Spectroscopy of clusters in the ESO Distant Cluster Survey (EDisCS)

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Outline

The ESO Distant Cluster Survey (EDisCS)

Spectral reduction and the improved sky subtraction

Results from the spectroscopy of the 20 EDisCS clusters

The ESO Distant Cluster Survey (EDisCS)

EDisCS is a project to study high redshift cluster galaxies in terms of their sizes, luminosities, morphologies, internal kinematics, star formation properties and stellar populations.

This is done by obtaining deep multi-band imaging of 20 clusters at $z = 0.4$–1 and deep spectroscopy of $\sim$100 galaxies per field.

EDisCS cluster selection

The EDisCS clusters are selected from the Las Campanas Distant Cluster Survey (LCDCS)

- 130 square degrees imaged in a single wide optical filter with a 1 m telescope in drift scan mode; effective exposure time: 3.5 min
- All detected objects are removed. For a high redshift cluster this only affects a few of the brightest galaxies in the cluster — the rest of the galaxies are not detected individually
- High redshift clusters can now be detected as diffuse light peaks with a typical scale of $10''$
- Result: 1073 cluster candidates with $z_{\mathrm{est}} = 0.3$–1.0
  (estimated false detection rate: 30%)

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EDisCS cluster selection

- 30 of the most luminous cluster candidates from LCDCS observed in two bands with the VLT
- 28 cluster candidates showed a significant overdensity of red galaxies
- 20 clusters chosen: 10 at $z_{\rm est} \sim 0.5$ and 10 at $z_{\rm est} \sim 0.8$

EDisCS data

ESO large programme (PI: White)

- VLT/FORS2 deep optical imaging (BVI or VRI) [14 nights]
- NTT/SOFI deep NIR imaging (K or JK) [20 nights]
- VLT/FORS2 deep optical spectroscopy [22 nights]

Early follow-up

- ESO 2.2m/WFI wide field imaging (VRI) of all 20 clusters
- HST/ACS mosaic imaging for 10 of the clusters (PI: Dalcanton)
- Hα narrow band imaging of 4 clusters

Later follow-up / spin-off projects

- Wide field spectroscopy (VIMOS, 2dF); deeper FORS2 spectroscopy
- ESO large programme to study $z \sim 6$ galaxies in 10 of the EDisCS fields (FORS2 z-band imaging and spectroscopy; PI: Bremer)
- Three approved Spitzer programmes

Spectral reduction

Goal of reduction: create sky subtracted 2D spectra which have wavelength on one axis and spatial coordinate on the other axis.

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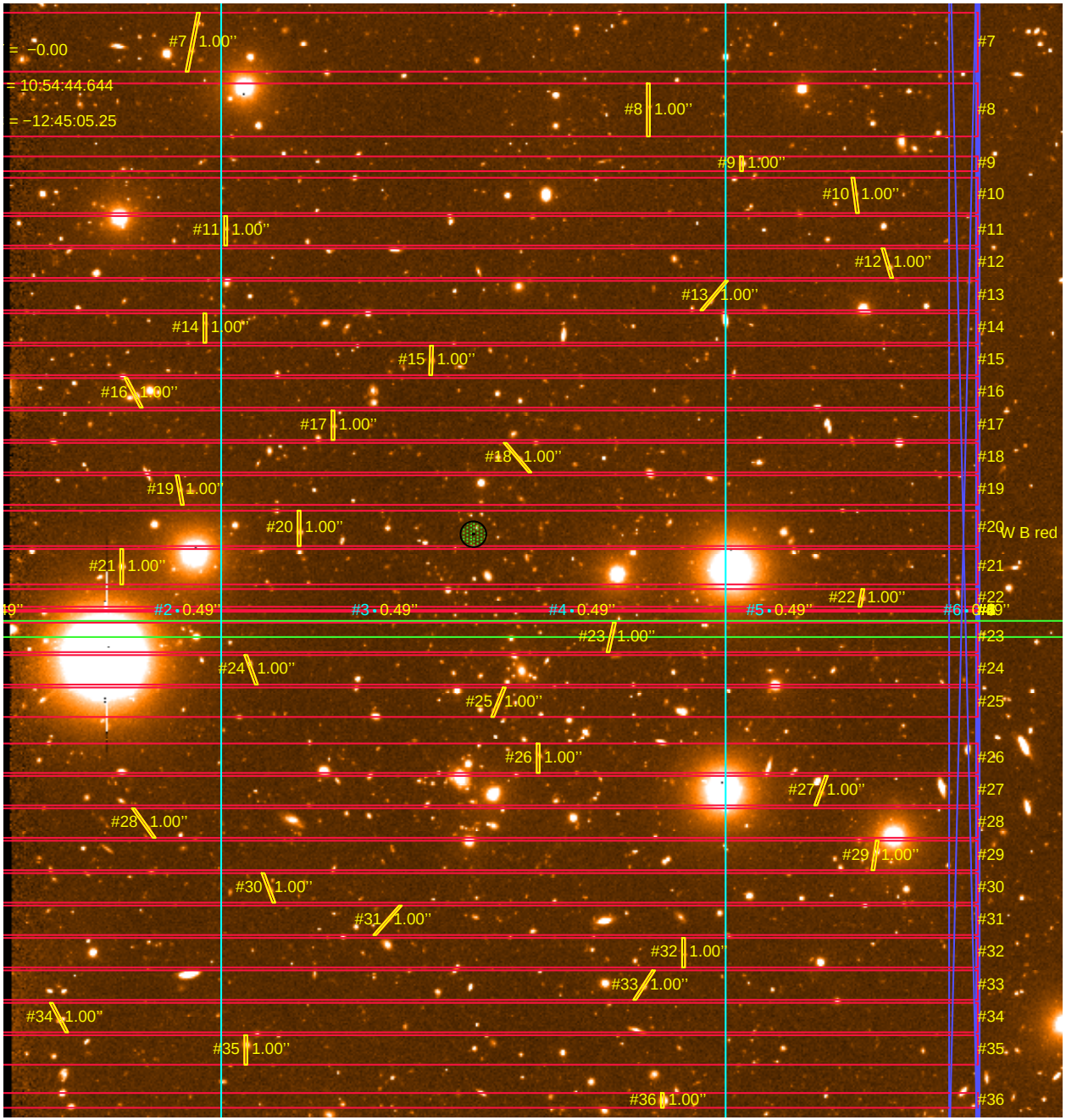
- The traditional way of doing sky subtraction leaves strong residuals where the sky lines have been subtracted, particularly for spectra from tilted slits
- The method described by Kelson (2003) can give photon noise limited sky subtraction. It still hasn't been used by many people. We have written software in IRAF and IDL implementing this method

Multi-slit spectroscopy (MXU) with VLT/FORS2

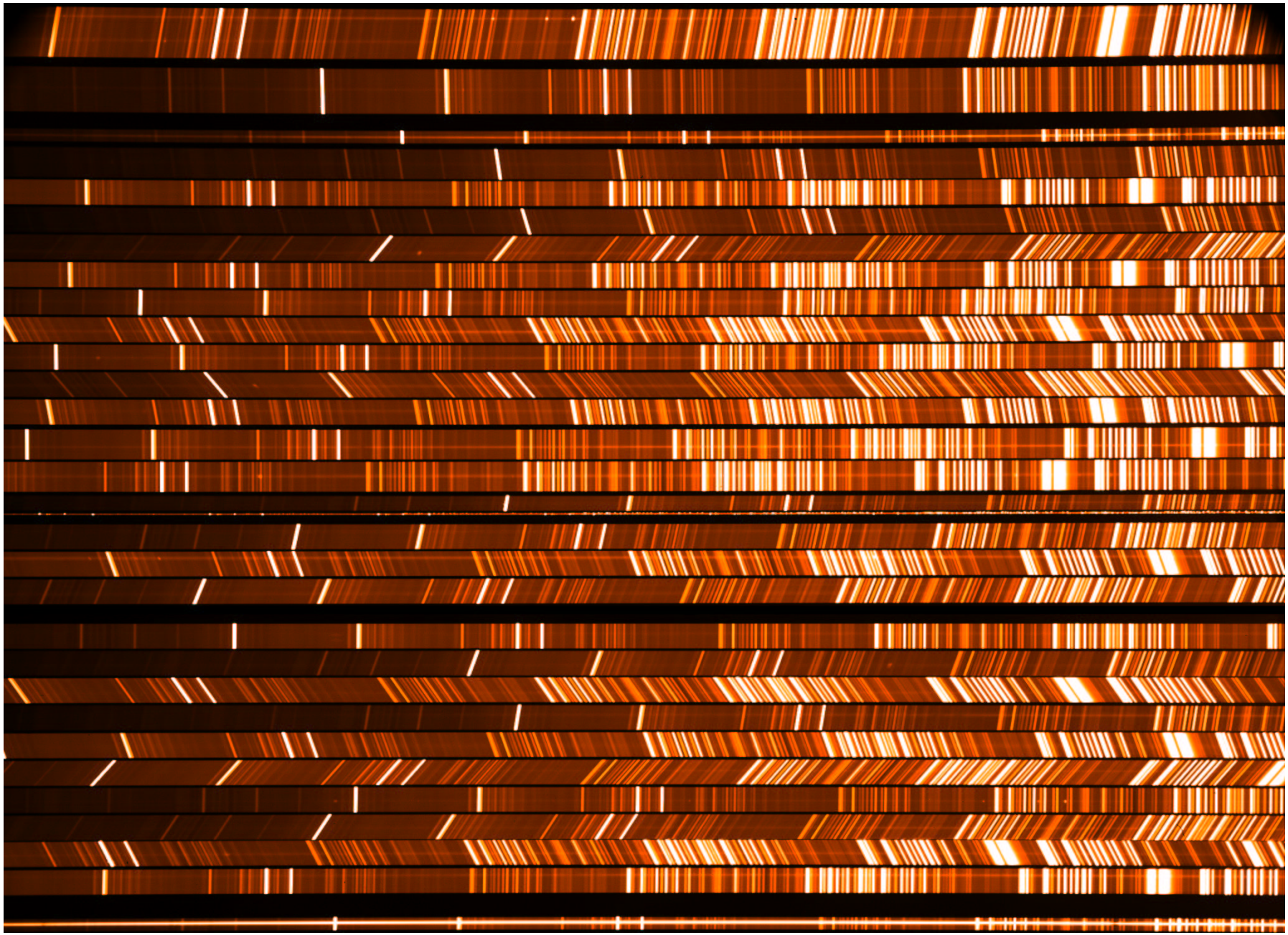
- Multi-slit masks with slits aligned with the major axes of the galaxies

- Grism 600RI, $\lambda \sim 5500$–8500 Å, resolution 6 Å FWHM
- Total: 86 masks over 22 nights

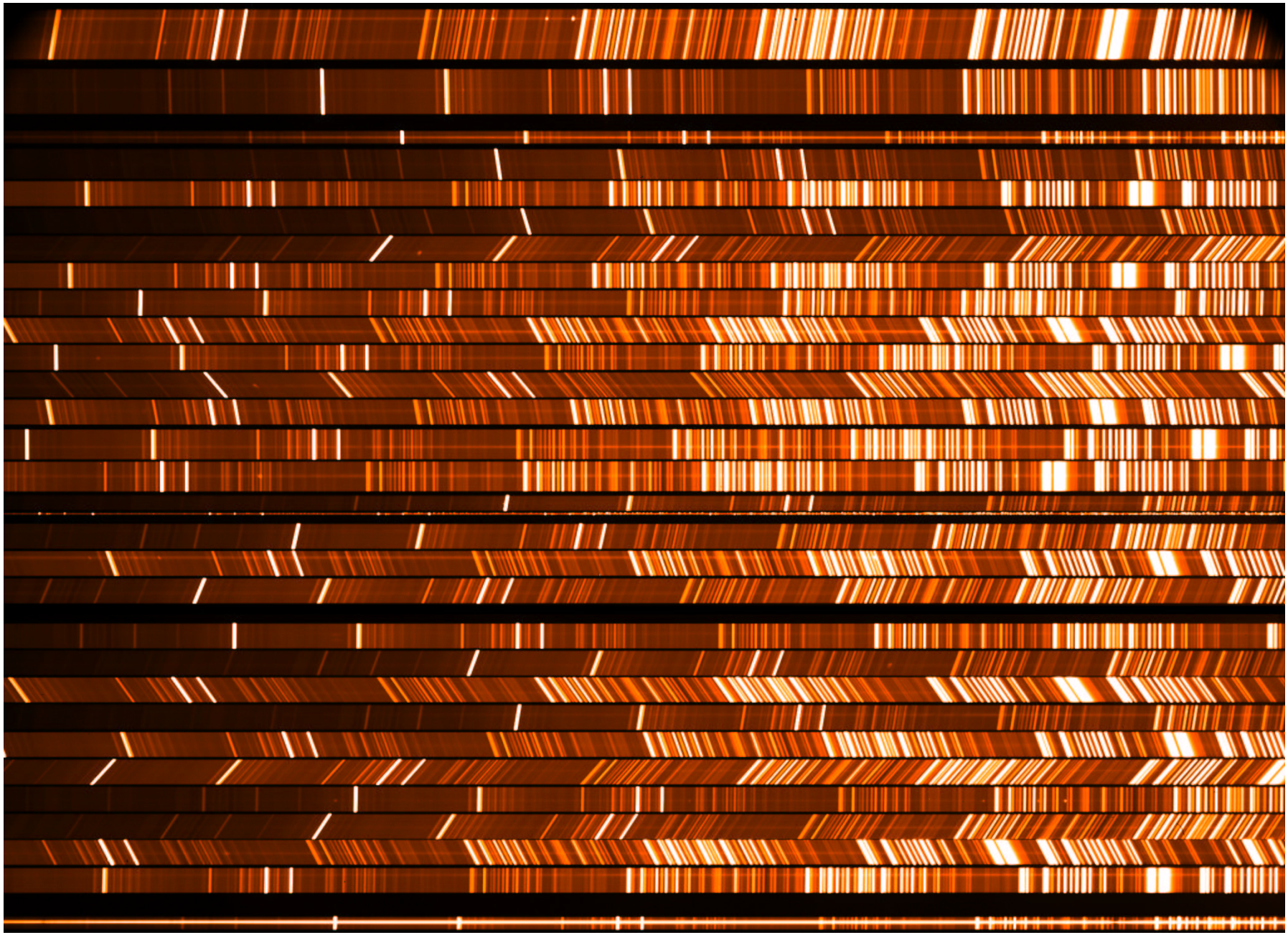
The mask design (note: ∼50% of the slits are tilted)



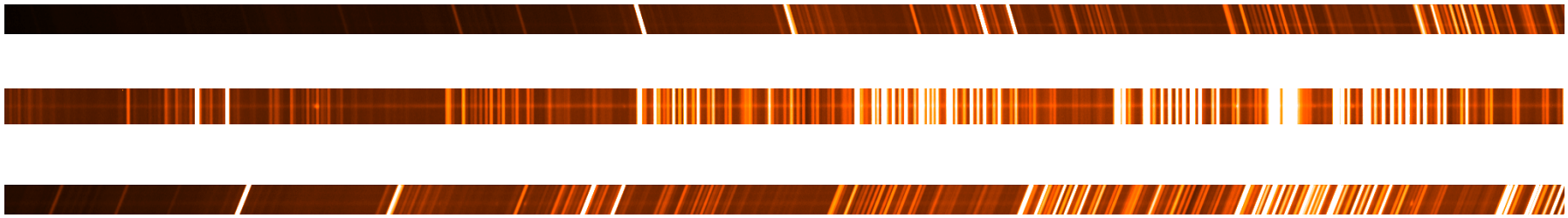
'Raw' full mask spectrum



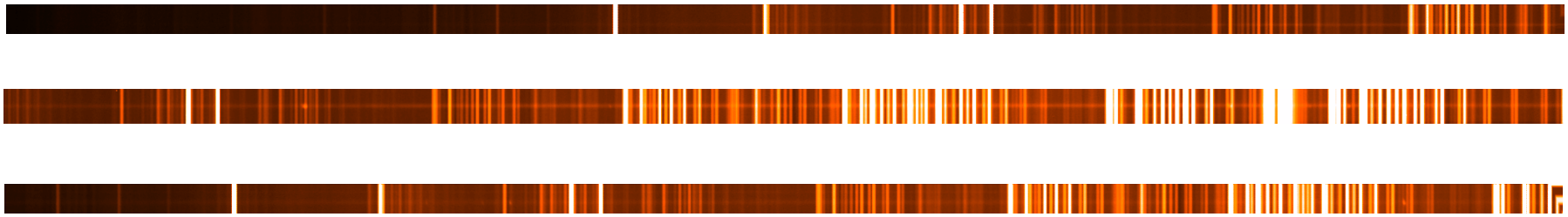
Geometrical distortion removed by interpolation in y



