Quasars in the SDSS

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28 June 2006

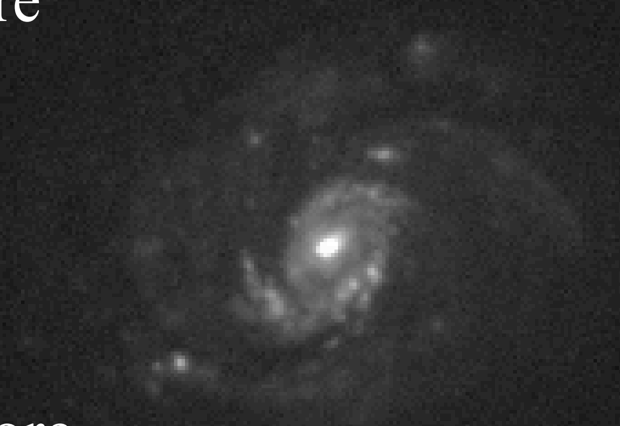
START CI-Team: *Variable Quasars Research Workshop*

Yerkes Observatory

NGC 1068

About 10% of all of the spectra in the SDSS database are of *quasars* (as opposed to galaxies and stars).

We selected quasars deliberately because they are extremely luminous: we can see them to huge distances, which allows us to map an enormous volume of space.



A census of the quasars shows that they were more common and/or more luminous billions of years ago.

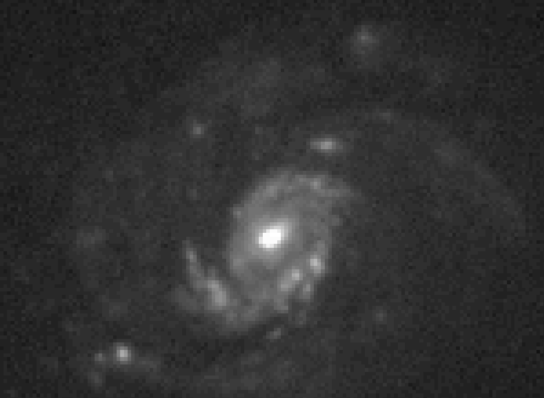
Statistical studies are greatly helped by the SDSS design: uniform selection, uniform data quality, and good calibrations.

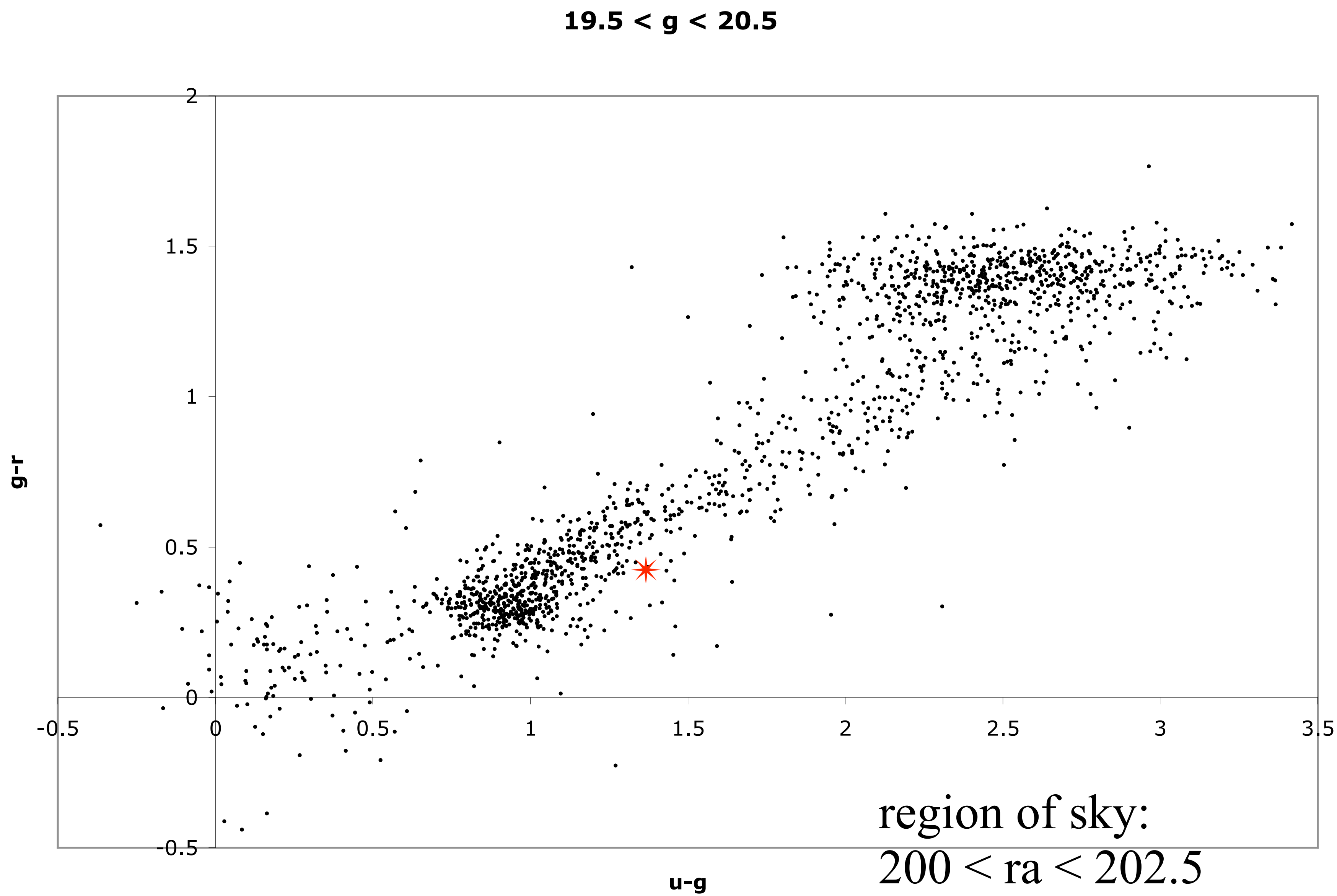
And, of course, large numbers: 80,000 quasar spectra in DR5, expect more than 100,000 at the end of operations.

In order to get a spectrum, we need first to identify an object as a possible quasar, based on the *u g r i z* imaging data of the SDSS.

This is done by exploiting the property that quasars do not shine by the same processes that stars do.

That means that their *colors* (u-g, g-r, r-i, i-z) will be unlike the colors of normal stars.



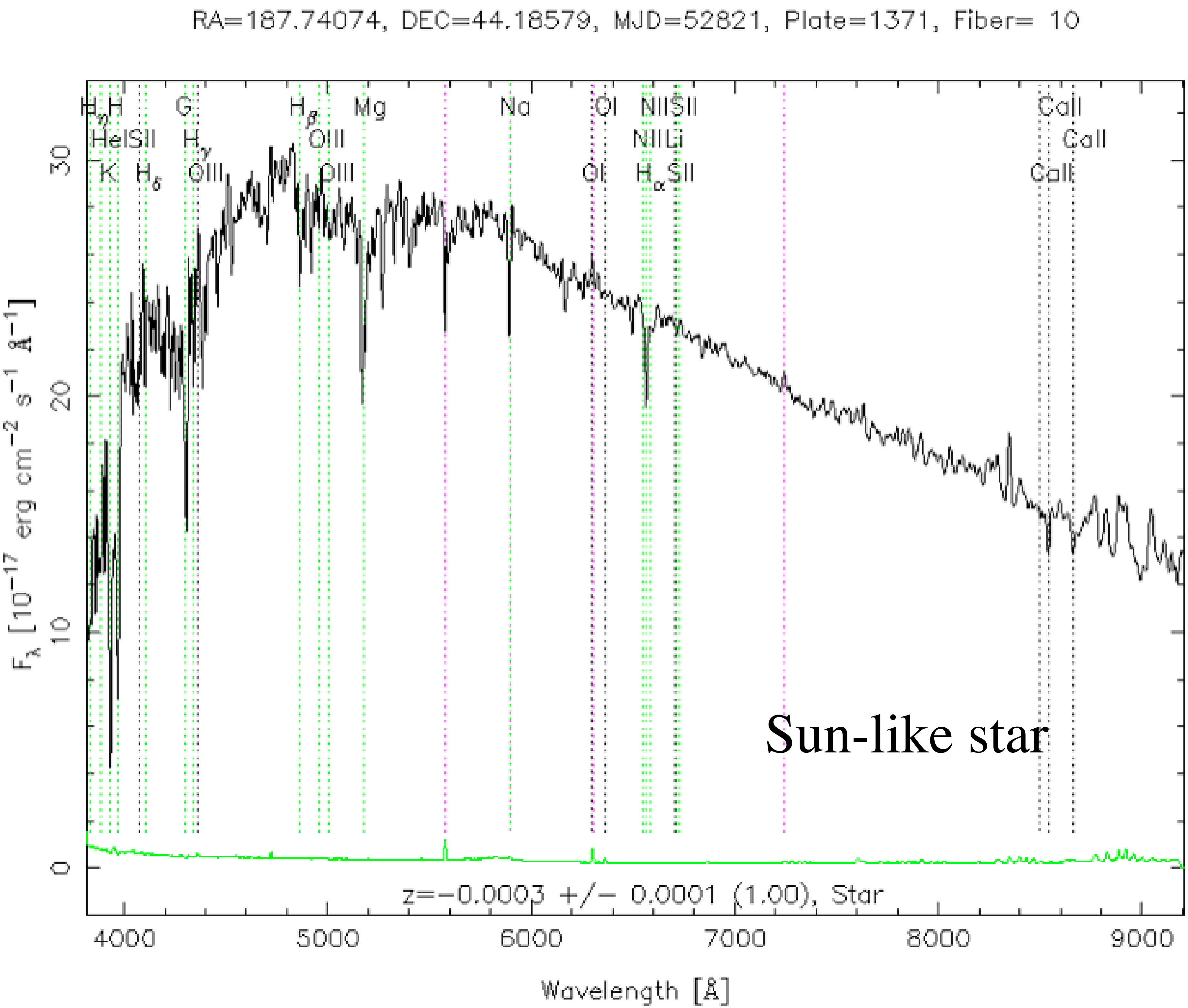


region of sky:
200 < ra < 202.5
43 < dec < 45.5

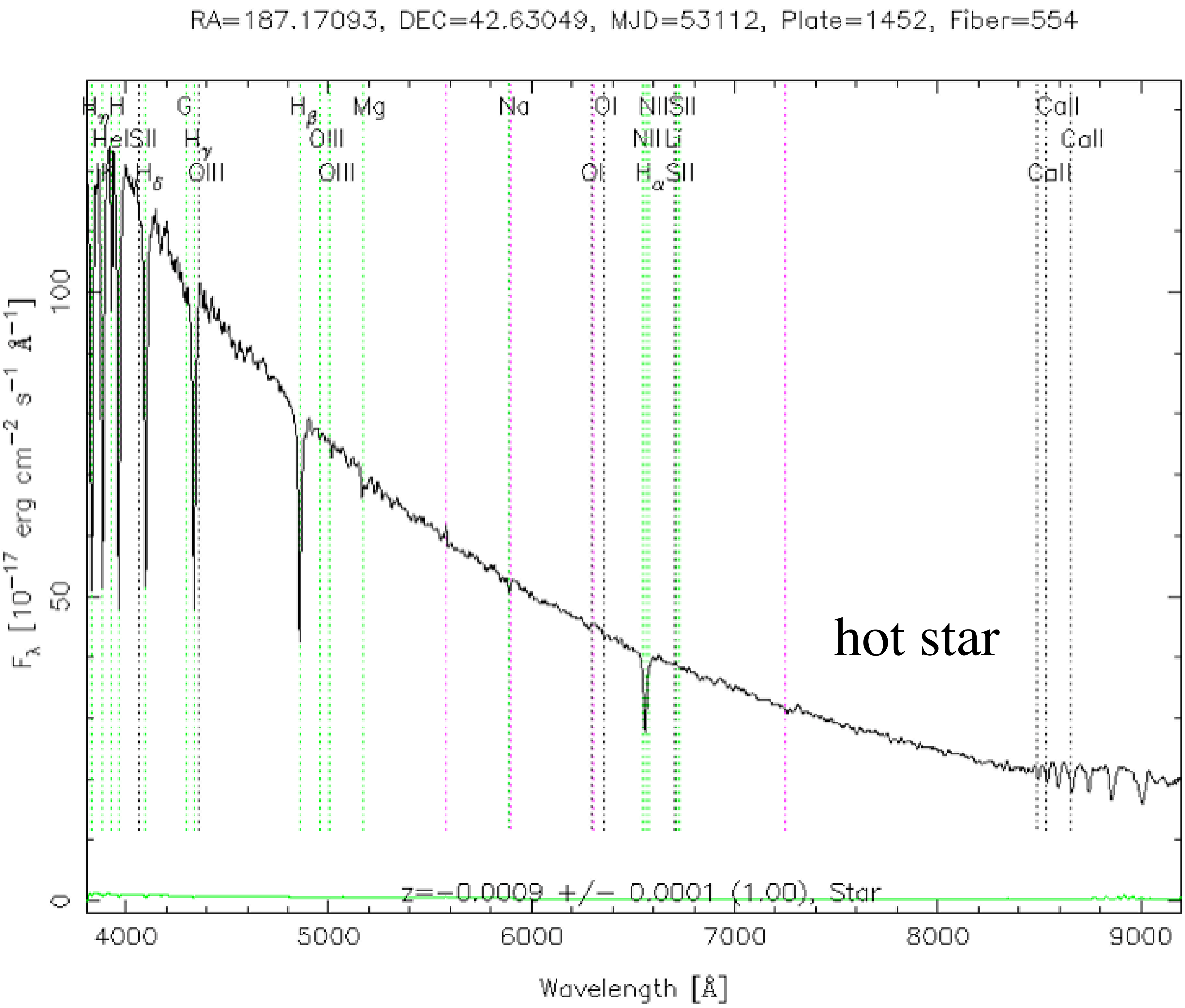
After spectra are obtained of all of the candidate quasars, how is it determined which ones really are quasars?

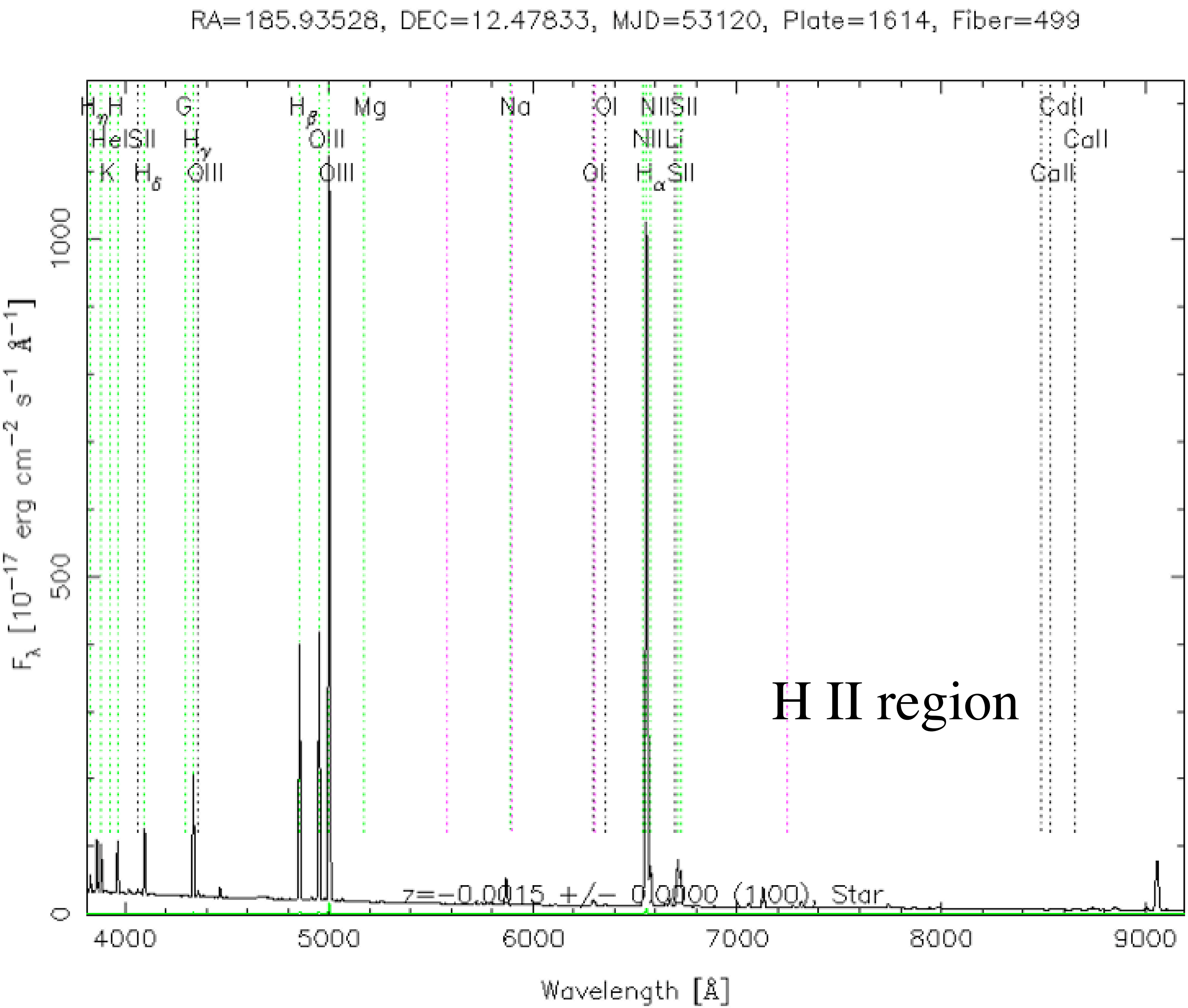
An automated analysis “pipeline” is run on each spectrum.

