Automatic analysis of optical AGN spectra

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in collaboration with:
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Tullia Sbarrato[4], Francesco Shankar[5], Monica Colpi[4]

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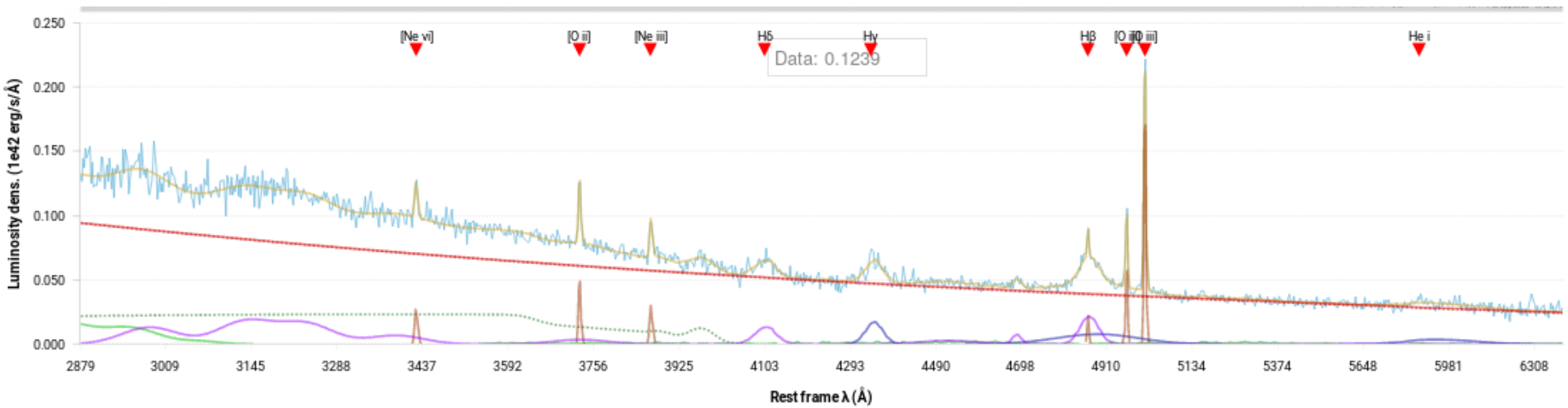
[3] *INAF – Osservatorio Astronomico di Brera,* [4] *Università degli studi di Milano–Bicocca,* [5] *University of Southampton (UK)*



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- estimate AGN spectral quantities (luminosities, slopes, emission line properties, etc...);
- do it **quickly** and **automatically** on large samples...;
- ...to generate a catalog of spectral quantities;

- analyze AGN spectra in a simple, replicable and shareable way using standardized recipes;
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Quasar spectral catalogs in literature

Shen et al. 2011 (S11) catalog

- Sample of 105,783 Type 1 AGNs:
  - M_i brighter than -22;
  - at least one line broader than 1000 km s^{-1};
- Spectra from SDSS/DR7 ($\sim$ 3800–9000Å)
- Catalog of spectroscopic properties, e.g.
  - Cont. luminosity λL_λ @ 5100Å, 3000Å and 1350Å
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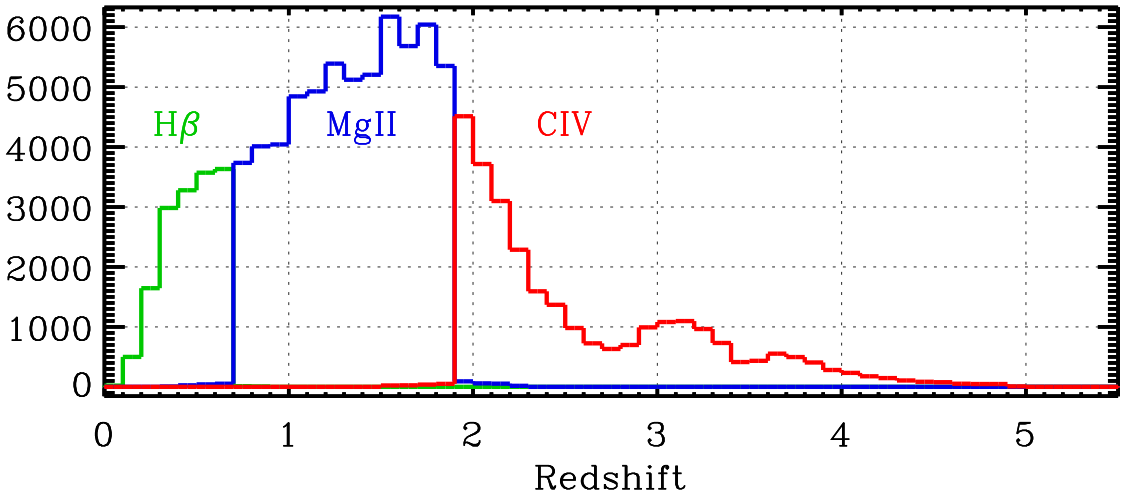

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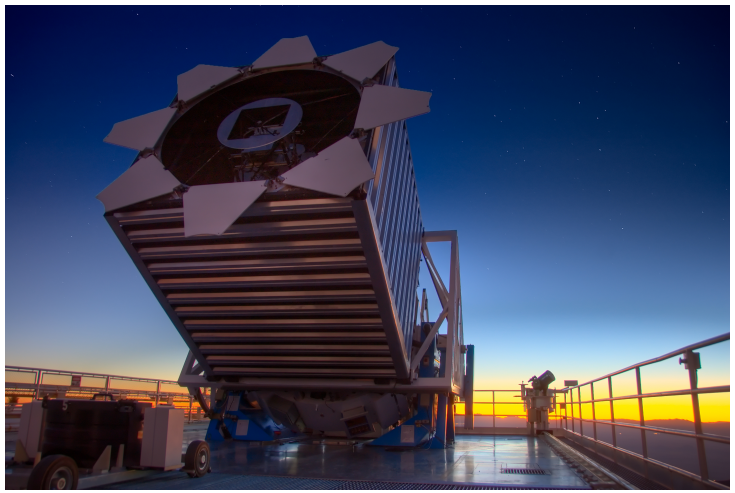

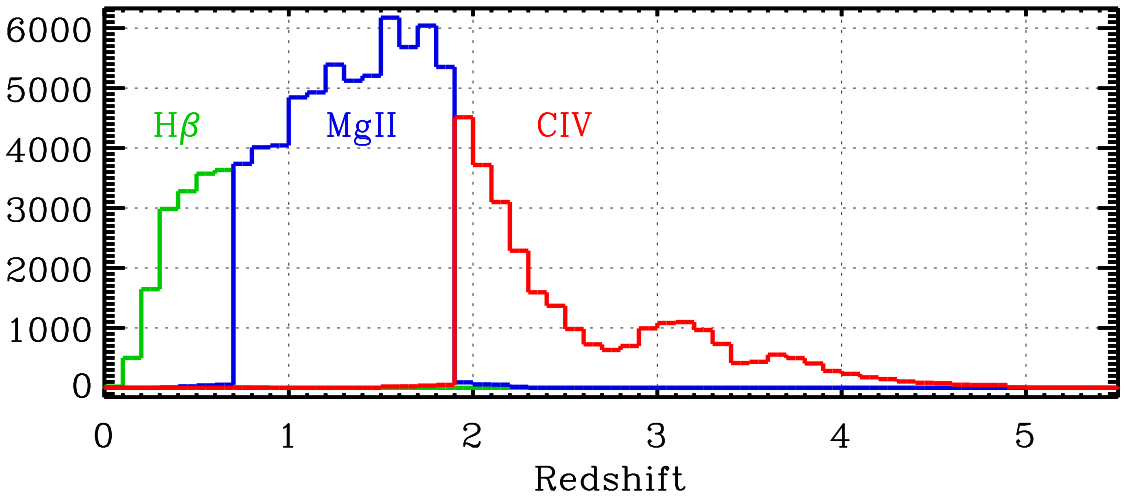

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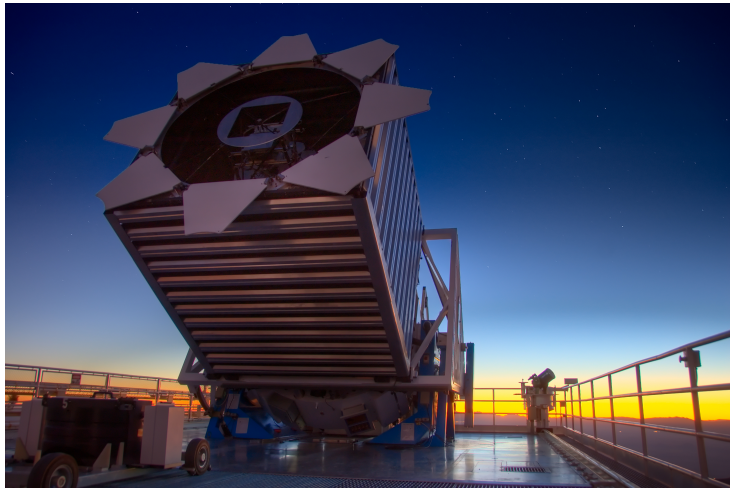

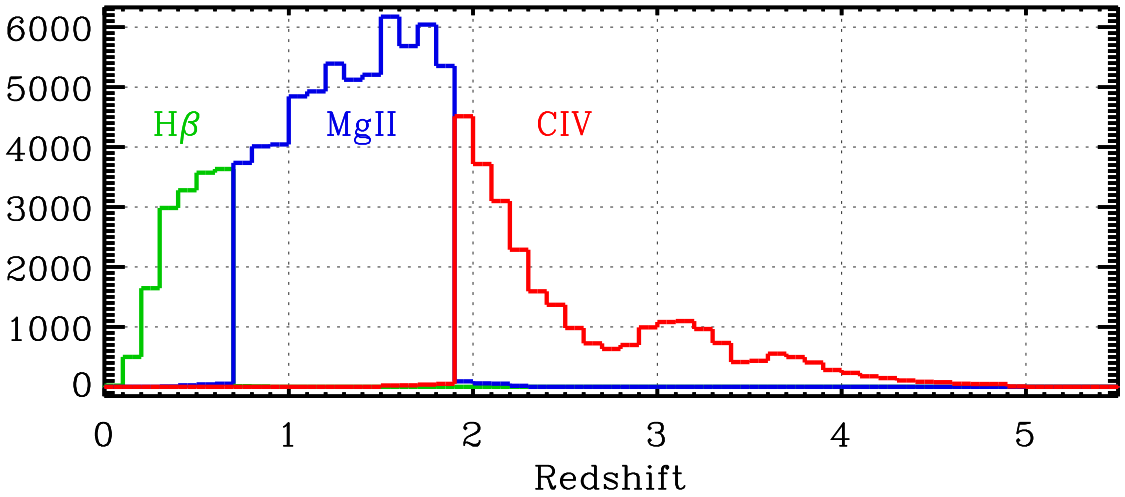

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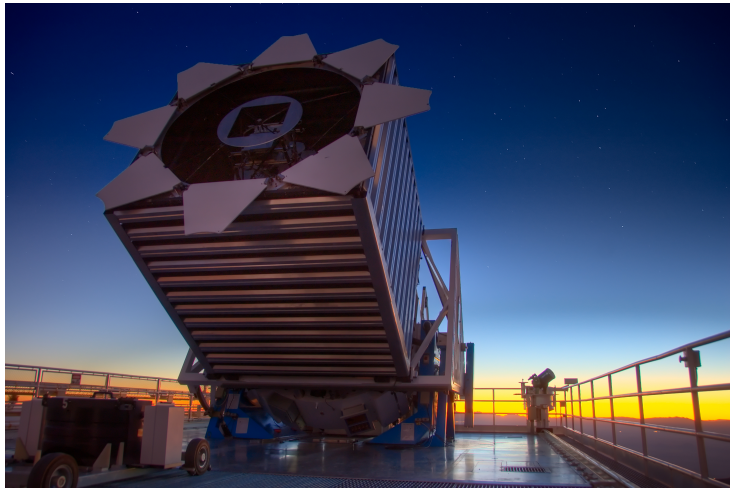

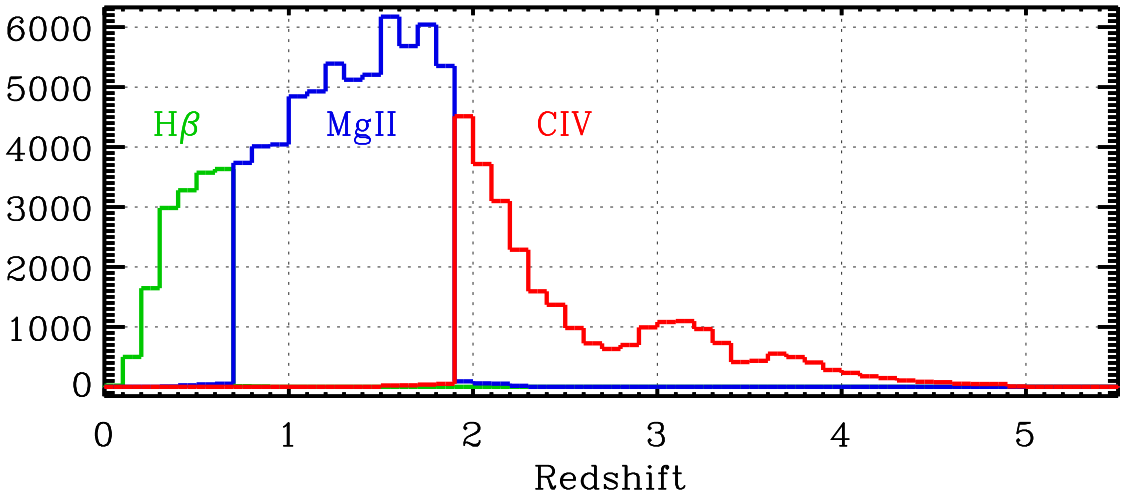

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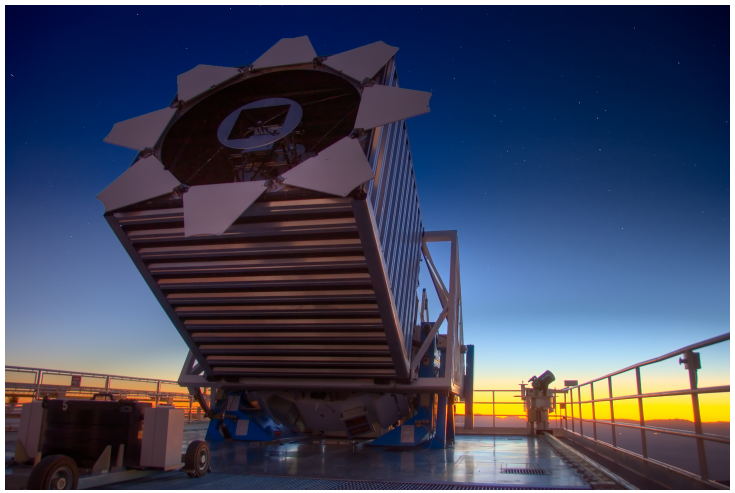

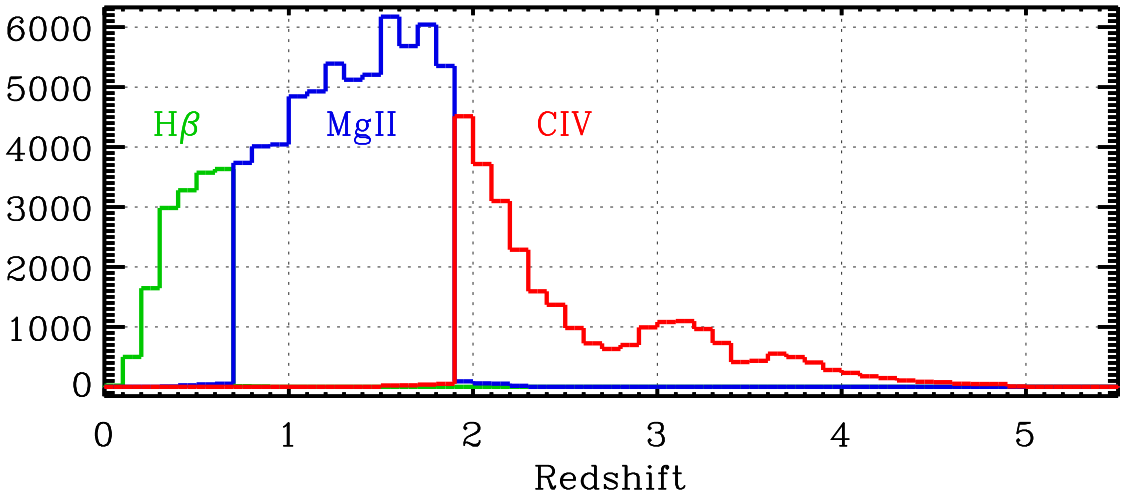

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Shen et al 2011 is a great work, but...

- do not accounts for host galaxy contribution;
- do not accounts for Balmer continuum;
- the continuum is constrained **locally**, in the neighborhood of an emission line;
- the data analysis is hardly reproducible (source code has not been released);

- ambiguity in emission line decomposition;
- new data can not be (easily) analyzed ;

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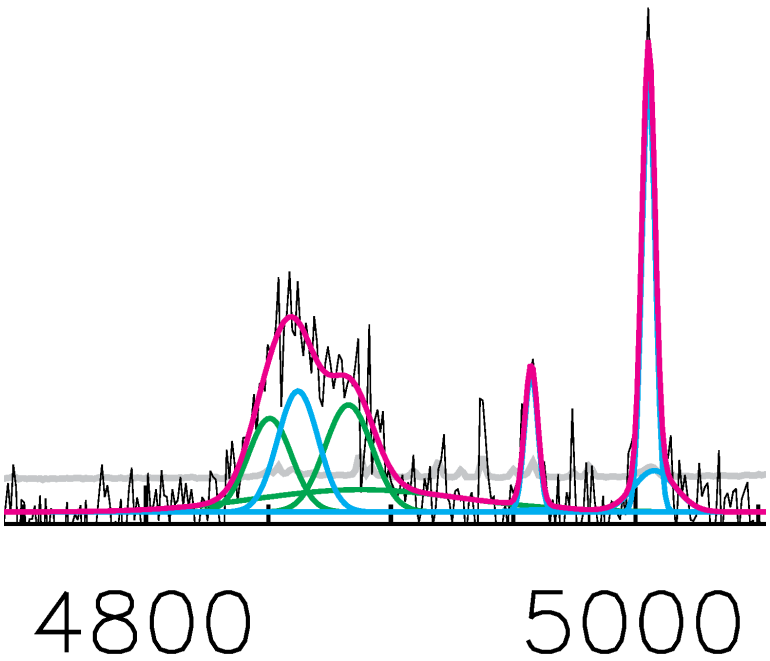

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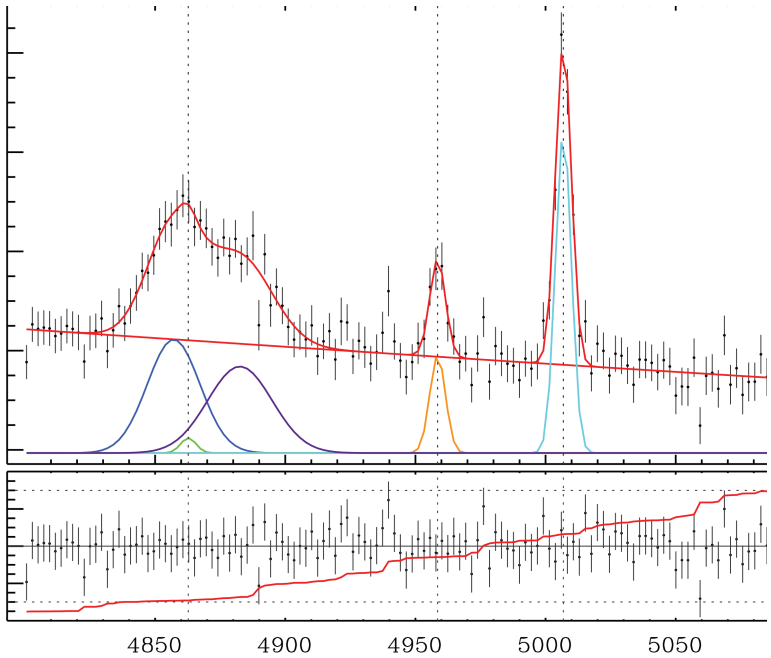

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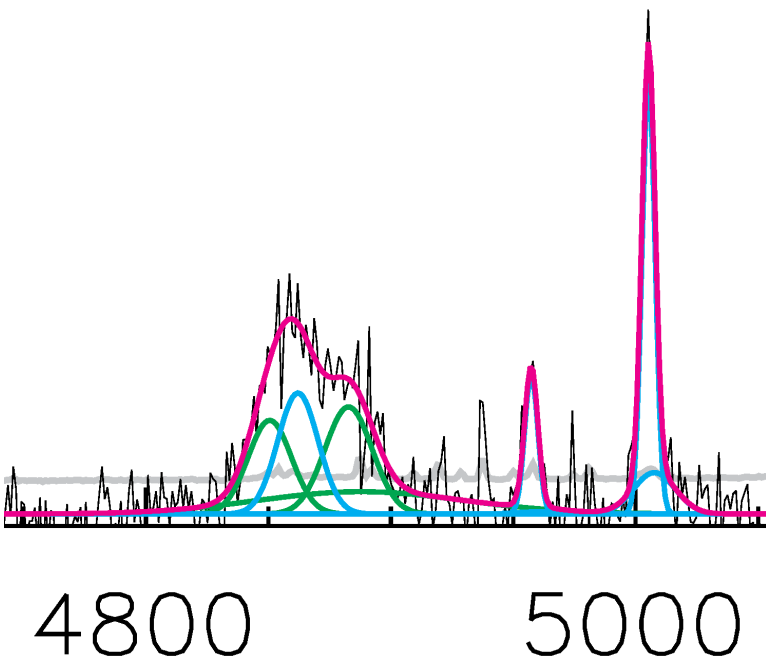

