

Optical spectroscopy of Blazars

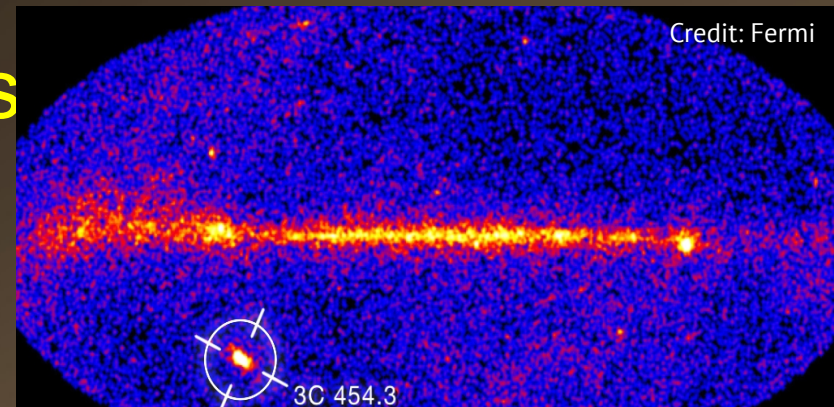
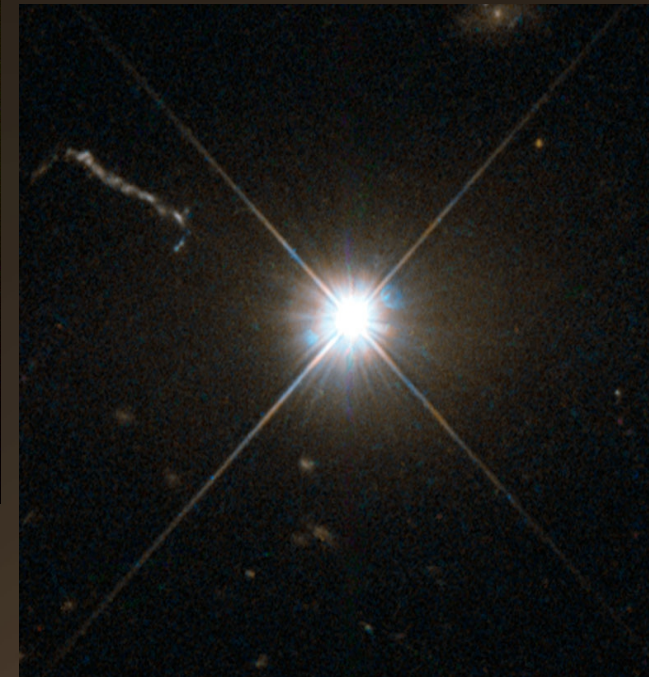
Noel Castro Segura (ULL)

& José Acosta Pulido (IAC, ULL)

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Outline:

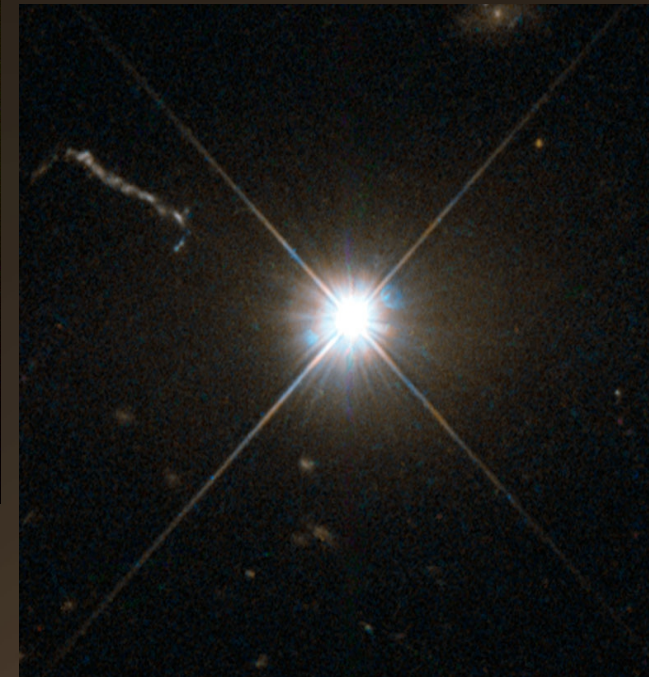
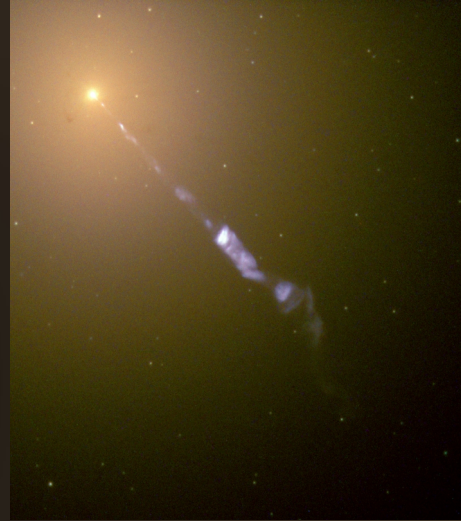
- Introduction
- Data set
- Classification
- Color-magnitude diagrams
- NMF
- Spectral measurements
- Summary of results



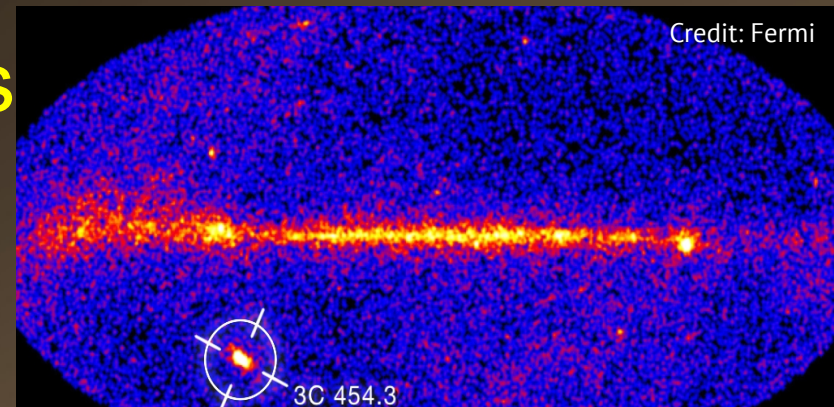
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Credit: HST

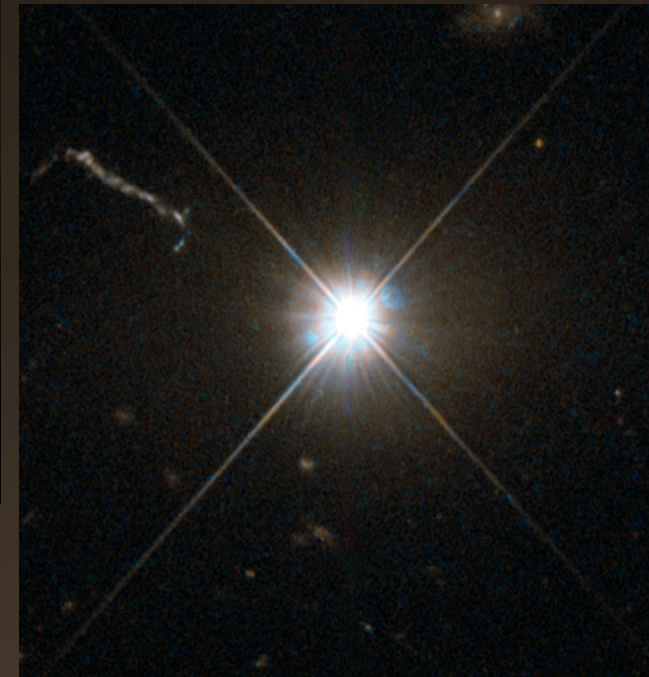
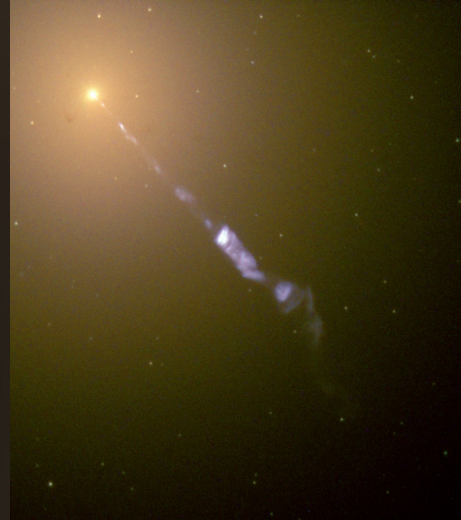


Credit: Fermi

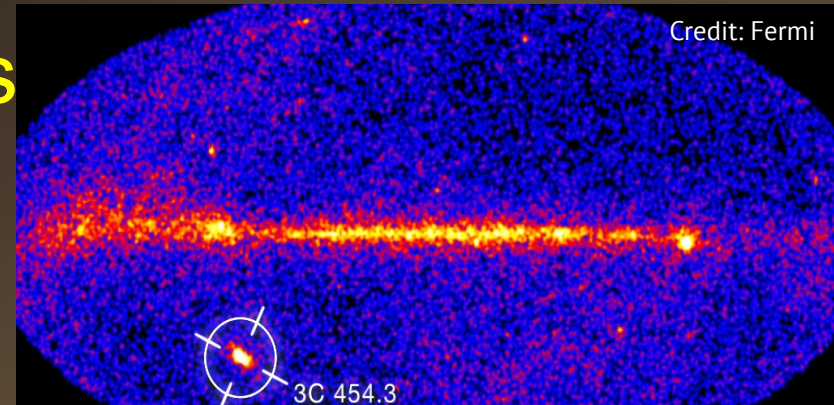
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Credit: Fermi

Data set: data base

- Campaign: ground-based Observational Support of the Fermi Gamma-ray Space Telescope @ Steward Observatory.
- Since October 2008.
- Data public at campaign website.
- Over 60 targets and 7900 observations (in 2015).
- This work: 5030 flux calibrated spectrum of 27 objects.

Data set: instrumentation

Steward Observatory

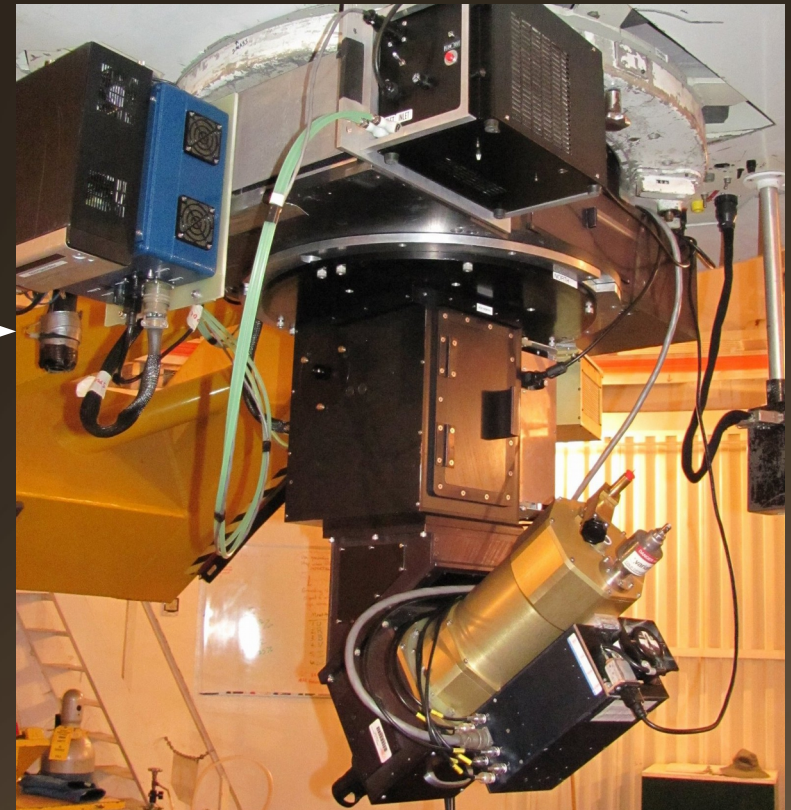


- 2.3m Bok Telescope



- 1.54m Kupier Tel.

