WO220222

Env22 Workshop

Global H I Properties of Galaxies via Stacking Analysis

To be submitted to JKAS

Minsu Kim and Se-Heon Oh†

SEJONG UNIVERSITY

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mandu447@gmail.com

Contents

INTRODUCTION

- ✓ A brief summary of H I 21cm extragalactic studies
- ✓ H I superprofiles of galaxies
- ✓ Previous works on H I superprofiles
- ✓ Our new approach

INTRODUCTION: A brief summary on H I 21cm extragalactic studies

H I: a useful tracer for gas kinematics of galaxies

- The most abundant element in the Universe
- Extended well beyond the optical radii of galaxies

Single dish H I 21cm observations of external galaxies

- Typical resolutions of a few arcminutes even for 100-meter dishes
- Not enough to resolve gas disk except for nearby galaxies
- Used in robust measurements of global H I properties of galaxies

  (e.g. total gas mass, systemic velocity, maximum rotational velocity etc.)

Interferometric H I 21cm observations of external galaxies

- Achieved sub-kpc resolution (GMC scales) H I kinematics distributions for nearby galaxies
- Used for testing current star formation models, ΛCDM cosmological galaxy formation theory at sub-kpc scales etc.

INTRODUCTION: A brief summary on H I 21cm extragalactic studies

H I gas velocity dispersion: a tool to examine the interplay between the ISM and hydronamical processes

- Baryonic processes (e.g., star formation) and tidal interactions in and around galaxies disturb the ISM in galaxies

  → Turbulent gas motions

  → Higher gas velocity dispersion

H I gas velocity dispersion via single dish observations

- Having low angular resolutions, several gas clouds with different kinematics could be included in a same beam

  → Beam smearing effect

- Worsen towards the central region of a galaxy where velocity gradient increases

H I gas velocity dispersion via interferometric observations

- Less suffer from beam smearing effect
- Expensive observations for faint H I galaxies - low H I column density levels in the outskirts of galaxies by photoionization

  → low S/N: large uncertainties of galaxy H I properties

INTRODUCTION: H I superprofiles of galaxies

A breakthrough: stacking method

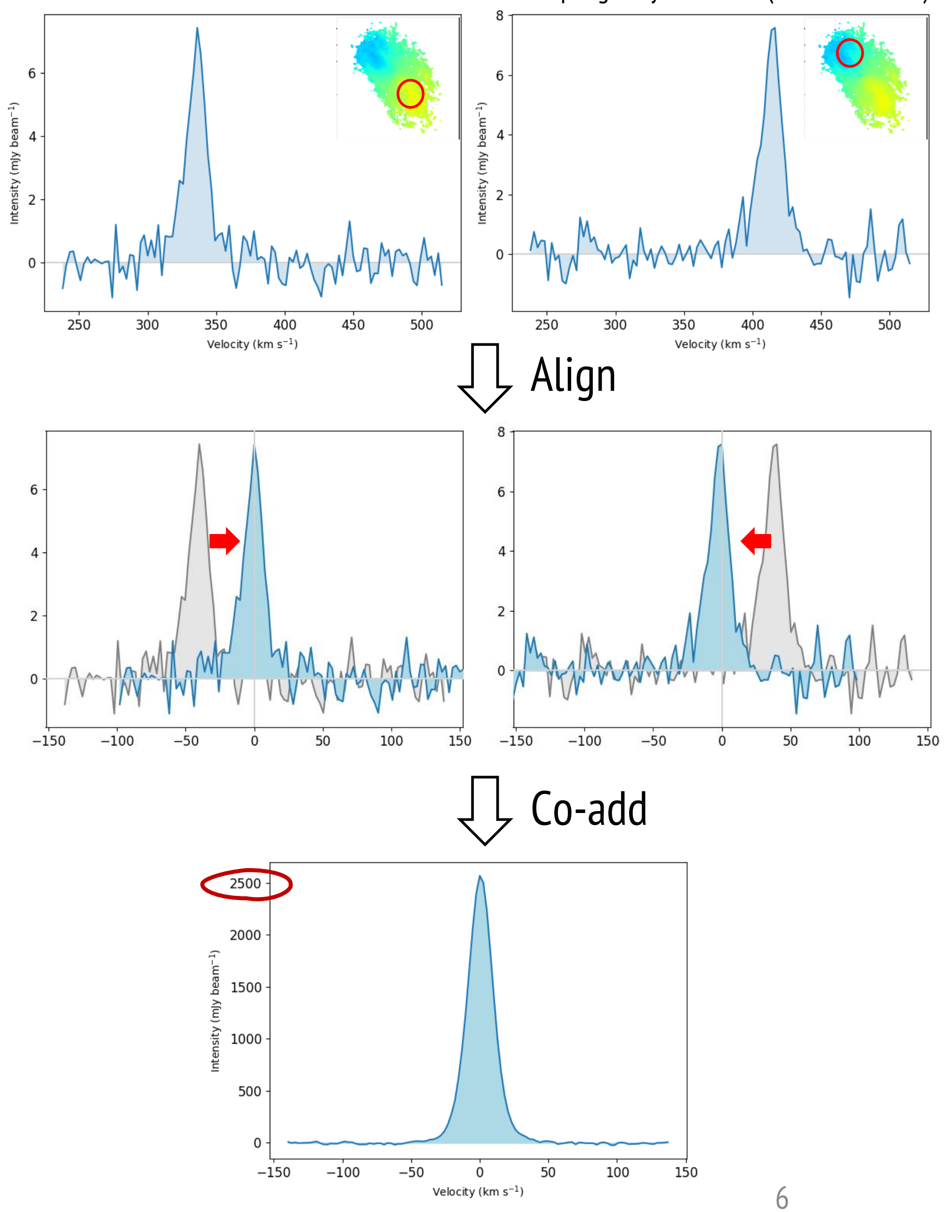
First used by Ianjamasimanana et al. (2012) and Stilp et al. (2013)

- Align the central velocities of individual H I profiles
- Construct an H I superprofile by co-adding the aligned profiles

⇒ *A SUPERPROFILE*

- The S/N of the superprofile increases with $\sqrt{N}$ as the noise decreases with $\sqrt{N}$ (N: the number of co-added profiles)
- A tradeoff between S/N and spatial information

