The Sloan Digital Sky Survey--Highlights

Frontiers in Cosmology
IHEP
Beijing, China
July 18, 2009

Project definition for SDSS

- Scientists agreed on central goal: LSS
- Thus: redshifts of QSOs and galaxies
- How big? Need enough objects so that large samples of typical objects still exist after cuts are made
  - Boundary effects
  - Unexpected physical correlations
  - Etc.
  - Guess was 1 million redshifts

Project definition for SDSS

- Scientists agreed on central goal: LSS
- Thus: redshifts of QSOs and galaxies
- How big? Need enough objects so that large samples of typical objects still exist after cuts are made
  - Boundary effects
  - Unexpected physical correlations
  - Etc.
  - Guess was 1 million redshifts

Defintion

- SO, needed 1% definition in systematics and photon stats at a magnitude faint enough to give 10^6 galaxies = ~17.5
- Drift scan to minimize sky errors and overheads
- Fixes integration time at one minute.
- Aperture etc. must give survey in reasonable time (trade between operations cost and aperture costs)
- Scale must allow star/galaxy separation to fainter limits.
- Magic numbers: f/5, 0.4 arcsec per pixel, 25 micron pixels, 2.5m aperture. Basically fixed by CCDs we could get.

Partnership (How to get $$?)

- Not scientific, yet determined much of project (incl. software) procedures.
- ~~AT&T~~, ~~NOAO~~, FNAL (big enough not to fit informal university-based collaboration)
- Like minded scientists who would agree to open access within collaboration and public dispersal in timely fashion
- Public is "right" because
  - It forces everyone to do things right
  - It leads to more data getting looked at faster, a faster discovery of errors so they can be fixed before the project shuts down*
  - You cannot analyze all the data anyway: full value only when data are prepared for later use by others with different views.

Functional goal

All of above reduces to one phrase that guided the project:

Create a public archive of 1 million galaxy spectra and their images

QSO limiting magnitude, star streams in the halo, mass metallicity relationship in LRGs, baryon oscillations, QSO absorption all came from the simple goal. Optimized for one thing, done very well.

Sloan Digital Sky Survey – Hardware ($25M)

2.5 meter telescope at Apache Point

2 instruments, camera and spectrograph

Camera used on best nights, photometric

Pipeline reductions in five bands, ugriz

Images composites of gri, coded as blue, green, red, resp.

Colors (magnitude differences in different filters) used
to select galaxies to a fixed limit (17.7)
QSOs to a fixed limit (19.1)
S/N 10/1 at plate limit (21)

All X ray sources and FIRST radio sources also targeted.

Database set up so used can select criteria to use in making fair samples for any purpose

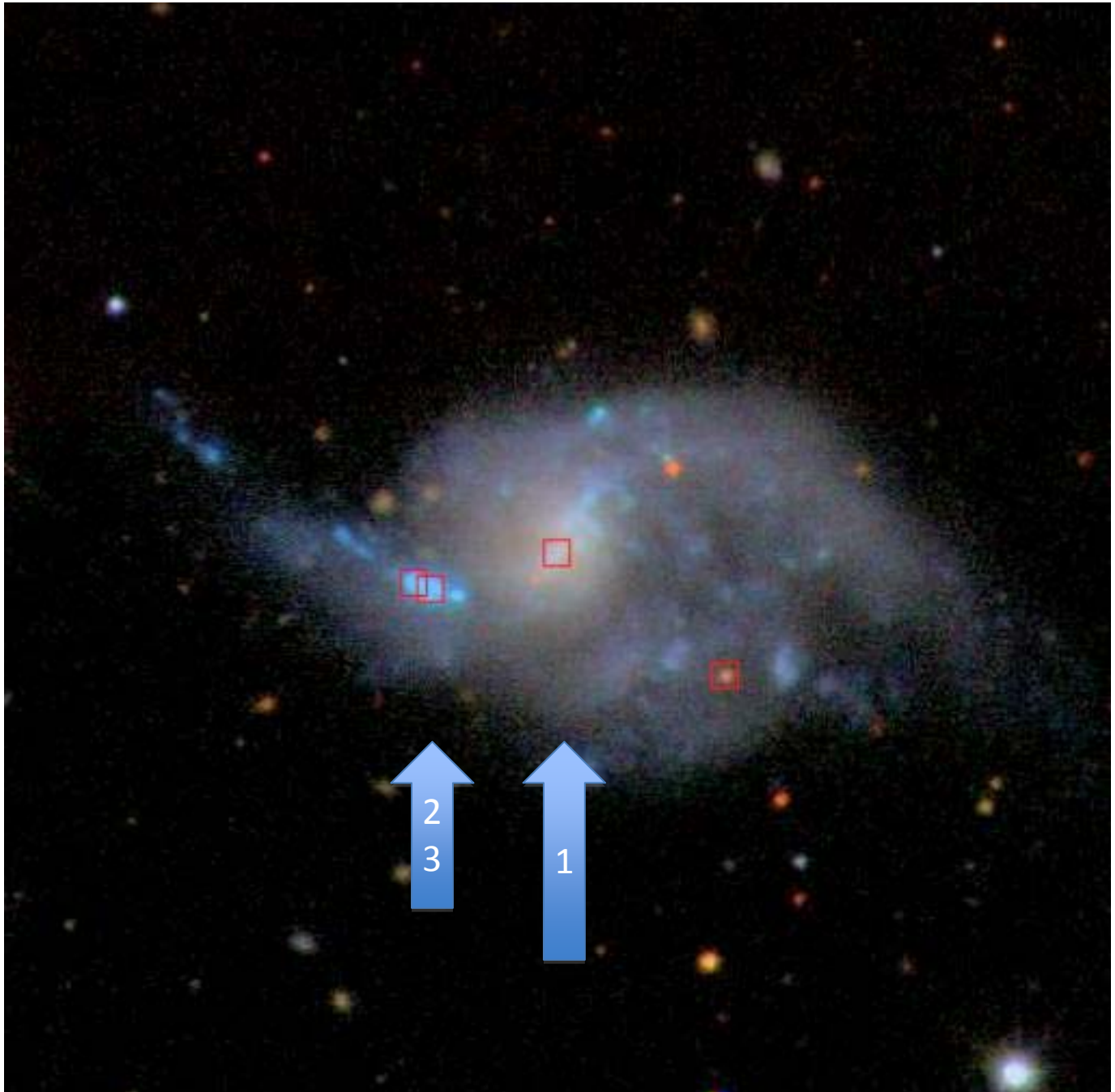
Software ($35M)

