Measuring and Modelling Variability in Quasars and Blazars

Paul Wiita

TCNJ THE COLLEGE OF NEW JERSEY

Extragalactic Relativistic Jets, 16 October 2015

Outline

- Light Curves from the Ground optical and radio telescopes in India, Bulgaria, Japan, Greece, USA (some of these have been discuss
- Light Curves from Space with X-ray (XMM-Newton, RXTE) and optical (Kepler) telescopes: will focus on Kepler
- Models of Variability: Turbulence and Bulk Changes

Main Collaborators:

Gopal-Krishna, Haritma Gaur, Arti Goyal (NCRA/TIFR)

Alok Gupta, Aditi Agarwal, Bindu Rani (ARIES)

Ann Wehrle (SSI), Stephen Unwin (JPL)

Mitchell Revalski, Victoria Calafut, Dawid Nowak,

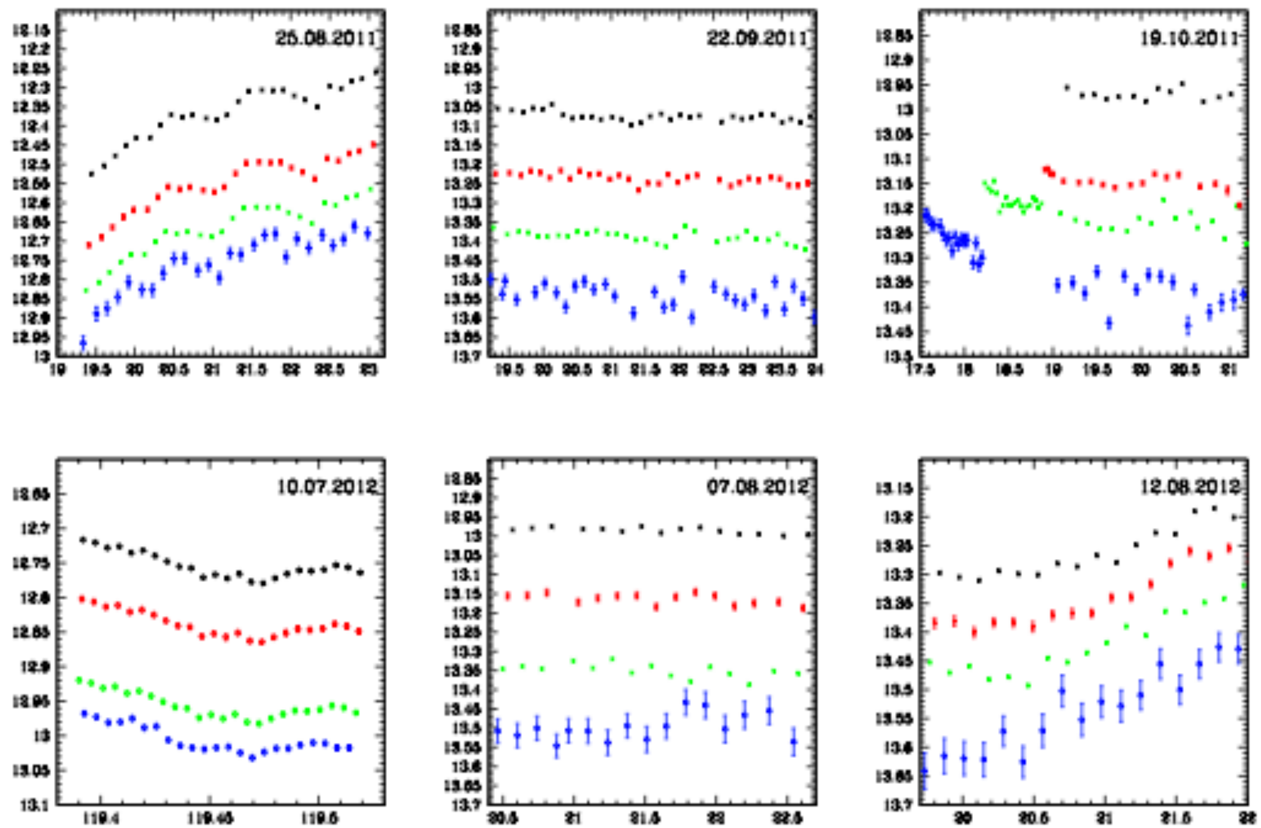
Maxwell Pollack, David Pauls, Paolo DiLorenzo,

Daniel Silano, Daniel Sprague (TCNJ)

Supported in part by NASA grants:

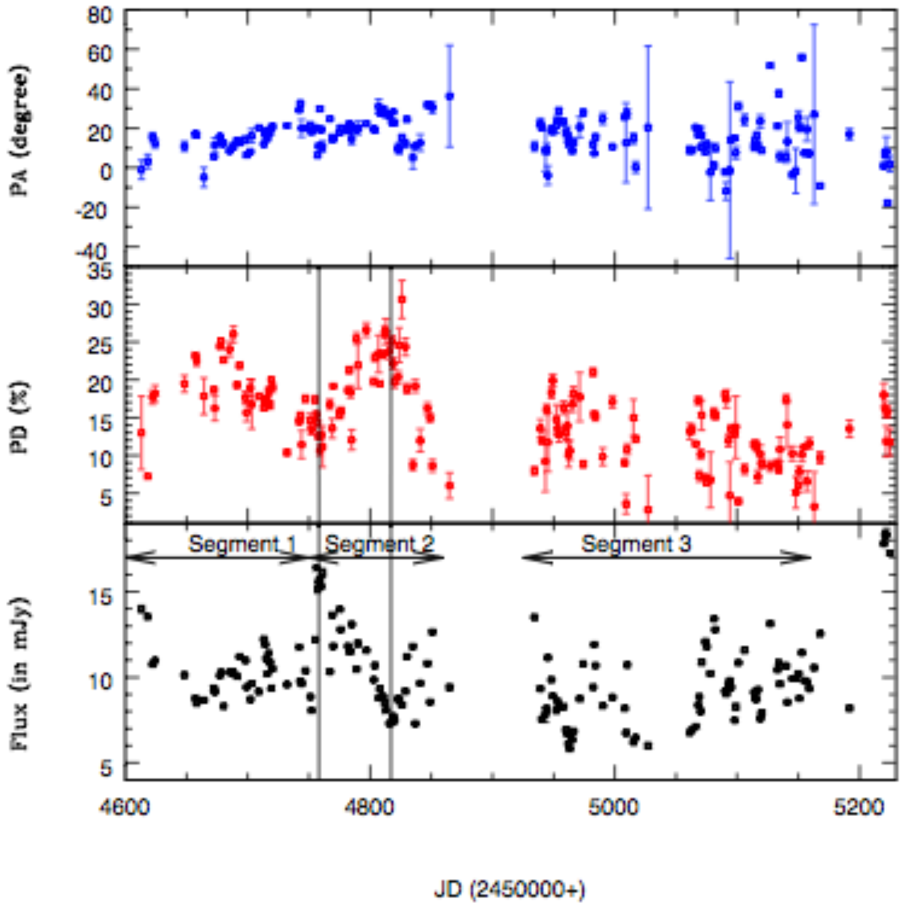
NNX11B90G, NNX12AC83G

Ground Based Blazar Observations



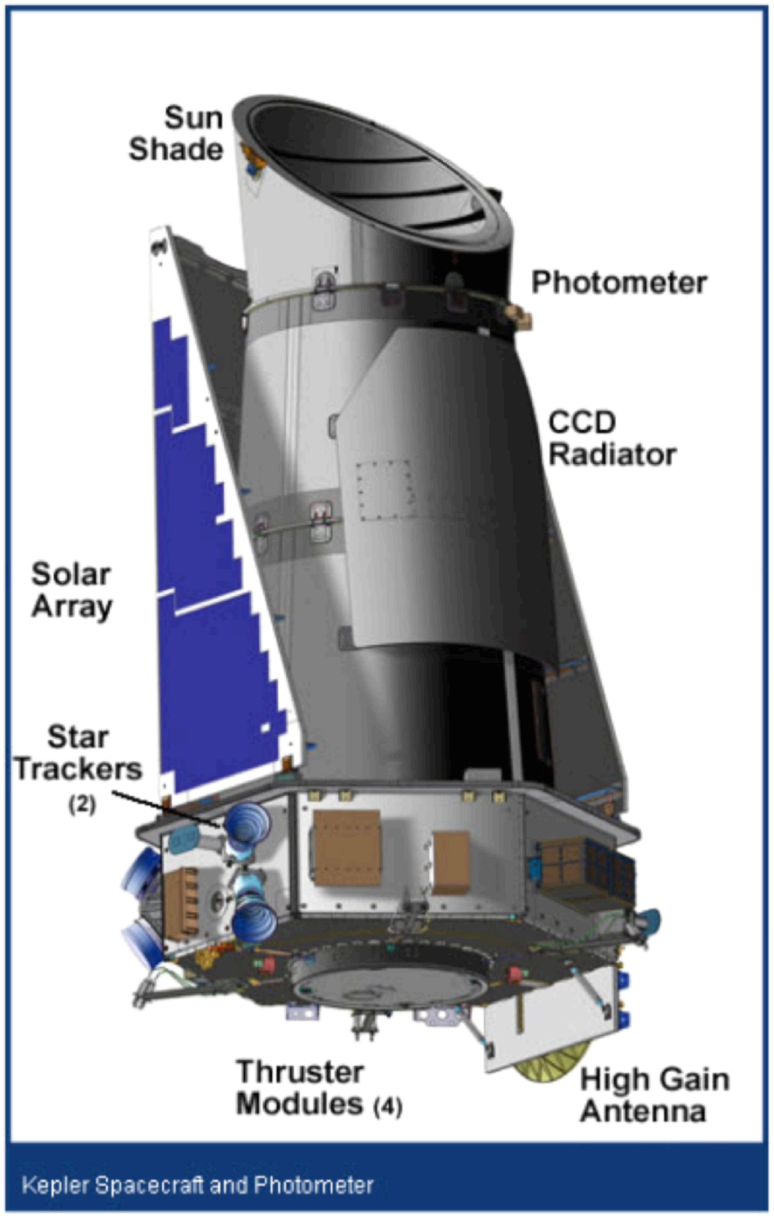
- BL Lac in 2011 and 2012 in B,V,R,I (Gaur et al. 2015b,
- MNRAS, 452, 4263)

