The Shapes of the HI Velocity Profiles from THINGS

Erwin de Blok
(ASTRON/UCT)

Roger Ianjamasimanana
Bradley Frank
Moses Mogotsi
Anahi Caldu-Primo

THINGS and HERACLES teams

THINGS

- **T**he **HI N**earby **G**alaxy **S**urvey - Walter et al (2008)
- VLA B,C,D array of 34 nearby Sa-Irr galaxies
- distance 3-15 Mpc
- ~6" spatial (100-500 pc), 2-5 km/s velocity resolution
- overlap with SINGS (Spitzer infrared) and GALEX NGS (UV)

THINGS

- **T**he **HI N**earby **G**alaxy **S**urvey - Walter et al (2008)
- VLA B,C,D array of 34 nearby Sa-Irr galaxies
- distance 3-15 Mpc
- ~6" spatial (100-500 pc), 2-5 km/s velocity resolution
- overlap with SINGS (Spitzer infrared) and GALEX NGS (UV)

HERACLES

- HERACLES - Leroy et al. (2009)
- **HE**terodyne **R**eceiver **A**rray **C**O **L**ine **E**xtragalactic **S**urvey
- HERA multipixel receiver on IRAM 30m telescope
- Maps CO J=2→1 of entire HI disk of 18 THINGS galaxies (+others)
- 13" spatial and 2.6 km/s velocity resolution (~ THINGS)

Outline

- Stacking of THINGS HI profiles
- Broad and Narrow HI components
- Comparison with CO from HERACLES
- Narrow-component HI and SF

THINGS

The HI Nearby Galaxy Survey

NGC 2841
NGC 3621
NGC 7331
NGC 4826 (M64)
NGC 6946
NGC 3184
NGC 925
NGC 3351 (M95)
NGC 3198
NGC 5194 (M51)
NGC 5236 (M83)
NGC 3521
NGC 4214
NGC 2976
DDO 53
NGC 1569
M81dwB
NGC 2366
Our Galaxy HI stars
M81dwA
IC 2574
NGC 4449
NGC 3627 (M66)
Holmberg II
NGC 7793
DDO 154
NGC 4736 (M94)
NGC 3077
Holmberg I
NGC 5055
NGC 2903
NGC 628 (M74)
NGC 5457 (M101)
NGC 3031 (M81)
NGC 2403

10 kpc

Data: Walter et al 2008
Milky Way HI map: Oort et al (1958)
Milky Way art: NASA/JPL, R. Hurt (SSC)

THINGS

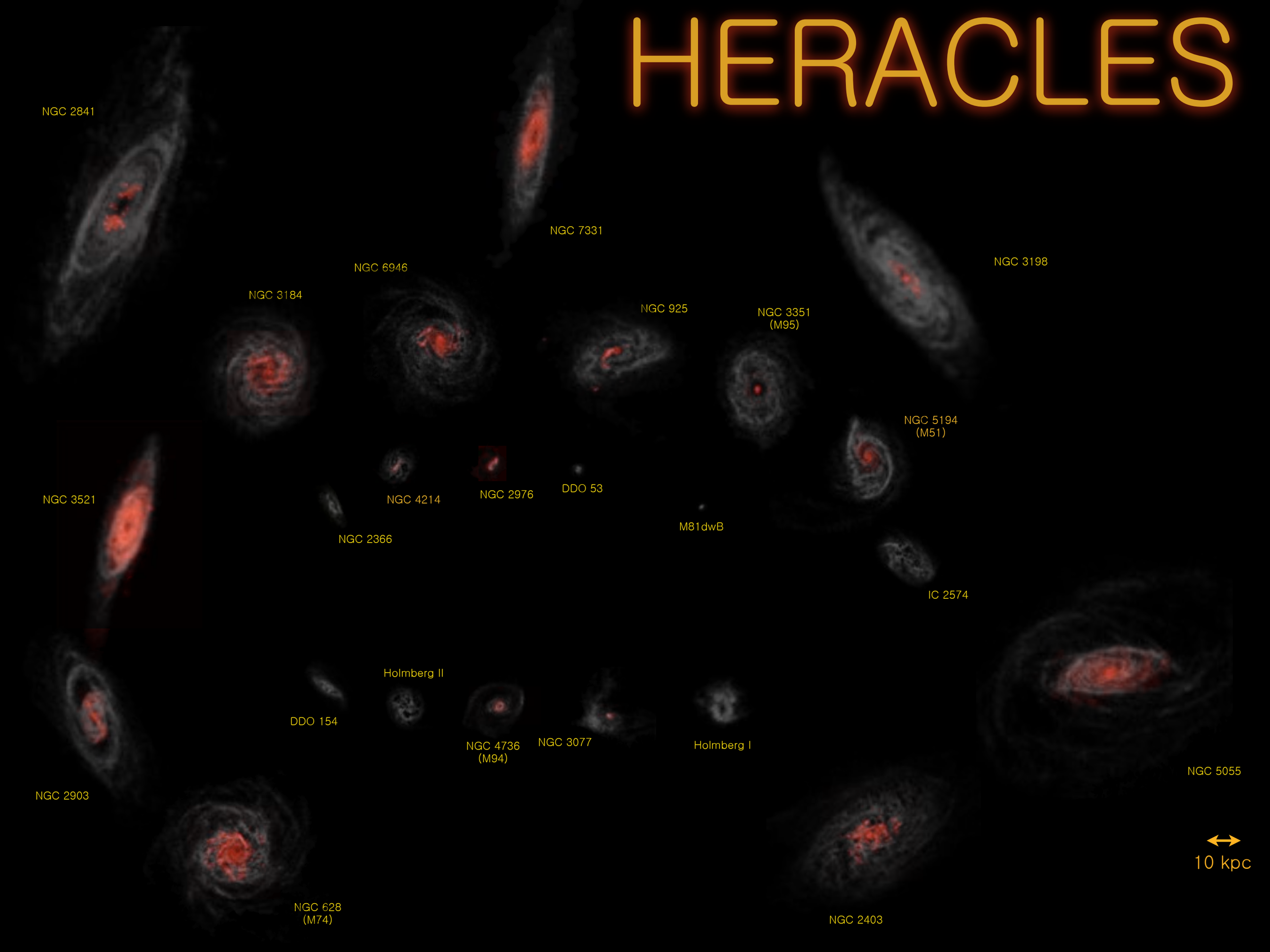
observed by HERACLES

Data: Walter et al 2008

Milky Way HI map: Oort et al (1958)

Milky Way art: NASA/JPL, R. Hurt (SSC)

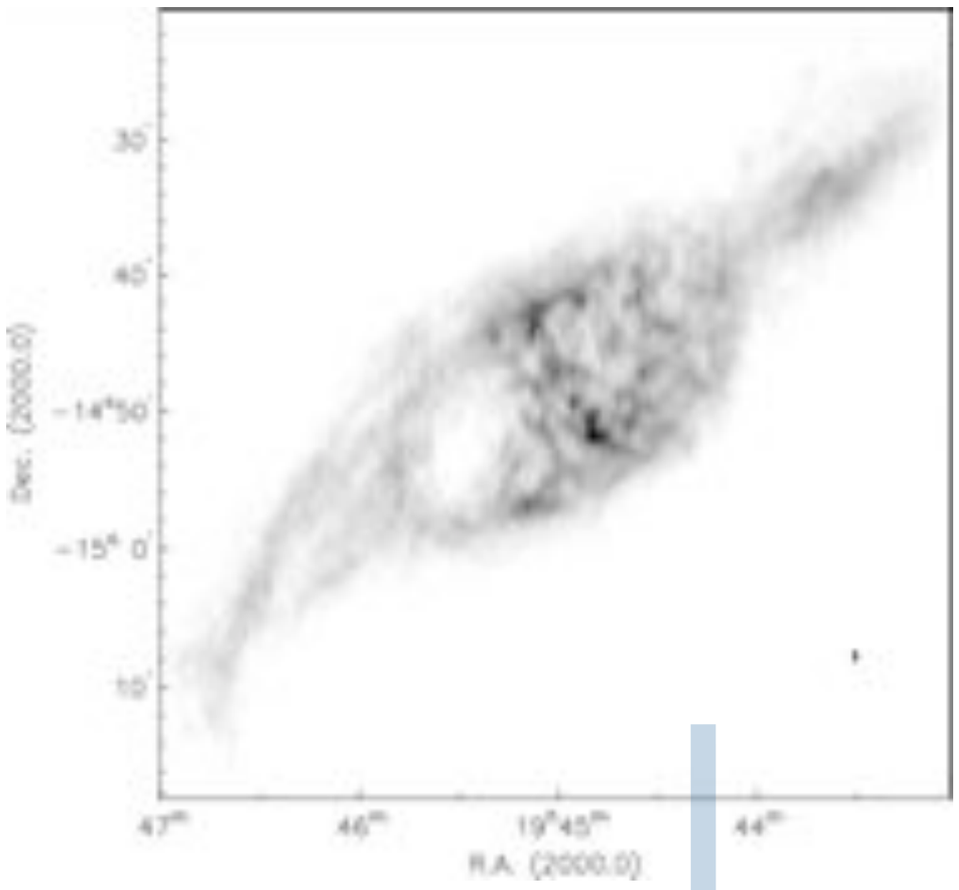
HERACLES

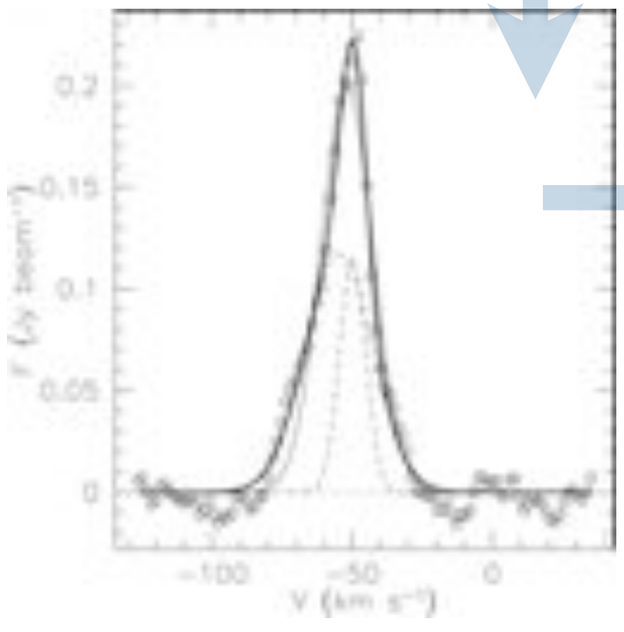

NGC 2841
NGC 7331
NGC 6946
NGC 3198
NGC 3184
NGC 925
NGC 3351
(M95)
NGC 5194
(M51)
NGC 3521
NGC 4214
NGC 2976
DDO 53
NGC 2366
M81dwB
IC 2574
Holmberg II
DDO 154
NGC 4736
(M94)
NGC 3077
Holmberg I
NGC 5055
NGC 2903
10 kpc
NGC 628
(M74)
NGC 2403

Needed for star formation

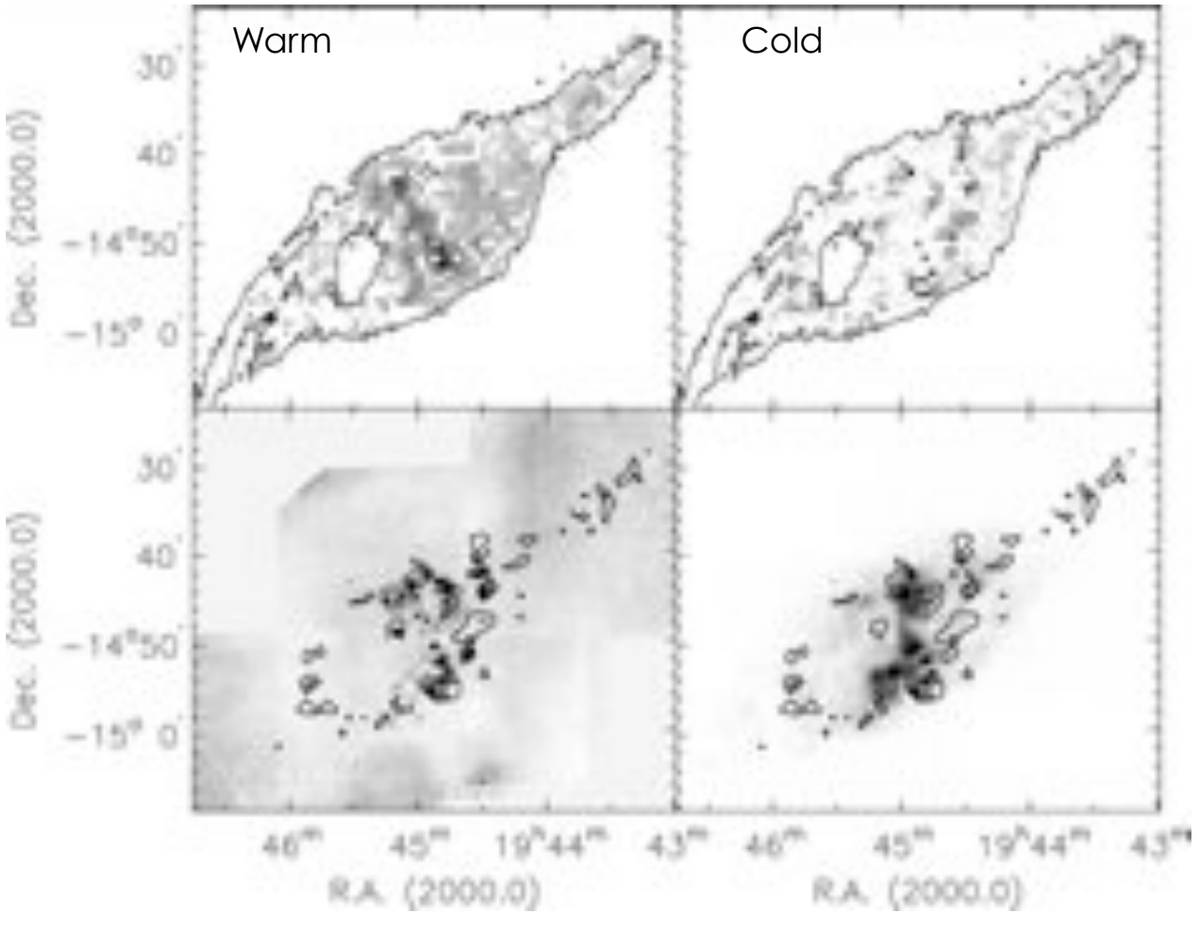
- "Cold" gas a necessary ingredient for star formation
- Neutral → cold neutral → molecular → SF
- Investigate cold neutral component: mass, distribution and velocity dispersion

Phases of the Neutral ISM





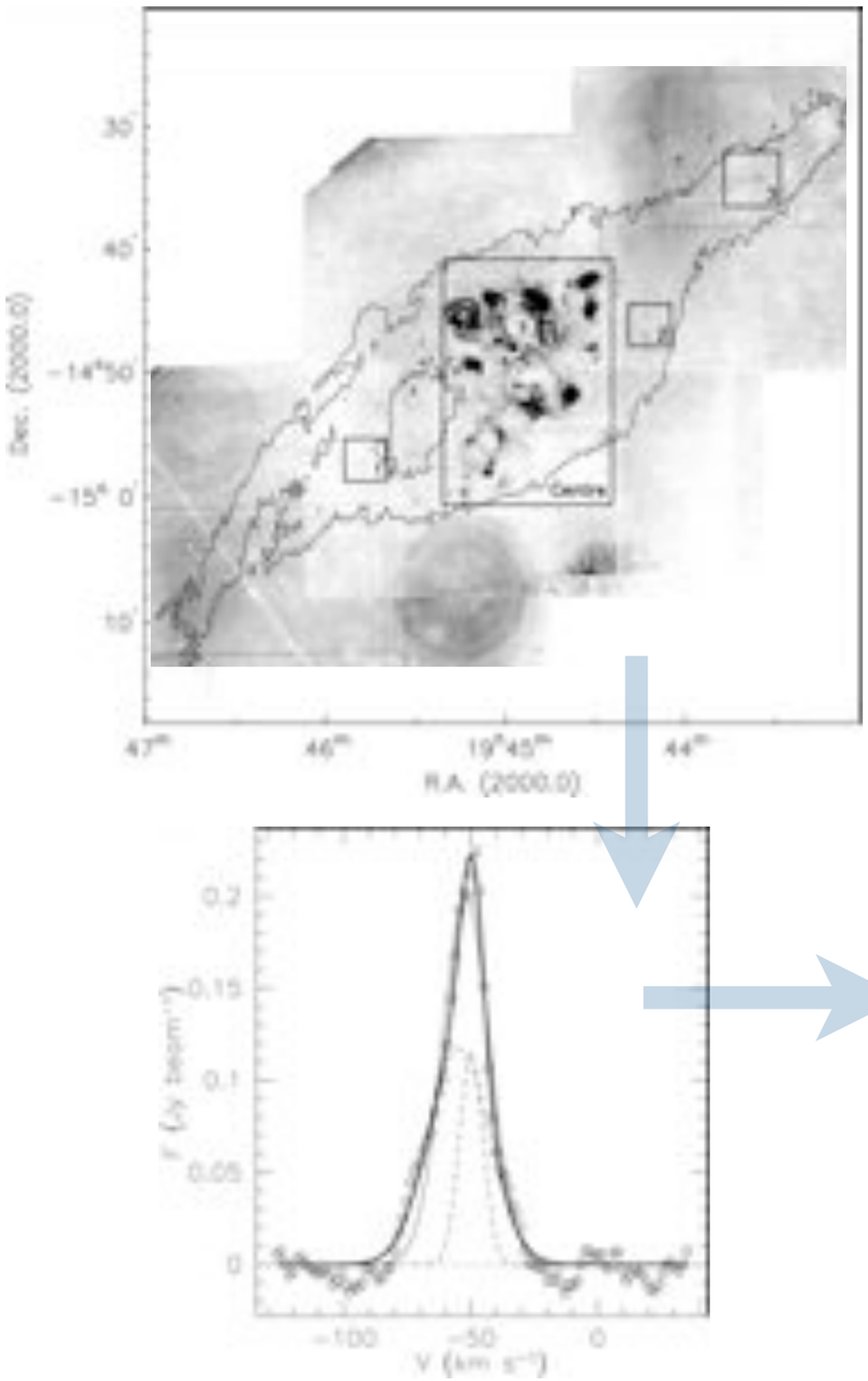
- Broad: Warm: T ~ 10^4 K
- Narrow: Cold: T ~ few 100 K
- but dispersions higher - turbulence et al



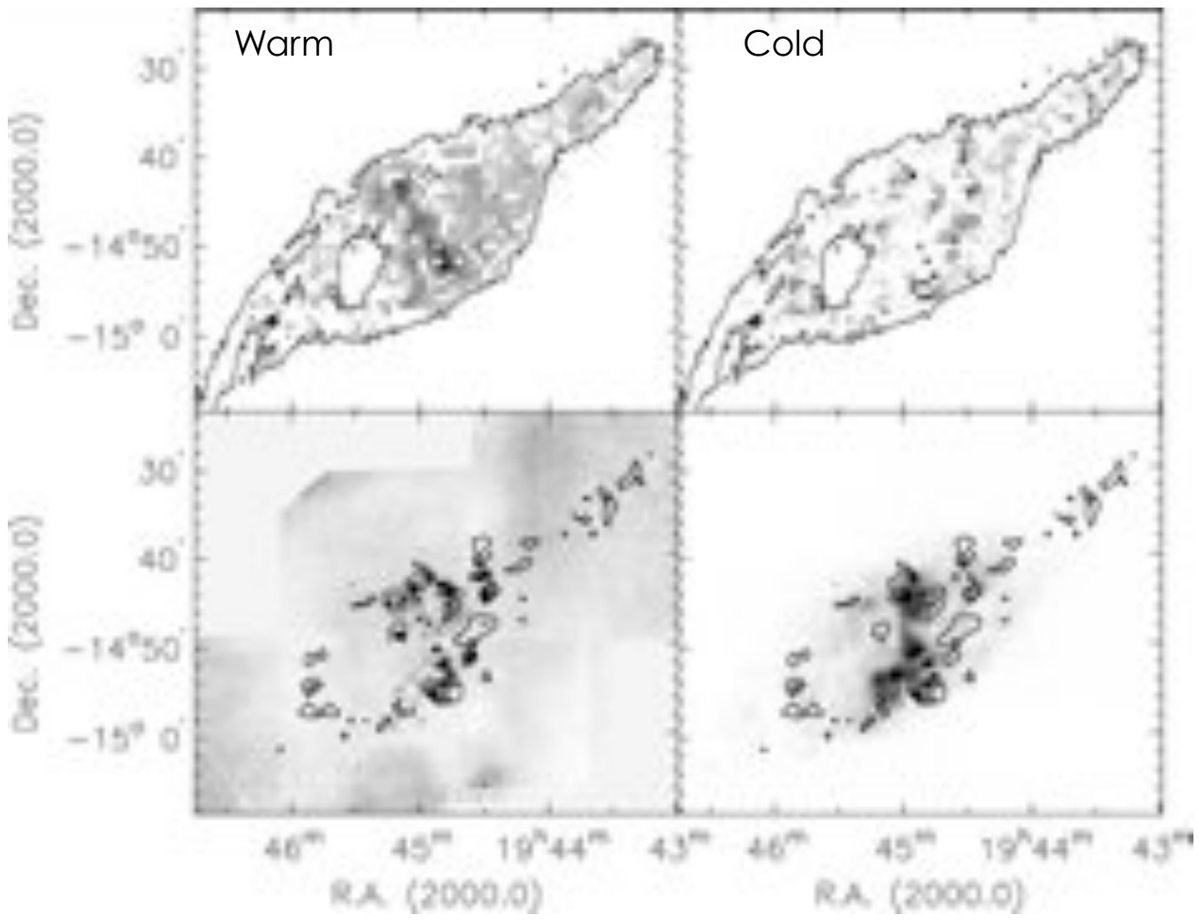
de Blok & Walter 2006a
also Young & Lo 1997, Braun 1997, etc

de Blok & Walter 2006

Phases of the Neutral ISM



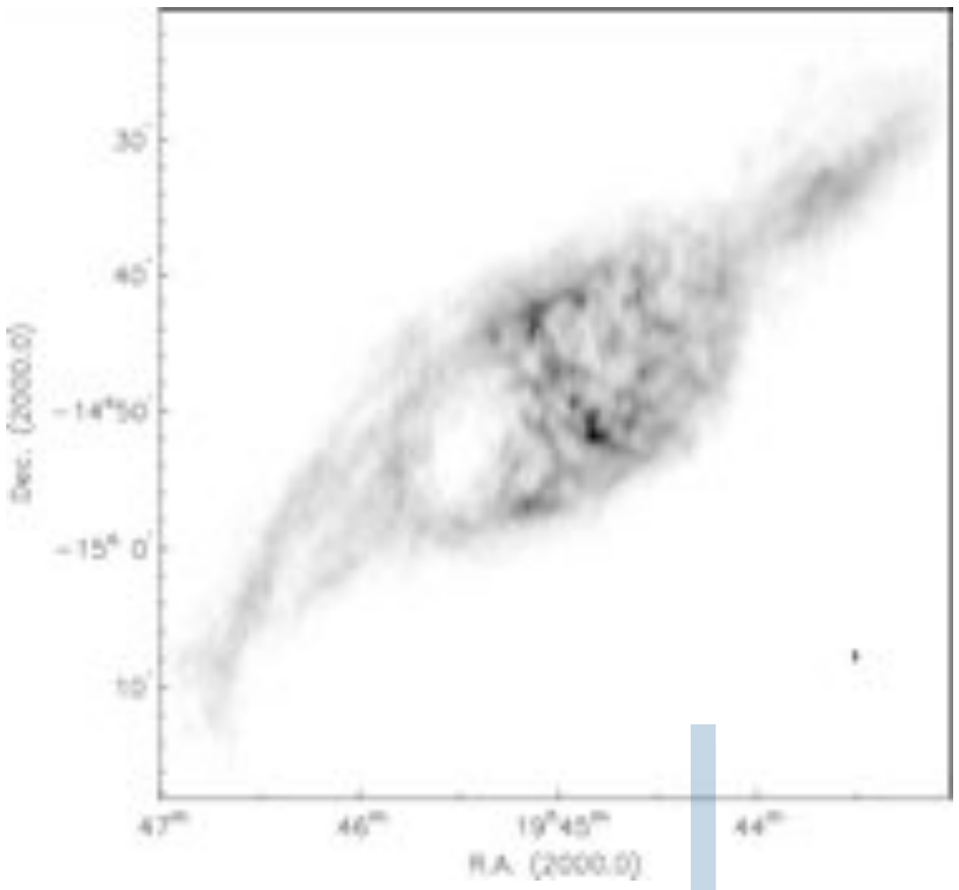
- Broad: Warm: T ~ 10^4 K
- Narrow: Cold: T ~ few 100 K
- but dispersions higher - turbulence et al