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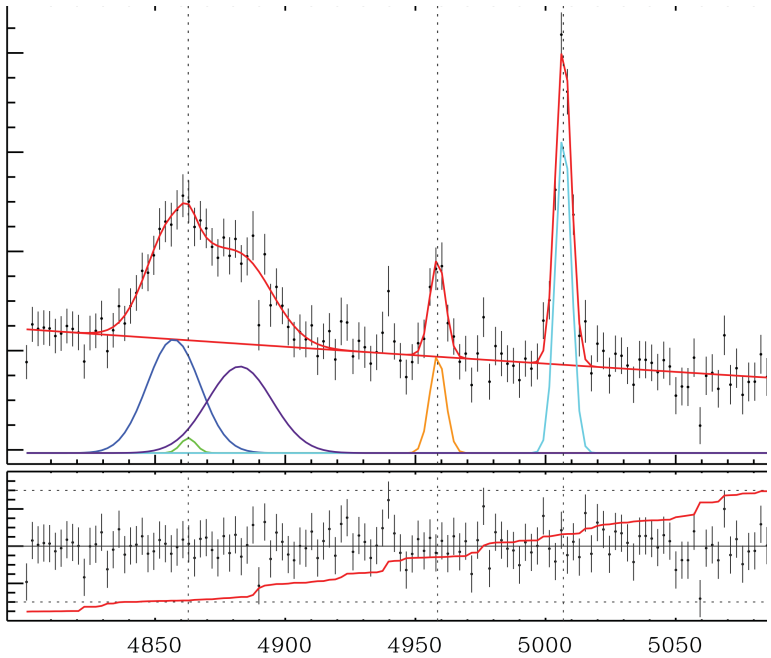

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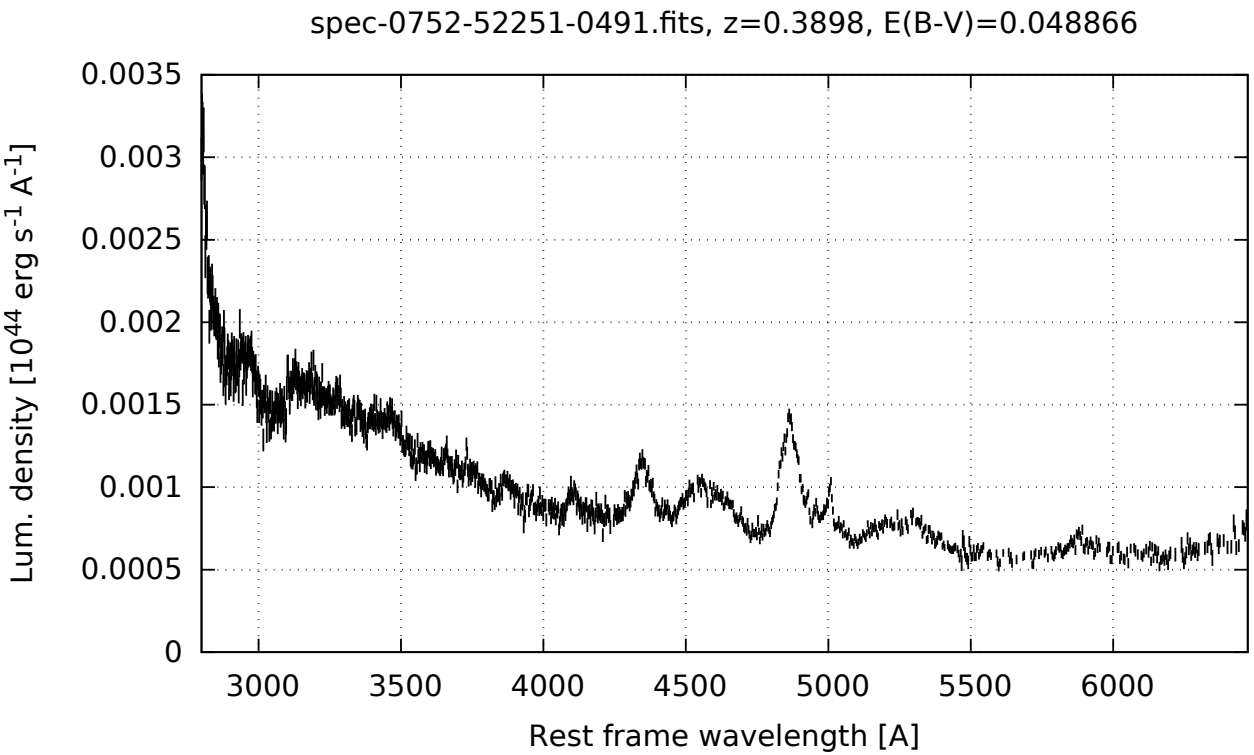
The challenge: automatic spectral analysis of $\sim 10^5$ sources



Quantities to estimate:

- continuum luminosity and slope (shape?);
- host galaxy contribution;
- iron luminosity and width;
- Balmer continuum
- Emission lines:
  - luminosity;
  - width (profile?);
  - velocity offset;

QSFit: Quasar Spectral FITting package

QSFit (empirical) recipe:

1. Fit continuum (PL), host galaxy contribution and Balmer continuum;
2. Subtract continuum offset: negative residuals: 50% $\rightarrow$ 10%;
3. Fit "known" lines;
4. Fit iron templates (UV and optical);
5. Fit "unknown" lines (to fix residuals);
6. Free all parameters and run the final fit.

- Galaxy template (elliptical):
  Polletta et al. 2007, ApJ, 663, 81
- Emission lines: Gaussian profile
- Iron UV template:
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C IV	1549.48	B	[O III]	5008.240	N
C III]	1908.734	B	He I	5877.30	B
Mg II	2799.117	B	[N II]	6549.86	N
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[O II]	3729.875	N			N
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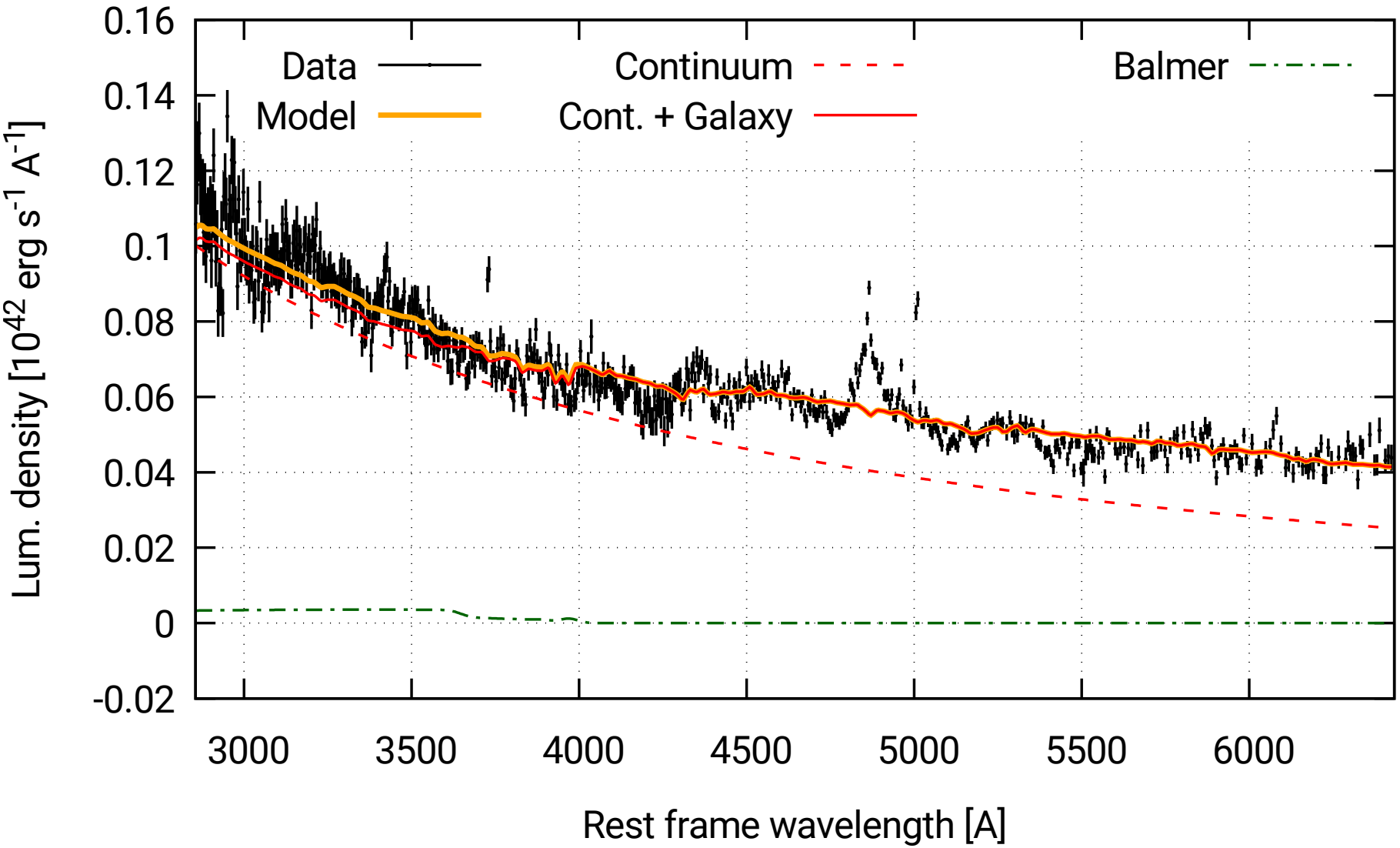
Data
Model
Continuum
Cont. + Galaxy
Balmer
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Rest frame wavelength [A]
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0.14
0.12
0.1
0.08
0.06
0.04
0.02
0
-0.02
3000
3500
4000
4500
5000
5500
6000

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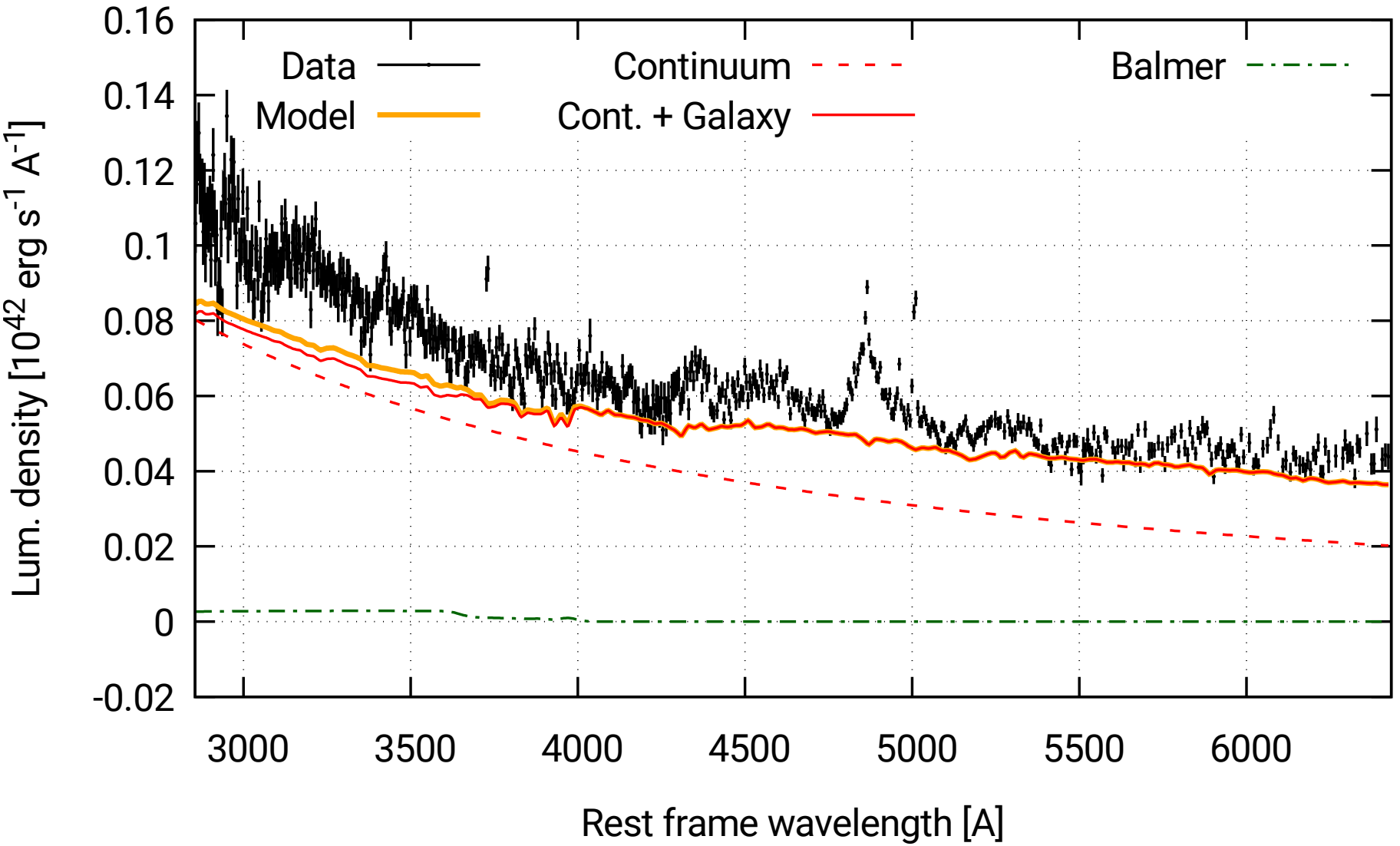
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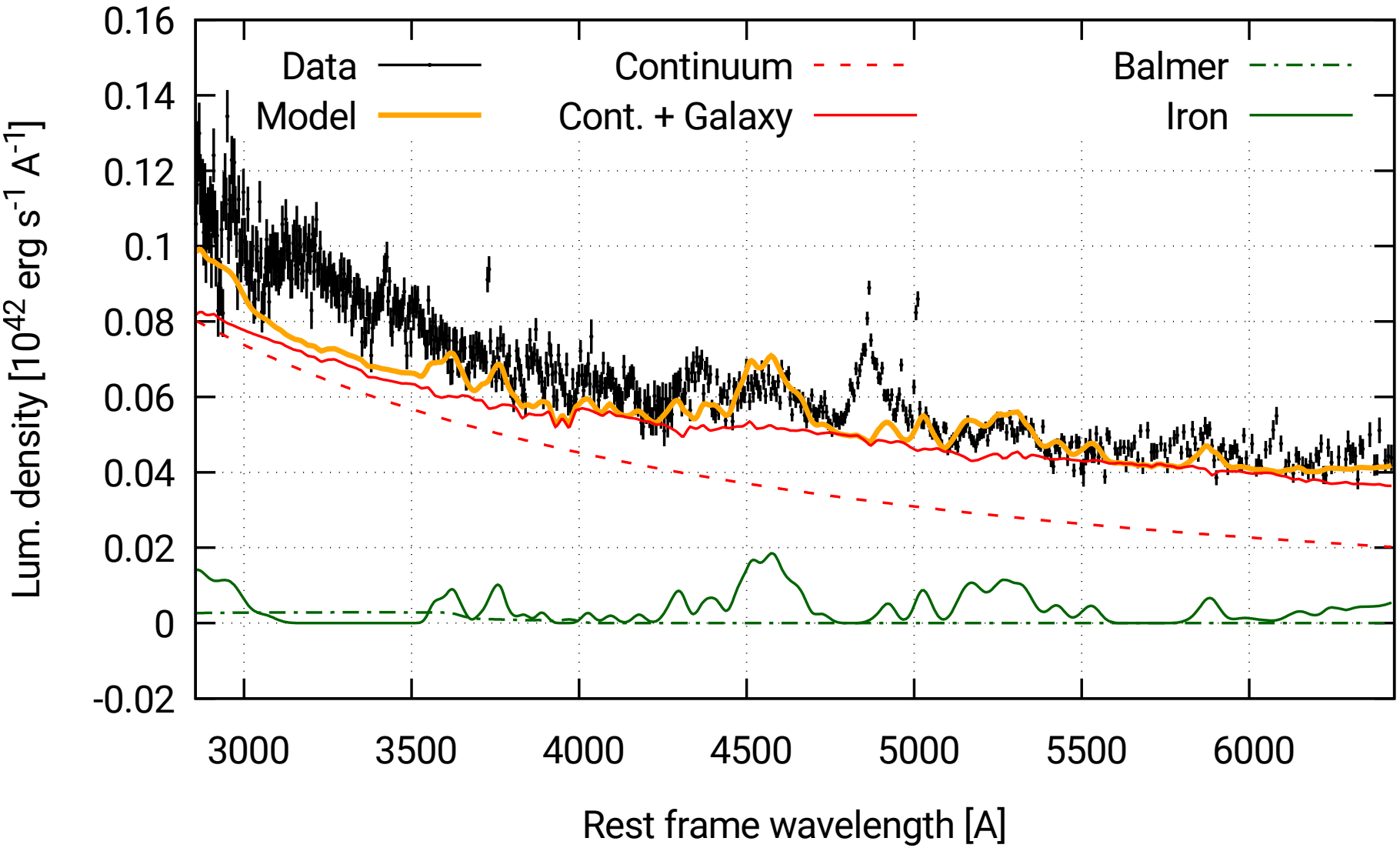
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Cont. + Galaxy
Balmer
Iron
Lum. density [10^42 erg s^-1 A^-1]
Rest frame wavelength [A]
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0.14
0.12
0.1
0.08
0.06
0.04
0.02
0
-0.02
3000
3500
4000
4500
5000
5500
6000

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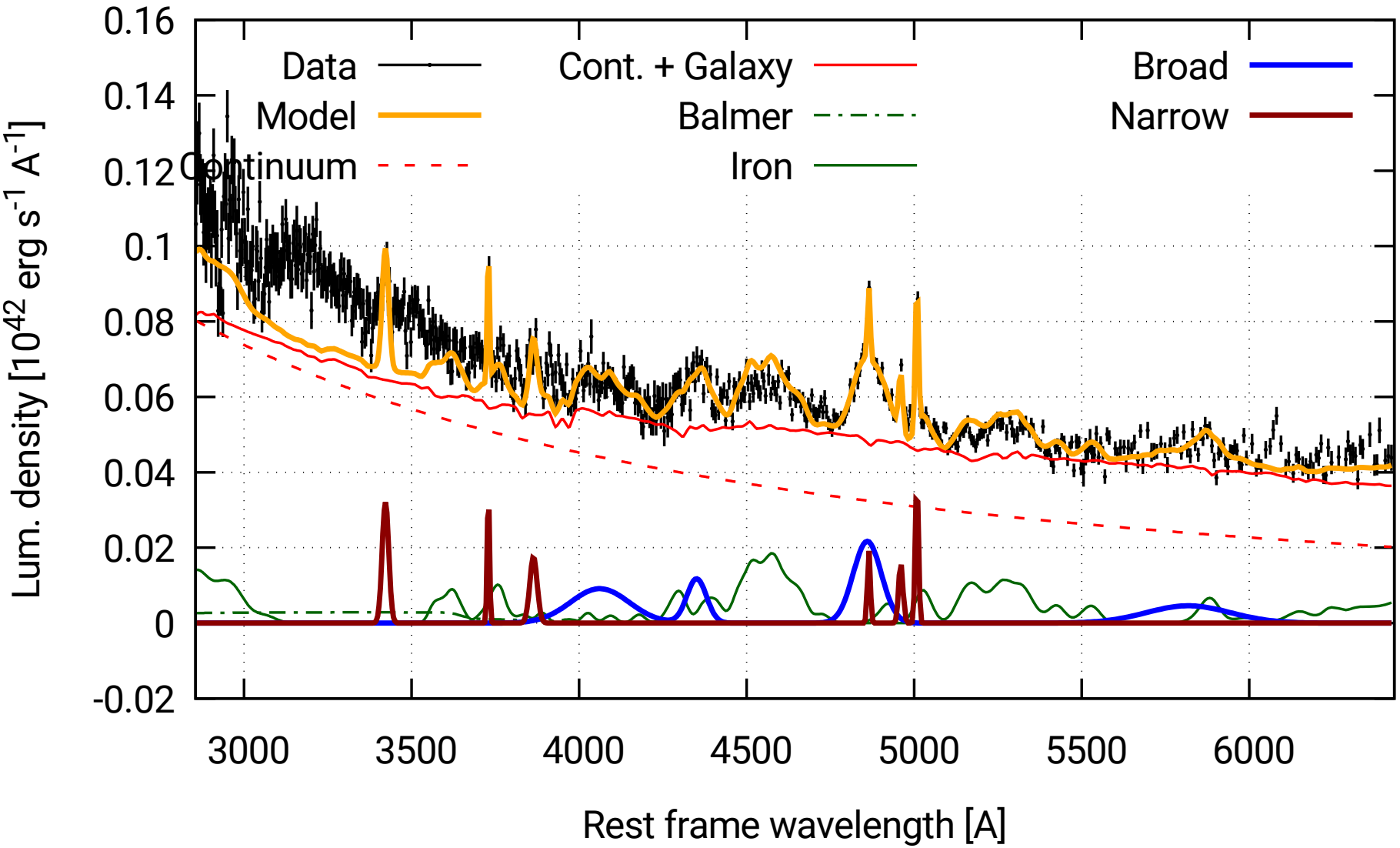
Data
Model
Continuum
Cont. + Galaxy
Balmer
Iron
Broad
Narrow
Lum. density [10^42 erg s^-1 A^-1]
Rest frame wavelength [A]
0.16
0.14
0.12
0.1
0.08
0.06
0.04
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0
-0.02
3000
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5500
6000

