An end-to-end X-IFU simulator: constraints on ICM kinematics

Mauro Roncarelli

DIPARTIMENTO FISICA E ASTRONOMIA - DIFA

INAF Osservatorio Astronomico di Bologna
Istituto Nazionale di Astrofisica

Stefano Ettori (INAF-OABO)

Massimo Gaspari (Princeton Univ.)

Fabrizio Brighenti (UNIBO-DIFA)

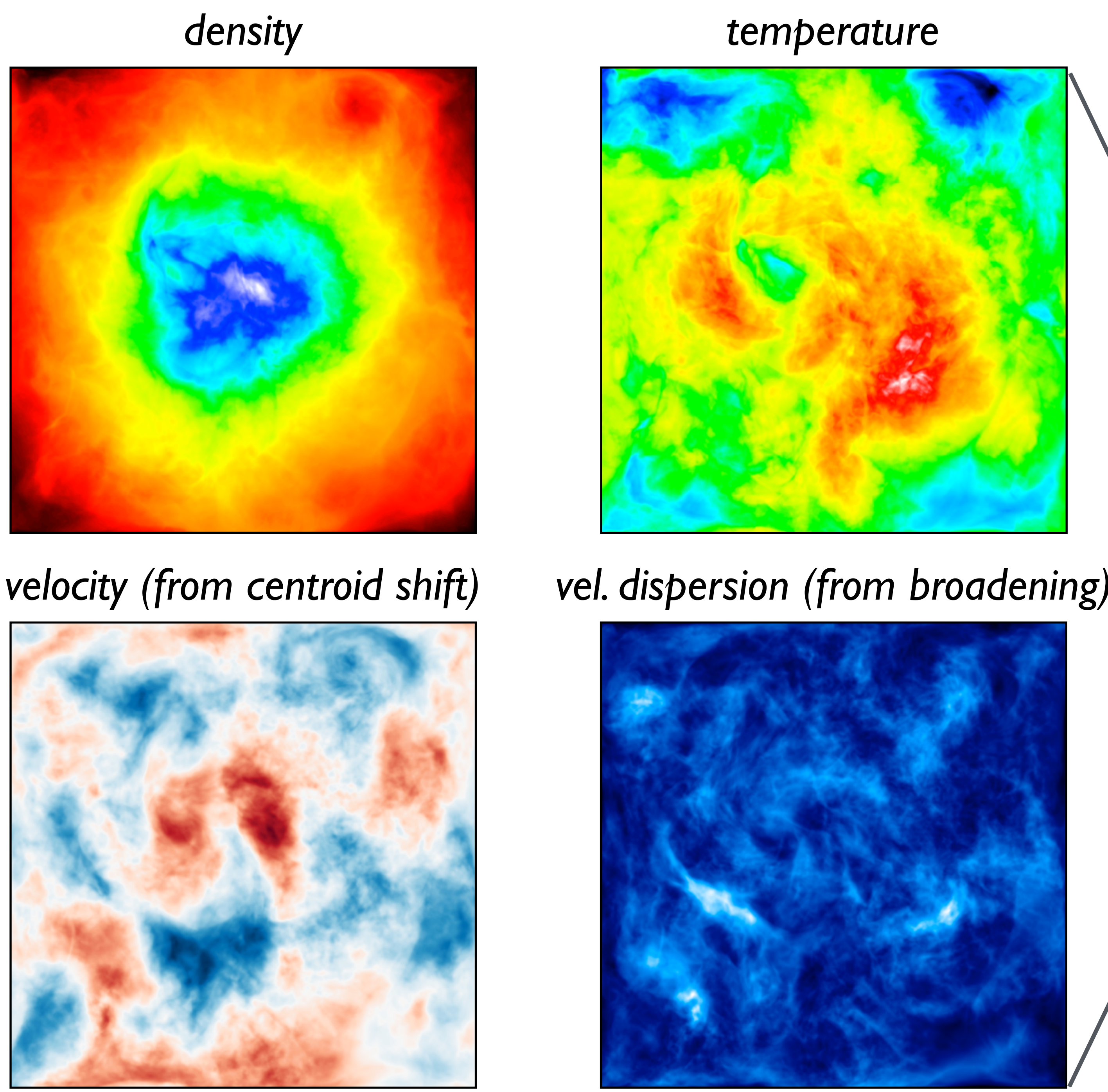
The Athena X-ray Integrated Field Unit (X-IFU)

Parameters	Requirements
Energy range	0.2-12 keV
Energy resolution: E < 7 keV	2.5 eV (249 μm pitch)
Energy resolution: E > 7 keV	E/dE = 2800
Field of View	5' (diameter) (3840 TES)
Effective area @ 0.3 keV	1500 cm^2
Effective area @ 1.0 keV	15000 cm^2
Effective area @ 7.0 keV	1600 cm^2
Gain error (RMS)	0.4 eV
Count rate capability - nominal bright sources	1 mCrab (>80% high-resolution events)
Count rate capability - brightest sources	1 Crab (>30% throughput)
Time resolution	10 μs
Non X-ray background (2-10 keV)	< 5 10^{-3} counts/s/cm^2/keV (80% of the time)

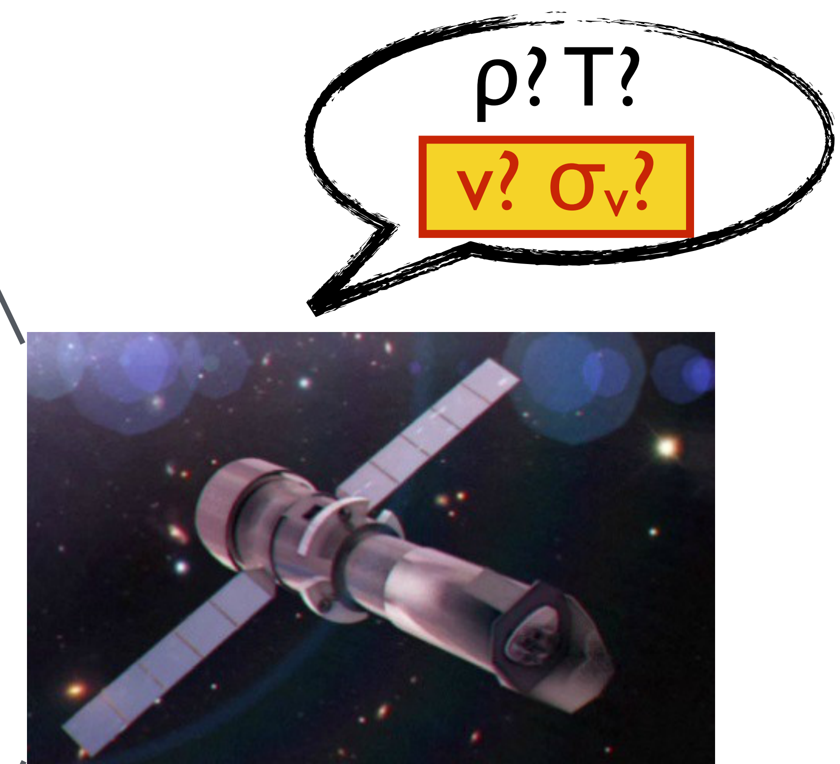
ang. res.
~5 arcsec

High-resolution spectroscopical imaging will require the definition of a new approach for X-ray data analysis

How well can X-IFU measure the ICM quantities in a realistic (inhomogeneous) scenario?



Simulated cluster by Gaspari & Churazov (2013)



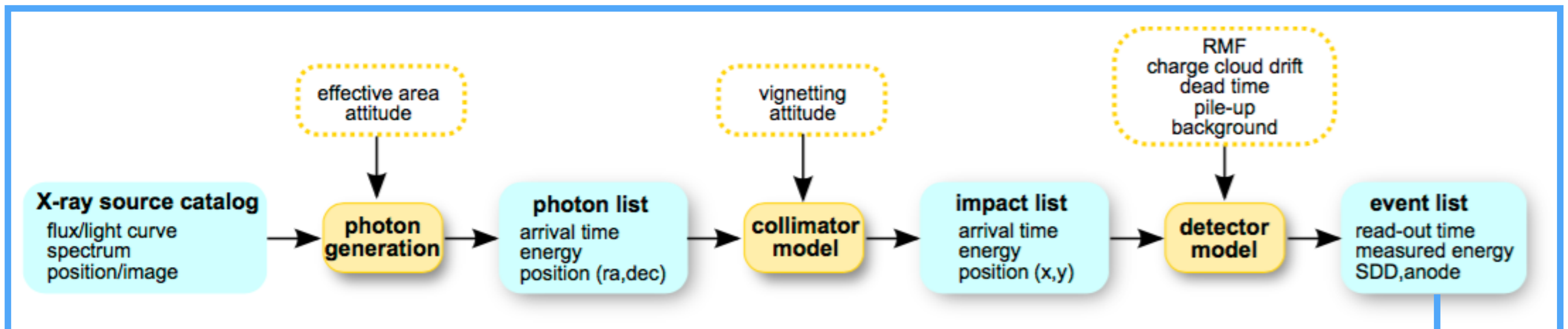
How well can we reconstruct v and σ_v? Will we be able to map them?

The SIXTE simulation package

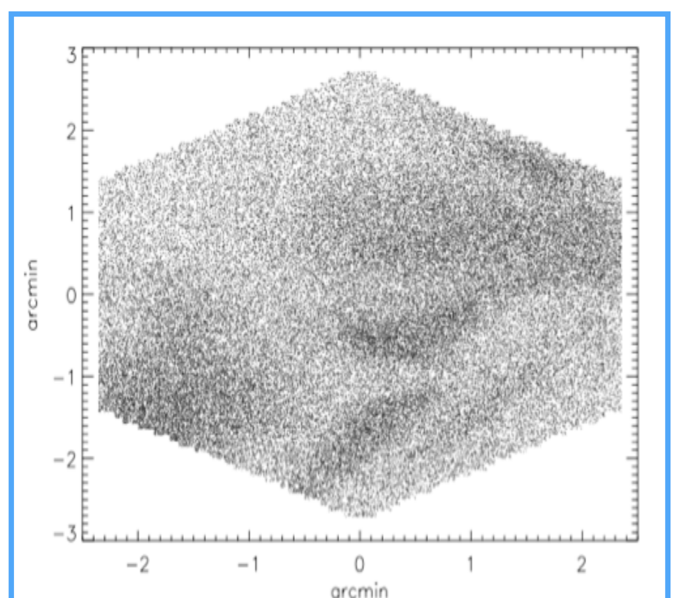
(C. Schmid, T. Brand, T. Dauser, P. Peille, J. Wilms)

SIXTE is a flexible simulator of X-ray detectors that computes mock photon lists from a set of generic input "sources"