Sample galaxy: DDO 154 (LITTLE THINGS)



INTRODUCTION: Previous works on H I superprofiles

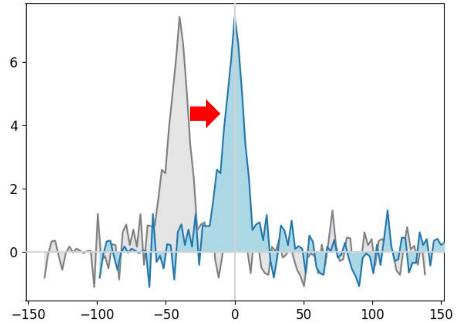
Some limits of conventional stacking methods

- Turbulent gas motions in galaxies often make their velocity profile shape non-Gaussian and asymmetric
- Conventional methods used moment analysis (1st moment) [Ianjamasimanana+12], fitting method (Gauss-Hermite h_3) [Ianjamasimanana+12, Stilp+13)], peak velocity [Koch+18] etc.

  → Gives single representative velocity per profile

  → Biased in estimating centroid velocities of asymmetric profiles

  → Could cause broadening of resulting superprofile



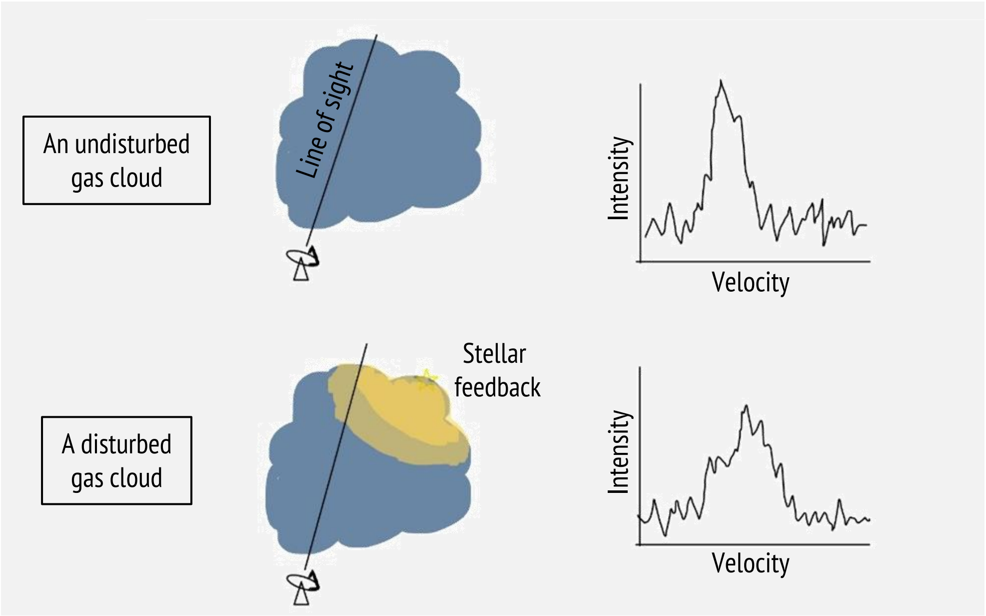
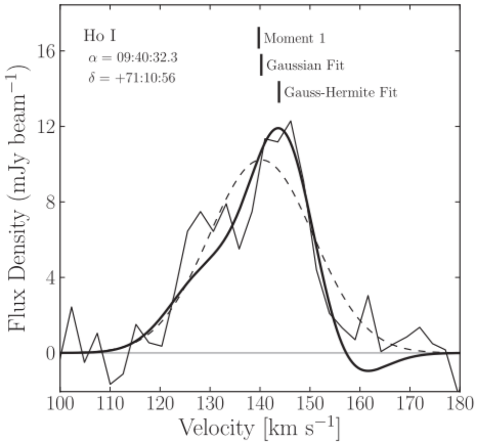


Fig. 2b., Stilp et al. (2013)



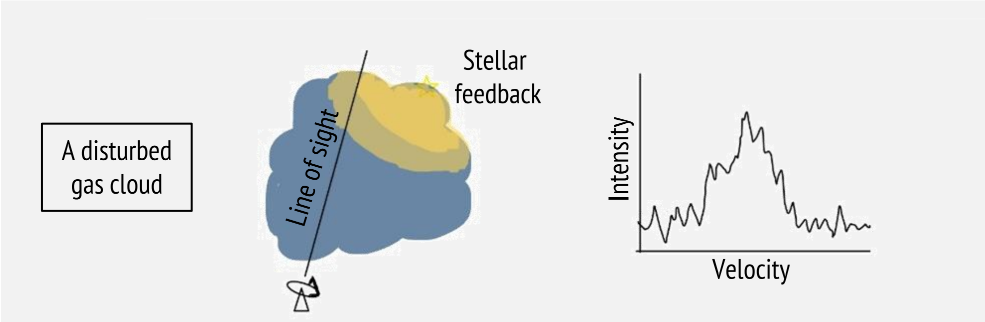
An example of an asymmetric HI velocity profile

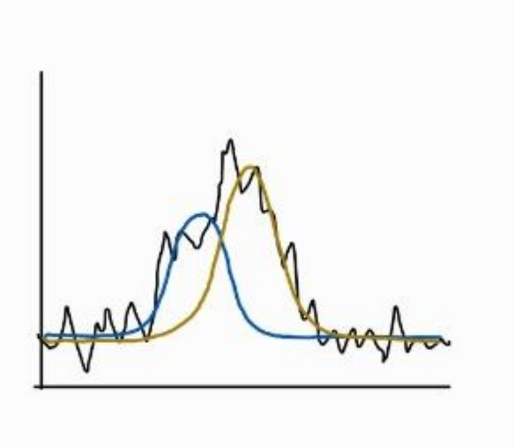
INTRODUCTION: Our new approach

Our new approach using profile decomposition

1) Decompose individual H I velocity profiles with an optimal number of Gaussian components

2) Co-add the optimally decomposed Gaussian components after aligning their centroid velocities





