The Largest Ever Optical Spectroscopic Survey of Blazars

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Collaborators

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- Roger Romani (PI)
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- Walter Max-Moerback
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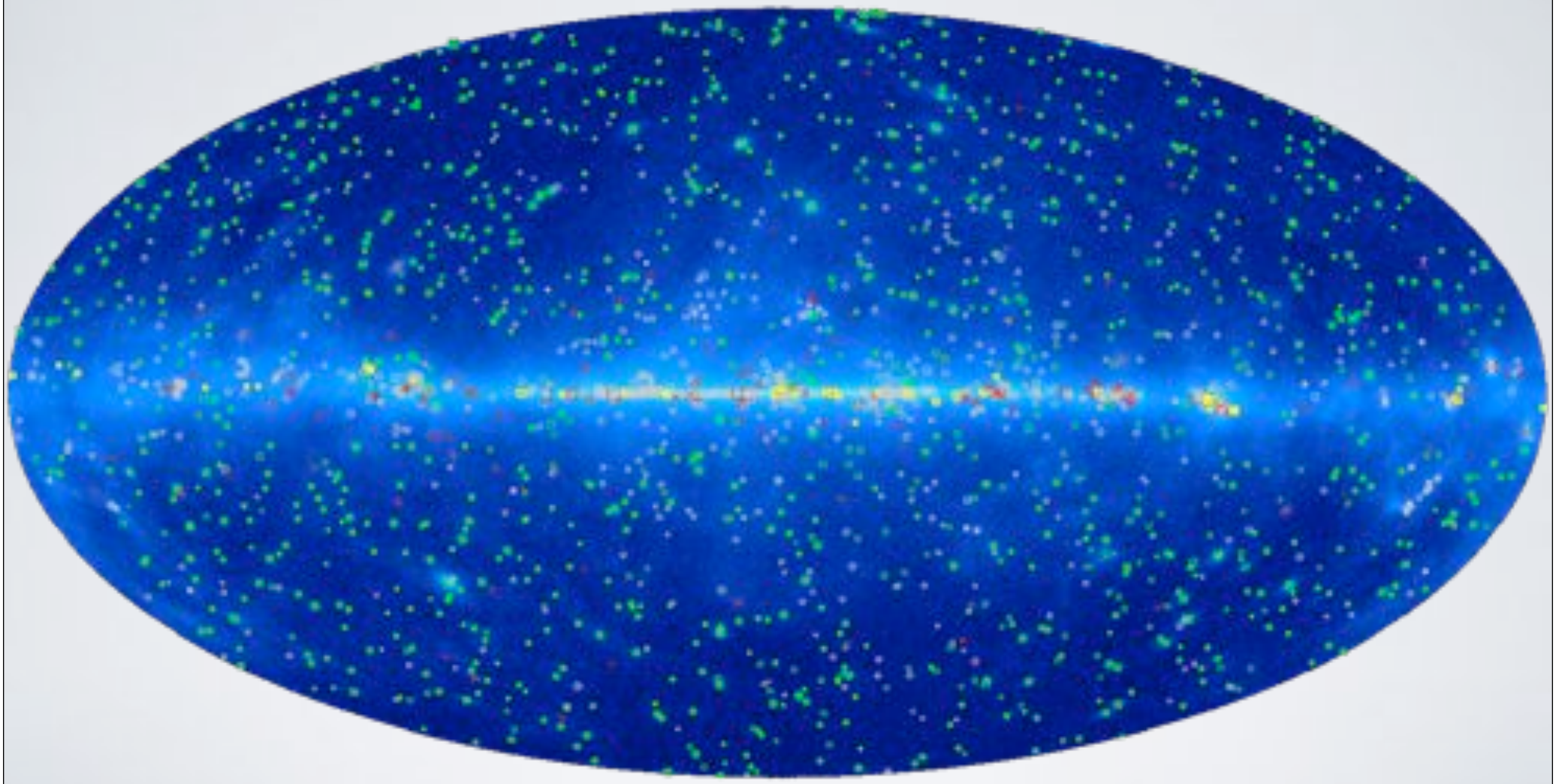
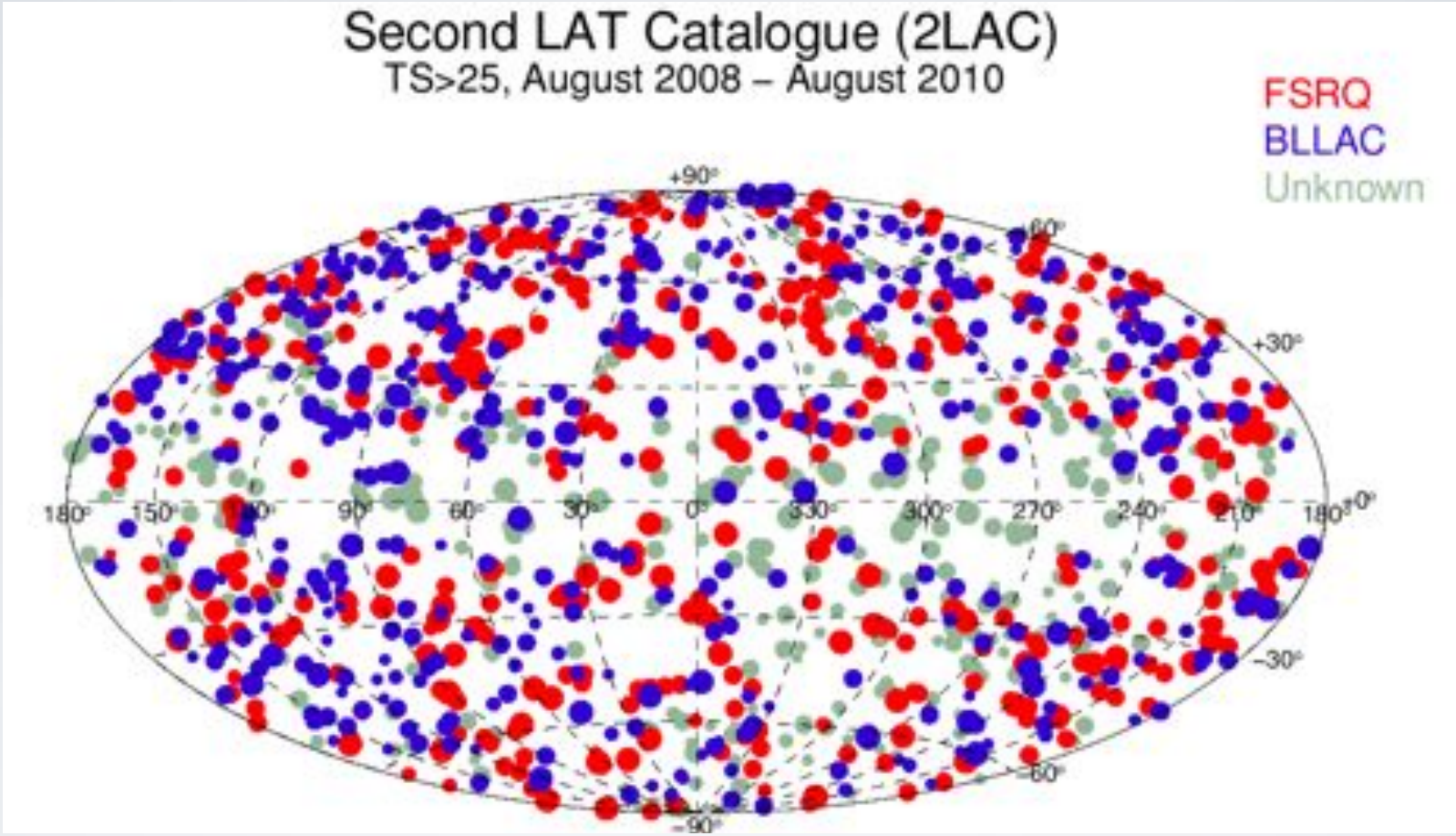
- Garret Cotter (PI)
- Will Potter

