Robotic Echo Mapping of 3c 120

Michael Hlabathe (U. Cape Town), et al.

Preliminary results in preparation for MNRAS.

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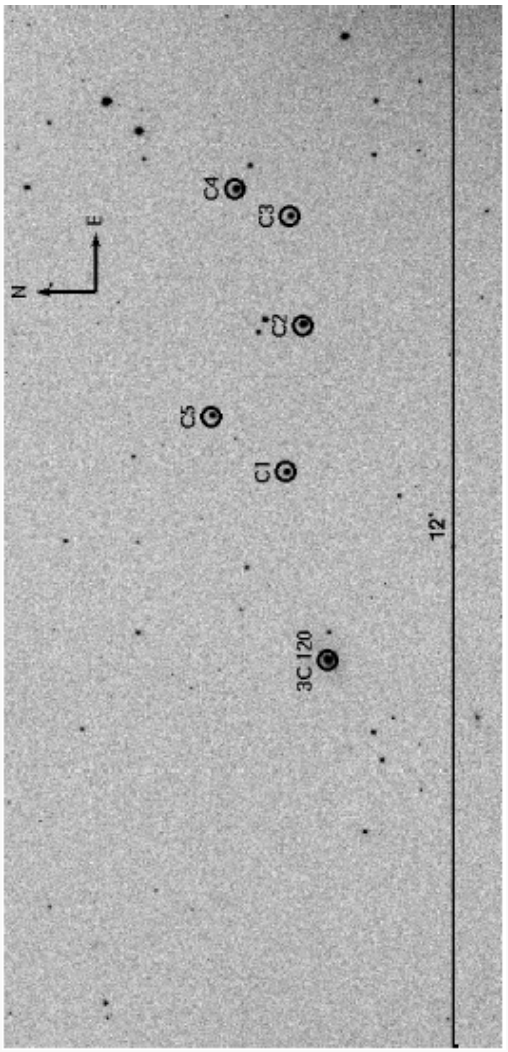
Reverberation Mapping of the Seyfert 1 Galaxy 3C 120

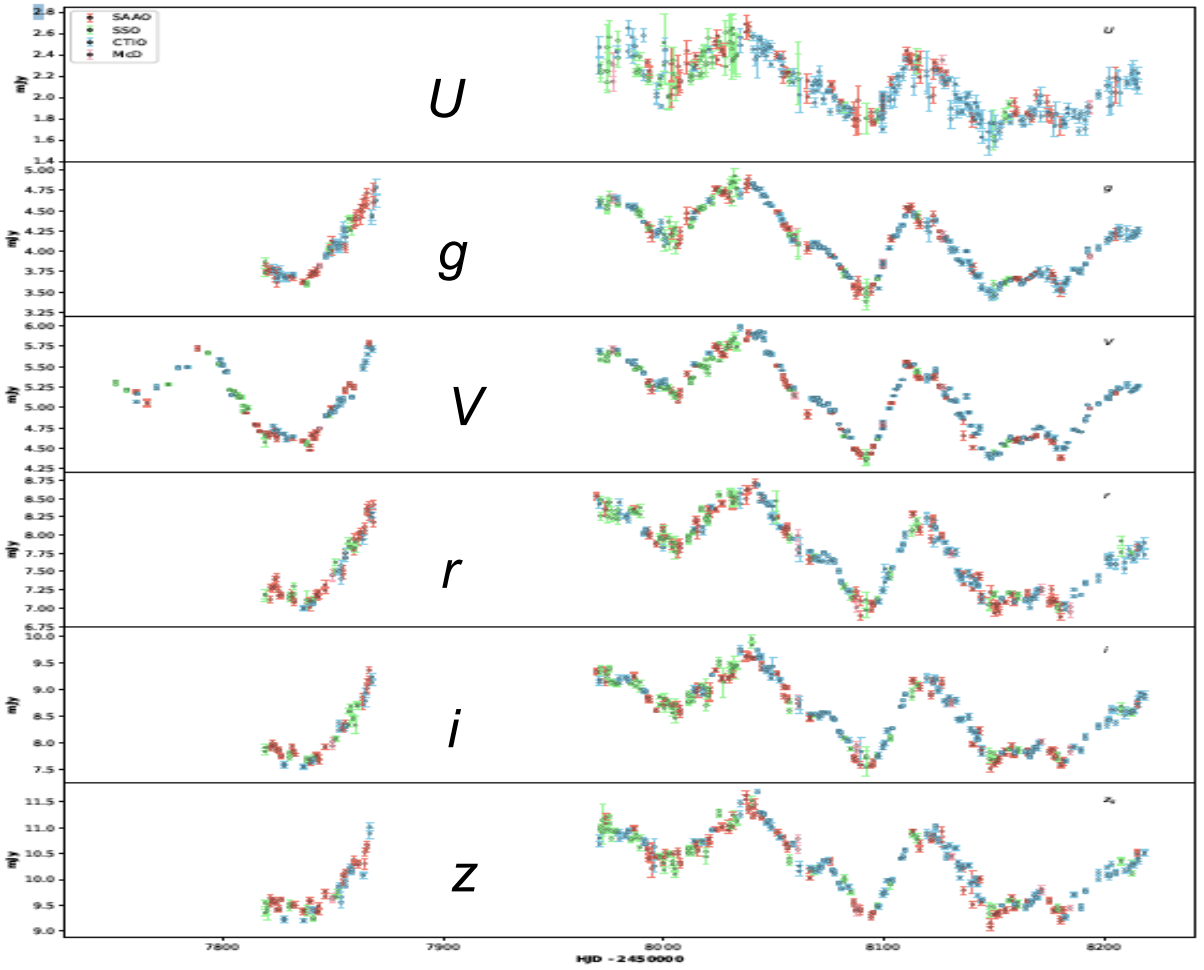
Michael S. Hlabathe[1,2★], David A. Starkey[3], Keith Horne[3], Encarni Romero-Colmenero[2,4], Steven M. Crawford[5], Stefano Valenti[6,7], Hartmut Winkler[8], Aaron J. Barth[9], Christopher A. Onken[10], David J. Sand[11], Tommaso Treu[12], Carolin Villforth[13]

Las Cumbres Observatory (LCO)
Global Robotic Telescope Network

- 3C120 observations : 2016 Dec – 2018 Apr
- UgVriz imaging photometry with LCO robotic 1m network.
- Floyds spectroscopy with 2m FTN/FTS in Hawaii/Australia.

