Gas Dynamics in Starbursting Dwarf Galaxies

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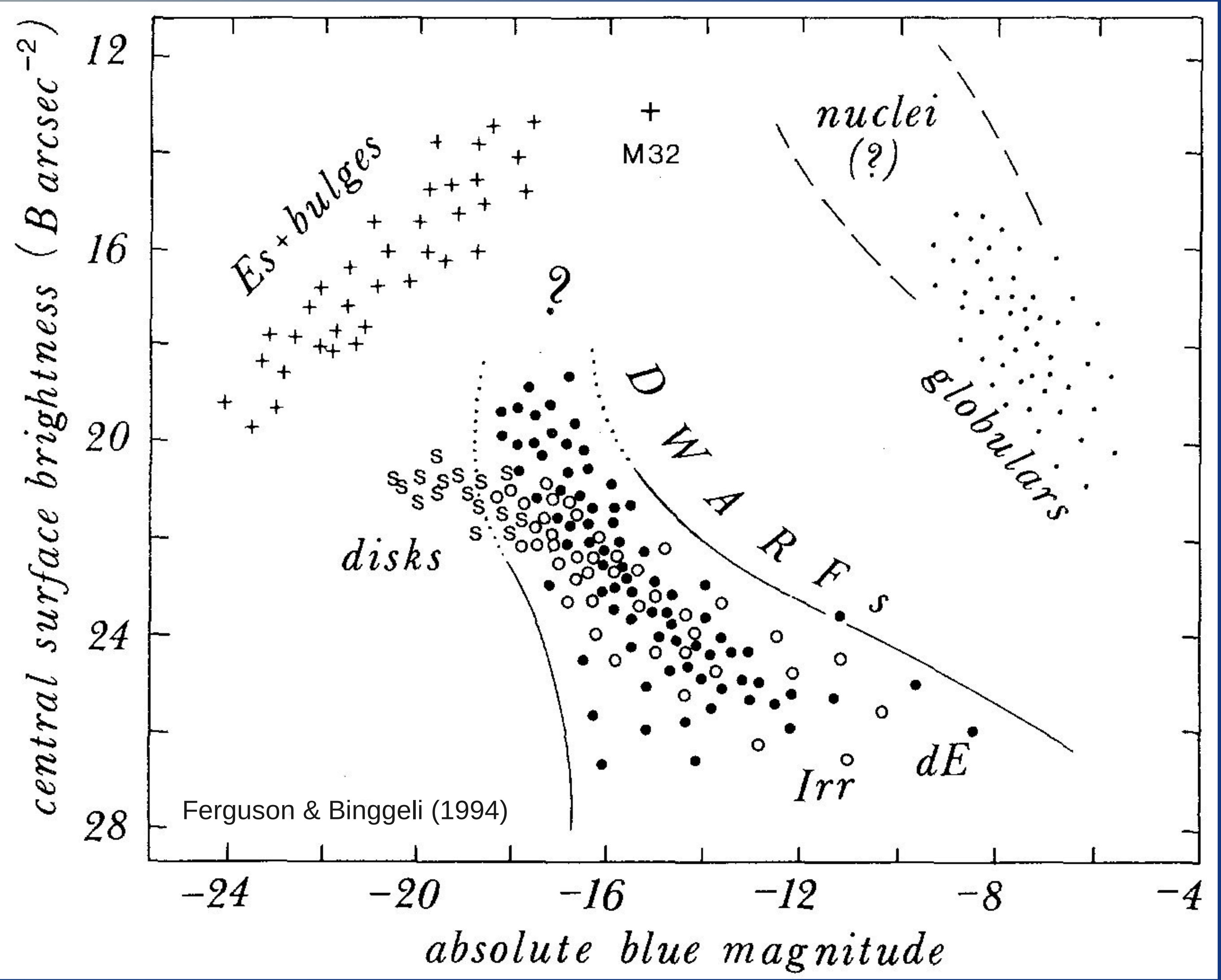
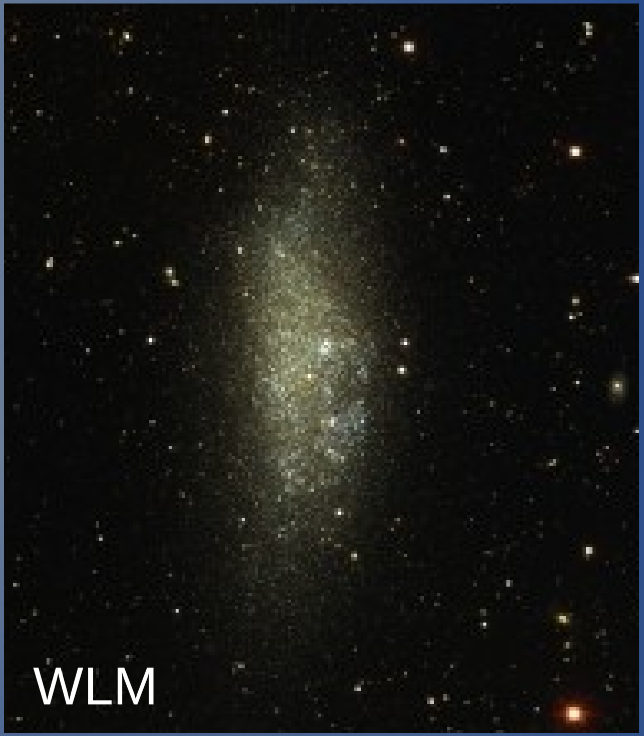
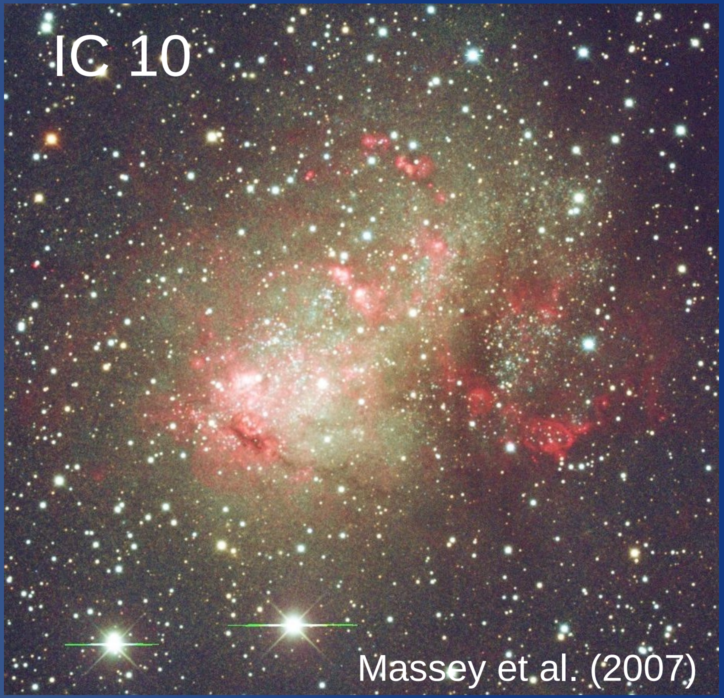


central surface brightness (B arcsec^{-2})
12
16
20
24
28
Es + bulges
M32
nuclei (?)
?
globulars
D W A R F s
disks
Irr
dE
Ferguson & Binggeli (1994)
−24
−20
−16
−12
−8
−4
absolute blue magnitude

Spheroidals	Irregulars	Starburst dwarfs
		
- Gas-poor	- Gas-rich	- Gas-rich
- No recent SF	- Constant SF	- Strong burst of SF
- Close to spirals *or* center of clusters	- Isolated, groups, *or* outskirts of clusters.	- Isolated, groups, *or* outskirts of clusters.
Other names:	Other names:	Other names:
early-type dwarfs, dEs	late-type dwarfs, Im, Sm	HII galaxies, BCDs

BCDs = Starbursting Dwarfs



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

The starburst is a *short-lived* event (~few 100 Myr)

→ BCDs are *transition-type* dwarfs

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Questions:

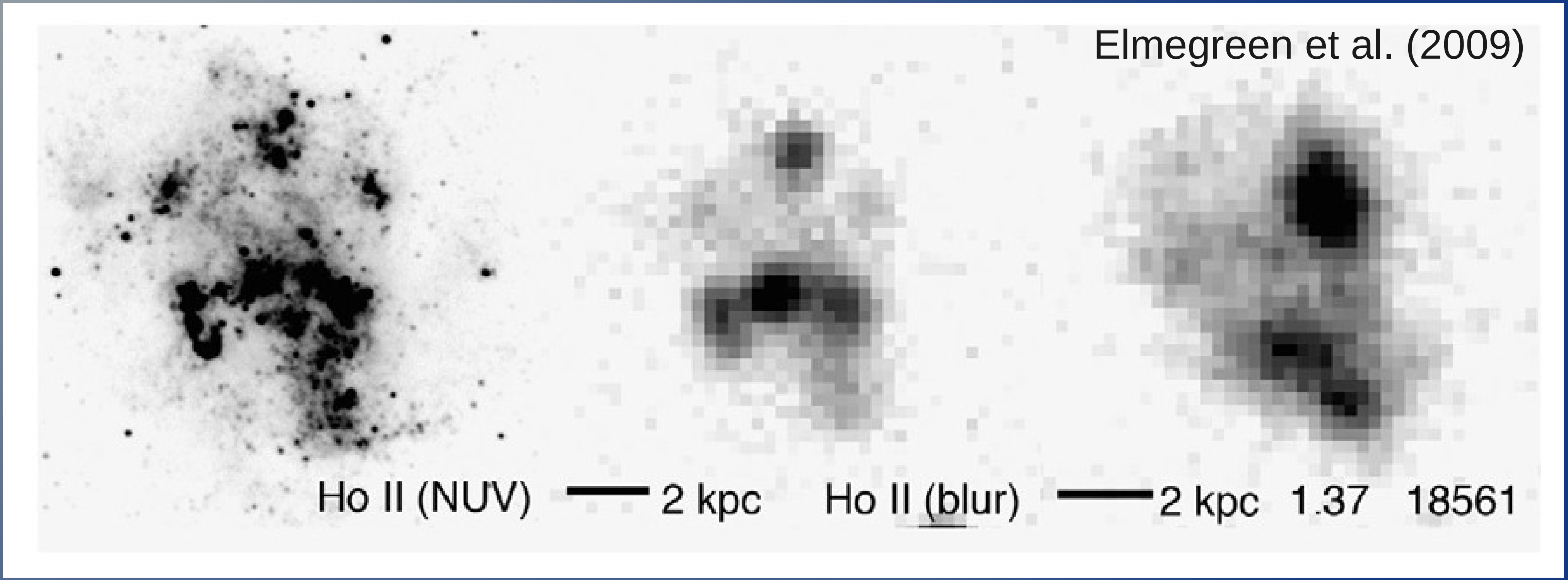
- What are the progenitors/descendants?

  (evolutionary links with Sphs and/or Irrs)

- What triggers the starburst?

  (external *vs* internal mechanisms)

BCDs ~ high-z galaxies ?



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

Outline

- Overview on BCDs:

  stellar populations, optical structure, HI properties

- Internal dynamics:

  clues to dwarf galaxy evolution

- Large-scale HI emission:

  clues to the starburst trigger

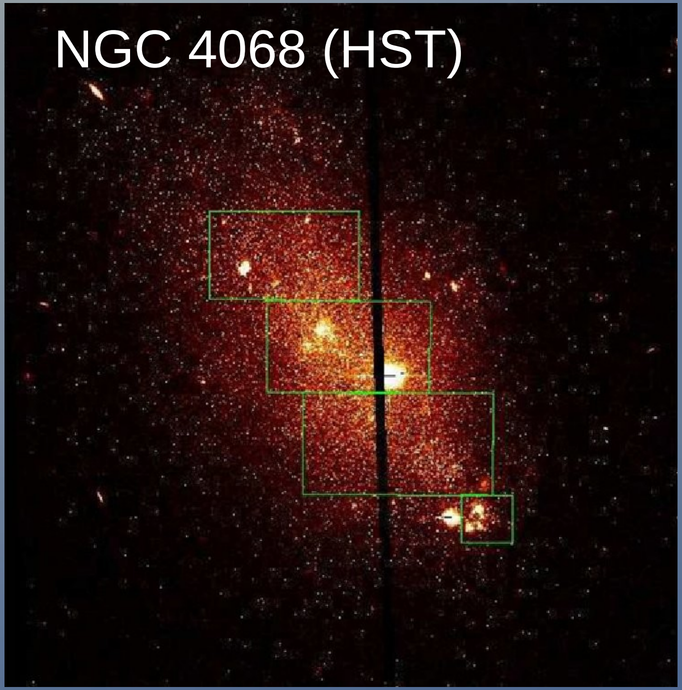
- Luminous – dark matter coupling:

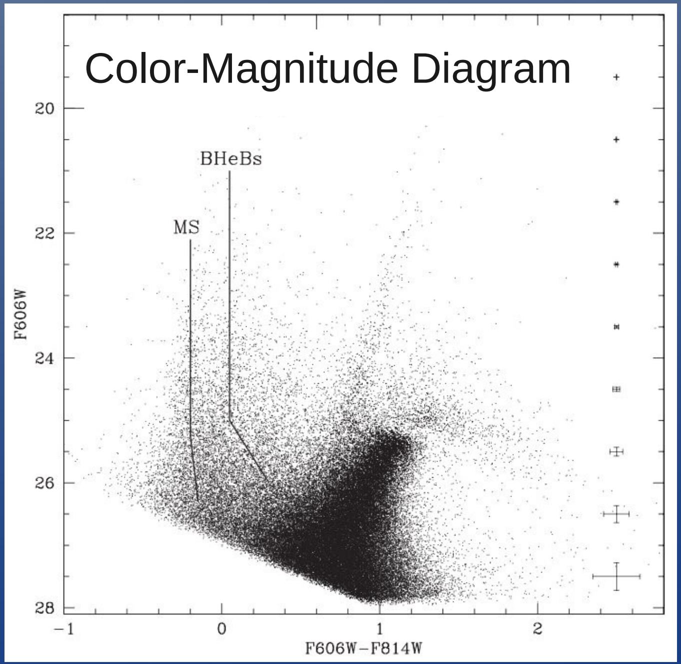
  clues to the nature of dark matter

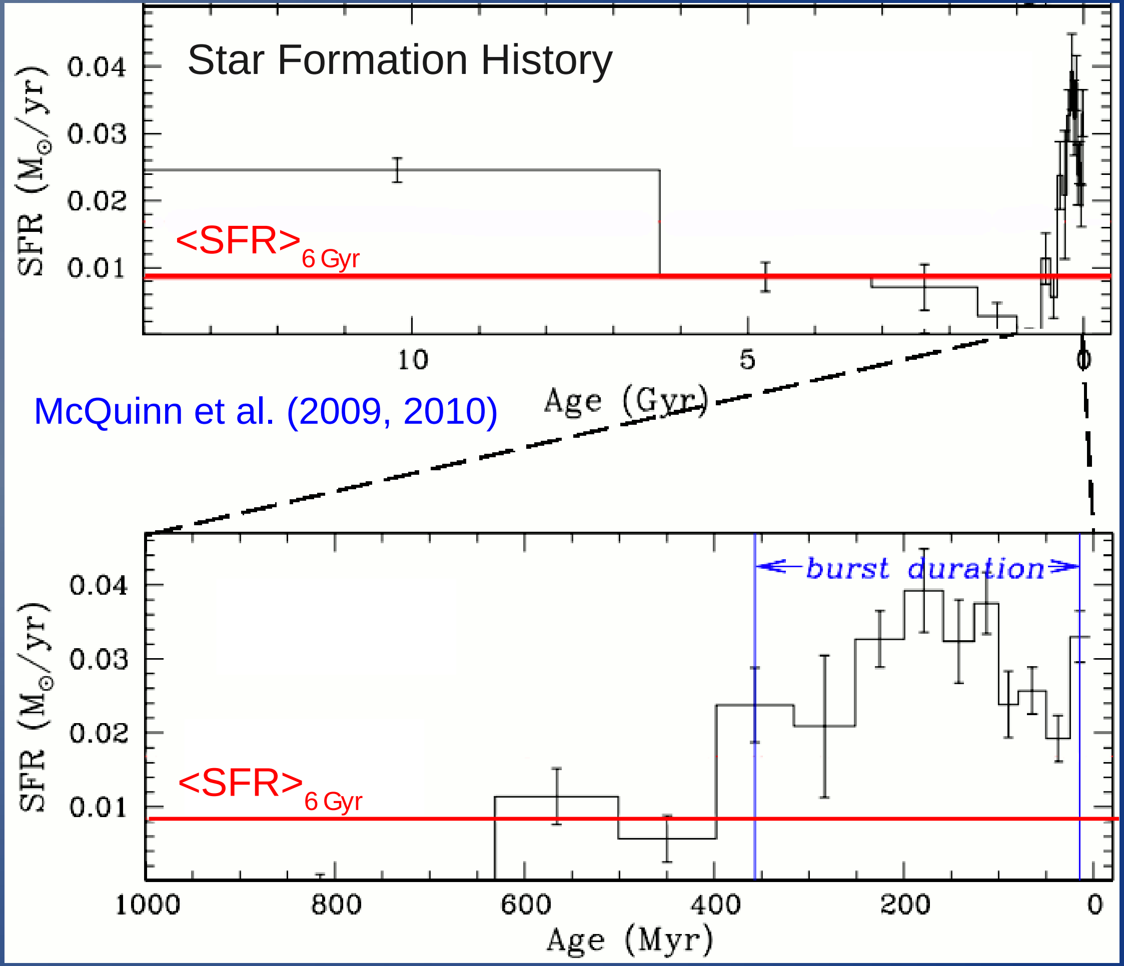
Overview on BCDs:

- Stellar populations
- Optical structure
- HI properties

Stellar populations of BCDs



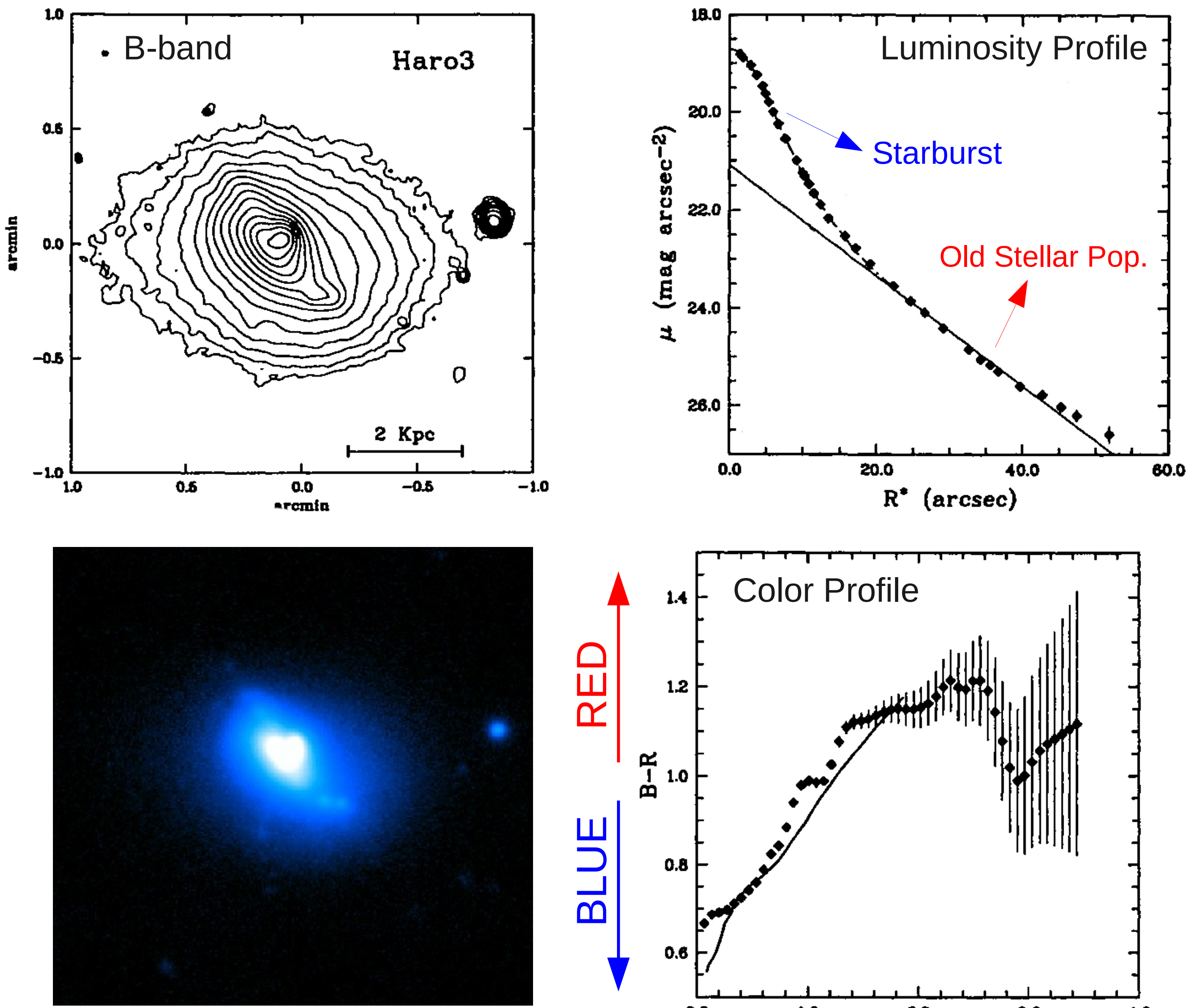




The SFH provides:

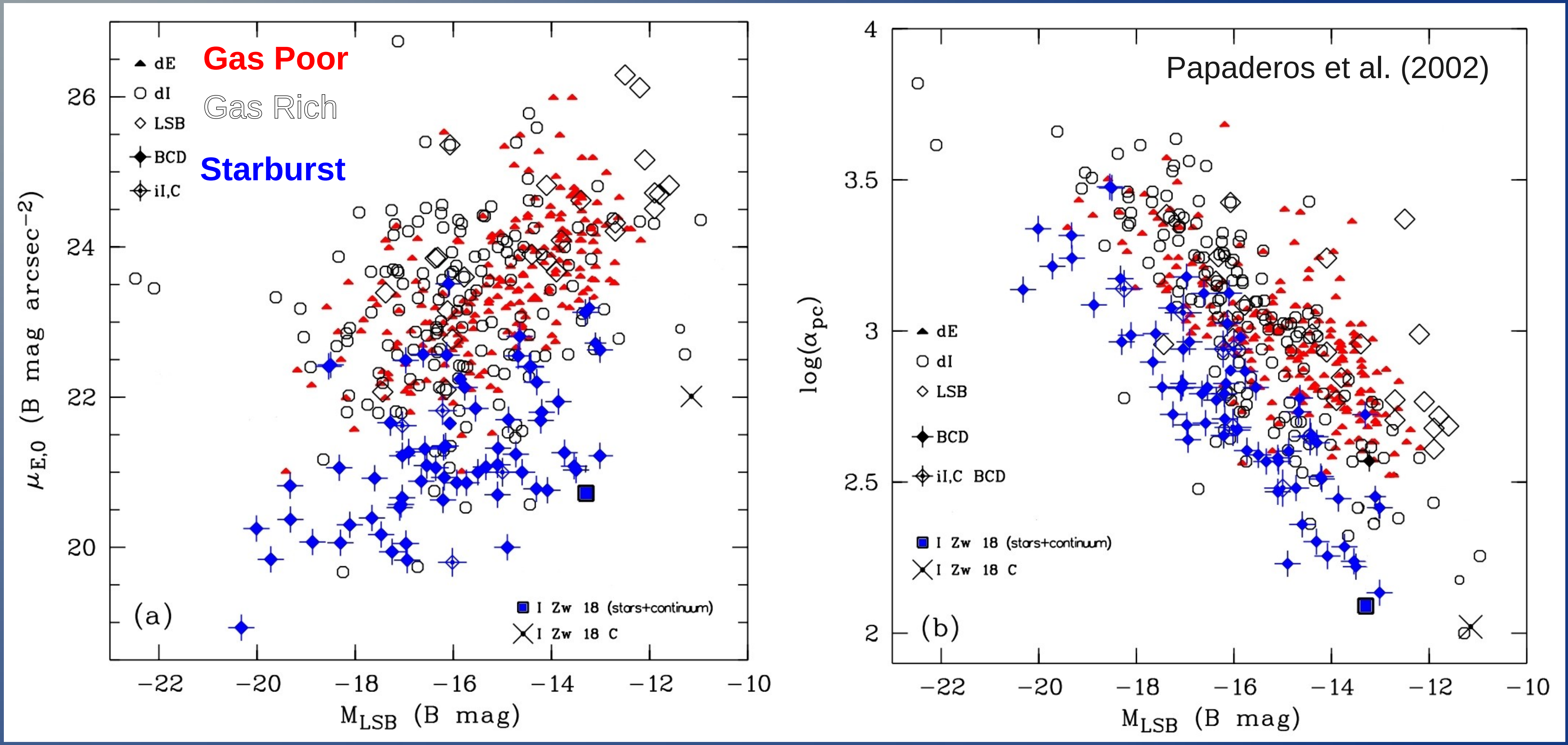
- starburst timescales (~ few 100 Myr)
- energies from SN
- mass in young & old stars

Optical Structure of BCDs



Papaderos et al. (1996)

Optical Structure of BCDs



Old component of BCDs: μ_0 ~ 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.

HI properties of BCDs

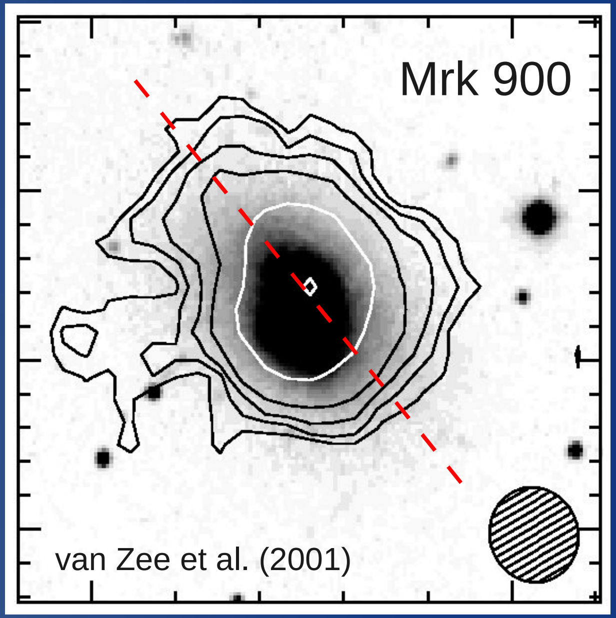
- Strong HI concentration

  Taylor et al. 1994; van Zee et al. 1998, 2001; Simpson & Gottesman 2000.

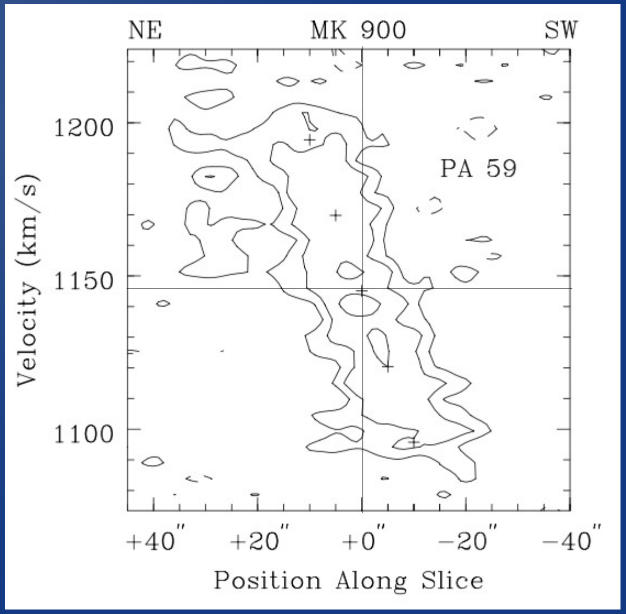
- Steep Velocity Gradients

  Meurer et al. 1996, 1998; van Zee et al. 2001.

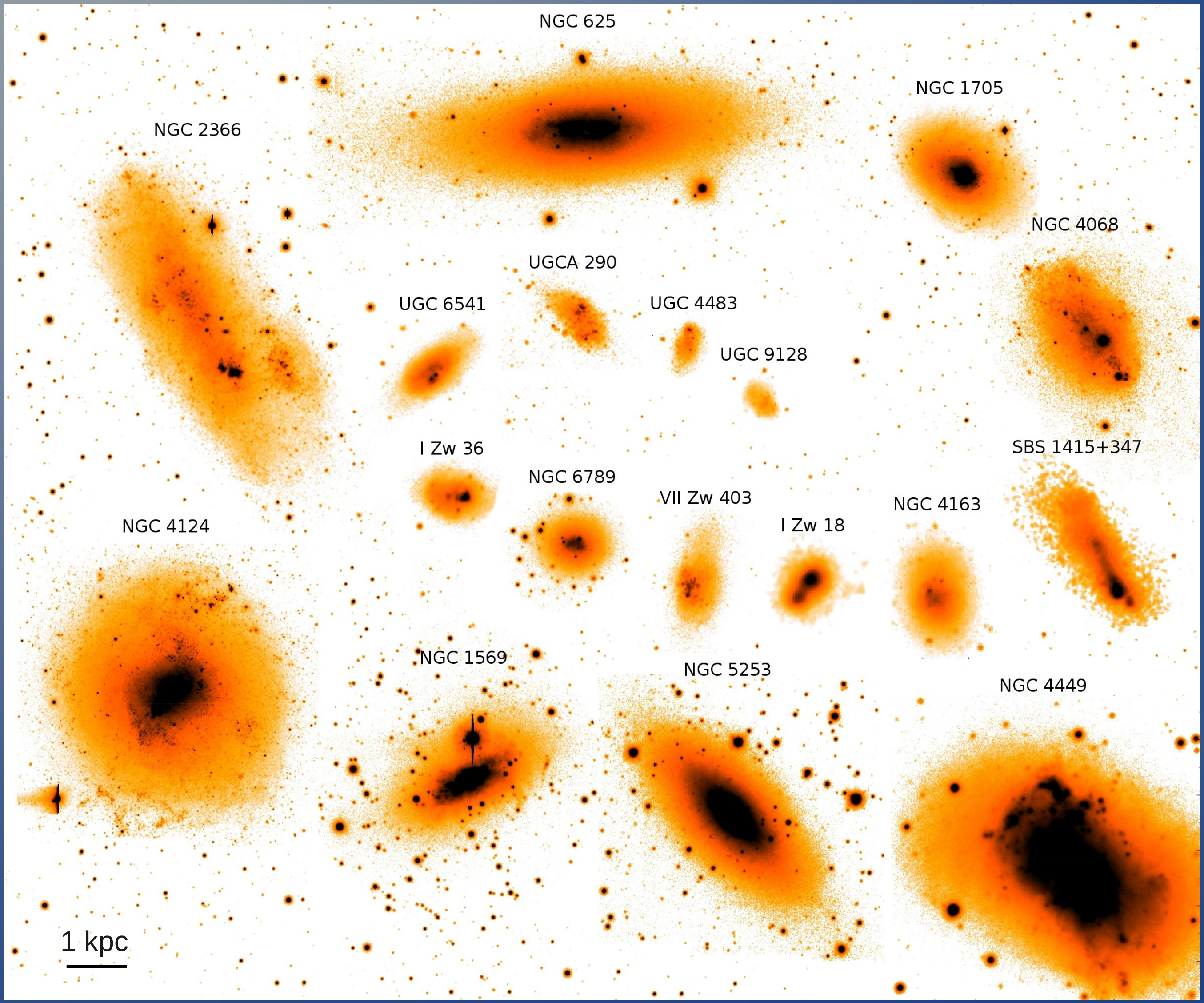
Optical + HI map



Postion-Velocity diagram



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



HST studies:

- Galaxy Distance
- Distribution stellar pop.
- Star Formation History
- Mass young & old stars

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

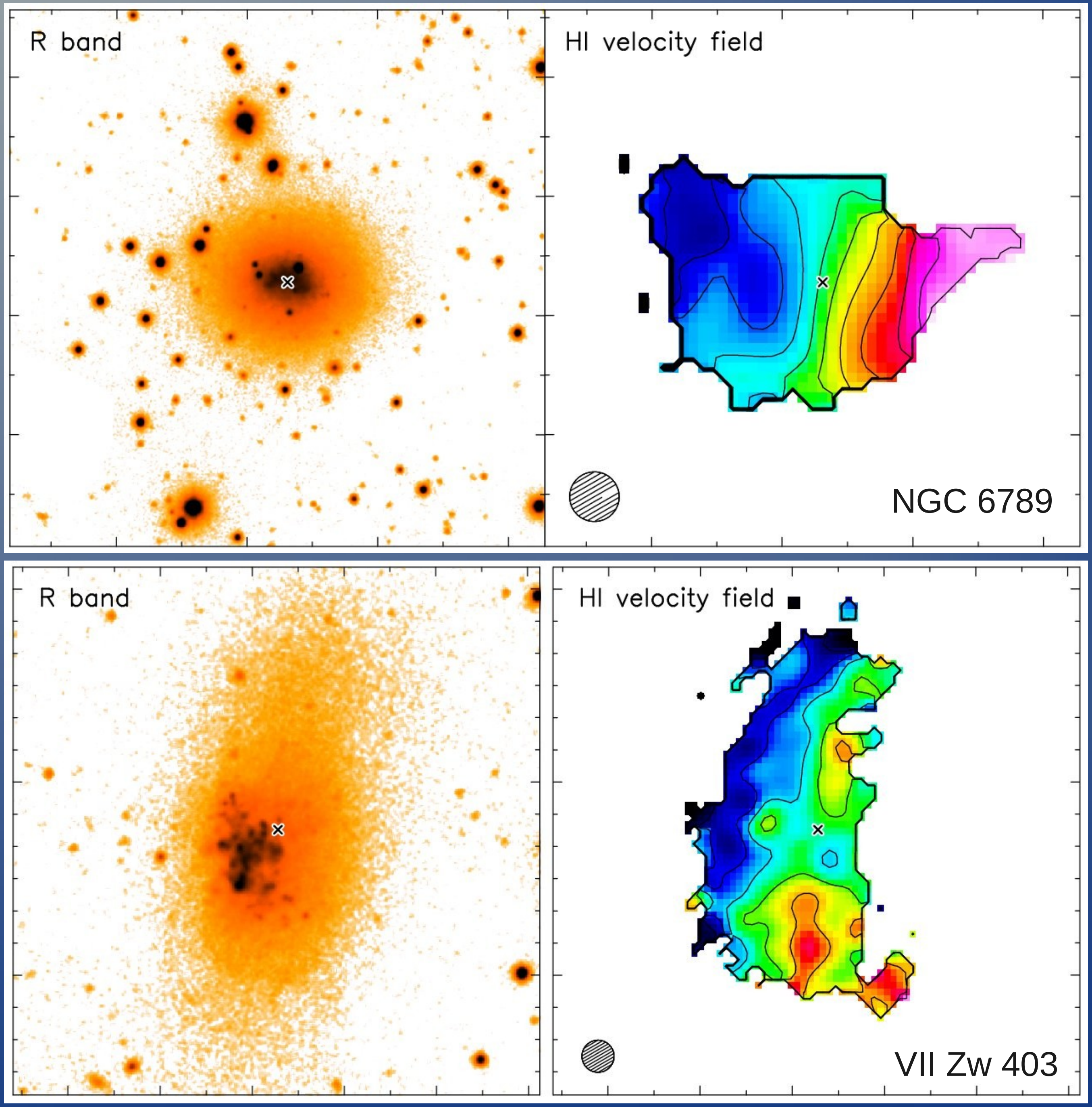
- HI distribution
- HI kinematics

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

Internal Dynamics:

clues to dwarf galaxy evolution

Gas kinematics of BCDs



Rotating HI disk:

9 galaxies (50%).

Rotation curve!

→ Mass distribution (dark & luminous)

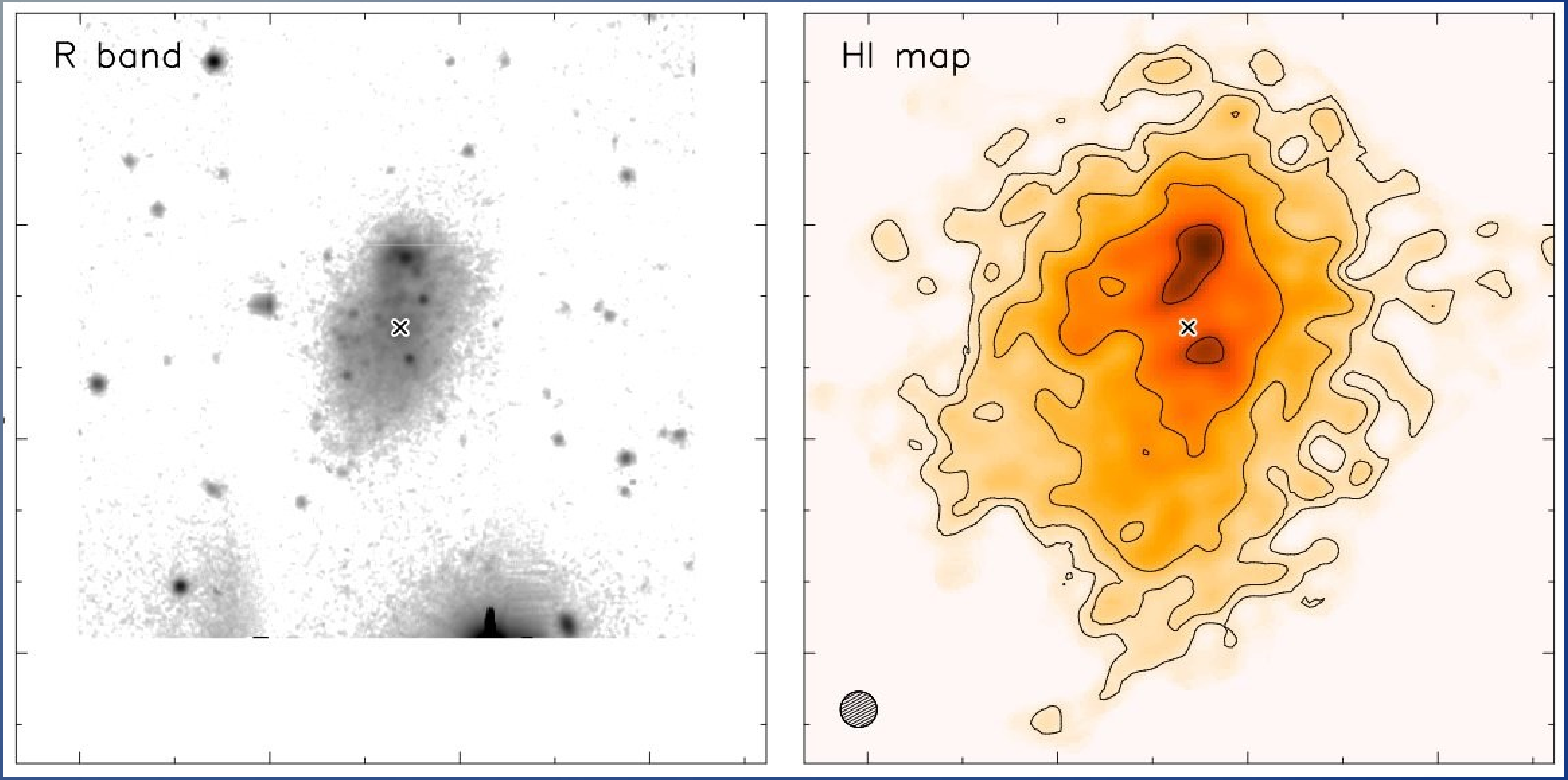
Complex / disturbed HI kinematics:

9 galaxies (50%).

No rotation curve.