Optical Polarization Variations



- V band LC of BL Lac between 5/2008 and 1/2010 (bottom)
- Polarization angle (top)
- Percentage pol (mid)
- Flux anti-correlated with pol percentage
- Implies two emission regions, with more variable having polarization~perpendicular to the more stable.

Gaur et al. (2014, ApJ, 781, L4)



From Space, with Kepler

- NASA Satellite: 0.95 m
- Earth-Trailing Orbit
- High Precision Photometric Data (<10^{-5} for 10^{th} mag)
- Designed to search for earth-sized Exoplanets

How We Use Kepler

- Study the few suspected blazars in its fields
- Kepler Guest Observer (GO) Program grants
- Data Downloaded each Quarter
- Advantages:
  - High Precision CCD Cameras
  - Above Earth's Distorting Atmosphere
  - Continuous Data Sets
  - Long (30 min) and occasionally,
  - Short (1 min) Cadence Data

Our Original Kepler Targets: Flat Spectrum Radio-Loud Quasars

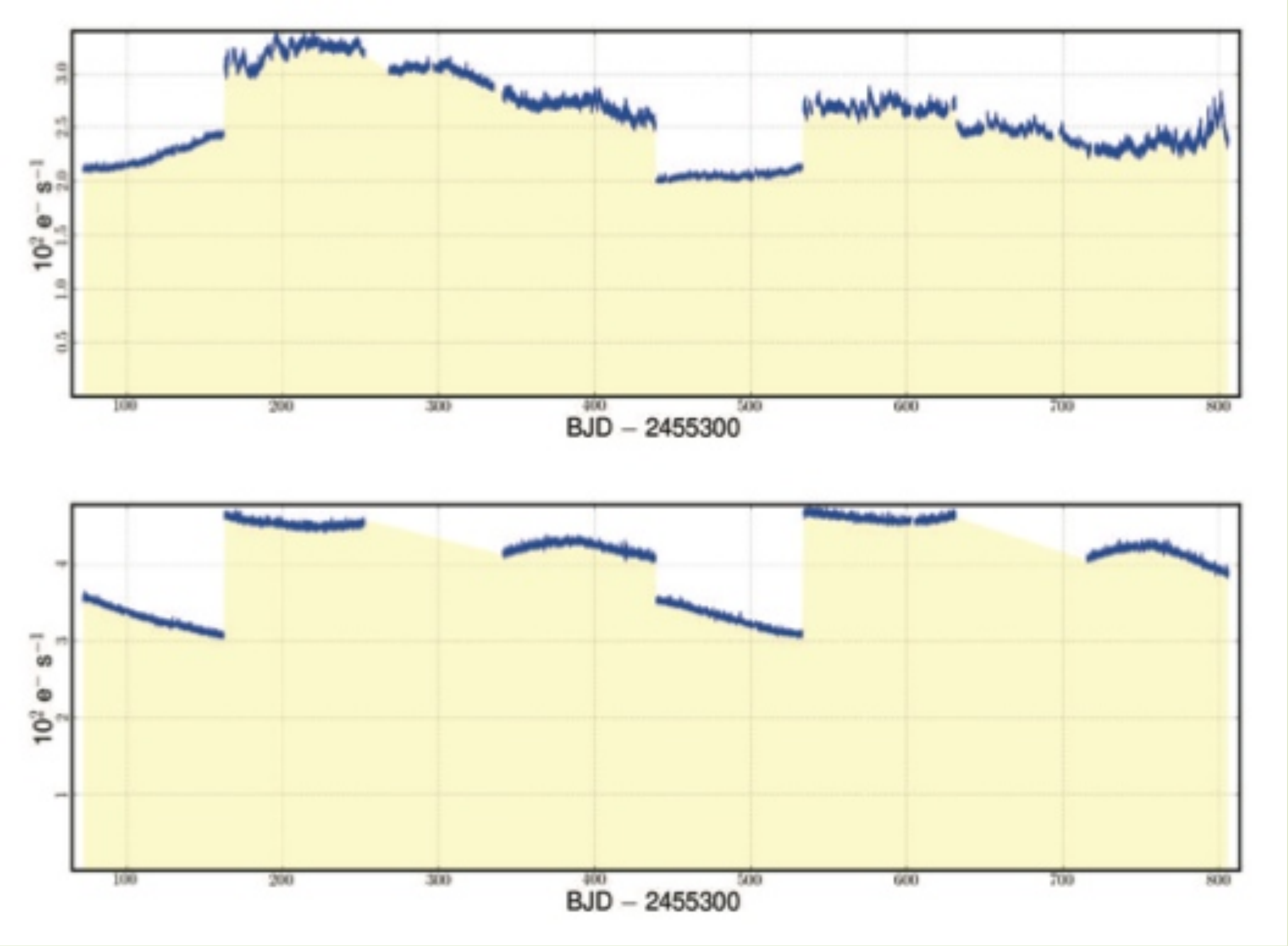
Table 1. Kepler AGN Monitoring Target List

Object Designation	Name	Kepler Input Catalog Number	Right Ascension (hh:mm:ss.s)	Declination (dd:mm:ss)	Kepler Input Catalog Magnitude	Redshift	Radio Spectral Index[a]
A	MG4 J192325+4754	10663134	19:23:27.24	47:54:17.0	18.6	1.520	0.32
B	MG4 J190945+4833	11021406	19:09:46.51	48:34:31.9	18.0	0.513	0.75
C	CGRaBS J1918+4937[b]	11606854	19:18:45.62	49:37:55.1	17.8	0.926	0.00
D	[HB89] 1924+507	12208602	19:26:06.31	50:52:57.1	18.4	1.098	0.19

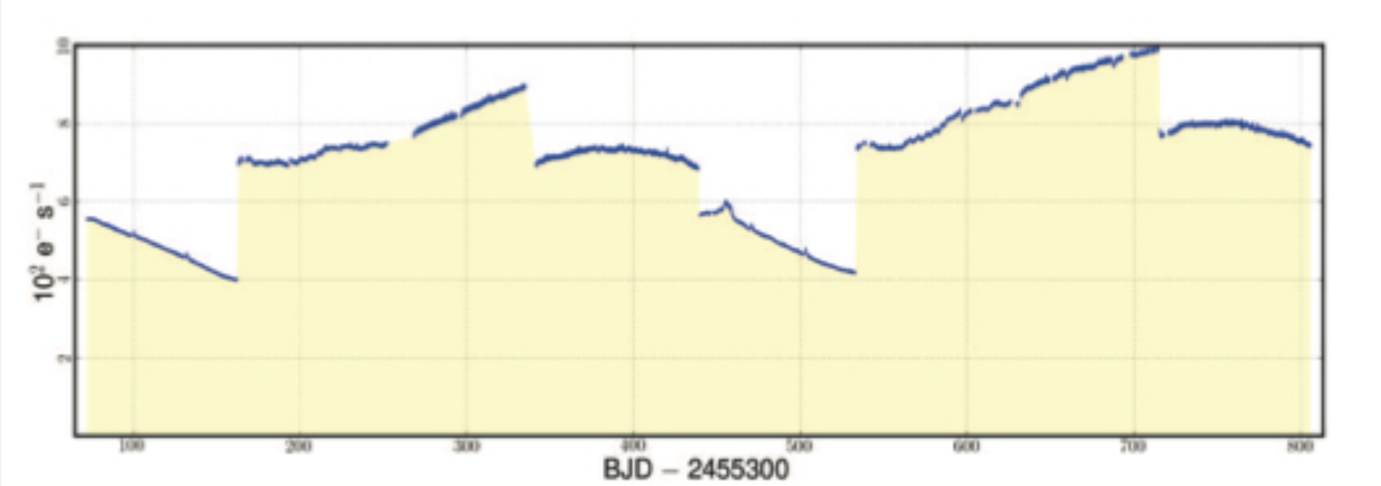
[a]Radio spectral index obtained from VLBA Calibrator website, defined between 2.3 and 8.3 GHz or 2.3 and 8.6 GHz with $S \propto \nu^{-\alpha}$