LCO Robotic 1m Imaging Photometry





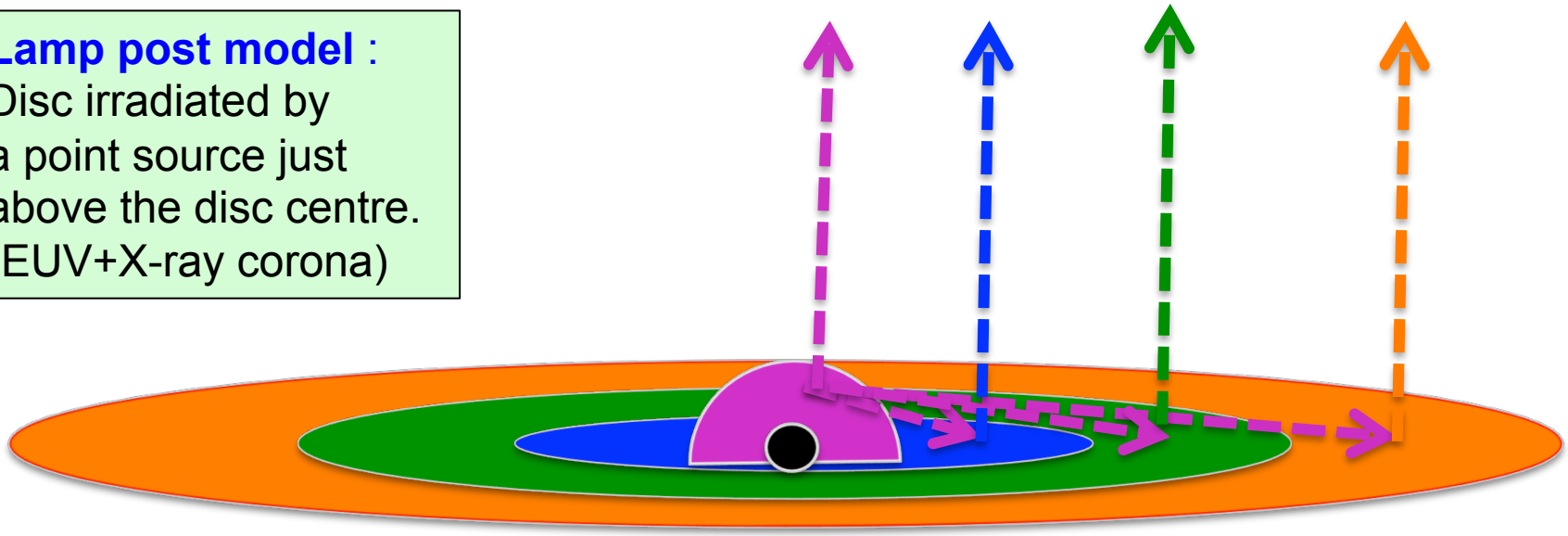
Aperture Photometry using AstroImageJ
Multi-site inter-calibrations using CREAM

Continuum Echo Mapping :
T(r) profiles of Accretion Discs

- Measure the time delay spectrum $\tau(\lambda)$
- To find the disk temperature profile $T(r)$
- Test disc models:

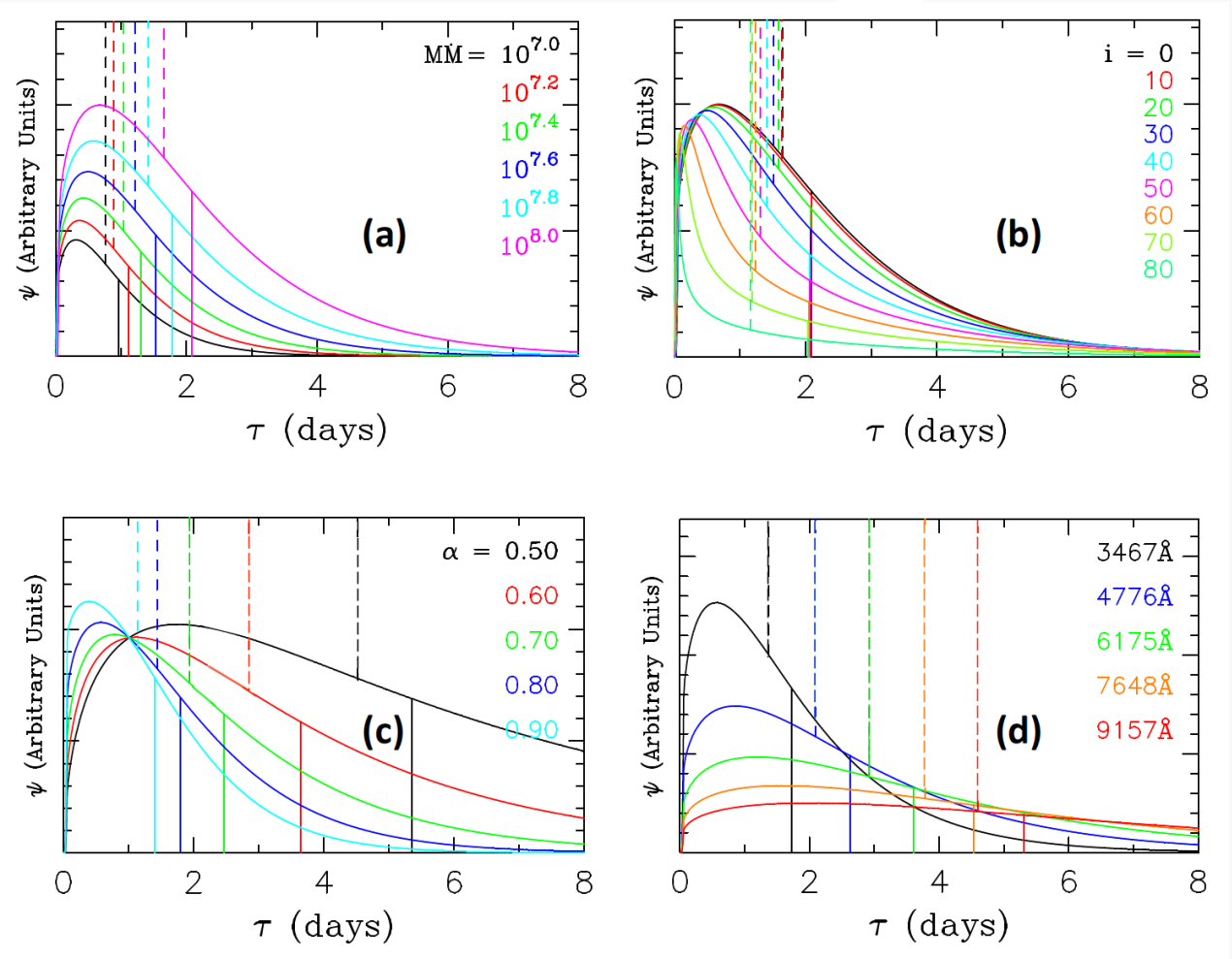
$$T(r) = \left(\frac{3\,G\,M\,\dot{M}}{8\,\pi\,\sigma\,r^3} \right)^{1/4} \rightarrow \begin{array}{l} \tau \propto \lambda^{4/3} \\ f_\nu \propto \nu^{1/3} \end{array}$$

Lamp post model :
Disc irradiated by
a point source just
above the disc centre.
(EUV+X-ray corona)



Blackbody Disc Delay Maps

$$T(r) = T_1 \left(r/r_1\right)^{-\alpha} \rightarrow \tau \propto \lambda^{-1/\alpha}$$



Mean delay
$< \tau > \sim (M\ \dot{M})^{1/3}\ \lambda^{4/3}$
Independent of disk inclination.