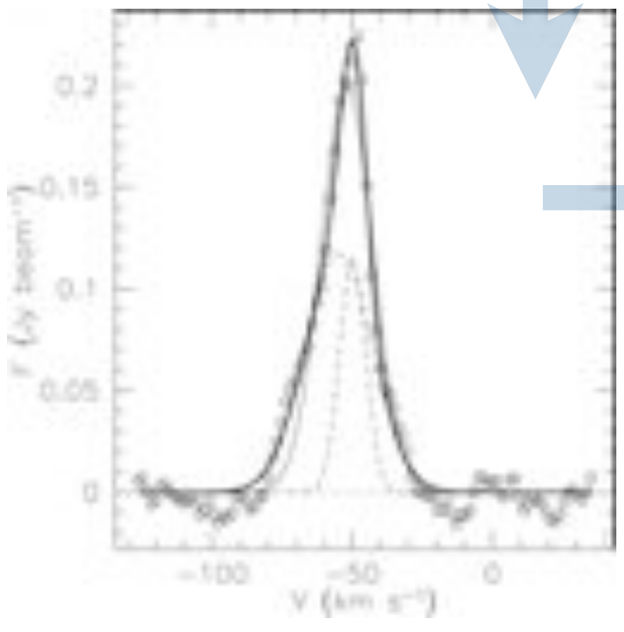


de Blok & Walter 2006a
also Young & Lo 1997, Braun 1997, etc

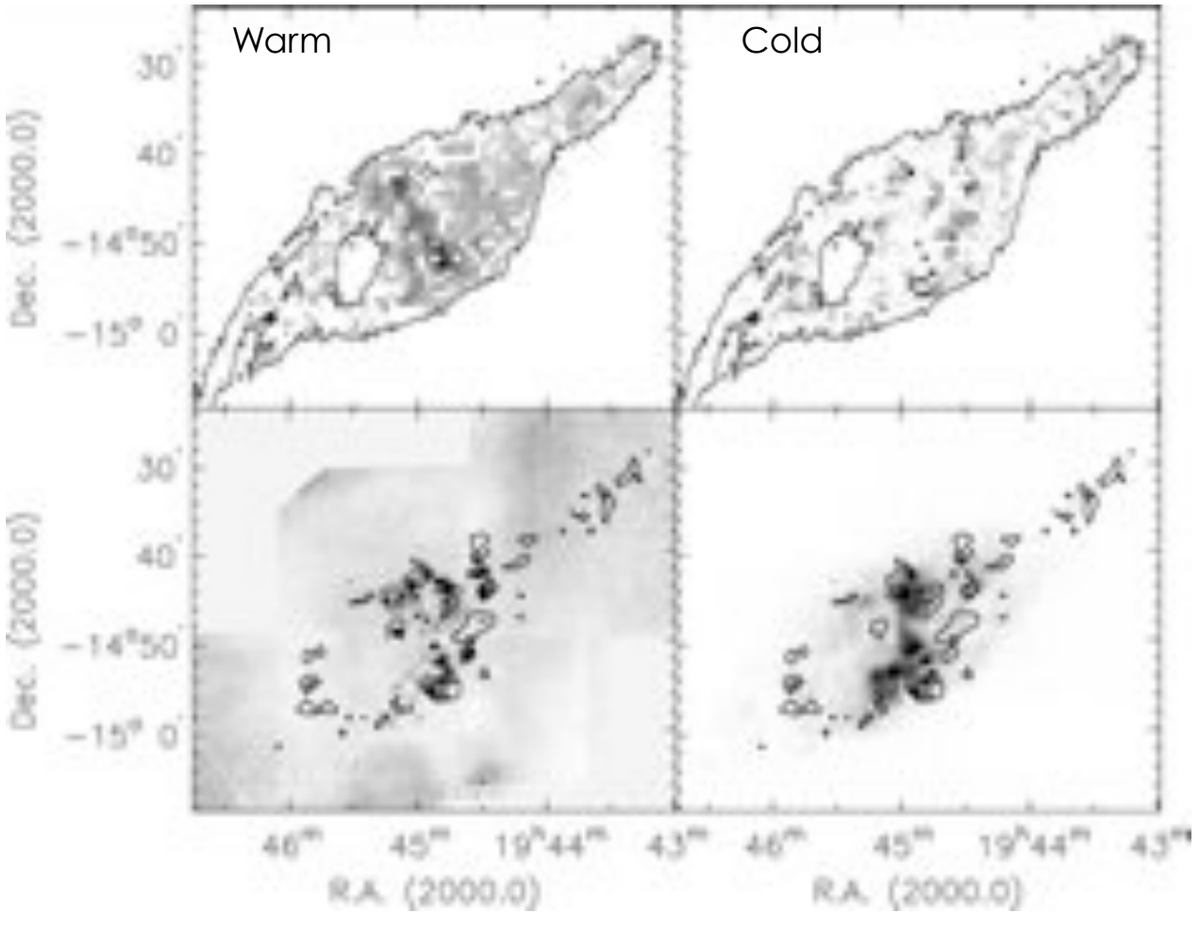
de Blok & Walter 2006

Phases of the Neutral ISM





- Broad: Warm: T ~ 10^4 K
- Narrow: Cold: T ~ few 100 K
- but dispersions higher - turbulence et al



de Blok & Walter 2006a
also Young & Lo 1997, Braun 1997, etc

de Blok & Walter 2006

THINGS

The HI Nearby Galaxy Survey

NGC 2841

NGC 3621

NGC 7331

NGC 6946

NGC 3184

NGC 925

NGC 3351 (M95)

NGC 3198

NGC 5194 (M51)

NGC 5236 (M83)

NGC 3521

NGC 4214

NGC 2976

DDO 53

NGC 1569

M81dwB

M81dwA

NGC 2366

Our Galaxy HI stars

IC 2574

NGC 4449

NGC 3627 (M66)

Holmberg II

NGC 7793

DDO 154

NGC 4736 (M94)

NGC 3077

Holmberg I

NGC 5055

NGC 2903

NGC 628 (M74)

NGC 5457 (M101)

NGC 3031 (M81)

NGC 2403

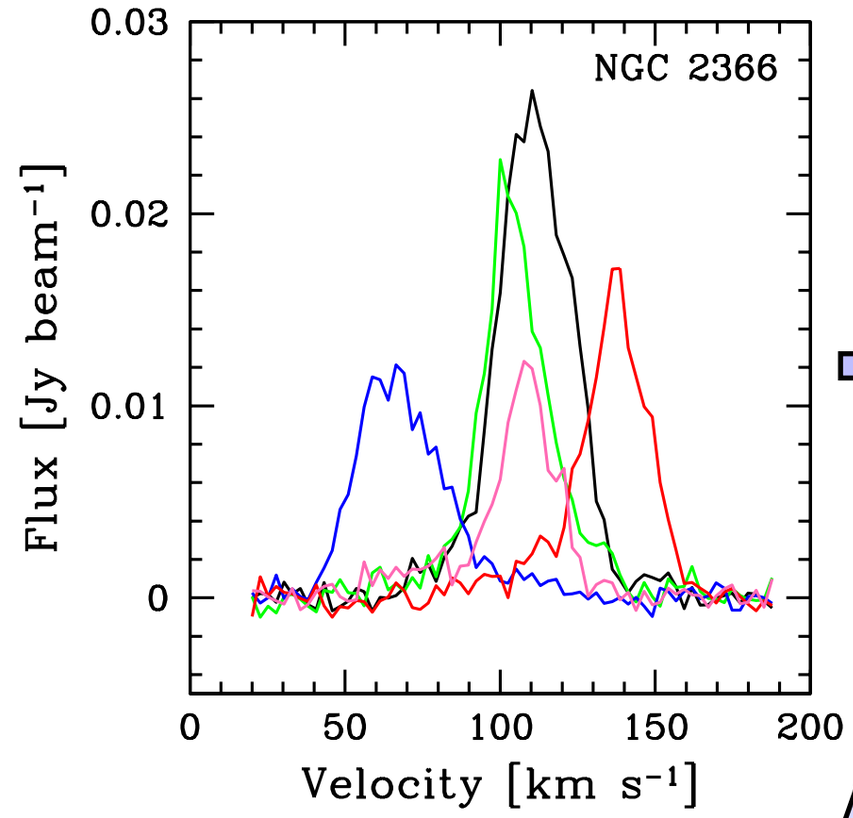
10 kpc

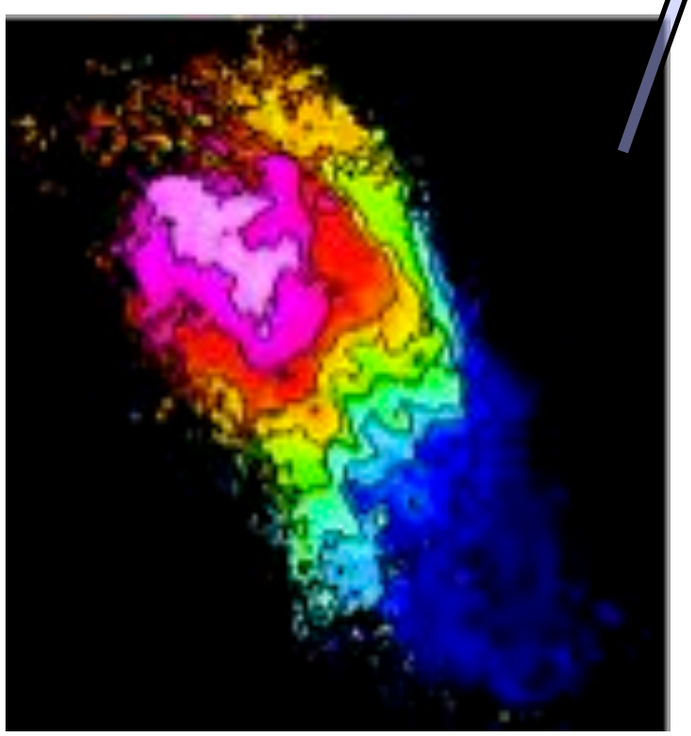
Data: Walter et al 2008

Milky Way HI map: Oort et al (1958)

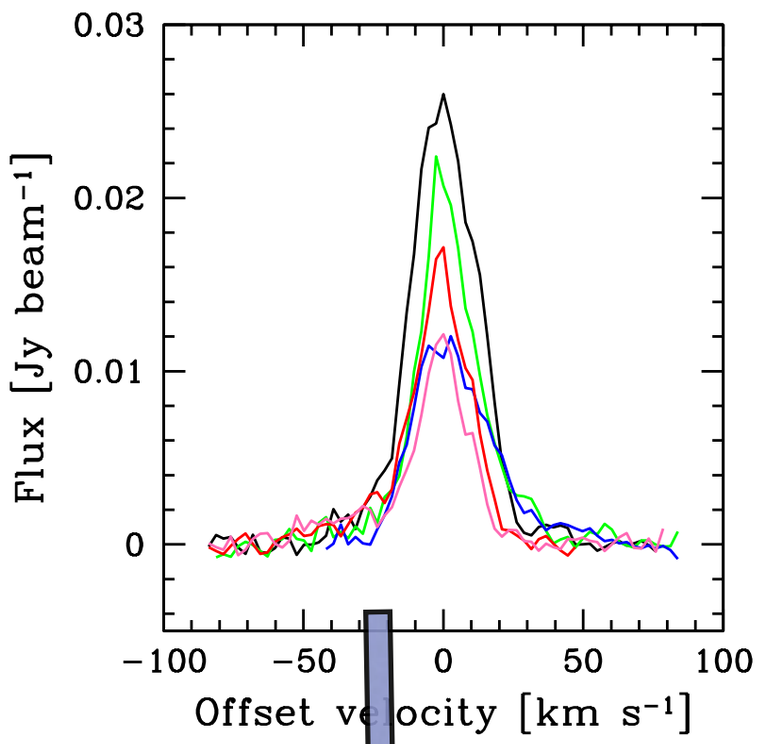
Milky Way art: NASA/JPL, R. Hurt (SSC)

Stacking the profiles

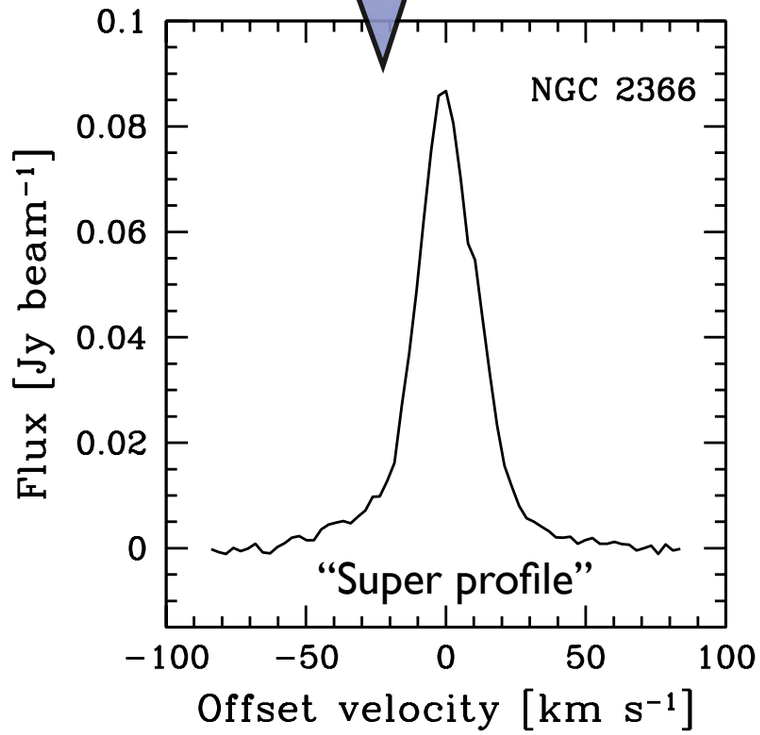




Shift

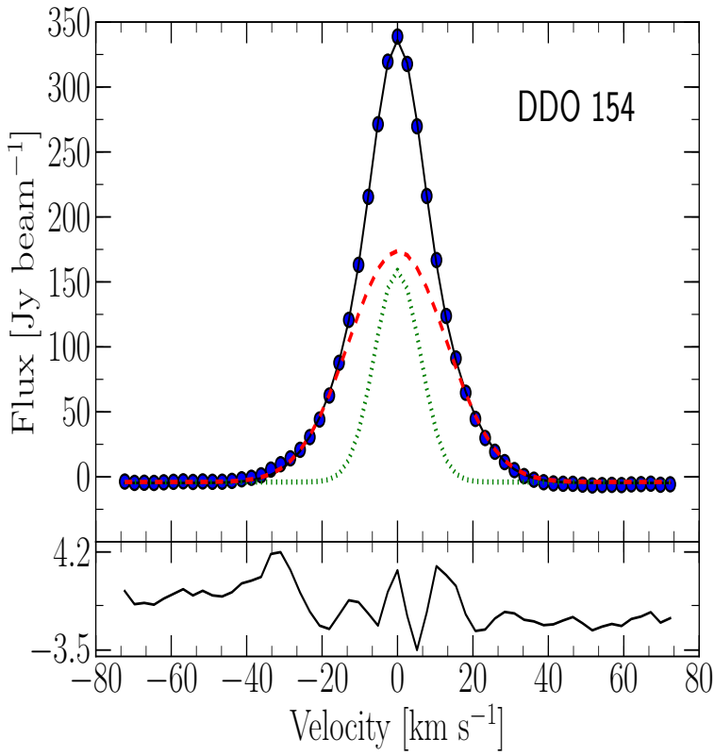


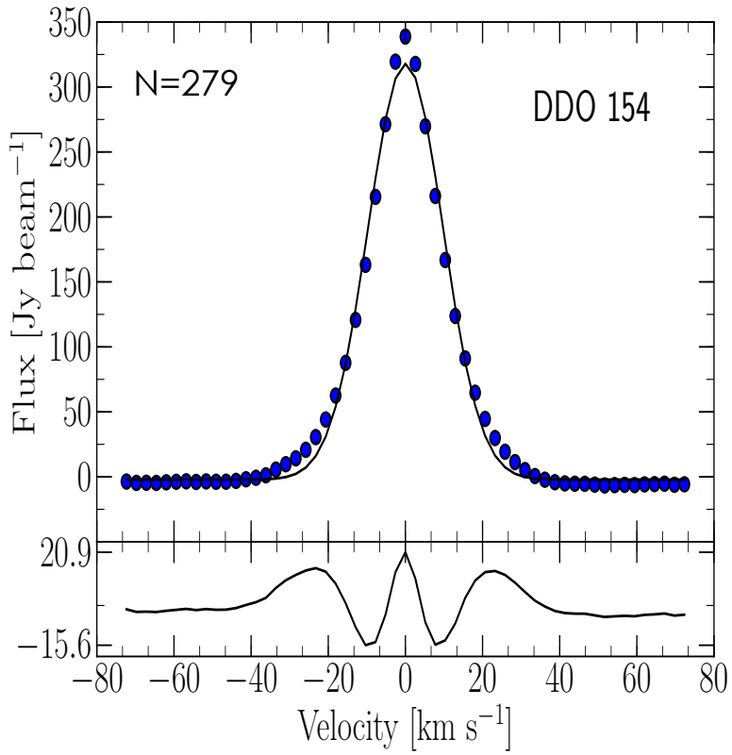
Sum

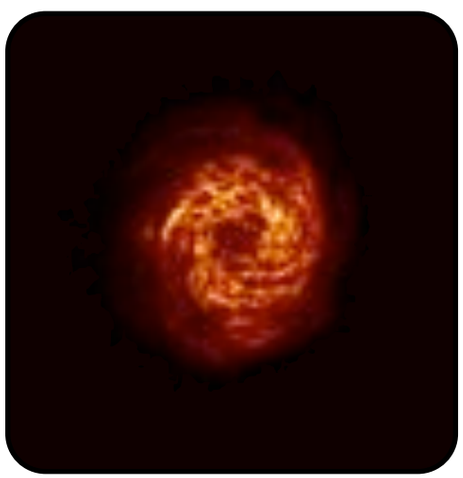


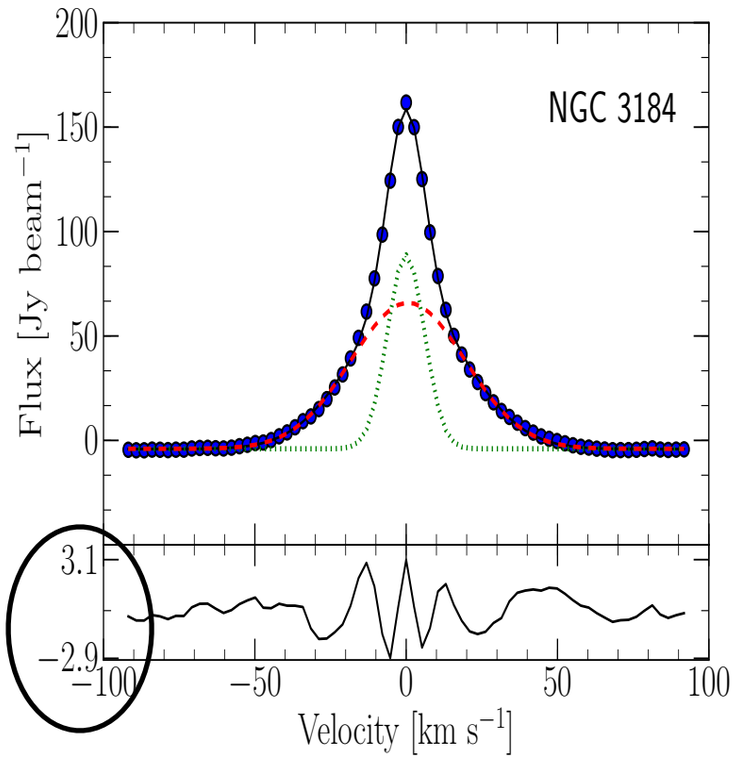
Ianjamasimanana et al. 2012
(accepted AJ: arXiv:1207.5041)

