THE SEARCH FOR BLAZAR-LIKE, RADIO LOUD NARROW-LINE SEYFERT 1 GALAXIES

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B2 1702+457

Image credit: H. R. Miller

Quote
Who, When, and Where??

- Variability timescales provide limits on the size of the emitting region "…unless there is relativistic bulk motion of the emitting material."
- "Among the most **distressing** observations that astronomers have made in recent years are those of the extremely rapid flux variations and apparent faster-than-light structural changes in an increasing number of compact extragalactic radio sources."

Collaborators

- Joseph Eggen
- Jeremy Maune
- Clay Turner
- Diana Gudkova
- Elizabeth Ferarra

Observations

Table 2.2: Summary of Optical Data by Telescope

(Number of allocated nights are in parentheses)

Telescope	Observing Nights	Observations
Whole Sample	285	11,920
Lowell 31"	80 (169)	3,903
Lowell 42"	57 (91)	3,678
Lowell 72"	68 (151)	4,183
SMARTS 1.3m	138	156

Motivation

- A small number of vRL NLSy1 galaxies in the Yuan et al. (2008) sample have been identified as gamma sources with Fermi.
- Are there more vRL NLSy1s that emit gamma-rays ? (Reminds one of the early days of BL Lac Object studies)
- What are their properties?
- Do they form another class of blazars?

Goals

- Monitor the Yuan et al(2008) and Komossa et al(2006) sample of vRL NLSy1s (34) for optical flux and polarization variability.
- Select candidates from the sample based upon blazar-like optical flux and polarization variations (including microvariability) .
- How do the properties of the selected vRL NLS1s compare to those of blazars?

Gamma Ray Emission

- Key element in demonstrating blazar-like character
- Normally requires TS > 25,Eggen (2014), Eggen, Miller, Maune(2016)
- Provisional identification with 9 < TS < 25;Eggen (2014),Eggen, Miller, Maune(2016) if also accompanied by the following properties:
  - Optical Variability (and microvariability)
  - Strong/variable optical polarization
  - Positional coincidence with strong radio source

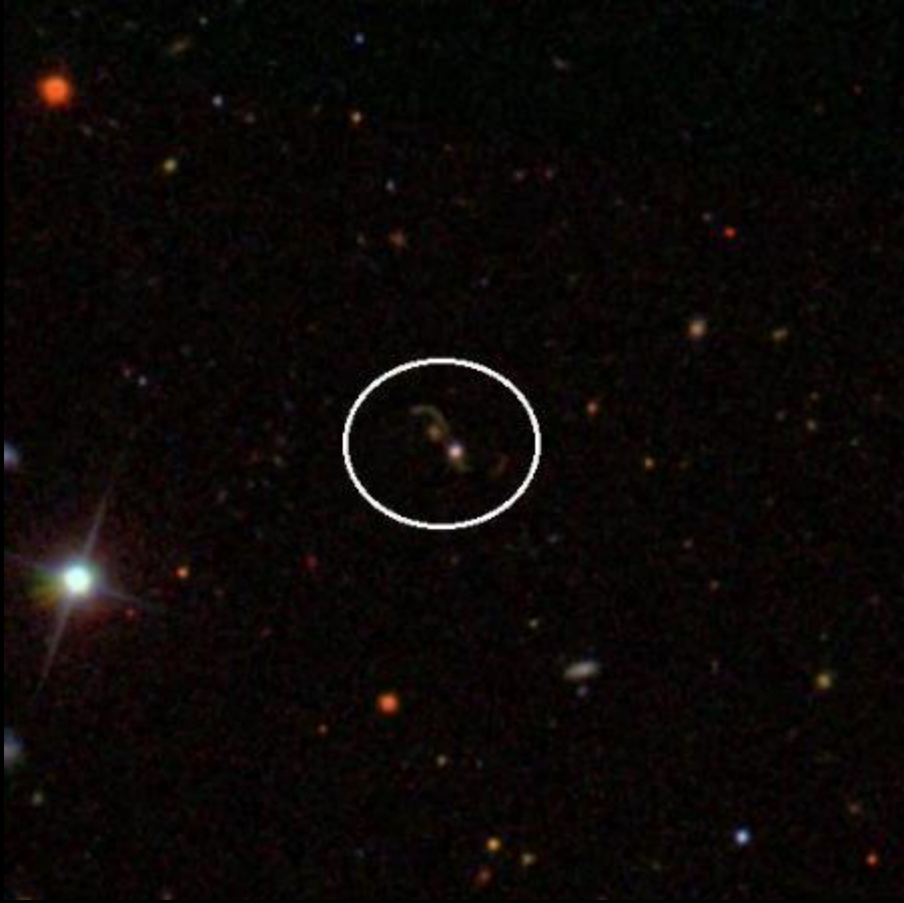
Sample collected from Yuan et al.(2008) and Komossa et al.(2006)

Object ID	R.A.	Dec.	z	log(R)
J0100-0200	01:00:32.22	-02:00:46.00	0.227	1.77
IRAS 01506+2554	01:53:28.262	26:09:39.232	0.326	1.40
1H 0323+342	03:24:41.16	34:10:45.86	0.063	2.50
J0706+3901	07:06:25.12	39:01:51.55	0.086	1.21
J0723+5054	07:23:02.33	50:54:48.00	0.203	1.29
J0744+5149	07:44:02.28	51:49:17.50	0.460	1.62
J0804+3853	08:04:09.240	38:53:48.829	0.211	1.18
J0849+5108	08:49:57.977	51:08:29.023	0.583	3.16
IRAS 09426+1926	09:45:29.22	19:15:48.70	0.284	1.56
PMN J0948+0022	09:48:57.317	00:22:25.511	0.584	2.93
J0956+2515	09:56:49.874	25:15:16.196	0.712	3.56
J1038+4227	10:38:59.582	42:27:42.213	0.220	1.30
J1047+4725	10:47:32.688	47:25:32.010	0.800	4.09
J1102+2239	11:02:23.383	22:39:20.686	0.453	1.28
J1140+4622	11:40:47.897	46:22:04.791	0.115	1.36
J1146+3236	11:46:54.289	32:36:52.384	0.465	2.19
J1227+3214	12:27:49.14	32:14:59.00	0.137	2.16
J1246+0238	12:46:50.20	02:40:16.00	0.091	2.38
J1333+4141	13:33:45.469	41:41:27.656	0.225	1.06
J1358+2658	13:58 45.371	26:58:08.483	0.330	1.11
J1405+2657	14:05:04.803	26:57:27.539	0.713	1.09
J1421+2824	14:21:14.057	28:24:52.899	0.538	2.14
J1435+3132	14:35:09.502	31:31:47.971	0.502	2.98
J1443+4725	14:43:18.558	47:25:56.663	0.703	3.03
PKS 1502+036	15:05:06.477	03:26:30.796	0.411	3.53
RX 16290+4007	16:29:01.306	40:07:59.941	0.272	1.61
J1633+4718	16:33:23.57	47:18:58.83	0.116	2.19
J1644+2619	16:44:42.534	26:19:13.305	0.145	2.73
B3 1702+457	17:03:30.41	45:40:47.08	0.061	2.01
J1709+2348	17:09:07.810	23:48:37.760	0.254	1.06
J1713+3523	17:13:04.462	35:23:33.646	0.083	1.05
IRAS 20181-2244	20:21:04.064	-22:35:25.775	0.185	1.57
J2314+2243	23:14:55.89	22:43:22.69	0.169	1.25

Object ID	R.A.	Dec.	log(R)	Bin #	TS	Flux(err)
1H 0323+342	51.2096	34.143	2.50	53	280.31	36.19(2.73)
J0849+5108	132.492	51.1414	3.16	35	790.76	26.34(2.20)
J0948+0022	147.221	0.349773	2.93	53	402.14	39.81(2.32)
J0956+2515	149.208	25.2545	3.56	20	95.95	10.24(2.34)
J1443+4725	220.827	47.4324	3.03	49-53	27.81	1.49(0.06)
PKS 1502+036	226.292	3.40703	3.53	43	36.60	9.58(2.71)
J1644+2619	251.177	26.3204	2.73	46-50	52.25	4.24(1.04)
PKS 2004-447	301.98	-44.579	3.80	13-24	53.77	2.26(0.52)

Object ID	R.A.	Dec.	log(R)	Bin #	TS	Flux(err)
J0100-0200	15.1342	-2.01278	1.77	8	9.65	5.87(0.56)
				25	9.52	3.17(2.23)
J0706+3901	106.605	39.031	1.21	23	10.30	0.76(.15)
				66	10.50	1.10(0.36)
J0804+3853	121.038	38.8969	1.18	34-36	10.77	8.49(0.15)
J1102+2239	165.597	22.6558	1.28	15-20	14.57	1.29(0.81)
J1146+3236	176.726	32.6145	2.19	5	12.61	3.58(1.66)
J1246+0238	191.709	2.67123	2.38	55-66	17.13	1.58(0.60)
J1713+3523	258.269	35.3926	1.05	22	12.03	6.21(0.23)
IRAS 20182-2244	305.268	-22.5884	1.57	9	9.42	2.24(1.89)
J2314+2243	348.732	22.7236	1.25	50	11.59	5.05(2.54)

BL Lac Objects(BA): Strittmatter et al(1972)



- Featureless opt. spect.
- Non-thermal SED
- Highly variable on all observed timescales and wavelengths
- Polarized optical emission
- Radio loud and many detected in gamma-rays

Image: J1102+2239

What are Radio-Loud NLSy1?

- Radio-Loud: $R \geq 10$ (where $R = f_{1.4\,GHz} / f_{4400\,Å}$)
  (Kellerman et al., 1989)
- Very Radio Loud: $R \geq 100$ (Yuan et al., 2008)
- NLS1 (Osterbrock & Pogge, 1985):
  - Disk-like Host Galaxy -> Spiral?
  - Low Mass SMBH, High Accretion Rate
  - FWHM(Hβ) ≤ 2000 km/s
  - Strong emission from Fe II (Goodrich, 1989)
- **Evidence suggests that a subset of this class possess properties similar to those of blazars**

