QSO variability and black hole mass

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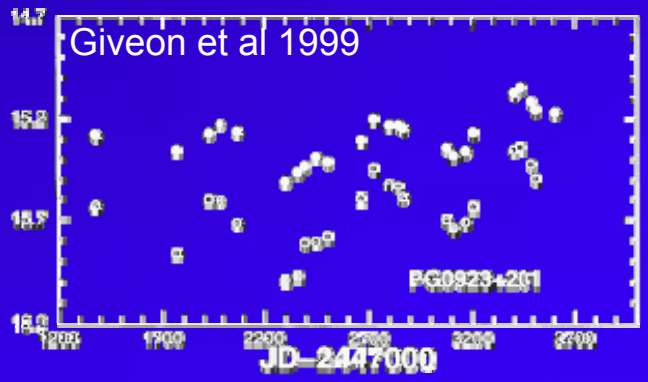
QSO optical/UV variability

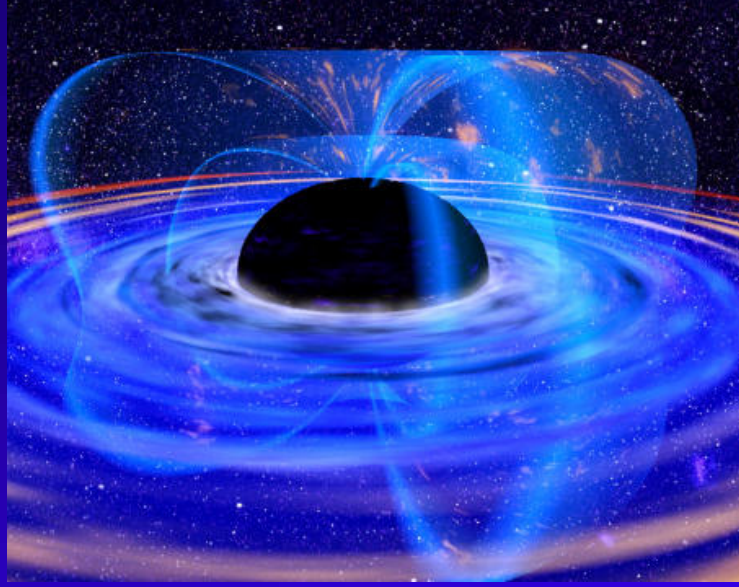
- optical/UV variability observed since (even before) the discovery of qsos
- non-periodic, erratic ; Δm ~ few tenths of a magnitude: changes in the energy generation mechanism
- holds clues to understanding the AGN mechanism



- temporal variability probes physical scales we cannot resolve
- reverberation mapping : structure of BLR and BH mass (e.g. Peterson et al 1998; 2004; Kaspi et al. 2000)

What is causing the fluctuations in quasar continua?

QSO optical/UV variability: Models

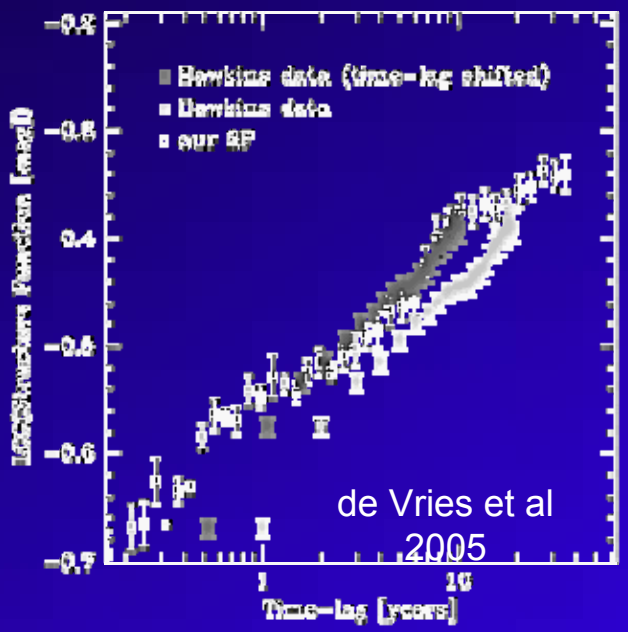


- short-term (days - weeks)
- long-term (months - decades)
  - relativistic beaming (projection effects in blazars) [Blandford & Rees 1978]
  - flares and optical depth variations in X-ray corona [e.g. Krolik et al 1991; Nandra et al 1991; review by Ulrich et al 1997]
  - starburst models (e.g. Terlevich et al 1992; Cid Fernandes et al 1996)
  - microlensing (e.g. Hawkins 1993; 2002; Alexander 1995; Yonehara et al 1999)
  - accretion disk instabilities (e.g. Kawaguchi et al 1998; Starling et al 1994)