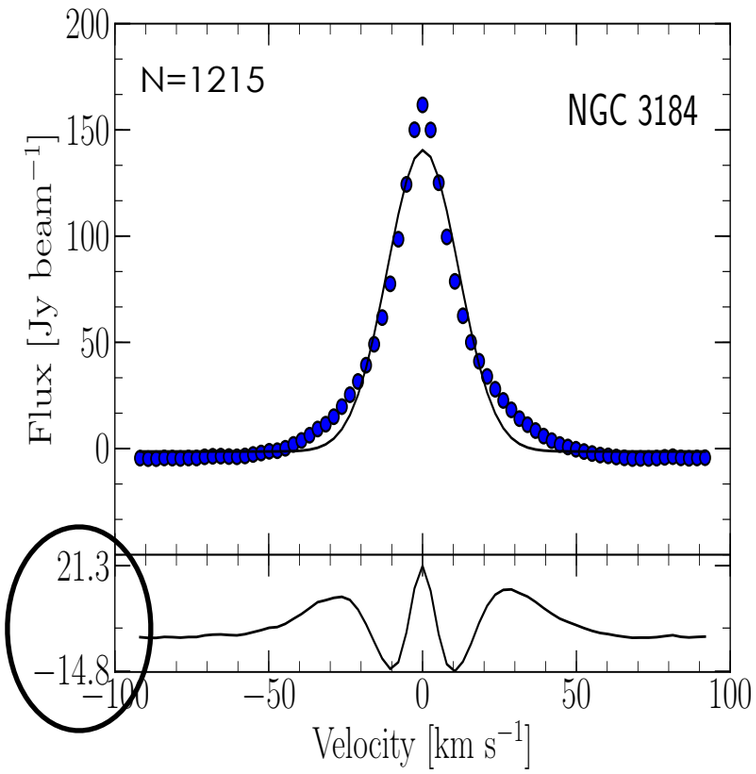
Super Profiles





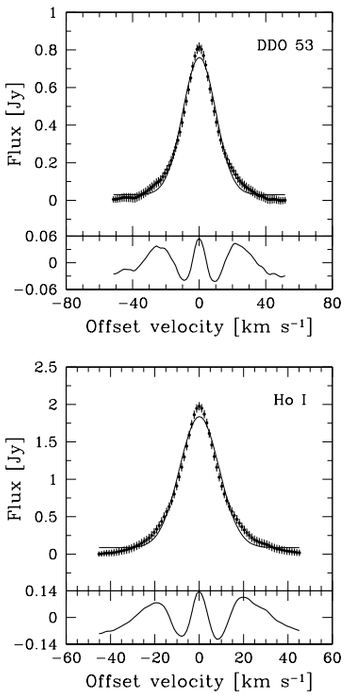


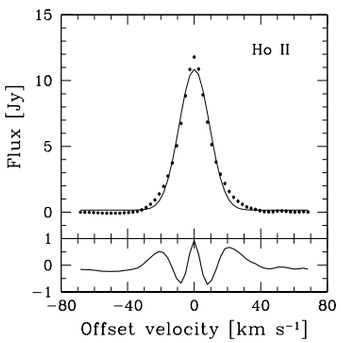


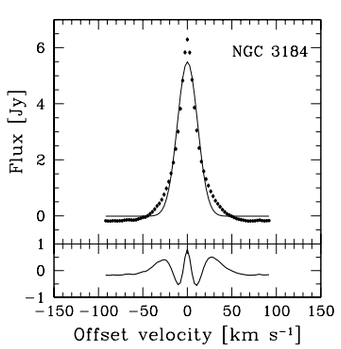


Profiles

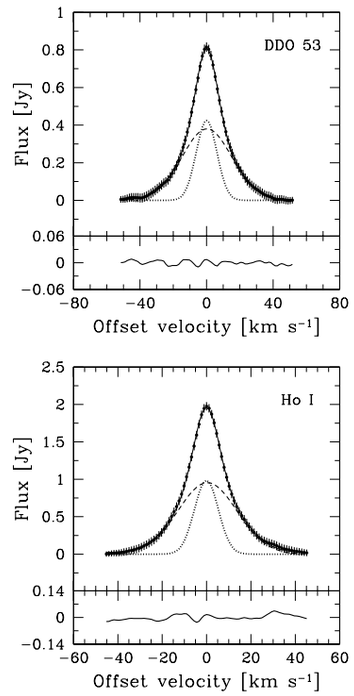
1G

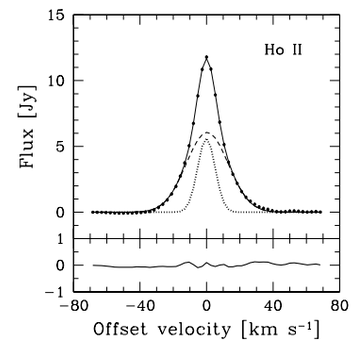


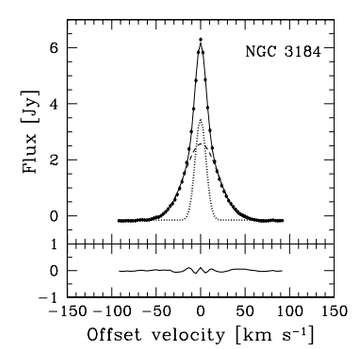




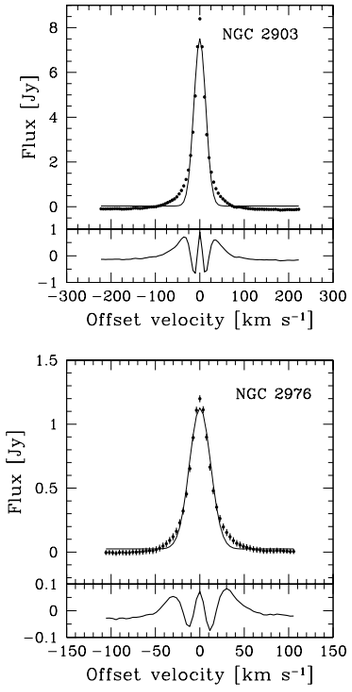
2G

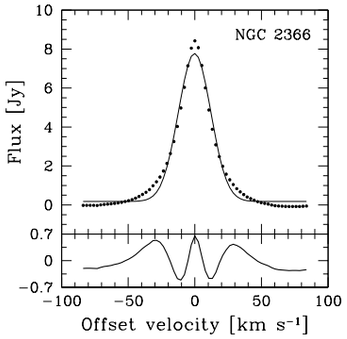


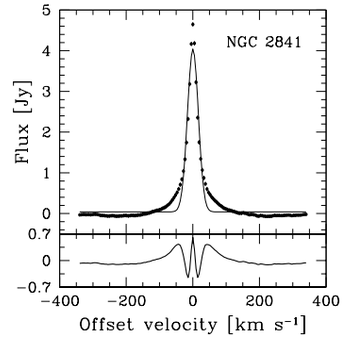




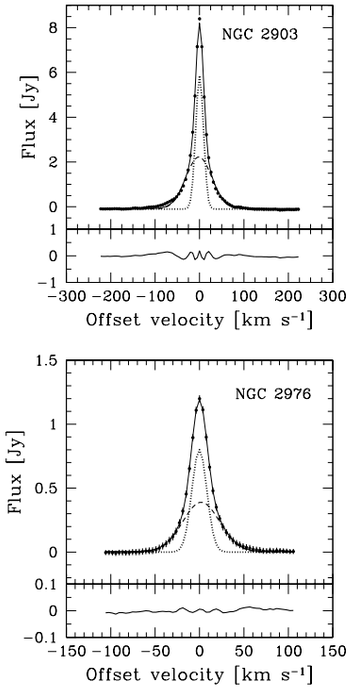
1G

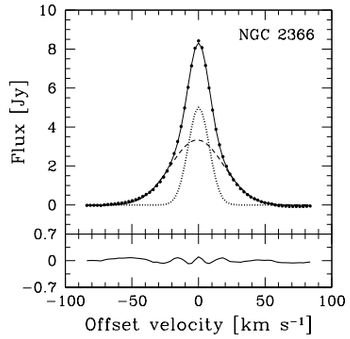


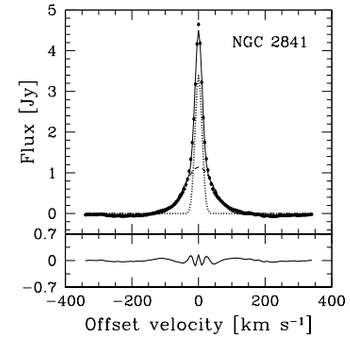




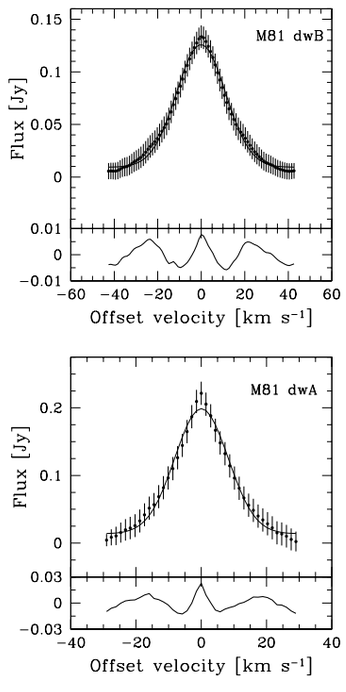
2G

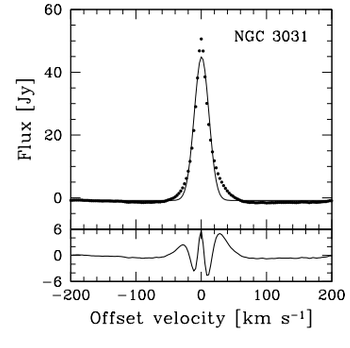


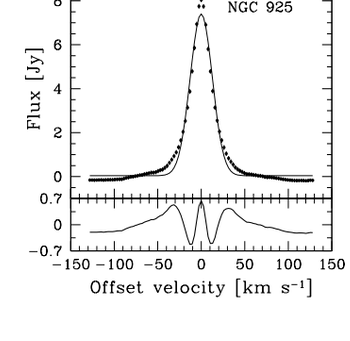




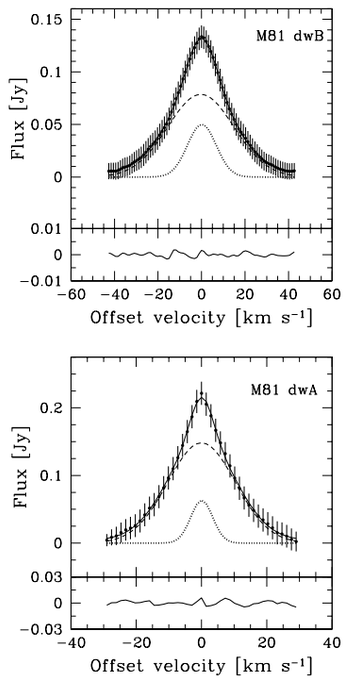
1G

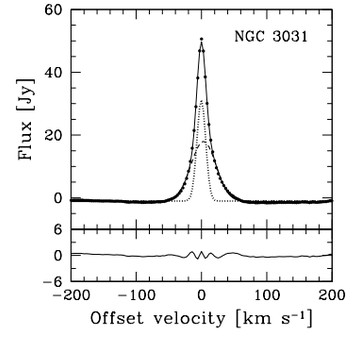


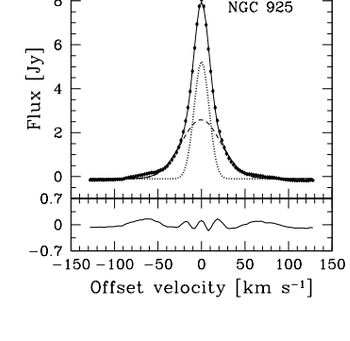




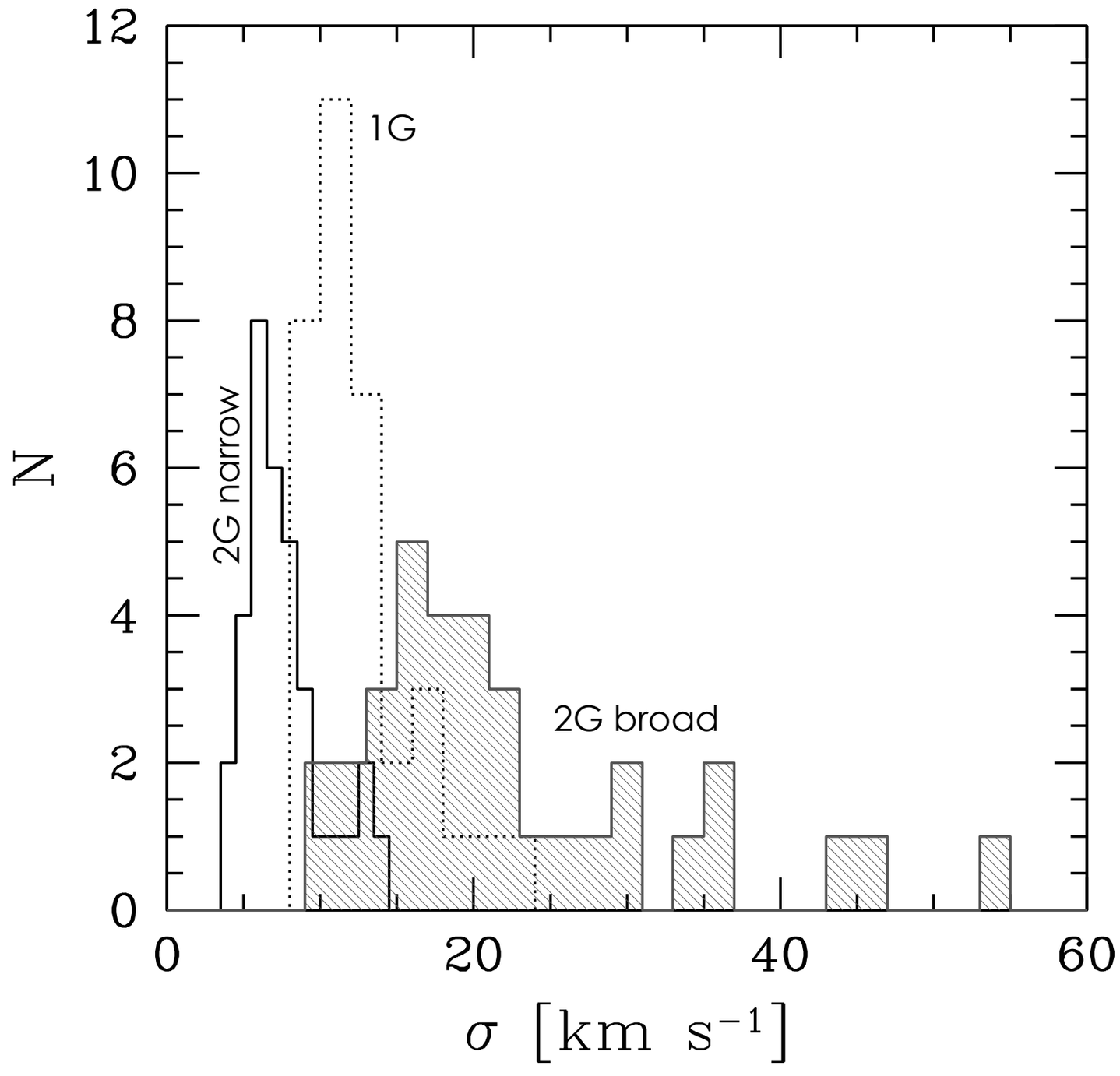
2G







Dispersions

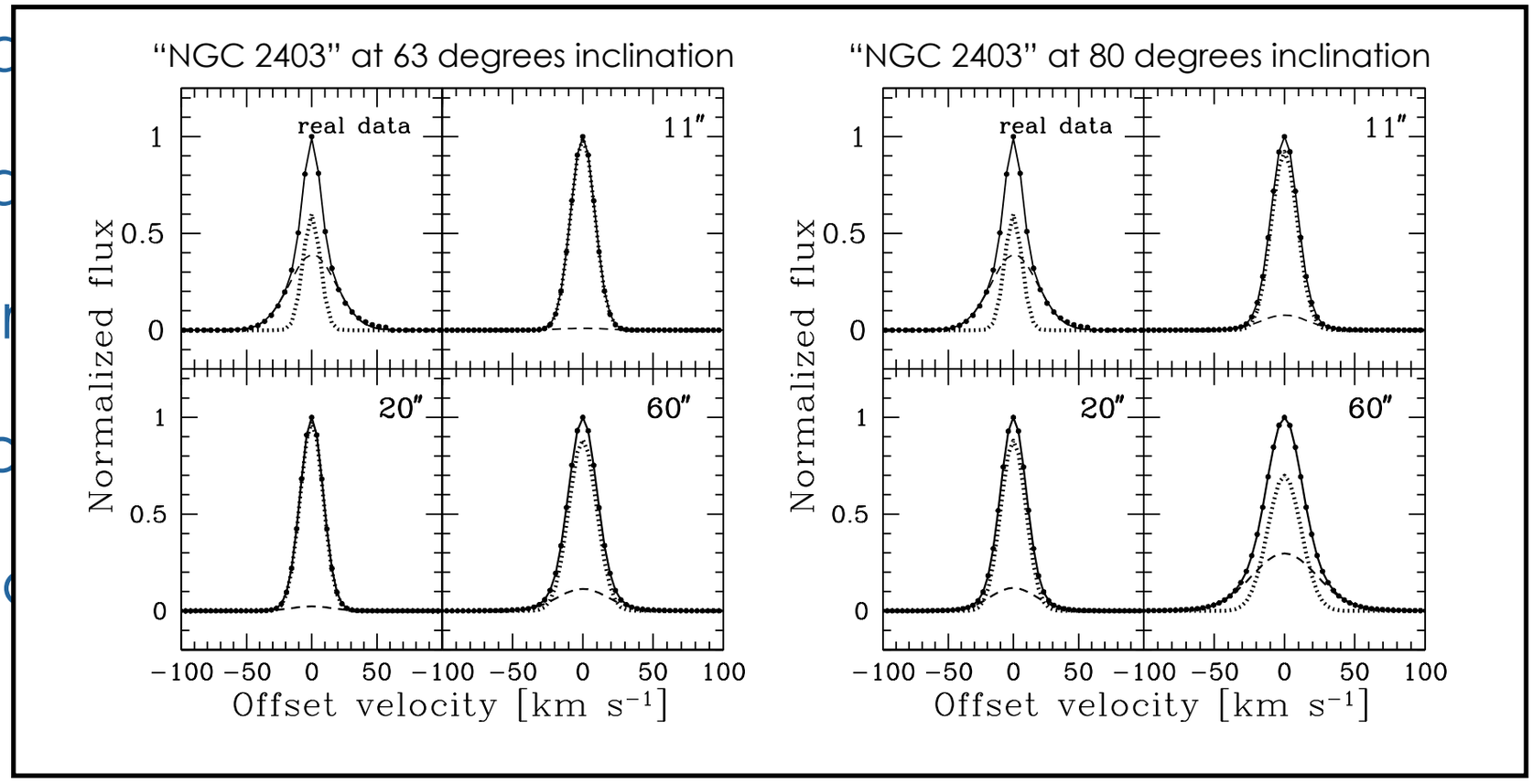


False Super Profiles

- Many ways to get a non-Gaussian super profile
  - Inclination and resolution effects
  - Dominant narrow profiles
  - Thick, lagging component
  - Skewed input profiles
  - Inaccurate shuffling
  - Bulk motions (galaxy interaction, starburst)
- Tested and under control: Ianjamasimanana et al 2012