J0948+0022: Radio and Gamma-Ray Loud

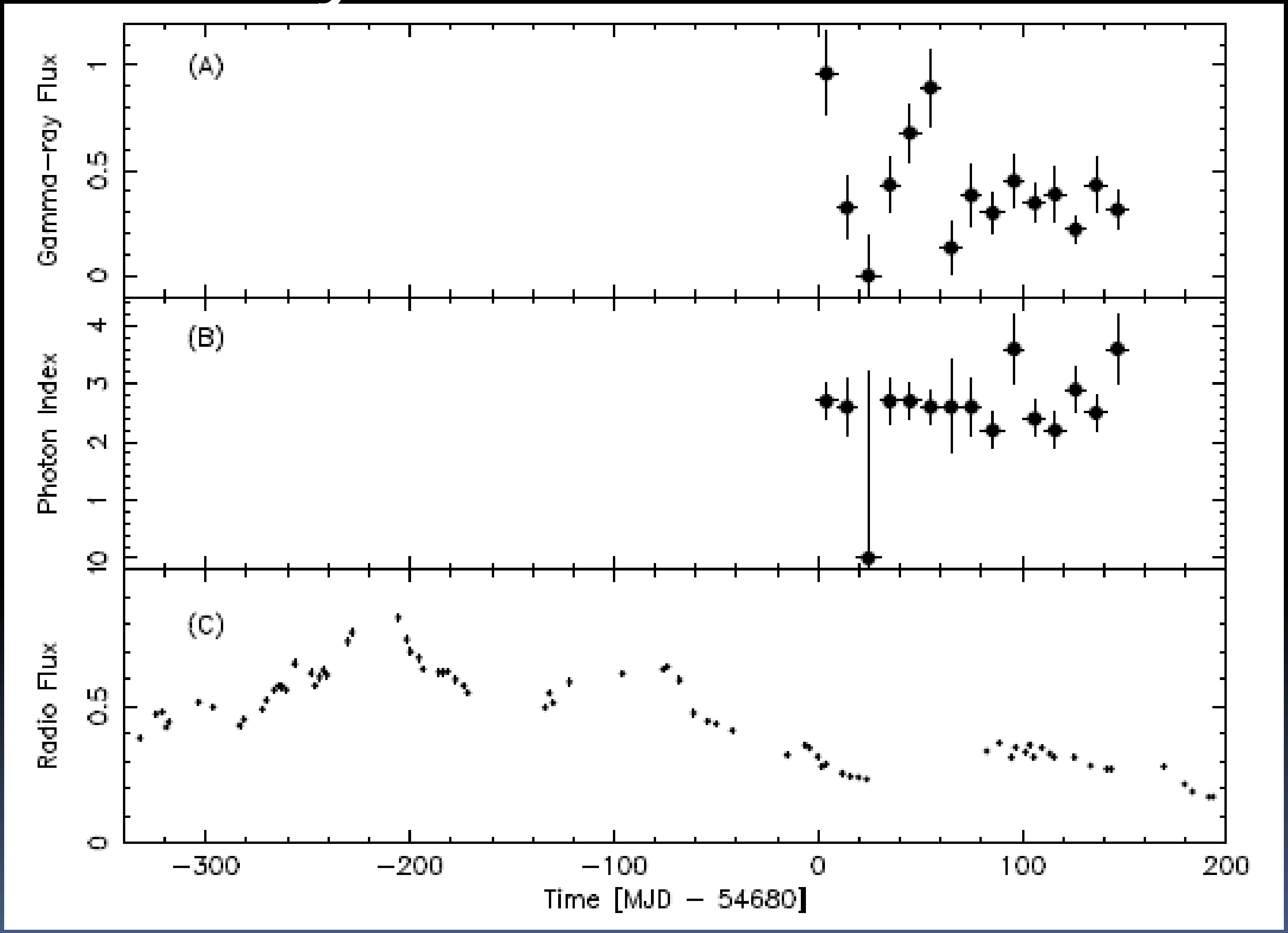


Image credit: Abdo et al. 2009a

J0948+0022: SED

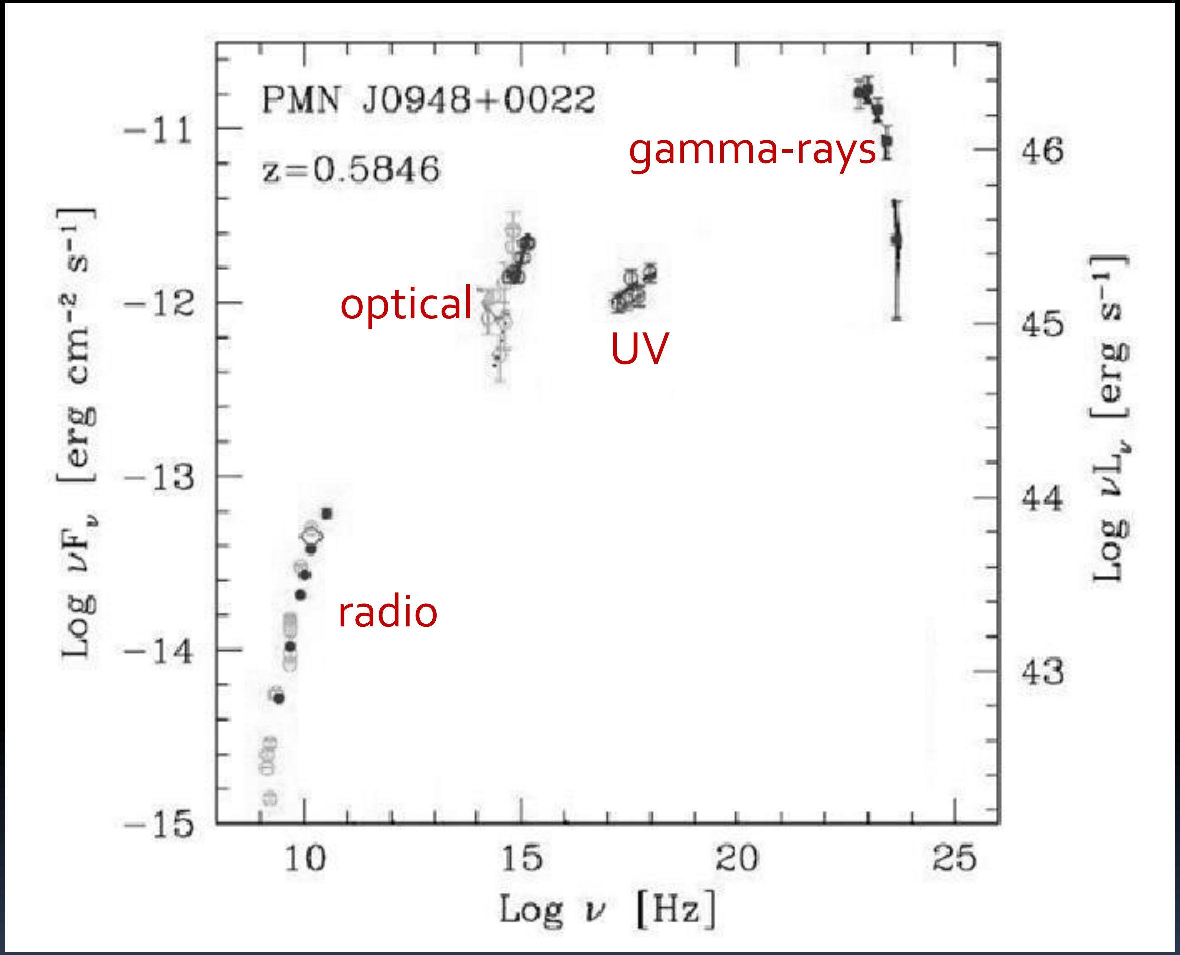
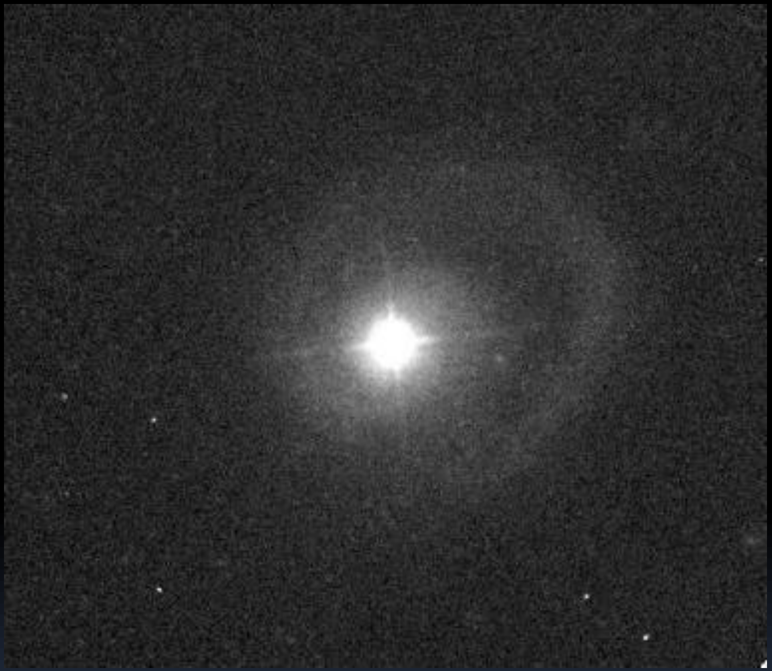


Image credit: Abdo et al. 2009b

Hypothesis: vRL NLSy1s are blazar-like objects

- Sample of 34 NLSy1s (Yuan et al, 2008) (Komossa et al, 2006)
    - All are radio loud
    - Range of radio loudness log(R) = ~1.0 – 4.0
- Objects *should* show blazar-like flux and polarization variability.

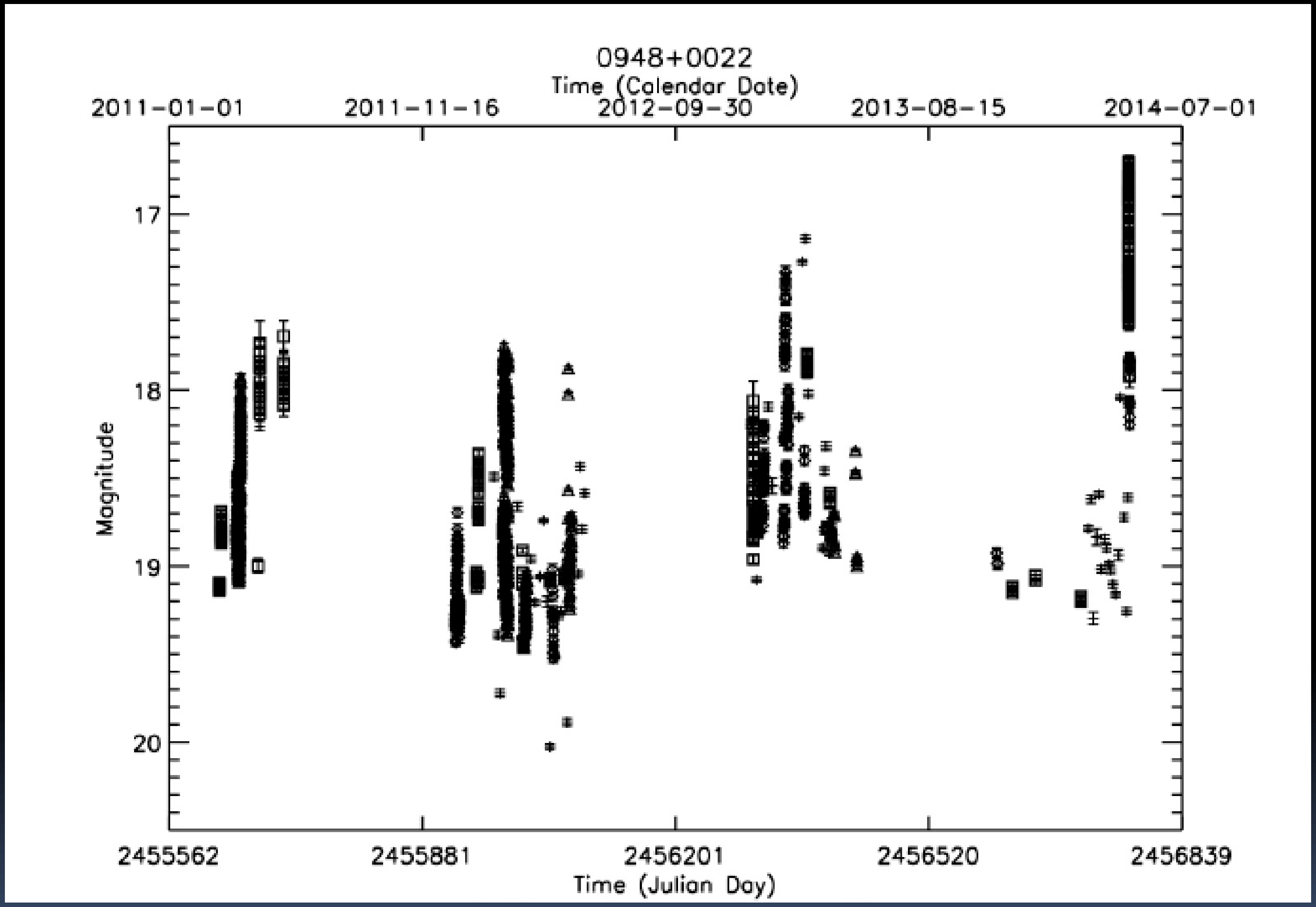


Hubble image of 1H 0323+342, one of the two closest objects in the sample.

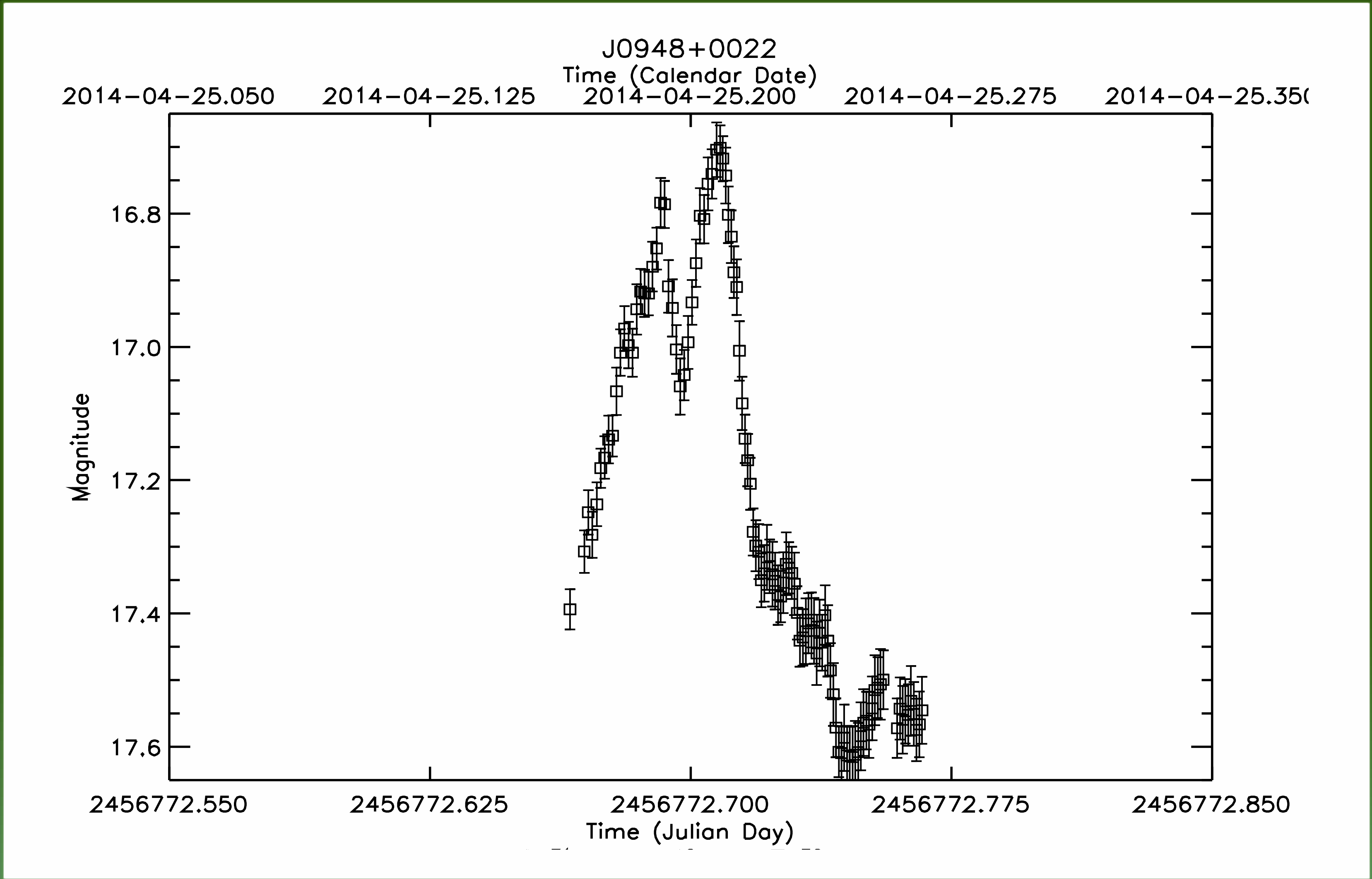
PMN J0948+0022

(Eggen, Miller, Maune, ApJ,773,147,2013)

