The smallest H I galaxies

Tom Oosterloo
Astron & Kapteyn Institute

- Survey for small H I galaxies
- H I in Leo T

Katarina Kovac, Thijs van der Hulst, Marc Verheijen, Emma Ryan-Weber,...

Why look for small H I galaxies?

- Formation of small galaxies still a puzzle
  - Slope mass- & luminosity functions shallower than halo mass function
  - Missing satellite problem

  - Small galaxies are not efficient in cooling their gas and form stars
  - Re-ionisation suppresses star formation in small galaxies
  - Gas expelled by SN & stellar winds

  - How many dwarfs should exist? Dark Galaxies exist?
  - Buildingblocks of larger systems; Fuel for accretion (talks Sancisi, Fraternali)
  - Relation with Compact High-Velocity Clouds

Narrow gap between small galaxies and HVCs

CVn Survey

- Survey aiming to detect $10^6\ M_\odot$ at a distance of a few Mpc

- Large region in CVn observed with WSRT

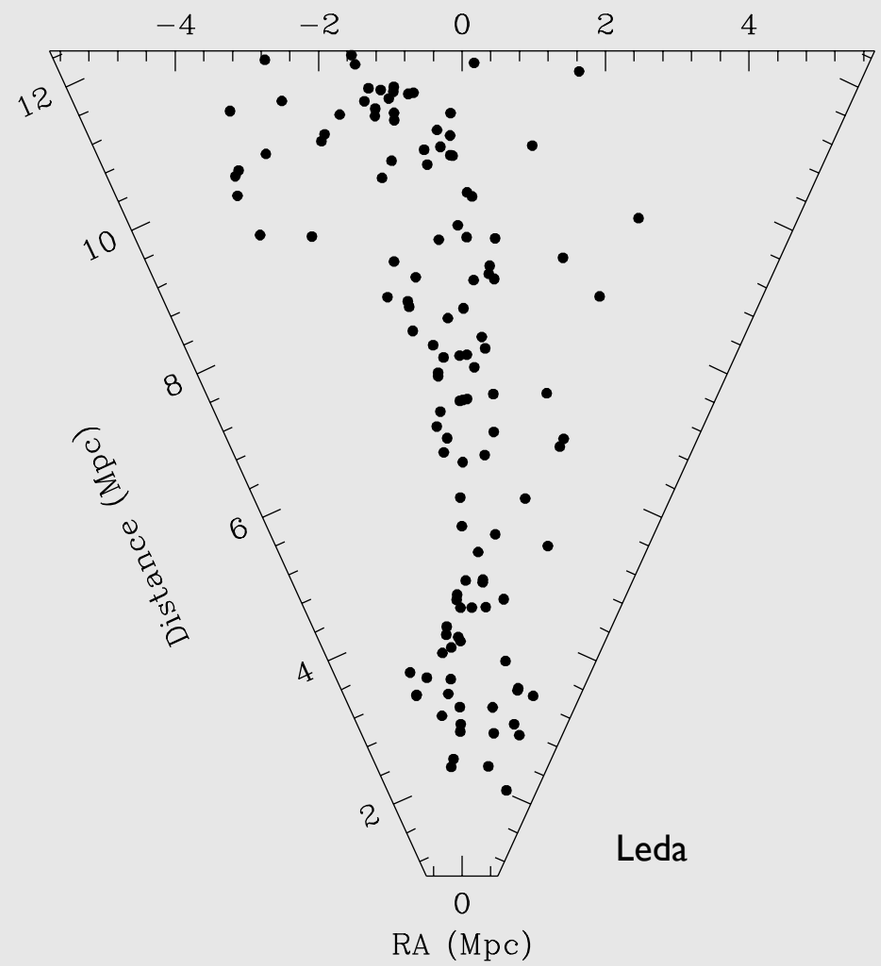
  $12^h\ 18^m < \alpha < 12^h\ 29^m$; $31^\circ < \delta < 46^\circ$; $-450 < cz < 1300$ km s^{-1}
  86 deg^2

- Chosen for cold Hubble flow along filament

  - 60 x 12 hrs; 24 pointings in each 12 hrs; 1372 pointings used
  - 30 arcsec and 33 km s^{-1} resolution
  - Effective integration time per position: 80 minutes
  - Noise in full-resolution data 0.8 mJy beam^{-1} $\leftrightarrow$ $1.6 \cdot 10^{19}$ cm^{-2}
  - Detection limit 4.7 x $10^4\ D^2\ M_\odot$

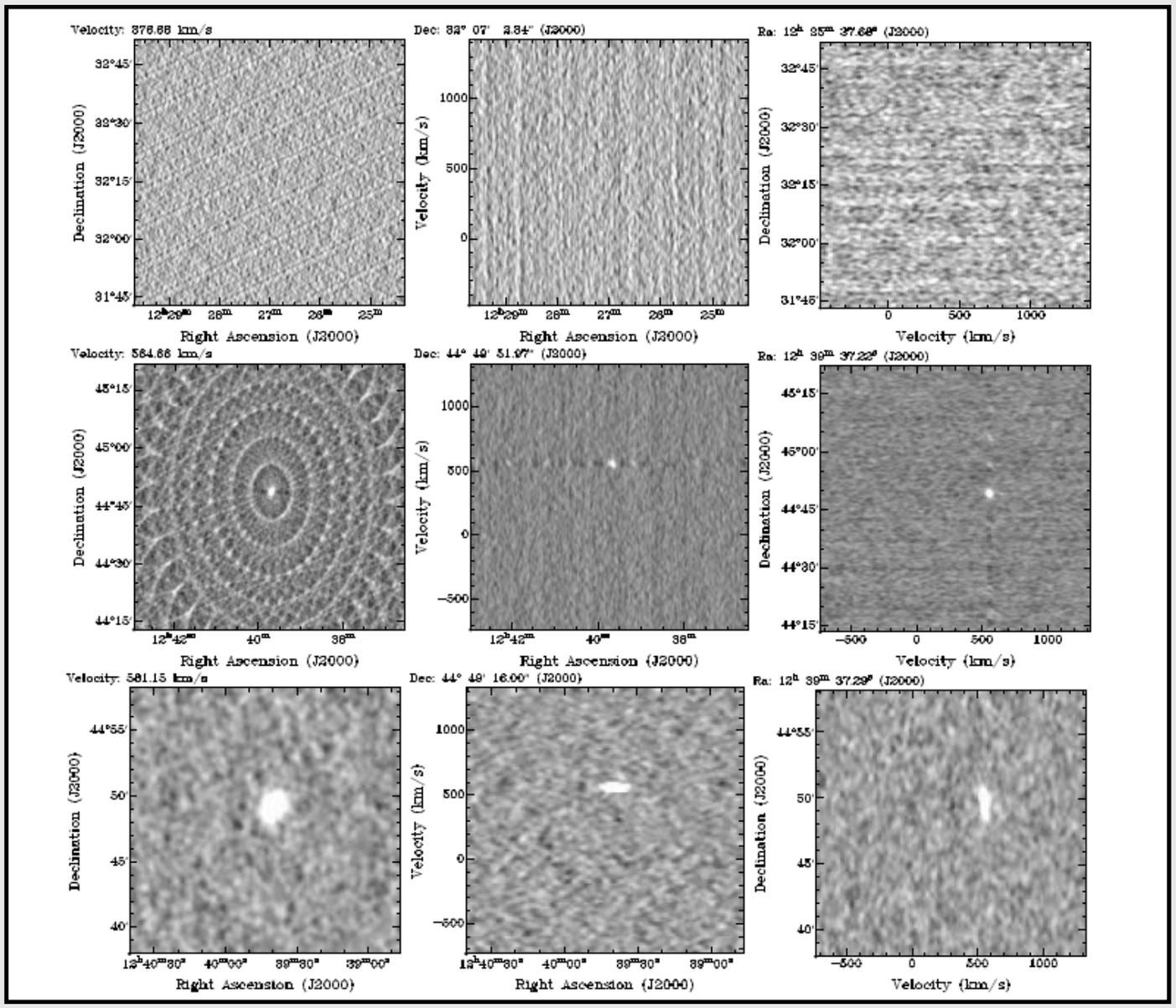
  - High-resolution follow up: 15 arcsec & 3 km s^{-1}; factor 2 deeper

  - Imaging in B & R at INT



69 detections - 19 new
from $3 \cdot 10^6$ to $10^{10}\ M_\odot$
all with visible galaxy

What the data look like

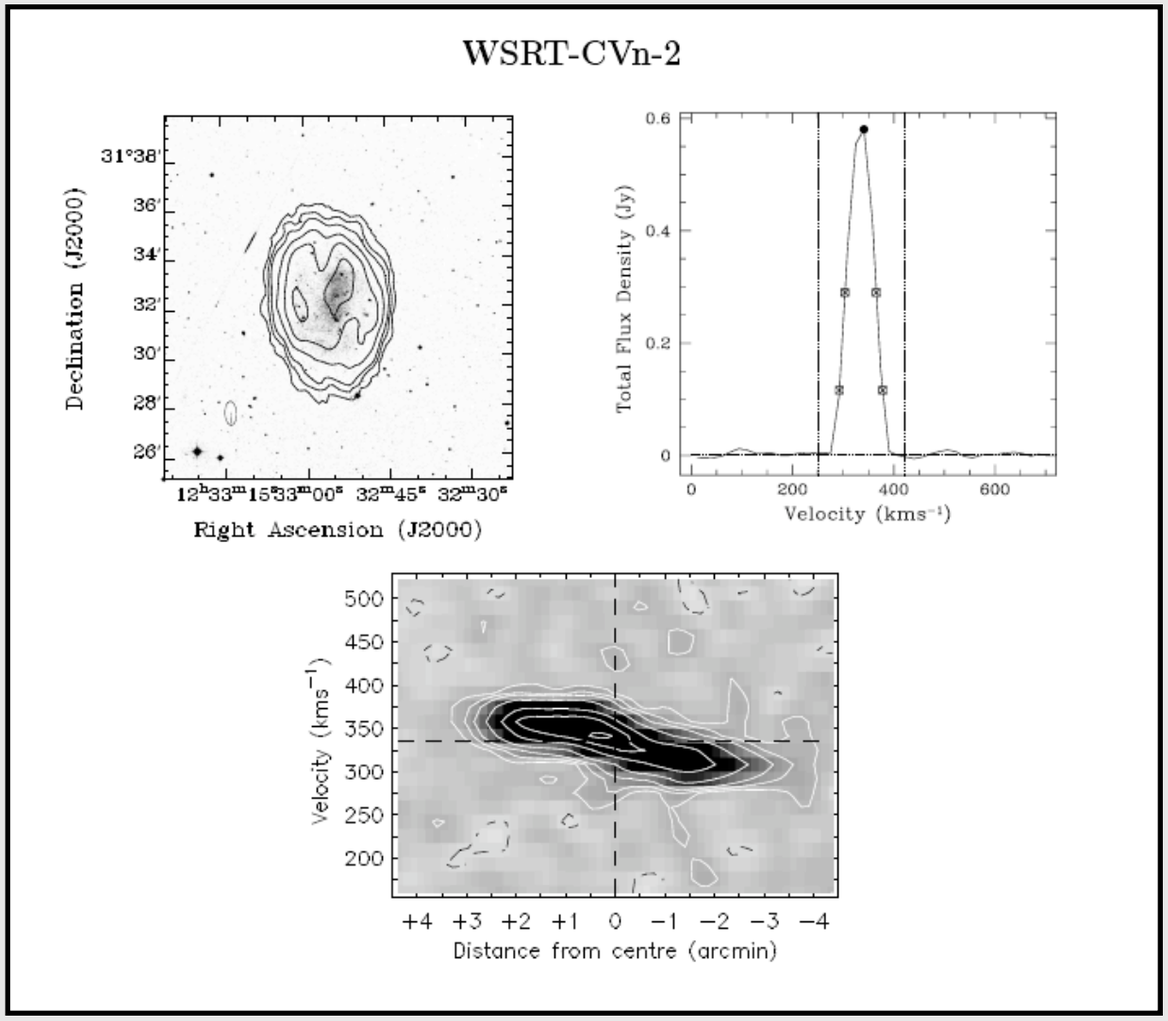


Galaxies detected using cubes with different resolutions (spatial and velocity)