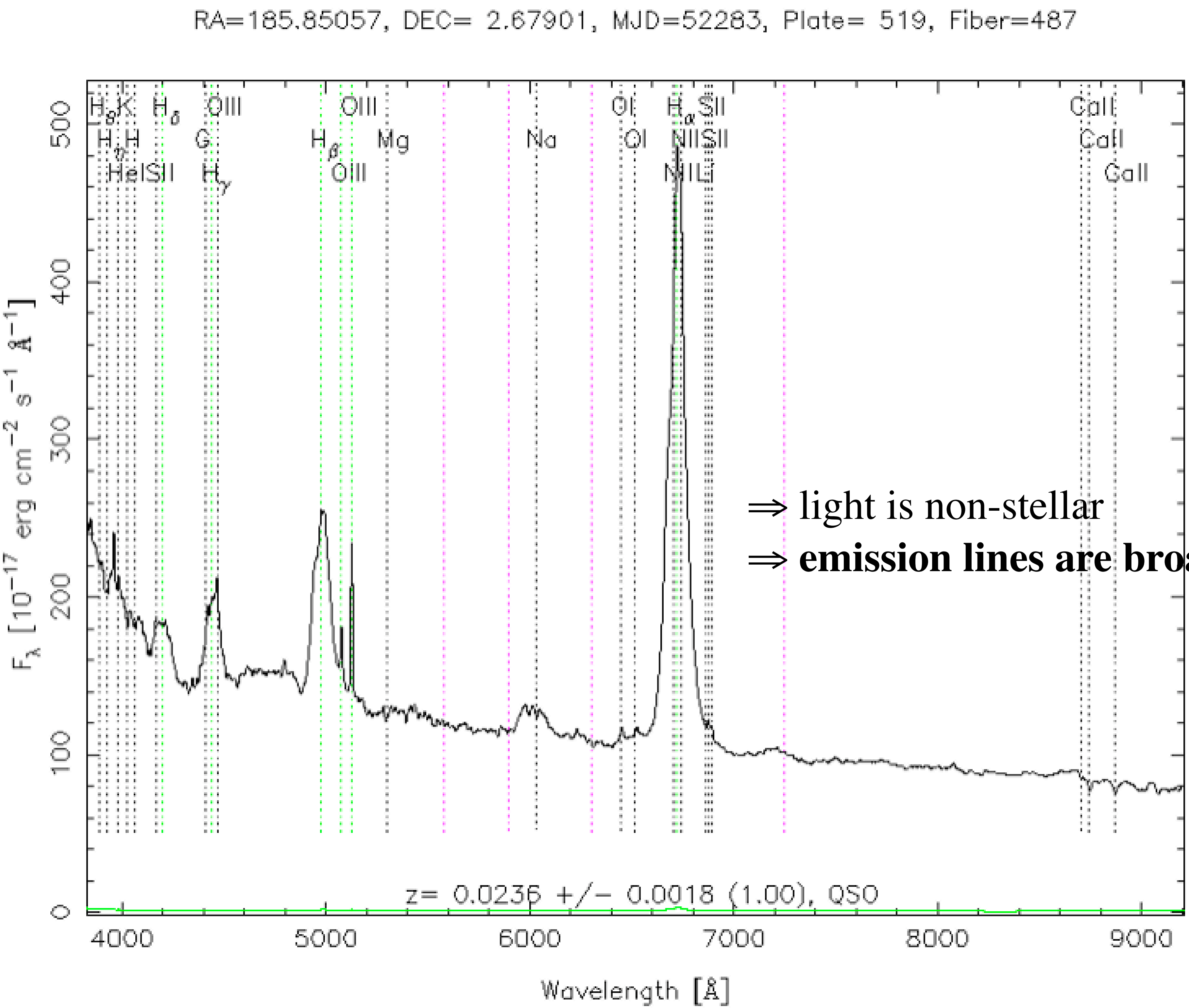
The algorithm looks for the presence of *broad emission lines*, which are characteristic of quasars.



RA=187.74074, DEC=44.18579, MJD=52821, Plate=1371, Fiber= 10
F_λ [10^{-17} erg cm^{-2} s^{-1} Å^{-1}]
Wavelength [Å]
z=-0.0003 +/- 0.0001 (1.00), Star
Sun-like star


RA=187.17093, DEC=42.63049, MJD=53112, Plate=1452, Fiber=554
Wavelength [Å]
hot star
z=-0.0009 +/- 0.0001 (1.00), Star


RA=185.93528, DEC=12.47833, MJD=53120, Plate=1614, Fiber=499
H II region
z=-0.0015 +/- 0.0000 (1.00), Star
Wavelength [Å]
F_λ [10^{-17} erg cm^{-2} s^{-1} Å^{-1}]
0
500
1000
4000
5000
6000
7000
8000
9000
H_η
H
HeI
SII
K
H_δ
G
H_γ
OIII
H_β
OIII
OIII
Mg
Na
OI
OI
NII
SII
NII
Li
H_α
SII
CaII
CaII
CaII



⇒ light is non-stellar

⇒ **emission lines are broad**

More quantitatively:

The software detects absorption and emission lines, and fits a Gaussian function to each line profile.

The parameters are:

height (10^{-17} erg sec^{-1} cm^{-2} Å^{-1}); + = em, - = abs

continuum (10^{-17} erg sec^{-1} cm^{-2} Å^{-1})

sigma (Ångstroms)

SDSS adopts a practical definition of a quasar: at least one line must have a full-width at half-maximum (FWHM) broader than 1000 km/sec.

to convert from sigma in Ångstroms to FWHM in km/sec:

$$\mathrm{FWHM} = c \times [(2.354 \times \mathrm{sigma}) / \lambda]$$

physical properties of quasars:

- high luminosity
- small emitting volume
- spectra show broad emission lines
- visible light + radio + X-rays
- variable (like the DJI)
- bipolar symmetry (especially at radio wavelengths)

physical model:

✧ central supermassive black hole that is accreting gas

✧ gas falls into the black hole because of viscosity (drag)

✧ as the gas falls, the gravitational energy of falling is converted into heat and light the emitting region (*active nucleus*) is tiny:

$$M_{bh} = 3 \times 10^7 \, M_{sun}$$

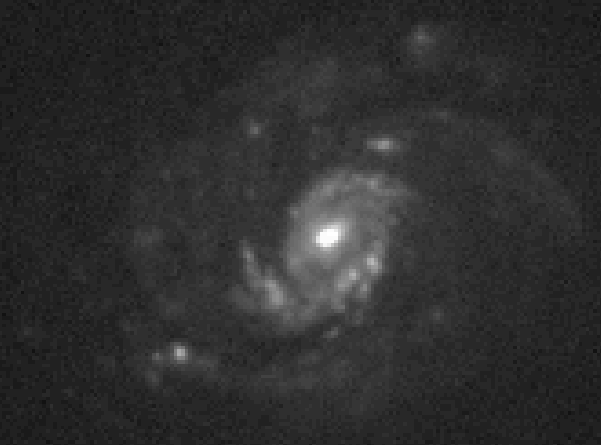
$$R_{Sch} = 2\,G\,M_{bh} / c^2 = 0.6 \text{ AU}$$

$$R_{accretion} \sim 10\,R_{Sch} = 6 \text{ AU} = 50 \text{ light-minutes}$$

compare to:

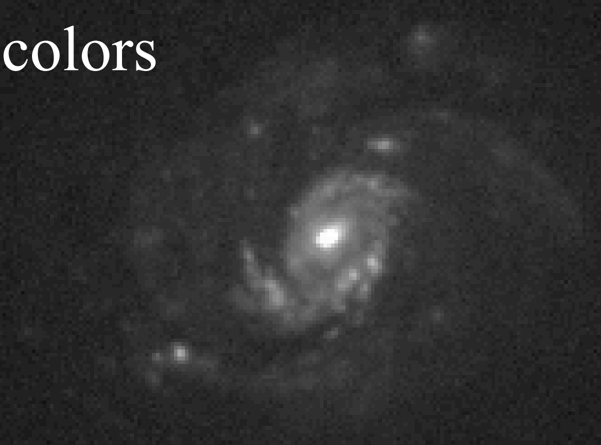
diameter of a galaxy ~ 70,000 light-years physical properties of quasars:

- ✦ high luminosity ✓
- ✦ small emitting volume ✓
- ✦ spectra show broad emission lines ✓
- ✦ visible light + radio + X-rays ✓
- ✦ variable ✓
- ✦ bipolar symmetry ✓



parameters of quasars in the SDSS database:

- redshift $\equiv$ distance
- apparent brightness in different filters; colors
- image structure
- lines
  - *height*
  - *sigma*
  - *continuum*



converting redshift to distance for quasars:

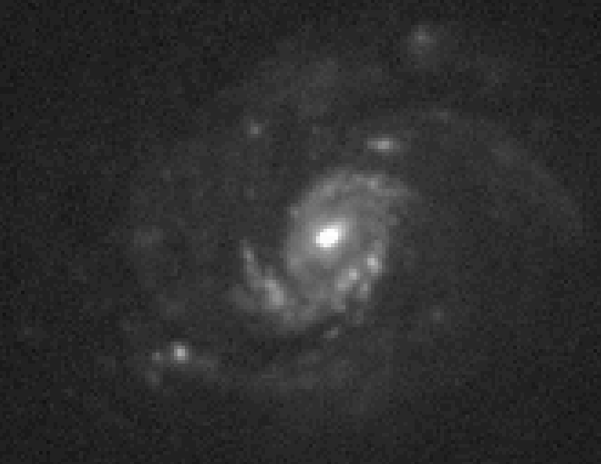
the symbol for the measured quantity of redshift is *z*

naive relation:

$$d = (c/H_0) \times z = 4200 \text{ megaparsecs} \times z$$

$$= 13.7 \text{ billion light-years} \times z$$

this is OK as long as $z \ll 1$

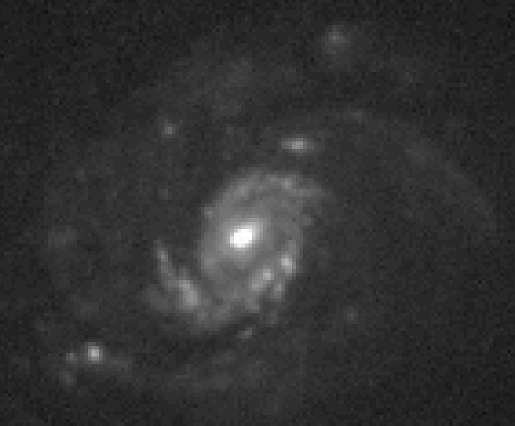


converting redshift to distance for quasars, continued:

- since the distances are so large, effects such as the geometrical curvature of space (*non-Euclidean geometry*) are important

moreover, in an expanding Universe, the distances between all objects are increasing with time

$\Rightarrow$ what exactly is meant by "distance?"



what exactly is meant by “distance?”

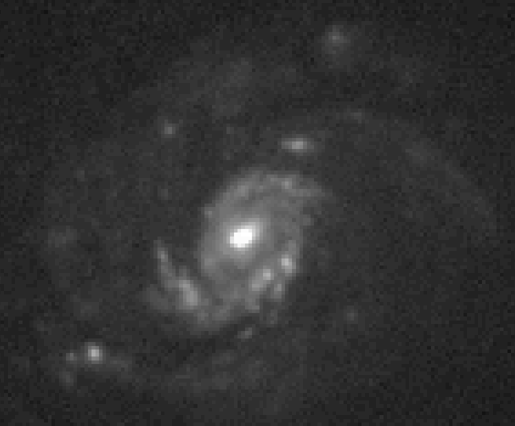
$L = 4\pi\, d^2 \times b$ d is “luminosity distance”

$R = d \times \theta$ d is “angular-size distance”

You can get the values for these distances at

http://www.astro.ucla.edu/~wright/CosmoCalc.html

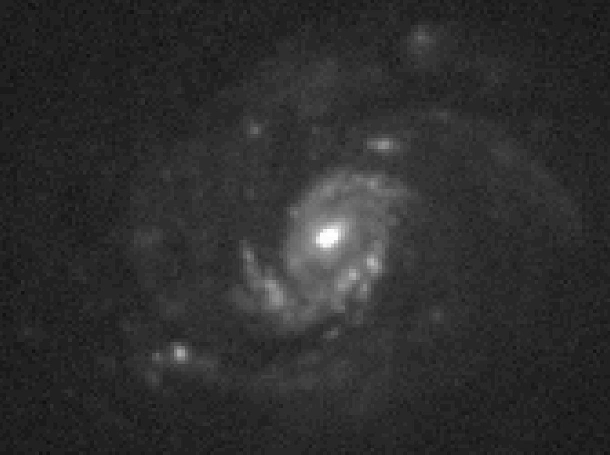
1) enter the redshift into the “z” window
2) leave the default cosmological parameters as they are
3) press “flat”

