Monitoring AGNs with Hbeta Asymmetry (MAHA) Using the Wyoming Infrared Observatory (WIRO)

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The MAHA Collaboration

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ATTEMPTS HIGH-FIDELITY REVERBERATION MAPPING

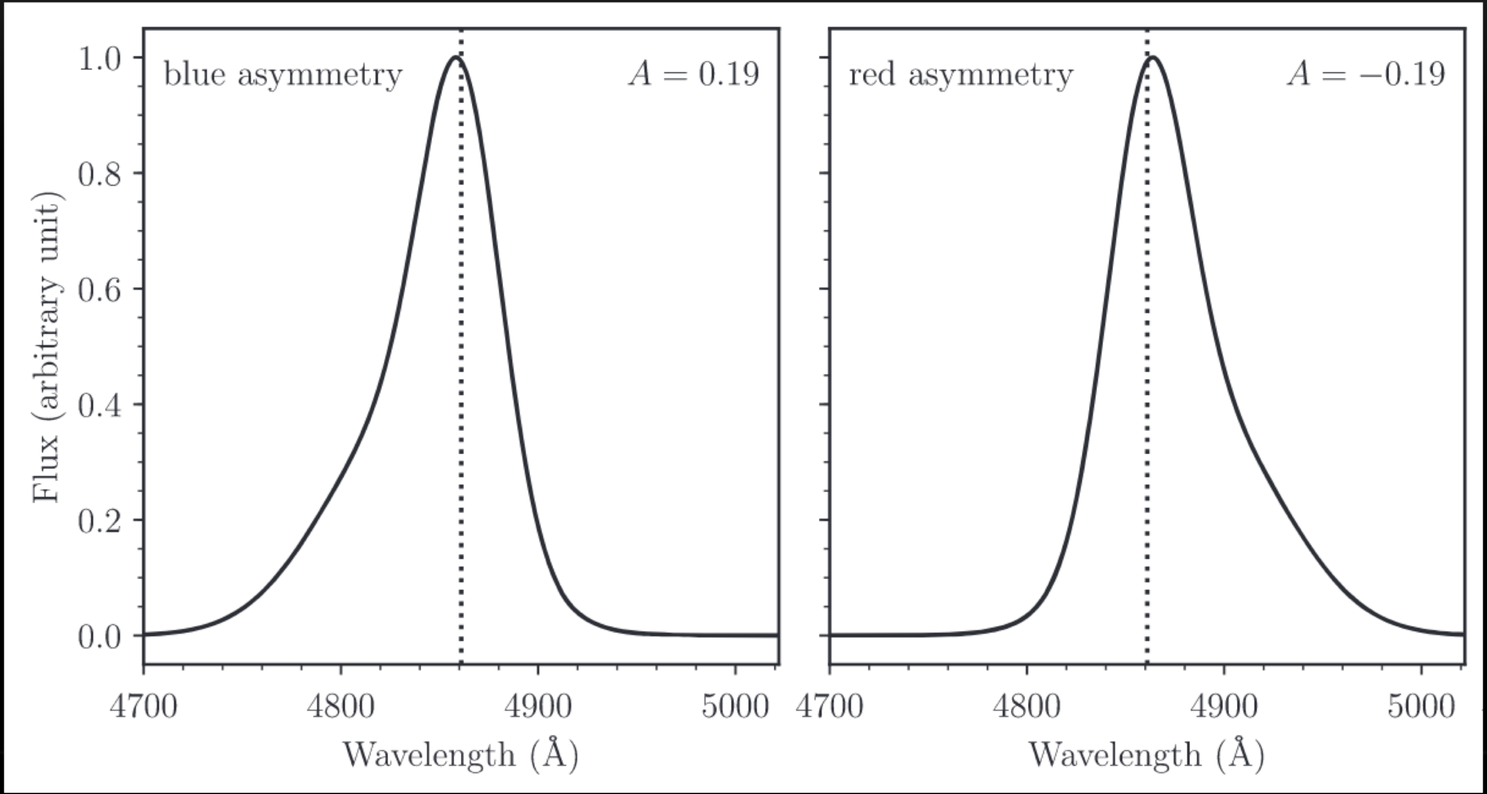
VELOCITY-RESOLVED TIME LAGS AND
2D VELOCITY DELAY MAPS

SUB-PARSEC BINARY BLACK HOLES?

BLR EVOLUTION

ODDITIES AND ANOMALOUS BLR RESPONSE

RED AND BLUE ASYMMETRIES



BOROSON & GREEN (1992) ASYMMETRIES

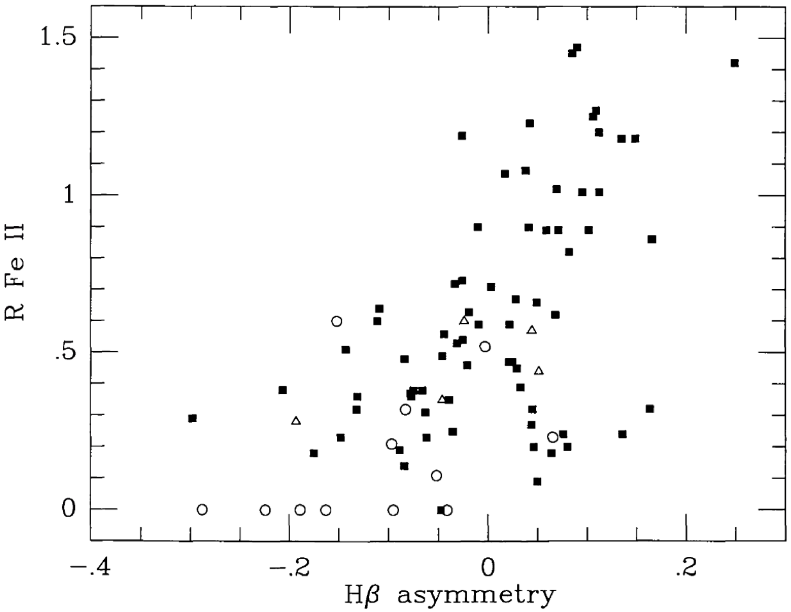


FIG. 5.—Ratio of the equivalent width of Fe II to that of Hβ plotted against the Hβ asymmetry index. The asymmetry index (in units of the FWHM of the line) is defined such that a positive index indicates excess emission on the blue wing. Symbols are as in Fig. 2.

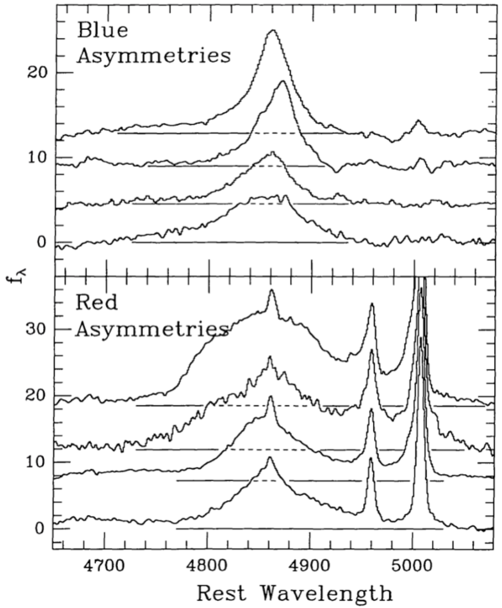
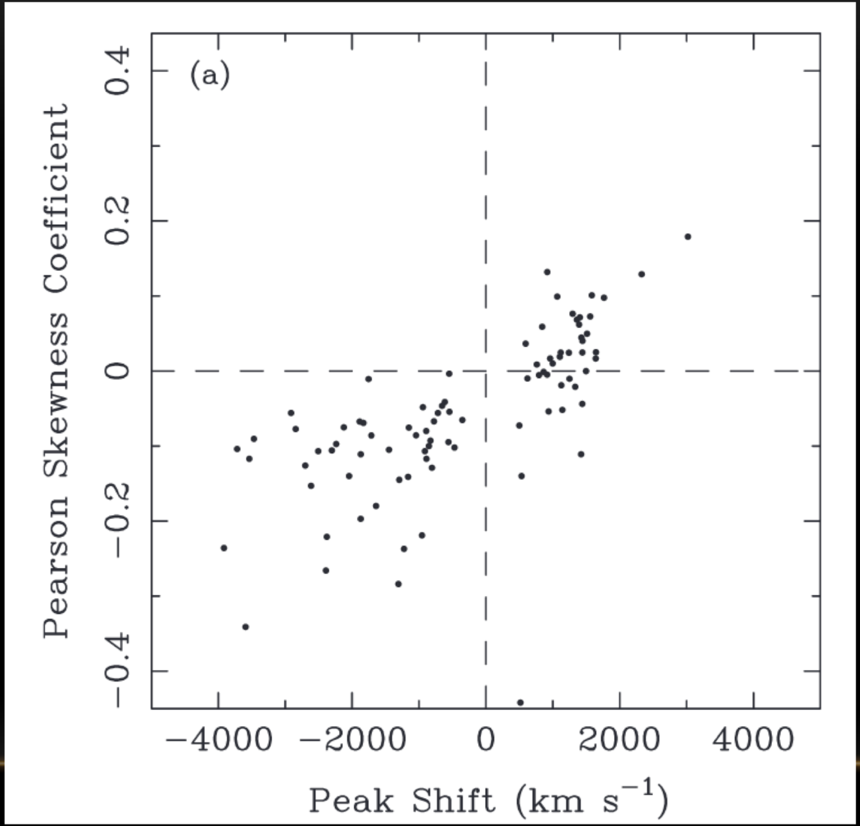


FIG. 6.—Examples of profile asymmetries in Hβ. Plotted are Fe II subtracted and continuum-subtracted spectra in f_λ units with arbitrary scaling and offsets against rest wavelength. Zero level of each spectrum is indicated. From top to bottom objects are (*top panel*) PG 1444+407, PG 1415+451, PG 1259+593, PG 0043+039, and (*bottom panel*) PG 1613+658, PG 2308+098, PG 1202+281, PG 0003+158. Note the difference in [O III] λλ4959, 5007 between the blue asymmetric and red asymmetric profiles.