Results from long-term QSO variability surveys

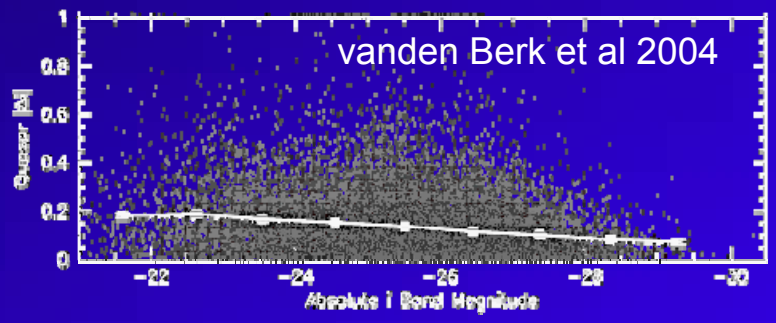
E.g. Hook et al 1994; Giveon et al 1999; Hawkins 2002; Helfand 2001; deVries et al 2003; 2005; vanden Berk 2004; Rengstorf et al 2004

I. variability - time lag

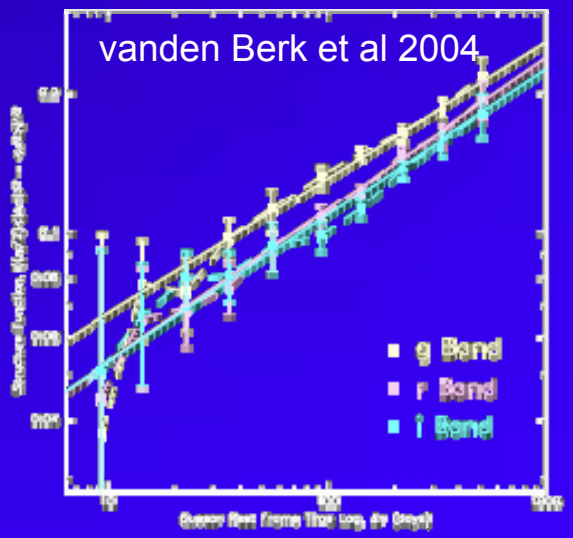


No turn-over ...

II. variability - luminosity



III. variability - wavelength



QSO variability is an intrinsic property

How does it depend on fundamental AGN parameters?

QSO variability and BH mass

Variability survey: *QUEST1*
*QU*asar *E*quatorial *S*urvey *T*eam
(Rengstorf et al 2004a,b)

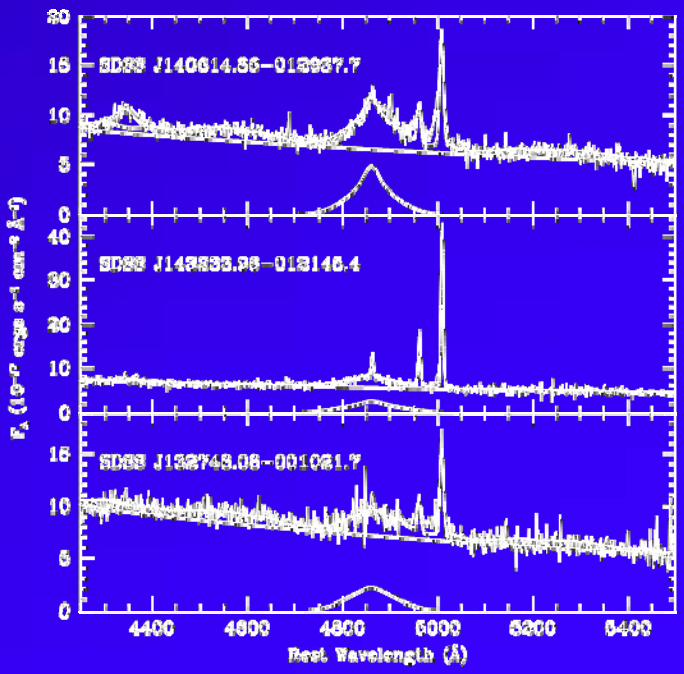
1m telescope at Llano del Hato Observatory, Venezuela

