Nebulium tests
the fine structure constant variation

Franco D. Albareti

PhD student
under the supervision of

Prof. Antonio L. Maroto and Prof. Francisco Prada

Instituto de Física Teórica
UAM-CSIC

Instituto de Física Teórica UAM/CSIC

30th March 2015

Nebulium tests
the fine structure constant variation

Franco D. Albareti

PhD student
under the supervision of

Prof. Antonio L. Maroto and Prof. Francisco Prada

Acknowledgements

Obra Social
Fundación "la Caixa"

Campus Internacional
excelencia UAM+CSIC

30th March 2015

Nebulium tests
the fine structure constant variation

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),
…

30th March 2015

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.

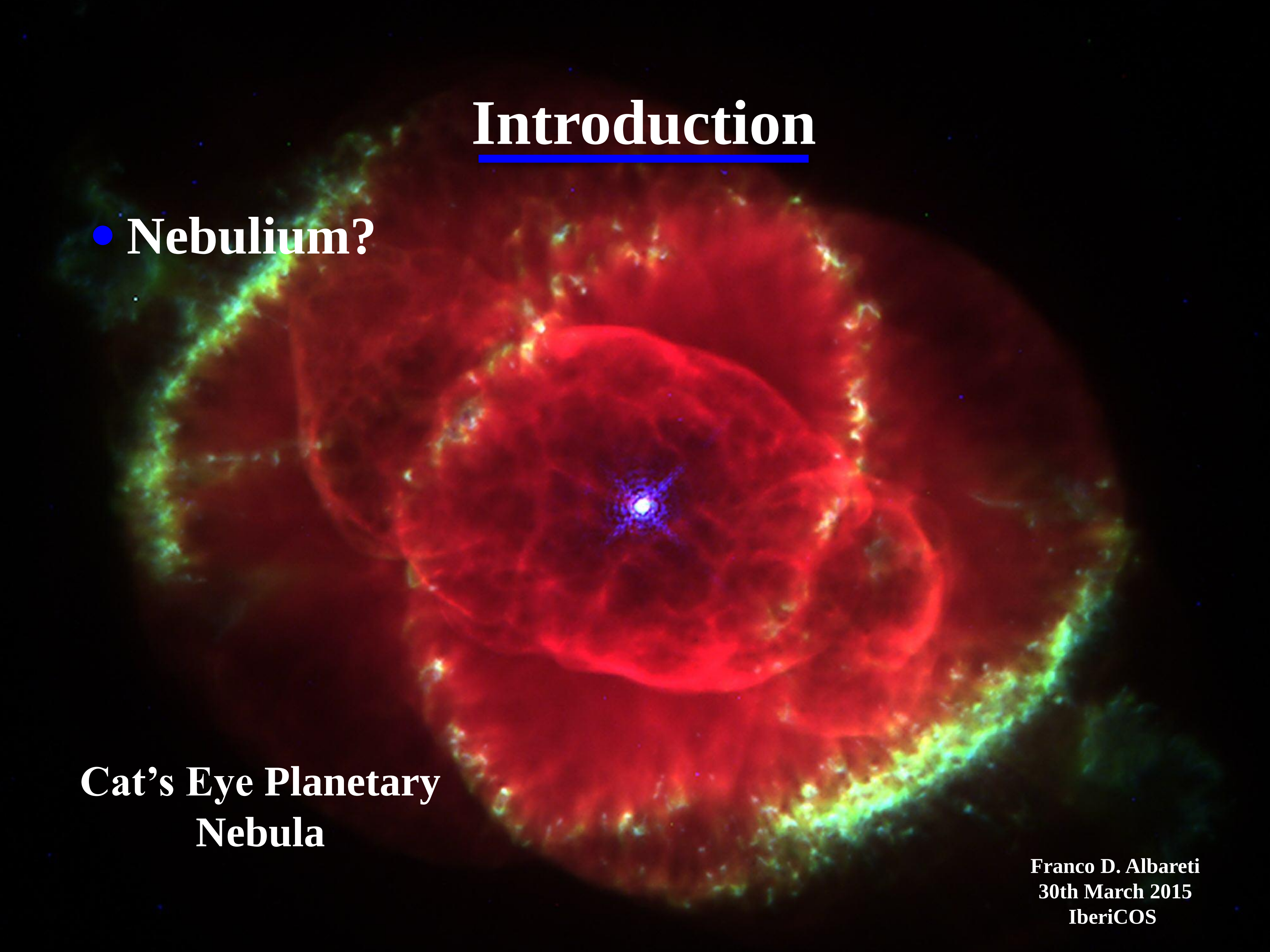
Fundamental constant of Nature

Introduction

- **Nebulium?**

Introduction

- Nebulium?

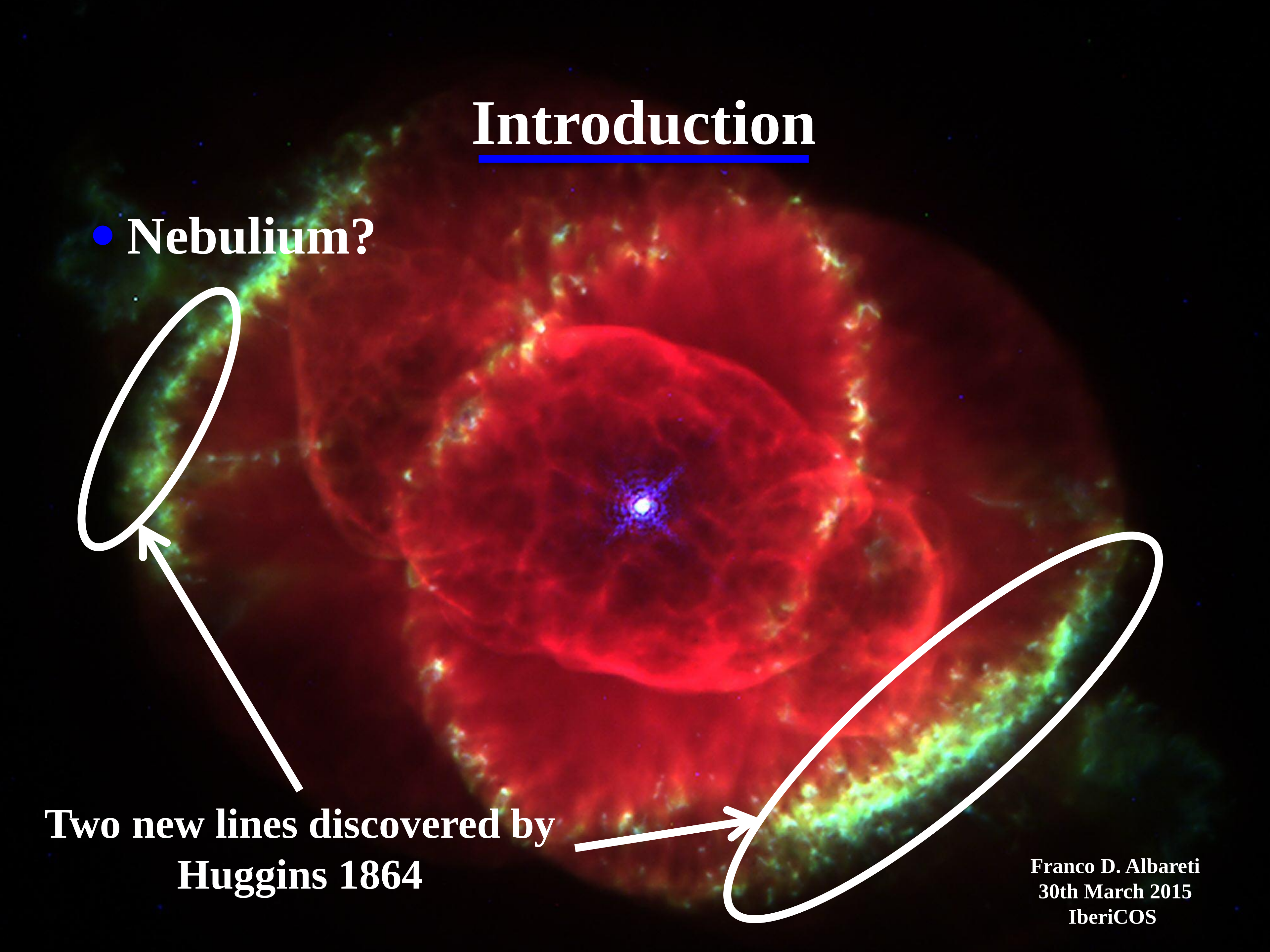


Cat's Eye Planetary Nebula

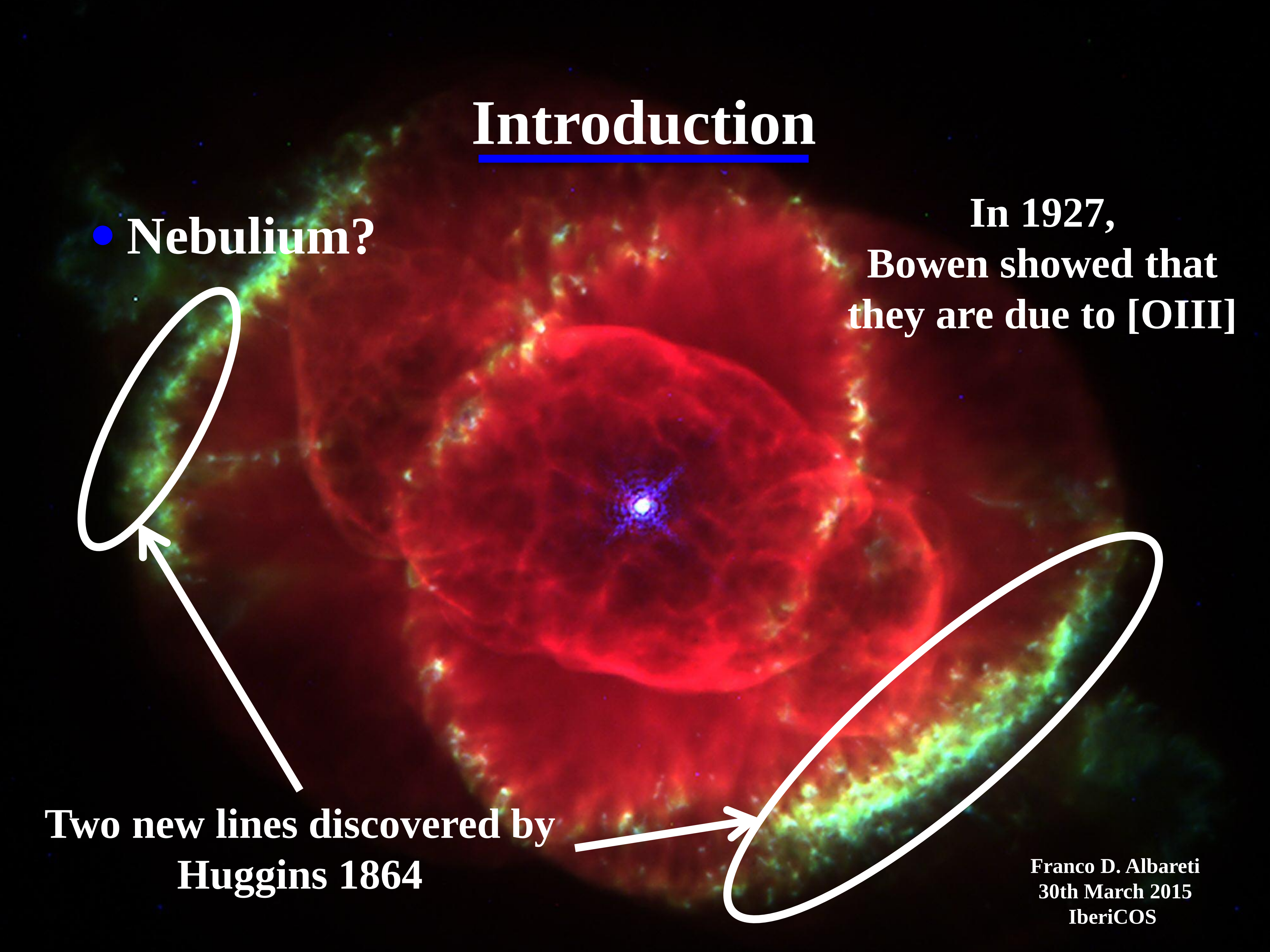
Franco D. Albareti
30th March 2015
IberiCOS

Introduction

- Nebulium?

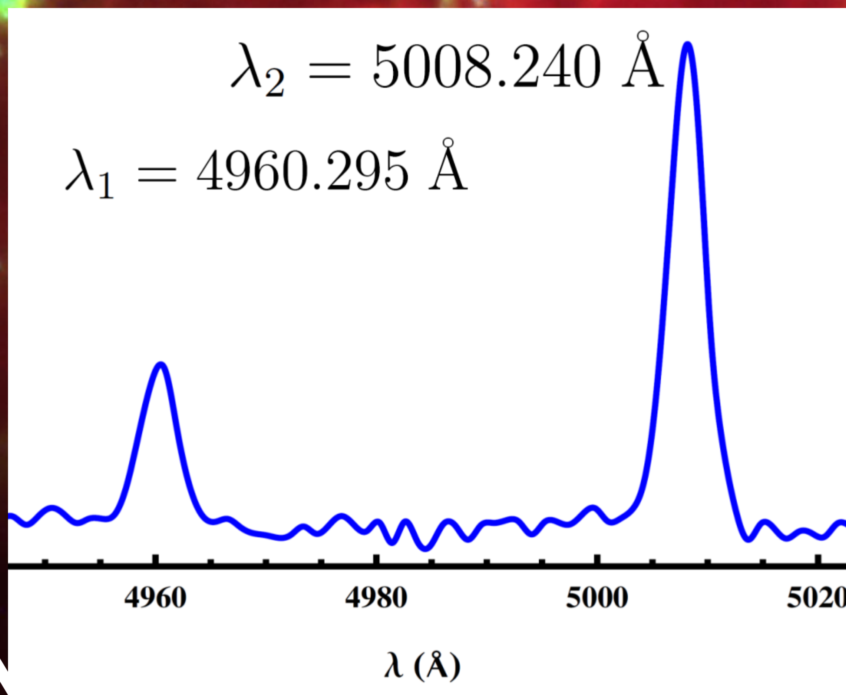


Franco D. Albareti
30th March 2015
IberiCOS


Introduction
Nebulium?
In 1927,
Bowen showed that
they are due to [OIII]
Two new lines discovered by
Huggins 1864
Franco D. Albareti
30th March 2015
IberiCOS

Introduction

- **Nebulium?**



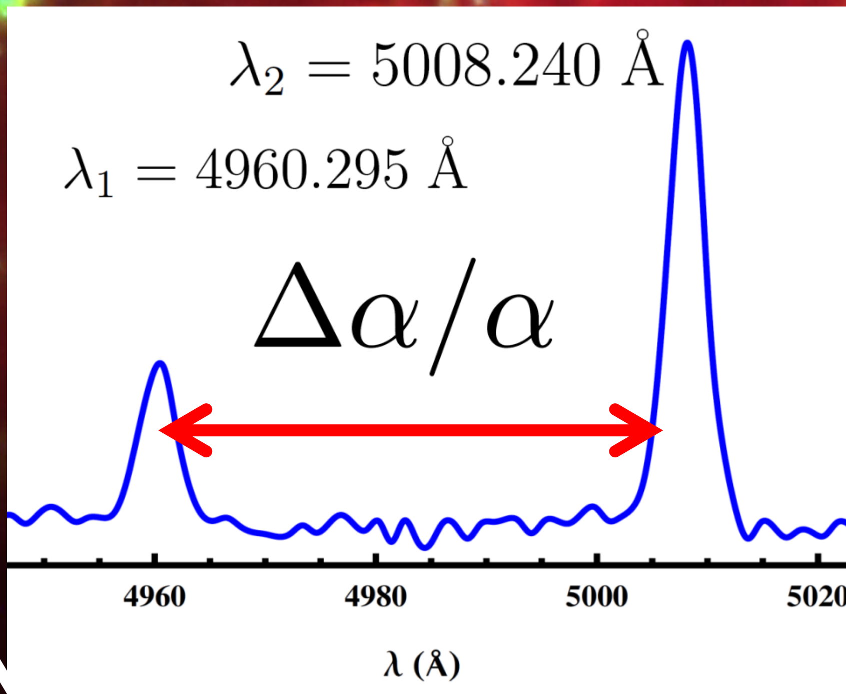
**In 1927,
Bowen showed that
they are due to [OIII]**

**Two new lines discovered by
Huggins 1864**

Franco D. Albareti
**30th March 2015
IberiCOS**

Introduction

- Nebulium?



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

Two new lines discovered by
Huggins 1864

Franco D. Albareti
30th March 2015
IberiCOS

Nebulium tests
the fine structure constant variation

Franco D. Albareti

PhD student
under the supervision of

Prof. Antonio L. Maroto and Prof. Francisco Prada

Instituto de Física Teórica
UAM-CSIC

Instituto de Física Teórica UAM/CSIC

30th March 2015

Nebulium or [OIII] tests the fine structure constant variation

Franco D. Albareti

PhD student
under the supervision of

Prof. Antonio L. Maroto and Prof. Francisco Prada

Instituto de Física Teórica UAM/CSIC

30th March 2015

Introduction

Where do we look for those lines?

Introduction

Where do we look for those lines?

[OIII] on quasar spectra → Cosmological probes

Introduction

Where do we look for those lines?

[OIII] on quasar spectra → Cosmological probes

Current constraints based on the [OIII] doublet method

Introduction

Where do we look for those lines?

[OIII] on quasar spectra → Cosmological probes

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

Introduction

Where do we look for those lines?

[OIII] on quasar spectra → Cosmological probes

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

Introduction

Where do we look for those lines?

[OIII] on quasar spectra → Cosmological probes

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

Sloan Digital Sky Survey

Outline

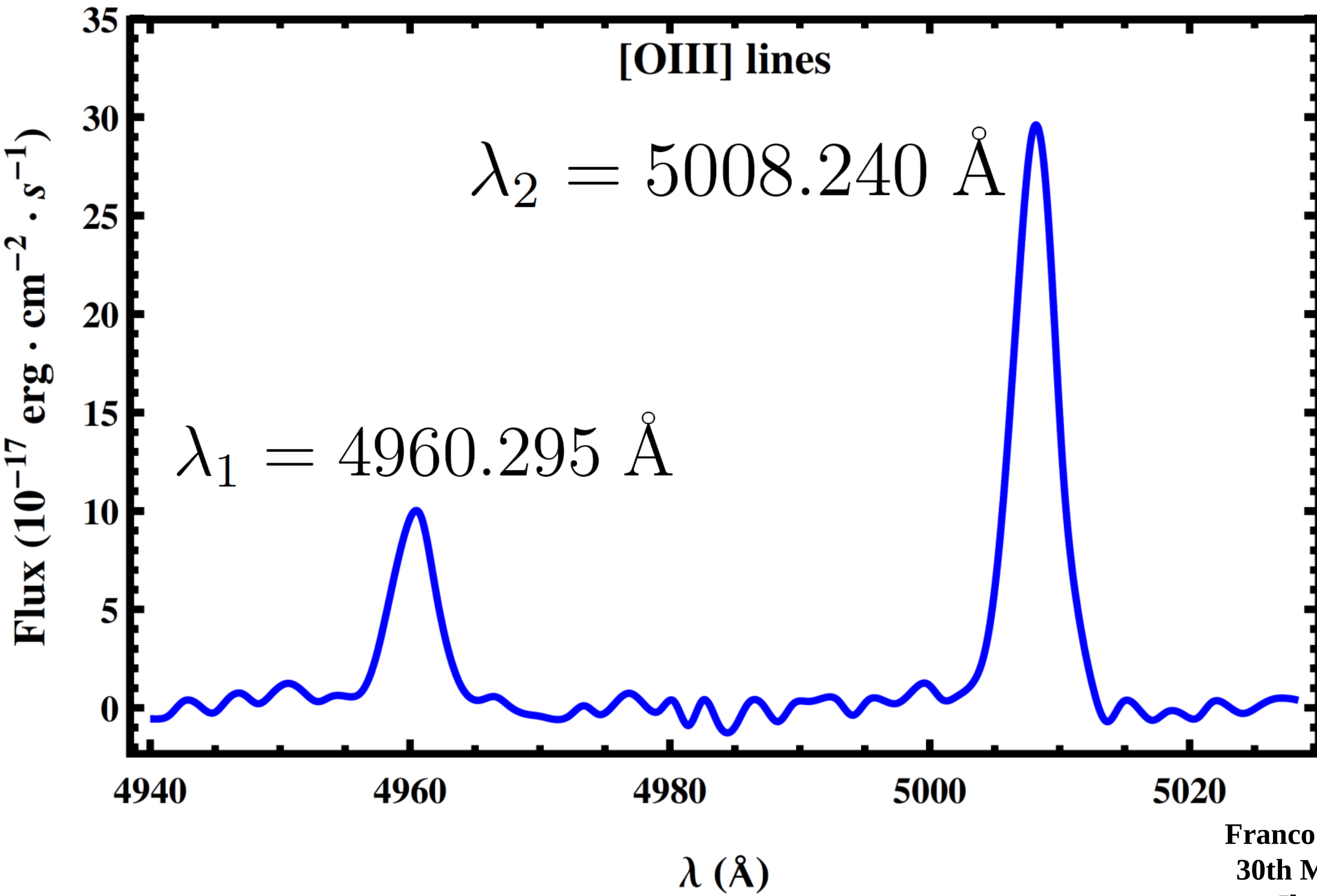
- Introduction ✓
- Methododology
- Sample selection
- Results
- Future projects

Outline

- Introduction ✓
- **Methododology**
- Sample selection
- Results
- Future projects