(Smith et al., 2009)

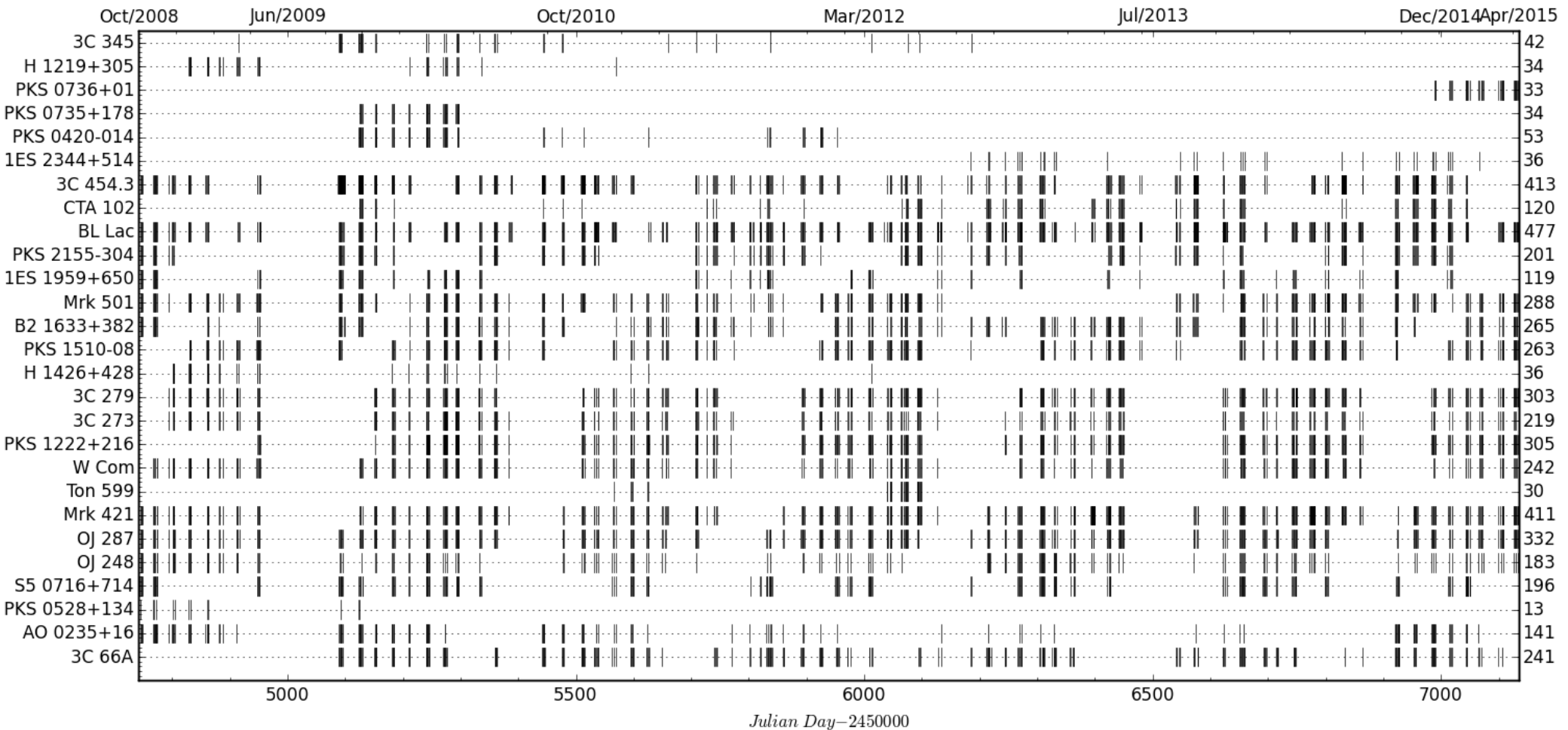


- SPOL Spectropolarimeter
Spectral resolution: 4-15 Å

Data set: data base

- Observing Blazars since 2008.

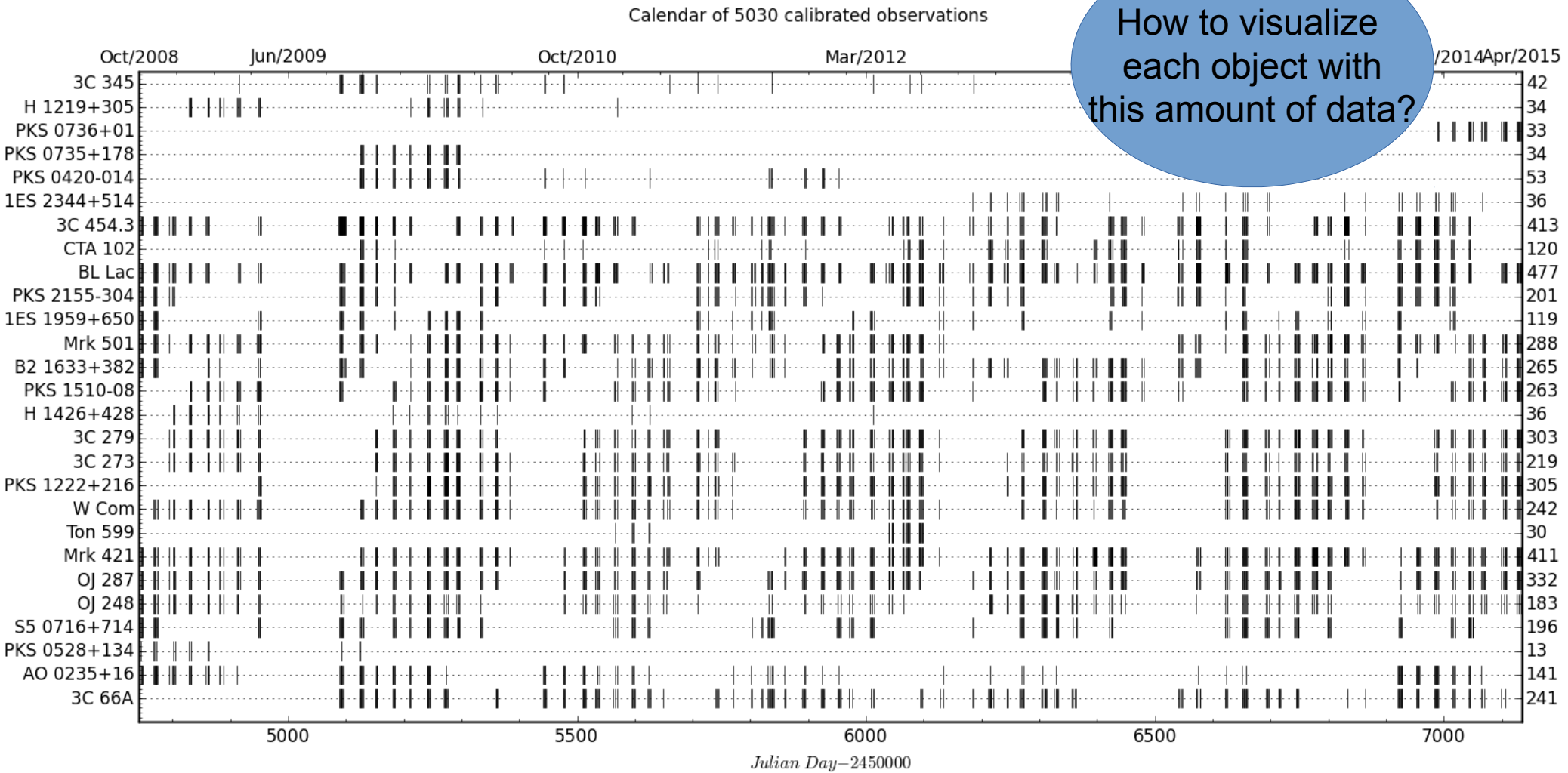
Calendar of 5030 calibrated observations



Data set: data base

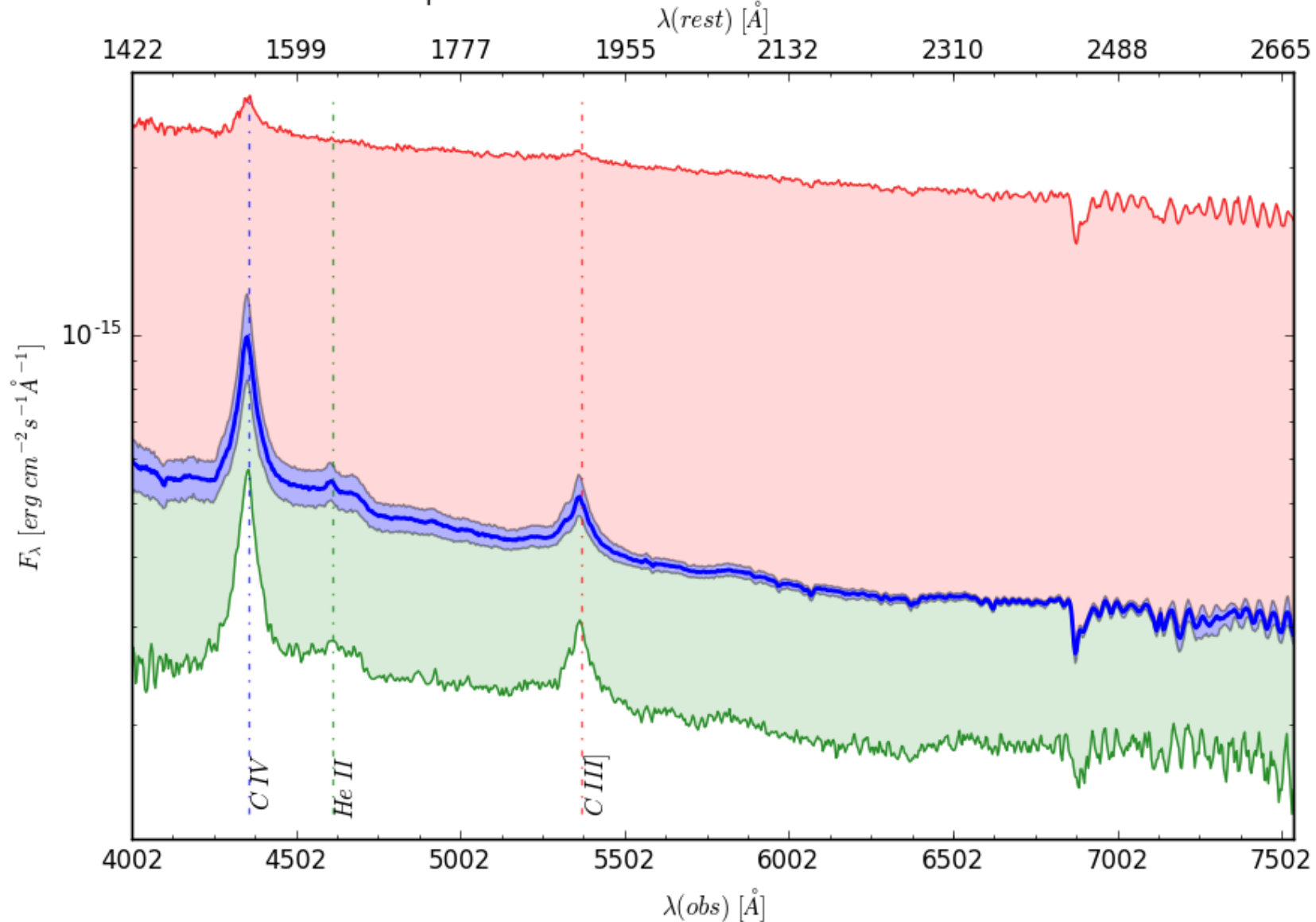
- Observing Blazars since 2008.

How to visualize each object with this amount of data?



Original representation

Median spectrum of B2 1633+382 at $Z:1.814$.Total files:265

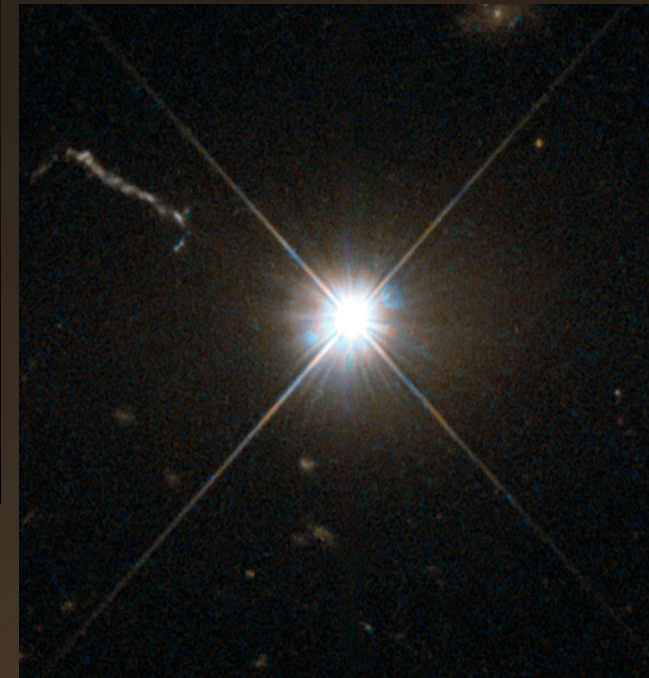
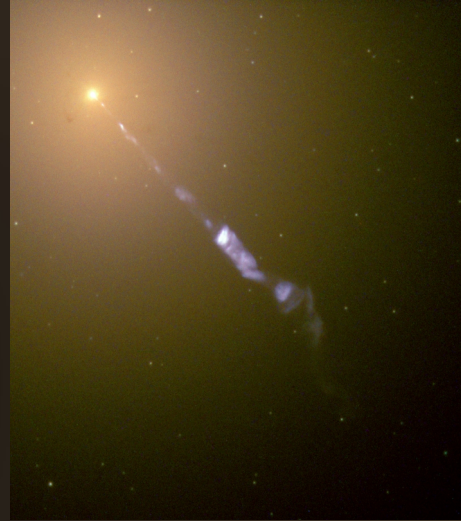


