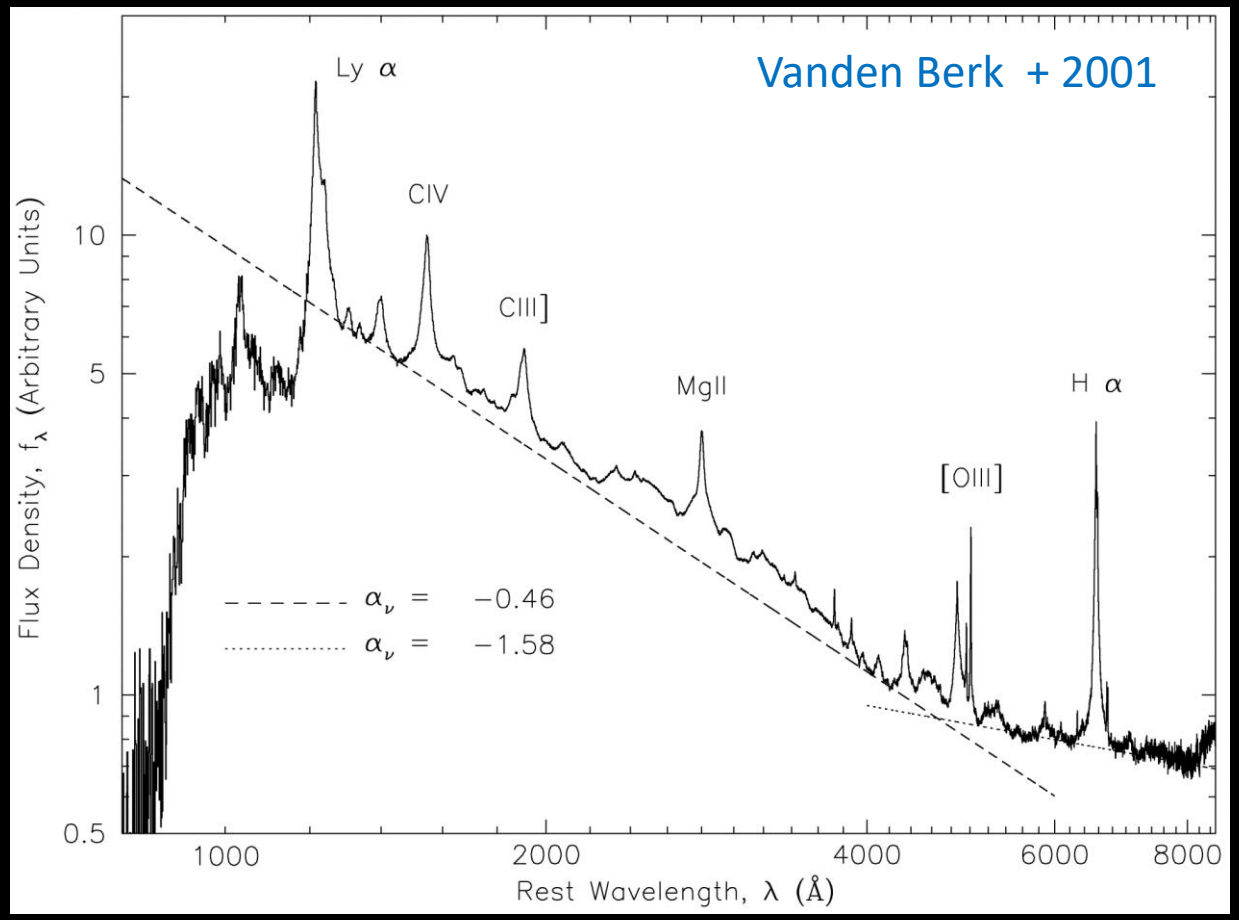
Insight into the Physics of Changing-State AGN from Multi-Wavelength Observations

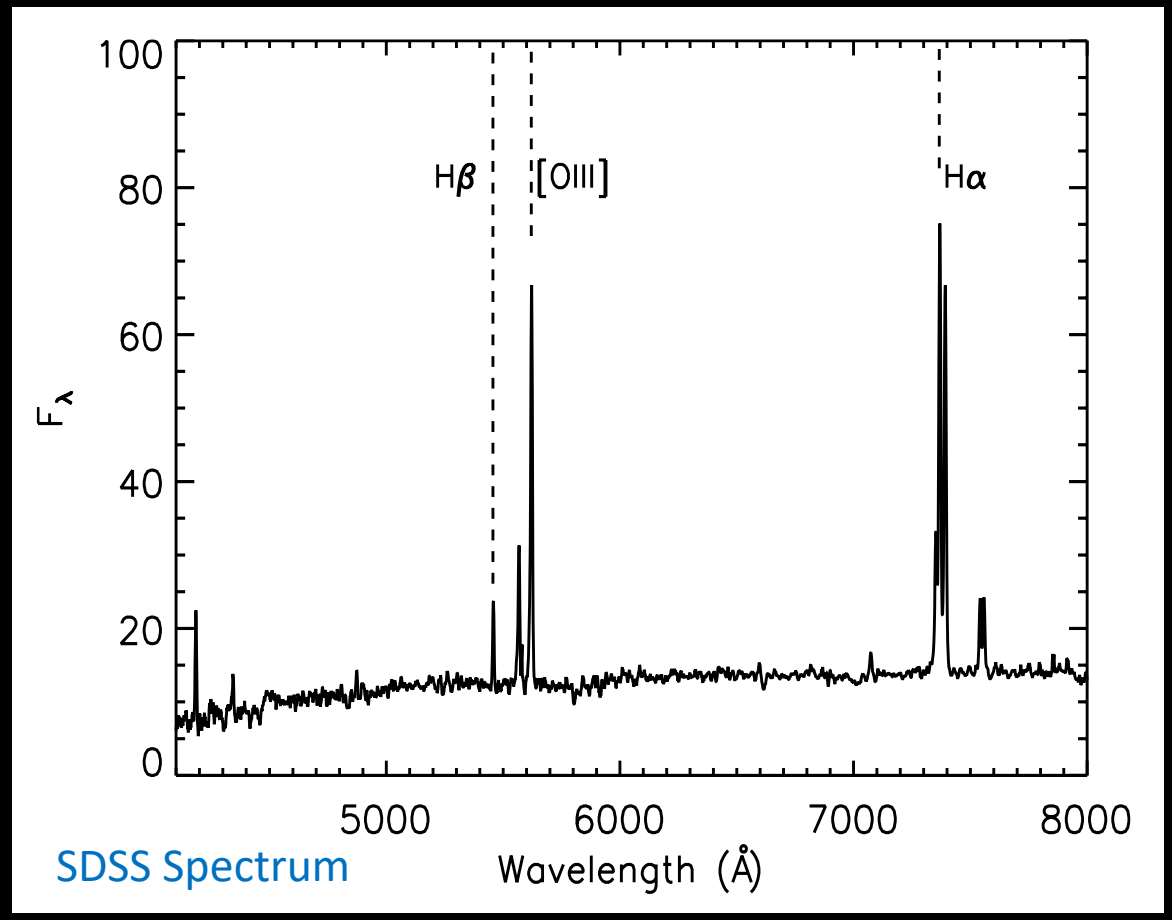
Stephanie LaMassa (STScI)

