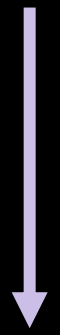
Insight into AGN Physics & Structure via Variability

Stephanie LaMassa (STScI)

AGN Variability Probes:

mild



extreme

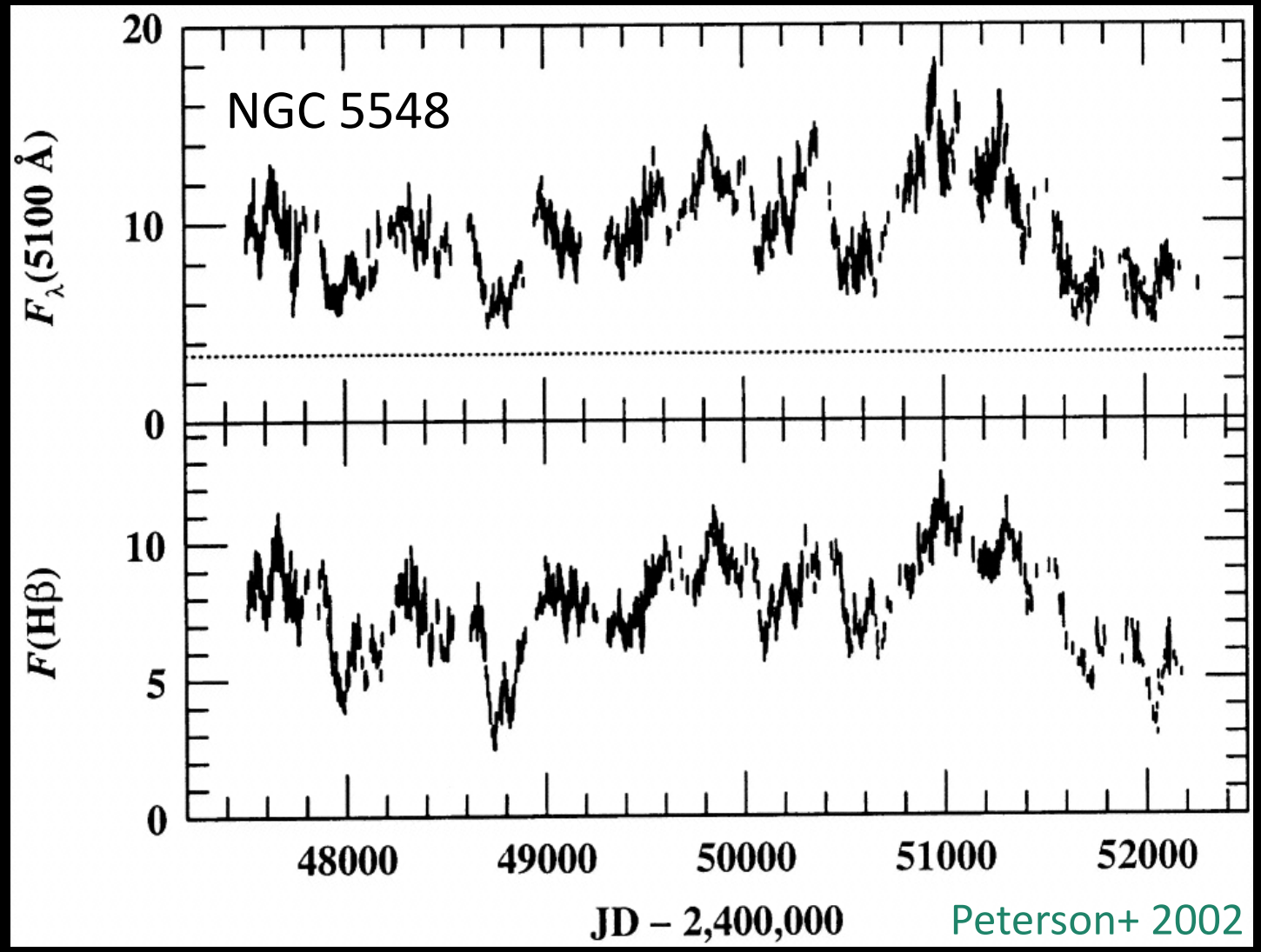
- Size of Broad Line Region & Torus — *Reverberation Mapping*
- Structure of obscuring gas/dust — *X-ray changing-look AGN*
- Accretion disk physics — *(most) optical changing-look AGN*

$$\tau = \frac{R}{c}$$

τ: time delay between continuum & reprocessing region

R: size of reprocessing region

Insights into Broad Line Region from Reverberation Mapping



Cross-correlation of continuum & Hβ:

- Hβ lags continuum ~6 – 20 days
- Simple photoionization equilibrium prediction:

$$L_{ion} \propto R^2$$

- Observations:

$$\tau \propto L_{UV}^{1/2}$$

see also Peterson+ 1991, 1992, 1993, 1994, 1999, 2001; Korista+ 1995; Clavel+ 1991; Netzer & Peterson 1997; Grier+ 2012, 2017; Bentz+ 2007, 2007, 2009a,b, 2010