Delay map shape depends on disk inclination

And slope α of
$T(r) \sim R^{-\alpha}$
temperature profile

Theory: $\alpha = 3/4$

Starkey, et al. 2016

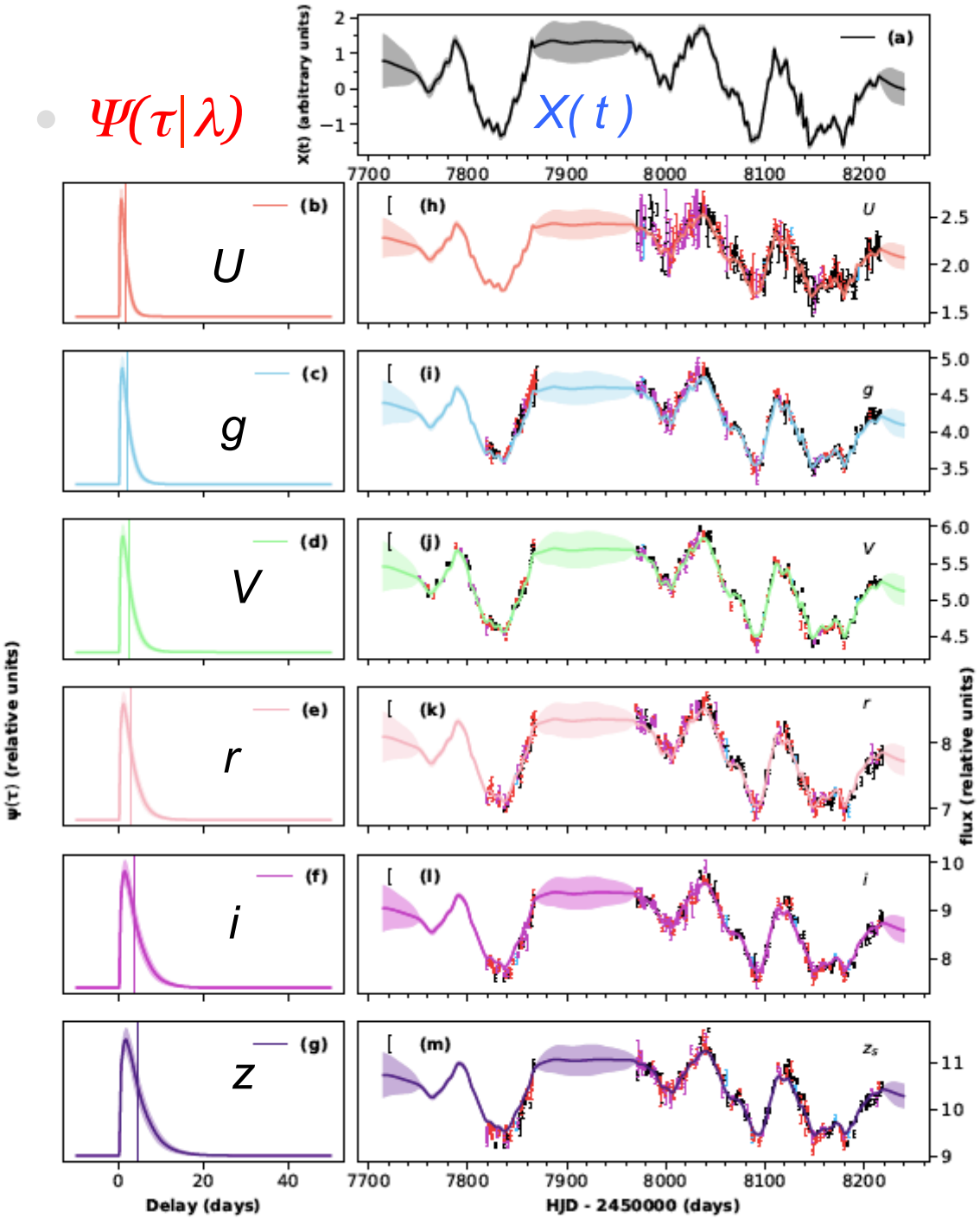
CREAM fit to Light Curves

(Starkey et al. 2016)

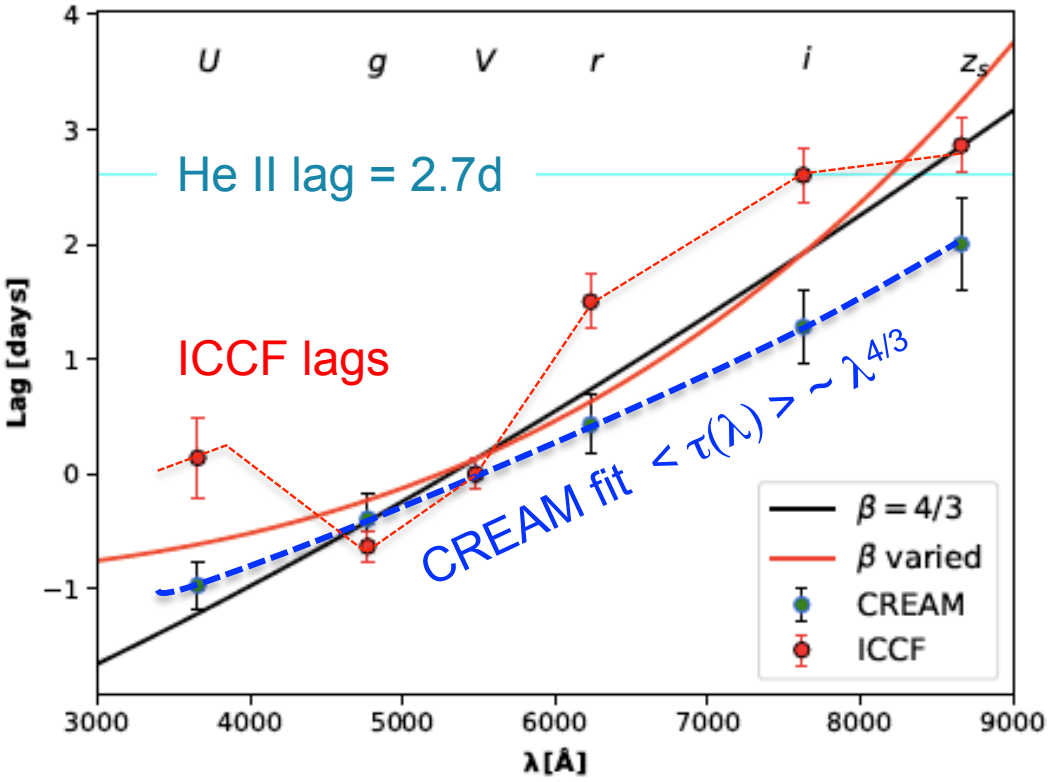
- CREAM: MCMC fit of
- lamp post model.
- Driving lightcurve: $X(t)$ = fourier series with DRW prior.
- $\Psi(\tau|\lambda)$ = echo maps
- face-on blackbody disc
- $T(r) = T_1 (r/r_1)^{-3/4}$

$$T_1 = \left(\frac{3\,G\,M\,\dot{M}}{8\,\pi\,\sigma\,r_1^3} \right)^{1/4}$$

- $\Psi(\tau|\lambda)$



Delay Spectrum: τ(λ) -> T(r) -> M dM/dt

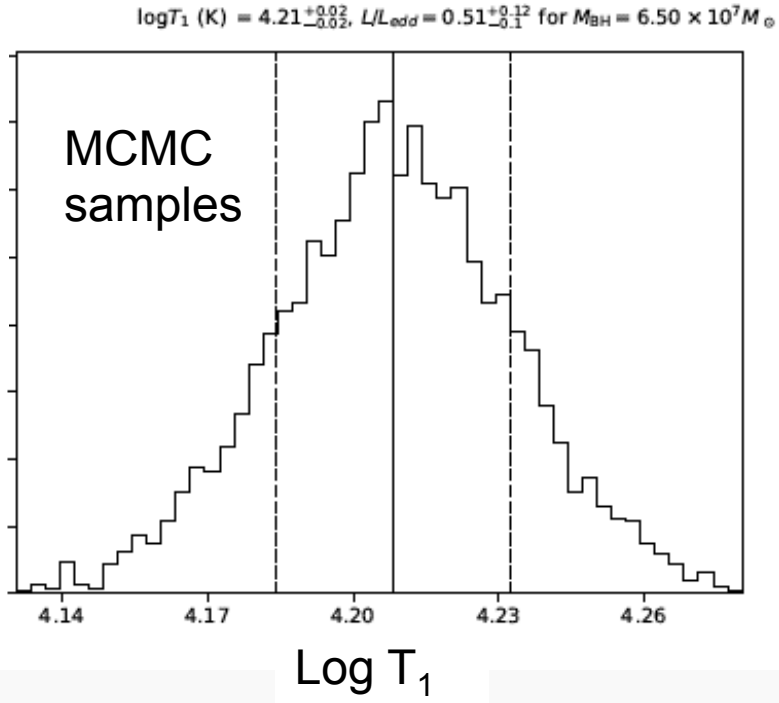


CREAM fit parameters:

$$\log T_1 = 4.21 \pm 0.02$$

=> $\dot{M}/\dot{M}_{\rm Edd} = 0.51 \pm 0.2$

for $M_{\rm BH} = 6.5 \times 10^7 M_\odot$

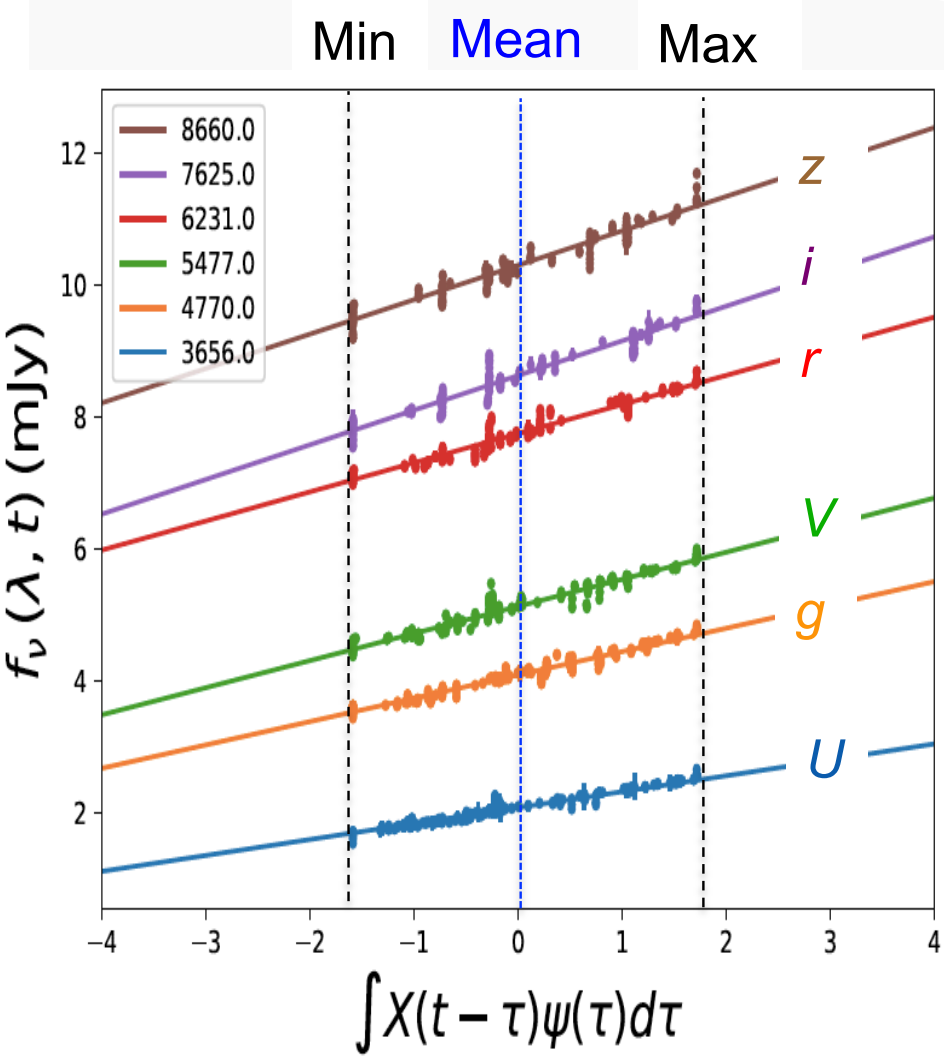


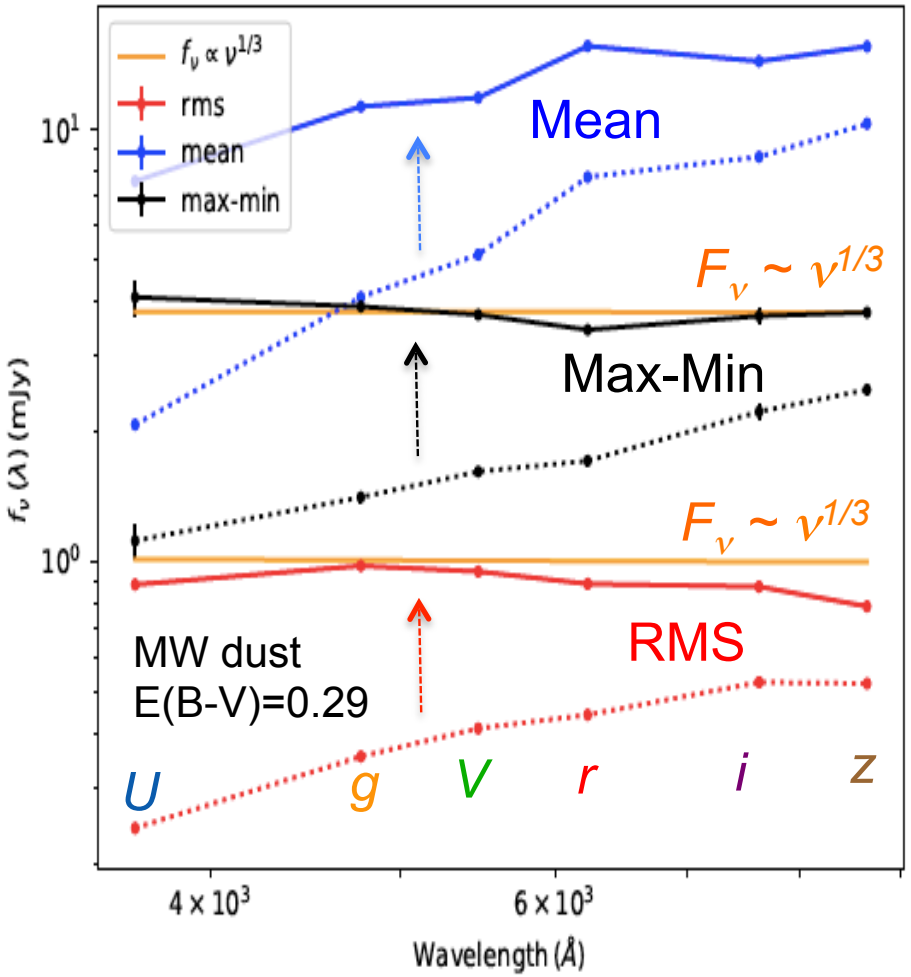
Caveat: ICCF lags show
3640A Balmer Jump (*U* to *g*)
8200A Paschen Jump (*i* to *z*)

=> HI Bound-Free Continuum from BLR?