Define AGN by Optical Spectra

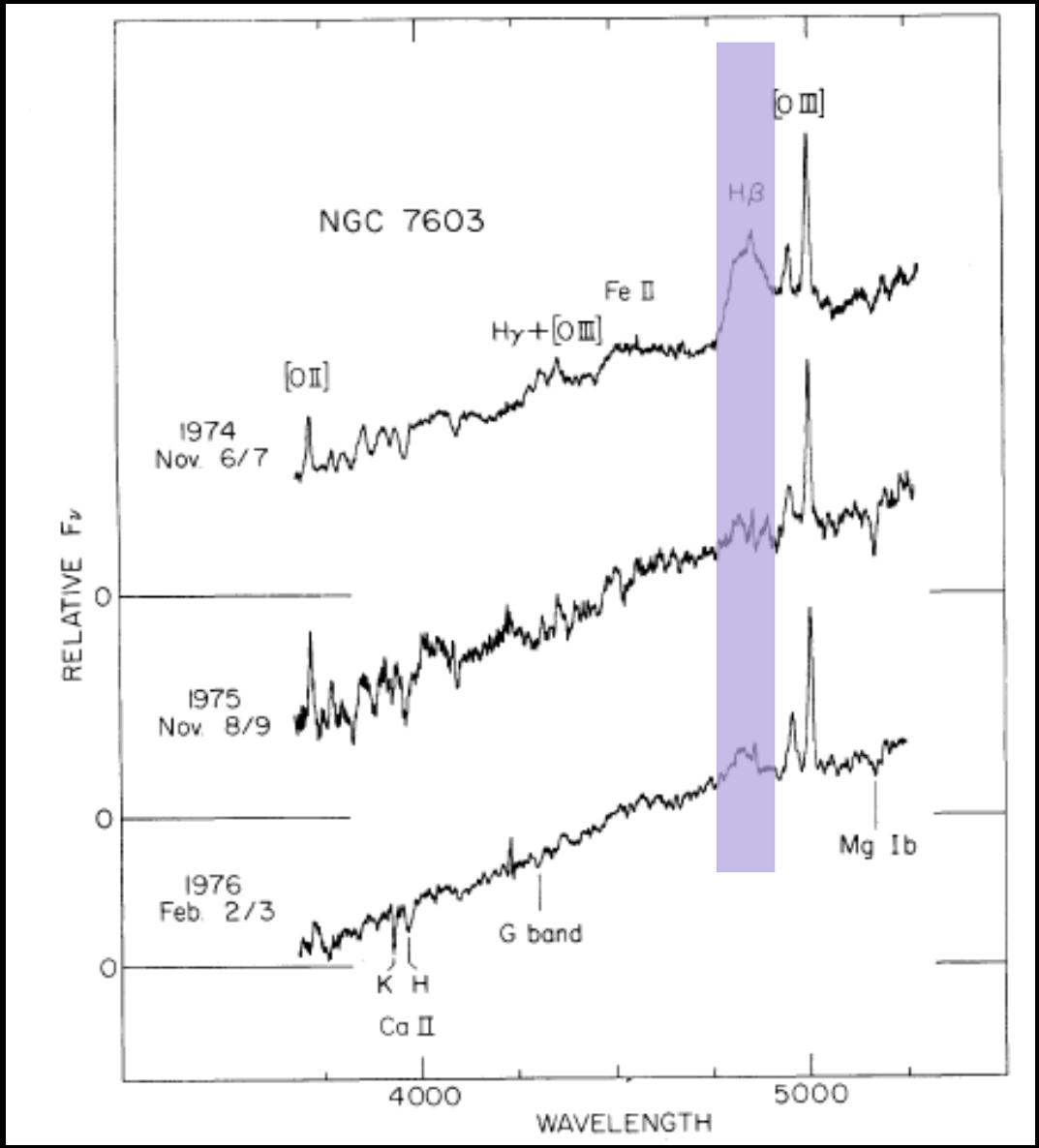
Type 1



Type 2



Optical Changing-Look AGN History

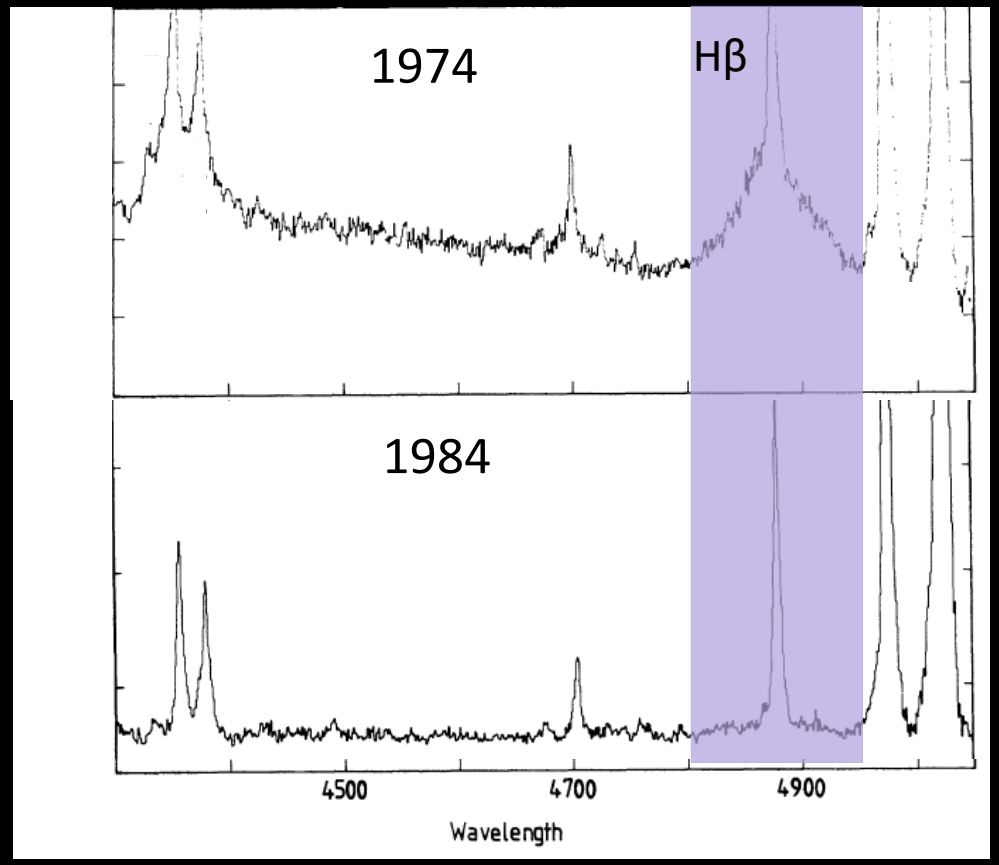


NGC 7603

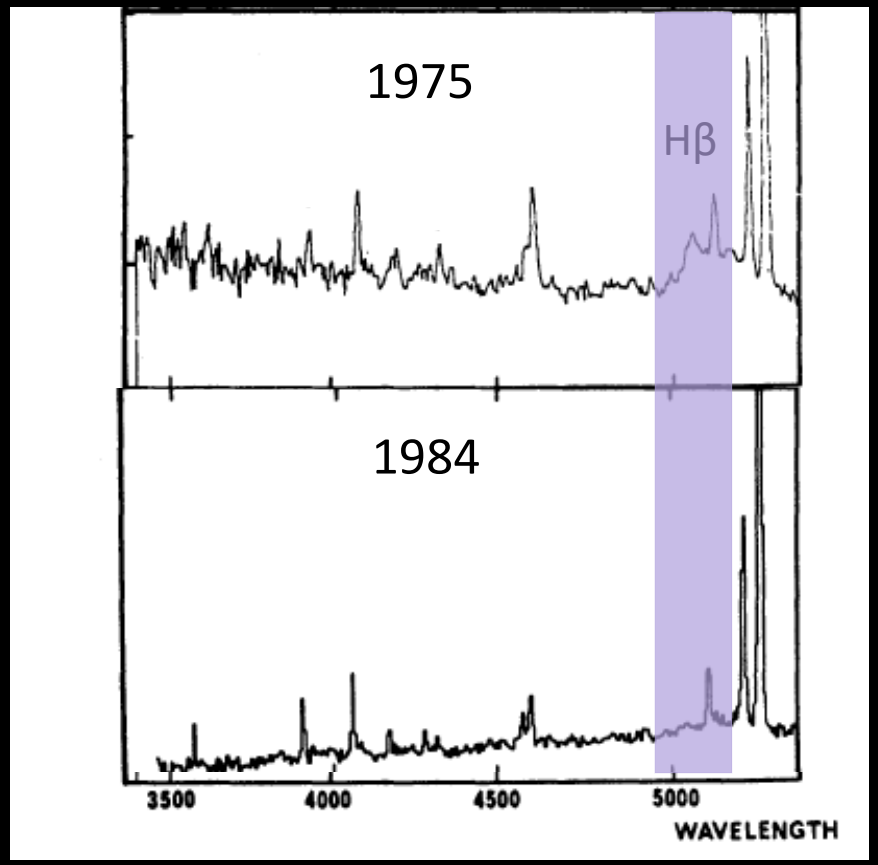
Tohline & Osterbrock '76

Optical Changing-Look AGN History: Disappearing Balmer Lines

NGC 4151



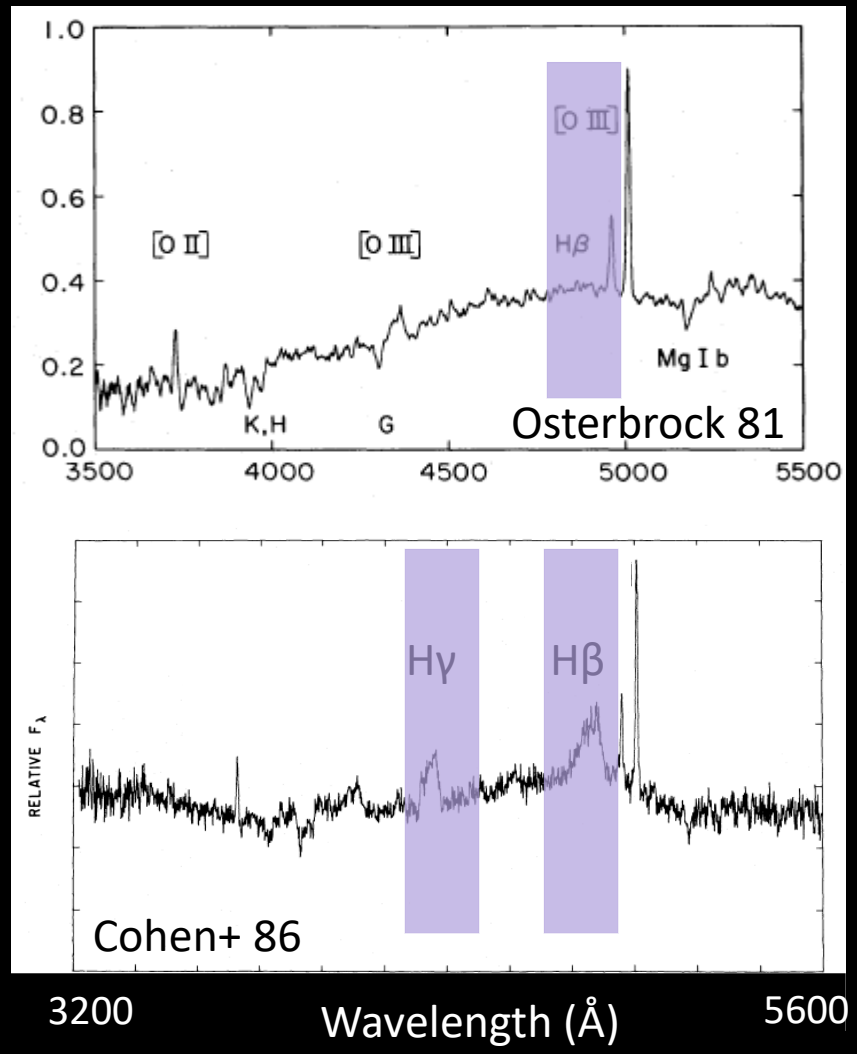
3C390.3



Penston & Perez 84; see also Goodrich 95

Optical Changing-Look AGN History: Appearing Balmer Lines

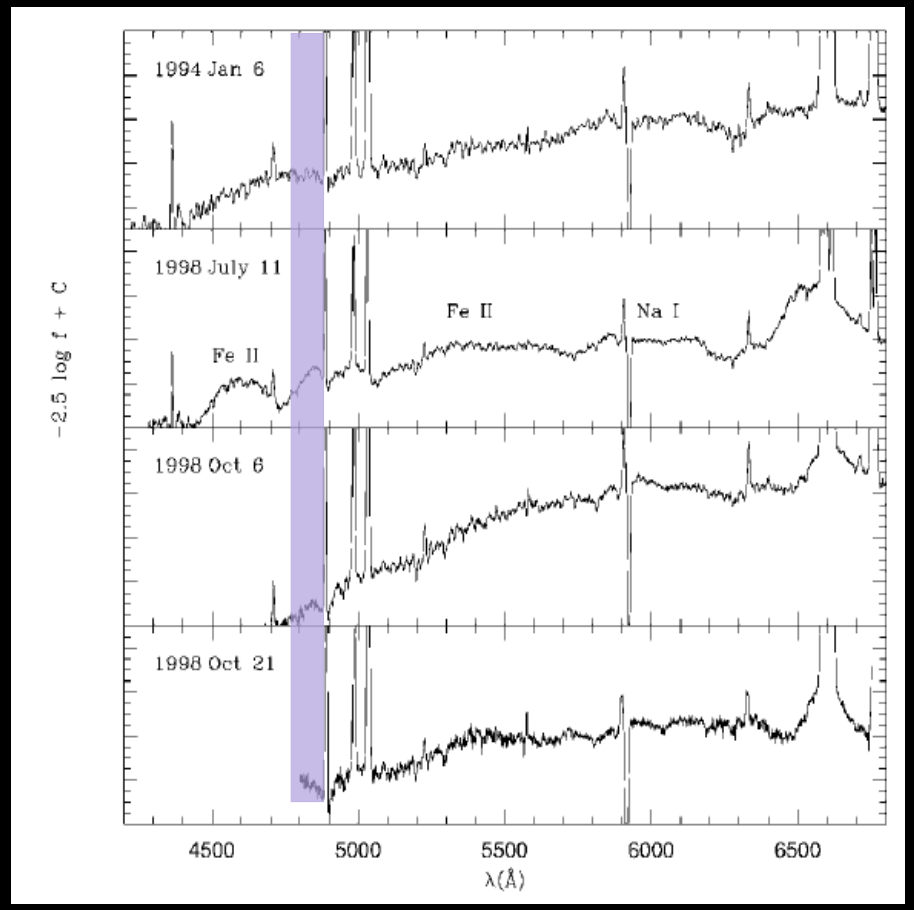
Mrk 1081



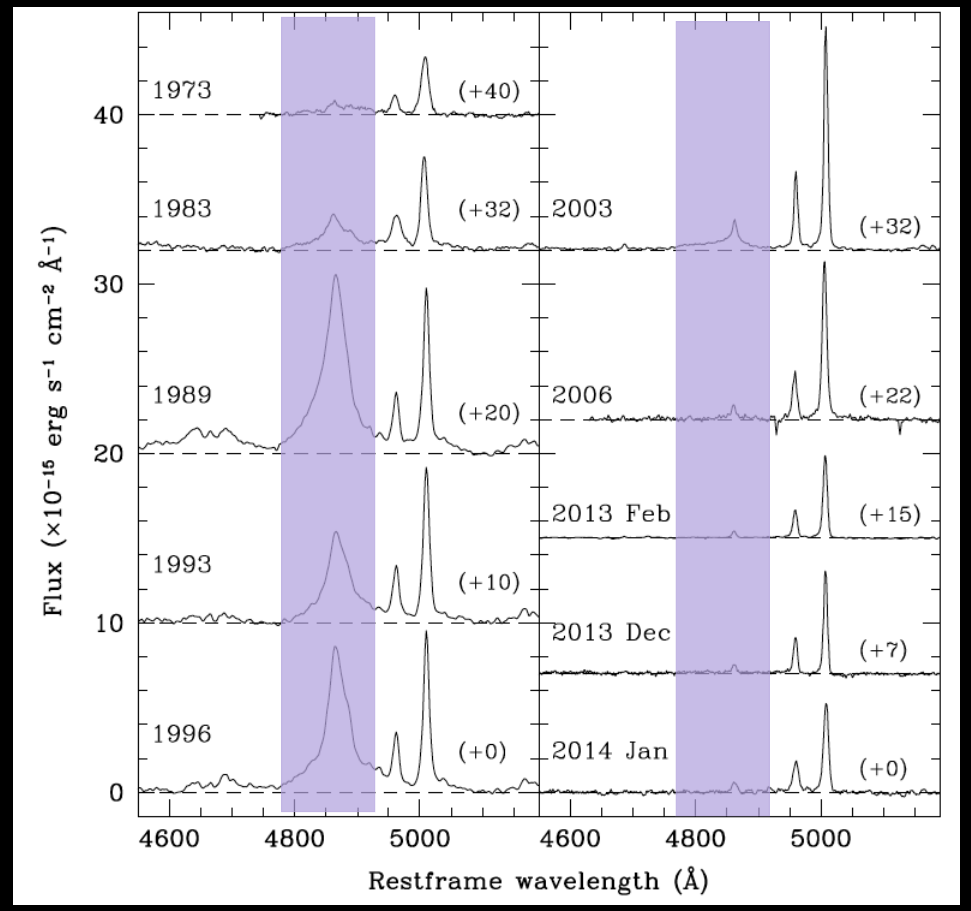
See also Tran+ 92, Storchi-Bergmann+ 93, Goodrich+ 95, Eracleous & Halpern 01, Shappe+ 14

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

  Tohline & Osterbrock 1976, Tran+ 1992, Storchi-Bergmann+ 1993, Goodrich+ 1995, Aretxaga+ 1999

