

# GMOS Nod & Shuffle

What is Nod & Shuffle ?

Why Nod & Shuffle ?

How to deal with Nod & Shuffle observations ?

Nod & Shuffle the result of DD / SV proposals to the director Matt Mountain and AD Jean-Rene Roy by

- Roberto Abraham (U. Toronto)
- Karl Glazebrook (Johns Hopkins)
- Patrick McCarthy (Carnegie)
- David Crampton (HIA)

The decision to implement Nod & Shuffle was made in Jan 2002, Kathy Roth - Gemini lead for commissioning

# The Gemini Deep Deep Survey Team

Bob Abraham  
(Toronto)



Co-initial evil schemer; Canadian PI; proposal writer; reduction software writer; analysis software writer; commissioning & SV observer; extractor; redshifter; OCDD writer; Morphology/stellar populations enthusiast. Survey summarizer.

Karl  
Glazebrook  
(Johns Hopkins)



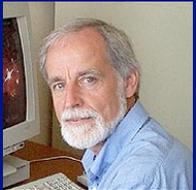
Co-initial evil schemer; Co-US PI; proposal writer; analysis software writer; nod & shuffle implementation consultant; OCDD writer; extractor; commissioning & SV observer; Redshift estimator. Mass function enthusiast.

Pat  
McCarthy  
(Carnegie  
Institution)



Co-initial evil schemer; Co-US PI; proposal writer; photometry co-czar; LCIR co-designer; mask designer; extractor; commissioning/SV observer; IR observer; redshifter; webmaster. Galaxy formation history enthusiast.

David  
Crampton  
(Herzberg  
Institute)



GMOS Co-PI, Initial N&S co-enthusiast and supporter who got us off the ground. Voice Of Reason. Redshift extractor & estimator; extraction debugger; SV observer. Talked Matt into it!

Rick  
Murowinski  
(Herzberg  
Institute)



Lead engineer on project; Got N&S actually working; Chief implementation specifier; Overall project scheduler; Detector Genius. OCDD writer. Chief person without whom we'd be totally screwed.

Sandra  
Savaglio  
(Johns  
Hopkins)



Spectral template gatherer; Supercombine spectrum maker; Absorption-line spectrum understander. Redshifter. Proposal writer.

Isobel Hook  
(Oxford)



N&S IFU mode lead schemer; N&S implementation consultant; OCDD writer; proposal writer; Co-Voice-Of-Reason. Extractor & redshifter. Commissioning observer.

Inger  
Jørgensen  
(Gemini  
Observatory)



N&S mode co-specifier; chief Contact with Telescope and Observatory Reality. Lead software enforcer; Can-carrier on GMOS at Gemini. Commissioning, SV, and Queue observer.

Kathy Roth  
(Gemini  
Observatory)



N&S mode co-specifier; Subsidiary Team Contact with Telescope Reality. Can-carrier on N&S mode at Gemini. Web pager. OCDD writer. Redshifter. Commissioning, SV, Queue observer.

Ray  
Carlberg  
(Toronto)



LCIR co-initiator. Correlation function calculator and photo-z understander. Spectral synthesizer. Co-Voice-Of-Reason with Isobel and David.

Ron Marzke  
(San Francisco  
State University)



Photometry Czar; LCIR co-initiator; optical data collector; Co-catalog constructor; co-photo-z gatherer; Emergency finding chart maker. IR observer. Luminosity function enthusiast.

Hsiao-Wen  
Chen  
(MIT)



Photometric Redshift Czarina; optical data collector; catalog constructor. Luminosity function enthusiast.

# Gemini Deep Deep Survey

## Timeline:

- Sept. 2001: First planning among team co-Is
- Jan. 2002: Team presented N&S proposal to Gemini - approved in February
- Feb. - May 2002: N&S implemented at DAO (\$10K)
- July 2002: N&S commissioned on Gemini

## Goal:

- Explore galaxy evolution near the peak epoch of galaxy building.
- Deep 100,000 sec MOS exposures on Las Campanas IR Survey fields to get redshifts of a complete  $K < 20.6$   $I < 24.5$  sample covering  $1 < z < 2$ 
  - use photo- $z$ 's to weed out low- $z$  galaxies (BVRIZJHK)
- Determine luminosity and mass functions
  - Constrain the space density at redshift of evolved high-mass galaxies
- Relate to galaxy morphology (ACS)
- Track SFH over  $1 < z < 2$ :
  - Age of galaxies, metallicities of population

# What is Nod & Shuffle ?

Nod: Telescope motion on the sky

- Small nods useful for point sources or for keeping objects in the slit
- Large nods useful for extended objects but on-sky efficiency decreased 2x

Shuffle: Charge shift up/down the detector

- micro-shuffle
- band shuffle

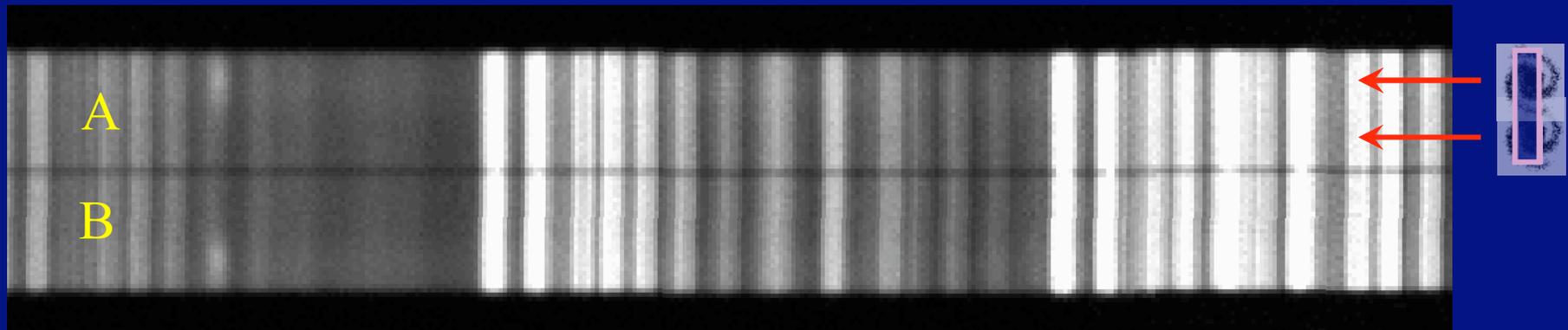
The size and direction of nods and shuffles do not necessarily have anything to do with one another

