Uncertainties in HI Stacking Experiments

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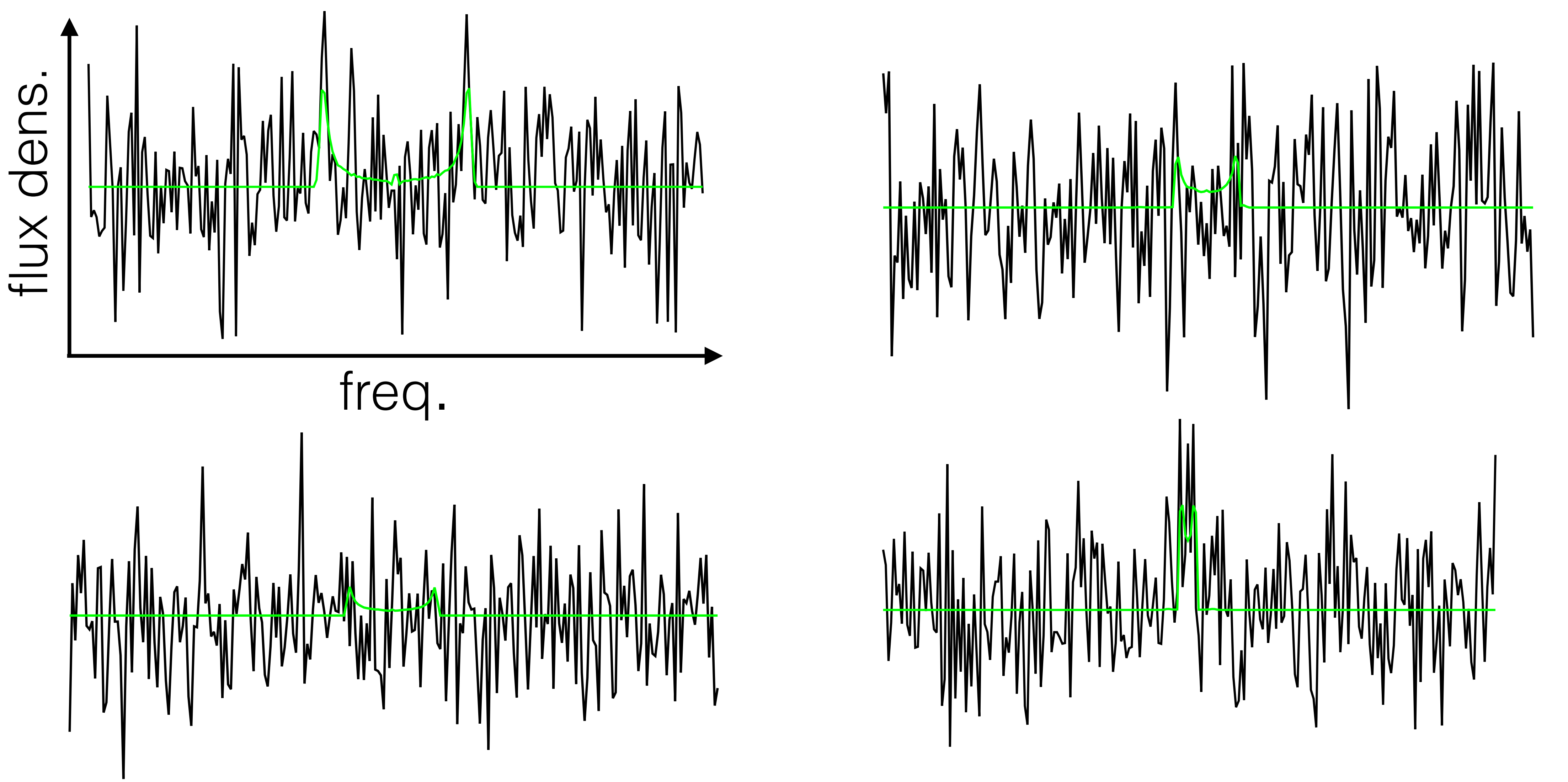
HI Stacking

- Galaxy surveys on the VLA, MeerKAT and SKA will use spectral line stacking to probe faint (distant) galaxy populations.



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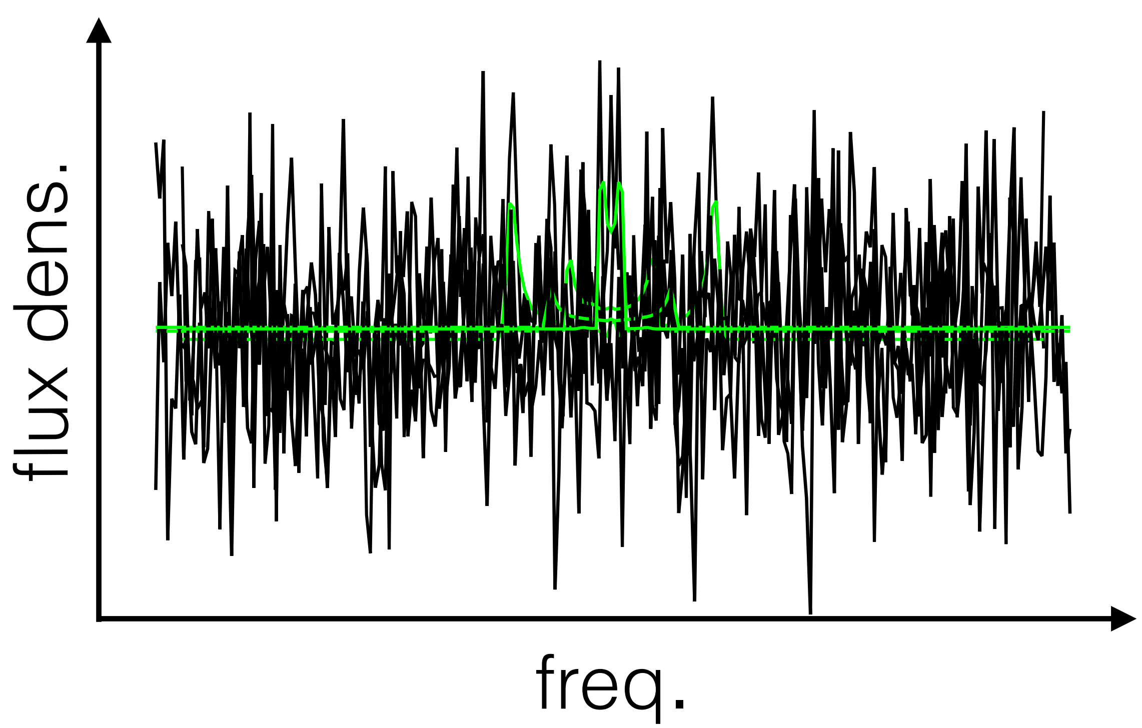

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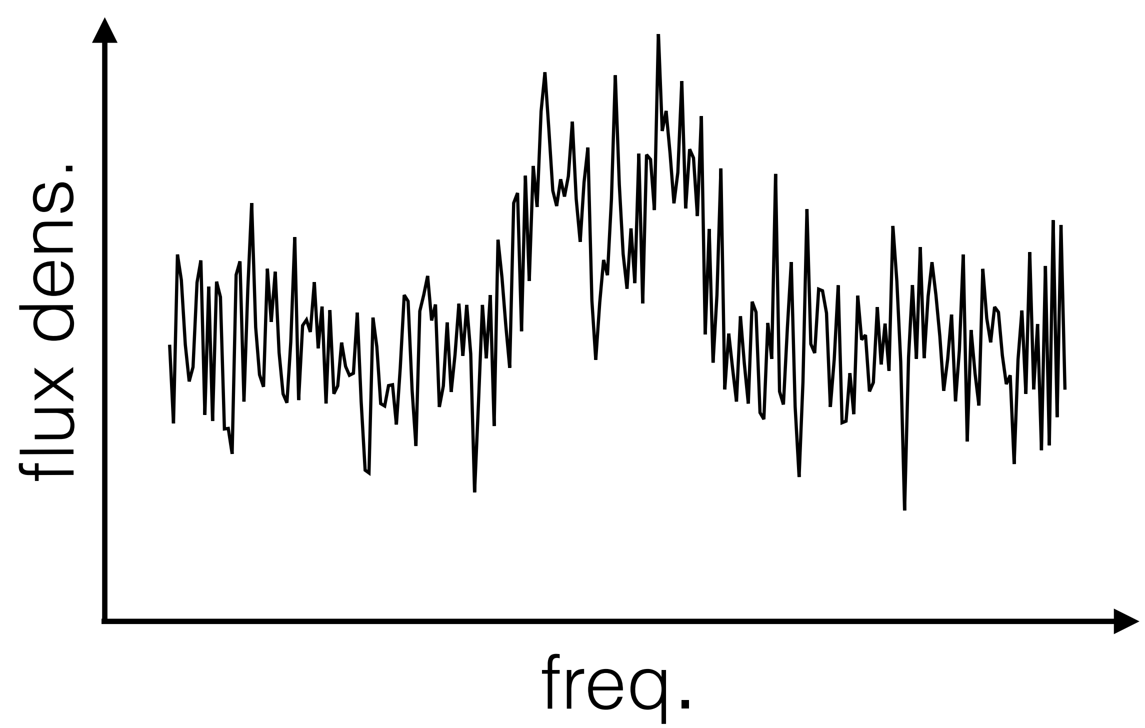

HI Stacking

Unappreciated short-coming of HI stacking:

source confusion

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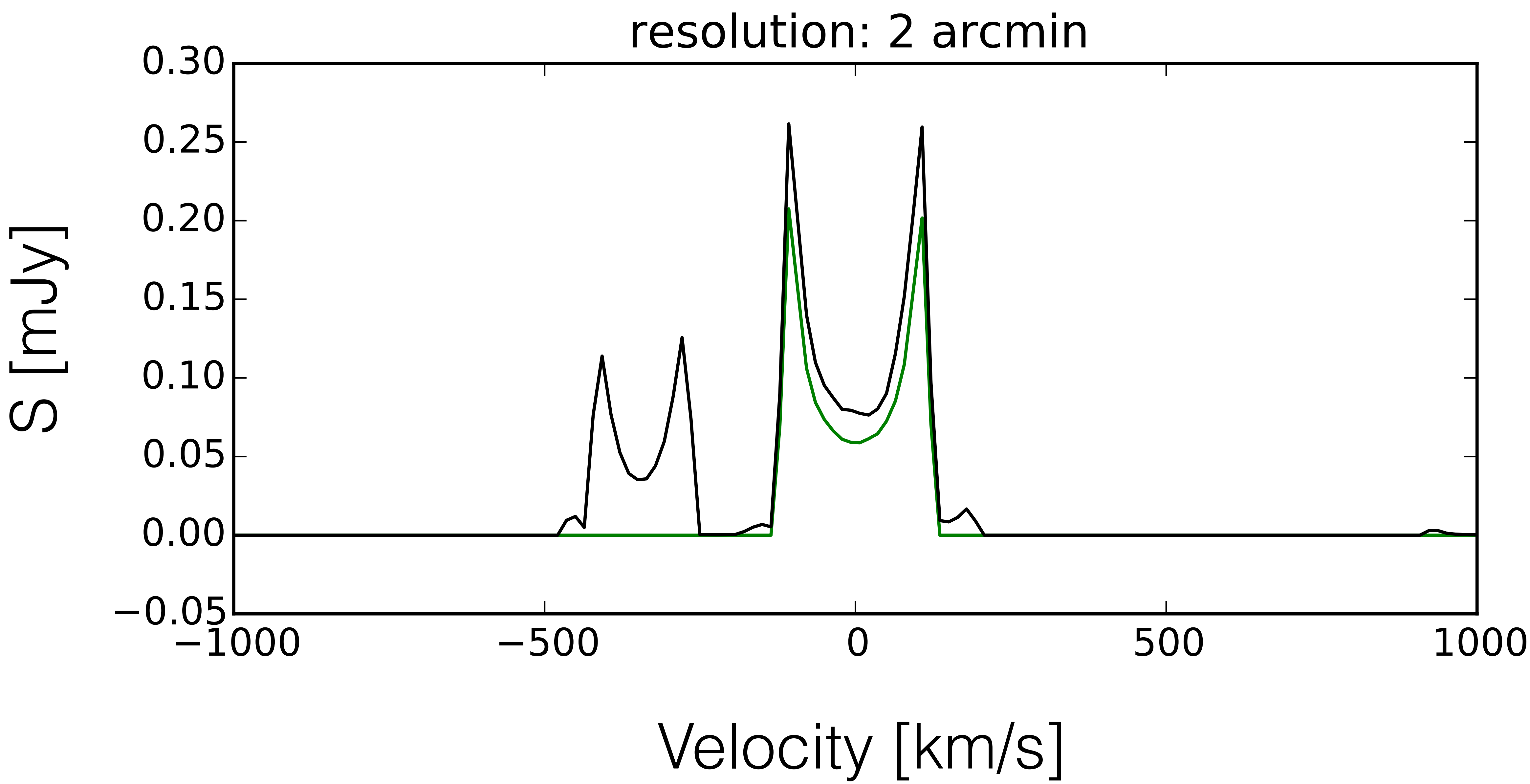
source confusion

In astronomy, we're usually concerned with *not* detecting emission from galaxies we *want* to detect. When it comes to HI stacking, we should be concerned with detecting emission from galaxies we *don't* want to detected.

Andrew Baker

Spectrum extracted from a noise-free simulated HI cube:



emission from target galaxy

emission from all galaxies

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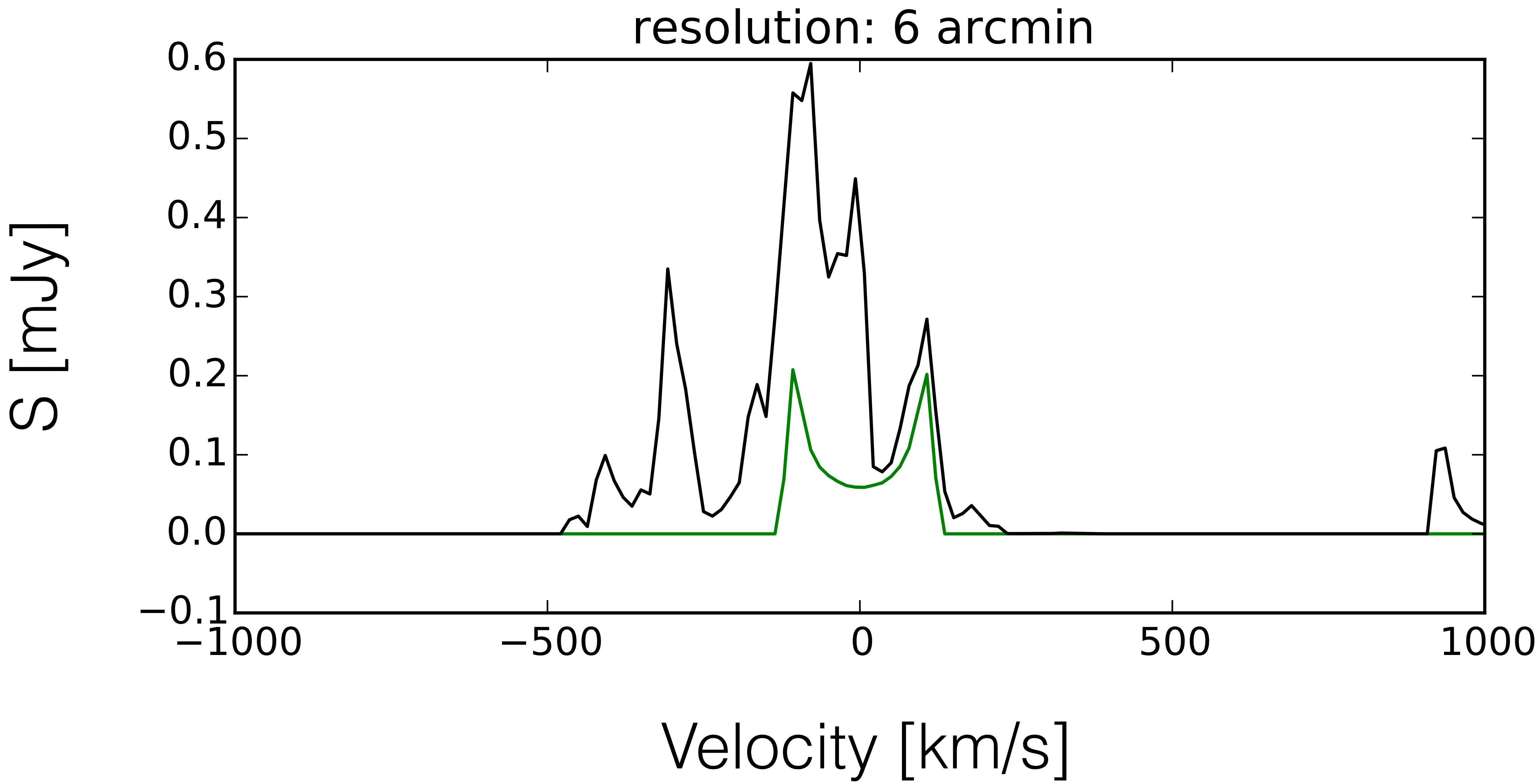

emission from target galaxy

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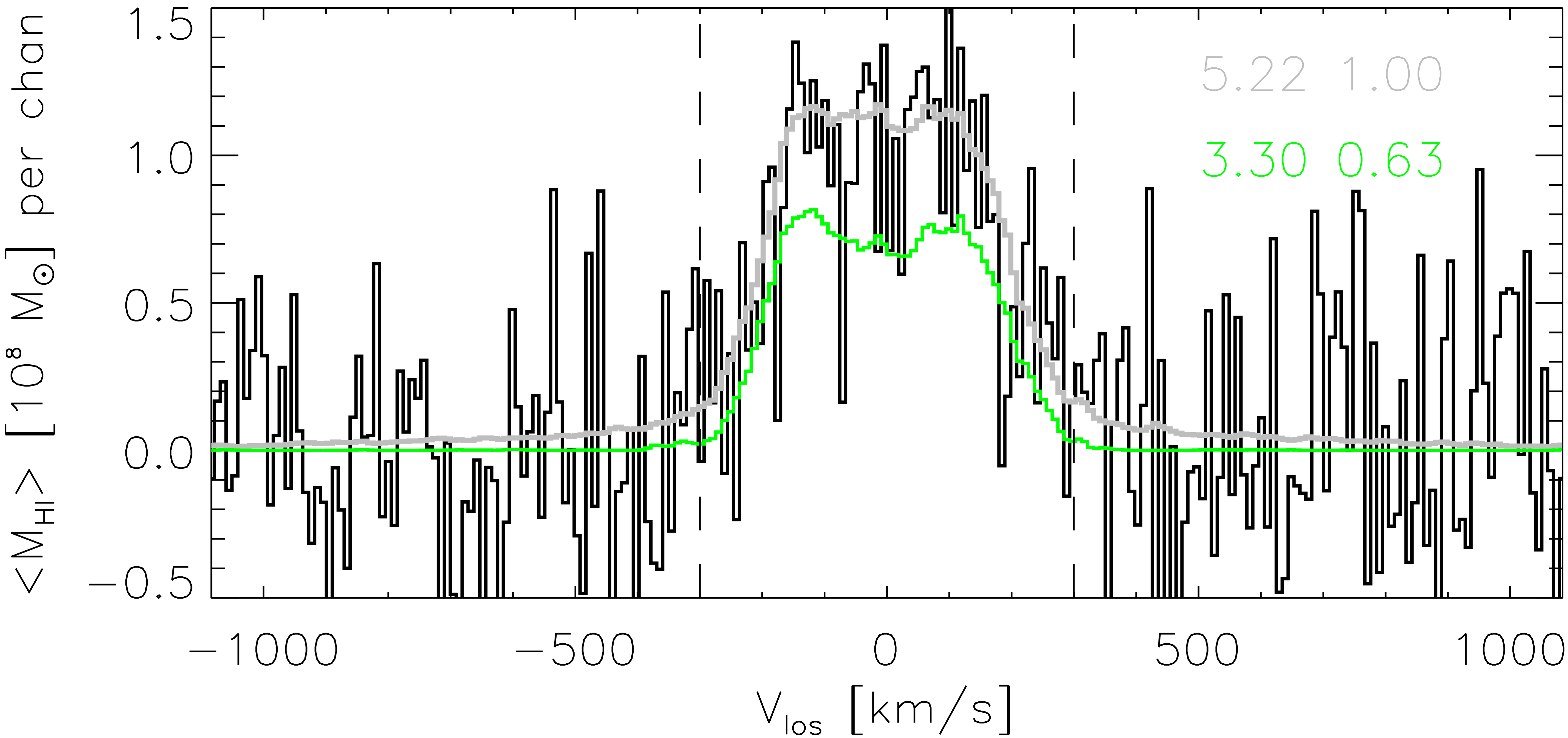
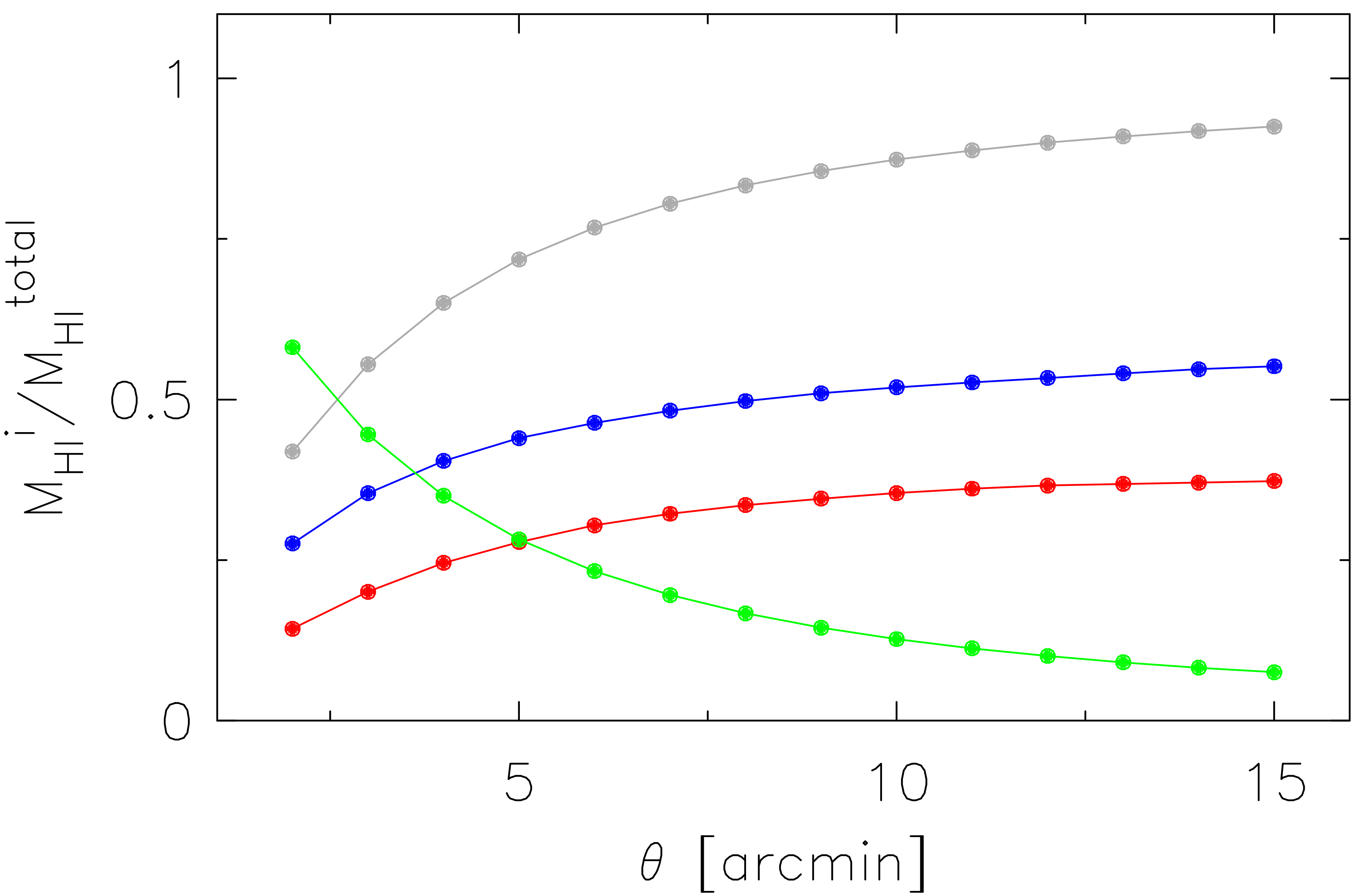
Co-added spectrum based on ~ 2700 spectra extracted from noise-filled simulated HI cube:



Amount of co-added signal is **too high** by factor ~ 1.58

Resolution matters a lot!!



