Testing Unified Model for Active Galactic Nuclei through Time-Domain Variability

Ching-Wa Yip
Johns Hopkins University

Collaborators

- Andrew Connolly
- Daniel Vanden Berk
- Ryan Scranton
- Simon Krughoff
- Alex Szalay
- László Dobos
- Christy Tremonti
- Tamas Budavári
- Istvan Csabai
- Rosemary Wyse
- Ivezic Željko

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PROBING SPECTROSCOPIC VARIABILITY OF GALAXIES AND NARROW-LINE ACTIVE GALACTIC NUCLEI IN THE SLOAN DIGITAL SKY SURVEY

C. W. YIP[1], A. J. CONNOLLY[2], D. E. VANDEN BERK[3], R. SCRANTON[4], S. KRUGHOFF[2], A. S. SZALAY[1], L. DOBOS[5], C. TREMONTI[6], M. TAGHIZADEH-POPP[1], T. BUDAVÁRI[1], I. CSABAI[5], R. F. G. WYSE[1], AND Ž. IVEZIĆ[2]
[1] Department of Physics and Astronomy, The Johns Hopkins University, 3701 San Martin Drive, Baltimore, MD 21218, USA
[2] Astronomy Department, University of Washington, Seattle, WA 98195, USA
[3] Saint Vincent College, 300 Fraser Purchase Road, Latrobe, PA 15650, USA
[4] Department of Physics, University of California, Davis, CA 95616, USA
[5] Department of Physics of Complex Systems, Eötvös Loránd University, H-1117 Budapest, Hungary
[6] Max-Planck-Institut für Astronomie, Königstuhl 17, D-69117, Heidelberg, Germany
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ABSTRACT

Under the unified model for active galactic nuclei (AGNs), narrow-line (Type 2) AGNs are, in fact, broad-line (Type 1) AGNs but each with a heavily obscured accretion disk. We would therefore expect the optical continuum emission from Type 2 AGNs to be composed mainly of stellar light and nonvariable on the timescales of months to years. In this work we probe the spectroscopic variability of galaxies and narrow-line AGNs using the multiepoch data in the Sloan Digital Sky Survey Data Release 6. The sample contains 18,435 sources for which there exist pairs of spectroscopic observations (with a maximum separation in time of $\sim$ 700 days) covering a wavelength range of 3900–8900 Å. To obtain a reliable repeatability measurement between each spectral pair, we consider a number of techniques for spectrophotometric calibration resulting in an improved spectrophotometric calibration of a factor of 2. From these data we find no obvious continuum and emission-line variability in the narrow-line AGNs on average—the spectroscopic variability of the continuum is 0.07 ± 0.26 mag in the g band and, for the emission-line ratios $\log_{10}([\mathrm{N\ II}]/\mathrm{H}\alpha)$ and $\log_{10}([\mathrm{O\ III}]/\mathrm{H}\beta)$, the variability is 0.02 ± 0.03 dex and 0.06 ± 0.08 dex, respectively. From the continuum variability measurement we set an upper limit on the ratio between the flux of the varying spectral component, presumably related to AGN activities, and that of the host galaxy to be $\sim$ 30%. We provide the corresponding upper limits for other spectral classes, including those from the BPT diagram, eClass galaxy classification, stars, and quasars.

Key words: galaxies: general – techniques: spectroscopic

(Yip et al. AJ 2009)

Question: do all active galactic nuclei (AGNs) vary with time?

- Two main types in the optical
  - Type 1 (broad line(s), FWHM > 1000 km/s)
  - Type 2 (narrow line(s), FWHM < 1000 km/s)
- Broad-line AGNs show UV/optical variability
  - continuum variability of amplitude ~ 10%
  - emission lines also vary with the continuum
- Both are expected to harbor supermassive black hole
- Do narrow-line AGNs vary in the optical?

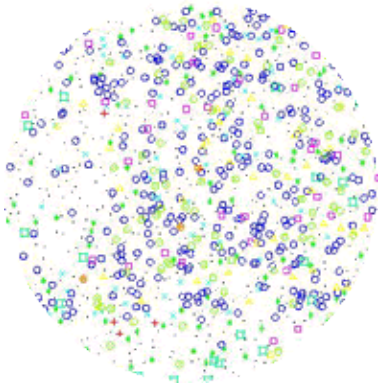
Physical Reason(s) behind AGN Variability

- Unknown! (Peterson 2001)
- Proposed scenarios
  - Accretion disk instability (Kawaguchi et al. 1998)
  - Micro-lensing by stars in the intervening galaxy (Hawkins 1993)
  - Supernova explosions (Aretxaga 1997)
  - Varying ionizing source and/or varying optical depth of material in the vicinity of light-generating region (Tohline & Osterbrock 1976; Goldrich 1989)

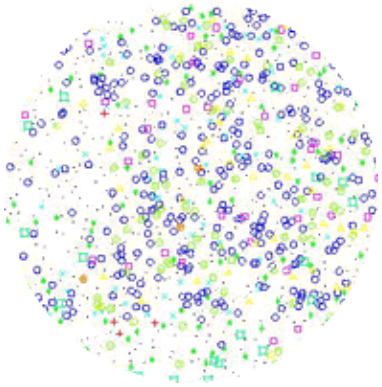
Sample: SDSS twice-observed spectra

- Some spectroscopic plates in the SDSS were observed more than once.
- Pairs of spectra are available.
- 18,435 sources of narrow-line galaxies.
- Maximum separation in time ~700 days.
- Restframe 3800 – 8900 Å (70 km/s).