ERACLEOUS ET AL. (2012) ASYMMETRIES



Monitoring AGNs with Hbeta Asymmetry (MAHA)

Wyoming Infrared* Observatory (WIRO)
2.3 meter telescope

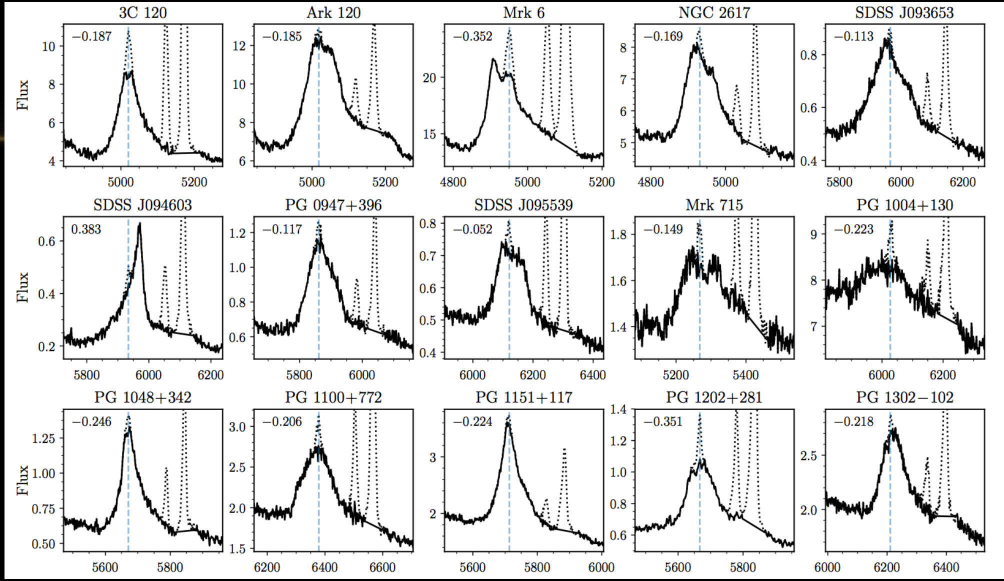
Wide slit, longslit spectroscopy
1.5 Angstrom/pix, 4000-7000A
1: Dec 2016-May 2017
2: Oct 2017-May 2018
3. August 2018-present (April 2020?)

Combine with ASAS-SN photometry when available with good enough quality.

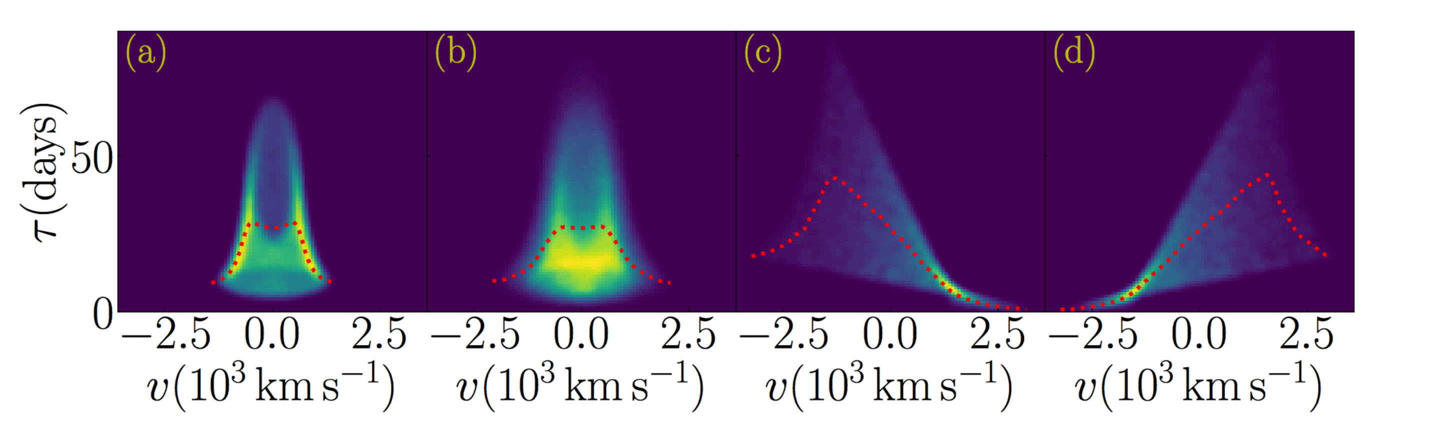
Monitoring AGN with Hbeta Asymmetry (MAHA)

~^0 AGN with z < 0.3, V < 17, see example WIRO spectra (Du et al. 2018):

- Asymmetric Hbeta profiles
- Binary Black Hole Candidates (e.g., periodicities, line shifts)
- Other Interesting Behavior (e.g., changing asymmetries)
- Both "Classic" and New Targets



Example Theoretical 2D Velocity-Delay Maps

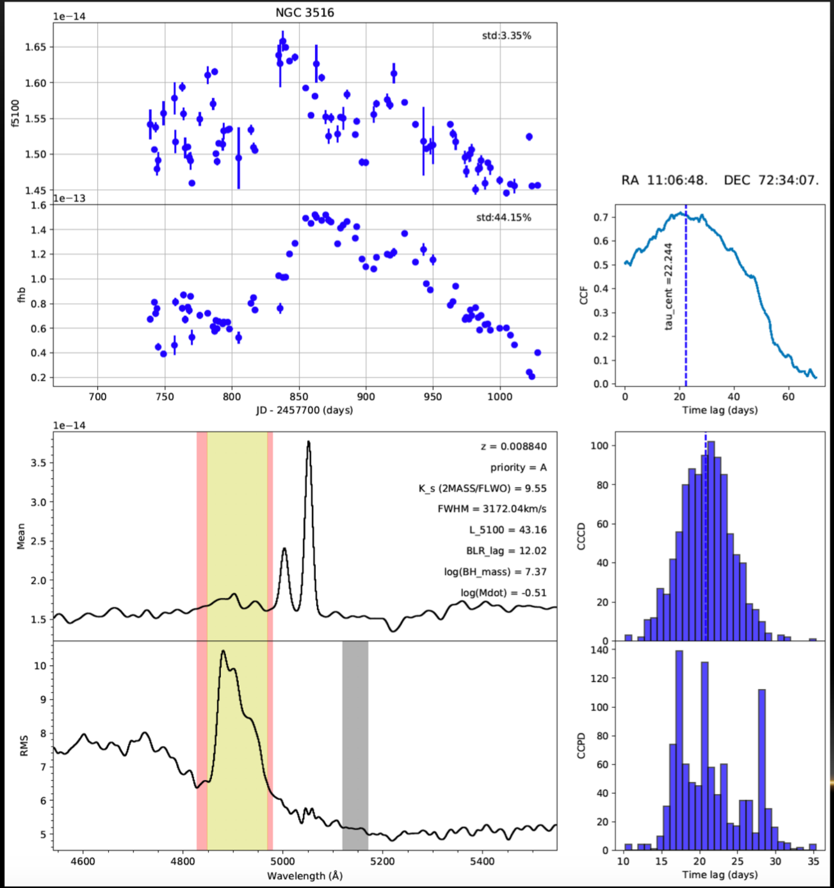


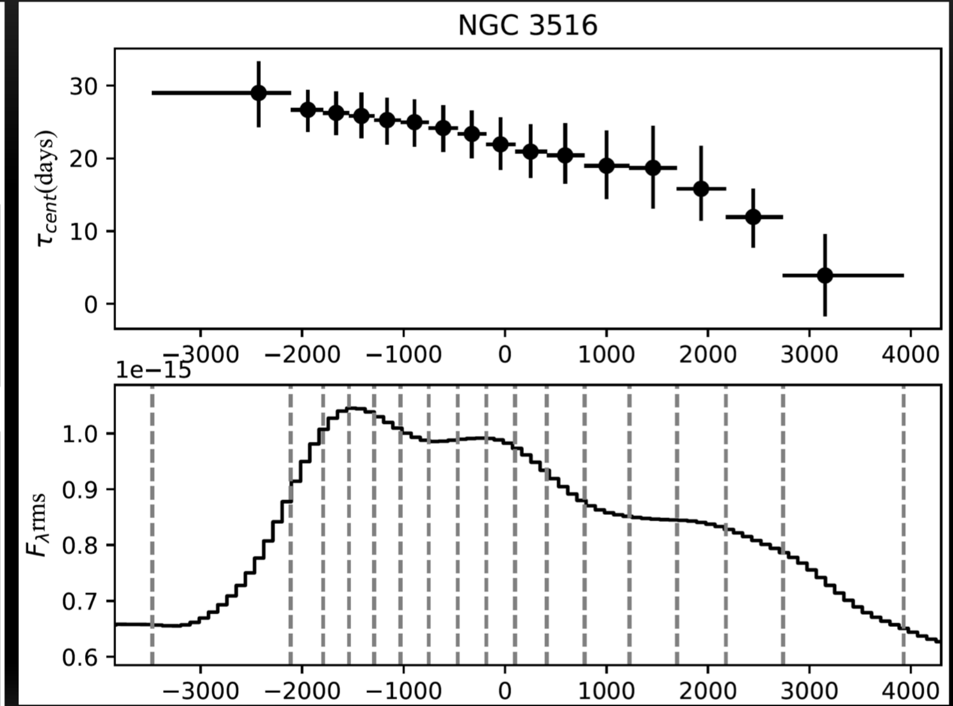
Thin Disk Thicker Disk Inflow Outflow

Wang et al. (2018)

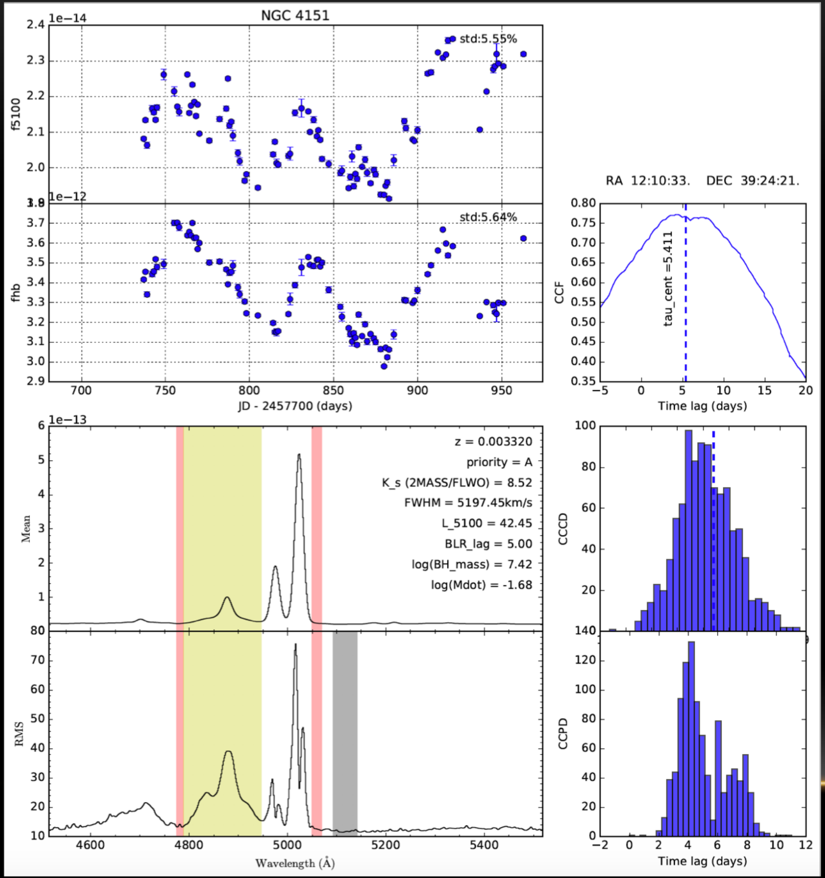
Important to understand the BLR. Not all AGNs have disk-like BLRs.
Are all kinematical structures virial?