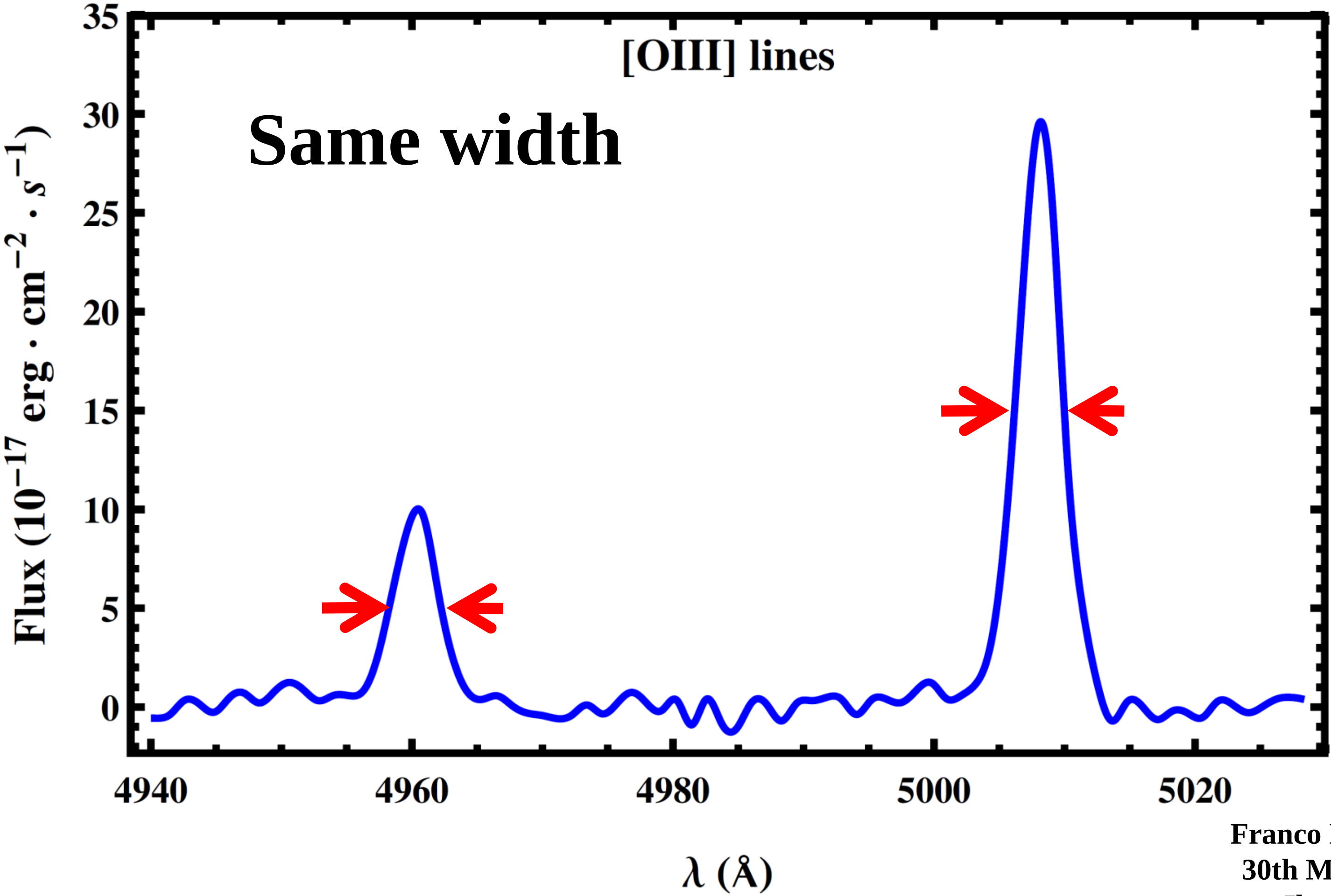
Methodology

Measurement method



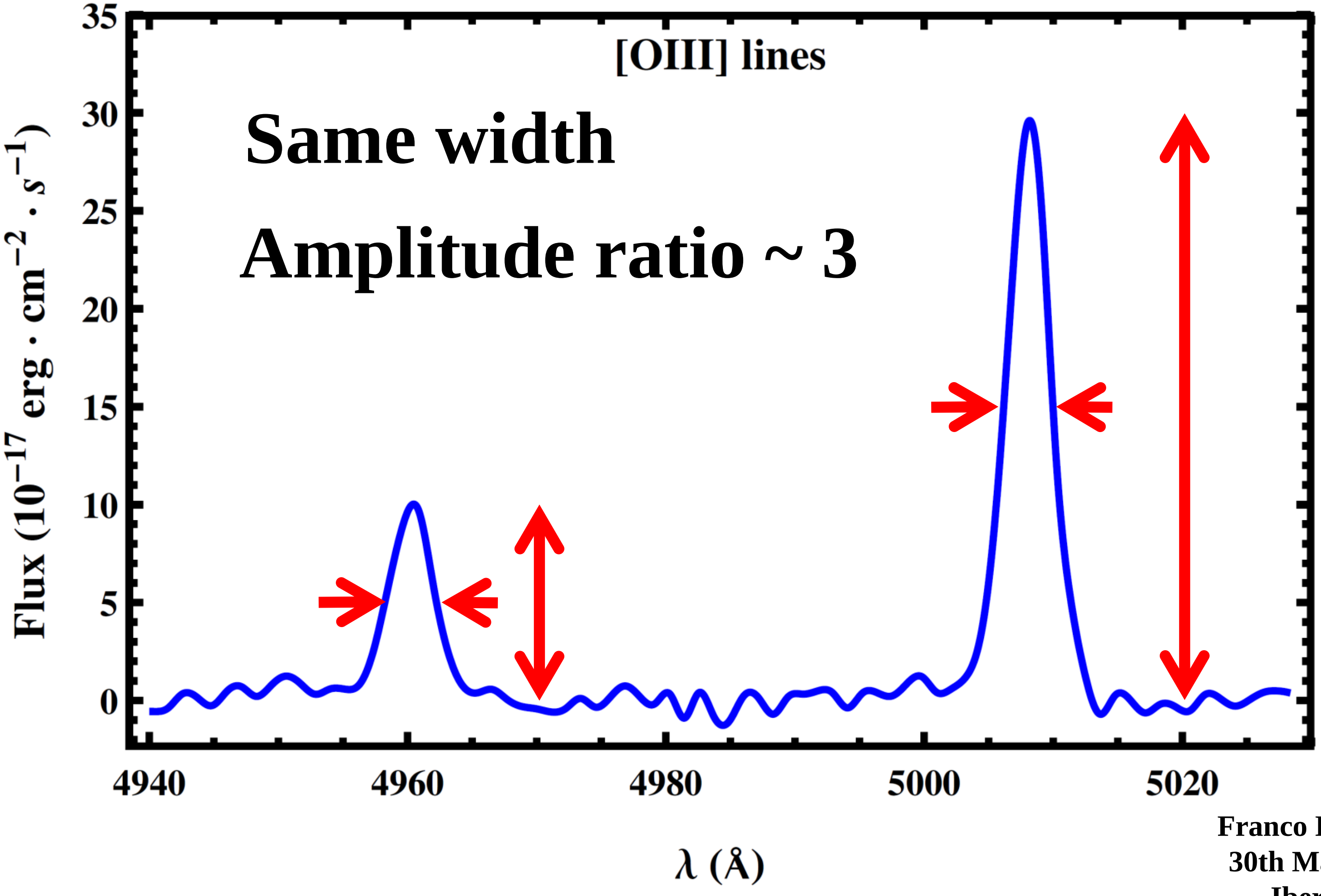
Methodology

Measurement method



Methodology

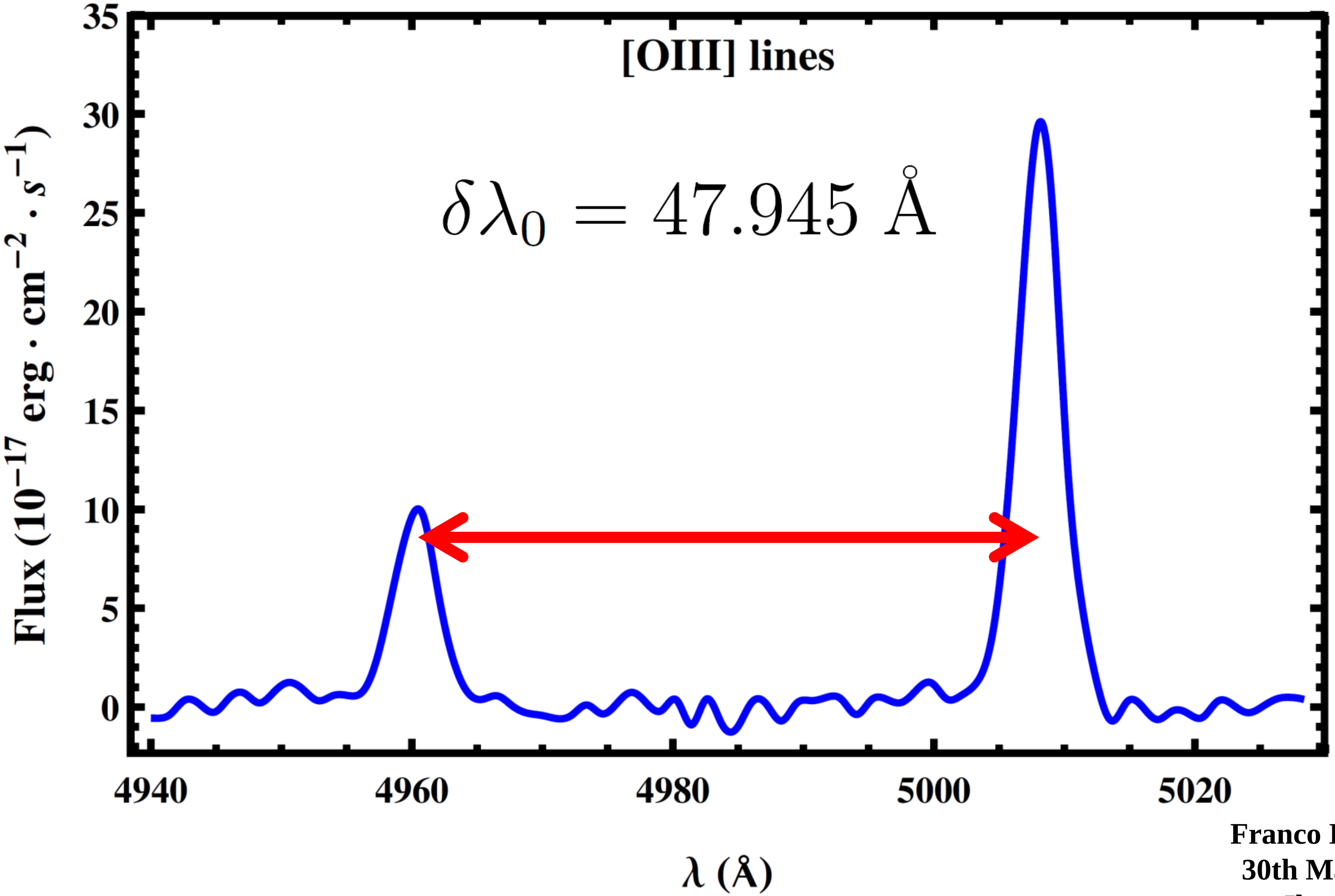
Measurement method



Franco D. Albareti
30th March 2015
IberiCOS

Methodology

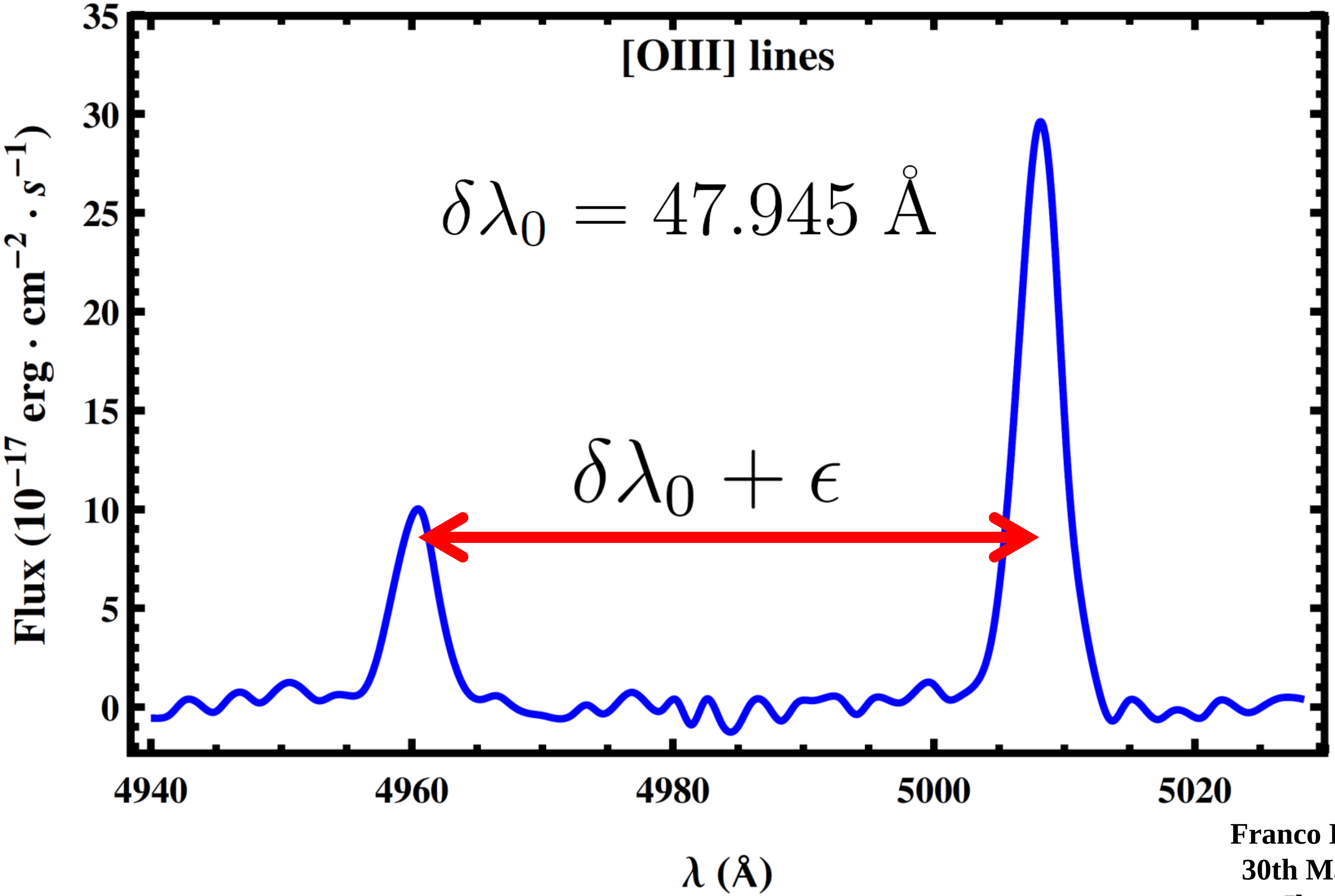
Measurement method



Franco D. Albareti
30th March 2015
IberiCOS

Methodology

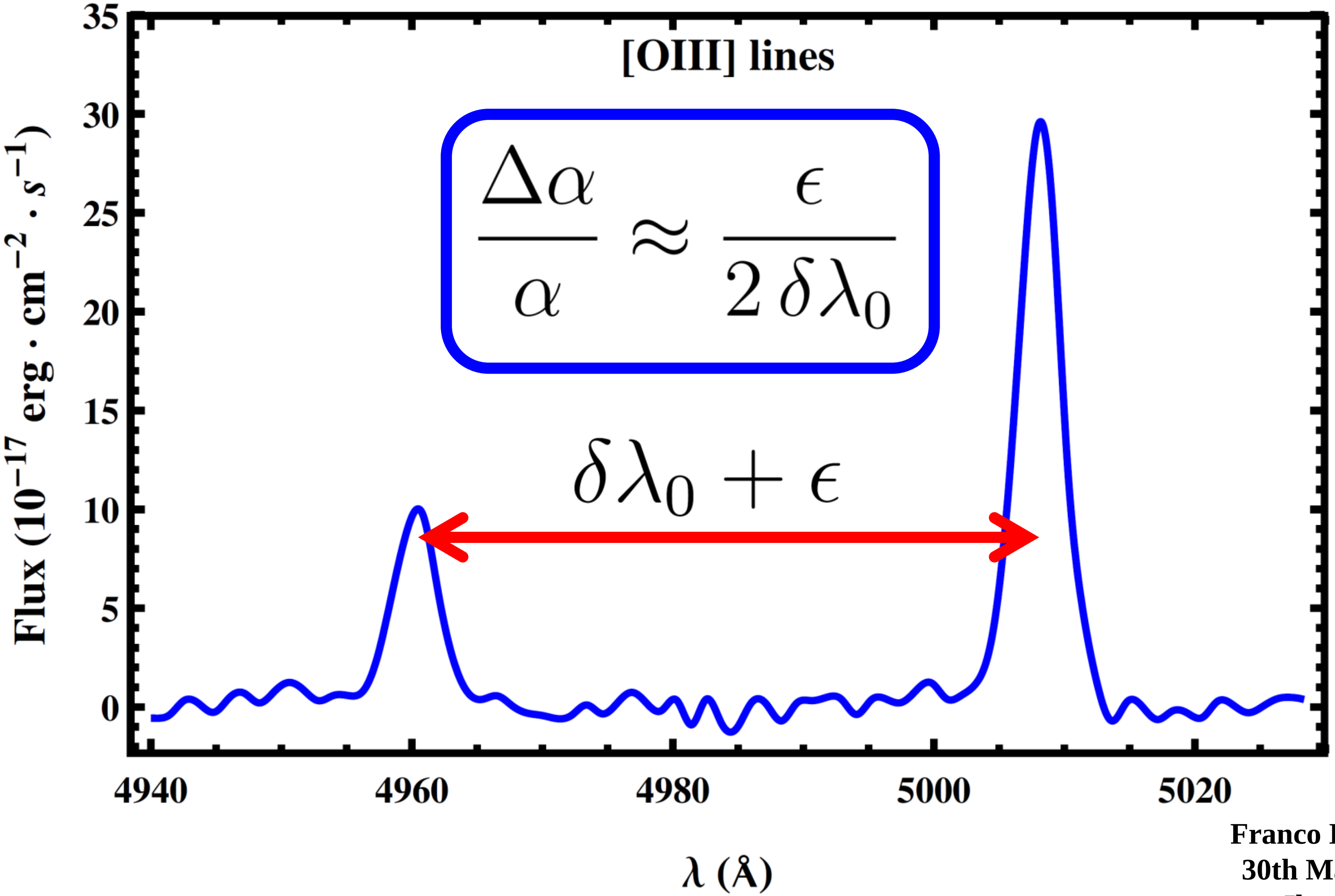
Measurement method



Franco D. Albareti
30th March 2015
IberiCOS

Methodology

Measurement method



Franco D. Albareti
30th March 2015
IberiCOS

Methodology

Measurement method

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

Redshift independent

Franco D. Albareti
30th March 2015
IberiCOS

Methodology

Measurement method

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

Redshift independent

[OIII] doublet

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

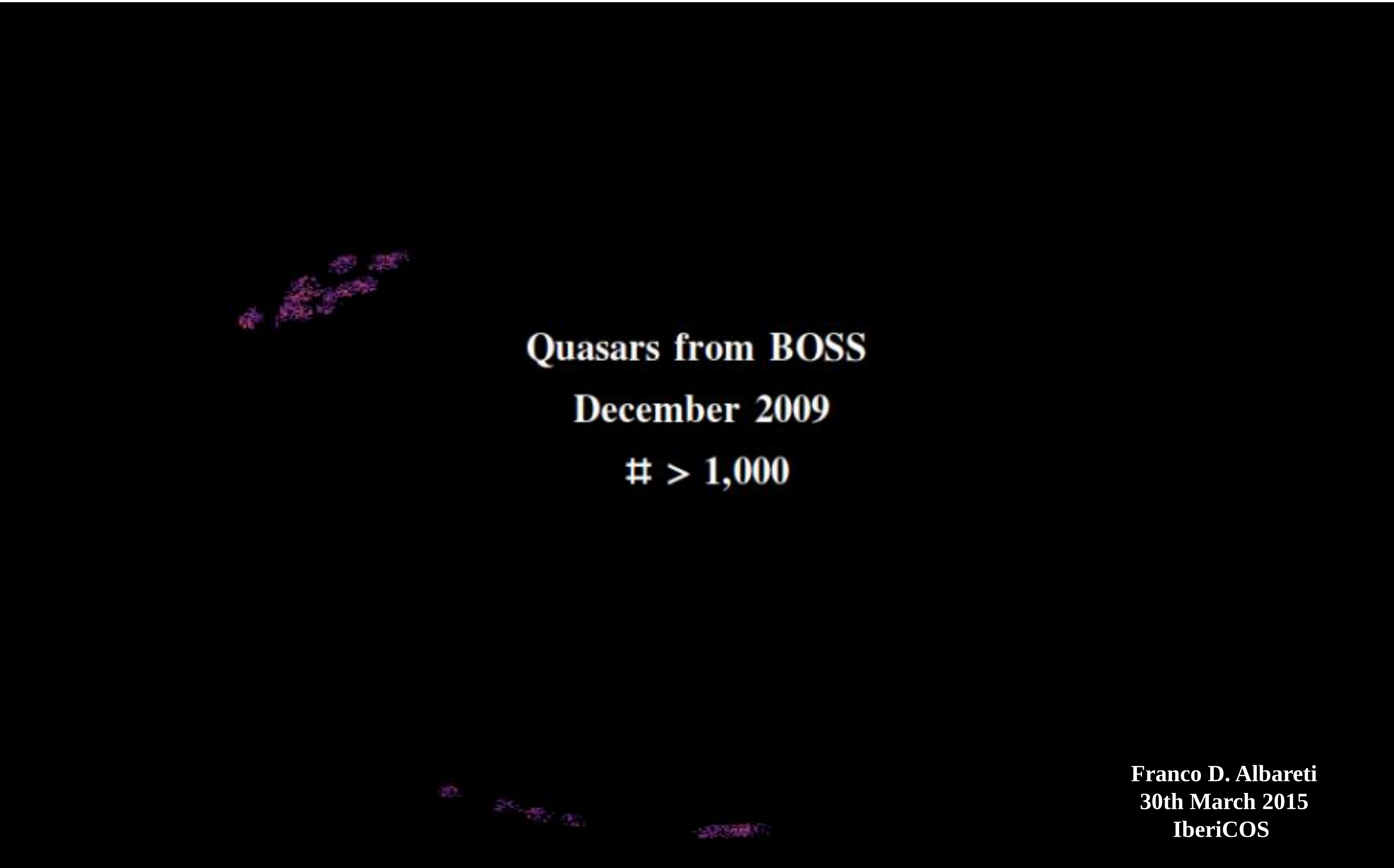
Outline

- Introduction ✓
- **Methododology** ✓
- Sample selection
- Results
- Future projects

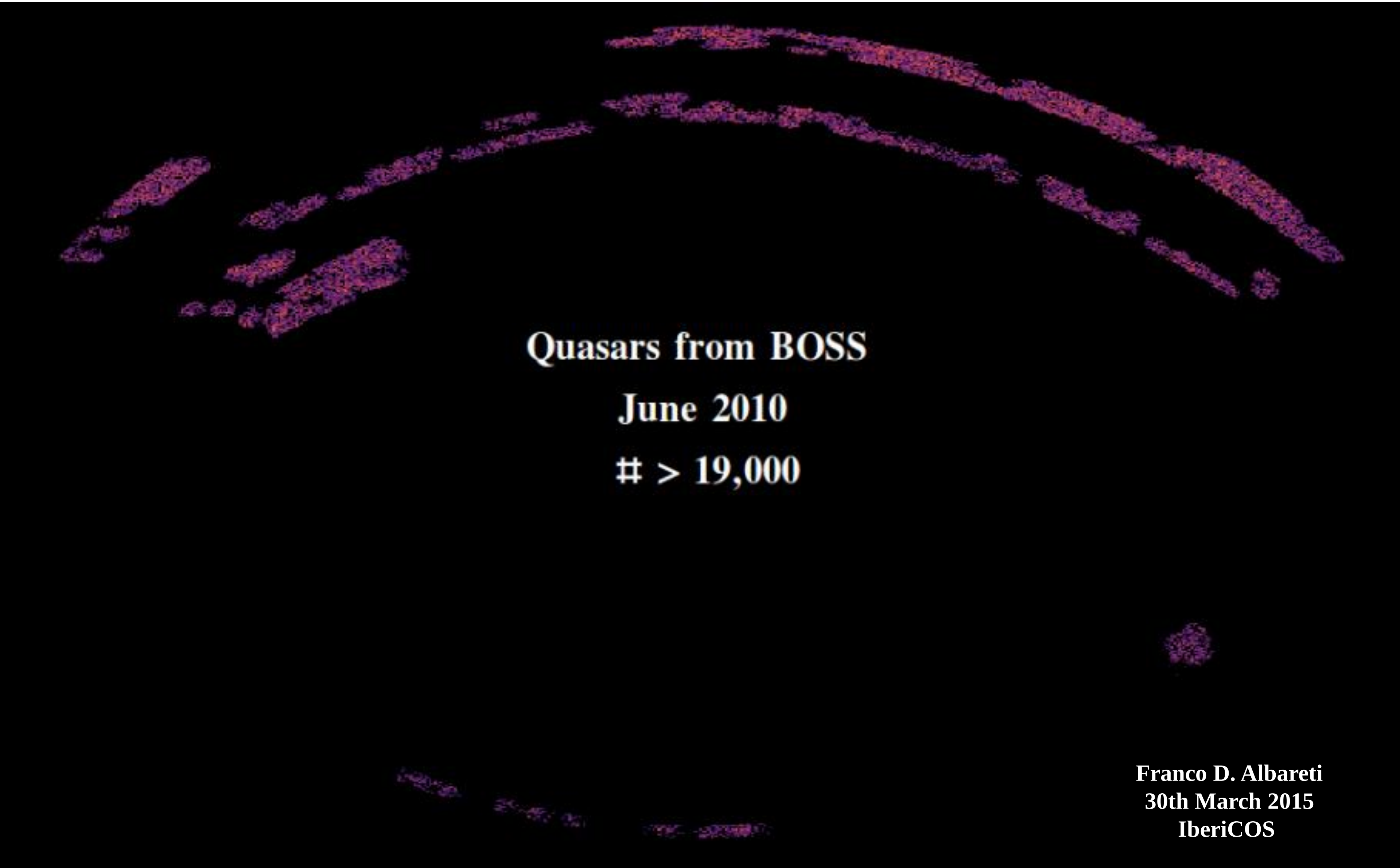
Outline

- Introduction ✓
- Methododology ✓
- **Sample selection**
- Results
- Future projects

Sample selection

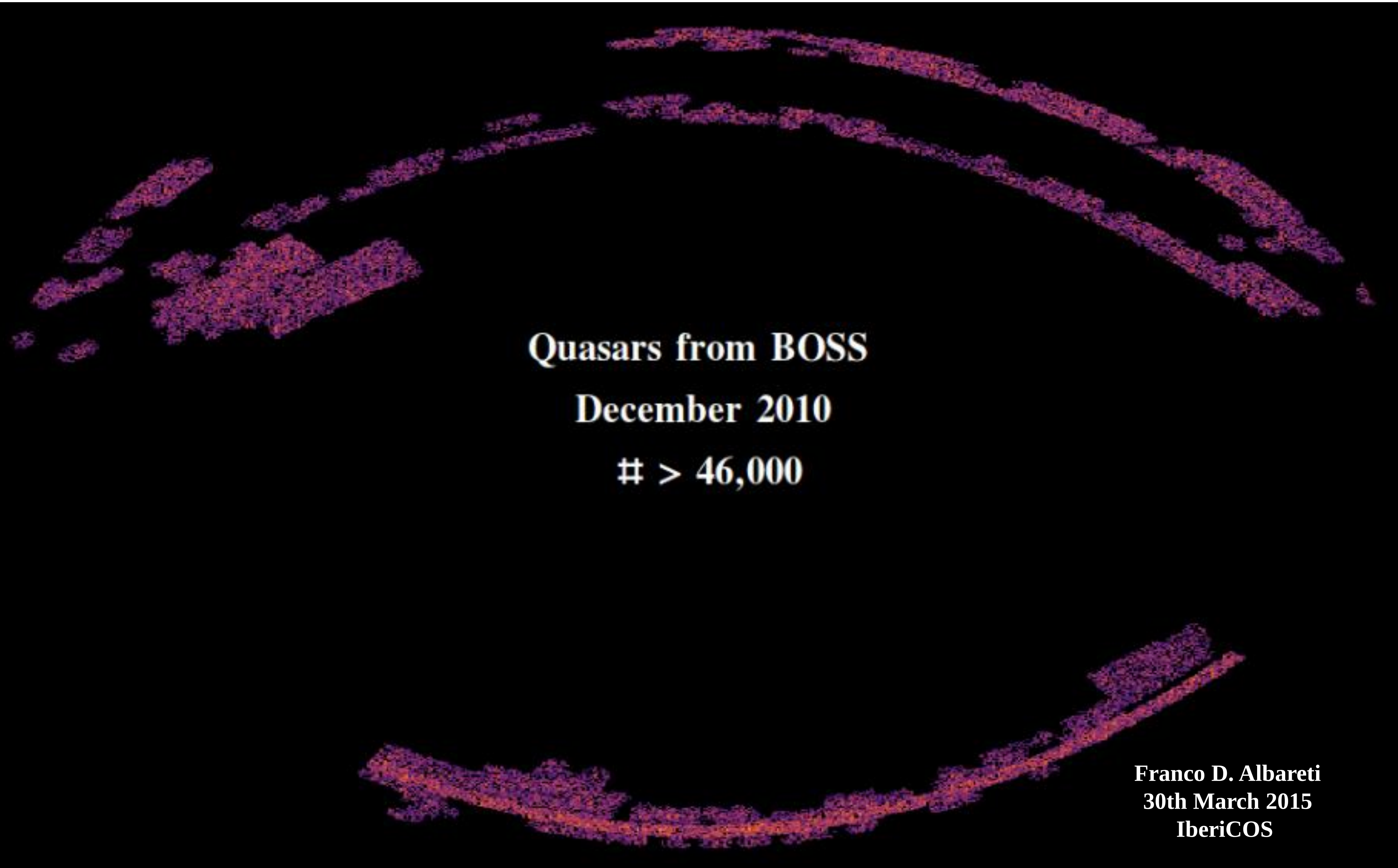


Sample selection

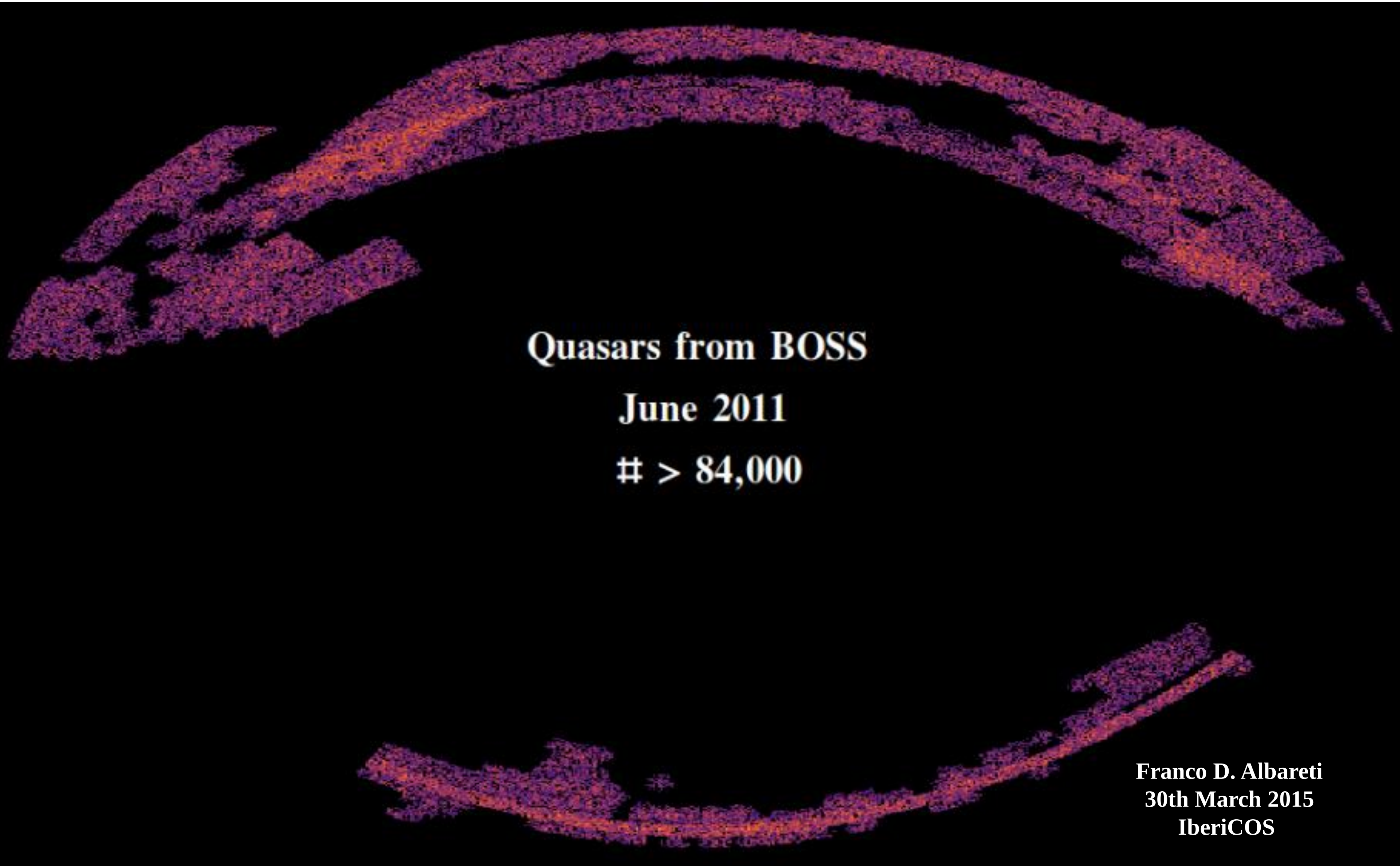


Franco D. Albareti
30th March 2015
IberiCOS

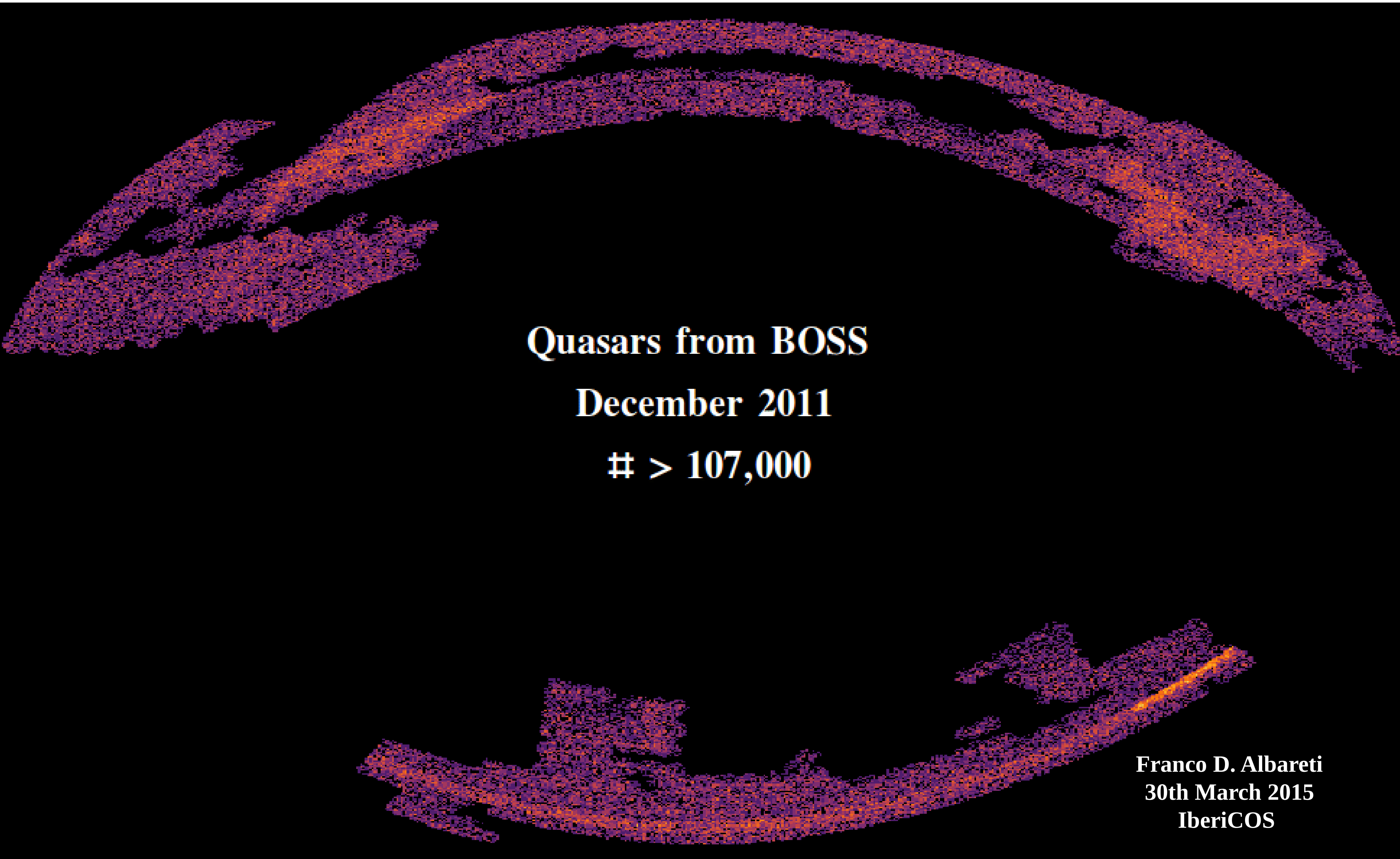
Sample selection



Sample selection

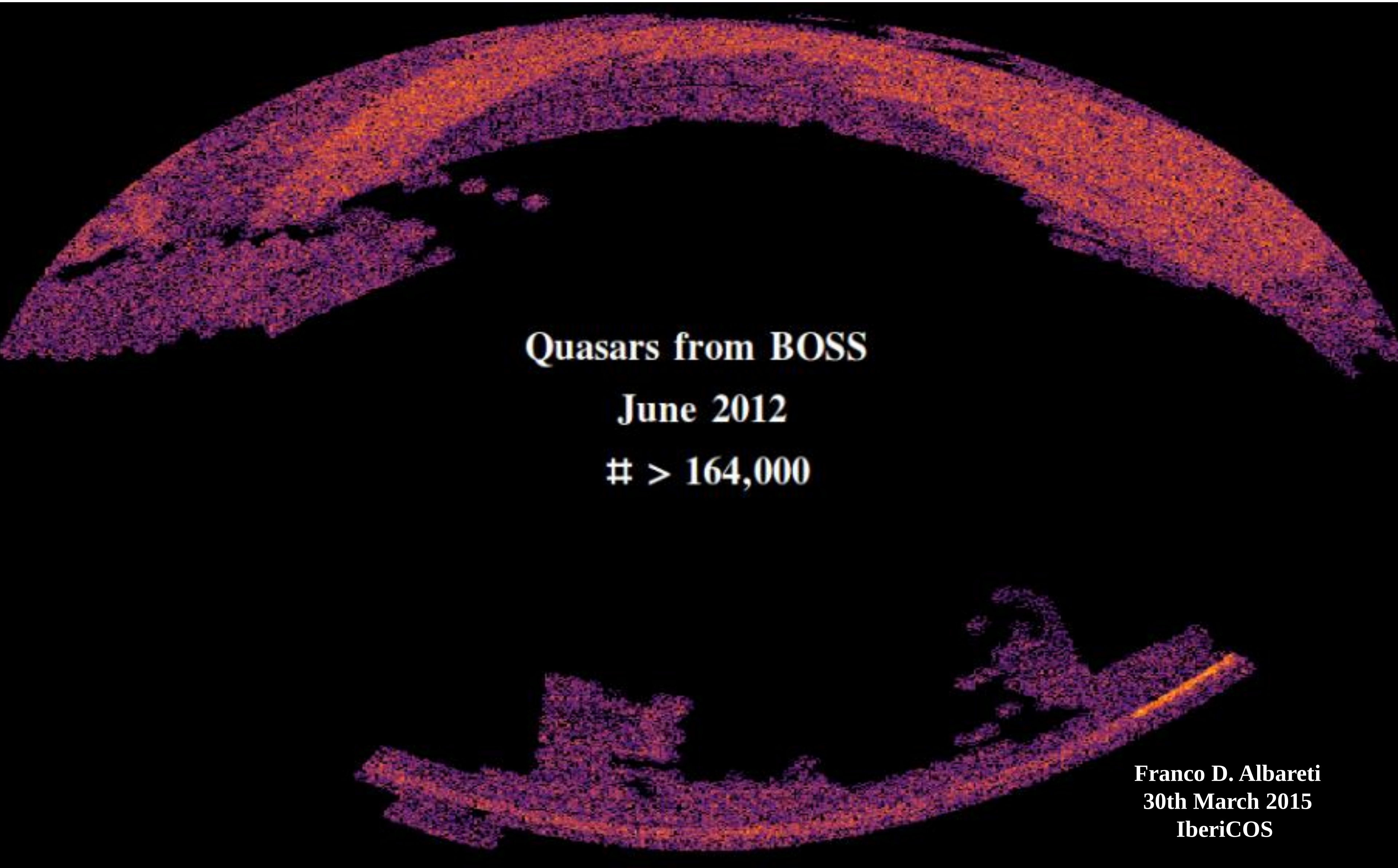


Sample selection



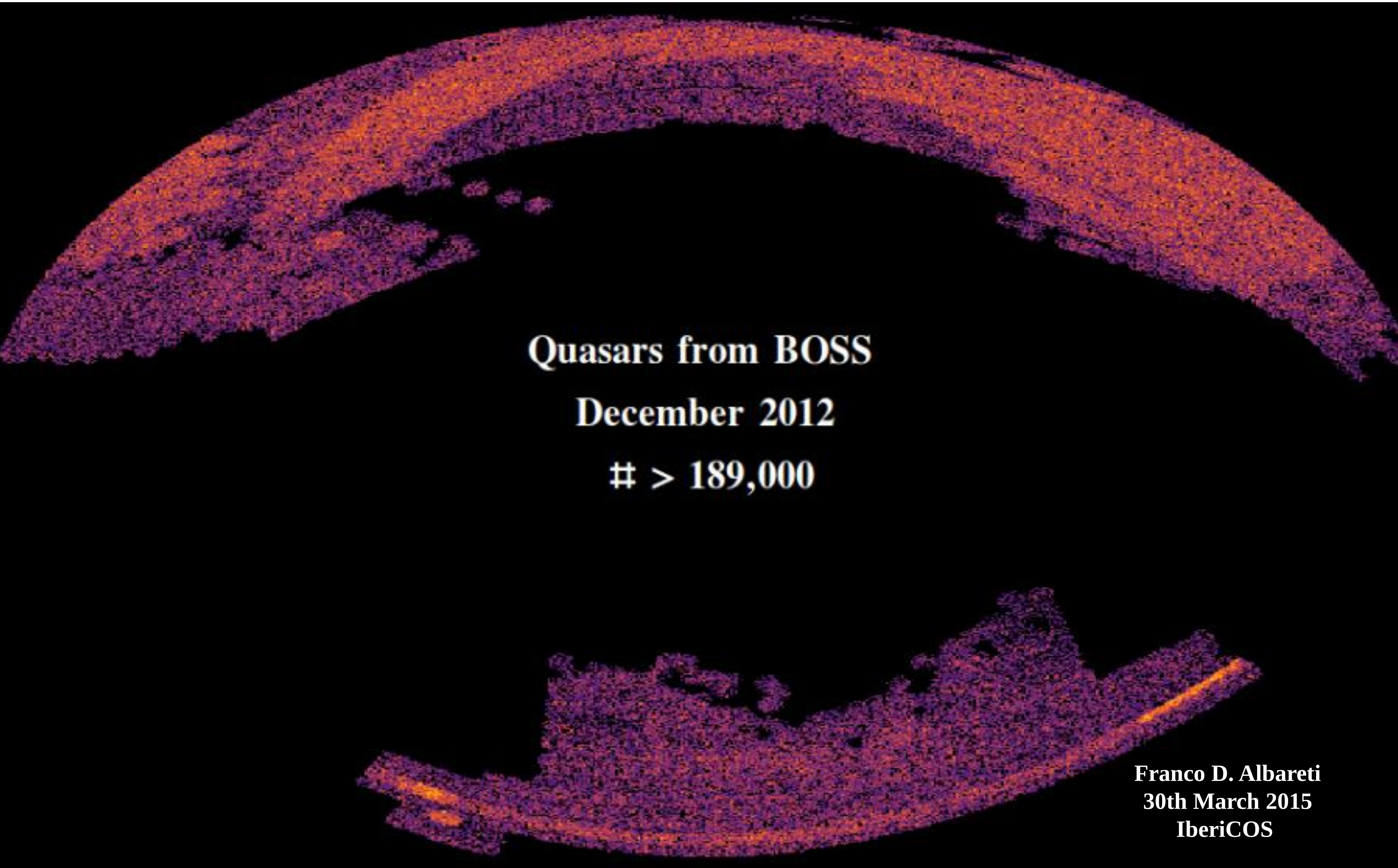
Franco D. Albareti
30th March 2015
IberiCOS

