HI in the Universe (STHIU-09)

Lecture outline

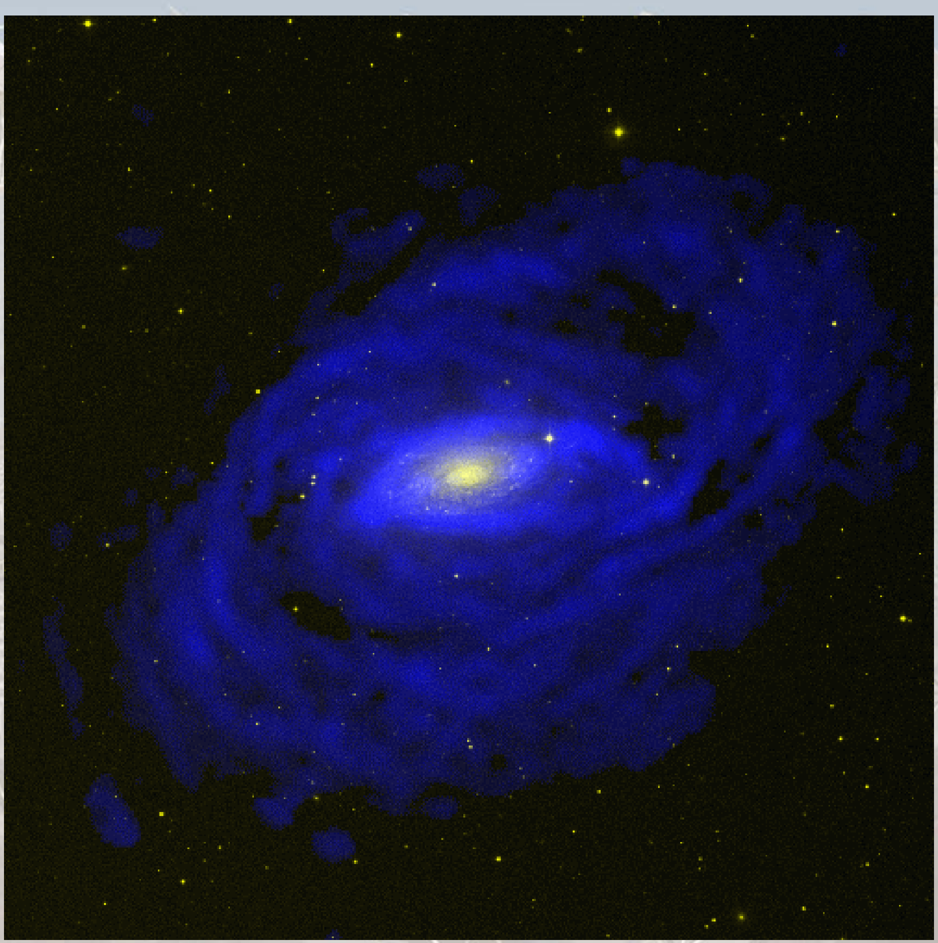
Week 1: basic physics, determination of HI properties of galaxies, overview of HI properties of galaxies in relation to other global galaxy properties

Week 2: HI as a tracer of galaxy dynamics, galaxy evolution, galaxy structure, star formation

Week 3: HI surveys: HI properties, HI Mass Function, HI properties as a function of environment

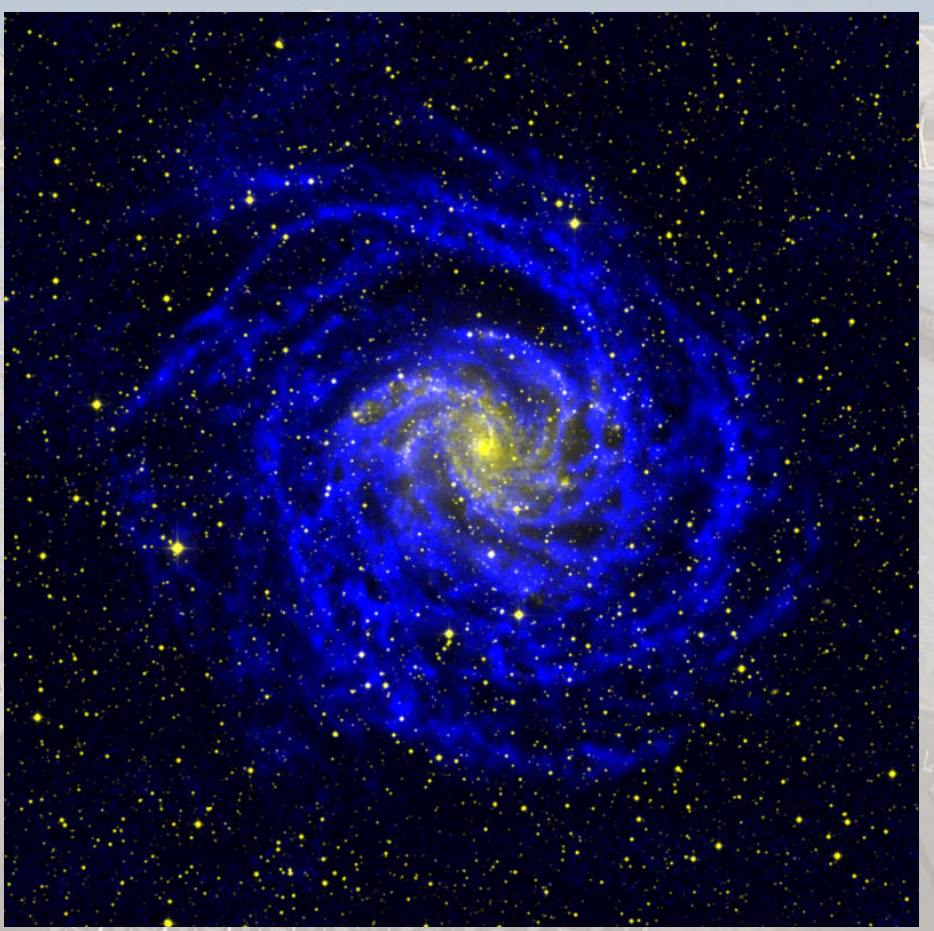
Week 4: relevance for galaxy formation and evolution, the cosmic picture, future observational capabilities

NGC 5055



Battaglia, Fraternali, Oosterloo and Sancisi 2006 A&A, 447, 49

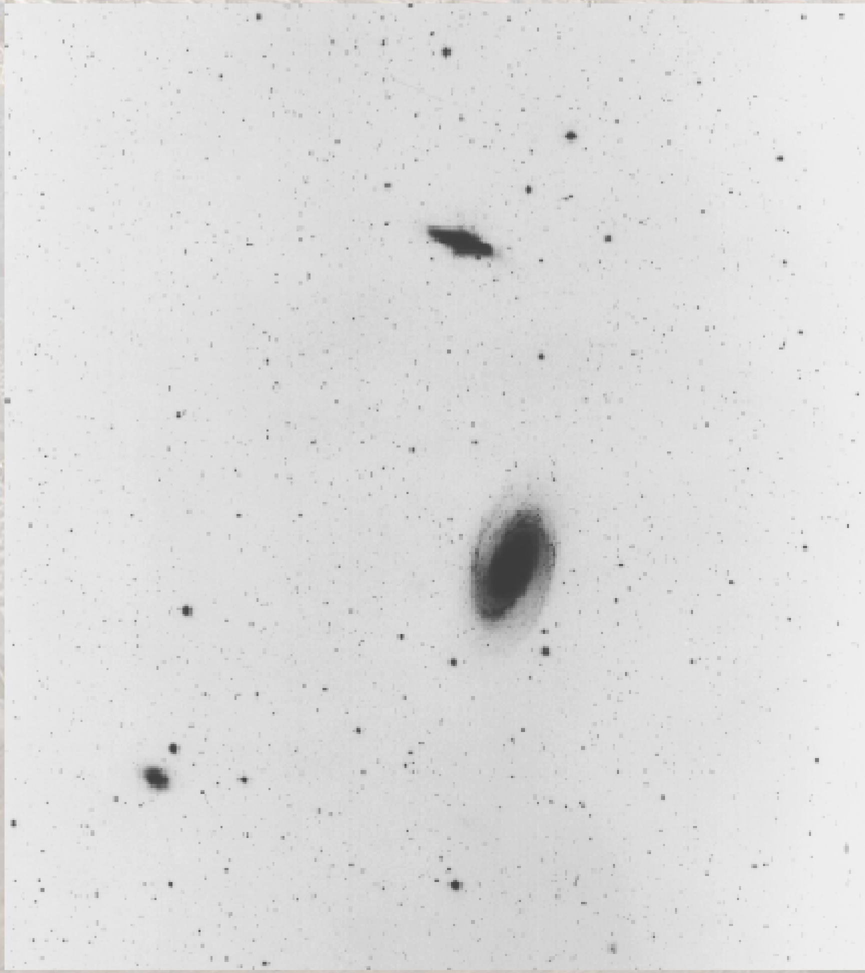
NGC 6946



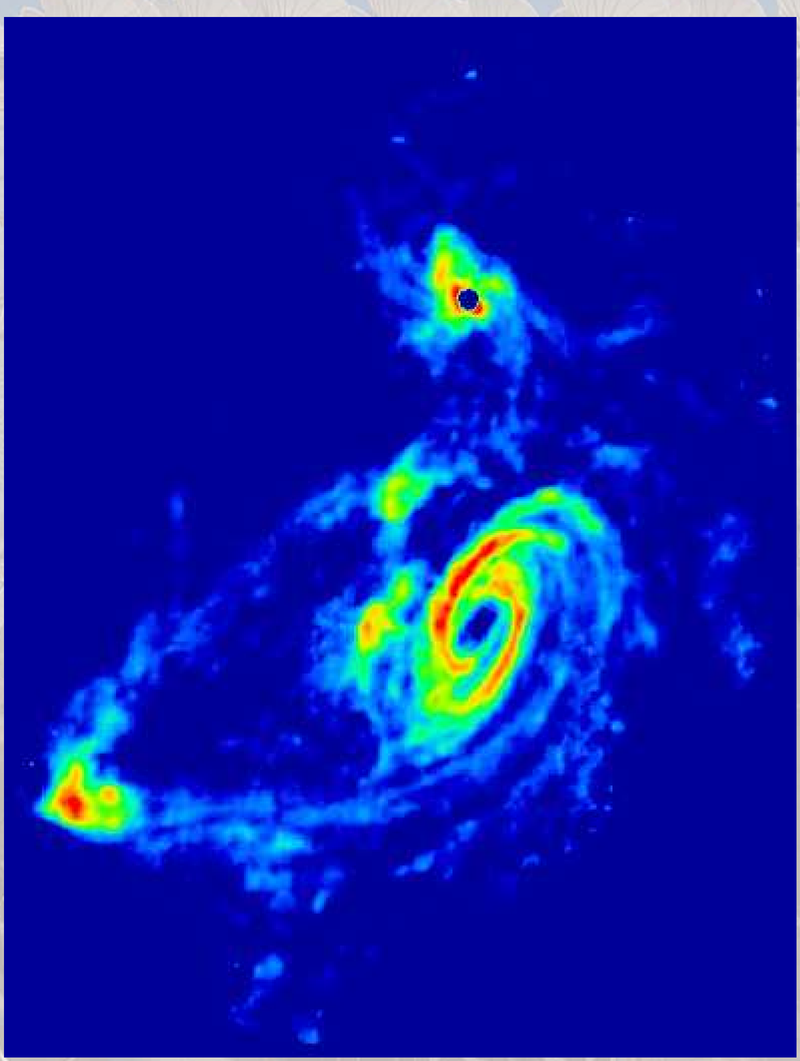
Boomsma, Oosterloo, Sancisi and van der Hulst, 2008 A&A, 490, 555

