Optical spectroscopy of unclassified Active Galactic Nuclei in the Fermi-2LAC catalogue

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Outline

1. Active Galactic Nuclei

2. Blazars

3. **Fermi-LAT**

4. Multi-wavelength observations

5. **Sample selection criteria**

6. **RESULTS: OPTICAL SPECTRA**

7. *Discussion & Conclusion*

Active Galactic Nuclei

What makes AGN special?

Active nucleus that outshines rest of galaxy

Extremely luminous ~ 10^{47} erg/s

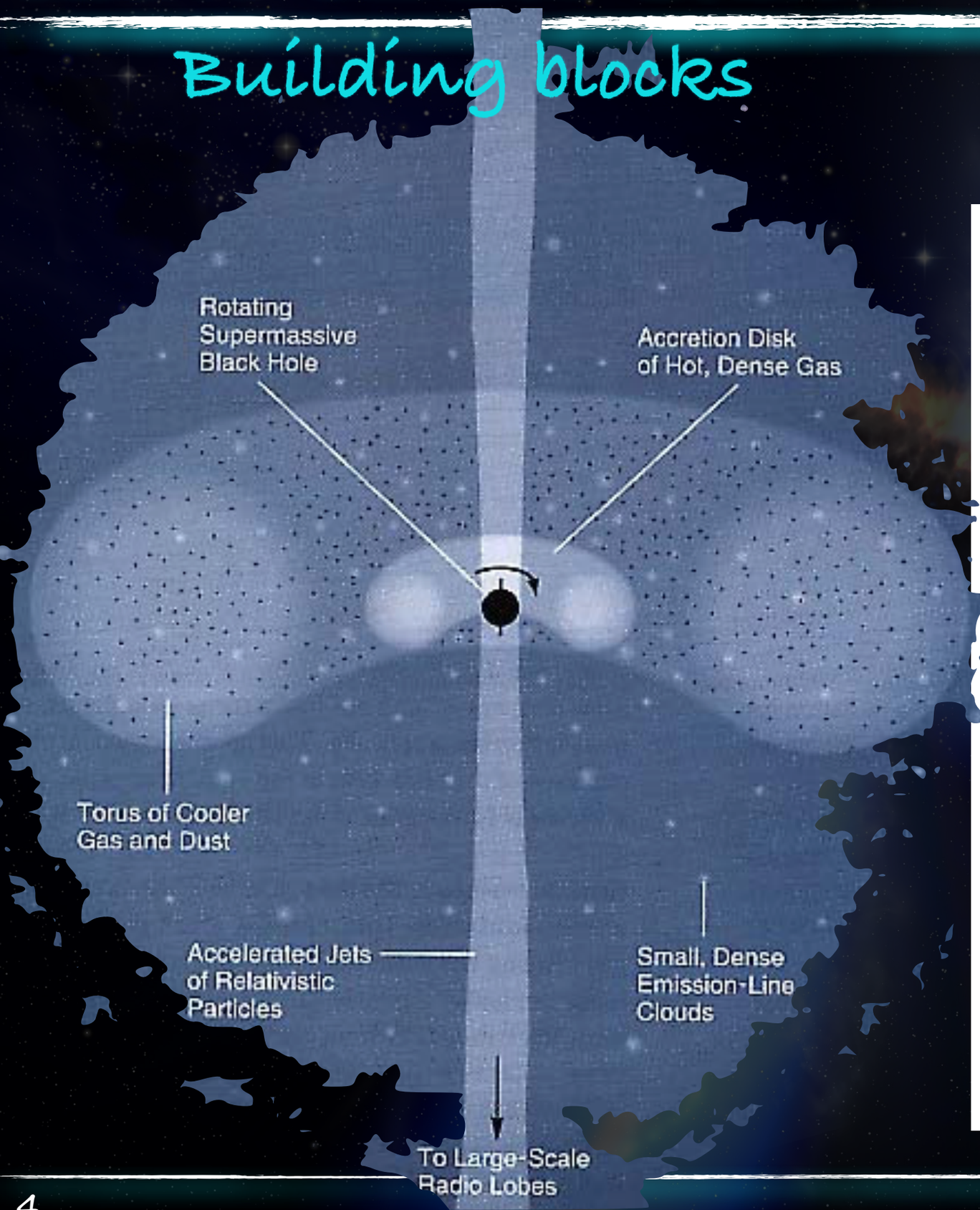
Multi-frequency emission: radio - γ-rays

Strong variability across EM spectrum at different time scales

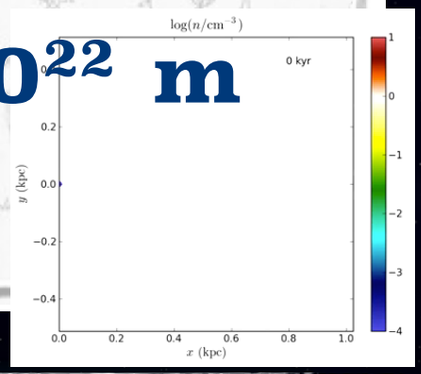
RADIO LOUD AGN: RELATIVISTIC JETS

Active Galactic Nuclei

Building blocks



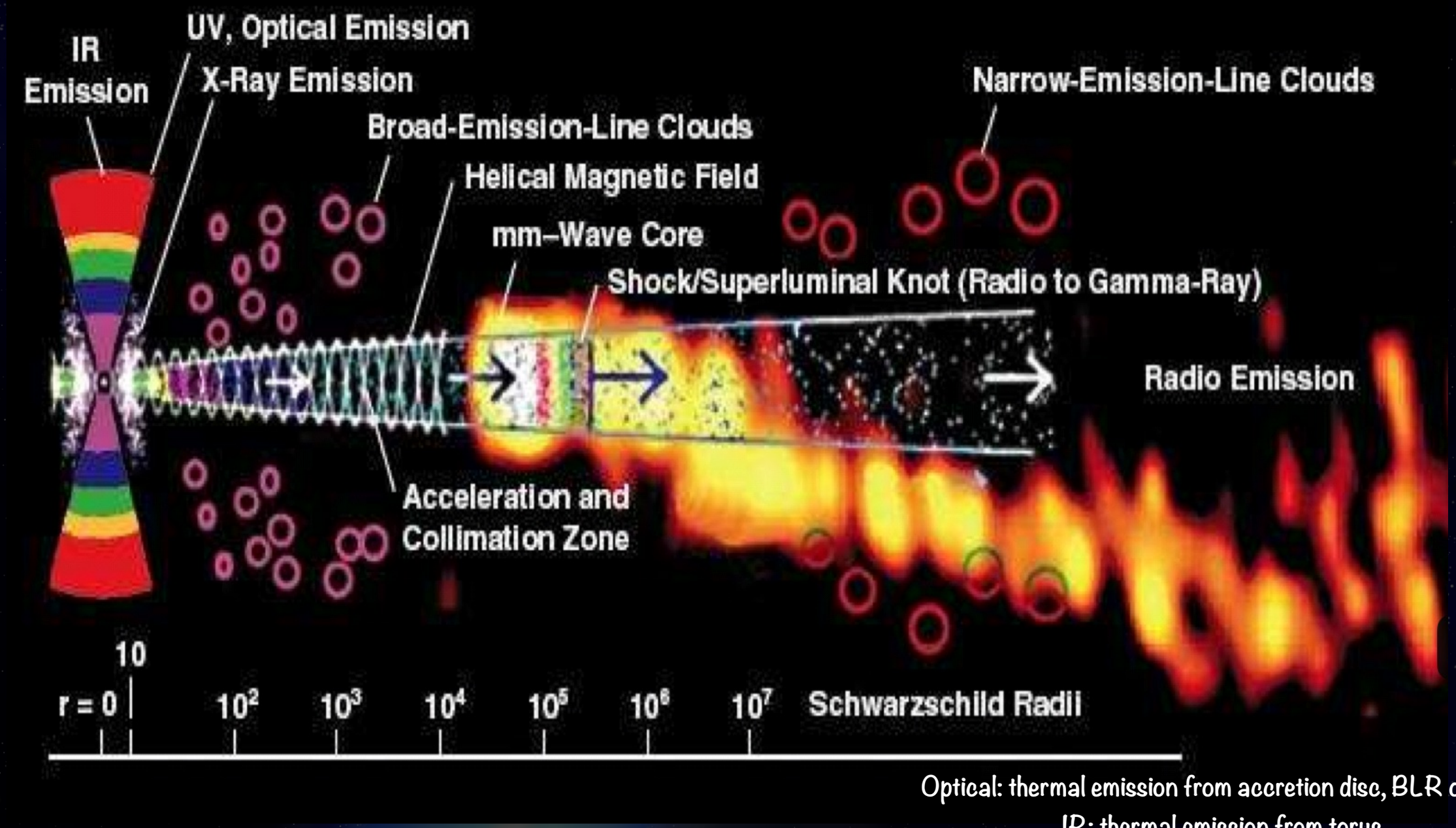
- SMBH ~ 10^8 $M_\odot$
- Accretion disc ~ 10^{12} m
- **Broad line region ~ 10^{14} m**
- Torus in radius ~ 10^{15} m
- **Narrow line region ~ 10^{17} m**
- **Jet ~ 10^{15} - 10^{22} m**



Urry & Padovani, PASP, 107, 803

Active Galactic Nuclei

Why multi-wavelength observations?



Optical: thermal emission from accretion disc, BLR or NLR.

IR: thermal emission from torus.

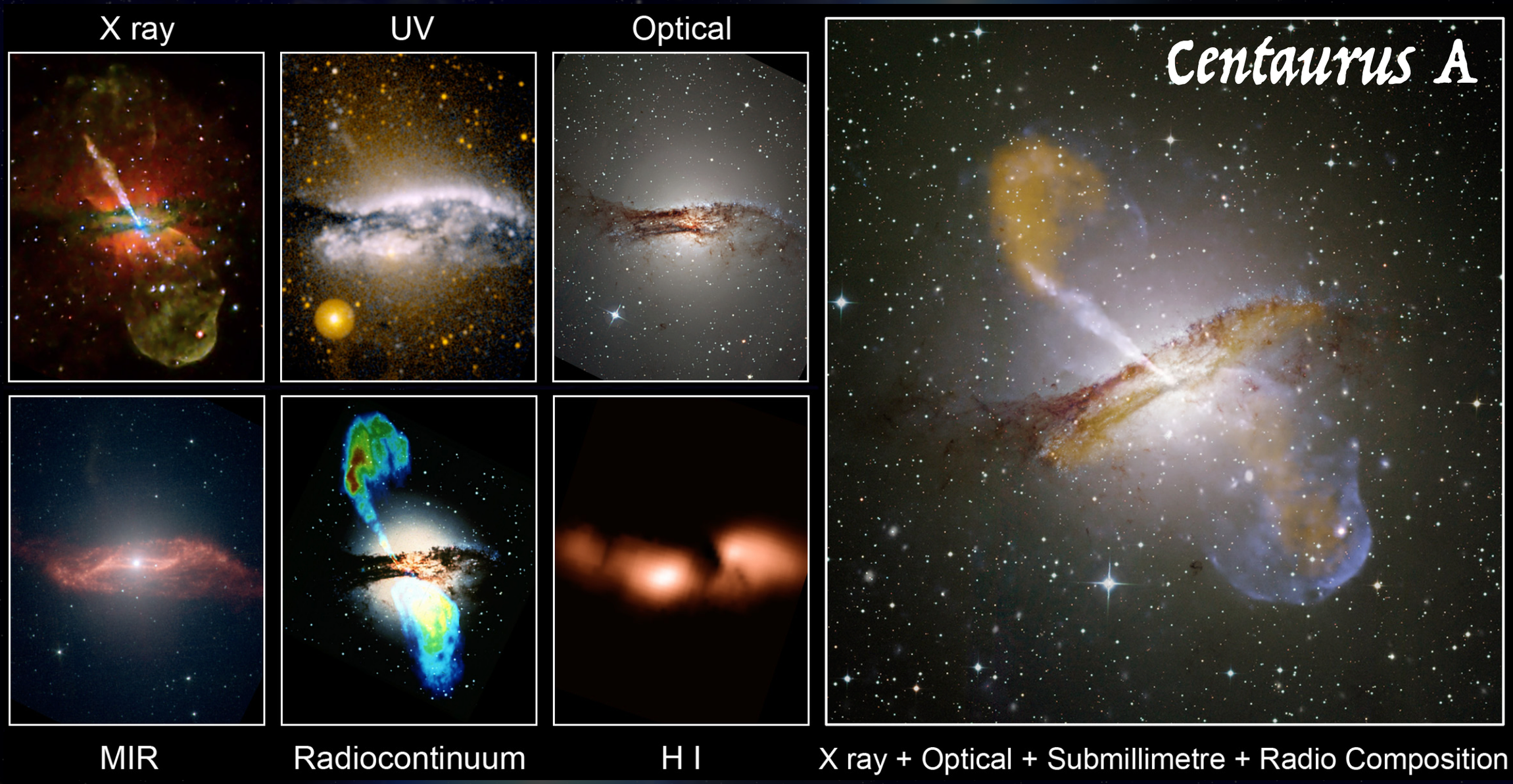
Radio: synchrotron emission of relativistic electrons in jet

X-rays to Gamma-rays: Inverse Compton (IC)

Wehrle et al. (2009)

Active Galactic Nuclei

Why multi-wavelength observations?

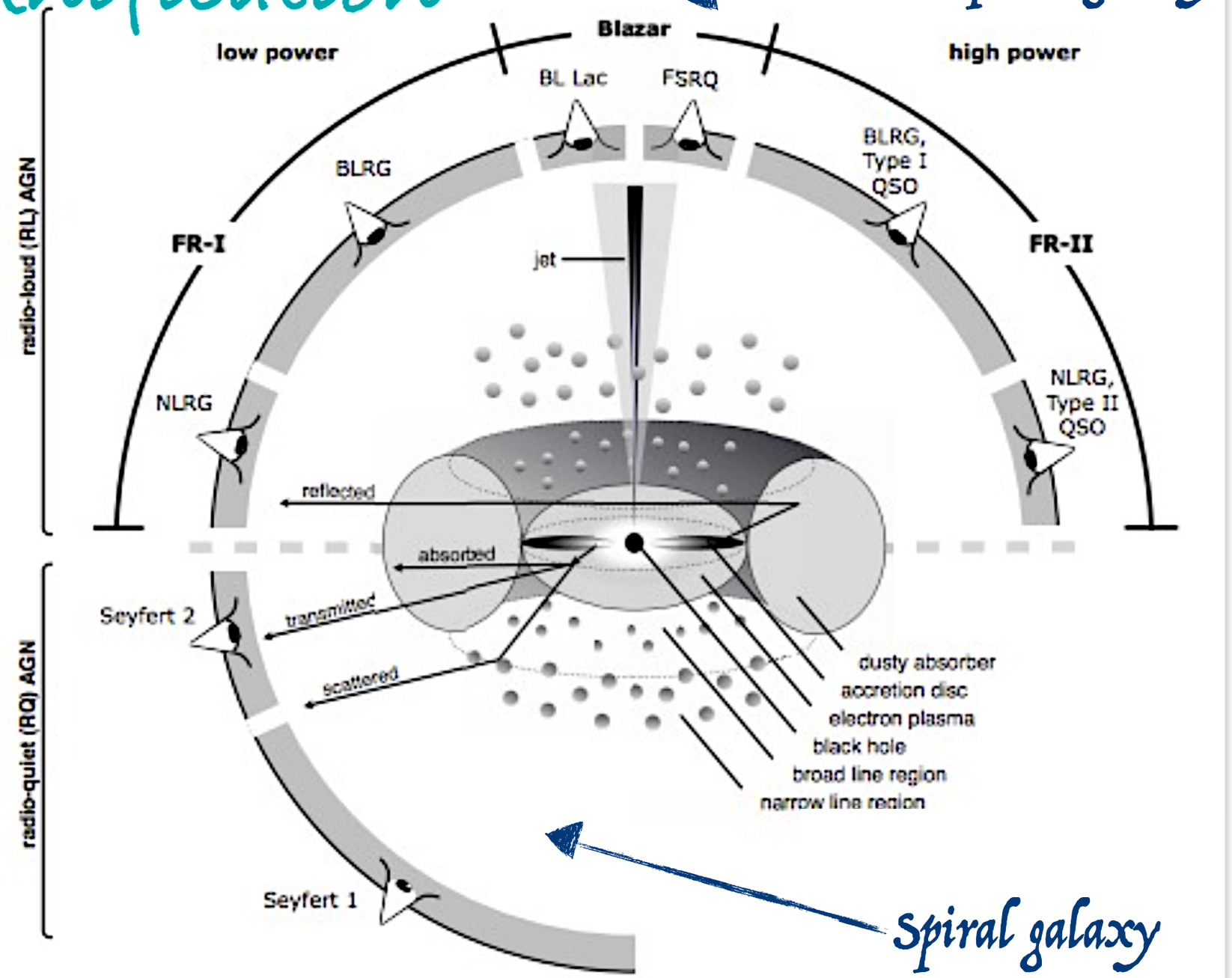


http://oldweb.aao.gov.au/local/www/alopez/multiwave.html

Active Galactic Nuclei

Unification

Elliptical galaxy



Spiral galaxy

Beckmann & Shrader, Astro-PH, 13021397

Blazars

When did it all start?

term blazar - coined in 1978 by Edward Spiegel

First proposed to be irregular variable stars in our own galaxy due to their irregular variability on timescales from days to years.

