The fine-structure constant with BOSS
&
APOGEE Quasar Survey

Franco D. Albareti

PhD student
under the supervision of

Prof. Francisco Prada and Prof. Antonio L. Maroto

Instituto de Física Teórica UAM/CSIC

28th September 2015

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Acknowledgements

MultiDark
Multimessenger Approach
for Dark Matter Detection

Obra Social
Fundación "la Caixa"

28th September 2015

The fine-structure constant with BOSS & APOGEE Quasar Survey

Franco D. Albareti

Work in collaboration with

Johan Comparat (IFT-UAM/CSIC), **Carlos M. Gutiérrez** (IAC),
Isabelle Pâris (Trieste Obs.), **David Schlegel** (LBNL),
Martín López-Corredoira (IAC), **Donald P. Schneider** (Penn. U),
…

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Introduction

- **Fine structure constant?**

$$\alpha = \frac{e^2}{\hbar c} \approx \frac{1}{137}$$

Strength of coupling between
the electromagnetic field/vector bosons and matter.

Fundamental constant of Nature

Does it change with cosmic time?

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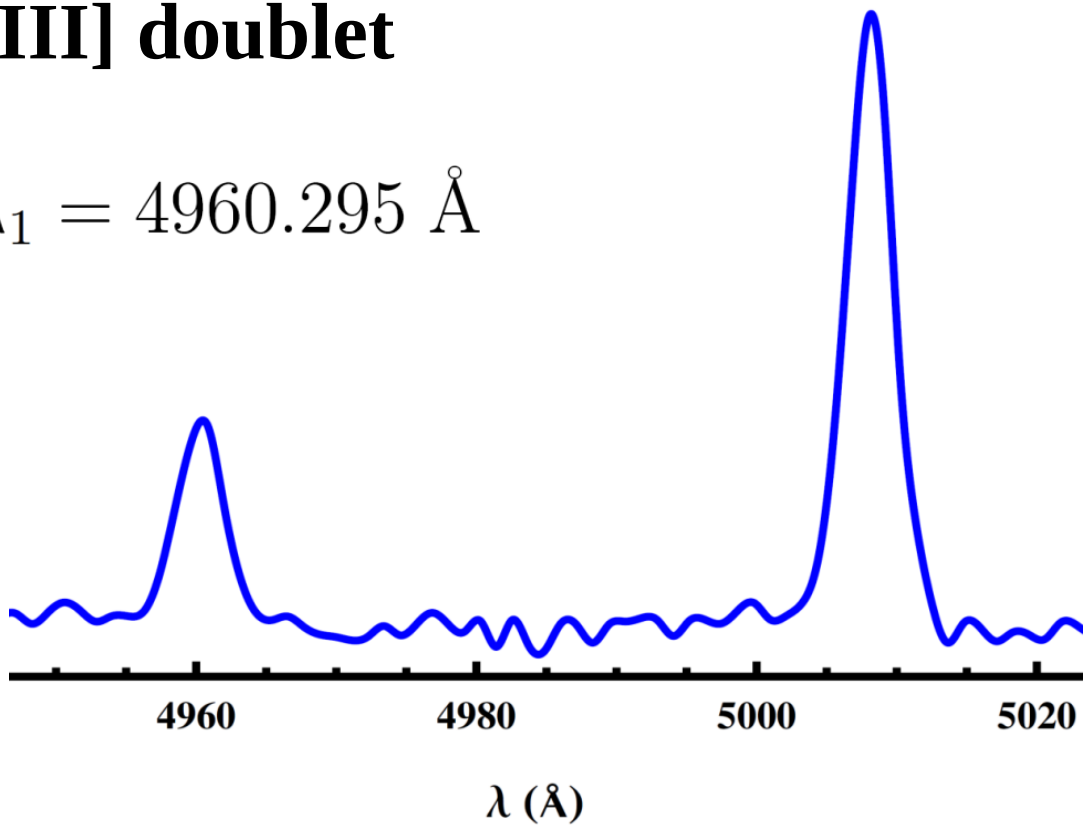
Introduction

- **How?**

[OIII] doublet

$\lambda_2 = 5008.240$ Å

$\lambda_1 = 4960.295$ Å



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Introduction

- **How?**

[OIII] doublet

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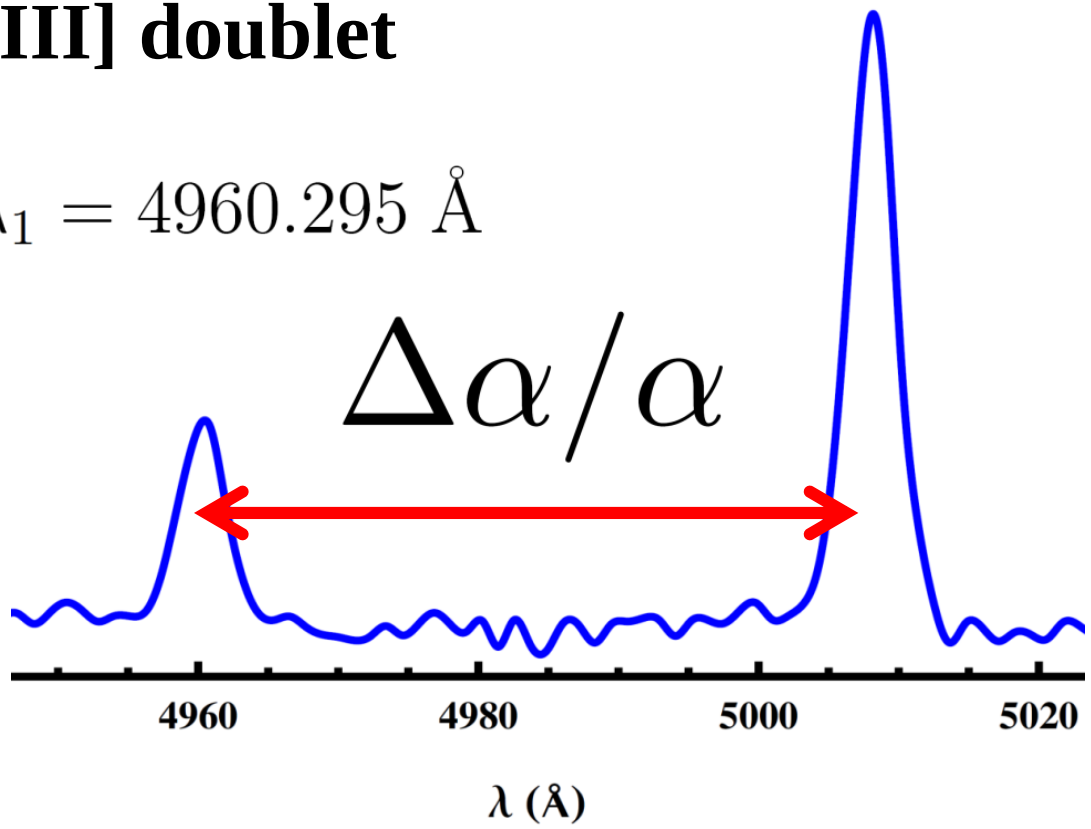

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Introduction

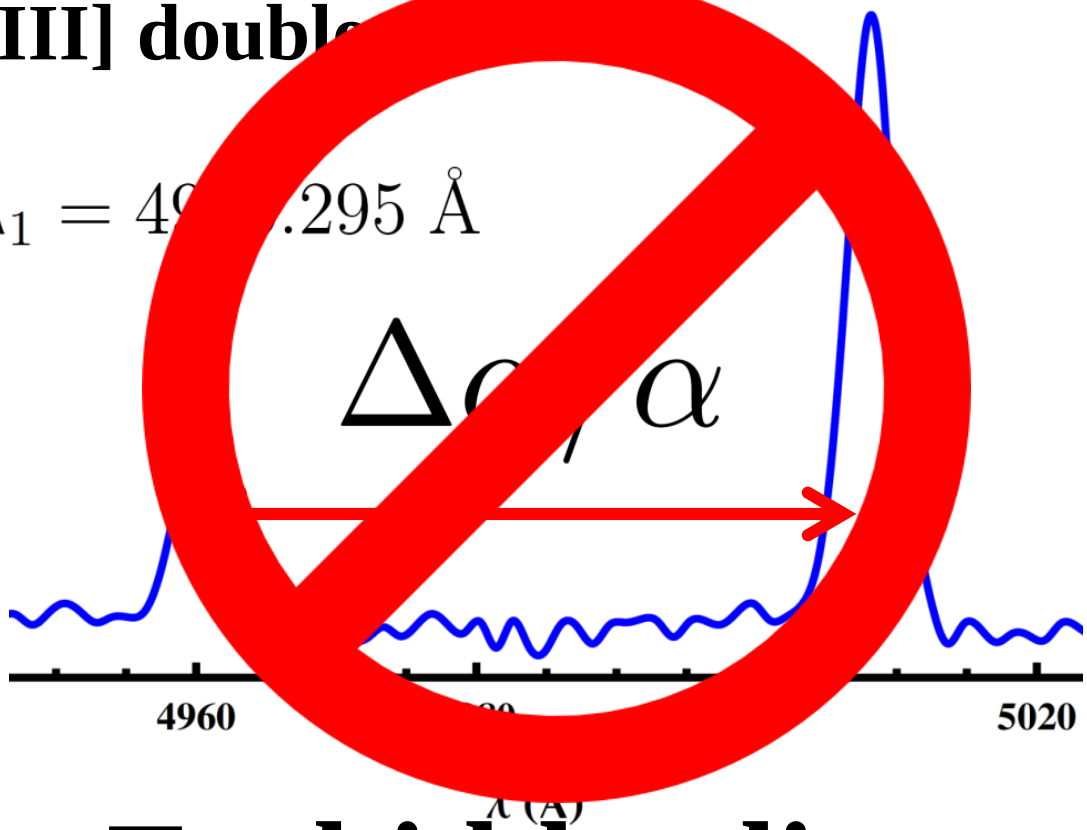
- **How?**

[OIII] doubl

$\lambda_2 = 5008.240$ Å

$\lambda_1 = 4$ .295 Å

$\Delta\alpha/\alpha$



Forbidden lines

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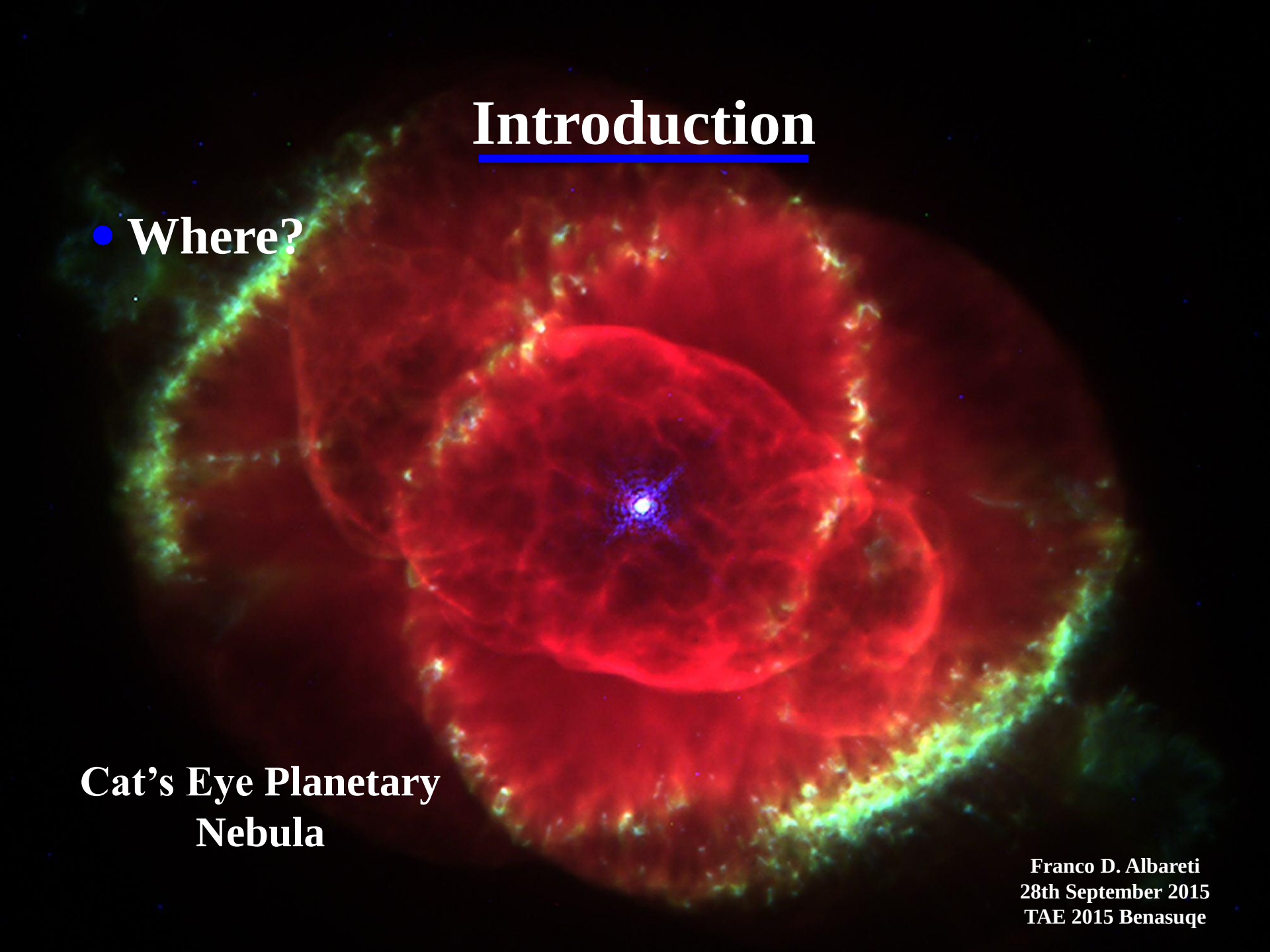
Introduction

- **Where?**

Introduction

- Where?



Cat's Eye Planetary Nebula

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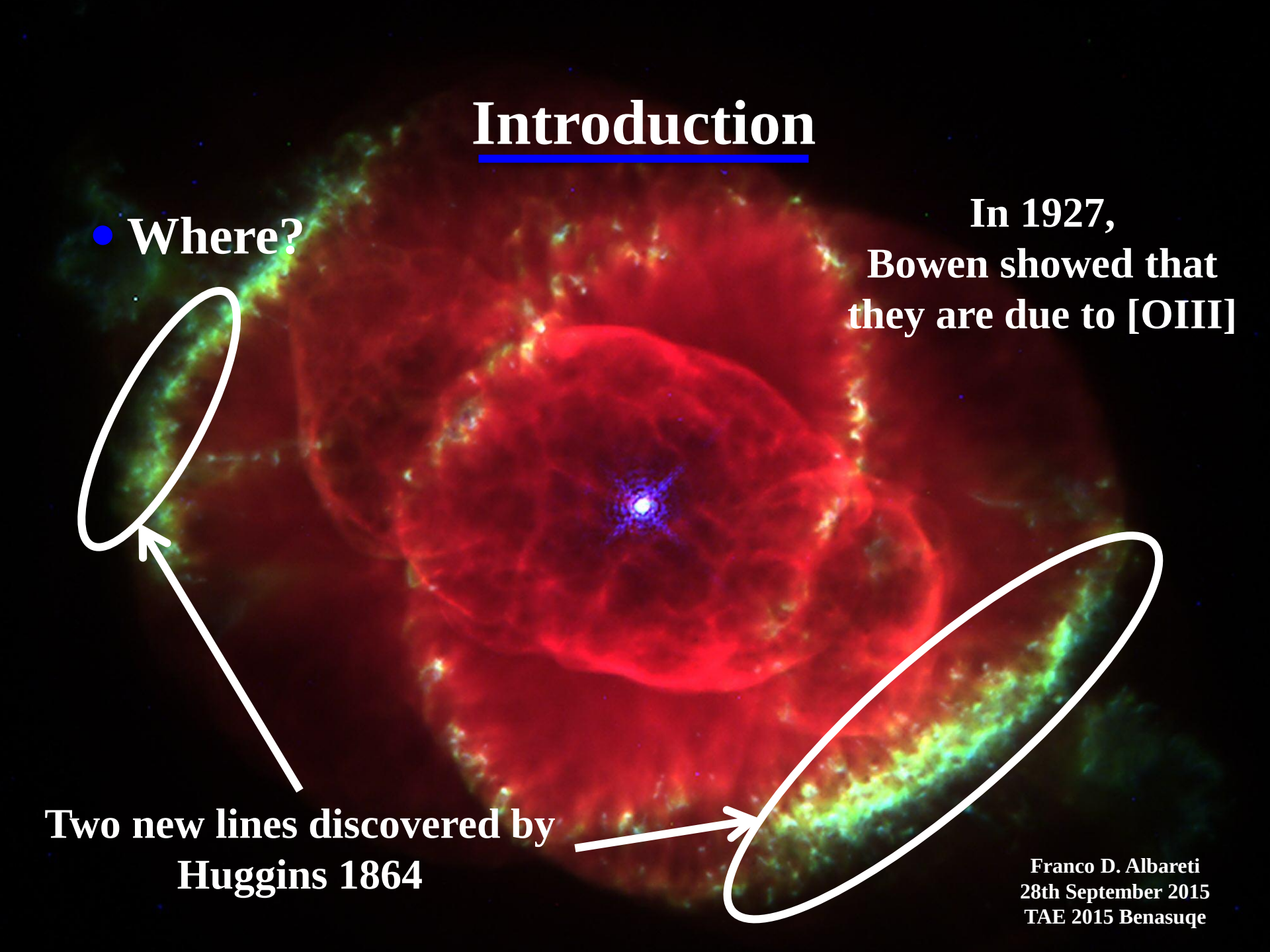
Introduction

- Where?

In 1927,
Bowen showed that
they are due to [OIII]



Two new lines discovered by
Huggins 1864

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Introduction

- **Where?**

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Introduction

- **Where?**

[OIII] on quasar spectra

Cosmological probes

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Introduction

- **Where?**

We need lots of them!

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Introduction

Current constraints based on the [OIII] doublet method

Reference	# QSO spectra	$\Delta\alpha/\alpha$ $(\times 10^{-5})$
Bahcall et al. (2004)	42	7 ± 14
Gutiérrez & López-Corredoira (2010)	1,568	2.4 ± 2.5
Rahmani et al. (2014)	2,347	-2.1 ± 1.6

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Sloan Digital Sky Survey

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Outline

- **Introduction** ✓
- **Methodology**
- **Sample selection**
- **Results**
- **APOGEE-Q**

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Outline

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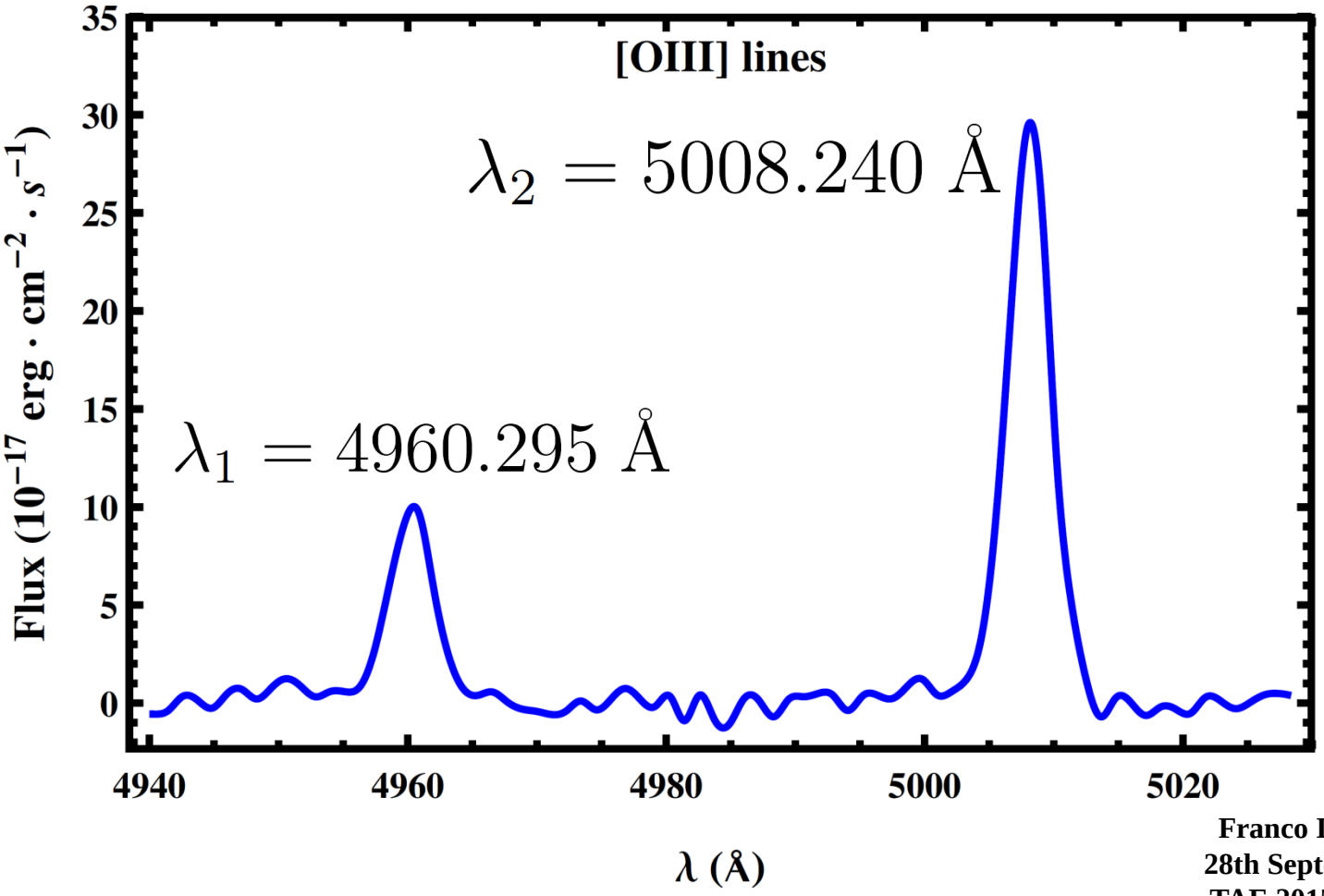
Methodology

Measurement method



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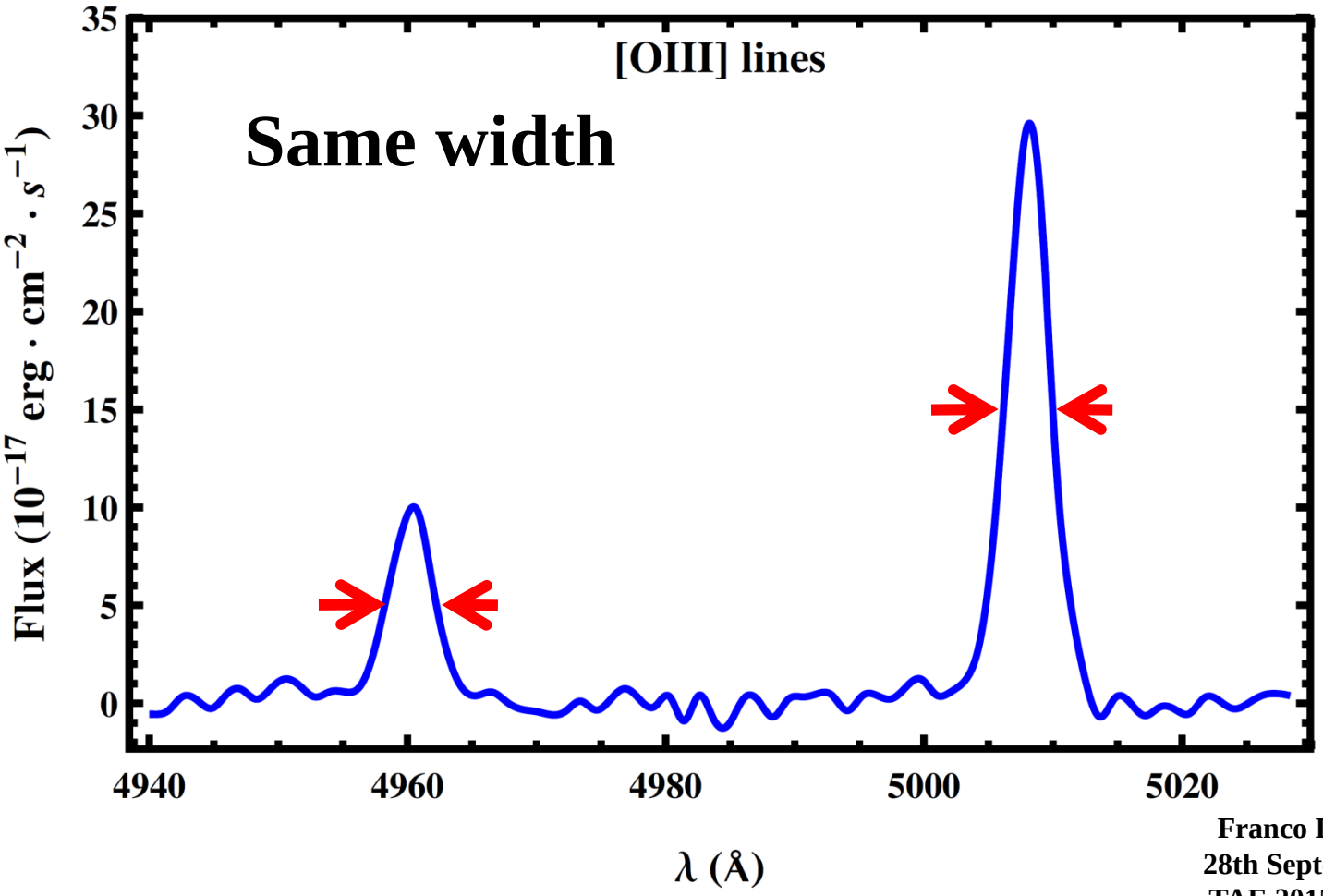
Methodology

Measurement method



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Methodology

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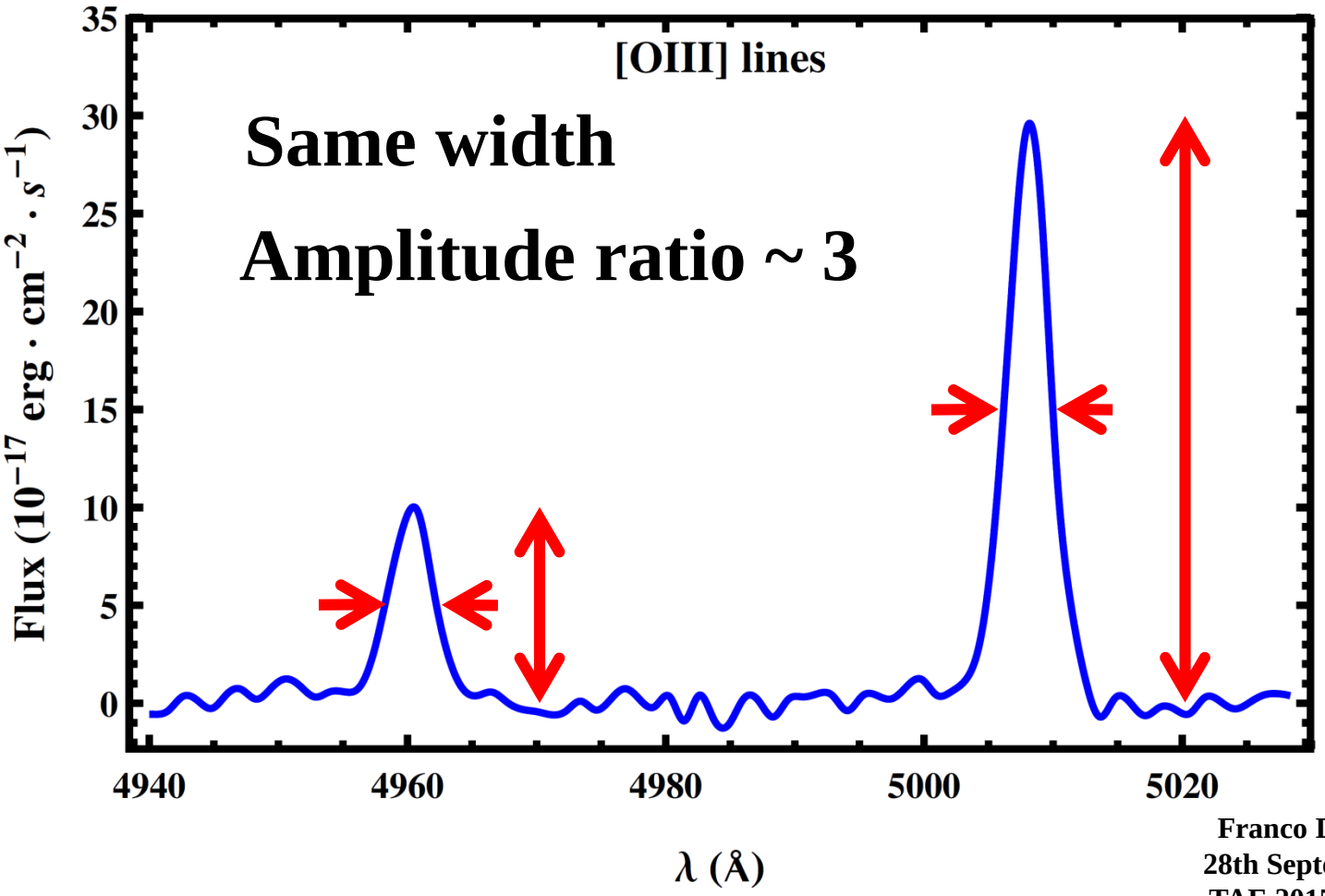

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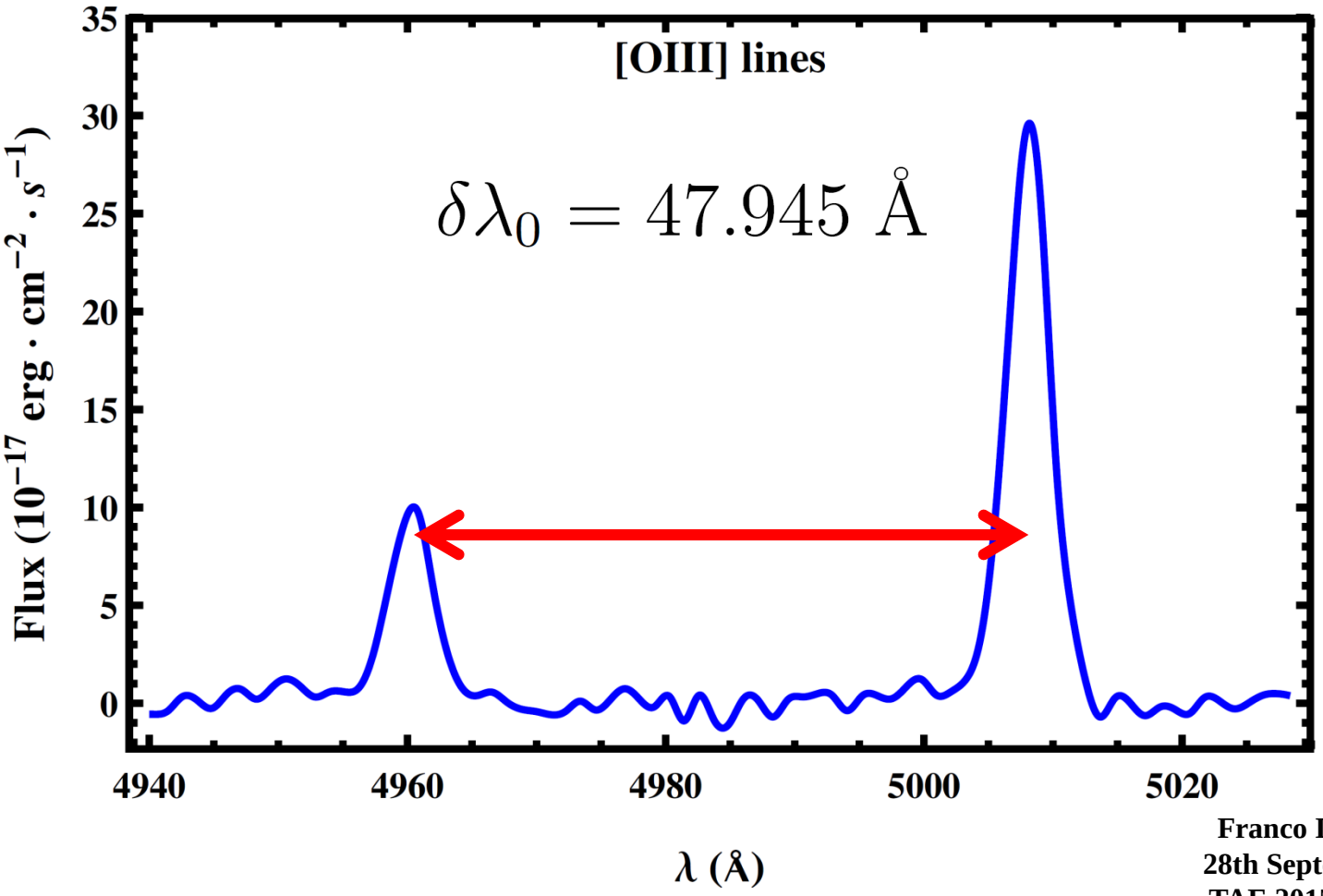

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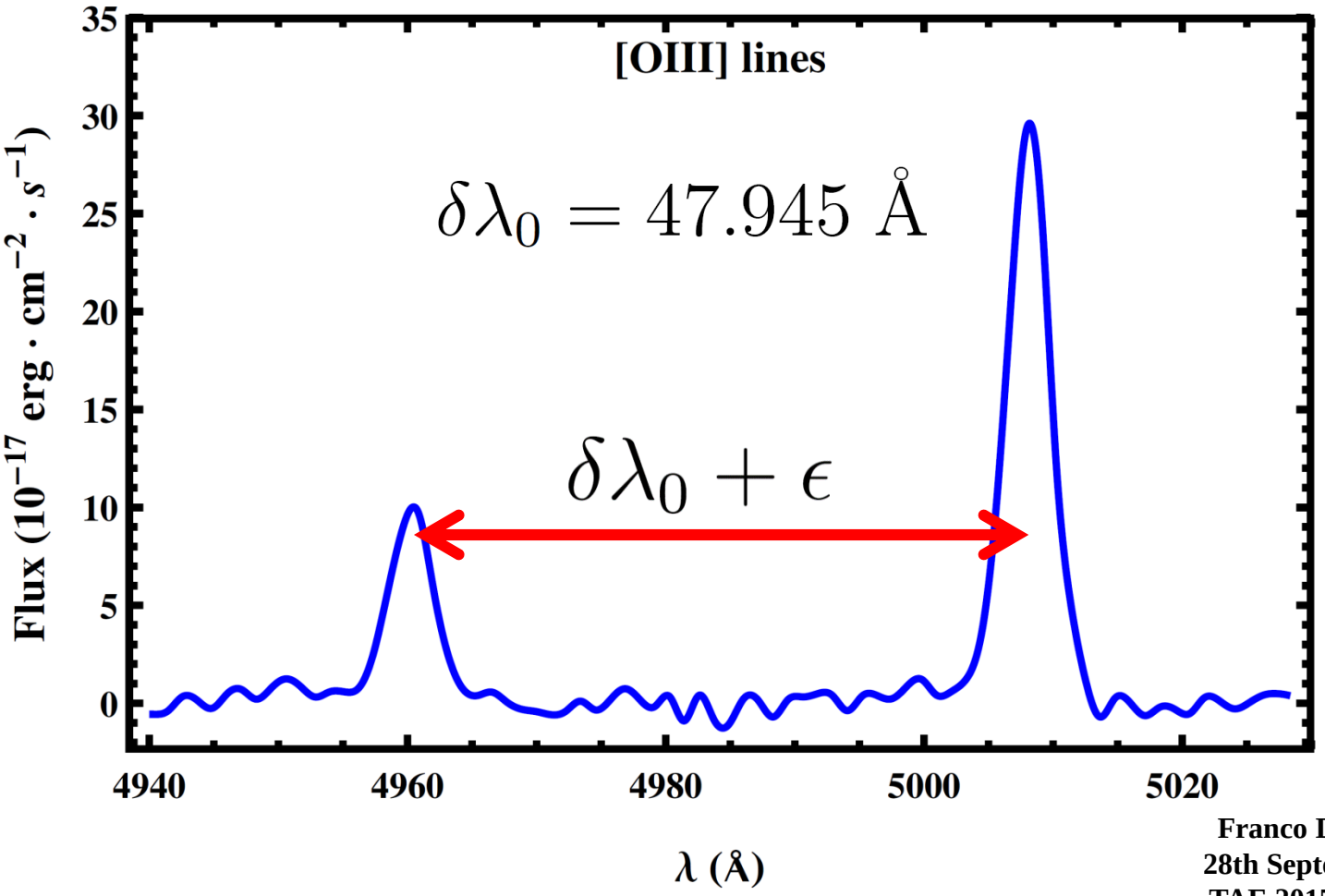
Methodology

Measurement method



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Methodology

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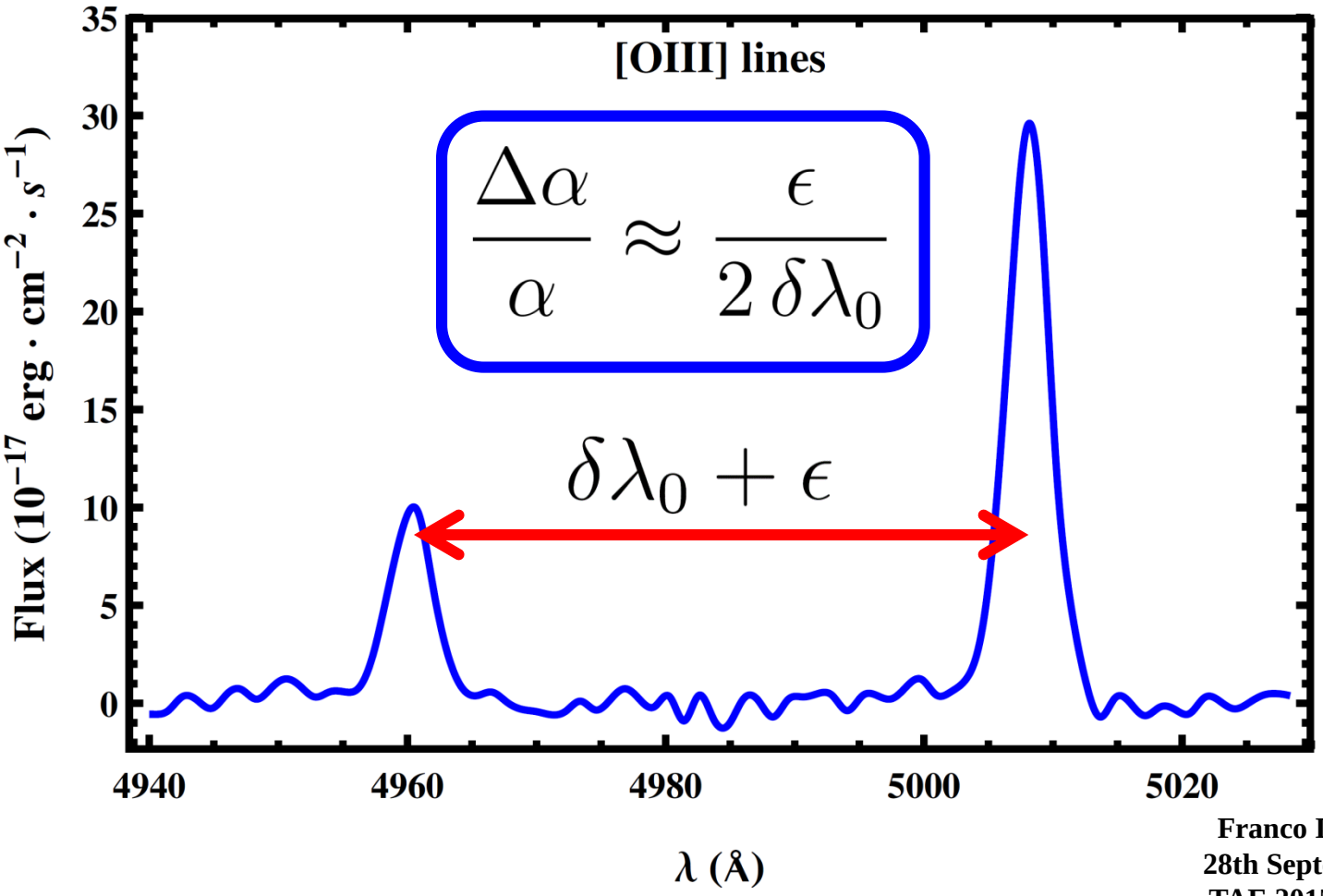

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Methodology

Measurement method

$$\frac{\Delta\alpha}{\alpha} \approx \frac{\epsilon}{2\,\delta\lambda_0}$$

Redshift independent

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Methodology

Measurement method

$$\frac{\Delta\alpha}{\alpha} \approx \frac{\epsilon}{2\,\delta\lambda_0}$$

Redshift independent

[OIII] doublet

$$\delta\lambda_0 = 47.945\ \text{Å} \longrightarrow \epsilon \approx 1\,\text{Å} \Rightarrow \frac{\Delta\alpha}{\alpha} \approx 10^{-2}$$

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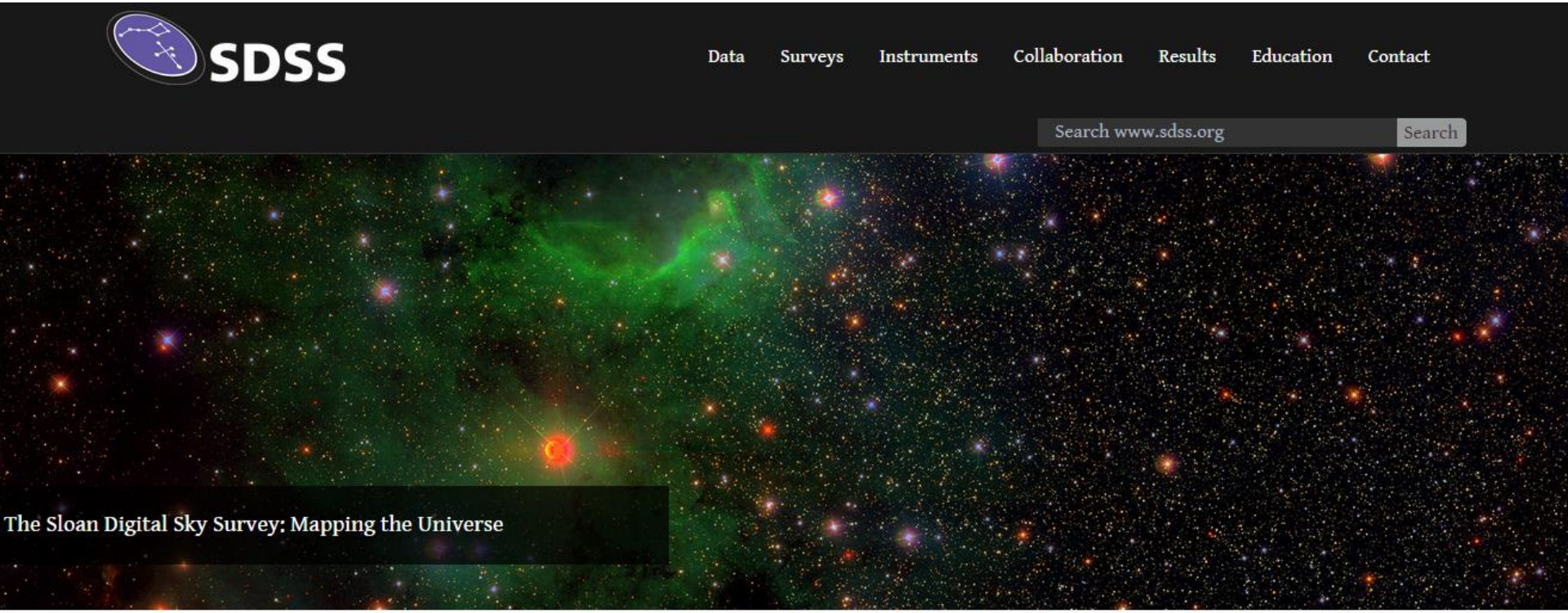
Sample selection

sdss.org

Sloan Digital Sky Survey



The Sloan Digital Sky Survey has created the most detailed three-dimensional maps of the Universe ever made, with deep multi-color images of one third of the sky, and spectra for more than three million astronomical objects. Learn and explore all phases and surveys—past, present, and future—of the SDSS.