Sample selection

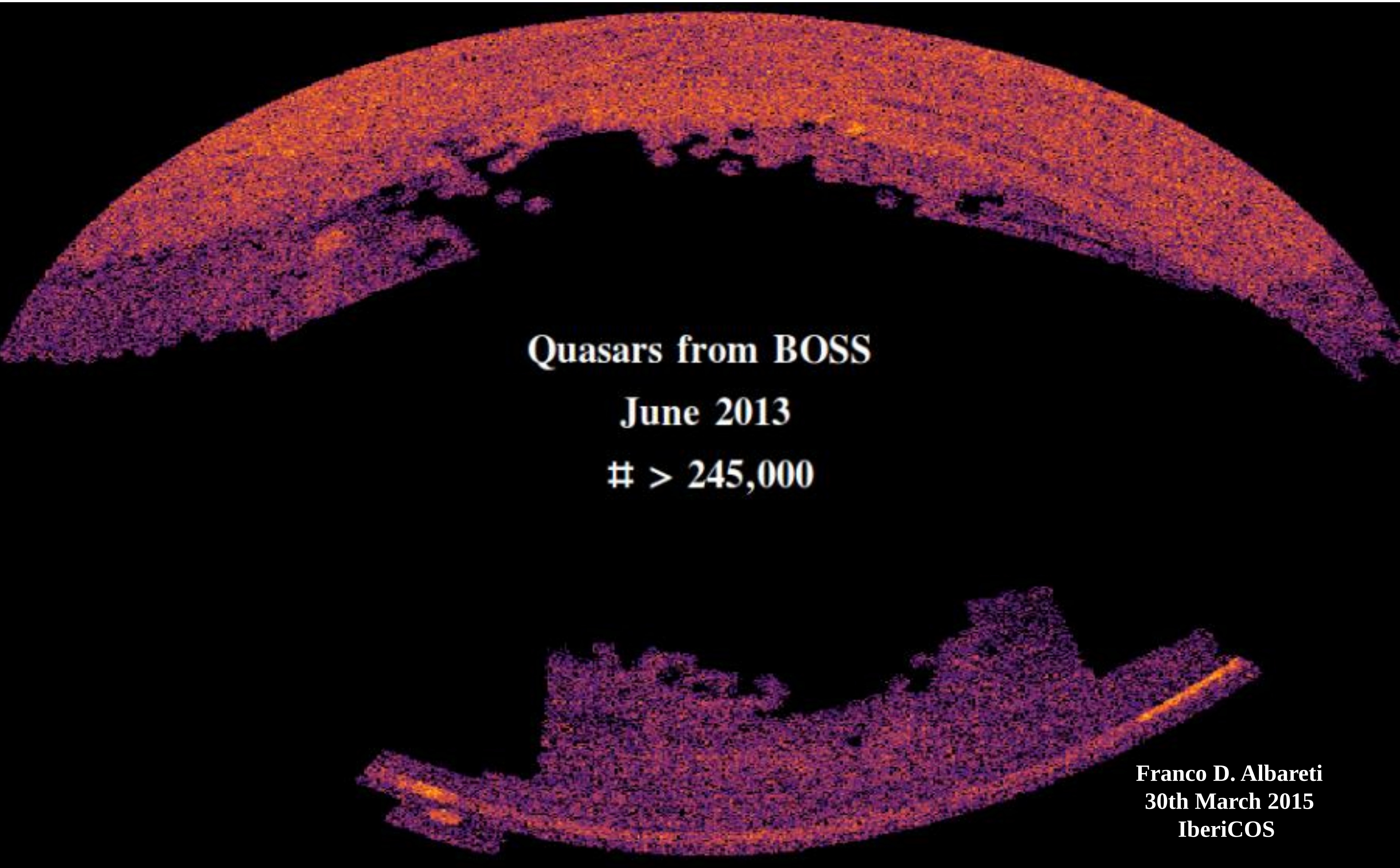


Franco D. Albareti
30th March 2015
IberiCOS

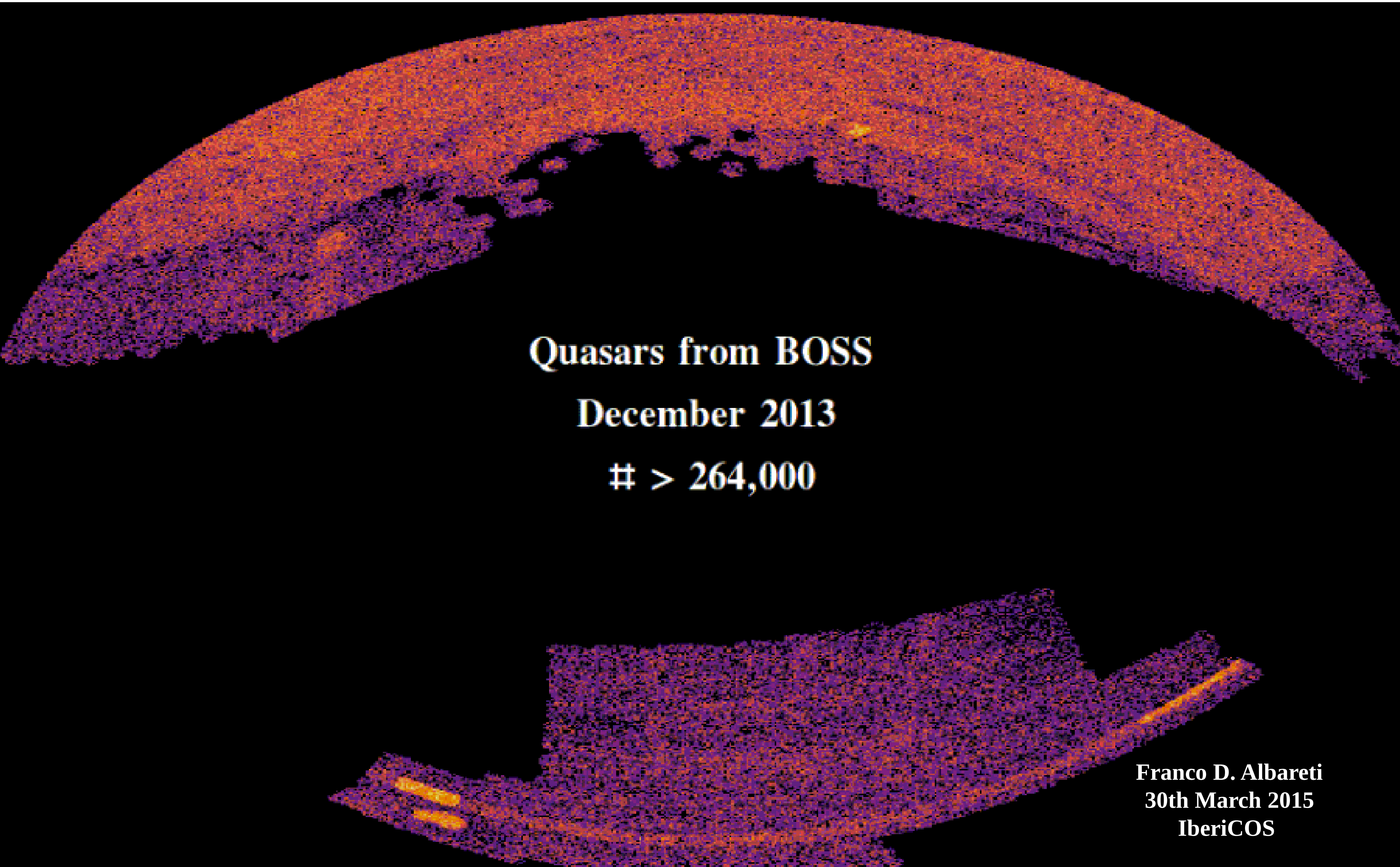
Sample selection



Sample selection

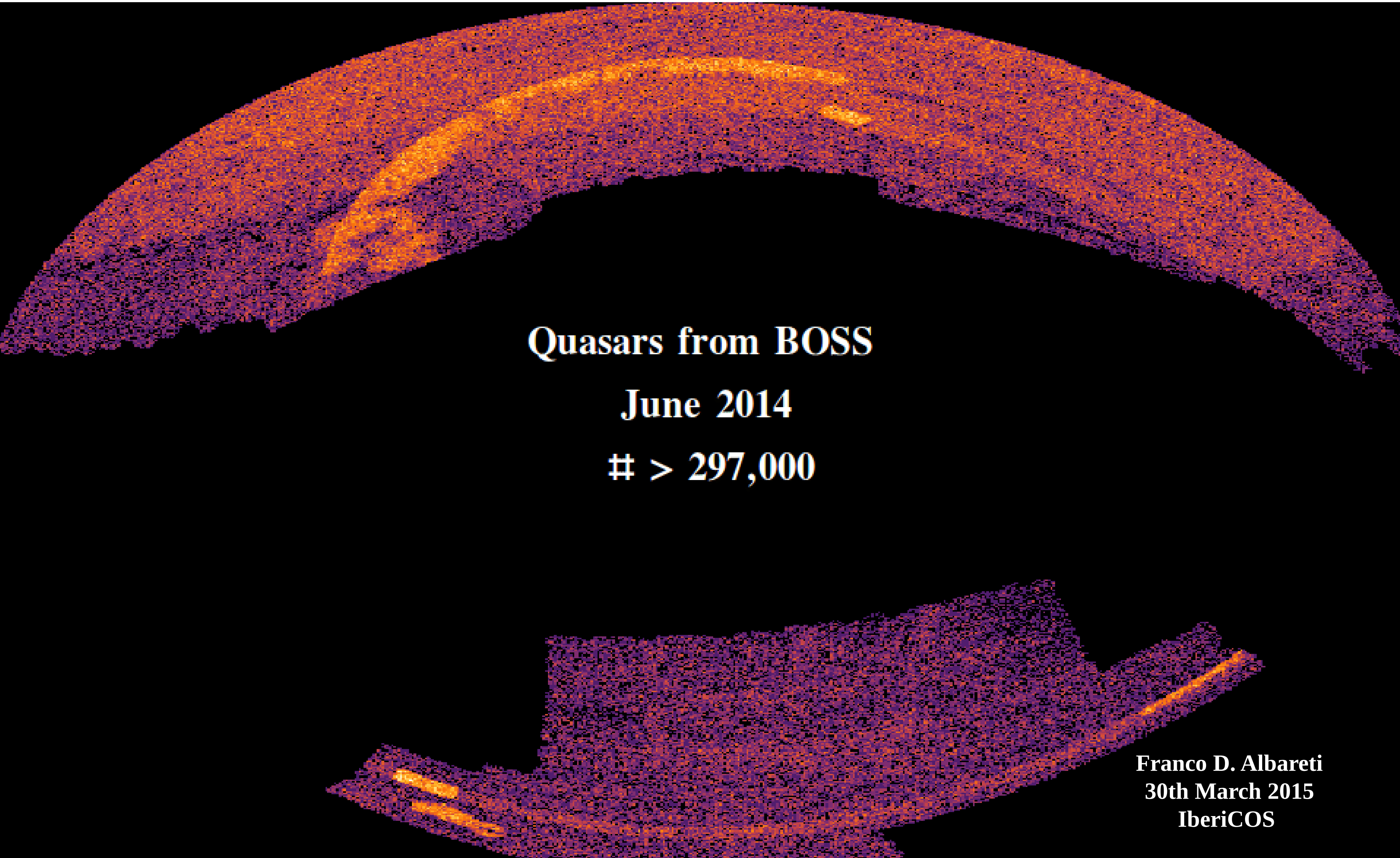


Sample selection



Franco D. Albareti
30th March 2015
IberiCOS

Sample selection



Franco D. Albareti
30th March 2015
IberiCOS

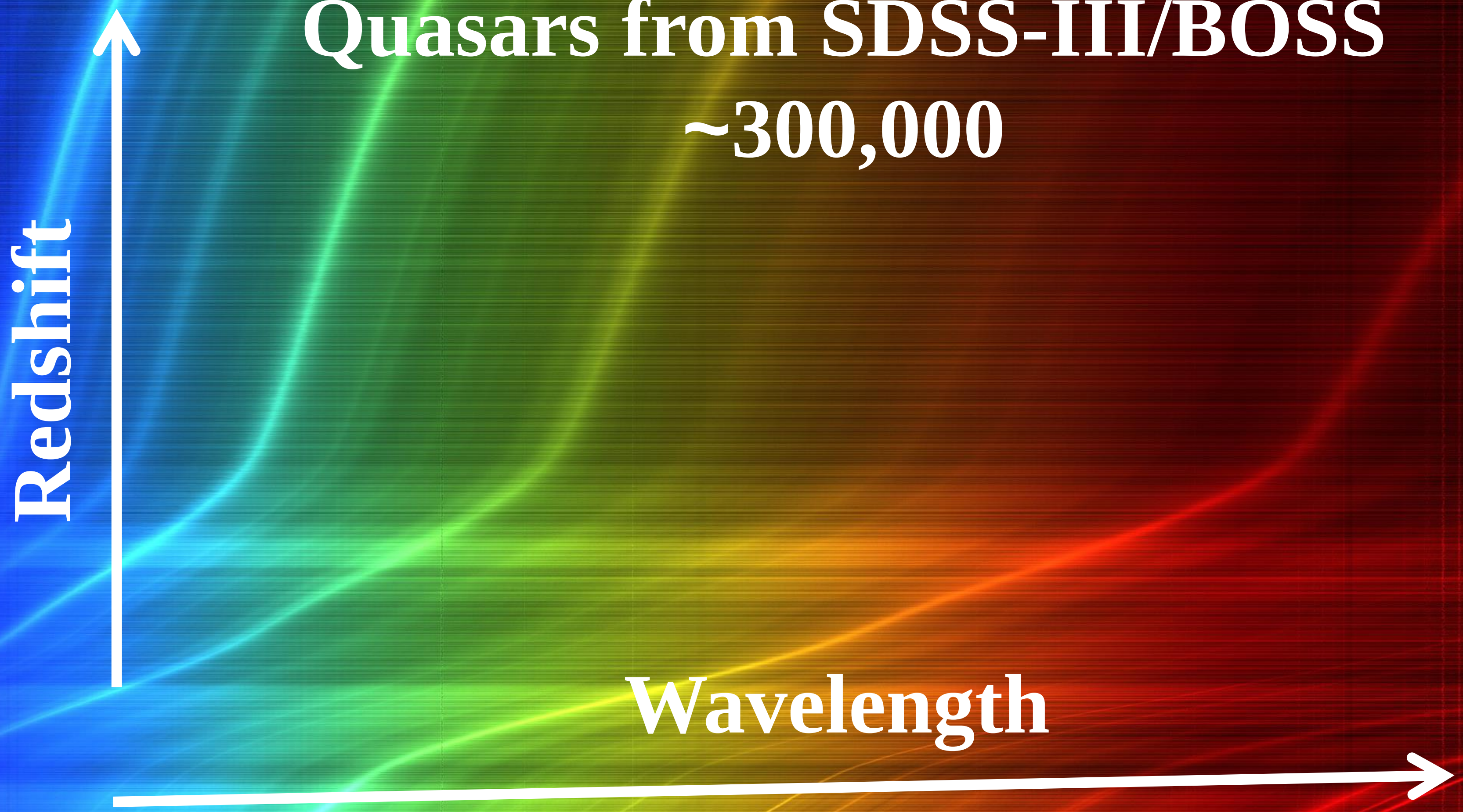
Sample selection

Quasars from SDSS-III/BOSS
~300,000

Franco D. Albareti
30th March 2015
IberiCOS

Sample selection

Quasars from SDSS-III/BOSS
~300,000



Franco D. Albareti
30th March 2015
IberiCOS

Sample selection

Quasars from SDSS-III/BOSS
~300,000

Lyα

CIV

CIII]

MgII

Hβ

Hα

↘

Franco D. Albareti
30th March 2015
IberiCOS

Sample selection

Quasars from SDSS-III/BOSS
~300,000

[OIII] 4960 5008 A

Franco D. Albareti
30th March 2015
IberiCOS

Sample selection

Quasars from SDSS-III/BOSS
~300,000

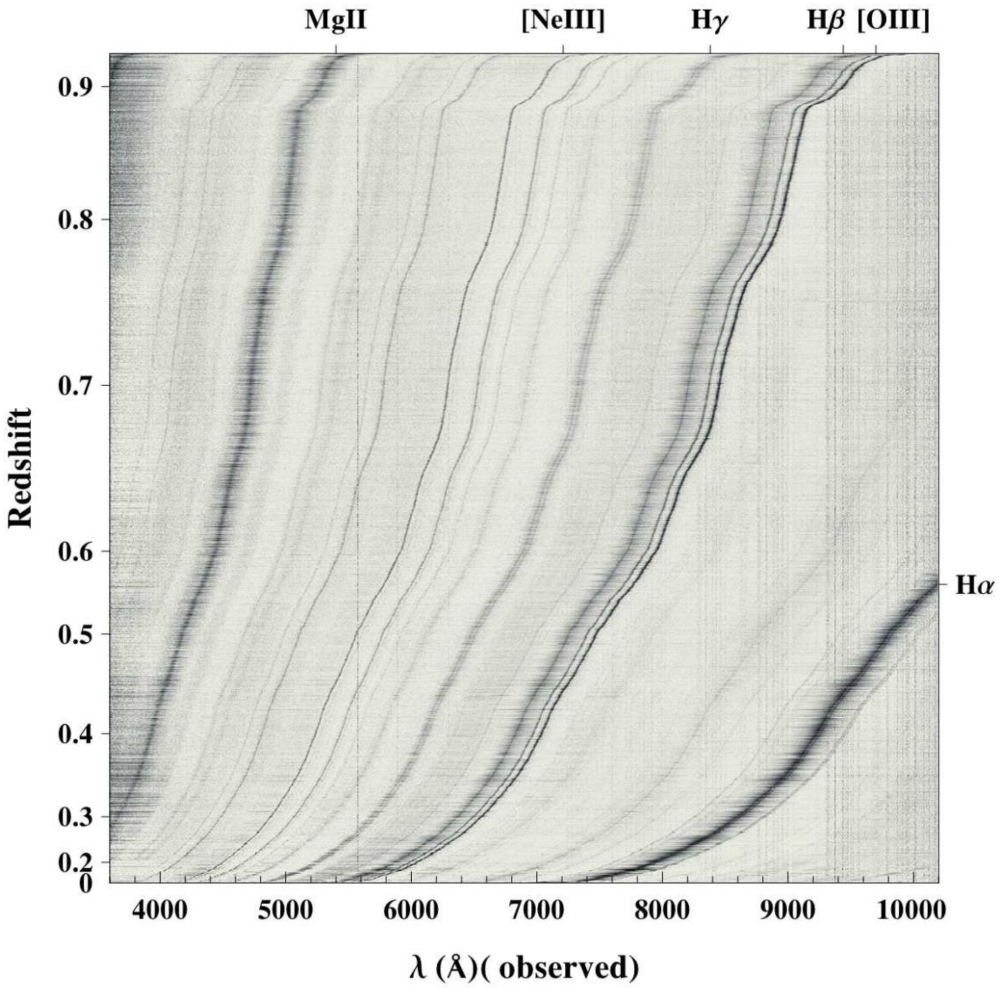
$z < 1$

[OIII] 4960 5008 A

Franco D. Albareti
30th March 2015
IberiCOS

Sample selection

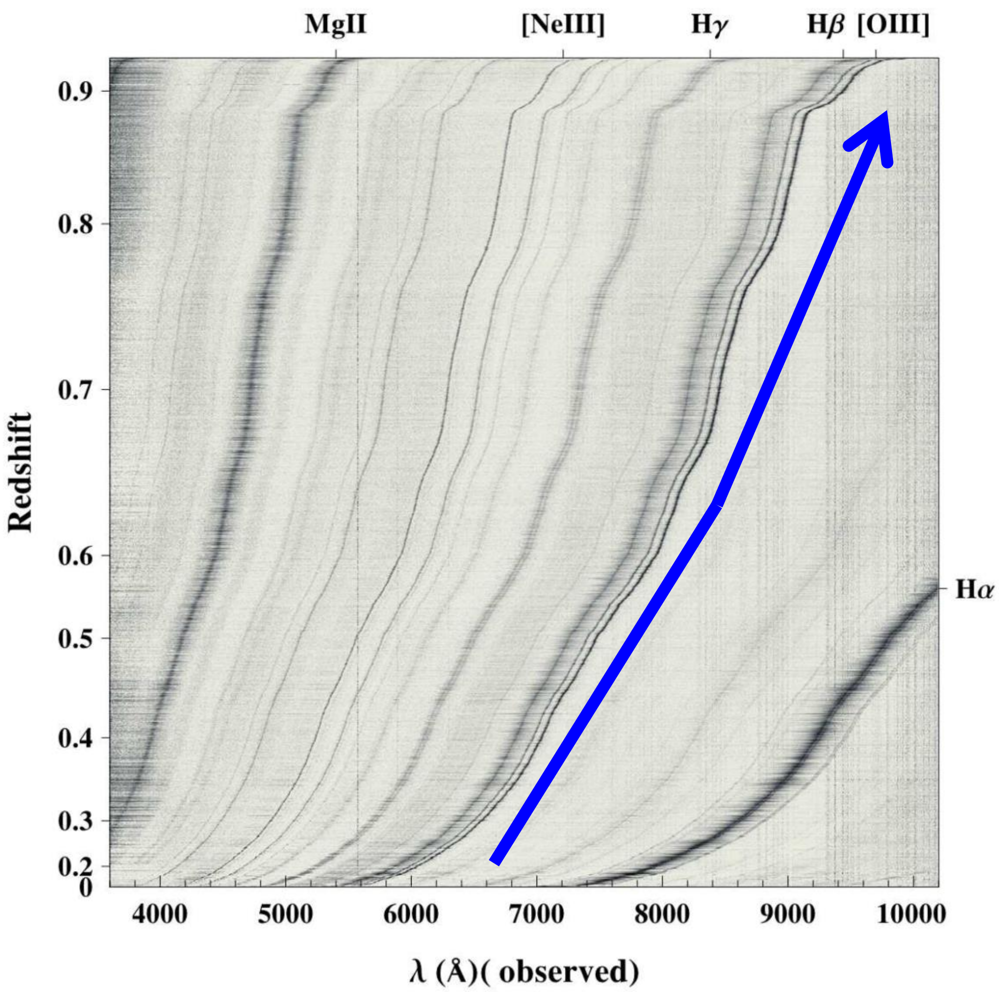
Quasars up to z = 1; >10,000 (clean)



Franco D. Albareti
30th March 2015
IberiCOS

Sample selection

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



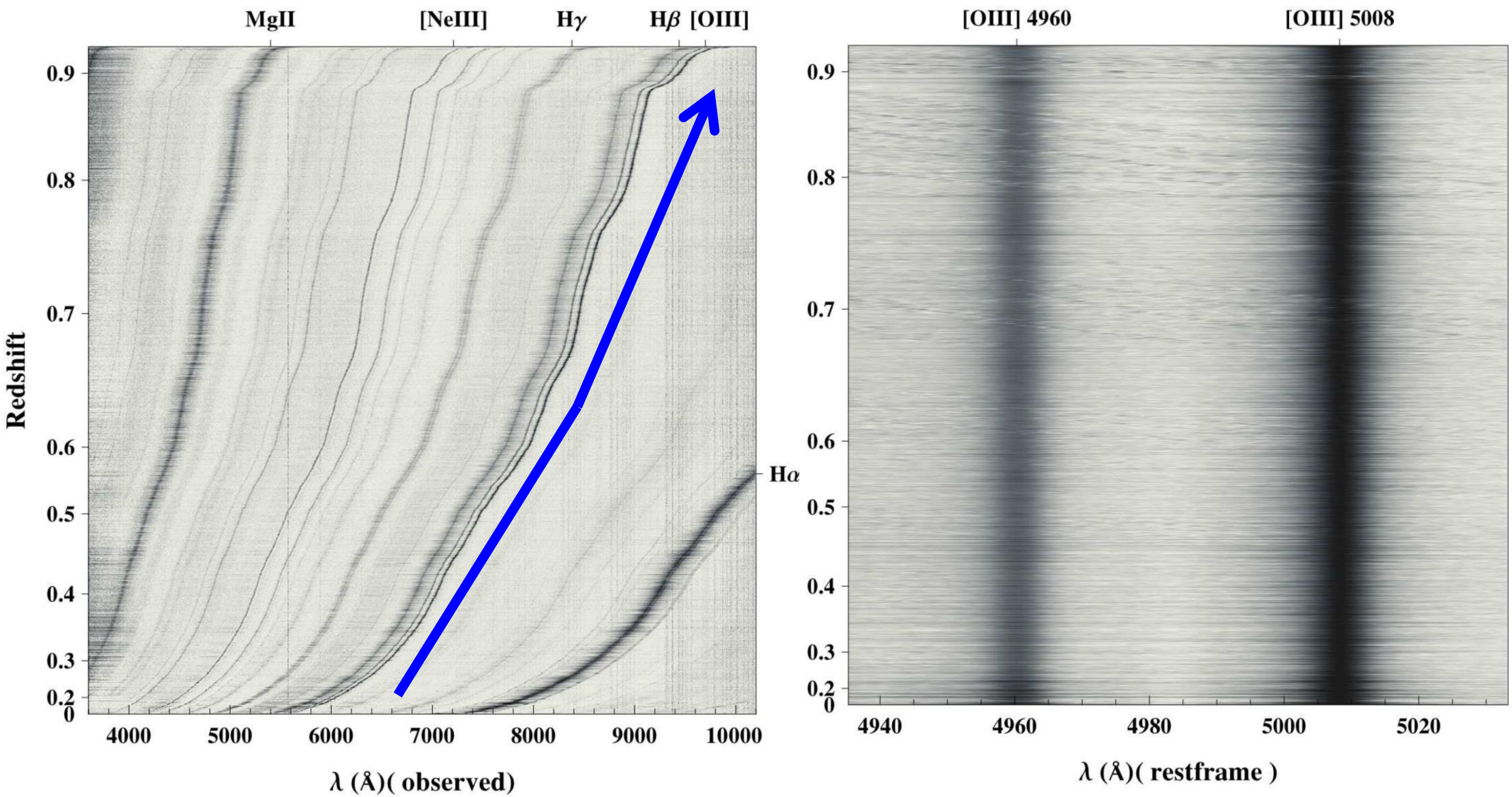
- S/N [OIII] > 10
- Converging Gaussian fits
- Outliers > 4σ

Aceptance rate ~ 1/4

Franco D. Albareti
30th March 2015
IberiCOS

Sample selection

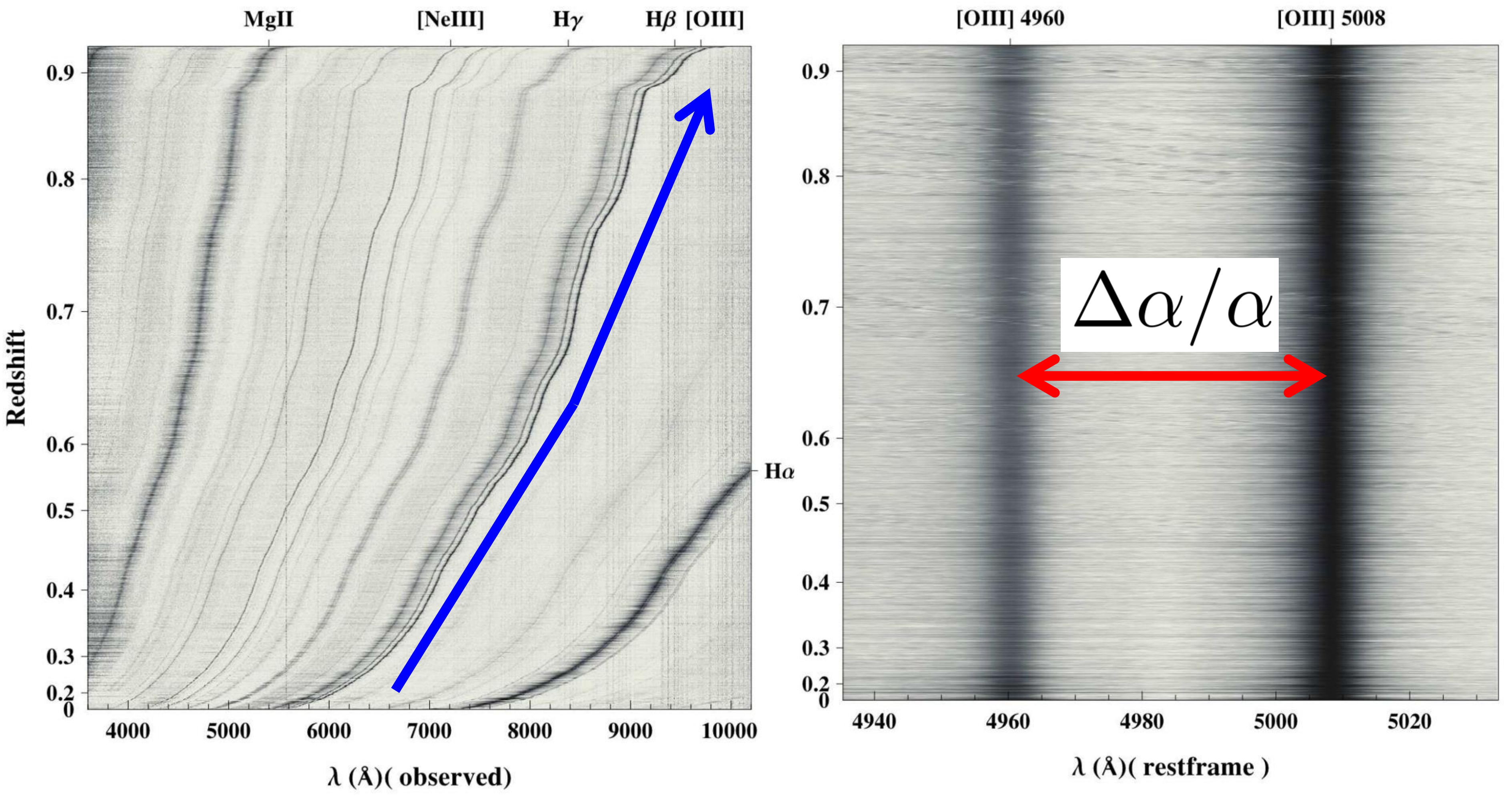
Quasars up to z = 1; >10,000 (clean)



Franco D. Albareti
30th March 2015
IberiCOS

Sample selection

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



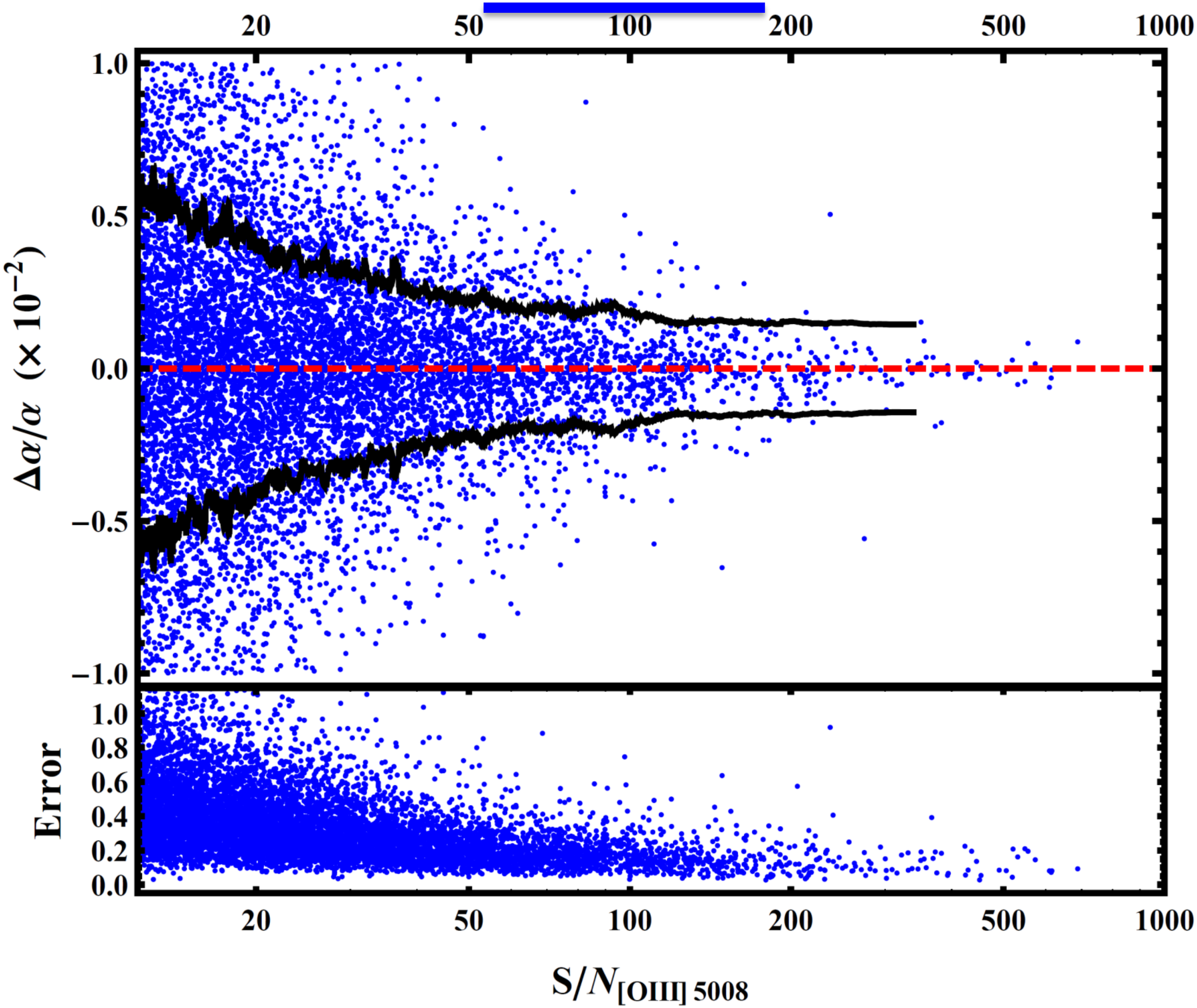
Outline

- Introduction ✓
- Methododology ✓
- **Sample selection** ✓
- Results
- Future projects

Outline

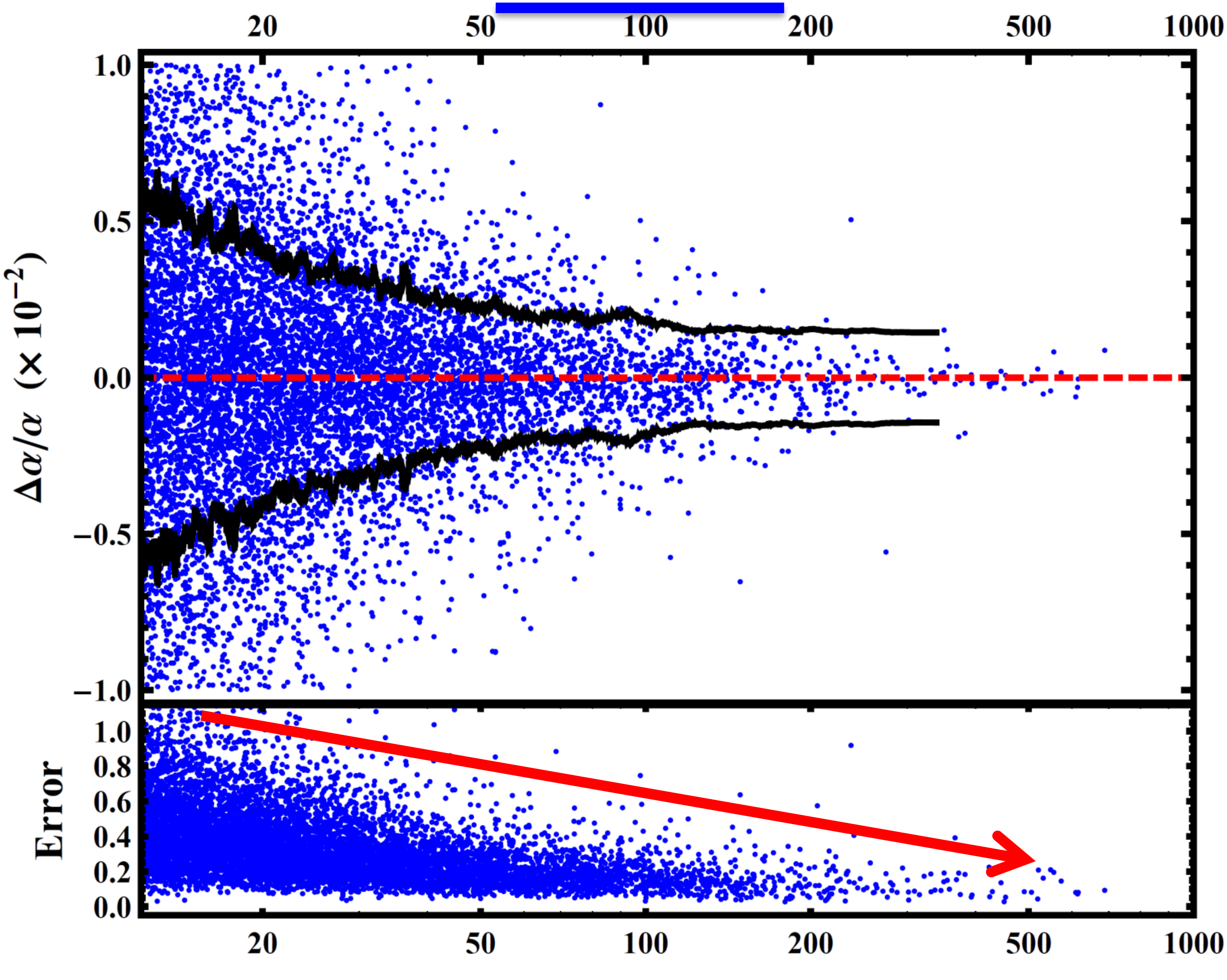
- Introduction ✓
- Methododology ✓
- Sample selection ✓
- **Results**
- Future projects

Results


20
50
100
200
500
1000
1.0
0.5
0.0
−0.5
−1.0
$\Delta\alpha/\alpha\ (\times 10^{-2})$
Error
1.0
0.8
0.6
0.4
0.2
0.0
$S/N_{[OIII]\ 5008}$

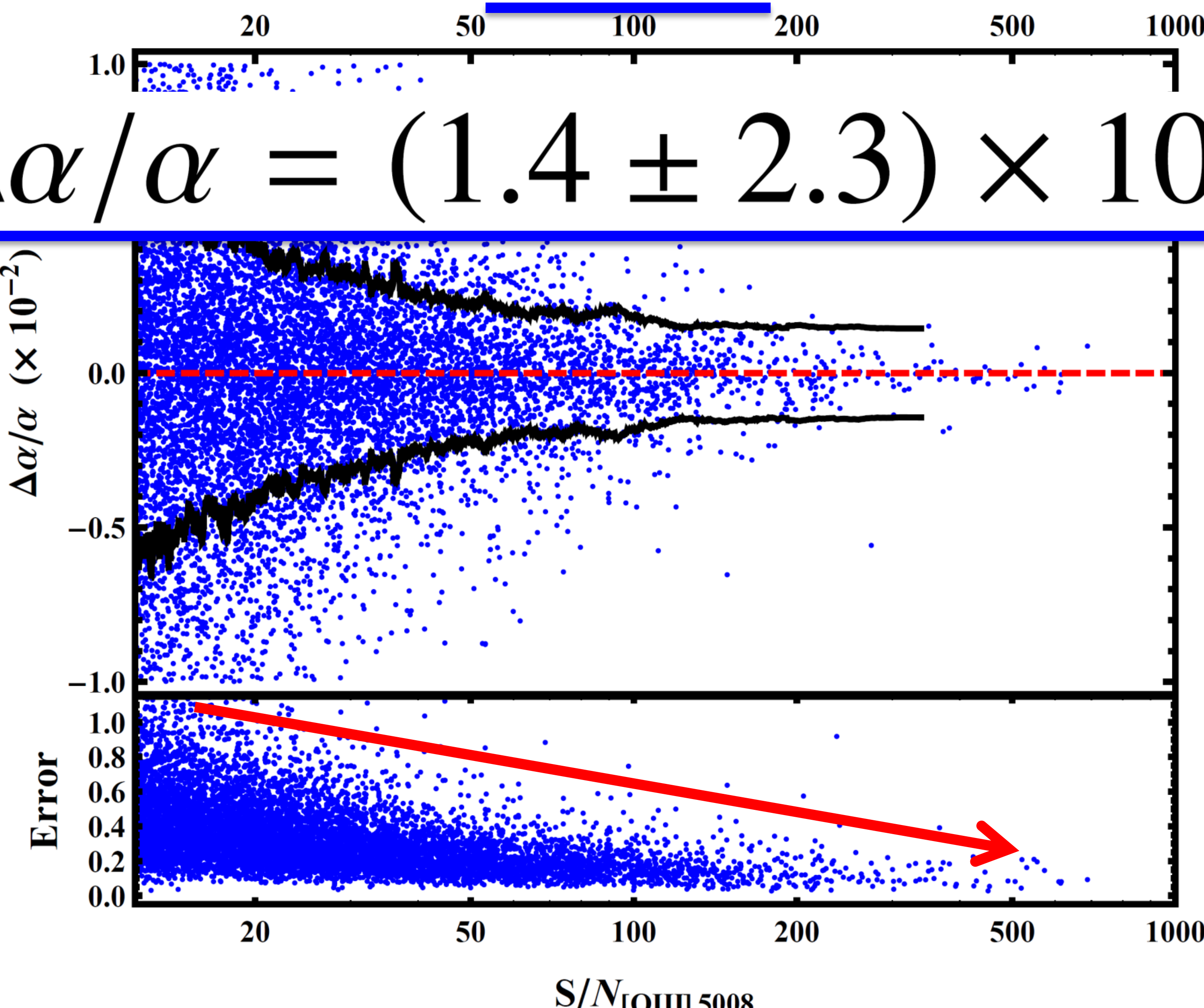
Franco D. Albareti
30th March 2015
IberiCOS

Results



Franco D. Albareti
30th March 2015
IberiCOS

Results



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

Results

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

Results

Systematics?

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

Results

Systematics?

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

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

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

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

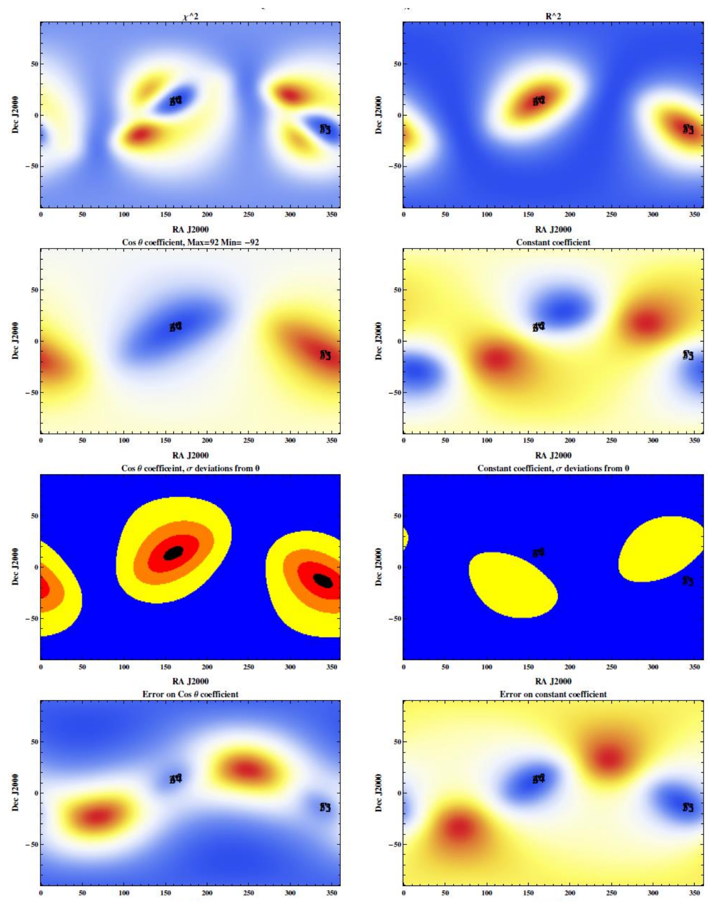
OK

Results

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

Spatial variation

Dipole?



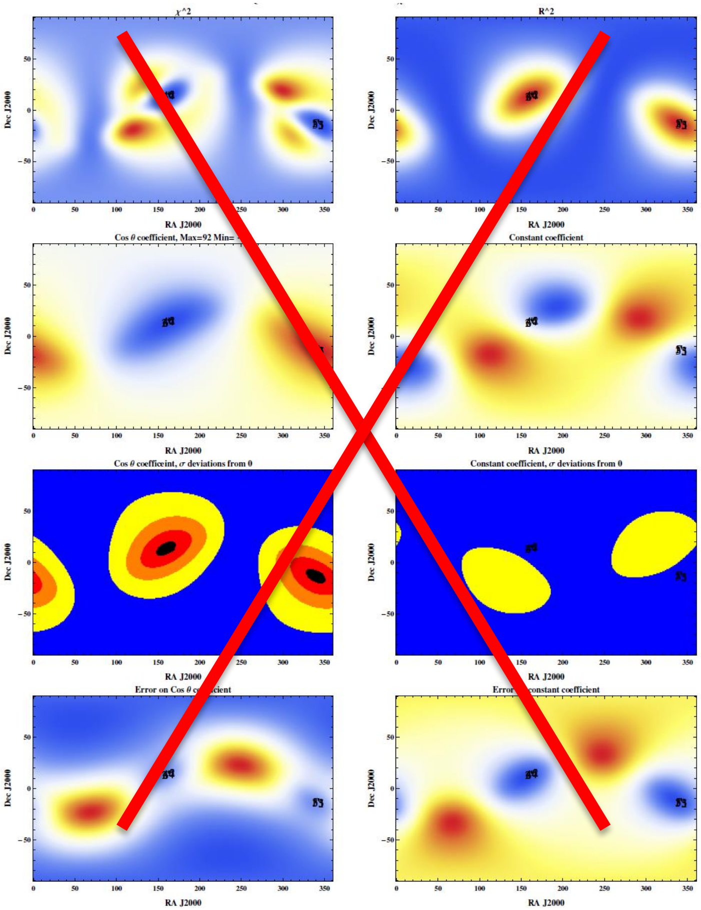
Franco D. Albareti
30th March 2015
IberiCOS

Results

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

Spatial variation

No statistical significance



Franco D. Albareti
30th March 2015
IberiCOS

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).

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"**

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…**

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).