Late 1950's the resolution of radio telescopes was sufficient detect radio sources with optical counterparts - led to the discovery of quasars (3C 273).

1968: connection between 'variable star' BL Lacerate and radio source VRO 42.22.01 was made. It showed characteristics of quasars, however resembled featureless spectra.

1974: BL Lacartae was ruled out to be a star.

Now a few hundred BL Lacs are know.

Characteristics

<5% of all AGN

jet points 'at' us obscuring the rest of galaxy

Flat radio spectrum

Strong variability through entire EM spectrum

RADIO LOUD AGN

Radio & optical polarization

Beckmann & Shrader, 2012, Active Galactic Nuclei, Physics Textbook, ISBN 978-3-527-41091-0

AGN - Blazars

Characteristics - variability

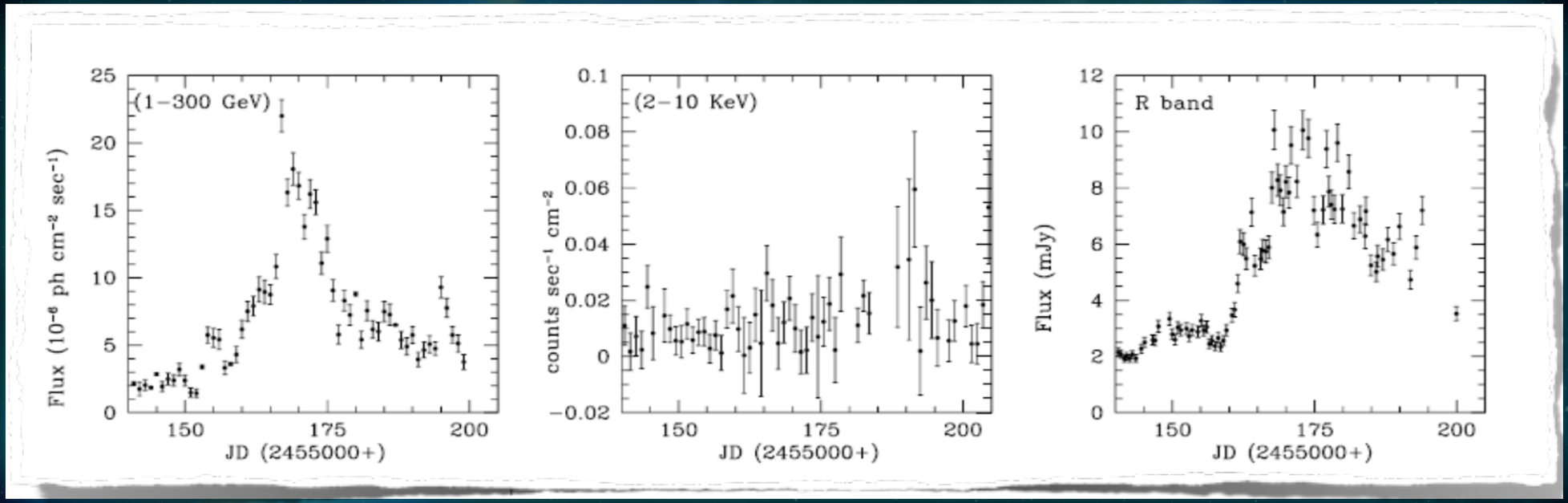
Intra-day variability (IDV); minutes to few hours → Rate at which the region varies and it gives an upper limit to the size of the innermost stable orbit of the accretion disc surrounding the supermassive black hole; estimate upper limit of **BH** mass.

Short term (STV); several weeks → Search for color variations

Long term; months to years → Broadband correlations to study emission mechanisms

Δm ~ 0.3 mag variations over time-scales of ≈3 h have been reported from BL Lacs (Fan et al. 2004) in observational campaigns.

Broadband observations is of importance to understand the emission mechanism of blazars and the physical properties of the emitting region in the different frequency bands.



Vercellone S. et al. 2008, Astro-PH, arXiv:0809.172v1; Gaur et al. 2012c, ApJ,143,23; Fossati et al. 2008, ApJ, 677,906; Rani et al. 2013,A&A, 552,A11

Blazars

Classification - "fingerprints"

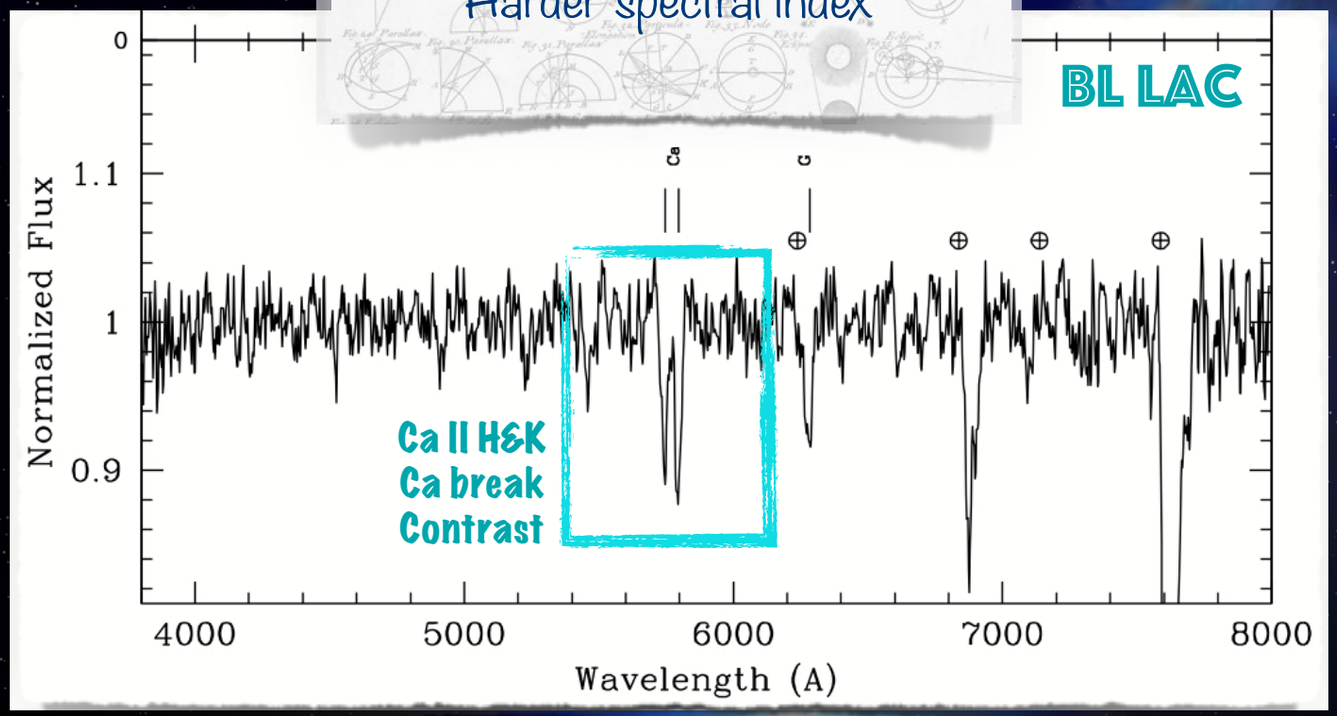
BL LAC OBJECTS

Weak or absent emission lines

FR I

Lower luminosity

Harder spectral index



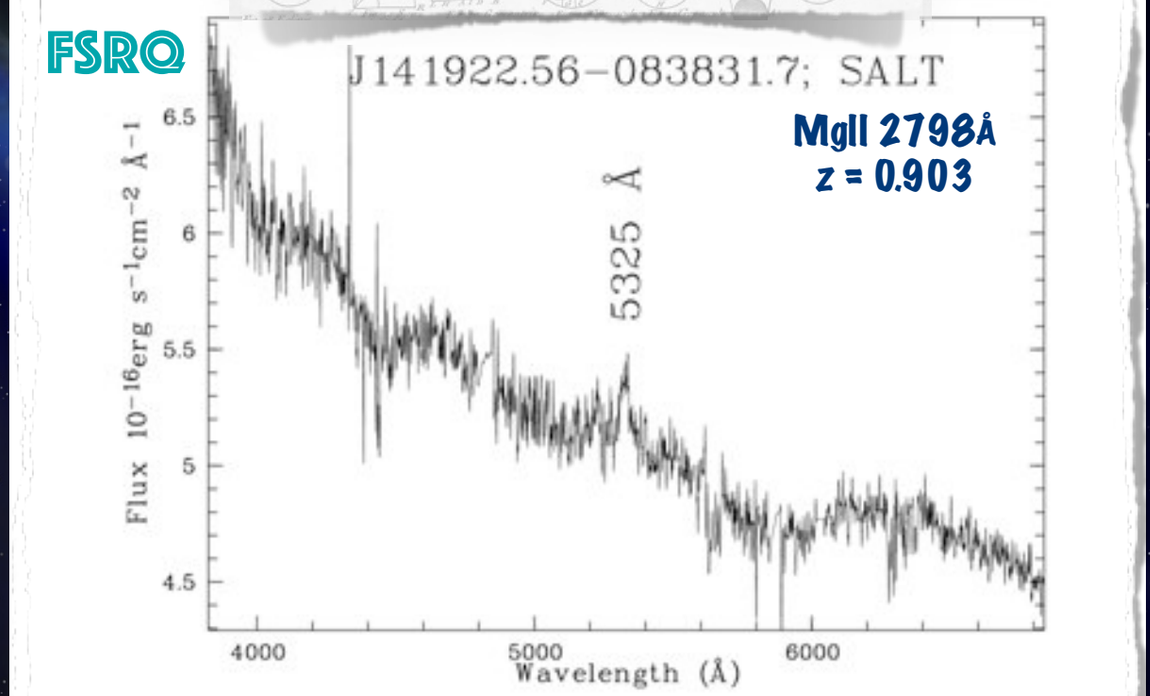
FLAT SPECTRUM RADIO QUASARS

Strong emission lines

FR II

Higher luminosity

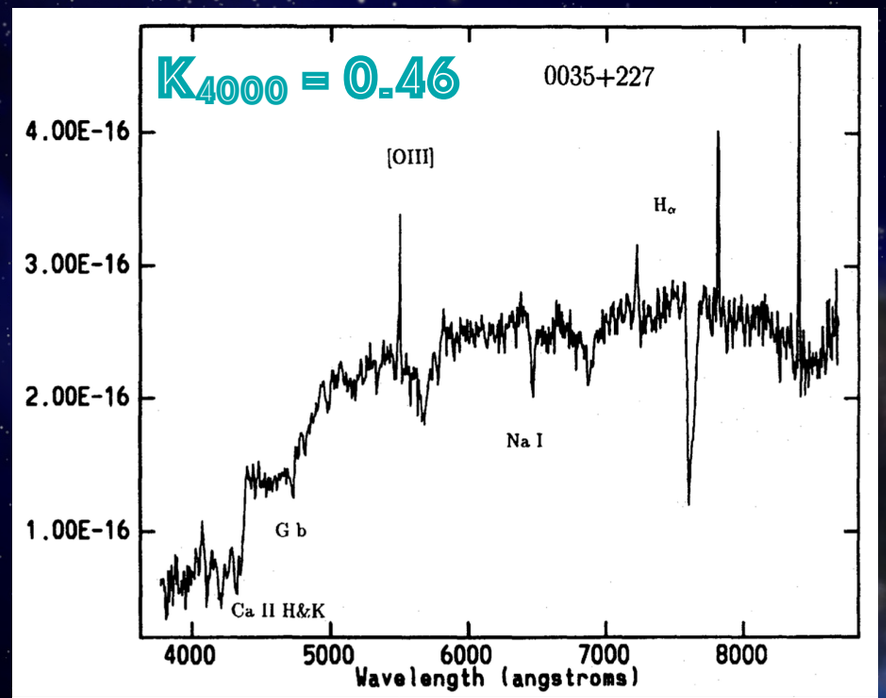
Softer spectral index



Sbarufatti B. et al. 2005, ApJ, 129, 559-566; XMM-Newton spectroscopy of an X-ray selected sample of RL AGNs, A&A, 430, 927-940

Blazars

Classification: The Ca break value



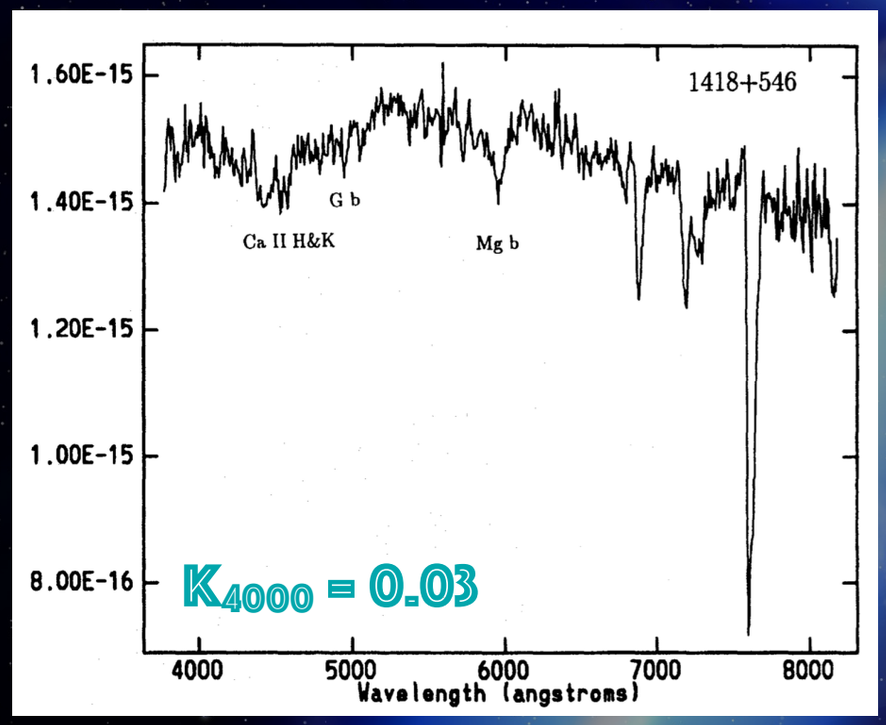
$$K_{4000} = (f^+ - f^-)/f^+$$

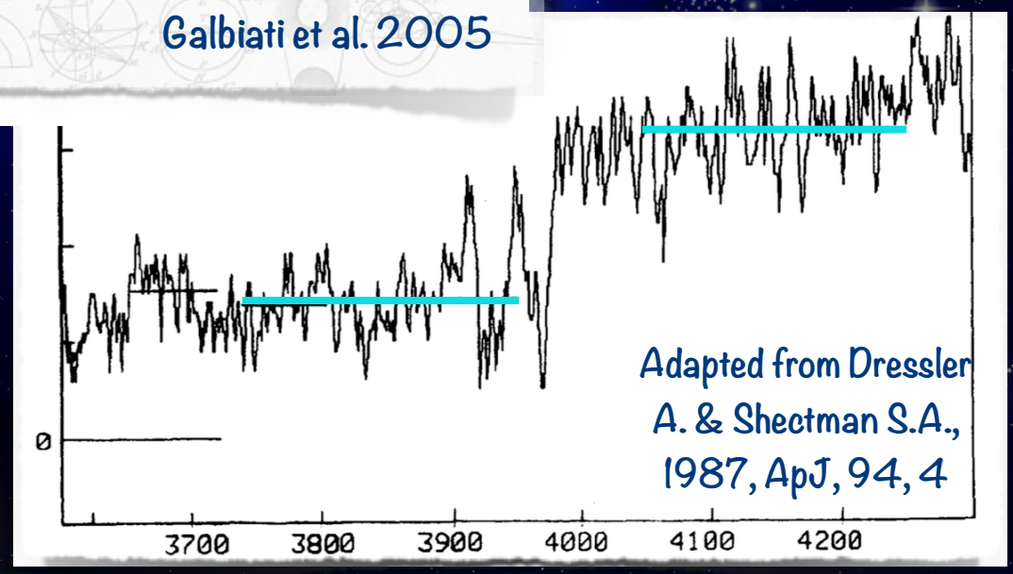
where $f^+ = f_{average}$ 3750 Å - 3950 Å

and $f^- = f_{average}$ 4050 Å - 4250 Å.