BLR radius – luminosity relationship

$$R_{\rm BLR} \propto L^{0.533}$$

Bentz+ 2013

see also Bentz+ 2006, 2009 c.f. Kaspi+ 2000, 2005

Measure Black Hole Mass

$$M_{\rm BH} = f\frac{RV^2}{G}$$

R: size of reprocessing region

V: velocity of BLR gas

G: gravitational constant

f: scale factor

use R~L relation for M_{BH} in absence of RM

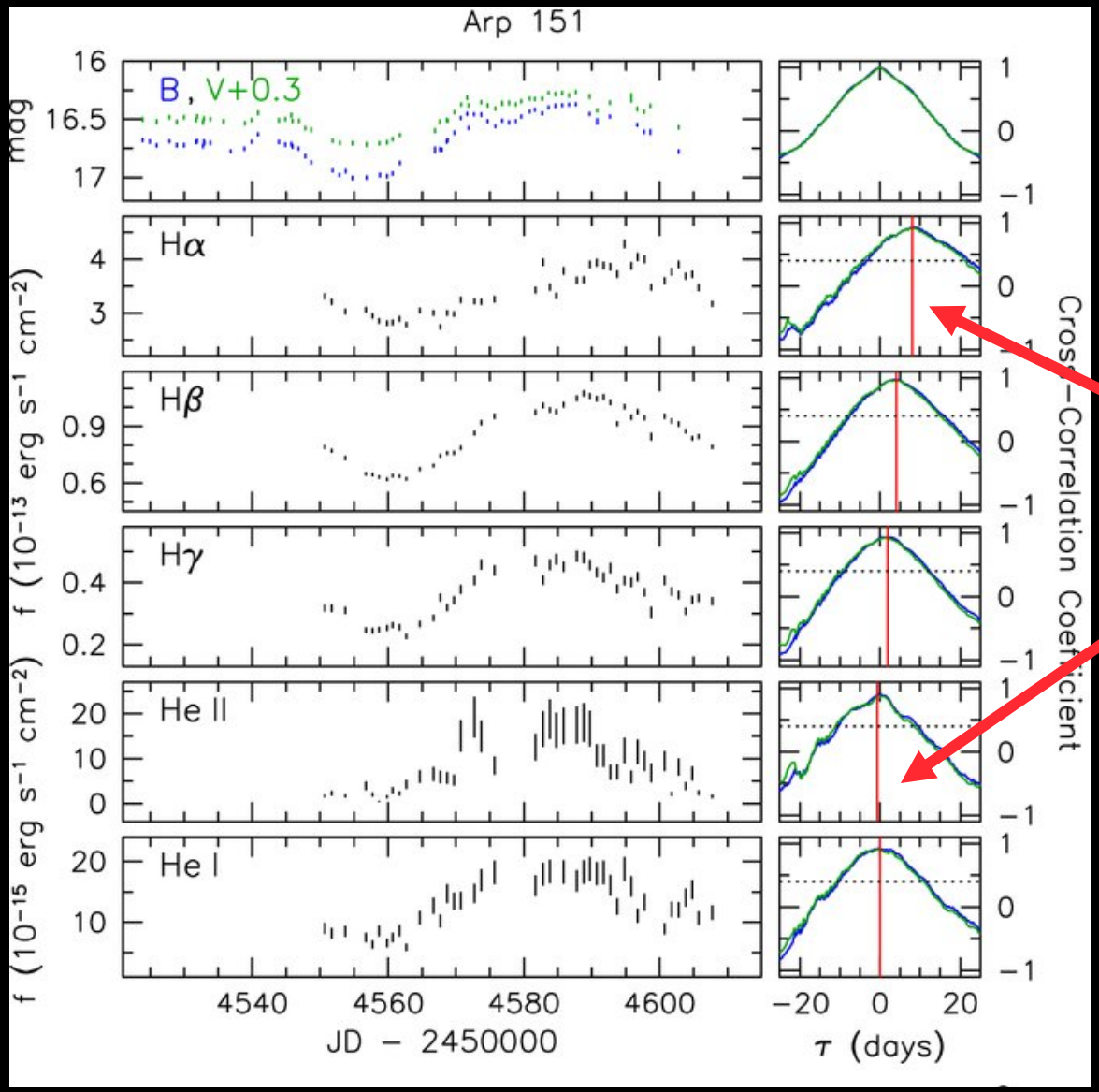
see Peterson+ 2013 for a review

BLR Ionization Stratification via variable τ

continuum

Balmer lines

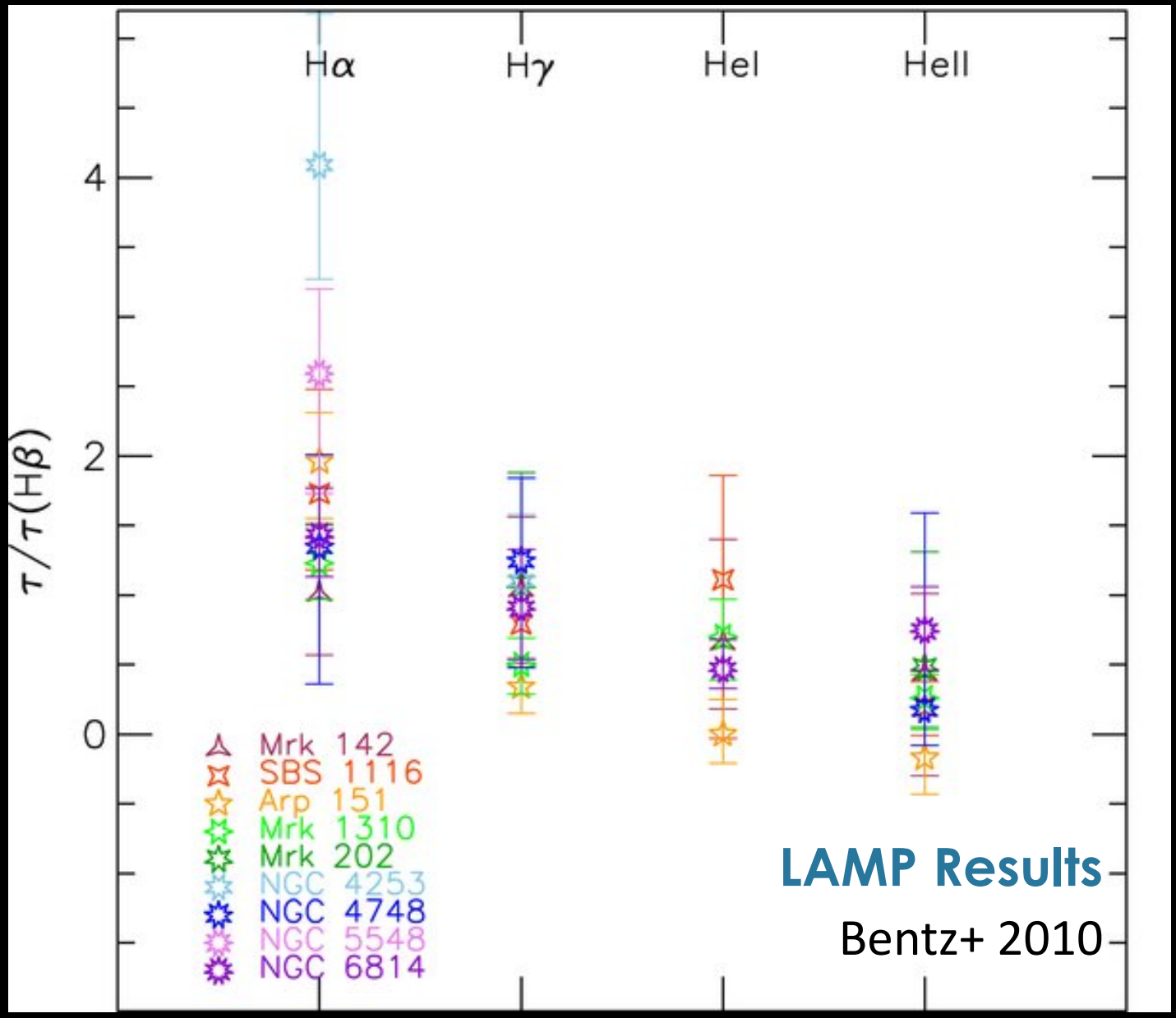
He lines



LAMP Results

Bentz+ 2010

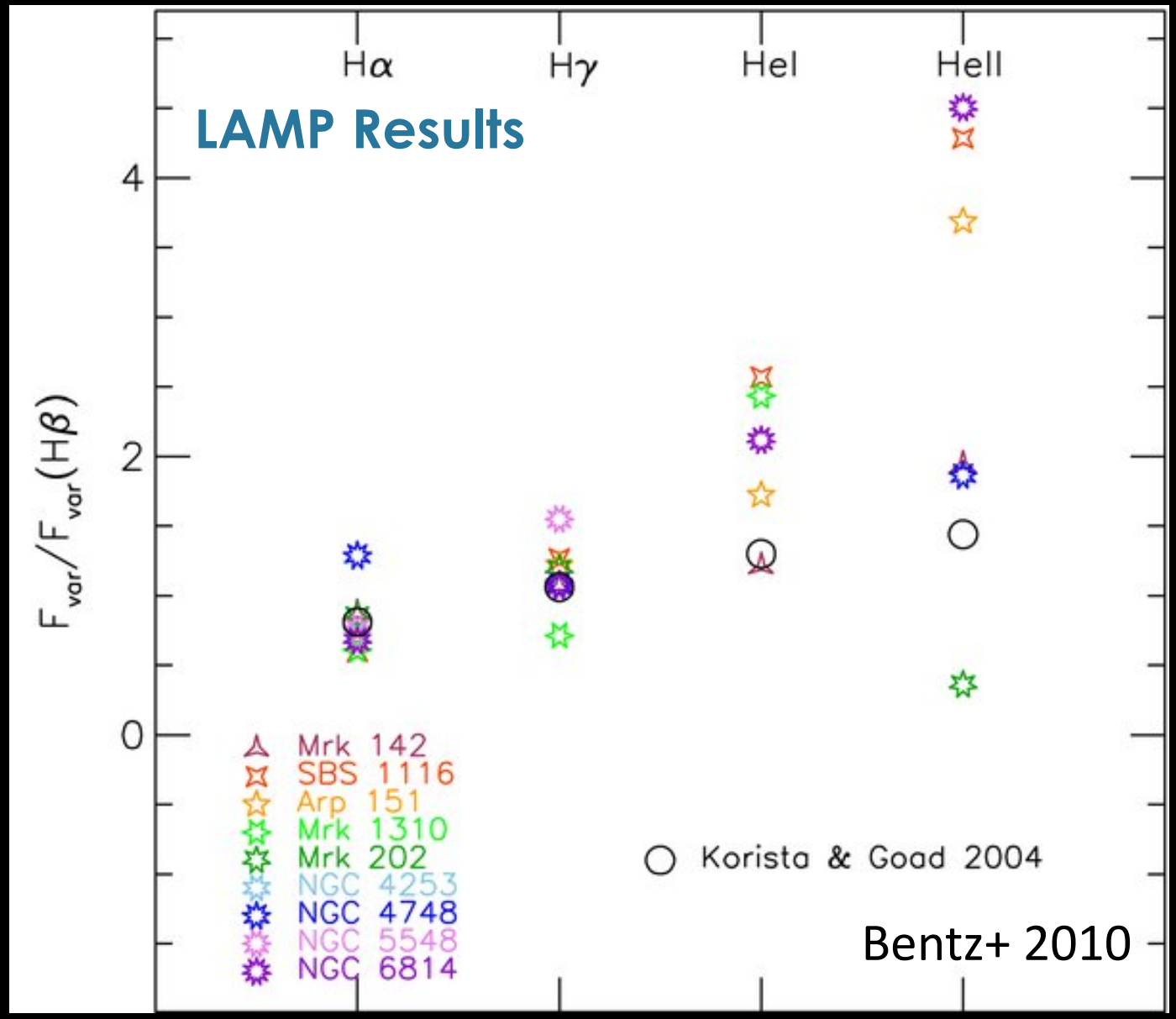
$\tau(\mathrm{H}\alpha) > \tau(\mathrm{H}\beta) > \tau(\mathrm{H}\gamma) > \tau(\mathrm{He\ I}) > \tau(\mathrm{He\ II})$



consistent w/ predictions of Korista & Goad 2004

see also Kaspi+ 2000, de Rosa+ 2015

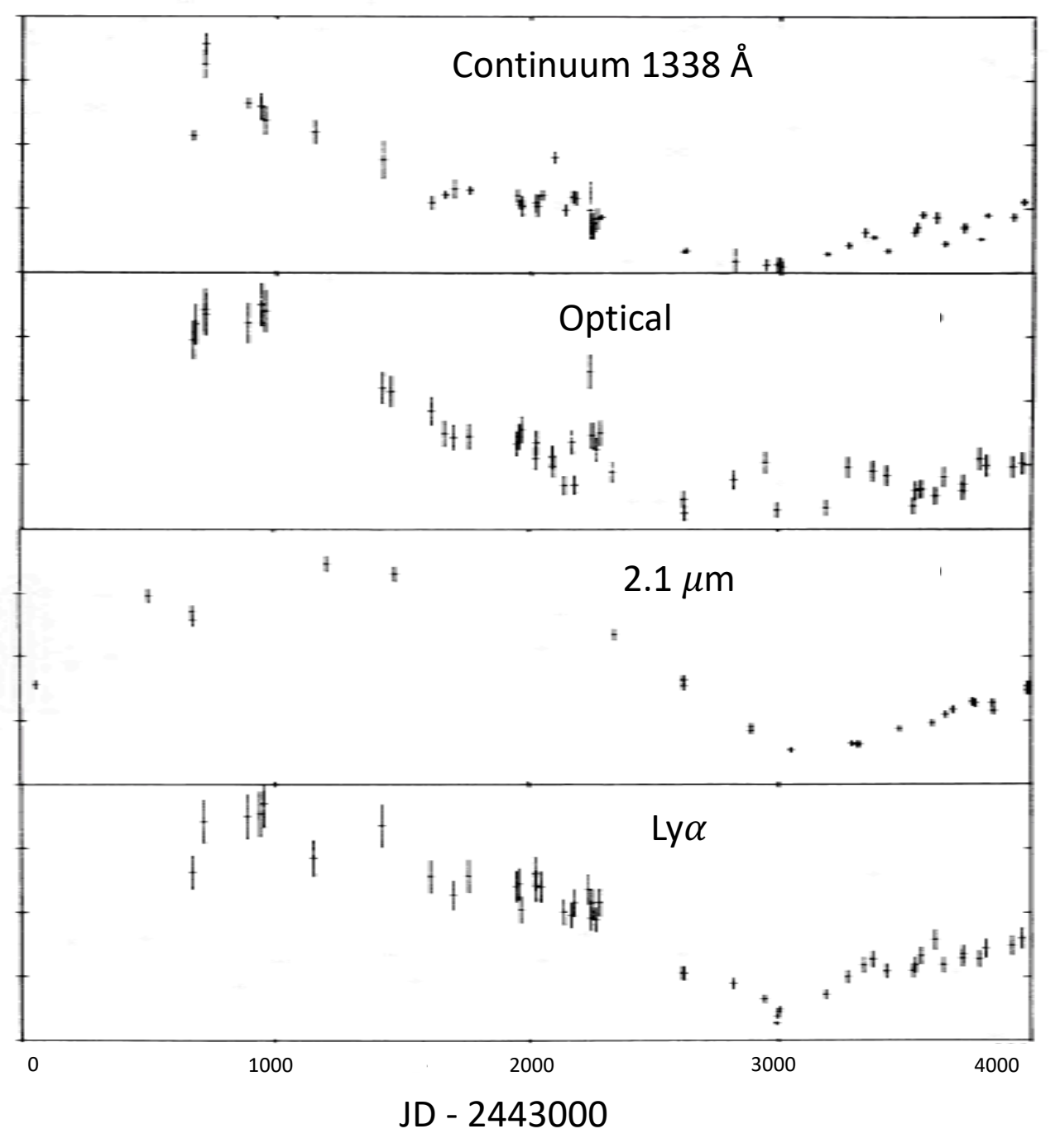
$\eta(\mathrm{H}\alpha) < \eta(\mathrm{H}\beta) < \eta(\mathrm{H}\gamma) < \eta(\mathrm{He\ I}) < \eta(\mathrm{He\ II})$