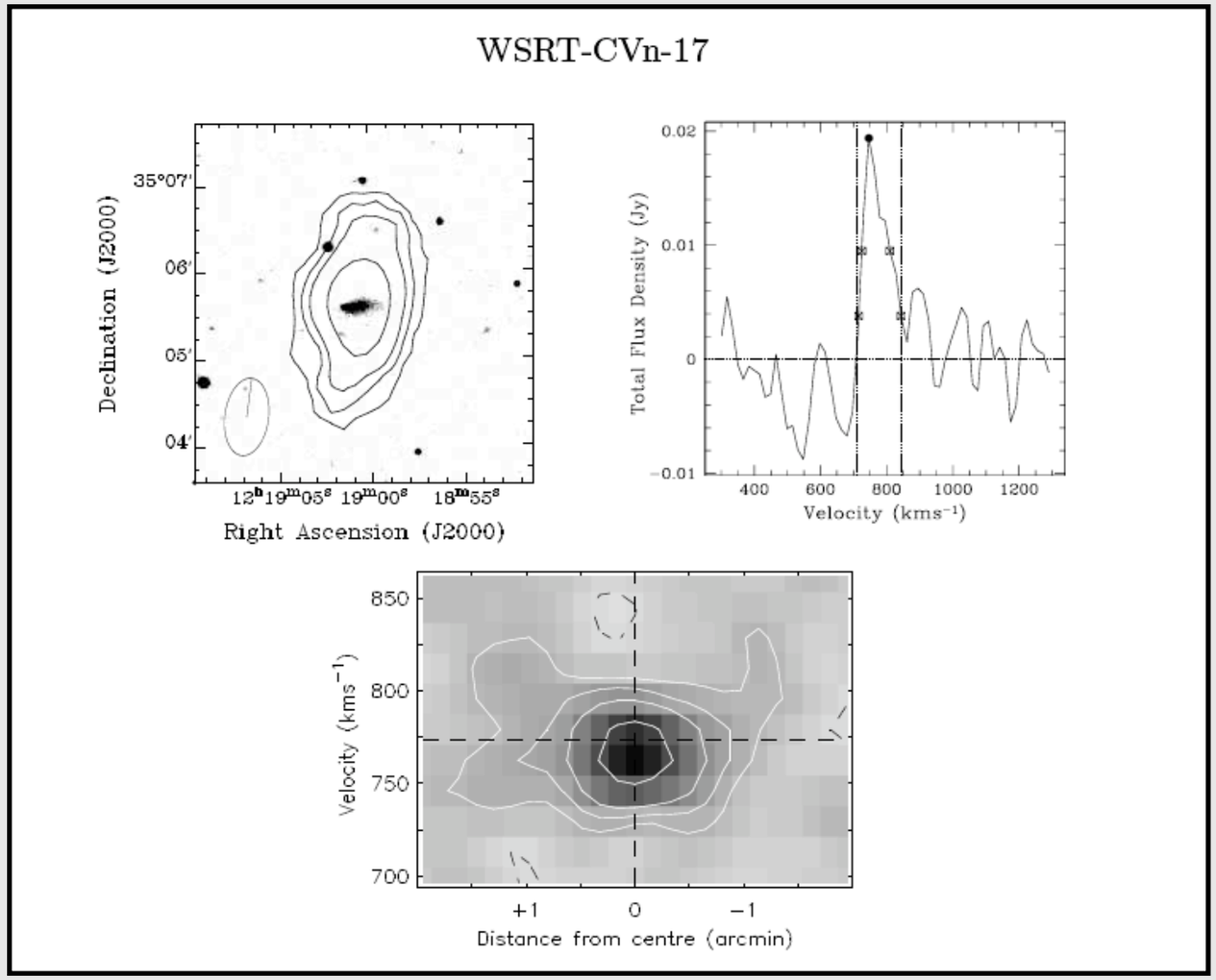
However: no additional objects found in lower-resolution cubes

⇒ No low-surface density objects

Example


WSRT-CVn-2
Declination (J2000)
31°38'
36'
34'
32'
30'
28'
26'
12h33m15s33m00s 32m45s 32m30s
Right Ascension (J2000)
Total Flux Density (Jy)
0.6
0.4
0.2
0
0
200
400
600
Velocity (kms−1)
Velocity (kms−1)
500
450
400
350
300
250
200
+4 +3 +2 +1 0 −1 −2 −3 −4
Distance from centre (arcmin)

Example

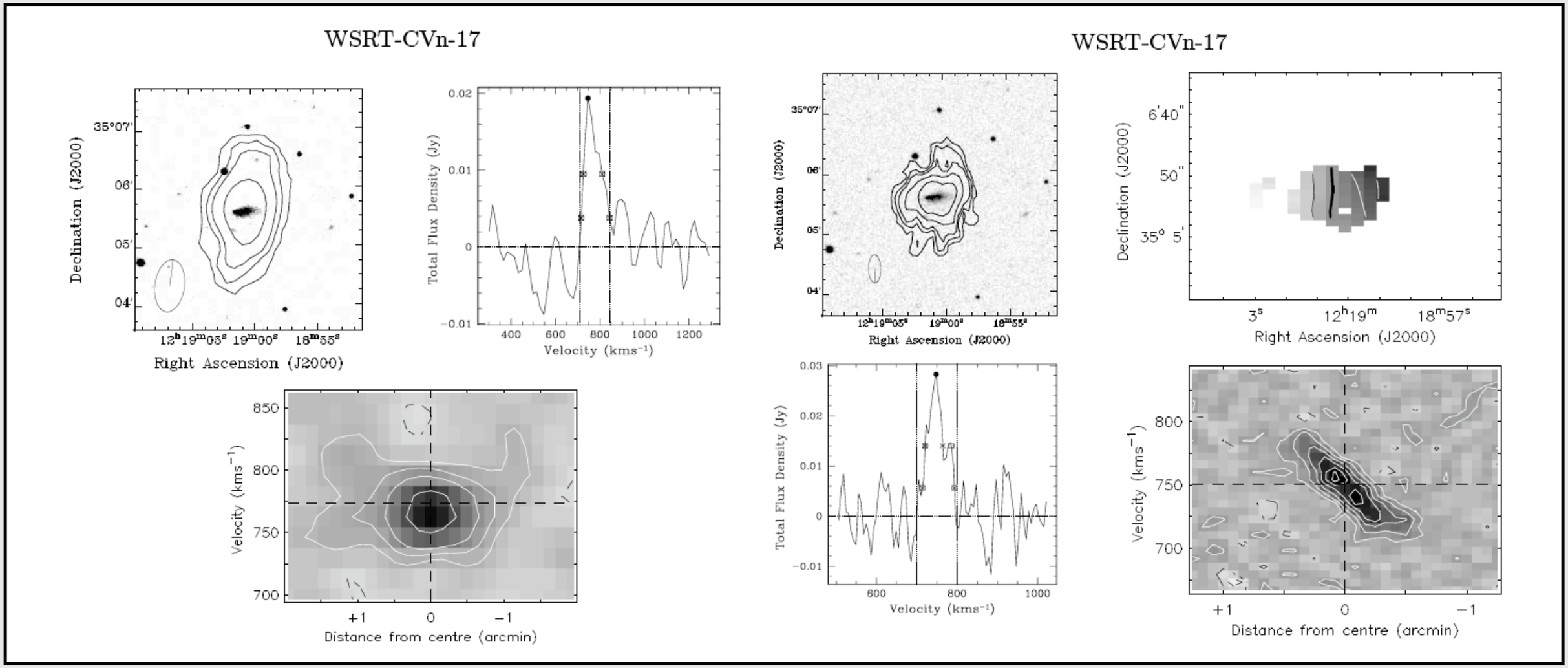


Kinematics unresolved

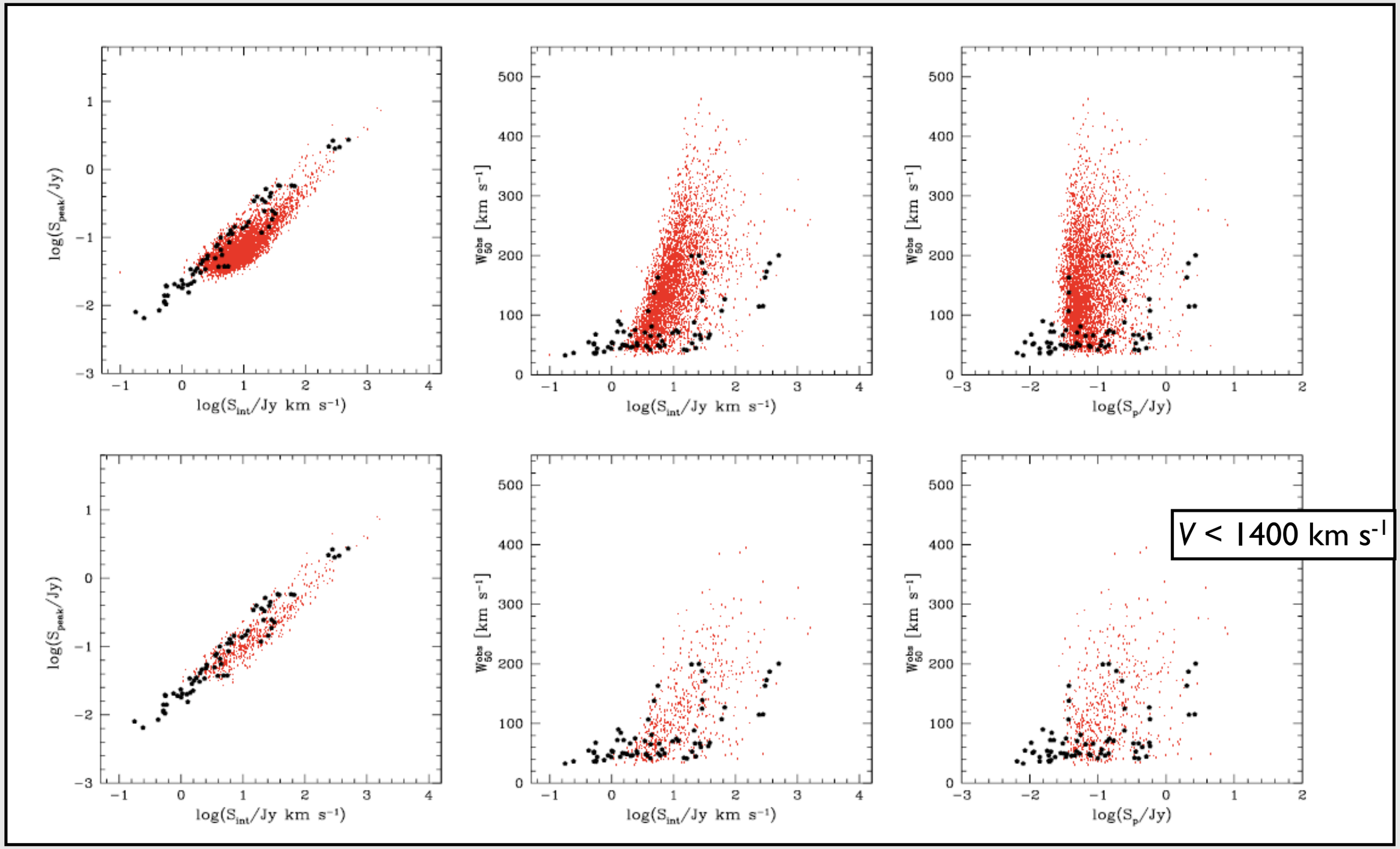
→ higher-resolution follow up

15 arcsec & 3 km s^{-1}
6 hrs per galaxy
1.0 mJy $beam^{-1}$ noise (over 3 km s^{-1})