- 200 deg² surveyed over 26 months
- up to 69 scans of same region
- 200k light curve catalog : SDSS overlap
- contains ~1000 known qsos (Rengstorf et al 2006)

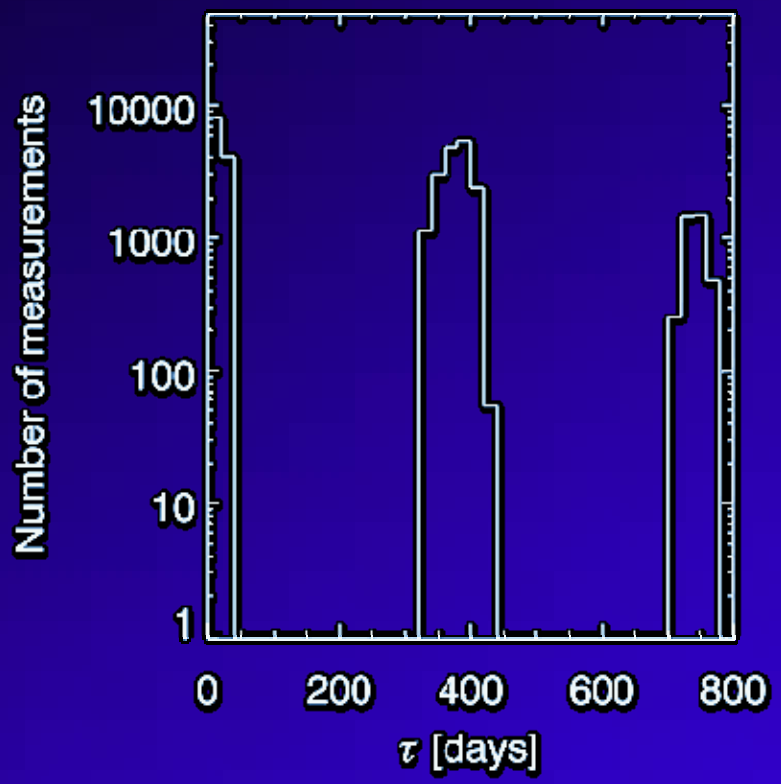
Sloan Digital Sky Survey
Mapping the Universe