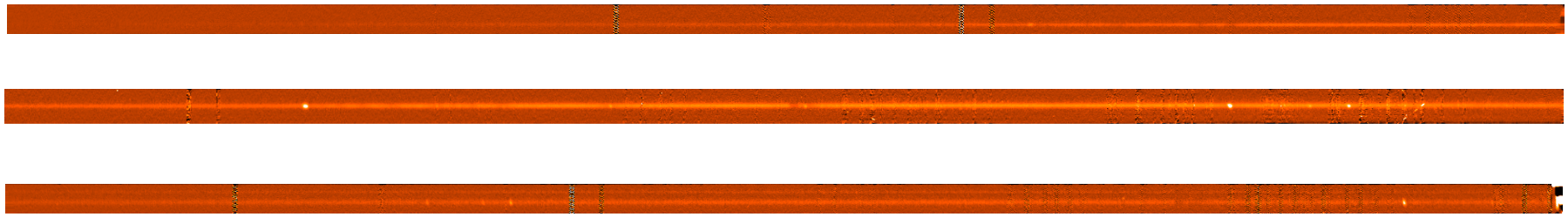
Individual cut-out slit spectra (3 examples)



Wavelength calibration applied (interpolation in x)

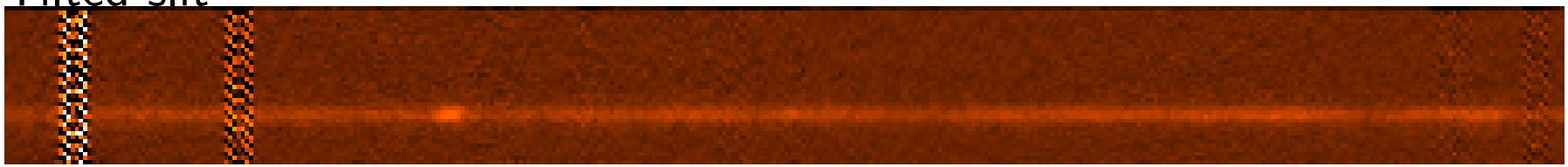


Traditional background subtraction

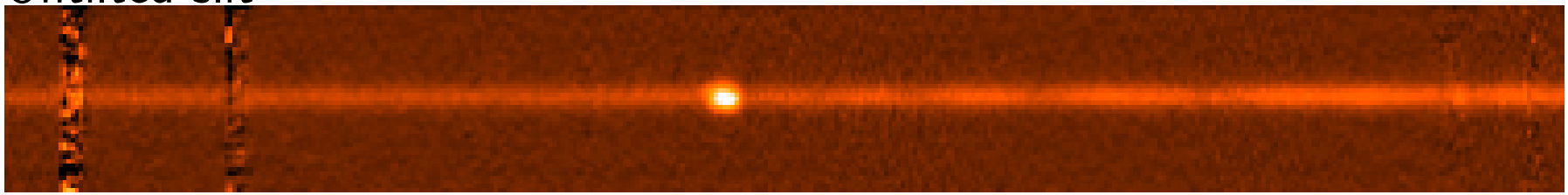


Traditional background subtraction: zoom 6275–6875 Å

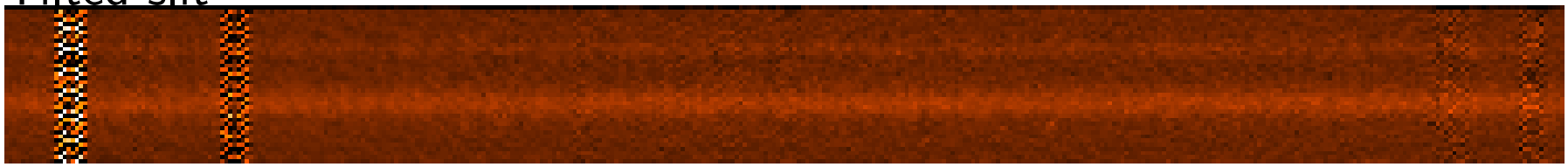
Tilted slit



Untilted slit

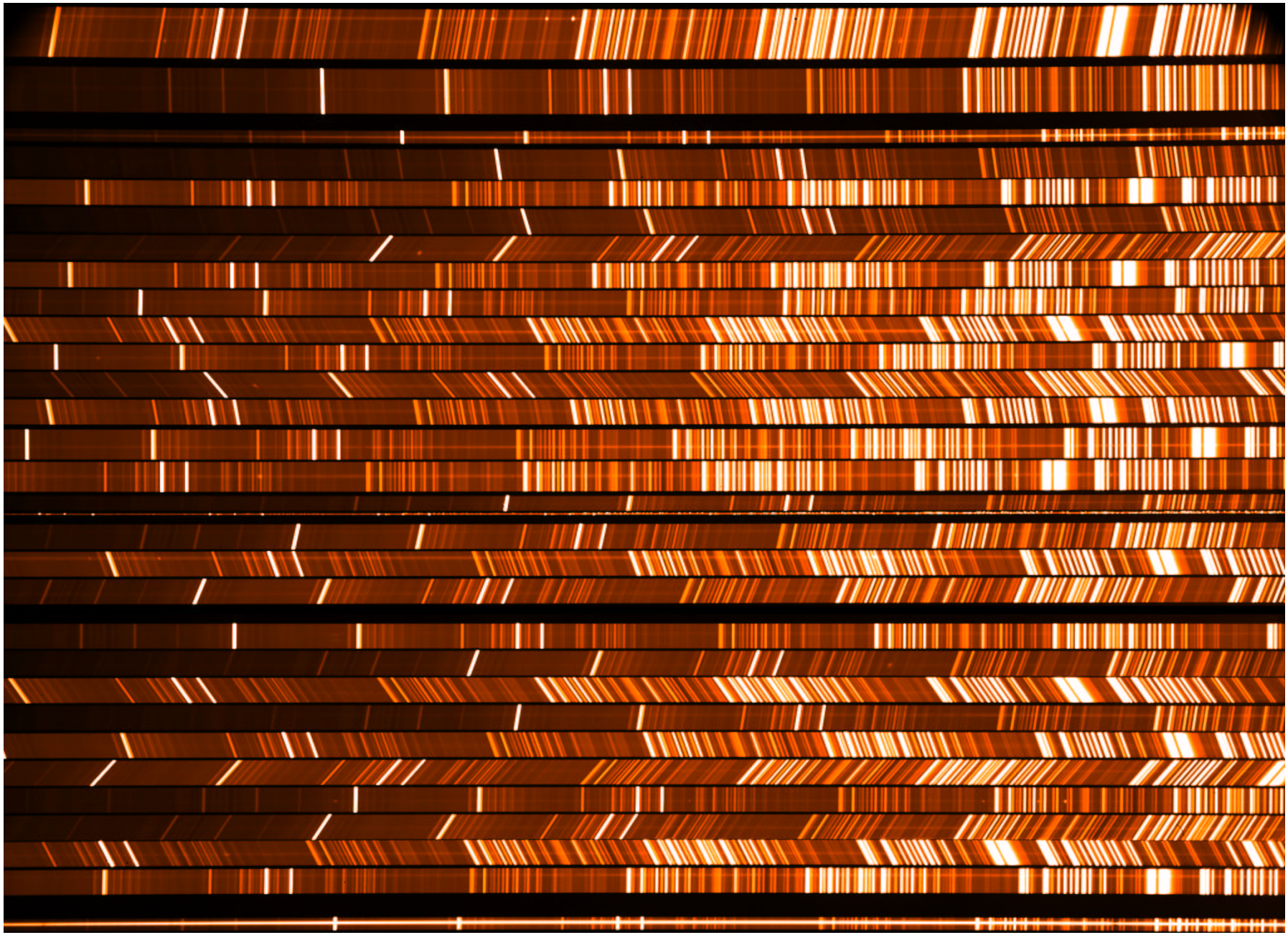


Tilted slit

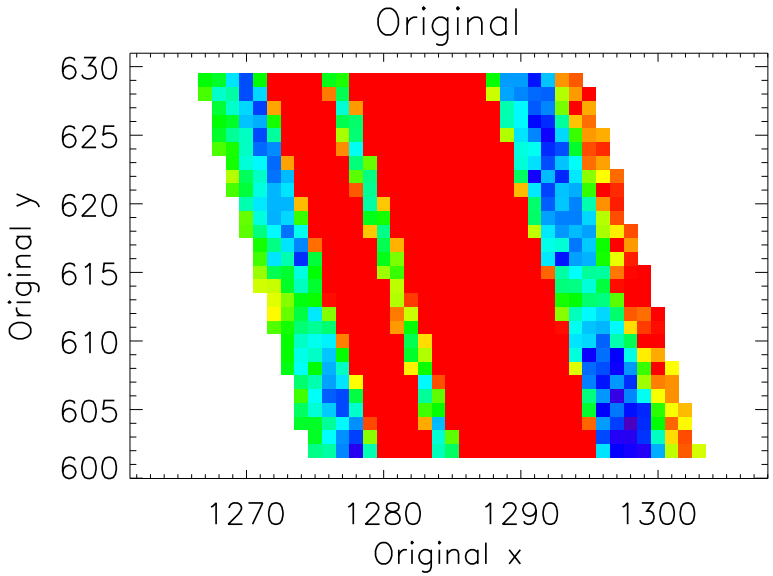


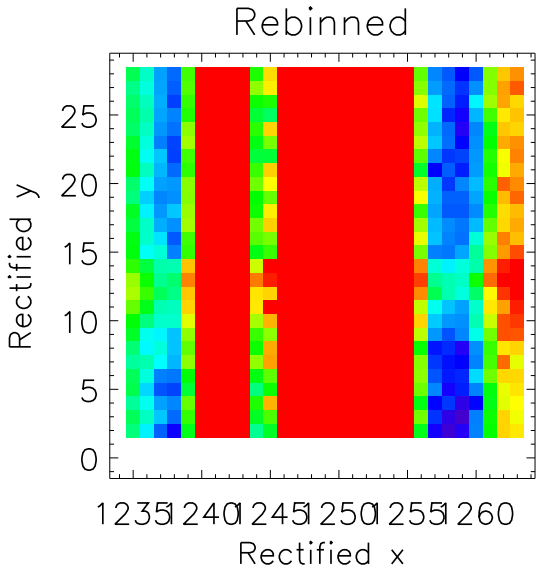
- Problem: strong aliasing pattern present where the rebinned, tilted sky lines have been subtracted
- Solution: subtract sky before rebinning

'Raw' full mask spectrum again



The unrebinned sky subtraction method





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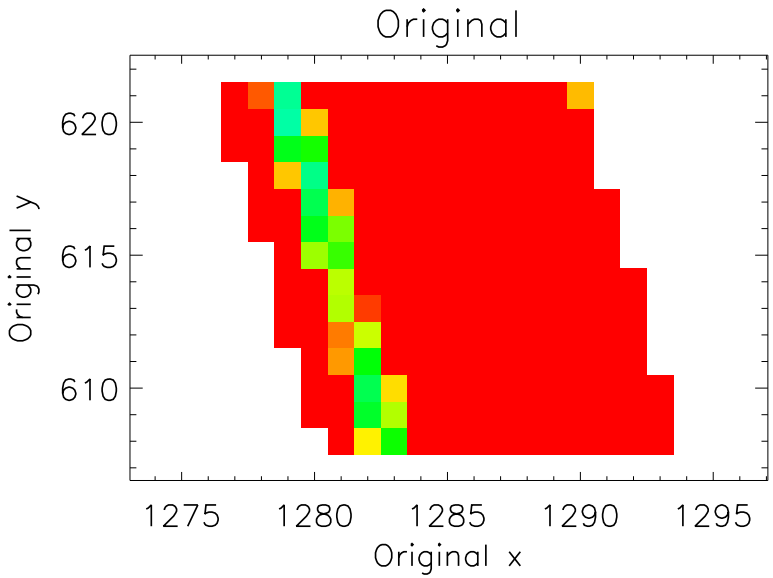

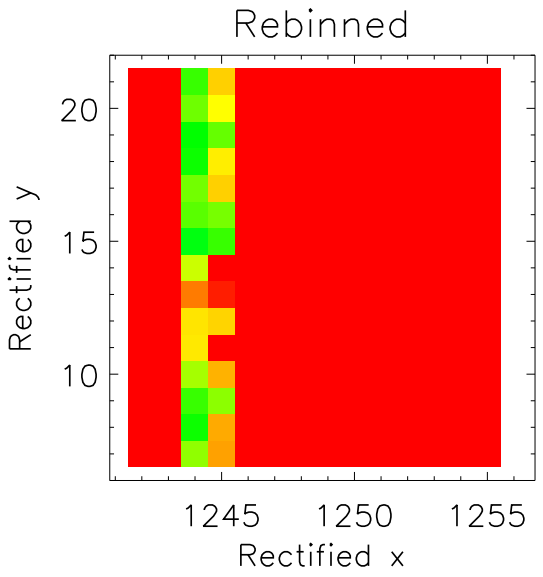

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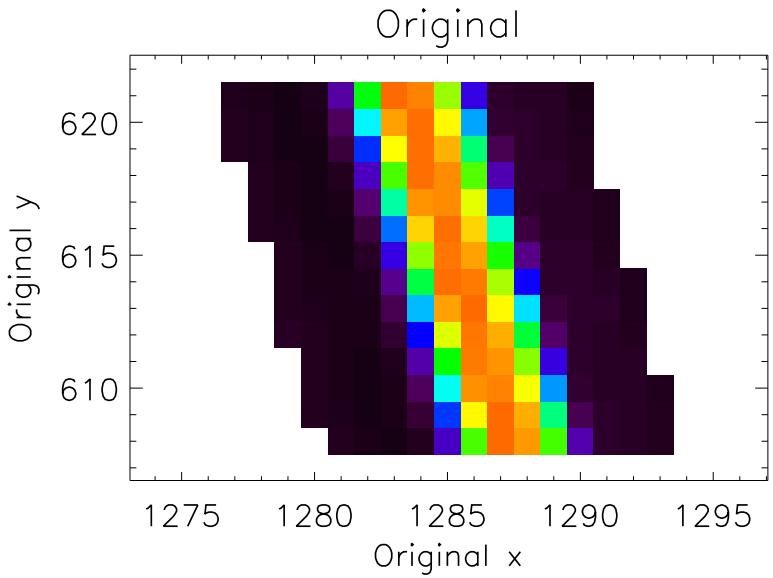

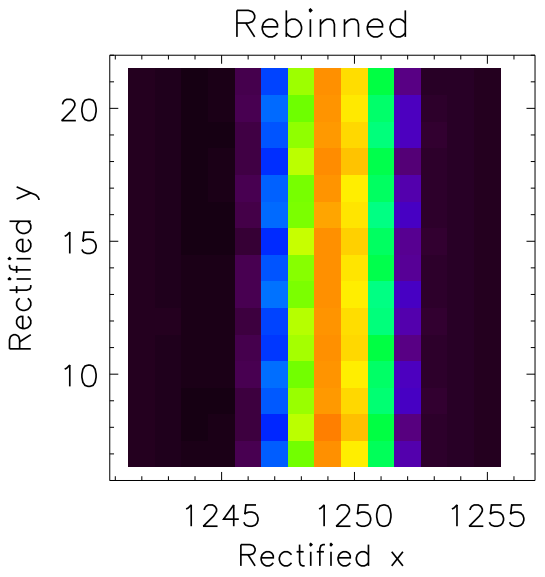

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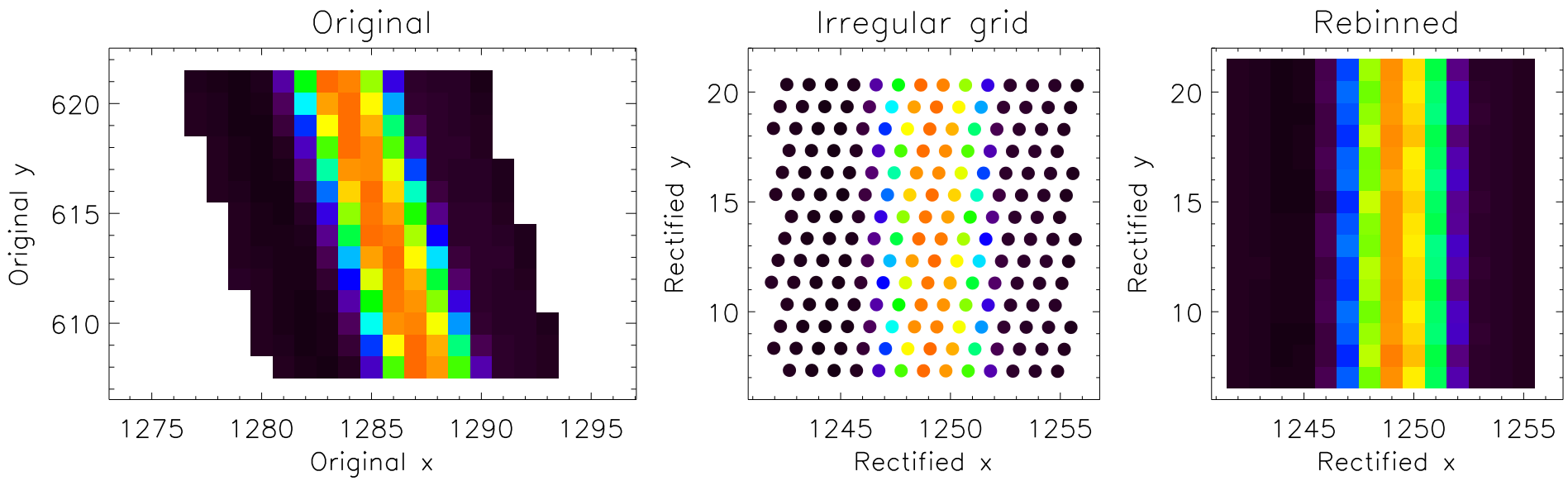