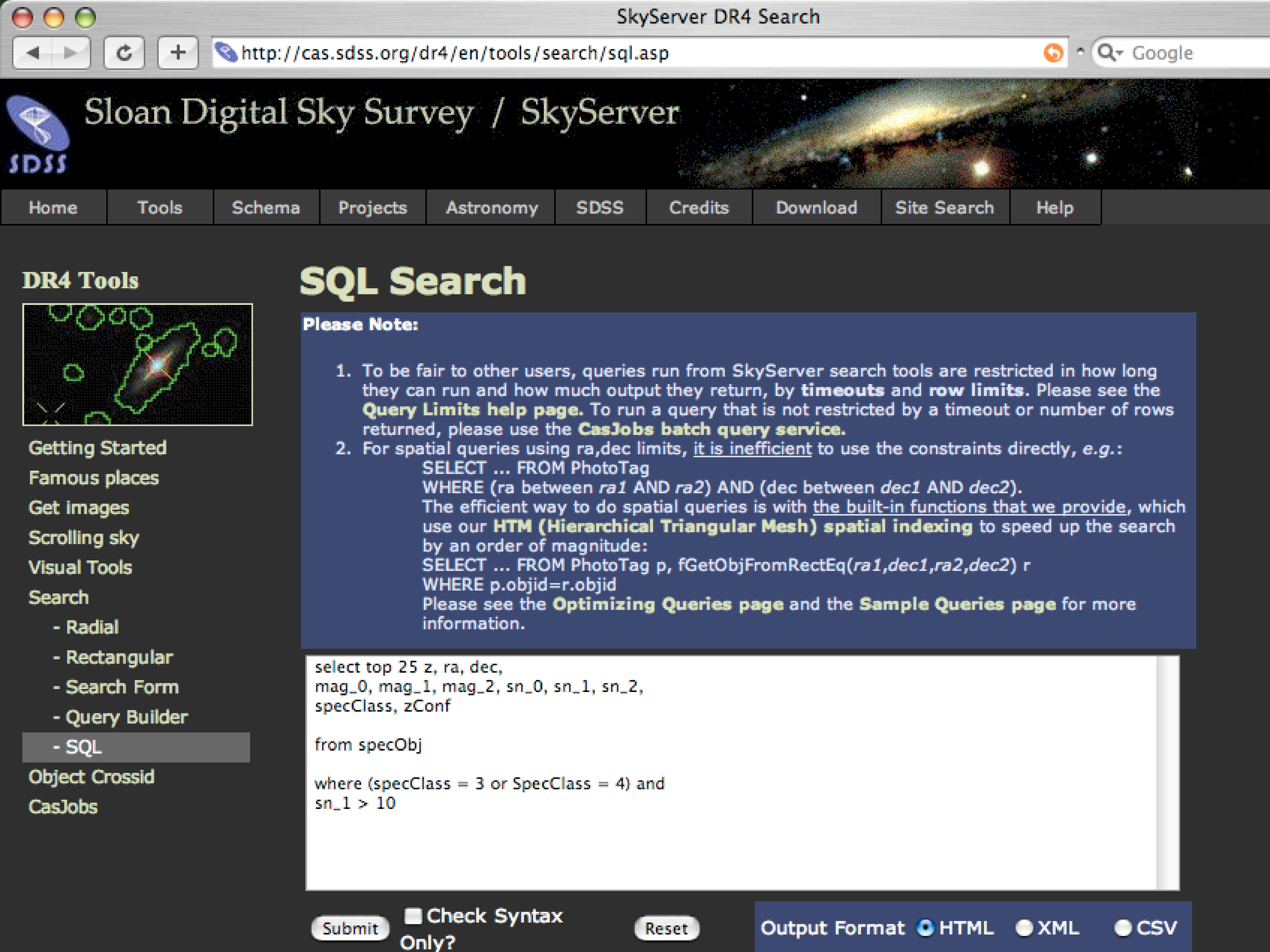


how do I get quasar data out of the SDSS database?

go to sdss.org ,

click on “skyserver,”
then “search,”
then “SQL”



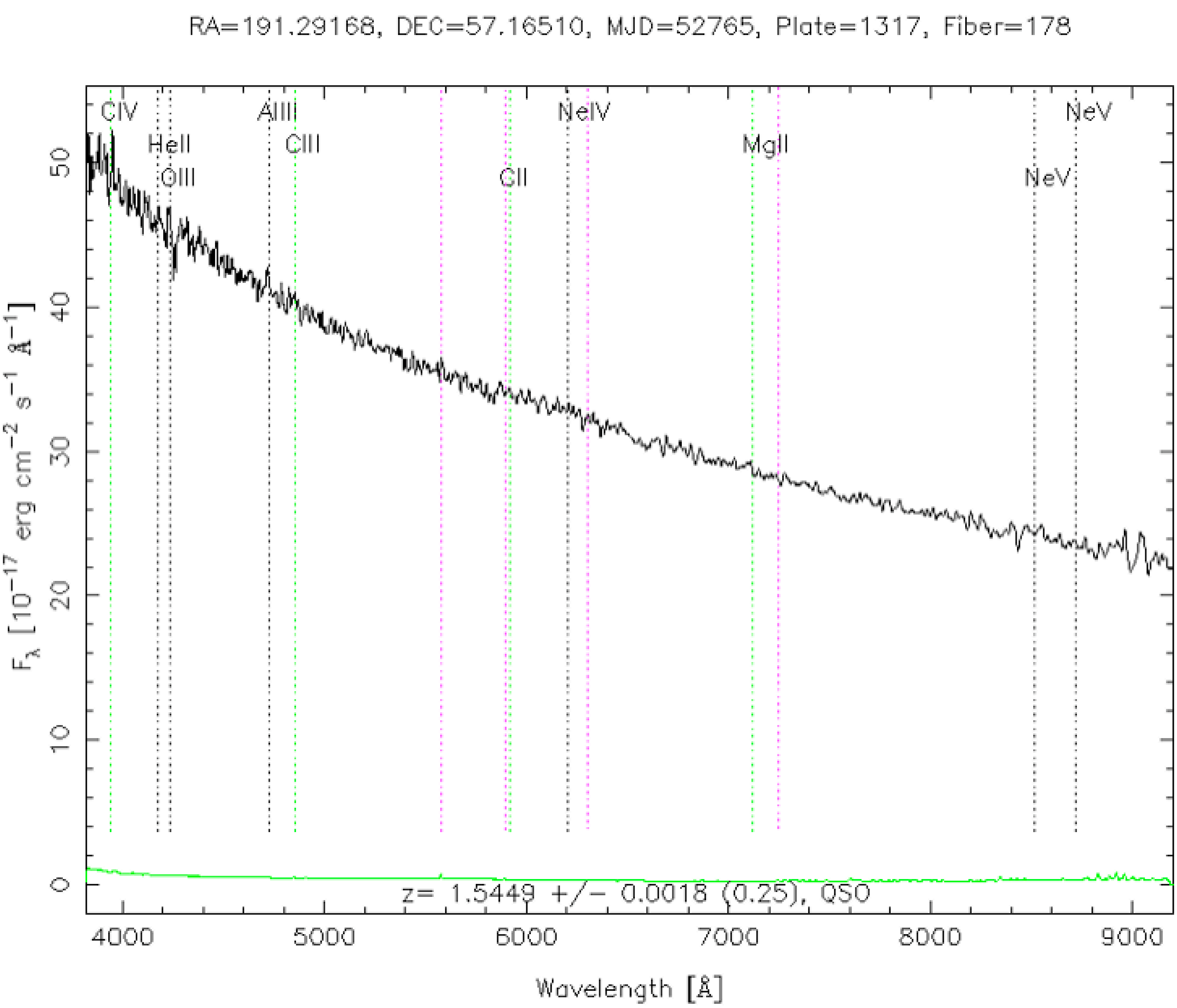

SkyServer DR4 Search
http://cas.sdss.org/dr4/en/tools/search/sql.asp
Google
Sloan Digital Sky Survey / SkyServer
SDSS
Home
Tools
Schema
Projects
Astronomy
SDSS
Credits
Download
Site Search
Help
DR4 Tools
Getting Started
Famous places
Get images
Scrolling sky
Visual Tools
Search
- Radial
- Rectangular
- Search Form
- Query Builder
- SQL
Object Crossid
CasJobs
SQL Search
Please Note:
1. To be fair to other users, queries run from SkyServer search tools are restricted in how long they can run and how much output they return, by timeouts and row limits. Please see the Query Limits help page. To run a query that is not restricted by a timeout or number of rows returned, please use the CasJobs batch query service.
2. For spatial queries using ra,dec limits, it is inefficient to use the constraints directly, e.g.:
SELECT ... FROM PhotoTag
WHERE (ra between ra1 AND ra2) AND (dec between dec1 AND dec2).
The efficient way to do spatial queries is with the built-in functions that we provide, which use our HTM (Hierarchical Triangular Mesh) spatial indexing to speed up the search by an order of magnitude:
SELECT ... FROM PhotoTag p, fGetObjFromRectEq(ra1,dec1,ra2,dec2) r
WHERE p.objid=r.objid
Please see the Optimizing Queries page and the Sample Queries page for more information.
select top 25 z, ra, dec,
mag_0, mag_1, mag_2, sn_0, sn_1, sn_2,
specClass, zConf
from specObj
where (specClass = 3 or SpecClass = 4) and
sn_1 > 10
Submit
Check Syntax Only?
Reset
Output Format
HTML
XML
CSV

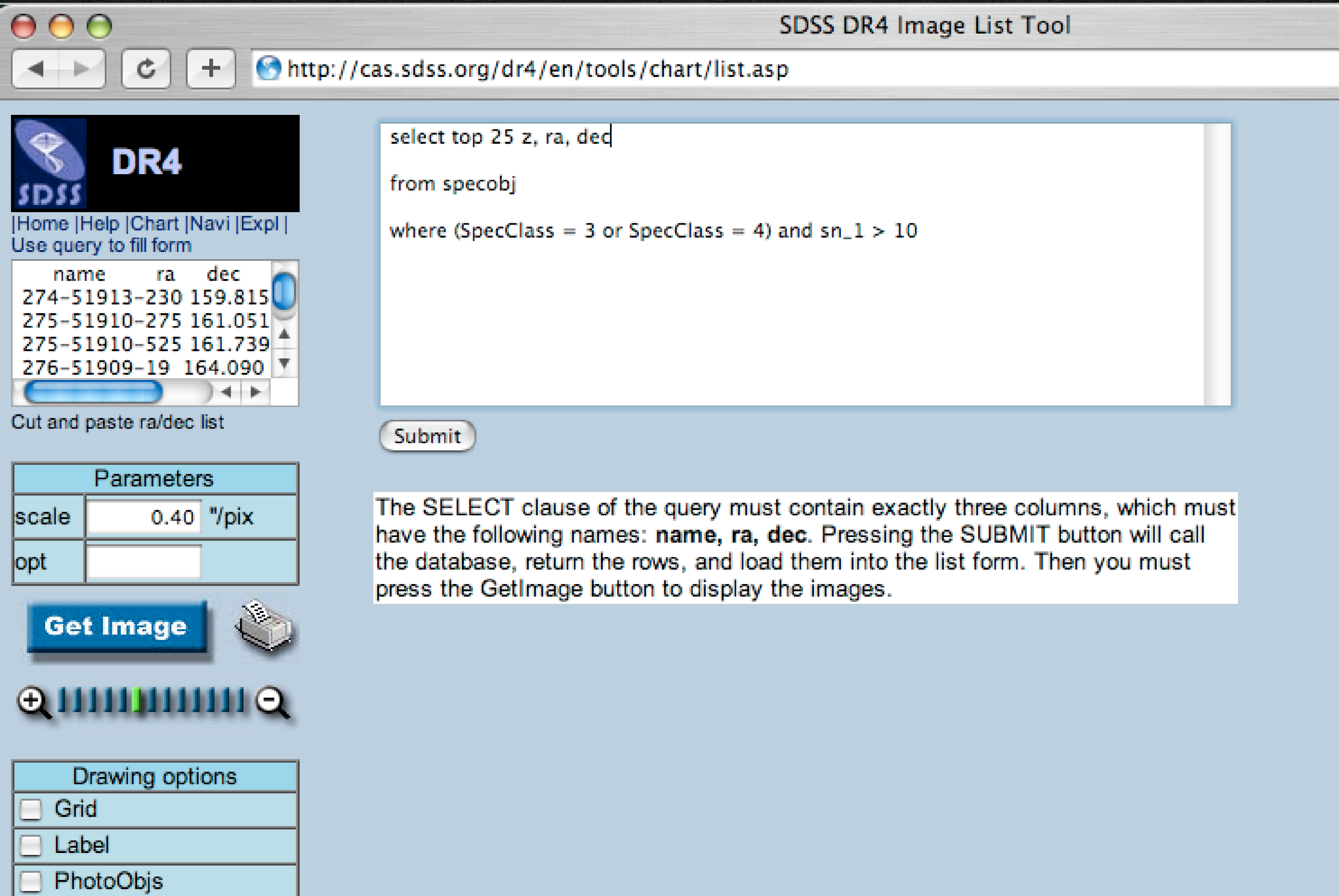
http://cas.sdss.org/dr4/en/tools/search/x_sql.asp

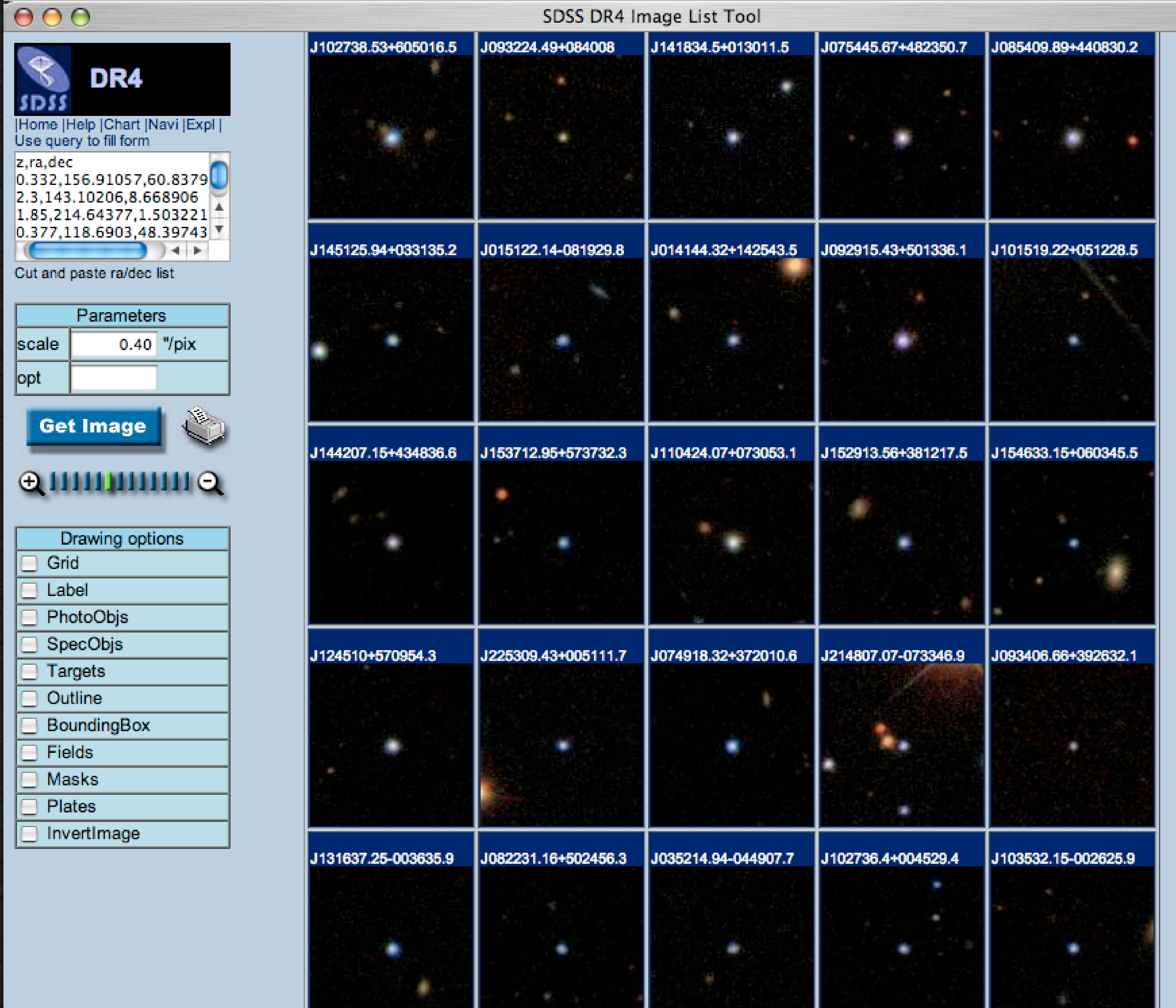
Your SQL command was:

```
select top 25 z, ra, dec,
mag_0, mag_1, mag_2, sn_0, sn_1, sn_2,
specClass, zConf
from specObj
where (specClass = 3 or SpecClass = 4) and
sn_1 > 10
```

z	ra	dec	mag_0	mag_1	mag_2	sn_0	sn_1	sn_2	specClass	zConf
1.391	222.85811	3.526447	18.898	18.574	18.496	14.272	18.256	14.955	3	0
1.545	191.29168	57.165099	17.695	17.355	17.13	24.905	31.644	30.705	3	0.254
4.395	197.42234	11.427833	20.358	18.98	18.219	5.567	14.216	17.922	3	0
0.37	142.31433	50.226704	17.372	16.998	16.736	24.515	30.804	30.149	3	0
0.39	179.72657	9.619919	18.795	18.486	18.287	12.208	16.001	15.024	3	0.211
0.673	220.5298	43.81019	18.429	18.078	17.849	18.901	23.909	23.008	3	0
0.768	327.0295	-7.563045	18.95	18.636	18.422	14.608	19.666	18.062	3	0.056
0.923	234.30397	57.625665	19.239	19.271	19.397	8.986	10.3	7.565	3	0.95
0.93	199.15525	-0.609992	18.652	18.337	18.346	16.563	23.143	19.996	3	0.65
1.062	232.30654	38.204876	18.85	18.625	18.469	15.214	18.962	17.803	3	0.246
1.305	236.63813	6.06265	19.443	19.151	19.078	9	12.649	10.315	3	0.213
0.044	143.52779	39.442272	19.009	18.636	18.337	13.263	17.407	16.869	3	0.085
0.899	125.62985	50.415639	19.546	19.372	19.456	11.553	12.898	9.235	3	0.289
0.899	58.062261	-4.818806	19.75	19.412	19.388	7.965	10.653	8.885	3	0.311
0.913	156.90169	0.758178	19.483	19.338	19.365	8.456	10.193	8.479	3	0.95
0.917	158.88399	-0.440529	19.148	18.93	18.941	10.12	13.028	11.091	3	0.314
0.917	170.93451	4.563568	19.463	19.239	19.198	9.526	11.793	9.527	3	0.344
0.919	222.46623	59.812517	19.44	19.327	19.459	11.484	12.981	9.352	3	0.295