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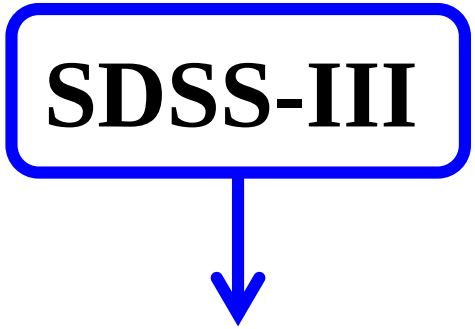
Sample selection



4 surveys

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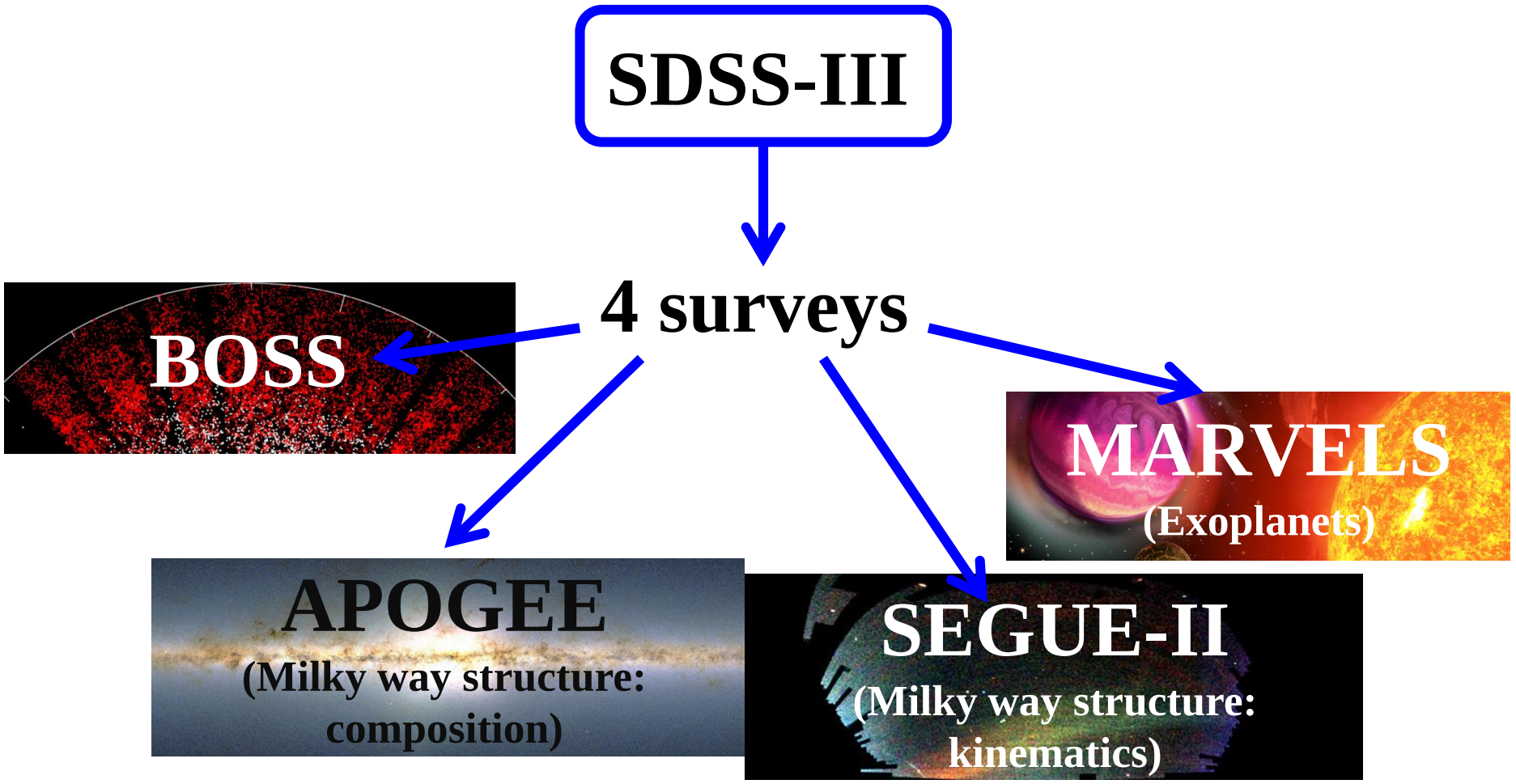
Sample selection



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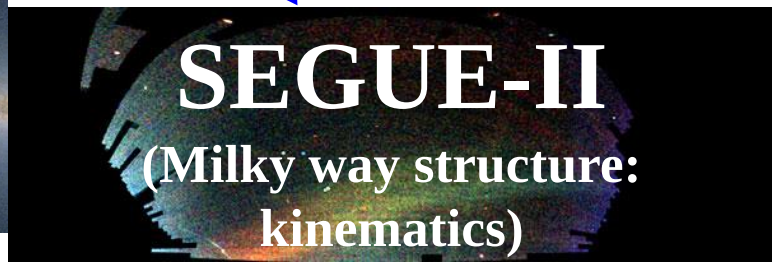
Sample selection

SDSS-III

Explore our neighborhood



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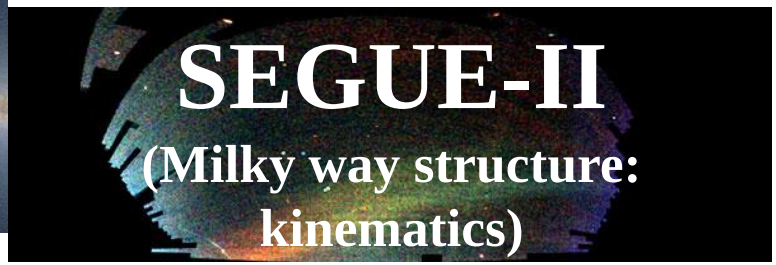
Sample selection

SDSS-III

Cosmological (really far away)



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Sample selection

SDSS-III

Baryonic Oscillation Spectroscopic Survey

BOSS spectrograph → **R ~ 2000**

Luminous Red Galaxies (LRGs)
&
Quasars

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Sample selection

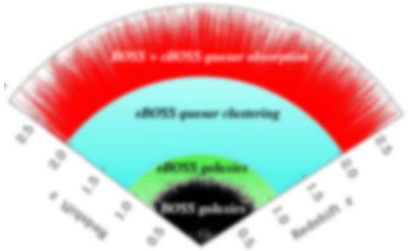
SDSS-III

Baryonic Oscillation Spectroscopic Survey

BOSS spectrograph → **R ~ 2000**

Luminous Red Galaxies (LRGs)
&
Quasars

SDSS-IV/eBOSS
(still further away)



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Sample selection

SDSS-III

Baryonic Oscillation Spectroscopic Survey

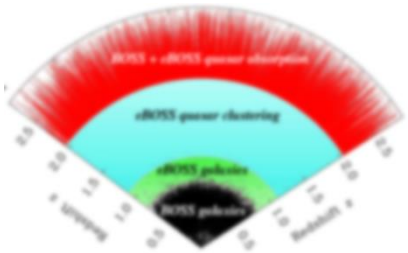
BOSS spectrograph → R ~ 2000

Luminous Red Galaxies (LRGs)

&

Quasars → ~300,000

SDSS-IV/eBOSS
(still further away)



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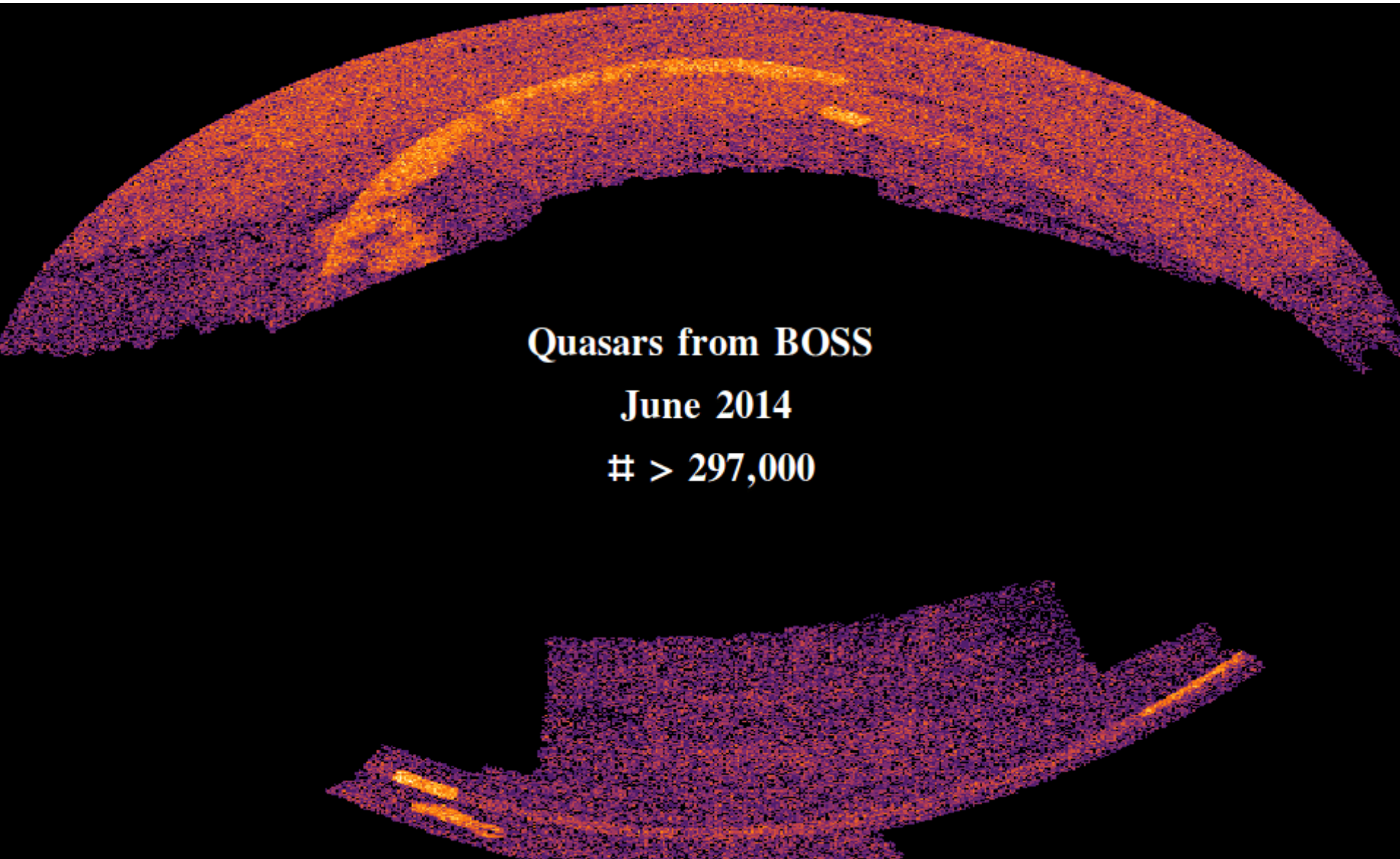
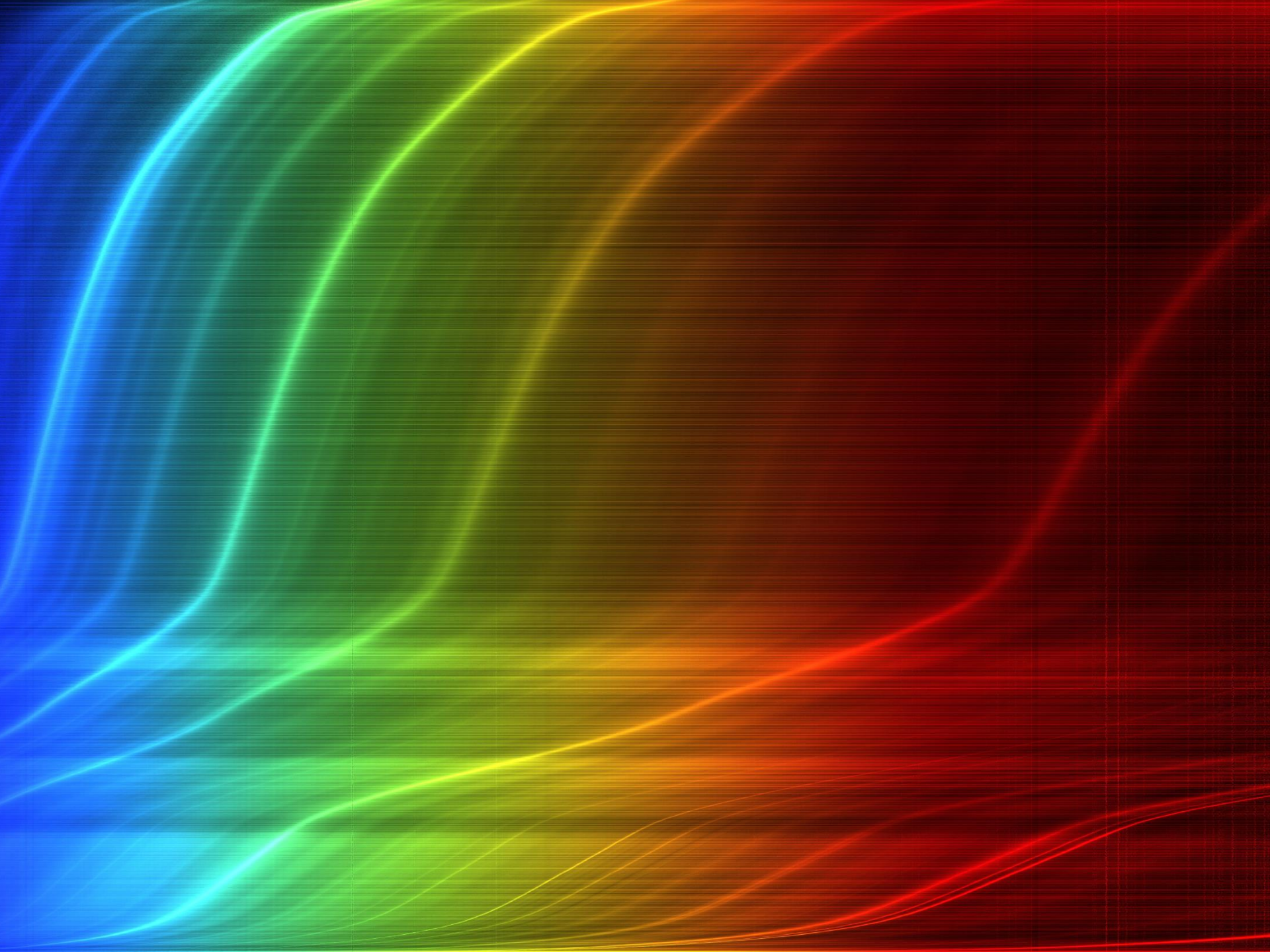
Sample selection





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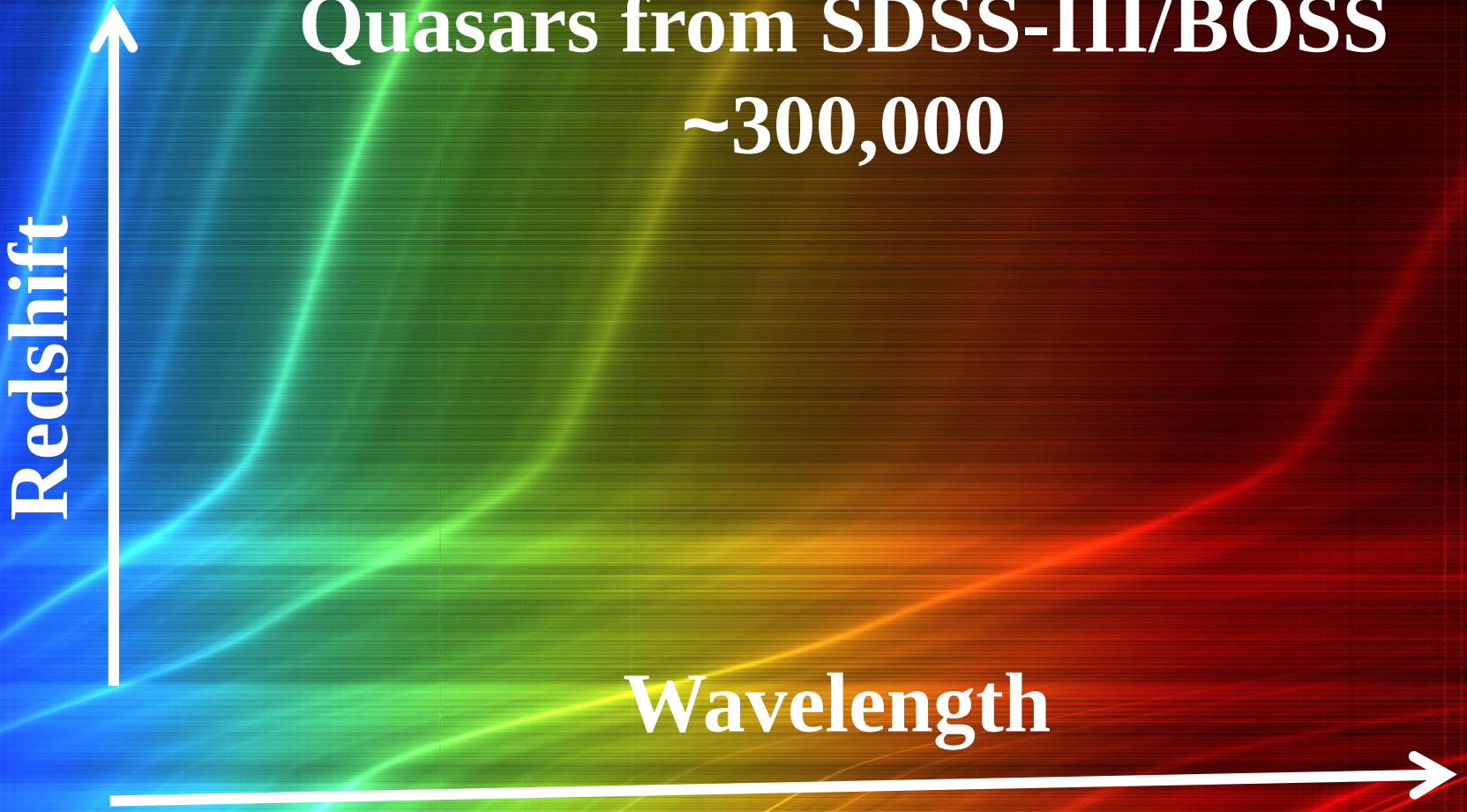
Sample selection

Quasars from SDSS-III/BOSS
~300,000



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Sample selection

Quasars from SDSS-III/BOSS
~300,000

Lyα

CIV

CIII]

MgII

Hβ

Hα

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Sample selection

Quasars from SDSS-III/BOSS
~300,000

[OIII] 4960 5008 A

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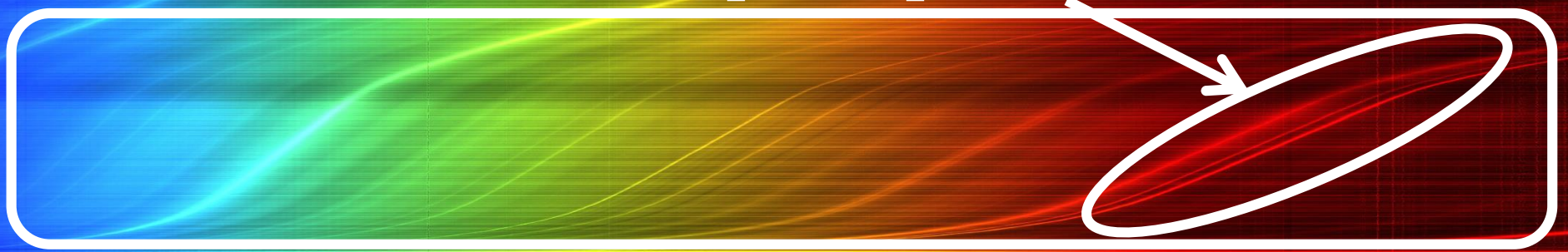
Sample selection

Quasars from SDSS-III/BOSS
~300,000

z < 1

[OIII] 4960 5008 A



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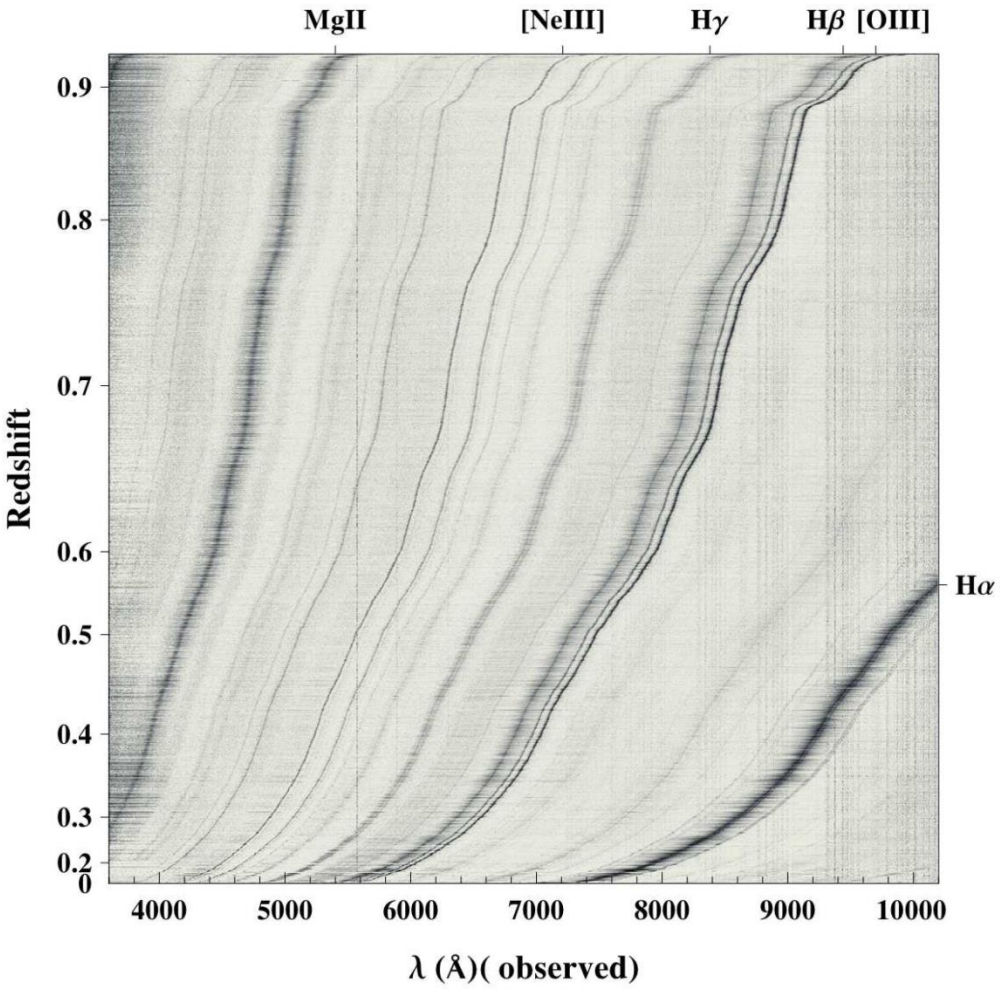
Sample selection

Quasars up to z = 1; >10,000 (clean)



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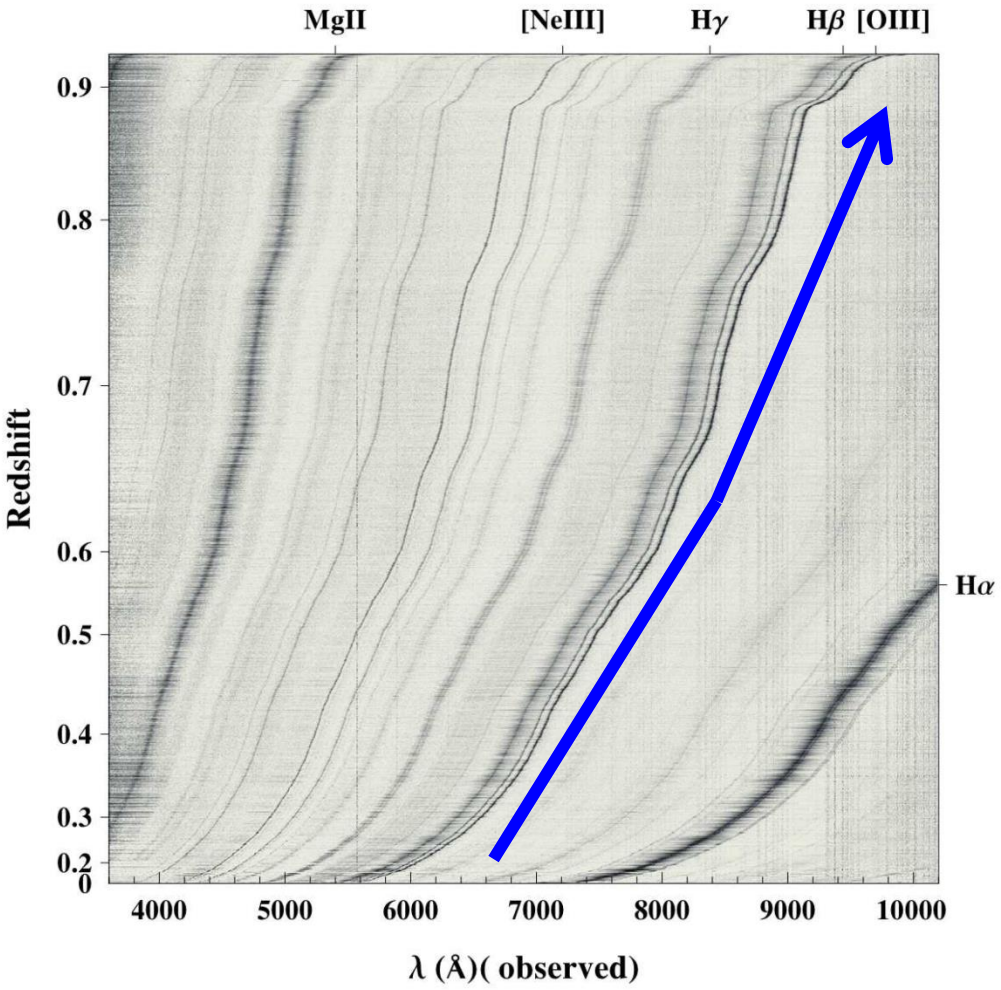

- S/N [OIII] > 10
- Converging Gaussian fits
- Outliers > 4σ

Aceptance rate ~ 1/4

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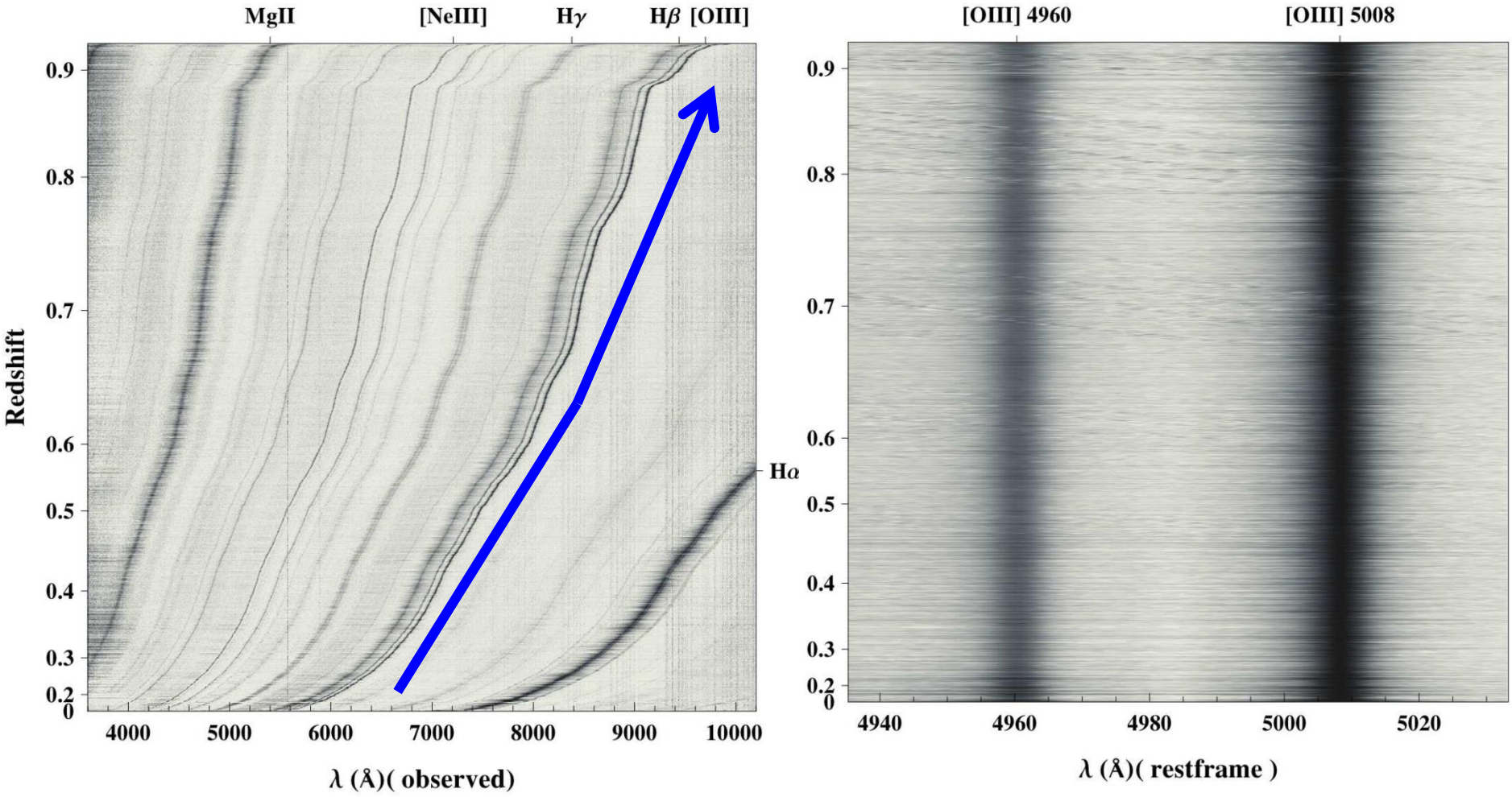

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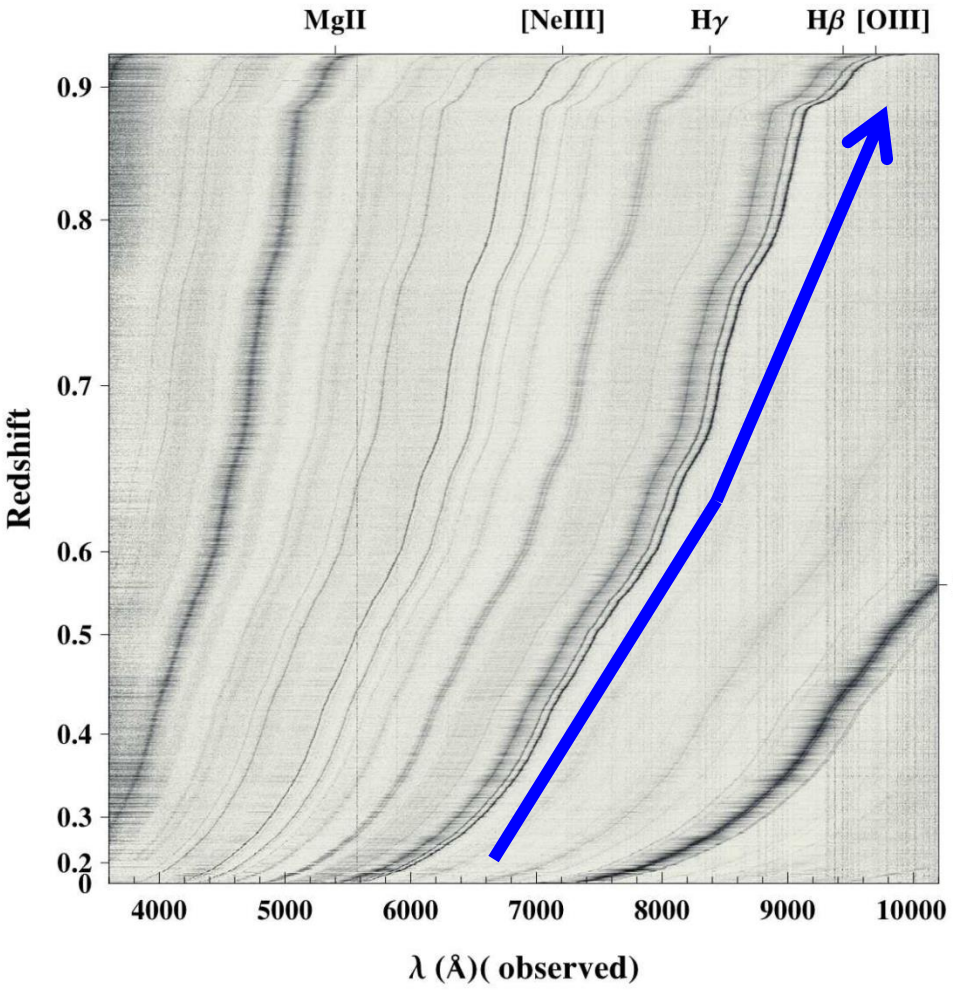

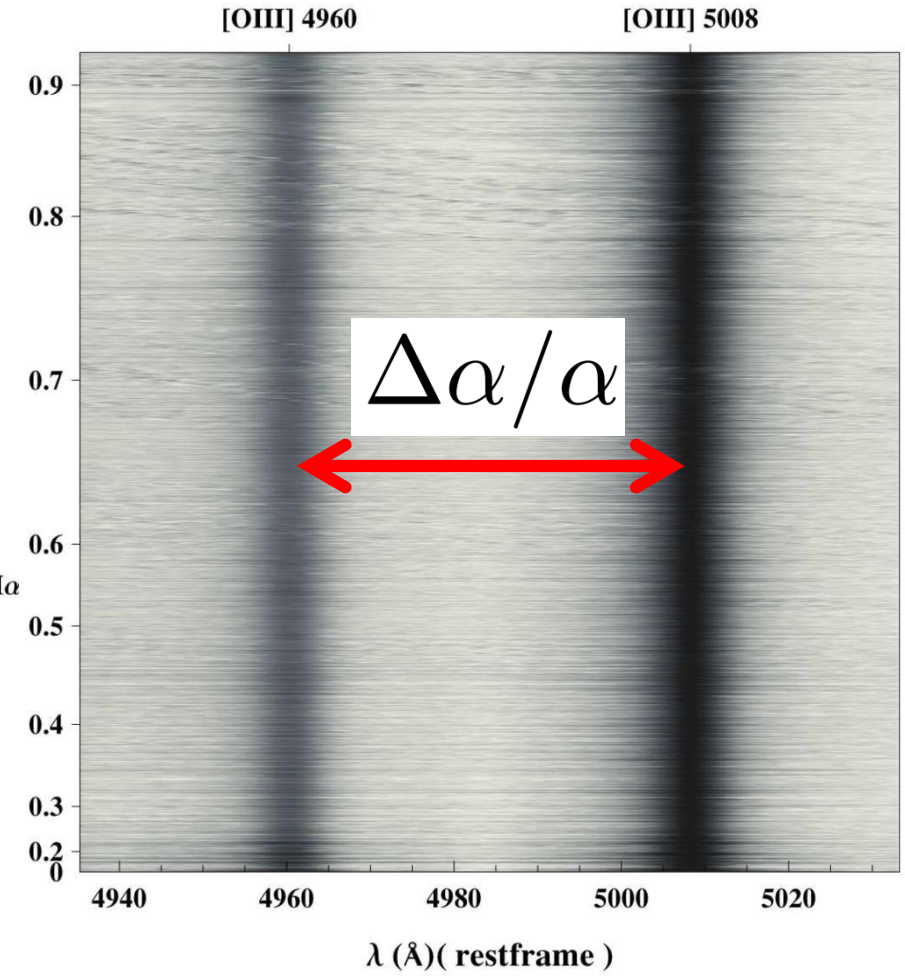

Outline

- Introduction ✓
- Methodology ✓
- **Sample selection** ✓
- Results
- APOGEE-Q

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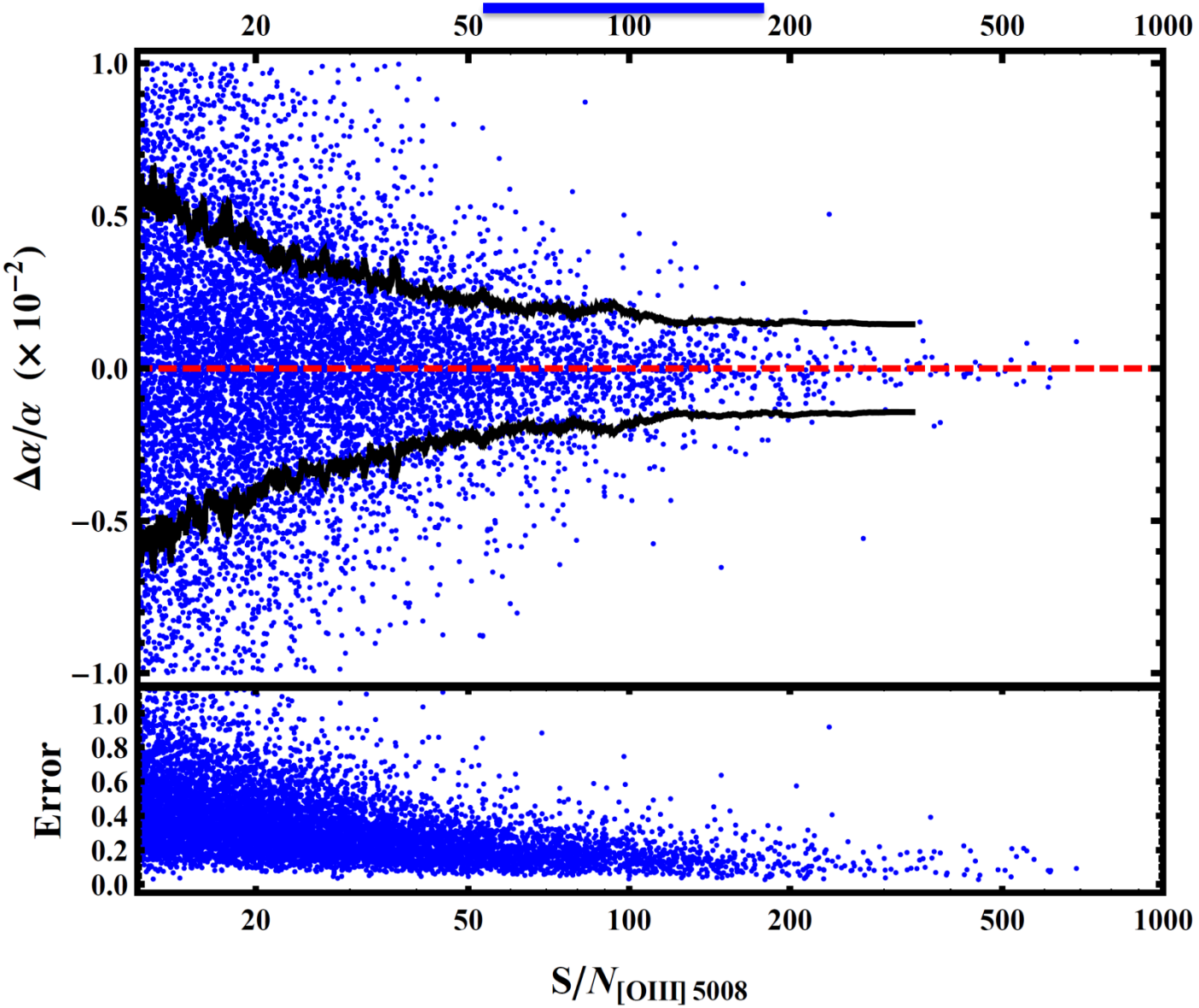
Results



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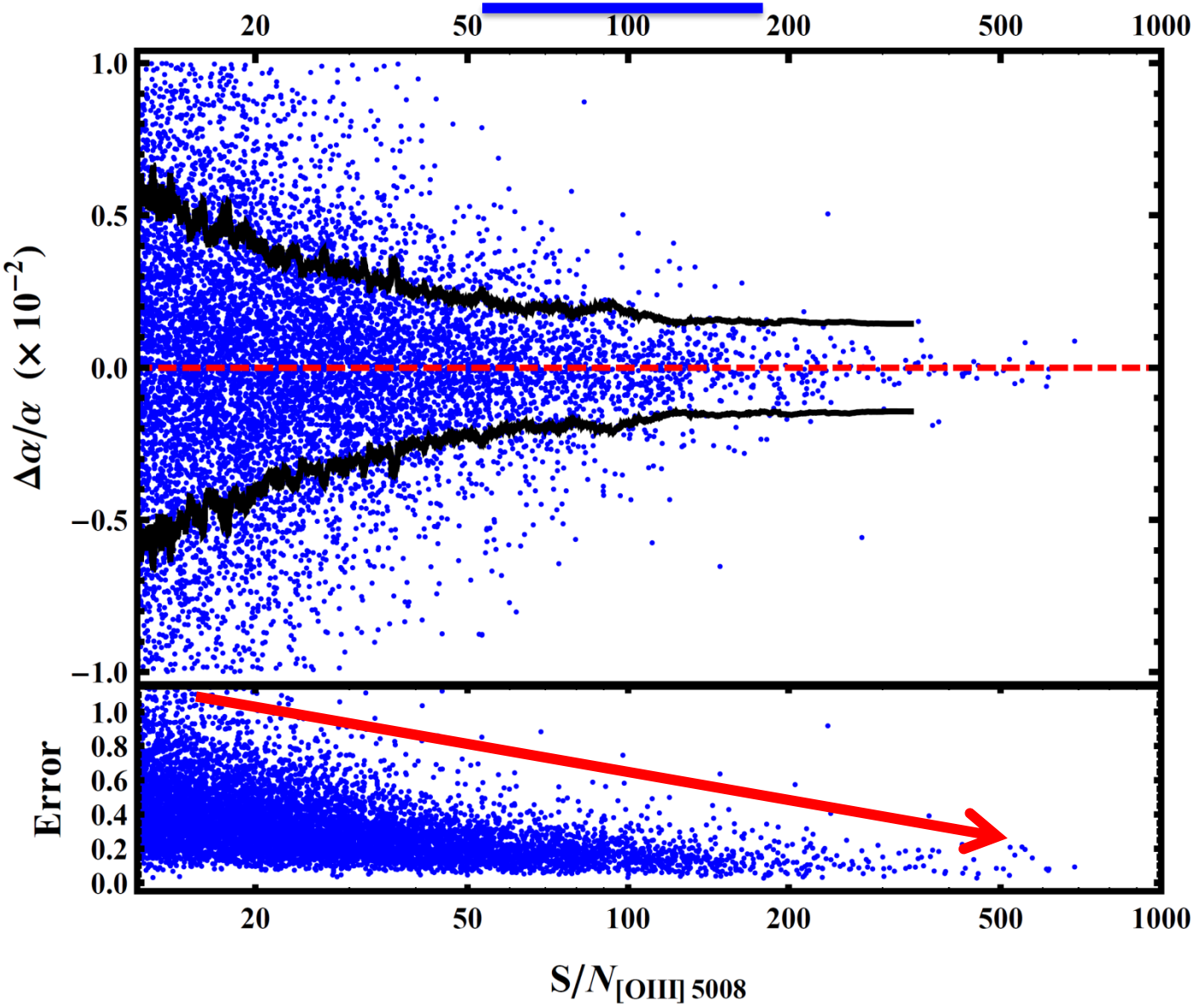
Results



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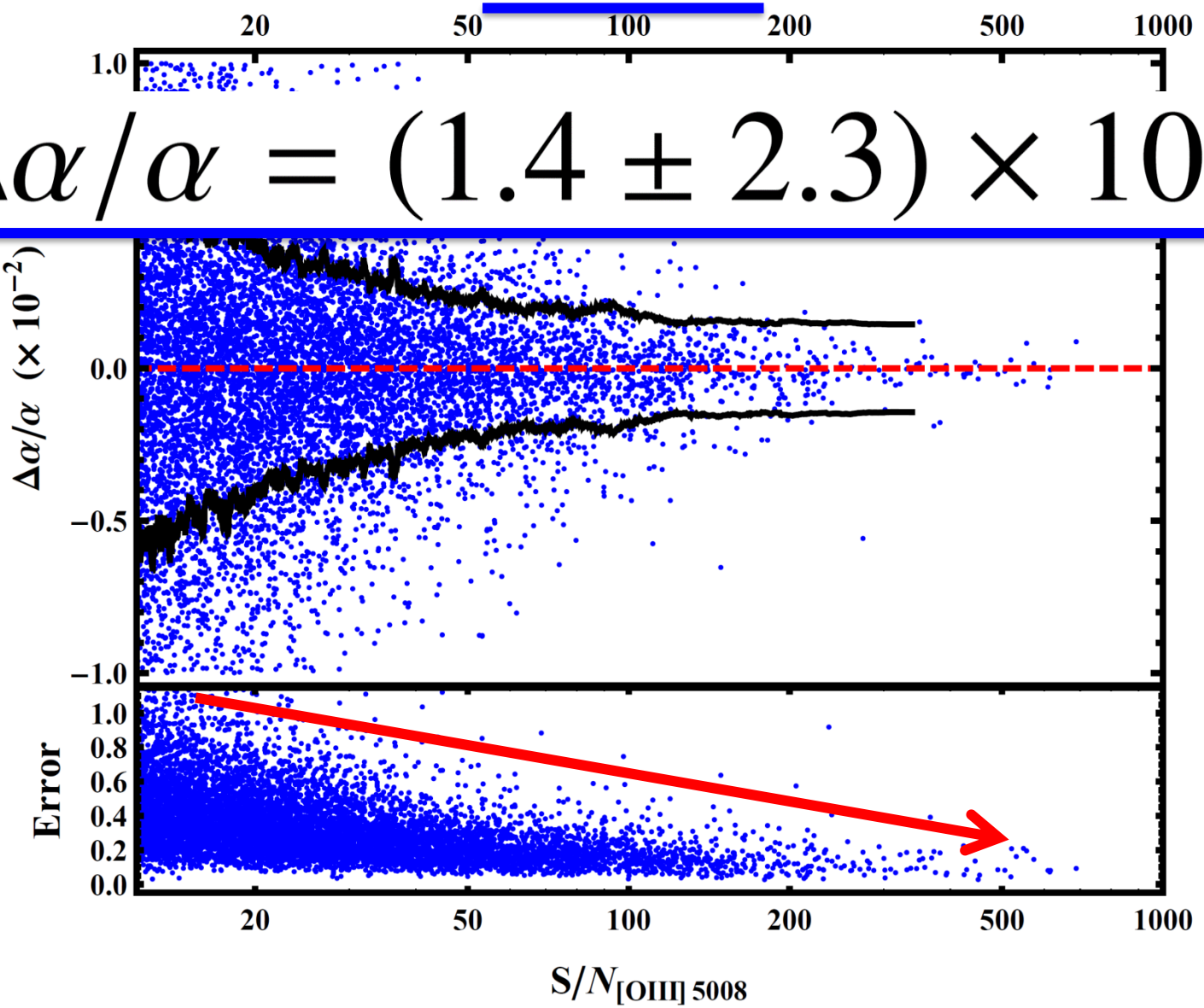
Results

$$\Delta\alpha/\alpha = (1.4 \pm 2.3) \times 10^{-5}$$



Results

Systematics?

$$\Delta\alpha/\alpha = (1.4 \pm 2.3) \times 10^{-5}$$

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Results

Systematics?

$$\Delta\alpha/\alpha = (1.4 \pm 2.3) \times 10^{-5}$$

- **Misidentification of the lines OK**
- **Interval for the Gaussian fits OK**
- **Hβ contamination OK**
- **Continuum subtraction OK**
- **Different fitting methods OK**

Results

$$\Delta\alpha/\alpha = (1.4 \pm 2.3) \times 10^{-5}$$

Spatial variation

Hemisphere	# QSO spectra	redshift	$\Delta\alpha/\alpha$ ($\times 10^{-5}$)
North	8,069	0.56 ± 0.21	2.6 ± 2.6
South	2,294	0.59 ± 0.20	-3.1 ± 4.9

Results

$$\Delta\alpha/\alpha = (1.4 \pm 2.3) \times 10^{-5}$$

Spatial variation

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South	2,294	0.59 ± 0.20	-3.1 ± 4.9

OK

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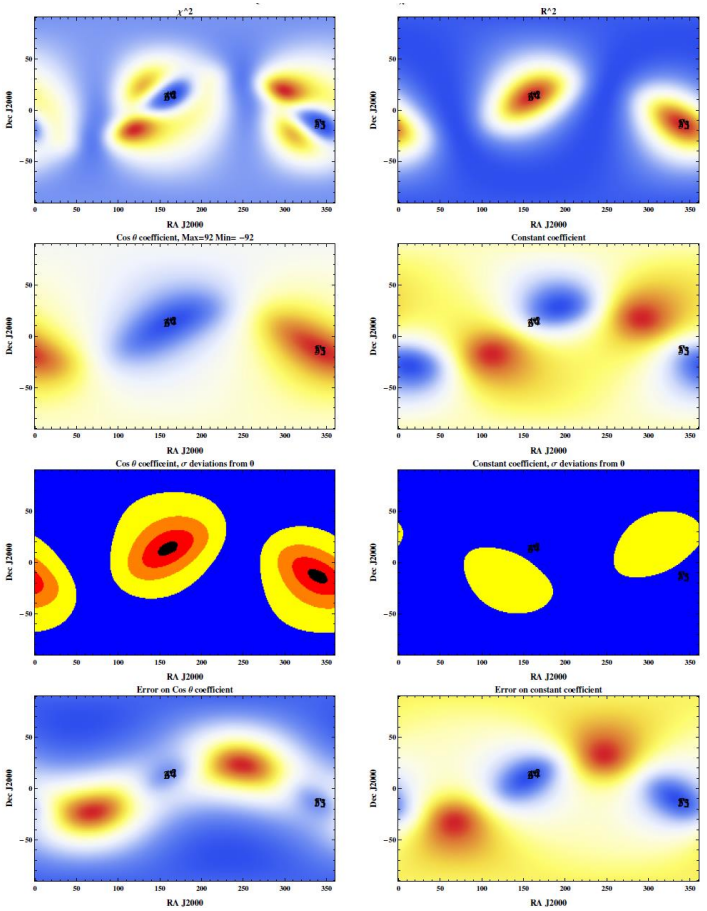
Results

$$\Delta\alpha/\alpha = (1.4 \pm 2.3) \times 10^{-5}$$

Spatial variation

Dipole?



