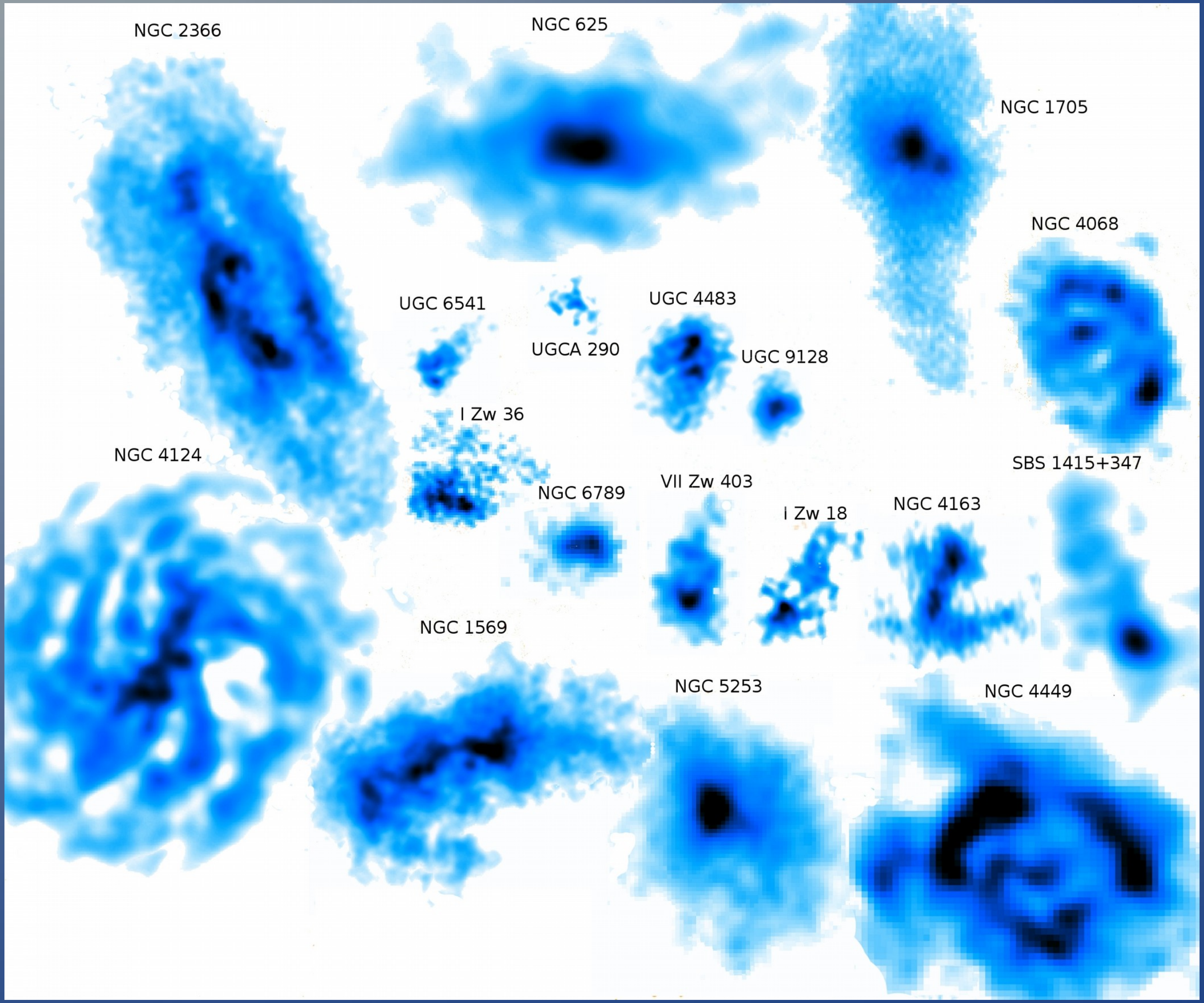

**Resolved into single stars by HST obs:**

- Distance ≃ 2-20 Mpc
- Star Formation History
- $b = SFR(burst)/\overline{SFR} \geq 3$

LELLI et al. (2014a,b,c)

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

# 18 Starburst & Post-Starburst Dwarfs




**Resolved into single stars by HST obs:**

- Distance ≃ 2-20 Mpc
- Star Formation History
- $b = SFR(burst)/\overline{SFR} \geq 3$

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

- HI distribution
- HI kinematics

LELLI et al. (2014a,b,c)

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

# Questions:

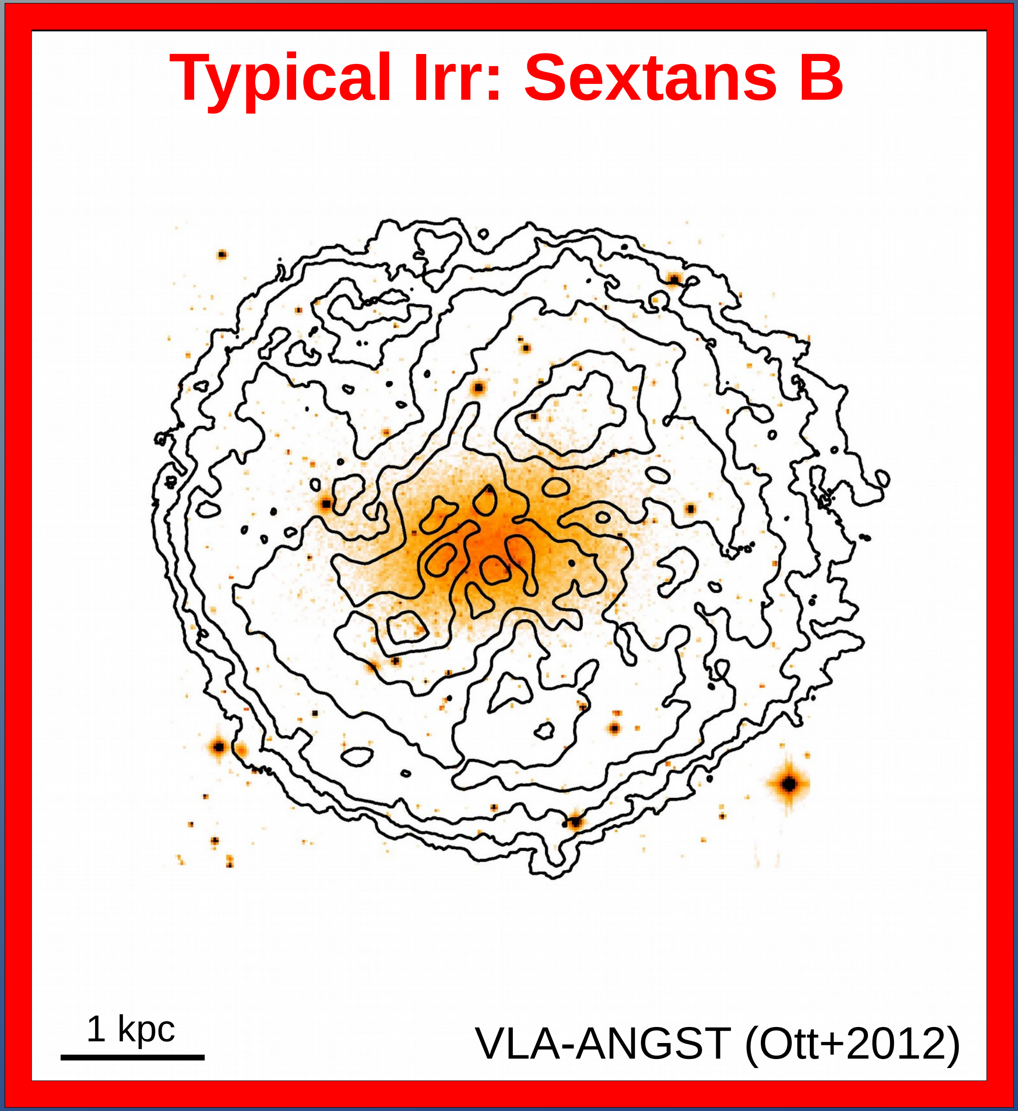
- What triggers the starburst?

  External *vs* Internal Mechanisms?

- What is the role of stellar feedback?

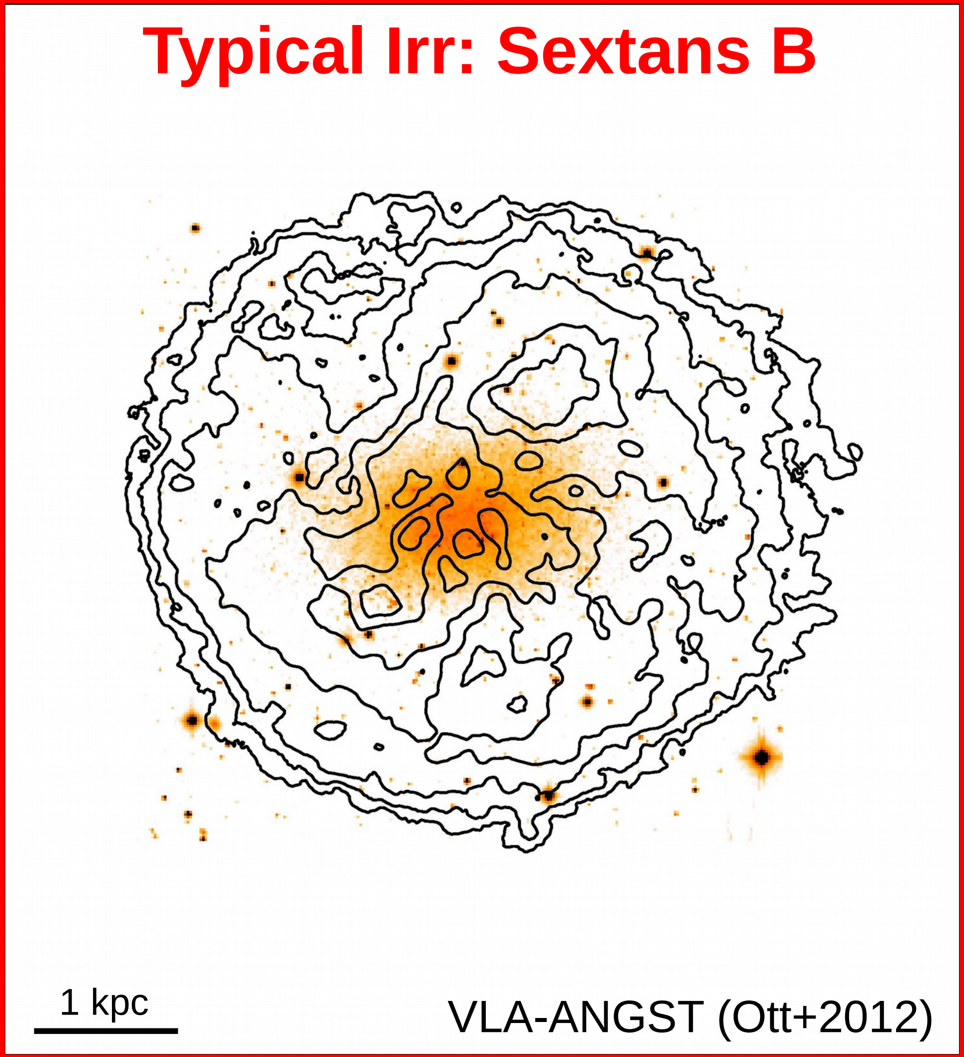
  Evidence for Outflows & Shocks? Self-quenching?