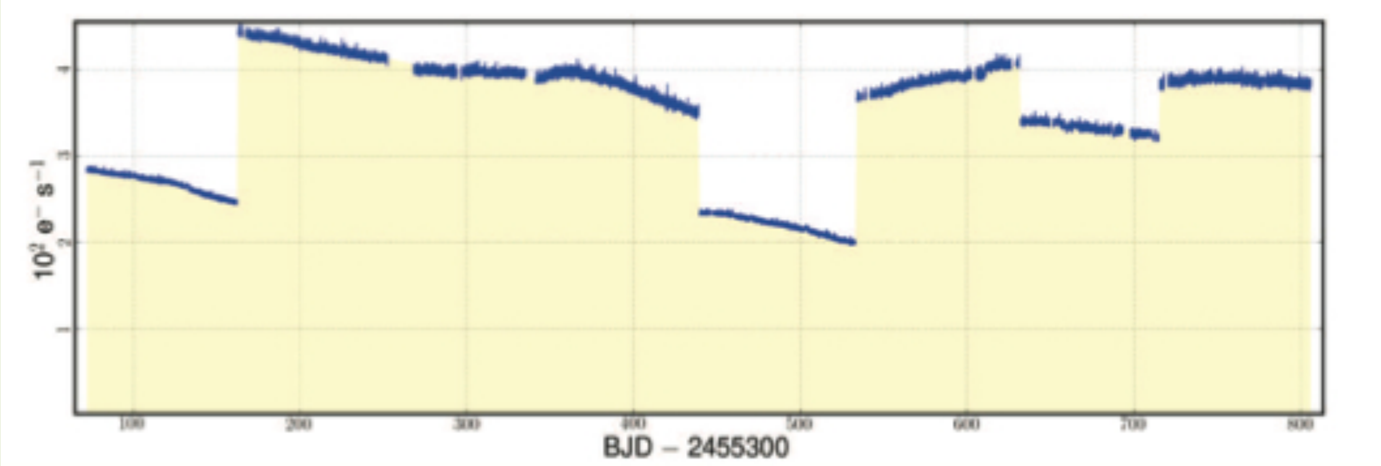
[b]Kepler Input Catalog incorrectly indicates that this target is a star with contamination 0.73, but we have verified it is an isolated quasar.