Many Thanks!

THE 2FGL SKY



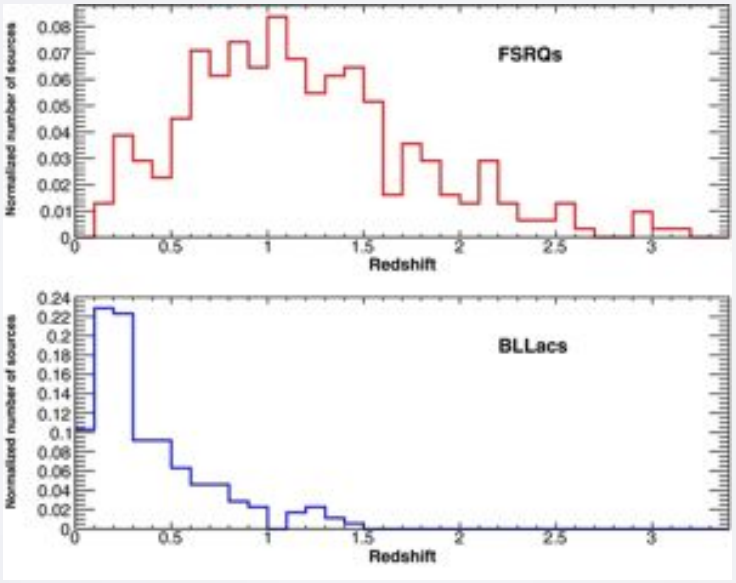
2LAC BLAZARS

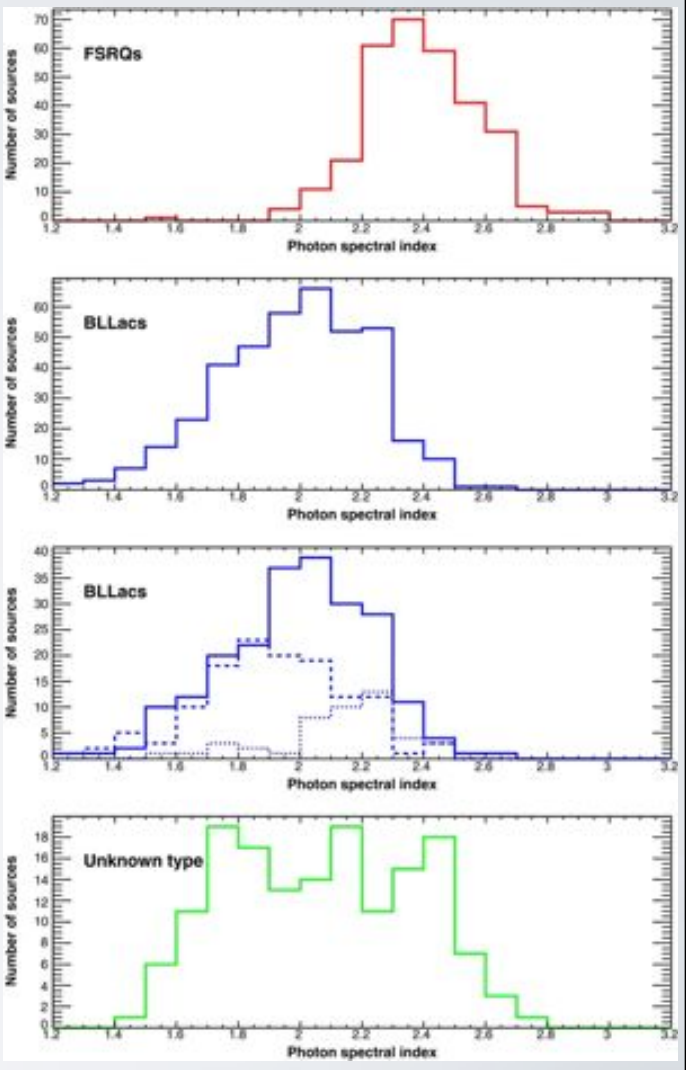


800+ Blazars across the extragalactic sky.
The dominant gamma-ray source class.
Many BL Lacs.