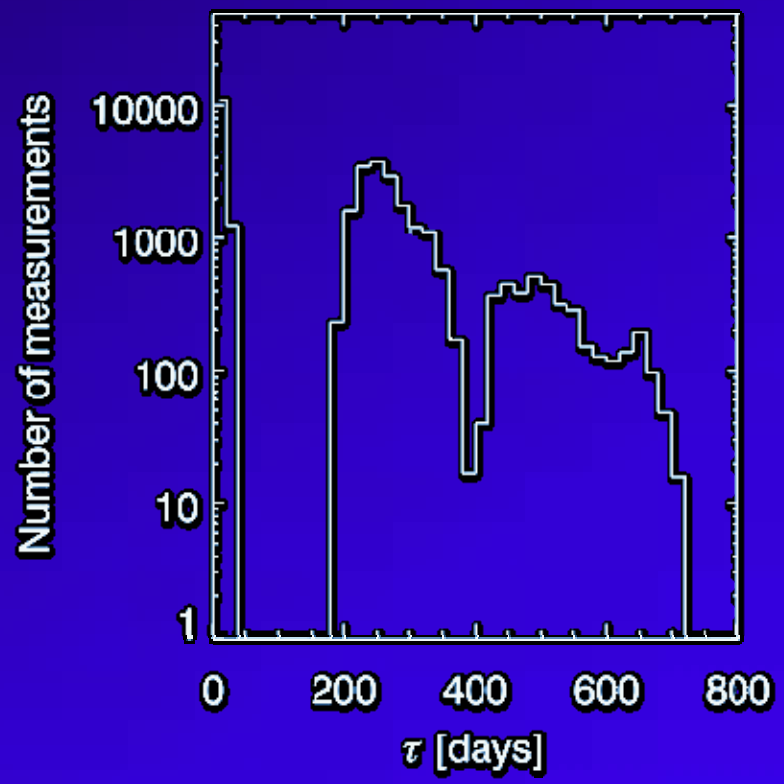
Abazajian et al 2004

- broad emission lines
- z < 0.75 (Hβ @ 4861Å)
- 104 qsos



SDSS - QUEST sample : temporal sampling



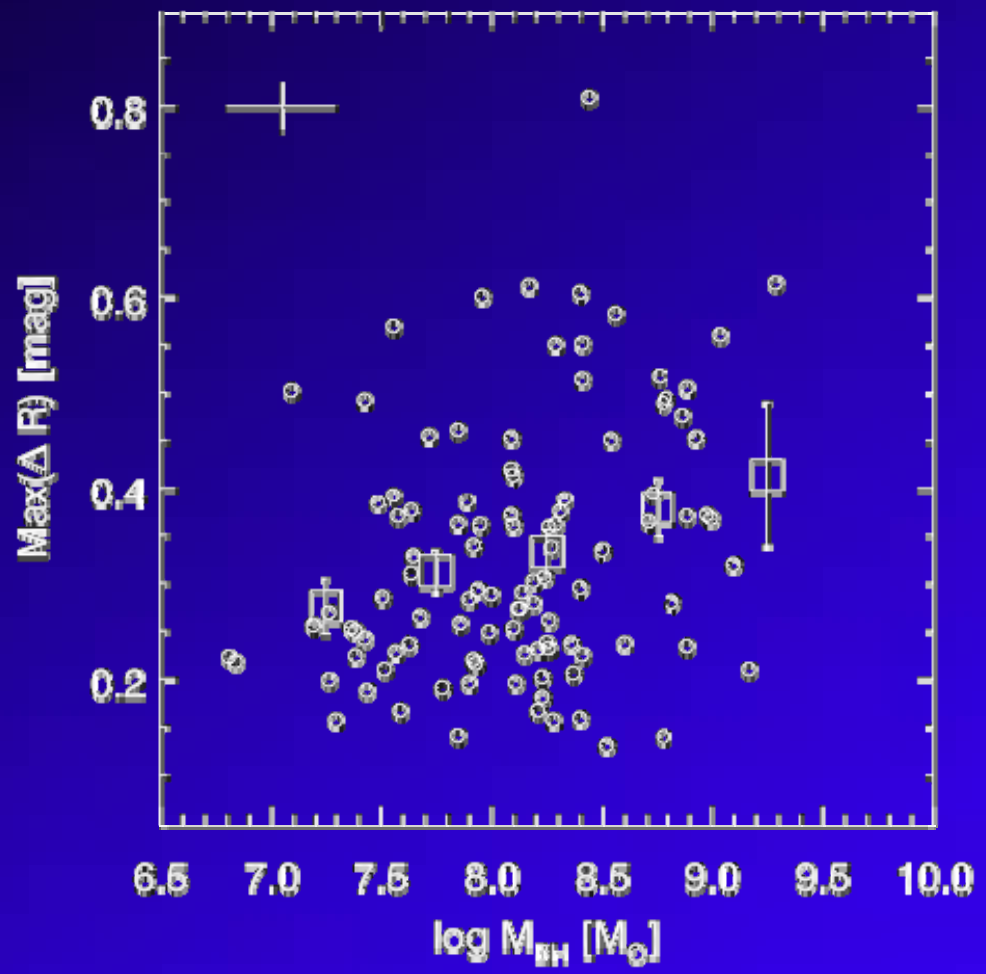


- rest-frame time lag t / (1+z)
- deredshifting:
- better light curve coverage
- shorter time span

See also Rengstorf et al 2006

M_{BH} - variability correlation

Wold, Brotherton & Shang 2007



Pearson correlation coeffs

	log M_{BH}	log L_{bol}	log L/L_{Edd}
Max(Δm)	0.285	0.146	-0.189
Mean(Δm)	0.273	0.137	-0.184
stddev(Δm)	0.248	0.102	-0.188

P=0.003, σ = 2.9

Selection effects?