- Instrument control
- QC at site
- Reduction of images
- Feed back to site from reductions
  - code improvement for QC
  - Drilled plates for fibers, enabling spectroscopy (confirming or finding false positives of color selection process; redshifts of galaxies, QSOs)
- Data stuffing, maintenance
- Three systems do not interact minute to minute or night to night
- Re-reduce full dataset at annual release*
  - Part of "public" commitment

Operational issues ($40M)

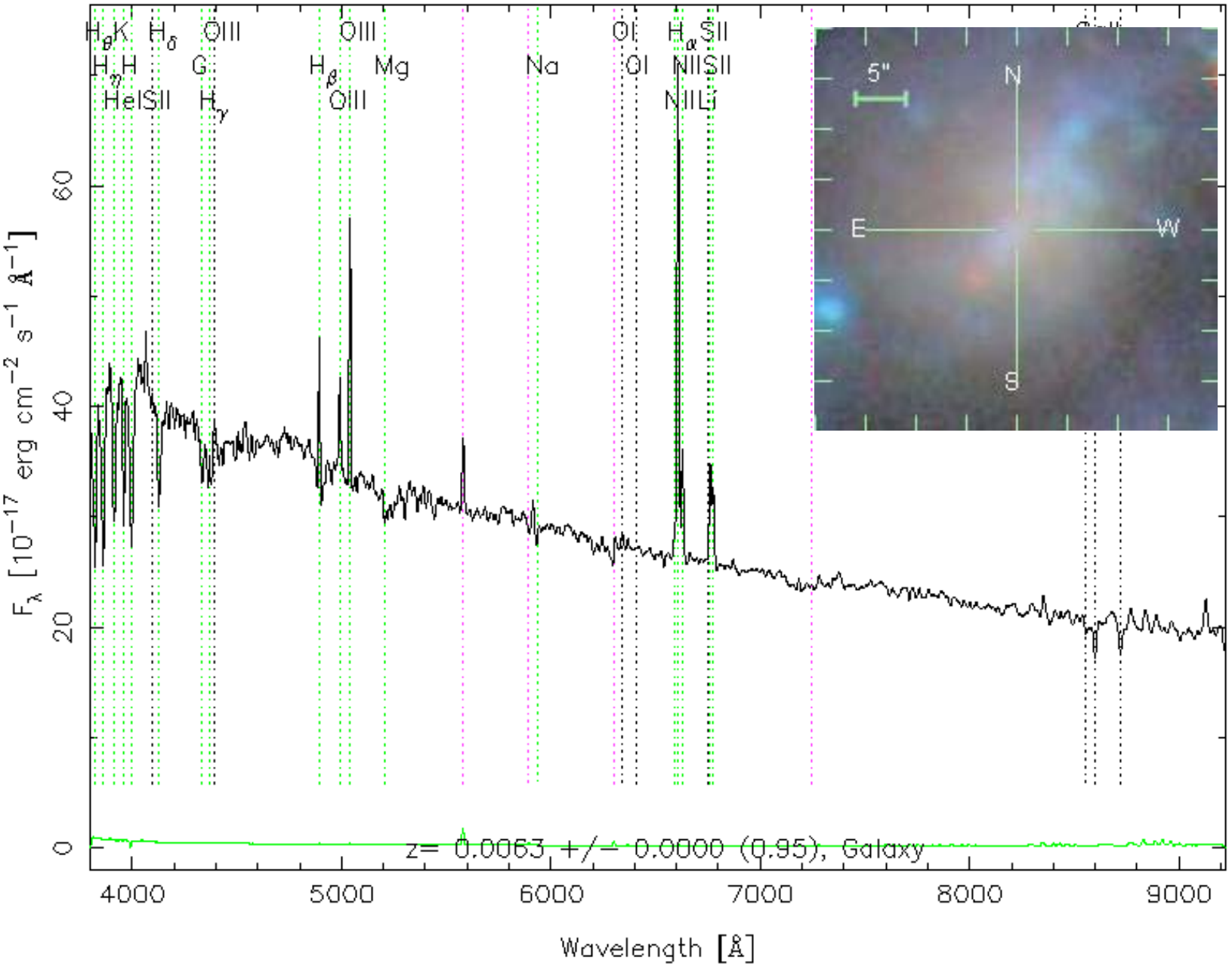
- Record images in 5 filters
- Form differences that give colors of objects (are they red or blue)
- Call resolved images “galaxies”
- Call point images “stars”
- Measure positions of all objects, post 3 color images
- If objects move between sequential filter images, reject as asteroids
- Second telescope with absolute flux calibration to observe standards in the 2.5 meter field of the moment (absolute fluxes to 1%).
- Train software to use colors and two-bit morphology to surmise nature of objects (galaxies, QSOs, stars)
- Drill holes in plates for highest priority targets: 450 galaxies, 100 QSOs, 50 stars, 50 flux and other standards.