Follow up


WSRT-CVn-17
Declination (J2000)
35°07'
06'
05'
04'
12h19m05s 19m00s 18m55s
Right Ascension (J2000)
Total Flux Density (Jy)
0.02
0.01
0
−0.01
400 600 800 1000 1200
Velocity (kms−1)
WSRT-CVn-17
Declination (J2000)
35°07'
06'
05'
04'
12h19m05s 19m00s 18m55s
Right Ascension (J2000)
Declination (J2000)
6'40"
50"
35° 5'
3s 12h19m 18m57s
Right Ascension (J2000)
Velocity (kms−1)
850
800
750
700
+1 0 −1
Distance from centre (arcmin)
Total Flux Density (Jy)
0.03
0.02
0.01
0
−0.01
600 800 1000
Velocity (kms−1)
Velocity (kms−1)
800
750
700
+1 0 −1
Distance from centre (arcmin)

Comparison with HIPASS



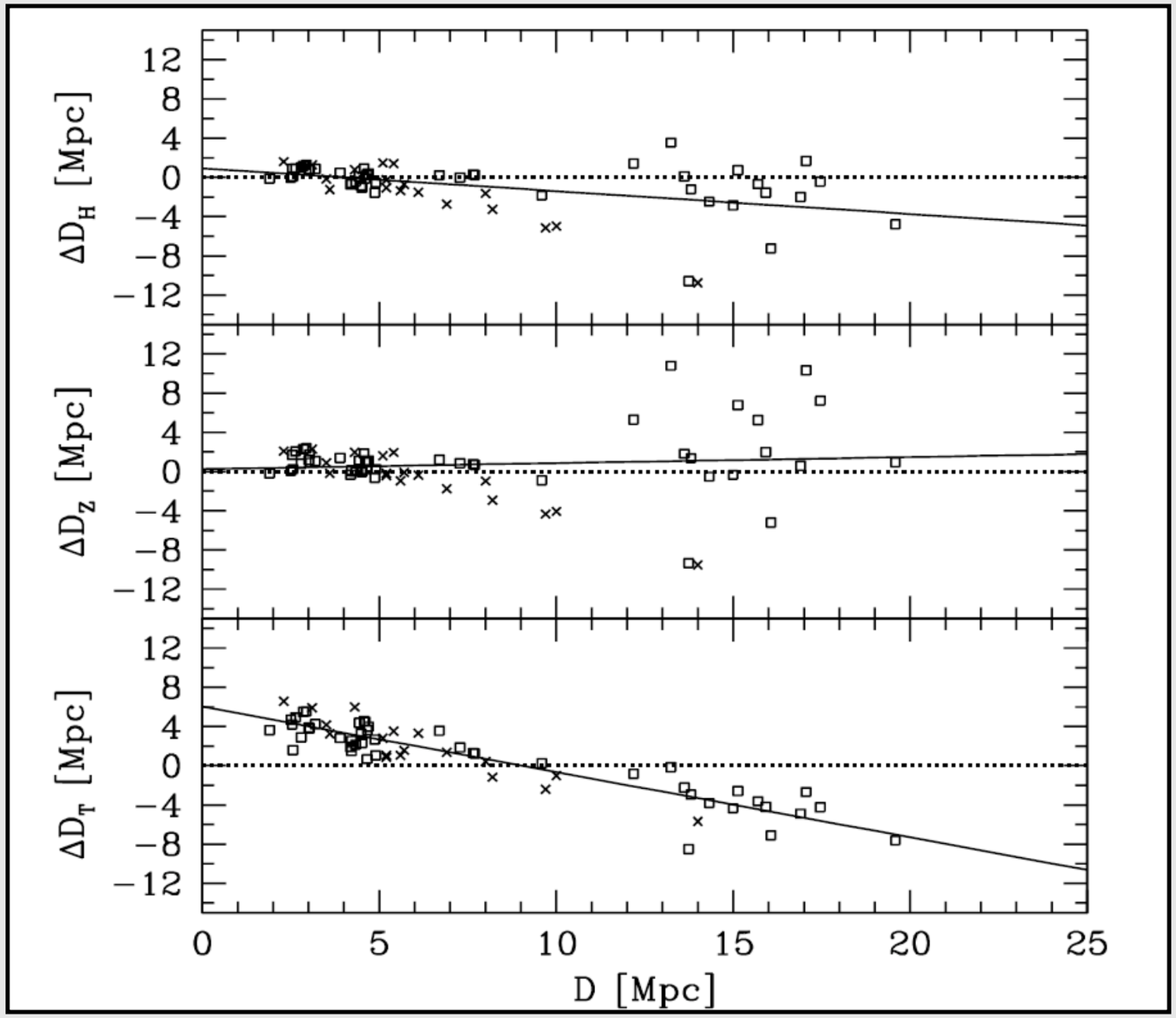
Distances

Many galaxies in the region have independent distance estimates

Hubble flow

Model of density field & peculiar motions (Zaroubi et al)

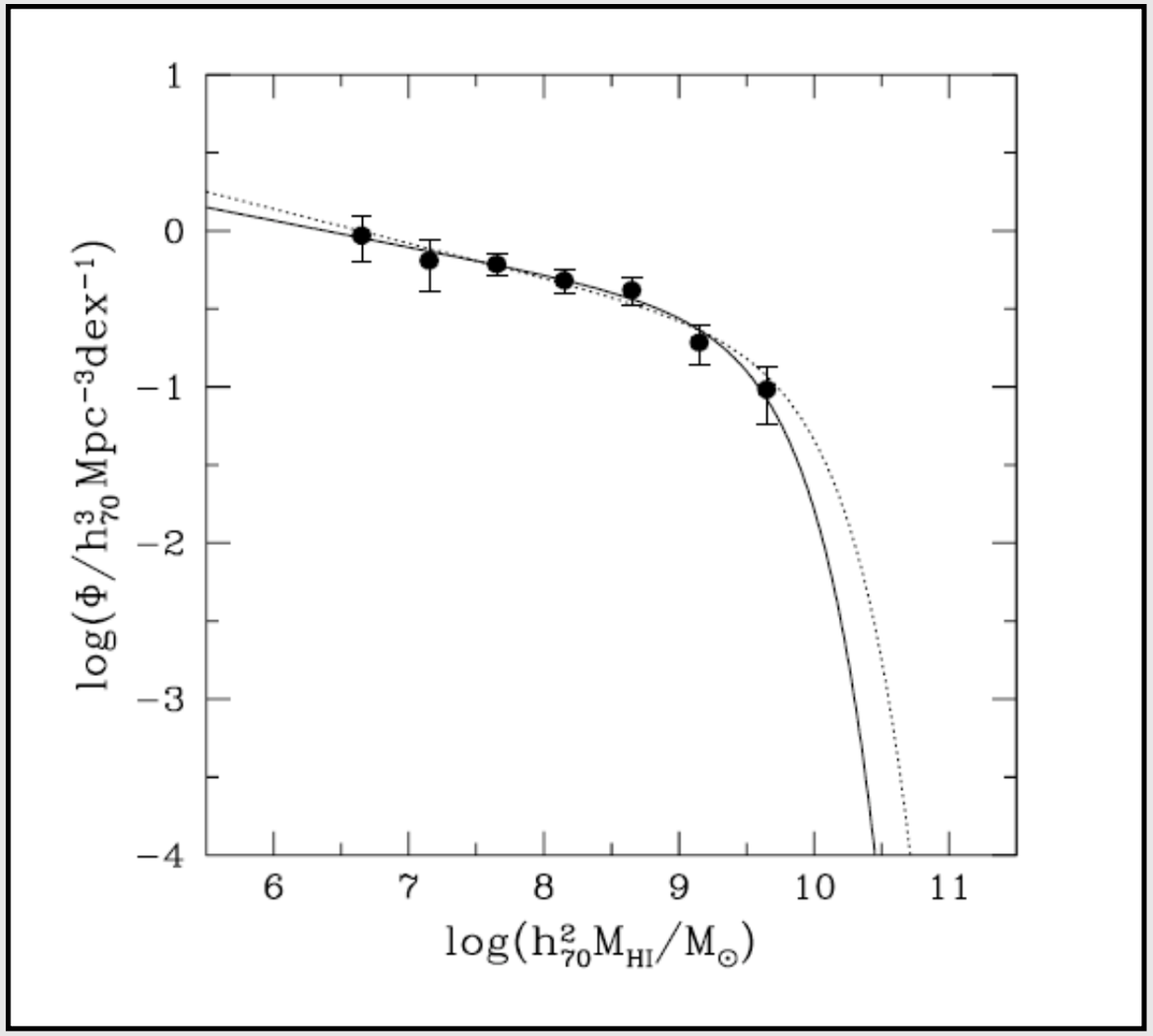
Parametric model of local velocity field (Tonry et al.)



