Star Formation Rate and Neutral Gas Content as a Function of Redshift and Environment

Philip Lah

Collaborators:
Mike Pracy, Jayaram Chengalur, Frank Briggs, Matthew Colless

Research School of Astronomy & Astrophysics

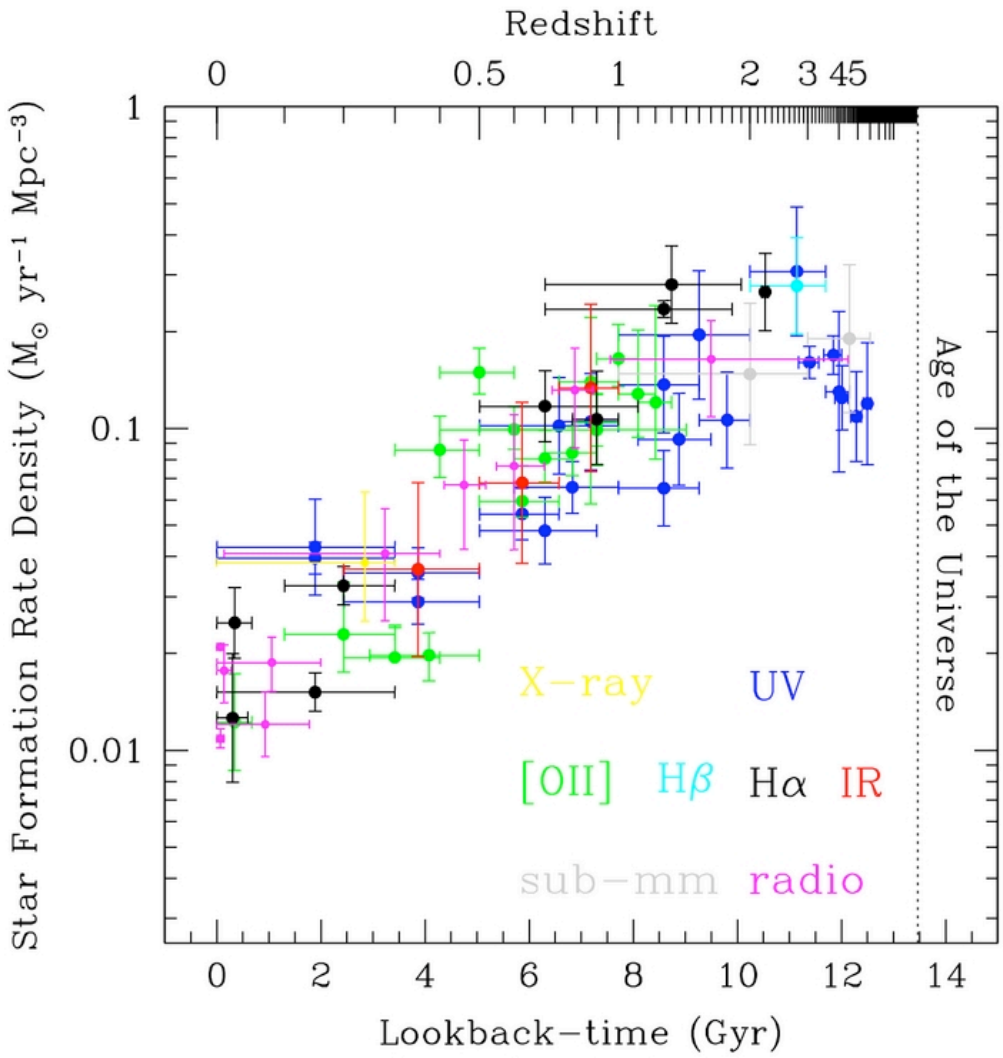
Mount Stromlo Observatory

THE AUSTRALIAN NATIONAL UNIVERSITY

Galaxy Metabolism:
Galaxy Evolution Near and Far 2009

The
Star Formation Rate
Density
of the Universe

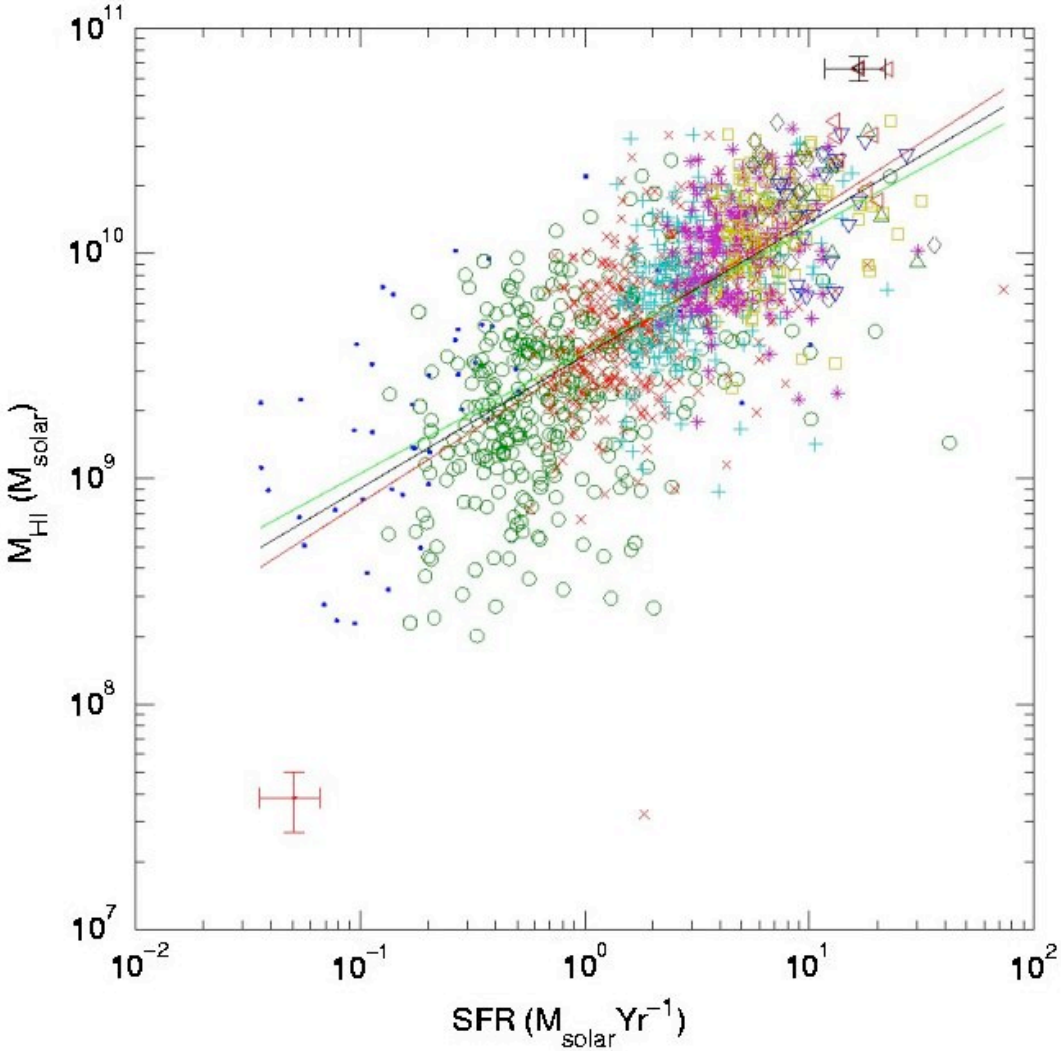
Star Formation Rate Density Evolution



Compilation
by Hopkins
2004

Galaxy HI mass
vs
Star Formation Rate

Galaxy HI Mass vs Star Formation Rate