⇒ Minimize the effect of turbulent gas motions in galaxies on the superprofiles

H I Superprofiles

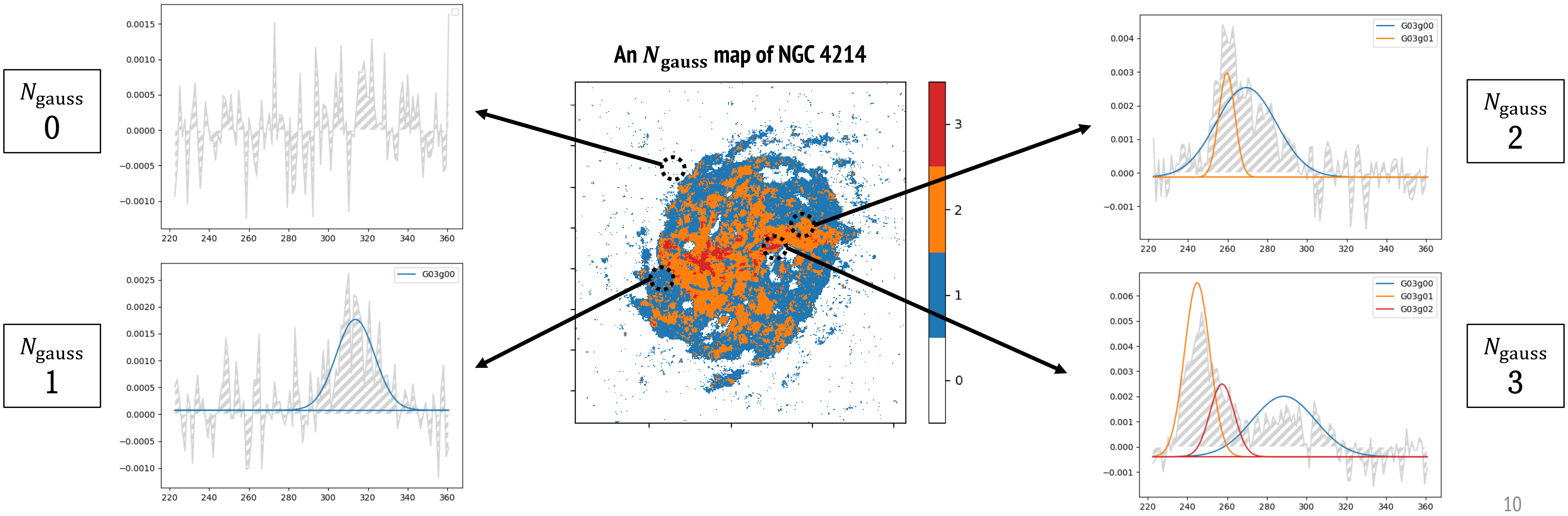
- ✓ Profile decomposition: BAYGAUD
- ✓ Constructing an H I superprofile
- ✓ Parameterizing an H I superprofile
- ✓ Comparison of the superprofiles derived using different methods

H I SUPERPROFILES: Profile decomposition: BAYGAUD

BAYGAUD (BAYesian GAUssian Decomposer; Oh et al. 2019)

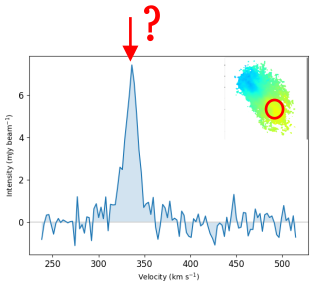
- A new profile analysis tool based on Bayesian analysis technique
- Fits a set of models comprised of a number of Gaussian components to individual LoS velocity profiles, then finds an optimal model based on Bayes factor

In short, BAYGAUD finds and fits the best number of Gaussians on a profile



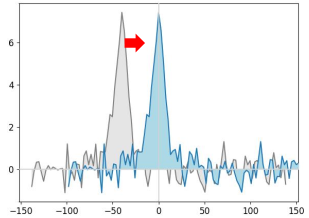
H I SUPERPROFILES: Constructing an H I superprofile

Previous methods



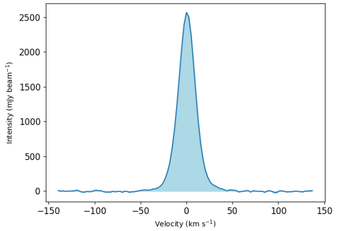
Determining centroid velocities

Derive LoS velocities



Aligning

Align the velocity profiles w/ respect to the centroid velocities



Stacking

Co-add the spectra

Our new procedure

Profile decomposition

Decompose individual velocity profiles into Gaussian components

N_{gauss} ?