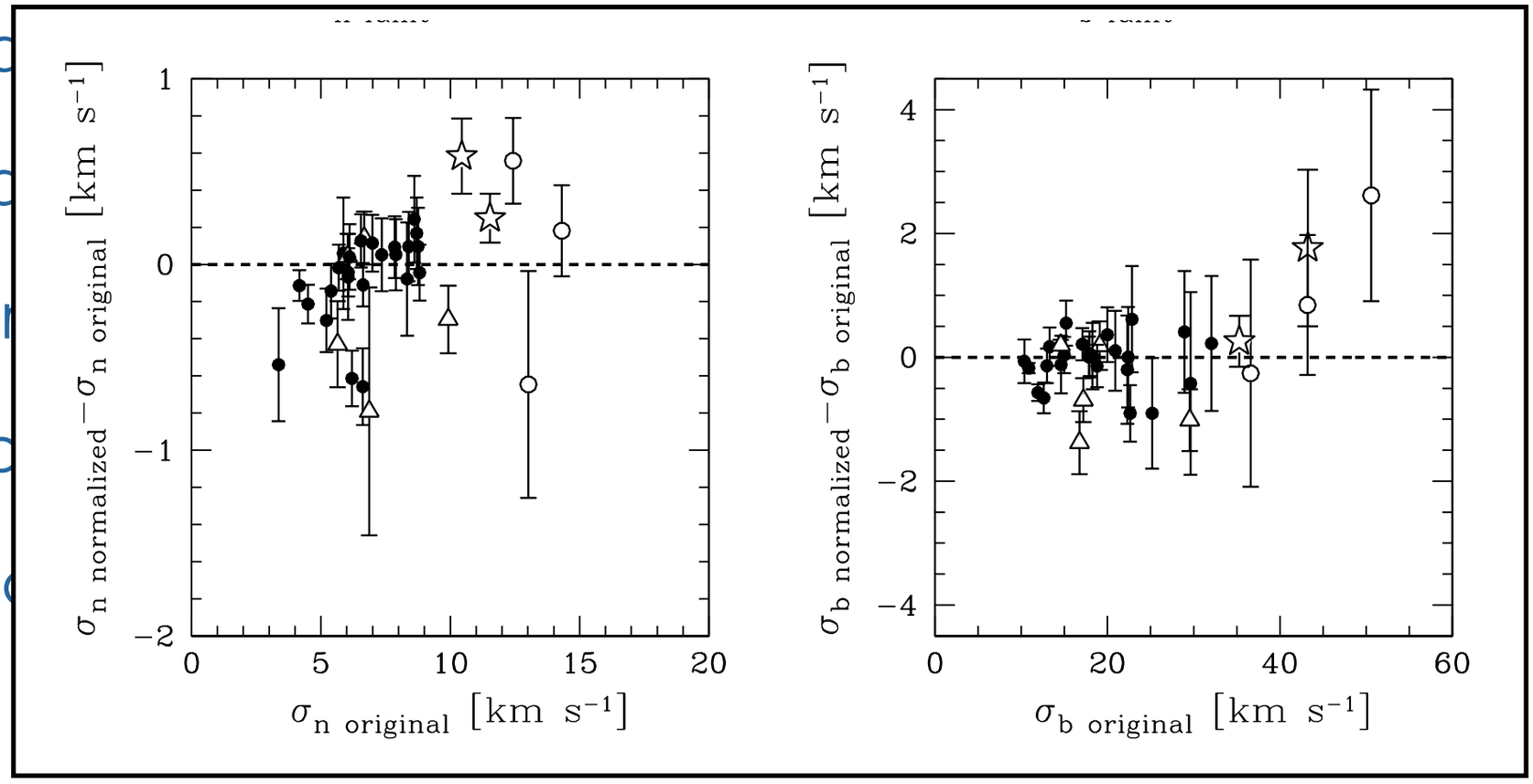
False Super Profiles

- Many ways to get a non-Gaussian super profile
  - **Inclination and resolution effects**
  - Dominant narrow profiles
  - Thick, lo
  - Skewed
  - Inaccur
  - Bulk mo
- Tested and



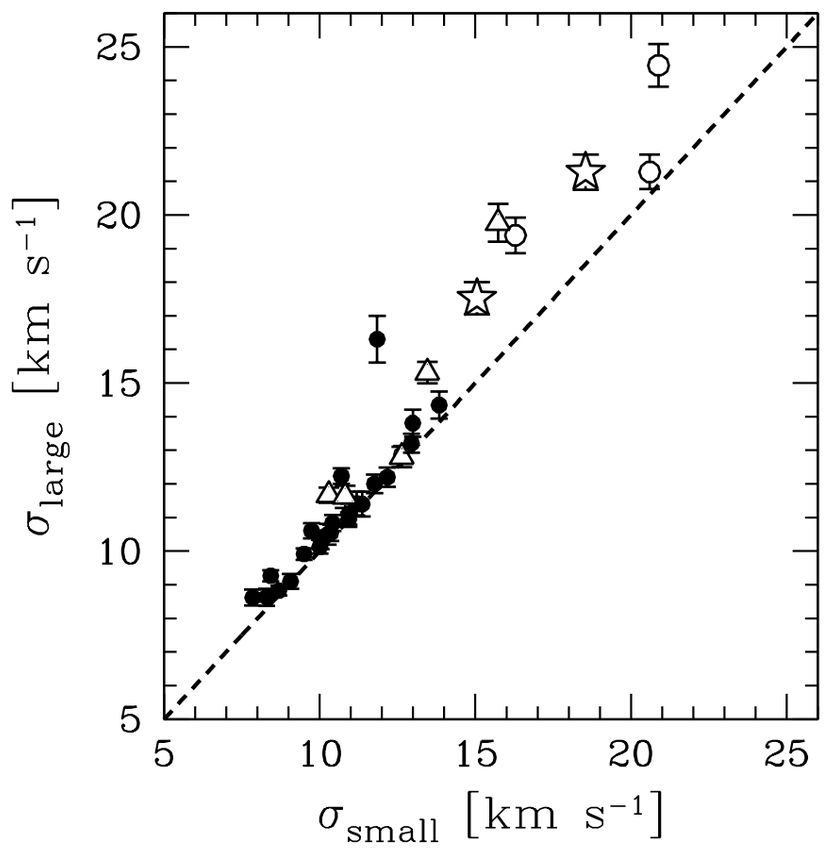
False Super Profiles

- Many ways to get a non-Gaussian super profile
  - Inclination and resolution effects
  - **Dominant narrow profiles**
  - Thick, lo
  - Skewed
  - Inaccur
  - Bulk mo
- Tested and

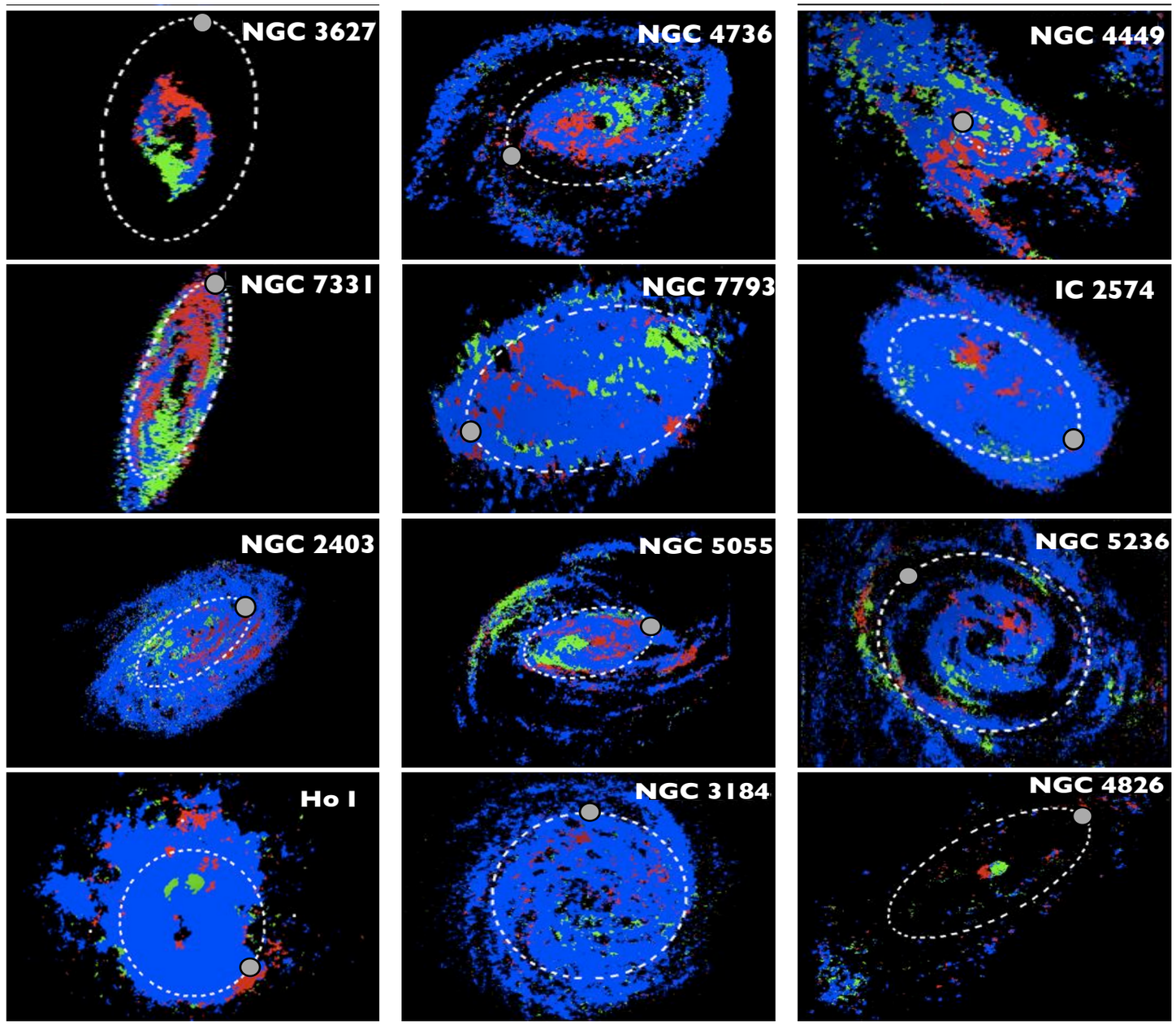


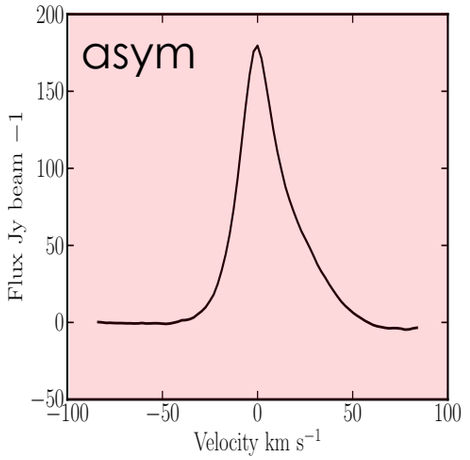
False Super Profiles

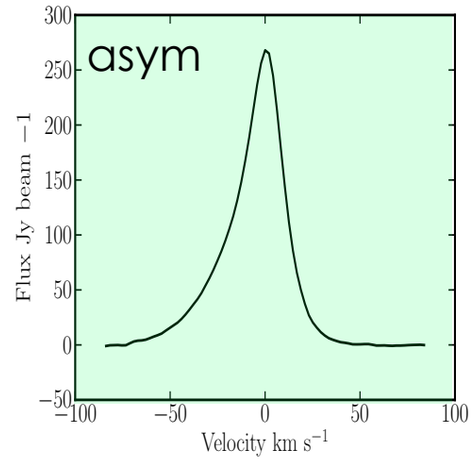
- Define clean sample of galaxies not obviously affected by these systematic effects (also no star burst, no interaction)
- Example: compare approaching and receding sides

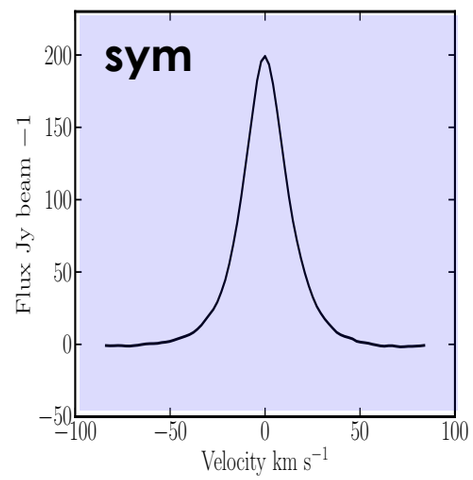


Symmetrical Profiles



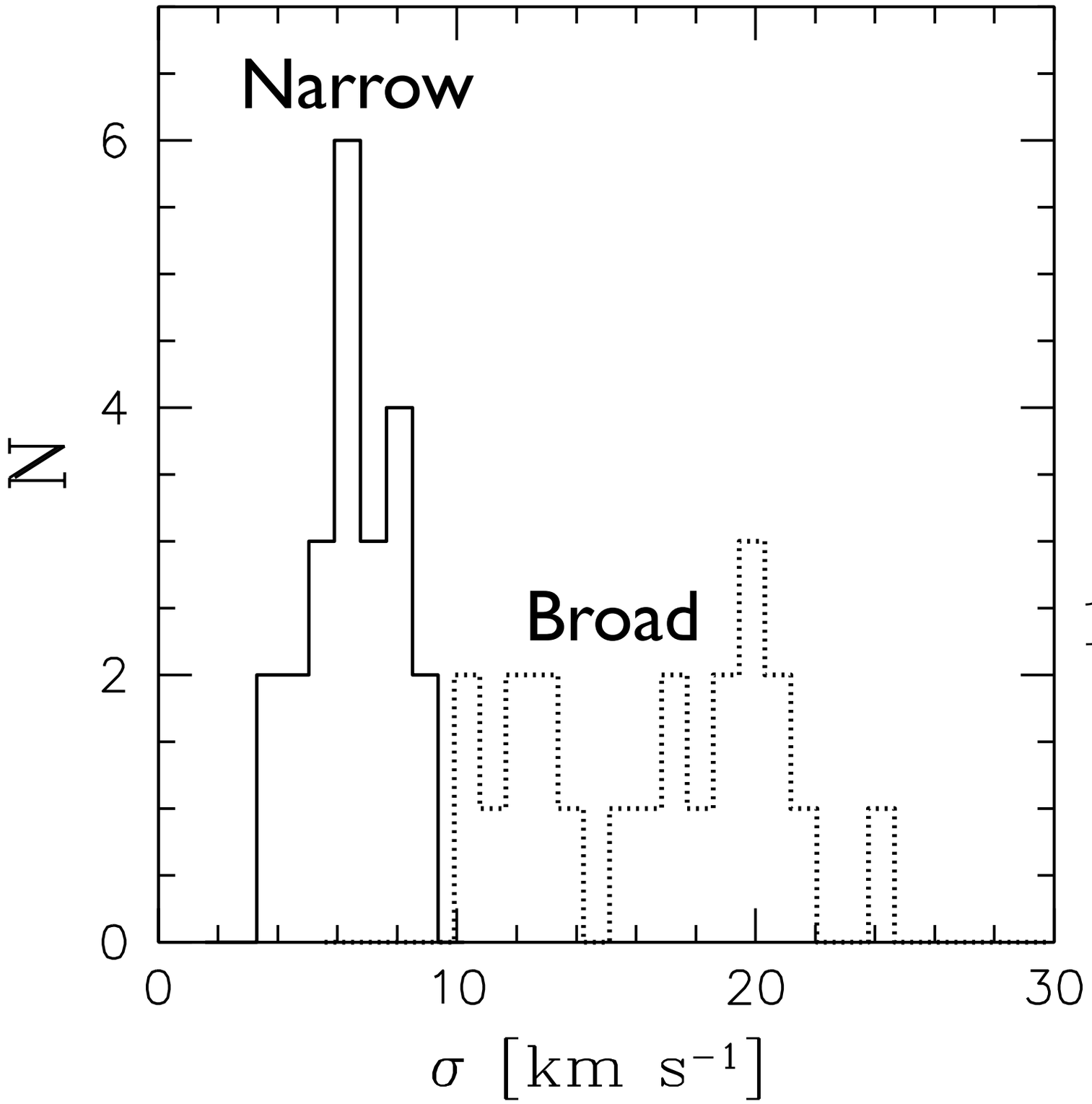






$|v_{Her3}-v_{IWM}| < 5$ km s^{-1} to identify symmetrical profiles

Velocity Dispersions



Narrow component:

6.5 ± 1.5 km s^{-1}

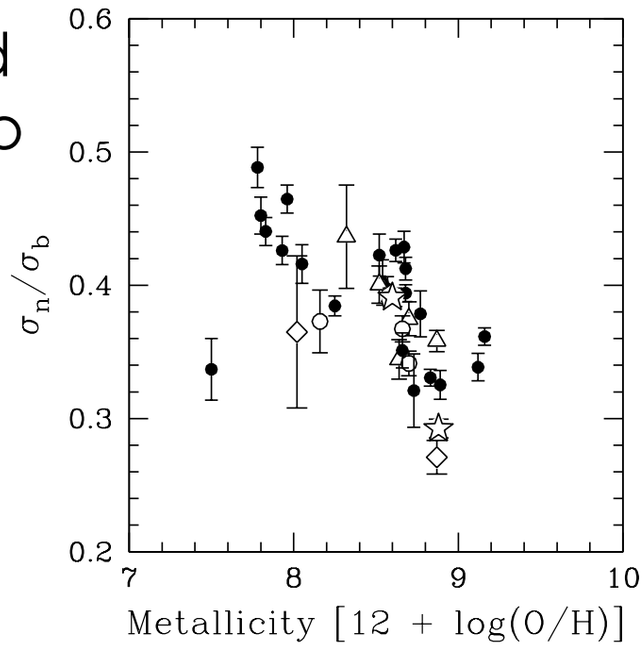
Broad component:

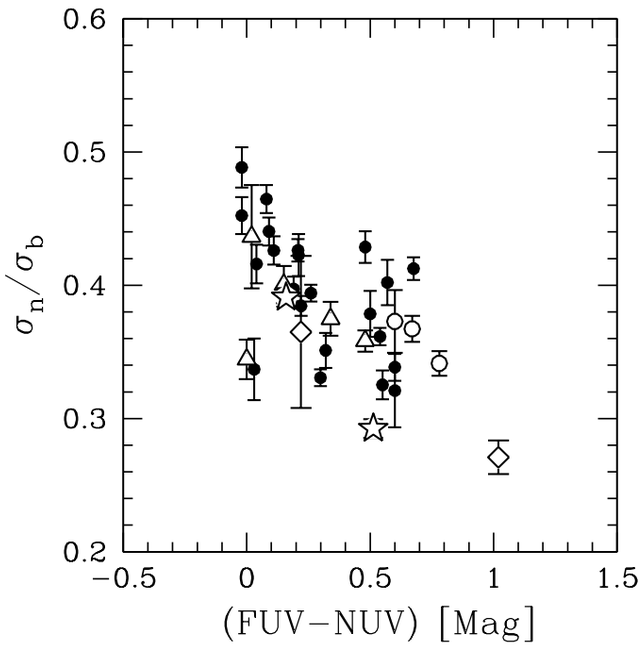
16.8 ± 4.3 km s^{-1}

But is this relevant for star formation?

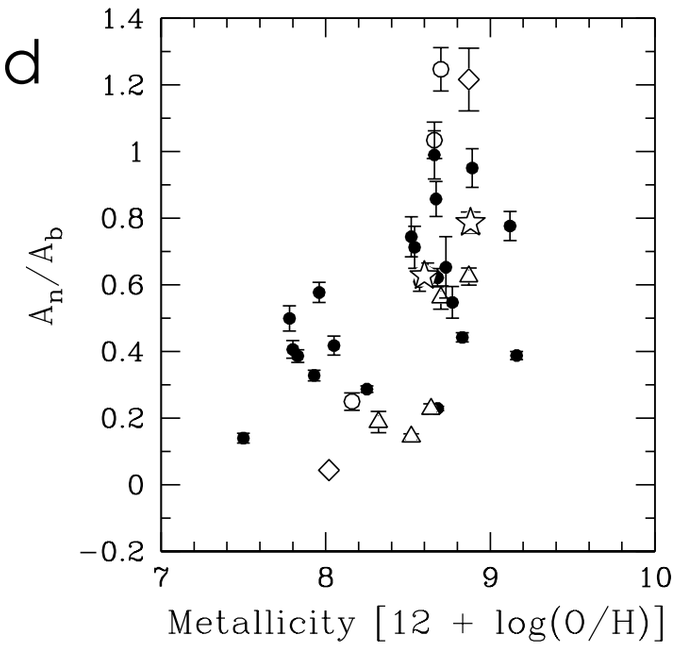
Global Properties

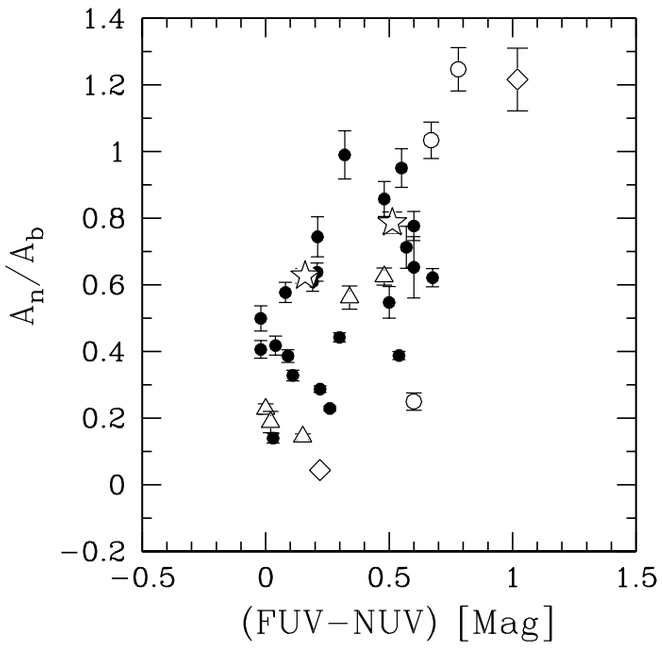
narrow/broad dispersion ratio





narrow/broad flux ratio





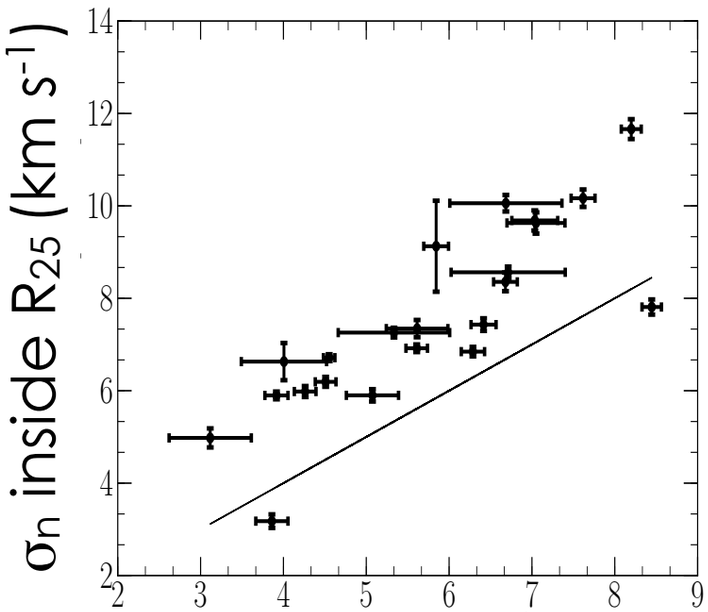
●: symm profs, clean sample
o△□☆: symm. profs, other gals