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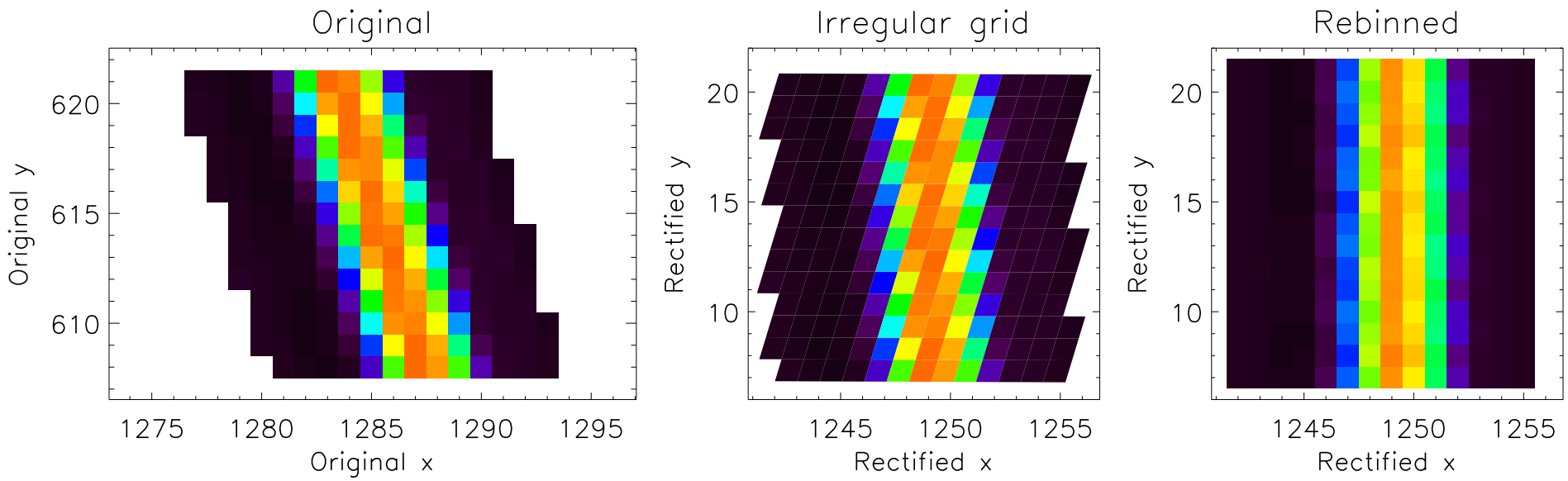

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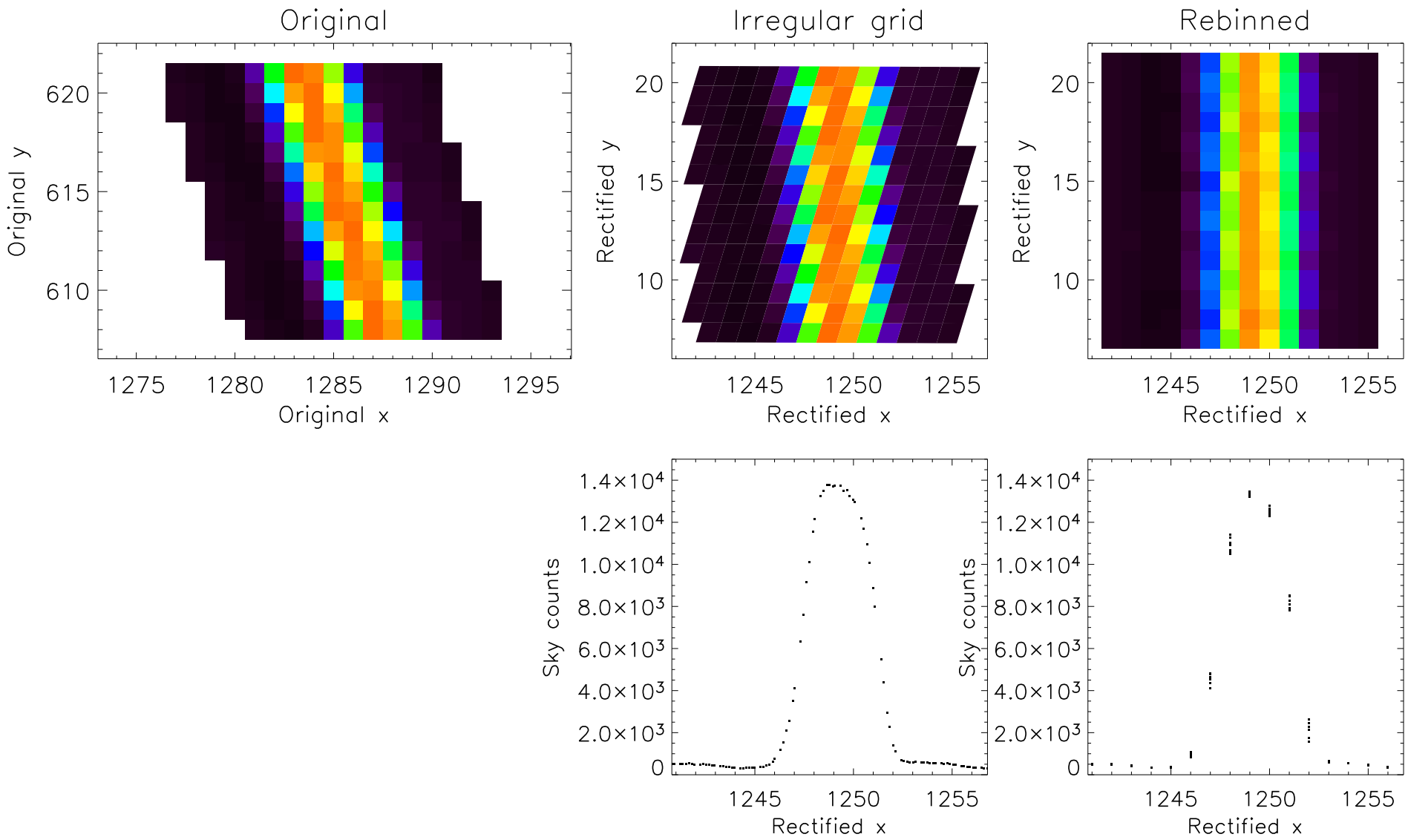

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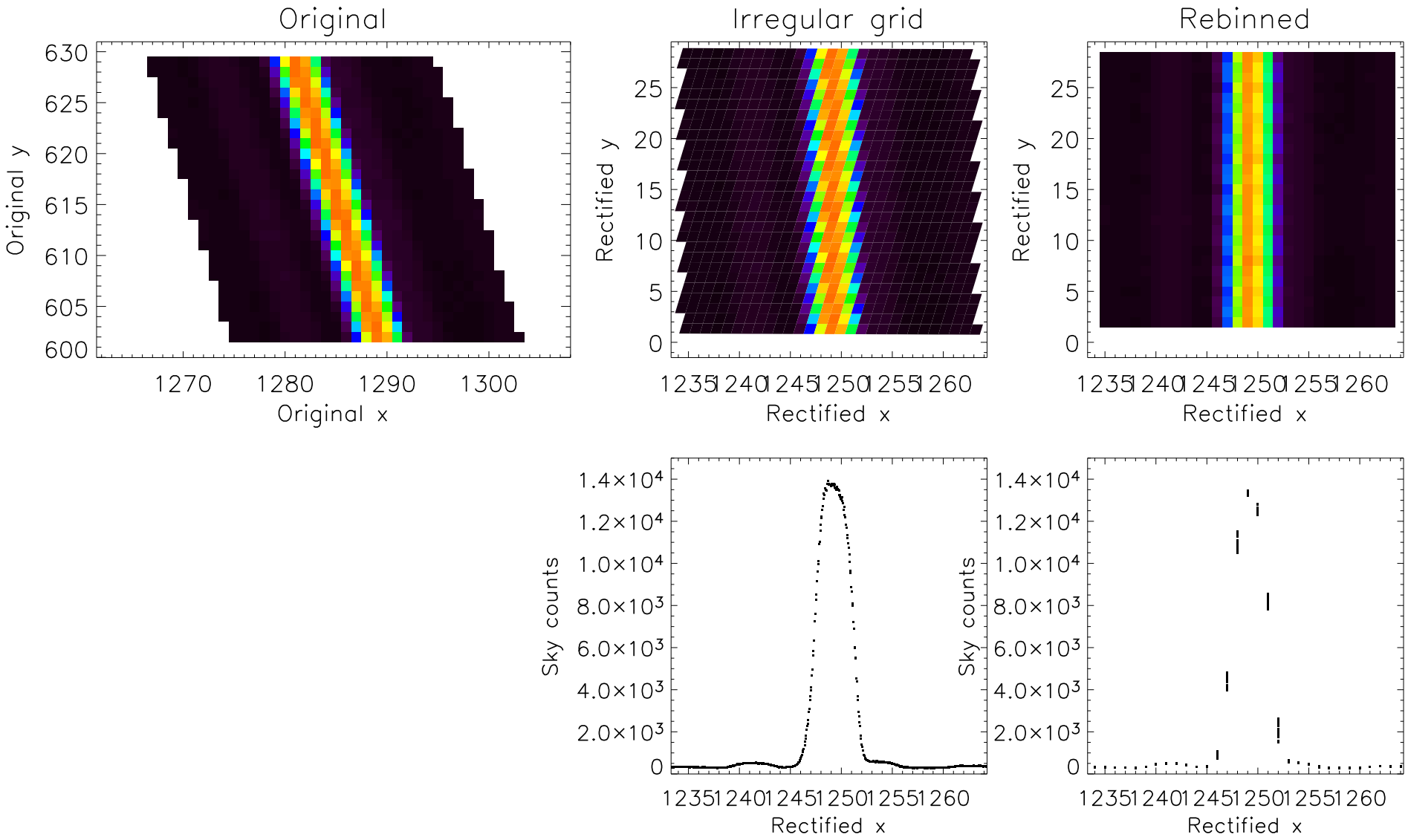
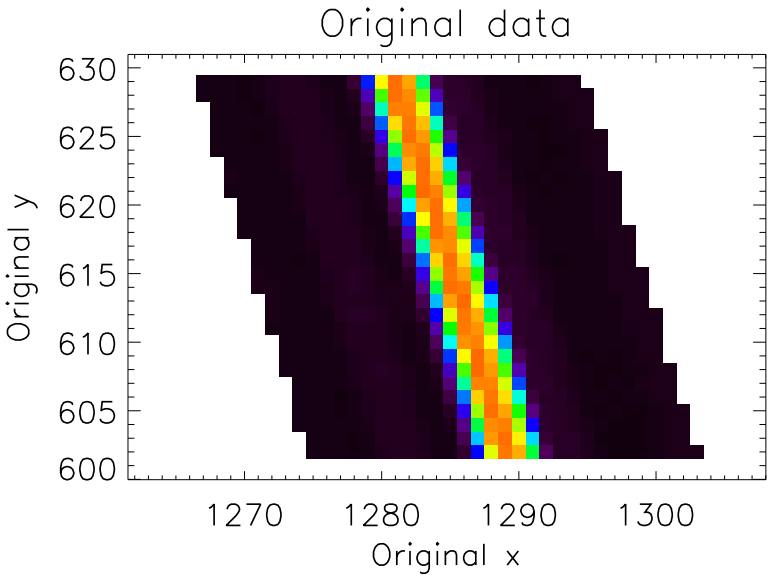
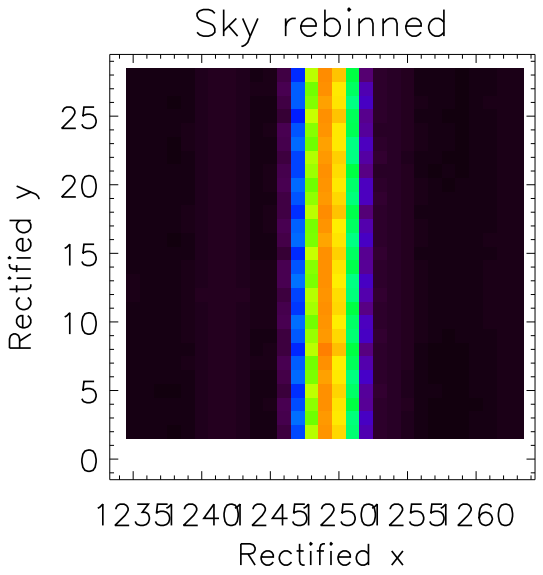


The achieved sky subtraction





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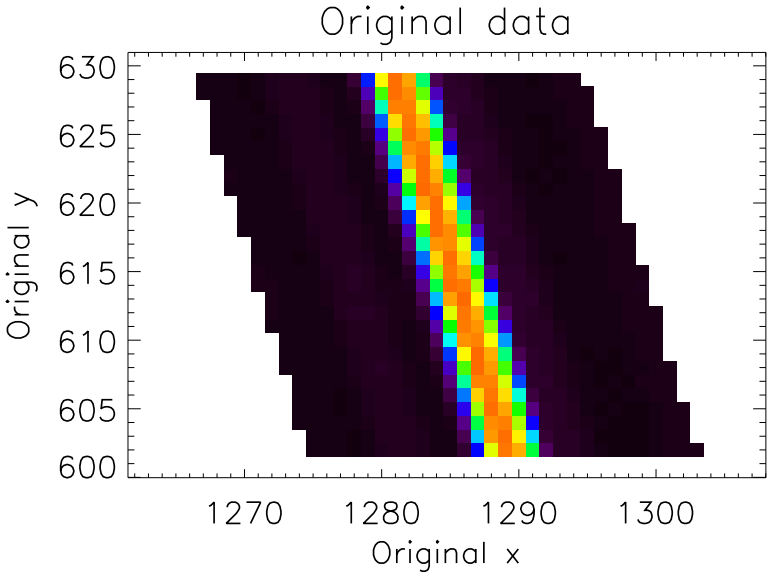