η = efficiency of converting change in ionizing flux to line flux

see also Peterson & Ferland 1986; Dietrich+ 1993; Kollatschny 2003b

Probing Torus via Infrared Reverberation Mapping

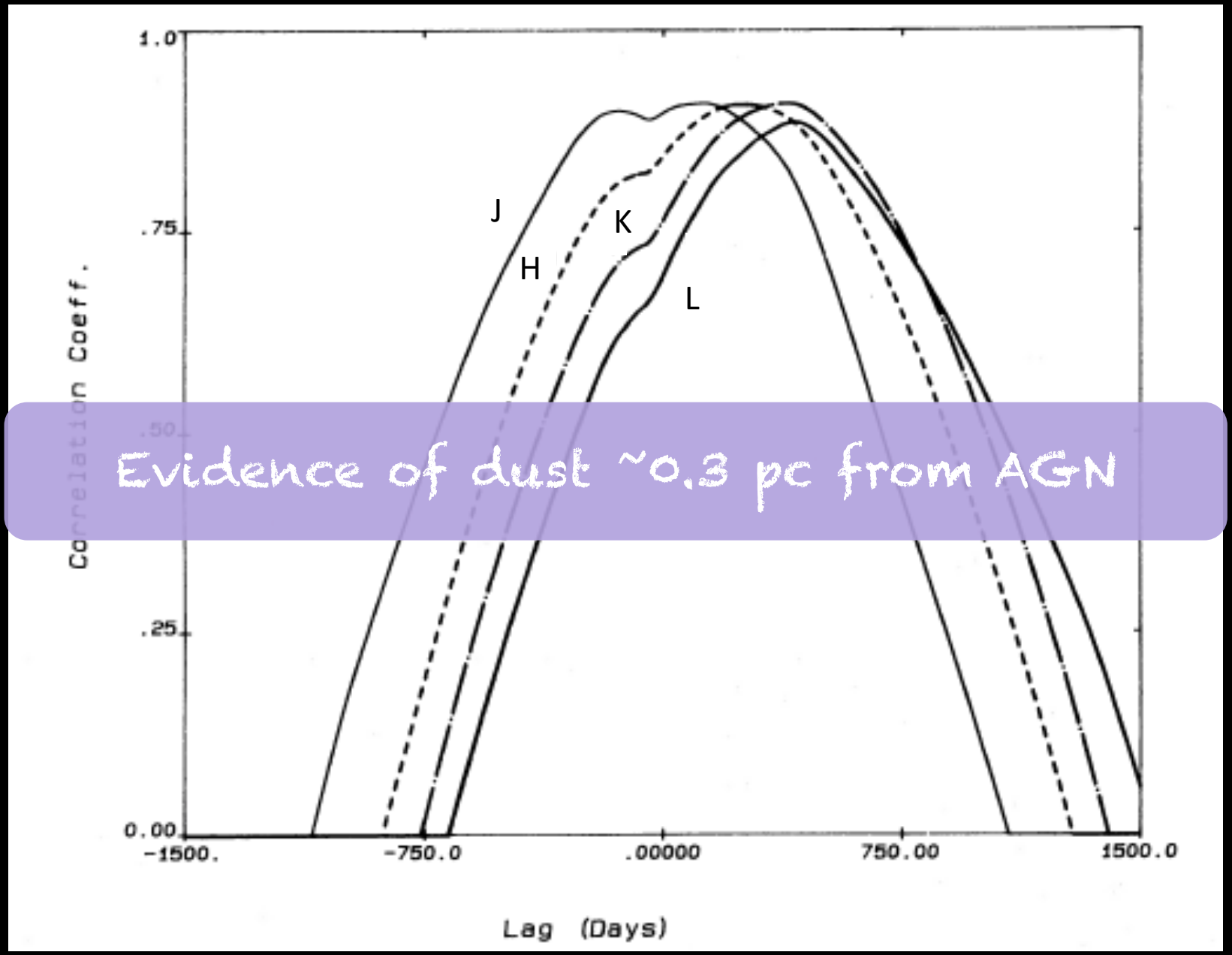


Fairall 9

- 1978 – 1987
- 54 UV & optical epochs
- 27 NIR epochs

➔ NIR lags optical

Clavel+ 1989



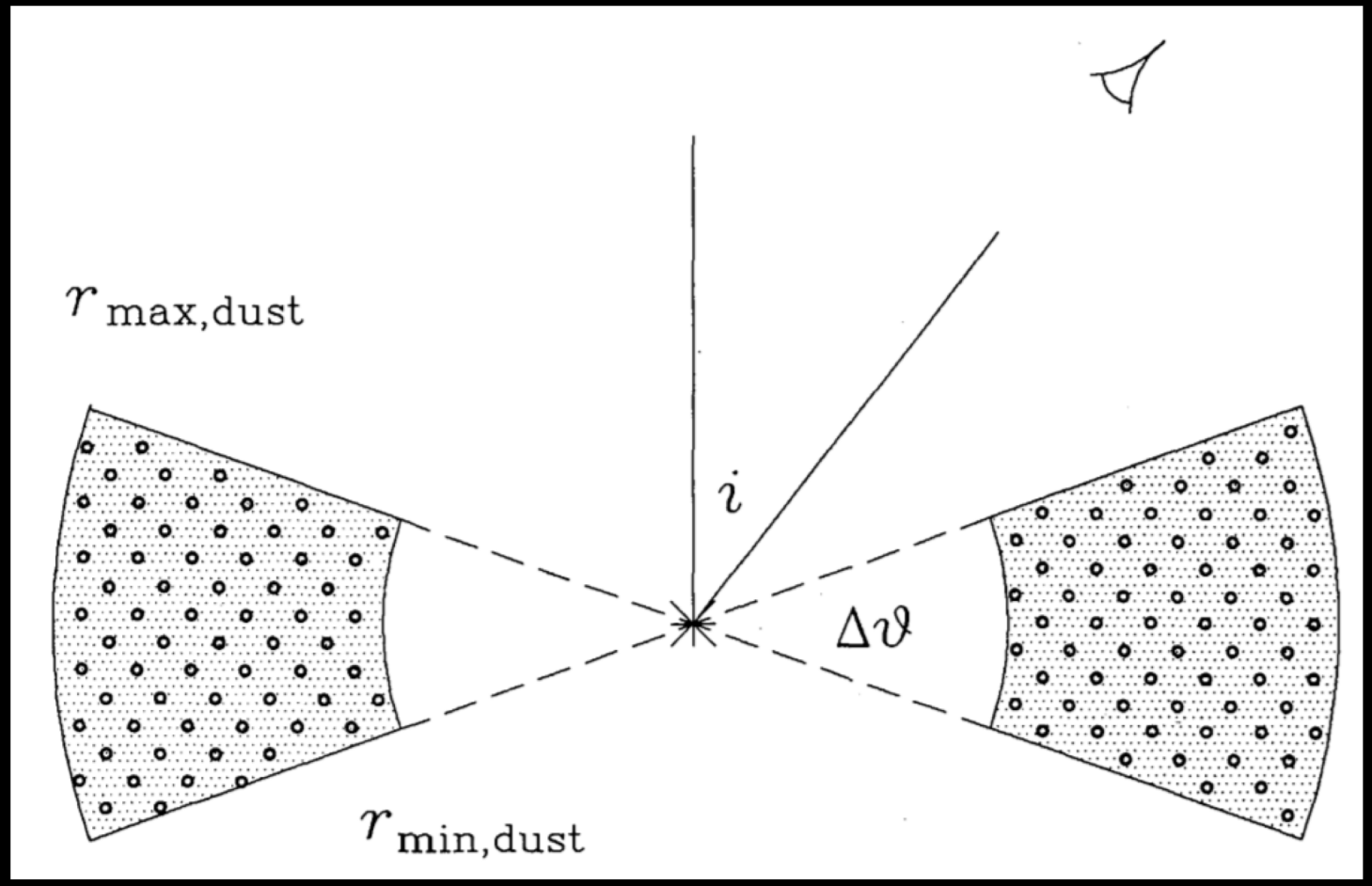
Evidence of dust ~0.3 pc from AGN

CCF w/ UV continuum

- NIR lags UV
- delay ↑ w/ λ
- τ ~ 410 days at 3.35 μm

Clavel+ 1989

Modelling of Fairall 9 NIR Light Curves

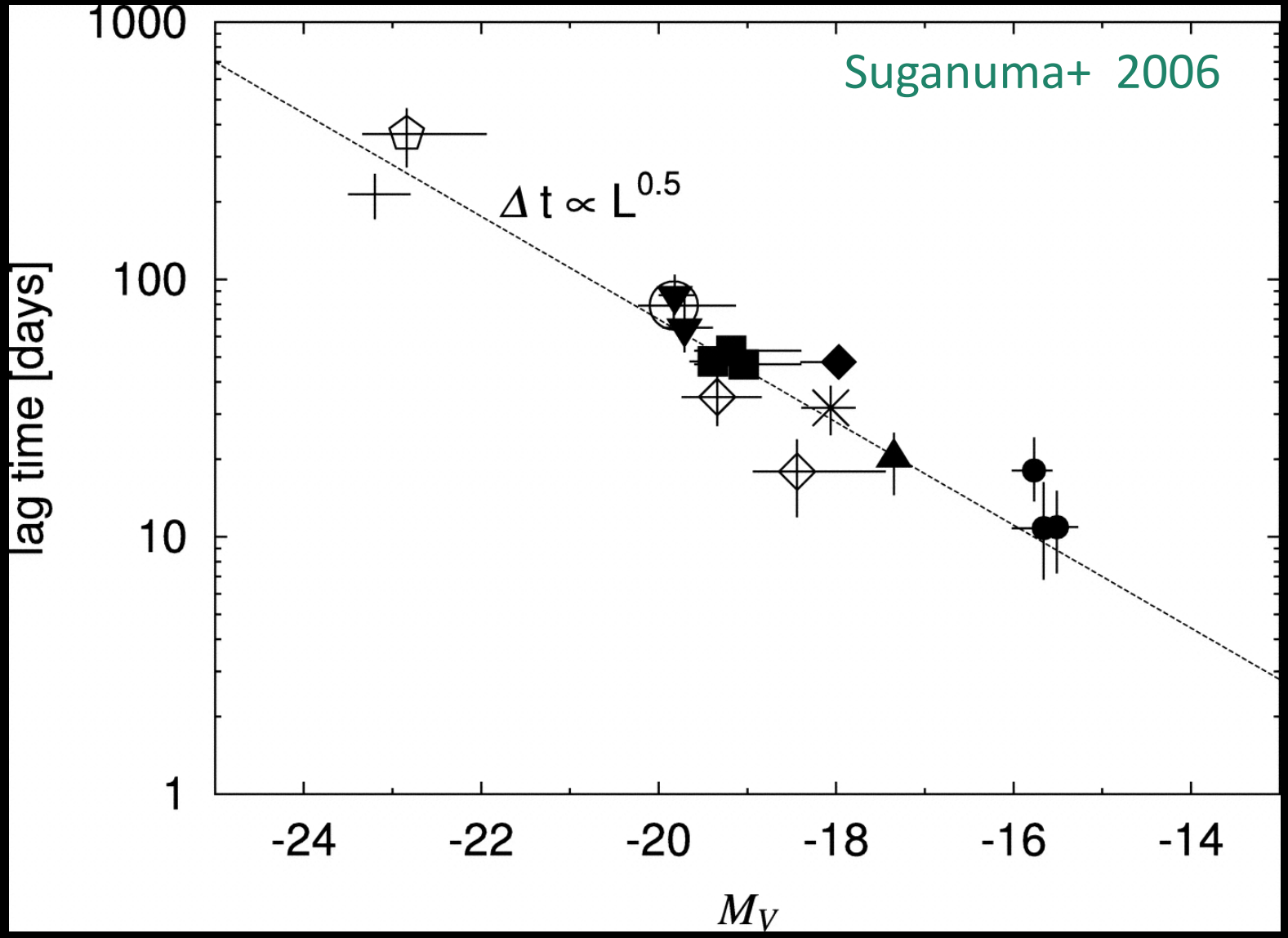


Clumpy torus

0.1 pc < R < 0.4 pc

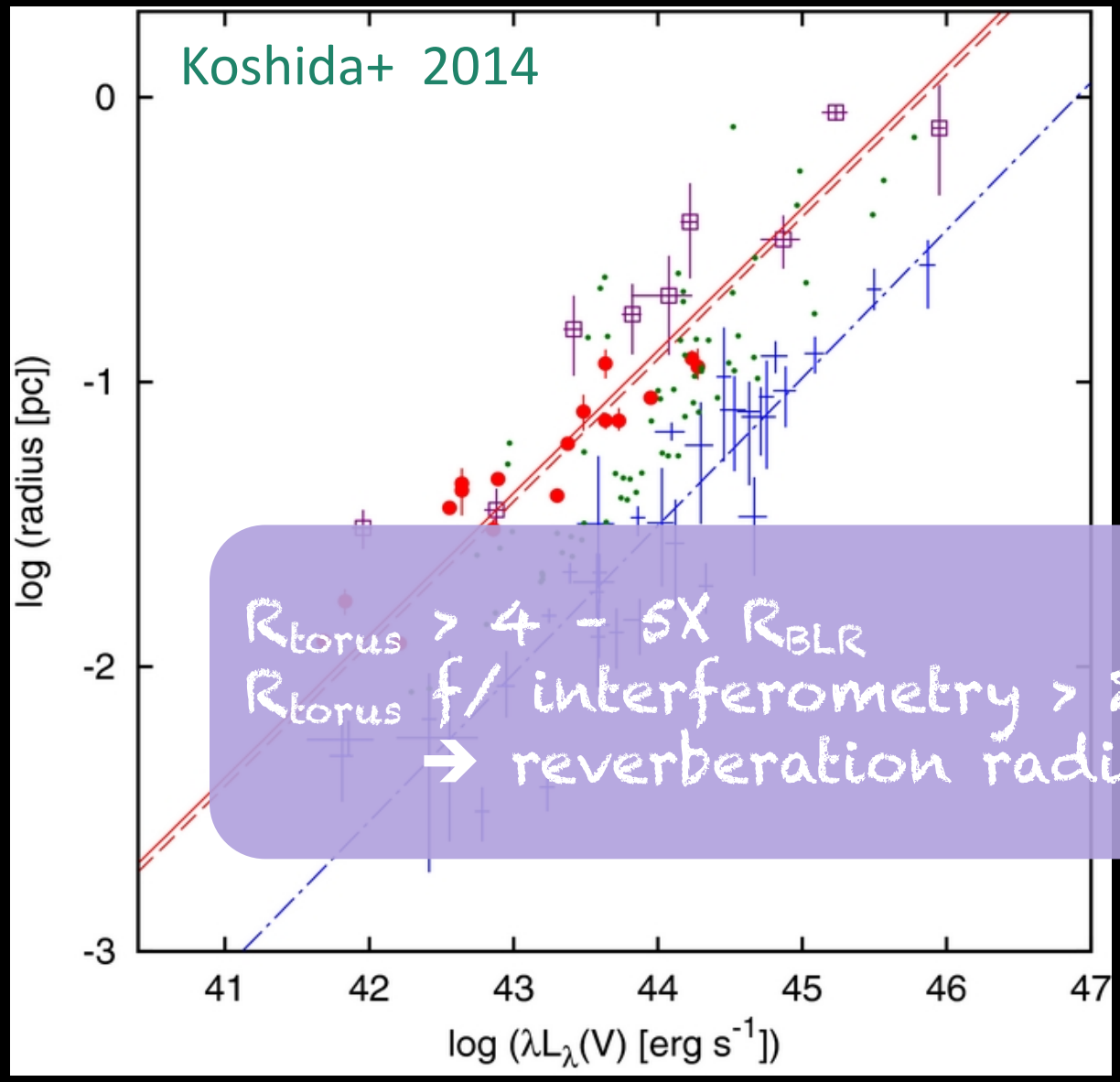
Barvainis 1992

K-band lags: similar L dependence cf BLR



see also Minezaki+ 2004, Suganuma+ 2006, Koshida+ 2009

Compare R_{torus} w/ R_{BLR}

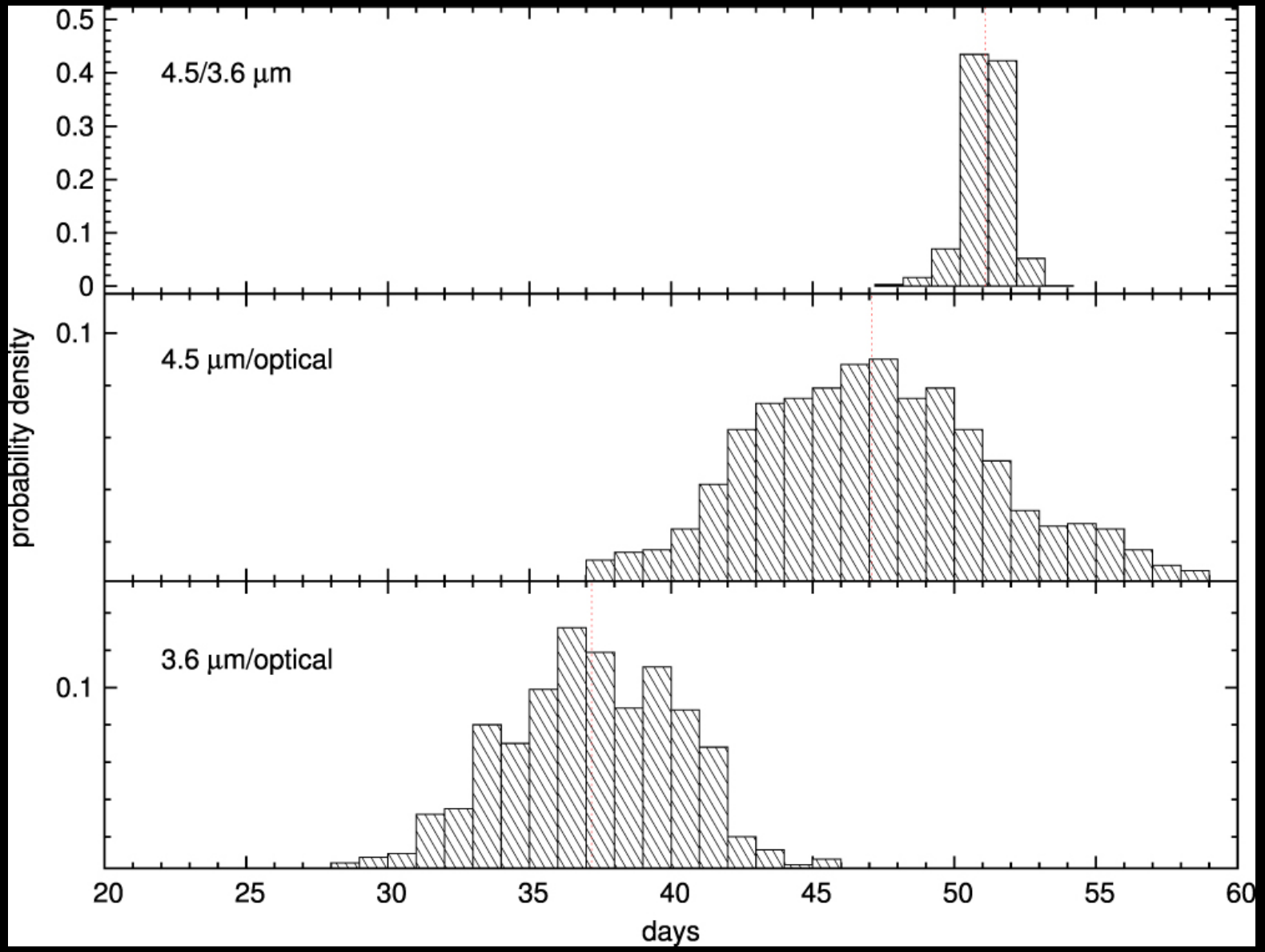


- K reverberation mapped R
- K interferometry R
  Kishimoto+ 2011, Weigelt+ 2012
- BLR *Bentz+ 2009*