Messier 81

Optical



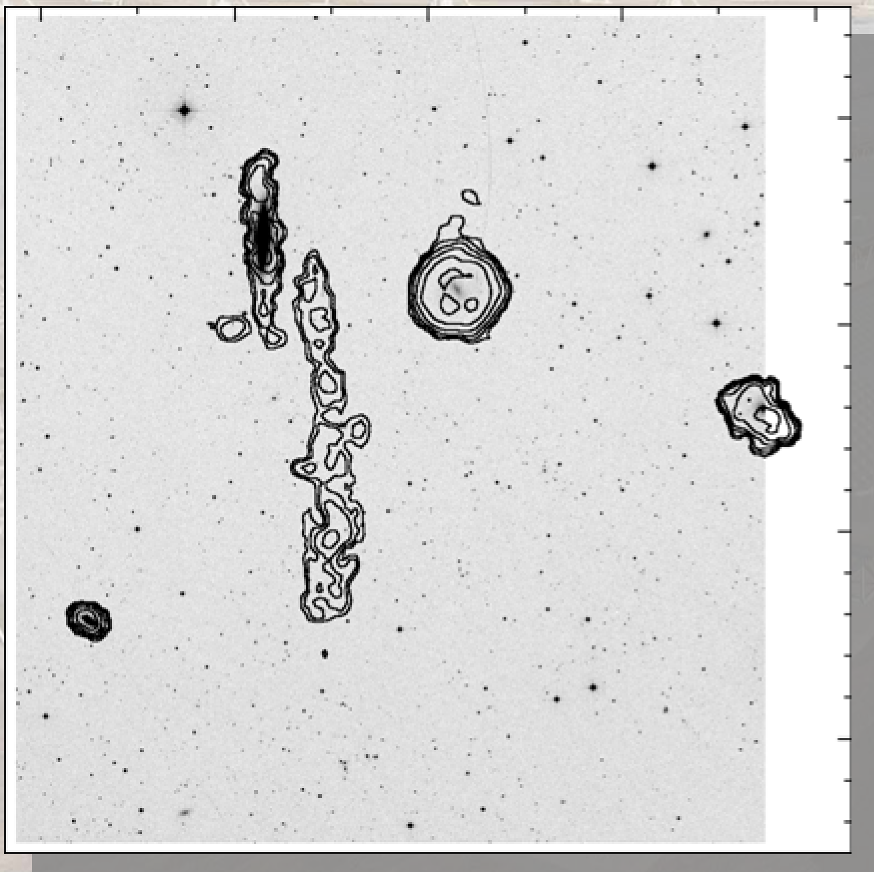
Neutral Hydrogen



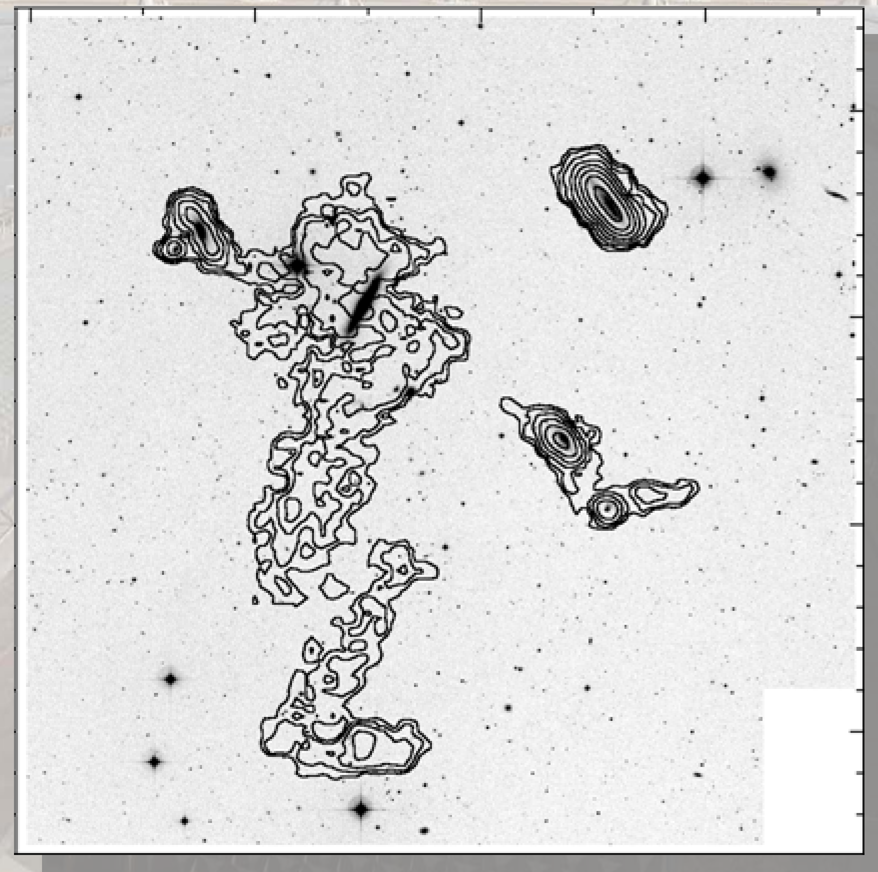
The brightest lenticulars in Ursa Major

Verheijen et al, 2001

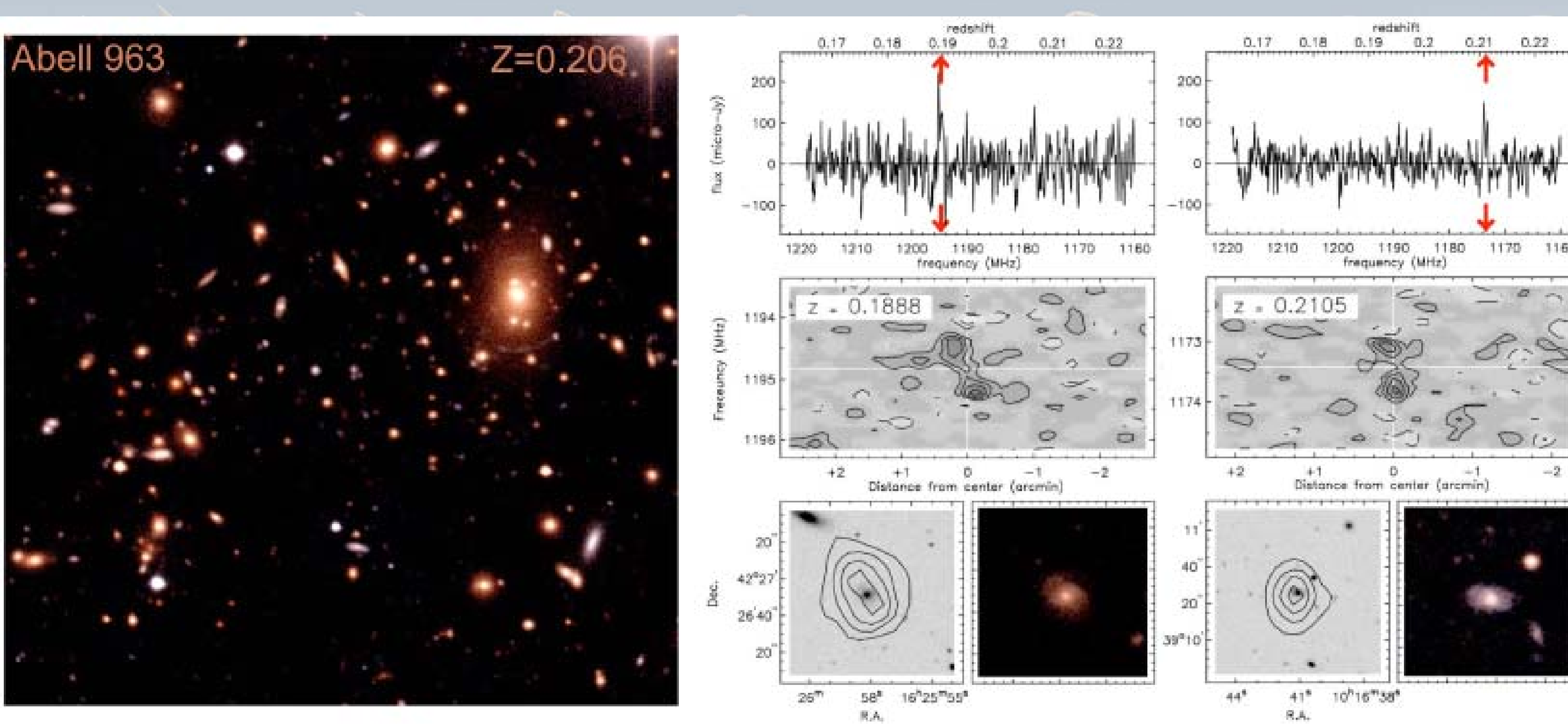
NGC 4026



NGC 4111



Present state of the art: imaging HI emission out to z = 0.2



Verheijen et al. ApJ, 668, L9, 2007

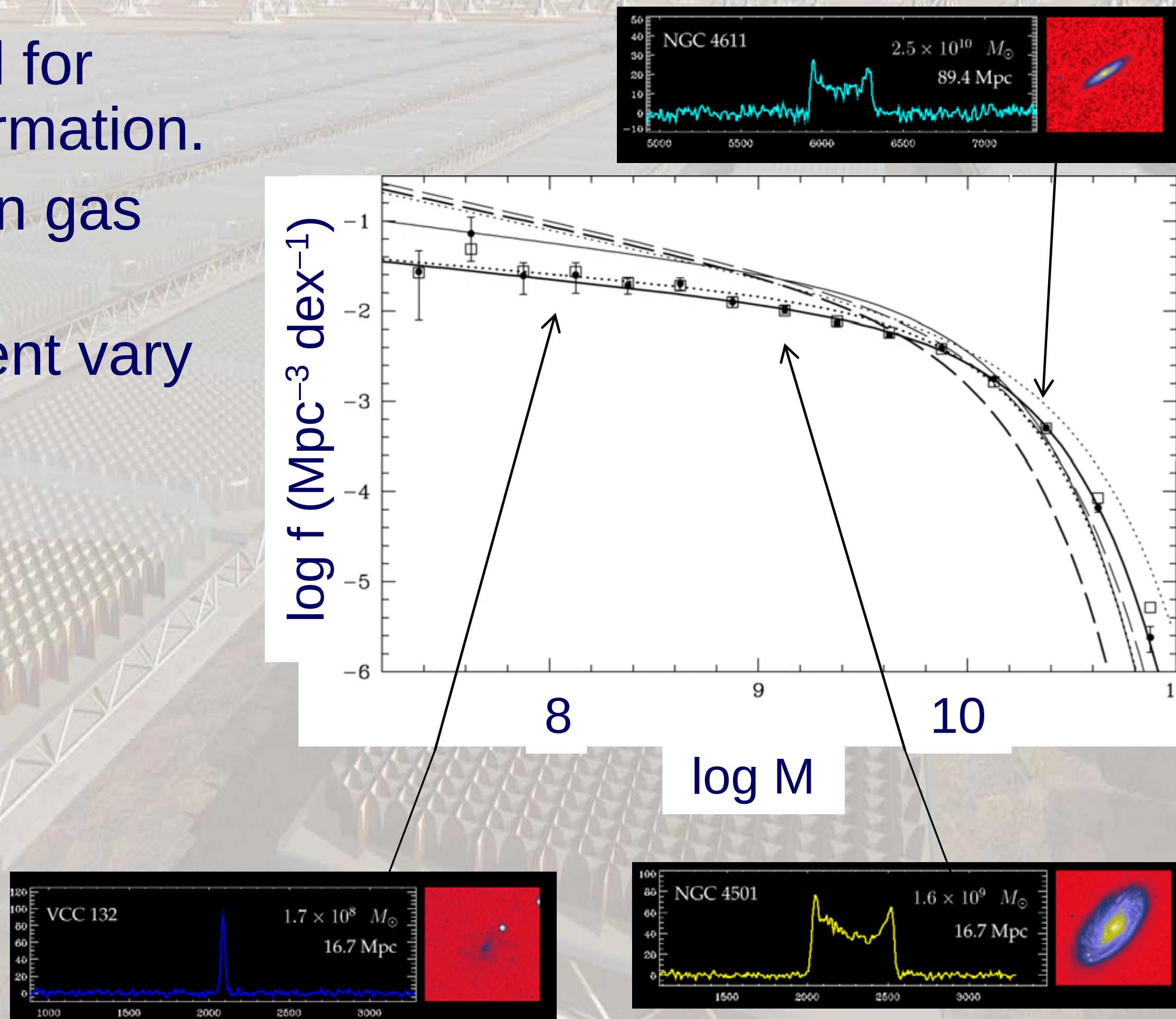
Effects of the environment are demonstrably present:

interactions: in clusters and groups
ram pressure: in cluster environments
cold accretion: everywhere

Galaxy Assembly & Evolution

H I is the raw material for galaxies and star formation.

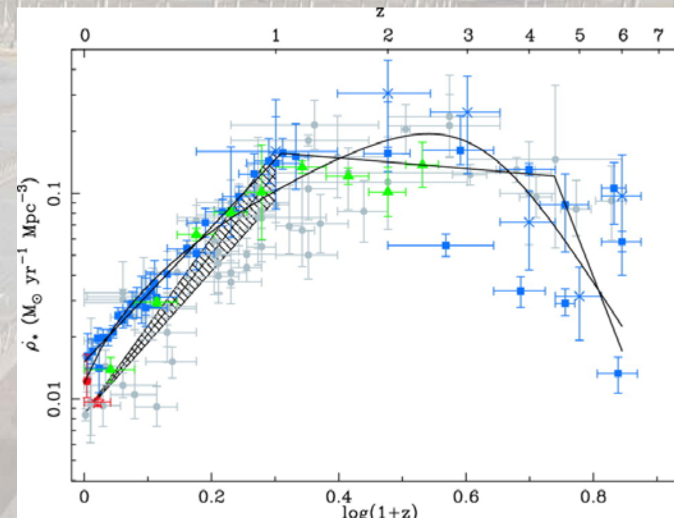
- How do galaxies turn gas into stars?
- How does gas content vary with
  - Morphology;
  - Redshift;
  - Environment;
  - Mergers;
  - Feedback;
  - …



Galaxy Assembly
Stars *and* Gas

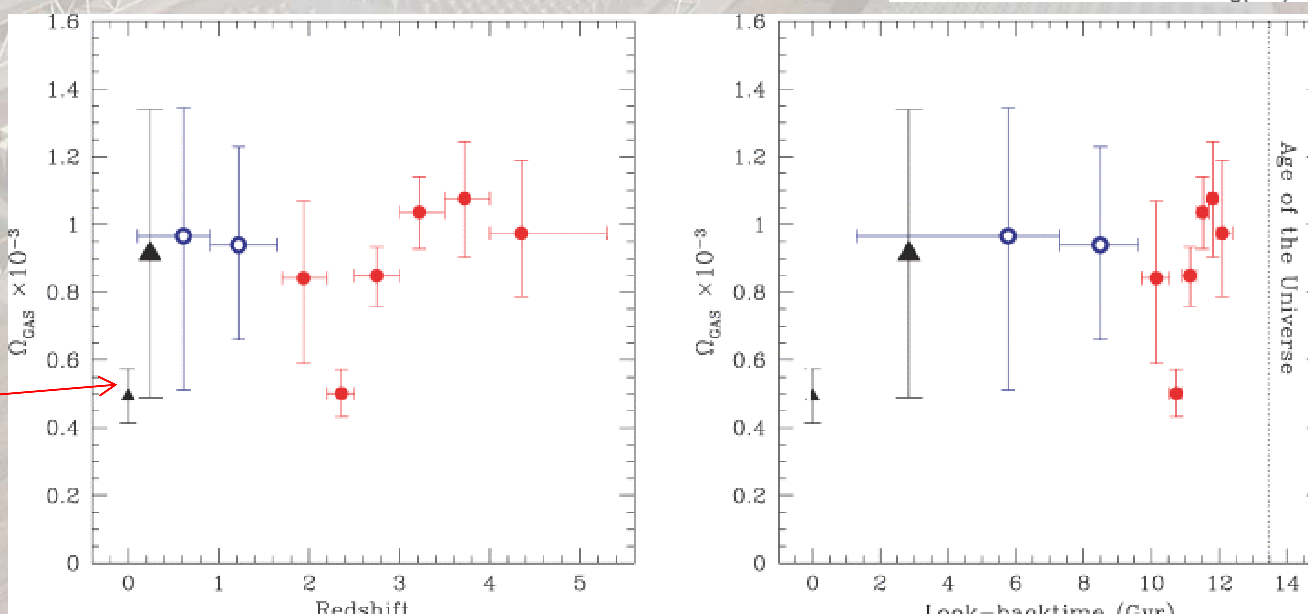
- Stellar “downsizing” since $z \sim 1$
- … but gas content unchanging!
- Gas content and dynamics becoming critical part of simulations.

stars



Hopkins & Beacom

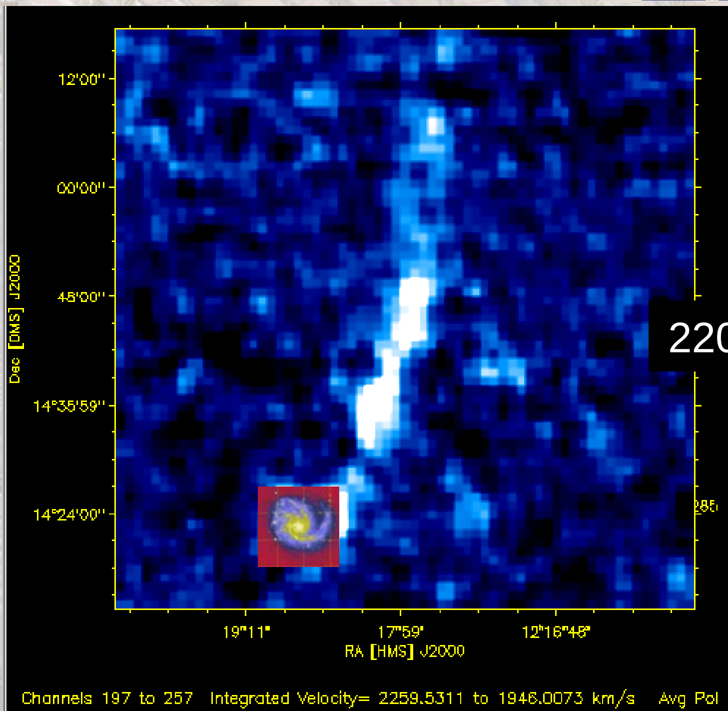
gas



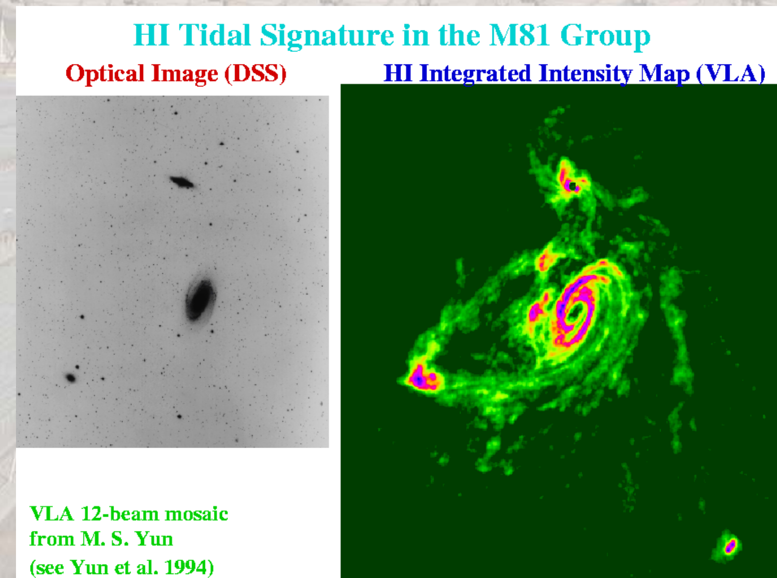
HIPASS (Parkes), ALFALFA (Arecibo)