Selection effects

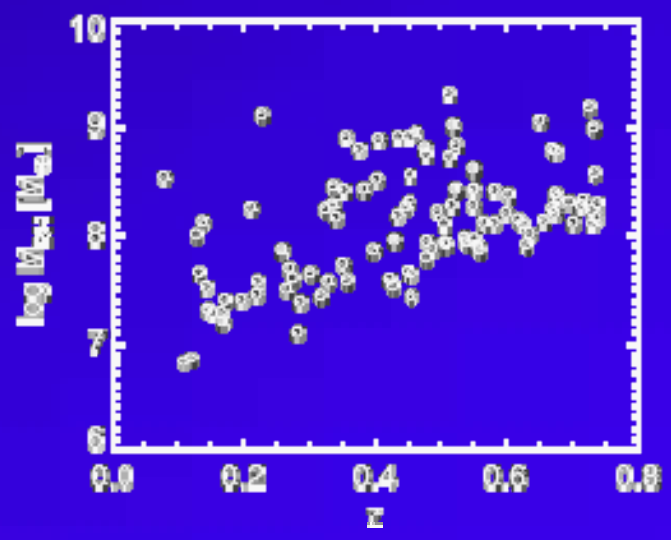
"Primary" correlations for QSOs:

1. variability - luminosity
2. variability - wavelength (redshift)
3. variability - time lag

Sample selection effects:

1. M_{BH} - redshift (ρ=0.466, σ=4.7)
2. M_{BH} - luminosity (ρ = 0.513, σ=5.2)

- M_{BH} - z + (variability - z) :
- Spearman's partial ρ=0.203, p=0.35%
- M_{BH} - variability at constant L_{bol} :
- Spearman's partial ρ=0.254, p=0.02%



Residual host galaxy contamination?

Affects low-luminosity qsos :

1) dilutes variability for high host:AGN ratios

2) overestimates BH mass (e.g. Kaspi et al 2000; 2005; Bentz et al 2006)

BUT :
- only a few SDSS spectra show signs of host galaxy light
- M_{BH} - variability correlation present also among high-luminosity qsos

Conclusions

- time scales probed ~6 months up to 2 yrs
  - accretion disk thermal time scales
- more massive black holes have larger variability amplitudes
- not easily explained by selection effects or host galaxy contamination
- no evident correlation with Eddington ratio, L_{bol}/L_{Edd}
- correlation supports models where the variability is intrinsic to the AGN
- larger samples and/or samples with better temporal sampling needed to confirm the robustness of the correlation