metallicity

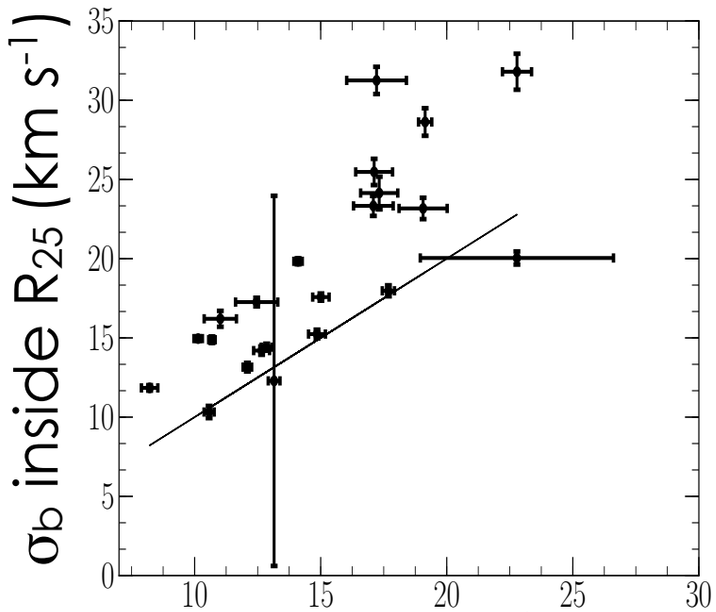
FUV-NUV

Refining the profiles

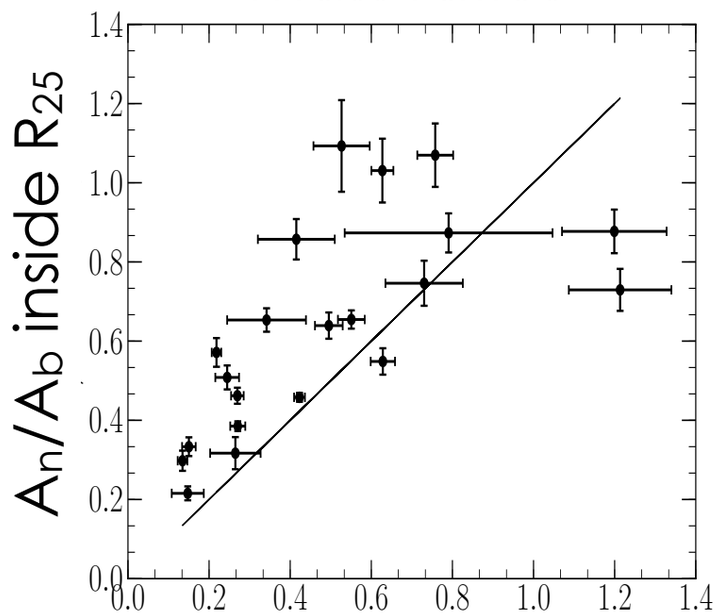
narrow



broad



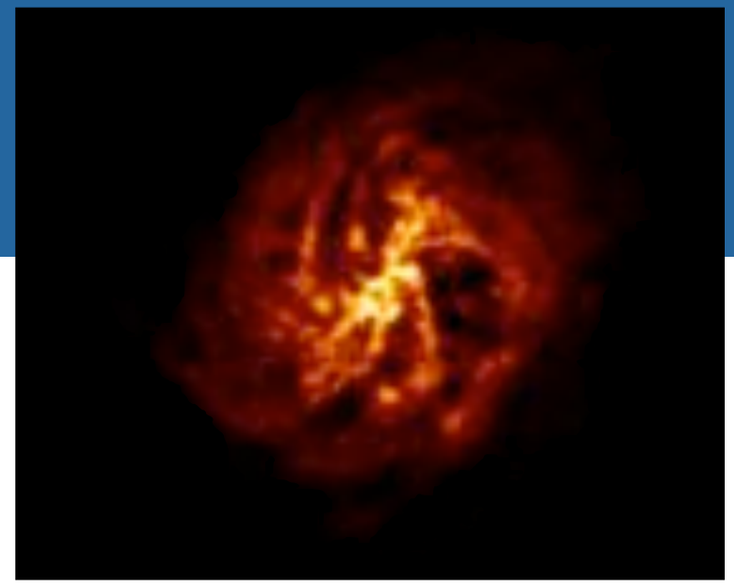
mass ratios

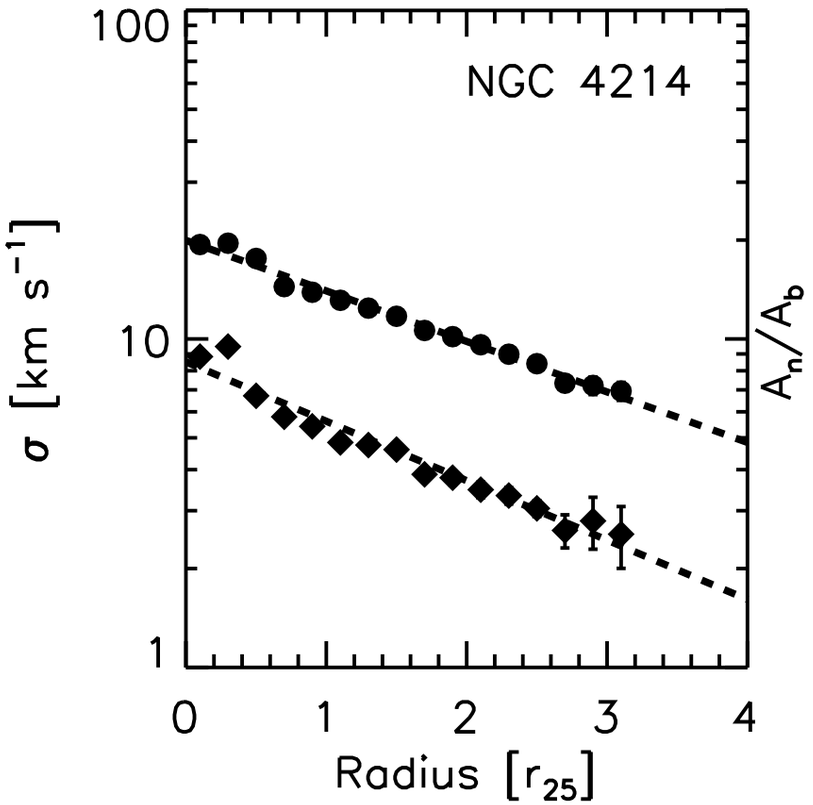


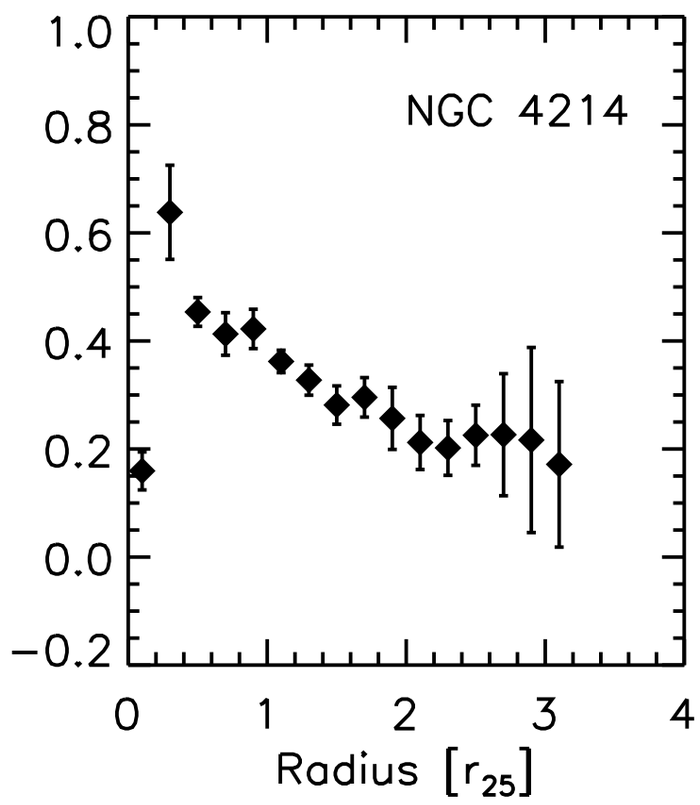
- Do properties change as a function of local environment?
- Create super profiles using masks
- Example: dispersions and mass ratios inside R_{25} (**high** star forming) and outside R_{25} (no or very **low** star formation)

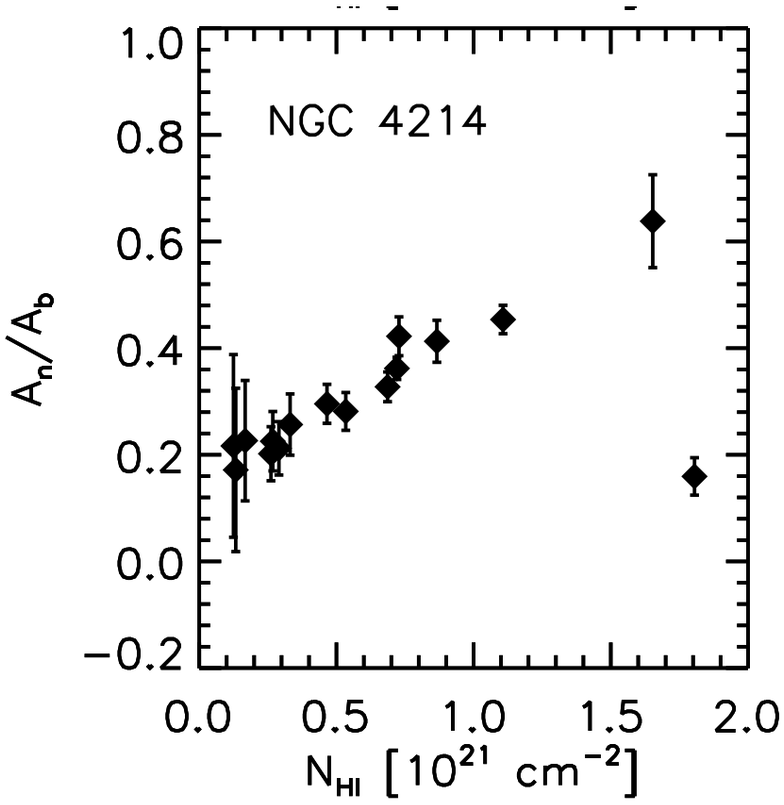
Preliminary

Radially

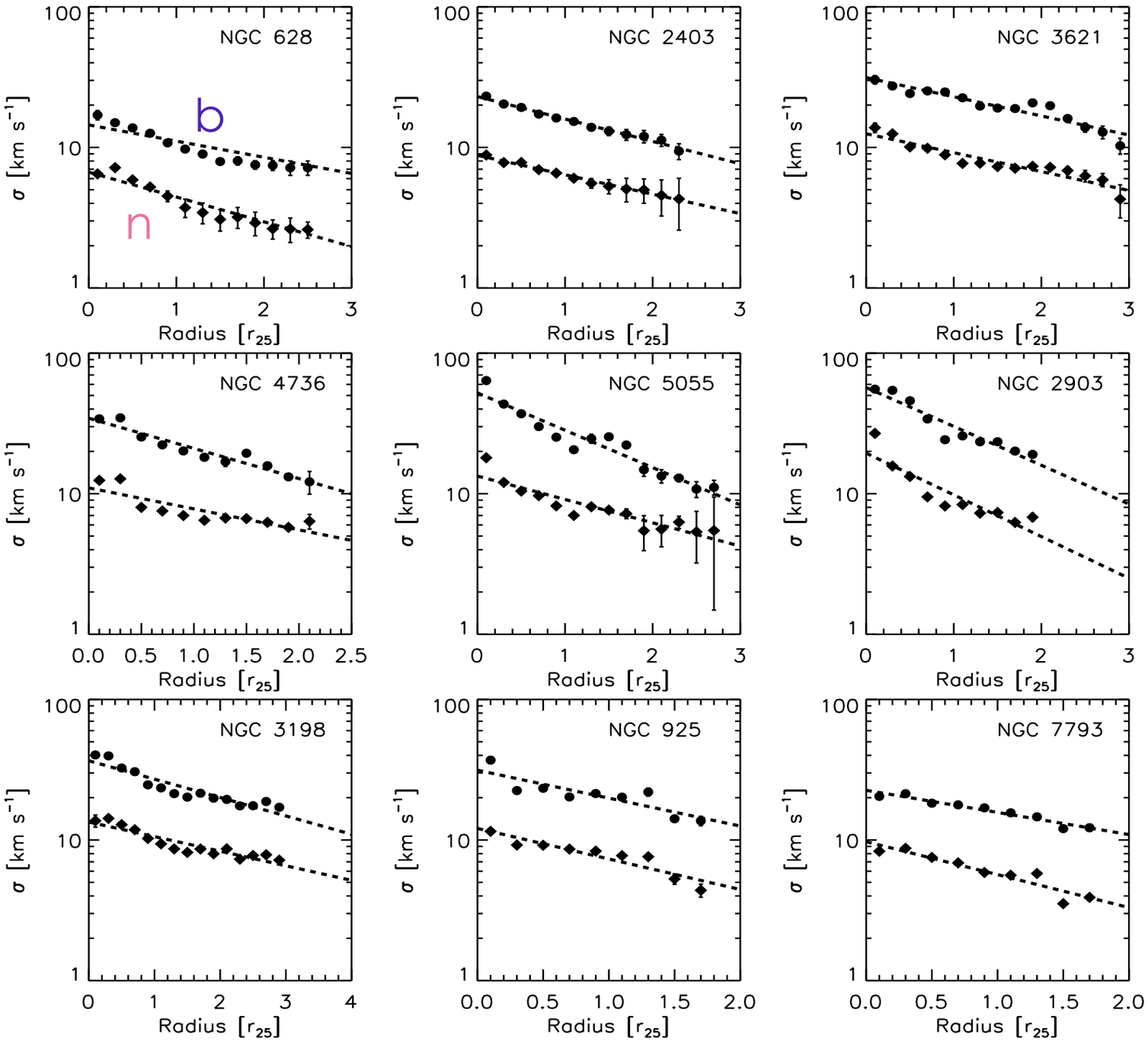








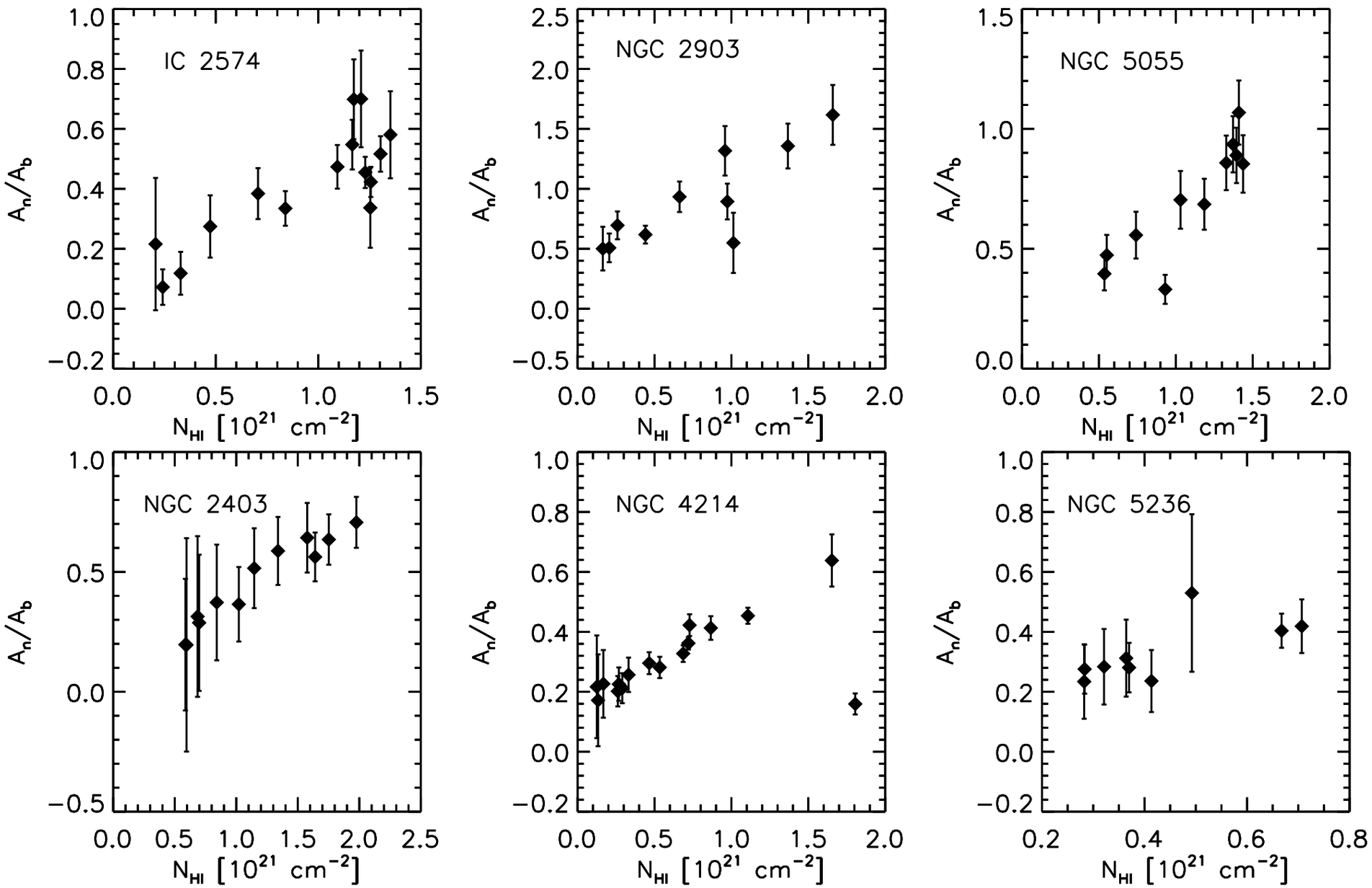
Radial trends



velocity dispersion

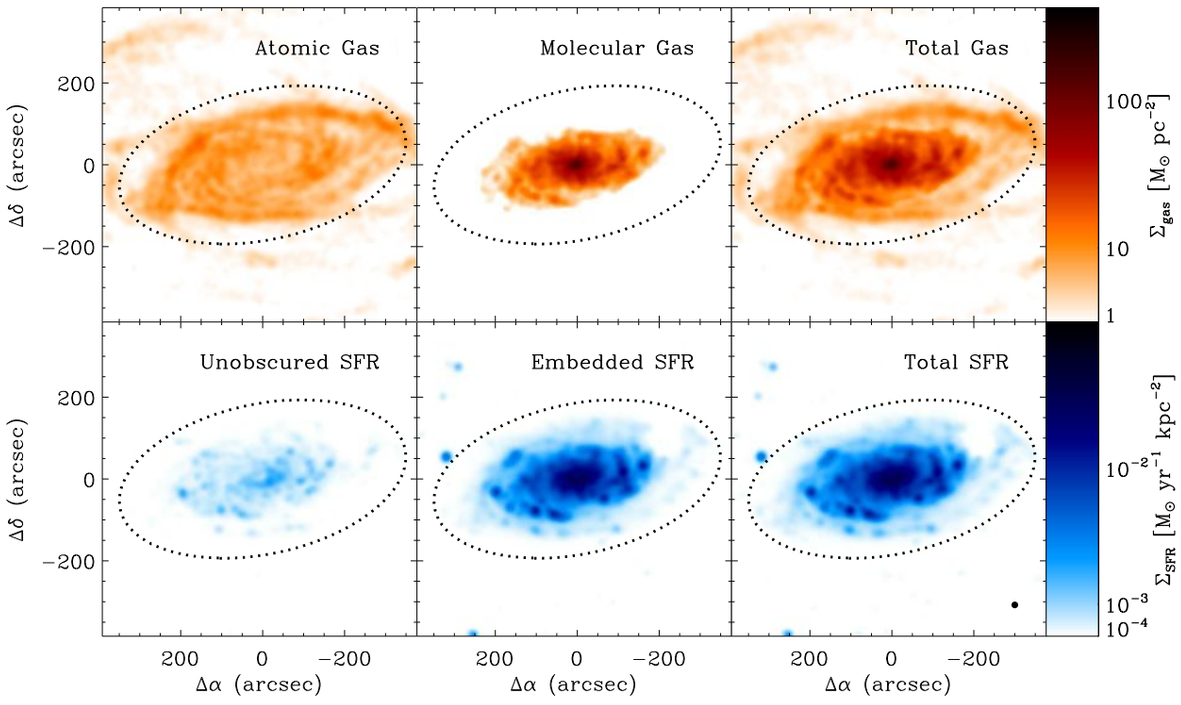
radius [R_{25}]