Example: UGC 4483

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



$M_* \sim 10^7 \, M_\odot$

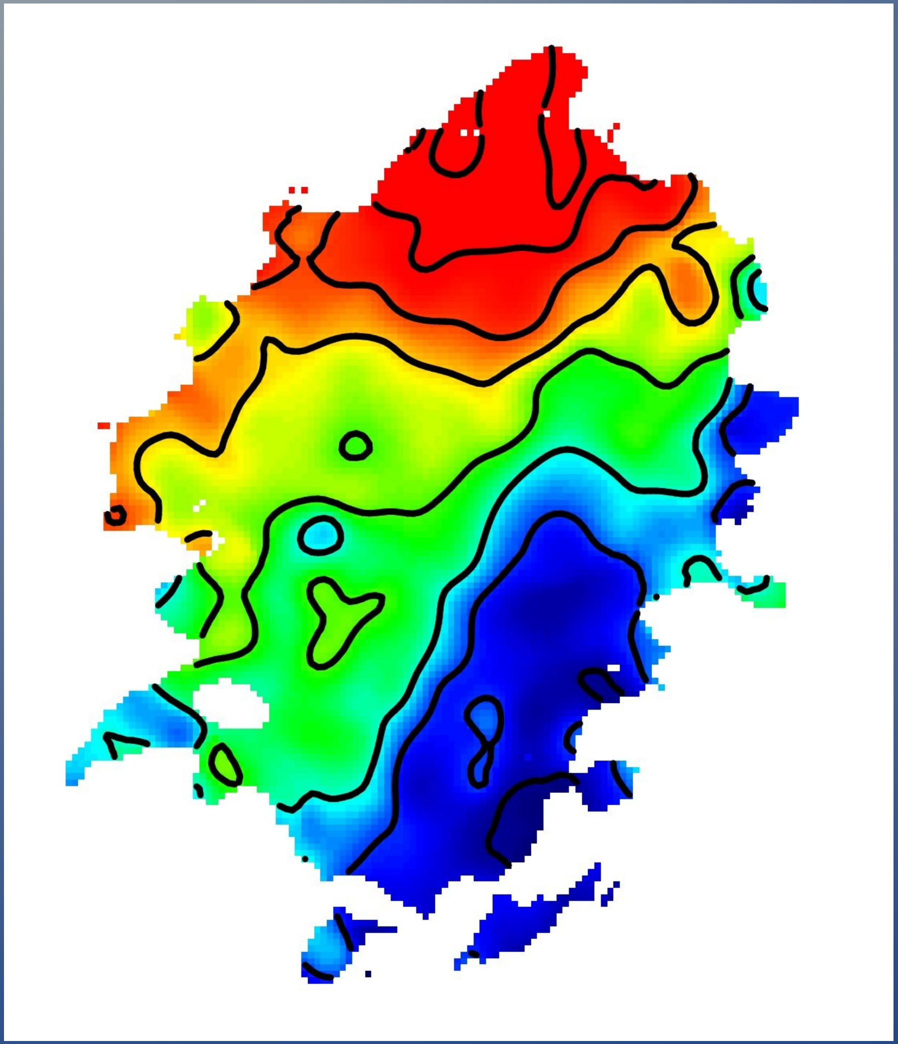
$R_d \sim 200$ pc

$M_{gas} \sim 3.3 \times 10^7 \, M_\odot$

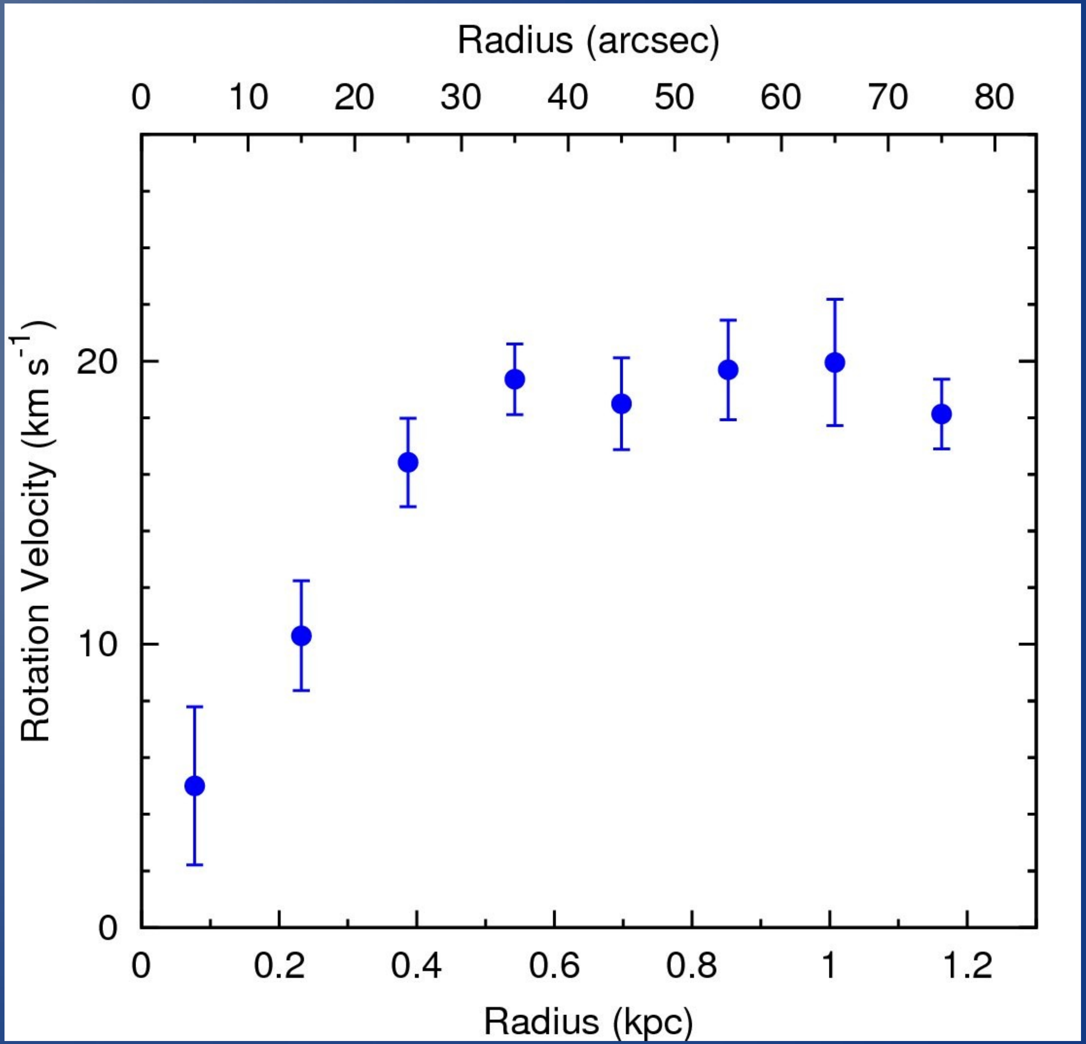
$V_{rot} \sim 20$ km/s

Kinematics of UGC 4483

Velocity Field

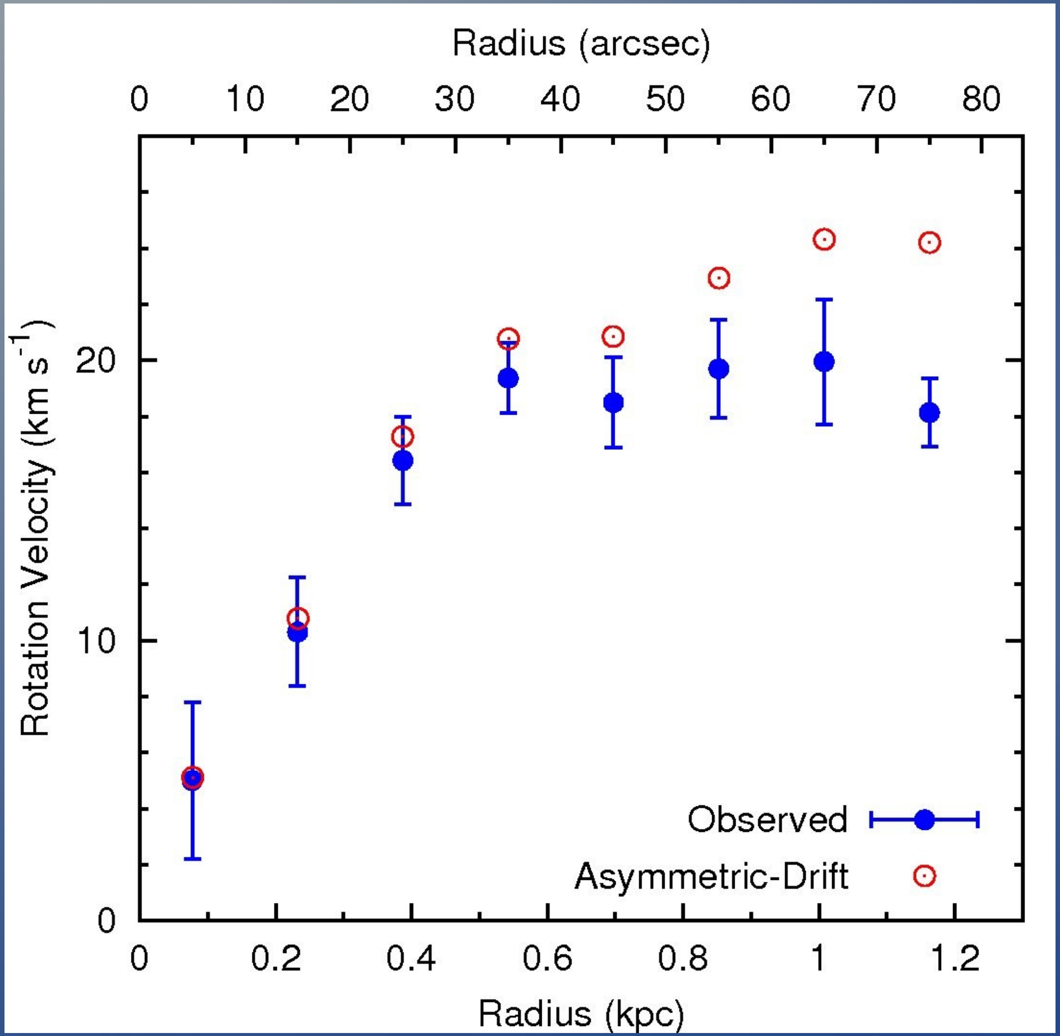


Rotation Curve



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

Asymmetric-Drift Correction



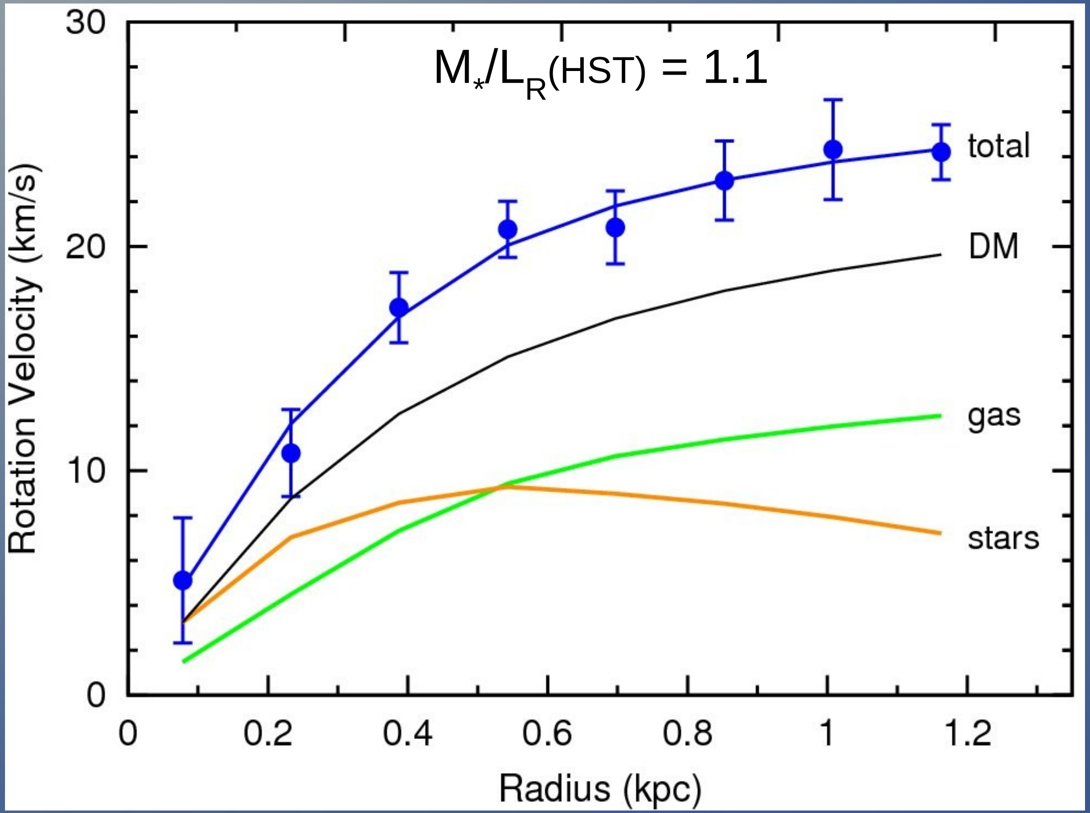
Assumptions:

- σ_{HI} is isotropic
- σ_{HI} = 8 km/s (constant with R)
- $\Sigma_{HI}(R) = \Sigma_0 \exp(-R^2/2s^2)$

$$V^2_{asym} = V^2_{rot} + \sigma_{HI}^2 (R^2/s^2)$$

Mass Model of UGC 4483

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



UGC 4483 mass budget:

M_{dyn} = (15 ± 3) x 10^7 $M_\odot$

M_*(HST) = (1.0 ± 0.3) x 10^7 $M_\odot$

assuming Salpeter IMF

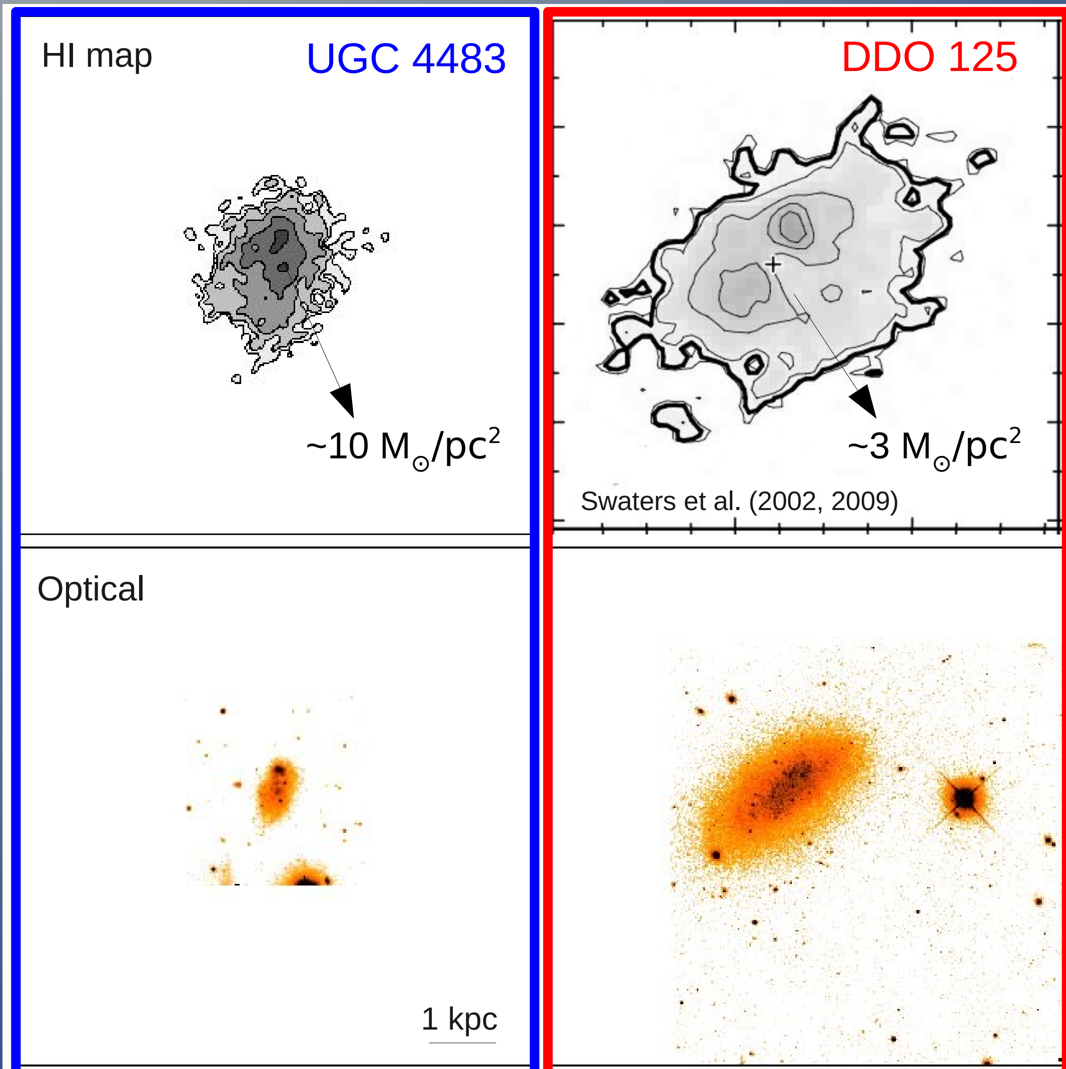
M_{gas} = (3.3 ± 0.4) x 10^7 $M_\odot$

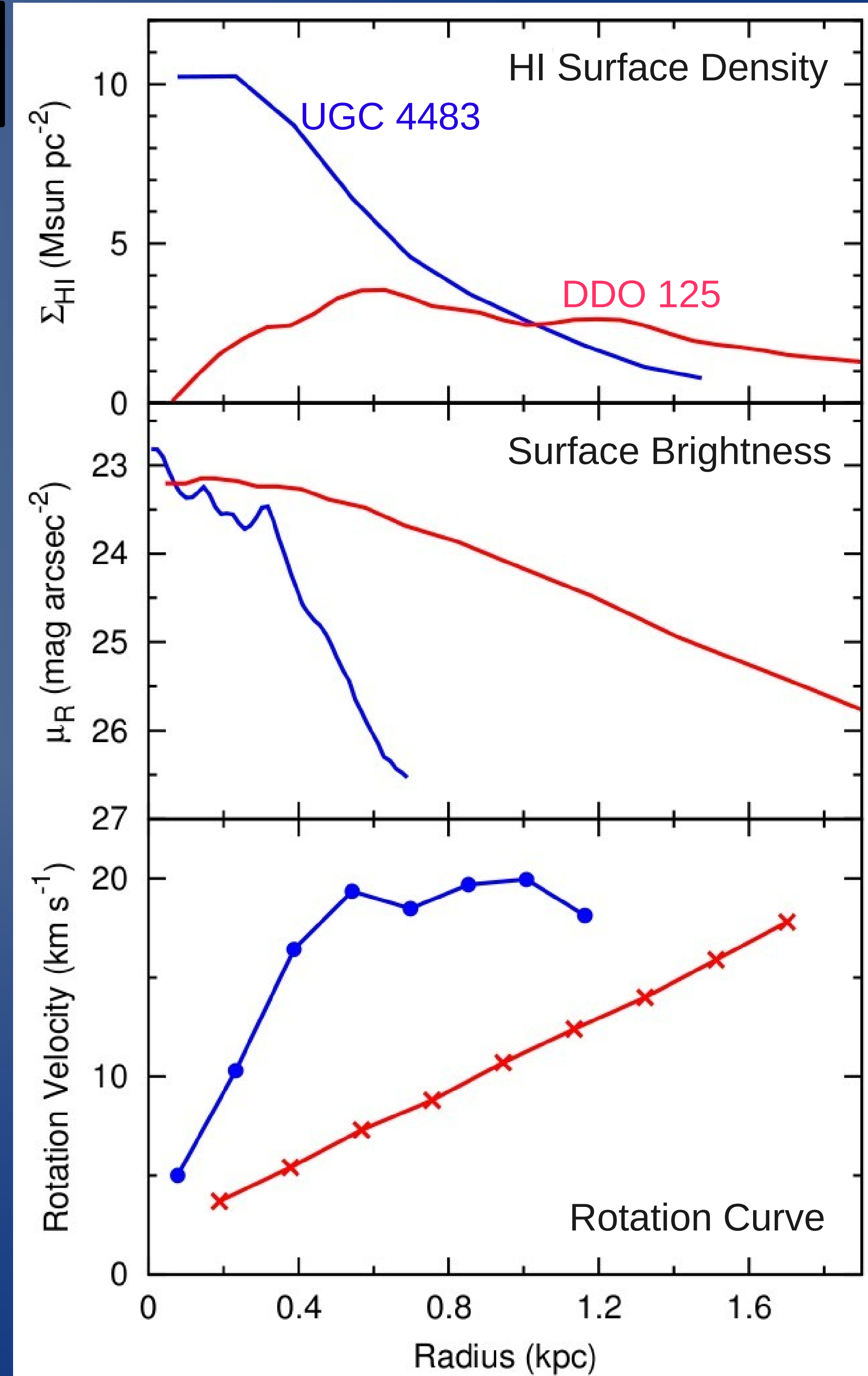
M_*(young) ~ 0.2 x 10^7 $M_\odot$

M(molecules) ~ 10^7 $M_\odot$? X_{CO} ~20 X_{CO}(MW)?

~30% of the total mass is baryonic (gas + *old* stars)