SDSS J094954.3+00:36:59.6 in NGC 3023



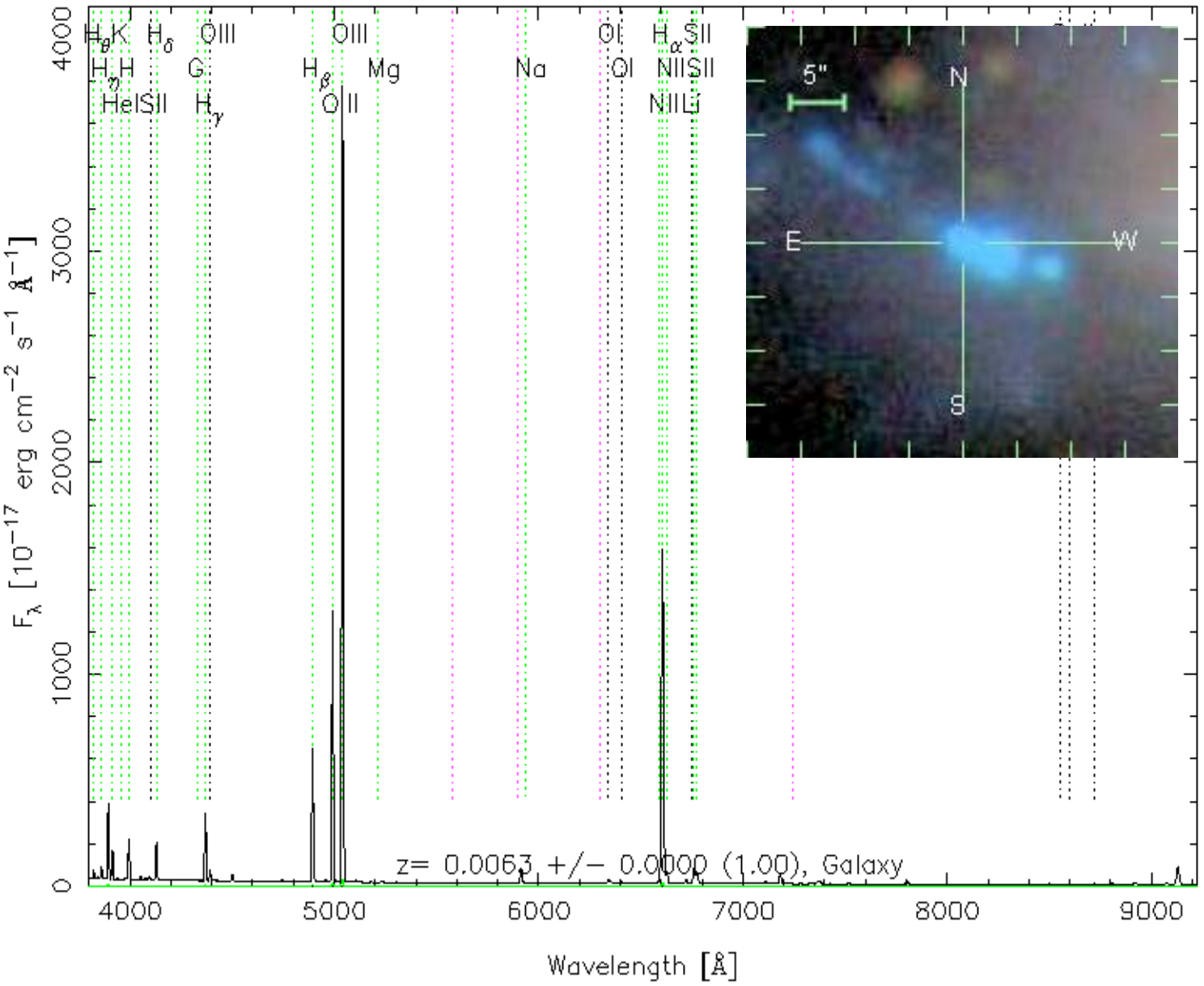
RA=147.46914, DEC= 0.61811, MJD=51989, Plate= 480, Fiber= 56

