The unusual morphology and kinematics of the gas in the central regions of M31

Michael Opitsch [1,2,3] Roberto Saglia [1,2] Ralf Bender [1,2]
Maximilian Fabricius [1,2,4] Michael Williams [1,5]

[1] Max Planck Institute for Extraterrestrial Physics, Garching, Germany
[2] University Observatory Munich, Germany
[3] Excellence Cluster Universe, Garching, Germany
[4] Subaru Telescope, Hawaii, USA
[5] Department of Astronomy, Columbia University, New York, USA

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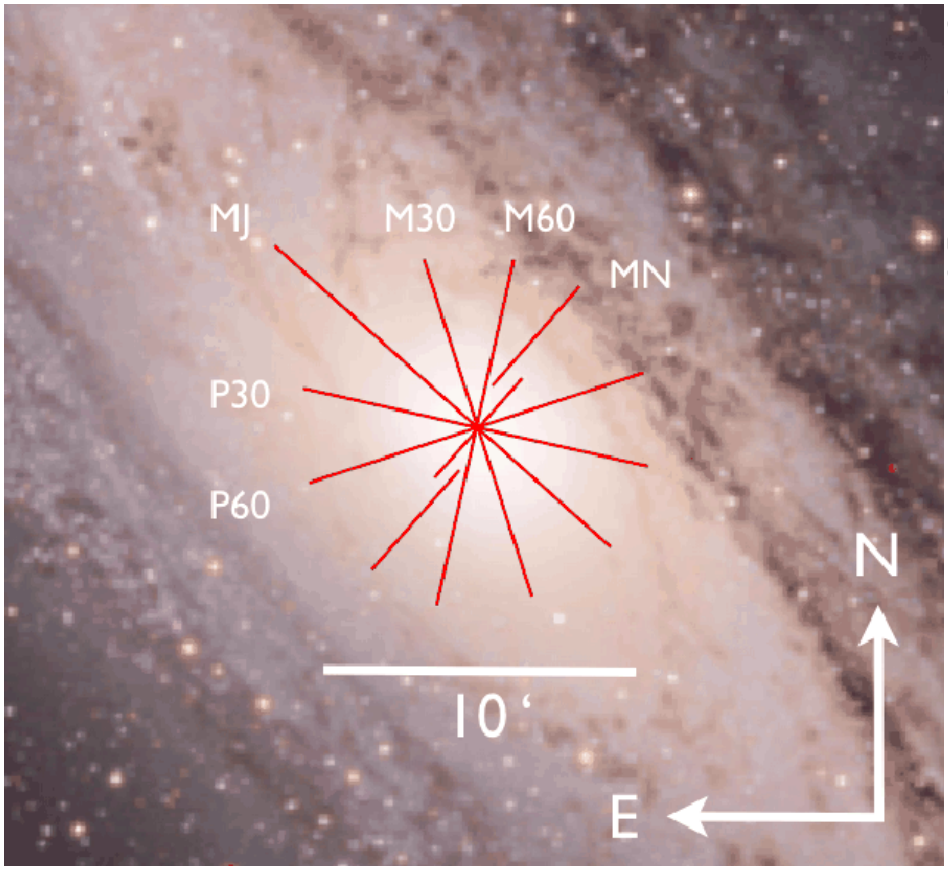
Outline

- Introduction
- Observations
- Data reduction and derivation of the kinematics
- Results: Gas kinematics

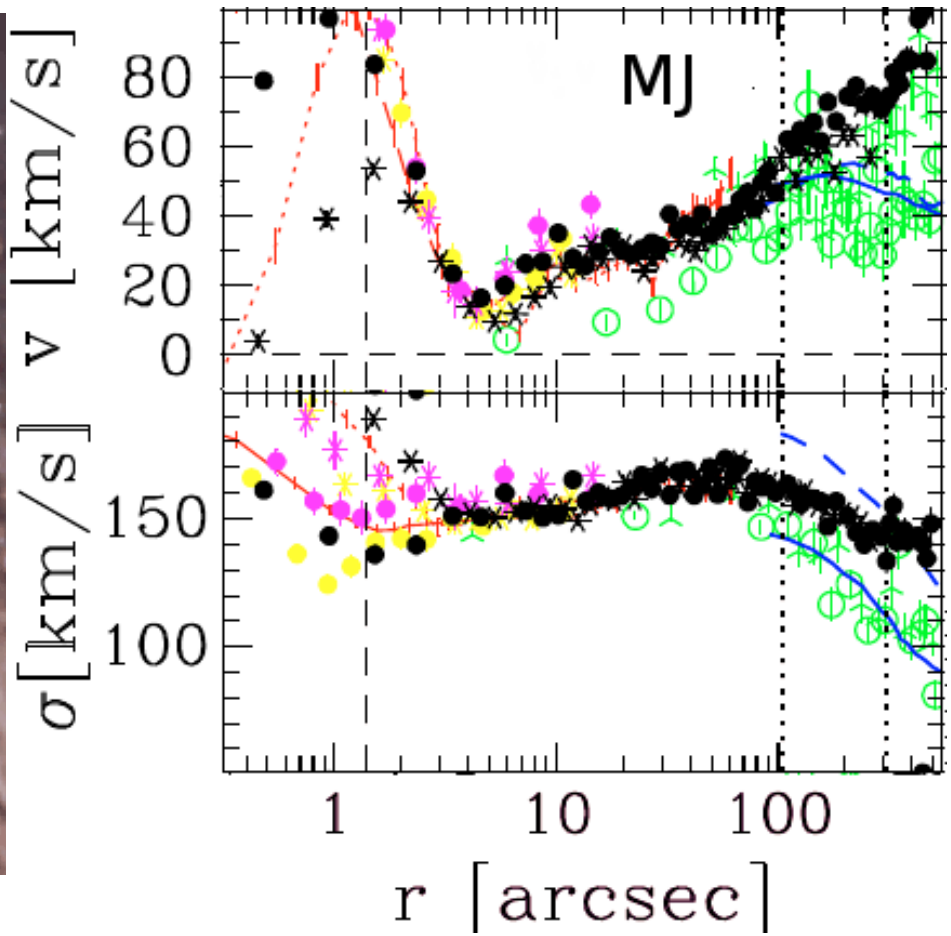
Introduction

- M31, the Andromeda Galaxy: nearest spiral galaxy to Milky Way
- $D = 0.78$ Mpc $\rightarrow$ 1 kpc = 4.4' = 264", 1' = 227 pc, 1"= 3.8 pc
- $M = 1.2 \cdot 10^{11} M_{\odot}$
- Starburst phase 8 billion years ago, since then star formation rate lower than in the Milky Way
- Approaching with 300 km/s, first encounter with Milky Way in 4 Gyr, final merger in 6 Gyr