Simple Hubble flow has lowest dispersion for nearby galaxies

Note: error in *D* increases with *D*→ error in mass "independent" of *D*

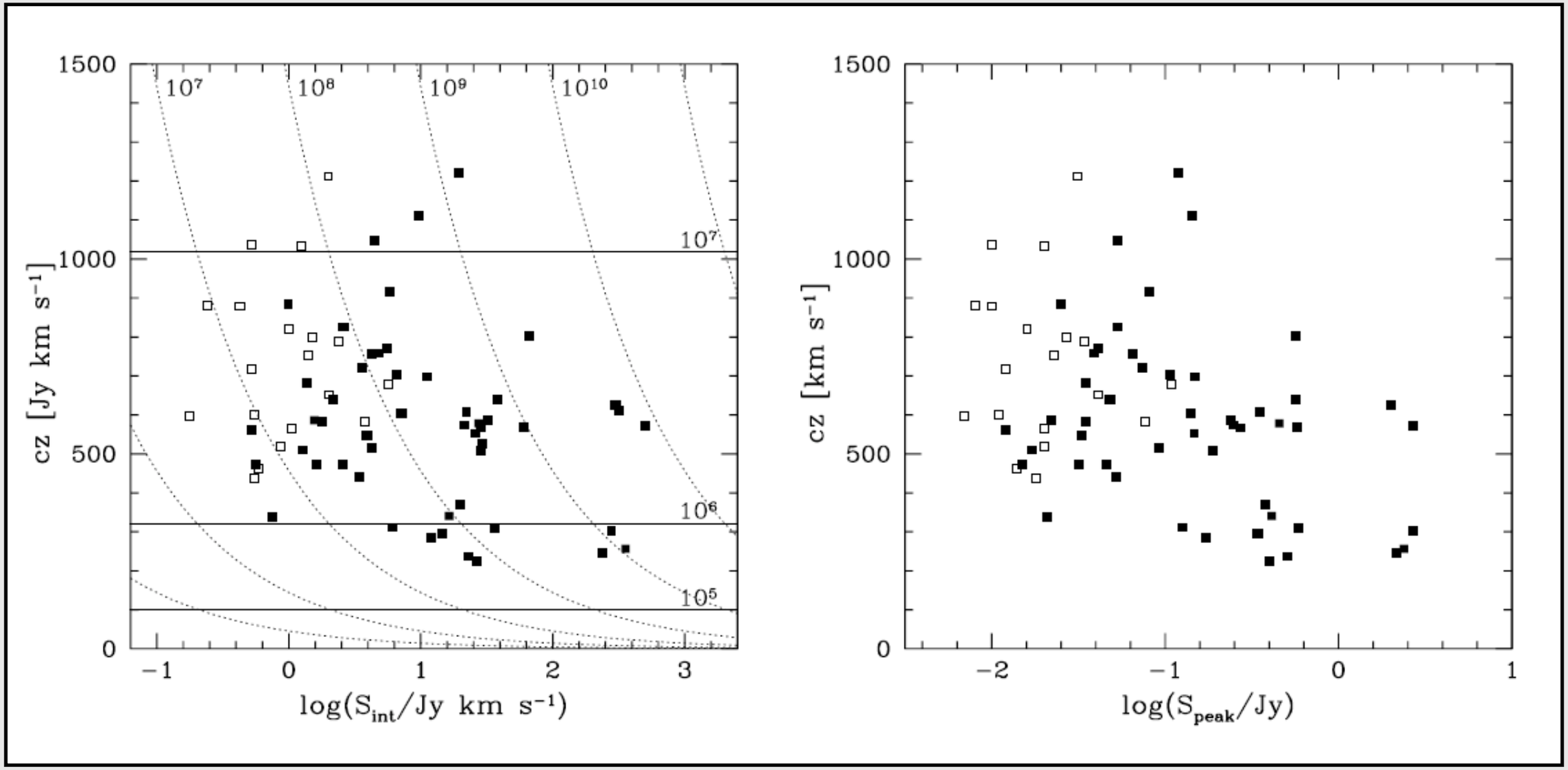
H I mass function



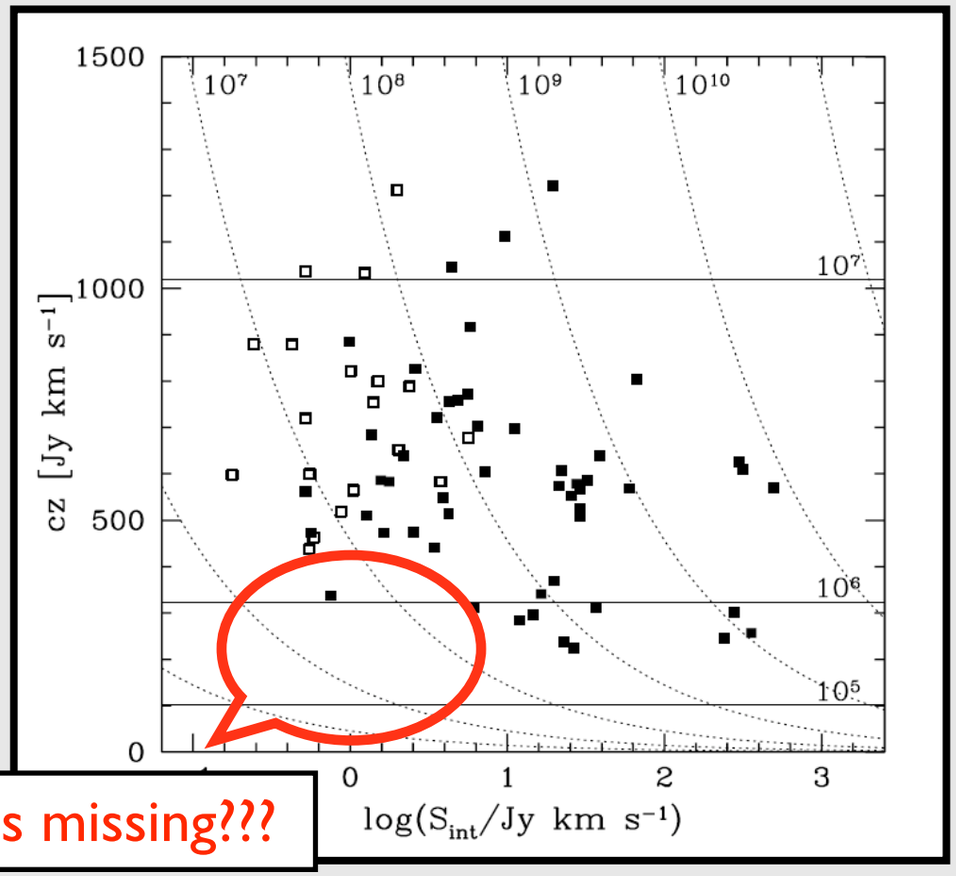
Mass function smooth

α = -1.2 log M_{HI*} = 9.6
ϕ_* = 0.125

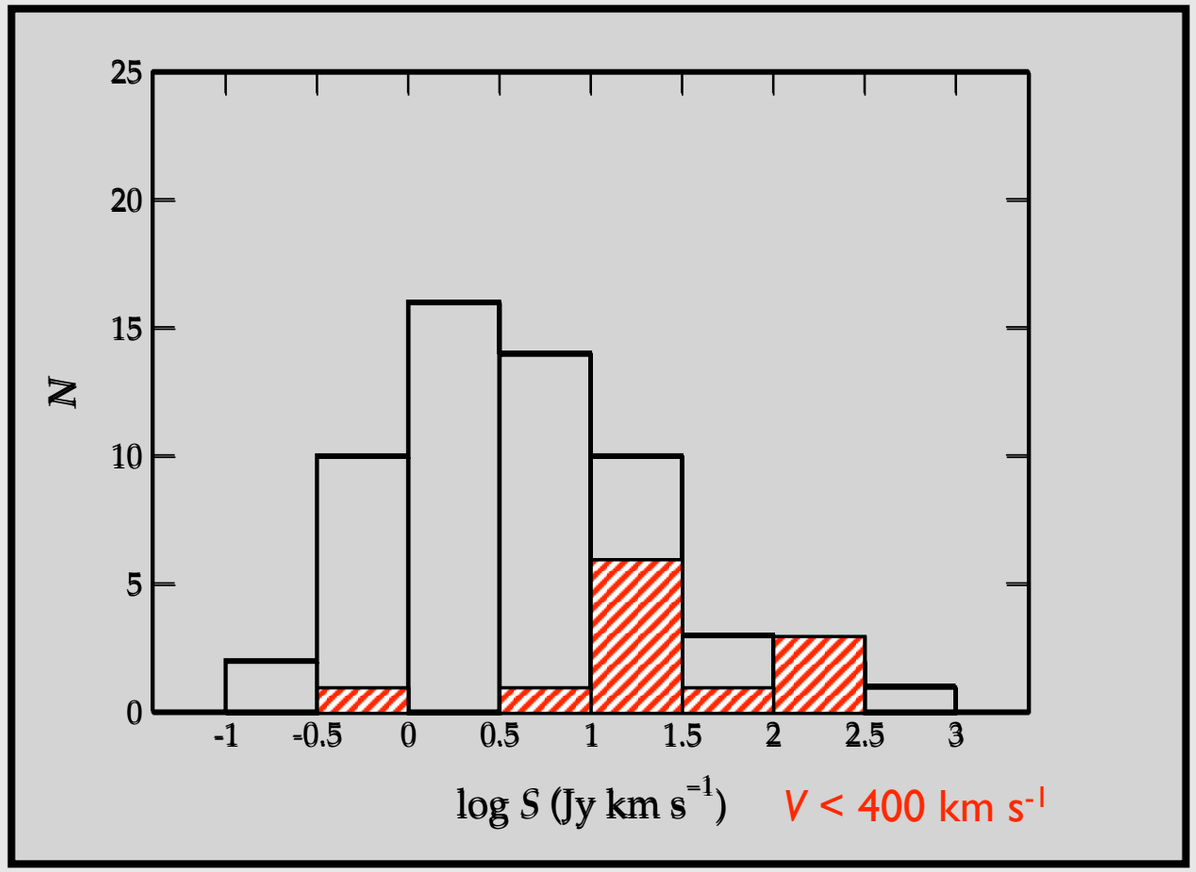
Small galaxies missing????



Lower limit to H I mass?



Galaxies missing???

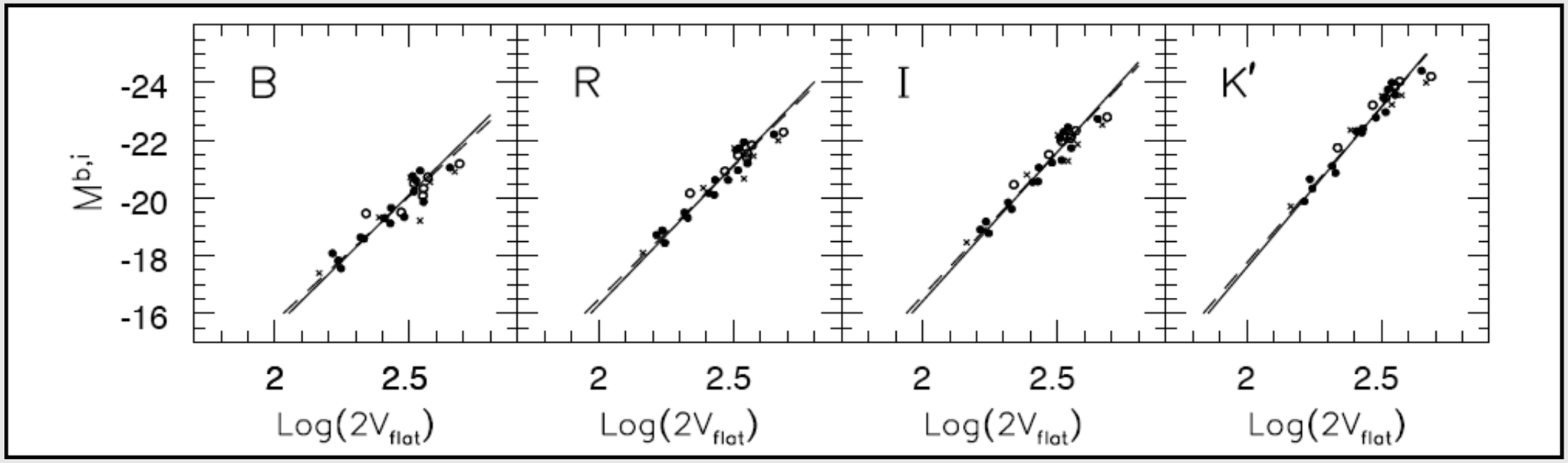


At 1% level: galaxies missing below few $\cdot 10^6 M_\odot$.

With Apertif, ~~xNTD~~, ~~MIRANdA~~, ASKAP,...

factor ~10 deeper

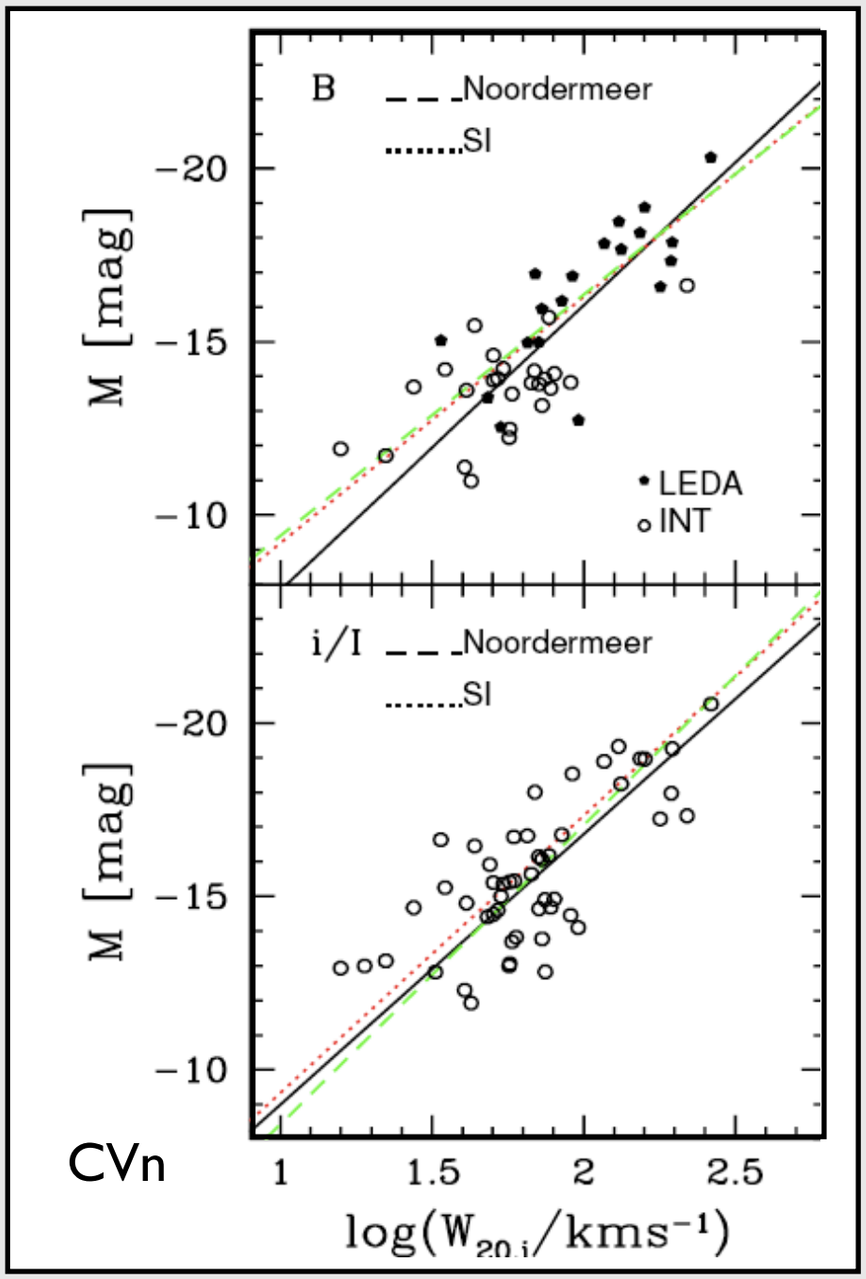
Tully-Fisher relations



Verheijen 2001

Tight relation between rotation velocity and luminosity, in particular when using V_{flat}