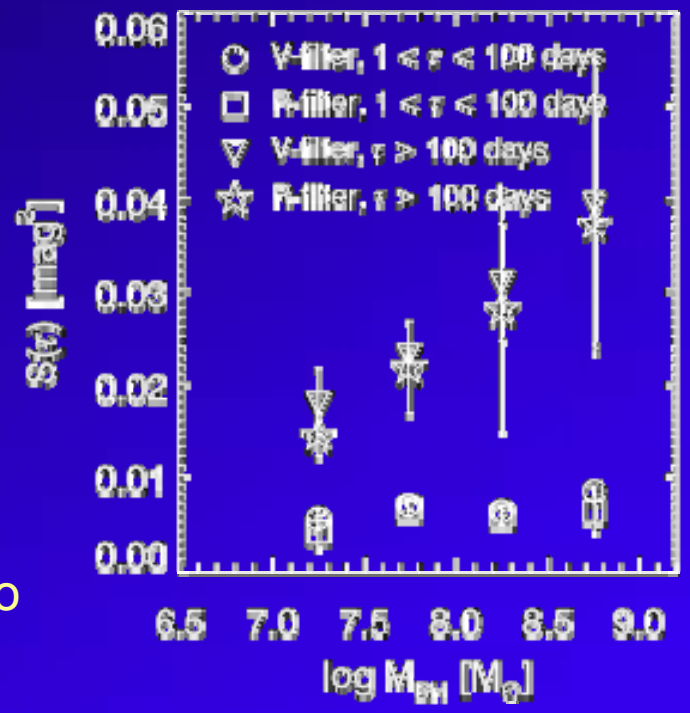
Selection effects

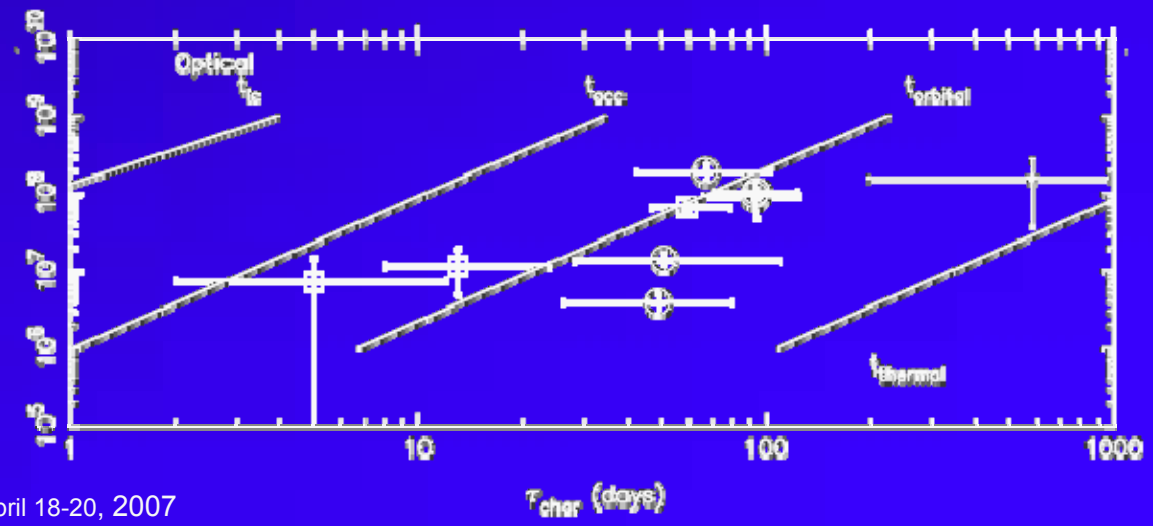
- QUEST samples time scales 1-2 yrs + most variability at 1-2 yrs (Rengstorf et al 2004; 2006)
- T_{char} depends on BH mass

Some arguments against:

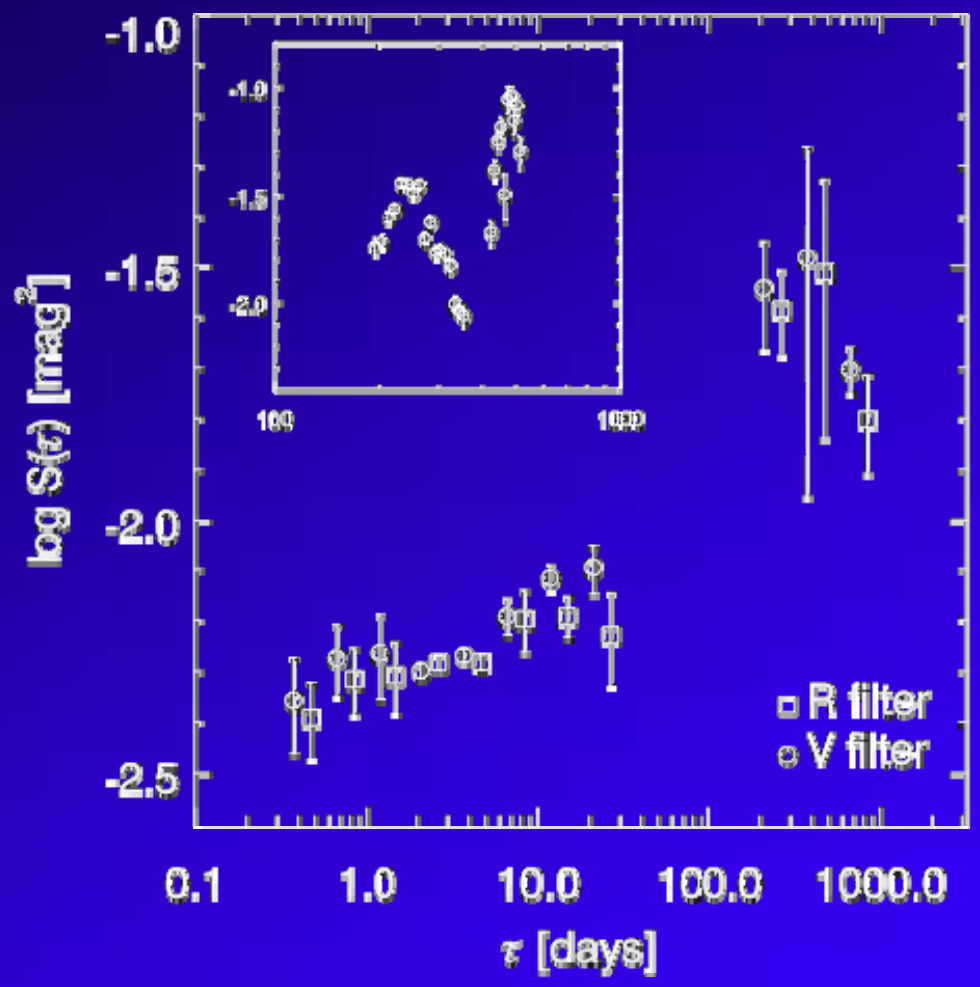
1. variability time scale must be associated with T_{char} (Collier & Peterson 2001)

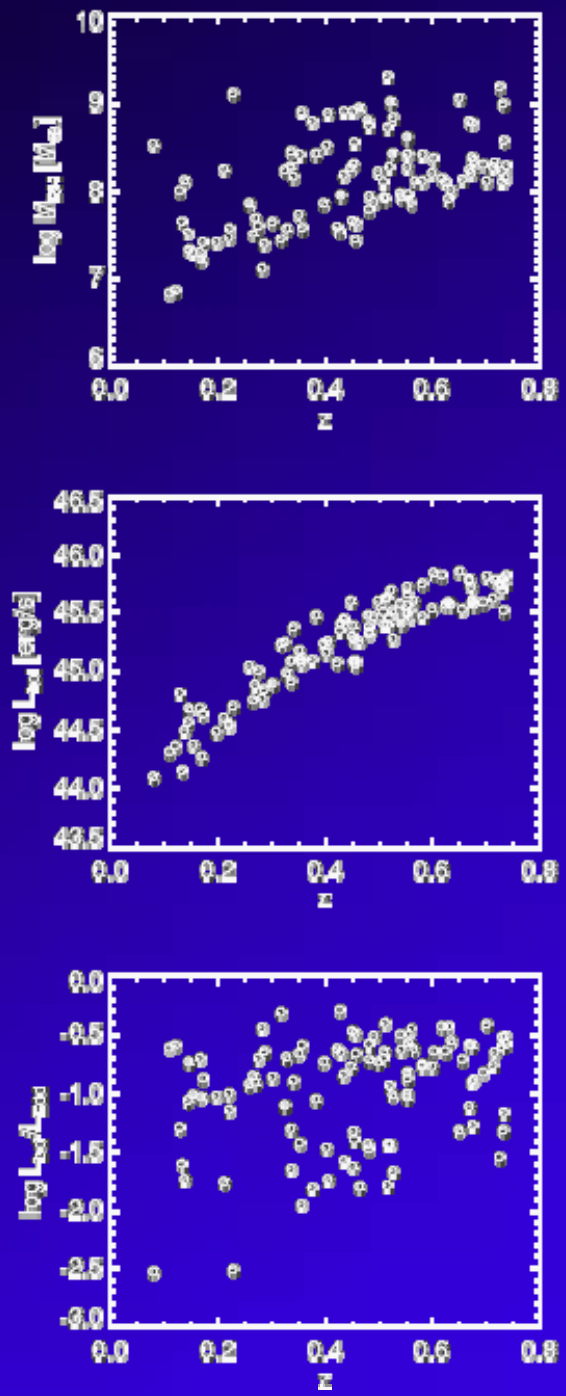
2. low-z qsos with lower BH masses contribute most to variability at longer time lags