Longslit spectroscopy by Saglia et. al 2010

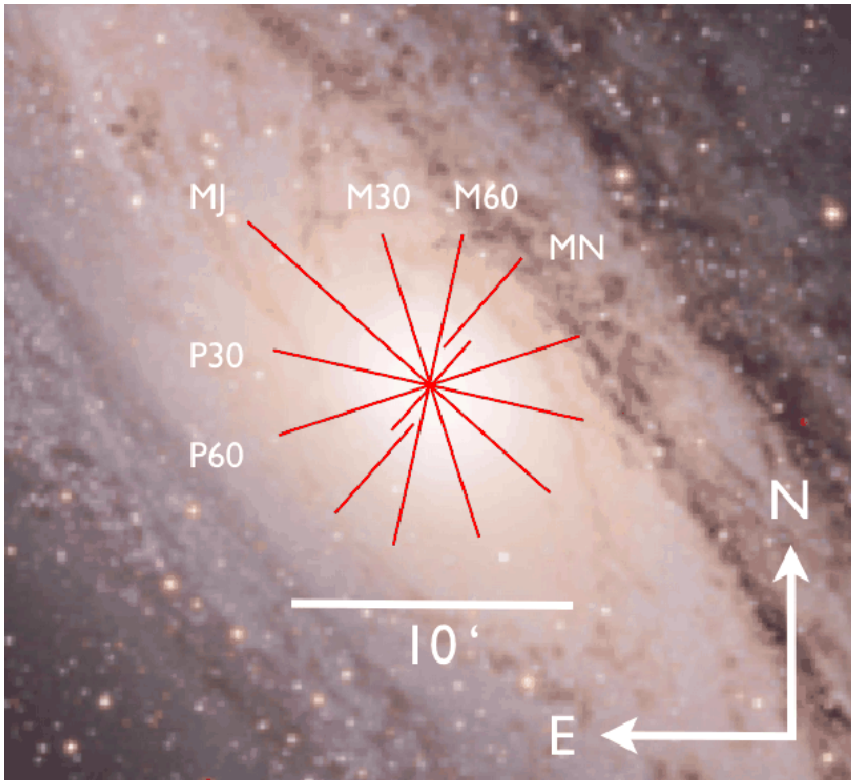


Coverage of longslit spectroscopy of Saglia et al., 2010

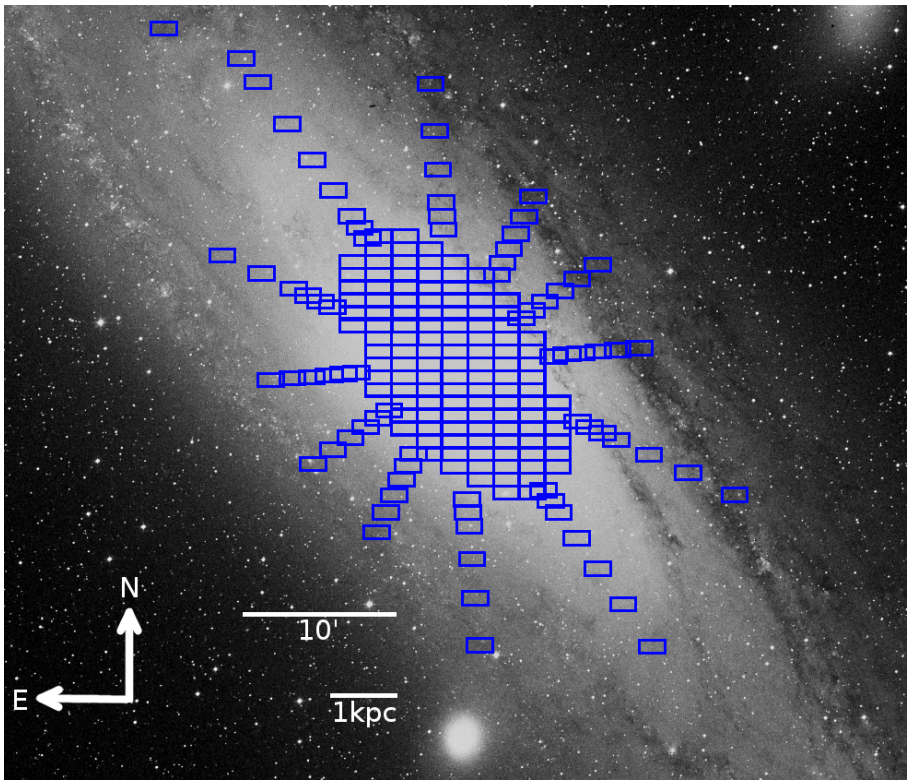


Major axis kinematics from Saglia et al., 2010

Longslit vs. IFU



Longslit coverage by Saglia et al., 2010



IFU coverage with VIRUS-W

VIRUS-W

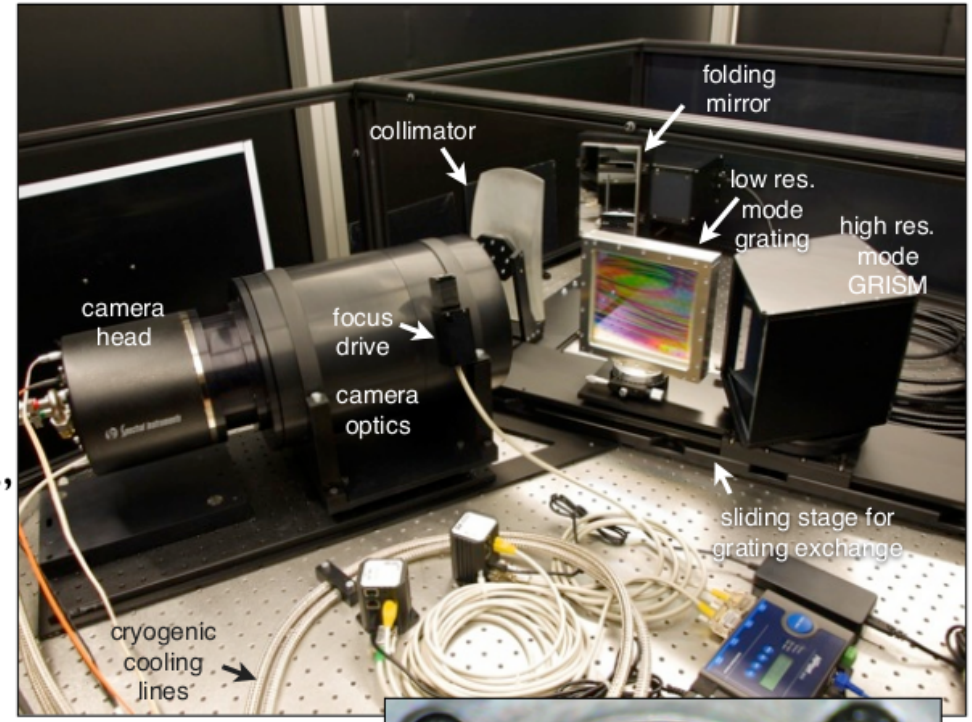
- Based on VIRUS for HETDEX
- Fiberfed IFU spectrograph
- Rect. field of view: 105“ x 55“
  =397 pc x 208 pc
- 267 fibers, fiberdiam. on sky 3.2”
  =12.1 pc
- two spectral resolutions:

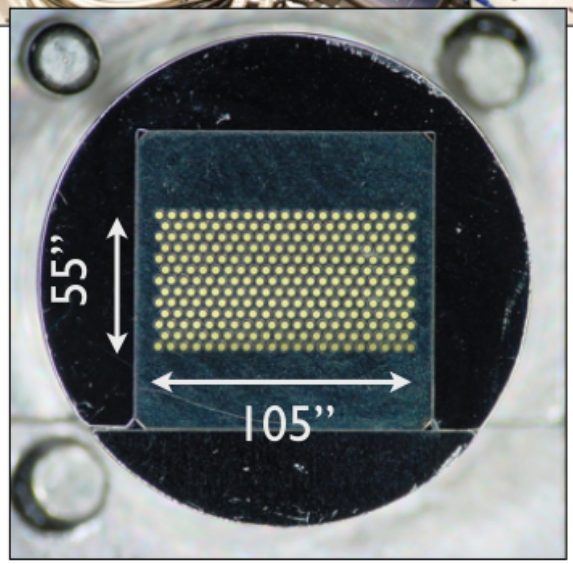
low res:

spectral coverage, nominal	4750 Å - 5600 Å
spectral coverage, actual	4340 Å - 6042 Å
resolution ($\Delta\lambda/\lambda$)	1700 to 3300 (depending on wavelength)
resolution (σ)	38 km/s to 75 km/s
linear dispersion	0.52 Å/px
grating	1900 ll/mm VPH grating

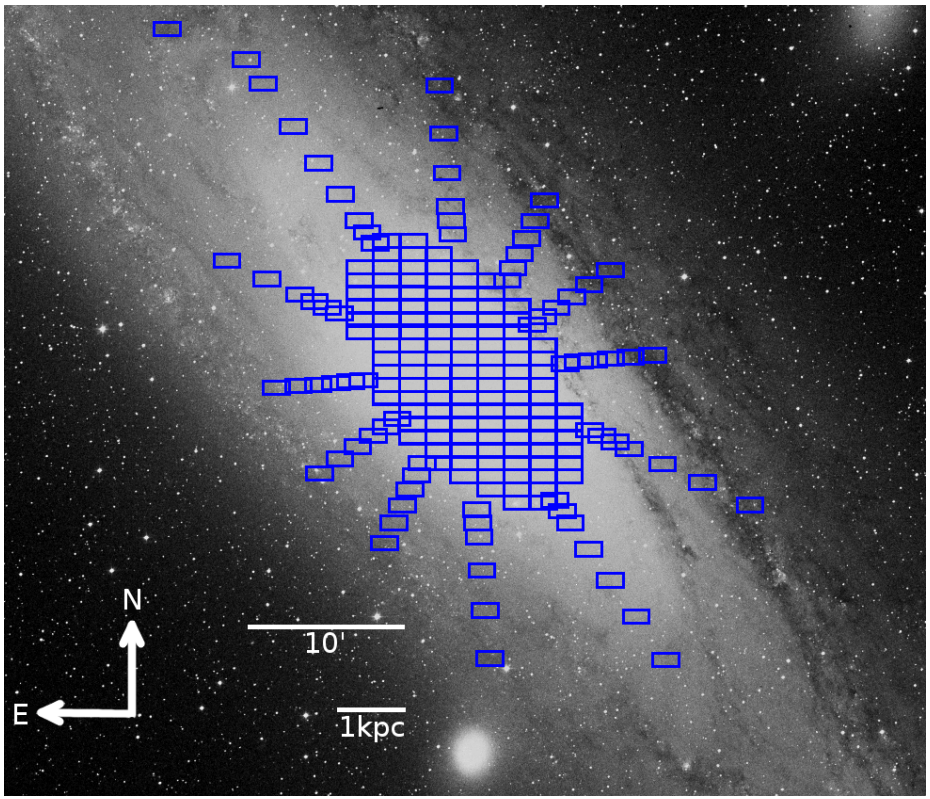
high res:

spectral coverage, nominal	4930 Å– 5445 Å
spectral coverage, actual	4850 Å– 5475 Å
resolution ($\Delta\lambda/\lambda$)	7900 to 9000 (depending on wavelength)
resolution (σ)	14 km/s to 16 km/s
linear dispersion	0.19 Å/px
grating	3300 ll/mm VPH grating sandwiched between two prisms