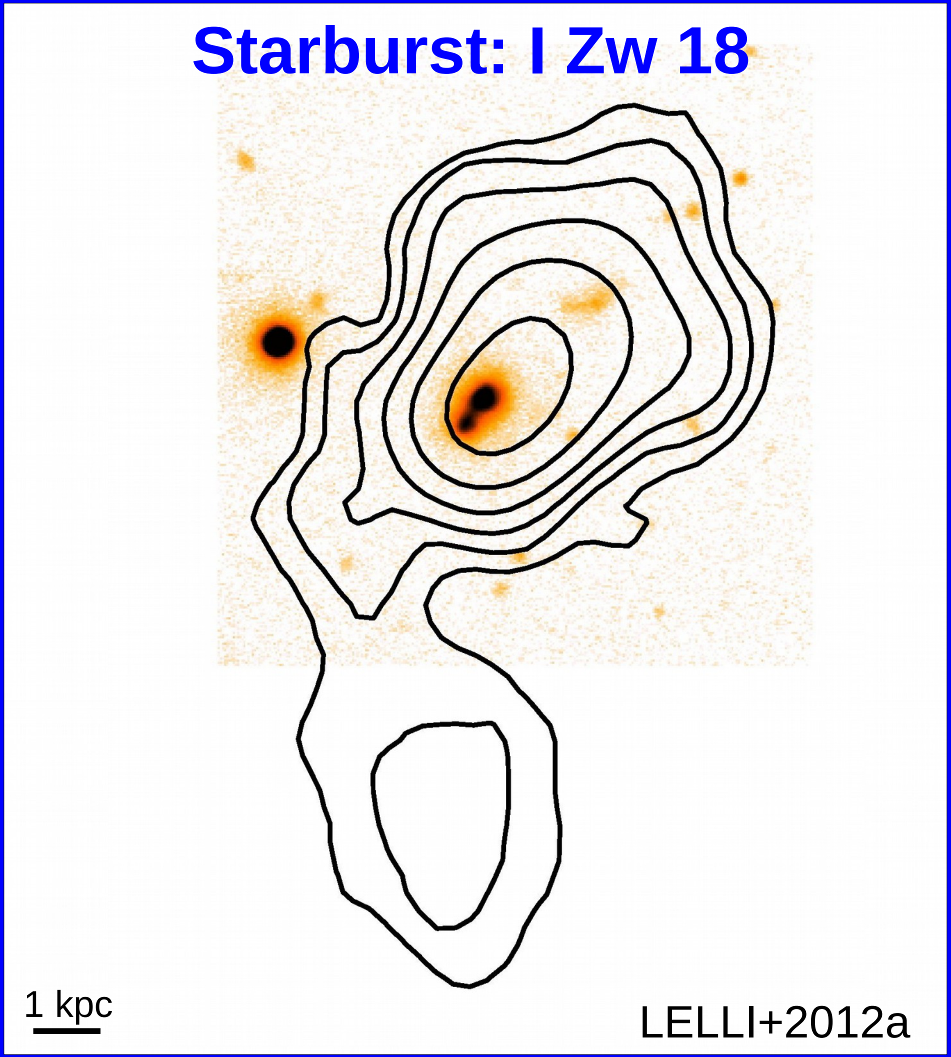
# What triggers the Starburst?




Deep, low-resolution HI data: Lowest contour = 5 x $10^{19}$ $cm^{-2}$

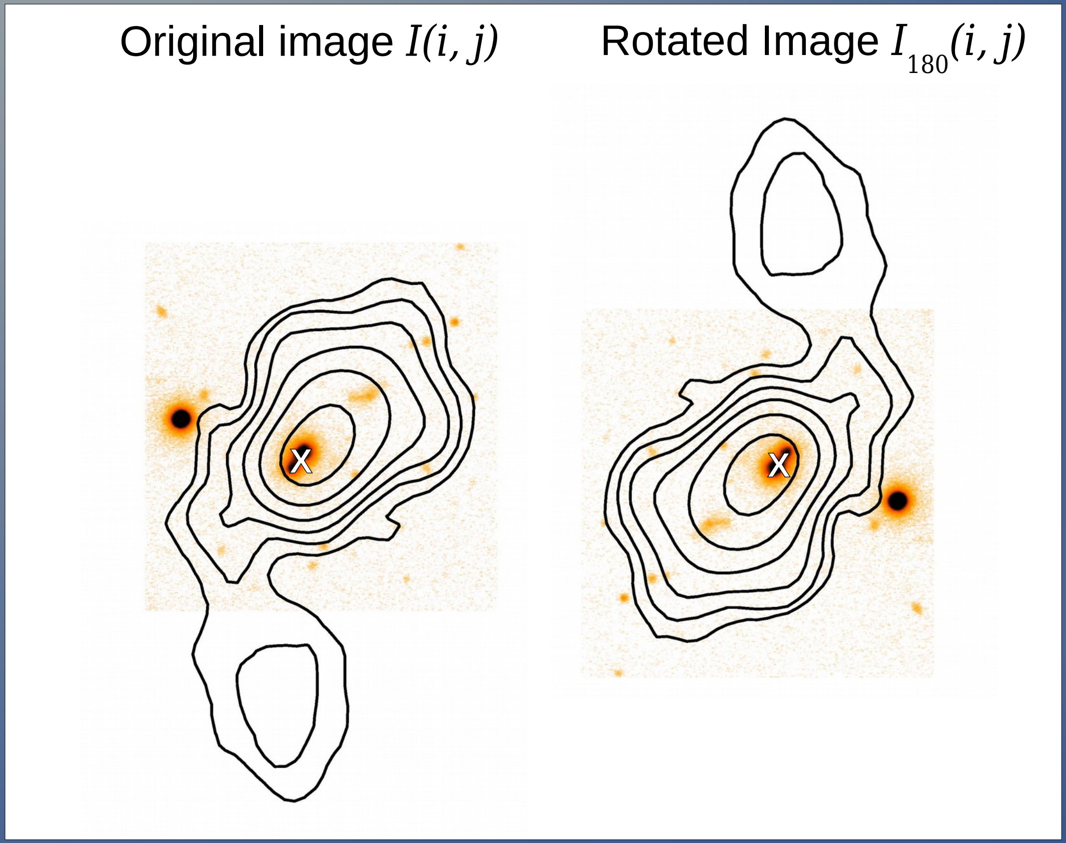
# What triggers the Starburst?




Deep, low-resolution HI data: Lowest contour = $5 \times 10^{19}$ $cm^{-2}$

# Quantifying the Outer HI Asymmetry




## Standard $A$ parameter

(e.g. Bershady 2000, Holwerda+2011)

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

## Our $A$ parameter (Lelli+2014c, MNRAS)

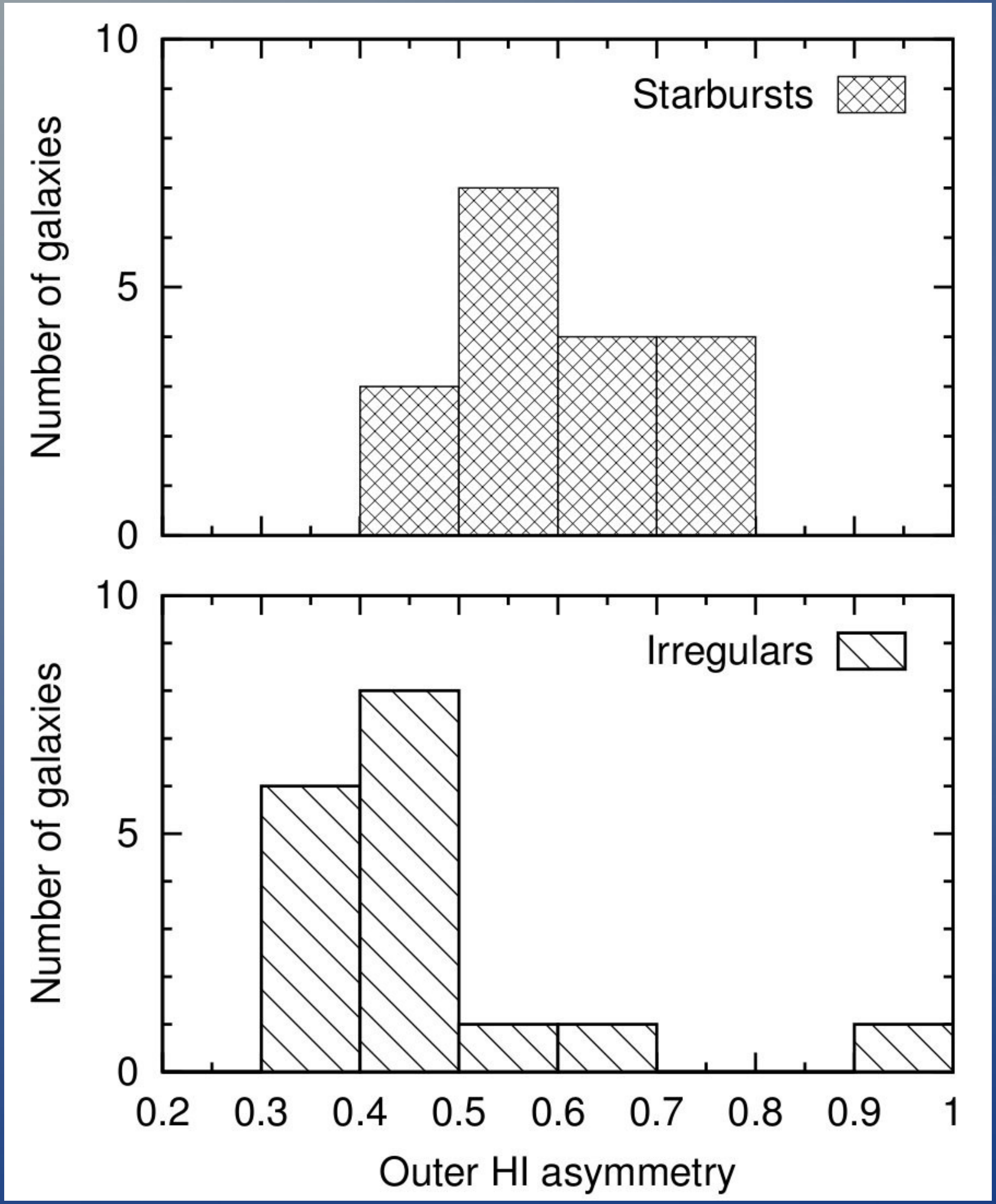
$$A = \frac{1}{N} \sum_{i,j}^{N} \frac{|I(i,j) - I_{180^\circ}(i,j)|}{|I(i,j) + I_{180^\circ}(i,j)|}$$

➡ Good for outer regions!

**For all galaxies:**

- Uniform column density sensitivity
- Similar linear resolution (in kpc)