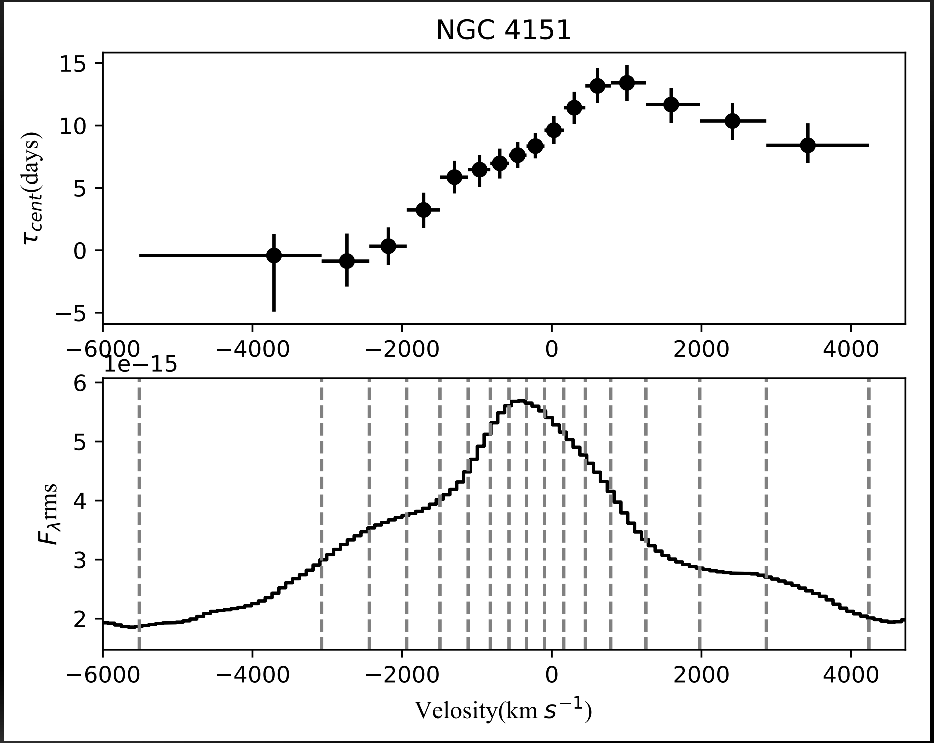
SOME GENERAL MAHA RESULTS: NGC 3516 (INFLOW, COMMON)





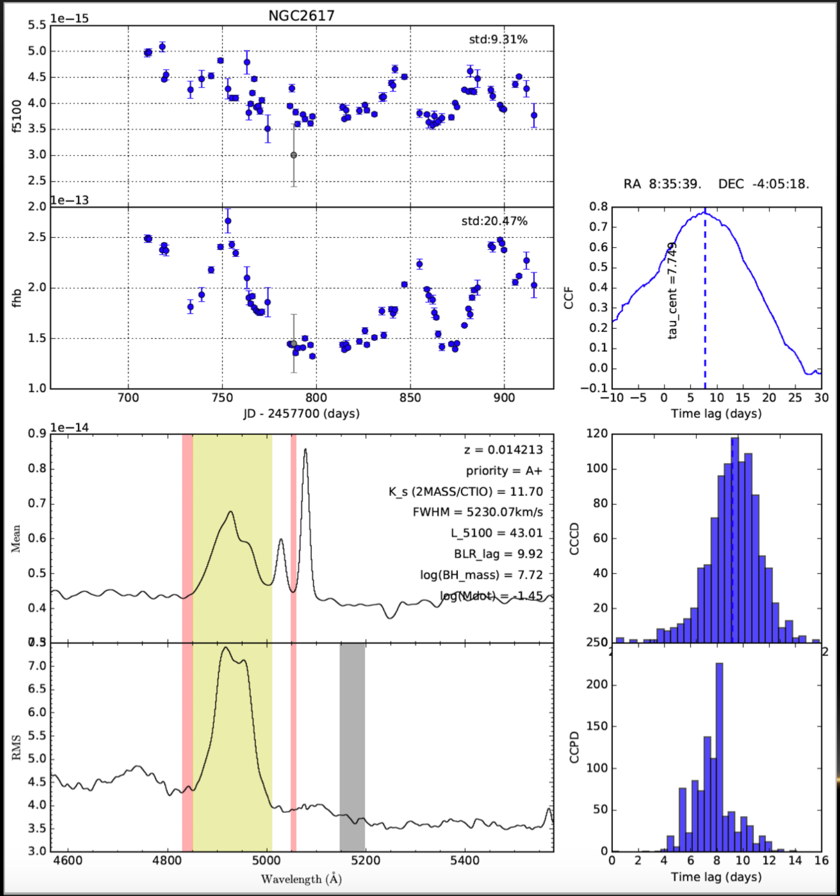
SOME GENERAL MAHA RESULTS: NGC 4151 (OUTFLOW, RARE)

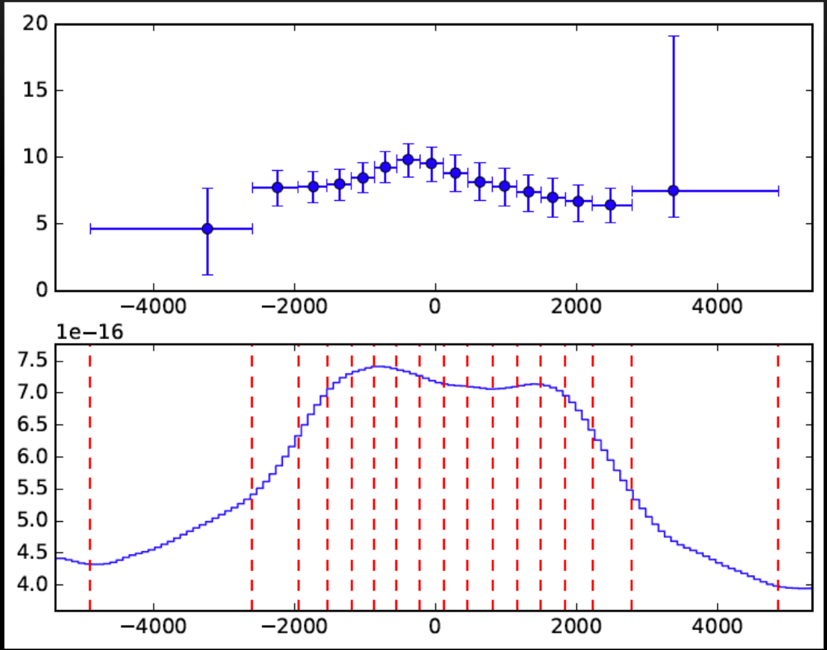




Probably not a binary as suggested by Bon et al. (2012)
A forthcoming 2D Velocity Delay Map will help.

SOME GENERAL MAHA RESULTS: NGC 2617 (DISK, RARE)

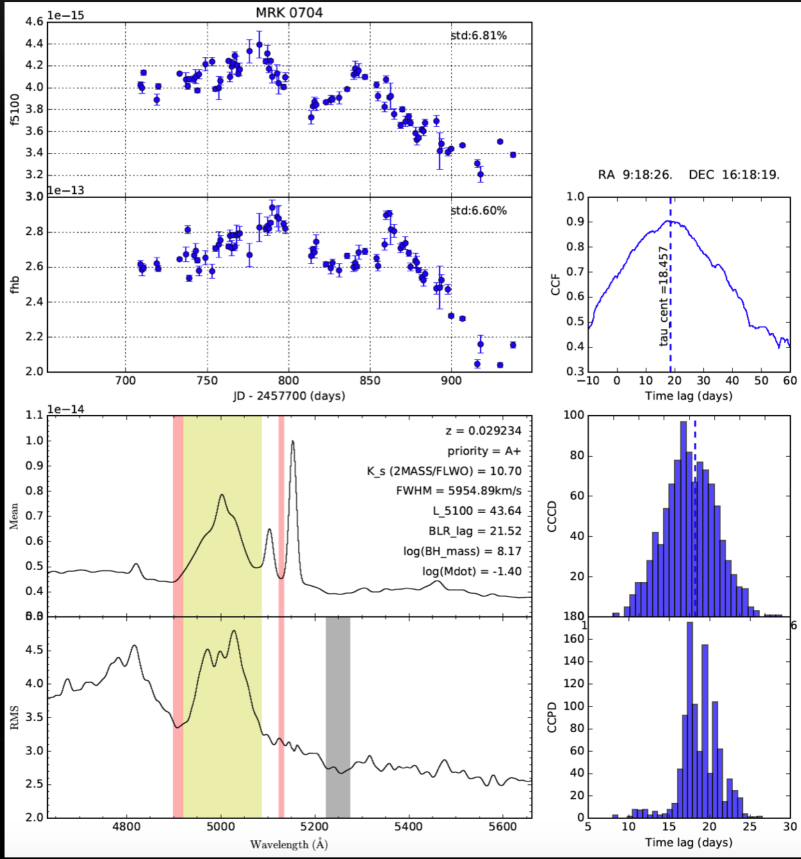


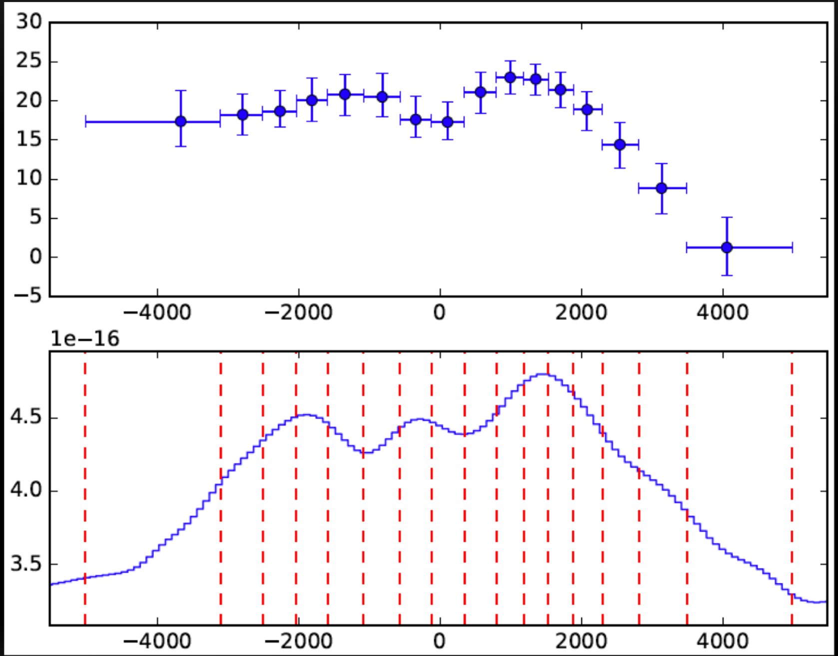


Note asymmetry change from Fausnaugh et al. (2017). Not the best example disk.