Elson, Blyth, Baker (2016)
MNRAS460.4366

Above: fractional contribution of targets (green) to total co-added mass (grey) as function of resolution, for z=0 stacking experiment.

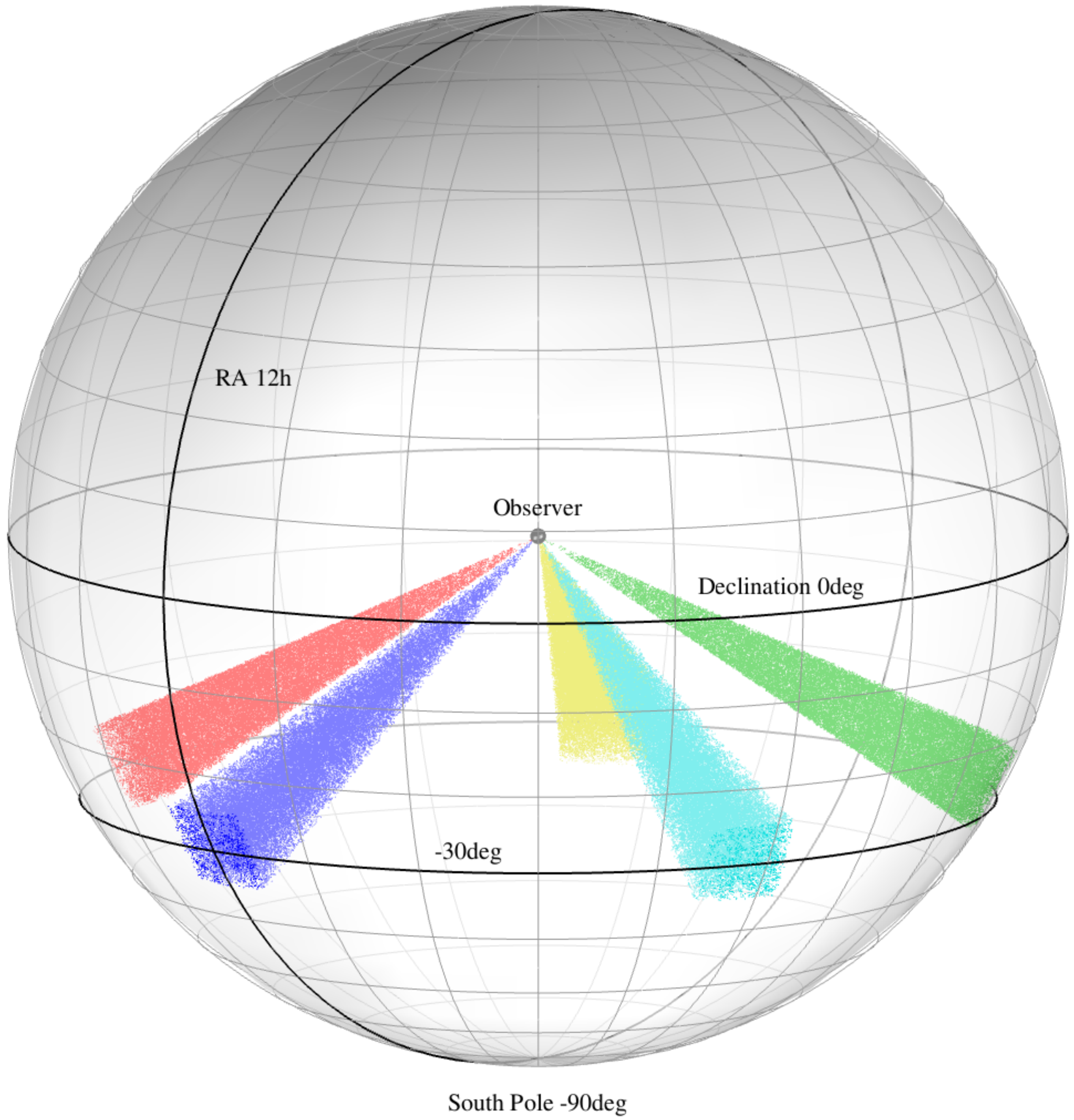
Simulations

- Pipeline to convert catalogue of galaxy parameters into a realistic synthetic HI data cube.
- Obreschkow & Meyer (2014) catalogues:
    - Based on S^3-SAX (Obreschkow+, 2009)
    - Physical models tracing evolution of HI and H_2 in +/- 3e7 galaxies.
    - Used as basis for SKA performance calculations.

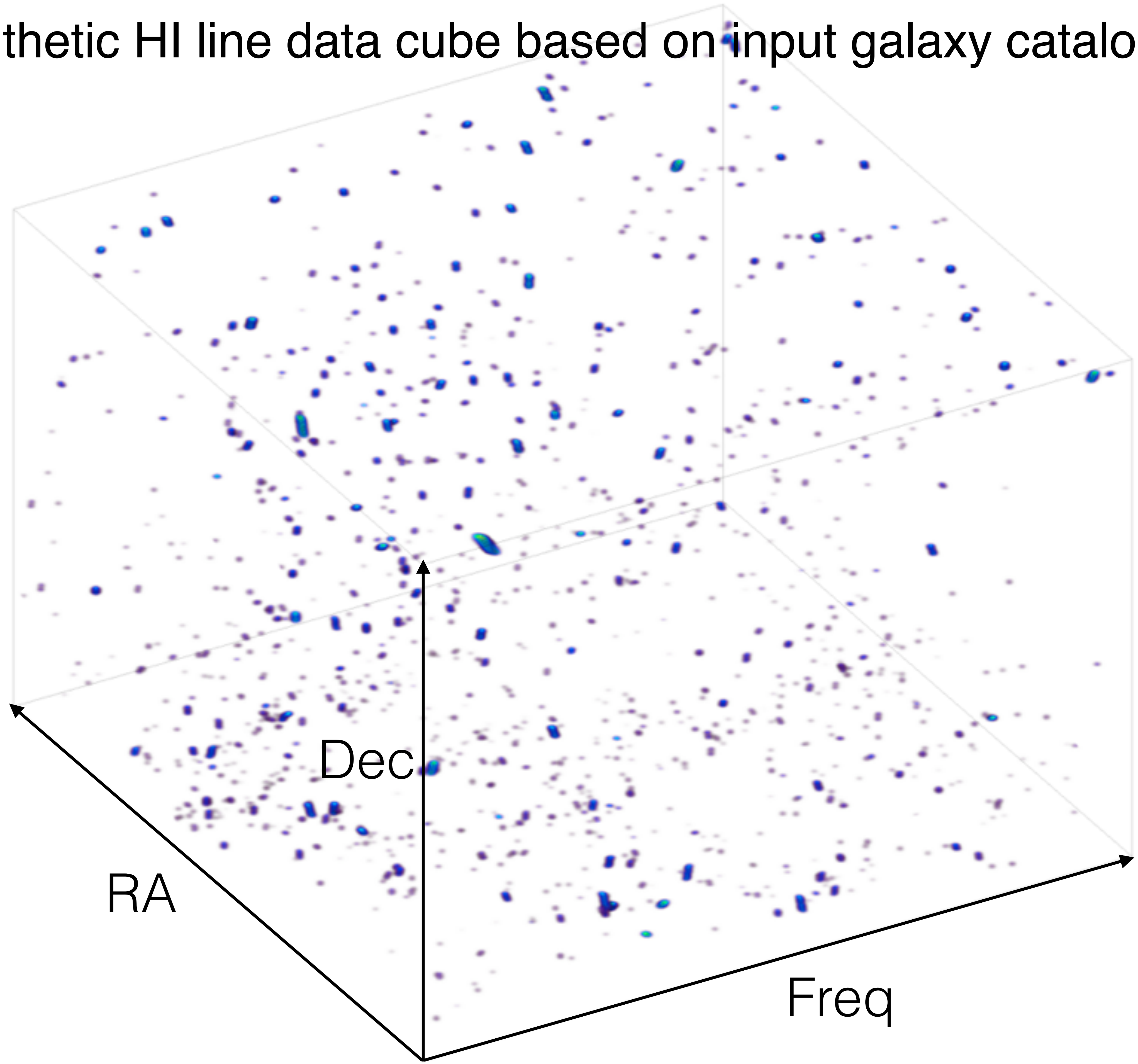
Obreschkow & Meyer (2014) sims:

Symbol	Unit	Description
ID	–	Unique galaxy identifier in the Munich Semi-Analytic Model "DeLucia2006a"
RA	deg	Right ascension of galaxy centre
Dec	deg	Declination of galaxy centre
z	–	Apparent redshift of galaxy centre, including the Doppler component due to peculiar motion relative to the Hubble expansion
i	deg	Galaxy inclination defined as the smaller angle $(0° - 90°)$ between the line-of-sight and the rotational axis of the galaxy
T	–	Numerical Hubble type ($-6...0$ for ellipticals, $0...10$ for spirals, 99 for morphologically unresolved objects, mostly dwarfs)
M_*	$M_\odot$	Stellar mass
$M_{\rm H\,I}$	$M_\odot$	Mass of neutral atomic hydrogen H I, without helium
$M_{\rm H_2}$	$M_\odot$	Mass of molecular hydrogen H_2, without helium
$S^{\rm int}_{\rm H\,I}$	$\rm Jy\,km\,s^{-1}$	Velocity-integrated flux of the redshifted 21 cm H I emission line, with velocity units defined in the galaxy rest-frame
$S^{\rm peak}_{\rm H\,I}$	Jy	Peak flux density of the H I emission line; typically the flux density of the 'horns'
$S^{\rm int}_{\rm CO}$	$\rm Jy\,km\,s^{-1}$	Velocity-integrated flux of the redshifted 115.27 GHz ^{12}CO(1–0) emission line, with velocity units defined in the galaxy rest-frame
$S^{\rm peak}_{\rm CO}$	Jy	Peak flux density of the ^{12}CO(1–0) emission line; typically the flux density of the 'horns'
$W^{50}_{\rm H\,I}$	$\rm km\,s^{-1}$	Width of the H I emission line, in galaxy rest-frame velocity units, measured at 50% of the peak flux density
$W^{20}_{\rm H\,I}$	$\rm km\,s^{-1}$	Width of the H I emission line, in galaxy rest-frame velocity units, measured at 20% of the peak flux density
$r^{\rm edge}_{\rm H\,I}$	arcsec	Apparent H I radius along the major axis out to a H I disk surface density of $1\,\rm M_\odot pc^{-2}$, corresponding to a face-on column density of $1.25 \cdot 10^{20}\rm cm^{-2}$
$r^{\rm half}_{\rm H\,I}$	arcsec	Apparent H I half-mass radius along the major axis
$M_{\rm R}$	mag	Absolute Vega R-band magnitude, corrected for intrinsic dust extinction; 99 if stellar mass and star formation history are insufficiently resolved to compute $M_{\rm R}$
$m_{\rm R}$	mag	Apparent Vega R-band magnitude; value 99 if no absolute magnitudes available
$r_{\rm e}$	arcsec	Effective radius, here approximated as the radius containing half the stellar mass if the galaxy were viewed face-on

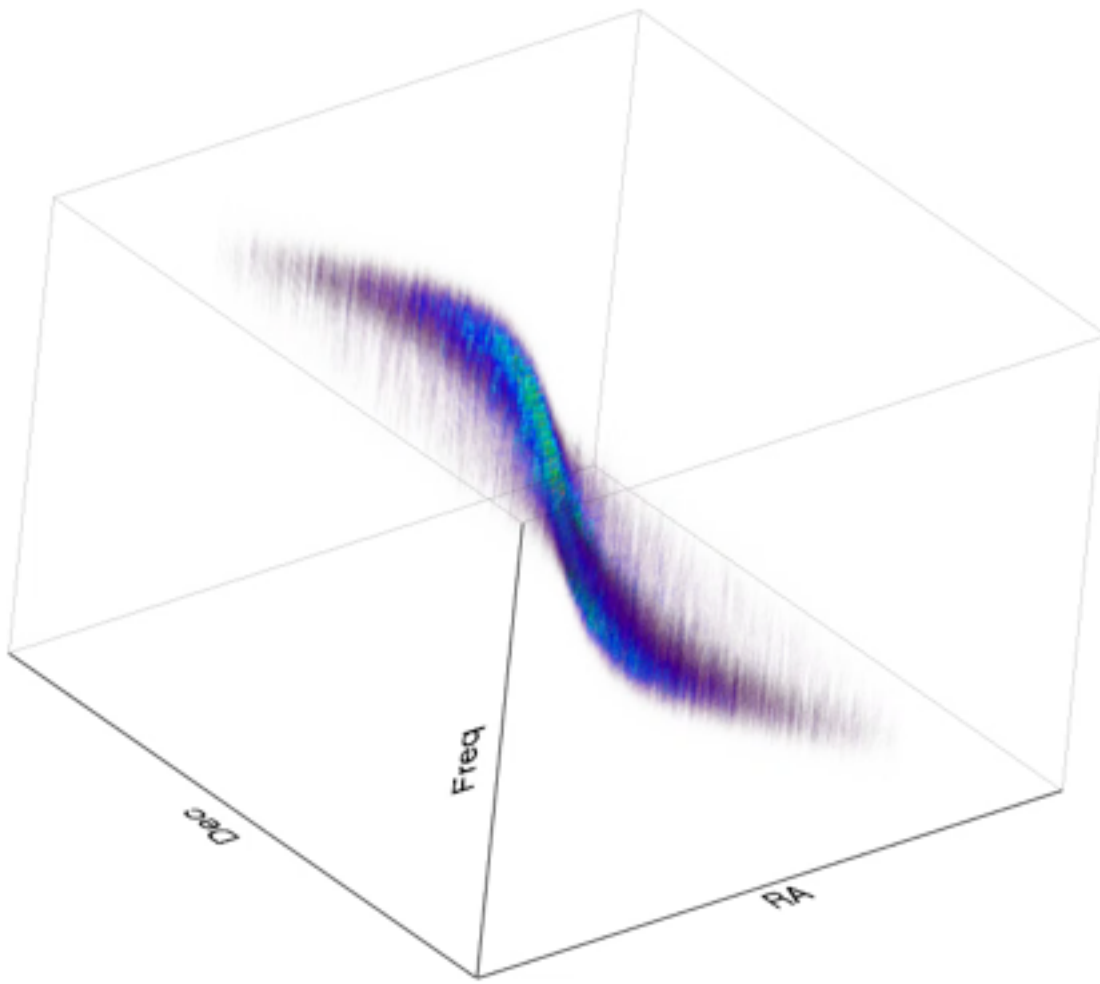
Table 1: Description of the columns of mock catalog in ASCII format.



Synthetic HI line data cube based on input galaxy catalogue:

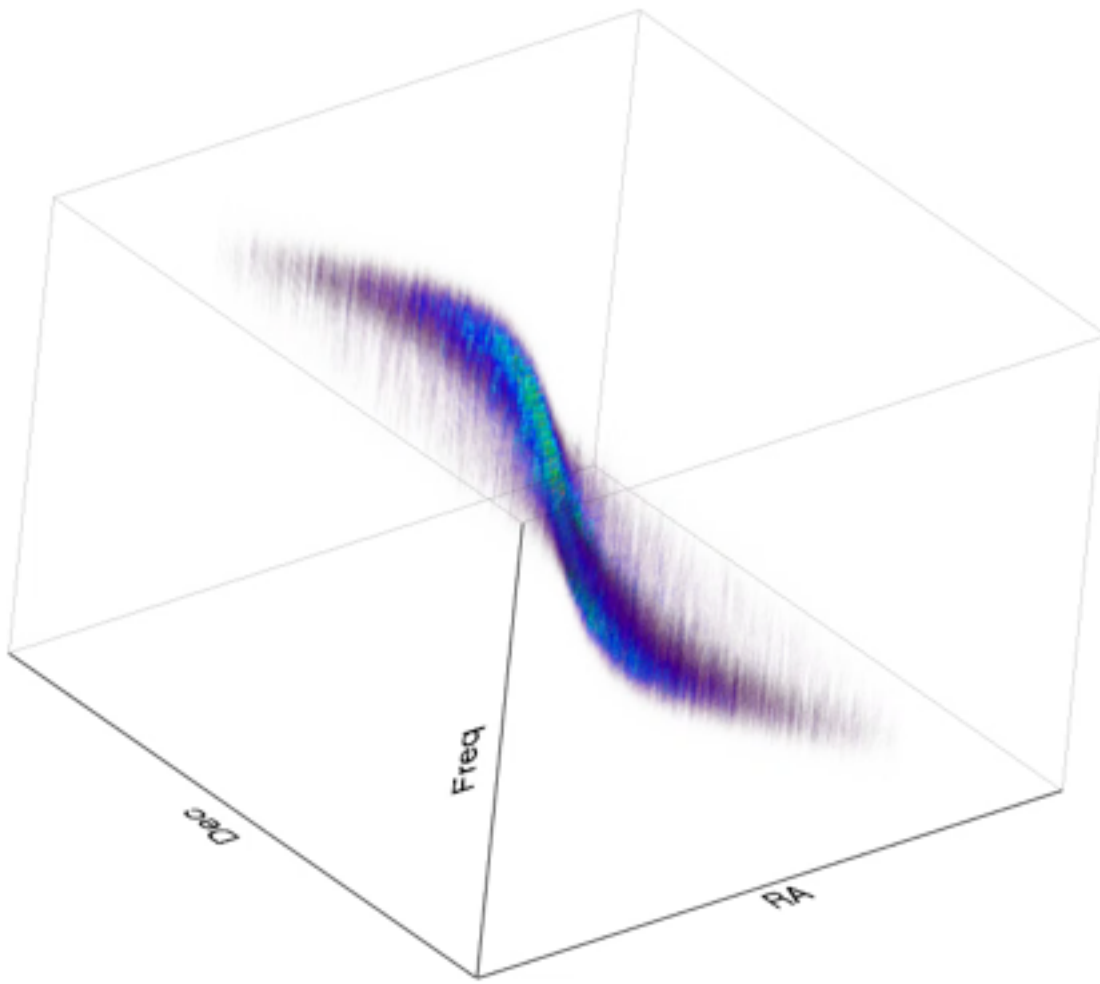


Galaxy models



- 3D model generated for each galaxy in catalogue.
- Realistic (unique) spatial & spectral HI distribution
- Fully automated using custom scripts.