# Outer HI Asymmetry: Starbursts *vs* Irrs



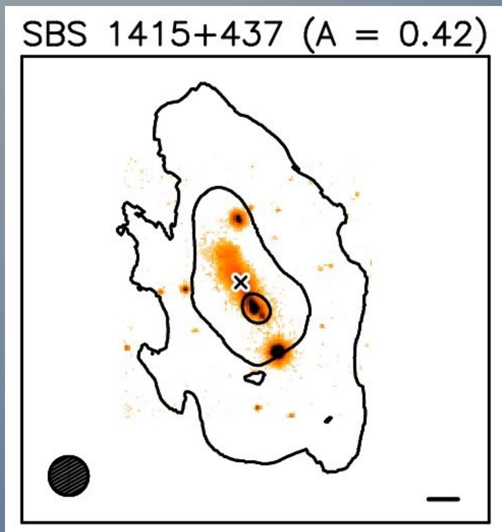

Starbursts have more asymmetric outer HI distributions than Irrs

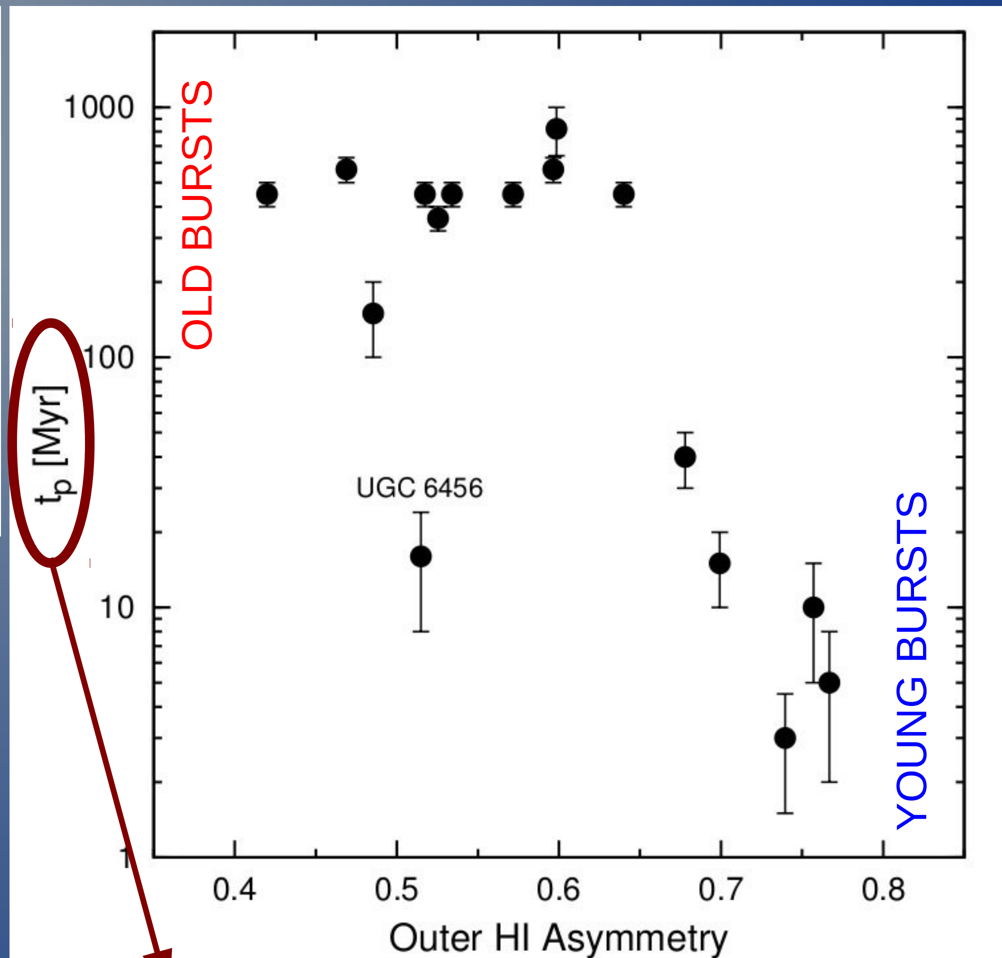
External mechanisms triggered the starburst:

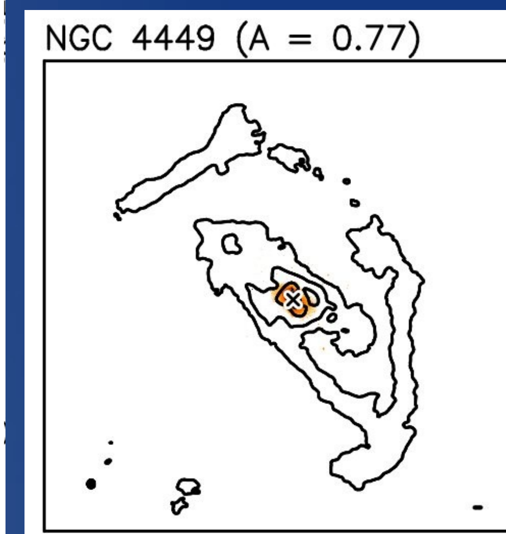
- Interactions/mergers?
- Cold gas accretion?

LELLI+2014c, MNRAS

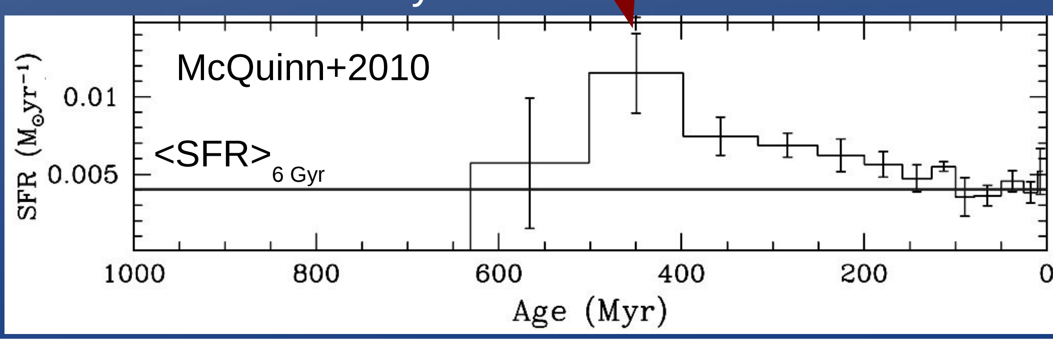
# Outer Asymmetry *vs* Starburst "Age"



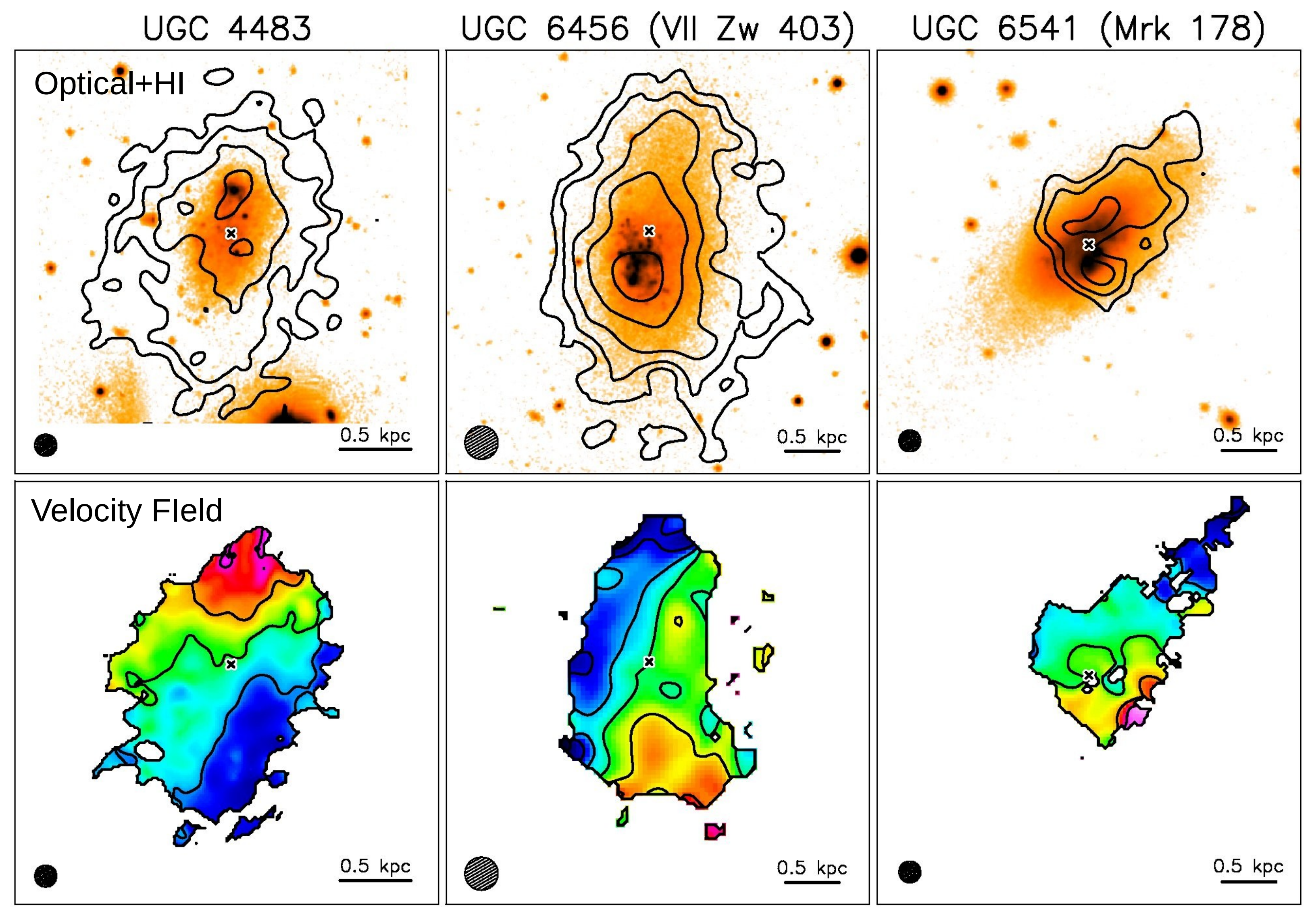

Star-Formation History:




FOR OLD BURSTS:

$t_p \sim t_{orb}$ in outer parts. HI distribution can be regularized by diff. rotation!

# Inner HI structure: Role of Feedback?

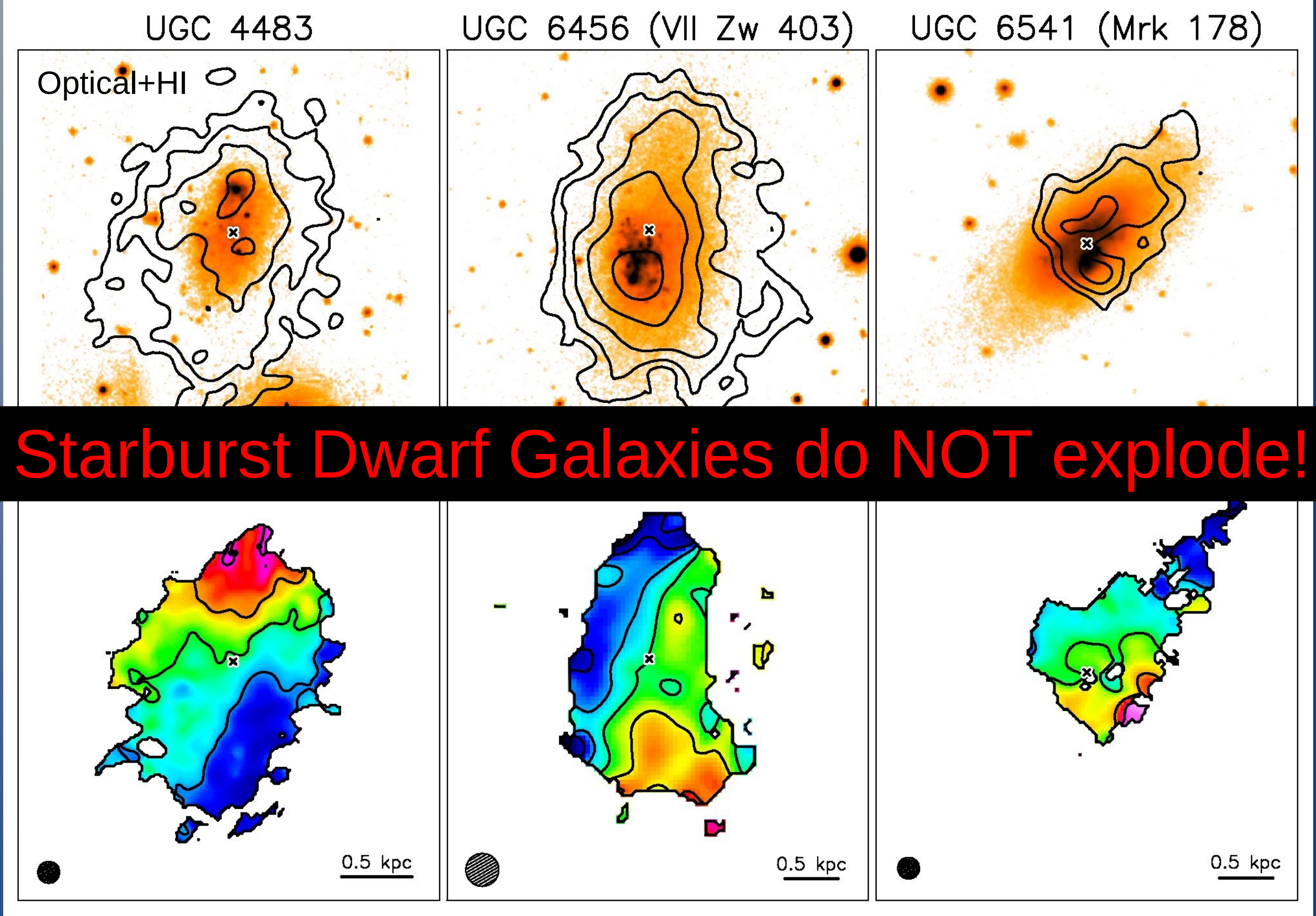



~50%
rotating HI disk

~40%
kin. disturbed HI disk

~10%
unsettled HI distr.