Observations

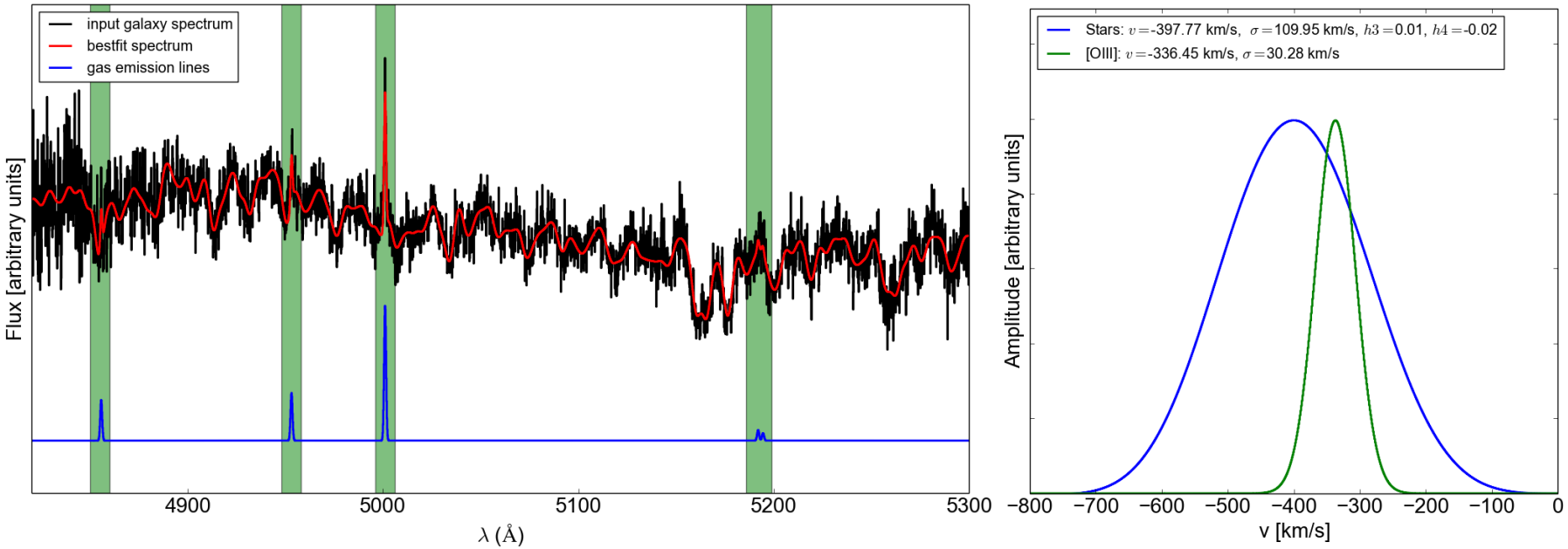


- 198 pointings observed in 15 nights
- Bulge covered completely
- Disk sampled along six directions, major axis covered out to 24'=5.45 kpc ($\approx 1\ R_d$)
- Each pointing observed for 10 minutes, intersected with 5 minutes sky

Data reduction and binning

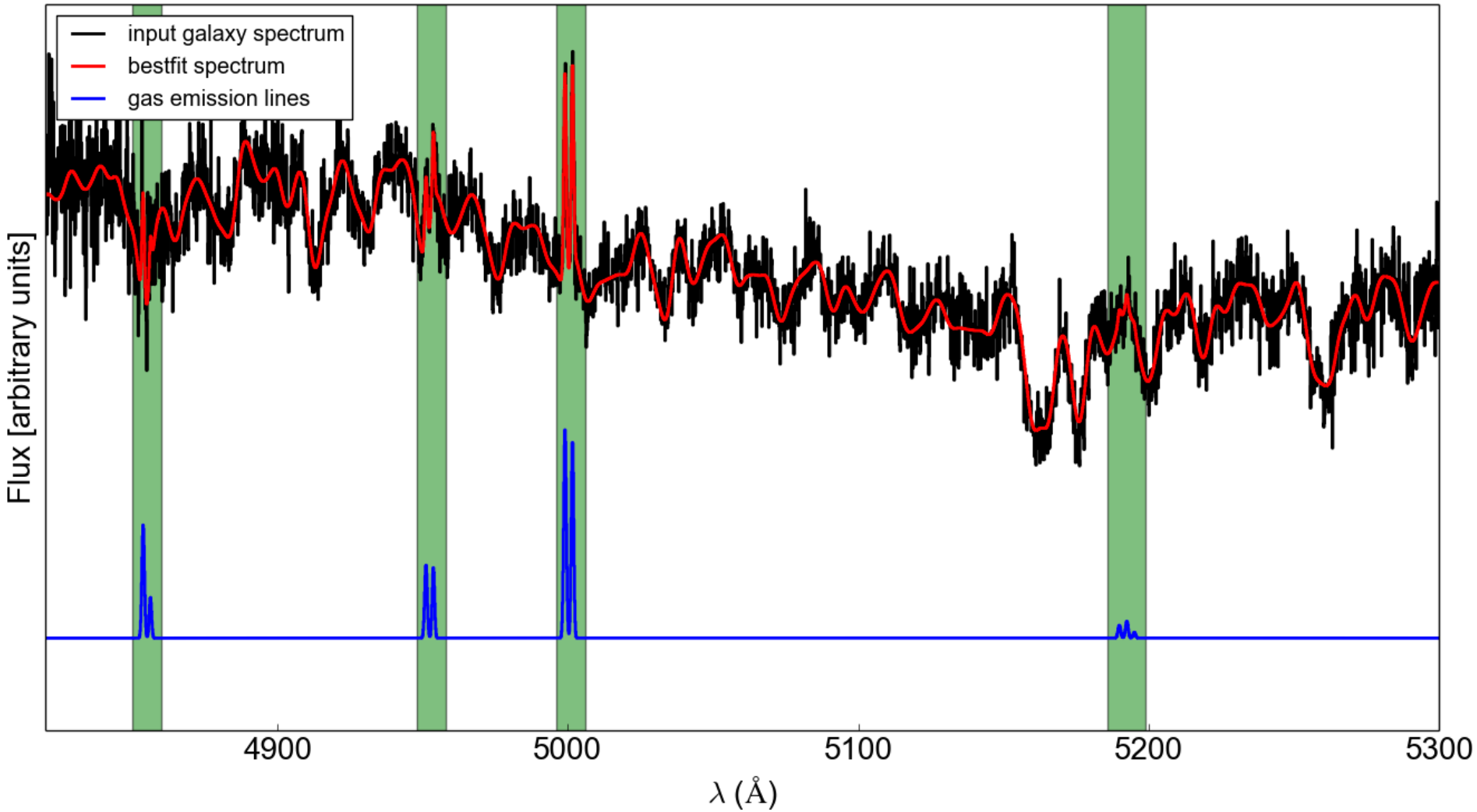
- Application of basic data reduction steps
- Voronoi binning of the spectra to get above a S/N value of 28
- Fitting the stellar kinematics with pPXF (Cappellari & Emsellem, 2004) and the gas kinematics with GANDALF (Sarzi et al. 2006)

Example of kinematical fit

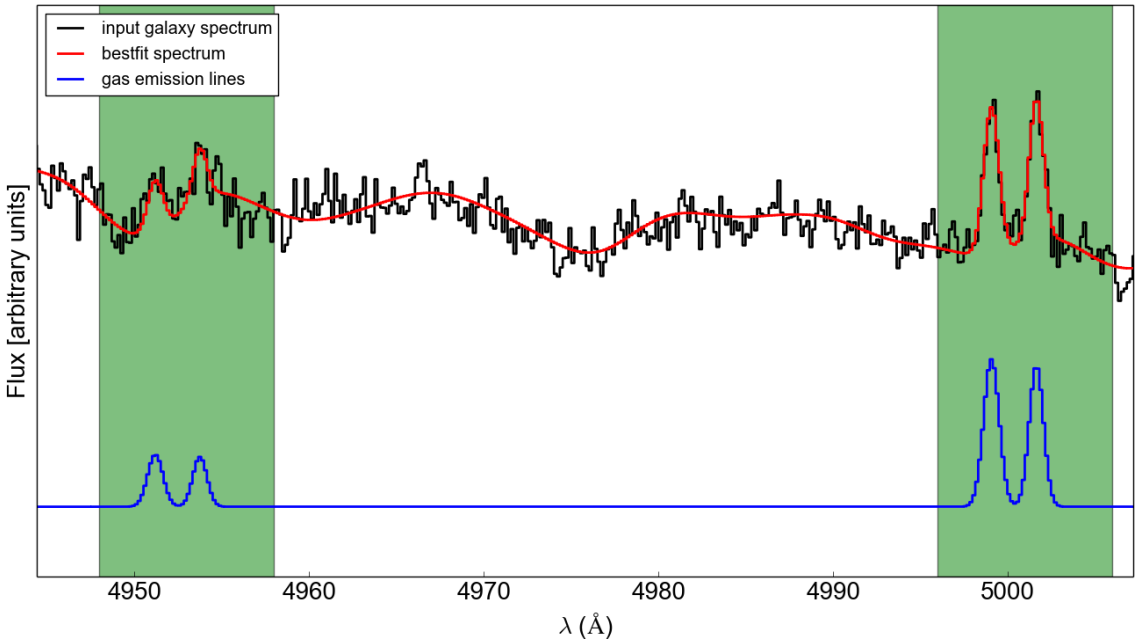


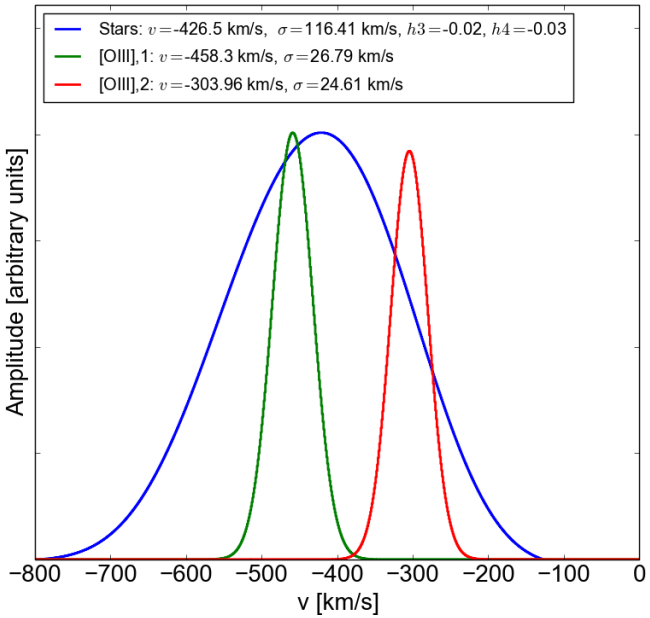
- Left: Fit to spectrum 7301
  Stellar continuum and emission lines Hβ (4861 Å), the [OIII] doublet (4959 Å, 5007 Å) and the [NI] doublet (5197 Å, 5200 Å)
- Right: Corresponding LOSVDs for stars (blue) and [OIII] 5007 Å (green)

