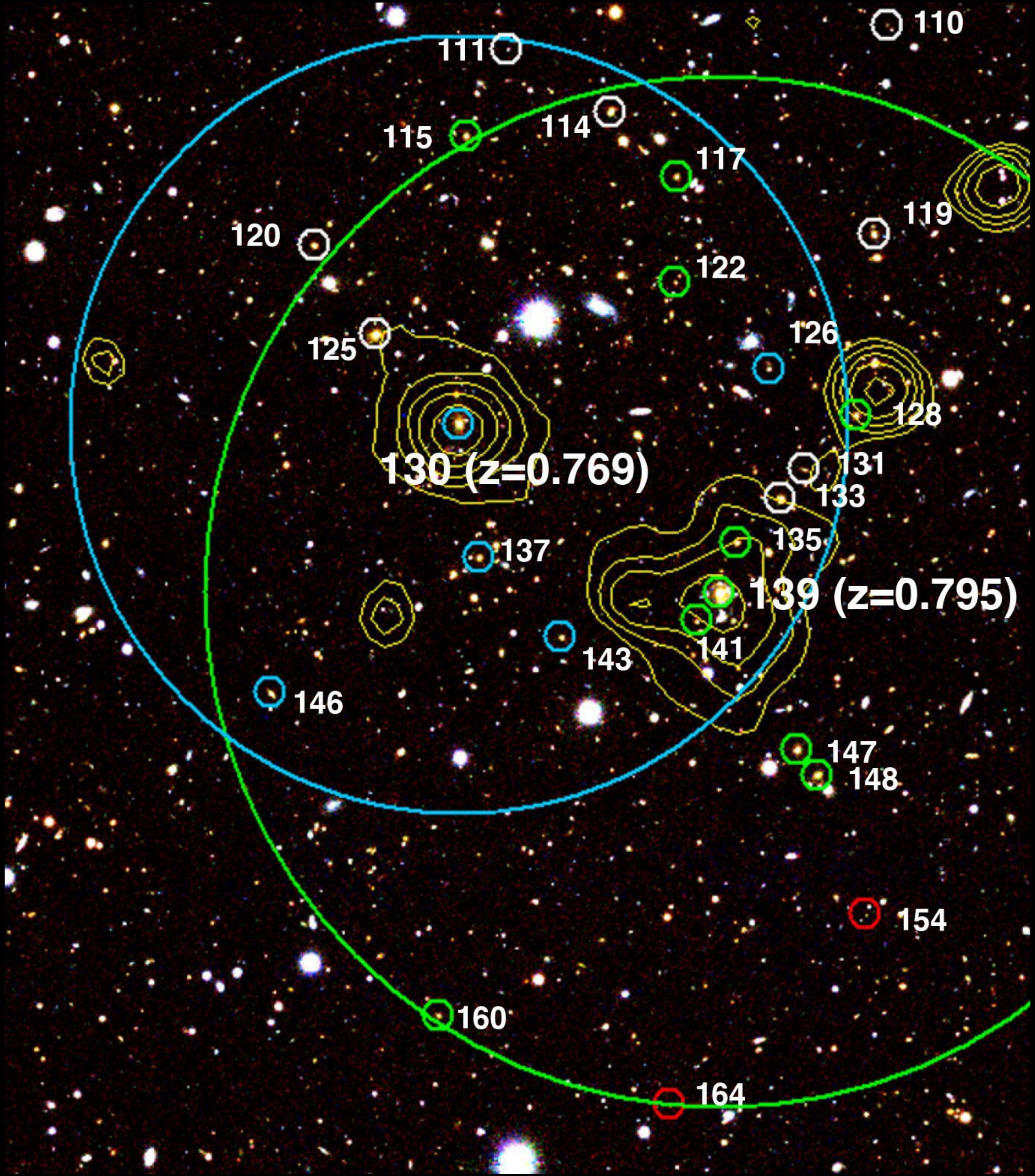
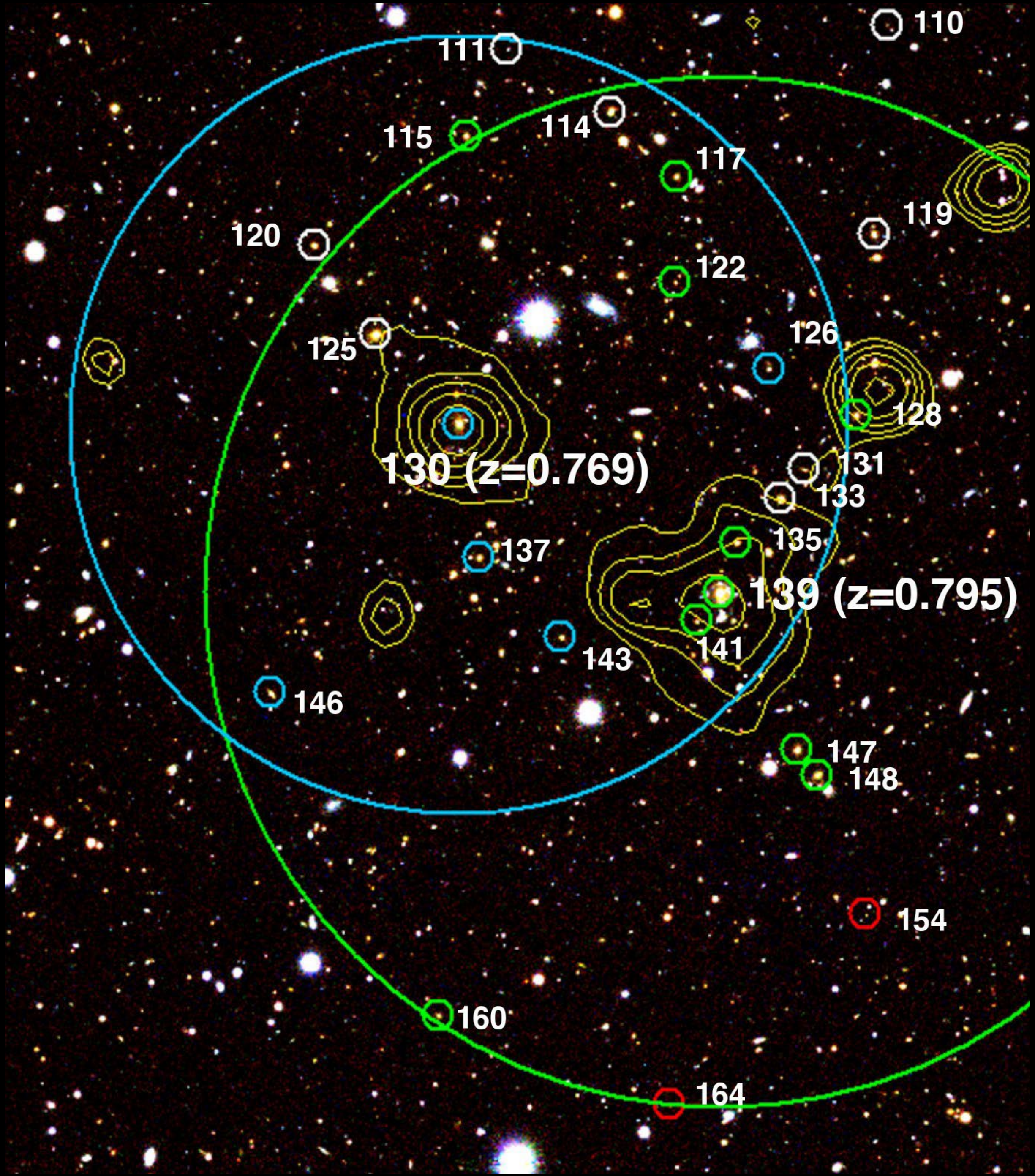


The Spectroscopic Survey of Galaxy Clusters at z~0.8 Using MMT/Binospec

Jiyun (Jaden) Di

4th-Year Undergrad

Steward Observatory, University of Arizona



Research Category

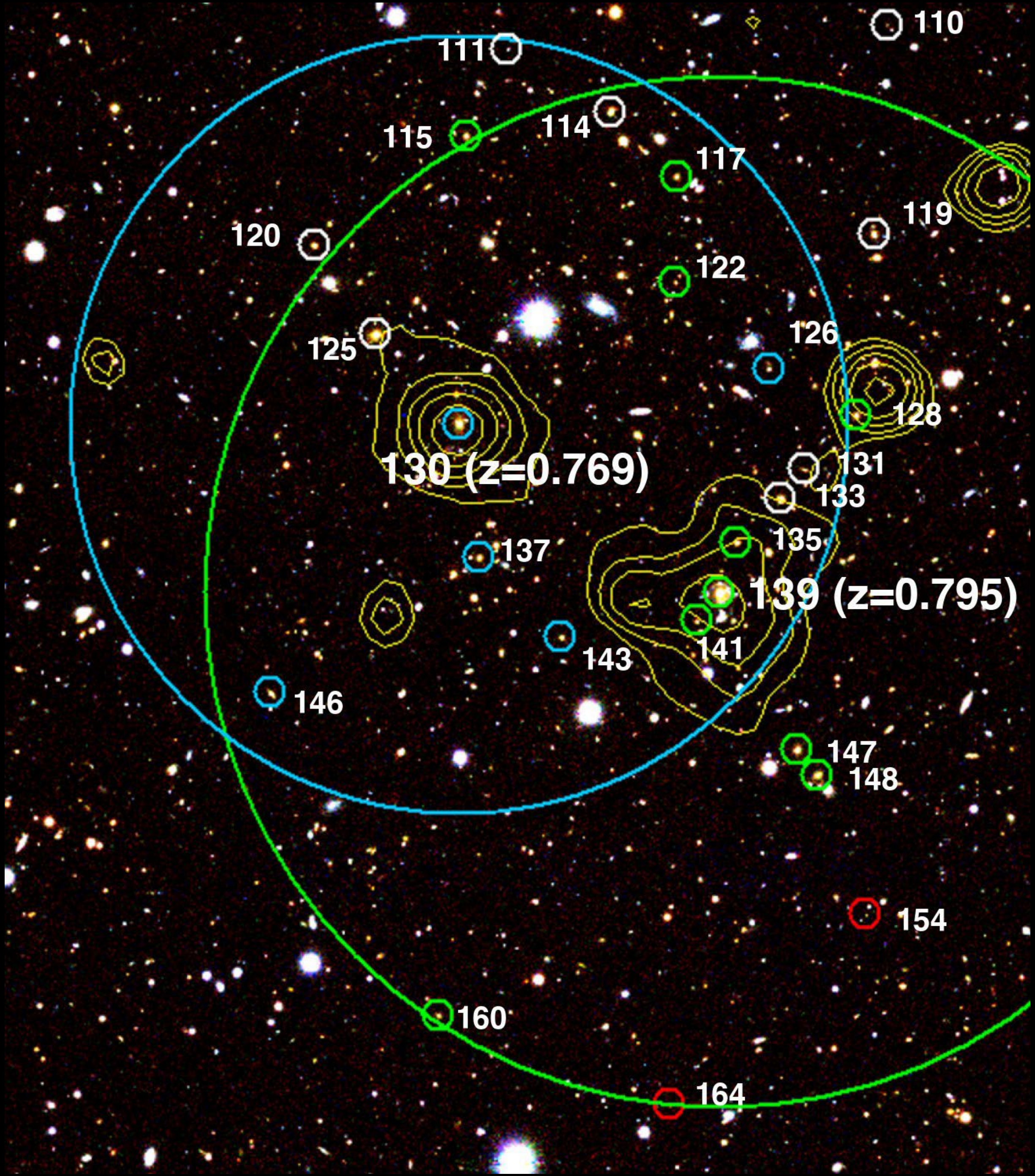
- Directed Research (ASTR 392, 492)
- Optical/IR Observation related
- Cosmology related
- Publishing research

Group

Eiichi Egami	(Supervisor, Steward faculty)
Jiyun Di	(Student PI)
Kenneth Wong	(Coll., U of Tokyo, NAOJ)

…

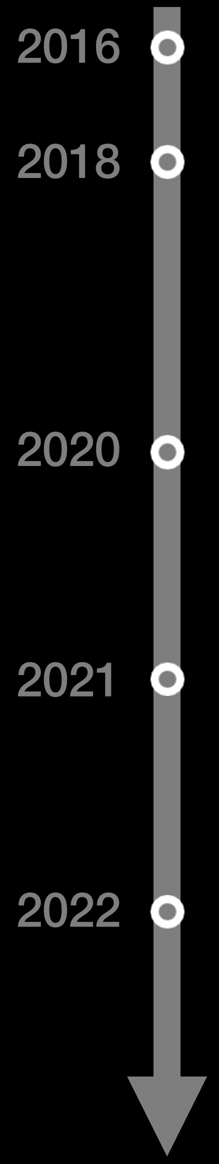
MMT/Binospec: z~0.8 Galaxy Cluster Spec Survey