SBS 1518+593 from Du et al. (2018) better disk example from MAHA.

SOME GENERAL MAHA RESULTS: MRK 704 (COMPLEX, COMMON)





Maybe just inflow? Forthcoming 2D Velocity Delay Map should help interpretation. (Suggests disk!)

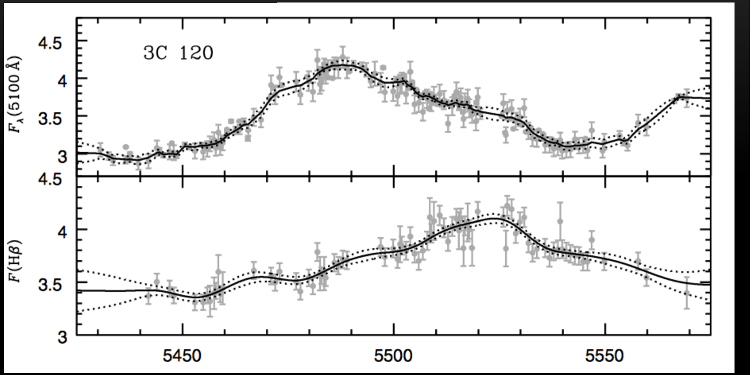
BLR EVOLUTION: HINTS TO ORIGIN OF BLR?

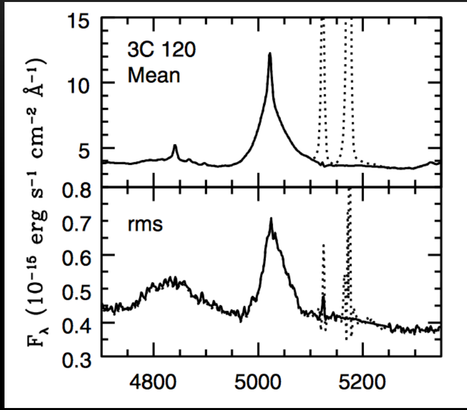
Dynamical timescale months to years, so not too surprising, but Hbeta profiles and the BLR seems to be changing in most objects with high-fidelity data sets over years. For example:

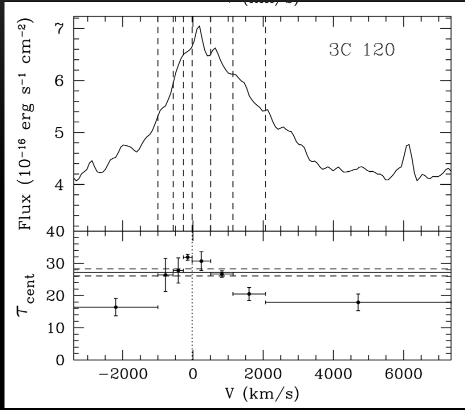
- NGC 5548: disk to inflow and back (e.g., Xiao et al 2018, using new and historical AGN Watch data)
- NGC 4151: disk De Rosa (2018), MAHA: outflow
- 3C 120: disk Grier et al (2013, 2017), MAHA: outflow
- NGC 3227: outflow, Denney et al. (2009), inflow De Rosa et al. (2018), MAHA: Inflow
- NGC 3516: Infall Denney et al (2009), outflow De Rosa et al. (2018), MAHA: Inflow

3C 120 RM IN 2010 (GRIER ET AL. 2012)

(Grier et al. 2012)

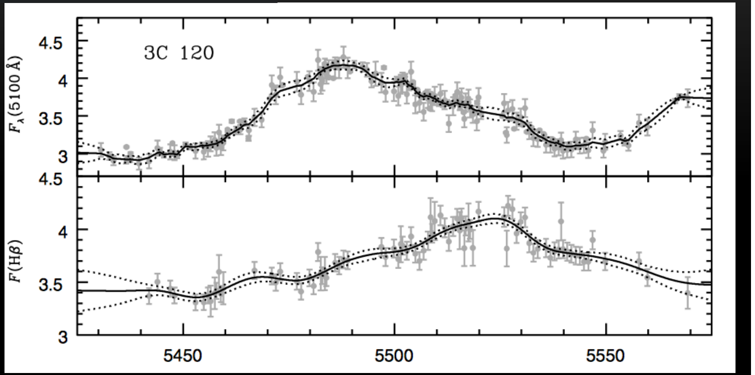


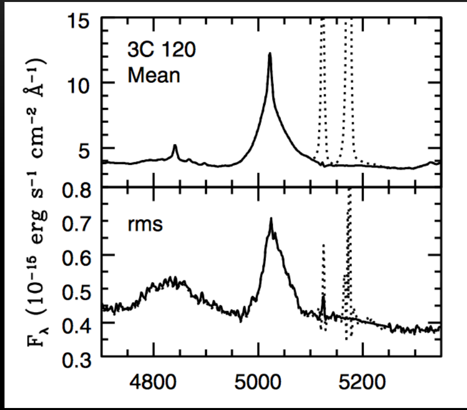


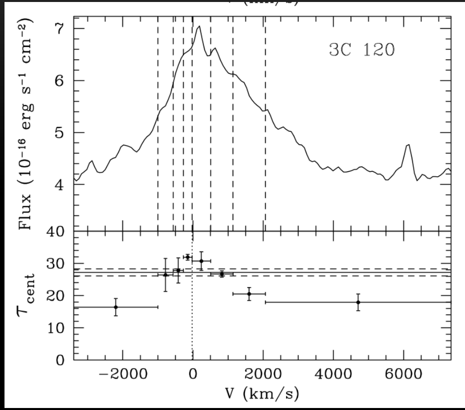


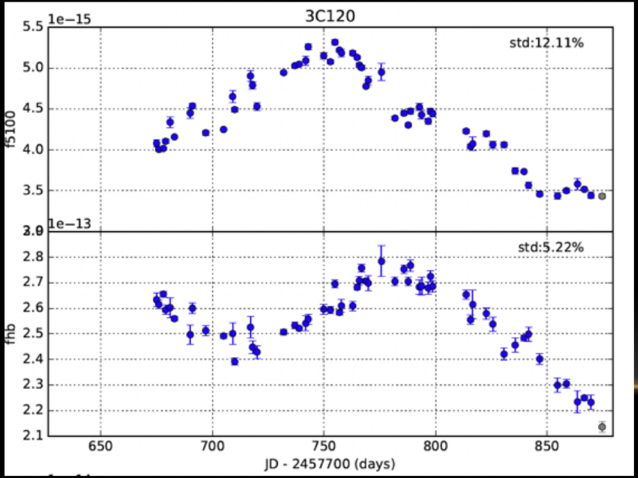
3C 120 RM IN 2010 (GRIER ET AL. 2012, VS. MAHA 2018)

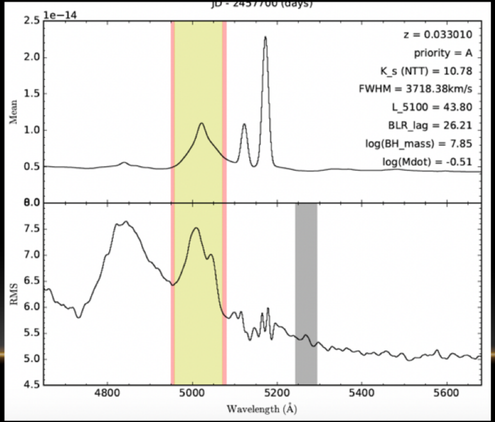
(Grier et al. 2012)

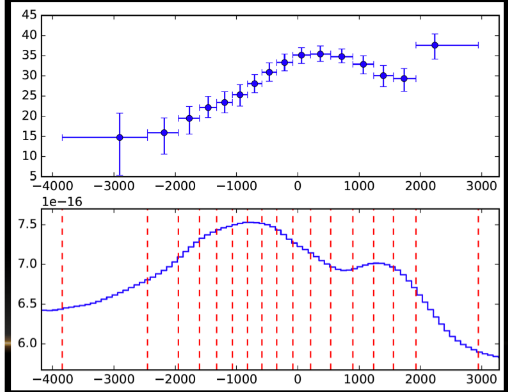






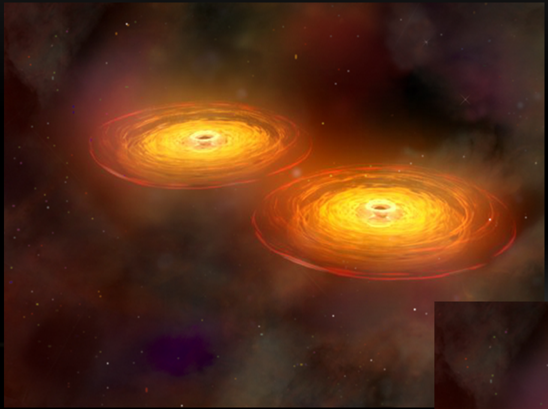


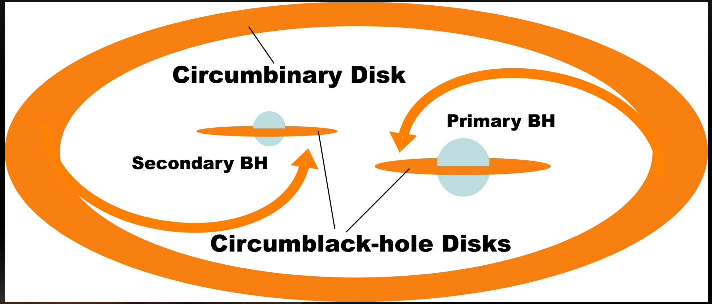


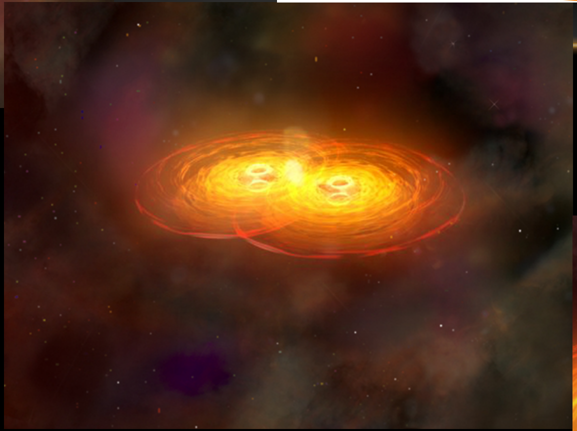


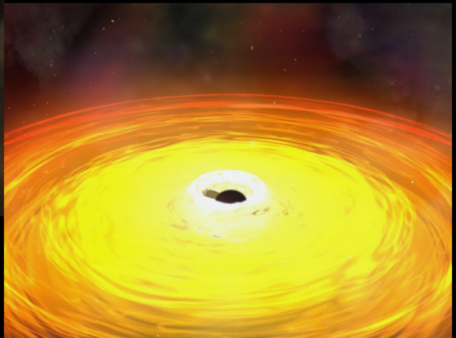
(MAHA 2018)

Close (sub-parsec) Binary Supermassive Black Holes?