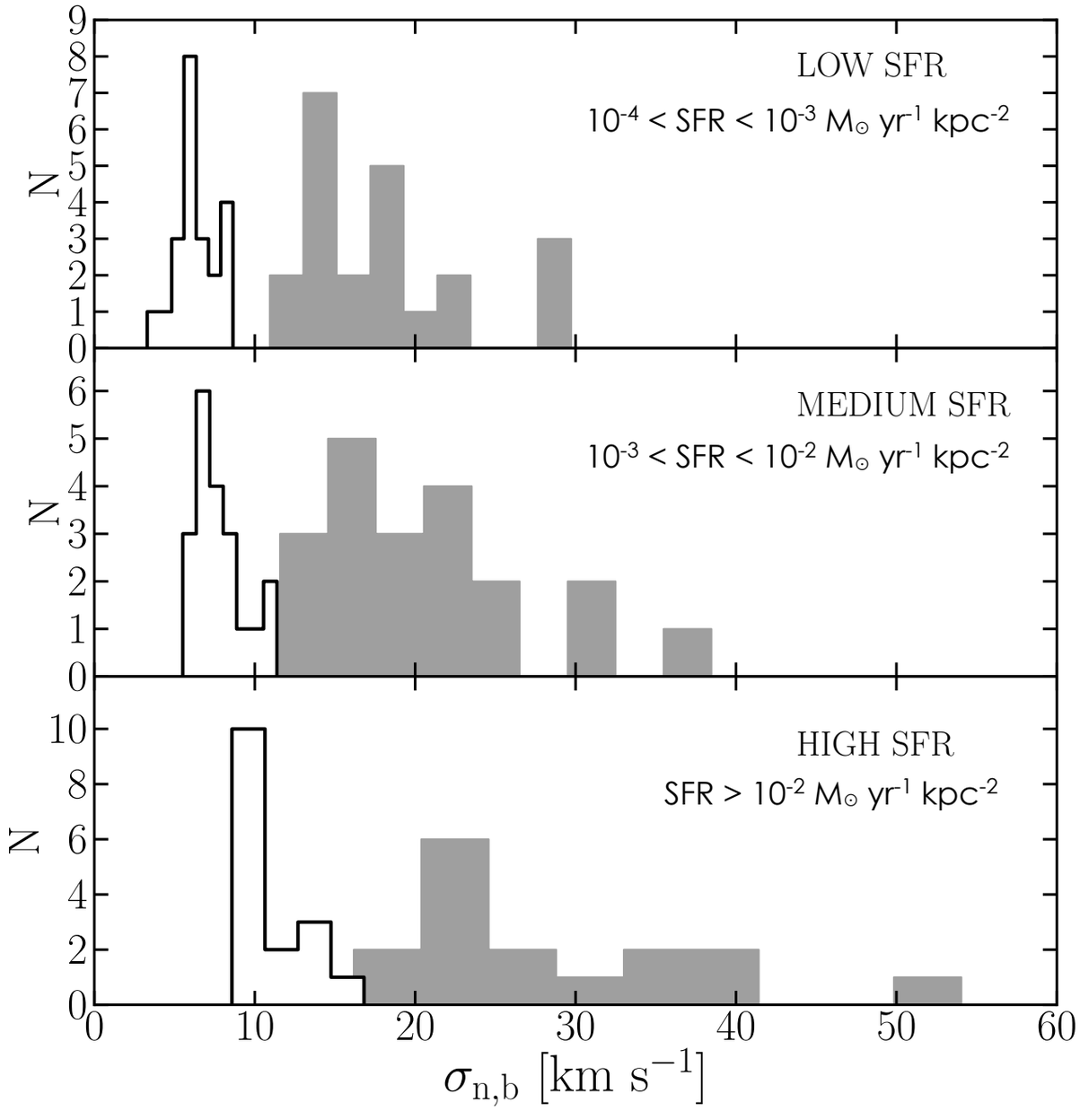
Trend with column density



A_n/A_b is the flux ratio of the broad and narrow components

Star formation rates



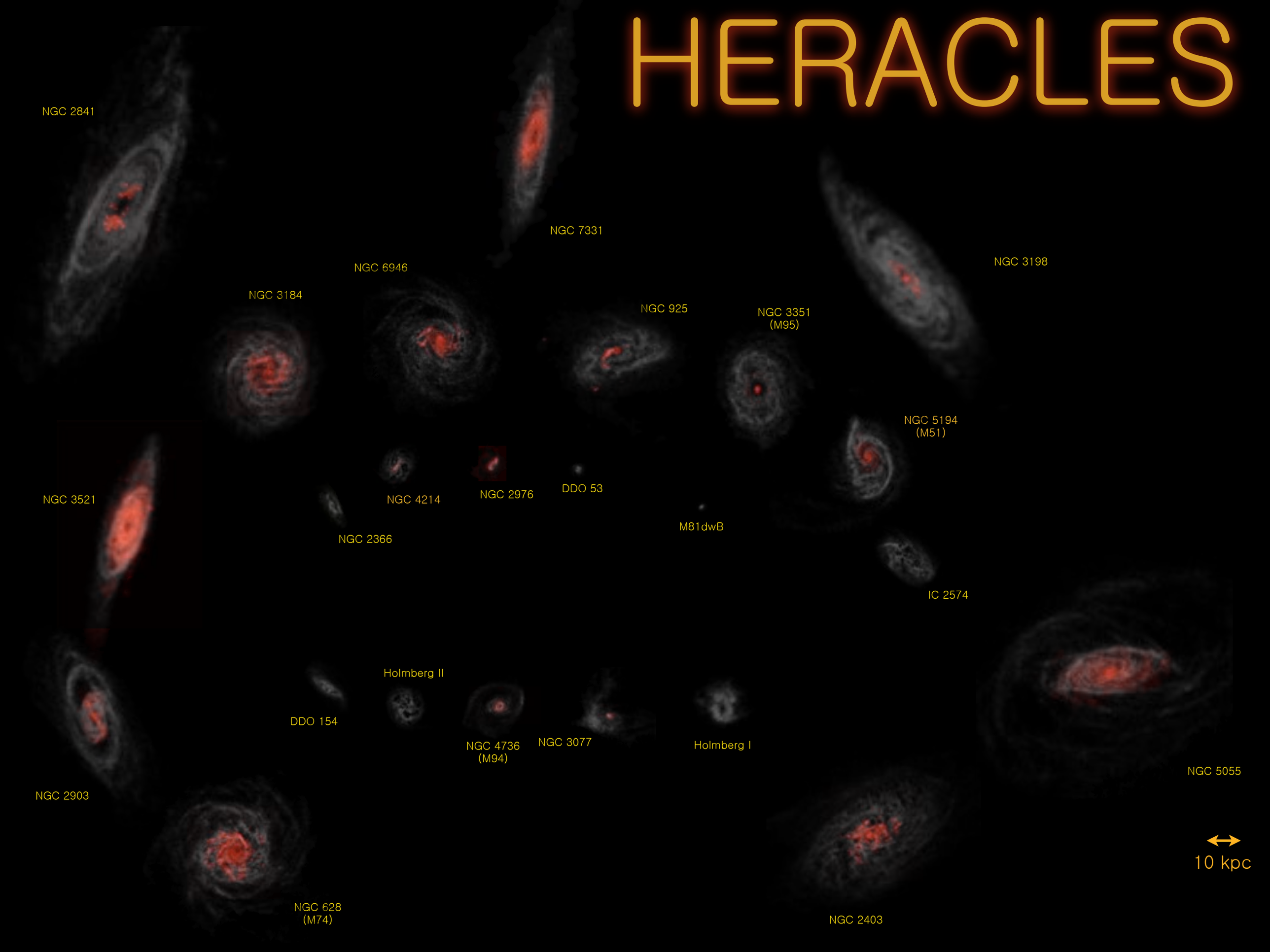


Define SFR masks using Leroy et al (2008) THINGS star formation rate maps (24μm Spitzer and GALEX FUX)

Preliminary

all profiles, all galaxies

HERACLES


NGC 2841
NGC 7331
NGC 6946
NGC 3198
NGC 3184
NGC 925
NGC 3351
(M95)
NGC 5194
(M51)
NGC 3521
NGC 4214
NGC 2976
DDO 53
NGC 2366
M81dwB
IC 2574
Holmberg II
DDO 154
NGC 4736
(M94)
NGC 3077
Holmberg I
NGC 5055
NGC 2903
10 kpc
NGC 628
(M74)
NGC 2403

NGC 2403 Example

Bradley S. Frank[1], W. J. G. de Blok[1,2],
The HERACLES Team
[1] The Astrophysics, Cosmology and Gravity Centre (ACGC), The University of Cape Town, South Africa
[2] Netherlands Institute for Radio Astronomy, ASTRON, Netherlands

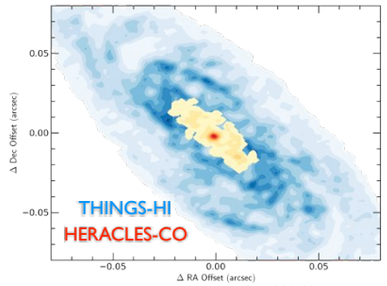
Abstract

The HERACLES survey is one the largest and most sensitive survey of CO in nearby galaxies. We compare the kinematics of the HI and the CO in the THINGS galaxies. In this poster we focus on two galaxies, NGC 3198 and NGC 7331. Both are late-type spirals with a central-depression in the HI emission, which shows high CO emission in the centre. We derive velocity fields and rotation curves for both galaxies, and show that combining the CO and HI produces a complete rotation curve for the case of NGC 7331. We find that, in the absence of bars, the overall dynamics of the CO to be very similar to that of the HI.

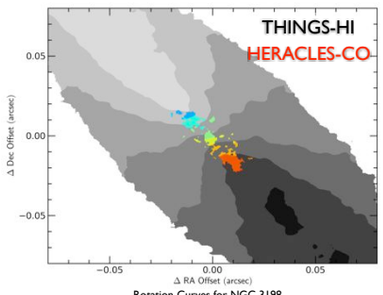
NGC 3198

SB type galaxy - CO emission concentrated in the centre.

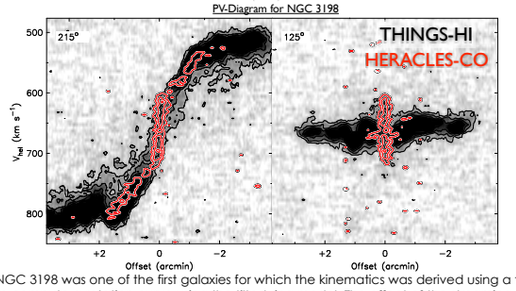
HI and CO Intensity Maps for NGC 3198



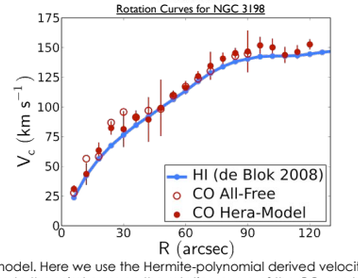
HI and CO Velocity Fields (Hermite) for NGC 3198



PV-Diagram for NGC 3198



Rotation Curves for NGC 3198

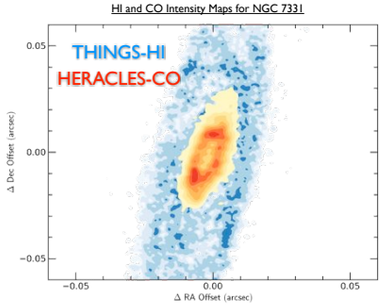


NGC 3198 was one of the first galaxies for which the kinematics was derived using a tilted-ring model. Here we use the Hermite-polynomial derived velocity-fields to compute a rotation curve using the tilted-ring model. The effect of the streaming-motions due to the spiral-arms on the rotation curve of the CO can be seen at 30" and ~ 85".

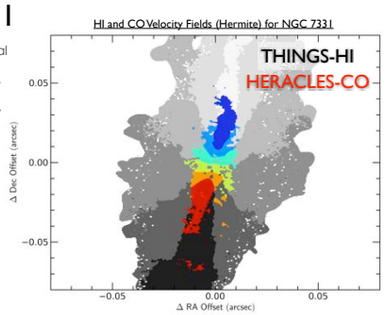
NGC 7331

Sb early-type spiral - Post-starburst galaxy - Central-depression in HI emission filled by CO.

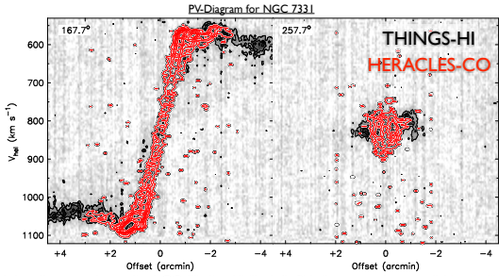
HI and CO Intensity Maps for NGC 7331



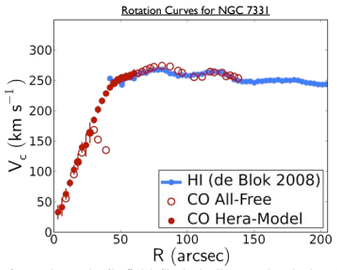
HI and CO Velocity Fields (Hermite) for NGC 7331



PV-Diagram for NGC 7331



Rotation Curves for NGC 7331

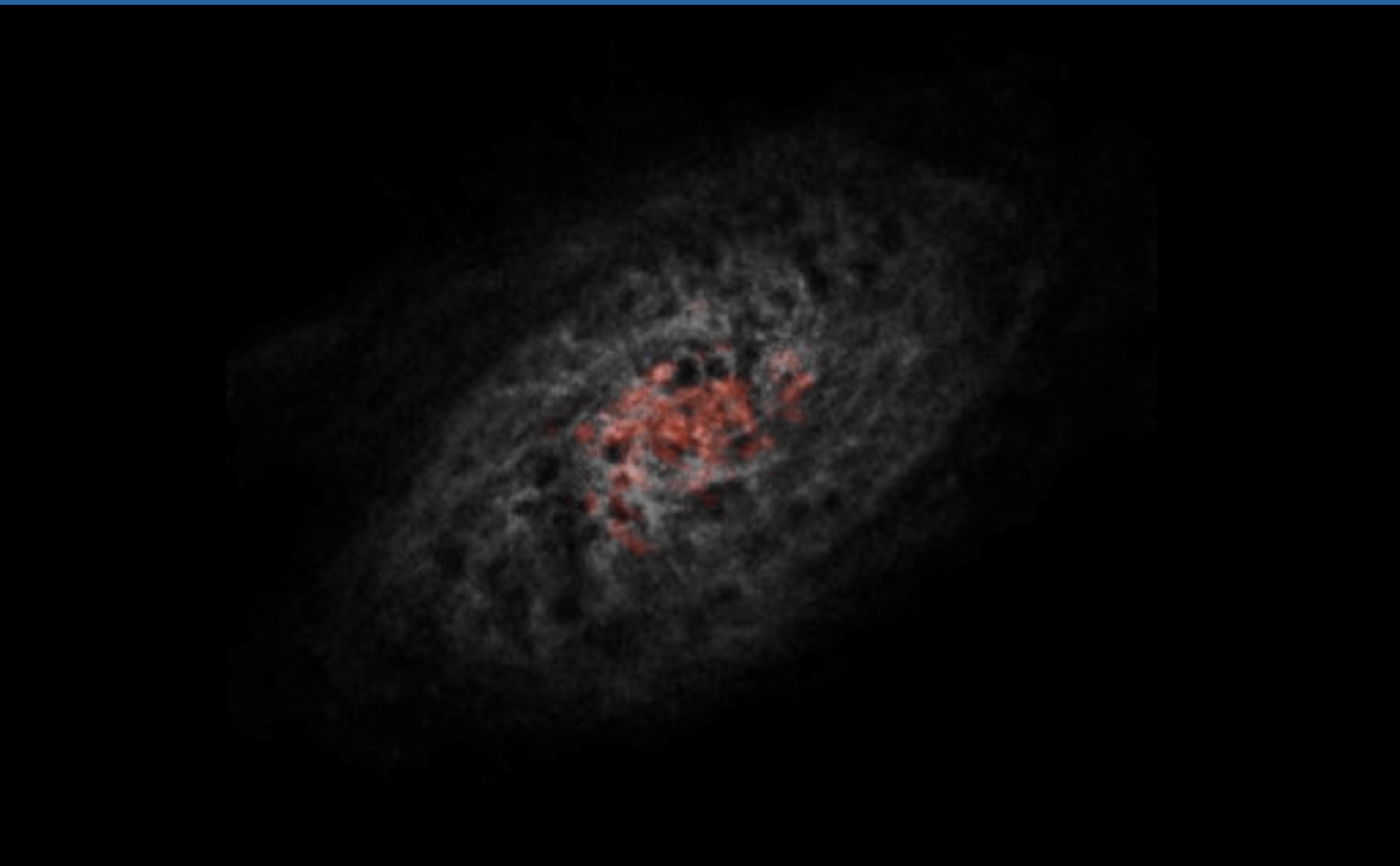


Intensity map shows that CO fills the HI "hole". PV-diagrams shows solid-body like kinematics in centre; velocity fields illustrate the overlap between HI and CO - ideal for combining rotation curves. Kinematic parameters converge to model after a few iterations, rotation curve in agreement with von Linden et al. (1996)

References: The HI Nearby Galaxy Survey, Walter et al. 2008 - HERACLES: The HERA CO Line Extragalactic Survey, Leroy et al. 2009 - THINGS Rotation Curves and Mass Models, de Blok et al. 2008 - The Dynamics of the Inner Part of NGC 7331, von Linden 1996

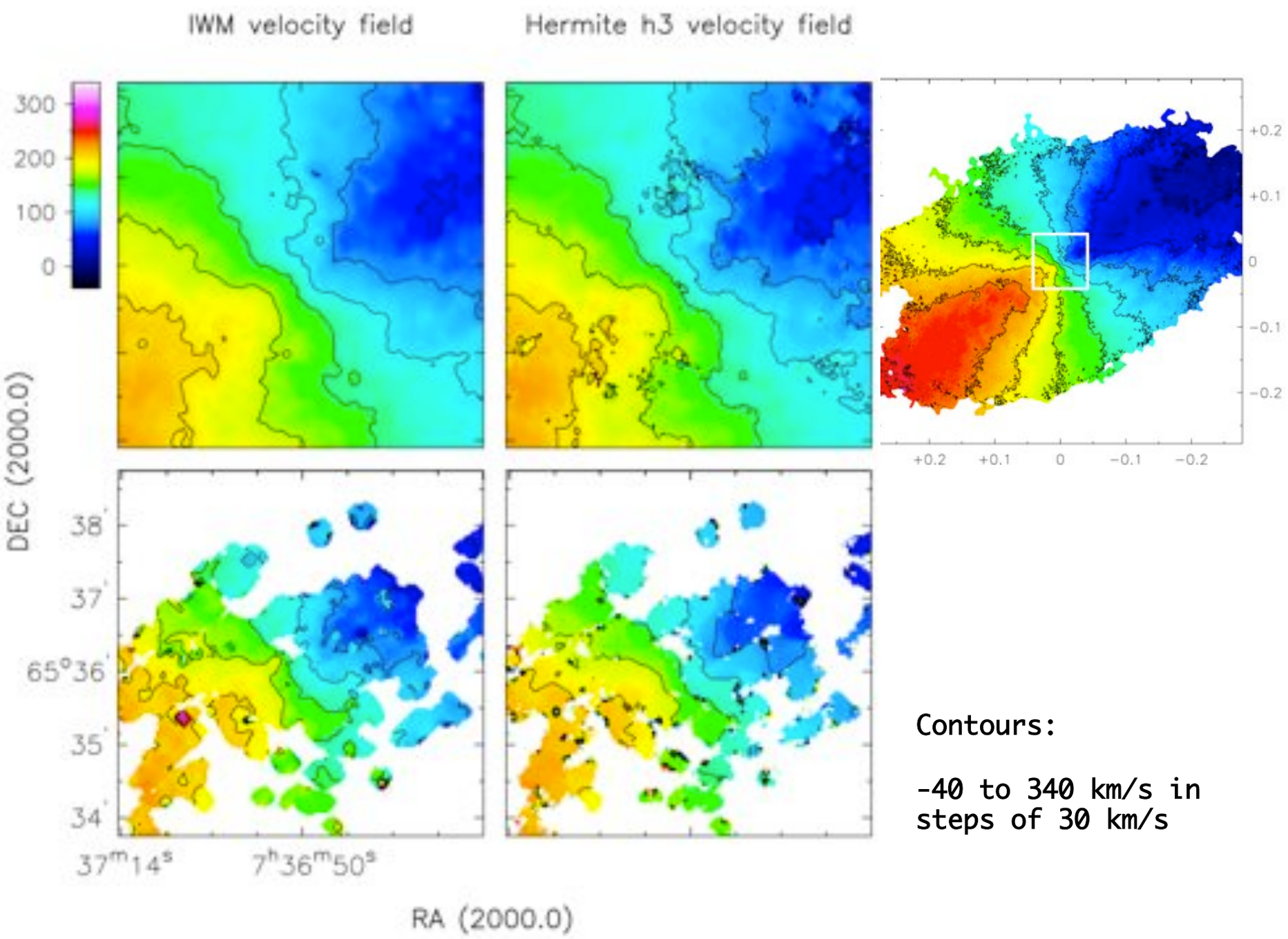
poster by Bradley Frank

NGC 2403 Example



NGC2403 VELOCITY FIELDS

HERACLES THINGS

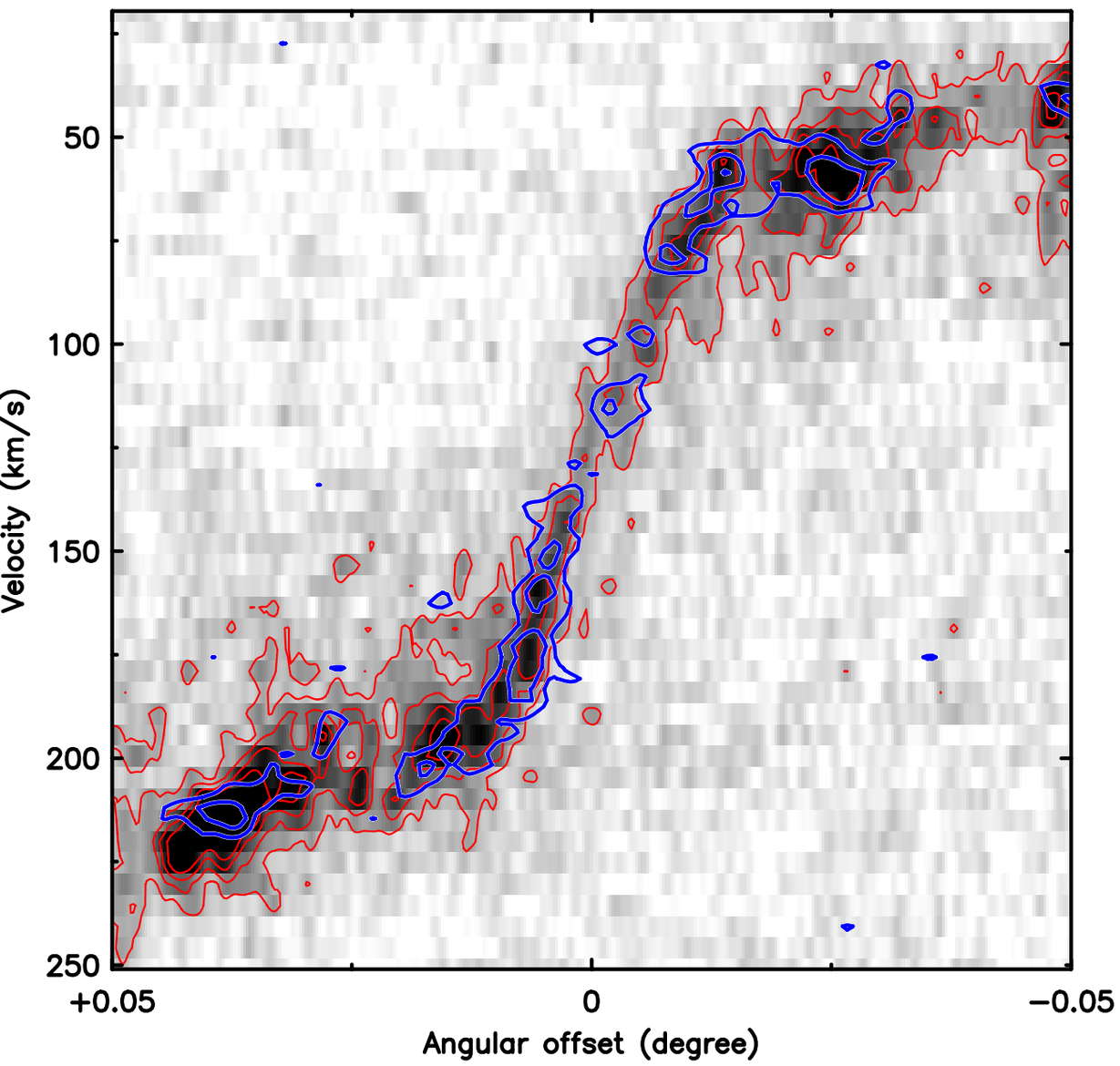


Contours:

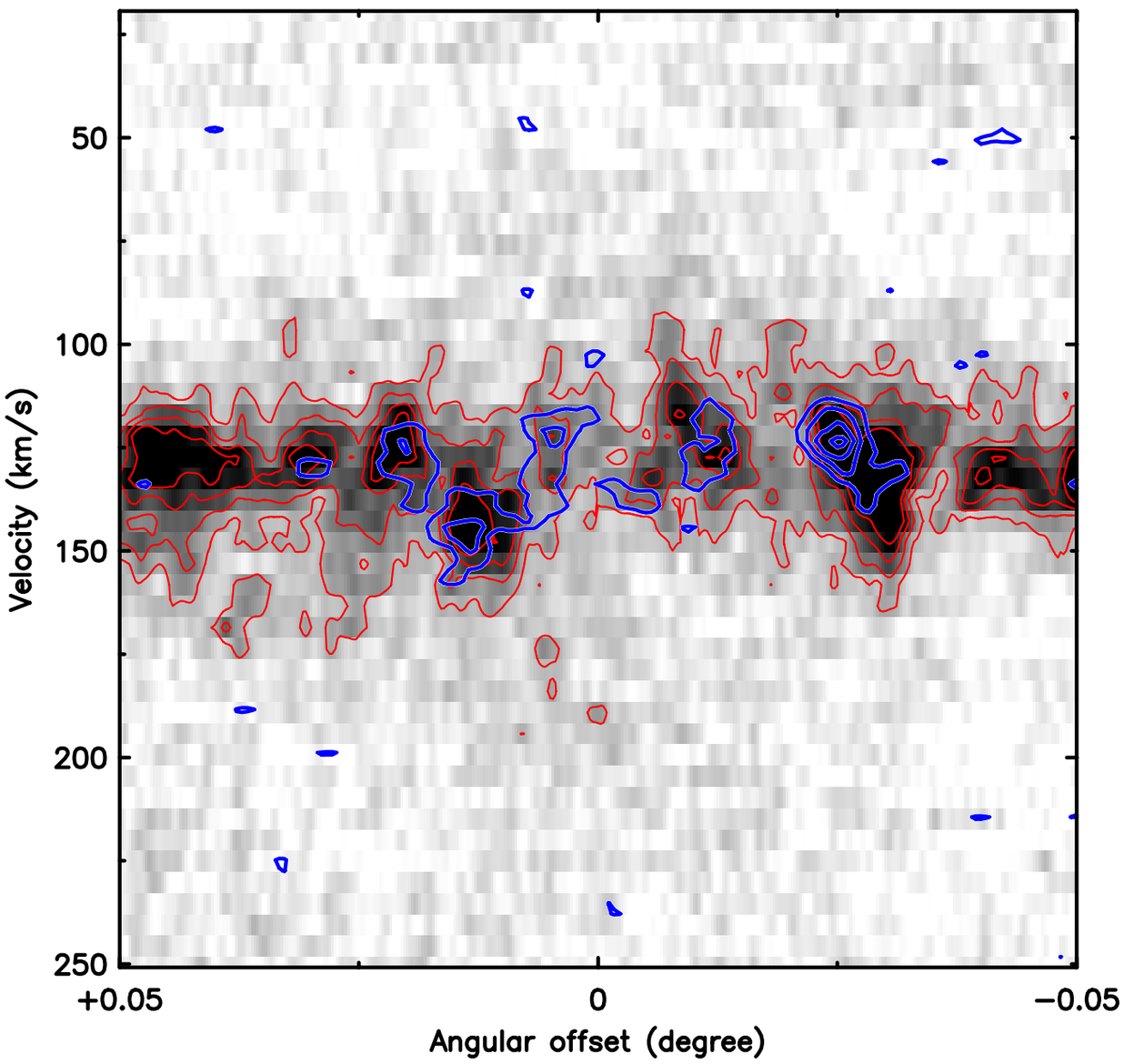
-40 to 340 km/s in steps of 30 km/s

NGC2403 POSITION VELOCITY

major-axis



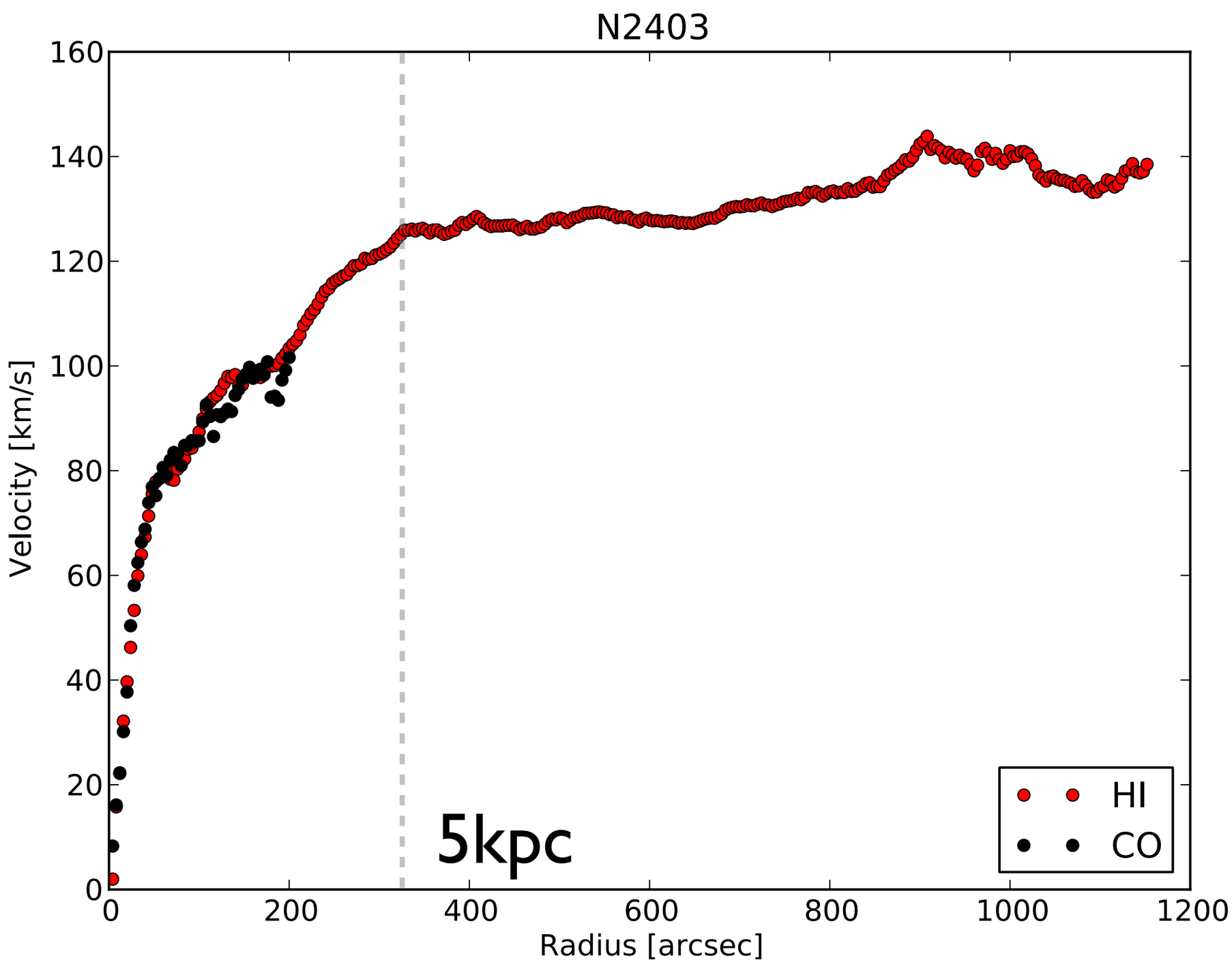
minor-axis



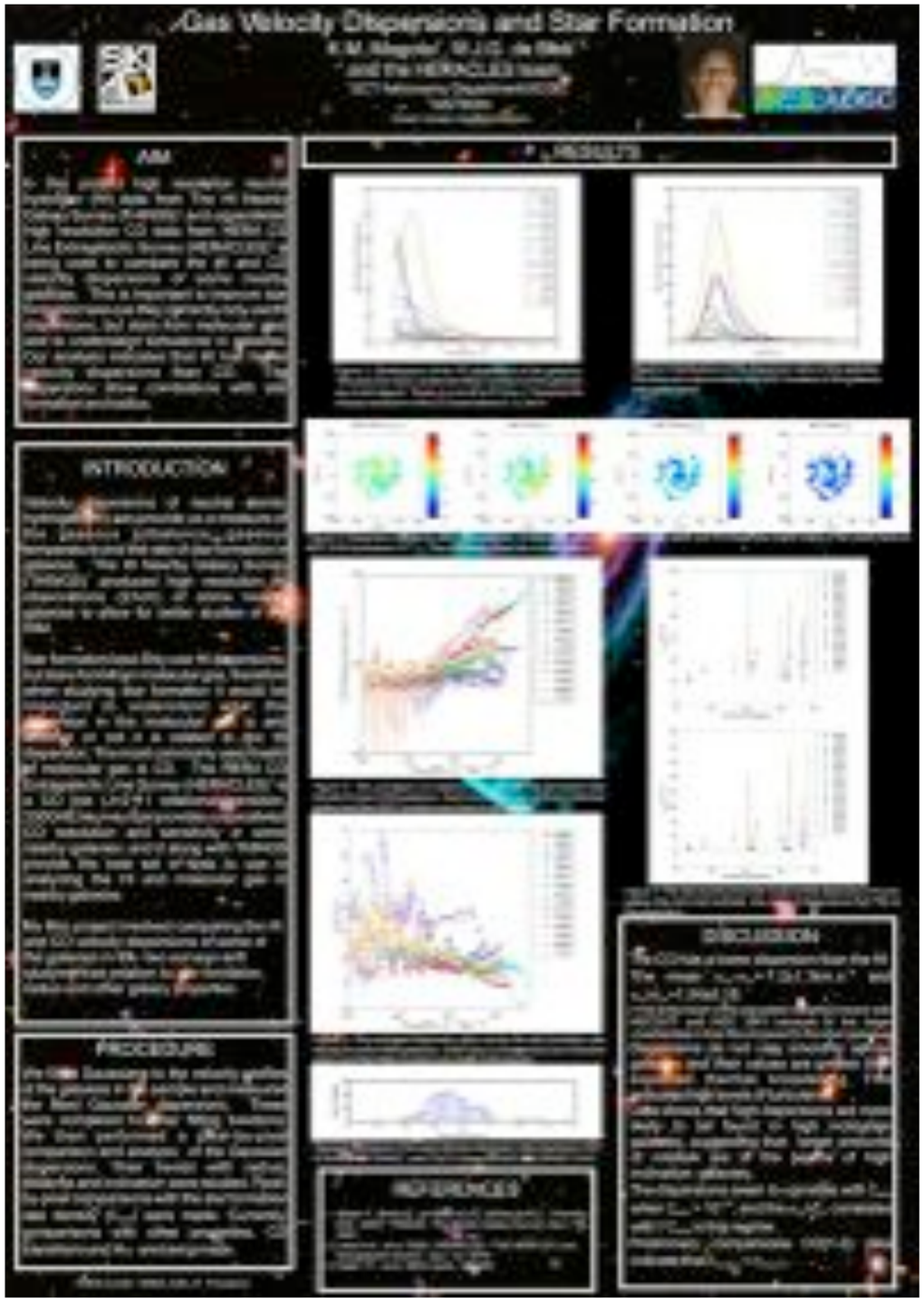
- HERACLES
- THINGS

contours start from +3σ
in steps of +3σ

NGC2403 ROTATION CURVES

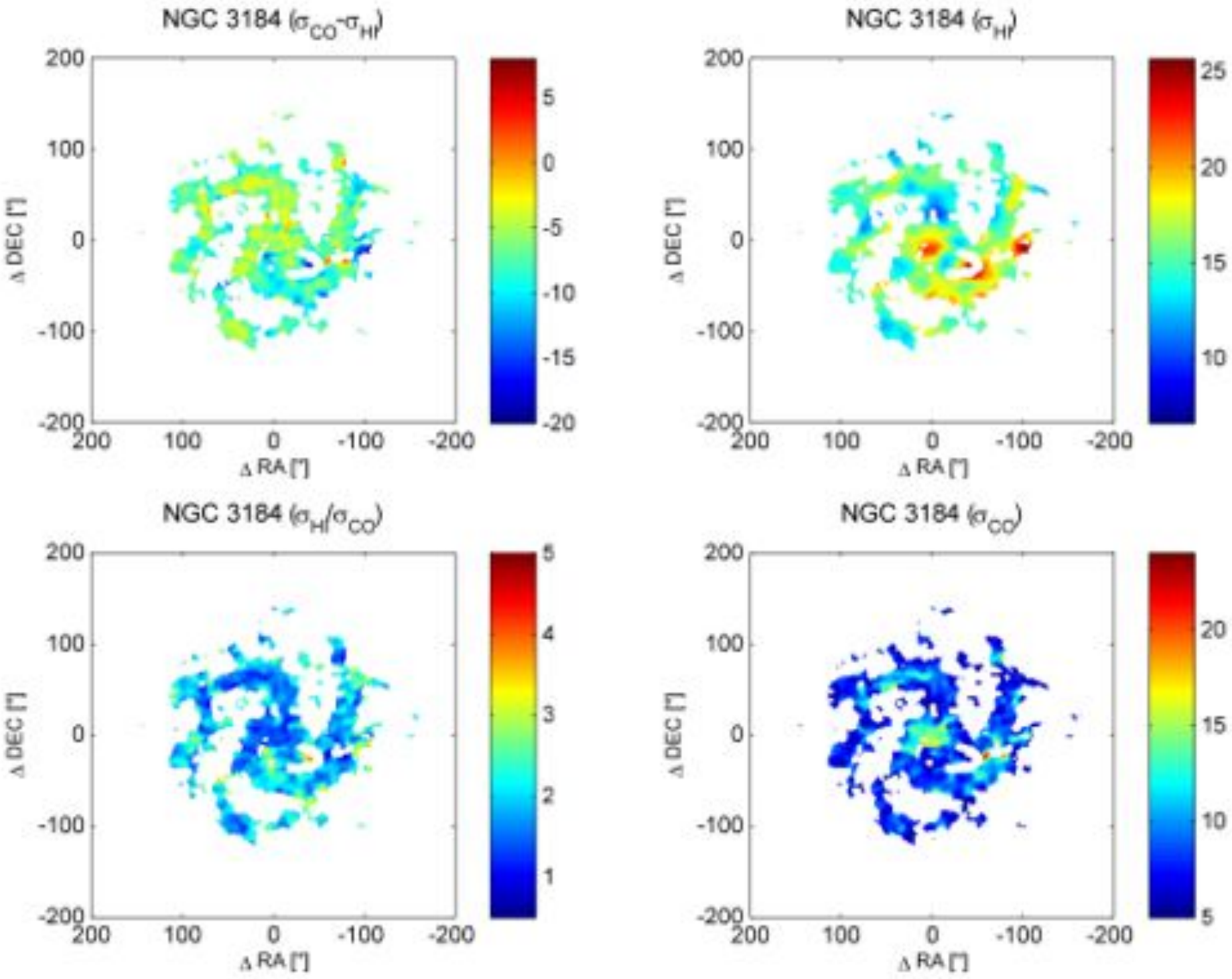


CO Dispersions

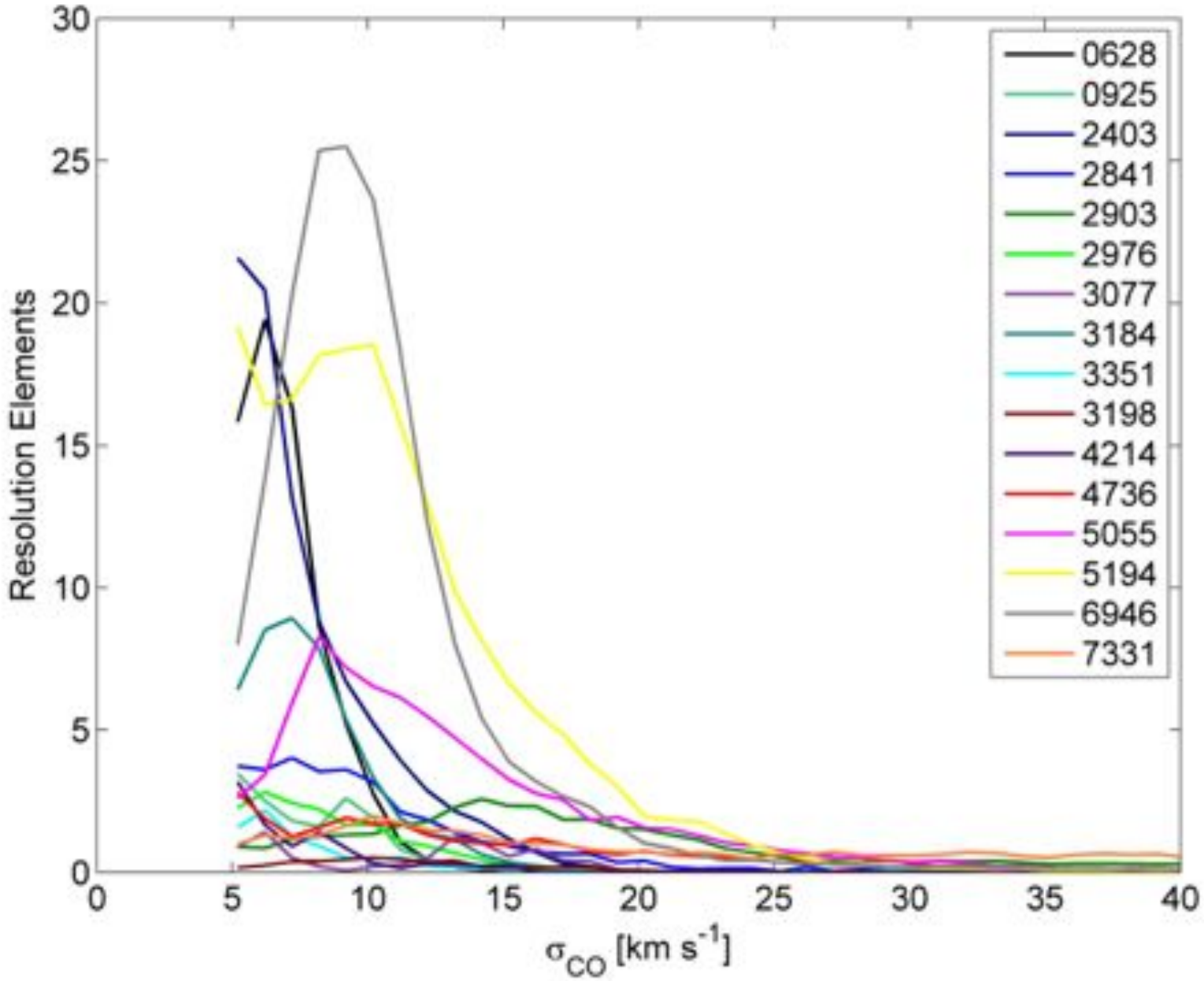


poster by Moses Mogotsi

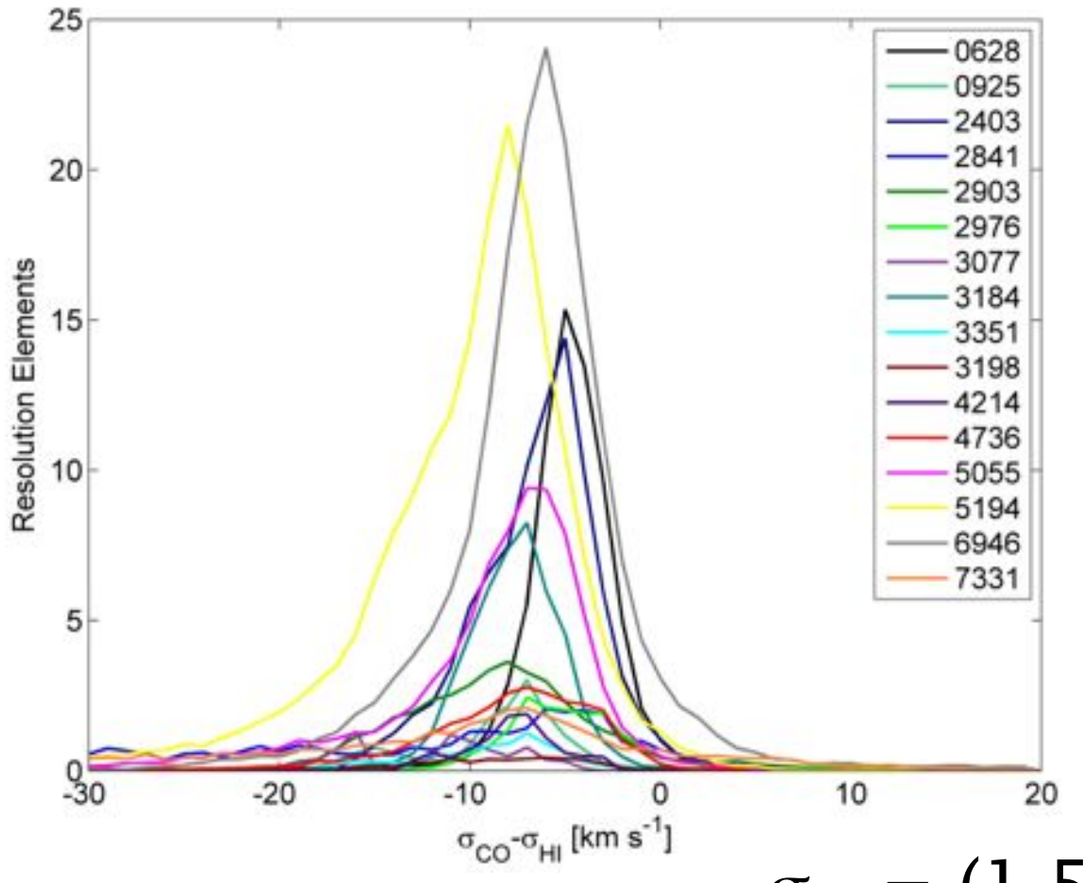
NGC 3184 Example

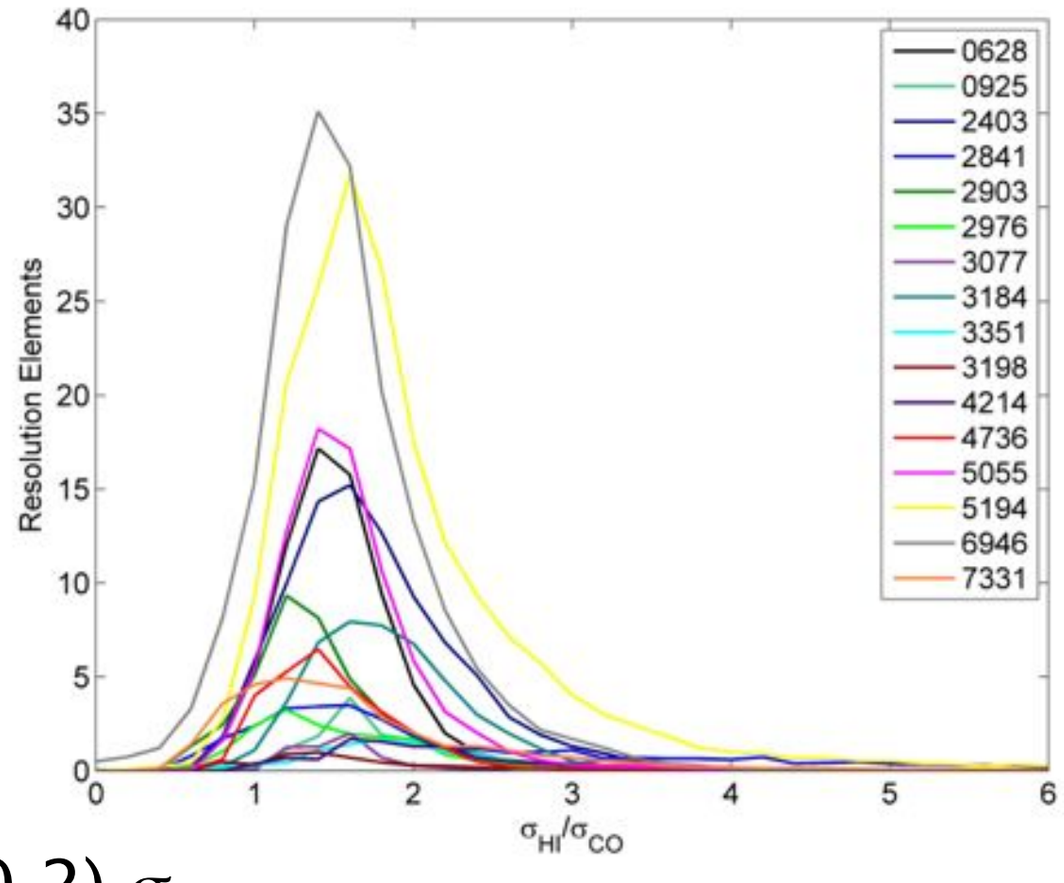


CO dispersions



HI-CO comparisons





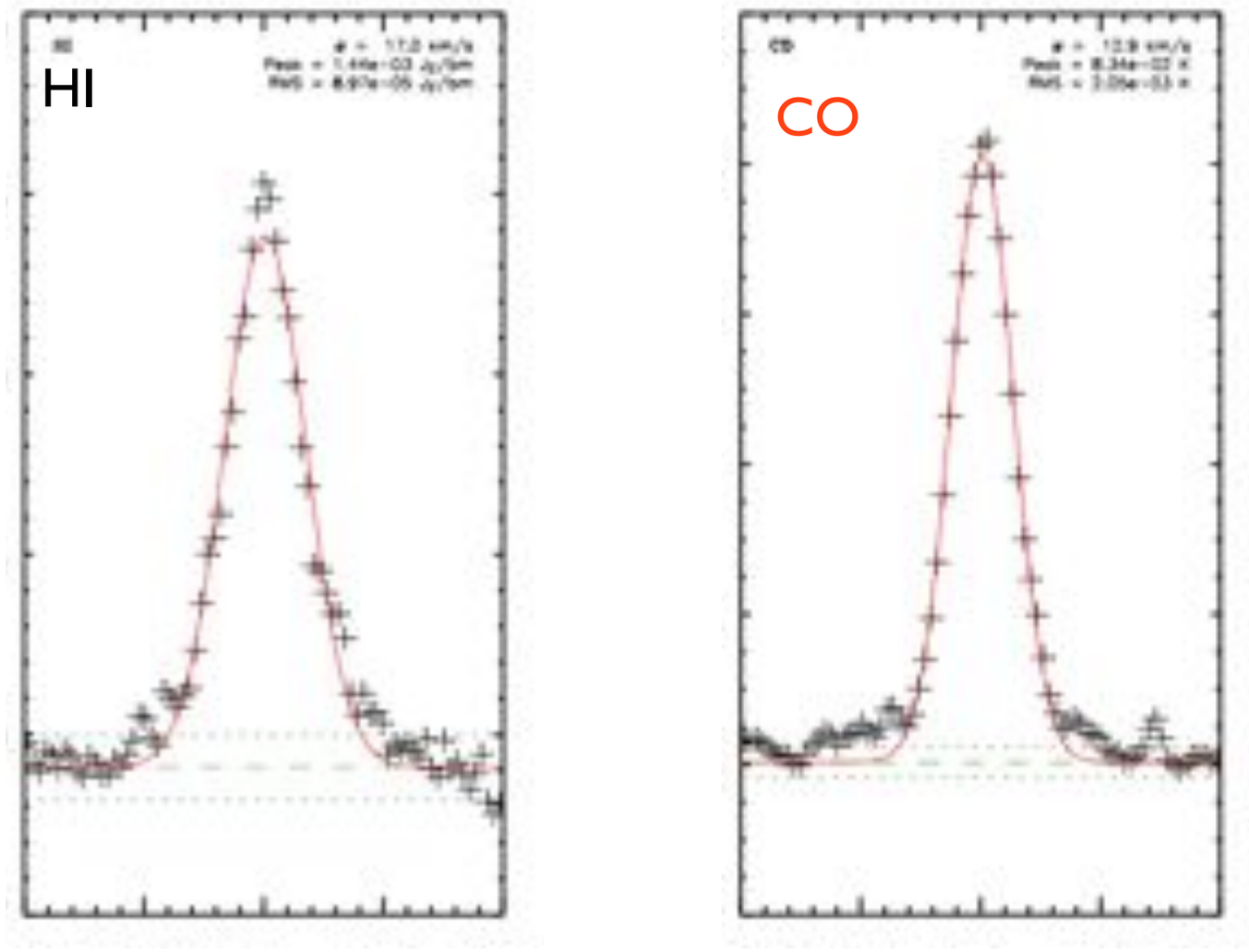
$\sigma_{HI} = (1.5 \pm 0.2)\ \sigma_{CO}$

$\sigma_{HI} - \sigma_{CO} = (7.2 \pm 1.3)$ km/s

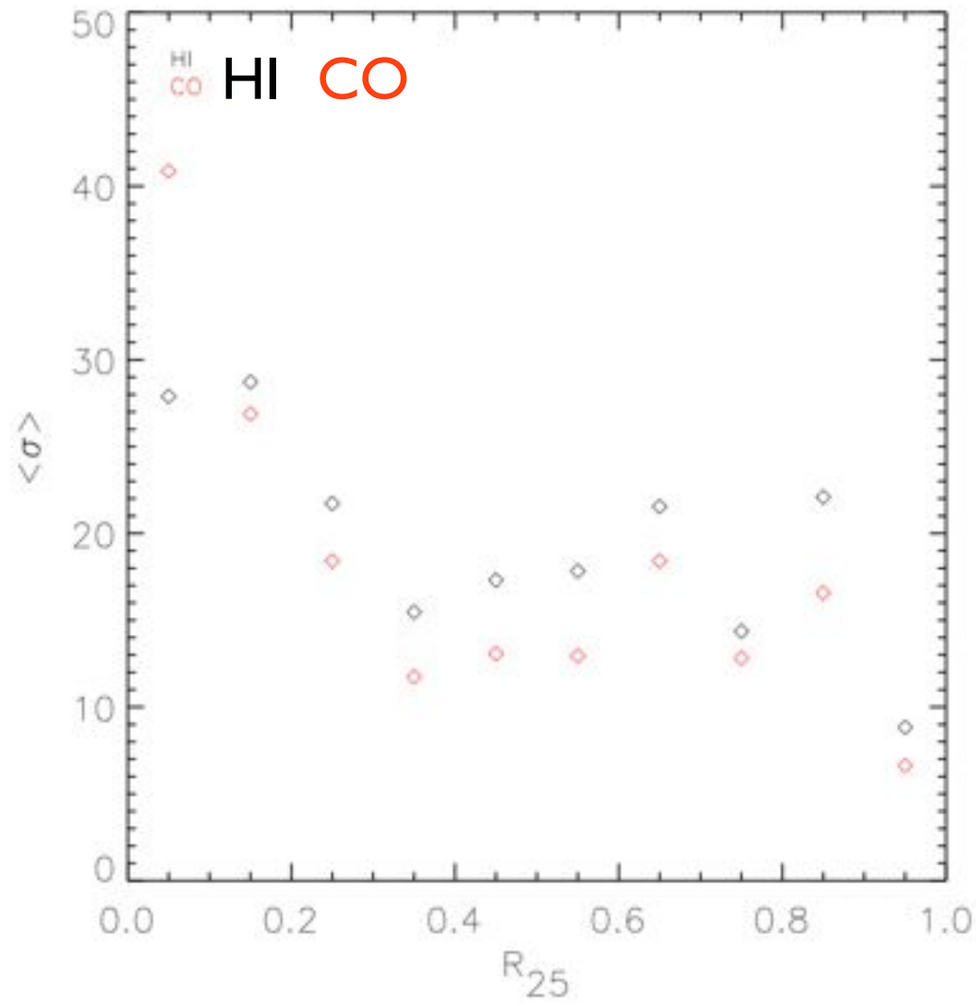
Note σ_{CO} and $\sigma_{HI,narrow}$ similar

Stacking the CO

Anahi Caldu-Primo and Fabian Walter



Stack HI, CO spectra in bins of radius, SFR, total gas

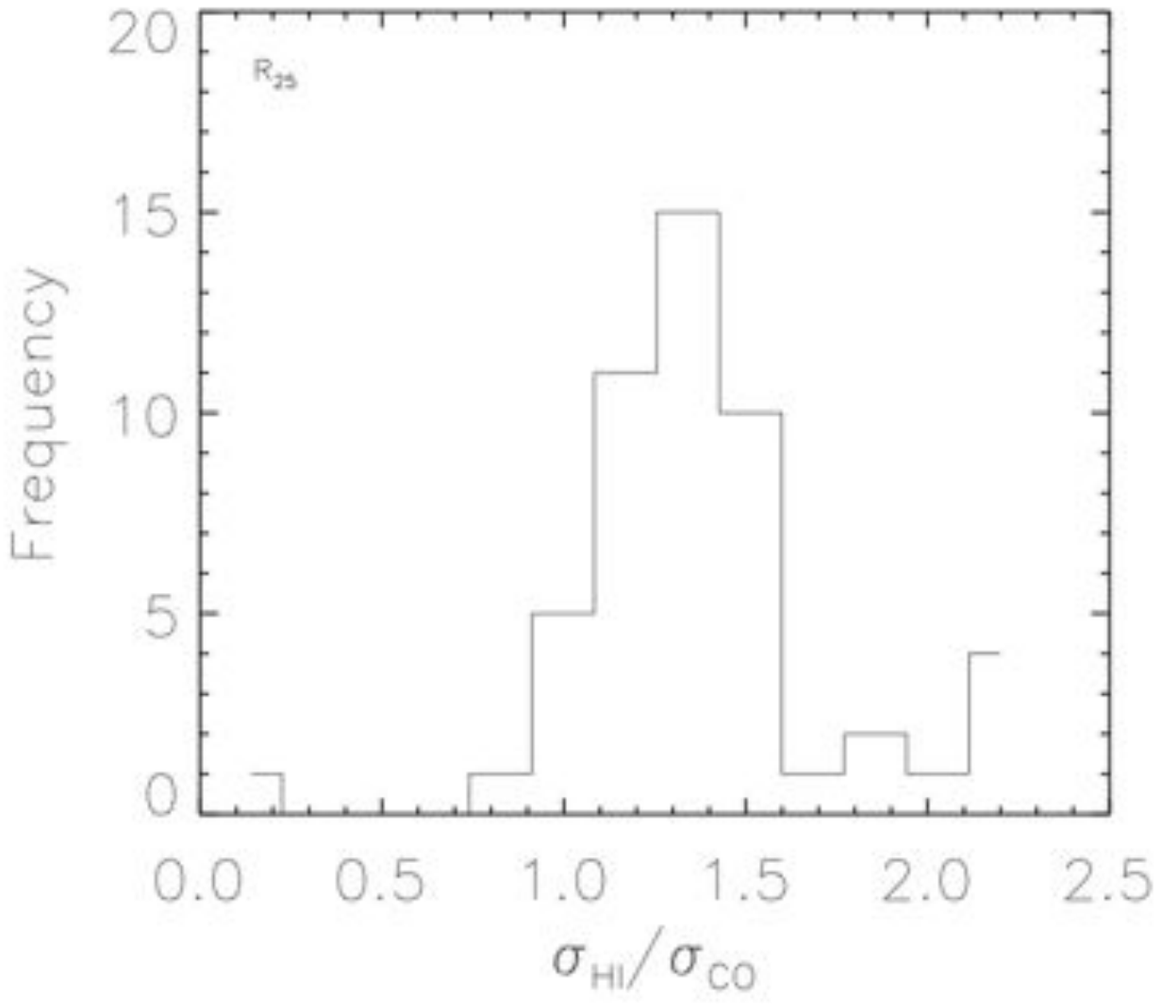