- Rapid Variability of Optical Flux
- Microvariability (discrete, rapid events)
- Optical Polarization
- Gamma Ray LC

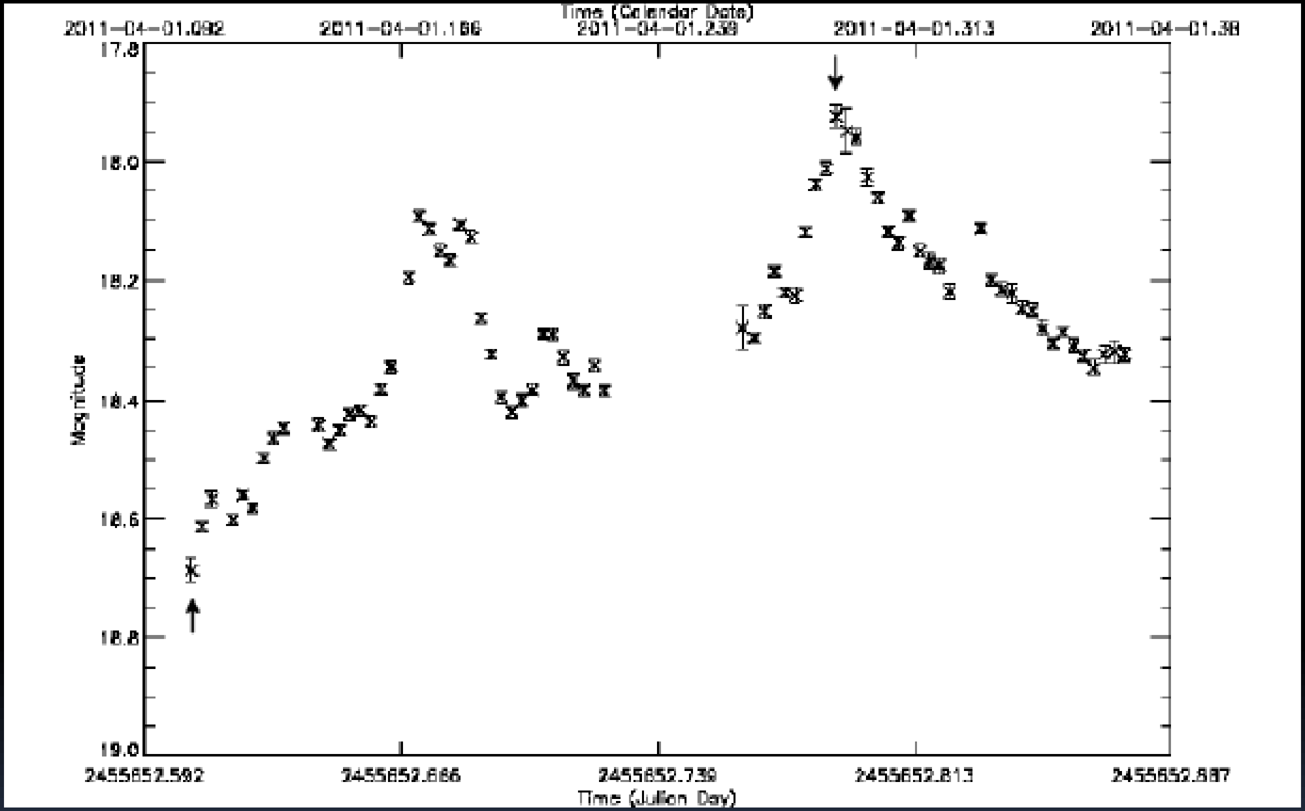

0948+0022
Time (Calendar Date)
2011-01-01
2011-11-16
2012-09-30
2013-08-15
2014-07-01
Magnitude
17
18
19
20
2455562
2455881
2456201
2456520
2456839
Time (Julian Day)

J0948+0022: Microvariability



Over 0.9 magnitude variation in less than one hour.

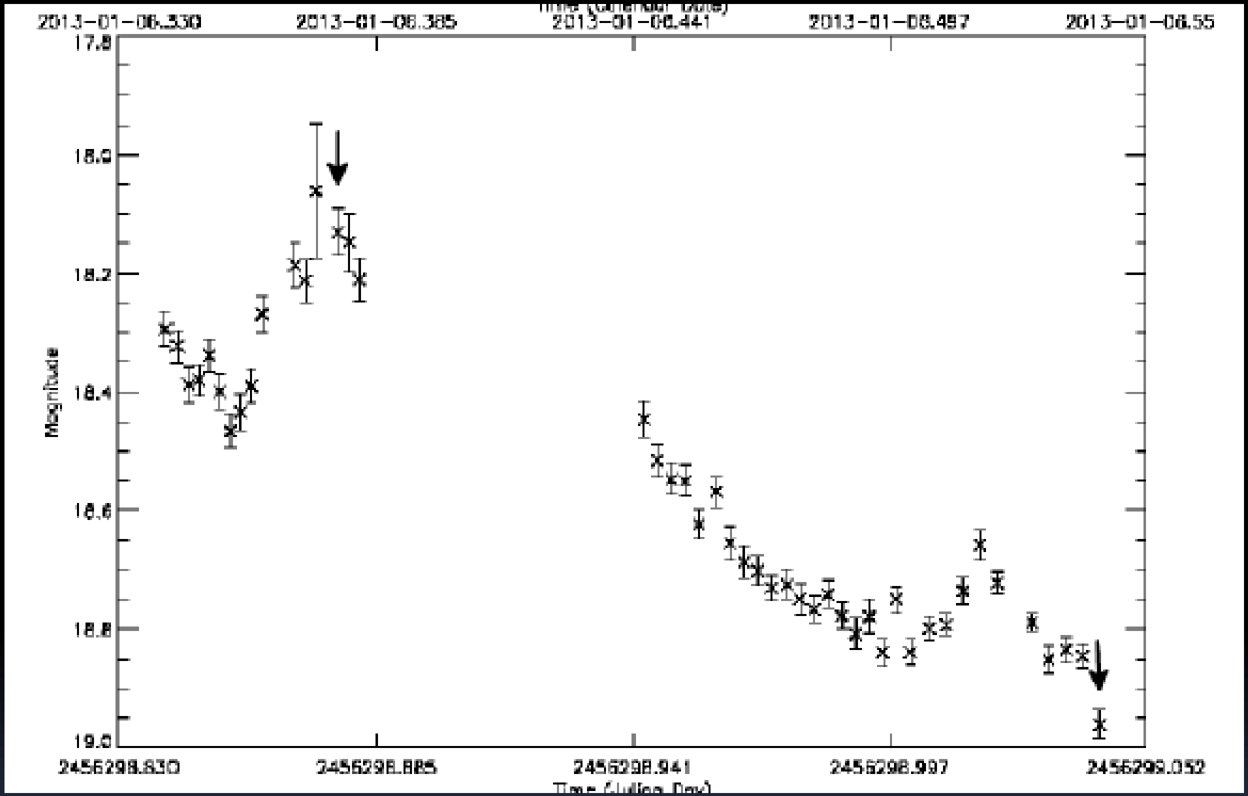
PMN J0948+0022
Flux doubling time = 4.39+/-0.19 hours



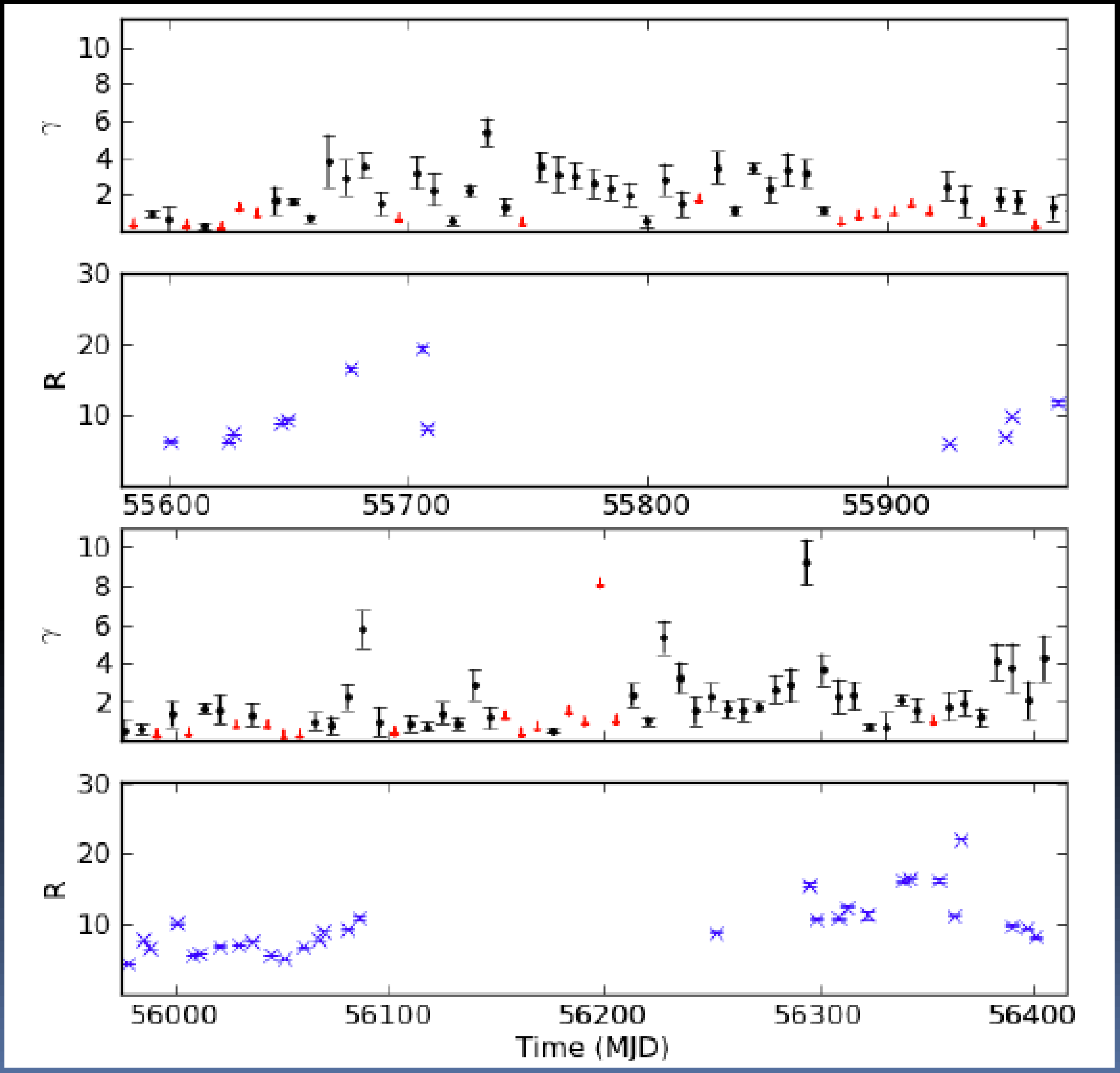
PMN J0948+0022

Flux halving time = 3.60+/-0.23 hours

(Small event duration ~1.4 hours)