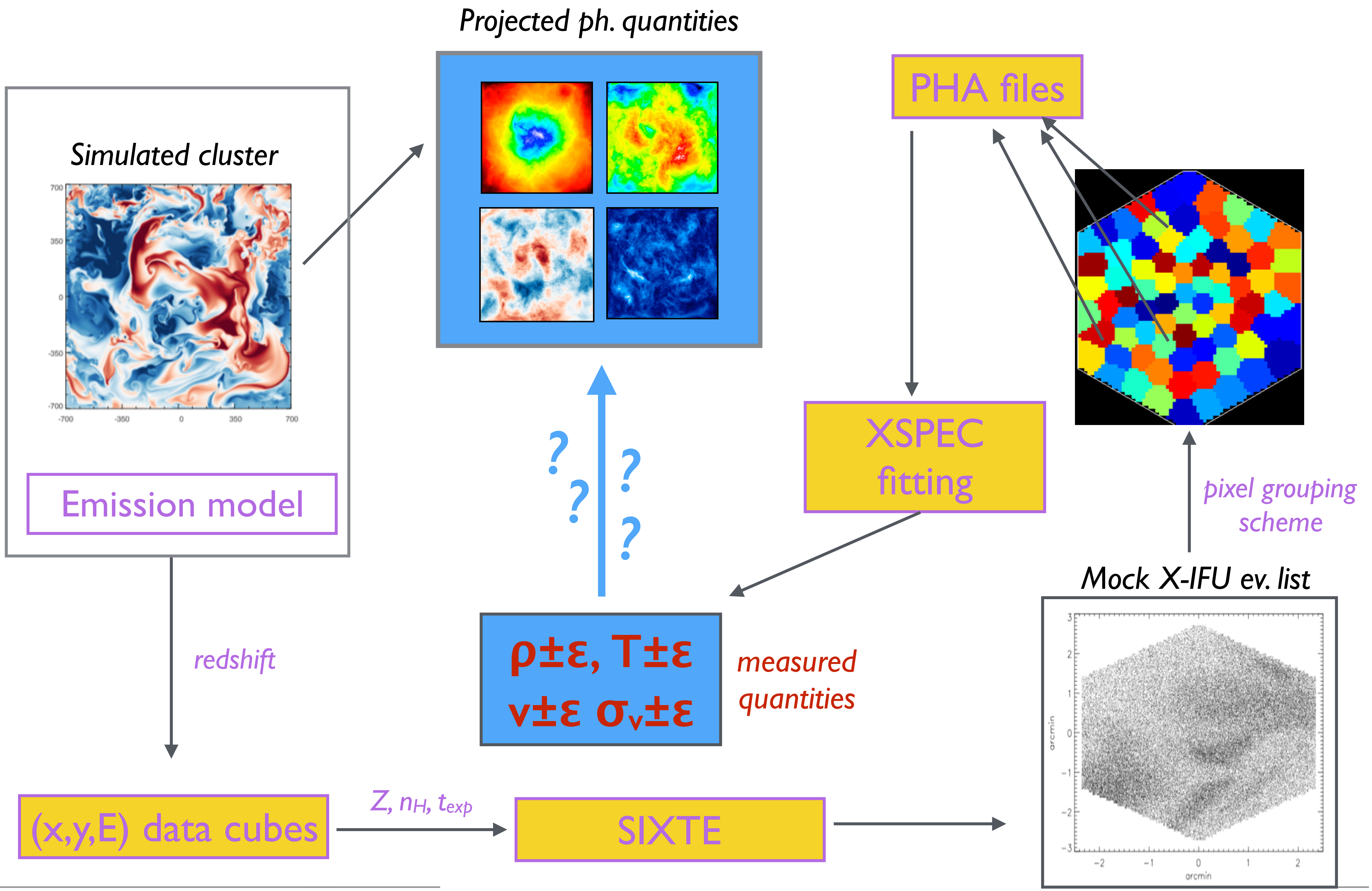
- Telescope model: pointing, ARF, vignetting, PSF
- Detector model: pileup, crosstalk, instrumental bkg.



Mock X-IFU ev. list

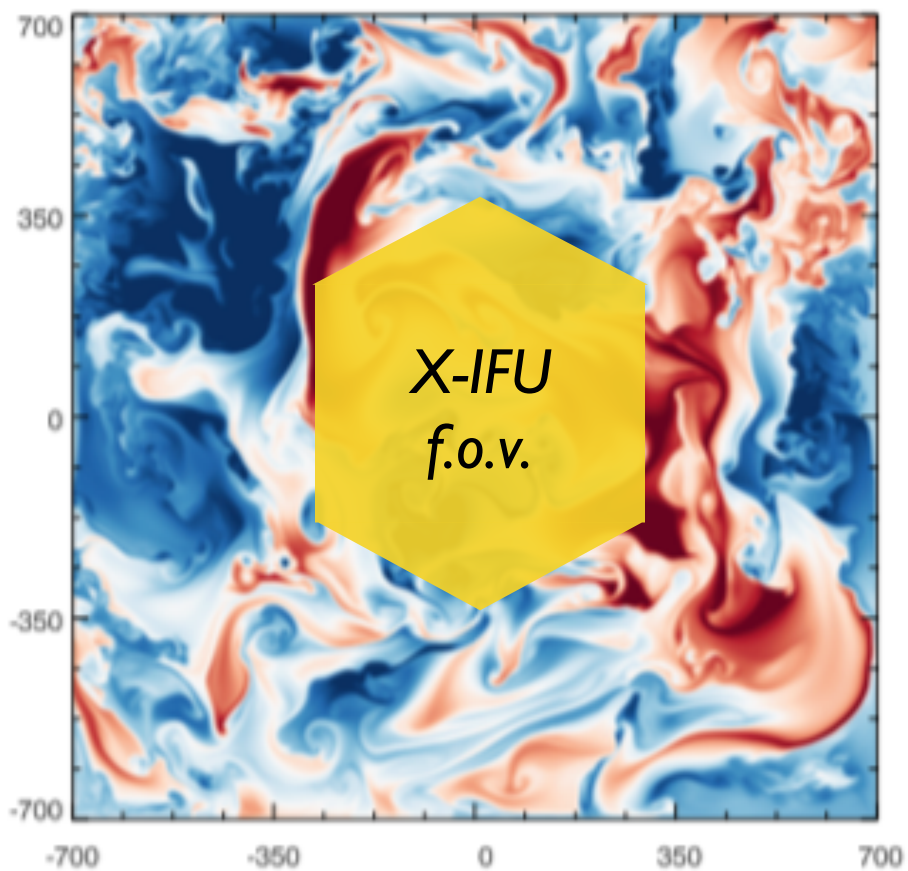


A complete end-to-end X-IFU simulator



Our (first) X-IFU end-to-end simulation

Simulated cluster
non-cool core, Coma-like,
with artificially injected turbulence



$\mathcal{M}$ = 0.5

Gaspari & Churazov (2013)

Favourable but realistic scenario

- $M_{500} \sim 5\text{x}10^{14}\ M_\odot$
- z=0.1 (f.o.v. ~700 kpc)
- $Z=0.3\ Z_\odot$
- $N_{cts} \sim 3\text{x}10^6$ (2-8 keV)
- $t_{exp} \sim$ 400ks (Coma)

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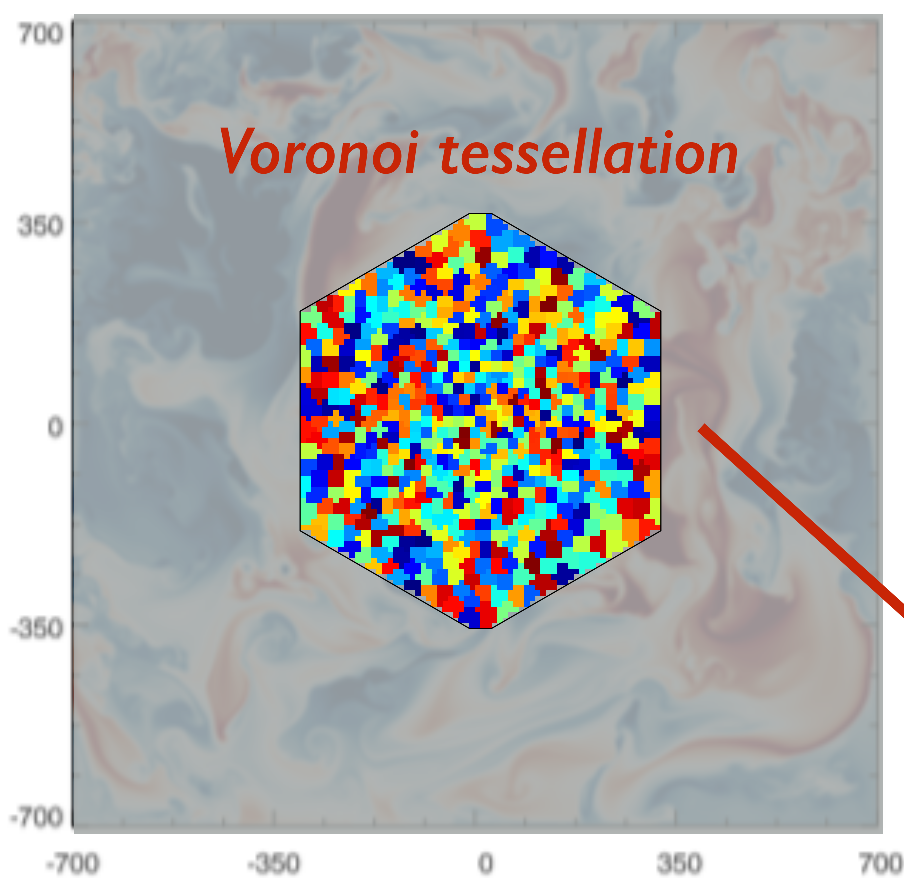

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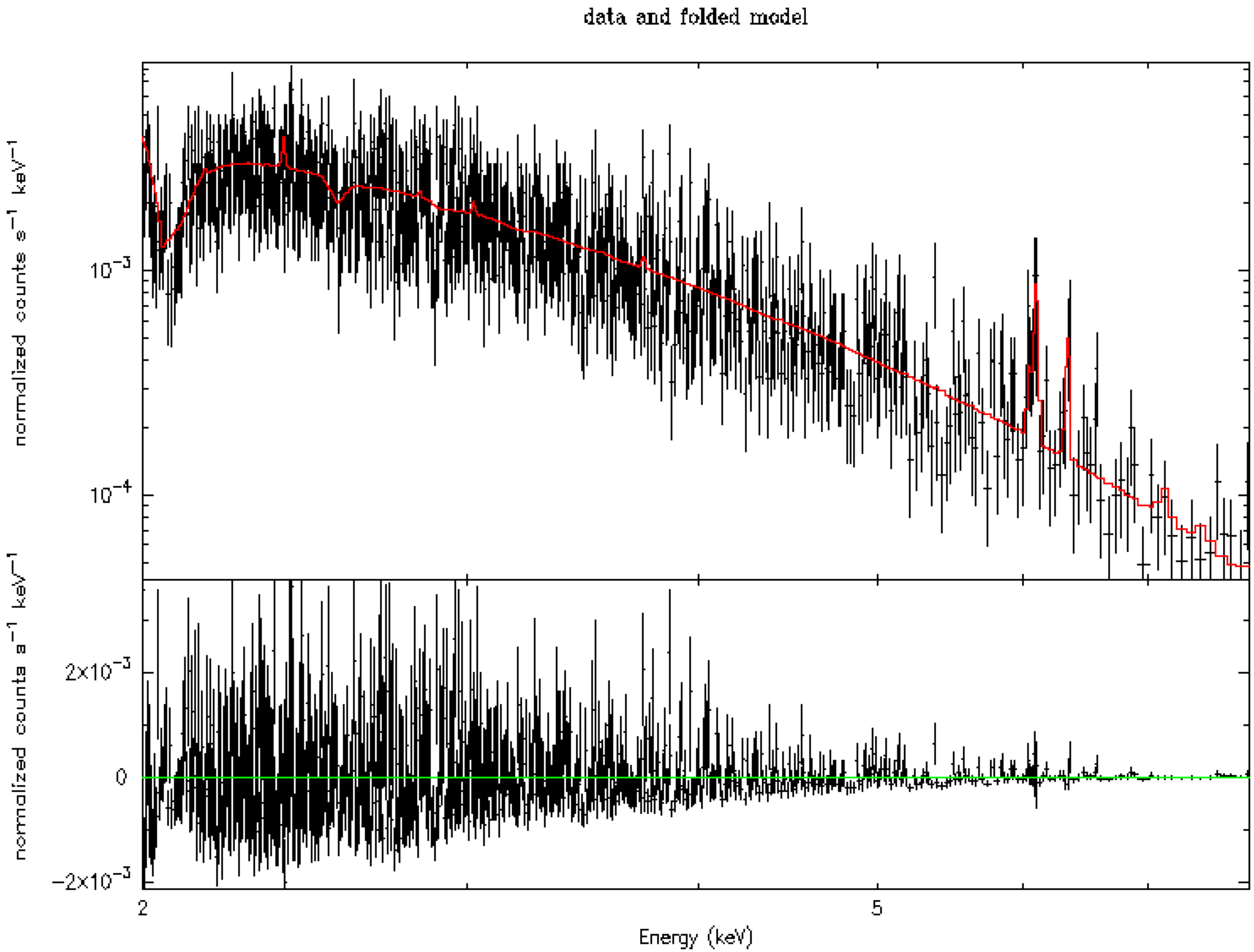
- 619 spectra (5000 cts)
- Fit with 5 free params: ρ^2, T, Z, v, σ_v