R_{torus} > 4 – 5X R_{BLR}
R_{torus} f/ interferometry > 2x R_{torus} f/ reverberation
→ reverberation radius is more compact

see also Suganuma+ 2006, Kishimoto+ 2011

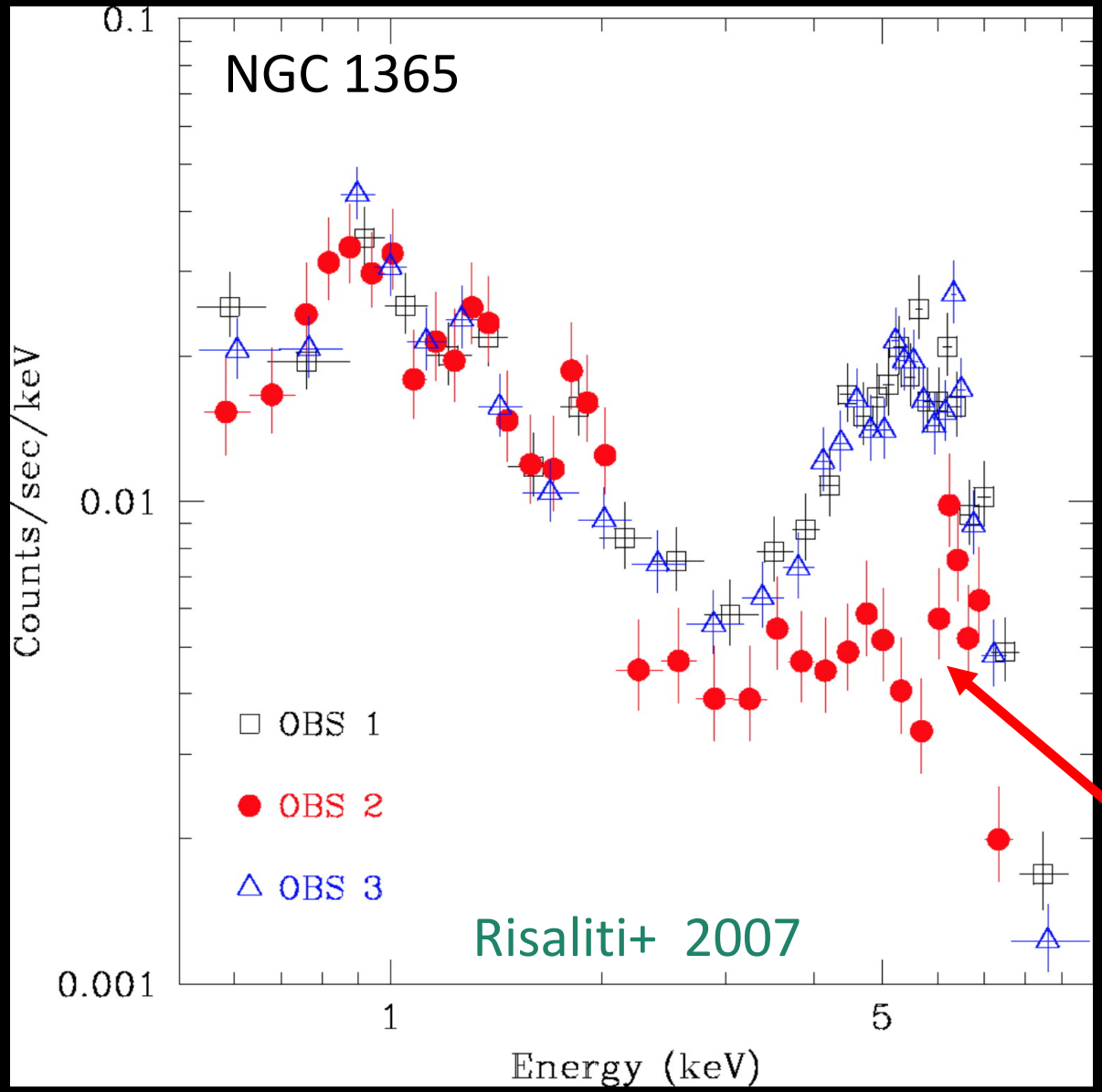
MIR lags: $\tau_{4.5\mu m} > \tau_{3.6\mu m}$



Vazquez+ 2015

Changing-Look AGN: Insight into Torus Structure & Accretion Physics

X-ray Changing-Look AGN: Variable N_H



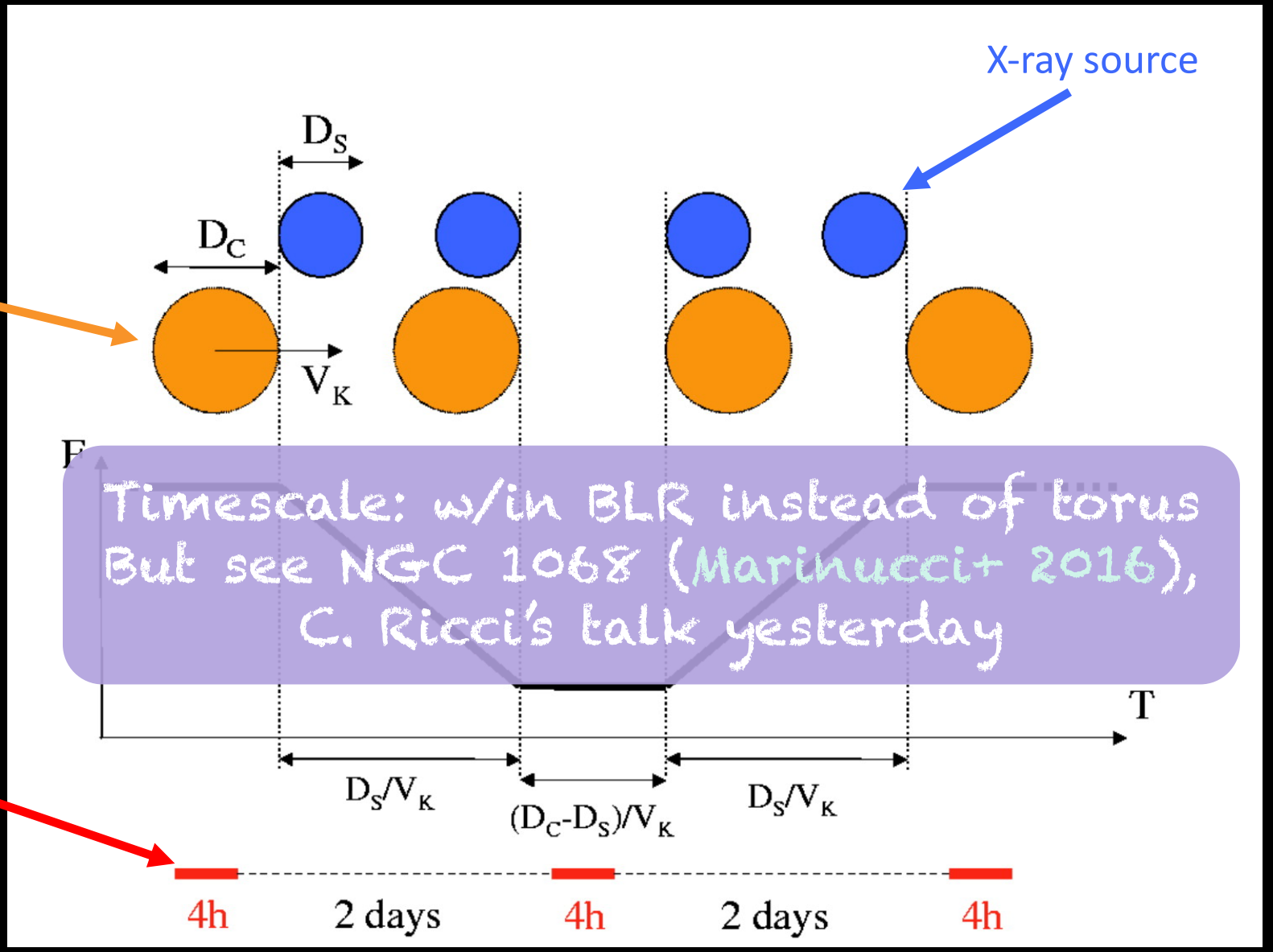
4 day interval:

Compton-thin →
Compton-thick →
Compton-thin

Compton-thick ($N_H > 10^{24}$ cm^{-2}) spectrum

see also Risaliti+ 2005

X-ray Changing-Look AGN: Variable N_H

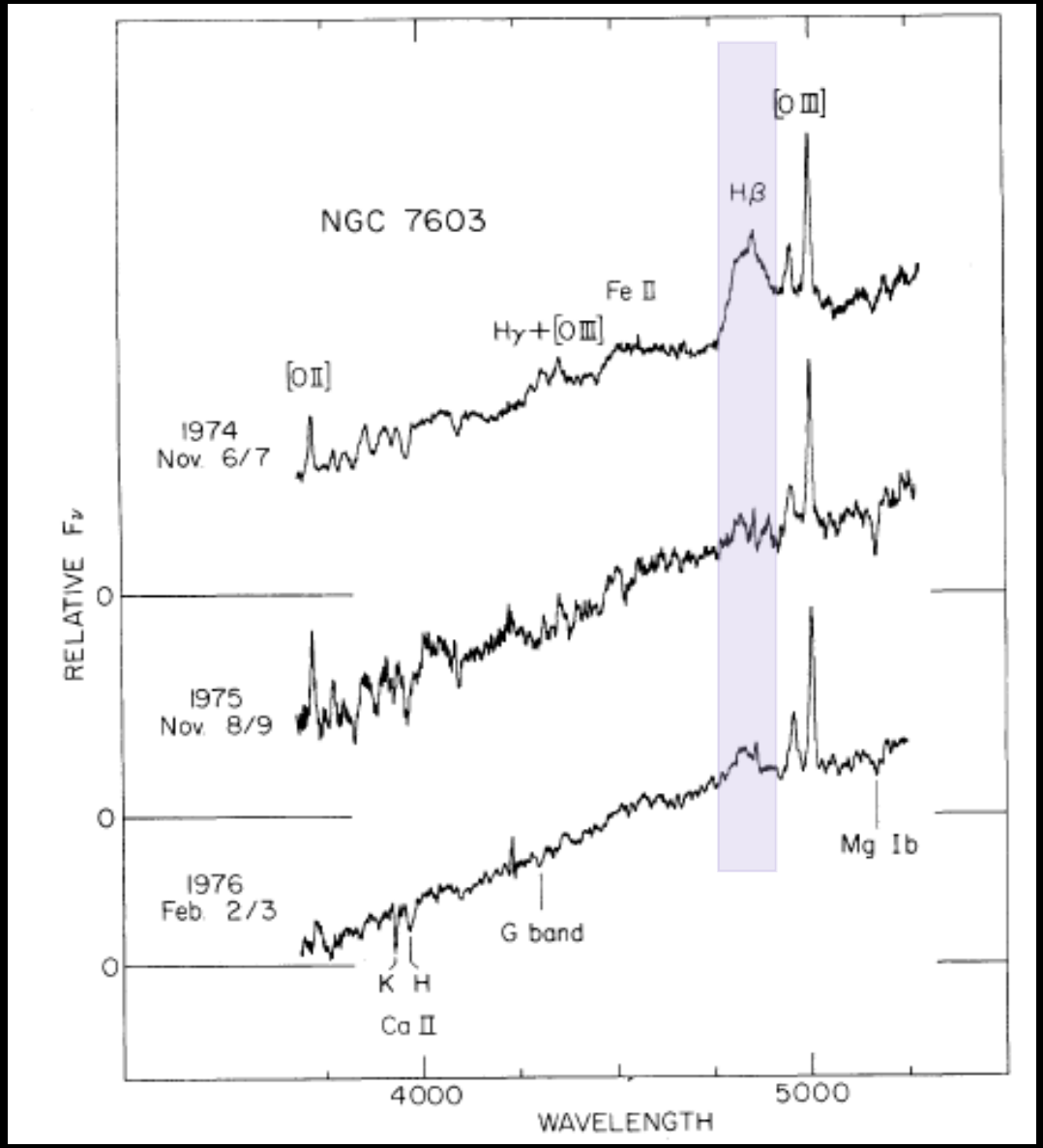


Timescale: w/in BLR instead of torus
But see NGC 1068 (Marinucci+ 2016),
C. Ricci's talk yesterday