RA=191.29168, DEC=57.16510, MJD=52765, Plate=1317, Fiber=178
CIV
HeII
OIII
AlIII
CIII
CII
NeIV
MgII
NeV
NeV
z= 1.5449 +/- 0.0018 (0.25), QSO
F_λ [10^{-17} erg cm^{-2} s^{-1} Å^{-1}]
Wavelength [Å]
0
10
20
30
40
50
4000
5000
6000
7000
8000
9000


SDSS DR4 Image List Tool
http://cas.sdss.org/dr4/en/tools/chart/list.asp
DR4
SDSS
|Home |Help |Chart |Navi |Expl |
Use query to fill form
name ra dec
274-51913-230 159.815
275-51910-275 161.051
275-51910-525 161.739
276-51909-19 164.090
Cut and paste ra/dec list
Parameters
scale 0.40 "/pix
opt
Get Image
Drawing options
Grid
Label
PhotoObjs
select top 25 z, ra, dec
from specobj
where (SpecClass = 3 or SpecClass = 4) and sn_1 > 10
Submit
The SELECT clause of the query must contain exactly three columns, which must have the following names: name, ra, dec. Pressing the SUBMIT button will call the database, return the rows, and load them into the list form. Then you must press the GetImage button to display the images.


SDSS DR4 Image List Tool
DR4
SDSS
|Home |Help |Chart |Navi |Expl |
Use query to fill form
z,ra,dec
0.332,156.91057,60.8379
2.3,143.10206,8.668906
1.85,214.64377,1.503221
0.377,118.6903,48.39743
Cut and paste ra/dec list
Parameters
scale
0.40
"/pix
opt
Get Image
Drawing options
Grid
Label
PhotoObjs
SpecObjs
Targets
Outline
BoundingBox
Fields
Masks
Plates
InvertImage
J102738.53+605016.5
J093224.49+084008
J141834.5+013011.5
J075445.67+482350.7
J085409.89+440830.2
J145125.94+033135.2
J015122.14-081929.8
J014144.32+142543.5
J092915.43+501336.1
J101519.22+051228.5
J144207.15+434836.6
J153712.95+573732.3
J110424.07+073053.1
J152913.56+381217.5
J154633.15+060345.5
J124510+570954.3
J225309.43+005111.7
J074918.32+372010.6
J214807.07-073346.9
J093406.66+392632.1
J131637.25-003635.9
J082231.16+502456.3
J035214.94-044907.7
J102736.4+004529.4
J103532.15-002625.9

SDSS DR4 Navigate Tool
DR4
SDSS
|Home |Help |Chart |List |Expl |
Parameters
ra
156.91057
deg
dec
60.837921
deg
opt
Get Image
Drawing options
Grid
Label
PhotoObjs
SpecObjs
Targets
Outline
BoundingBox
Fields
Masks
Plates
InvertImage
N
E
W
S
156.91057, 60.83792
Selected object
ra 156.91056
dec 60.83793
type STAR
u 17.78
g 17.53
r 17.31
i 17.22
z 16.87
Explore
Recenter
Add to notes
Show notes

SkyServer Object Explorer

DR4 SDSS

Explore Home

Search by
ObjId
Ra,dec
5-part SDSS
Plate-MJD-Fiber
SpecObjId

Summary

PhotoObj
More Observations
Field
Frame
PhotoZ
Neighbors
Finding chart
Navigate
FITS

SpecObj
All Spectra
SpecLine
SpecLineIndex
XCredShift
ELredShift
Spectrum
Plate
FITS

NED search
SIMBAD search
ADS search

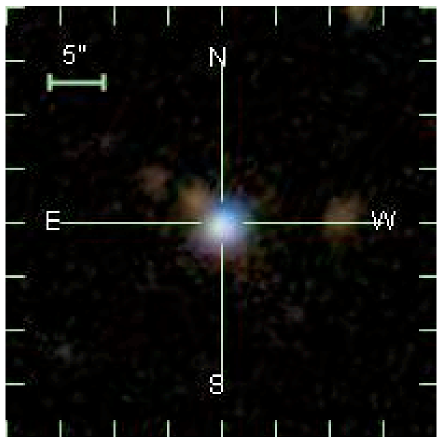
Notes
Save in Notes
Show Notes

Print

SDSS J102738.53+605016.5

STAR ra=156.910563, dec=60.837925, ObjId = 587725472808173616

mode	PRIMARY
status	TARGET PRIMARY OK_STRIPE OK_SCANLINE PSEGMENT RESOLVED OK_RUN GOOD SET
flags	BINNED1 CHILD
PrimTarget	TARGET_ROSAT_D TARGET_ROSAT_C TARGET_ROSAT_B TARGET_ROSAT_A TARGET_QSO_FIRST_CAP TARGET_QSO_CAP TARGET_QSO_HIZ
SecTarget	



run	rerun	camcol	field	obj	rowc	colc
1332	40	1	46	48	756.7	799.0

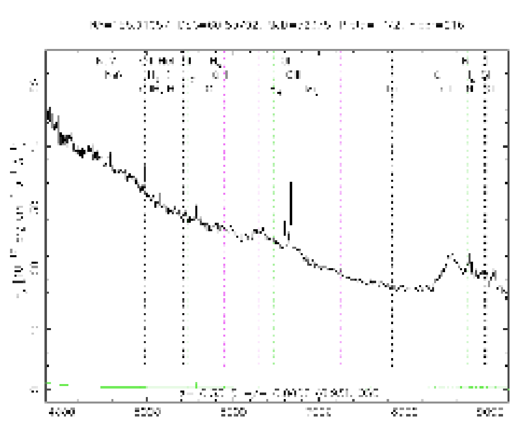
u	g	r	i	z
17.78	17.53	17.31	17.22	16.87

fiberMag_r	petroMag_r	devMag_r	expMag_r	psfMag_r	modelMag_r
17.70	17.31	17.31	17.32	17.39	17.31

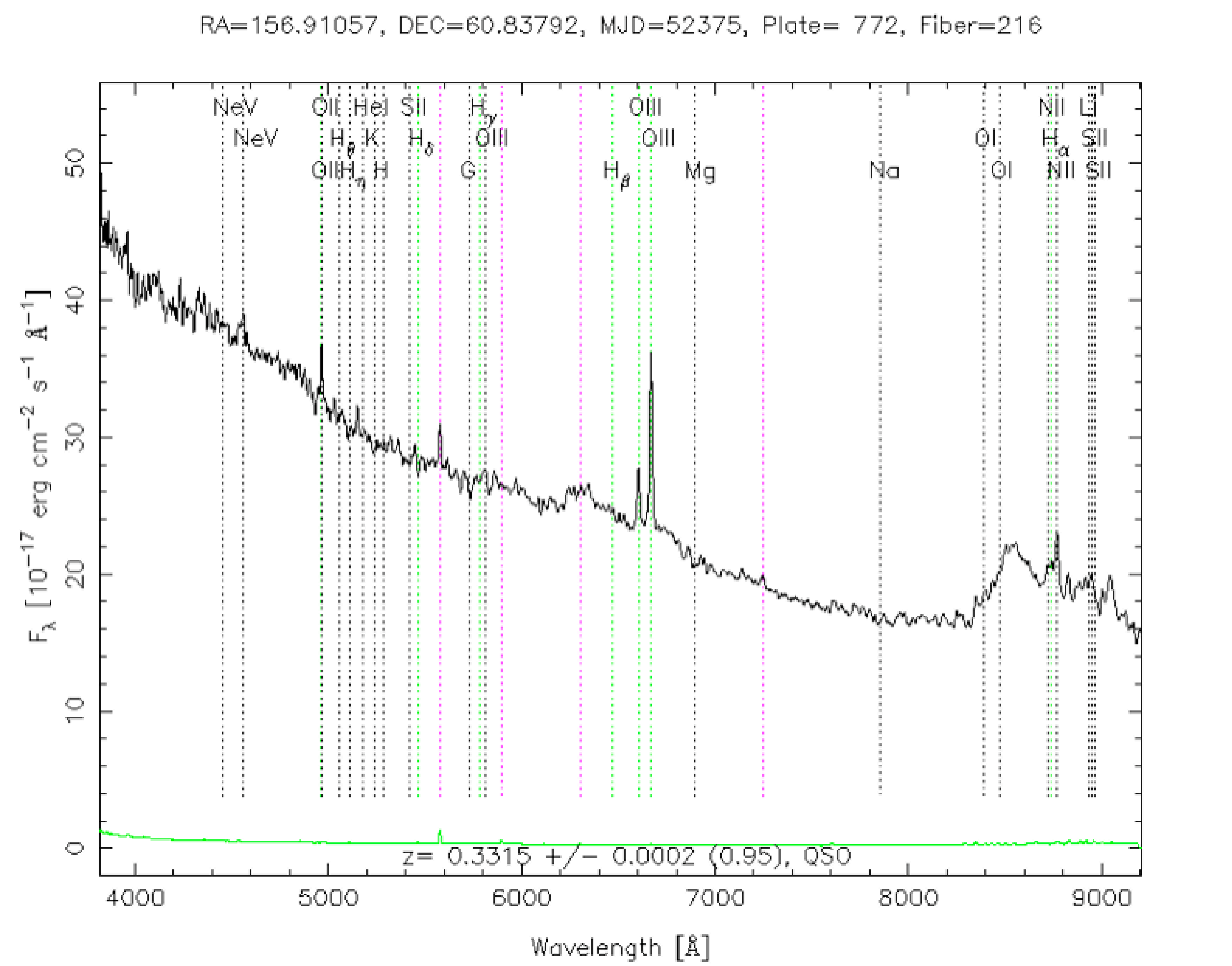
extinction_r	petroRad_r	parentId	nChild
0.02	1.604	587725472808173615	0

SpecObjID = 217523631838724096

plate	mjd	fiberId	z	zErr	zConf	specClass	ra	dec	fiberMag_r	objId
772	52375	216	0.332	0.00016	0.95	QSO	156.91057	60.83792	17.59	587725472808173616



zStatus	FAILED
zWarning	NOT_QSO
PrimTarget	TARGET_ROSAT_D TARGET_ROSAT_C TARGET_ROSAT_B TARGET_QSO_CAP TARGET_QSO_HIZ
SecTarget	
eClass	0.587
emZ	0.331
emConf	0.751
xcZ	5.996
xcConf	0.179



RA=156.91057, DEC=60.83792, MJD=52375, Plate= 772, Fiber=216
NeV
NeV
OII
OII
HeI
K
H
SII
G
OIII
OIII
OIII
Mg
Na
OI
OI
NII
NII
SII
SII
z= 0.3315 +/- 0.0002 (0.95), QSO
Wavelength [Å]

the shape of a quasar emission line on a plot of flux *versus* wavelength is called the *profile*

if all the emitting gas were quiescent (no relative motion), then the line would look like a narrow spike

$\Rightarrow$ analysis of the profile tells us about the *velocity distribution of the emitting gas*

The velocity distribution of the emitting gas could be due to pressure of some sort (like weather, winds). For example, gas in the Milky Way is pushed around by the expanding shells of supernovae.

If there is no pressure, gas in a circular orbit around a mass M at radius R would have a velocity

$$v^2 = G M / R$$

where G is Newton’s gravitational constant

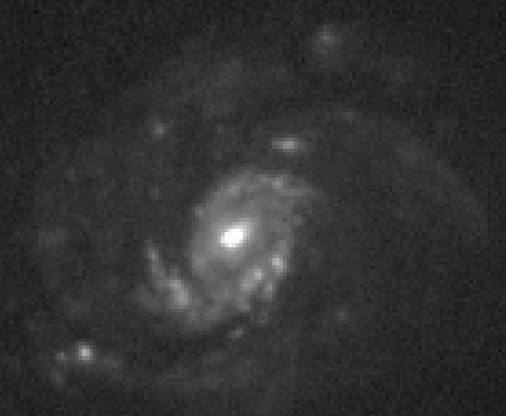
v for Earth orbiting the Sun = 30 km/sec

v for Sun orbiting the center of the Milky Way = 220 km/sec

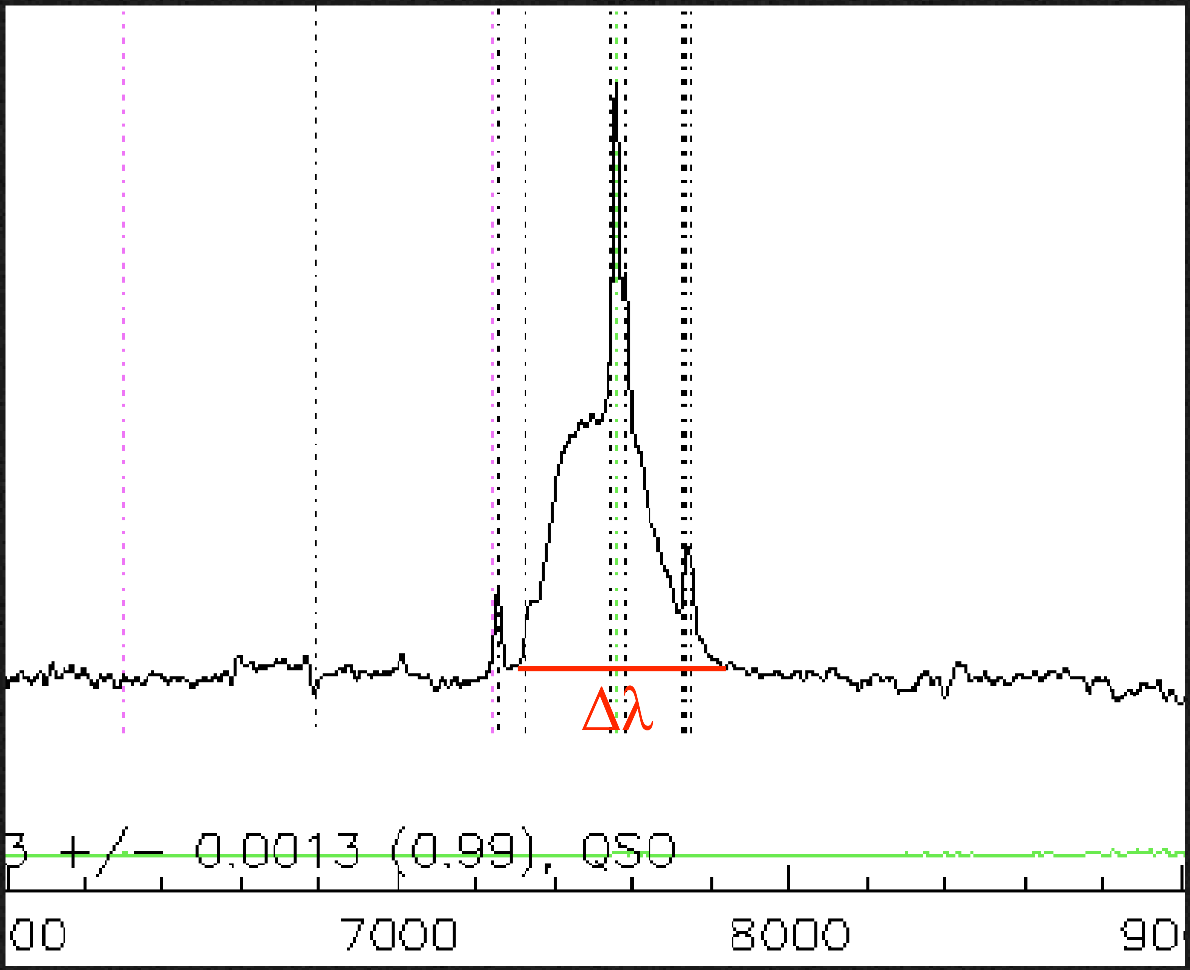
The *Doppler shift* allows us to determine the velocity from a measurement of the observed wavelength.

