

PENNSTATE



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# Spectroscopic Search for Binary Supermassive Black Holes

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& Hélène Flohic

# **The Elusive, Bound Binaries**

# In the beginning...

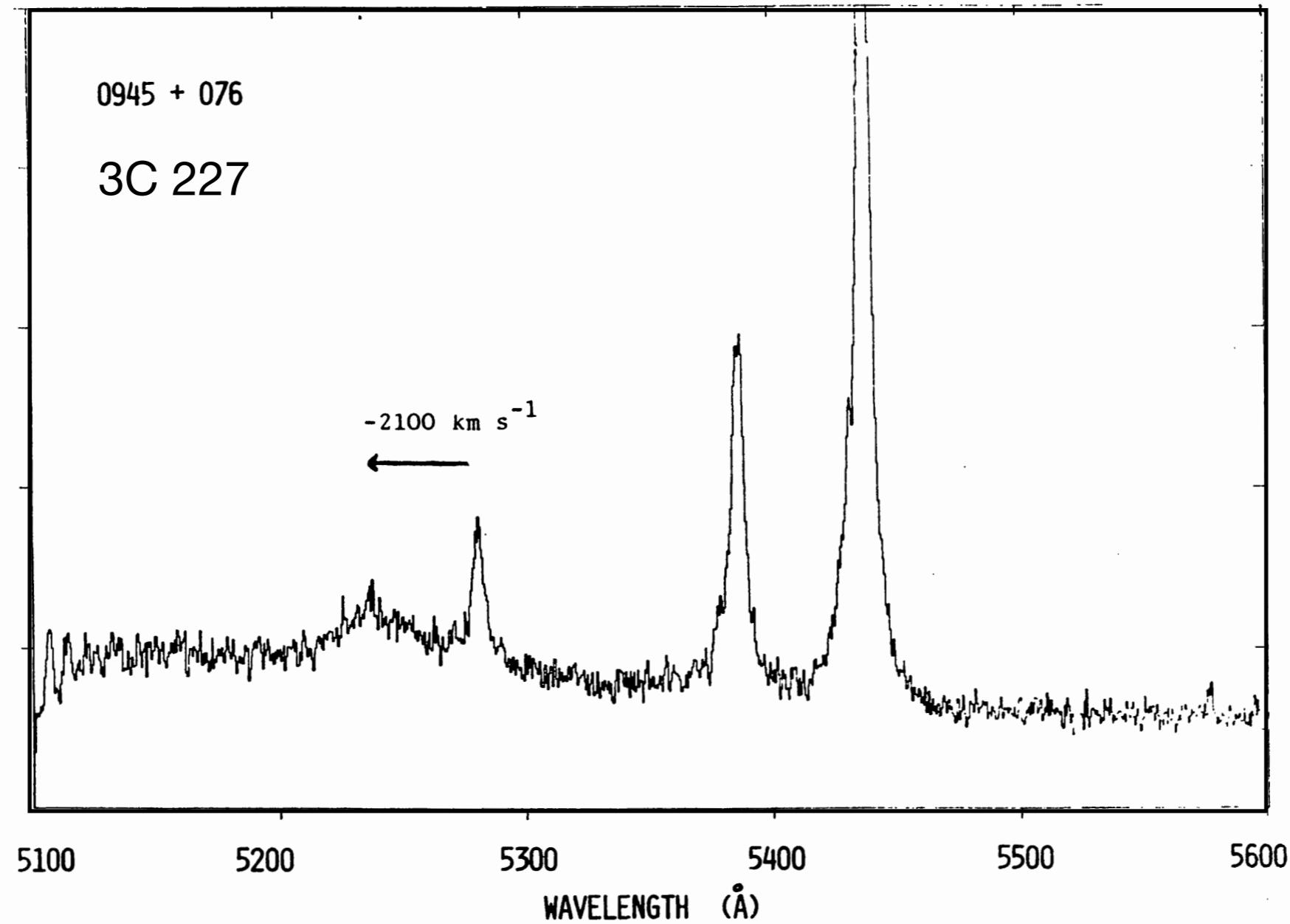


figure from Gaskell (1983)