Chandra obs

Risaliti+2007;
see also Risaliti+ 2005

Optical Changing-Look AGN History

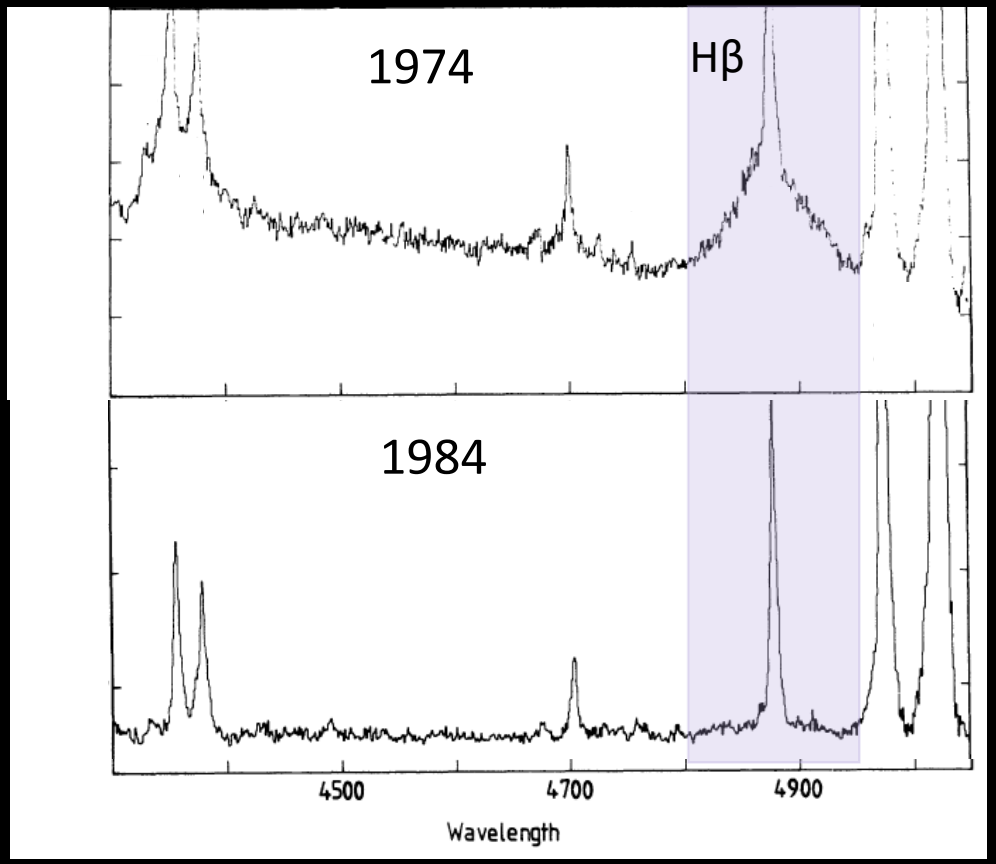


NGC 7603

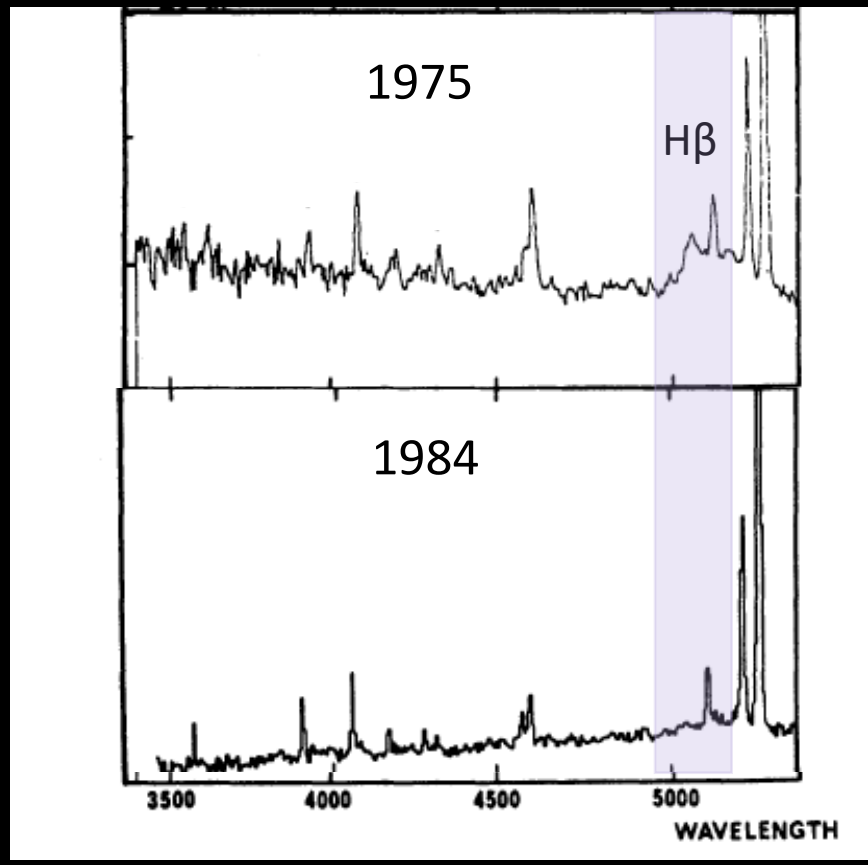
Tohline & Osterbrock ‘76

Optical Changing-Look AGN History: Disappearing Balmer Lines

NGC 4151



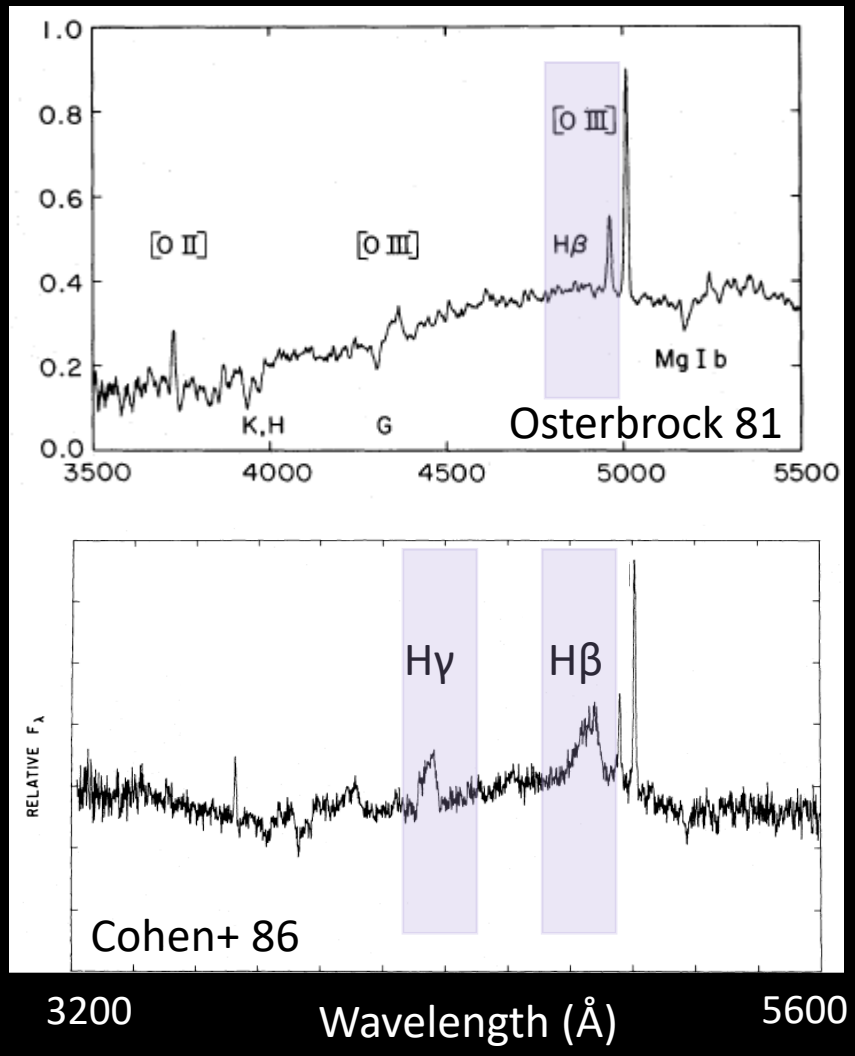
3C390.3



Penston & Perez 84; see also Goodrich 95

Optical Changing-Look AGN History: Appearing Balmer Lines

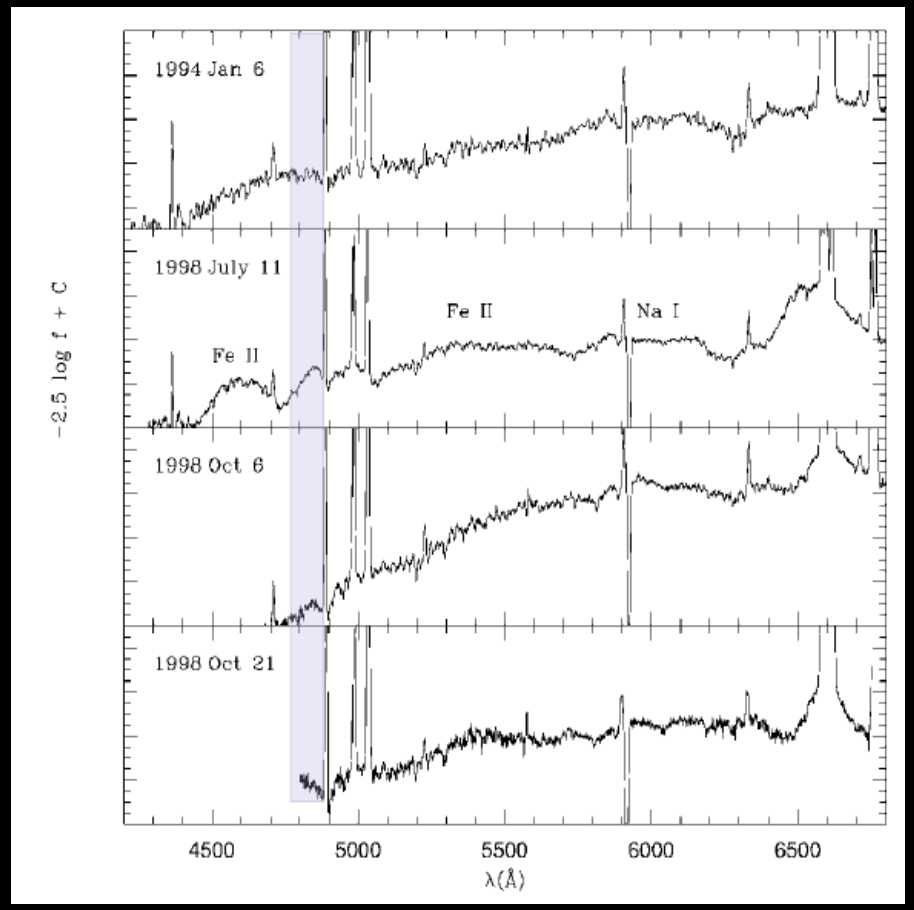
Mrk 1081



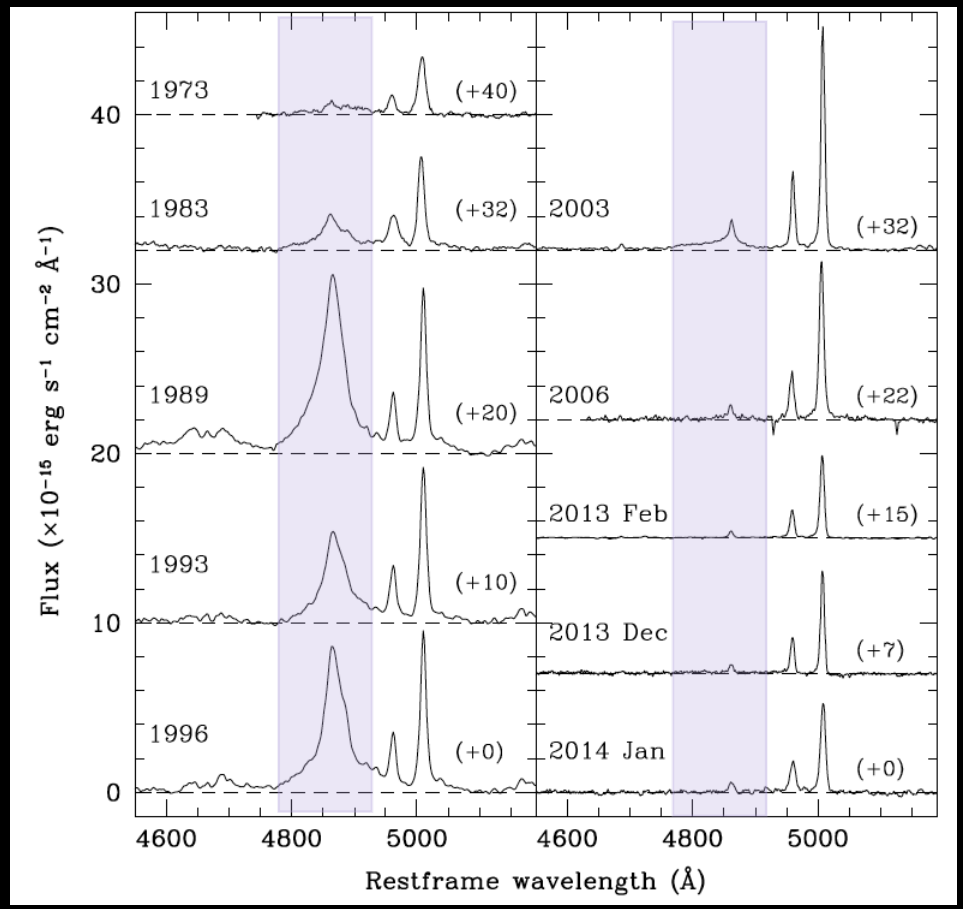
See also Tran+ 92, Storchi-Bergmann+ 93, Goodrich+ 95, Eracleous & Halpern 01, Shappe+ 14

Optical Changing-Look AGN History: There & Back Again Balmer Lines

NGC 7582 *Aretxaga+ 99*



Mrk 590 *Denney+ 14*



see also McElroy+ 2016, MacLeod+ 2016

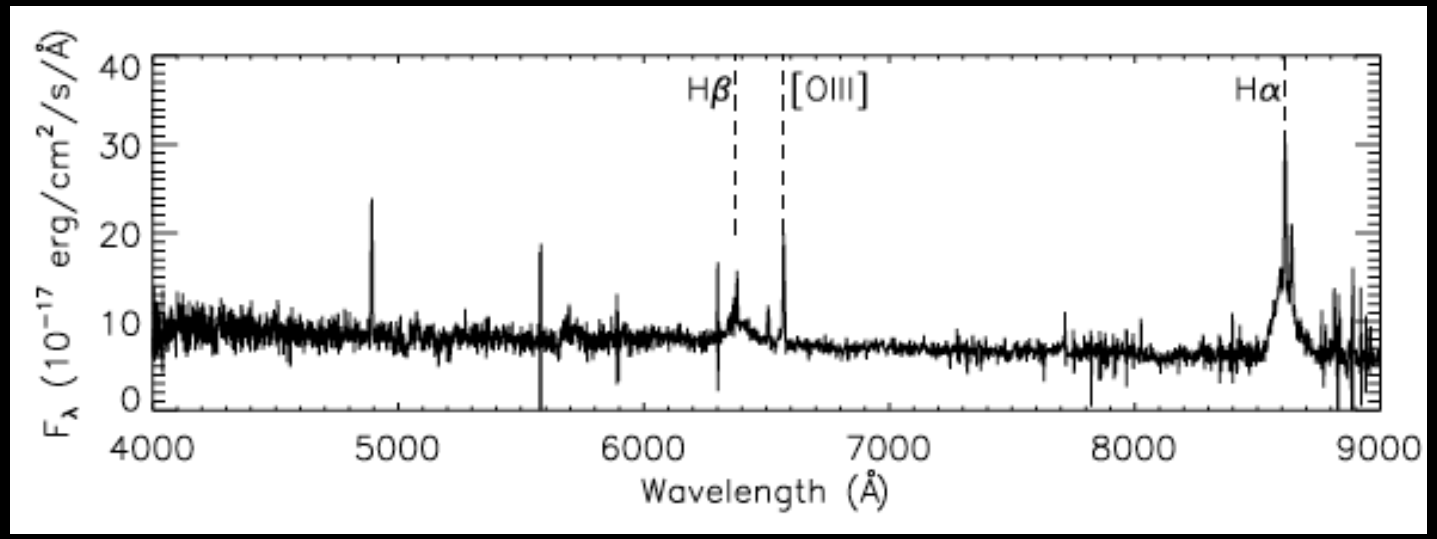
Drivers of Optical Changing-Look AGN

- Variable absorption Mrk 1018, Mrk 993, NGC 7603, NGC 1097, NGC 7582 (?)

