

# QSO Reverberation Mapping

via PanSTARRS+MMT

Stephen Fine (U. Western Cape)  
+ Tom Shanks (Durham) et al

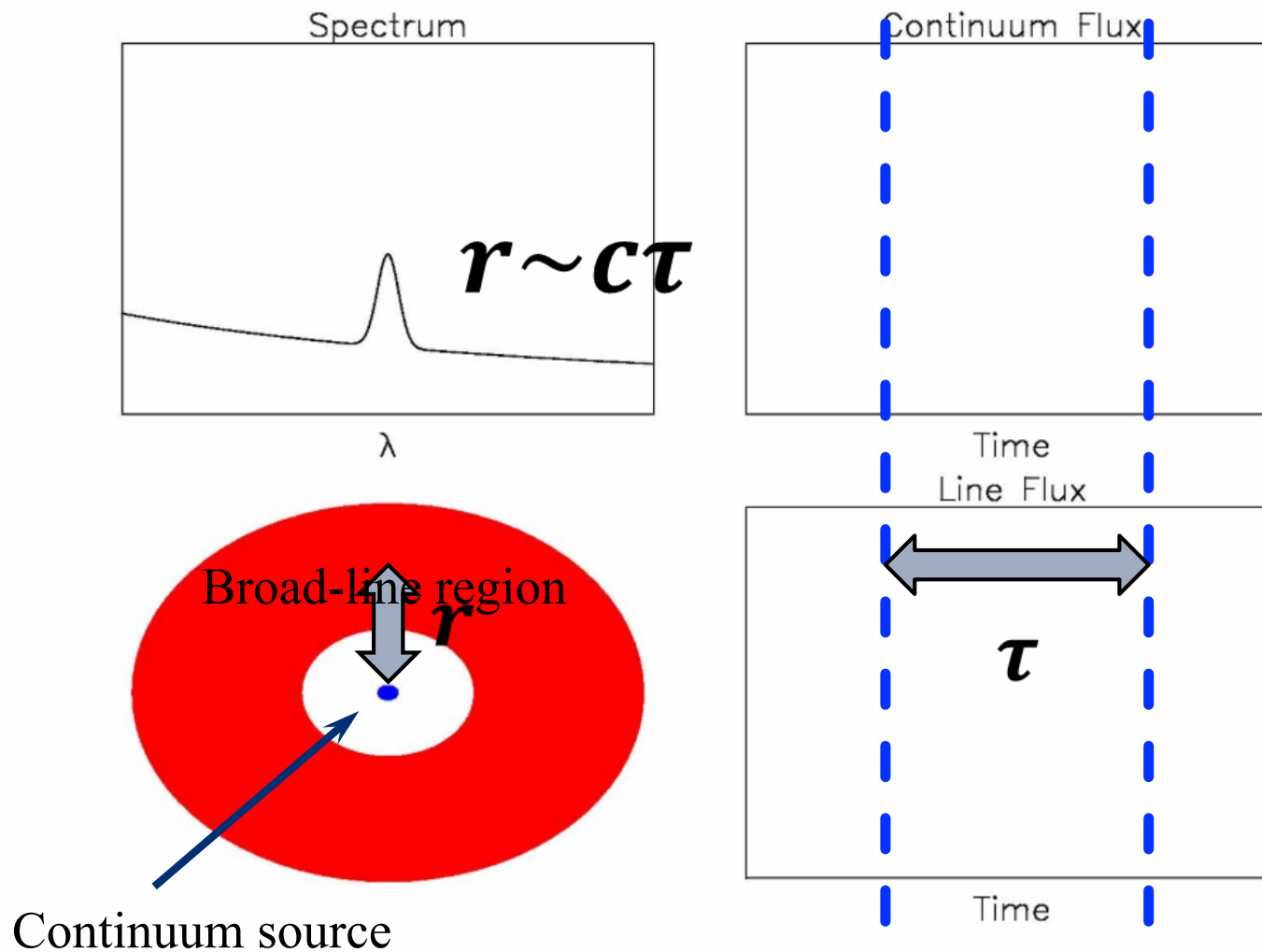
# Summary

- \* Standard reverberation mapping
- \* Stacked reverberation mapping
- \* First results with PanSTARRS and MMT Hectospec

# Reverber'n Mapping-Basic Idea

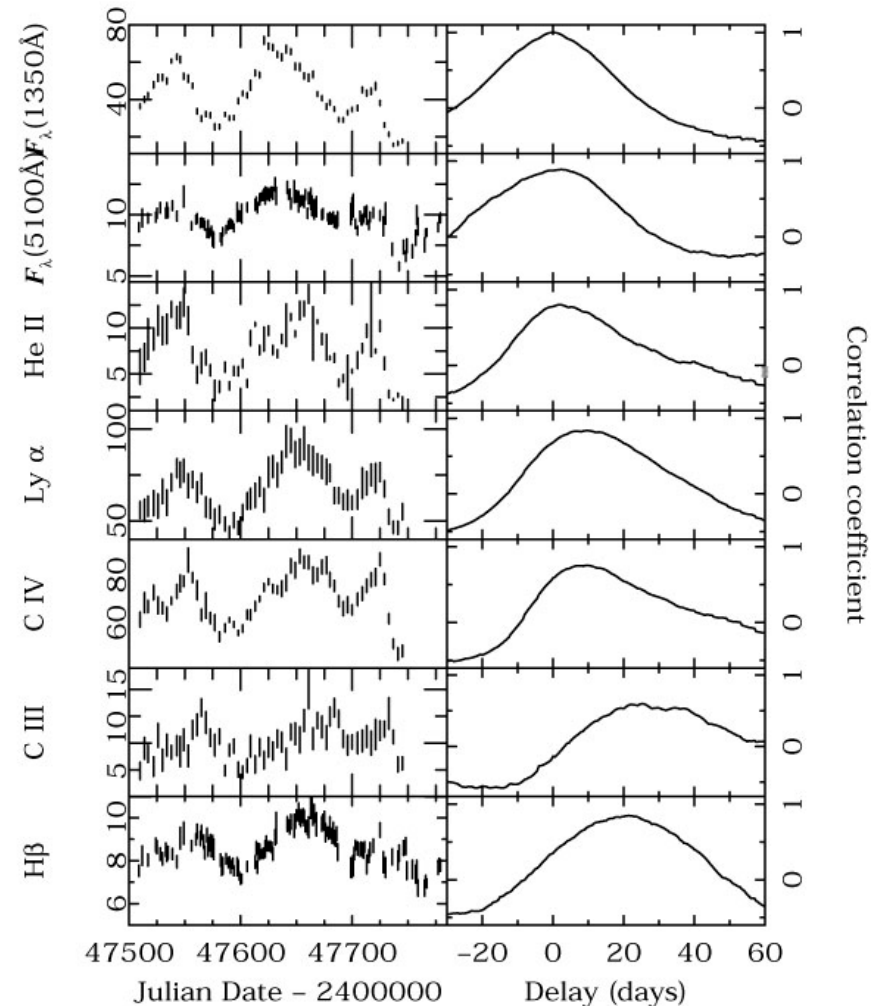
- \* AGN continuum produced by accretion disc close to central BH
- \* Broad emission lines produced in gas clouds further away, excited by continuum radiation
- \* Any change in continuum takes time,  $\tau$ , to reach BLR, so  $R_{\text{BLR}} = c\tau$ ,
- \* Then  $M_{\text{BH}} \sim \sigma^2 R_{\text{BLR}}$  from virial theorem, assuming broad line velocity width,  $\sigma$ , dominated by gravitational motions