Light Curves: Quasars A & B for Quarters 6-13

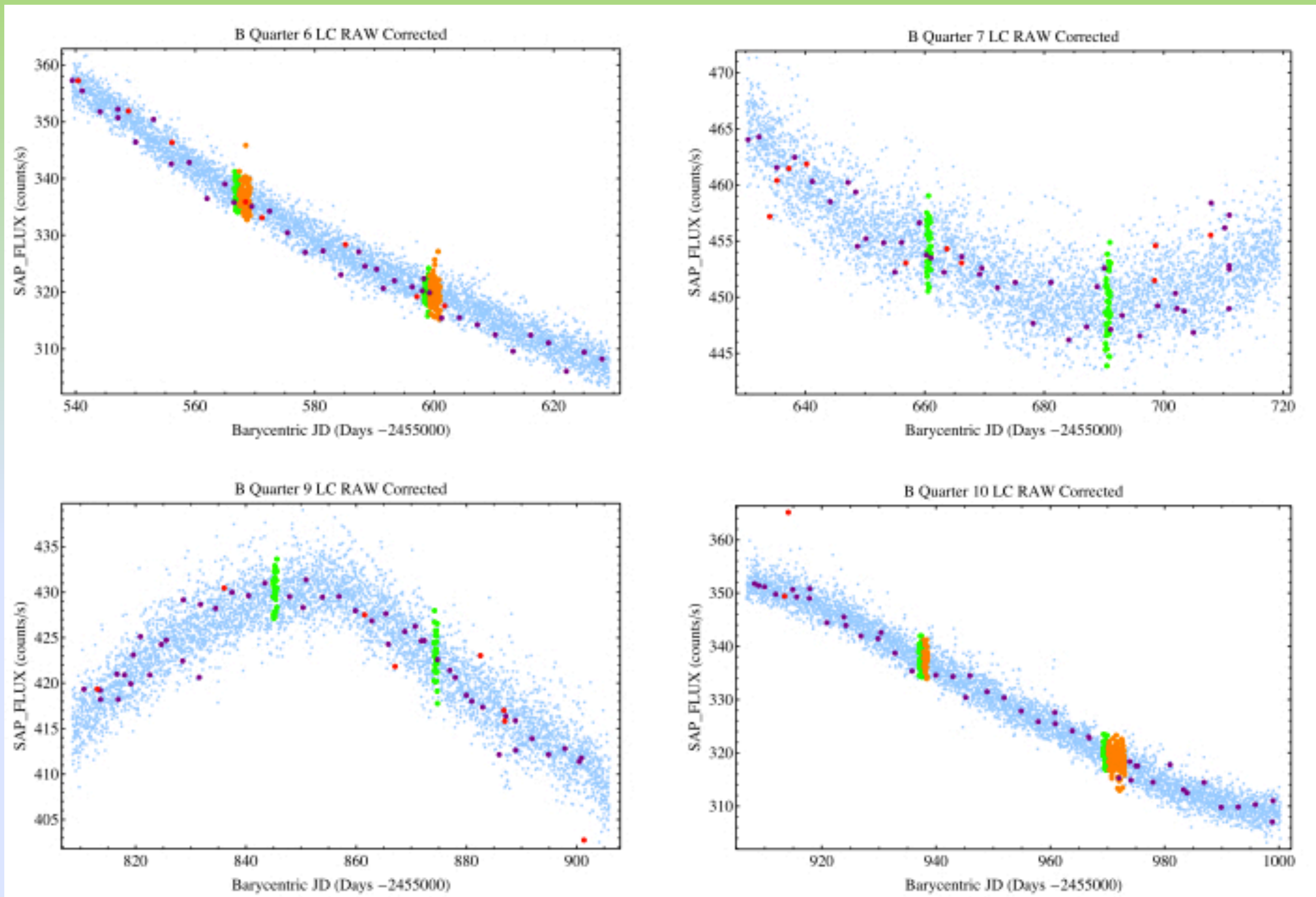


Light Curves: QSOs C & D



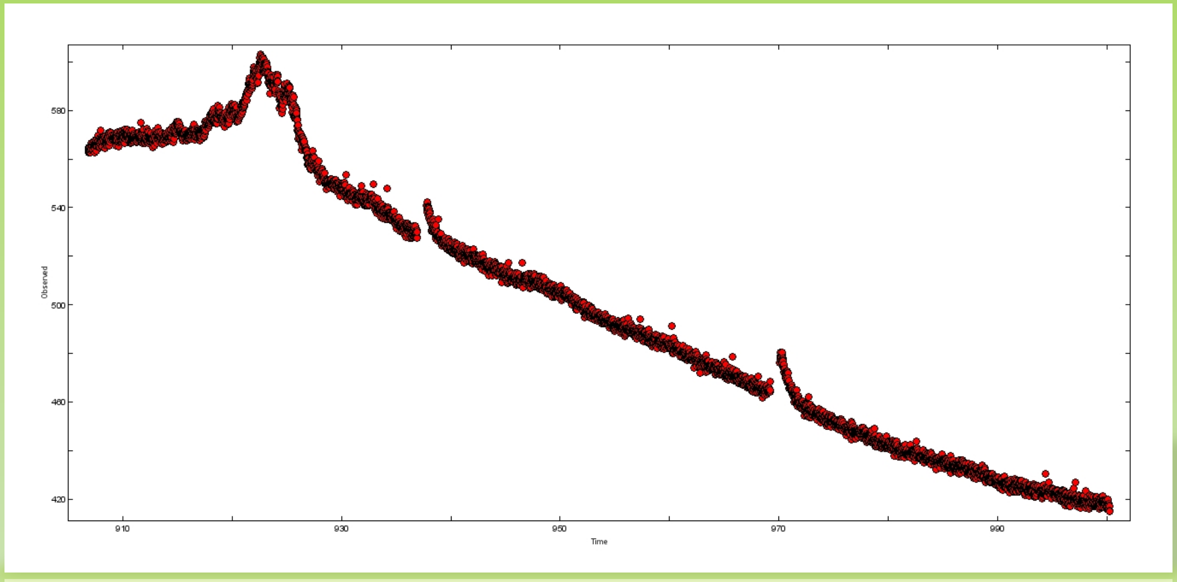


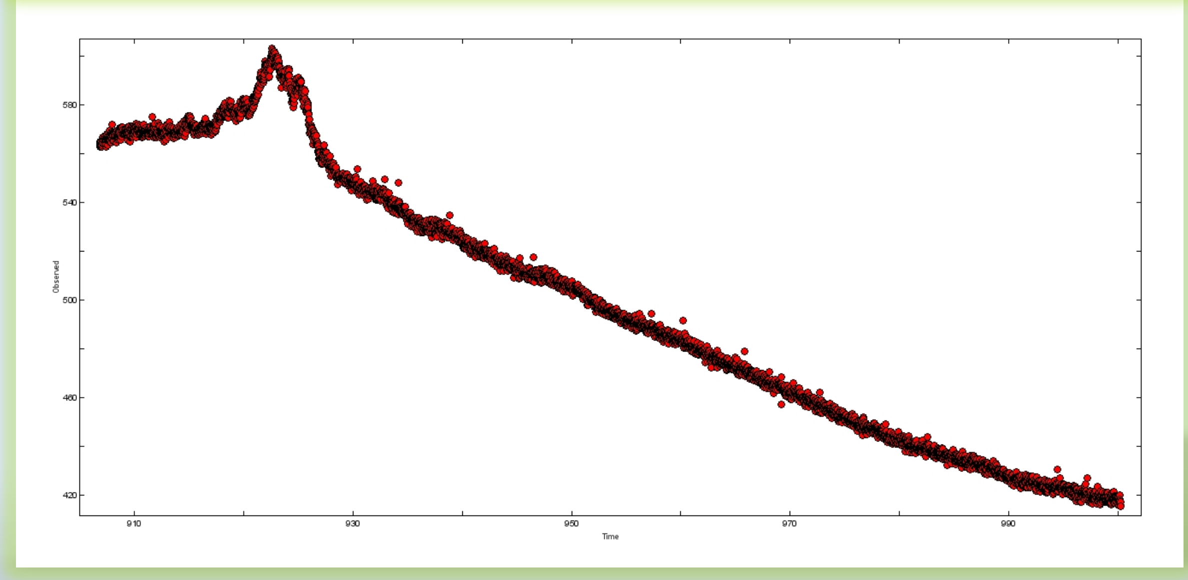
Some Corrected Light Curves



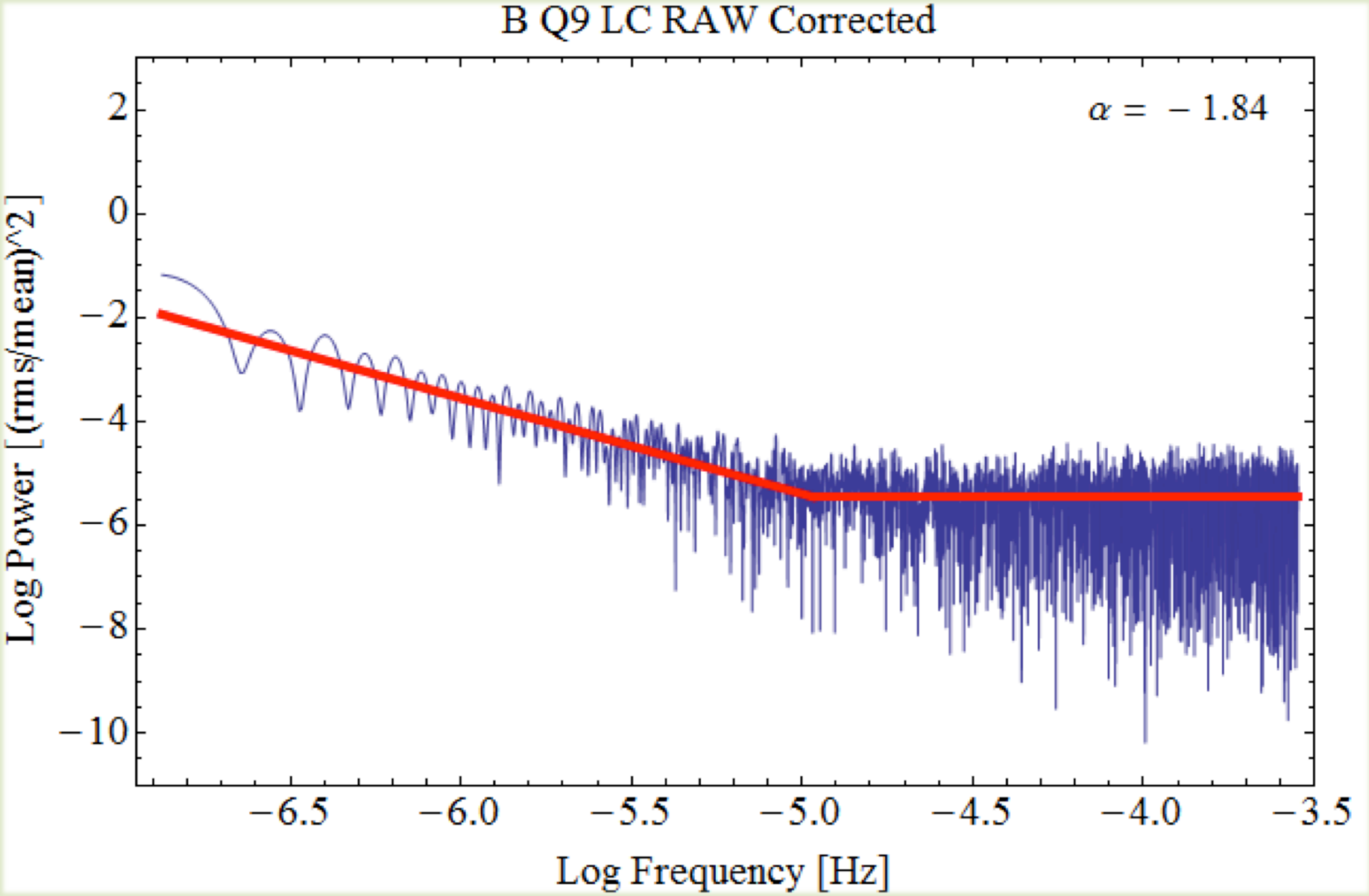
Object B, Quarters 6,7,9,10

Before and After (Object C, Q10)





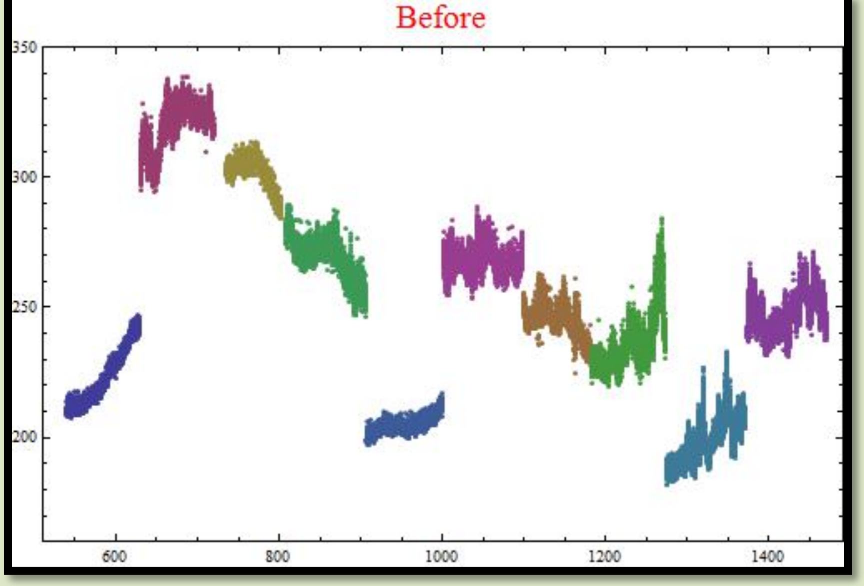
Power Spectral Density: Red noise to white