K_{4000} < 0.4: SOURCE HAS A STRONG NON-THERMAL EMISSION

Caccianiga et al. 199a, Galbiati et al. 2005

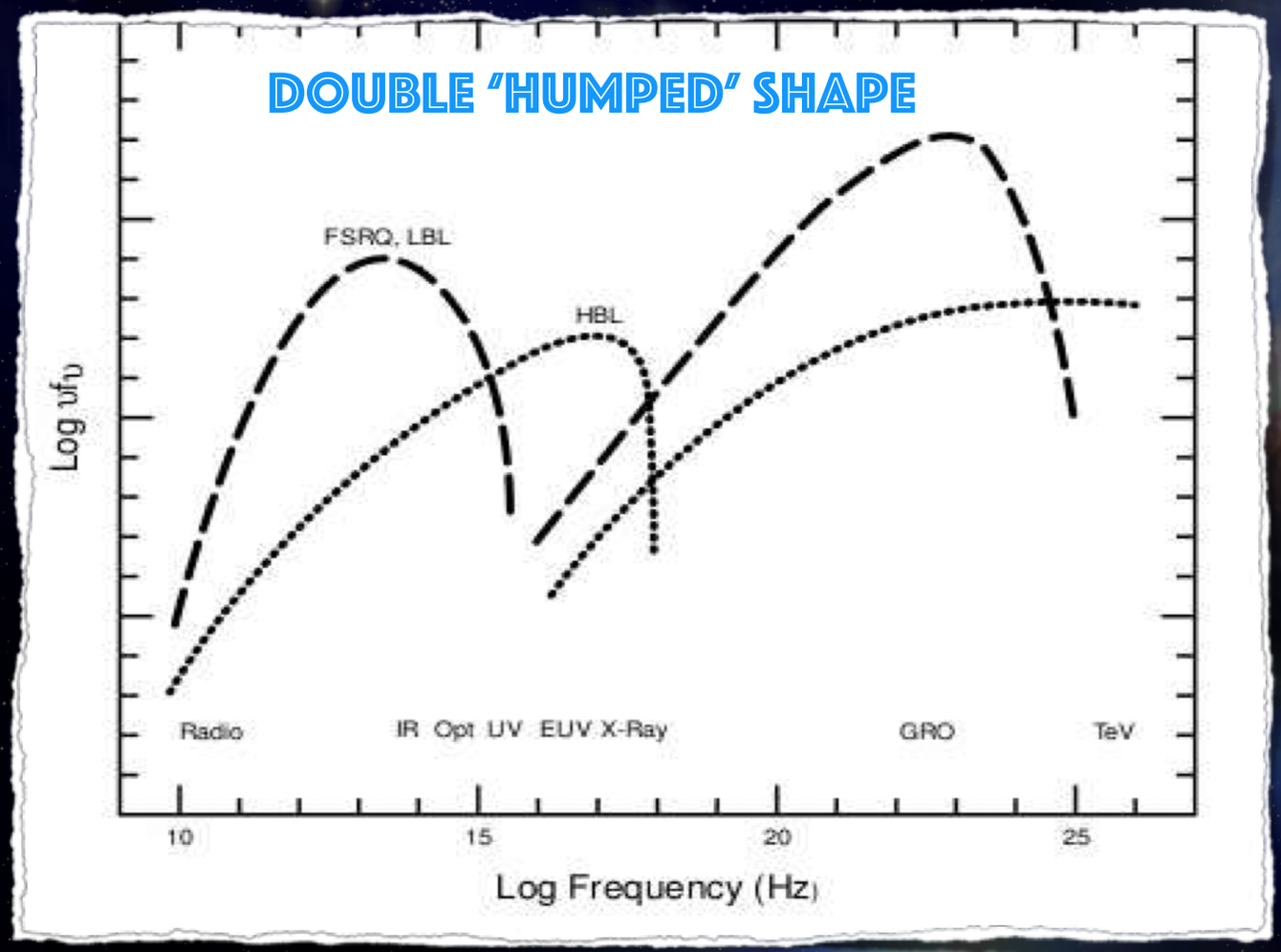




Adapted from Dressler A. & Shectman S.A., 1987, ApJ, 94, 4

Spectral Energy Distribution

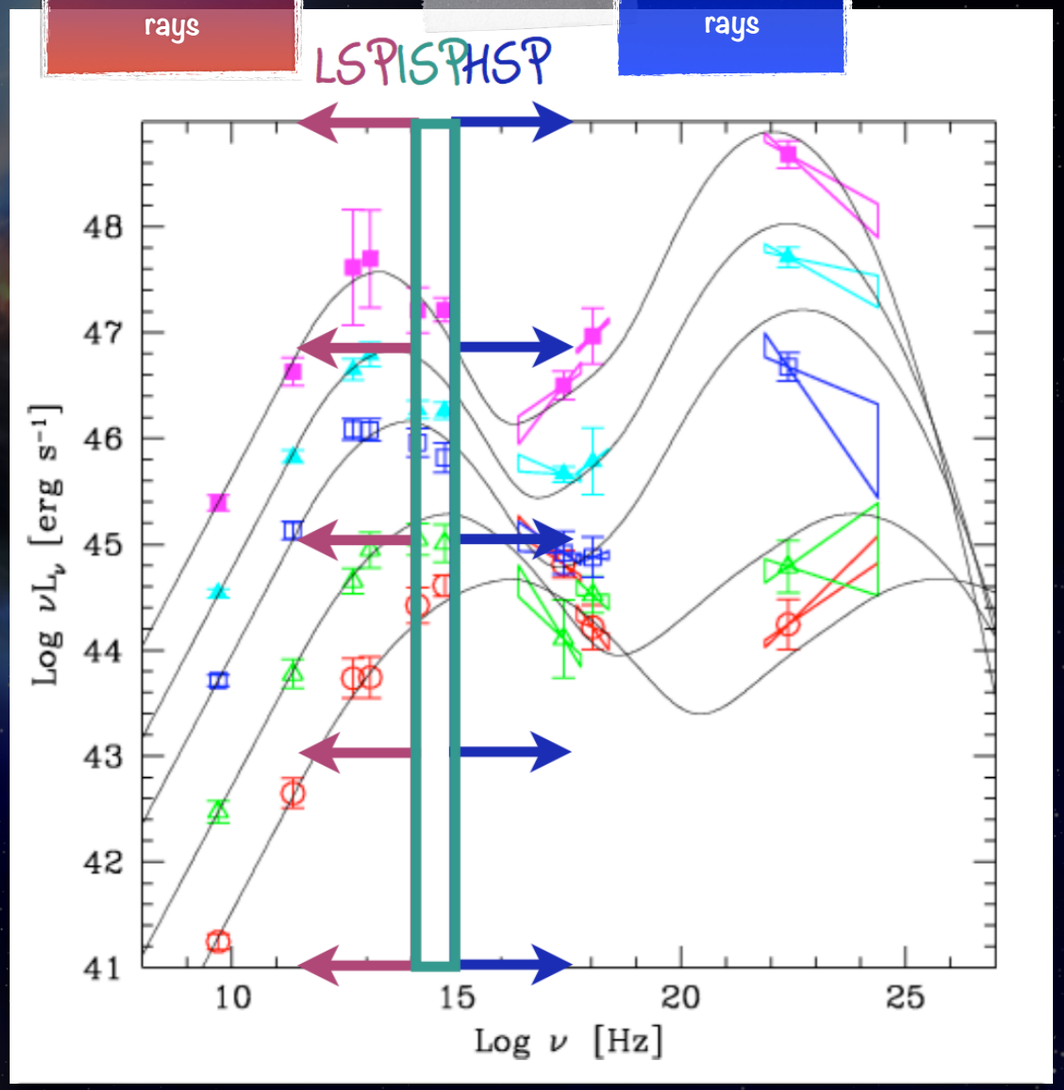
The whole picture



ν_{peak} at IR/ optical & GeV γ-rays

ν_{peak} at optical-near UV & GeV γ-rays

ν_{peak} at UV/X-rays & TeV γ-rays



Low-energy peak: synchrotron emission from relativistic electrons in jet

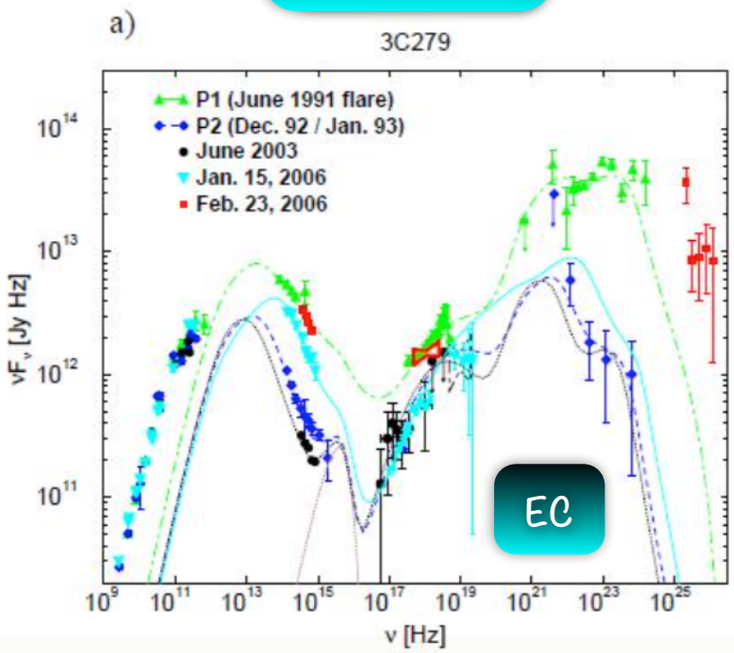
High-energy peak: Source of origin still under debate **LEPTONIC** *or* **HADRONIC**

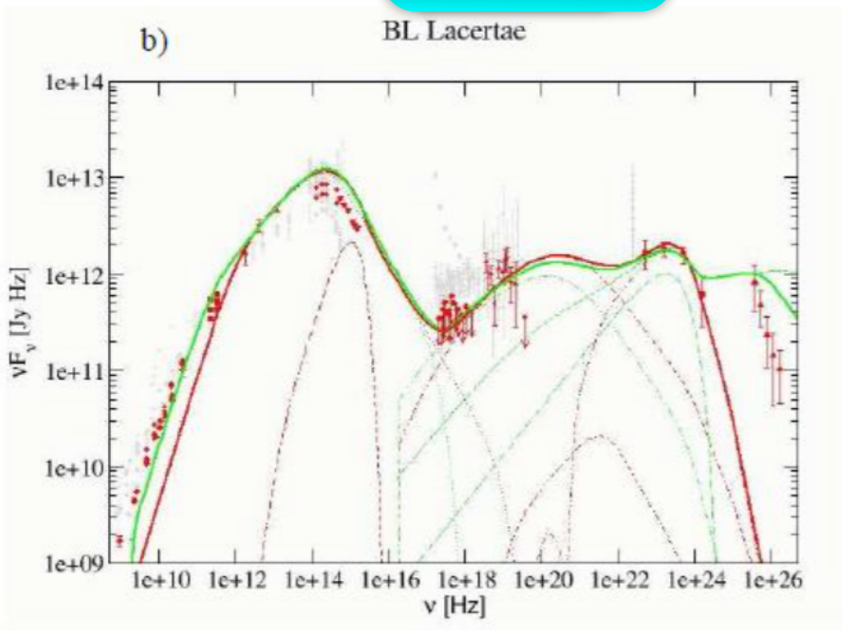
Urry, 1998, AdSpR, 21, 89; Böttcher M, Reimer A, Sweeney K and Prakash A 2013 ApJ 768 54;Mannheim K and Biermann PL 1992 A&A 253 L21; Aharonian FA 2000 NewA 5 377; Mücke A and Protheroe RJ 2001 APh 15 121; Mücke A, Protheroe RJ, Engel R, Rachen JP and Stanev T 2003 APh 18 593

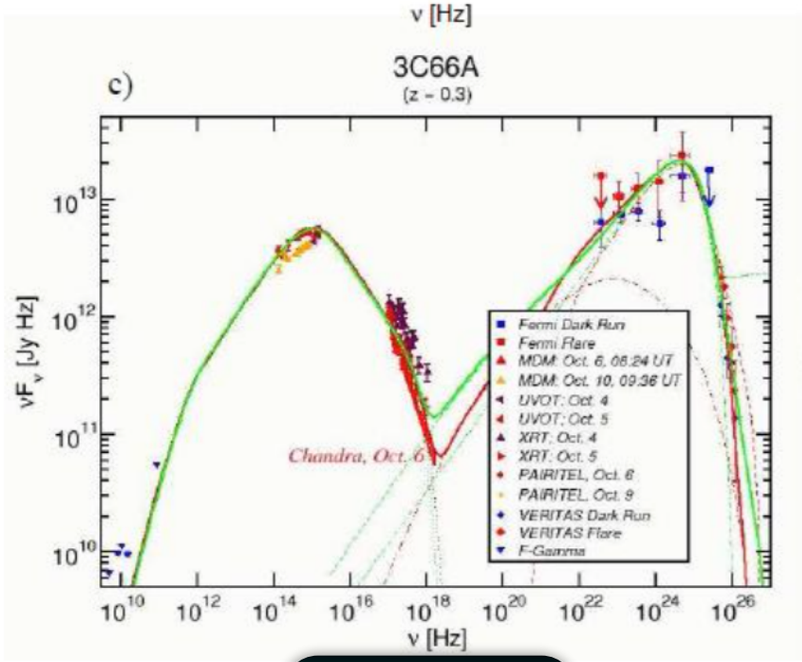
Spectral Energy Distribution

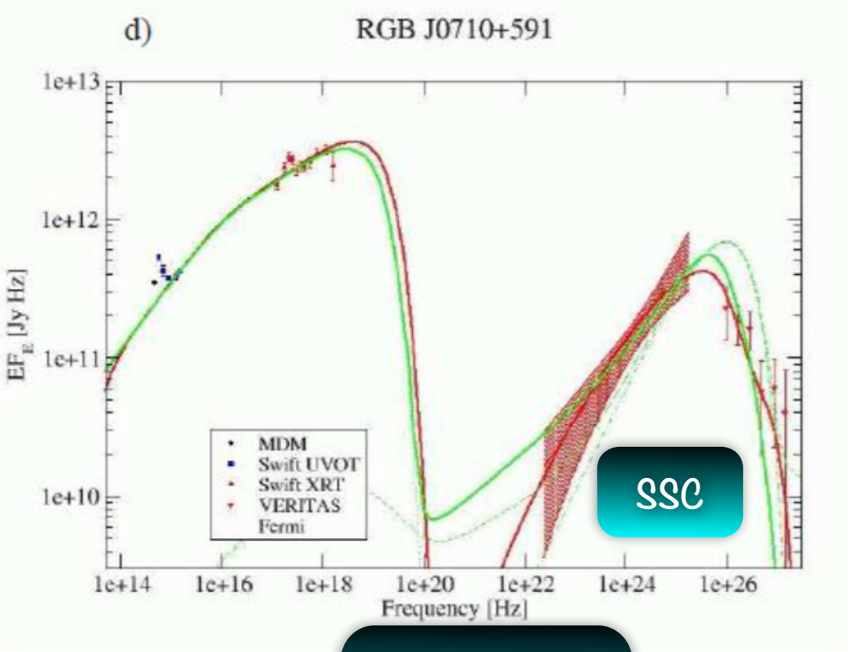
FSRQ

LSP









ISP

HSP

Acciari et al., 2009; Acciari et al., 2010; Abdo et al 2011; Böttcher, 2012, Fermi & Janksy proceedings; Böttcher, 2013, ApJ, 768, 54