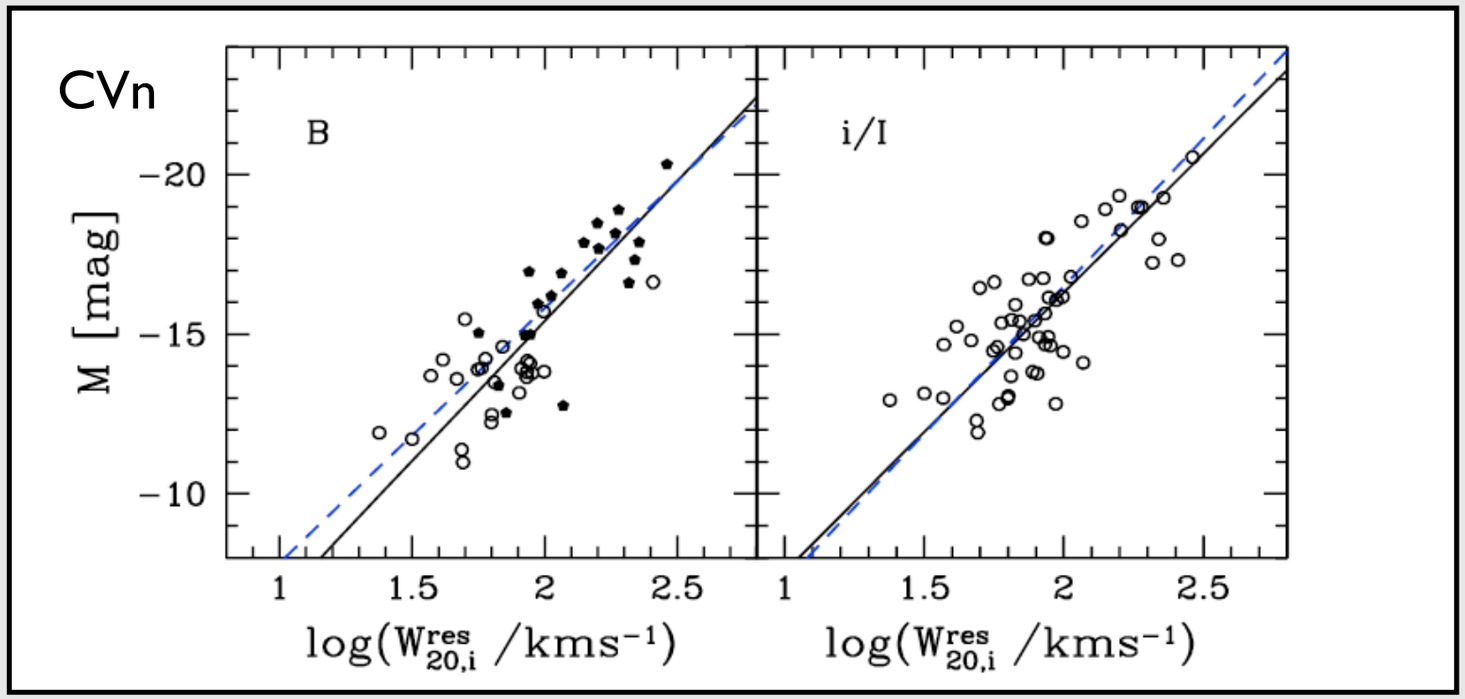
Strong coupling between total mass, baryonic mass and star formation



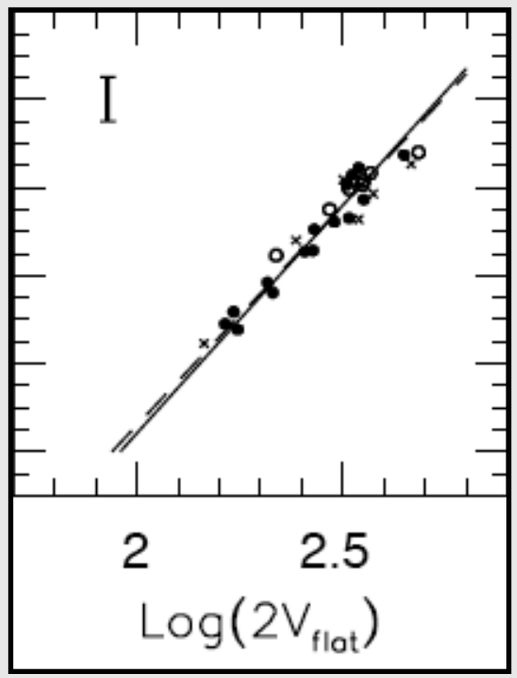
TFs of
Noordermeer 2006
& Verheijen 2001