The Doppler shift only measures the part of the velocity that is along the line-of-sight.

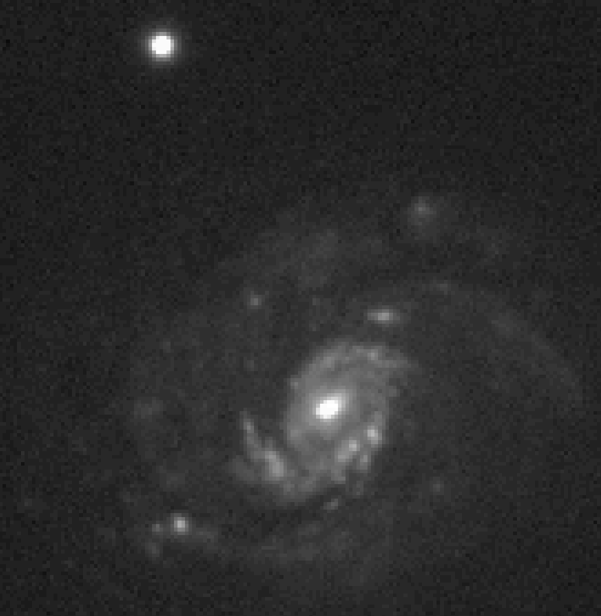
By convention, positive means motion away from us, negative means motion towards us.



how fast is the gas moving inside this quasar?



$v / c = \Delta\lambda / \lambda$



$\Delta\lambda = 600$ Å, $\lambda = 7600$ Å

$v / c = \Delta\lambda / \lambda = 0.08$

$v = 24{,}000$ km/sec (!)

If we can find the quasars with the widest lines, we would find the ones with gas moving at the highest velocities.

This is interesting because we would then be looking relatively close to the central black hole: high v means a high value for the quantity M/R (*if* the motion is due to gravity).

What do we know about quasars with the widest lines?

double-peaked line profile for Arp 102B: evidence for an *accretion disk*?

Chen, Halpern, and Filippenko 1989

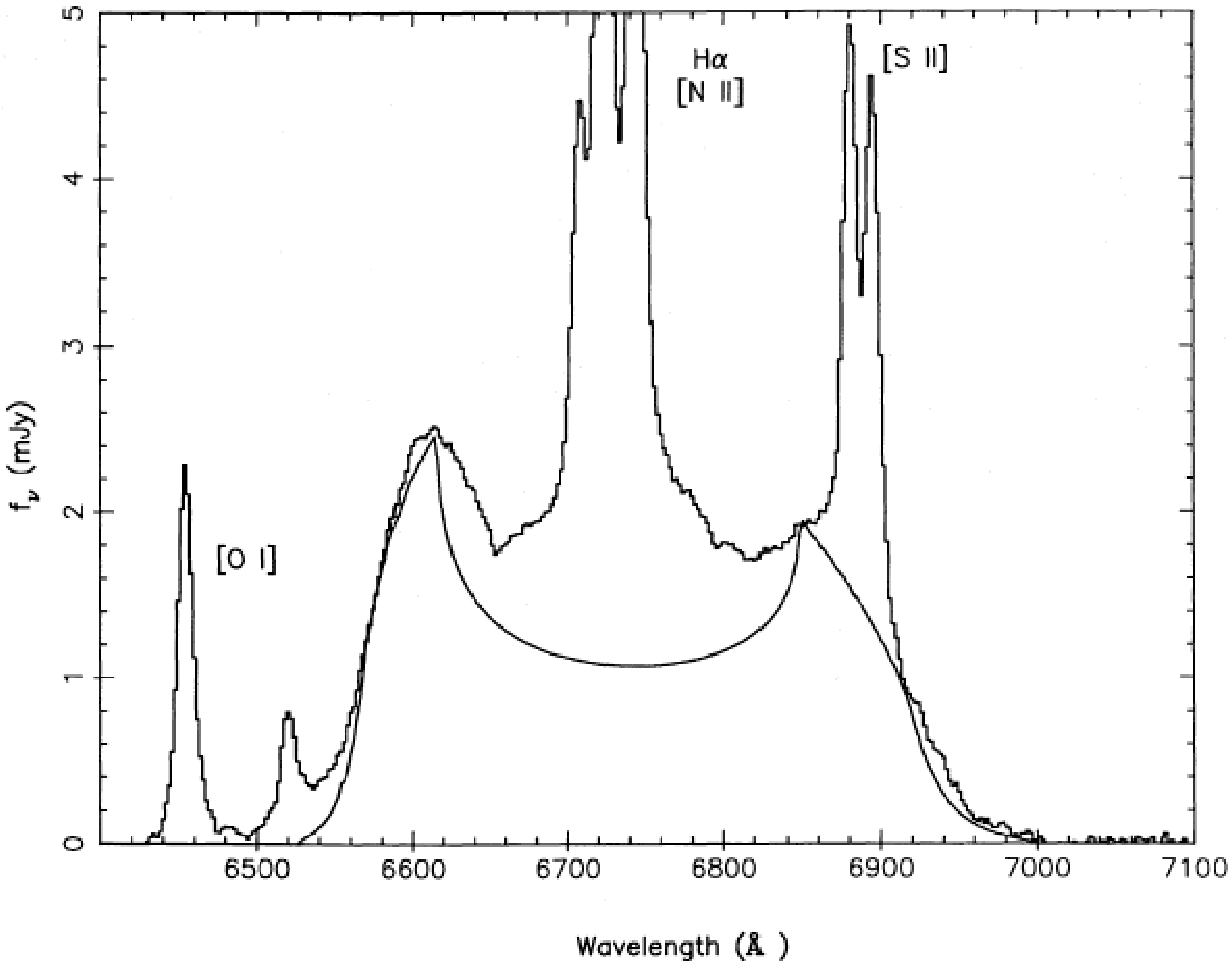
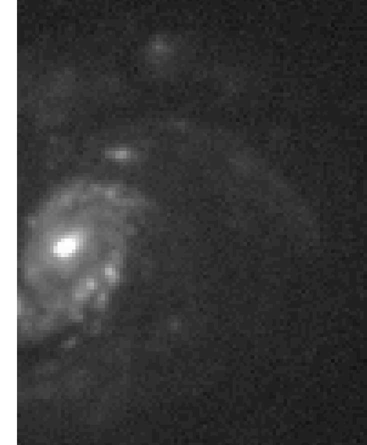
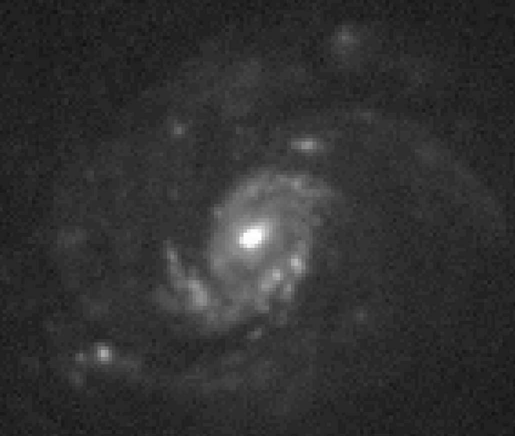


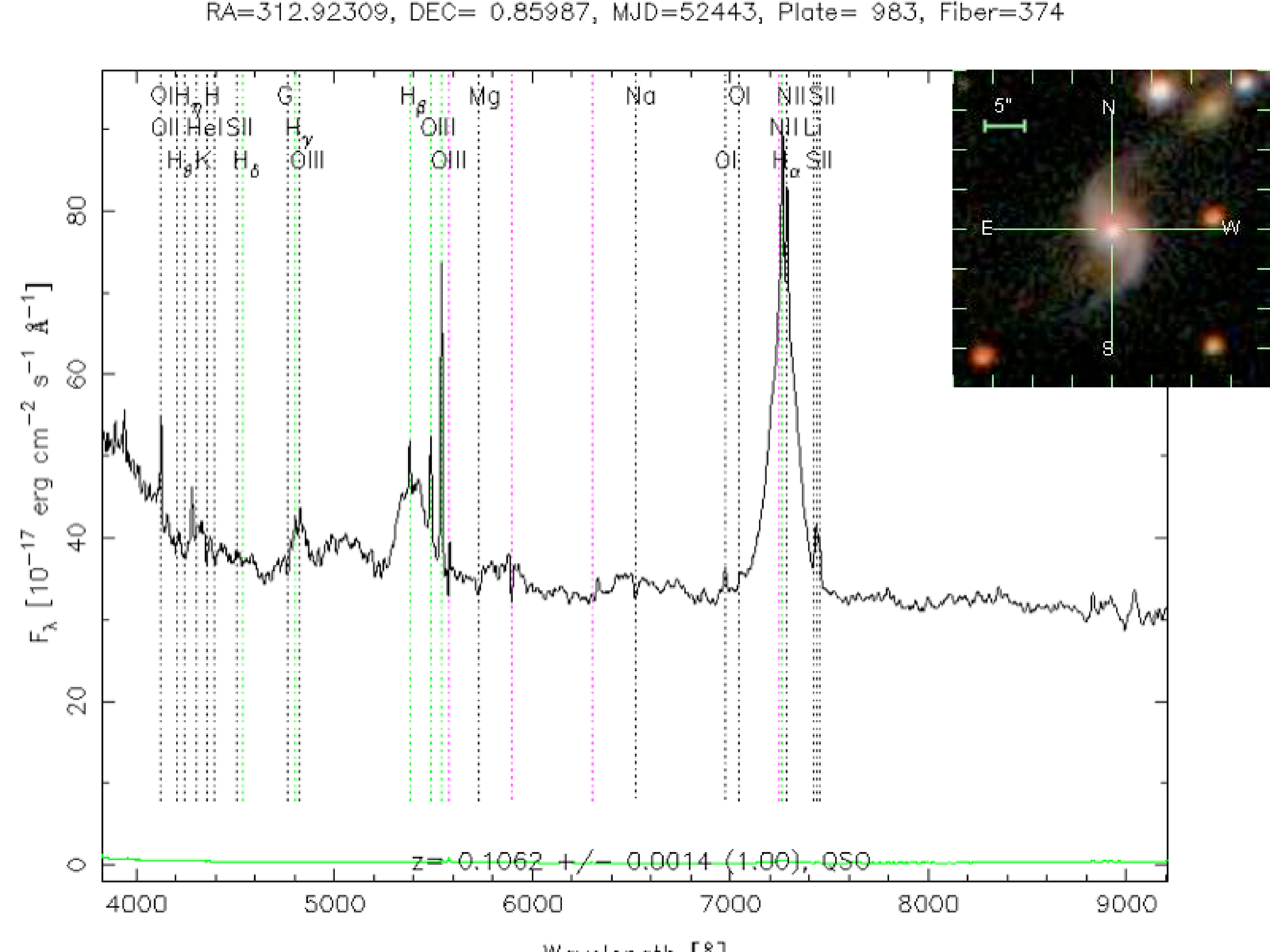
FIG. 3.—The parameters of the fit are $i = 33\overset{\circ}{.}5$, $q = 3.0$ for $450 < \xi < 1020$, and $q = -3.0$ for $250 < \xi < 450$. Observed wavelength is plotted.



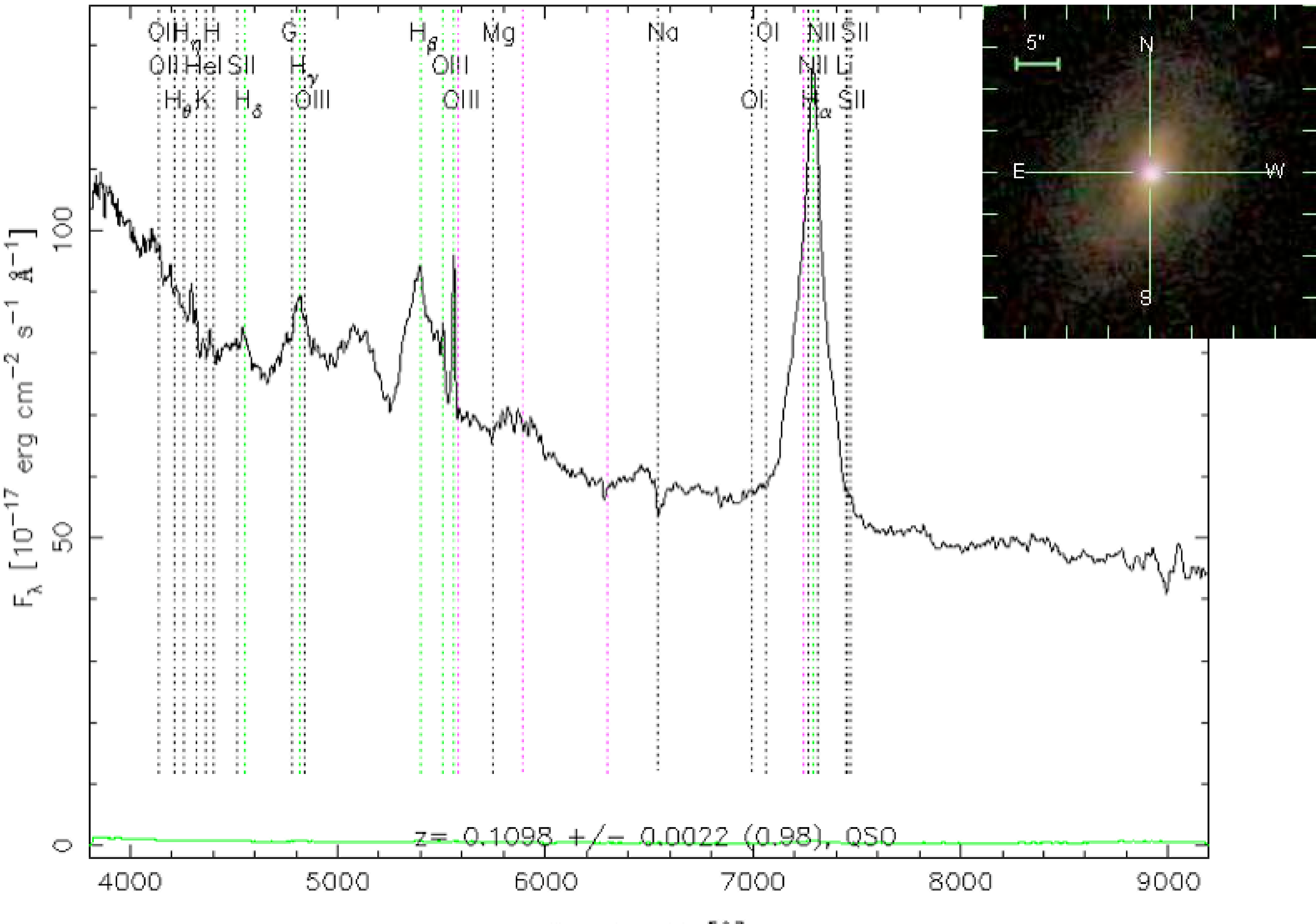
this query finds broad Hα emission lines:

```
SELECT S.z, S.ra, S.dec, S.plate, S.mjd, S.fiberid,
S.mag_0, S.mag_1, S.mag_2,
S.zConf,
L.continuum, L.height, L.sigma, L.ew

FROM specobj as S, specline as L

WHERE L.specobjid = S.specobjid and
(S.z between 0.1 and 0.36) and
L.lineID = 6565 and L.category = 2 and
L.height > 3 and L.sigma > 50 and
S.sn_1 > 15
```