# Reverberation mapping

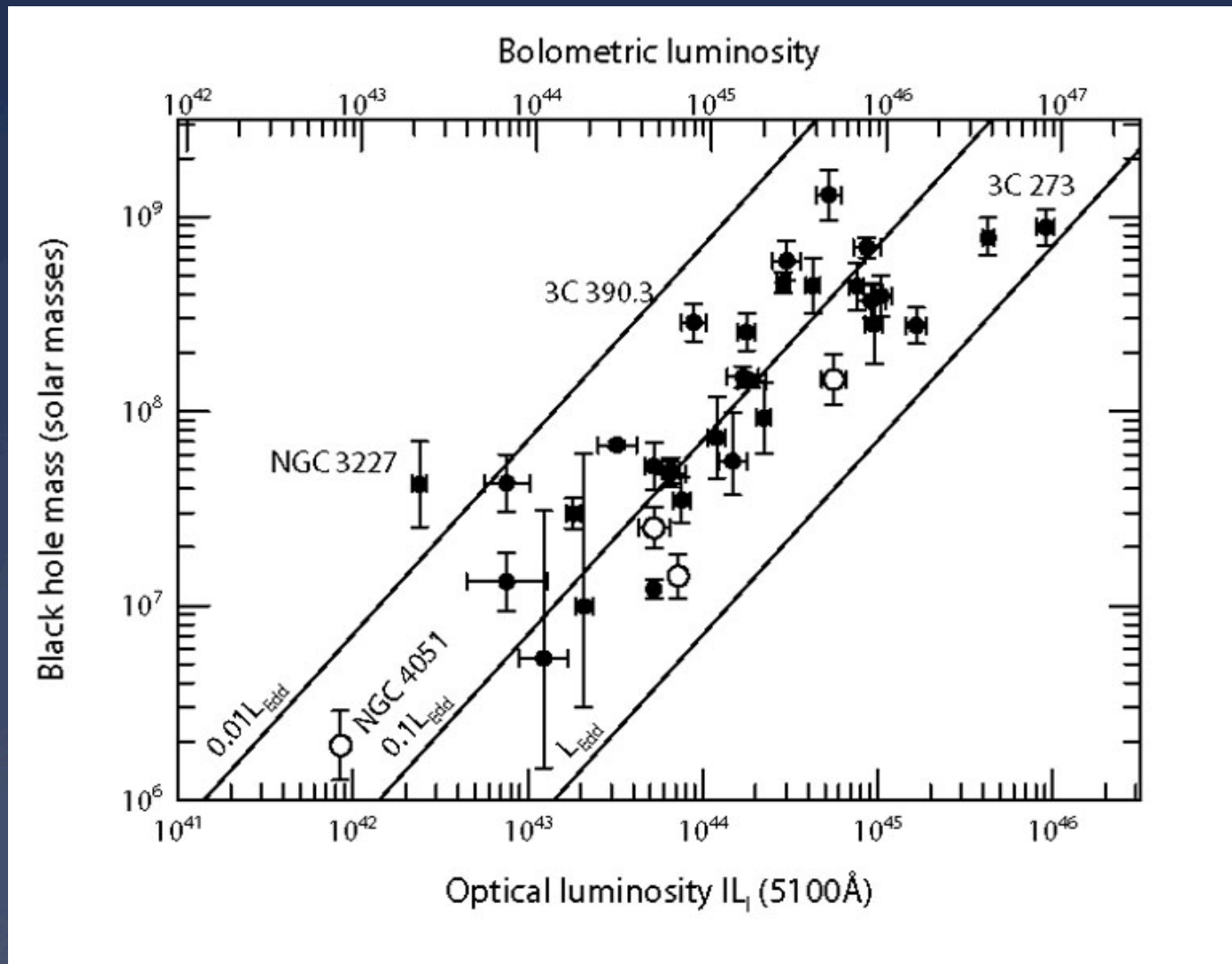


# Standard reverberation mapping

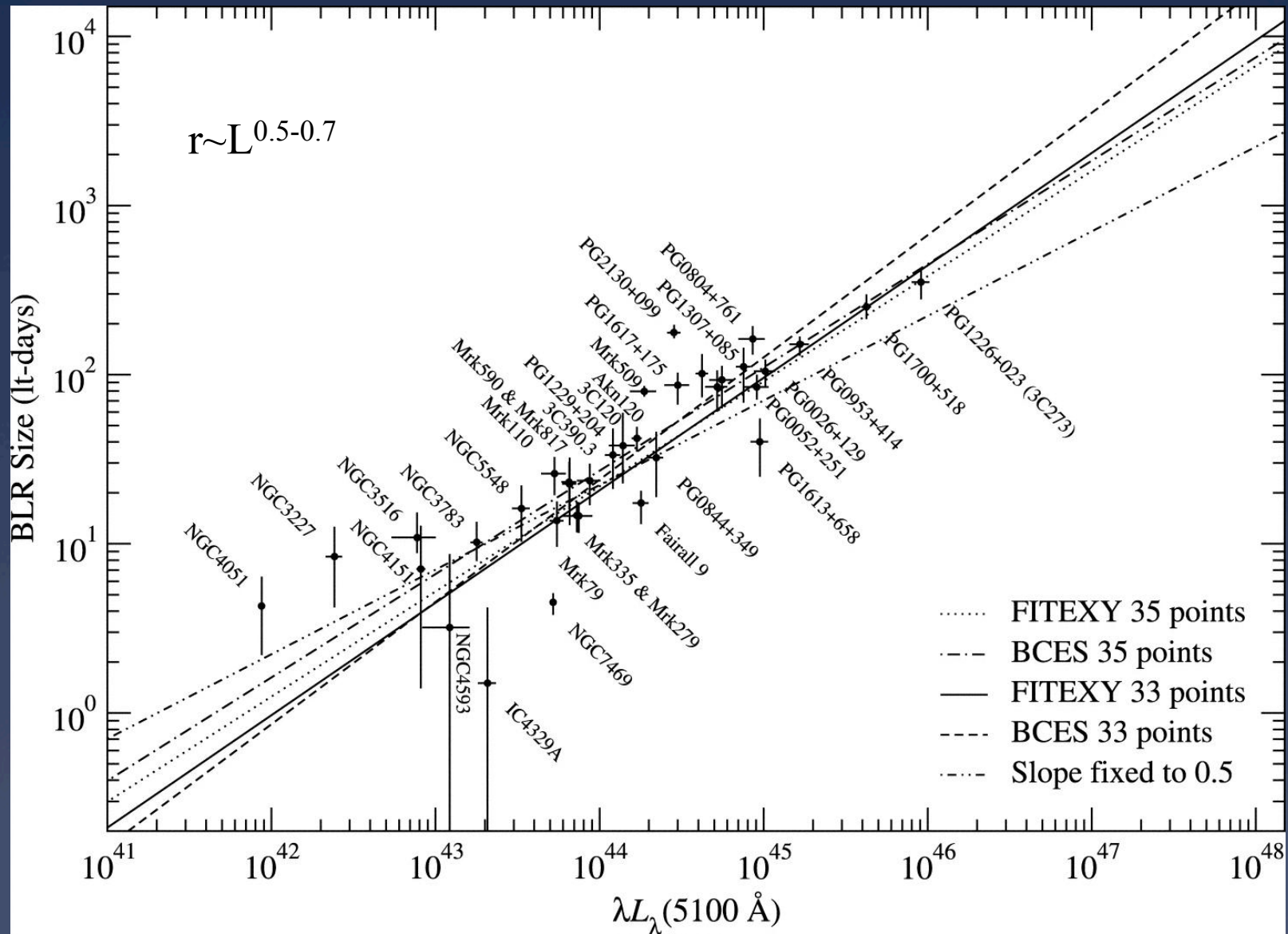
- \* Cross correlate continuum and emission line light curves
- \* Requires 10s to 100s of observational epochs to build up the light curves.
- \* Extremely observationally expensive
- \* For brighter objects the situation is worse since they have longer timescales and vary less
- \* To date essentially no reverberation mapping has been performed at  $z > 0.1$ ,  $M < -24$  or with UV lines