# Double-Peaked Emitters

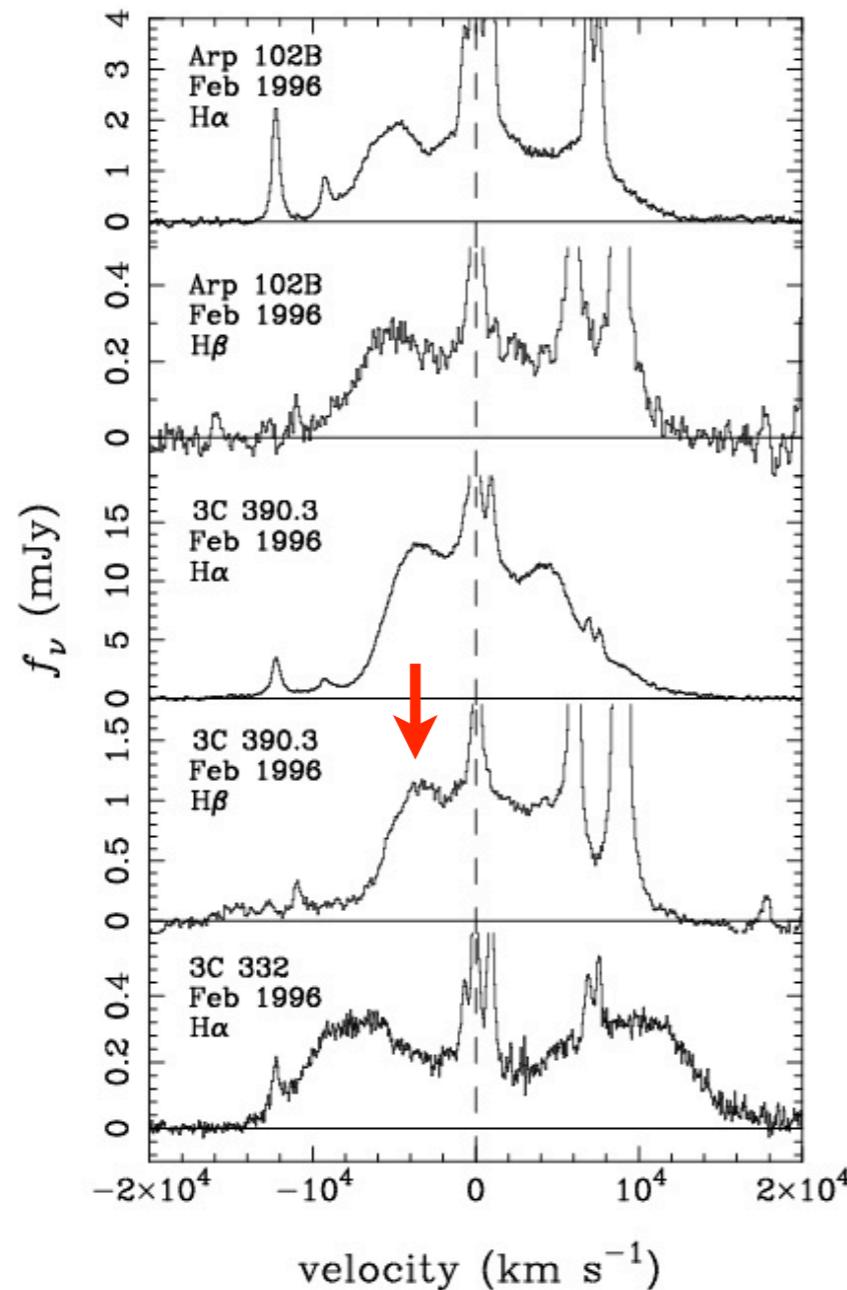