Original representation: Time evolution

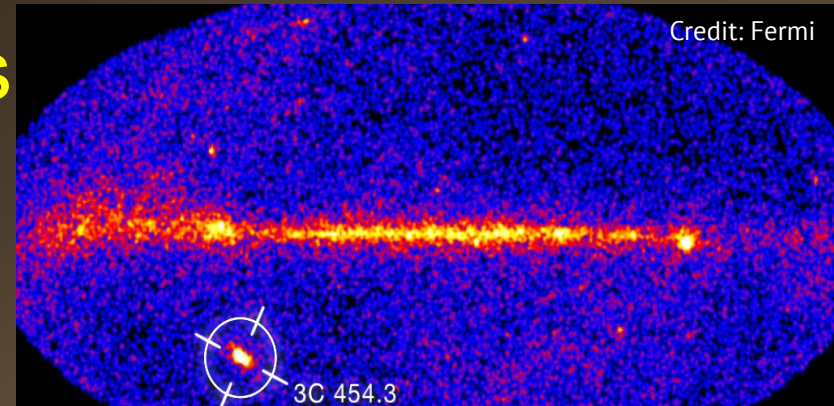
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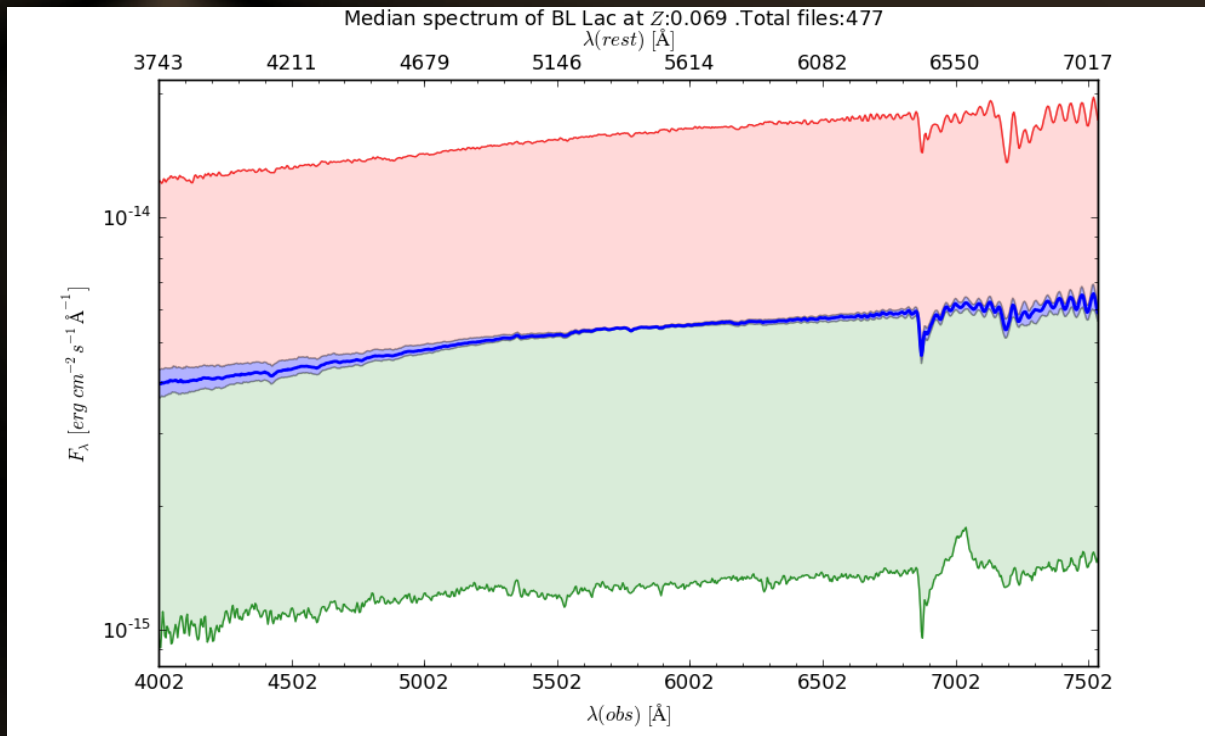


Credit: Fermi

Classification

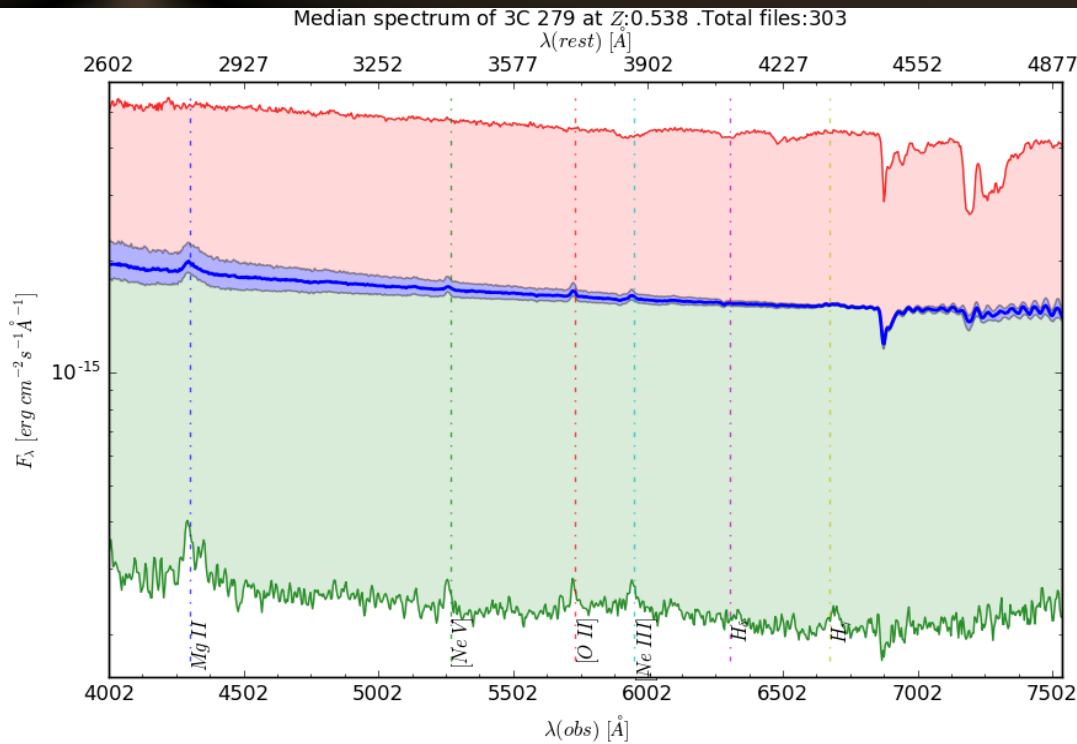
- **Traditional Classification: $EW < 5 (1+z)\text{\AA}$**
(eg. Stickel et al. 1991; Stocke et al. 1991).
- **Spectral shape characterized from median spectrum.**
 - BL-Lacertae: no emission lines or $EW[\text{rest}] < 5\text{\AA}$.
 - FSRQ: prominent emission lines.
 - Stellar population dominated: absorption lines

Classification: BL-Lacertae



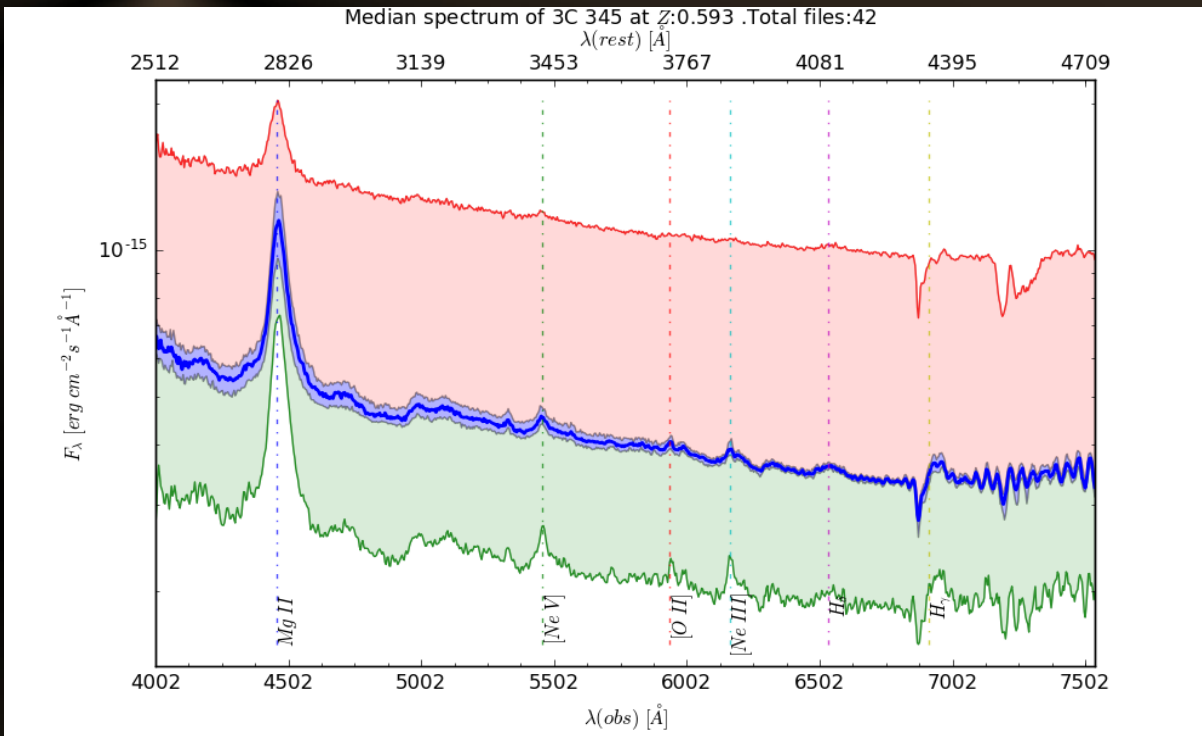
BL Lacertae		
Name	Z	Key
Mrk 421	0,031	P
1ES 1959+650	0,048	P
BL Lac	0,069	P? E
W Com	0,102	P
PKS 2155-304	0,116	P
H 1219+305	0,182	P
S5 0716+714	0,3	P
OJ 287	0,306	P
PKS 0735+178	0,424	P S
3C 66A	0,444	P
3C 279	0,538	H E N V
AO 0235+16	0,94	H E A

Classification: BL-Lacertae



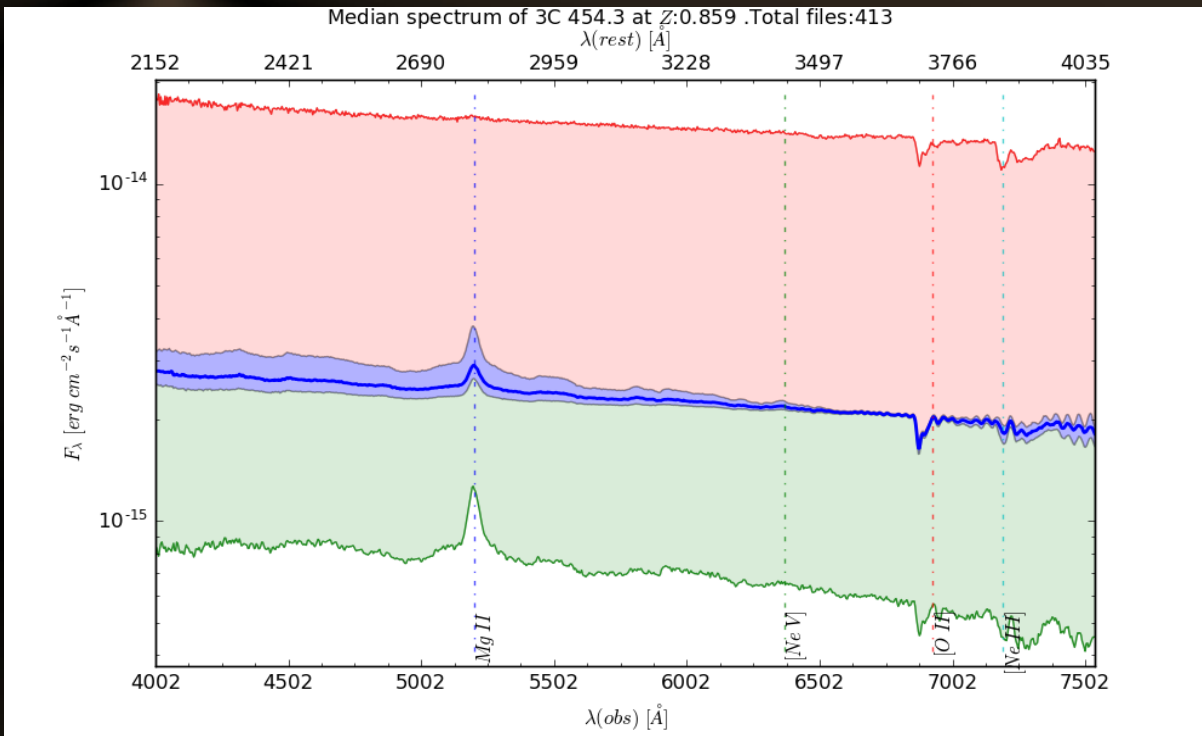
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Classification: FSRQ



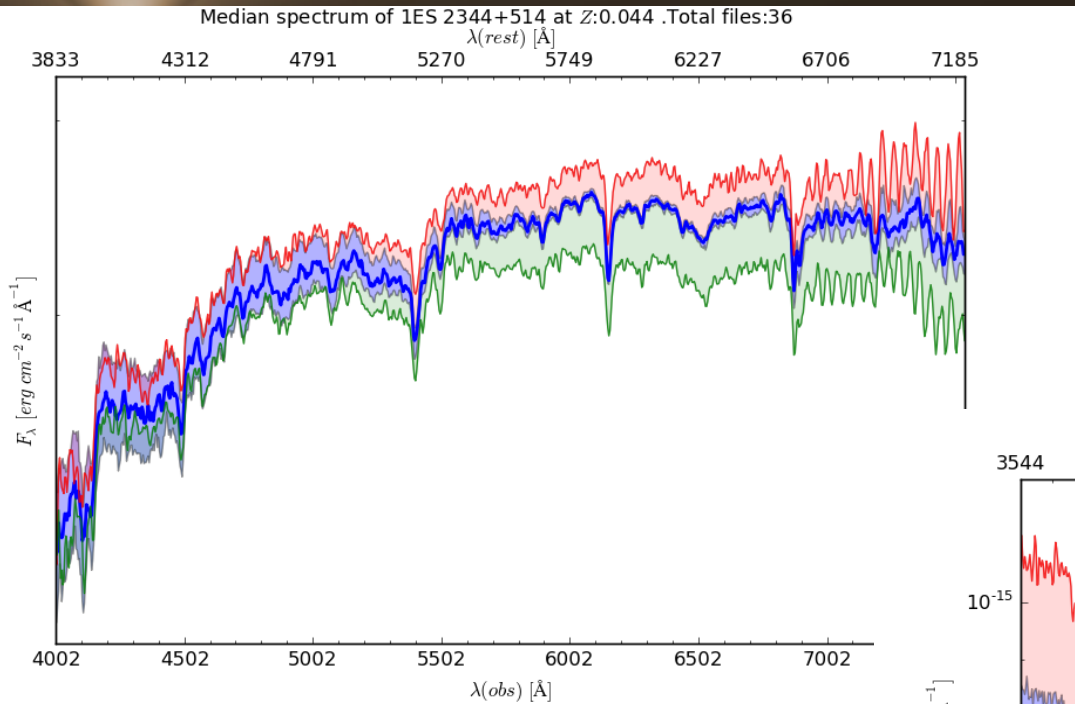
Flat Spectrum Radio Quasar		
Name	Z	Key
3C 273	0,158	P E N S
PKS 0736+01	0,191	H E N V
PKS 1510-08	0,36	H E N V
PKS 1222+216*	0,435	H E N V
3C 345	0,593	P E N V
Ton 599	0,725	H E N V
3C 454.3	0,859	H E V
PKS 0420-014	0,915	H E A V
OJ 248	0,939	H E A V
CTA 102	1,037	H E V
B2 1633+382	1,814	H E V
PKS 0528+134	2,06	P E N V