PMN J0948+0022: Gamma Ray/ Optical Data



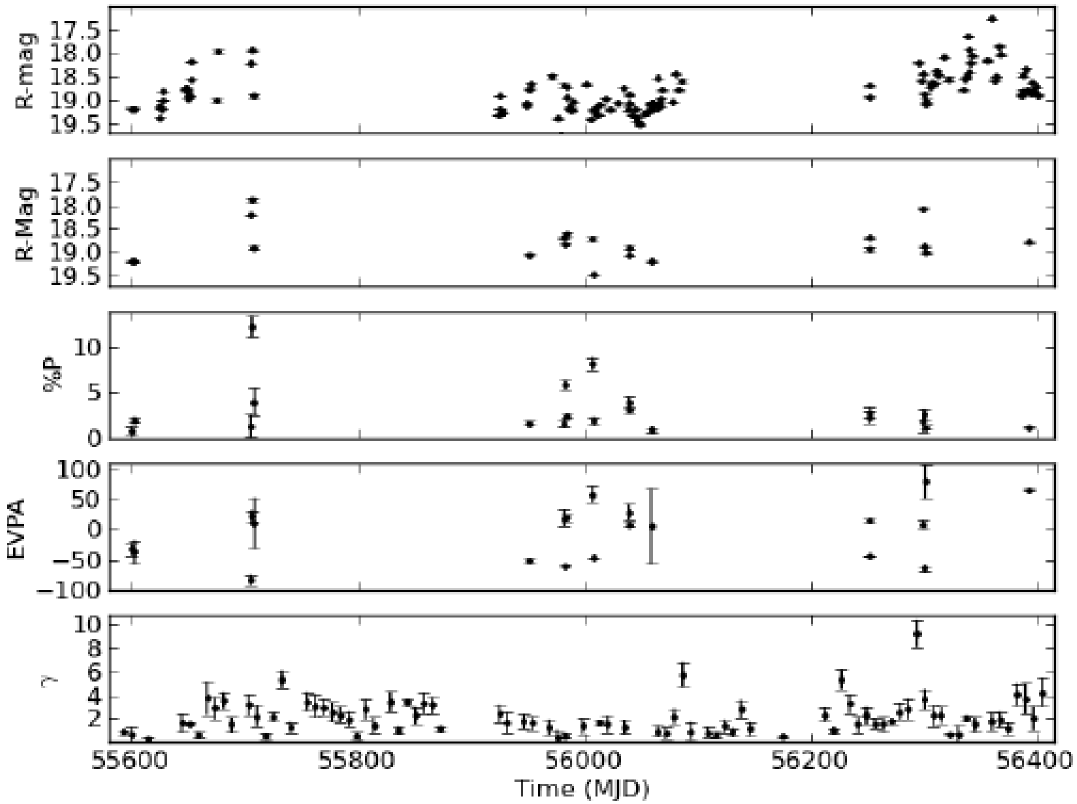
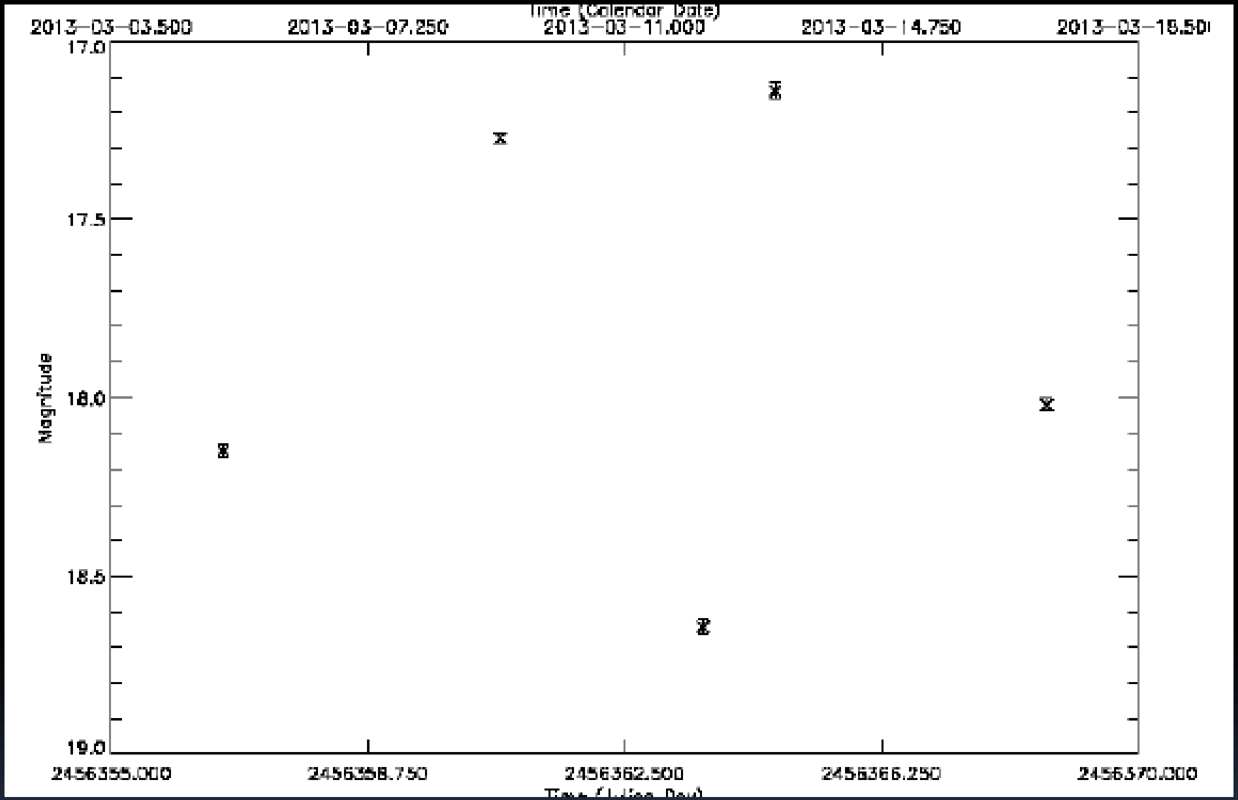


Figure 3.1: PMN J0948+0022: multi-wavelenght data
A comparison of all R-band optical data binned at 24-hour intervals (top panel), only optical data obtained with polarimetry (second panel), the Percent Polarization (third panel), position of the electric vector in degrees (fourth panel), and the integrated γ-ray flux (bottom panel) of PMN J0948+0022. Upper limits have been removed for clarity. Details on the photopolarimetric data can be found in Table 3.2. The same horizontal axis is common to all five plots.

PMN J0948+0022: Orphan optical/IR flare??



J0948+0022: Summary

- Extragalactic source
- Double peaked SED
- Radio loud
- Variable Polarization
- Detected at gamma-ray energies
- Highly variable on all observed timescales and wavelengths

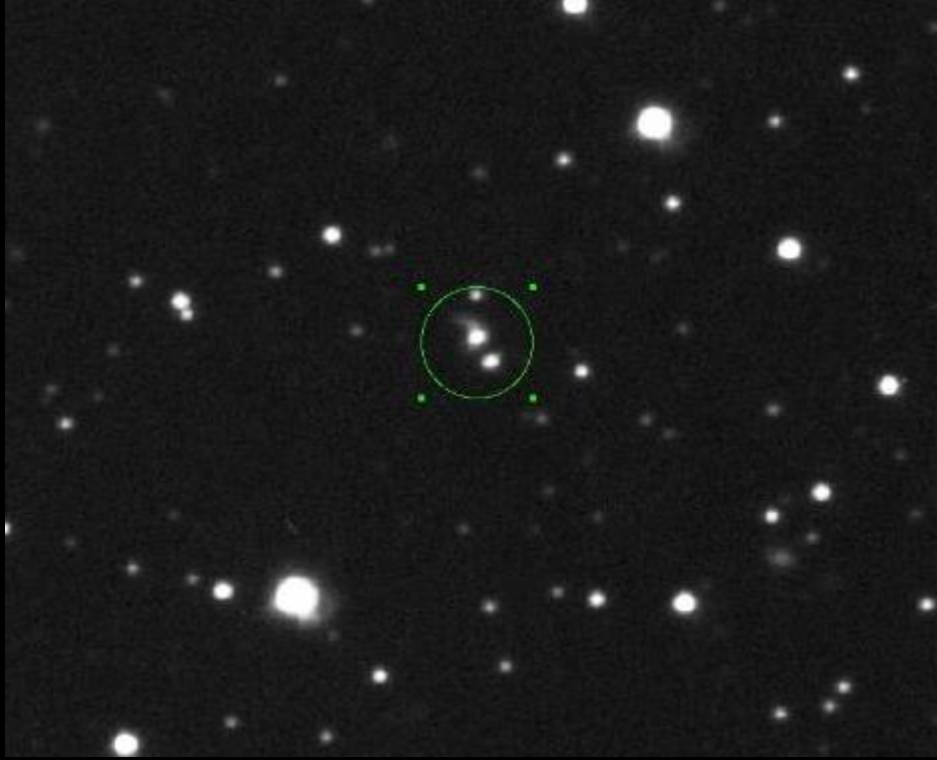
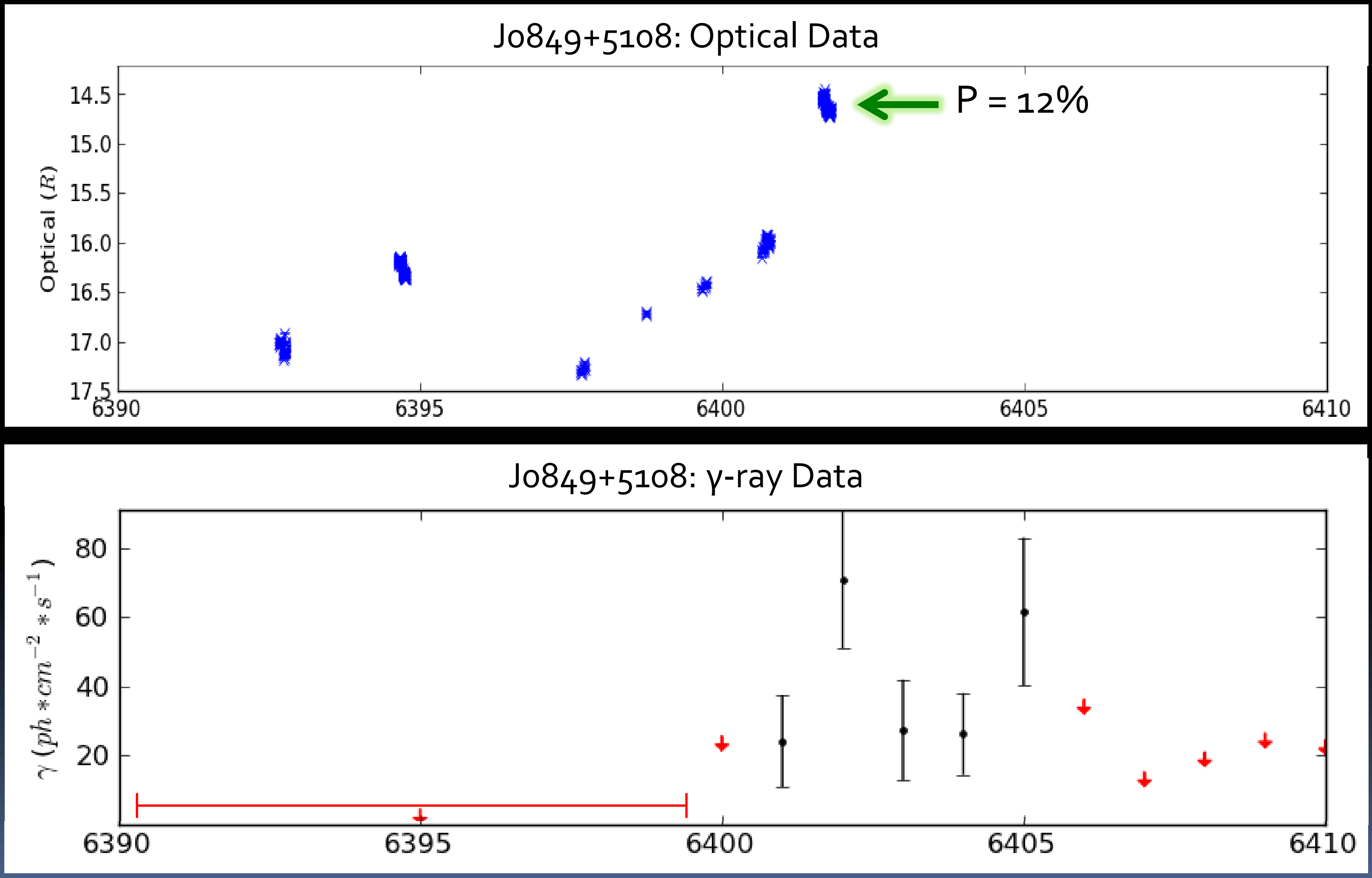
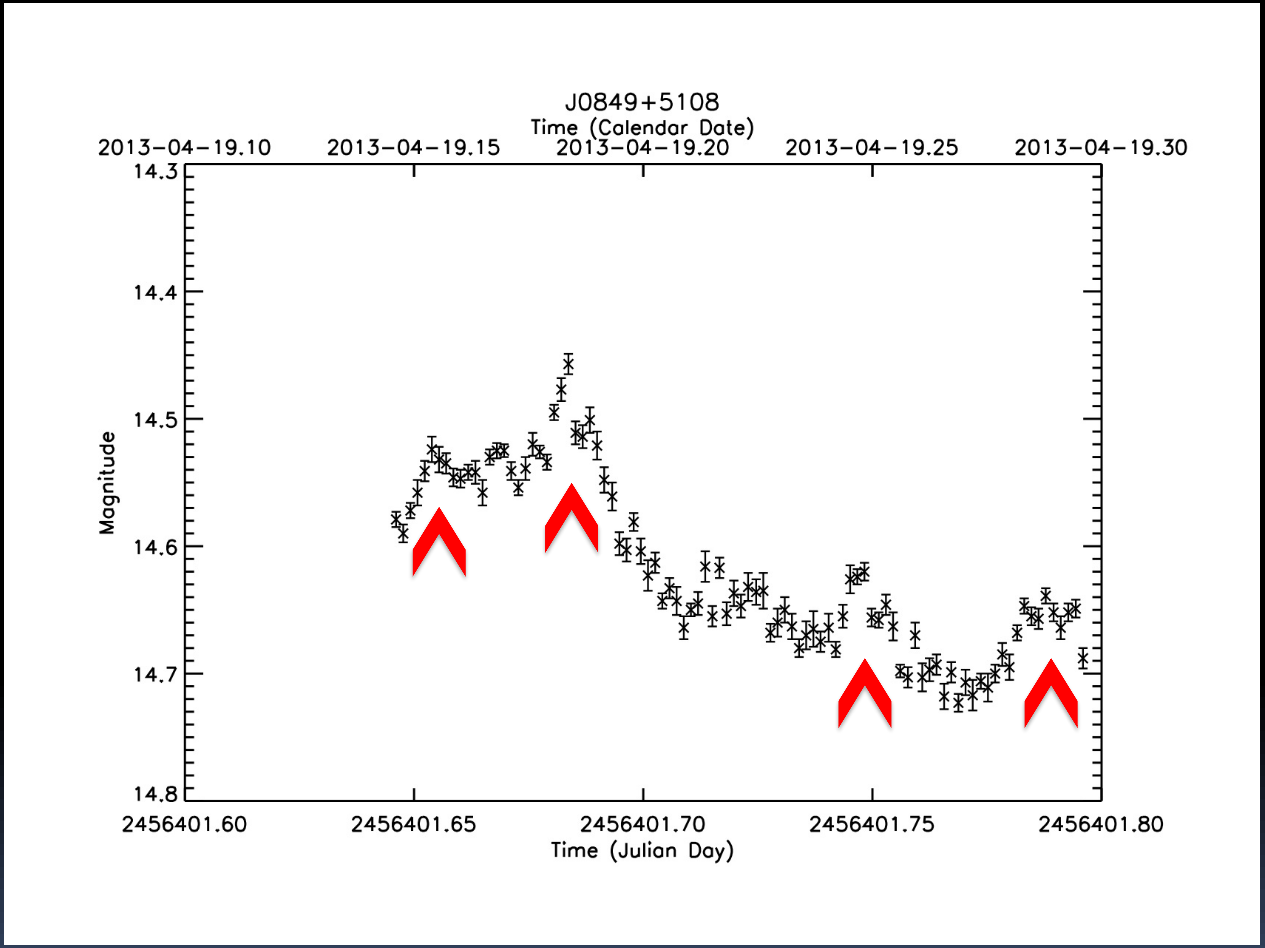