Origins
First Light
Galaxy Evolution

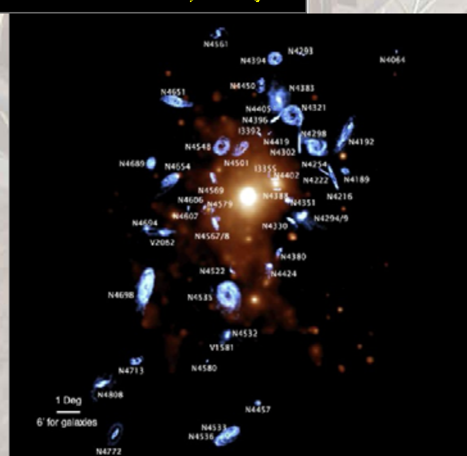
Evolution and Environment



NGC 4254 in Virgo (ALFALFA)



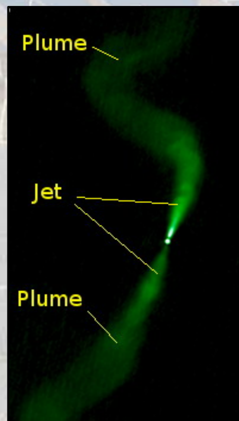
VIVA



- How do galaxies gain and lose gas?
- Infall vs. removal processes
- Gas serves as a tracer of interactions.

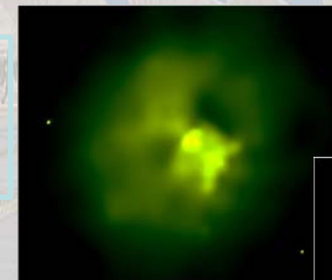
Origins
First Light
Galaxy Evolution

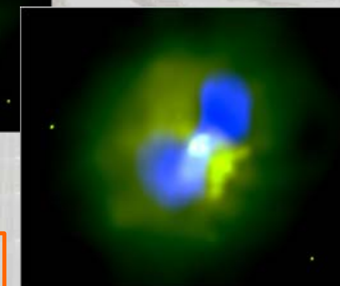
… and Feedback



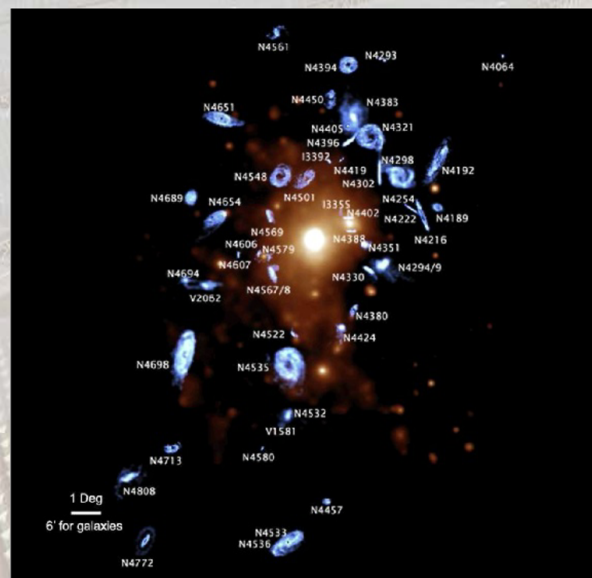
Radio Jet activates

Heats X-ray gas





Offset X-ray cooling



BH accretion

X-ray cooling

BH stops accreting

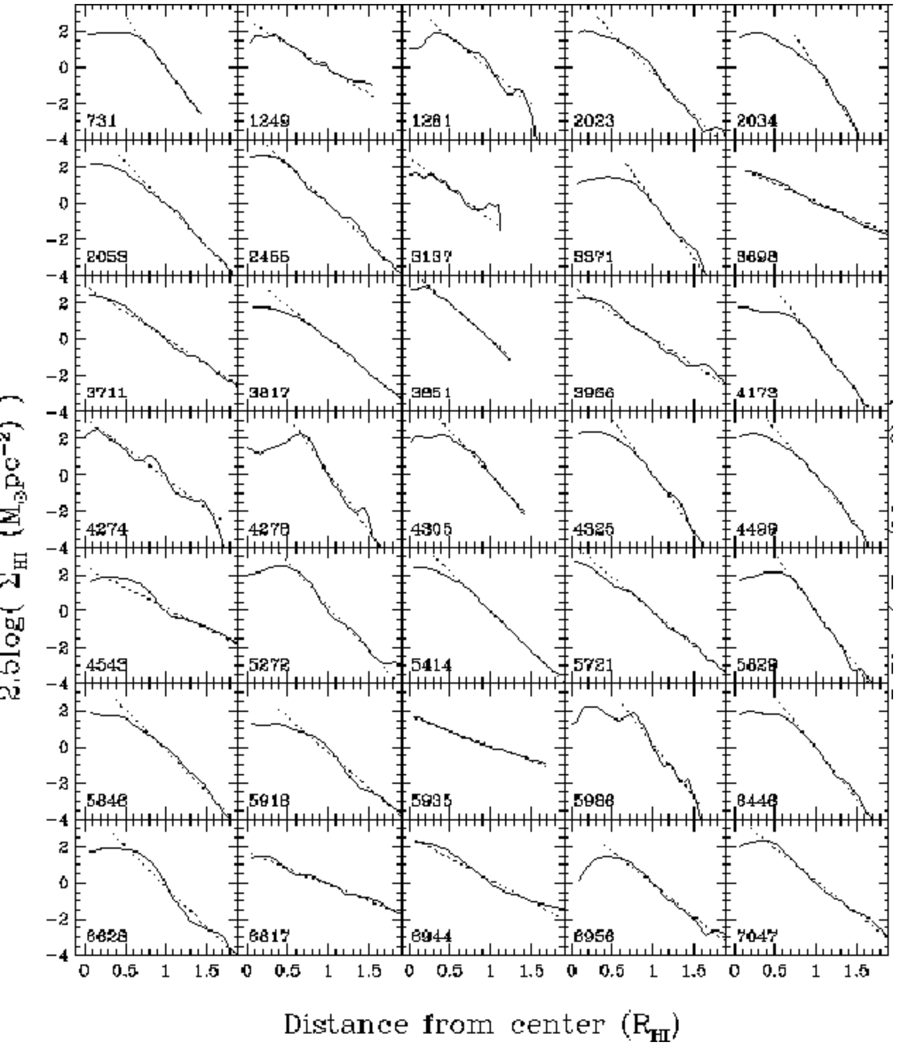
RG is quiescent

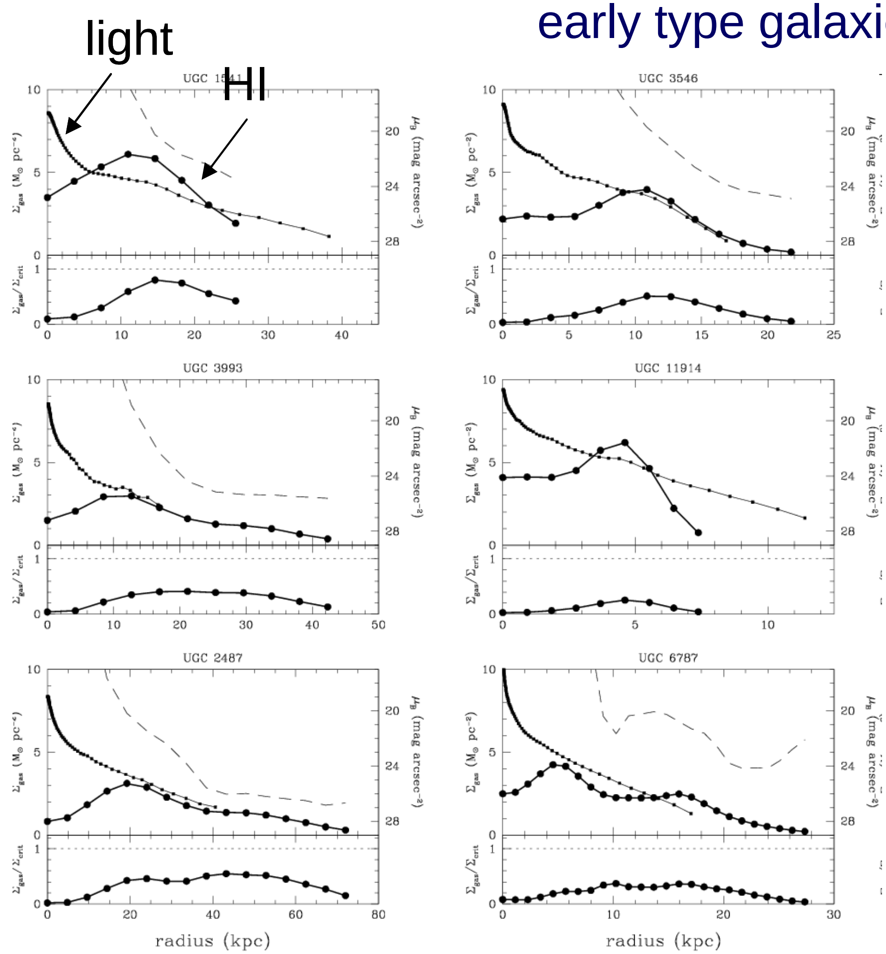
Clarke, Feretti

Radial distributions: late type galaxies: Swaters et al. 2002, A&A 390, 829;
early type galaxies: Noordermeer et al 2005, A&A 442, 137