- Ionizing continuum change

  Cohen+ 1986, Penson & Perez 1995, Goodrich+ 1995, Eracleous & Halpern+ 2001

- Supernova

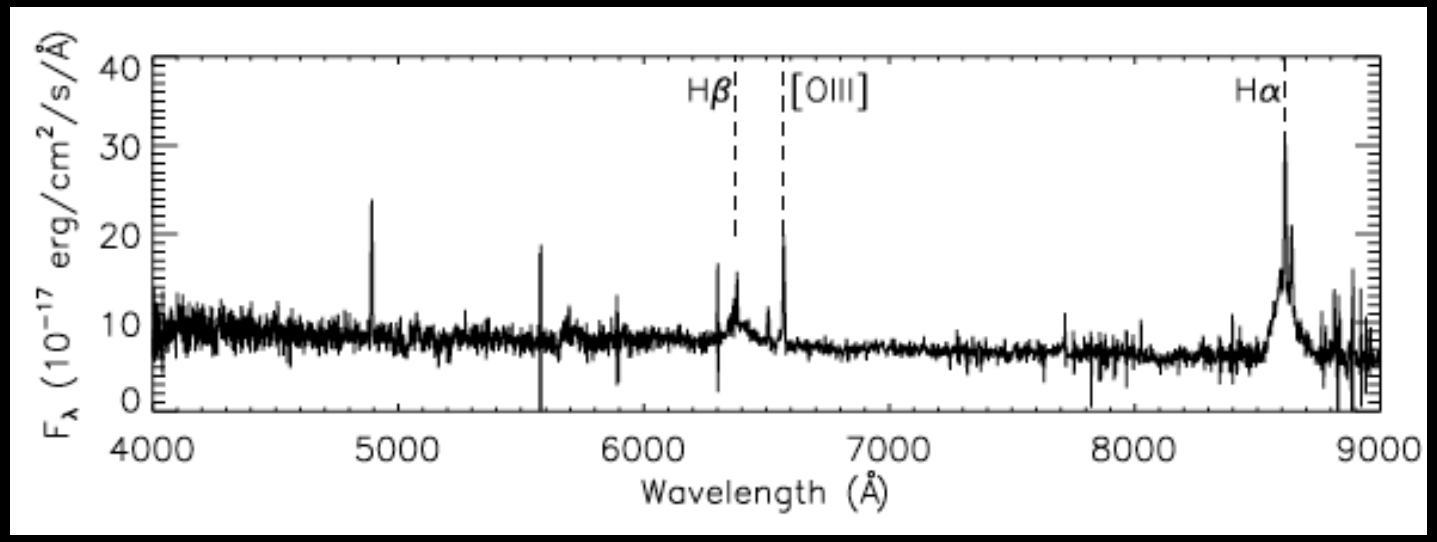
  Aretxaga+ 1999

- Tidal Disruption Event

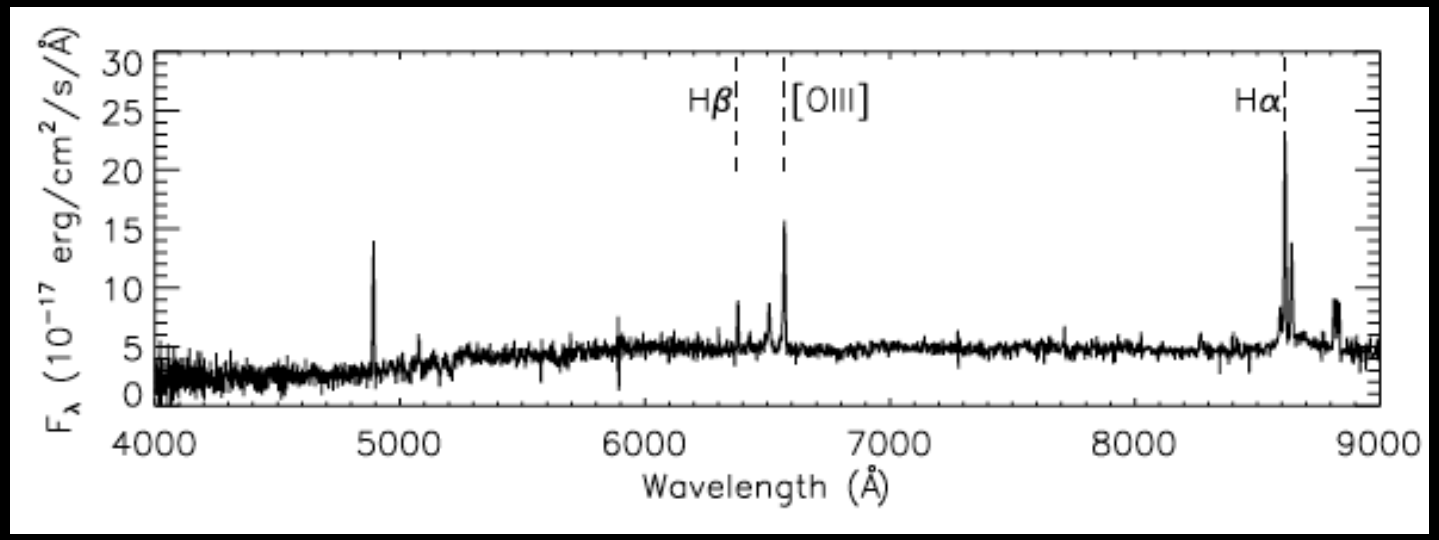
  Aretxaga+ 1999, Eracleous & Halpern+ 2001, Merloni+ 2015

Clues from Optical Spectra: Testing Extinction

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



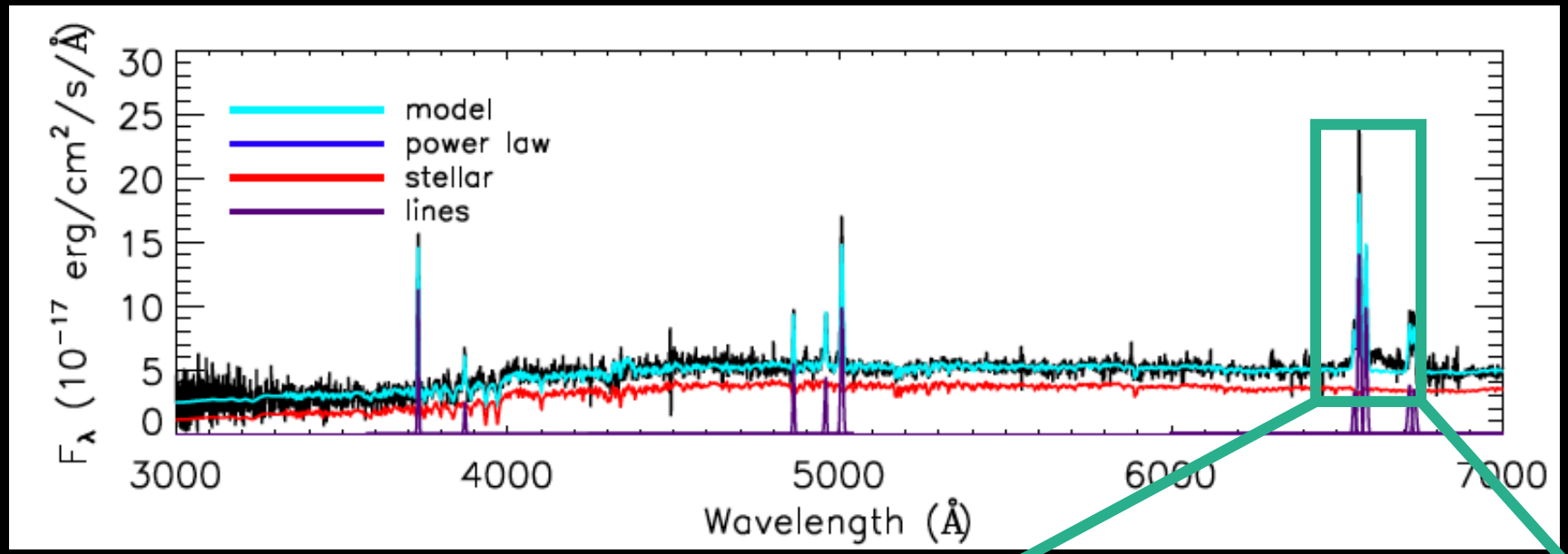
2000 (SDSS)
Type 1

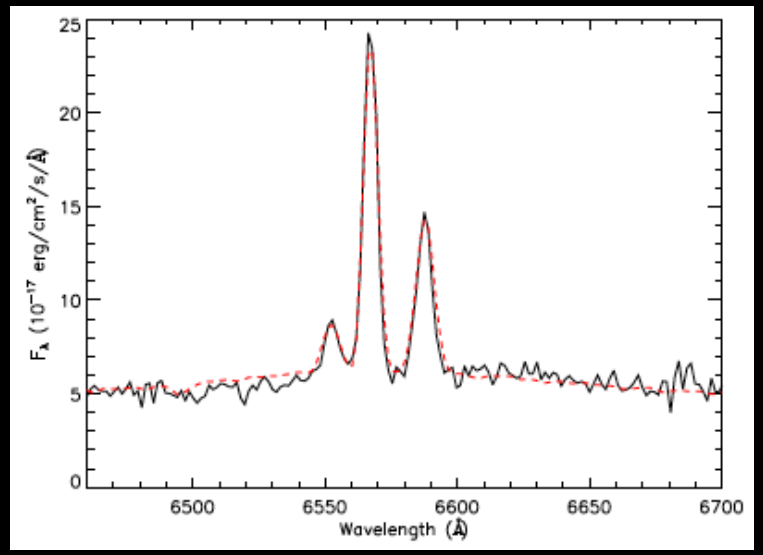


2010 (BOSS)
Type 1.9

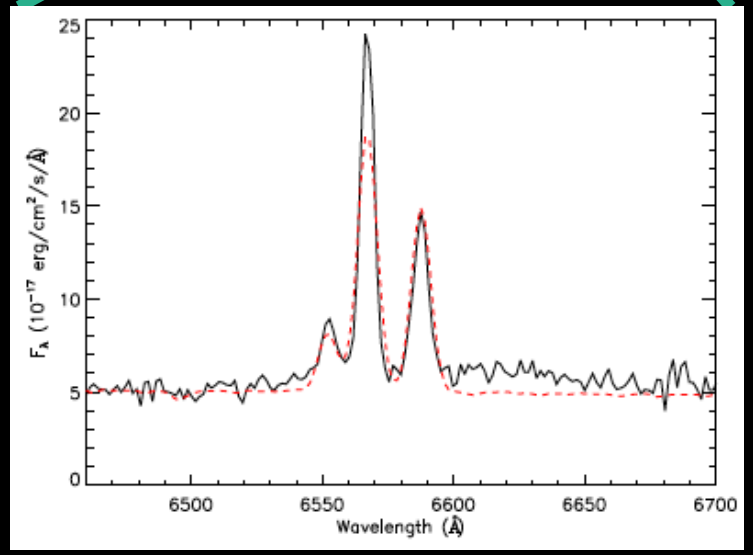
LaMassa+ 2015

Extinction Does Not Fully Model Dim State Spectrum





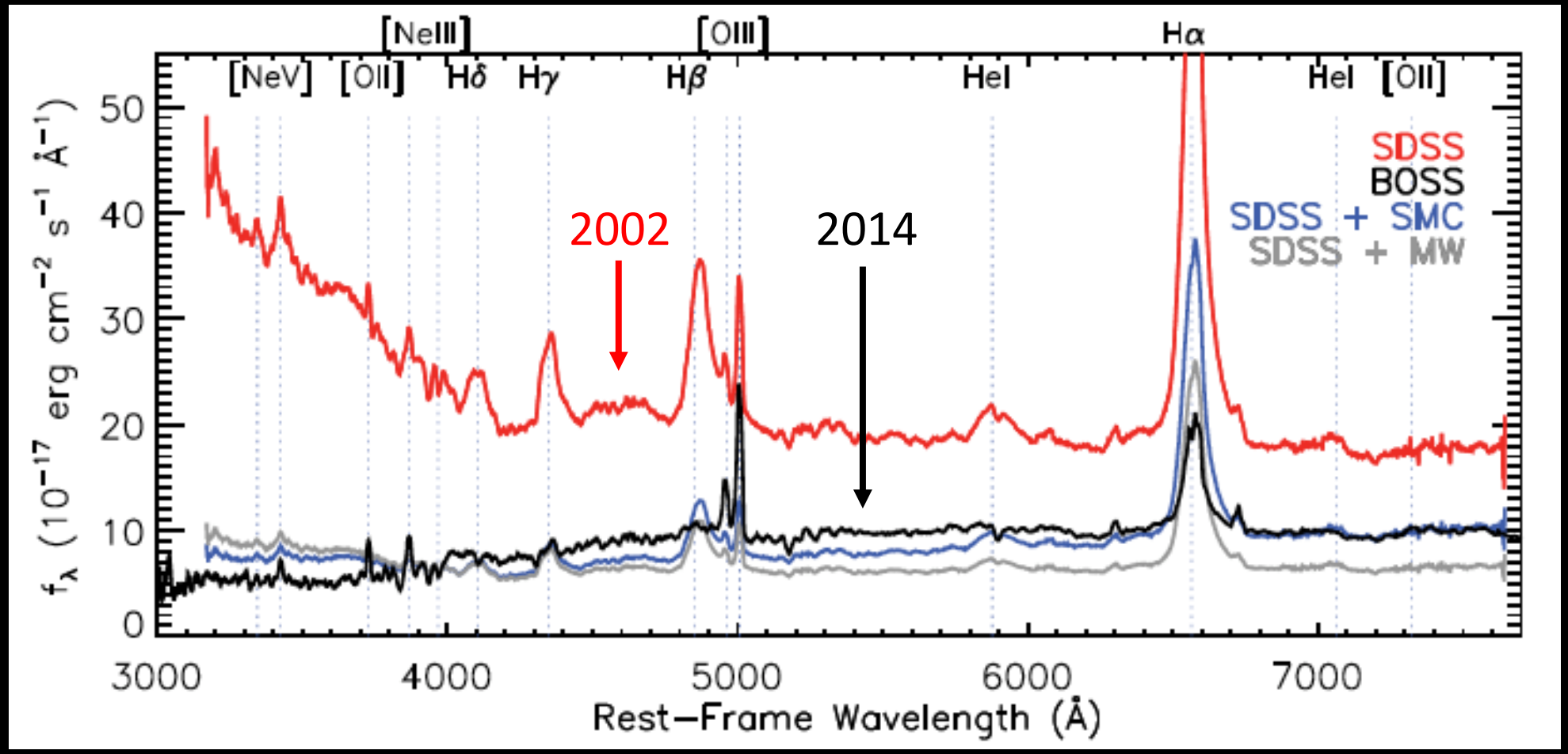
vs.