Galaxy models



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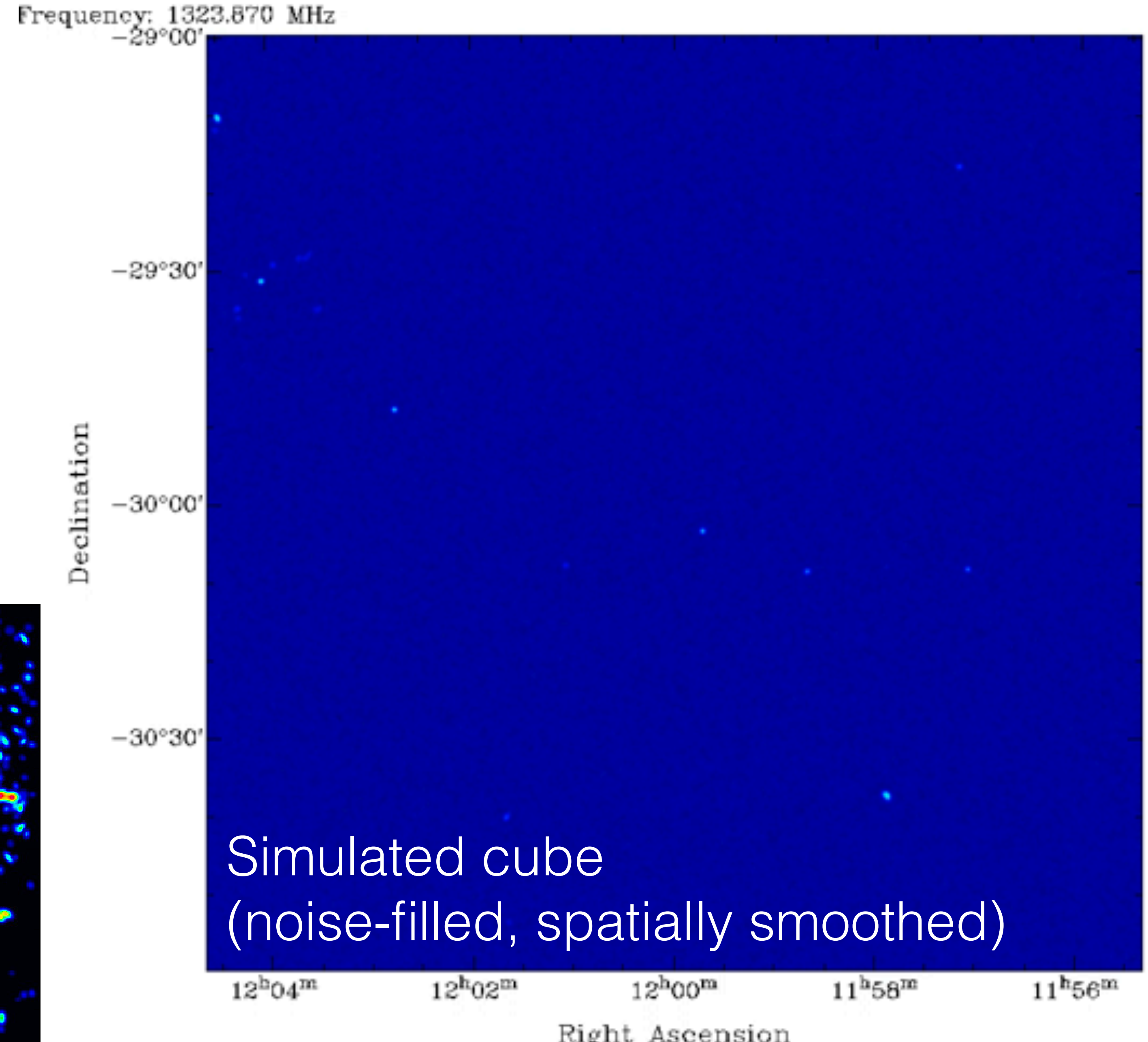
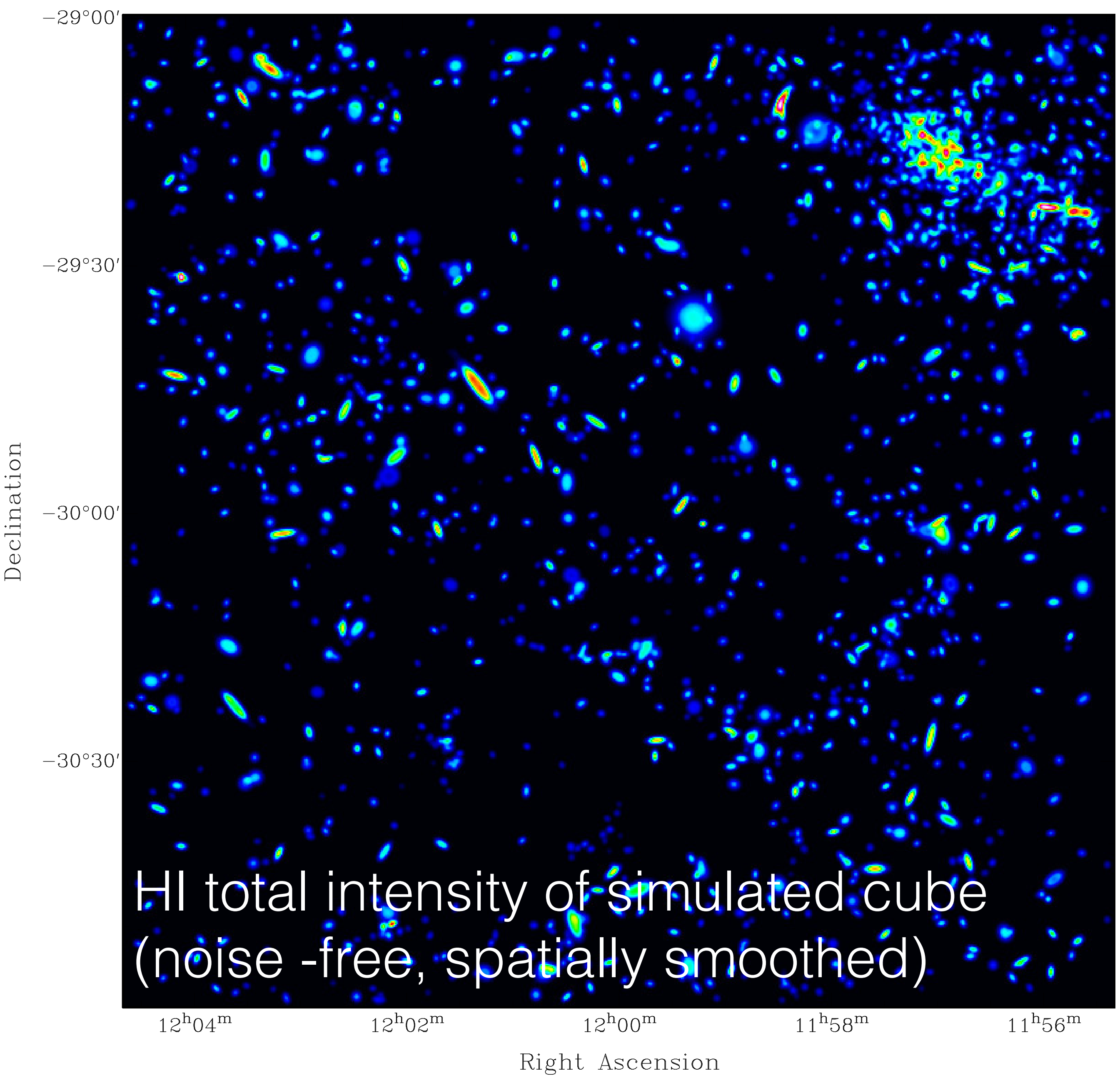


Frequency: 1323.870 MHz
−29°00′
−29°30′
−30°00′
−30°30′
Declination
12h04m
12h02m
12h00m
11h58m
11h56m
Right Ascension
Simulated cube
(noise-filled, spatially smoothed)



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HI total intensity of simulated cube
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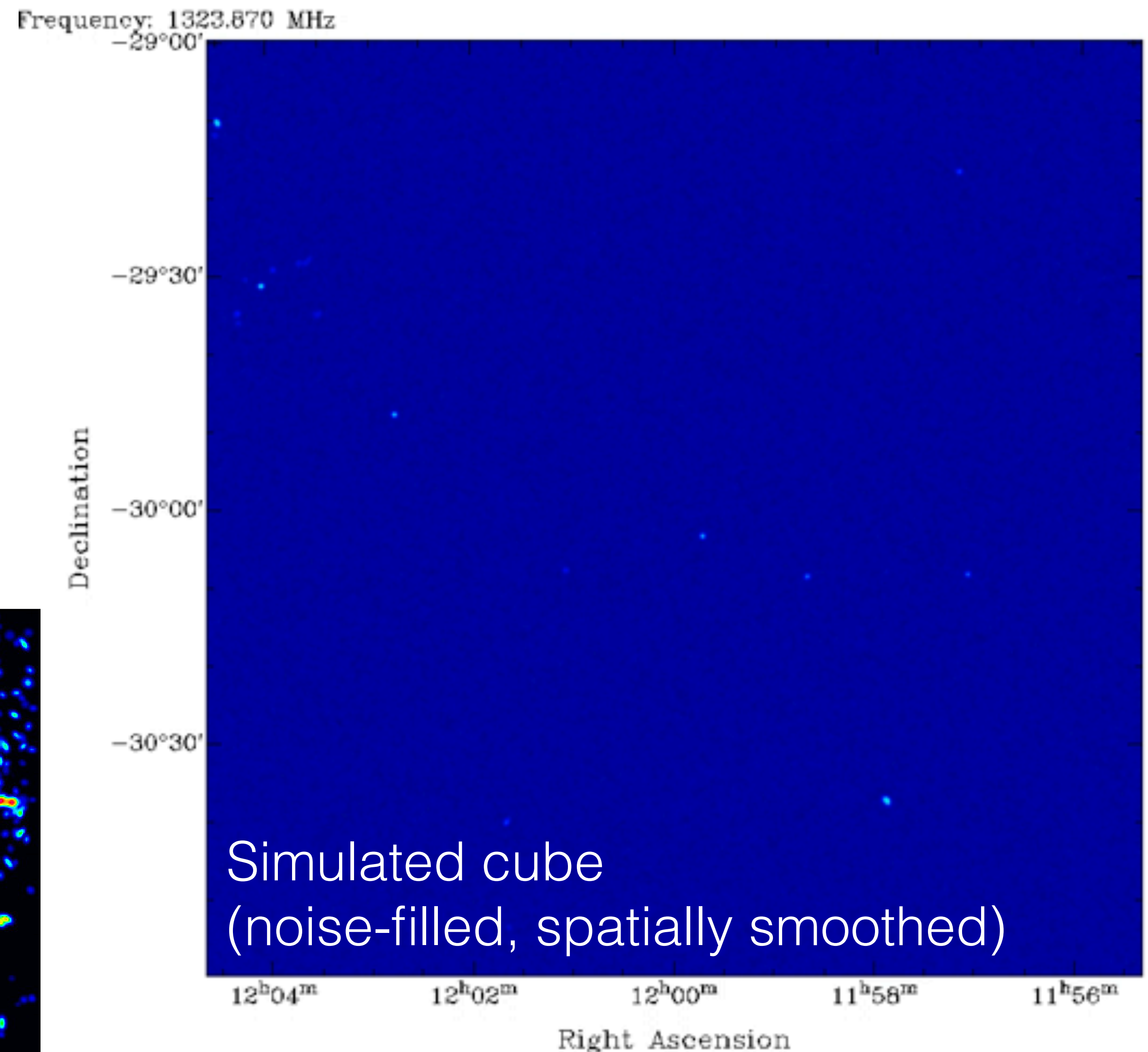
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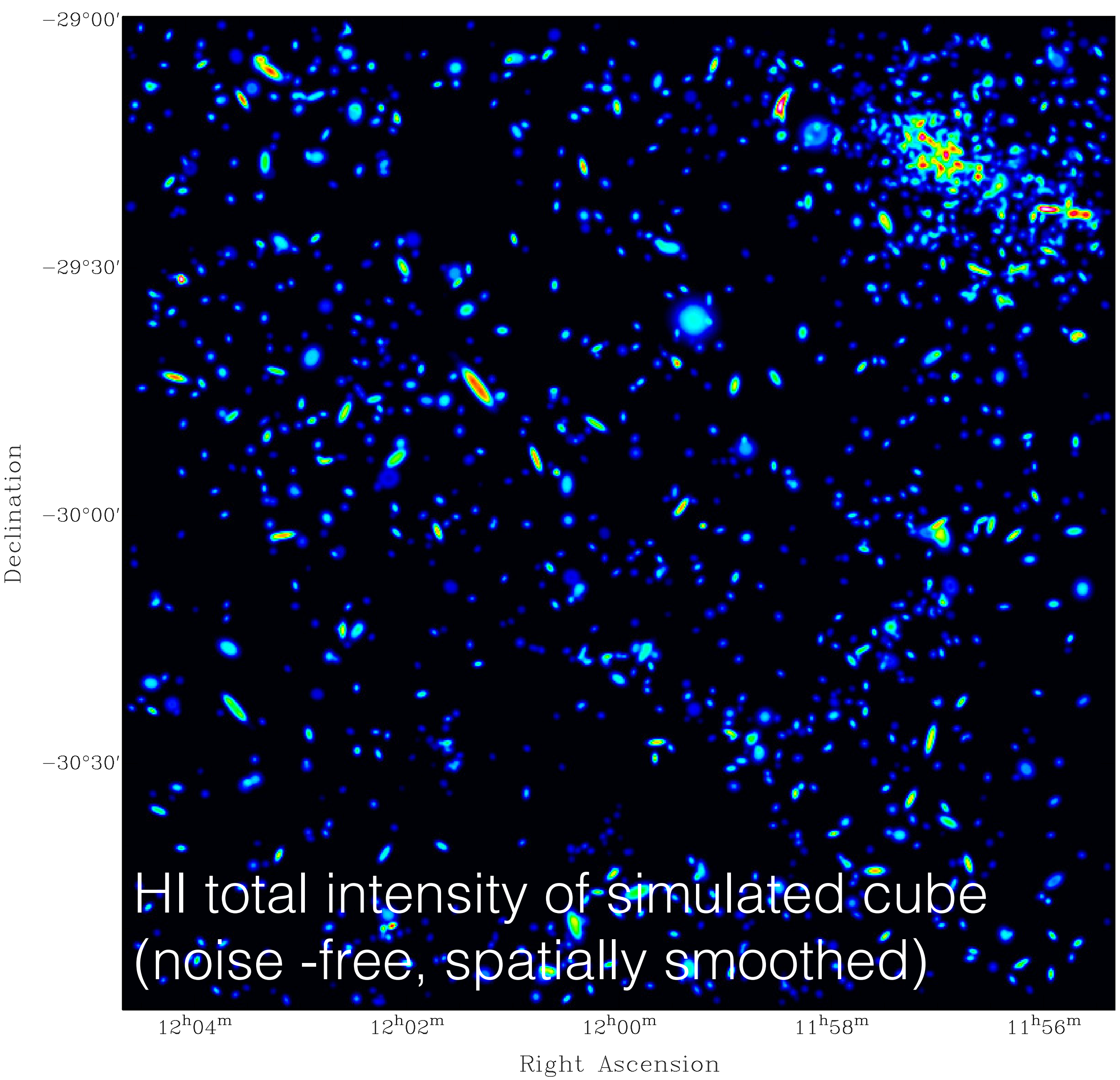
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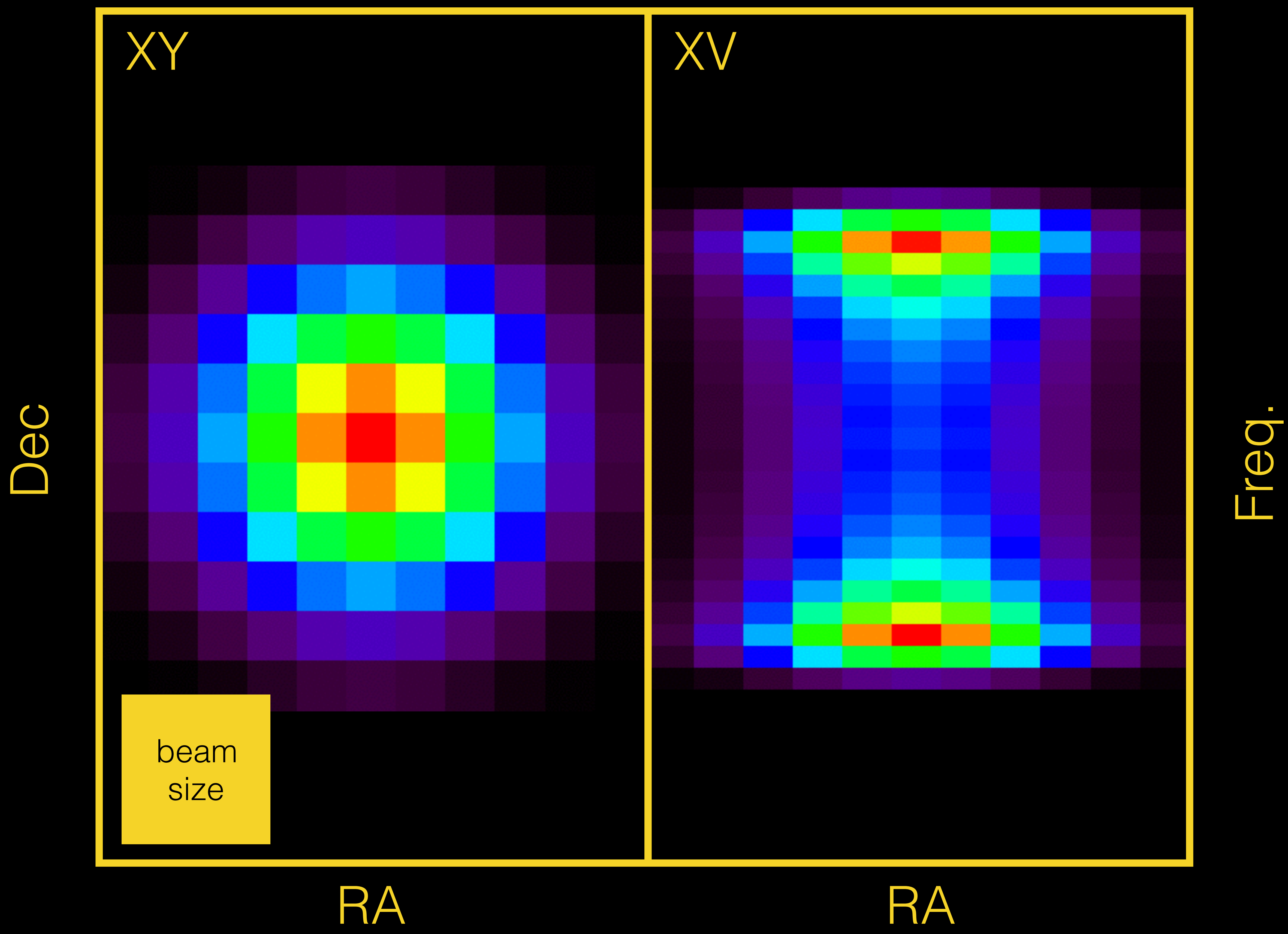
Extracting galaxy spectra

- 3 things needed to specify a sub-volume containing HI emission from a galaxy:
  - size of spatial aperture
  - size of spectral aperture
  - (x,y,z) location at which to centre the apertures

- There are many ways to do this.