late type galaxies

early type galaxies

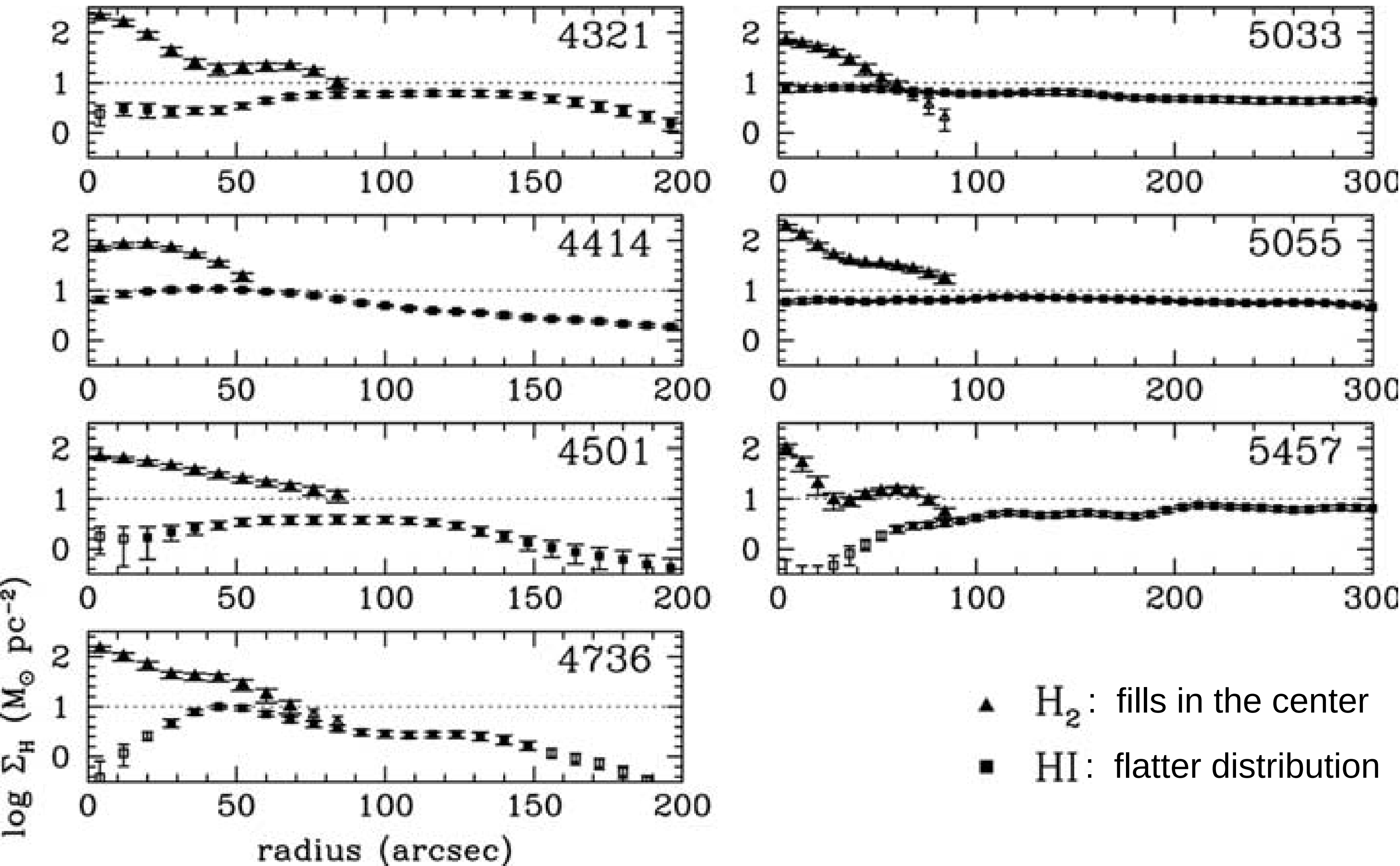


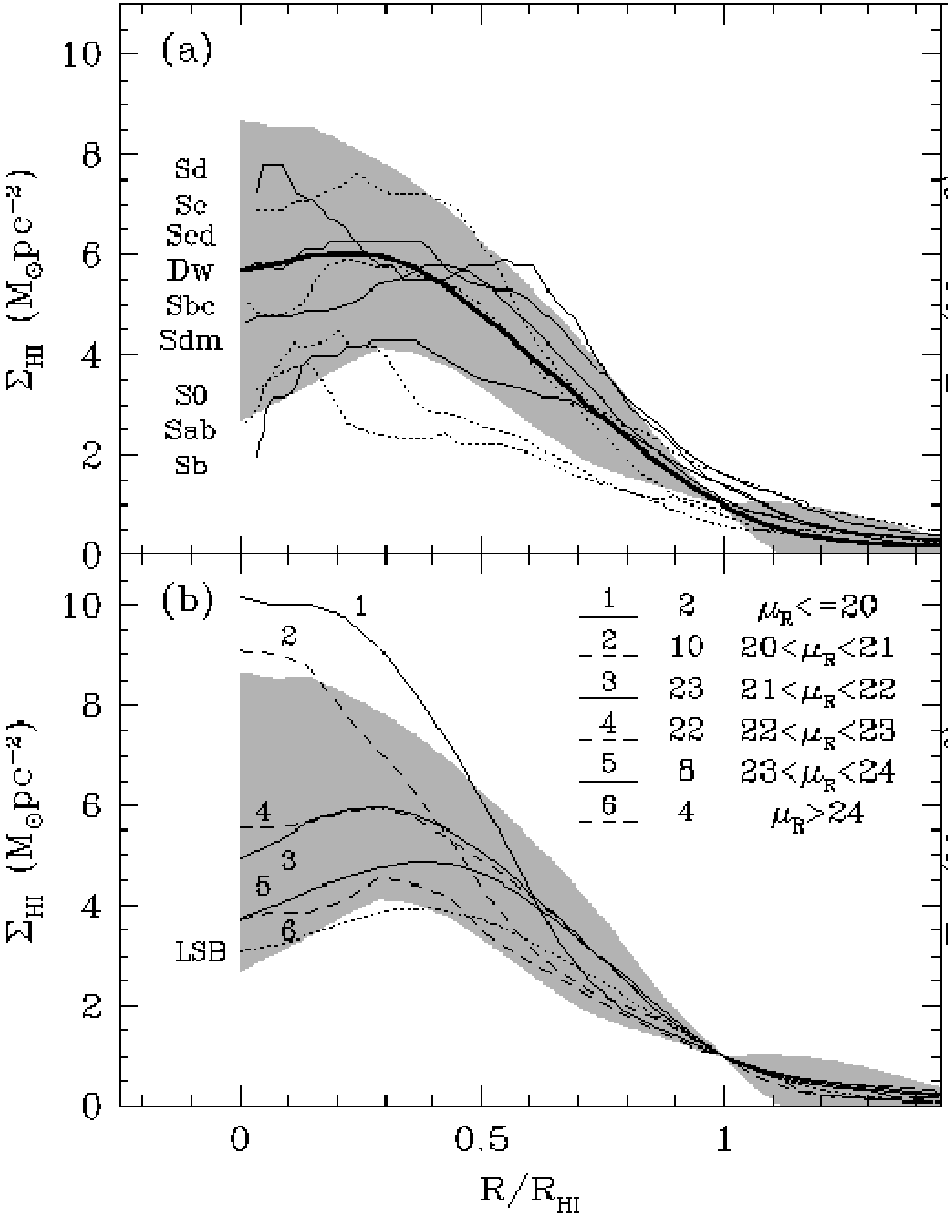


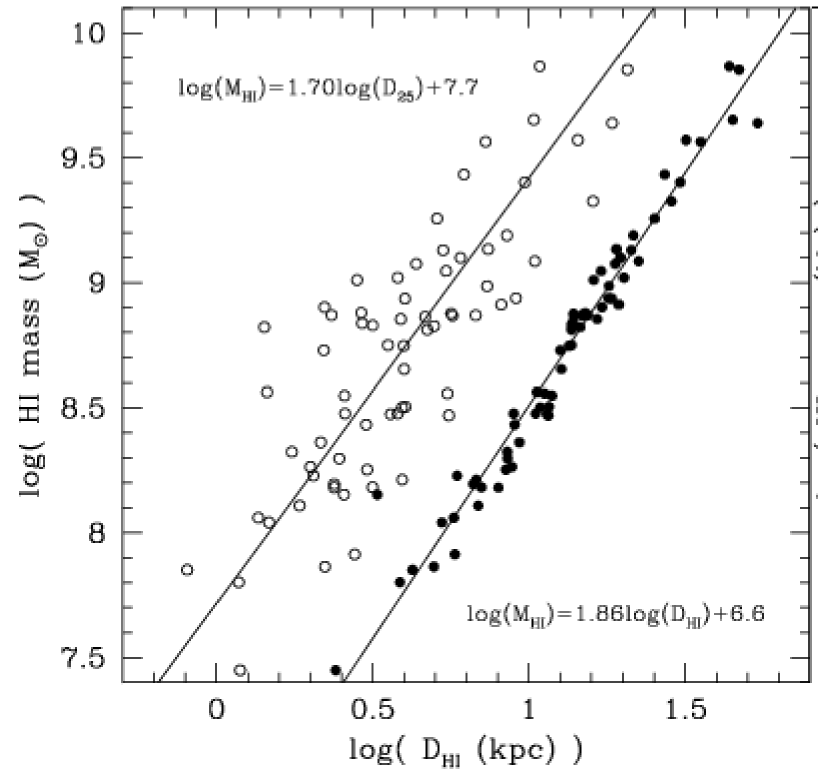
------ $\Sigma_{crit} = \alpha \frac{\kappa c}{3.36 G}$.

Some more on properties

Radial distribution of HI (Wong et al. Ap. & Sp. Sc. 2004, 289, 211):





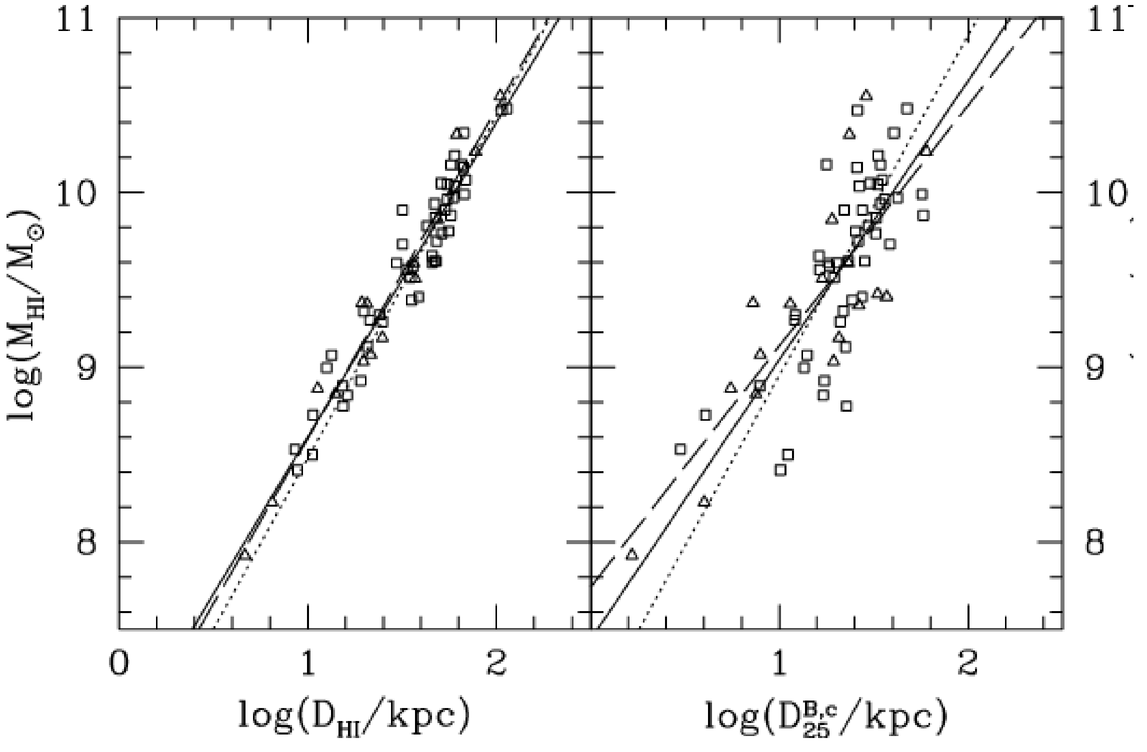


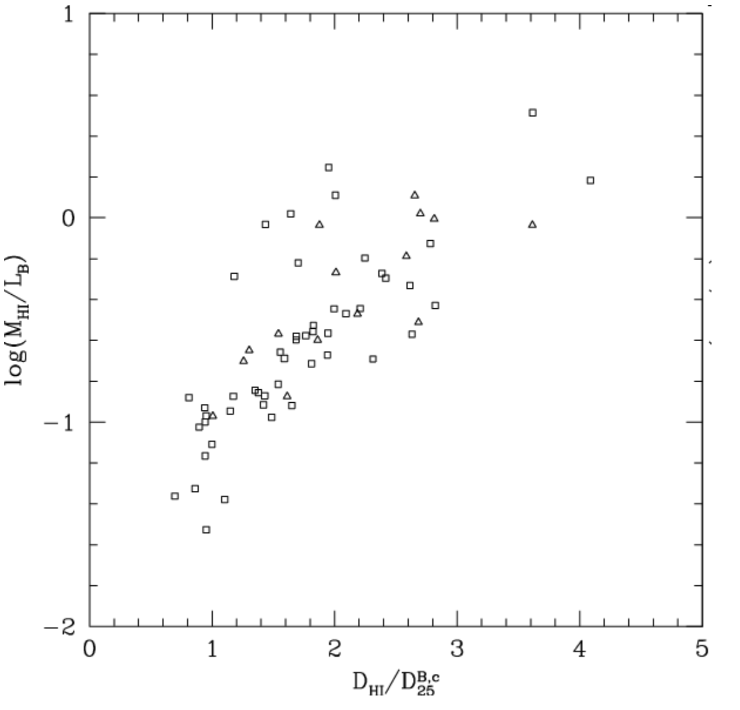
HI mass versus diameter for late type galaxies