Variations isolate the Disk Spectrum

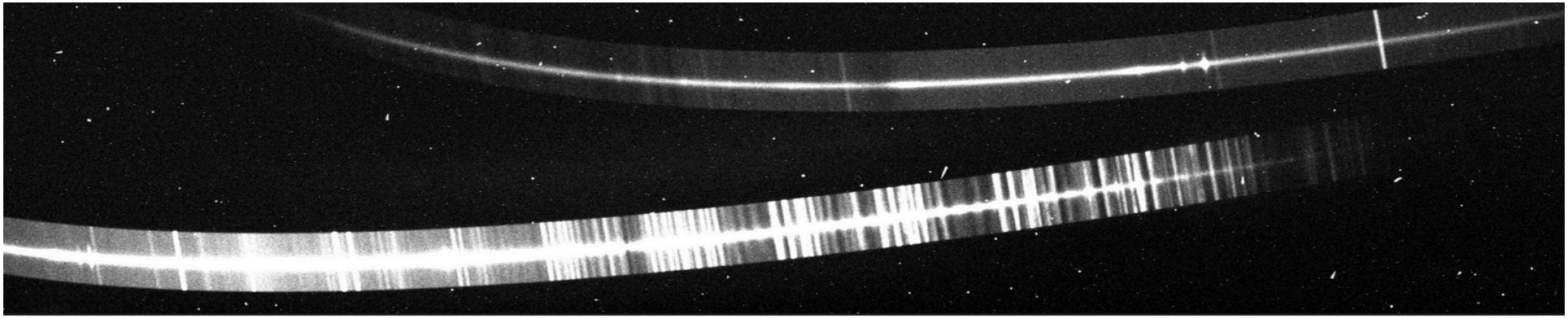
$$F(t,\lambda) = \bar{F}(\lambda) + \Delta F(\lambda) \int \Psi(\tau|\lambda)\, X(t-\tau)\, d\tau$$