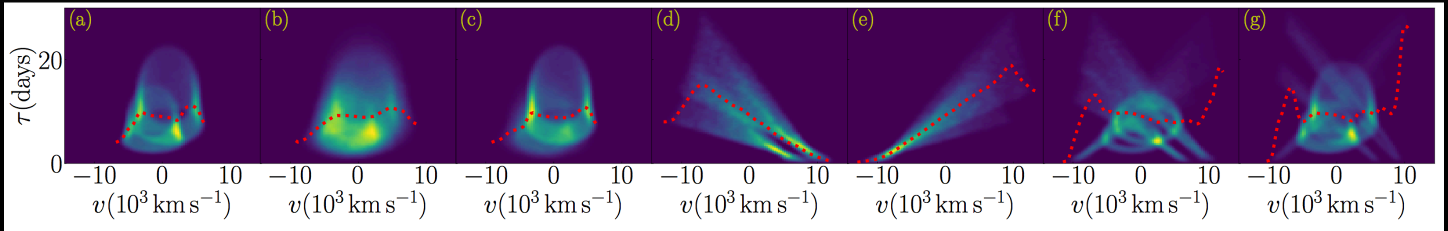


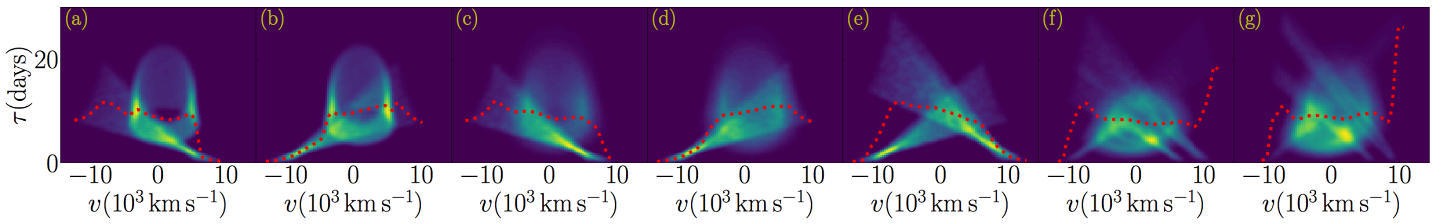


CXC/NASA/M. Weiss

Theoretical Binary 2D Velocity-Delay Maps

a: 2⊗thin-disk; b: 2⊗thick-disk; c: (thin⊗thick)-disks; d: 2⊗inflow; e: 2⊗outflow; f and g: 2⊗(thin-disk+inflows+outflows)

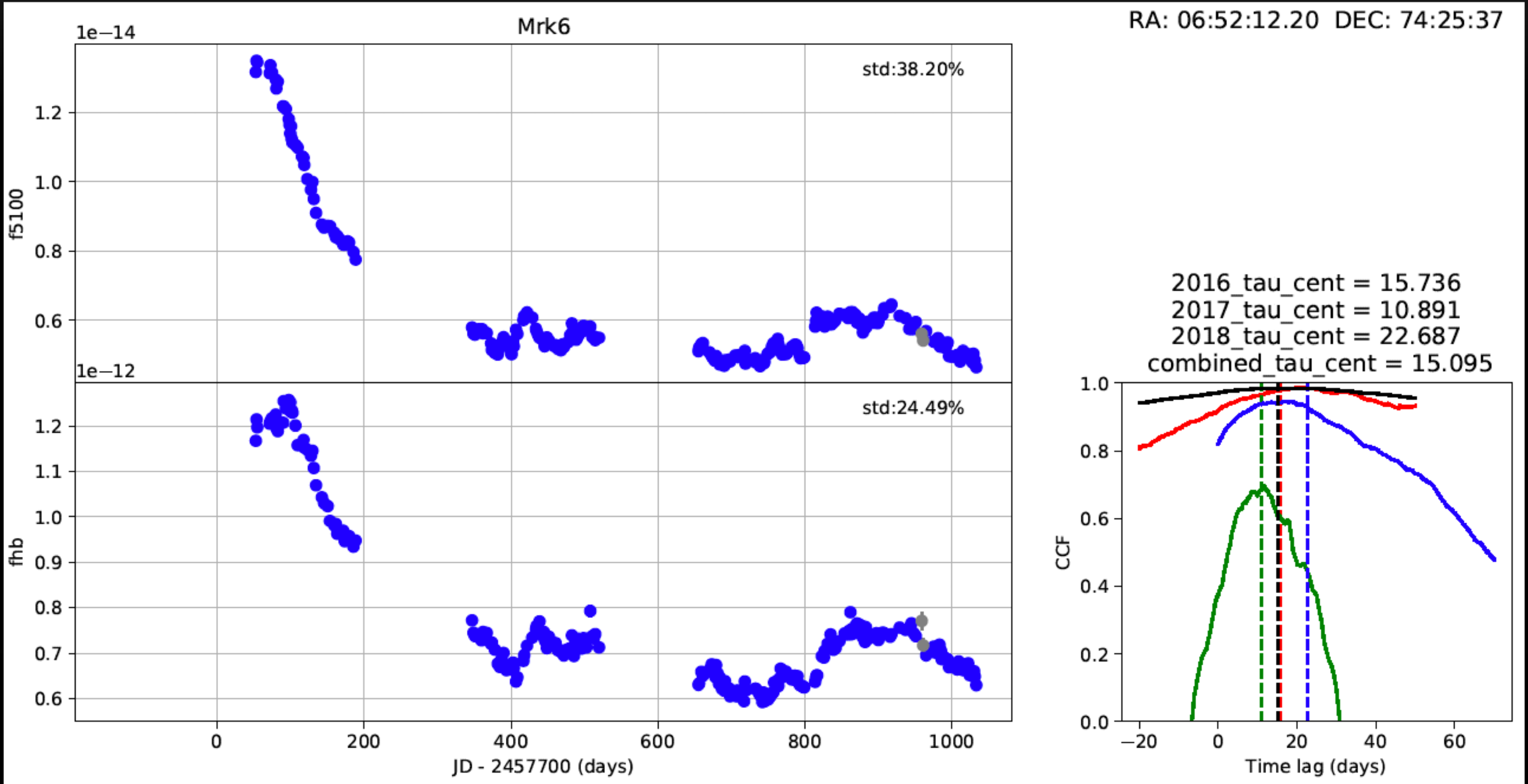




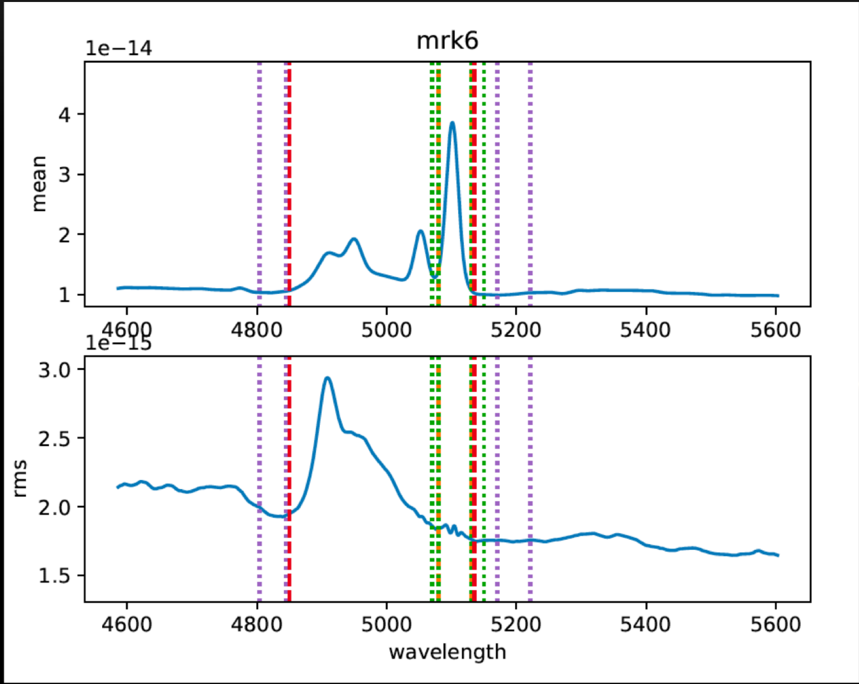
a: thin-disk⊗inflow; b: thin-disk⊗outflow; c: thick- disk⊗inflow; d: thick-disk⊗outflow; e: inflows⊗outflow; f & g: 2⊗(thick-disk+inflow+outflow)