Swaters et al. 2002, A&A 390, 829

HI distributions for different types and surface brightnesses

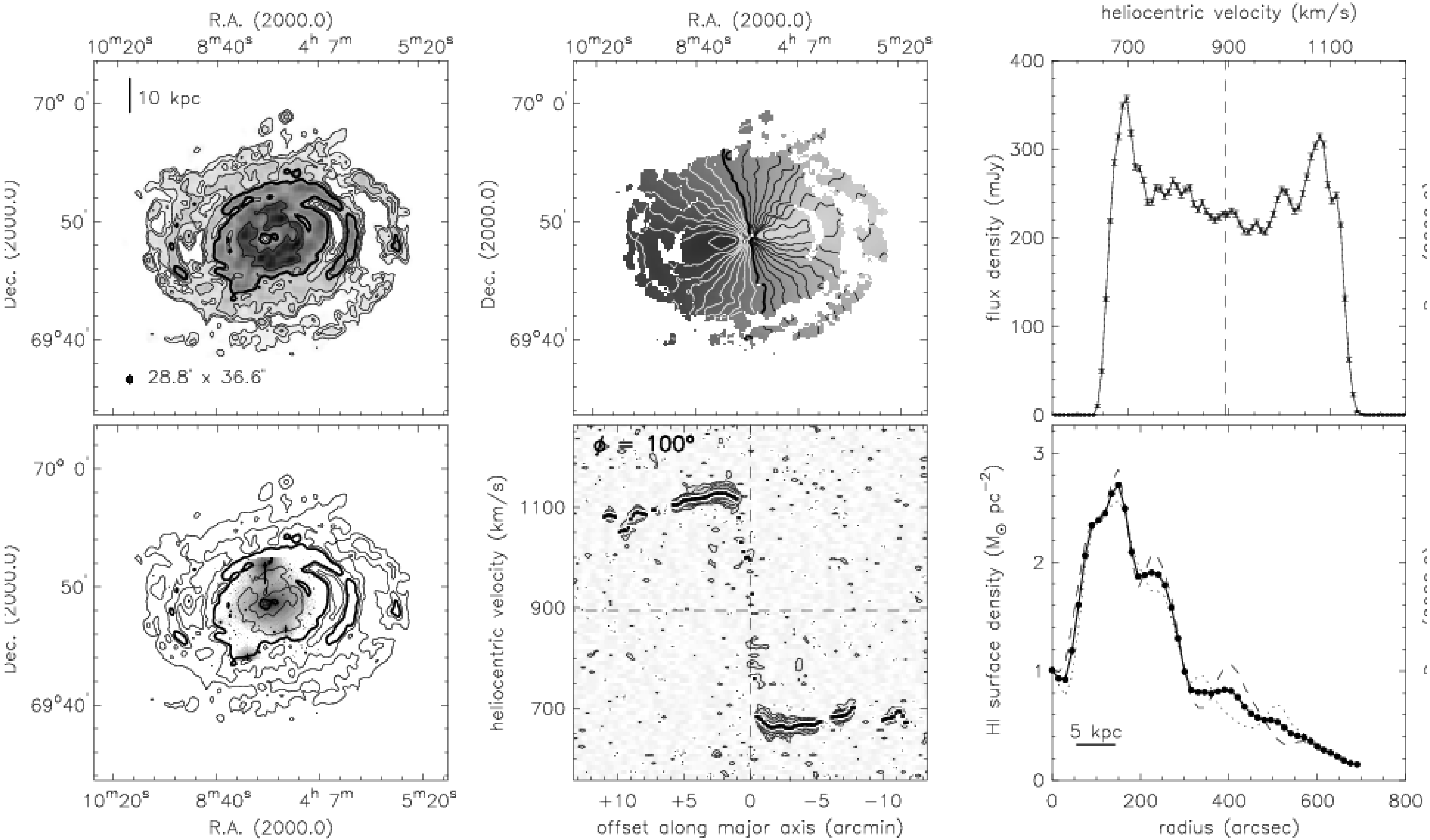
HI properties of early type galaxies





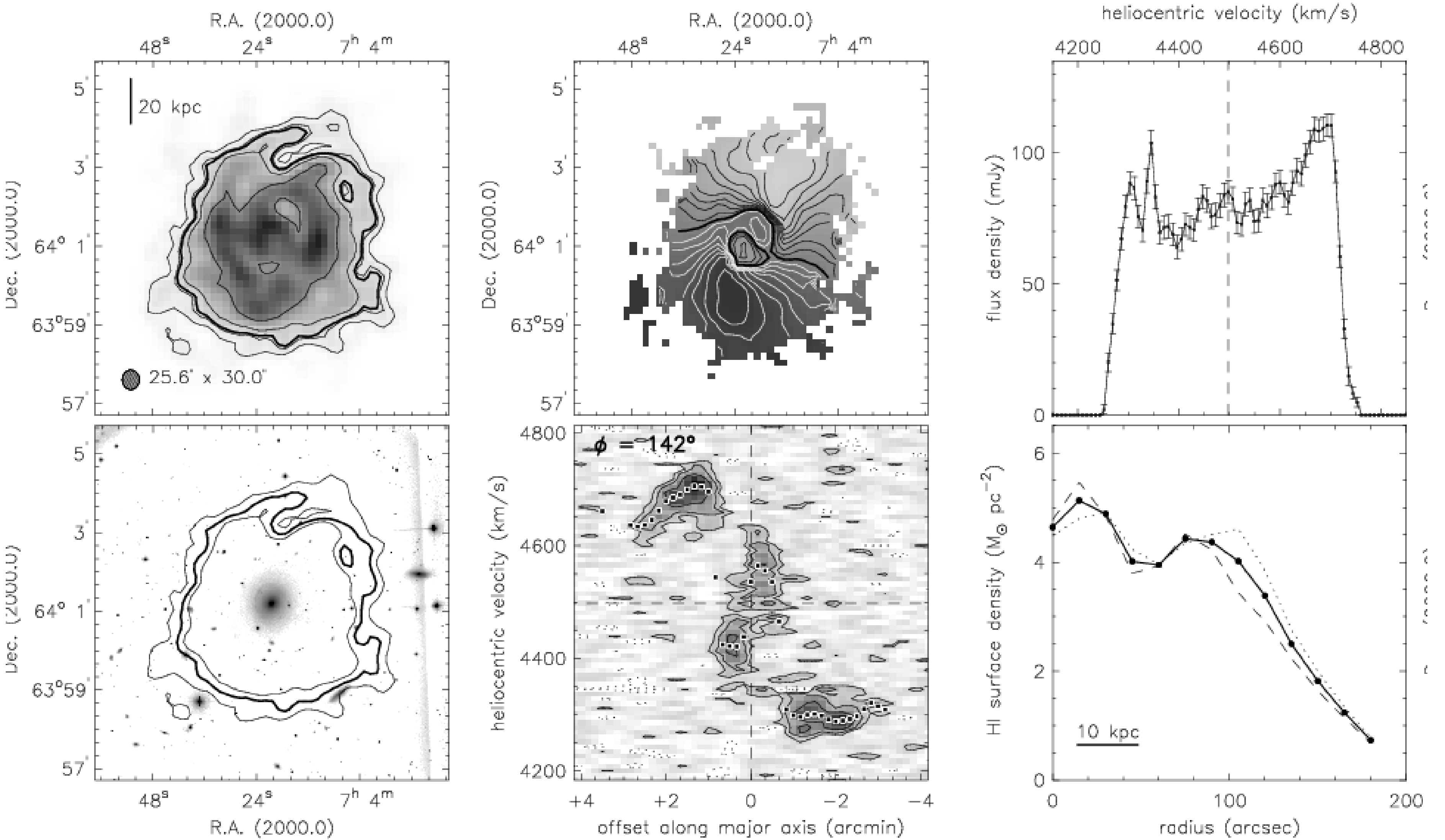
Noordermeer at al. 2005, A&A 442, 137

UGC 2953



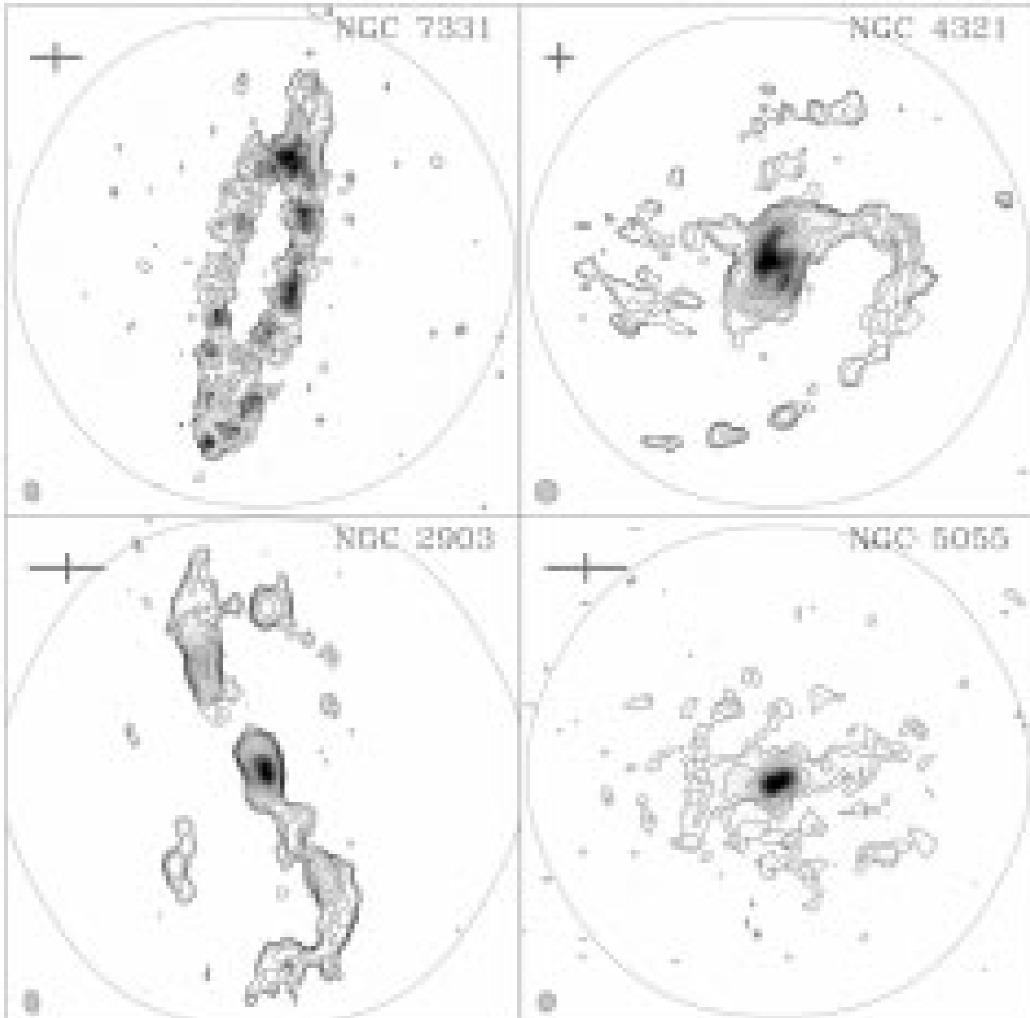
R.A. (2000.0)
10m20s
8m40s
4h 7m
5m20s
Dec. (2000.0)
70° 0'
50'
69°40'
10 kpc
28.8" x 36.6"
heliocentric velocity (km/s)
700
900
1100
flux density (mJy)
0
100
200
300
400
φ = 100°
offset along major axis (arcmin)
+10
+5
0
−5
−10
HI surface density (M⊙ pc−2)
5 kpc
radius (arcsec)
0
200
400
600
800

UGC 3642



R.A. (2000.0)
48s
24s
7h 4m
5'
3'
64° 1'
63°59'
57'
Dec. (2000.0)
20 kpc
25.6" x 30.0"
heliocentric velocity (km/s)
4200
4400
4600
4800
flux density (mJy)
0
50
100
φ = 142°
+4
+2
0
−2
−4
offset along major axis (arcmin)
HI surface density (M⊙ pc−2)
10 kpc
radius (arcsec)
200

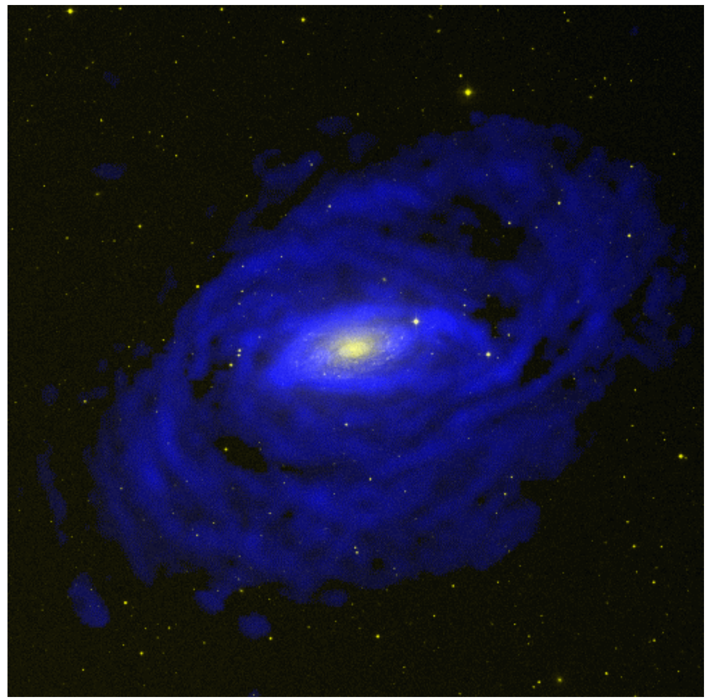
CO mostly confined to the inner parts of galaxies.



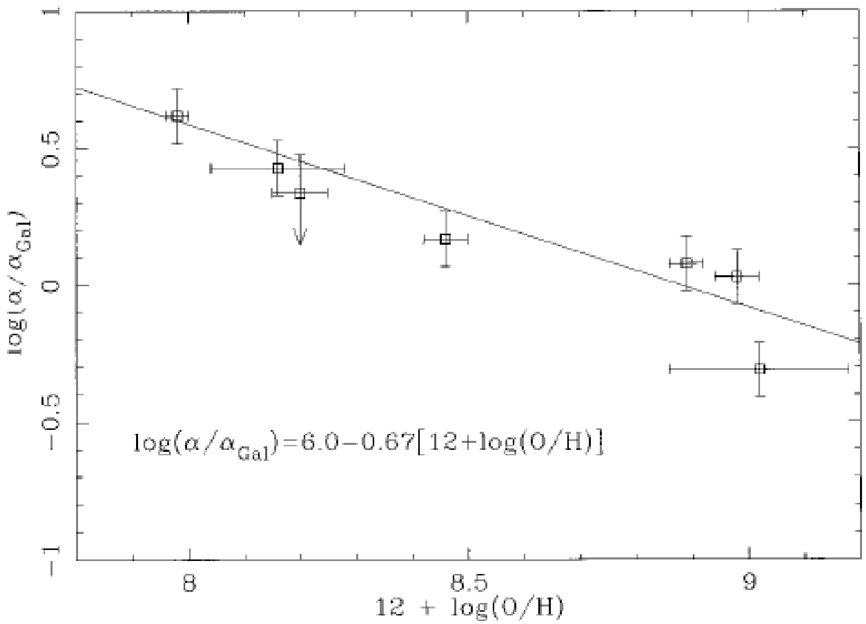
BIMA SONG CO survey

Thornley et al. 1999 Ap&SS. 269, 391

NGC 5055



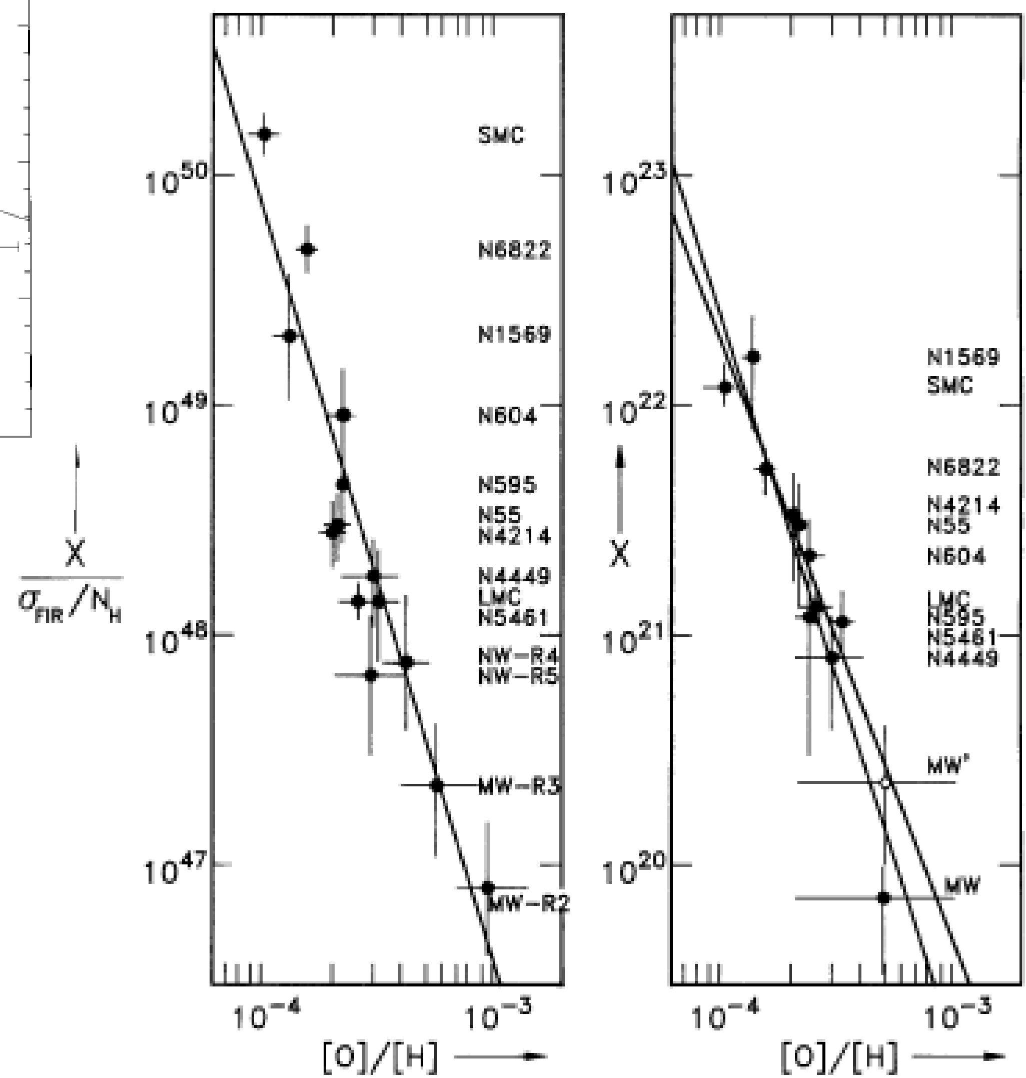
Wilson, 1995, ApJ 448, L97



X : conversion factor from CO luminosity to H_2 column density (depends on metallicity)

$$X = \frac{N(H_2)}{I(CO)} 10^{21} cm^{-2}$$

Israel, 1997, A&A 228, 471



Star formation thresholds

Skillman, NASA Conf. Pub. CP-2466, 263
Kennicutt, 1989, ApJ, 344, 685
Schaye, 2004, ApJ 609, 667