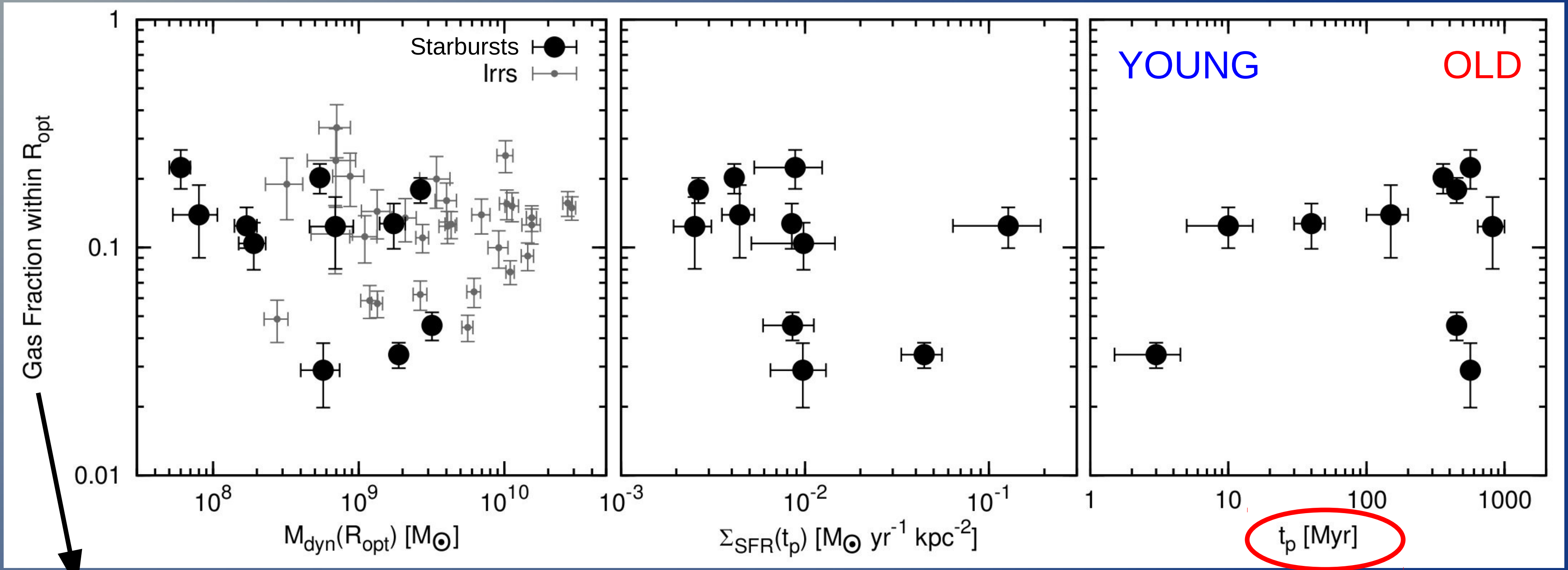
# Inner HI structure: Role of Feedback?




**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

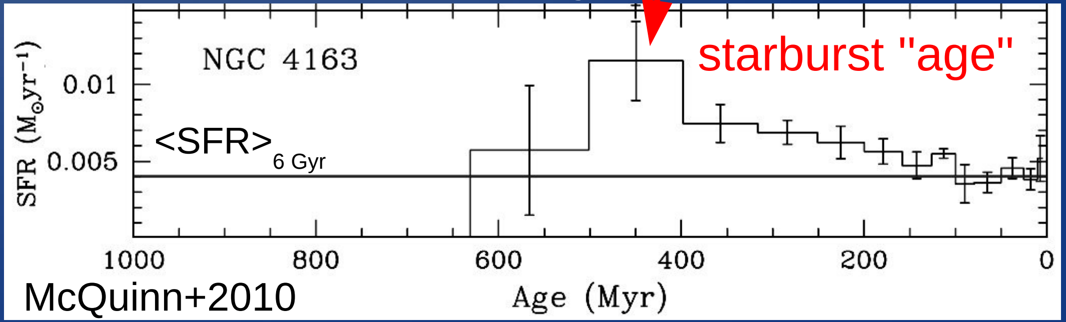
## Same $f_{gas}$ as Typical Dwarfs:

- No massive gas outflows
- No massive gas consumption

  $t_{dep}$ = 10-100 Gyr for Irregulars

  3-10 Gyr for Starbursts

Star-Formation History



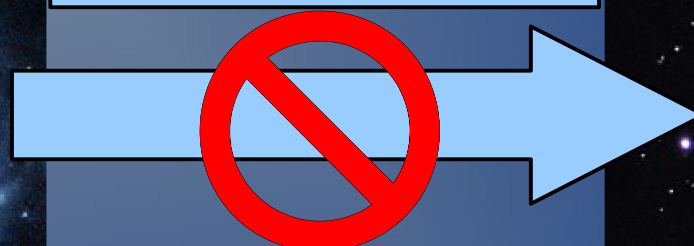
# Quenching of Dwarf Galaxies

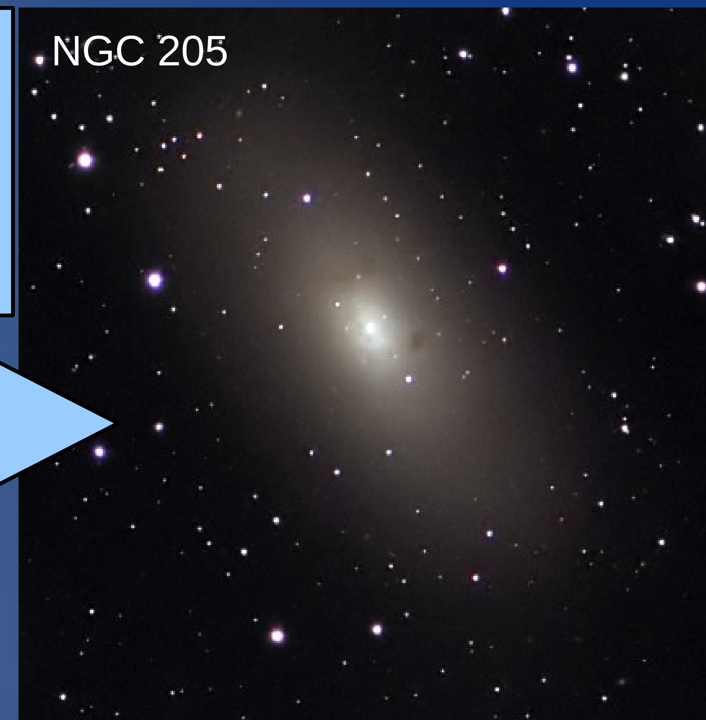
## Gas-rich Dwarf

## Gas-poor Dwarf


**Internal Processes:**

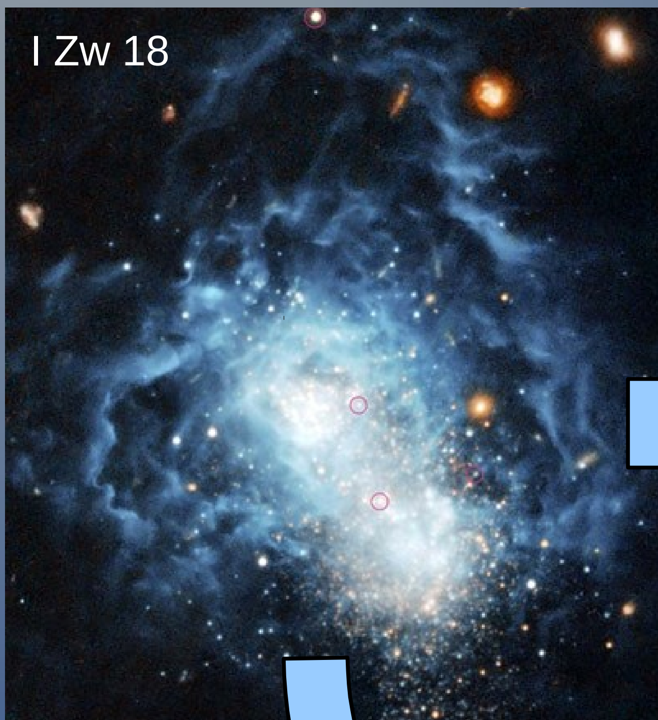
- Gas Consumption
- Stellar Feedback
  (e.g. Dekel & Silk 1986)



