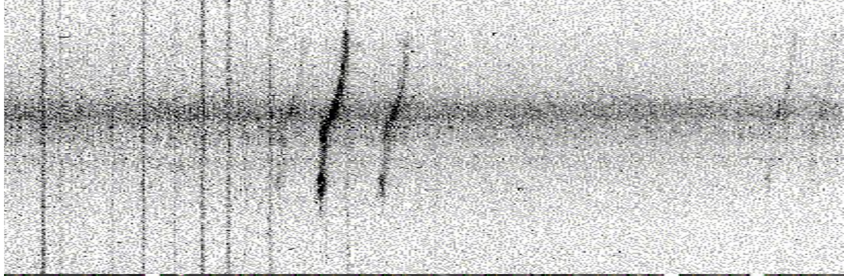
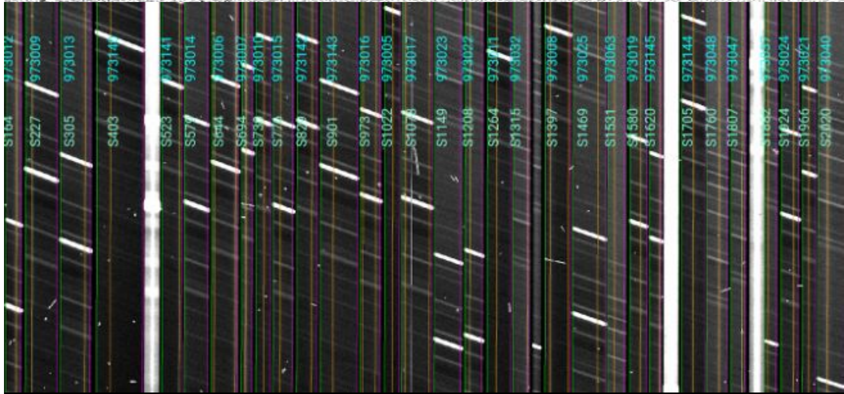
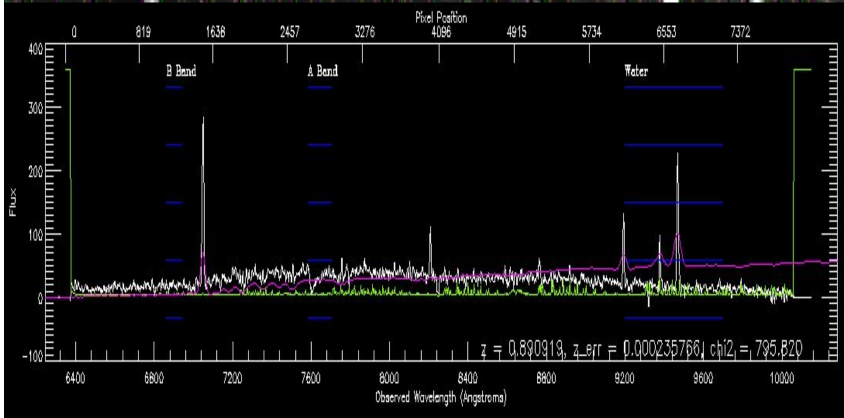
Kinematic Weak Lensing on “Weighing the Giants” Galaxy Clusters







Presenter

Jiyun Di

Astronomy Group of Prof. Anja von der Linden

Stony Brook University

Sunday, November 5, 2023

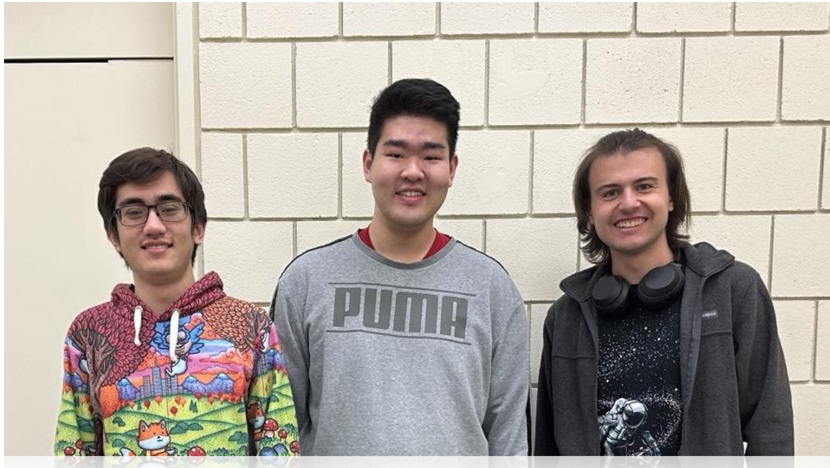
Kinematic Weak Lensing on “Weighing the Giants” Galaxy Clusters

Spec Team is advised by **Prof. Anja von der Linden**.

Anja

Group Members

Jiyun Di	Joined Sep 2022, 2nd-year MA student
Alden Beck	Joined Nov 2022, high-energy lab, Columbia U
Aaron Burke	Joined Jan 2023, 1st-year MA student
Tobias Weiss	Joined Sep 2023, 1st-year MA student



Aaron Jiyun Alden

Kinematic Weak Lensing on “Weighing the Giants” Galaxy Clusters

Weak lensing = result of weakly distorted cluster galaxies

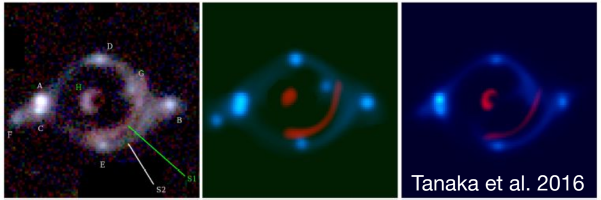
Reminder: **strong lensing**

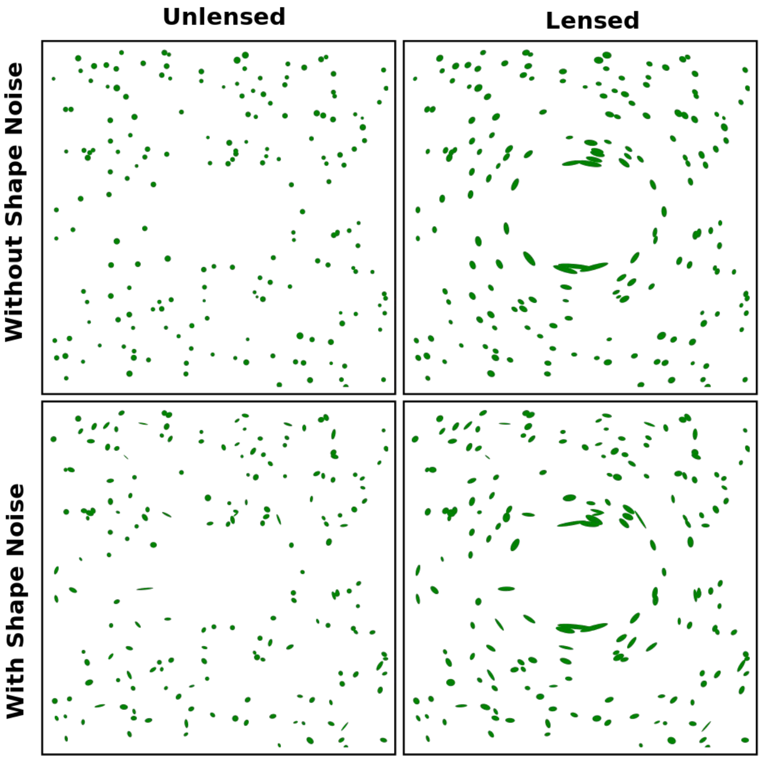
- >1 arcs — ring-like — lens size: galaxy

Kinematic WL = a new method for reducing shape noise (relying on spectroscopy, needs velocities along galaxy’s axes - “kinematic”; goal: intrinsic orientations of galaxy disks)

Big issue: We don’t know if **a elliptical galaxy is being lensed** or **if it is just naturally elliptical.**

Strong





Credits: WikiPedia/TallJimbo

Solve for: how much galaxy was lensed and intrinsic ellipticity

Explanation of Galaxy Rotating Orientation

(a) → inclines w/ an angle → (b) → rotates on sky → (c) → weak lensing → (d) → no other effects

Kinematic lensing shear inference 3327

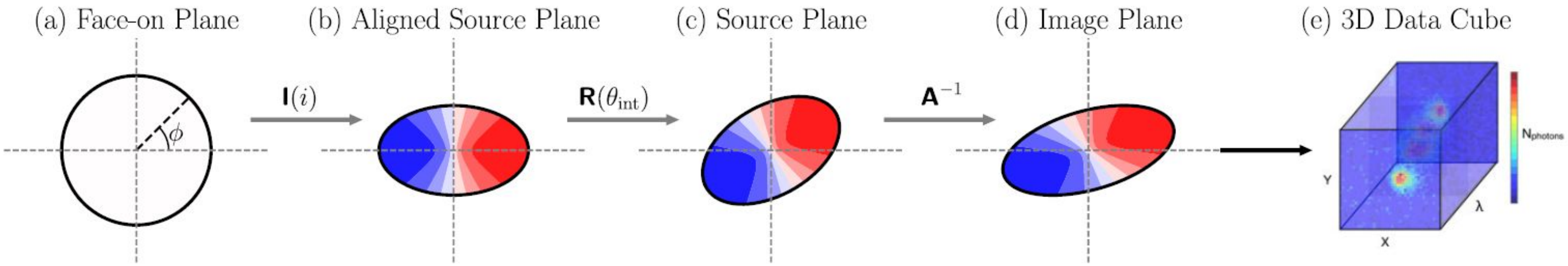


Figure 2. Coordinate transformations performed to compute the observed spectrum data cube. The galaxy isophote is shown as a solid black line and the LoS velocity as blue–red contours. Panel (a): In the face-on plane, the galaxy is a circular disc with a zero LoS velocity component. Panel (b): The circular disc is inclined to account for the galaxy's intrinsic ellipticity, which also introduces a LoS velocity field. Panel (c): The inclined disc is rotated to account for the galaxy's intrinsic position angle. Panel (d): The LoS velocity field in the image plane is obtained by applying the shear transformation. Panel (e): Combining the LoS velocity field with the emission line profile and galaxy photometry results in a 3D data cube which is then used to compute the 2D spectrum.