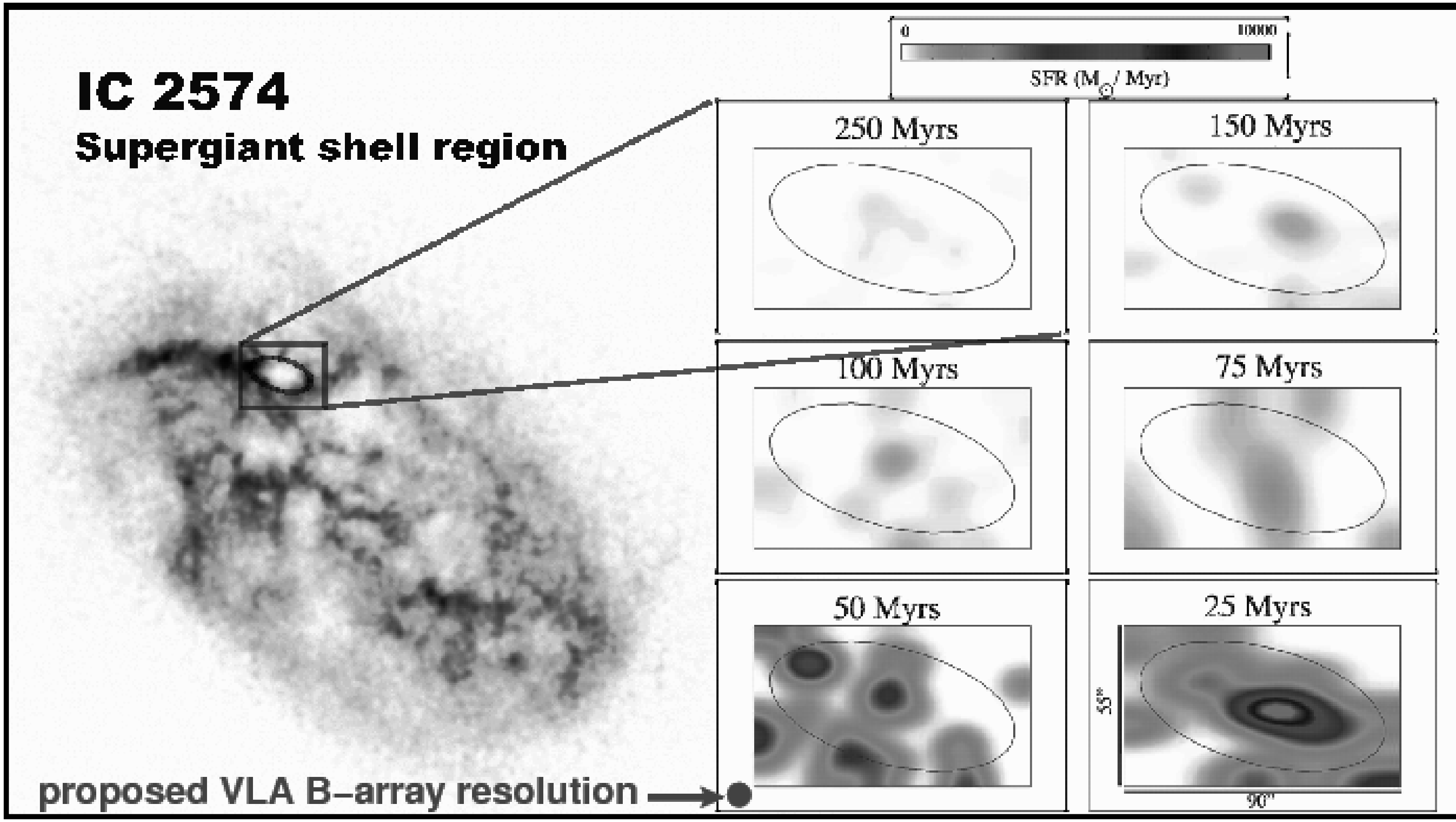
Original idea: if column density exceeds 10^{21} cm^{-2} then star formation will proceed

Dynamical estimate: if surface density exceeds critical density then star formation will proceed

critical density: $$\sum_{crit} = \alpha \frac{\kappa\sigma}{3.36G}$$

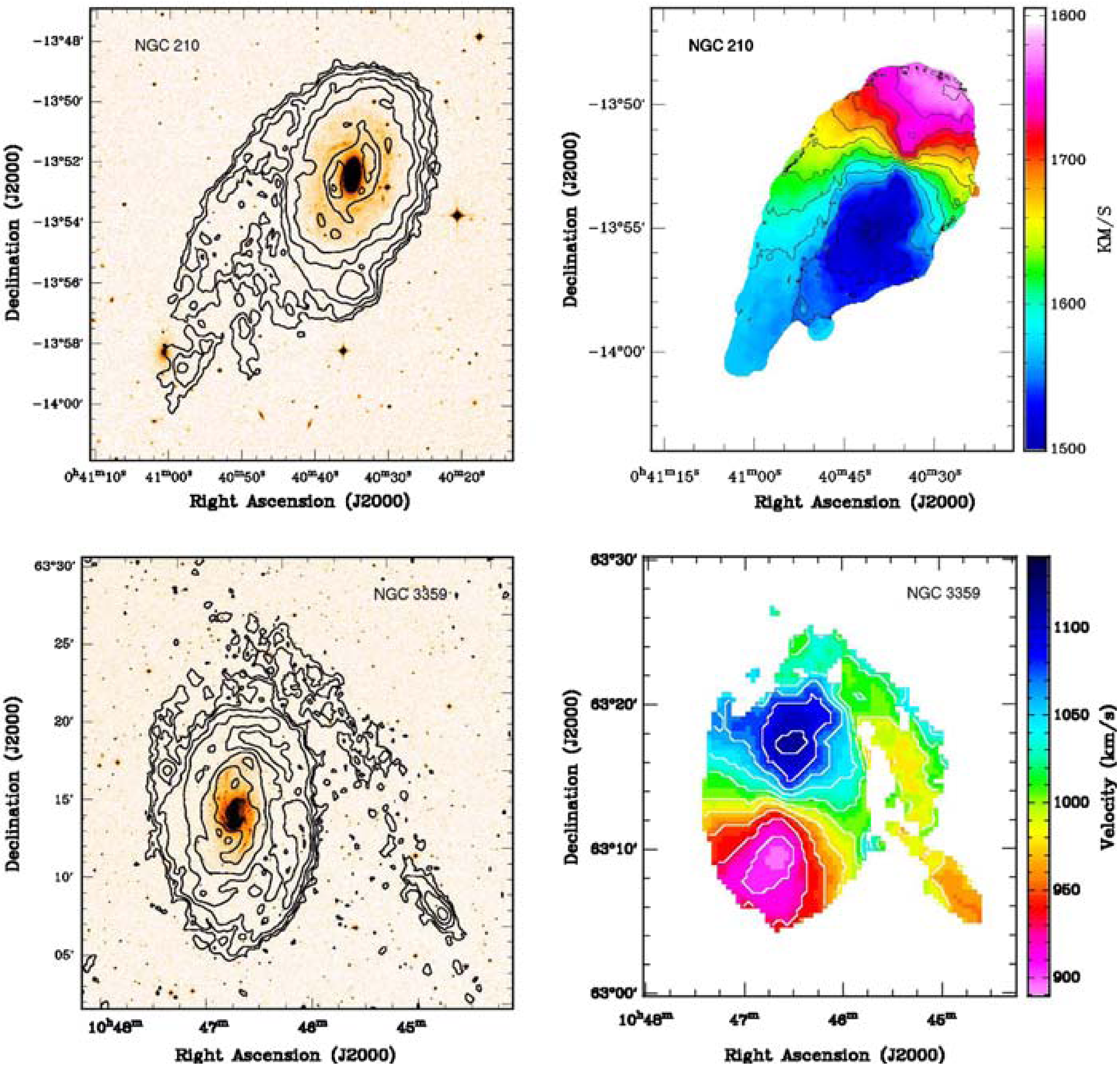
epicyclic frequency: $$\kappa = 1.41 \frac{V}{R}\left(1 + \frac{R}{V}\frac{dV}{dR}\right)^{1/2}$$

Advanced Camera for Surveys Nearby Galaxy Survey Treasury: ANGST



Star formation history (right panels) reconstructed from resolved stellar population studies using ACS on HST.

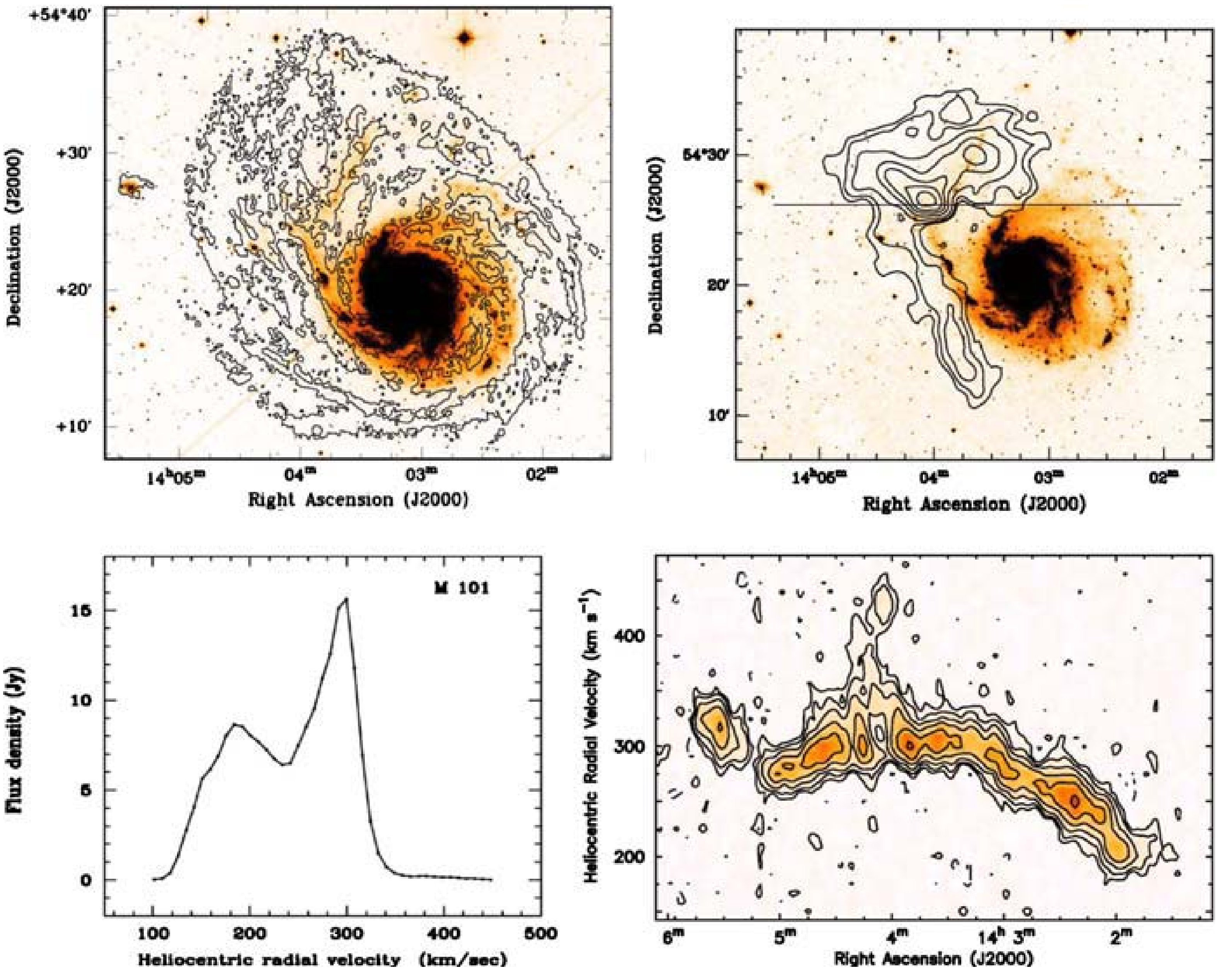
Ott et al. Galaxies in the Local Volume, p.321, 2008, Springer Verl.