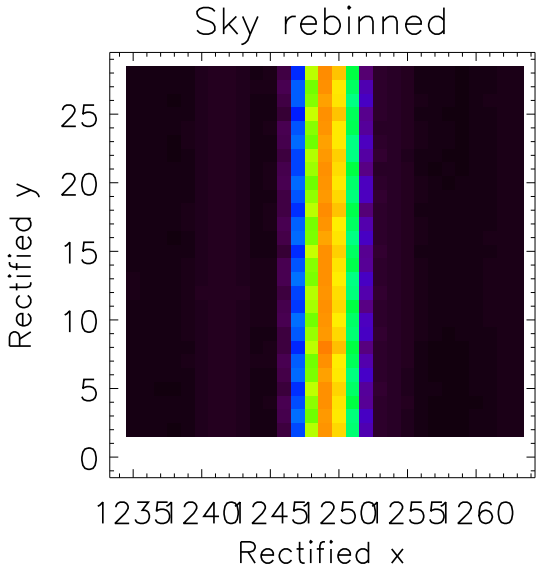

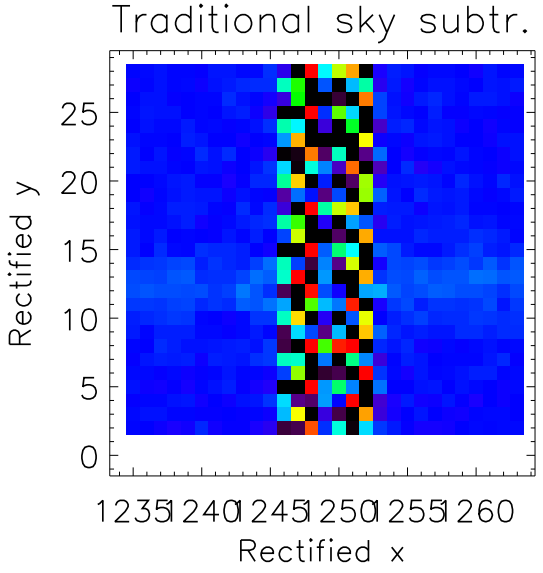

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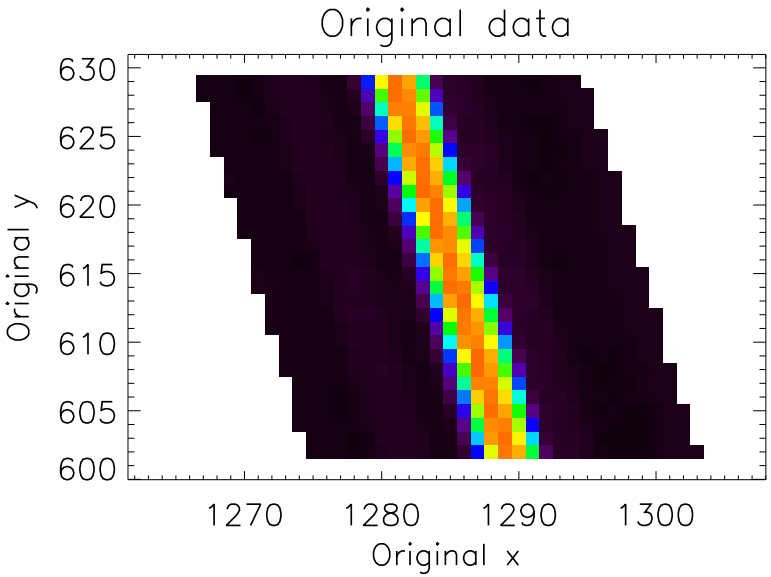

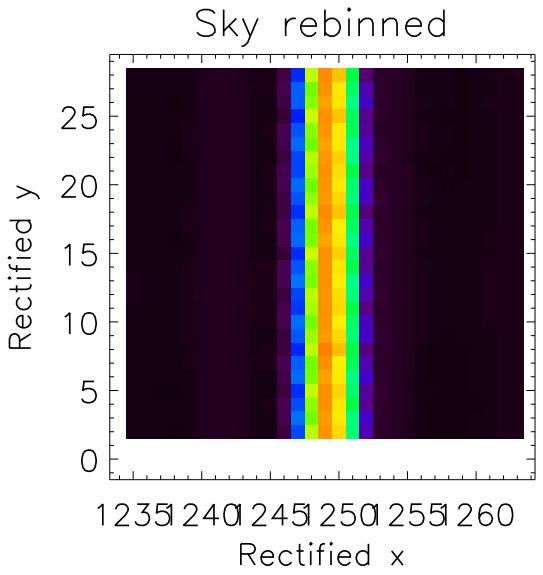

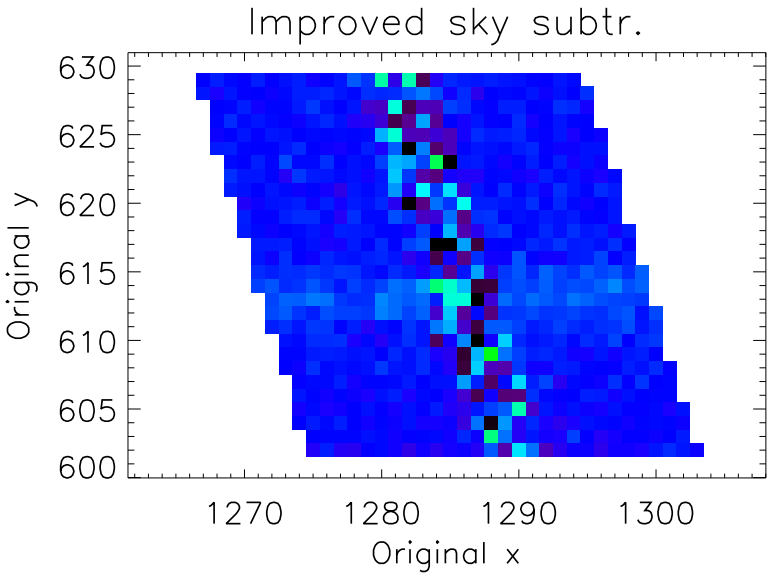

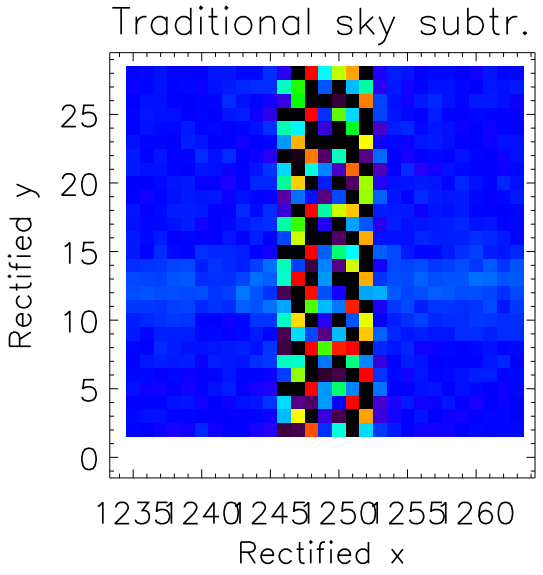

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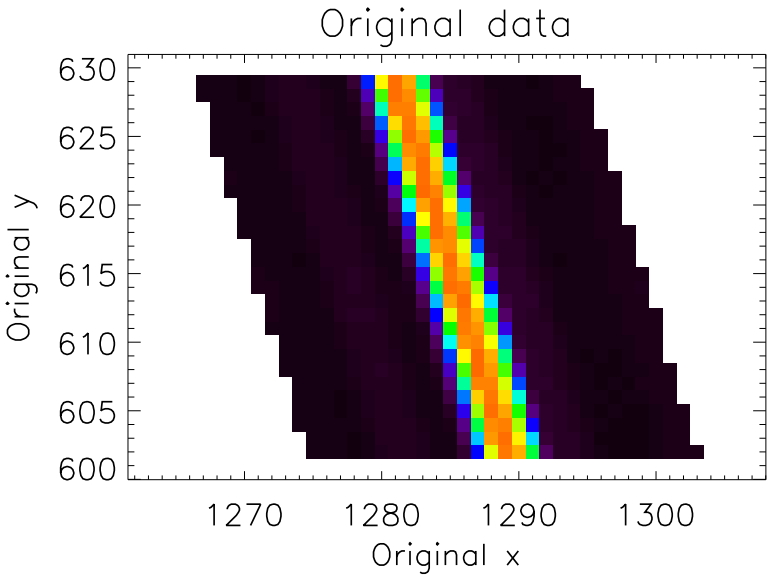
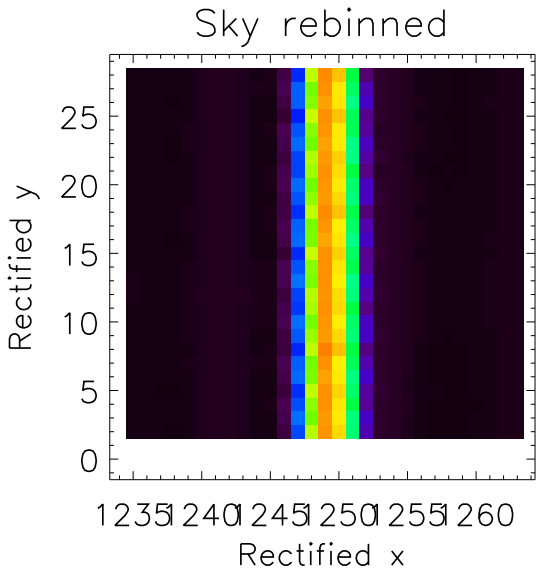
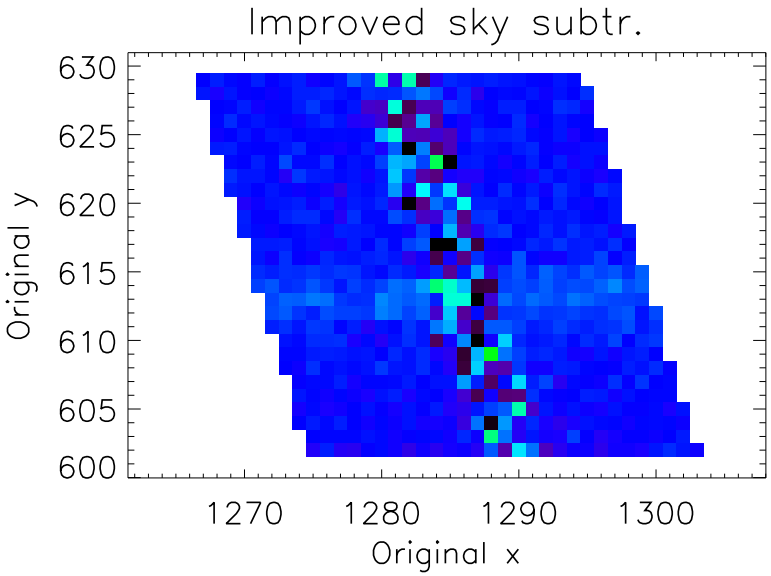
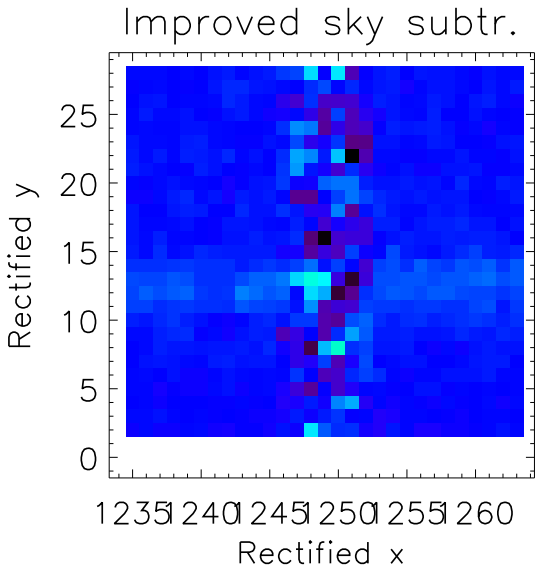
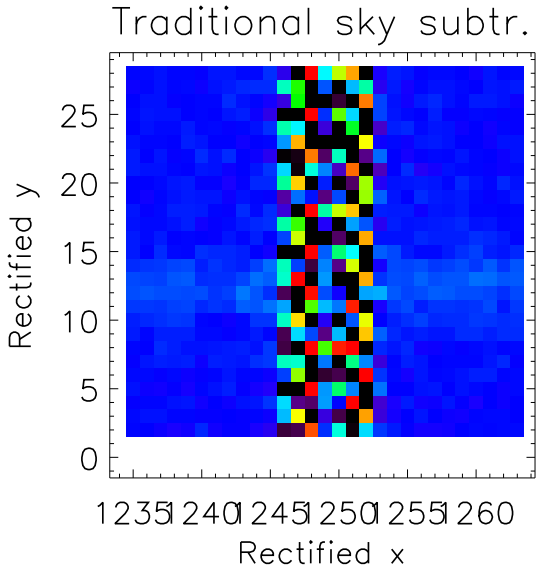


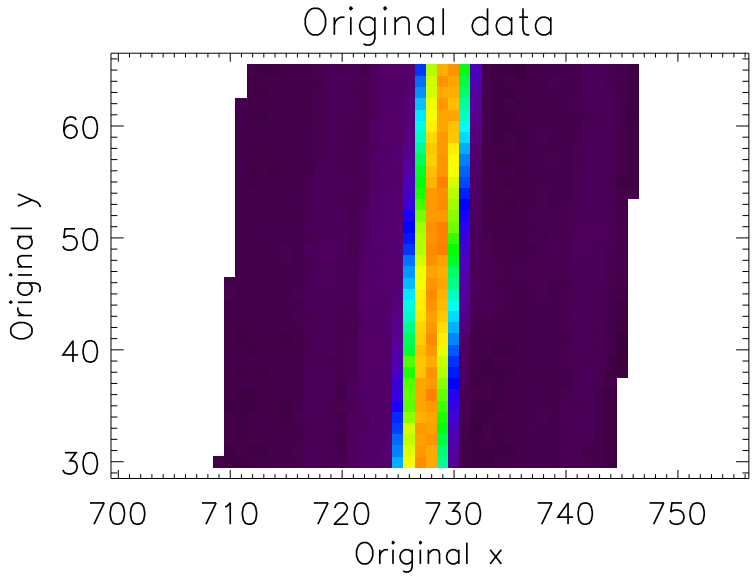


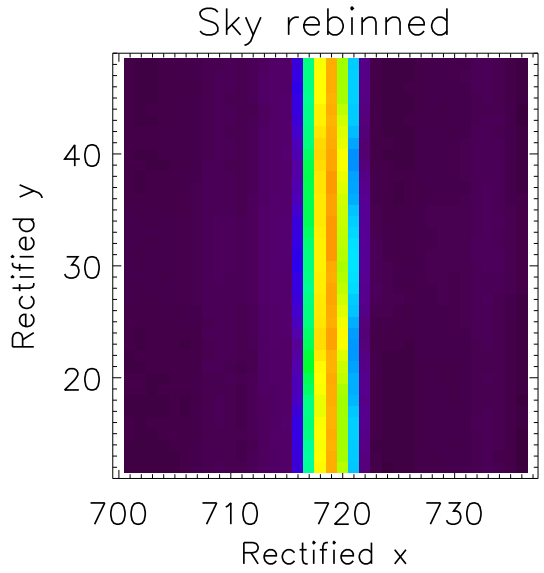


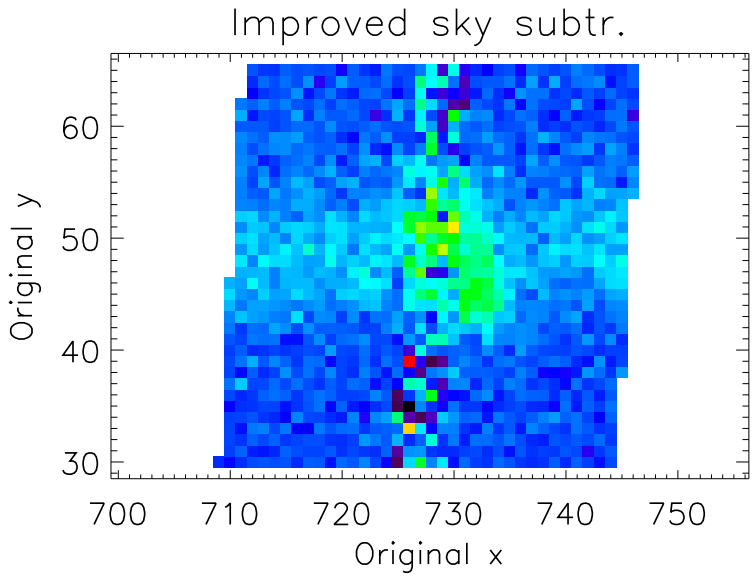


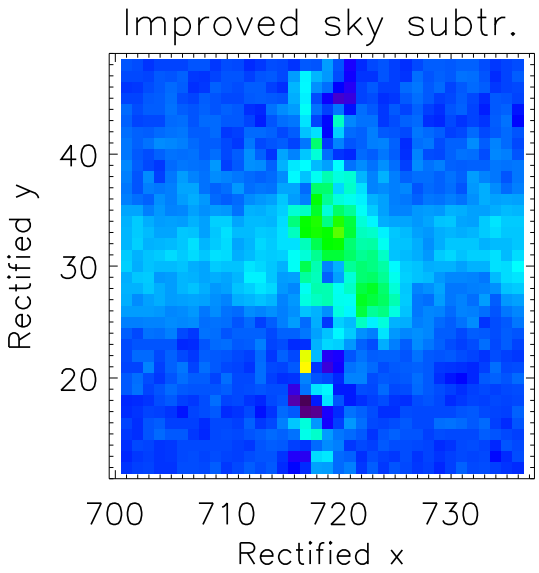


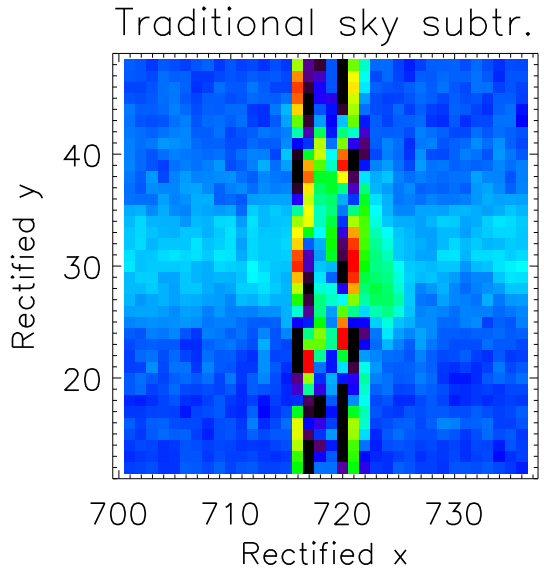
Example: [OII]3727 at $z = 0.71$ on 6364Å skyline