Starburst vs Irregular



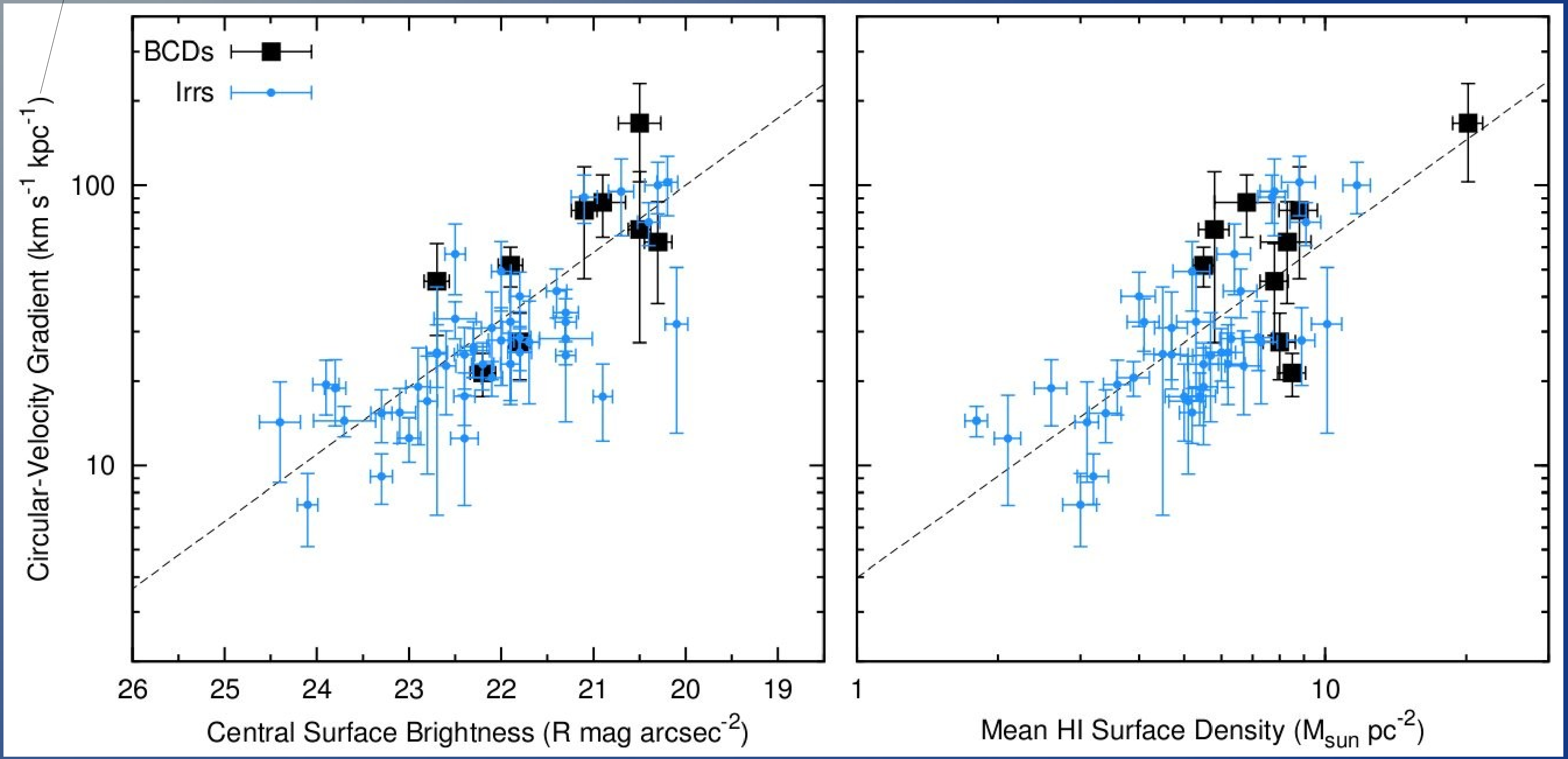


$M_{dyn} \sim 1\text{-}2 \times 10^{8}\ M_{\odot}$

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

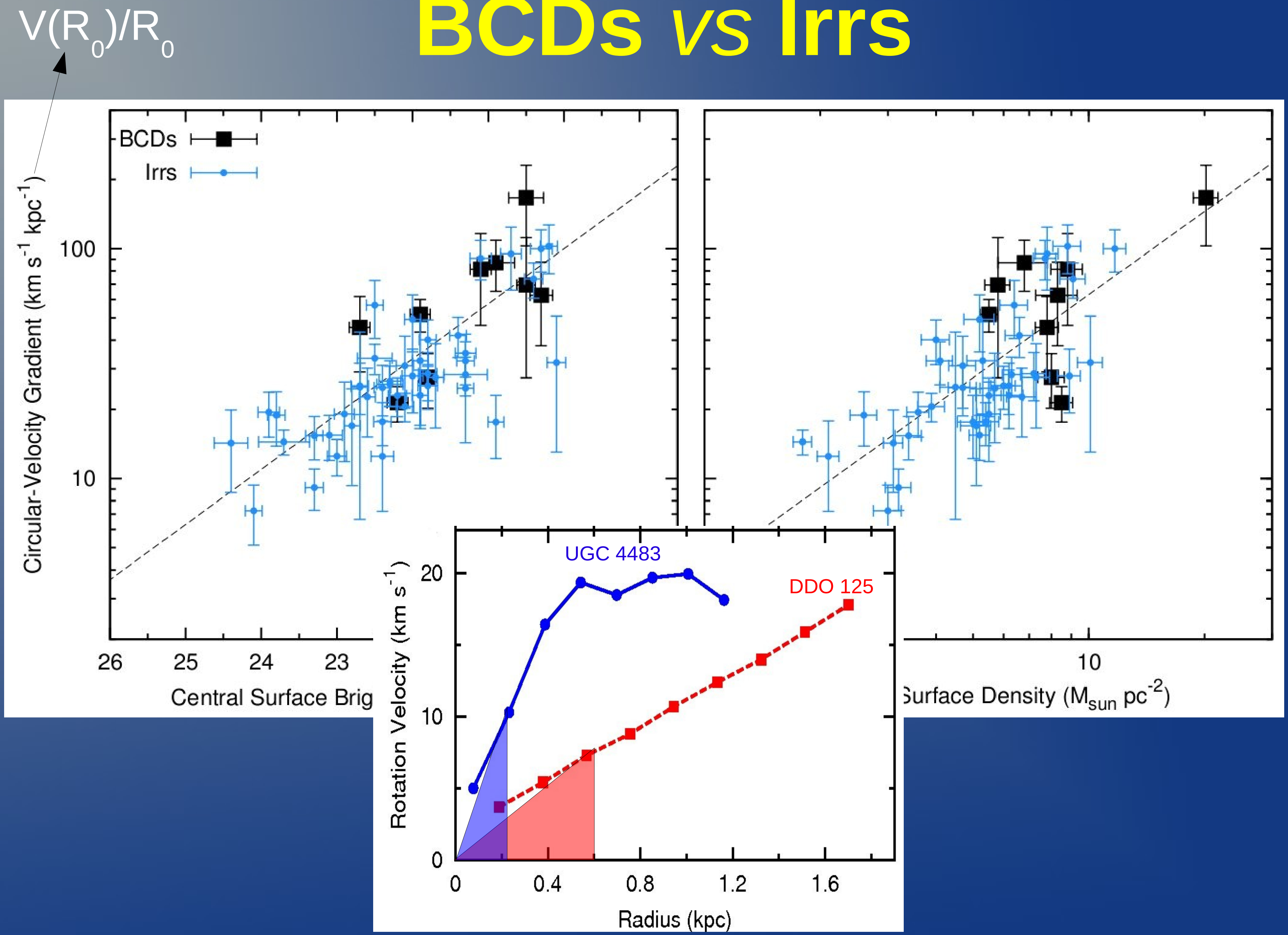
BCDs *vs* Irrs

$V(R_0)/R_0$



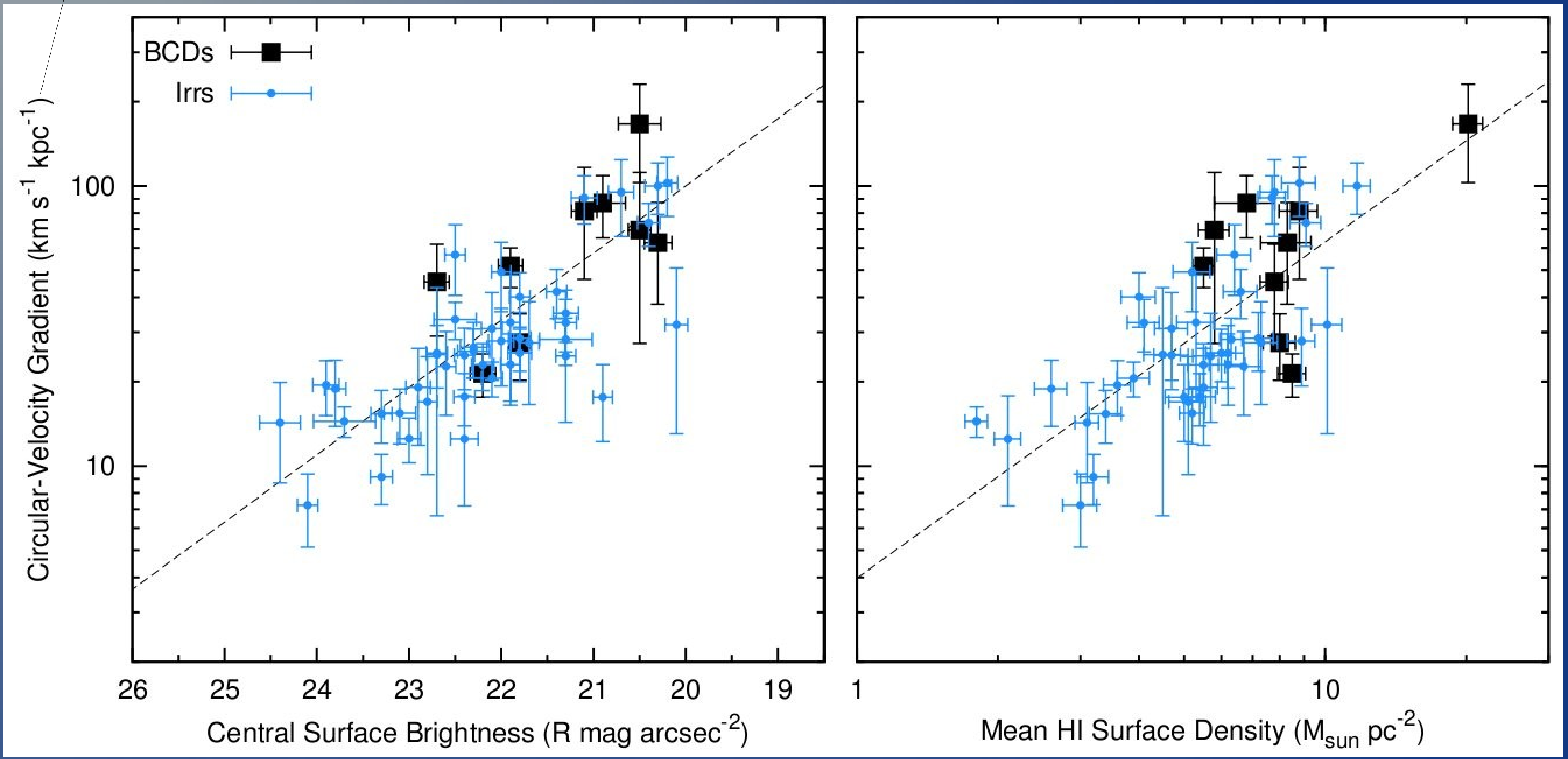
Irrs from Swaters et al. (2009)

BCDs *vs* Irrs


V(R0)/R0
BCDs
Irrs
Circular-Velocity Gradient (km s-1 kpc-1)
100
10
26
25
24
23
Central Surface Brig
10
Surface Density (Msun pc-2)
UGC 4483
DDO 125
Rotation Velocity (km s-1)
20
10
0
0
0.4
0.8
1.2
1.6
Radius (kpc)

V(R_0)/R_0

BCDs *vs* Irrs

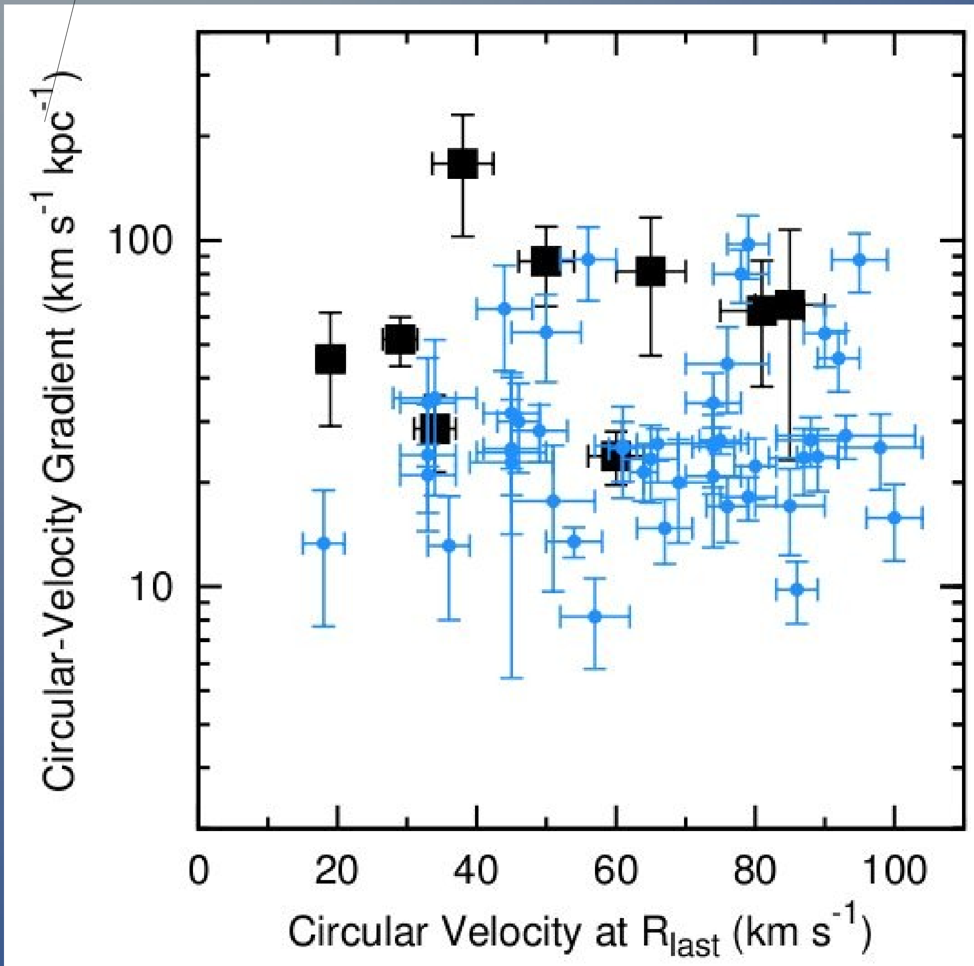


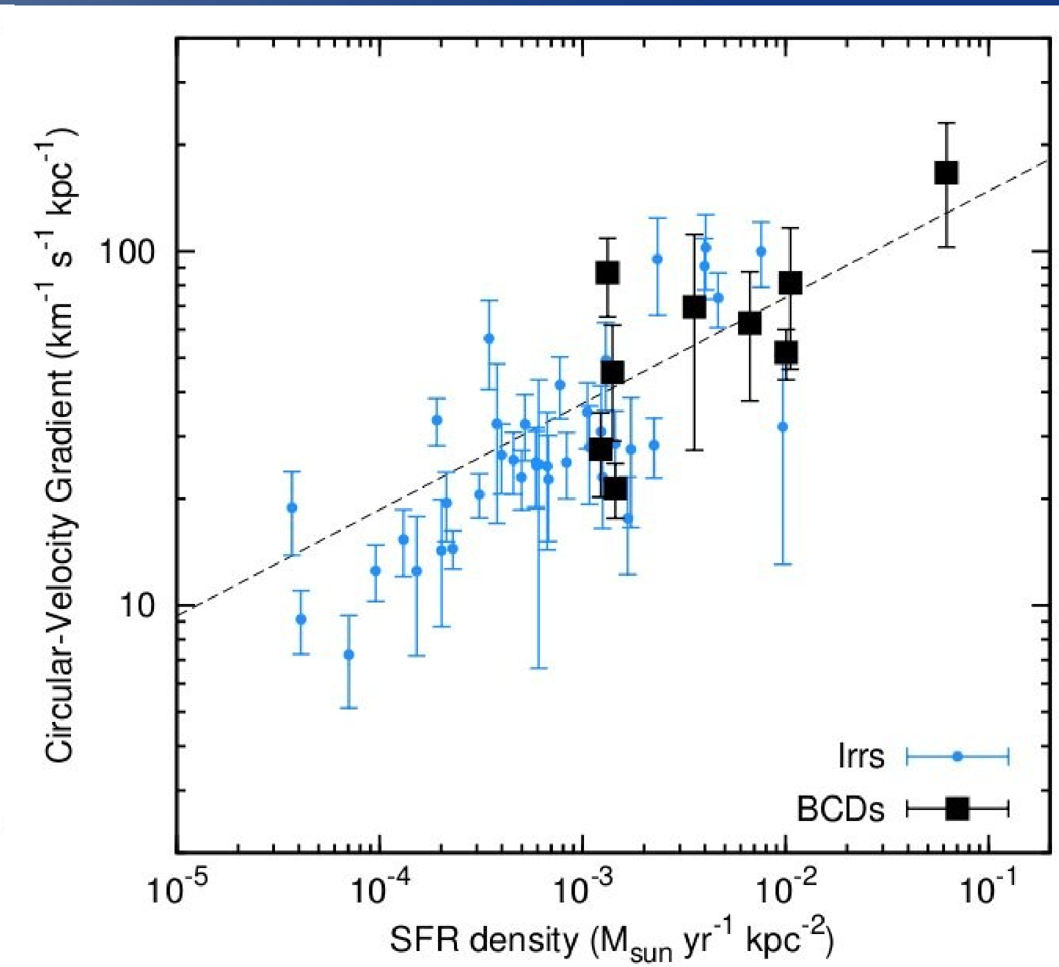
Starburst ⟺ Gravitational Potential + HI concentration

Irrs from Swaters et al. (2009)

V(R_0)/R_0

BCDs *vs* Irrs

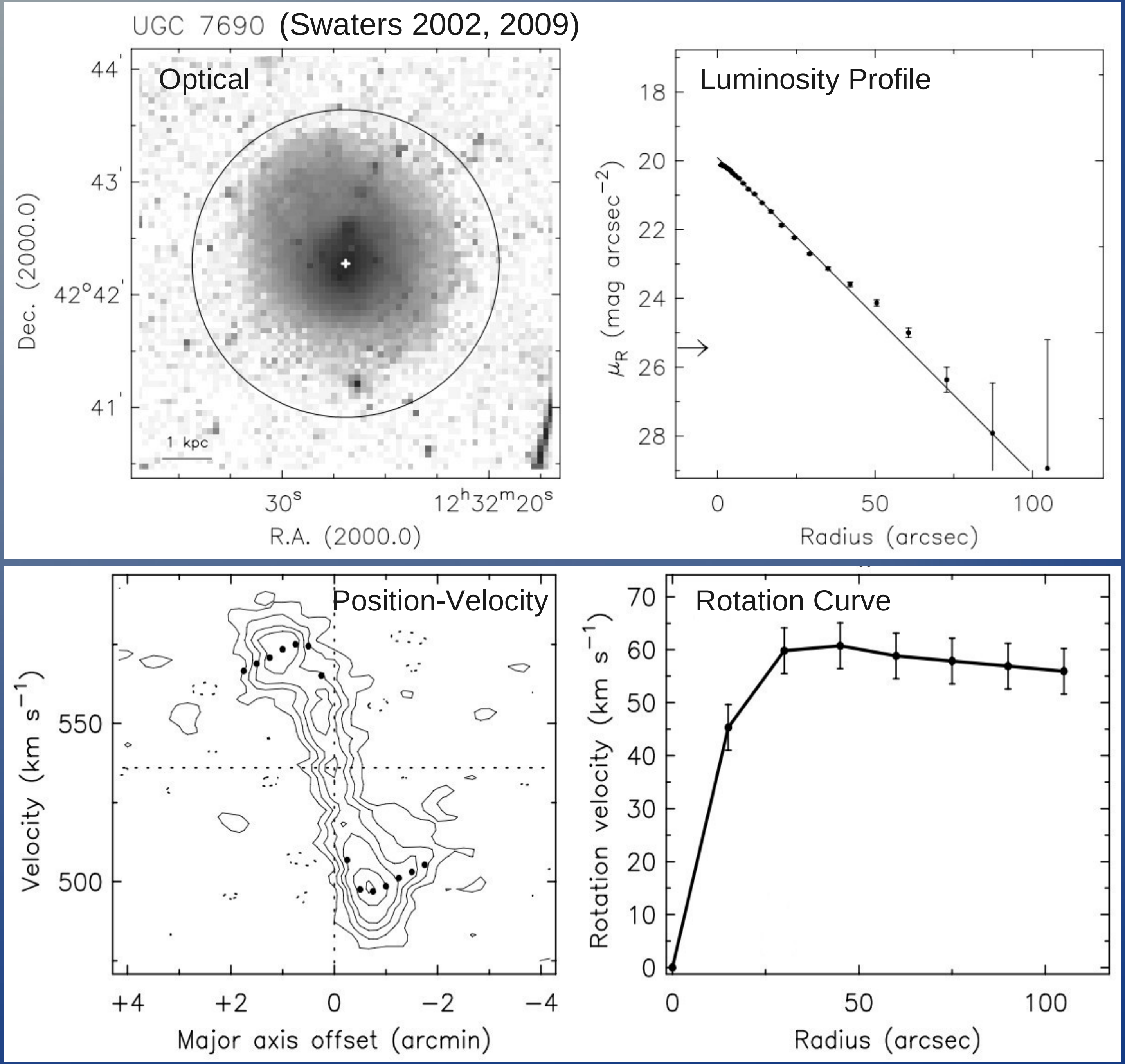




Starburst ⟺ Gravitational Potential + HI concentration

Hα fluxes from James et al. (2004) and Kennicutt et al. (2008)

Progenitors/Descendants of BCDs?



HSB Irrs

Photometry:

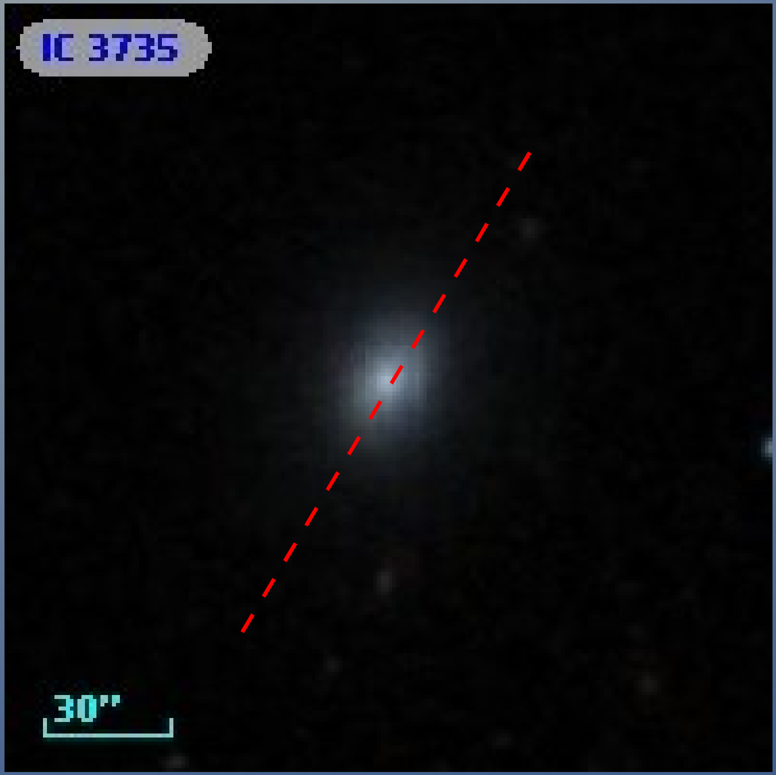
μ_0 ~ 20 mag arcsec^{-2}

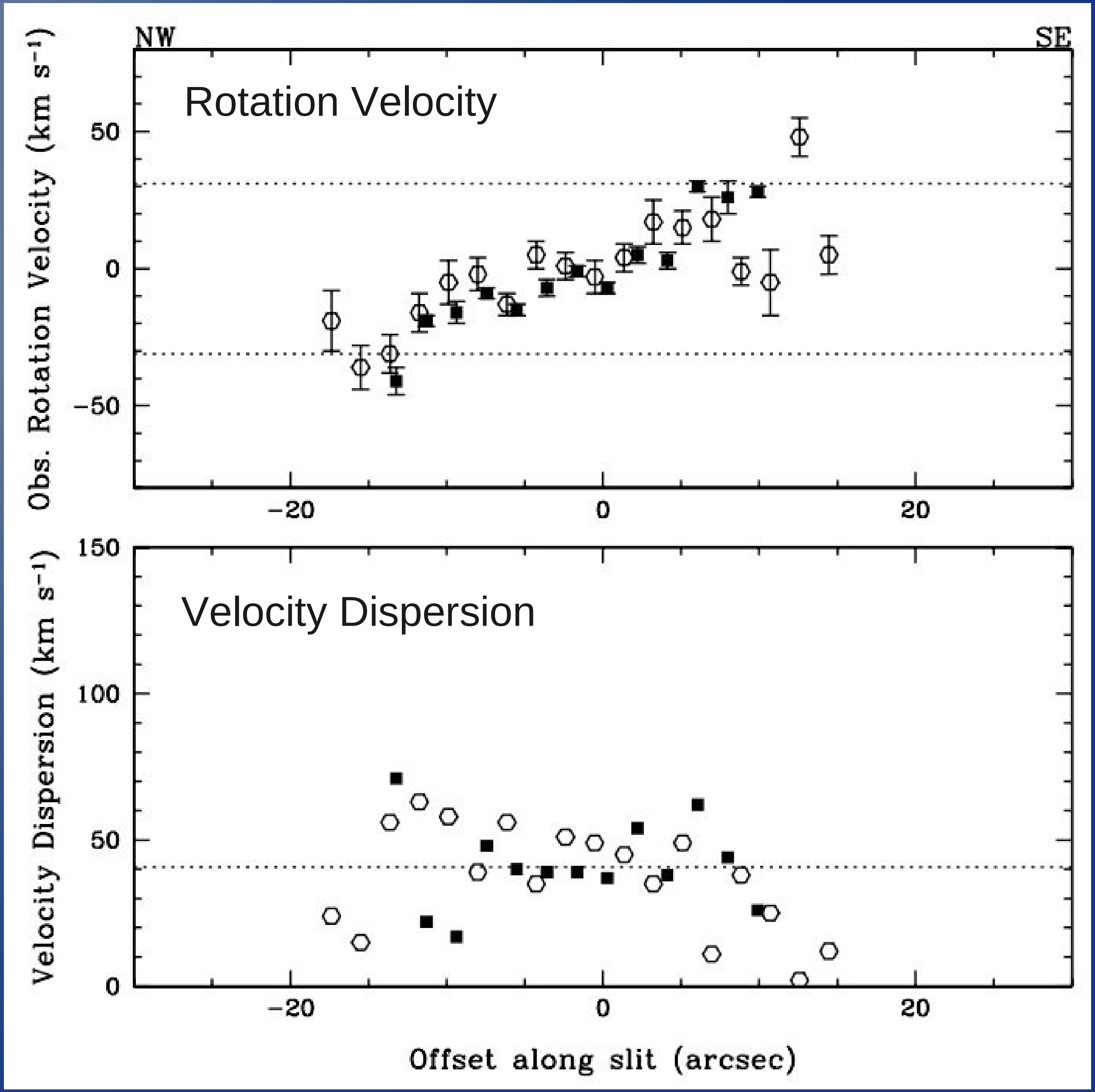
R_0 ~ 450 pc

HI kinematics:

Steeply-rising rotation curve!