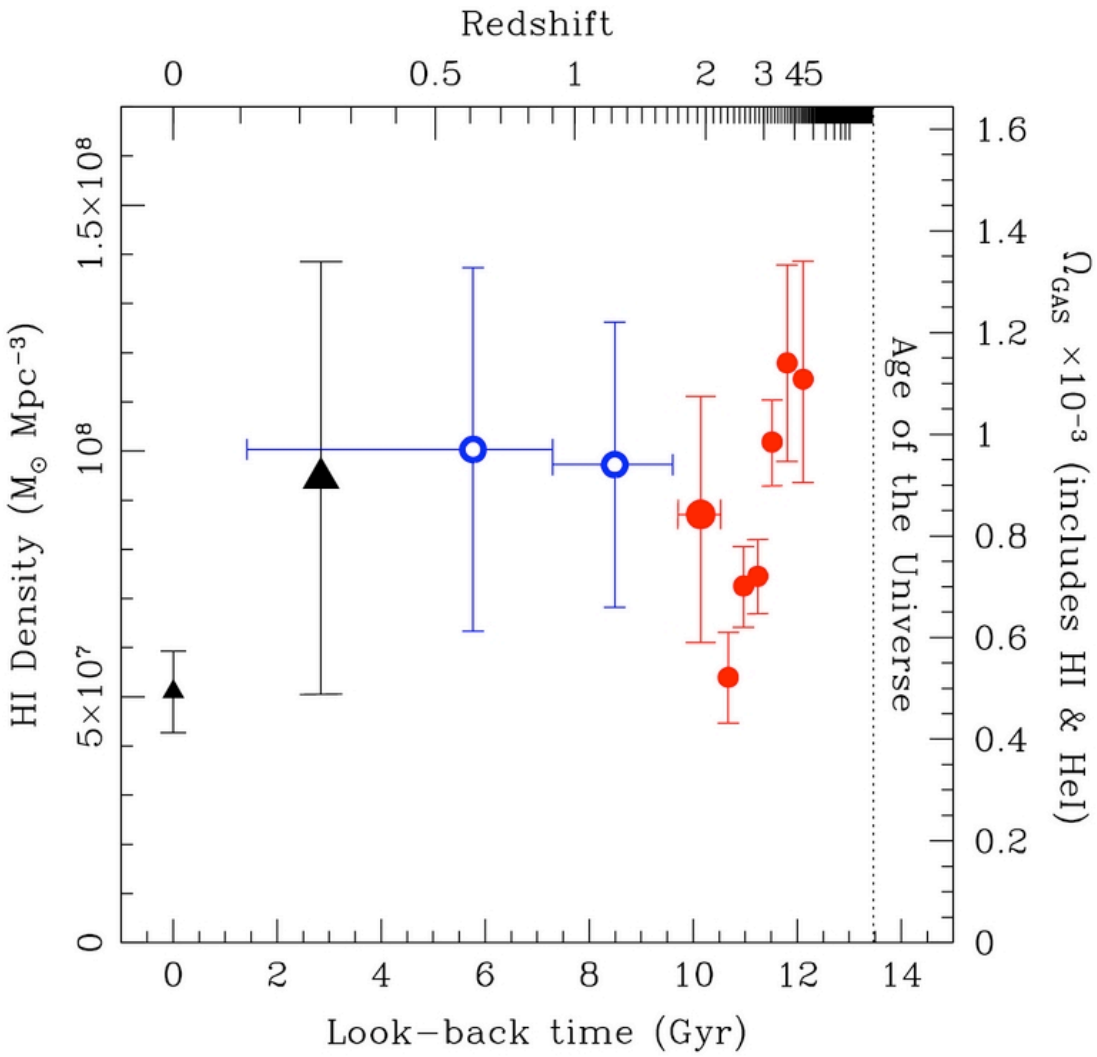
HIPASS
&
IRAS
data
z ~ 0

Doyle &
Drinkwater
2006

The
HI Gas Density
of the Universe

HI Gas Density Evolution

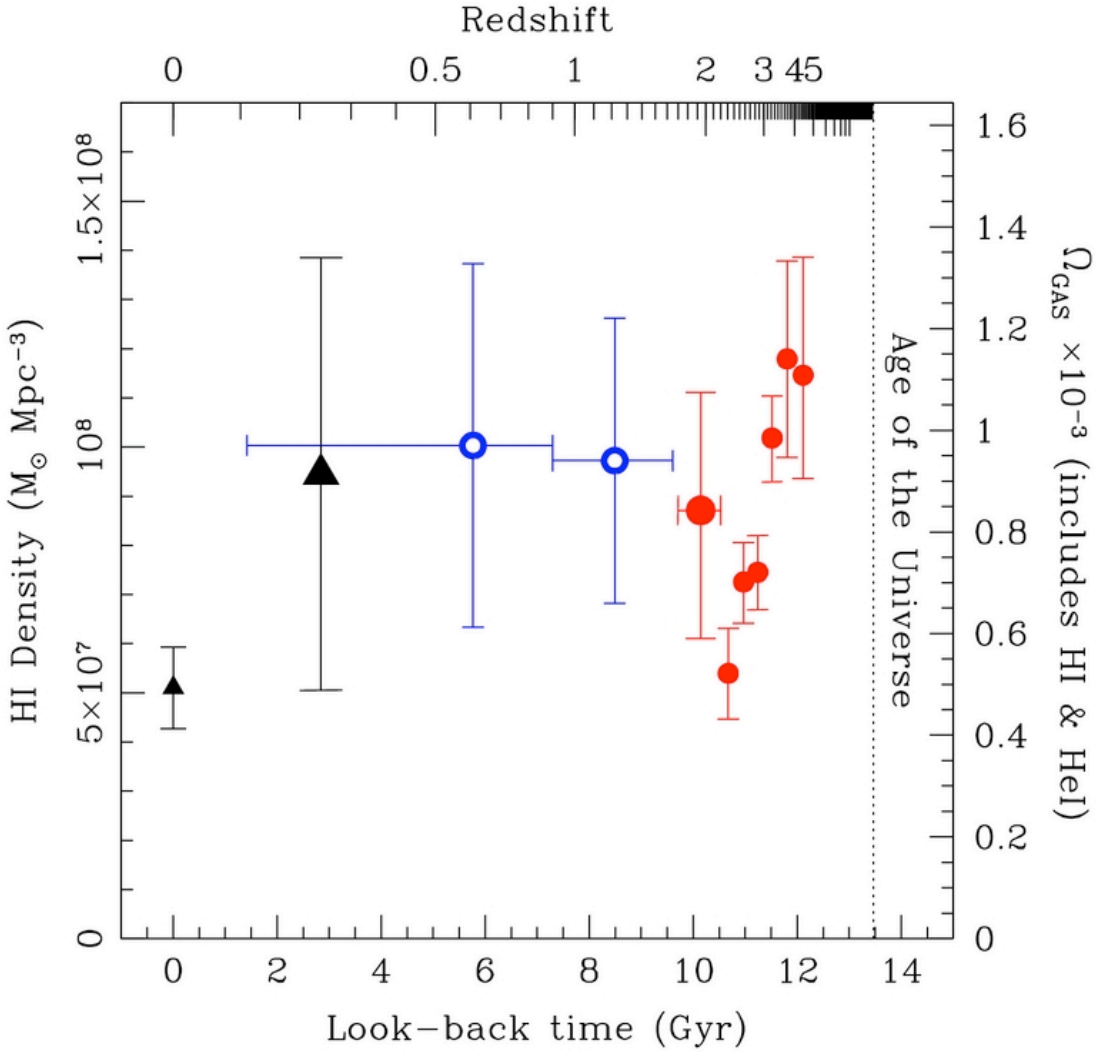
Not a log scale



HI Gas Density Evolution

Lah et al. 2007 coadded HI 21cm

Zwaan et al. 2005 HIPASS HI 21cm



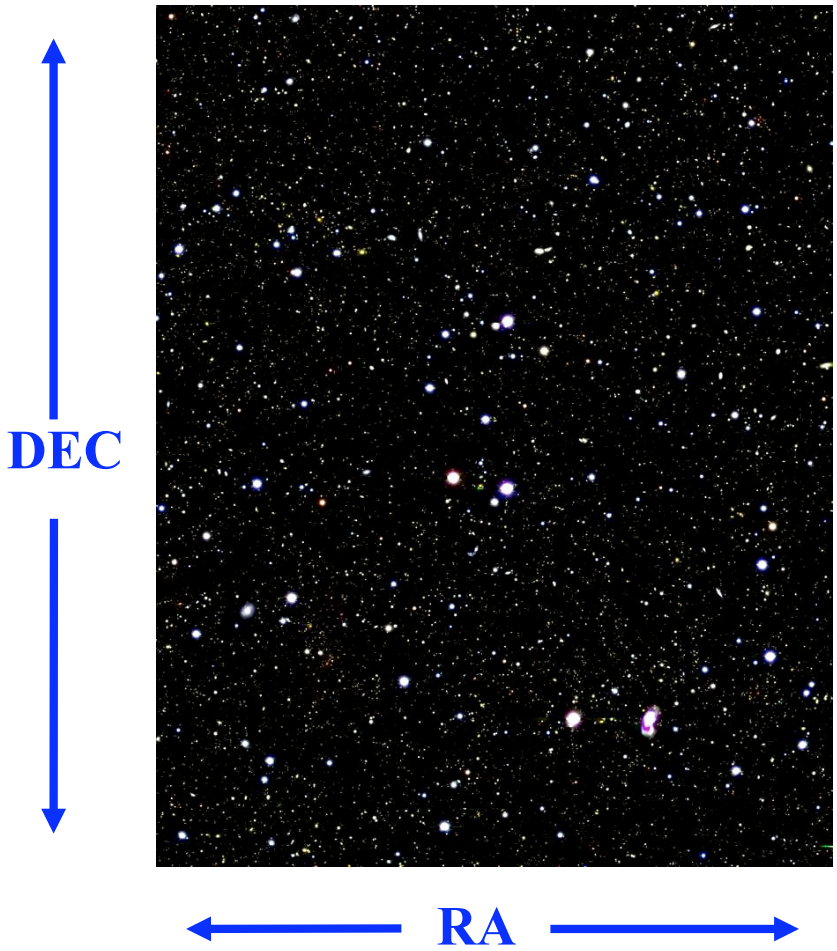
Prochaska et al. 2005 & 2009 DLAs

Rao et al. 2006 DLAs from MgII absorption

The Fujita galaxies

Hα emission galaxies at z = 0.24

The Fujita Galaxies



Subaru Field 24’ × 30’

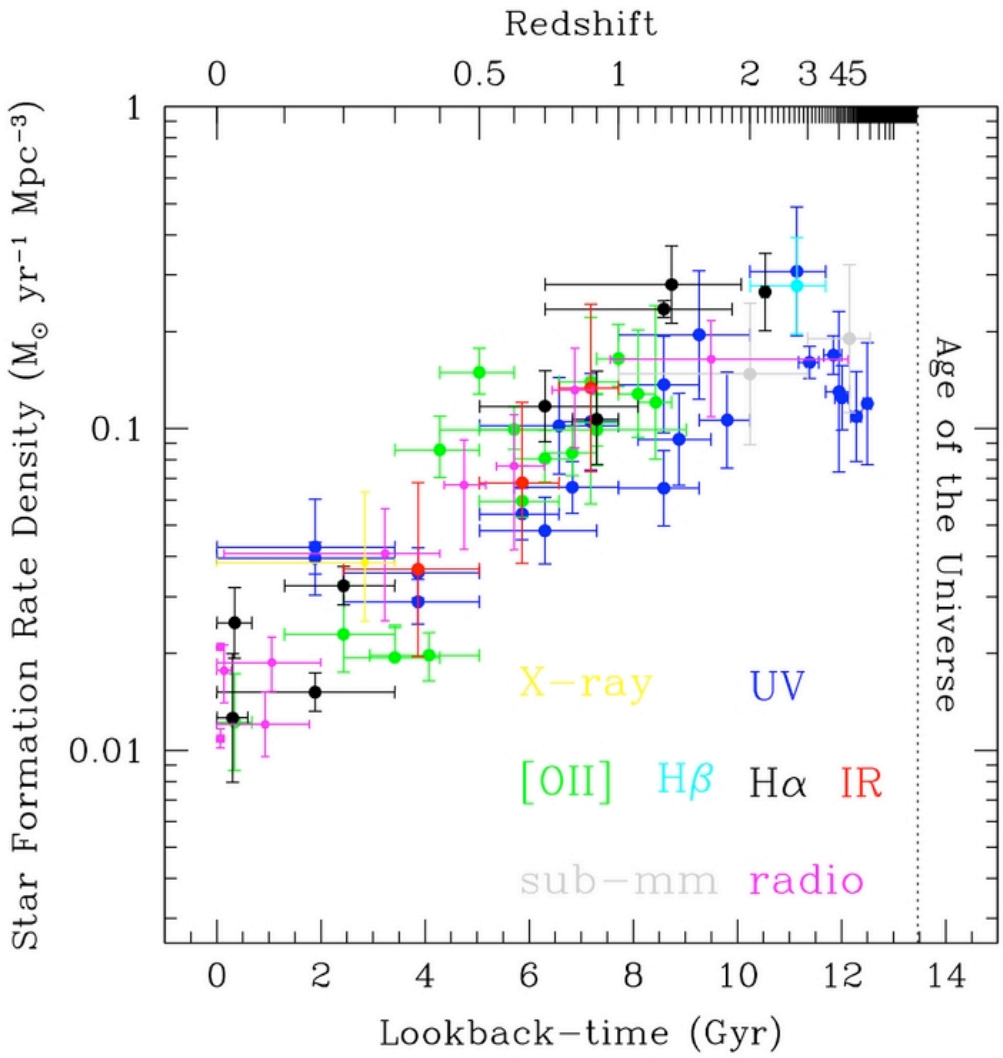
narrow band imaging ⇨
Hα emission at z = 0.24
(Fujita et al. 2003,
ApJL, 586, L115)