# Nod & Shuffle

Cuillandre, J.C. et al. 1994, A&A 281, 603; Sembach, K. and Tonry, J.L. 1996, AJ 112, 797;  
Glazebrook, K. and Bland-Hawthorn, J. 2001, PASP, 113: 197

- An optical version of common infrared practice
  - Exposure times are short because skylines vary with time
  - Nod object along the slit and subtract subsequent frames
- Unlike in the IR, CCDs cannot be read out as quickly or as often because read noise dominates, not sky noise
- The GMOS CCDs have significant fringing in the red
- Nod & Shuffle instead of reading out the data every 60 seconds
  - Expose in nod position "A"
  - Nod the telescope to position "B" and electronically "shuffle" the charge collected during nod position "A" to an unexposed portion of the detector and store it while exposing nod position "B"
  - Nod back to position "A" and electronically shuffle the charge back again and expose in nod position "A" again
  - Repeat many times
- Nod & Shuffle has associated additional overheads, typically 10-20%

# Sky cancellation: Nod & Shuffle Demonstration

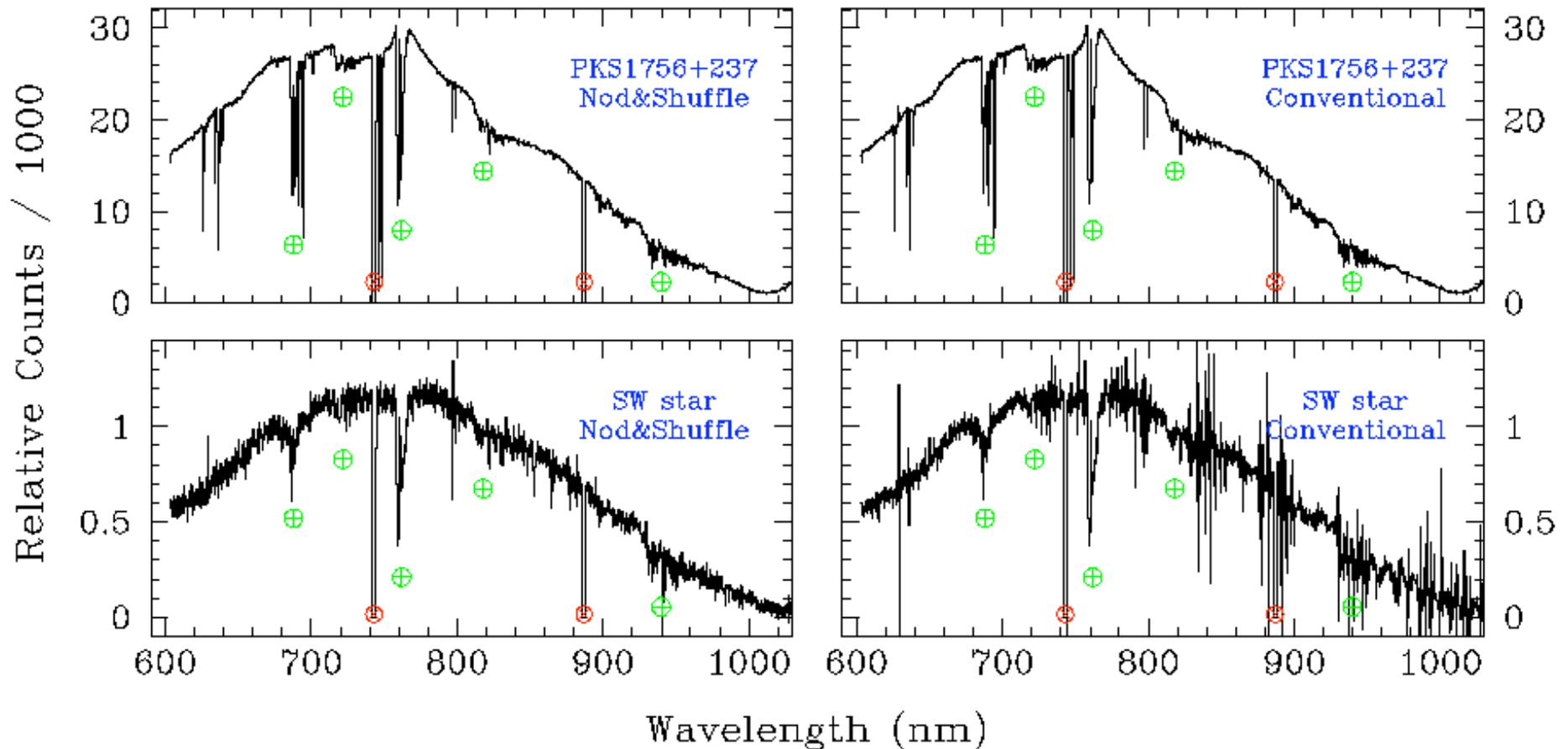


Typically A=60s/15 cy: 1800s exposure  $\Rightarrow 10^{-3}$  subtraction

# Improved Skyline Residuals

Improvement seen for faint targets particularly longward of  $\sim 770$  nm.