Drivers of Optical Changing-Look AGN

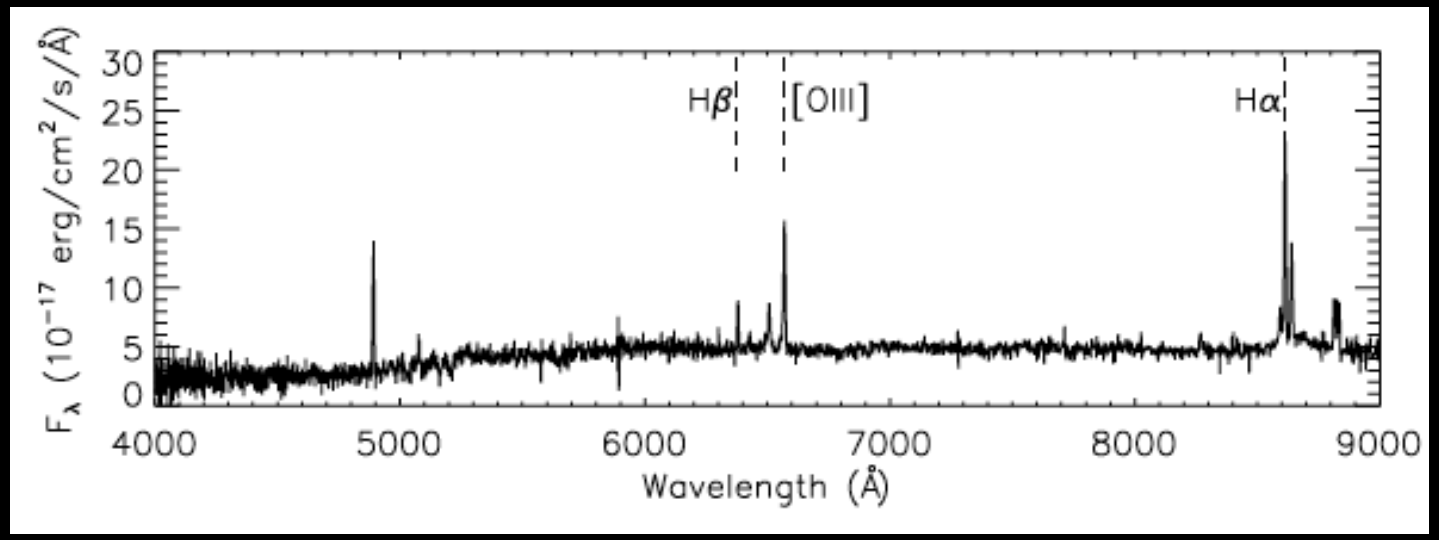
- Variable absorption Mrk 1018, Mrk 993, NGC 7603, NGC 1097, NGC 7582 (?)
- Ionizing continuum change Mrk 590, NGC 2617, Mrk 883, NGC 3065, J0159+0033
- Supernova NGC 7582 (?)
- Tidal Disruption Event NGC 3065 (?), NGC 7582 (?), J0159+0033 (?)

1st Changing-Look "Quasar": SDSS J0159+0033



2000 (SDSS)

Type 1

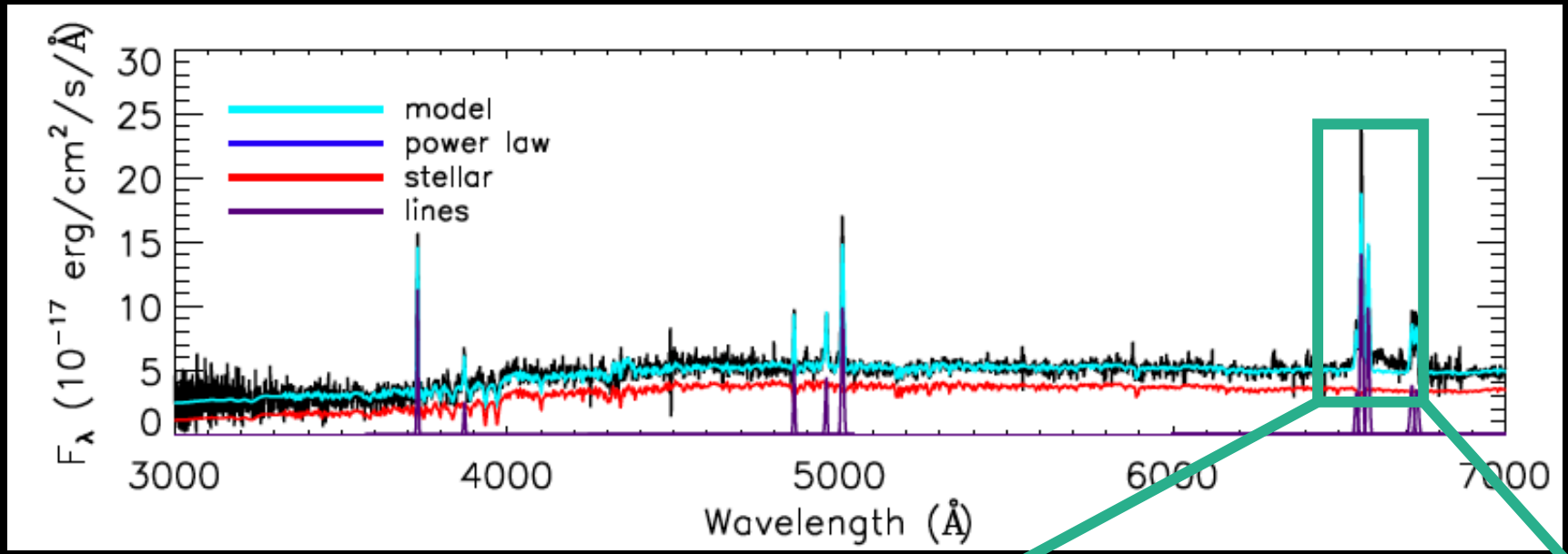


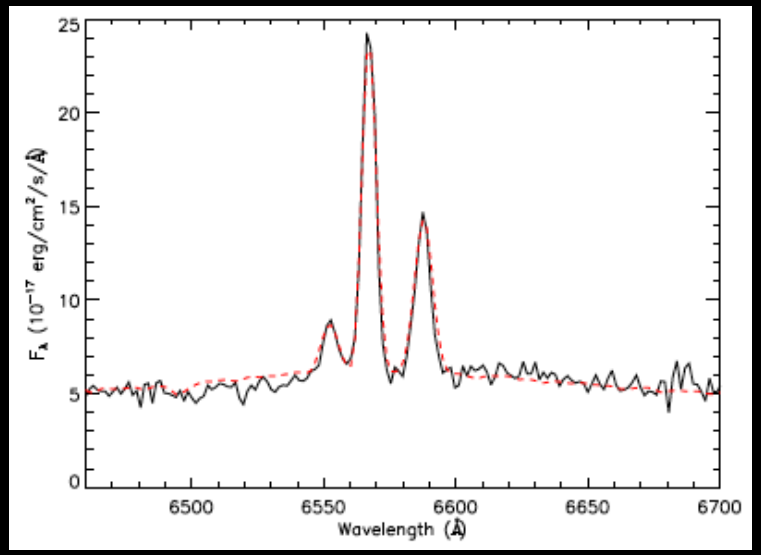
2010 (BOSS)

Type 1.9

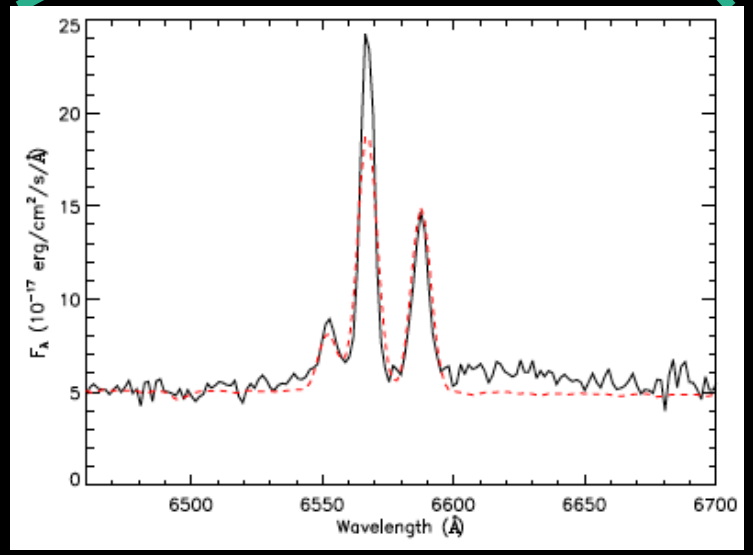
LaMassa+ 2015

Variable Absorption?





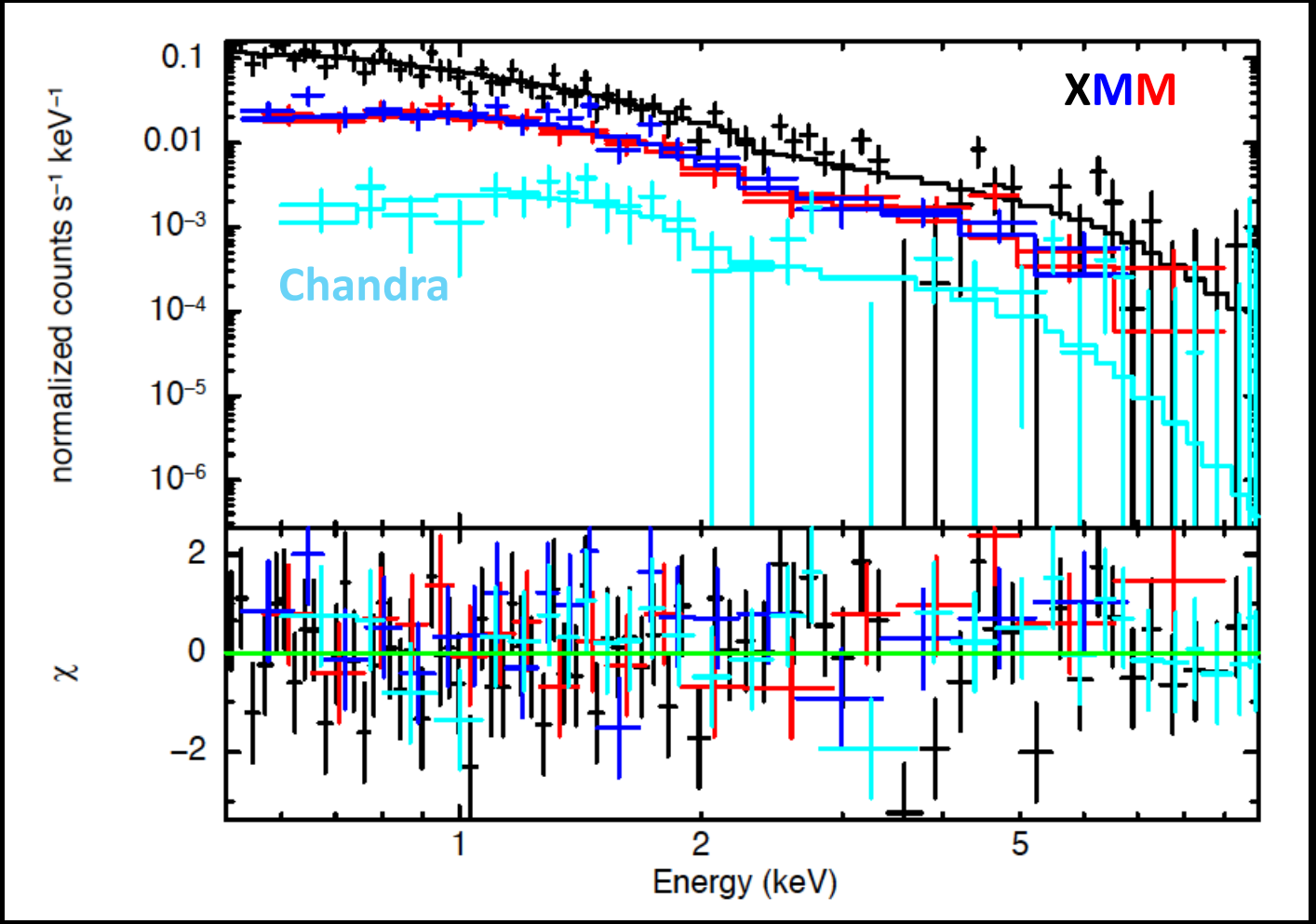
vs.