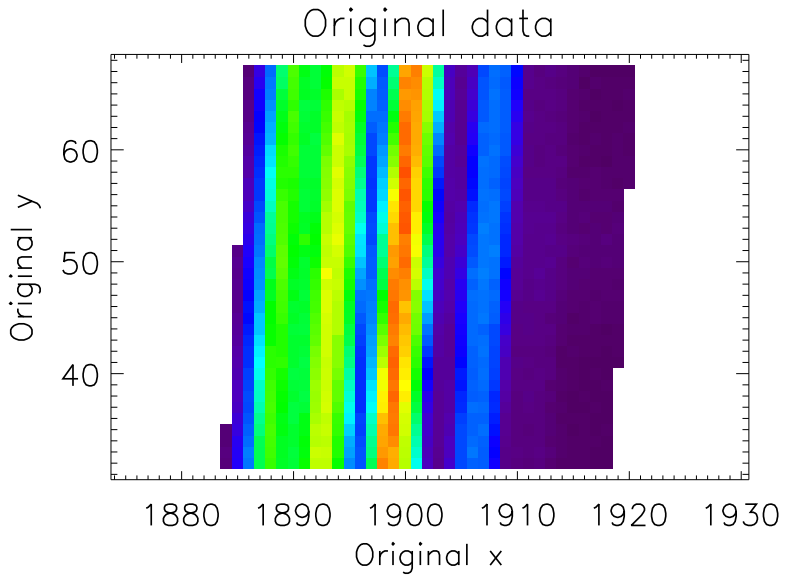


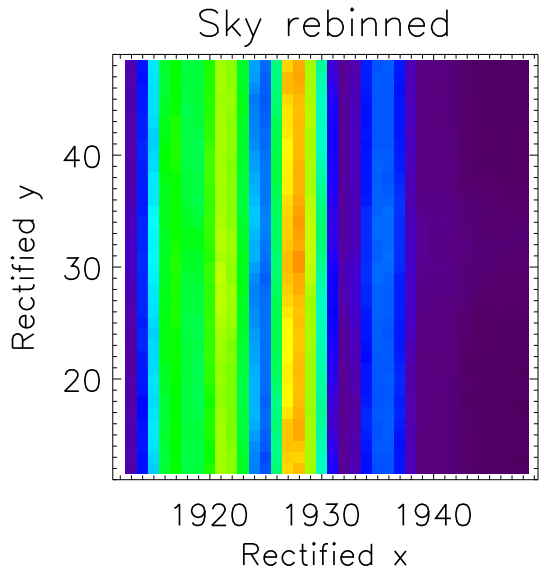


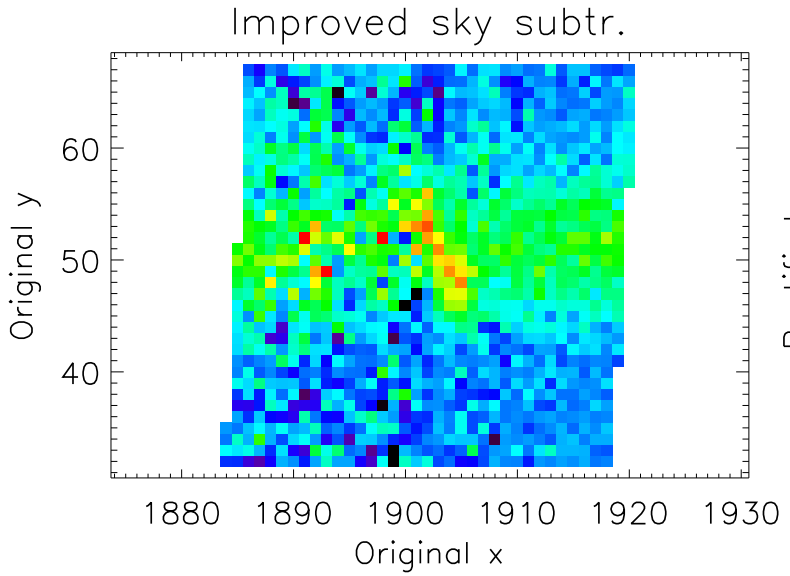


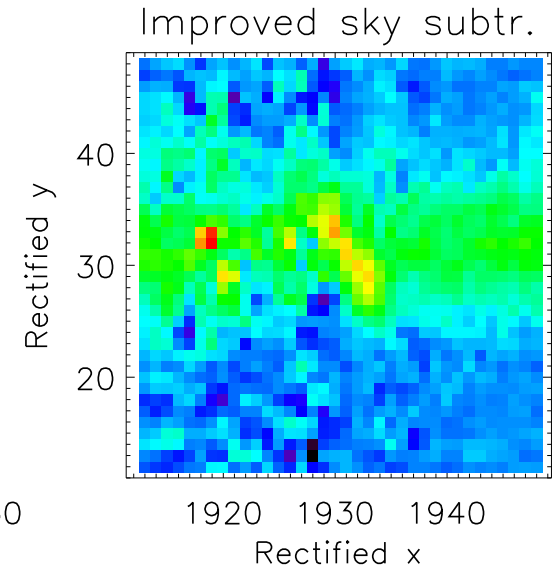


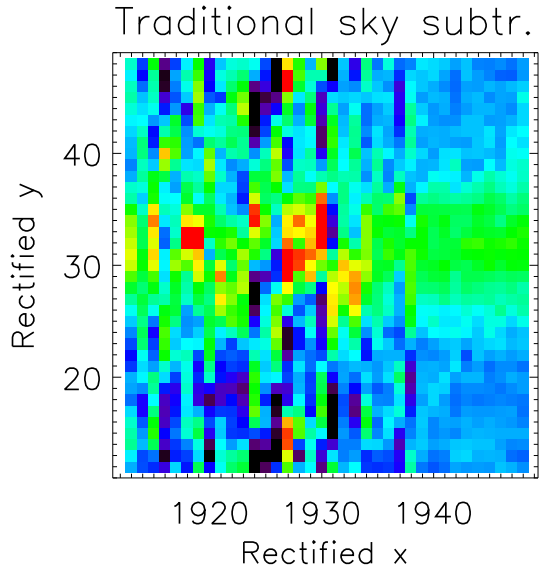
Example: Hβ at $z = 0.71$ on 8300Å skyline



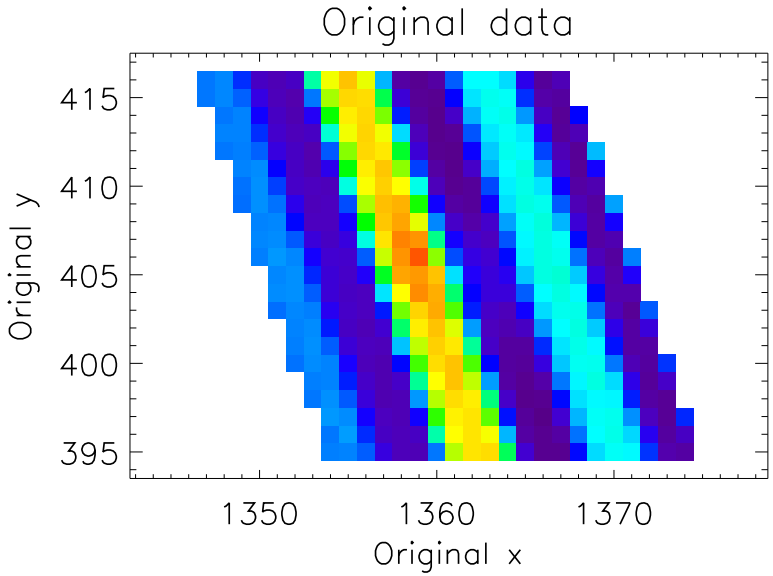


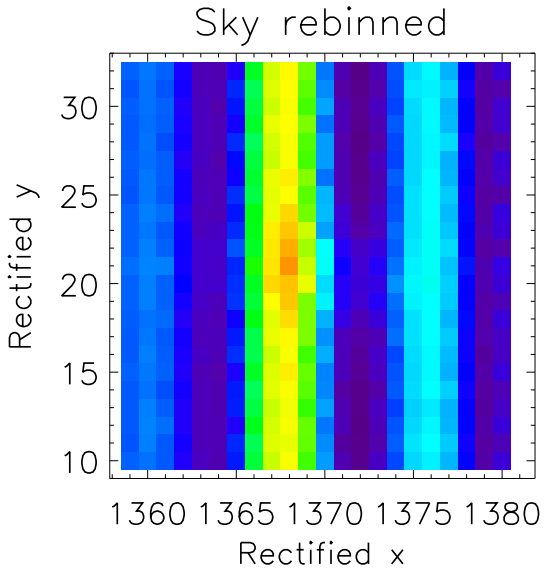


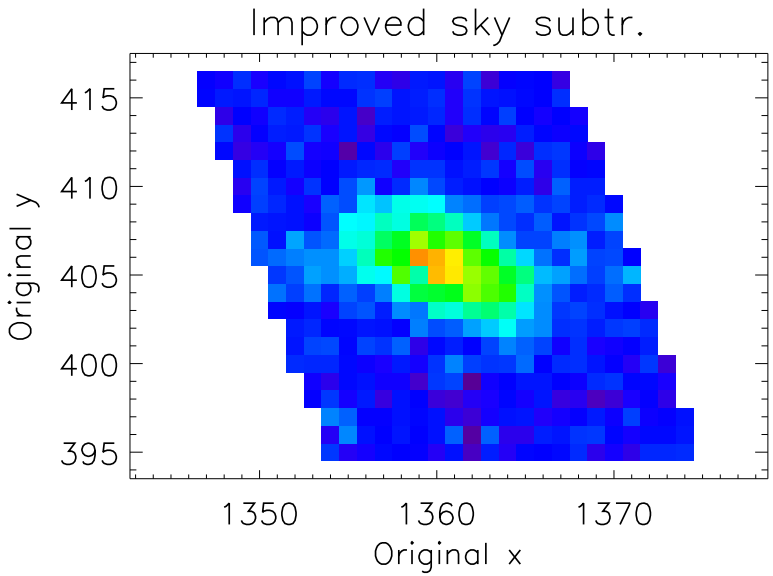


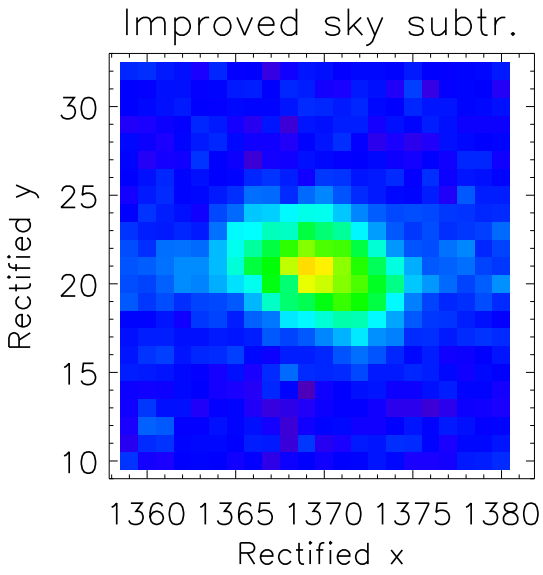


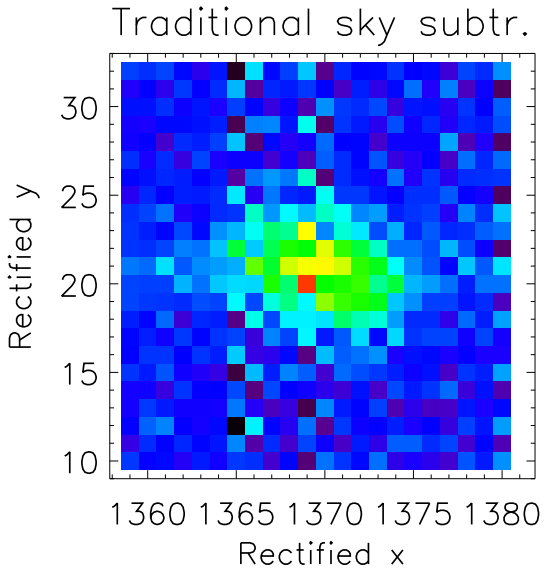
Example: [OII]3727 at $z = 0.96$ on 7317Å skyline