An optical Approach

- Substantial uncertainty in spectral types
- BL Lac z distribution systematically biased





Figures from Ackermann et al, 2011 (2LAC)

The Observing Campaign

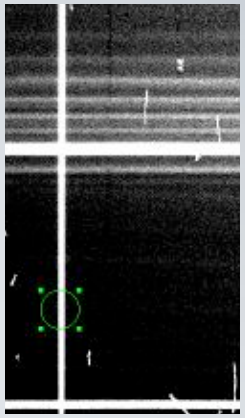
Telescope	Time	Type IDs	Redshifts	Institution	PI
	150 hours	84	38	Stanford	Romani
	8 nights	56	8	Caltech	Readhead
	9 nights	88	40	Caltech	Readhead
	6 nights	41	14	ESO	Cotter
	2 nights 10 hours	40	28	ESO	Cotter

Completeness

	Total	Archival z	Spectro. z	Quantitative Constraints	Unknown z
2LAC	1017	319 *31%*	312 *31%*	230 *23%*	156 *15%*
		= 62%			
2LAC BL Lac	456	110 *24%*	100 *22%*	222 *49%*	23 *5%*
		= 46%			

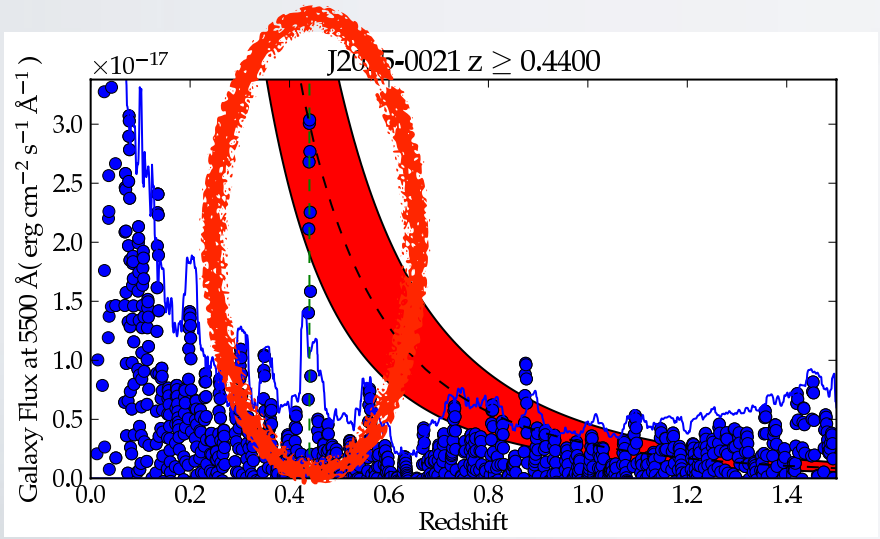
BLL Spectroscopic redshifts + constraints = **95%**