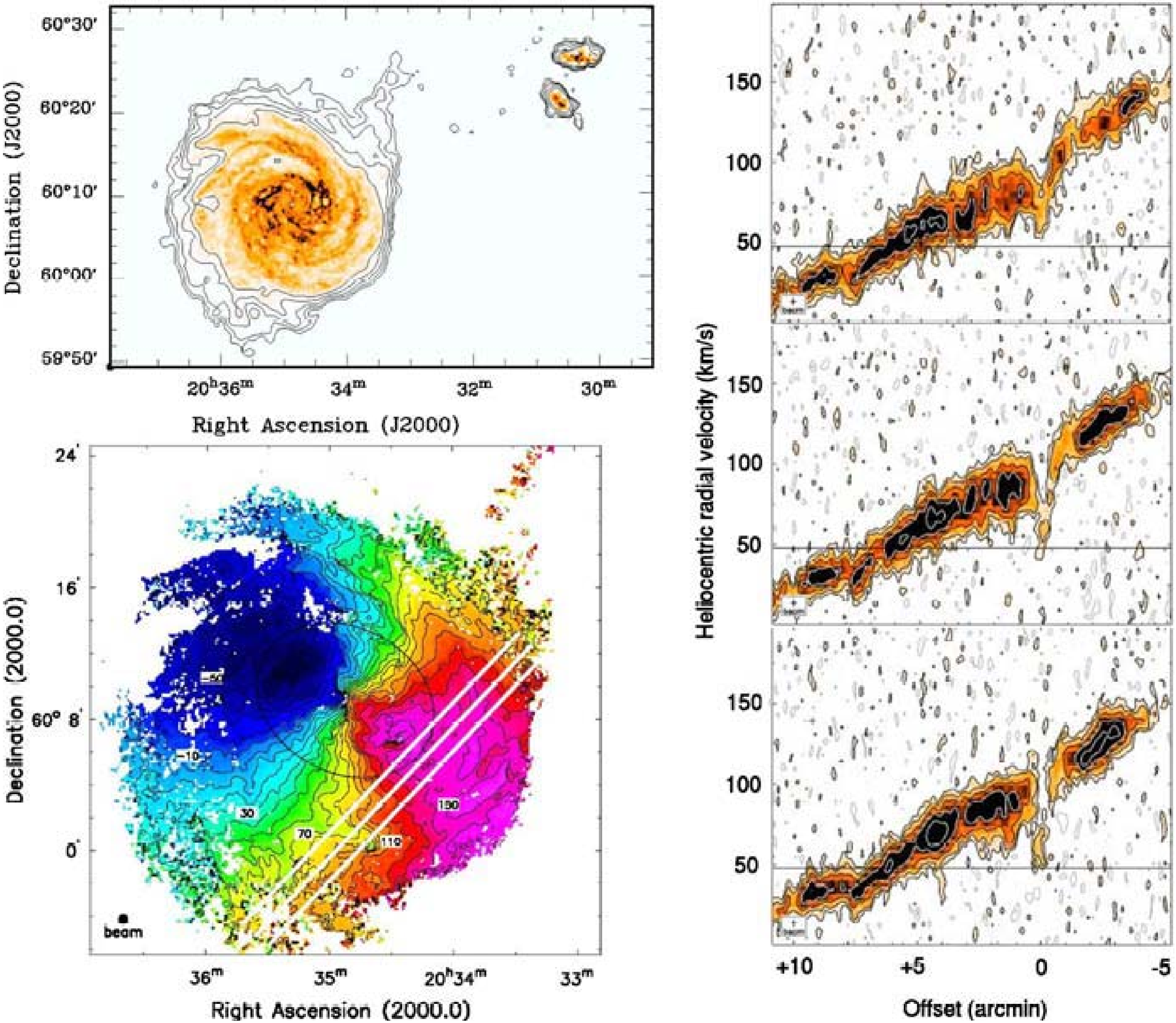
Sancisi et al. 2007
A&ARev 15, 189

Examples of
lopsided galaxies

High velocity gas in M101: first discovery in a lopsided galaxy



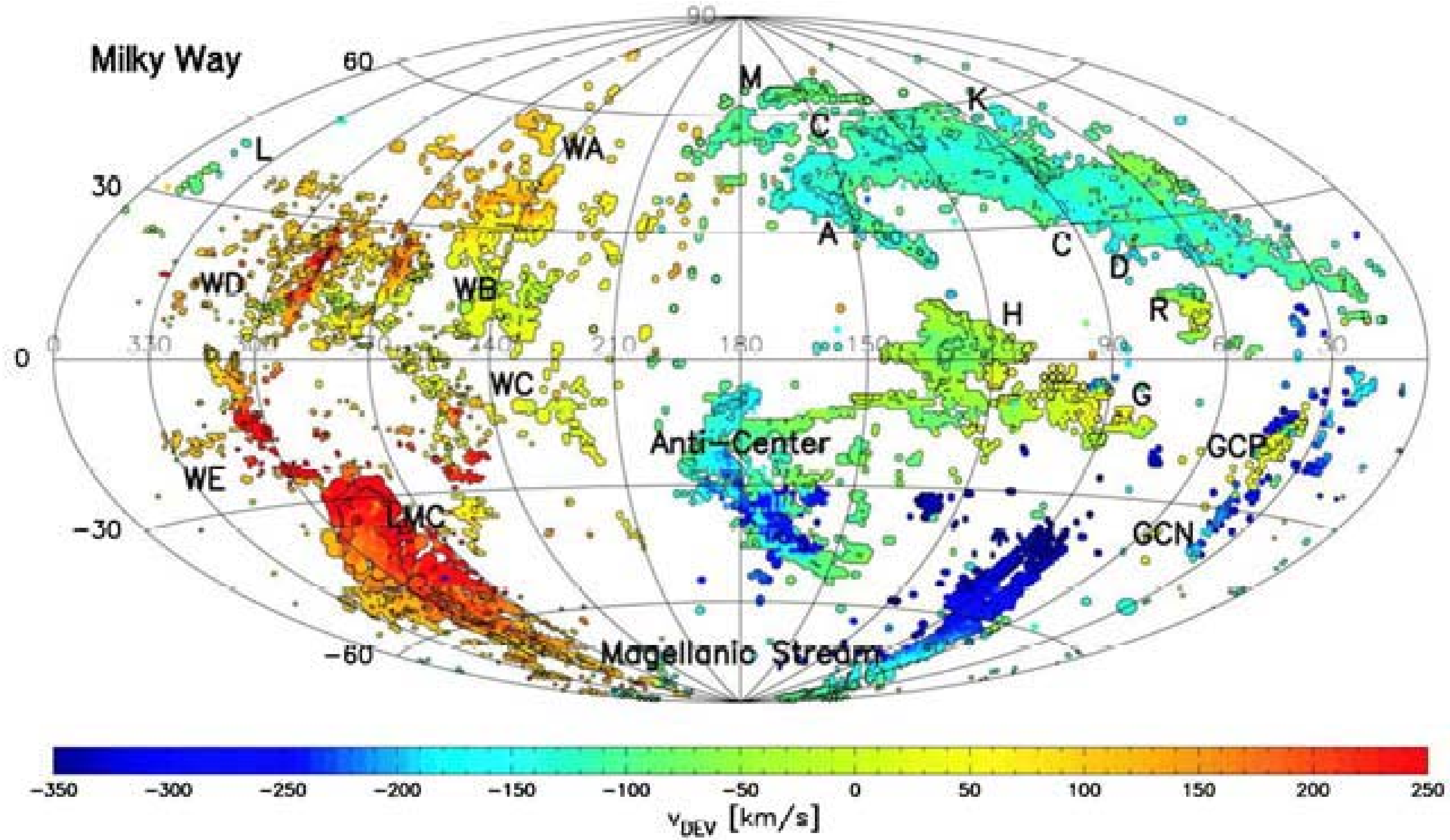
NGC 6946

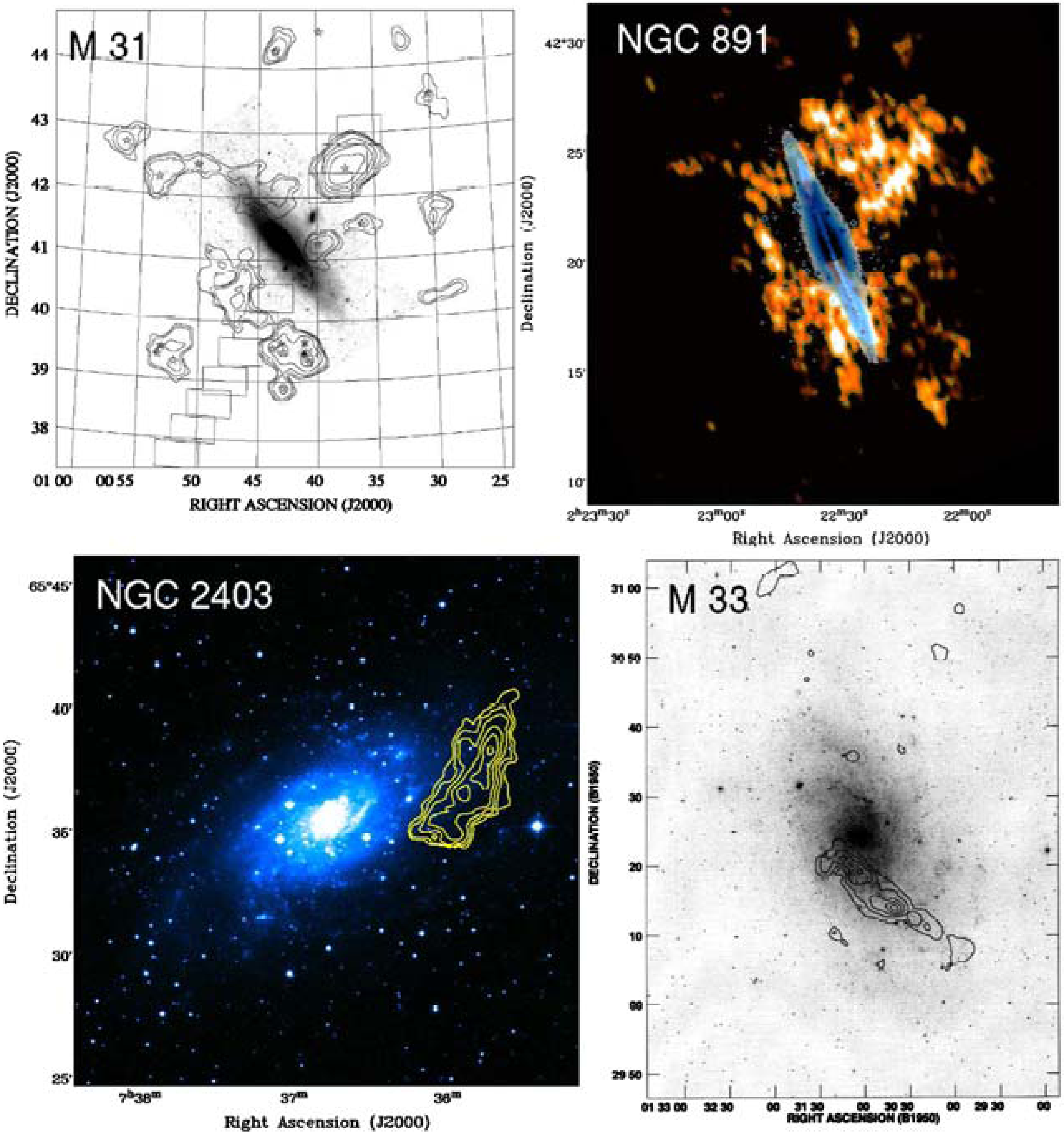


60°30′
60°20′
60°10′
60°00′
59°50′
Declination (J2000)
20h36m
34m
32m
30m
Right Ascension (J2000)
24′
16′
60° 8′
0′
Declination (2000.0)
-50
-10
30
70
110
150
beam
36m
35m
20h34m
33m
Right Ascension (2000.0)
Heliocentric radial velocity (km/s)
150
100
50
+10
+5
0
-5
Offset (arcmin)