348 Fujita galaxies

121 redshifts using AAT

GMRT ~48 hours on field

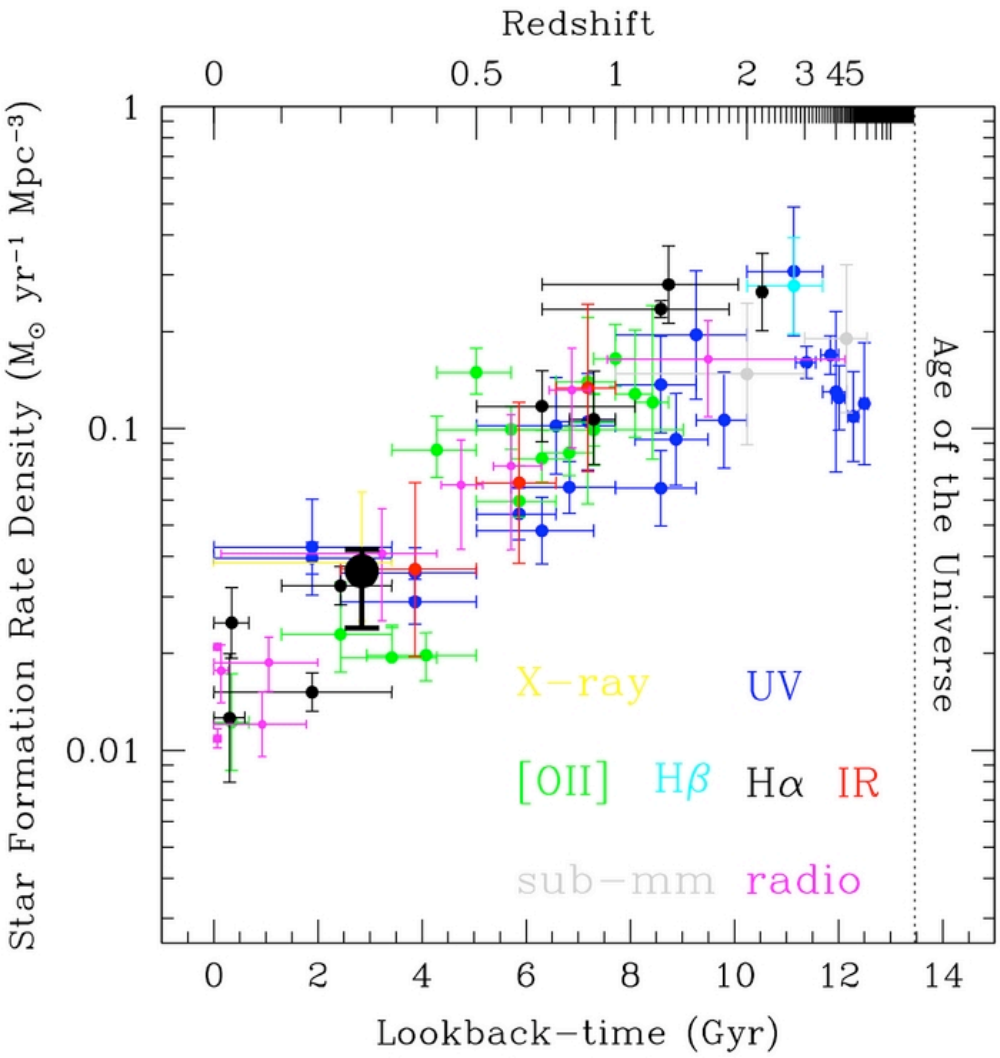
Star Formation Rate Density Evolution



Compilation
by Hopkins
2004

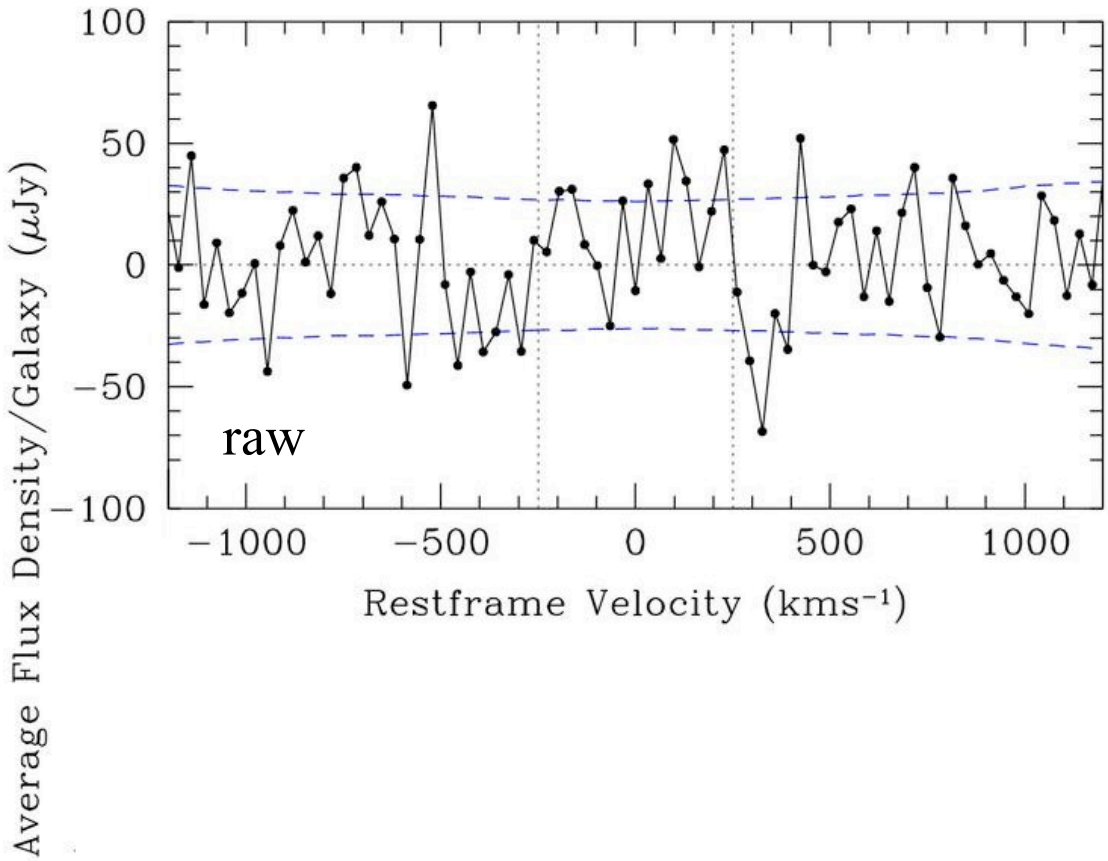
Star Formation Rate Density Evolution

Fujita et al. 2003 value



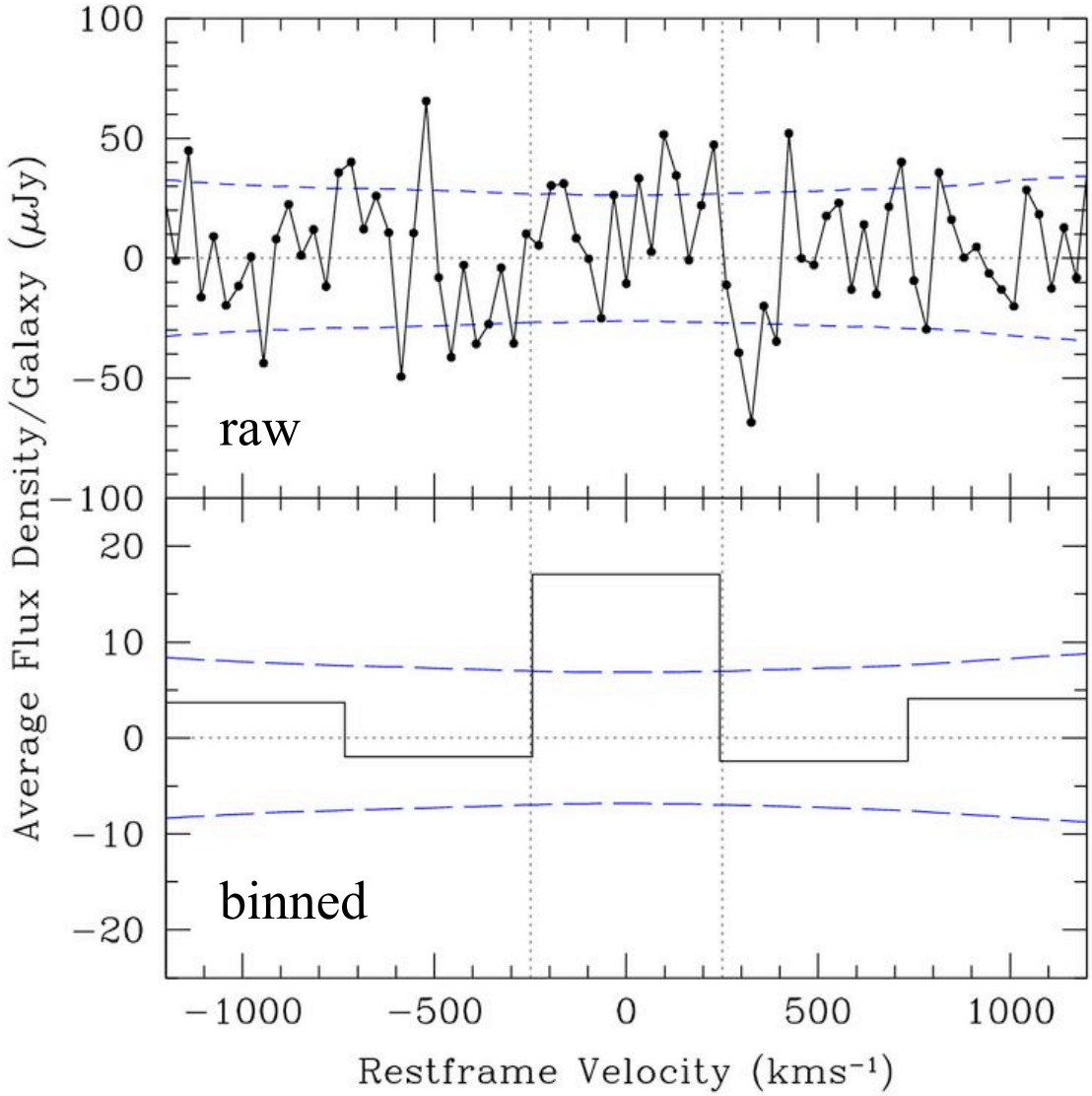
Compilation by Hopkins 2004

Coadded
HI
Spectrum



Fujita galaxies coadded HI spectrum

using 121 redshifts
- weighted average



Fujita galaxies coadded HI spectrum