Extracted Spectra Comparison

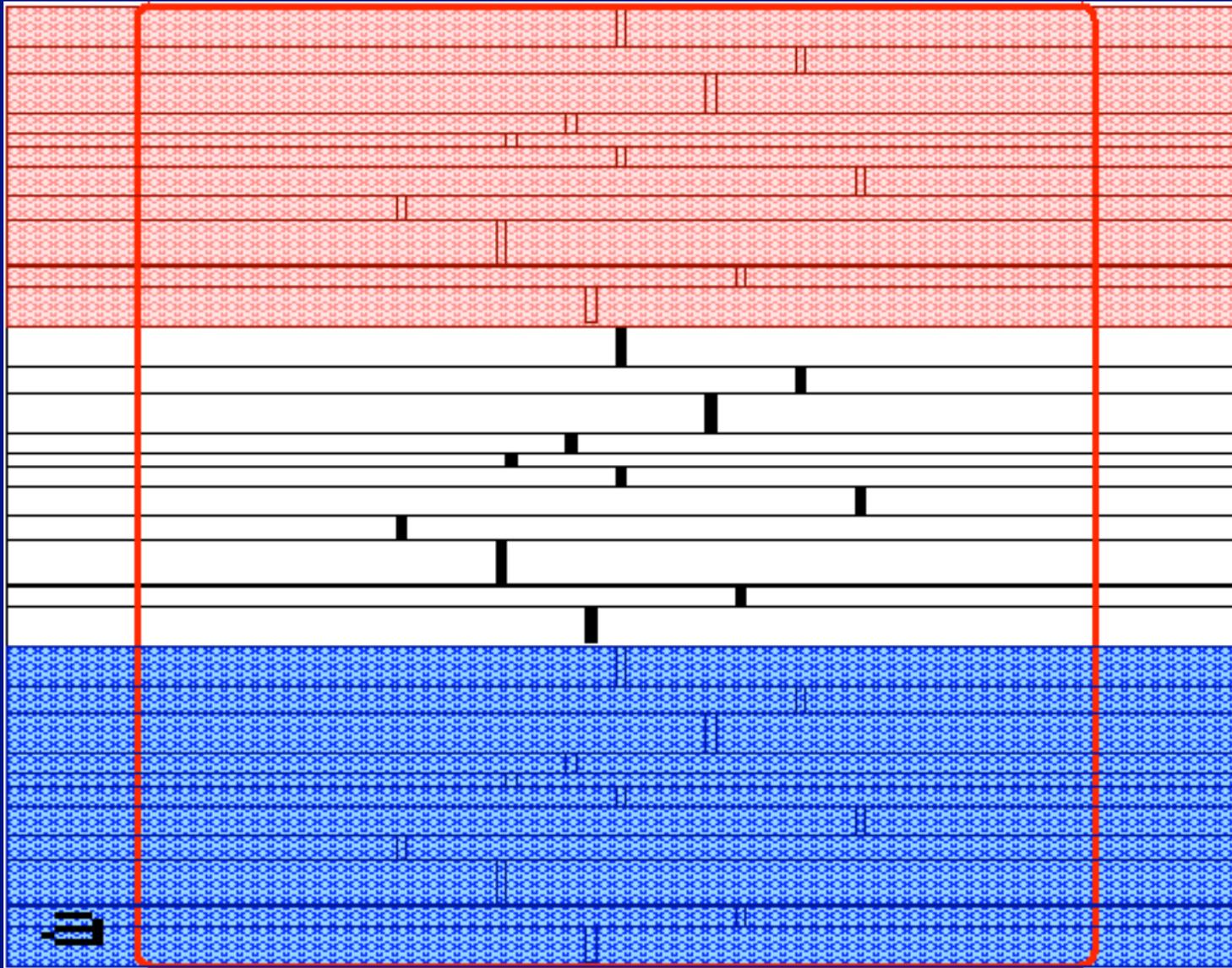


- ⊗ Gaps in spectral coverage result from spacing between GMOS detectors
- ⊕ Telluric absorption features

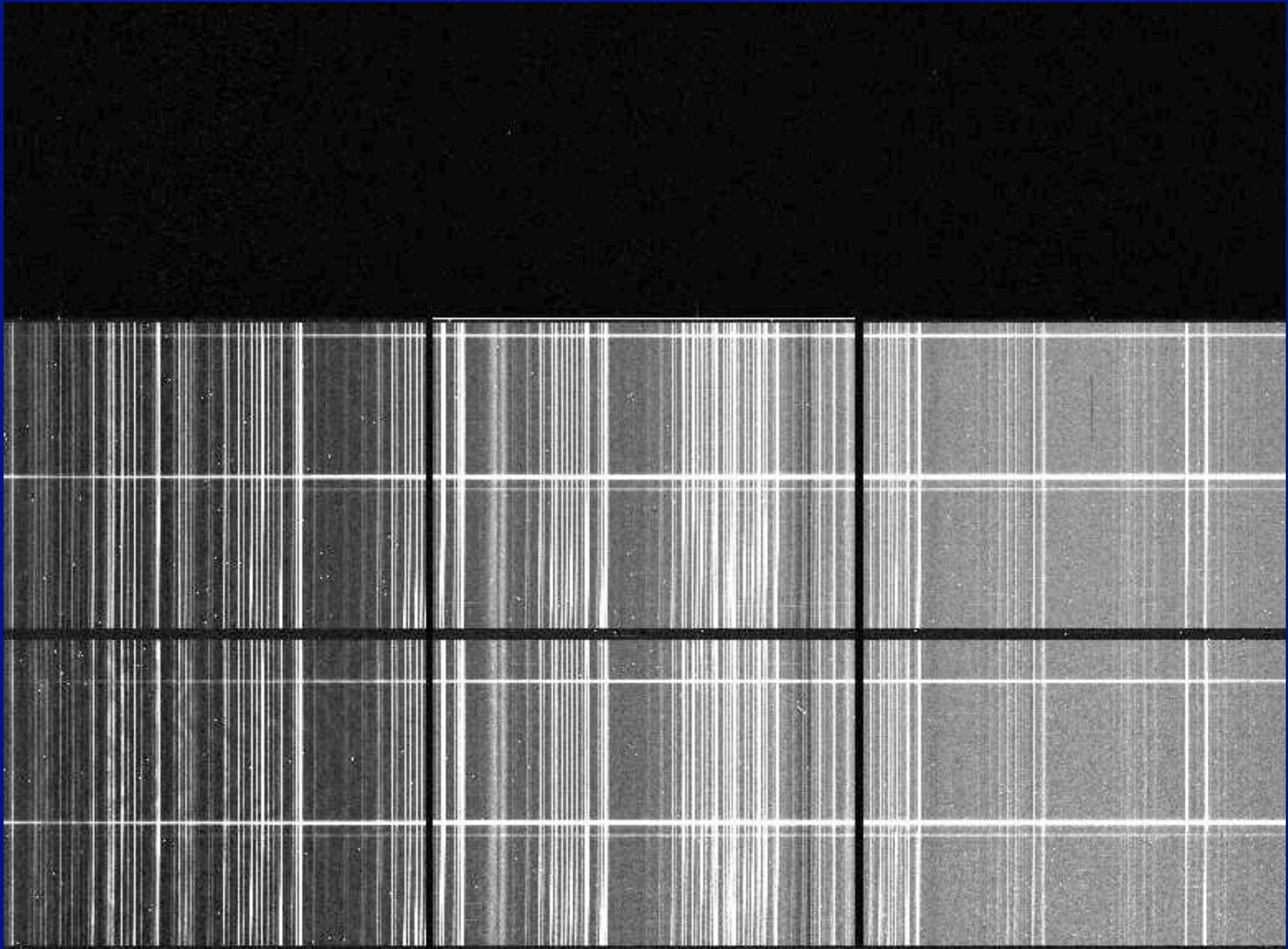
# Band-Shuffling

- Band Shuffling: there are evenly spaced regions of alternating storage and science regions, multiple slitlets of any length can be placed within the science regions as long as no slits intrude into the storage regions.
- Band Shuffling is usually employed when the science targets are extended objects and the targets are only in the slits half of the time.
- Band Shuffling is also very useful when the science is concerned with obtaining multiple spectra of objects in a very crowded region and having spatial coverage over the full detector is less important than the slit density.
- Longslit Nod & Shuffle spectroscopy uses Band Shuffling with a single band which is the same thing as having Micro Shuffling with one slit that is 111.7 arcsec long.