Classification: FSRQ

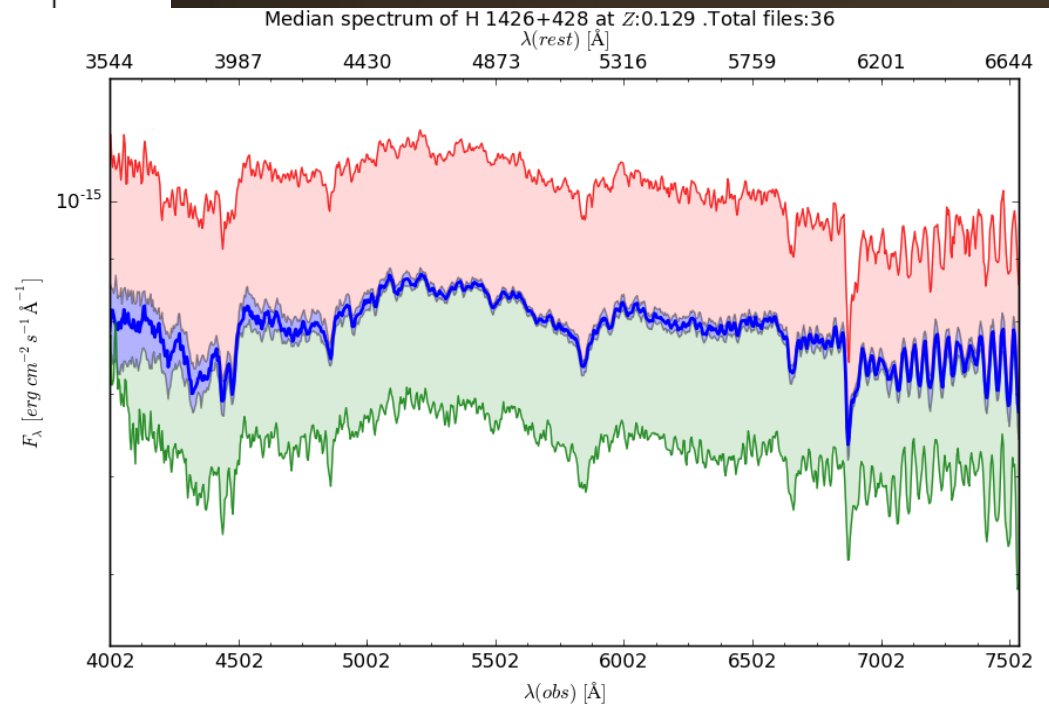


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CTA 102	1,037	H E V
B2 1633+382	1,814	H E V
PKS 0528+134	2,06	P E N V

Classification: stellar population



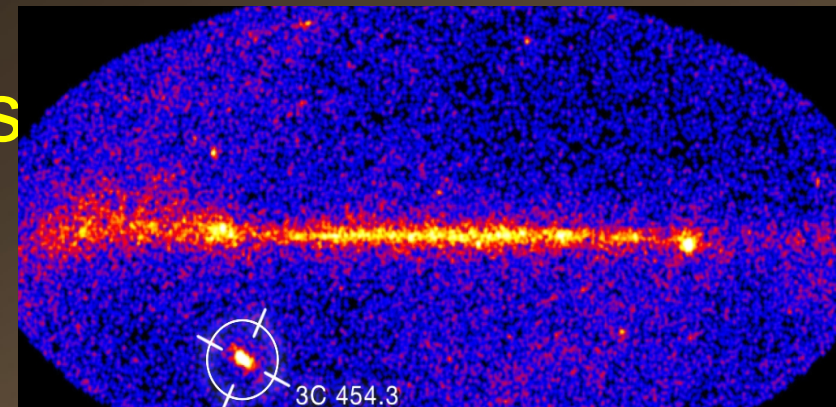
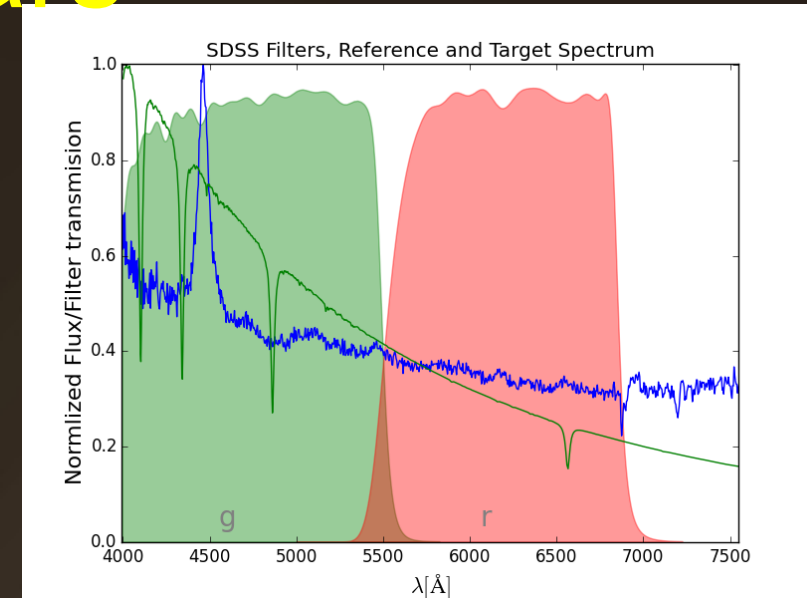
Galaxy dominated		
Name	Z	Key
Mrk 501	0,033	P N
1ES 2344+514	0,044	P S
H 1426+428	0,129	P



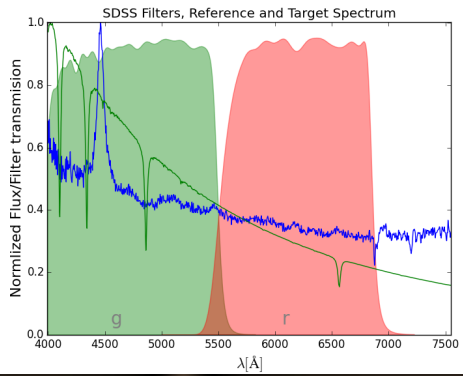
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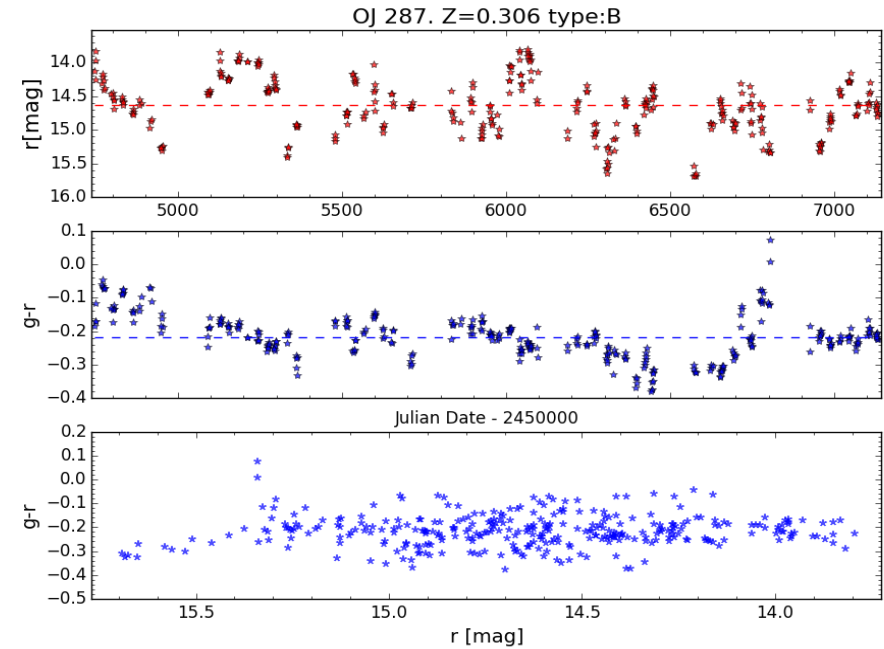
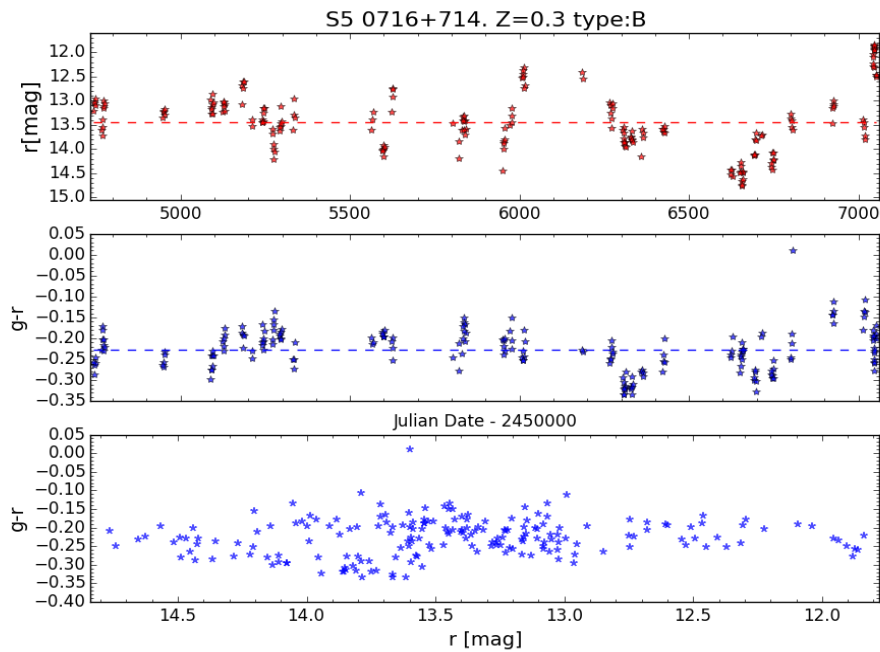
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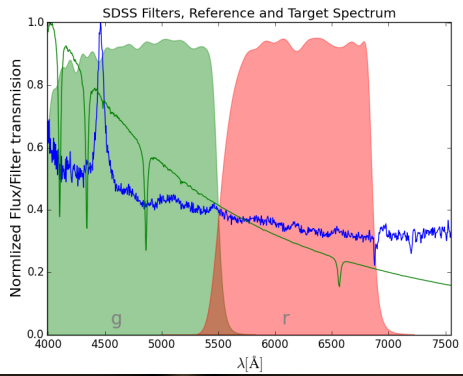
Color-magnitude diagrams