Double gas lines



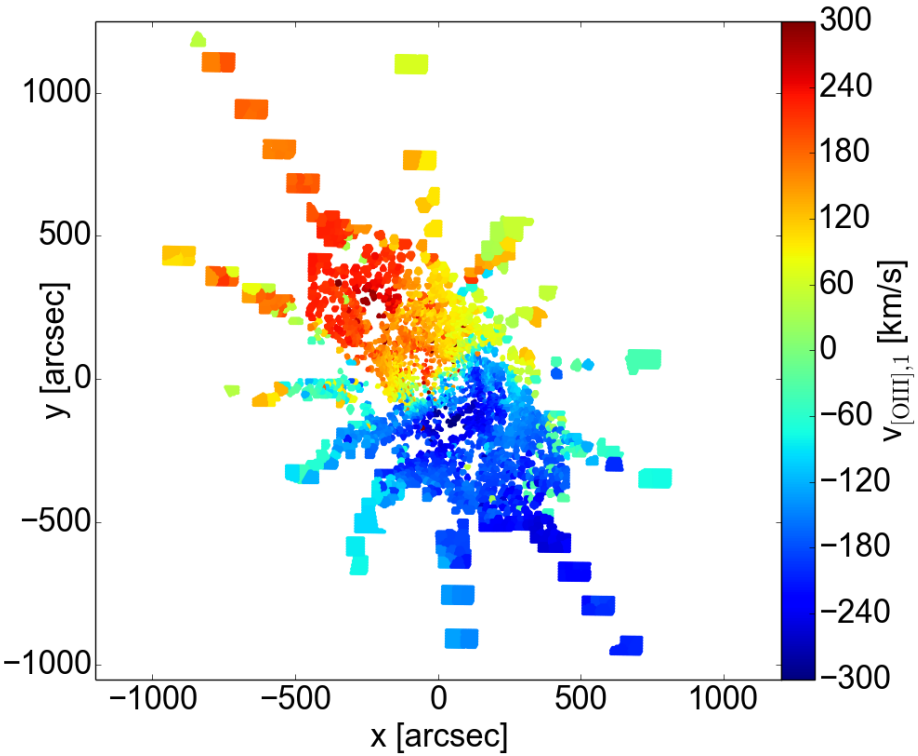
Zoom onto [OIII]

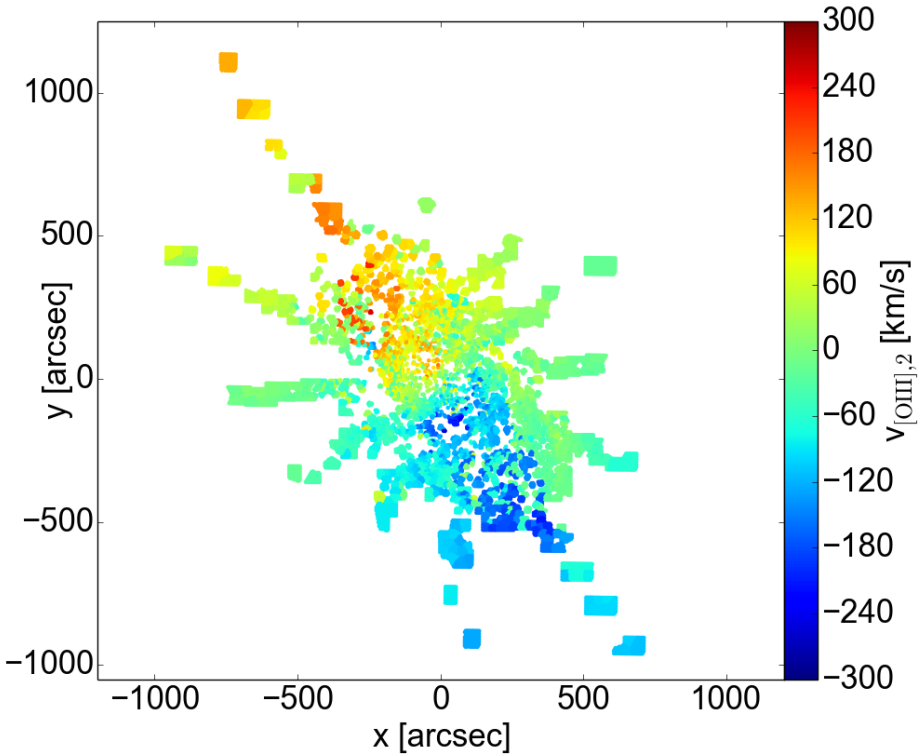




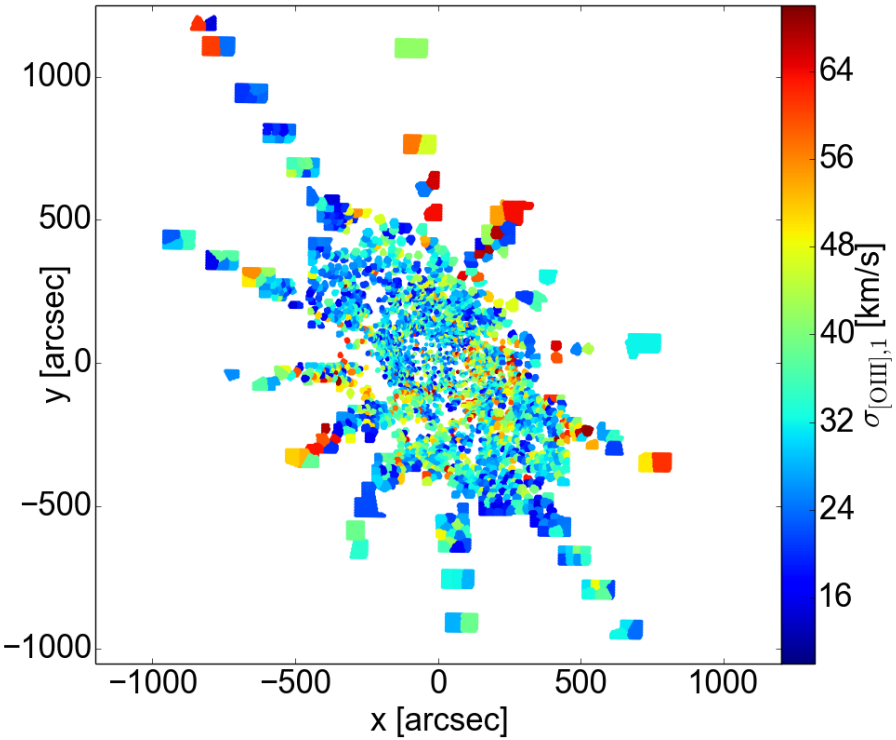
- Spectrum 7232: Clearly two different gas components
- [*OIII*] line at 5007 Å:
  - $\lambda_1 = 4999.13$ Å$\rightarrow v = -458$ km/s
  - $\lambda_2 = 5002.92$ Å$\rightarrow v = -304$ km/s, at systemic velocity of M31
  - $\Delta v = 154$ km/s