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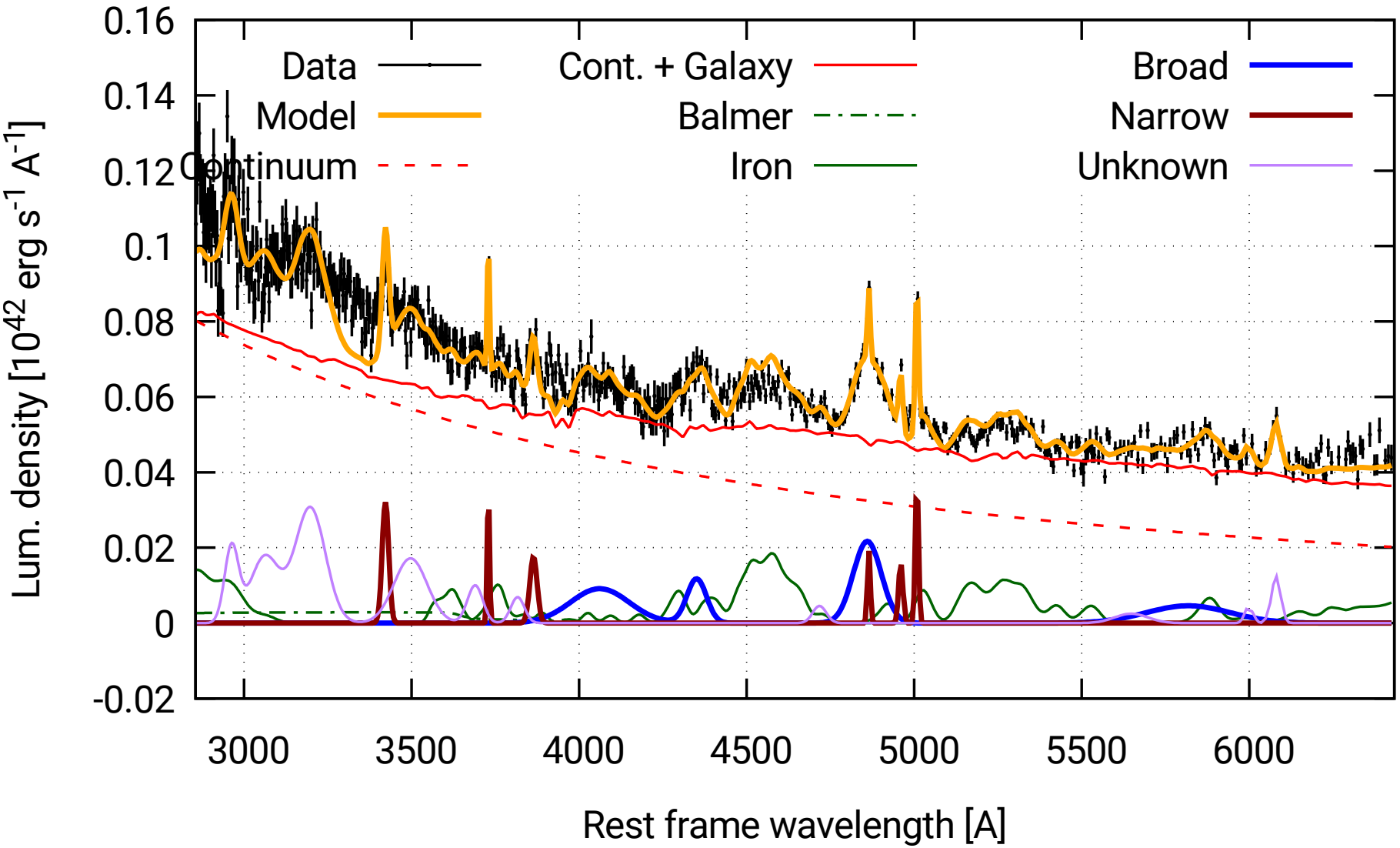
Data
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Continuum
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Balmer
Iron
Broad
Narrow
Unknown
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Rest frame wavelength [A]
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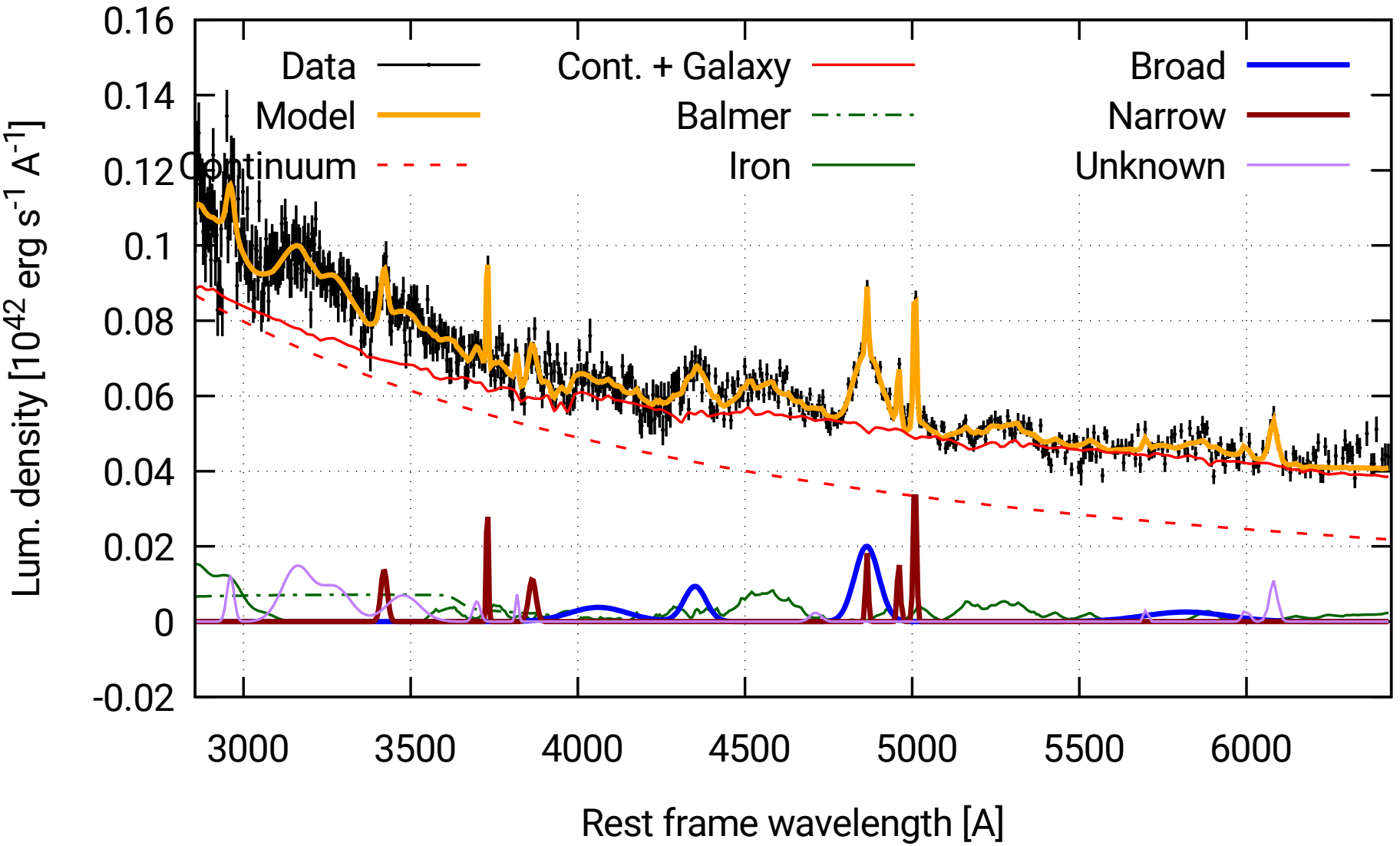
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Lum. density [10^42 erg s^-1 A^-1]
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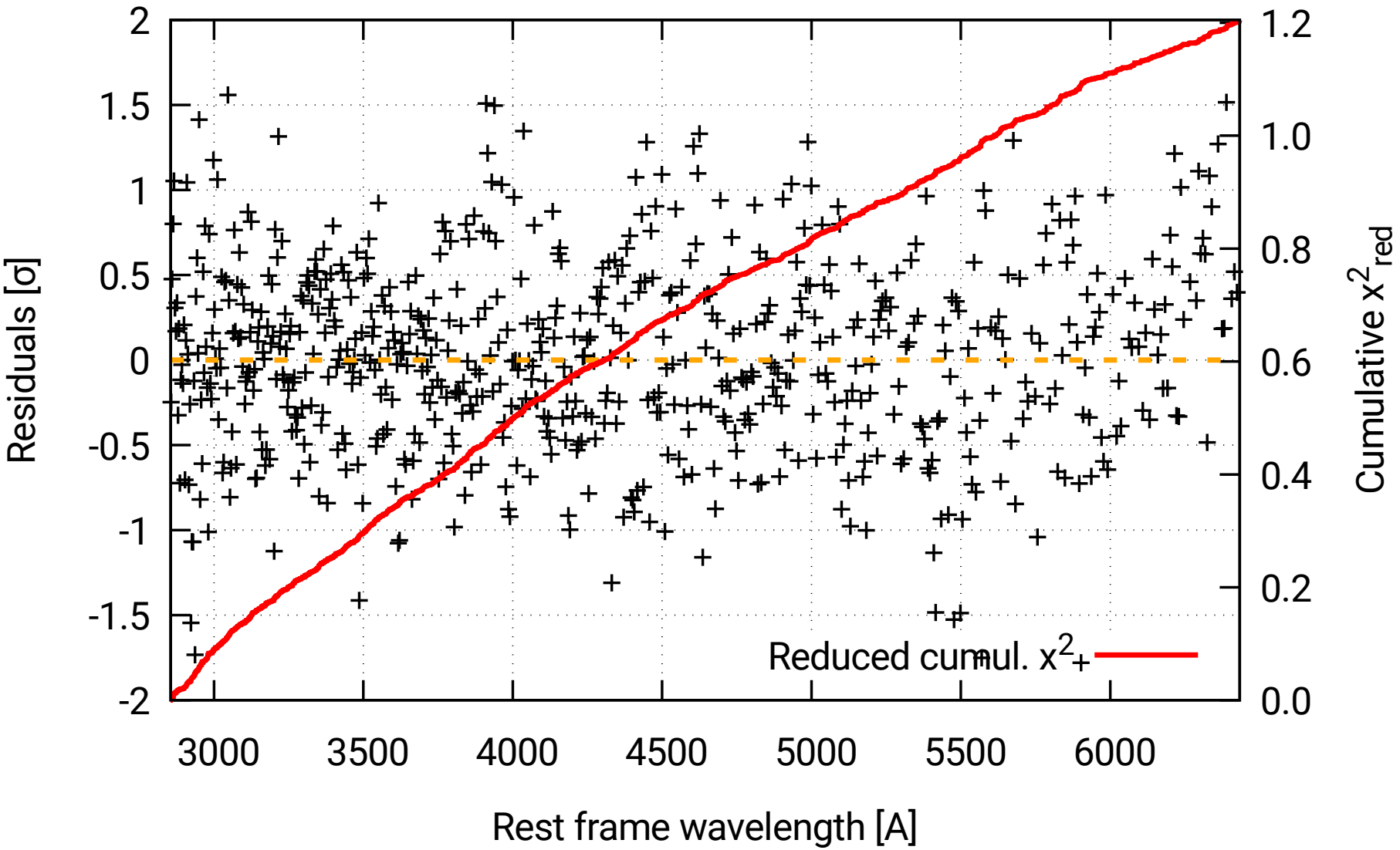
Residuals [σ]
Cumulative x2red
Reduced cumul. x2
Rest frame wavelength [A]
2
1.5
1
0.5
0
-0.5
-1
-1.5
-2
1.2
1.0
0.8
0.6
0.4
0.2
0.0
3000
3500
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New quasar spectral catalog: *The QSFit catalog*

- Start from S11 sample (105,783 Type 1 AGNs):
- Spectra from SDSS/DR7 ($\sim$ 3800–9000Å)
- Drop sources with $z > 2$
  (to avoid issues in fitting the Lyα line);
- Drop sources flagged as BAL
  (to avoid issues in fitting absorption lines);

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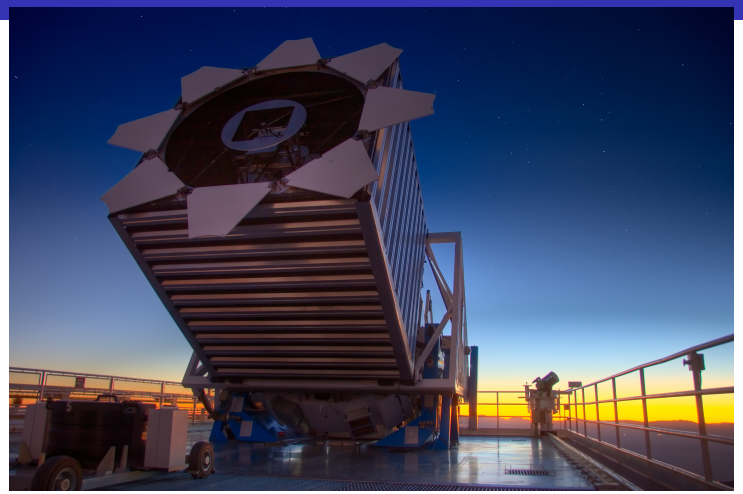

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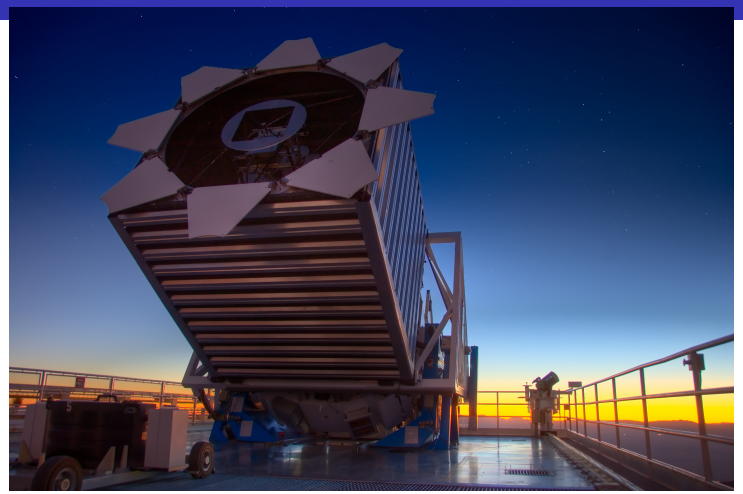

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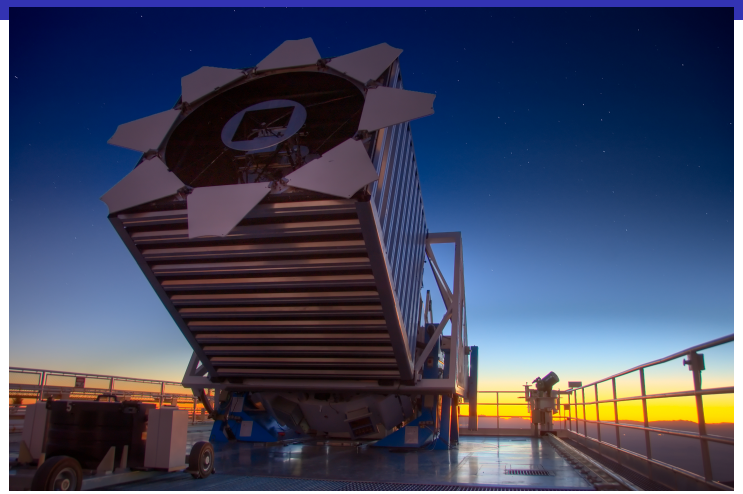

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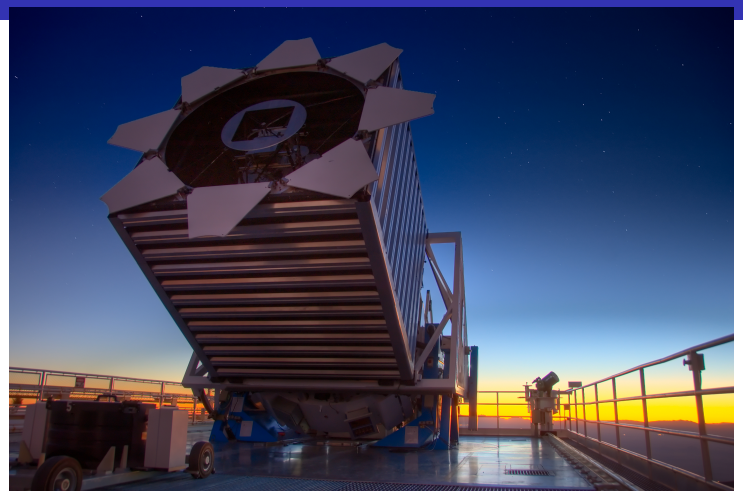

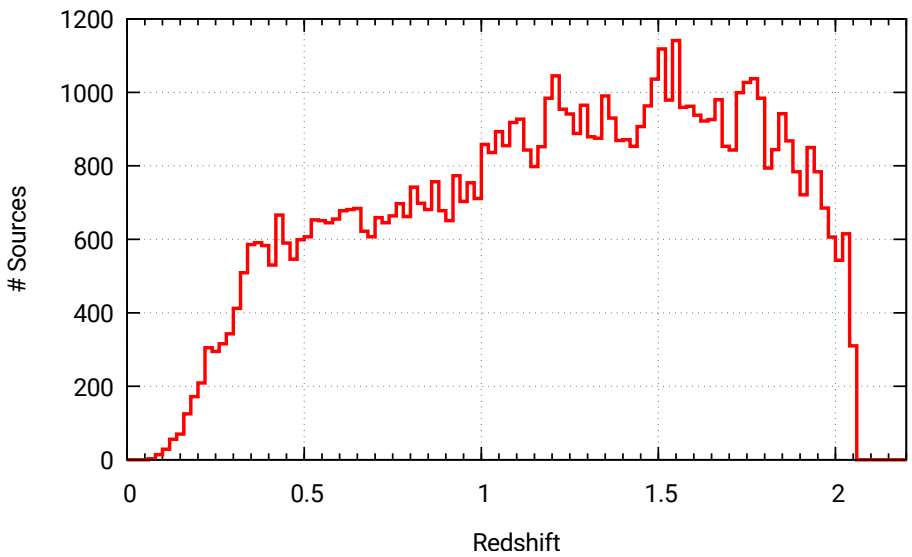

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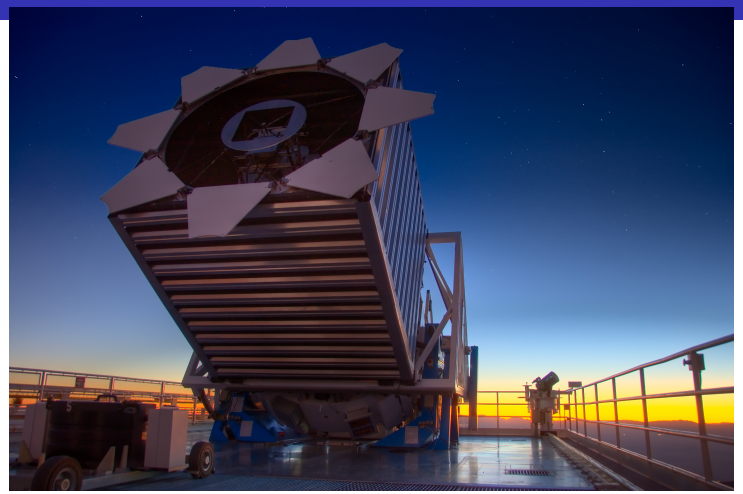

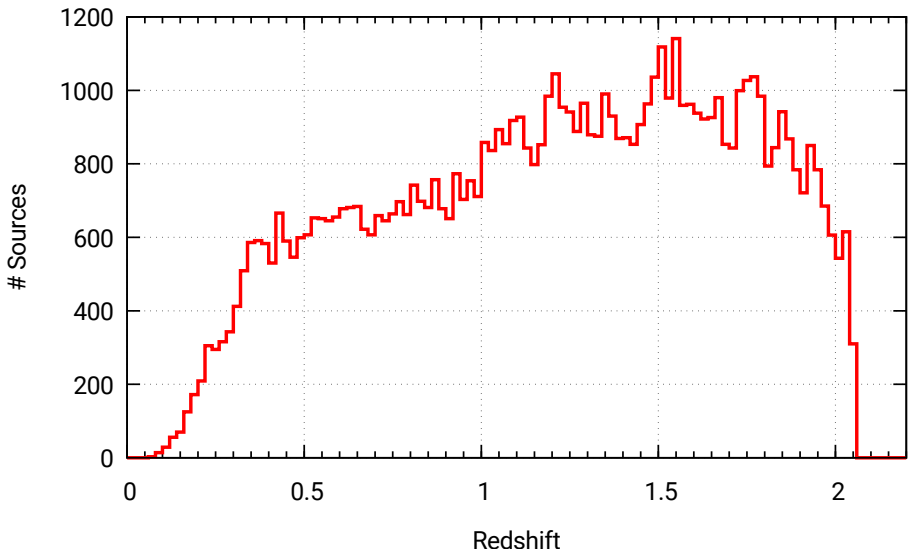

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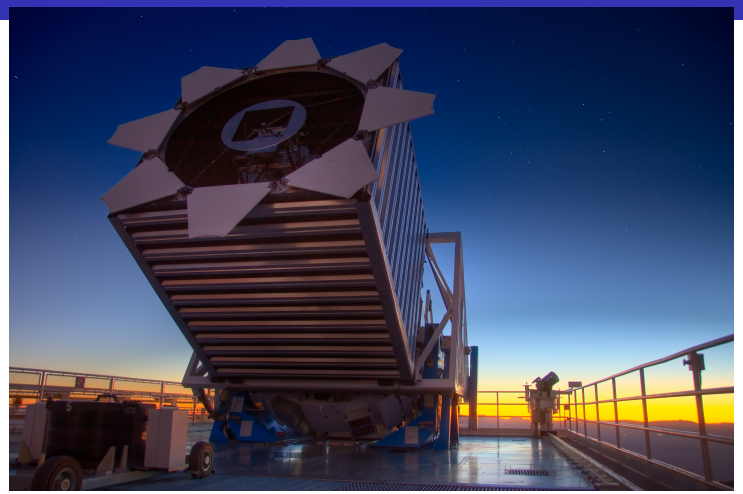