Fermi Gamma-ray Space telescope

August 4, 2008

Fermi-LAT

Large Area Telescope (LAT)
20 MeV - 300 GeV

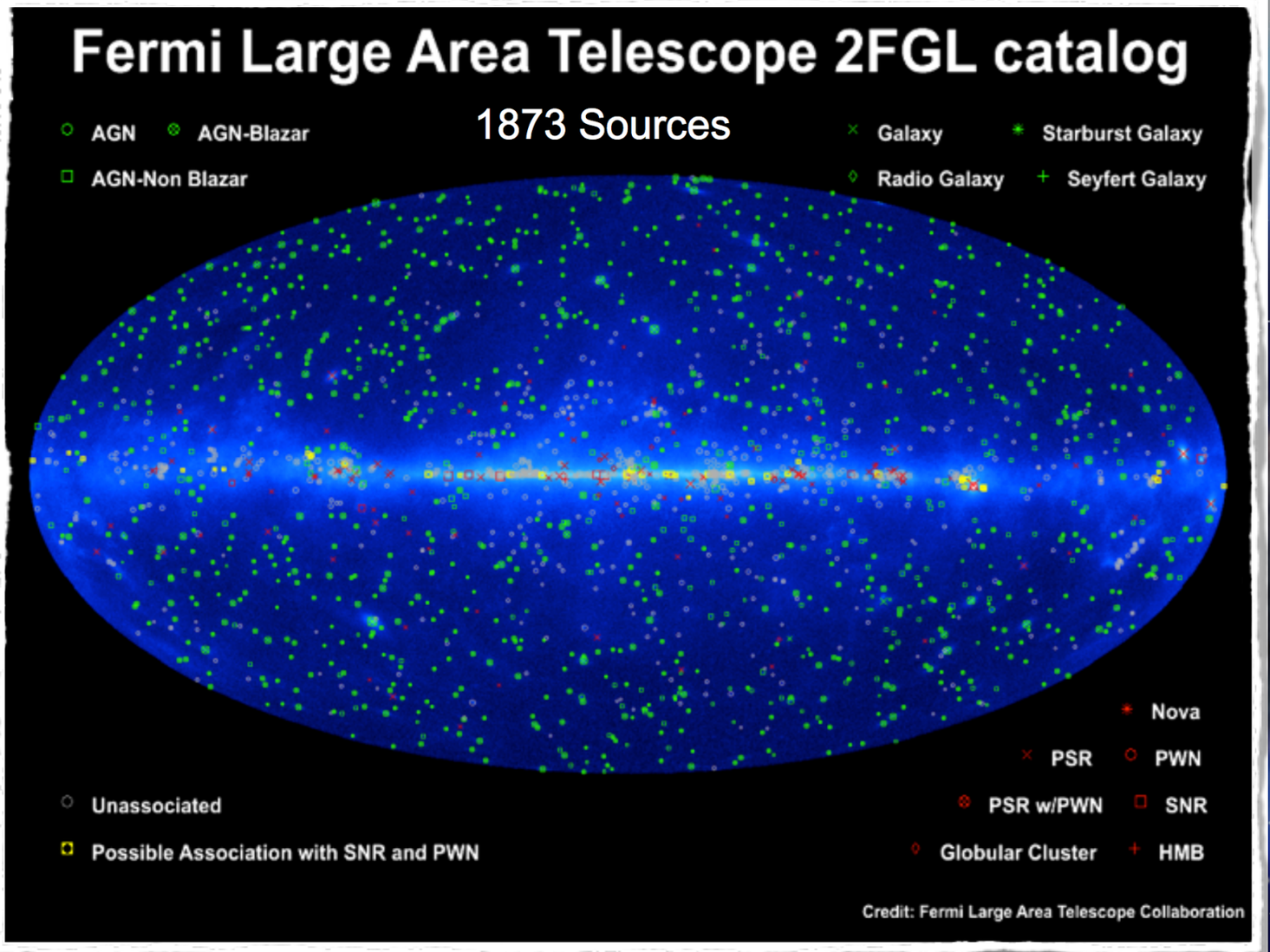
Gamma-ray Burst Monitor (GBM)
8 keV - 40 MeV

Large FoV:

- LAT: 2.4 sr; 20% of the sky at any instant

Fermi-2LAC

Fermi LAT second AGN catalogue



- 1017 γ-ray sources located at high Galactic latitudes (|b| > 10°)
- Clean Sample:
  - 886 AGNs
  - 395 BL Lacertae objects (BL Lac objects)
  - 310 flat-spectrum radio quasars (FSRQs)
  - 157 candidate blazars of unknown type
  - 8 misaligned AGNs,
  - 4 narrow-line Seyfert 1 (NLS1s)
  - 10 AGNs of other types
  - 2 starburst galaxies

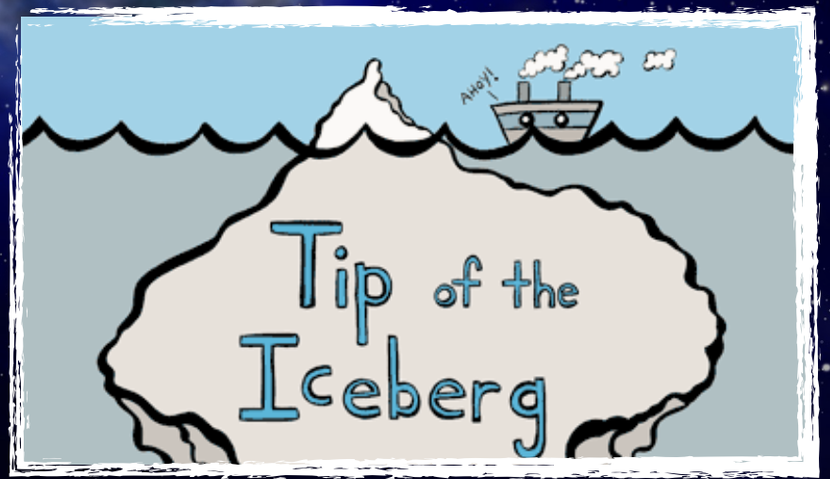
3LAC:

Selected sources in sample: Blazar candidate of unknown type (BCU)

1873 SOURCES

1298 IDENTIFIED/ASSOCIATED

84% AGN*



Ackermann et al. 2011

Multi-wavelength observations

Optical observations

The Watcher 16-inch Robotic Telescope

Detect short/long term variability
UBVRI observations
December 2014 till present

The Boyden/UFS 1.5-m telescope

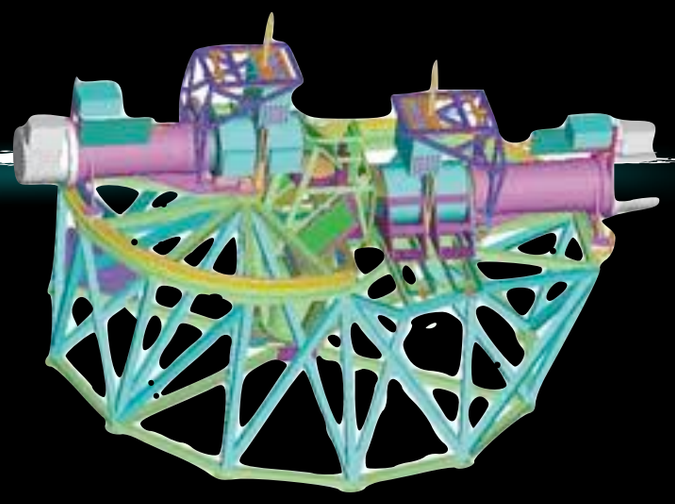
Determine if detection is possible
Clear filter
May - June 2014

The SAAO 1.9-m telescope (utilising SHOC and SpCCD)

Low-resolution spectra & IDV/STV
May 2014, December 2014 & May 2015

Multi-wavelength observations

Optical observations: SALT



Robert Stobie Spectrograph (RSS)

Low-resolution spectra to obtain broadband: 3800 - 10 000 Å

2014-2-SCI-055

Sem I: Nov 2014 - April 2015

Longslit – pg0300 with 0.6”

2 camera stations: 3500 Å – 10 000Å

central resolution @ 5774 Å~ 815

2015-1-SCI-053

Sem II: May 2015 - October 2015

Longslit – pg0900 with 2.0”

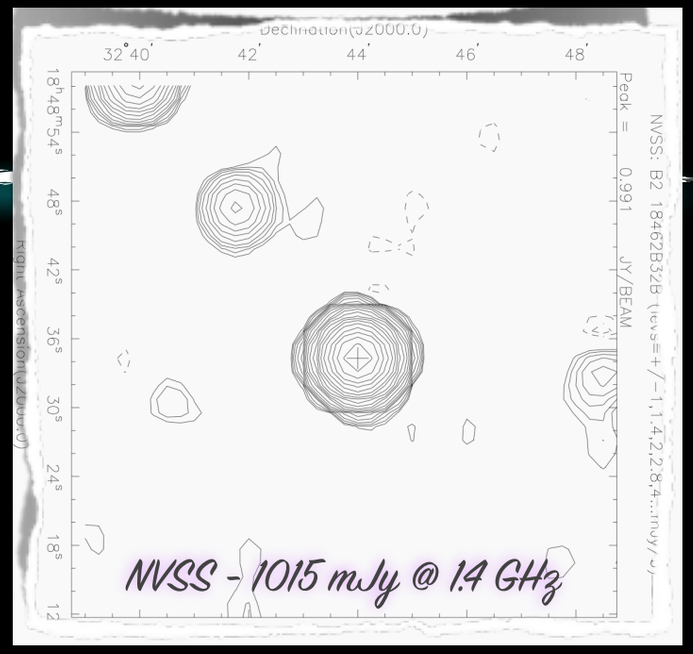
2 camera stations: 4000 Å – 8750Å

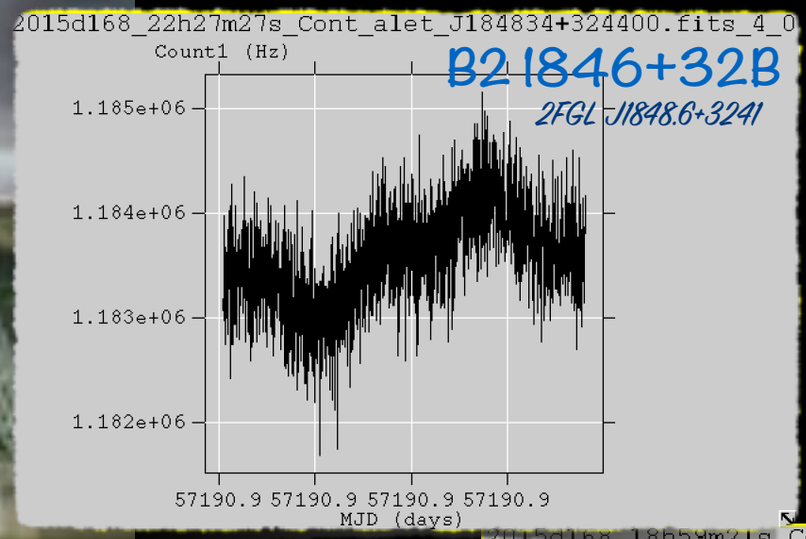
central resolution @ 6800 Å~ 919

Multi-wavelength observations

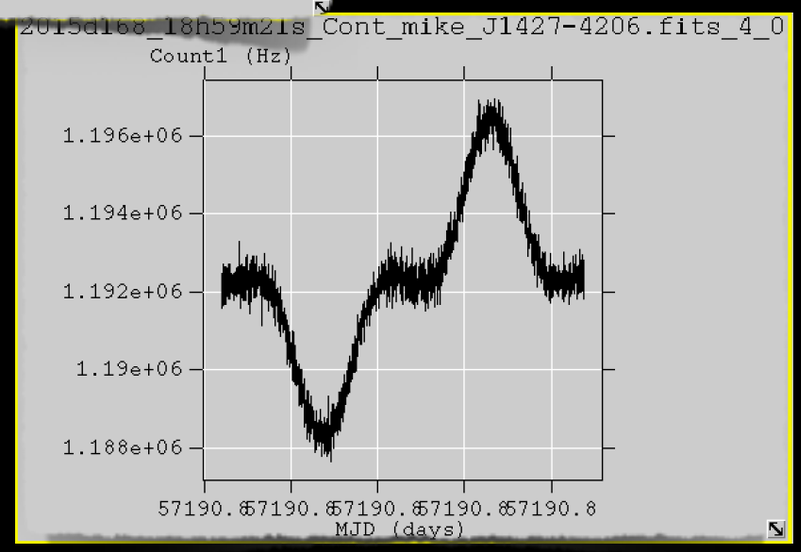
Radio observations

The HartRAO 26-m radio telescope





Dual-polarization, continuum radiometry observations at 5 GHz & 8.4 GHz, using the dual-feed Dicke- switched.

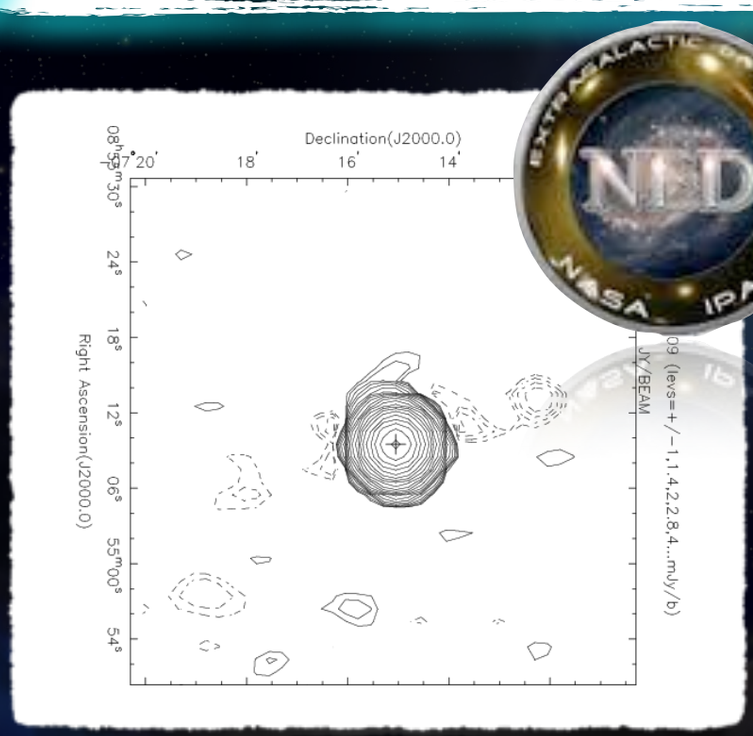


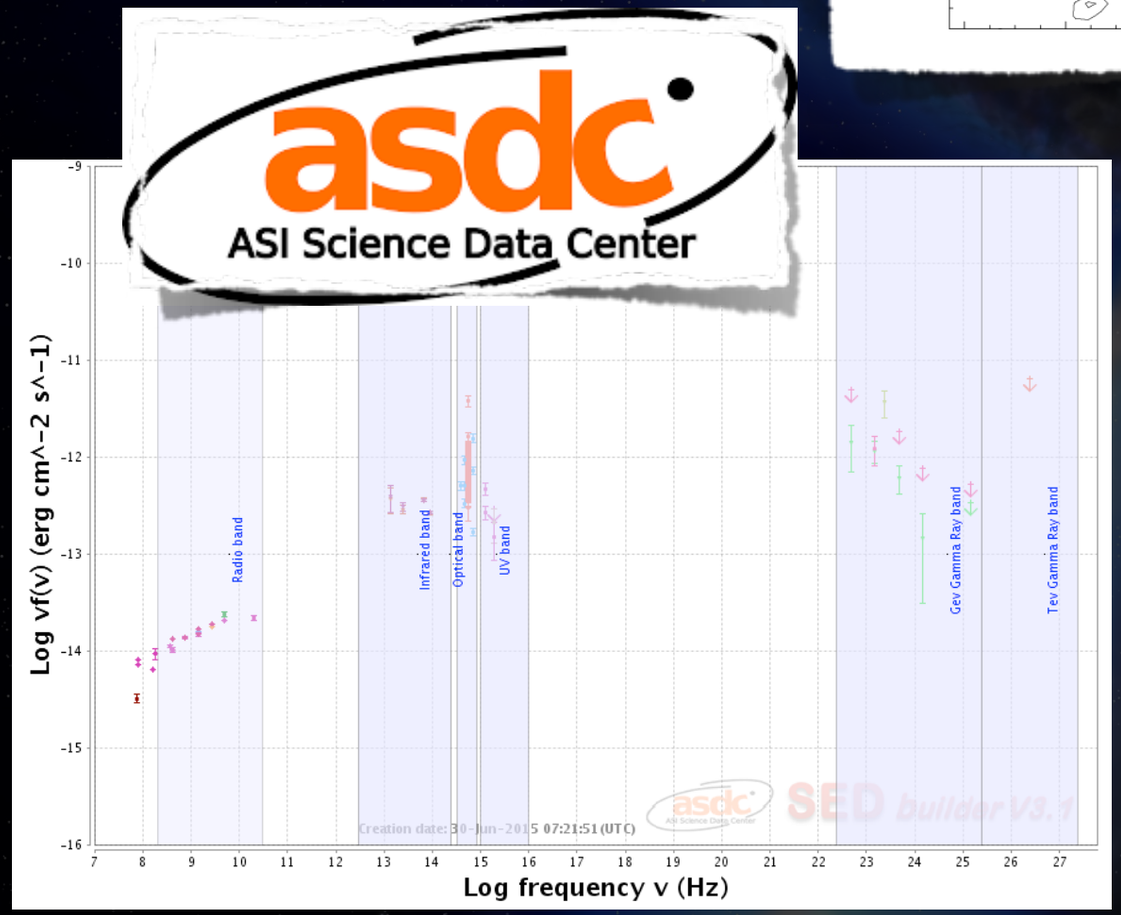
- ★ Determine the variability and whether it is consistent with blazars.
- ★ Establish/verify the flux density at radio wavelengths in order to contribute towards the construction of Spectral Energy Distributions (SEDs) for these sources.