Deriving kinematics information from the spectrum



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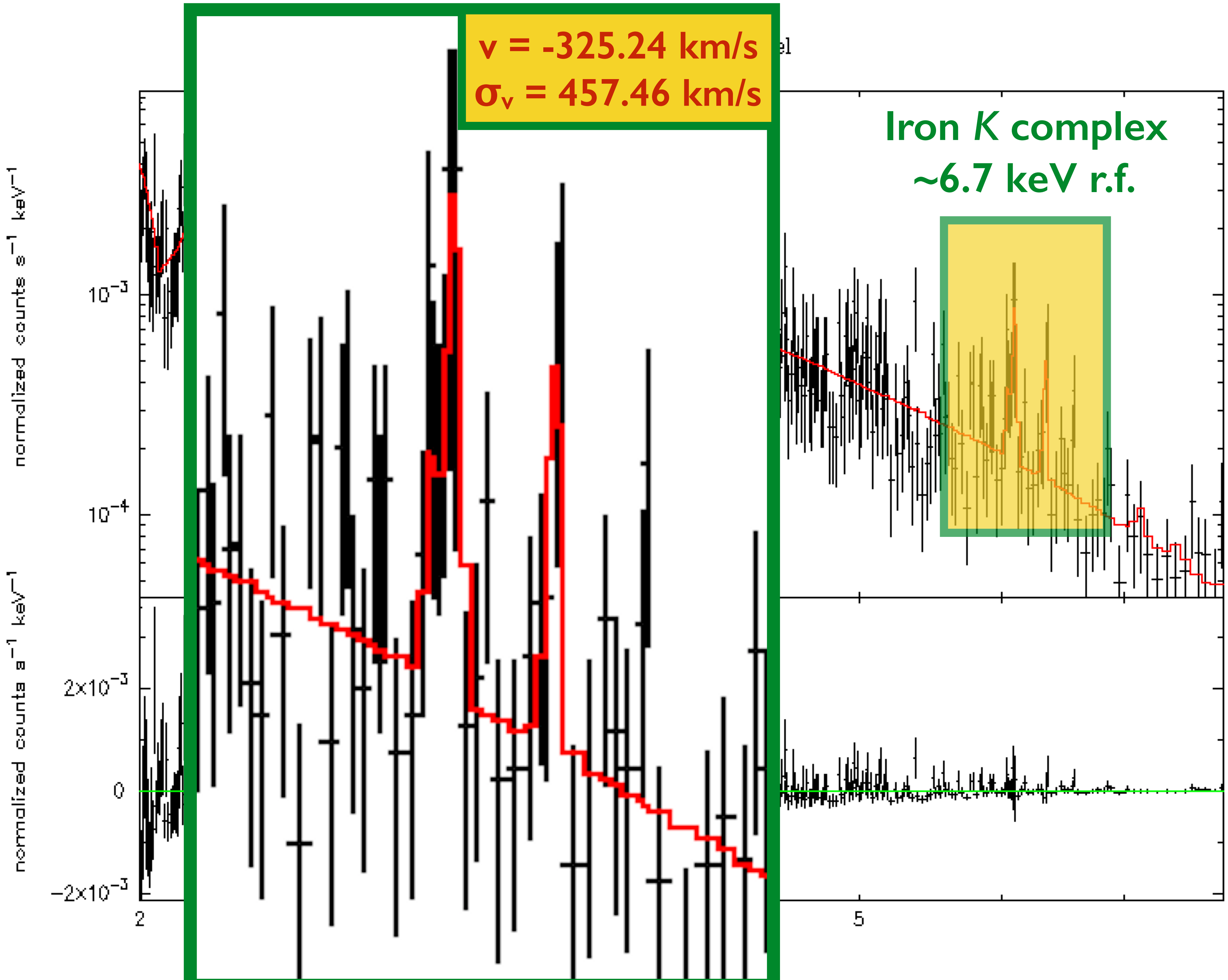
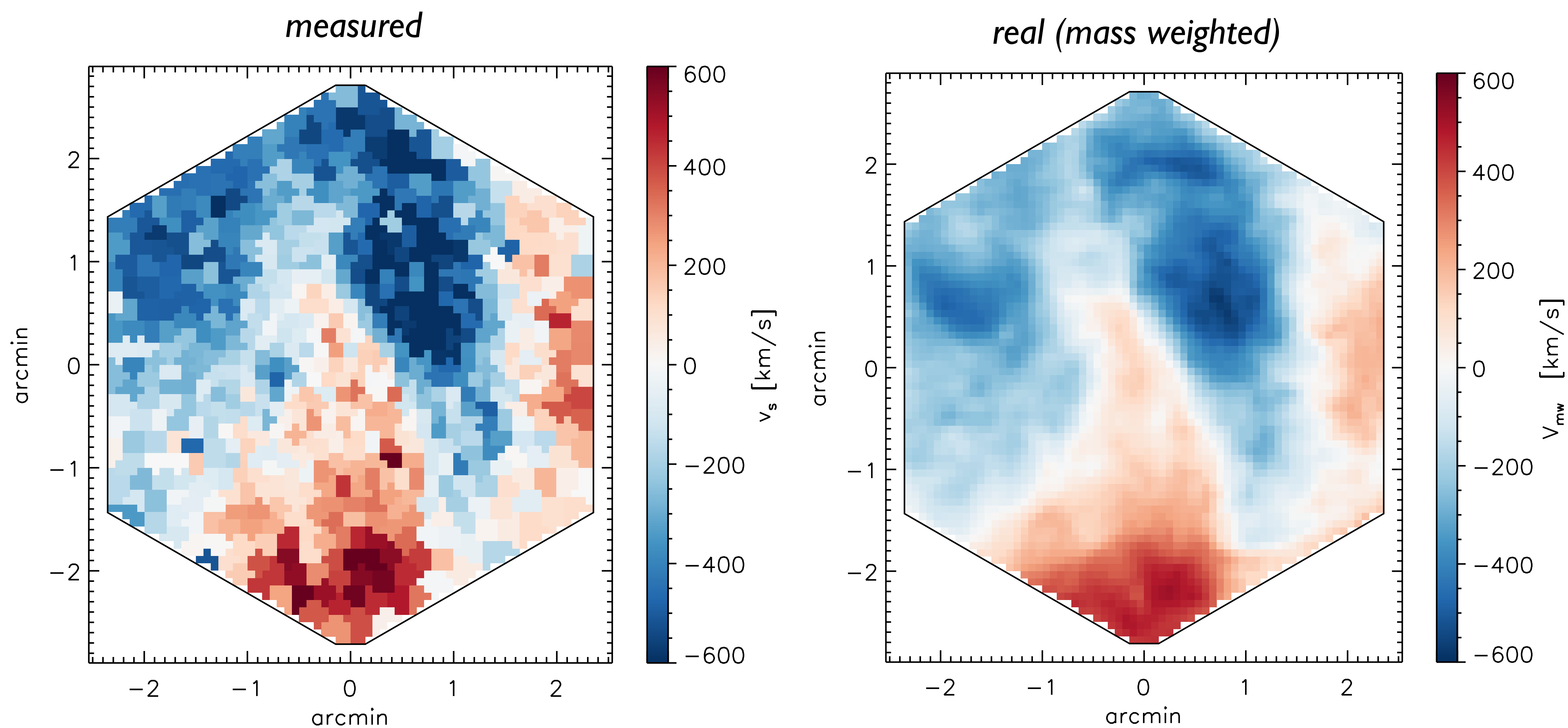


RESULTS!

Centroid shift measurement

mass-weighted velocity

$$v_{\rm mw} = \frac{\int \rho v \, d\ell}{\int \rho \, d\ell}$$



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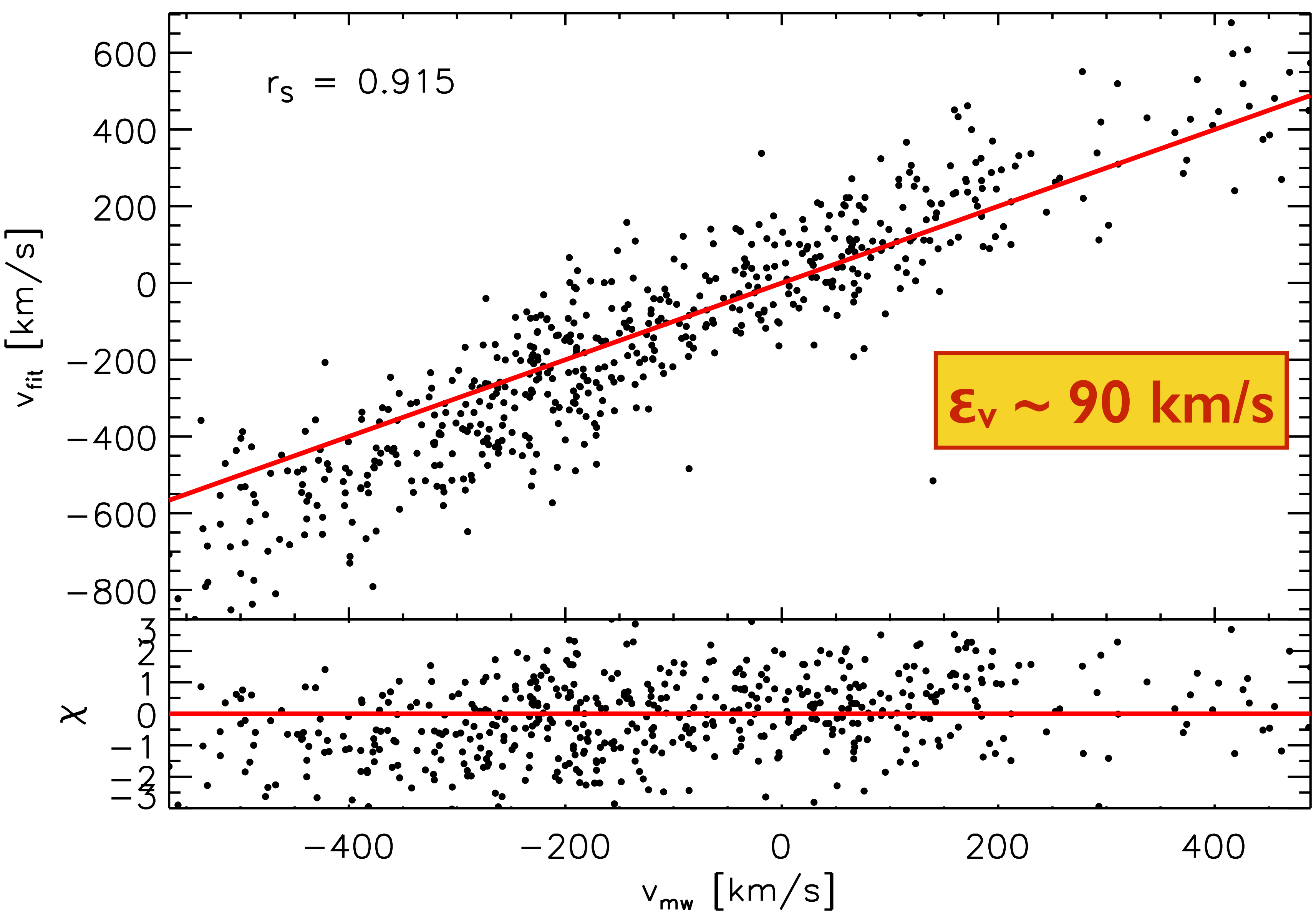