Pranjal-R-S et al. (2022)

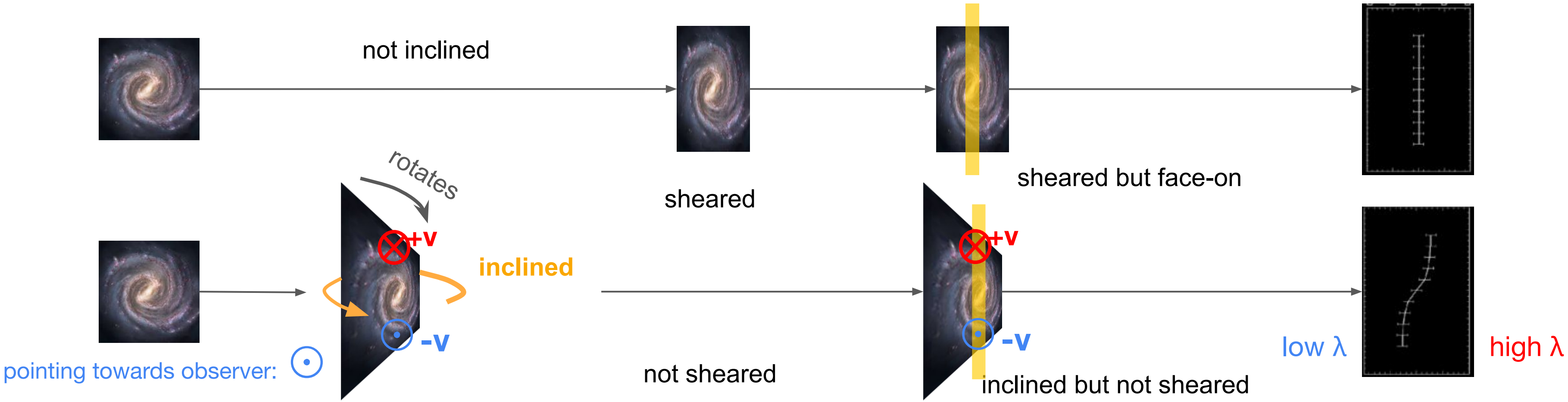
Solve for: how much galaxy was lensed and intrinsic ellipticity

Rotation Curves

The orientation of the lensed galaxy can be determined from the rotation curve from **spectroscopy**.

- A face-on galaxy ←→ a vertical line
- An **inclined** galaxy ←→ **a rotation curve**
  - One side of the galaxy should be redshifted (λ↑), the other blueshifted (λ↓)
  - An extreme case: an edge-on ←→ a straight tilted line

Now we can tell ellipticity is due to an inclination or weak-lensing → **shape noises reduced**



Data

…	For each galaxy cluster	…other ~50 galaxy clusters

- ➢ Up to ~51 galaxy clusters studied in the "Weighing the Giants" (von der Linden et al. 2014) project.
  - X-ray weak lensing masses
  - Keck/DEIMOS and VLT/VIMOS spectra
  - Optical images available
- ➢ Currently working on Keck/DEIMOS

Data

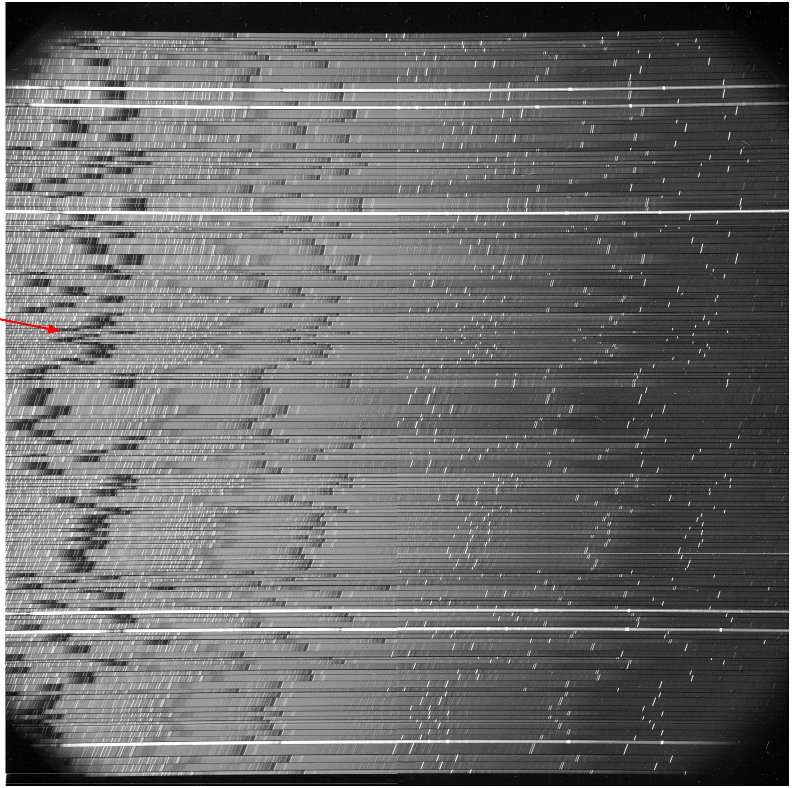
…

For each galaxy cluster

…other ~50 galaxy clusters

Spectrum Data from Observatory Archives
(e.g. Keck/DEIMOS, VLT-UT3/VIMOS)

Raw spec `fits` data



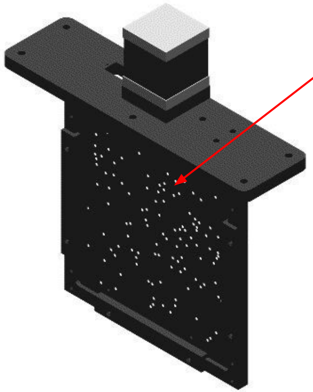
How does spectrograph work?
How to solve for wavelength?

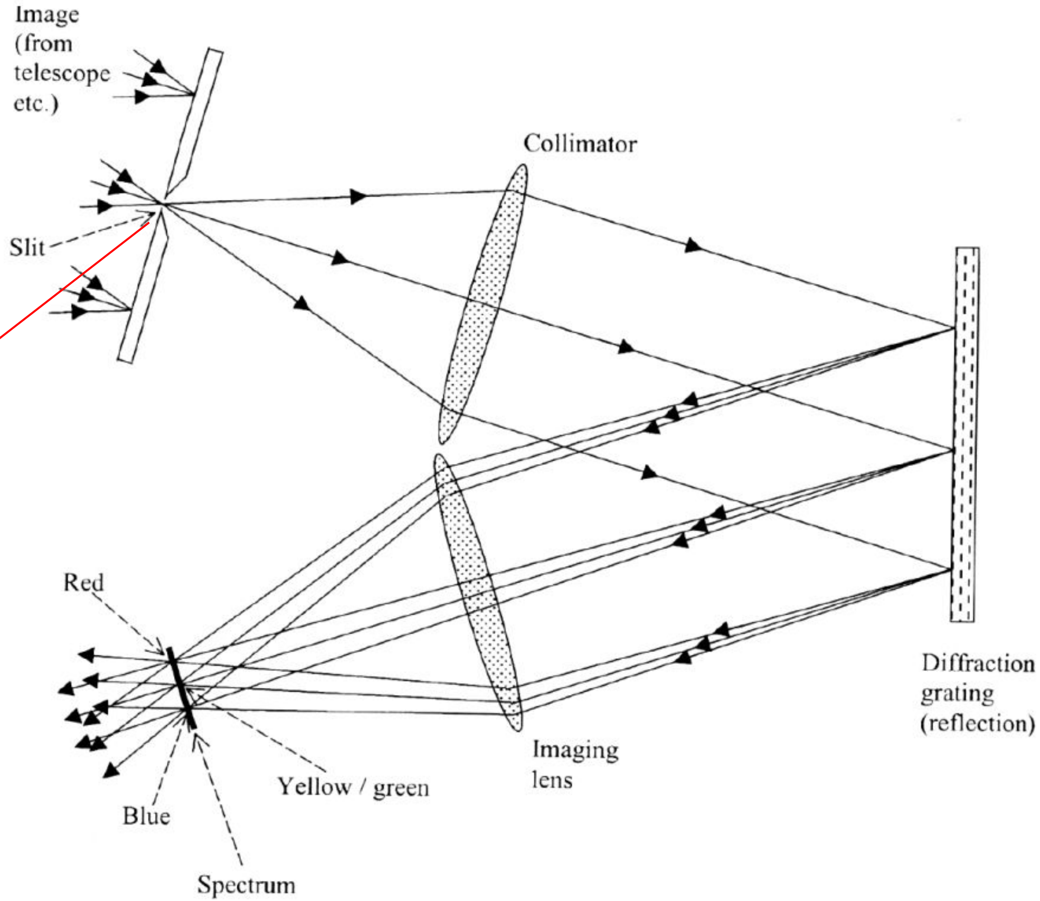
Spectrograph - before the grating

Type: diffraction grating

Goal: spectra of some selected galaxies

So, place a mask on focal plane with designed slits (can filter out other objects)

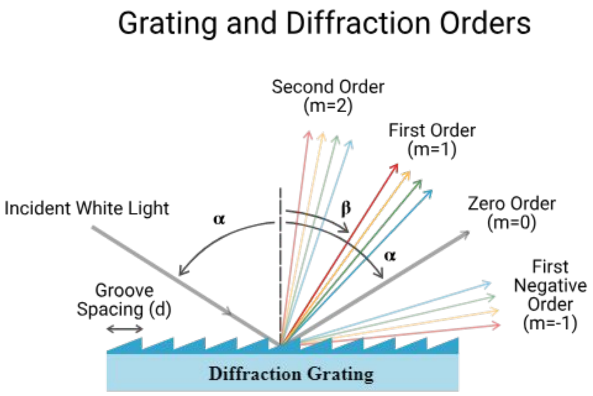




Spectrograph - Grating

A key instrument used to generate wavelength-dependent interference patterns at all wavelengths.