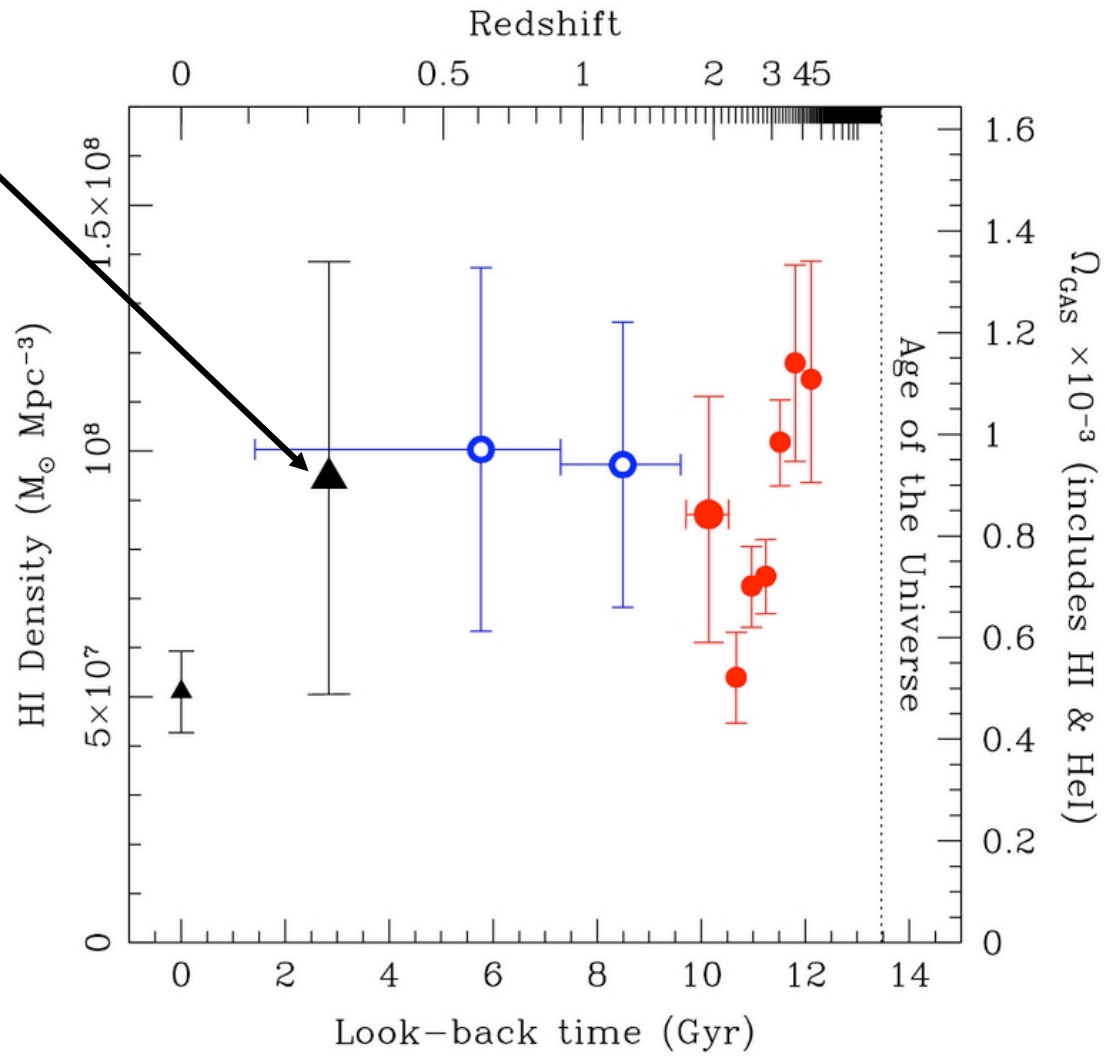
using 121 redshifts - weighted average

$$M_{HI} = (2.26 \pm 0.90) \times 10^9 \, M_\odot$$

The
HI Gas Density
of the Universe

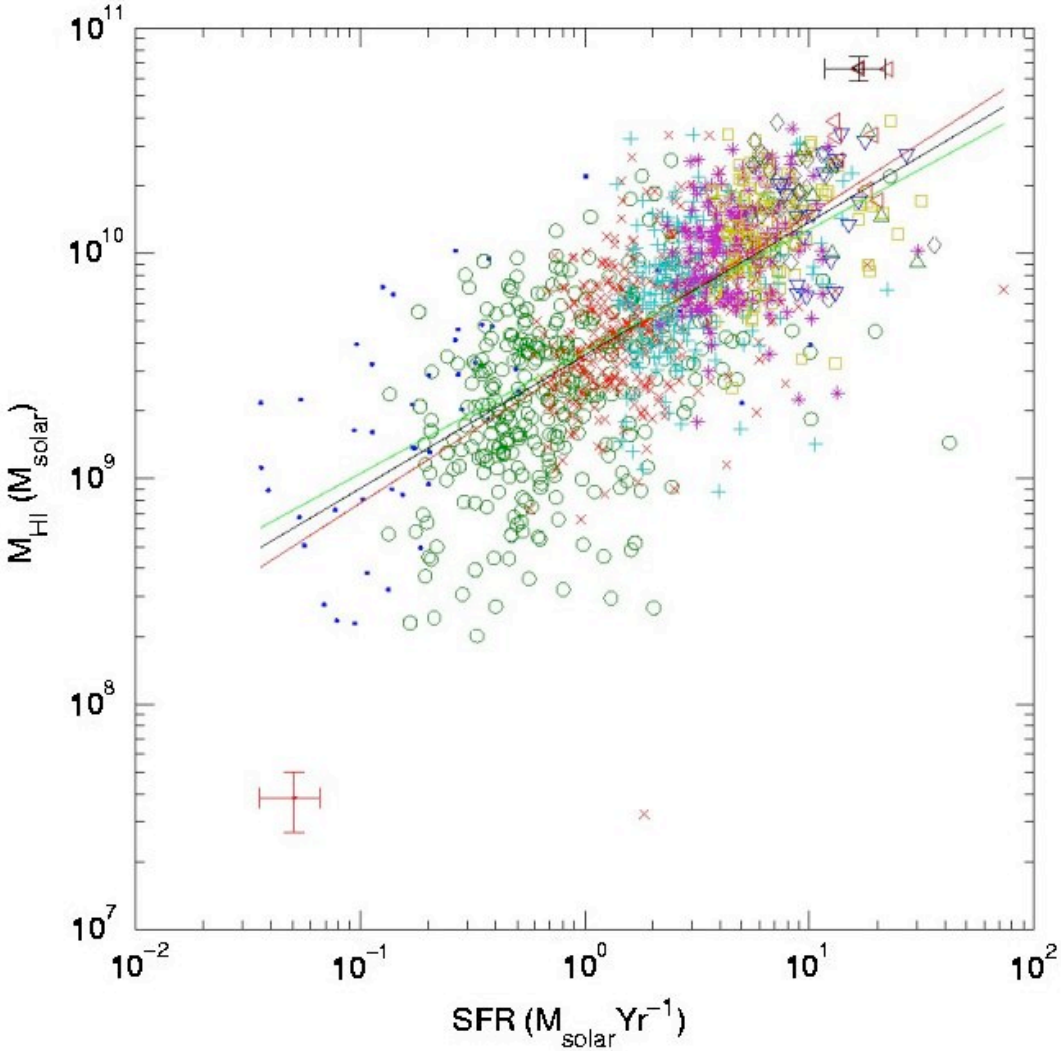
HI Gas Density Evolution

Lah et al. 2007 coadded HI 21cm



Galaxy HI mass
vs
Star Formation Rate

Galaxy HI Mass vs Star Formation Rate

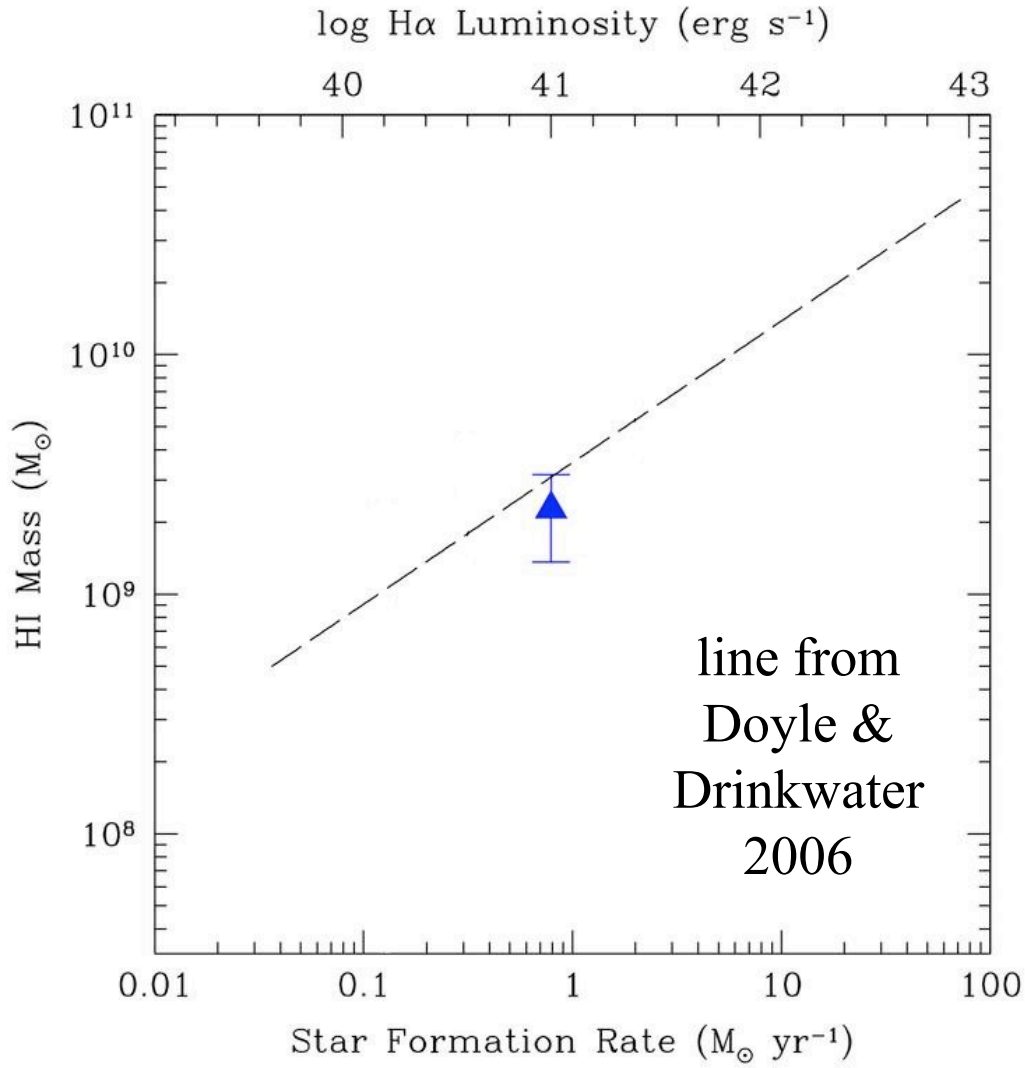


HIPASS
&
IRAS
data
z ~ 0

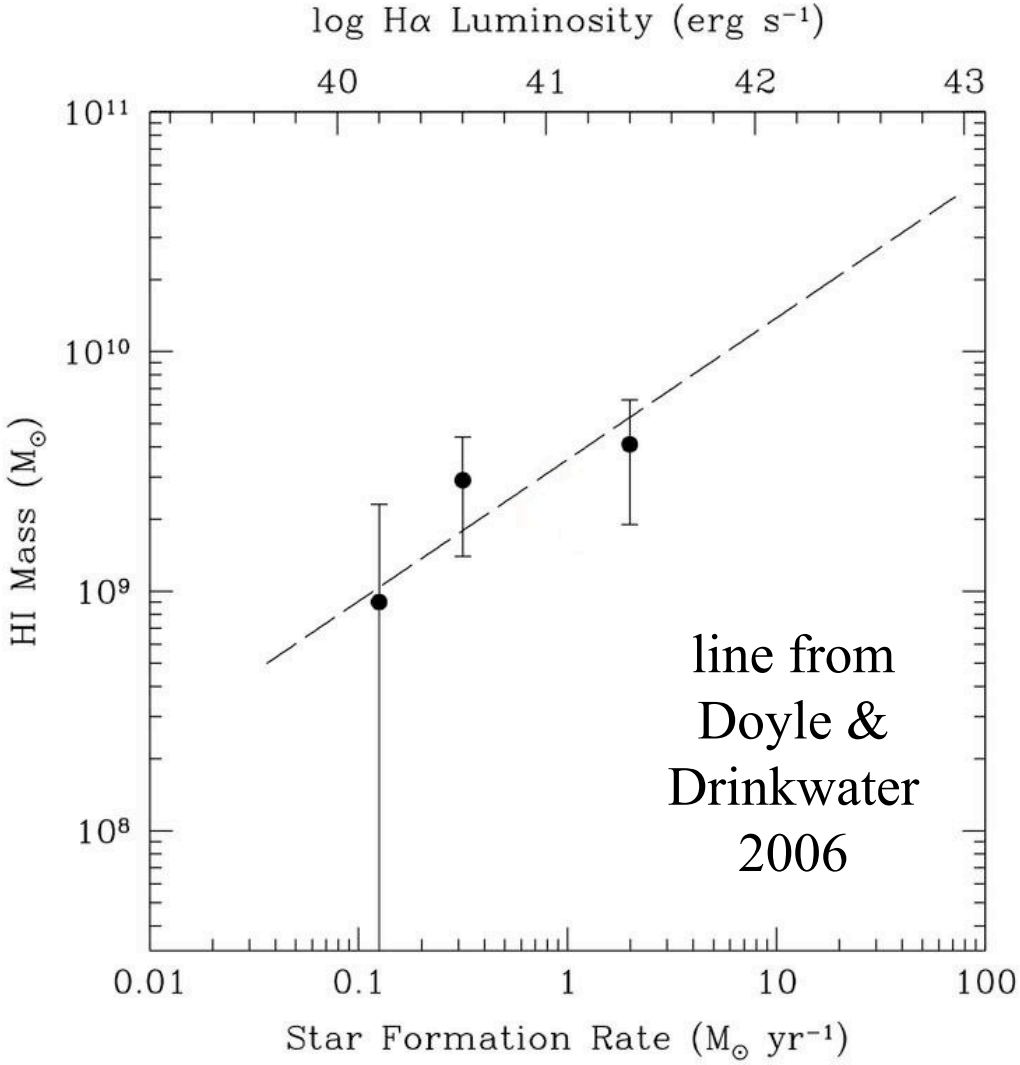
Doyle &