Further evidence against obscuration

LaMassa+ 2015

- No absorption signatures in X-ray spectrum



Further evidence against obscuration

LaMassa+ 2015

- No absorption signatures in X-ray spectrum
- Similar drop in optical & X-ray fluxes
- Similar BH masses in bright & dim states
- Hα profile change cf. λL_{5100} change
- t_{cross} for cloud to eclipse BLR

$$t_{\rm cross} = 0.07 \left[\frac{r_{\rm orb}}{1{\rm lt-day}}\right]^{3/2} M_8^{-1/2} \arcsin\left[\frac{r_{\rm src}}{r_{\rm orb}}\right] \ {\rm yr},$$

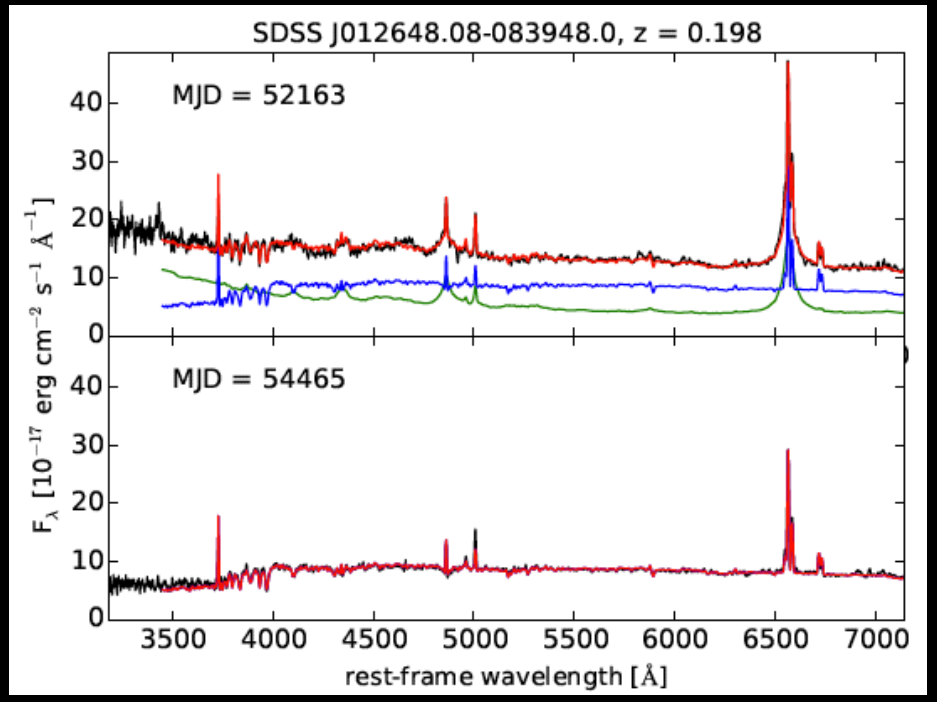
t_{cross} > 10-20 yrs

t_{change} ~ 3 yrs

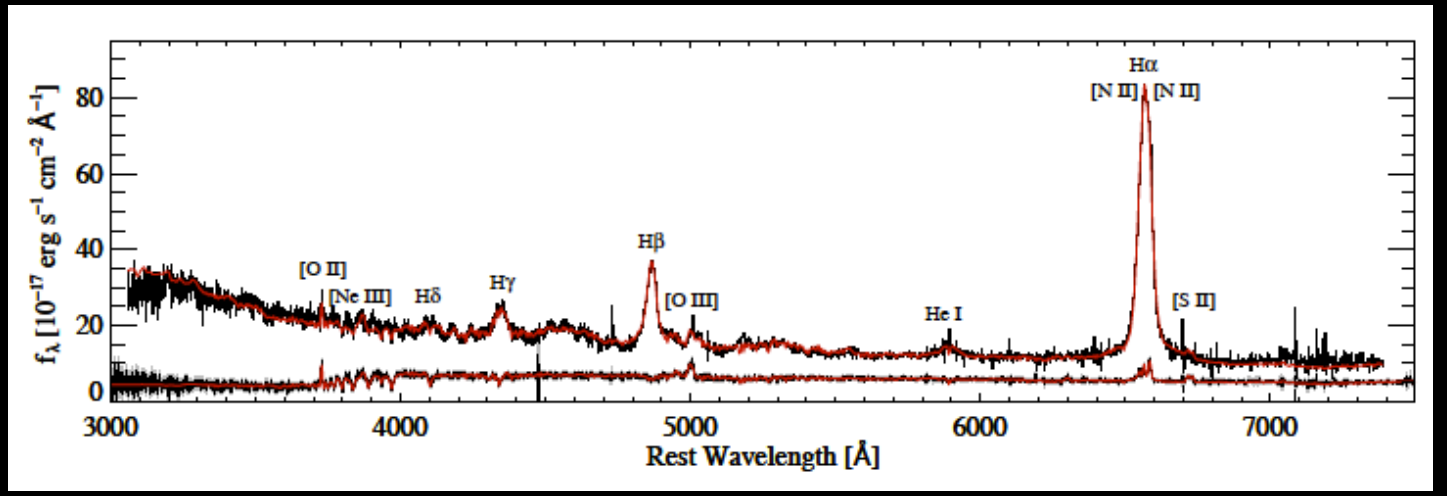
Driver: Change in Ionizing Continuum

- Accretion disk? --> viscous time scale too long
- TDE? Merloni+ 2015

Treasures in Archival Data: Optical Selection

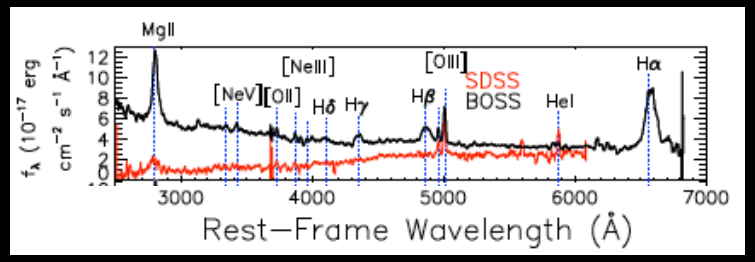


Ruan,…SML,...+2016

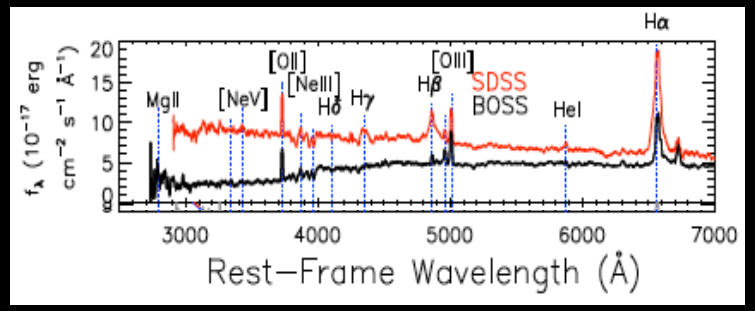


Runnoe,…SML,…+2016

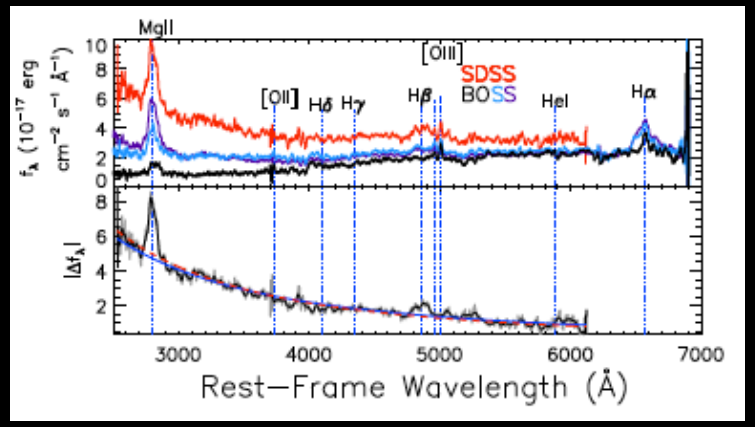
Treasures in Archival Data: Optical Selection