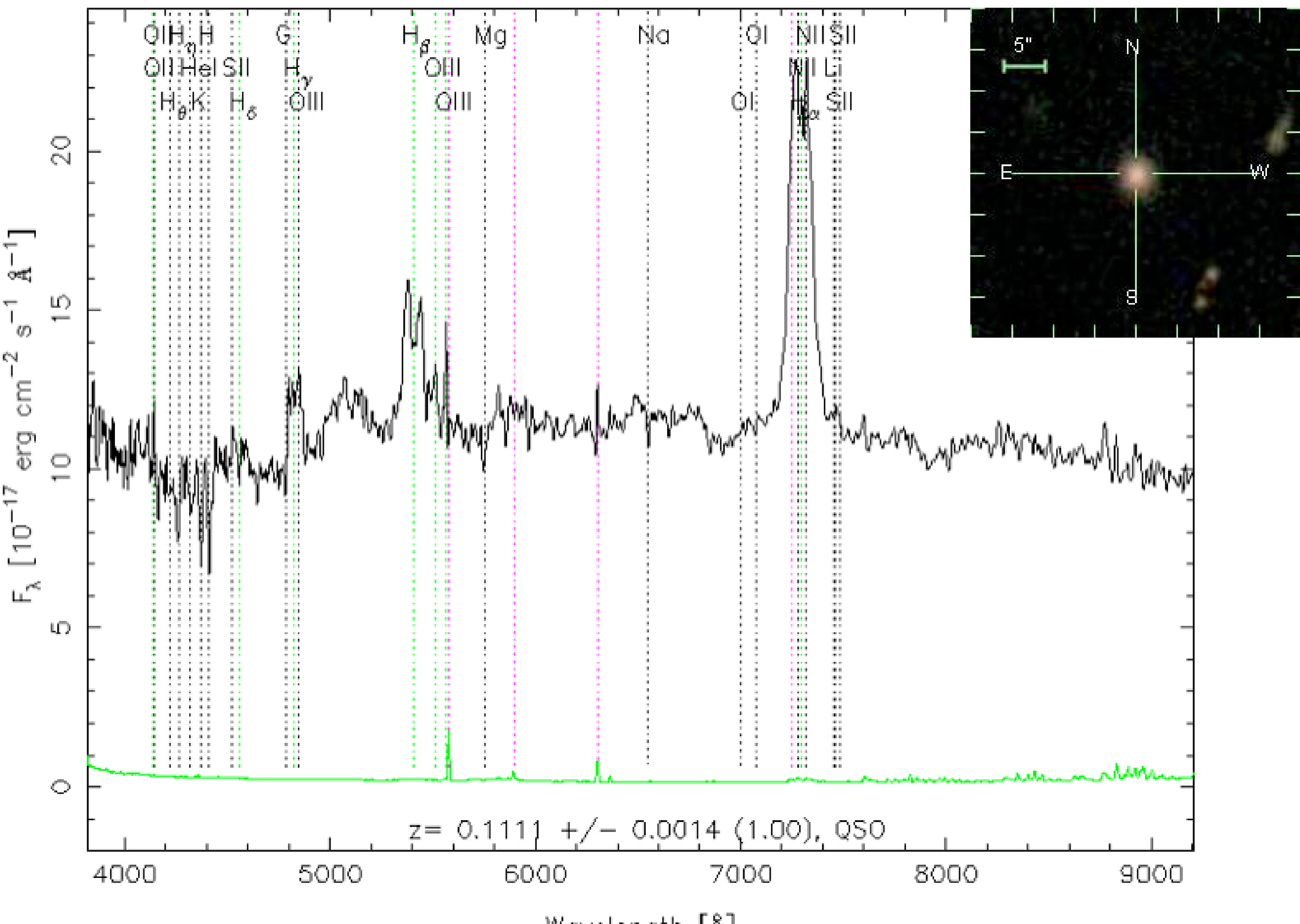



RA=312.92309, DEC= 0.85987, MJD=52443, Plate= 983, Fiber=374
OI H H
OII HeI SII
H_δ K
H_δ
G
H_γ
OIII
H_β
OIII
OIII
Mg
Na
OI
OI
NII SII
NII Li
H_α SII
5"
N
E
W
S
F_λ [10^{-17} erg cm^{-2} s^{-1} Å^{-1}]
0
20
40
60
80
4000
5000
6000
7000
8000
9000
z= 0.1062 +/- 0.0014 (1.00), QSO

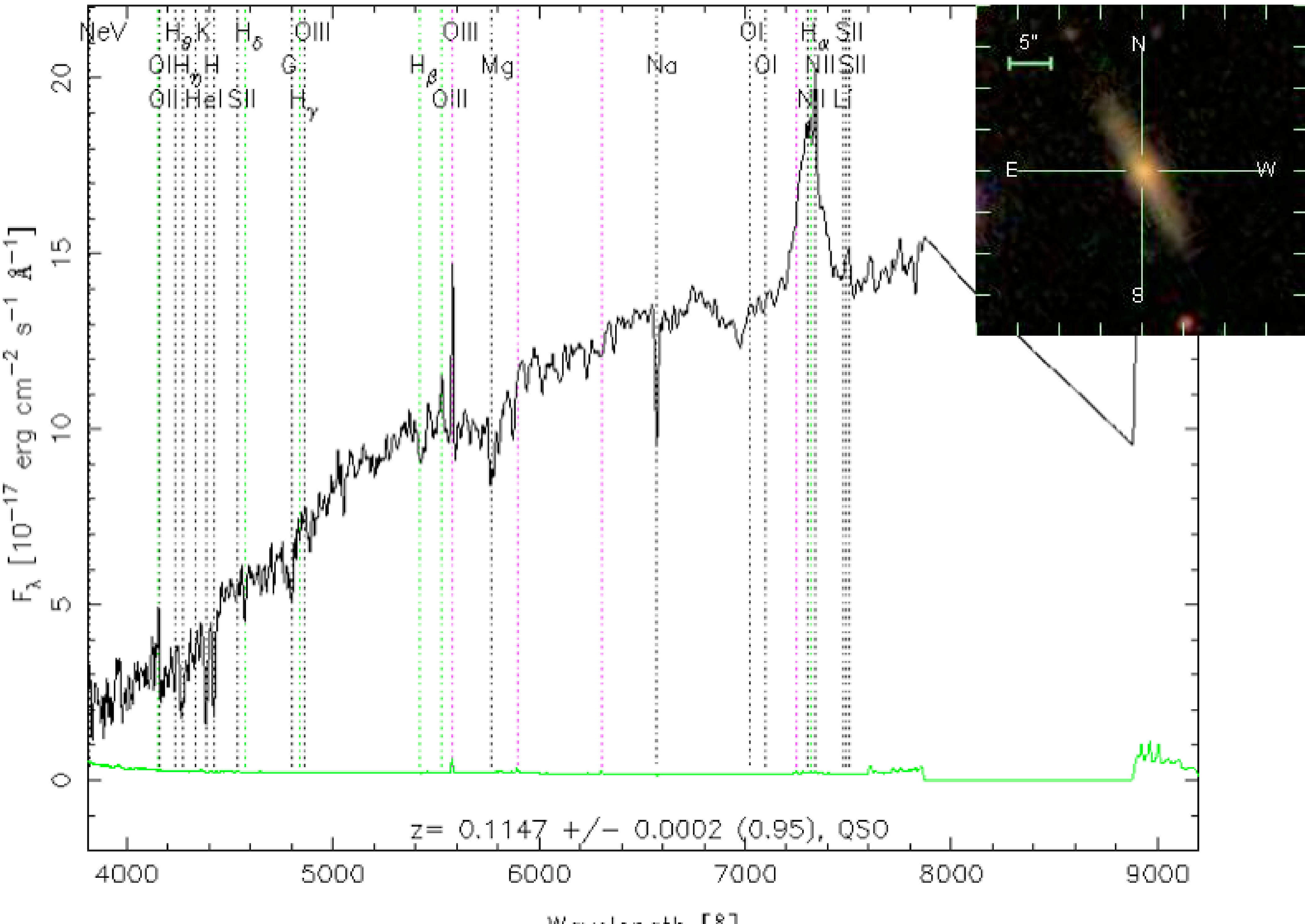
RA=237.72153, DEC= 5.35338, MJD=53172, Plate=1822, Fiber=308



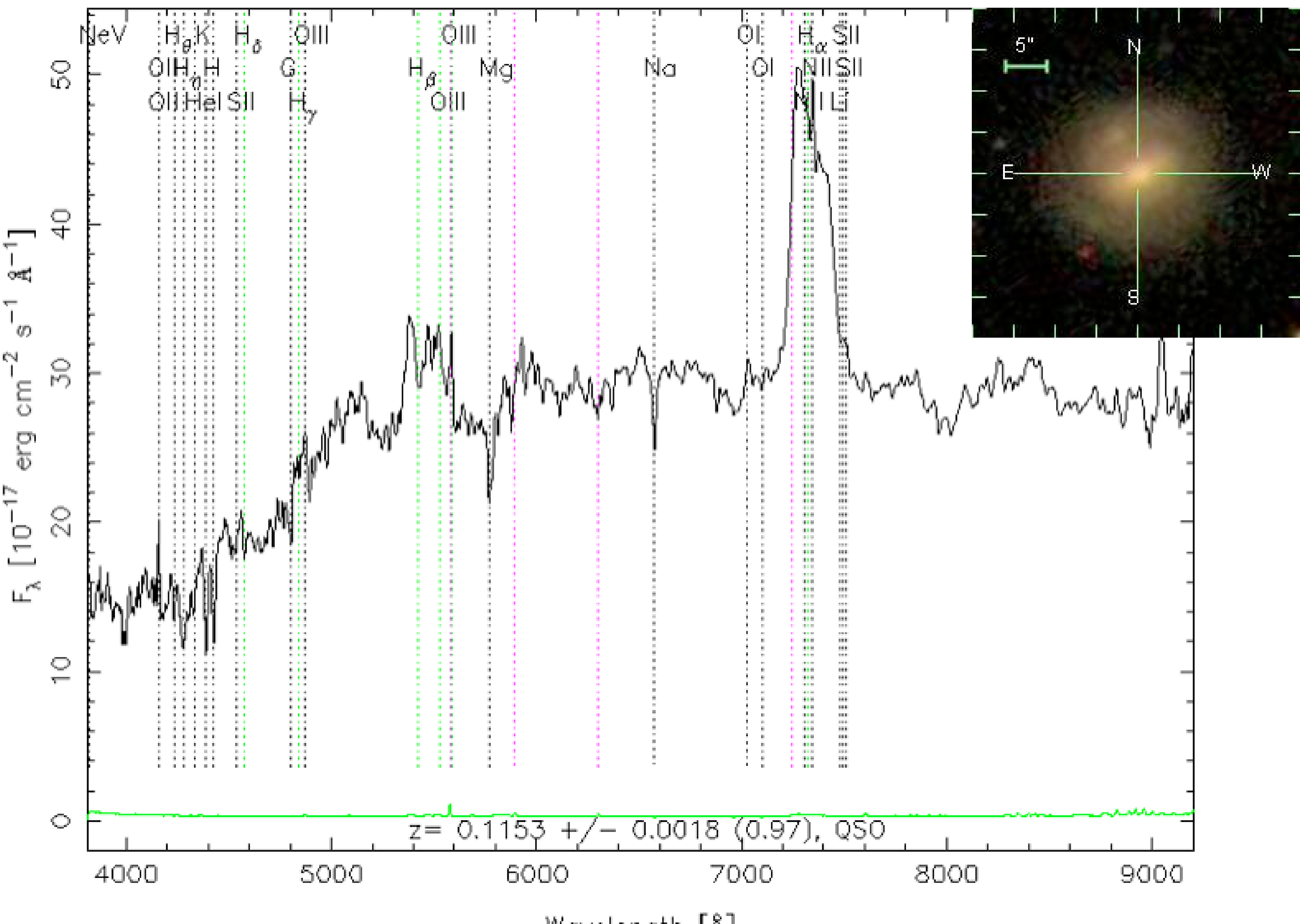
RA=326.47932, DEC=12.17616, MJD=52221, Plate= 732, Fiber=606