Polychromatic light → “rainbows”

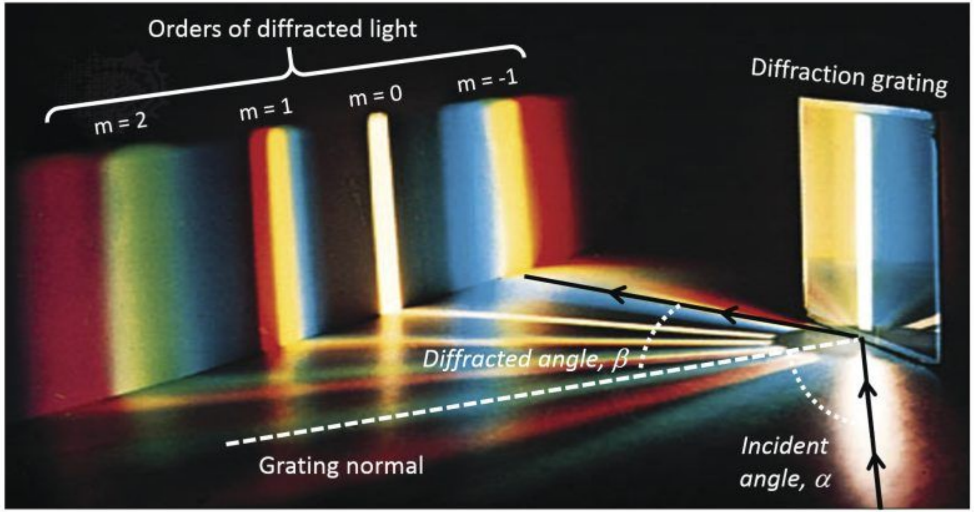


Grating and diffraction orders

https://www.meetoptics.com/academy/groove-density

- A ~**Linear** relation of pixel (or angle β), i.e. “Grating Equation”:

$$m\lambda = d(\sin\alpha - \sin\beta)$$



Polychromatic light diffracted from a grating

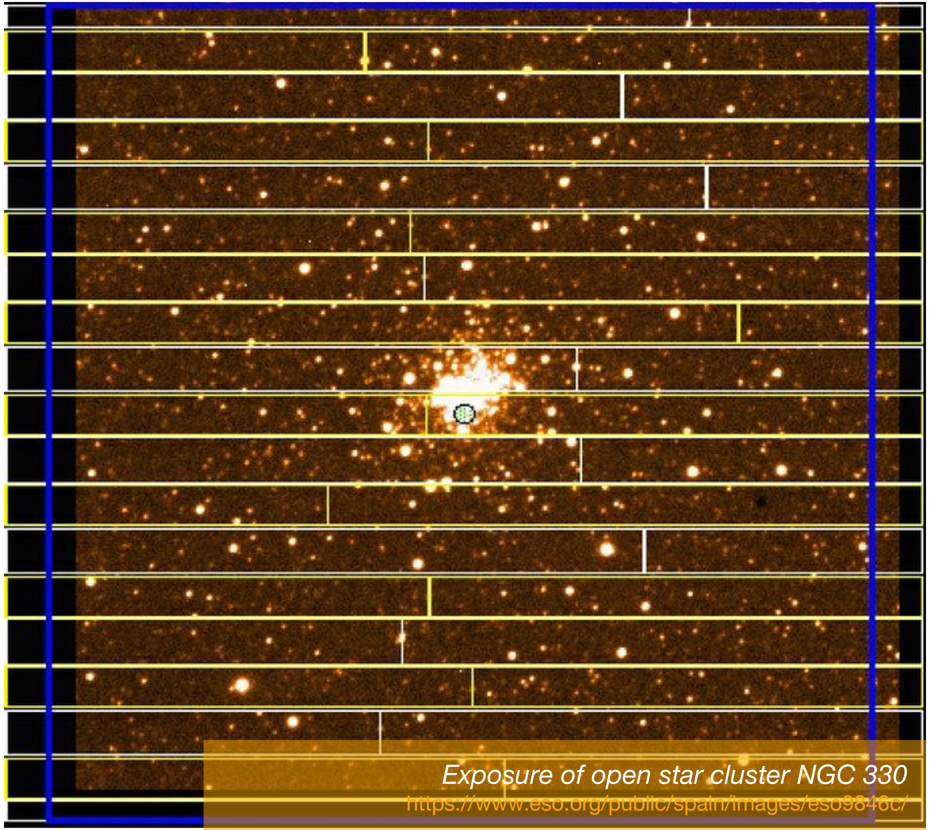
https://www.newport.com/n/diffraction-grating-physics

Spectrograph - Mask

Type: diffraction grating

Goal: spectra of some selected galaxies

So, place a mask on focal plane with designed slits (can filter out other objects)



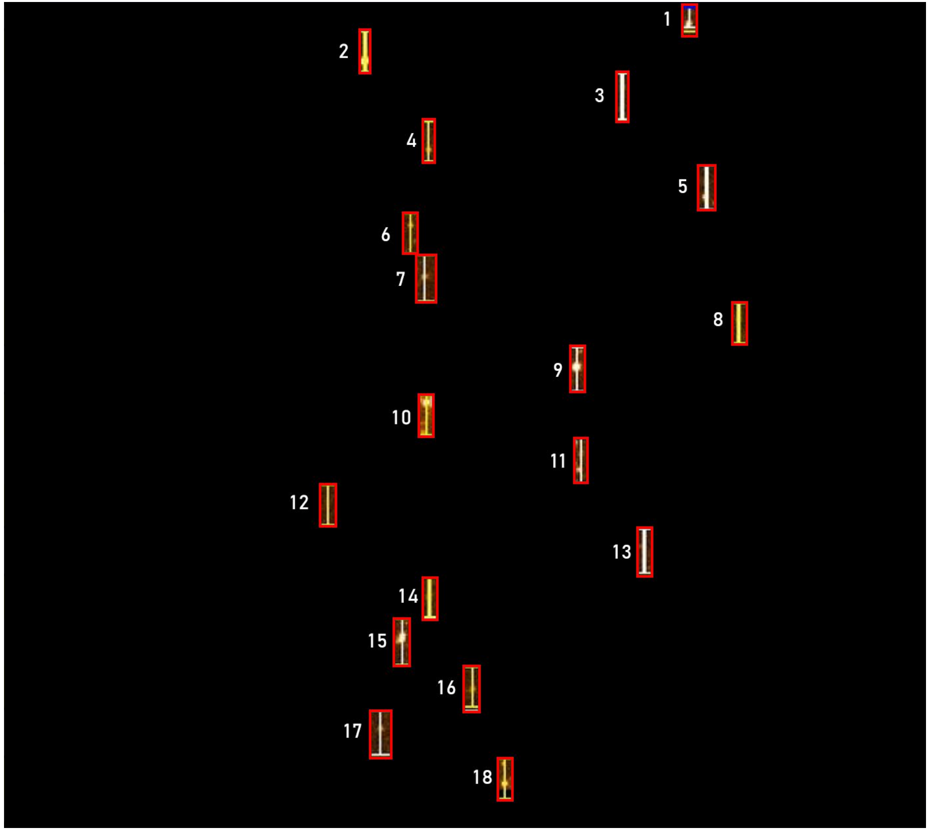
Exposure of open star cluster NGC 330
https://www.eso.org/public/spain/images/eso9846c/

Spectrograph - Mask & Slits

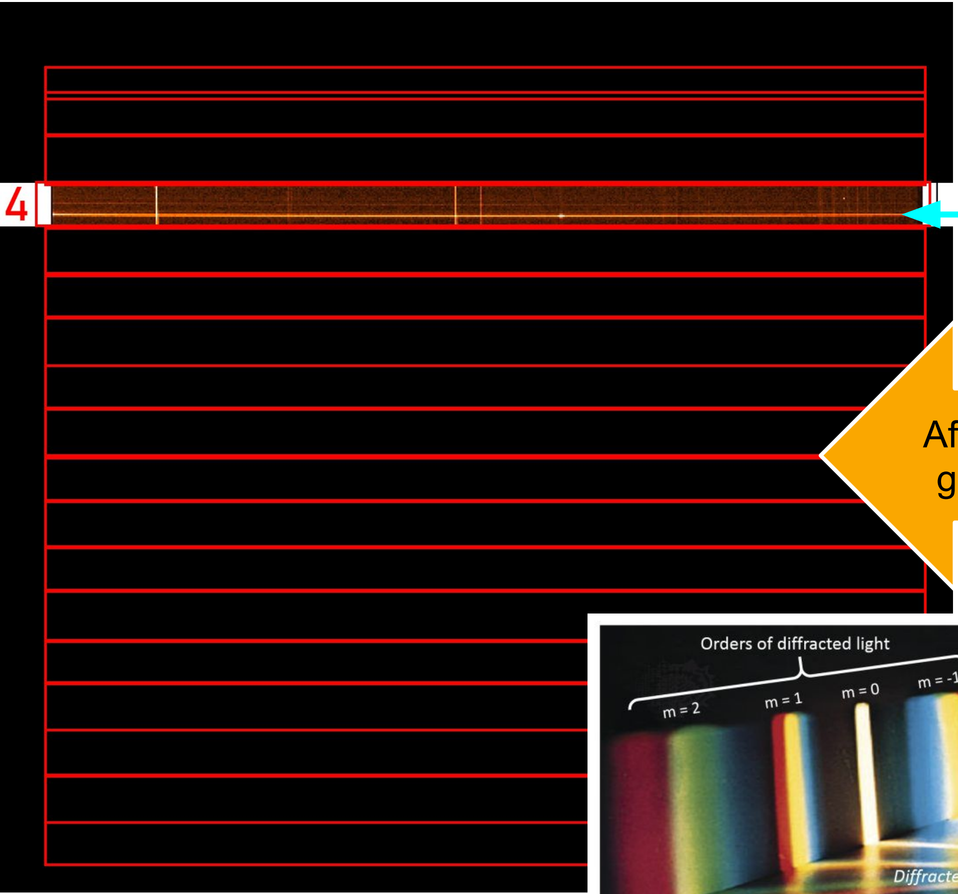
Type: diffraction grating

Goal: spectra of some selected galaxies

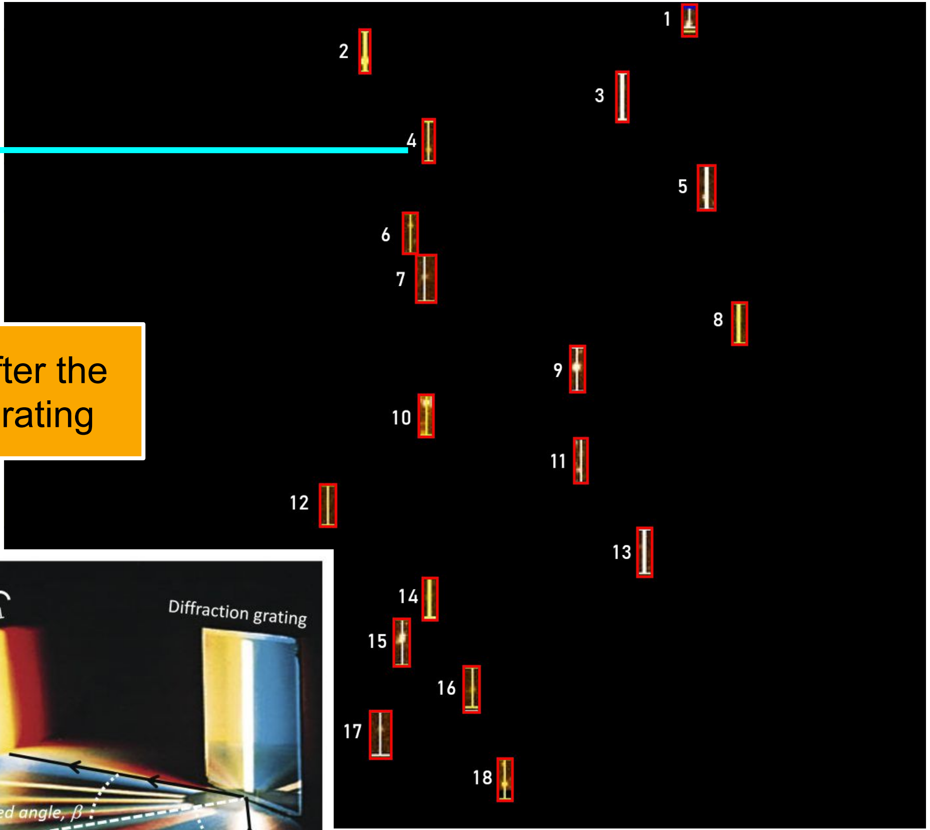
So, place a mask on focal plane with designed slits (can filter out other objects)