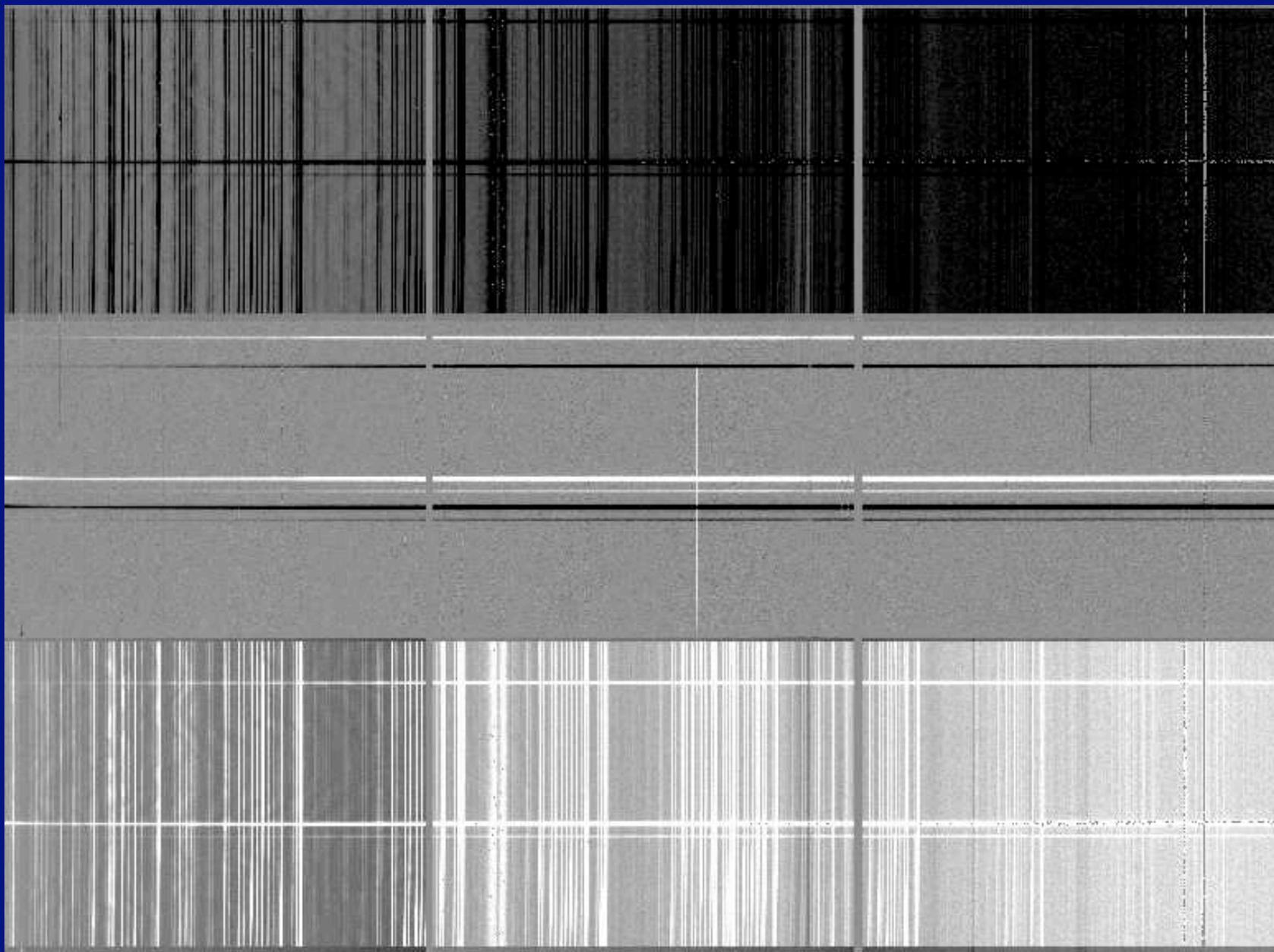
# Single Band Shuffling



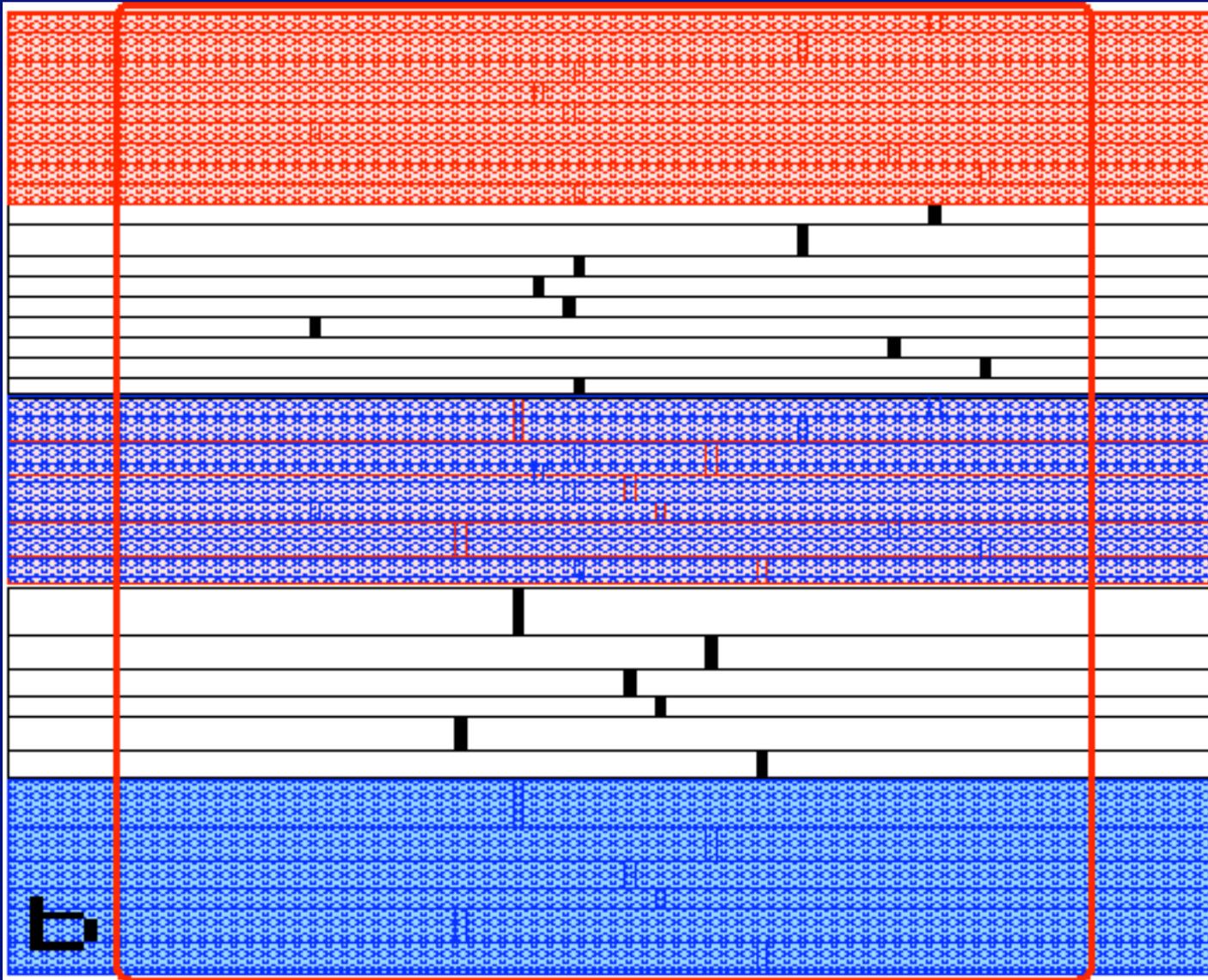
# Raw Longslit N&S Spectrum



# Reduced Longslit spectrum



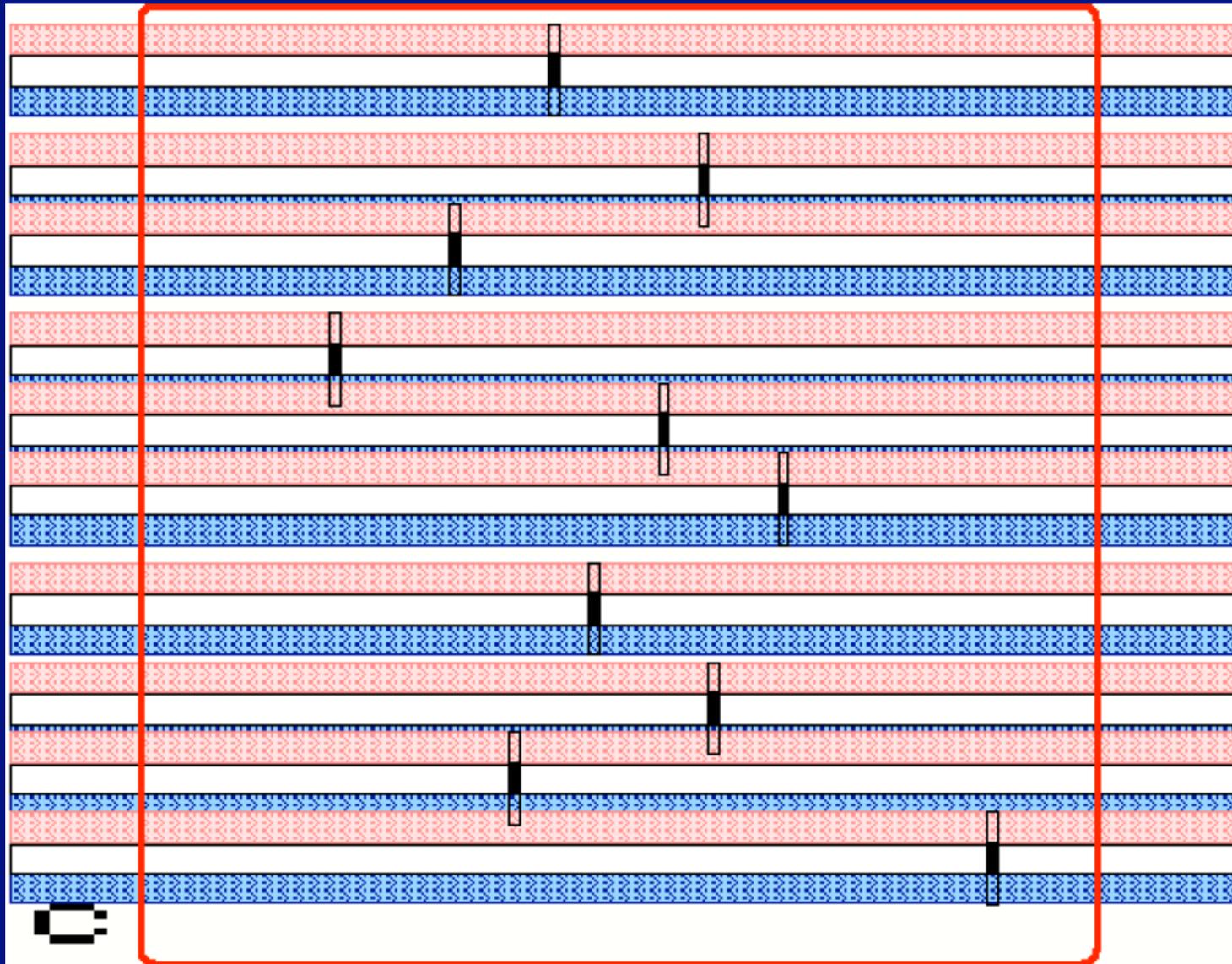
# Band Shuffling with 2 bands



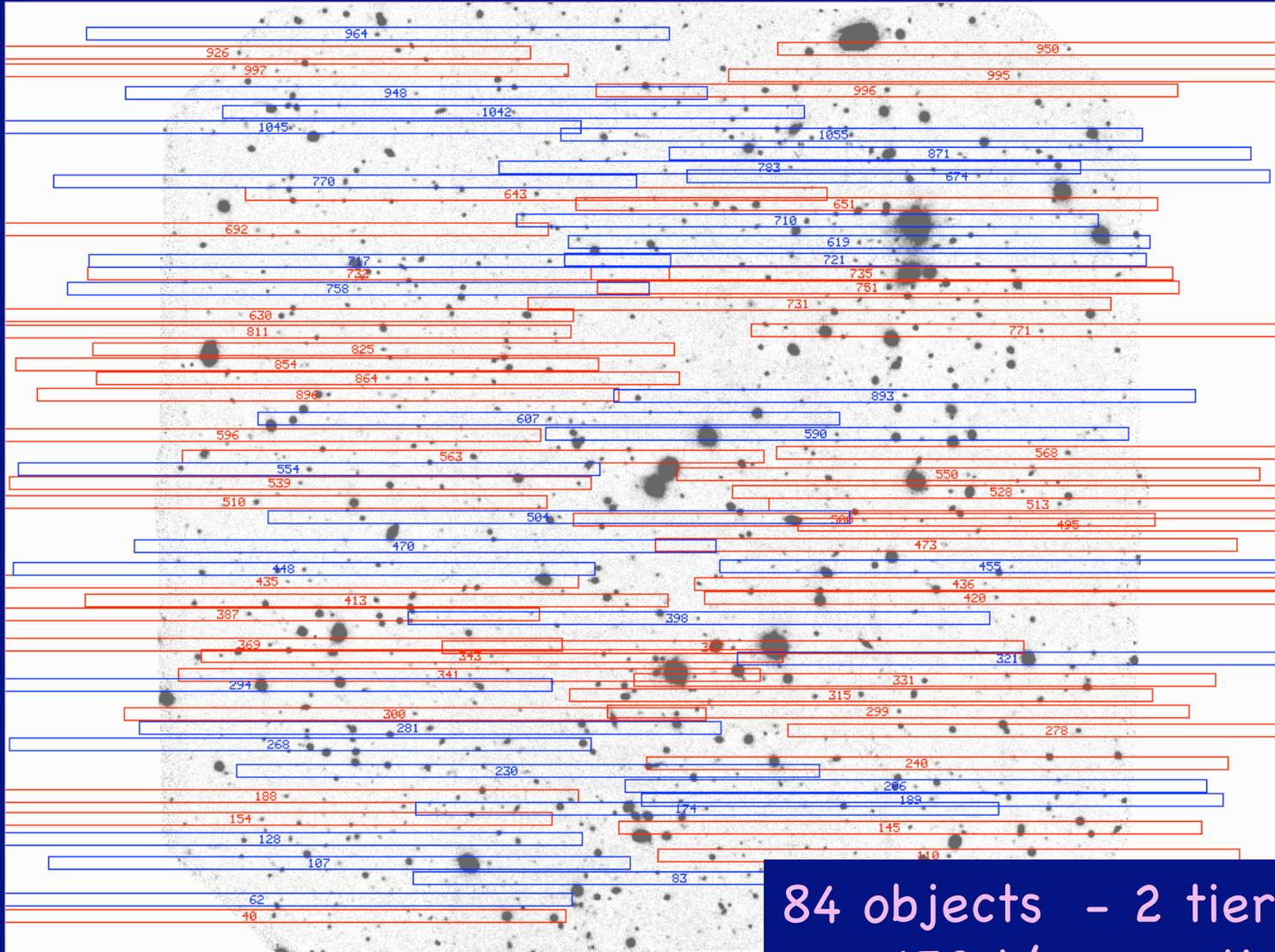
# Micro-Shuffling

- Micro Shuffling: every slitlet on the MOS mask has the same length and there are storage regions immediately above and below that have the same height in which there must be no slitlets or acquisition boxes
- Micro Shuffling is usually employed when the science targets are point sources (or small) and the associated nod is designed to keep the objects in the slitlets at all times.
- All of the GDDS MOS masks used micro shuffling.
- Longslit Nod & Shuffle spectroscopy can also be thought of as Micro Shuffling with one 111.7 arcsec long slitlet.

# Micro Shuffling schematic



# Sample GDDS Mask



84 objects - 2 tiers with  
150 l/mm grating

# Why Nod & Shuffle

Advantage: Lower sky-line residuals

- Intrinsic variability of sky lines
- Sky response measured with the same pixels used to record the target response (flat-field features, fringing)
- Shorter slits possible  $\Rightarrow$  more slits