Rotating Sphs in Virgo

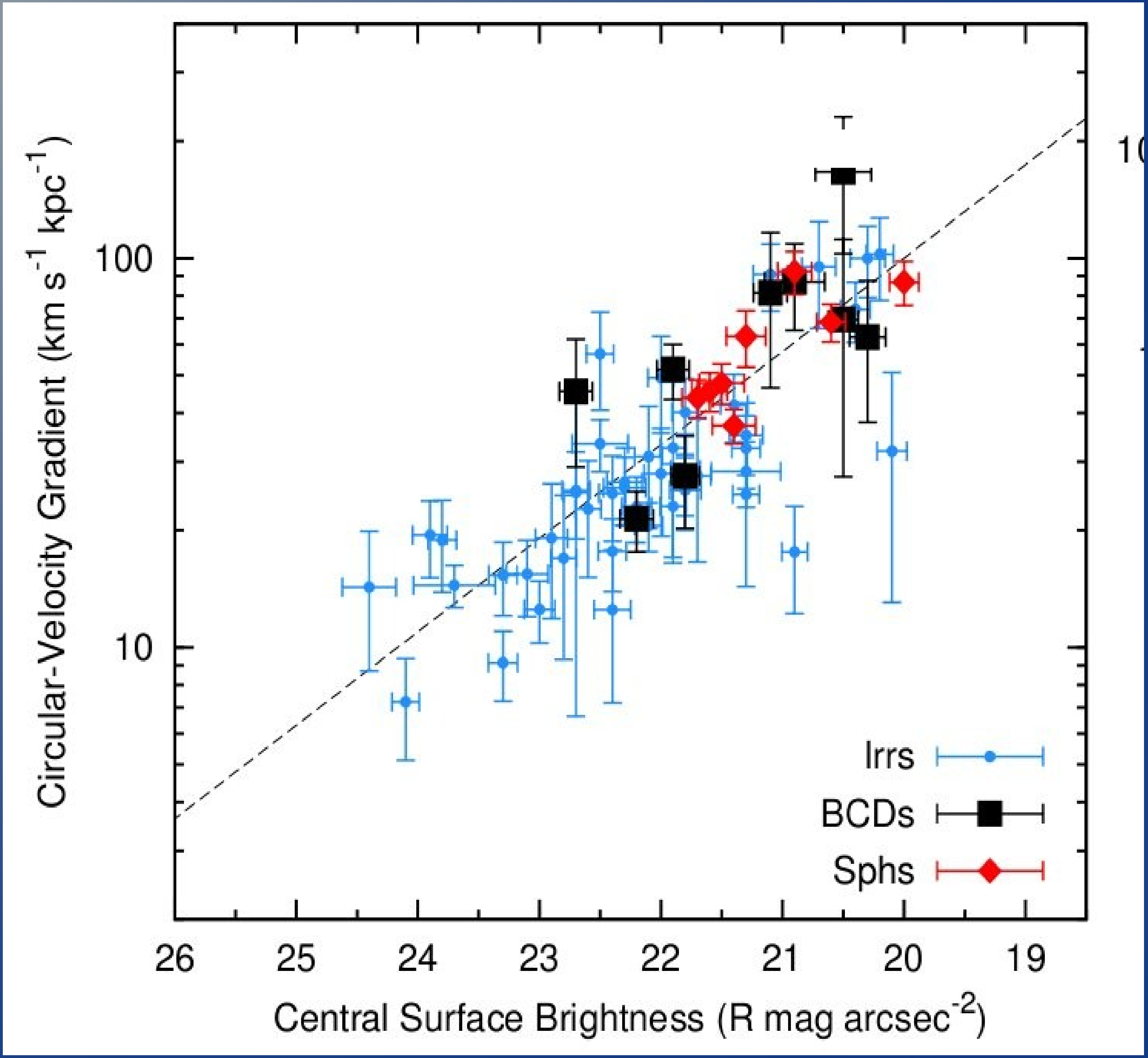




Van Zee et al. (2004)

Toloba et al. (2011)

Rotating Sphs in Virgo



BCDs are different from Irrs:

steeply-rising rotation curves

strong concentration of mass (old stars & dark matter)

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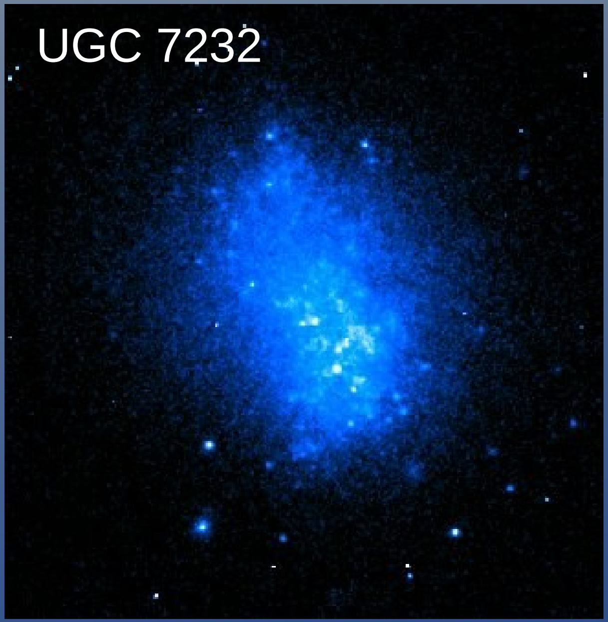
steeply-rising rotation curves

→ strong concentration of mass (old stars & dark matter)

Irr



mass redistribution

BCD

...but there are also HSB Irrs & rotating Sphs.

New Dynamical Quantity:

Circular-Velocity Gradient (V_0/R_0) correlates with

- Central surface brightness
- Average HI surface density
- SFR surface density

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Circular-Velocity Gradient (V_0/R_0) correlates with

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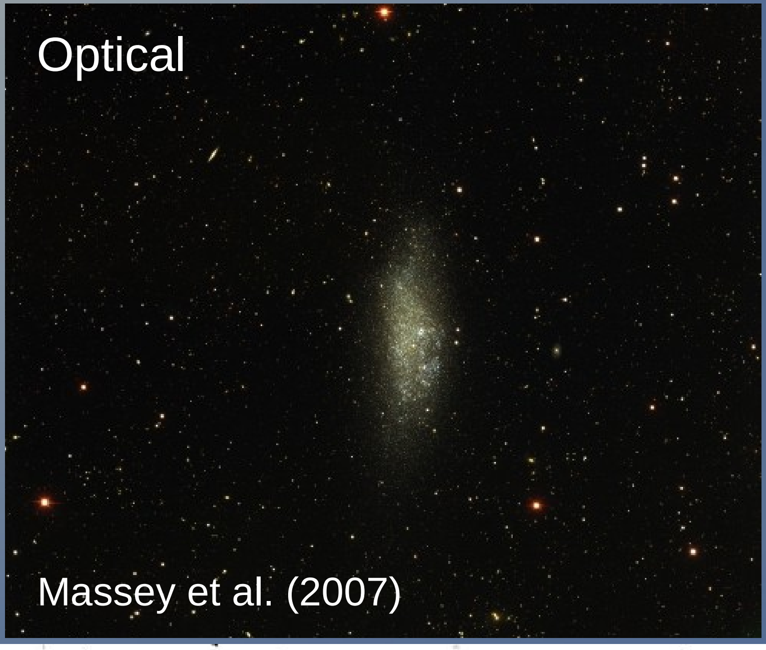
BCDs are in the upper part of these distributions:

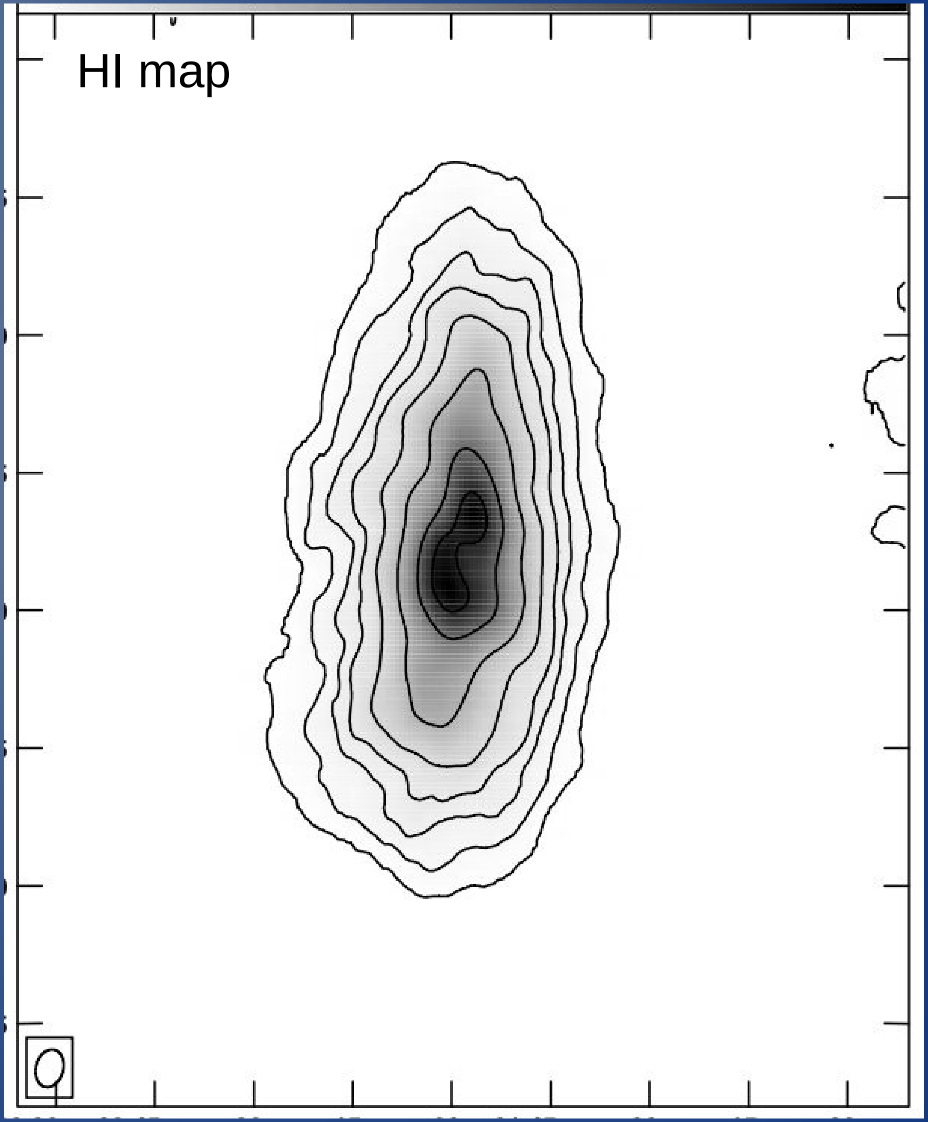
Starburst ⟺ Gravitational Potential + HI concentration

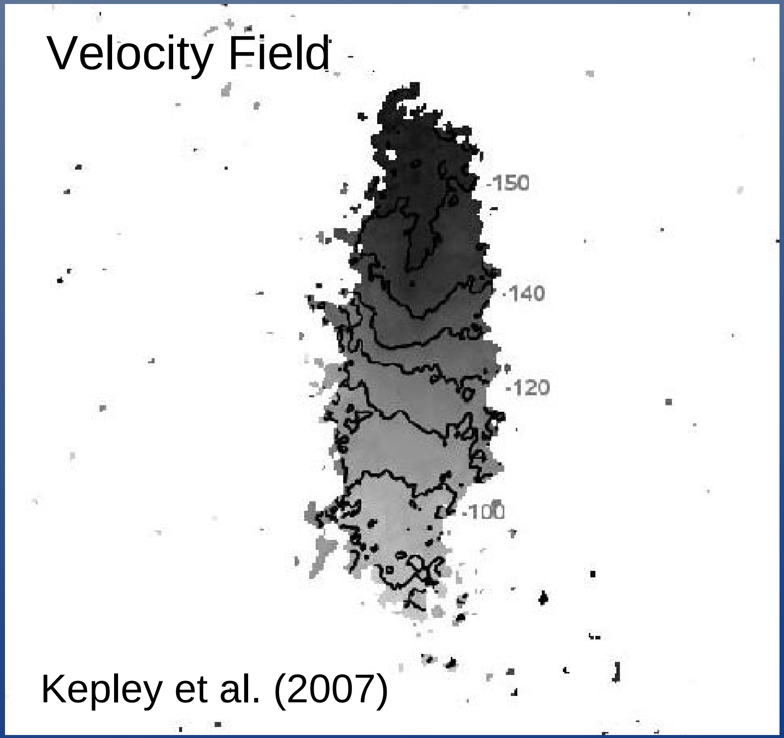
Large-scale HI Emission:

clue to the starburst trigger

Typical Irregular: WLM



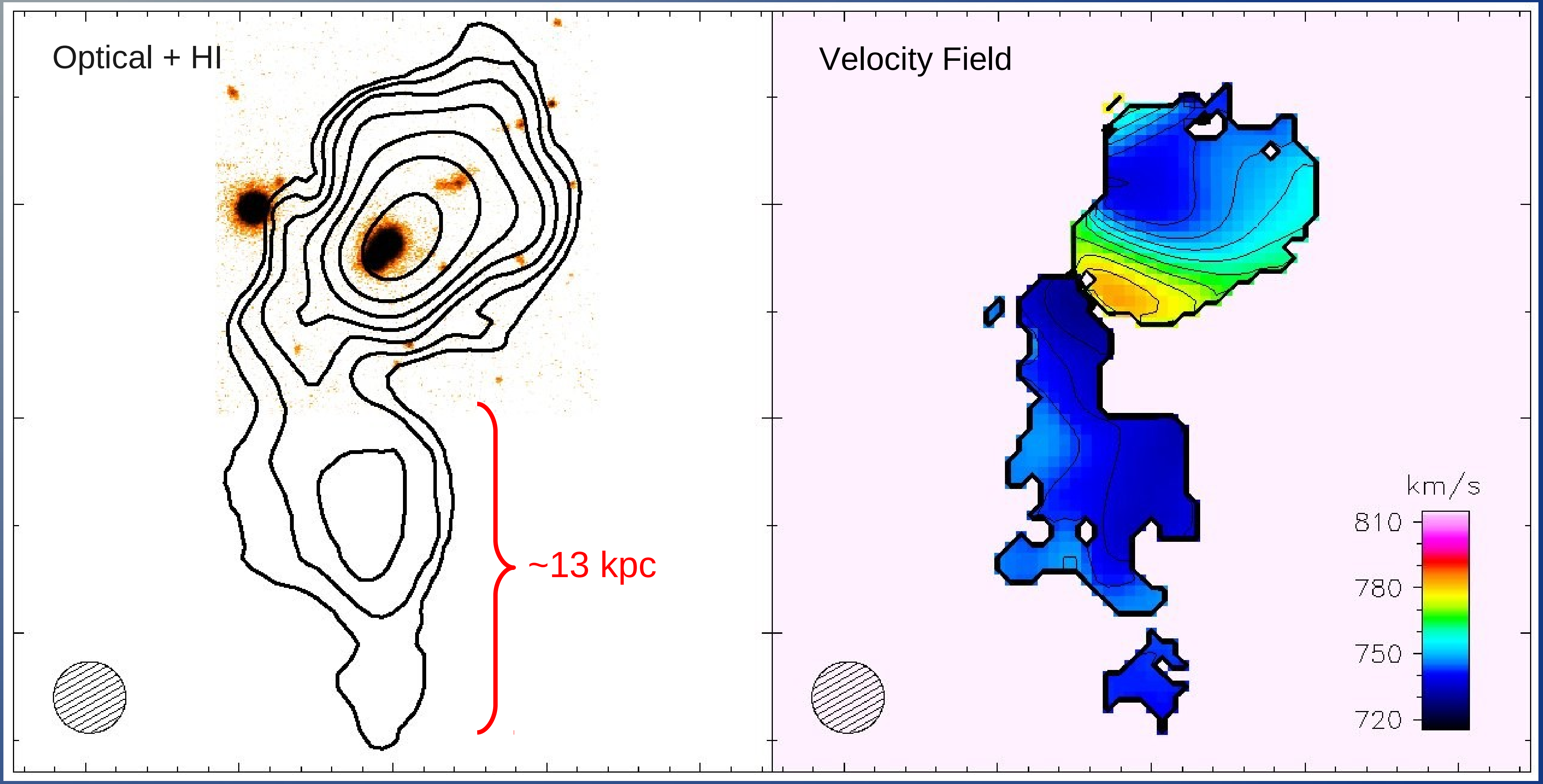




$M_* = 2 \times 10^7\ M_\odot$ (Lee et al. 2006)

$M_{HI} = 6 \times 10^7\ M_\odot$ (Kepley et al. 2007)

I Zw 18



$M_{*(max)} = 0.9 \times 10^8\ M_\odot$

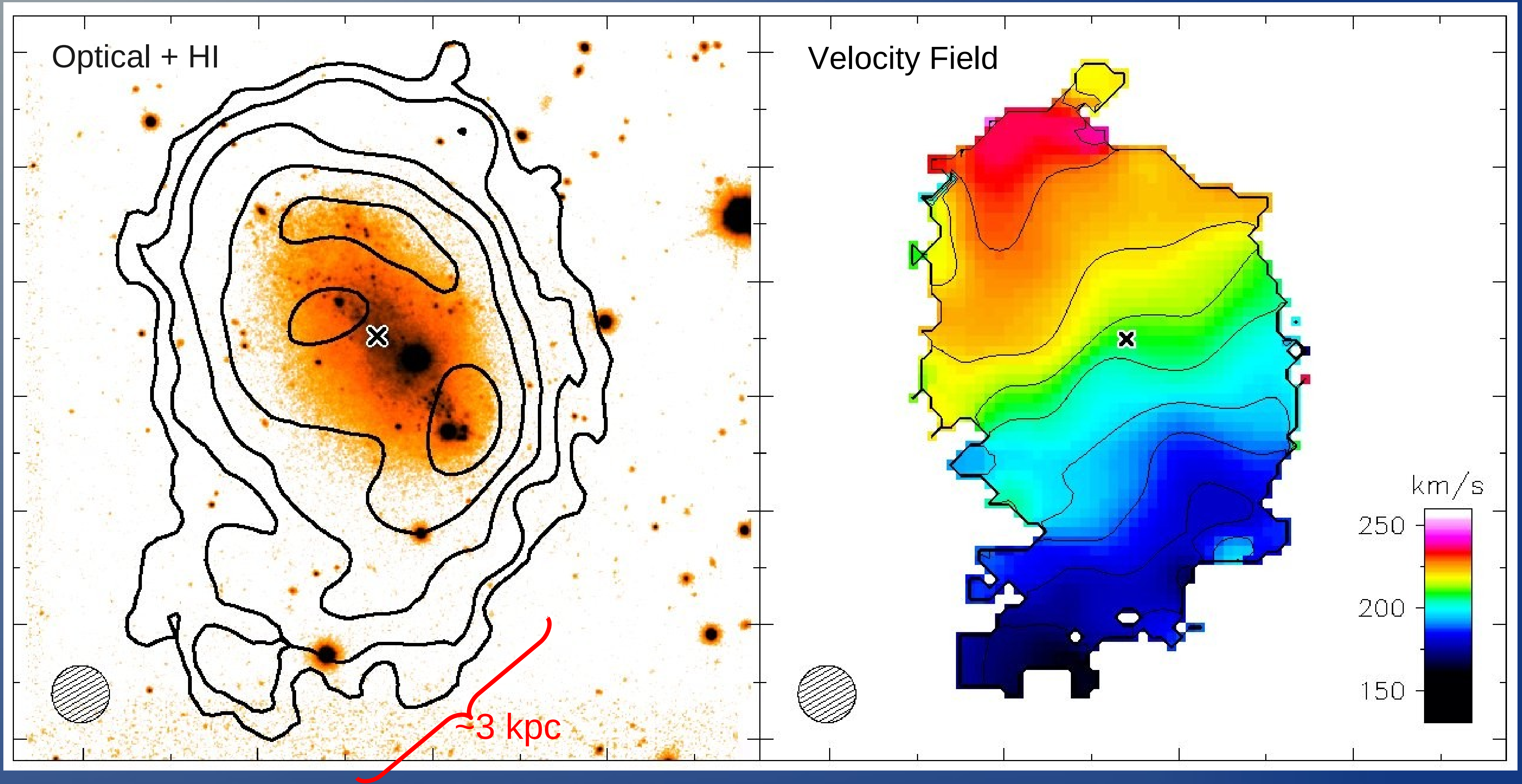
$\Sigma_{SFR} = 0.16\ M_\odot/yr/\,kpc^2$