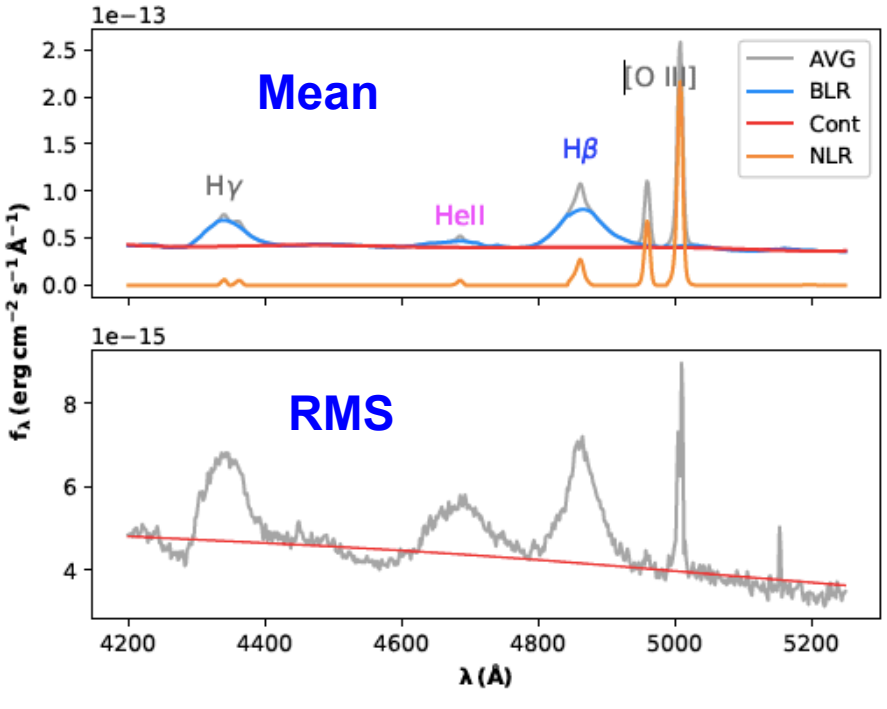


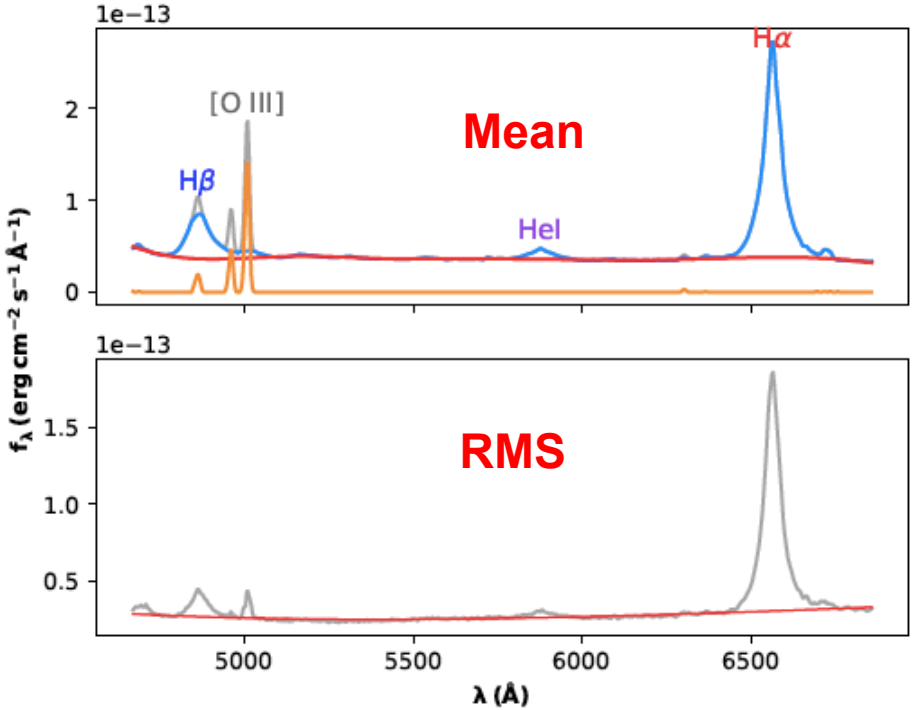


No sign of Balmer/Paschen jumps

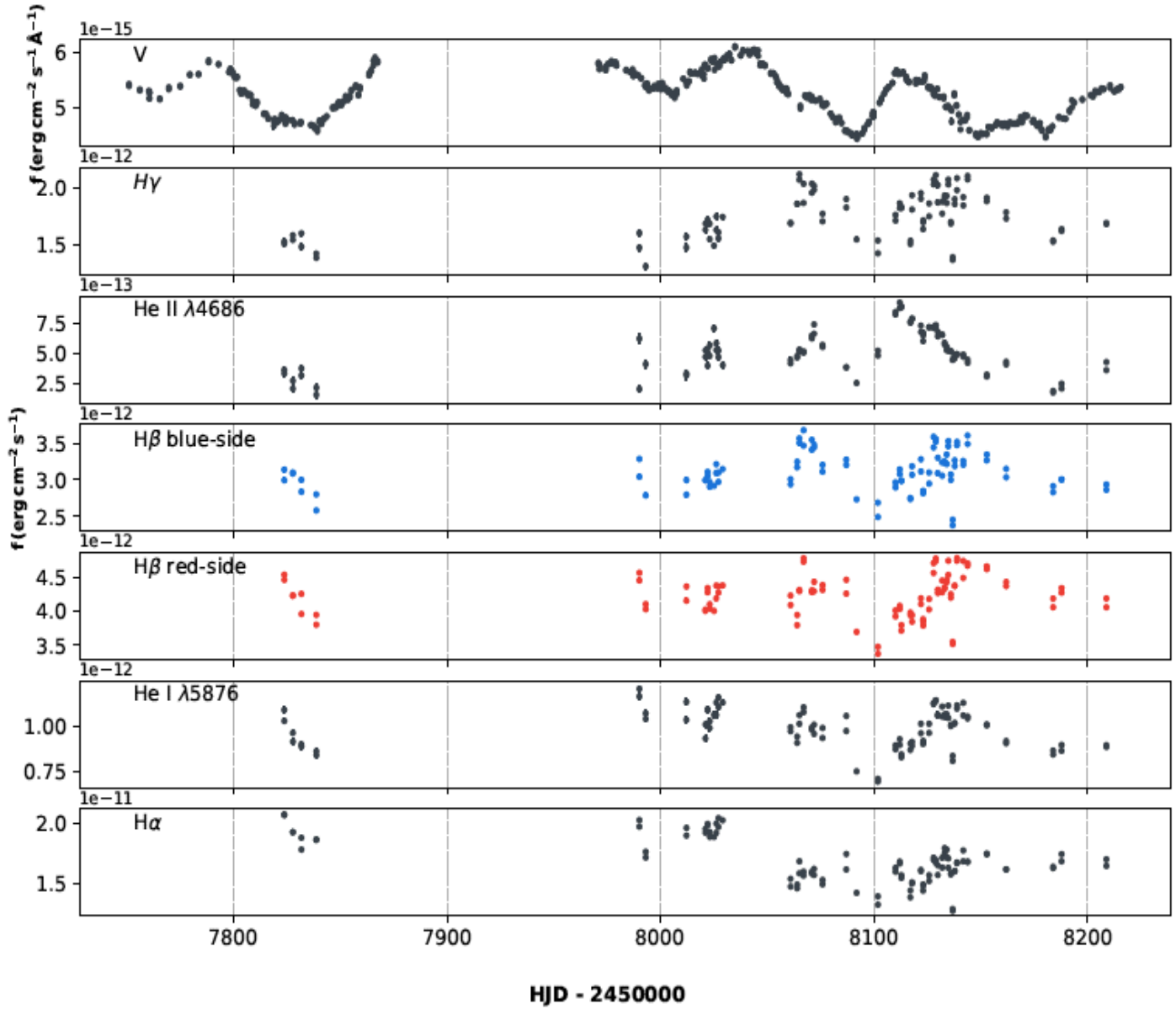
LCO Robotic 2m/Floyds Spectra