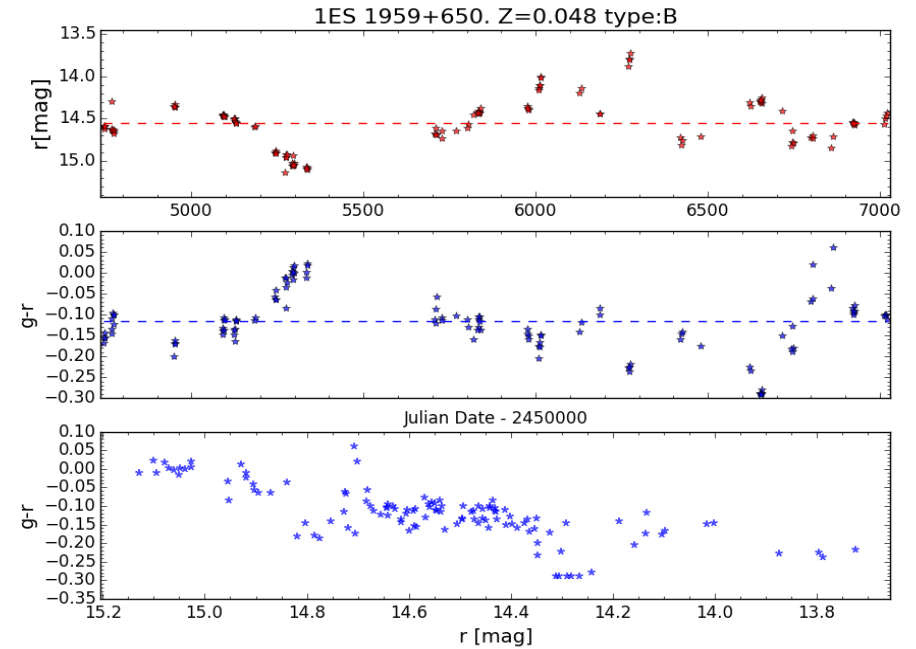
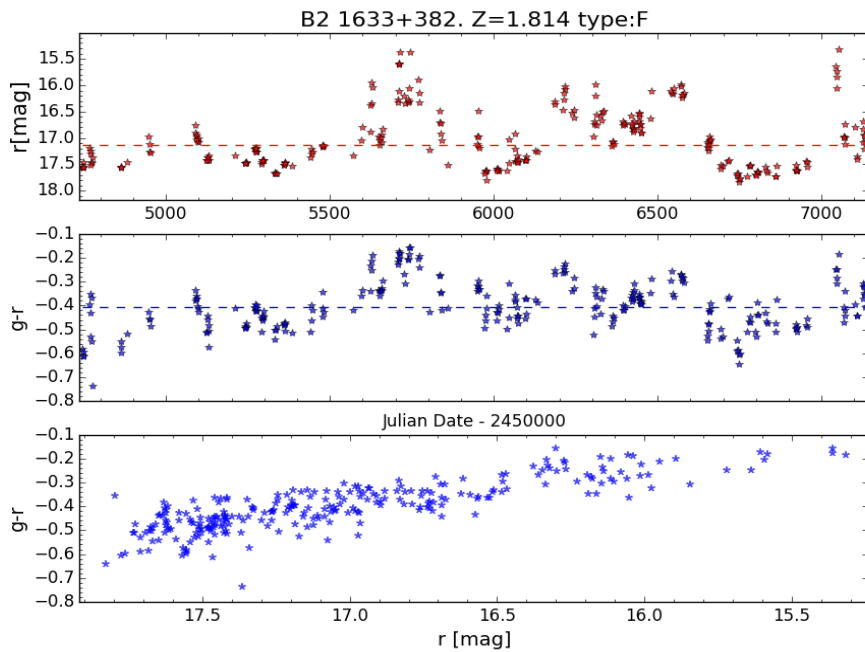
- No Color-magnitude correlation \rightarrow constant spectral shape



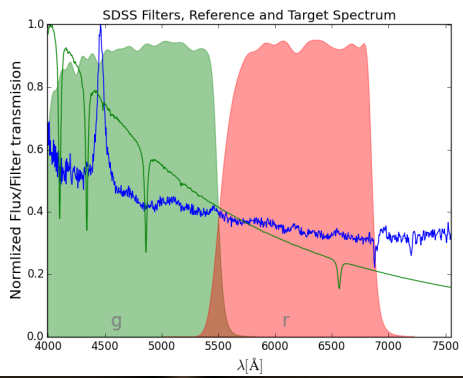
Color-magnitude diagrams



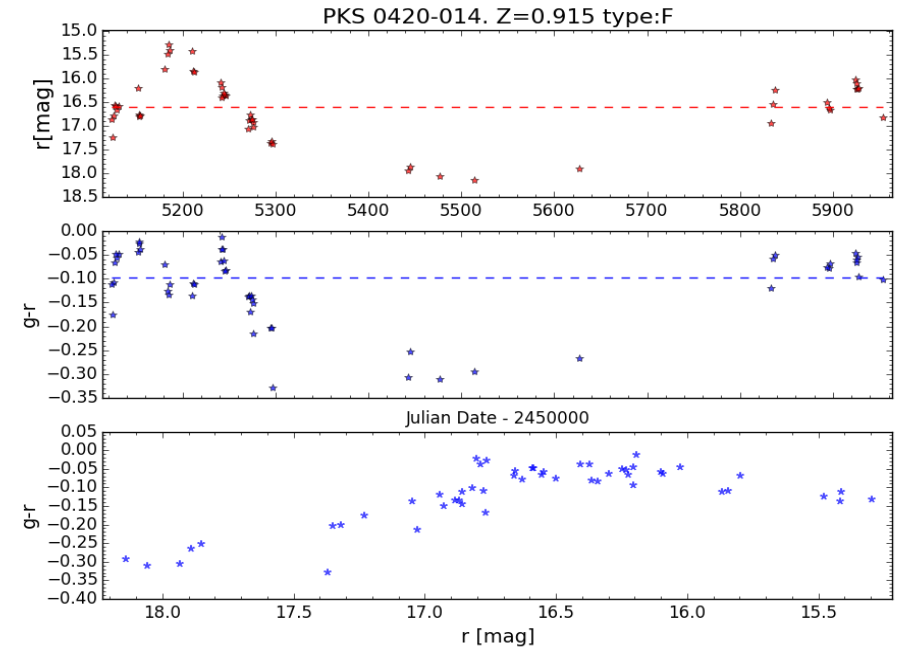
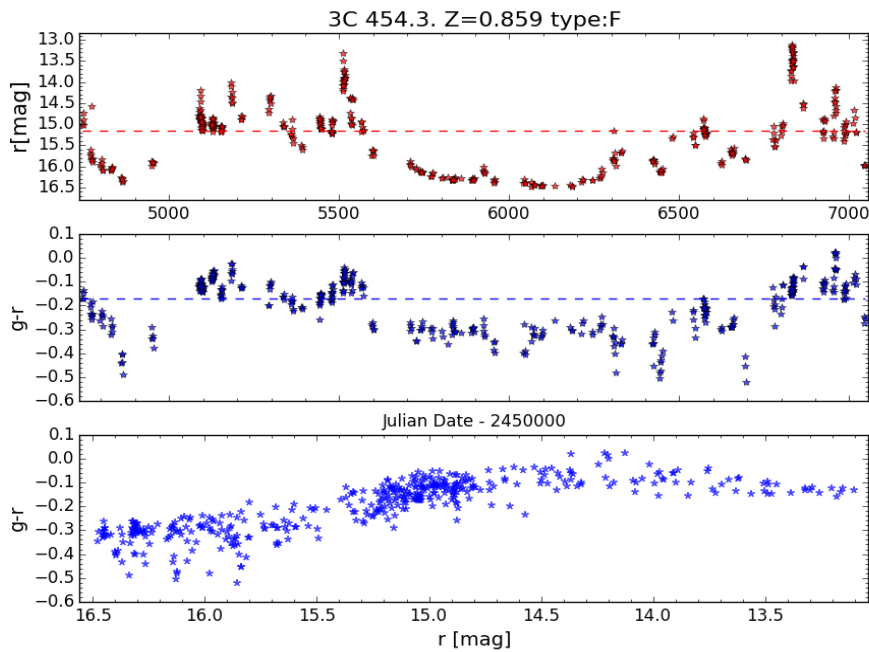
- Color-magnitude correlation \rightarrow spectral shape variation.



Color-magnitude diagrams



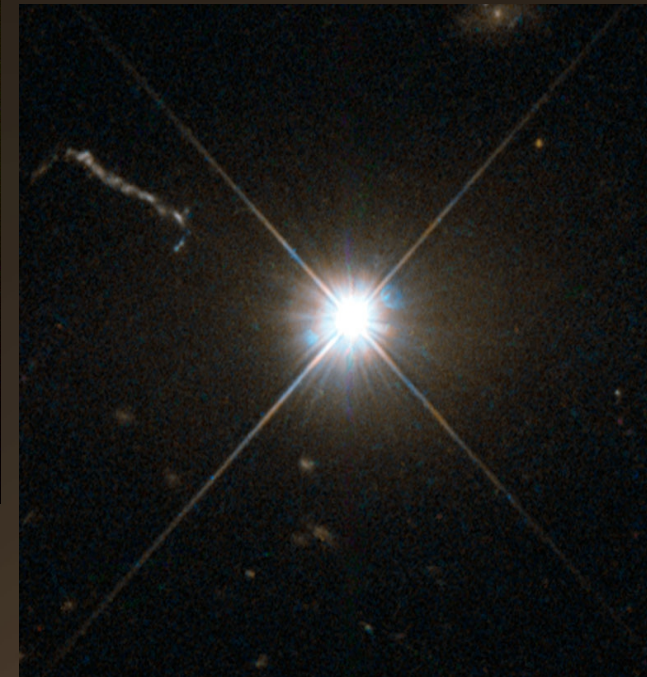
- Color-magnitude correlation
- Inflection magnitude (eg. Raiteri et al., 2012; Villata et al., 2006)



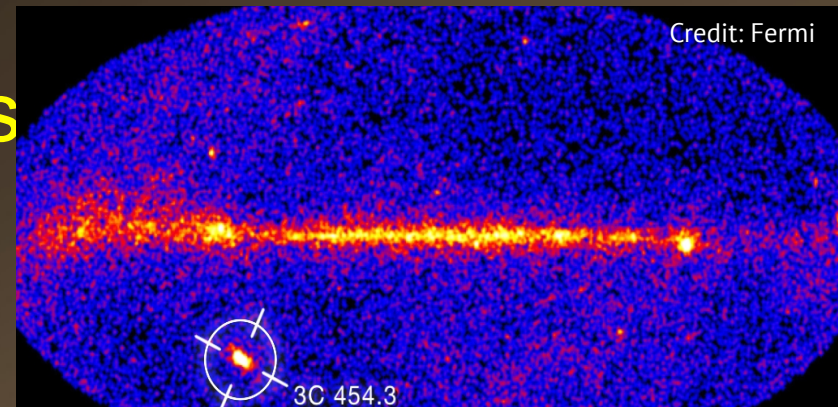
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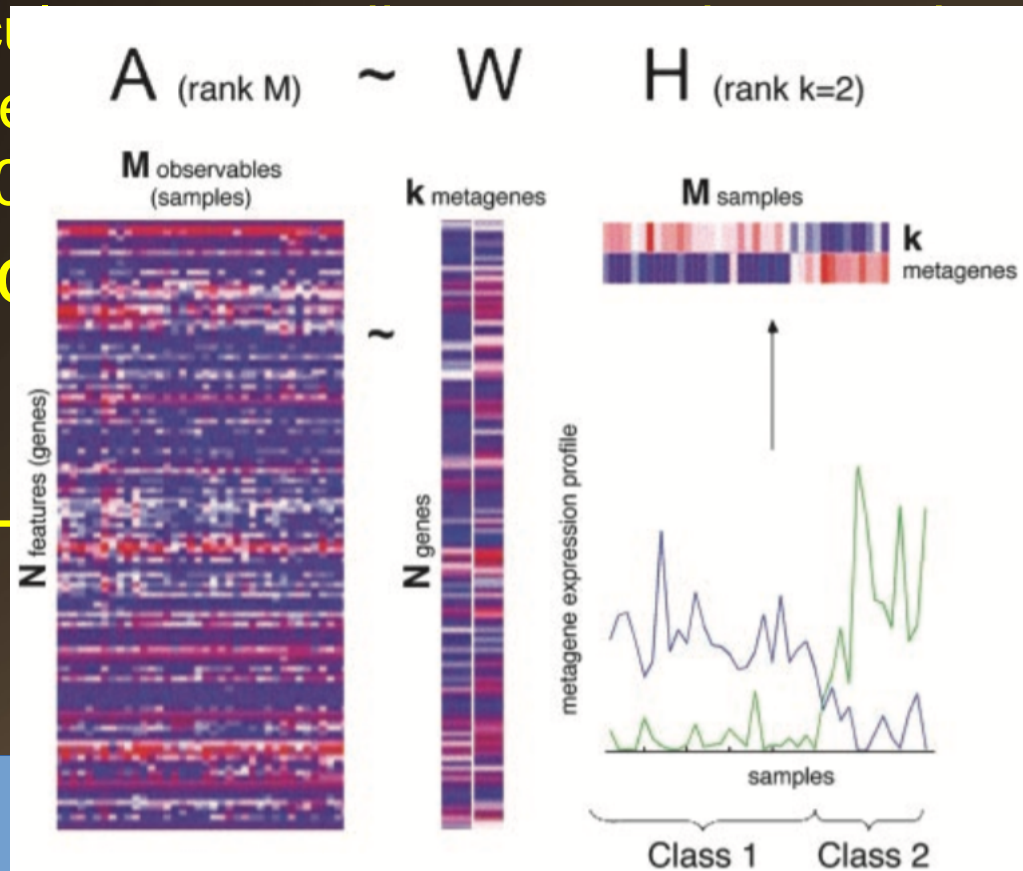
Credit: HST