$M_{HI} = 2 \times 10^8\ M_\odot$

Lelli et al. (2012), A&A, 537

NGC 4068

Data from WHISP



$M_* = 7 \times 10^7\ M_\odot$

$M_{HI} = 2 \times 10^7\ M_\odot$

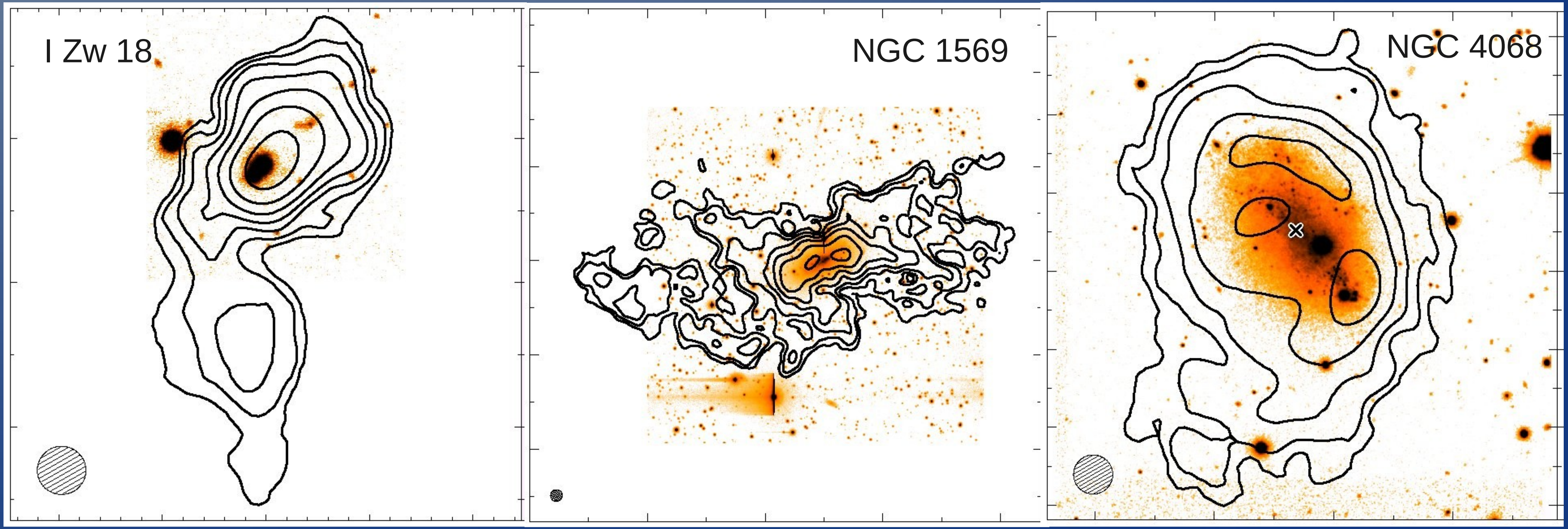
$\Sigma_{SFR} = 0.002\ M_\odot/yr/\ kpc^2$

Lelli et al. (in preparation)

Distrubed outer HI morphologies:

- Irrs (Swaters et al. 2002, 73 objects) ~35% of the cases
- BCDs (our sample, 18 objects) ~90% of the cases

Interactions/mergers? Cold gas accretion?



Observational evidence on BCDs:

- Central concentration of mass (gas, stars, & DM)
- Disturbed outer HI morphogies
- Similar environment of Irrs

→ mergers between gas-rich Irrs ?

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Future Prospects:

Very-deep photometry (~29-30 B mag asec^{-2})

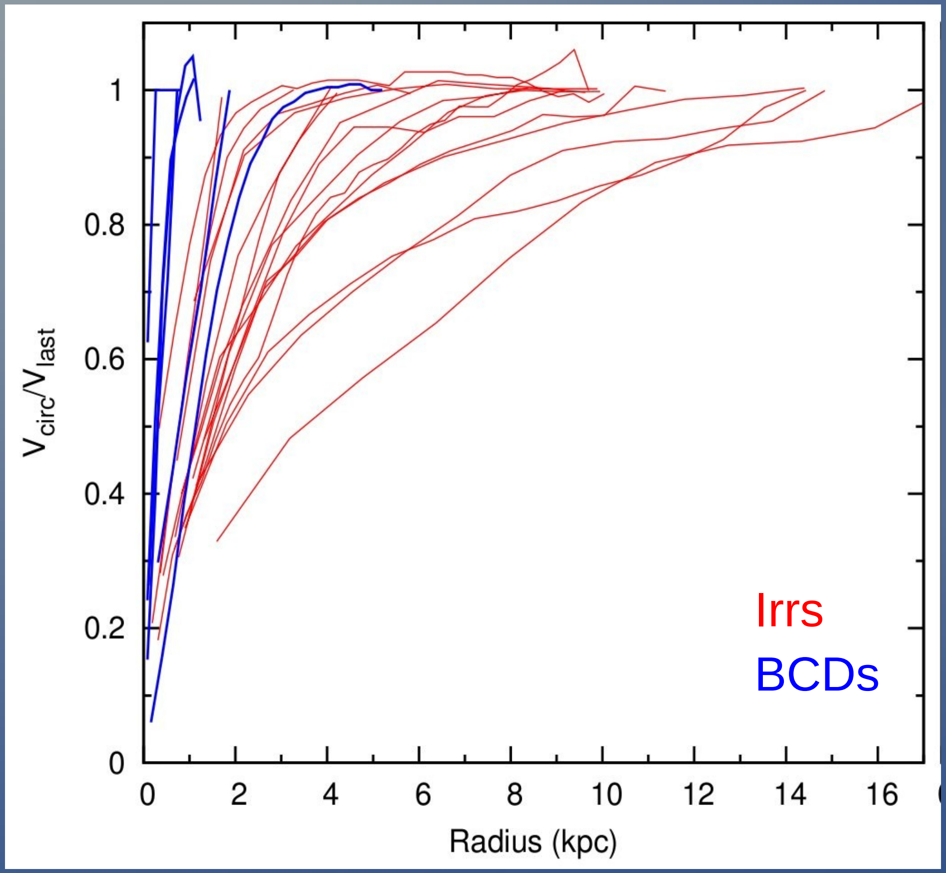
to search for stellar tidal features

Luminous-DM coupling:

clues to the nature of dark matter

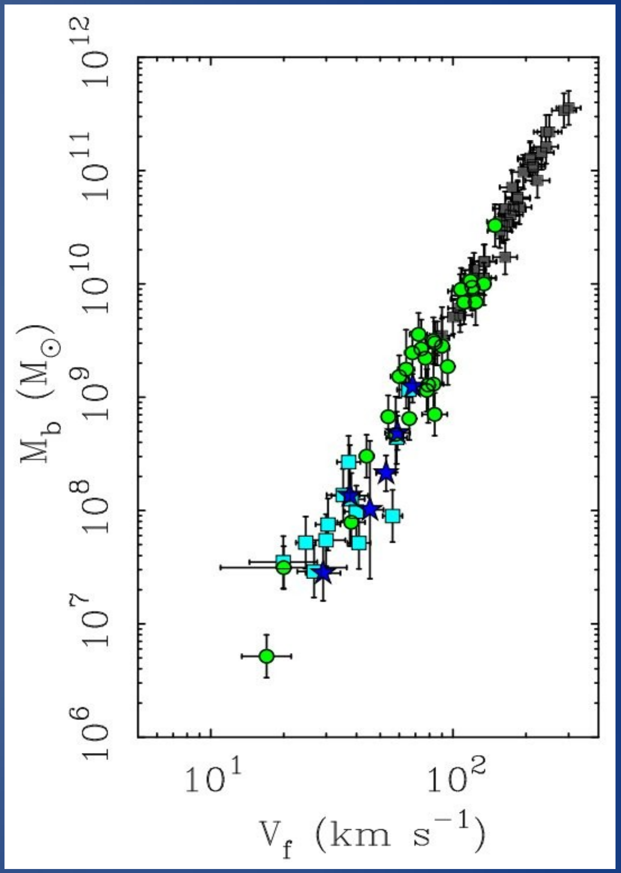
A luminous - dark matter coupling?

Rotation curve scaling V/V$_{flat}$



Lelli et al. (in prep.). See also: Swaters et al. (2009); Amorisco & Bertin (2010)

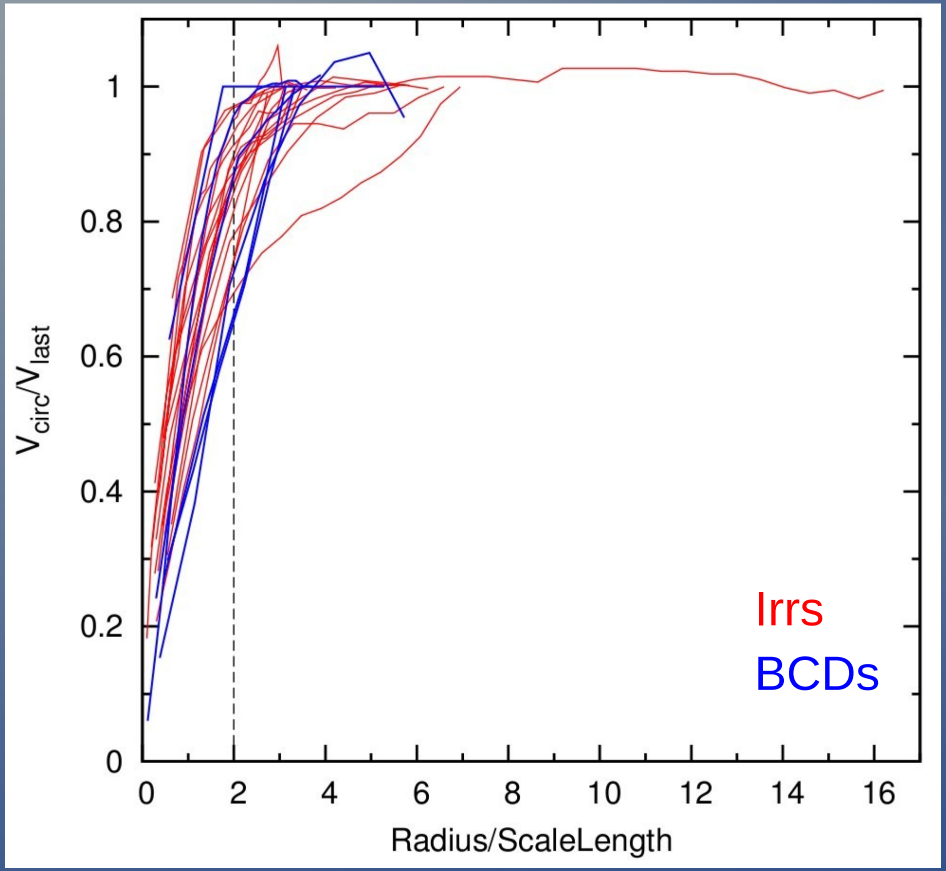
Baryonic TF relation



McGaugh (2012)

A luminous - dark matter coupling?

Rotation curve scaling R/R_0 & V/V_{flat}



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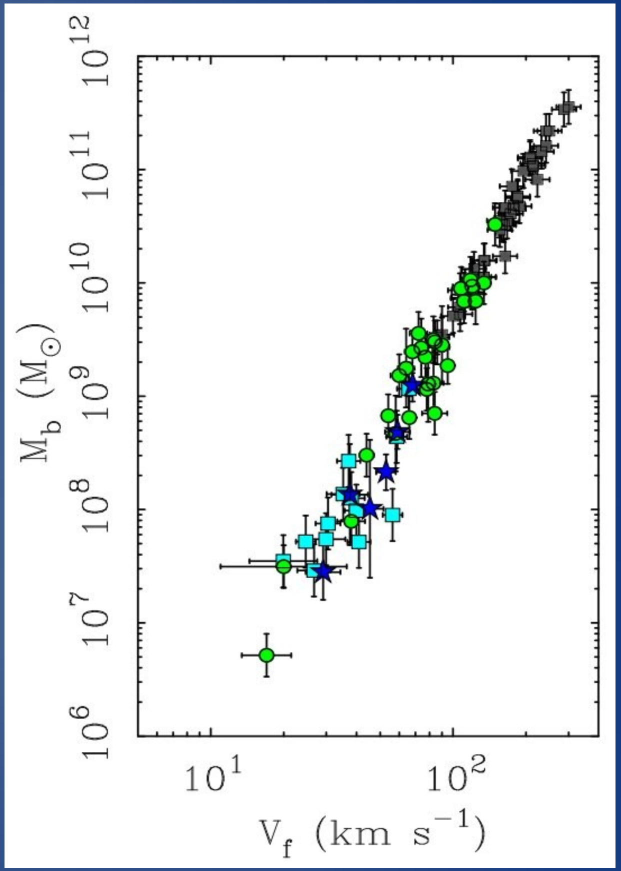

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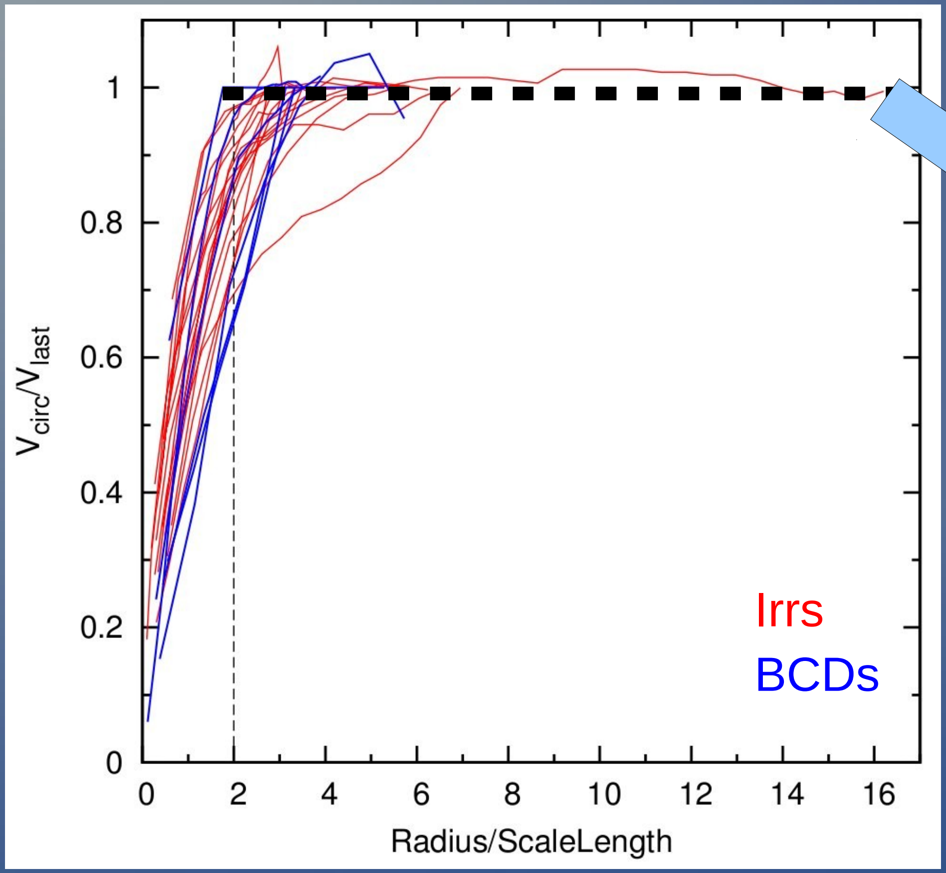

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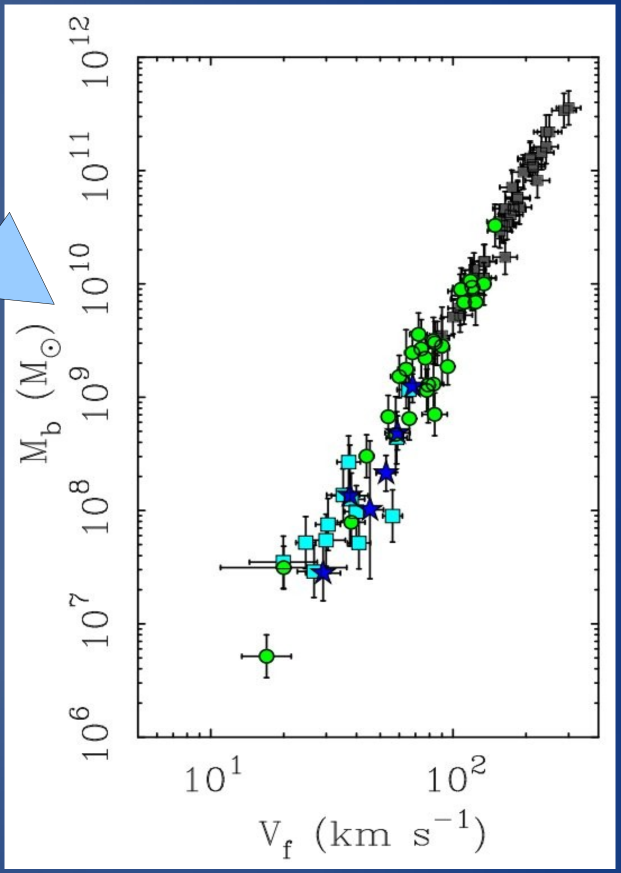

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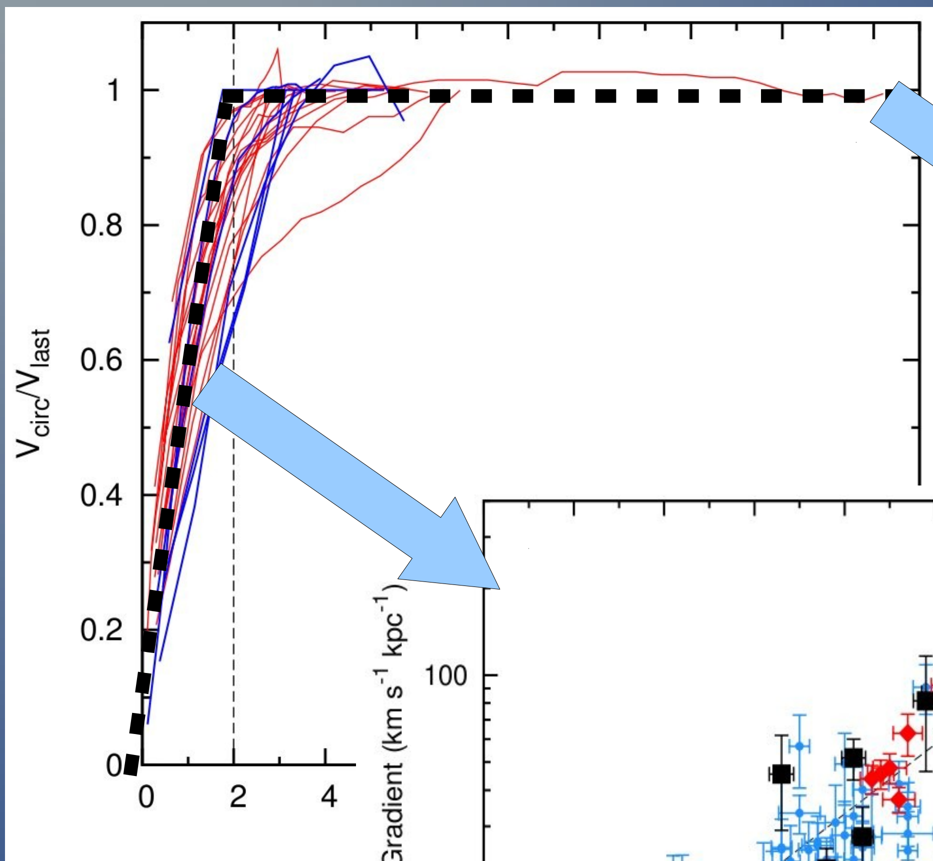
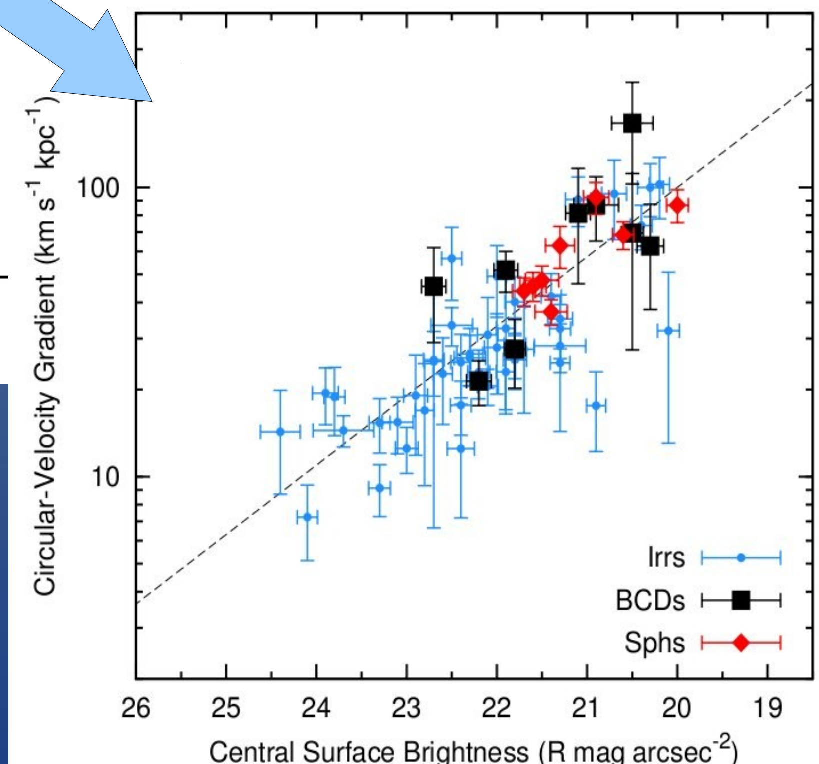
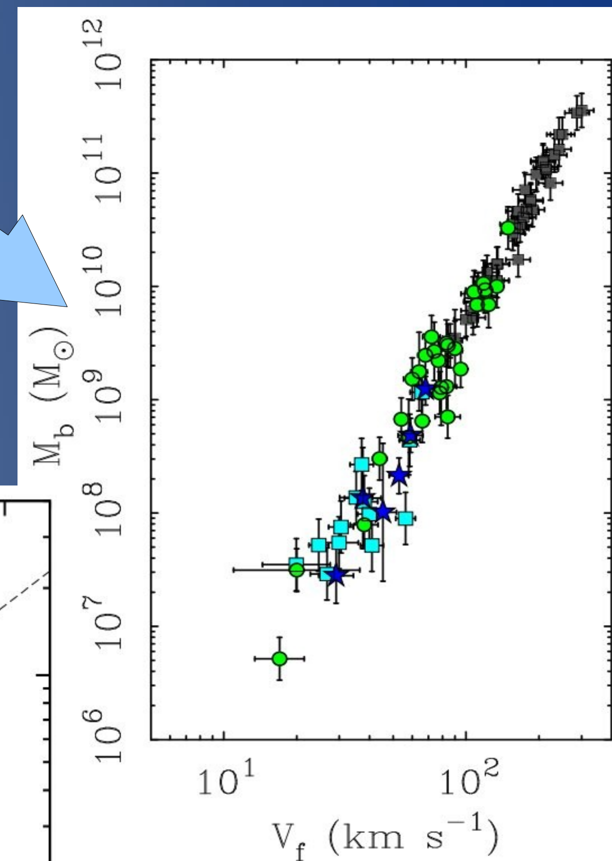