Integrated XY & XV images of a model galaxy:



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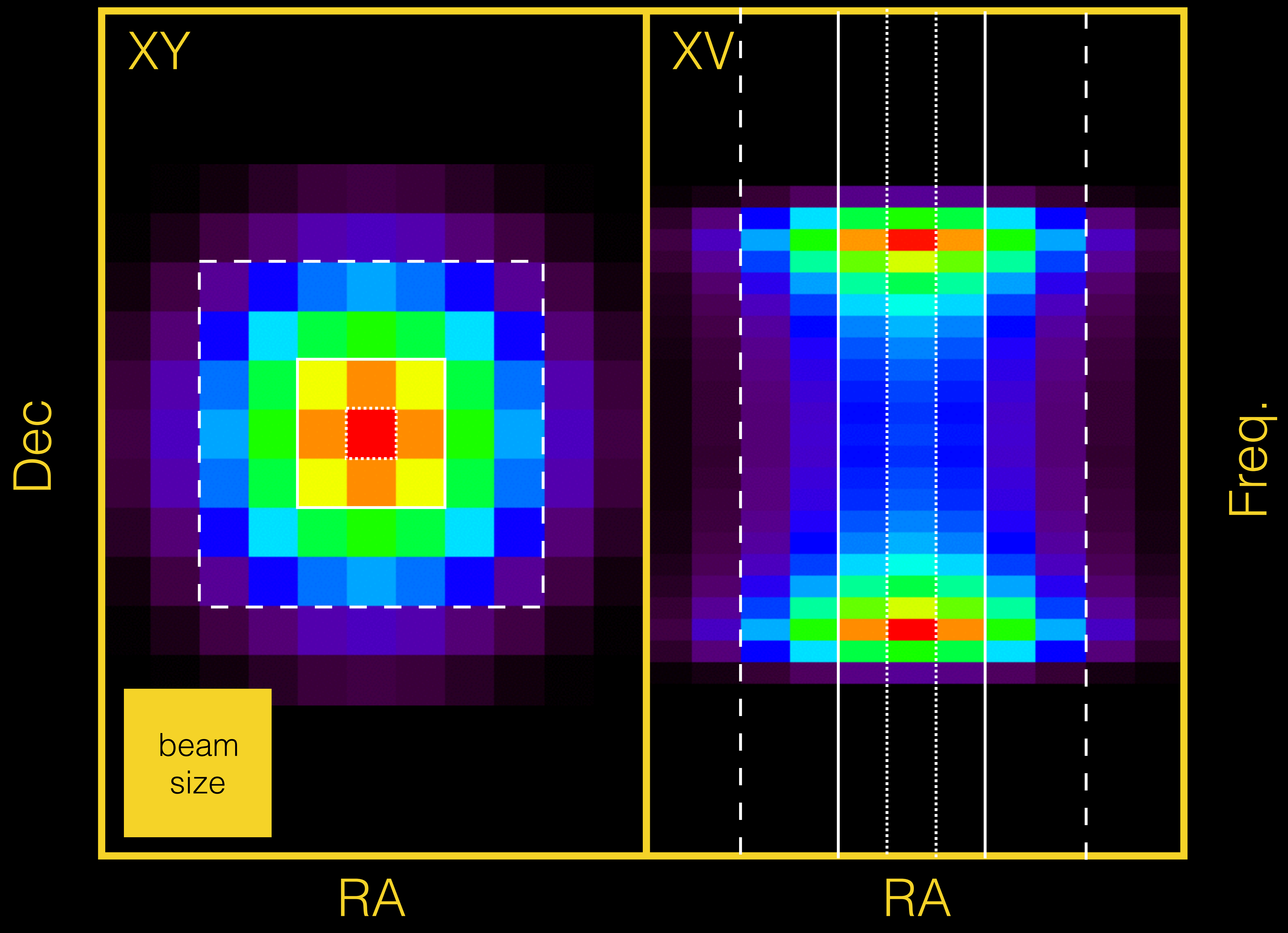

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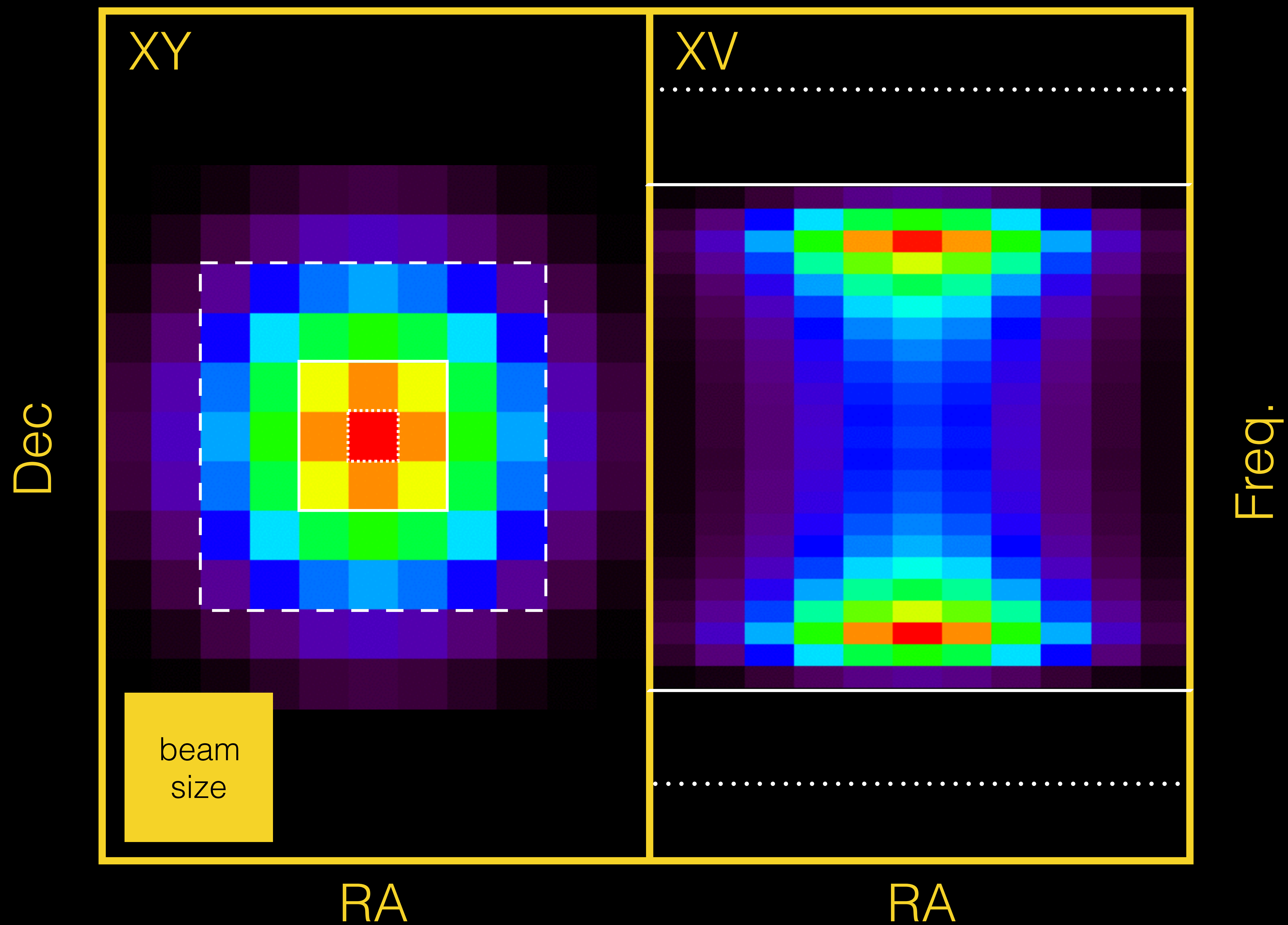

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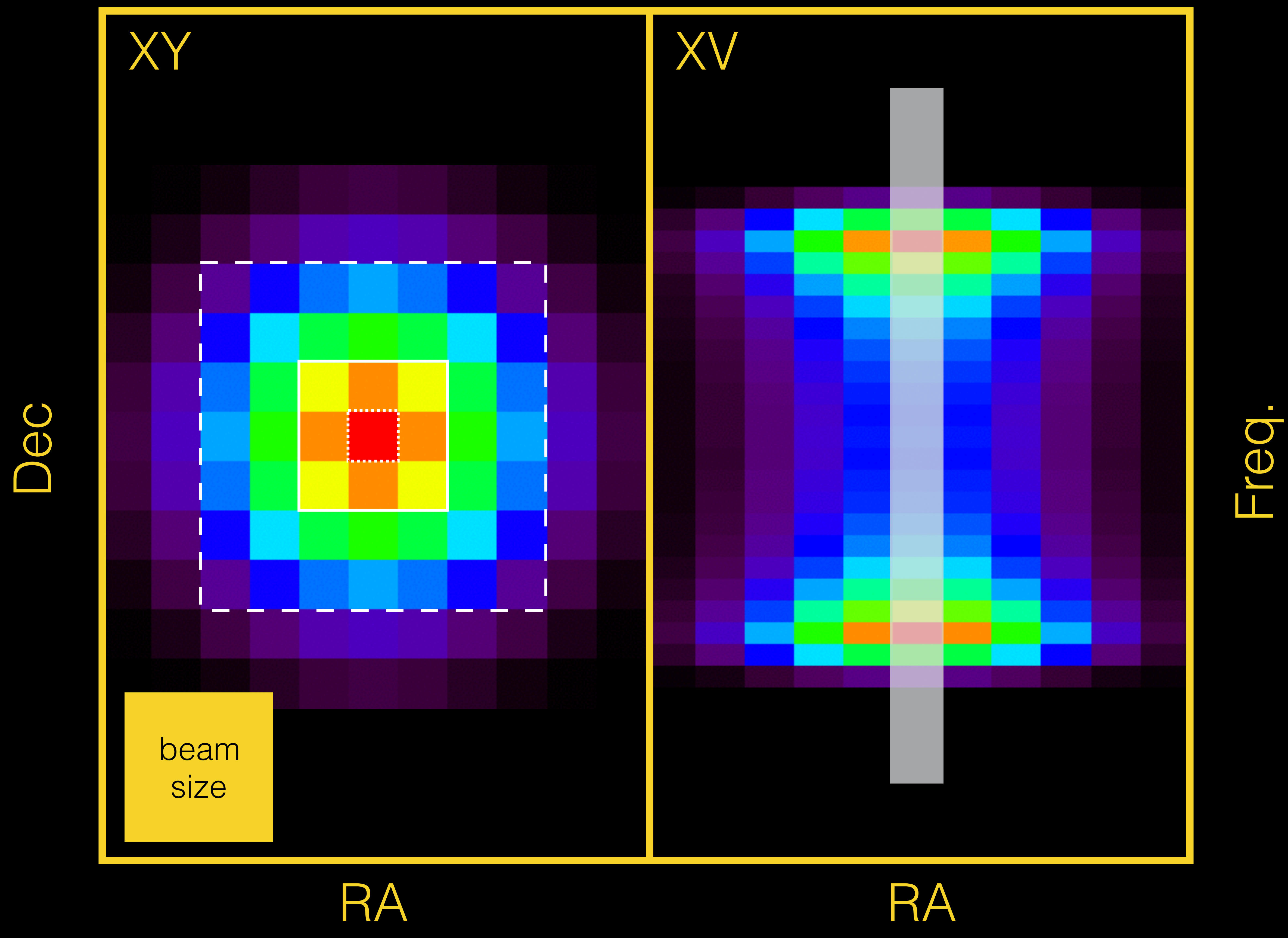

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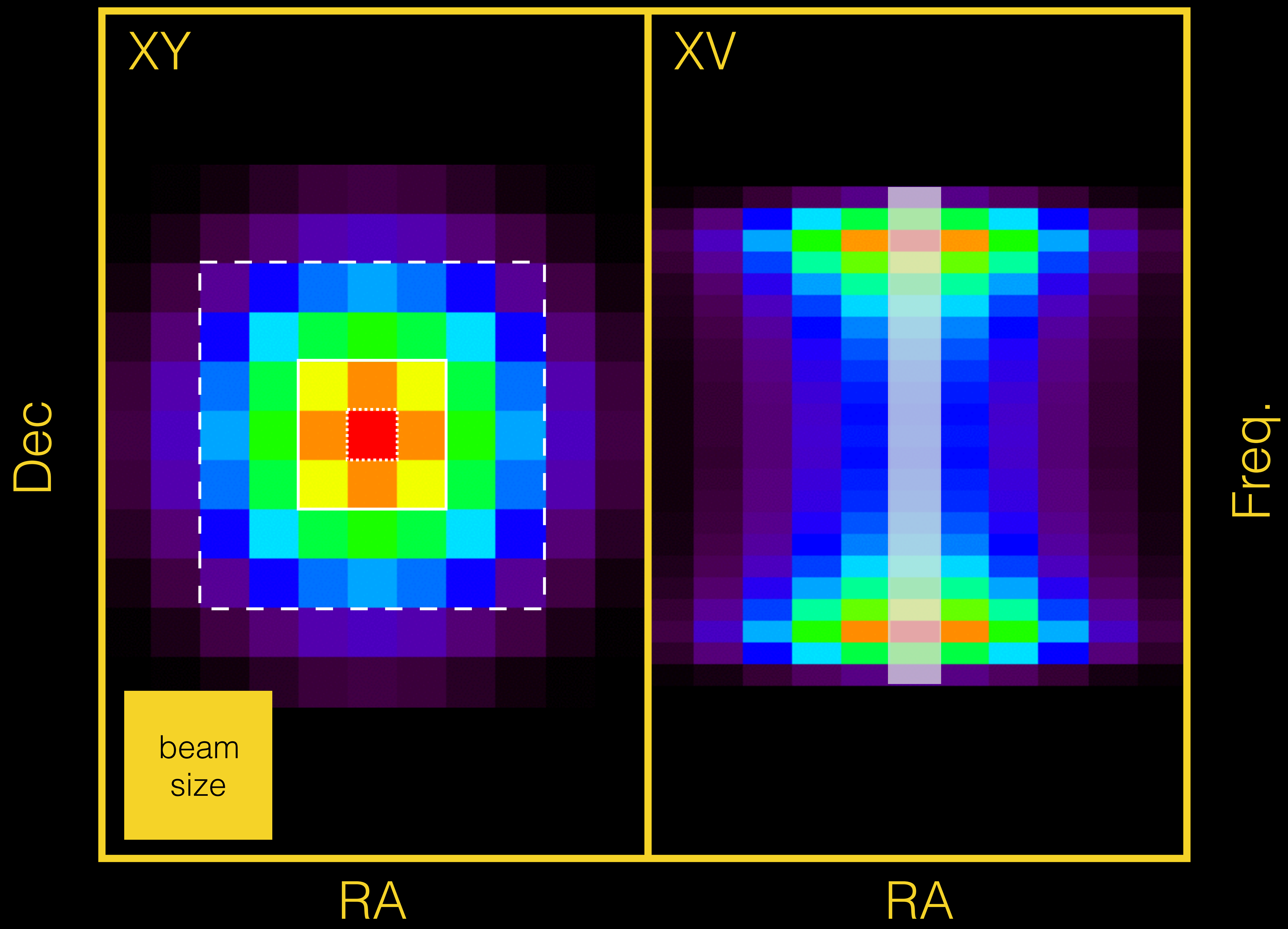

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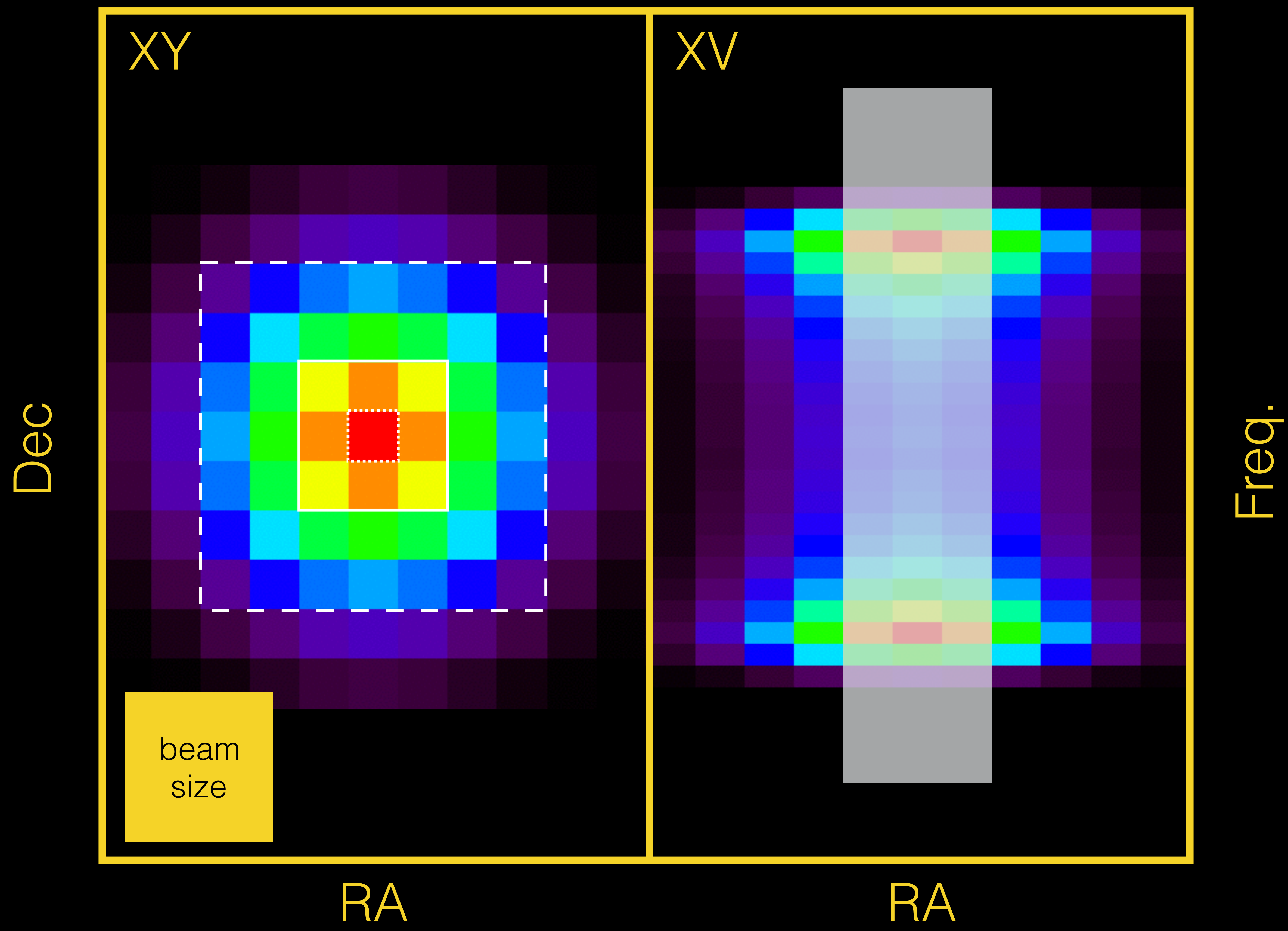

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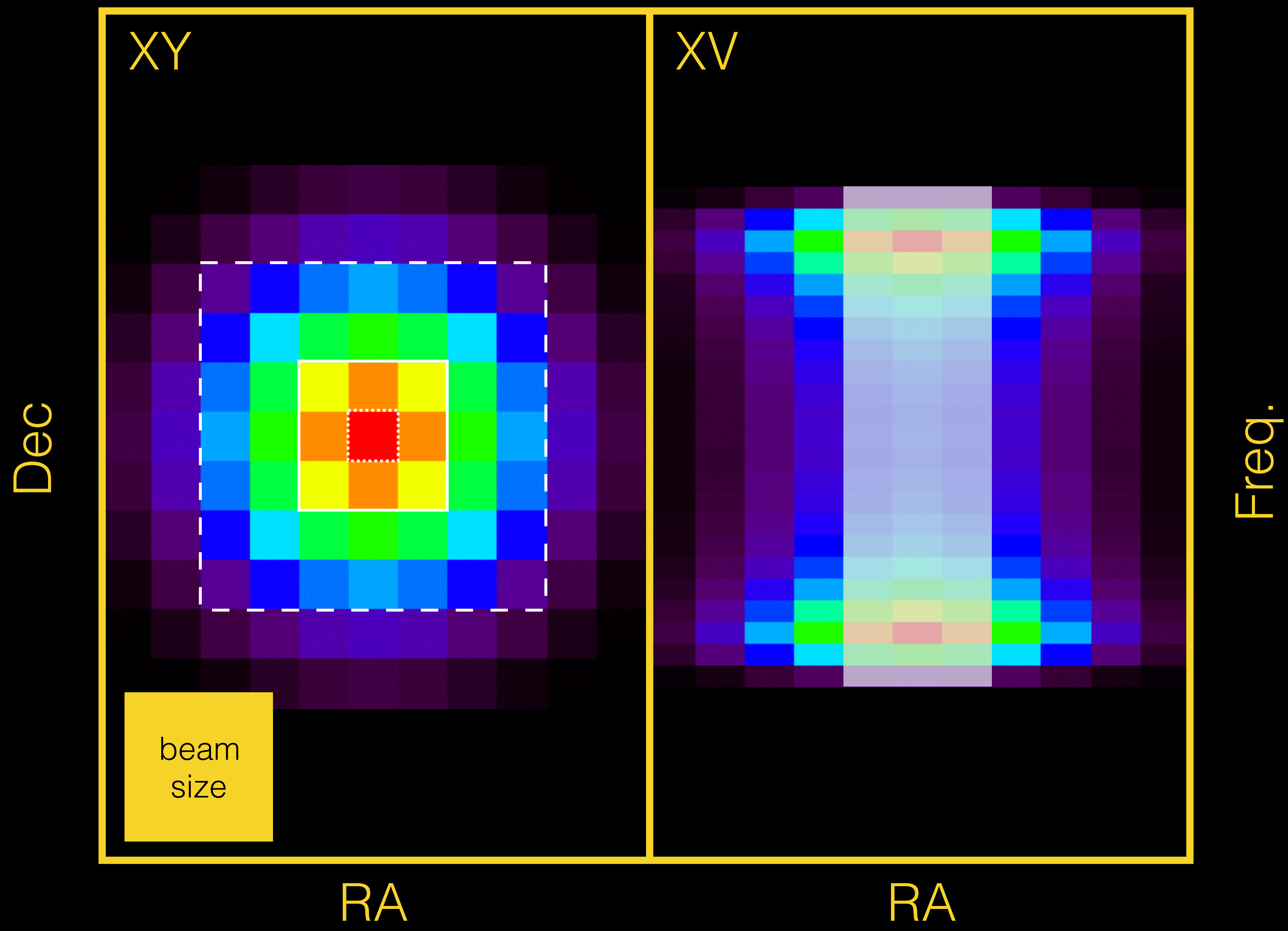