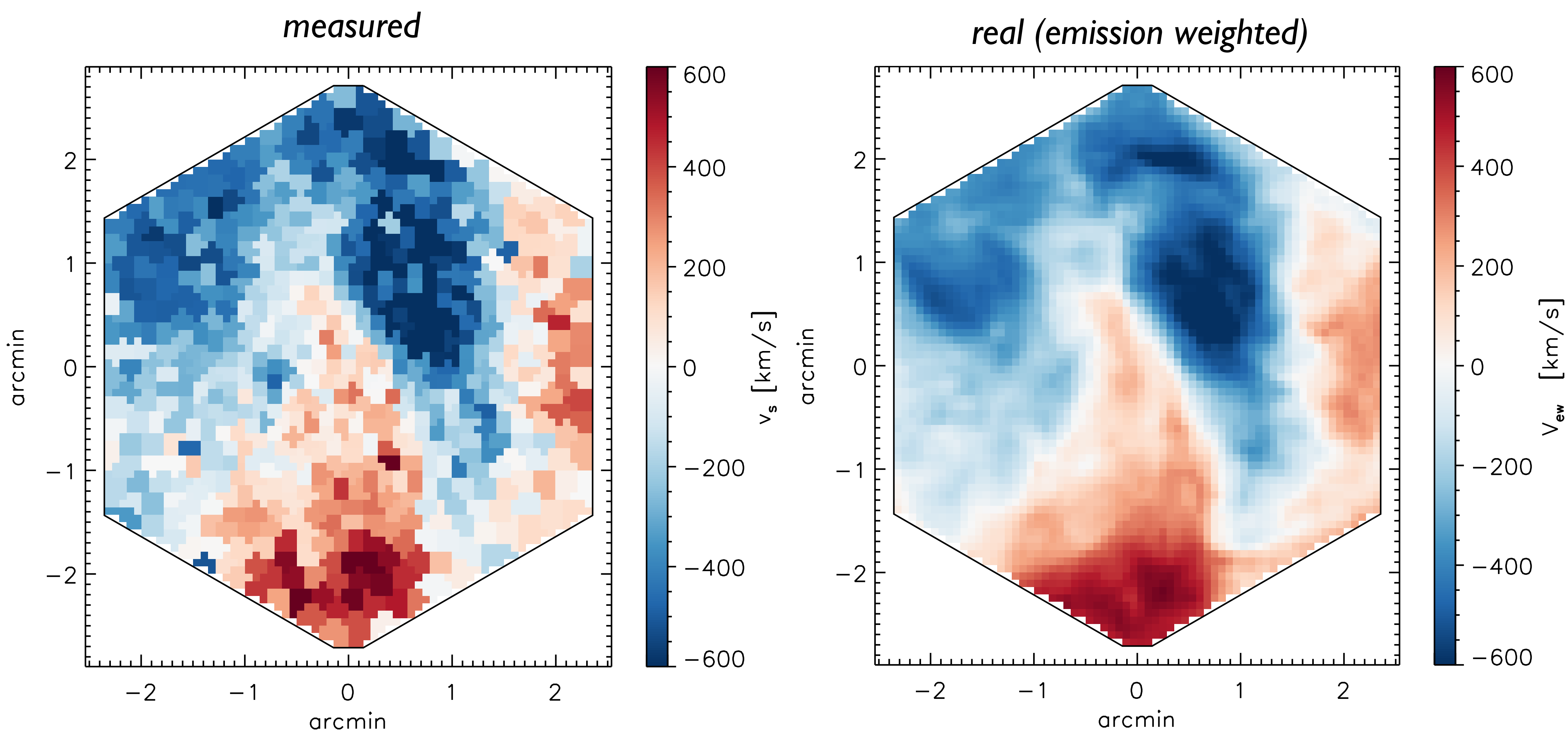
$\varepsilon_v \sim 90$ km/s

Good correlation but small systematic overestimate of the real value

Centroid shift measurement

emission-weighted velocity

$$v_{\rm ew} = \frac{\int \rho^2 v \, d\ell}{\int \rho^2 \, d\ell}$$



Centroid shift measurement

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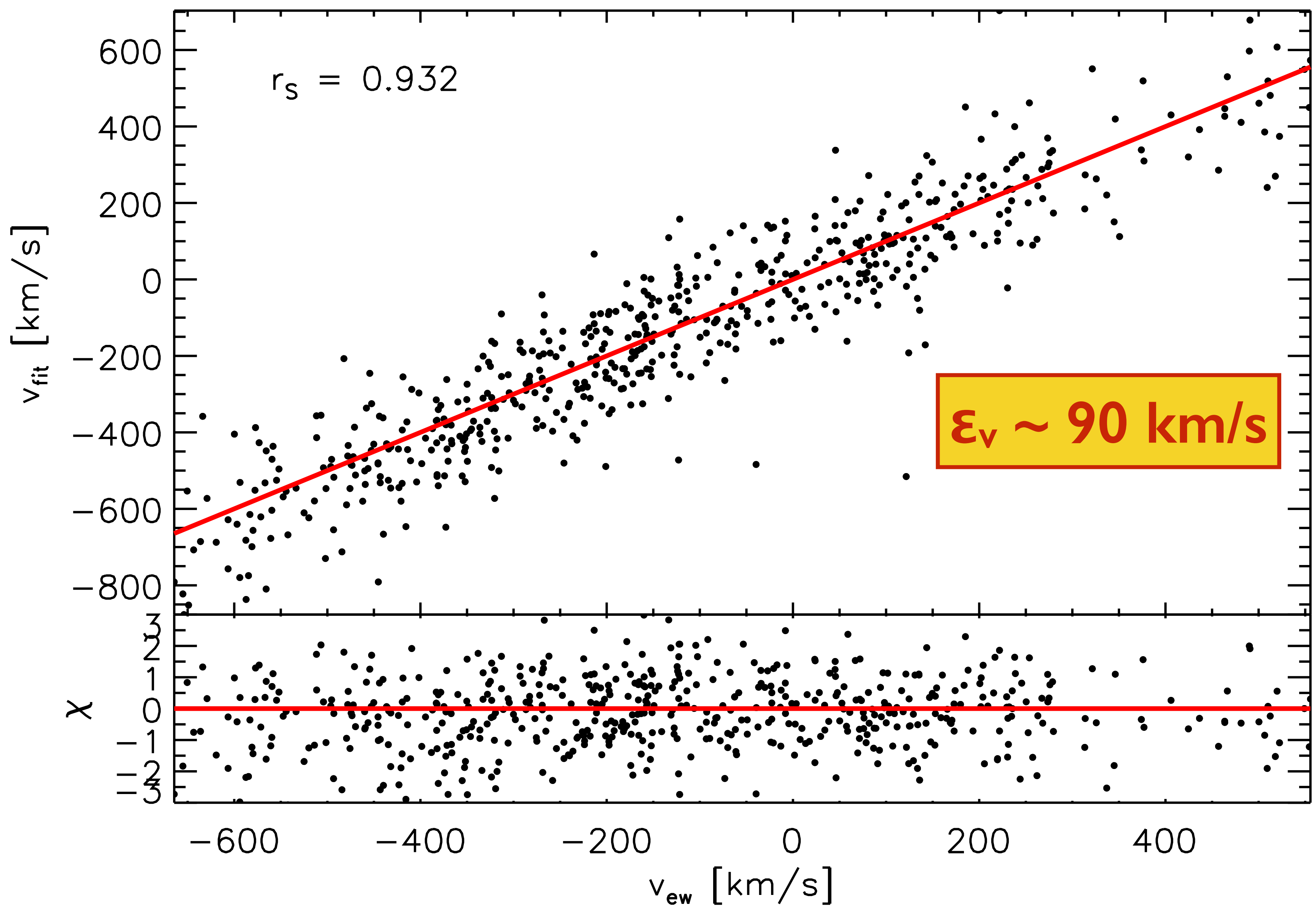


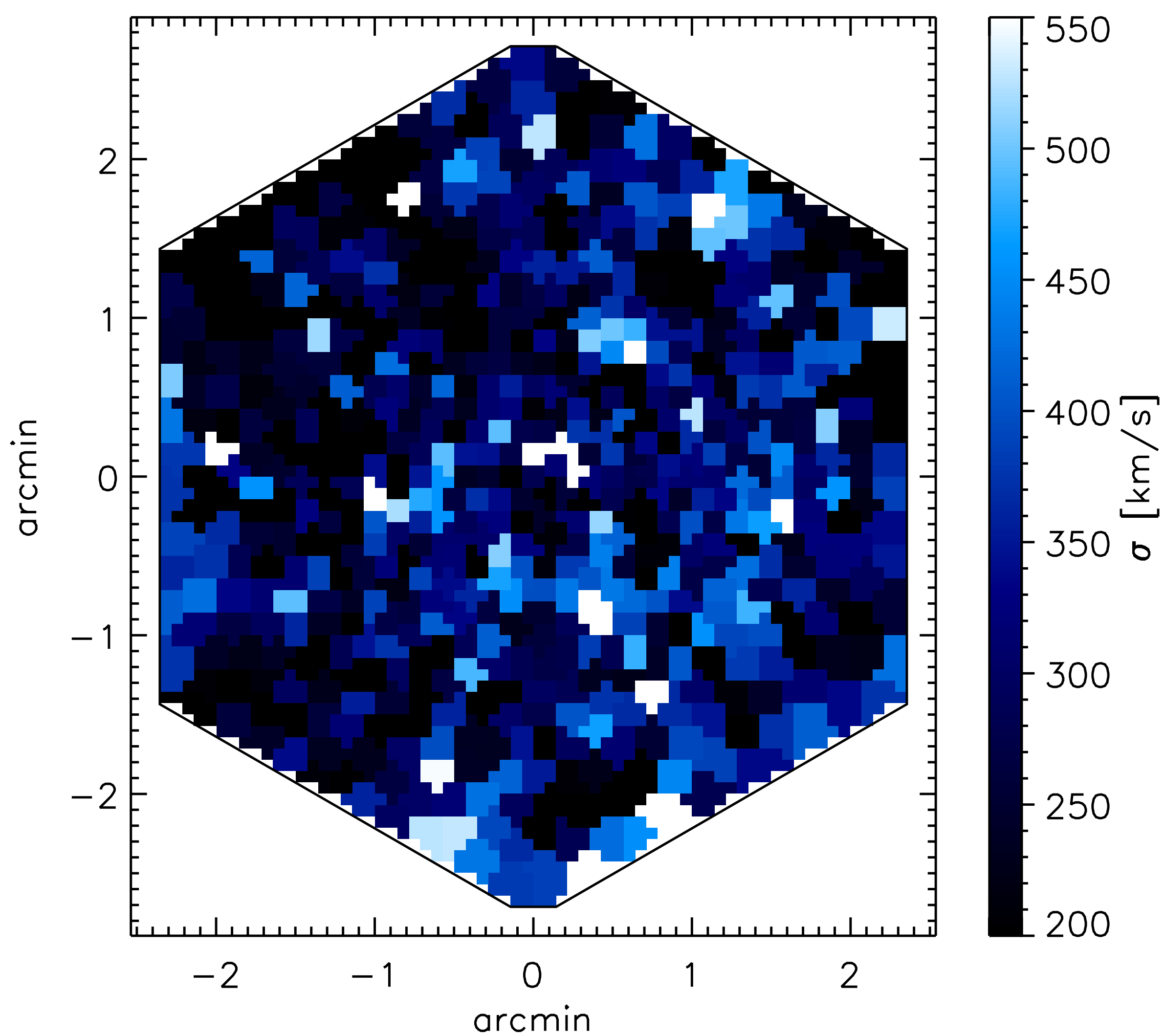
Better correlation, no systematics (already seen in Biffi et al. 2013)