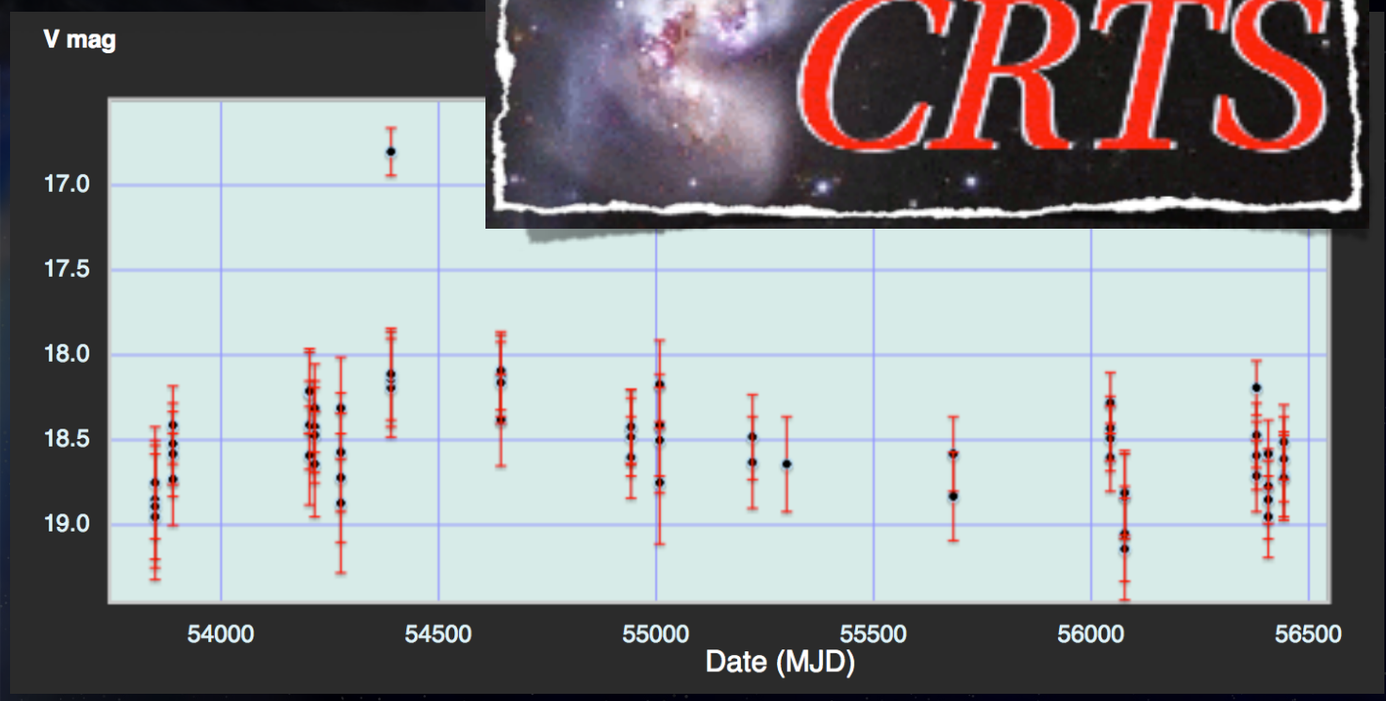
OBSERVATIONS STARTED 2 WEEKS AGO - DELAYED DUE TO VLBI OBSERVATIONS AND WEATHER

Multi-wavelength observations

Archive data







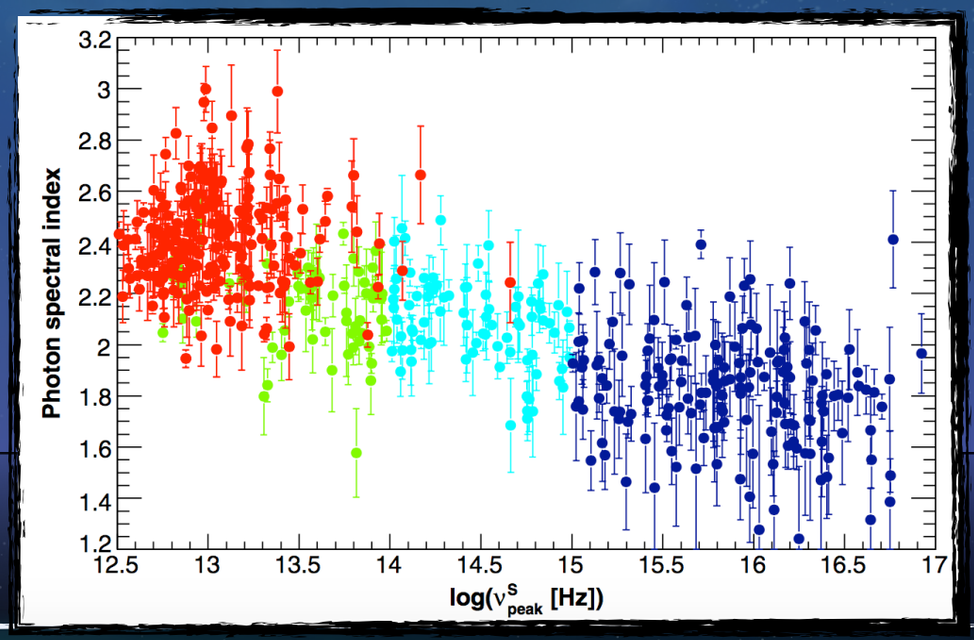
The CRTS survey is funded by the National Aeronautics and Space Administration under Grant No. NNG05GF22G issued through the Science Mission Directorate Near-Earth Objects Observations Program.

Target Sample

Selection criteria

BASED ON CRITERIA EMPLOYED BY NKUNDABAKURA & MEINTJES (NKUNDABAKURA, 2011, PHD THESIS) IN A STUDY OF 13 UNIDENTIFIED SOURCES LISTED IN THE ENERGETIC GAMMA RAY EXPERIMENT TELESCOPE (EGRET) CATALOGUE (3EG CATALOGUE).

- Remove candidate sources that have been identified (e.g. Shaw et al. 2013, literature reviews)
- High Galactic latitude sources: $|b| > 10°$
- Counterparts within 95% error circle of Fermi-2LAC: potential counterparts in the radio, IR, optical and X-ray bands.
- Gamma-ray variability: VI > 41.6 have a 99% chance to be variable over the two year observation period.
- Gamma-ray photon spectral index: power-law spectral function $dN/dE \propto E^{-\Gamma}$; $1.2 < \Gamma < 3$
- Radio brightness: $F_{radio} > 100$ mJy @ 4.85 GHz (GB6 & PMN catalogues).
- Observability: $-90° < \delta < +35°$; Vmag < 21
- Redshifts: no available spectra.



Ackermann et al. 2011; Gregory et al. 1996

Target Sample

19 selected AGU sources

Table: Original AGU target sample and 10 selected targets of special interest

2LAC name	RAJ2000 "h:m:s"	DECJ2000 "d:m:s"	Vmag	$S_{4.85\ GHz}$ mJy	X-ray Flux 10-16W/m2	Error radius deg	Redshift, z	Gamma-ray Spectral Index	Variability index	3LAC class
J0044.7-3702	00 45 12.07	-37 05 47.6	19.60	330.00		0,153	-	2.57	92,672	bcu
J0201.5-6626	02 01 07.47	-66 38 13.5	20.56	168.00	3.26	0,171	-	2.25	39,768	bcu
J0644.2-6713	06 44 27.73	-67 12 57.2	20.69	218.00		0,05	-	2.16	99,627	bcu
J0730.6-6607	07 30 49.48	-66 02 18.6	15.13	82.00	33.90	0,092	-	1.34	26,782	bcu
J0855.1-0712	08 55 09.46	-07 15 03.0	19.78	1157.00		0,213	-	2.62	31,205	bcu
J0919.3-2203	09 19 22.30	-22 07 57.4	19.95	26.00	5.25	0,163	-	2.00	16,283	-
J1059.0+0222	10 59 06.24	+02 25 04.8		97.00		0,151	-	2.29	25,524	-
J1106.3-3643	11 06 24.04	-36 46 59.5	17.41	92.00		0,143	-	2.20	24,046	bcu
J1154.1-3242	11 54 06.21	-32 42 42.7	18.88	212.00		0,078	-	2.03	20,478	bcu
J1218.8-4827	12 19 02.25	-48 26 27.9	17.53	65.00		0,144	-	2.40	26,671	bcu
J1407.5-4257	14 07 39.67	-43 02 31.5	17.47	149.00	2.52	0,088	-	1.91	22,870	bcu
J1617.6-2526	16 17 20.54	-25 37 22.7		120.00		0,168	-	2.52	21,454	bcu
J1624.4+1123	16 24 44.37	+11 10 01.1	17.64	113.00		0,306	-	2.65	15,318	-
J1803.6+2523	18 03 12.42	+25 21 18.4	14.19	166.00		0,290	-	2.83	36,212	-
J1848.6+3241	18 48 34.36	+32 44 00.3	17.77	1015.00		0,116	-	2.43	32,962	-
J1955.0-5639	19 55 02.99	-56 40 30.9	17.25	9.00	27.90	0,076	-	1.88	23,700	bcu
J2040.2-7109	20 40 08.50	-71 14 52.3	17.47	481.00	62.70	0,123	0,162	2.03	22,979	bcu
J2049.8+1001	20 49 45.92	+10 03 15.2		295.00	0.66	0,139	-	2.38	41,549	bcu
J2108.6-1603	21 08 33.11	-16 07 24.3		7.00	7.09	0,214	-	2.59	33,223	-

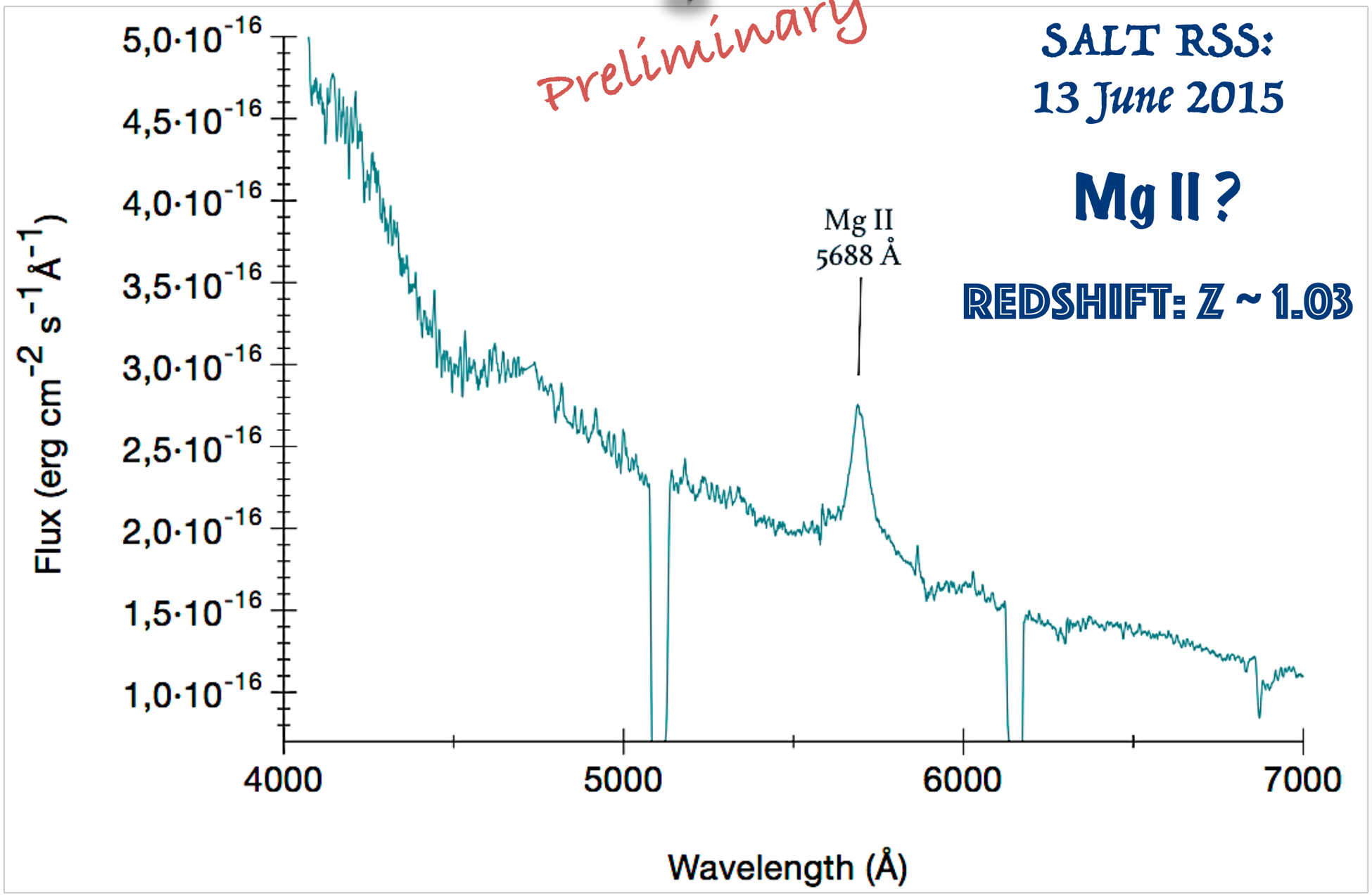
Results

Vmag = 19.60

PKS J0045-3705

2FGL J0044.7-3702

Preliminary



SALT RSS:
13 June 2015

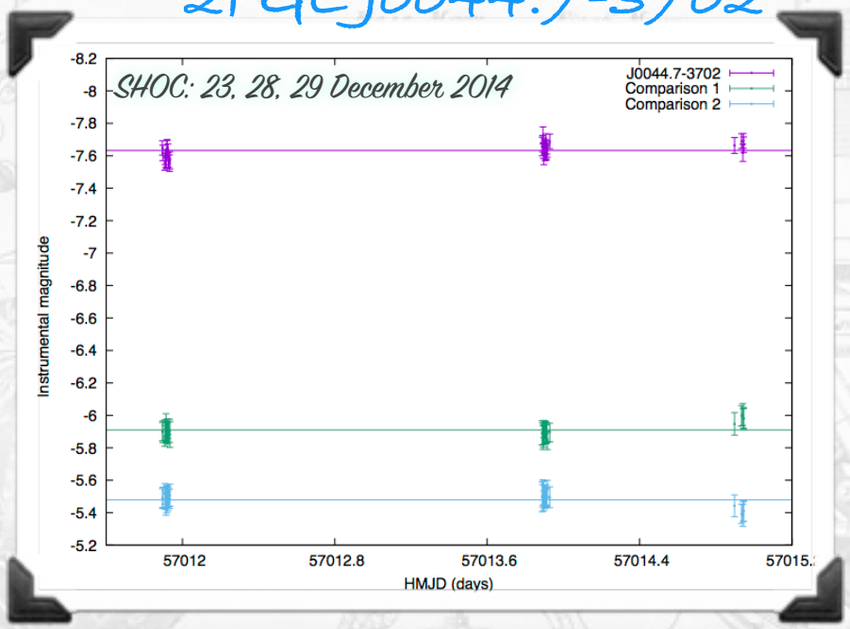
Mg II ?