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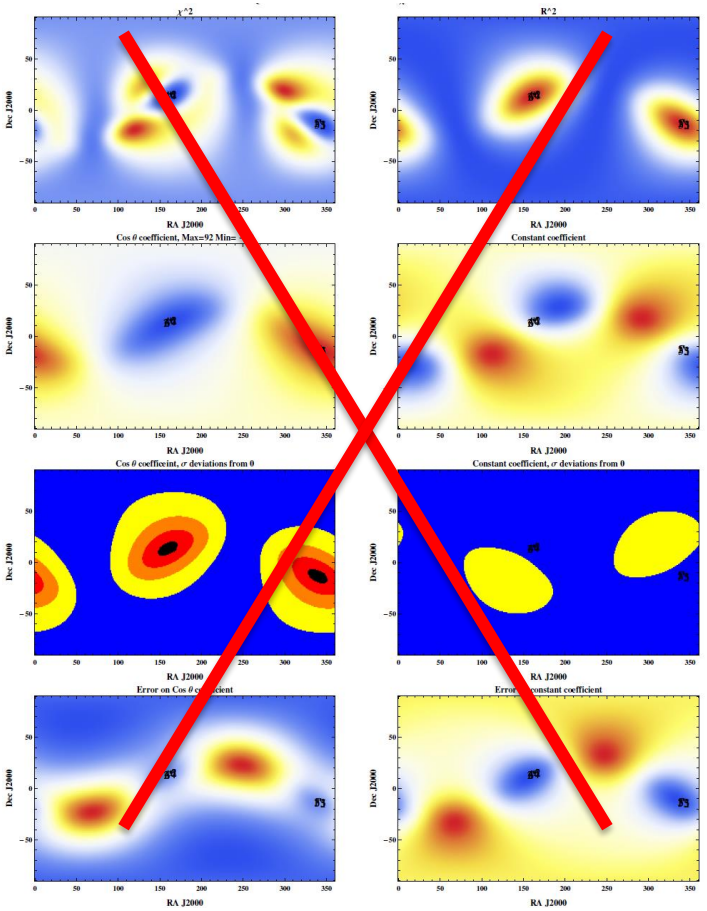
Results

$$\Delta\alpha/\alpha = (1.4 \pm 2.3) \times 10^{-5}$$

Spatial variation

No statistical significance



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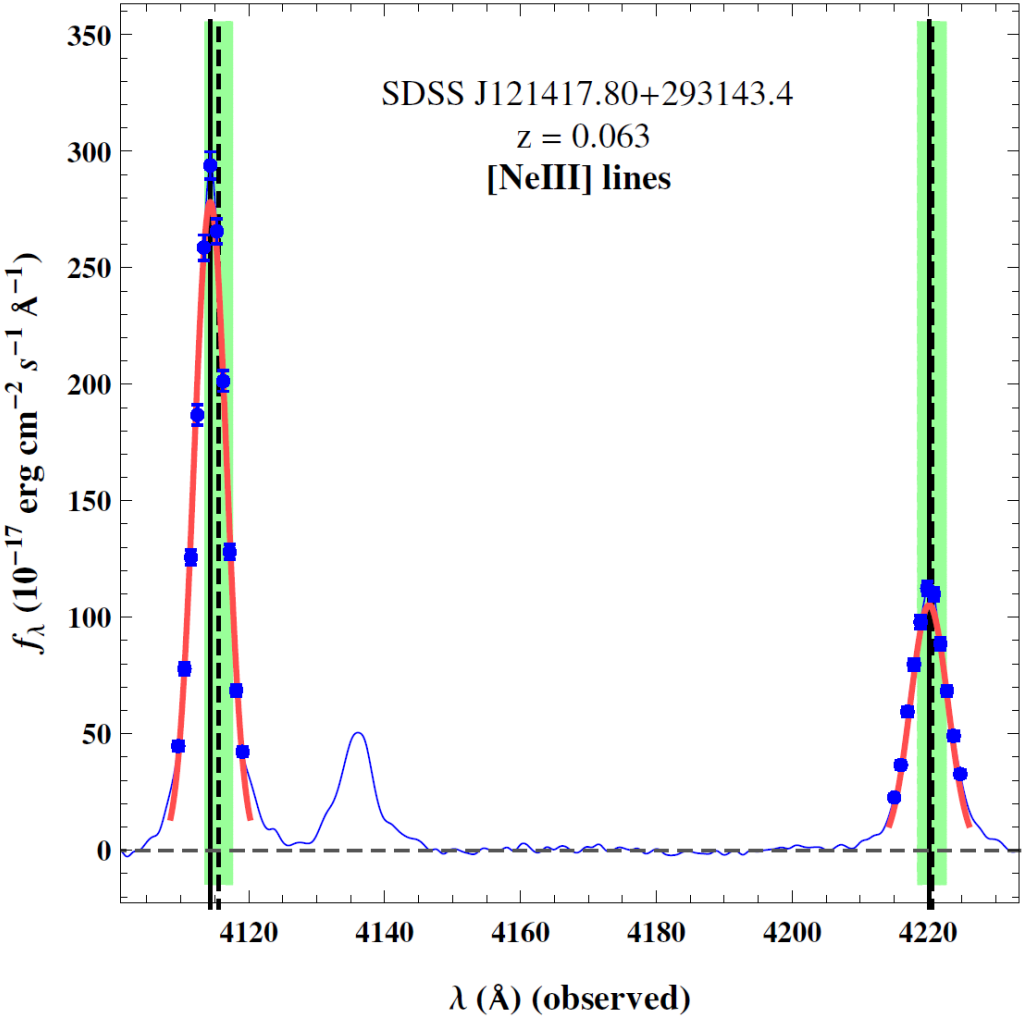
[NeIII] lines

Results



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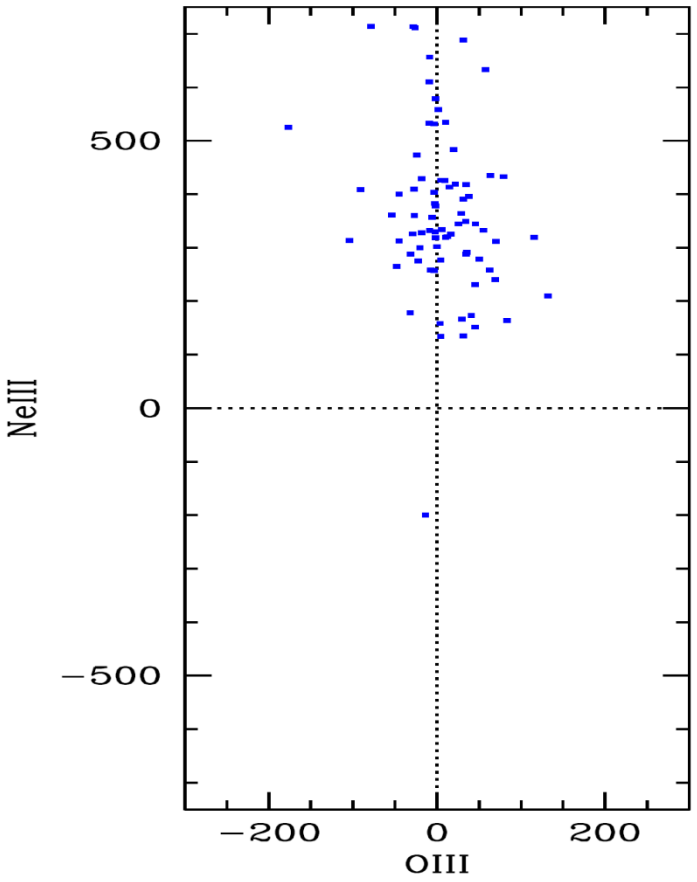
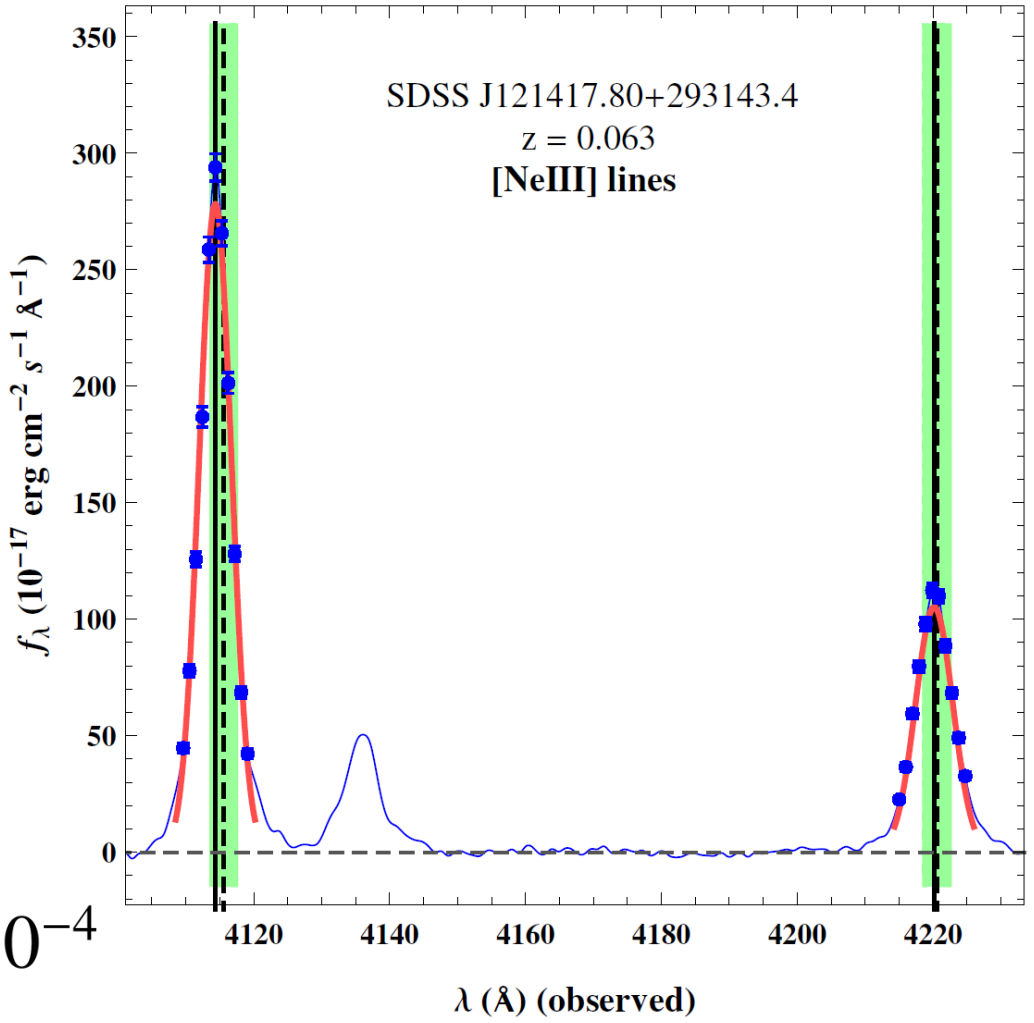
[NeIII] lines

Results





$$\Delta\alpha/\alpha_{[\mathrm{NeIII}]} = (36 \pm 1)\times 10^{-4}$$

Gutiérrez & López-Corredoira (2010)

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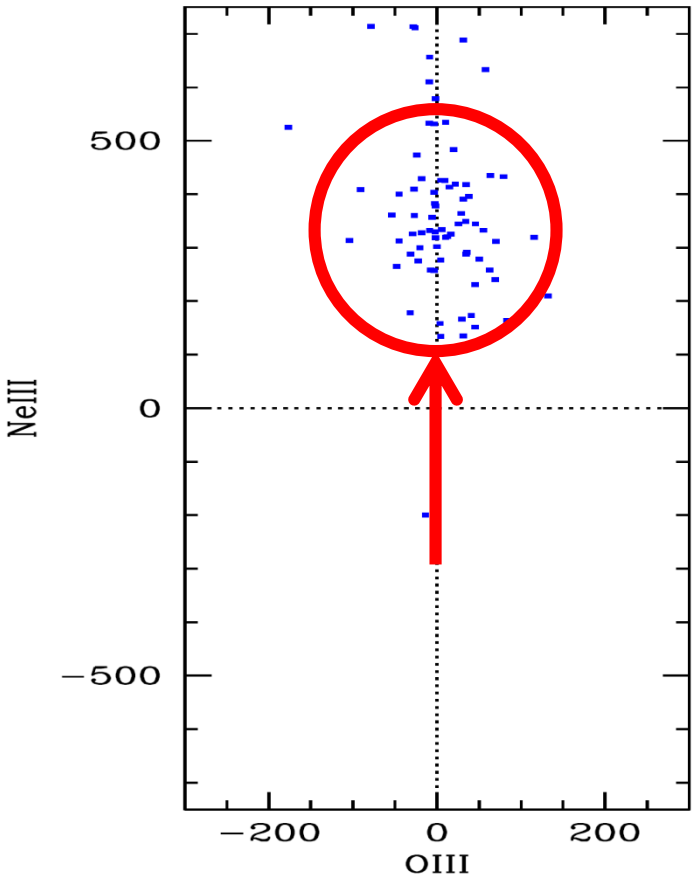
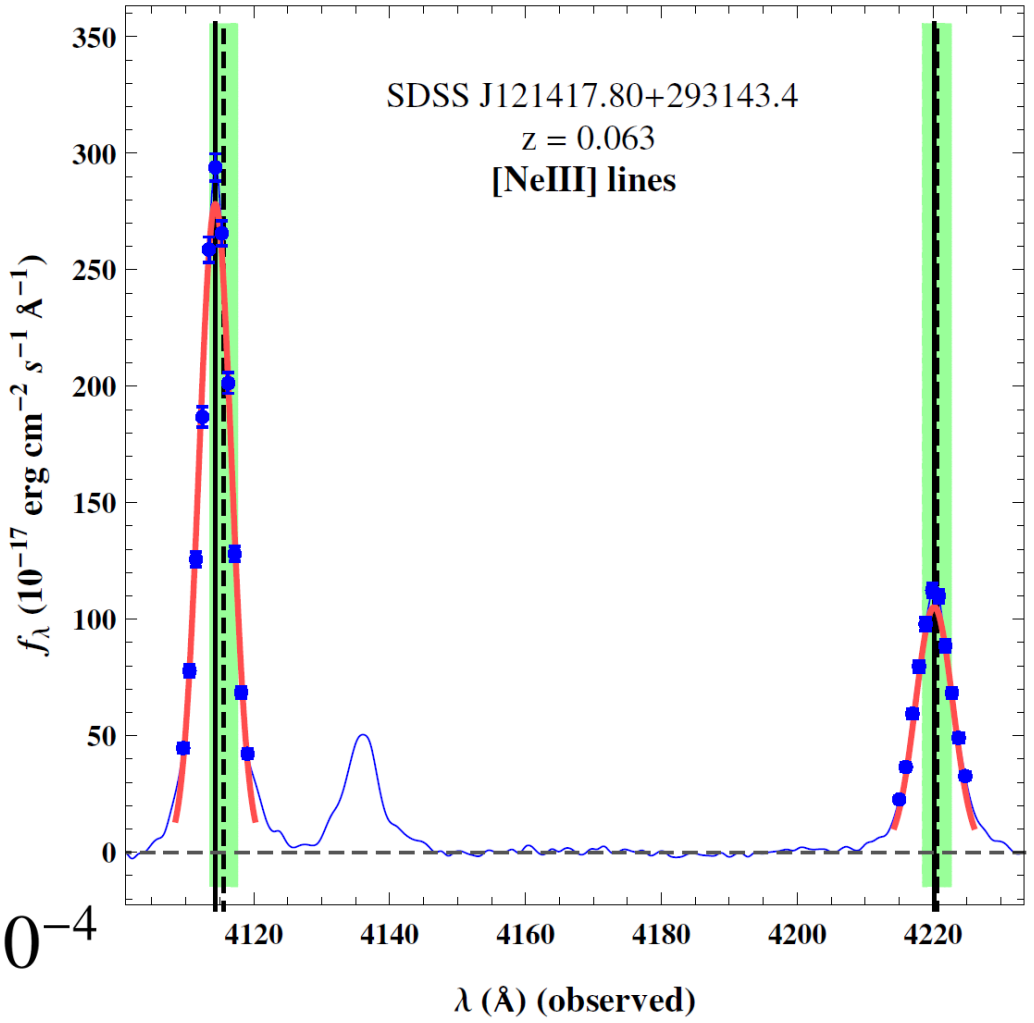
[NeIII] lines

Results





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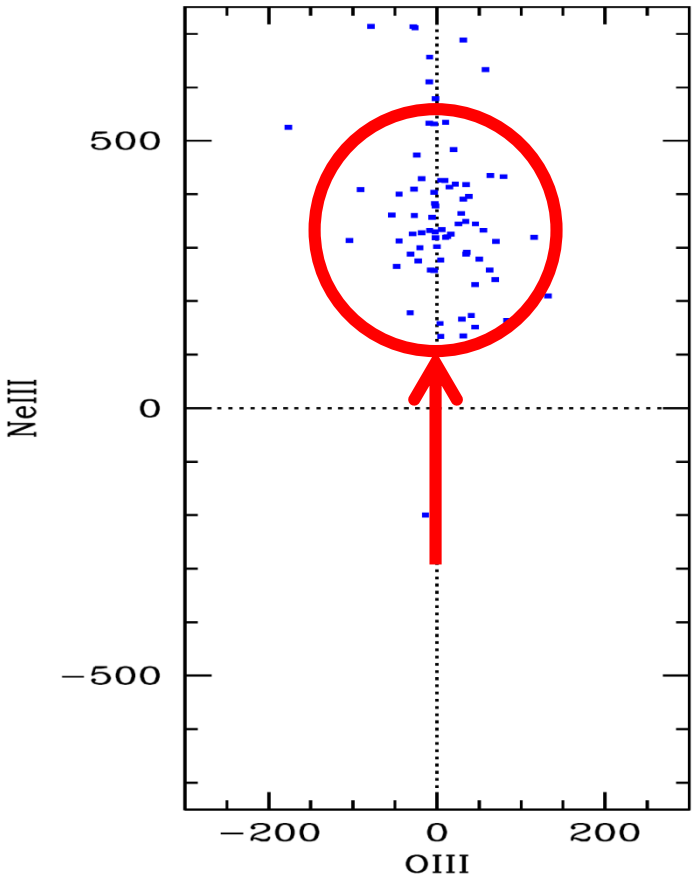
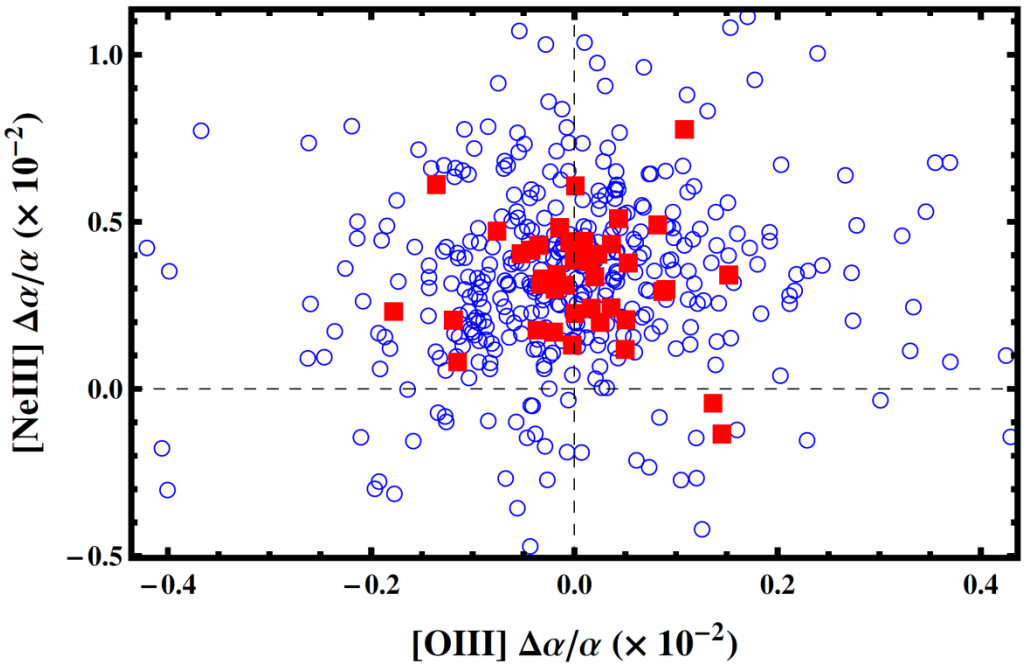
[NeIII] lines

Results





$$\Delta\alpha/\alpha_{[\mathrm{NeIII}]} = (36 \pm 1)\times 10^{-4}$$

Gutiérrez & López-Corredoira (2010)

$$\Delta\alpha/\alpha_{[\mathrm{NeIII}]} = (34 \pm 1)\times 10^{-4}$$

This work (2015)

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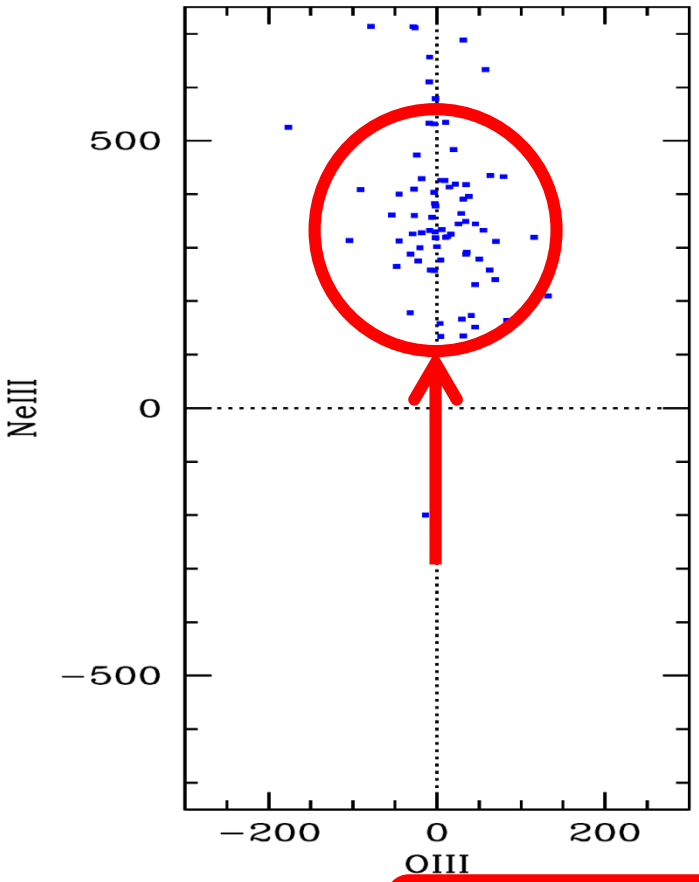
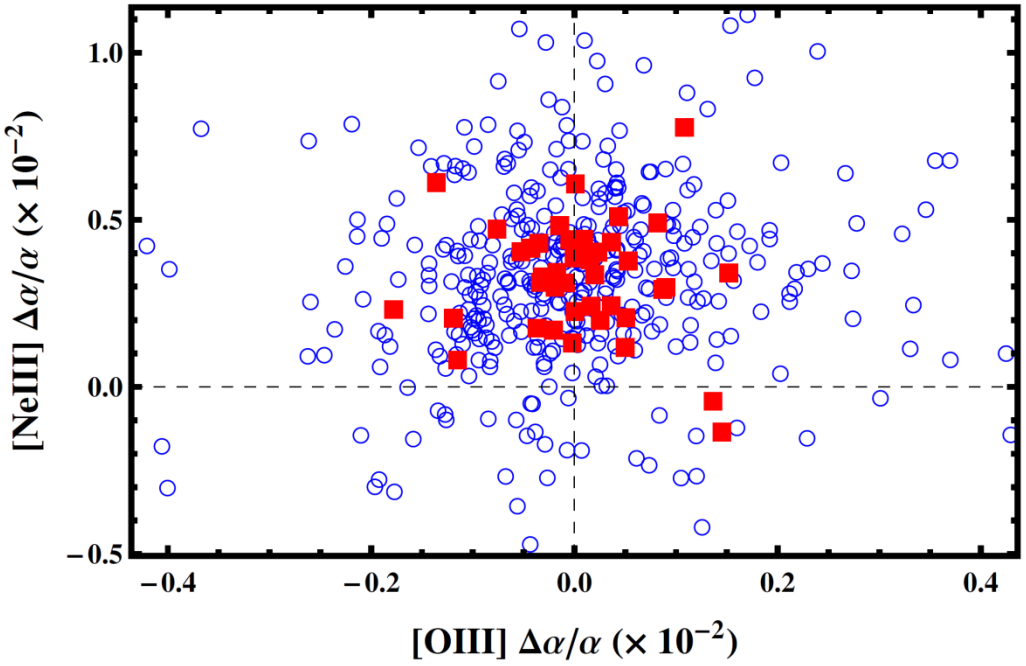
[NeIII] lines

Results





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Gutiérrez & López-Corredoira (2010)

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This work (2015)

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[NeIII] lines Results

IC 418 (spirograph nebula)

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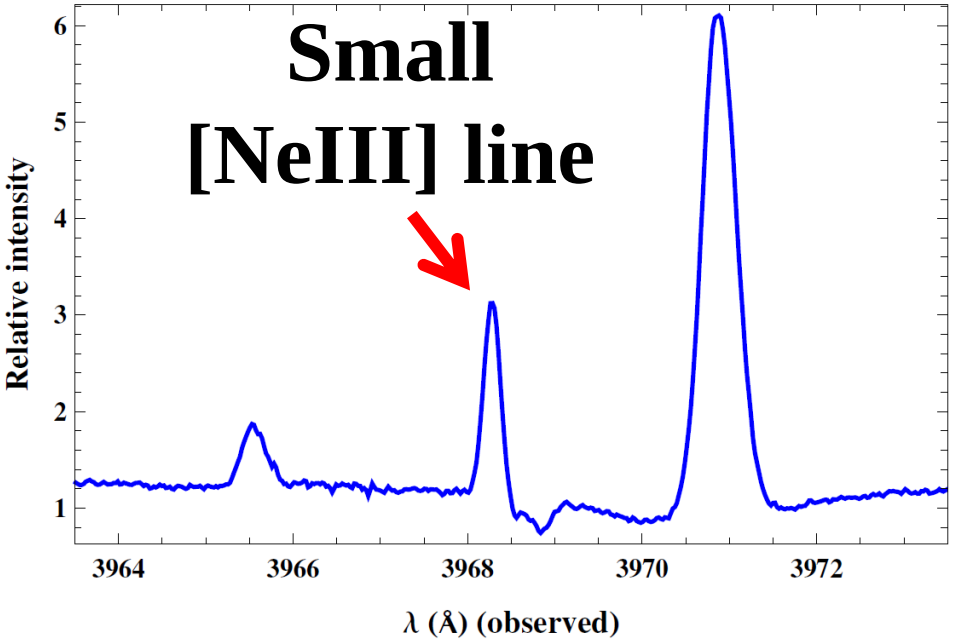
[NeIII] lines

Results

IC 418 (spirograph nebula)



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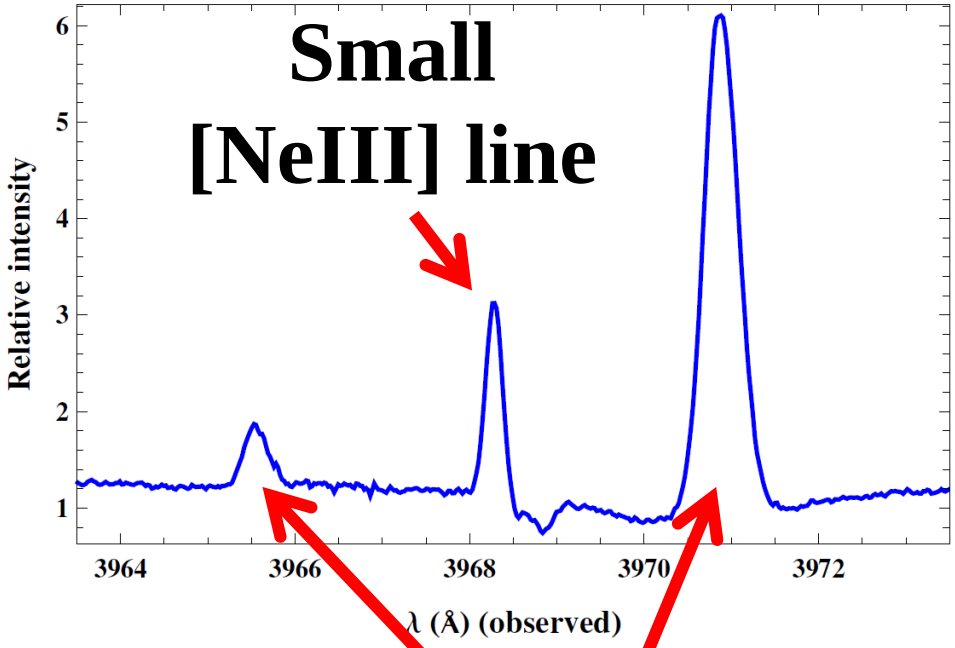
[NeIII] lines Results

IC 418 (spirograph nebula)



blended with Hε and HeI

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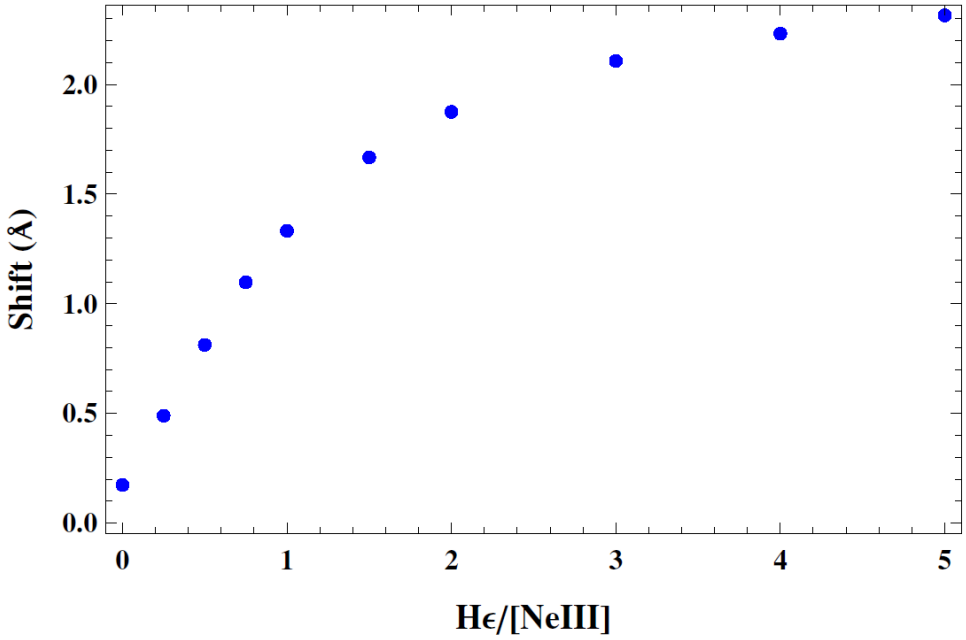
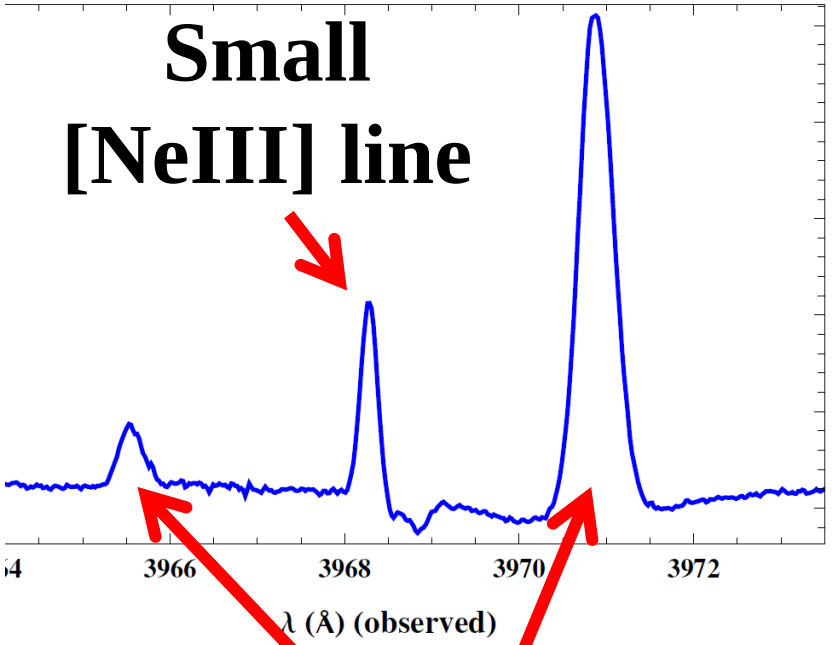
[NeIII] lines Results

IC 418 (spirograph nebula)



convolved spectrum



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[NeIII] lines Results

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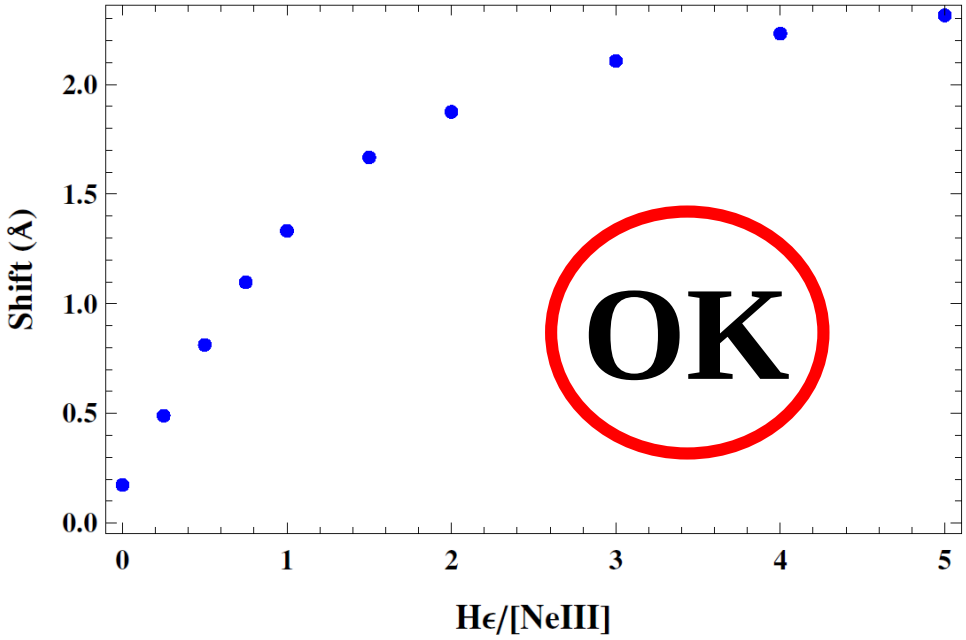

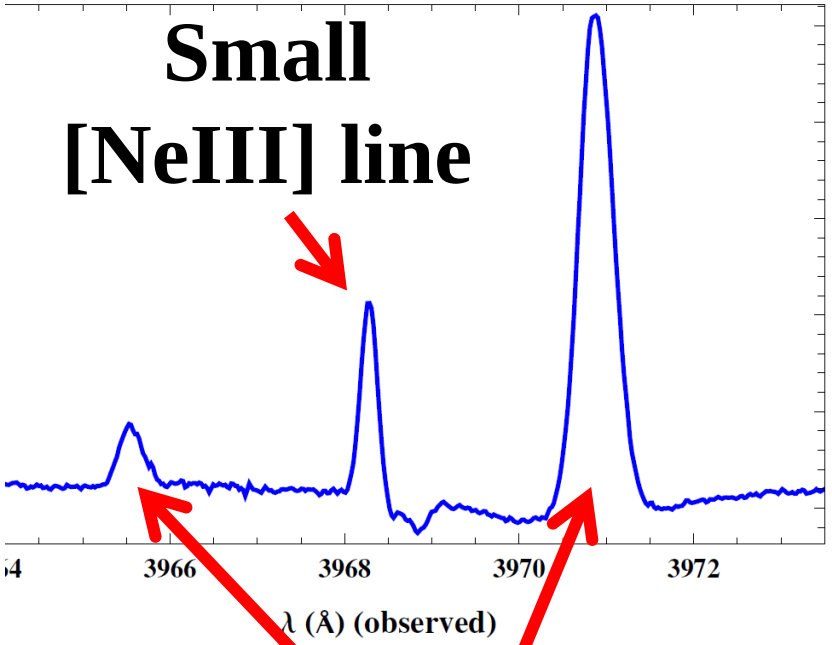

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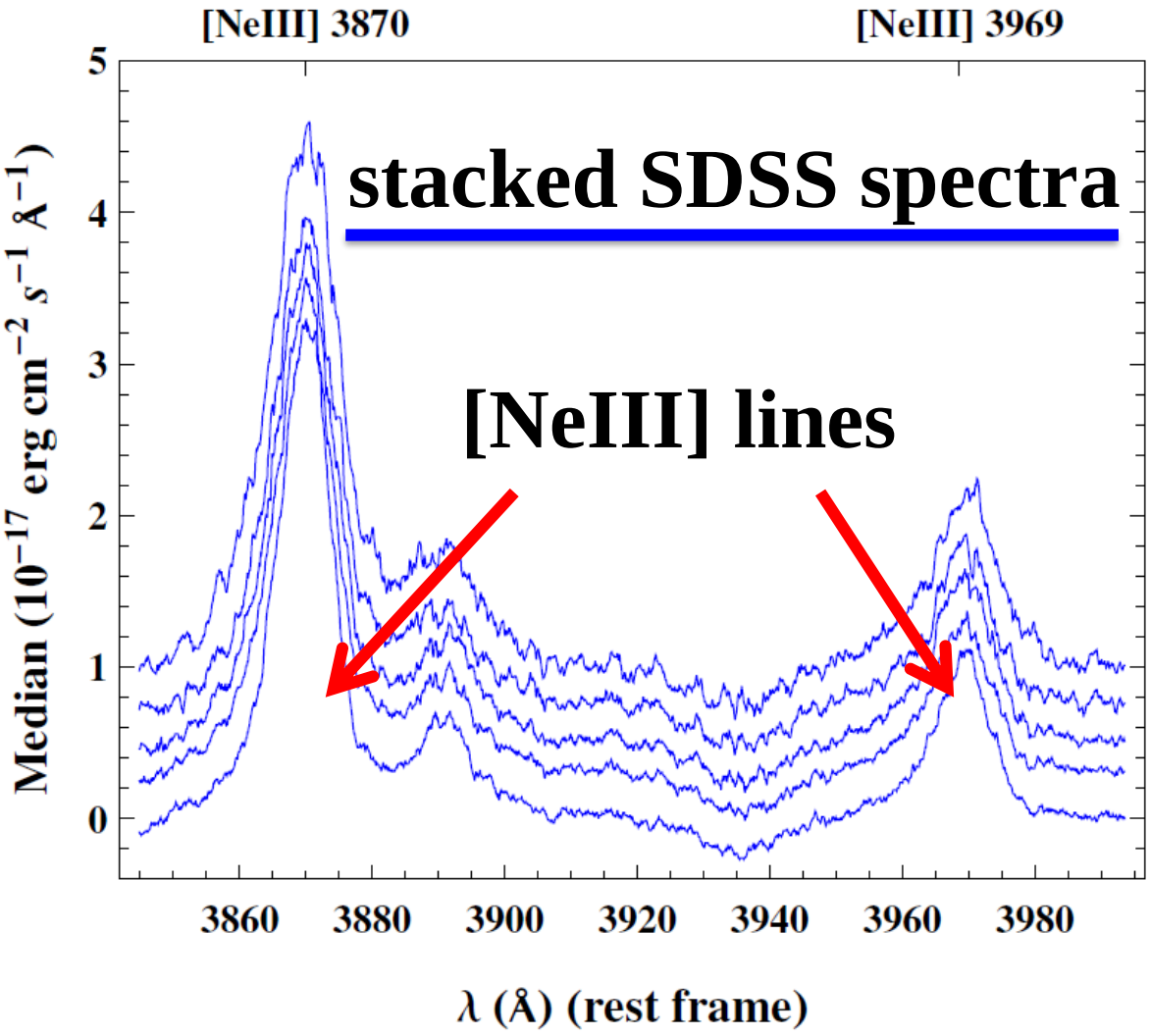
Results



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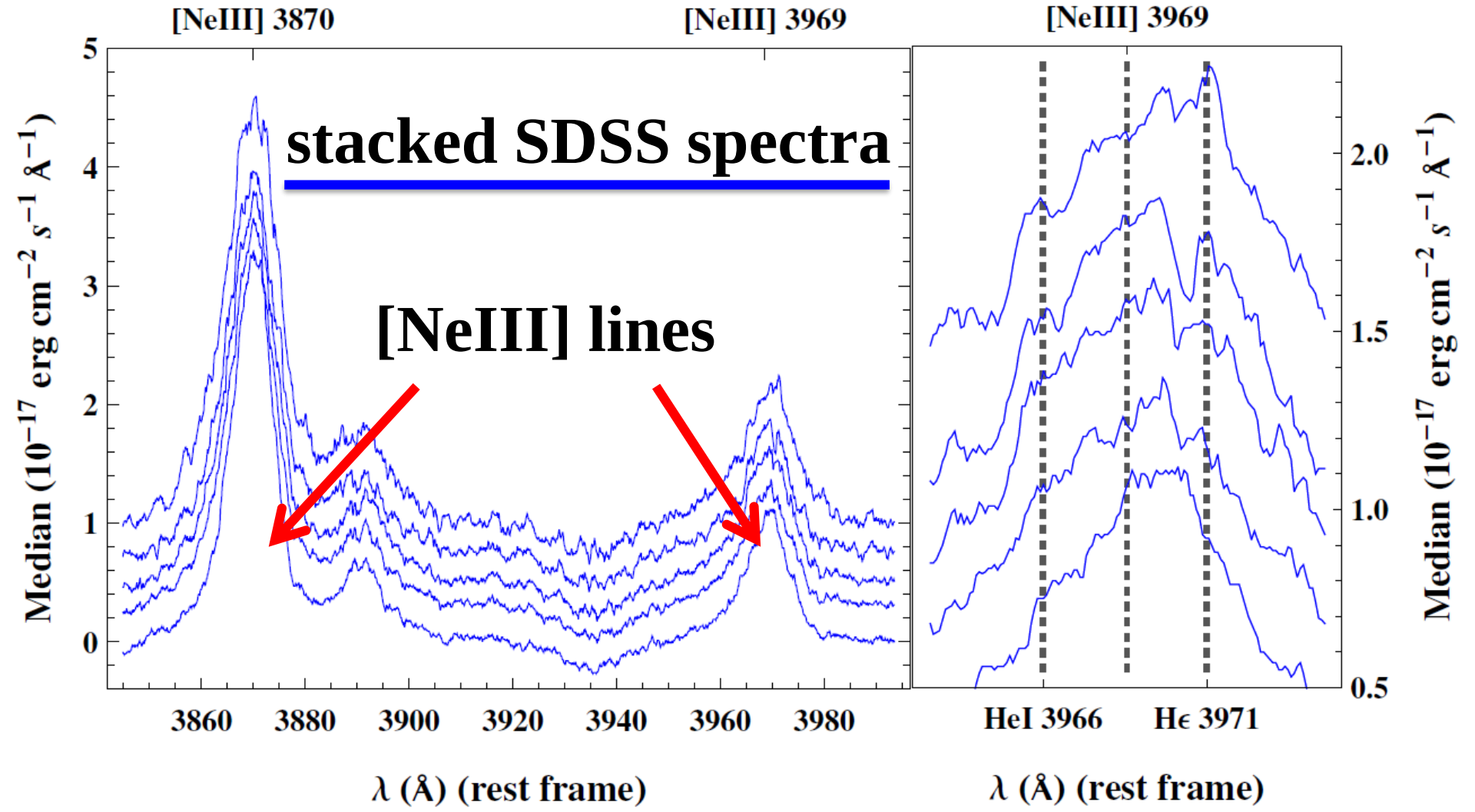
[NeIII] lines

Results



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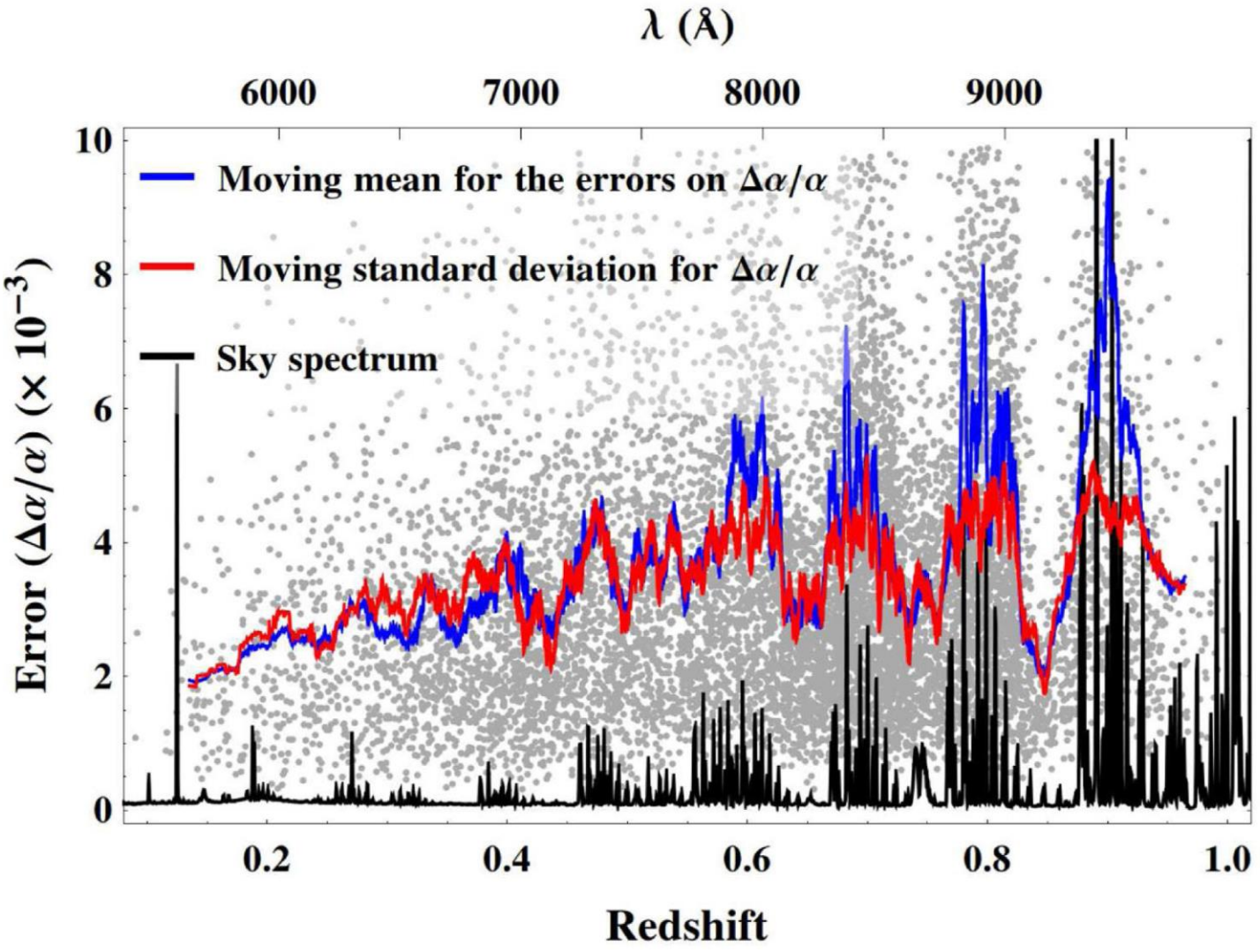
Results



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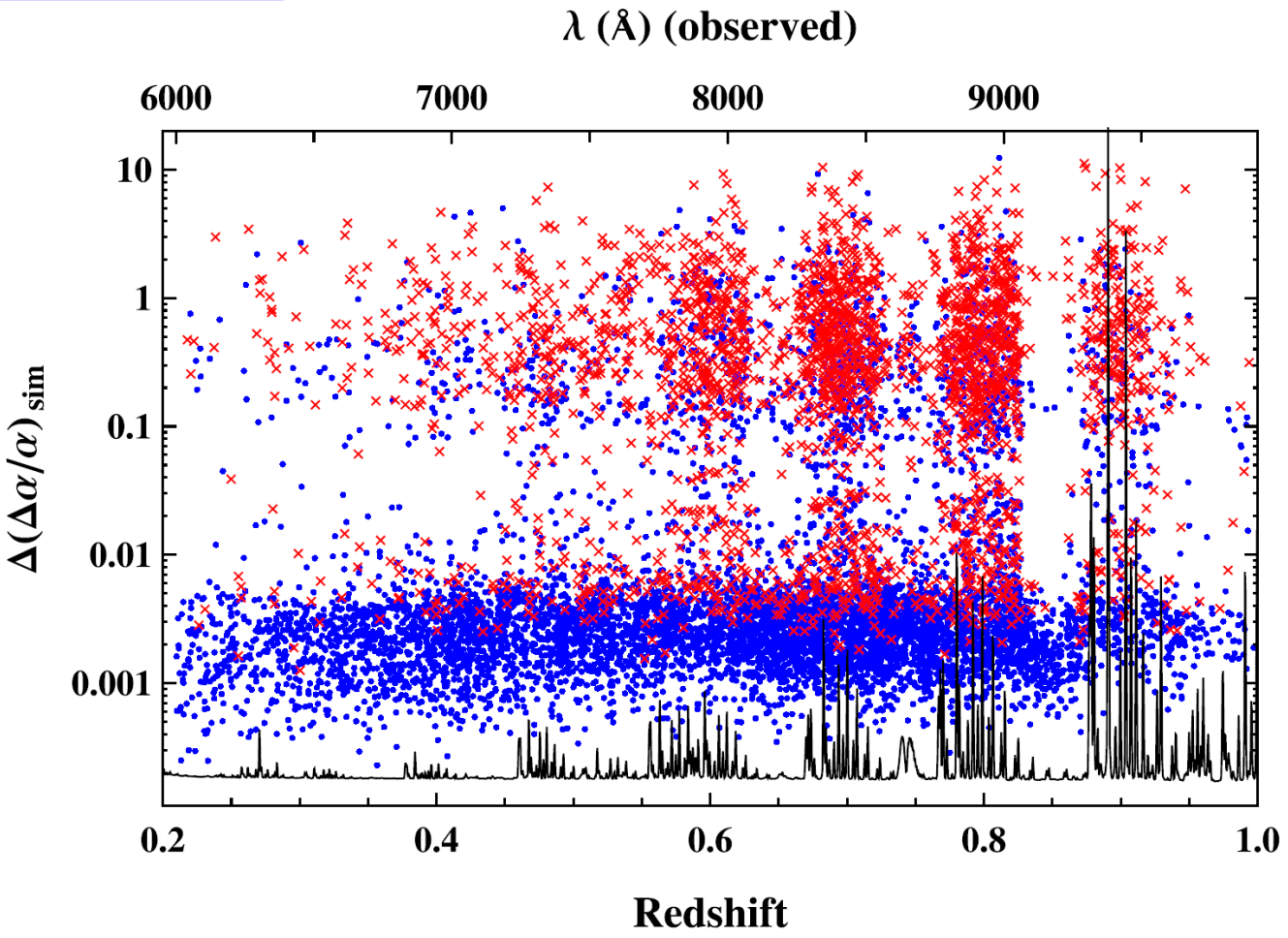
Simulations

Results



The precision is limited by the sky subtraction

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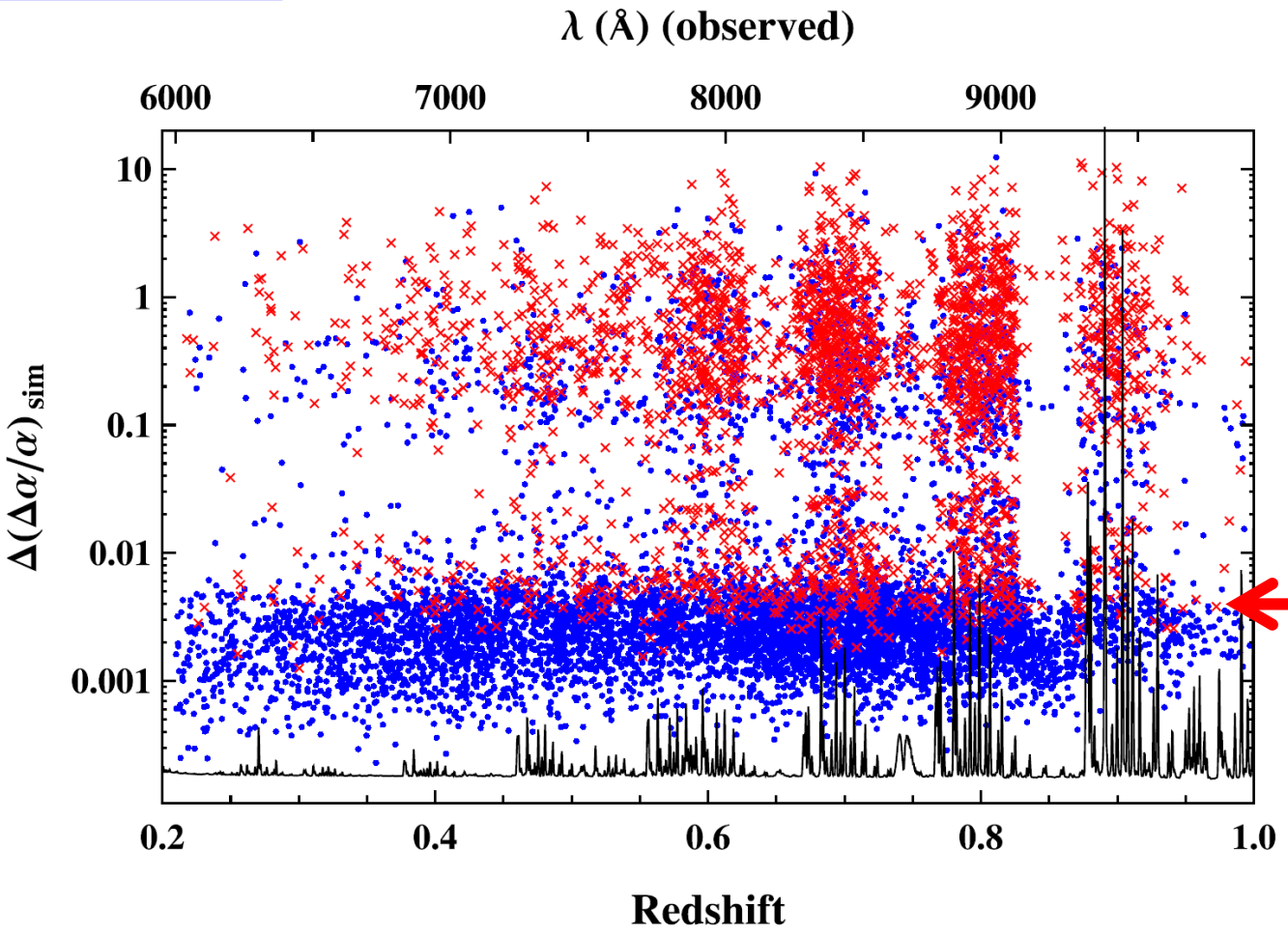
Results