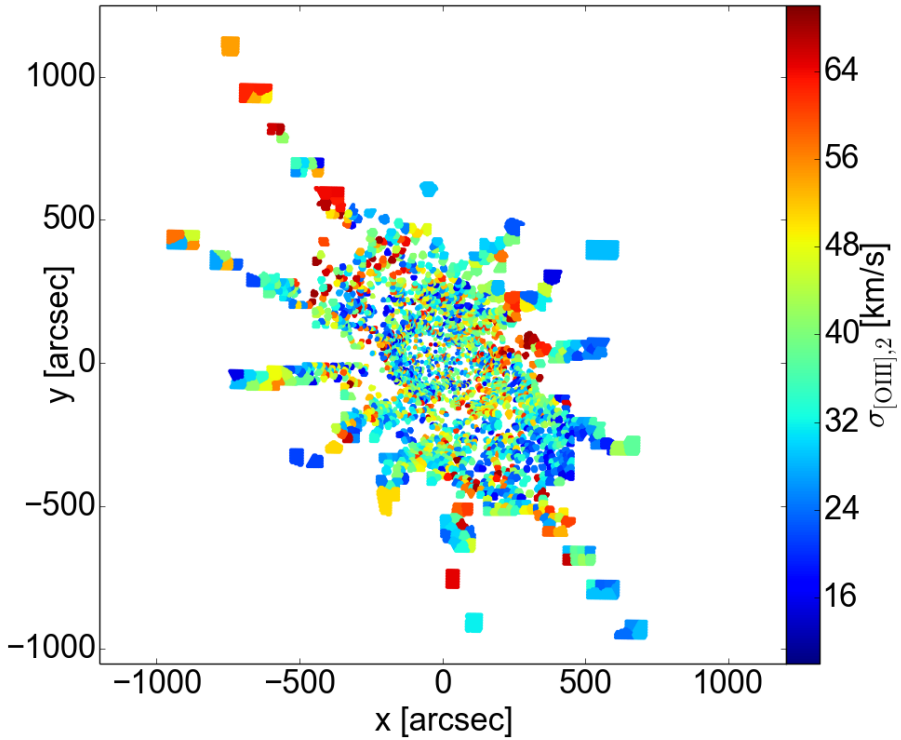
[OIII]: Velocity



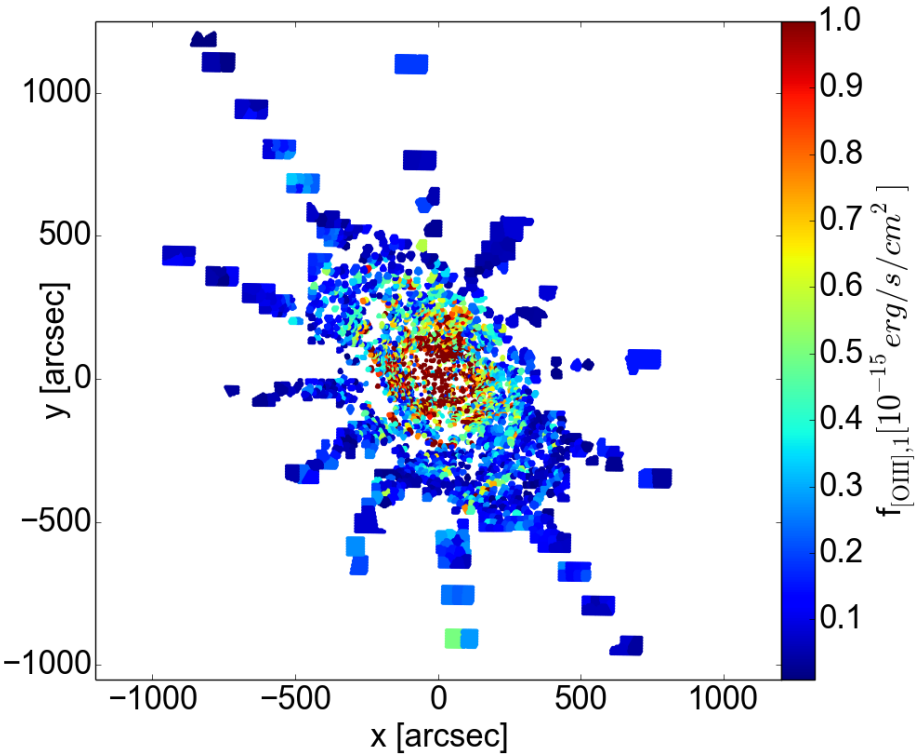


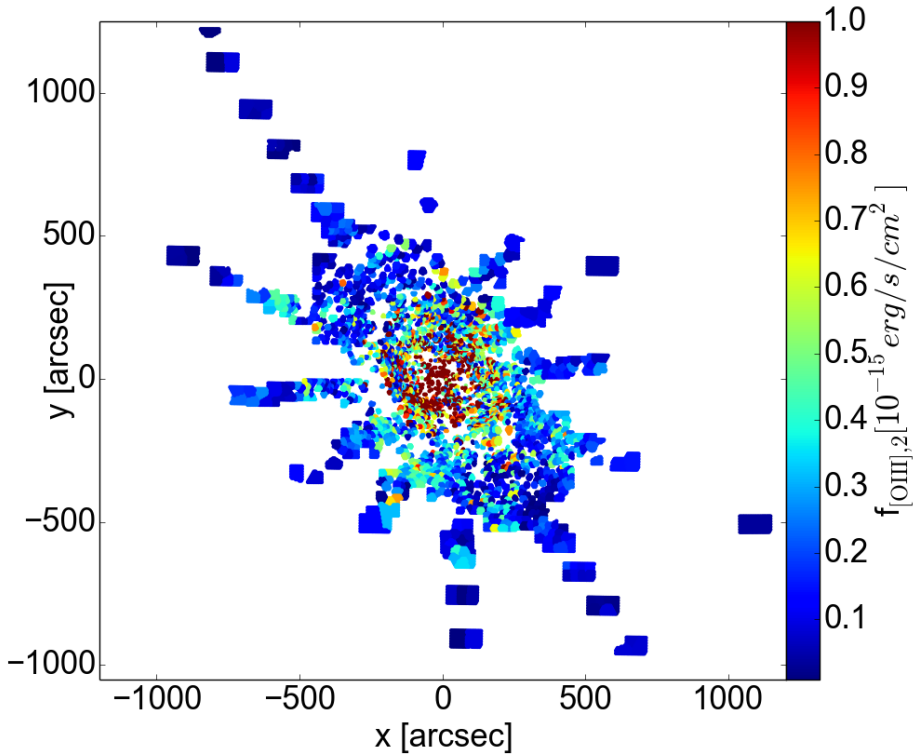
[OIII]: Velocity dispersion



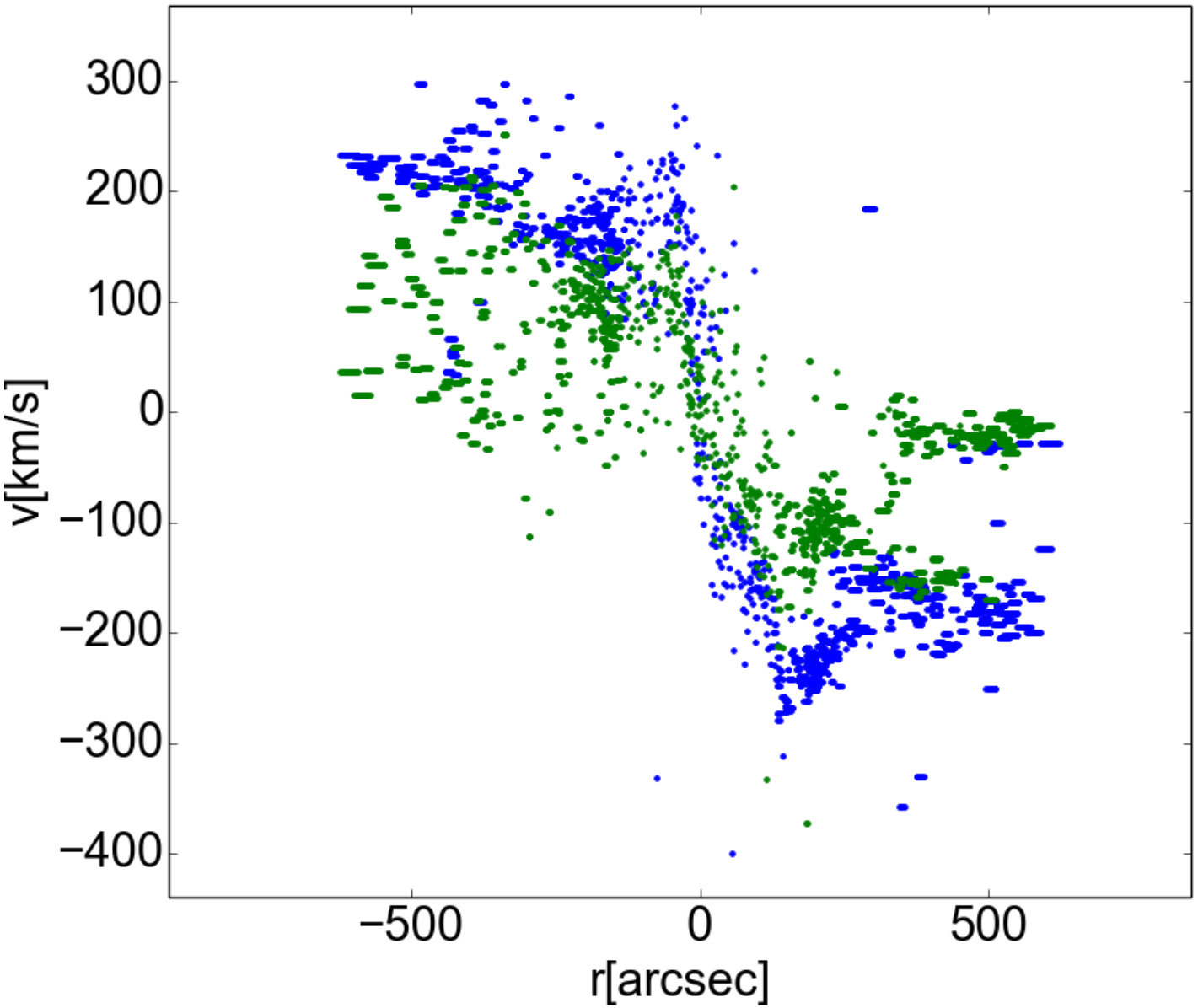


[OIII]: Flux

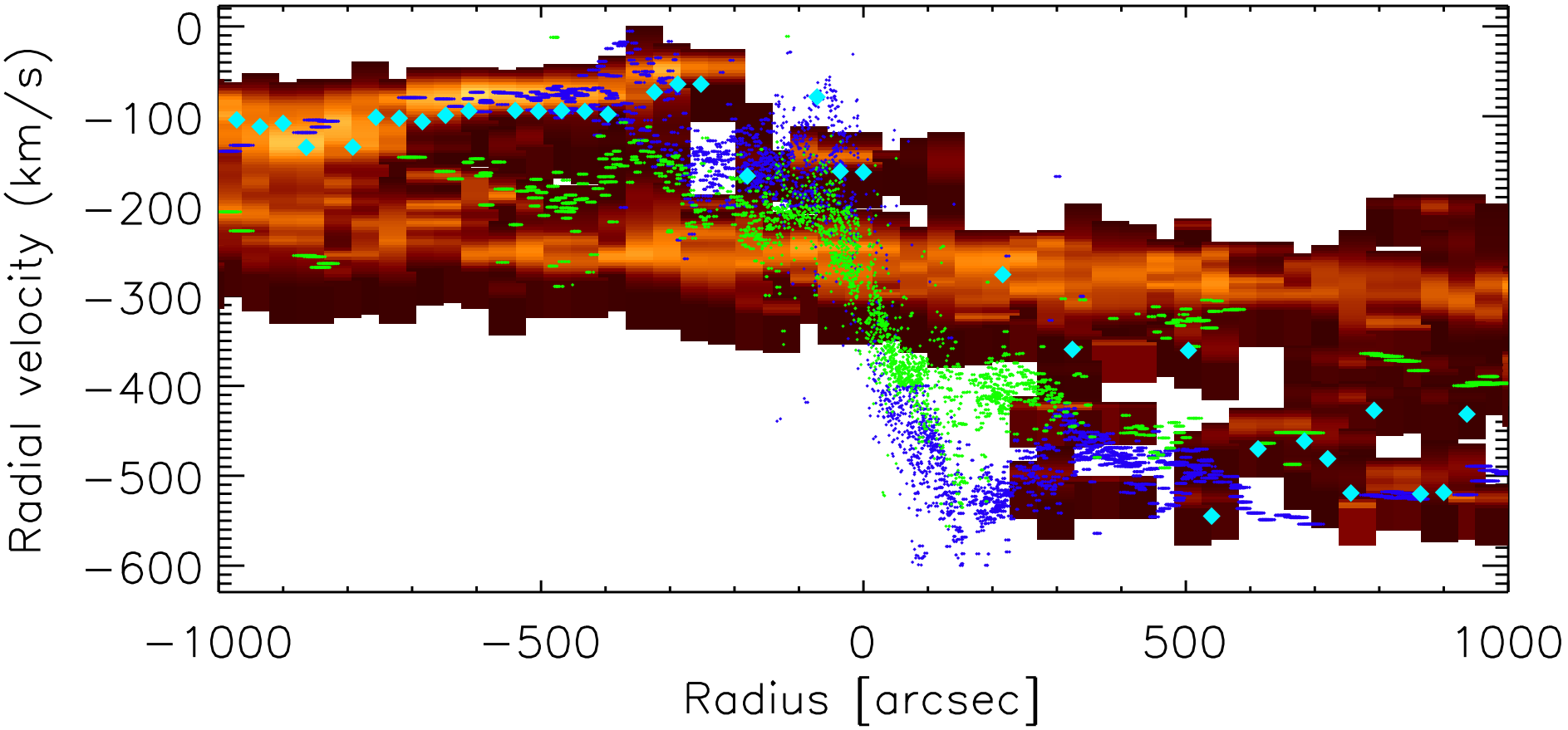

1000
500
0
−500
−1000
y [arcsec]
−1000
−500
0
500
1000
x [arcsec]
1.0
0.9
0.8
0.7
0.6
0.5
0.4
0.3
0.2
0.1
$f_{[OIII],1}[10^{-15} erg/s/cm^2]$


1000
500
0
−500
−1000
y [arcsec]
−1000
−500
0
500
1000
x [arcsec]
1.0
0.9
0.8
0.7
0.6
0.5
0.4
0.3
0.2
0.1
$f_{[OIII],2}[10^{-15} erg/s/cm^2]$

Cut along bulge major axis (PA = 48°)

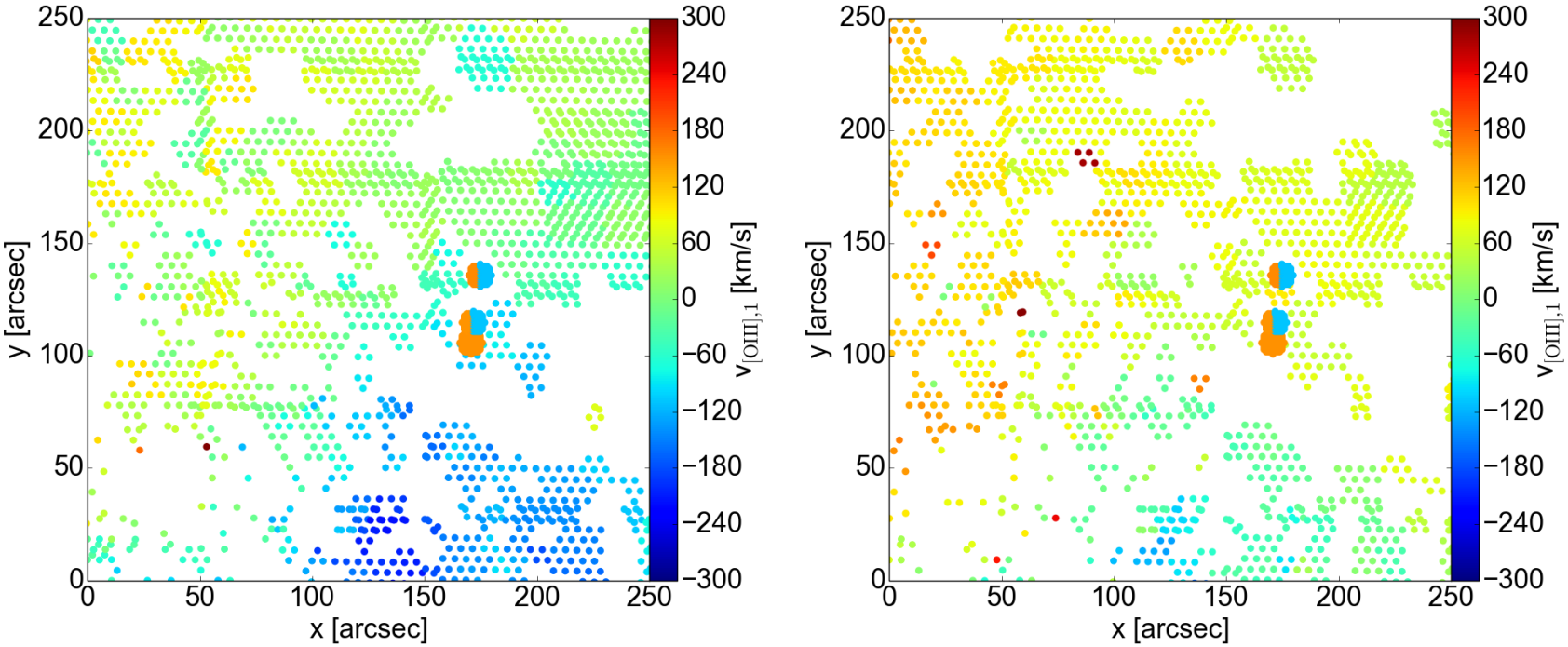


Comparison with HI observations



- Cut along the disk major axis (PA=38°)
- Blue and green: two [OIII] components
- Orange: HI observations by Chemin et al. 2009
- Blue diamonds: main HI component

Comparison with CO observations



- Three CO pointings by Melchior & Combes, 2011, two of which show double lines overlaid over the two [OIII] components
- For one component, the velocities correspond (v=-60 km/s), for the other CO velocities, they don't.

Summary

- Observations of kinematics of M31 with IFU VIRUS-W in unprecedented detail
- Gas kinematics complicated, double peaks on emission lines, corresponding to multiple components
- Arm in southeast at very low velocities
- Counter-rotating component in the northwest
- Probably warp in gas disk $\rightarrow$ low velocities from outer disk projected into inner disk
- Fast [OIII] component similar to main HI component
- First CO component comparable to first [OIII] component, second one too high