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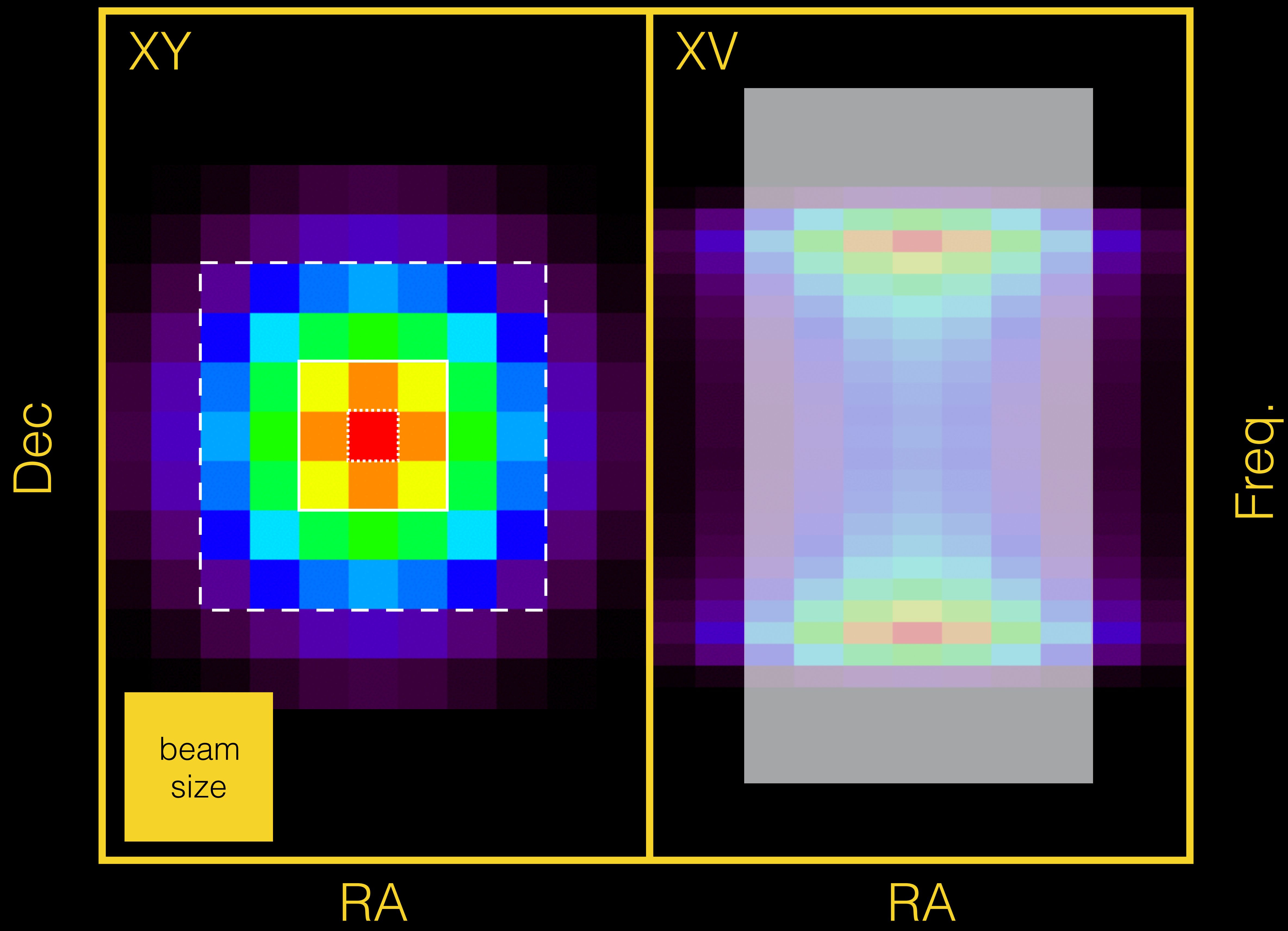

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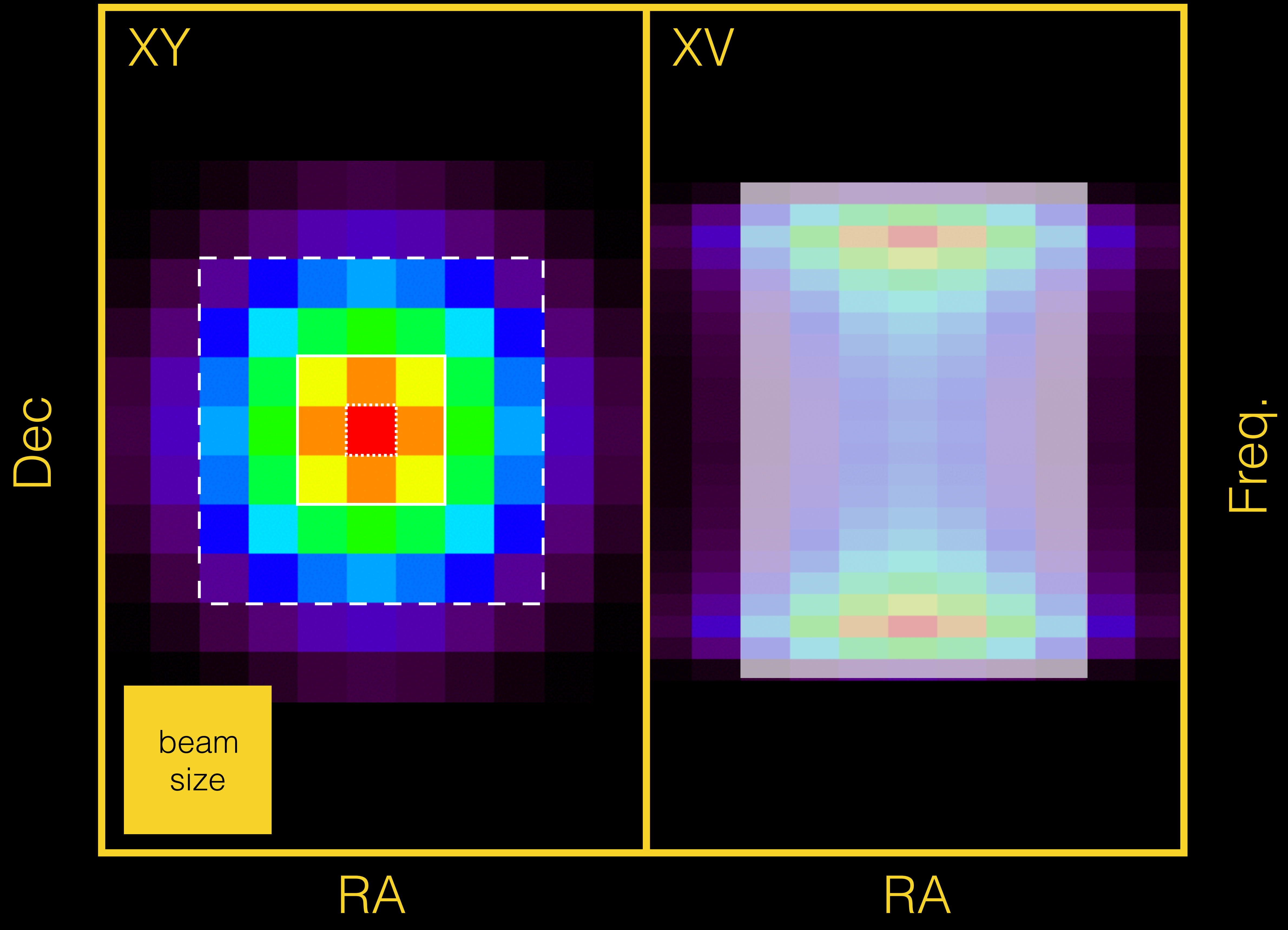

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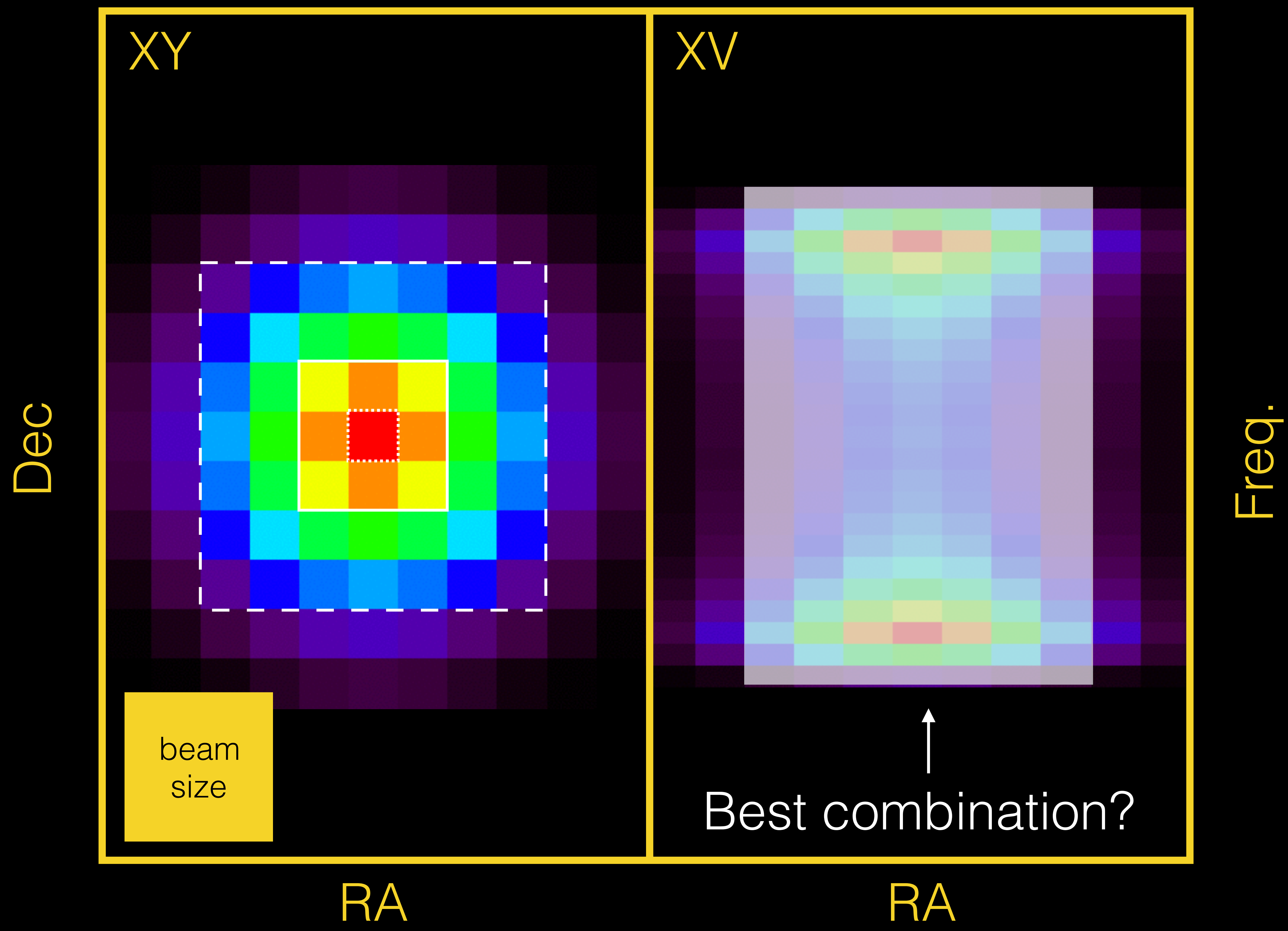

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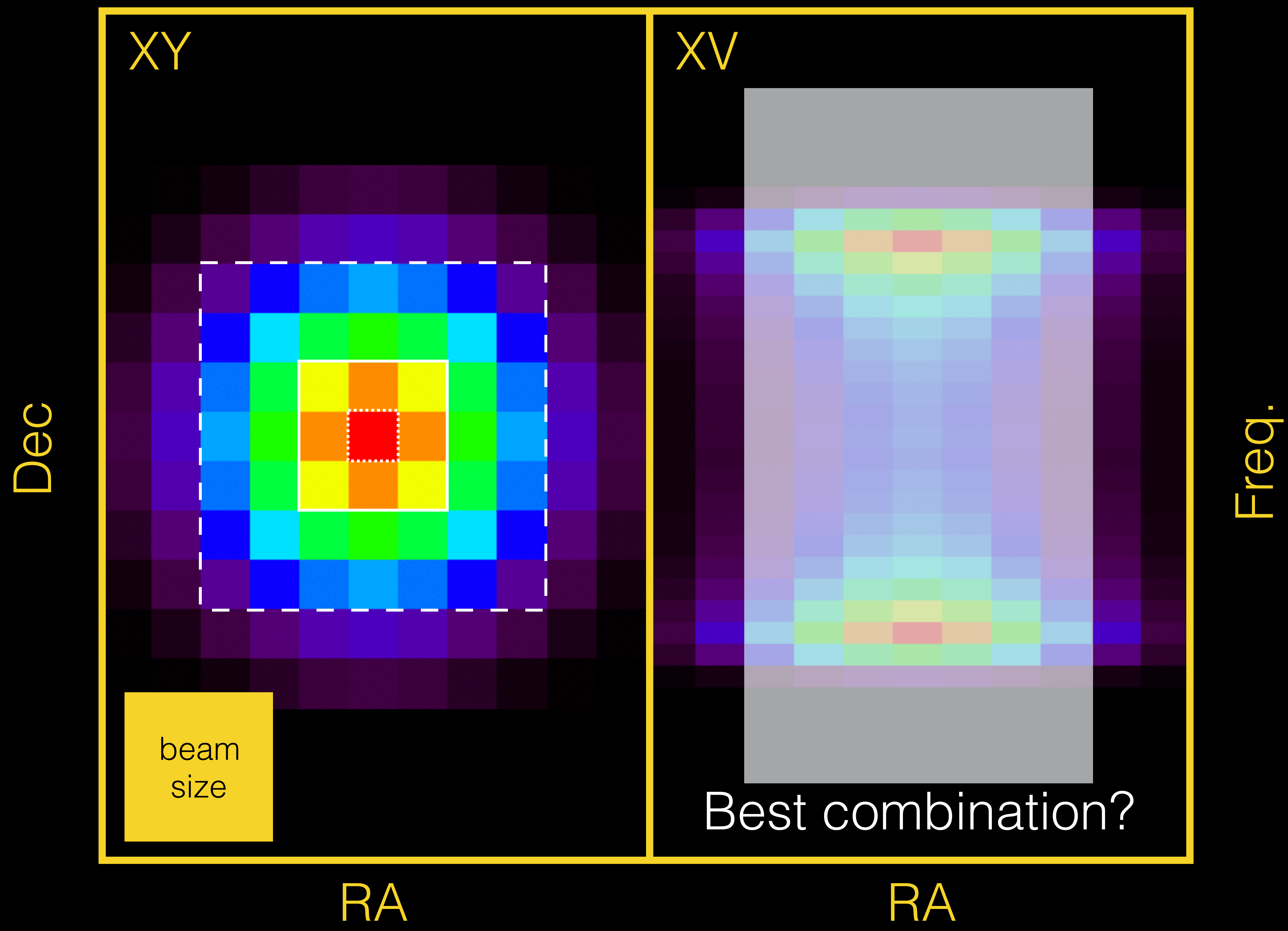
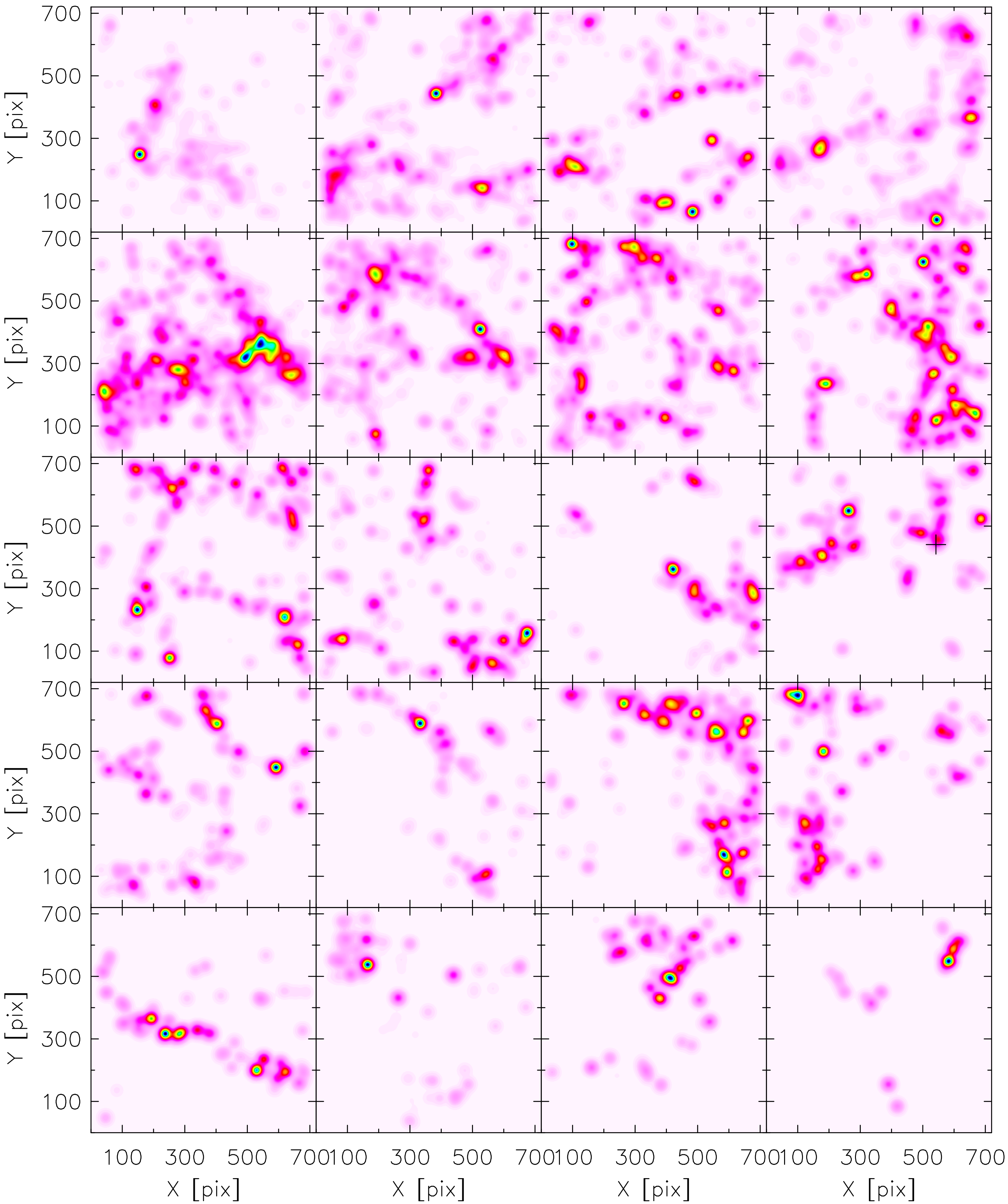
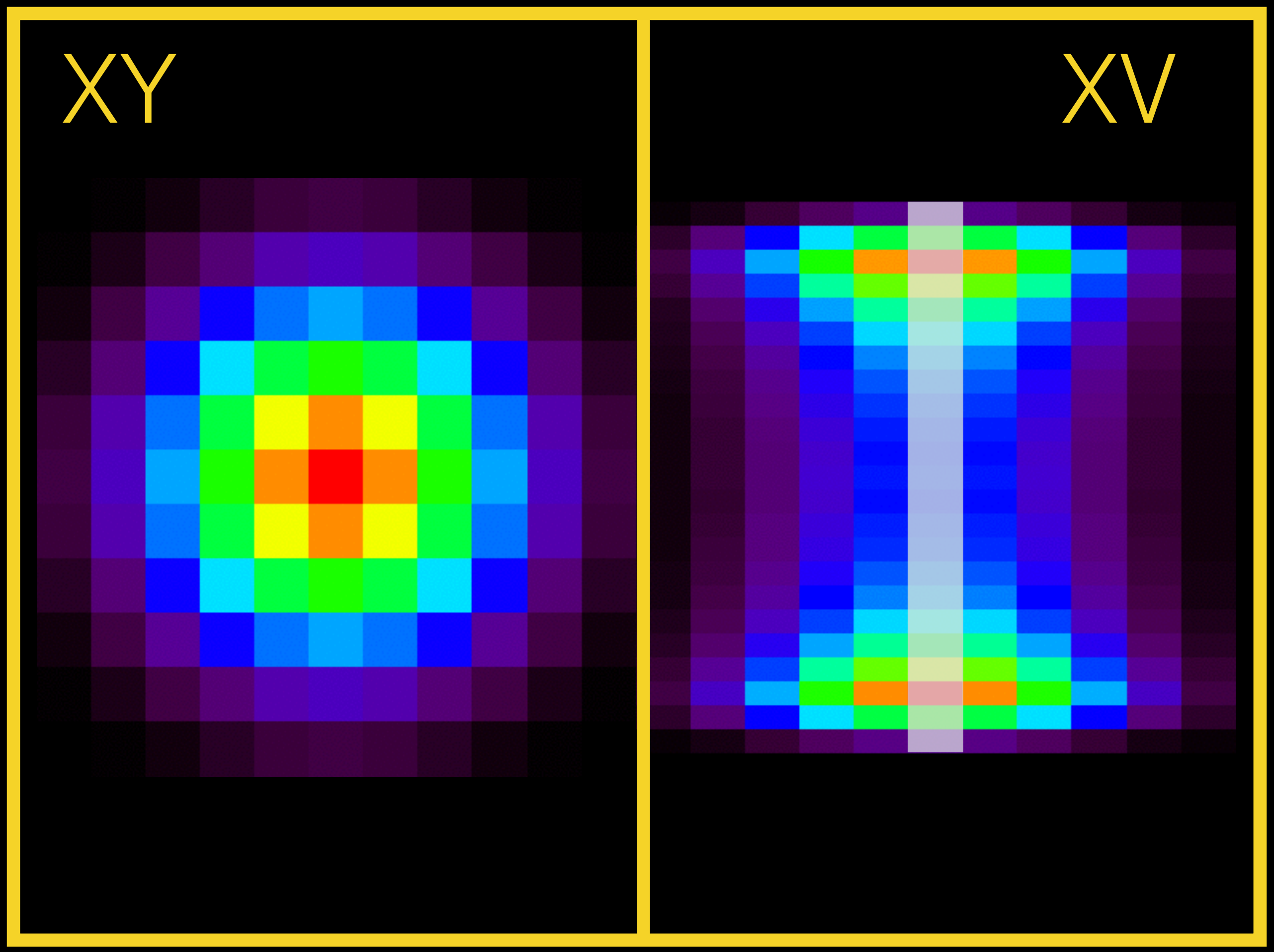
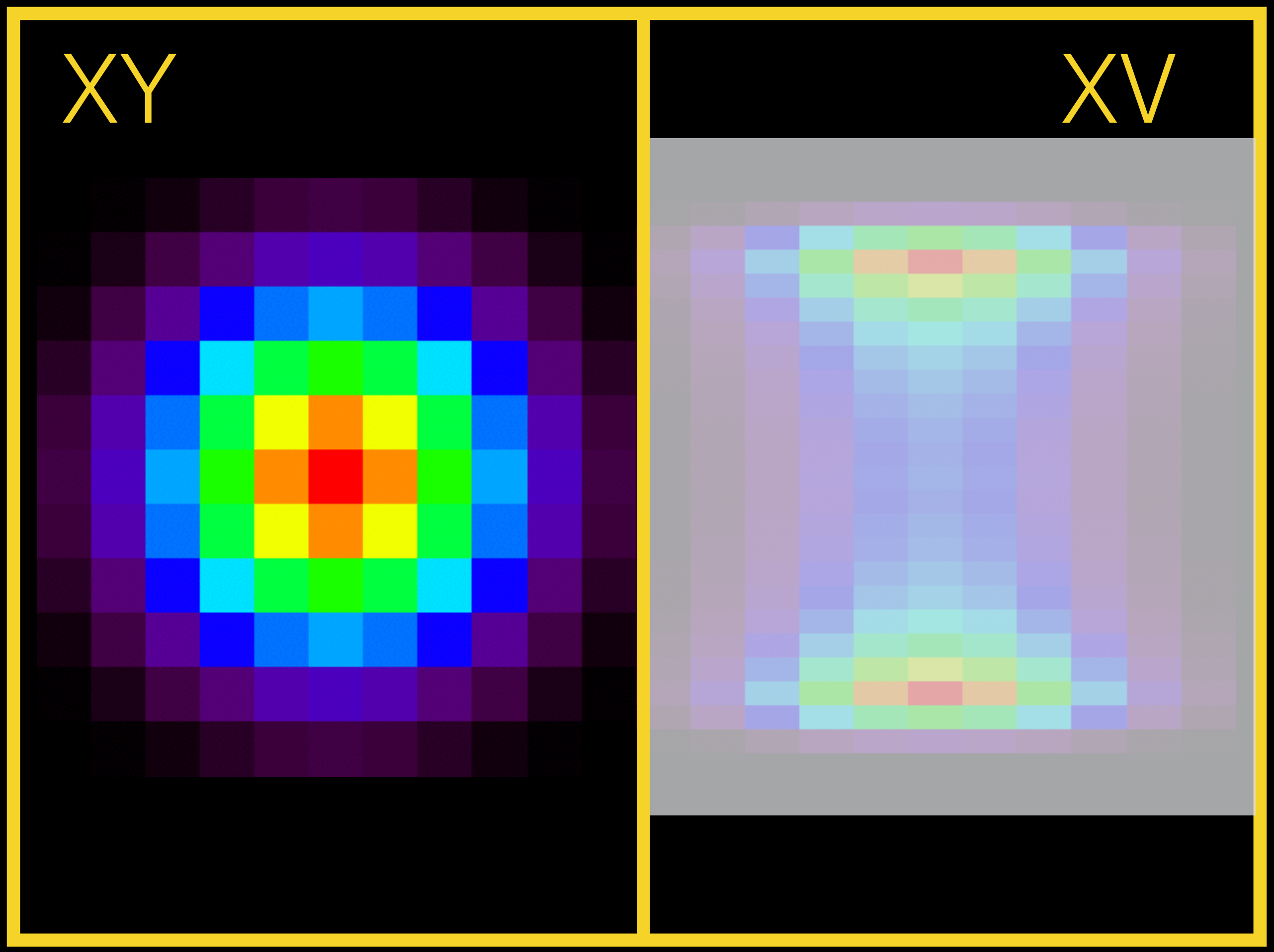