> 1

Example case $N_{\mathrm{gauss}} = 2$

Subtracting

Subtract model G1 from the spectrum | Subtract model G2 from the spectrum

$= 1$

Aligning

Align the velocity profiles w/ respect to the centroid velocities

Stacking

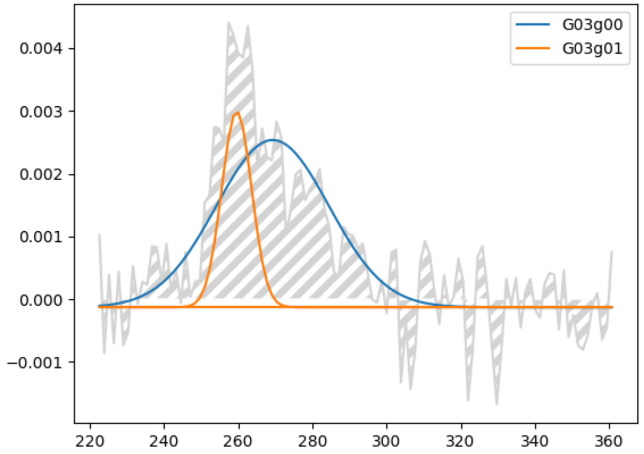
Co-add the spectra

H I SUPERPROFILES: Constructing an H I superprofile: Subtraction zoomed-in

Example case
$N_{\text{gauss}} = 2$

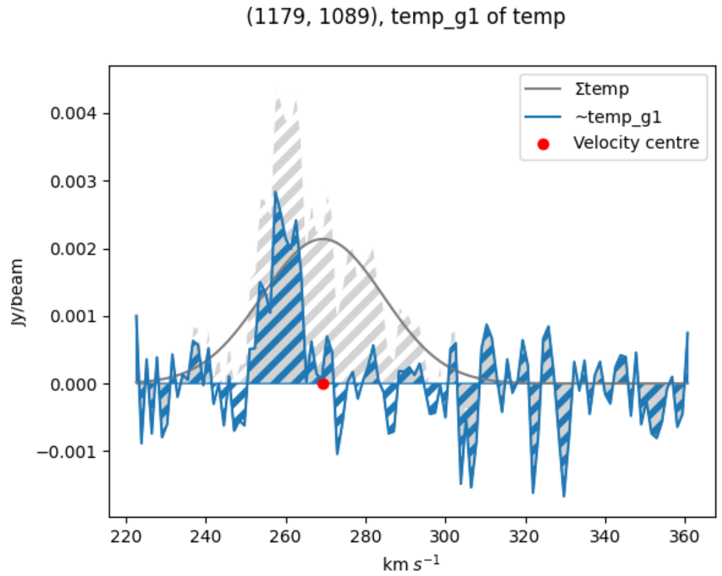
Subtracting

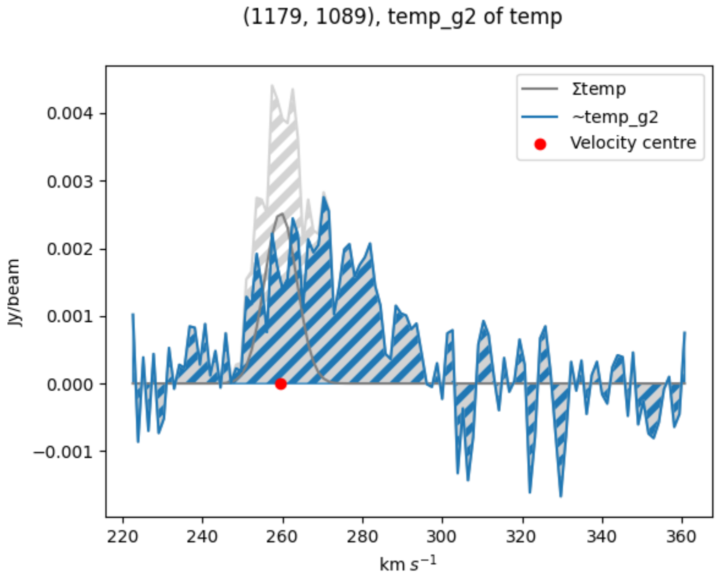
Subtract model G1 from the spectrum | Subtract model G2 from the spectrum



Subtract [blue]

Subtract [orange]





H I SUPERPROFILES: Parameterizing an H I superprofile

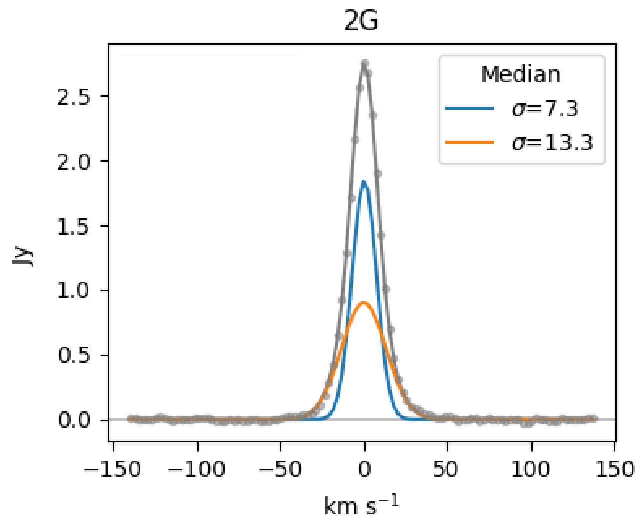
Parameterization of the H I superprofile

- Fits a double Gaussian model with a constant baseline to the superprofile (using python tool `emcee`)
- 7 free parameters:

Narrow component	Broad component	+α
a_n: amplitude v_n: central velocity σ_n: velocity dispersion	a_b: amplitude v_b: central velocity σ_b: velocity dispersion	B: baseline

Parameters from the superprofile

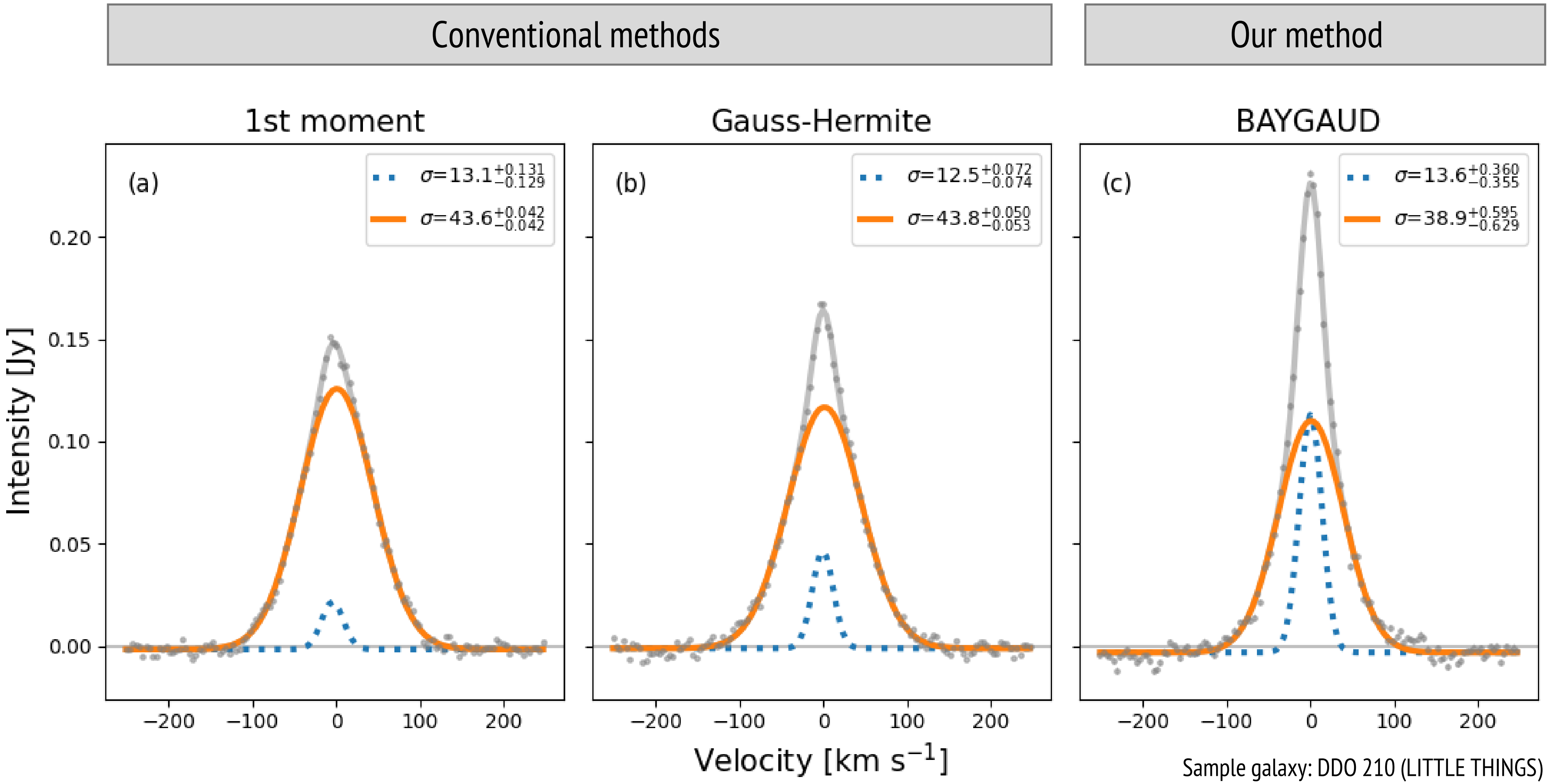
- σ_n: the velocity dispersion of a narrow component
- σ_b: the velocity dispersion of a broad component
- A_n: the area of a narrow component
- A_b: the area of a broad component