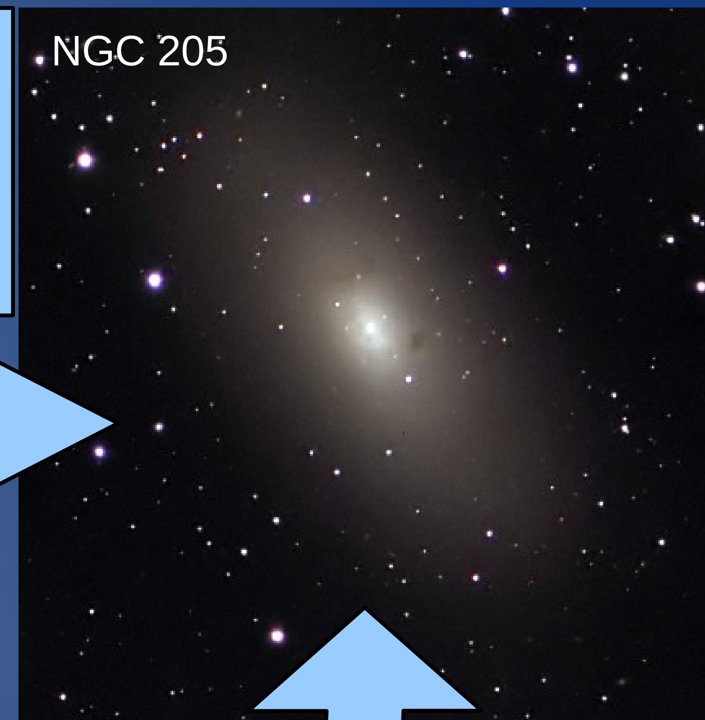


# Quenching of Dwarf Galaxies

## Gas-rich Dwarf




## Gas-poor Dwarf




**Internal Processes:**

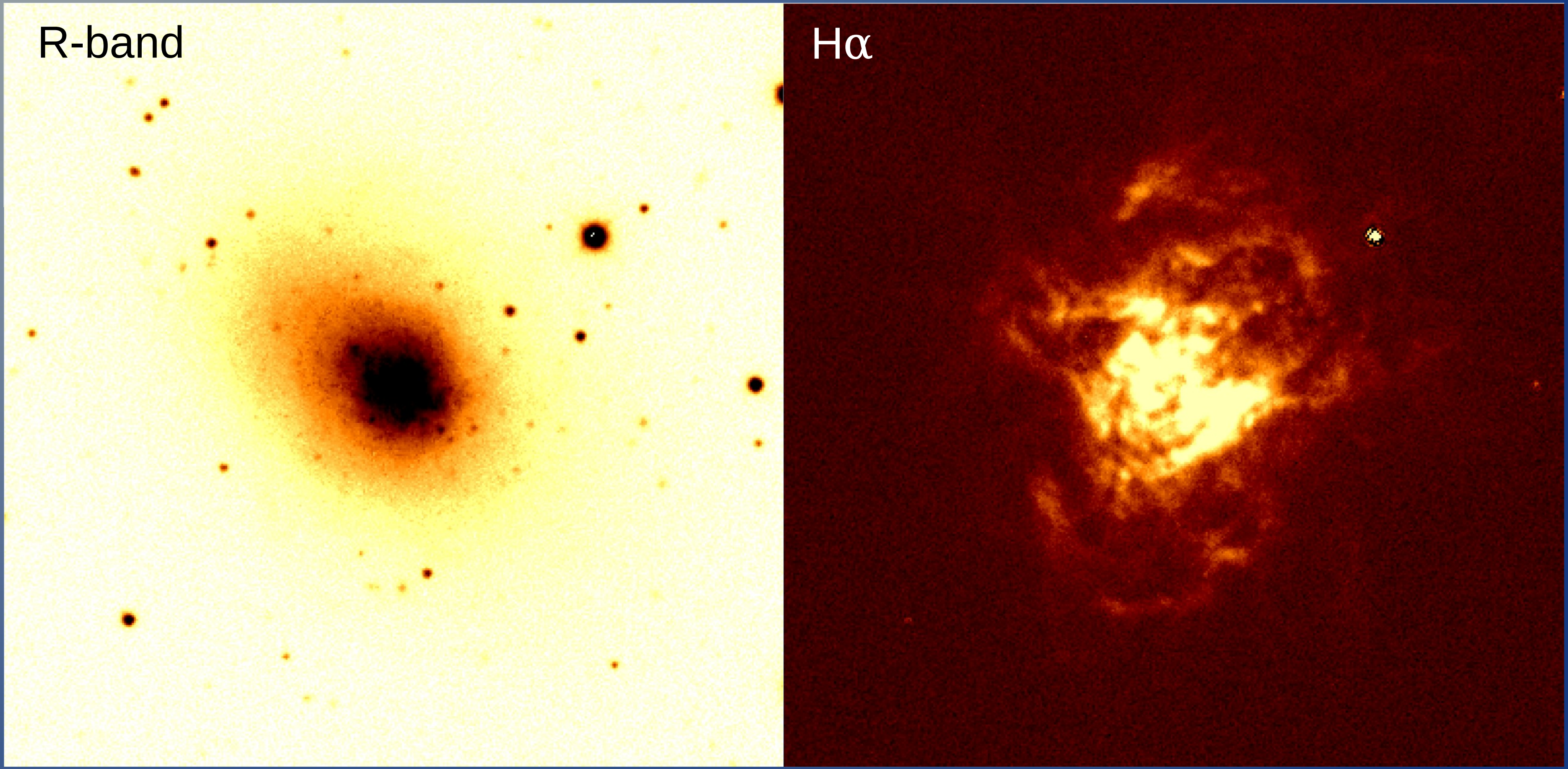
- Gas Consumption
- Stellar Feedback
  (e.g. Dekel & Silk 1986)

**External Processes:**

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

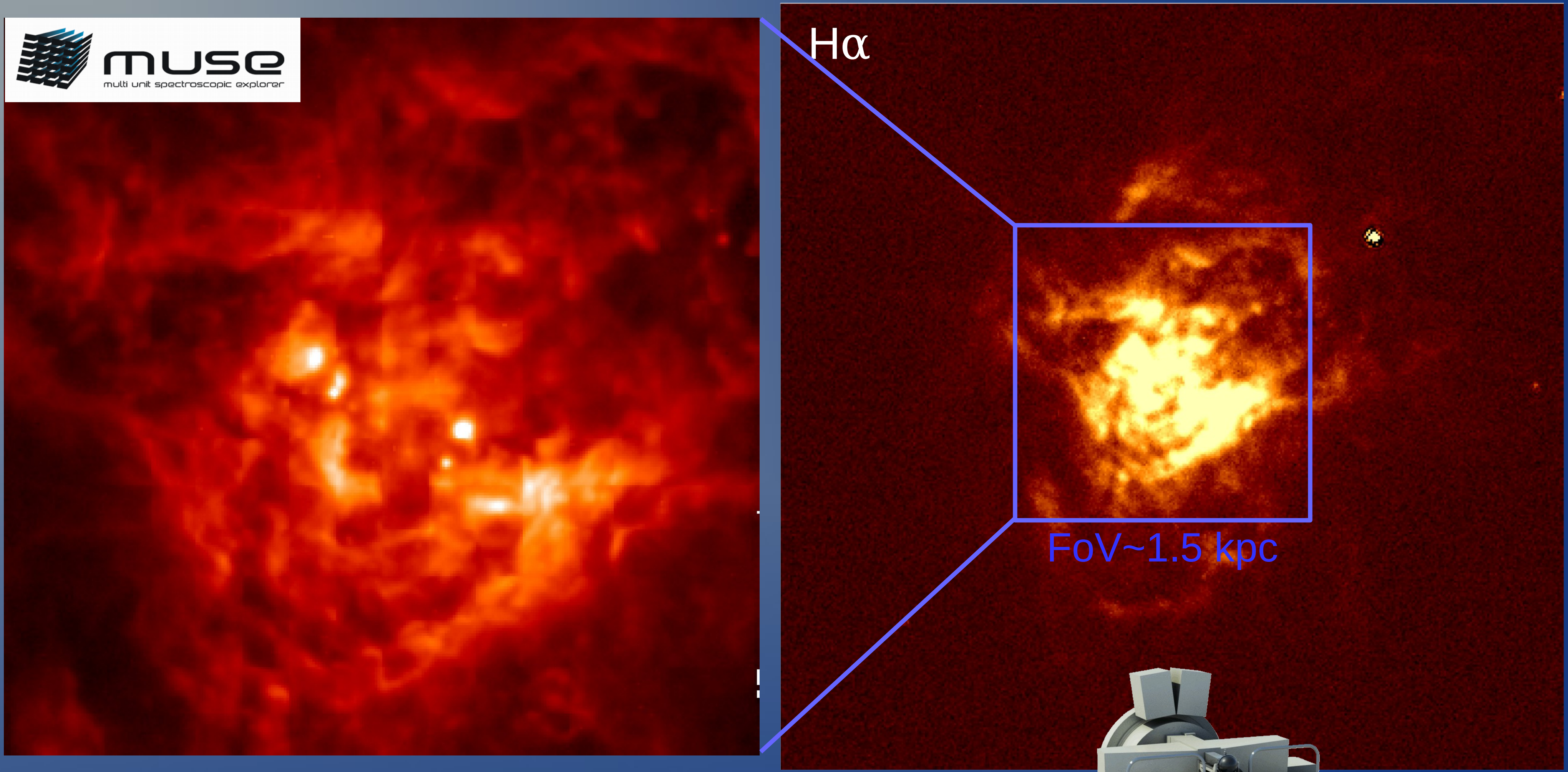
In line with the strong morphology-density relation for dwarfs.

# NGC 1705: evidence for an outflow?



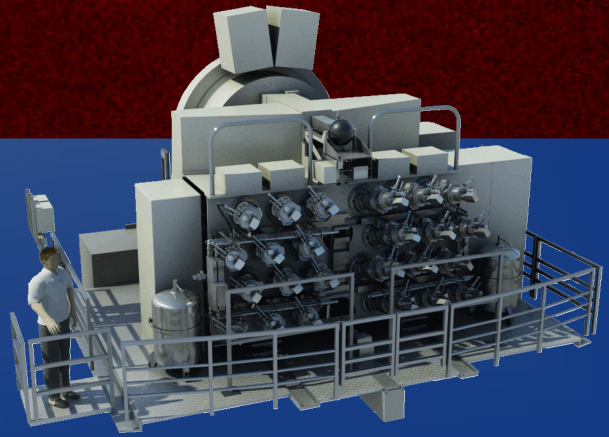

- Extended Hα morphology suggests an ionized gas outflow (Meurer+1992)
- Blueshifted UV absorption lines (Heckman & Leitherer 1997; Heckman+2001)

# NGC 1705: a case-study with MUSE




- Similar maps for Hβ, HeI, [NII], [OIII], etc.
- MUSE data for 5 more starburst dwarfs

McLeod, LELLI, Beccari et al. (in prep.)



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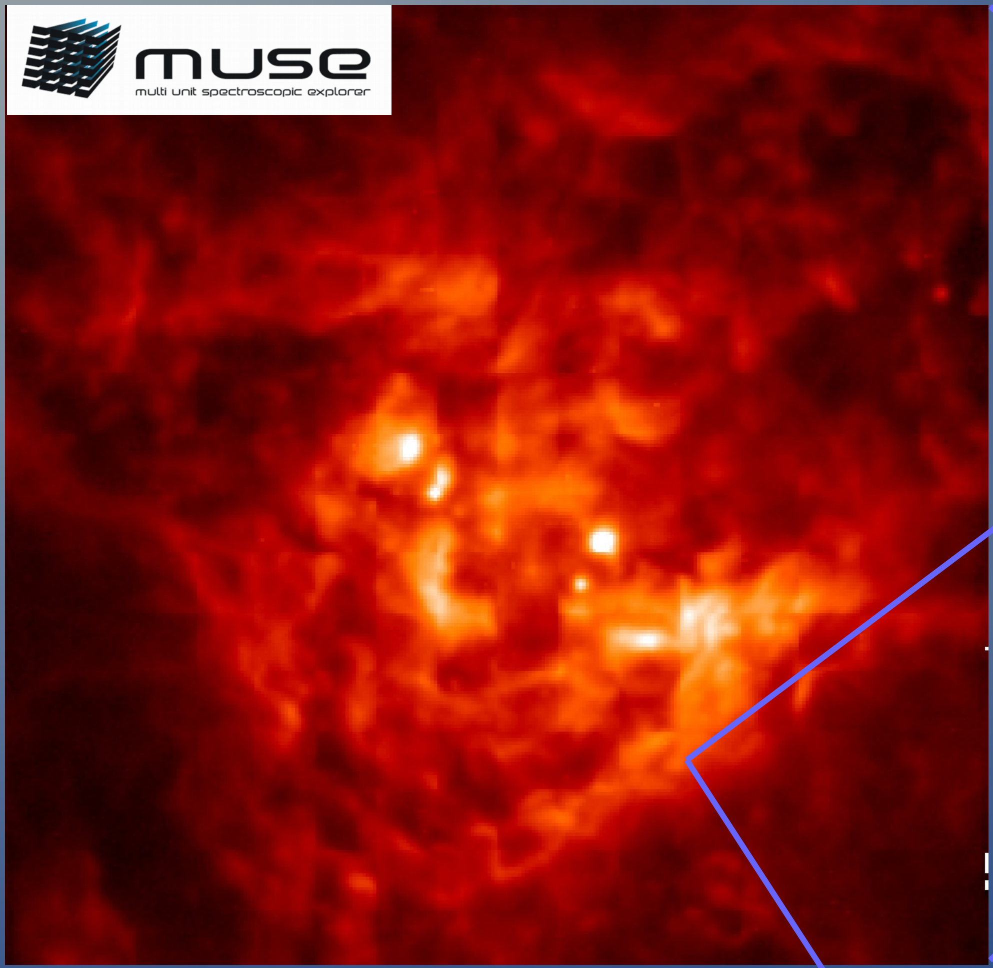
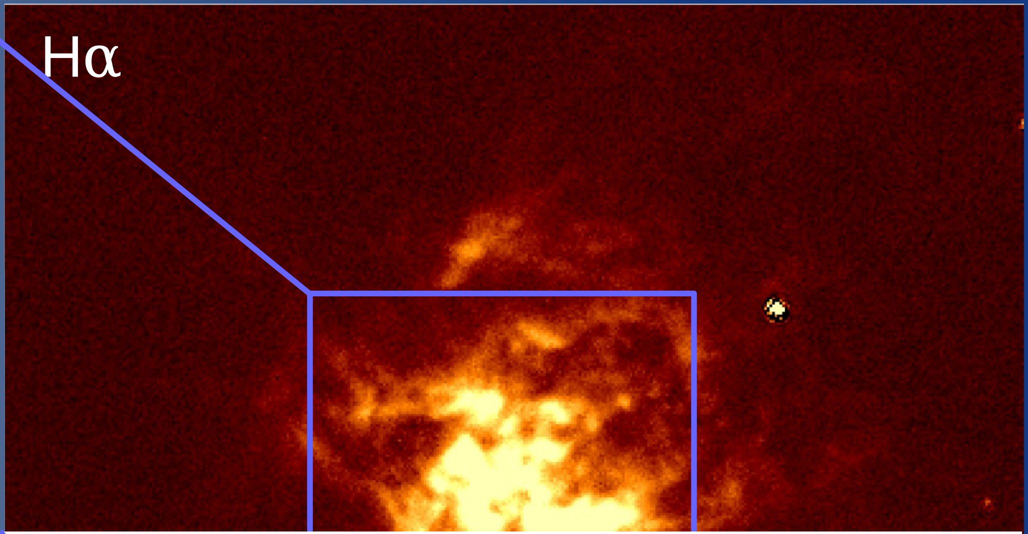
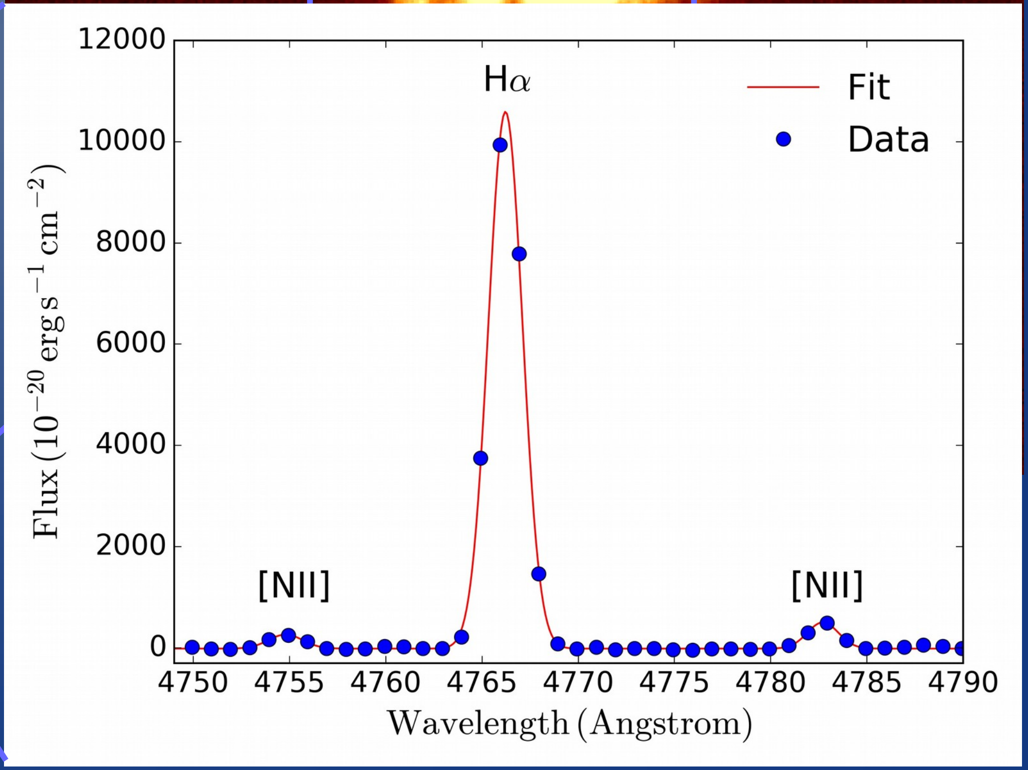