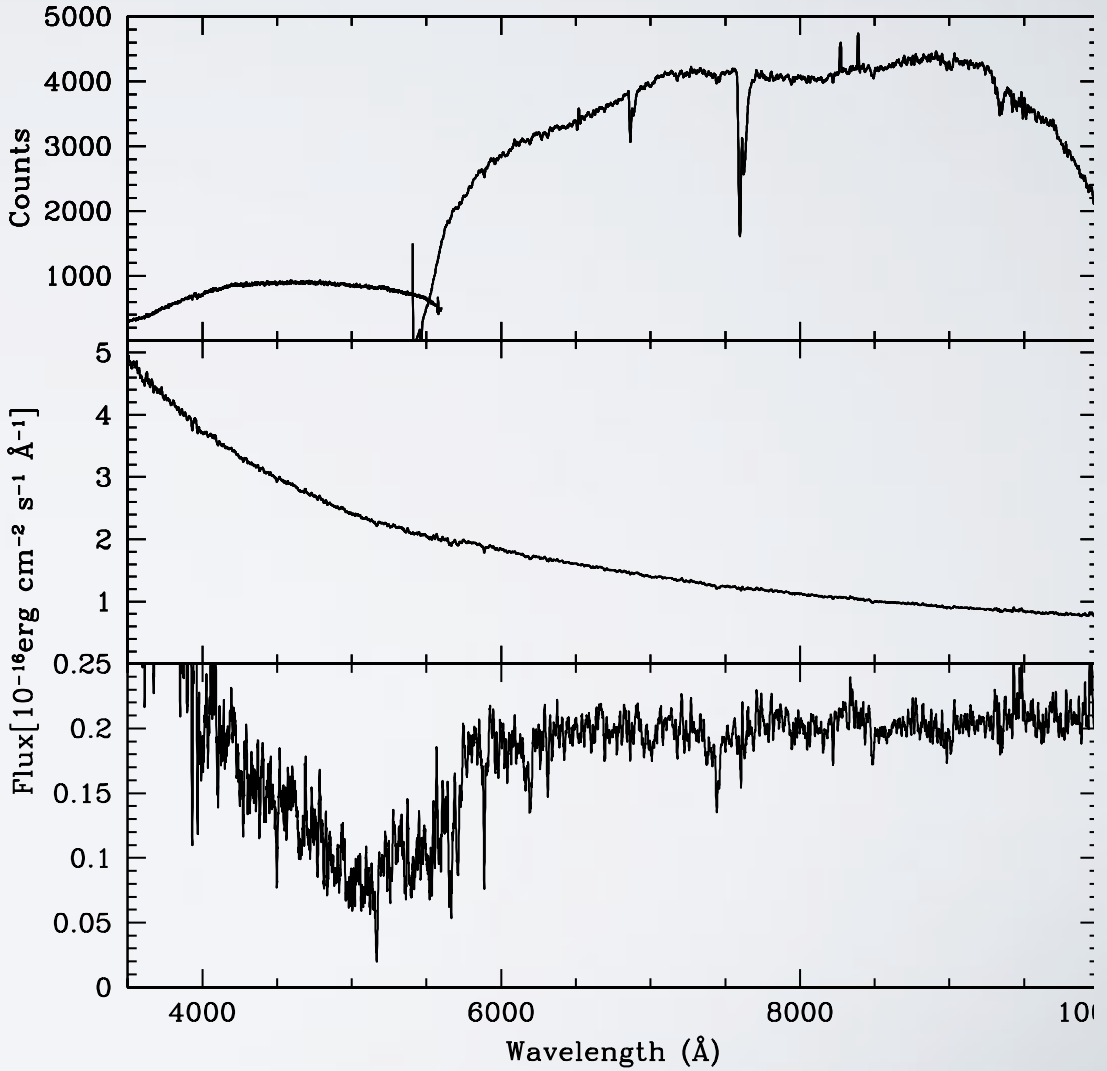
Story of a Blazar



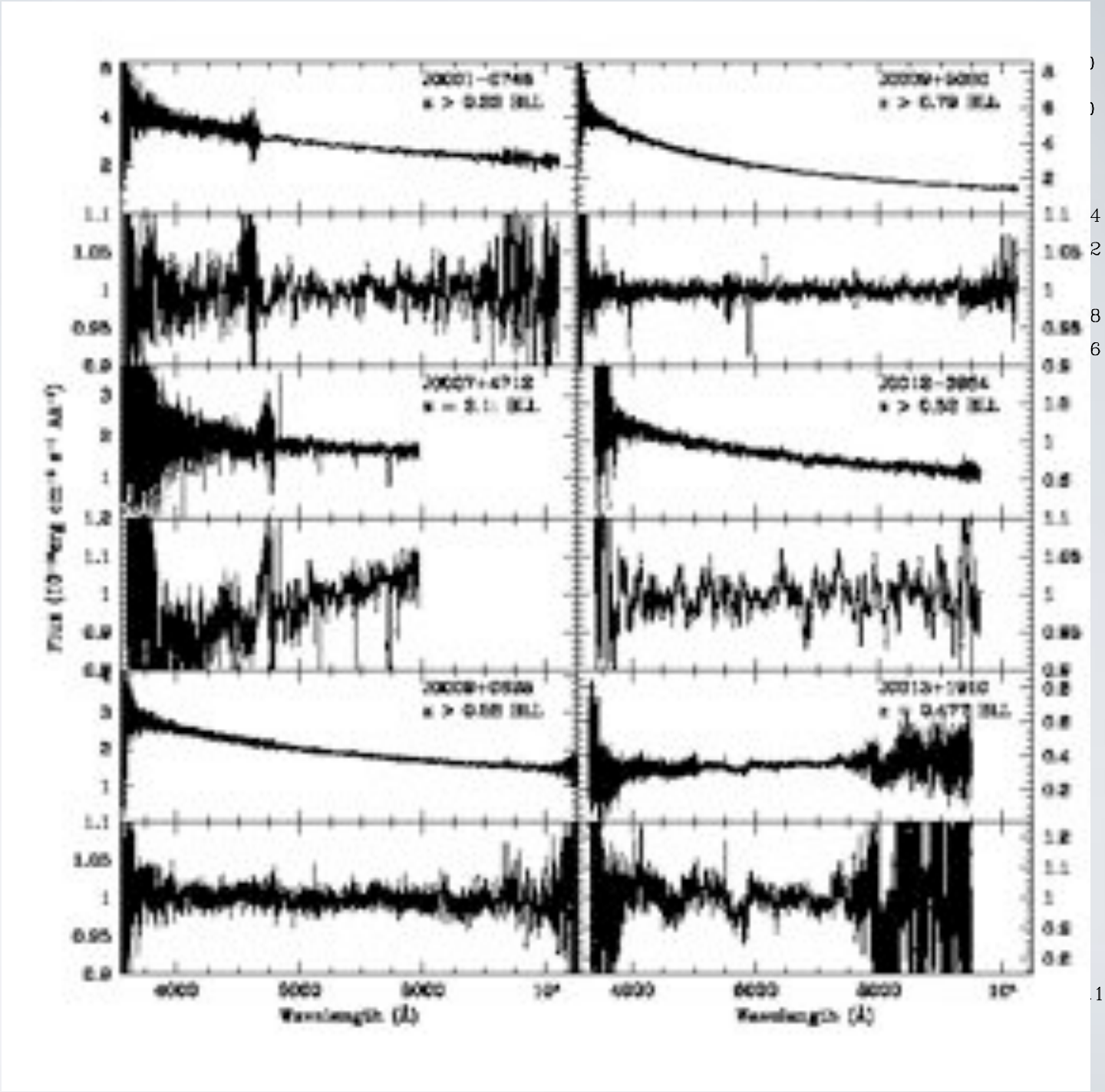
- J2055-0021: a bright BLL
- Observed with Keck LRIS
- Despite bright continuum:

z = 0.440



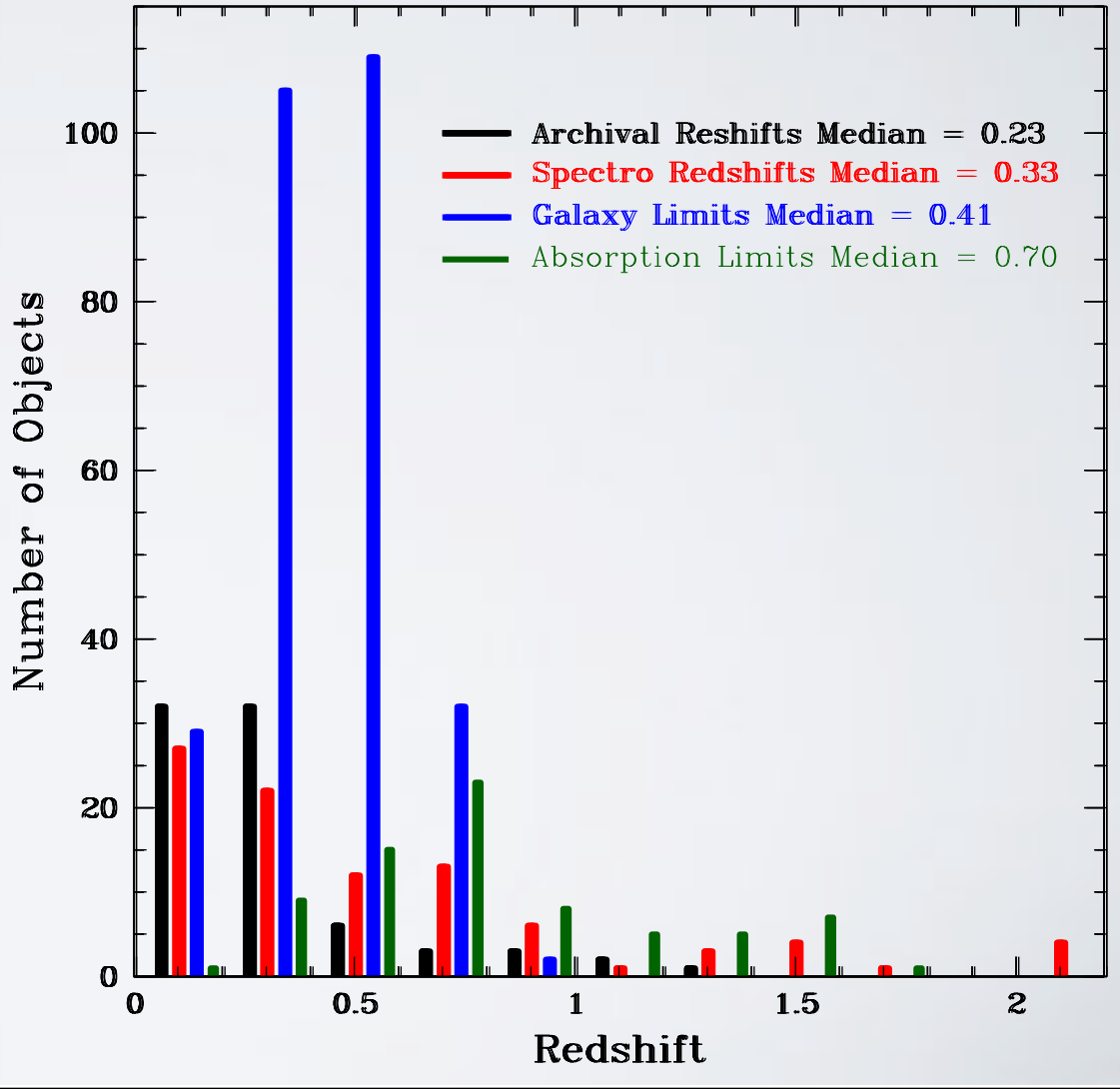


The Spectra

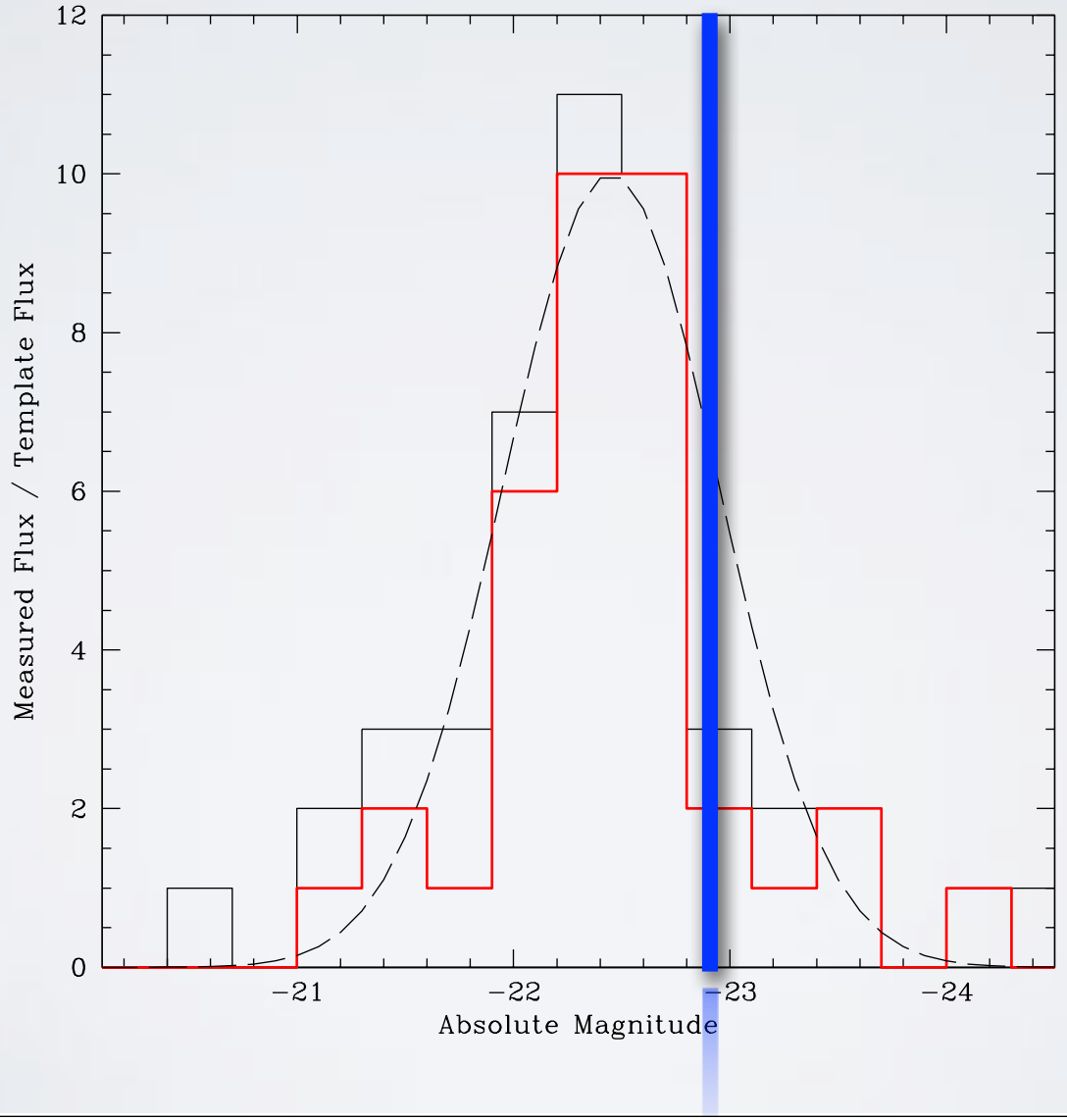


BL Lac Redshifts

- BL Lacs not only at low z
- `Negative' evolution disfavored
- Substantial selection effects remain
- Limits suggest substantial higher z population