Image: IRAS 20181-2244

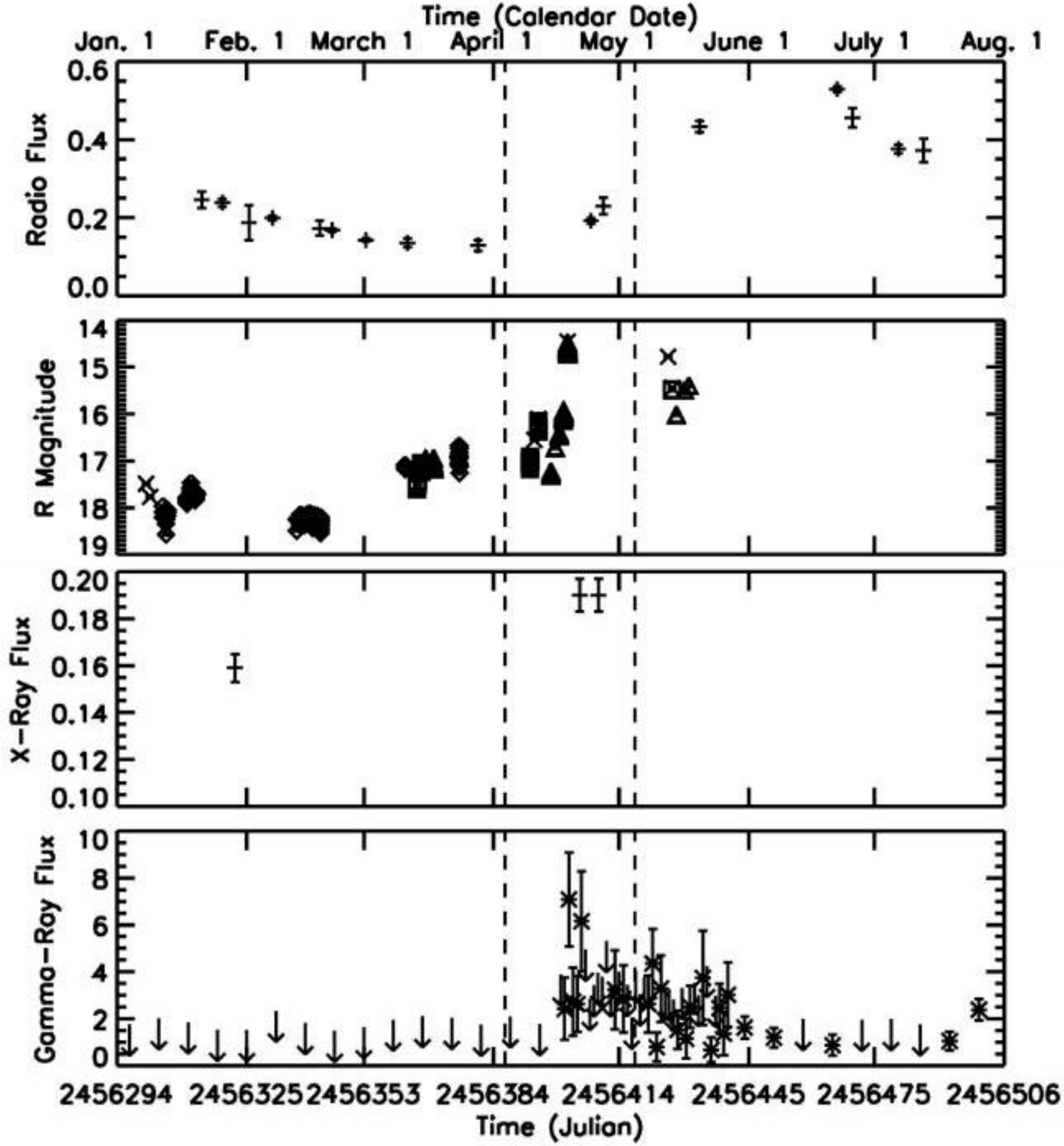
J0849+5108



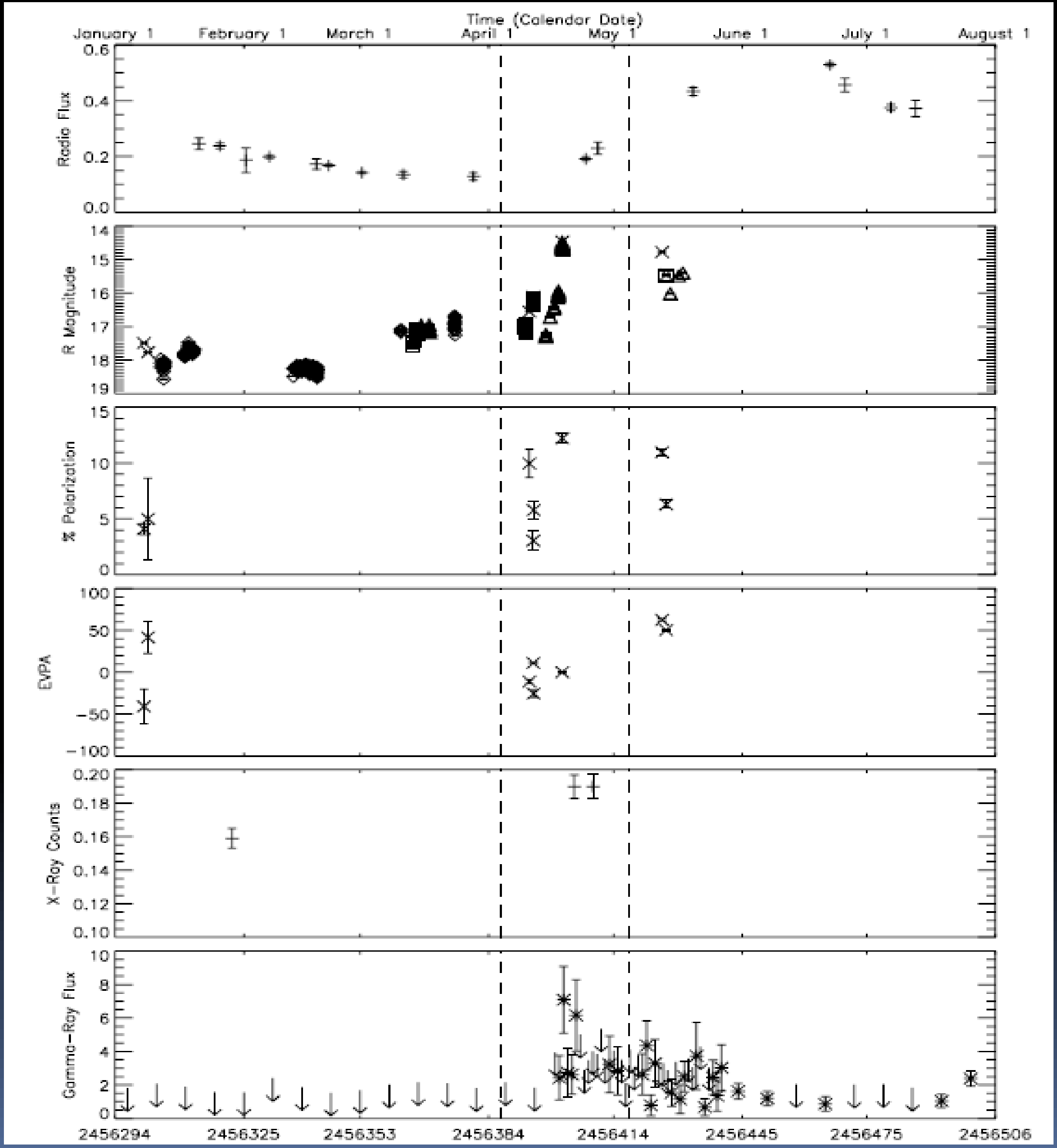
Maune, Eggen , Miller et al 2014



J0849+5108
Time (Calendar Date)
2013-04-19.10
2013-04-19.15
2013-04-19.20
2013-04-19.25
2013-04-19.30
Magnitude
14.3
14.4
14.5
14.6
14.7
14.8
2456401.60
2456401.65
2456401.70
2456401.75
2456401.80
Time (Julian Day)



Maune, Eggen, Miller,et al., 2014


Time (Calendar Date)
January 1
February 1
March 1
April 1
May 1
June 1
July 1
August 1
Radio Flux
R Magnitude
% Polarization
EVPA
X-Ray Counts
Gamma-Ray Flux
2456294
2456325
2456353
2456384
2456414
2456445
2456475
2456506