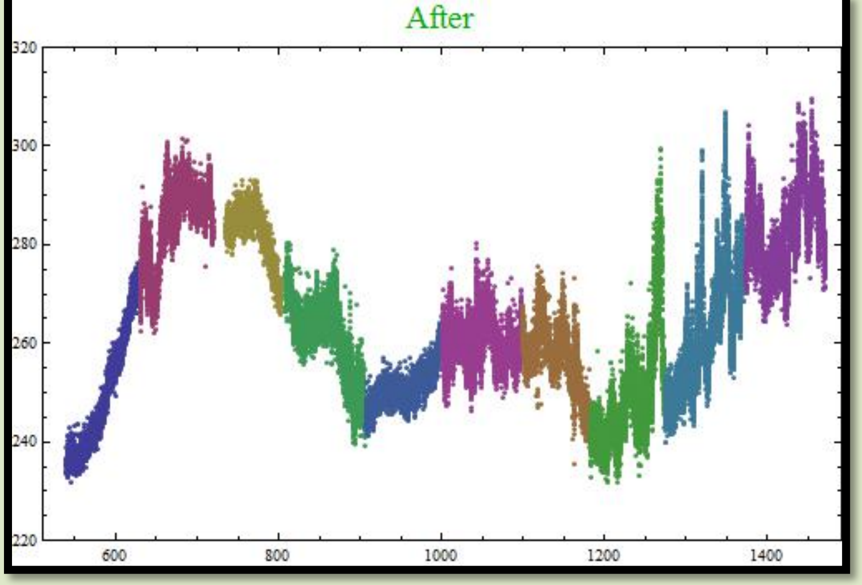


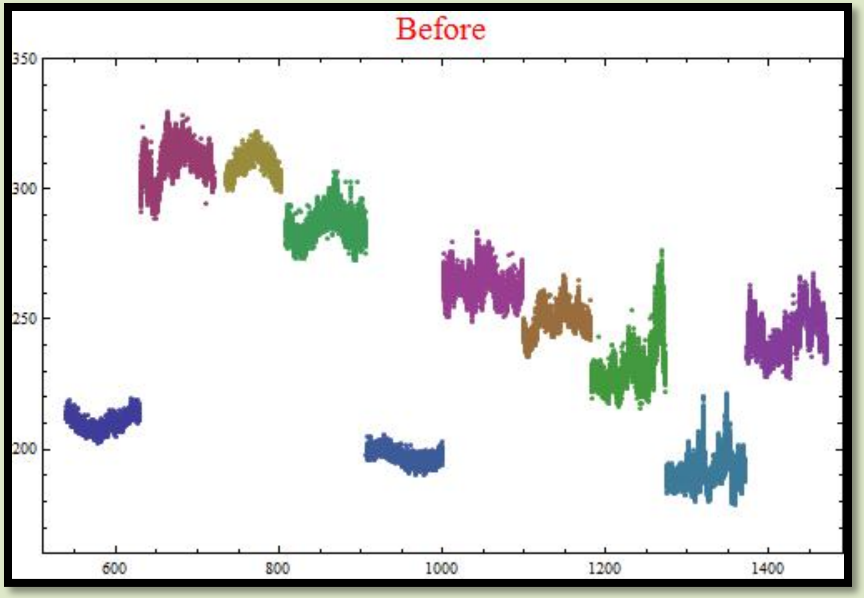
-6.9 to -5.9 = 90 to 9 days, -5.9 to -4.9 = 9 to .9 days,
-4.9 to -3.9 = .9 to .09

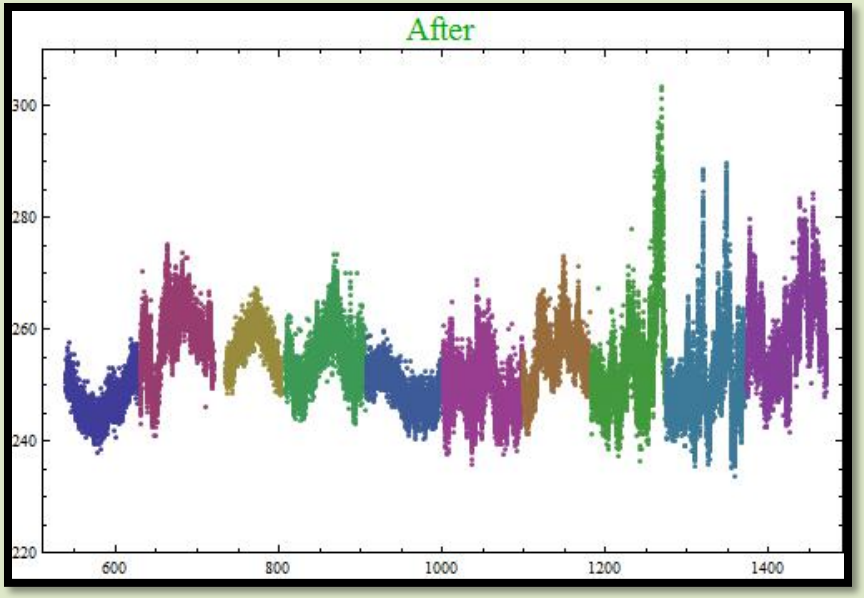
Quarter Stitching

- Extends data range, allows for searching of longer term variations at lower frequencies
- Quarterly data falling on various CCDs with differing sensitivities causes multiplicative offsets
- Programs written to remove major instrumental drifts and scale individual quarters to an average value

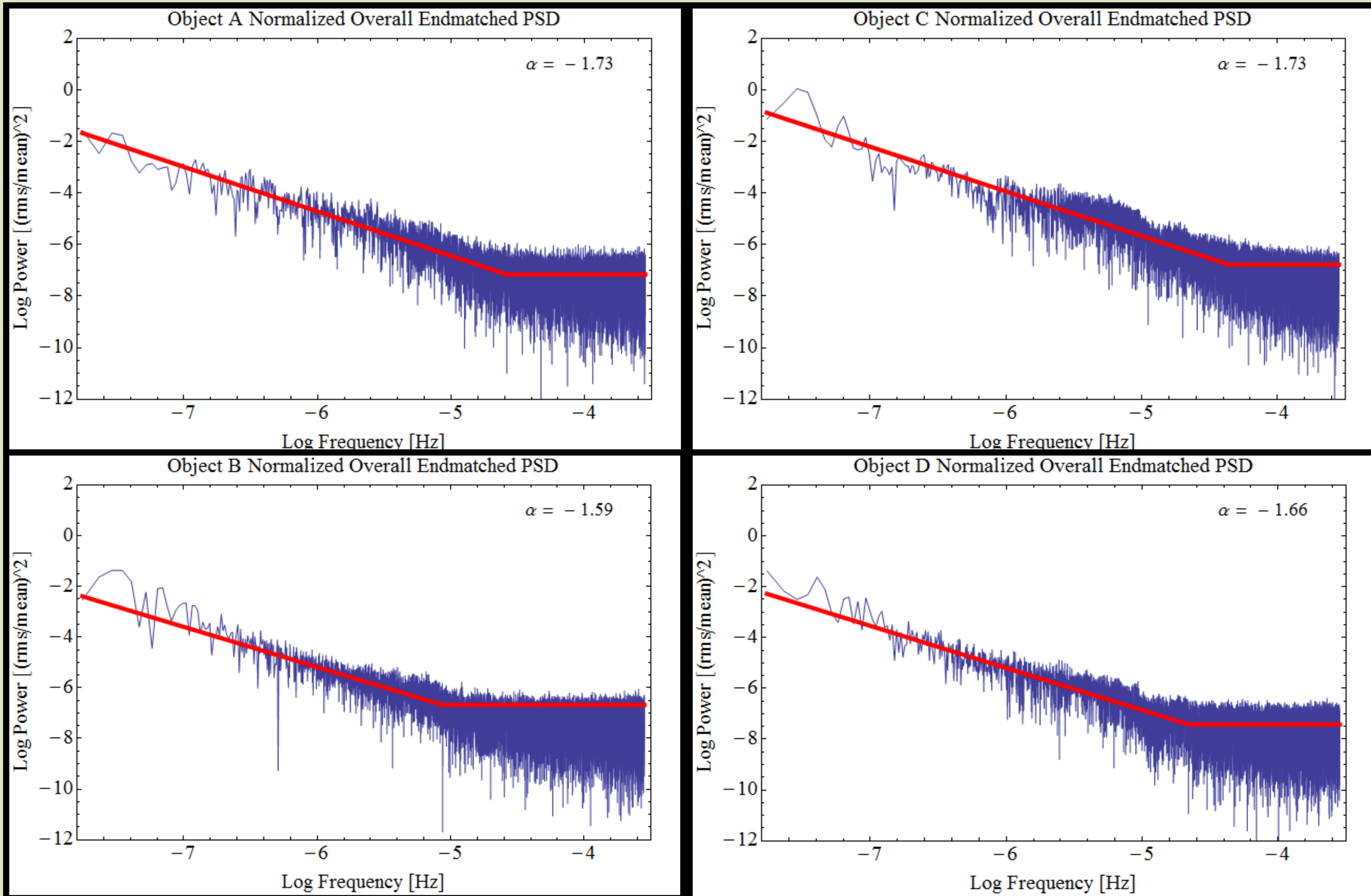

Before
350
300
250
200
600
800
1000
1200
1400


After
320
300
280
260
240
220
600
800
1000
1200
1400


Before
350
300
250
200
600
800
1000
1200
1400


After
300
280
260
240
220
600
800
1000
1200
1400

Kepler Power Spectral Densities



Our Kepler Results

Table 3. Power Spectral Density (PSD) Slopes for Q6-15 Stitched Together Data

	Original PSDs		Binned PSDs		Quarter 6-15 PSD Averages & Std Devs			
Object Name	Slope Original	Slope End-Match	Slope Original	Slope End-Match	Slope Original	Slope SD	Slope End-Match	Slope SD
A	-1.8	-1.7	-1.7	-1.6	-1.9	0.20	-1.7	0.27
B	-1.7	-1.6	-1.8	-1.9	-1.8	0.17	-1.4	0.30
C	-1.9	-1.7	-1.9	-1.8	-1.9	0.19	-1.9	0.20
D	-1.7	-1.7	-1.8	-1.8	-1.6	0.42	-1.3	0.30