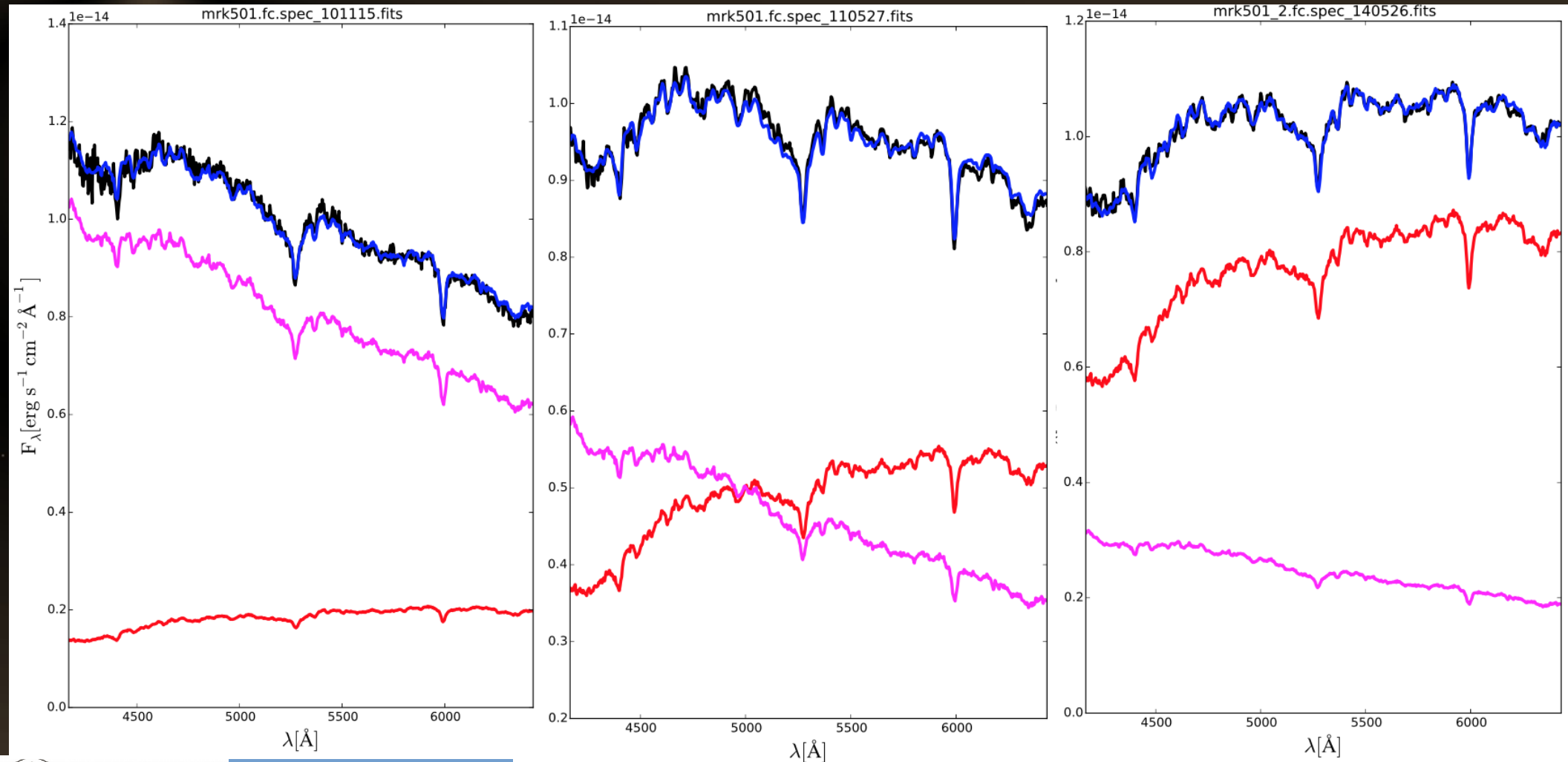
Credit: Fermi

NMF: Non Negative Matrix Factorization (PCA-like)

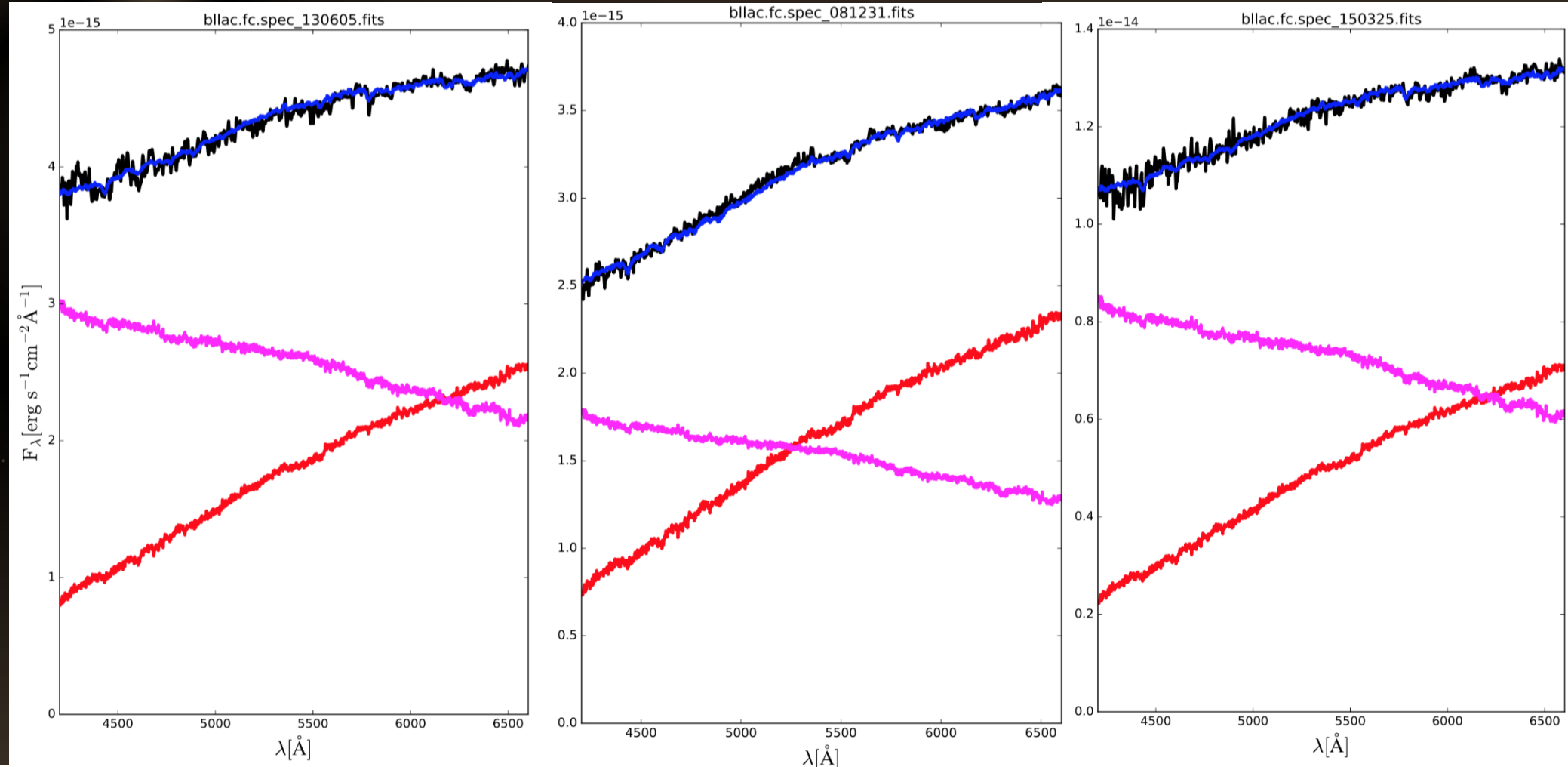
- An objective method for characterize spectral components
- Based in: Jean-P. Brunet, Pablo Tamayo, Todd R. Golub and Jill P. Mesirov. Metagenes and molecular classification. In Proceedings of the National Academy of Sciences of the USA, 101(12): 4164-4169, 2004
- Used for genetic correlation
 - Leukemia
 - Medulloblastoma
 - Central Nervous System T



NMF: Non Negative Matrix Factorization

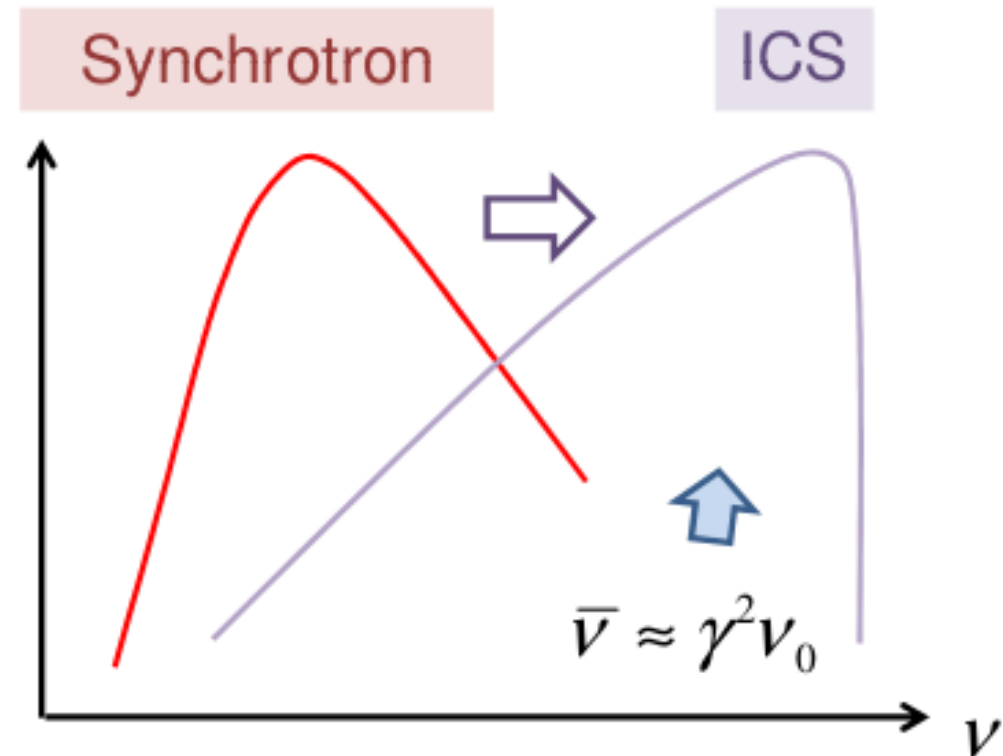
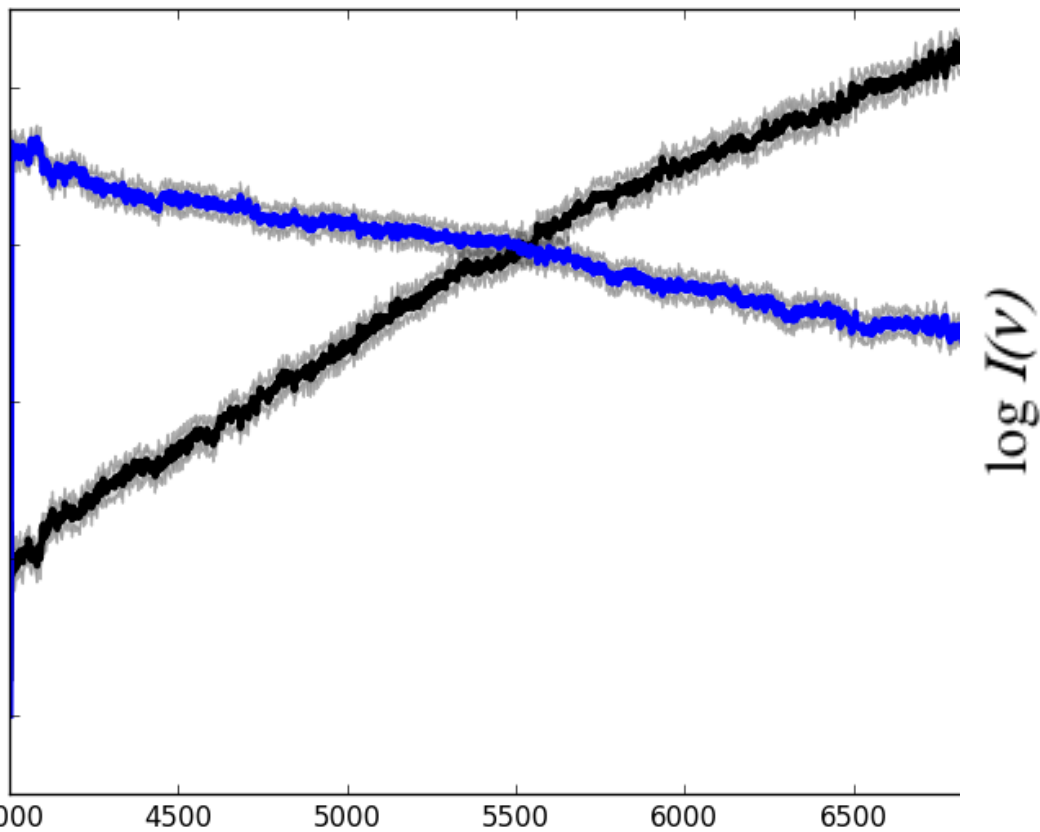


NMF: Non Negative Matrix Factorization



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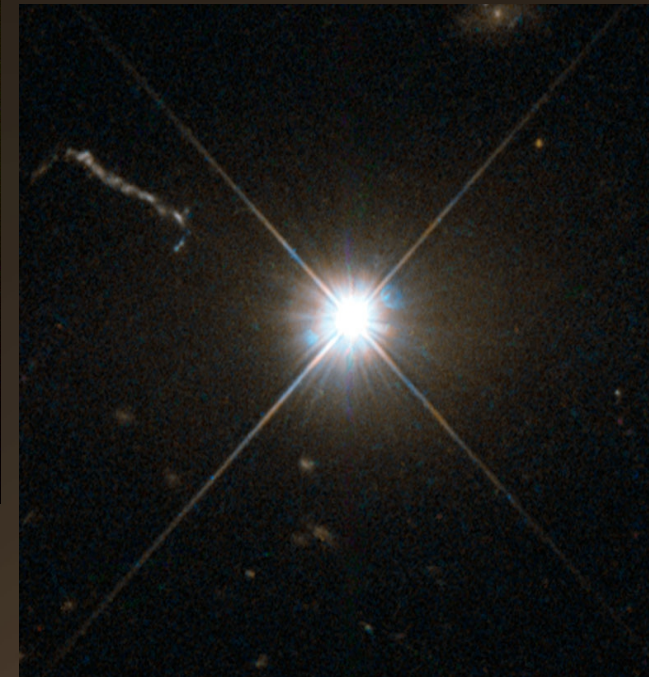
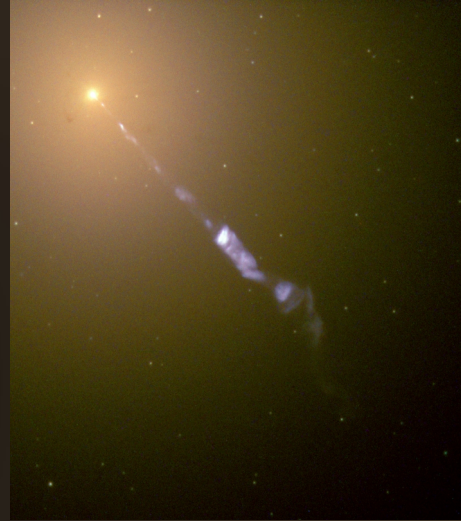
BL-Lac