Drinkwater
2006

HI Mass vs Star Formation Rate at z = 0.24

all 121 galaxies



HI Mass vs Star Formation Rate at z = 0.24



42 bright L(Hα) galaxies

42 medium L(Hα) galaxies

37 faint L(Hα) galaxies

Abell 370

a galaxy cluster at z = 0.37

Abell 370, a galaxy cluster at z = 0.37

Abell 370 cluster core, ESO VLT image

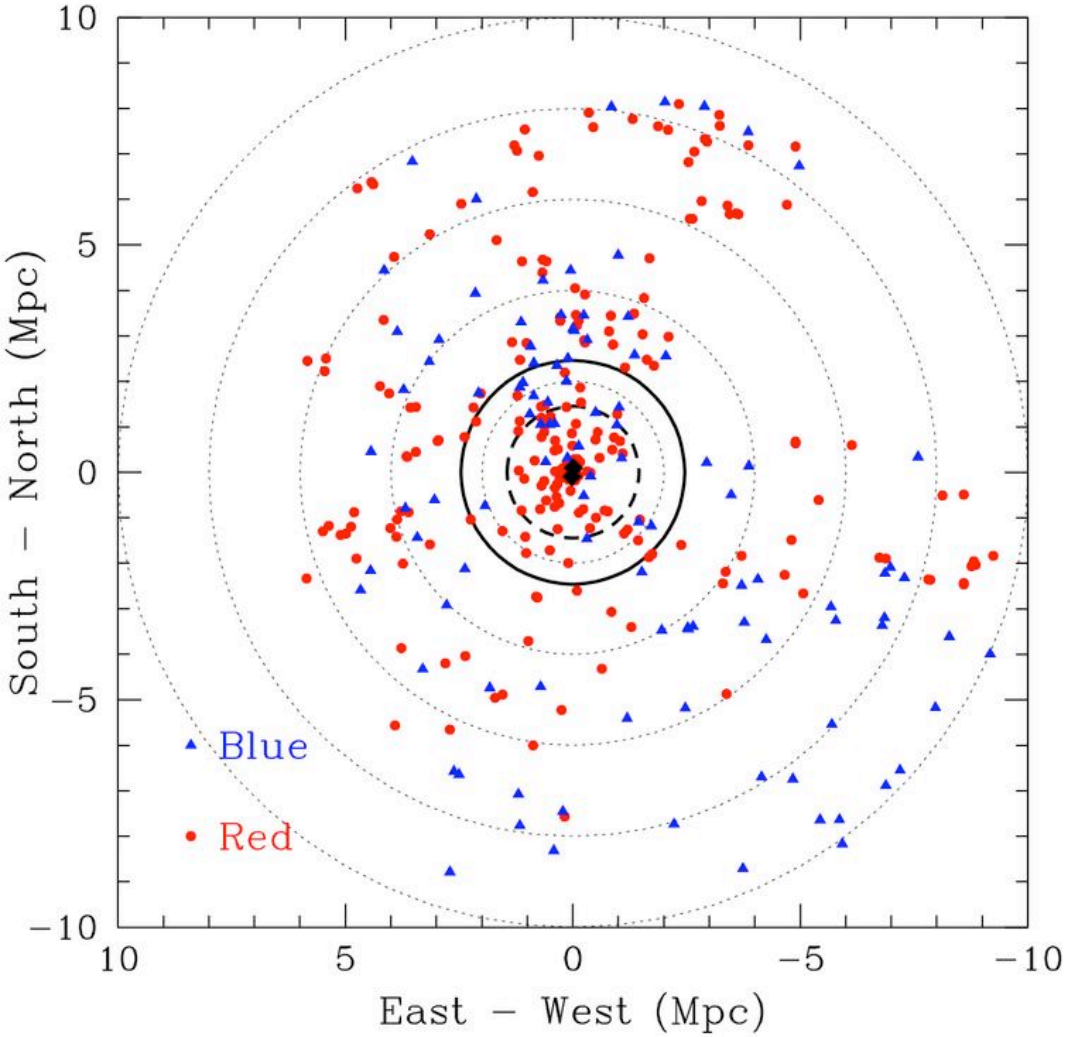
large galaxy cluster of order same size as Coma
⇨ similar cluster velocity dispersion and X-ray gas temperature