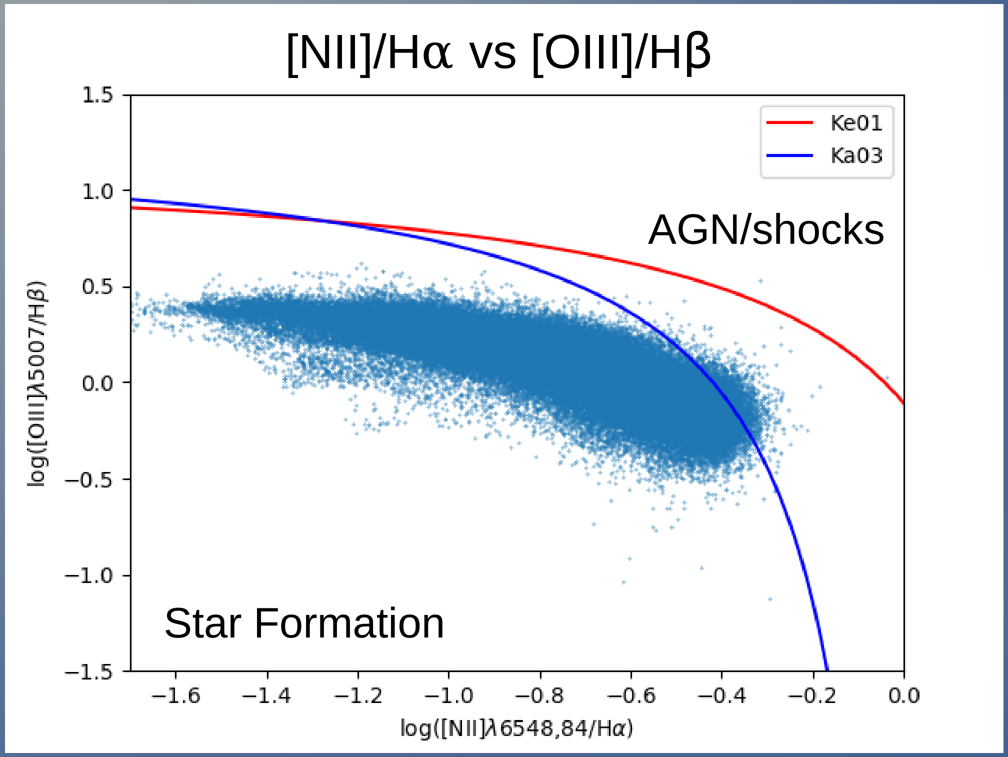

Profiles are narrow and single-peaked:

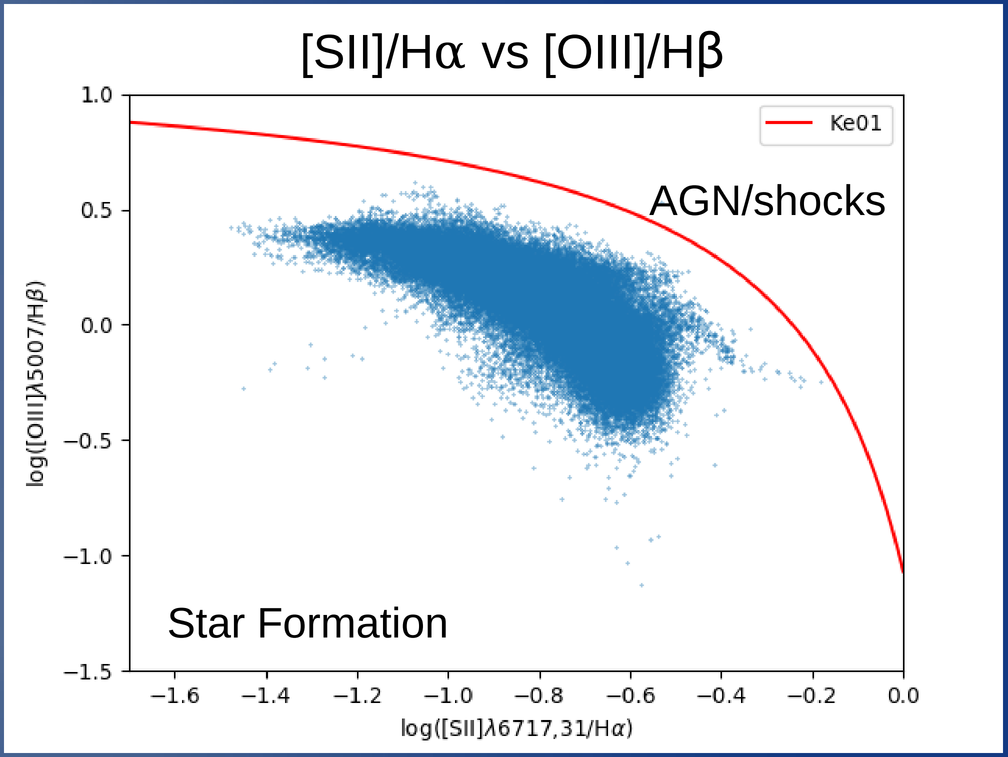
$V_{out}$ < 100 km/s < $V_{esc}$ (not escaping!)

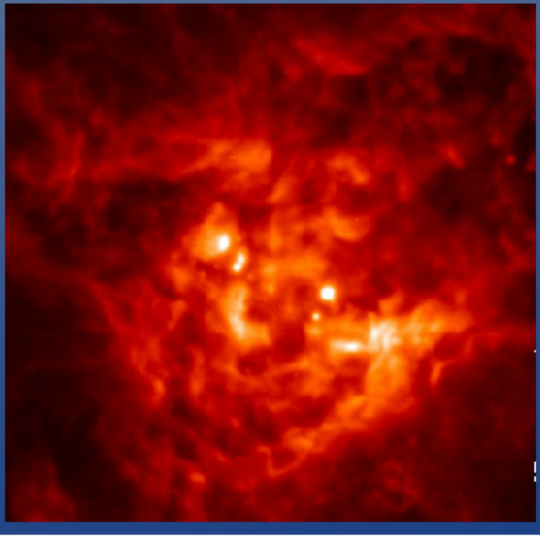
In line with Hα long-slit spectroscopy

(Martin 1996, 1998; van Eymeren+2009, 2010)

# Spatially-Resolved BPT Diagrams



No evidence for shocks or fast outflows.

Gas is pushed "gently" and ionized by SF.

Stellar feedback may act on local scales.

McLeod, LELLI, Beccari et al. (in prep.)

# Conclusions on Dwarf Galaxies:

- Starbursts are triggered by external mechanisms

  Interactions/Mergers between dwarf galaxies?

  Cold gas accretion from the IGM at z=0?