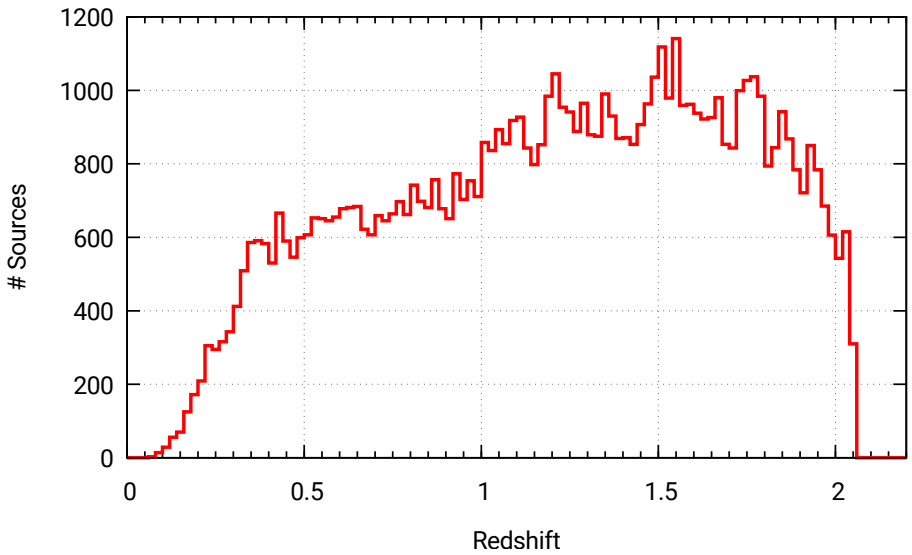

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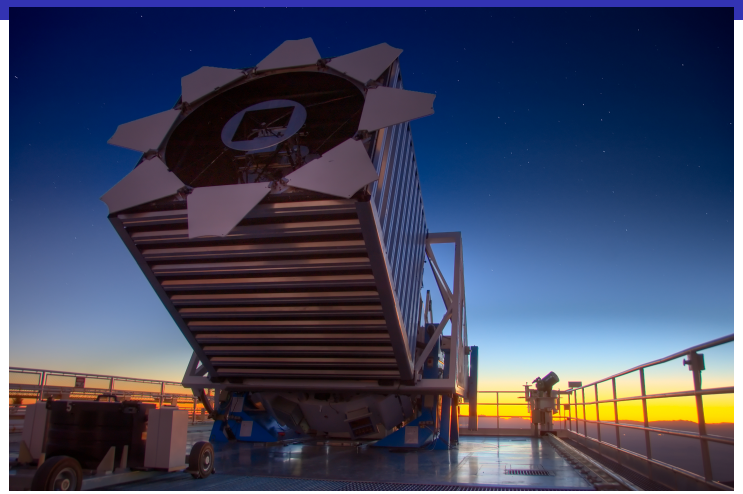

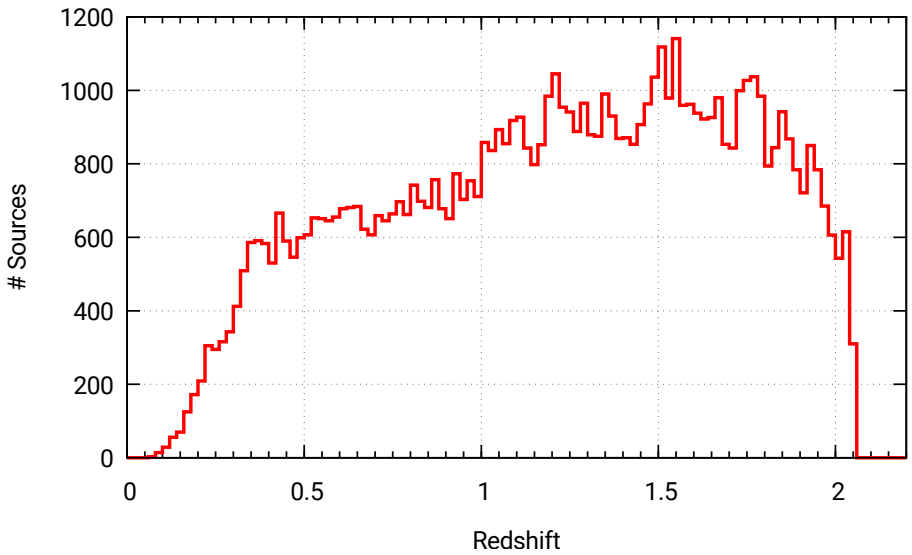

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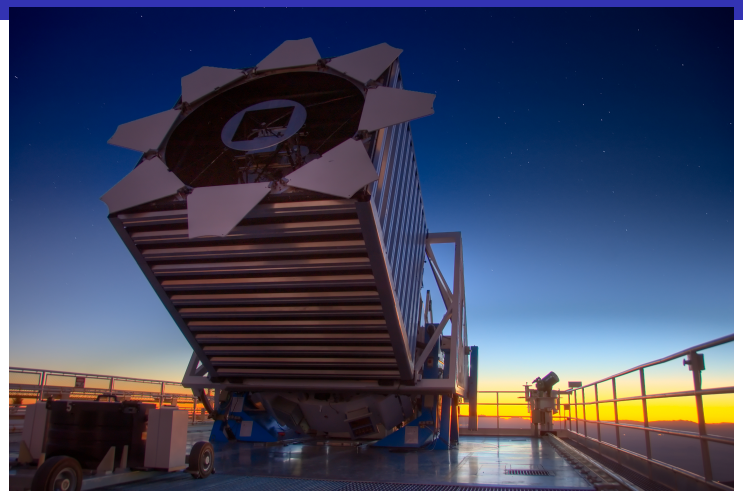

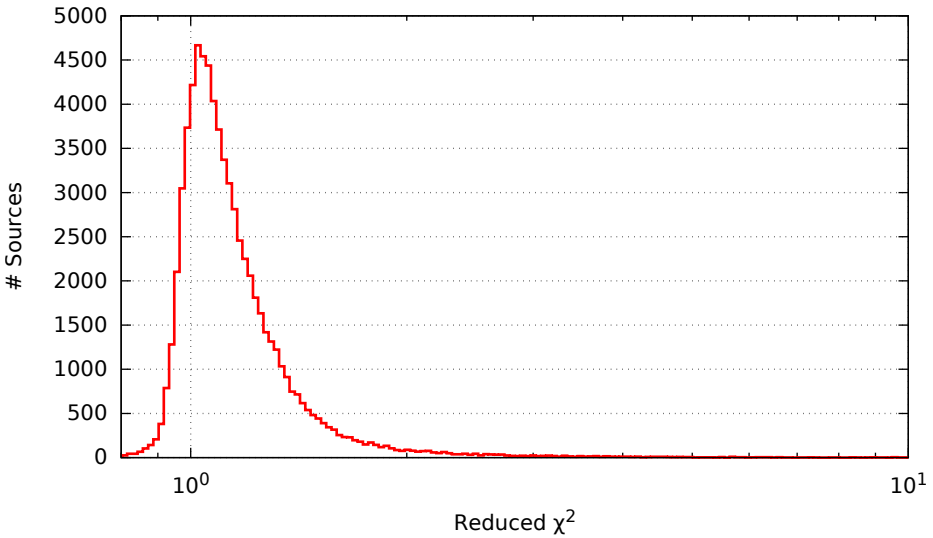

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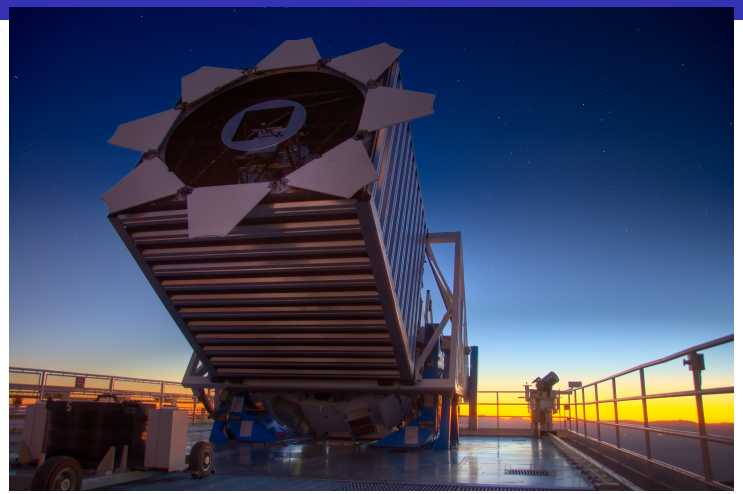

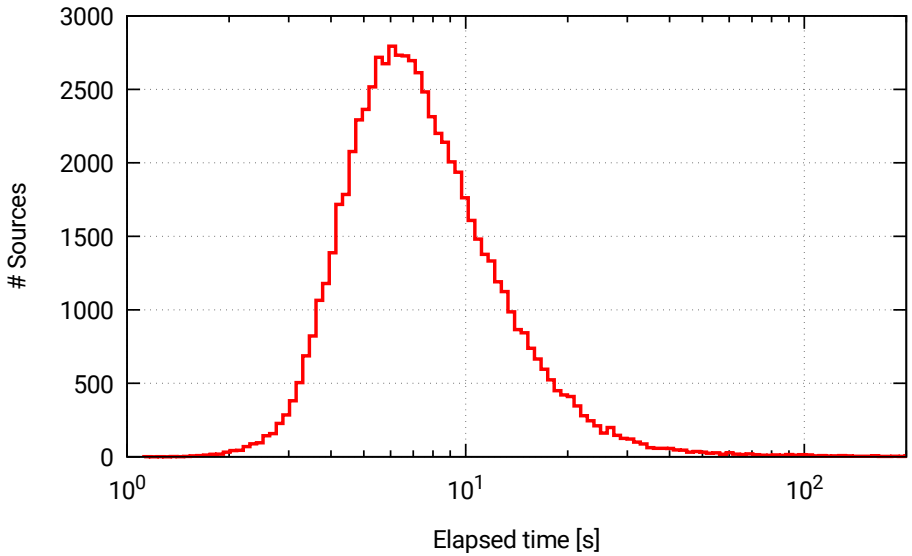

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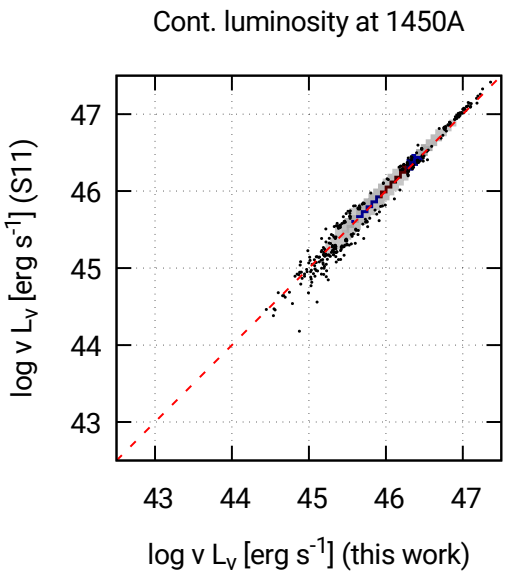
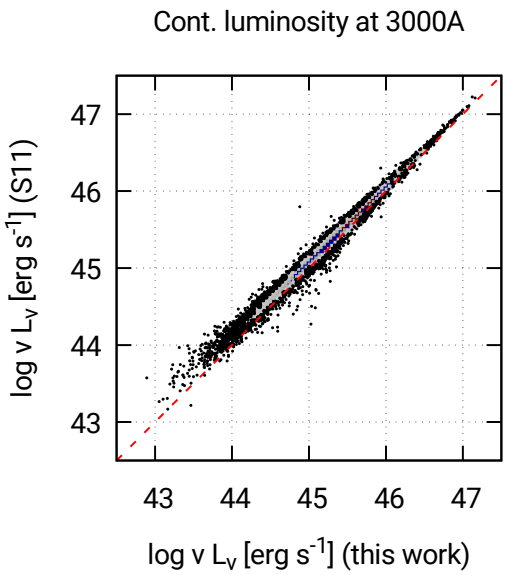
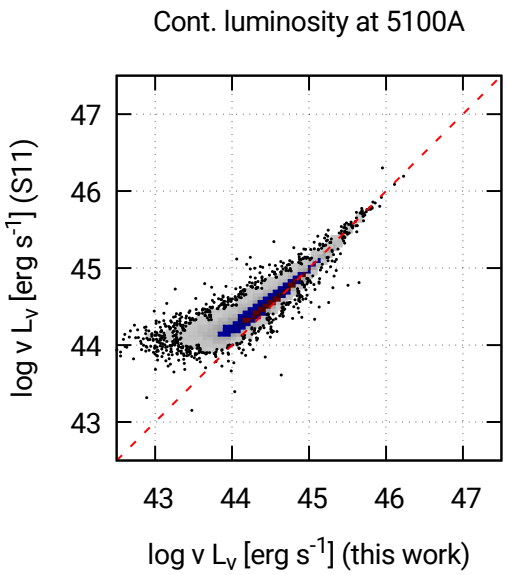
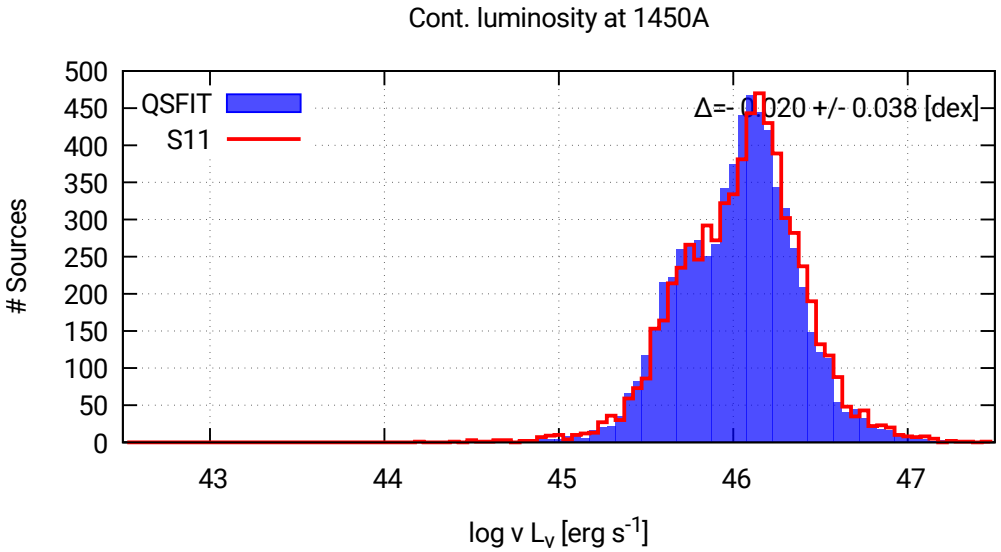
S11 $\leftrightarrow$ QSFit comparison: λL_λ continuum luminosity









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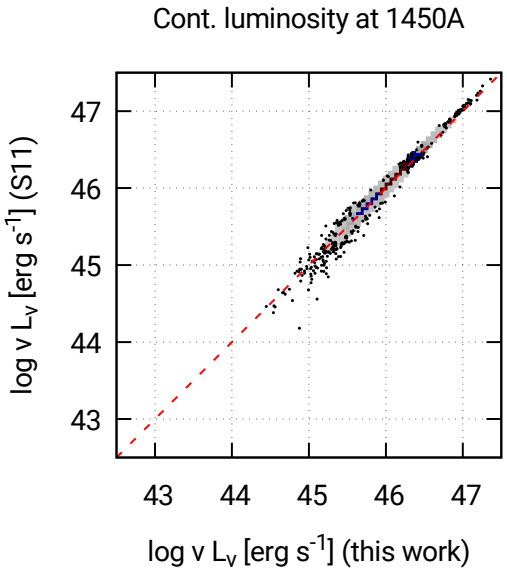

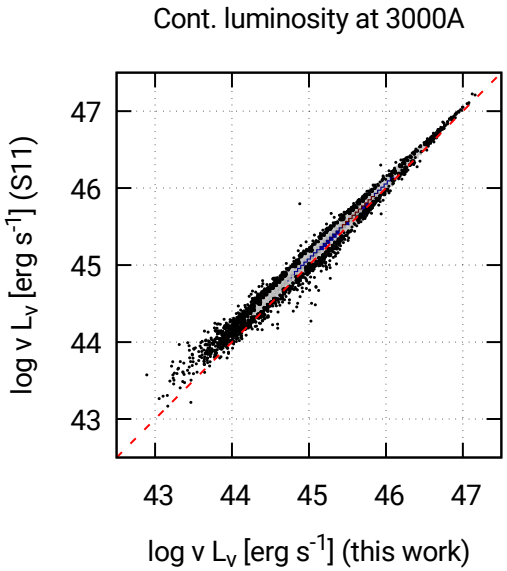

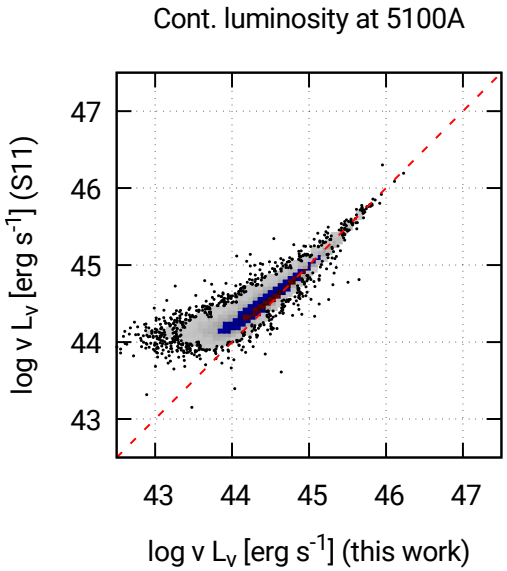

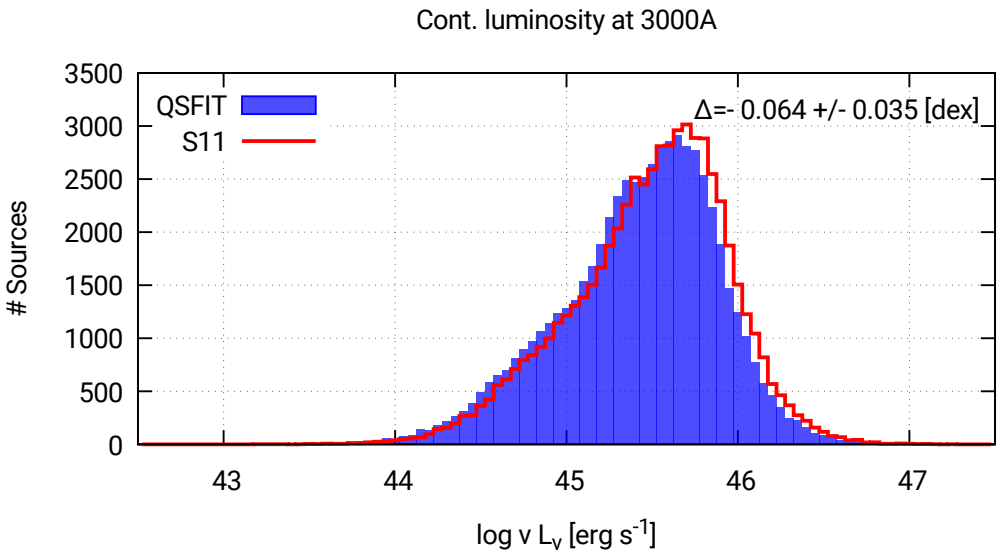

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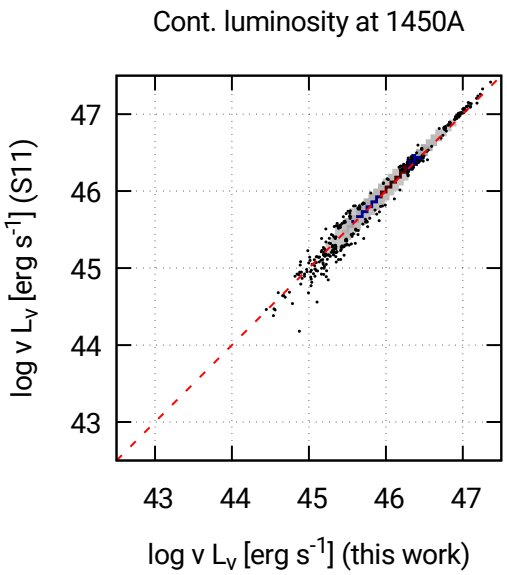