Velocity Dispersion
as function of radius

Stacking the CO

Anahi Caldu-Primo and Fabian Walter

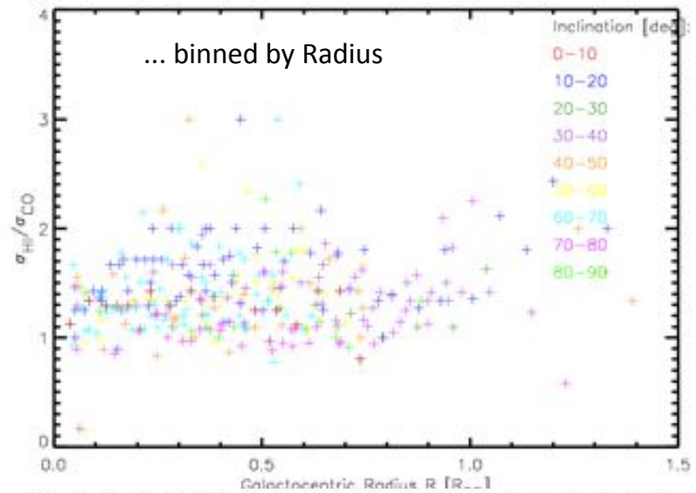
Ratio of HI/CO Velocity Dispersion for all Galaxies

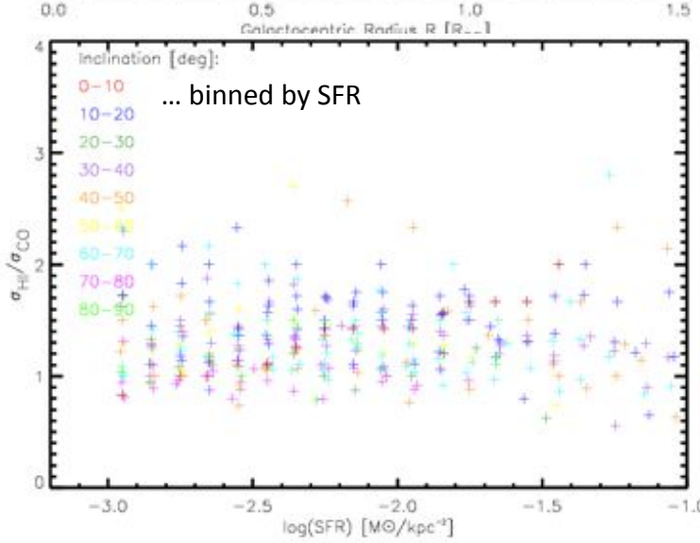


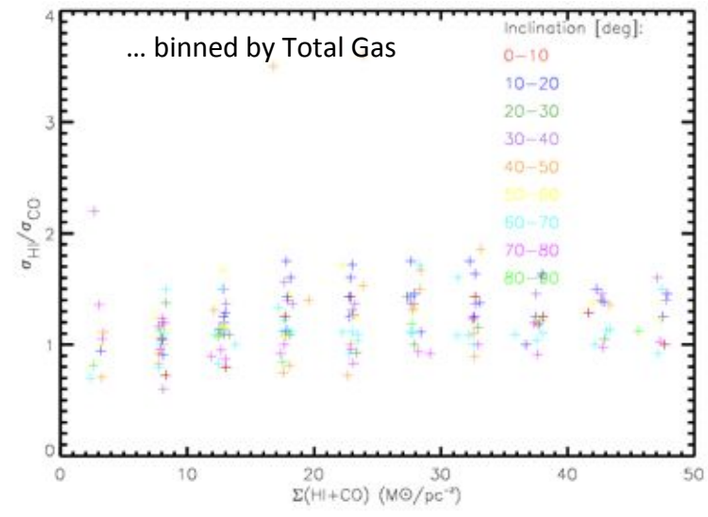
Average Ratio is 1.41 ± 0.34

consistent with non-stacked value

Ratio of HI/CO Velocity Dispersion …







Summary

- Stacking can be used to identify broad and narrow components in THINGS galaxy profiles
- Narrow component: 6.5 ± 1.5 km s^{-1}
- Broad component: 16.8 ± 4.3 km s^{-1}
- Dispersions decline exponentially
- Narrow component associated with star formation
- CO dispersions ~1.5 times smaller than "single component" HI dispersions, and similar to "narrow component" HI dispersion
- Future work: quantify the "narrow HI"-CO (H_2) connection - "narrow HI" SF law
- Increase S/N of individual profiles, more sophisticated stacking, smaller areas, CO super profiles