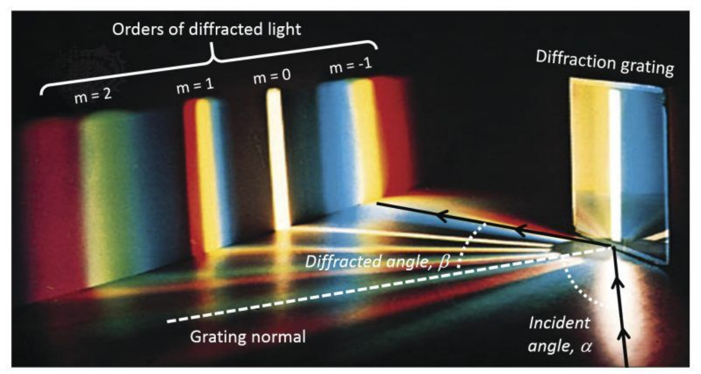


Spectrograph - 2D spectra / Mask & Slits

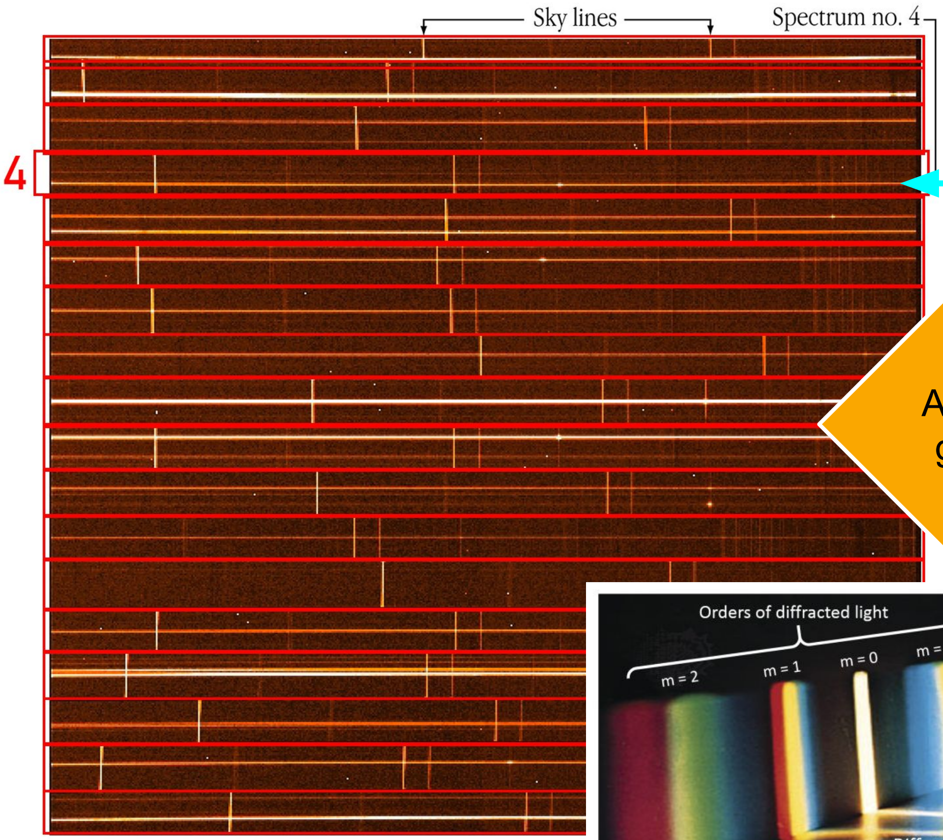


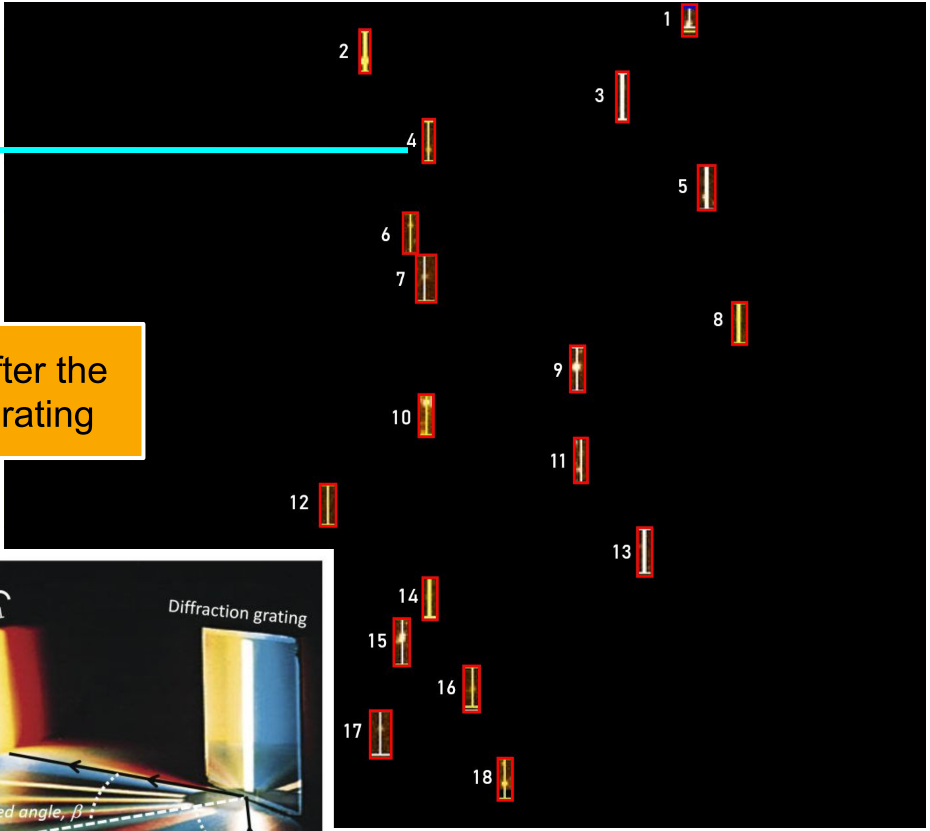
After the grating



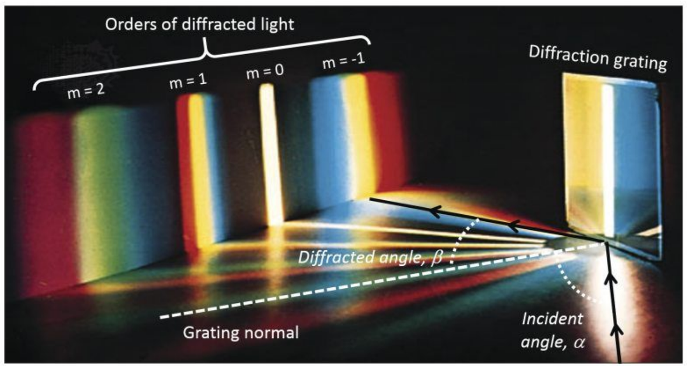


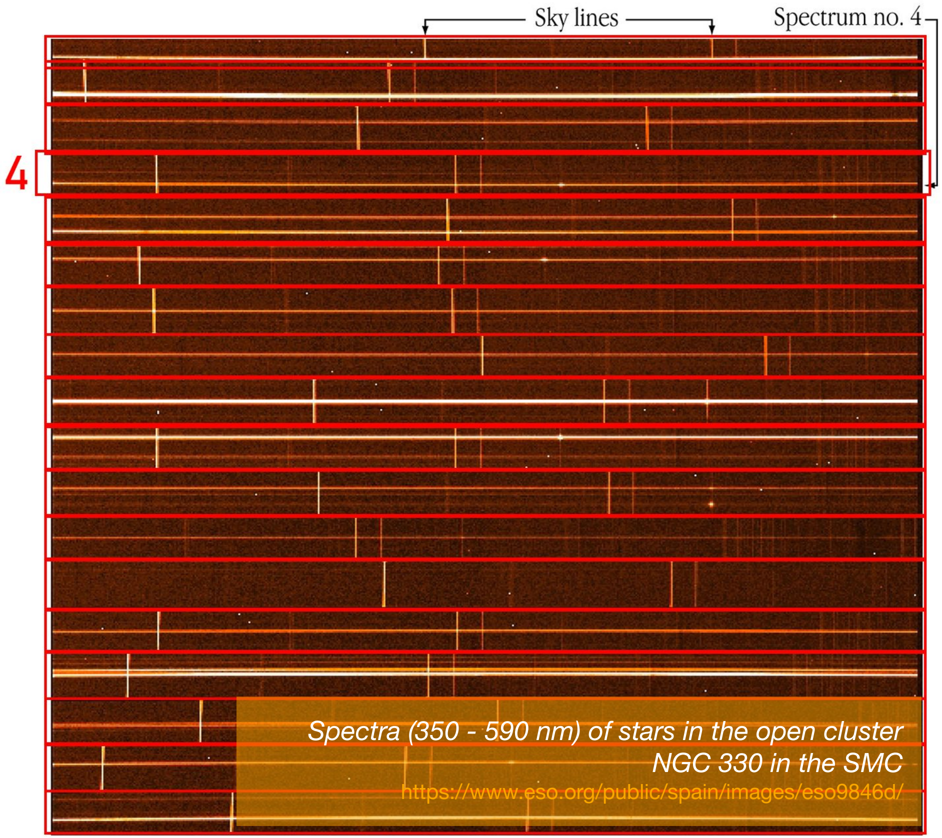
Spectrograph - 2D spectra (y-pixel vs wavelength)





After the grating





Spectra (350 - 590 nm) of stars in the open cluster NGC 330 in the SMC
https://www.eso.org/public/spain/images/eso9846d/

- The spectra are generated from **(point-like) sources** to **a bright continuum line** across the dispersion direction.
- Dispersion direction ⊥ grooves in the grating, at all times
- Note — Slit direction is not necessary vertical to continuum.
- So slits are placed with a angle to align the major axis of targeted galaxy.