optical imaging ANU 40 inch telescope

spectroscopic follow-up with the AAT

GMRT ~34 hours on cluster
HI z = 0.35 to 0.39

Abell 370 galaxy cluster

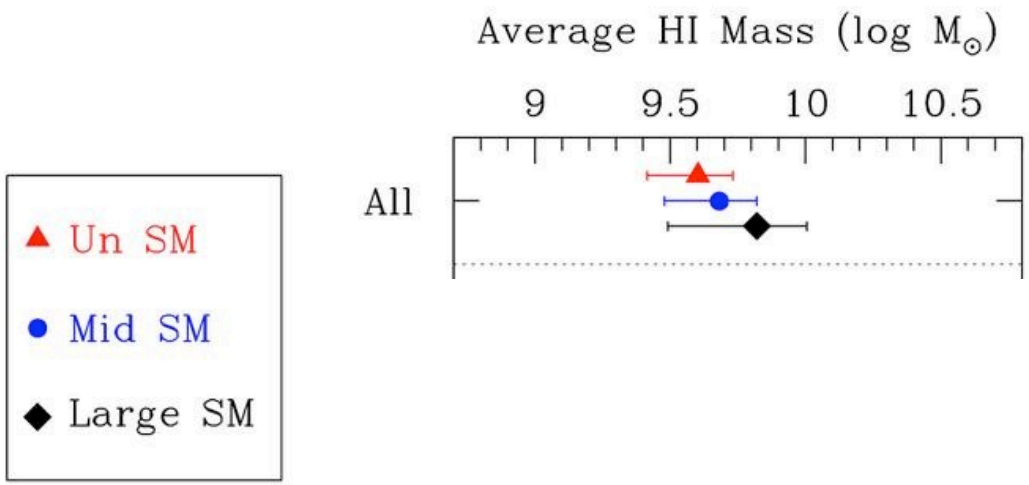


324 galaxies

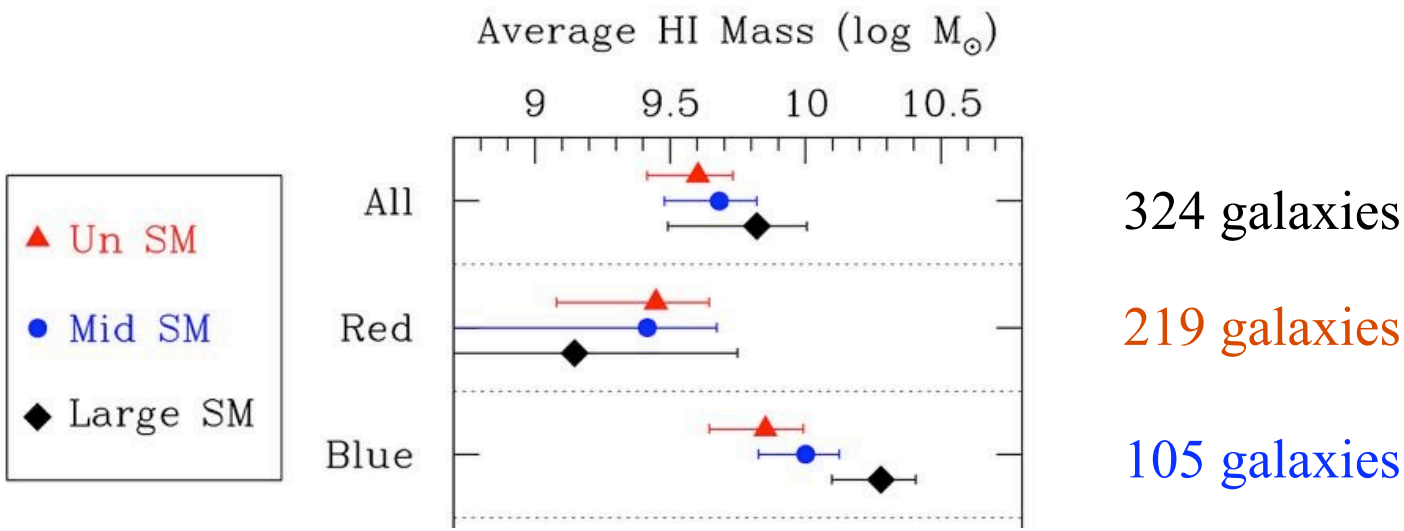
105 blue
(B-V ≤ 0.57)

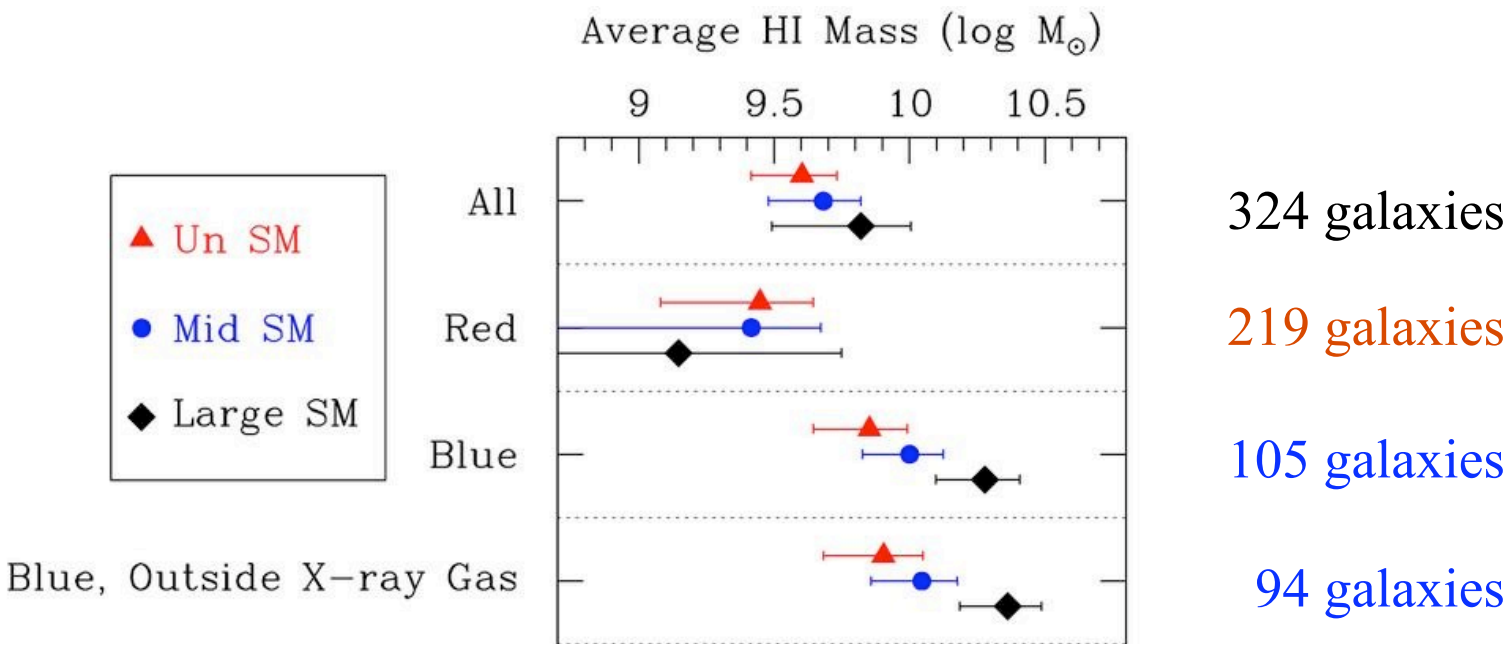
219 red
(B-V > 0.57)