Epoch 1

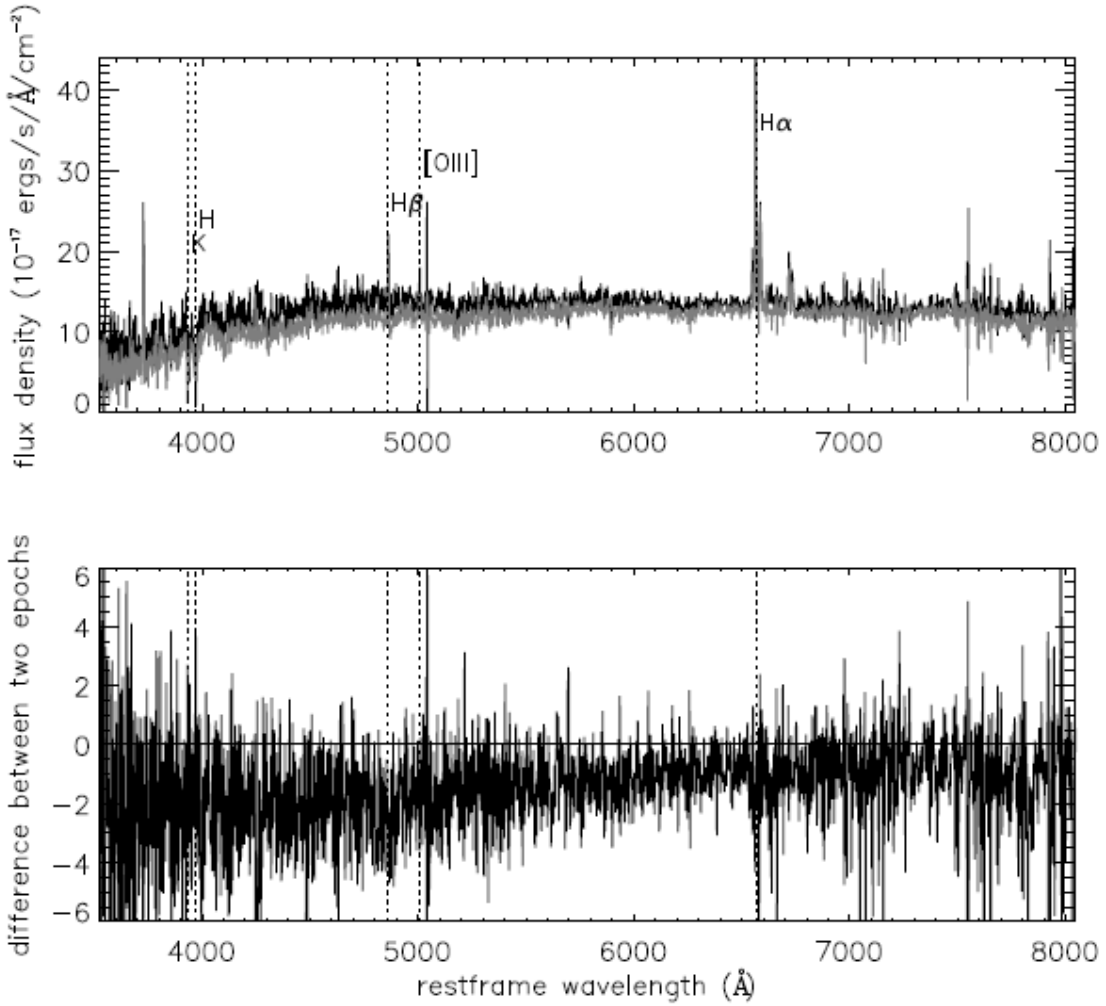


Epoch 2



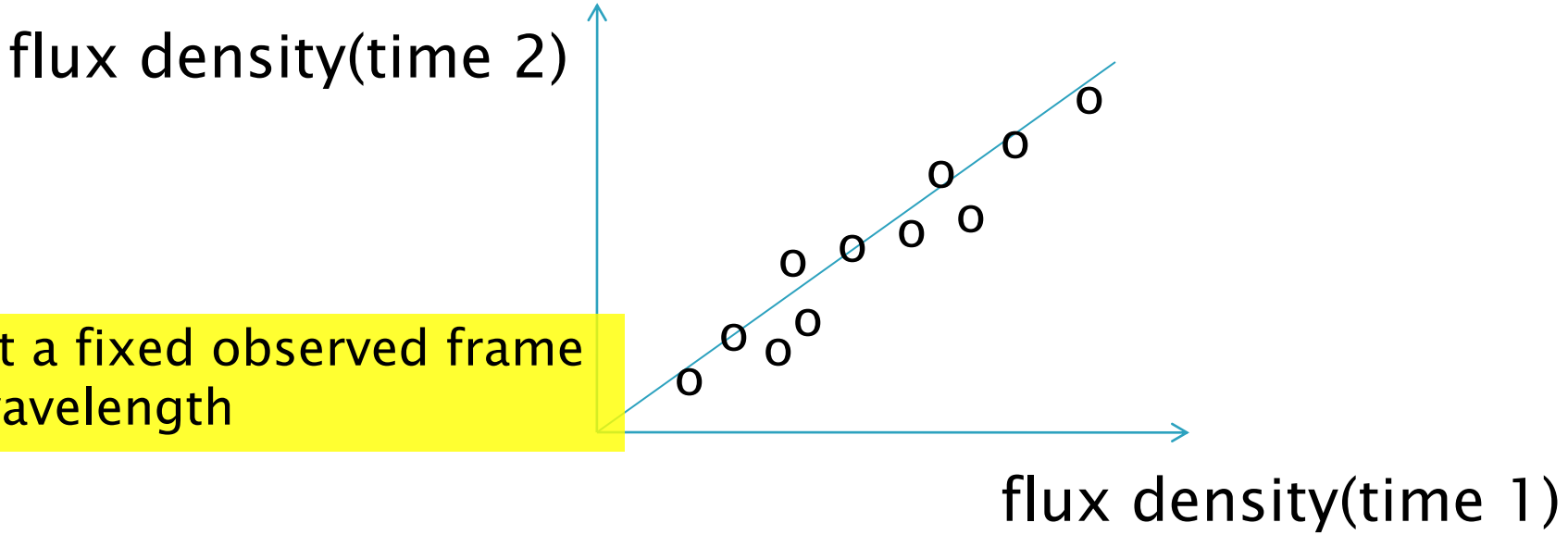
SDSS spectra at two epochs – original from the pipeline (DR6)