Soon, we'll see a correlation with a parameter

$$\frac{A_n}{A_{tot}} \equiv \frac{A_n}{A_n + A_b}$$

H I SUPERPROFILES: Comparison of the superprofiles derived using different methods



Sample galaxy: DDO 210 (LITTLE THINGS)

Practical Application to Nearby Galaxies

- ✓ Data: THINGS and LITTLE THINGS

- ✓ Correlation with star formation rate
  : Comparison with the previous analysis

A PRACTICAL TEST: Data

THINGS (The HI Nearby Galaxy Survey; Walter et al. 2008)

- VLA H I 21cm survey
- 34 nearby galaxies (< 10 Mpc)
- Resolution (spatial / spectral): $6'' / \leq 5.2$ km s^{-1}
- Mass range ($M_\odot$): $10^7 \lesssim M_{\rm HI} \lesssim 10^{10}$

LITTLE THINGS (Local Irregulars That Trace Luminosity Extremes, THINGS; Hunter et al. 2012)

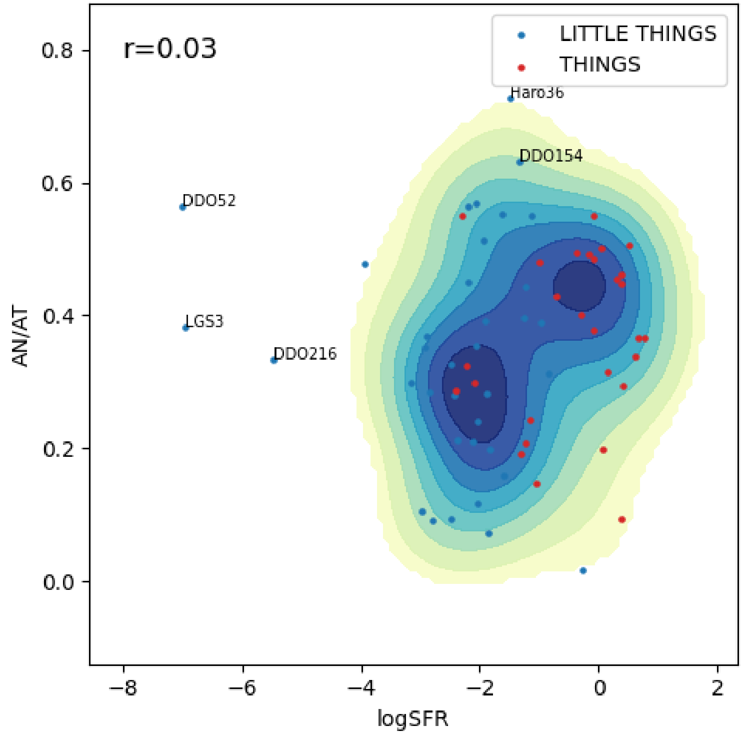
- VLA H I 21cm survey
- 41 nearby dwarf irregulars (dIrrs) and blue compact dwarfs (BCDs) (< 10 Mpc)
- Resolution (spatial / spectral): $6'' / \leq 2.6$ km s^{-1}
- Mass range ($M_\odot$): $10^5 \lesssim M_{\rm HI} \lesssim 10^9$

Both surveys are complemented with observations at multi wavelengths

⇒ star formation rate (SFR) info available

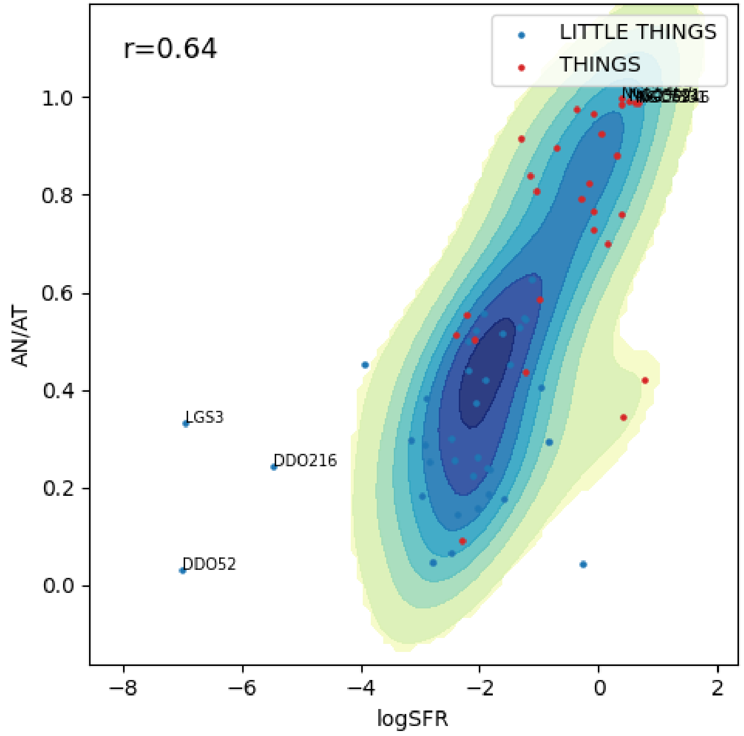
A PRACTICAL TEST: Correlation with star formation rate: Comparison with previous analysis method