J0849+5108: SED at various

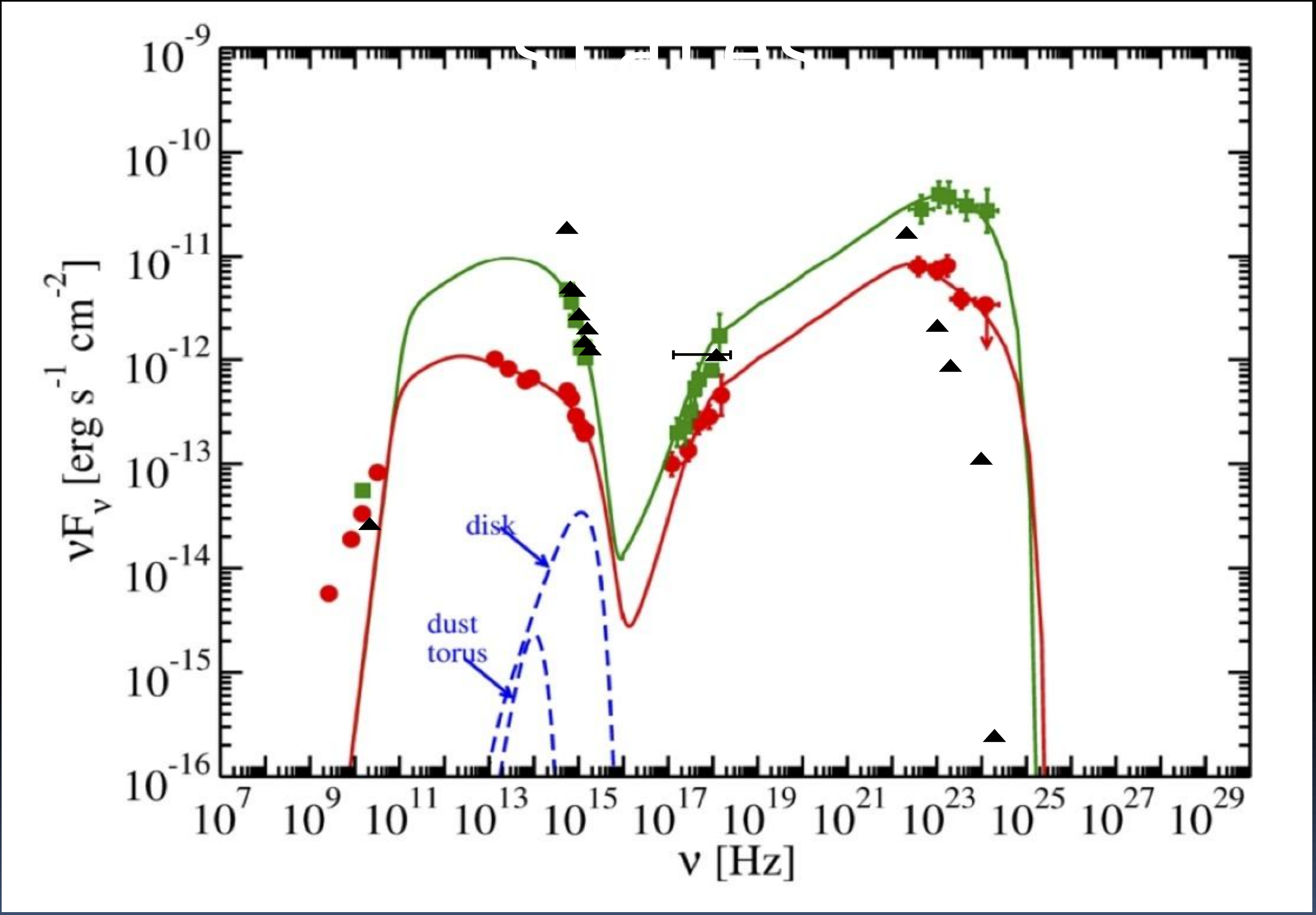
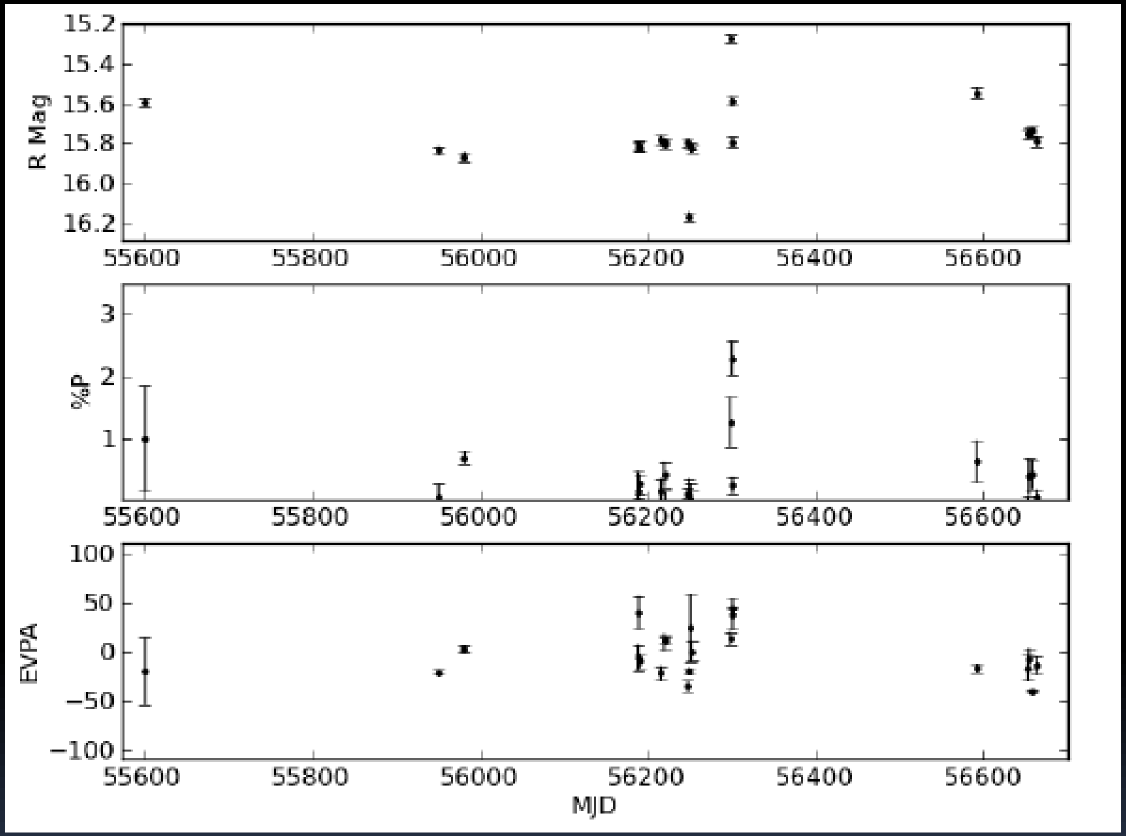
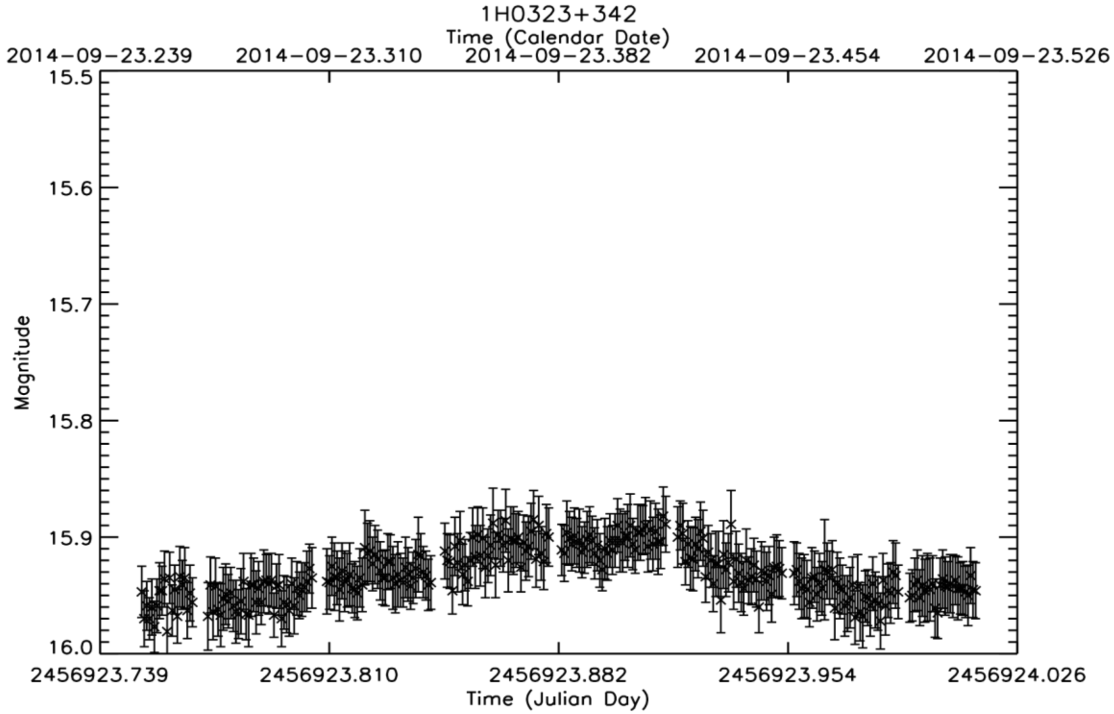


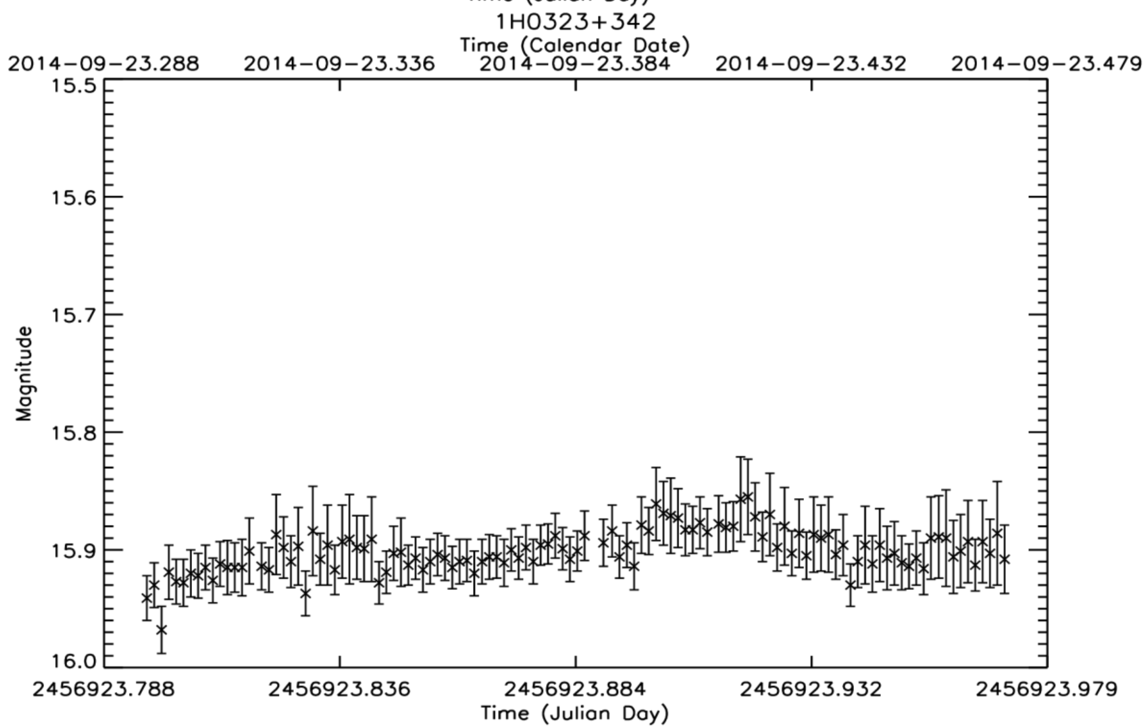
Figure taken from D'Ammando 2012.
Black triangles are new data from Maune et al. (2014)

1H 0323+342

- Paliya et al. (MNRAS, 428, 2450,2013)
  - Microvariations
- Paliya et al.(ApJ, 789, 143, 2014)
  - Microvariations
  - Rapid gamma-ray variability(3hr /3x-time)