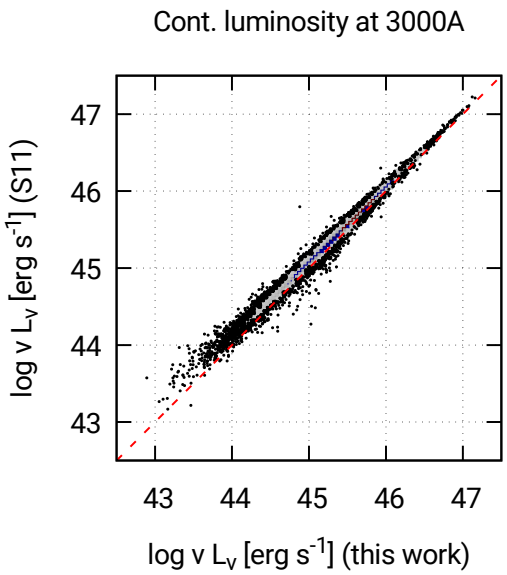

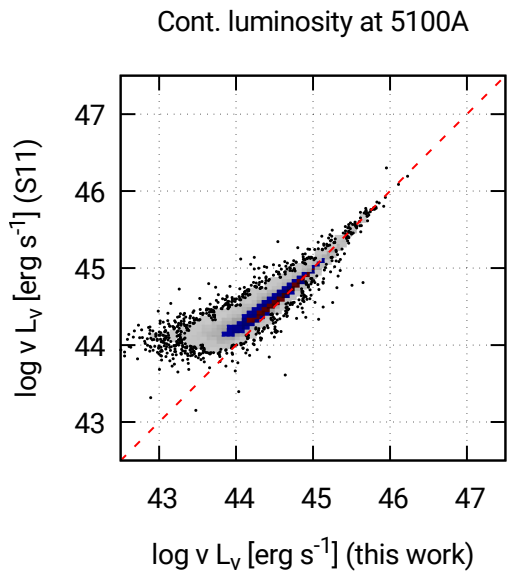

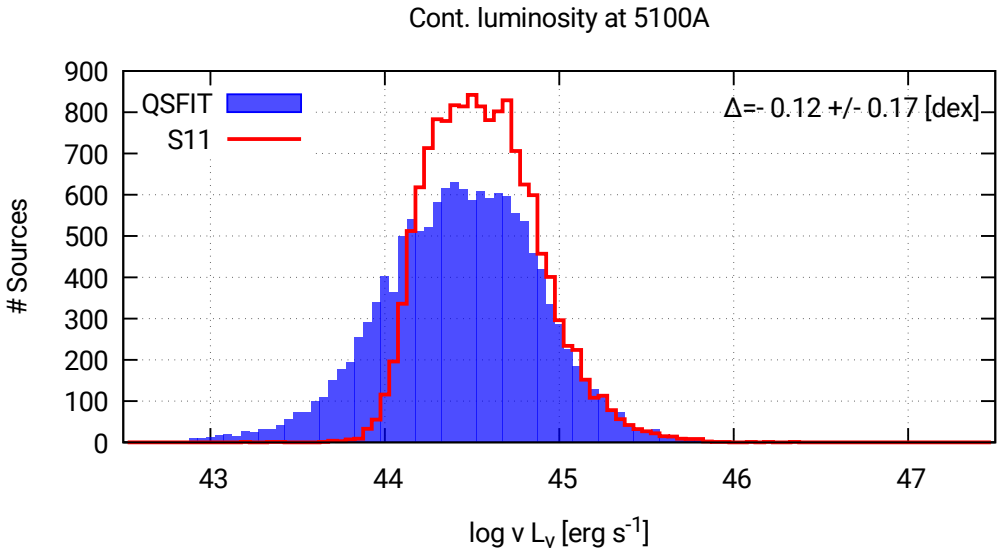

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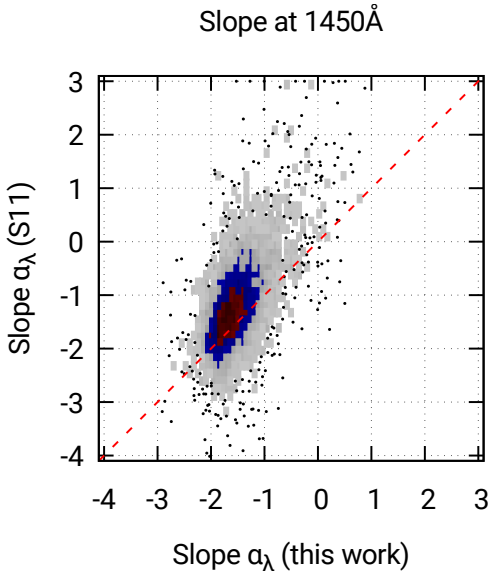
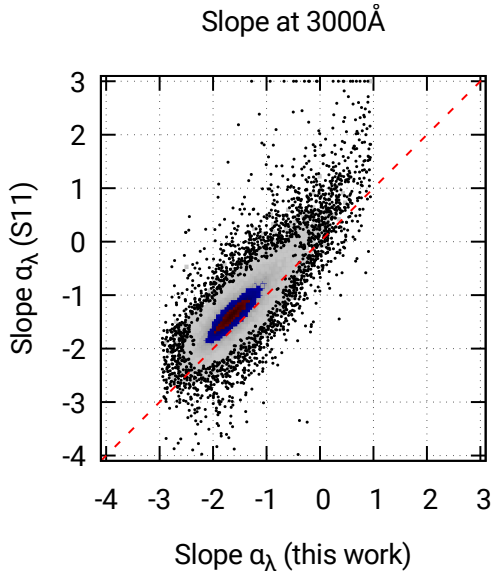
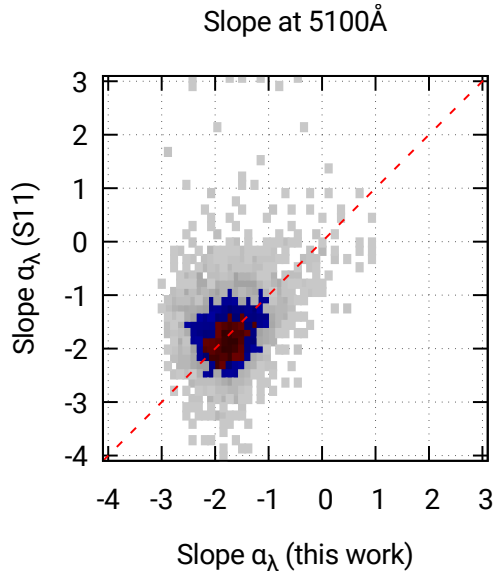
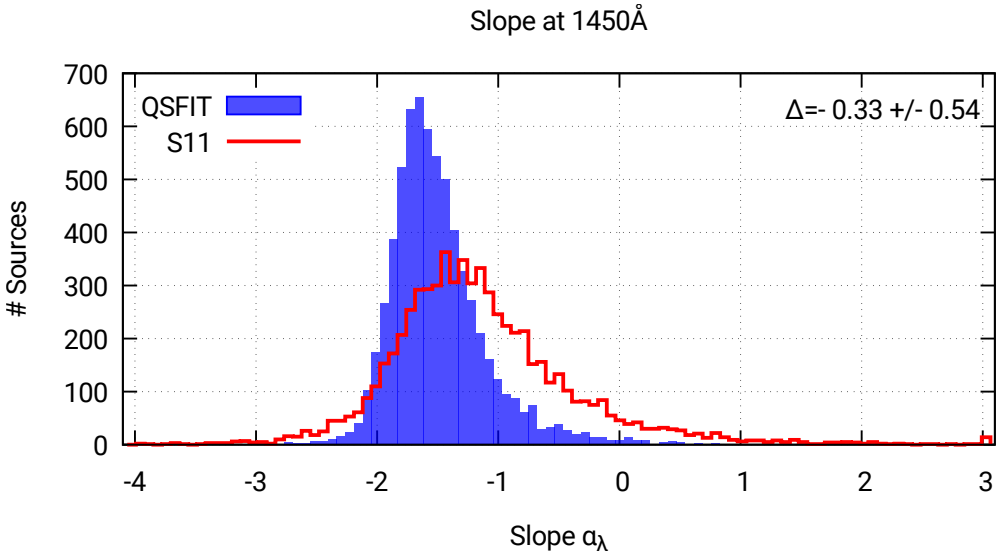
S11 $\leftrightarrow$ QSFit comparison: slope (νL_ν)









- slopes are only weakly correlated;
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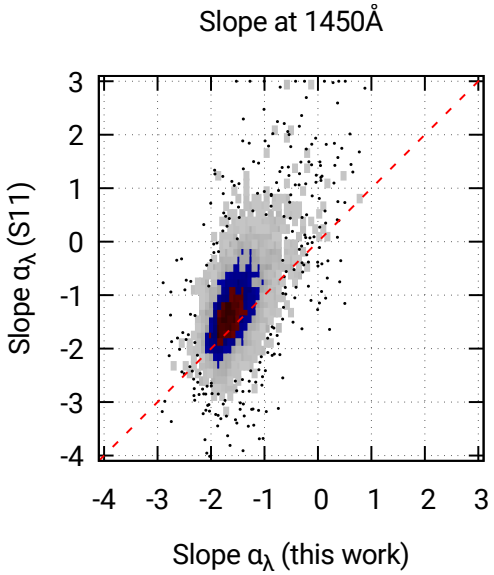

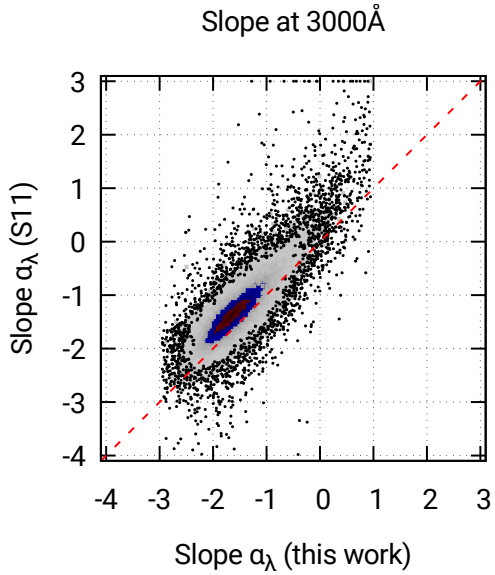

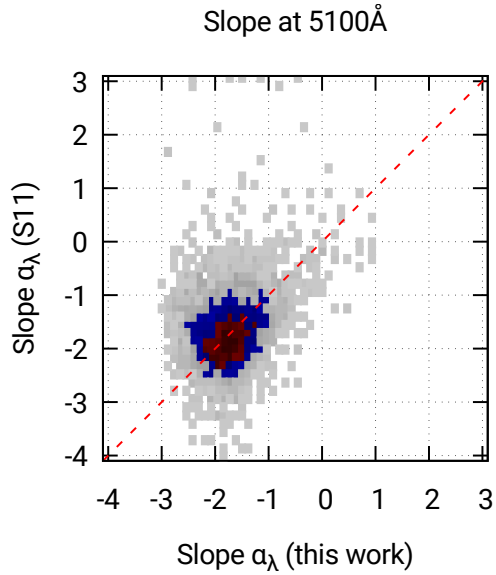

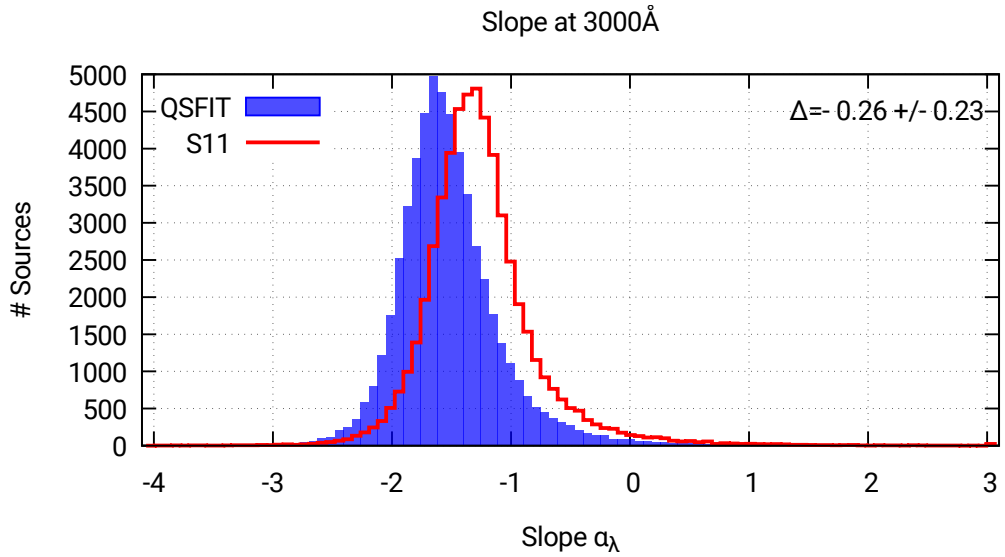

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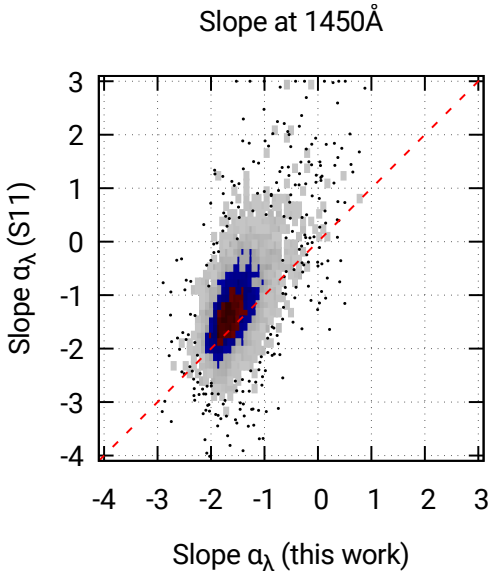

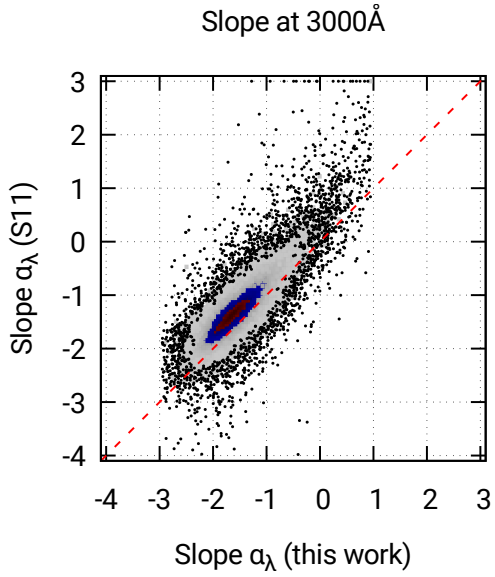

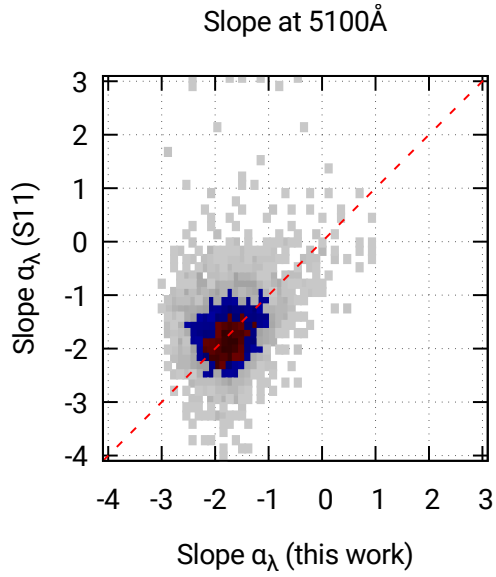

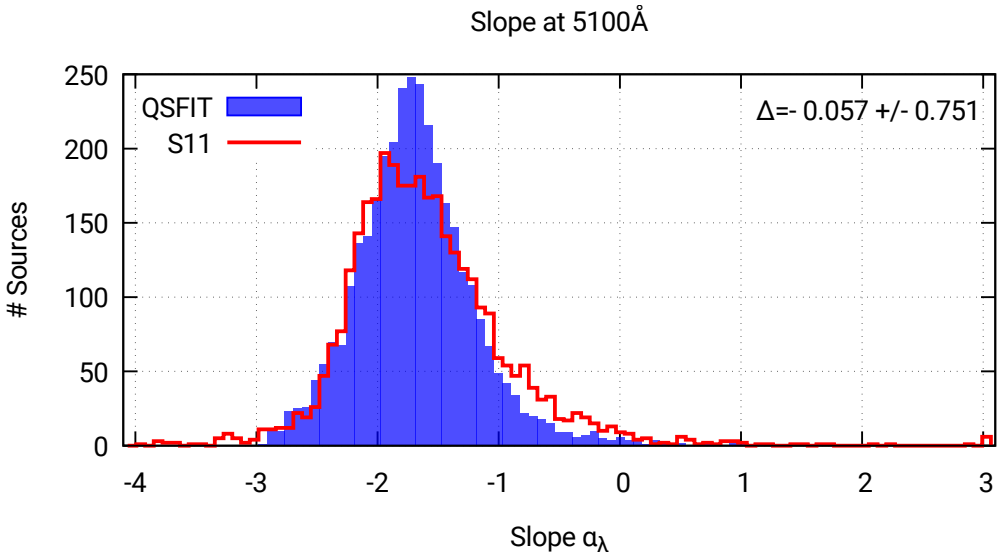

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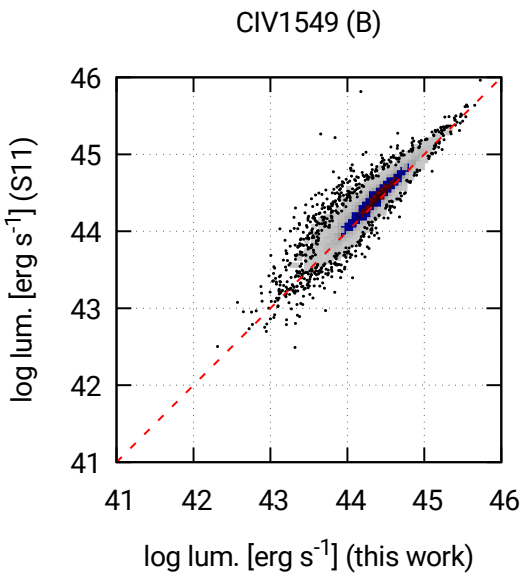

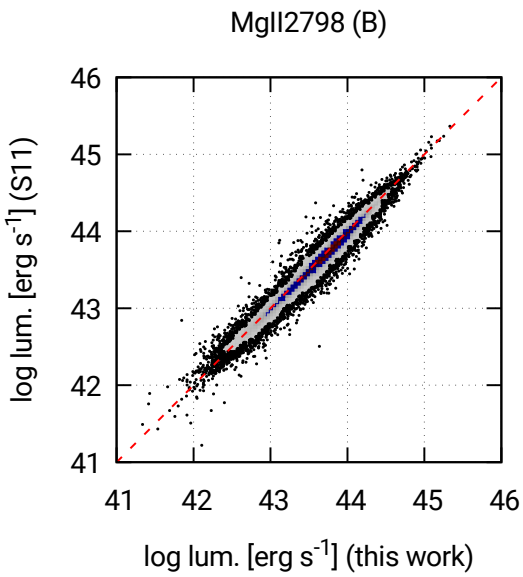

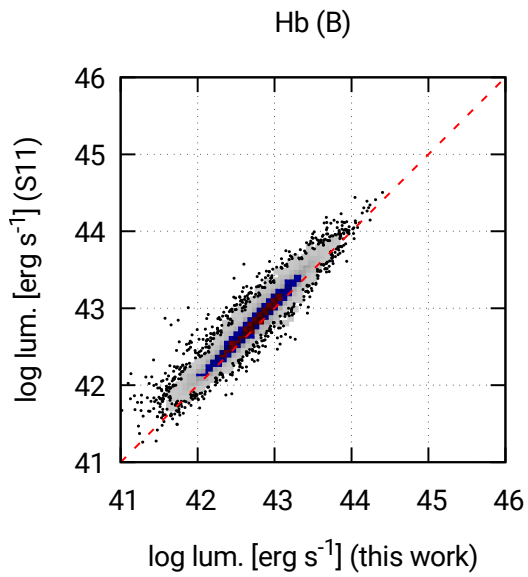

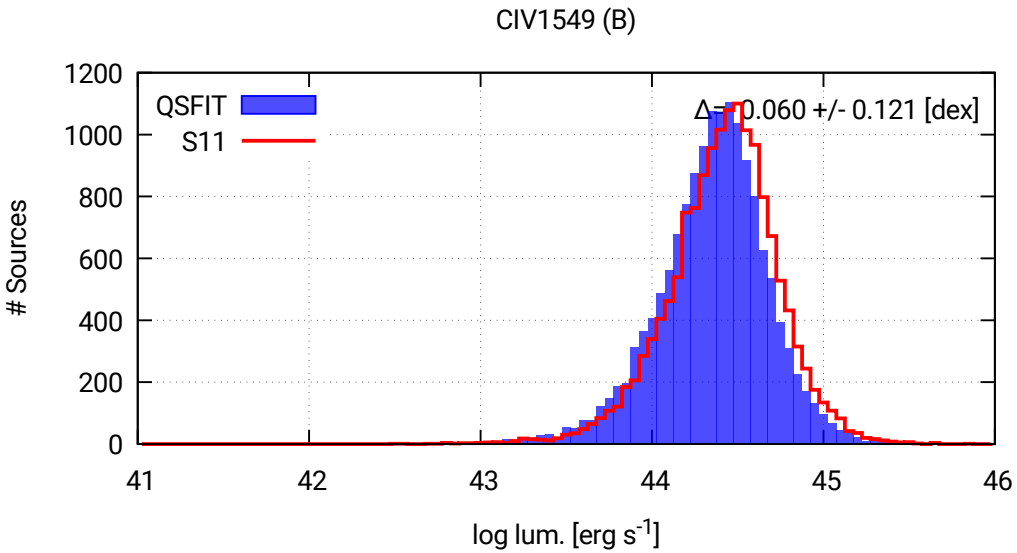

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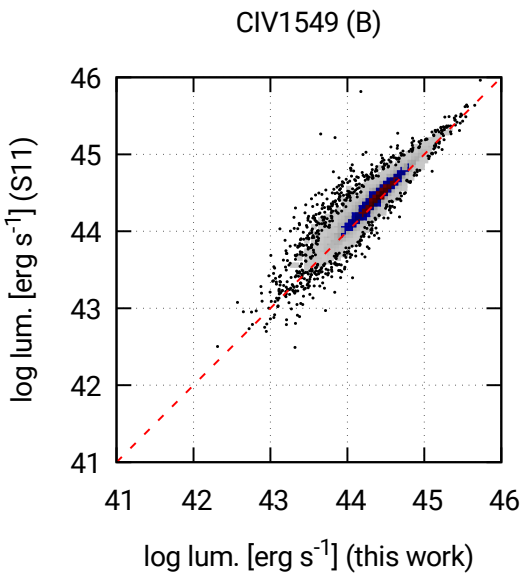
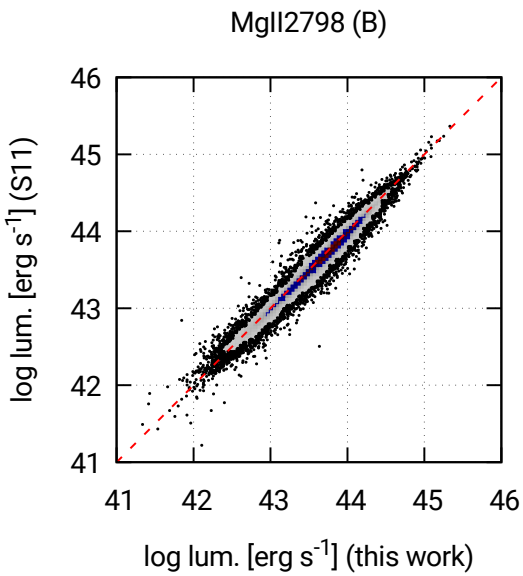
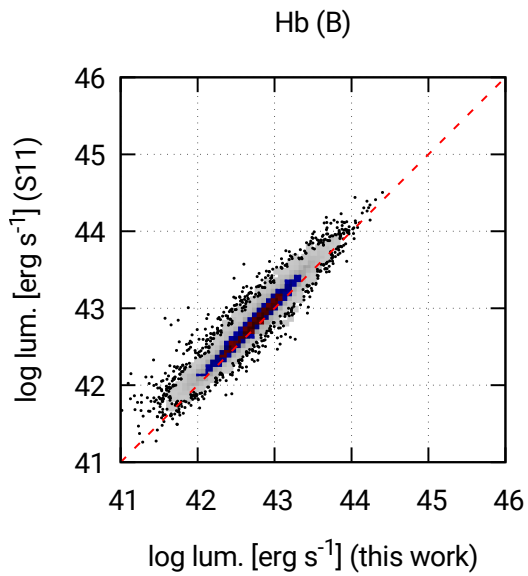
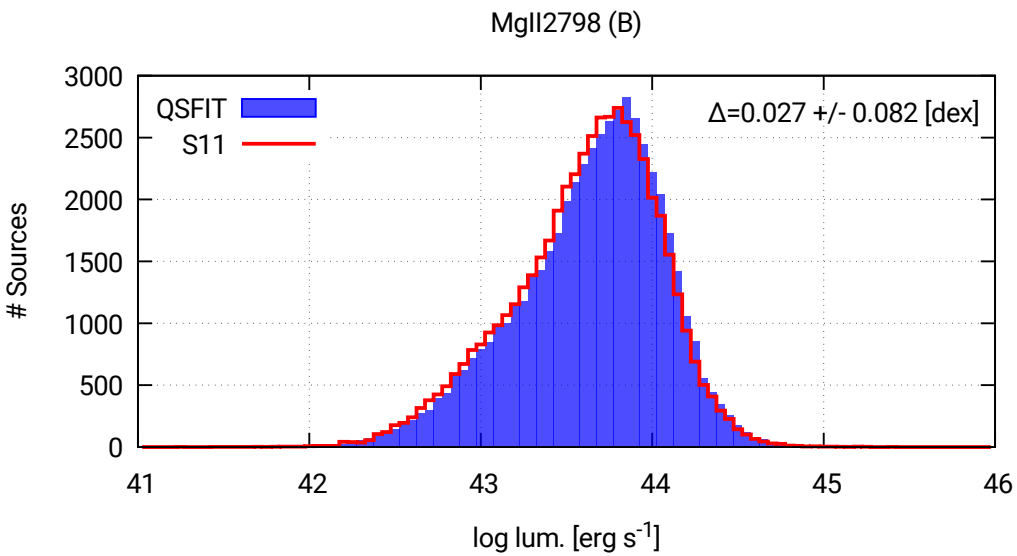