Overall: CVn galaxies seem to follow same TF relation as large galaxies

No indication for systematic deviation



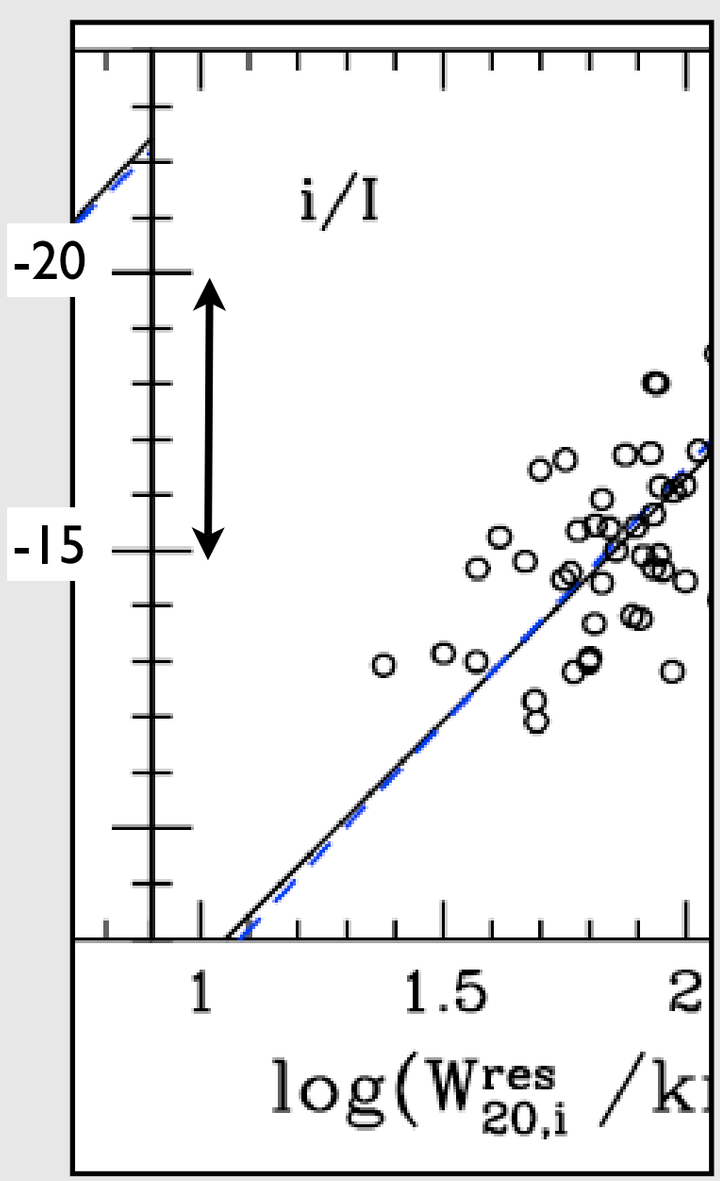
TF of Sakai et al. 2000

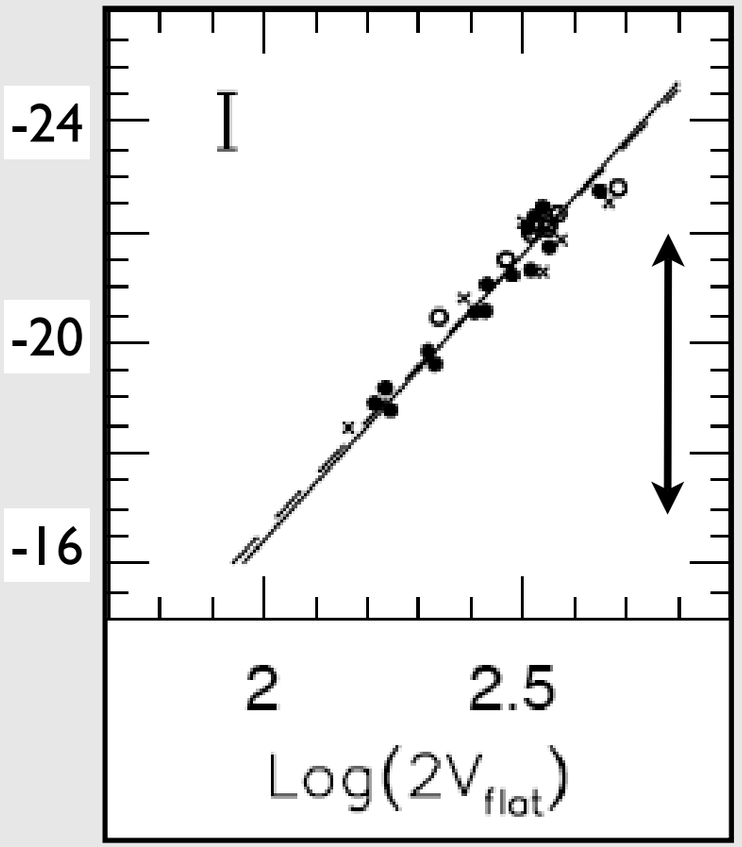


UMa

Verheijen 2001

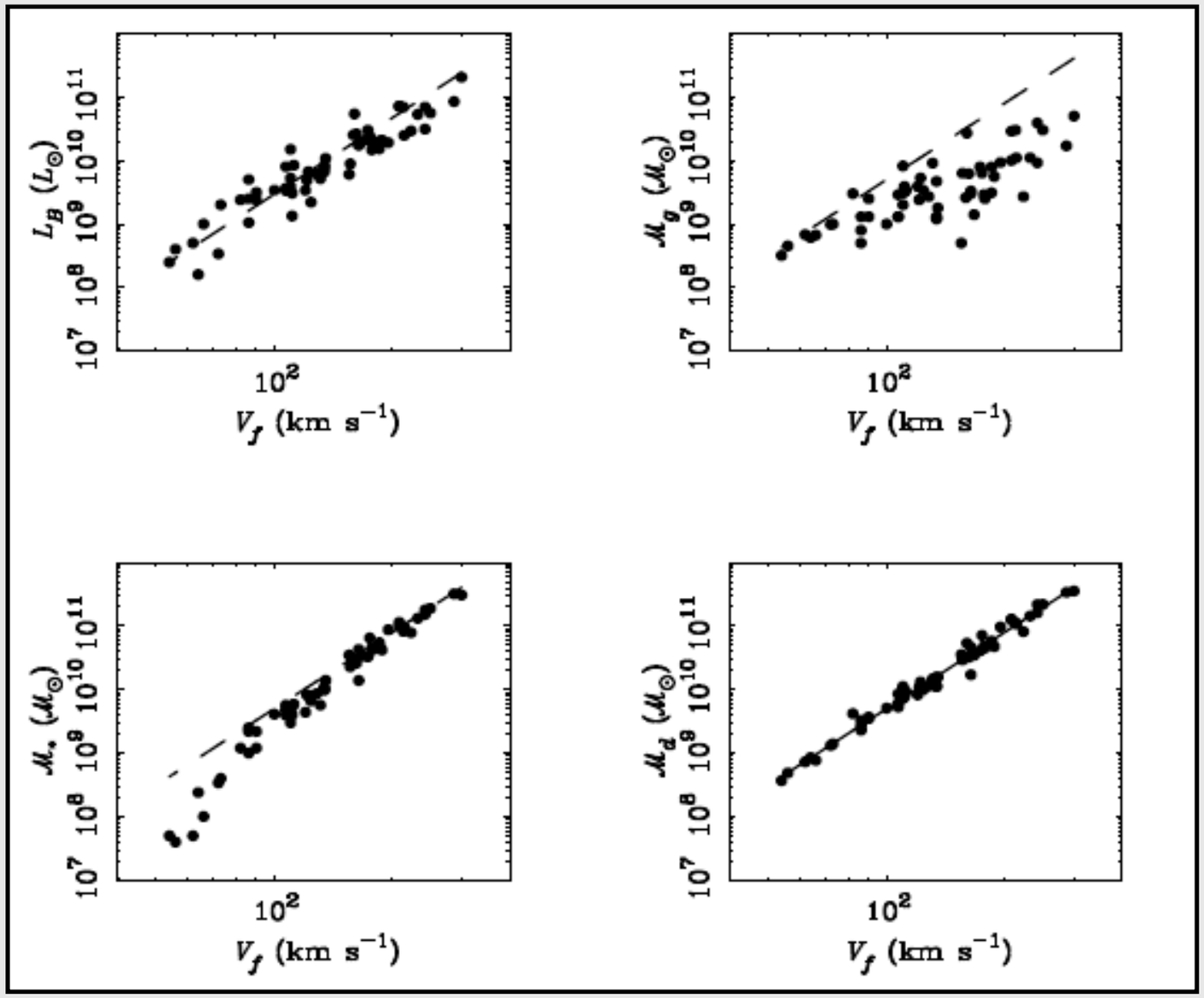
Small galaxies: no TF anymore





Strong coupling between *observed* baryons and *observed* DM halo disappears

Baryonic TF

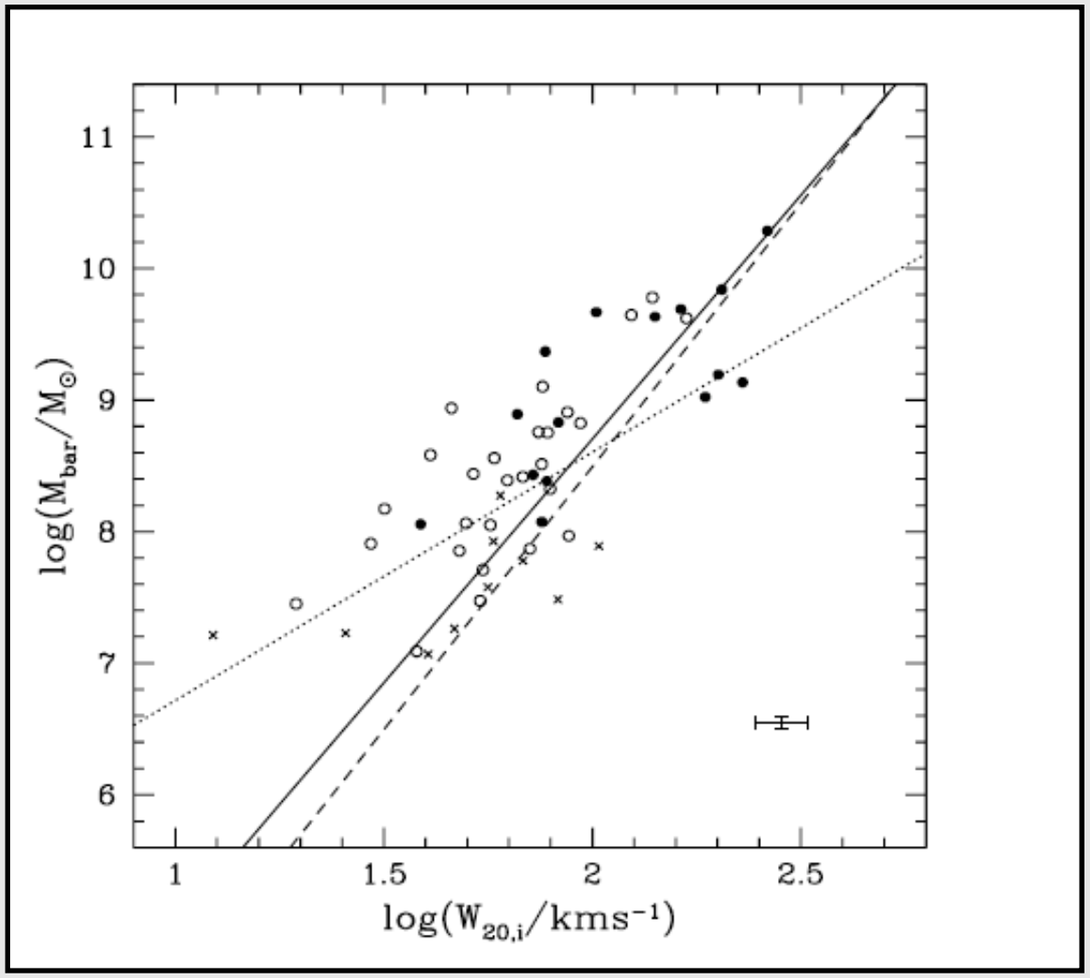


McGaugh 2005

in general : TF relation improves when taking all baryons in to account
AND
use flat part of rotation curve

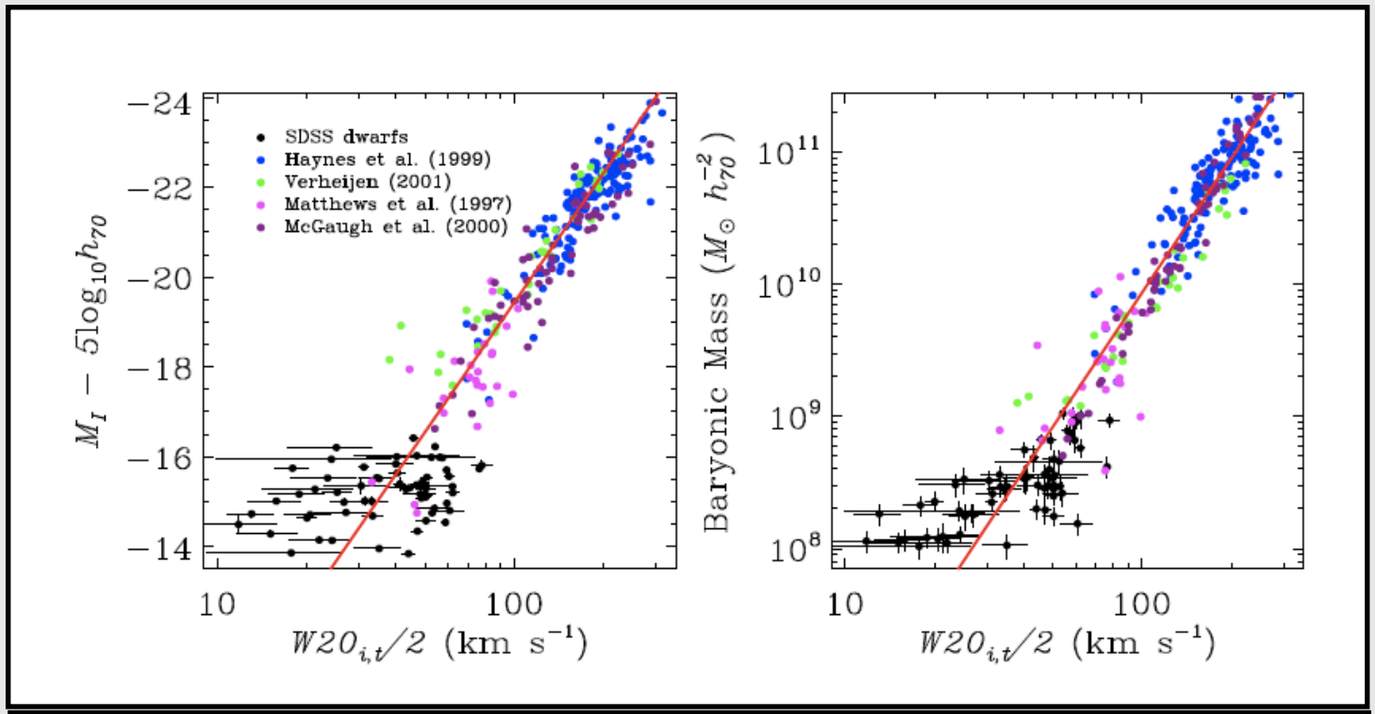
When using V_{flat}:
small galaxies below relation with stellar mass

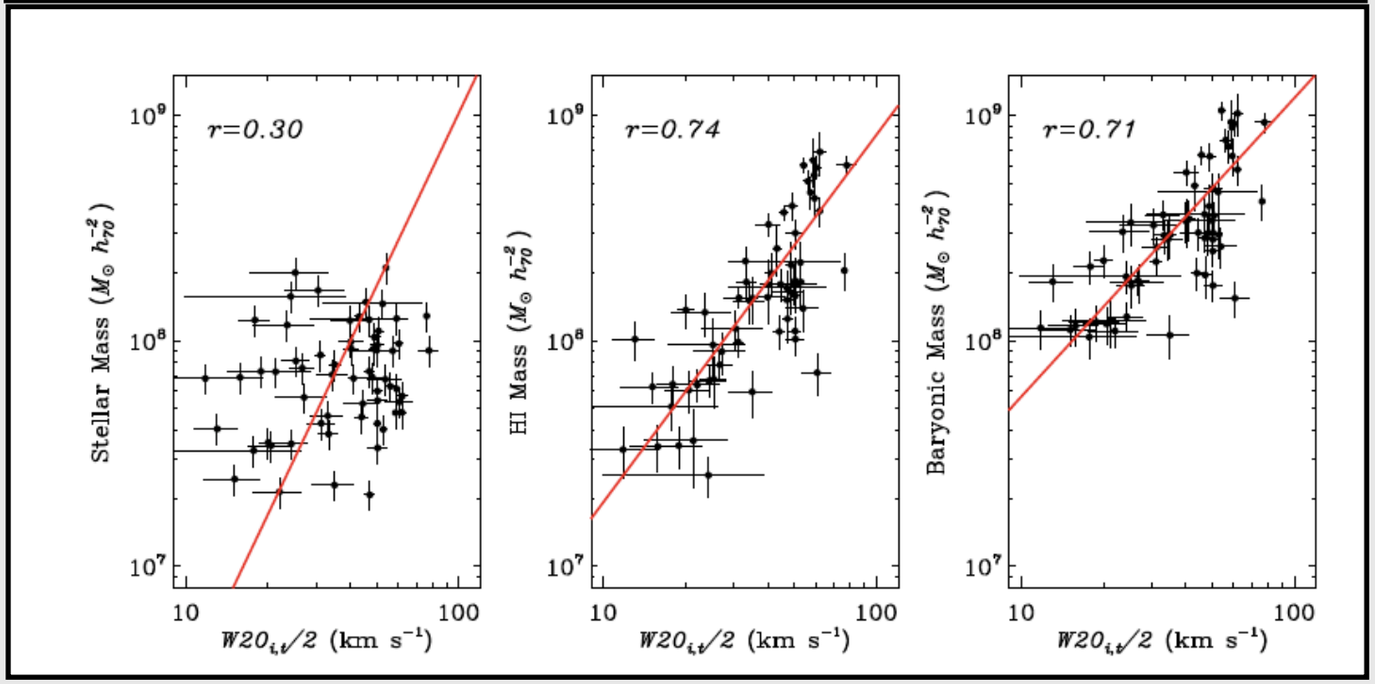
Baryonic TF



CVn

For small galaxies: TF disappears
but still some kind of BTF,
but with large scatter