Data

…

For each galaxy cluster

…other ~50 galaxy clusters

Spectrum Data from Observatory Archives
(e.g. Keck/DEIMOS, VLT-UT3/VIMOS)

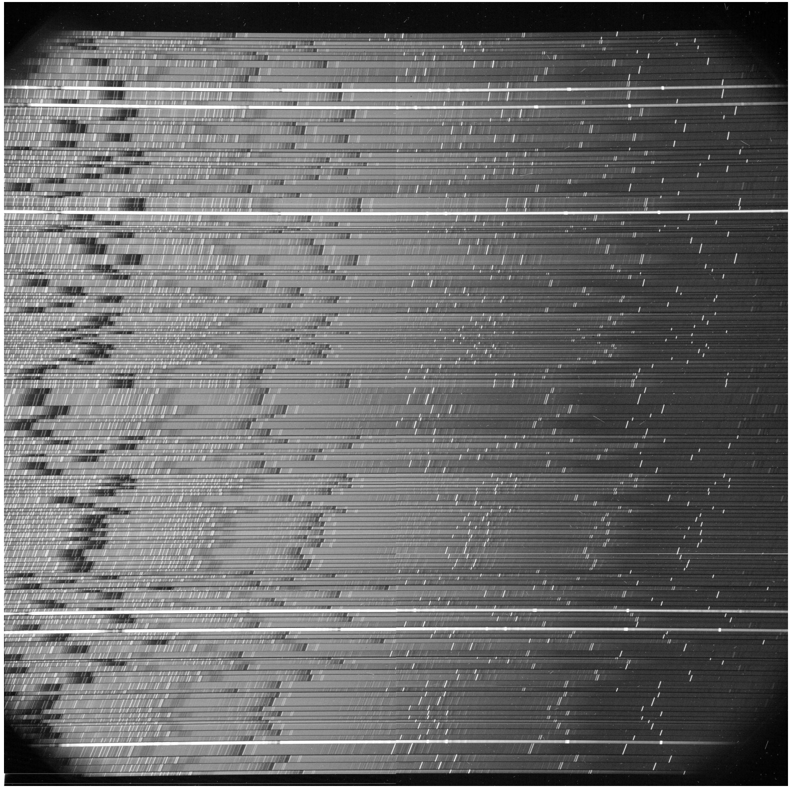
↓

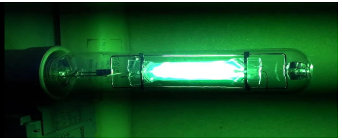
Raw spec fits data

↓ PypeIt

Wavelength calibrated, coadded spectra on CCD

↓



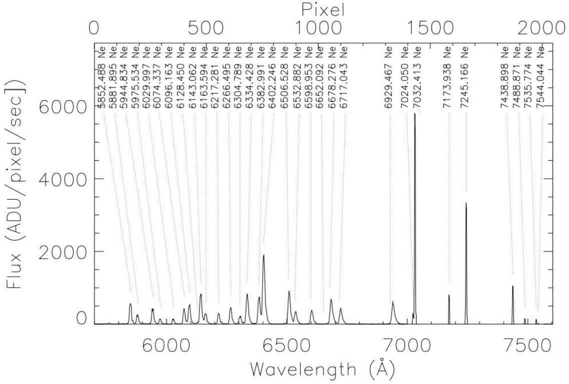


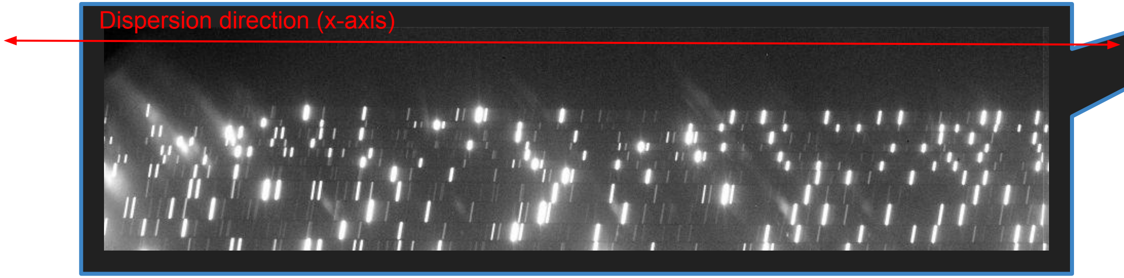
PypeIt **Wavelength Calibration** — Find λ

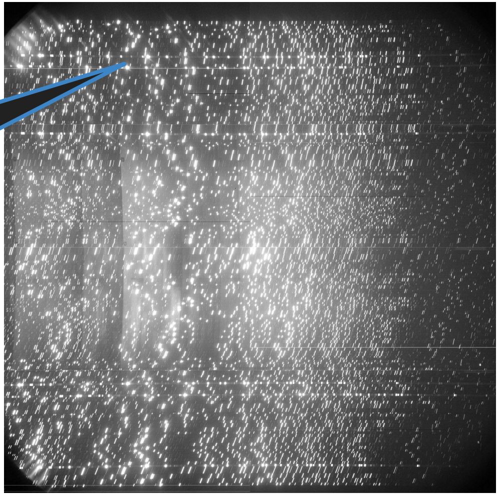
One of *the latest Python-based reduction for the popular multi-object spectrograph instruments*

PypeIt runs the wavelength calibration using arc lamp images, tilts, and flats:

1. Arc: **Map pixel position to emission wavelengths.**
   We **know** wavelengths from arc-lamp light.
   → Identify wavelength at each x-pixel
   (Right plot: $_{10}$Ne *arc lamp flux-wavelength plot from Keck/Iris*)



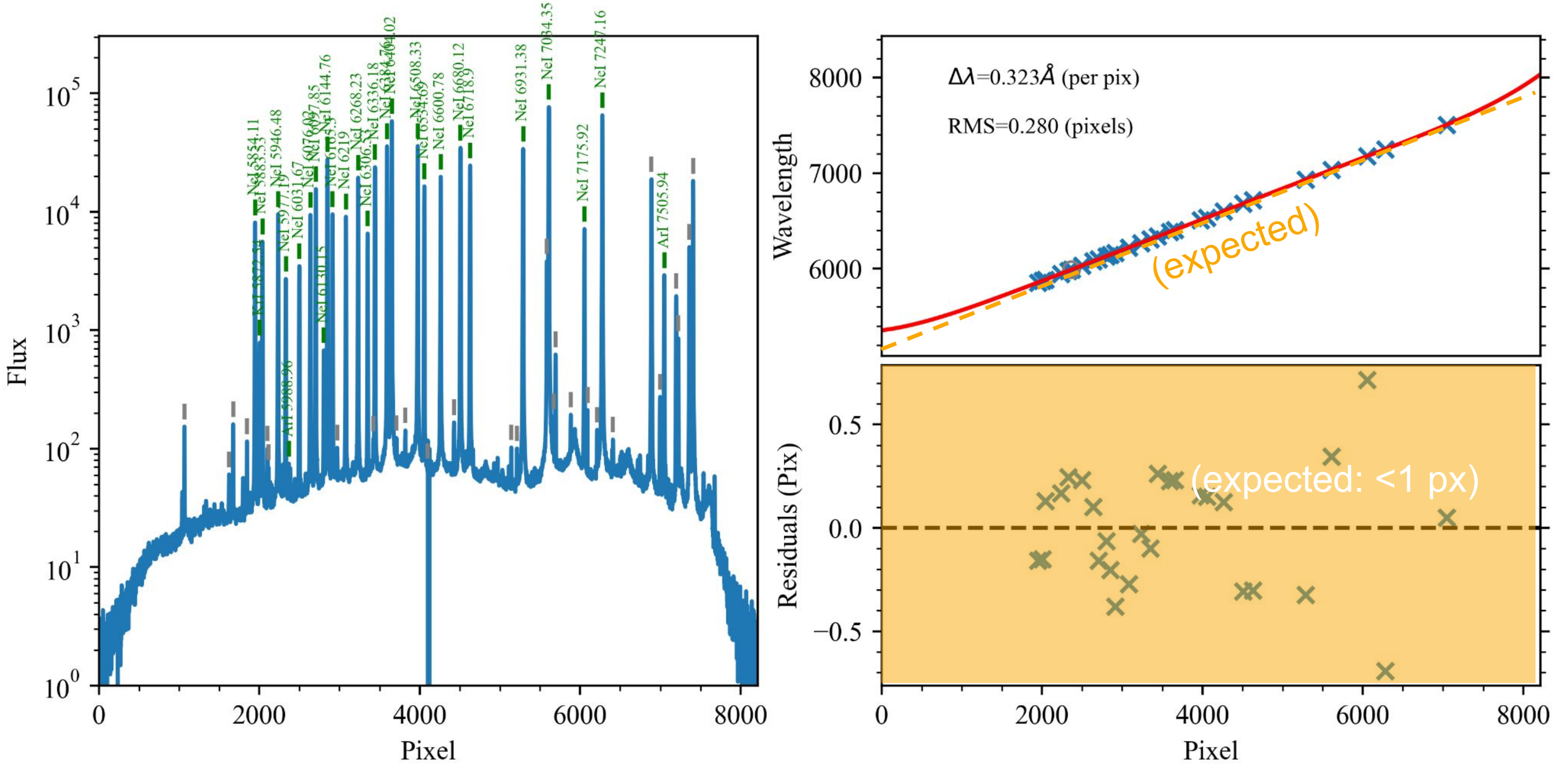




A raw Arc image of Cluster A2261 on DEIMOS CCD.
Each horizontal strip is a spectrum passed through a slit on designed mask.