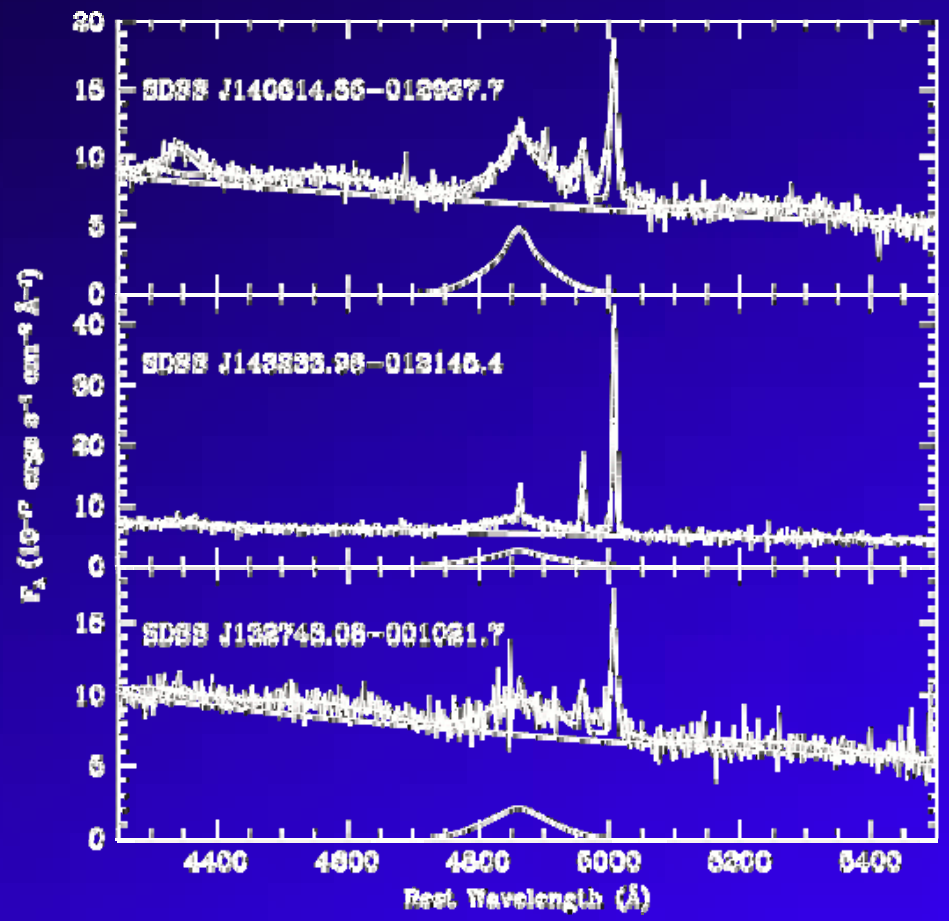


Collier & Peterson 2001


-1.0
-1.5
-2.0
-2.5
log S(τ) [mag²]
0.1
1.0
10.0
100.0
1000.0
τ [days]
R filter
V filter


log M_BH [M_⊙]
10
9
8
7
6
0.0
0.2
0.4
0.6
0.8
z
log L_bol [erg/s]
46.5
46.0
45.5
45.0
44.5
44.0
43.5
0.0
0.2
0.4
0.6
0.8
z
log L_bol/L_Edd
0.0
-0.5
-1.0
-1.5
-2.0
-2.5
-3.0
0.0
0.2
0.4
0.6
0.8
z

BH mass estimation



Virial BH masses estimated from Hβ line widths and 5100 Å continuum luminosity
(Kaspi et al 2000; Vestergaard & Peterson (2006)

Fundamental AGN parameters:
M_{BH}, L_{bol}, L_{Edd}, L_{bol}/L_{Edd}

correlate with variability measures