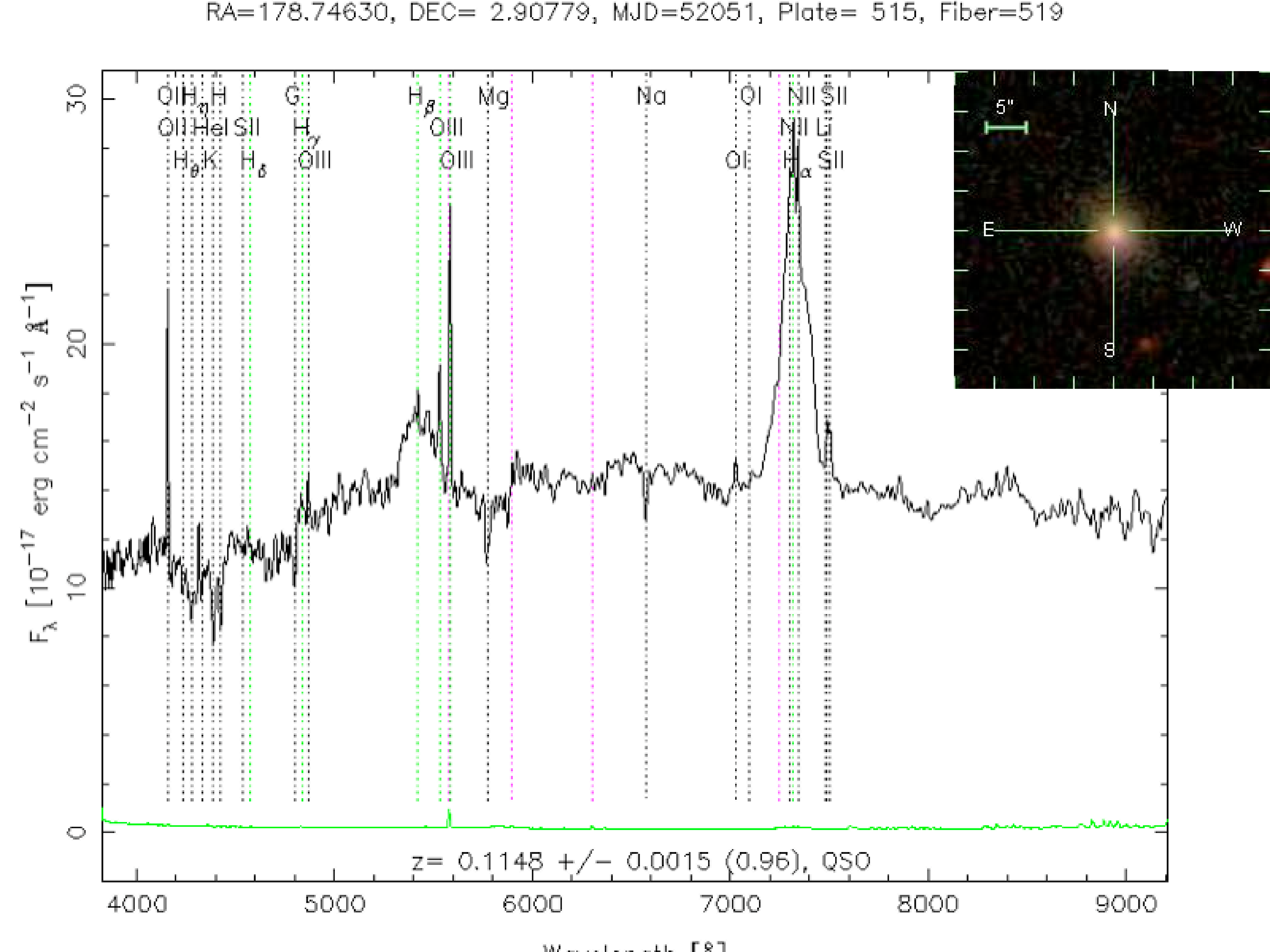


RA=228.44038, DEC=35.55359, MJD=53083, Plate=1353, Fiber=175

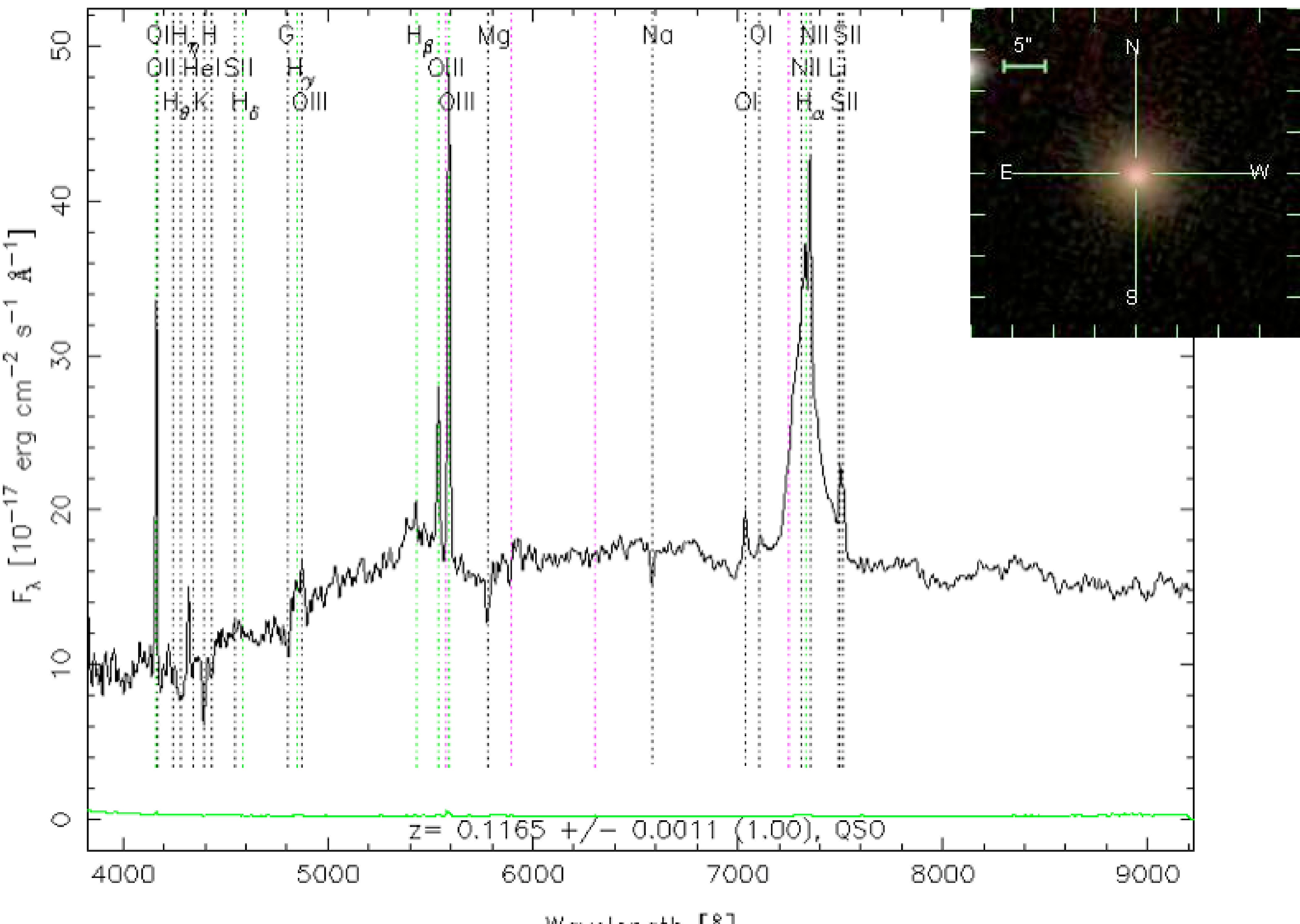


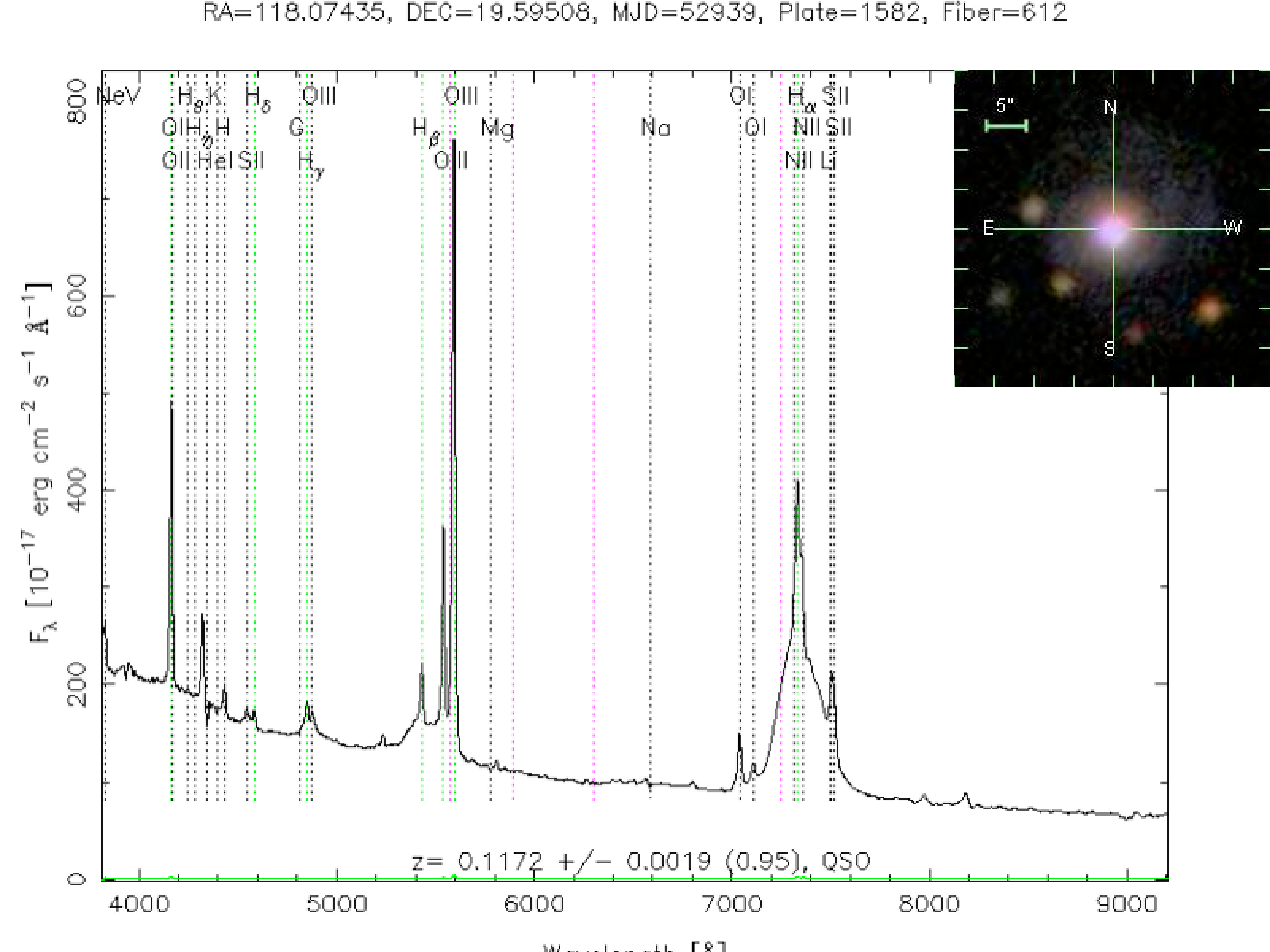
RA=236.26209, DEC=35.30507, MJD=52872, Plate=1402, Fiber=590

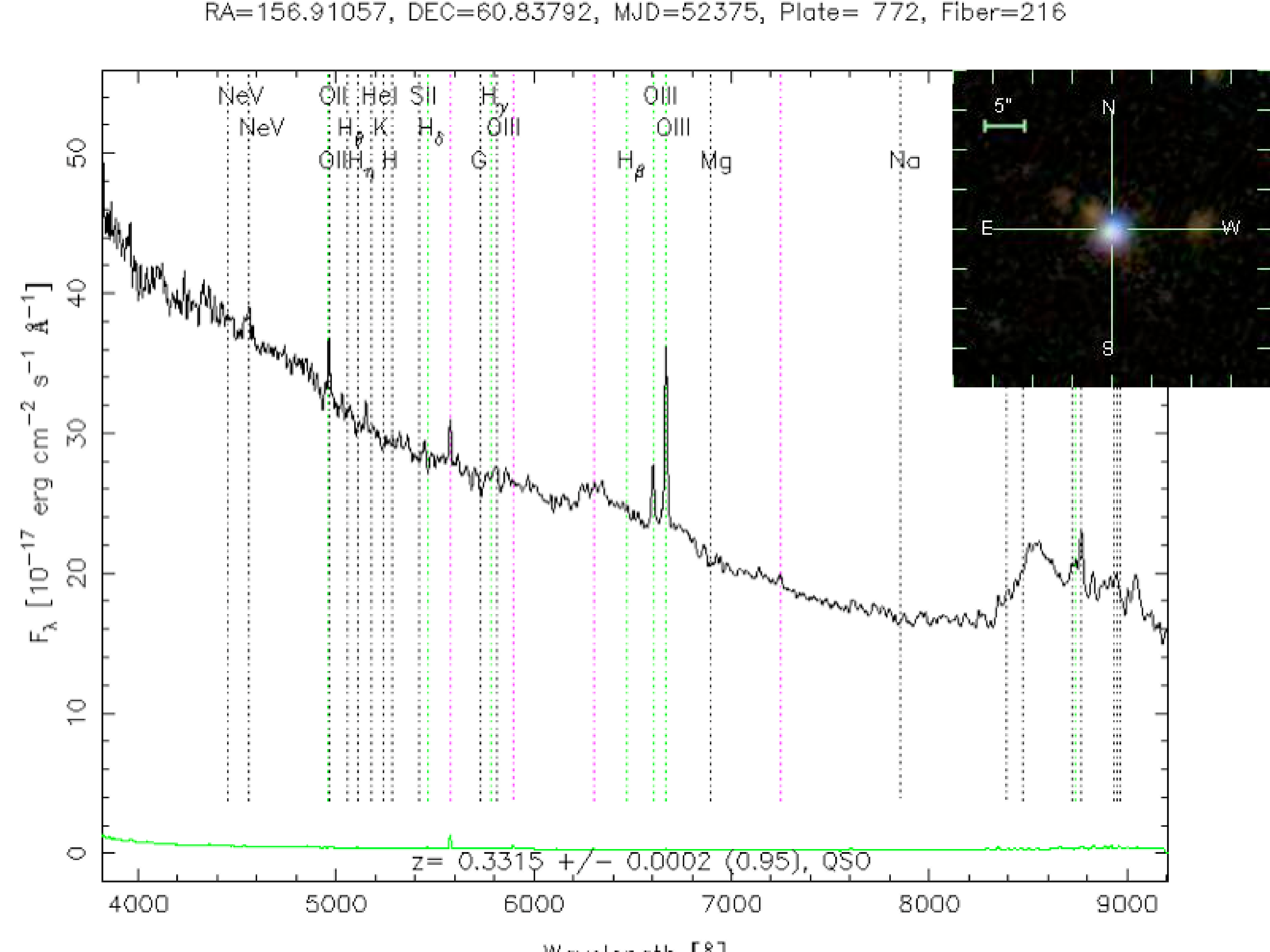


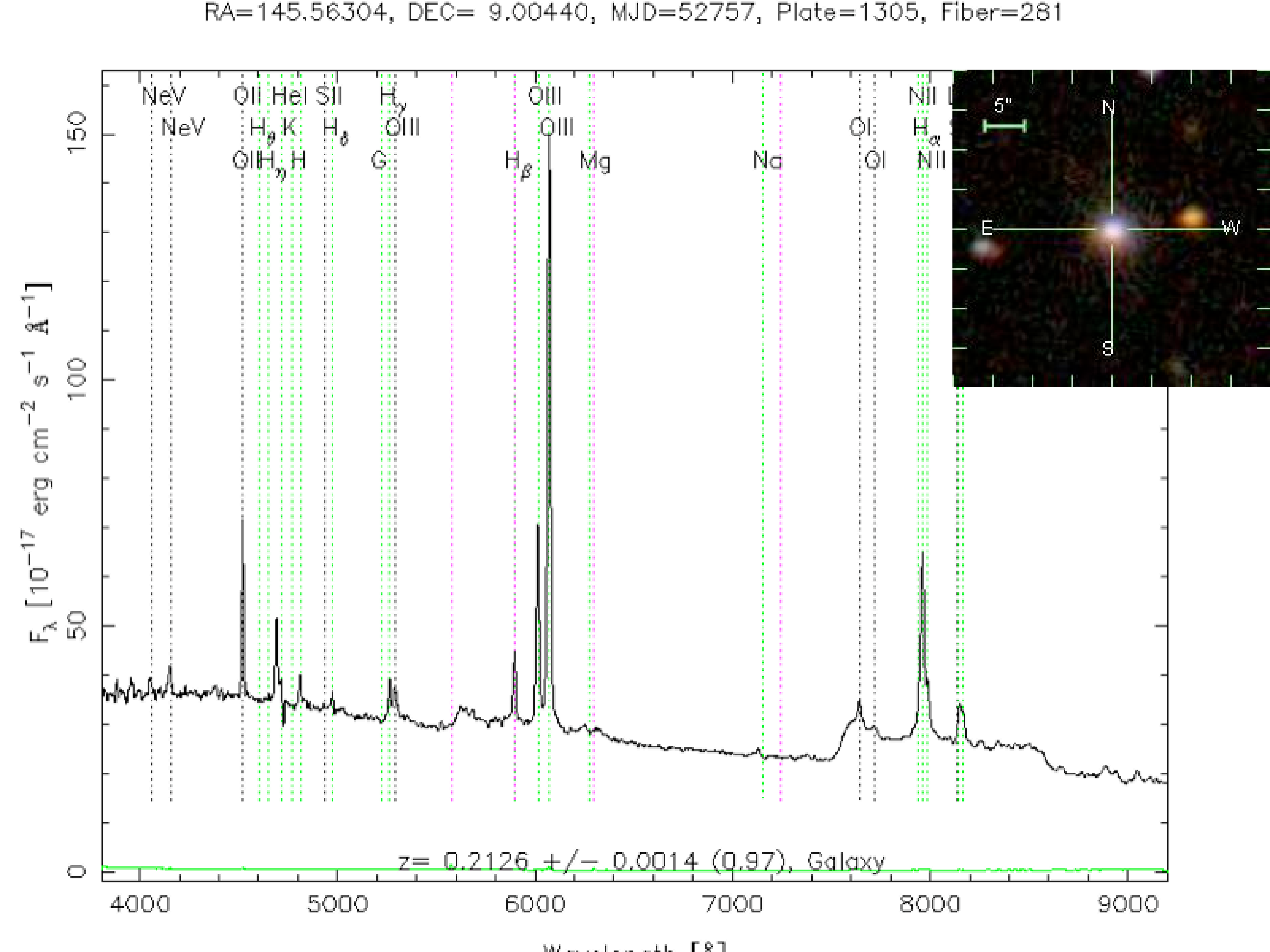

RA=178.74630, DEC= 2.90779, MJD=52051, Plate= 515, Fiber=519
OII Hη H
OII HeI SII
Hθ K Hδ
G
Hγ
OIII
Hβ
OIII
OIII
Mg
Na
OI
OI
NII SII
NII Li
Hα SII
5"
N
E
W
S
30
20
10
0
F_λ [10^-17 erg cm^-2 s^-1 Å^-1]
z= 0.1148 +/- 0.0015 (0.96), QSO
4000
5000
6000
7000
8000
9000