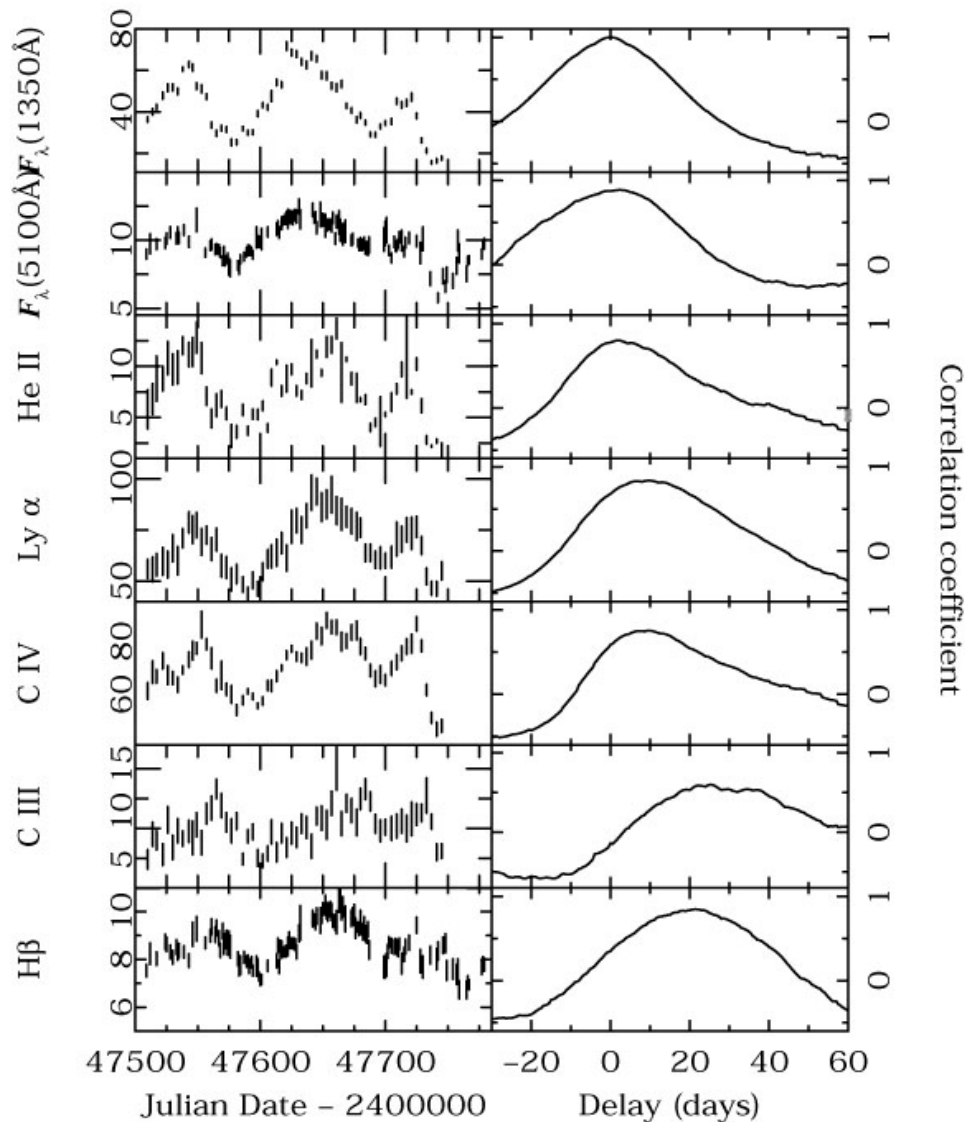
# Rev mapping results – $M_{\text{BH}}-L$



# Reverberation mapping results: $r-L$ relation



# Reverberation mapping results: Line stratification



Weaker continuum  
 Low-ionisation lines  
 H $\beta$ , MgII...

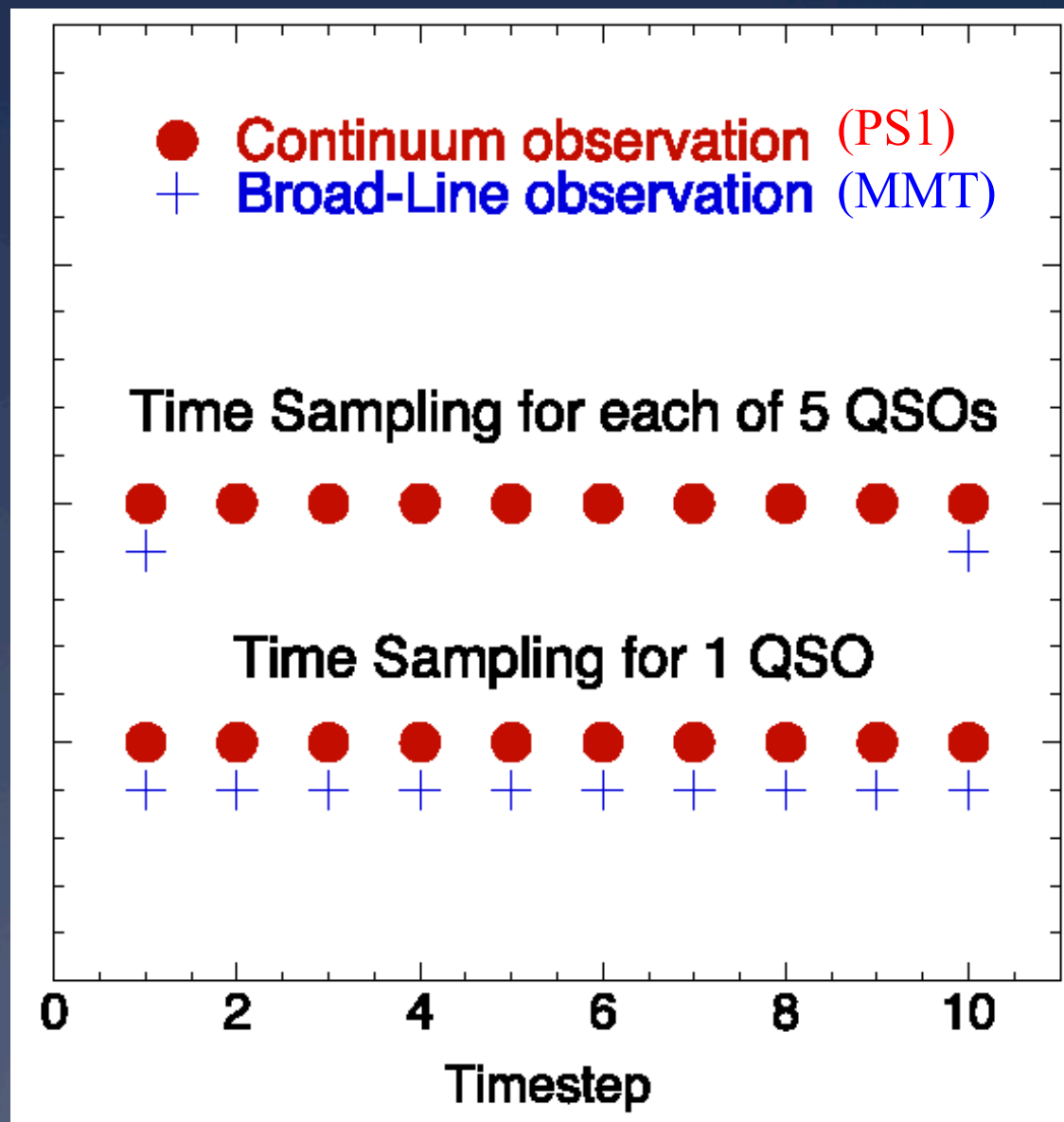
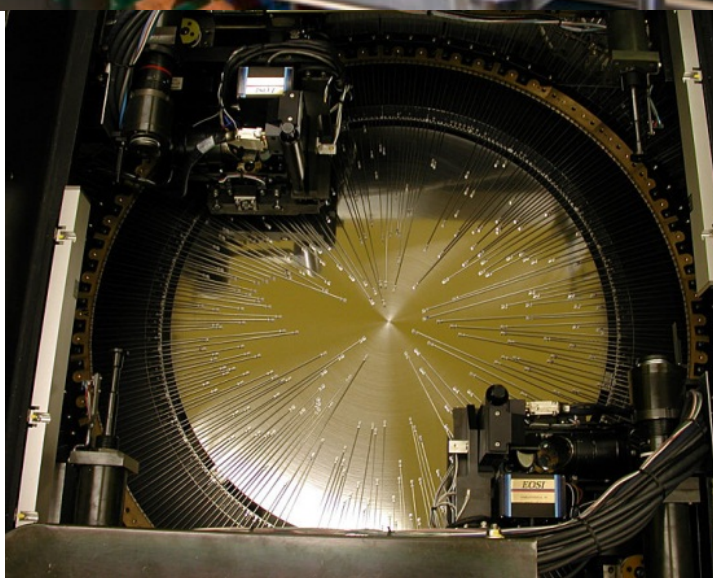
Strong continuum  
 High-ionisation lines  
 CIV, HeII...