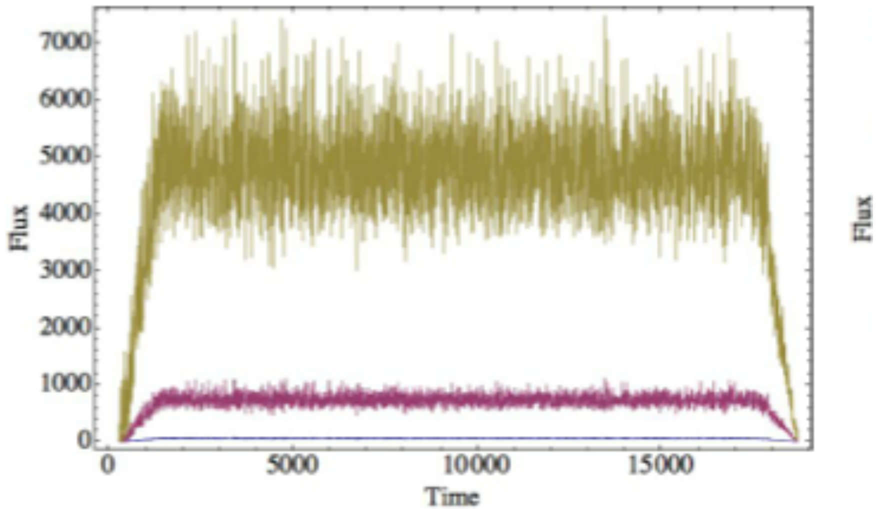
Kepler Conclusions

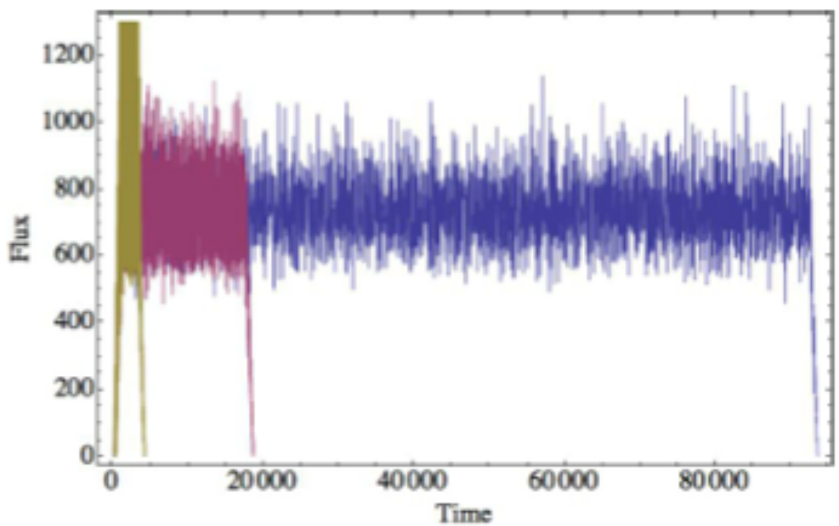
- Best sampled, high quality photometry available to date for active galaxy research
- Allows for probing of lower frequencies
- We obtain quasar PSDs with reasonable red-noise slopes, comparable to those of ground based optical observations and to X-ray observations of Seyferts
- Our methods appear to be appropriately combining the individual data sets
- No (quasi-)periodicities detected, unsurprisingly
- Three of our objects are in low activity states

Ongoing Kepler Work

- We can perform a similar analysis on new targets: we are collecting data for several brighter AGN
- But only for 80 days in the new Kepler fields
- Developed programs allow for quick processing
- Paper on results for Q6-13: Wehrle, Wiita, Unwin, Di Lorenzo, Revalski, Silano & Sprague, ApJ, 773, 89 (2013)
- Paper on Q14-16 and data stitching: Revalski, Nowak, Wiita, Wehrle & Unwin, ApJ, 785, 60 (2014)

Modeling Variability 1: Turbulent Relativistic Jets





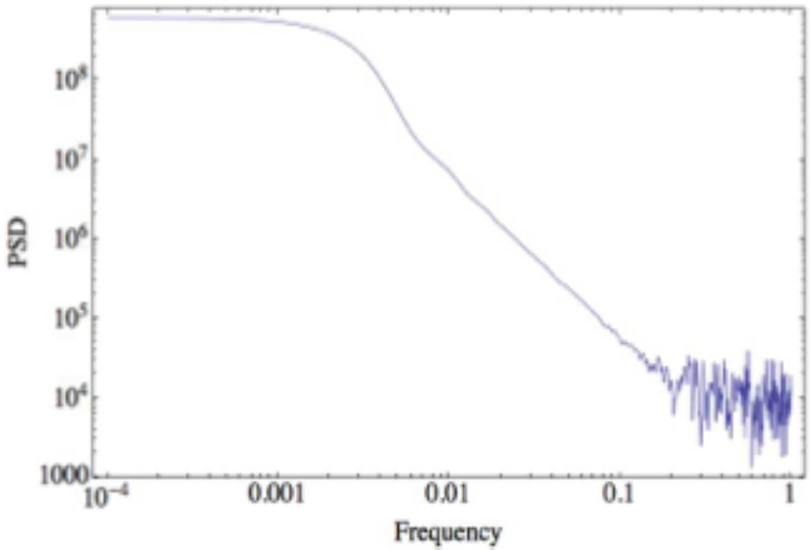
Calafut & Wiita (2015): relativistic turbulent spectrum (Zrake & MacFadyen 2013) compared with usual Kolmogorov. Modeled using 9 levels of embedded cells.

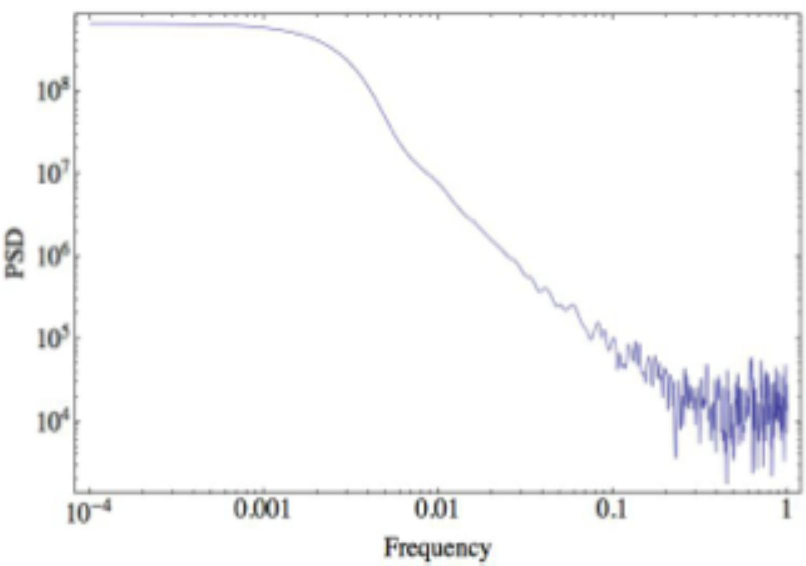
Top: V_b = .99c, V_t = 0.3c,
$\theta = 3^o, 10^o, 30^o$ (top to bottom)

Bottom: V_b = .99c, $\theta = 10^o$ for
V_t = 0.9c, 0.3c, 0.1c (L to R)

V_t > 0.6c $\Rightarrow$ bad light curves

Power Spectra of Turbulent Jets





Both for V_b = 0.99c and θ = 10^o all for the relativistic turbulence spectrum.

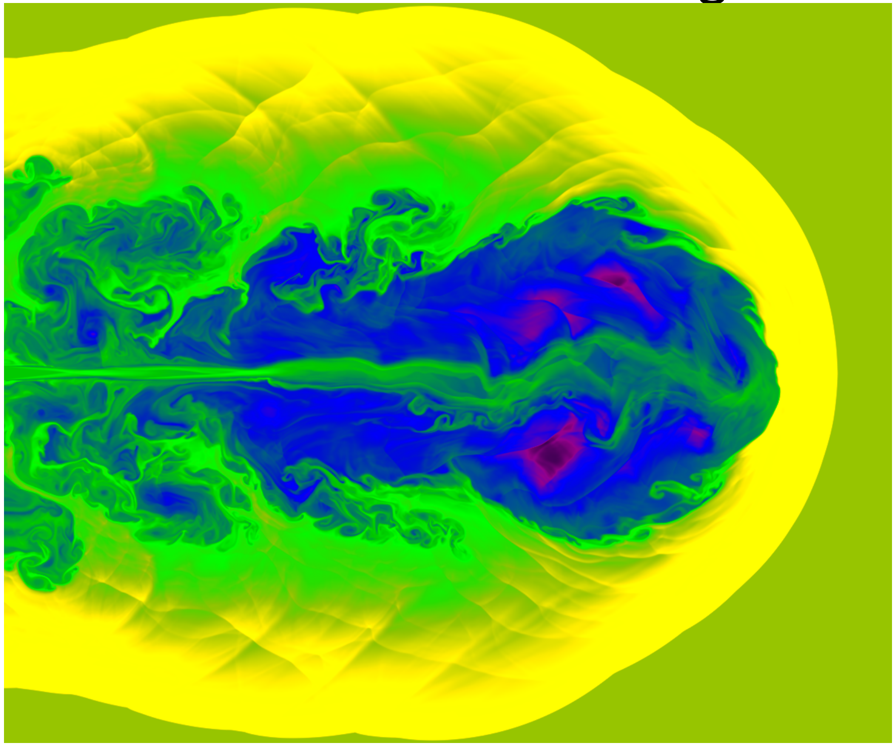
Top: V_t = 0.1c: red-noise slope, α = -2.15

Bottom: V_t = 0.6: α = -2.05

Reasonable agreement with data, but covers only 2 decades in frequency.