20% change?
But this is a star-forming galaxy ☹



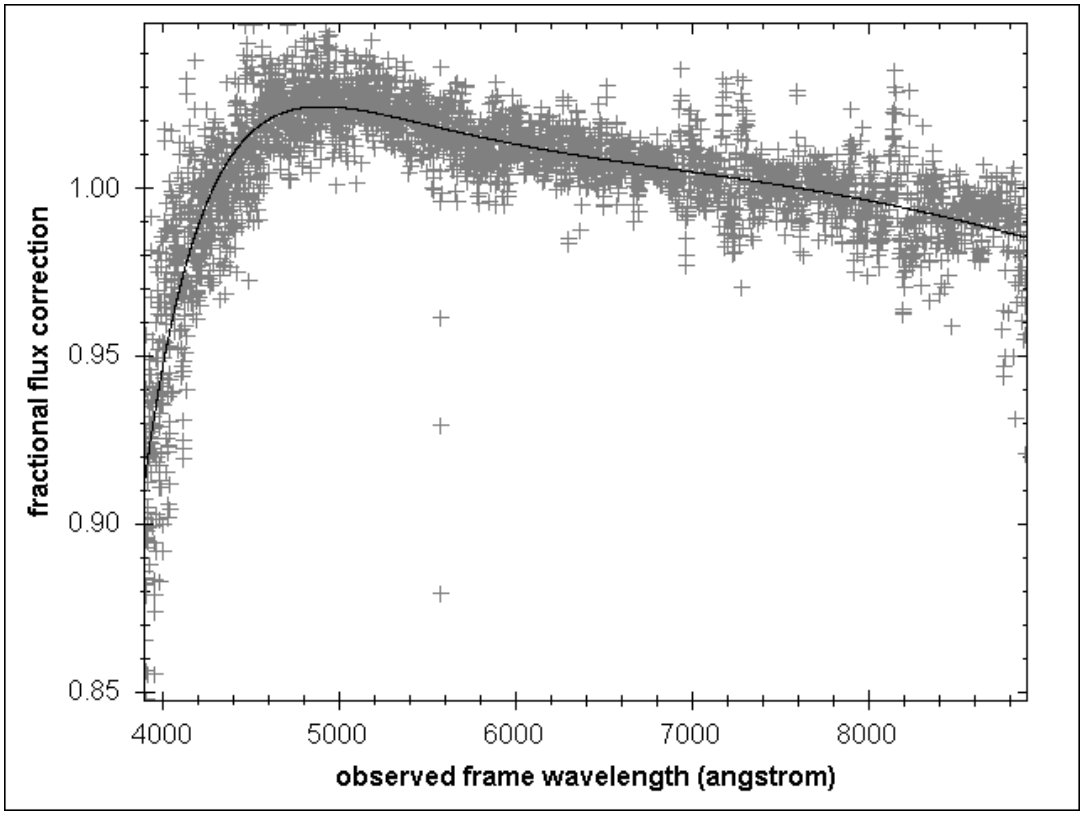
Refining SDSS Spectrophotometry

- Flux-density (ergs/s/cm^2/Å) correction is done in two steps
  - 1. wavelength-dependent correction (Wilhite et al. 2001), on plate(t1)-to-plate(t2) basis.
  - 2. wavelength-independent correction, on pair-to-pair basis.