Wavelength Calibration: pixel → wavelength (Expectation: ~linear relation)

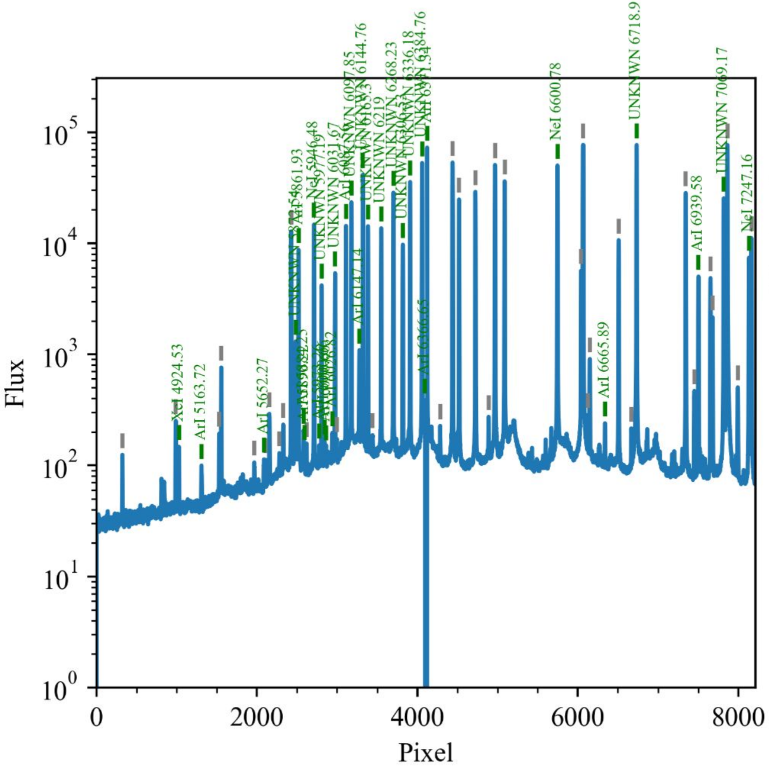
$$m\lambda = d(\sin\alpha - \sin\beta)$$

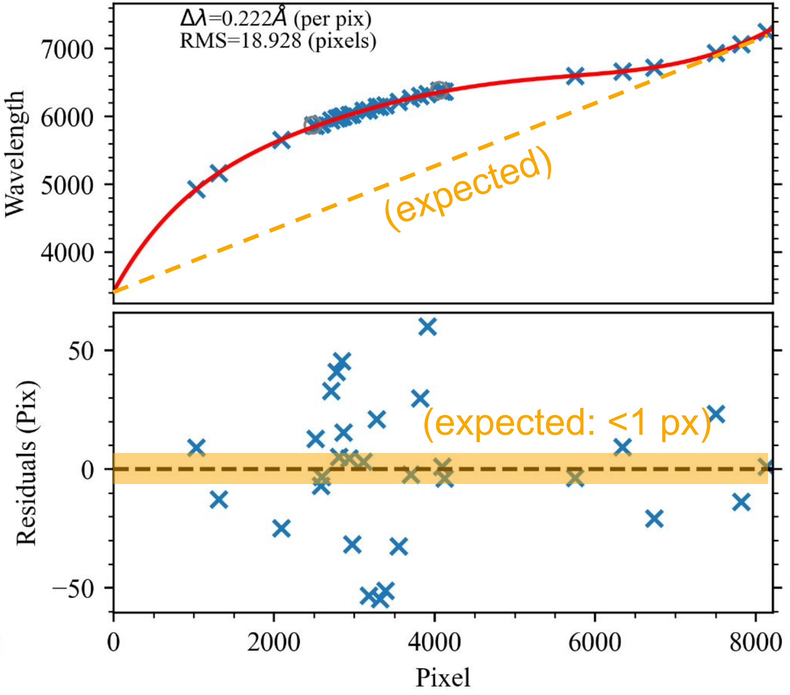


Bad calibrated slits: mismatched Arc lines → Non-linear (Expectation: ~linear)

PypeIt has many ways to fix

$$m\lambda = d(\sin\alpha - \sin\beta)$$

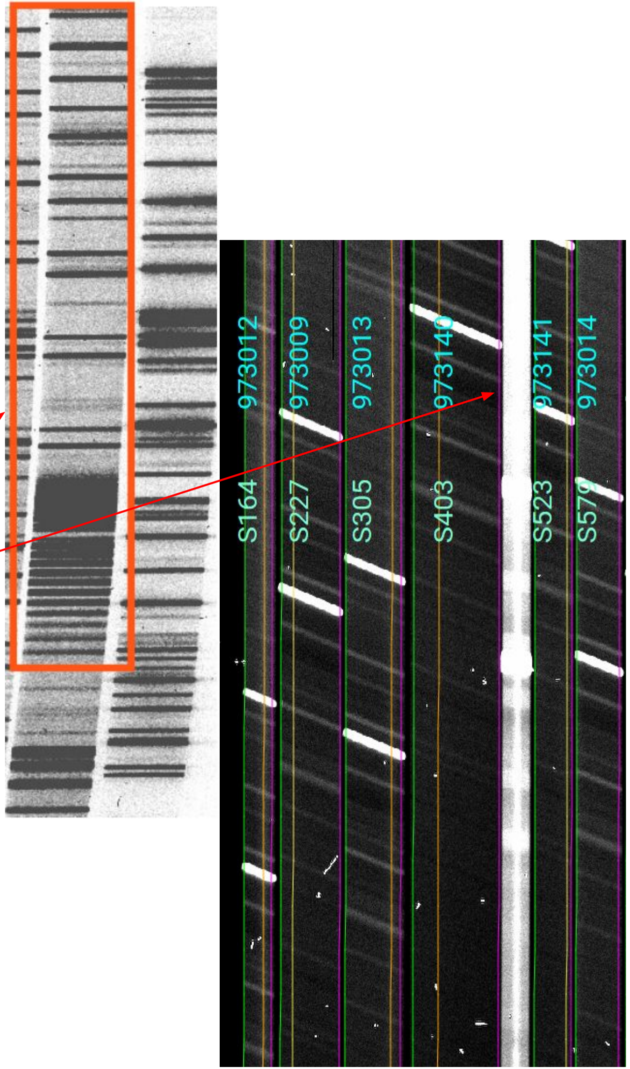




PypeIt Wavelength Calibration

PypeIt runs the wavelength calibration using arc lamp images, tilts, and flats:

1. Arc
2. Tilt: **Plane-of-Focus** doesn't map out entire CCD due to telescope geometry
3. Flat: Correcting pixel-to-pixel variations and illumination, e.g. **sensitivity on CCD**
4. Slit-marking: identify which slit corresponds to which strip on image, and give you what position **coordinates of targeted galaxy**



Note: Tilted lines are mainly due to slit PA.
Not from Tilt problems.

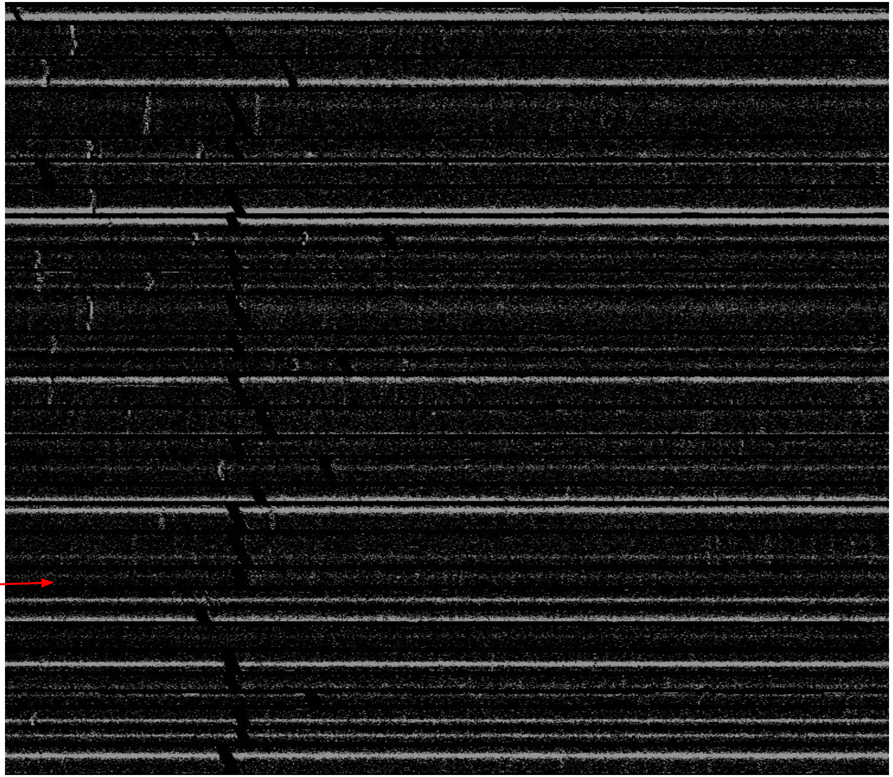
PypeIt

Final steps:

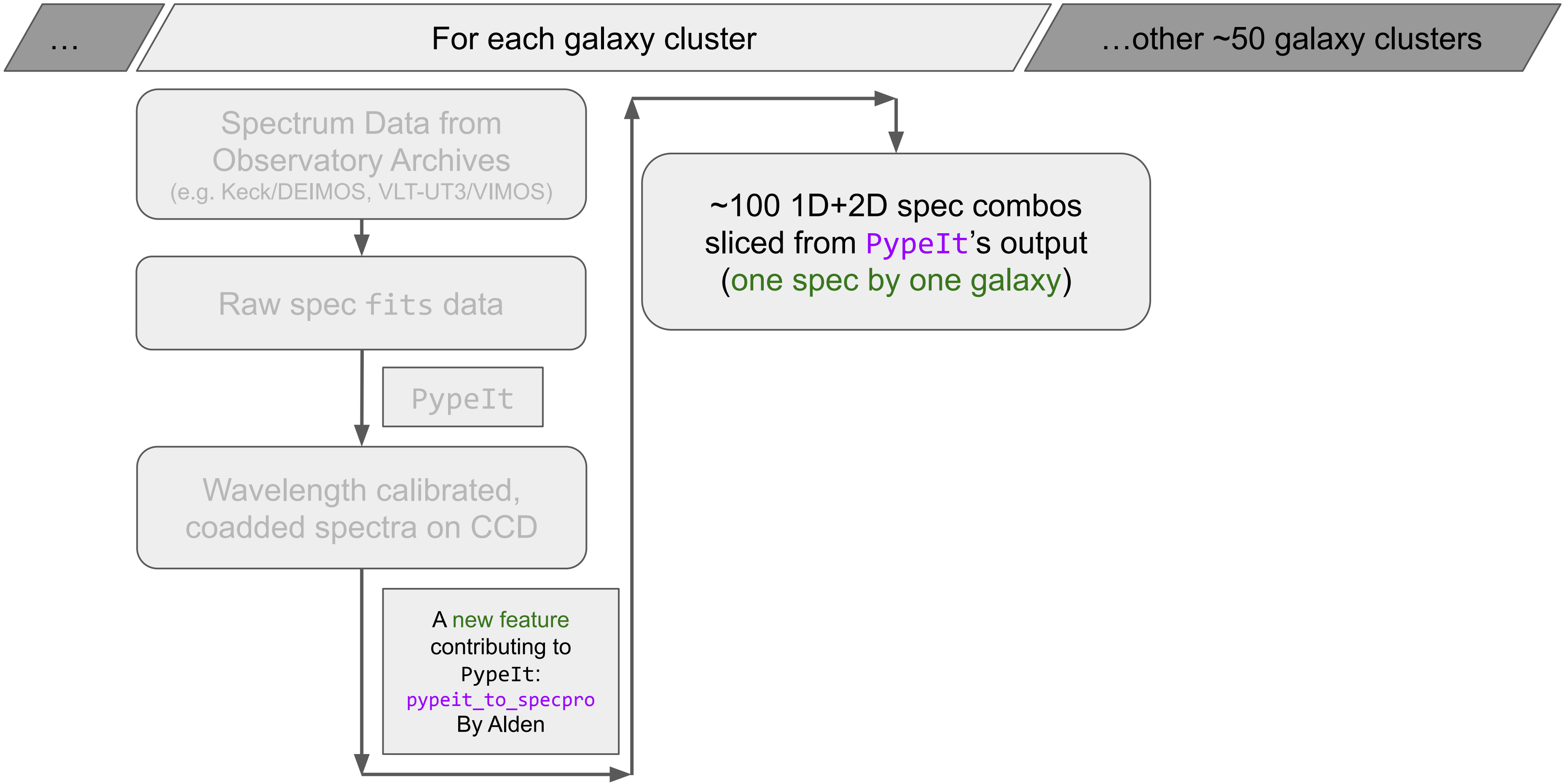
- Subtract sky lines
- Remove background noise
- Co-add all exposures

In co-adds, you will get:

- Wavelength solution from Arc
- Slit information TXT
- 1D-spec (flux vs wavelength) for all objects
- 2D-spec (x-pixels: wavelength direction) for all objects on entire CCD



Data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…other ~50 galaxy clusters
Spectrum Data from Observatory Archives
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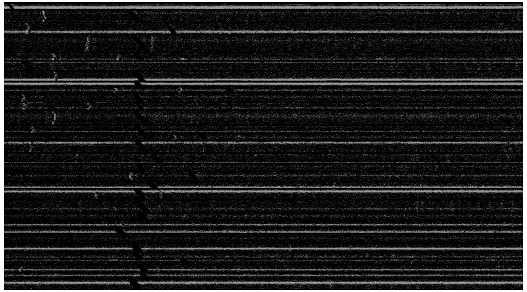
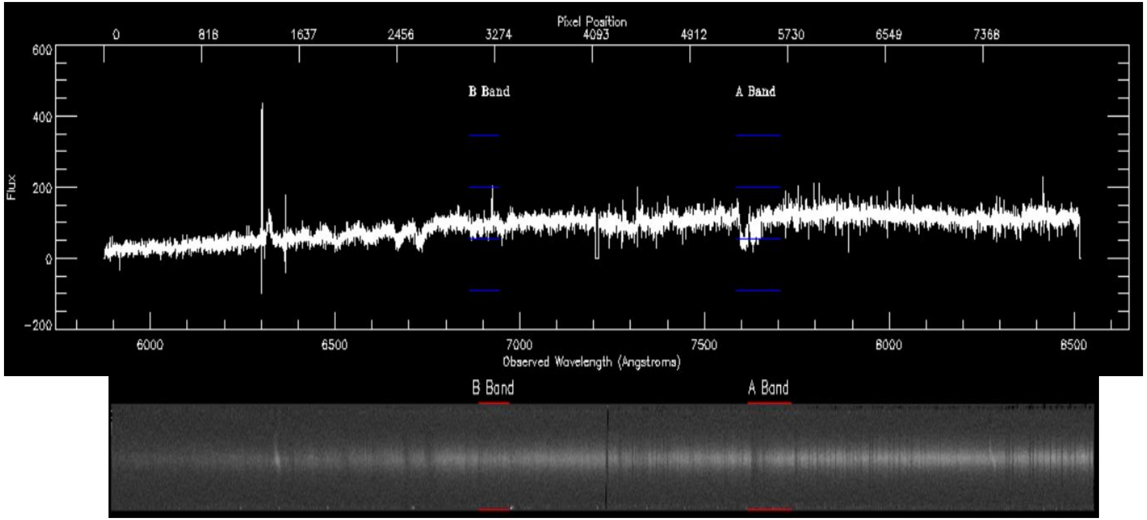
Raw spec fits data
PypeIt
Wavelength calibrated, coadded spectra on CCD
A new feature contributing to PypeIt:
pypeit_to_specpro
By Alden
~100 1D+2D spec combos sliced from PypeIt's output
(one spec by one galaxy)

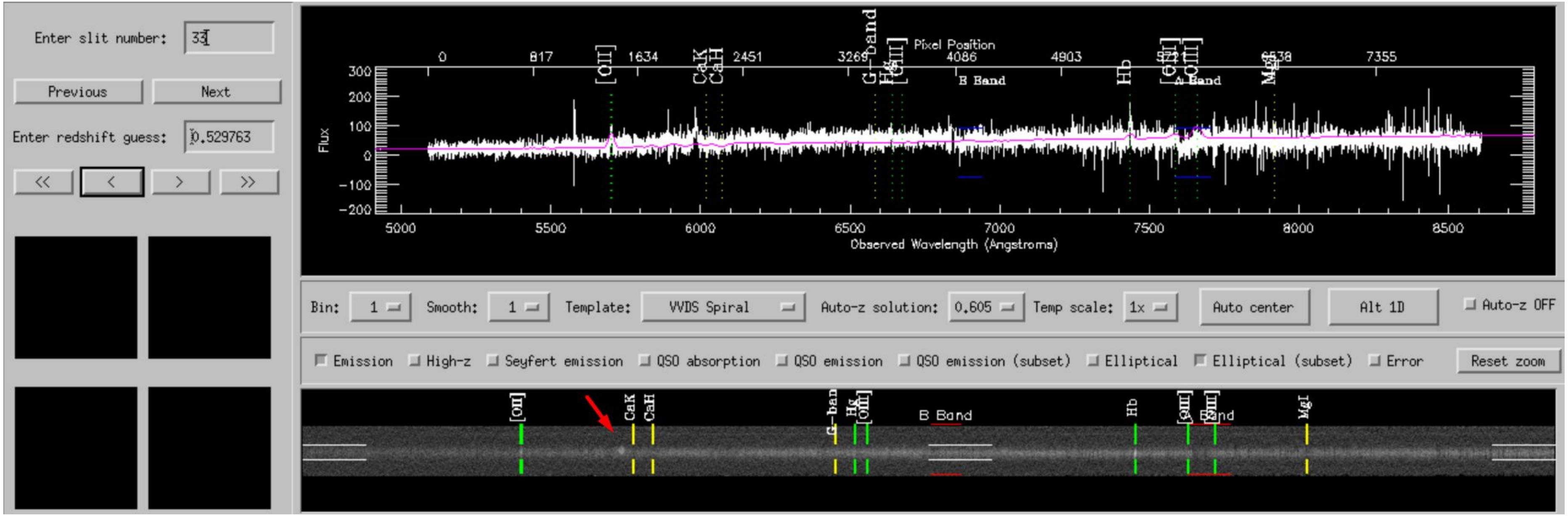
pypeit_to_specpro.py

Our original pipeline for slit-cutting to one 1D+2D combo per slit and converting `PypeIt` *outputs to IDL* `SpecPro` *acceptable spec files*
Developer: Alden Beck