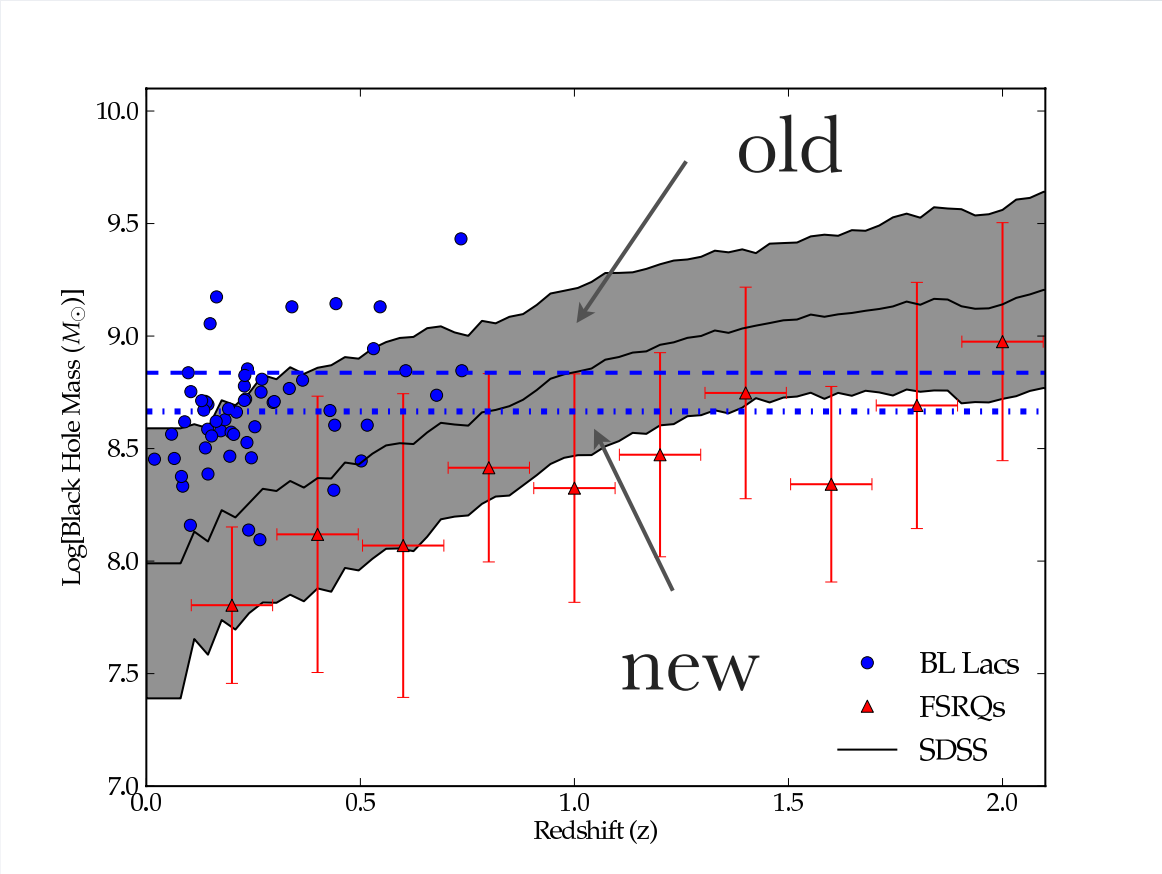


Calibrating Standard Candles



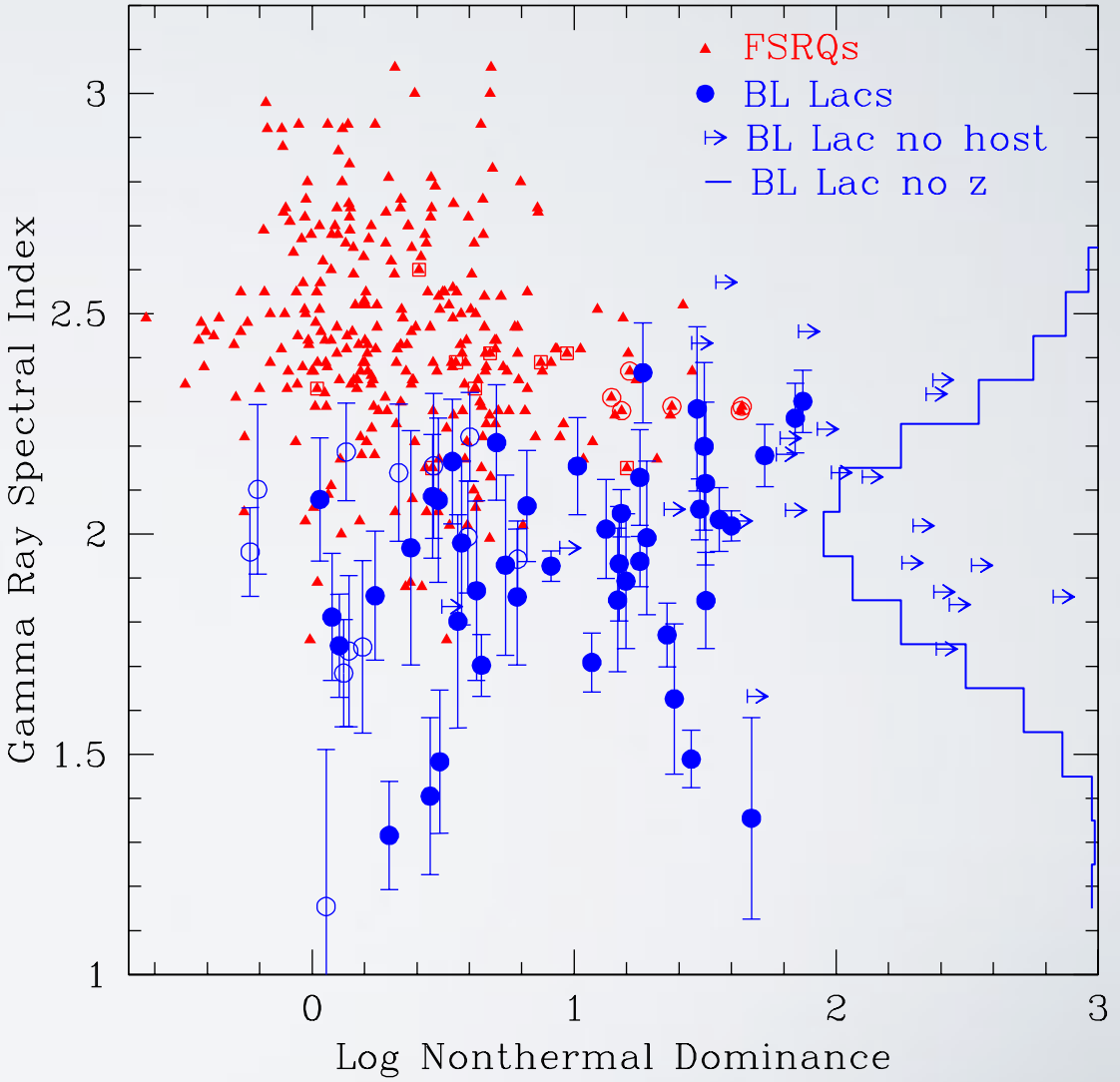
Black Hole Masses

- FSRQs: Preferentially lower BH masses
  - Likely due to preferred orientation of BLR
- BL Lacs: Preferentially higher BH masses
- Possible selection effects



Nonthermal Dominance (NTD)

- Quantitative measure of ``BL Lac-ness'' in optical
- Loosely correlated with gamma-ray spectral index
- Within BL Lacs, extends to extreme values



Where to Find the Data

FSRQs

Submitted to ApJ, October 13, 2011
Preprint typeset using LaTeX style emulateapj v. 5/2/11

SPECTROSCOPY OF BROAD LINE BLAZARS FROM 1LAC

Michael S. Shaw[1], Roger W. Romani[1], Garret Cotter[2], Stephen E. Healey[1], Peter F. Michelson[1], Anthony C. S. Readhead[3], Joseph L. Richards[3], Walter Max-Moerbeck[3], Oliver G. King[3], William J. Potter[2]

Submitted to ApJ, October 13, 2011

ABSTRACT

We report on optical spectroscopy of 165 Flat Spectrum Radio Quasars (FSRQs) in the *Fermi* 1LAC sample, which have helped allow a nearly complete study of this population. *Fermi* FSRQ show significant evidence for non-thermal emission even in the optical; the degree depends on the γ-ray hardness. They also have smaller virial estimates of hole mass than the optical quasar sample. This appears to be largely due to a preferred (axial) view of the γ-ray FSRQ and non-isotropic ($H/R \sim 0.4$) distribution of broad-line velocities. Even after correction for this bias, the *Fermi* FSRQ show higher mean Eddington ratios than the optical population. A comparison of optical spectral properties with Owens Valley Radio Observatory radio flare activity shows no strong correlation.

Subject headings: galaxies: active — Gamma rays: galaxies — quasars: general — surveys

1. INTRODUCTION

The *Fermi* Gamma-Ray Space Telescope was launched on 2008 June 11. Its primary instrument is the Large Area Telescope (Atwood et al. 2009, LAT). *Fermi* generally operates in sky survey mode, observing the entire sky every 3 hours, and providing approximately uniform sky coverage on time scales of days to years.