References

- Opitsch et al., in prep.
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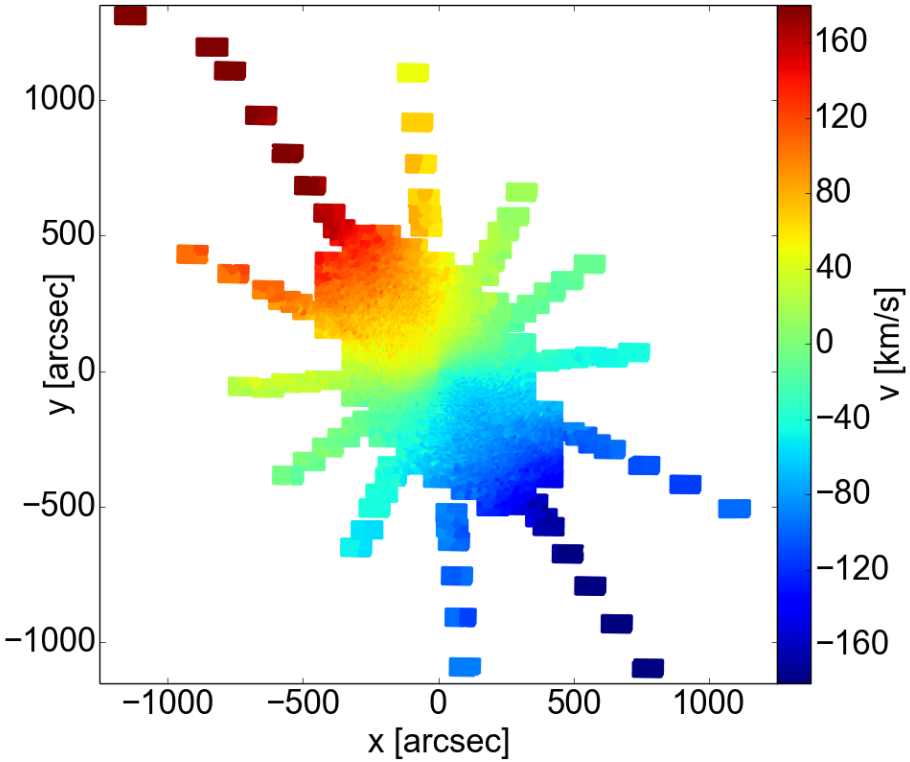
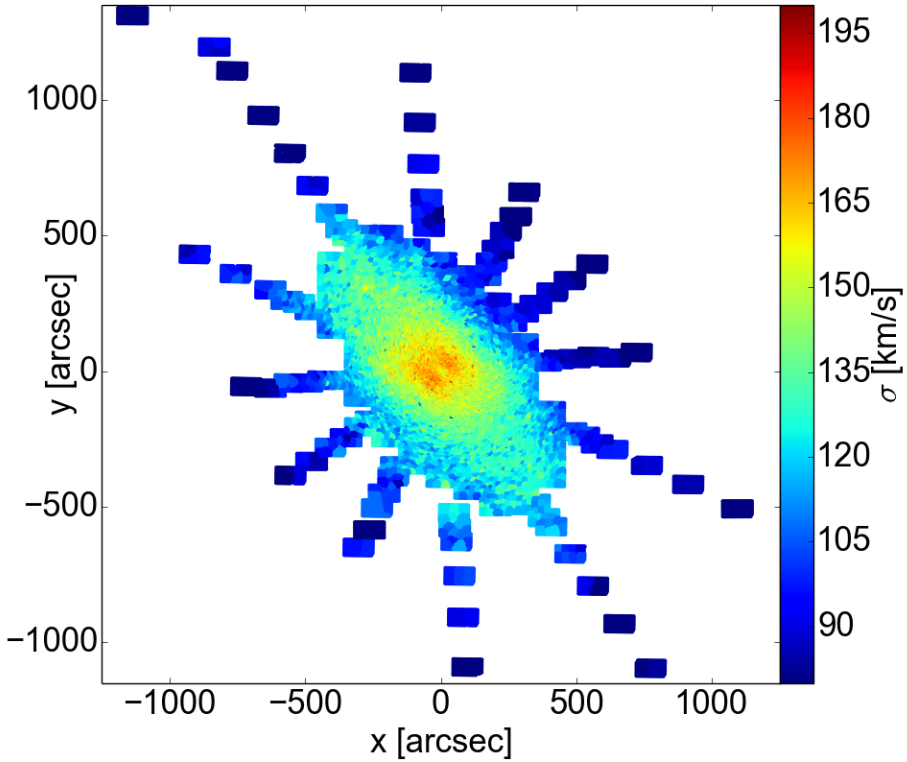
- M. Cappellari & Y. Copin, 2003, MNRAS, 342, 345
- M. Cappellari & E. Emsellem, 2004, PASP, 116, 138
- S. Courteau et al., 2011, ApJ, 739, 20
- T.J. Davidge et al., 2012, ApJ, 751, 74
- N.W. Evans & M.I. Wilkinson, 2000, MNRAS, 316, 929
- Gerhard 1986, MNRAS, 219, 373
- C.-H. Lee et al., 2012, AJ, 143,89
- Melchior & Combes, 2011, A&A, 536, A52
- F. de Lorenzi et al., 2007, MNRAS, 376, 71
- R. Saglia et al., 2010, A&A, 509, A61
- M. Sarzi et al., 2006, MNRAS, 366, 1151
- A. Riffeser et al., 2006, ApJS, 263, 225
- M. Smith et al., 2012, ApJ, 756, 40
- R. van der Marel et al., 2012, ApJ, 753, 9
- F. Vilardell et al., 2006, A&A, 459, 321

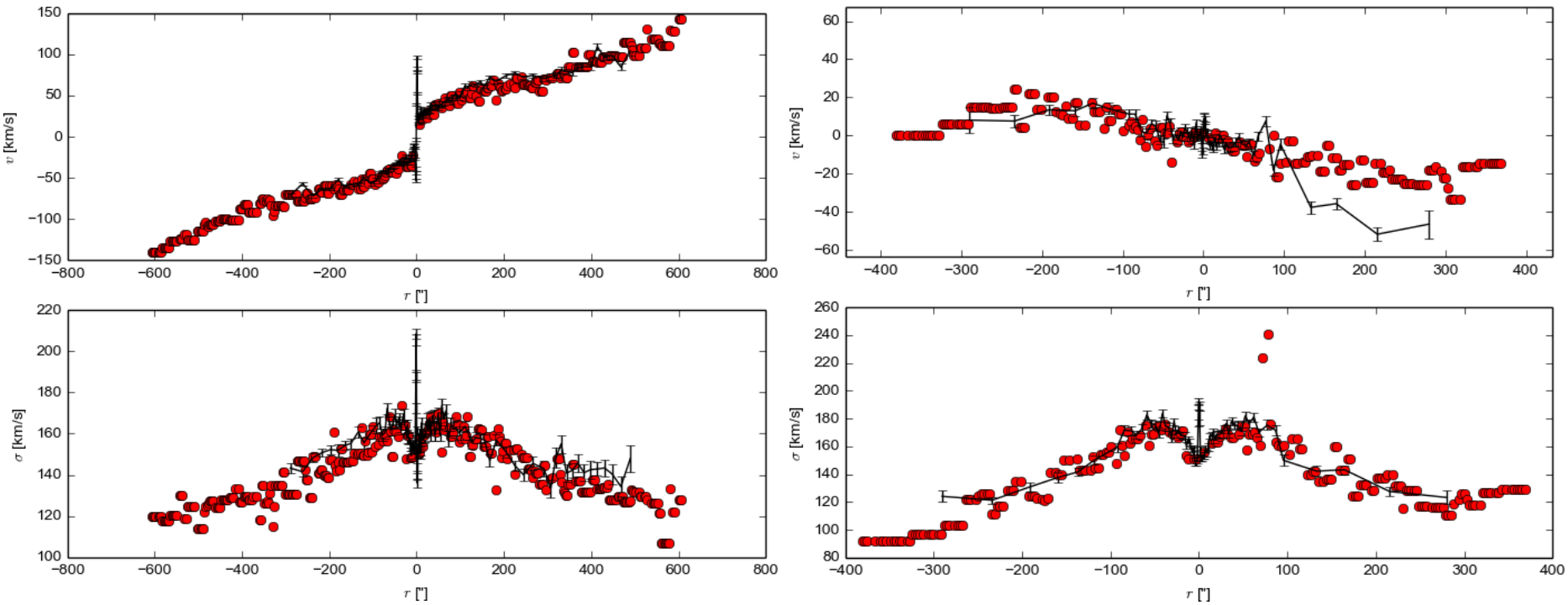
Stellar velocity and velocity dispersion





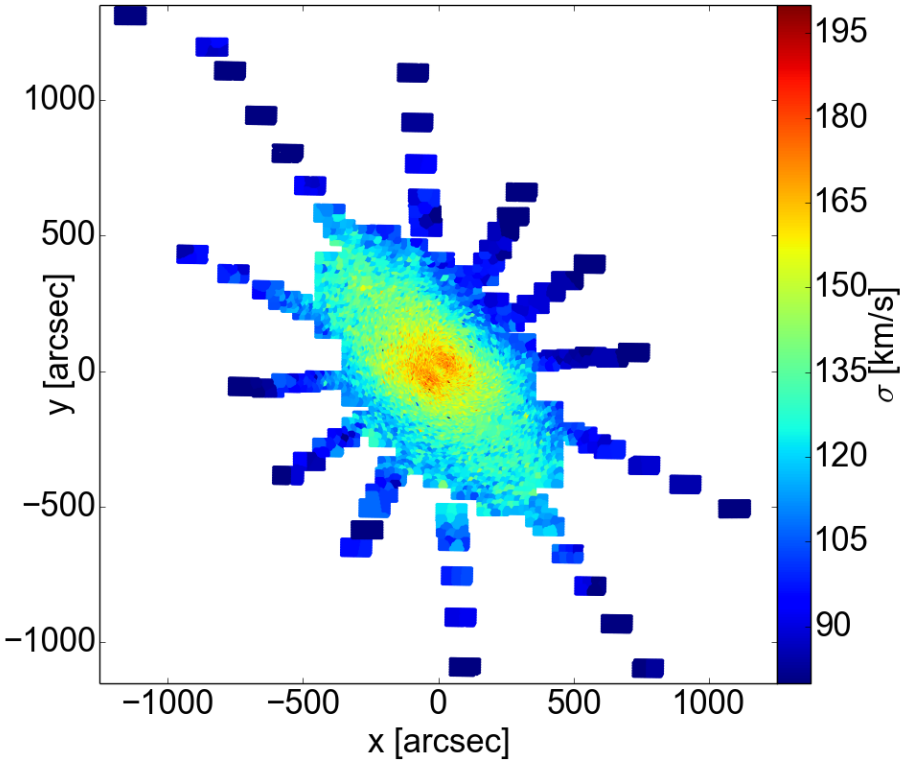
- No large asymmetry in velocity
- $\sigma_{stars} > 60 \frac{km}{s} \rightarrow$ Disk not dynamically cold

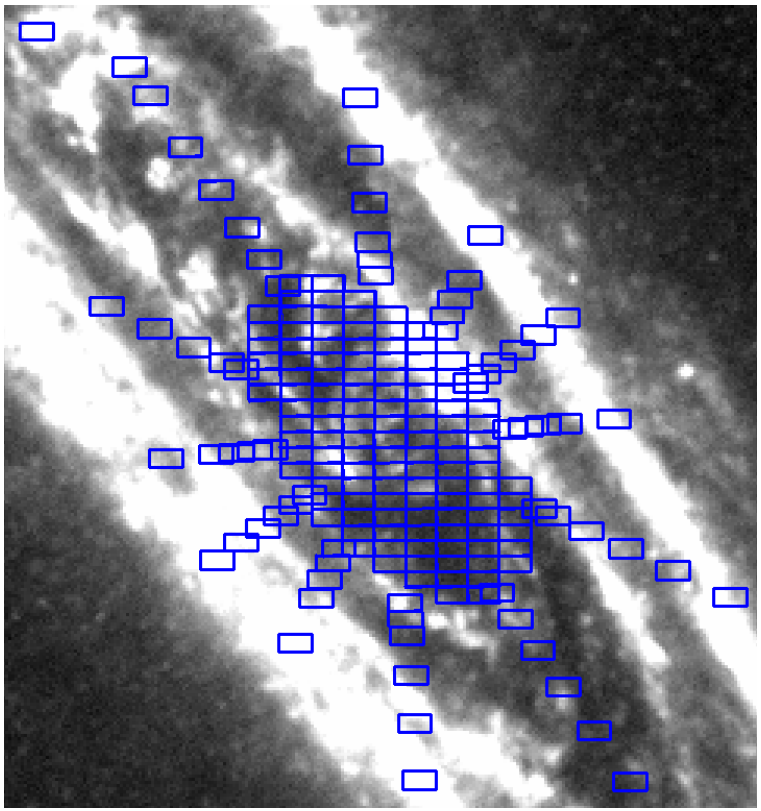
Comparison with Saglia 2010



- Left: cut along major axis, red: cut through VIRUS-W data, black: data from Saglia et al., 2010
- Right: cut along minor axis