Broadening measurement

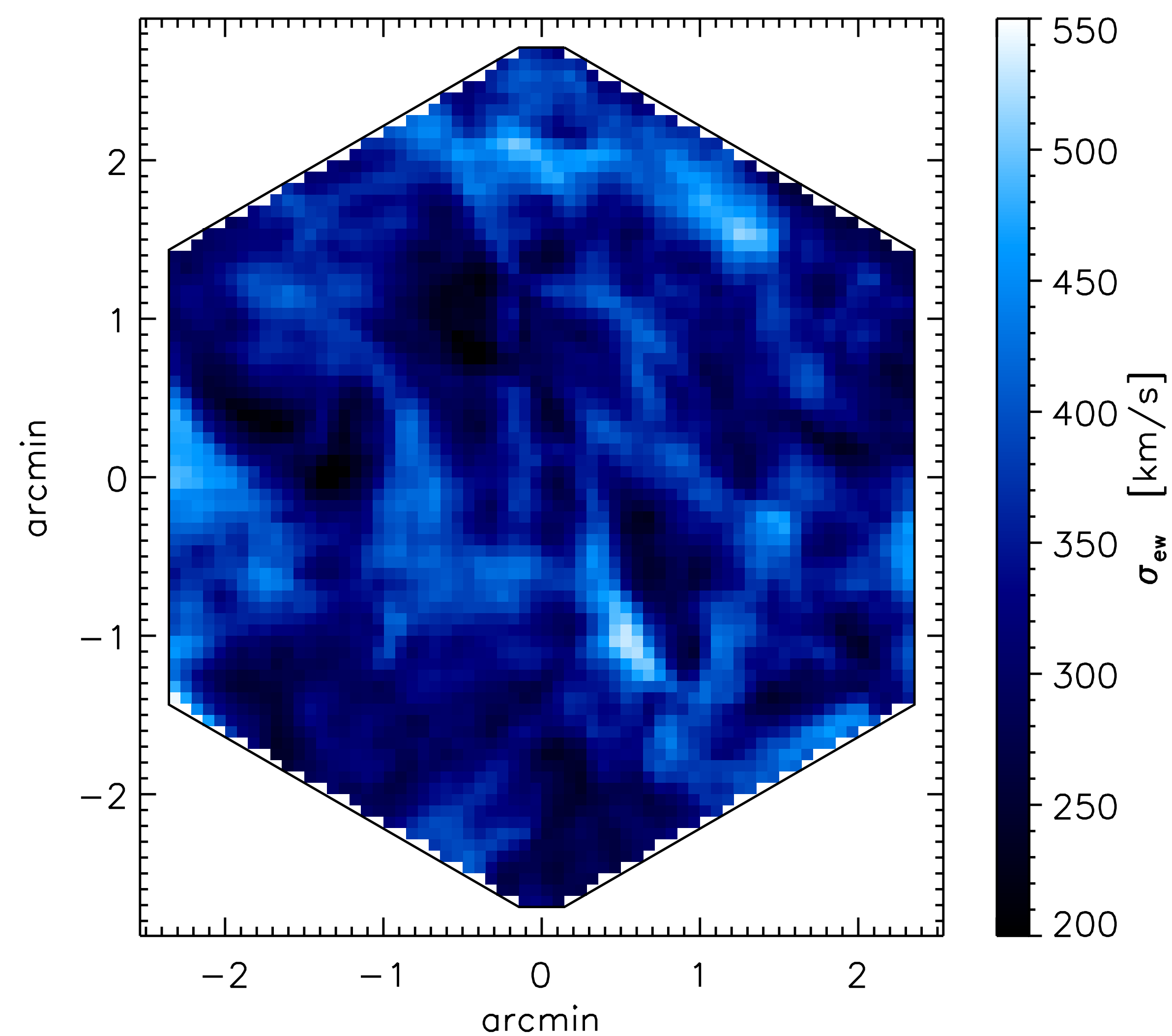
emission-weighted velocity dispersion

$$\sigma_{\rm ew}^2 = \frac{\int \rho^2 (v - v_{\rm ew})^2 \, d\ell}{\int \rho^2 \, d\ell}$$

measured



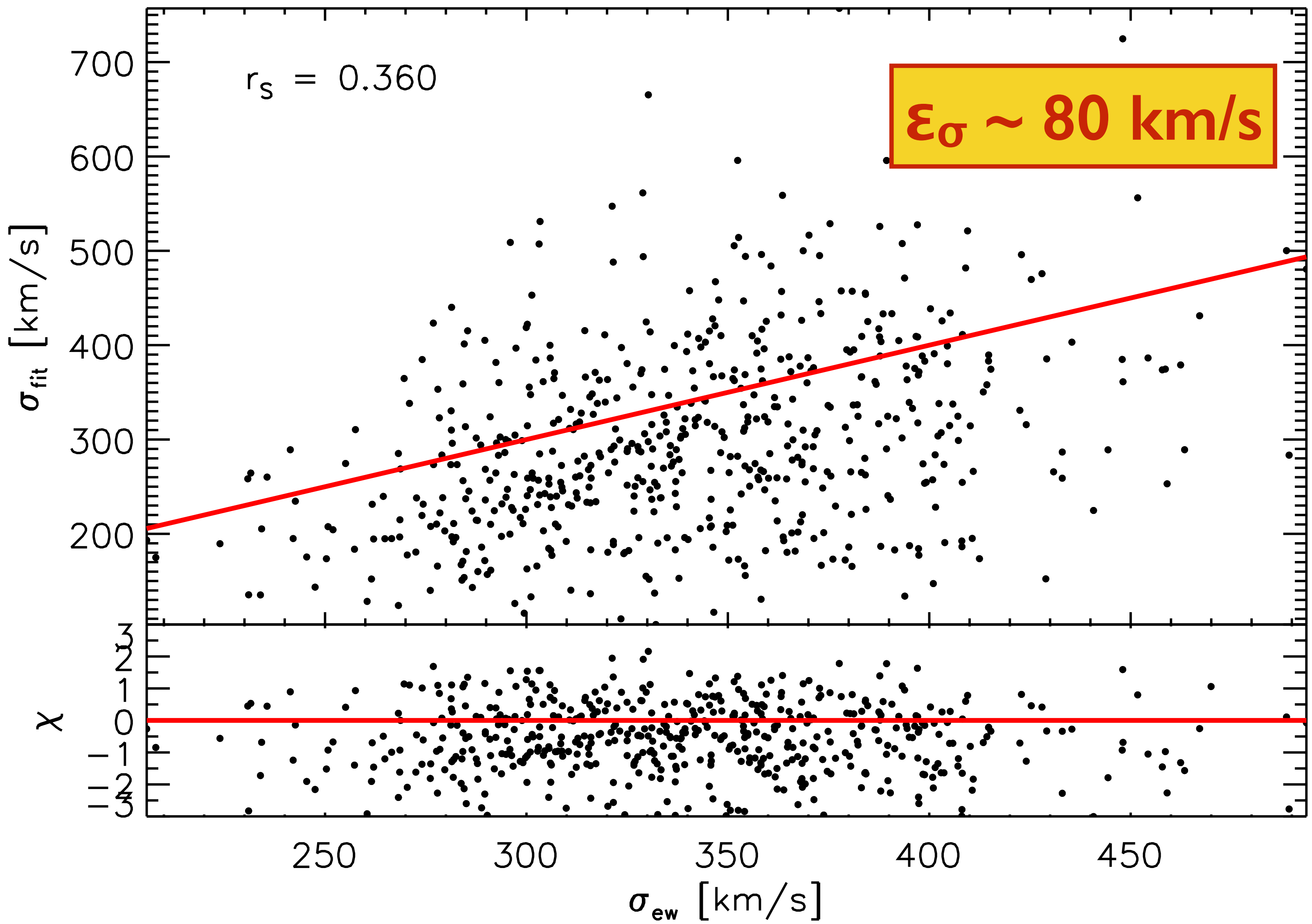
real (emission weighted)



Broadening measurement

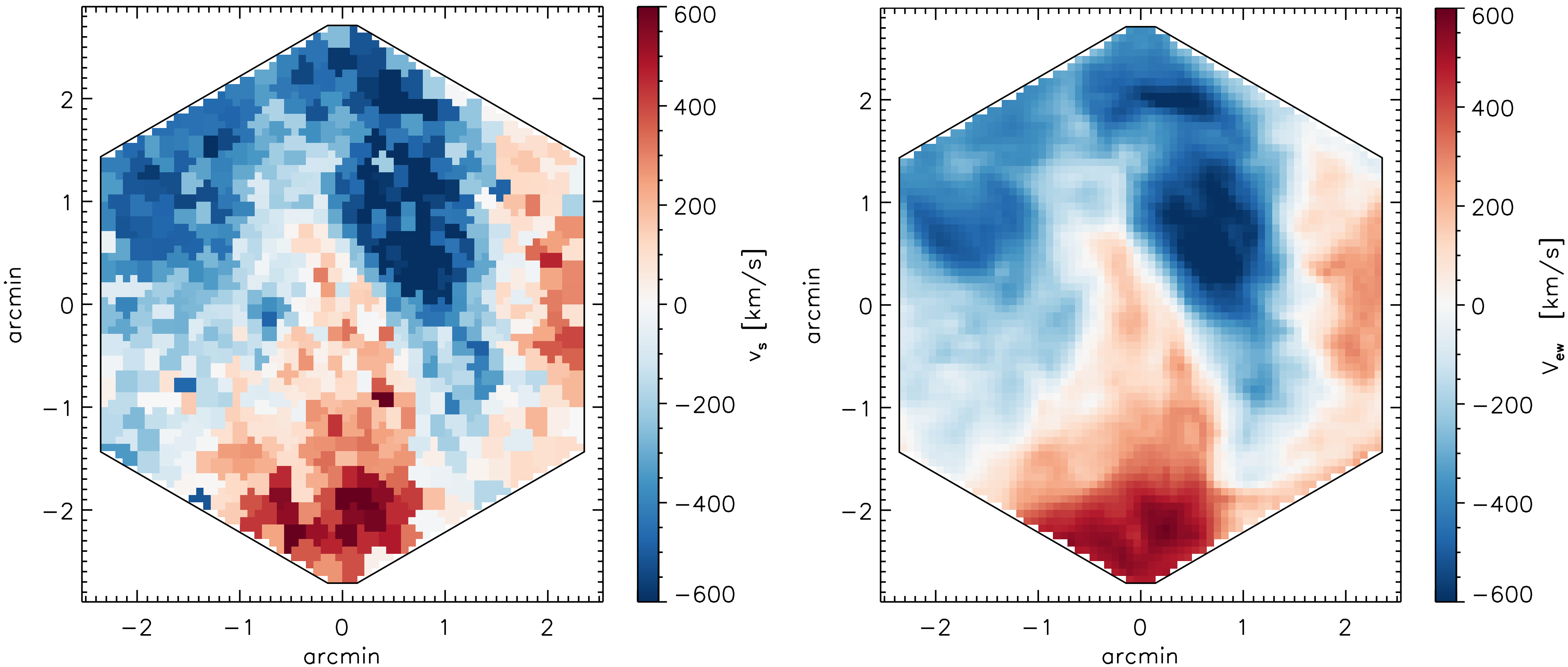
emission-weighted velocity dispersion

$$\sigma_{\rm ew}^2 = \frac{\int \rho^2 (v - v_{\rm ew})^2 \, d\ell}{\int \rho^2 \, d\ell}$$