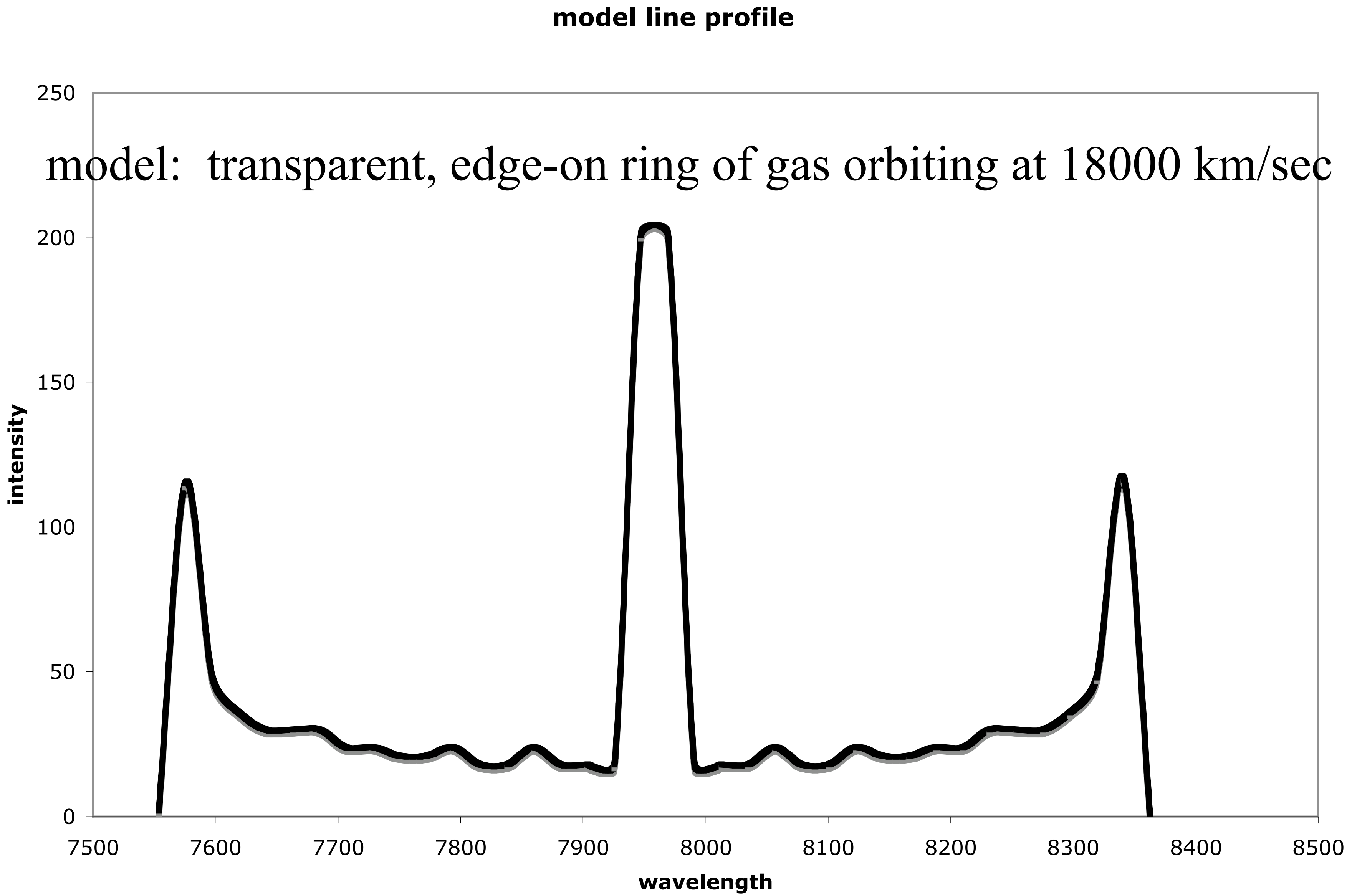
RA=159.68353, DEC=39.13444, MJD=53003, Plate=1432, Fiber=128



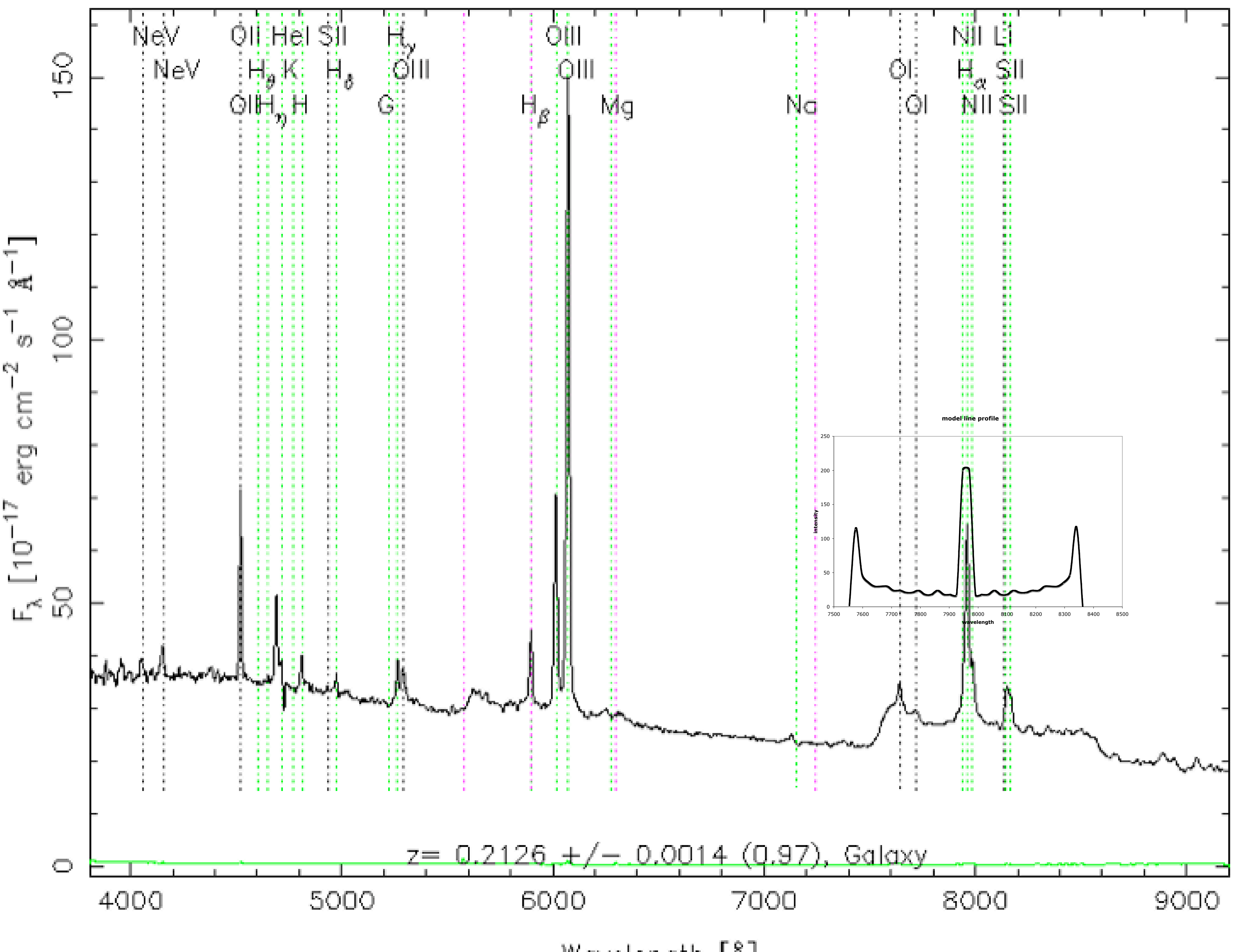

RA=118.07435, DEC=19.59508, MJD=52939, Plate=1582, Fiber=612
NeV
OII
OII
H_θ K
H_η H
HeI
H_δ
SII
G
OIII
H_γ
H_β
OIII
OIII
Mg
Na
OI
OI
H_α
NII
NII
SII
SII
Li
5"
N
E
W
S
z= 0.1172 +/- 0.0019 (0.95), QSO
F_λ [10^{-17} erg cm^{-2} s^{-1} Å^{-1}]
0
200
400
600
800
4000
5000
6000
7000
8000
9000
Wavelength [Å]


RA=156.91057, DEC=60.83792, MJD=52375, Plate= 772, Fiber=216
NeV
NeV
OII
OII
H_β
H_η
HeI
K
H
SII
H_δ
H_γ
OIII
G
OIII
OIII
H_β
Mg
Na
5"
N
E
W
S
F_λ [10^{-17} erg cm^{-2} s^{-1} Å^{-1}]
0
10
20
30
40
50
4000
5000
6000
7000
8000
9000
z= 0.3315 +/- 0.0002 (0.95), QSO


RA=145.56304, DEC= 9.00440, MJD=52757, Plate=1305, Fiber=281
NeV
NeV
OII
HeI
SII
OII
K
H
G
OIII
OIII
Mg
Na
OI
OI
NII
NII
5"
N
E
W
S
150
100
50
0
z= 0.2126 +/- 0.0014 (0.97), Galaxy
4000
5000
6000
7000
8000
9000


model line profile
model: transparent, edge-on ring of gas orbiting at 18000 km/sec
250
200
150
100
50
0
intensity
7500
7600
7700
7800
7900
8000
8100
8200
8300
8400
8500
wavelength

RA=145.56304, DEC= 9.00440, MJD=52757, Plate=1305, Fiber=281



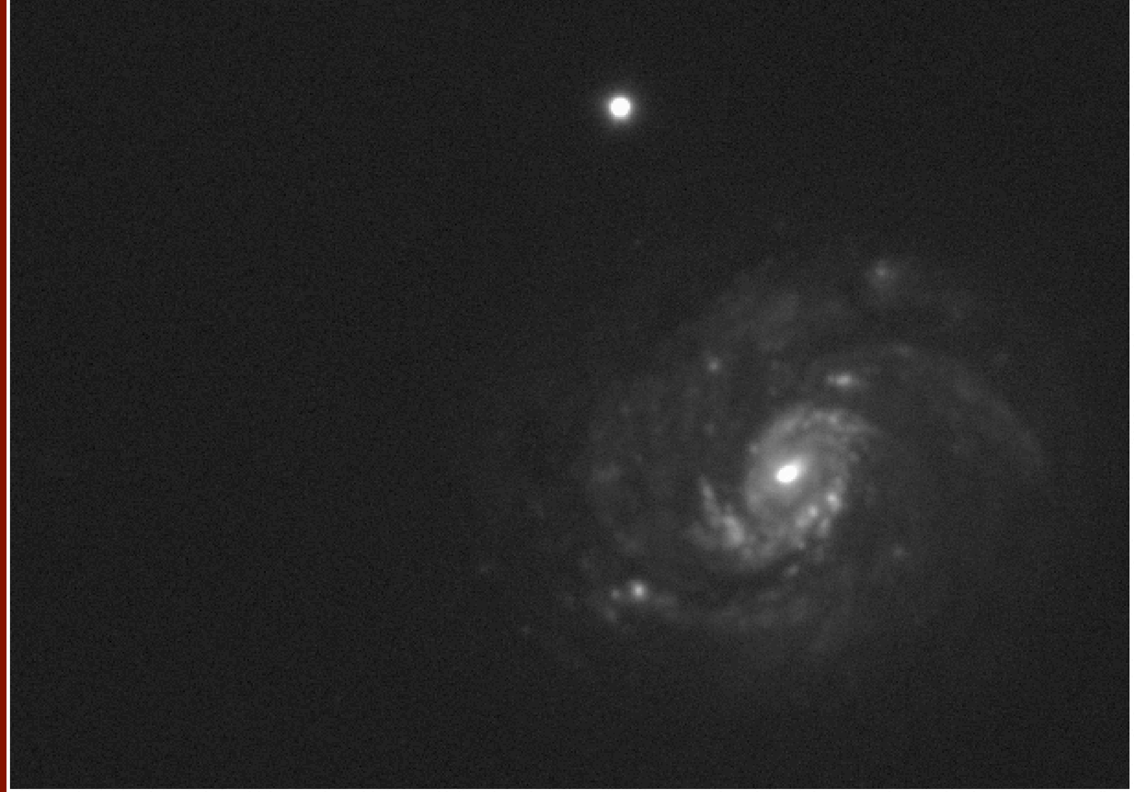
some ideas for projects:

✦ within the “supernova stripe” area, look for spectroscopic objects with high S/N but low zConf. These could be BL Lac objects. BL Lac objects are highly variable. The supernova database http://www.sdss.org/drsn1/DRSN1_data_release.html enables study of their variability.

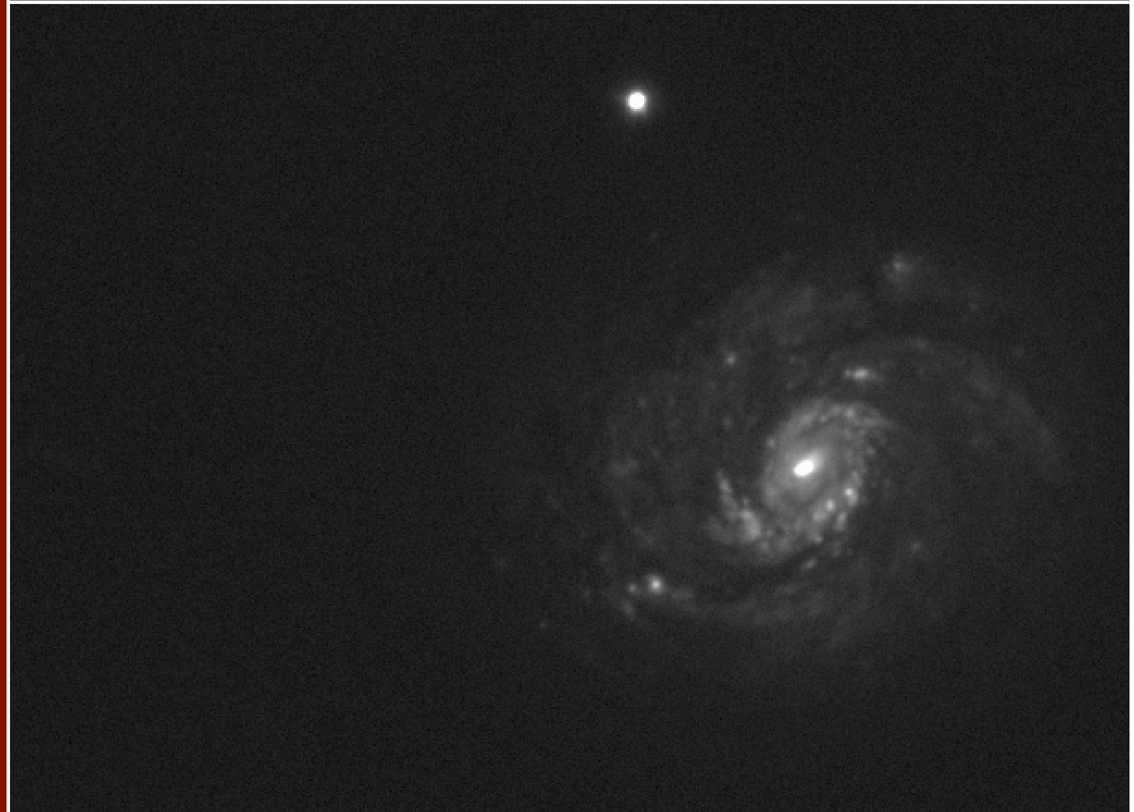
✦ correlate a list of hard X-ray sources with the footprint of the supernova stripe ($300 < ra < 60$; $-1.25 < dec < 1.25$). Identify optical counterparts and look for variability.

✦ search for changes in line profiles among quasars on the spectroscopic plates observed multiple times. Quasars with wide lines might vary on relatively short time scales. Wilhite did not look at $z < 0.5$.

✦ for quasars at sufficiently low z that the host galaxy can be seen, investigate whether there are correlations between the properties of the emission lines (e.g. width, shape) and the properties of the host galaxy (e.g. inclination angle, luminosity)



run 2738,
November 2001



run 5823,
November 2005