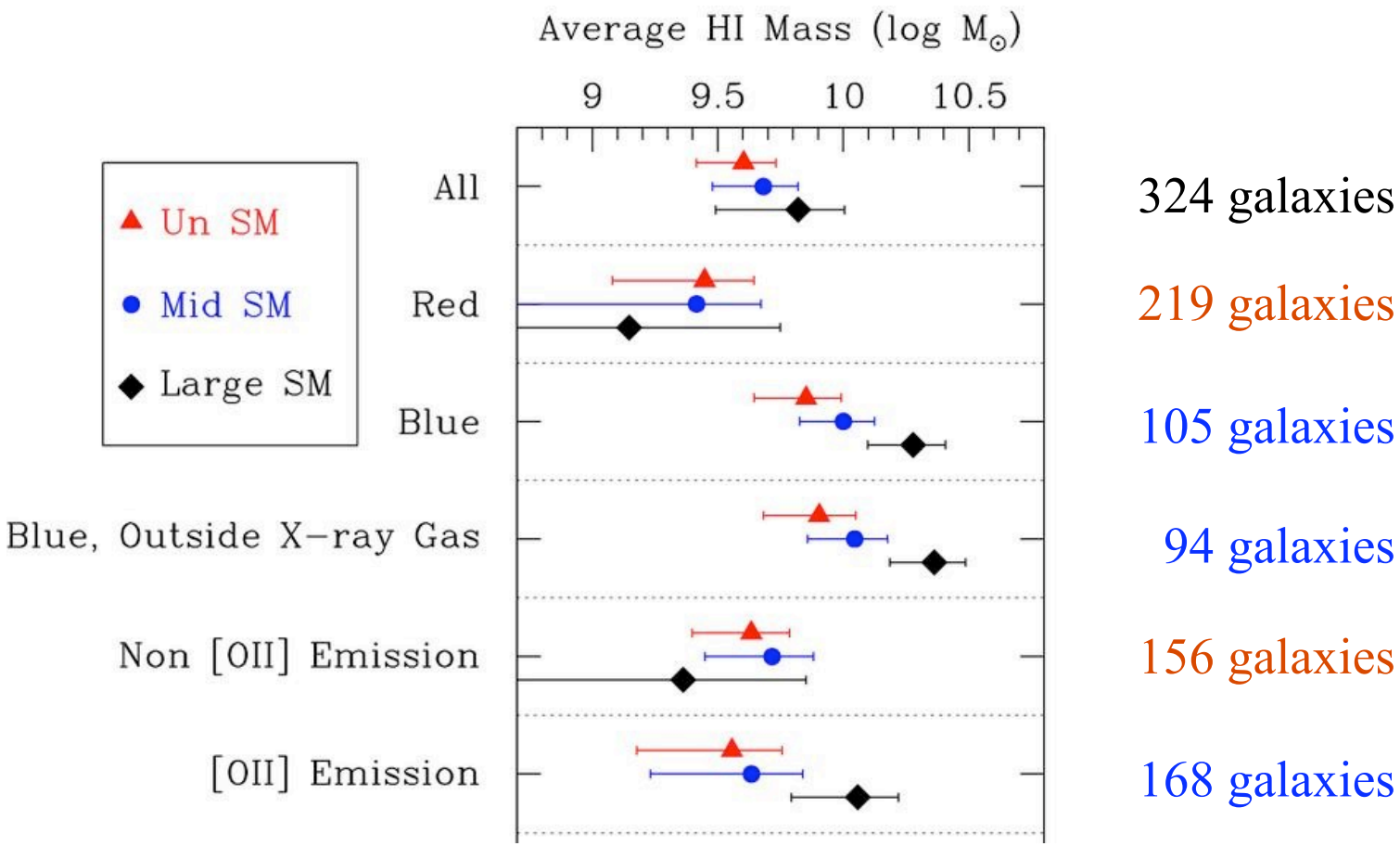
HI Mass Measurements

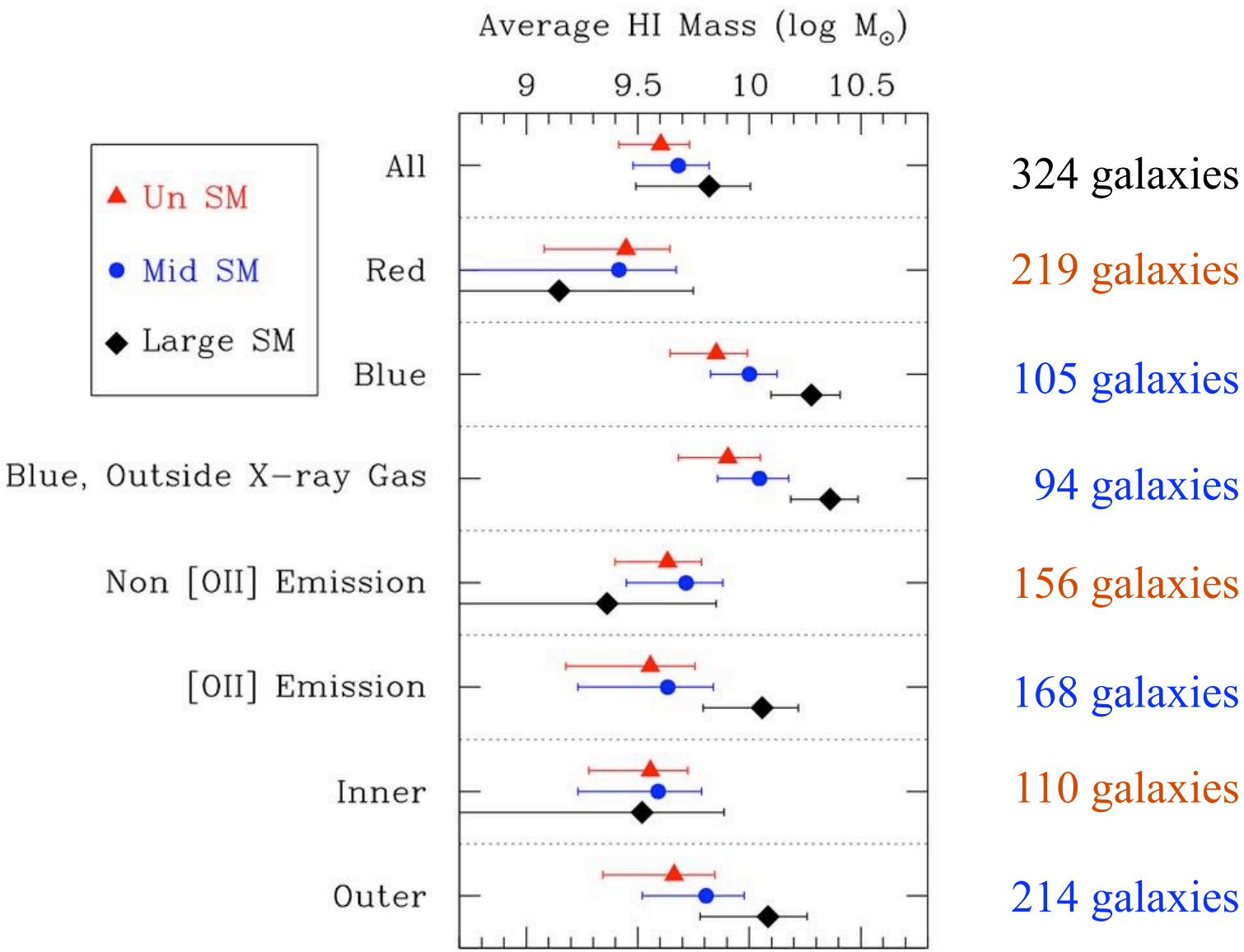


324 galaxies


Average HI Mass (log M$_\odot$)
9
9.5
10
10.5
Un SM
Mid SM
Large SM
All
Red
Blue
324 galaxies
219 galaxies
105 galaxies

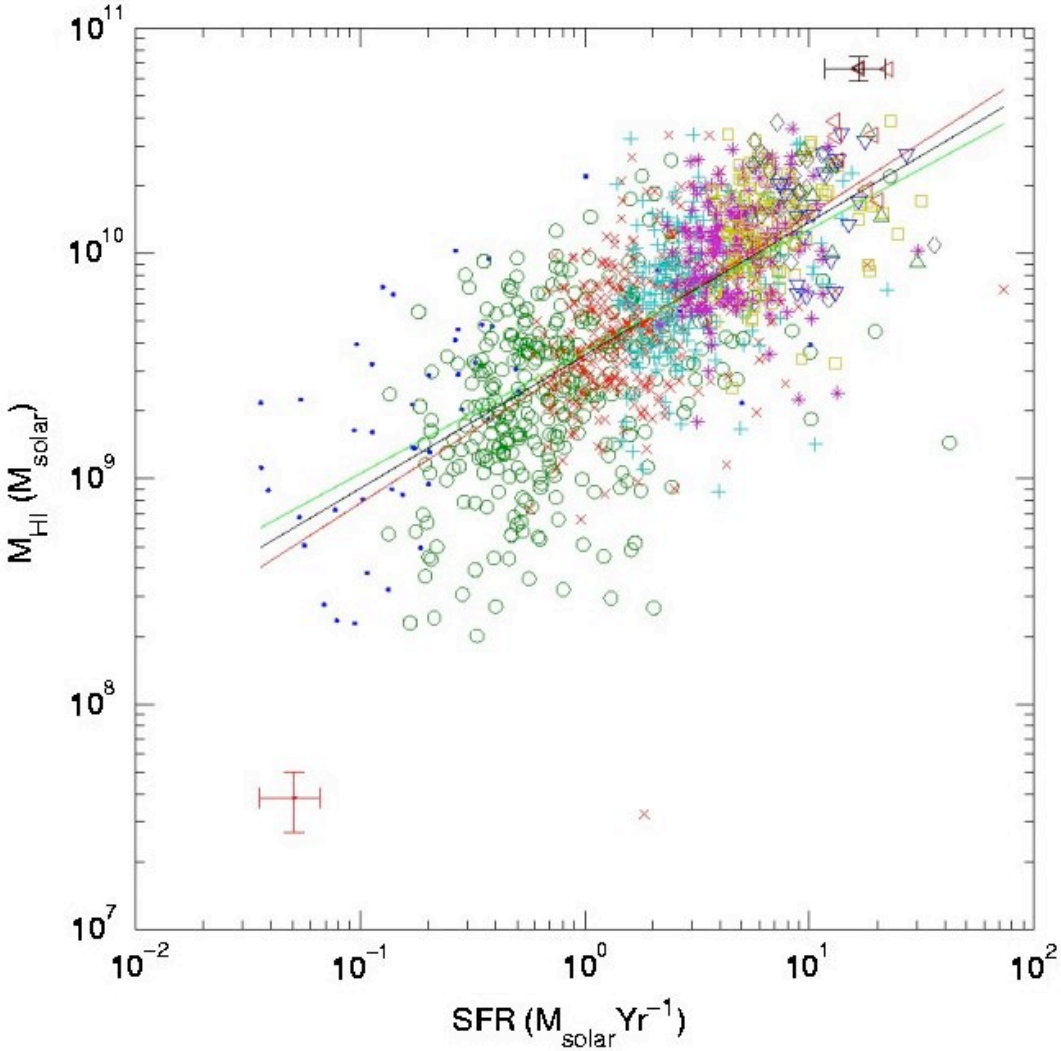

Average HI Mass (log M$_\odot$)
9
9.5
10
10.5
Un SM
Mid SM
Large SM
All
Red
Blue
Blue, Outside X-ray Gas
324 galaxies
219 galaxies
105 galaxies
94 galaxies


Average HI Mass (log M⊙)
9
9.5
10
10.5
Un SM
Mid SM
Large SM
All
Red
Blue
Blue, Outside X-ray Gas
Non [OII] Emission
[OII] Emission
324 galaxies
219 galaxies
105 galaxies
94 galaxies
156 galaxies
168 galaxies


Average HI Mass (log M⊙)
9
9.5
10
10.5
Un SM
Mid SM
Large SM
All
Red
Blue
Blue, Outside X−ray Gas
Non [OII] Emission
[OII] Emission
Inner
Outer
324 galaxies
219 galaxies
105 galaxies
94 galaxies
156 galaxies
168 galaxies
110 galaxies
214 galaxies