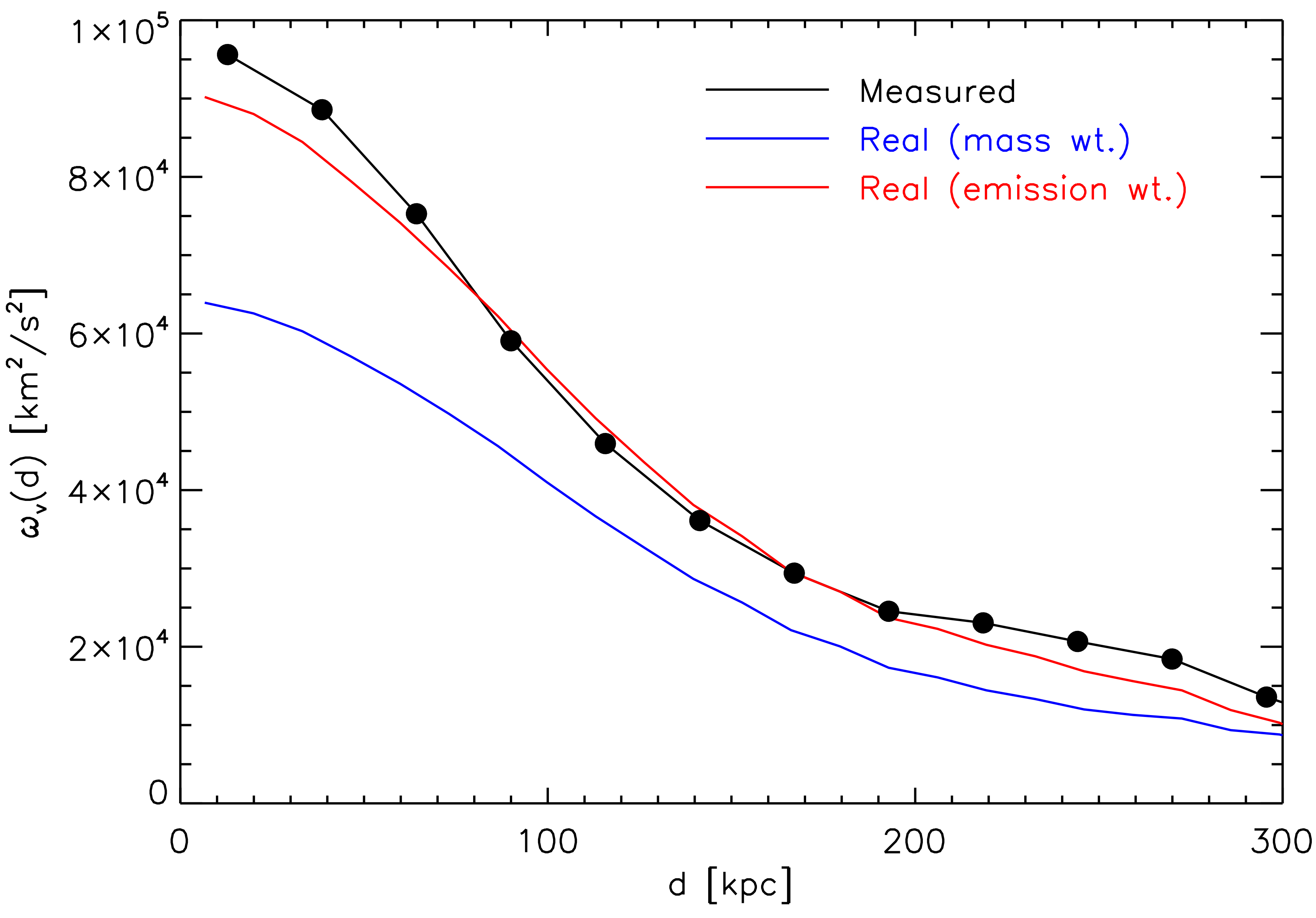
The average value is recovered but the one-to-one correlation is weak

Autocorrelation function of the velocity field



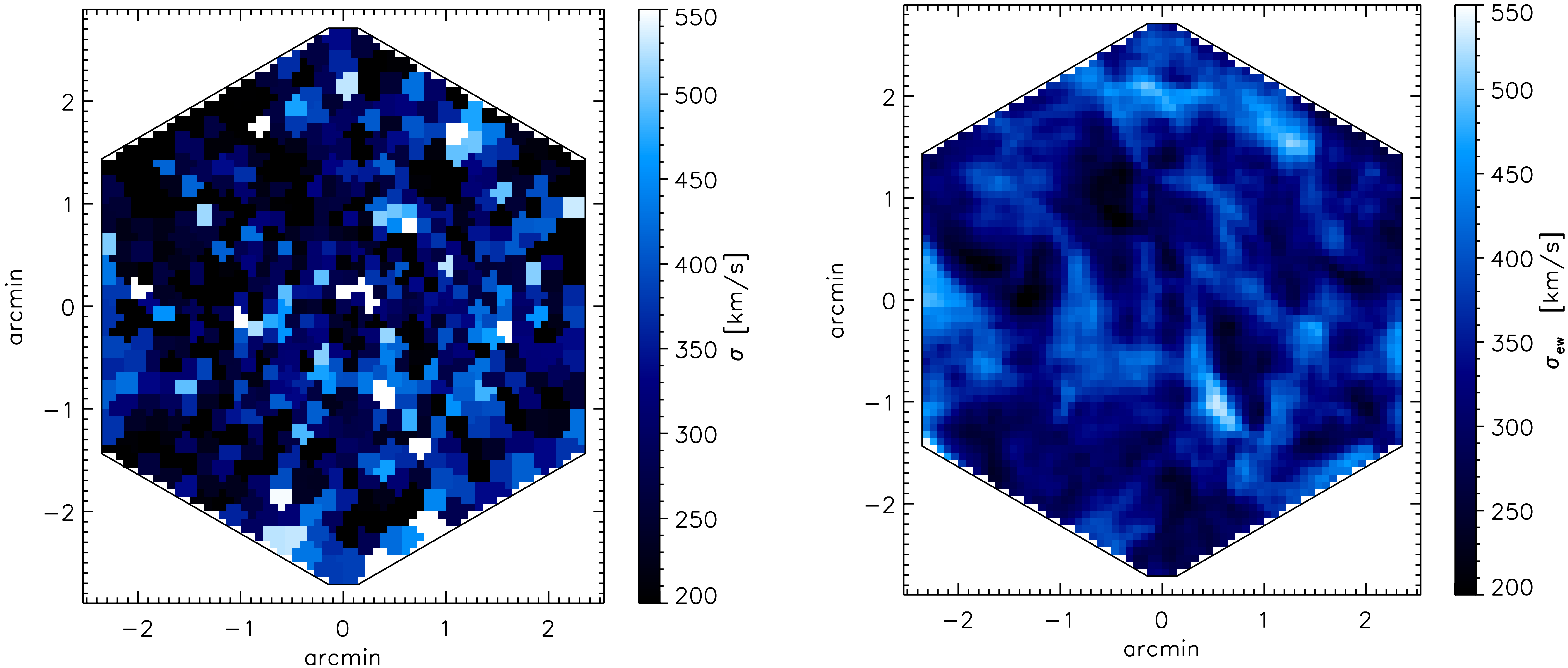
$$w_v(\theta) = \langle v(\vec{x}) v(\vec{x} + \vec{\theta}) \rangle$$