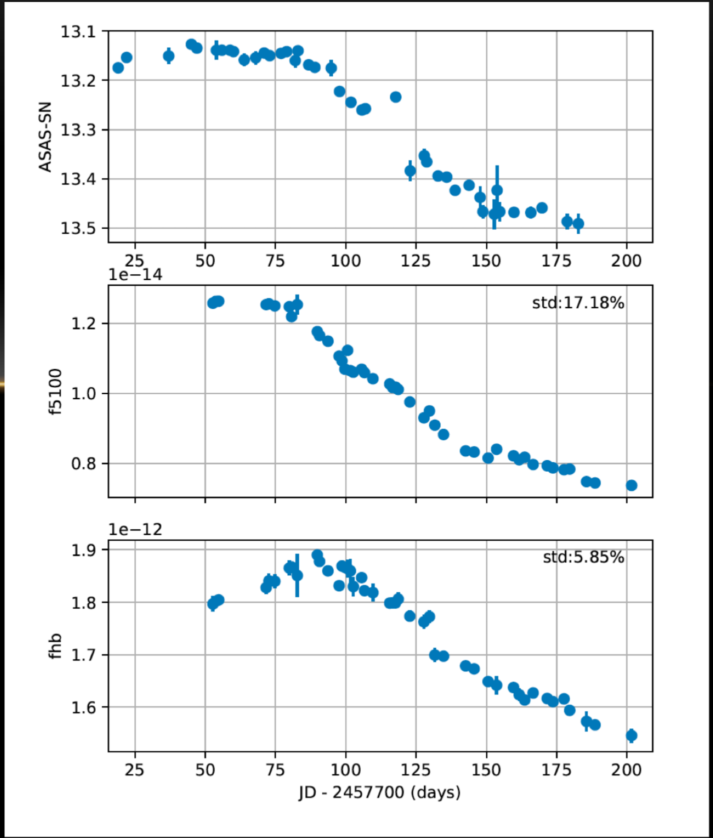
Wang et al. 2018

SOME CANDIDATE BINARY AGNS FROM MAHA: FOCUS ON MRK 6

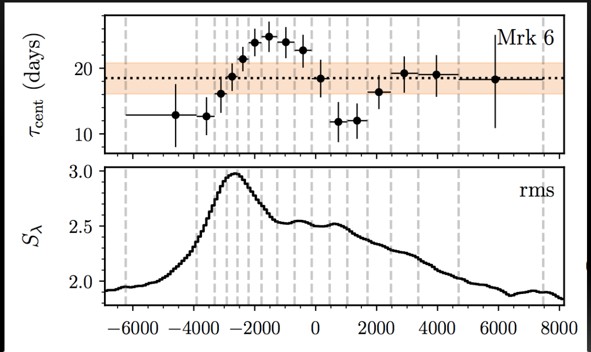


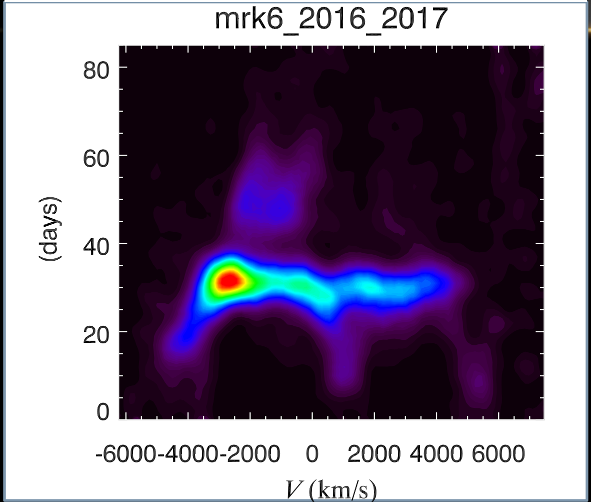
MAHA Results year 1: Mrk 6 (Du et al. 2018)



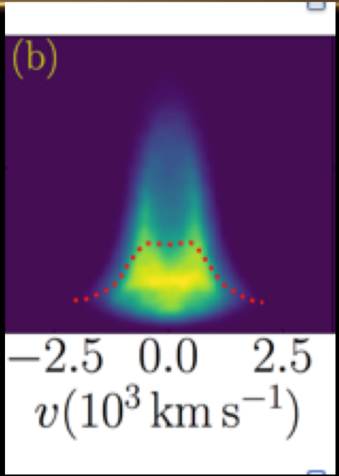


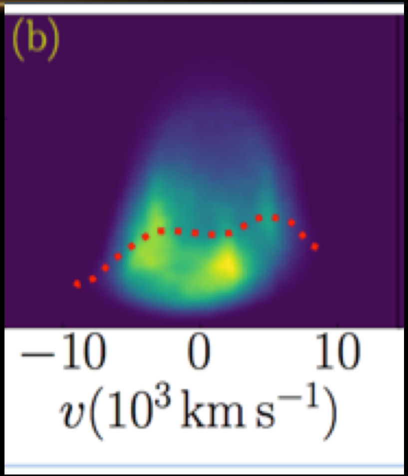
MAHA Results year 1: Mrk 6



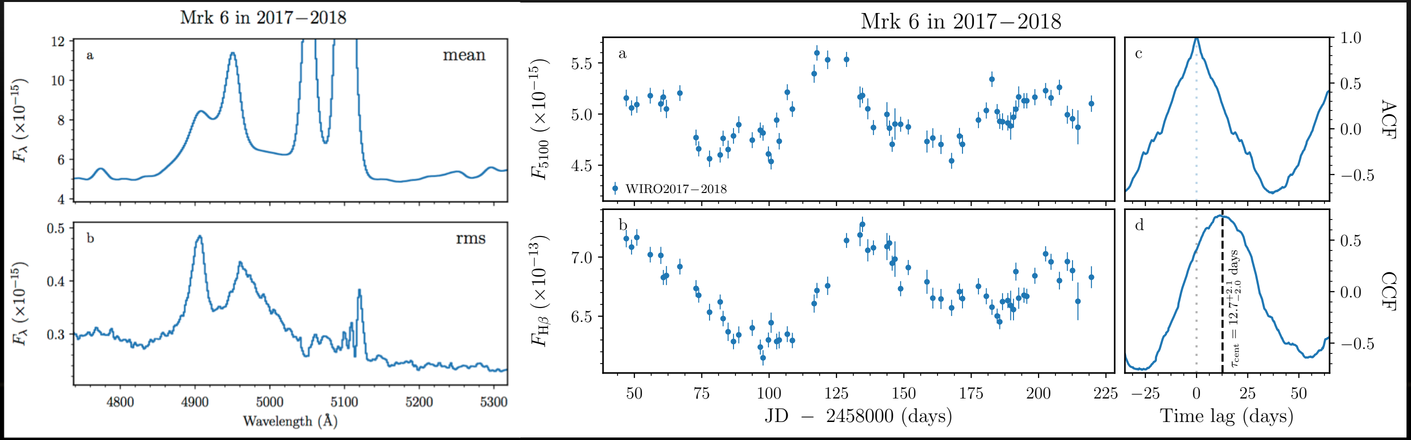


Single or Binary?