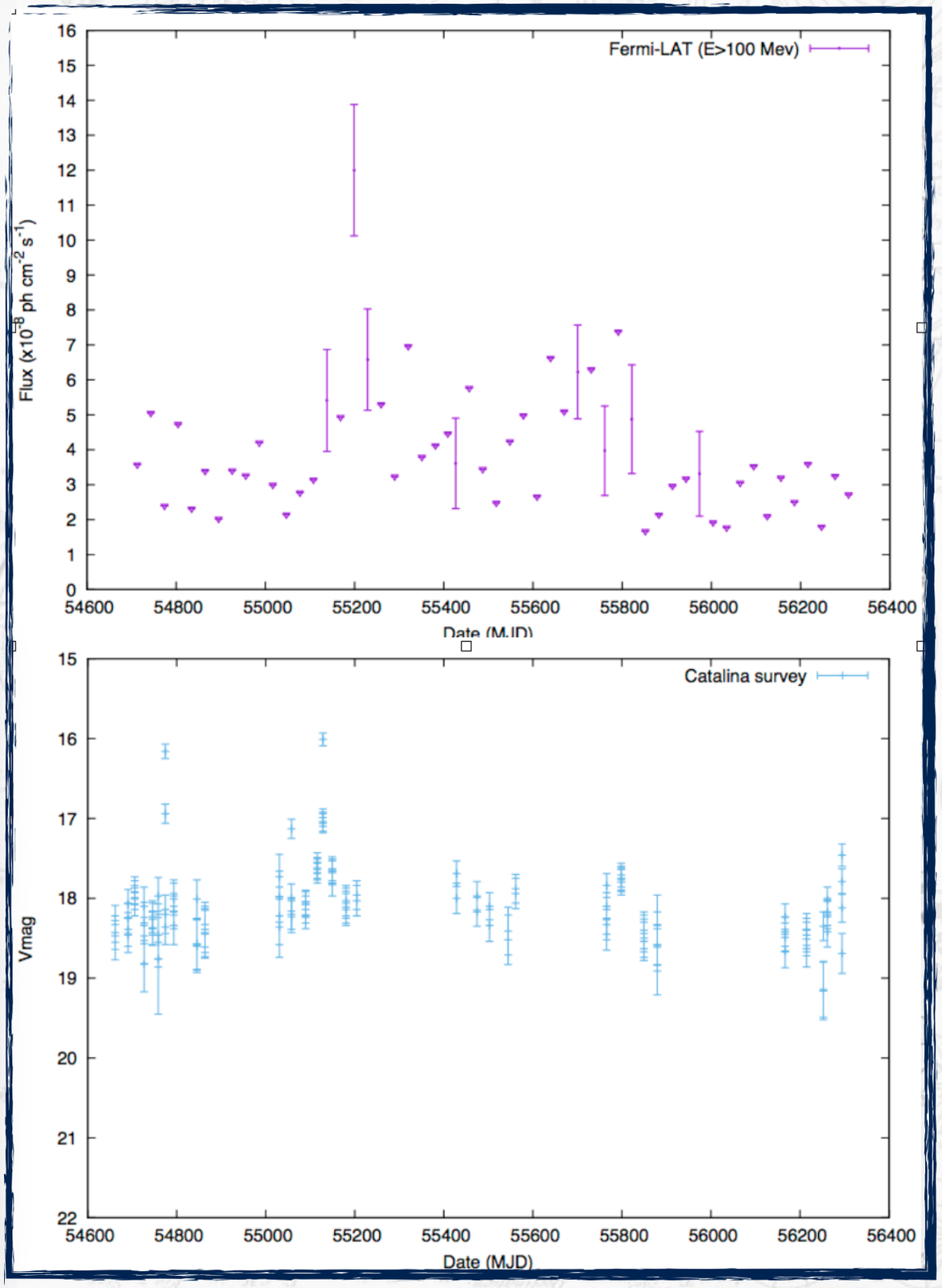
REDSHIFT: Z ~ 1.03

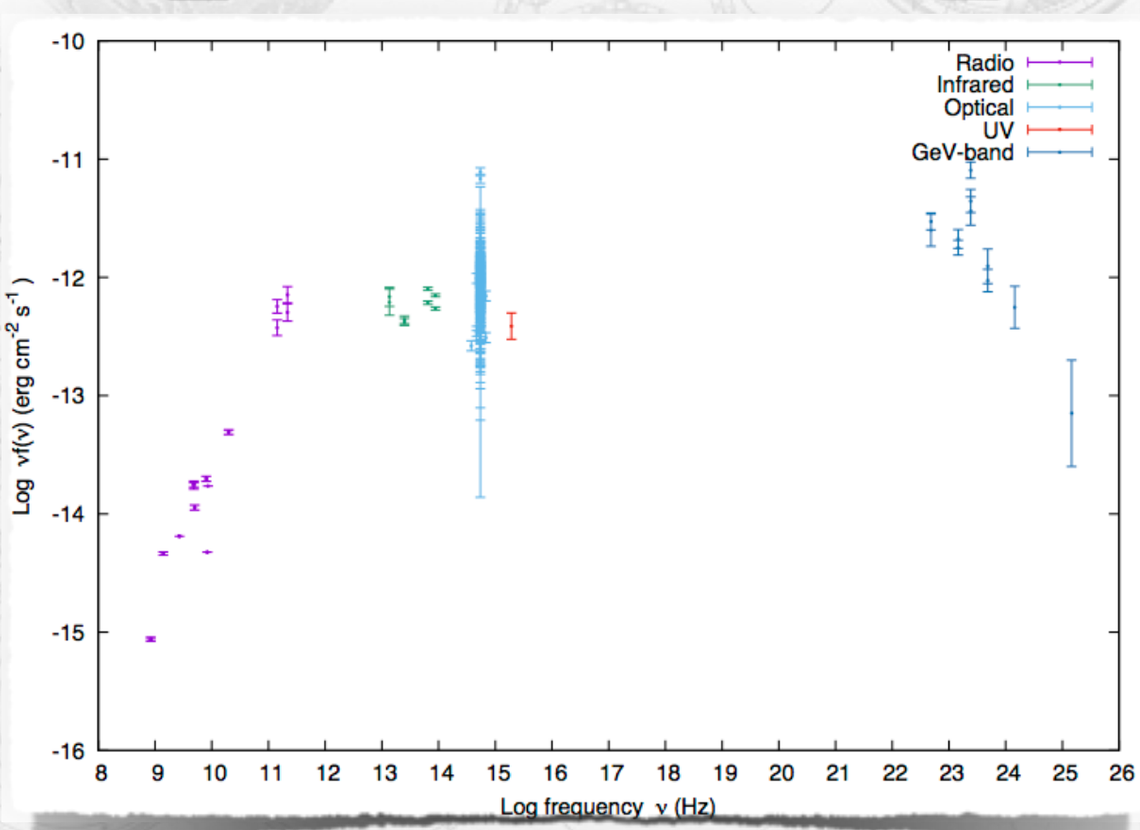
Results

PKS J0045-3705

2FGL J0044.7-3702





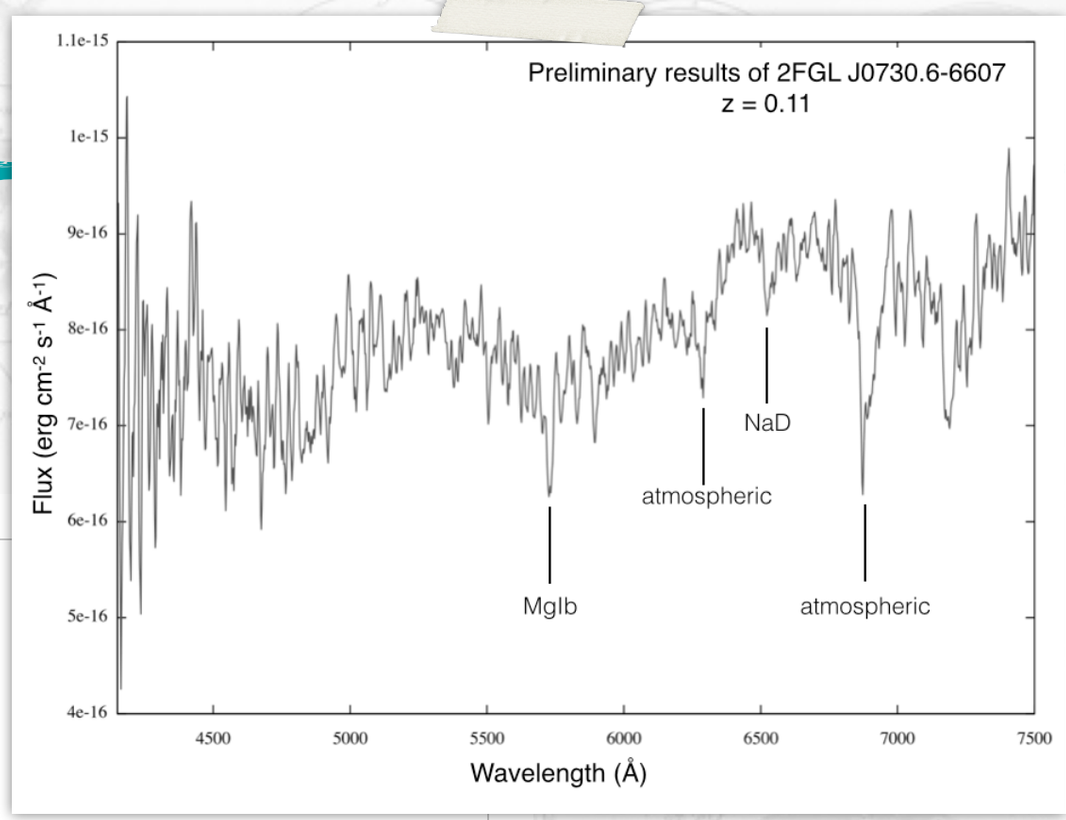


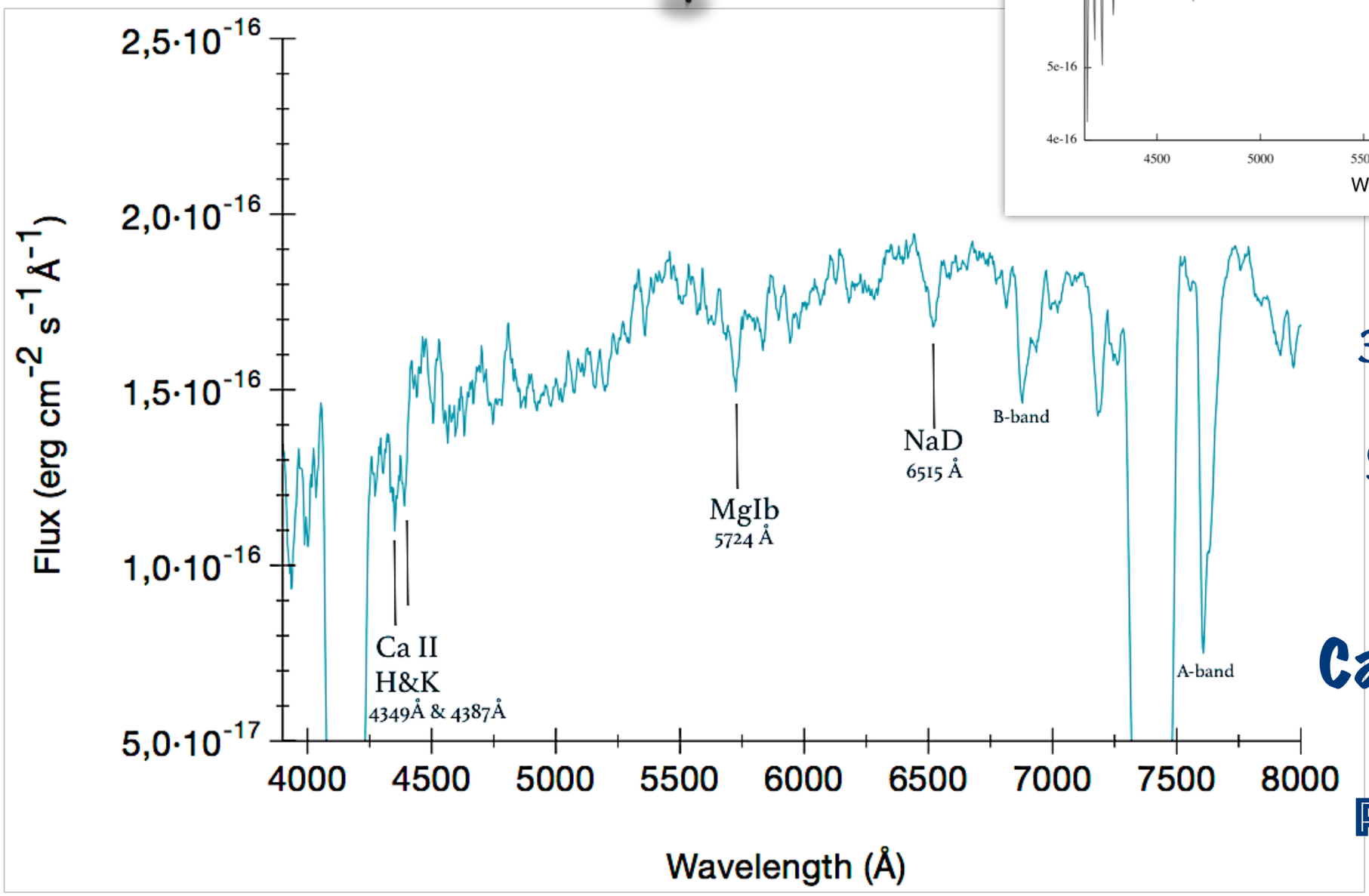
Results

Vmag = 15.13

PMN J0730-6602

2FGL J0730.6-6607





SALT RSS:
31 December 2014

SAAO 1.9-m SpCCD:
22 May 2014

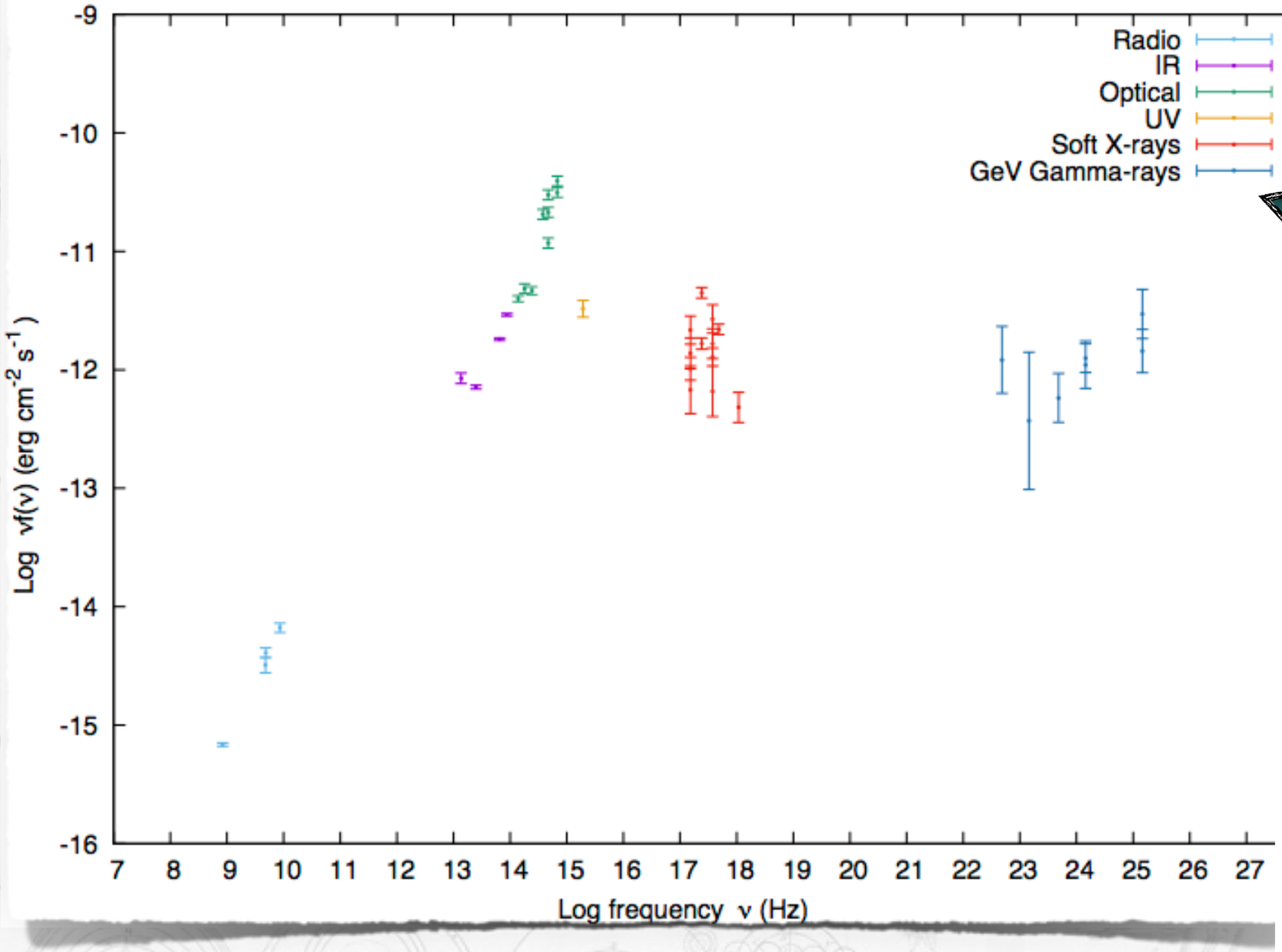
Ca II H&K; MgIb; NaD

REDSHIFT: Z ~ 0.11

Results

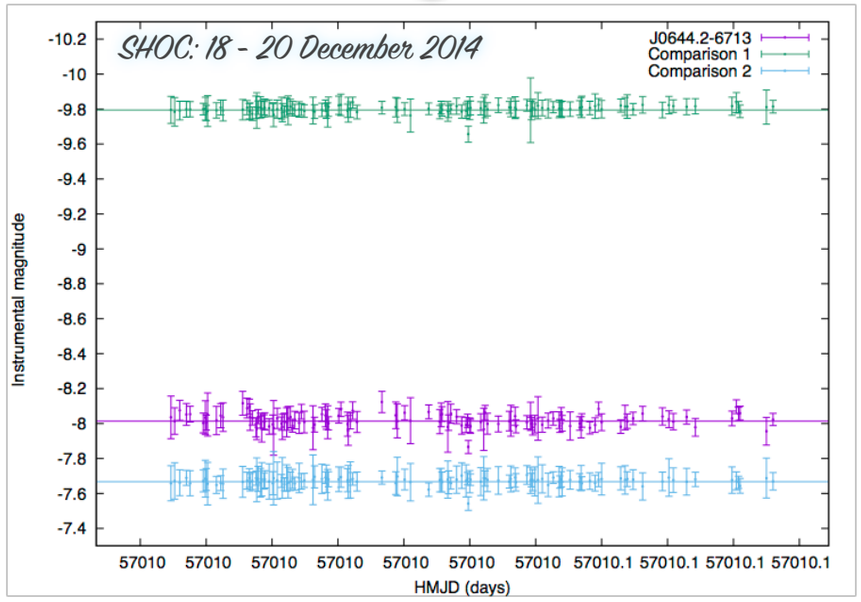
PMN J0730-6602

2FGL J0730.6-6607



HSP?