Emission-Line Light Curves



V

Hγ

HeII 4686

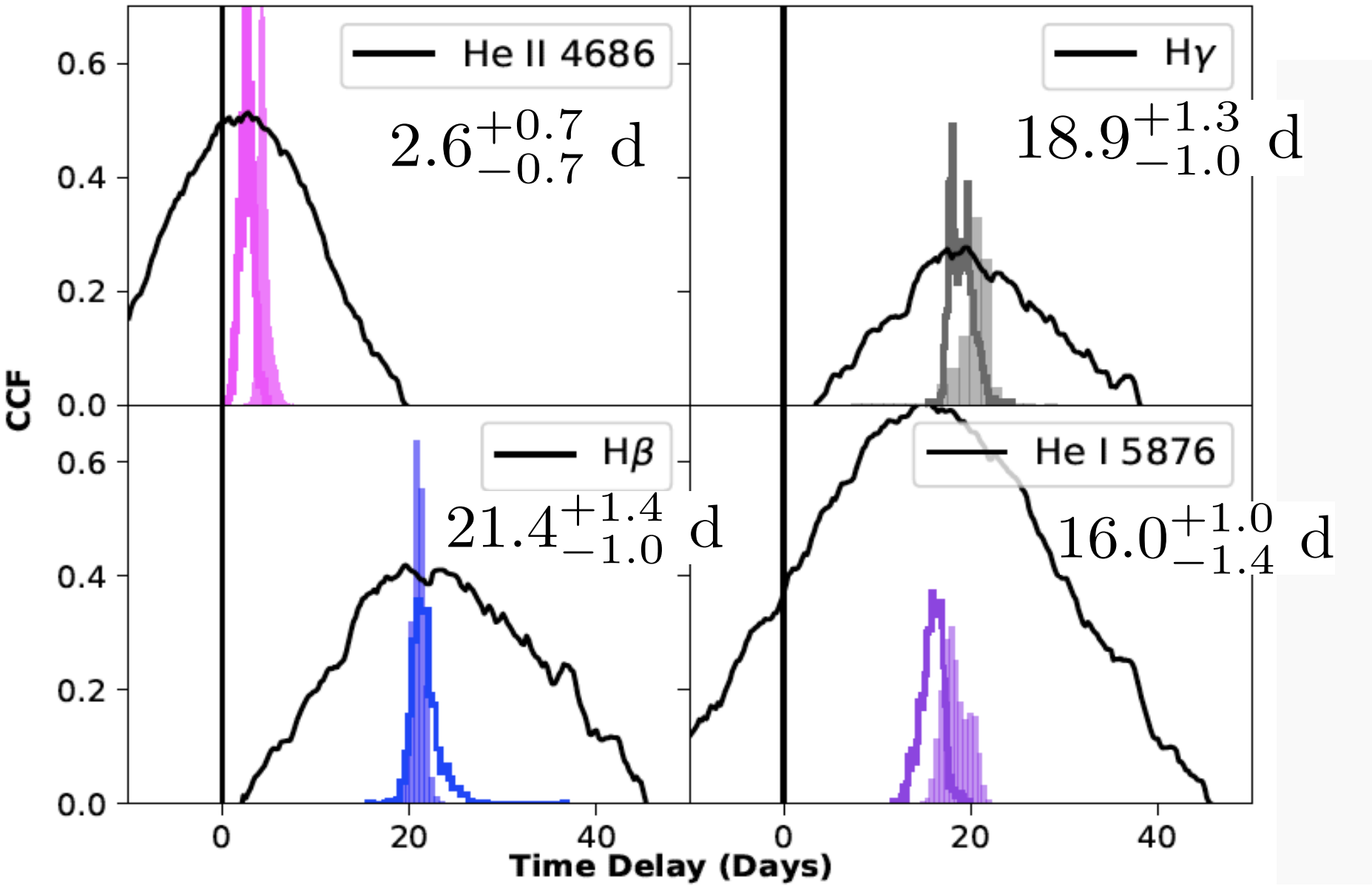
Hβ

Hβ

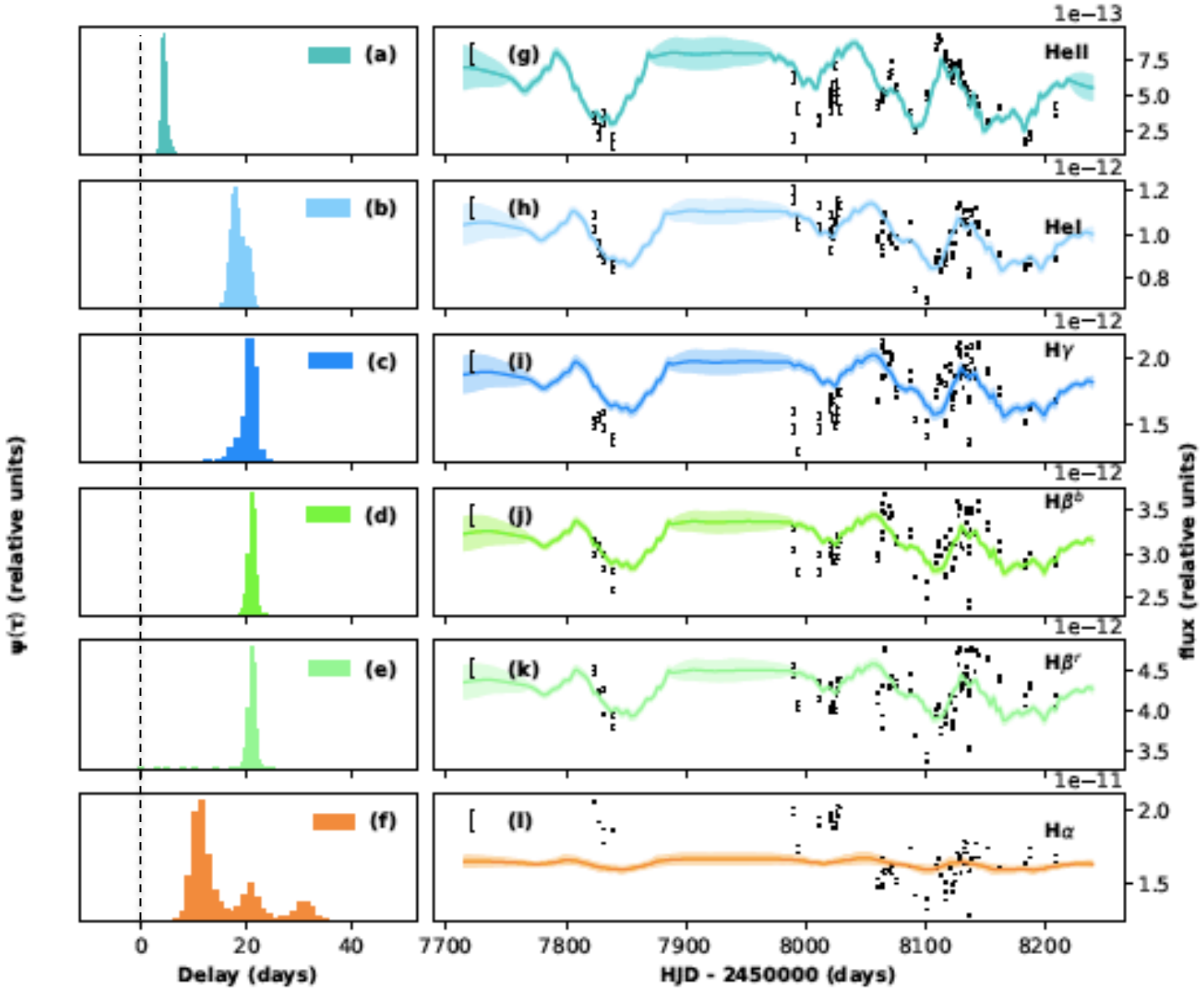
HeI 5876

Hα

ICCF Lags (and CREAM Lags)