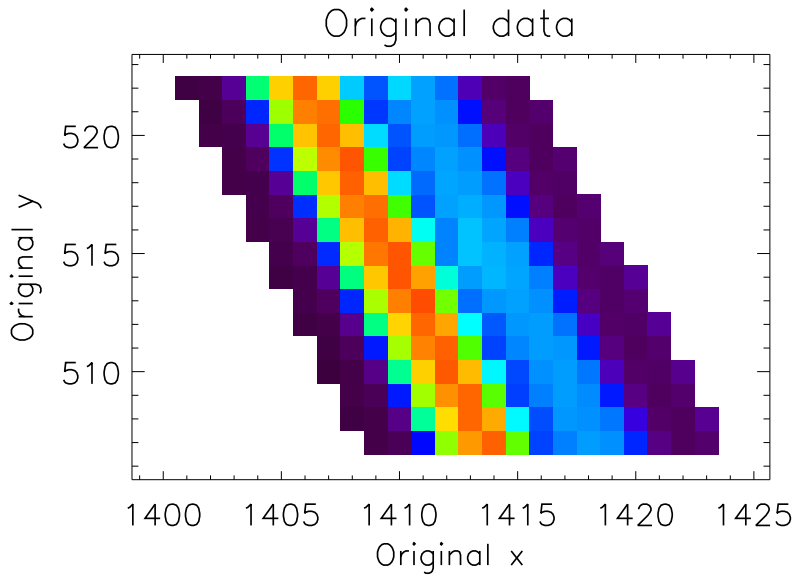


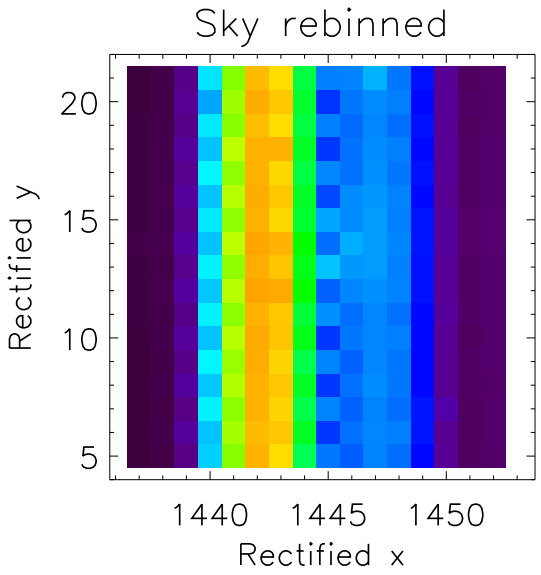


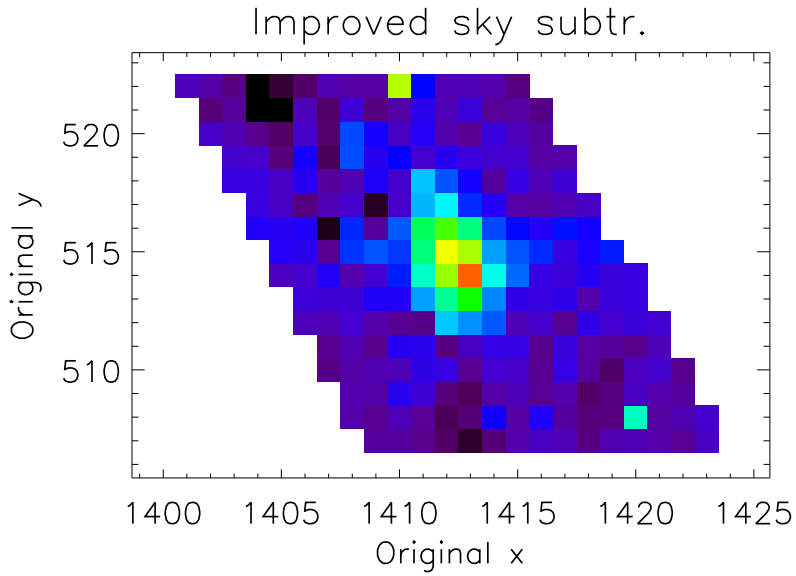


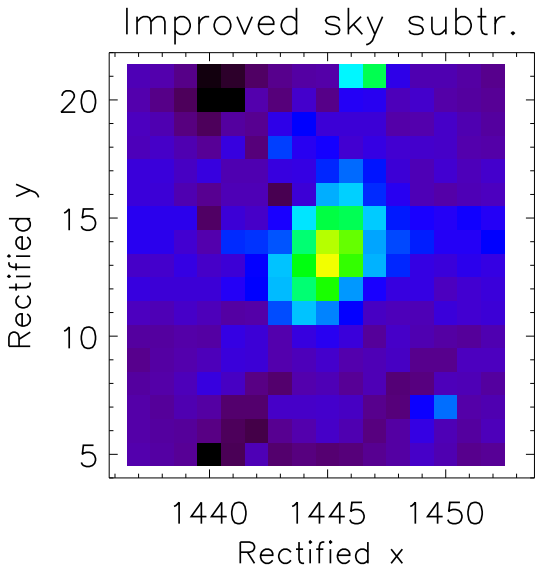


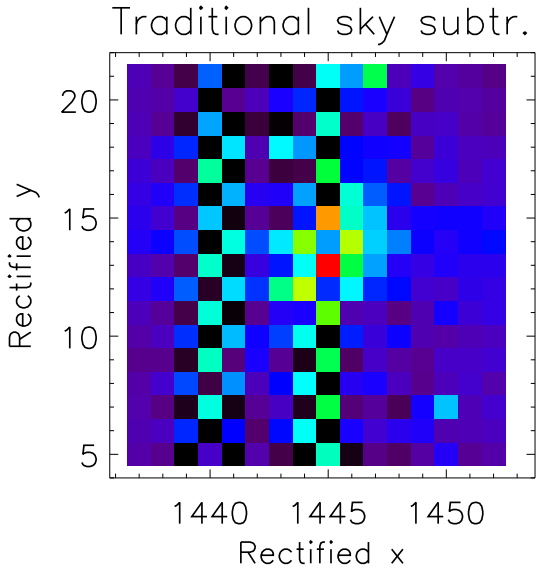
Example: Hα at $z = 0.27$ on 8351Å skyline



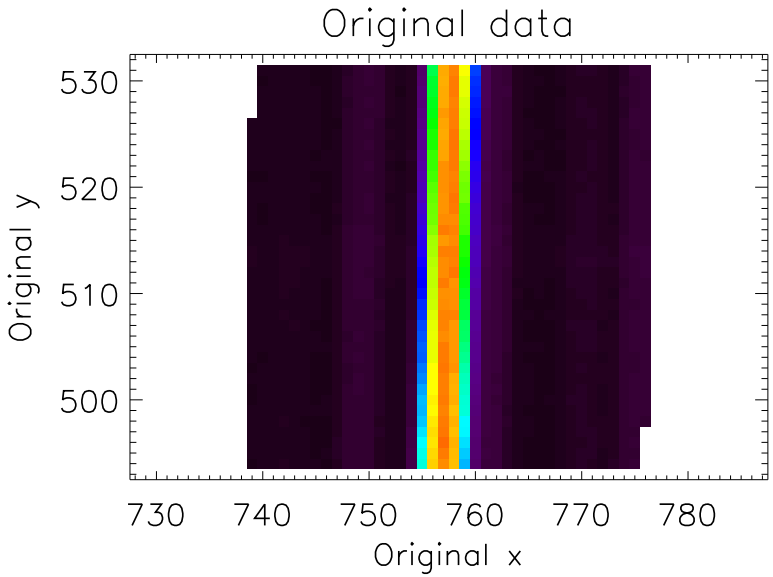


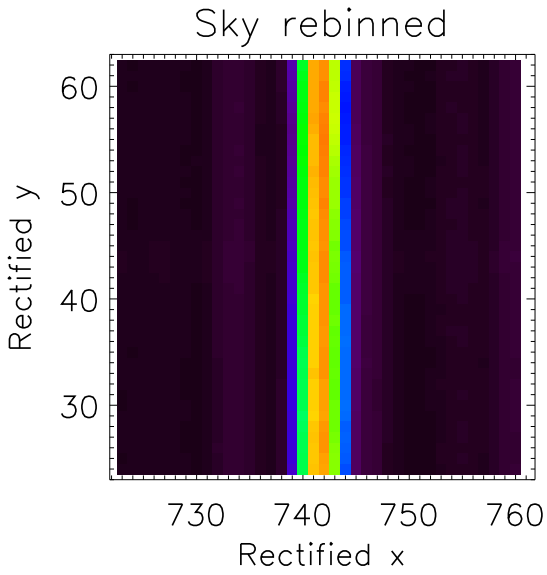


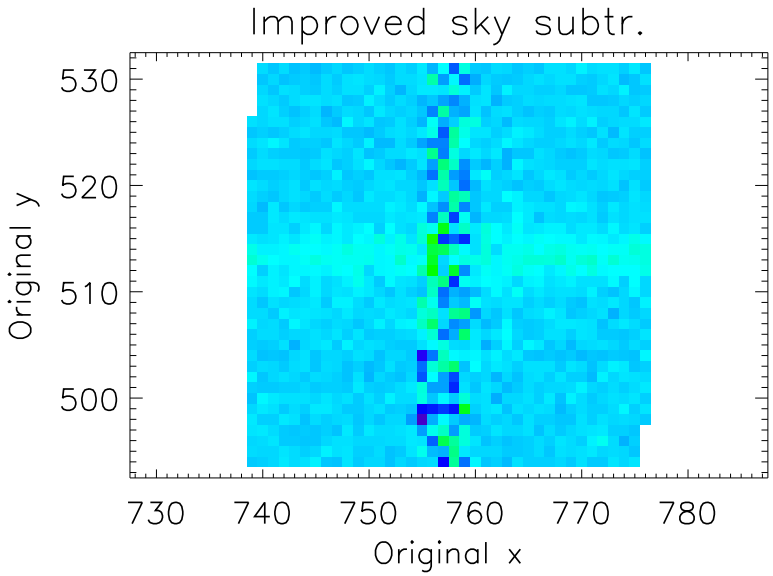


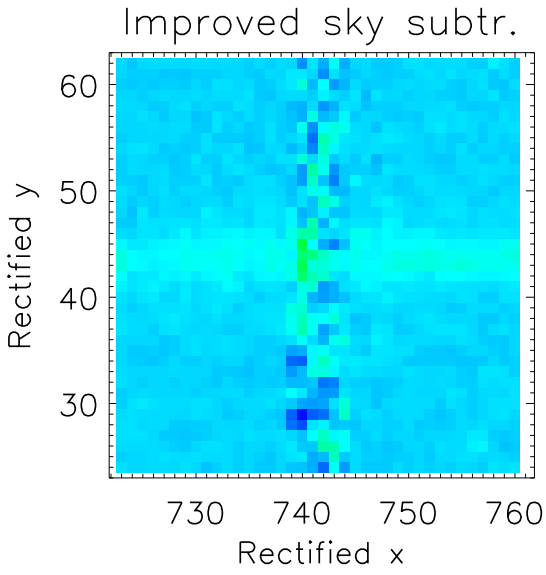


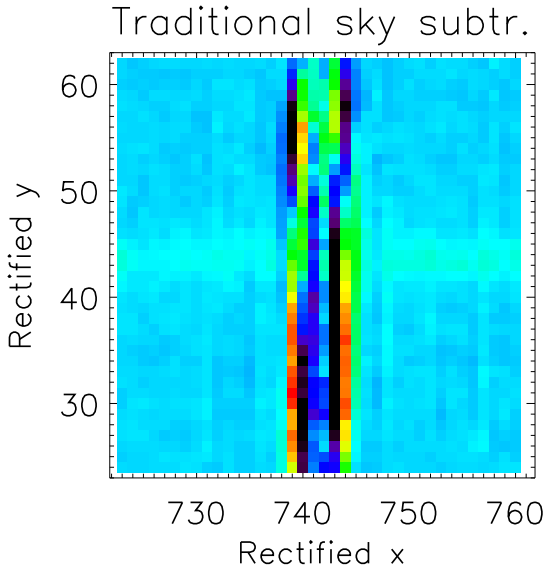
Example: slit is untilted, but spectrum is slightly tilted