LaMassa+ 2015

Extinction Does Not Fully Model Dim State Spectrum

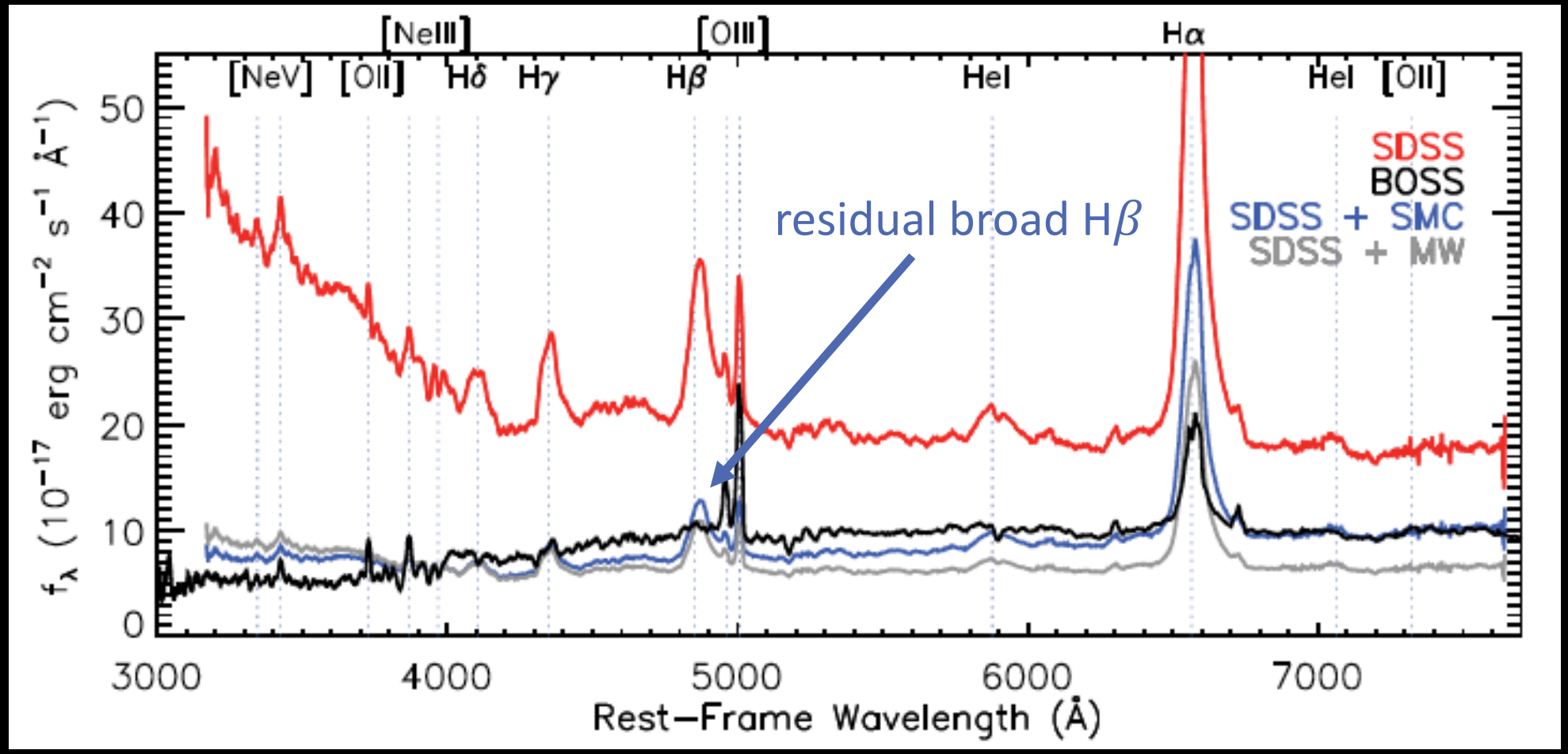
SDSS J1021+4645



MacLeod+ 2016 (see also Ruan+ 2016)

Extinction Does Not Fully Model Dim State Spectrum

SDSS J1021+4645

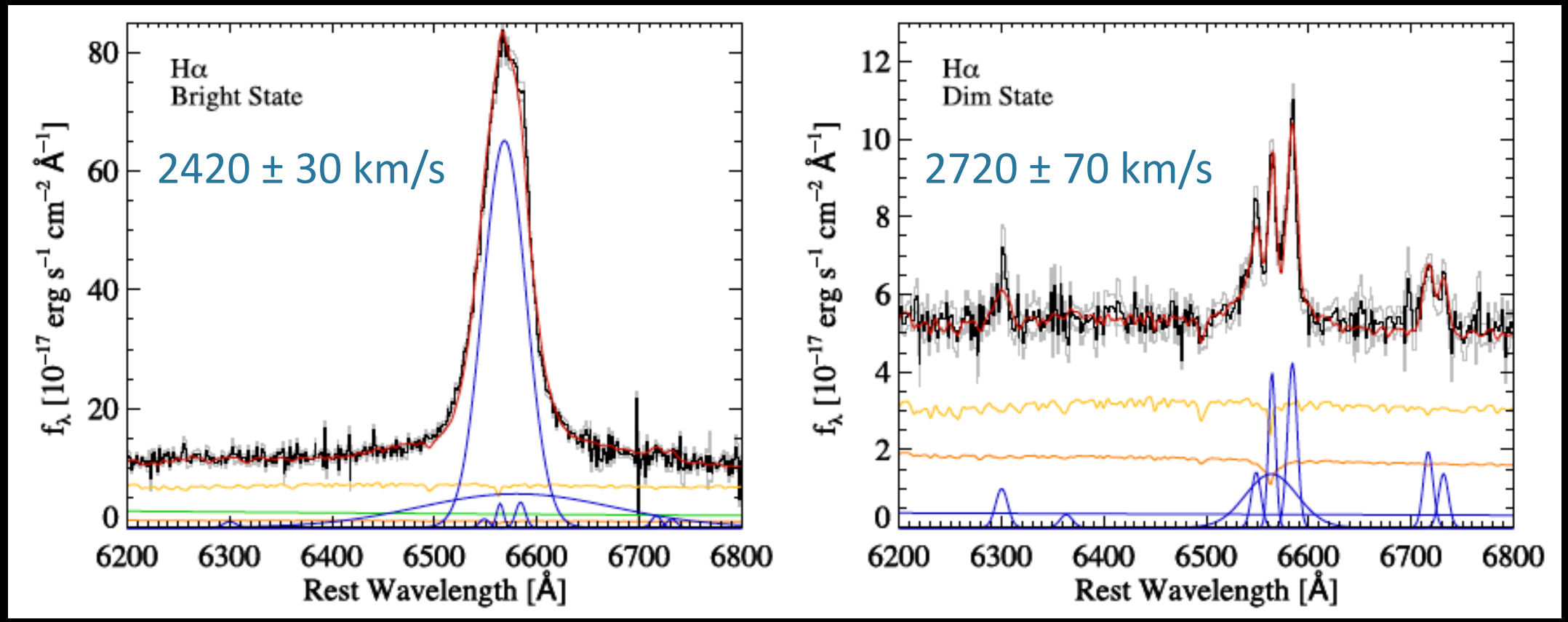


MacLeod+ 2016 (see also Ruan+ 2016)

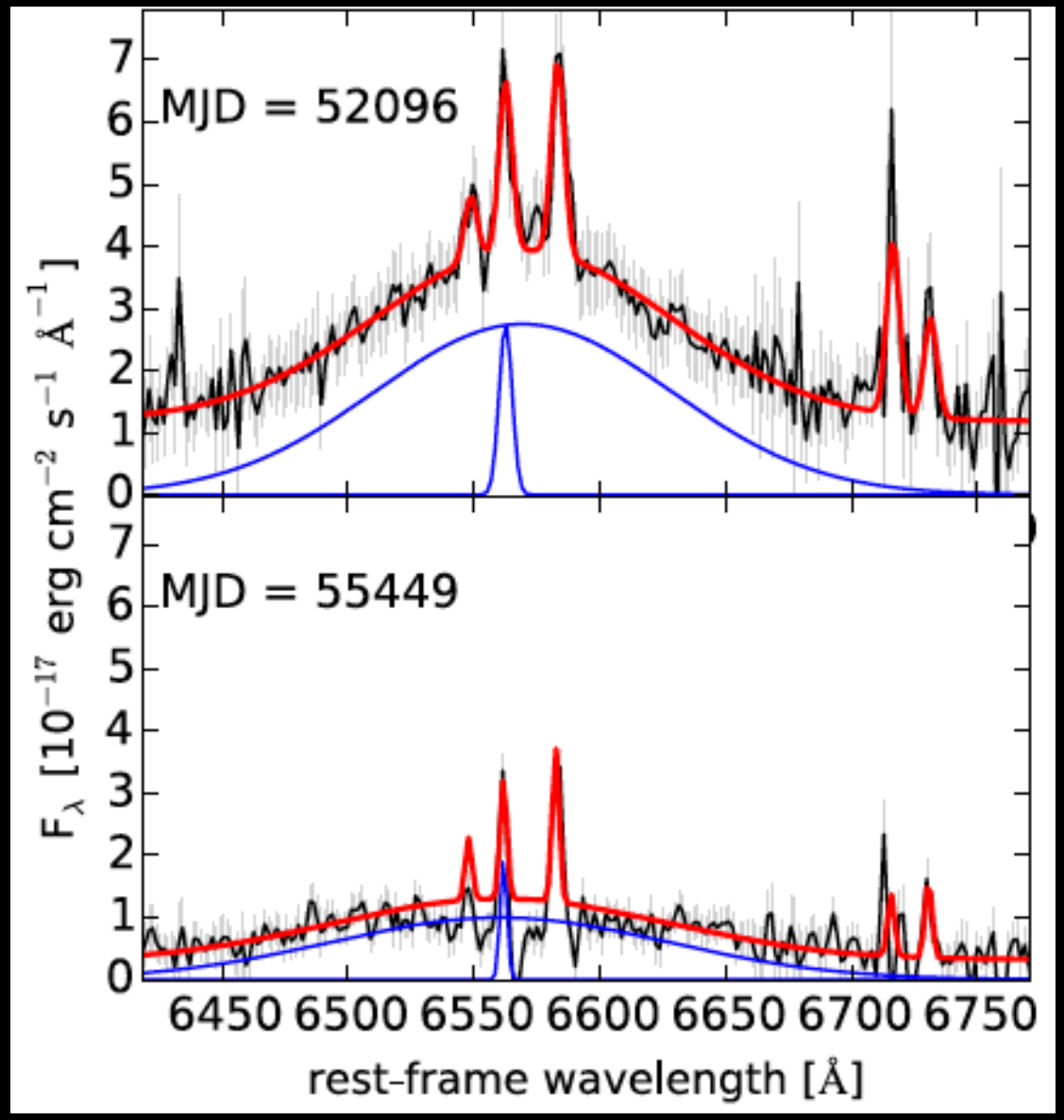
Clues from Optical Spectra: Insight from Line Profiles

Hα: broader while dimmer

J1011+5442 (Runnoe+ 2016)



Hα: broader while dimmer



J2336+0017 (Ruan+ 2016)

Hα_{bright} = 6289 ± 1180 km/s

Hα_{dim} = 7290 ± 1367 km/s

Hα: broader while dimmer

- J0159+0033 (LaMassa+ 2015)

Hα_{bright} = 3917 ± 174 km/s
Hα_{dim} = 5869 ± 777 km/s

$$M_{\rm BH} = 9.7 \times 10^6 \left[\frac{\rm FWHM(H\alpha)}{1000\ {\rm km\ s^{-1}}}\right]^{2.06} \left[\frac{\lambda L_{5100}}{10^{44}\ {\rm erg\ s^{-1}}}\right]^{0.519} {\rm M}_\odot,$$

Greene et al. 2010

$M_{BH,bright}$ = 1.7 ± 0.1 x 10^8 $M_\odot$
$M_{BH,dim}$ = 1.6 ± 0.4 x 10^8 $M_\odot$

Hα: broader while dimmer

- J0159+0033 (LaMassa+ 2015)

$H\alpha_{bright}$ = 3917 ± 174 km/s
$H\alpha_{dim}$ = 5869 ± 777 km/s

$FWHM \sim R_{BLR}^{-1/2}$; $R_{BLR} \sim L^{1/2}$ (e.g. Bentz+ 06)

➔ $FWHM \sim L^{-1/4}$

$(FWHM_{H\alpha,bright}/FWHM_{H\alpha,dim}) = 0.67$

$(\lambda L_{5100,bright}/\lambda L_{5100,dim})^{-1/4} = 0.65$

Clues from Optical Photometry

Timescale for cloud to eclipse BLR

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

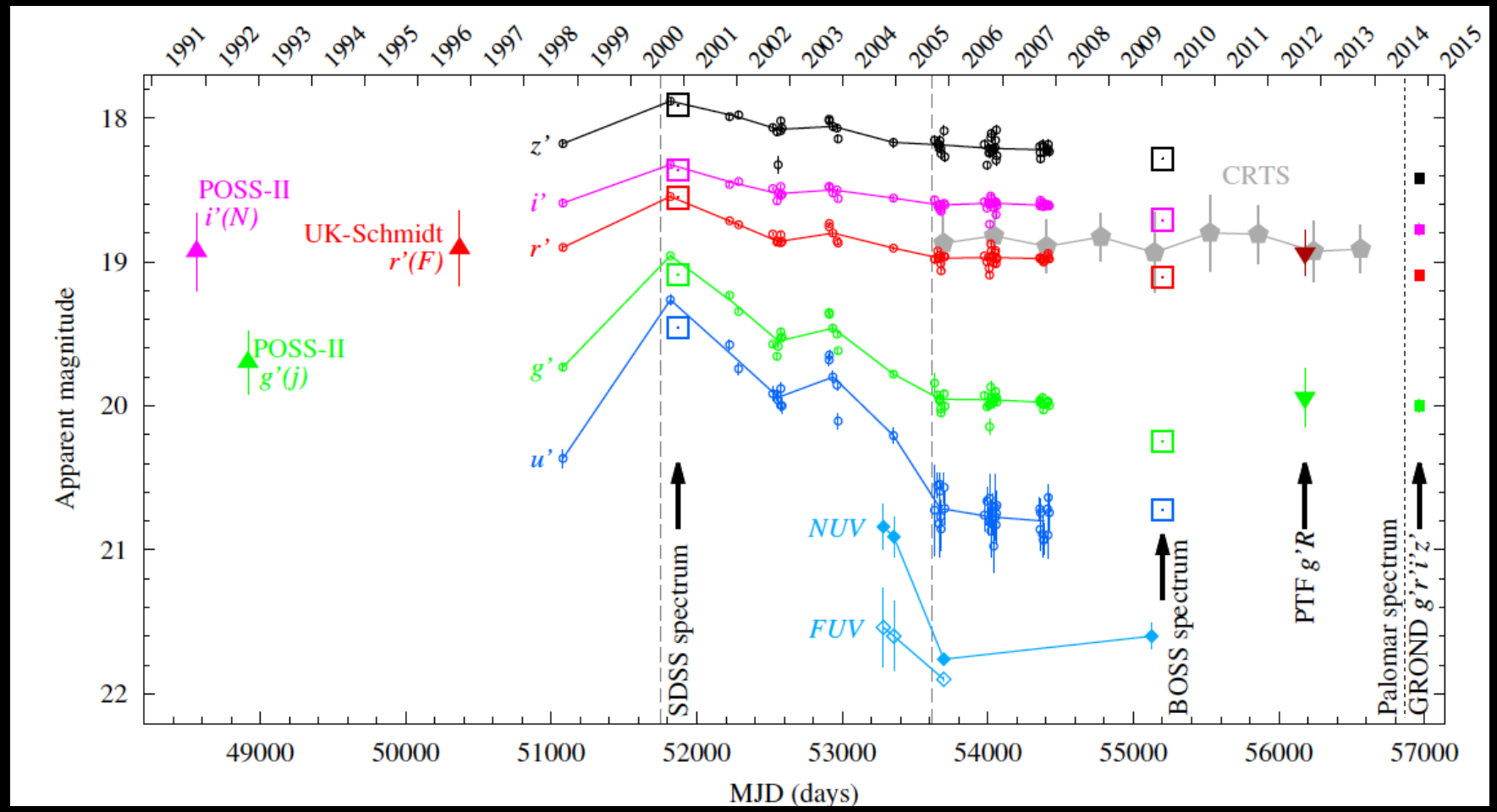
r_{orb}: orbiting radius of occulting object