Simulations



Typical errors from the Gaussian fitting

The precision is limited by the sky subtraction

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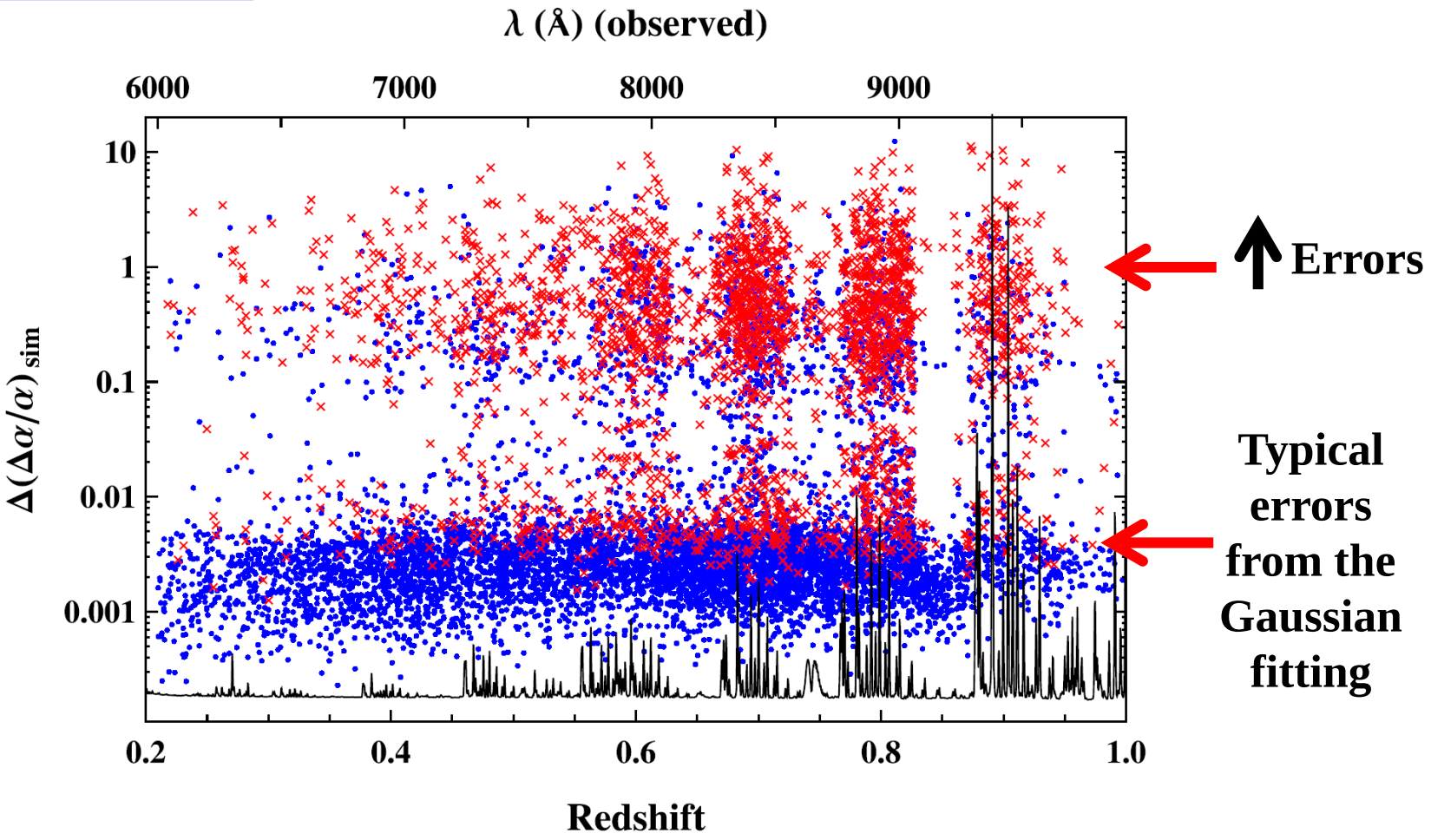
Results

Simulations



The precision is limited by the sky subtraction

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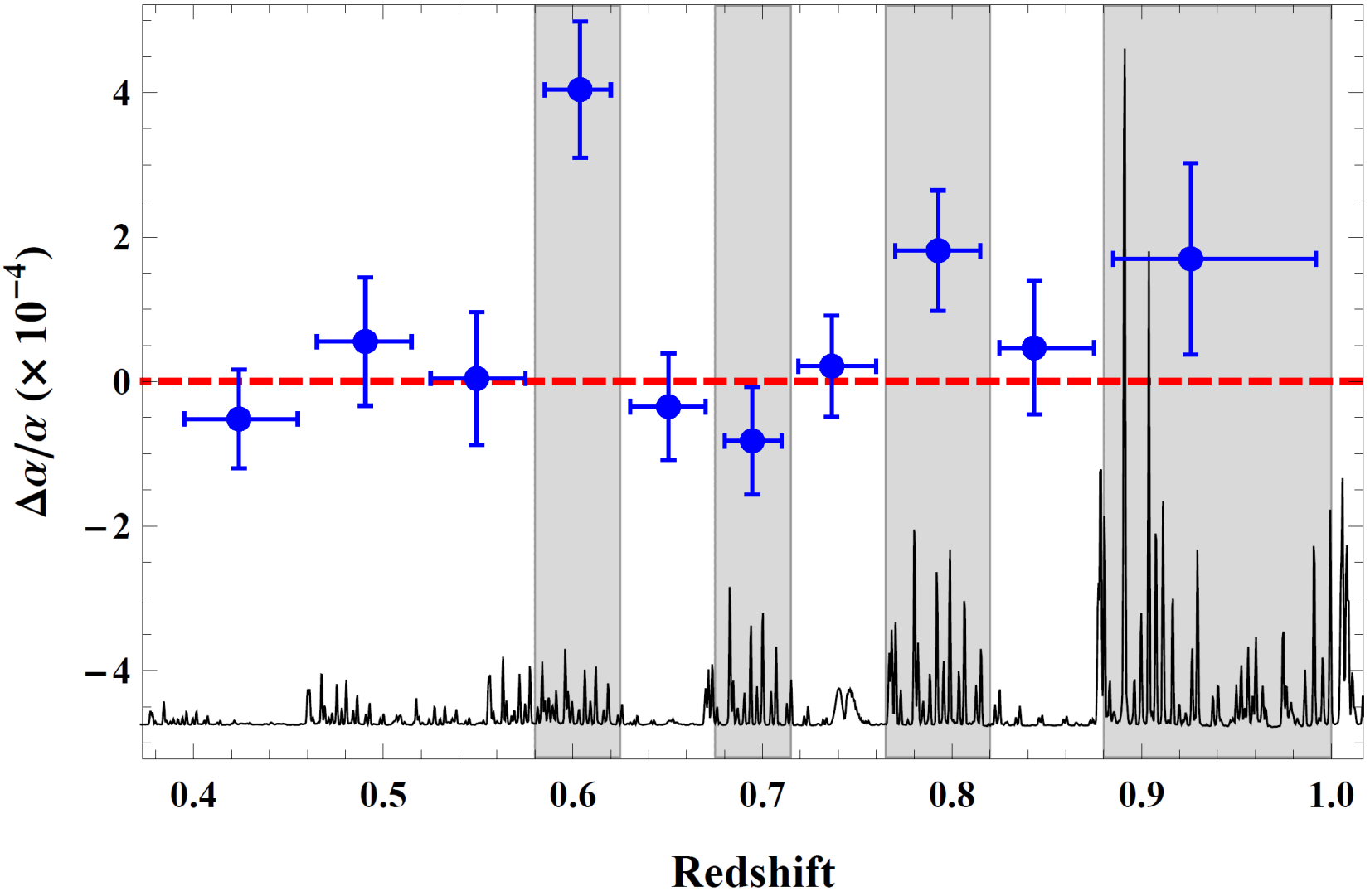
Results

Redshift bins



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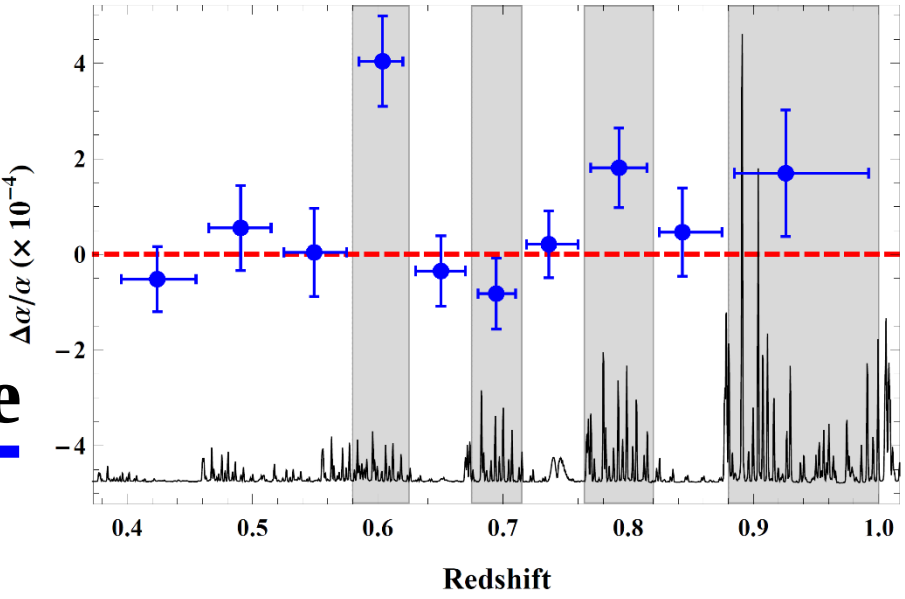
Results

$$\Delta\alpha/\alpha = a\,z + b$$

Linear redshift dependence



$$a = (0.7 \pm 2.1) \times 10^{-4}$$

$$b = (0.7 \pm 1.4) \times 10^{-4}$$

Results

$$\Delta\alpha/\alpha = (0.9 \pm 1.8) \times 10^{-5}$$

- **Combining with quasars from DR7**
- **SDSS spectrograph**
- **Reanalizing the spectra** $\approx 3,000$ SDSS – I/II

  $\approx 10,000$ SDSS – III/BOSS

$> 13,000$ quasars

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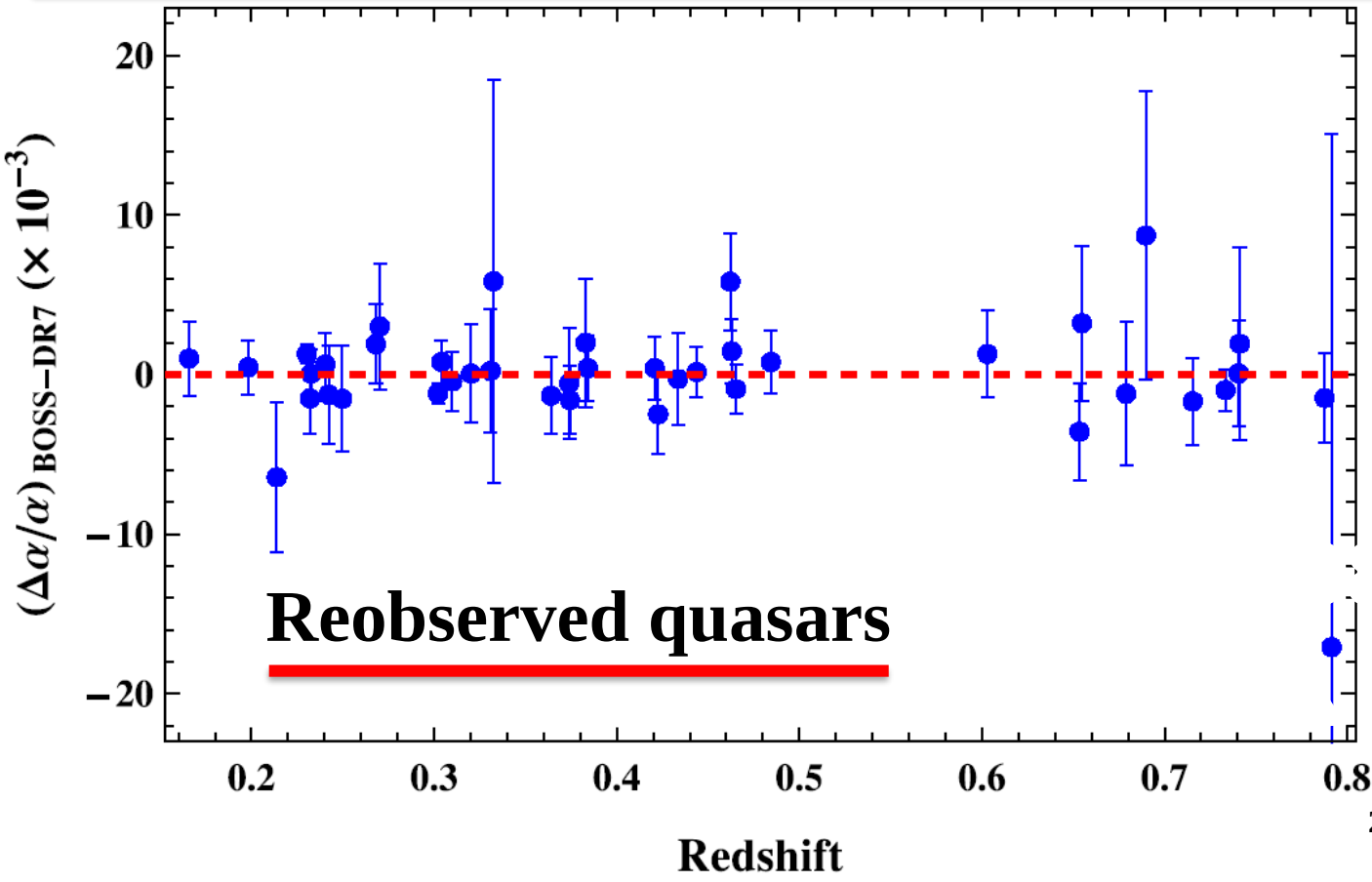
Results

$$\Delta\alpha/\alpha = (0.9 \pm 1.8) \times 10^{-5}$$



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Results

$$\Delta\alpha/\alpha = (0.9 \pm 1.8) \times 10^{-5}$$

- **Robust constraint** for the variation of the fine structure constant at **z ~ 0.6 (5.7 Gyr ago)** (more than **35 samples** analyzed).

- **For further details**, **"FDA, J. Comparat, F. Prada *et al.*, MNRAS 452 (2015) 4153,** arXiv:**1501.00560"**

Outline

- Introduction ✓
- Methodology ✓
- Sample selection ✓
- **Results** ✓
- APOGEE-Q

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Outline

- Introduction ✓
- Methodology ✓
- Sample selection ✓
- Results ✓
- **APOGEE-Q**

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APOGEE-2 Ancillary Science Proposal

April 3, 2015

APOGEE-Q
APOGEE Quasar Survey

Type of request: 1

PI

Franco D. Albareti

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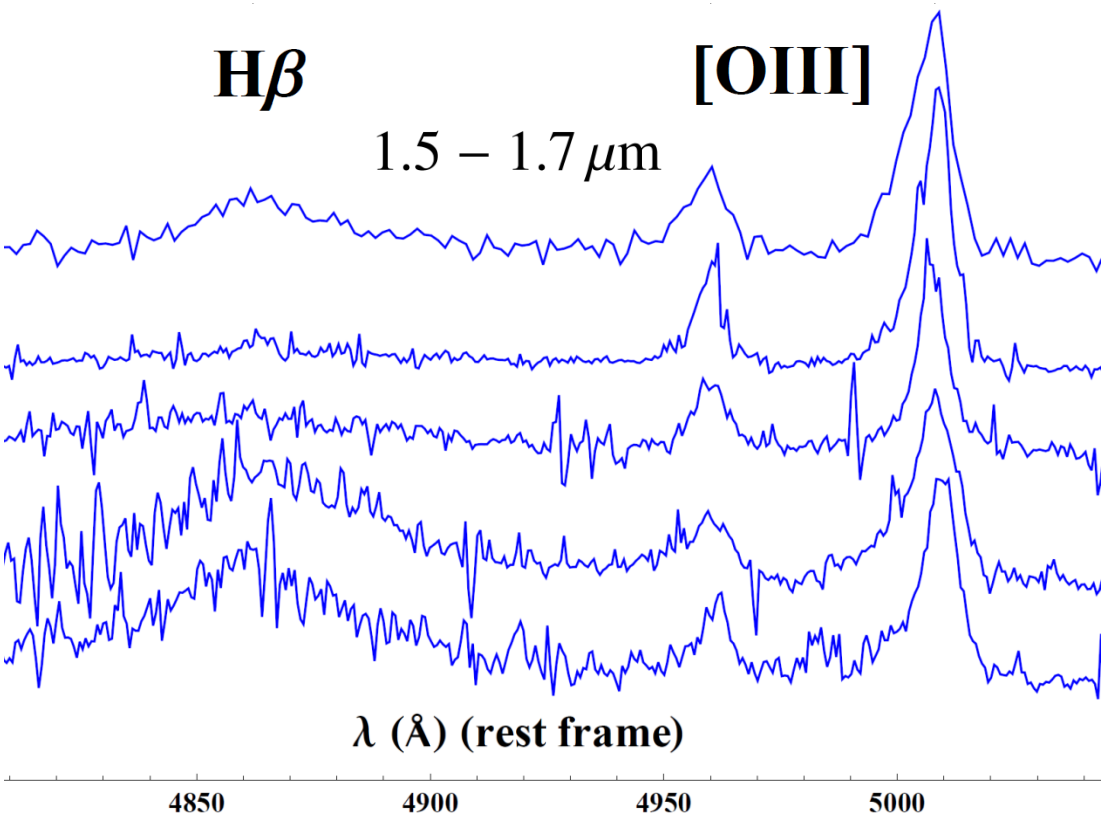
Cantoblanco, C/ Nicolás Cabrera, 13-15, 28049 Madrid
Phone number: +34 91 299 98 71
E-mail: franco.albareti@uam.es

APOGEE Quasar Survey



$2.0 < z < 2.4$

- **Fine-structure constant**
- **Black hole mass**
- **Redshifts**
  [OIII] → APOGEE
  MgII, CIV → BOSS
- **???**

Pilot program 2015/16

40 targets, 12 visits → 450 fiber hours

Collaborators: **F.D. Albareti, J. Comparat, F. Prada, I. Pâris, A. Font, D. Schlegel, J. Hennawi, J-P. Kneib, D.P. Schneider, A. Myers, W. Brandt, J.K Parejko,** *your name here...*

Thanks!

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Backslides

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Exact formula for the determination of the variation of the fine structure constant

$$\frac{\Delta\alpha}{\alpha}(z) = \frac{1}{2}\left\{\frac{\left[(\lambda_2 - \lambda_1)\,/\,(\lambda_2 + \lambda_1)\right]_z}{\left[(\lambda_2 - \lambda_1)\,/\,(\lambda_2 + \lambda_1)\right]_0} - 1\right\}$$

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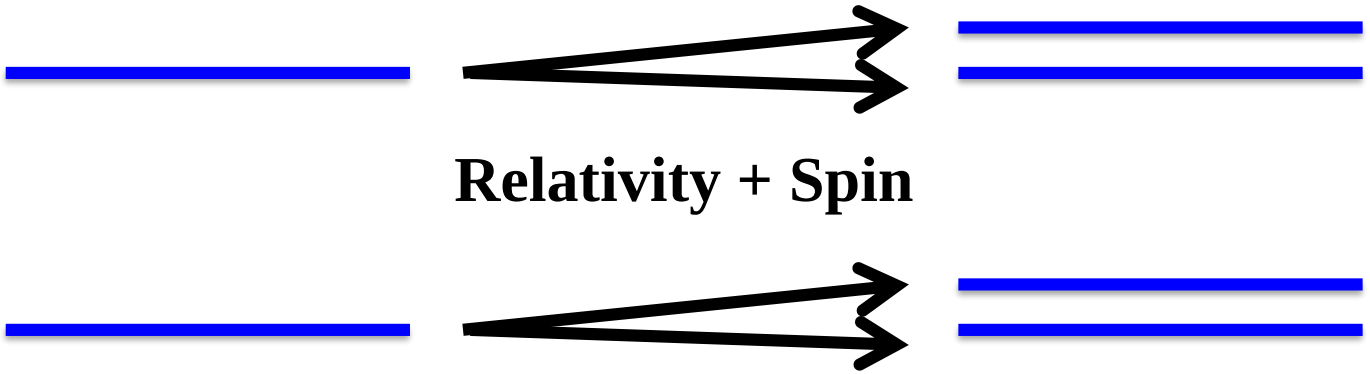
Introduction

- **Fine structure constant?**

$$\alpha = \frac{e^2}{\hbar c} \approx \frac{1}{137}$$

Energy levels



Relativity + Spin

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Introduction

$$\alpha \approx 1/137$$

How do we measure its variation?

- **Geological constraints** → **Oklo phenomenon z=0.15**
  → **Meteorites z=0.45**
- **Local measurements** → **10 years**
- **Astronomical tests**
  - **Absorption z = 0.6-4**
  - **Emission z = 0.05-1.0**

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Introduction

$$\alpha \approx 1/137$$

How do we measure its variation?

- **Absorption lines from quasars**

  (Many-multiplet method)
- **More precise**
- **Several assumptions**
- **Controversial**

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Introduction

$$\alpha \approx 1/137$$

How do we measure its variation?

- **Emission lines doublet from quasars**
  - **Less precise**
  - **Straight-forward**
  - **No assumptions**

Fine structure of the emission lines

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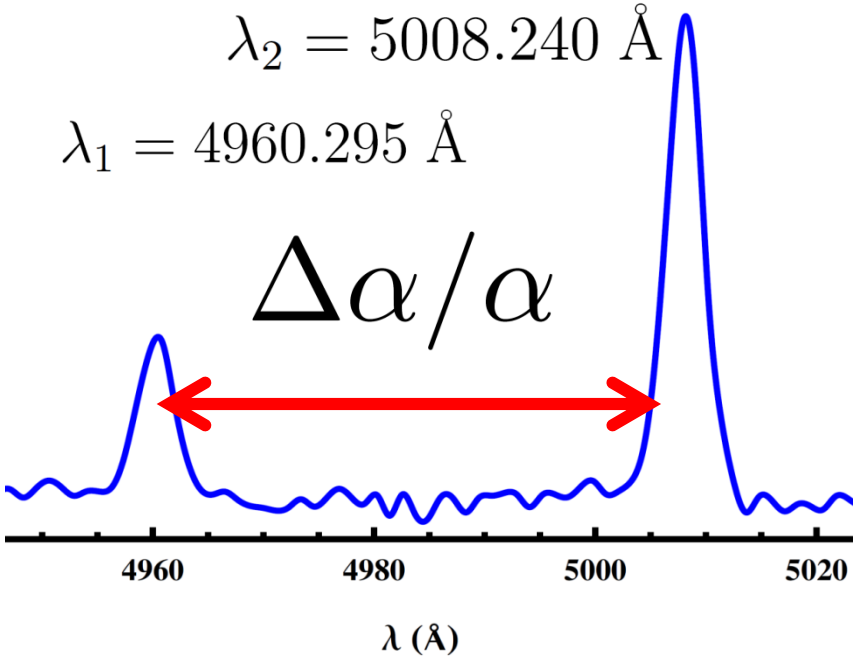
Introduction



- **Forbidden lines**
- **Electric quadrupole and magnetic dipole transitions**
- **Found in extremely rarefied media**

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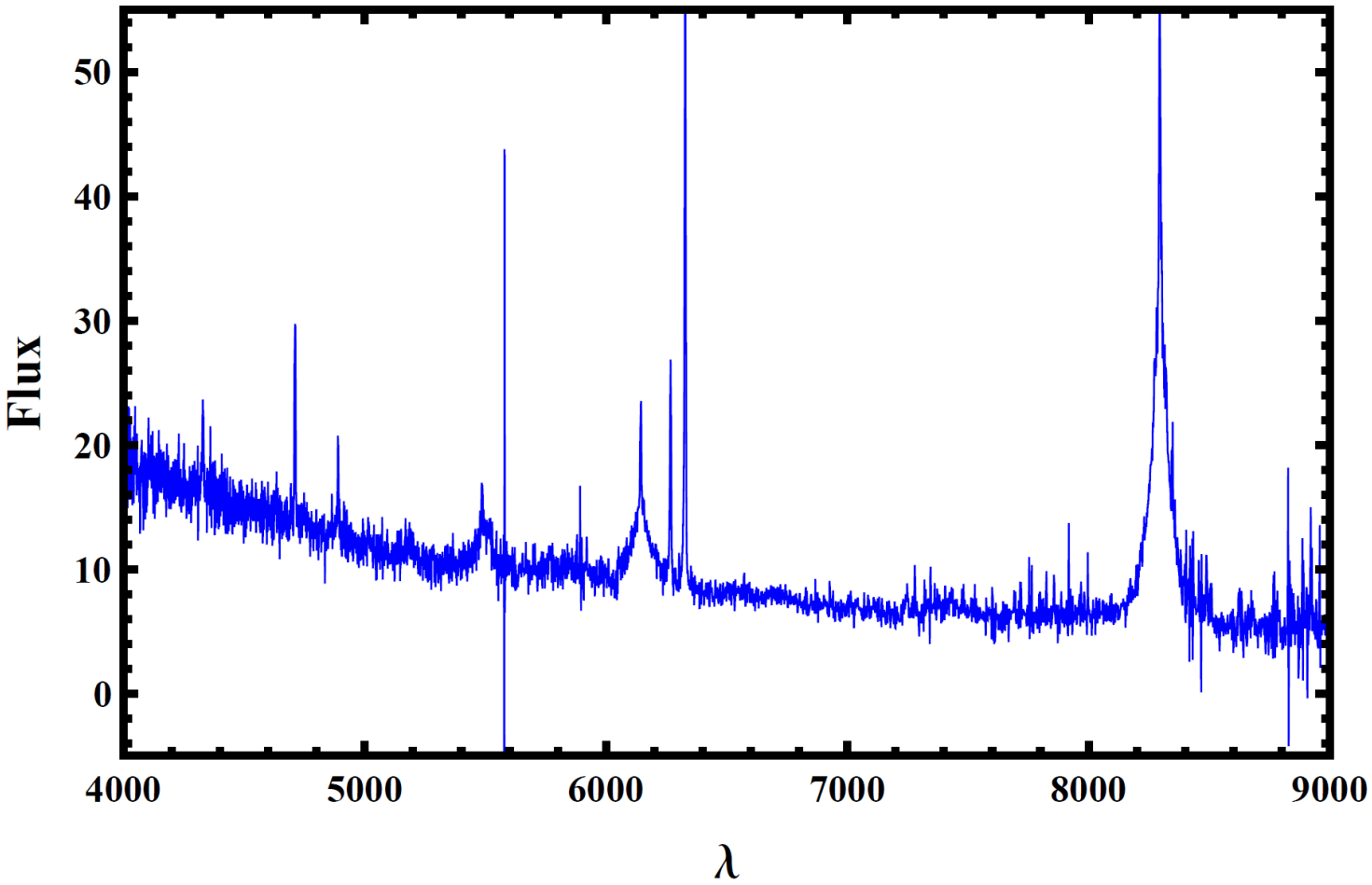
Methodology

***Continuum fit*: seven-order polynomial**

$H\alpha$, $H\beta$, $H\gamma$, $H\delta$, MgII



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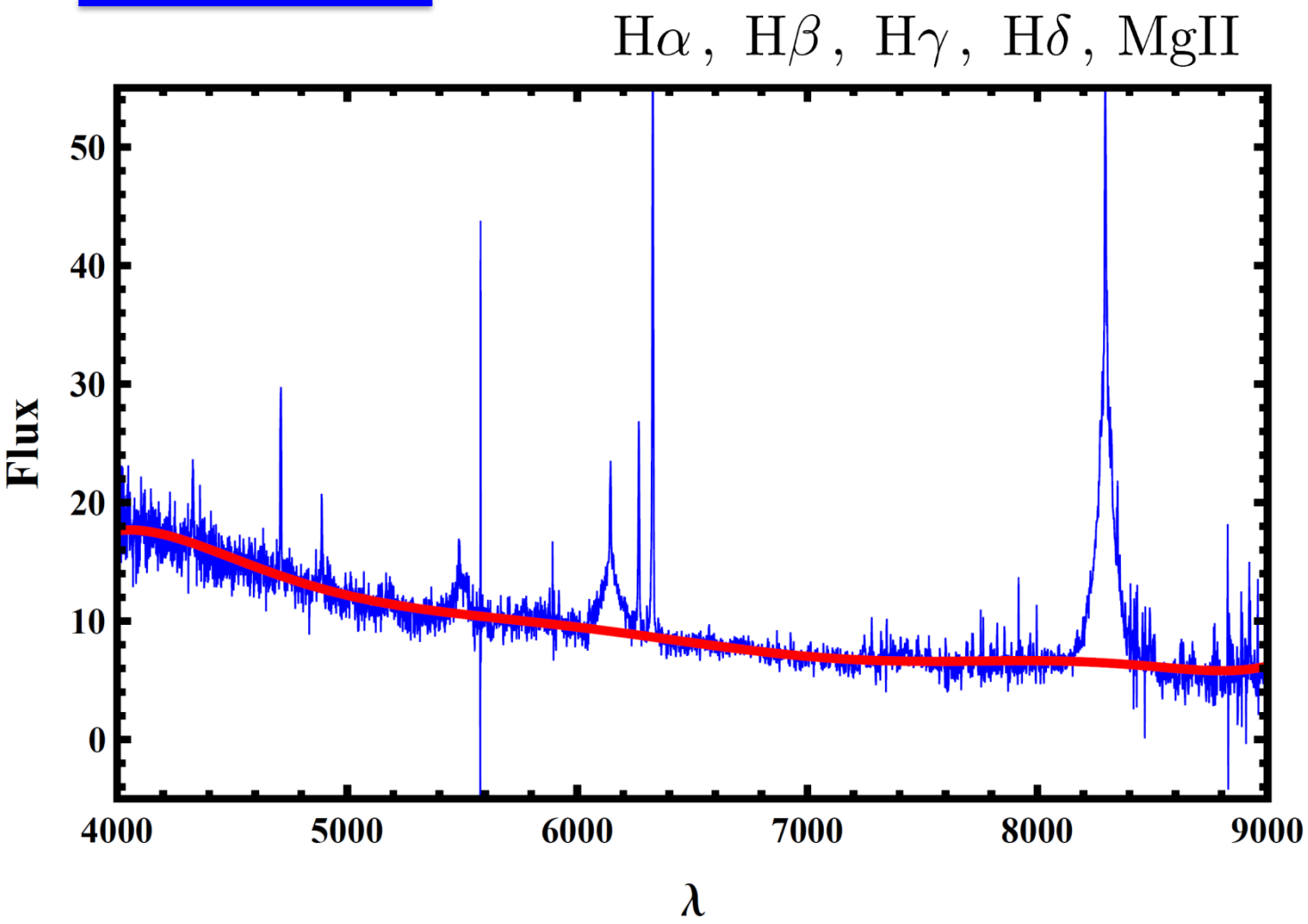
Methodology

***Continuum fit*: seven-order polynomial**



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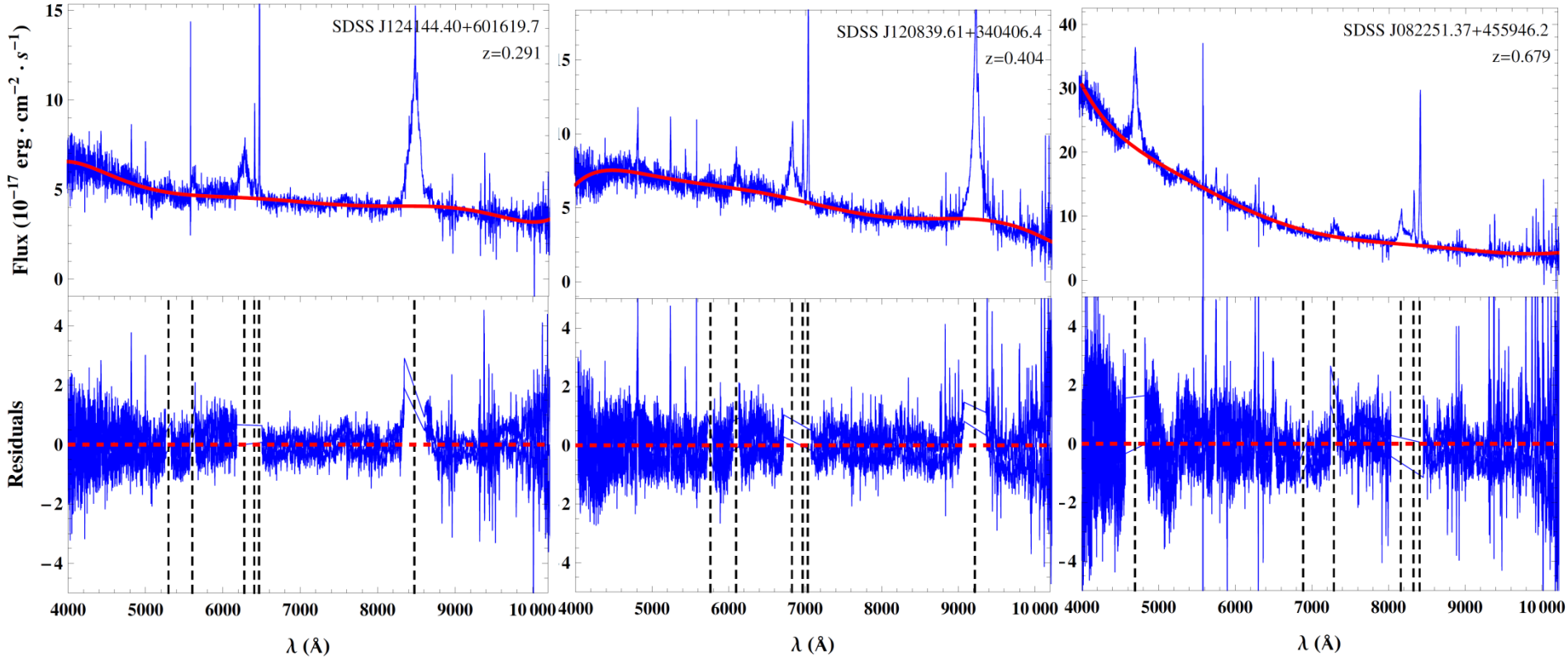
Methodology

Continuum fit: seven-order polynomial

$$H\alpha,\ H\beta,\ H\gamma,\ H\delta,\ MgII$$



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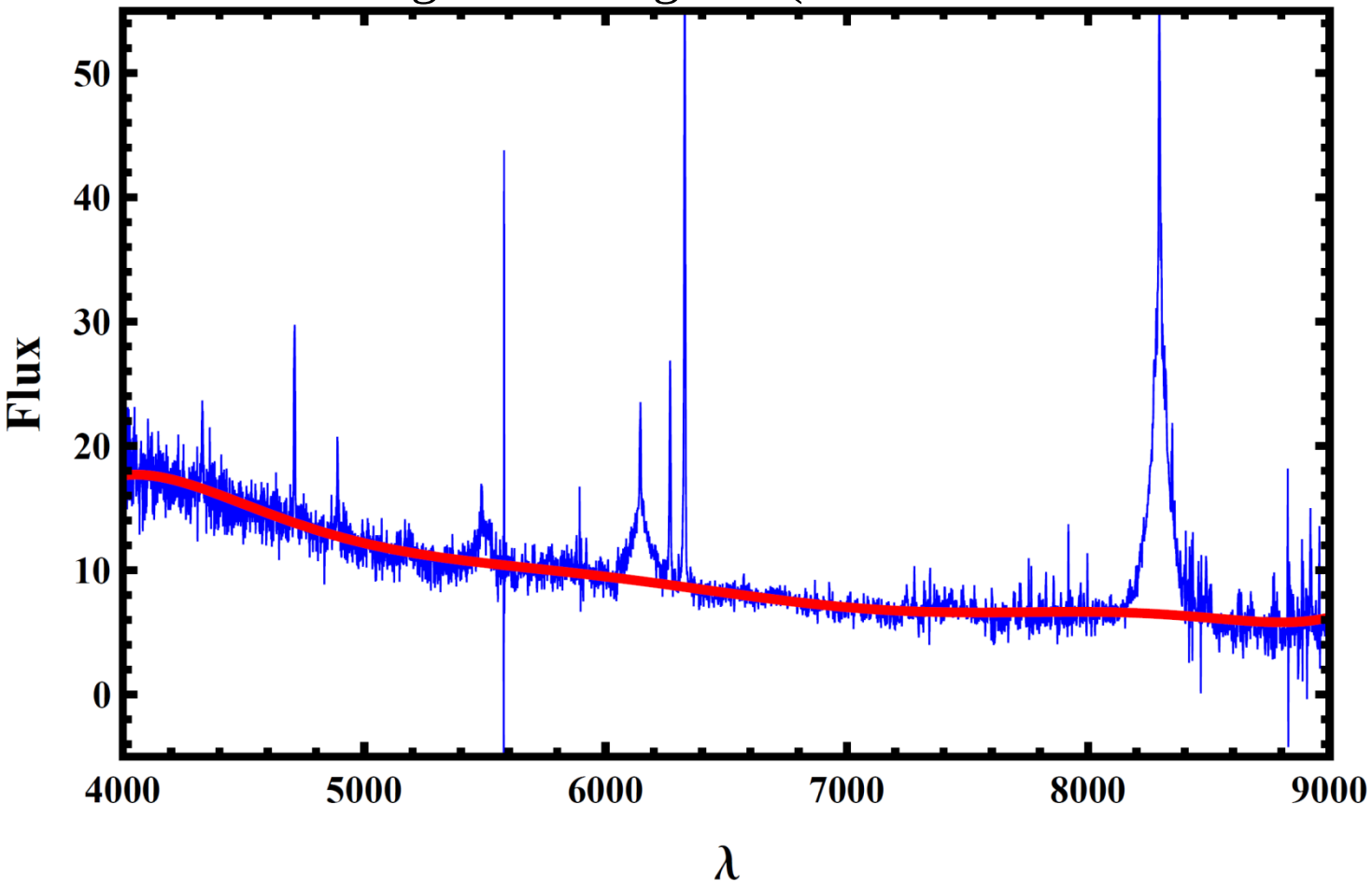
Methodology

Find the lines → ***SDSS Redshift***

Three significant figures (error estimates $10^{-4} - 10^{-5}$)



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Methodology

Find the lines → ***SDSS Redshift***

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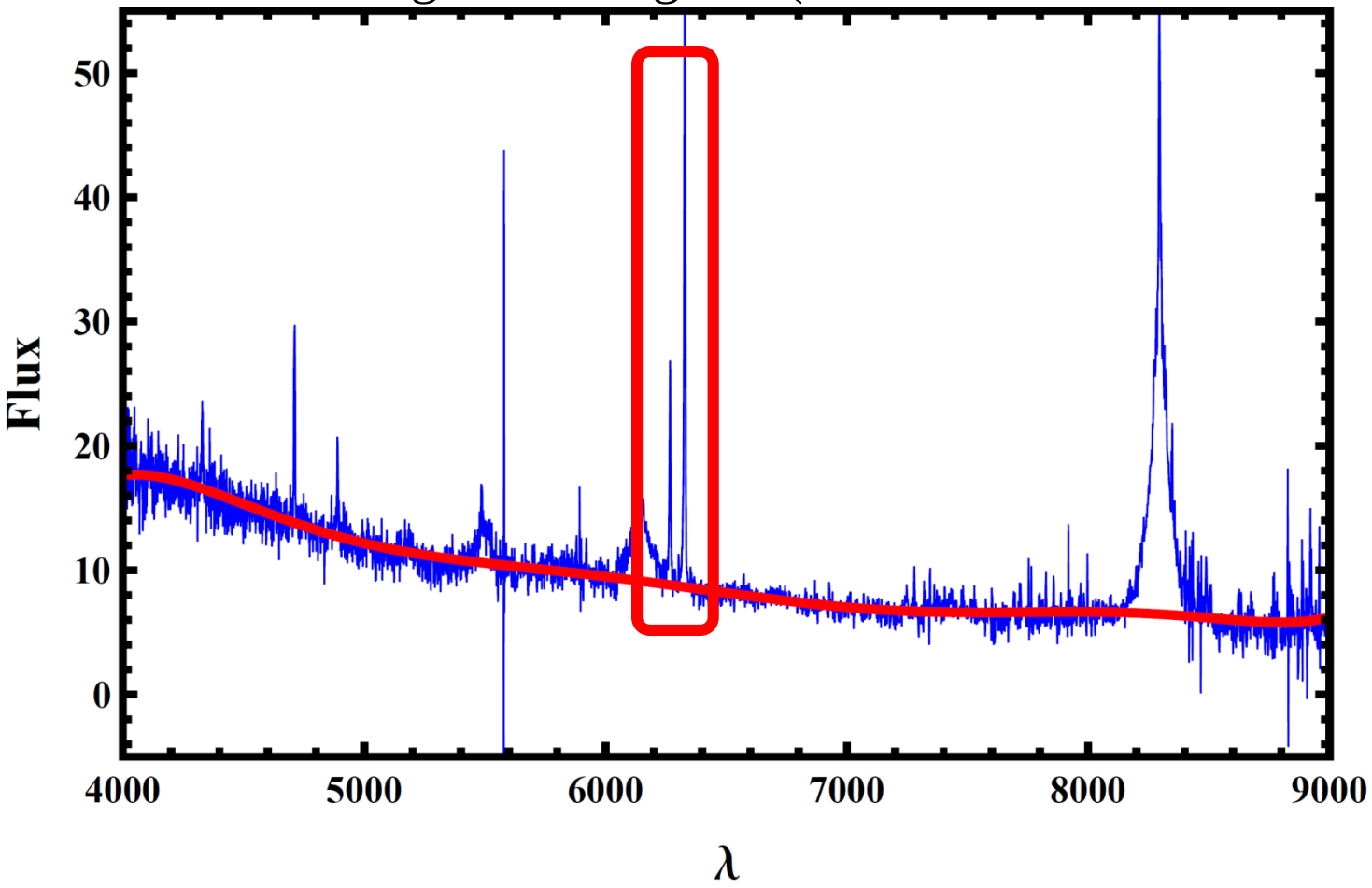

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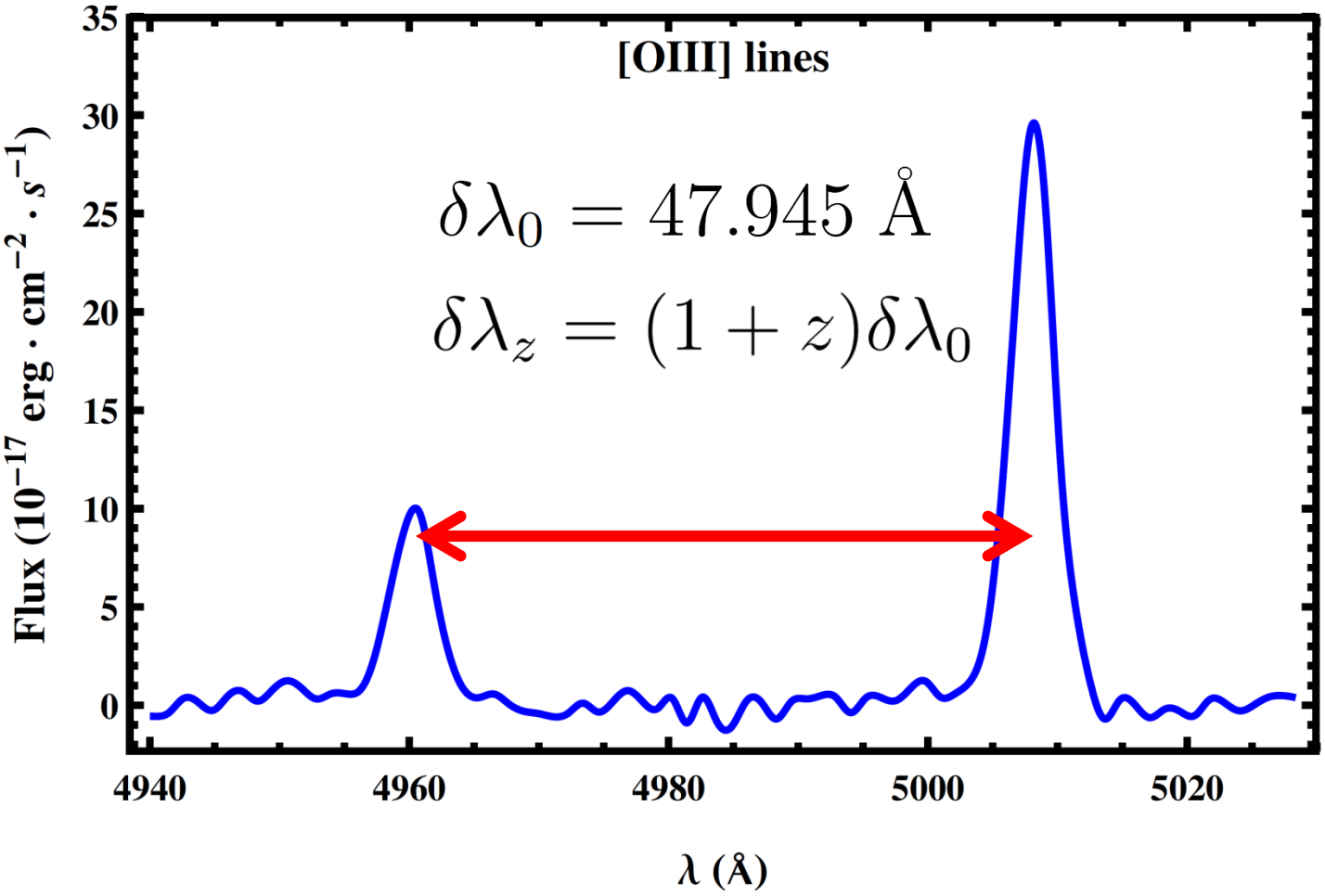
Methodology

Measurement method



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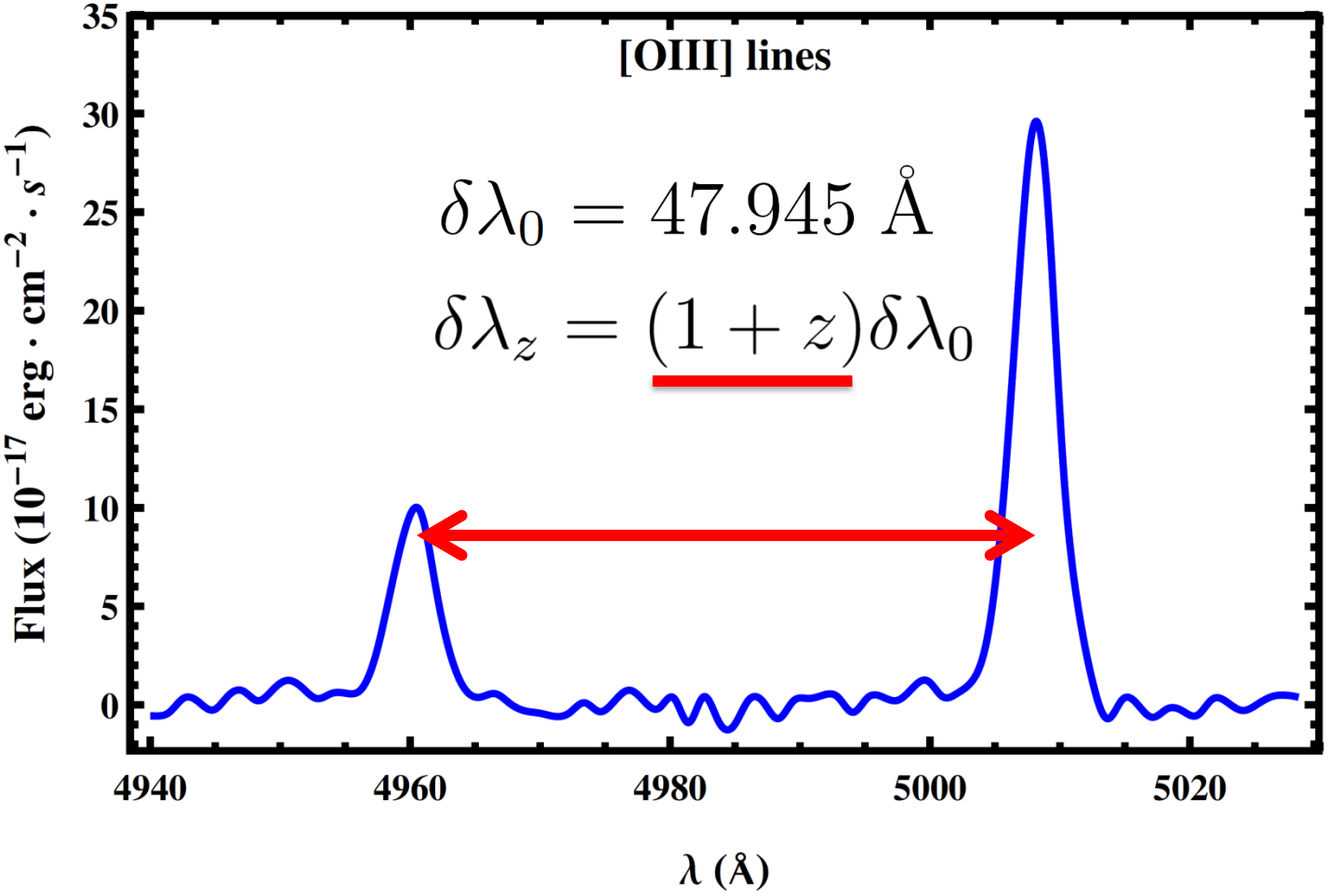
Methodology

Measurement method



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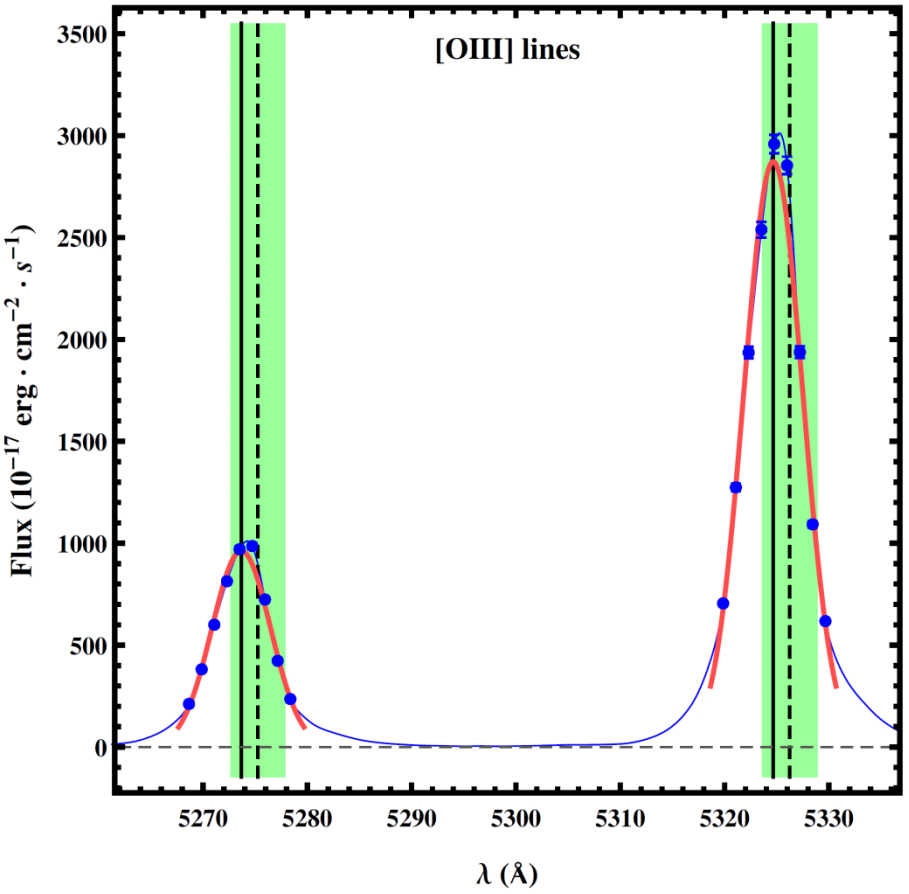
Methodology

Line positions



[OIII] lines

Real pixels (with errors)