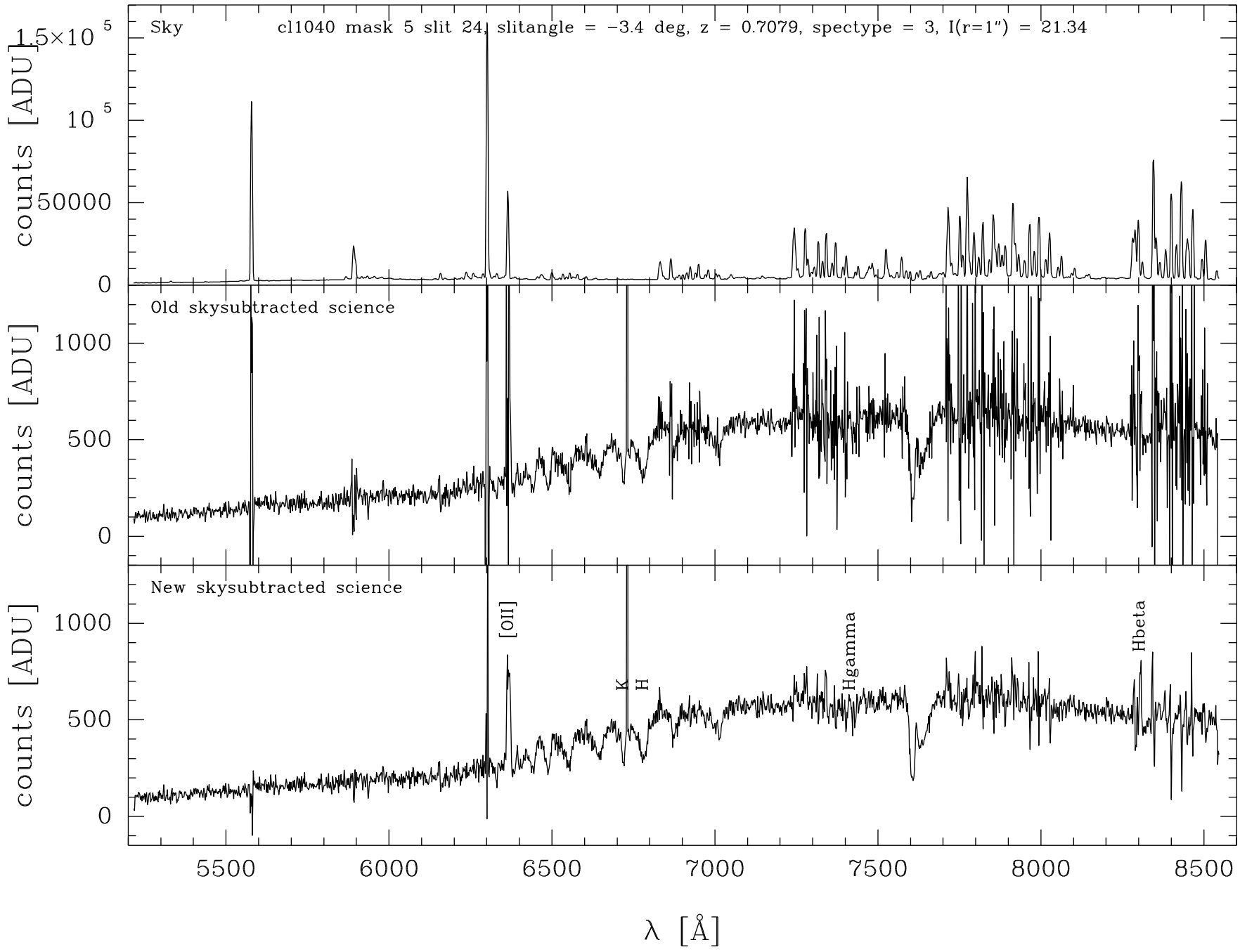




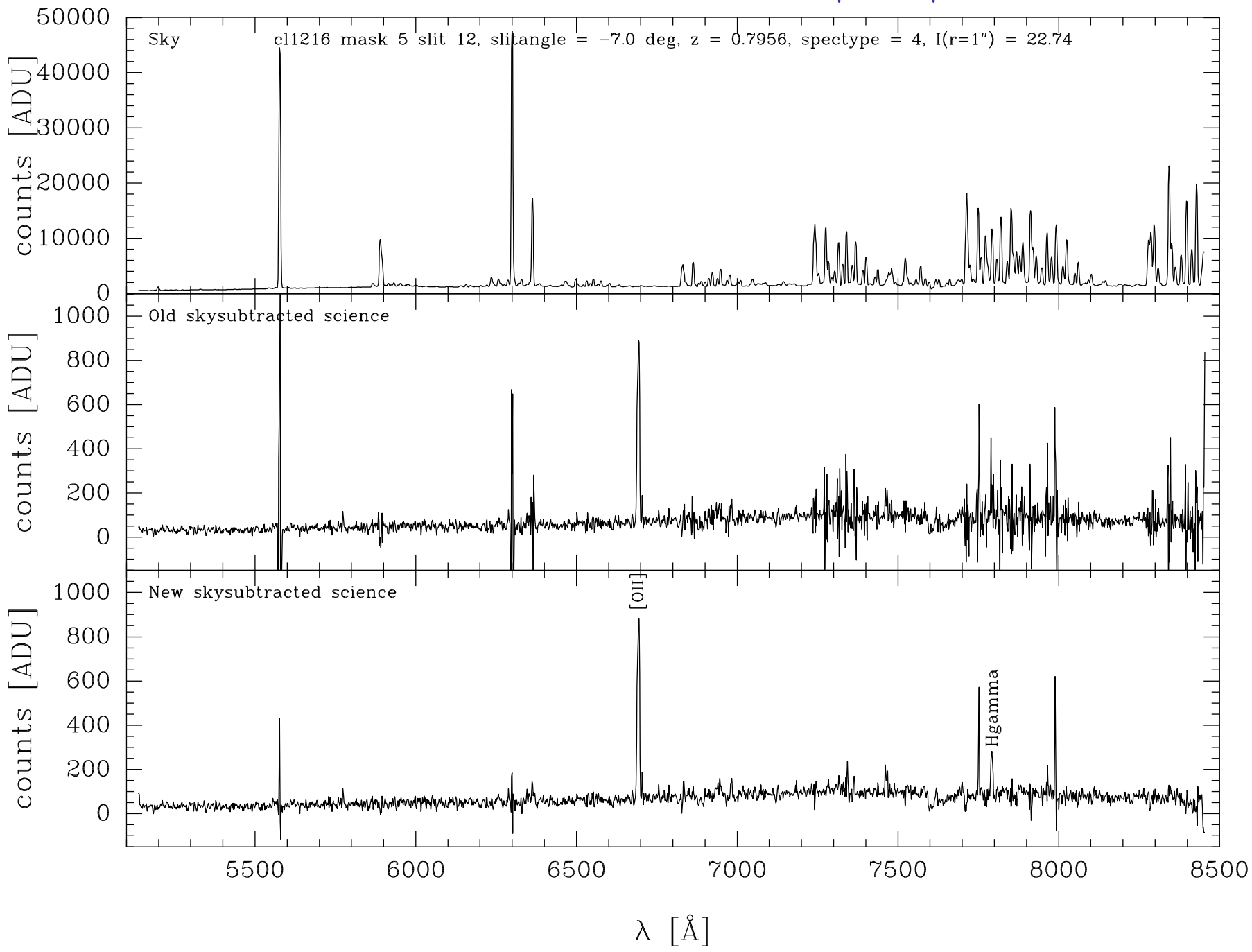




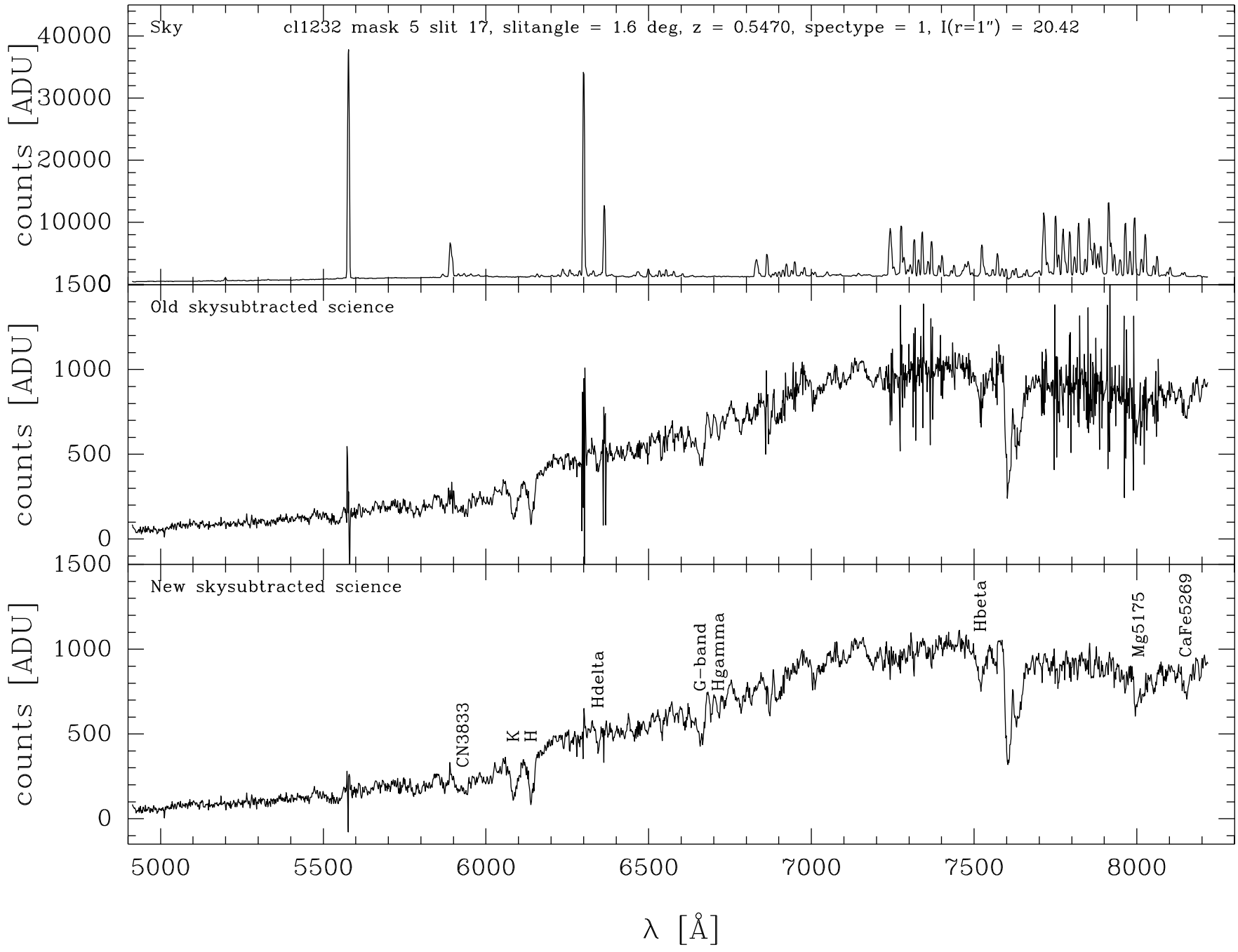
Example: $z = 0.71$, $I = 21.3$, $|\theta_{\text{slit}}| = 3.4°$



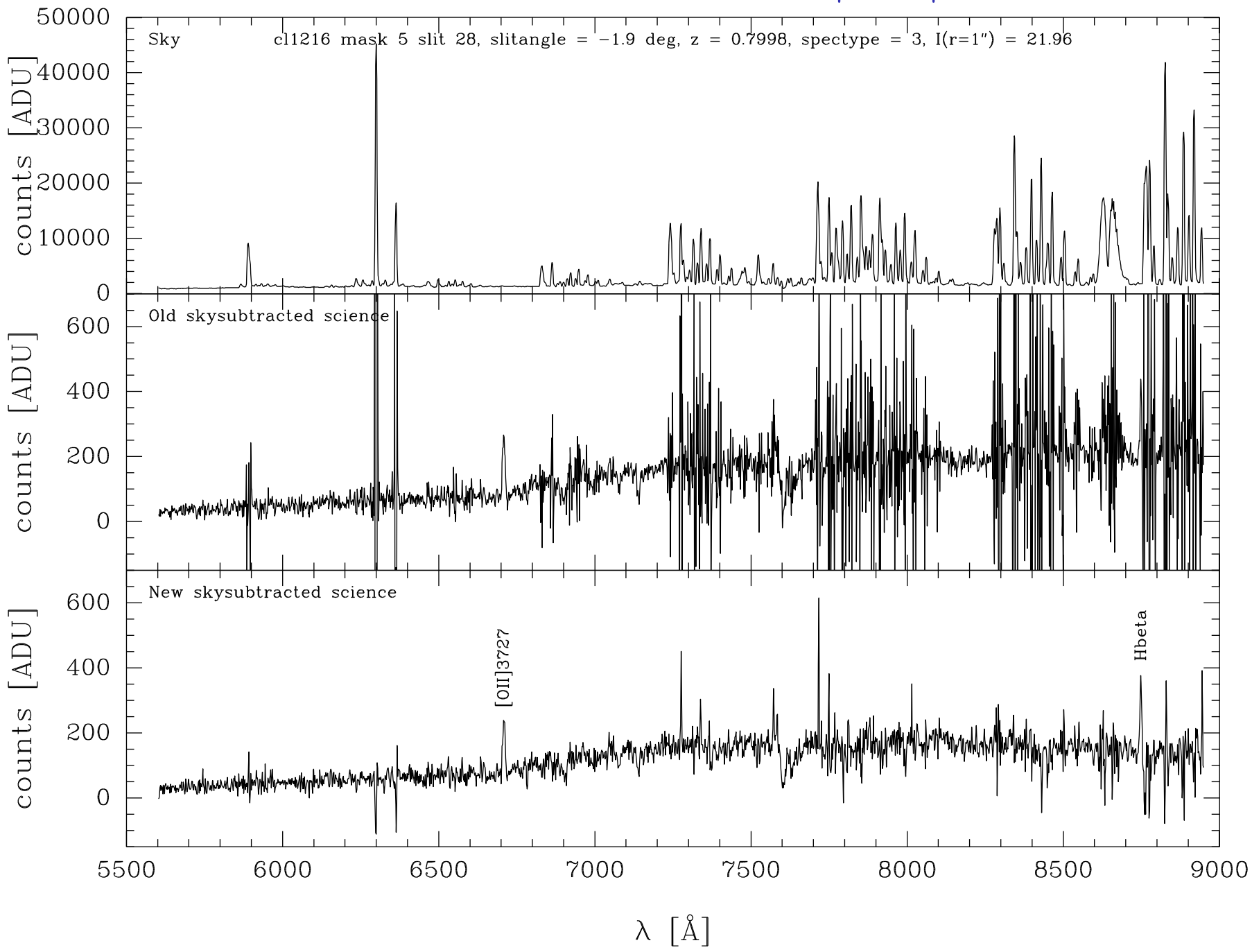
Example: $z = 0.80$, $I = 22.7$, $|\theta_{\text{slit}}| = 7.0°$



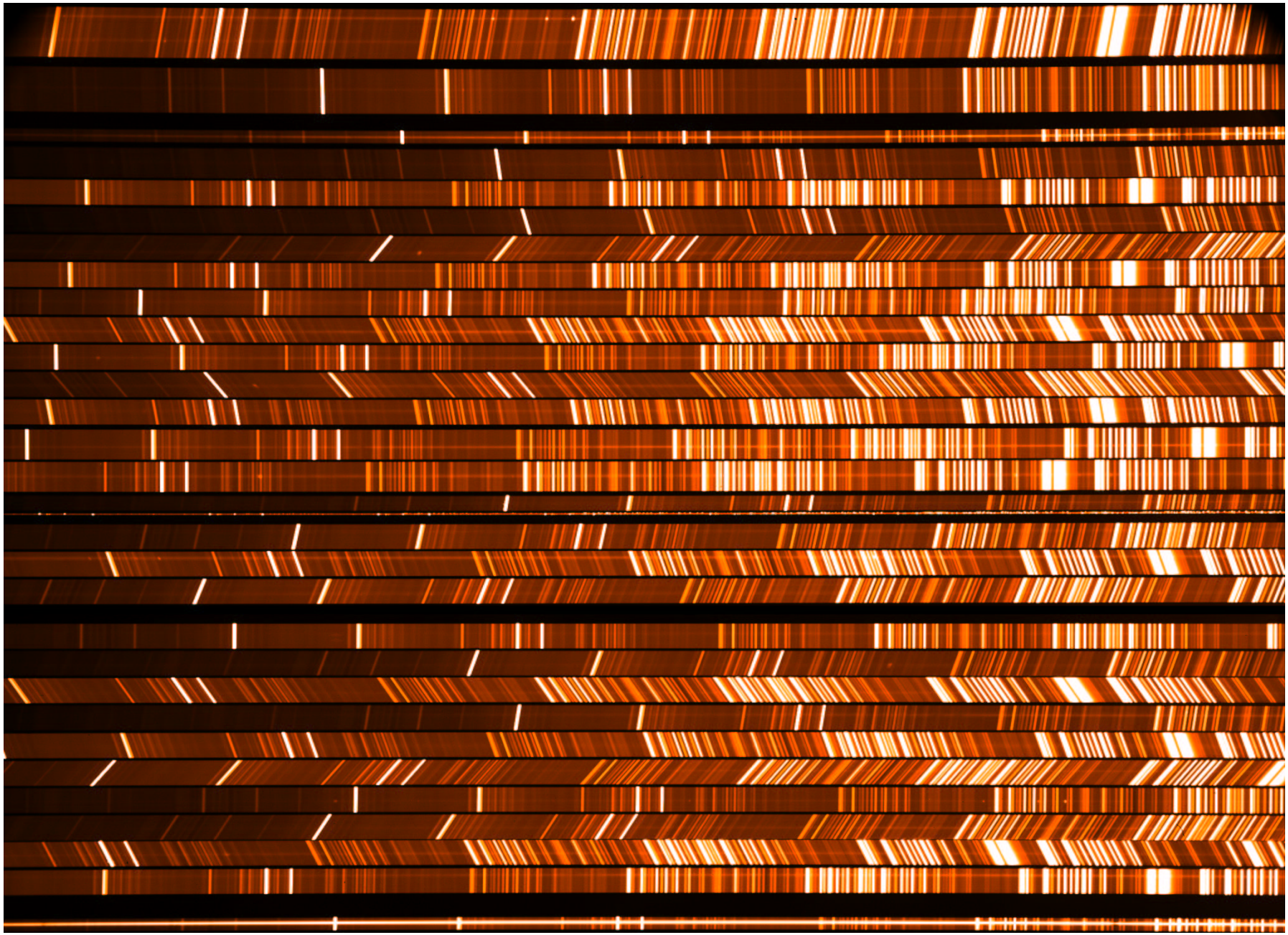
Example: $z = 0.55$, $I = 20.4$, $|\theta_{\text{slit}}| = 1.6°$



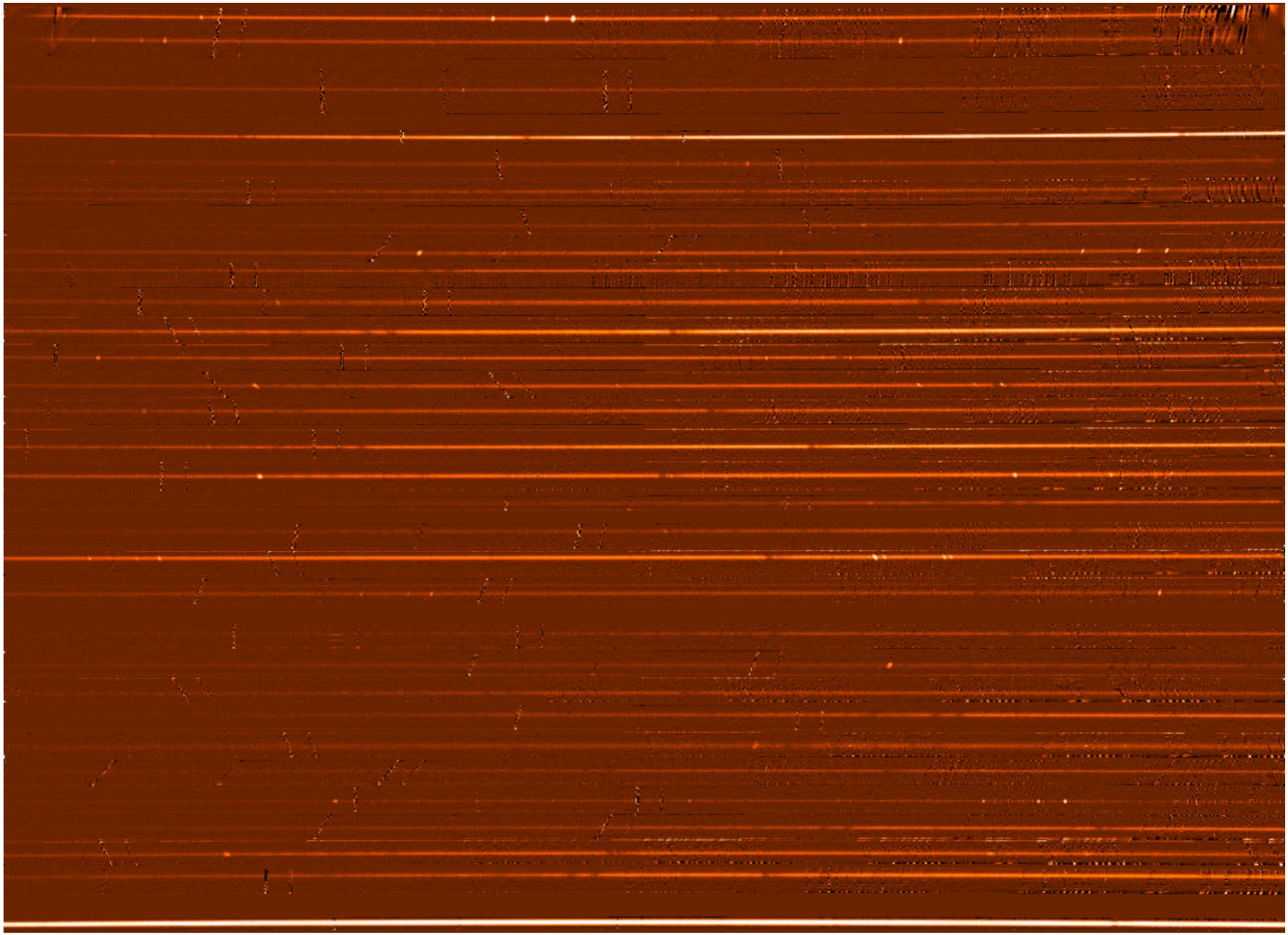
Example: $z = 0.80$, $I = 22.0$, $|\theta_{\text{slit}}| = 1.9°$