CANDIDATE FOR TEV FOLLOW-UP OBSERVATIONS



Results

Vmag = 17.41

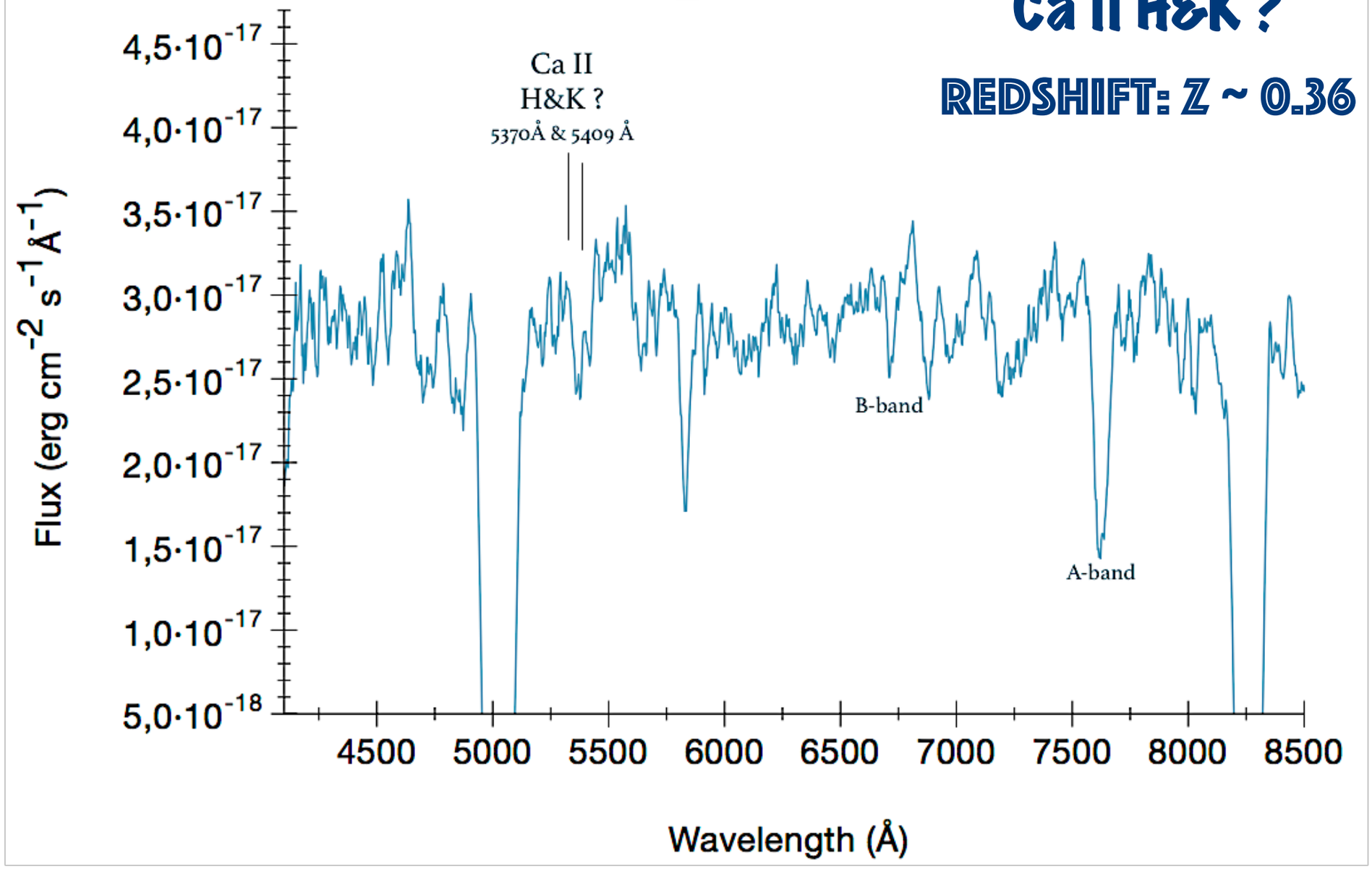
PMN J1106-3647

2FGL J1106.3-3643

SALT RSS:
9 March 2015

Ca II H&K ?

REDSHIFT: Z ~ 0.36



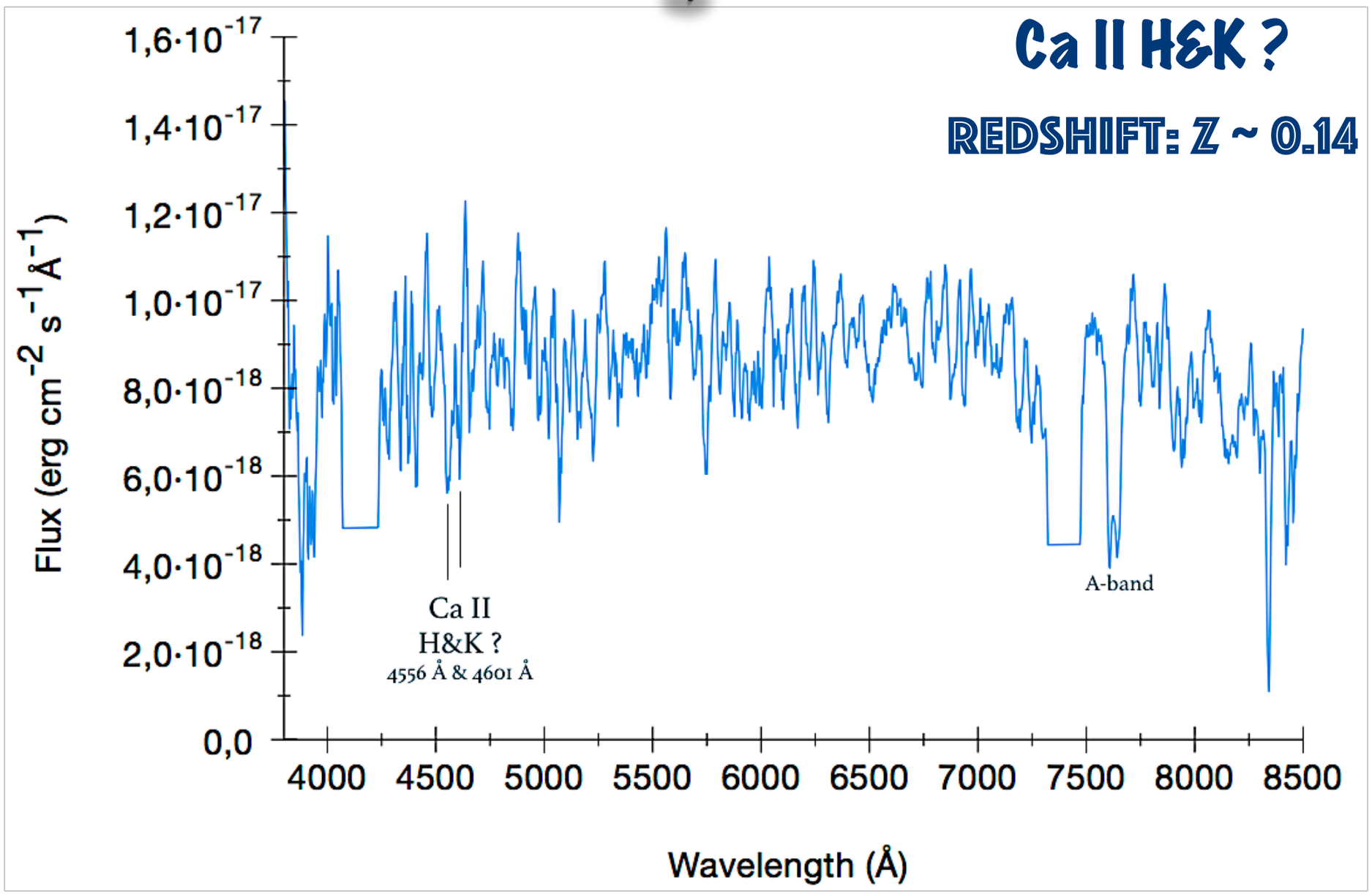
Results

Vmag = 18.88

PKS 1151-3242

2FGL J1154.1-3242

SALT RSS:
9 March 2015

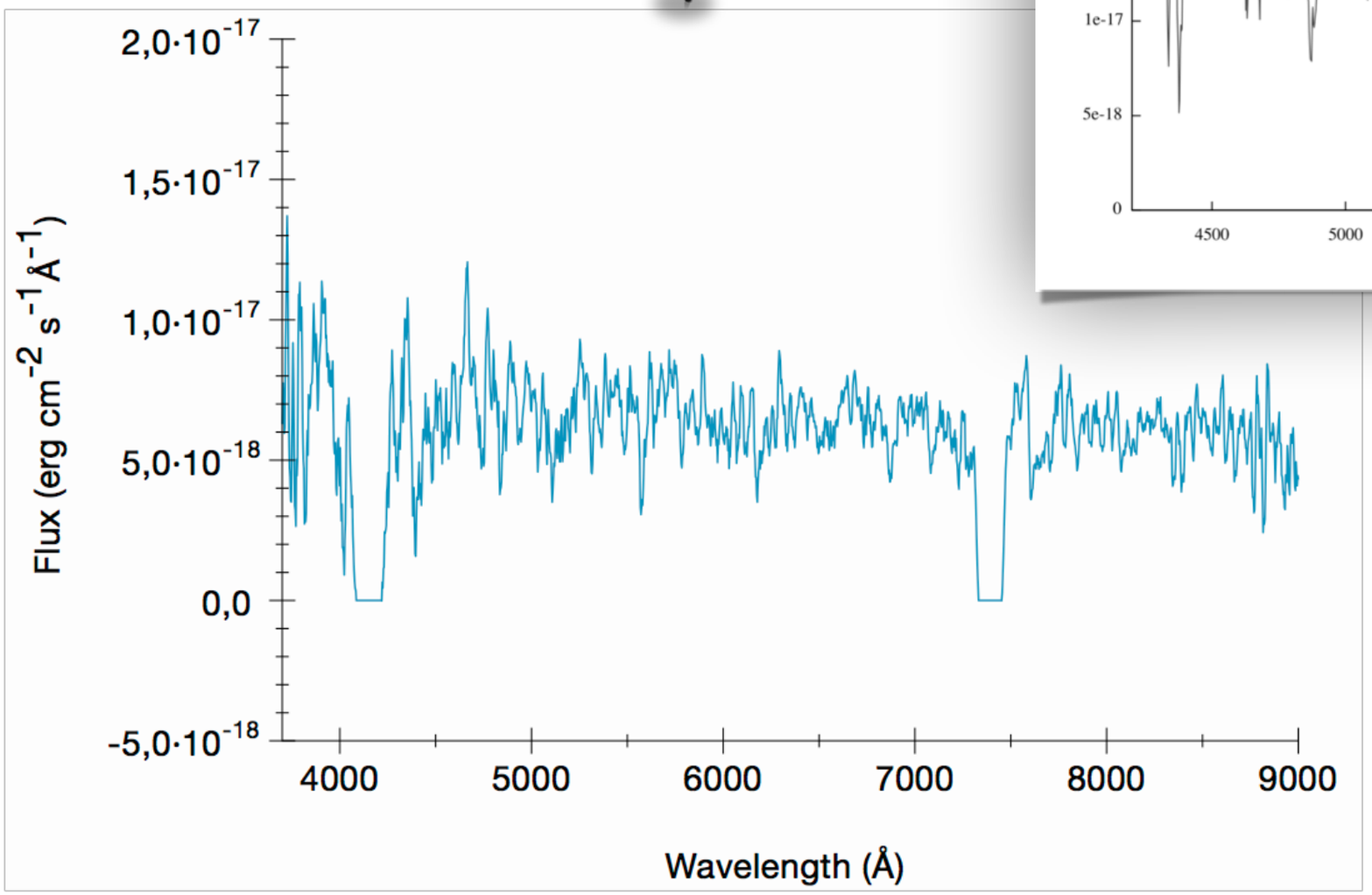


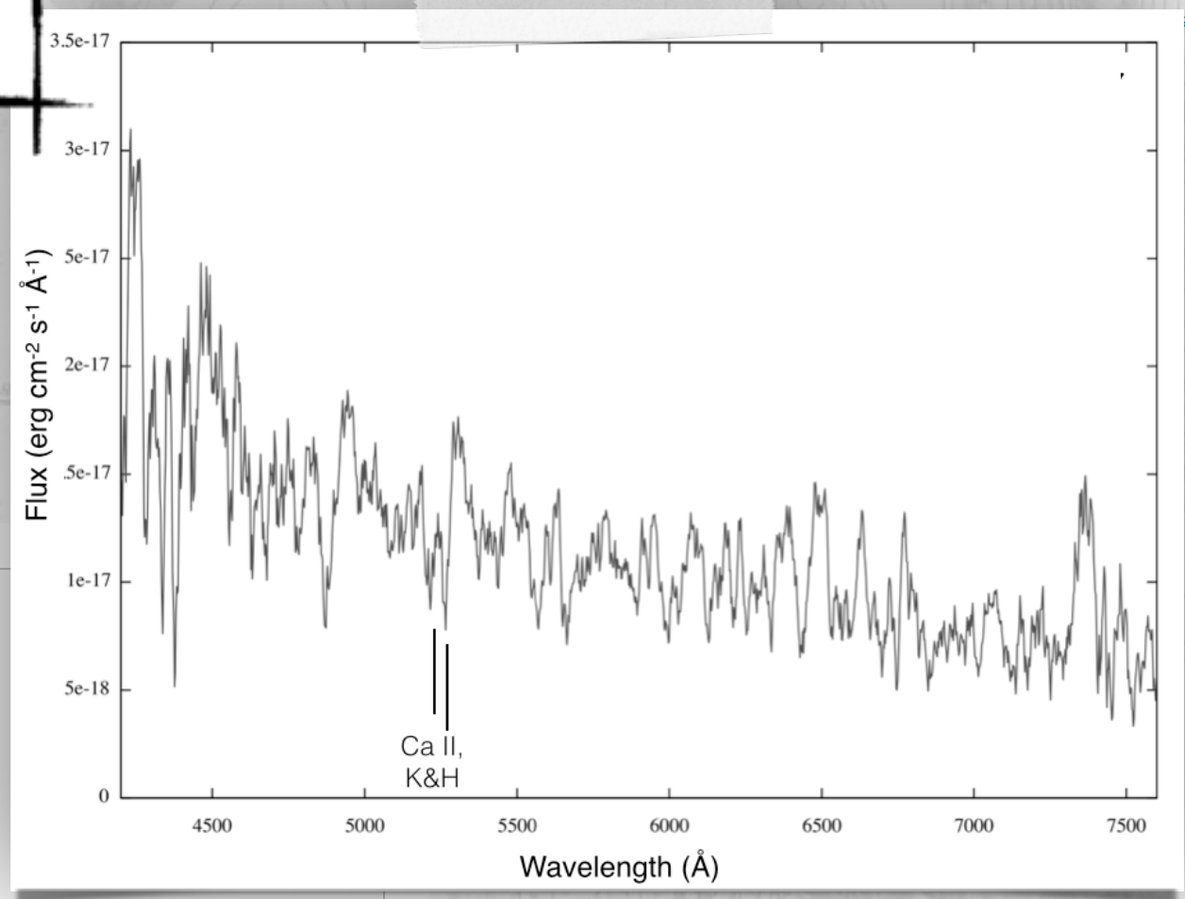
Results

CGRaBS J1407-4302

2FGL J1407.5-4257

Vmag = 17.47





SALT RSS:
9 February 2015

SAAO 1.9-m SpCCD:
21 May 2014

Ca II H&K ?