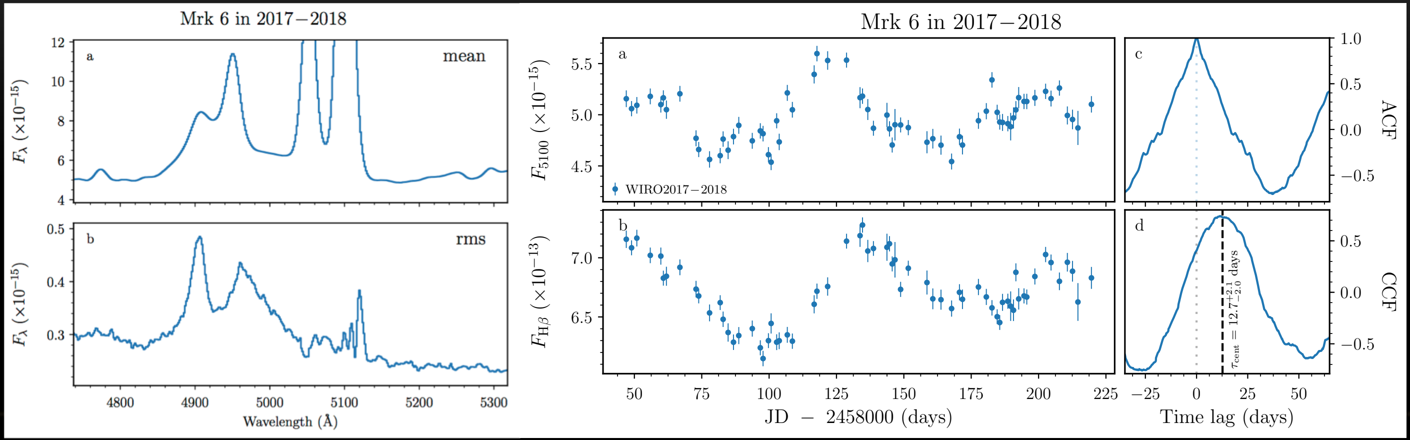


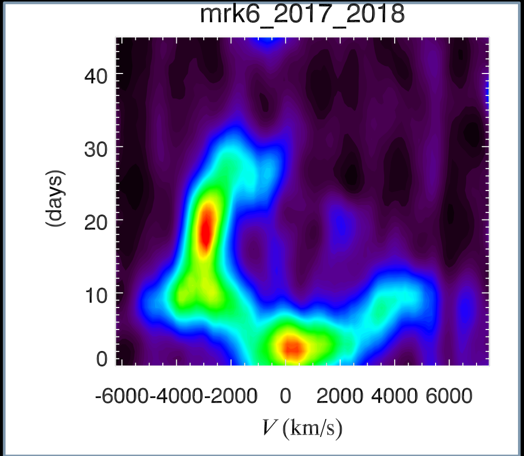


MAHA Results year 2: Mrk 6

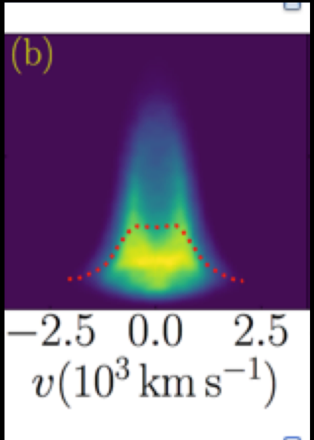


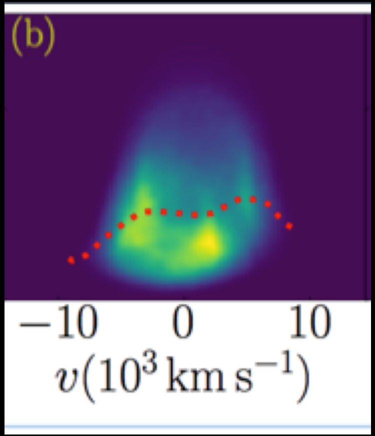
MAHA Results year 2: Mrk 6



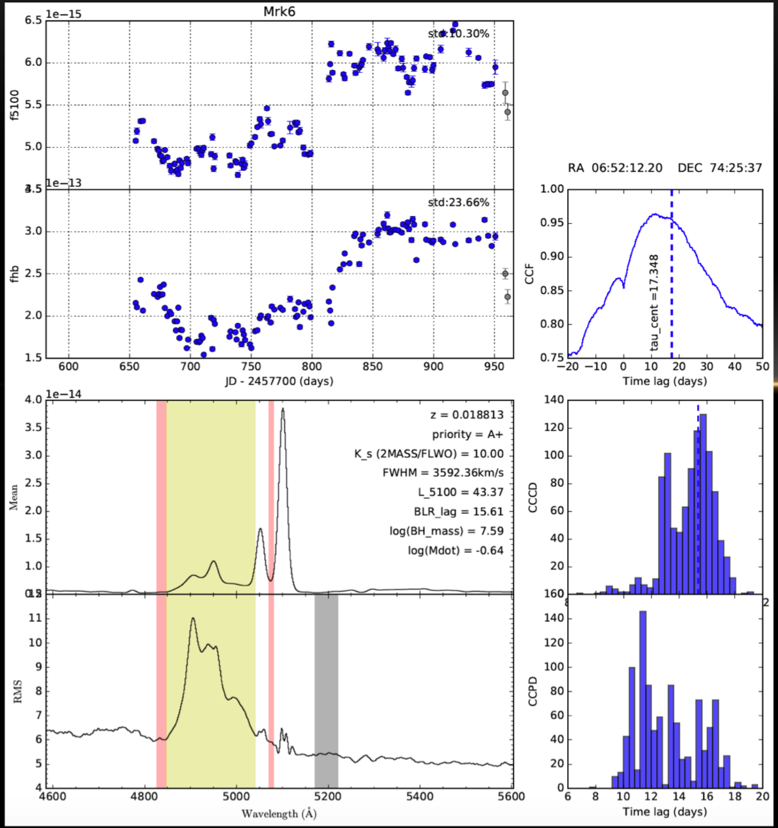


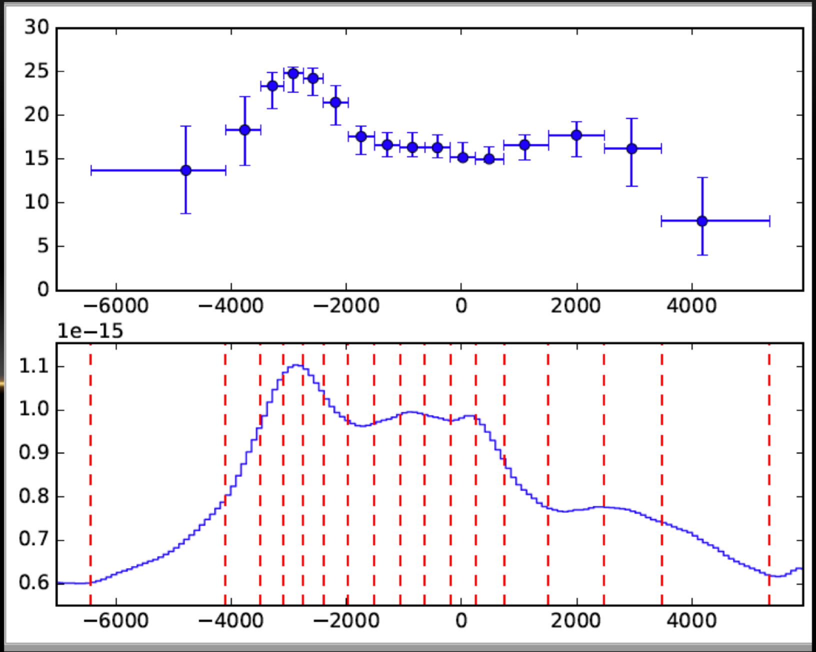
Single or Binary?