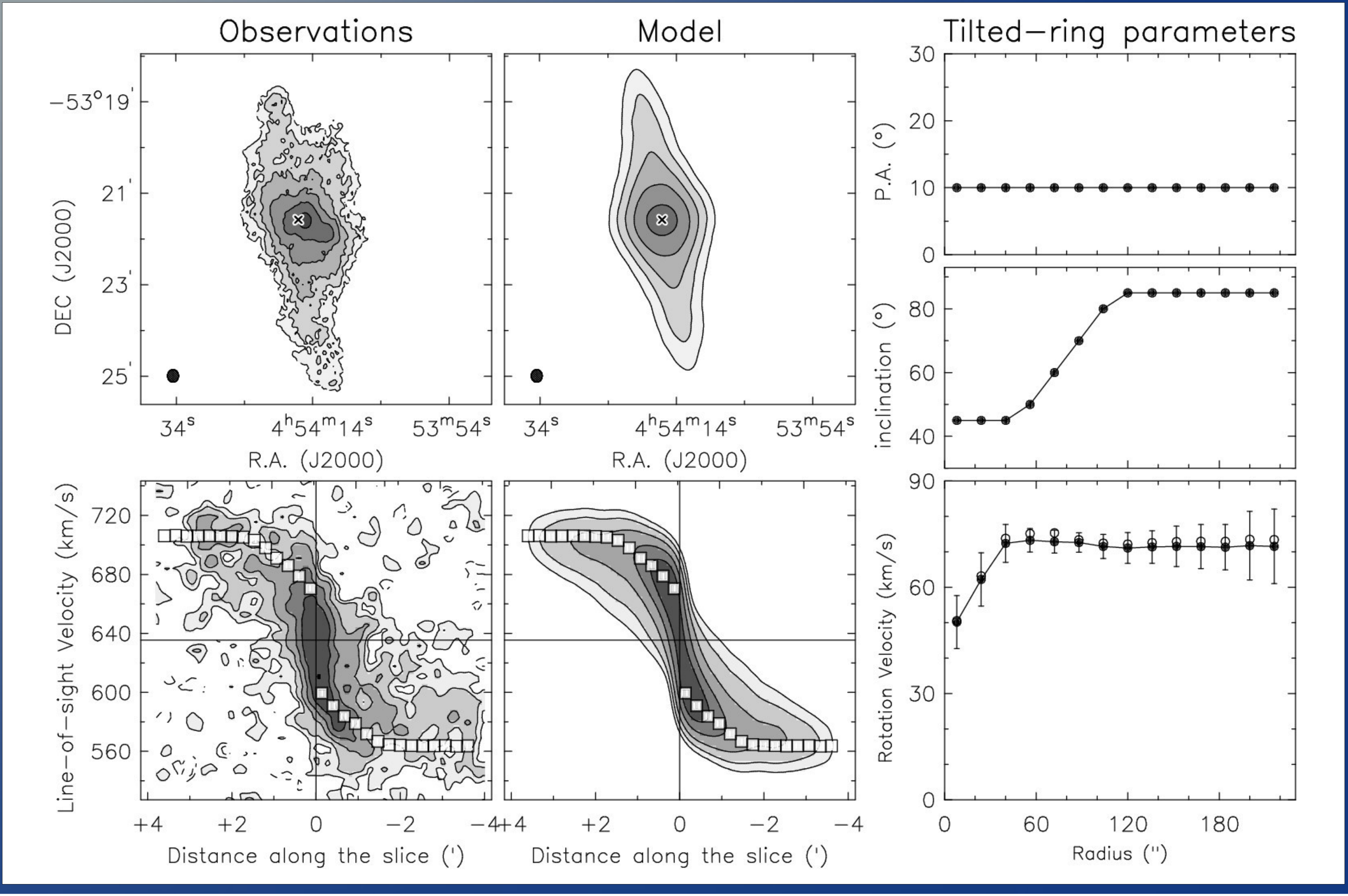
- NO evidence for massive or fast outflows, nor shocks

  Gas is pushed gently and ionized by young stars

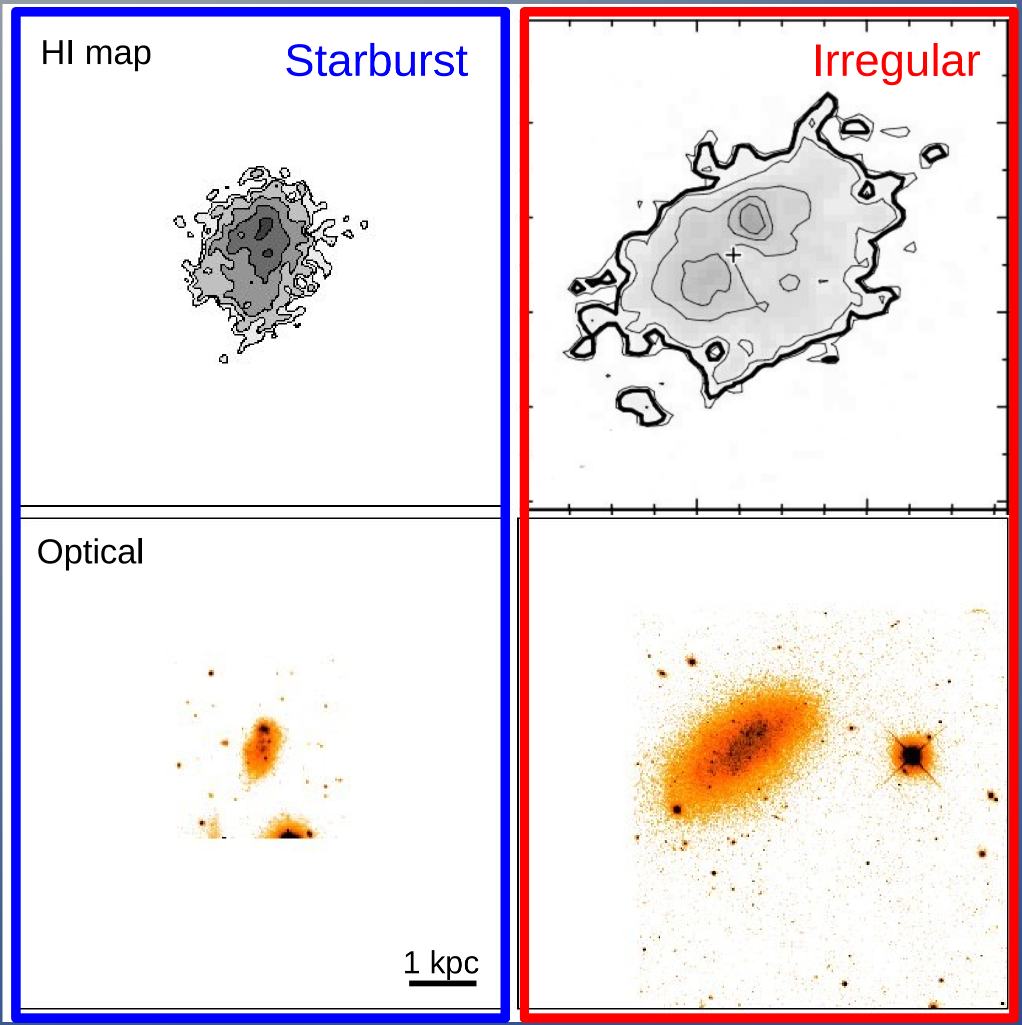
  Feedback doesn’t eject the whole ISM (no self-quenching)

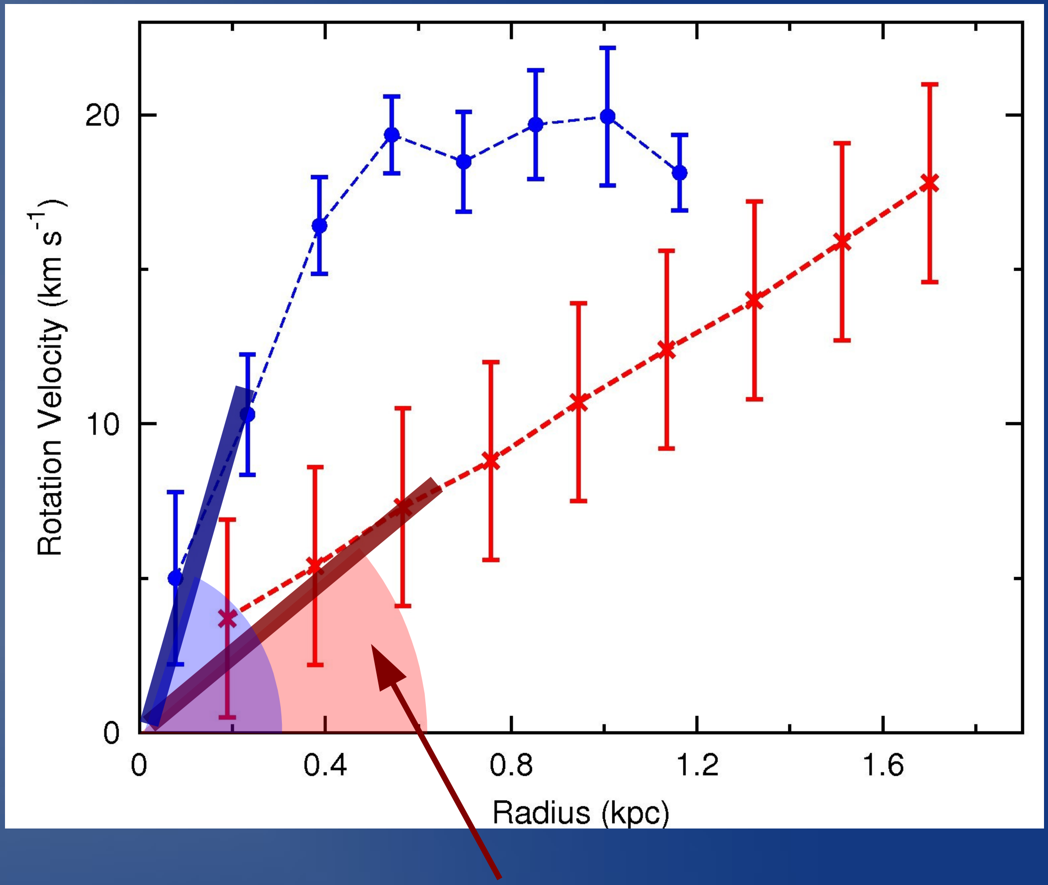
# More Slides

# NGC 1705: HI modelling



# Rotation Curves: Starbursts *vs* Irrs




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

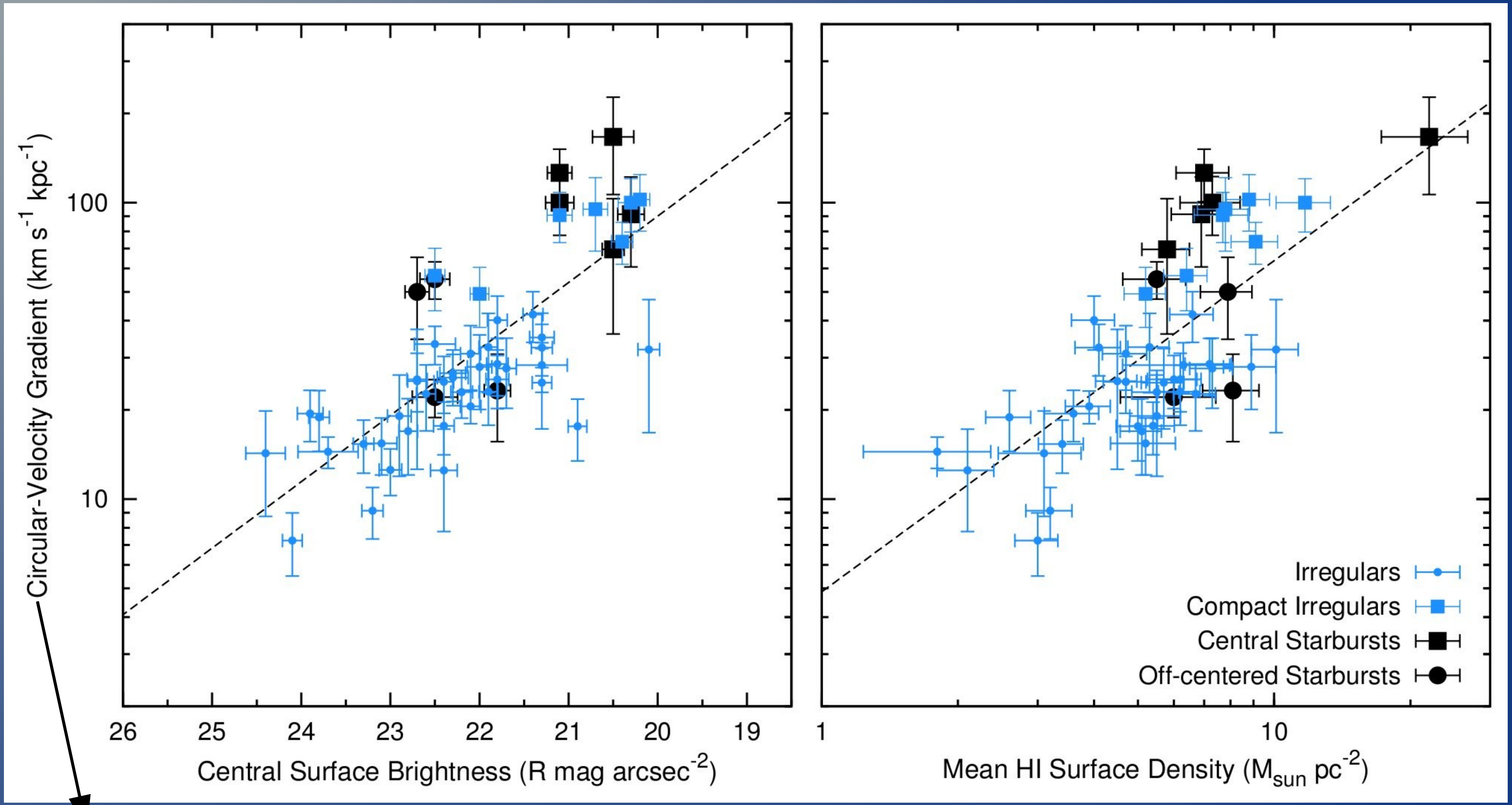
Lelli et al. (2012a,b; 2014a,b)