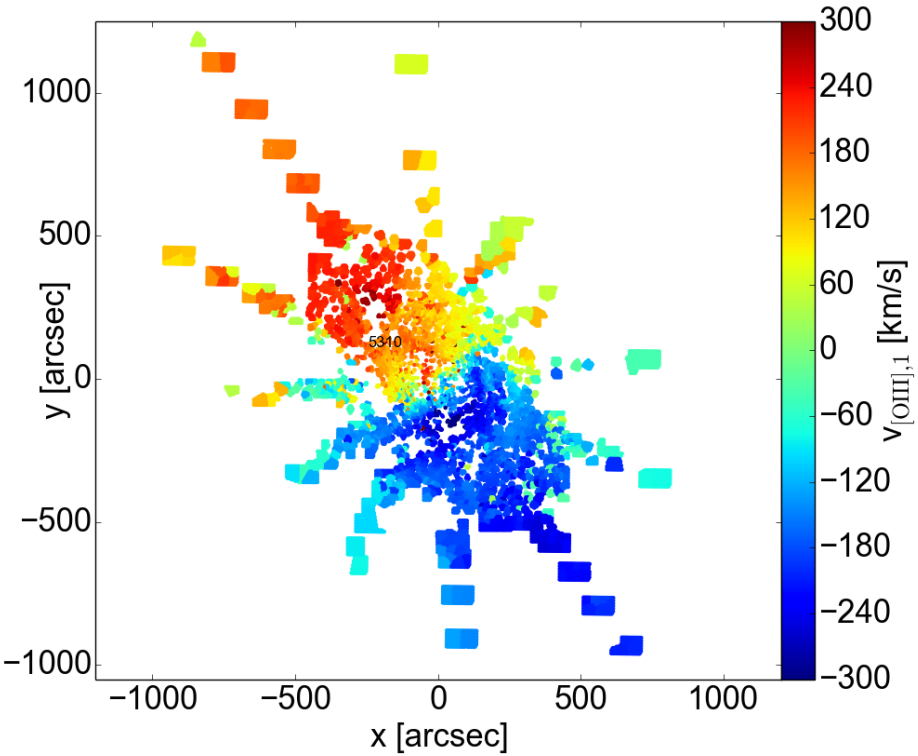
Comparison to Herschel data

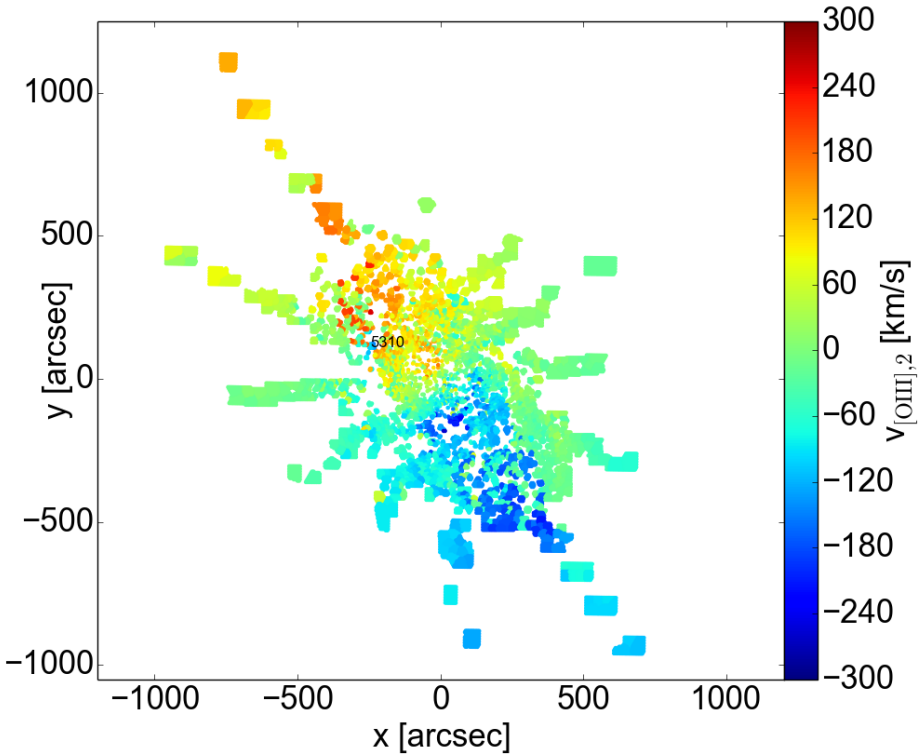




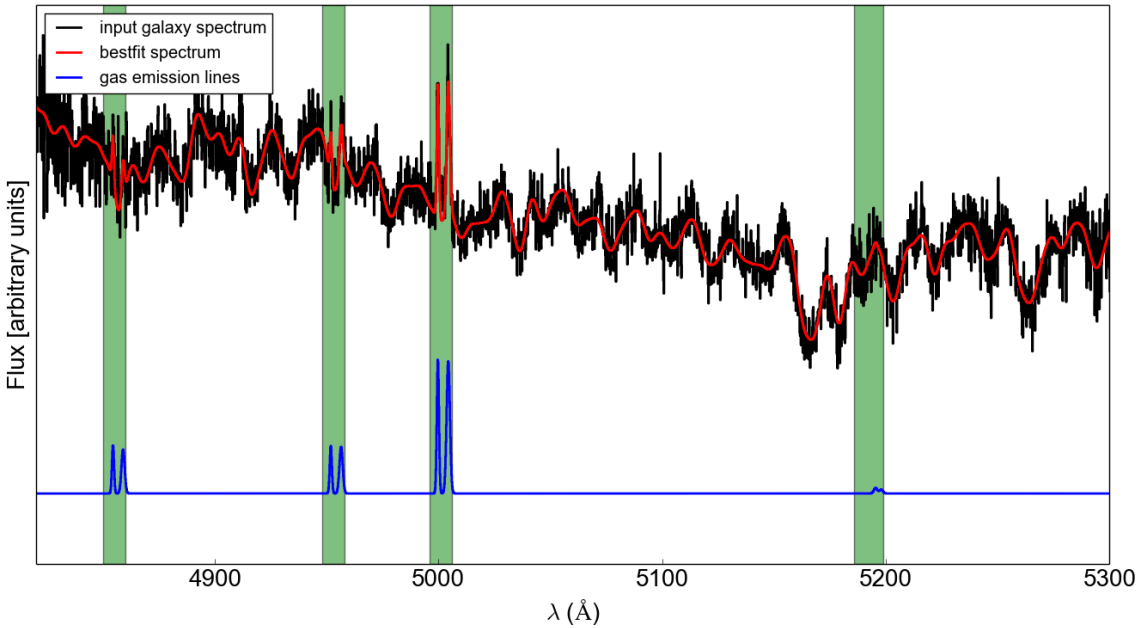
- Low stellar velocity dispersion in the northwest corresponding to dust lane.

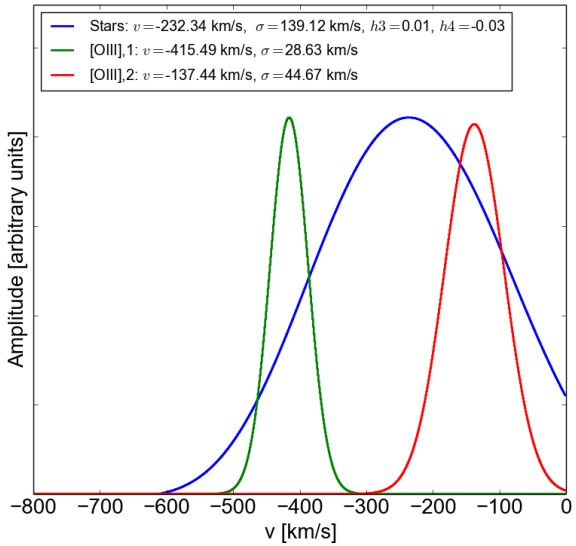
Bin 5310


5310
1000
500
0
−500
−1000
y [arcsec]
−1000
−500
0
500
1000
x [arcsec]
300
240
180
120
60
0
−60
−120
−180
−240
−300
$v_{[OIII],1}$ [km/s]


5310
1000
500
0
−500
−1000
y [arcsec]
−1000
−500
0
500
1000
x [arcsec]
300
240
180
120
60
0
−60
−120
−180
−240
−300
$v_{[OIII],2}$ [km/s]

Bin 5310


input galaxy spectrum
bestfit spectrum
gas emission lines
Flux [arbitrary units]
4900
5000
5100
5200
5300
λ (Å)


Stars: v=-232.34 km/s, σ=139.12 km/s, h3=0.01, h4=-0.03
[OIII],1: v=-415.49 km/s, σ=28.63 km/s
[OIII],2: v=-137.44 km/s, σ=44.67 km/s
Amplitude [arbitrary units]
−800
−700
−600
−500
−400
−300
−200
−100
0
v [km/s]