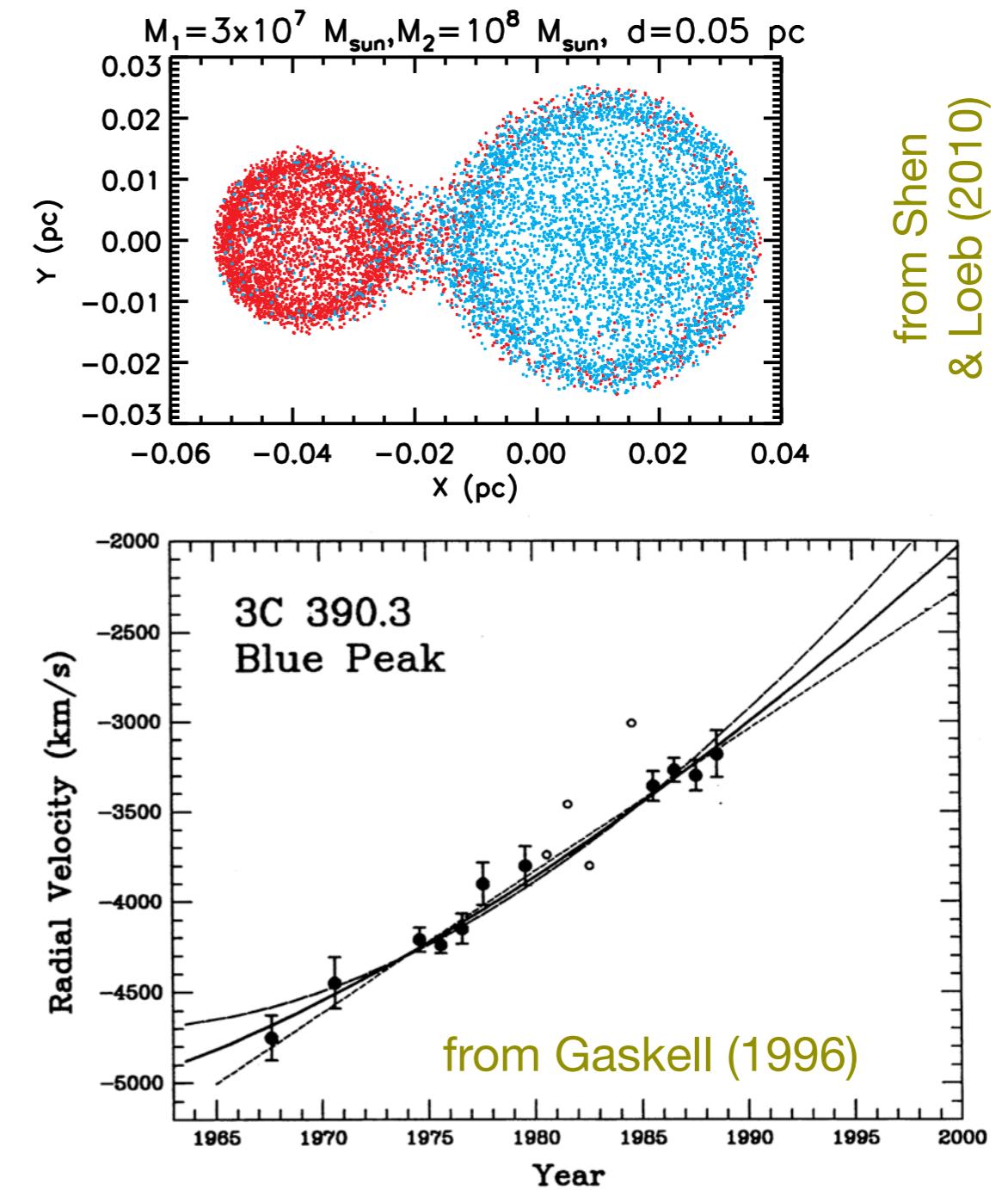