Uninterpolated frame: with sky

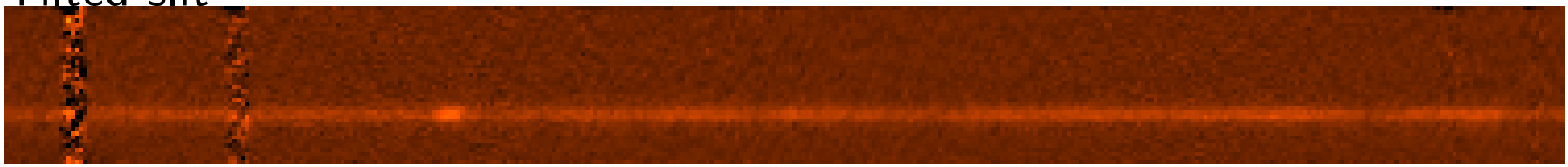


Uninterpolated frame: without sky

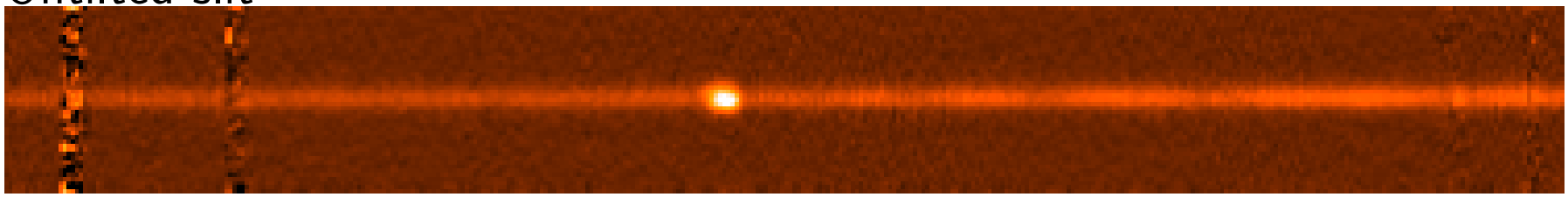


. . . and *then* interpolation to get rectified spectra

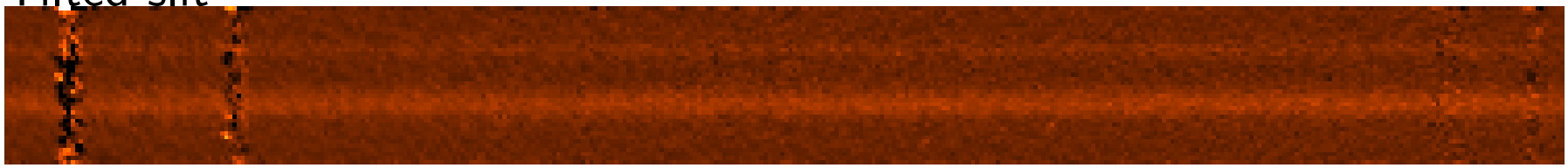
Tilted slit



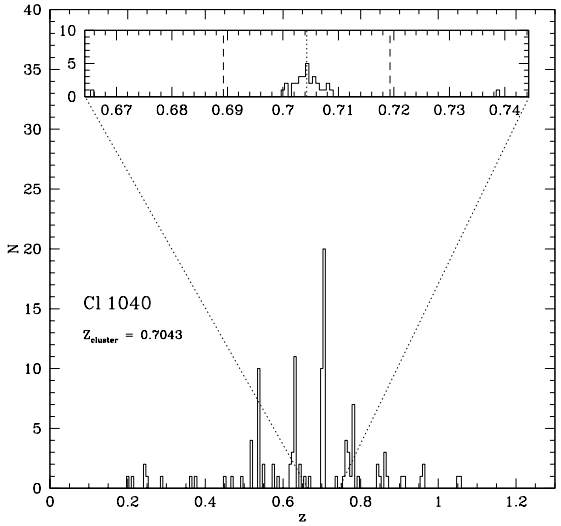
Untilted slit

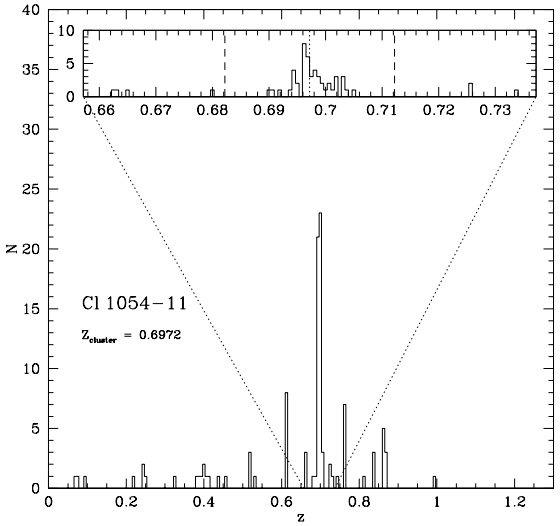


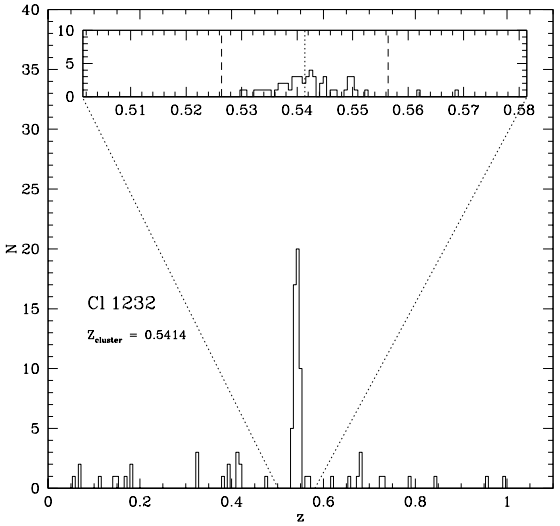
Tilted slit

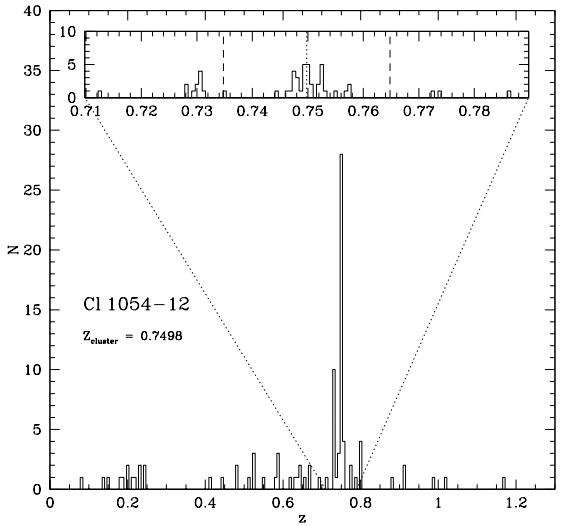


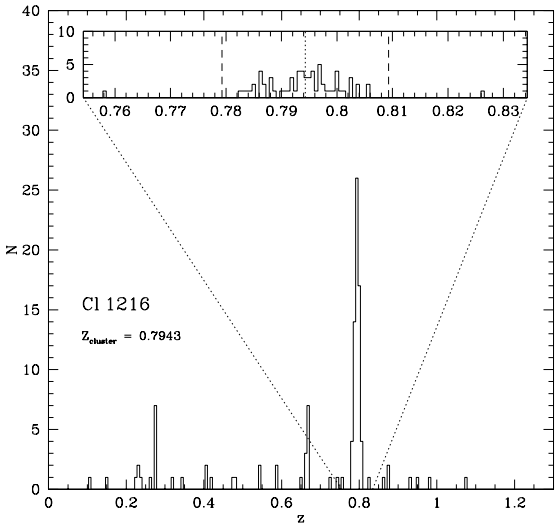
Example redshift histograms



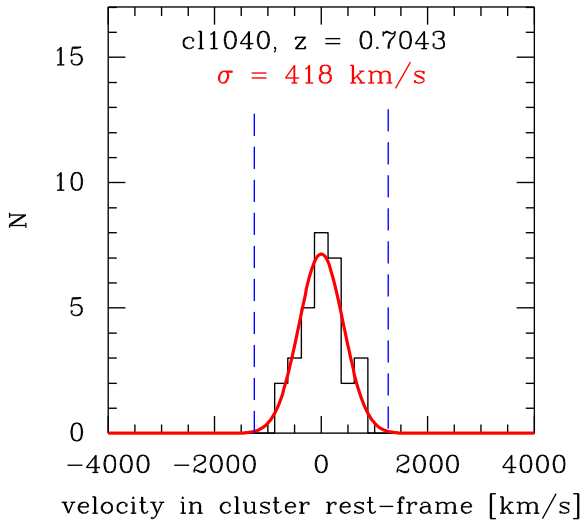


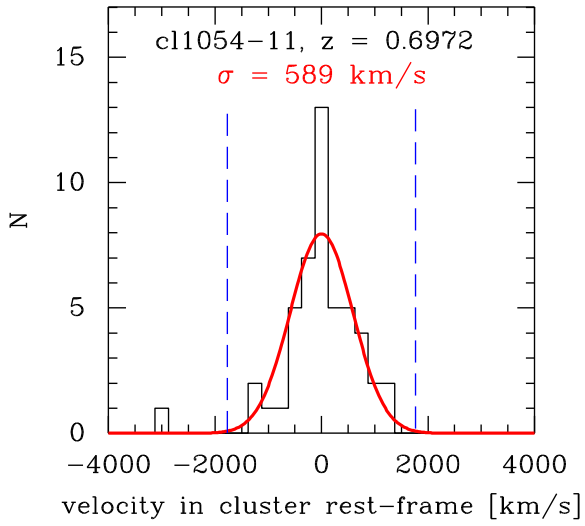


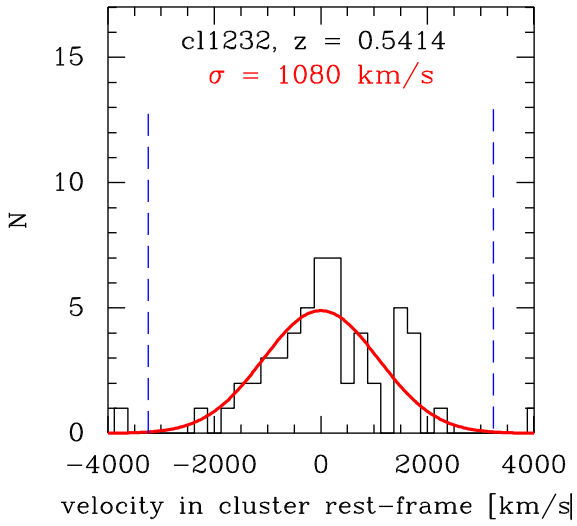


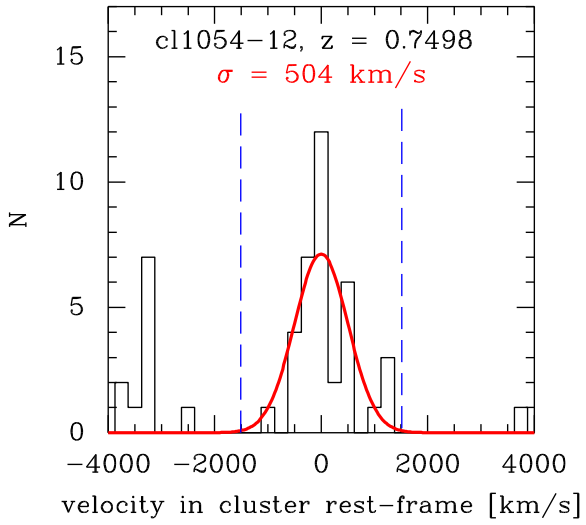


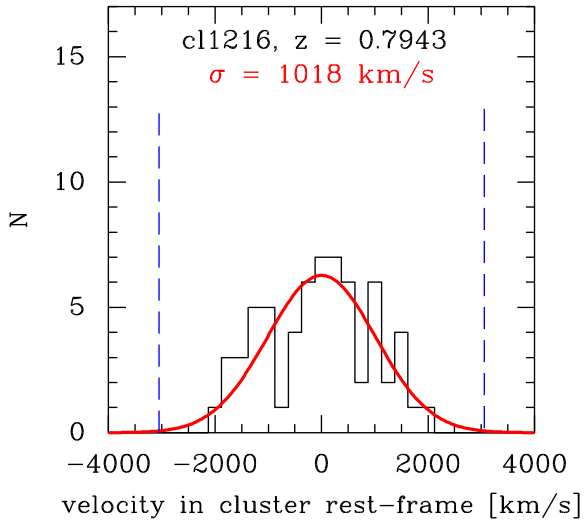
Rest-frame velocity histograms and velocity dispersions





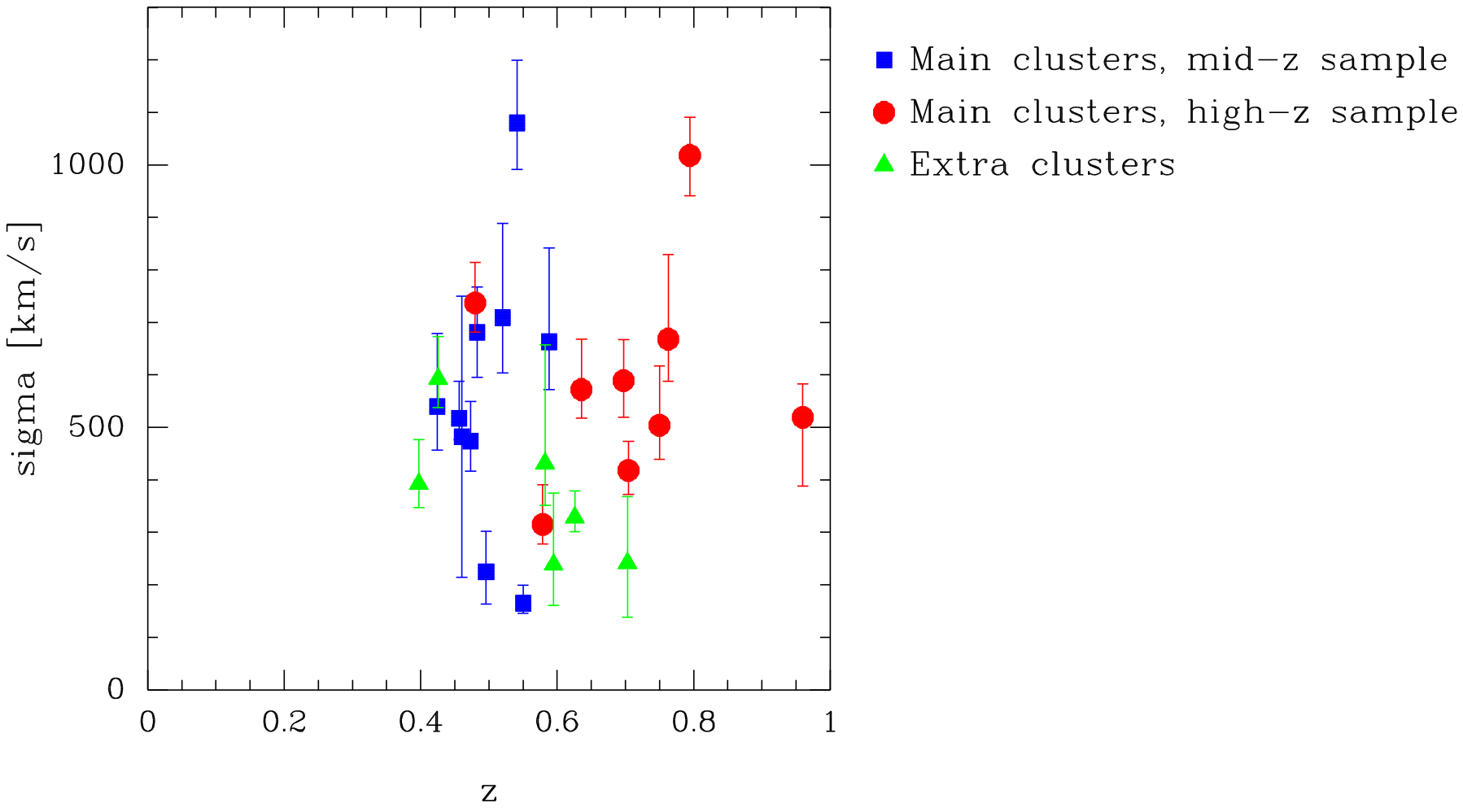






Velocity dispersions measured using the biweight estimator (Beers et al. 1990) using 3σ clipping.

Cluster redshifts and velocity dispersions: full sample



(Halliday et al. 2004, Milvang-Jensen et al., in prep.)

Summary

- The ESO Distant Cluster Survey (EDisCS) has obtained a high quality photometric and spectroscopic dataset for 20 galaxy clusters
- Our implemention of the Kelson (2003) sky subtraction method (Milvang-Jensen et al., in prep.) gives vastly improved sky subtraction for tilted slits
- Cluster redshifts and velocity dispersions have been measured for the EDisCS clusters (Halliday et al. 2004, Milvang-Jensen et al., in prep.)
  - z $= 0.42$–0.96 (mean: 0.60)
  - σ $= 170$–$1100\,\mathrm{km/s}$ (mean: $570\,\mathrm{km/s}$)
  - N_{members} $= 4$–66 (mean: 29)