Velocity (centroid shift) autocorrelation



The emission weighted autocorrelation is well recovered up to large scales

Autocorrelation of the velocity dispersion field

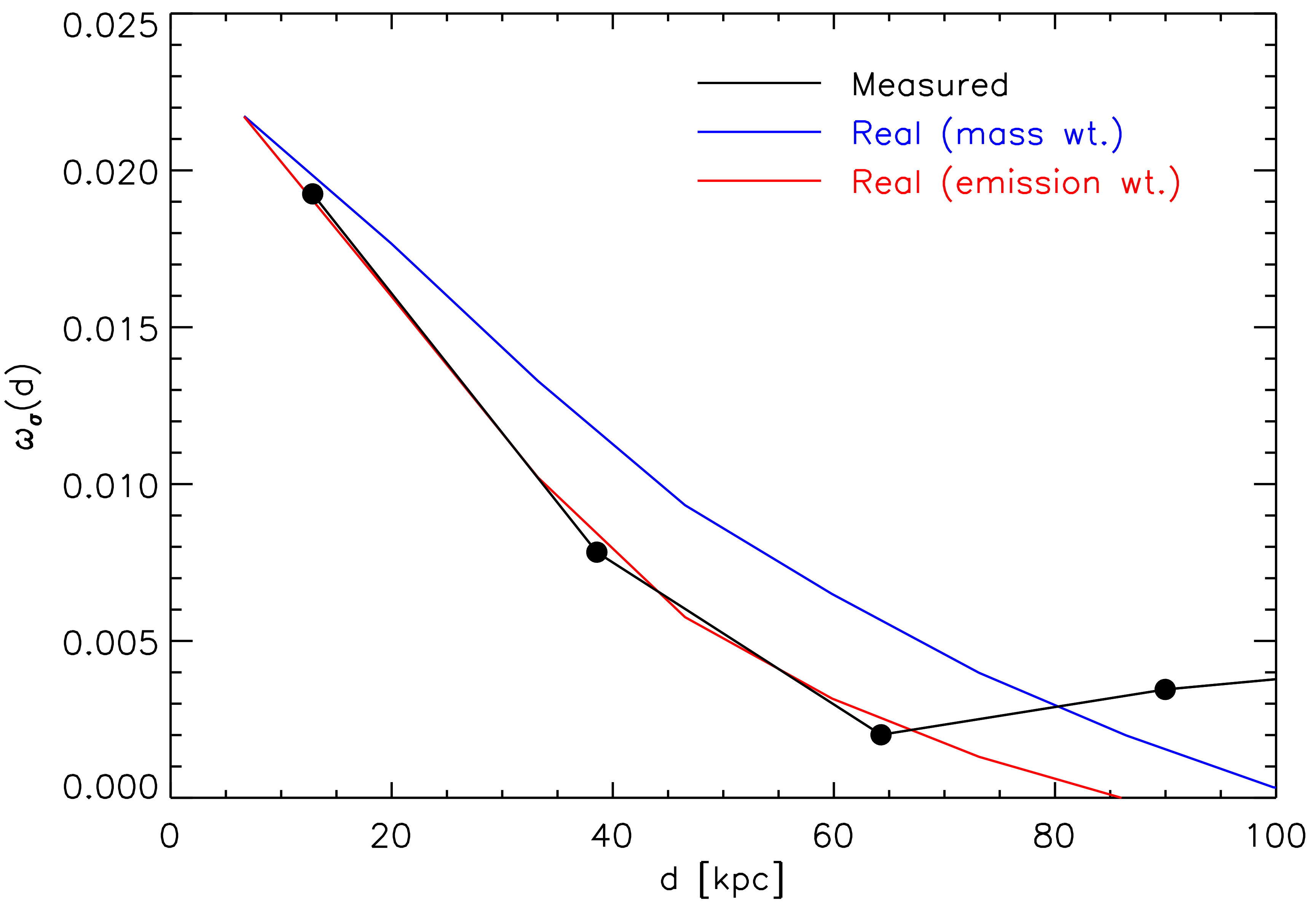


Map density constrast

$$\delta_\sigma = \frac{\sigma(\vec{x})}{\langle\sigma\rangle} - 1$$

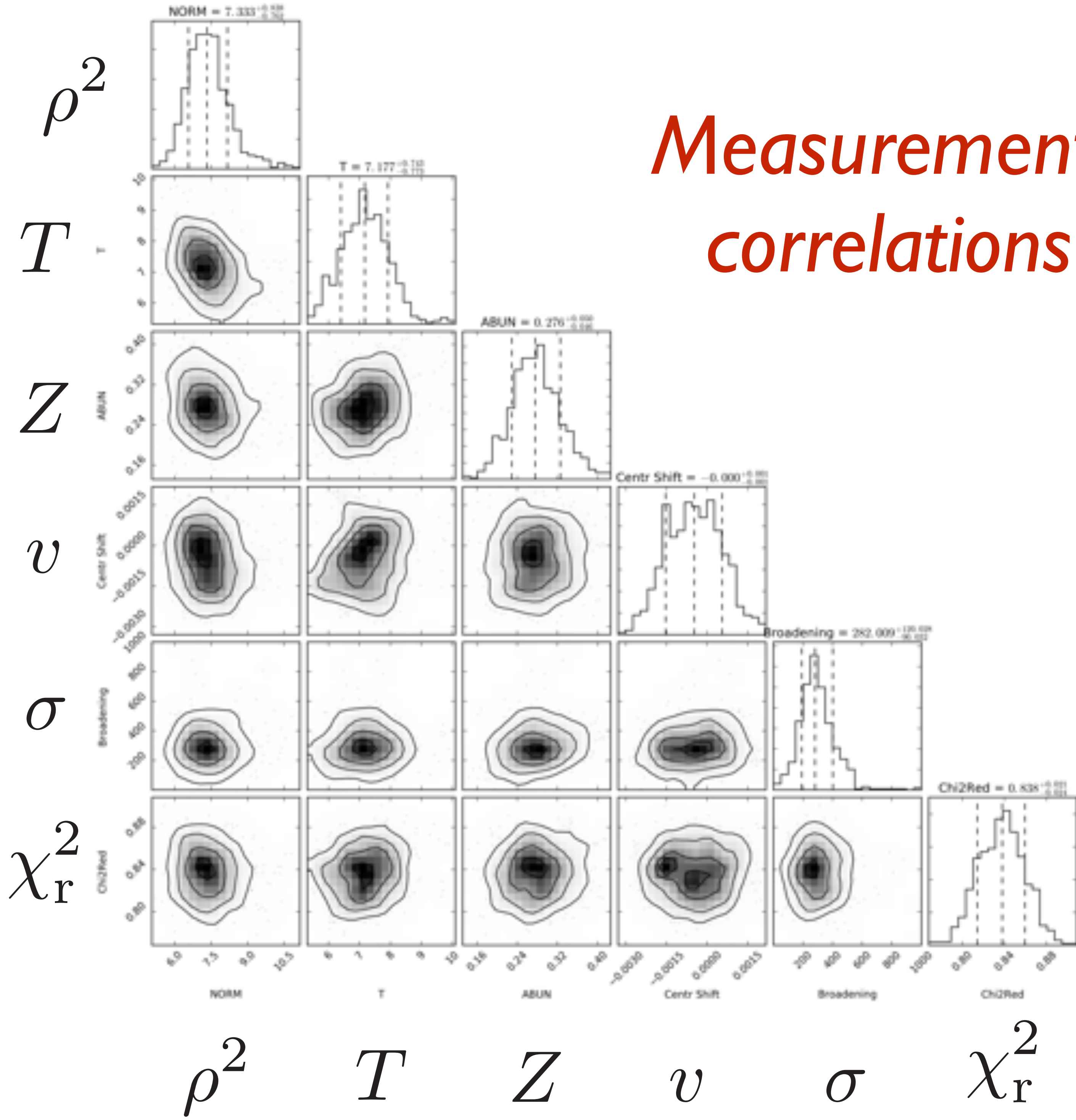
$$w_\sigma(\theta) = \langle \delta_\sigma(\vec{x})\delta_\sigma(\vec{x}+\vec{\theta})\rangle$$

Velocity dispersion (broadening) autocorrelation



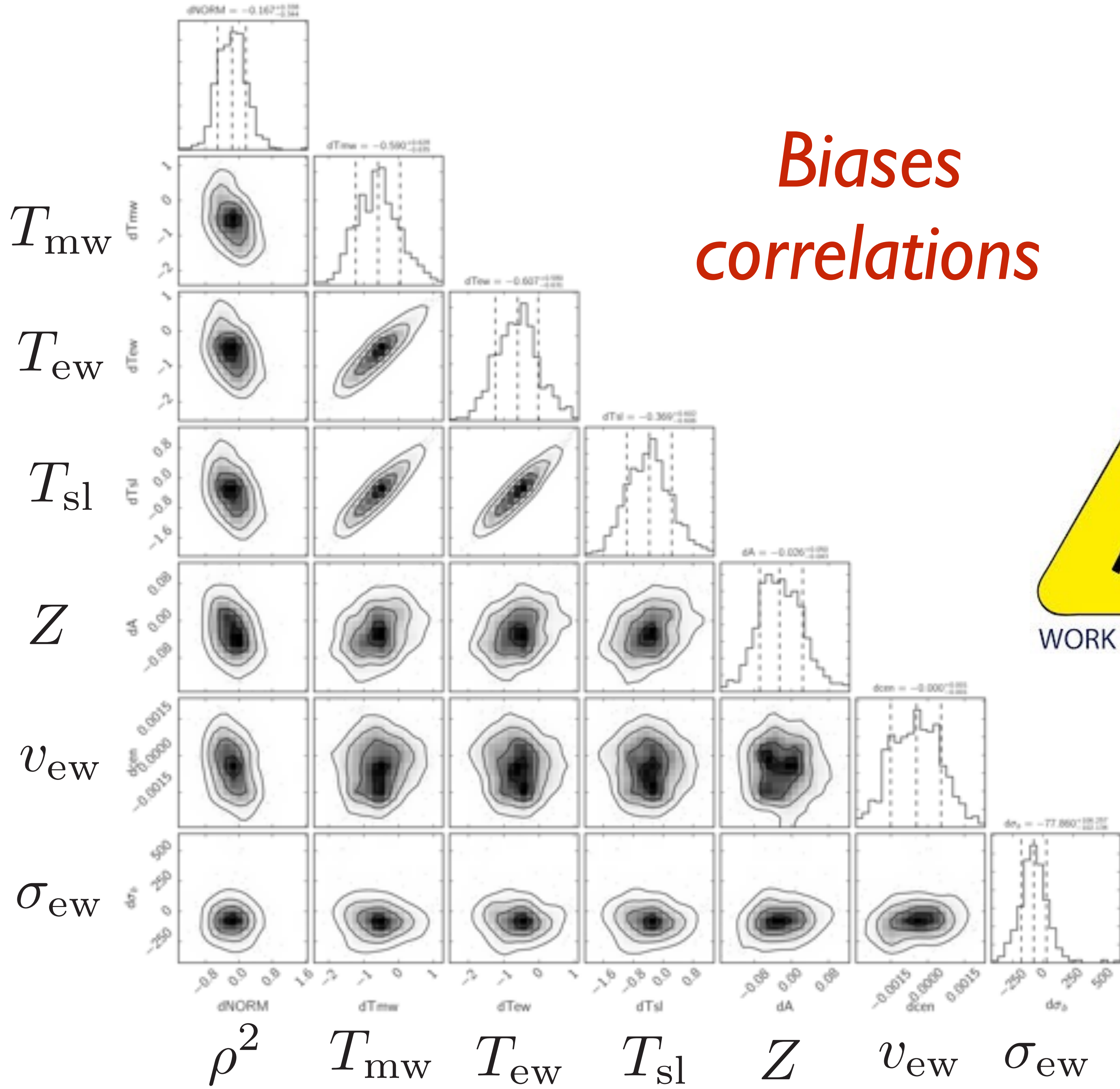
Both amplitude and scale of the autocorrelation are recovered!!

Preliminary: measurements and biases correlation



Measurements correlations

Preliminary: measurements and biases correlation



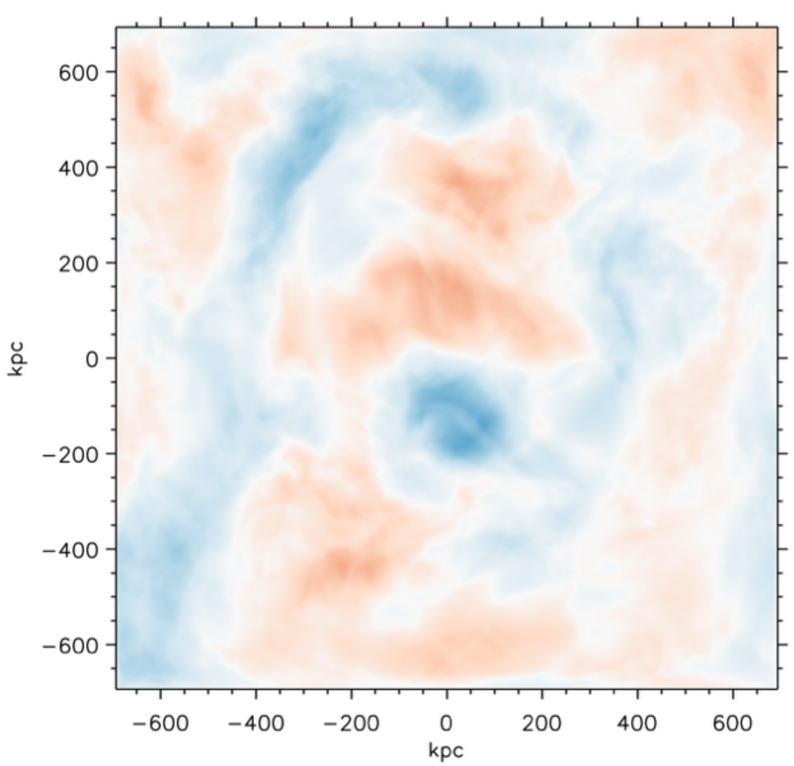
Biases correlations

SOME STEPS FORWARD

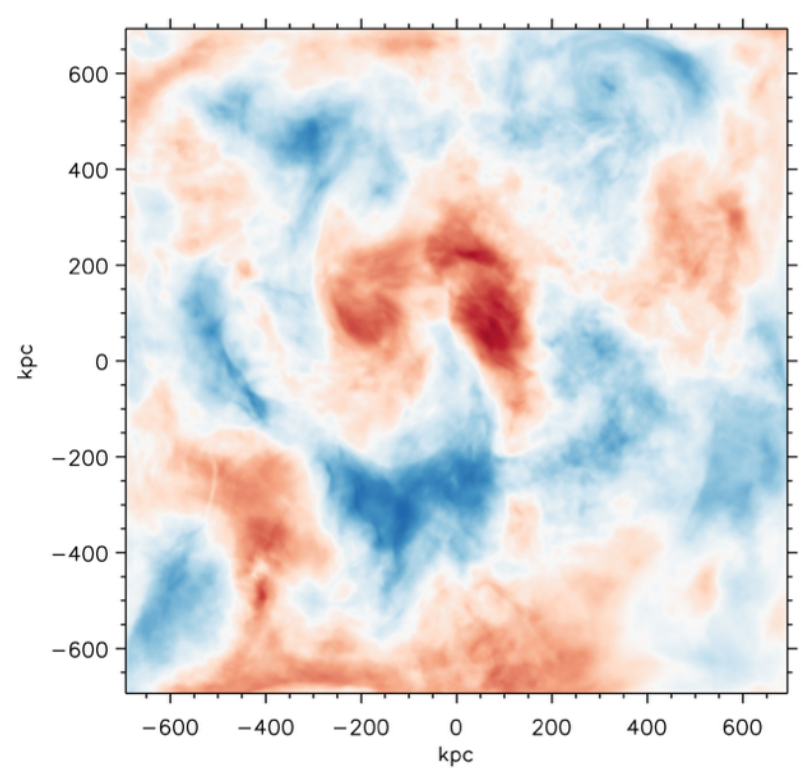
Discriminating different turbulence models

We can apply our pipeline to models that assume different plasma parameters (i.e. Mach numbers), see if we can distinguish them and, possibly, recover the parameters themselves.