The *Fermi* LAT First Source Catalog (Abdo et al. 2010a, 1FGL) catalogs the 1451 most significant sources detected in *Fermi*'s first year of operation. Based on the 1FGL catalog, The First Catalog of AGN Detected by the *Fermi* LAT (Abdo et al. 2010c, 1LAC) is the largest radio-γ selected sample of blazars to date, associating 671 γ-ray sources to 709 AGN (some may be unresolved composites) in the high-latitude sample.

Our quest is to optically characterize these sources, seeking maximum completeness in spectroscopic identifications and using the spectra to constrain the properties of these AGN. Optically, the *Fermi* sources are evenly split between Flat Spectrum Radio Quasars (FSRQs) and BL Lacerate Objects (BL Lacs). In this paper, we focus on the FSRQs. A companion paper (Shaw et al, in prep.) addresses the BL Lac objects.

In §2, we discuss the observational program and the data reduction process. In §3, we describe the measurements and derived data products. In §4, we measure the continuum emission and non-thermal pollution. In §5, we estimate the black hole masses and Eddington ratio of the *Fermi* FSRQ. In §6, we discuss the orientation and shape of the the broad line region in this population, and in §7, we relate this data set to on-going radio monitoring of these AGN.

In this paper, we assume an approximate concordance cosmology – $\Omega_m = 0.3$, $\Omega_\Lambda = 0.7$, and $H_0 = 70$ km s^{-1} Mpc^{-1}.

2. OBSERVATIONS AND DATA REDUCTION

2.1. *The FSRQ Sample*

This paper reports on a multi-year observing campaign to follow-up the *Fermi* blazars. A principal aim is to achieve high redshift completeness for the 1LAC sample (Abdo et al. 2010c).

In this paper, we discuss the spectra of FSRQs and other LAT blazar associations with strong emission lines. A major contribution is new spectroscopy of 165 of these blazars. To extend this analysis, we also measured archival spectra of 64 SDSS blazars in the sample, for a total of 229 spectra.

This work takes the 1LAC high latitude sample to 96% level completeness, with 316 FSRQs, 322 BL Lacs, 33 other AGNs, 4 LINERs, and 9 Galaxies. There are 3 remaining associated flat spectrum radio sources of unknown type – optically these represent objects that are optically extreme faint ($R > 23$) or show faint continuum-dominated spectra, where current spectroscopy does not have sufficient S/N to unambiguously confirm a BL Lac-type ID.