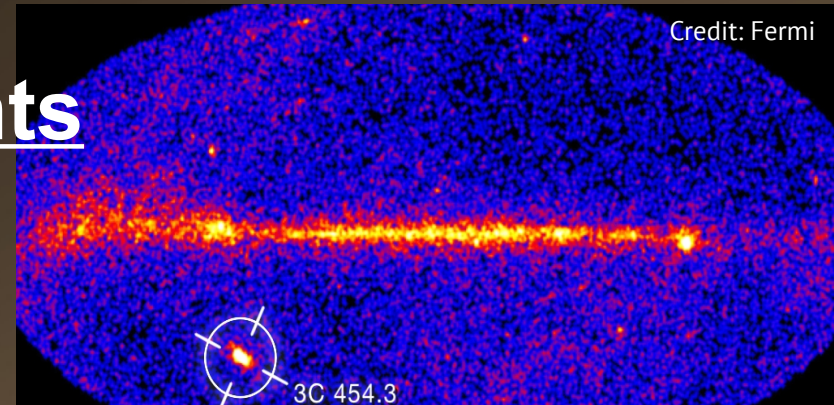
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Credit: Fermi

Spectral measurements: Iron template

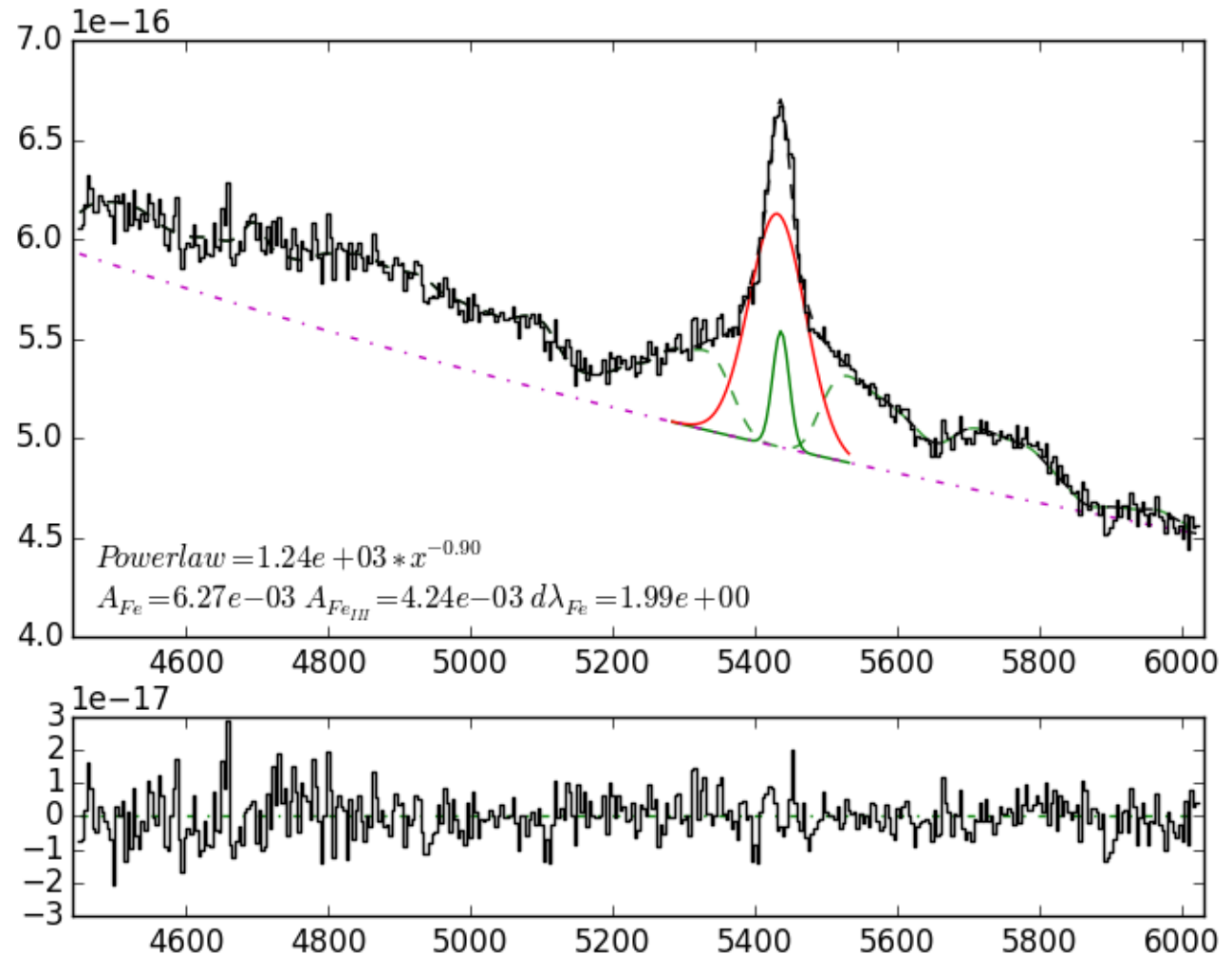
Continuum

+

Iron template

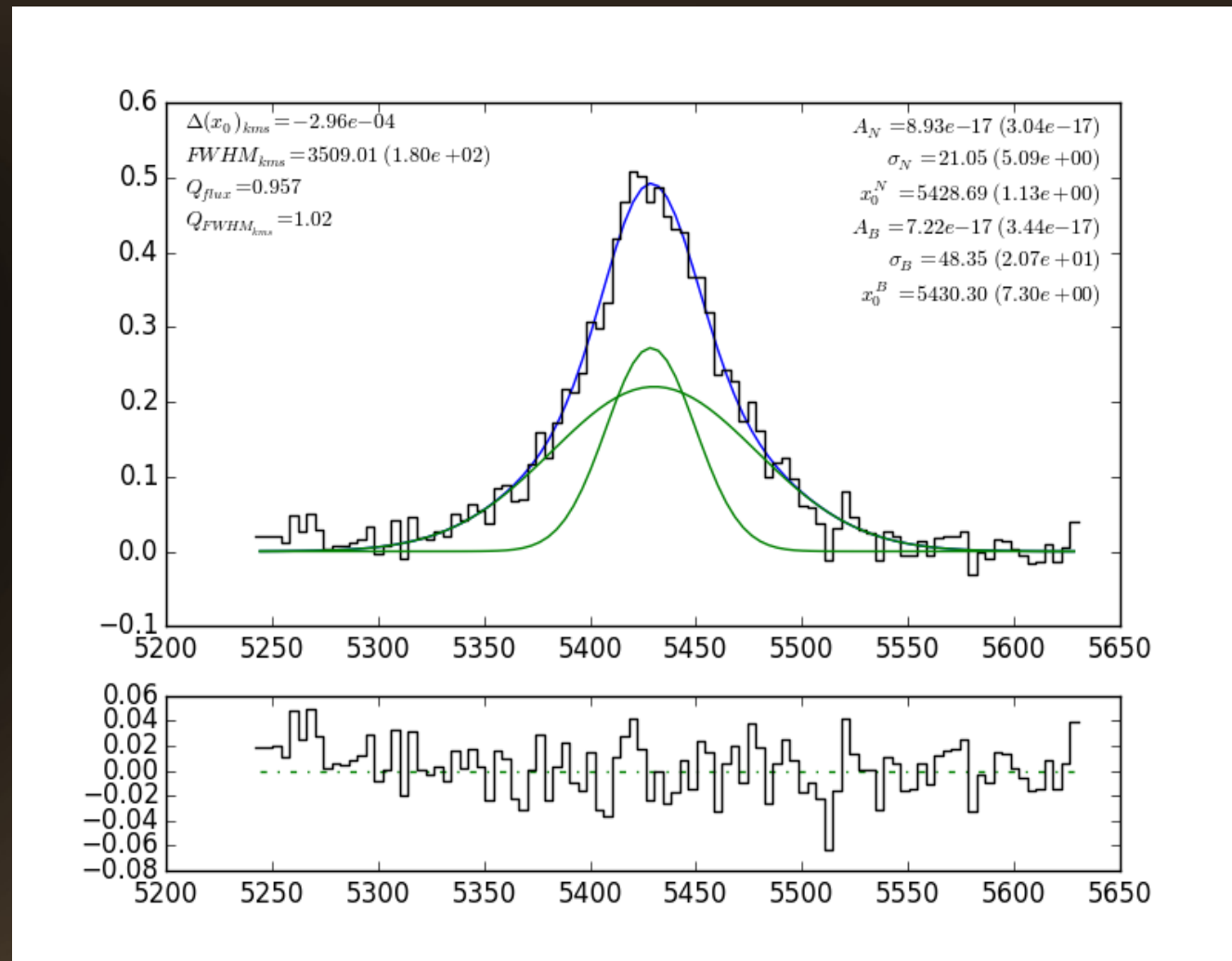
(Vestergaard, M. & Wilkes, B. J. 2001)

Fitted at once

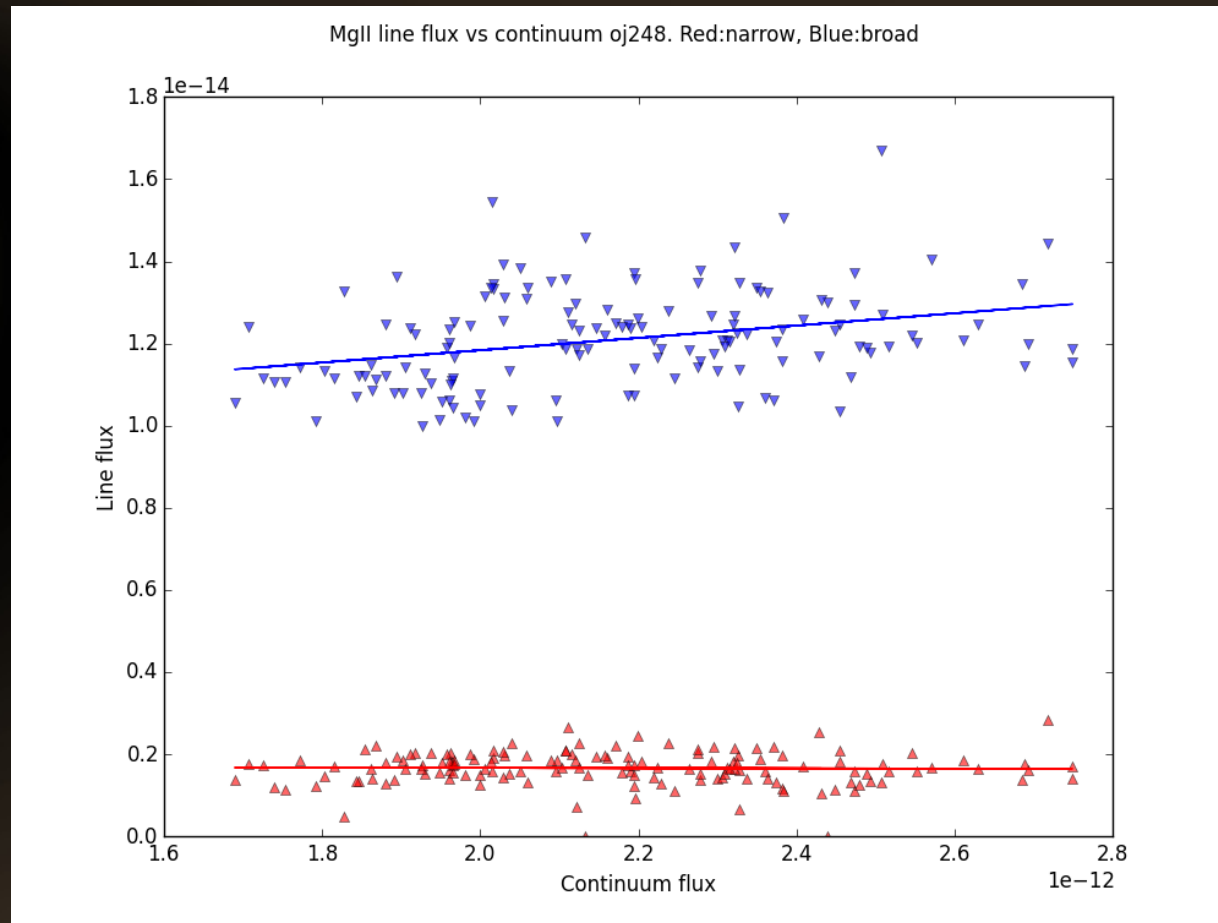


Spectral measurements: Line fit.