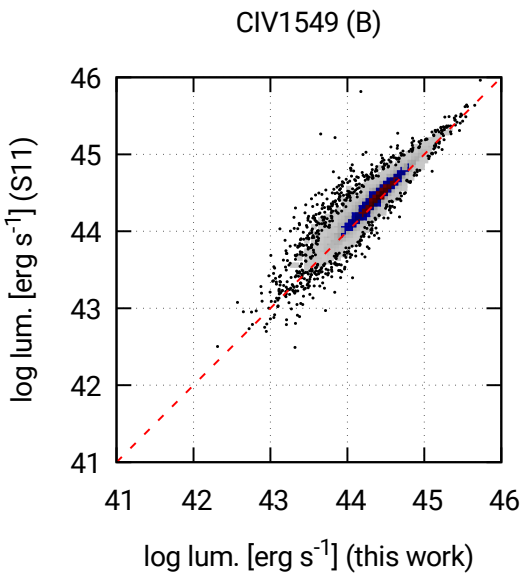


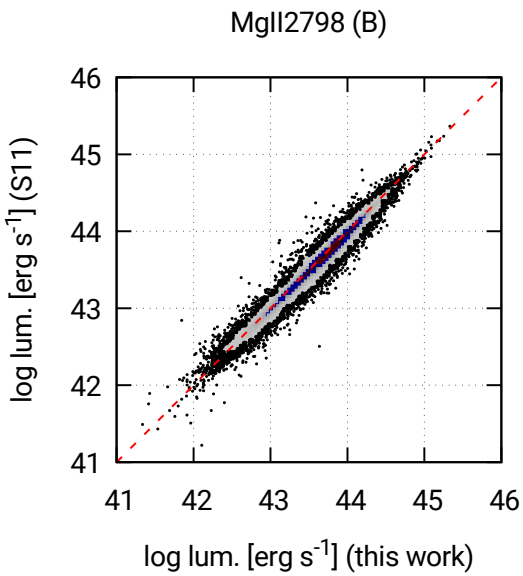


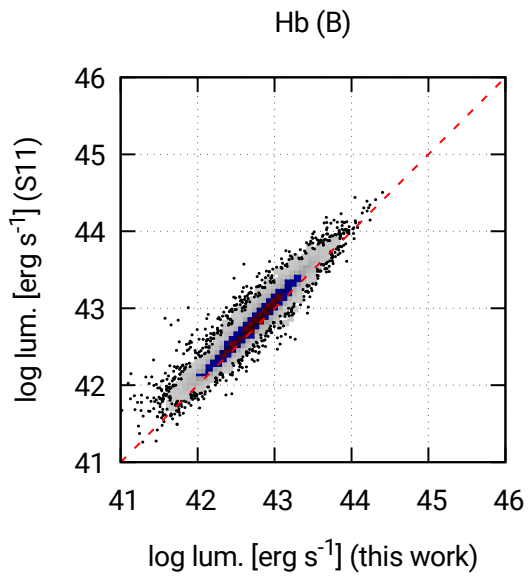


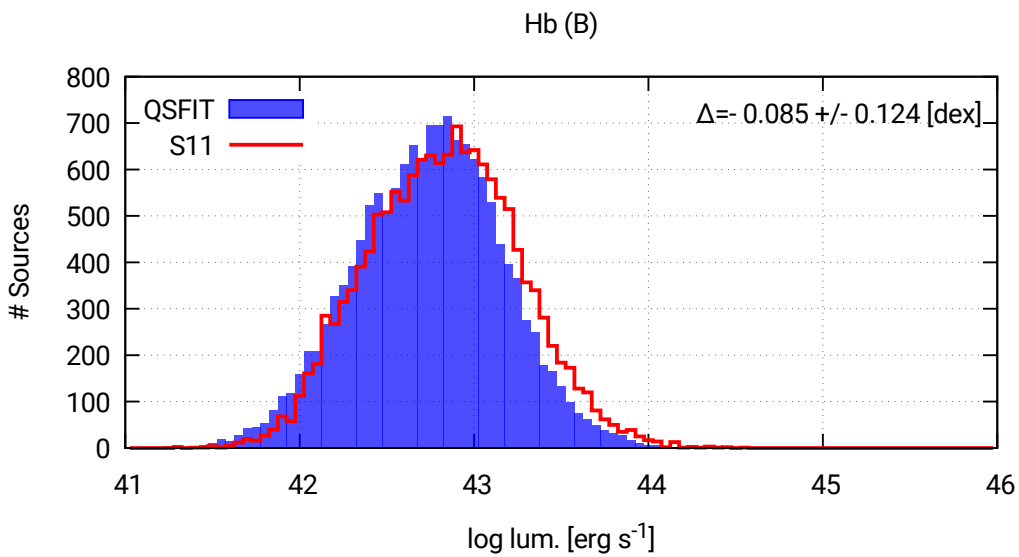
- line lum. are strongly correlated;
- the differences are due to the different continuum definition;

S11 ↔ QSFit comparison: Em. line luminosity









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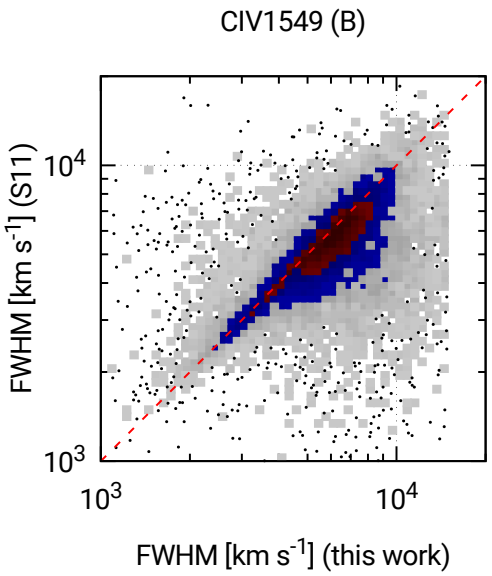
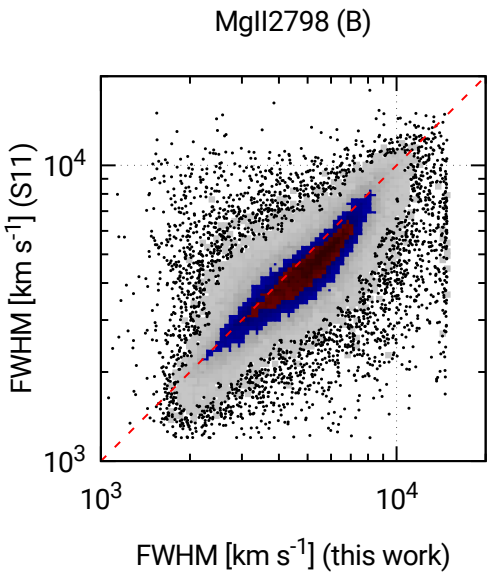
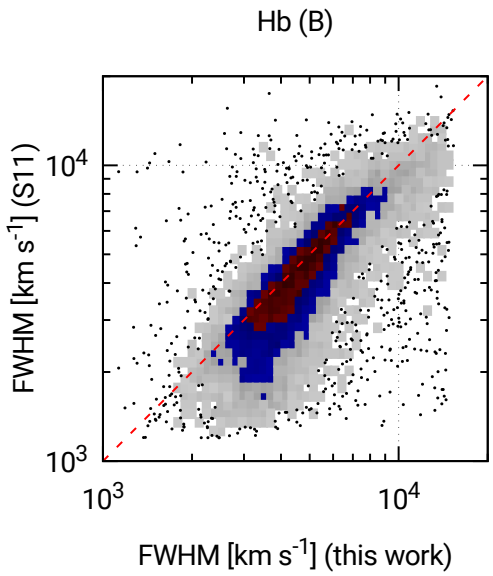
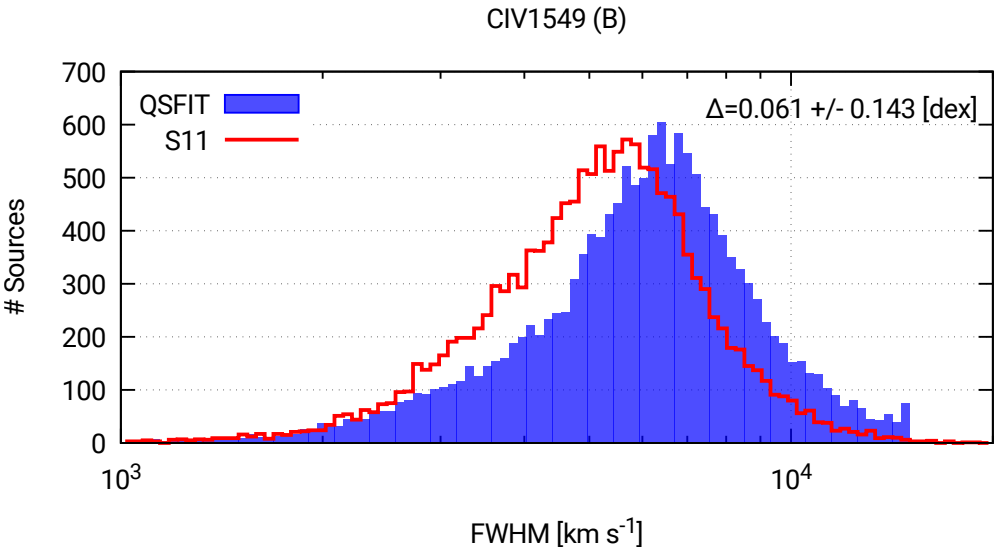
S11 ↔ QSFit comparison: Em. line FWHM









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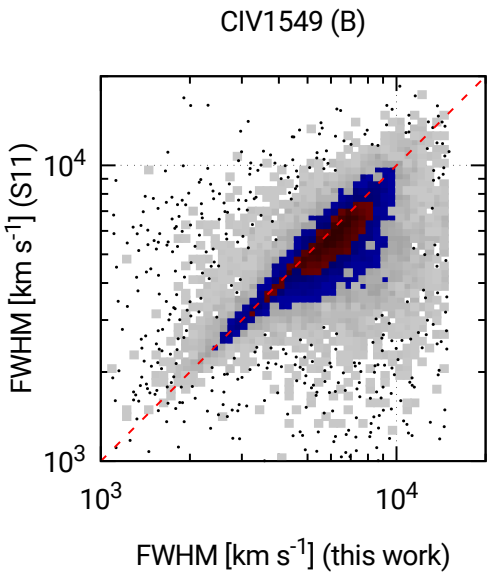

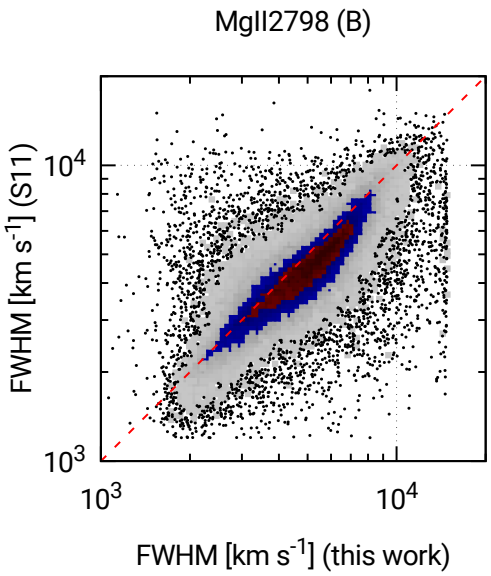

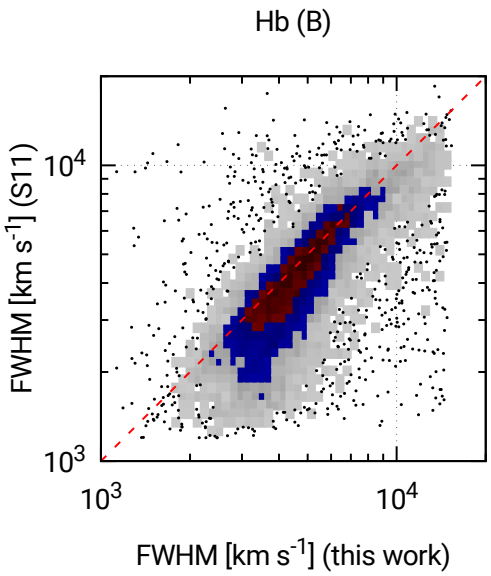

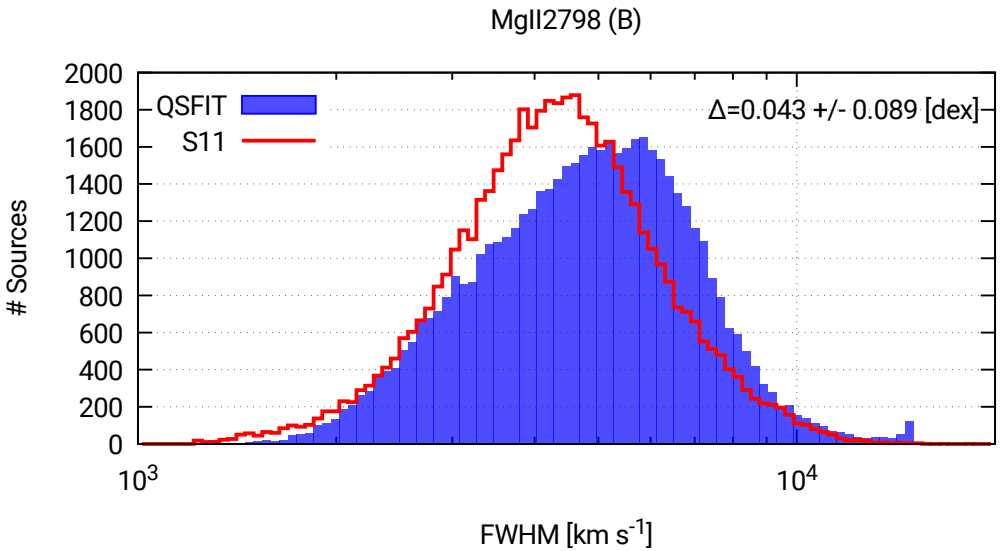

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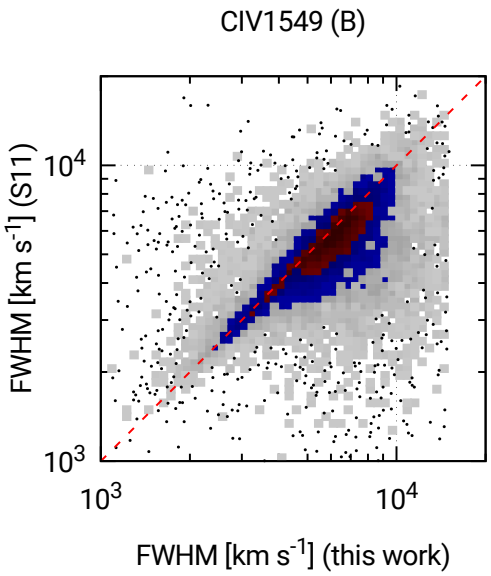

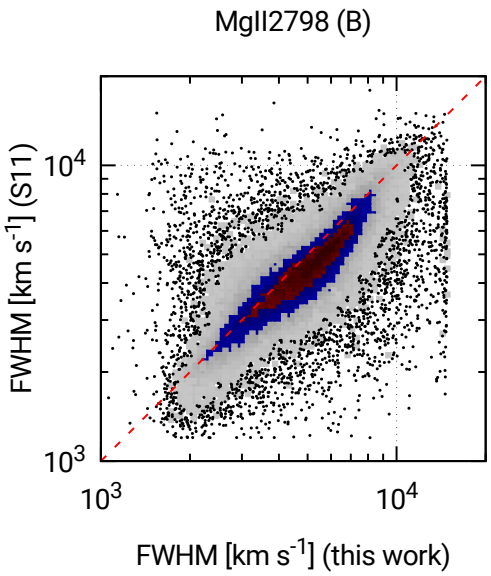

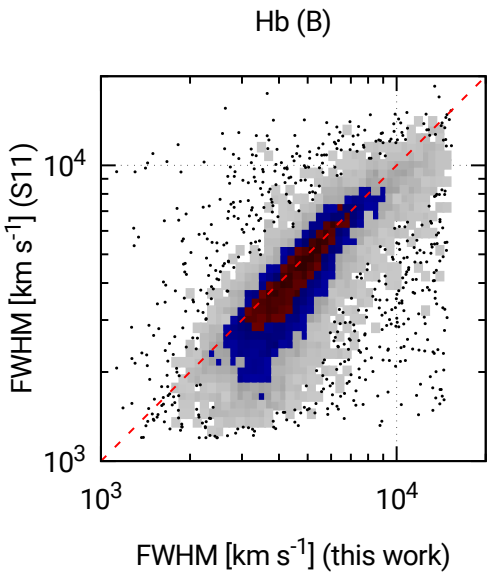

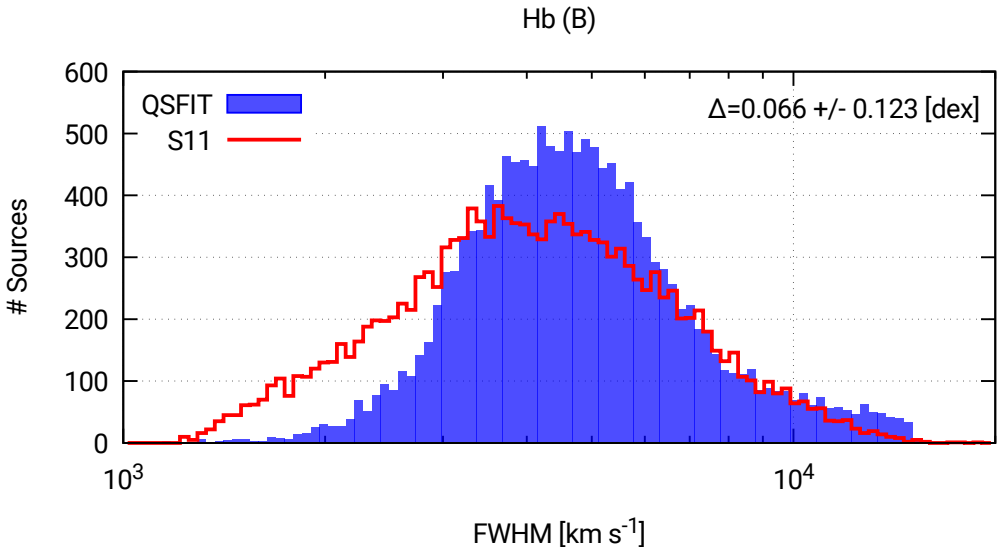

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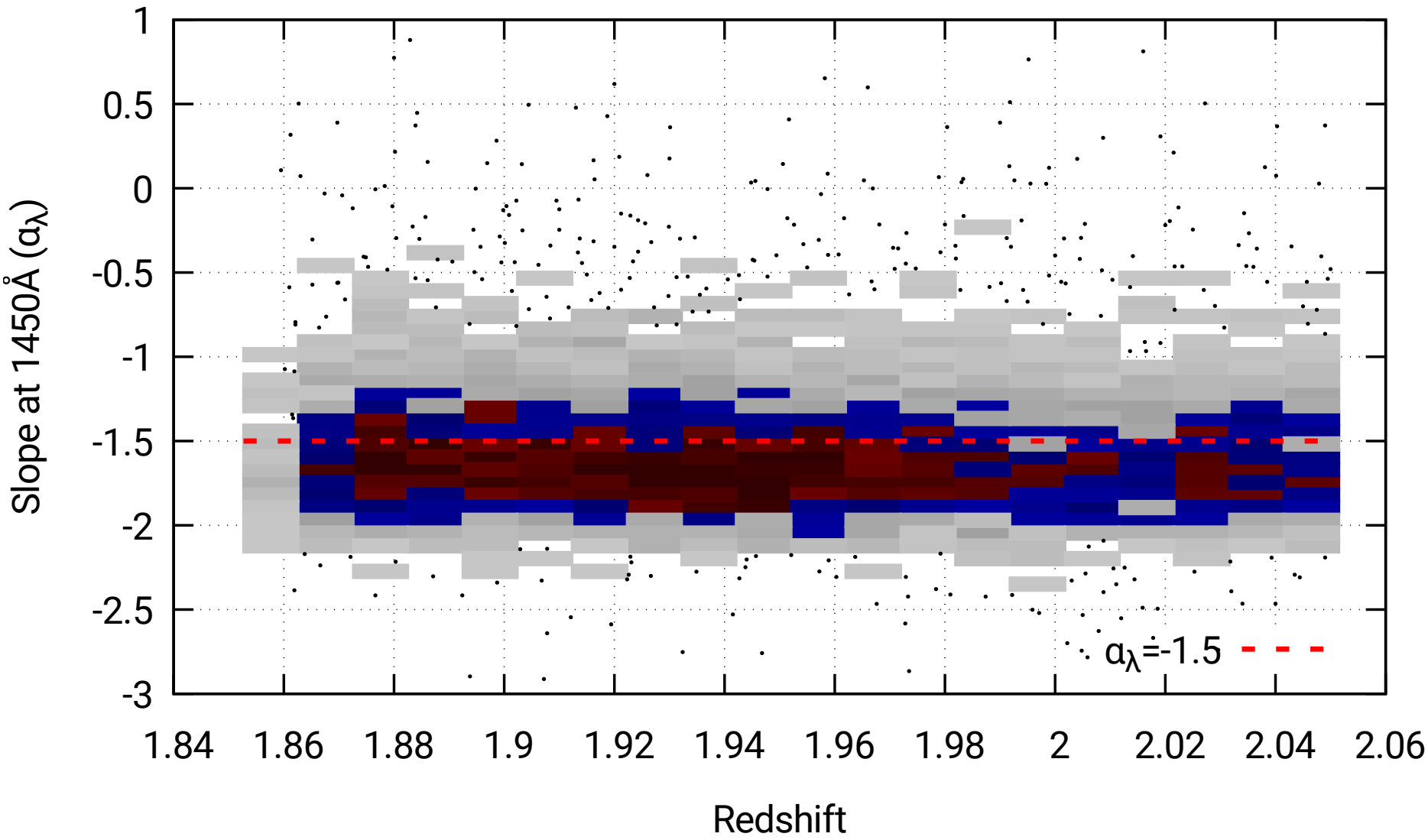
QSFit results: trend with redshift