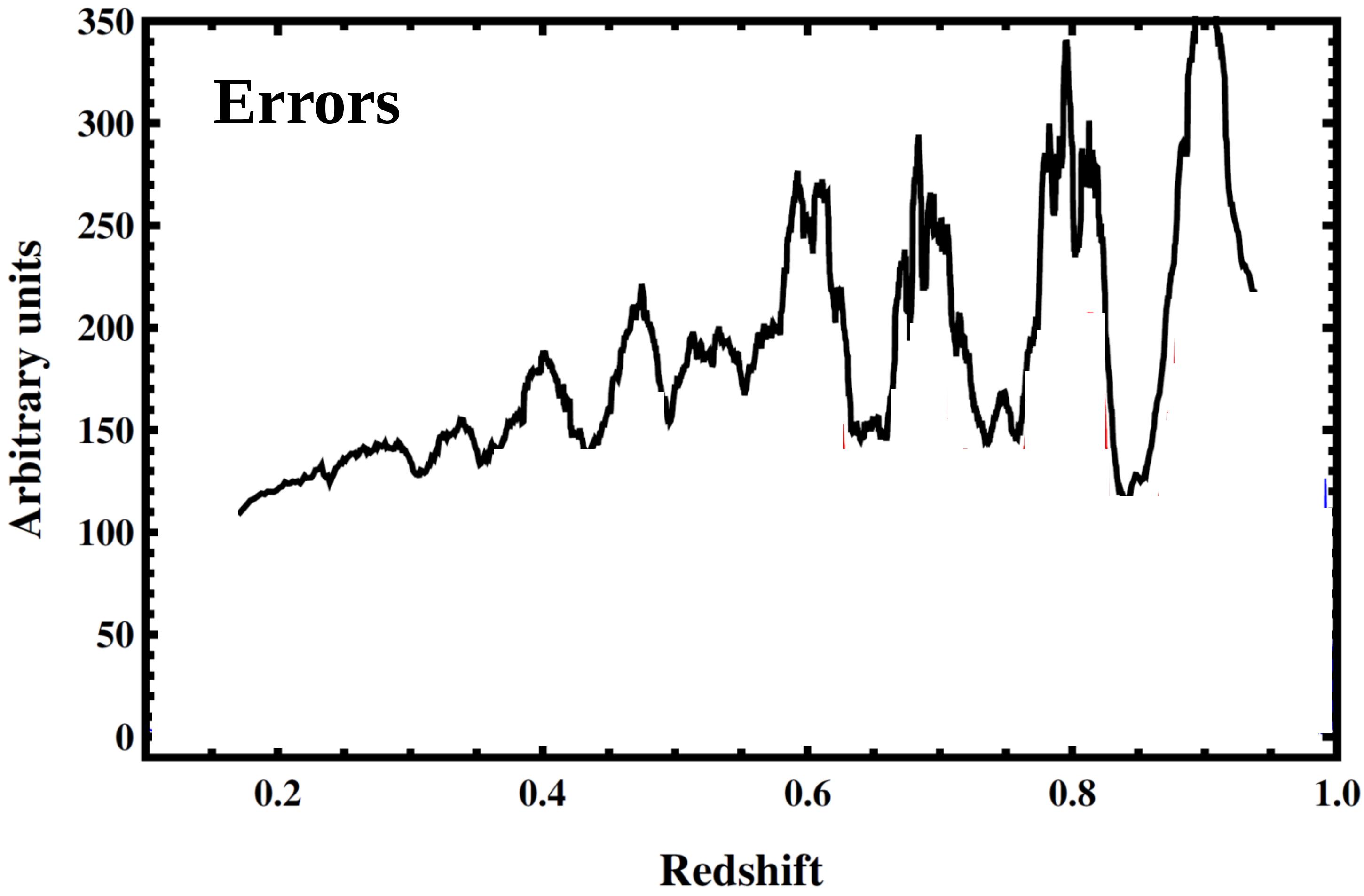
- **For further details,** **"FDA, J. Comparat, F. Prada *et al.*,** arXiv:**1501.00560"**

- **Well…, it is not a big improvement…**

Franco D. Albareti
30th March 2015
IberiCOS

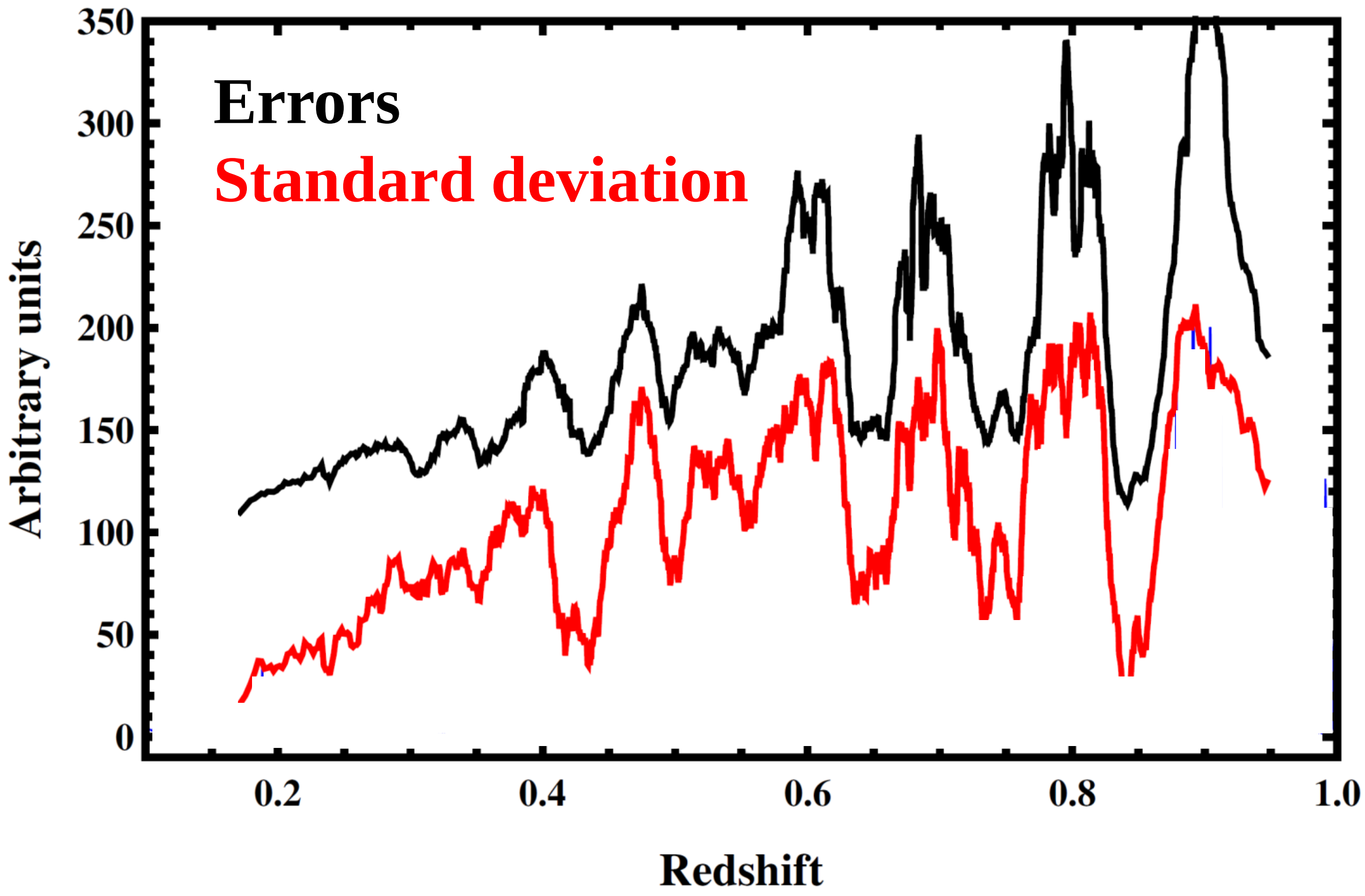
Franco D. Albareti
30th March 2015
IberiCOS

Results



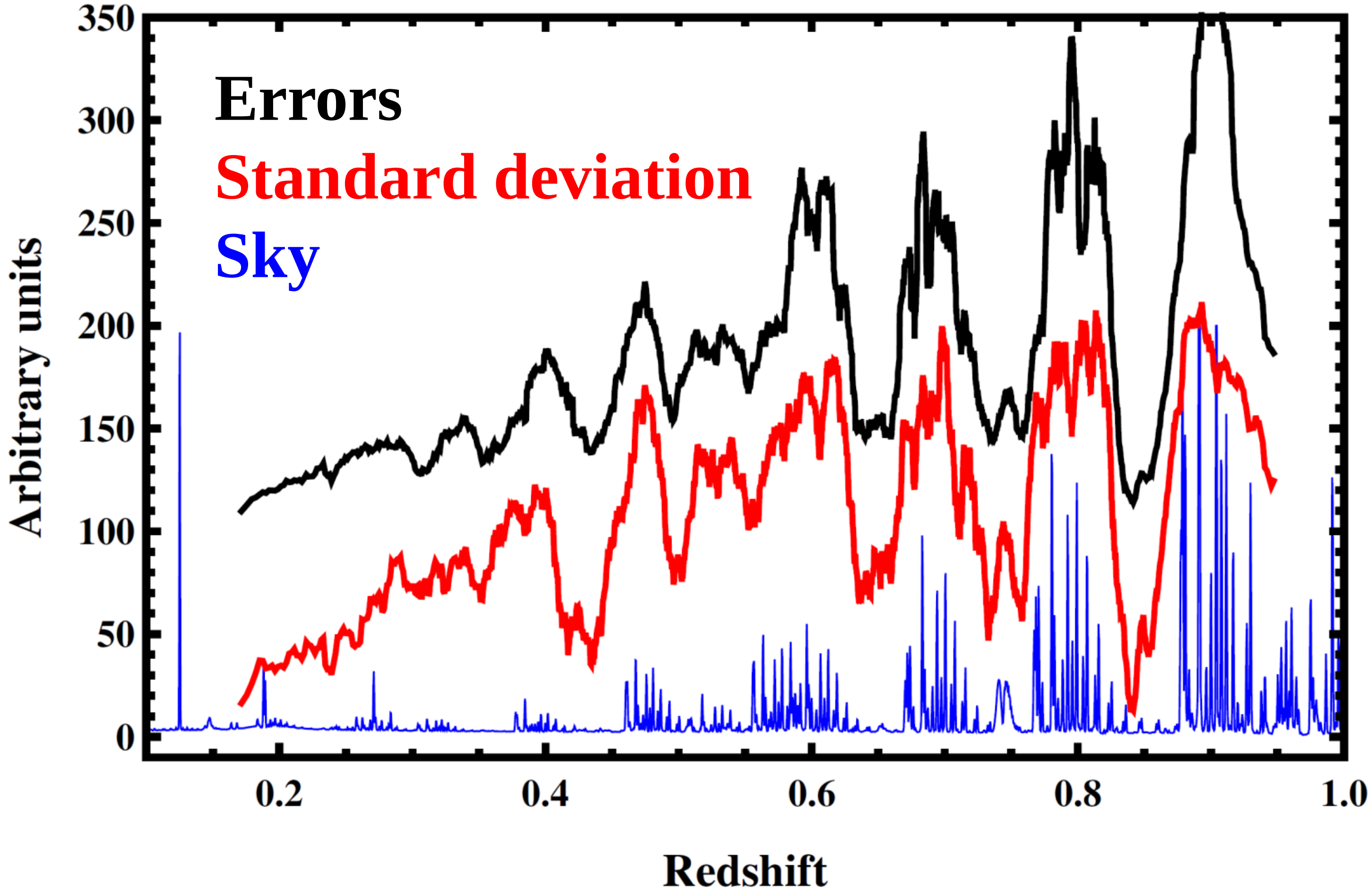
Franco D. Albareti
30th March 2015
IberiCOS

Results



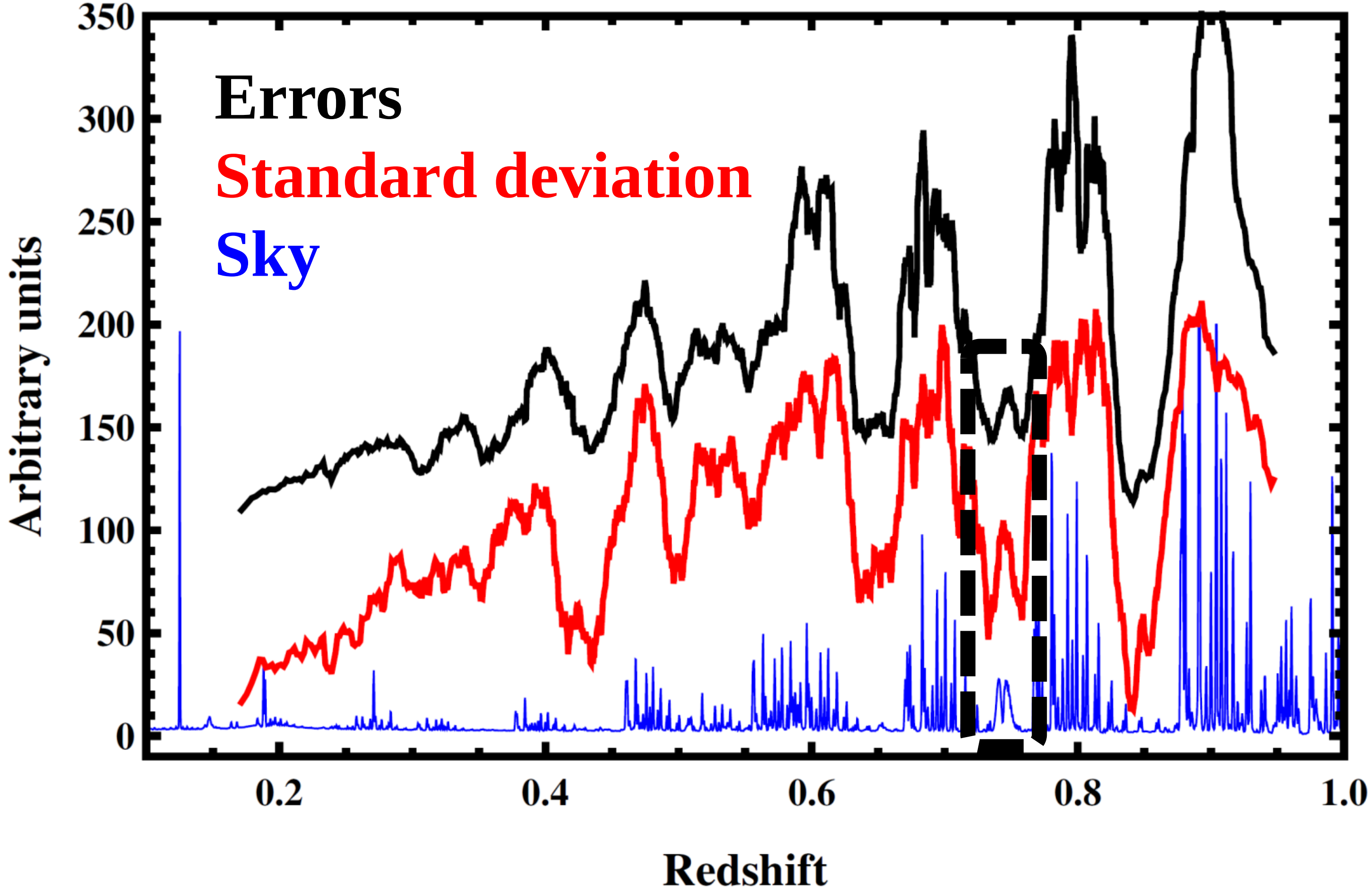
Franco D. Albareti
30th March 2015
IberiCOS

Results



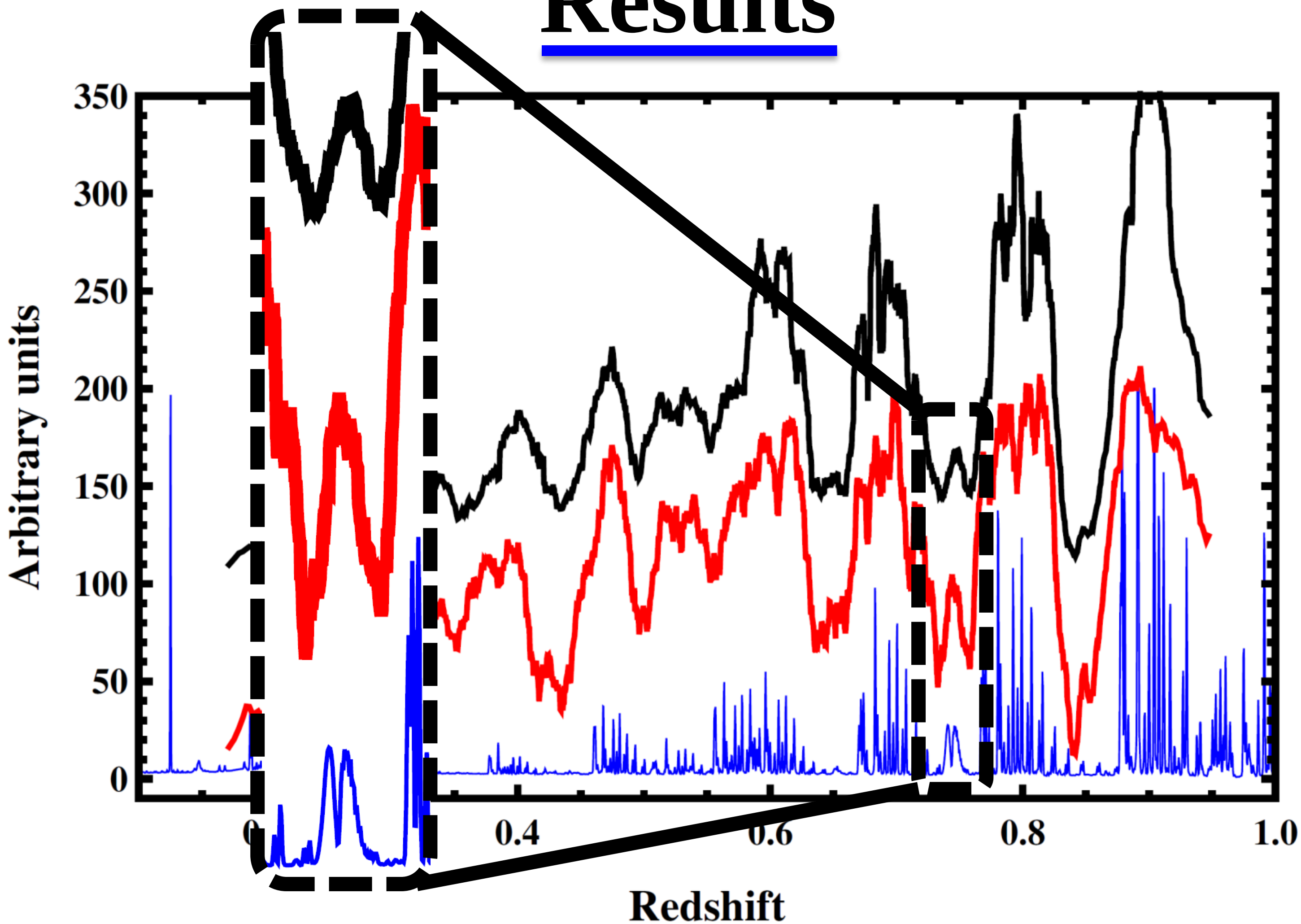
Franco D. Albareti
30th March 2015
IberiCOS

Results



Franco D. Albareti
30th March 2015
IberiCOS

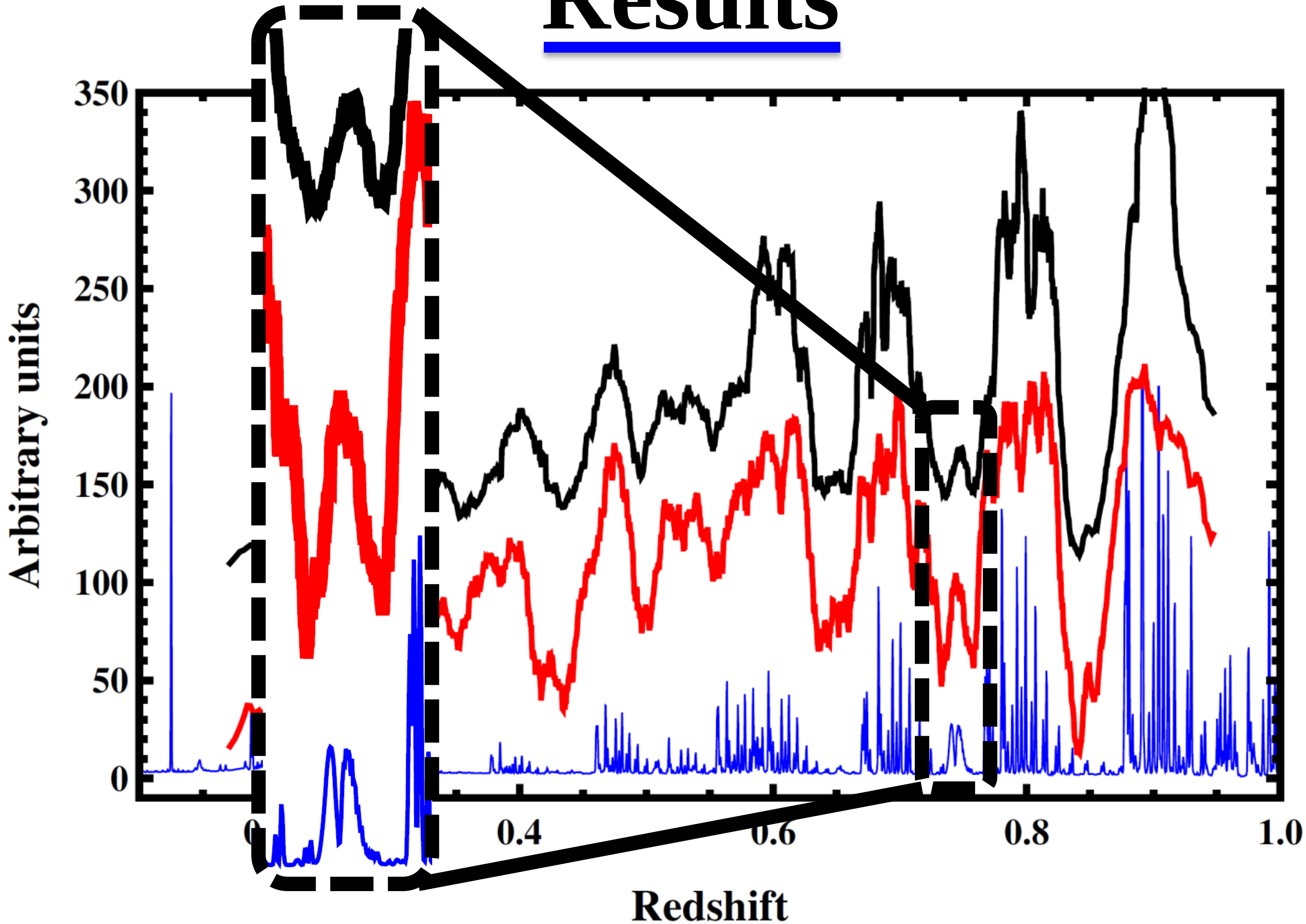
Results



Atmospheric O2 airglow emission

Franco D. Albareti
30th March 2015
IberiCOS

Results

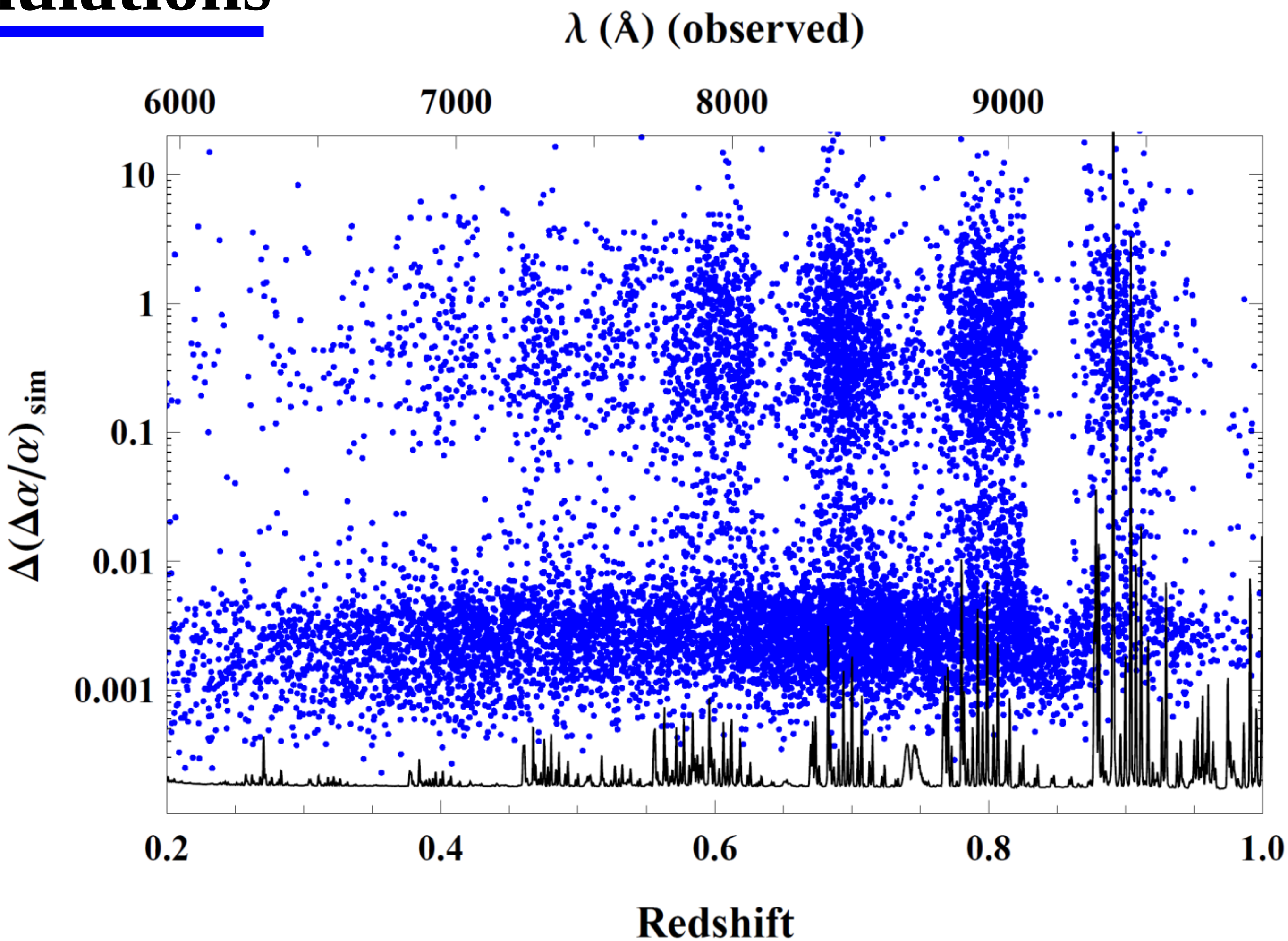


The precision is limited by the sky subtraction

Franco D. Albareti
30th March 2015
IberiCOS

Results

Simulations

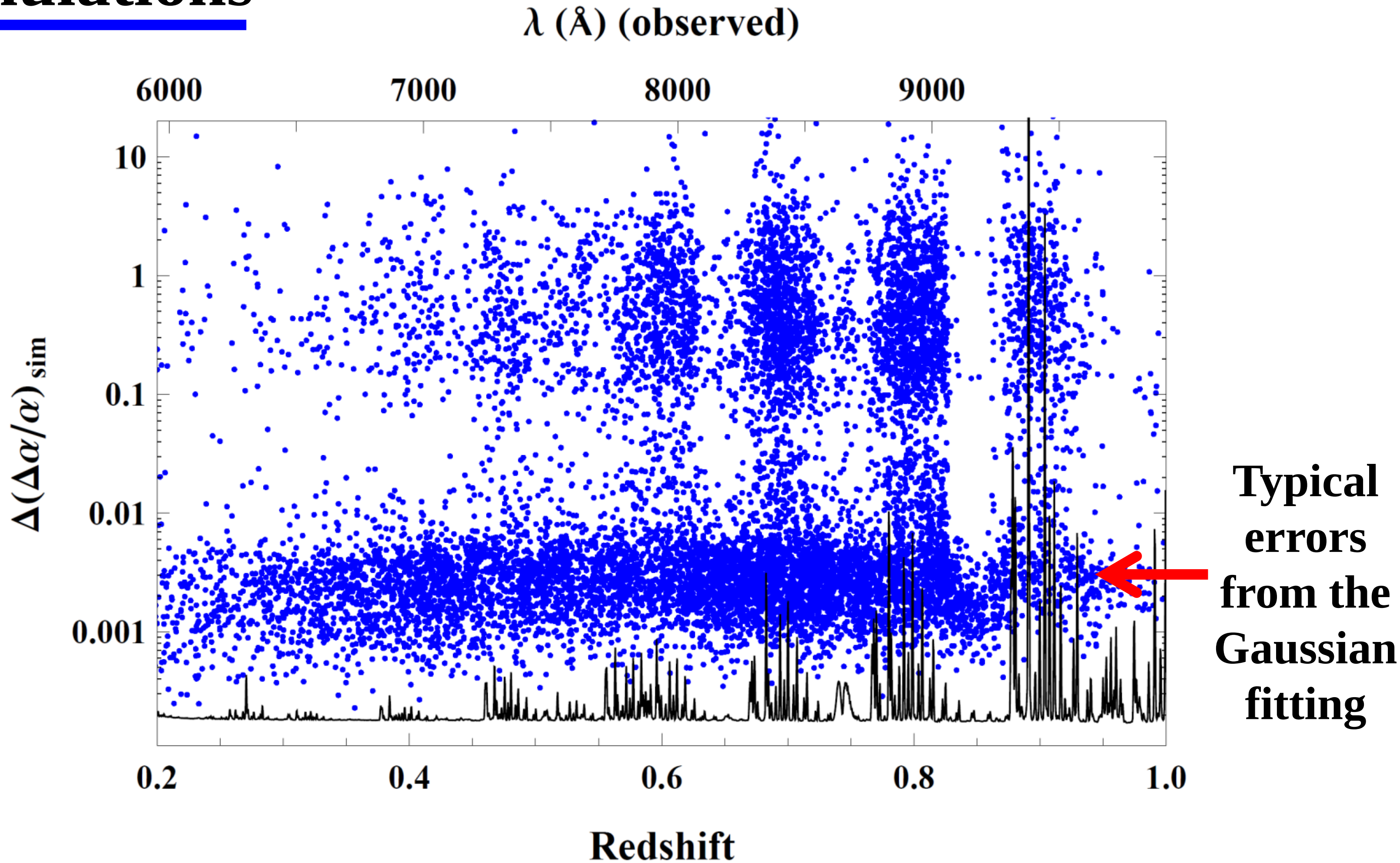


The precision is limited by the sky subtraction

Franco D. Albareti
30th March 2015
IberiCOS

Results

Simulations

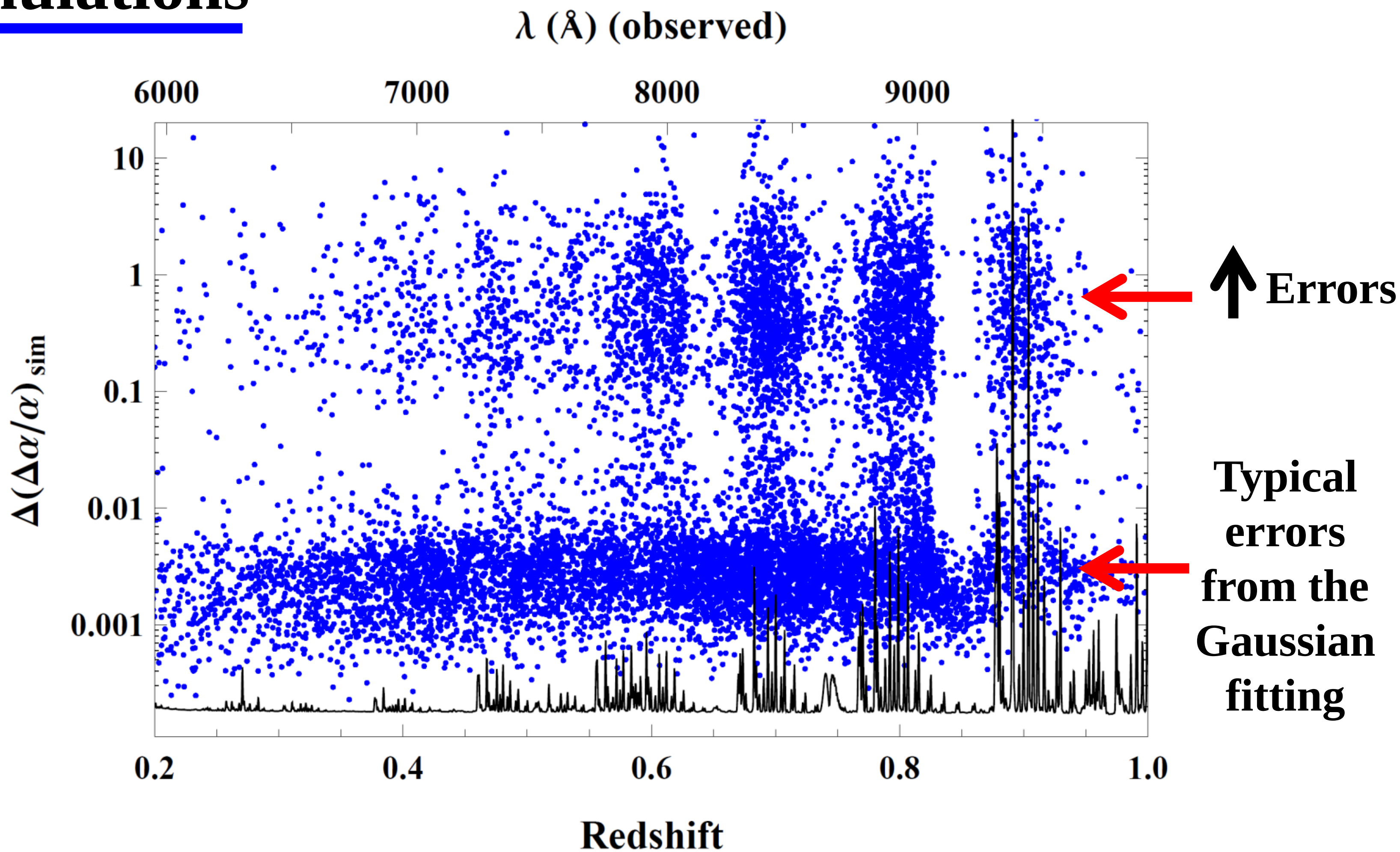


The precision is limited by the sky subtraction

Franco D. Albareti
30th March 2015
IberiCOS

Results

Simulations

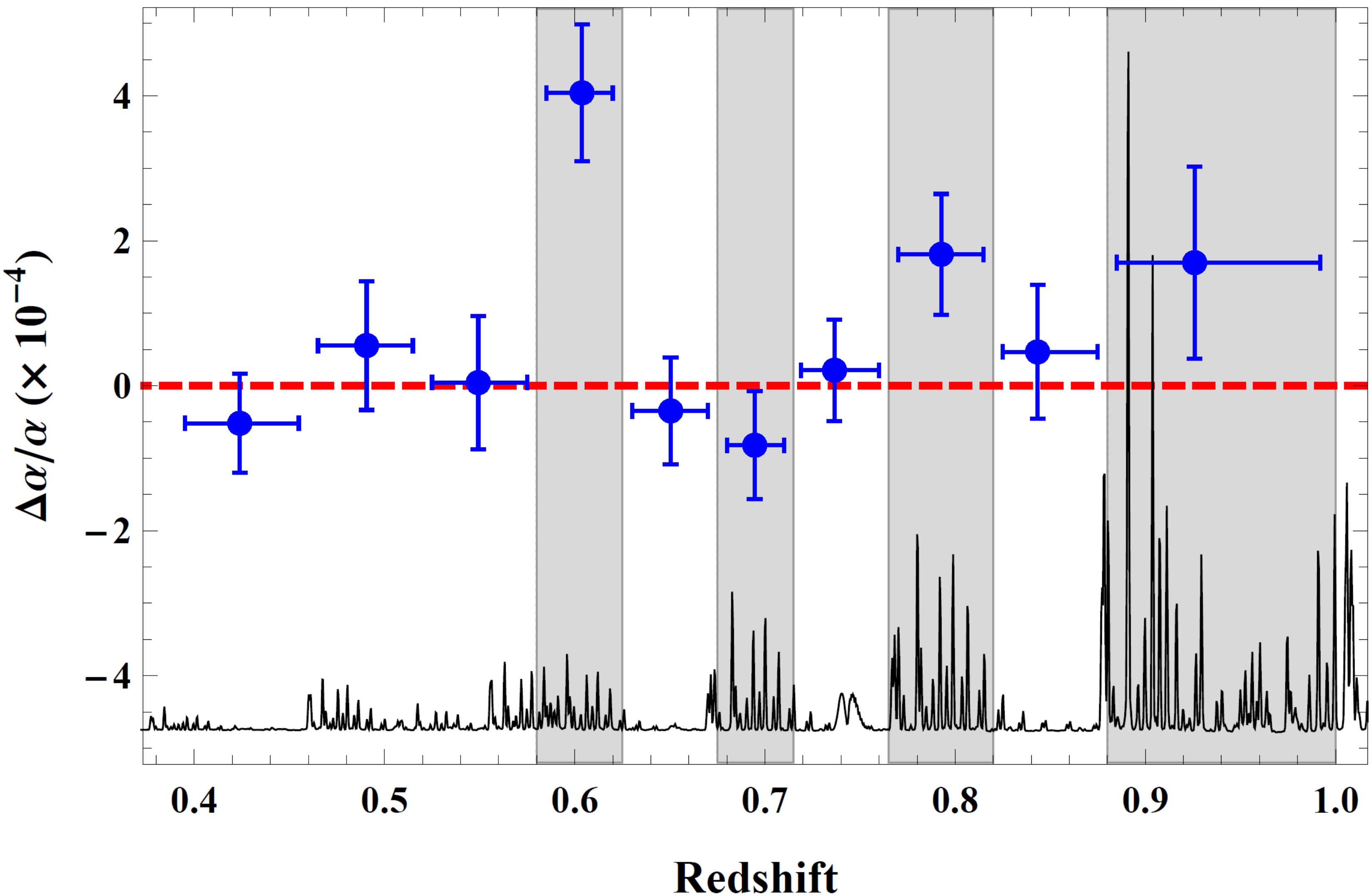


The precision is limited by the sky subtraction

Franco D. Albareti
30th March 2015
IberiCOS

Results

Redshift bins



Outline

- Introduction ✔
- Methododology ✔
- Sample selection ✔
- **Results** ✔
- Future projects

Outline

- Introduction ✓
- Methododology ✓
- Sample selection ✓
- Results ✓
- **Future projects**