CORE NGC 3023--2

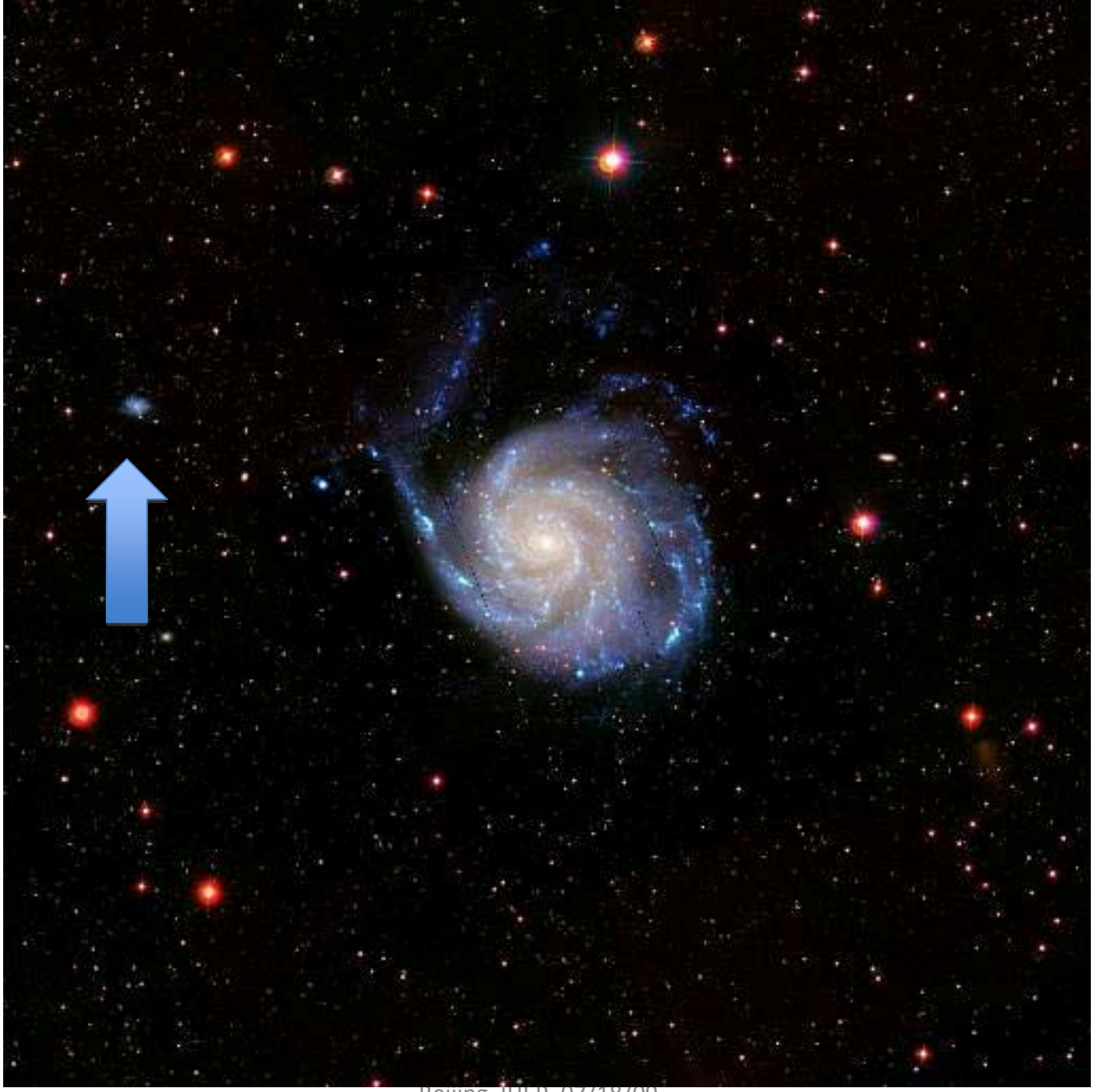


RA=147.47641, DEC= 0.61660, MJD=51908, Plate= 481, Fiber=289

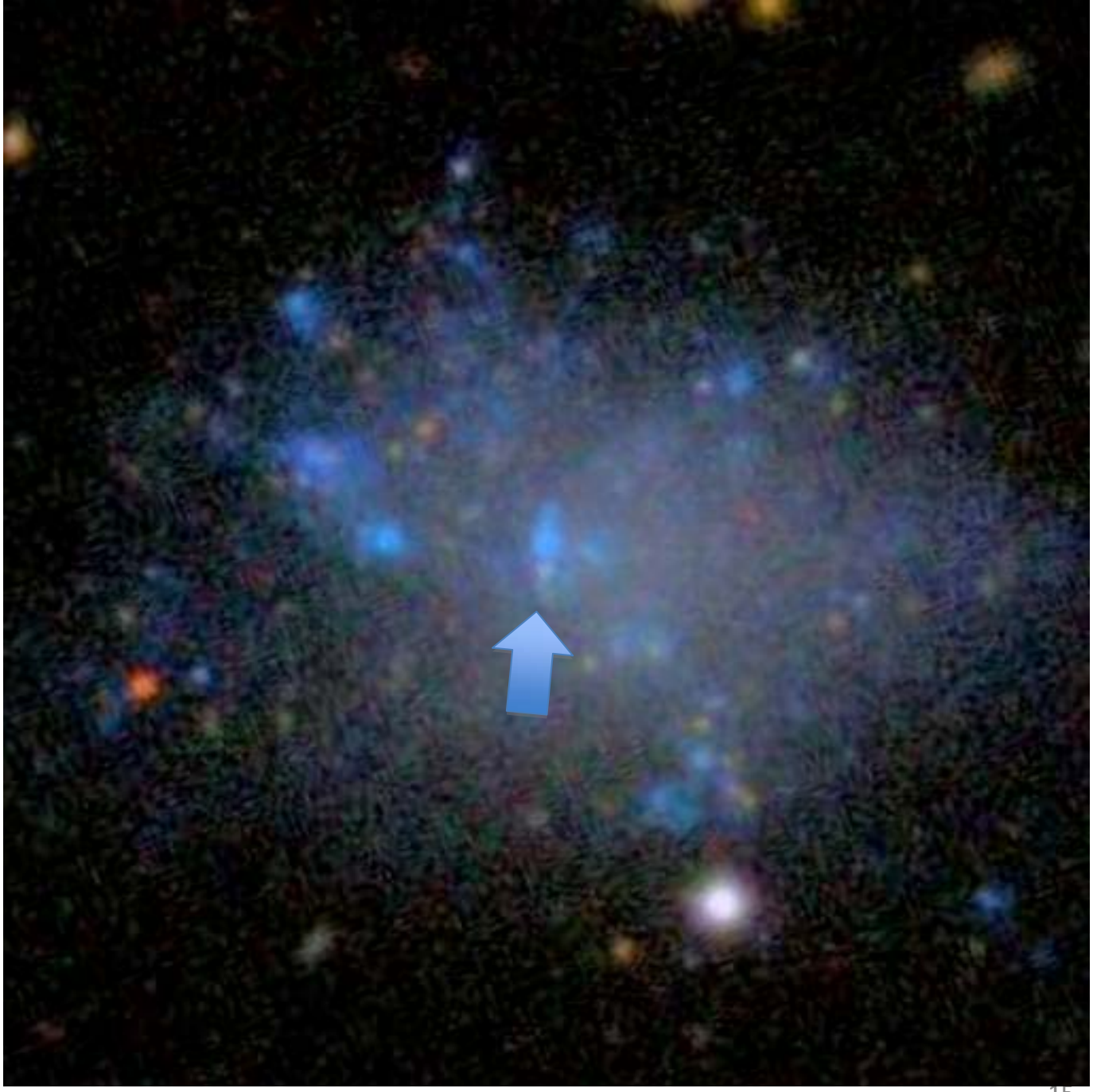
NGC 3023—pea 3

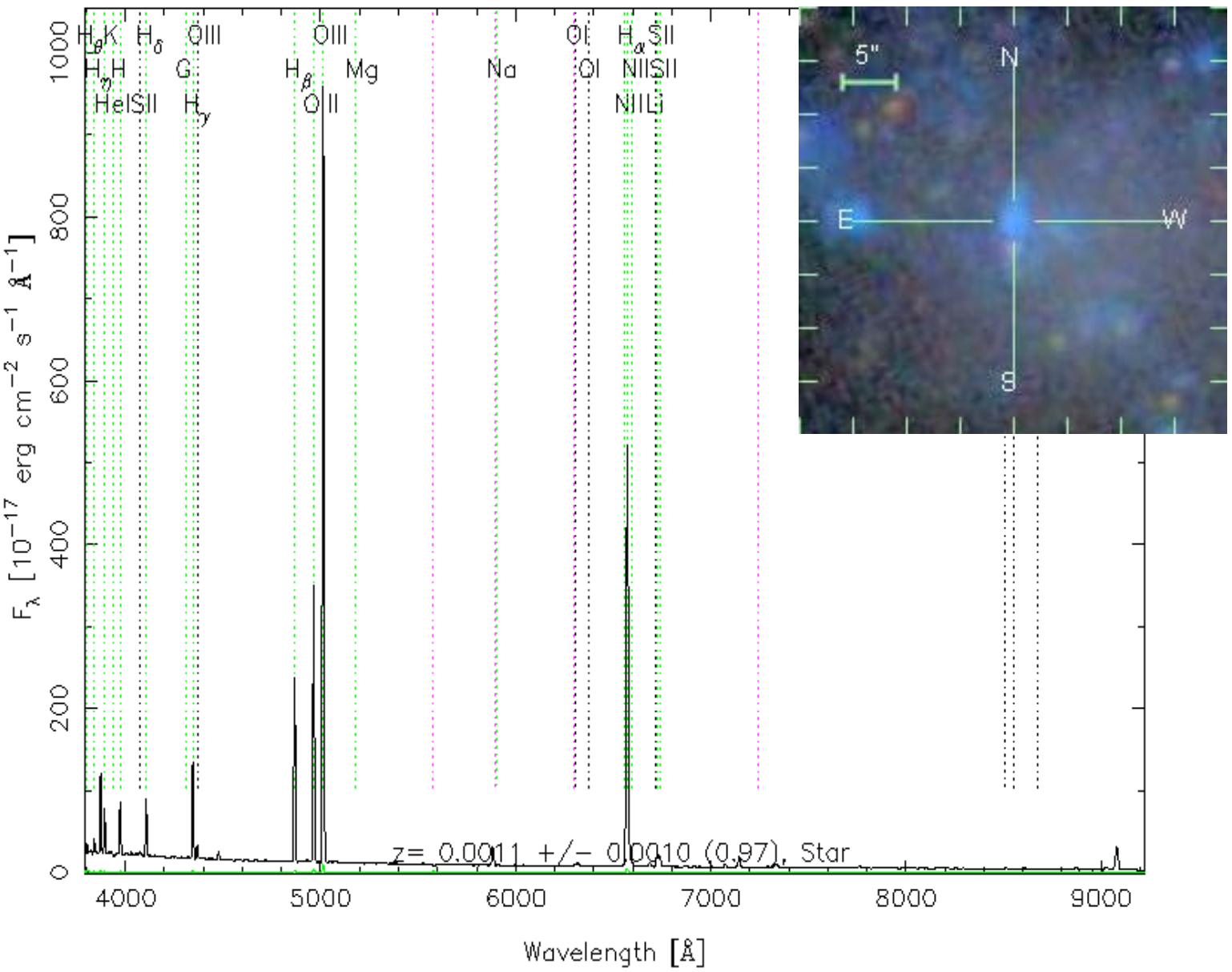


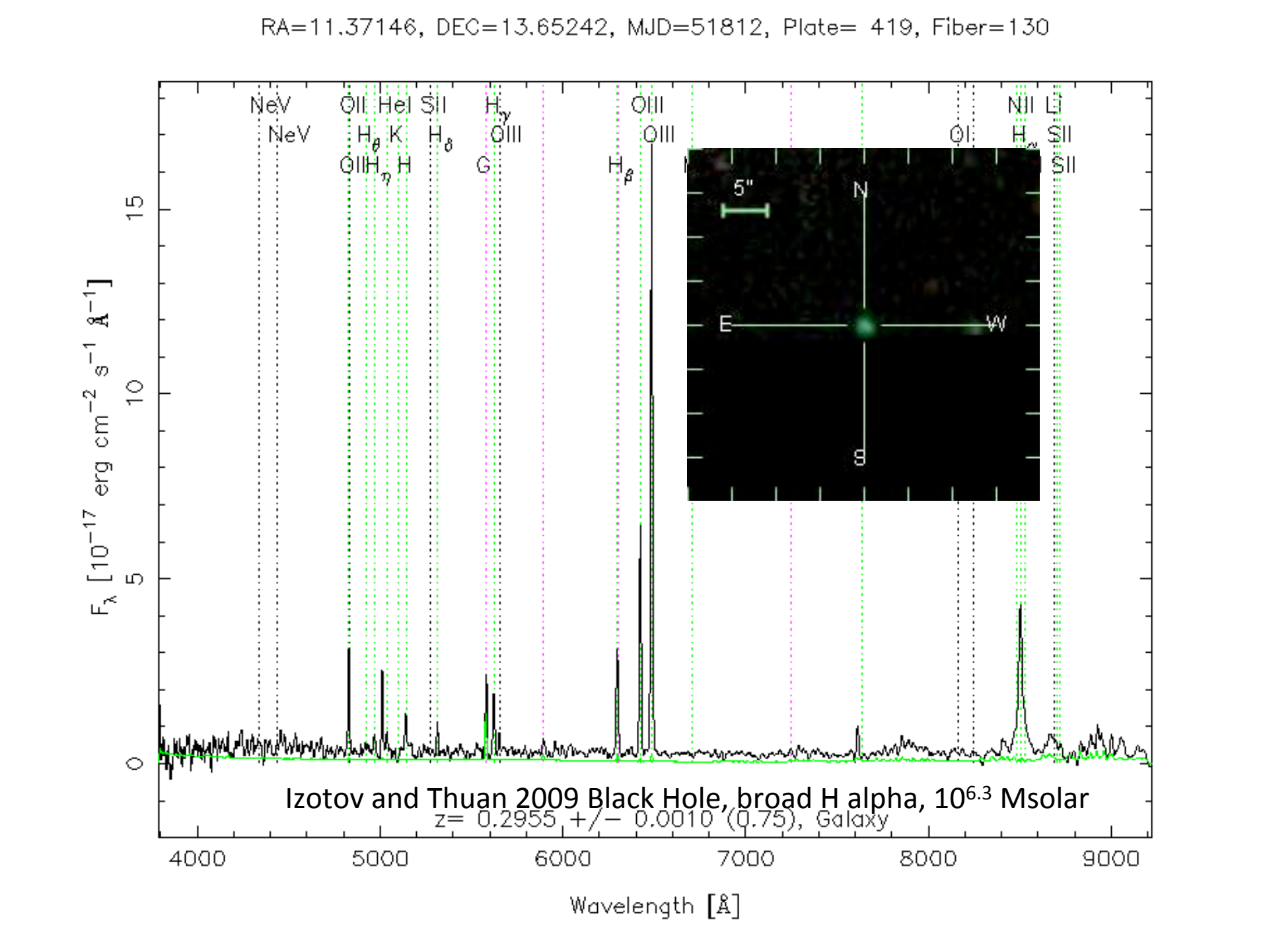
M101
NGC 5457

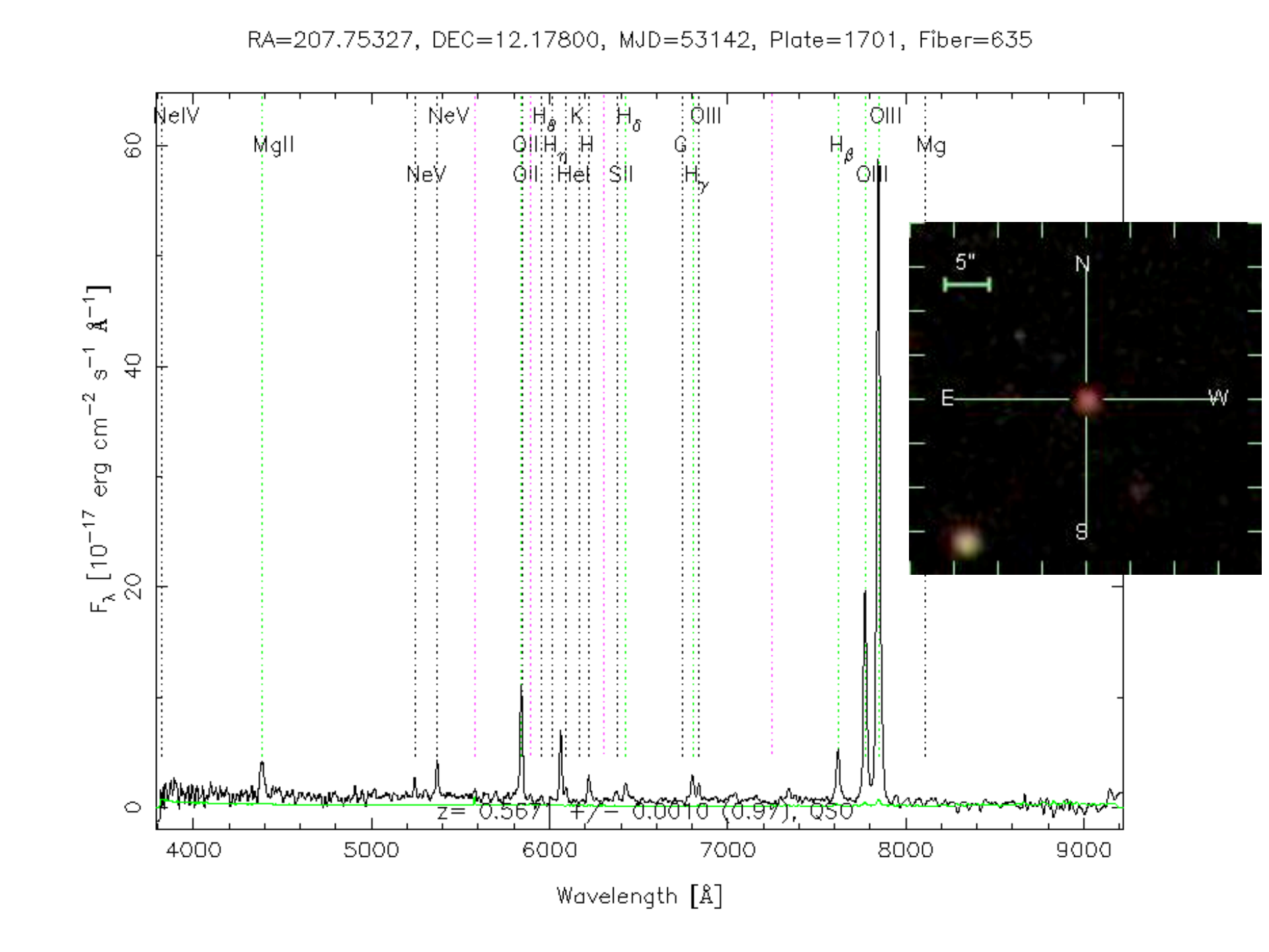


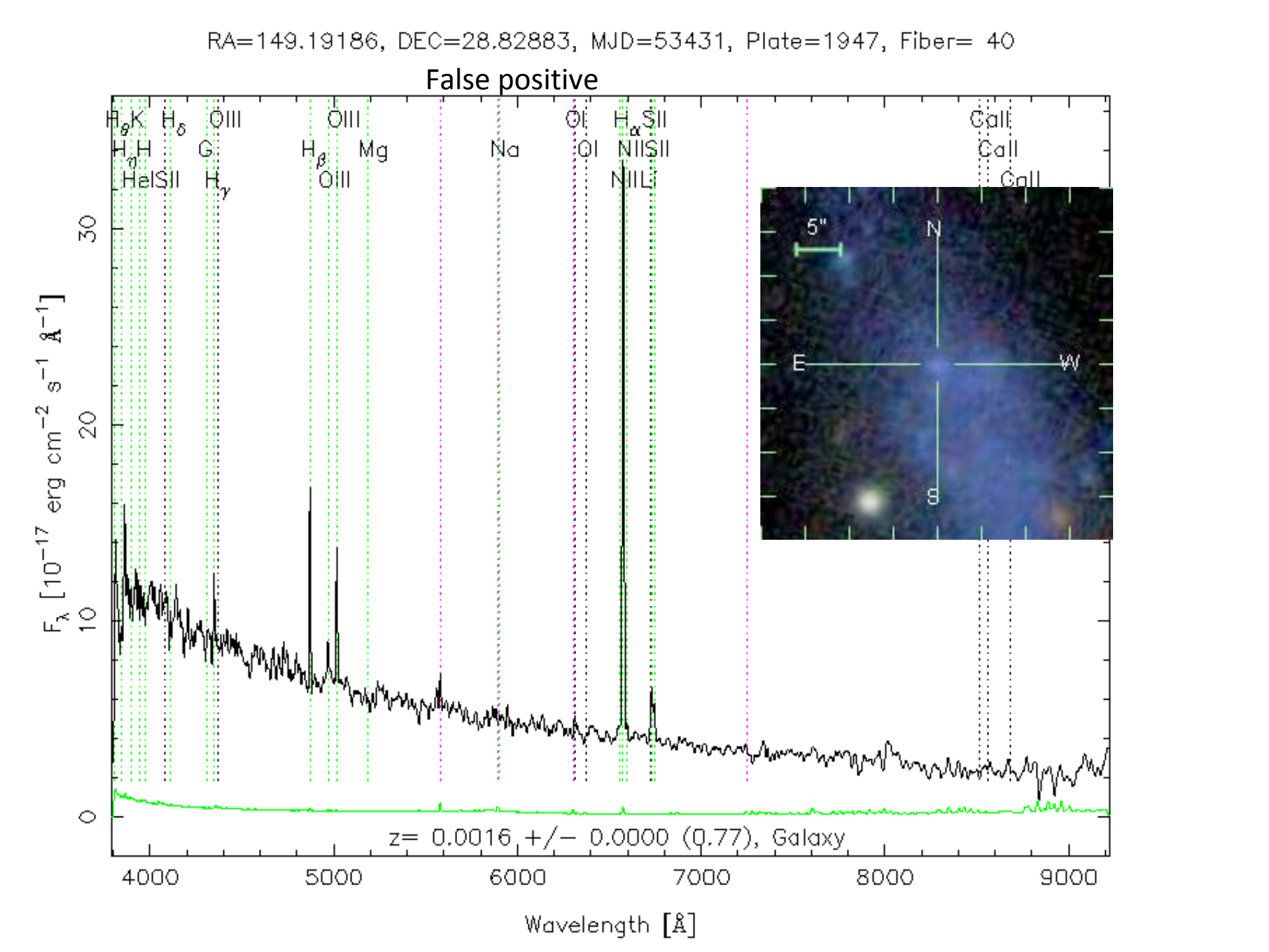
NGC 5471 in M101

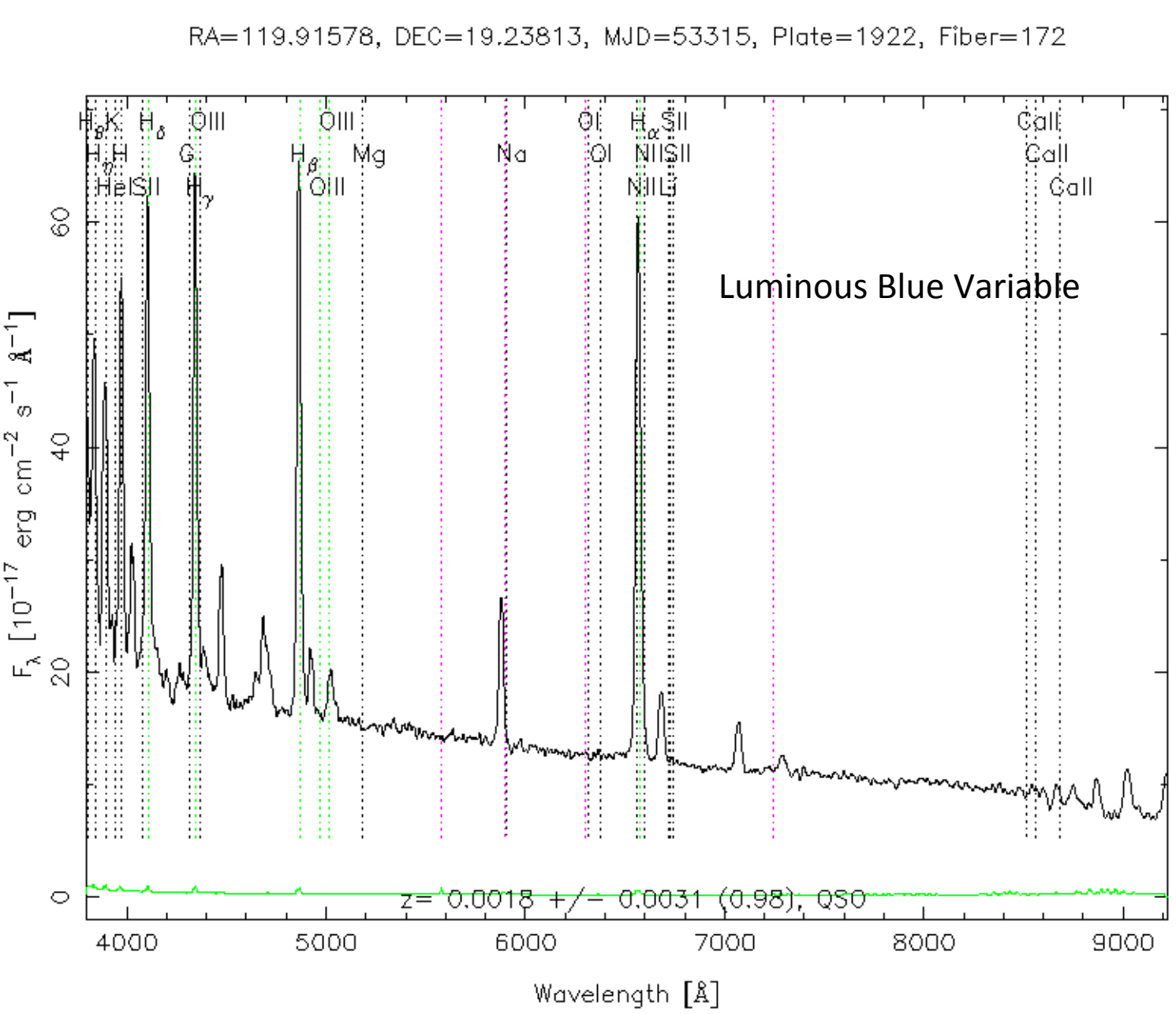


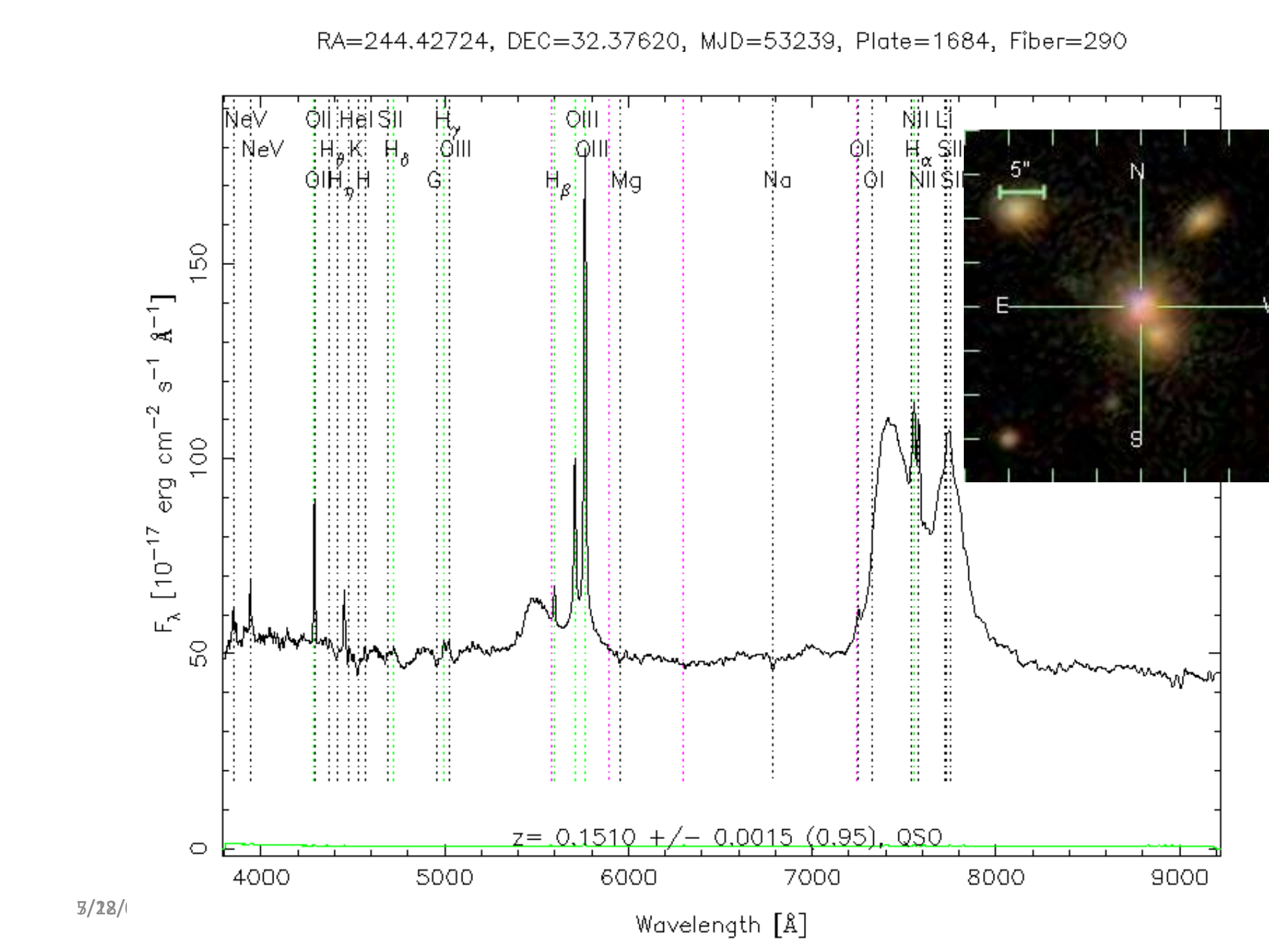

RA=211.38883, DEC=54.46116, MJD=53088, Plate=1324, Fiber=183
H$_\theta$
K
H$_\delta$
OIII
OIII
OI
H$_\alpha$
SII
H$_\beta$
H
G
H$_\beta$
Mg
Na
OI
NII
SII
HeI
SII
H$_\gamma$
OII
NII
L
5"
N
E
W
S
F$_\lambda$ [10^{-17} erg cm^{-2} s^{-1} Å^{-1}]
0
200
400
600
800
1000
z= 0.0011 +/- 0.0010 (0.97), Star
4000
5000
6000
7000
8000
9000
Wavelength [Å]


RA=11.37146, DEC=13.65242, MJD=51812, Plate= 419, Fiber=130
NeV
NeV
OII
H$_\theta$
OIIIH$_\eta$
HeI
K
H
SII
H$_\delta$