Ianja+12's method

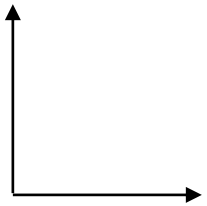


Ianja+12 used only THINGS galaxies for their analysis.
To make a comparison, we made a same approach as Ianja+12
on LITTLE THINGS galaxies

Our method



$$\frac{A_n}{A_{tot}} = \frac{A_n}{A_n + A_b}$$



$\log \mathrm{SFR}\ \ (M_\odot\ \mathrm{yr}^{-1})$

- More prominent positive correlation found

EXTENSION TO OTHER STUDIES

- ✓ Useful for statistical studies of global H I properties of galaxies

- ✓ Useful for tracing turbulent gas motions (probably caused by hydrodynamical processes) as well as galaxy environmental effects

  → See the talk by Shin-Jeong Kim tomorrow
  (H I gas kinematics of galaxy pairs in cluster environments from ASKAP pilot observations)

- ✓ Future applications:

  Correlation with different physical properties (e.g., metallicity, total mass of a galaxy)
  Upcoming large H I surveys (WALLABY, SKA etc.)

SUMMARY

- ✓ We present a new method for deriving H I superprofiles of galaxies
- ✓ The new method performs
  1. profile decomposition of velocity profiles of an input H I data cube a cube,
  2. Aligns their centroid velocities, and stacks them
- ✓ The new HI superprofiles constructed from our method appear to have narrower wings and higher peaks in shape than the ones derived using the previous methods
- ✓ As a practical test, we apply our method to nearby galaxies from THINGS and LITTLE THINGS
- ✓ A tighter correlation between star formation rate and the narrower Gaussisan component's intensities compared to the previous analysis