Franco D. Albareti
30th March 2015
IberiCOS

Future projects

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

$\Delta\alpha/\alpha$ **< 10^-6**

R ~ 62,000 – 110,000

z ~ 0,6

Franco D. Albareti
30th March 2015
IberiCOS

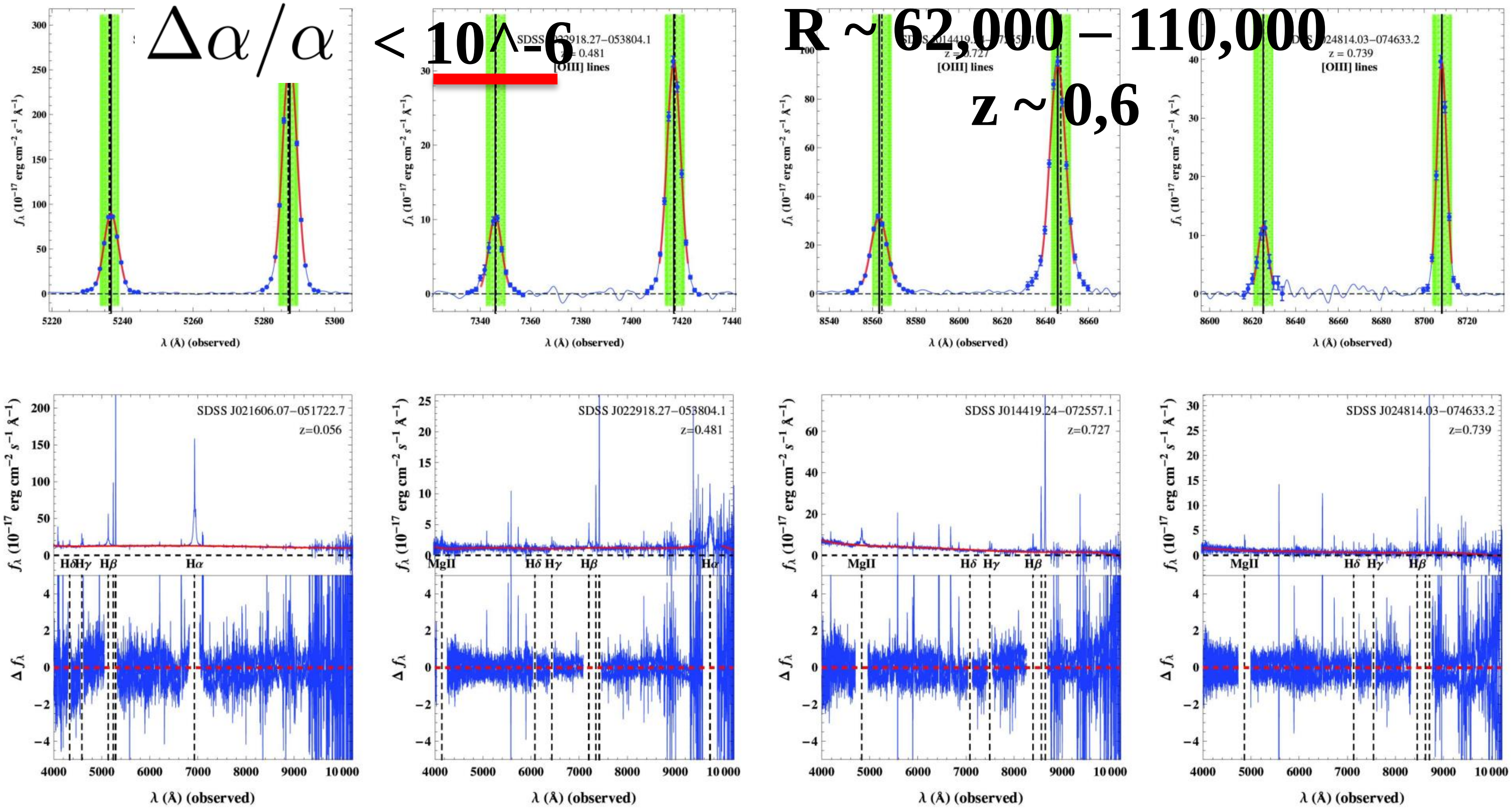
Future projects

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

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

R ~ 62,000 – 110,000

z ~ 0,6



Franco D. Albareti
30th March 2015
IberiCOS

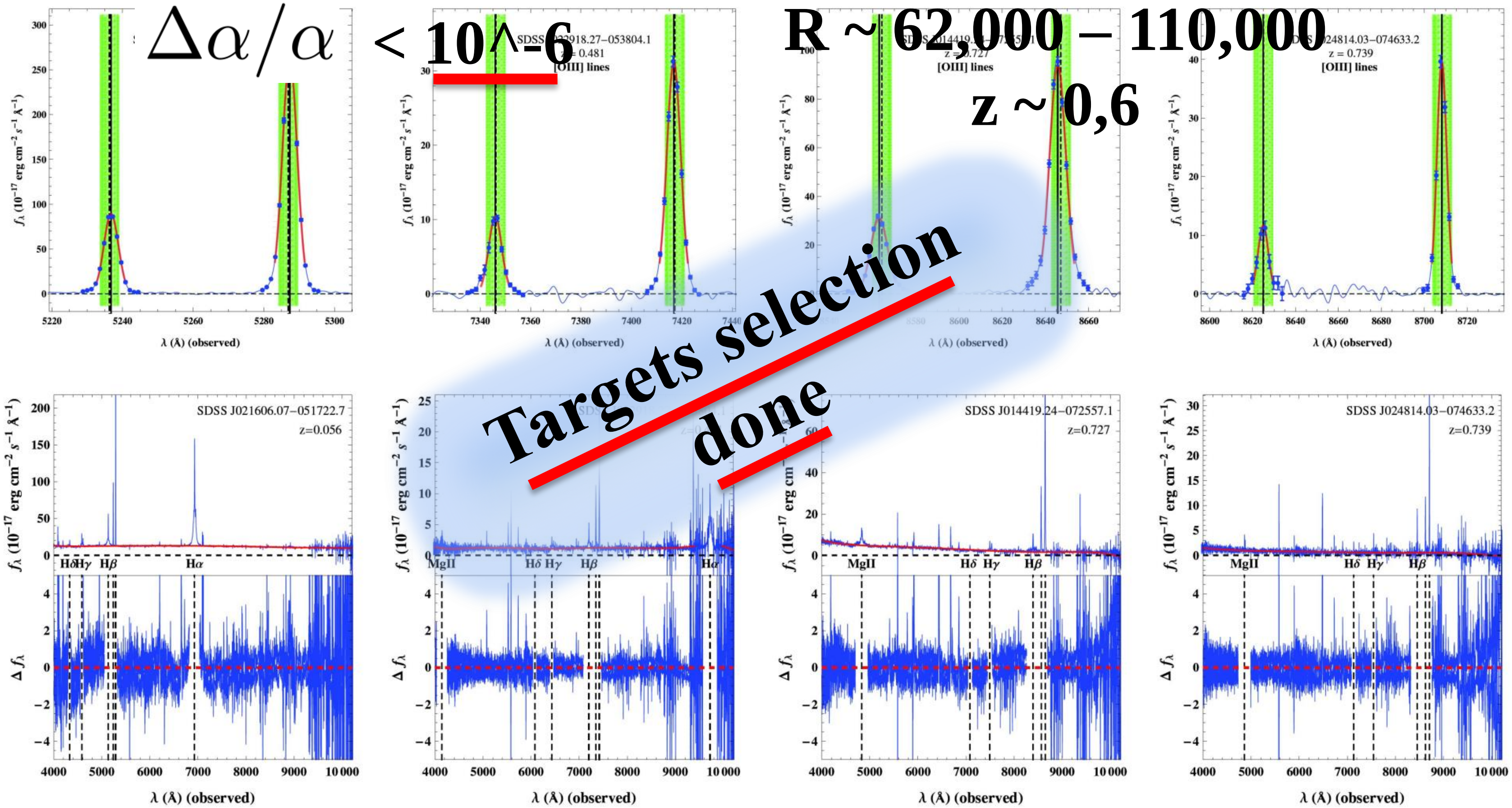
Future projects

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

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

R ~ 62,000 – 110,000

z ~ 0,6



Targets selection done

Proposal submitted…

Franco D. Albareti
30th March 2015
IberiCOS

Future projects

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

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

  R ~ 62,000 – 110,000

  z ~ 0.6

- **APOGEE-N → Med-resolution spectrograph**

  R ~ 22,000

  $\Delta\alpha/\alpha$ < 10^-5

  z ~ 2.2

Franco D. Albareti
30th March 2015
IberiCOS

Future projects

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

APOGEE-2 Ancillary Science Proposal

March 18, 2015

APOGEE-Q

APOGEE Quasar Survey

Type of request: 1

PI

Franco D. Albareti
Instituto de Física Teórica UAM/CSIC
Cantoblanco, C/ Nicolás Cabrera, 13-15, 28049 Madrid
Phone number: +34 91 299 98 71
E-mail: franco.albareti@uam.es

Co-Is

Johan Comparat
Instituto de Física Teórica UAM/CSIC

Francisco Prada
Instituto de Física Teórica UAM/CSIC

Isabelle Pâris
Instituto Nazionali di Astrofisica/Osservatorio Astronomico di Trieste

Andreu Font
Lawrence Berkeley National Laboratory

David Schlegel
Lawrence Berkeley National Laboratory

Joseph Hennawi
Max-Planck-Institut für Astronomie

Jean-Paul Kneib
École Polytechnique Fédérale de Lausanne

All participants are SDSS-IV members

SDSS

- **APOGEE-N → Med-resolutio**

$\Delta\alpha/\alpha$ < 10^-5

R ~ 2

z ~

Franco D. Albareti
30th March 2015
IberiCOS

Future projects

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

APOGEE-2 Ancillary Science Proposal

March 18, 2015

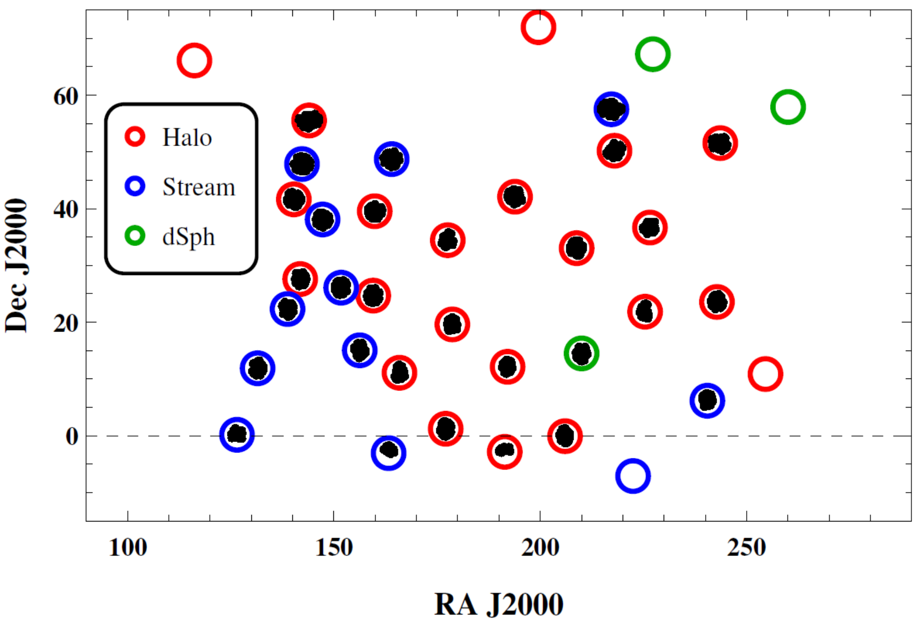
APOGEE-Q

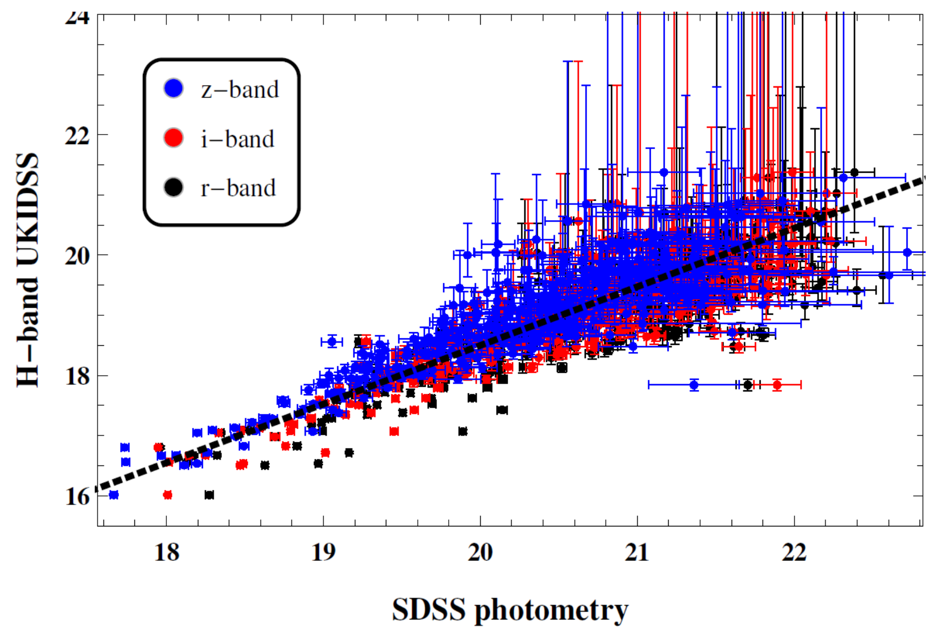
APOGEE Quasar Survey

Type of request: 1

PI

Franco D. Albareti
Instituto de Física Teórica UAM/CSIC
Cantoblanco, C/ Nicolás Cabrera, 13-15, 28049 Madrid

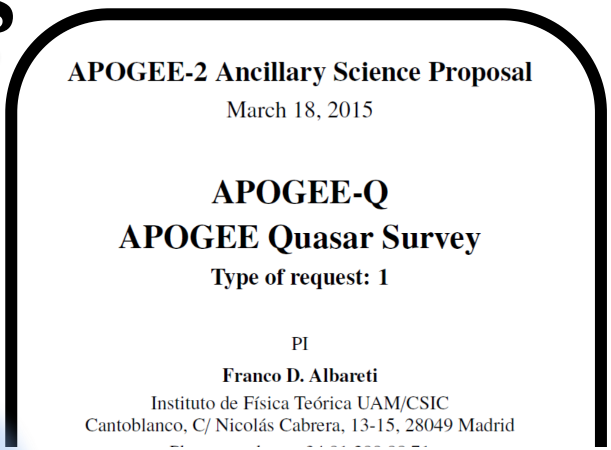




Franco D. Albareti
30th March 2015
IberiCOS

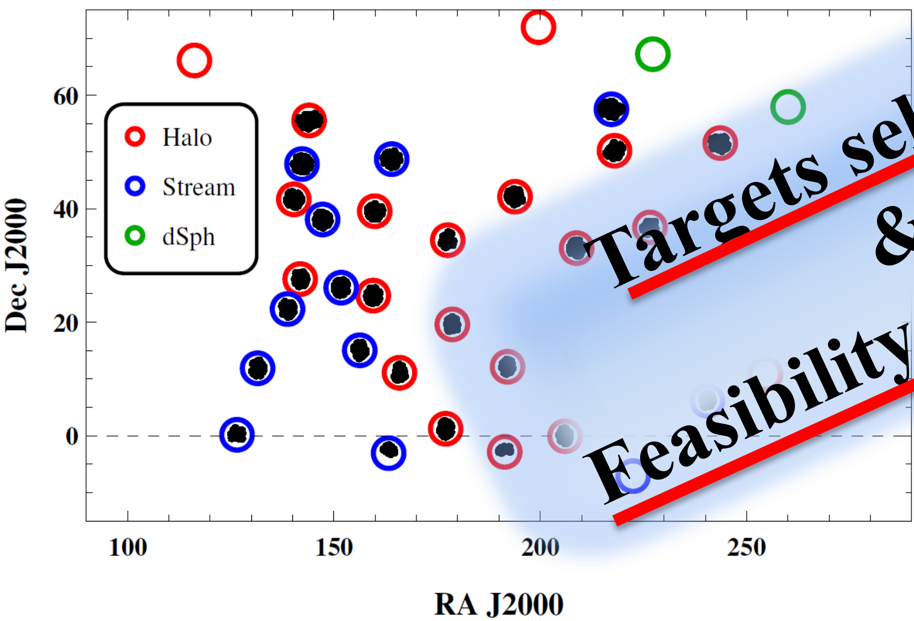
Future projects

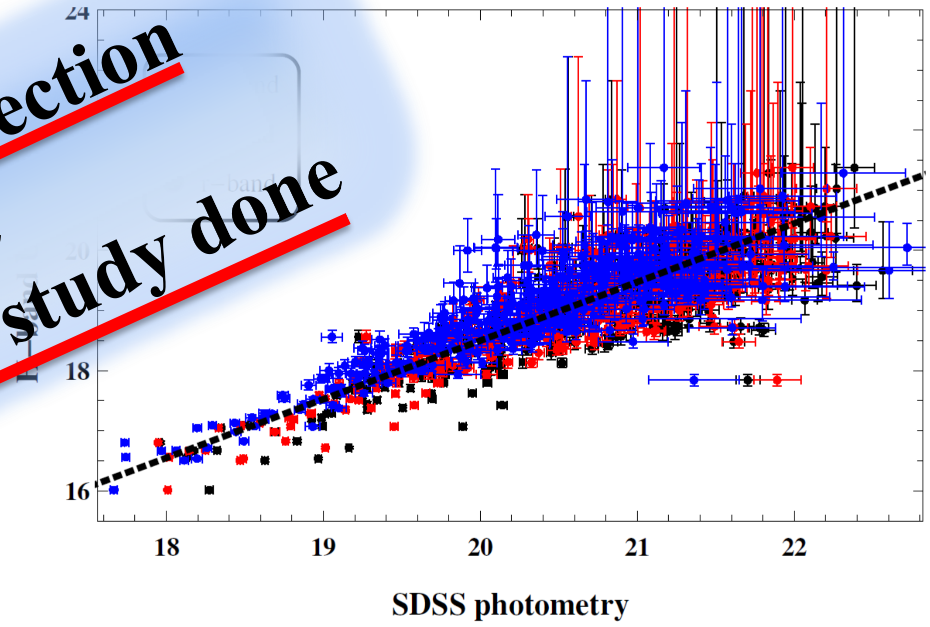
APOGEE-Q
Ancillary Science Proposal
For SDSS-IV/APOGEE-2


APOGEE-2 Ancillary Science Proposal
March 18, 2015

APOGEE-Q
APOGEE Quasar Survey
Type of request: 1

PI
Franco D. Albareti
Instituto de Física Teórica UAM/CSIC
Cantoblanco, C/ Nicolás Cabrera, 13-15, 28049 Madrid





Targets selection
&
Feasibility study done

Thanks!

Backslides

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

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

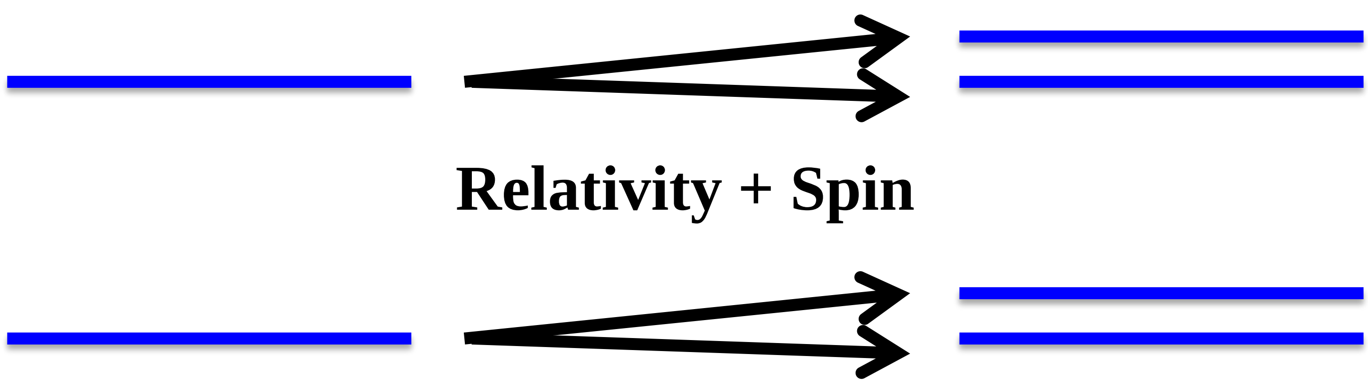
Franco D. Albareti
30th March 2015
IberiCOS

Introduction

- **Fine structure constant?**

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

Energy levels



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

Franco D. Albareti
30th March 2015
IberiCOS

Introduction

$$\alpha \approx 1/137$$

How do we measure its variation?

- **Absorption lines from quasars**

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

Introduction

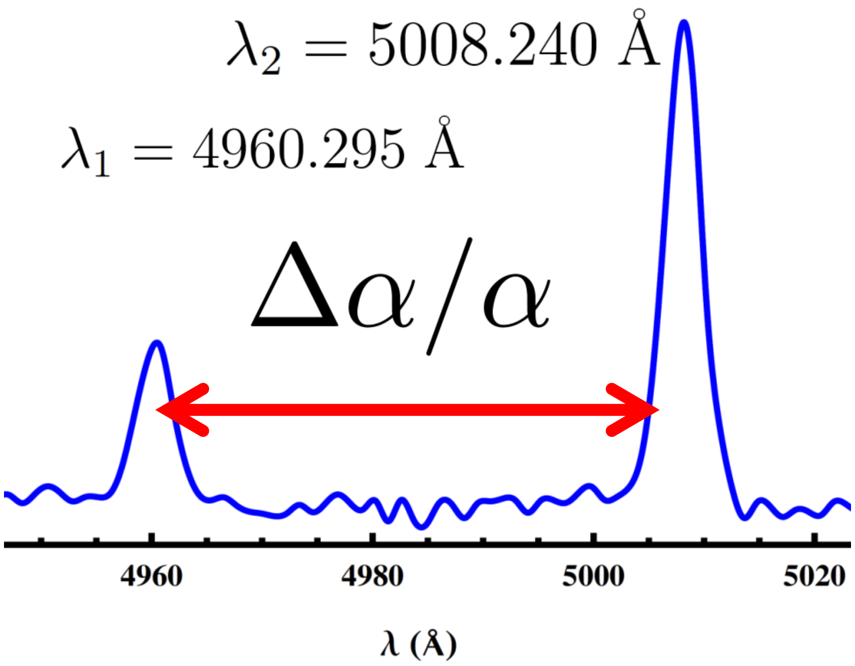
$$\alpha \approx 1/137$$

How do we measure its variation?

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

Fine structure of the emission lines

Introduction

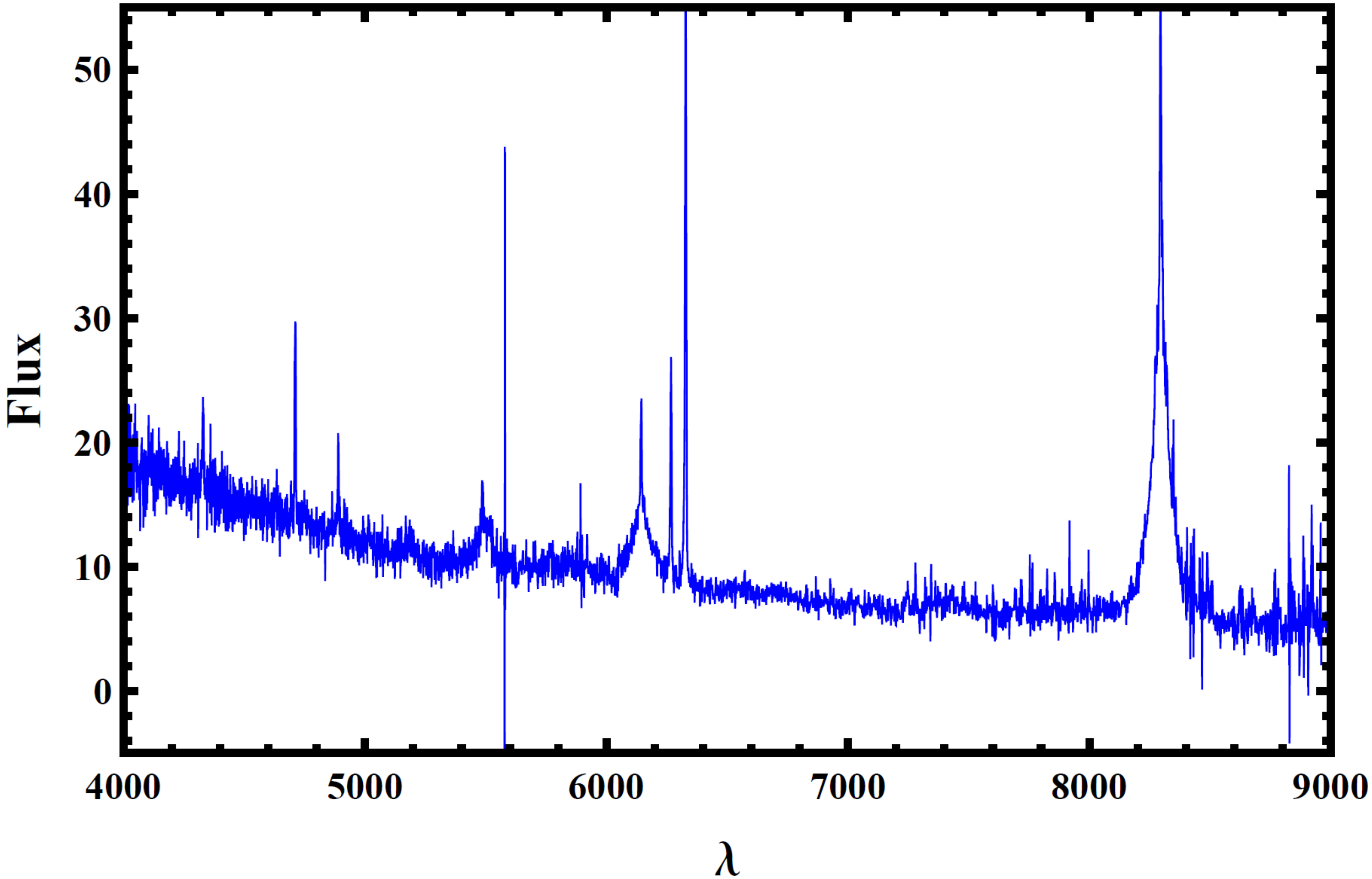


- **Forbidden lines**
- **Electric quadrupole and magnetic dipole transitions**
- **Found in extremely rarefied media**

Methodology

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

$H\alpha\,,\ H\beta\,,\ H\gamma\,,\ H\delta\,,\ \mathrm{MgII}$

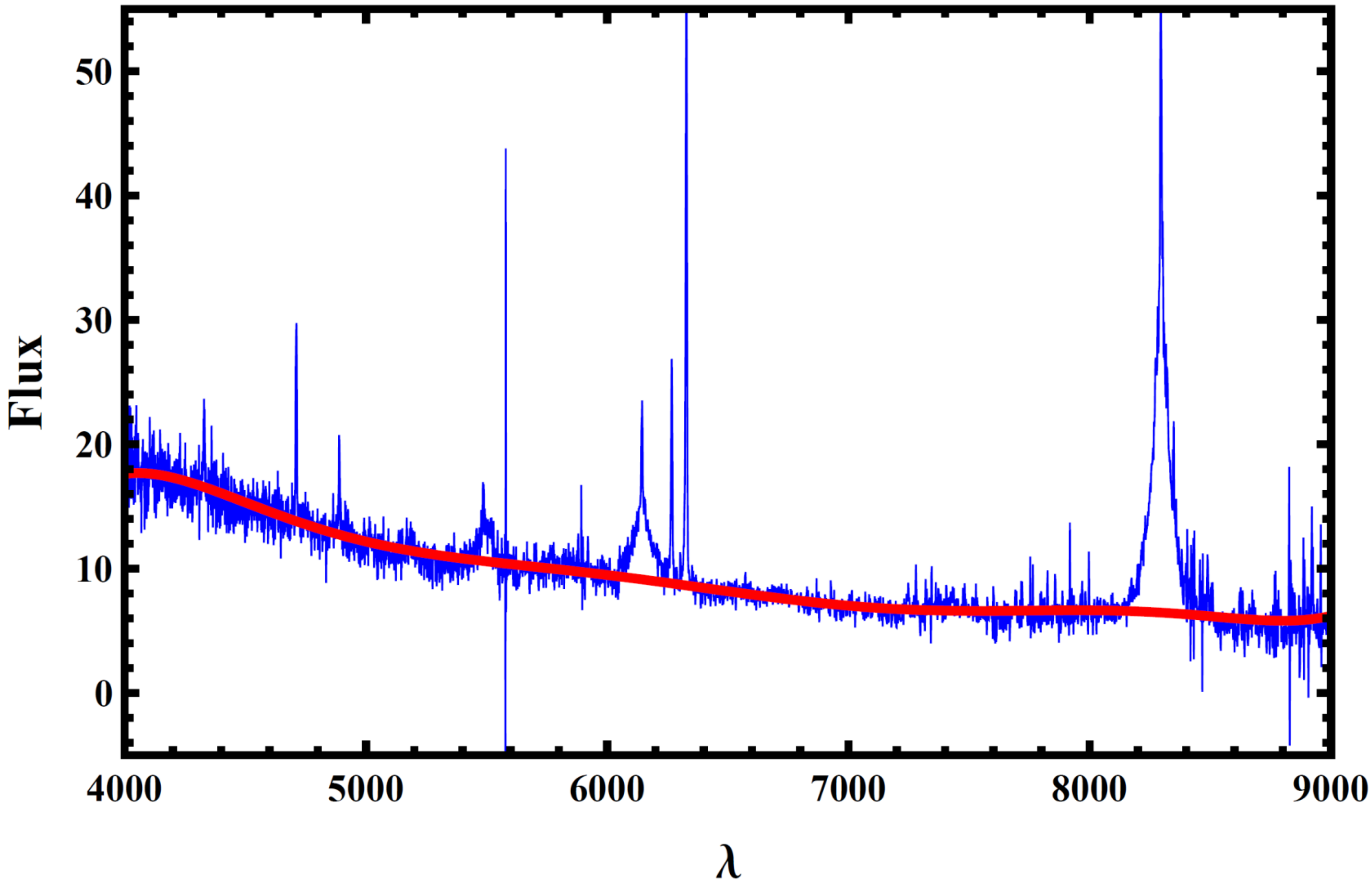


Franco D. Albareti
30th March 2015
IberiCOS

Methodology

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

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



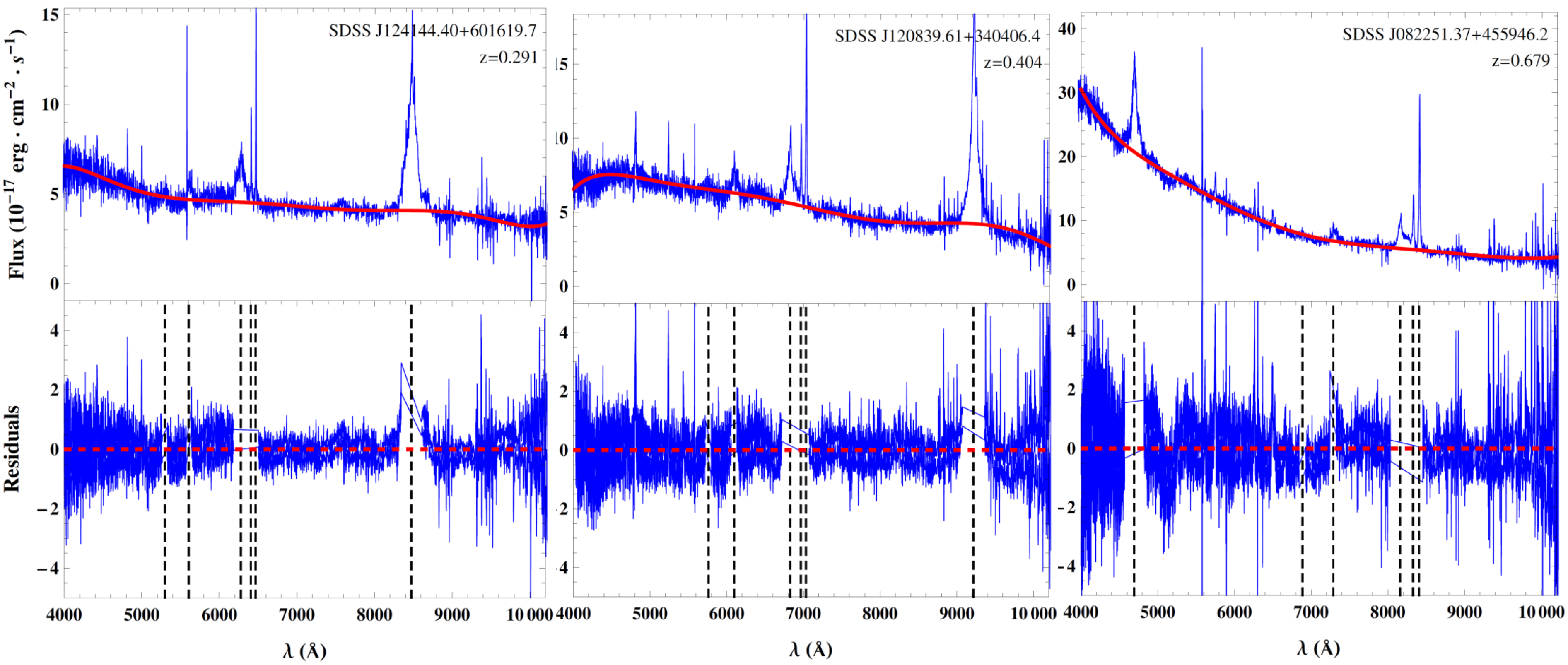
Franco D. Albareti
30th March 2015
IberiCOS

Franco D. Albareti
30th March 2015
IberiCOS

Methodology

Continuum fit: seven-order polynomial

$$\mathrm{H}\alpha\,,\ \mathrm{H}\beta\,,\ \mathrm{H}\gamma\,,\ \mathrm{H}\delta\,,\ \mathrm{MgII}$$