r_{src}: size of BLR

M_8: mass of black hole in units of 10^8 $M_\odot$

$t_{cross} > t_{change}$

J0159+0033



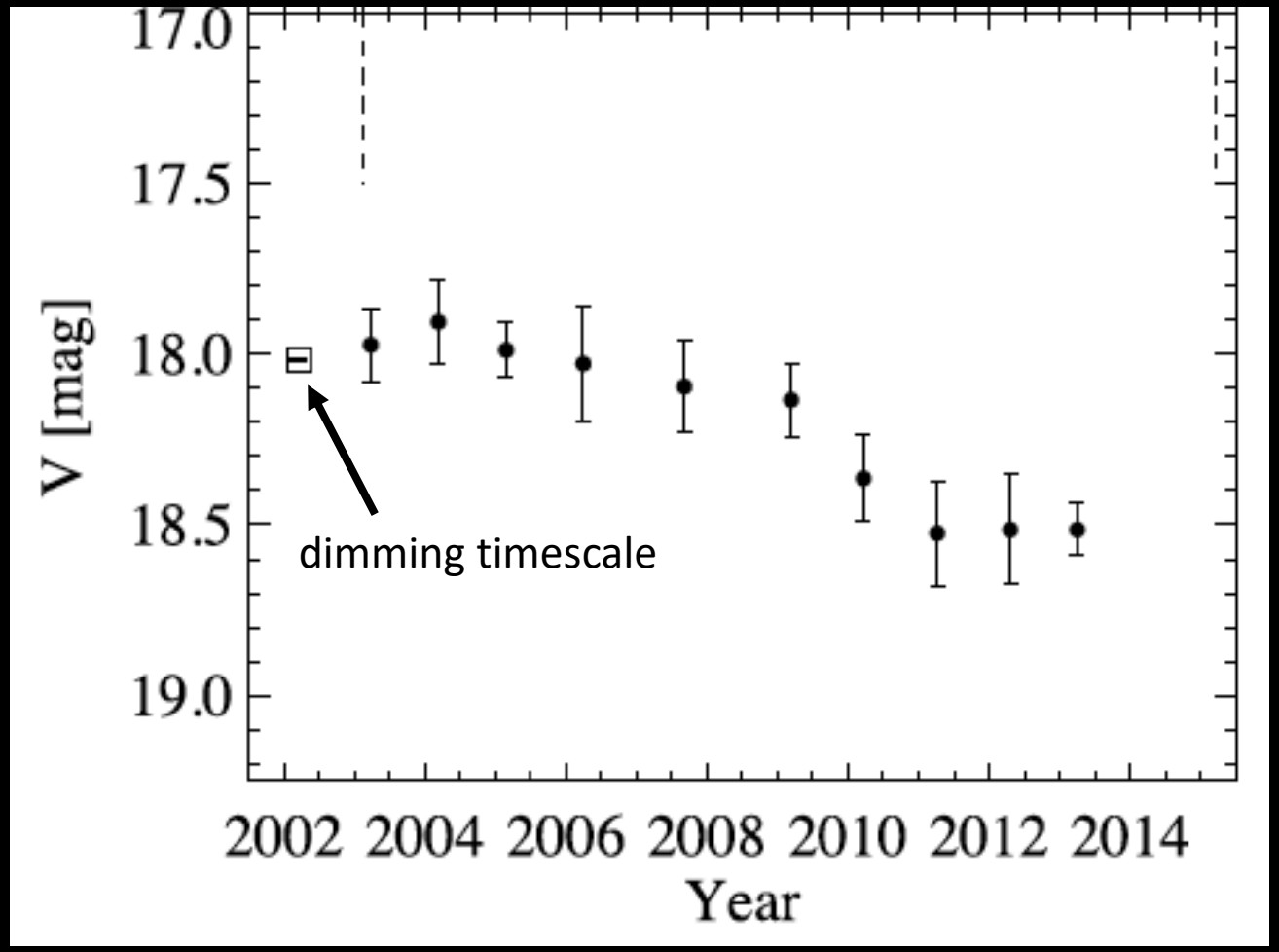
Merloni+ 2015

t_{cross} > 10-20 yrs
(LaMassa+ 2016)

t_{change} ~ 3 yrs

$t_{cross} > t_{change}$

J1011+5442



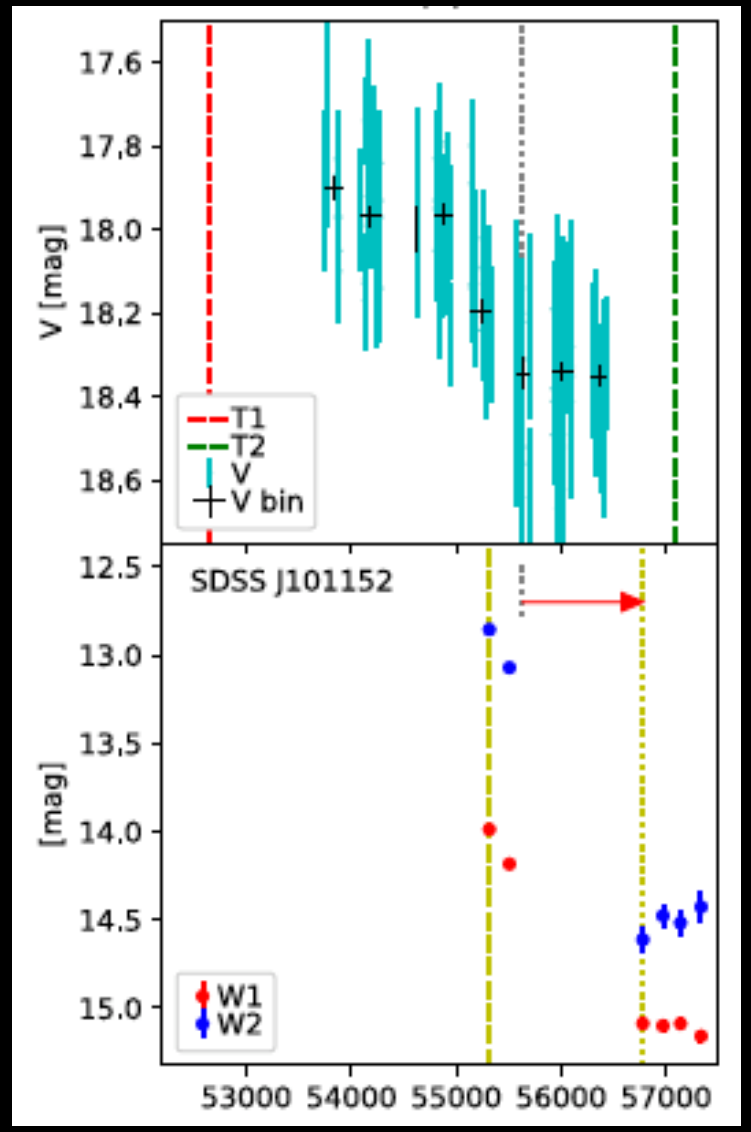
t_{cross} > 31 yrs

t_{change} ~ 1.4 yrs

Runnoe+ 2016; see also MacLeod+ 2016

Clues from Mid-Infrared Photometry

Comparing Optical v. MIR variations



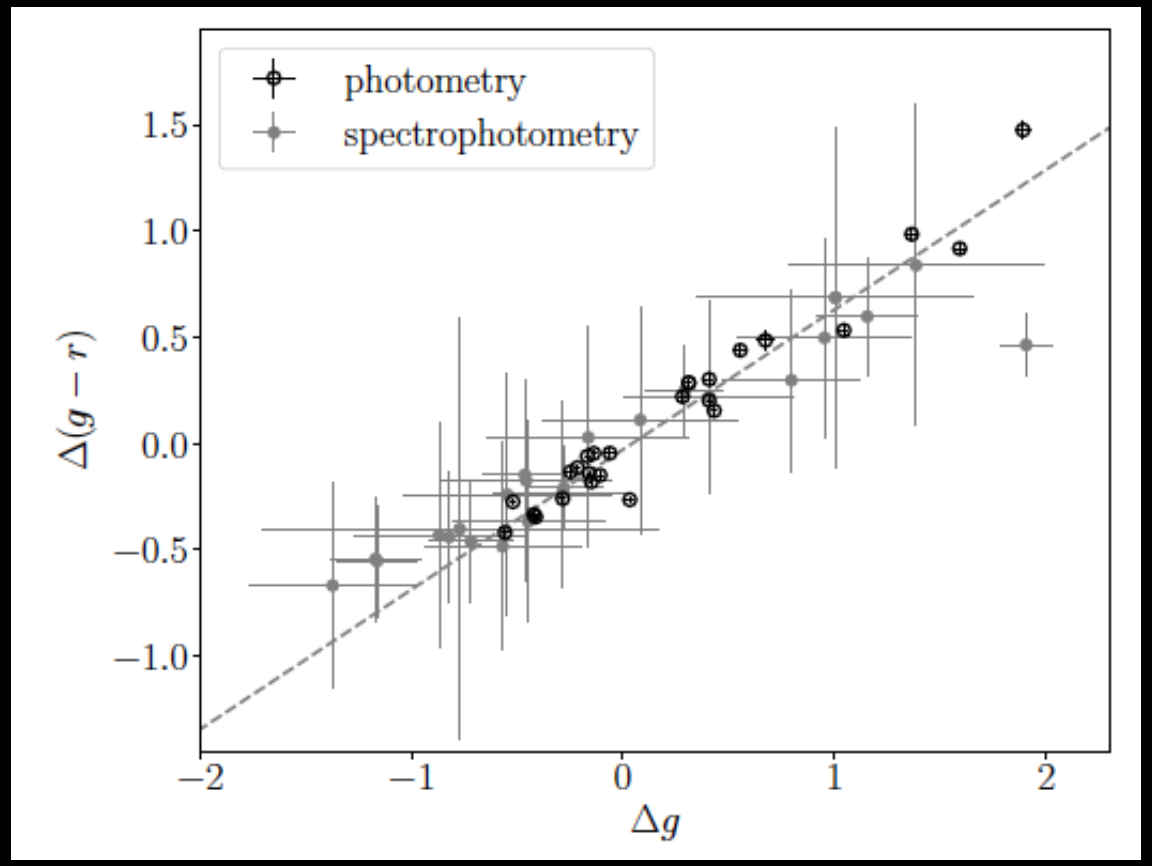
MIR variability rules out obscuration

- timescale argument ($t_{cross} > t_{change}$)
- Extinction needed to obscure MIR >> observed optical attenuation