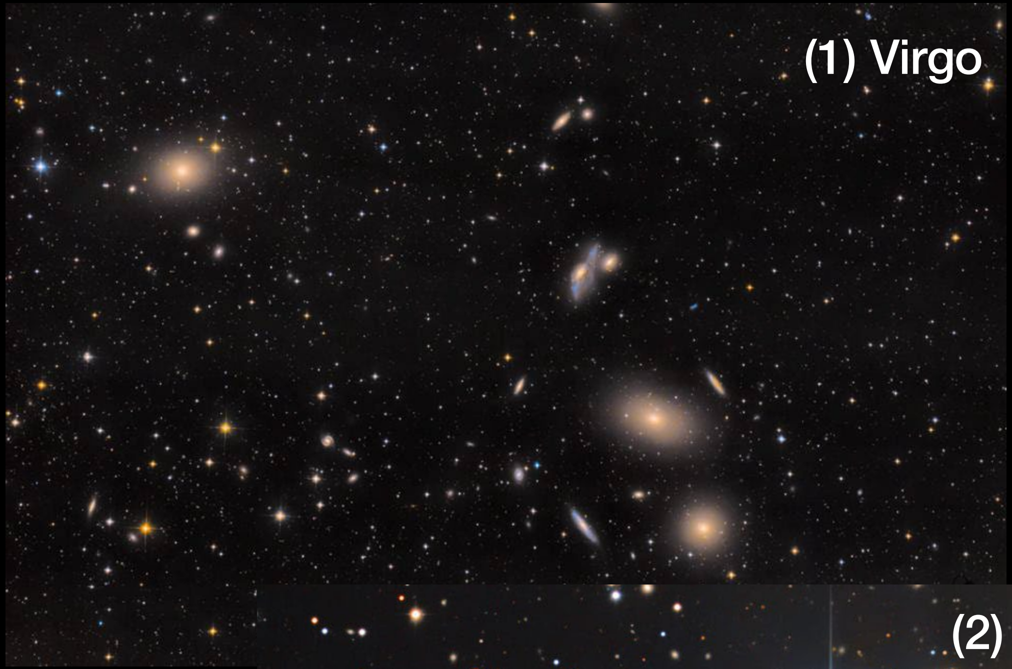


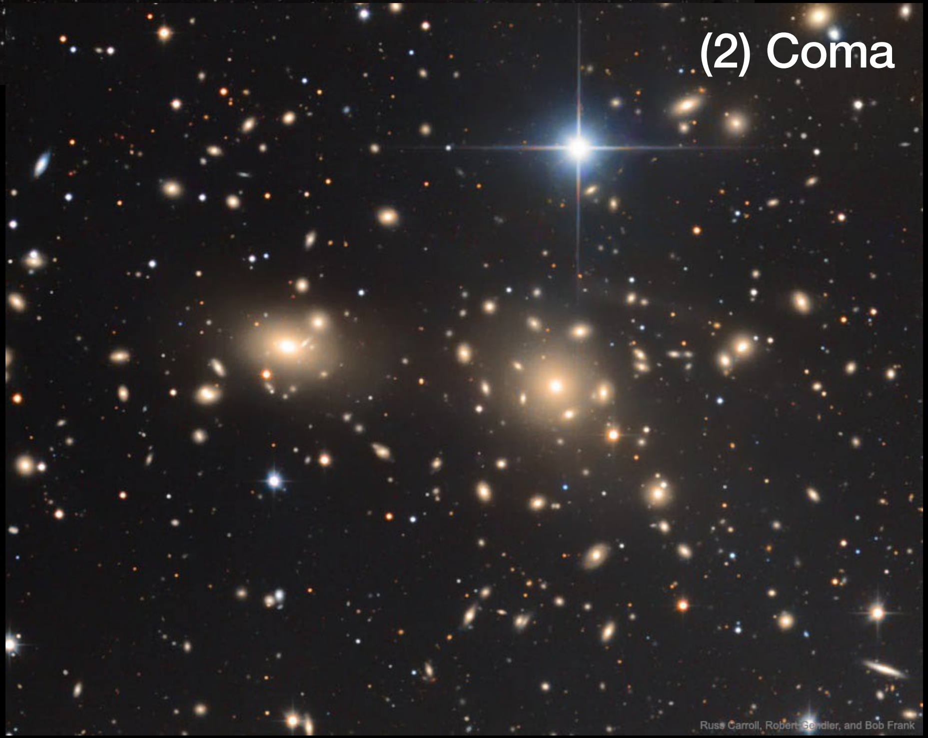
Timeline of this research

Outline

1. Background
2. Introduction
3. Observations
4. Play with spectra!
5. Results
6. Future goals







Credits: (1) Fernando Pena (2) NASA/Carroll et al

Background Knowledge

- Cluster of Galaxies (CoG)
  - Largest gravitational field labs
  - Dark matter halo wrapped
  - E.g., Virgo (~$10^{15}M_\odot$), Coma (~$10^{14}M_\odot$)
  - Gravitational lensing (strong)

- Gravitational Lens (GL)

  "How the light from galaxies were bended?"

  "Masses!"

  --- Zwicky, 1937

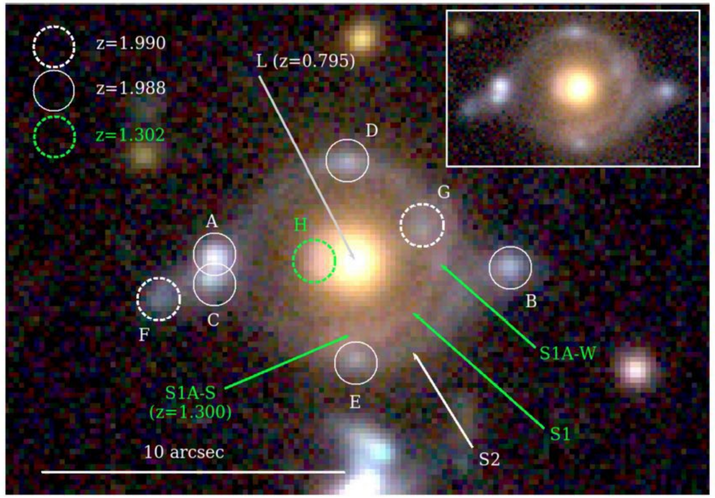


Figure 1. *riz* color composite of *Eye of Horus*. The lens galaxy is labeled "L," and the inner and outer sources are labeled "S1" and "S2," respectively. The knots in the sources are labeled alphabetically in approximate order of brightness. Note that the two rings clearly have different colors. The spectroscopic redshifts of the various features are indicated by the colored circles in the upper left. The angular scale is shown by the bar at the bottom left. The inset shows the lens system with no labels overlaid.

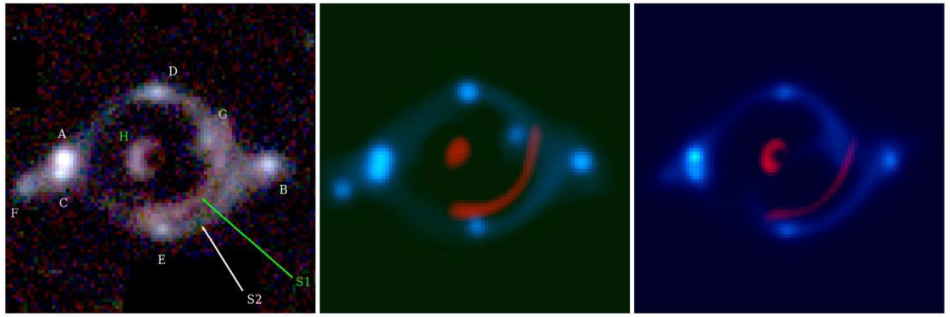
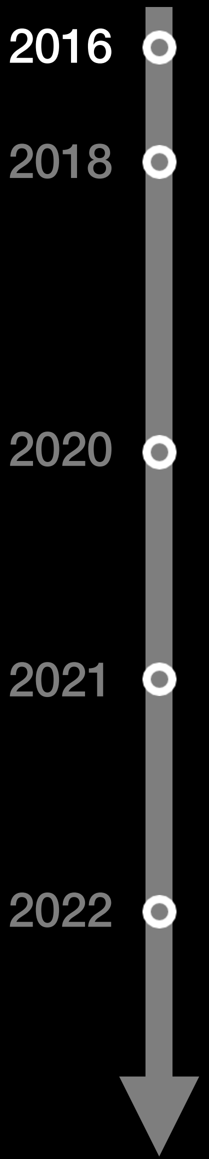


Figure 3. Left: lens-subtracted *riz* image. Feature H is clearly seen once the lens galaxy is subtracted. Center: reconstructed image configuration from GLEE. The red source represents S1, while the blue source represents S2. Right: same as center panel, but from GLAFIC. Both models require an additional mass component to split features A and C into two distinct components.

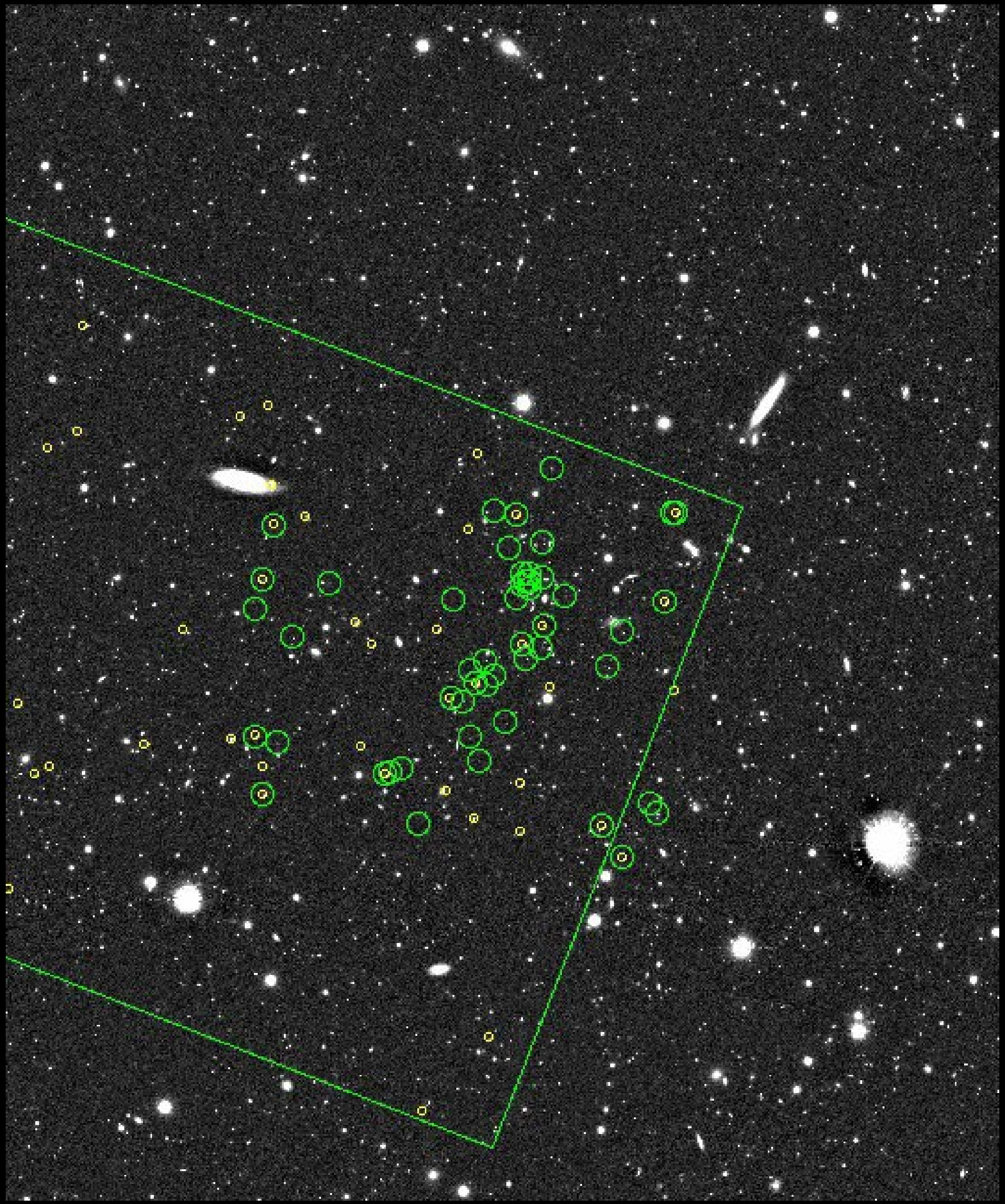
Project Introduction



1. Discovery of "The Eye of Horus" GL
   - A rare (<10), Double Source Plane system

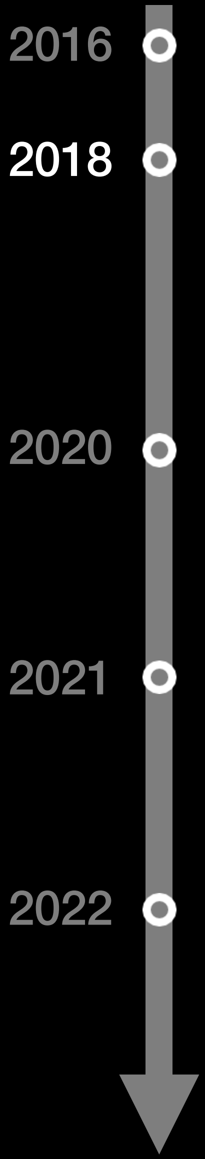
   - Redshift~0.8
   - Need a mass model accurate enough to describe this system