Broad Lines Appear
4 Quasars

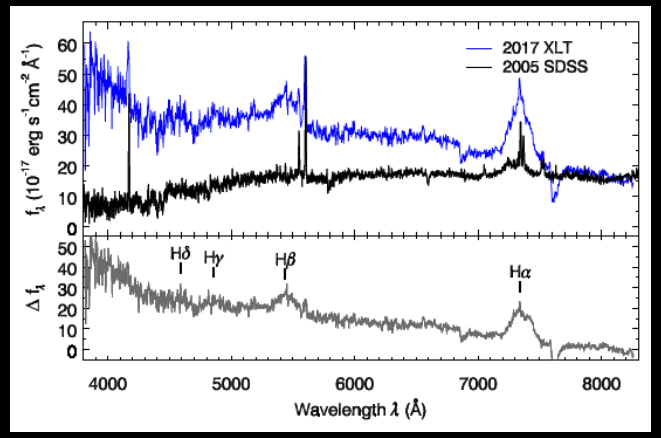


Broad Lines Disappear
5 Quasars

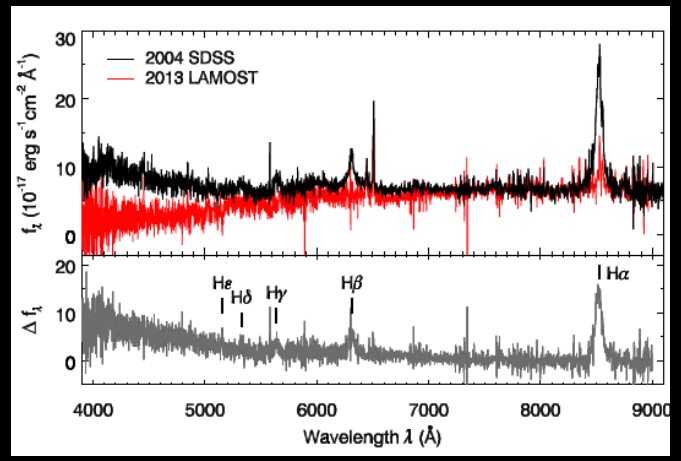


Broad Lines Disappear
then Reappear
1 Quasar

MacLeod+ 2016



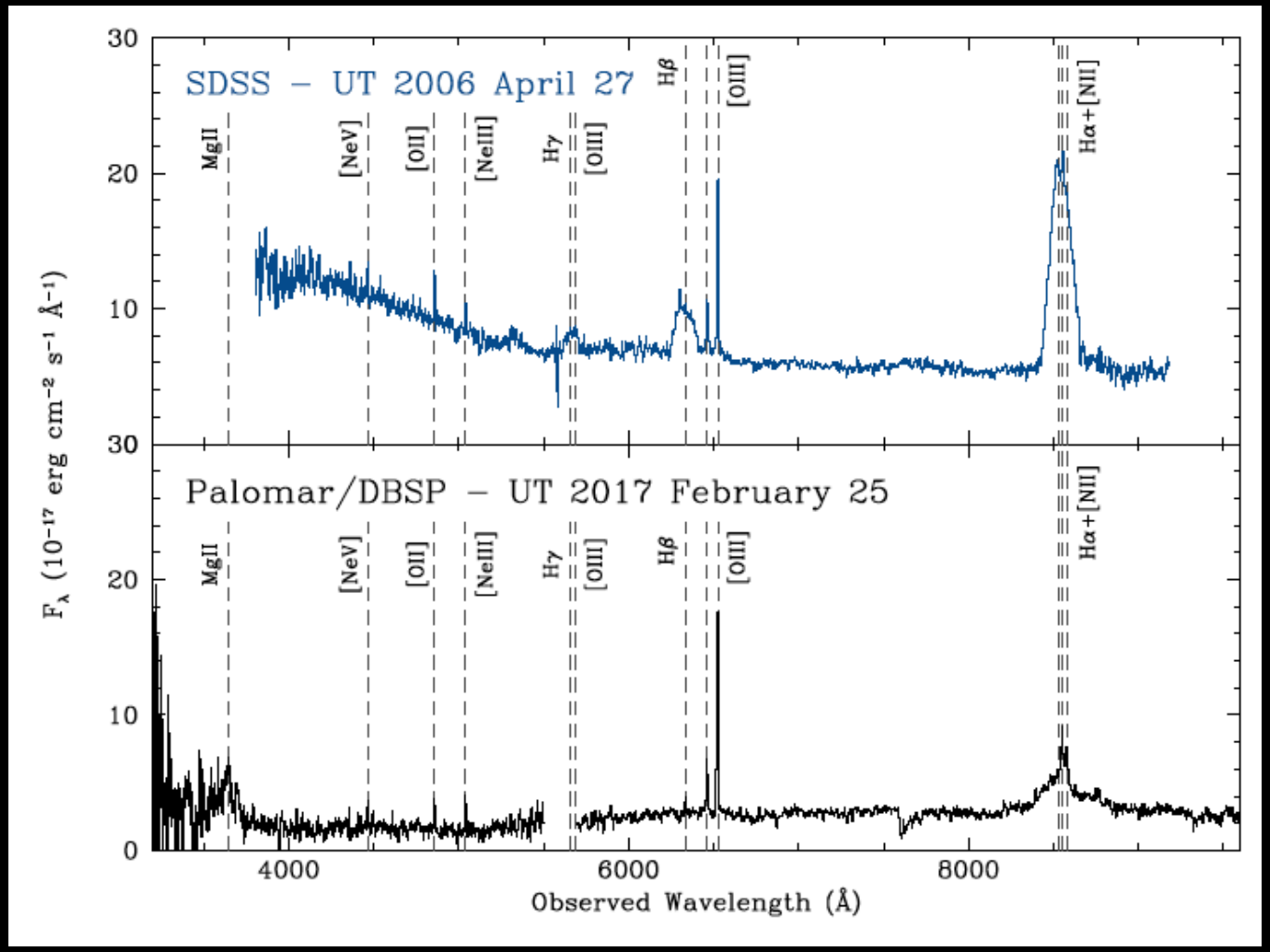
Broad Lines Appear
15 AGN



Broad Lines Disappear
6 AGN

Yang+ 2017

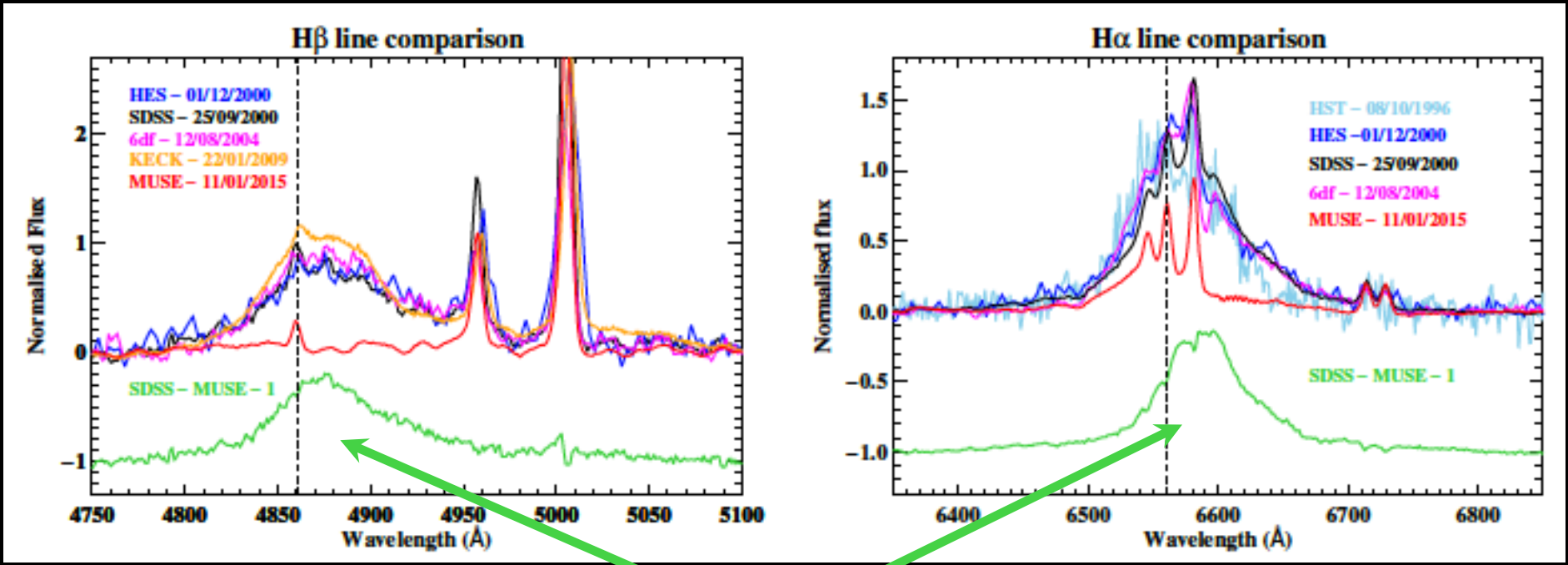
Treasures in Archival Data: Infrared Selection



Stern+ 2017

Serendipitous Discoveries: Monitoring Programs

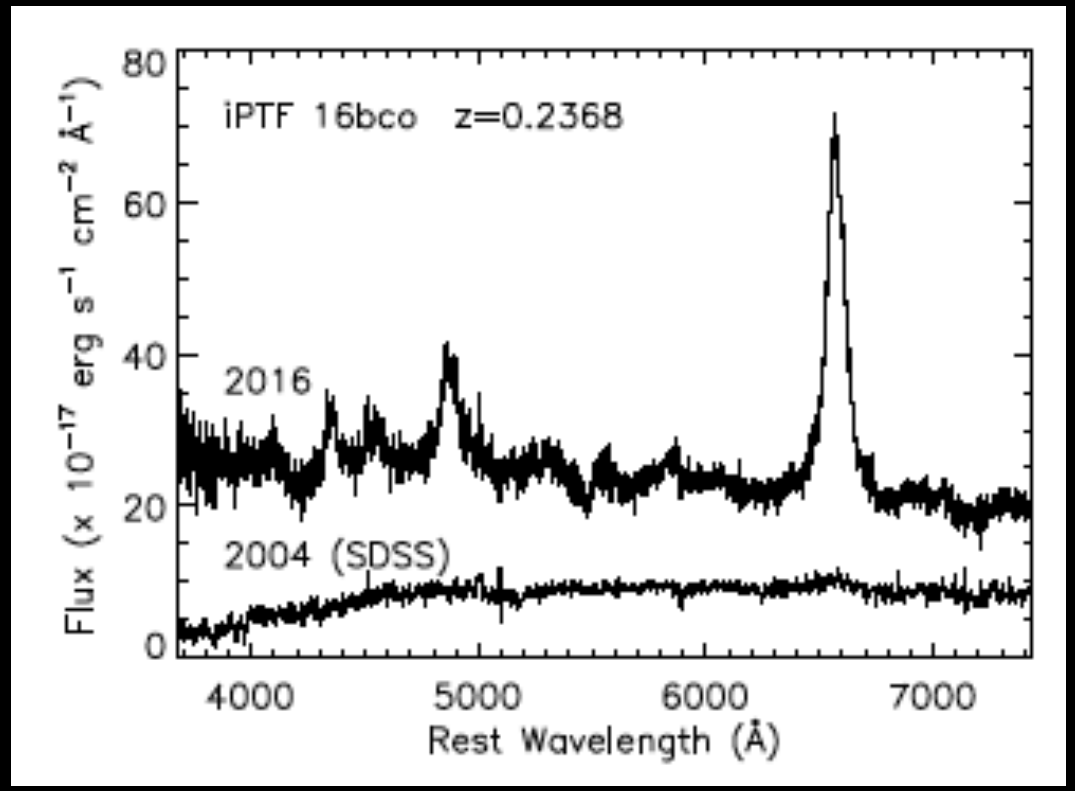
Mrk 1018 McElroy+ 2016



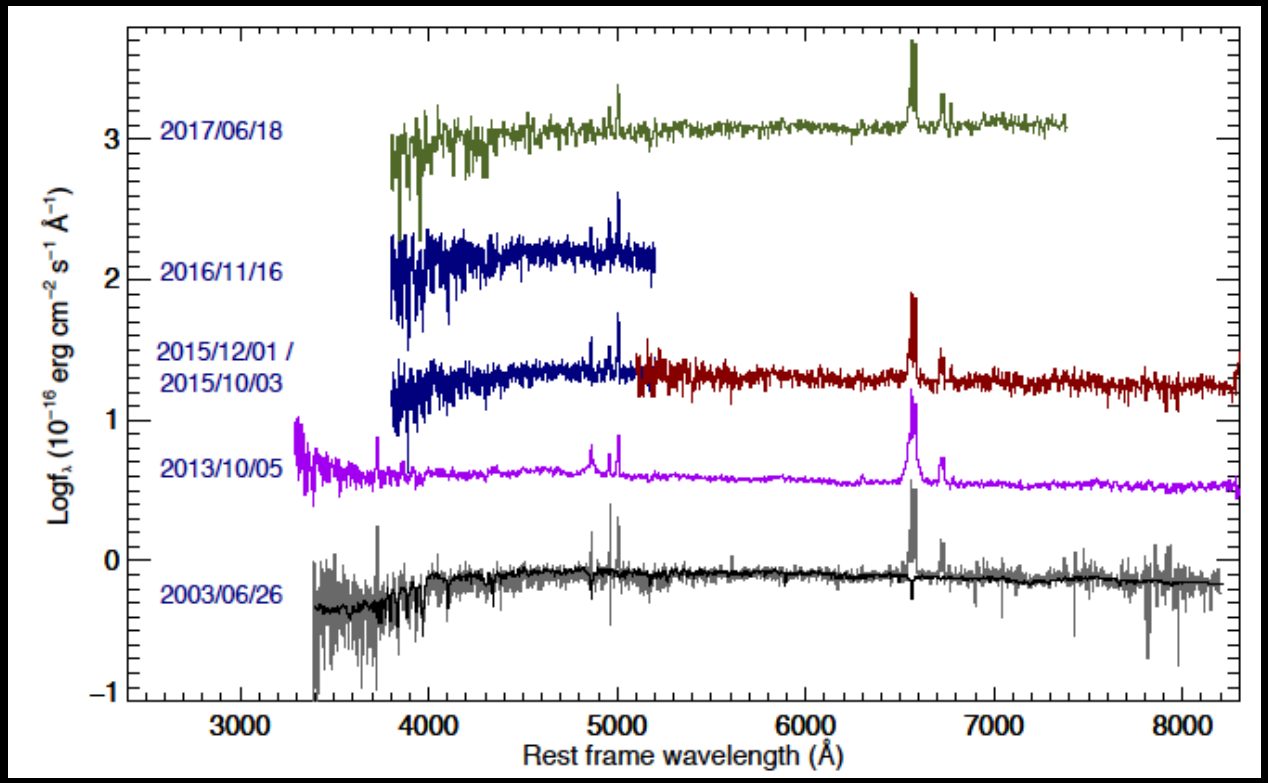
Weakening of broad Balmer lines between 2000 & 2015

See Husemann+ 2016, LaMassa+ 2017 for X-ray Analysis

Serendipitous Discoveries: Transient Surveys



Gezari+ 2017



Katebi+ 2018

Changing-Look AGN Implications

- Variable absorption & TDE explanations ruled out for discoveries >= 2016
  - optical & MIR light curves important constraint Yang+ 2017, Stern+ 2017

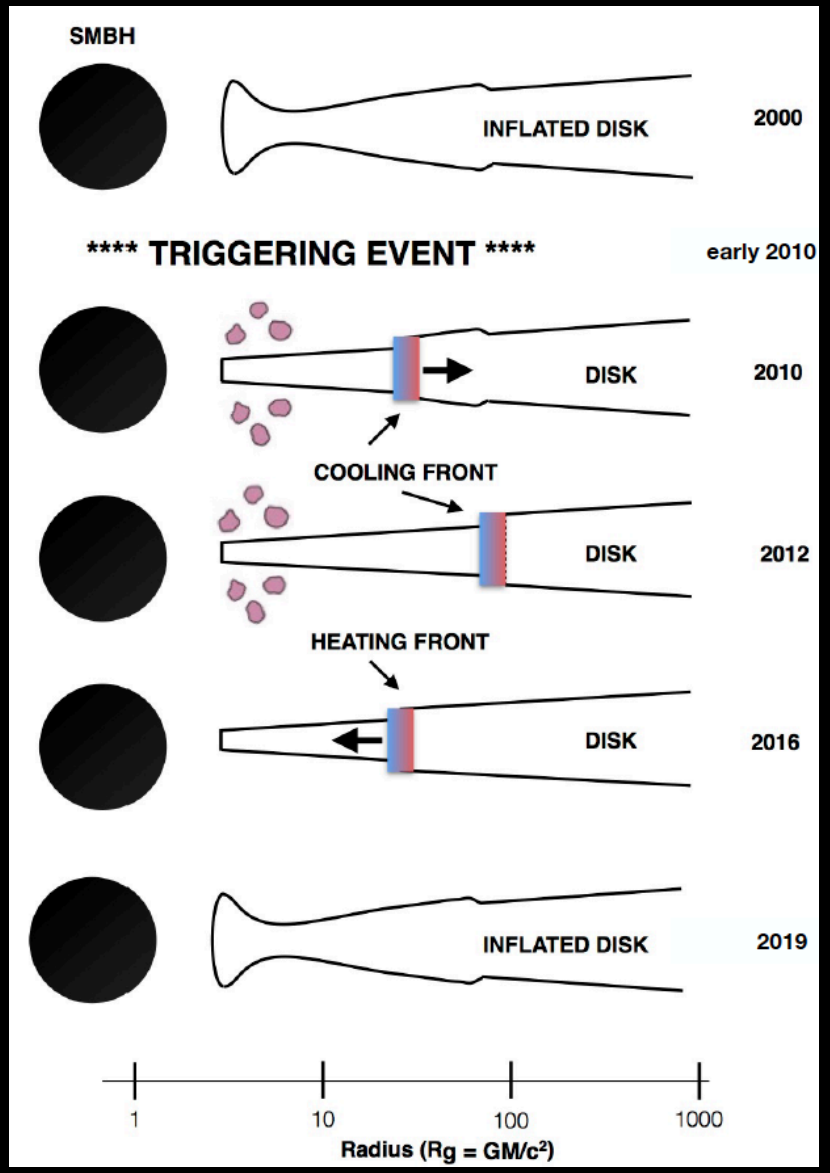
➔Fundamentally different from X-ray changing-look AGN?

- Monitoring nearby CL-AGN (Mrk 1018, Mrk 590) show dimming → rebrightening behavior Krumpe+ 2017, Mathur+ 2018

➔episodic accretion events?

Changing-Look AGN Physical Explanations

- Related to inner accretion disk
  - thermal timescale Stern+ 2017, Katebi+ 2018
  - cooling front propagating outwards (AGN fades), followed by heating front propagating inwards (AGN re-brightens) Ross+ 2017



Changing-Look AGN Physical Explanations

- Related to inner accretion disk
  - thermal timescale Stern+ 2017, Katebi+ 2018
  - cooling/heating front propagation Ross+ 2017
- Spectral state transition *ala* stellar mass black hole binaries Noda & Done 2018
  - lose “soft X-ray excess” to power BLR ionizing photons → predict geometrically thick disk in “dim” AGN state
- Disk supported by magnetic pressure → short inflow time triggered by drop in accretion rate or thermal fluctuations Dexter & Begelman 2018
- Oscillating recoiled SMBH (Mrk 1018) Kim et al. 2018

Conclusions

- Reverberation mapping provides scale of:
  - Broad Line Region
    - ➔ see talk by P. Sánchez, J. Esser, poster by V. Bennertm D. De Cicco
  - Torus
    - ➔ see talks by T. Almeyda, F. Pozo Nuñez, posters by D. Esparza Arredondo, A. Tanimoto, E. Guise, R. Carraro
  - ➔ see talks by M. Ward, D. Boulderstone (connect BLR w/ Torus)
- Variable X-ray emission probes continuum & absorption changes
  - ➔ see talks by N. Osorio-Clavijo, A. Zaino, poster by T. Turner
- Extreme variability drives (dis)appearance of broad Balmer lines, related to black hole feeding habits
  - ➔ see talks by M. Kokuba, S. Mattila, D. Hustemekers