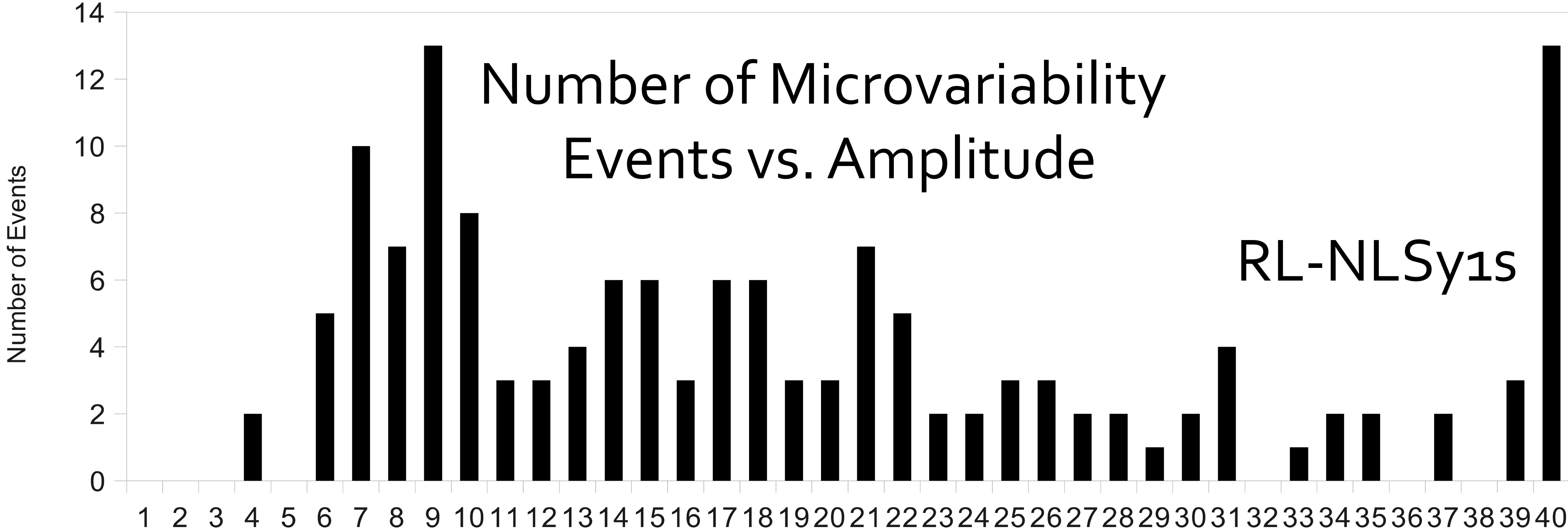

15.2
15.4
15.6
15.8
16.0
16.2
R Mag
55600
55800
56000
56200
56400
56600
3
2
1
%P
100
50
0
−50
−100
EVPA
MJD

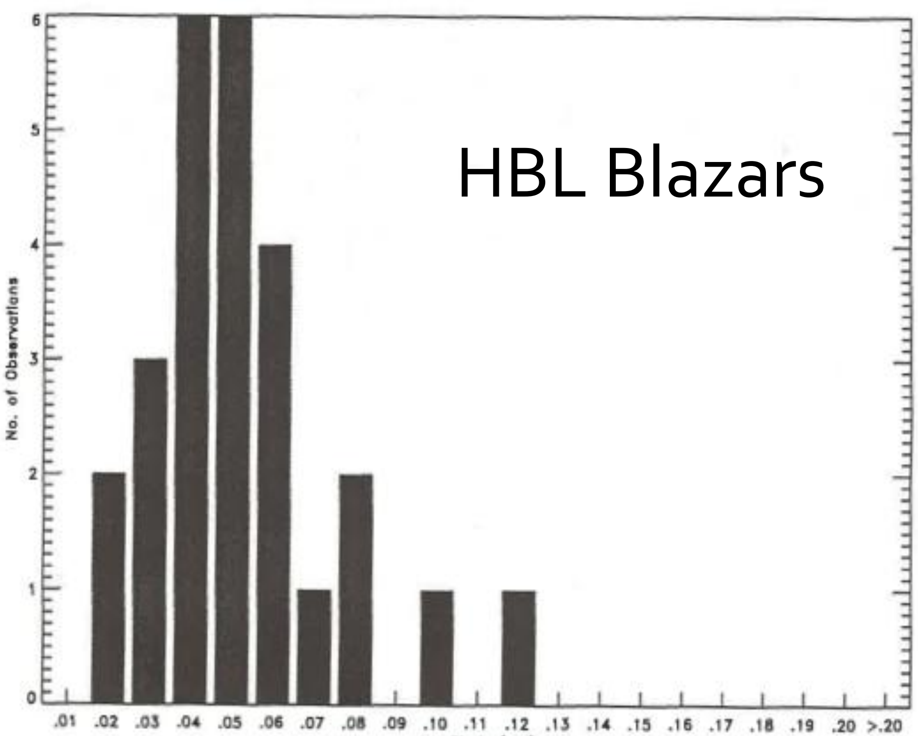

1H0323+342
Time (Calendar Date)
2014-09-23.239
2014-09-23.310
2014-09-23.382
2014-09-23.454
2014-09-23.526
Magnitude
15.5
15.6
15.7
15.8
15.9
16.0
2456923.739
2456923.810
2456923.882
2456923.954
2456924.026
Time (Julian Day)

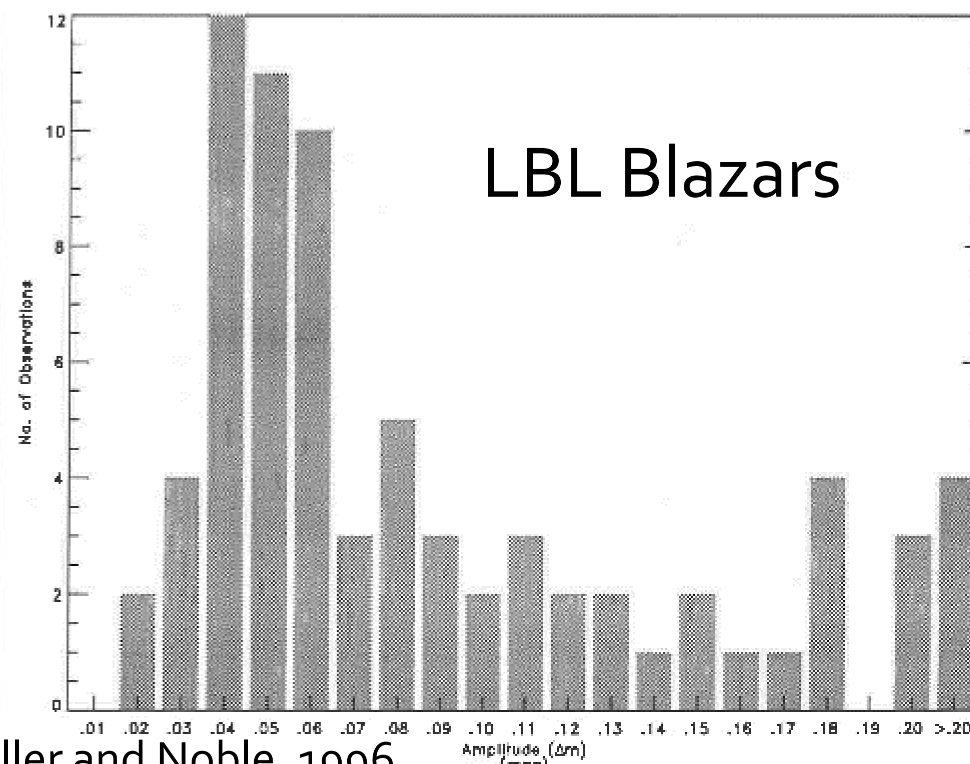

1H0323+342
Time (Calendar Date)
2014-09-23.288
2014-09-23.336
2014-09-23.384
2014-09-23.432
2014-09-23.479
Magnitude
15.5
15.6
15.7
15.8
15.9
16.0
2456923.788
2456923.836
2456923.884
2456923.932
2456923.979
Time (Julian Day)