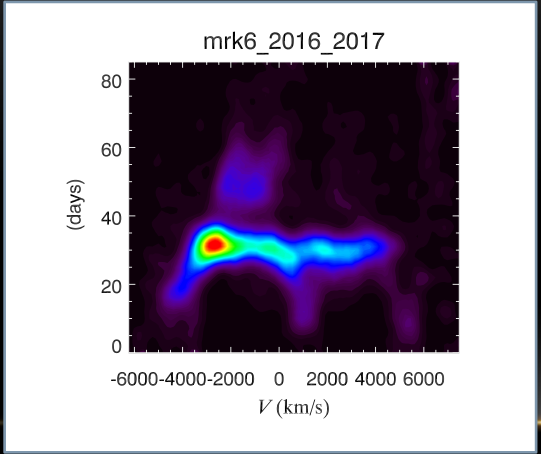


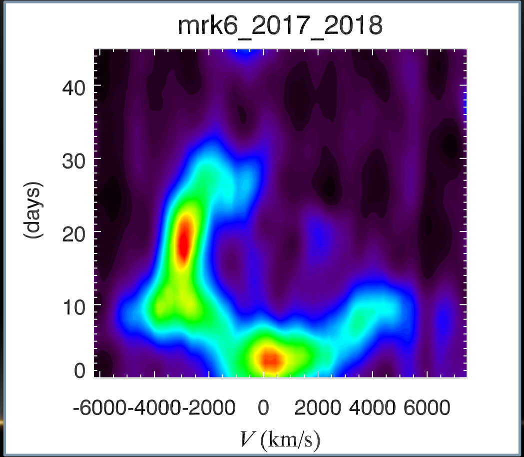
MAHA Results year 3: Mrk 6

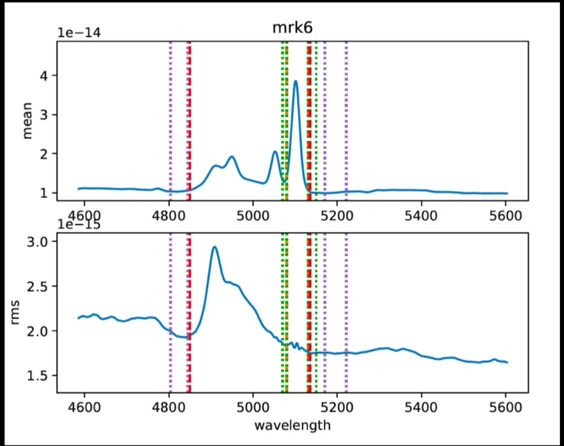


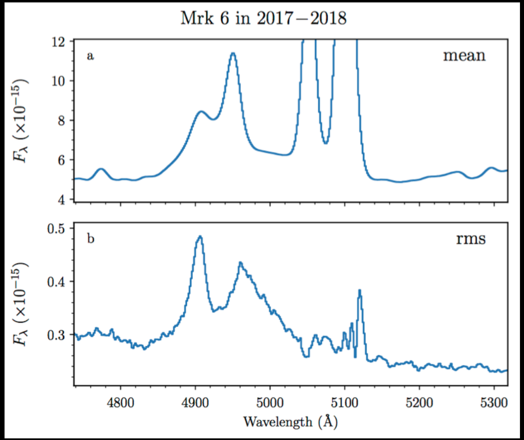


Mrk6 Results Year 1 & 2 Comparison

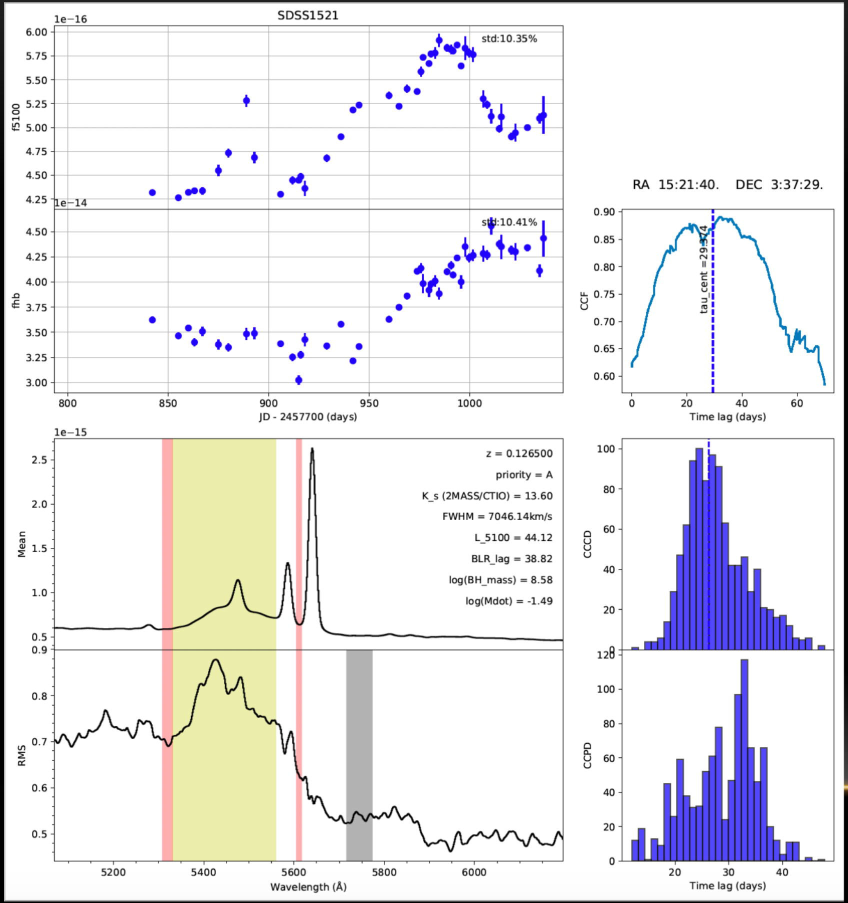




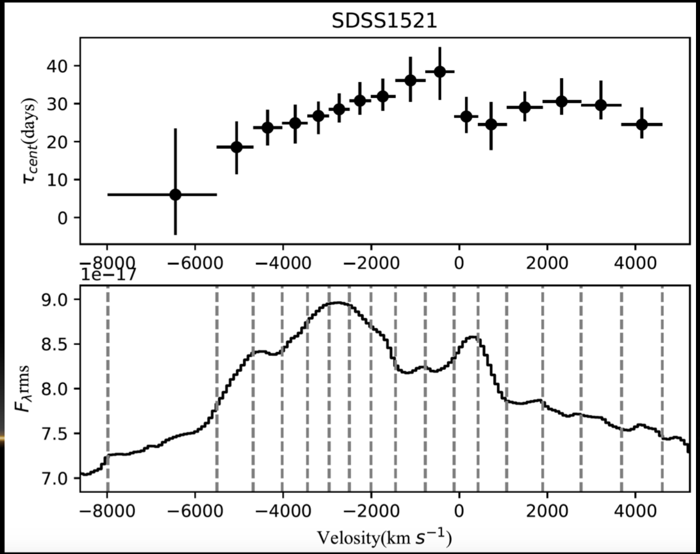




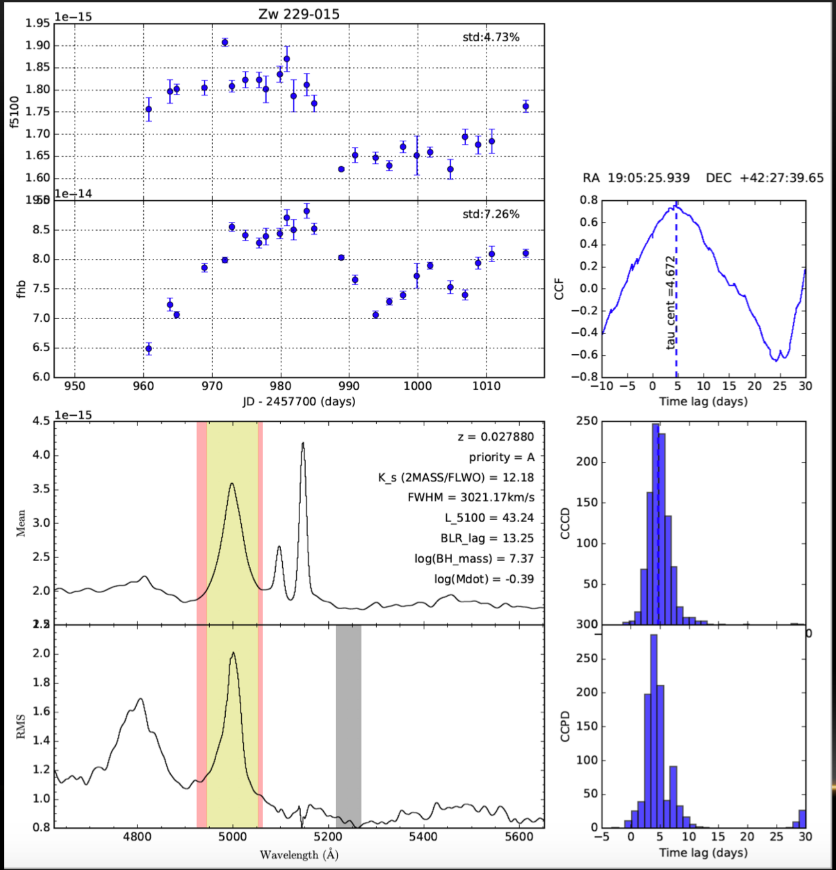
ANOMALOUS RESULTS: SDSS J1521+0337



This object had a quick but weak response to a flare (about 1 week), but rose in response to a continuum increase on a similar timescale…but has failed to drop now. Shows complex time lags.

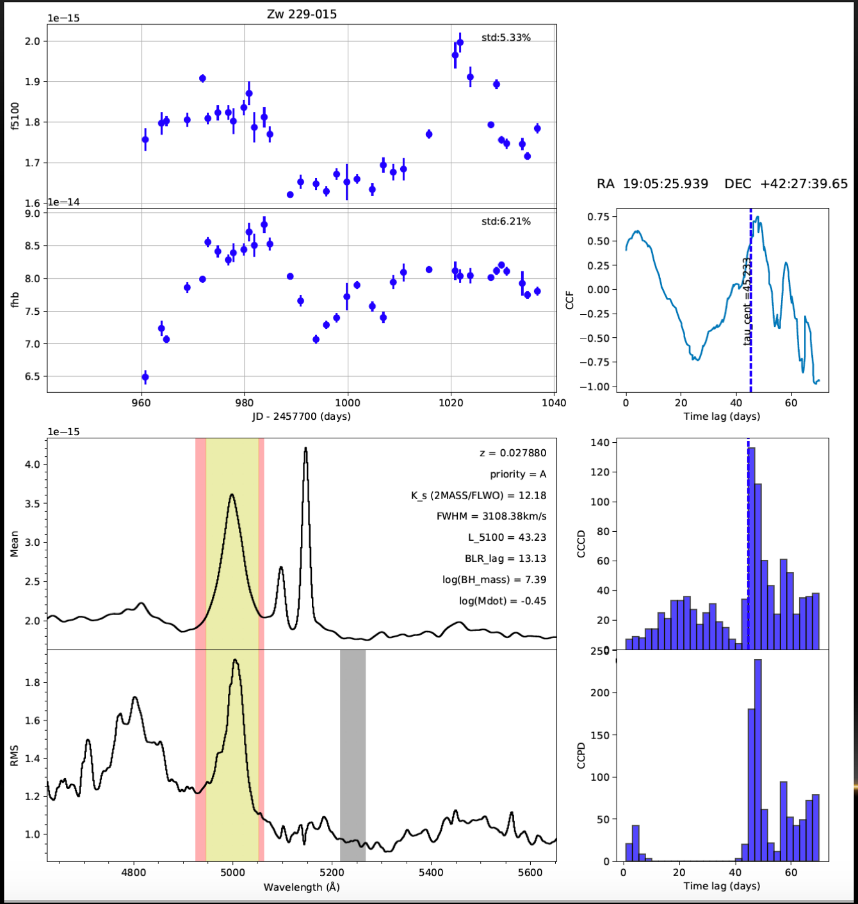


ANOMALOUS RESULTS: ZW 229-015



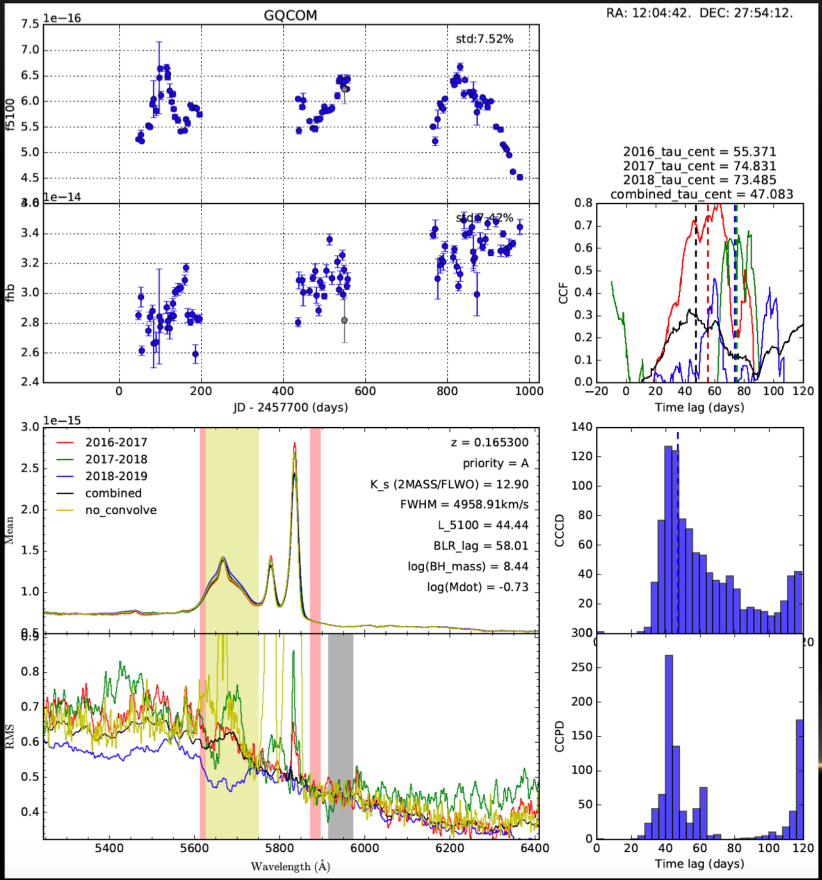
First 50 days this summer. Nice clear result with 5 day time lag, very similar to that reported from LAMP (Barth et al. 2011). Continue to get high-fidelity dataset to examine dynamics and compare to Williams et al. (2018).

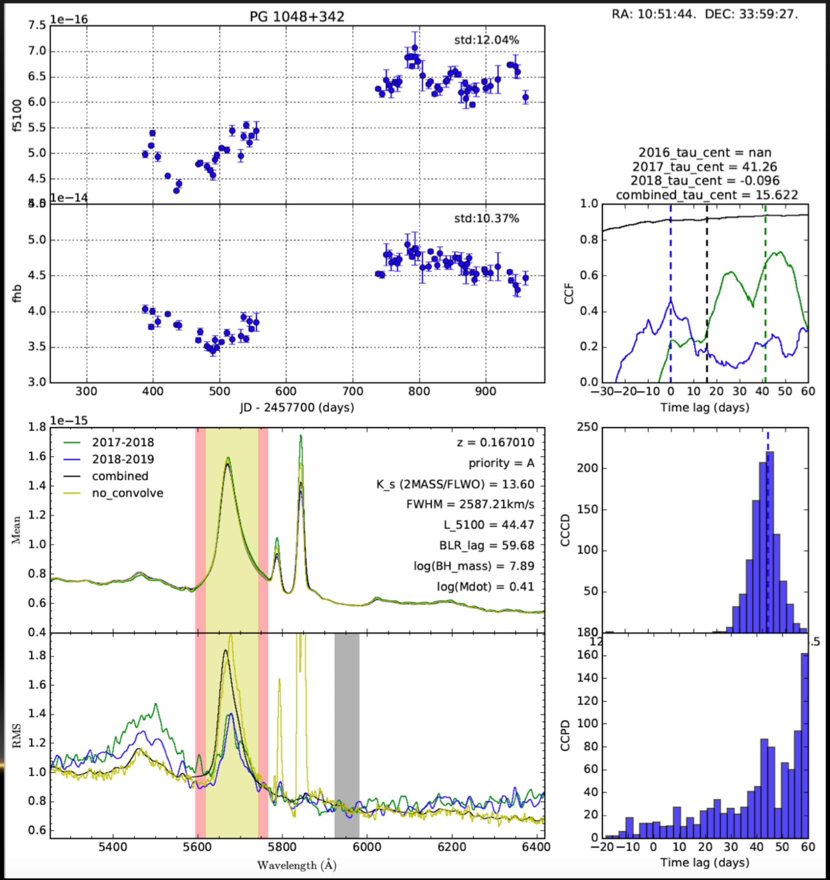
ANOMALOUS RESULTS: ZW 229-015



First 80 days now, with data through the first week of September 2019. Nice clear result with 5 day time lag is now "toast." The BLR "took a holiday." Explanation not established but likely involves geometry, difference between ionizing and optical continuum, and obscuration in some combination. Other explanations also possible.

LESS "SUCCESS-BIASED" RESULTS: GQ COM & PG1048+342





Summary

MAHA has about 30 Time Lags so far out of about 60 targets (updated annually), most with High-Quality Data, many over several years, and the campaign is ongoing, along with more sophisticated analyses.

AGN BLR origin and evolution not yet understood in detail. Exploring the full diversity of AGN profiles will provide insights.

The details are important for understanding black hole masses. Do asymmetric profiles signify fundamentally different BLR structures? Inflows, outflows? Binary black holes? No clear systematics so far.

A lot of work (and papers) coming up for MAHA. So far Du et al. (2018), Brotherton et al. (2019, almost submitted) on year 1 results.