- Simulated HI cube (noise-free):
    - 30 deg²
    - z = 0.04 - 0.13
    - 48 234 galaxies
    - 15 arcmin res.
    - 1 panel = 10 channels ~ 143 km/s
    - Elson, Blyth, Baker (2016)



	Pros	Cons
small apertures	low contamination	incomplete target flux
big apertures	complete target flux	high contamination



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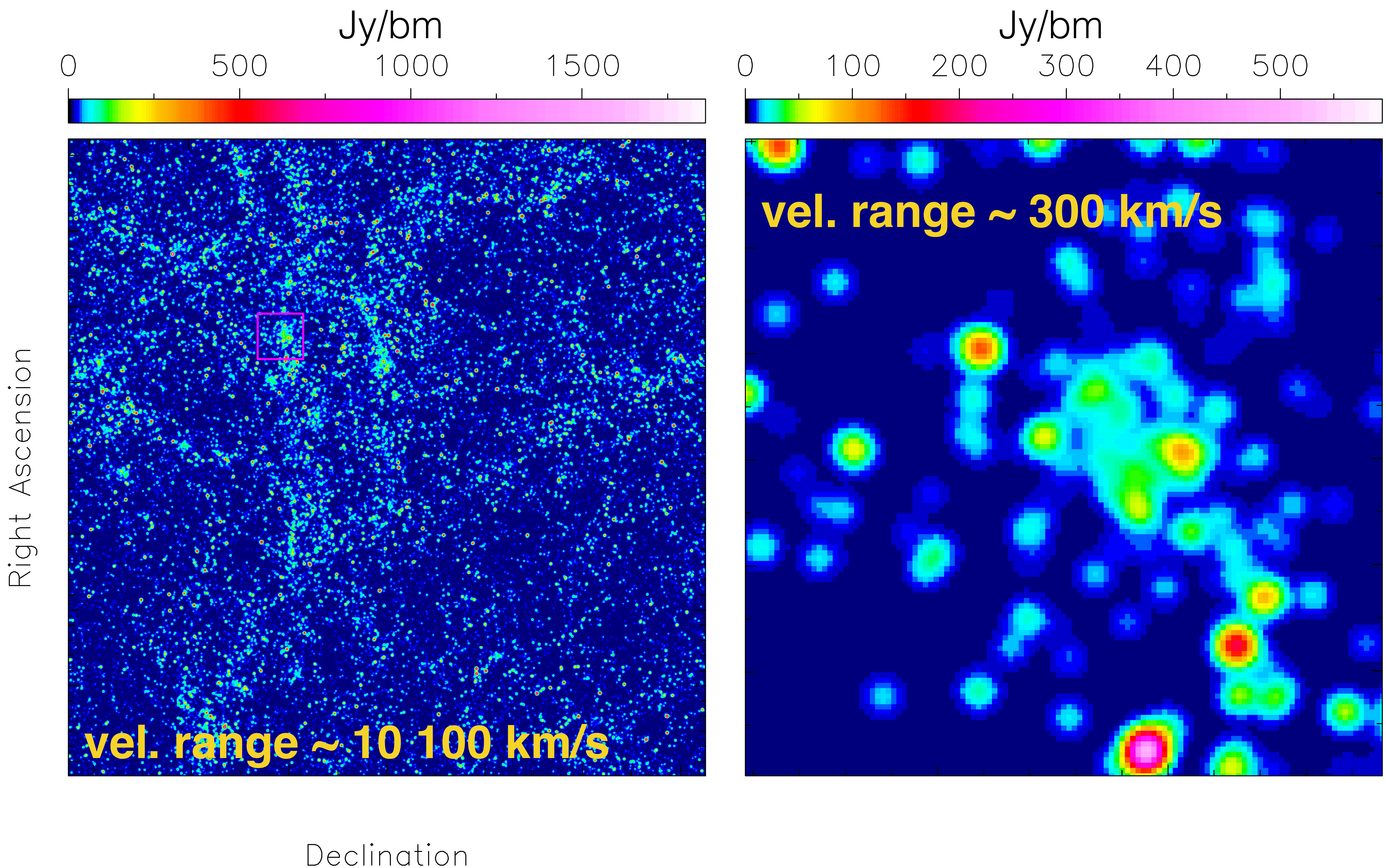
Mock stacking experiments

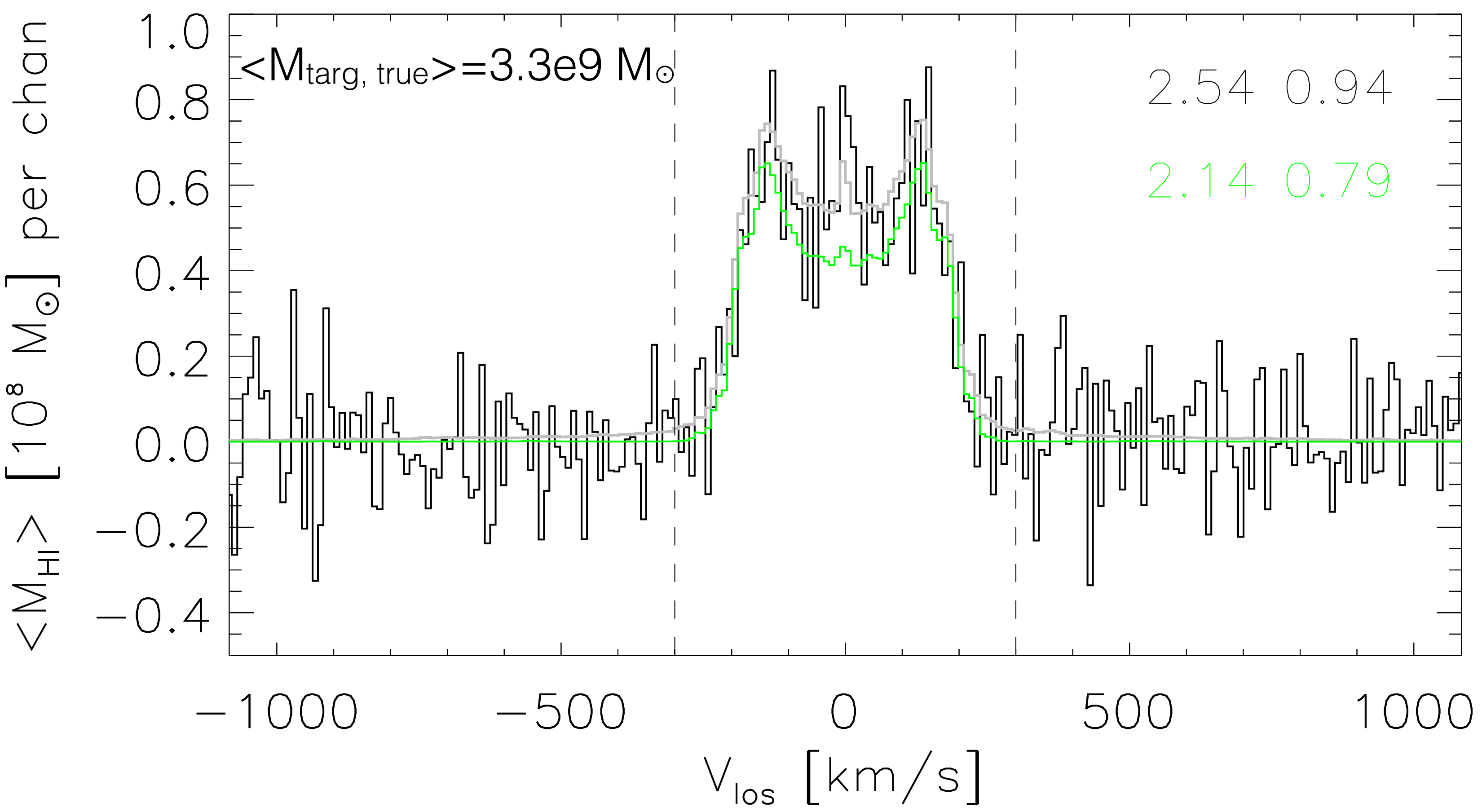
- In Elson, Blyth, Baker (2017, in prep.) we use a synthetic cube to carry out stacking experiments based on various aperture and z_{err} combinations.
- Cube properties:
    - 1.4° x 1.4°, z = 0.7 - 0.758
    - 15′′ arcsec resolution, 26 kHz channels (~ 9.5 km/s)
    - 52 622 galaxies
    - Gaussian noise, σ = 28.8e-6 Jy/bm (1000 hr LADUMA)
- Extracted spectra of galaxies with $M_* > 10^{10}\ M_\odot$.

Synthetic HI data cube (noise-free) total intensity maps:



Stacking experiment 1

- Extract all spectra over 230 channels (~ 2185 km/s) using spatial aperture sizes of 1, 2, 3 HPBWs (15′′, 30′′, 45′′).



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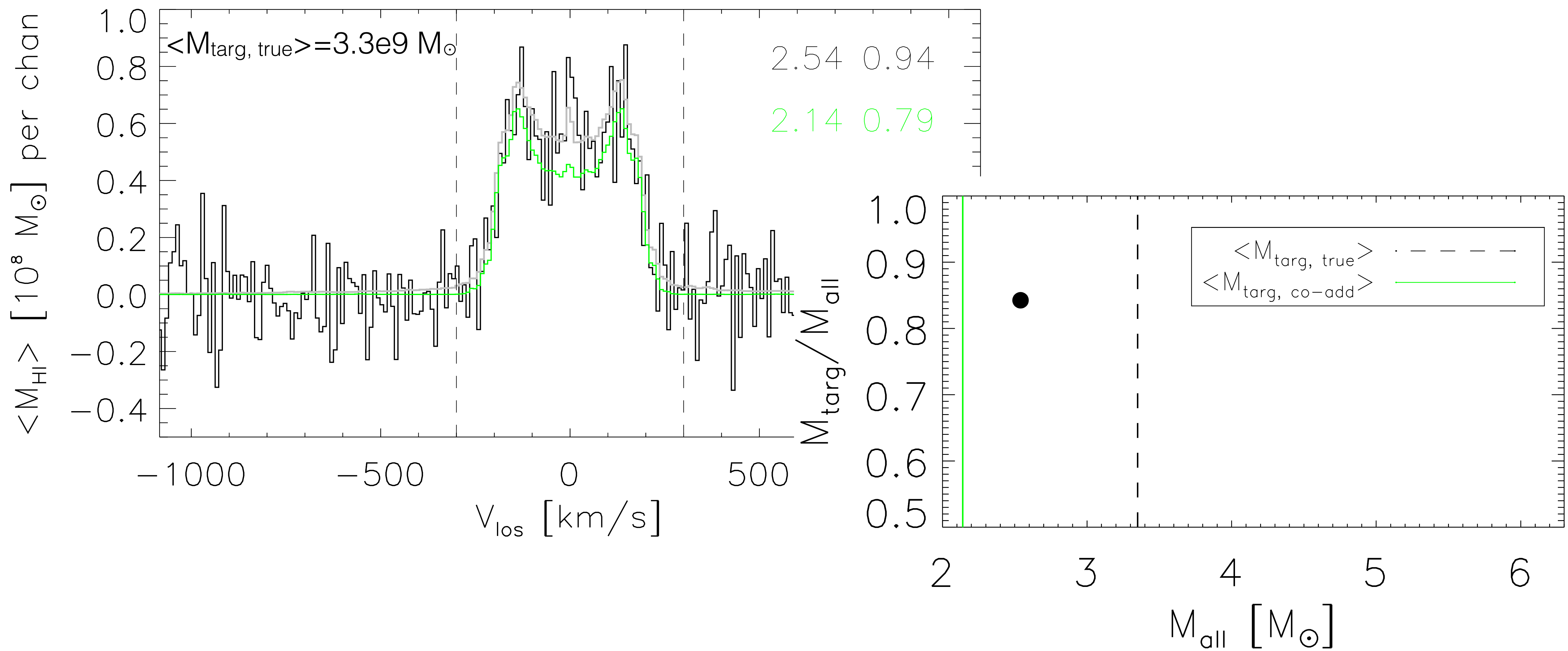

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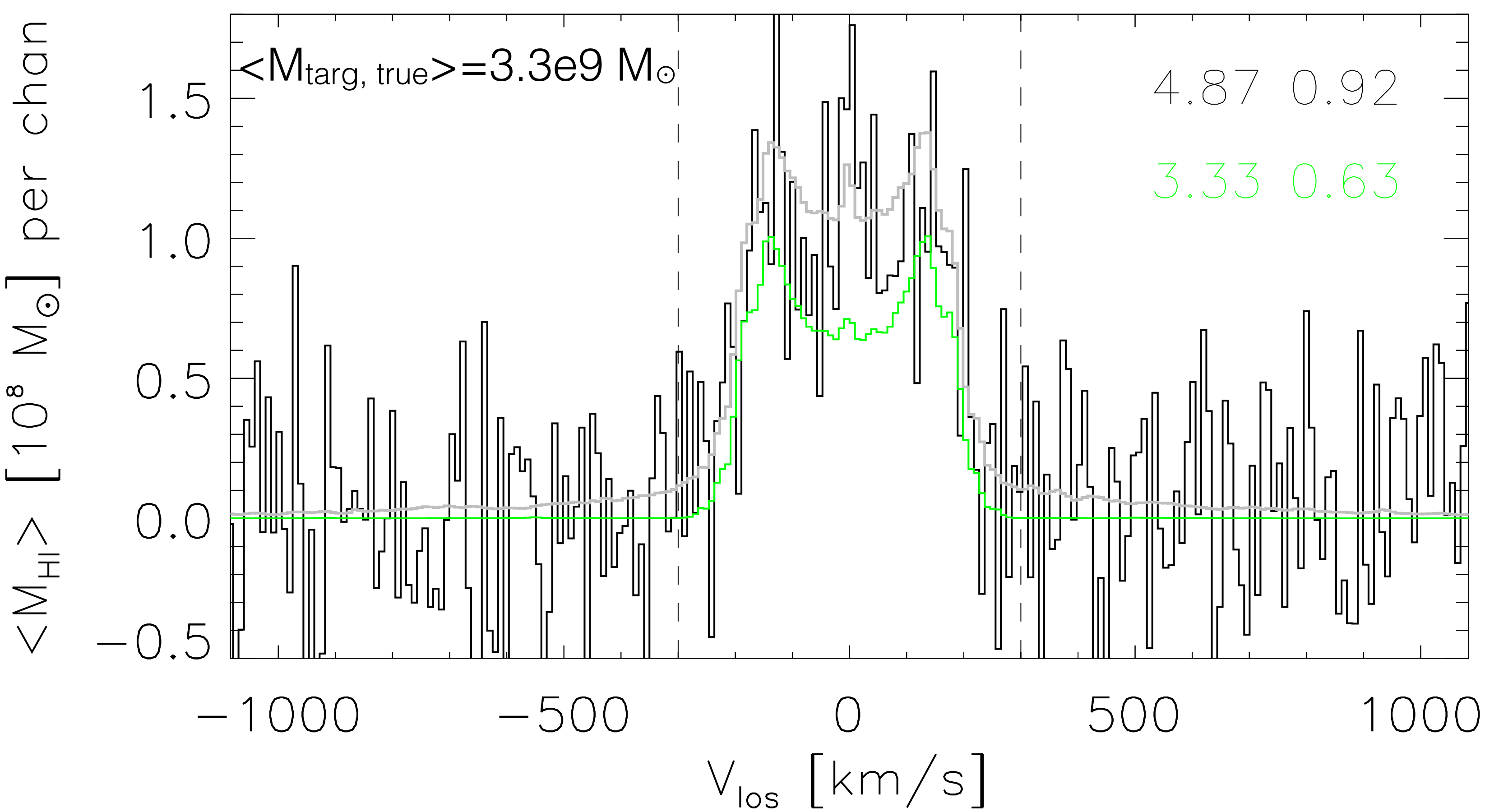

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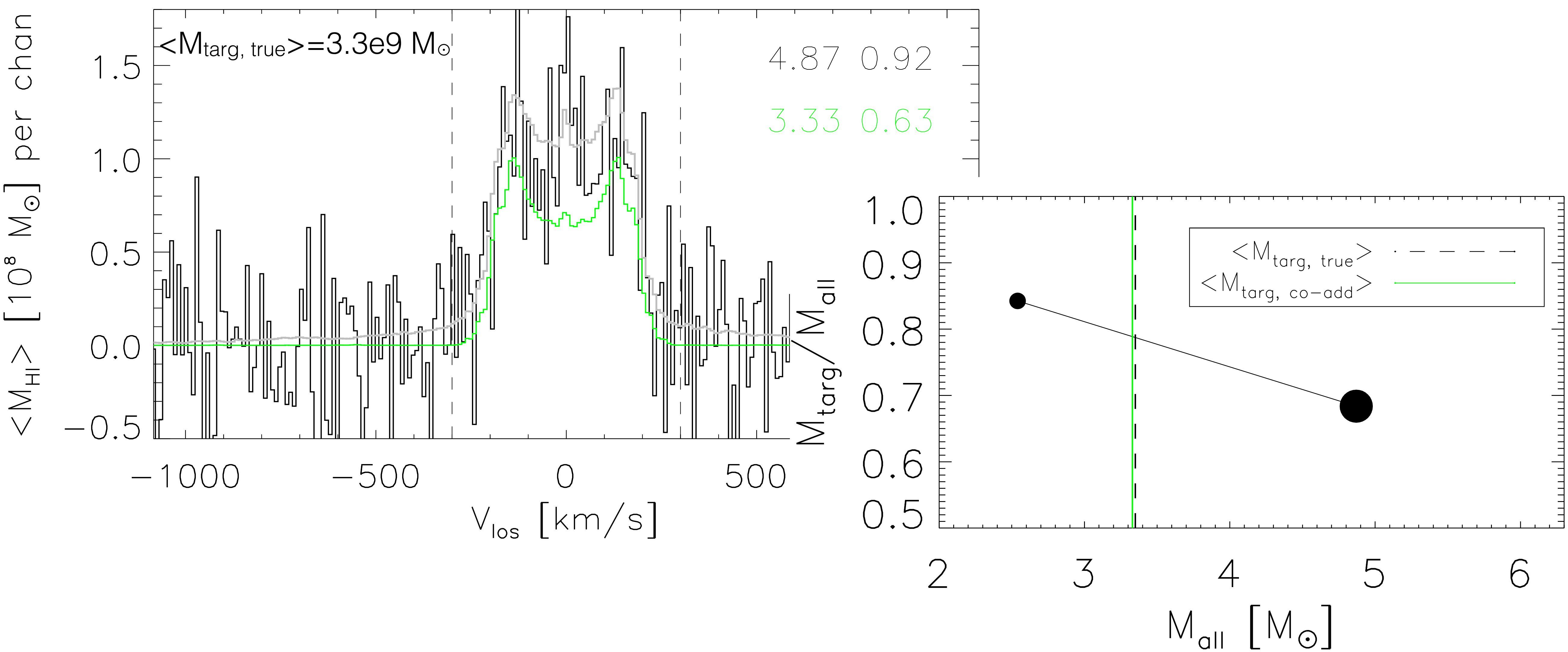