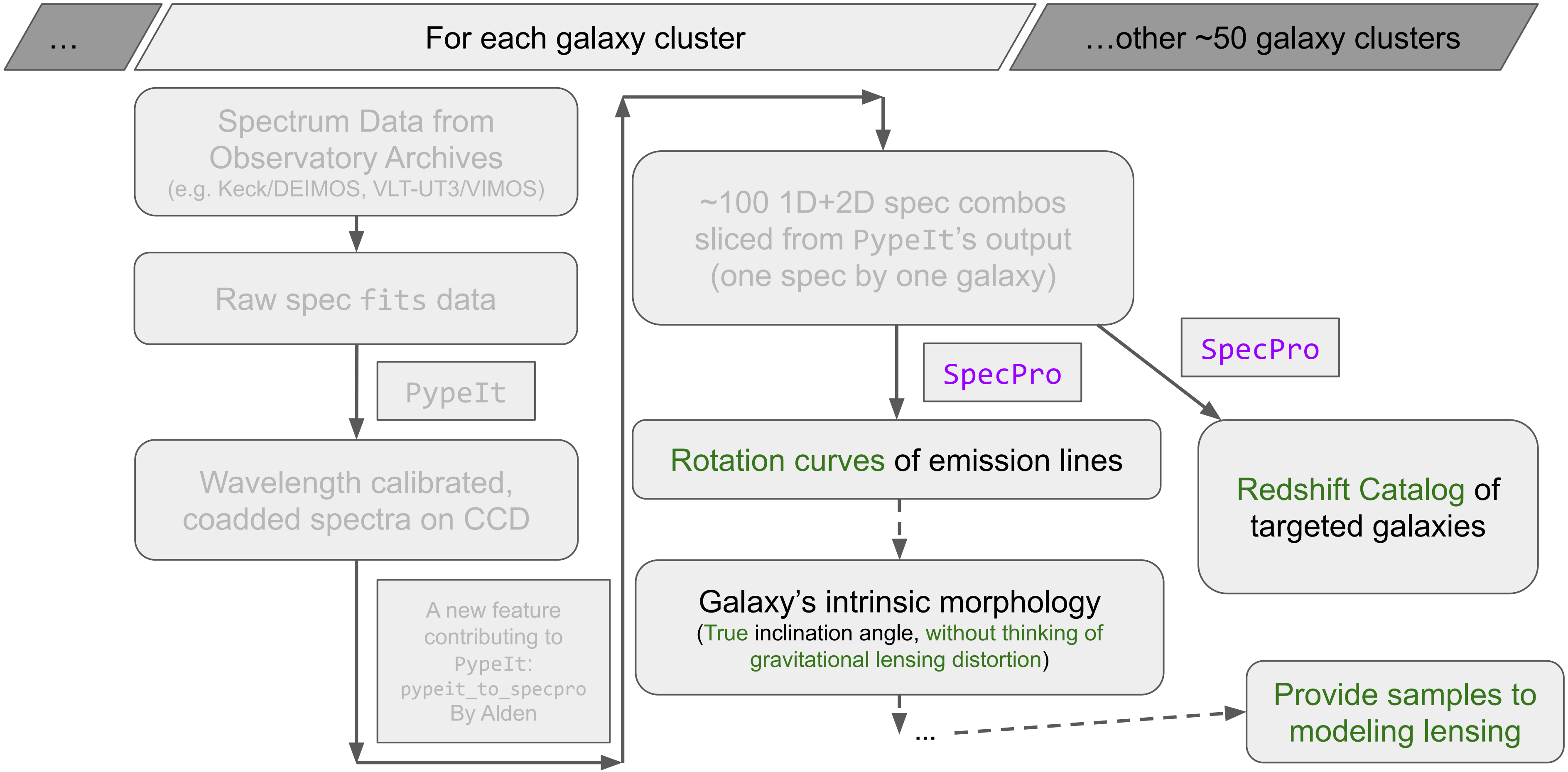




IDL SpecPro


Enter slit number:
33
Previous
Next
Enter redshift guess:
0.529763
Pixel Position
B Band
Flux
Observed Wavelength (Angstroms)
Bin:
Smooth:
Template:
VVDS Spiral
Auto-z solution:
0.605
Temp scale:
1x
Auto center
Alt 1D
Auto-z OFF
Emission
High-z
Seyfert emission
QSO absorption
QSO emission
QSO emission (subset)
Elliptical
Elliptical (subset)
Error
Reset zoom

Data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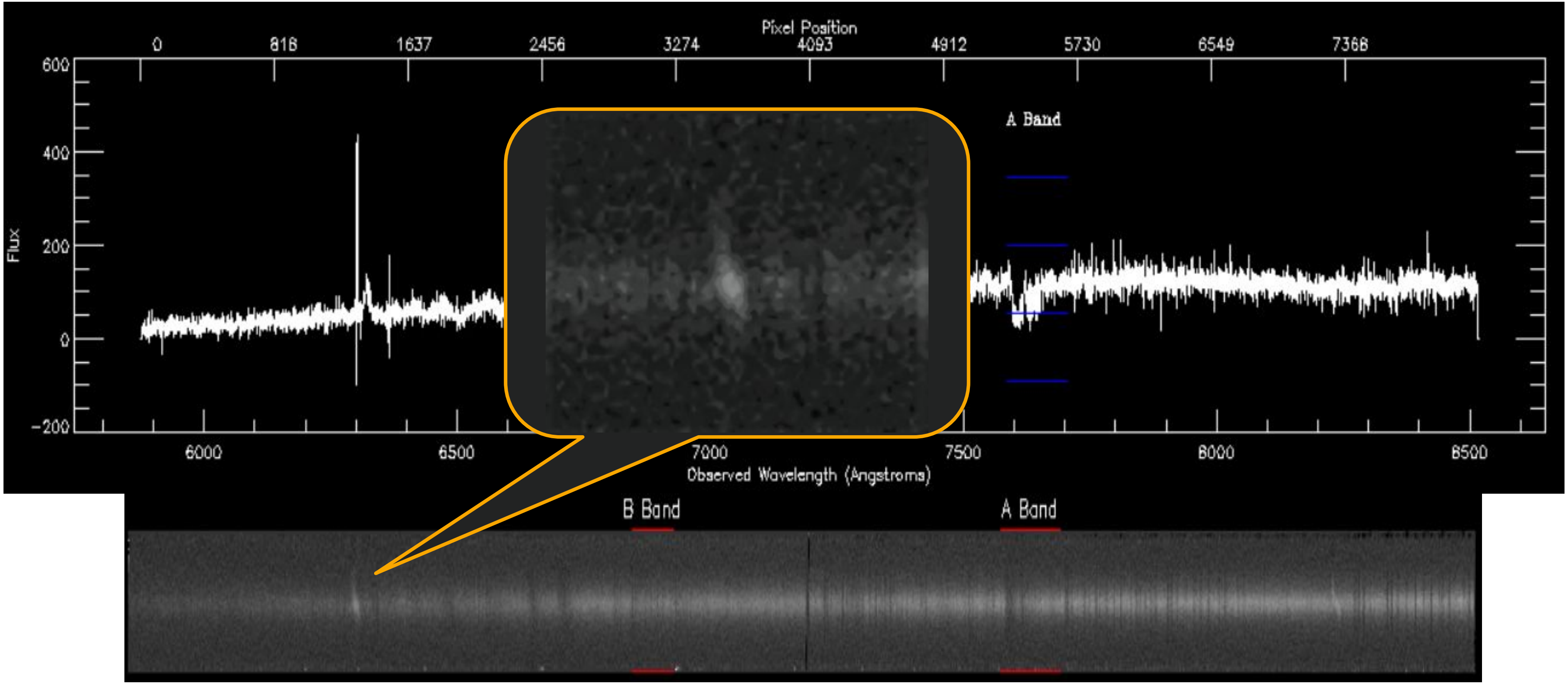
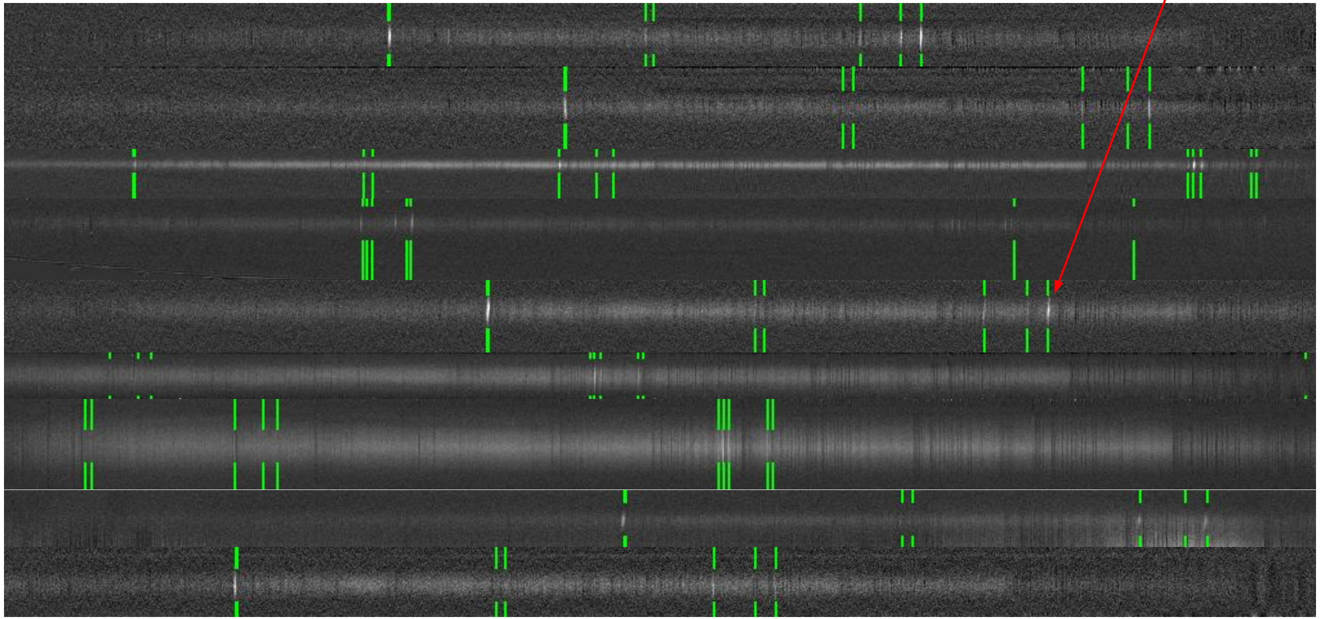
A new feature contributing to PypeIt: pypeit_to_specpro By Alden
~100 1D+2D spec combos sliced from PypeIt's output (one spec by one galaxy)
SpecPro
SpecPro
Rotation curves of emission lines
Redshift Catalog of targeted galaxies
Galaxy's intrinsic morphology
(True inclination angle, without thinking of gravitational lensing distortion)
...
Provide samples to modeling lensing

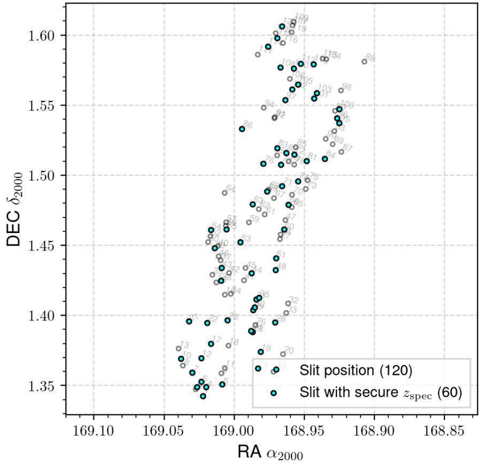
Outcomes - Rotation curves

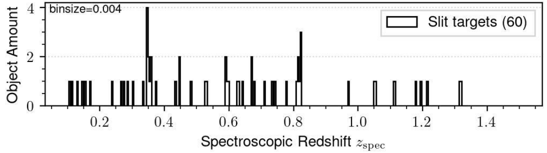


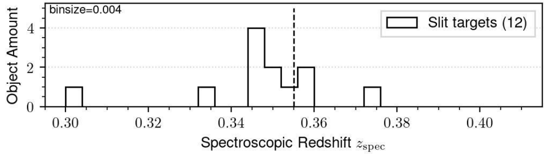
Outcomes - Rotation curves in S-shape

Example: MACS J1115.8 (z_{cl}=0.355)









Summary

- Apply the kinematic weak lensing method on the galaxies targeted in the “Weighing the Giants” (von der Linden et al. 2014) project.
- Get the intrinsic shapes of the galaxies before the cluster shear, that both have rotation curves shown on spectra and have higher redshifts than the cluster.
- A spectroscopic weak lensing experiment has the potential to greatly improve on the statistical and systematic errors (~26% to ~4%) of conventional lensing measurements. (Huff et al. 2013, Pranjal-R-S et al. 2022)