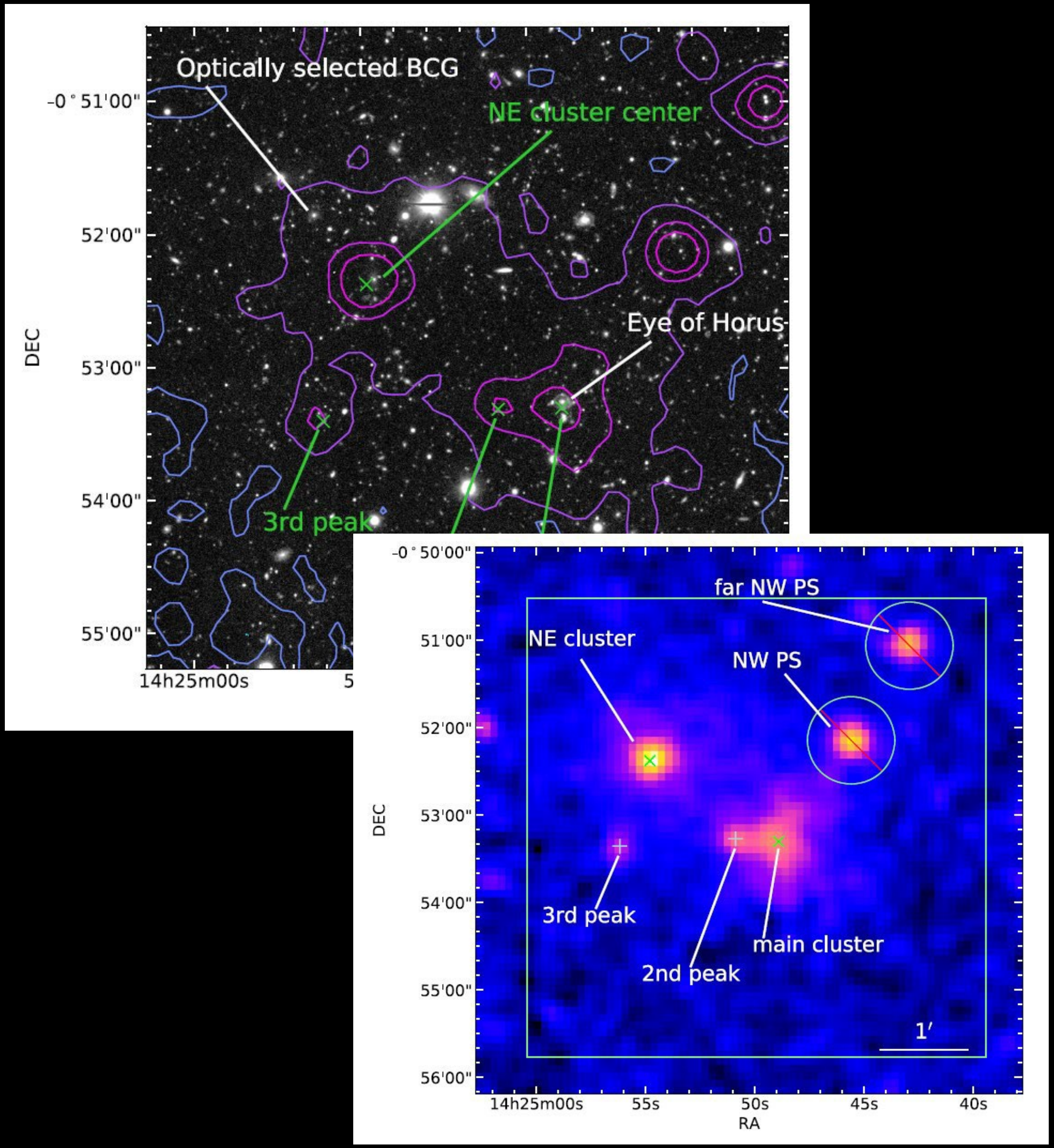
Credits: Tanaka et al. (2016)



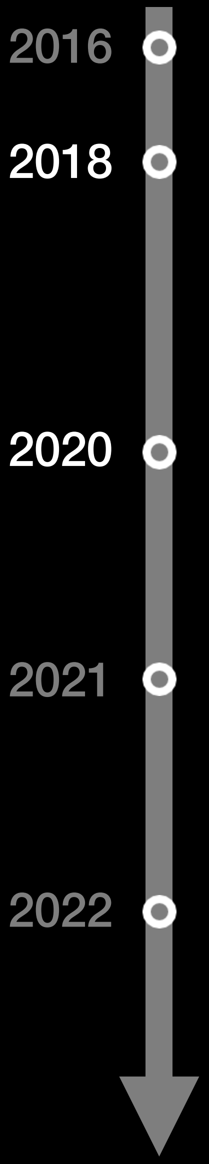
Project Introduction

2. Two galaxy clusters? (Oguri et al.)
   - Around redshifts z~0.8
   - Photometric methods





Project Introduction



2. Two galaxy clusters? (Oguri et al.)
   - Around redshifts z~0.8
   - Photometric methods

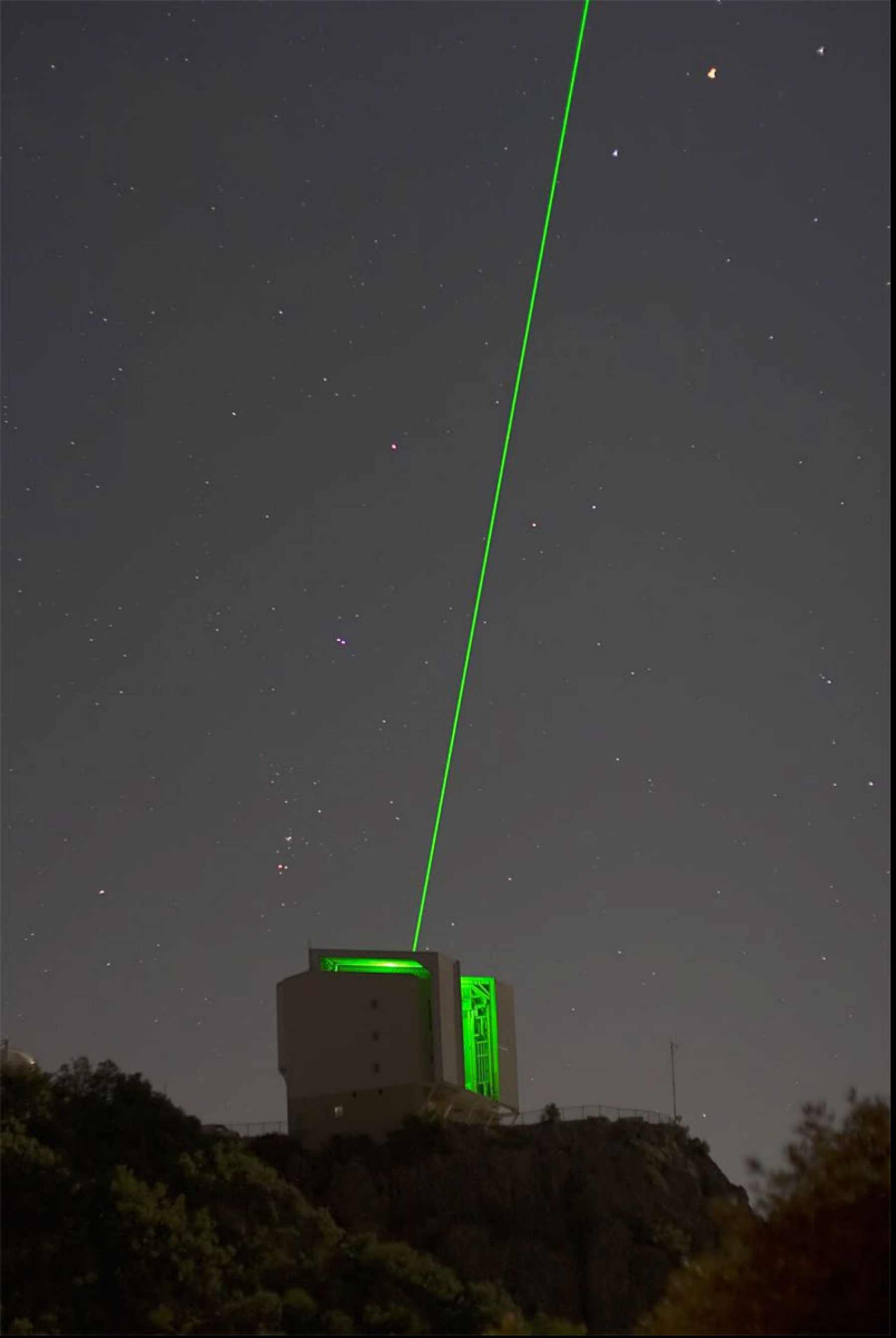
3. X-ray Mapping (Tanaka et al.)
   - Signal of hot plasma in Intra-Cluster Medium (ICM) with Free-Free radiation
   - Two brightest center galaxies (BCGs) at z~0.795 and z~0.761
   - 100'' Separation
   - Still, no accurate info on spec-z

Credits: Tanaka et al. (2020)

The Spectroscopic Survey of Galaxy Clusters at z~0.8 Using MMT/Binospec

Big Questions

1. How many cluster(s) of galaxies are located near EoH GL system?
2. Is this combination a cluster merger or a superposition along the light of sight?
3. Masses derived from spectroscopic observations



Credits: mmto.org

Observation

2016

2018

2020

2021

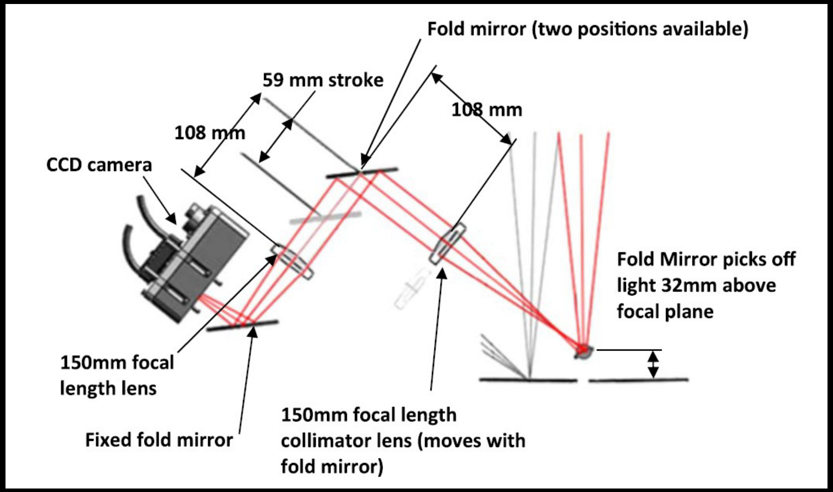
2022

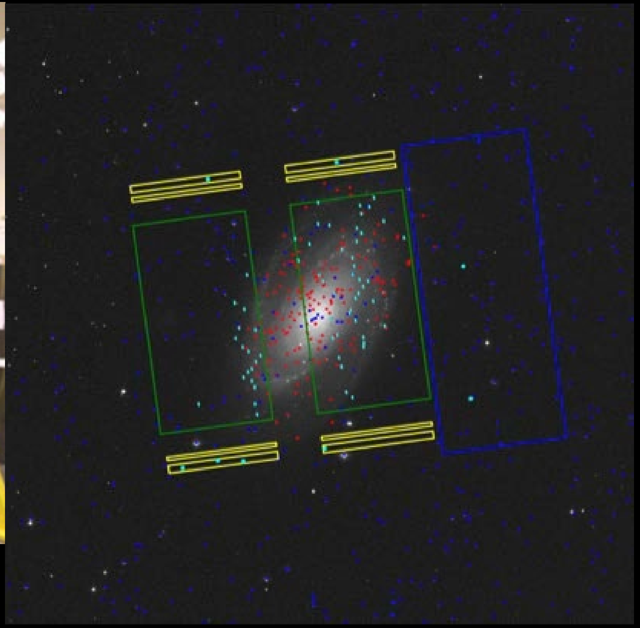
MMT

- Was Multiple Mirror Telescope
- Mt. Hopkins, Tucson, AZ
- 6.5m in diameter
- The same size, mirror casting as Magellan I&II 6.5m