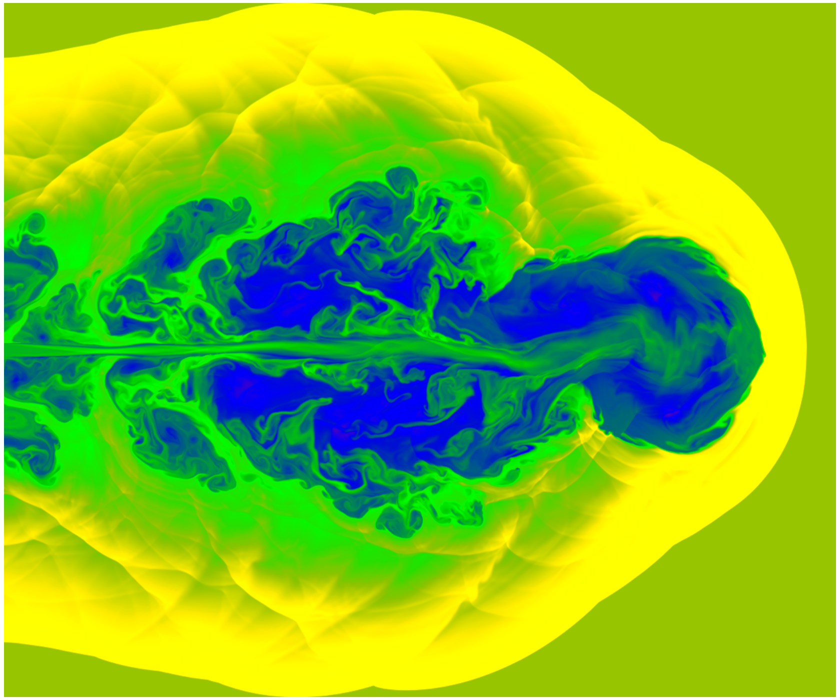
Modeling 2: Turbulence in Propagating Jets

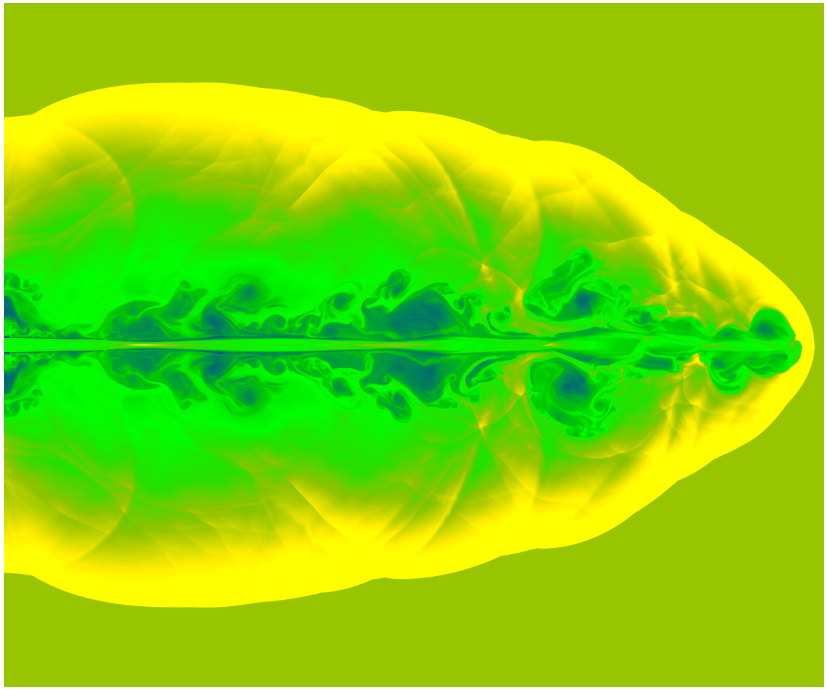
- We use the Athena relativistic magnetohydrodynamics code in its hydro mode and inject a relativistic jet into a constant density ambient medium (Pollack, Pauls & Wiita, ApJ, submitted).
- Jet density ranges from 0.1 to 0.001 of ambient,and V_b from 0.9c to 0.998c, similar to radio jets in active galaxies.
- Plots show densities on log scale: yellow to violet



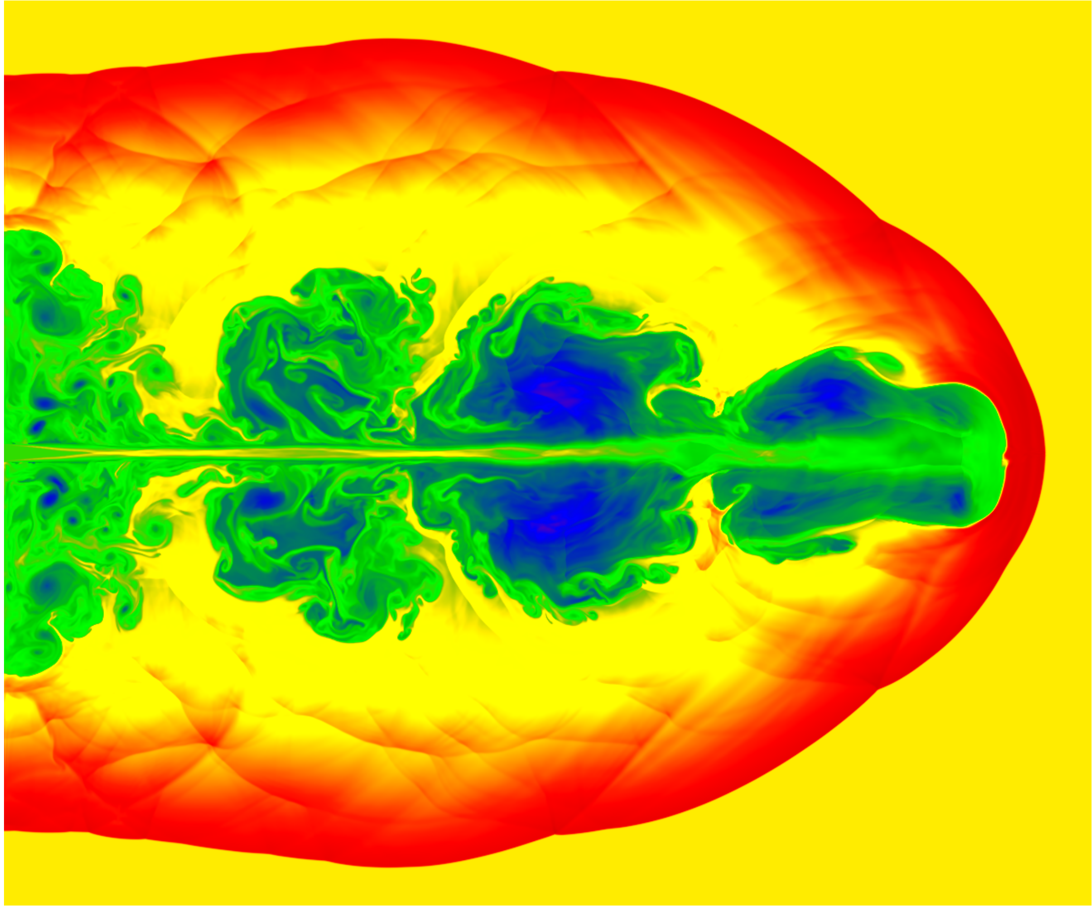
Modeling 2: Turbulence in Propagating Jets