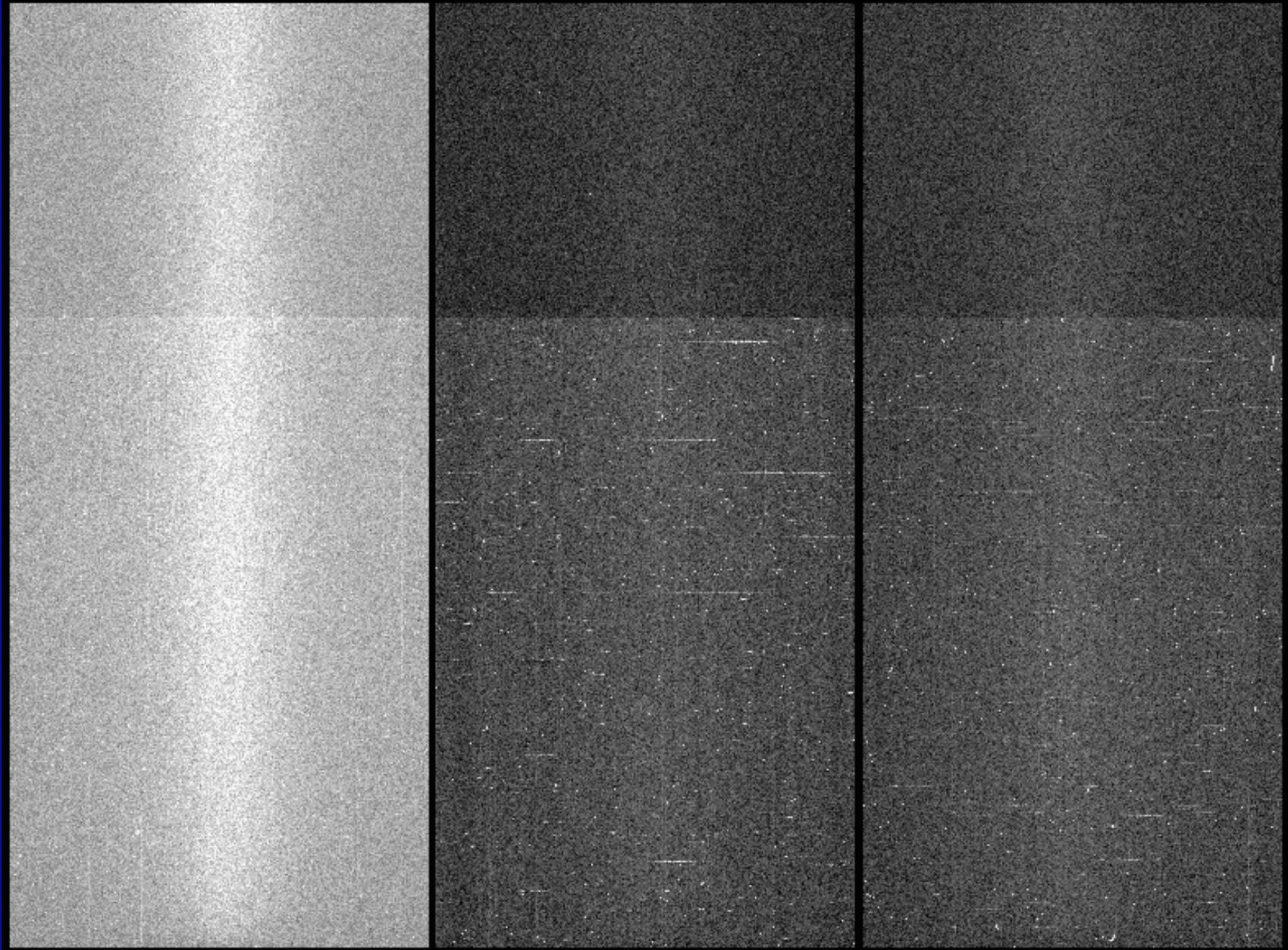
Disadvantage: Higher overheads

- Large nods ( $> 2$  arcsec) require motion of the OIWFS probe arm
- Telescope nods quickly, but needs to settle
- Higher noise in sky subtraction between sky lines
- Storage regions above and below slits/bands  $\Rightarrow$  decreased total sky coverage
- Charge traps

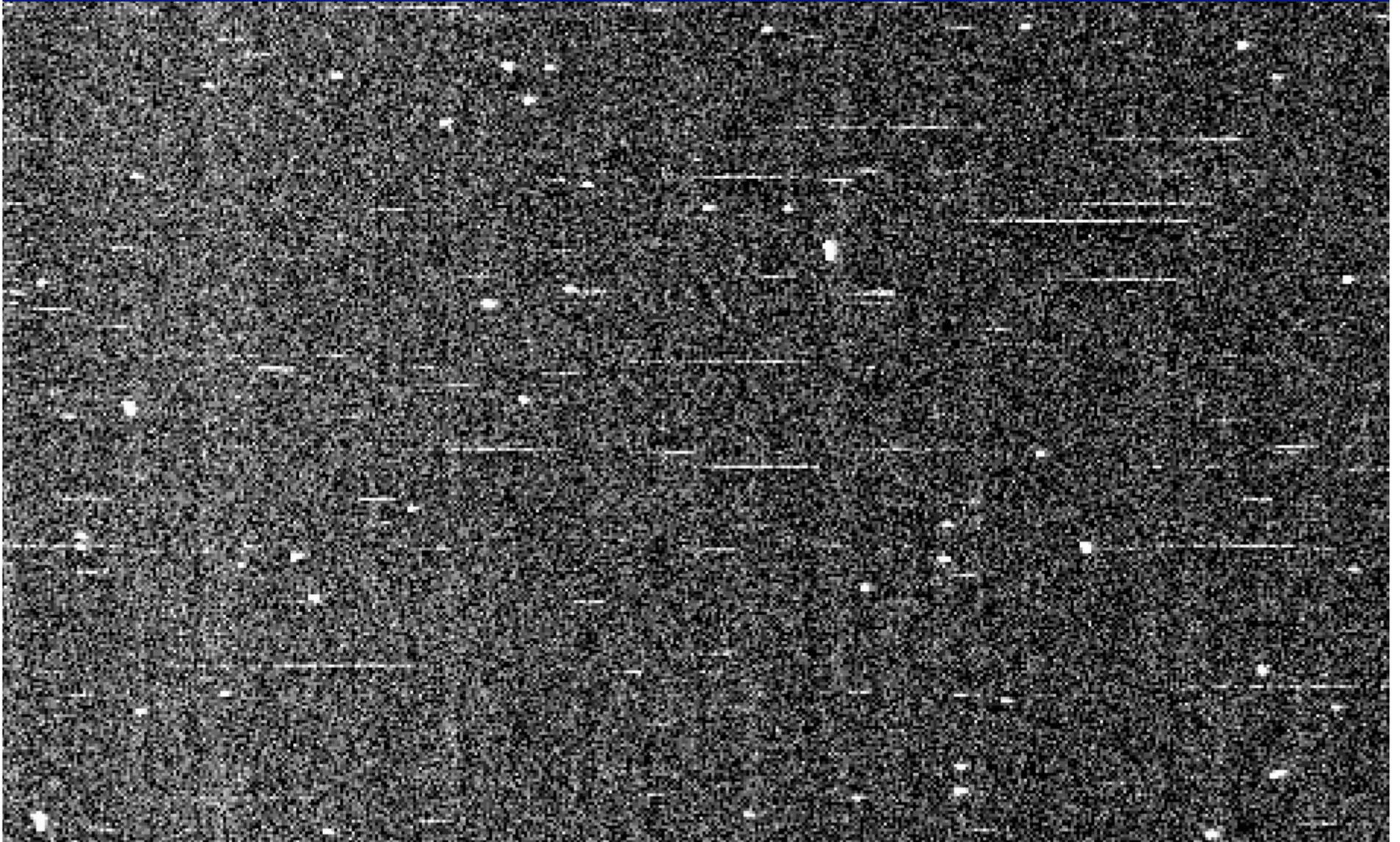
# Charge Traps

- “Charge traps” is what we call them and is not meant to imply that this necessarily is what is going on
- CCD3 has the most charge traps, CCD1 the fewest GMOS-N
- Features are narrow in y but can be quite extended in x
- The same features can actually be seen in long exposure spectra of faint targets (eg. IFU spectra) if the data is taken immediately after a flat field
- Nod & Shuffle darks taken with the same offset and binning as the science data contain the same features, these actually subtract out fairly well
- Dithering the detector by moving the DTA-X position also helps to alleviate the effect of remaining charge trap features that do not dark subtract out completely