Binospec

- Resolving power R~3500 (2Å at IR band)
- More spectral lines are legible (Ca H&K)
- Two field-of-views (8’ × 15’ each FoV)





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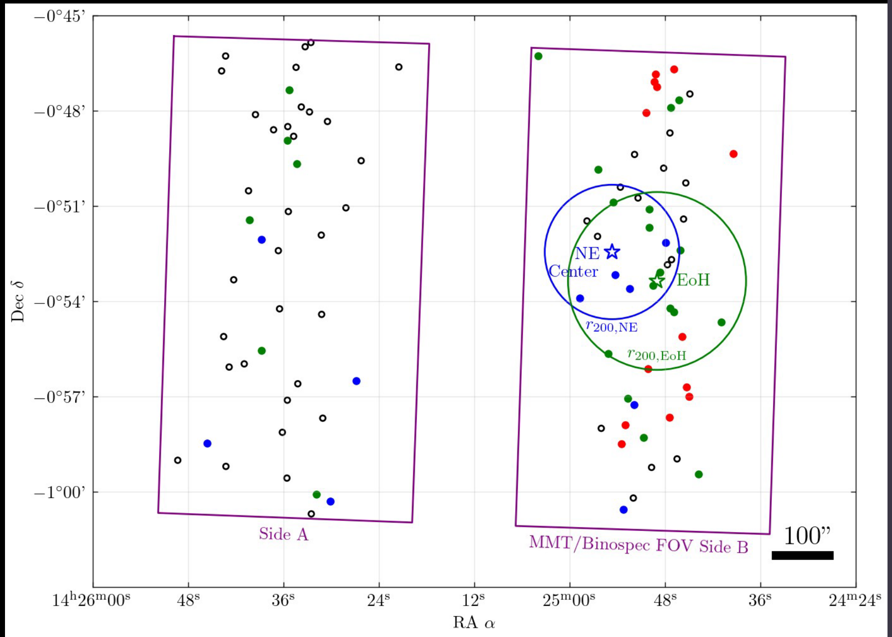
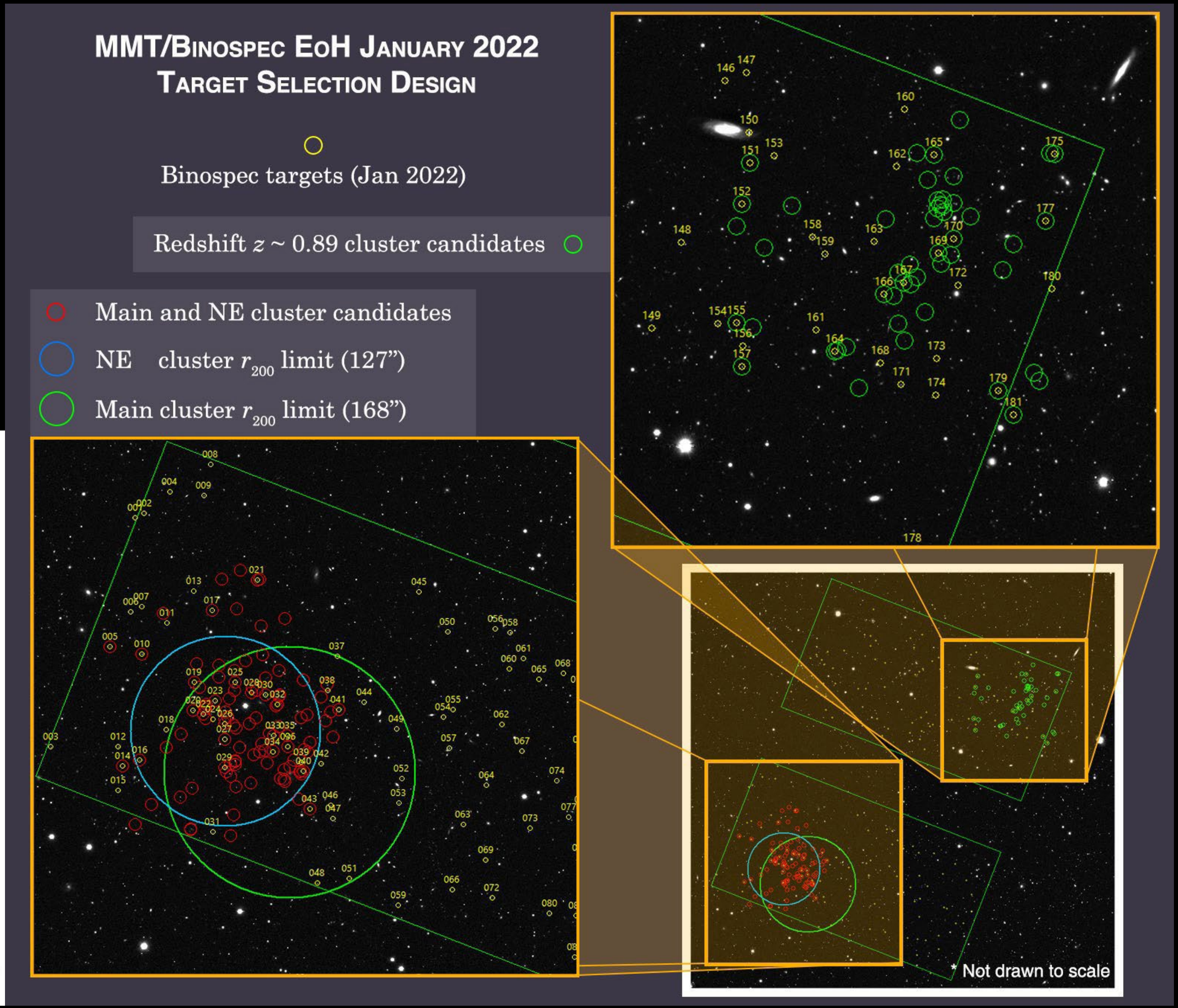
2016
2018
2020
2021
2022

Credits: Fabricant et al. 2019, mmto.org

Target Selection

- CAMIRA survey: candidates with close angular separations and similar photometric redshifts in the FoV
- Similar magnitudes

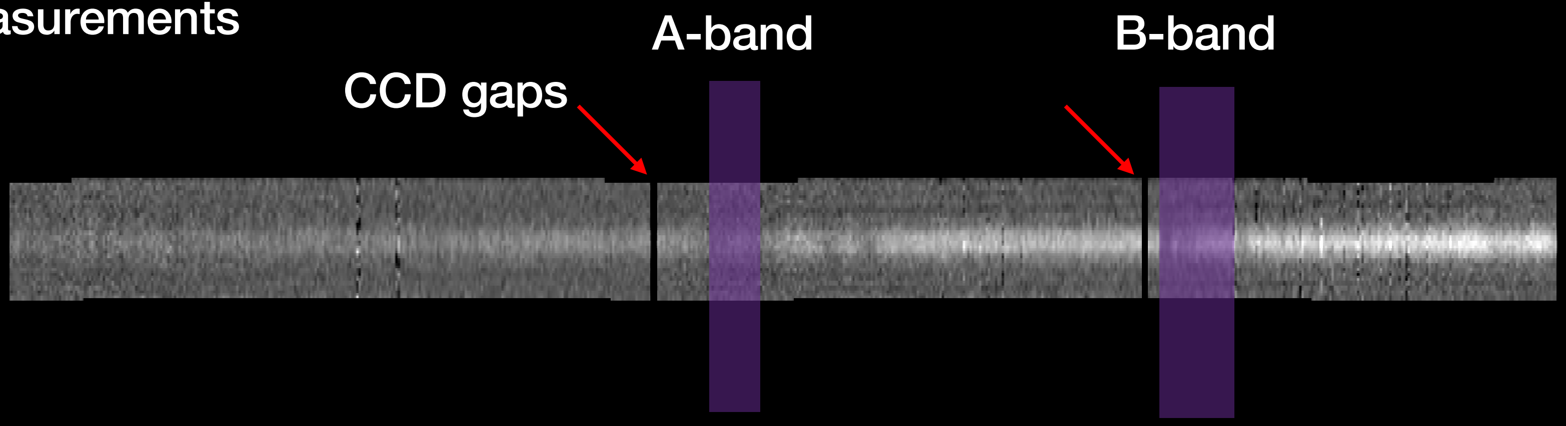




2016
2018
2020
2021
2022

Spectra

Redshift measurements



2016

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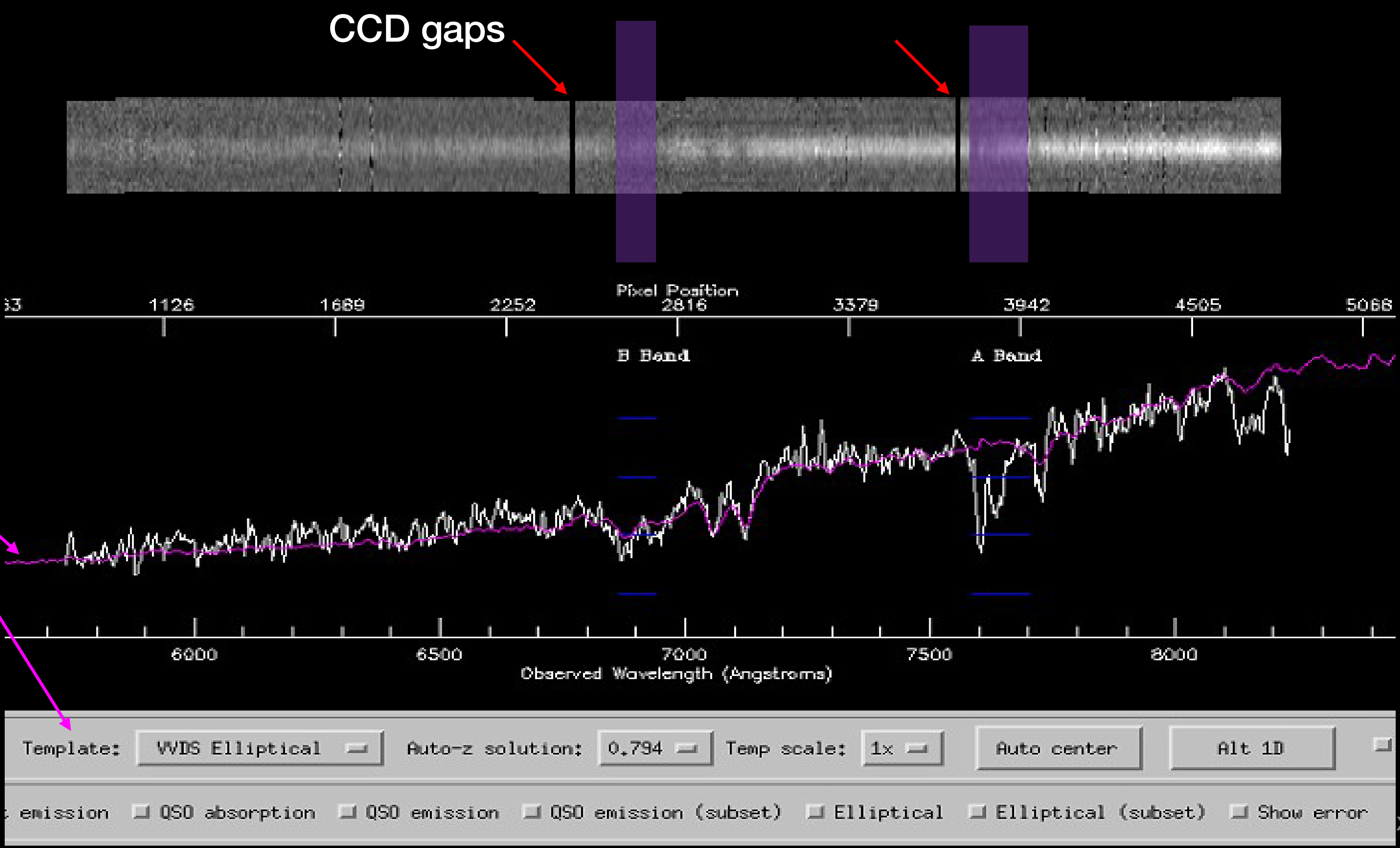
2020