H$_\gamma$
OIII
G
OIII
OIII
H$_\beta$
OI
NII
H$_\alpha$
SII
SII
5"
N
E
W
S
F$_\lambda$ [10^{-17} erg cm^{-2} s^{-1} Å^{-1}]
0
5
10
15
Izotov and Thuan 2009 Black Hole, broad H alpha, 10$^{6.3}$ Msolar
z= 0.2955 +/- 0.0010 (0.75), Galaxy
4000
5000
6000
7000
8000
9000
Wavelength [Å]


RA=207.75327, DEC=12.17800, MJD=53142, Plate=1701, Fiber=635
NeIV
MgII
NeV
NeV
OII
OII
H$_\theta$
H$_\eta$
K
H
HeI
H$_\delta$
SII
OIII
G
H$_\gamma$
H$_\beta$
OIII
OIII
Mg
5"
N
E
W
S
z= 0.567 +/- 0.0010 (0.97), QSO
F$_\lambda$ [10^{-17} erg cm^{-2} s^{-1} Å^{-1}]
0
20
40
60
4000
5000
6000
7000
8000
9000
Wavelength [Å]


RA=149.19186, DEC=28.82883, MJD=53431, Plate=1947, Fiber= 40
False positive
H$_\epsilon$ K H$_\delta$ OIII
H$_\alpha$ H G
HeI SII H$_\gamma$
H$_\beta$ OIII
OIII Mg
Na
OI OI
H$_\alpha$ SII
NII SII
NII
CaII
CaII
CaII
5"
N
E
W
S
F$_\lambda$ [10^{-17} erg cm^{-2} s^{-1} Å^{-1}]
0
10
20
30
z= 0.0016 +/- 0.0000 (0.77), Galaxy