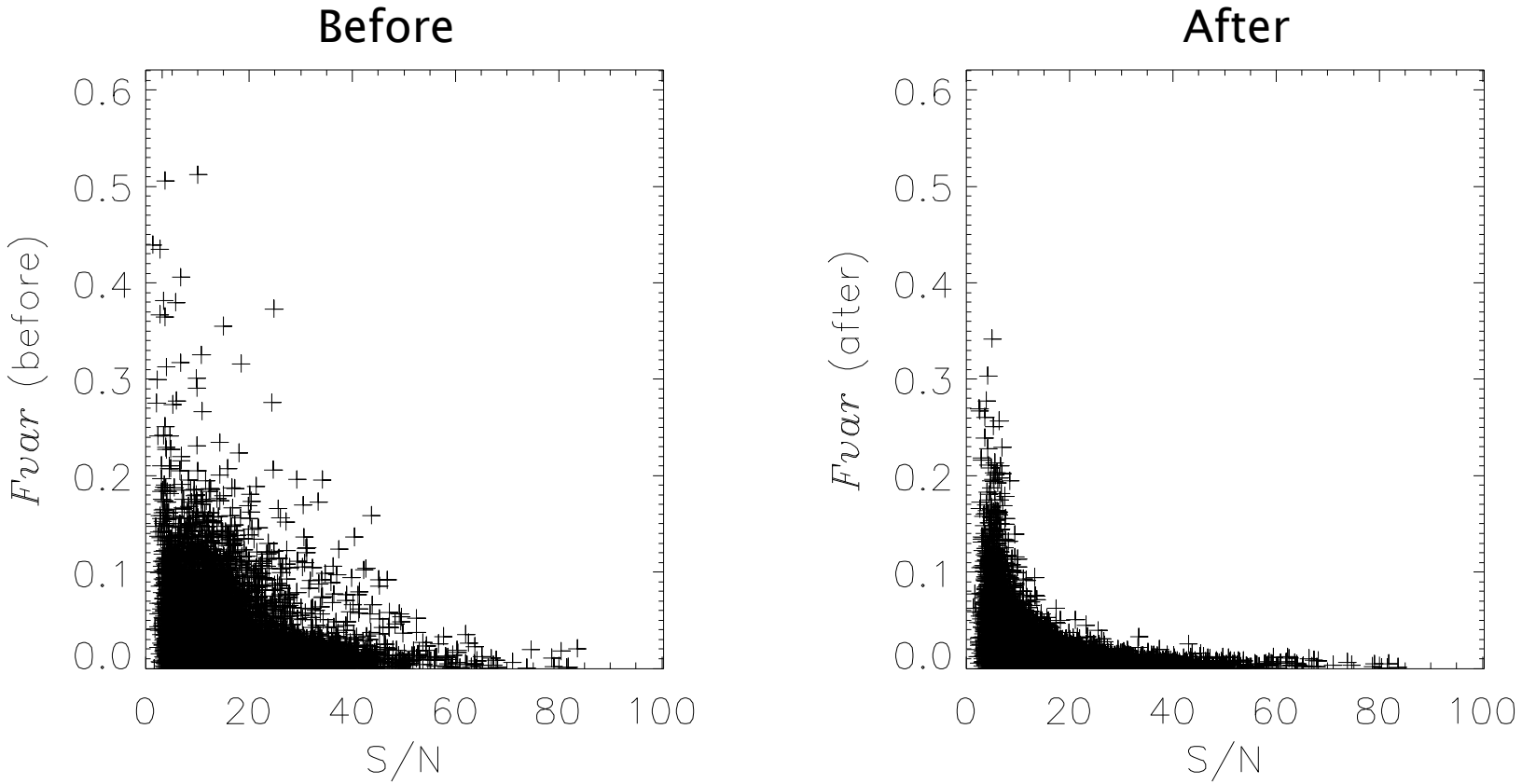
Wavelength-dependent flux correction per 2 epochs

- For each spectral pair, spectrum at the low-SN epoch is corrected.
- Example: SDSS Spectroscopic Plate 390.



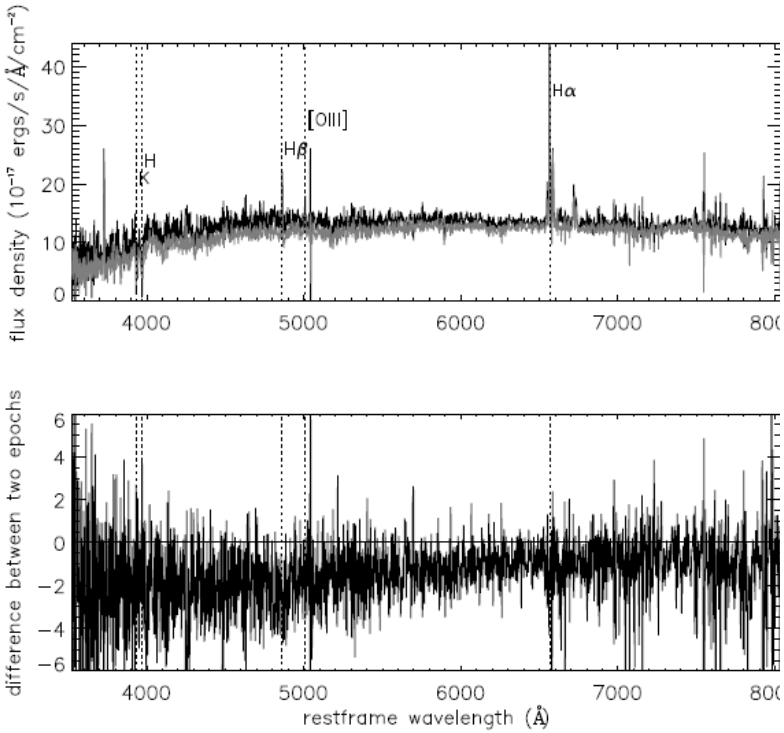
Refining SDSS Spectrophotometry

- On average a factor of 2 improvement upon the original spectrophotometric calibration.