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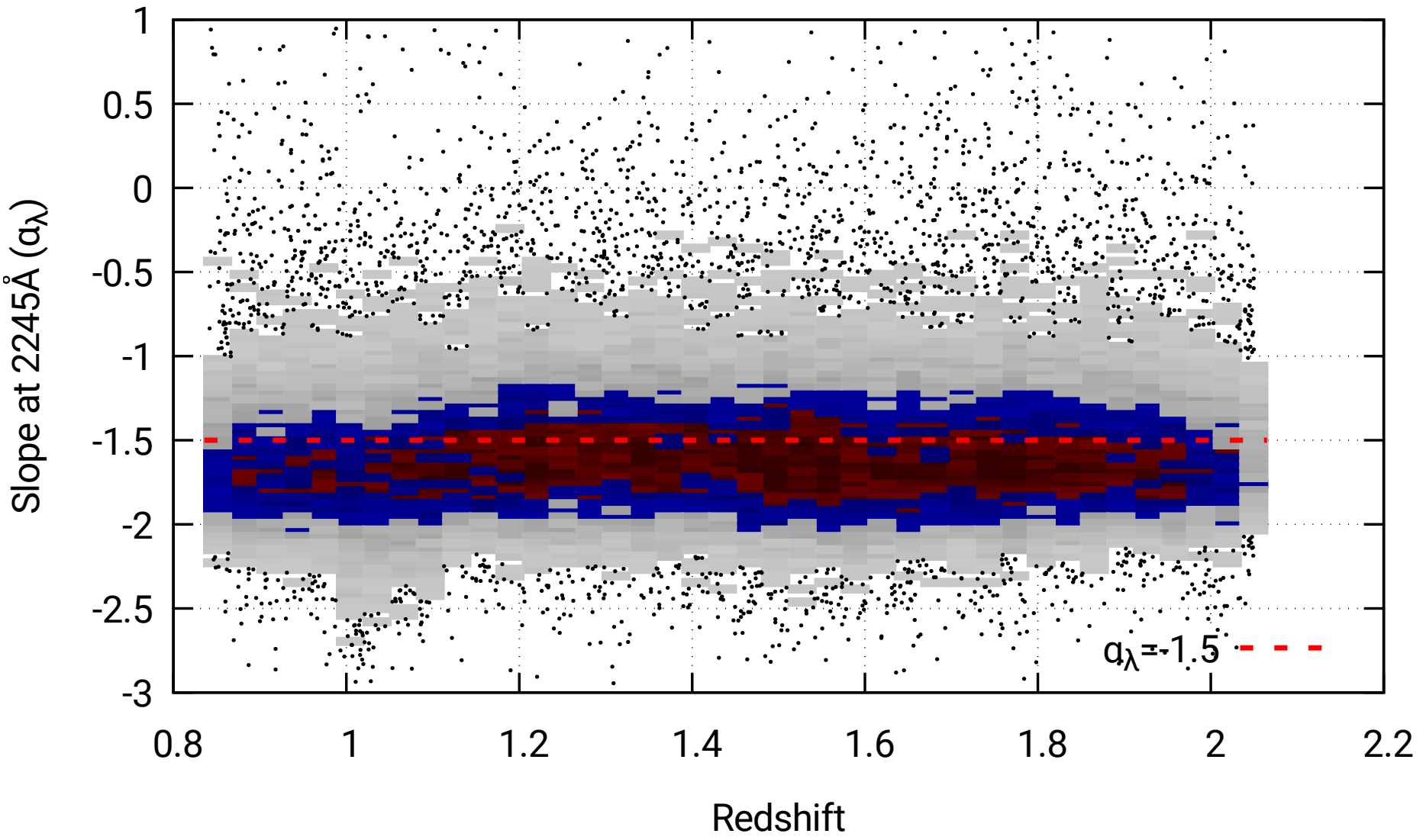

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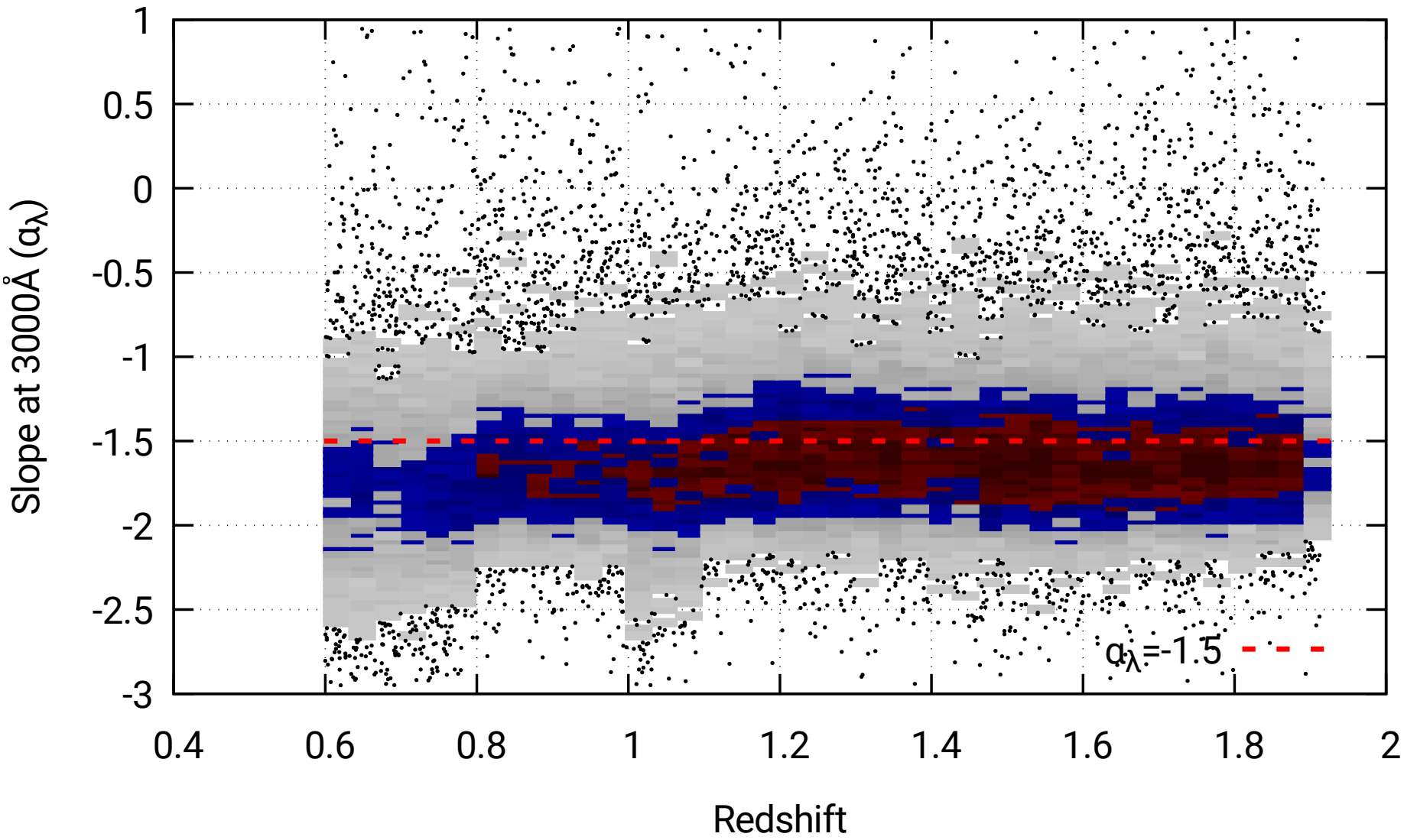

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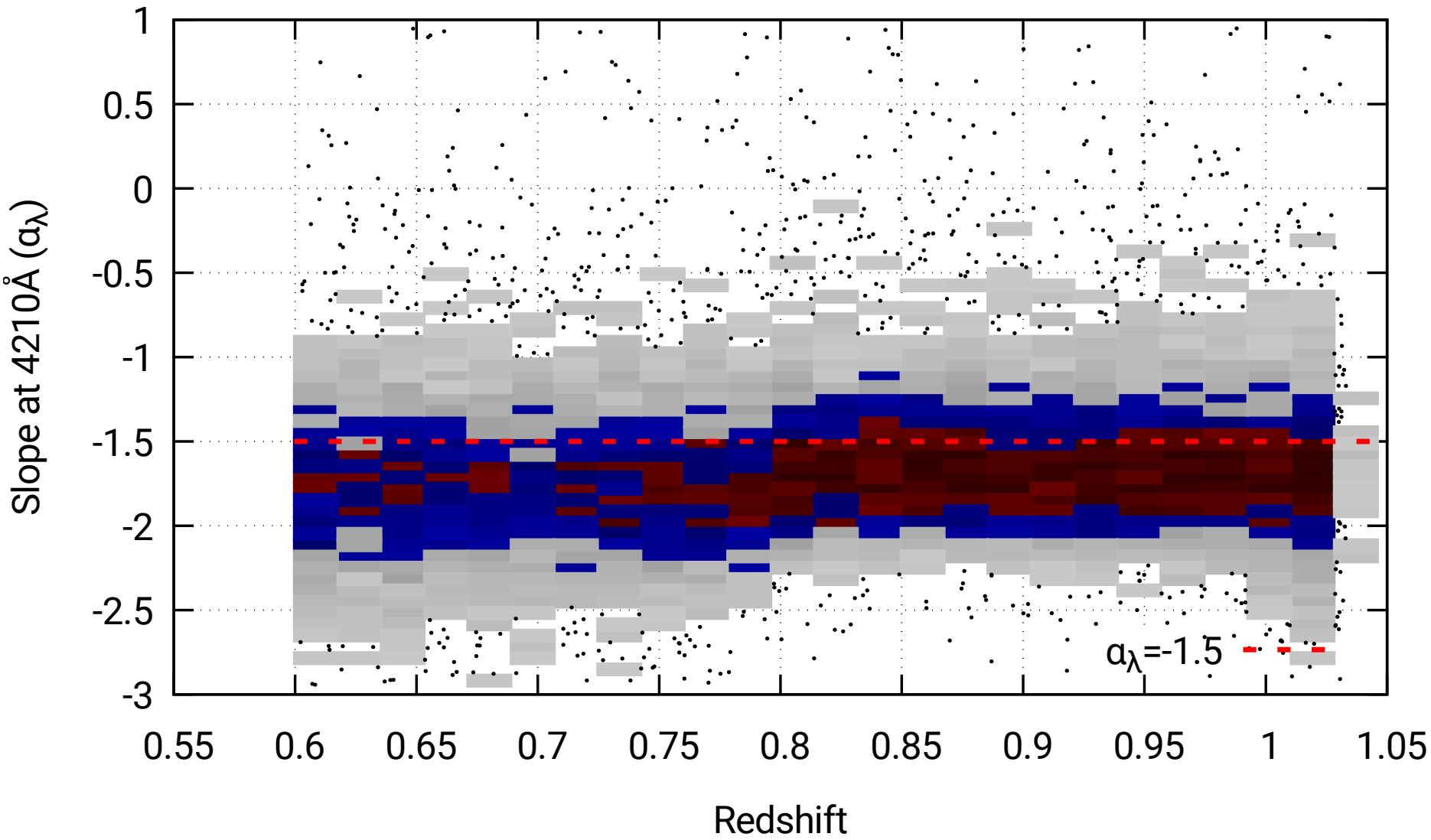

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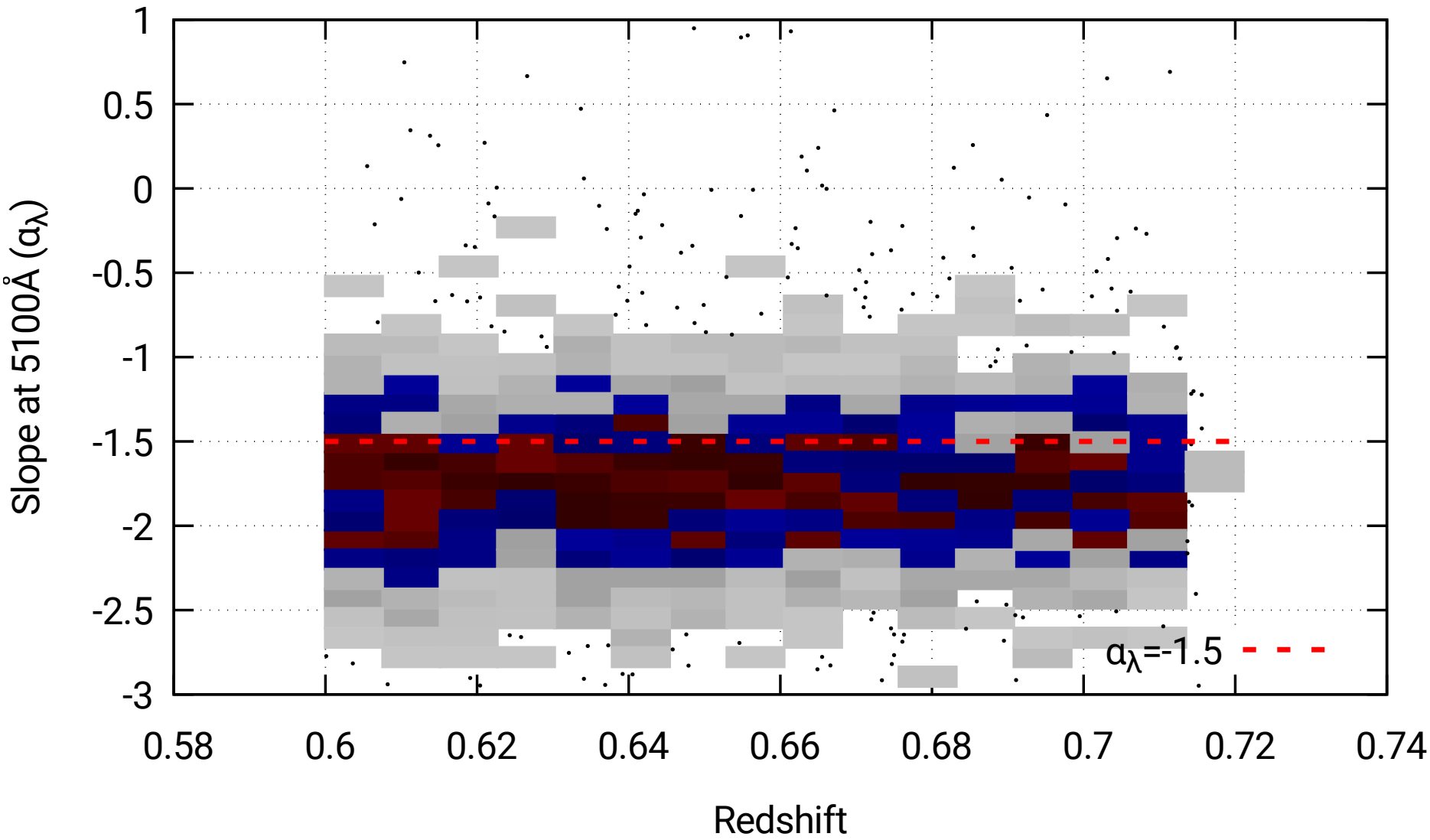

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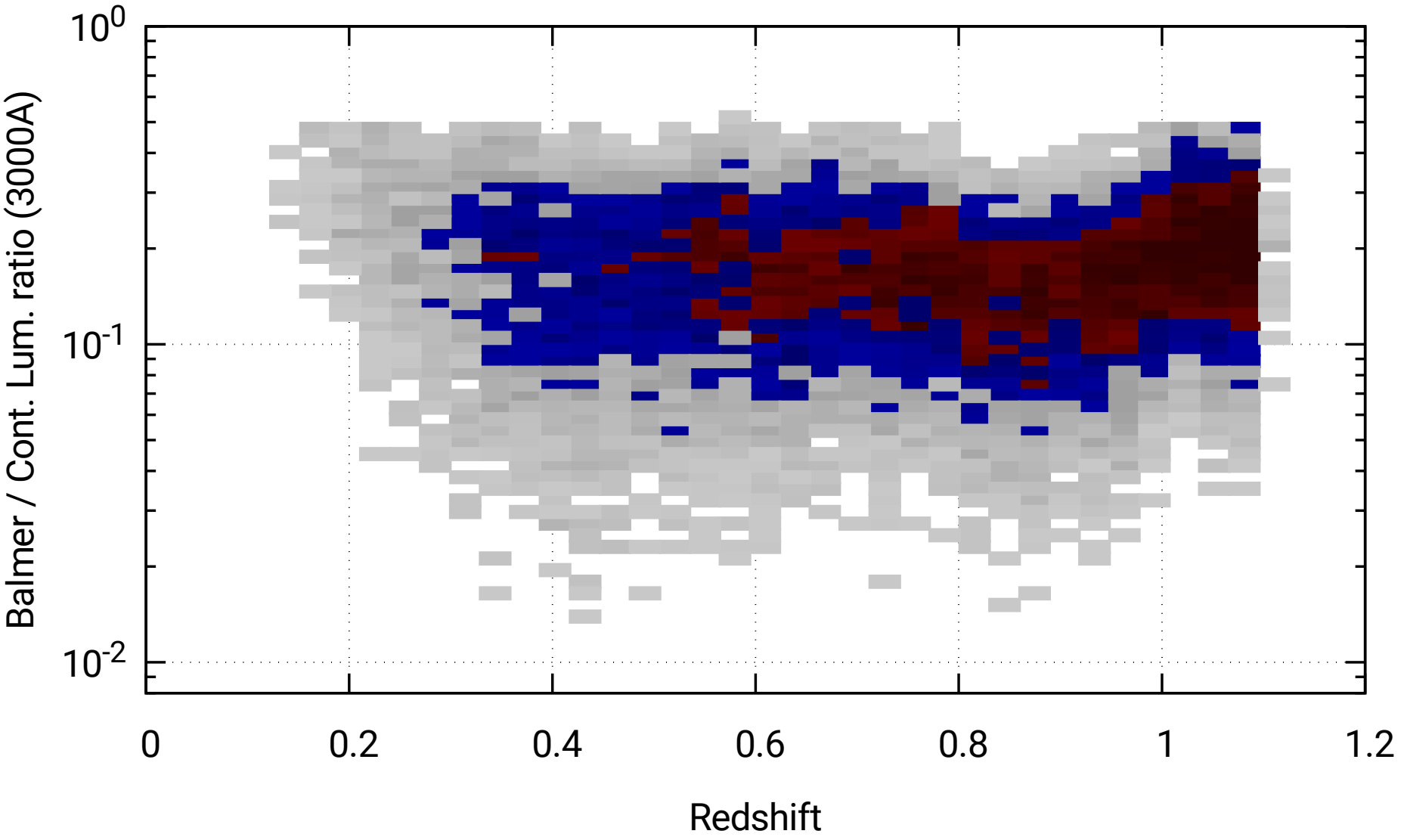

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QSFit - Quasar Spectral FITting package

QSFit is a software package to automatically perform spectral analysis of Active Galactic Nuclei (AGN) optical/UV spectra. It provides estimates of:

- AGN continuum luminosities and slopes at several rest frame wavelengths;
- host galaxy luminosities (for sources with $z < 0.8$);
- luminosities, widths and velocity offsets of 20 individual emission lines (Hα, Hβ, MgII, [OIII], CIV, etc.), and luminosity of the blended Balmer lines ($n \geq 7$);
- luminosities of iron blended lines at optical and UV wavelengths;
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- several "quality flags" to assess the reliability of the results.