High Velocity Clouds in the Milky Way

Wakker et al. 2004, Ap&SS 289, 381



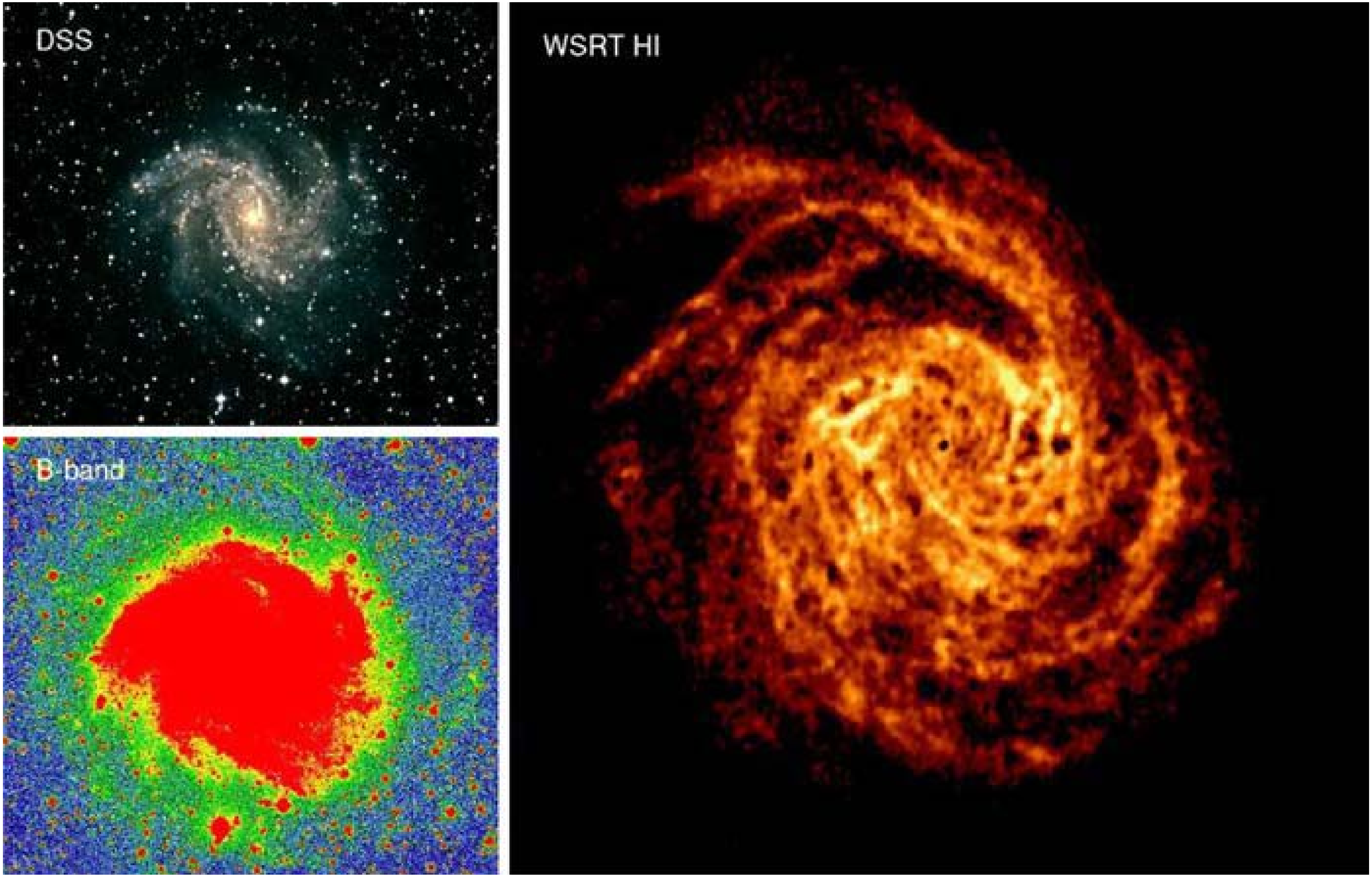


High velocity gas
in other galaxies

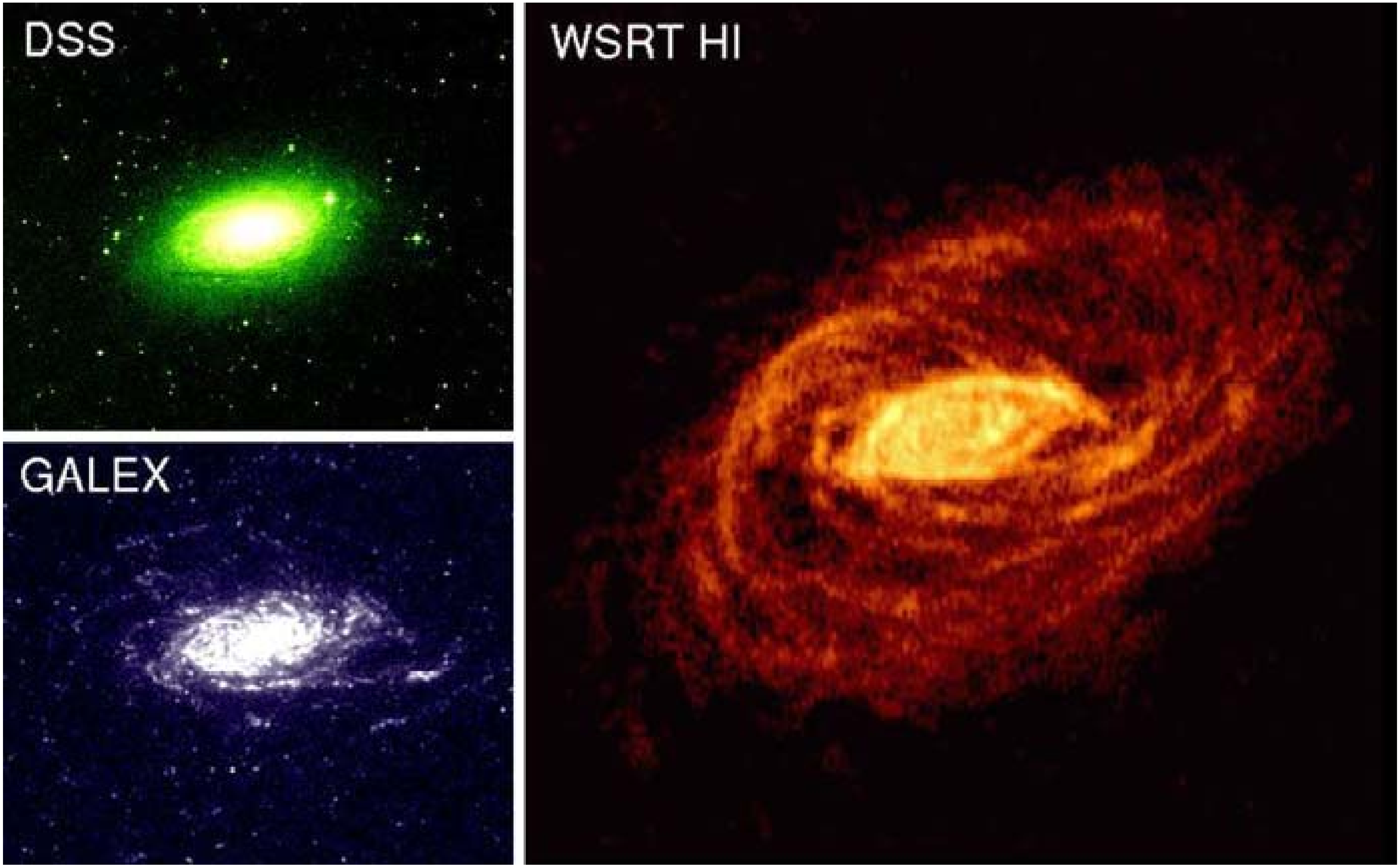
Signs of inflow and
outflow

Sancisi et al. 2008
A&ARev 15, 189

NGC 6946: optical, deep optical and HI

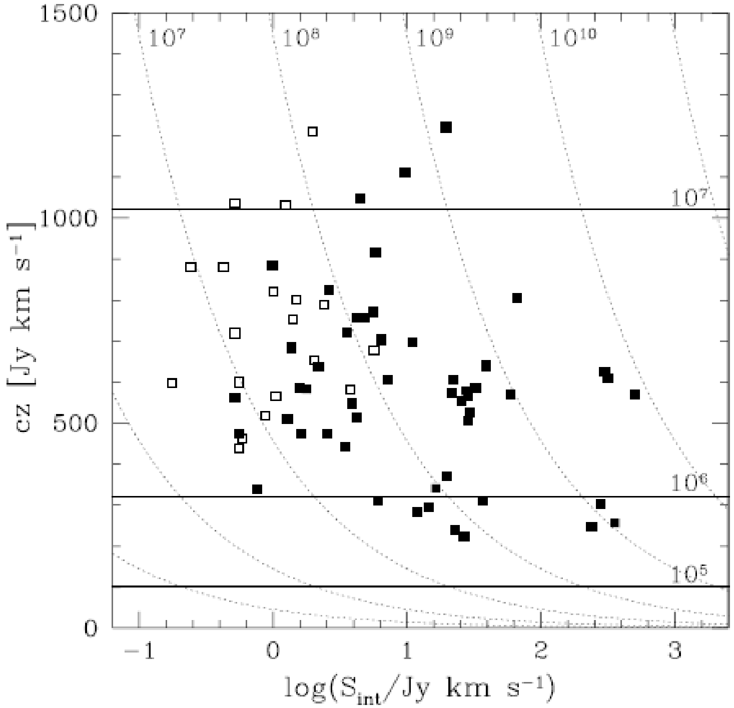


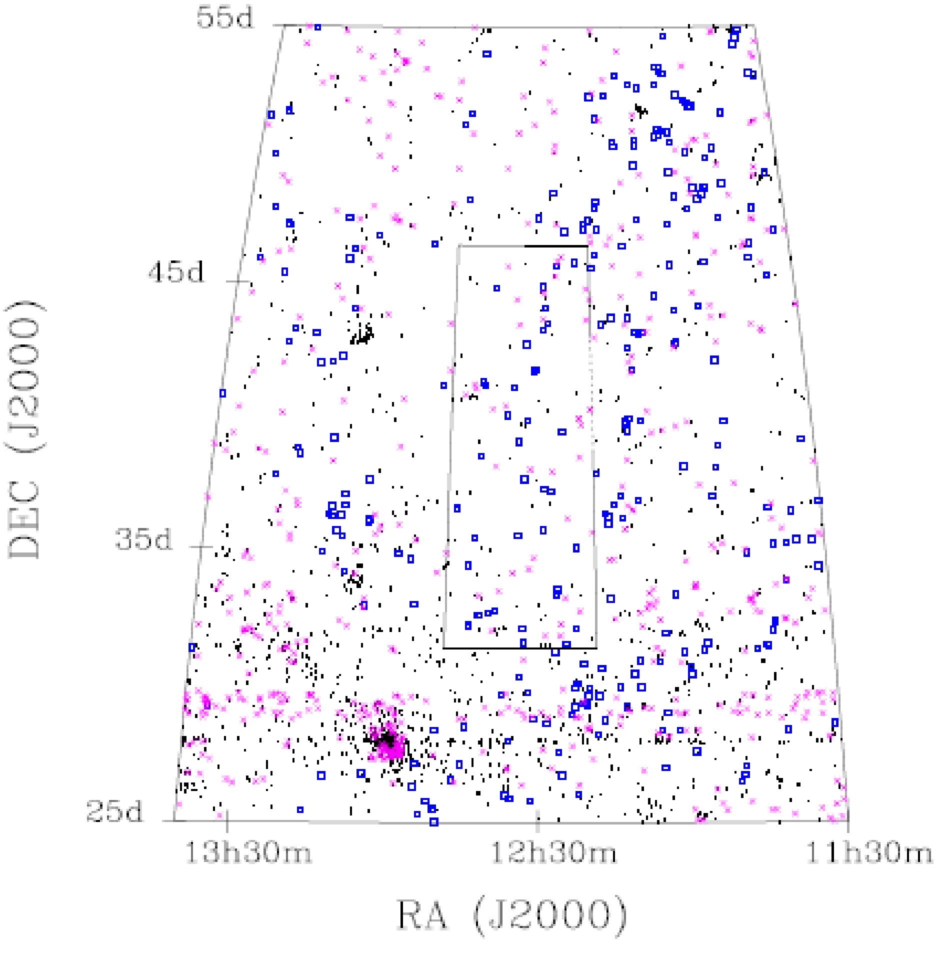
NGC 5055: optical, UV and HI



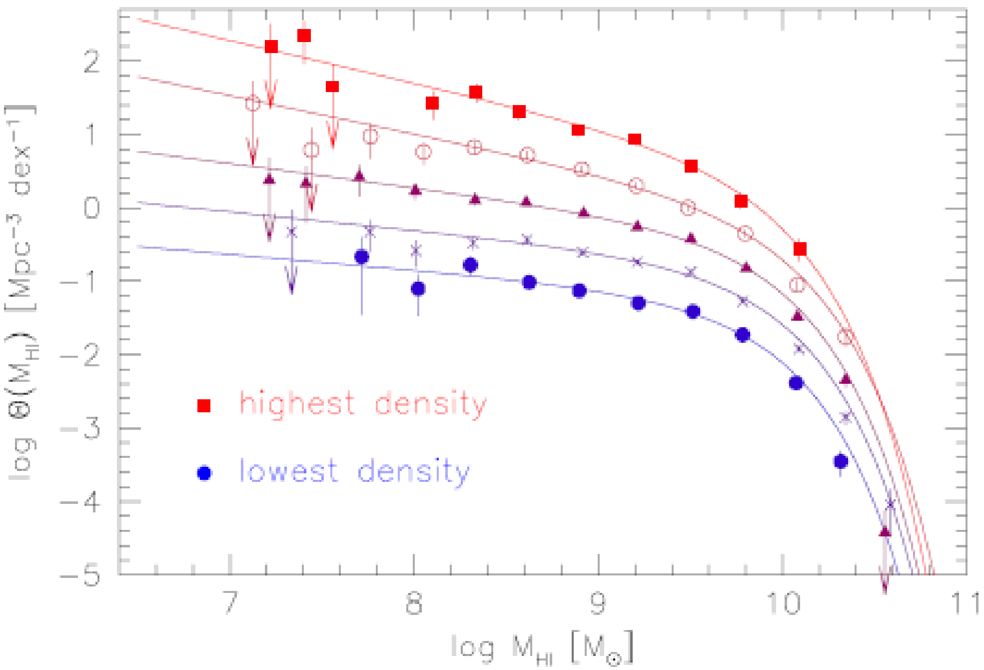
Blind HI surveys

CVn I & II	80 deg2	Kovac et al. 2009 MNRAS 400, 743
		Kovac PhD thesis, Groningen, 2007
AHISS	65	
HIPASS	21346	
ALFALFA	7000	
ADBS	430	
HIJASS	1115	

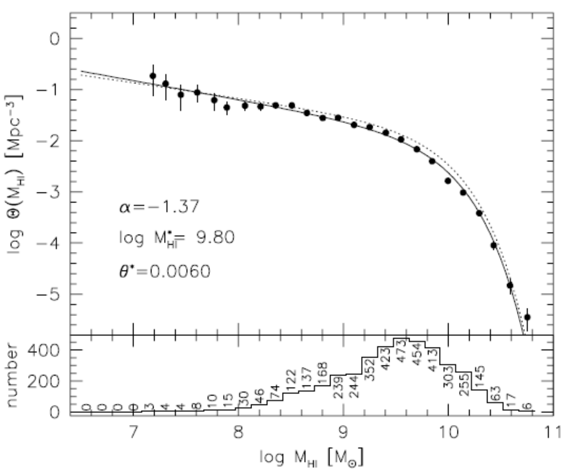




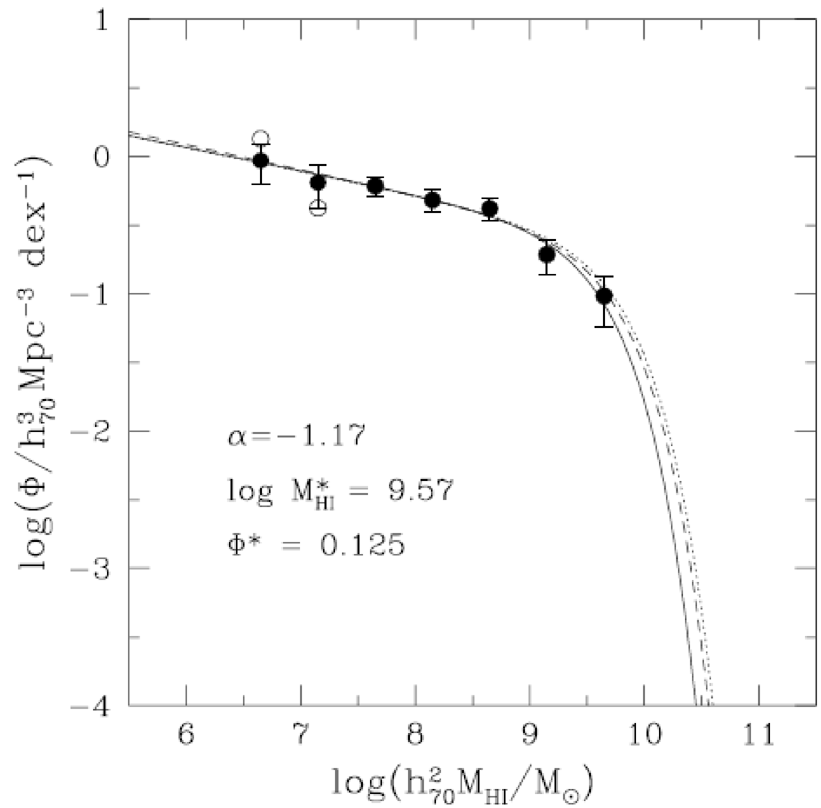
HI mass function for different environments



Zwaan et al. 2005, MNRAS 359, L13



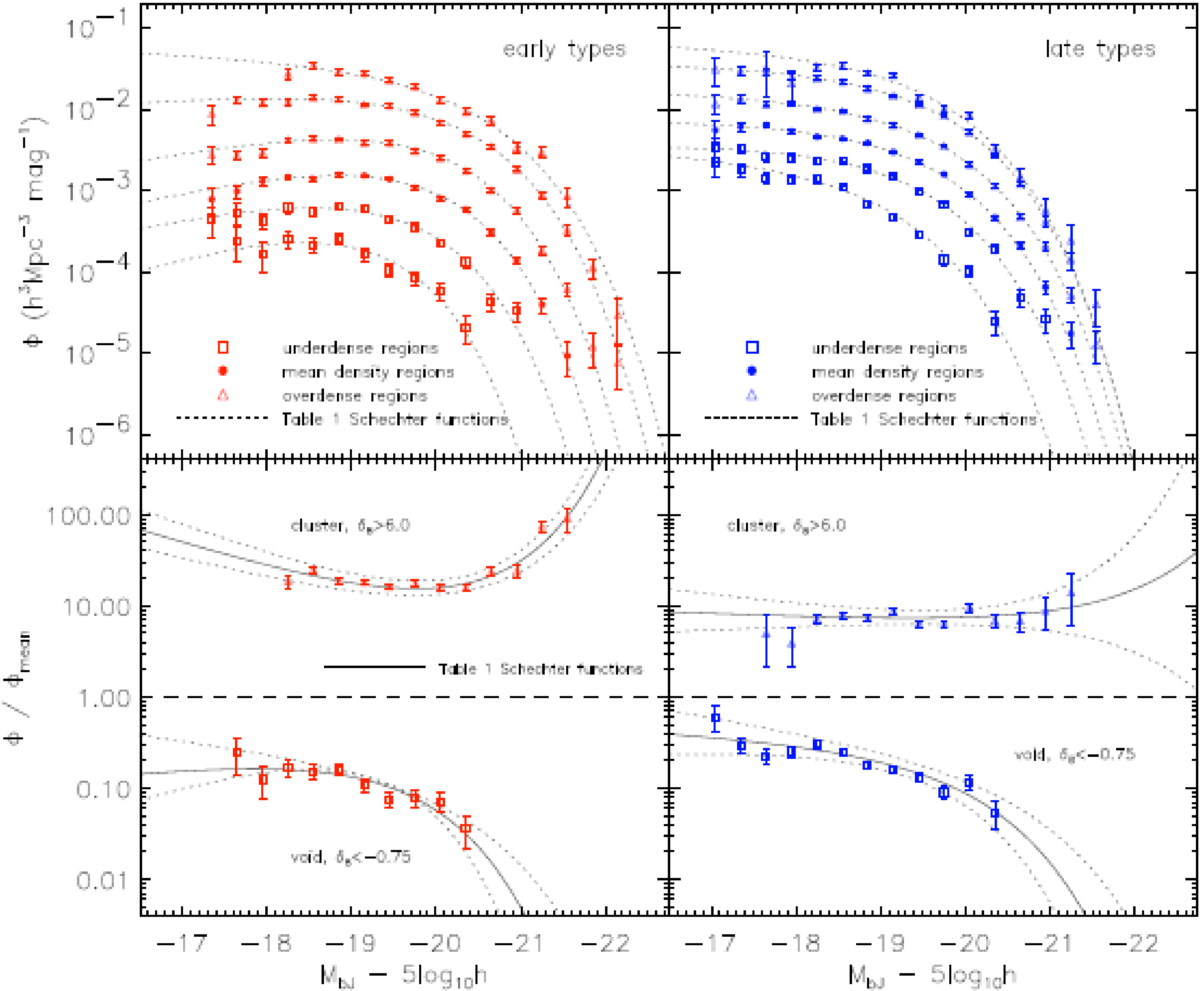
CVn I & II Groups



Kovac, 2007, PhD Thesis

Optical luminosity functions in different environments

Darren et al. 2005, MNRAS 356, 1155



HI Mass Function may probe average galaxy evolution

Variation with environment possible but uncertain

Optical luminosity functions show the same behaviour
slight steepening of the faint end in denser regions