Full Sample

- Microvariations/DC
- Polarization Variations
- Gamma Ray Detection





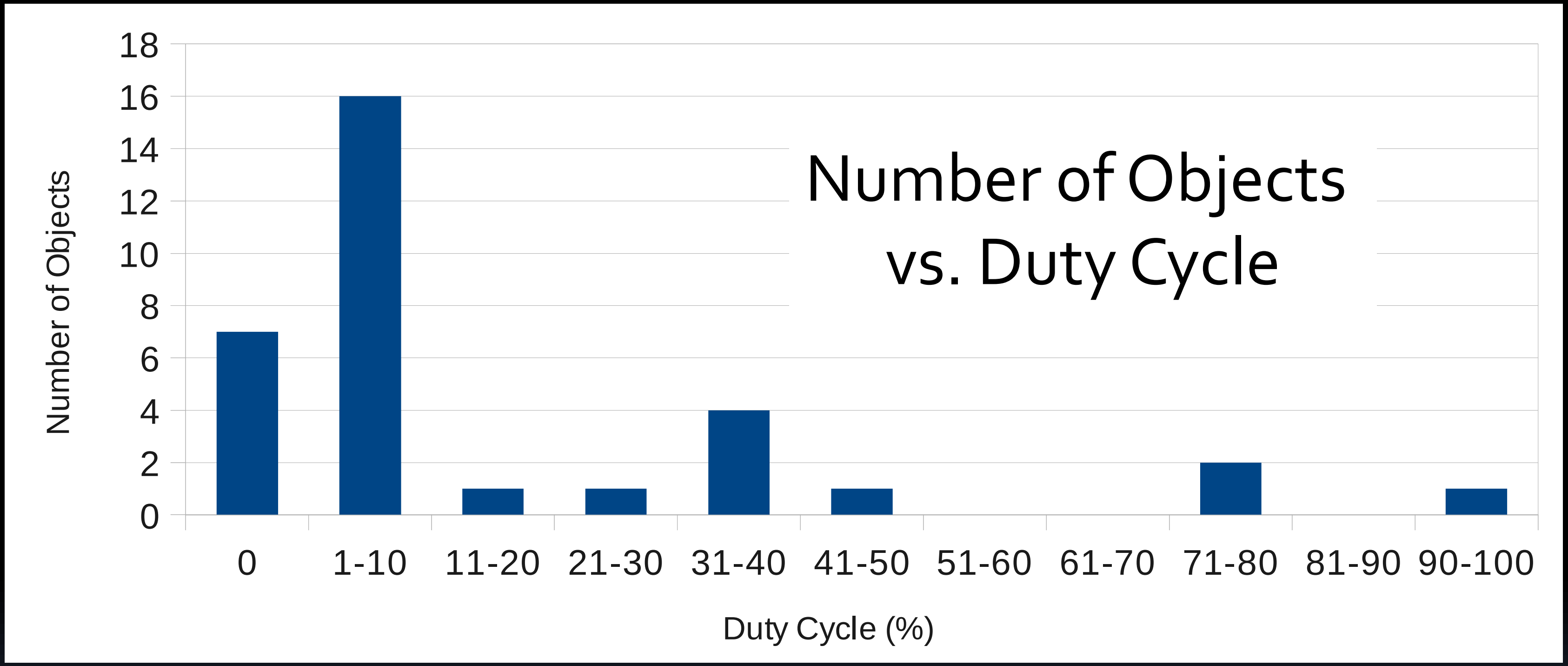


Figures from Miller and Noble, 1996

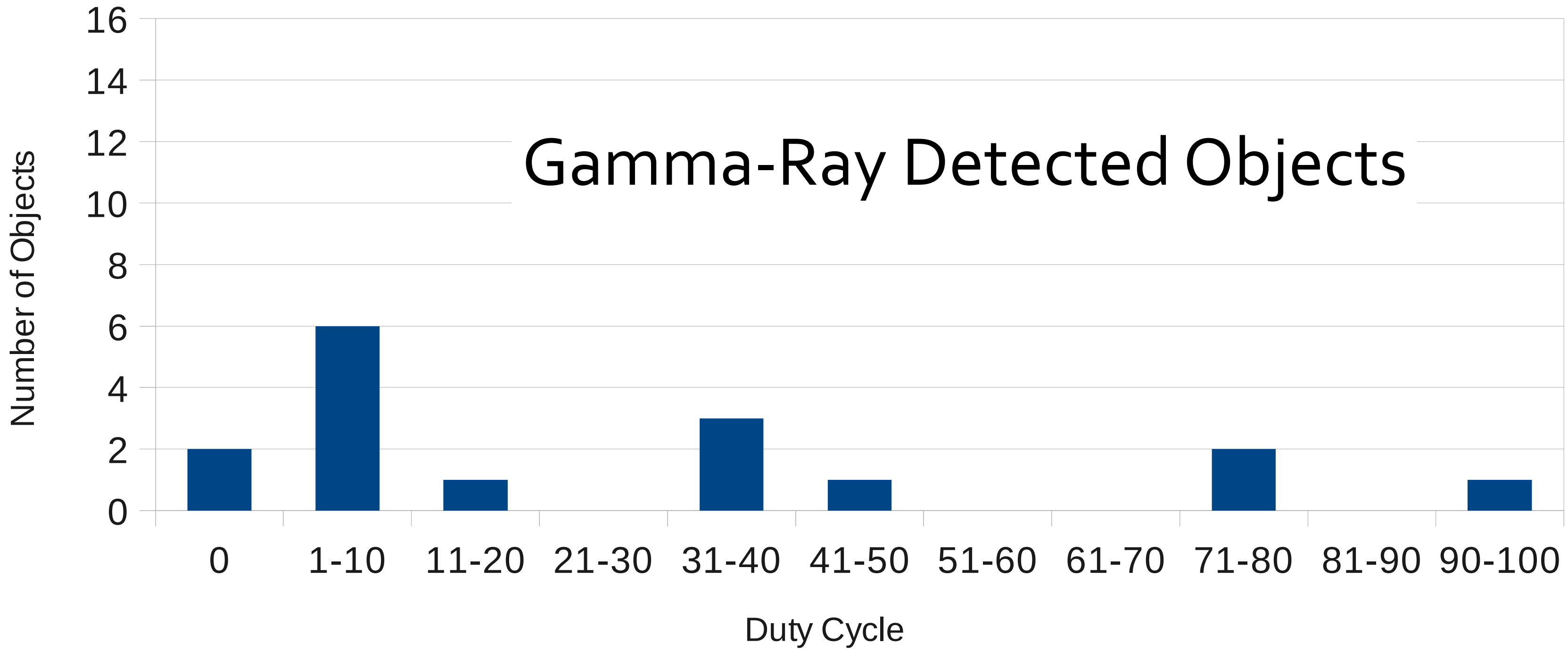
Microvariability: Duty Cycles

Source Type	Approximate Duty Cycle	Approximate Maximum Amplitudes Microvariability	Long-Term Variability
Radio Quiet NLSy1s	4%[1]	$\Delta m \sim 0.05$	$\Delta m \sim 1$
Radio Quiet Quasars	10%[2]	$\Delta m \sim 0.10$	$\Delta m \sim 1$
Radio-Loud Quasars	19%[2]	$\Delta m \sim 0.10$	$\Delta m \sim 1$
HBL and TeV Blazars	45%[2]	$\Delta m < 0.15$	$\Delta m < 2$
LBL Blazars	80%[3]	$\Delta m > 0.20$	$\Delta m \sim 3$

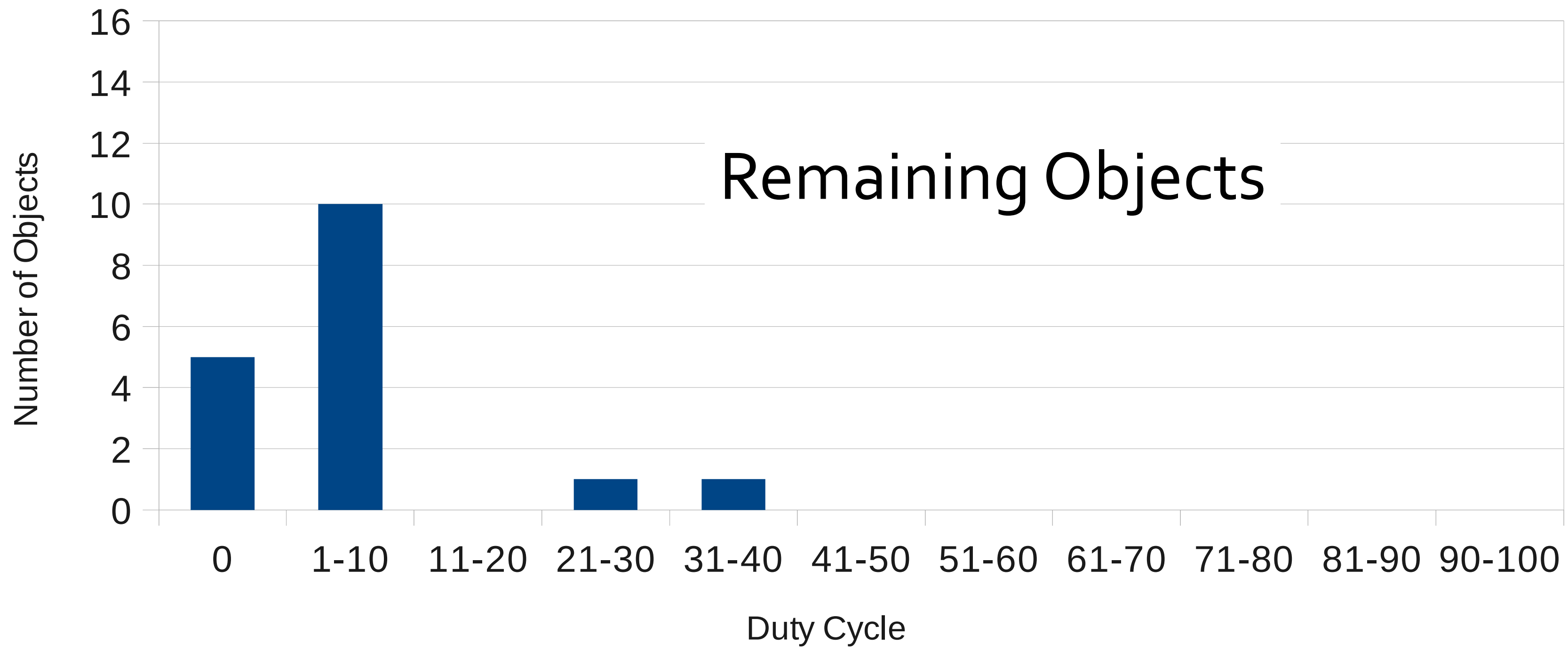
(1) (Ferrara, 2000), (2) Carini et al. (2003), (3) Miller and Noble (1996)



Number of Objects vs. Duty Cycle
Number of Objects
18
16
14
12
10
8
6
4
2
0
0
1-10
11-20
21-30
31-40
41-50
51-60
61-70
71-80
81-90
90-100
Duty Cycle (%)

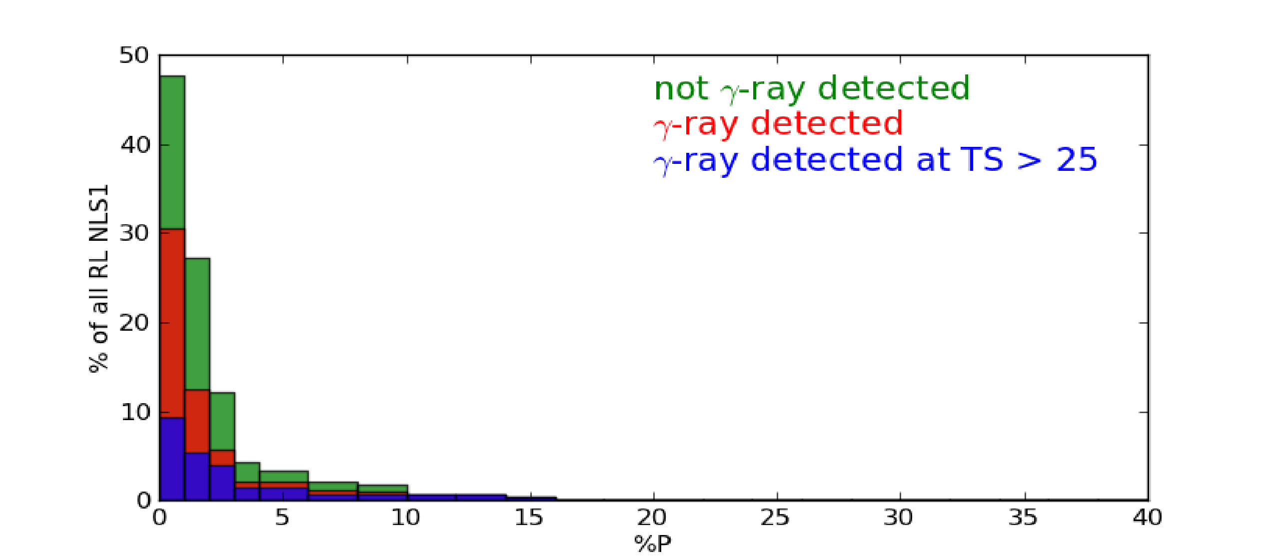


Gamma-Ray Detected Objects
Number of Objects
0
2
4
6
8
10
12
14
16
0
1-10
11-20
21-30
31-40
41-50
51-60
61-70
71-80
81-90
90-100
Duty Cycle



Remaining Objects
Number of Objects
0
2
4
6
8
10
12
14
16
0
1-10
11-20
21-30
31-40
41-50
51-60
61-70
71-80
81-90
90-100
Duty Cycle

Polarimetric Results – vRL NLS1 Galaxies



Conclusions

- Some (but not all) radio-loud narrow line Seyfert 1s show blazar-like optical variability
  - Radio loudness is a poor indicator
  - Gamma-ray detection is likely required for blazar-like variability.
- Microvariability, DC and polarization are consistently LBL-like when detected.
- J0948+0022 variability suggests that source of optical emission is a extremely compact region.

Sample from Yuan et al.(2008)

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J0723+5054	07:23:02.33	50:54:48.00	0.203	1.29
J0744+5149	07:44:02.28	51:49:17.50	0.460	1.62
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J1102+2239	11:02:23.383	22:39:20.686	0.453	1.28
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J1146+3236	11:46:54.289	32:36:52.384	0.465	2.19
J1227+3214	12:27:49.14	32:14:59.00	0.137	2.16
J1246+0238	12:46:50.20	02:40:16.00	0.091	2.38
J1333+4141	13:33:45.469	41:41:27.656	0.225	1.06
J1358+2658	13:58 45.371	26:58:08.483	0.330	1.11
J1405+2657	14:05:04.803	26:57:27.539	0.713	1.09
J1421+2824	14:21:14.057	28:24:52.899	0.538	2.14
J1435+3132	14:35:09.502	31:31:47.971	0.502	2.98
J1443+4725	14:43:18.558	47:25:56.663	0.703	3.03
PKS 1502+036	15:05:06.477	03:26:30.796	0.411	3.53
RX 16290+4007	16:29:01.306	40:07:59.941	0.272	1.61
J1633+4718	16:33:23.57	47:18:58.83	0.116	2.19
J1644+2619	16:44:42.534	26:19:13.305	0.145	2.73
B3 1702+457	17:03:30.41	45:40:47.08	0.061	2.01
J1709+2348	17:09:07.810	23:48:37.760	0.254	1.06
J1713+3523	17:13:04.462	35:23:33.646	0.083	1.05
IRAS 20181-2244	20:21:04.064	-22:35:25.775	0.185	1.57
J2314+2243	23:14:55.89	22:43:22.69	0.169	1.25

Object ID	R.A.	Dec.	log(R)	Bin #	TS	Flux(err)
1H 0323+342	51.2096	34.143	2.50	53	280.31	36.19(2.73)
J0849+5108	132.492	51.1414	3.16	35	790.76	26.34(2.20)
J0948+0022	147.221	0.349773	2.93	53	402.14	39.81(2.32)
J0956+2515	149.208	25.2545	3.56	20	95.95	10.24(2.34)
J1443+4725	220.827	47.4324	3.03	49-53	27.81	1.49(0.06)
PKS 1502+036	226.292	3.40703	3.53	43	36.60	9.58(2.71)
J1644+2619	251.177	26.3204	2.73	46-50	52.25	4.24(1.04)
PKS 2004-447	301.98	-44.579	3.80	13-24	53.77	2.26(0.52)

Object ID	R.A.	Dec.	log(R)	Bin #	TS	Flux(err)
J0100-0200	15.1342	-2.01278	1.77	8	9.65	5.87(0.56)
				25	9.52	3.17(2.23)
J0706+3901	106.605	39.031	1.21	23	10.30	0.76(.15)
				66	10.50	1.10(0.36)
J0804+3853	121.038	38.8969	1.18	34-36	10.77	8.49(0.15)
J1102+2239	165.597	22.6558	1.28	15-20	14.57	1.29(0.81)
J1146+3236	176.726	32.6145	2.19	5	12.61	3.58(1.66)
J1246+0238	191.709	2.67123	2.38	55-66	17.13	1.58(0.60)
J1713+3523	258.269	35.3926	1.05	22	12.03	6.21(0.23)
IRAS 20182-2244	305.268	-22.5884	1.57	9	9.42	2.24(1.89)
J2314+2243	348.732	22.7236	1.25	50	11.59	5.05(2.54)

Best Candidate Objects

- Gamma Ray (9<TS<25)
- Optical Variability (including microvariations)
- Strong and Variable Optical Polarization

Best Future Gamma-Ray Candidates

- J0100-0200
- J0804+3853
- J1102+2239
- J1146+3236
- IRAS 20182-2244

(Foschini et al.(2016) recently confirmed 1443+47*,1644+26, and 2314+22*)

Who is Alan Marscher?

- Theorist? or Observational Astronomer?
- Teacher? or Administrator?
- Colleague? and Friend?
- All of the above!
    - HAPPY BIRTHDAY ALAN!!