2021

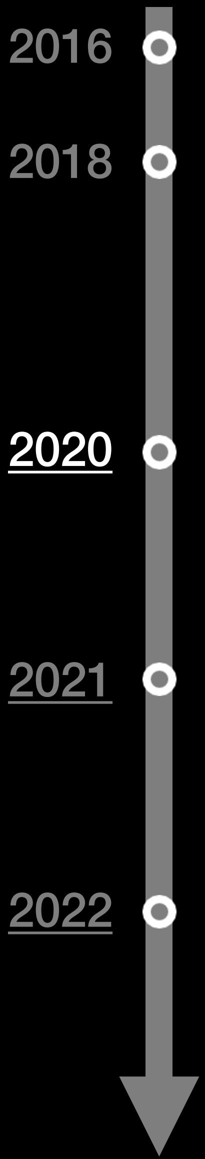
2022

Spectra

Redshift measurements



Spectrum Templates

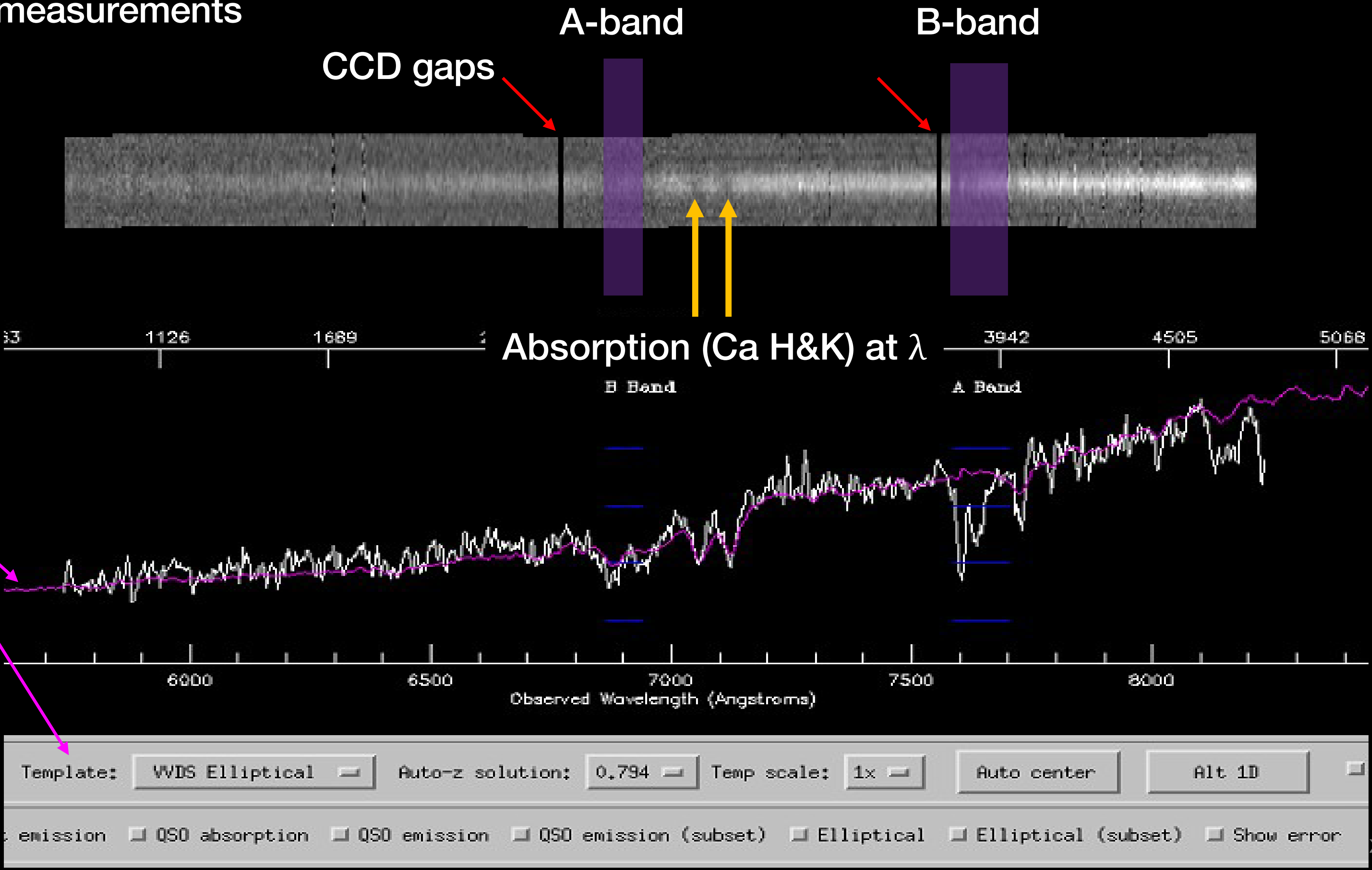


xy Cluster Spec Survey

Spectra

Redshift measurements

Spectrum Templates



2016
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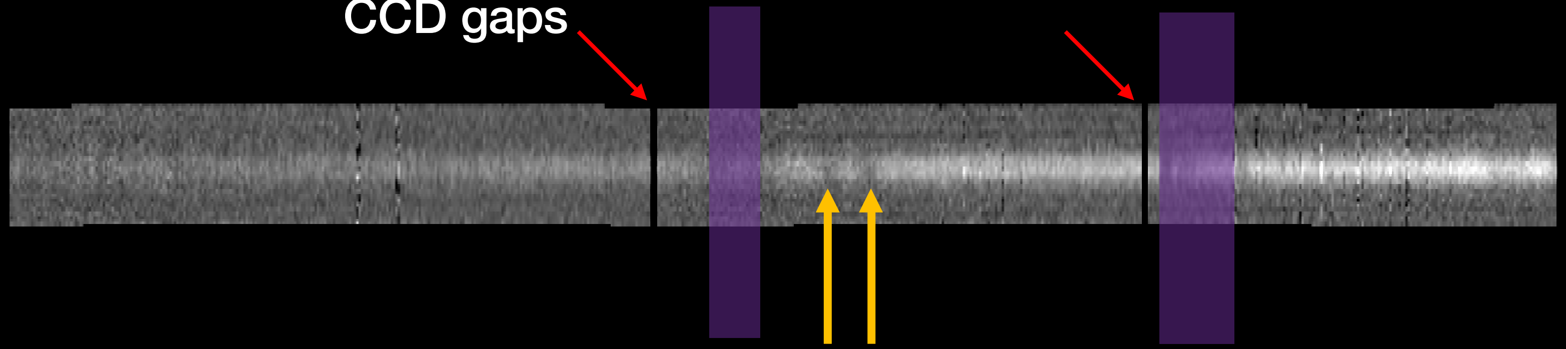
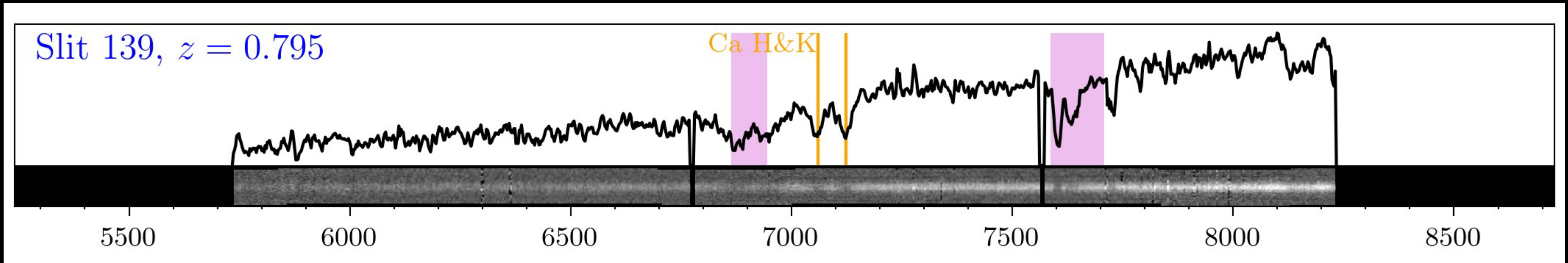
2020
2021
2022

Spectra

Redshift measurements



Redshift $z = \dfrac{\lambda - \lambda_0}{\lambda_0}$ λ_0 = 3933Å at z=0



2016
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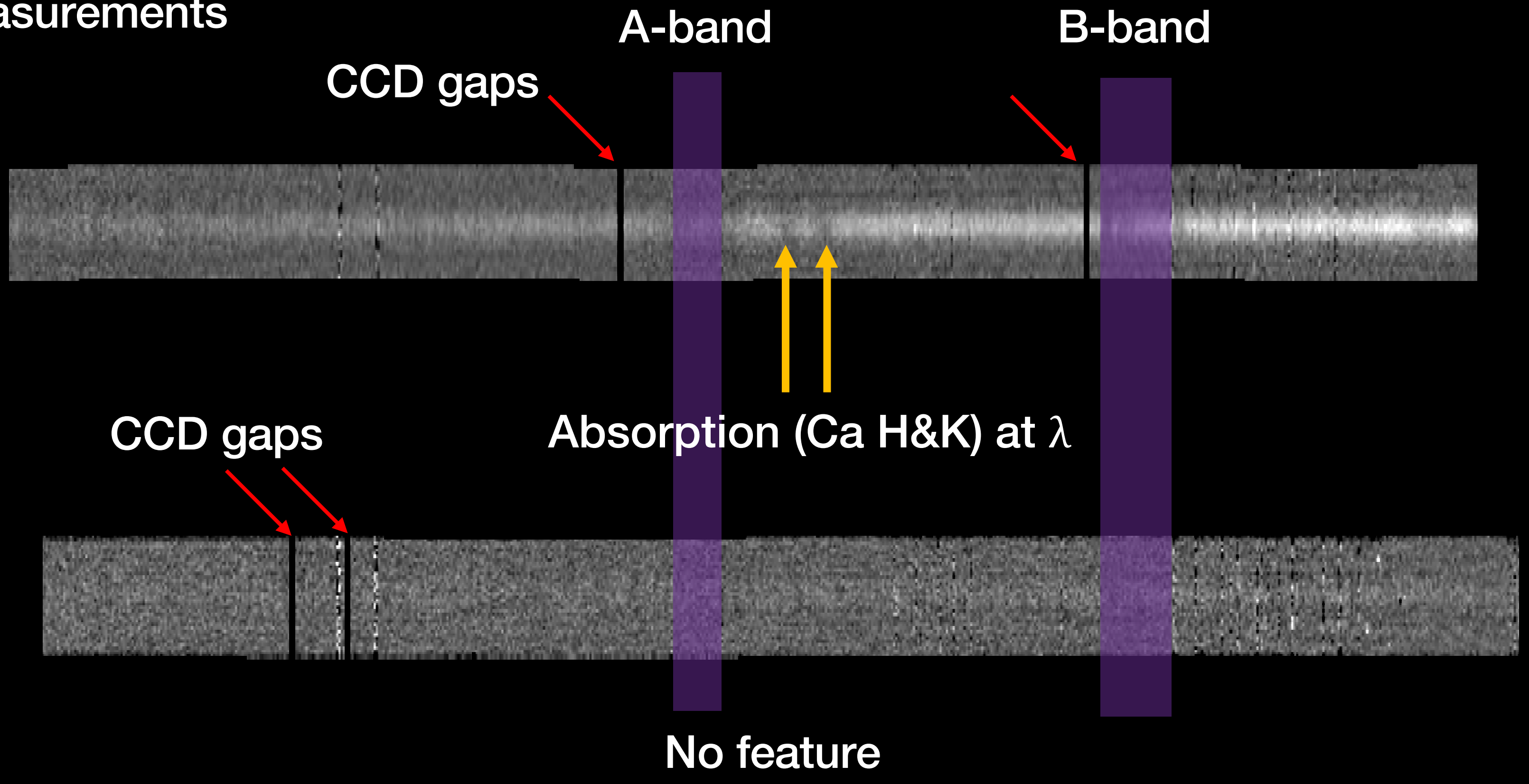
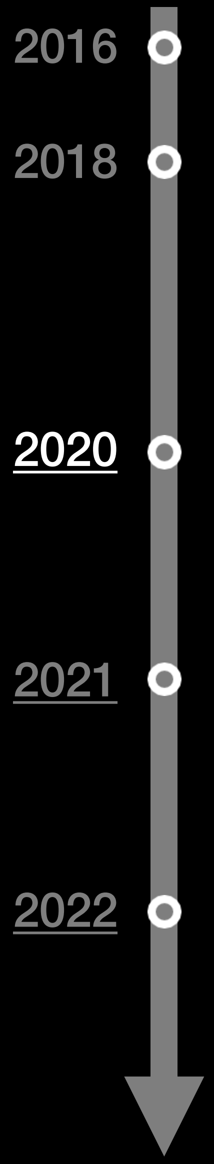
2021
2022