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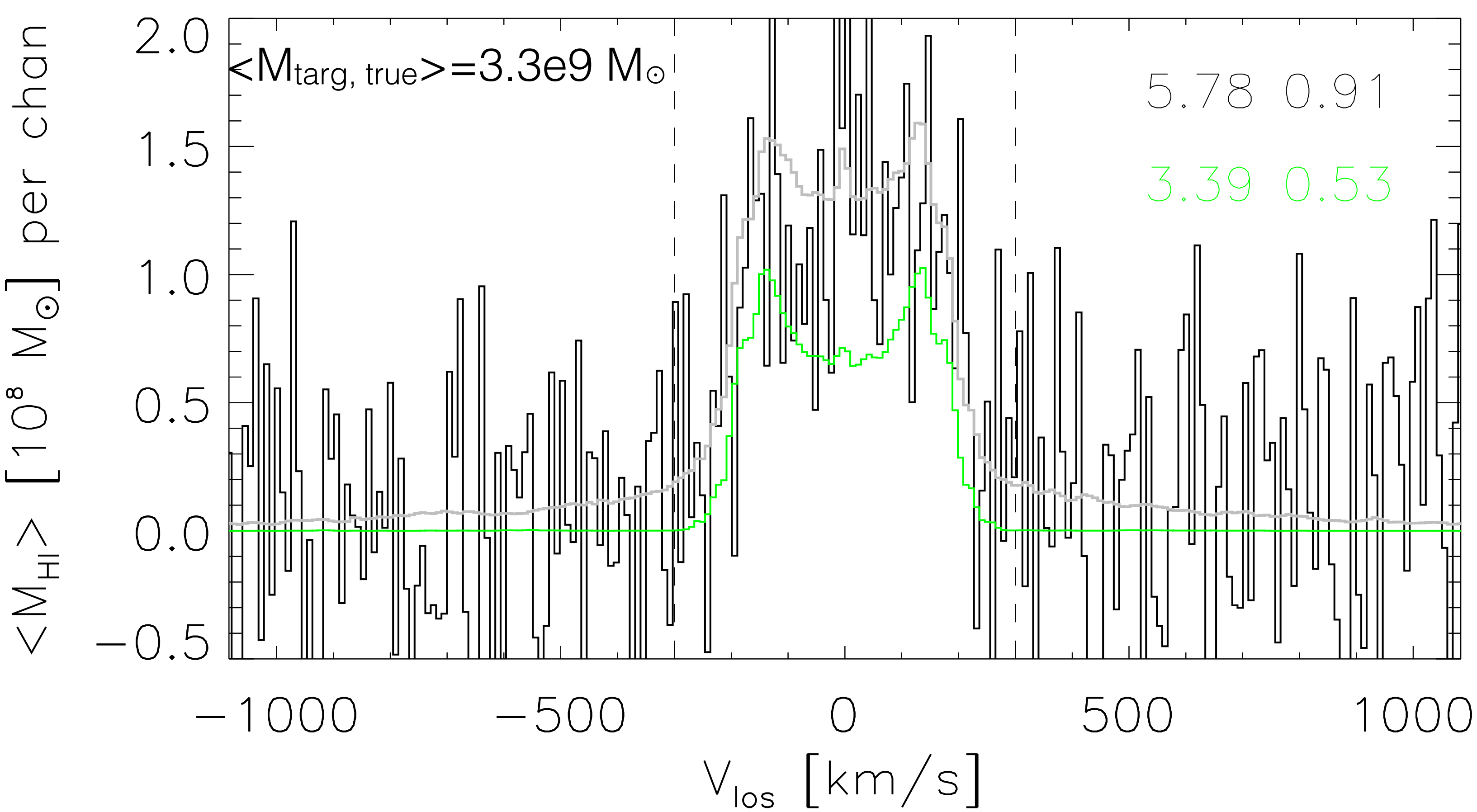

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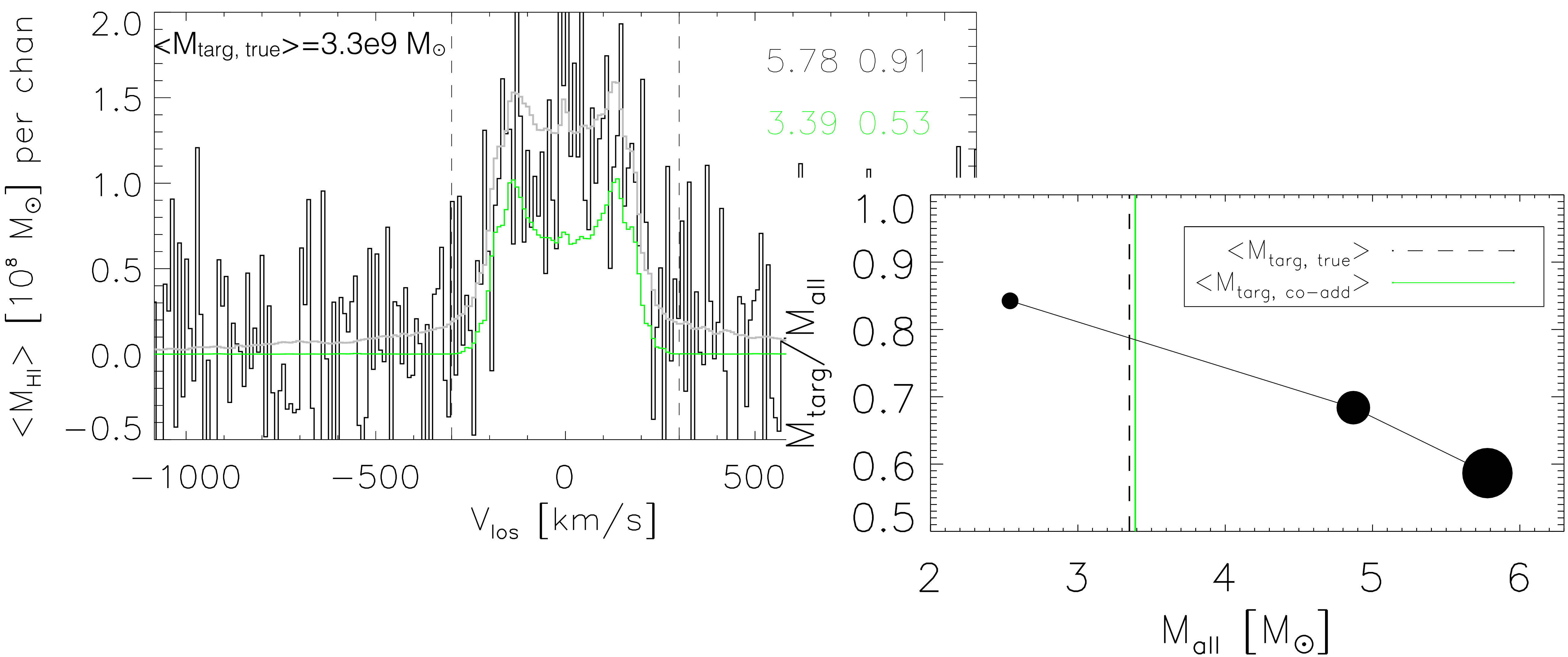

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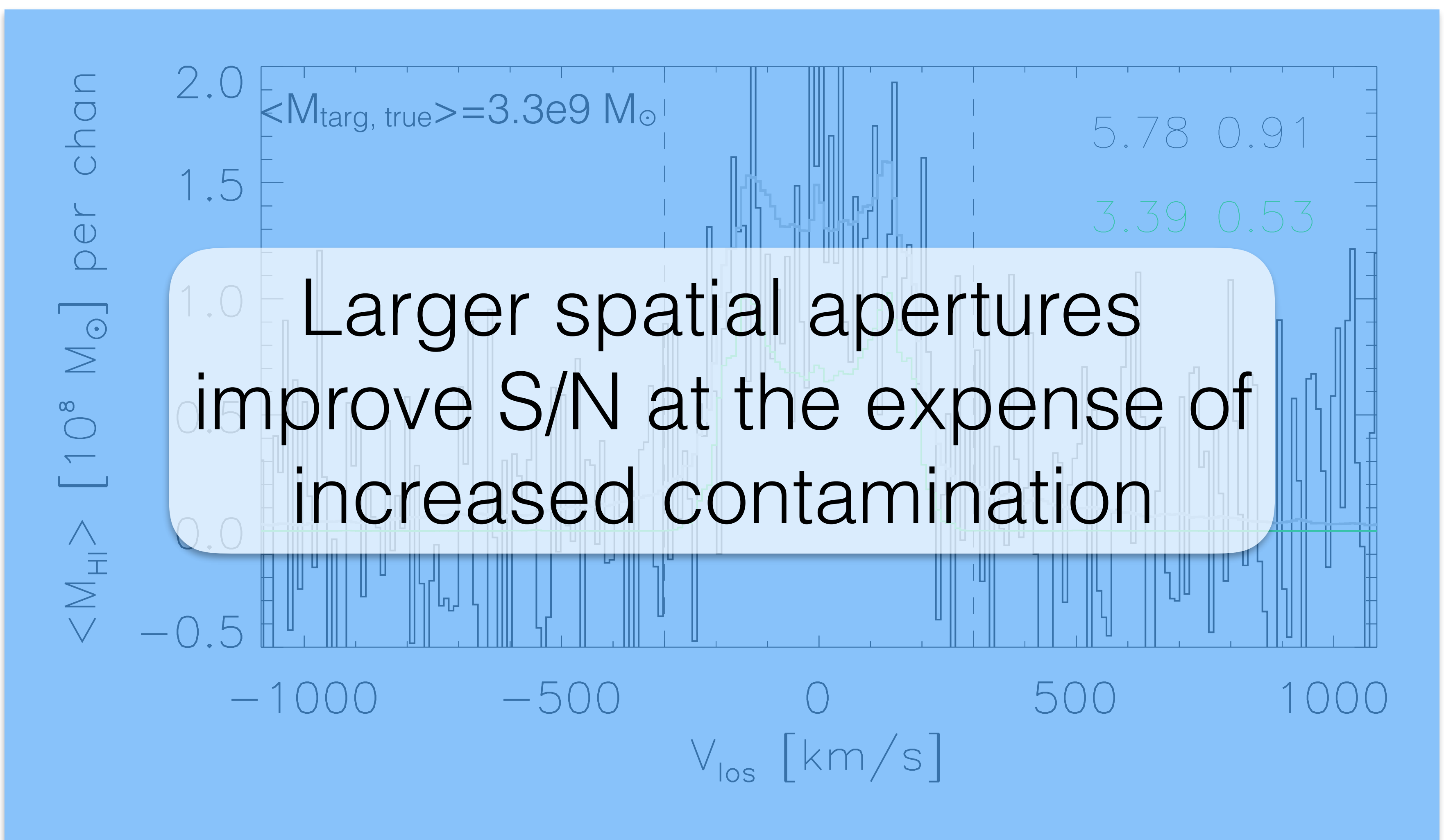
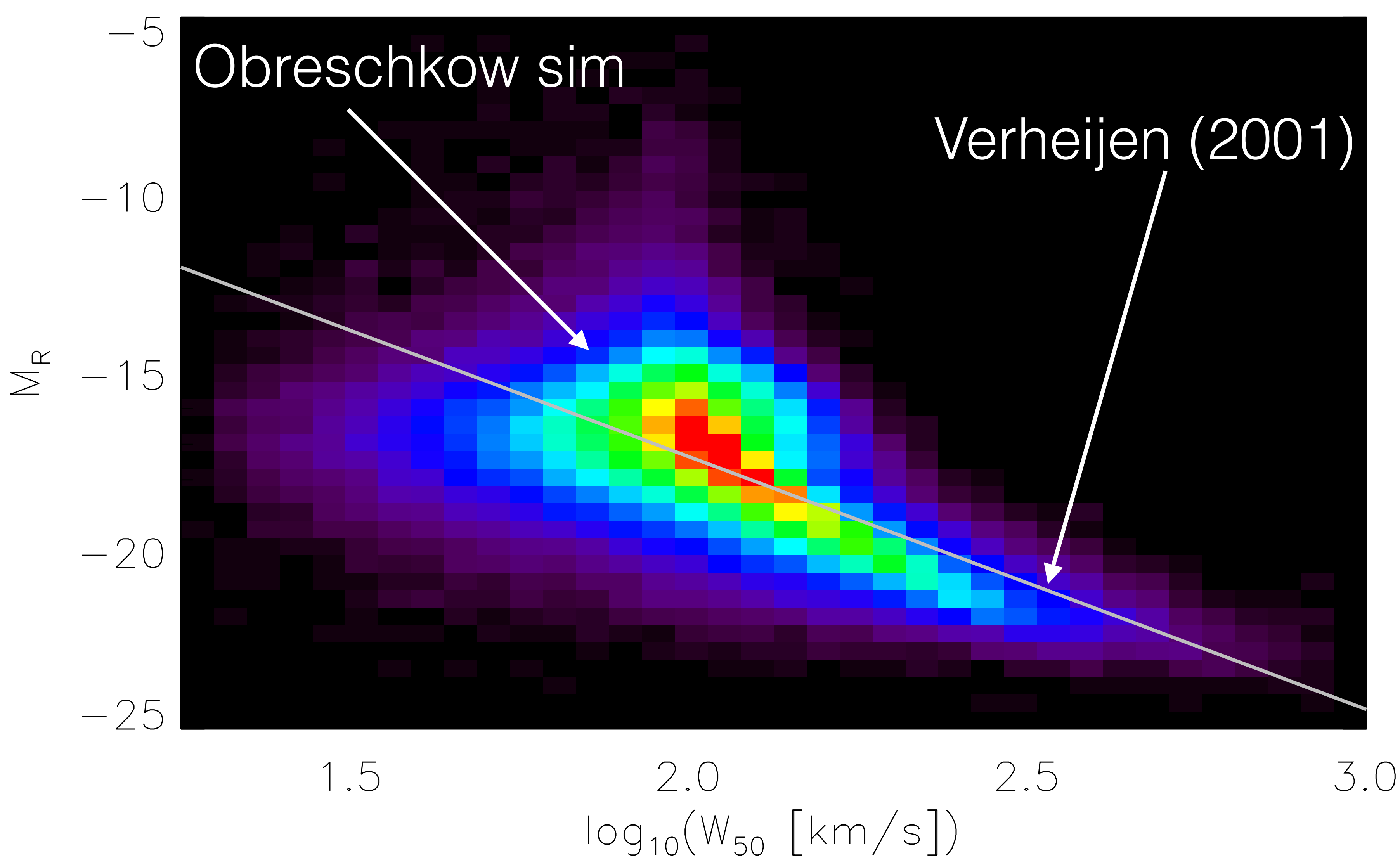


Stacking experiment 2

- Extract spectra over Tully-Fisher HI line width, using spatial aperture sizes of 1, 2, 3 HPBWs (15′′, 30′′, 45′′).



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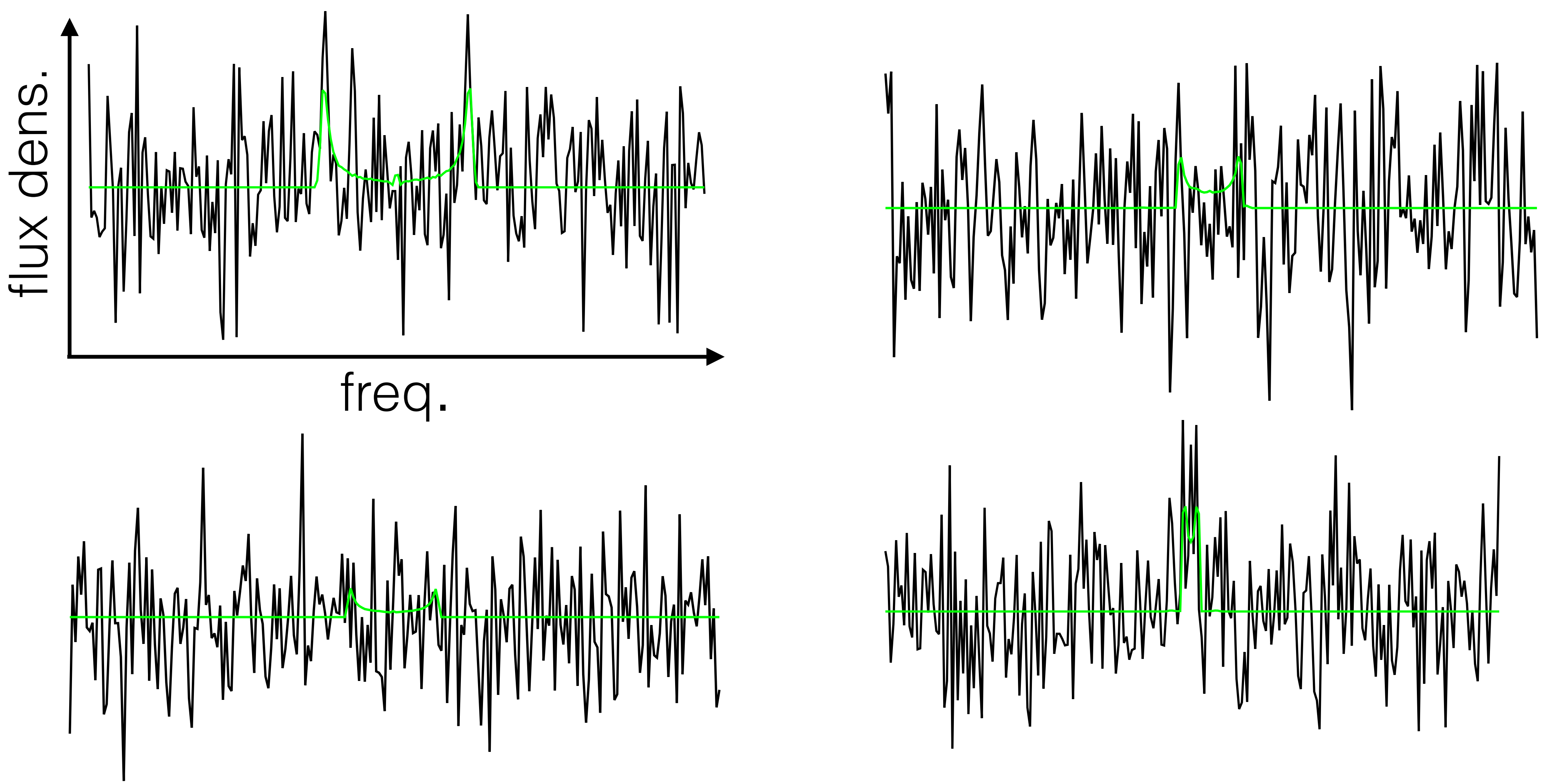