Gaussian fits

Expected line position

Error for $\Delta\alpha/\alpha$ **~ 10^-3,-4**

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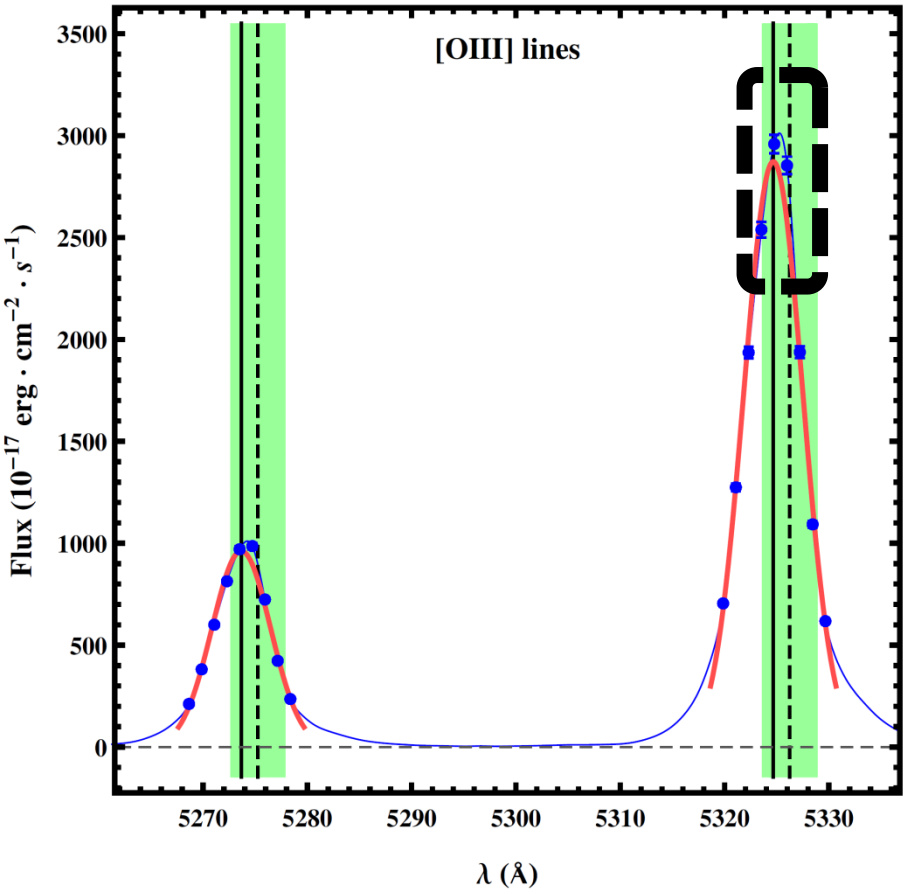
Methodology

Line positions



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Methodology

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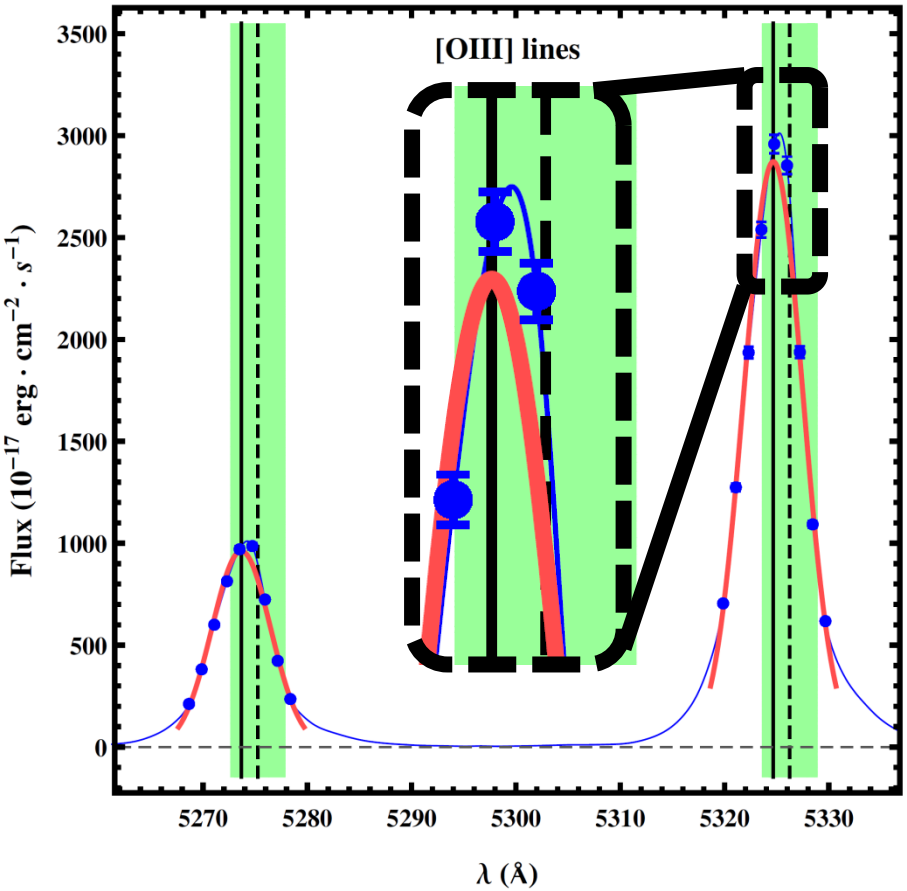

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Methodology

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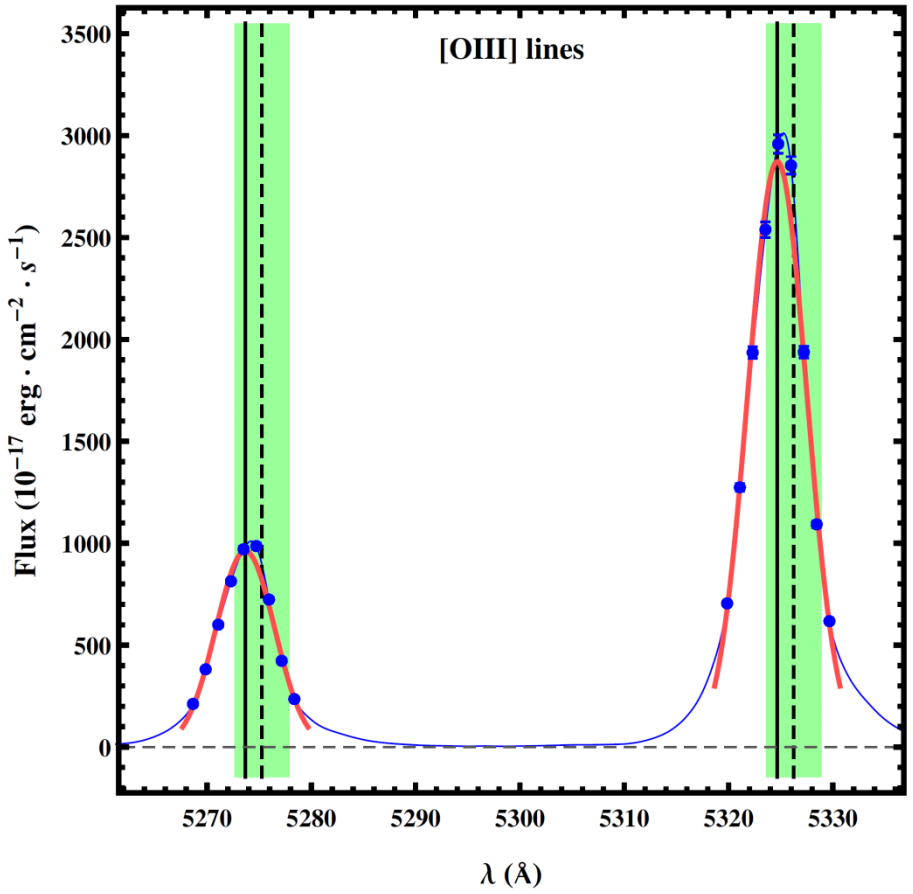
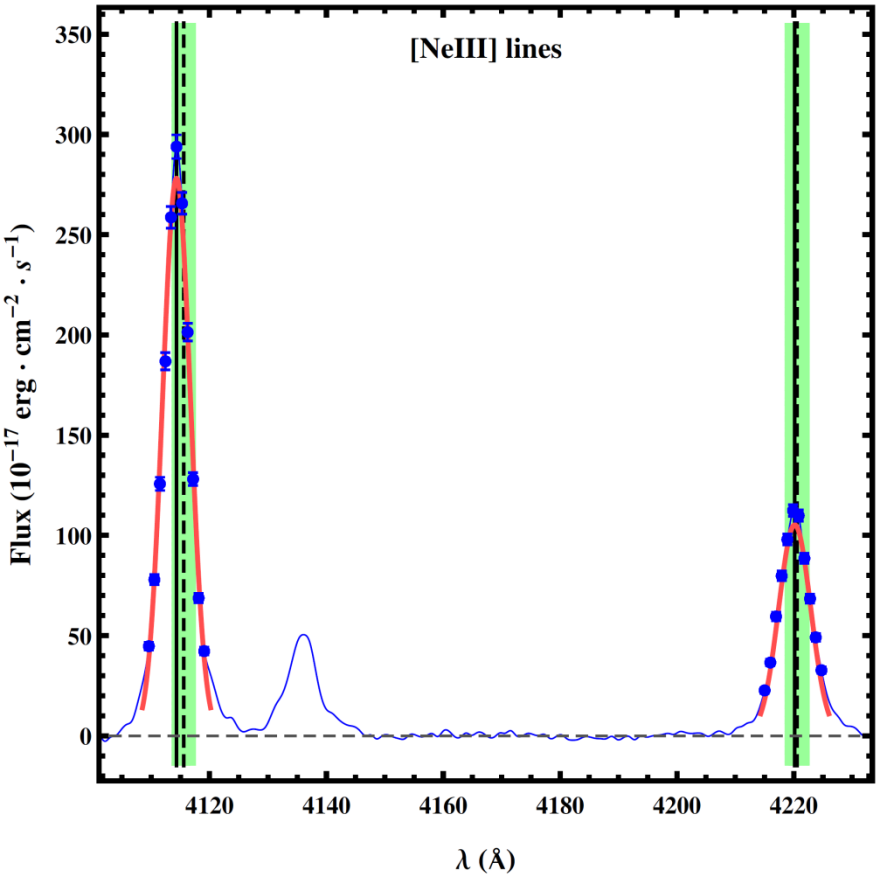


[OIII] lines



[NeIII] lines

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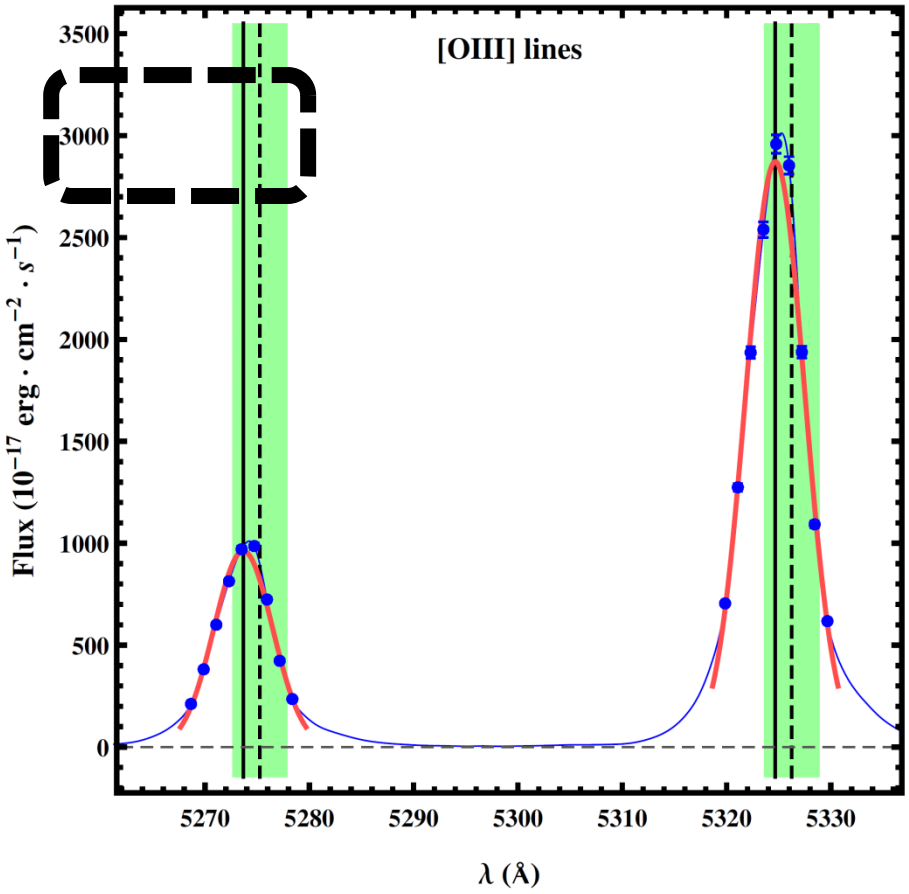
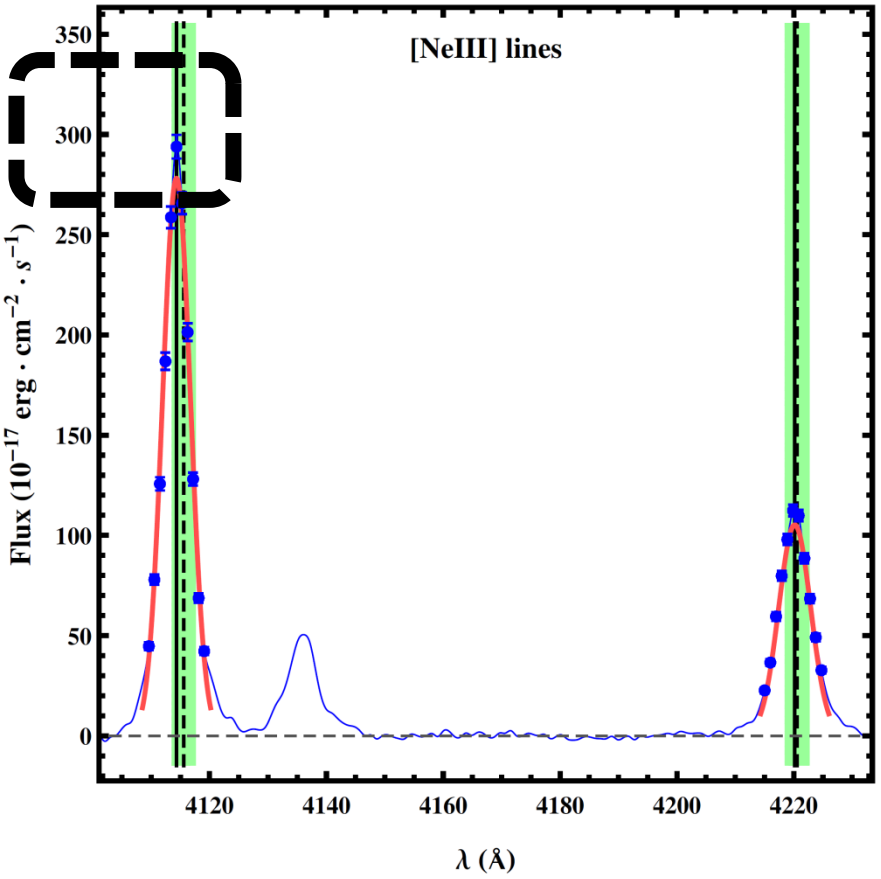
Methodology

Line positions



[OIII] lines



[NeIII] lines

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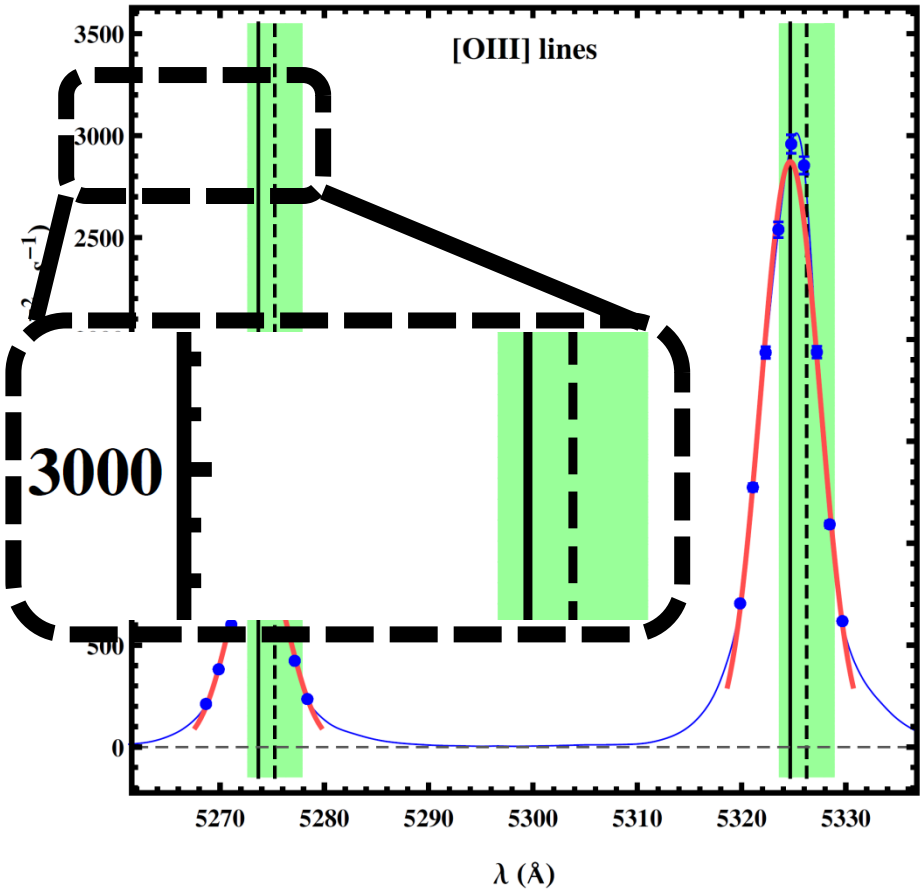
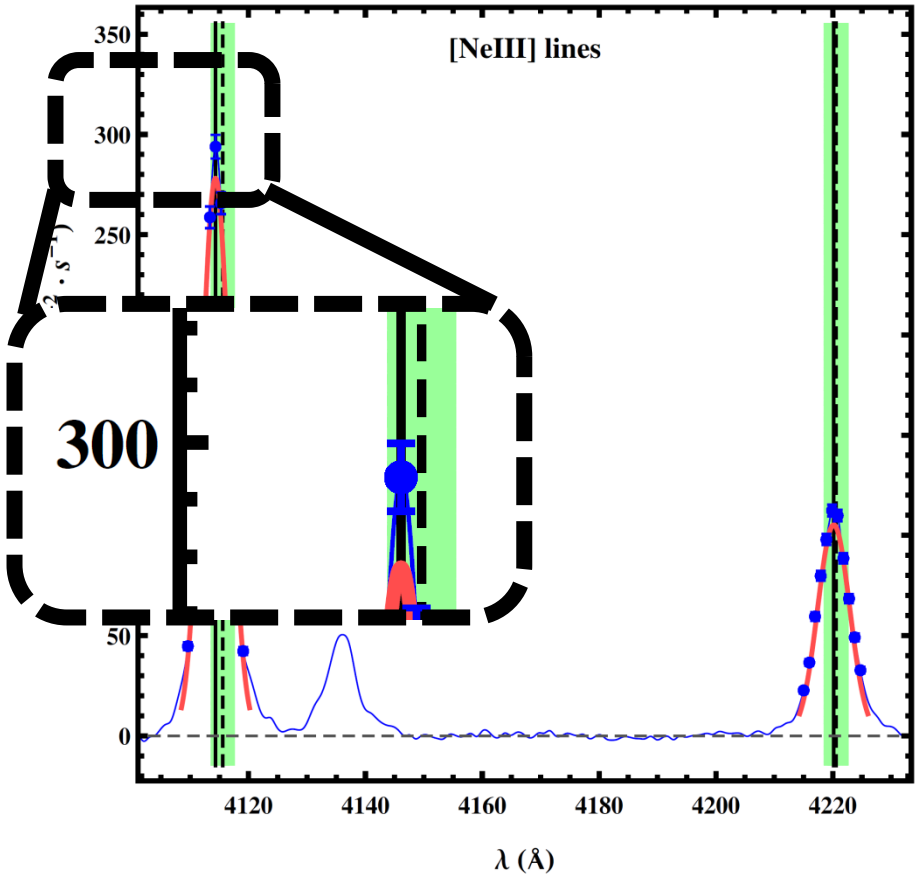
17th April 2015
12th MultiDark

Methodology

Line positions



[OIII] lines



[NeIII] lines

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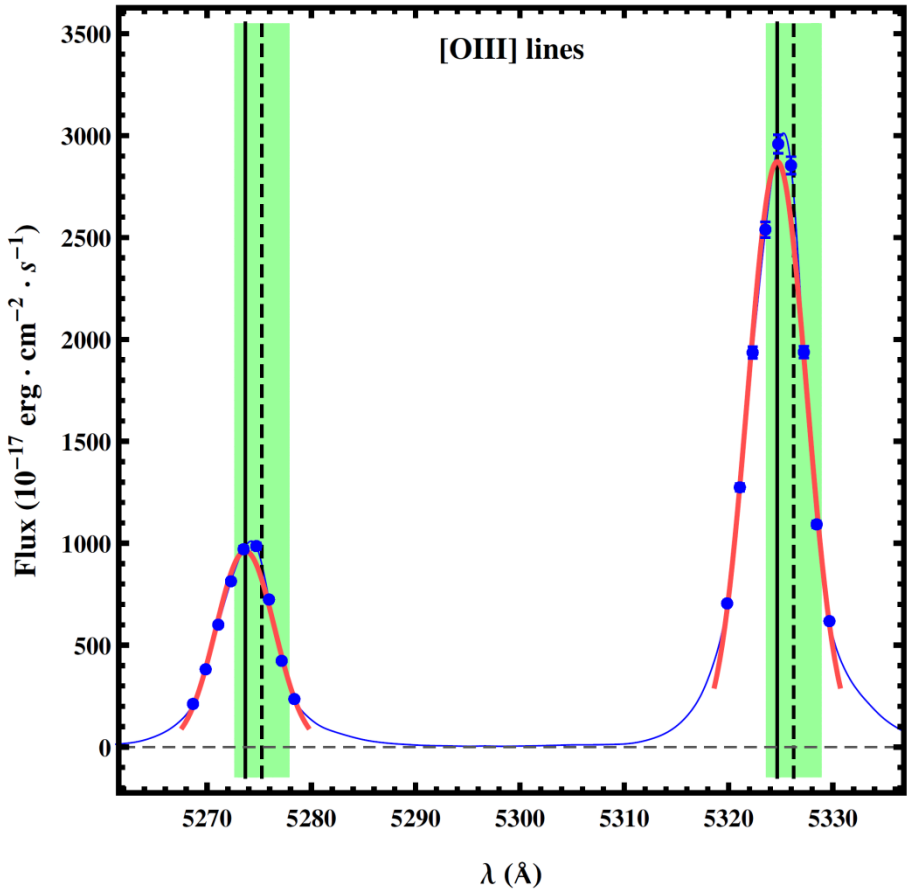
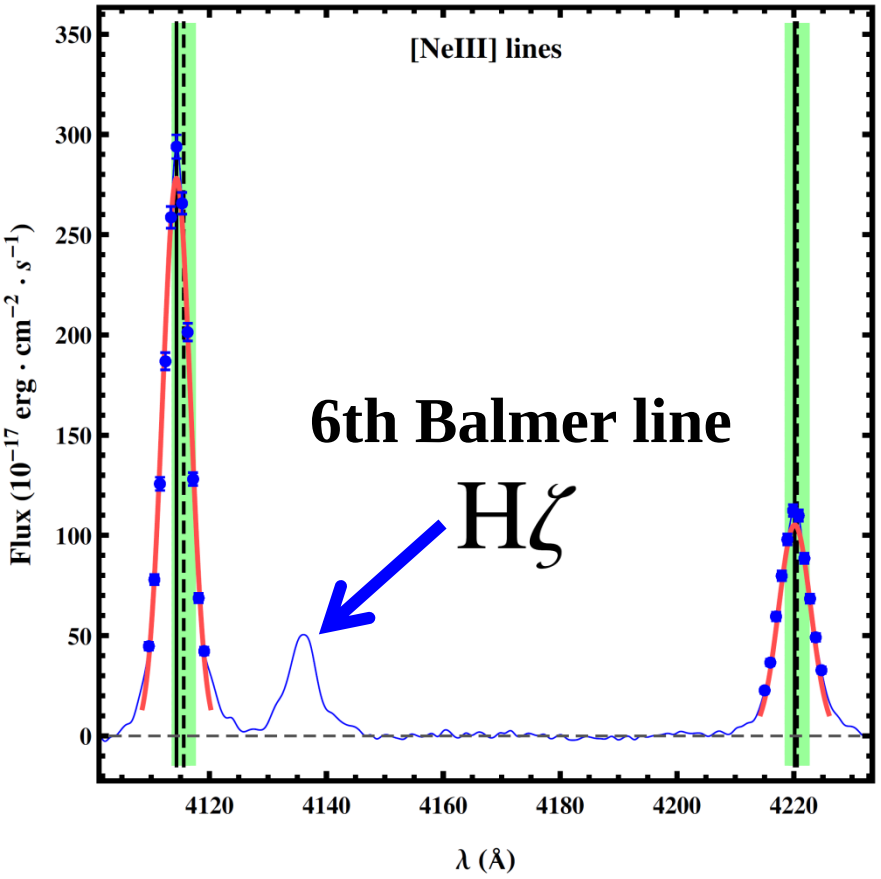
17th April 2015
12th MultiDark

Methodology

Line positions



[OIII] lines



[NeIII] lines

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Sample selection

~300,000

Criteria

- **Redshift** $z < 1$

~45,000

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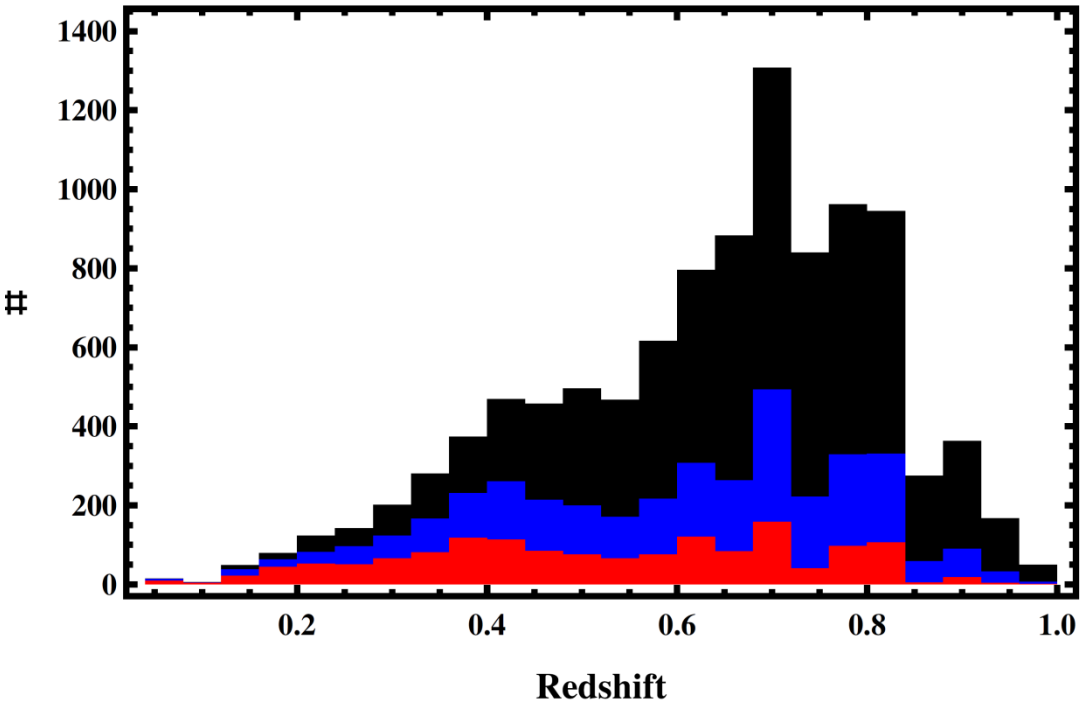
Sample selection

~300,000

Criteria

- **Redshift** $z < 1$ ~45,000
- **Noise** $S/N_{[OIII]5008} > 10$ ~13,000



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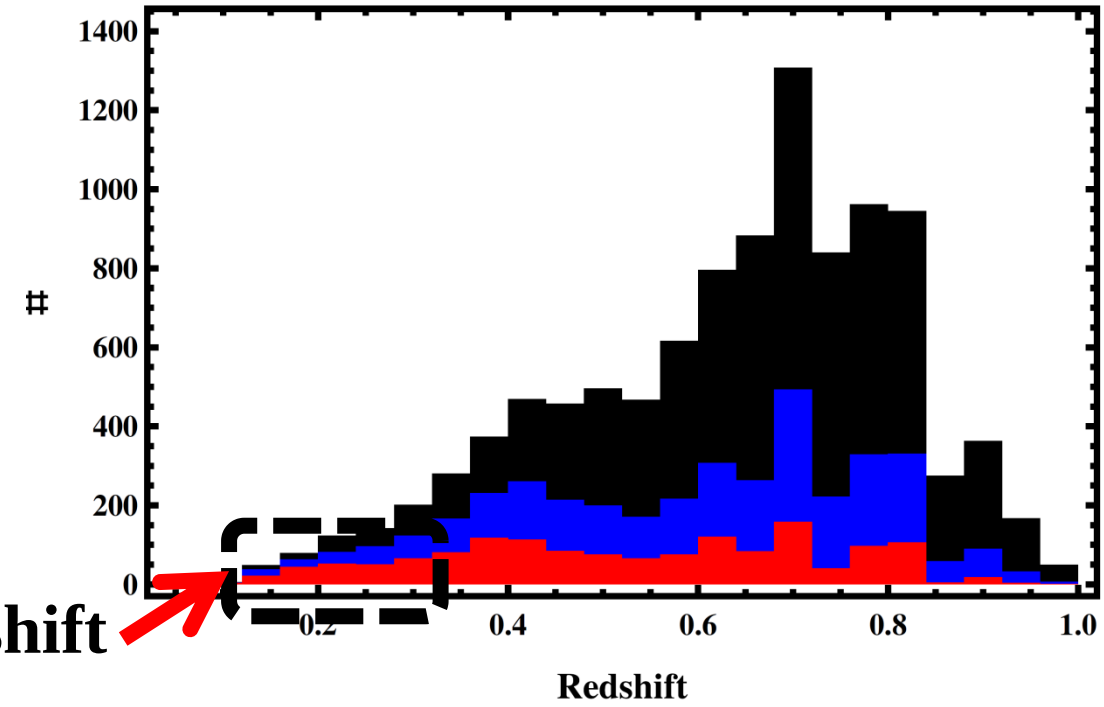
12th MultiDark

Sample selection

Criteria

- **Redshift** $z < 1$ **~300,000**
- **Noise** $S/N_{[OIII]5008} > 10$ **~45,000**

~13,000



Low redshift

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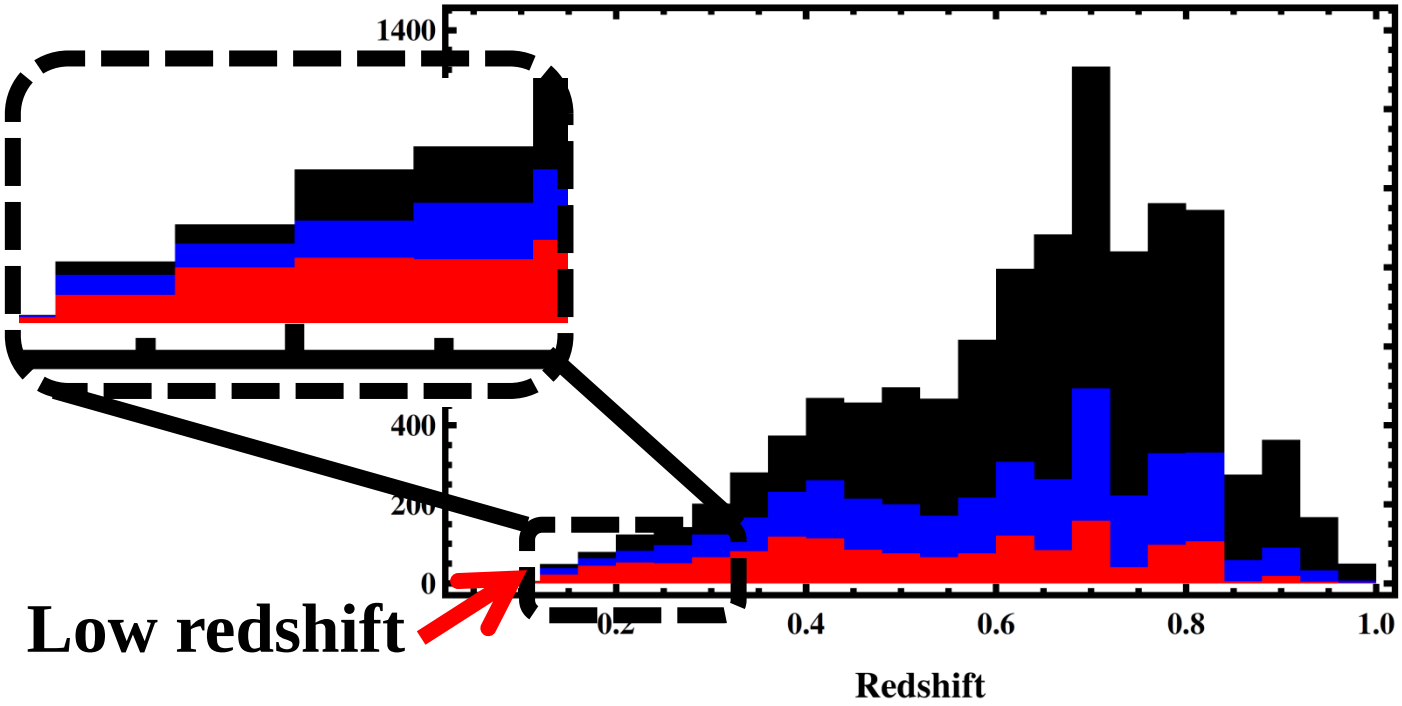
Sample selection

~300,000

Criteria

- **Redshift** $z < 1$ ~45,000
- **Noise** $S/N_{[OIII]5008} > 10$ ~13,000



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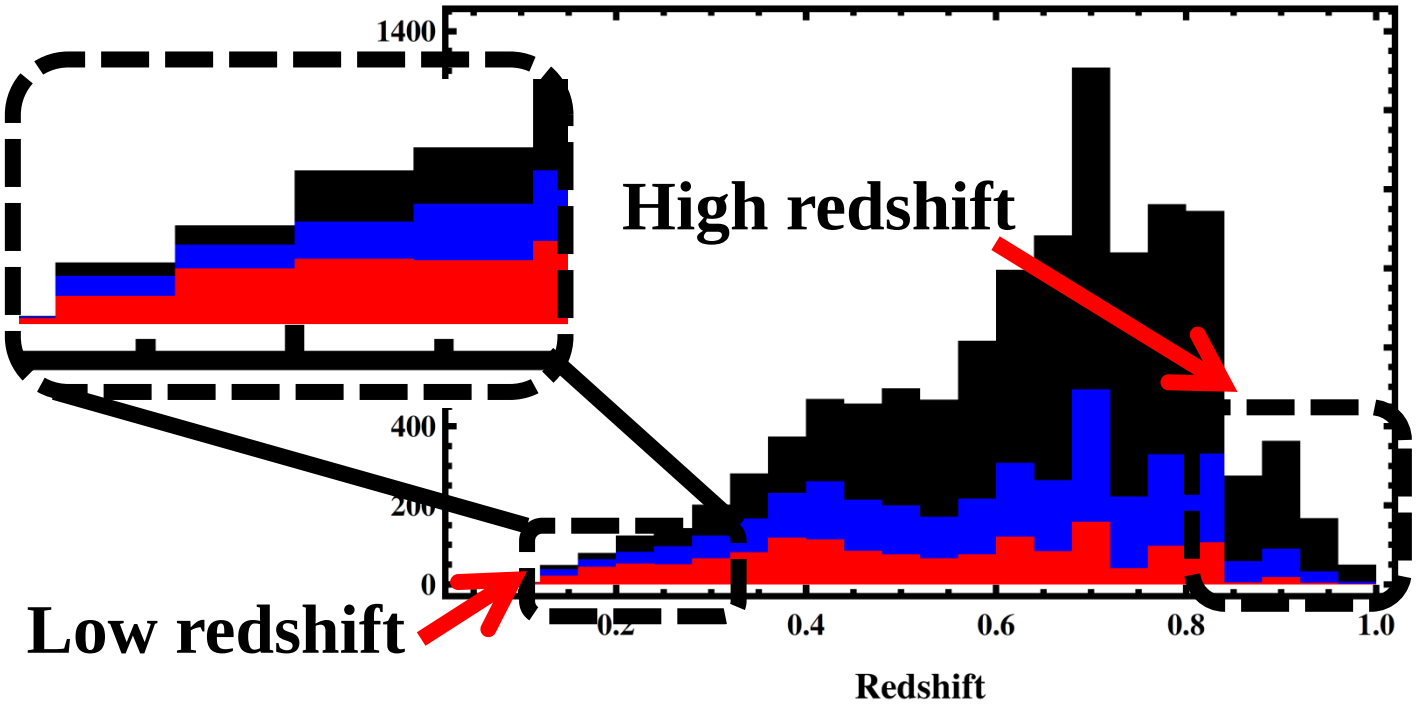
Sample selection

~300,000

Criteria

- **Redshift** $z < 1$ ~45,000
- **Noise** $S/N_{[OIII]5008} > 10$ ~13,000



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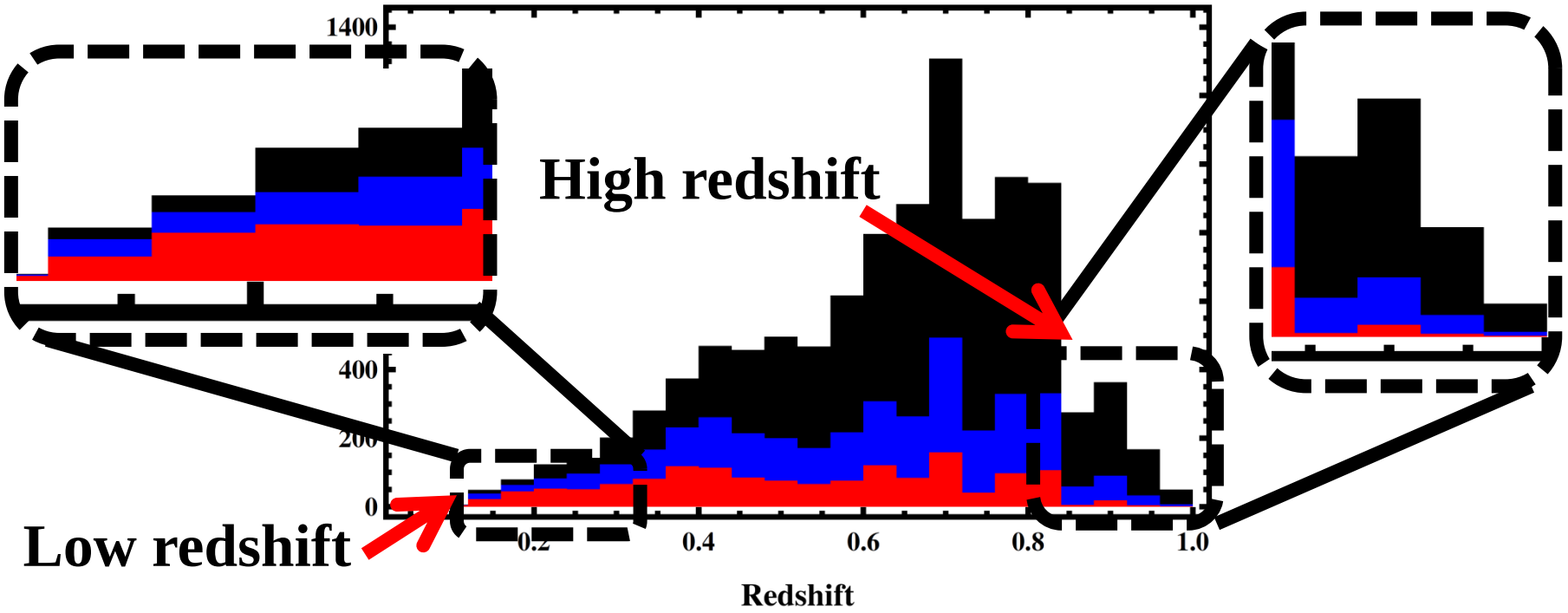
12th MultiDark

Sample selection

~300,000

Criteria

- **Redshift** $z < 1$ ~45,000
- **Noise** $S/N_{[OIII]5008} > 10$ ~13,000



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12th MultiDark

Sample selection

~300,000

Criteria

- **Redshift** $z < 1$ — ~45,000
- **Noise** $S/N_{[OIII]5008} > 10$ — ~13,000
- **Non-converging Gaussian fits** — ~12,000

Franco D. Albareti
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Sample selection

~300,000

Criteria

- **Redshift** $z < 1$ — ~45,000
- **Noise** $S/N_{[\mathrm{OIII}]5008} > 10$ — ~13,000
- **Non-converging Gaussian fits** — ~12,000
- **Outlier points** $> 2.5\,\sigma$ — ~11,000

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Sample selection

~300,000

Criteria

- **Redshift** $z < 1$ — ~45,000
- **Noise** $S/N_{[\mathrm{OIII}]5008} > 10$ — ~13,000
- **Non-converging Gaussian fits** — ~12,000
- **Outlier points** $> 2.5\,\sigma$ $(> 4\,\sigma)$ — ~11,000

Franco D. Albareti
17th April 2015
12th MultiDark

Sample selection

~300,000

Criteria

- **Redshift** $z < 1$ — ~45,000
- **Noise** $S/N_{[\mathrm{OIII}]5008} > 10$ — ~13,000
- **Non-converging Gaussian fits** — ~12,000
- **Outlier points** $> 2.5\,\sigma$ $(> 4\,\sigma)$ — ~11,000

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17th April 2015
12th MultiDark

Sample selection

~300,000

Criteria

- **Redshift** $z < 1$ — ~45,000
- **Noise** $S/N_{[\mathrm{OIII}]5008} > 10$ — ~13,000
- **Non-converging Gaussian fits** — ~12,000
- **Outlier points** $> 2.5\,\sigma$ $(> 4\,\sigma)$ — ~11,000

4%

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17th April 2015
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Sample selection

~300,000

Criteria

- **Redshift** $z < 1$ — ~45,000
- **Noise** $S/N_{[\mathrm{OIII}]5008} > 10$ — ~13,000
- **Non-converging Gaussian fits** — ~12,000
- **Outlier points** $> 2.5\,\sigma$ $(> 4\,\sigma)$ — ~11,000

4%

Mild constraints

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17th April 2015
12th MultiDark

Sample selection

~300,000

Criteria

- **Redshift** $z < 1$ — ~45,000
- **Noise** $S/N_{[\mathrm{OIII}]5008} > 10$ — ~13,000
- **Non-converging Gaussian fits** — ~12,000
- **Outlier points** $> 2.5\,\sigma$ $(> 4\,\sigma)$ — ~11,000

4%

Mild constraints

$$\Delta\alpha/\alpha = (1.4 \pm 2.3) \times 10^{-5}$$

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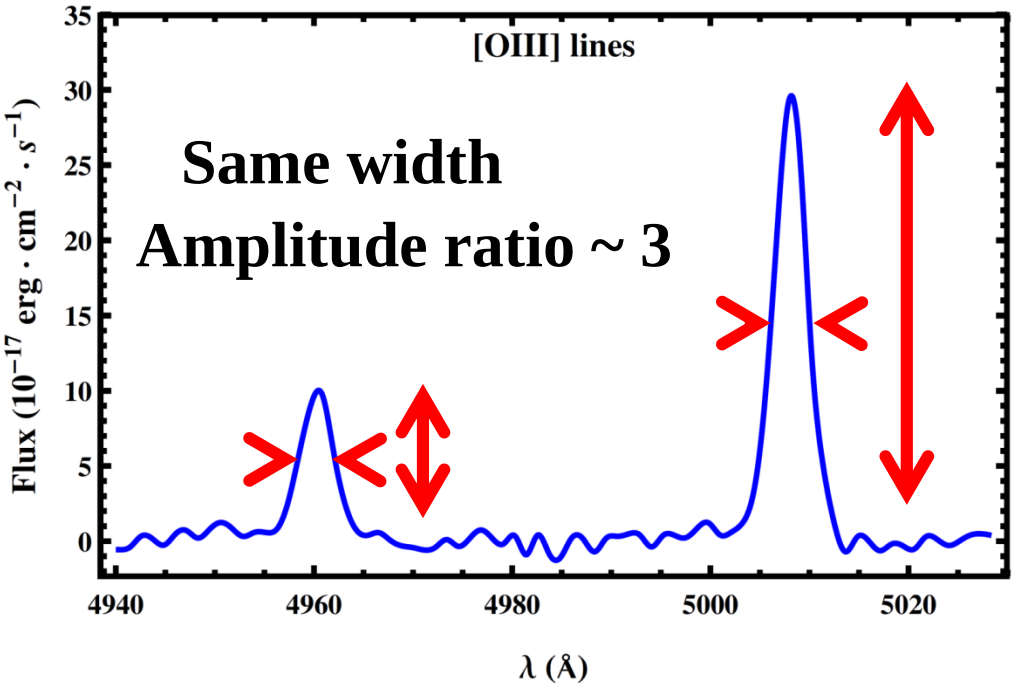
12th MultiDark

Results

Systematics?

$$\Delta\alpha/\alpha = (1.4 \pm 2.3) \times 10^{-5}$$

- **Misidentification of the lines?**



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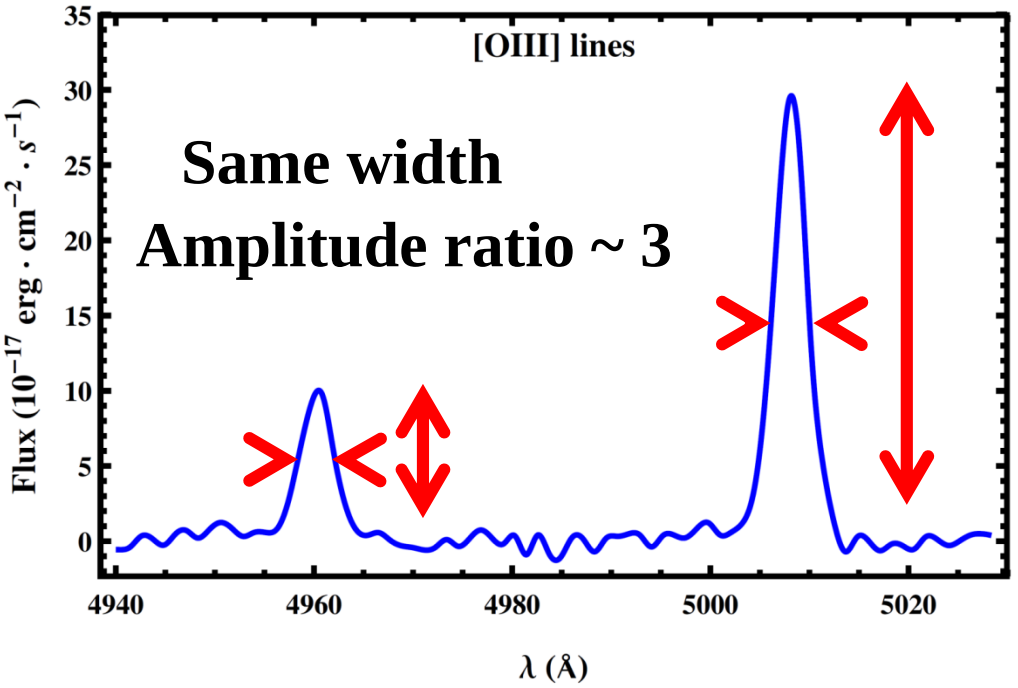
Results

Systematics?

$$\Delta\alpha/\alpha = (1.4 \pm 2.3) \times 10^{-5}$$

- **Misidentification of the lines OK**



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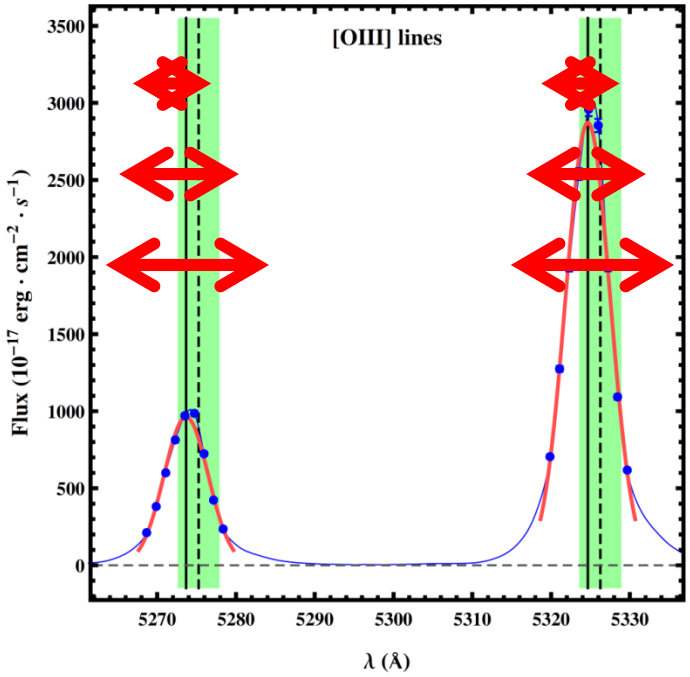
Results

Systematics?

$$\Delta\alpha/\alpha = (1.4 \pm 2.3) \times 10^{-5}$$

- **Misidentification of the lines OK**
- **Interval for the Gaussian fit?**



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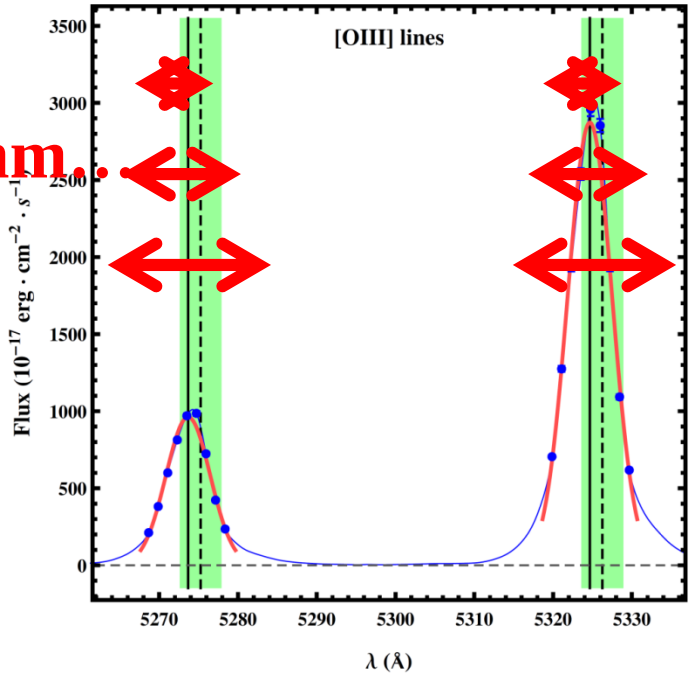
Results