Geha 2006

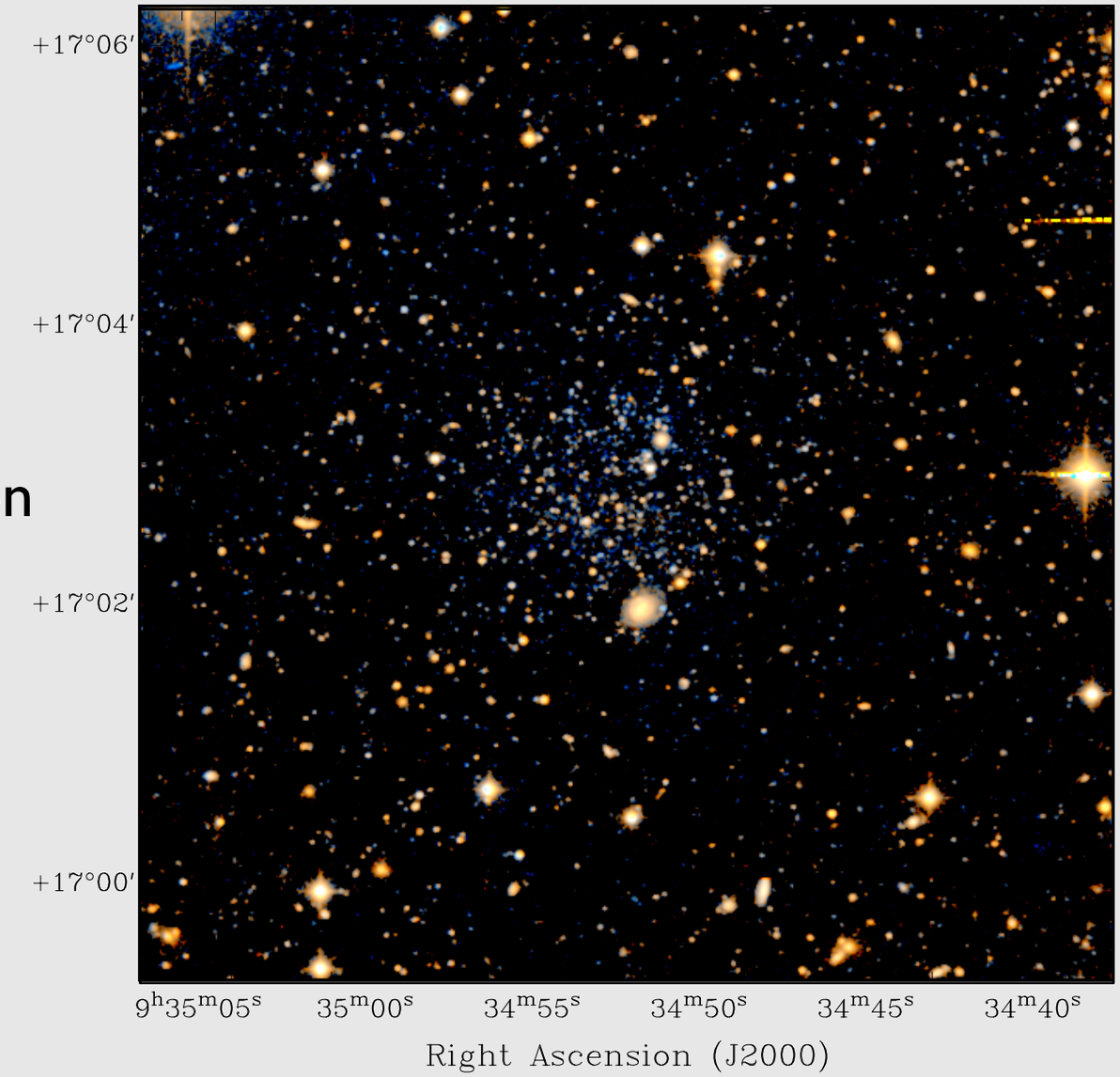
Small galaxies above BTF of large galaxies
Main reason: do not reach flat part of rotation curve?

Leo T

- Star formation history of LG dwarfs very complex, no 2 are alike
- Some have H I, often in offset clouds

- Recently discovered dwarf companion of the Galaxy (Irwin et al. Jan 2007)
- D = 420 kpc
- Metal poor: [Fe/H] = -1.6 - -2.3
- Young subpopulation (200 Myr)
- M_V = -7
- Transition object dSphr/dIrr, like Phoenix or LGS3 (M_V ~ -10), but much smaller

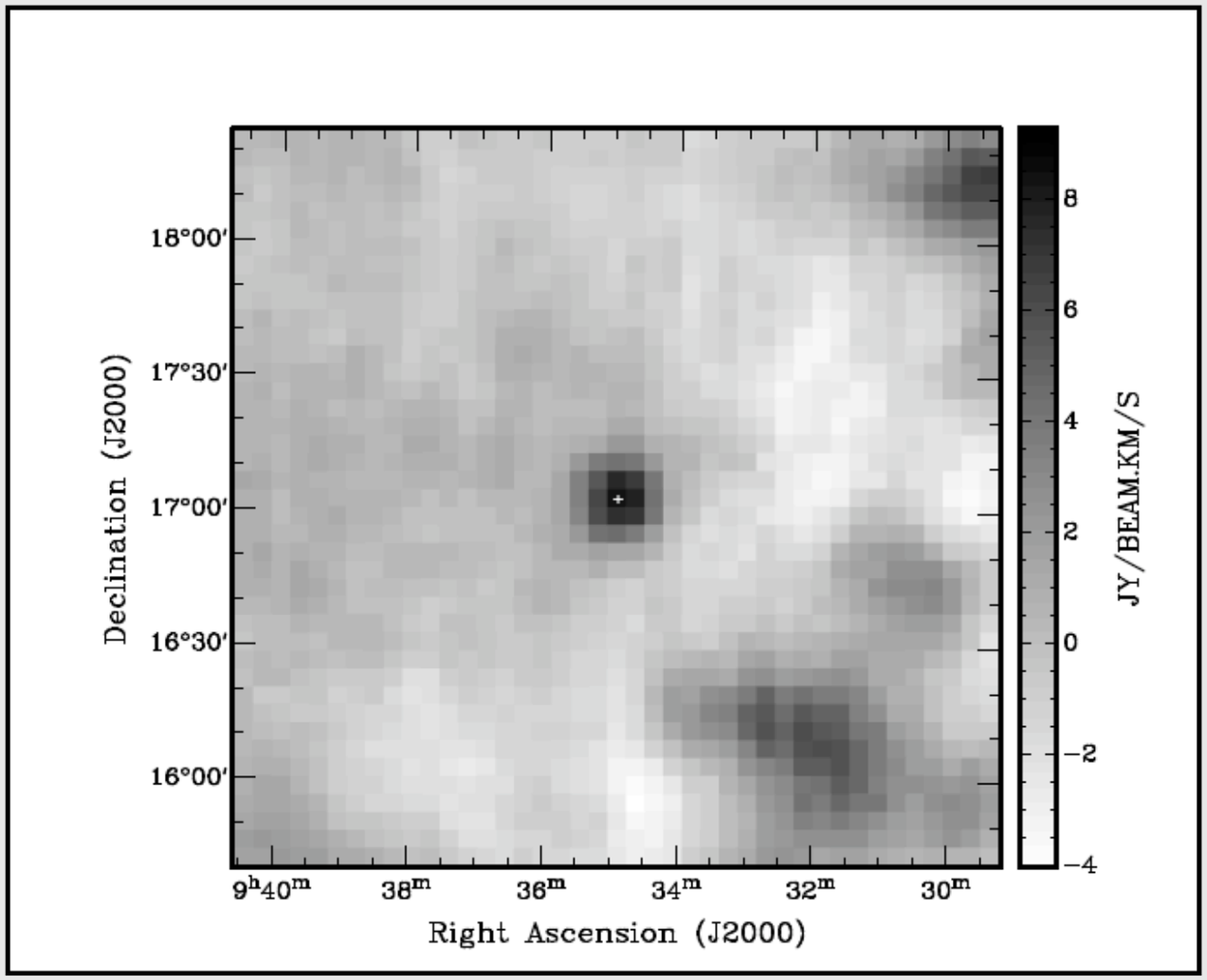
- Smallest system with young population



Leo T is gas rich

HIPASS suggests Leo T has H I

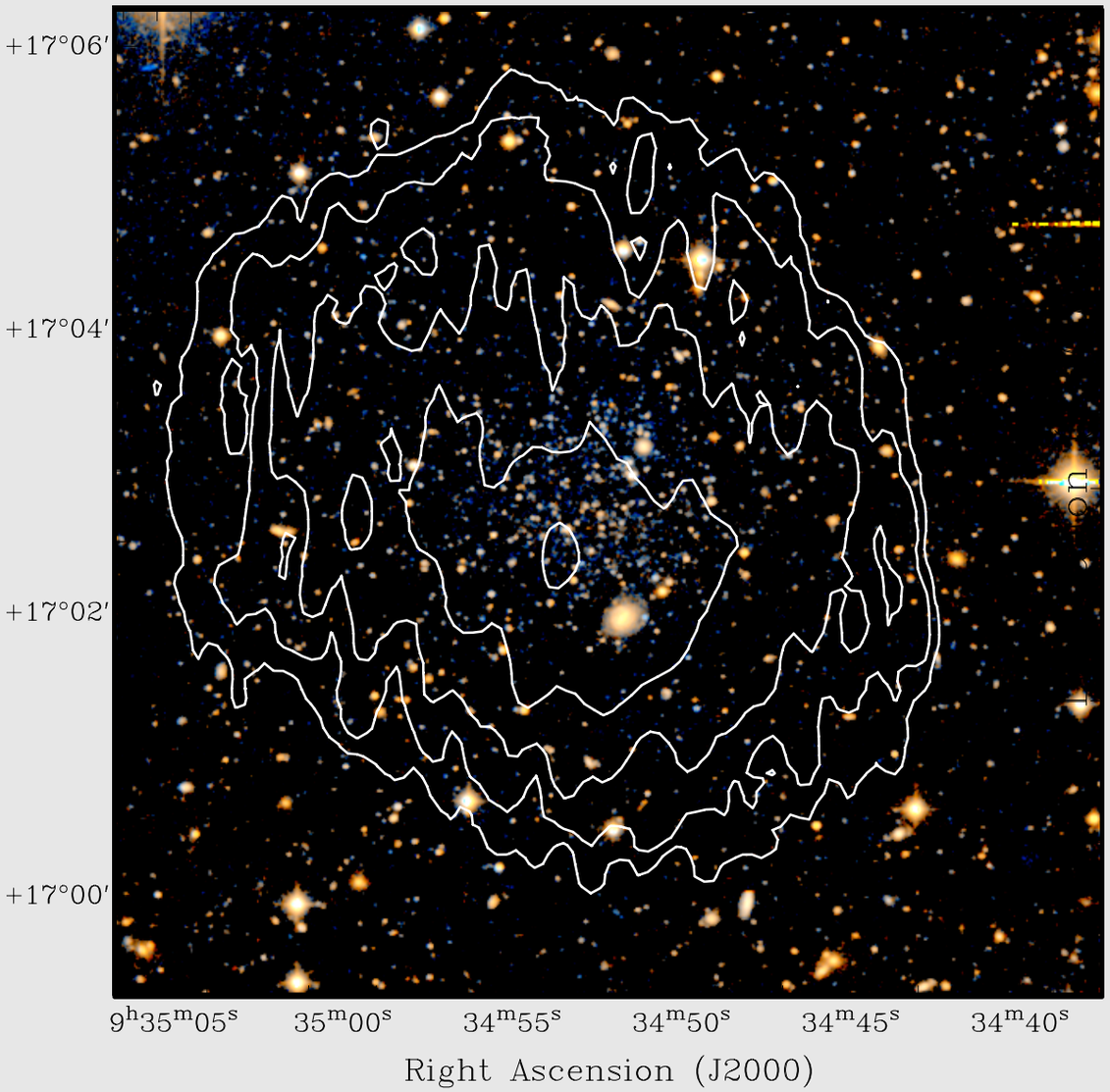
- $M_{HI} = 3 \cdot 10^5\, M_\odot$ $M_{HI}/L_V = 5$ (Phoenix 0.1; LGS3 0.3)
- $M_{HI}/M_{bar} = 0.8$