Broad Line Region


 Ionising continuum source

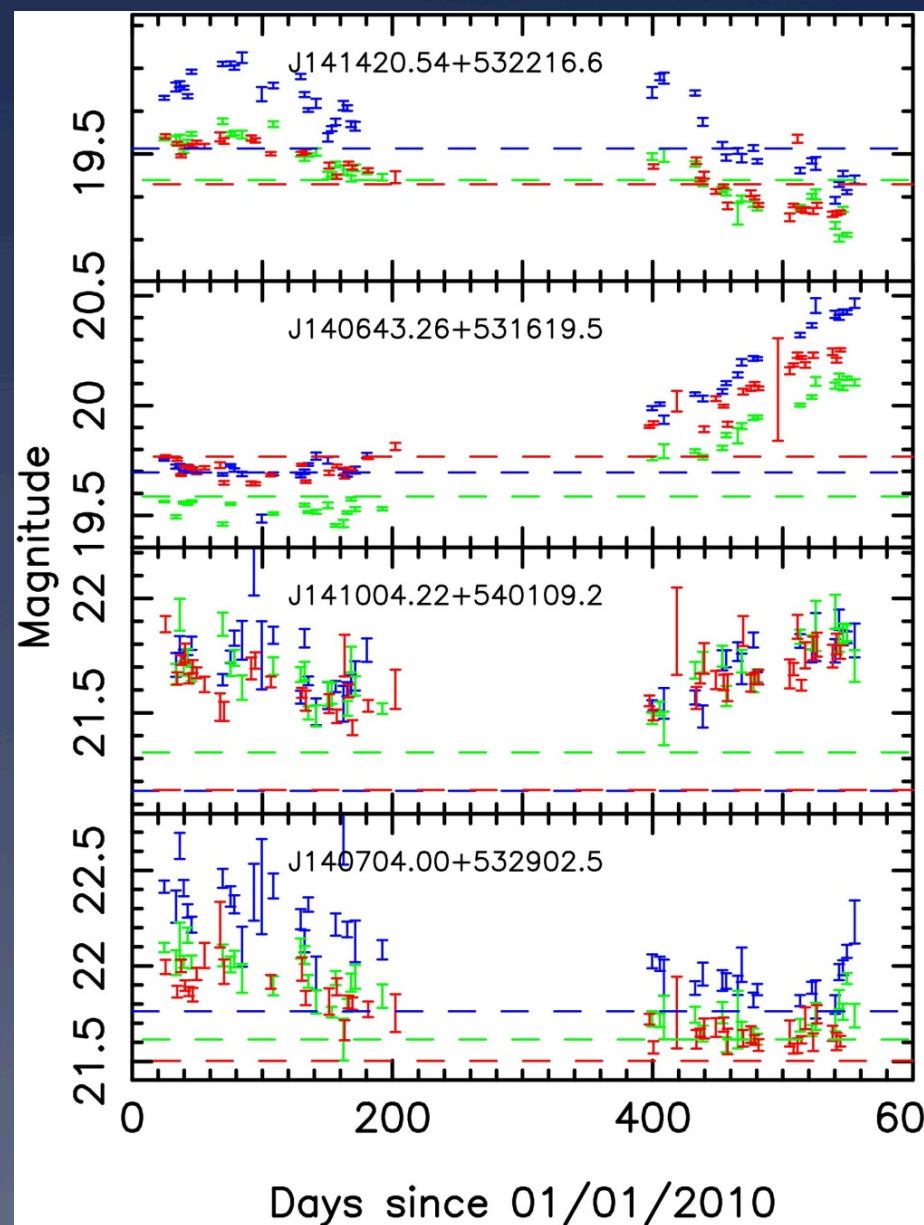


# Stacked reverberation mapping

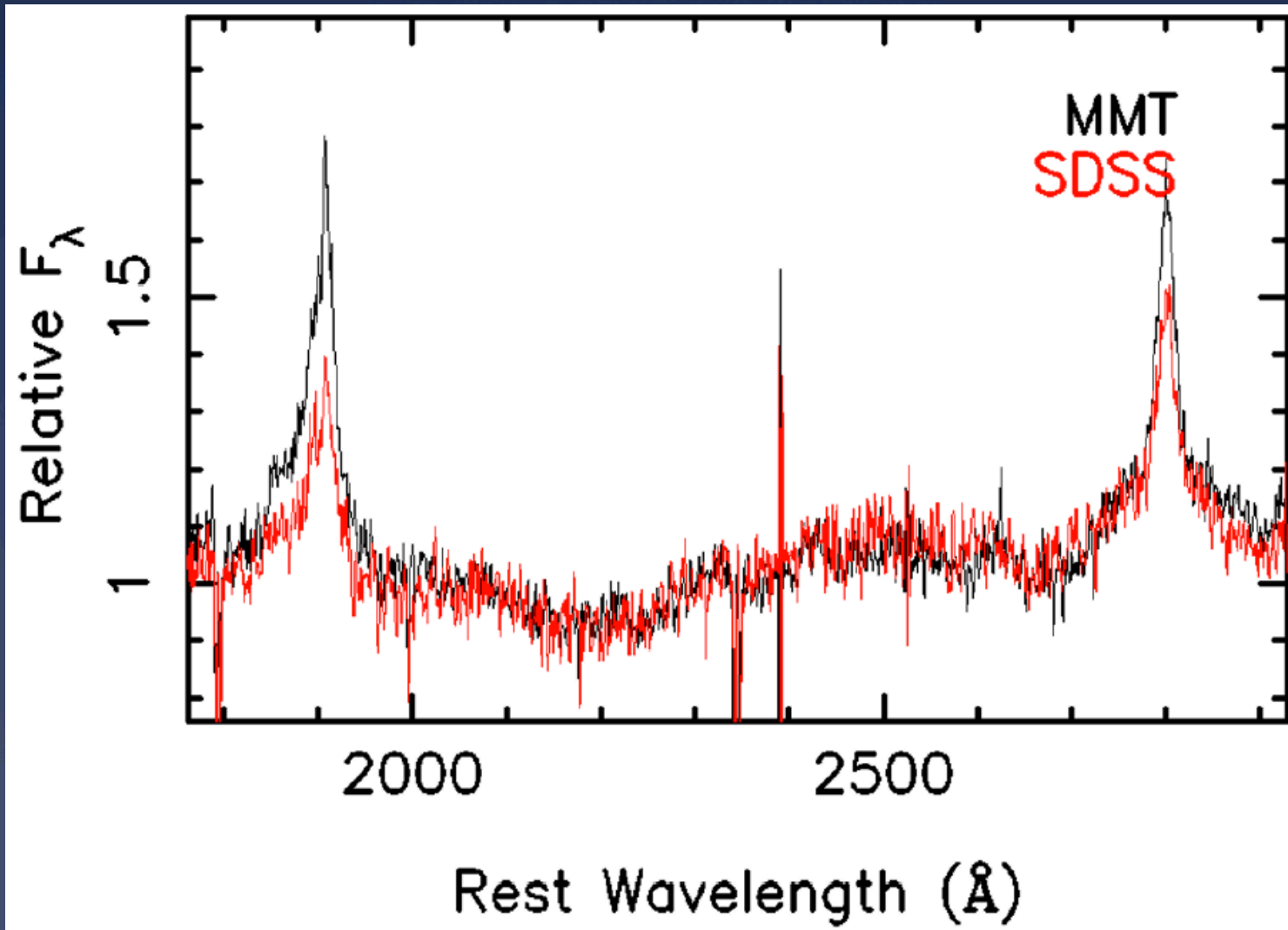


# First attempt: PS1+MMT Hectospec

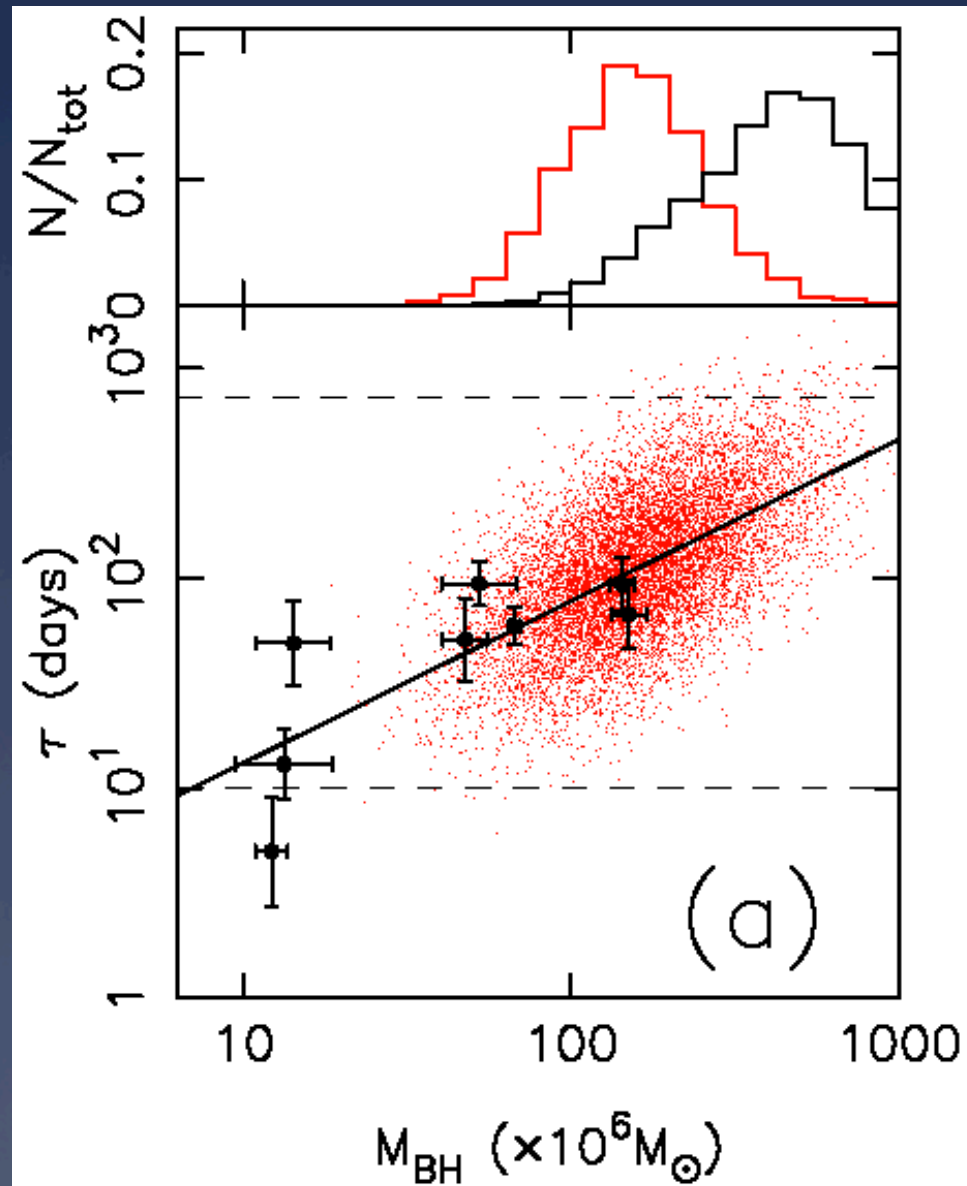
- \* We have repeat spectroscopy from MMT Hectospec of 368 quasars in a Pan-STARRS field that is monitored photometrically ~weekly
- \* 100/75 of these have a good MgII/CIV line in their spectrum.
- \* Is this enough to do some reverberation mapping?