Spectra

Redshift measurements





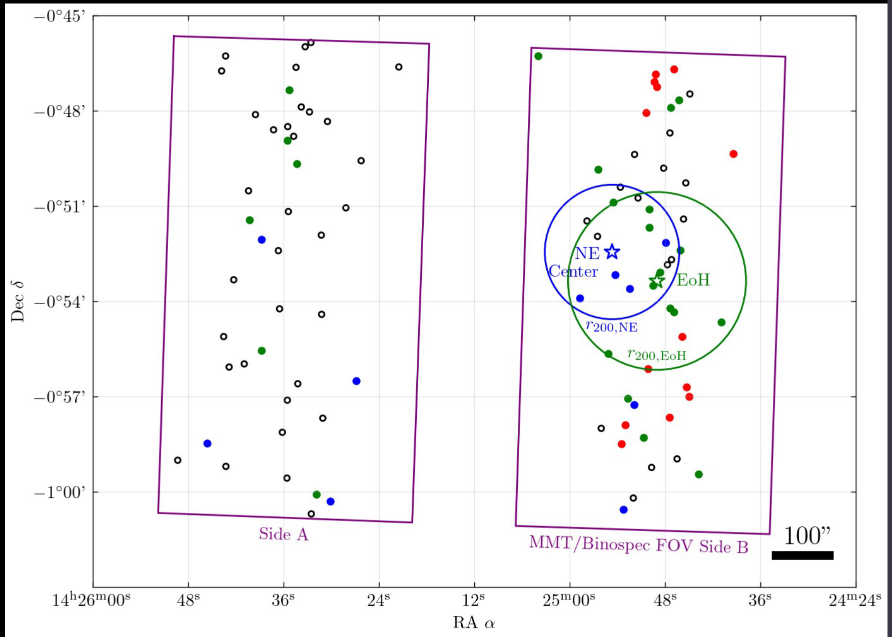
Spectra

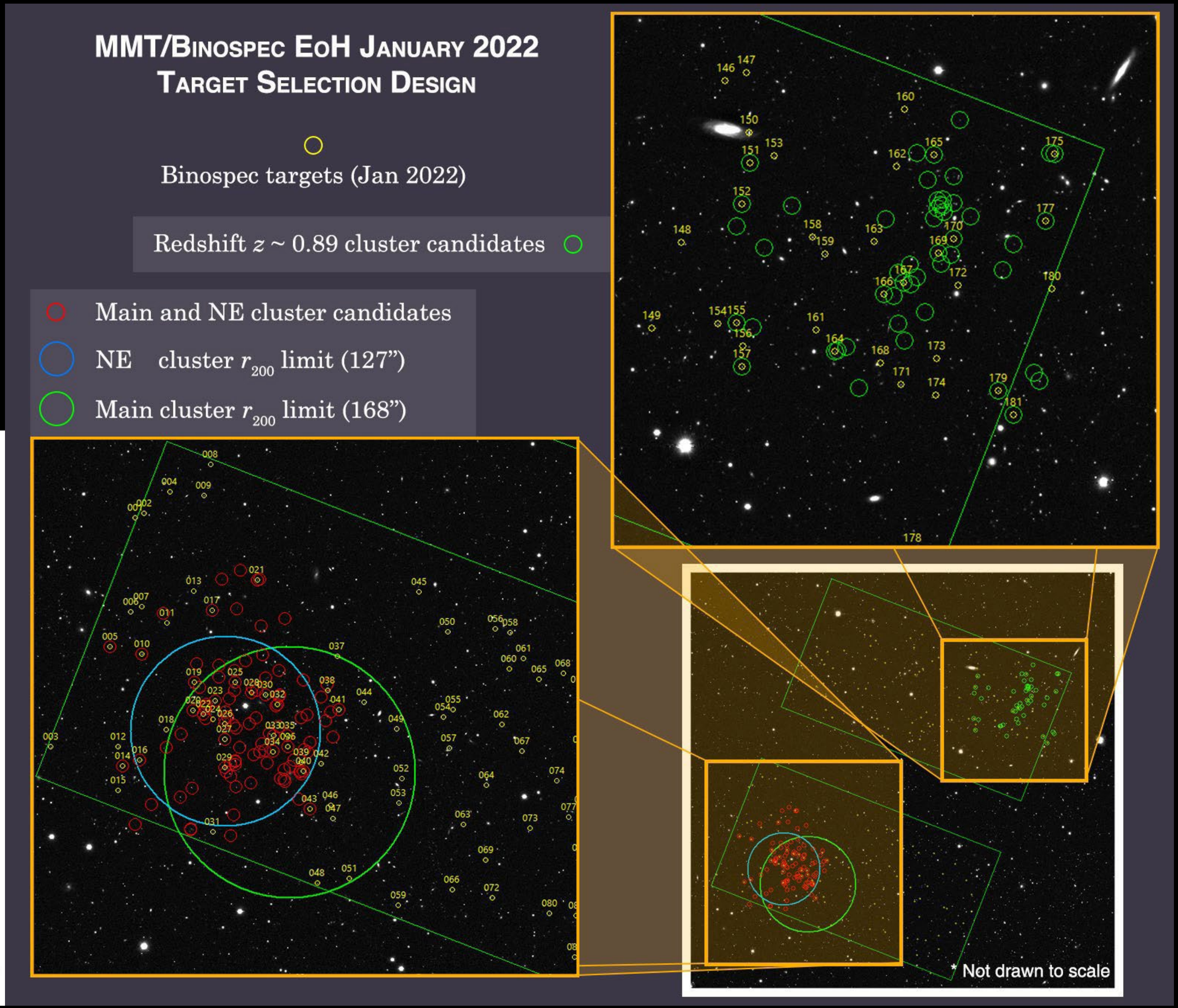
July 2019 Observation

•190 slits, 97 redshifts obtained

January 2022 Observation

- 181 slits, 117 redshifts obtained





2016
2018
2020
2021
2022

Results

1. Cluster Identification

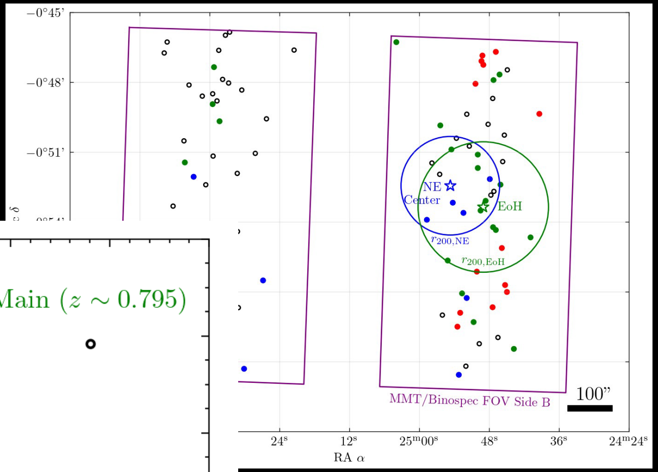
- Redshift distribution
- Criteria: Δ>500km/s or 0.003
  clear b/w peaks
- Main 0.785-0.805
- NE 0.761-0.775

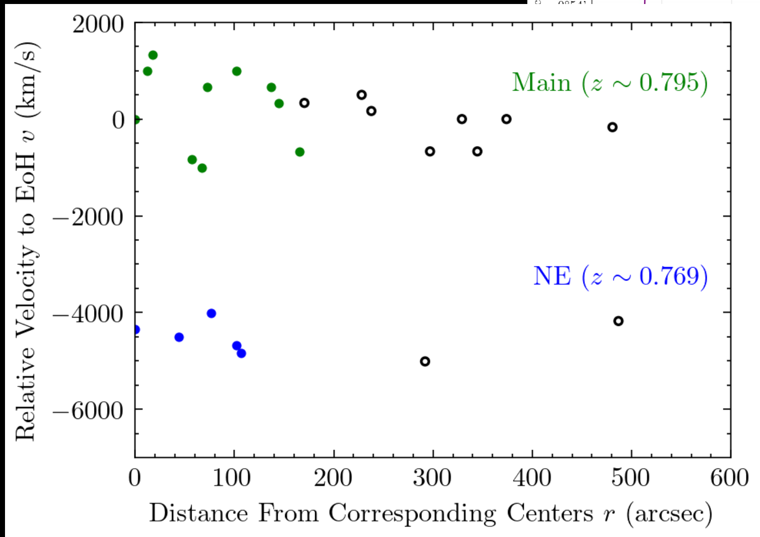
<u>Big Question 2</u>

Is this combination a cluster merger or a superposition along the light of sight?

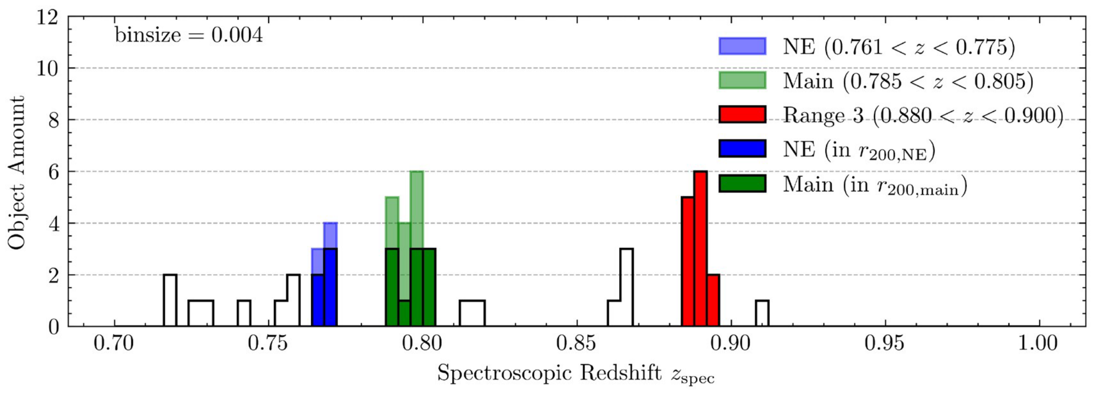
<u>Answer</u>

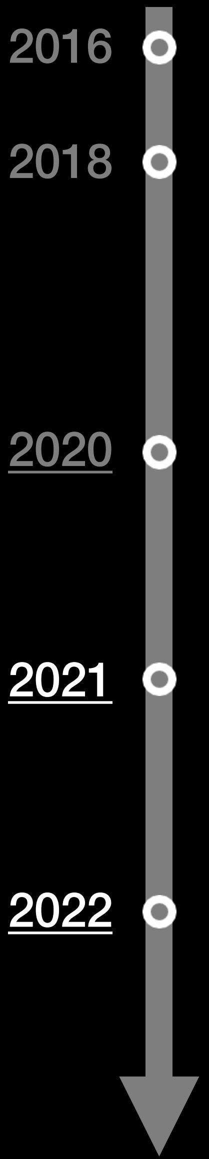
NOT a merger





July 2019

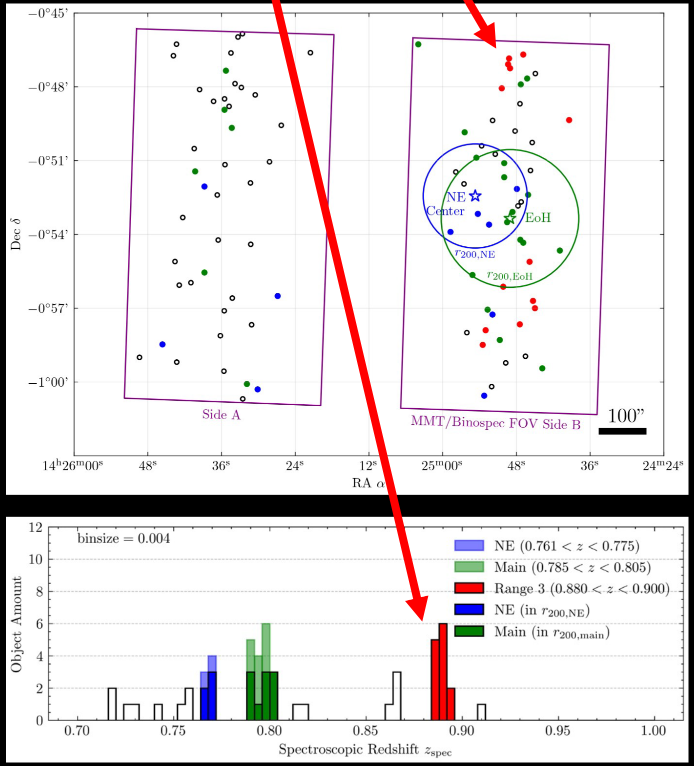




Results

2. The third cluster?

(Range 3)