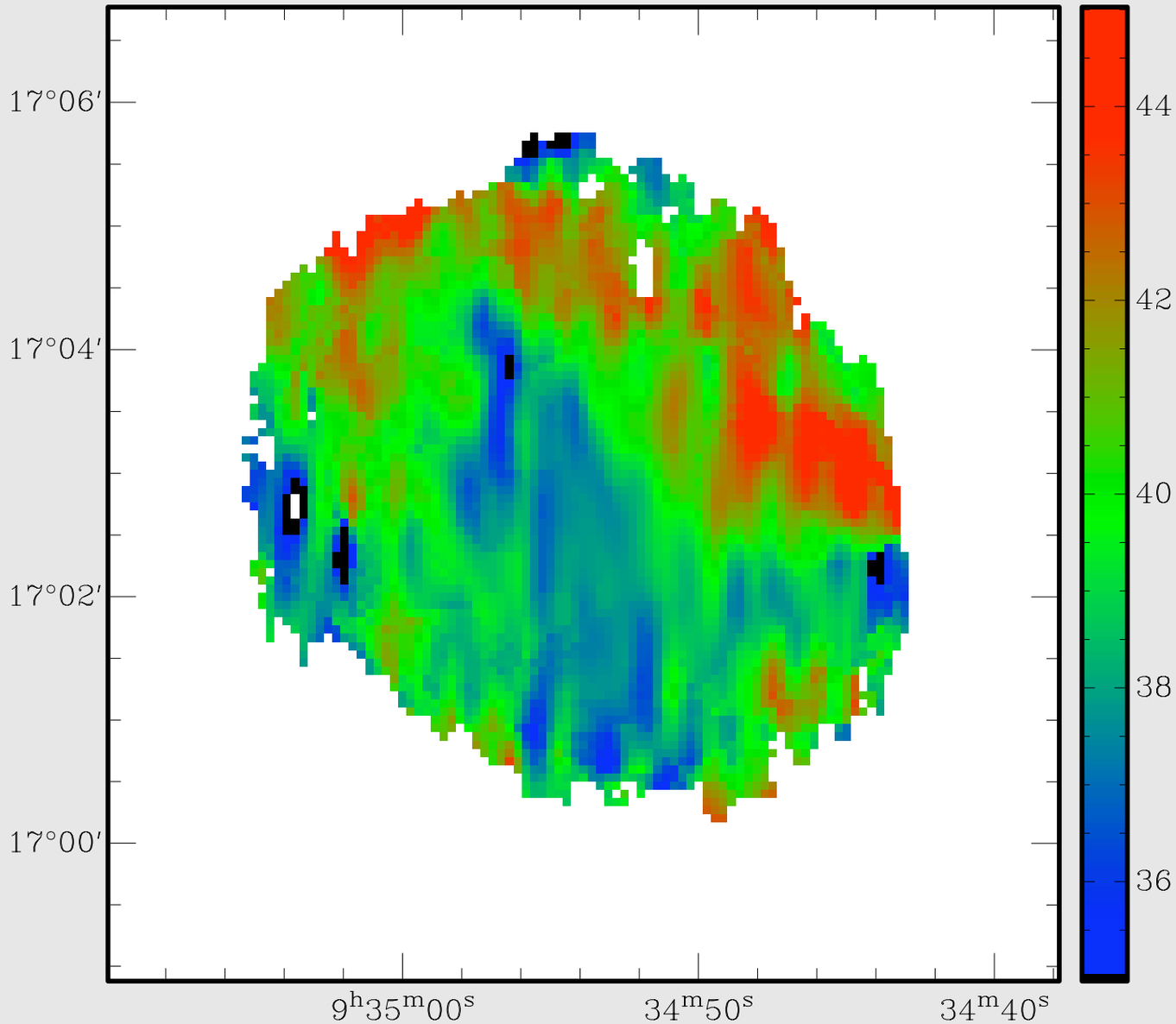
HIPASS image

WSRT observations

- Nice, regular HI distribution. Some rotation???????
- H I velocity matches optical velocity: 39 vs 38 km s^{-1}
- Velocity dispersion H I: 7 km s^{-1}, stars 8 km s^{-1}
- M_{dyn}/L_V ~ 125



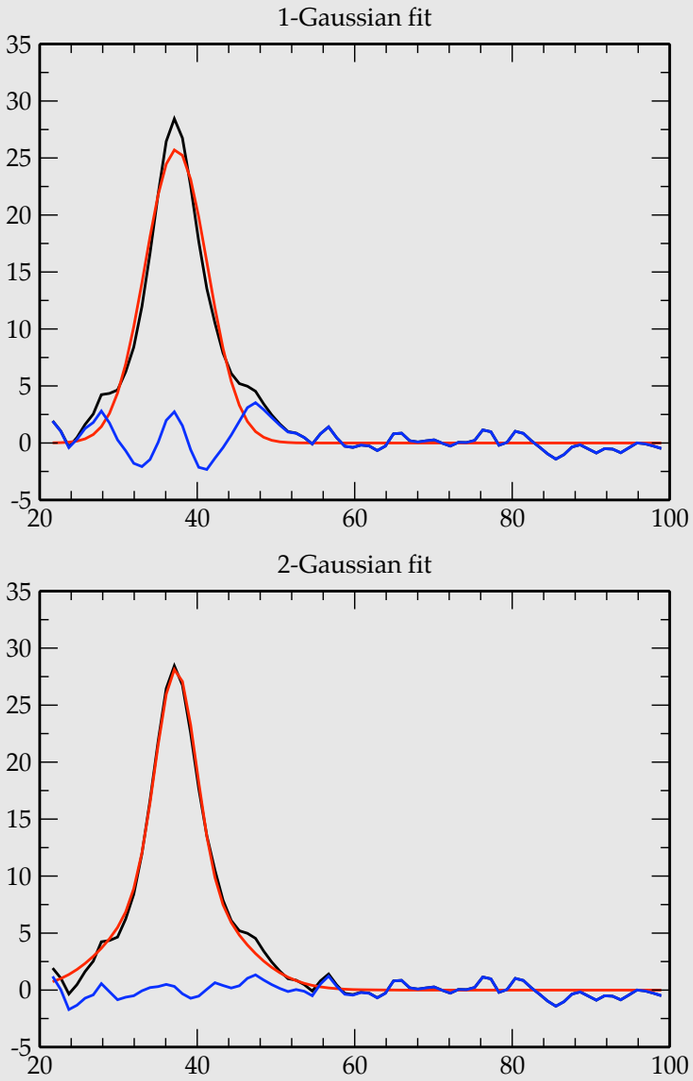
contours 2, 5, 10, 20, 50 ·10^{19} cm^{-2}

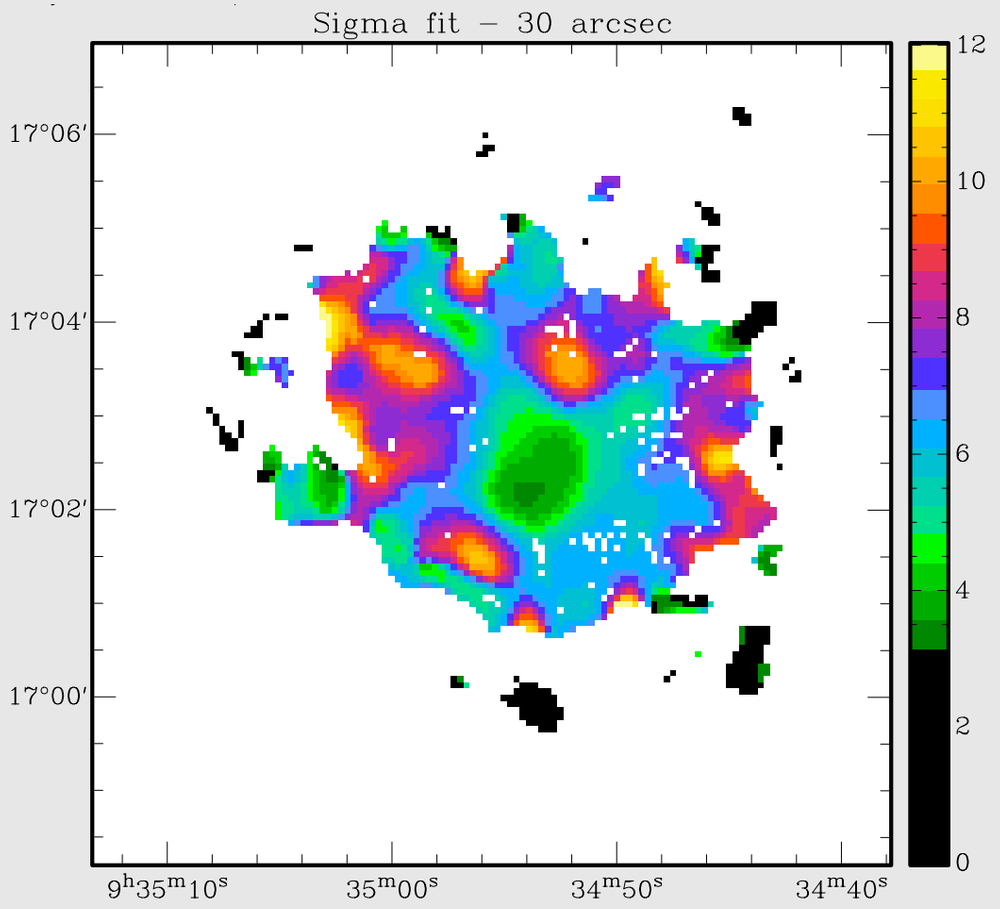


CNM vs WNM

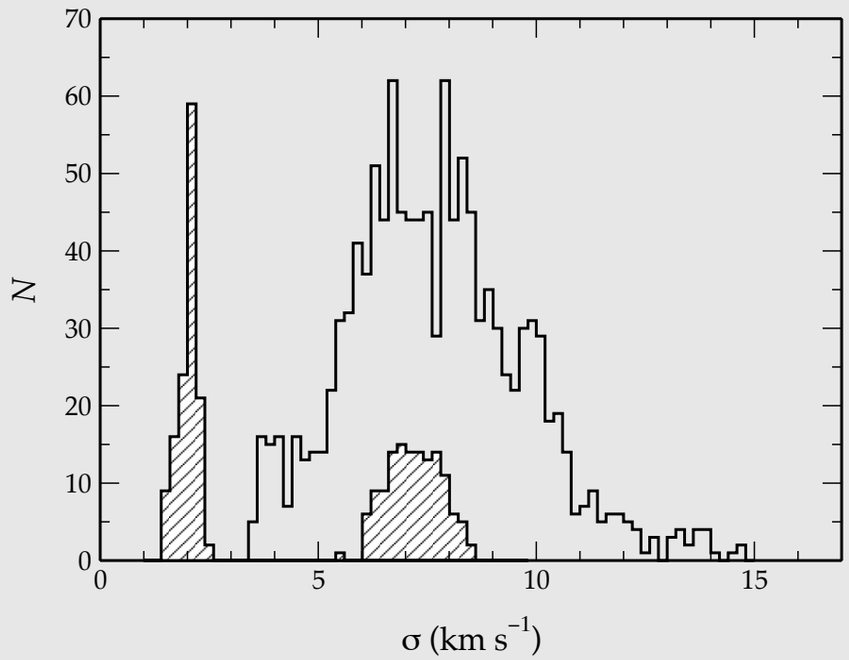
- Structure in dispersion
- Bright H I → smaller widths
- More complicated:
- If columndensity above $3 \cdot 10^{20}$ cm^{-2} : two components.

  Also seen in SagDIG but not in LGS3





If columndensity above critical value of 3 -5 $M_\odot$ kpc^{-2}:
CNM present and stars can form
consistent with e.g. Taylor & Webster 2005



Summary

- WSRT survey for small galaxies in CVn
  - 69 galaxies, down to $3 \cdot 10^6 M_\odot$;
  - No dark galaxies, faint-end slope mass function -1.2
  - Hint for lack of smaller H I galaxies
  - Tully-Fisher relation has very large scatter, effectively disappears
  - BTF has smaller scatter, but scatter is large:

    fail to reach flat part of rotation curve, do not sample DM halo well enough

- Leo T
  - Smallest galaxy with young stellar population
  - Regular H I distribution. Rotation?
  - Two-phase ISM: CNM and WNM present, consistent with models