Systematics?

$$\Delta\alpha/\alpha = (1.4 \pm 2.3) \times 10^{-5}$$

- **Misidentification of the lines OK**
- **Interval for the Gaussian fits? mmm...**



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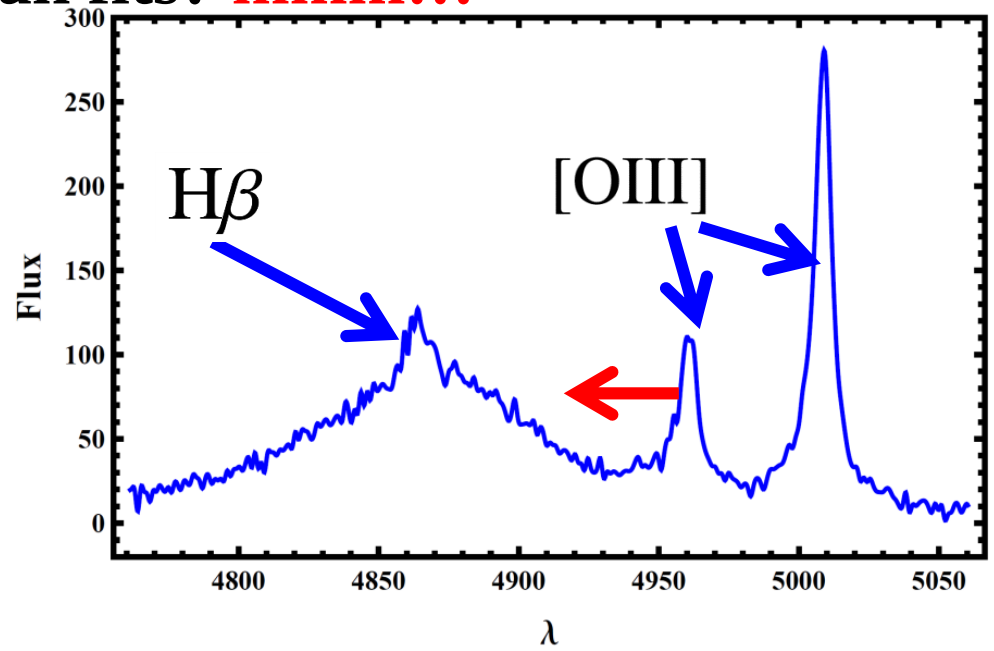
Results

Systematics?

$$\Delta\alpha/\alpha = (1.4 \pm 2.3) \times 10^{-5}$$

- **Misidentification of the lines OK**
- **Interval for the Gaussian fits? mmm…**
- **Hβ contamination?**

$$\Delta\alpha/\alpha \uparrow$$



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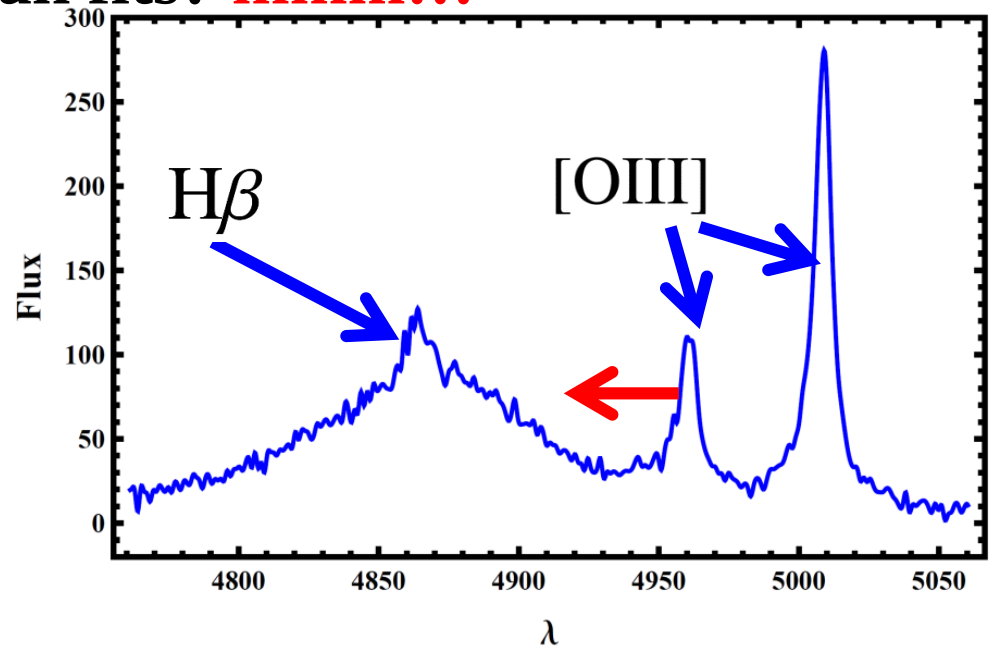
Results

Systematics?

$$\Delta\alpha/\alpha = (1.4 \pm 2.3) \times 10^{-5}$$

- **Misidentification of the lines OK**
- **Interval for the Gaussian fits? mmm…**
- **Hβ contamination OK**

$$\Delta\alpha/\alpha \uparrow$$



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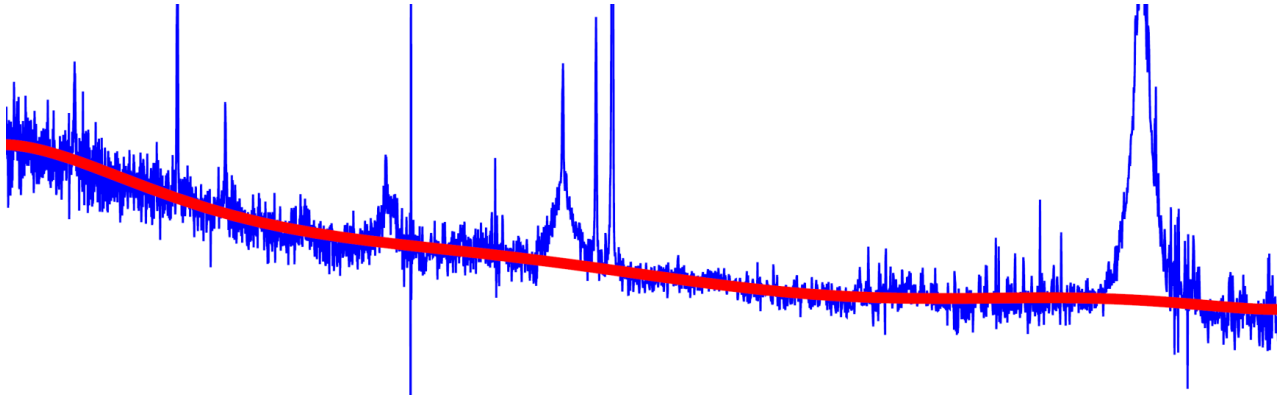
Results

Systematics?

$$\Delta\alpha/\alpha = (1.4 \pm 2.3) \times 10^{-5}$$

- **Misidentification of the lines OK**
- **Interval for the Gaussian fits? mmm…**
- **Hβ contamination OK**
- **Continuum subtraction?**



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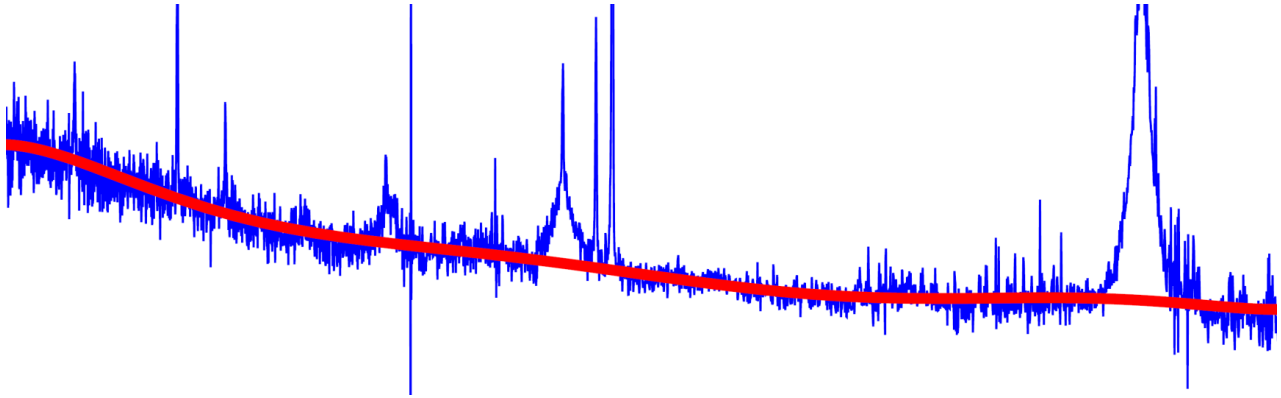
Results

Systematics?

$$\Delta\alpha/\alpha = (1.4 \pm 2.3) \times 10^{-5}$$

- **Misidentification of the lines OK**
- **Interval for the Gaussian fits? mmm…**
- **Hβ contamination OK**
- **Continuum subtraction OK**



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Results

Systematics?

$$\Delta\alpha/\alpha = (1.4 \pm 2.3) \times 10^{-5}$$

- **Misidentification of the lines OK**
- **Interval for the Gaussian fits? mmm…**
- **Hβ contamination OK**
- **Continuum subtraction OK**
- **Different fitting methods?**

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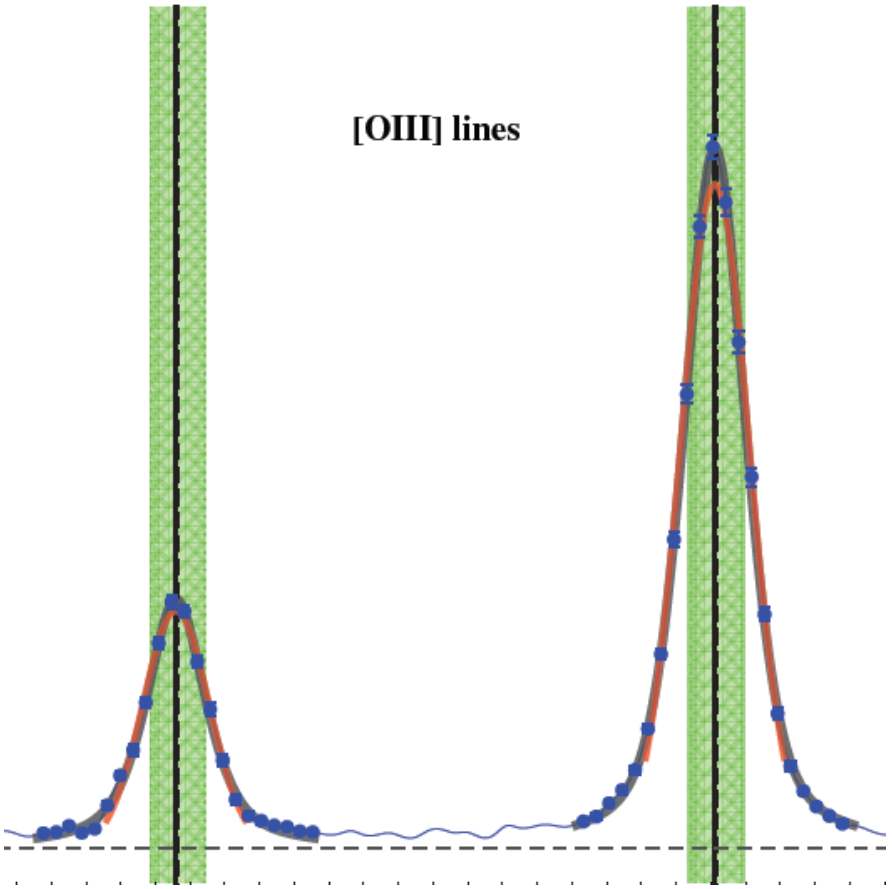
Results

Systematics?

$$\Delta\alpha/\alpha = (1.4 \pm 2.3) \times 10^{-5}$$

- **Different fitting methods?**



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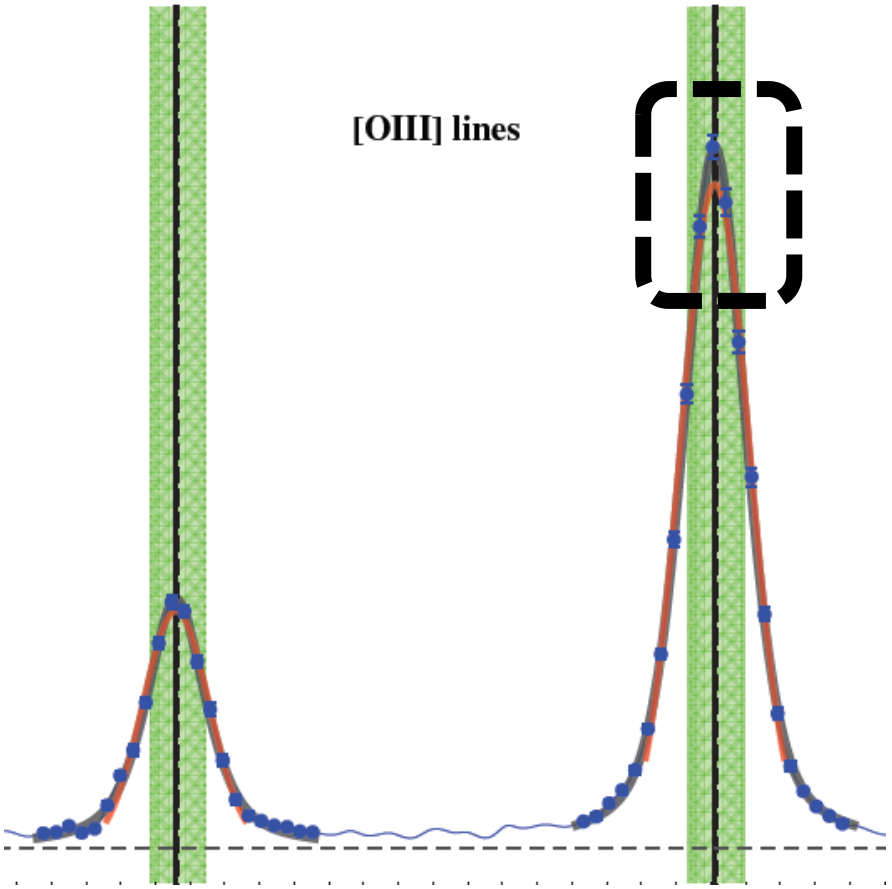
Results

Systematics?

$$\Delta\alpha/\alpha = (1.4 \pm 2.3) \times 10^{-5}$$

- Different fitting methods?



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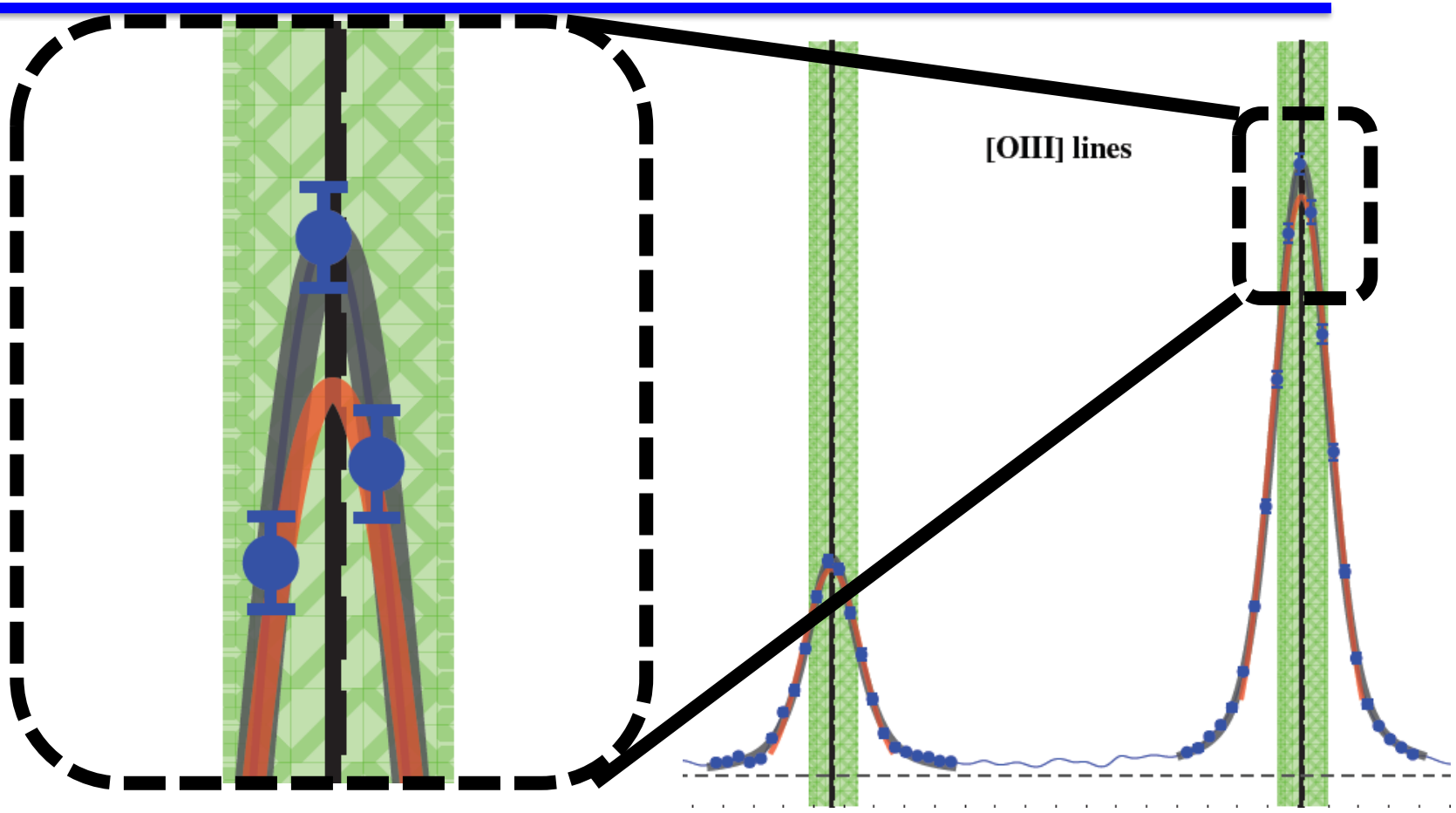
Results

Systematics?

$$\Delta\alpha/\alpha = (1.4 \pm 2.3) \times 10^{-5}$$



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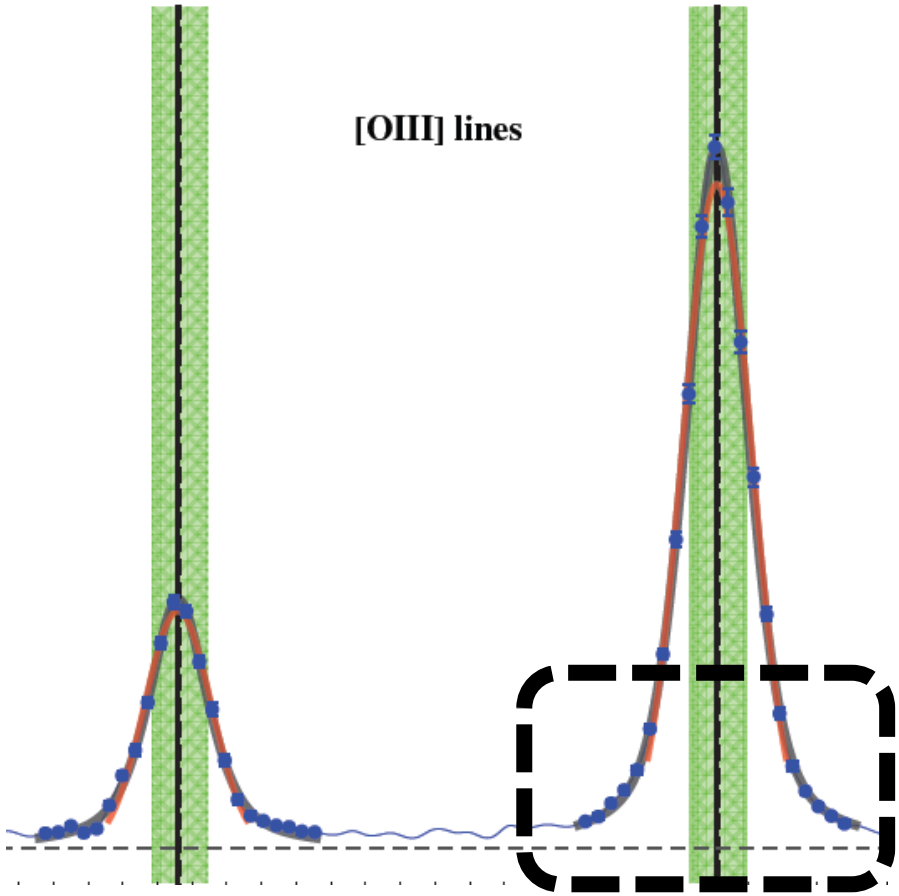
Results

Systematics?

$$\Delta\alpha/\alpha = (1.4 \pm 2.3) \times 10^{-5}$$

- Different fitting methods?



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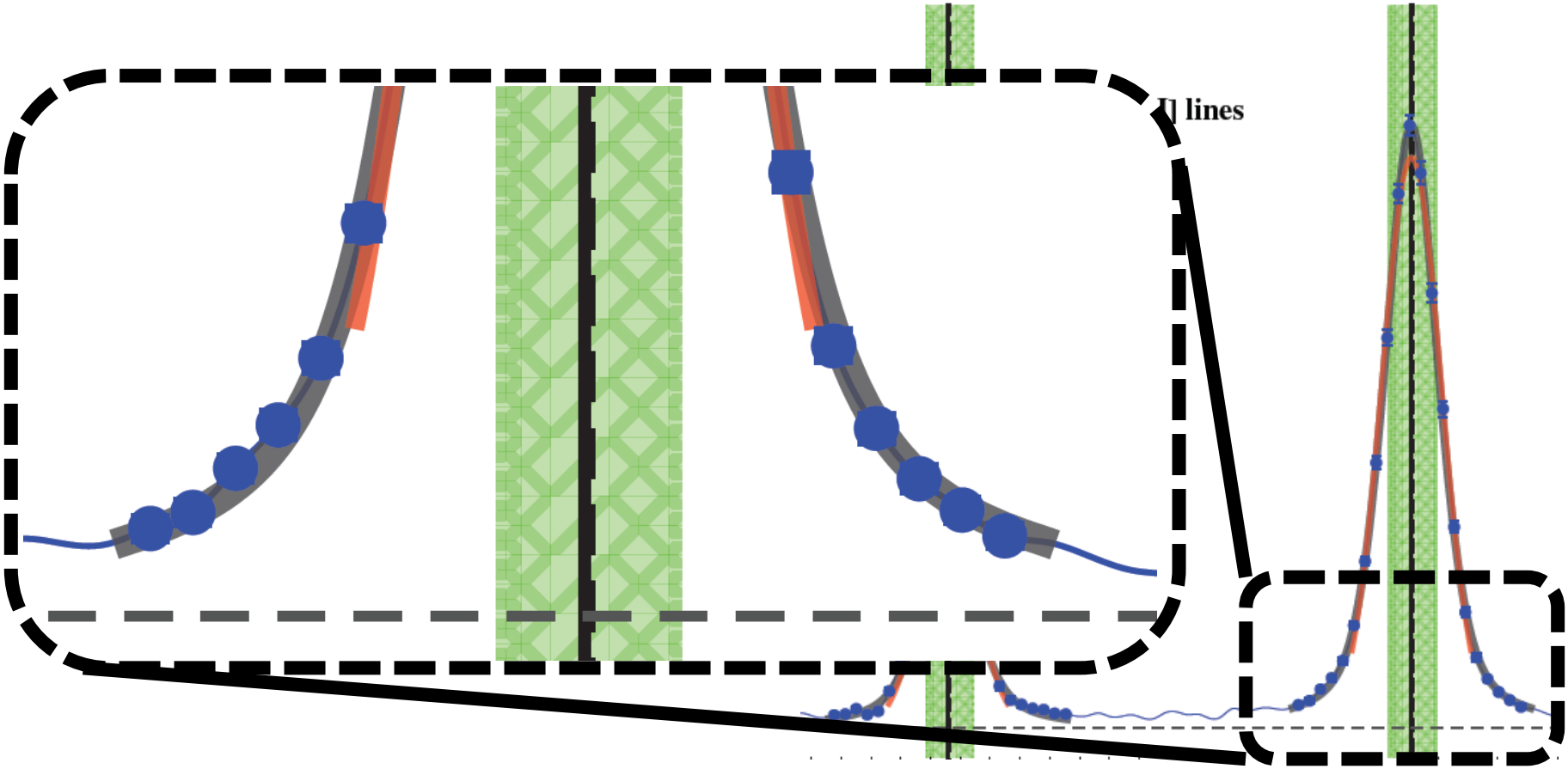
Results

Systematics?

$$\Delta\alpha/\alpha = (1.4 \pm 2.3) \times 10^{-5}$$



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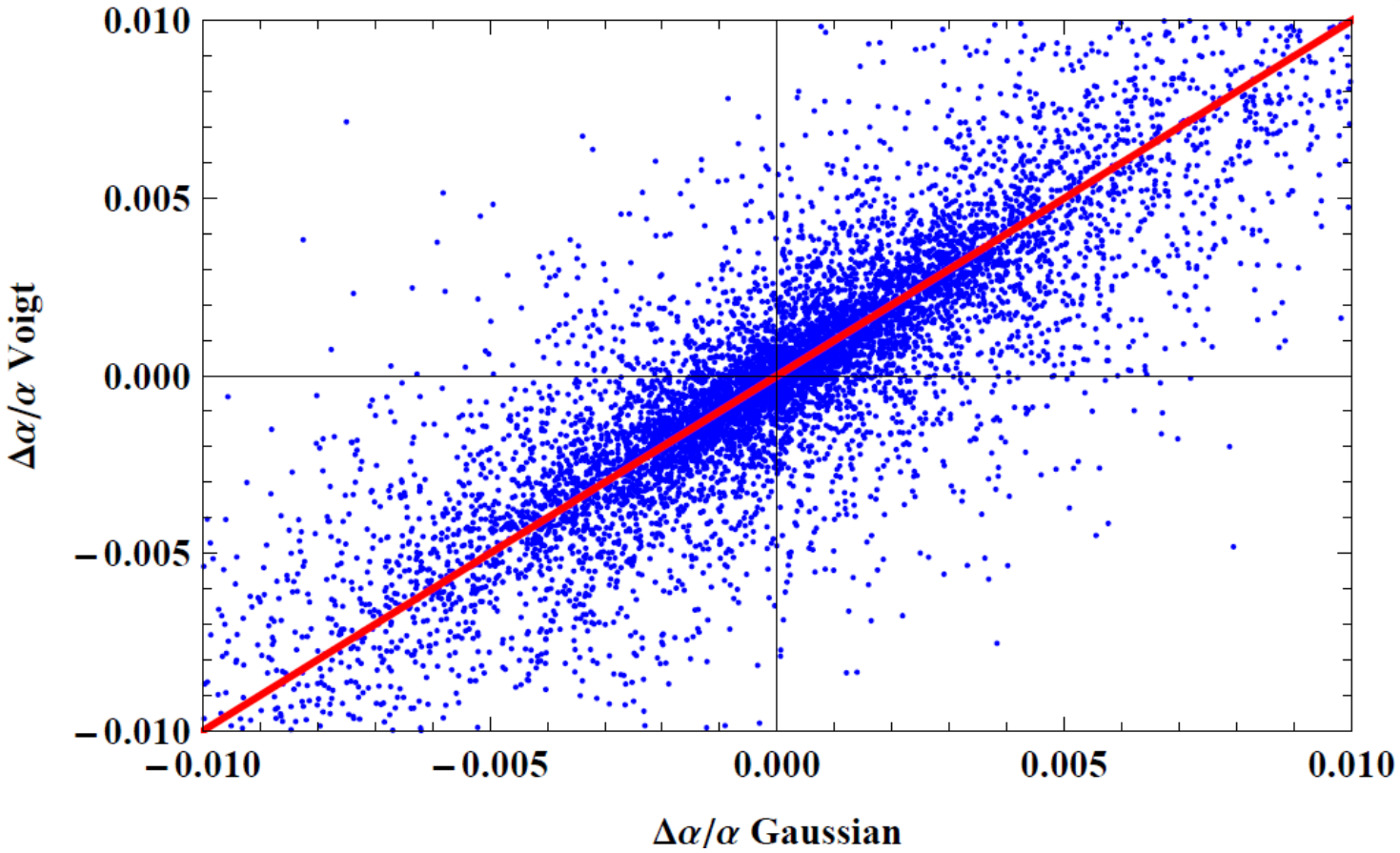
Results

Systematics?

$$\Delta\alpha/\alpha = (1.4 \pm 2.3) \times 10^{-5}$$



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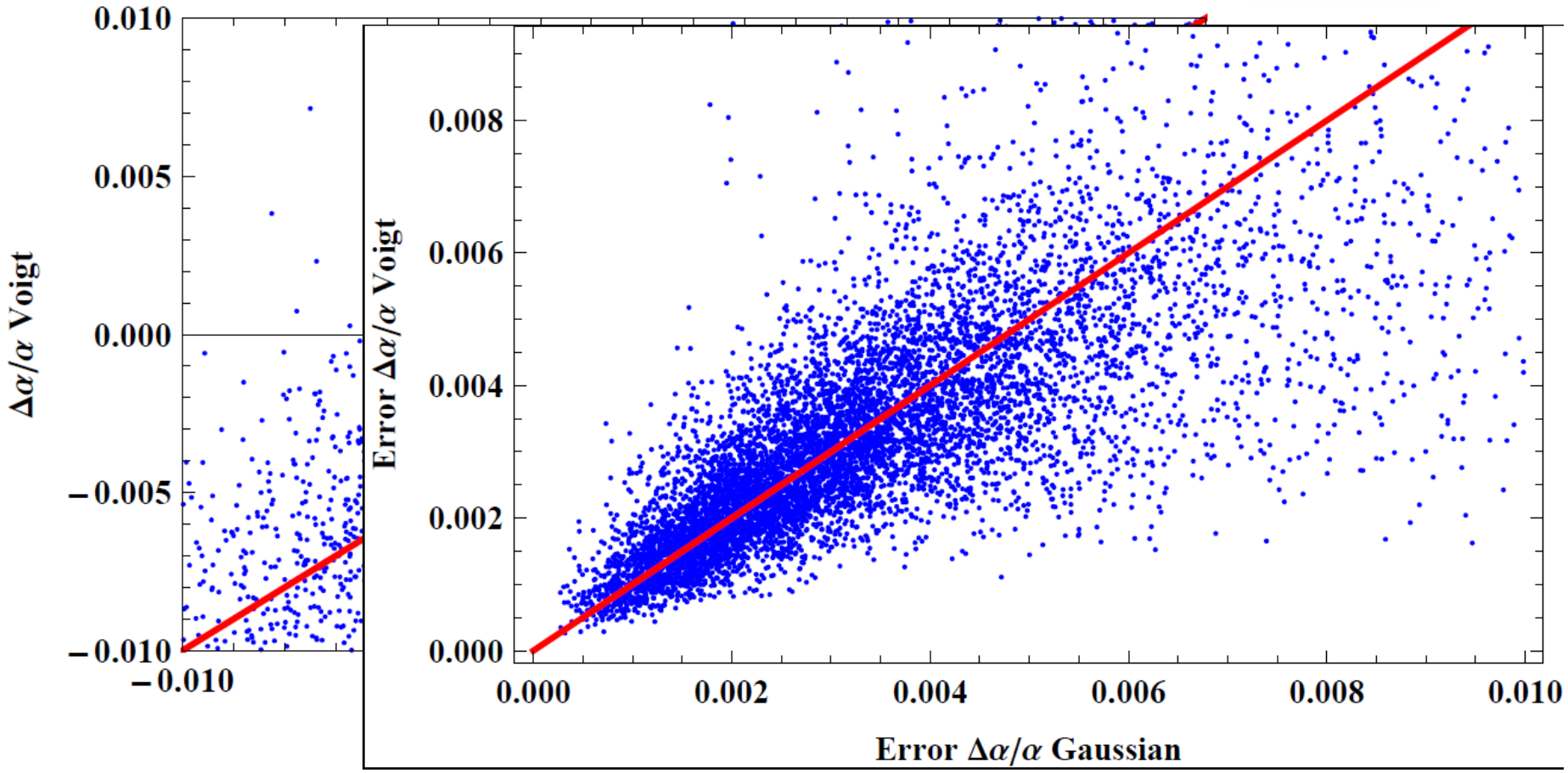
Results

Systematics?

$$\Delta\alpha/\alpha = (1.4 \pm 2.3) \times 10^{-5}$$



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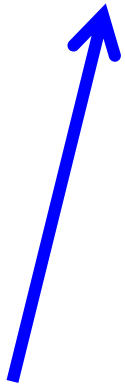
Results

Systematics?

$$\Delta\alpha/\alpha = (1.4 \pm 2.3) \times 10^{-5}$$

- **Misidentification of the lines OK**
- **Interval for the Gaussian fits mmm…**
- **Hβ contamination OK**
- **Continuum subtraction OK**
- **Different fitting methods OK**



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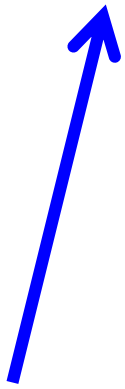
Results

Systematics?

$$\Delta\alpha/\alpha = (1.4 \pm 2.3) \times 10^{-5}$$

- **Misidentification of the lines OK**
- **Interval for the Gaussian fits OK**
- **Hβ contamination OK**
- **Continuum subtraction OK**
- **Different fitting methods OK**



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Systematics

- **Misidentification of the lines**

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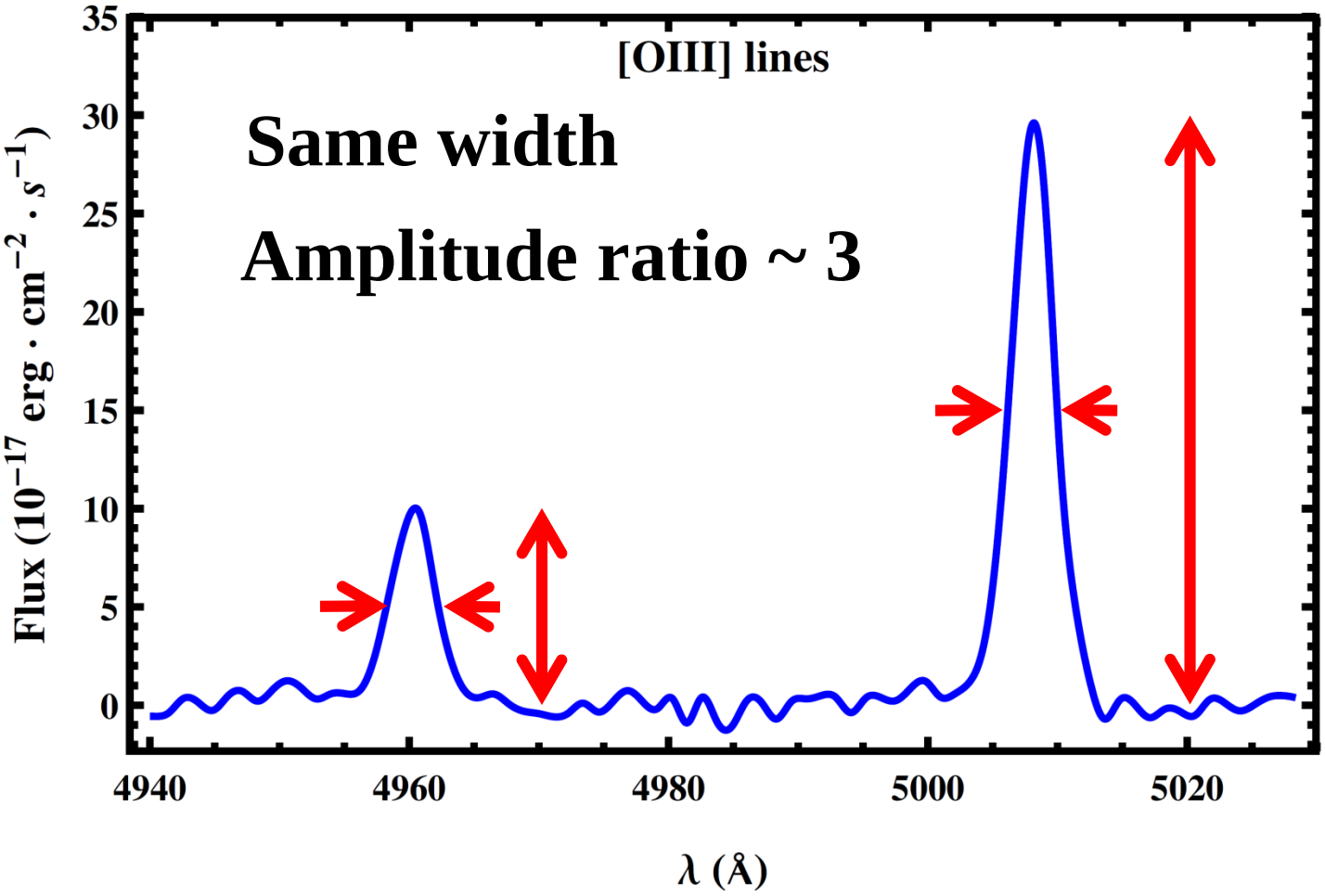
Systematics

- **Misidentification of the lines**



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Systematics

- **Misidentification of the lines**

$\sigma_{4960}/\sigma_{5008} - 1$ (%)	# QSO spectra	redshift	$\Delta\alpha/\alpha$ ($\times 10^{-5}$)
$< 50\%$	10,028	0.56 ± 0.21	1.6 ± 2.3
$< 25\%$	8,877	0.56 ± 0.21	1.9 ± 2.3
$< 10\%$	5,846	0.56 ± 0.21	1.7 ± 2.5
$< 5\%$	3,458	0.54 ± 0.22	-0.9 ± 3.0
$[A \times \lambda]_{5008} / [A \times \lambda]_{4960}$	# QSO spectra	redshift	$\Delta\alpha/\alpha$ ($\times 10^{-5}$)
3.00 ± 0.50	8,308	0.56 ± 0.21	1.8 ± 2.4
3.00 ± 0.25	5,752	0.55 ± 0.21	-0.2 ± 2.6
3.00 ± 0.10	2,677	0.54 ± 0.21	-0.4 ± 3.4
3.00 ± 0.05	1,411	0.52 ± 0.22	2.9 ± 4.5

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Systematics

- **Misidentification of the lines**

$\sigma_{4960}/\sigma_{5008} - 1\,(\%)$	# QSO spectra	redshift	$\Delta\alpha/\alpha\ (\times 10^{-5})$
$< 50\%$	10,028	0.56 ± 0.21	1.6 ± 2.3
$< 25\%$	8,877	0.56 ± 0.21	1.9 ± 2.3
$< 10\%$	5,846	0.56 ± 0.21	1.7 ± 2.5
$< 5\%$	3,458	0.54 ± 0.22	-0.9 ± 3.0
$[A \times \lambda]_{5008}\ /\ [A \times \lambda]_{4960}$	# QSO spectra	redshift	$\Delta\alpha/\alpha\ (\times 10^{-5})$
3.00 ± 0.50	8,308	0.56 ± 0.21	1.8 ± 2.4
3.00 ± 0.25	5,752	0.55 ± 0.21	-0.2 ± 2.6
3.00 ± 0.10	2,677	0.54 ± 0.21	-0.4 ± 3.4
3.00 ± 0.05	1,411	0.52 ± 0.22	2.9 ± 4.5

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12th MultiDark

Systematics

- **Misidentification of the lines**

$\sigma_{4960}/\sigma_{5008} - 1$ (%)	# QSO spectra	redshift	$\Delta\alpha/\alpha$ ($\times 10^{-5}$)
$< 50\%$	10,028	0.56 ± 0.21	1.6 ± 2.3
$< 25\%$	8,877	0.56 ± 0.21	1.9 ± 2.3
$< 10\%$	5,846	0.56 ± 0.21	1.7 ± 2.5
$< 5\%$	3,458	0.54 ± 0.22	-0.9 ± 3.0
$[A \times \lambda]_{5008} / [A \times \lambda]_{4960}$	# QSO spectra	redshift	$\Delta\alpha/\alpha$ ($\times 10^{-5}$)
3.00 ± 0.50	8,308	0.56 ± 0.21	1.8 ± 2.4
3.00 ± 0.25	5,752	0.55 ± 0.21	-0.2 ± 2.6
3.00 ± 0.10	2,677	0.54 ± 0.21	-0.4 ± 3.4
3.00 ± 0.05	1,411	0.52 ± 0.22	2.9 ± 4.5

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12th MultiDark

Systematics

- **Misidentification of the lines**

$\sigma_{4960}/\sigma_{5008} - 1\,(\%)$	# QSO spectra	redshift	$\Delta\alpha/\alpha\ (\times 10^{-5})$
$< 50\%$	10,028	0.56 ± 0.21	1.6 ± 2.3
$< 25\%$	8,877	0.56 ± 0.21	1.9 ± 2.3
$< 10\%$	5,846	0.56 ± 0.21	1.7 ± 2.5
$< 5\%$	3,458	0.54 ± 0.22	-0.9 ± 3.0

$[A \times \lambda]_{5008} / [A \times \lambda]_{4960}$	# QSO spectra	redshift	$\Delta\alpha/\alpha\ (\times 10^{-5})$
3.00 ± 0.50	8,308	0.56 ± 0.21	1.8 ± 2.4
3.00 ± 0.25	5,752	0.55 ± 0.21	-0.2 ± 2.6
3.00 ± 0.10	2,677	0.54 ± 0.21	-0.4 ± 3.4
3.00 ± 0.05	1,411	0.52 ± 0.22	2.9 ± 4.5

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12th MultiDark

Systematics

- **Misidentification of the lines**

$\sigma_{4960}/\sigma_{5008} - 1\,(\%)$	# QSO spectra	redshift	$\Delta\alpha/\alpha\ (\times 10^{-5})$	
$< 50\%$	10,028	0.56 ± 0.21	1.6 ± 2.3	OK
$< 25\%$	8,877	0.56 ± 0.21	1.9 ± 2.3	
$< 10\%$	5,846	0.56 ± 0.21	1.7 ± 2.5	
$< 5\%$	3,458	0.54 ± 0.22	-0.9 ± 3.0	

$[A \times \lambda]_{5008} / [A \times \lambda]_{4960}$	# QSO spectra	redshift	$\Delta\alpha/\alpha\ (\times 10^{-5})$	
3.00 ± 0.50	8,308	0.56 ± 0.21	1.8 ± 2.4	OK
3.00 ± 0.25	5,752	0.55 ± 0.21	-0.2 ± 2.6	
3.00 ± 0.10	2,677	0.54 ± 0.21	-0.4 ± 3.4	
3.00 ± 0.05	1,411	0.52 ± 0.22	2.9 ± 4.5	

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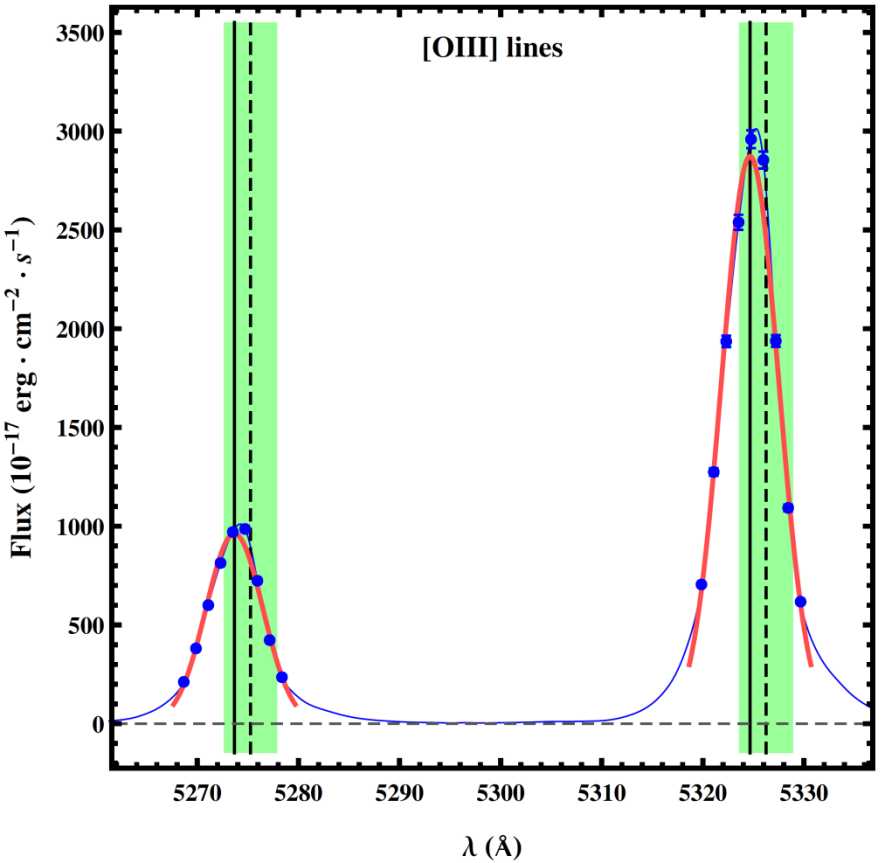
17th April 2015
12th MultiDark

Systematics

- **Misidentification of the lines OK**
- **Interval for the Gaussian fits**



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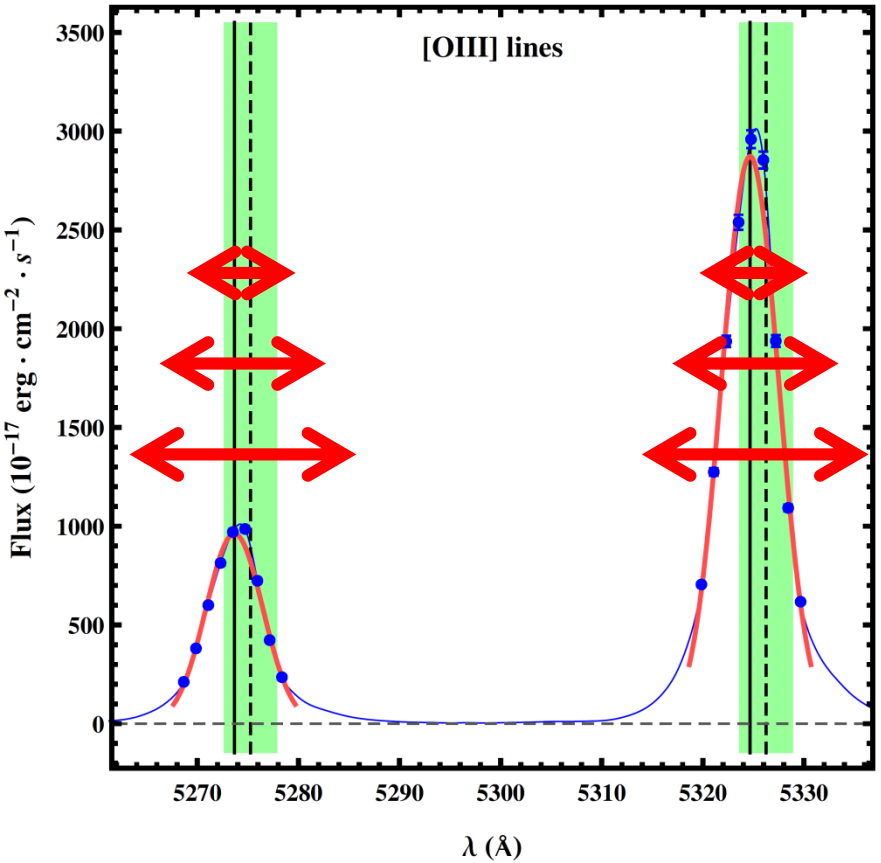
Systematics

- **Misidentification of the lines OK**
- **Interval for the Gaussian fits**



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17th April 2015
12th MultiDark

Systematics

- **Misidentification of the lines OK**
- **Interval for the Gaussian fits**

Fit width	# QSO spectra	redshift	$\Delta\alpha/\alpha$ ($\times 10^{-5}$)
2σ	10,363	0.56 ± 0.21	1.4 ± 2.3
3σ	10,252	0.59 ± 0.20	5.5 ± 2.5
4σ	9,978	0.59 ± 0.20	7.1 ± 2.7
5σ	9,727	0.59 ± 0.20	5.3 ± 2.6

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Systematics

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Systematics

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More affected by noise and Hbeta

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Systematics

- **Misidentification of the lines OK**
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OK

More affected by noise and Hbeta

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OK

More affected by noise and Hbeta

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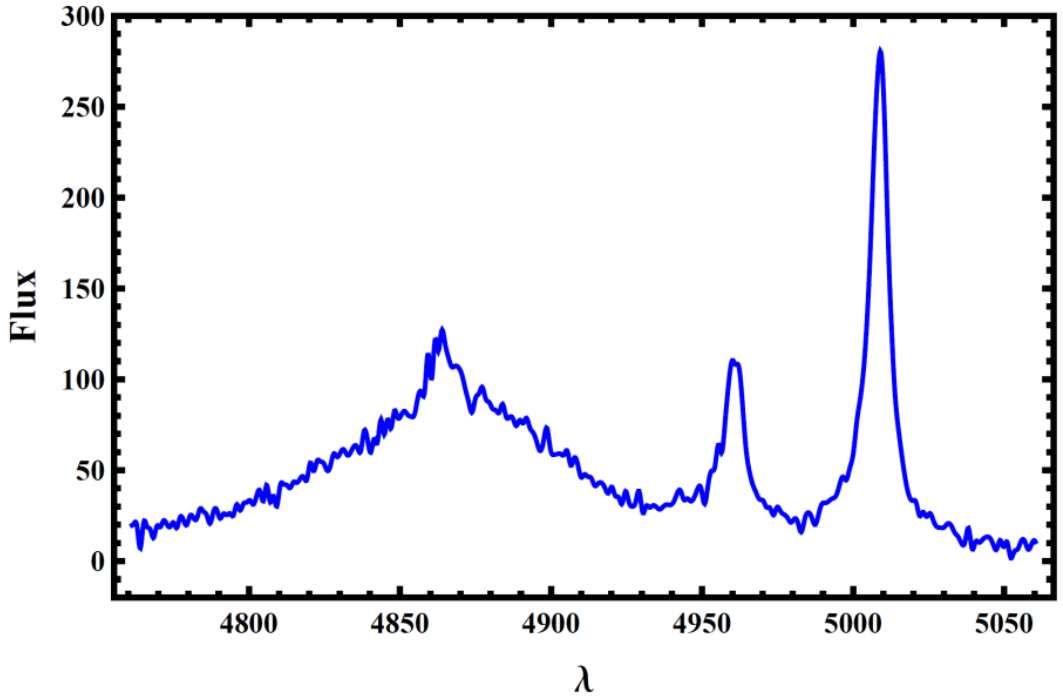
17th April 2015
12th MultiDark