- 2 Component modeling + direct measurement.
- Boundary conditions for narrow line: [800, 2000] km/s (McLure & Dunlop, 2004)
- Noise impact (Monte Carlo)



Results: Correlation broad line – continuum at low activity



Results: BLR size

- Delay in broad line-continuum flux \rightarrow size.
- Discrete Correlation Function (Edelson & Krolik, 1988).
- No clear correlation was found.
- More observations needed to determine line-continuum delay.
- This technique might be successful with low NTD objects

Black hole mass measurements

$$\log \left(\frac{M_{\bullet, \text{vir}}}{M_{\odot}} \right) = a + b \times \log \left(\frac{\lambda L_{\lambda}}{10^{44} \text{ erg s}^{-1}} \right) + 2 \times \log \left(\frac{FWHM}{\text{km s}^{-1}} \right)$$

- Virial mass estimation.
 - From continuum:
 - $(a, b)[\text{cont}] = (0.505, 0.62) \leftrightarrow$ Vestergaard & Osmer, 2009

– From line luminosity:

$$\lambda L_{\lambda} \longrightarrow L_{MgII}$$

- $(a, b)[\text{line}] = (1.70, 0.63) \leftrightarrow$ Shen et al., 2011

Ionizing continuum

- Line luminosity give a non collimated continuum estimation:

$$\log \left(\frac{L_{pred}^{cont}[3000\text{\AA}]}{\text{erg s}^{-1}} \right) = (1,016 \pm 0,003) \times \log \left(\frac{L_{Mg II}}{\text{erg s}^{-1}} \right) + (1,22 \pm 0,011)$$

Shen et al. (2011) calibration for radio quiet objects

- Non-Thermal Dominance (NTD):

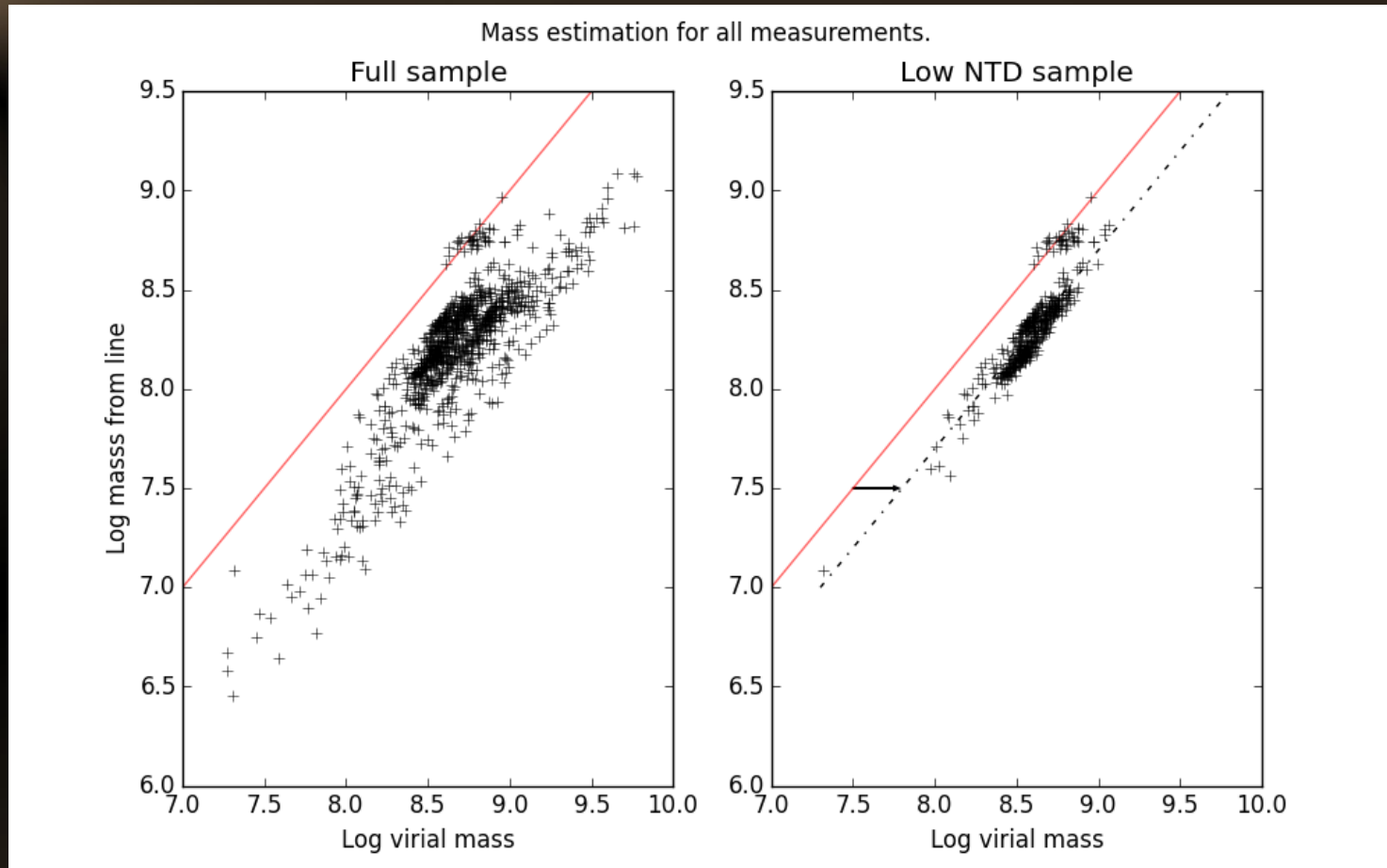
$$L[\text{obs}] / L[\text{pred}]$$

(Shaw et al., 2013)

NTD=1 → Disk luminosity dominated

NTD > 1 → Jet contribution

Results: Black hole mass



Mass from lines underestimated in 0.30 dex.

Results: Accretion rate

- Quasi-isotropic thermal luminosity (Urry & Padovani, 1995)
- Bolometric thermal luminosity: $L[\text{pred}] \rightarrow L[\text{bol}]$

$$L_{\text{bol}}/L_{3000} = 5,15$$

(Richards et al., 2006)

- Virial mass estimation:
 - $L[\text{pred}] \rightarrow (a,b)[\text{cont}] \rightarrow L[\text{Edd}]$

$\langle L[\text{bol}] / L[\text{Edd}] \rangle = 0.4$ for FSRQ

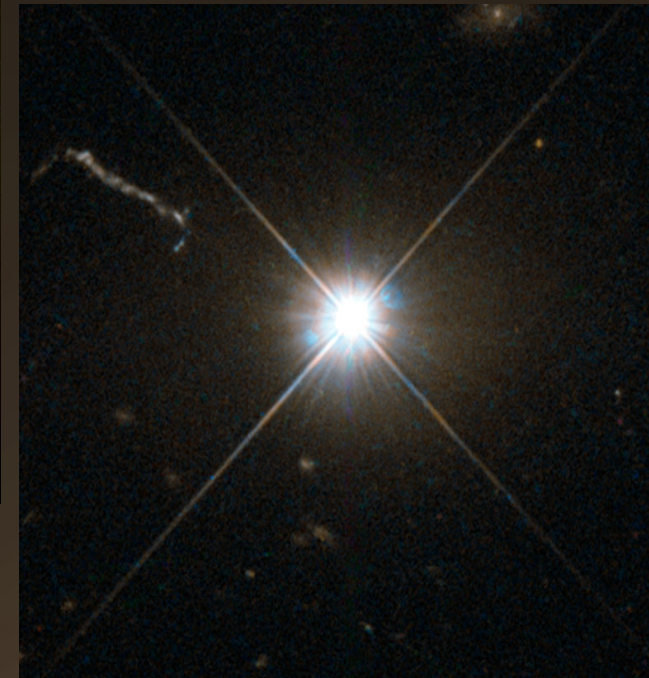
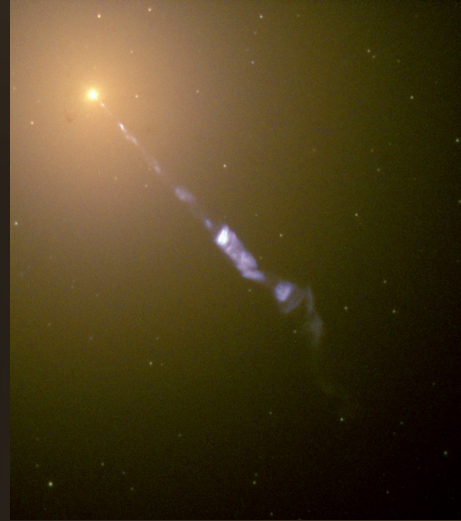
$\langle L[\text{bol}] / L[\text{Edd}] \rangle = 0.2$ for BL-Lac

- FSRQ are more active accretors (Ghisellini et al. 2011)

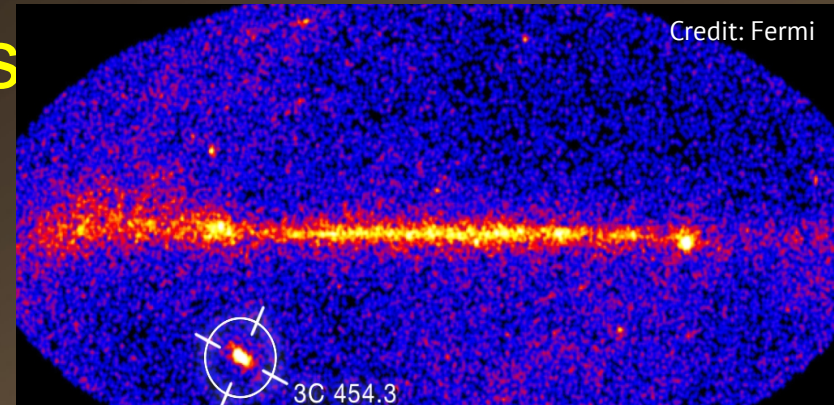
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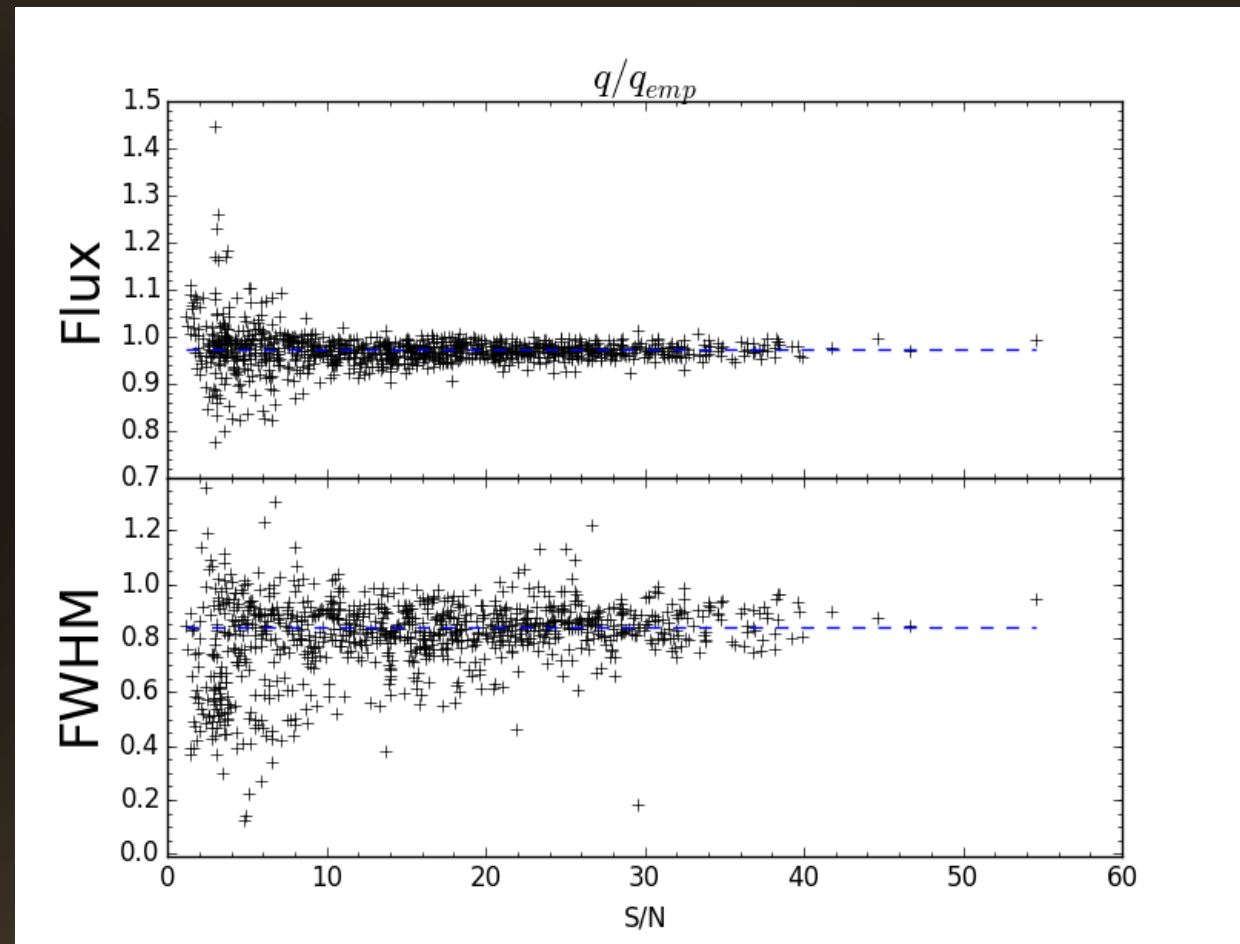
- Different behavior in VIS range
 - Flux variation → Constant color
 - Flux variation → Color variation
 - Redder when brighter
 - Bluer when brighter
 - Both
- Inflection magnitude → Changes on dominant source radiation.
- NMF show good component estimation, reproduces fairly well the spectrums and low component objects are correlated with color measurements.

Summary of results

- Mass estimators have to be used carefully when only few spectra are available.
- NTD can be used for quantify the goodness of mass estimation.
- BLR shape may not be spherical at all.
- FSRQ are more active accretors.
- Broad component – continuum flux correlation at short time scales rather than narrow component.

Spectral measurements: Goodness of measurements.

- Quality factor
- Improve for
- $S/N > 10$
- Low confidence in FWHM



NO? Classification: High energy flux

- Galaxy population objects produces lower energy at GeV rather than FSRQ