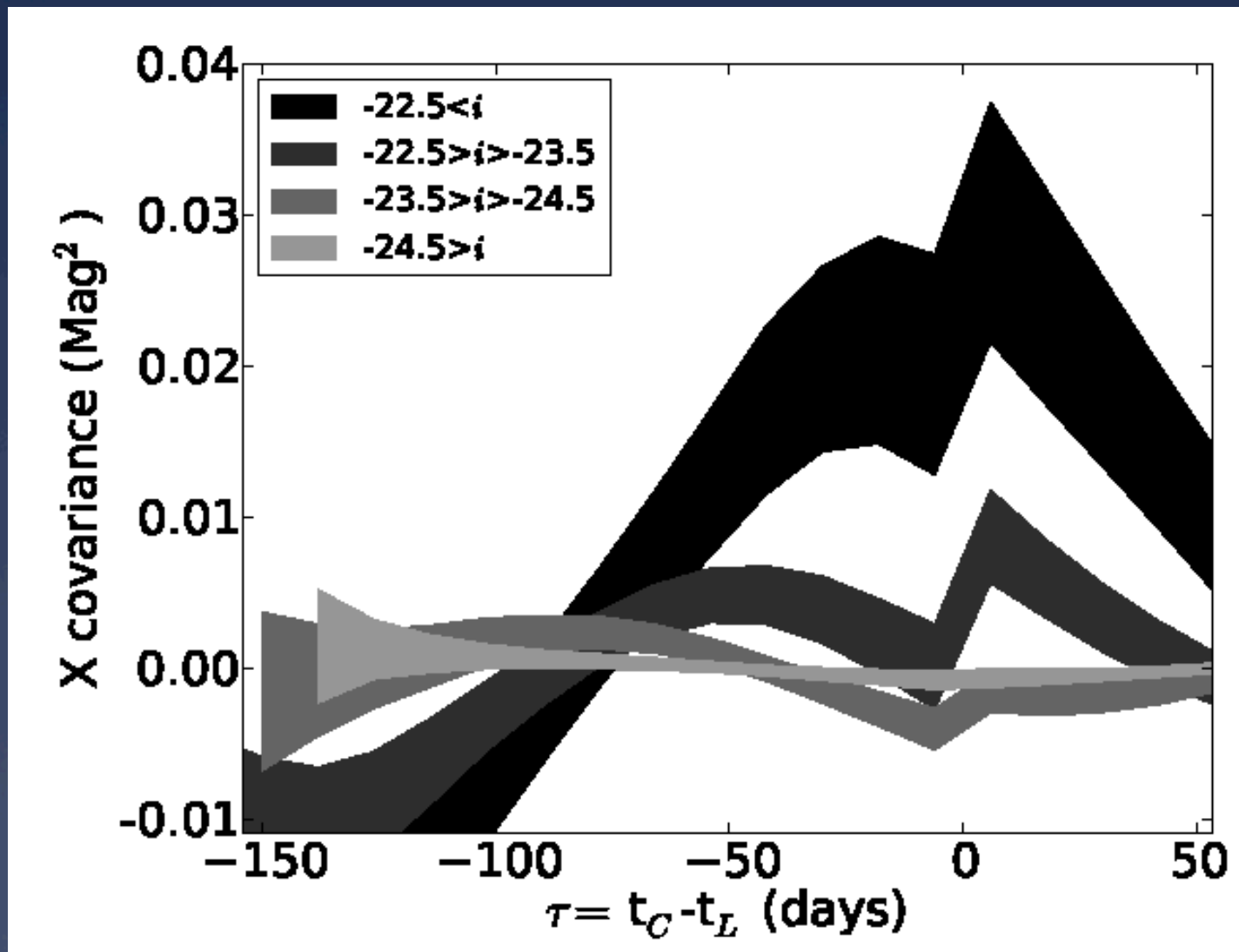
# QSO Broad Line variability



# Simulated delays for $g < 22.5$

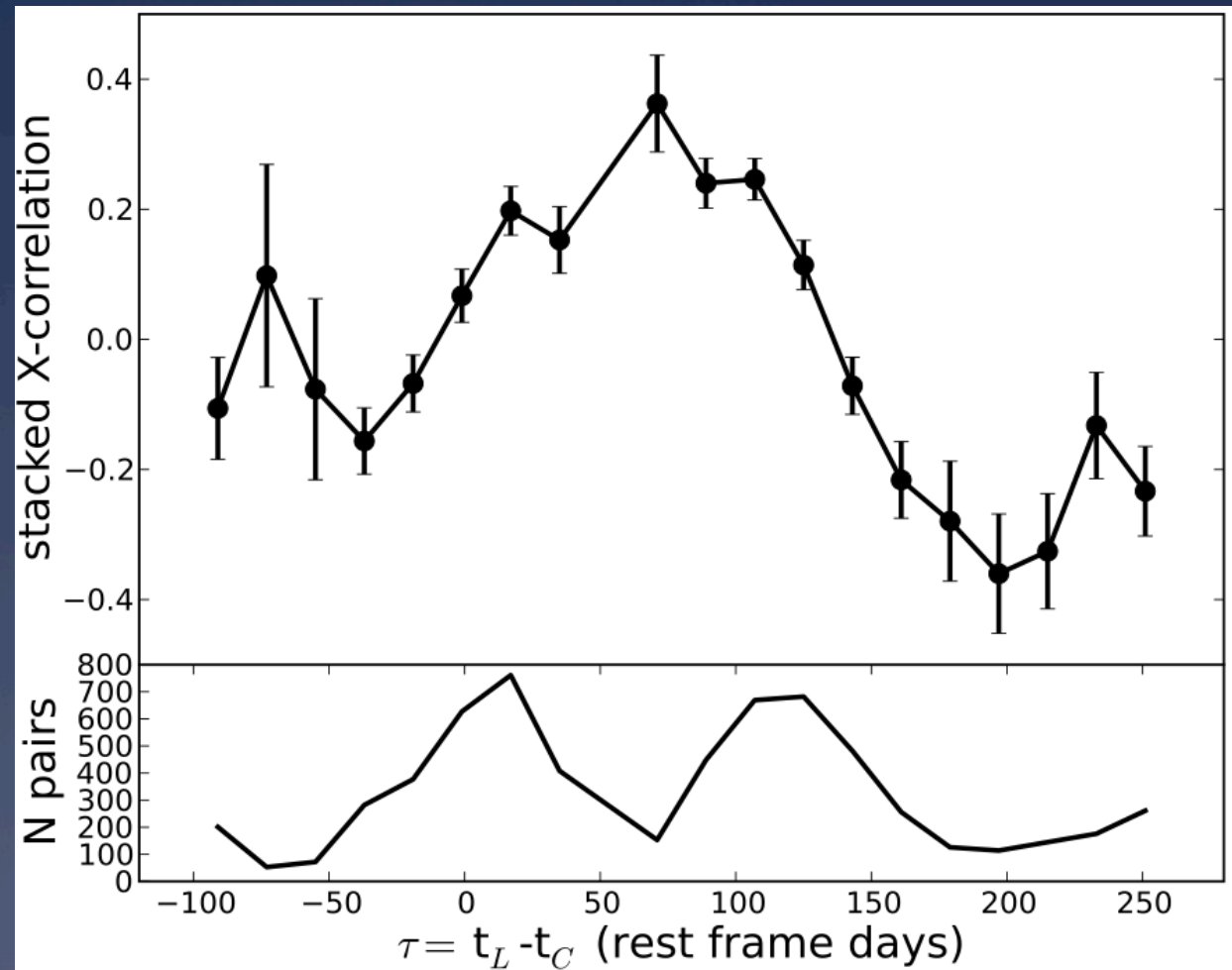


# Stacked xcor simulations



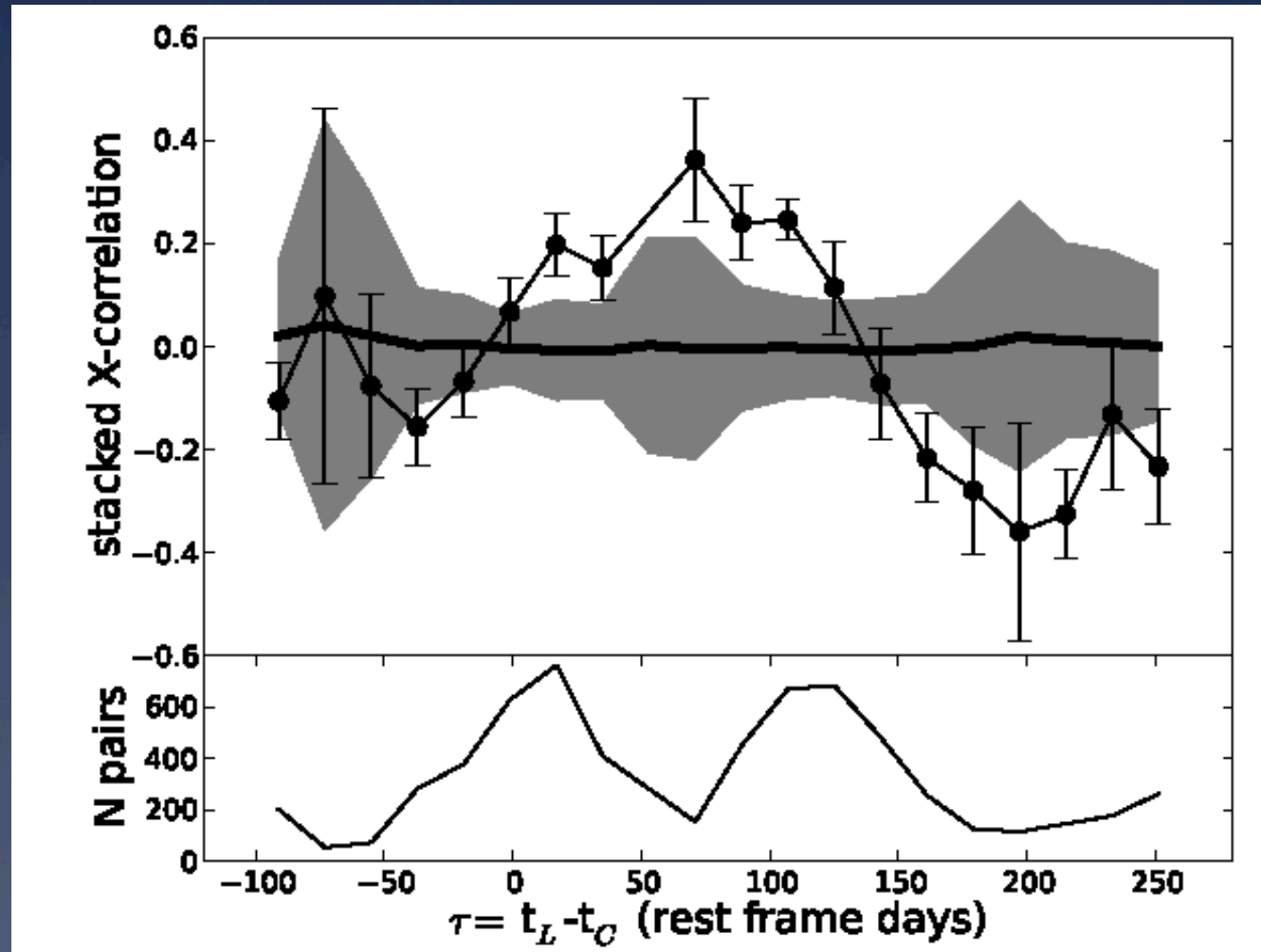
# Stacked reverberation mapping

- \* 368/2200 PS1 QSOs
- \* Observed twice at MMT Hectospec
- \* Stacked CIV – continuum cross-correlation
- \* Line-continuum lag of ~75days?
- \* Fine et al (2011,2012)