2016

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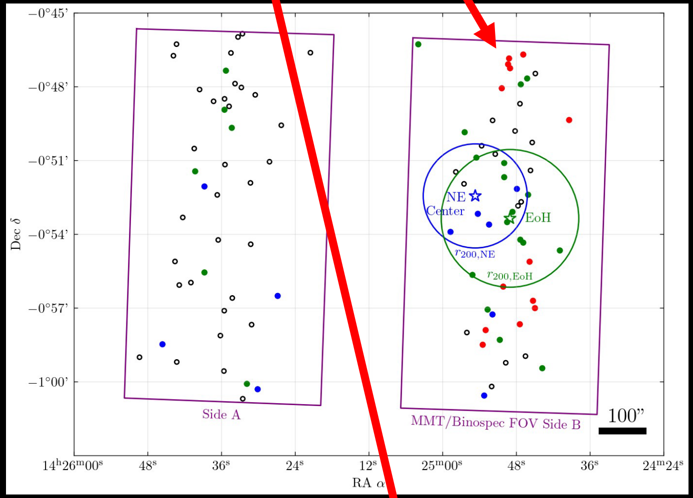
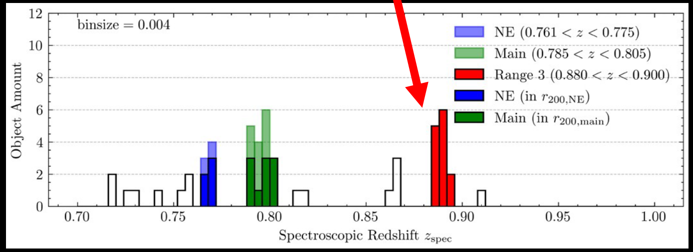
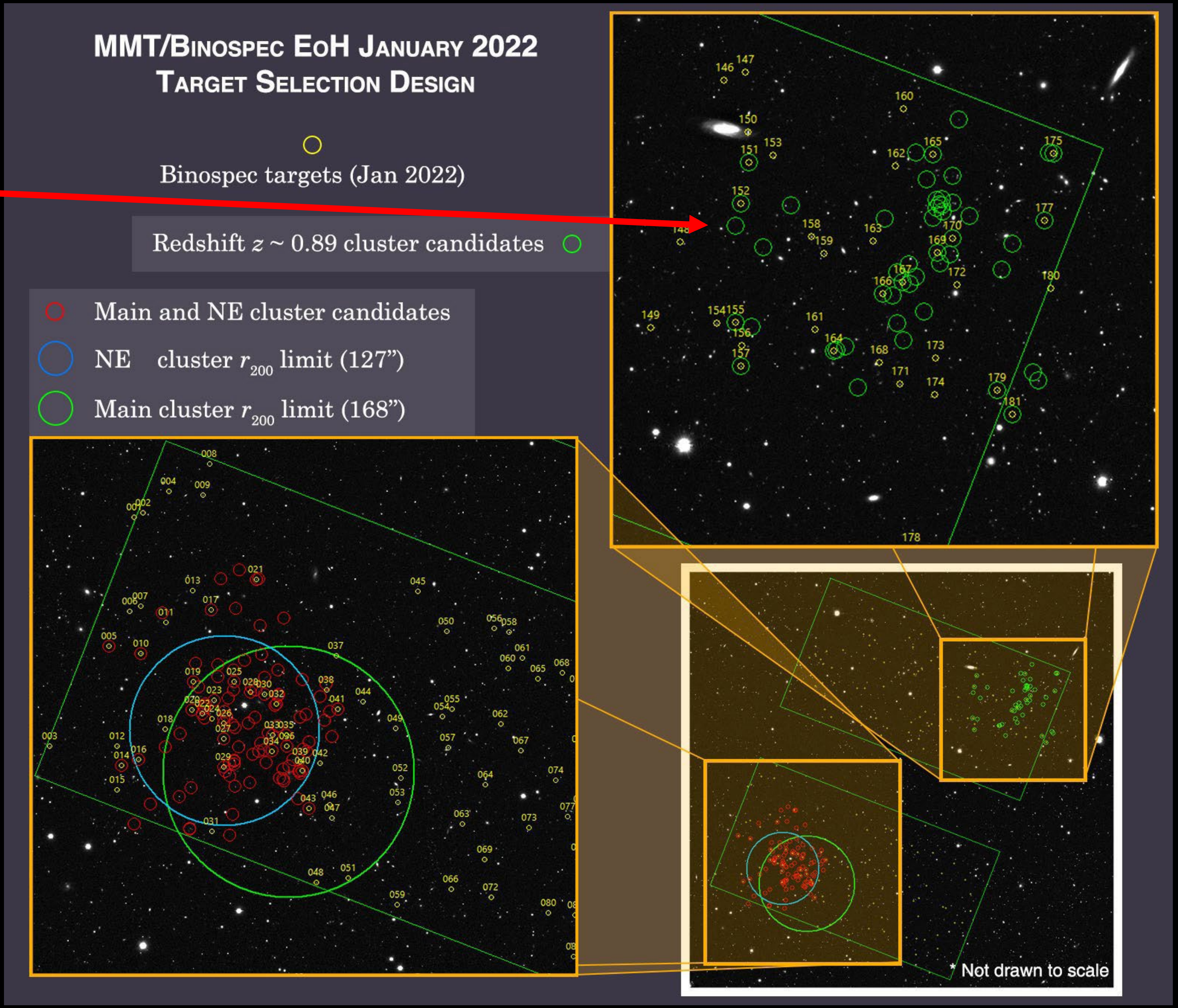
Results

2. The third cluster?

(Range 3)







2016

2018

2020

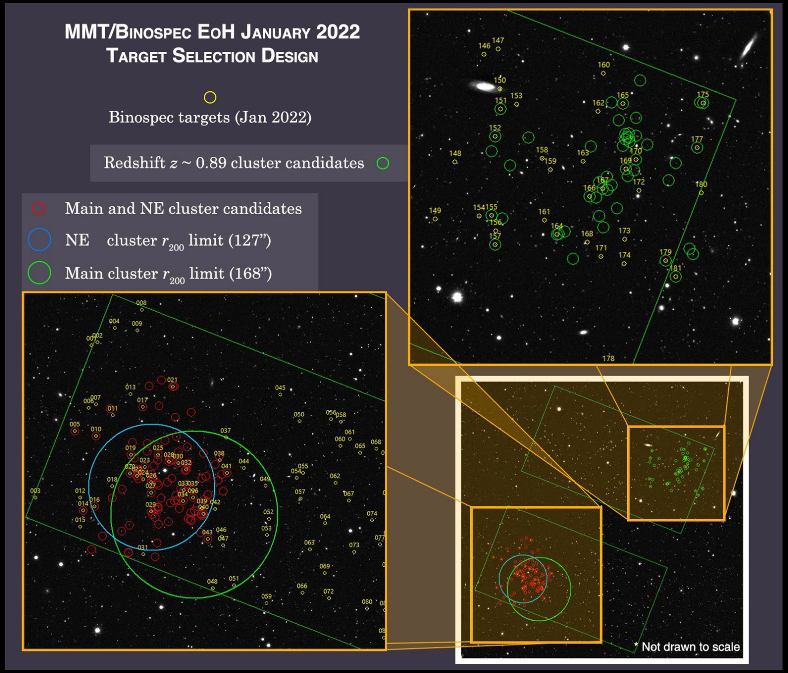
2021

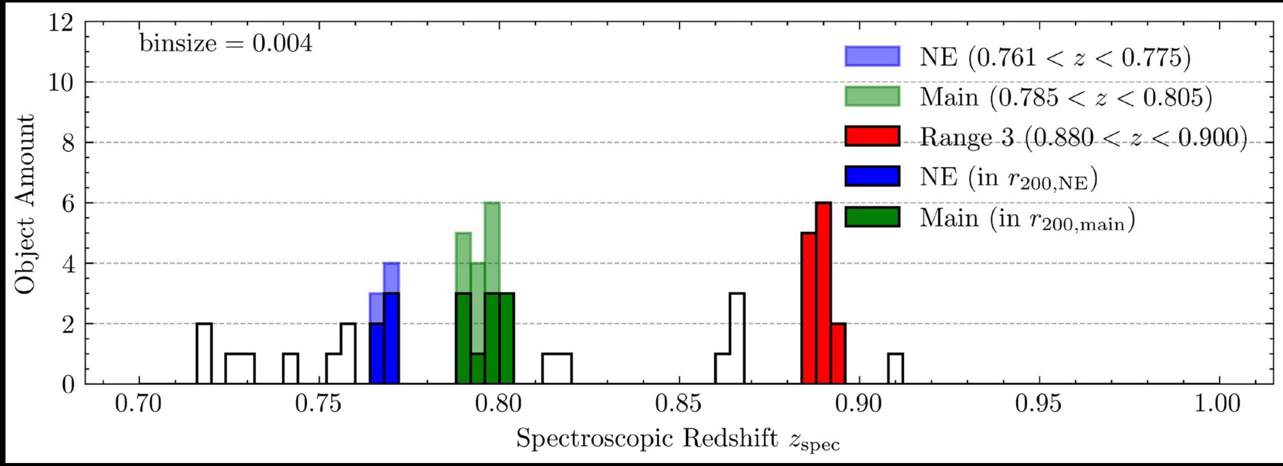
2022

Results

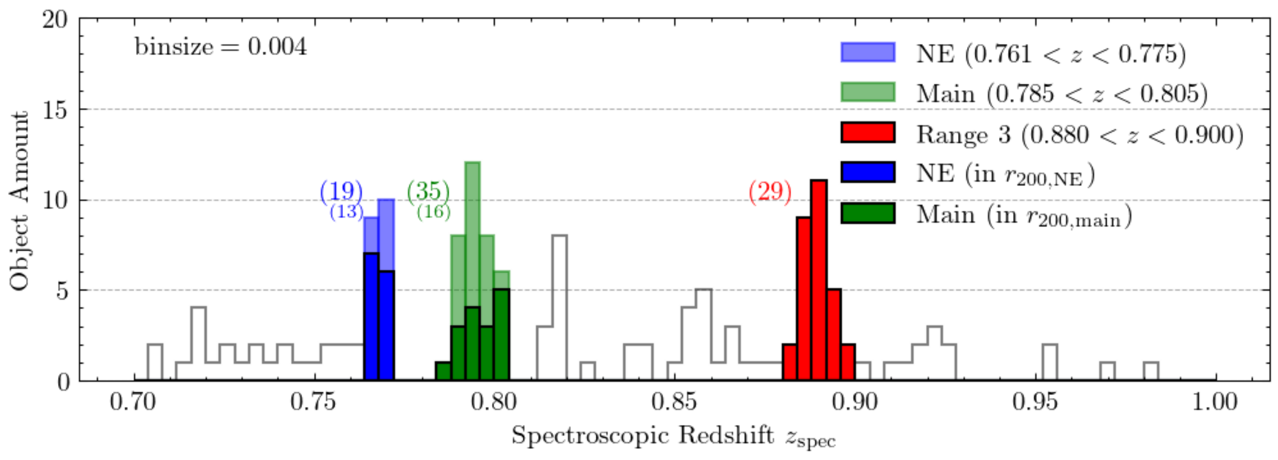
2. The third cluster? (Range 3)