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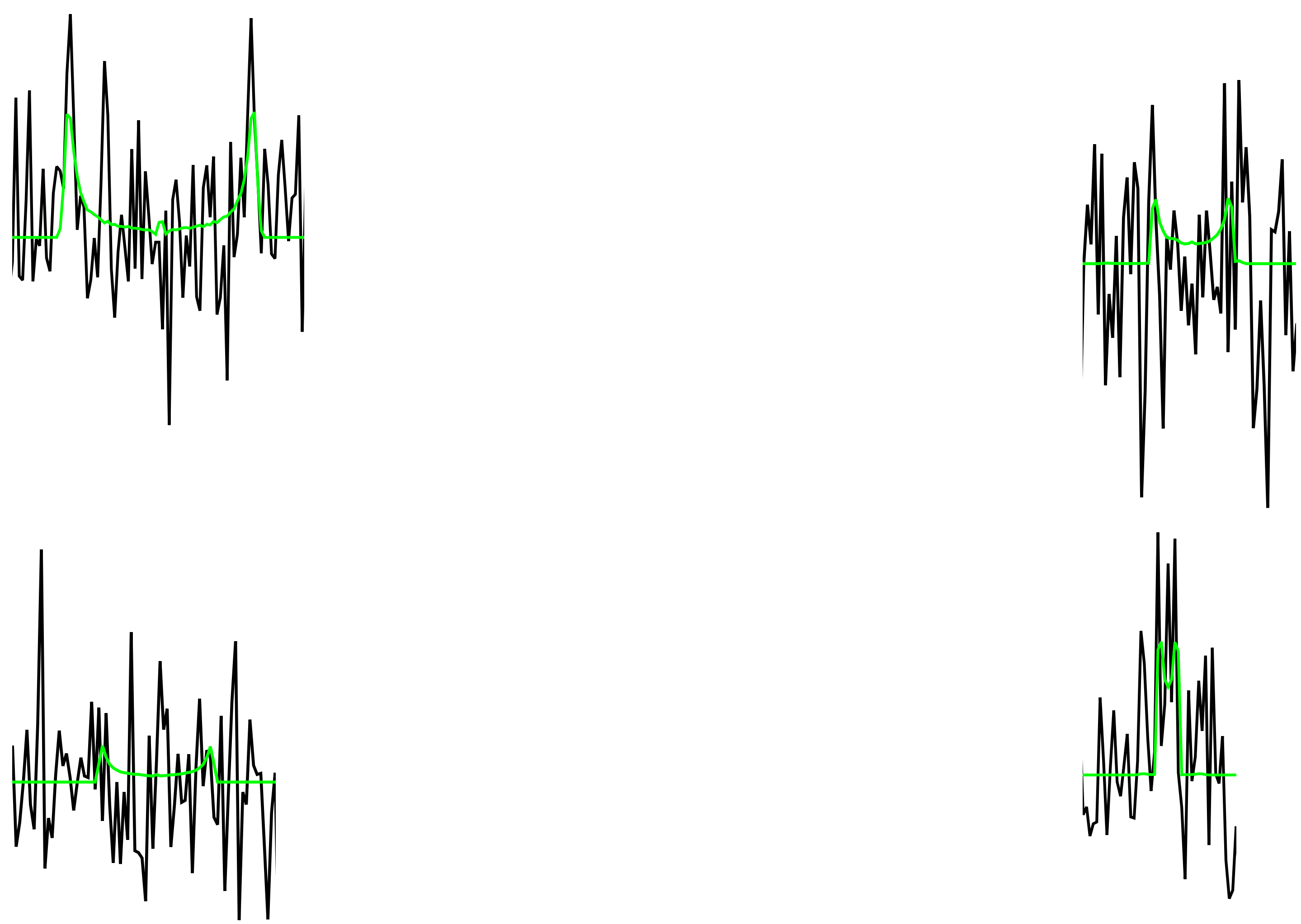

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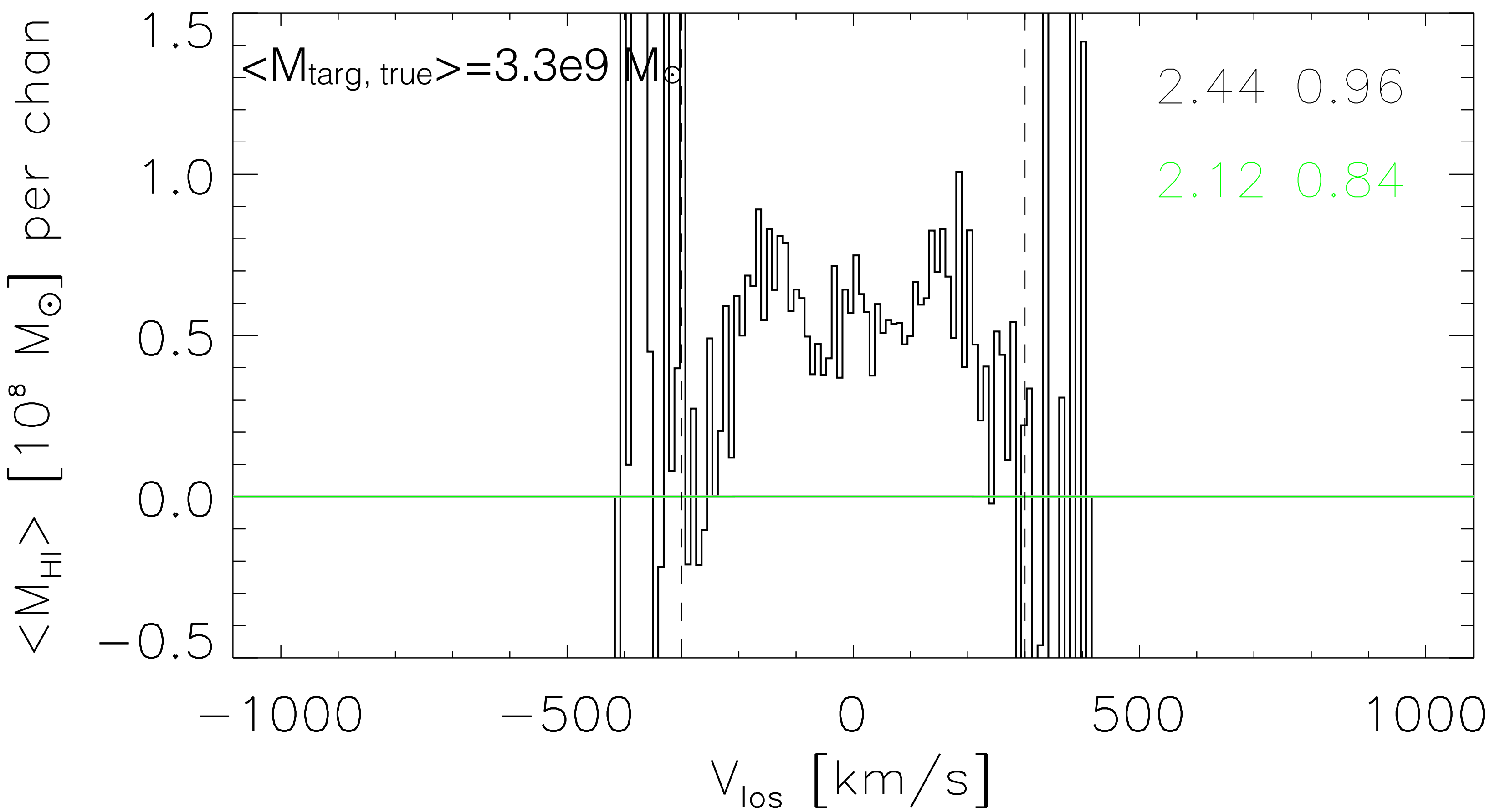

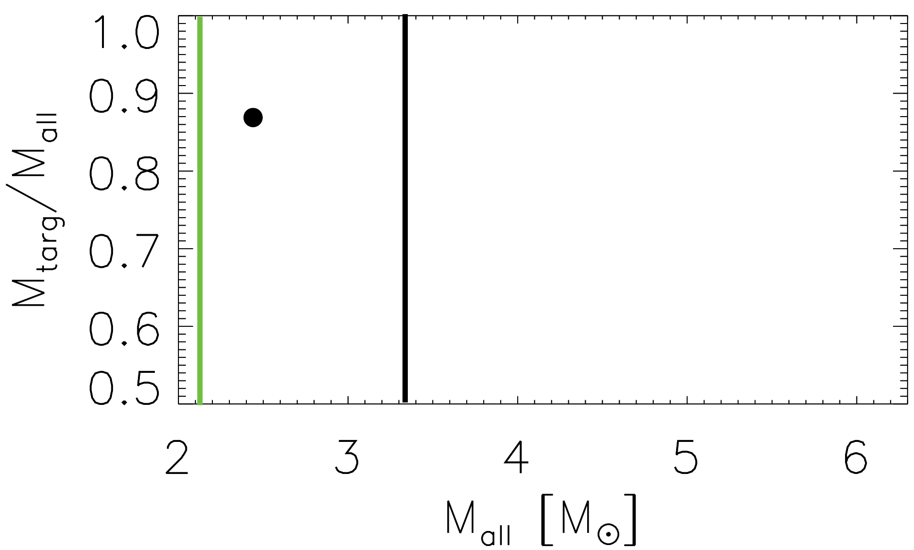

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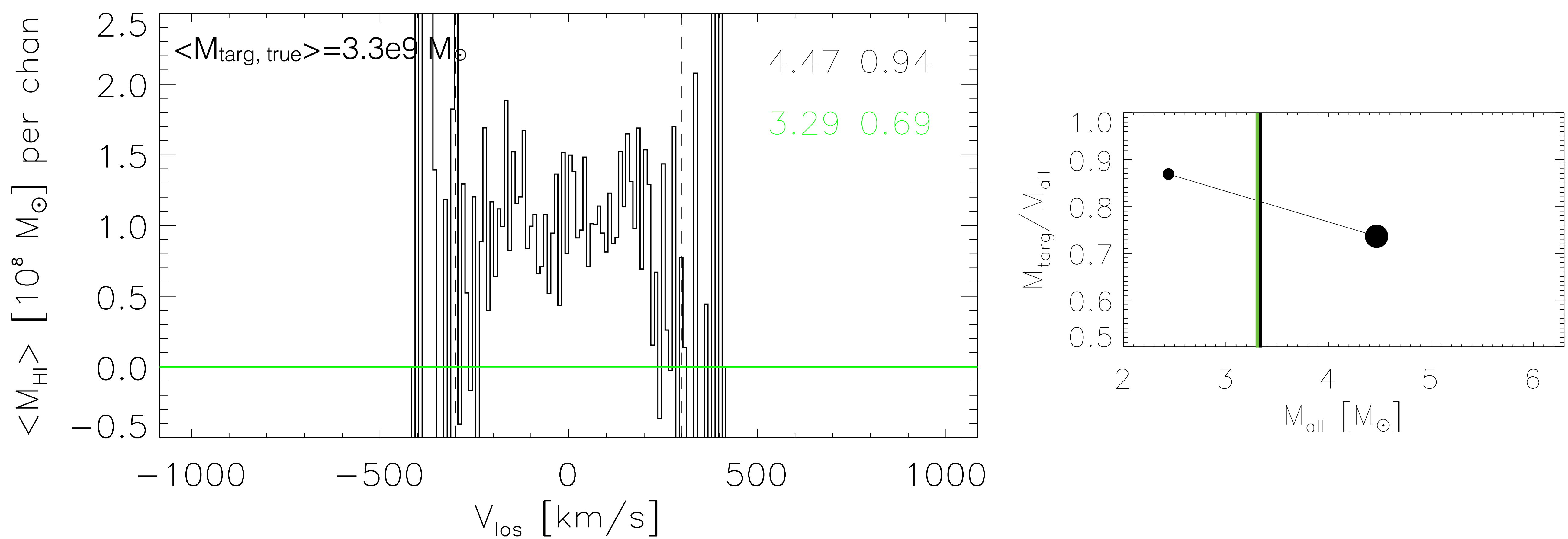

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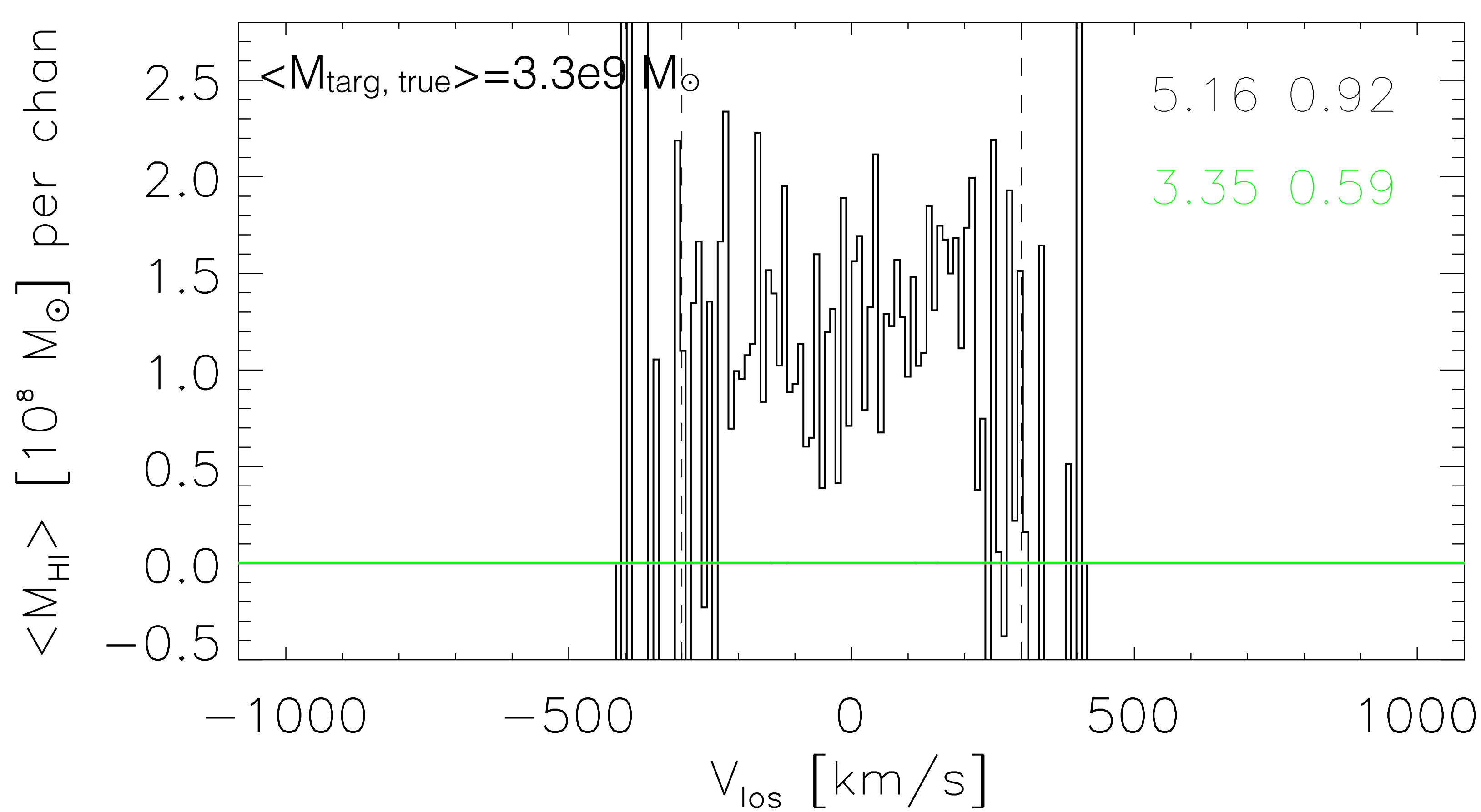

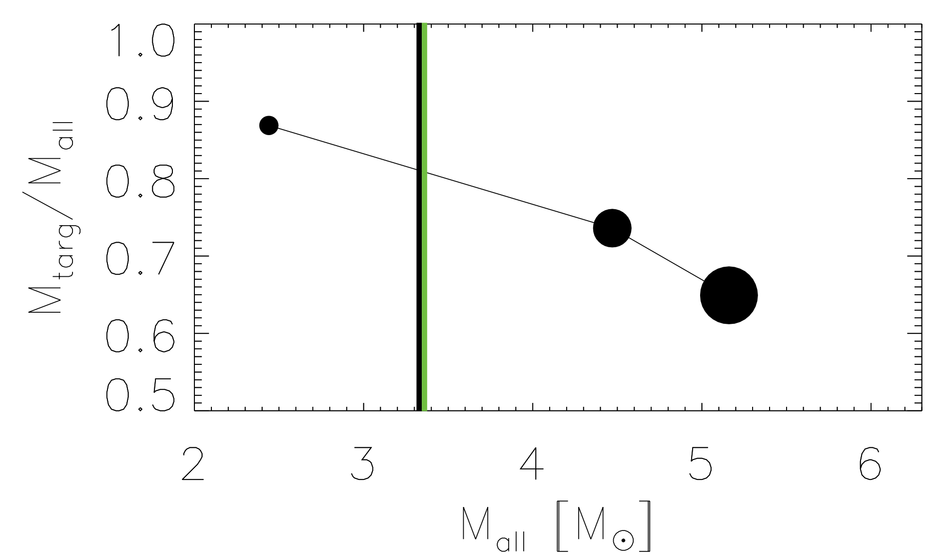

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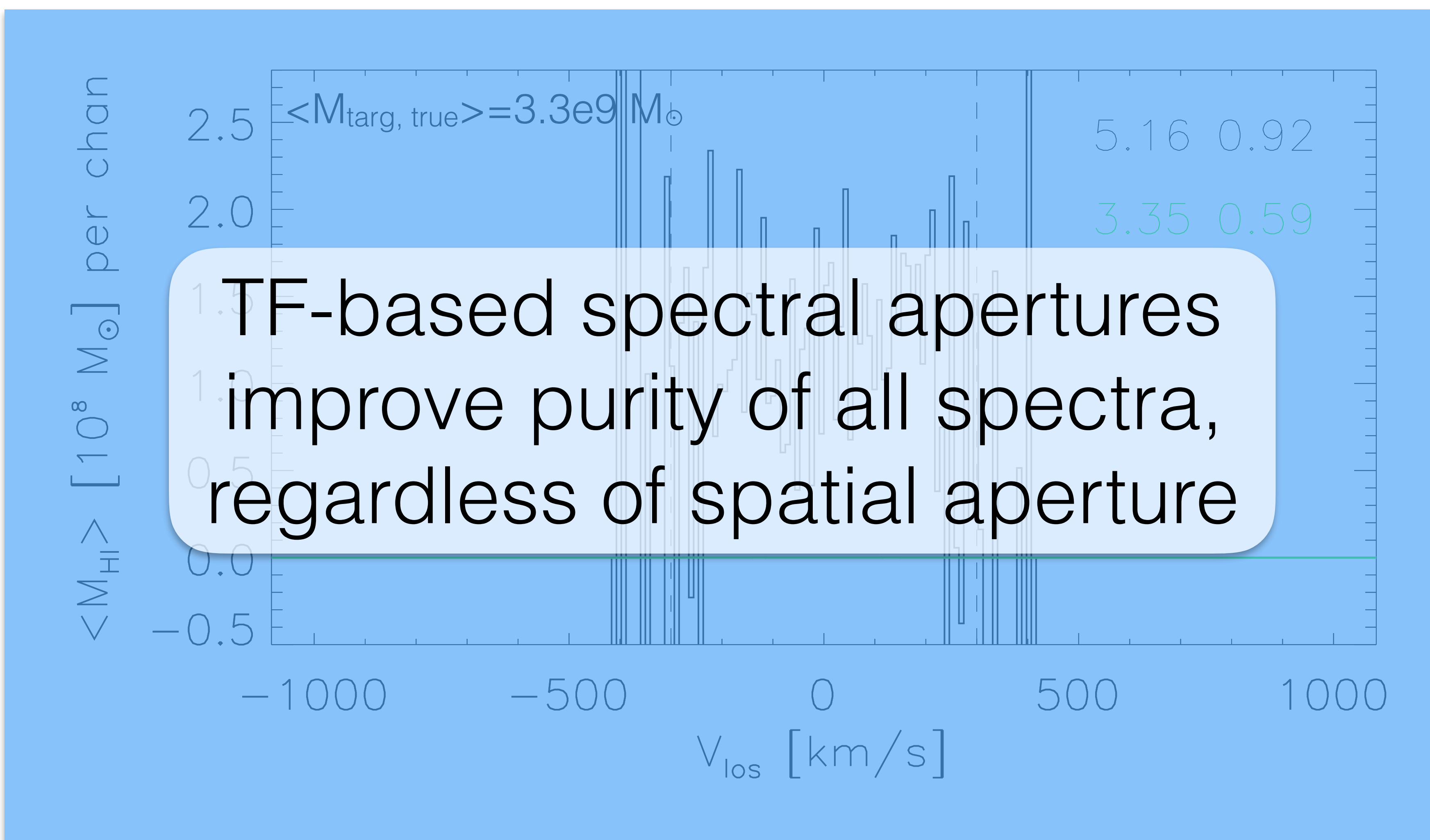

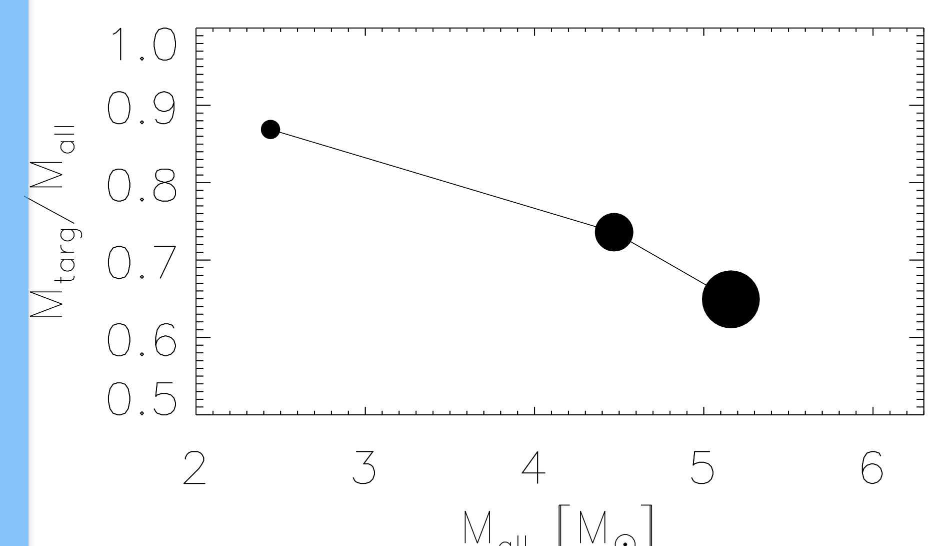

Main conclusions

- For high-z stacking experiments:
  - Use a spatial aperture = 2 or 3 x HPBW.
    - Co-add contains correct amount of target galaxy flux
    - One correction needed for contaminant flux.
  - Use a TF-based spectral aperture.
    - Significantly improves purity of all spectra, even when redshift uncertainties are large.