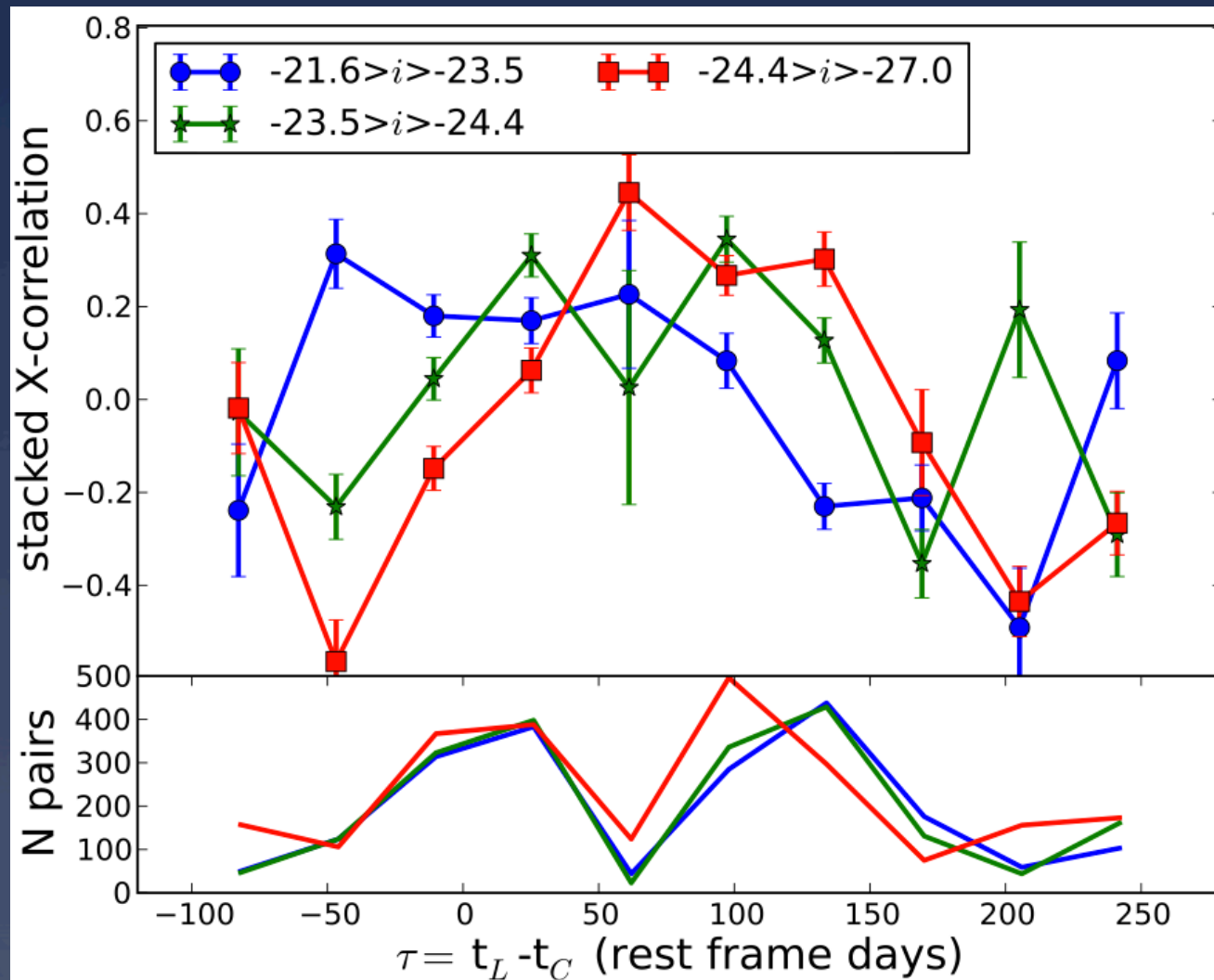


# Stacked reverberation mapping

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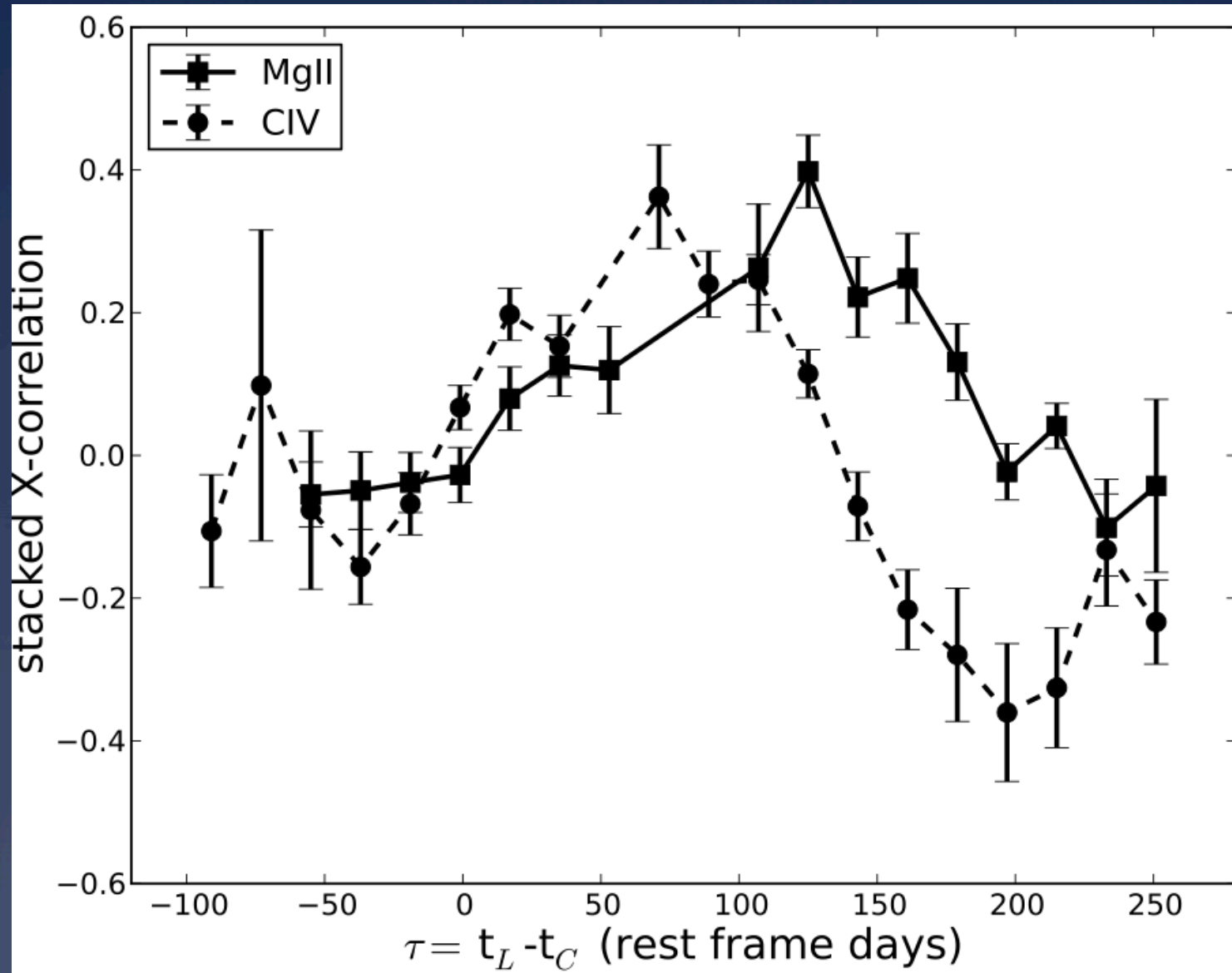


# CIV Lag – L dependence?

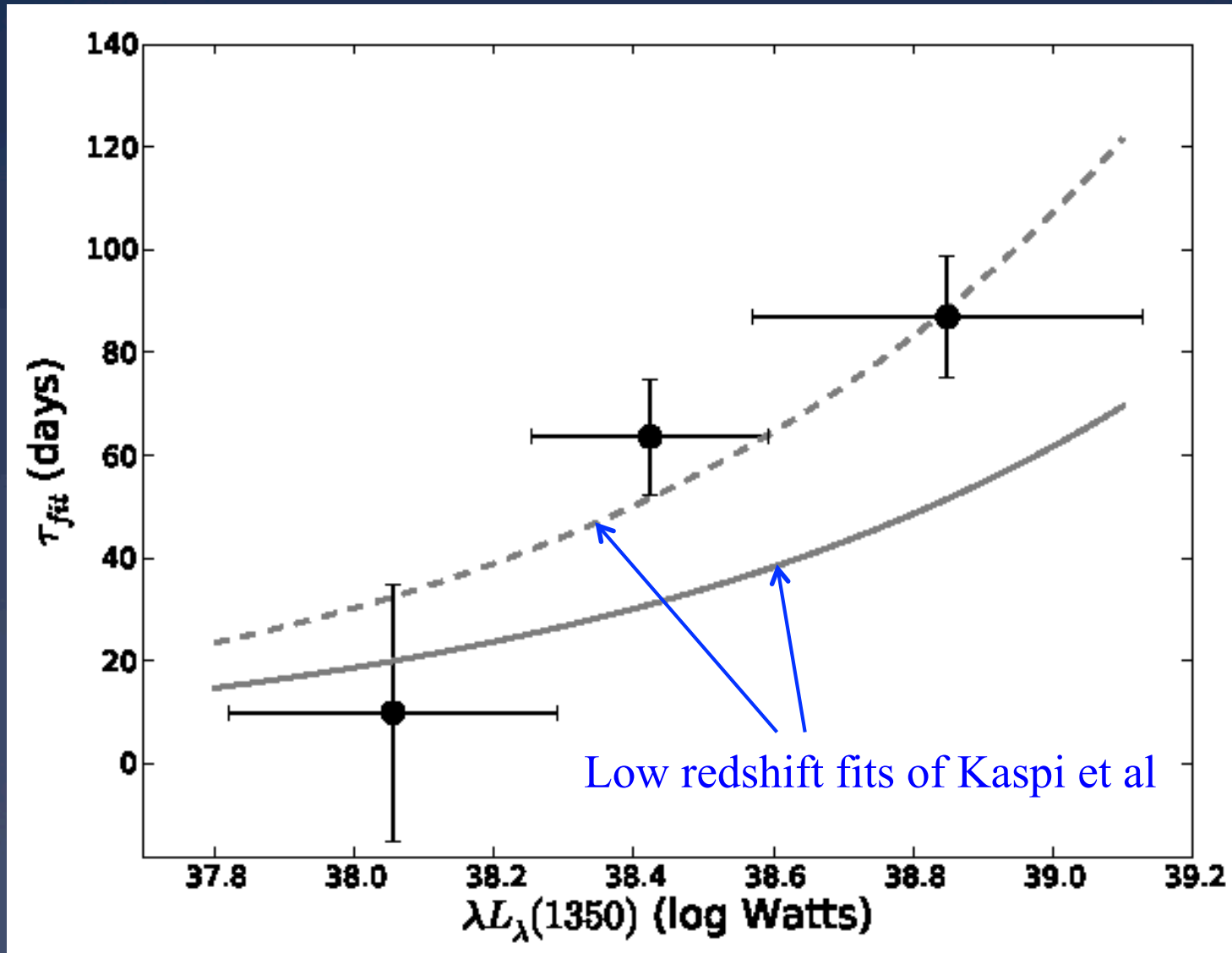




# Lag versus line ionisation



# Stacked CIV Lag v Luminosity



# Conclusions

- \* Reverberation results provide direct measurements of quasar BLR radii and BH masses
- \* Reverberation mapping needed for quasars at high redshifts and high luminosities
- \* Stacking continuum- broad-line strengths cross-correlations over many quasars may provide a more observationally efficient route than single object reverberation mapping
- \* First results using PanSTARRS and MMT Hectospec show potential of the technique