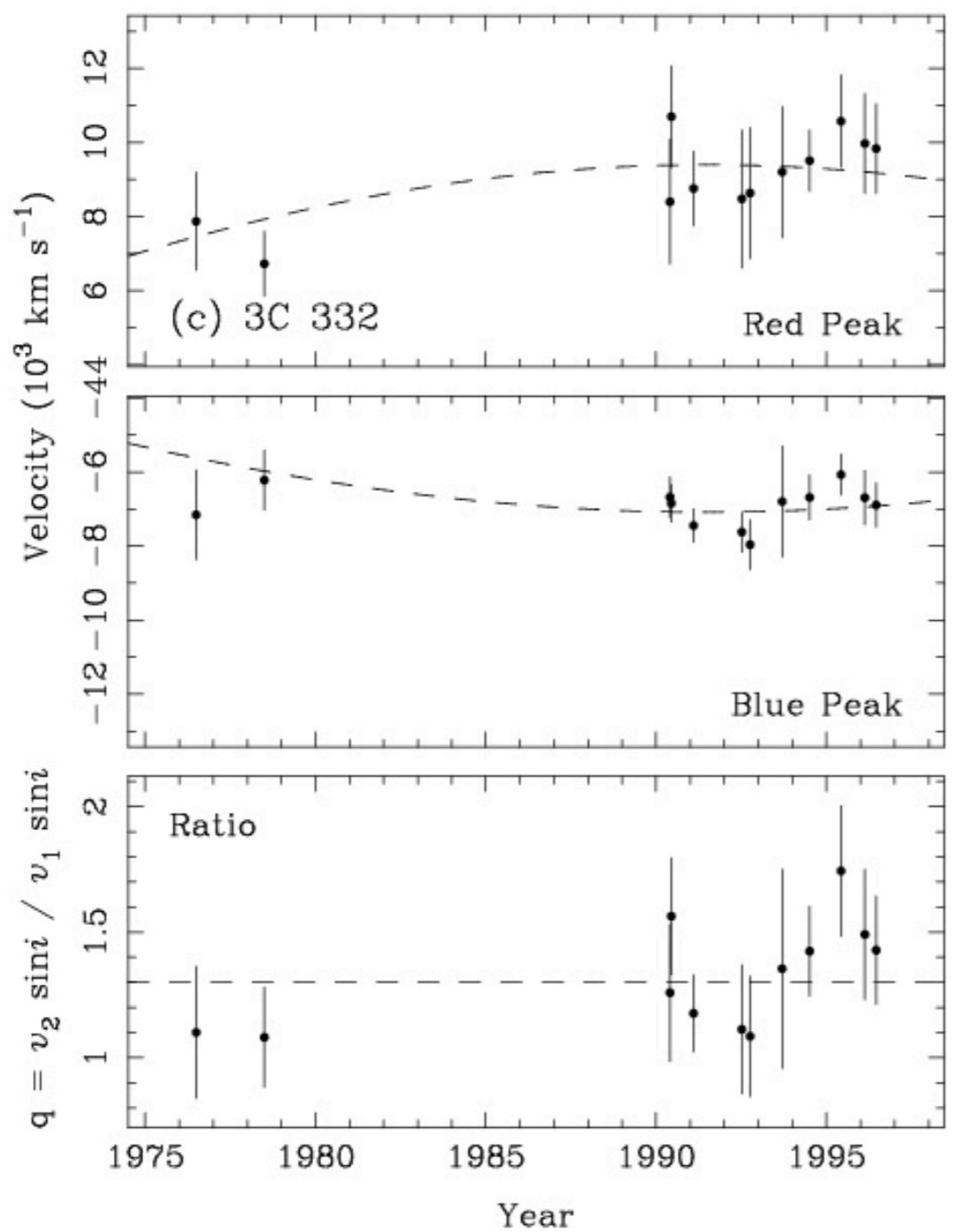