Sheng+ 2017; see also Stern+ 2018

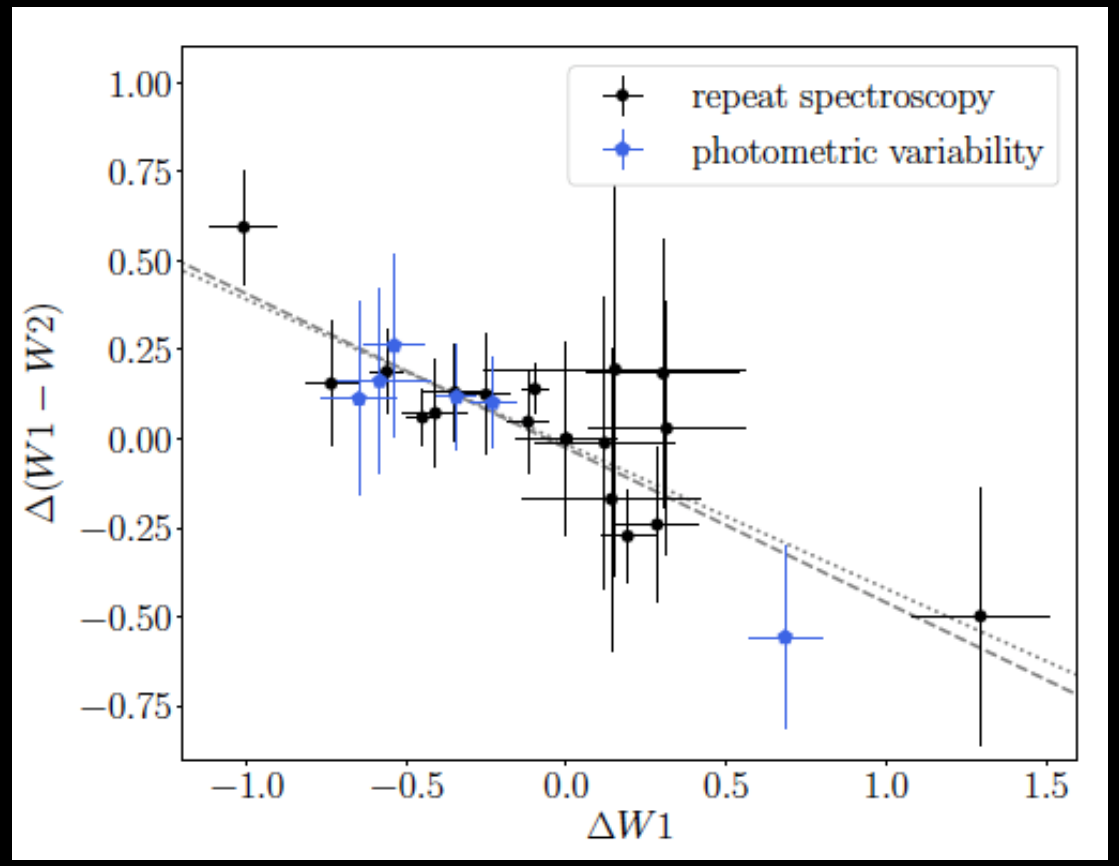
Optical:
Bluer when Brighter

MIR:
Redder when Brighter



red

blue

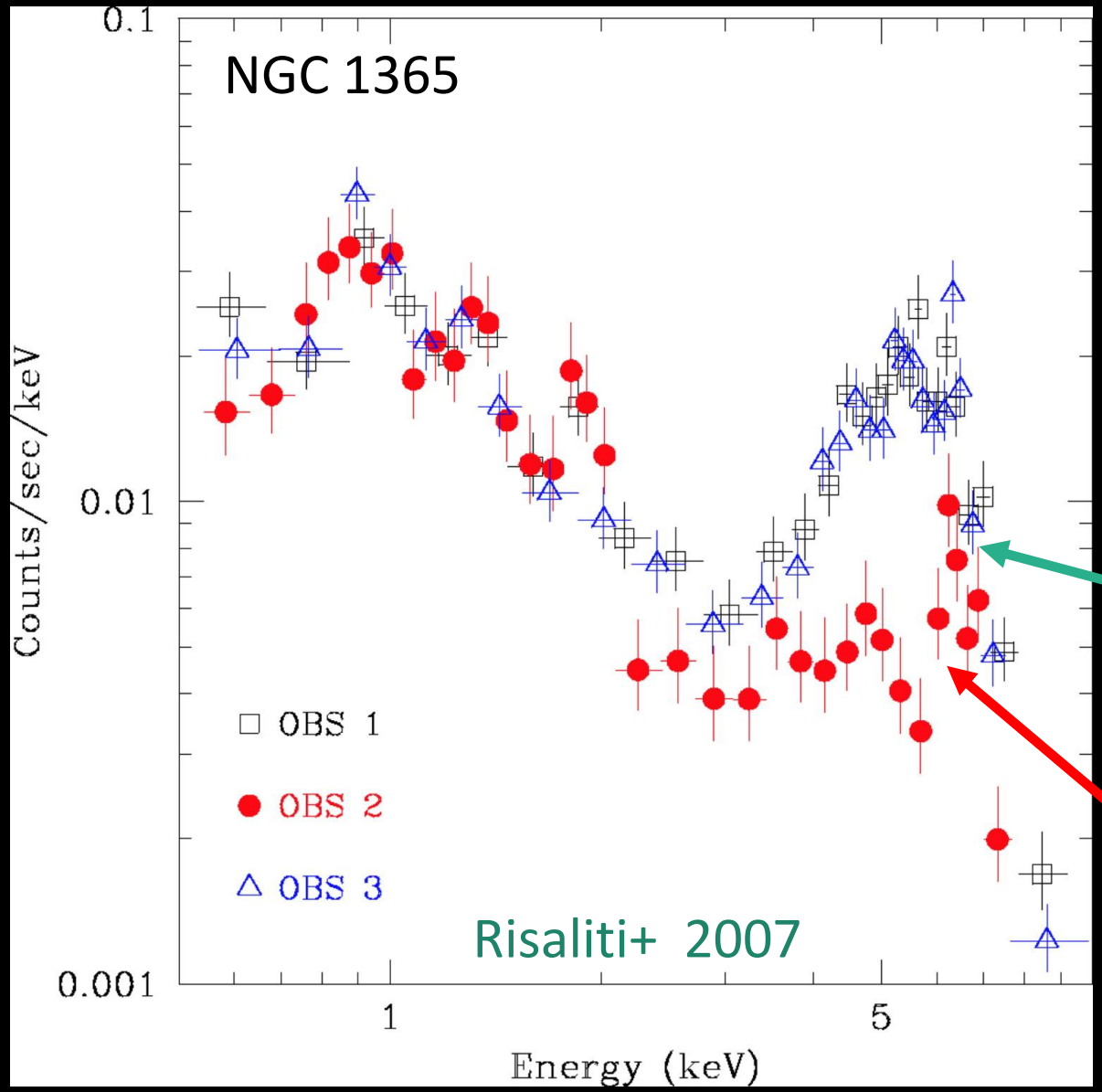


brighter

Yang+ 2018, but see Graham+ 2019

Clues from X-ray Spectra

X-ray Changing-Look AGN: Variable N_H



4 day interval:

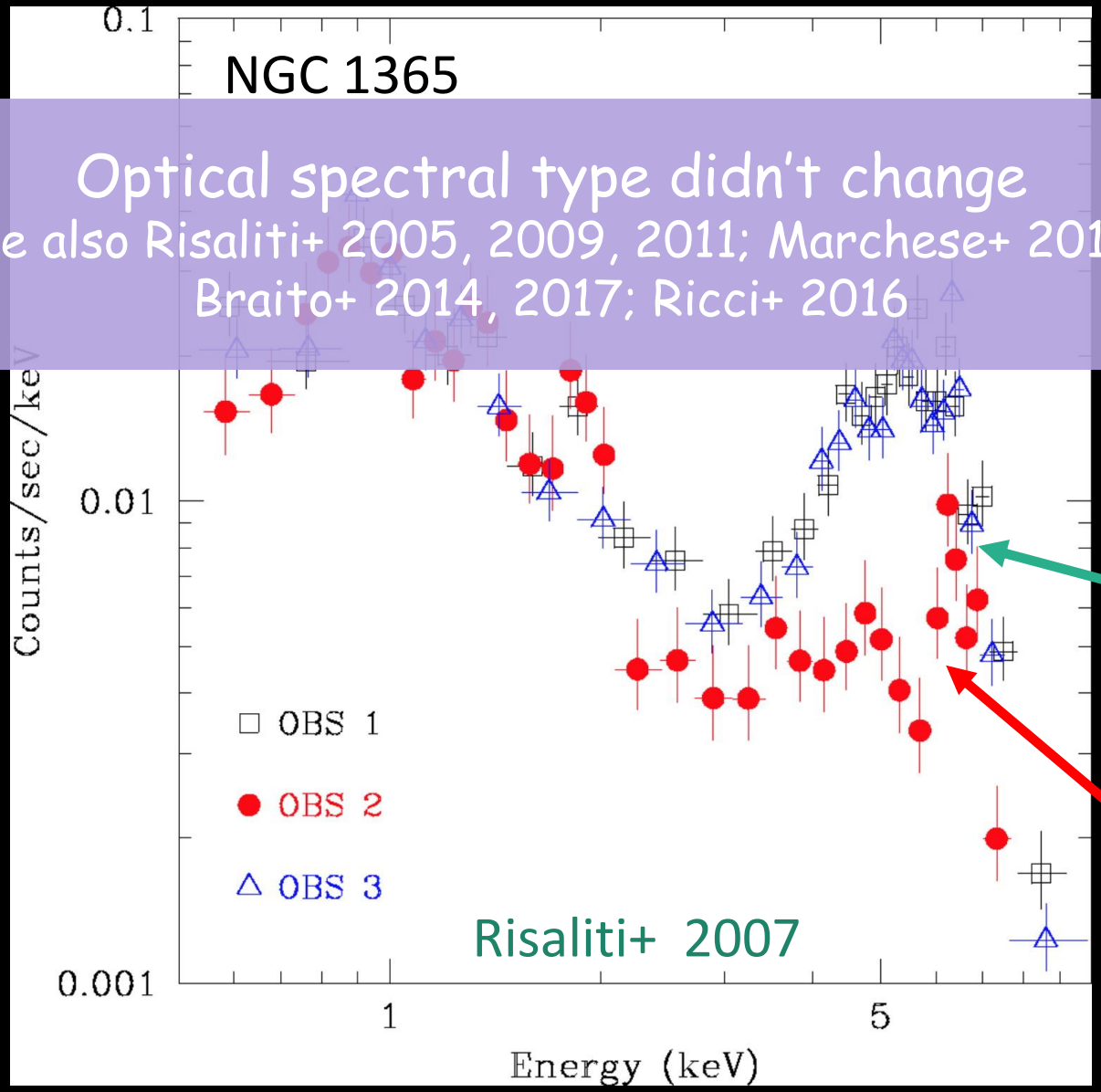
Compton-thin →
Compton-thick →
Compton-thin

Fe Kα

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

see also Risaliti+ 2005

X-ray Changing-Look AGN: Variable N_H



Optical spectral type didn't change

see also Risaliti+ 2005, 2009, 2011; Marchese+ 2012; Braito+ 2014, 2017; Ricci+ 2016

4 day interval:

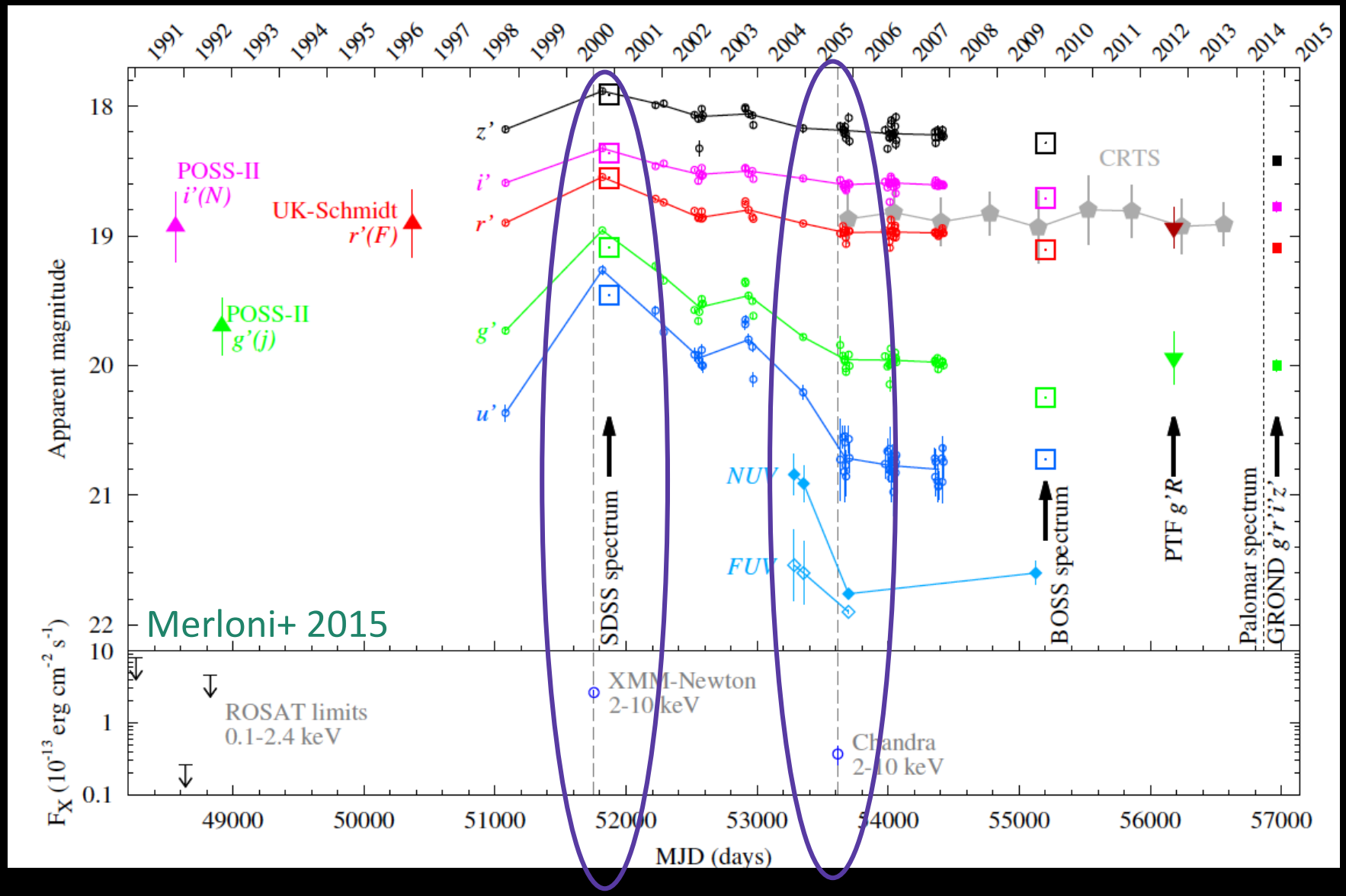
Compton-thin →
Compton-thick →
Compton-thin