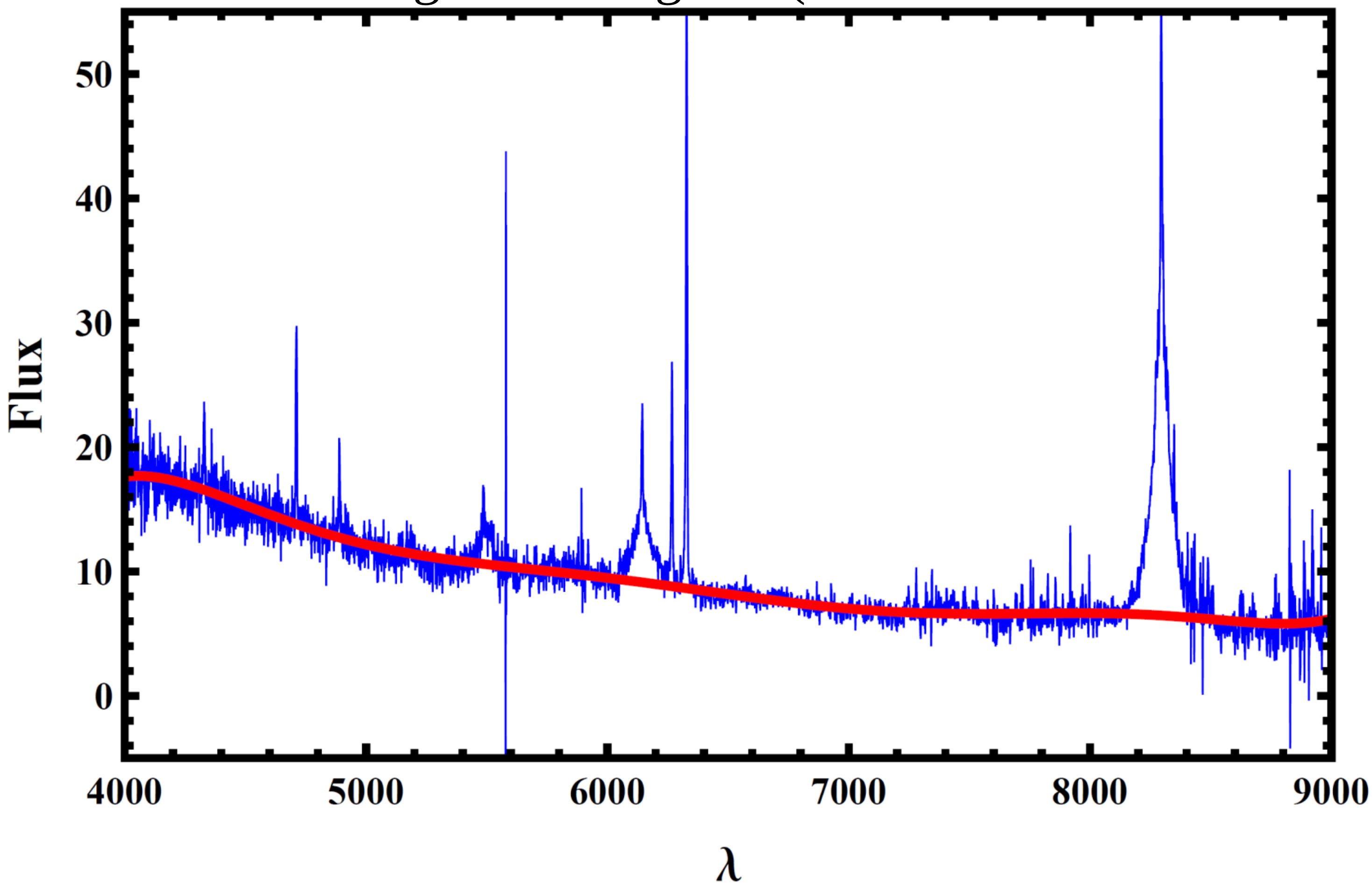


Franco D. Albareti
30th March 2015
IberiCOS

Methodology

Find the lines → ***SDSS Redshift***

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

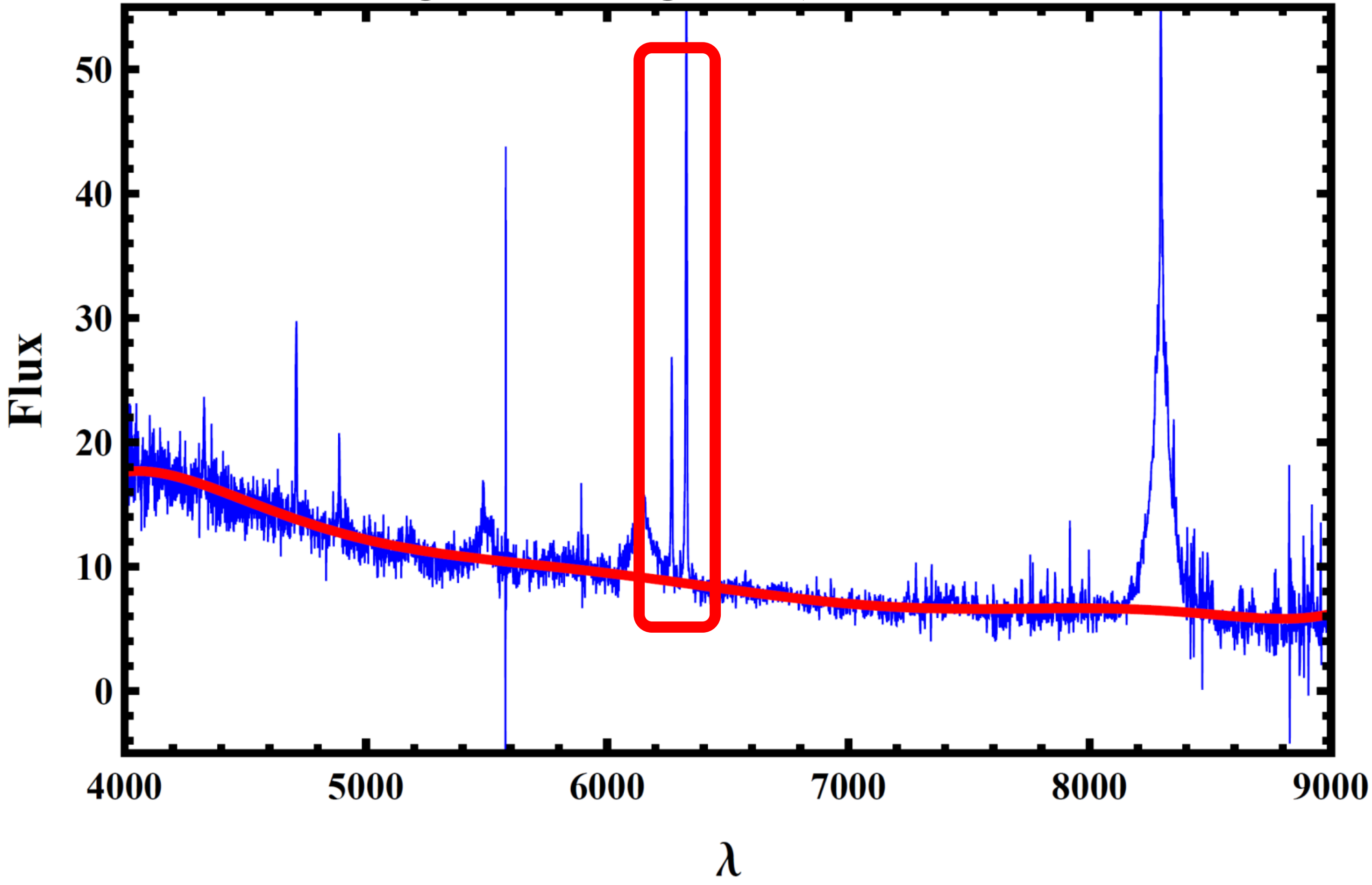


Franco D. Albareti
30th March 2015
IberiCOS

Methodology

Find the lines → ***SDSS Redshift***

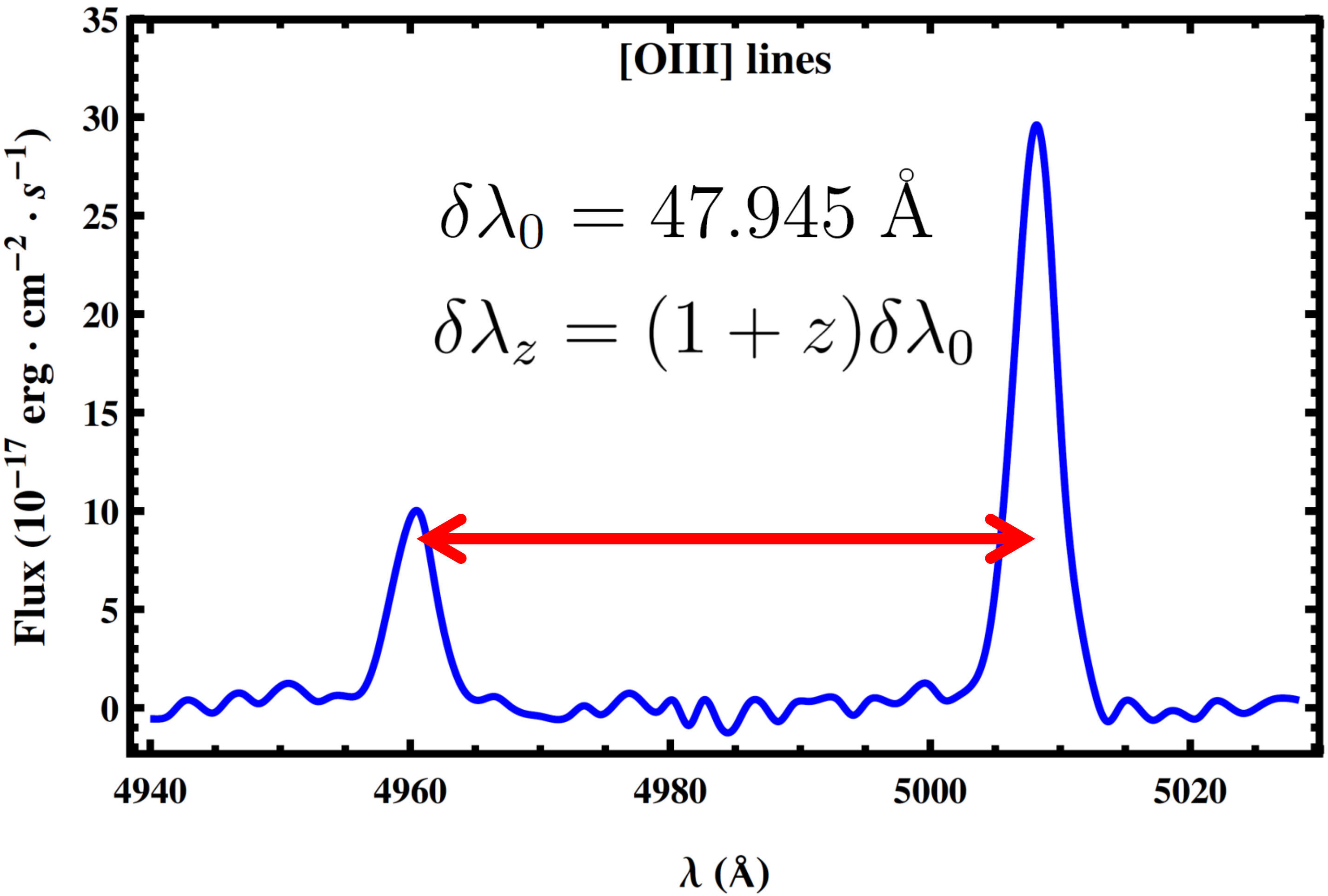
Three significant figures (error estimates $10^{-4} - 10^{-5}$)



Franco D. Albareti
30th March 2015
IberiCOS

Methodology

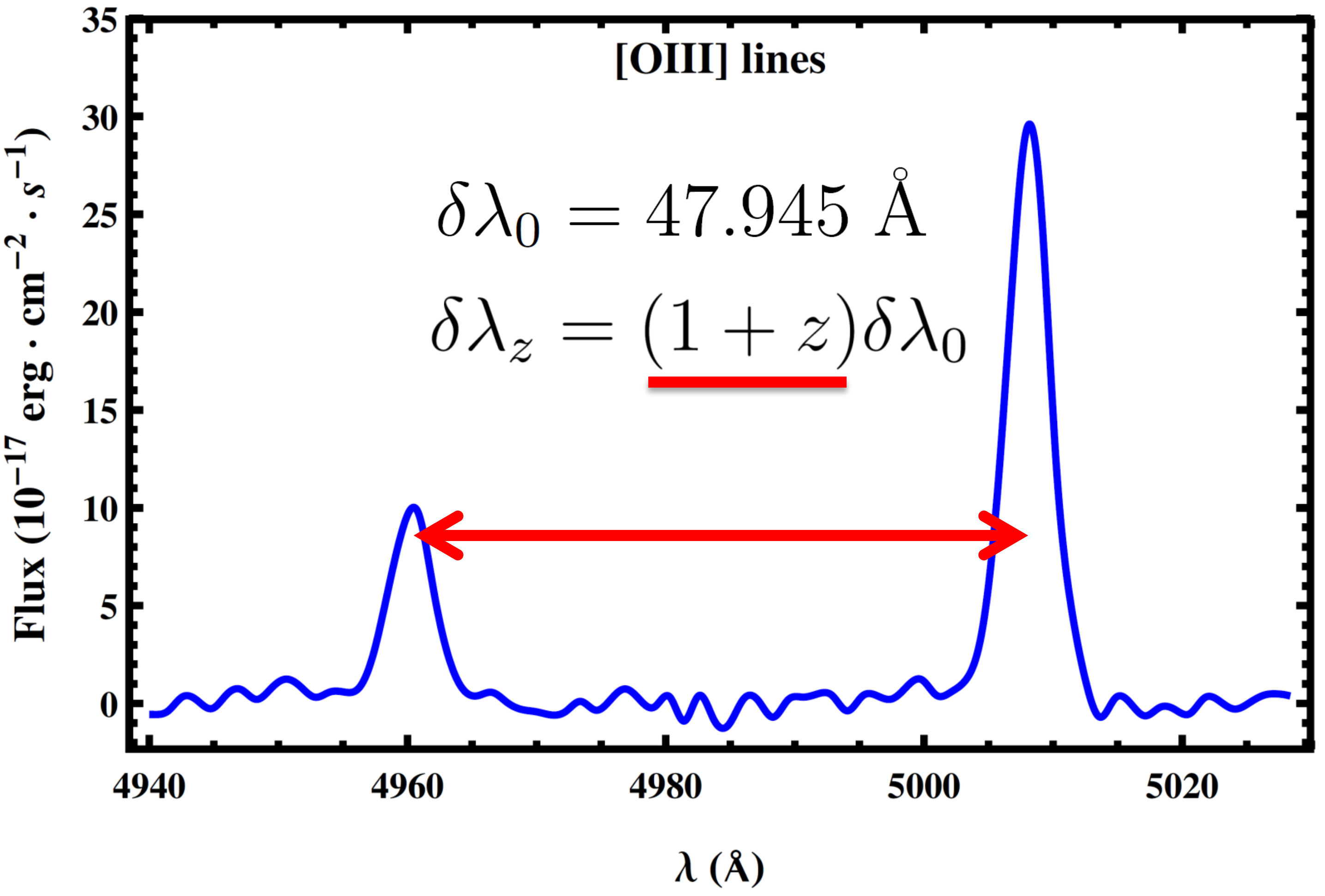
Measurement method



Franco D. Albareti
30th March 2015
IberiCOS

Methodology

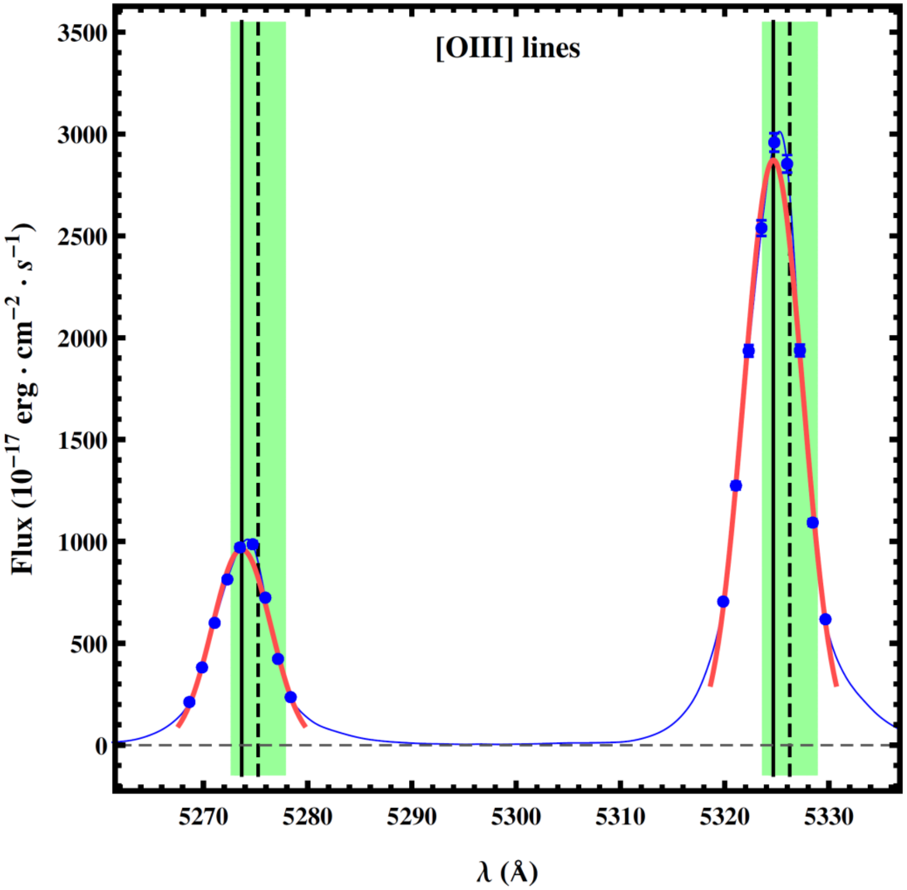
Measurement method



Franco D. Albareti
30th March 2015
IberiCOS

Methodology

Line positions



[OIII] lines

Real pixels (with errors)

Gaussian fits

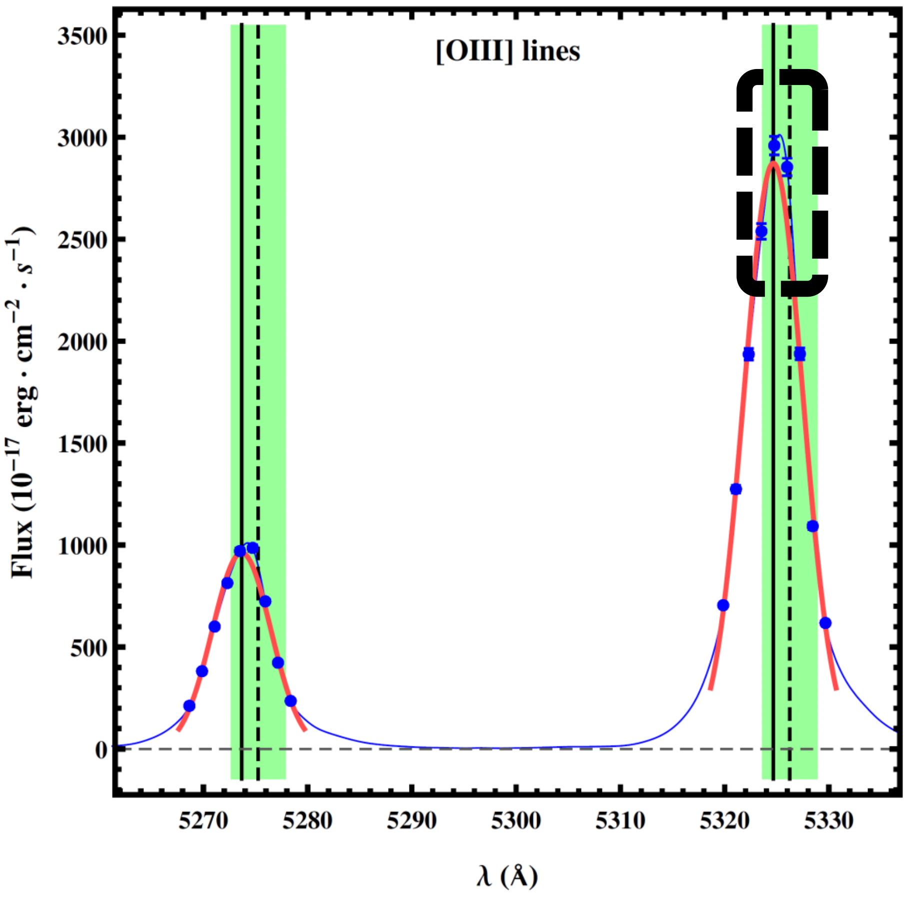
Expected line position

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

Franco D. Albareti
30th March 2015
IberiCOS

Methodology

Line positions



[OIII] lines

Real pixels (with errors)

Gaussian fits

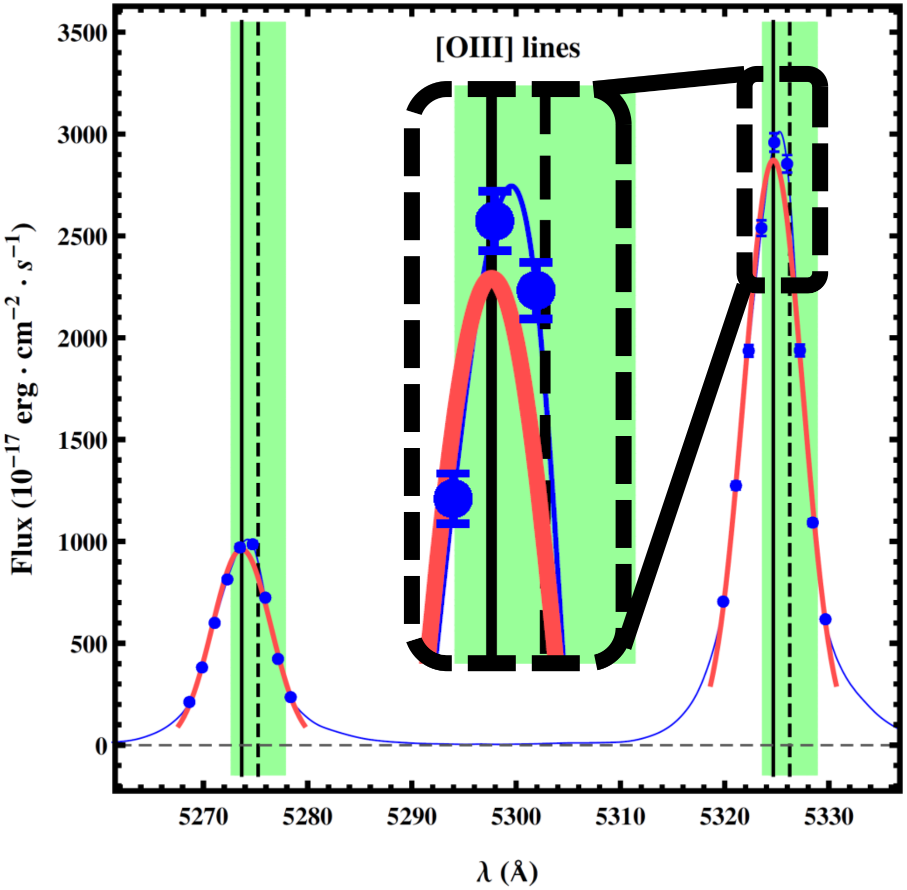
Expected line position

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

Franco D. Albareti
30th March 2015
IberiCOS

Methodology

Line positions



[OIII] lines

Real pixels (with errors)

Gaussian fits

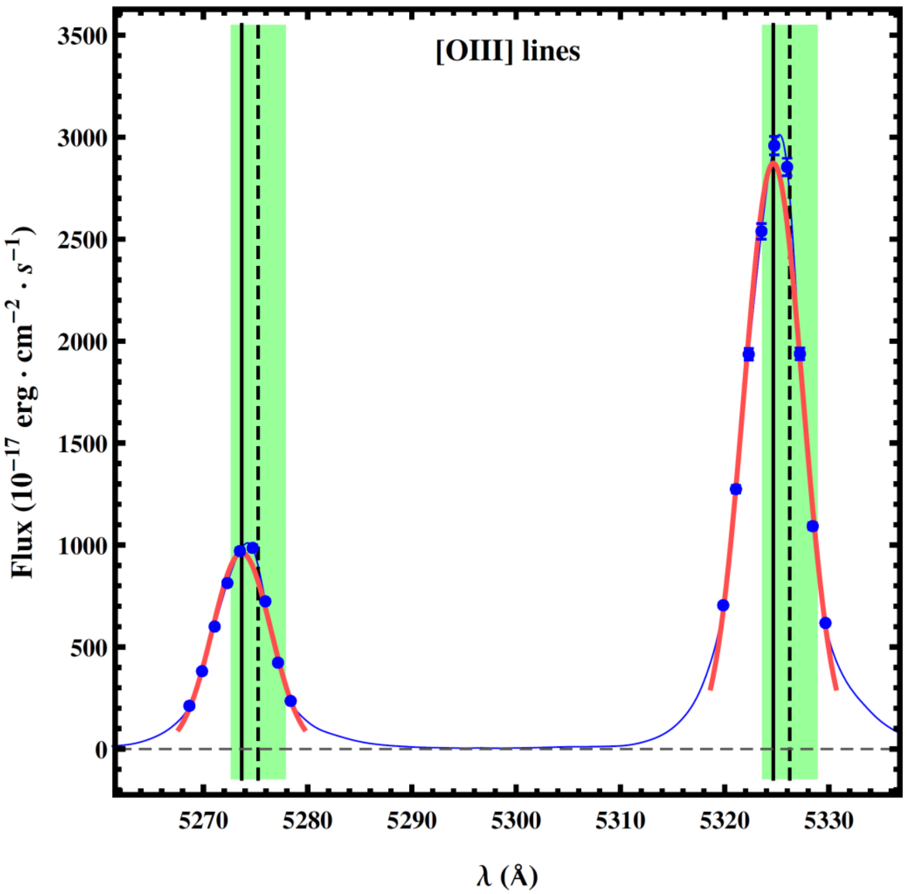
Expected line position

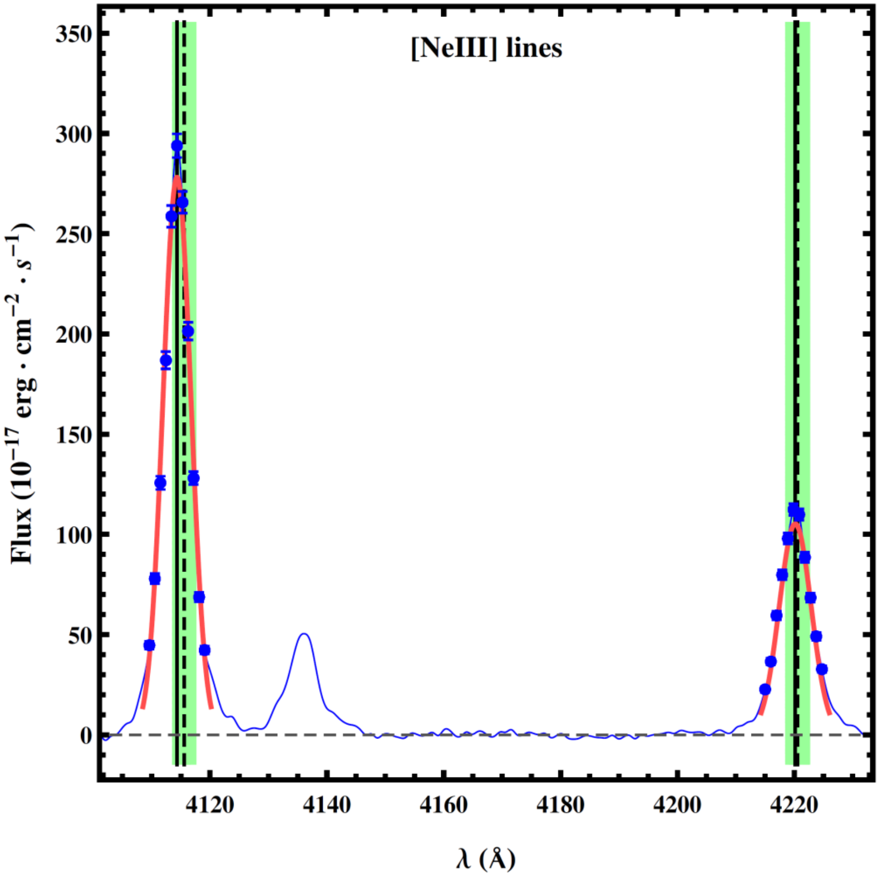
Error for $\Delta\alpha/\alpha$ **~ 10^-3,-4**

Franco D. Albareti
30th March 2015
IberiCOS

Methodology

Line positions



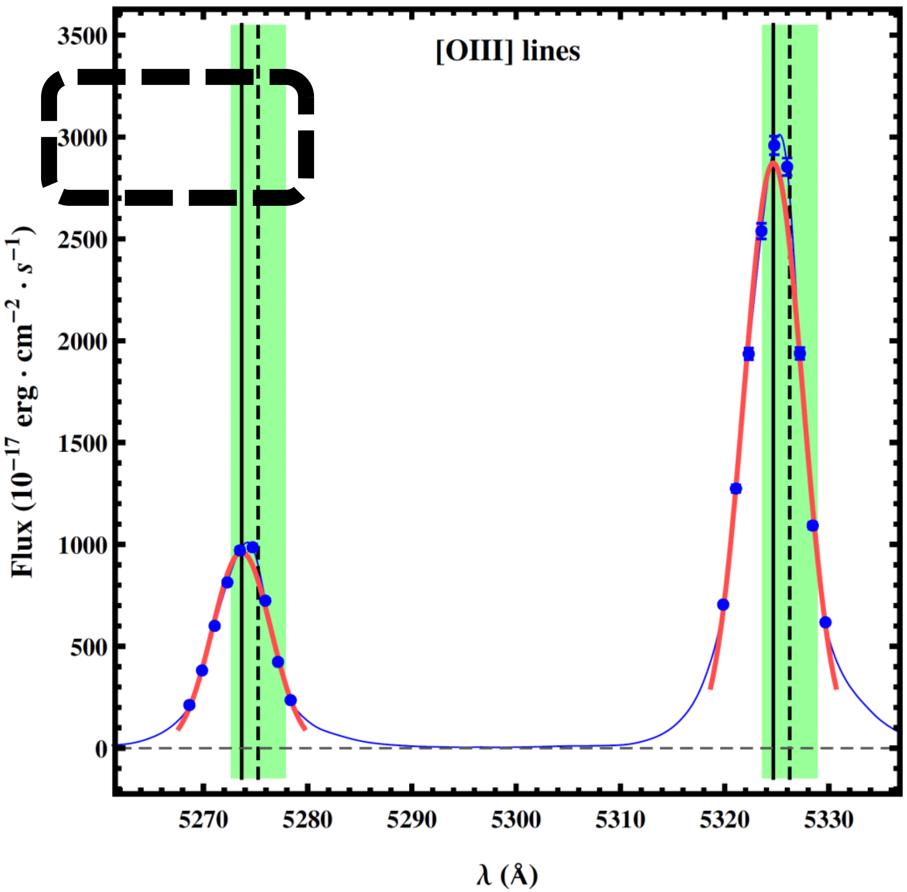


[OIII] lines **[NeIII] lines**

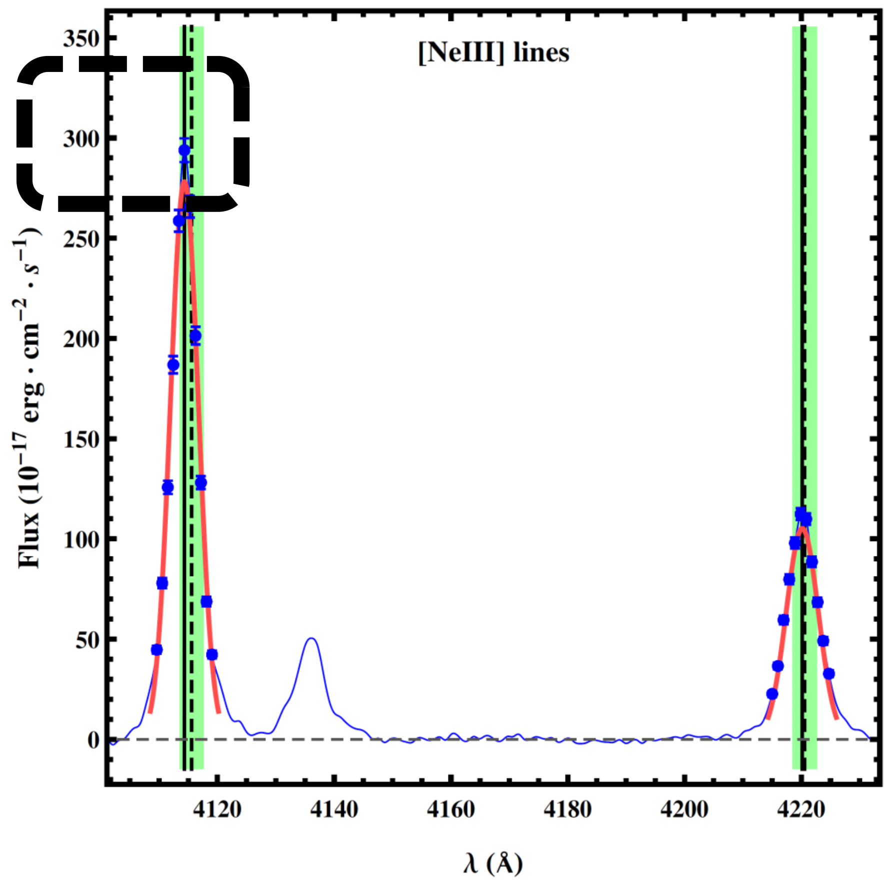
Franco D. Albareti
30th March 2015
IberiCOS

Methodology

Line positions



[OIII] lines

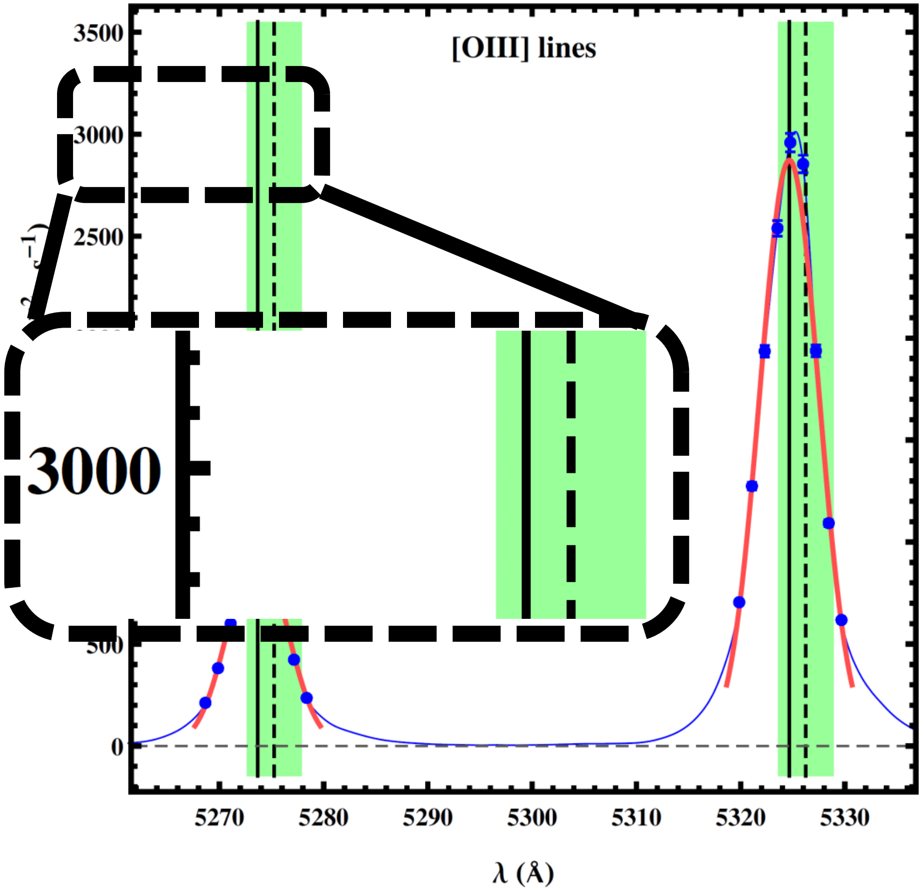


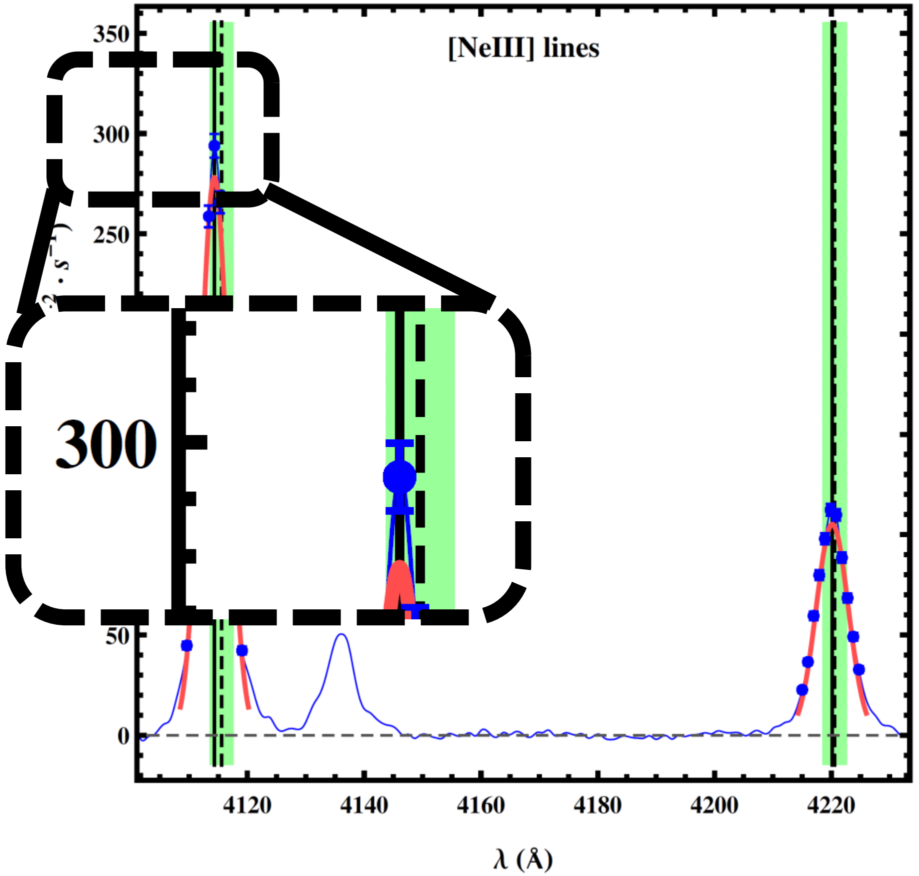
[NeIII] lines

Franco D. Albareti
30th March 2015
IberiCOS

Methodology

Line positions





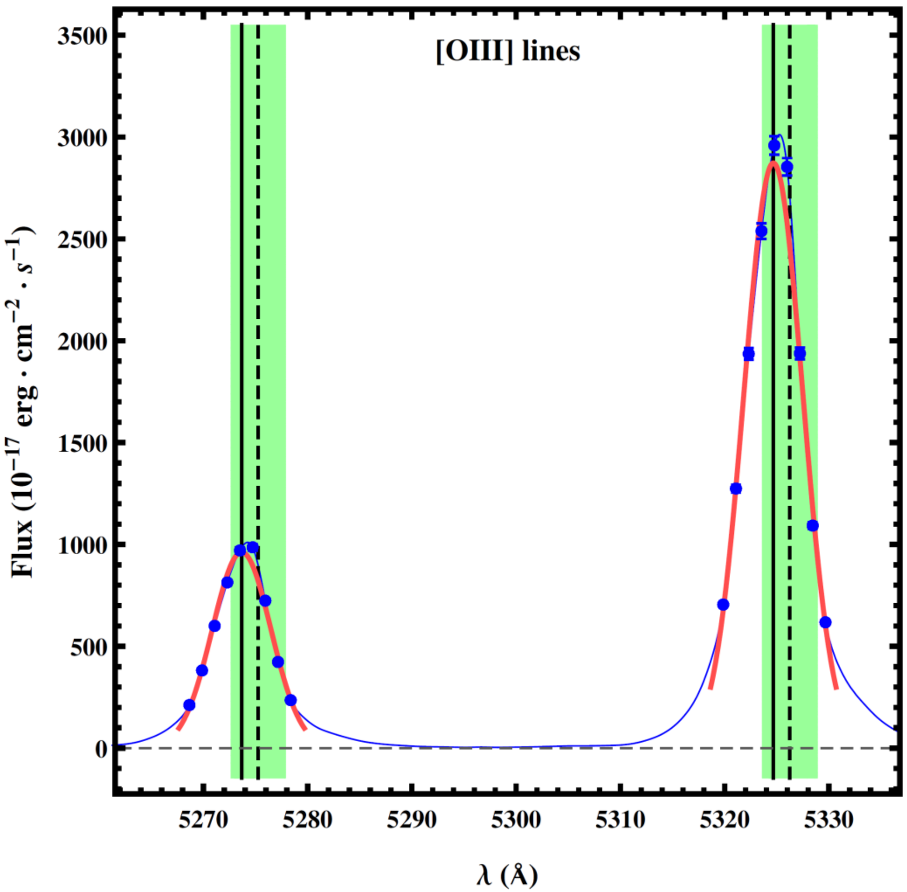
[OIII] lines

[NeIII] lines

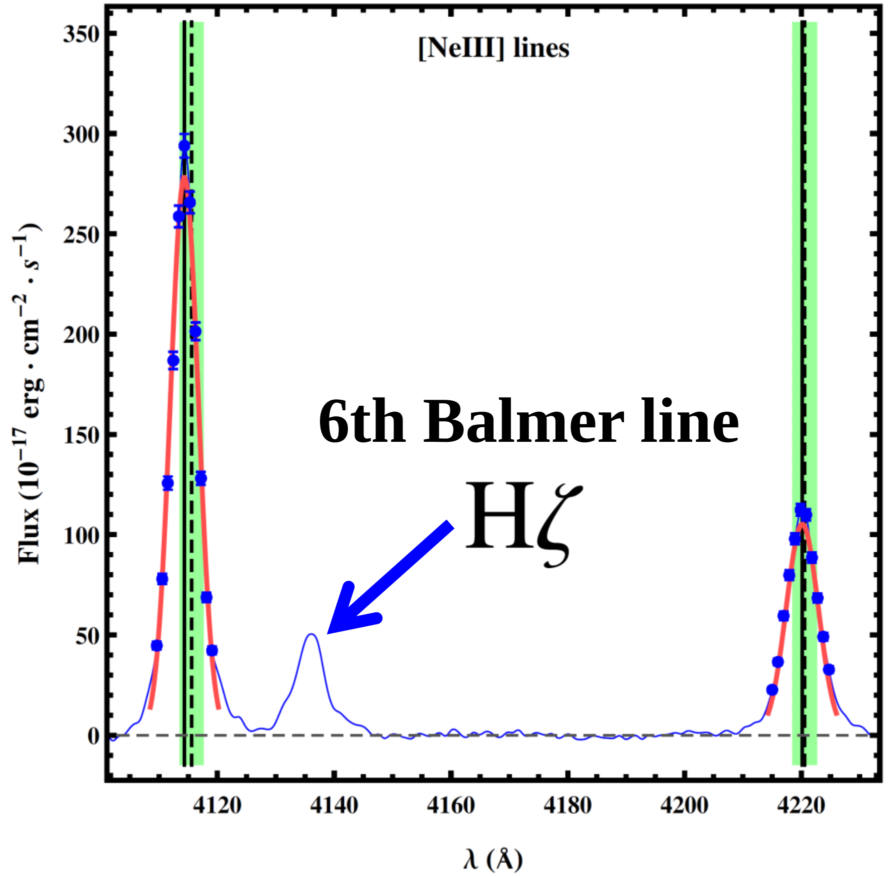
Franco D. Albareti
30th March 2015
IberiCOS