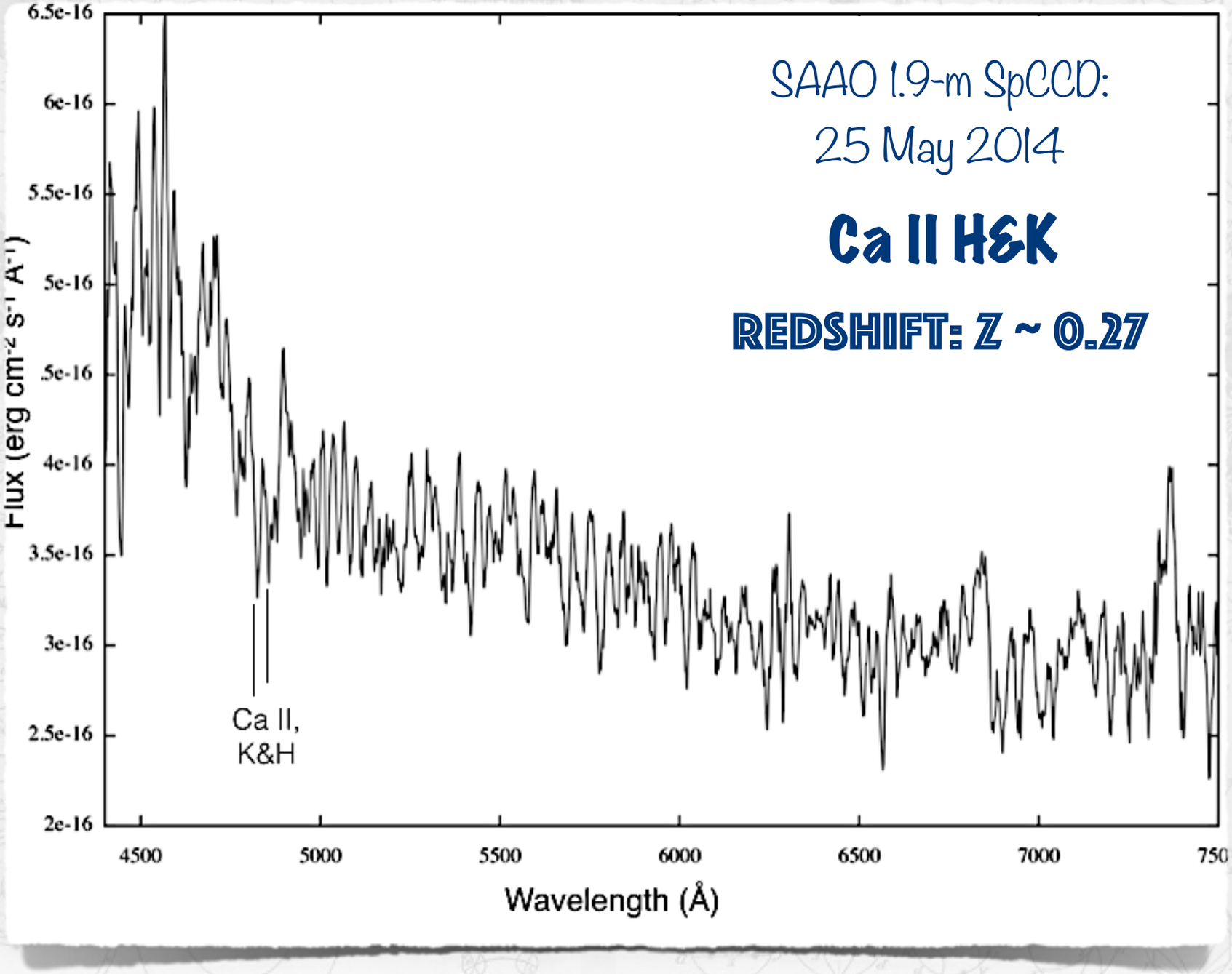
REDSHIFT: Z ~ 0.33

Results

Vmag = ?

PKS 2047+098

2FGLJ2049.8+1001



SAAO 1.9-m SpCCD:
25 May 2014

Ca II H&K

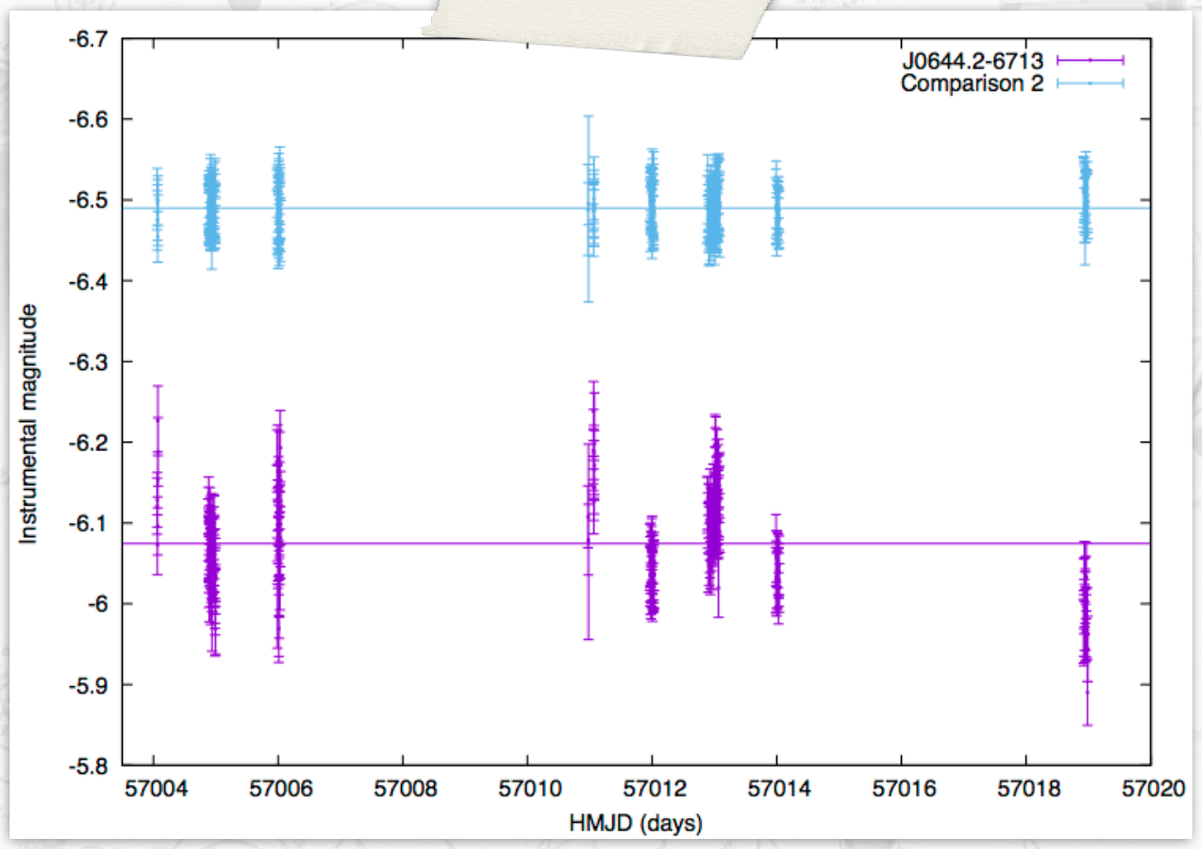
REDSHIFT: Z ~ 0.27

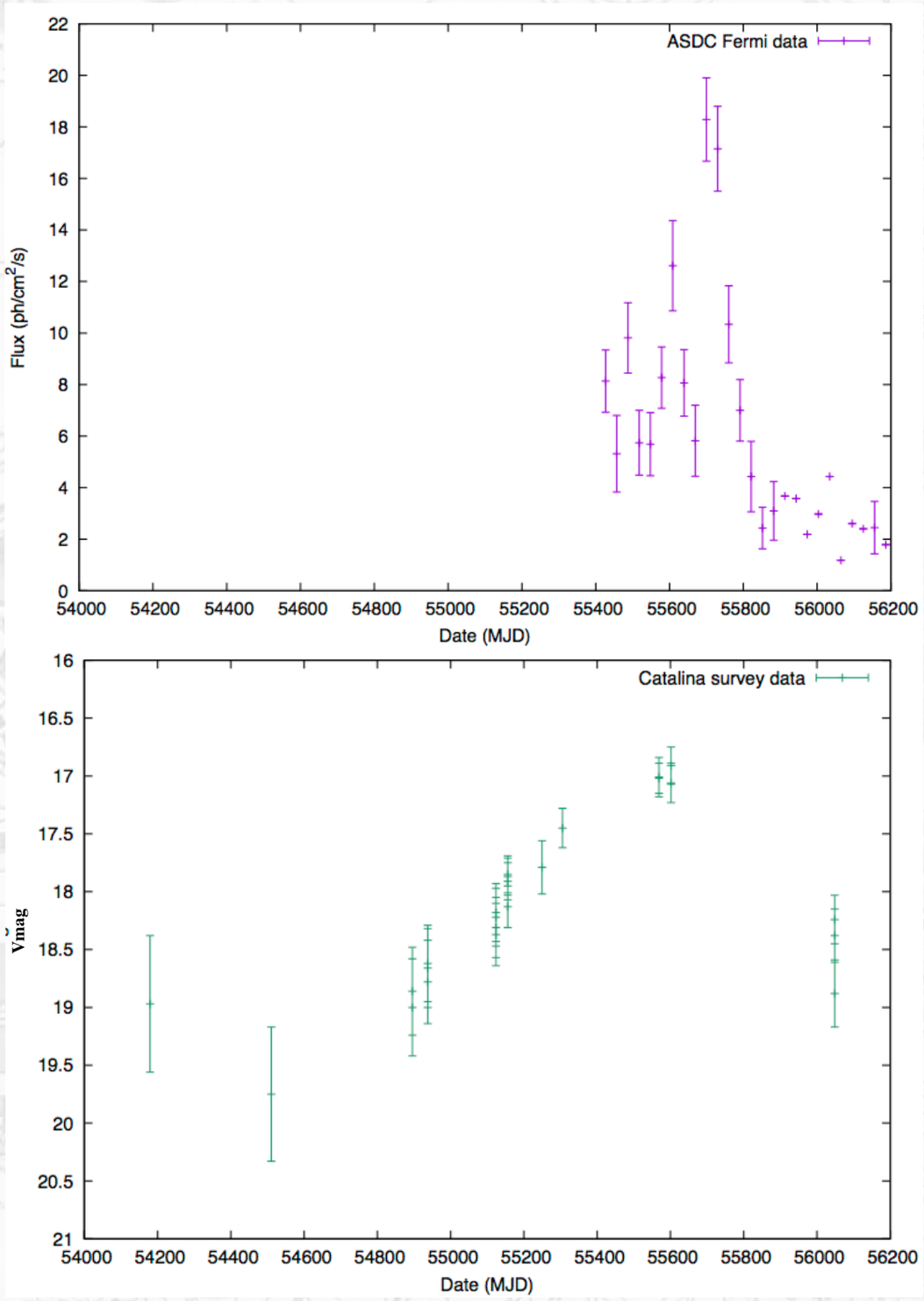
Results

PKS 0644-6713

Vmag = 20.69

2FGL J0644.2-6713





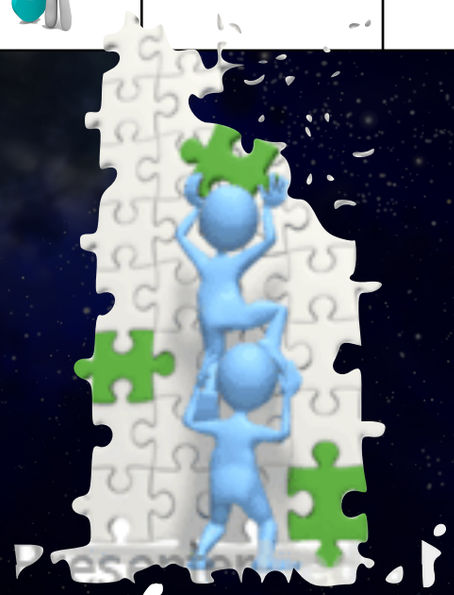
Coming SOON SALT spectrum ;)

Summary

Optical spectroscopic results

2FGL Name	Observations			Spectral lines				Redshift, z
	SAAO 1.9-m SpCCD	SALT Sem I	SALT Proposed Sem II	Ca II H&K 3935Å & 3970Å	MgI 5174 Å	NaD 5894 Å	Mg II 2798 Å	
J0044.7-3702	-	-	✔				5688 Å ?	1.03 ?
J0644.2-6713	-	-	✔					
J0730.6-6607	✔	✔	-	4349Å & 4387Å	5724 Å	6515 Å		0.11
J1106.3-3643	-	✔	-	5370Å & 5409Å				0.36
J1154.1-3242	✔	✔	✔	4556Å & 4601Å ?				0.14 ?
J1218.8-4827	✔	✔	-	?	?	?		?
J1407.5-4257	✔	✔	✔	5210Å & 5254Å				0.33
J1955.0-5639	✔	-	✔	4863Å & 4899Å				0.27

0.11 < Z < 1.03



"A picture paints a thousand words, spectra paints a thousand pictures"

- Liz Bartlett

To conclude...

We have obtained SAAO 1.9-m spectra for four targets of our sample during May 2015 which potentially exhibit absorption features such as Ca II H&K, MgIb and NaD.

The 2015-Sem I SALT spectra yielded promising results showing Ca II H&K in most of the spectra.

The 2015-Sem II SALT spectrum of 2FGL J0044.7-6607 clearly has a broad emission feature which we speculate to be Mg II allowing for a redshift estimate of z = 1.03. However we require more data to elaborate.

0.11 < Z < 1.03

Optical spectra:

Await new SALT spectra for the fainter sources.

Start looking at methods to 'easier' identify potential lines.

Determine Ca break value where possible.

Determine equivalent widths of spectral features.

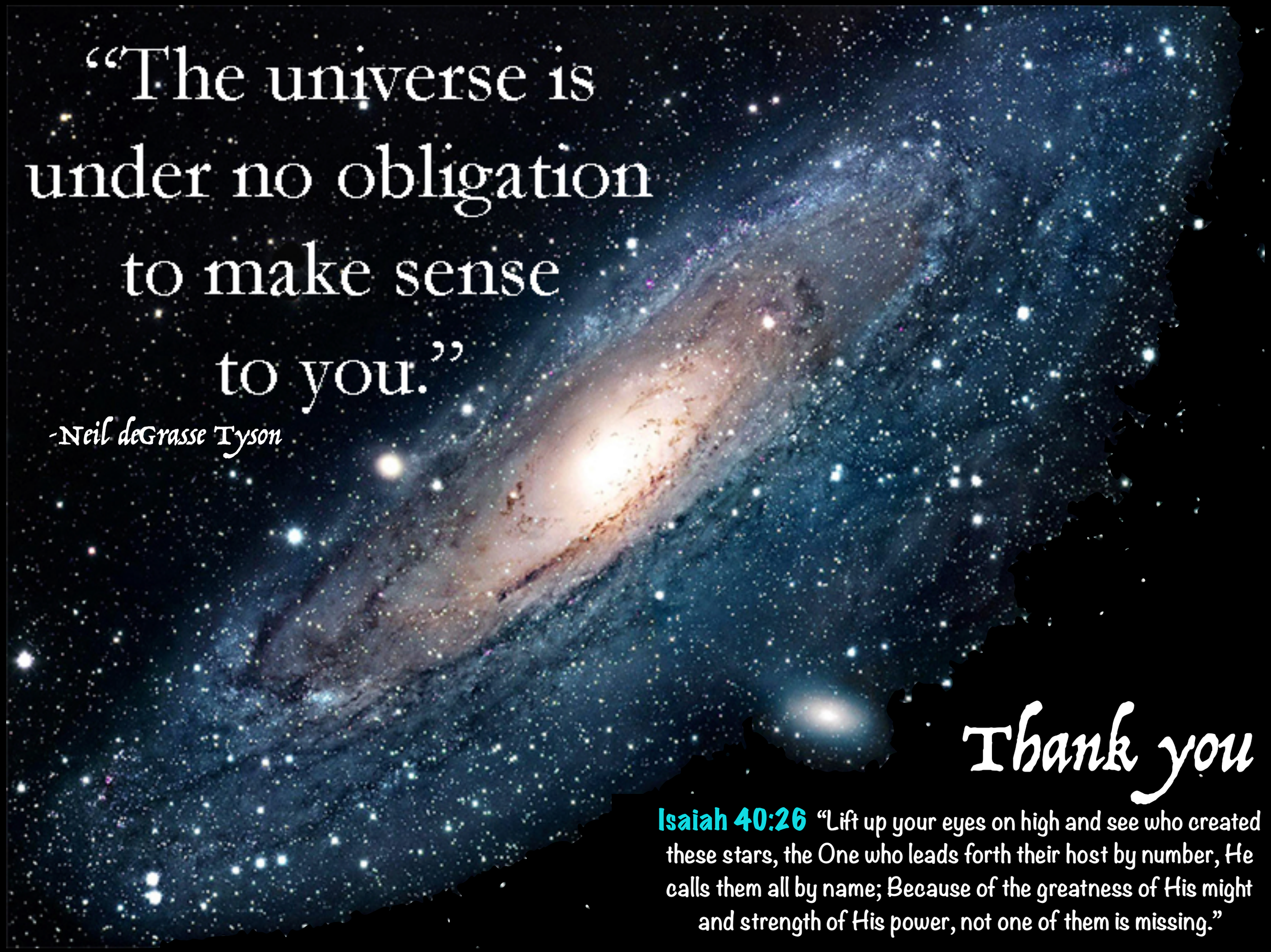
Radio:

Establish/verify the flux density @ different radio frequency bands.

Multi-frequency:

Multi-frequency: Construct SEDs and classify the AGUs listed in our target sample.

variability


"The universe is
under no obligation
to make sense
to you."
-Neil deGrasse Tyson
Thank you
Isaiah 40:26 "Lift up your eyes on high and see who created these stars, the One who leads forth their host by number, He calls them all by name; Because of the greatness of His might and strength of His power, not one of them is missing."