CREAM fit : Emission-Line Light Curves



HeII 4686

HeI 5876

Hγ

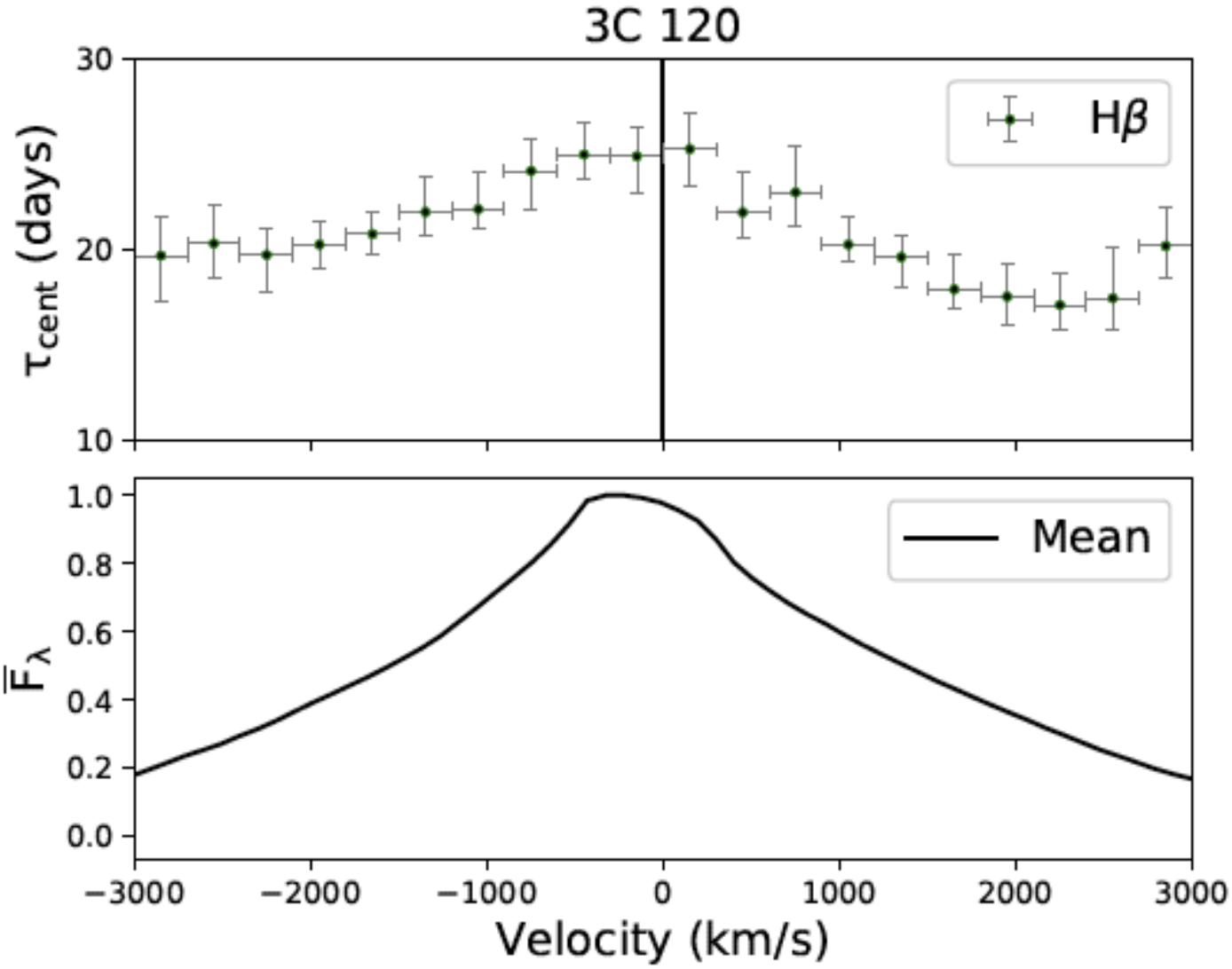
Hβ

Hβ

Hα

Velocity-Resolved CCF Lags

Symmetric “disc-like” kinematics



Black Hole Mass from Hβ

$$M_{\rm BH} = f\,\frac{\Delta V^2\, c\,\tau}{G}$$

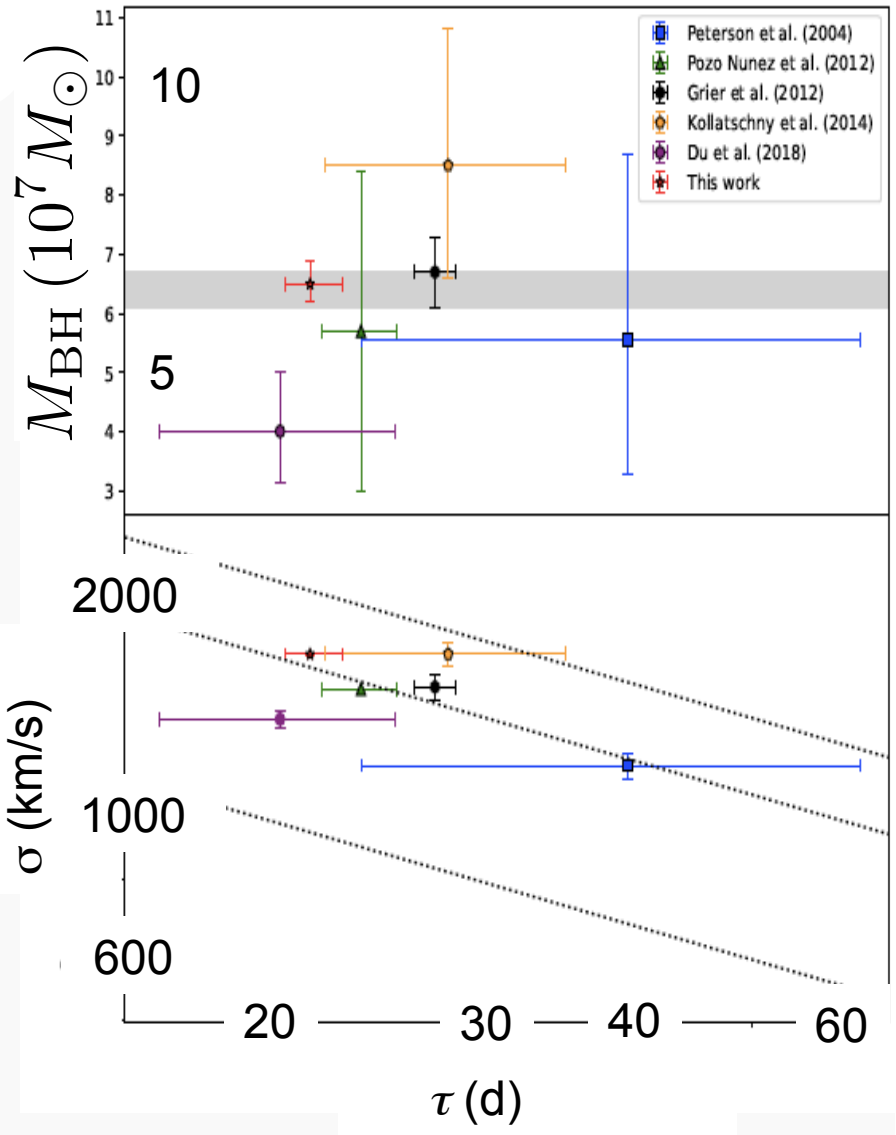
$$\tau = 21.4^{+1.4}_{-1.0}\,{\rm d}$$

$$\Delta V = \sigma(RMS) = 1690\,{\rm km/s}$$

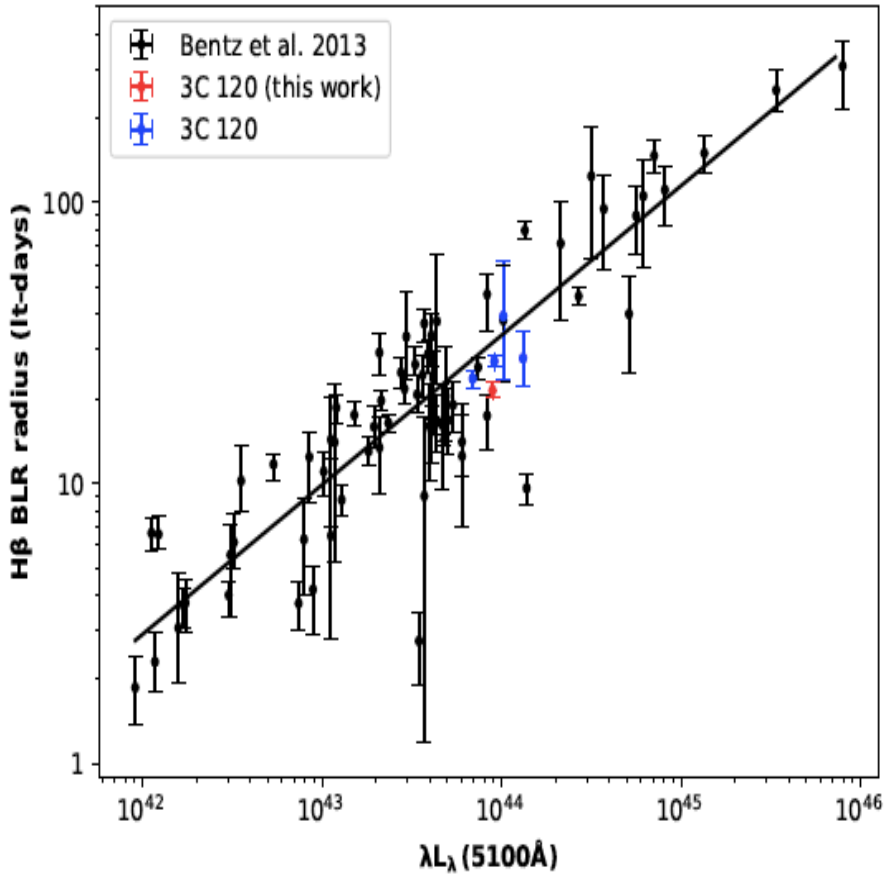
$$\frac{M_{\rm BH}}{10^7\,M_\odot} = [6.5^{+0.4}_{-0.3}]\,\left(\frac{f}{5.5}\right)$$

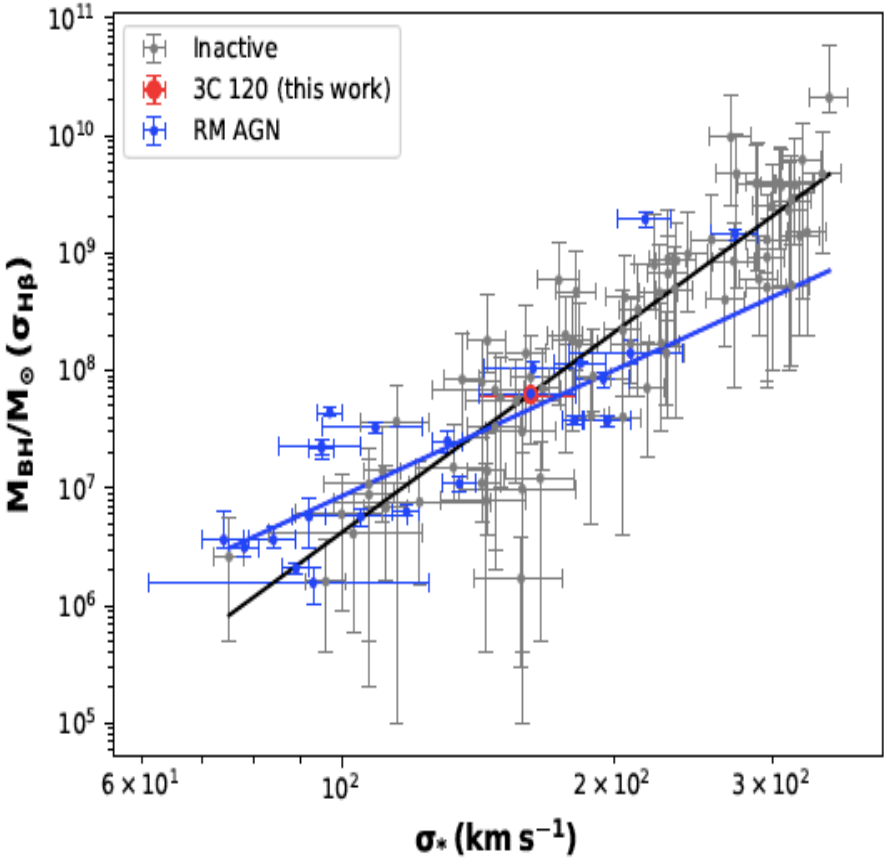
Lag uncertainties dominate the error on Virial Product (*f* uncertainty ~0.4 dex)

Agrees with weighted mean of previous results (shifted to *f*=5.5).



$R_{H\beta}$ vs L_{5100} and M_{BH} vs σ_*





3C120 is close to pivot point on both relations.

Summary of Main Conclusions

- 0. Robotic RM works, and is very efficient of human time.
- 1. Continuum (UgVriz) lags rise with wavelength.
- Delays span 3 or 4 days - compatible with $\tau \sim \lambda^{4/3}$.
- CREAM fits a standard thin blackbody disc with L/L_{Edd} ~0.5.
- 2. Caveat: Balmer (and Paschen) Jump in $\tau(\lambda)$ from CCF lags
- => possible HI Bound-Free contamination.
- 3. Caveat to Caveat: Disc flux spectrum, isolated by variations, matches disc theory $f_\nu \sim \nu^{1/3}$ (no sign of Bound-free edges)

- 4. HeII lag similar to r,i continuum lags, 2.6d relative to V.
- 5. Hβ lag =21 d => $M_{BH} = 6.5 \times 10^7 (f/5.5) M_{sun}$
- 6. Velocity-resolved lags => symmetric disc-like kinematics

Thanks for Listening !

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