Fe Kα

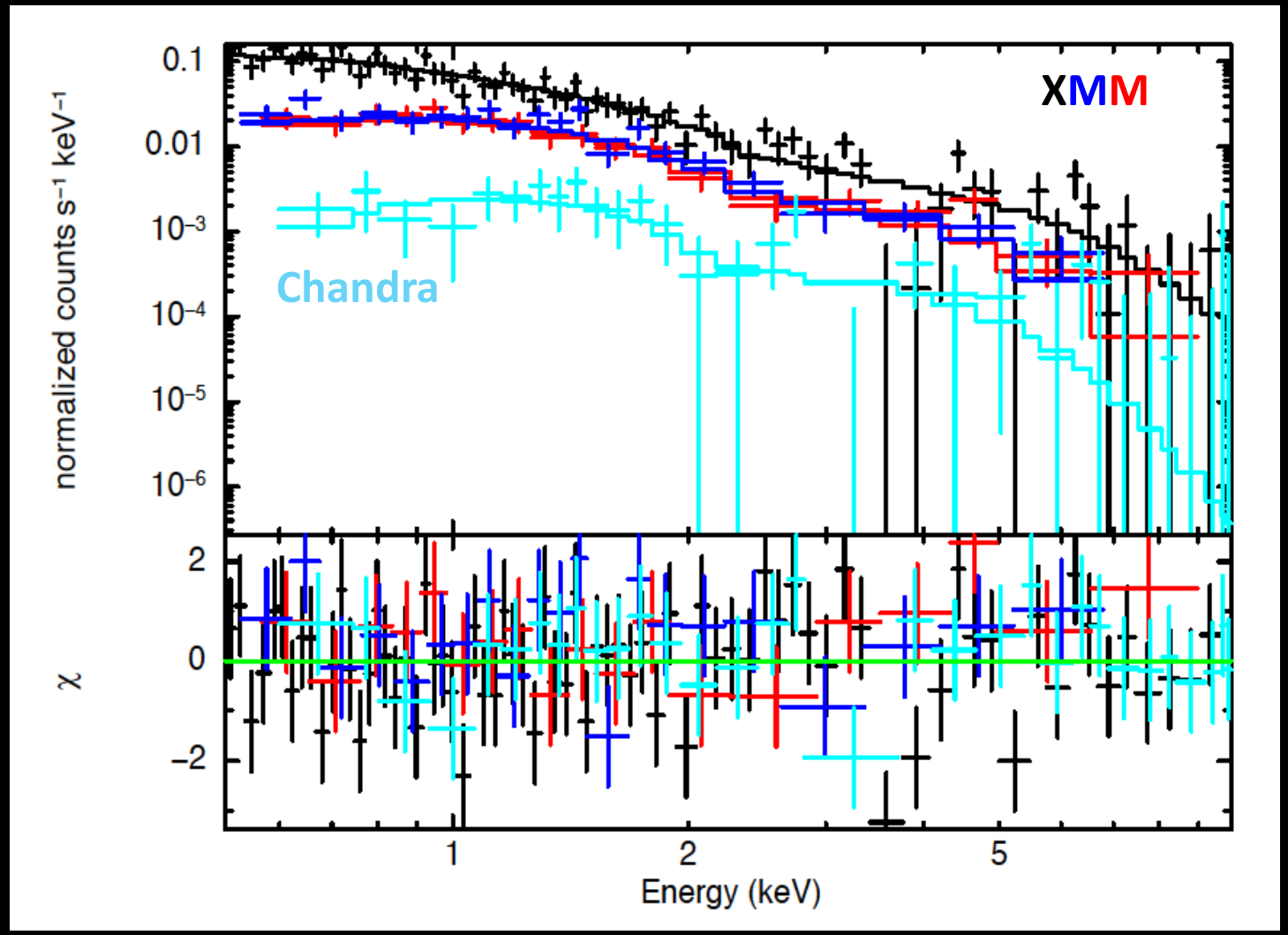
Compton-thick ($N_H > 10^{24}$ cm^{-2}) spectrum