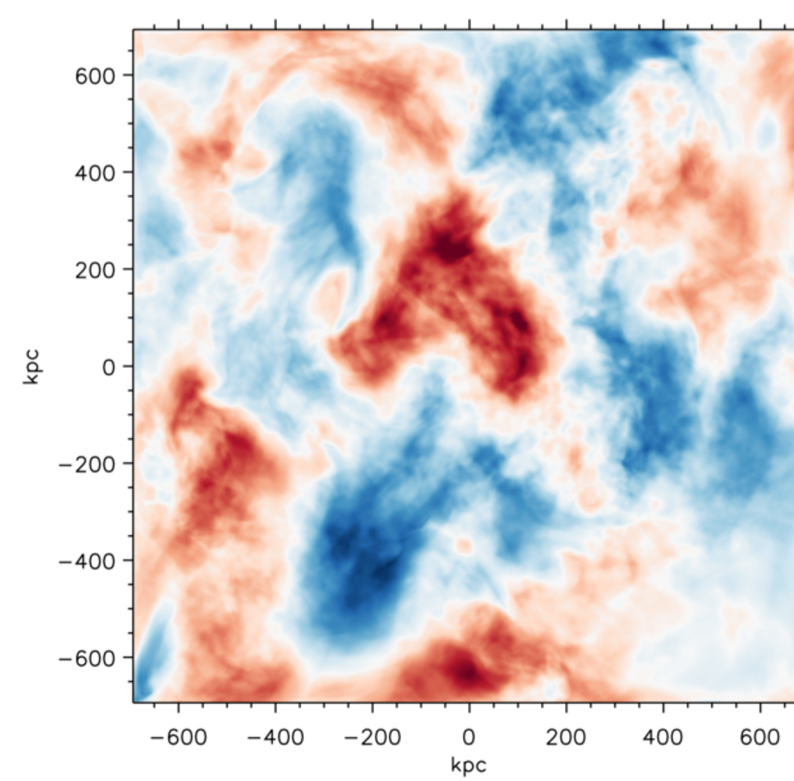
$\mathcal{M} = 0.25$



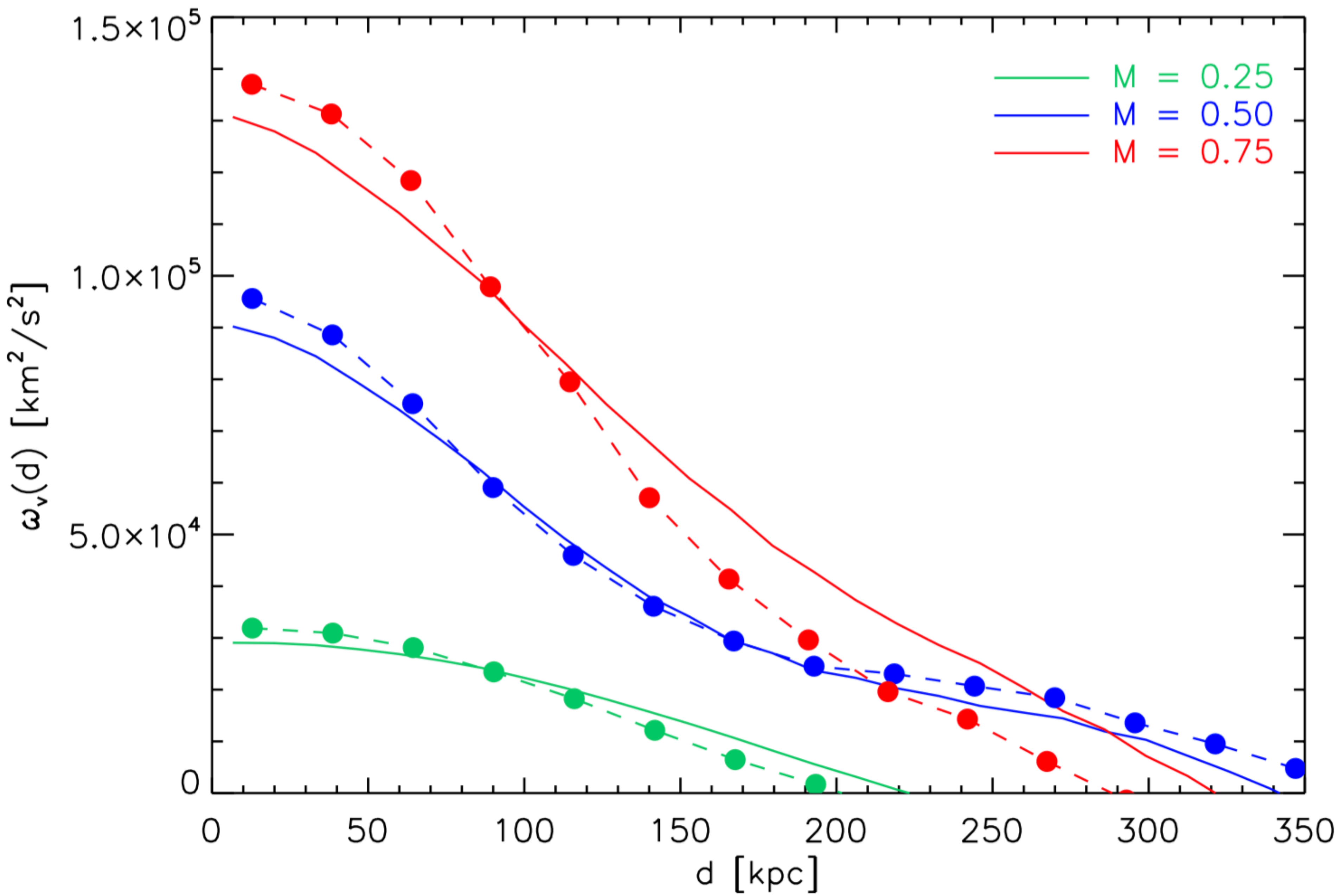
$\mathcal{M} = 0.5$



$\mathcal{M} = 0.75$

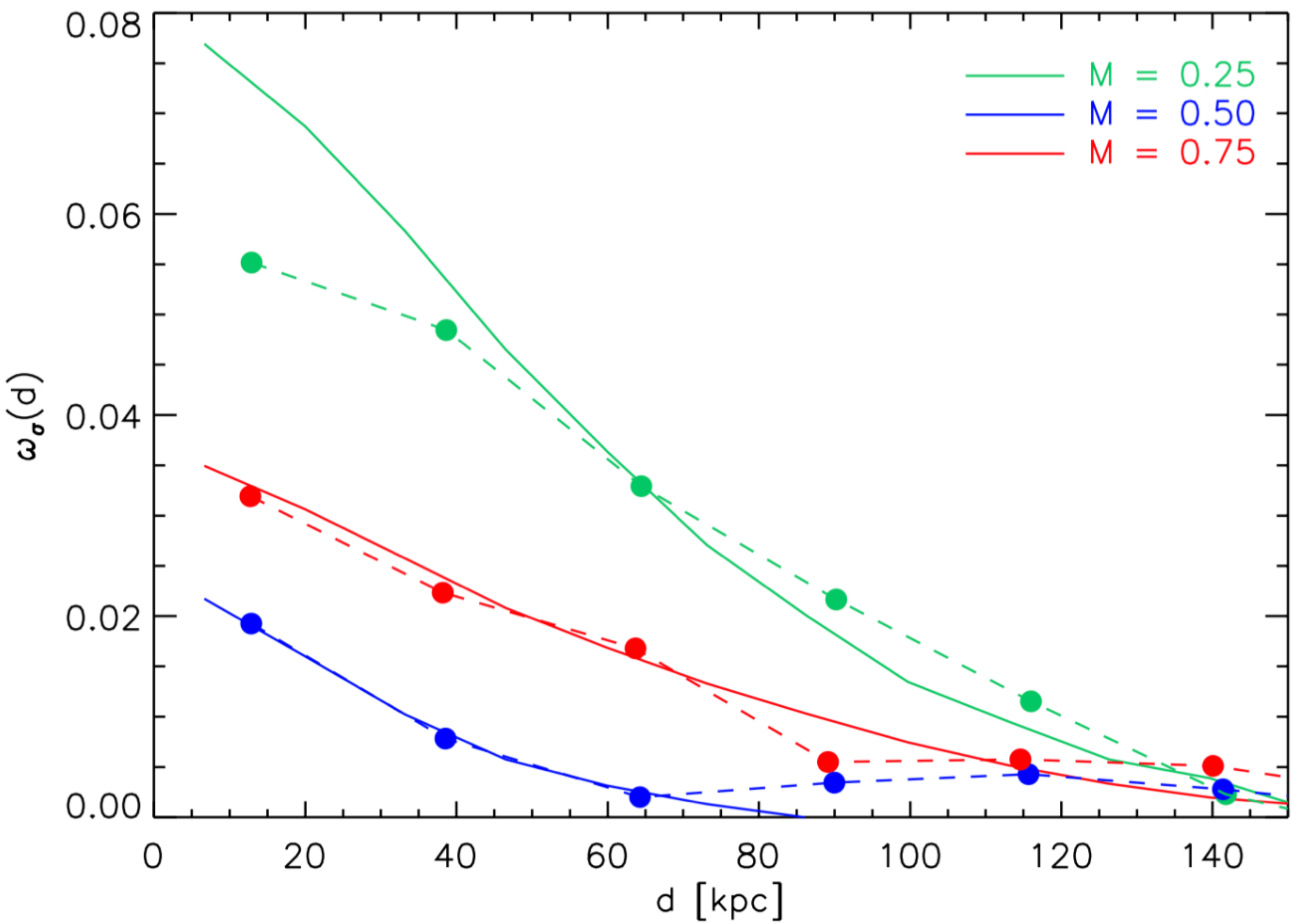


Velocity (centroid shift) autocorrelation



The different shapes of the velocity autocorrelation functions are recovered

Velocity dispersion (broadening) autocorrelation



Same as before also for the σ_v autocorrelation functions

Conclusions

- We have in hand a full **<u>end-to-end X-IFU simulator</u>** (that includes SIXTE): this allows realistic Xspec-like analyses and a direct comparisons with simulated quantities

- In a favourable but realistic case (M_{500}~$5x10^{14}$ $M_{\odot}$, z=0.1, Z=0.3 $Z_{\odot}$, t_{exp}~400ks) X-IFU will be able to **map bulk velocities with great accuracy**. This can provide information on rotation, gas dynamics and constrain the velocity power spectrum at large scales (~100s kpc)

- While a global broadening measurement is easy to achieve, **mapping σ_v is more challenging** due to its intrinsic inhomogeneities (σ_v is dominated by small scale motions)

- Despite this, X-IFU observations can measure the **autocorrelation function (power spectrum) of σ_v fluctuations** with good accuracy, potentially allowing to constrain the velocity power spectrum also at small scale (~10 kpc)