- Plots show densities on log scale: yellow to violet

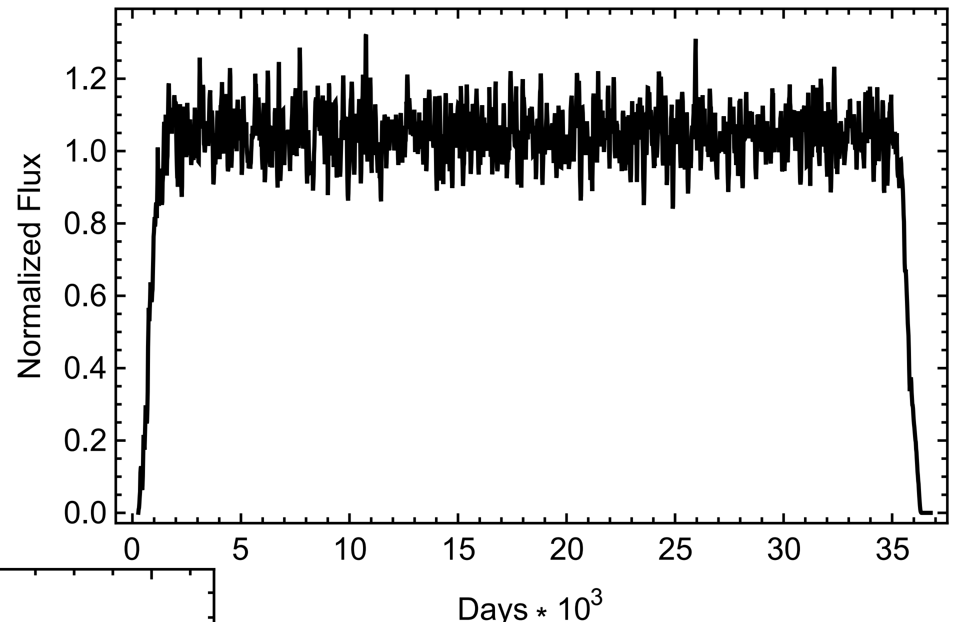


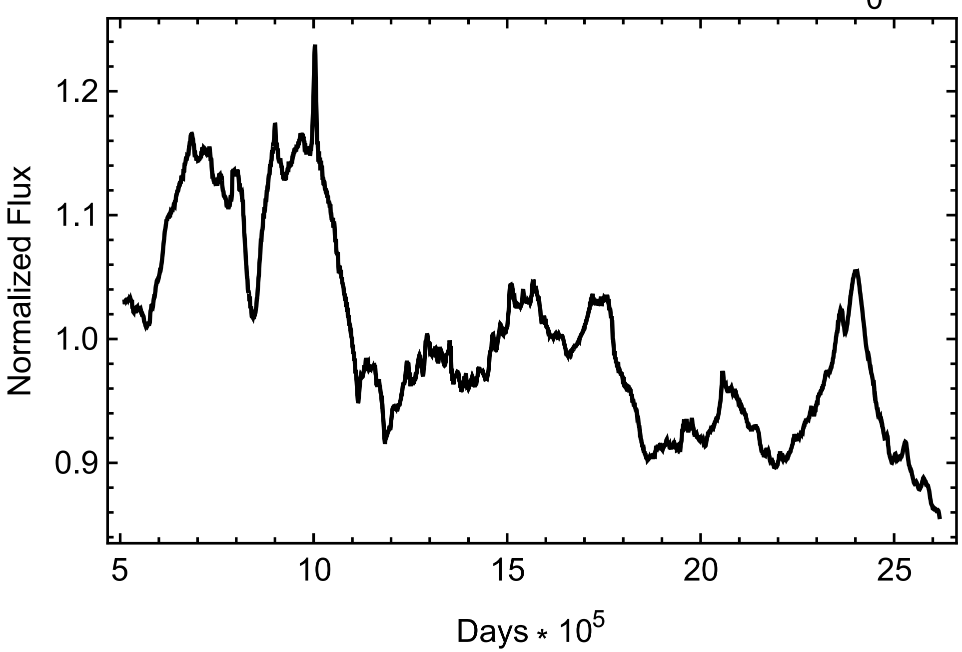


Variations from bulk Doppler changes in region behind confinement shock + turbulence

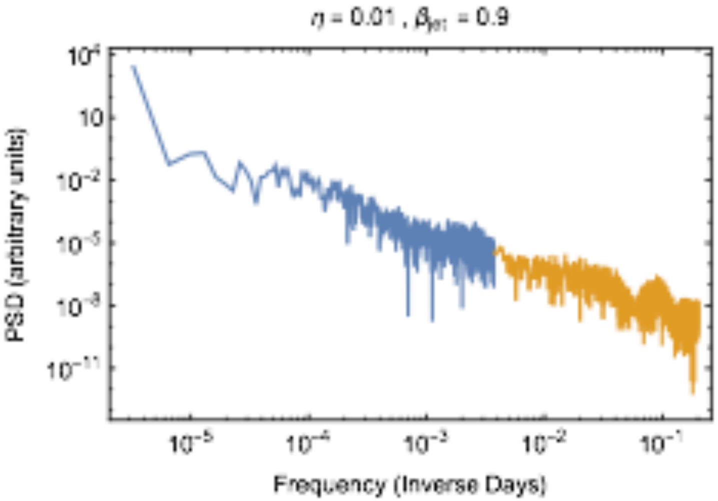


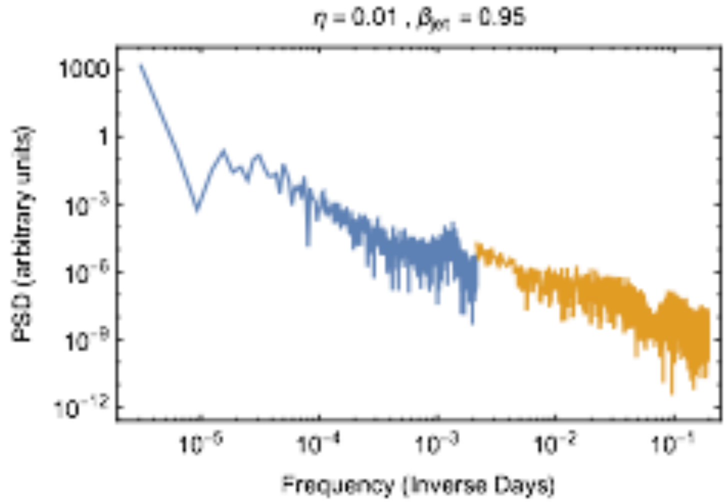
Light Curves: Turbulent and Bulk Variability

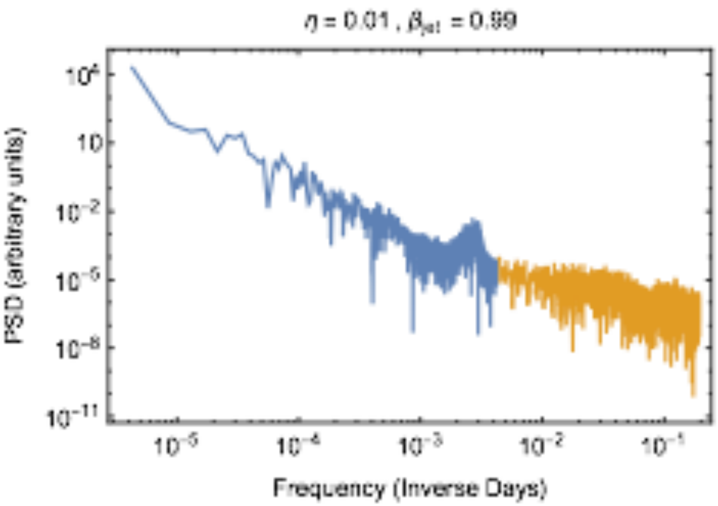


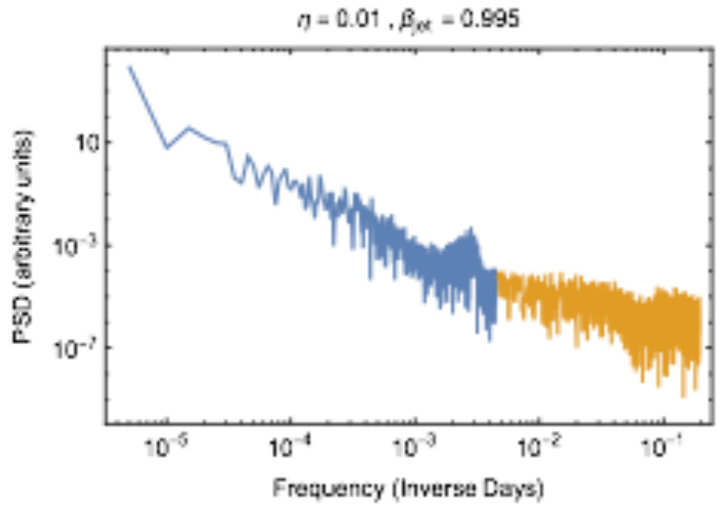


Combined Power Spectra









Conclusions from Modelling

- Turbulence behind strong jet shocks is expected.
- Reasonable turbulent spectra and jet parameters can provide LCs and PSDs that look like observations over shorter times.
- Jets change as they propagate: slight changes in the direction or speed of bulk velocities yield substantial observed variations over longer time scales.
- Together these can provide good fits to LCs and PSDs over 5 decades (days to decades).
- Movies to follow.

Bulk velocity = 0.995c, η=0.01:
Stable, like powerful radio quasars: FR II

V_b=0.9c and η=0.0316:
Unstable, like weaker BL Lacs, FR I