Refining SDSS Spectrophotometry

Before (20% flux-density change)



After (no change)

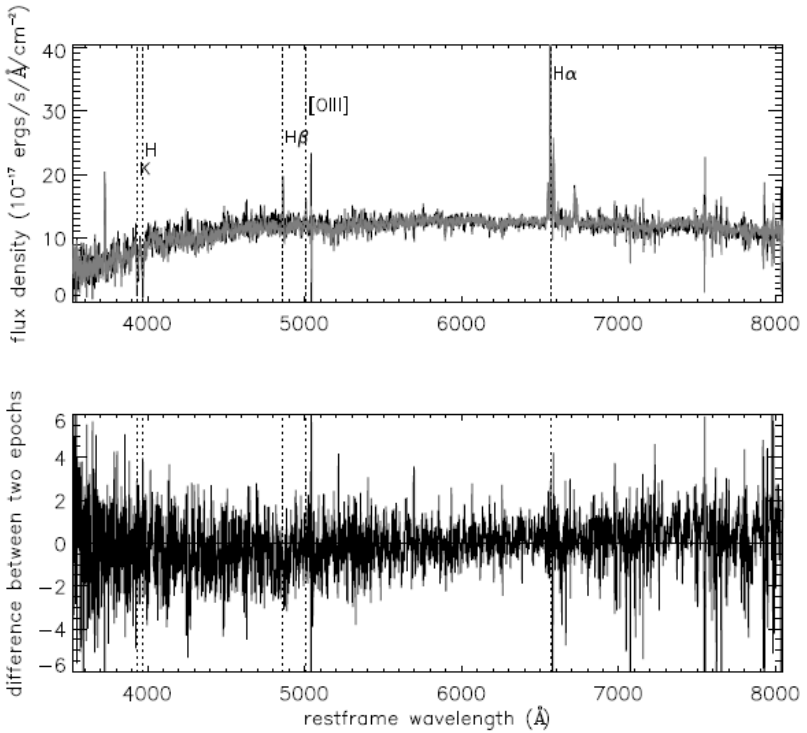
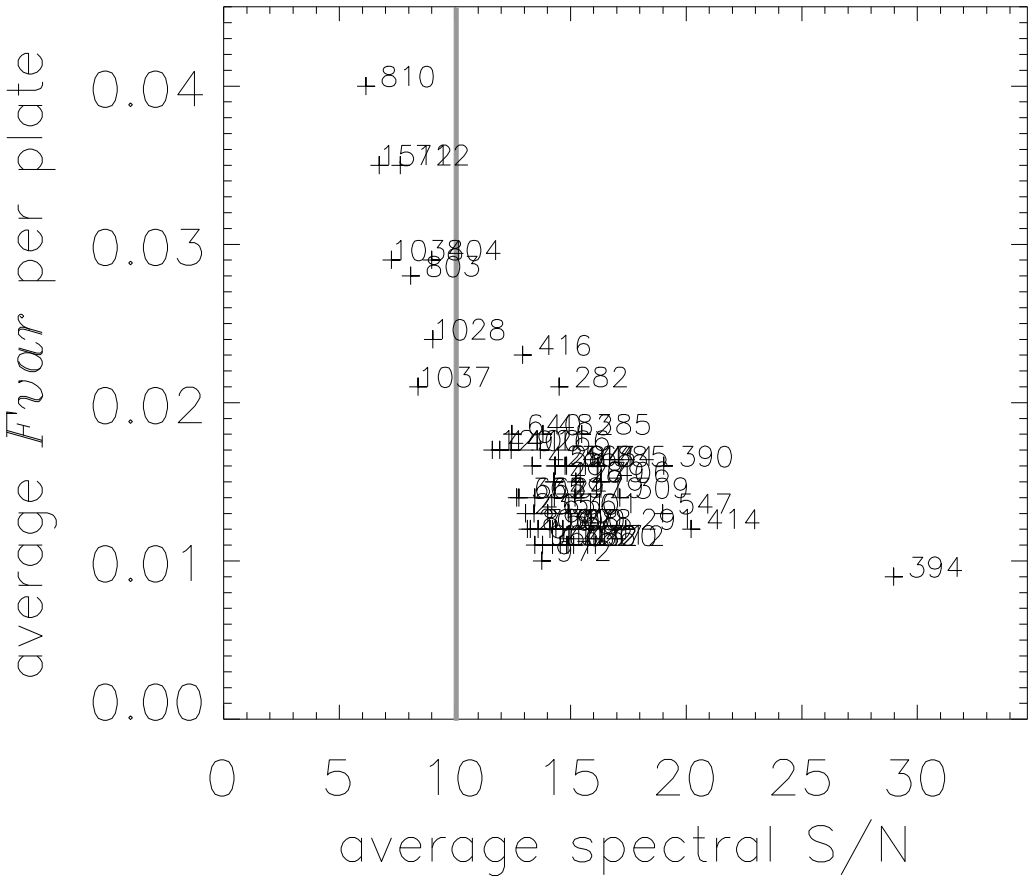