Methodology

Line positions



[OIII] lines



[NeIII] lines

Franco D. Albareti
30th March 2015
IberiCOS

Sample selection

~300,000

Criteria

- **Redshift** $z < 1$

~45,000

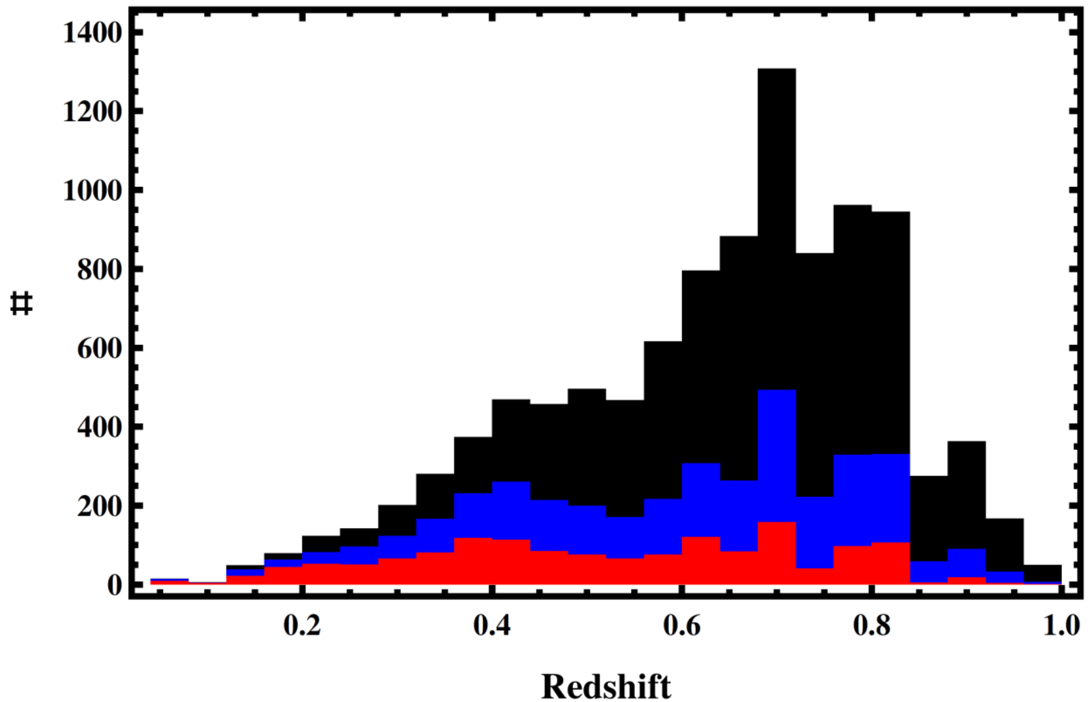
Franco D. Albareti
30th March 2015
IberiCOS

Sample selection

~300,000

Criteria

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



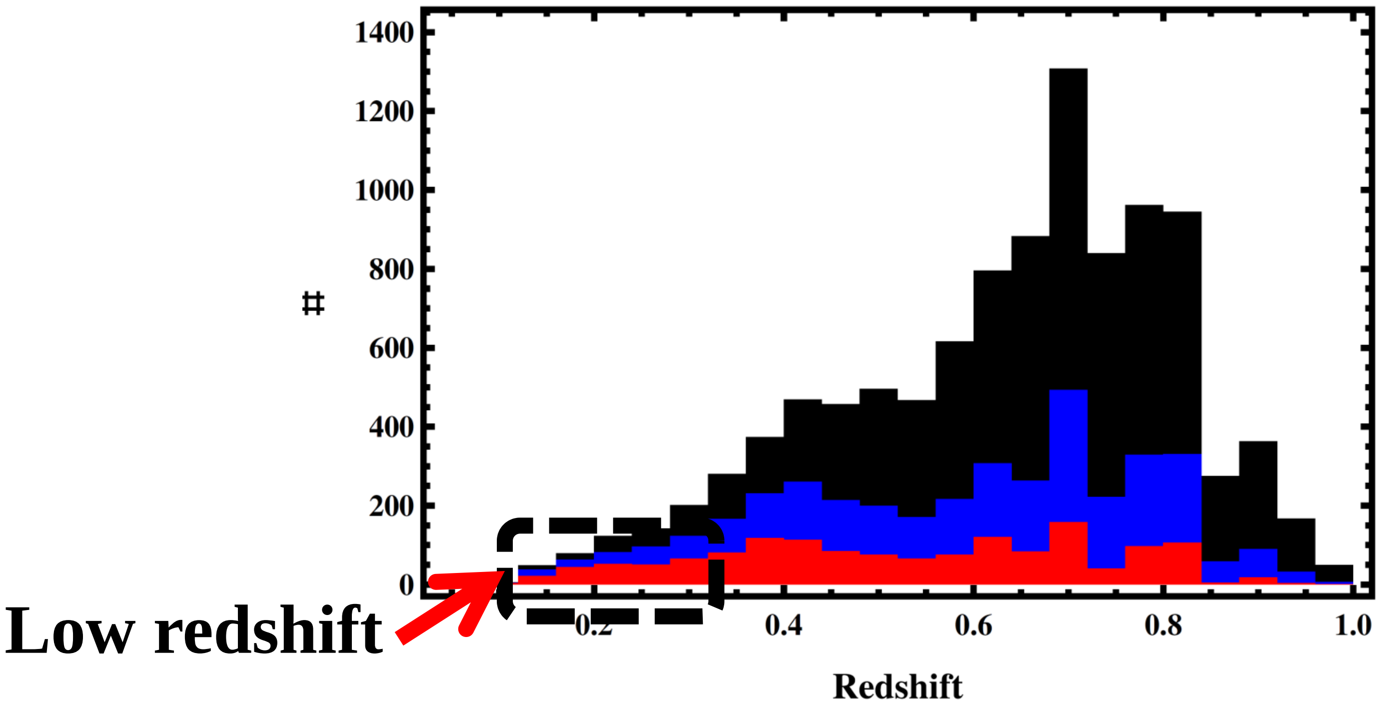
Franco D. Albareti
30th March 2015
IberiCOS

Sample selection

~300,000

Criteria

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



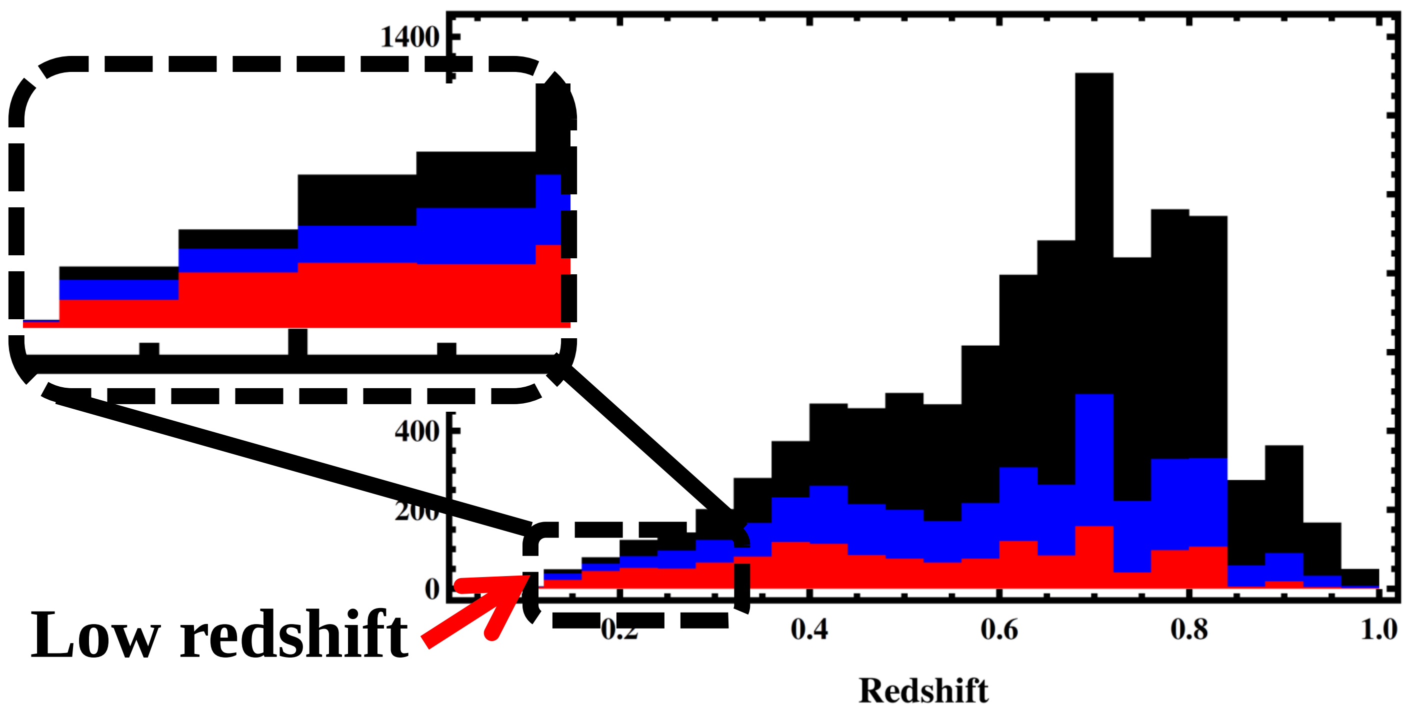
Franco D. Albareti
30th March 2015
IberiCOS

Sample selection

~300,000

Criteria

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



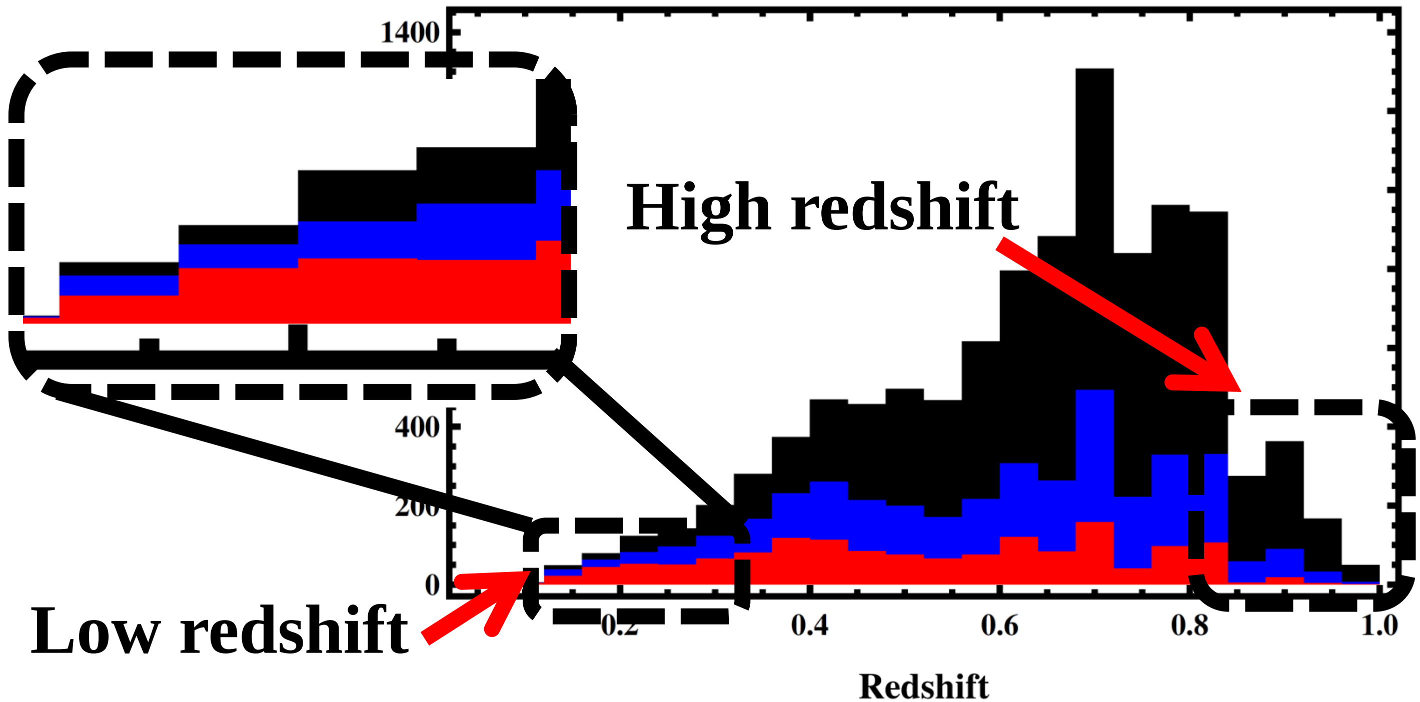
Franco D. Albareti
30th March 2015
IberiCOS

Sample selection

~300,000

Criteria

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



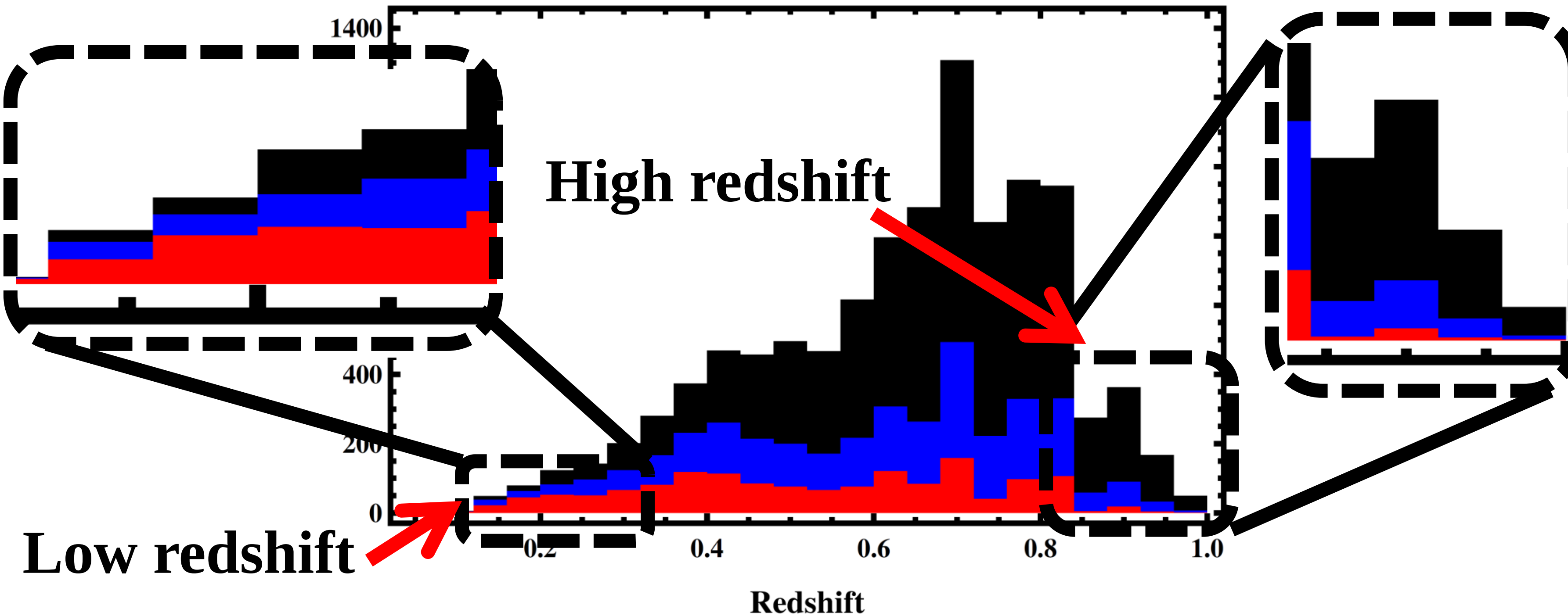
Franco D. Albareti
30th March 2015
IberiCOS

Sample selection

Criteria

~300,000

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



Franco D. Albareti
30th March 2015
IberiCOS

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**

Franco D. Albareti
30th March 2015
IberiCOS

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**

Sample selection

~300,000

Criteria

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

Sample selection

~300,000

Criteria

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

Franco D. Albareti
30th March 2015
IberiCOS

Sample selection

~300,000

Criteria

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

4%

Sample selection

Criteria

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

Mild constraints

~300,000

~45,000

~13,000

~12,000

~11,000

4%

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

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

Franco D. Albareti
30th March 2015
IberiCOS

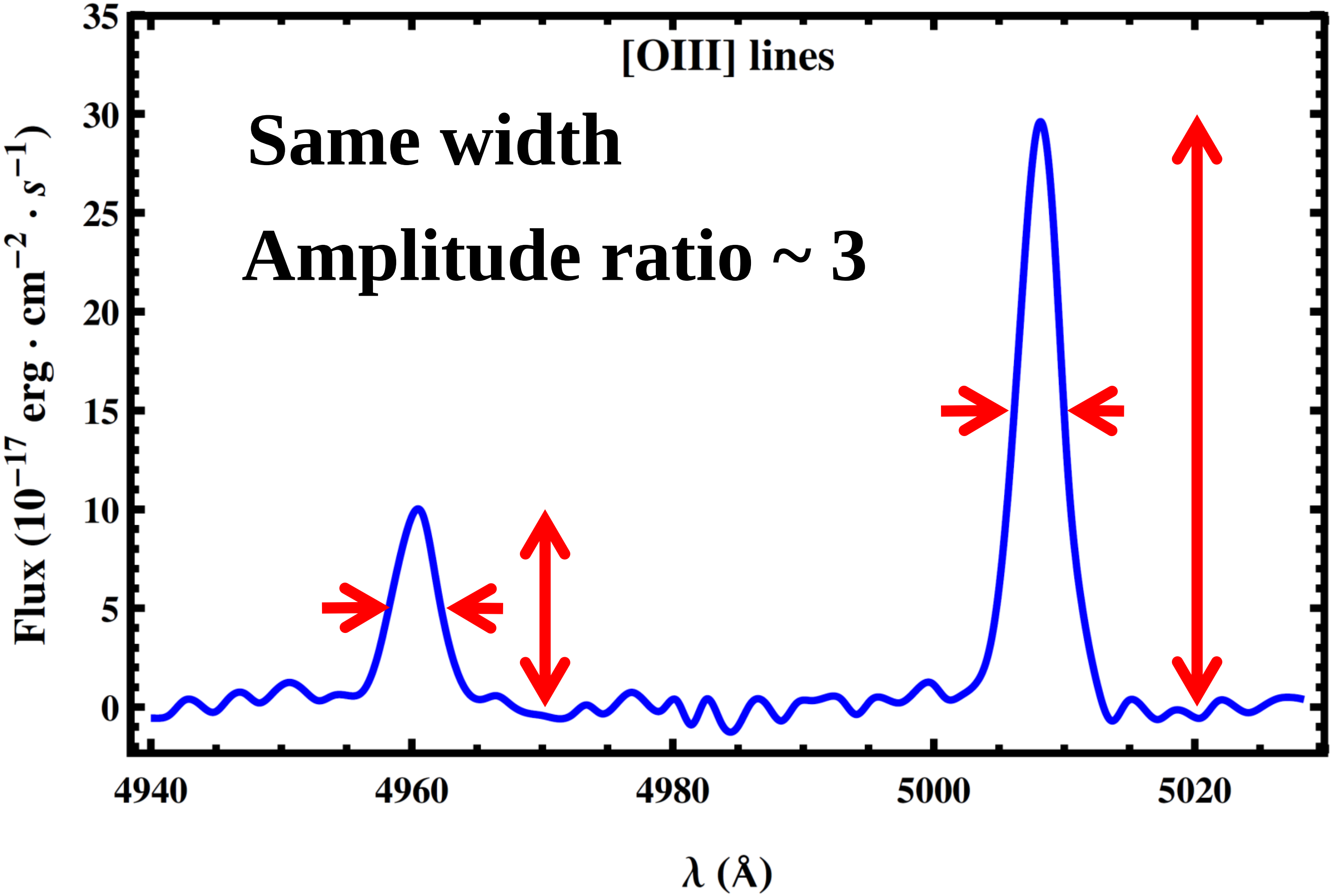
Systematics

- **Misidentification of the lines**

Franco D. Albareti
30th March 2015
IberiCOS

Systematics

- **Misidentification of the lines**



Franco D. Albareti
30th March 2015
IberiCOS

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

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

Franco D. Albareti
30th March 2015
IberiCOS

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

Franco D. Albareti
30th March 2015
IberiCOS

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

Franco D. Albareti
30th March 2015
IberiCOS

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

OK

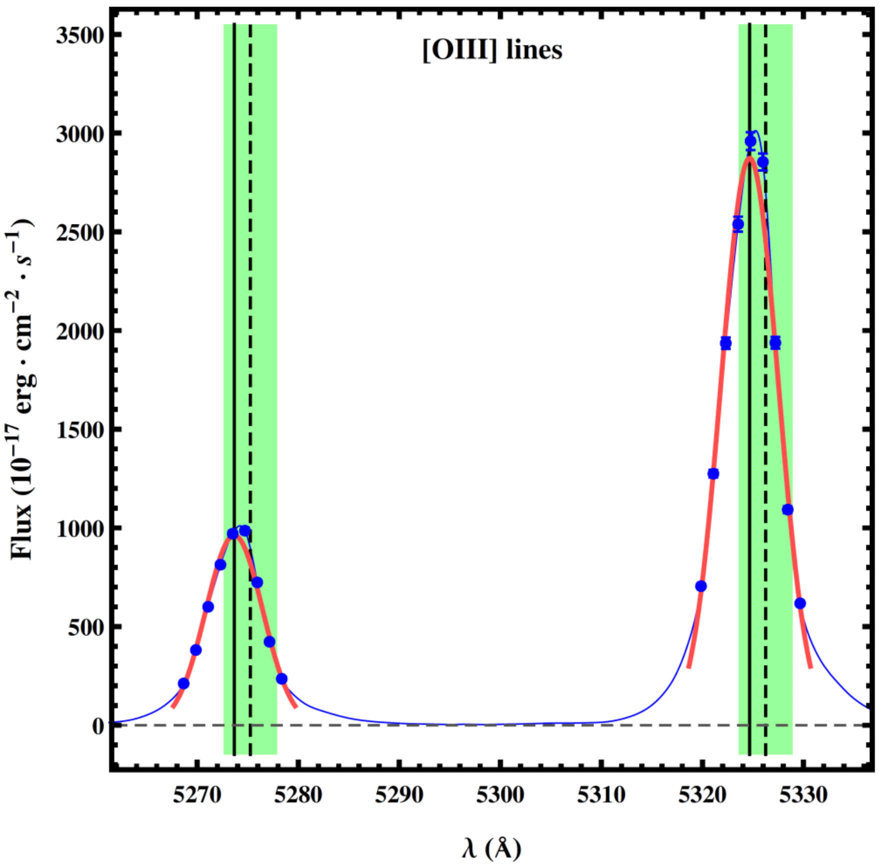
$[A \times \lambda]_{5008}\ /\ [A \times \lambda]_{4960}$	# QSO spectra	redshift	$\Delta\alpha/\alpha\ (\times 10^{-5})$
3.00 ± 0.50	$8,308$	0.56 ± 0.21	1.8 ± 2.4
3.00 ± 0.25	$5,752$	0.55 ± 0.21	-0.2 ± 2.6
3.00 ± 0.10	$2,677$	0.54 ± 0.21	-0.4 ± 3.4
3.00 ± 0.05	$1,411$	0.52 ± 0.22	2.9 ± 4.5

OK

Franco D. Albareti
30th March 2015
IberiCOS

Systematics

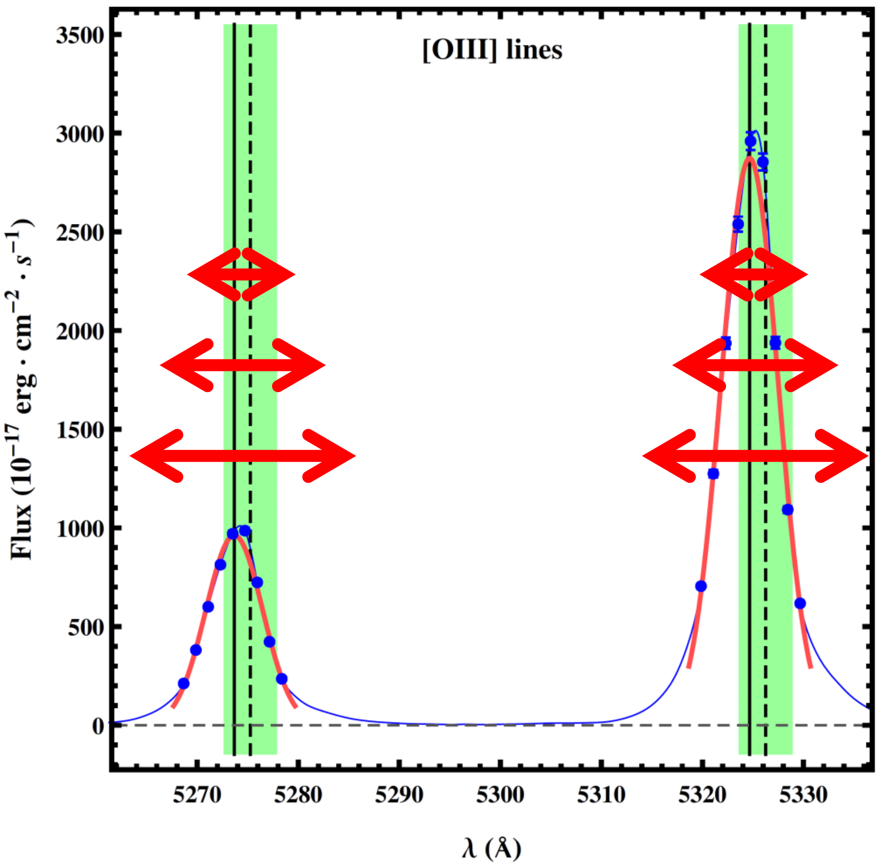
- Misidentification of the lines **OK**
- Interval for the Gaussian fits



Franco D. Albareti
30th March 2015
IberiCOS

Systematics

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



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

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

Franco D. Albareti
30th March 2015
IberiCOS

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

More affected by noise and Hbeta

Franco D. Albareti
30th March 2015
IberiCOS

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

OK

More affected by noise and Hbeta

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

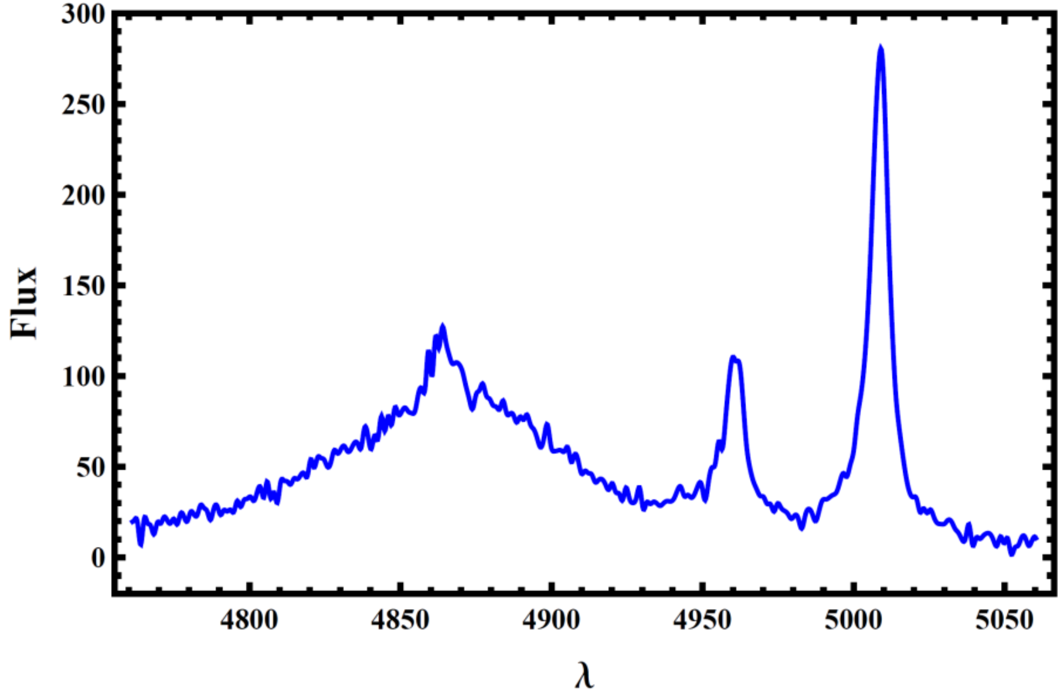
OK

More affected by noise and Hbeta

Franco D. Albareti
30th March 2015
IberiCOS

Systematics

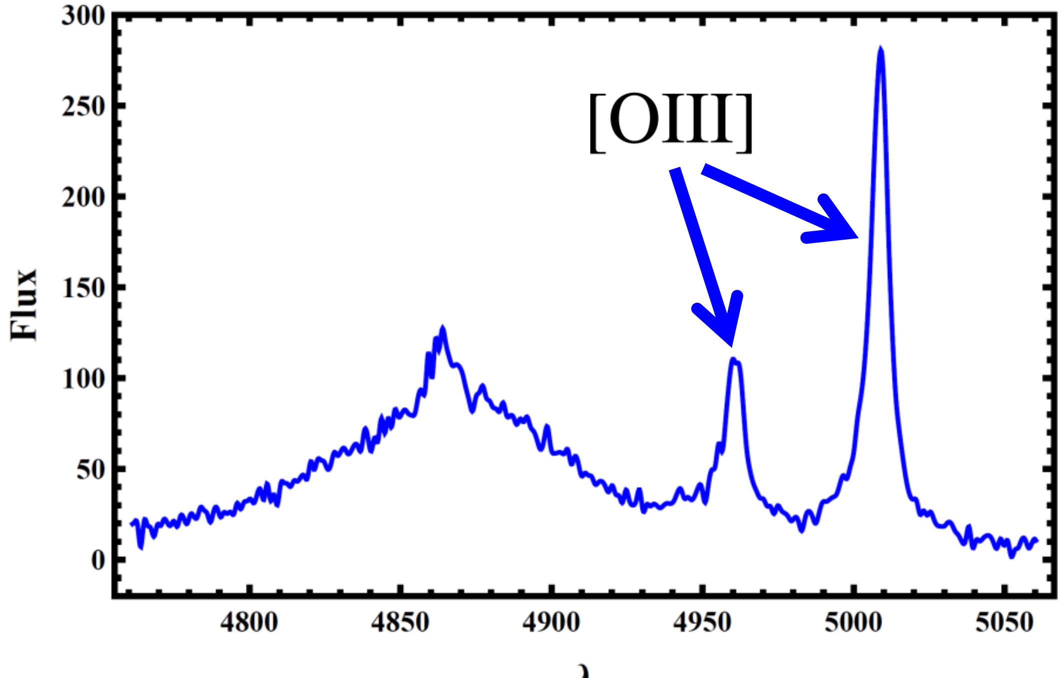
- Misidentification of the lines **OK**
- Interval for the Gaussian fits **OK**
- Hbeta contamination



Franco D. Albareti
30th March 2015
IberiCOS

Systematics

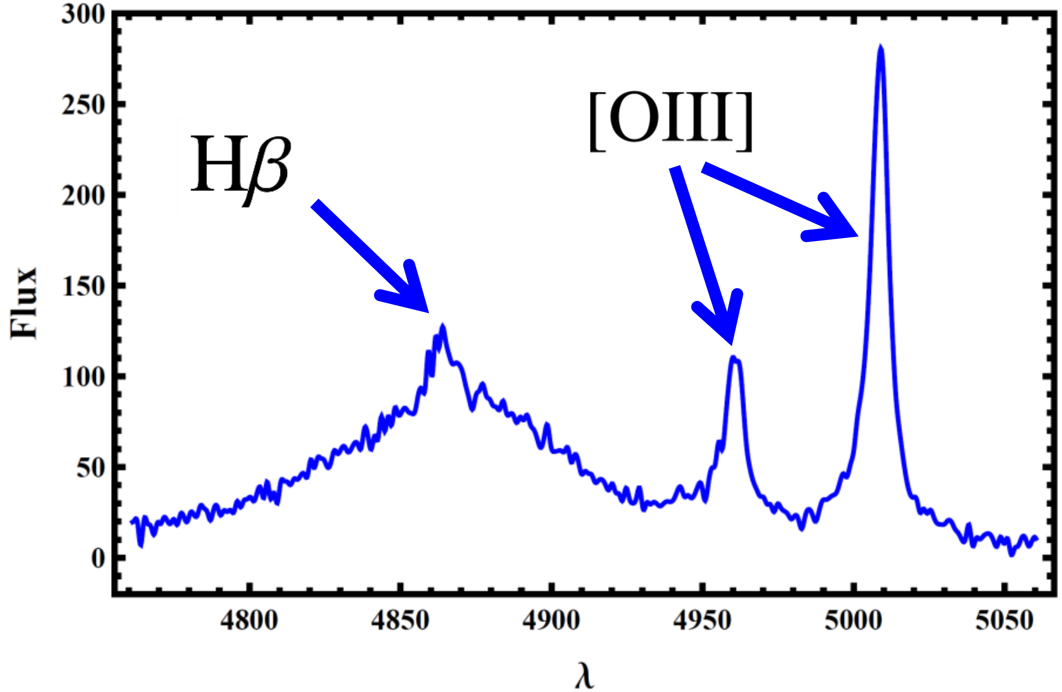
- Misidentification of the lines **OK**
- Interval for the Gaussian fits **OK**
- Hbeta contamination



Franco D. Albareti
30th March 2015
IberiCOS

Systematics

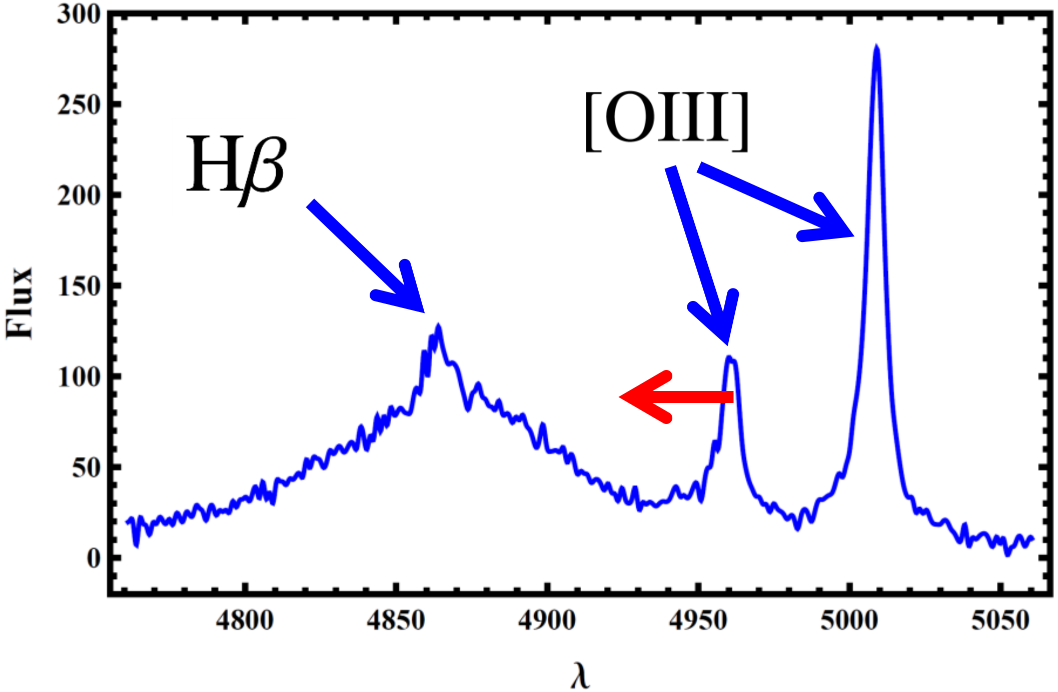
- Misidentification of the lines OK
- Interval for the Gaussian fits OK
- Hbeta contamination