4000
5000
6000
7000
8000
9000
Wavelength [Å]


RA=119.91578, DEC=19.23813, MJD=53315, Plate=1922, Fiber=172
Luminous Blue Variable
z= 0.0018 +/- 0.0031 (0.98), QSO
Wavelength [Å]
F_λ [10^{-17} erg cm^{-2} s^{-1} Å^{-1}]


RA=244.42724, DEC=32.37620, MJD=53239, Plate=1684, Fiber=290
NeV
NeV
OII
H$_\beta$
OII
HeI
K
H
SII
H$_\delta$
H$_\gamma$
OIII
G
H$_\beta$
OIII
OIII
Mg
Na
OI
OI
NII
H$_\alpha$
SII
SII
LiI
5"
N
E
S
F$_\lambda$ [10^{-17} erg cm^{-2} s^{-1} Å^{-1}]
0
50
100
150
z= 0.1510 +/- 0.0015 (0.95), QSO
4000
5000
6000
7000
8000
9000
Wavelength [Å]

RESULTS

- 1 million accurate redshifts (distances) (nearest 1% of the Universe)
- 200 million coarse redshifts (quarter way to the edge of the Universe)
- 100,000 QSO redshifts (to the edge of the Universe)
- 1,000,000 coarse redshifts (1%)
- 100,000 high z galaxies in absorption against QSOs
- 300,000 stars in the halo
- 200,000 asteroids (new)