Systematics

- **Misidentification of the lines OK**
- **Interval for the Gaussian fits OK**
- **Hbeta contamination**



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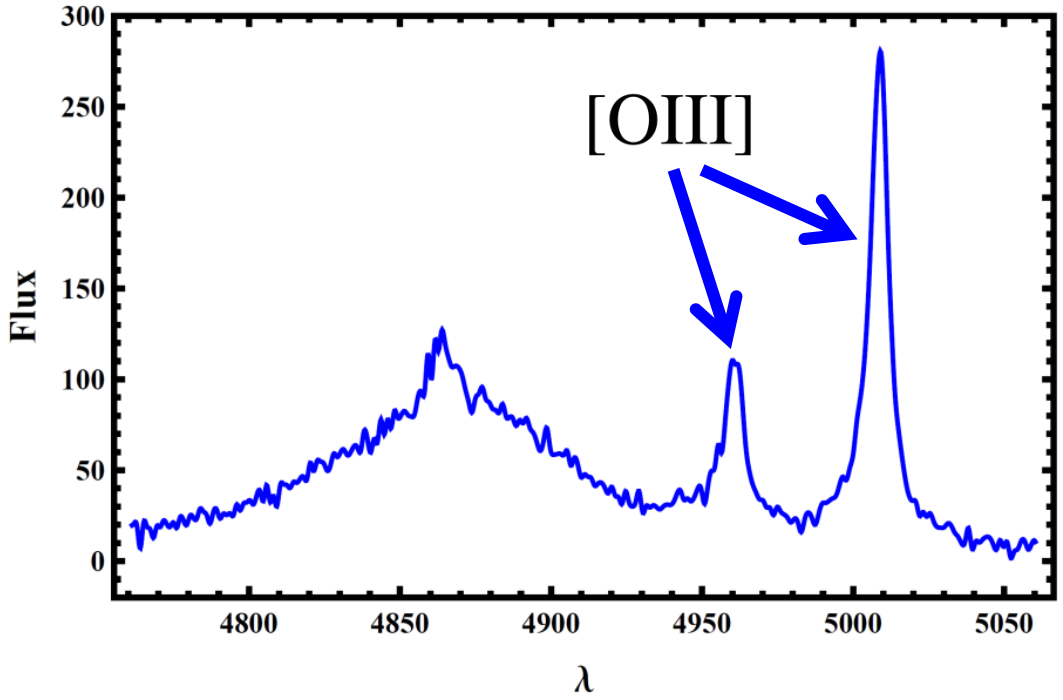
Systematics

- **Misidentification of the lines OK**
- **Interval for the Gaussian fits OK**
- **Hbeta contamination**



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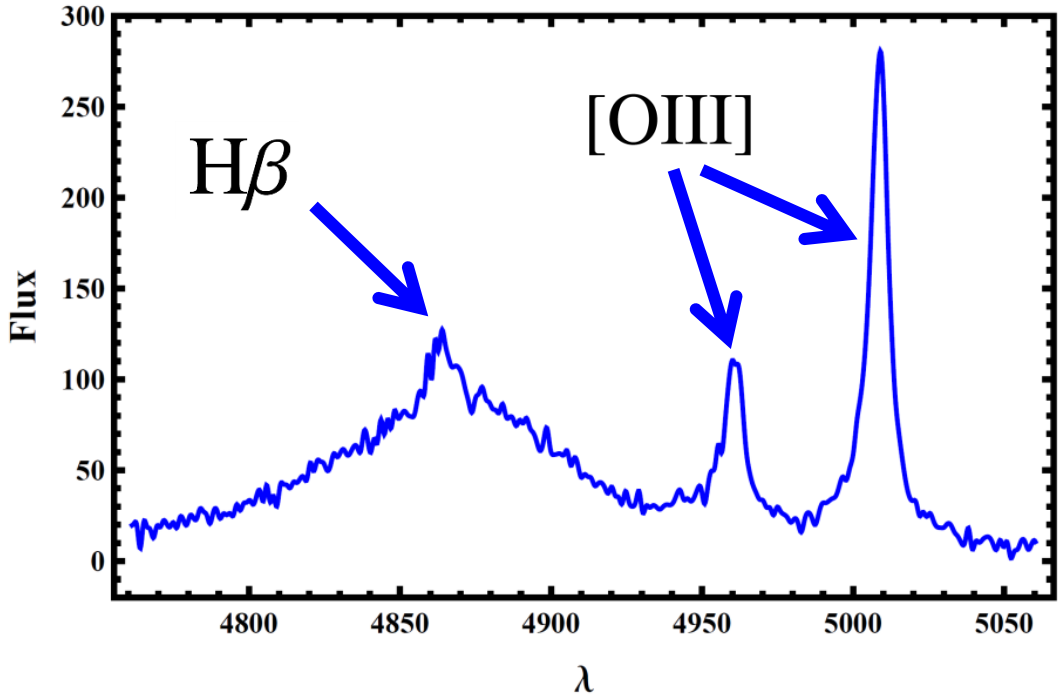
Systematics

- **Misidentification of the lines OK**
- **Interval for the Gaussian fits OK**
- **Hbeta contamination**



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Systematics

- **Misidentification of the lines OK**
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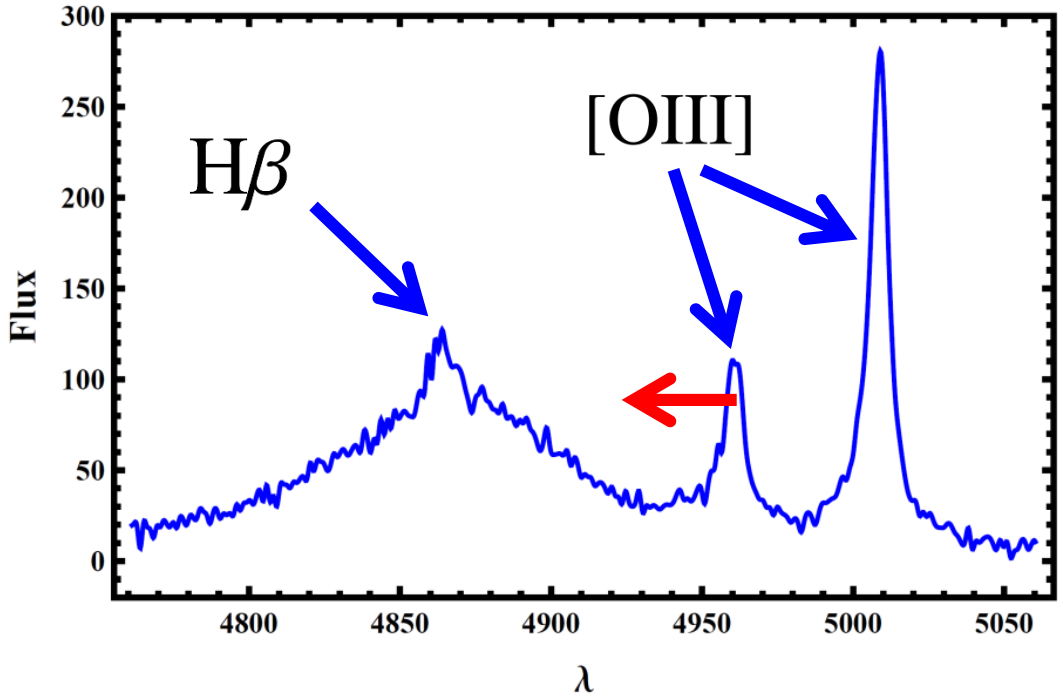

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Systematics

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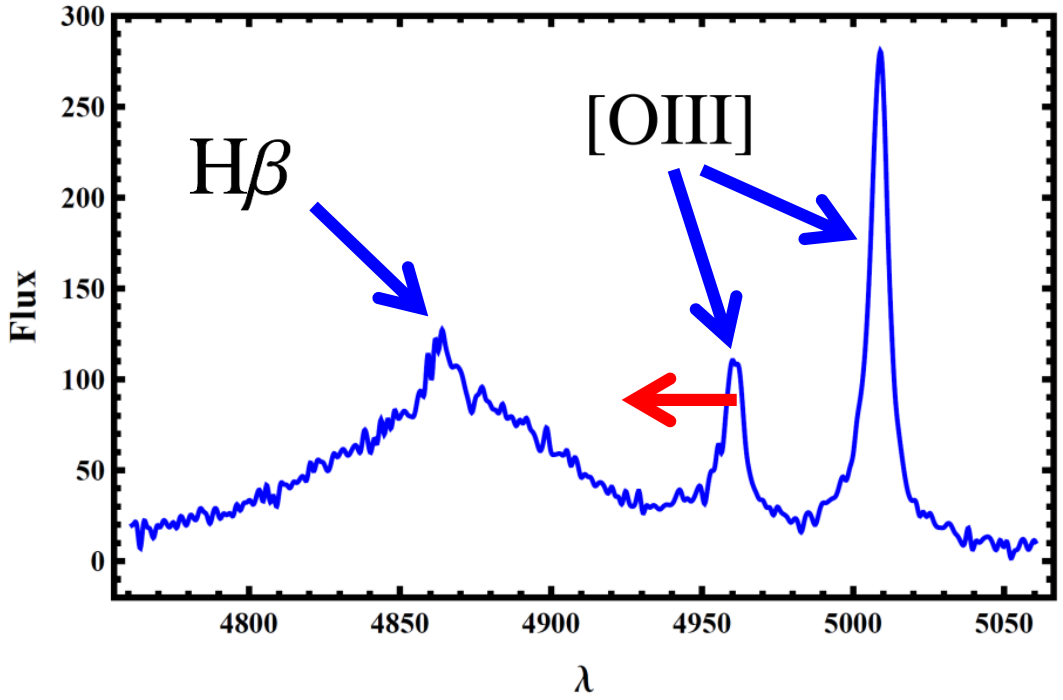
- **Interval for the Gaussian fits OK**
- **Hbeta contamination**



$\Delta\alpha/\alpha$

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Systematics

- **Misidentification of the lines OK**
- **Interval for the Gaussian fits OK**
- **Hbeta contamination**

$S/N_{H\beta/[OIII]4960}$	# QSO spectra	redshift	$\Delta\alpha/\alpha$ ($\times 10^{-5}$)
< 5	10,338	0.57 ± 0.21	1.4 ± 2.3
< 2	9,831	0.57 ± 0.21	0.6 ± 2.3
< 1	8,162	0.57 ± 0.21	0.1 ± 2.5
< 0.5	5,831	0.58 ± 0.21	-0.7 ± 2.8

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Systematics

- **Misidentification of the lines OK**
- **Interval for the Gaussian fits OK**
- **Hbeta contamination**

$S/N_{H\beta/[OIII]4960}$	# QSO spectra	redshift	$\Delta\alpha/\alpha$ ($\times 10^{-5}$)
< 5	10, 338	0.57 ± 0.21	1.4 ± 2.3
< 2	9, 831	0.57 ± 0.21	0.6 ± 2.3
< 1	8, 162	0.57 ± 0.21	0.1 ± 2.5
< 0.5	5, 831	0.58 ± 0.21	-0.7 ± 2.8

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Systematics

- **Misidentification of the lines OK**
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OK

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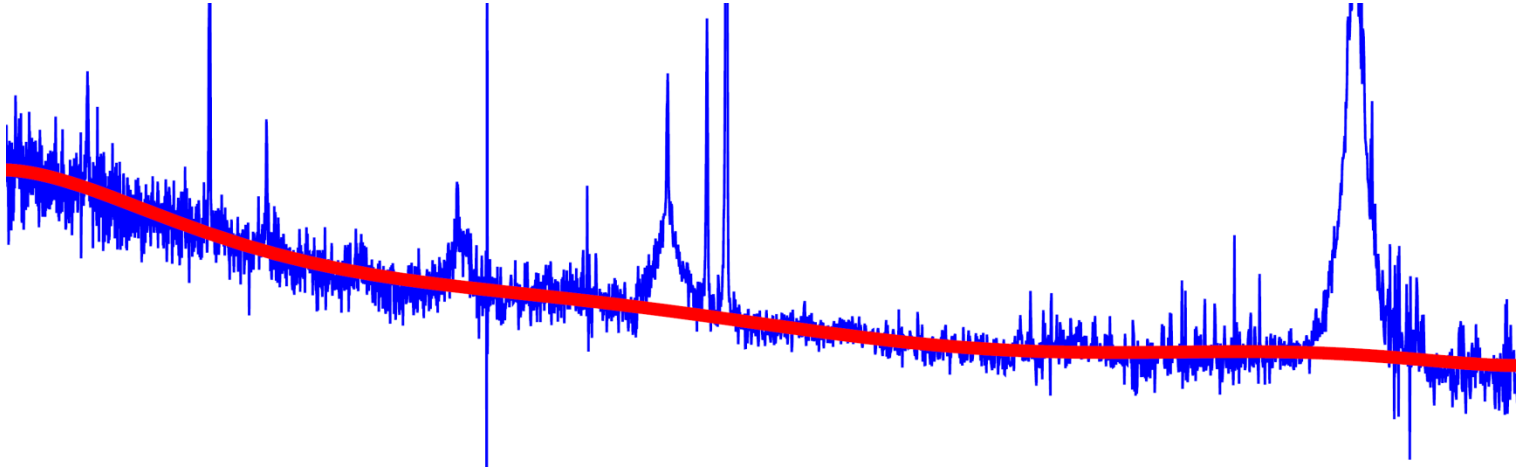
Systematics

- **Misidentification of the lines OK**
- **Interval for the Gaussian fits OK**
- **Hbeta contamination OK**
- **Continuum subtraction**



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Systematics

- **Misidentification of the lines OK**
- **Interval for the Gaussian fits OK**
- **Hbeta contamination OK**
- **Continuum subtraction**

Pol. order (continuum)	# QSO spectra	redshift	$\Delta\alpha/\alpha$ ($\times 10^{-5}$)
3	10,529	0.57 ± 0.21	1.0 ± 2.3
5	10,550	0.57 ± 0.21	1.3 ± 2.3
7	10,363	0.56 ± 0.21	1.4 ± 2.3
9	10,471	0.56 ± 0.21	-1.1 ± 2.3

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Systematics

- **Misidentification of the lines OK**
- **Interval for the Gaussian fits OK**
- **Hbeta contamination OK**
- **Continuum subtraction**

Pol. order (continuum)	# QSO spectra	redshift	$\Delta\alpha/\alpha$ ($\times 10^{-5}$)
3	10, 529	0.57 ± 0.21	1.0 ± 2.3
5	10, 550	0.57 ± 0.21	1.3 ± 2.3
7	10, 363	0.56 ± 0.21	1.4 ± 2.3
9	10, 471	0.56 ± 0.21	-1.1 ± 2.3

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Systematics

- **Misidentification of the lines OK**
- **Interval for the Gaussian fits OK**
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OK

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Systematics

- **Misidentification of the lines OK**
- **Interval for the Gaussian fits OK**
- **Hbeta contamination OK**
- **Continuum subtraction OK**
- **Different methods**

Method	# QSO spectra	redshift	$\Delta\alpha/\alpha$ ($\times 10^{-5}$)
Gaussian (weighted)	4, 537	0.58 ± 0.20	-0.4 ± 2.8
Gaussian	4, 537	0.58 ± 0.20	1.2 ± 4.5
Integration	4, 537	0.58 ± 0.20	3.6 ± 4.8
Modified Bahcall	4, 537	0.58 ± 0.20	0.8 ± 4.4
Median	4, 537	0.58 ± 0.20	1.8 ± 1.4

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Systematics

- **Misidentification of the lines OK**
- **Interval for the Gaussian fits OK**
- **Hbeta contamination OK**
- **Continuum subtraction OK**
- **Different methods**

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Median	4,537	0.58 ± 0.20	1.8 ± 1.4

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Systematics

- **Misidentification of the lines OK**
- **Interval for the Gaussian fits OK**
- **Hbeta contamination OK**
- **Continuum subtraction OK**
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Gaussian (weighted)	4,537	0.58 ± 0.20	-0.4 ± 2.8
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OK

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Systematics

- **Misidentification of the lines OK**
- **Interval for the Gaussian fits OK**
- **Hbeta contamination OK**
- **Continuum subtraction OK**
- **Different methods OK**
- **And more…(simulations)**

"**F. D. Albareti *et al.***, arXiv: 1501.00560"

Systematics

Final results

Reference	# QSO spectra	$\Delta\alpha/\alpha$ $(\cdot 10^{-5})$
Bahcall et al. (2004)	42	7 ± 14
Gutiérrez & López-Corredoira (2010)	1,568	2.4 ± 2.5
Rahmani et al. (2014)	2,347	-2.1 ± 1.6
This work (2014)	10,363	1.4 ± 2.3

Systematics

Final results

Reference	# QSO spectra	$\Delta\alpha/\alpha$ $(\cdot 10^{-5})$
Bahcall et al. (2004)	42	7 ± 14
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Systematics

Final results

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This work (2014)	10,363	1.4 ± 2.3

A factor 2.5 of improvement is expected…?

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Results

$$\Delta\alpha/\alpha = (1.4 \pm 2.3) \times 10^{-5}$$

- **Robust constraint** for the variation of the fine structure constant at **z ~ 0.6 (5.7 Gyr ago)** (more than **35 samples** analyzed).
- **For further details**, **"FDA, J. Comparat, F. Prada *et al.*,** arXiv:**1501.00560"**
- **Well…, it is not a big improvement…**

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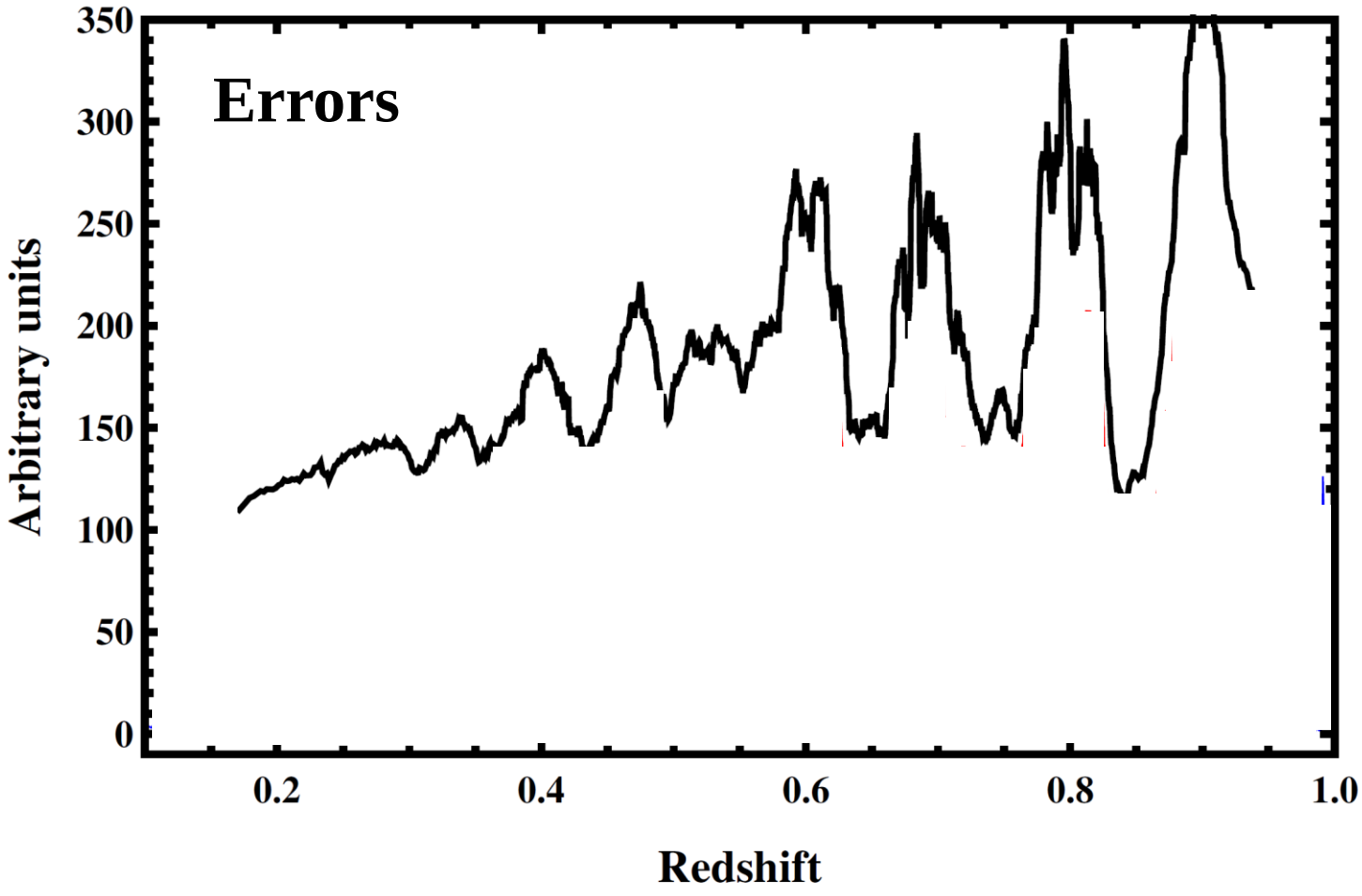
Results



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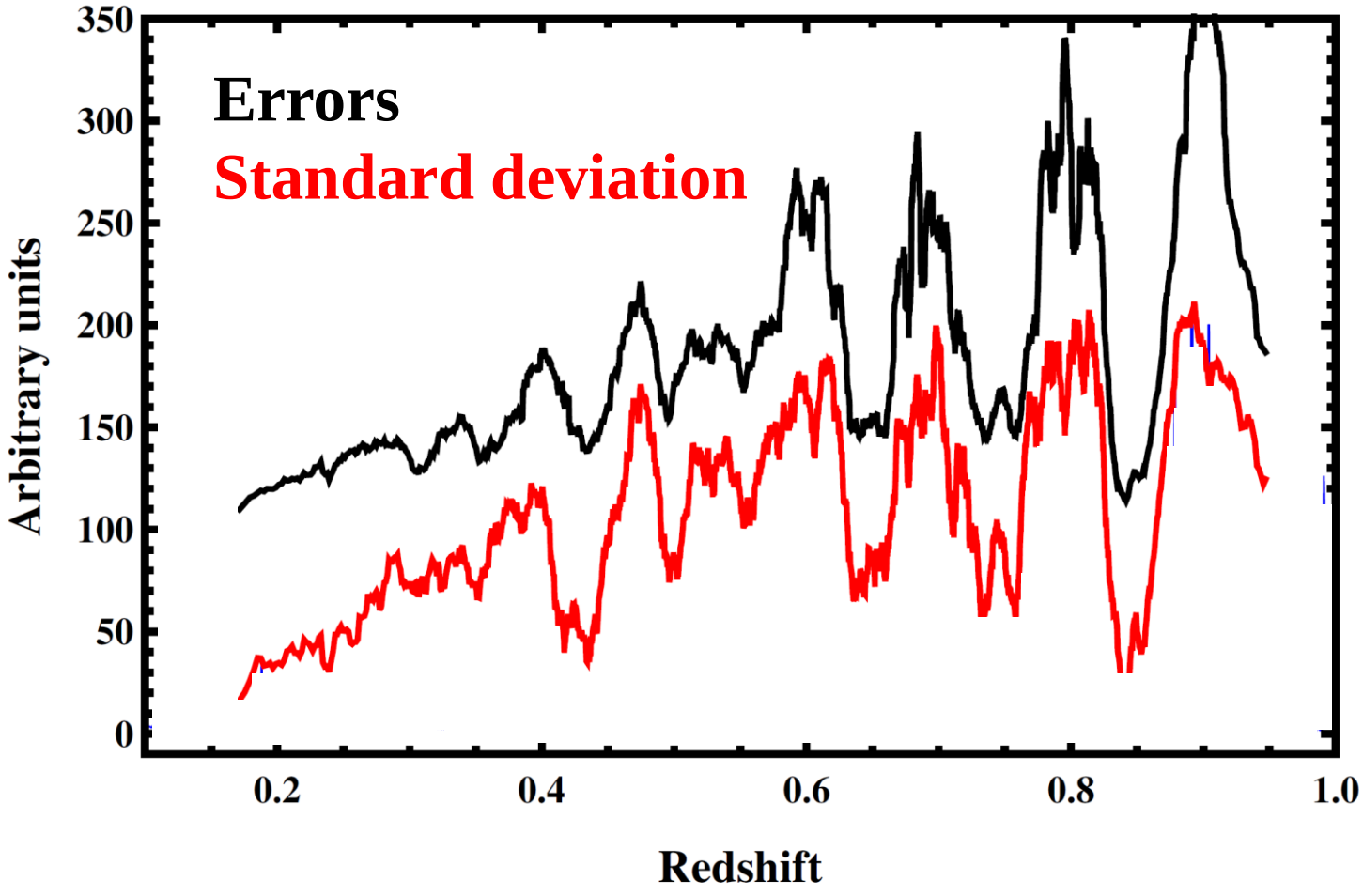
Results



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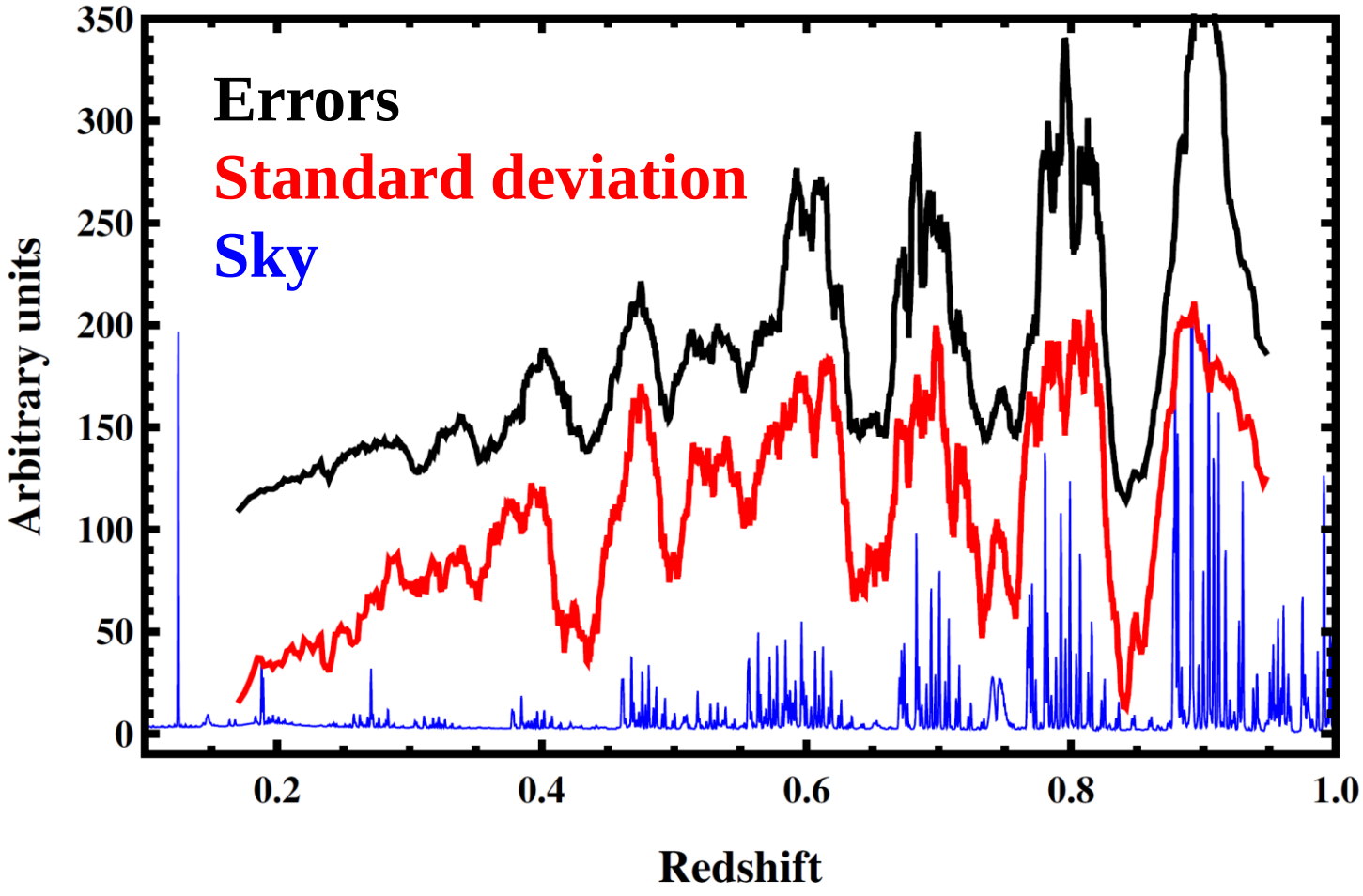
Results



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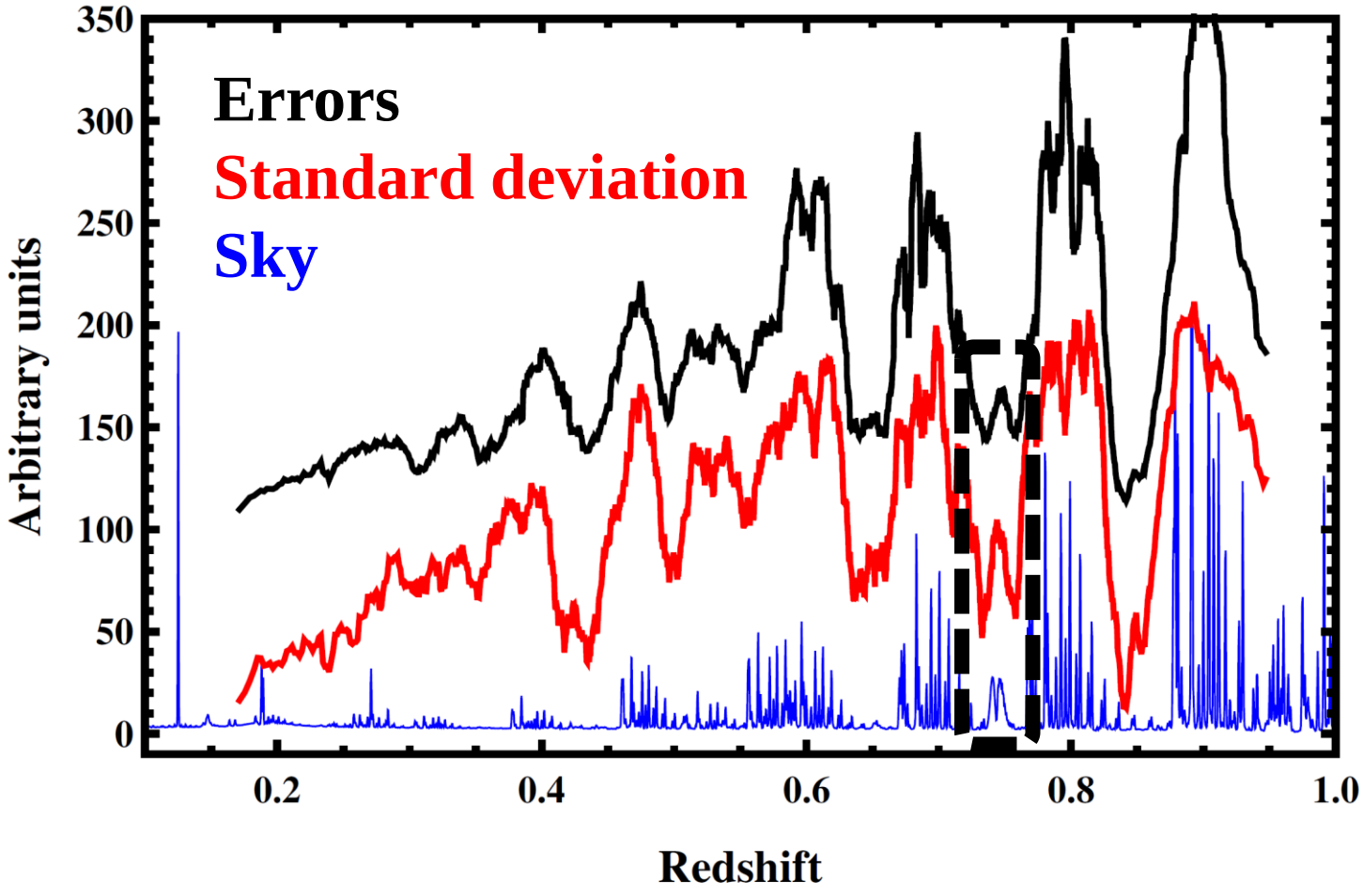
Results



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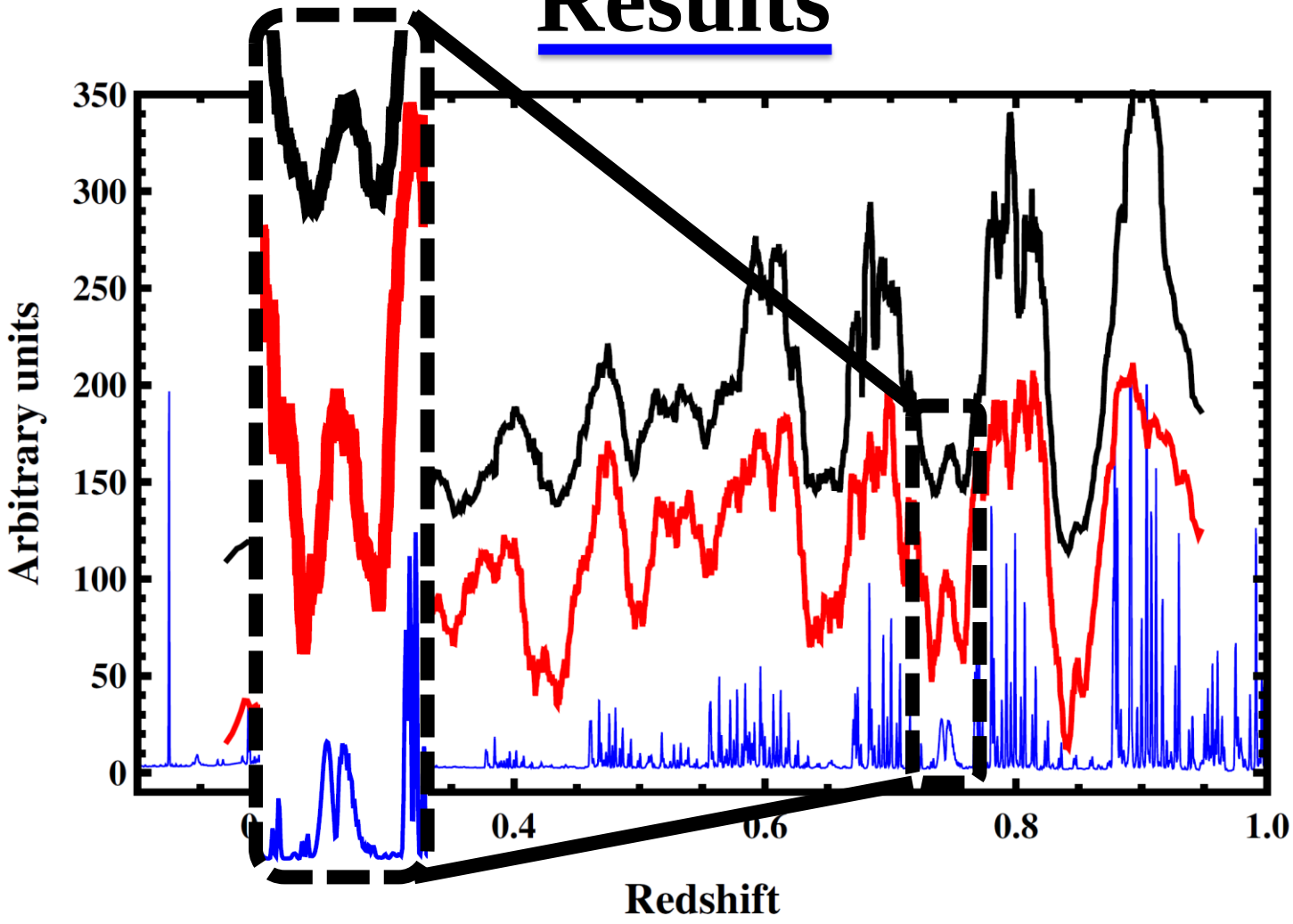
Results



Atmospheric O2 airglow emission

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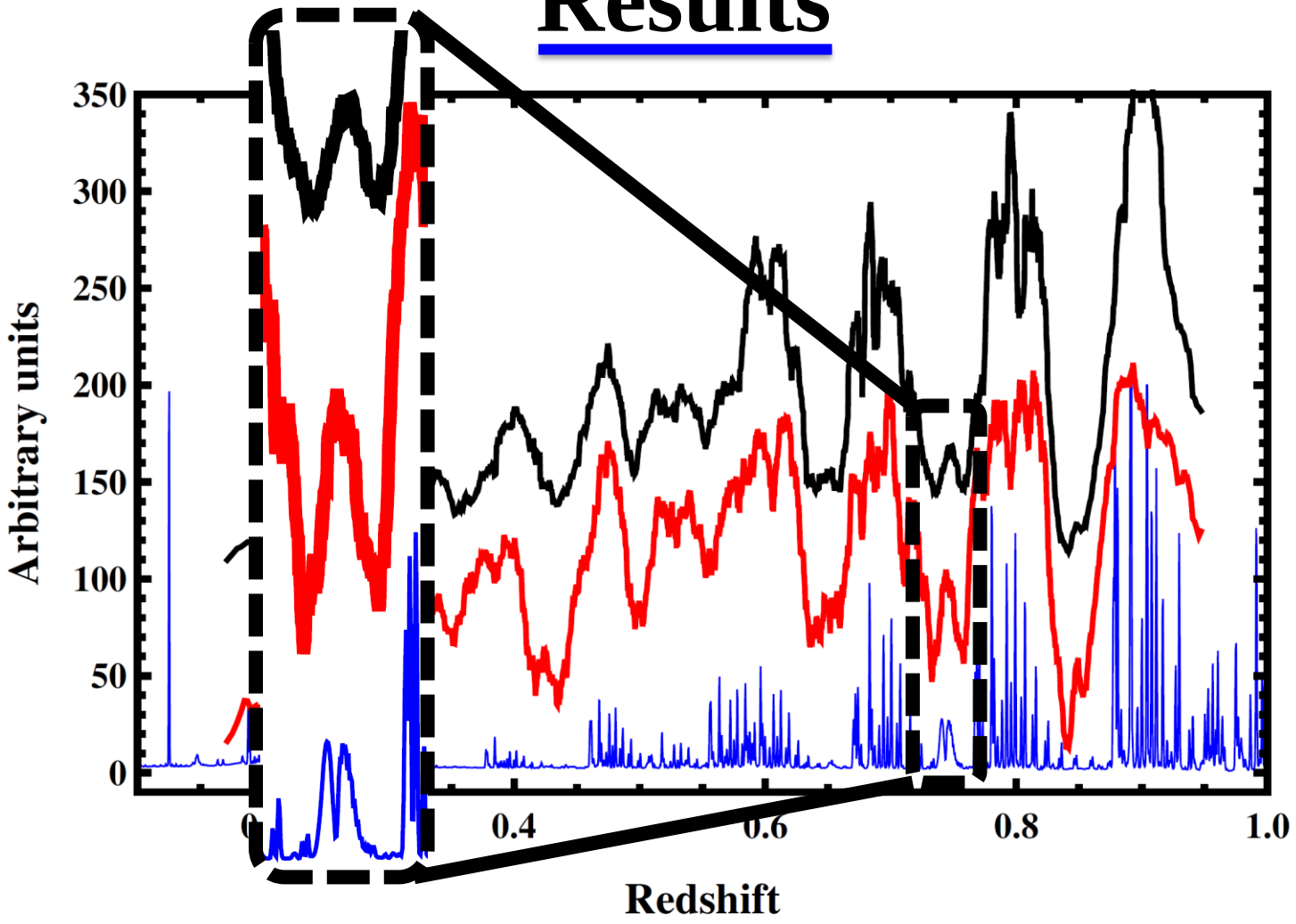
Results



The precision is limited by the sky subtraction

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Future projects

- **VLT/UVES → High-resolution spectrograph**

  R ~ 62,000 – 110,000

  z ~ 0.6

$$\Delta\alpha/\alpha < 10^{-6}$$

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Future projects

- **VLT/UVES → High-resolution spectrograph**

R ~ 62,000 – 110,000

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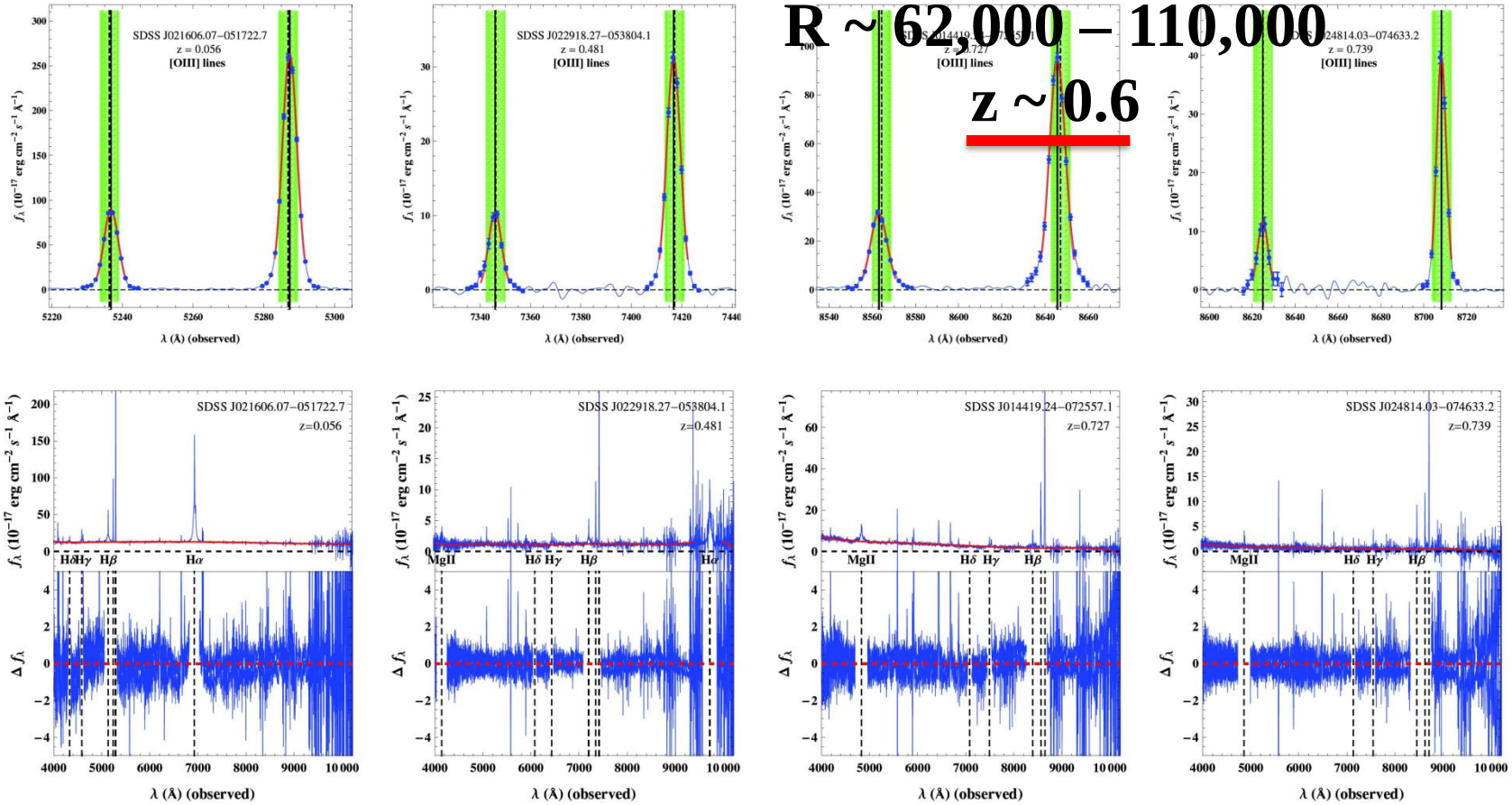

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Future projects

- **VLT/UVES → High-resolution spectrograph**

R ~ 62,000 – 110,000

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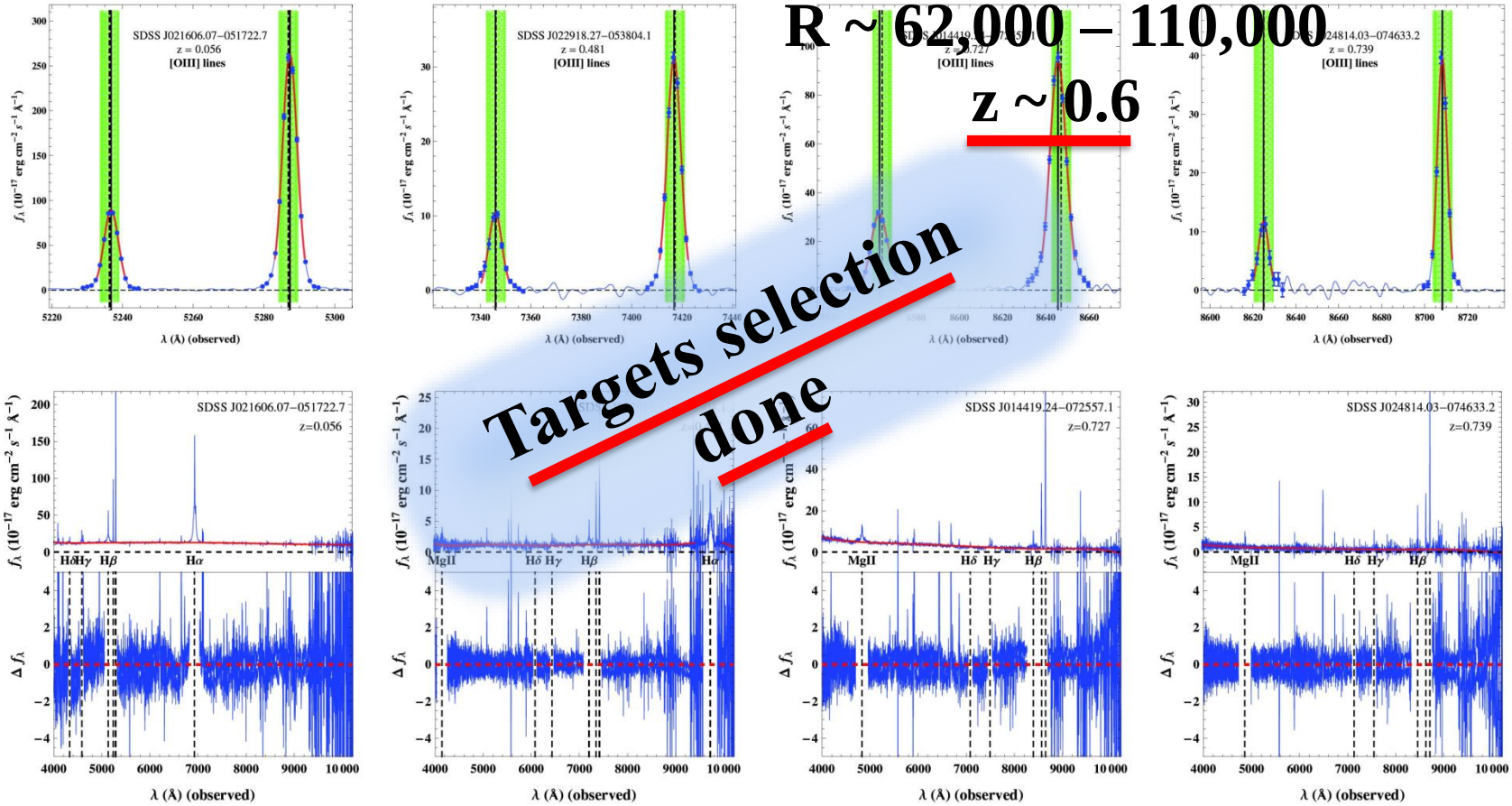

Targets selection done

Proposal submitted…

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Future projects

- **VLT/UVES → High-resolution spectrograph**
  R ~ 62,000 – 110,000
  z ~ 0.6

- **NOT/FIES → High-resolution spectrogpraph**
  R ~ 62,000 – 110,000
  z ~ 0.3

$$\Delta\alpha/\alpha < \text{10\^{}-6}$$

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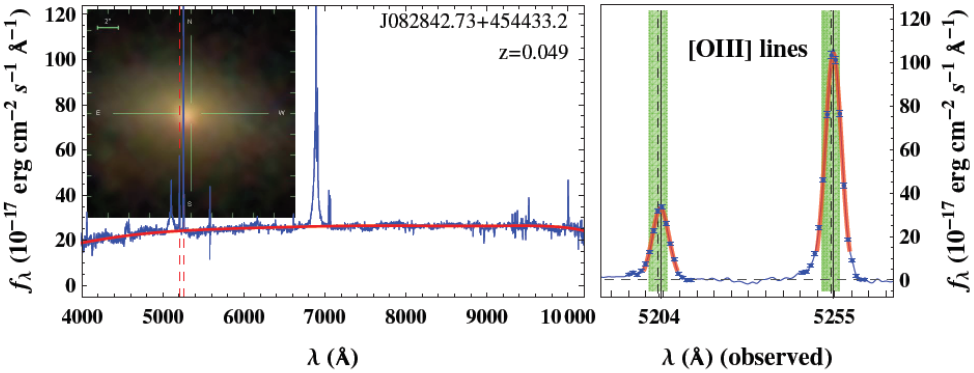
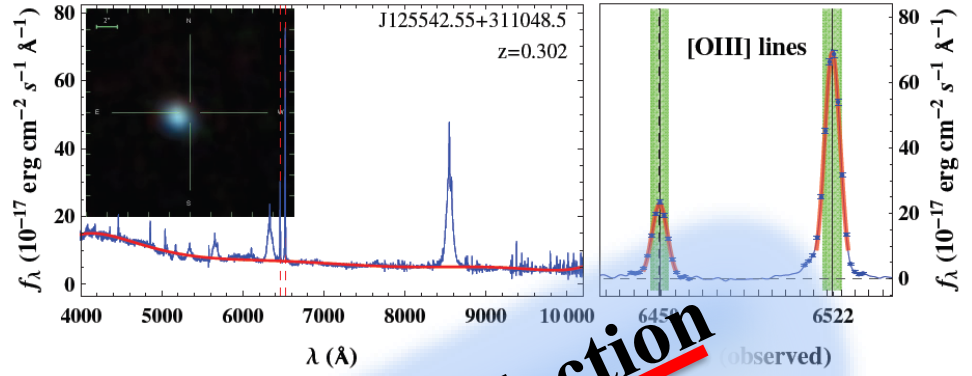
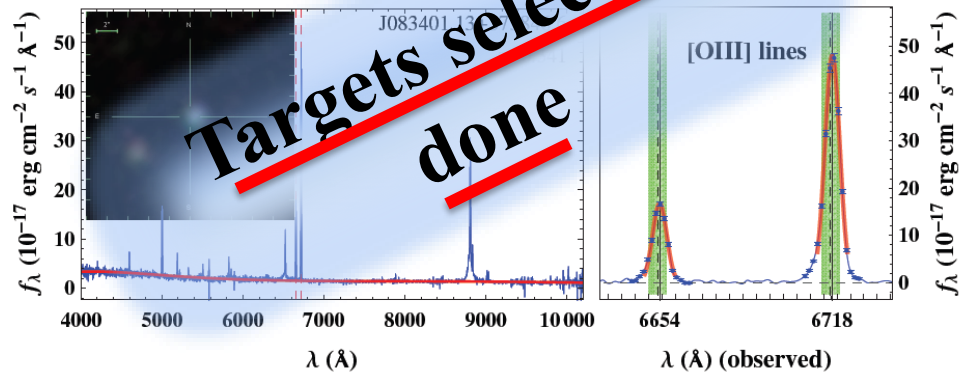
Future projects

- VLT/U ctrograph
  0,000
- NOT/F ctrogpraph
  10,000







Targets selection done

Proposal submitted….