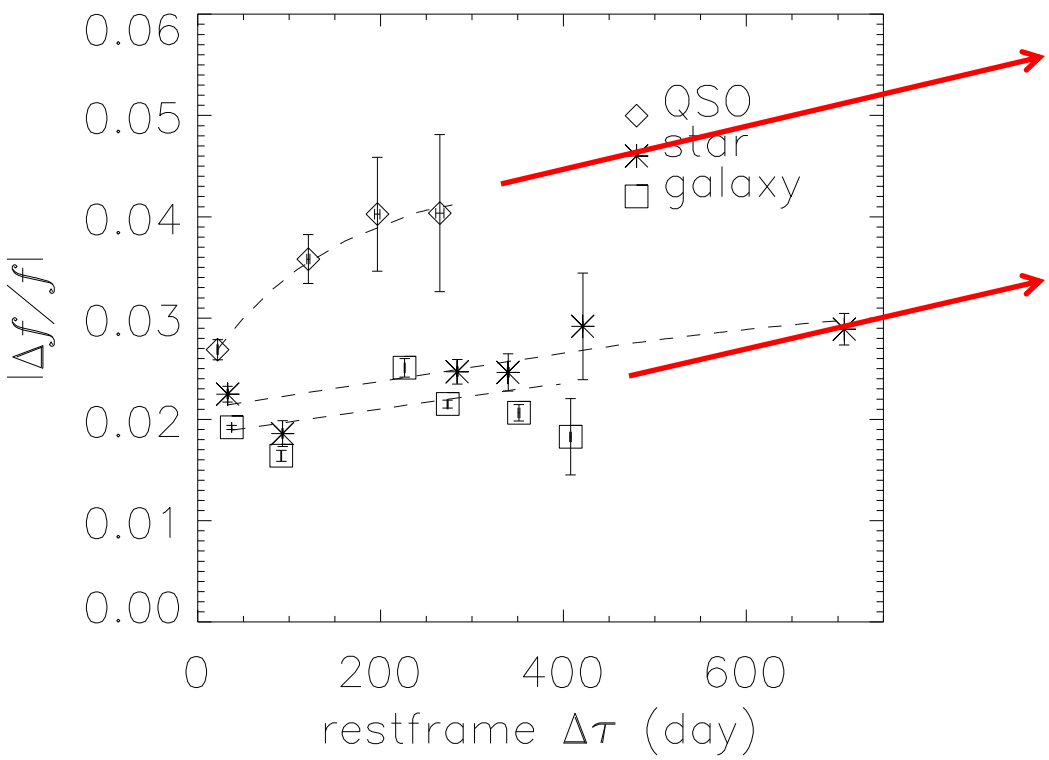
Plate-to-plate variation

- The average variability measurement exhibits plate-to-plate variation (DR6).



Variability properties of AGNs: continuum

- There is a marked difference between the variability properties of broad-line and narrow-line AGNs.