The main purpose of QSFit is to allow anyone to perform AGN spectral analysis in a simple, replicable and shareable way. The code is available on Github and can be easily customized for specific purposes.

Reference Paper

The paper has been accepted for publication in MNRAS. You can download a preprint from **arXiv**.

If you make use of the catalog or the code, please unknowledge as: **Calderone et al., 2017, arXiv:1612.01580**

Catalog of spectral properties (ver. 1.2)

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The catalog can be **explored online** or downloaded as a **FITS file**.
The complete data analysis can be easily replicated by running QSFit (as shown in the example above) on all the spectra in the sample.

The old version (1.0) is available here.

Source Code (Github)

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The QSFit package already comes with a SDSS DR-10 FITS file to test the code. The commands to run the analysis and plot the results are:

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res = qsfit('data/spec-0752-52251-0323.fits', z=0.3806, ebv=0.06846)
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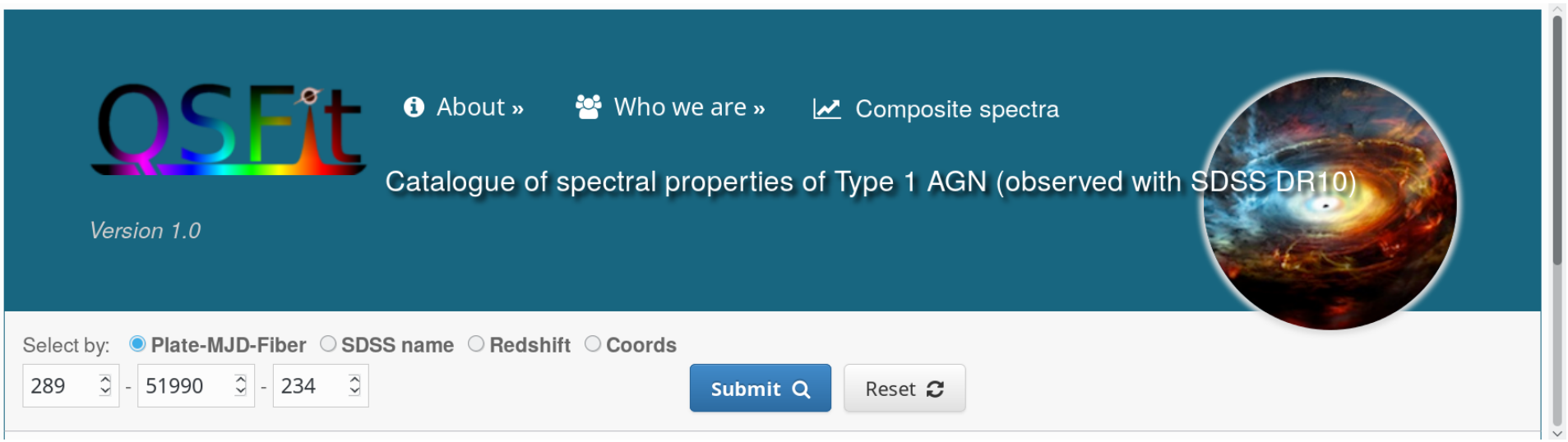
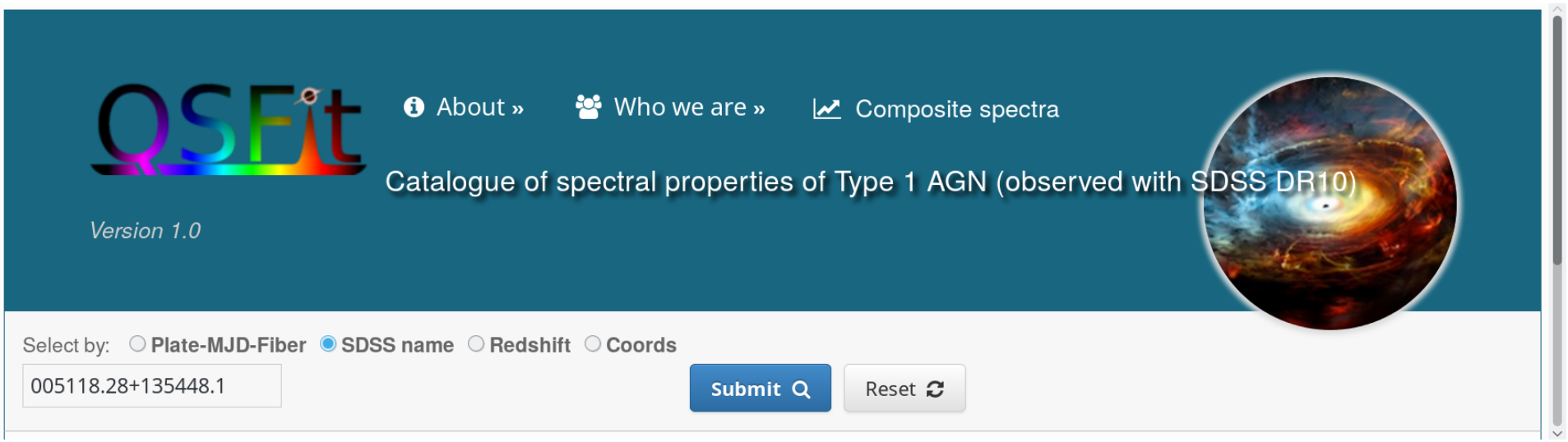
The QSFit catalog: search the catalog



The QSFit catalog: search the catalog



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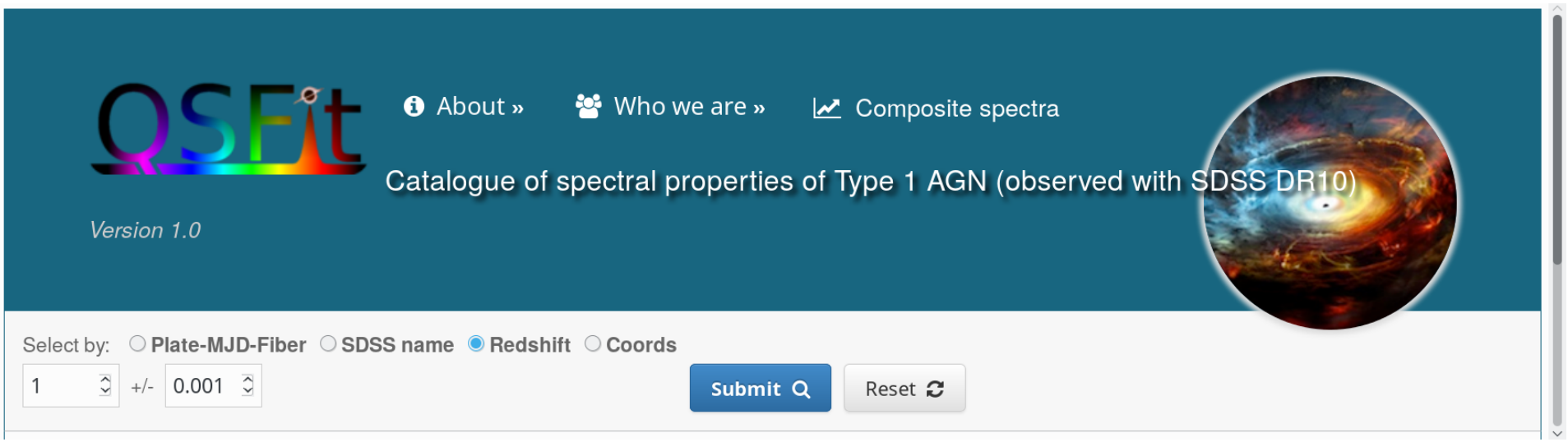

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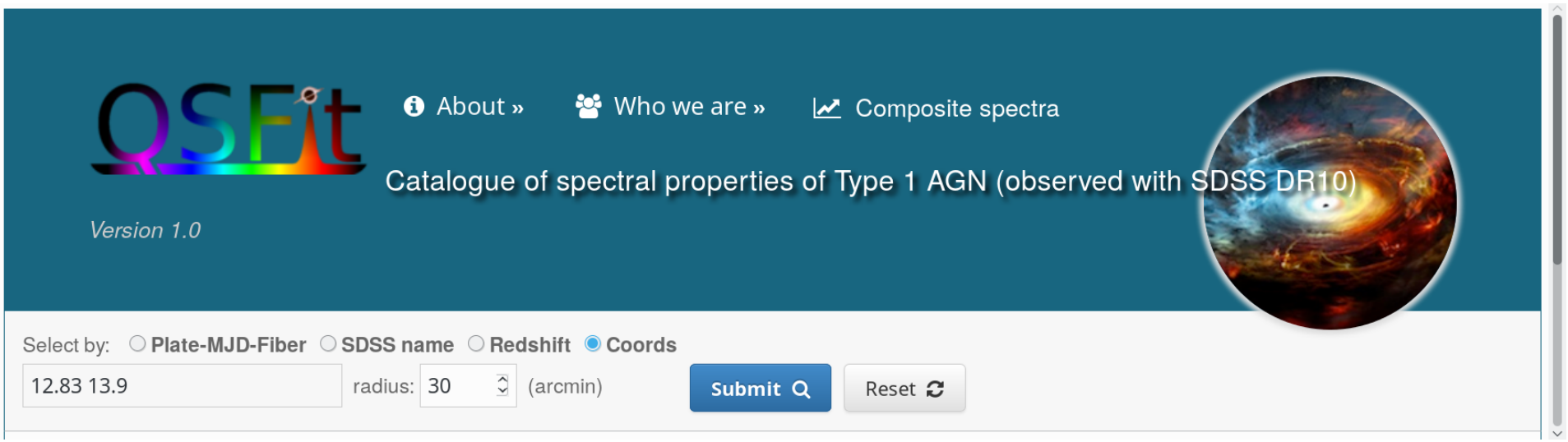
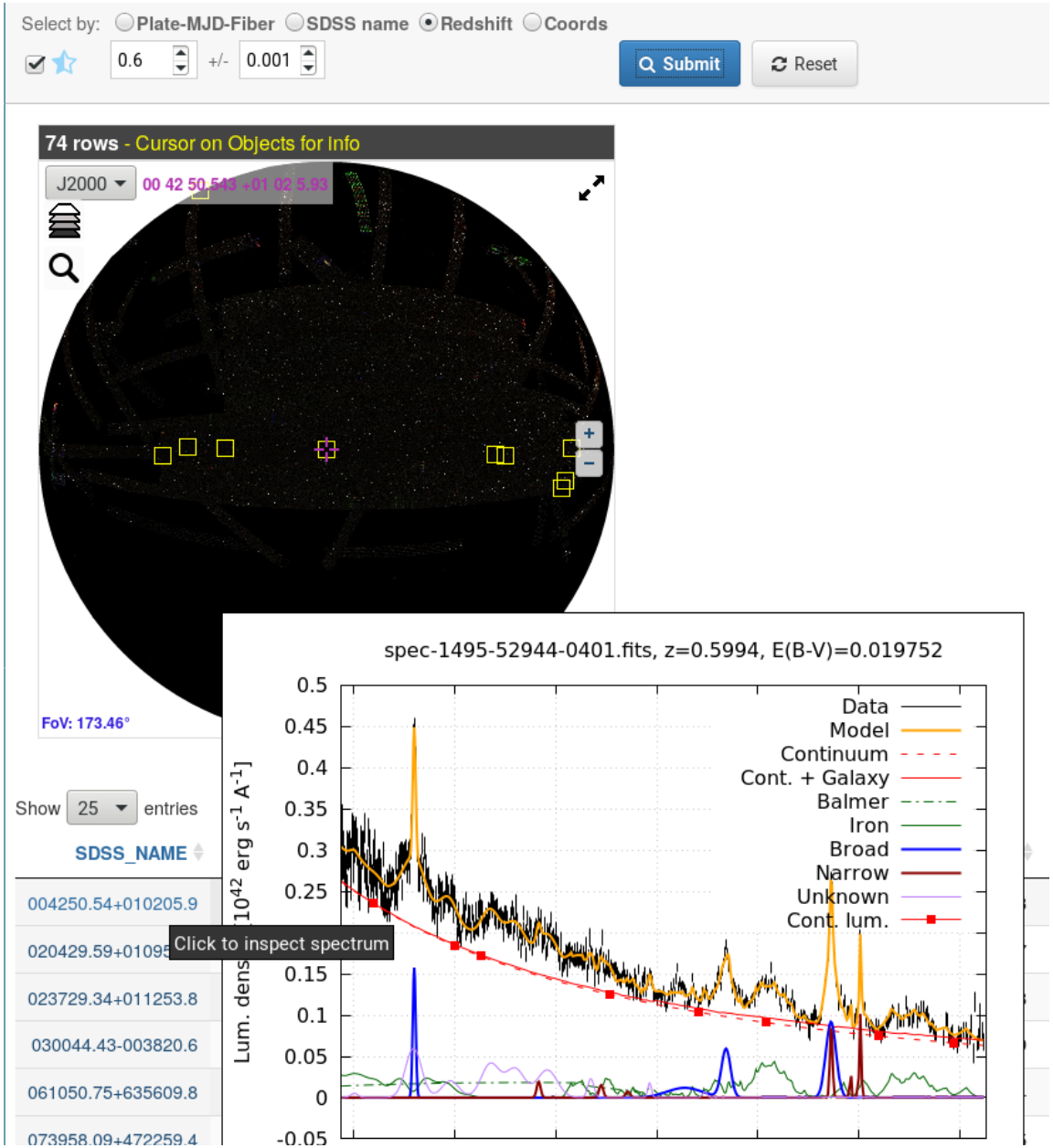
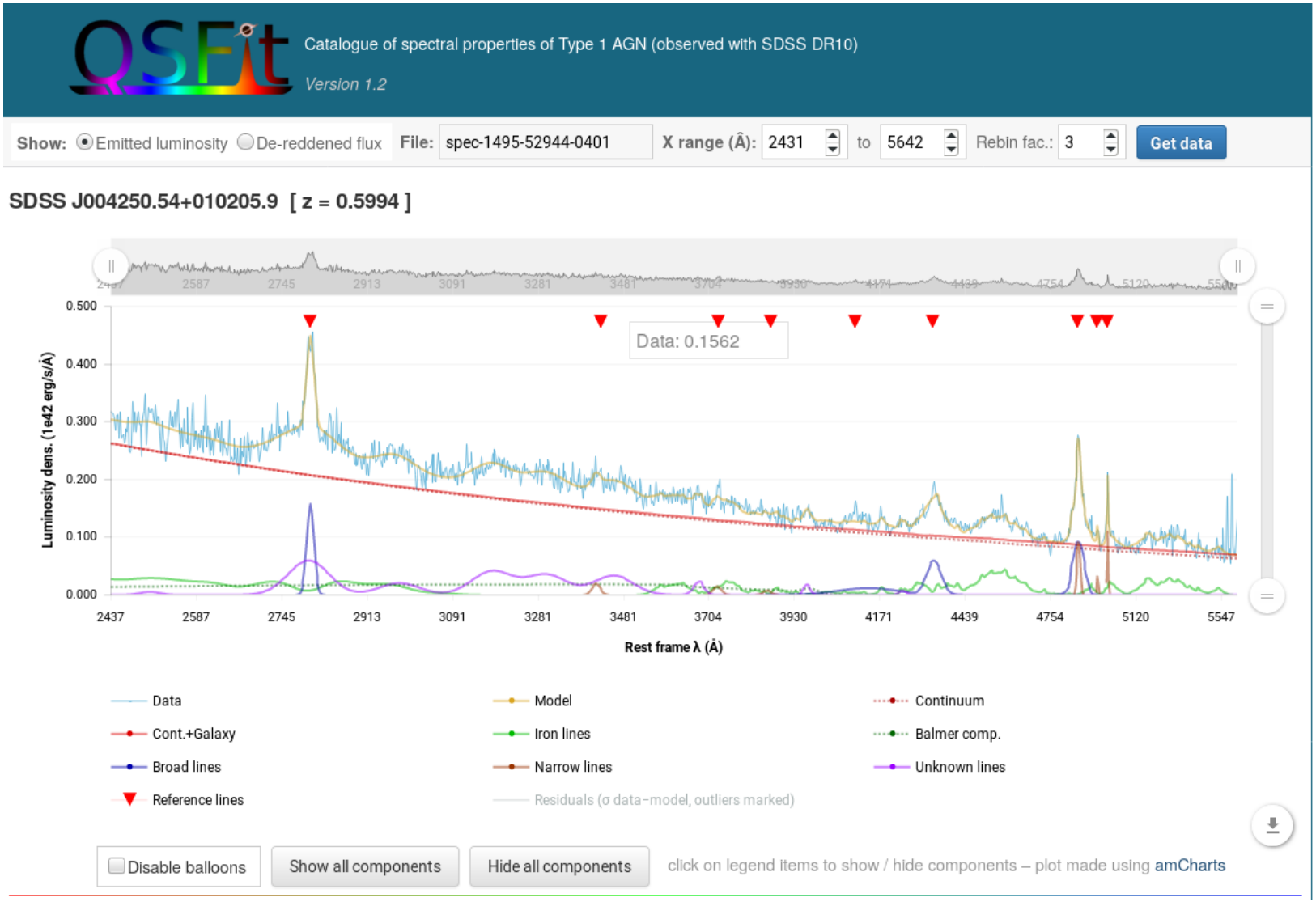


The QSFit catalog: results

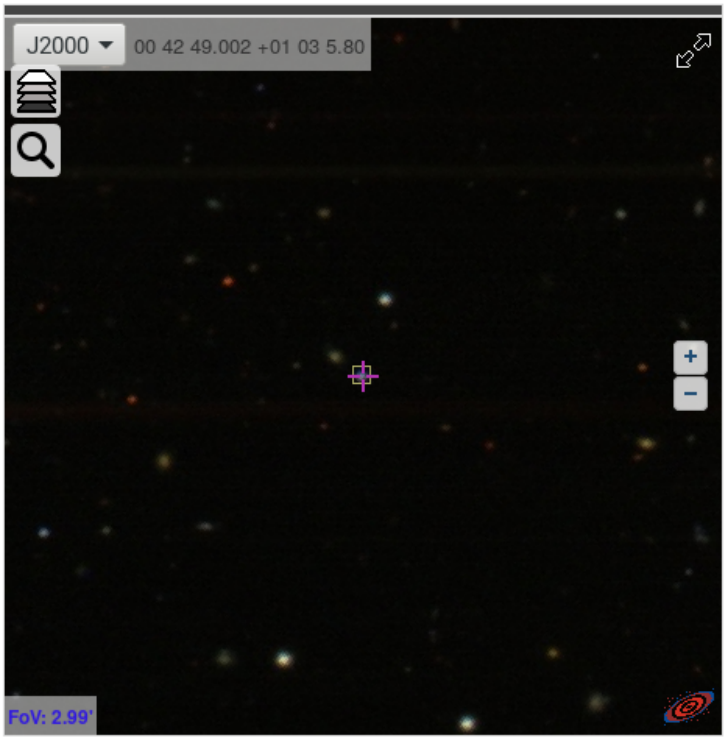


The QSFit catalog: browse the spectrum



The QSFit catalog: browse the spectrum

Sky view & Catalogue selected fields



RA	10.71059	CONT5100__LUM	381.031
DEC	1.03498	GALAXY__LUM	34.2103
PLATE	1495	BR_CIV_1549__LUM	null
MJD	52944	BR_CIV_1549__FWHM	null
FIBER	401	BR_MGII_2798__LUM	8.78398
SPEC	spec-1495-52944-0401	BR_MGII_2798__FWHM	2312.27
E_BV	0.019752	BR_HB__LUM	5.78621
Flux to Lum. fac.	1.5218e-2	BR_HB__FWHM	3633.69
CONT1450__LUM	null	BR_HA__LUM	null
CONT3000__LUM	552.43	BR_HA__FWHM	null

Re-center on source | View all fields

Associated files

View fit log file | Preview PNG | Download: [Log file | Gnuplot data | Gnuplot residuals | IDL data | SDSS DR10 FITS]

Query: SELECT * FROM `spec-1495-52944-0401` WHERE x >= 1000 AND x <= 10000 ORDER BY x

INAF ISTITUTO NAZIONALE DI ASTROFISICA NATIONAL INSTITUTE FOR ASTROPHYSICS

L. Nicastro & G. Calderone 2016, 2017

Conclusions

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- We applied the **QSFit** recipe to a sample of 71,251 sources with $z < 2 \Rightarrow$ QSFit catalog:
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- We need **standardized** recipes to avoid ambiguities and ensure **reproducibility of results** $\Rightarrow$ **QSFit** free software;
- We applied the **QSFit** recipe to a sample of 71,251 sources with $z < 2$ $\Rightarrow$ QSFit catalog:
  - all results, plots and logs, are publicly released in a dedicated website;
- **QSFit** $\leftrightarrow$ literature comparison:
  - continuum and line luminosities are compatible (except at 5100Å *Rightarrow* host galaxy;
  - slopes are significantly different, but our definition probes the broad band AGN continuum;
  - line widths are correlated, but the scatter is $\sim$ 2000 km s^{-1};
- **QSFit** results:
  - Continuum slopes do not show any trend with redshift, the average slope is $\alpha_\nu \sim -0.5$;
  - The Balmer cont. / AGN cont. ratio is $\sim$ 0.15, at all redshifts;
  - **This is first time these quantities are estimated on a very large sample;**
  - **ALL results in the catalog can be easily re–analyzed, and the analysis recipes customized.**
- **QSFit** applications:
  - black hole mass estimates through AD modeling;
  - comparison of different galaxy templates, emission line models, etc...
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