# Raw Nod & Shuffle Dark Image



# Raw Nod & Shuffle Dark Image (zoom)



# Designing Nod & Shuffle Observations

- Low resolution spectroscopy (R150, R400) benefit from Nod & Shuffle more than higher resolution
- Central wavelengths longward of  $\sim 770$  nm (or features of interest at those wavelengths) benefit from Nod & Shuffle more than shorter wavelength spectroscopy
- For longer exposures of faint targets the gain in sky residual reduction outweighs the costs of overheads
- The offset (detector rows) defined in the OT is given in unbinned pixels and must equal the value used in the N&S mask design (if using GMMPS)
- The nod (arcsec) given as P and Q in the OT is the amount the telescope nods, usually either (0,0) and (a large value) if offsetting to sky or  $\pm$  (0, a small value) if nodding the target along the slit.
- There can be no science slitlets or acquisition objects in the storage regions for N&S MOS masks

# Observing Tool N&S Component

## Gemini Multi-Object Spectrograph (North)

2010B

The GMOS North instrument is configured with this component.

Filter  Exposure Time (sec)

Disperser  Central Wavelength (nm)

Order   MOS pre-imaging  Use Nod & Shuffle

CCD manufacturer

**Position Angle**  Set to (deg E of N)   
 Use Average Parallactic Angle  
 Follow in Parallactic Angle

**Focal Plane Unit**  Built-in   
 Custom Mask MDF

CCD Readout \ Translation Stage \ Regions of Interest \ ISS Port \ Nod & Shuffle

### Nod (arcsec)

p  q  OIWS

#	p	q	OIWS
0	0.0	-0.8	guide
1	0.0	0.8	guide

Use Electronic Offsetting?

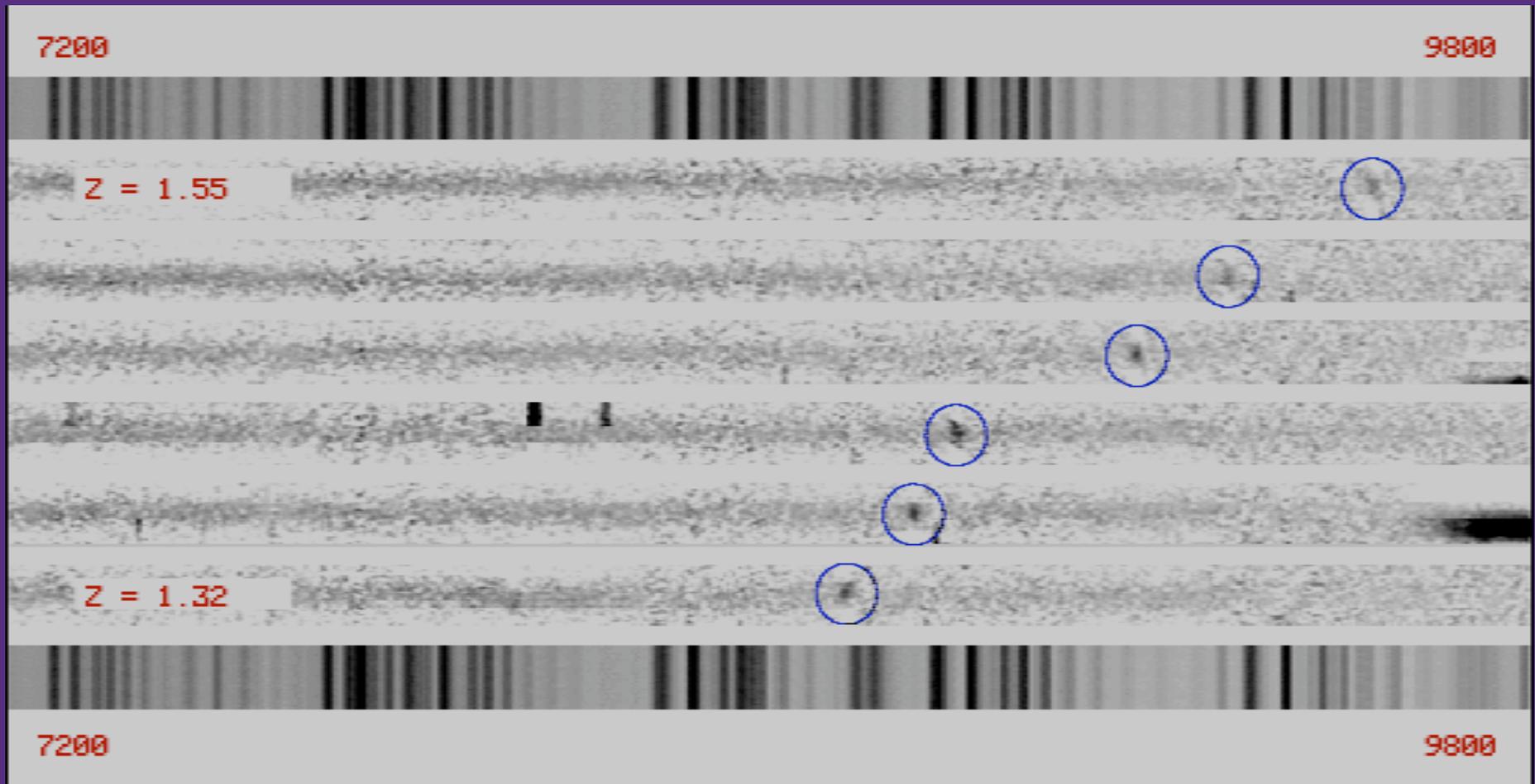
Offset (arcsec)  Offset (detector rows)

Number of N&S Cycles  Total Observe Time (sec)

# Reducing Nod & Shuffle Data (that's the easy part)

- Overscan correct your science data, N&S dark data
- Make your N&S combined dark (can use gbias since gdark does not exist) **gnsdark does exist now!**
- Subtract the N&S combined dark from the science data (can use gsreduce with bias = dark frame)
- Sky subtract the dark corrected science data (can use gnsskysub)
- Flatfield your data
- Remove DTA-X dithers (gnscombine can help with this)
- Combine the DTA-X dither corrected, flat-fielded, sky-subtracted, dark-subtracted science frames (gnscombine can help with this...)
- Normal MOS procedures to extract spectra, only the sky subtraction is already done.
- If object nodded along the slit there will be two spectra in each slitlet, positive and negative. Extract both and combine them.

# [OII] Redshifts from GDDS



$$23.7 < I(AB) < 24.2$$