- Possible
- Center location

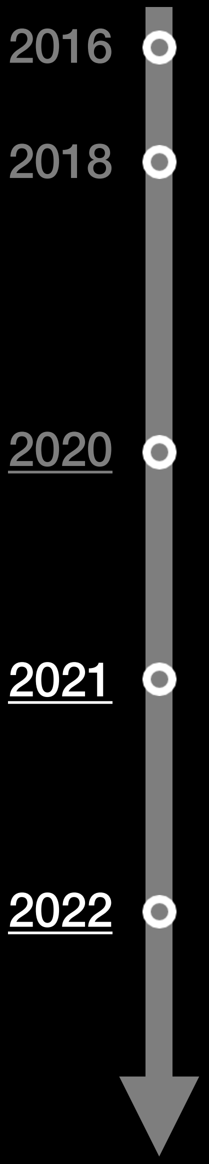




July 2019



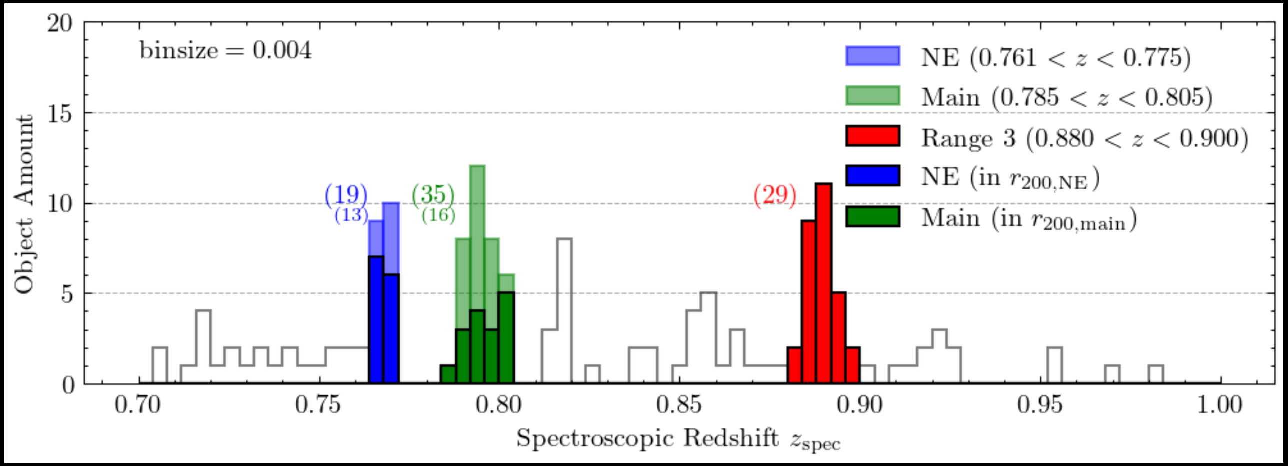
January 2022 + July 2019



Results

2. The third cluster? (Range 3)

- Possible
- Center location?



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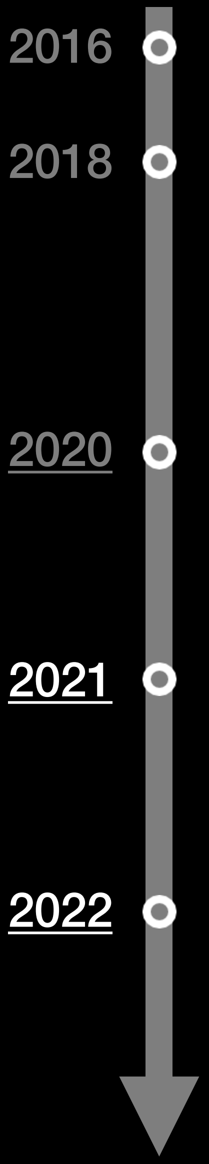


Big Question 1

How many cluster(s) of galaxies are located near EoH GL system?

Answer

2 clusters: NE and main.

Results

2016
2018
2020
2021
2022

3. Masses

Virial

Use Virial Theorem to describe the random motion of galaxies in cluster

Statistical

The relationship between the redshifts and masses of galaxy clusters at similar redshifts

Hydrostatic

Derived from high energy hot plasma (at energy kT and resulting mass density) in ICM

Results

Results from this research

3. Masses

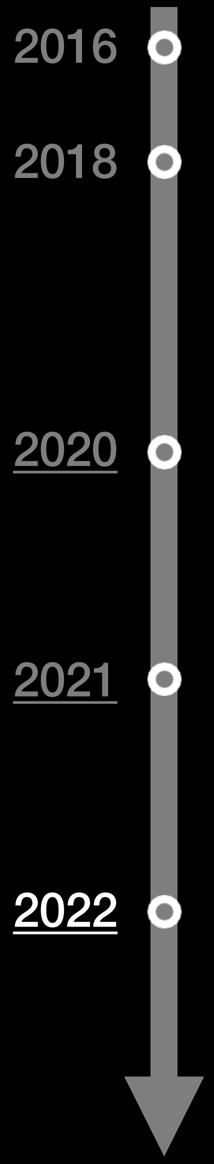
Virial

Statistical

Hydrostatic

Results

	σ (km/s)	Girardi (10^{14} M$_\odot$)	Tran (10^{14} M$_\odot$)	Within r_{200}	r_{200} (″)	σ_{200} (km/s)	Sifon (10^{14} M$_\odot$)	X-ray (10^{14} M$_\odot$)
July 2019								
NE (7)	366.1	**3.49** (918%)	**6.02** (1584%)	NE (5)	127	326.0	**0.38** (100%)	2.2 (319%)
Main (18)	687.4	**10.98** (218%)	**23.53** (468%)	Main (10)	168	837.9	**5.03** (100%)	5.6 (106%)
January 2022 + July 2019								
NE (19)	422.9	**4.03** (584%)	**6.71** (972%)	NE (13)	127	407.1	**0.69** (100%)	2.2 (319%)
Main (35)	683.6	**14.71** (279%)	**32.39** (613%)	Main (16)	168	852.7	**5.28** (100%)	5.6 (106%)



Results

3. Masses

Results from this research

Virial | Statistical | Hydrostatic

Results

	σ (km/s)	Girardi (10^{14} M$_\odot$)	Tran (10^{14} M$_\odot$)	Within r_{200}	r_{200} ($''$)	σ_{200} (km/s)	Sifon (10^{14} M$_\odot$)	X-ray (10^{14} M$_\odot$)
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2016
2018
2020
2021
2022

Results

Results from this research

3. Masses

Virial

Statistical

Hydrostatic

Results

	σ (km/s)	Girardi (10^{14} M$_\odot$)	Tran (10^{14} M$_\odot$)	Within r_{200}	r_{200} (″)	σ_{200} (km/s)	Sifon (10^{14} M$_\odot$)	X-ray (10^{14} M$_\odot$)
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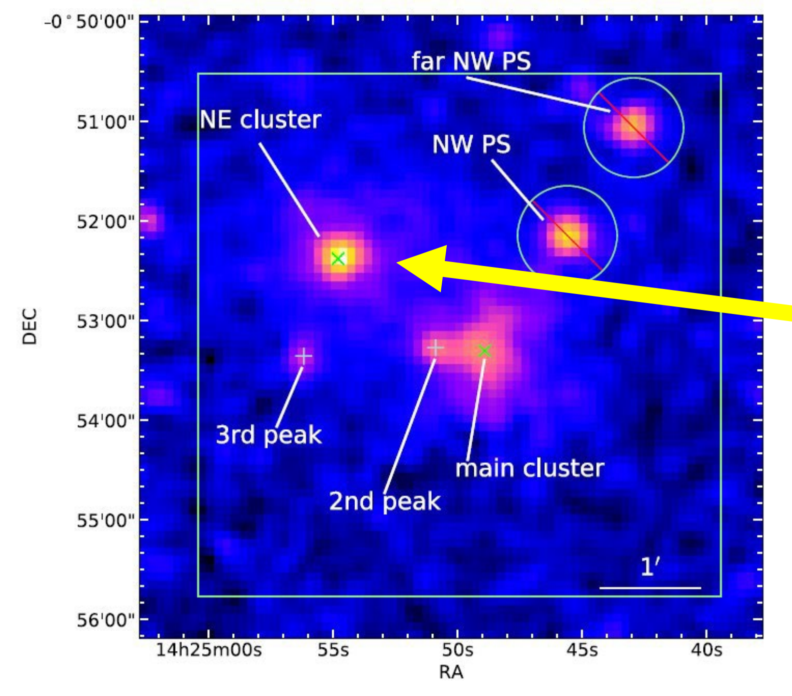
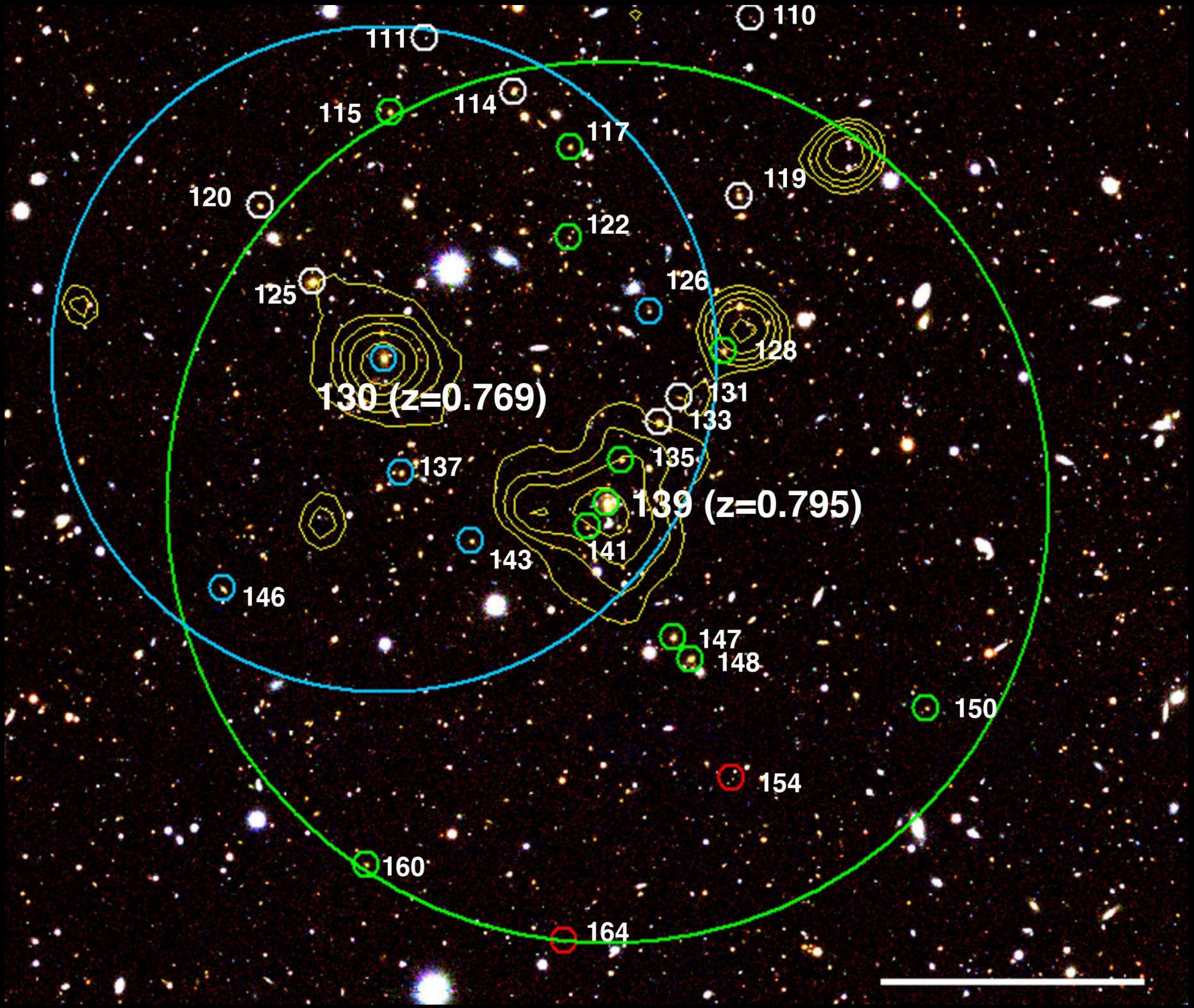
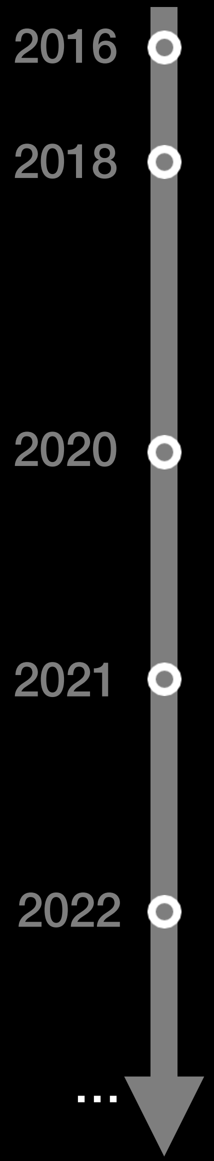


2016
2018
2020
2021
2022

Future goals

- Analysis on masses
- Galaxy spectrum aging
- More on cosmology





MMT/Binospec: z~0.8 Galaxy Cluster Spec Survey