Franco D. Albareti
30th March 2015
IberiCOS

Systematics

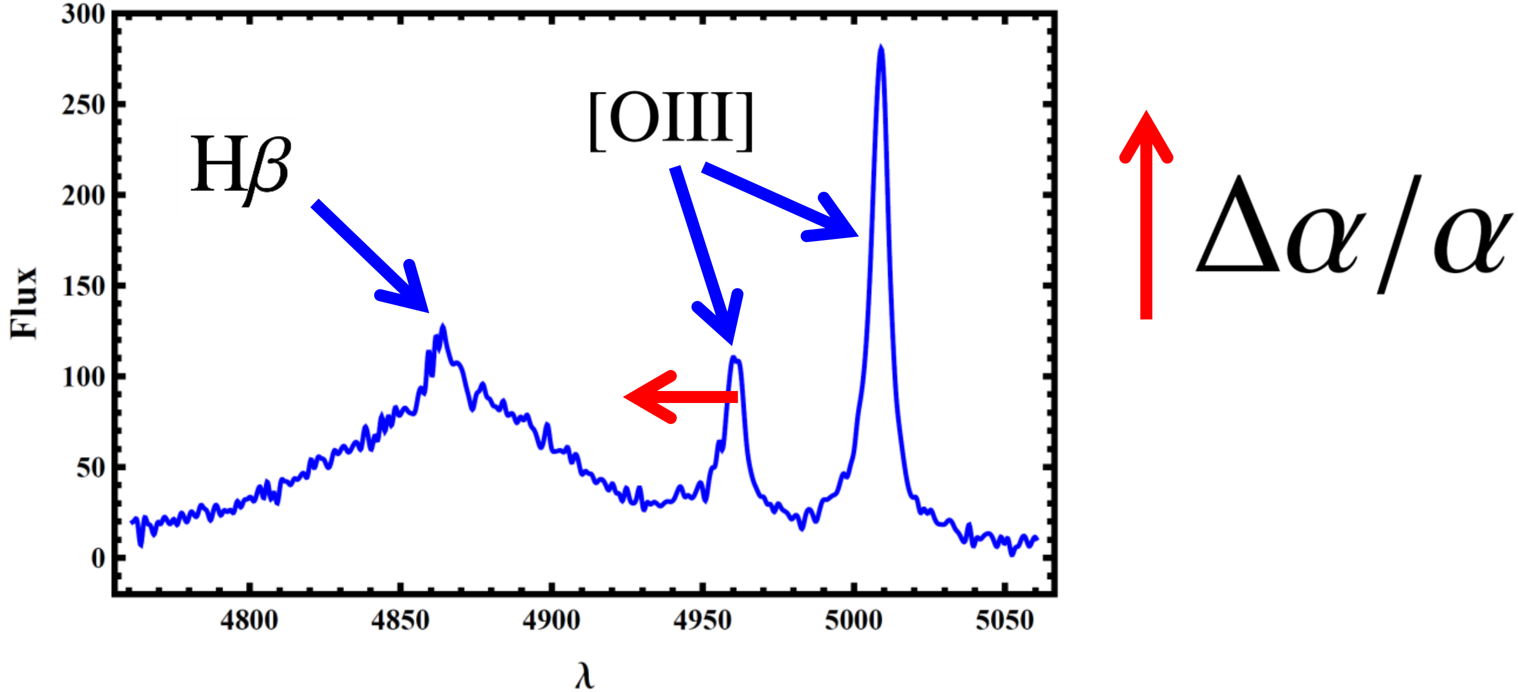
- Misidentification of the lines **OK**
- Interval for the Gaussian fits **OK**
- Hbeta contamination



Franco D. Albareti
30th March 2015
IberiCOS

Systematics

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



Franco D. Albareti
30th March 2015
IberiCOS

Systematics

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

$S/N_{\mathrm{H}\beta/[\mathrm{OIII}]4960}$	# 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

Franco D. Albareti
30th March 2015
IberiCOS

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

Franco D. Albareti
30th March 2015
IberiCOS

Systematics

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

$S/N_{\mathrm{H}\beta/[\mathrm{OIII}]4960}$	# 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

Franco D. Albareti
30th March 2015
IberiCOS

Systematics

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

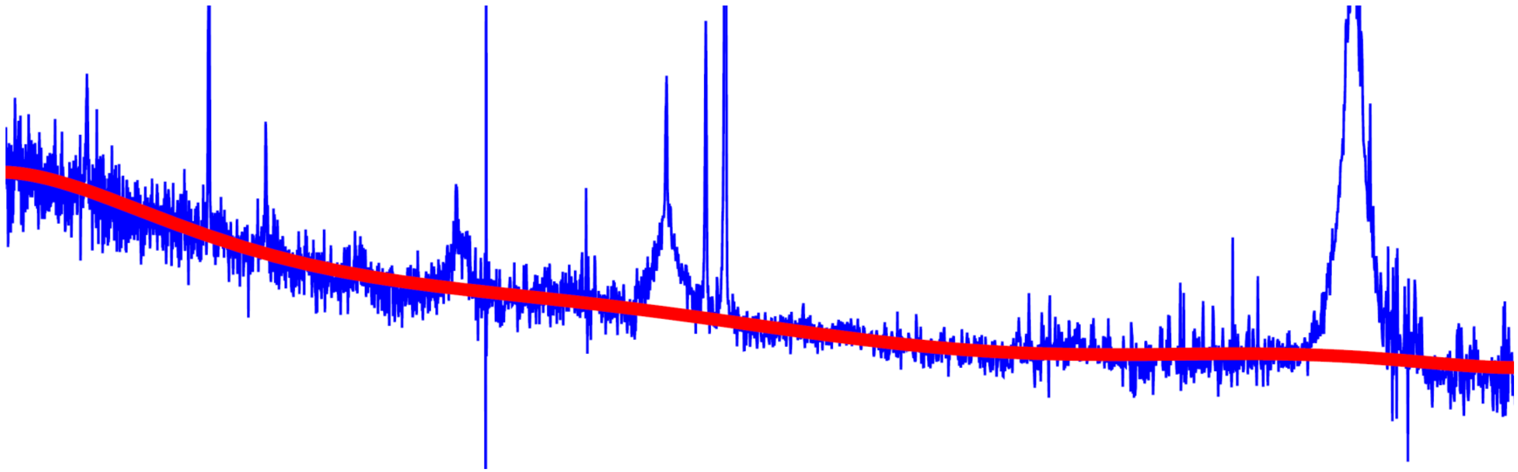
$S/N_{\mathrm{H}\beta/[\mathrm{OIII}]4960}$	# QSO spectra	redshift	$\Delta\alpha/\alpha$ $(\times 10^{-5})$
< 5	10,338	0.57 ± 0.21	1.4 ± 2.3
< 2	9,831	0.57 ± 0.21	0.6 ± 2.3
< 1	8,162	0.57 ± 0.21	0.1 ± 2.5
< 0.5	5,831	0.58 ± 0.21	-0.7 ± 2.8

OK

Franco D. Albareti
30th March 2015
IberiCOS

Systematics

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



Systematics

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

Pol. order (continuum)	# QSO spectra	redshift	$\Delta\alpha/\alpha$ ($\times10^{-5}$)
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

Franco D. Albareti
30th March 2015
IberiCOS

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

Franco D. Albareti
30th March 2015
IberiCOS

Systematics

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

Pol. order (continuum)	# QSO spectra	redshift	$\Delta\alpha/\alpha$ ($\times10^{-5}$)
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

OK

Franco D. Albareti
30th March 2015
IberiCOS

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

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

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

OK

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"

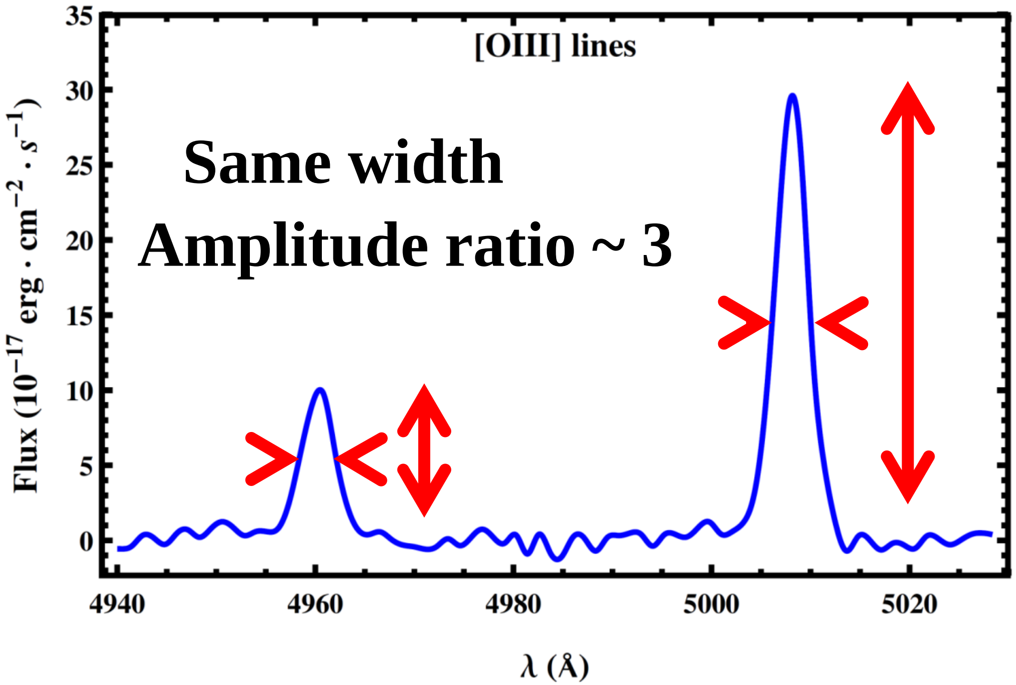
Franco D. Albareti
30th March 2015
IberiCOS

Results

Systematics?

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

- **Misidentification of the lines?**



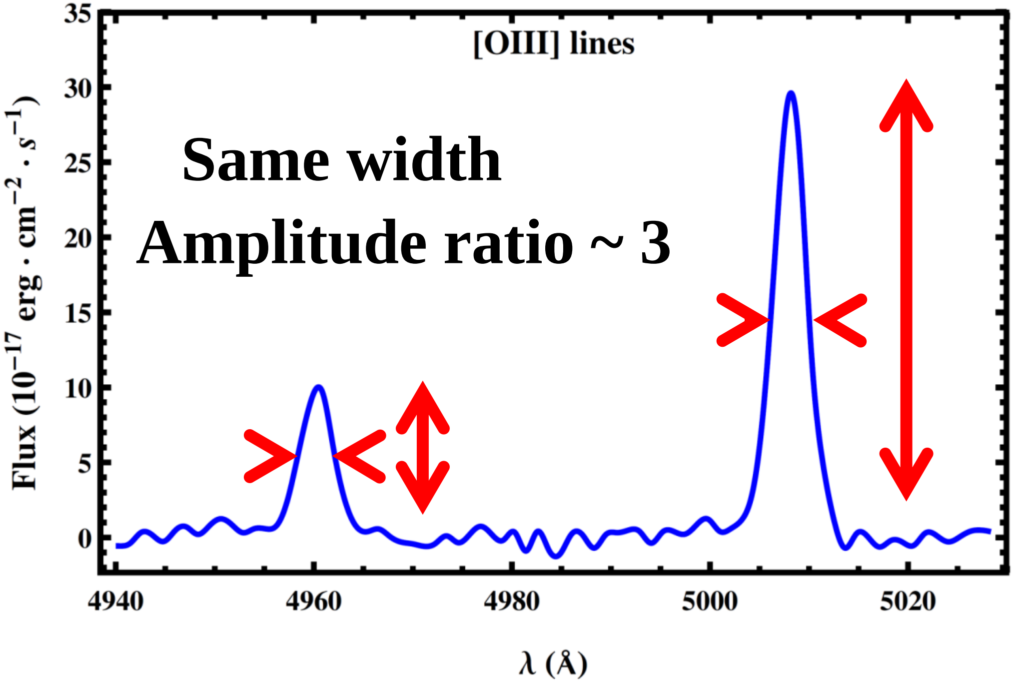
Franco D. Albareti
30th March 2015
IberiCOS

Results

Systematics?

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

- **Misidentification of the lines OK**



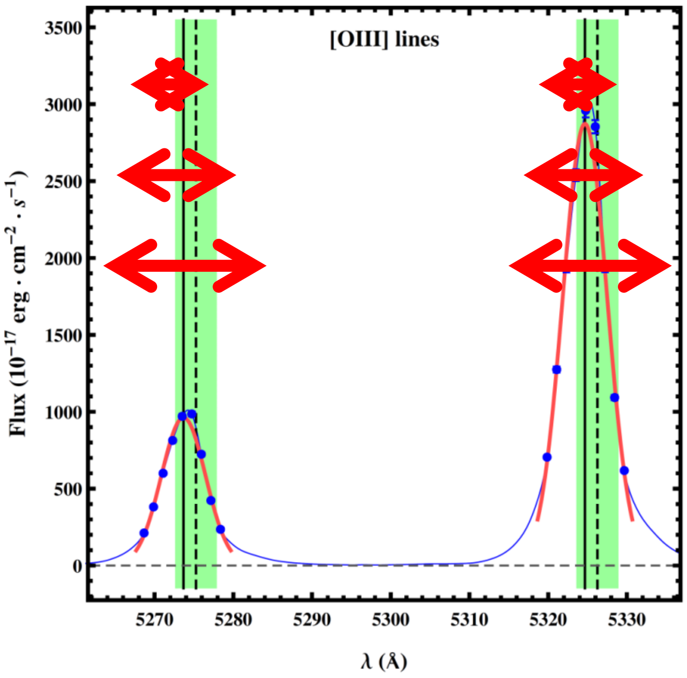
Franco D. Albareti
30th March 2015
IberiCOS

Results

Systematics?

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

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



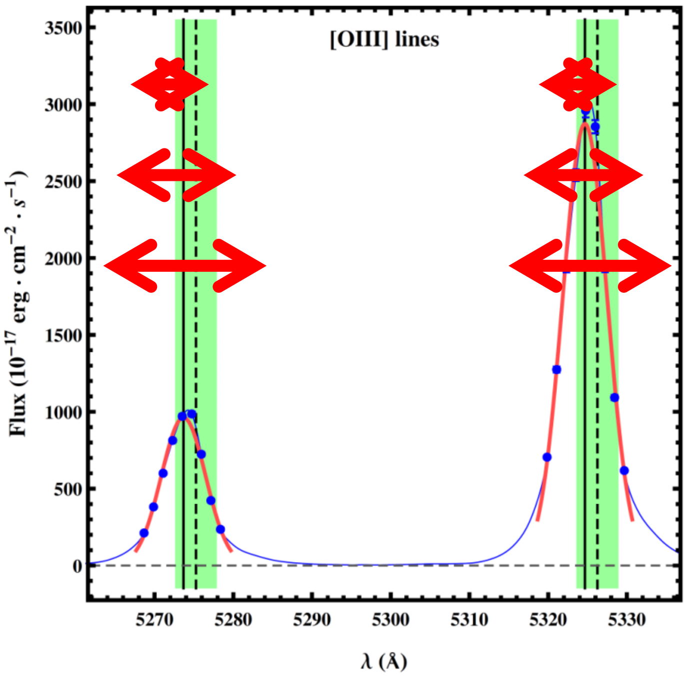
Franco D. Albareti
30th March 2015
IberiCOS

Results

Systematics?

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

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



Franco D. Albareti
30th March 2015
IberiCOS

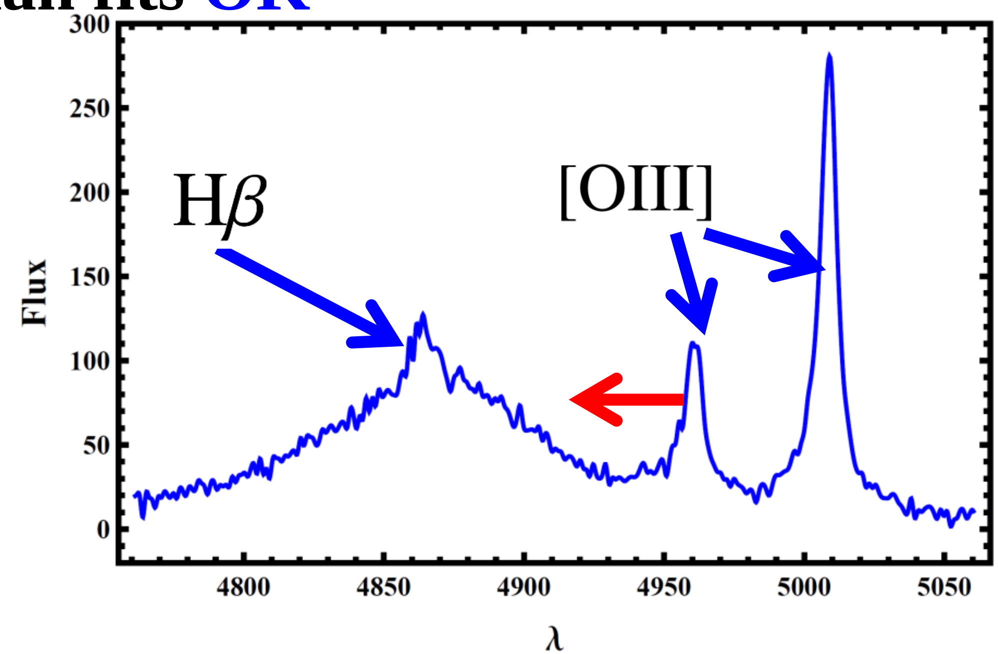
Results

Systematics?

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

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

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



Franco D. Albareti
30th March 2015
IberiCOS

Results

Systematics?

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

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

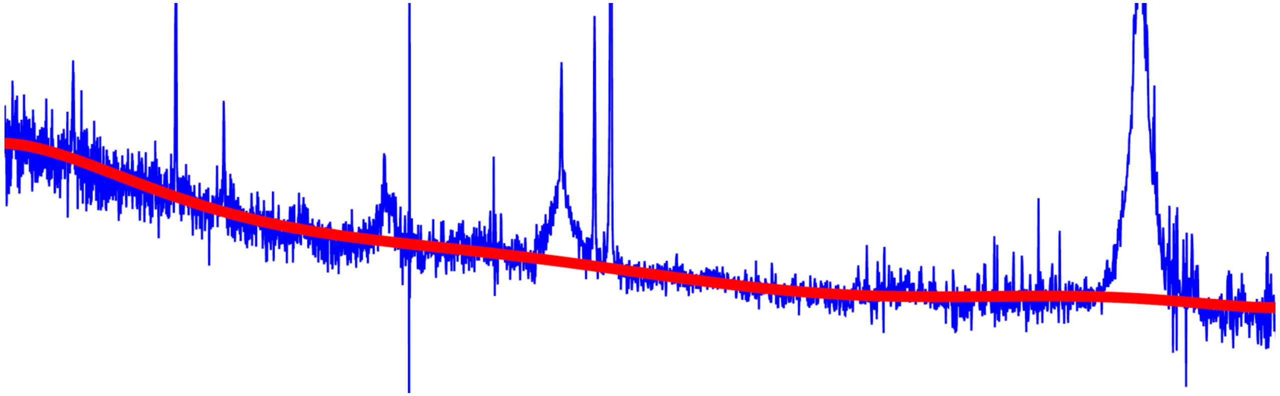
Franco D. Albareti
30th March 2015
IberiCOS

Results

Systematics?

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

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



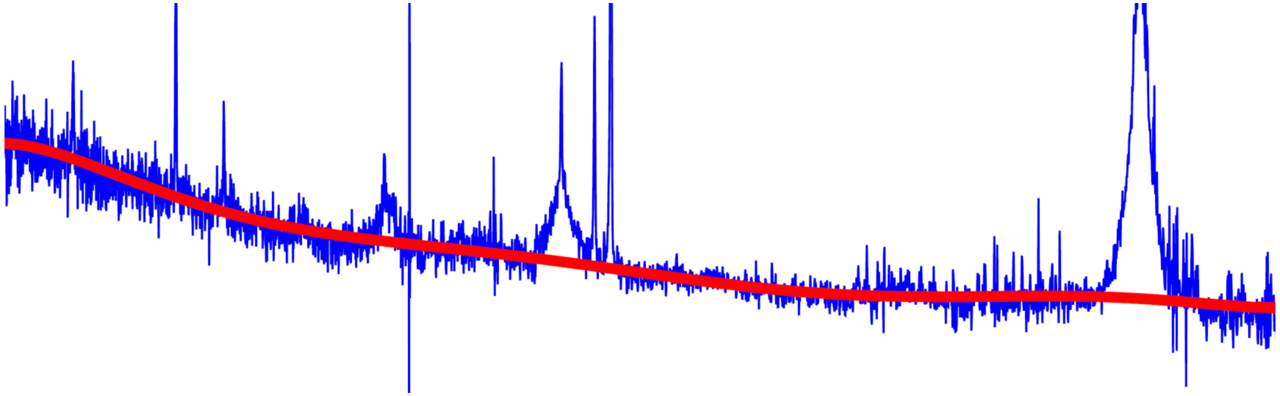
Franco D. Albareti
30th March 2015
IberiCOS

Results

Systematics?

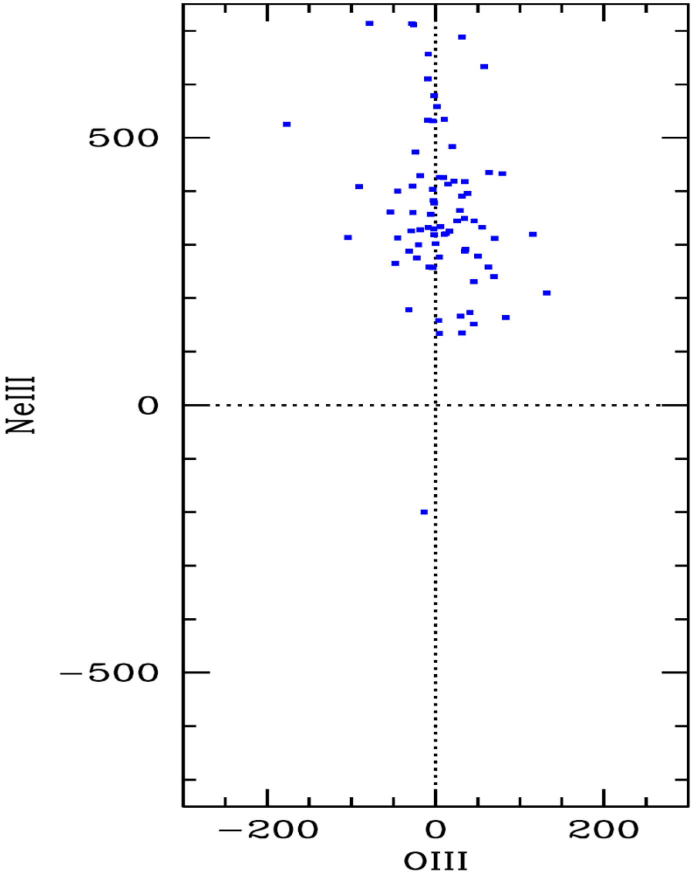
$$\Delta\alpha/\alpha = (1.4 \pm 2.3) \times 10^{-5}$$

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



Franco D. Albareti
30th March 2015
IberiCOS

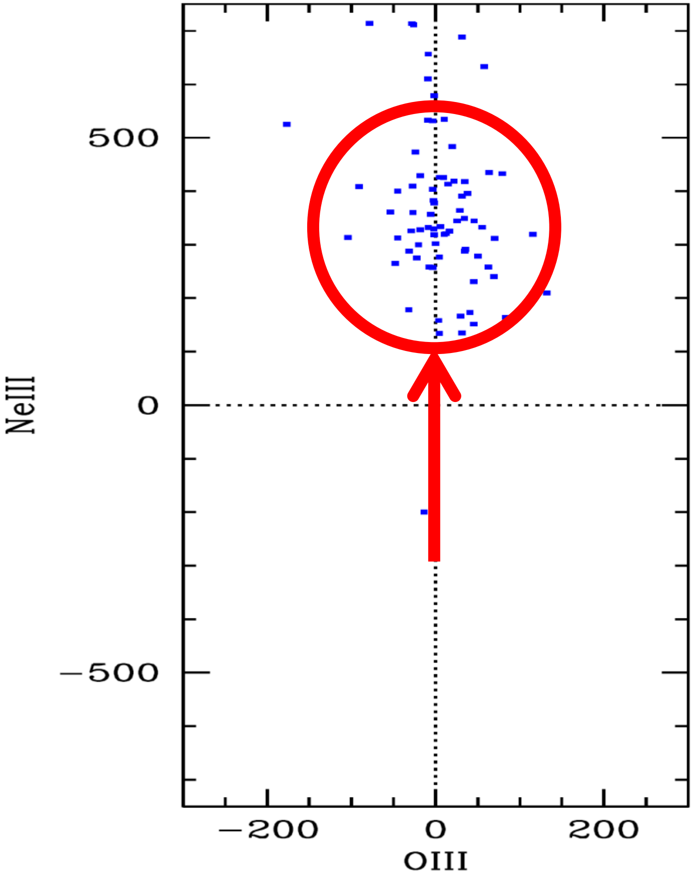
Systematics



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

Gutiérrez & López-Corredoira (2010)

Systematics

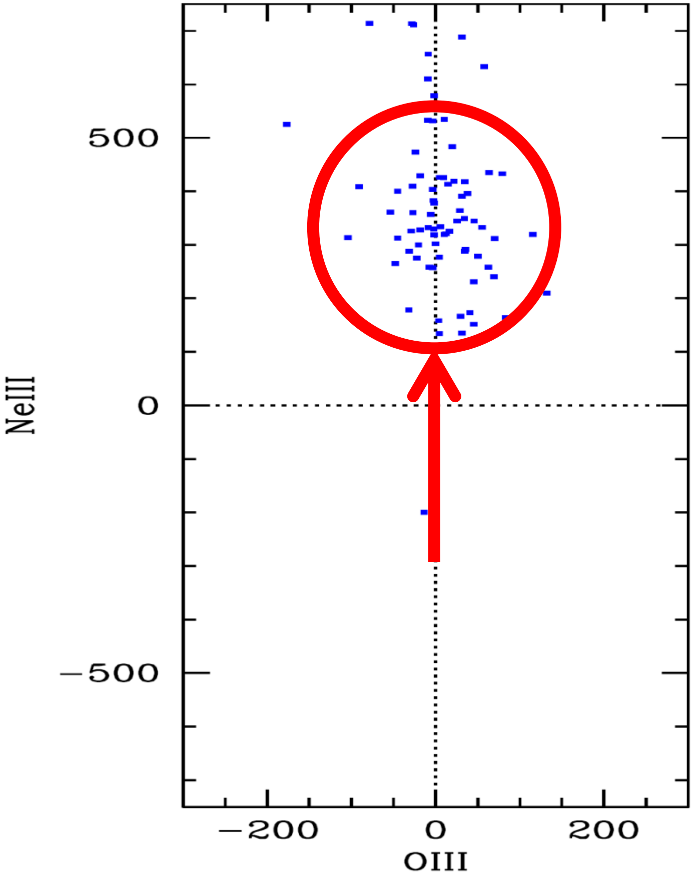


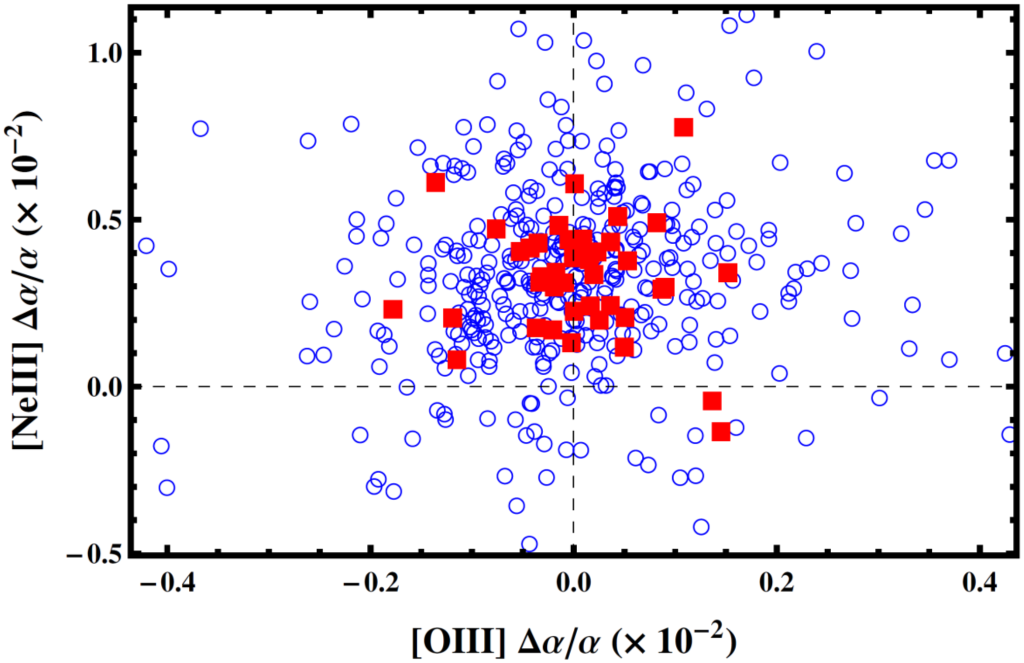
$$\Delta\alpha/\alpha_{[\mathrm{NeIII}]} = (36 \pm 1) \times 10^{-4}$$

Gutiérrez & López-Corredoira (2010)

Franco D. Albareti
30th March 2015
IberiCOS

Systematics





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

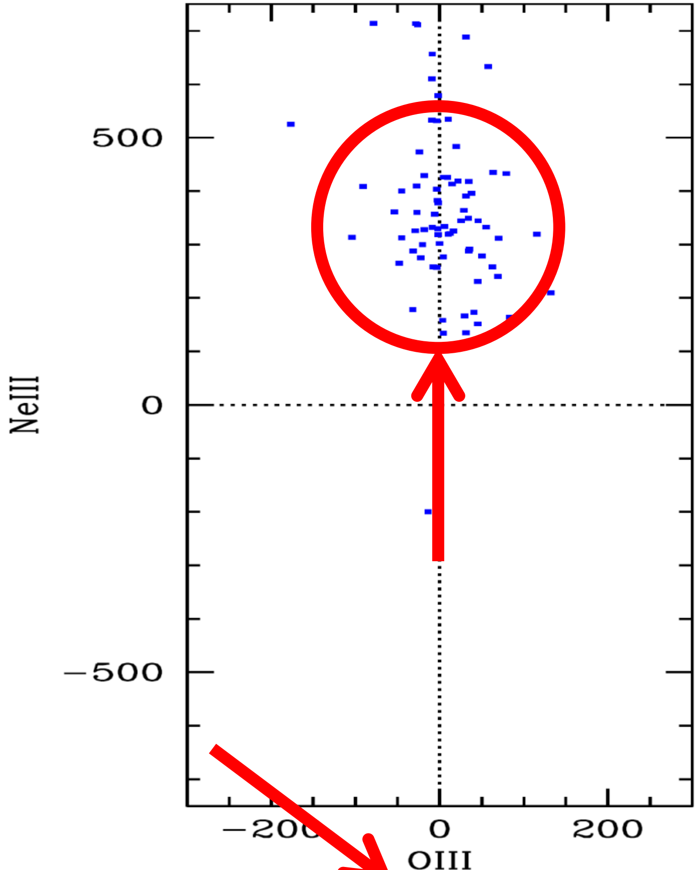
$$\Delta\alpha/\alpha_{[\mathrm{NeIII}]} = (34 \pm 1)\times 10^{-4}$$

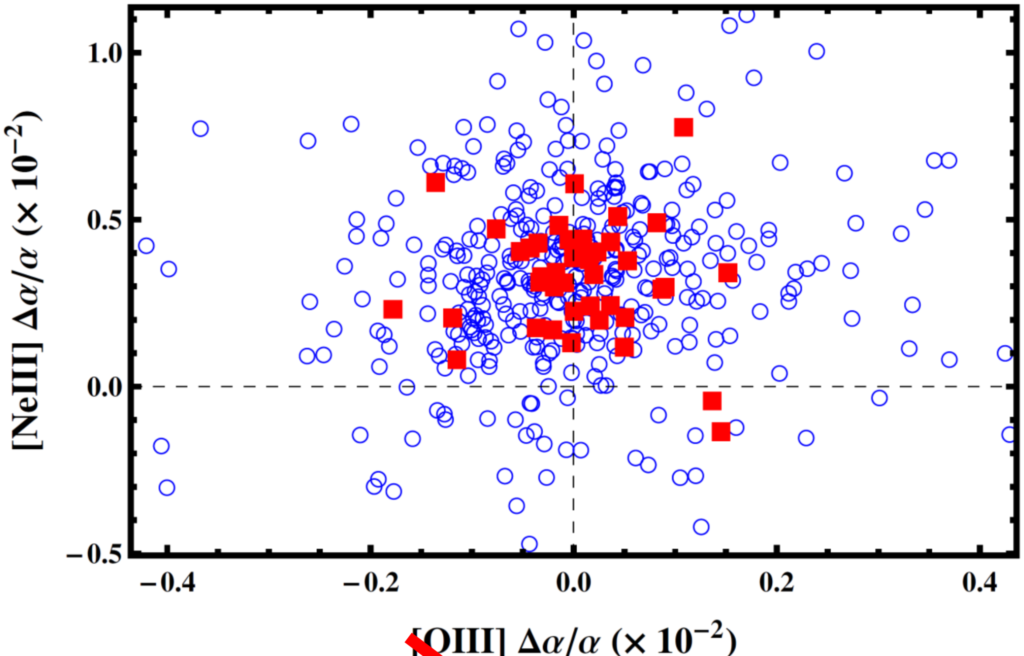
Gutiérrez & López-Corredoira (2010)

This work (2014)

Franco D. Albareti
30th March 2015
IberiCOS

Systematics





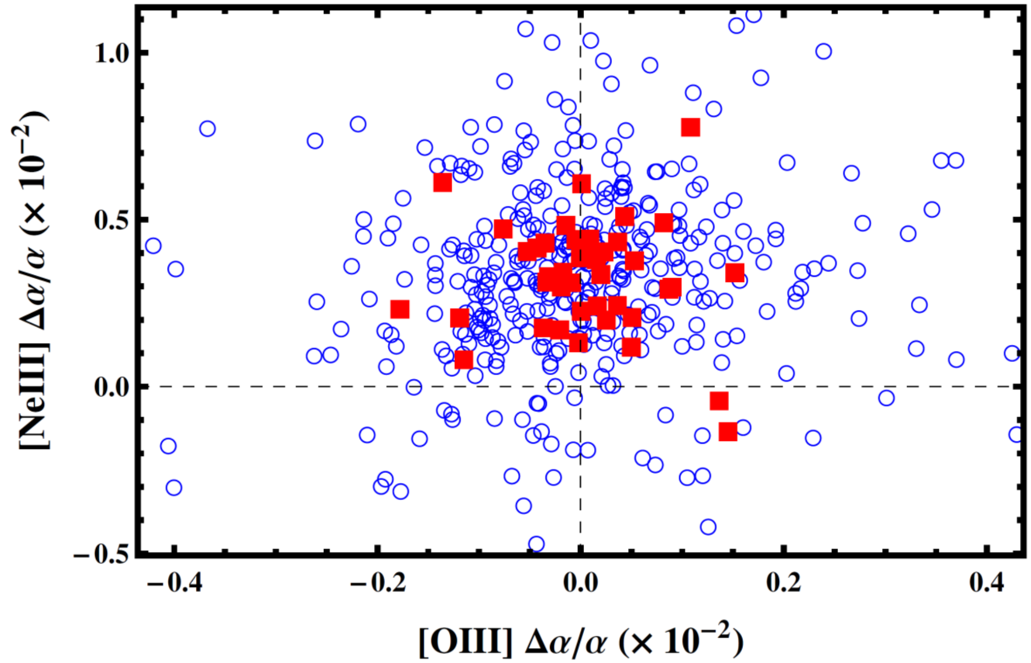
$\Delta\alpha/\alpha_{[NeIII]} = (36 \pm 1)\times 10^{-4}$ $\Delta\alpha/\alpha_{[NeIII]} = (34 \pm 1)\times 10^{-4}$

Gutiérrez & López-Corredoira (2010) This work (2014)

Franco D. Albareti
30th March 2015
IberiCOS

Systematics

- **Errors in absolute wavelengths (~1 A)?**
- **Bad SDSS calibration?**



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

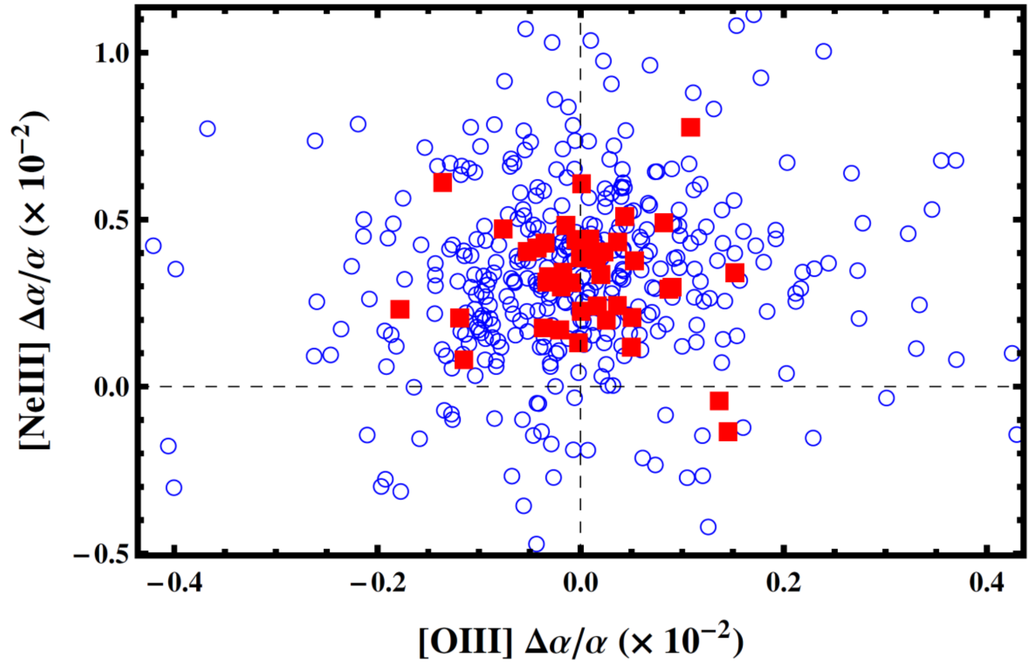
This work (2014)

Franco D. Albareti
30th March 2015
IberiCOS

Systematics

- **Errors in absolute wavelengths (~1 A)?**
- **Bad SDSS calibration?**

It is unlikely…



We don’t know yet…

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

This work (2014)

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
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
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

A factor 2.5 of improvement is expected…?