Thank you for your attentions

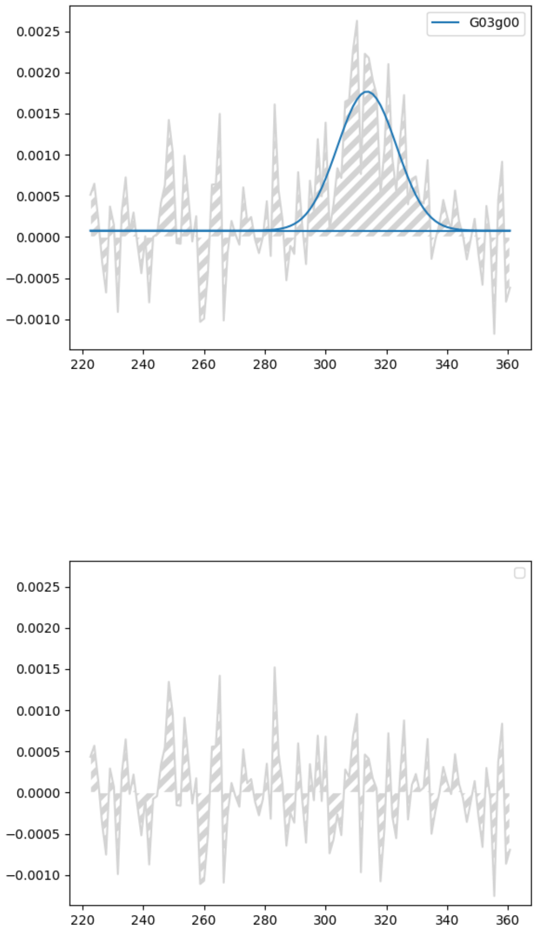
SEJONG UNIVERSITY

mandu447@gmail.com

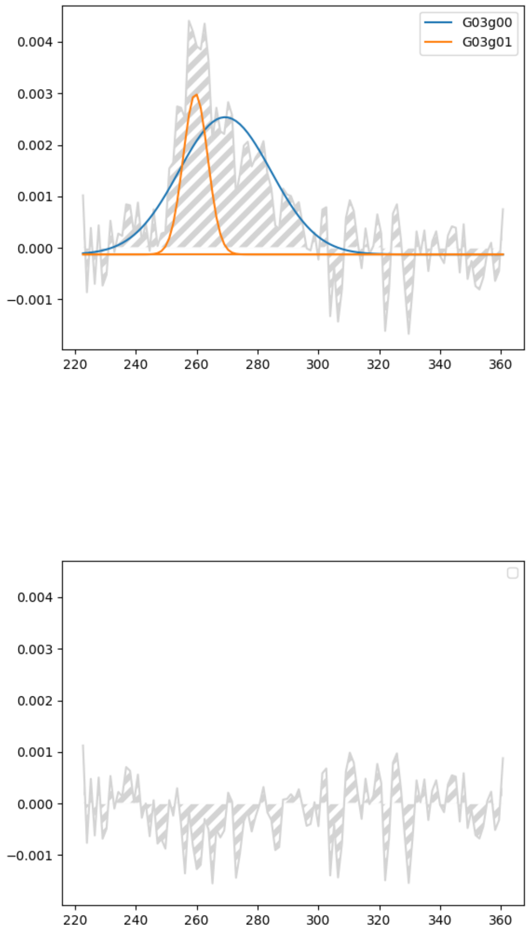
Supplementary Materials

SUPPLEMENTARY MATERIALS1: Fit quality of spectra @ slide 9

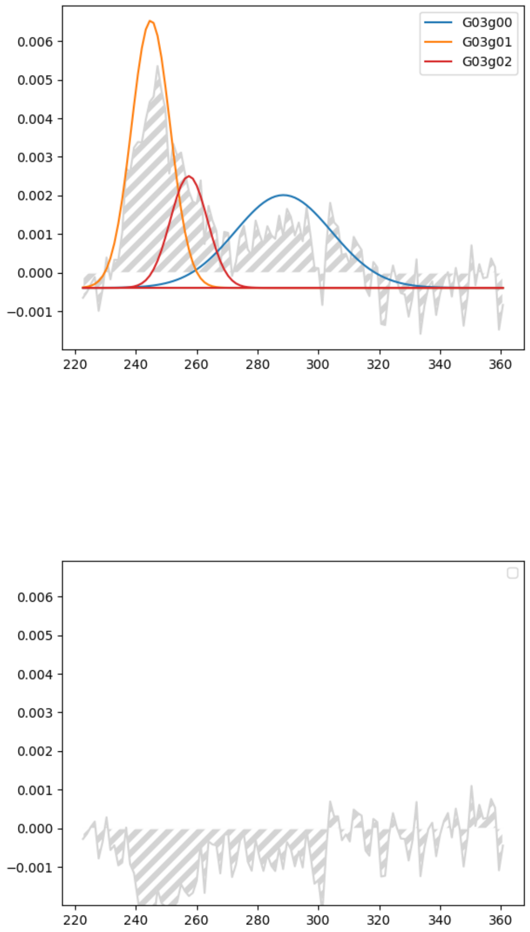
N_{gauss} 1



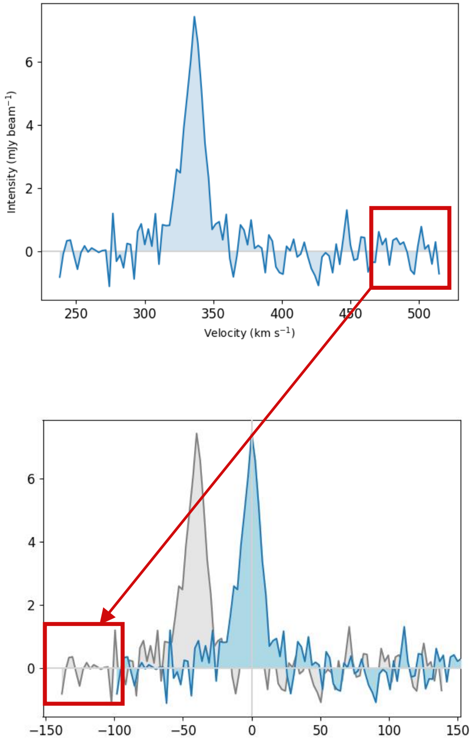
N_{gauss} 2



N_{gauss} 3



SUPPLEMENTARY MATERIALS2: What to do w/ leftover parts?



Parameterization of the H I superprofile

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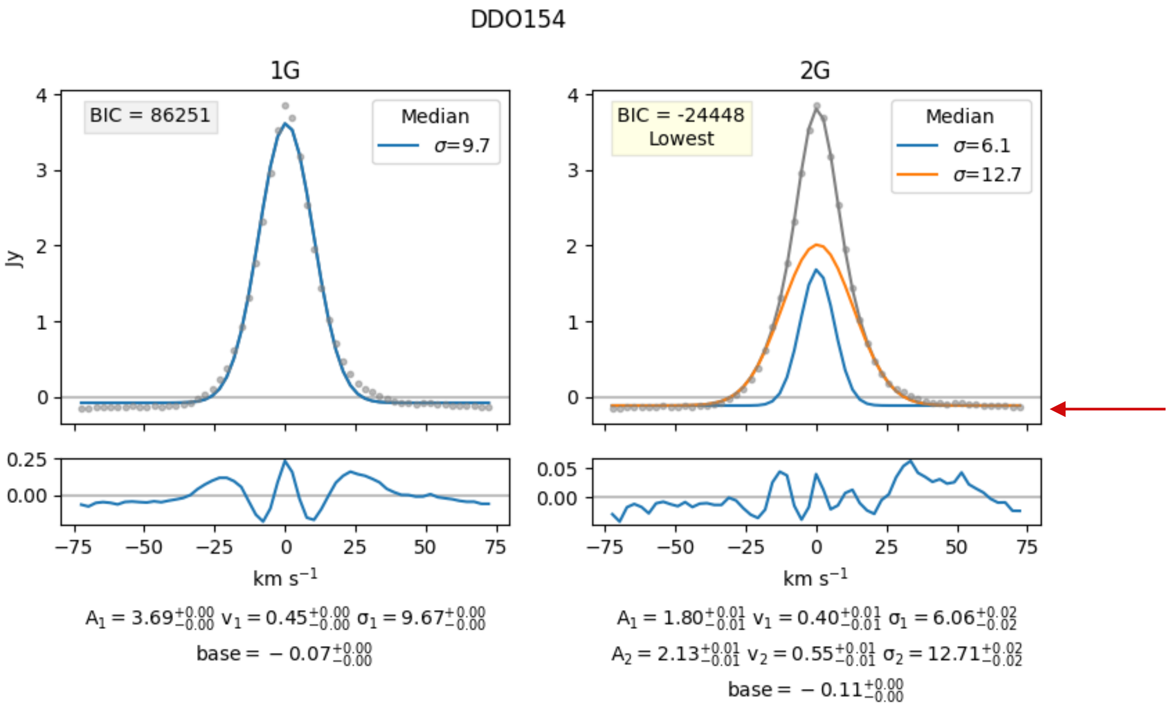
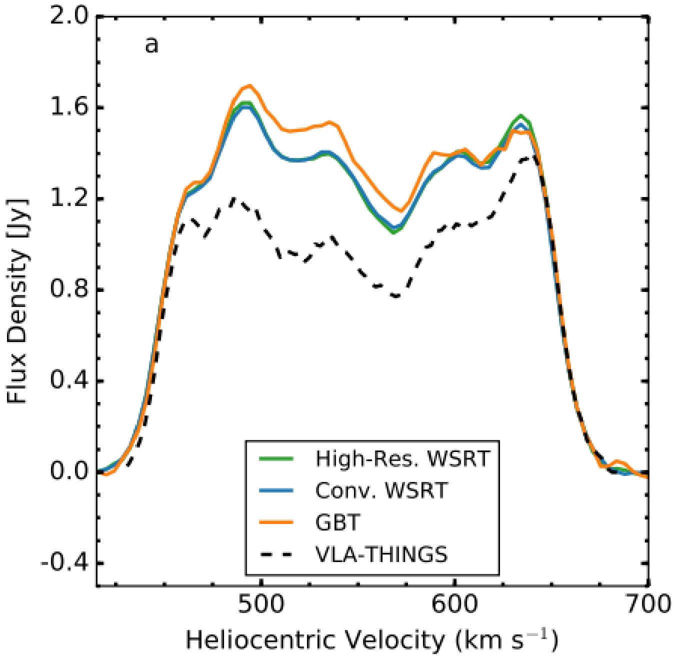
v_n: central velocity	v_b: central velocity	
σ_n: velocity dispersion	σ_b: velocity dispersion	