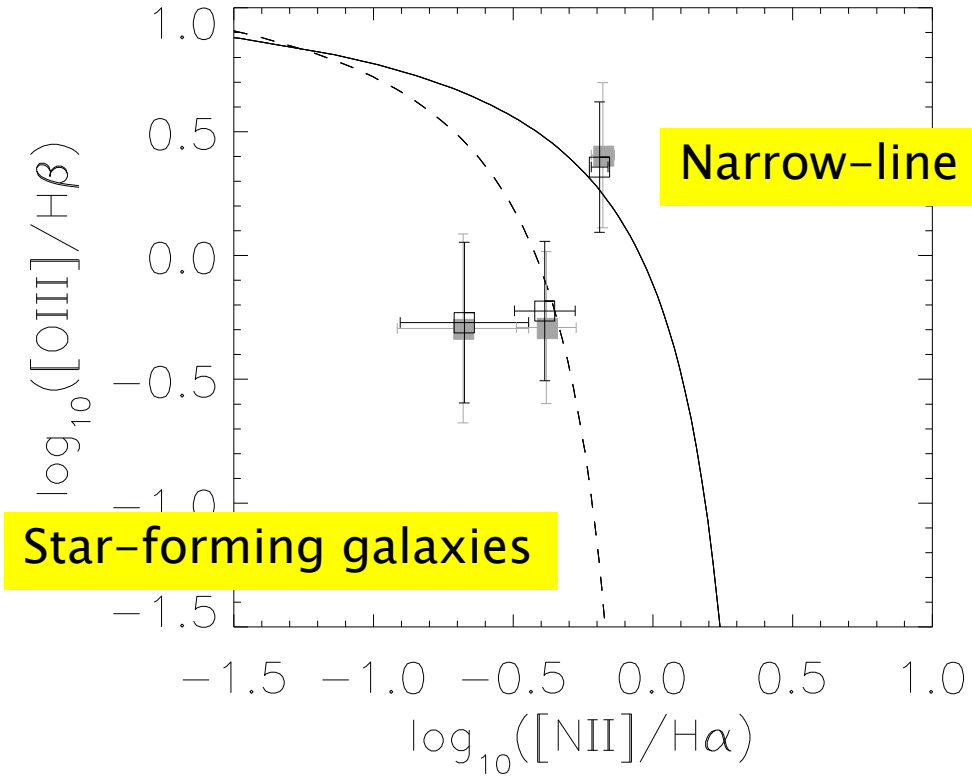


Broad-line AGNs

Narrow-line AGNs

Variability properties of narrow-line AGNs: emission lines

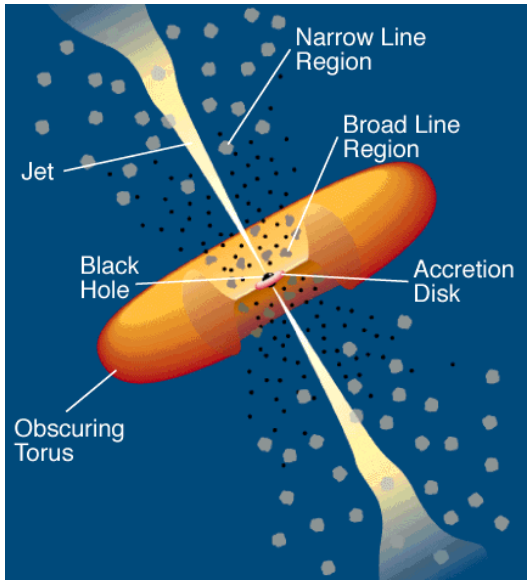
- Line ratios do not show variability: epoch 1 (empty) vs. epoch 2 (solid).
- Low density gas (electron density ~ 1000 /cm^3) results in long recombination time (100 years)

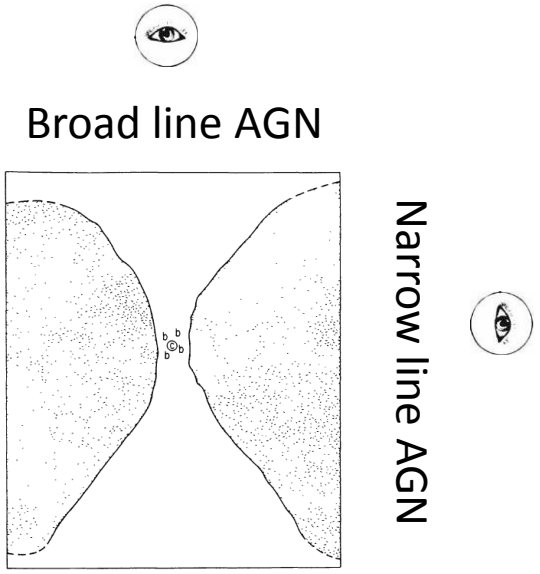


BPT diagram

If both types of AGNs harbor supermassive blackhole…

- Why are their continuum variability properties different?
- AGN unified model (Antonucci 93 ; Urry & Padovani 95) offers an answer
  - If the unified model is true, the optical continuum of narrow-line AGNs should be dominated by stars, and therefore should not vary



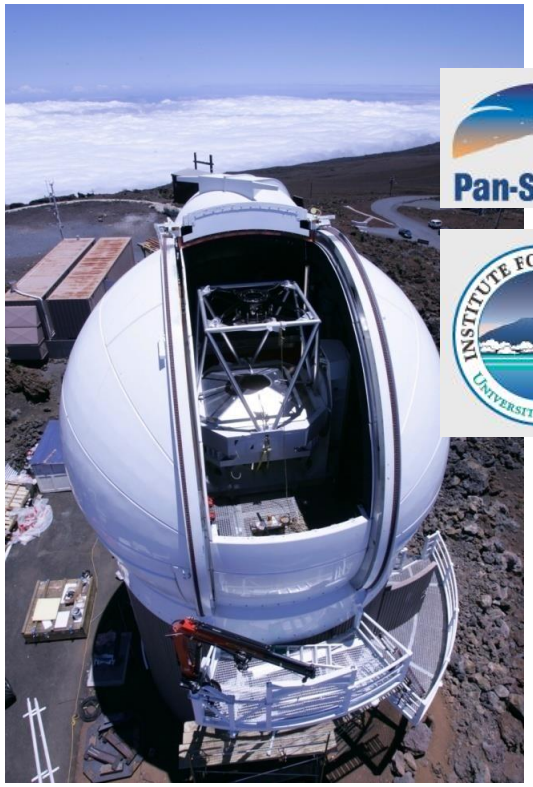


(Antonucci 93)