see also Risaliti+ 2005

J0159+0033: 2 Serendipitous X-ray Observations



SDSS J0159+0033: No absorption signatures in X-ray Spectrum



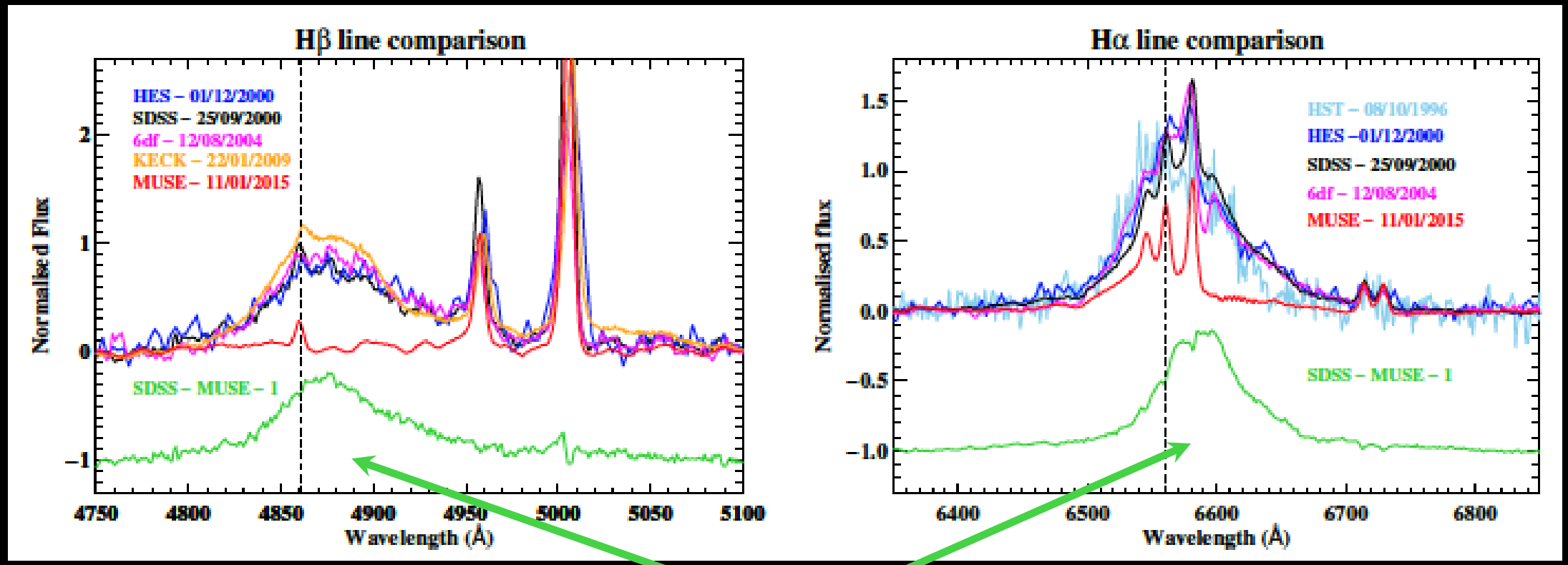
Similar drop in optical & X-ray fluxes

$(\lambda L_{5100,bright}/\lambda L_{5100,dim}) = 5.5$

$(F_{2\text{-}10keV,bright}/F_{2\text{-}10keV,dim}) = 7.2$

LaMassa+ 2015

Mrk 1018: Type 1 → Type 1.9

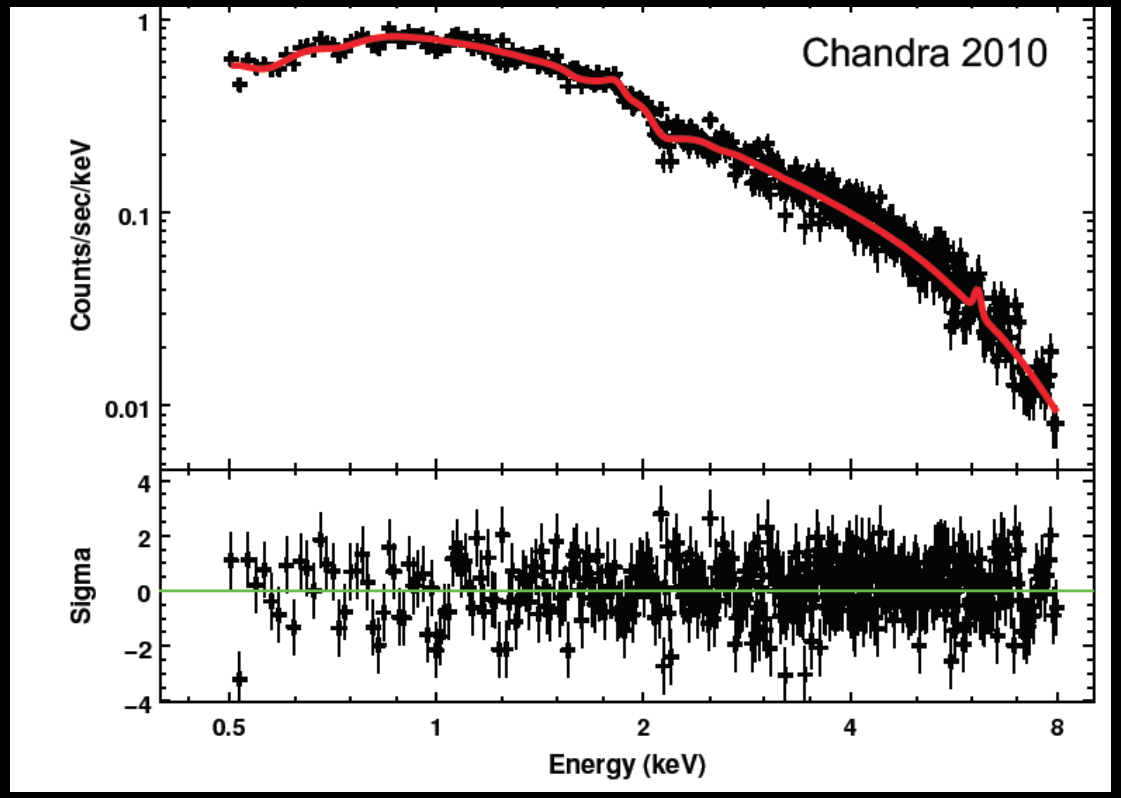


Weakening of broad Balmer lines between 2000 & 2015

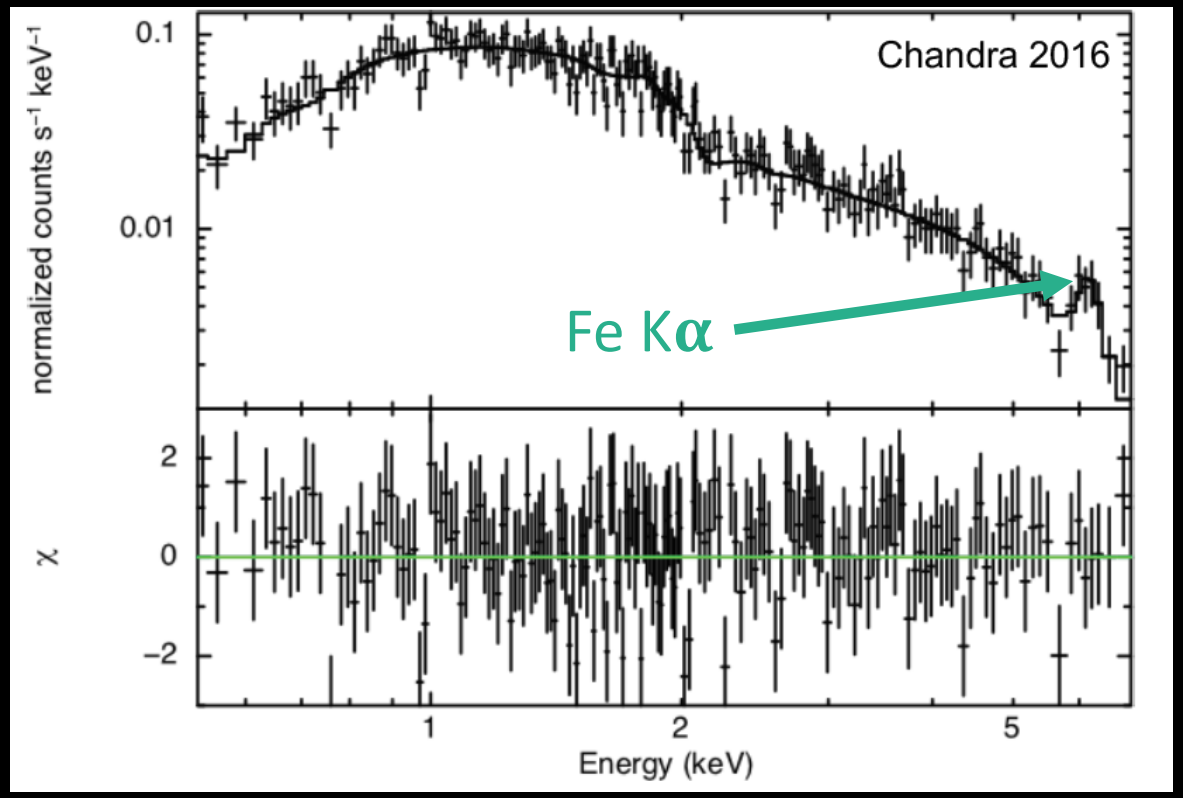
McElroy+ 2016

Mrk 1018: More Complex X-ray Spectrum…

Optical Type 1



Optical Type 1.9



LaMassa+ 2017; see also Husemann+ 2016

Mrk 1018: More Complex X-ray Spectrum…

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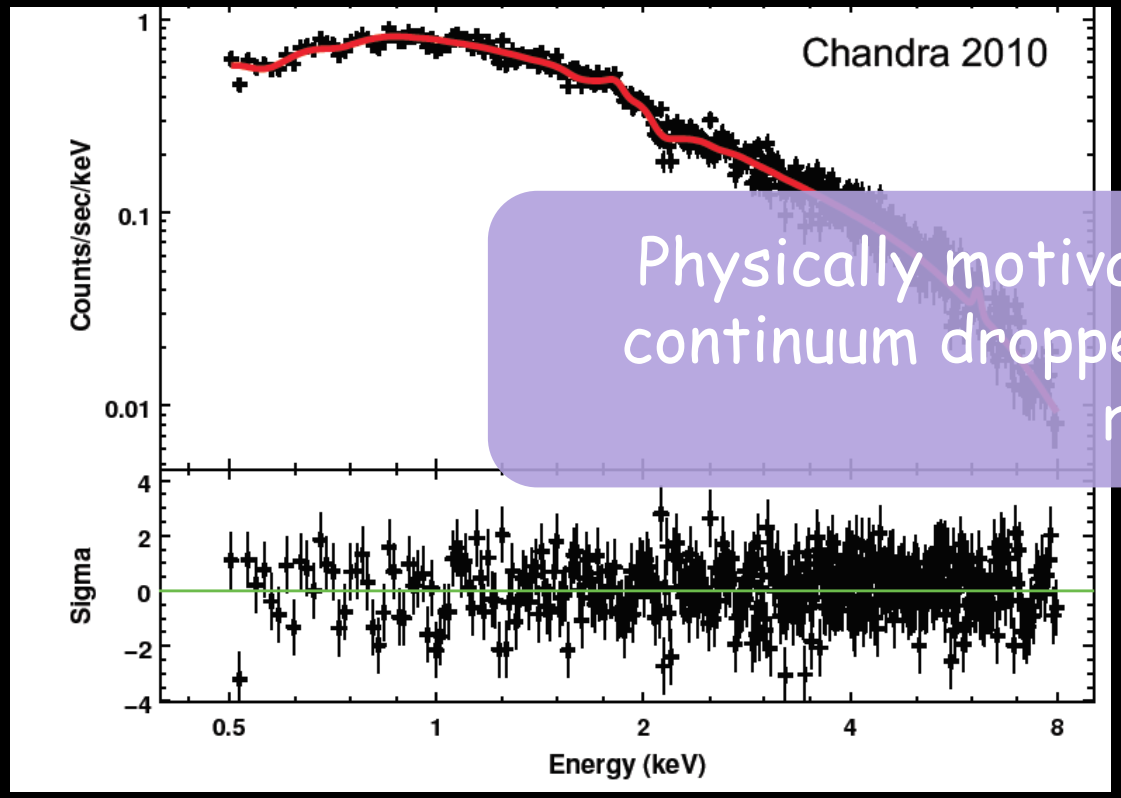
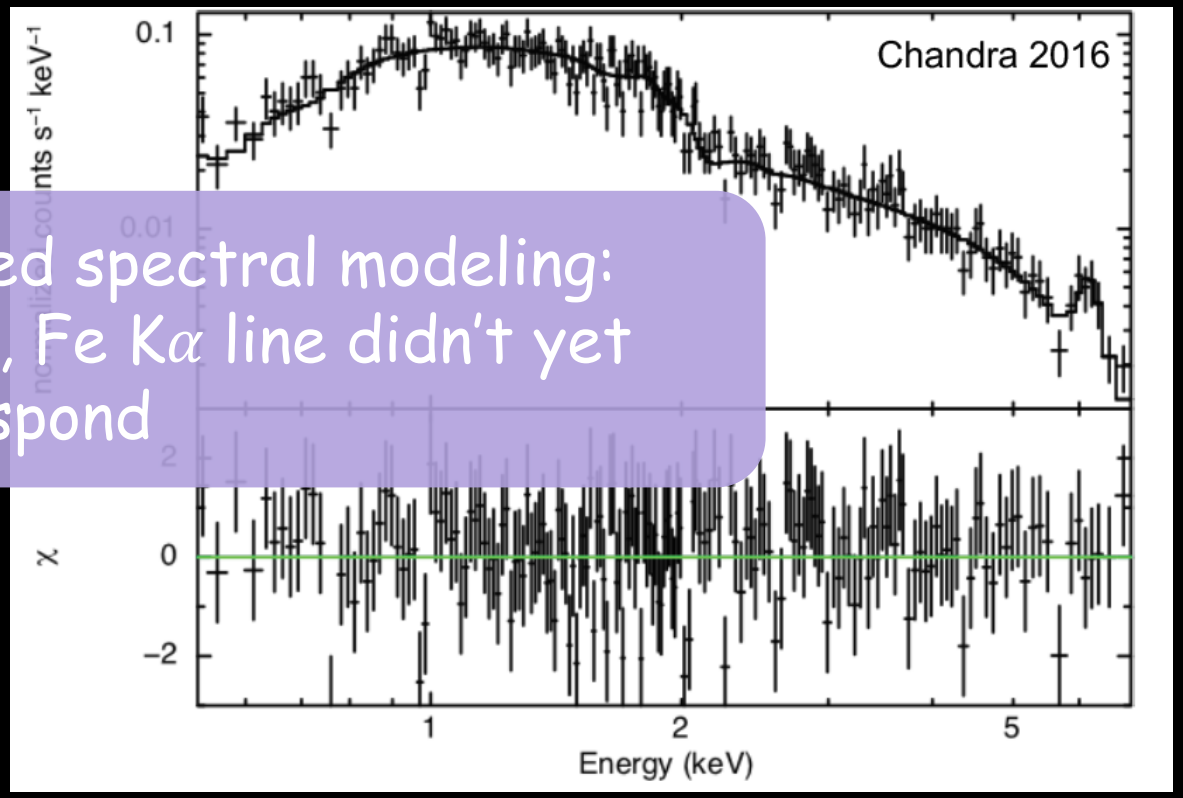


Optical Type 1.9

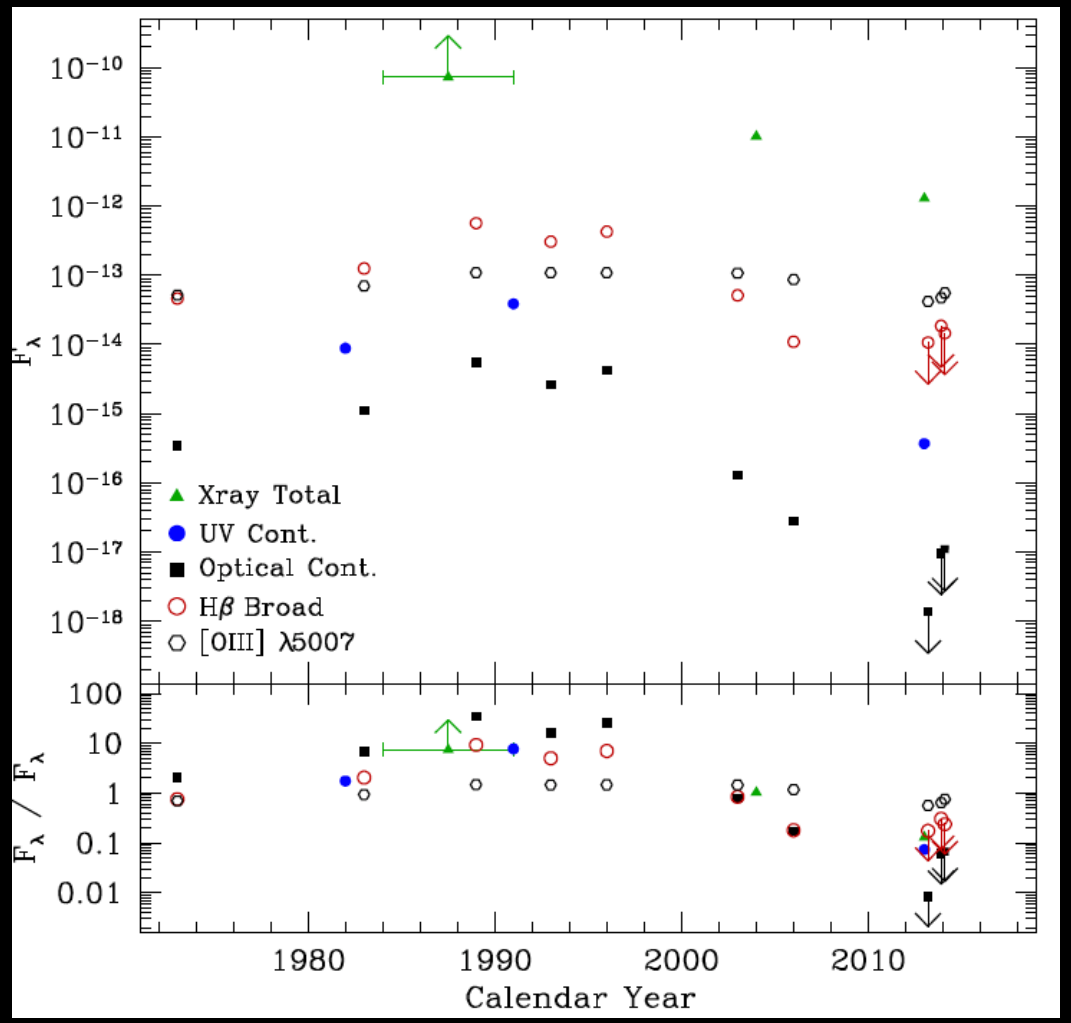


Physically motivated spectral modeling: continuum dropped, Fe Kα line didn't yet respond

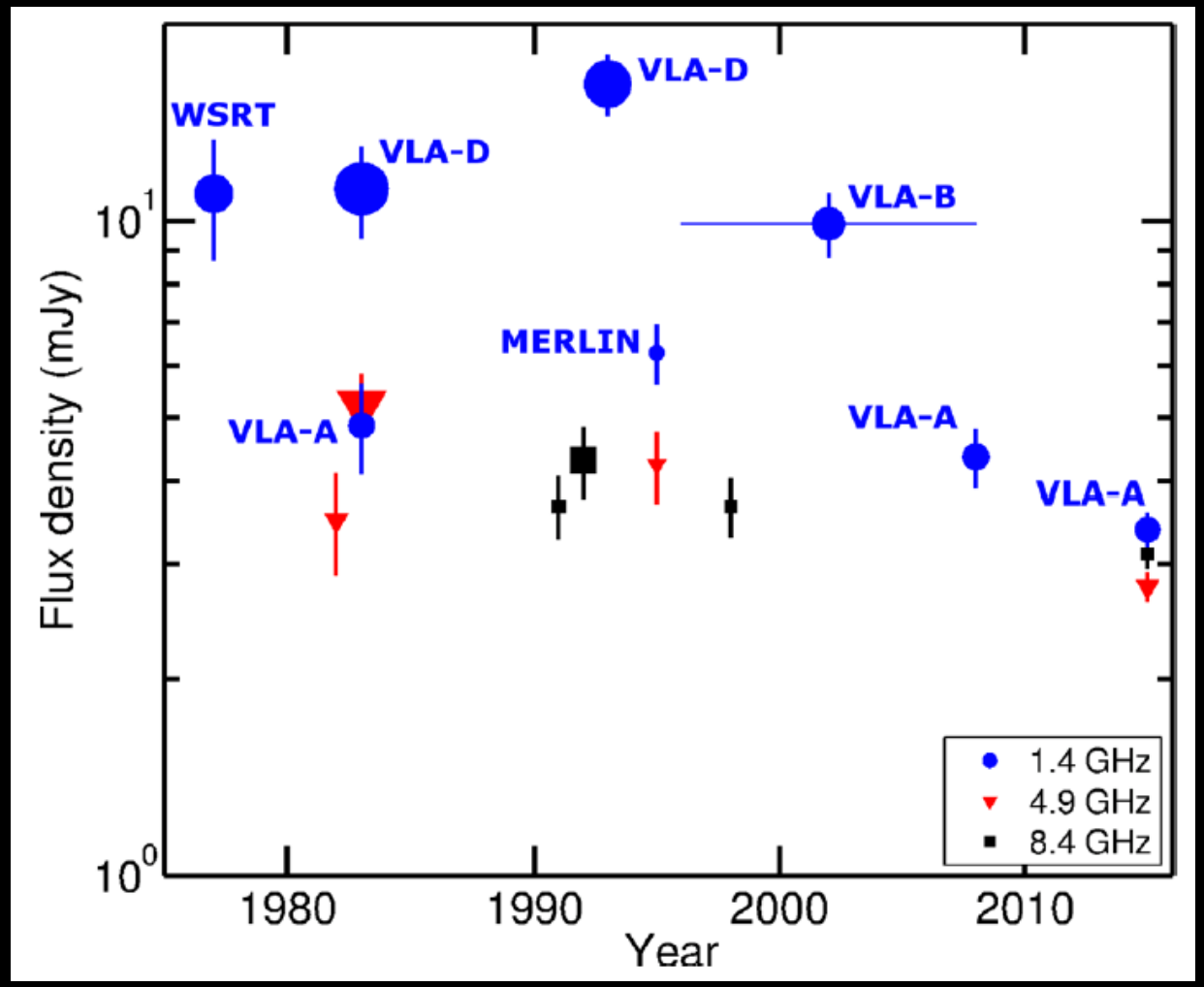
LaMassa+ 2017; see also Husemann+ 2016

Clues from Radio Emission

Mrk 590: Radio variability correlated with Optical/UV & X-ray variability



Denney+ 2014



Koay+ 2016

Changing-Look AGN

- $\lambda\lambda\lambda$ observations
  - optical spectra not well modeled by extinction *LaMassa+ 2015, MacLeod+ 2016, Ruan+ 2016*
  - broad Balmer line profiles *LaMassa+ 2015, Runnoe+ 2016, Ruan+ 2016*

    M. Eracleous, B. Trakhtenbrot
  - optical photometry & spectroscopy; MIR photometry constraints on timescale *LaMassa+ 2015, Runnoe+ 2016, MacLeod+ 2016; Sheng+ 2017, Stern+ 2018*

    Y. Ai, C. MacLeod, D. Xu, M. Eracleous, X.-B. Wu
  - MIR colors (redder when brighter) *Yang+ 2018*

    X.-B. Wu
  - X-ray spectroscopy *LaMassa+ 2015, 2017, Husemann+ 2016*

    J.Ruan

    For X-ray time domain, see D. Costanzo, C. Done, Hernández Santisteban, I. Papadakis
  - radio variability correlated with optical, UV, X-ray variability *Koay+ 2016*

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

  B. Husemann, M. Parker

Changing-State AGN

Graham+ 2019

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