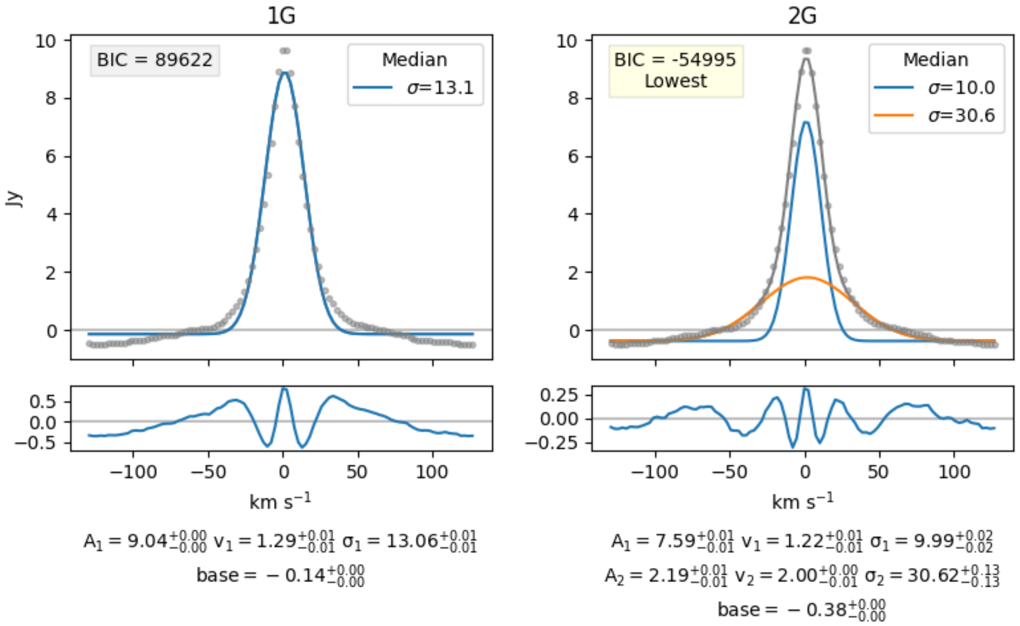


SUPPLEMENTARY MATERIALS3: Difference w/ low-resolution observations?

Fig. 6a., Pingel et al. (2018)



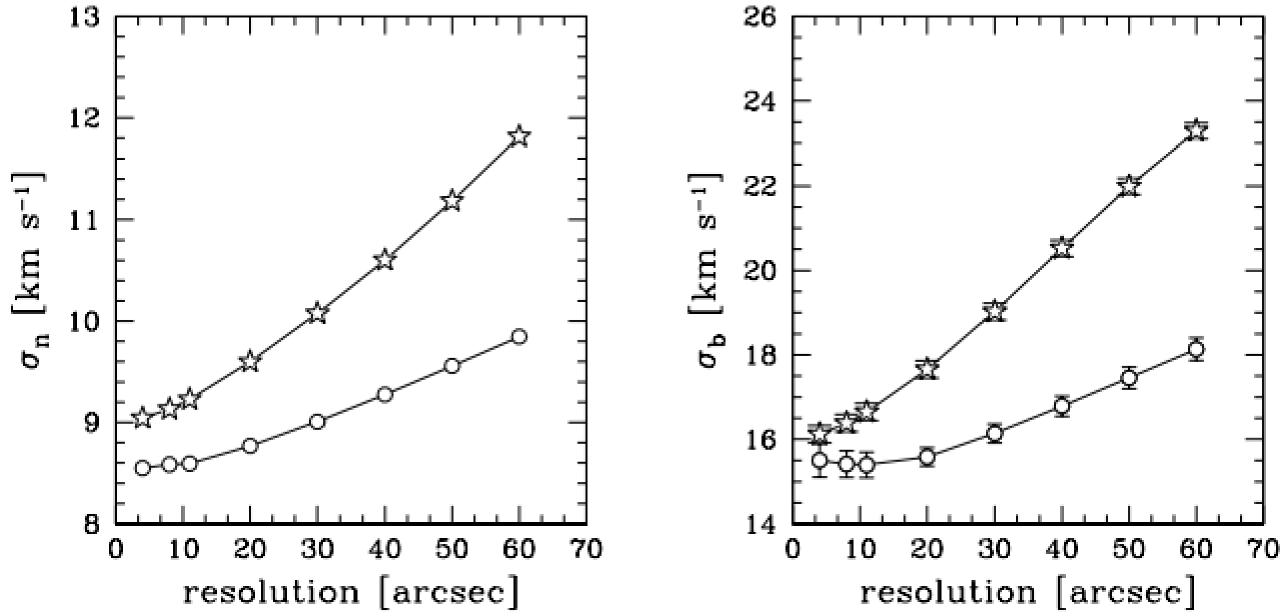
GBT H I spectrum of NGC 925 ($\theta_{\mathrm{FWHM}} = 9.1'$)



Superprofiles (Using THINGS data)

SUPPLEMENTARY MATERIALS4: Effect of beamsize on superprofiles?

Fig. 4., Ianjamasimanana et al. (2012)



Dispersions of the narrow component of the superprofiles

Dispersions of the broad component of the superprofiles

☆ : a model w/ $i = 80°$
○ : a model w/ $i = 63°$