Testing AGN unified model with Pan-STARRS

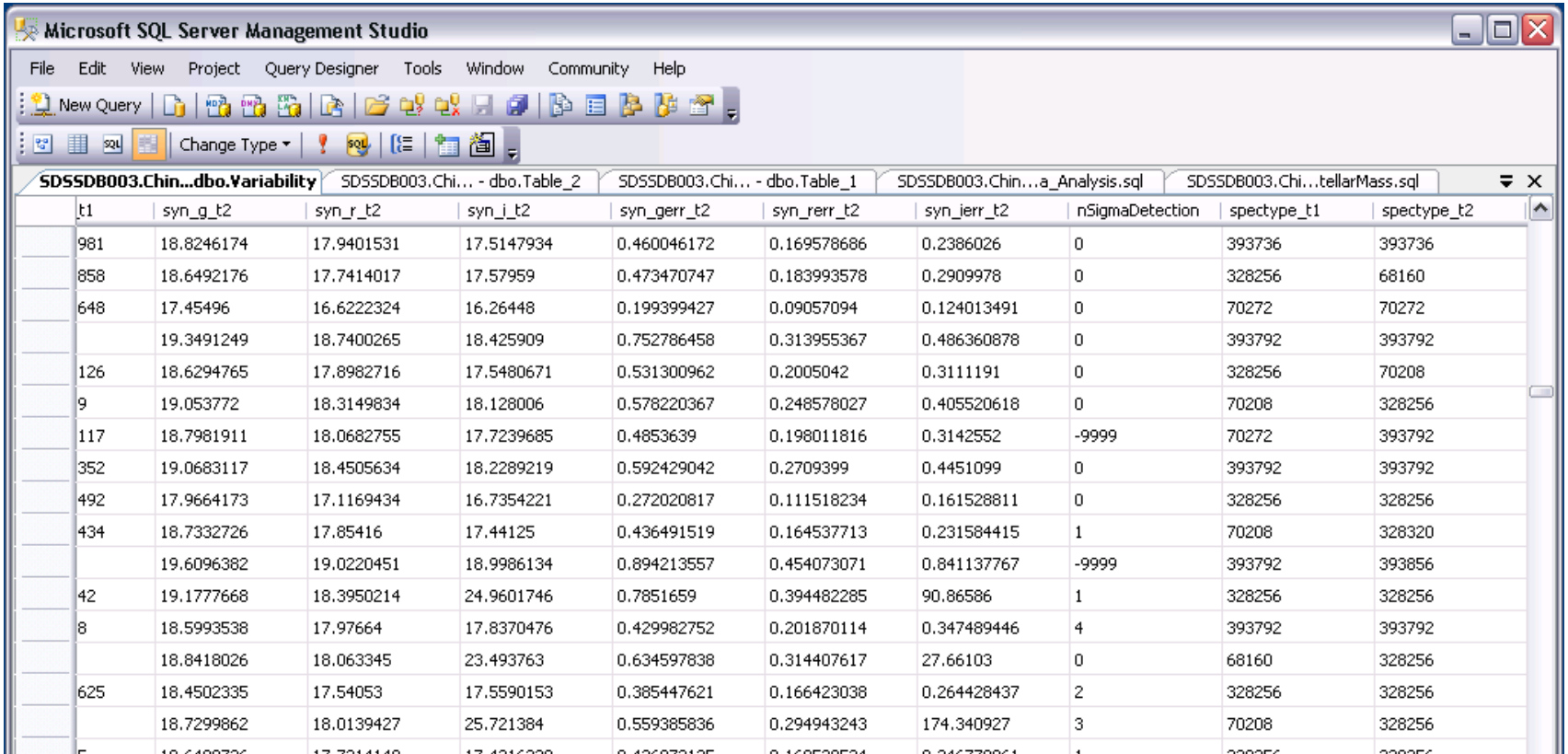
- To extend to longer time baseline (> 700 days)
- To reduce random uncertainty in variability measurements ($\sigma \sim 1/\sqrt{N}$)
- Cross calibration studies
  - SDSS spectra vs. PS photometry
- Collaborations
  - KP 10 (Chambers and Walter)
  - Standard Projects

  concerning AGN variability



Next Steps

- DR7 spectroscopic non-variable and variable source catalogs (László Dobos)
- SDSS Stripe 82 variability analyses (Gyongyi Kerekes)



t1	syn_g_t2	syn_r_t2	syn_i_t2	syn_gerr_t2	syn_rerr_t2	syn_ierr_t2	nSigmaDetection	spectype_t1	spectype_t2
981	18.8246174	17.9401531	17.5147934	0.460046172	0.169578686	0.2386026	0	393736	393736
858	18.6492176	17.7414017	17.57959	0.473470747	0.183993578	0.2909978	0	328256	68160
648	17.45496	16.6222324	16.26448	0.199399427	0.09057094	0.124013491	0	70272	70272
	19.3491249	18.7400265	18.425909	0.752786458	0.313955367	0.486360878	0	393792	393792
126	18.6294765	17.8982716	17.5480671	0.531300962	0.2005042	0.3111191	0	328256	70208
9	19.053772	18.3149834	18.128006	0.578220367	0.248578027	0.405520618	0	70208	328256
117	18.7981911	18.0682755	17.7239685	0.4853639	0.198011816	0.3142552	-9999	70272	393792
352	19.0683117	18.4505634	18.2289219	0.592429042	0.2709399	0.4451099	0	393792	393792
492	17.9664173	17.1169434	16.7354221	0.272020817	0.111518234	0.161528811	0	328256	328256
434	18.7332726	17.85416	17.44125	0.436491519	0.164537713	0.231584415	1	70208	328320
	19.6096382	19.0220451	18.9986134	0.894213557	0.454073071	0.841137767	-9999	393792	393856
42	19.1777668	18.3950214	24.9601746	0.7851659	0.394482285	90.86586	1	328256	328256
8	18.5993538	17.97664	17.8370476	0.429982752	0.201870114	0.347489446	4	393792	393792
	18.8418026	18.063345	23.493763	0.634597838	0.314407617	27.66103	0	68160	328256
625	18.4502335	17.54053	17.5590153	0.385447621	0.166423038	0.264428437	2	328256	328256
	18.7299862	18.0139427	25.721384	0.559385836	0.294943243	174.340927	3	70208	328256

Summary

- We found the emission lines of narrow-line (Type 2) AGNs to be non-variable
  - Consistent with narrow-line region being low density (electron density ~ 1000 /cm^3) and therefore a long (~100 years) recombination time
- We found the continuum of narrow-line AGNs to be non-variable
  - Upper flux limit of variability is ~30%
  - Consistent with AGN unified model
- On spectral classification in the optical
  - Variability measurement alone cannot distinguish narrow-line AGNs from inactive galaxies