The most important sub-set of this emission-line sample are the objects with traditional FSRQ properties – in addition to a flat spectrum radio core emission which allow the LAT counterpart association, we require emission lines with kinematic FWHM > 1000 km s^{-1} and bolometric luminosity $> 10^{42}$ erg s^{-1}. We find that 188 FSRQ meet these criteria, including 10 low-latitude sources with 1LAC FSRQ associations. In addition, some 11 BL Lacs show well-detected broad lines. For this paper we adopt the traditional heuristic BL Lac definition: continuum-dominated objects with observed frame line equivalent width (EW) of < 5 Å and, where measured, Balmer break strength of < 0.5 (Healey et al. 2008). We classify an object as a 'BL Lac' if it meets these spectroscopic criteria at any epoch. For 6 of the 11 BL Lac our spectra includes epochs in a 'low' state where decreased continuum reveals broad emission lines with > 5 Å EW. The other 5 objects satisfy the BL Lac criteria in all of our spectra, but nevertheless show highly significant, albeit low EW, broad lines.

The emission line sample contains 29 other objects – spectroscopically these are 9 galaxies, 5 LINERs, and 15

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BL Lacs

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SPECTROSCOPY OF THE LARGEST EVER γ-RAY SELECTED BL LAC SAMPLE

Michael S. Shaw[1], Roger W. Romani[1], Garret Cotter[2], Stephen E. Healey[1], Peter F. Michelson[1], Anthony C. S. Readhead[3], Joseph L. Richards[3], Walter Max-Moerbeck[3], Oliver G. King[3], Will Potter[2]

Submitted to The Astrophysical Journal

ABSTRACT

We report on spectroscopic observations covering most of the 456 BL Lacs in the 2^{nd} *Fermi* LAT catalog of AGN. Including archival measurements (correcting several erroneous literature values) we now have spectroscopic redshifts for 46% of the BL Lacs. We establish firm lower redshift limits via intervening absorption systems and statistical lower limits via searches for host galaxies for an additional 49% of the sample leaving only 5% of the BL Lacs unconstrained. The new redshifts raise the median spectroscopic $\bar{z}$ from 0.23 to 0.33 and include redshifts as large as $z = 2.2$. Spectroscopic redshift minima from intervening absorbers have $\bar{z} = 0.70$, showing a substantial fraction at large z and arguing against strong negative evolution. We find that detected BL Lac hosts are bright ellipticals with hole masses $M_\bullet \sim 10^{8.5-9}$, substantially larger than the mean of optical AGN and LAT Flat Spectrum Radio Quasar samples. A slow increase in $M_\bullet$ with z may be due to selection bias. We find that the power-law dominance of the optical spectrum extends to extreme values, but this does not strongly correlate with the γ-ray properties, suggesting that strong beaming is the primary cause of the range in continuum dominance.

Subject headings: BL Lacertae objects: general — galaxies: active — Gamma rays: galaxies — quasars: general — surveys

1. INTRODUCTION

The *Fermi* Second Source Catalog (Nolan et al. 2012, 2FGL) lists the 1873 most significant sources detected by the Large Area Telescope (Atwood et al. 2009, LAT) during *Fermi*'s first two years of sky survey observations. The majority of these sources are associated with jet-dominated Active Galactic Nuclei, the so-called blazars, many of which are bright, compact radio sources. There are, in fact, 1017 such identifications, collected in the Second Catalog of AGN Detected by the *Fermi* LAT (Ackermann et al. 2011, 2LAC). These AGN are further classified as Flat-Spectrum Radio Quasars (FSRQ) when the optical spectrum is dominated by thermal disk and broad-line region emission (BLR; Ghisellini et al. 2011), where the optical spectrum is dominated by continuum synchrotron radiation, and a collection of miscellaneous (mostly low luminosity related sources. In 2LAC, the sample included 410 BLL, 357 FSRQ, 27 AGN of other types (generally low z, lower luminosity Seyferts), and 199 AGN of (then) unknown type.

These 'Blazars' (BLL and FSRQ) are the brightest extra-Galactic point sources in the microwave and γ-ray bands; study of their population and evolution are central topics in high energy astrophysics. To support such studies we have acquired sensitive spectroscopic observations of this sample. In a companion paper (Shaw et al. 2012, hereafter S12), we reported on measurements of a large fraction of the FSRQ. Here we concentrate on the BL Lac objects. Our study has also found types for some of the unclassified blazars; the 'unknowns' have now decreased to 156 (15%), and the confirmed BLLs have increased to 456 (45% of all 2LAC AGN).

In §2, we outline the sample properties, data collection, and data reduction steps. We also summarize principal features of the spectra. In §3, we describe our spectroscopic constraints on the redshift, including a technique to provide uniform redshift limits based on searches for host galaxy emission. In §4, we give estimates of the BLL black hole masses. We turn to comments on the principal BLL feature, the non-thermal dominance in the optical in §5, and conclude with general remarks in §6.

In this paper, we assume an approximate concordance cosmology – $\Omega_m = 0.3$, $\Omega_\Lambda = 0.7$, and $H_0 = 70$ km s^{-1} Mpc^{-1}.

2. OBSERVATIONS AND DATA REDUCTION

2.1. *The BLL Sample*

BLLs were originally identified as optical violently variable AGN, and are often characterized by an optical continuum dominated by synchrotron emission. Their broad-band spectral energy distribution is described by a low-E synchrotron component peaking in the far-IR/X-ray bands, and a high-E Compton component peaking in the MeV to GeV range. In the radio these sources display strong core dominance. According to the unified model (Urry & Padovani 1995) BLLs are the high luminosity end of the FR I radio galaxy population, while the FSRQ are associated with FR IIs. However, the principal BLL characteristic, a dominant and varying synchrotron continuum, is a sign of a powerful jet whose emission is beamed closely toward the Earth line of sight. Thus the distinction between the traditional BLL and the FSRQ is sensitive to the precise state and orientation of the jet (e.g. Giommi et al. 2012) and, indeed, variations in jet power or direction bring individual sources in or out of the BLL class (S12).

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Conclusions

- **95%** of *Fermi* BL Lacs have redshifts or constraints
  - Sets the stage for groundbreaking EBL work: Ajello, 2:45PM
- BL Lac assumptions challenged:
  - Standard candle? Maybe. Negative evolution? Probably not.
- Systematic difference in BH mass: impact on AGN evolution?
- FSRQs: Shaw et al, 2012 ; BLLs: Shaw et al, submitted to ApJ

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