See also Meurer+1998; van Zee+2001

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

$\rho_0$ = central dynamical mass density (baryons and dark matter)

# Dynamics: Starbursts *vs* Irrs

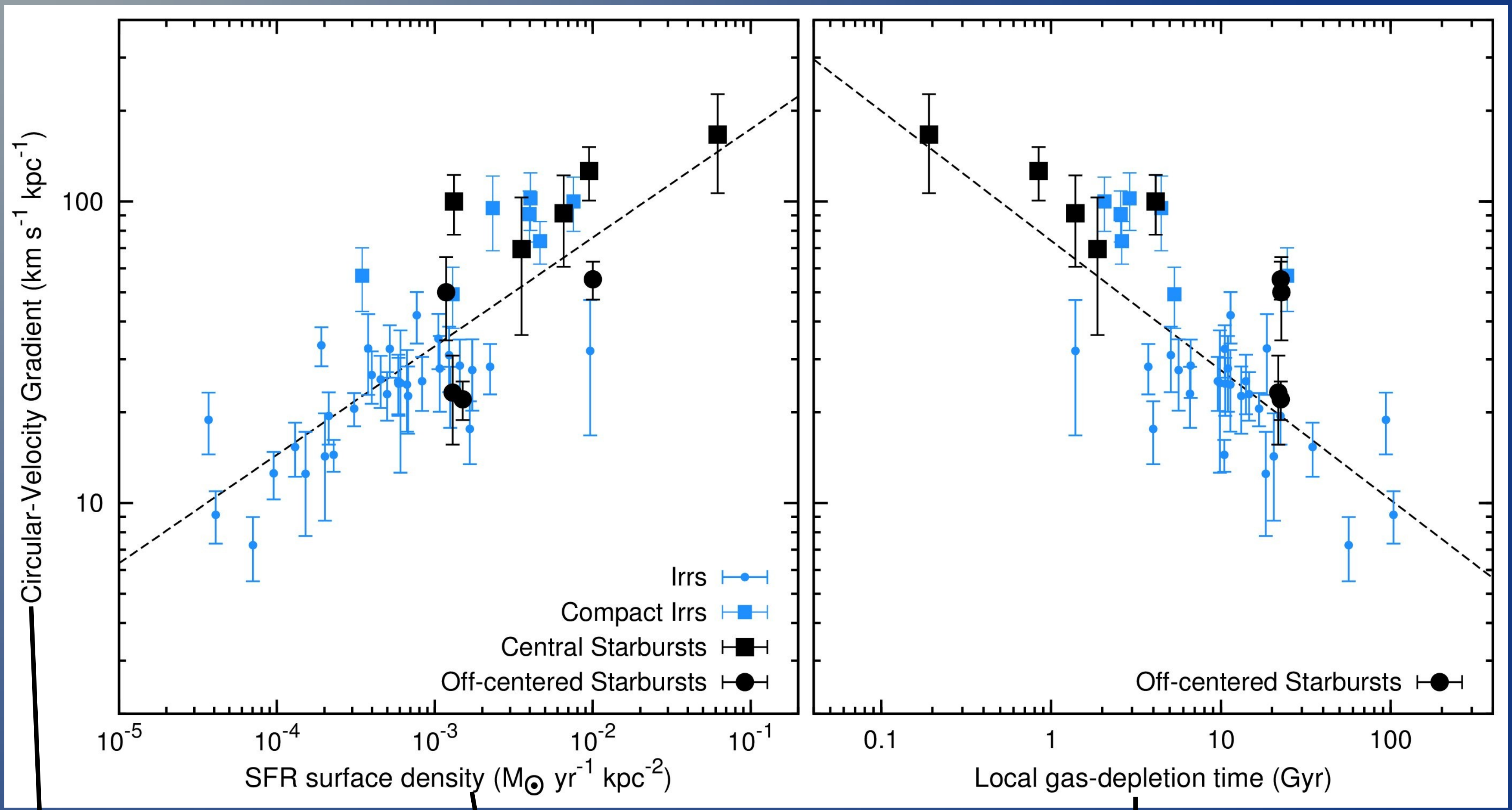



$V(R_d)/R_d \propto \sqrt{\rho_0}$

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

Starburst dwarfs are more compact than Irrs in stars, gas, and DM!

# Link: Dynamics - Star Formation



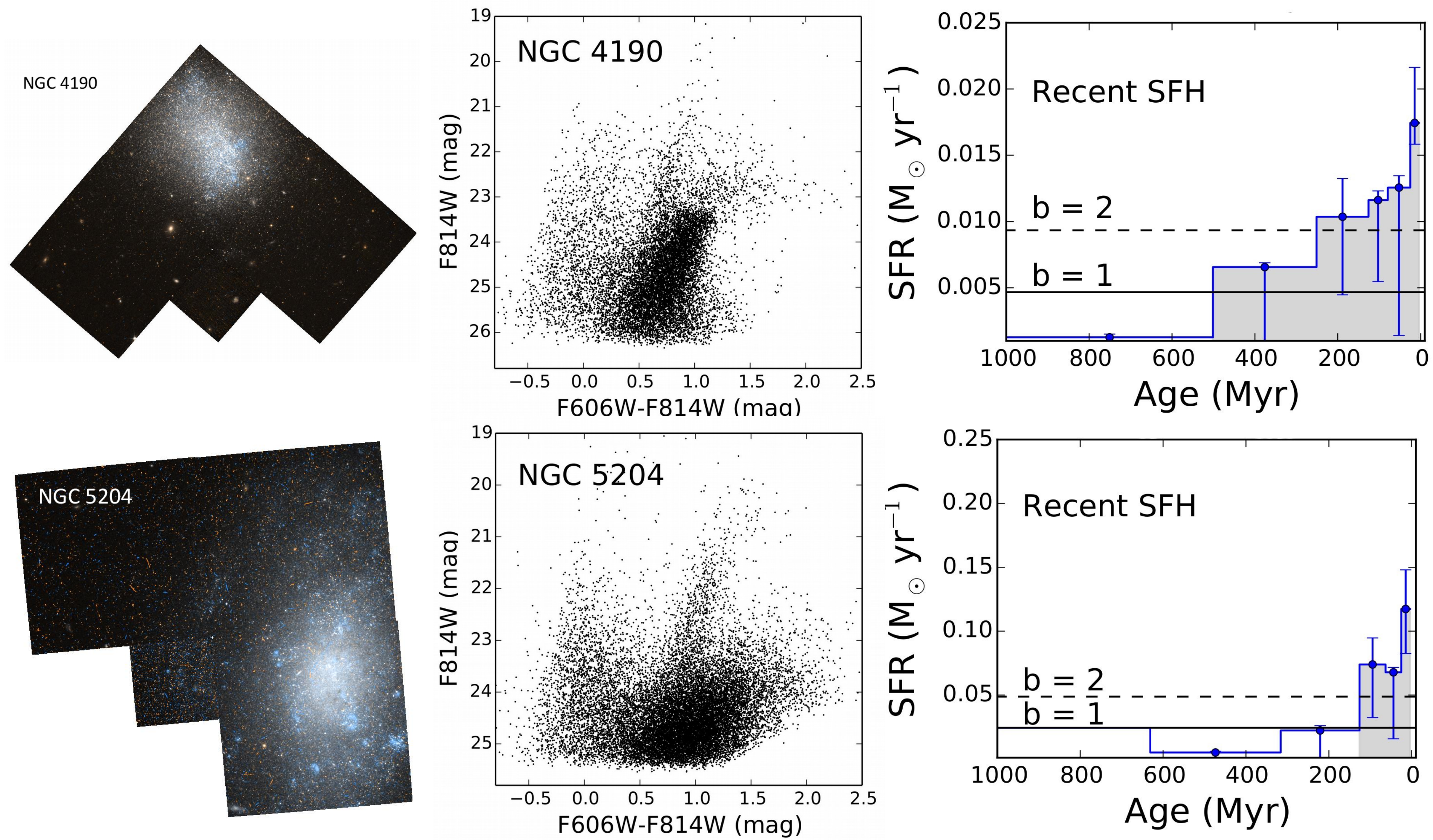

$V(R_d)/R_d \propto \Sigma_{Toomre}$

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

Hα fluxes from Kennicutt+2008

$T_{dep} = \Sigma_{SFR} / \Sigma_{gas}$

# SFHs of "compact" Irrs

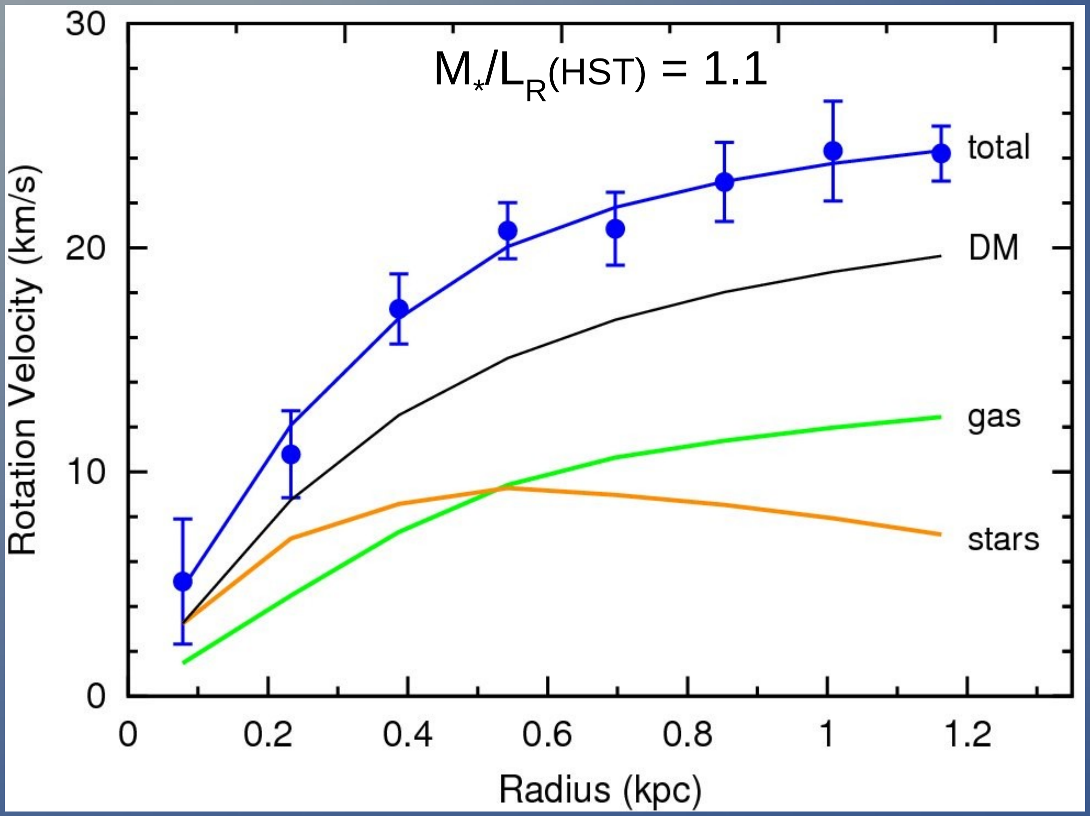



Very recent starbursts: BCD progenitors!

McQuinn, Lelli, Skillman et al. 2015

# 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)