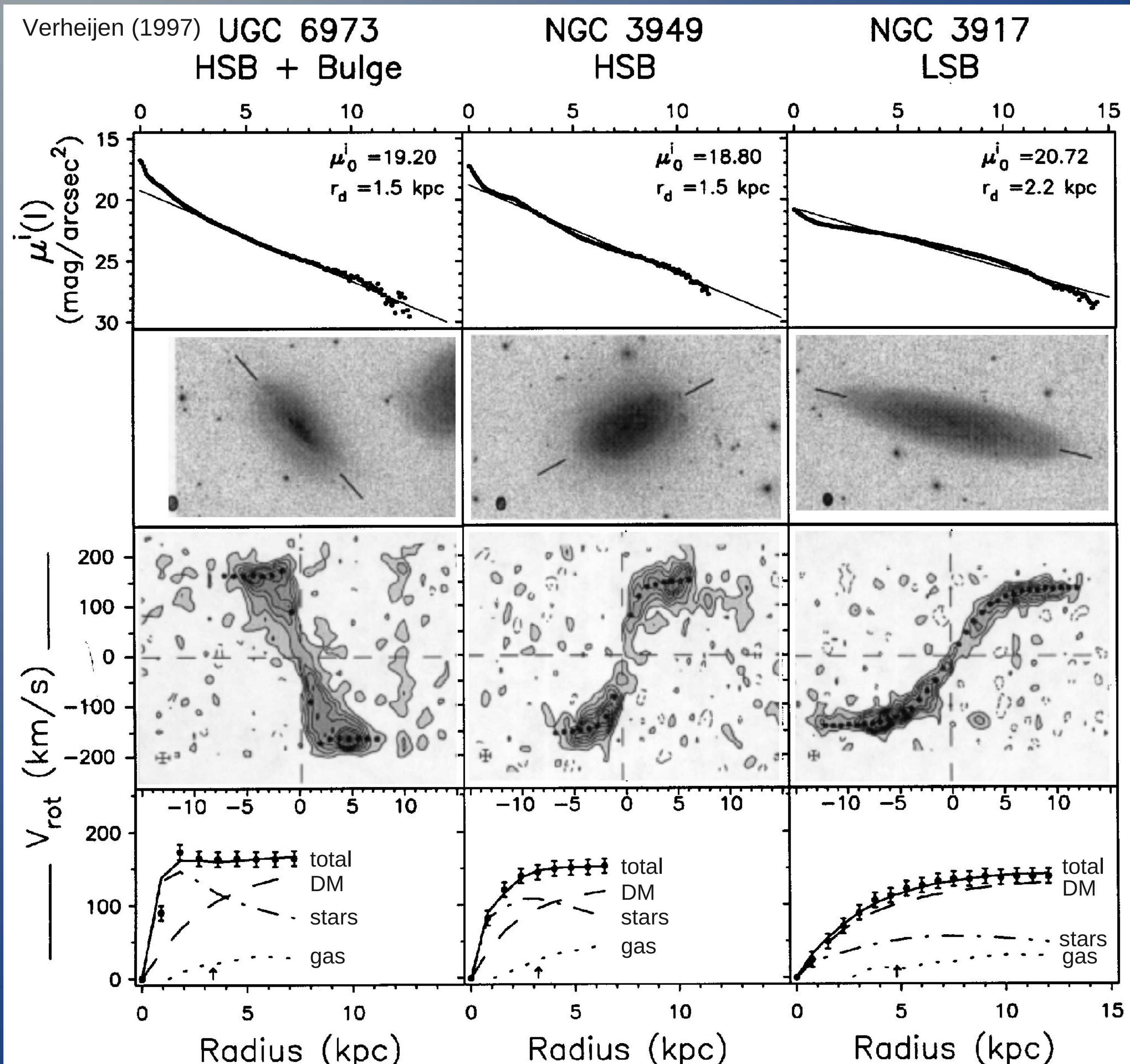


Baryonic TF relation



McGaugh (2012)

A Luminous – Dark Matter Coupling?



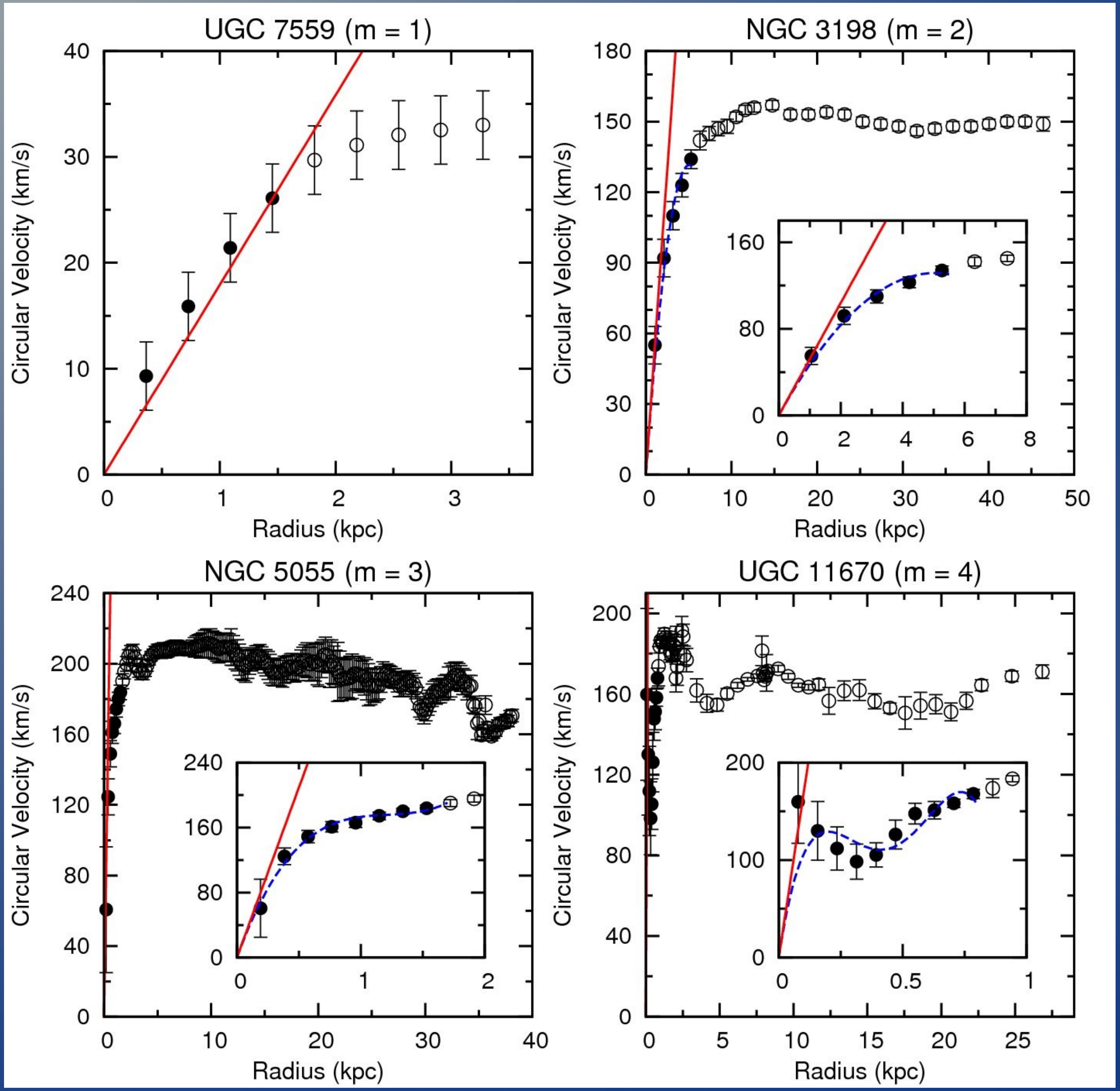
Renzo's Rule:

Distribution of Light

Shape of the Rotation Curve (Distribution of Mass)

Sancisi (2004)

Polynomial Fit to Rotation Curves:



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

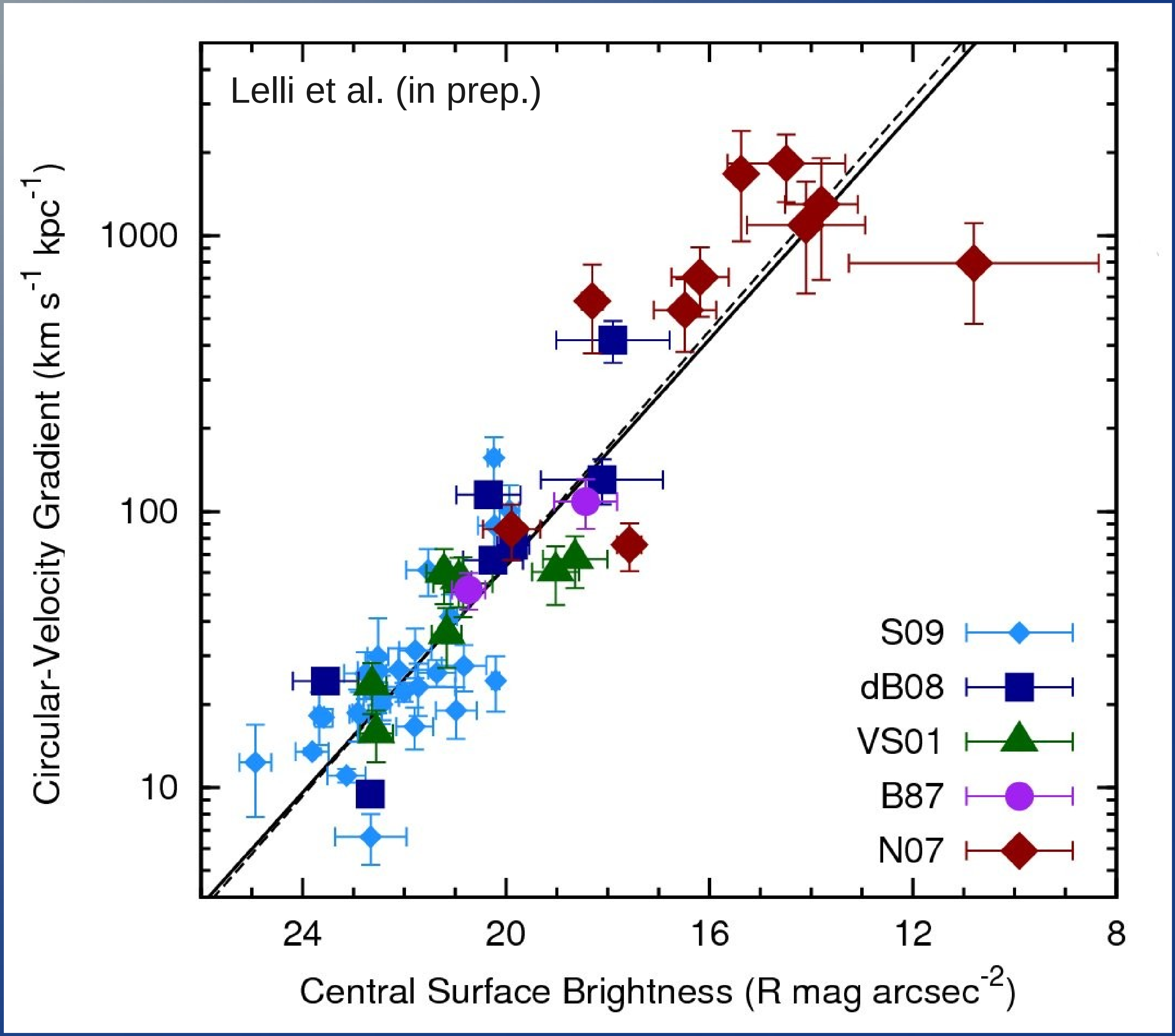
$$a_1 = \lim_{R\to 0} dV/dR.$$

m determined by a statistical procedure.

5 Galaxy Samples:

- *Swaters et al. (2009)* Sd – Irrs
- *Begeman (1987)* Sb – Sc
- *Verheijen & Sancisi (2001)* UMa cluster: Sb – Irrs
- *de Blok et al. (2008)* THINGS: Sab – Irrs
- *Noordermeer et al. (2007)* S0 – Sa

A new scaling-relation for disk galaxies?



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 ($f_{\mathrm{bar},0}$)

Conclusions:

- BCDs have high concentration of mass (~30% in baryons)

Starburst ↔ Gravitational Potential + HI concentration

BCDs ↔ Irrs requires redistribution of mass

...but it's ok for HSB Irrs & rotating Sphs

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BCDs ⟺ ? Irrs requires redistribution of mass

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- BCDs have disturbed outer HI morphologies

⟹ interactions/mergers? Cold gas accretion?

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...but it's ok for HSB Irrs & rotating Sphs

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⇒ interactions/mergers? Cold gas accretion?

- Local coupling between luminous-DM matter:

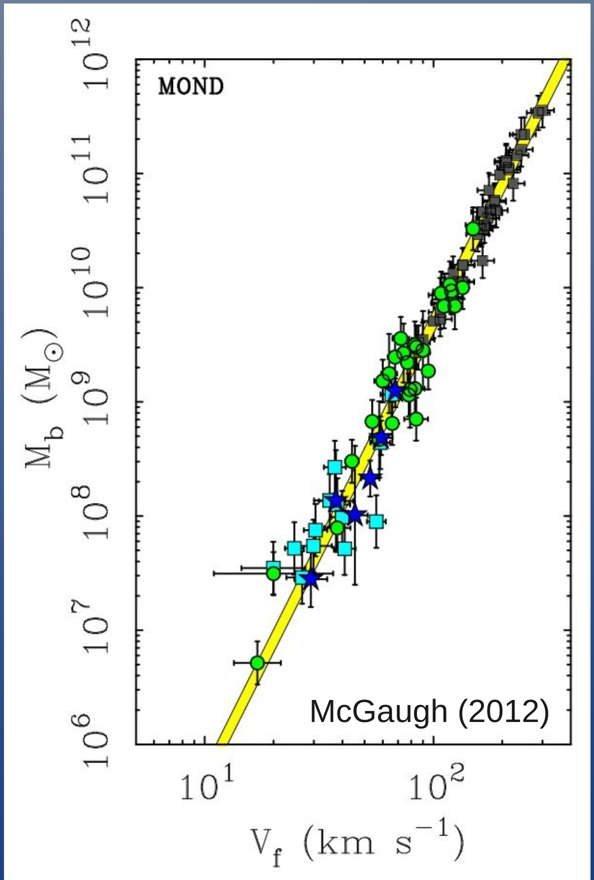
Central SB *vs* Circular-Velocity Gradient

More Slides

Two 30 years old predictions of MOND:

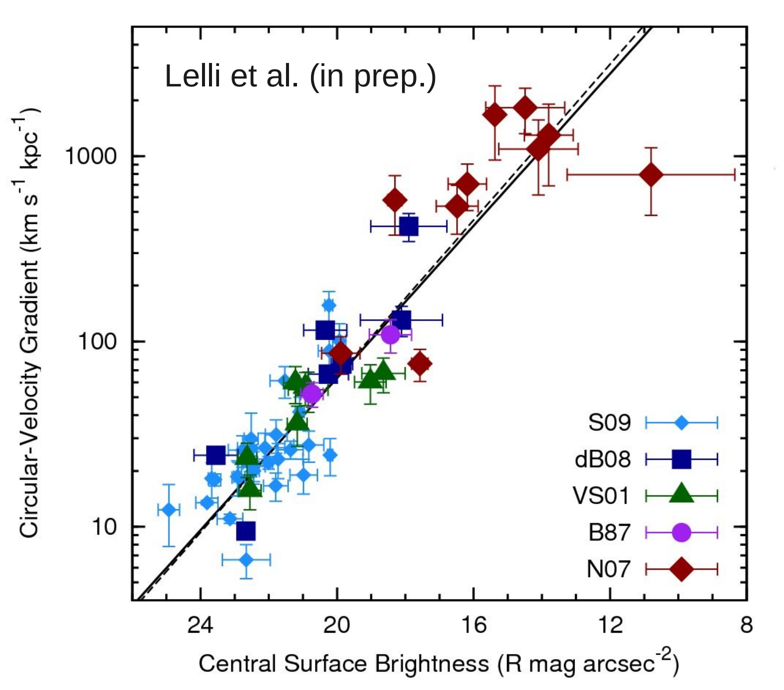
``The relation between the asymptotic velocity (V_f) and the mass of the galaxy (M) ($V_f^4 = MGa_0$) is an absolute one''

Milgrom (1983)

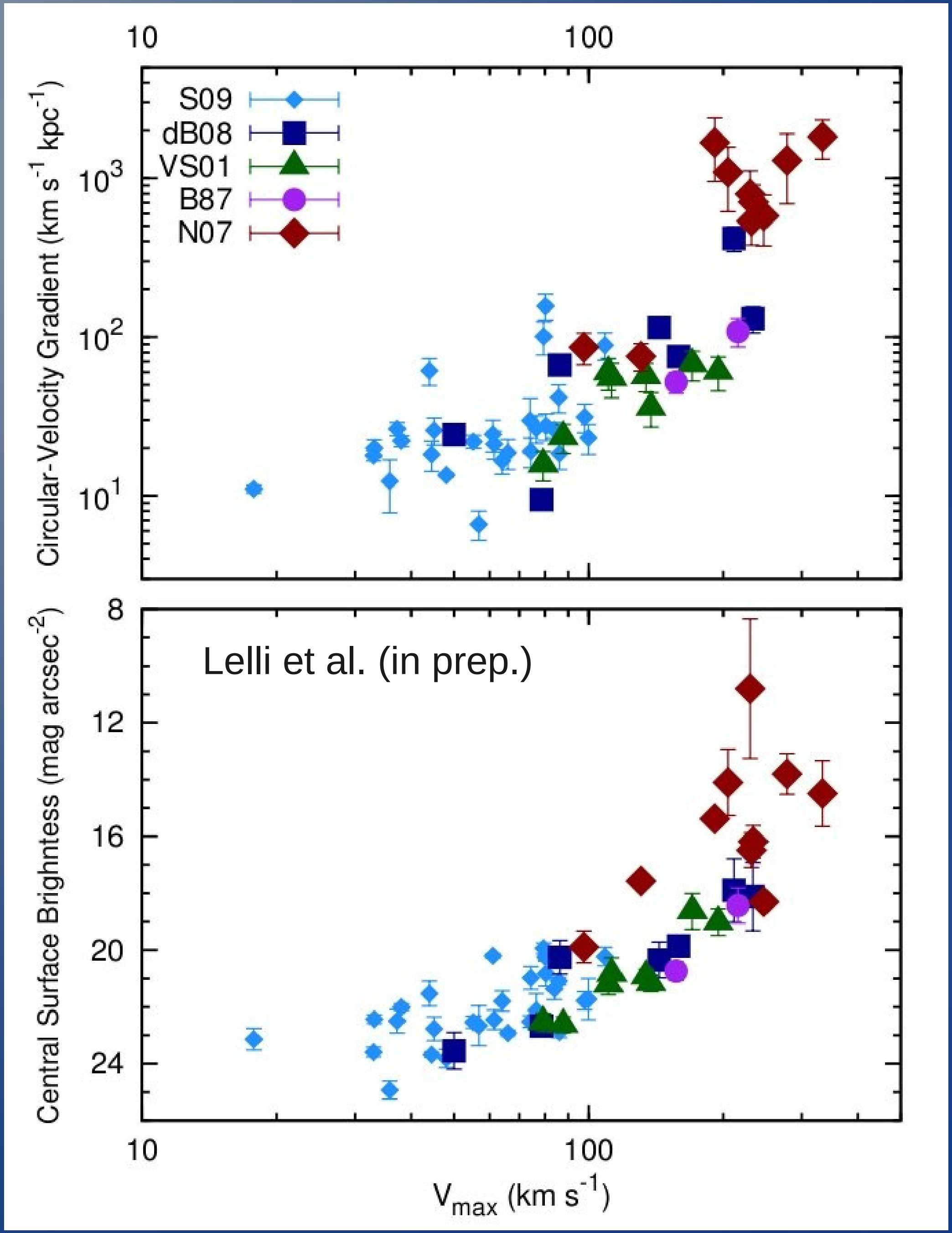


``We predict a correlation between the value of the average surface density (surface brightness) and the steepness with which the rotational velocity rises to its asymptotic value''