Galaxy HI mass
vs
Star Formation Rate

Galaxy HI Mass vs Star Formation Rate

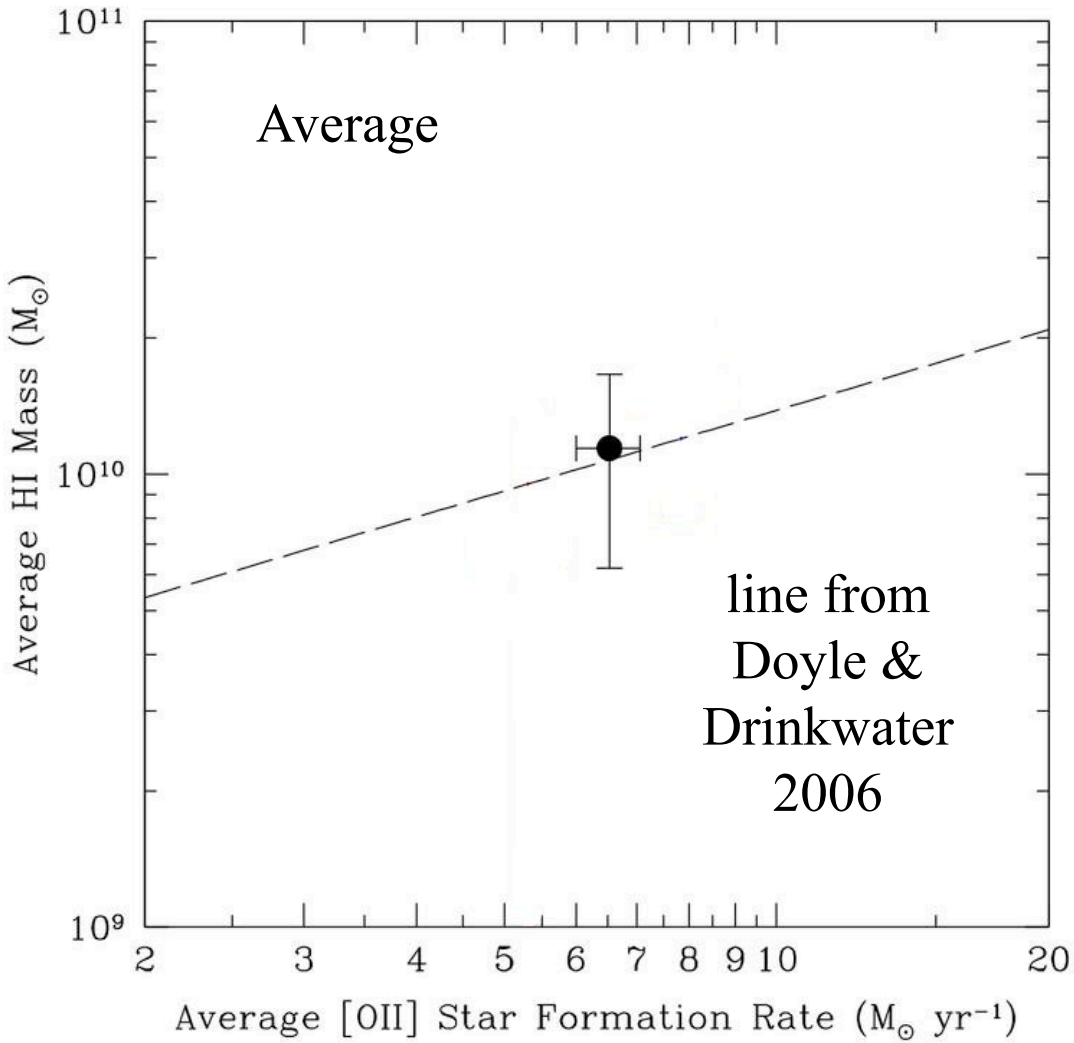


HIPASS
&
IRAS
data
z ~ 0

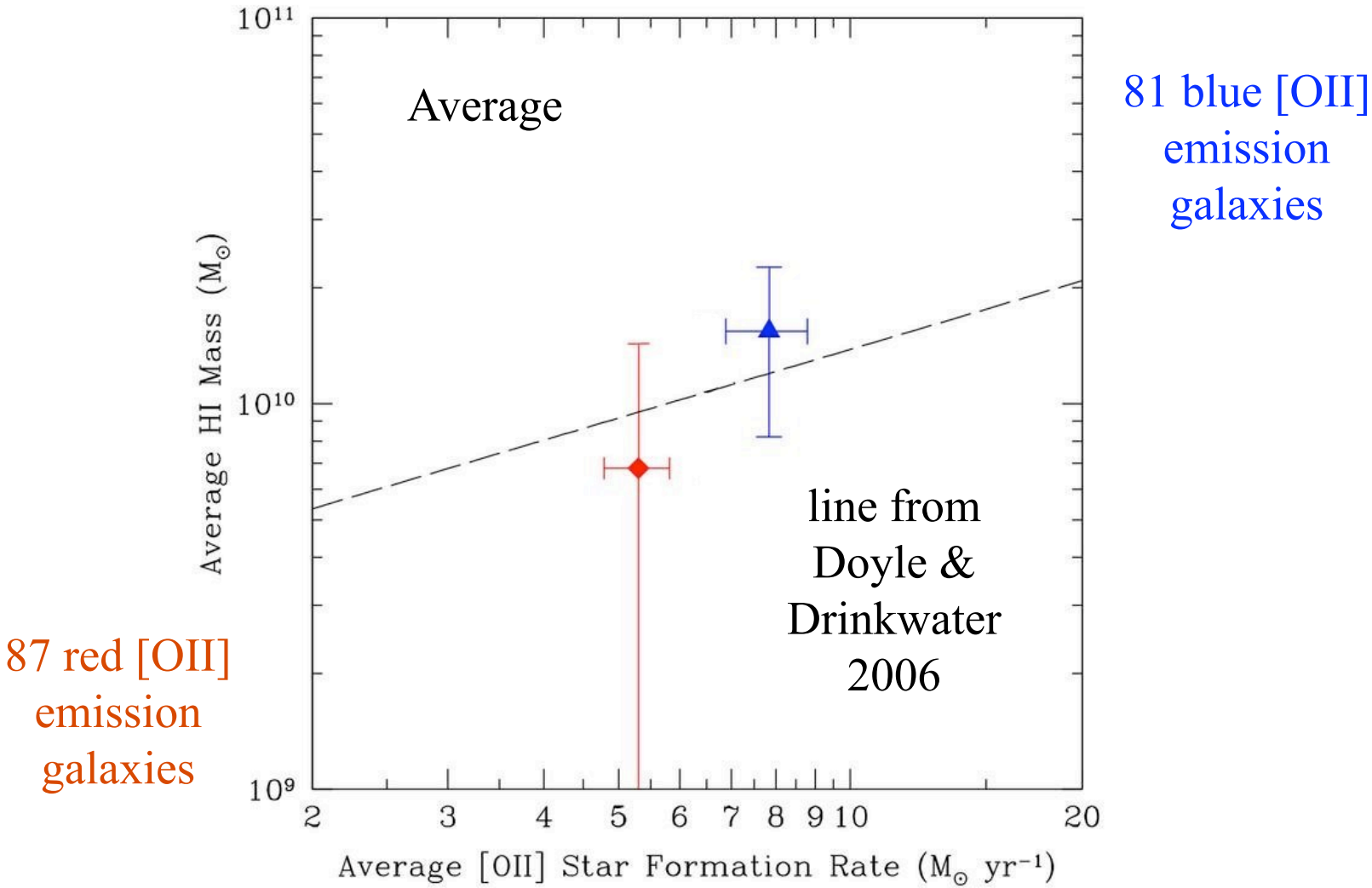
Doyle &
Drinkwater
2006

HI Mass vs Star Formation Rate in Abell 370

all 168 [OII] emission galaxies



HI Mass vs Star Formation Rate in Abell 370



Why is there a

dramatic evolution in the

Cosmic Star Formation Rate Density

and only minimal evolution in the

Cosmic HI Gas Density?

Evolution of HI Gas in Galaxies

$$\log(\mathrm{SFR}) \propto \log(M_{\mathrm{HI}})$$

Evolution of HI Gas in Galaxies

$$\log(\mathrm{SFR}) \propto \log(M_{HI})$$

$$\mathrm{SFR} = a\,(M_{HI})^{m}$$

Evolution of HI Gas in Galaxies

$$\log(SFR) \propto \log(M_{HI})$$

$$SFR = a\,(M_{HI})^m$$

$$\rho_{HI} = \frac{\Sigma\, M_{HI}}{Vol} \qquad SFRD = \frac{\Sigma\, SFR}{Vol}$$

Evolution of HI Gas in Galaxies

$$\log(SFR) \propto \log(M_{HI})$$

$$SFR = a\,(M_{HI})^m$$

$$\rho_{HI} = \frac{\Sigma\, M_{HI}}{Vol} \qquad SFRD = \frac{\Sigma\, SFR}{Vol}$$

$$SFRD = \frac{a}{Vol} \times \Sigma\,(M_{HI})^m$$

Evolution of HI Gas in Galaxies

$$\log(\mathrm{SFR}) \propto \log(M_{HI})$$

$$\mathrm{SFR} = a\,(M_{HI})^m$$

$$\rho_{HI} = \frac{\Sigma\, M_{HI}}{\mathrm{Vol}} \qquad \mathrm{SFRD} = \frac{\Sigma\, \mathrm{SFR}}{\mathrm{Vol}}$$

$$\mathrm{SFRD} = \frac{a}{\mathrm{Vol}} \times \Sigma\,(M_{HI})^m$$

$m \sim 1.7$ at $z = 0$ (Doyle & Drinkwater 2006)

Downsizing

• the stellar populations of the most massive galaxies formed at early times (Heavens et al. 2004, Thomas et al. 2005 & others)

Downsizing

- the stellar populations of the most massive galaxies formed at early times (Heavens et al. 2004, Thomas et al. 2005 & others)

- the sites of active star formation shift from the high-mass galaxies at earliest times to the lower-mass galaxies at later periods (Cowie et al. 1996, Gunzman et al. 1997 & others)

Downsizing

- the stellar populations of the most massive galaxies formed at early times (Heavens et al. 2004, Thomas et al. 2005 & others)

- the sites of active star formation shift from the high-mass galaxies at earliest times to the lower-mass galaxies at later periods (Cowie et al. 1996, Gunzman et al. 1997 & others)

- high-mass galaxies with active star formation ⇒ highest HI gas content?

Future Observations -
HI coadding with SKA Pathfinders

- large field of view

  ASKAP 30 deg^2 (focal plane array)

  MeerKAT 1.2 to 4.8 deg^2 (1420 to 700 MHz)

- frequency coverage out 700 MHz $\Rightarrow$ HI redshift $z = 1.0$

- optical redshift surveys

  ASKAP use WiggleZ

  MeerKAT use zCOSMOS and others

Conclusion

Conclusion

- used coadded HI 21-cm emission to measure the cosmic HI gas density at $z = 0.24$; value is consistent with that from damped Lyα measurements; shown SFR–M_{HI} relationship holds at $z = 0.24$

Conclusion

- used coadded HI 21-cm emission to measure the cosmic HI gas density at $z = 0.24$; value is consistent with that from damped Lyα measurements; shown SFR–M_{HI} relationship holds at $z = 0.24$

- galaxies around Abell 370 at $z = 0.37$ have significantly amounts of gas; shows clear environmental trends similar to nearby systems; shown SFR–M_{HI} relationship holds at $z = 0.37$

Conclusion

- used coadded HI 21-cm emission to measure the cosmic HI gas density at $z = 0.24$; value is consistent with that from damped Lyα measurements; shown SFR–M_{HI} relationship holds at $z = 0.24$

- galaxies around Abell 370 at $z = 0.37$ have significantly amounts of gas; shows clear environmental trends similar to nearby systems; shown SFR–M_{HI} relationship holds at $z = 0.37$

- to explain difference in evolution between SFR and HI gas postulated either a varying SFR–M_{HI} relationship or a varying HI mass function