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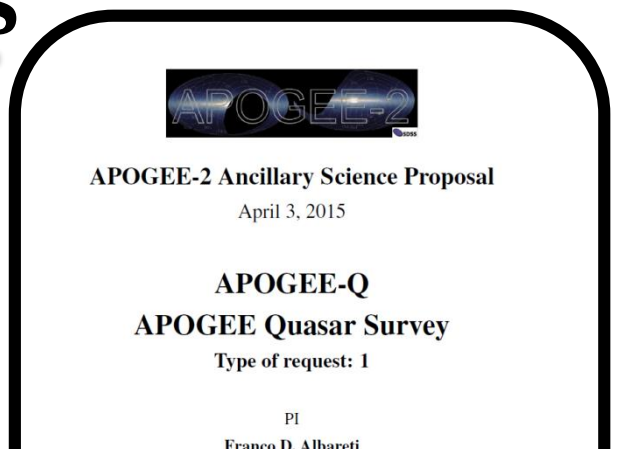
17th April 2015
12th MultiDark

Future projects

APOGEE-Q
Ancillary Science Proposal
For SDSS-IV/APOGEE-2


APOGEE-2

APOGEE-2 Ancillary Science Proposal

April 3, 2015

APOGEE-Q

APOGEE Quasar Survey

Type of request: 1

PI

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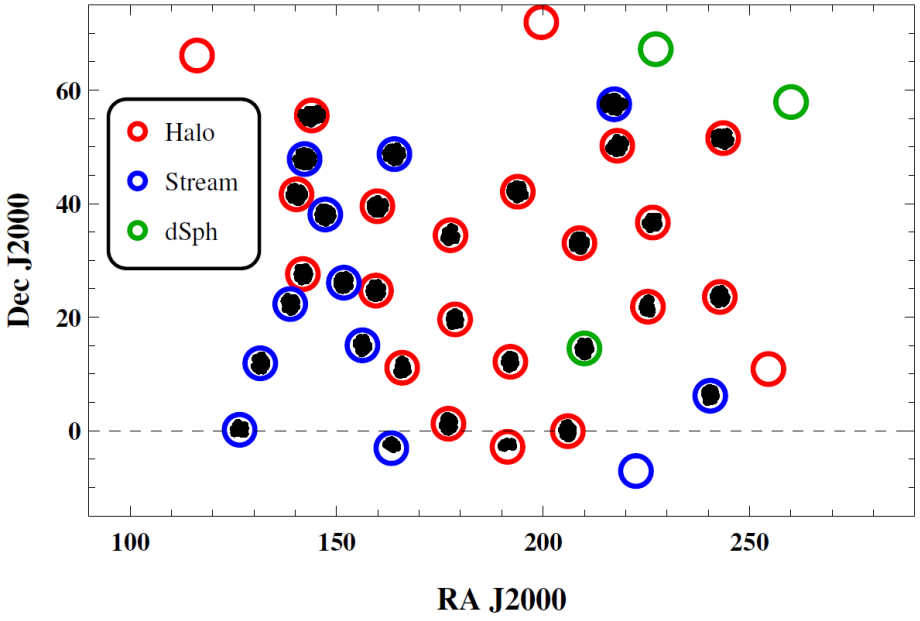

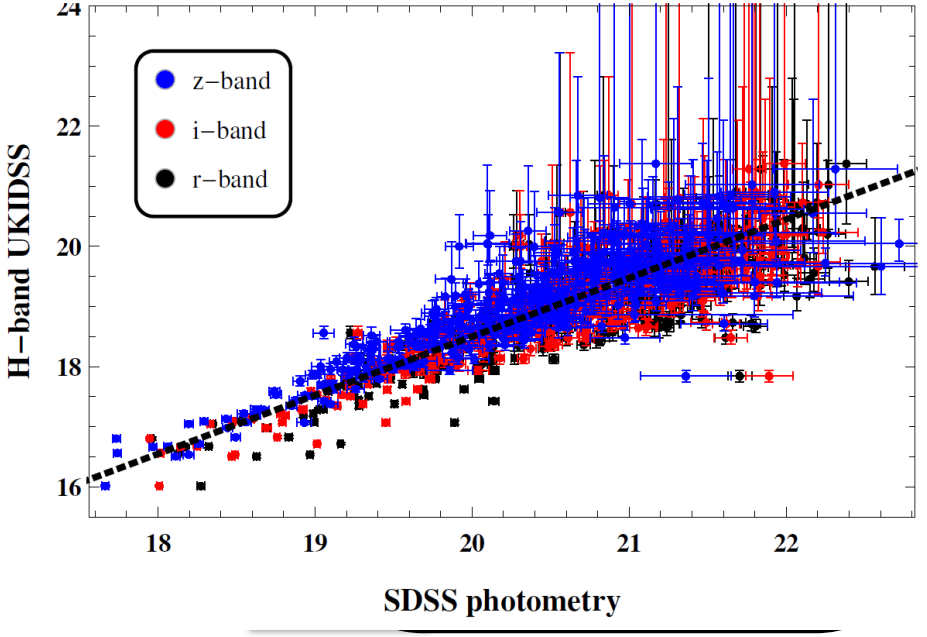

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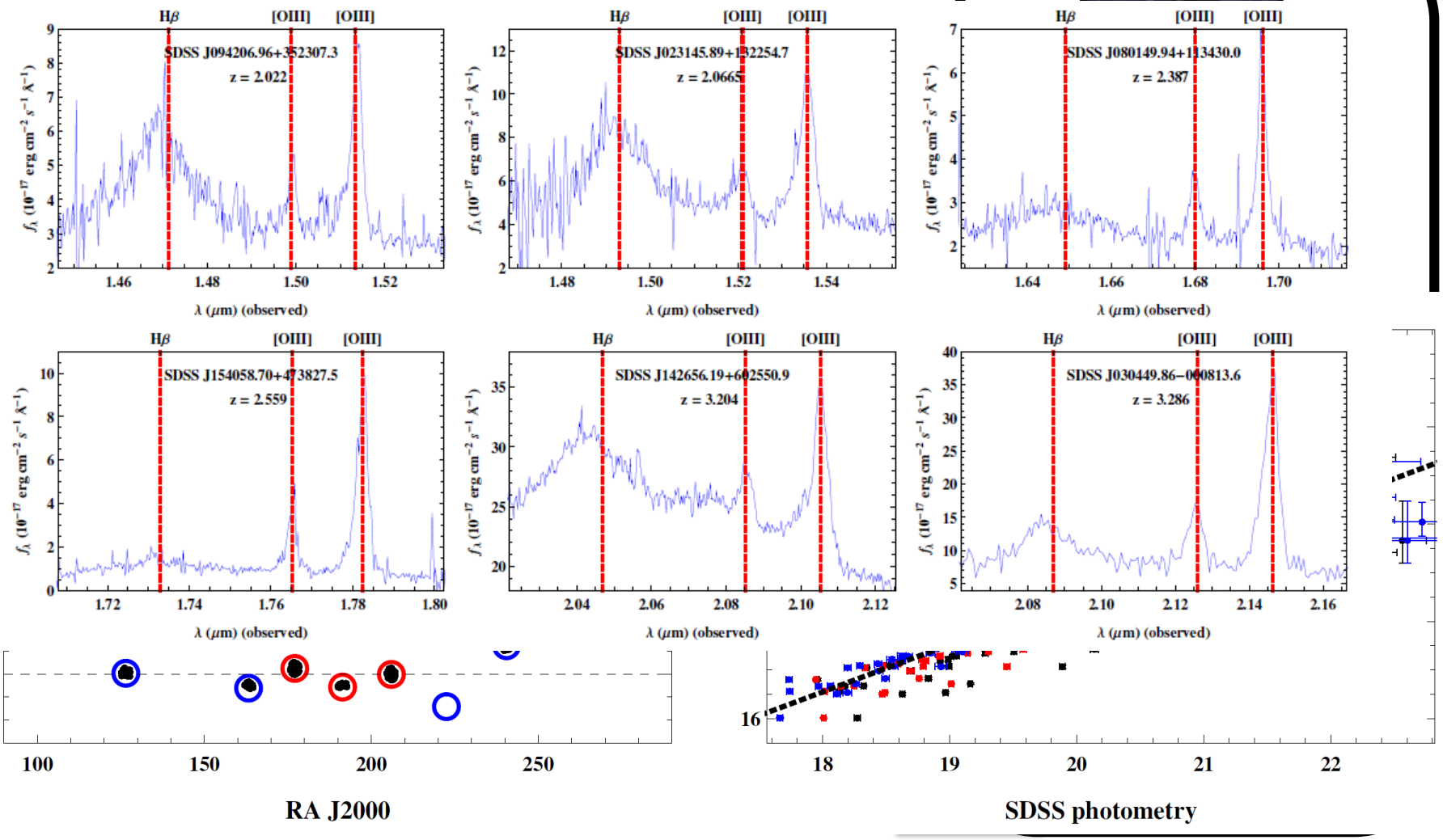
Future projects



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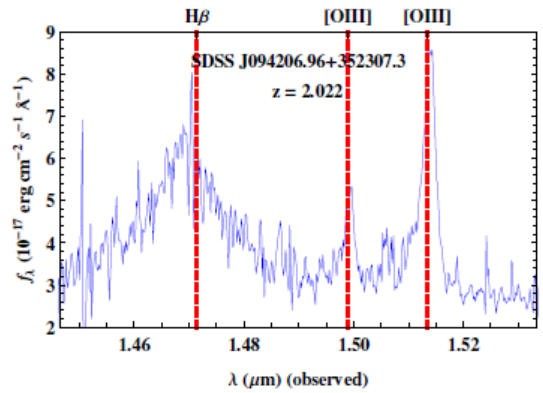
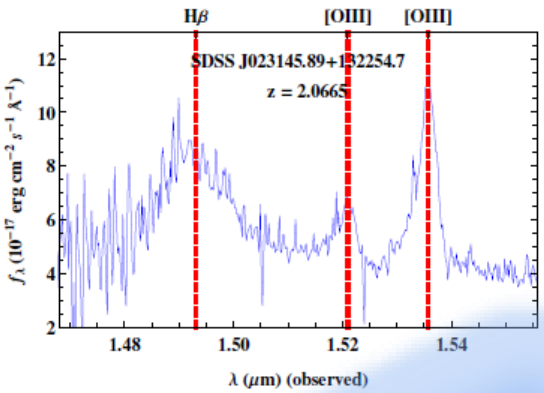
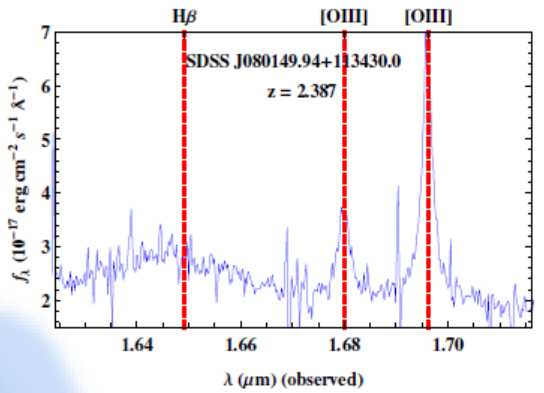
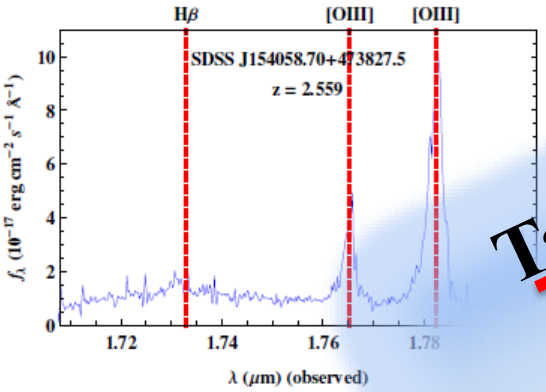
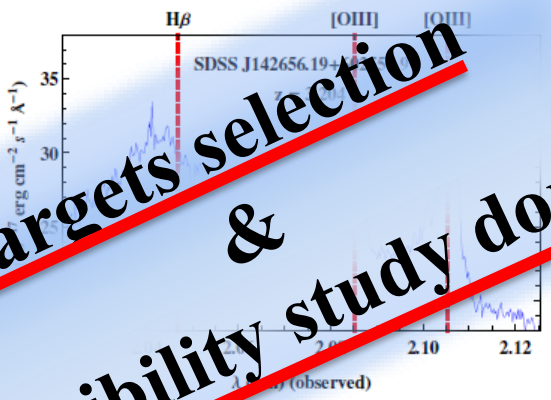
Future projects

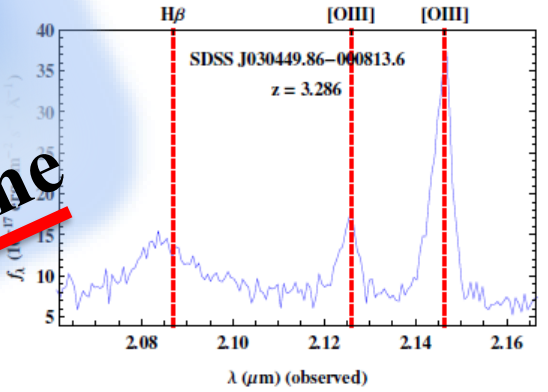




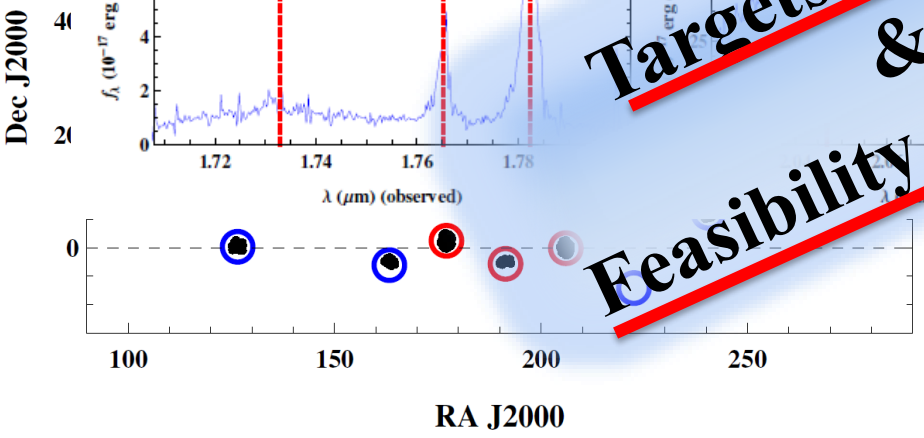


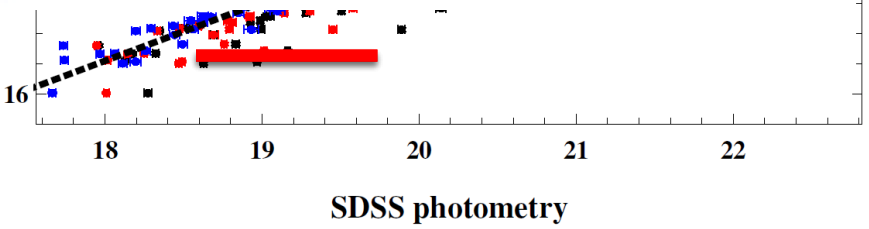




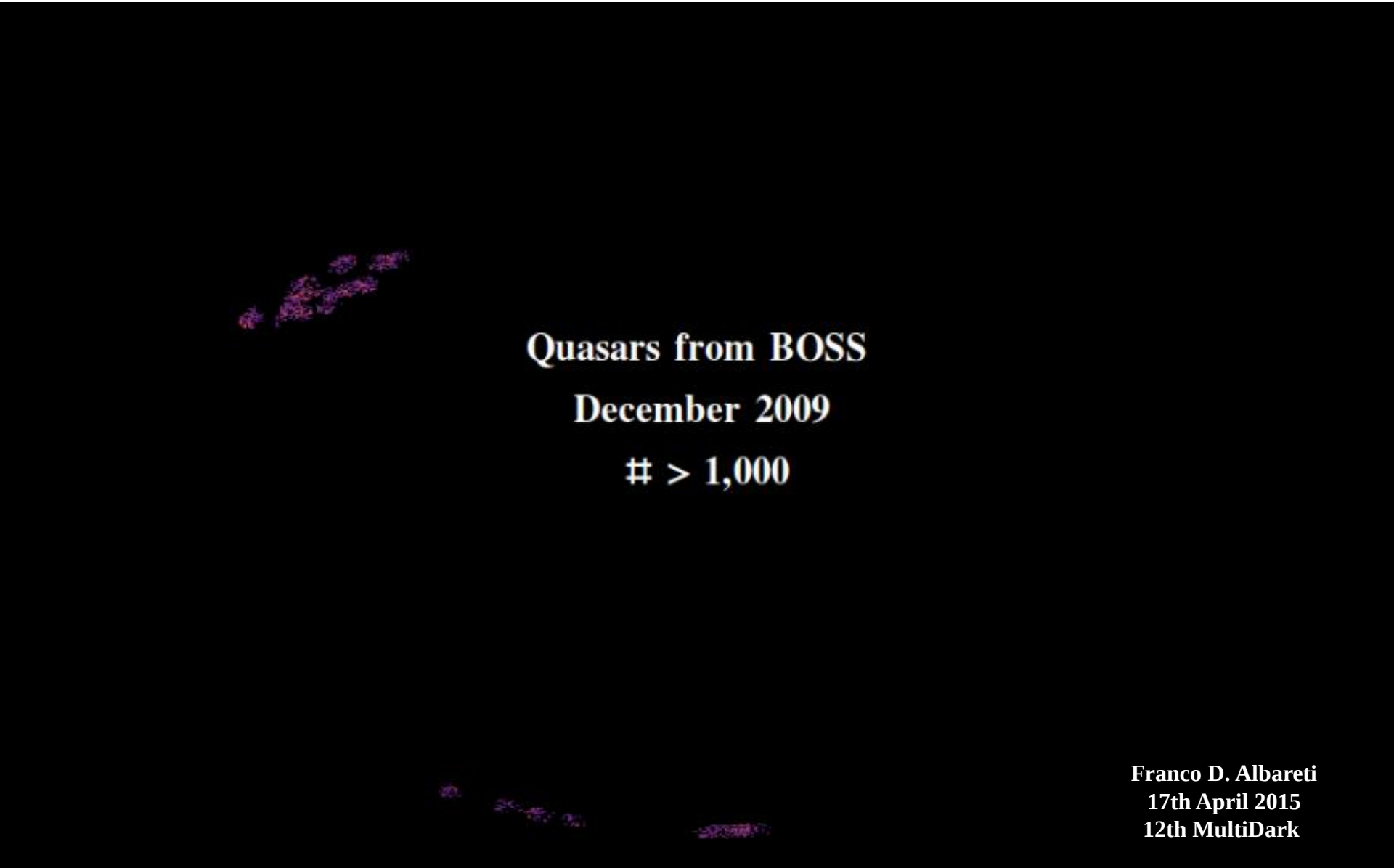


Targets selection
&
Feasibility study done





Sample selection



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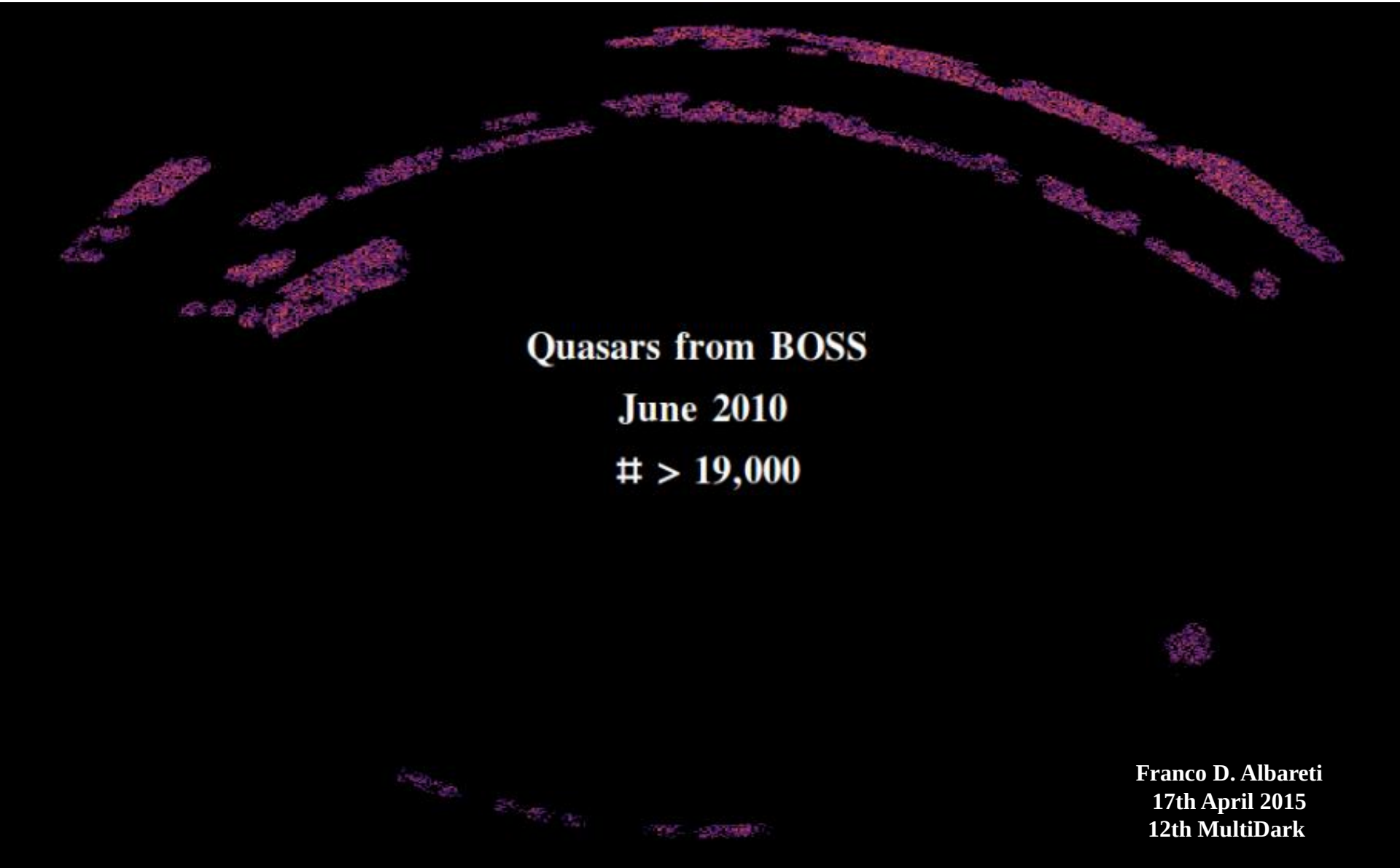
Sample selection



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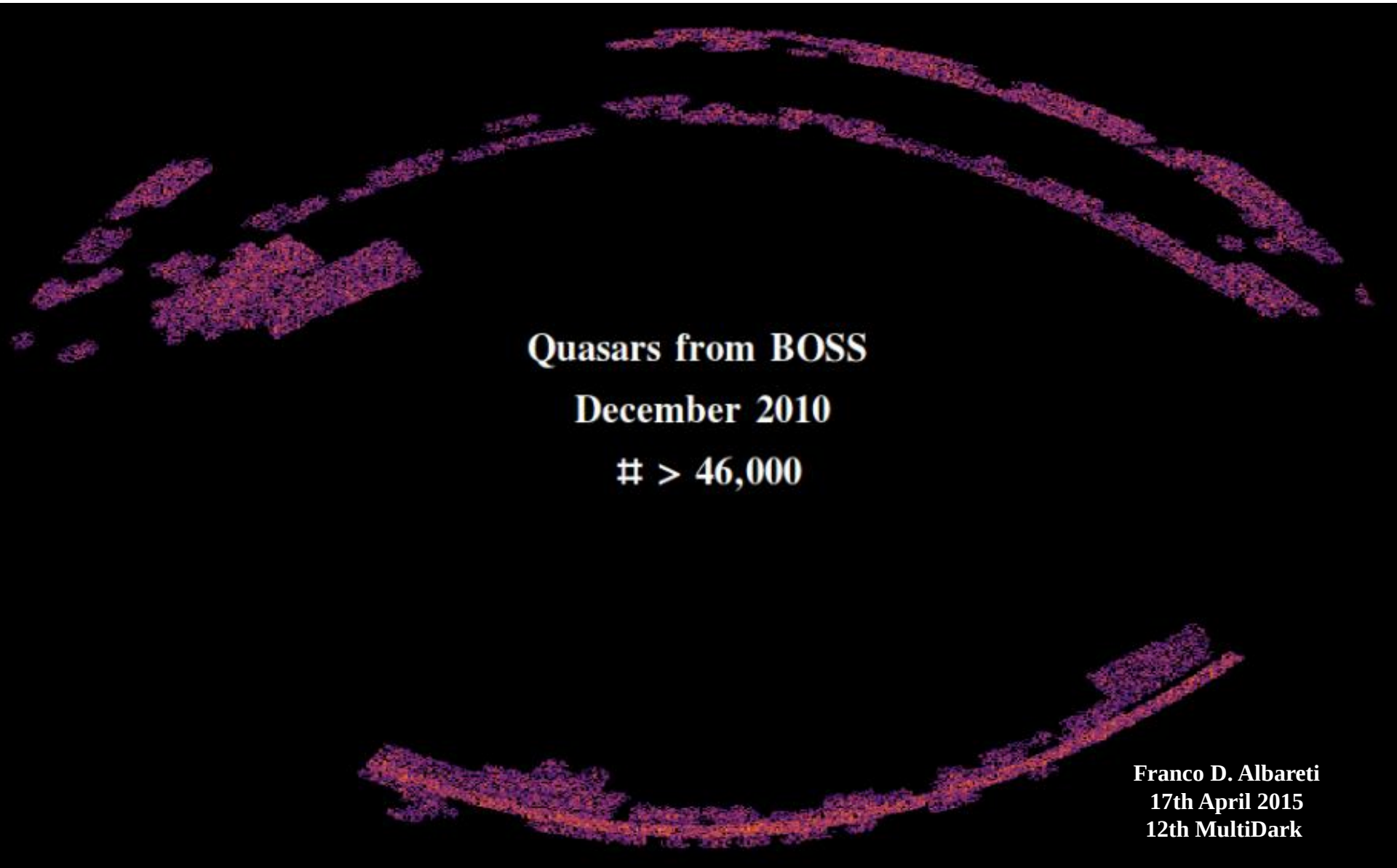

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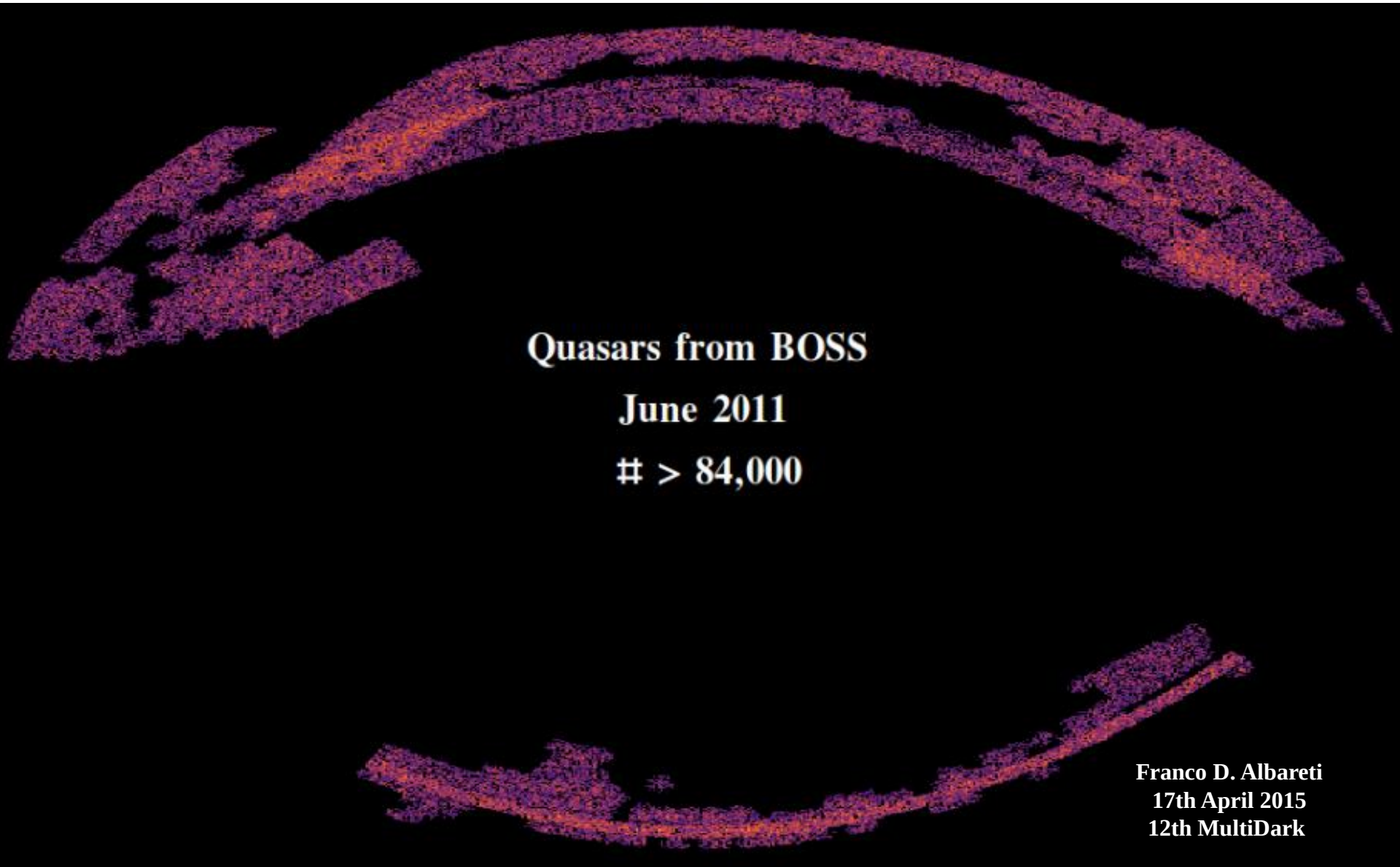

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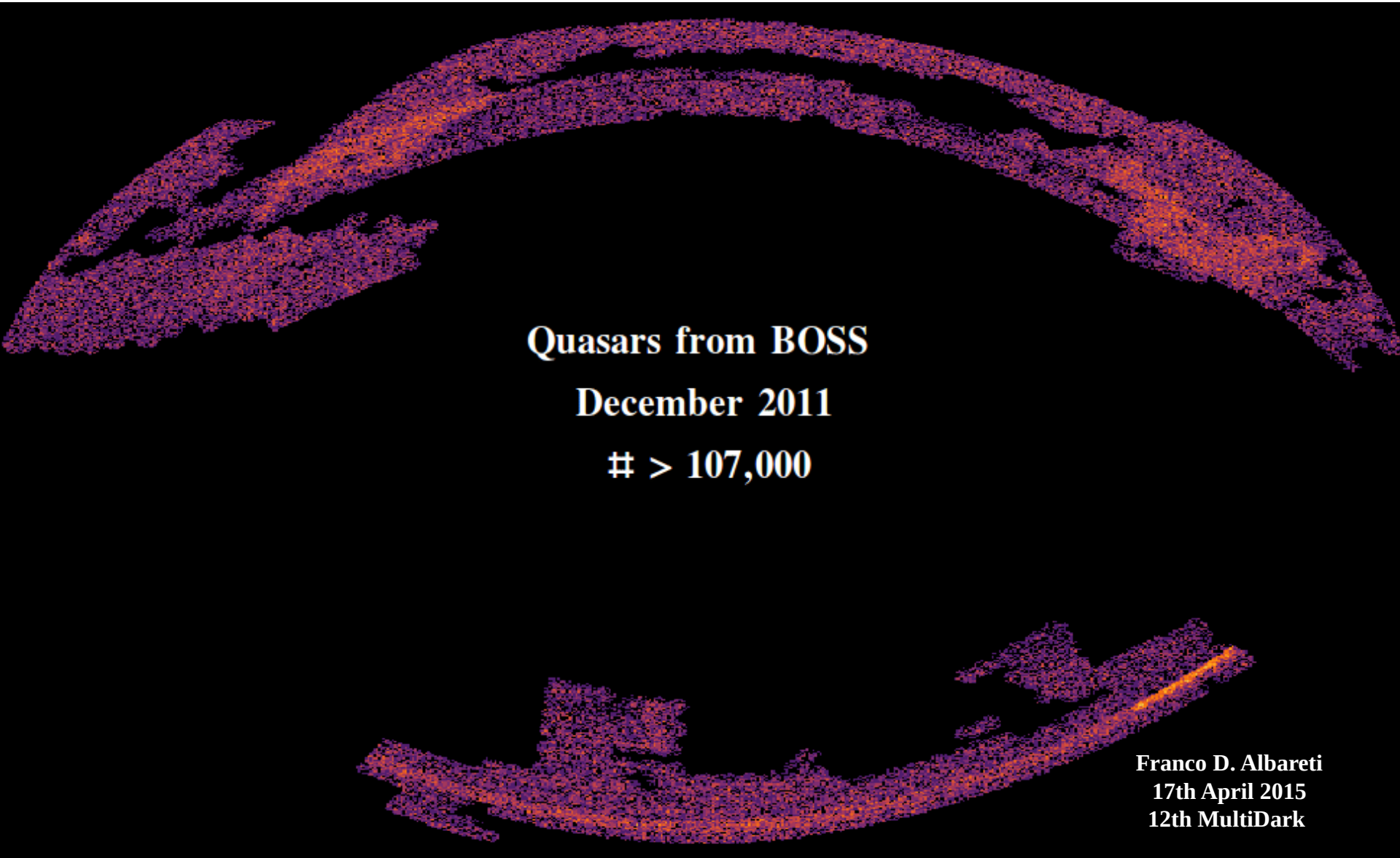

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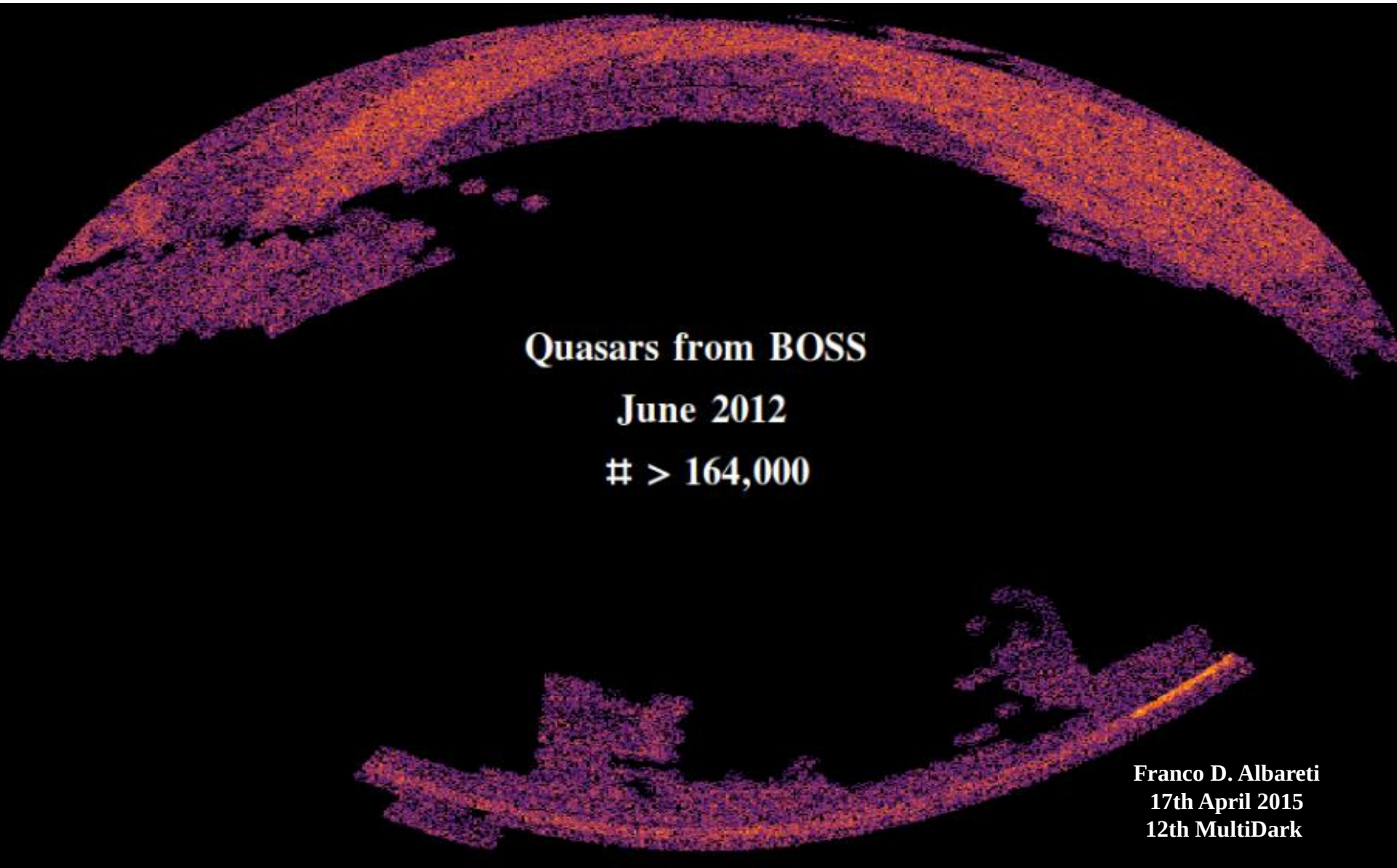
Sample selection



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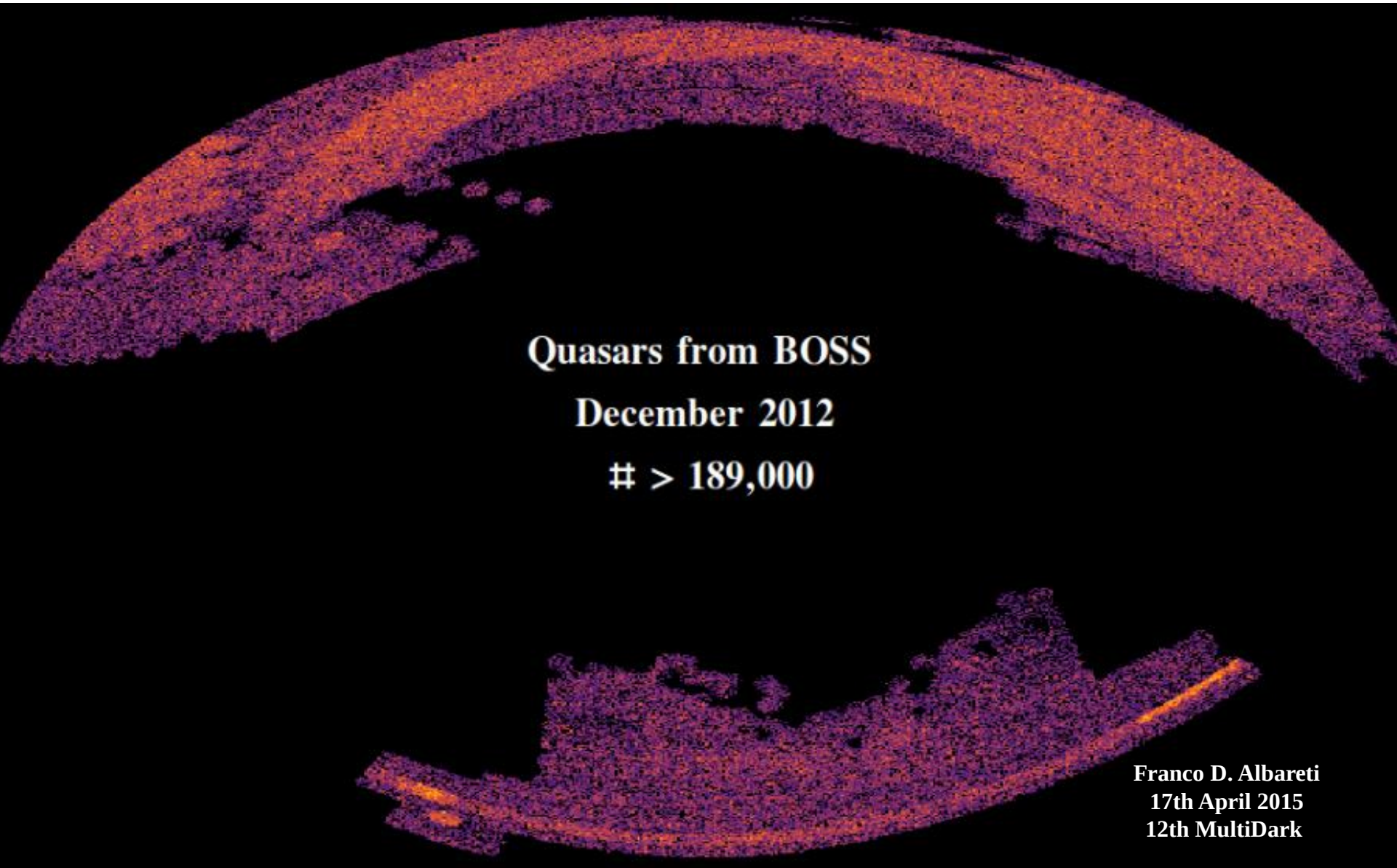
Sample selection



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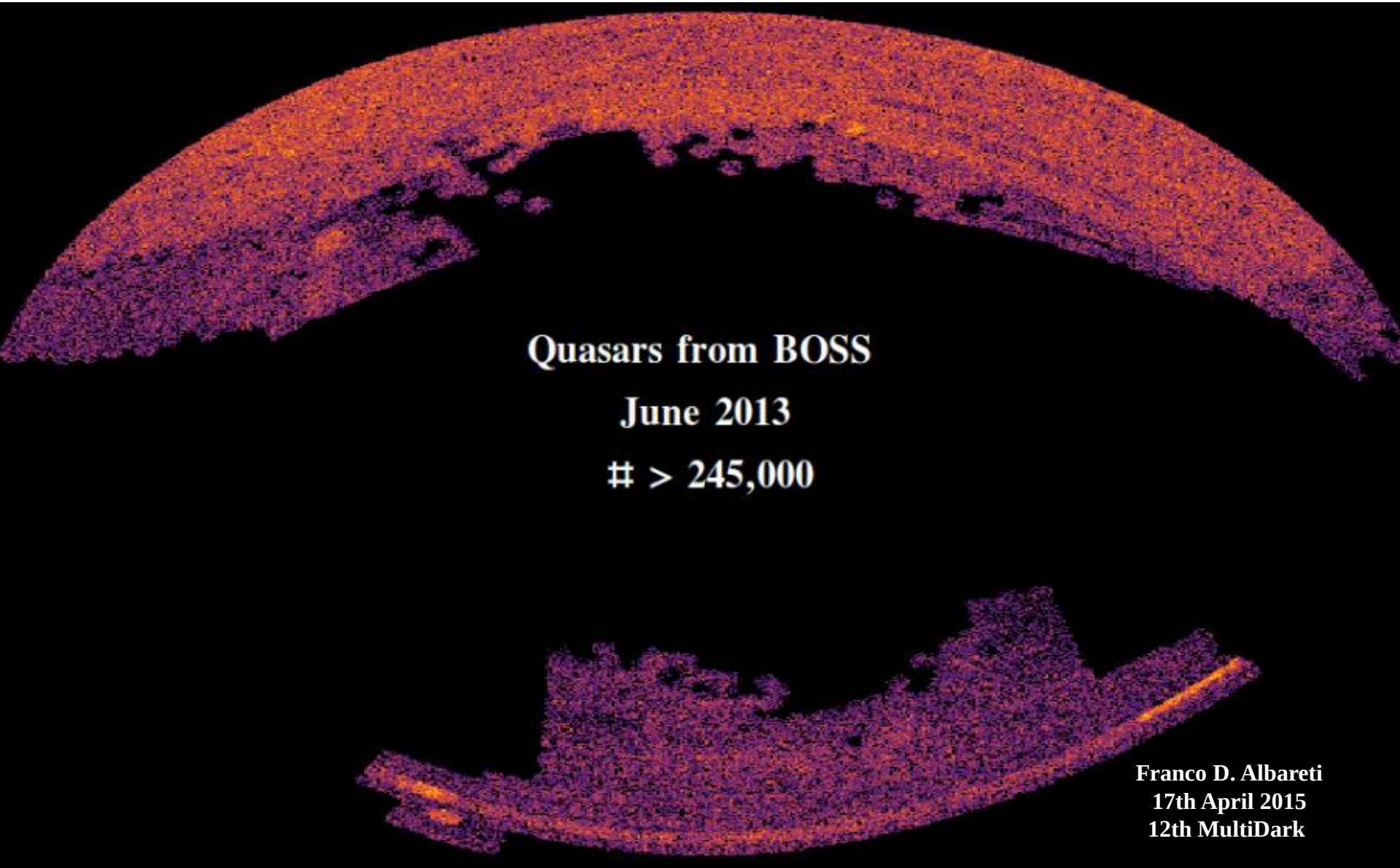
Sample selection



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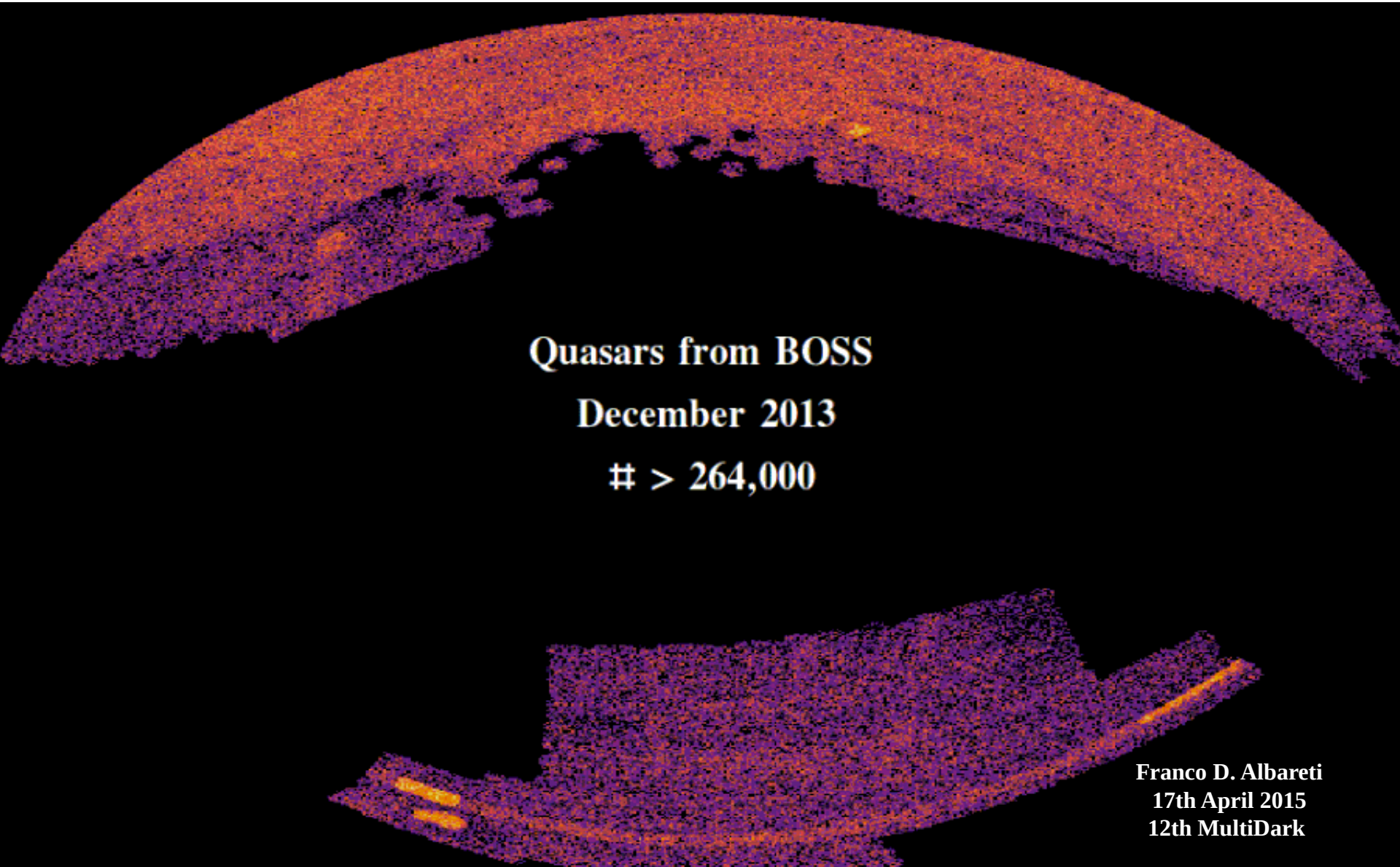

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