- 100 gravitationally lensed QSOs (well defined sample)
- 119 double-disk QSOs (binary?,massive, merging BH?)
- Most highly cited project by FAR for 5 years running
- Roughly half the published papers are from the public archive by non-SDSS participants

Science Results

- Large scale structure of QSOs, galaxies, QSO absorbers is very similar
- Galaxy environment not relevant to nature of QSOs
- Bulge mass of galaxy ~ 1000 x BH mass of central AGN
- All galaxies have dark matter (seen directly by weak lensing, alignment of distant galaxies in gravitational field of foreground galaxies)
- Confirmation of numerical simulations of dark matter halo picture
- Old, dead, red galaxies are the most massive and have fully solar abundances. Turns element evolution picture on its head.

•Highest redshift QSOs look just like lowest z QSOs (BH form easily within first 0.5B years (out of 13.5)
• Multiple confirmations of Dark Energy independent of SNe
(gravitational lenses, clusters, nature of LSS)
• Detection of baryon oscillations from before recombination.
• Absolute distance scale at z=0.25, 0.35, 2.
• Detection of halo streams that imply the Milky Way is built of disintegrated globular clusters and accreted satellites.

Conclusions

- Small group of unfunded individuals with the right idea can have a revolutionary impact on the oldest of sciences.
- Collegiality and willingness to share many years of their lives are critical.
- Focus on a single goal to set requirements. Good things will happen.
- Cultures may need to be mixed: university astronomy and national centers each have advantages built into their cultures that are essential to the work required.
- Be careful about photometric redshifts: calibrate, calibrate, calibrate.
- Insist on doing the very best that can be done: the tension with managers will kill you, but the outcome will bring you back to life.