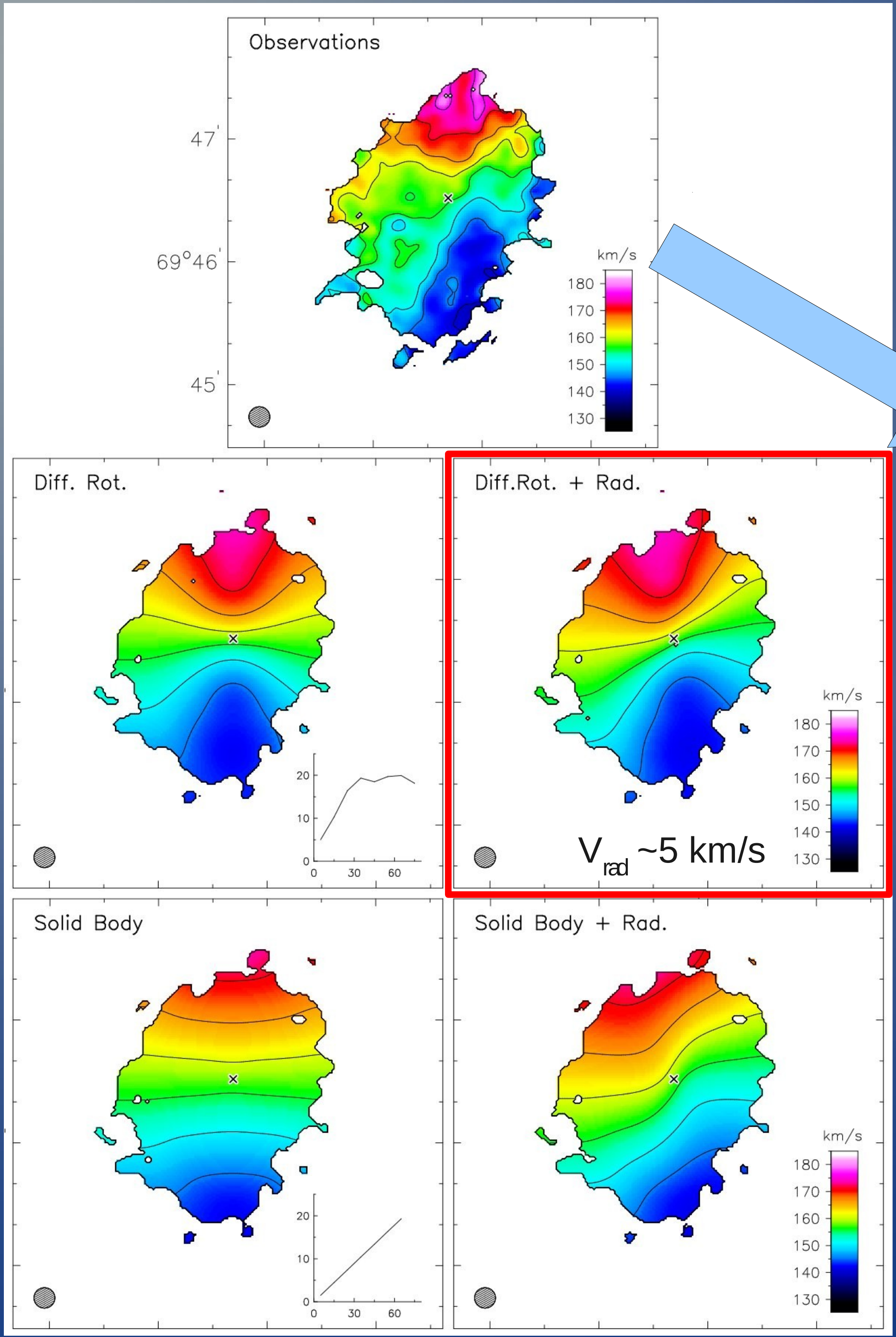
Milgrom (1983)



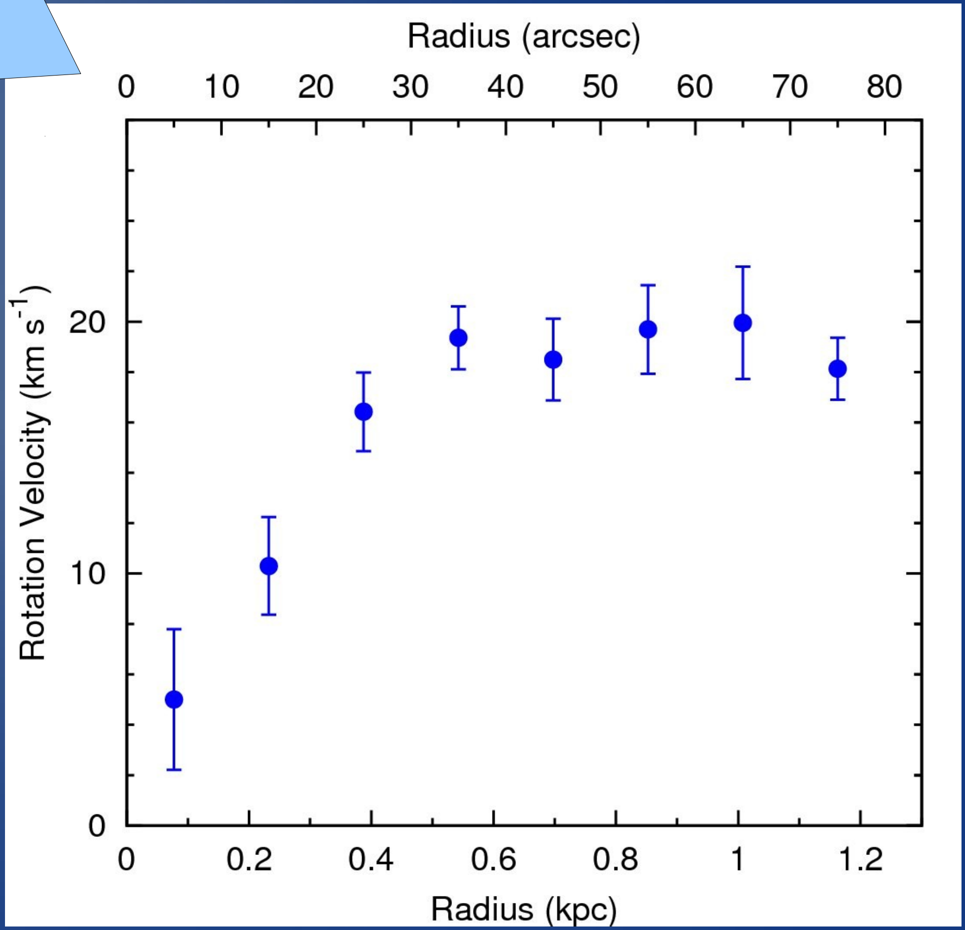
Circular-Velocity Gradient *vs* Vmax



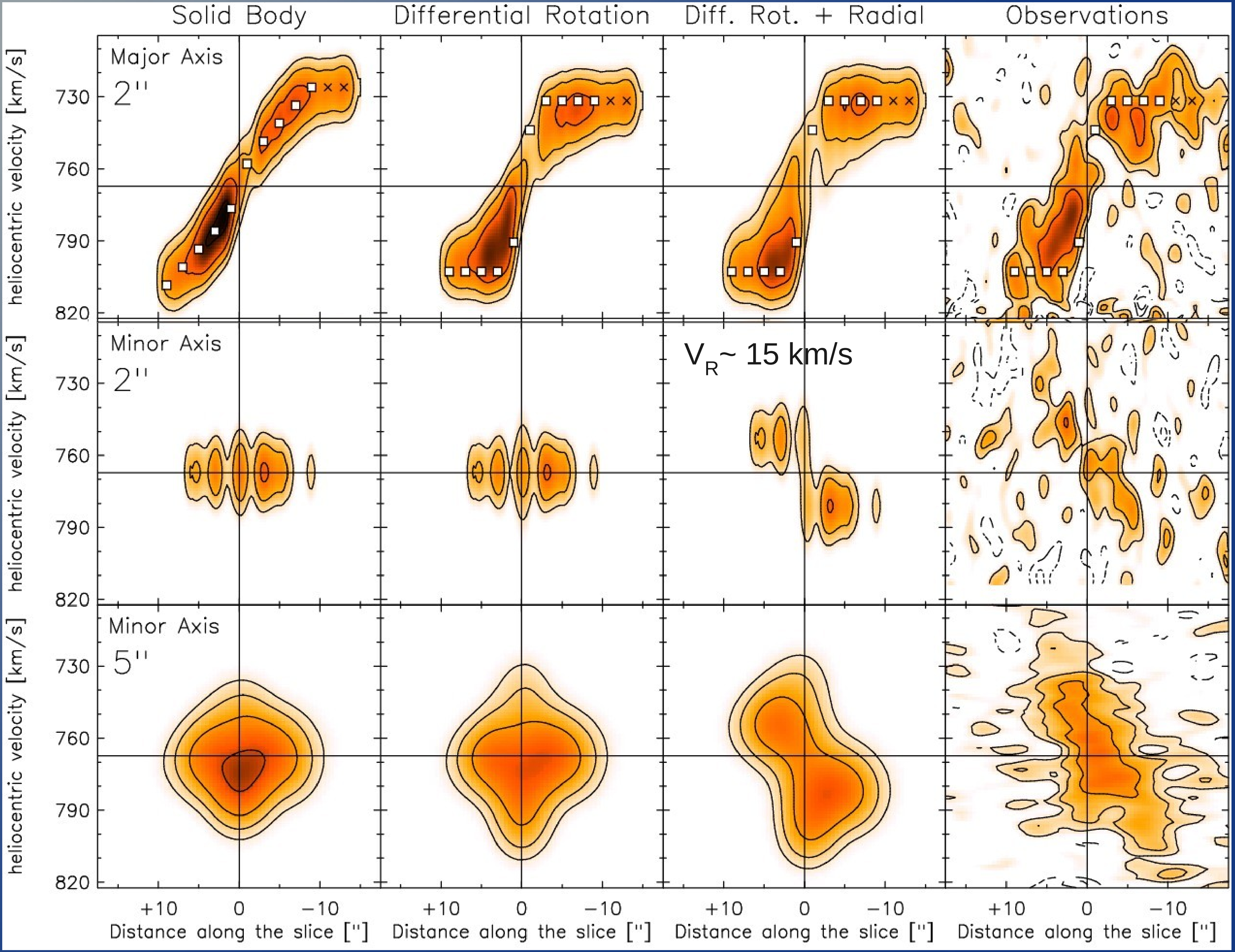
HI kinematics of UGC 4483



Rotation curve:



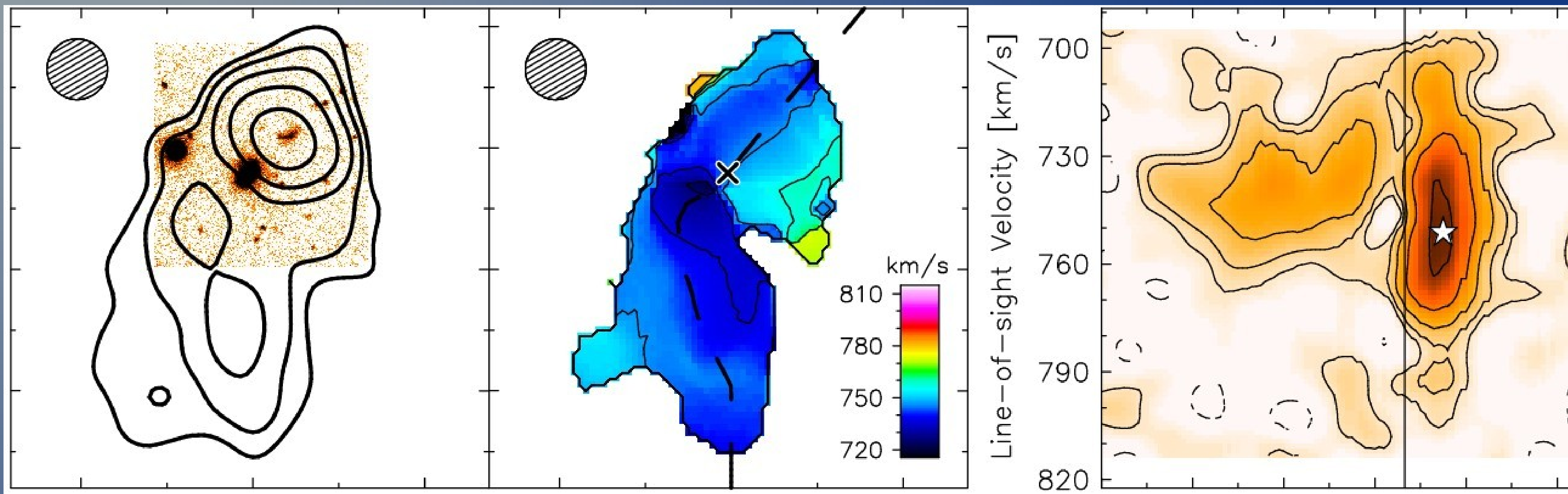
Lelli et al. 2012, A&A, 544, 145L

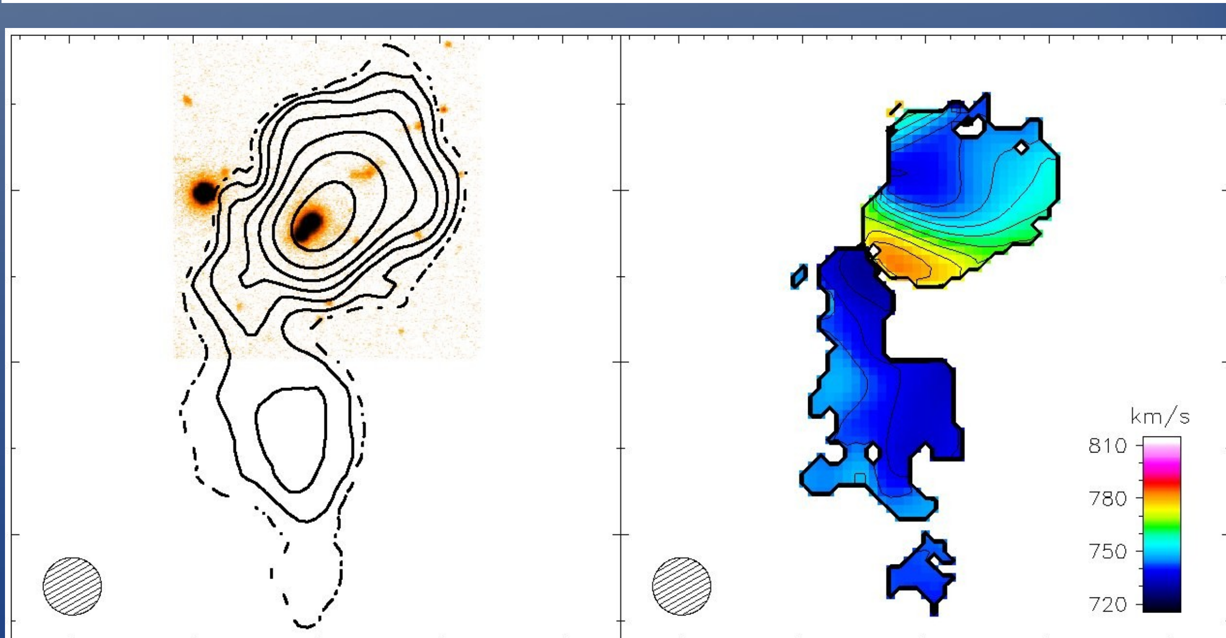


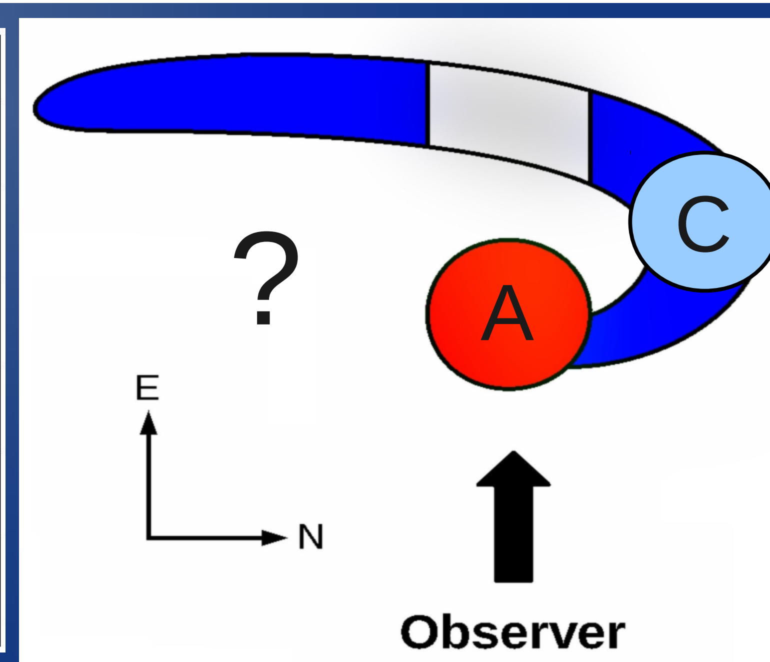
Solid Body
Differential Rotation
Diff. Rot. + Radial
Observations
Major Axis
2''
Minor Axis
2''
Minor Axis
5''
V_R ~ 15 km/s
heliocentric velocity [km/s]
730
760
790
820
+10
0
−10
Distance along the slice ['']

I Zw 18 – Disk Subtraction (Lelli et al. 2012)

Optical + HI map | Velocity Field | Position Velocity

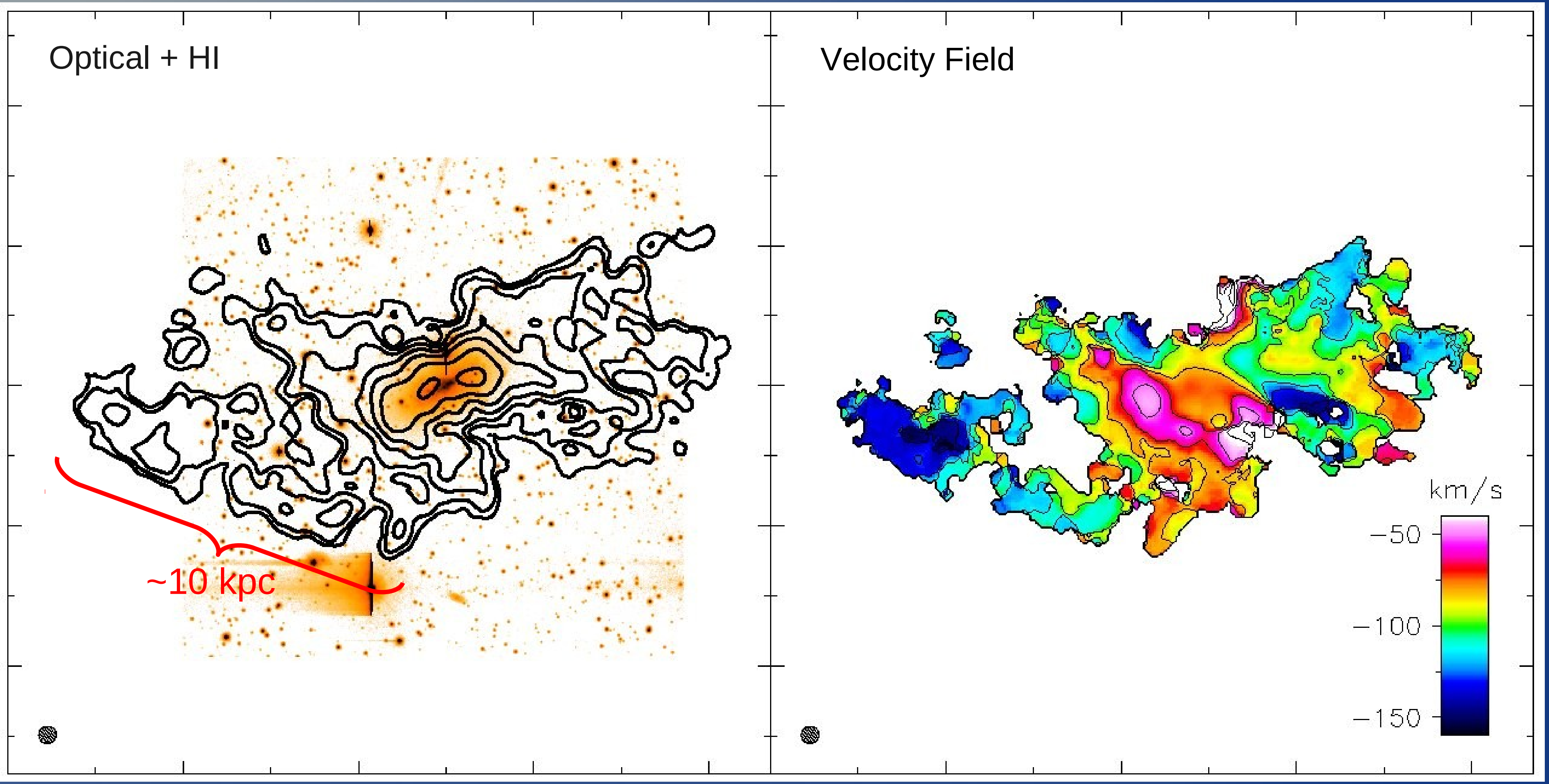






NGC 1569

Data from THINGS



$M_* = 7 \times 10^8\ M_\odot$

$M_{HI} = 4 \times 10^8\ M_\odot$

$\Sigma_{SFR} = 4\ M_\odot/yr/\ kpc^2$

Lelli et al. (in preparation)