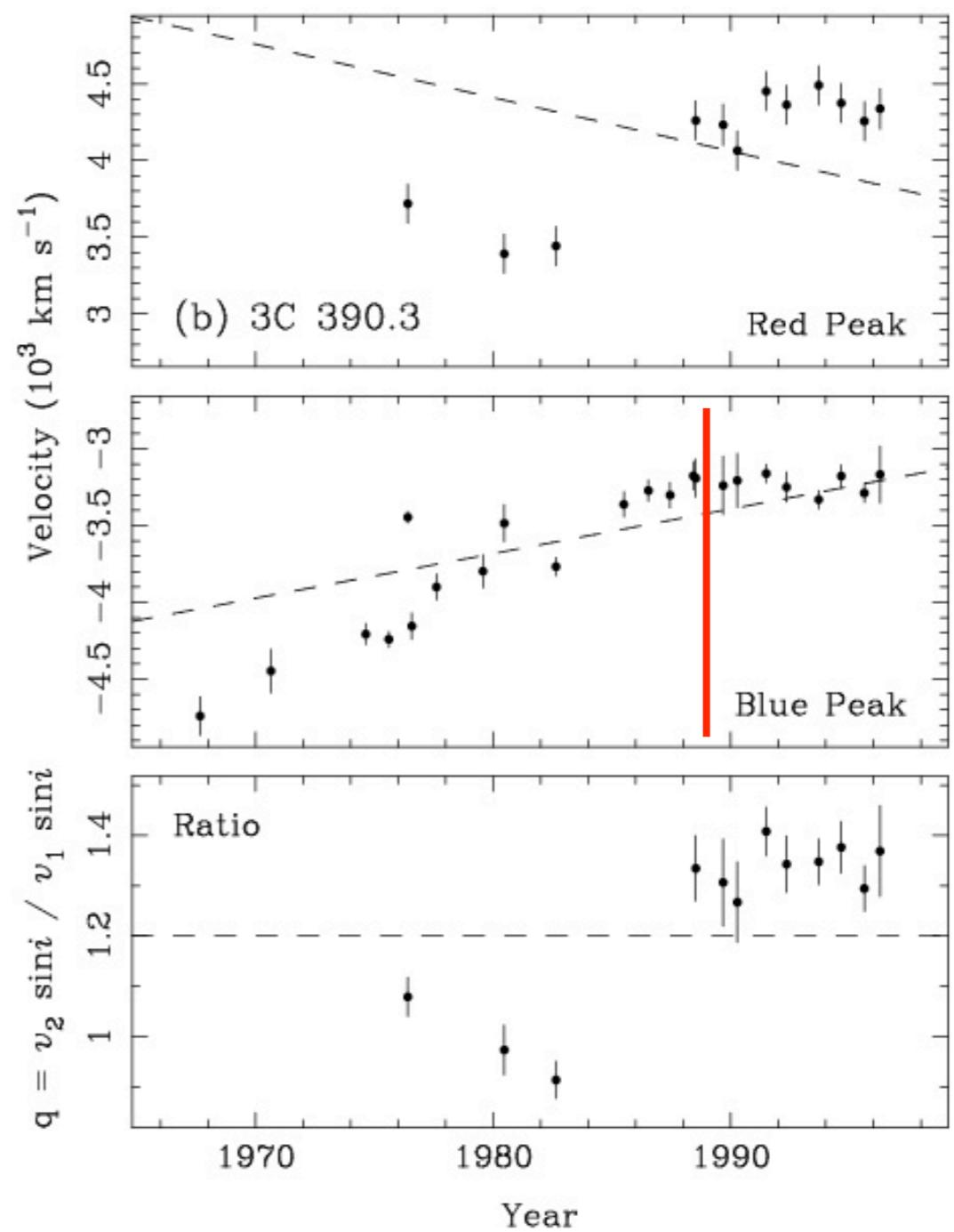
figure from Eracleous et al. (1997)



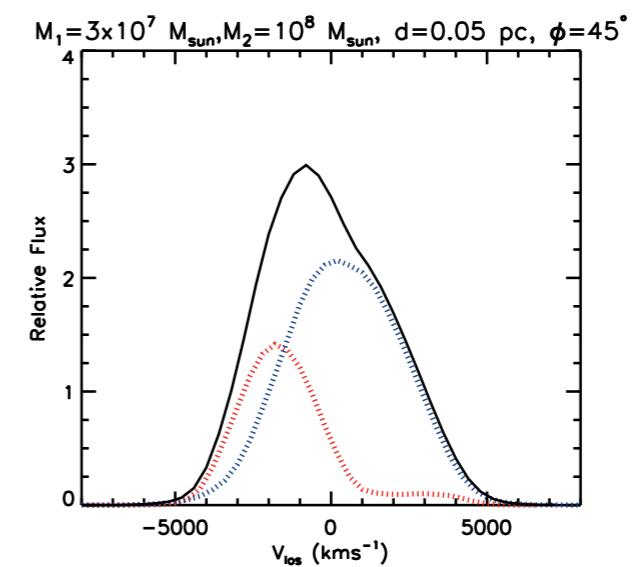
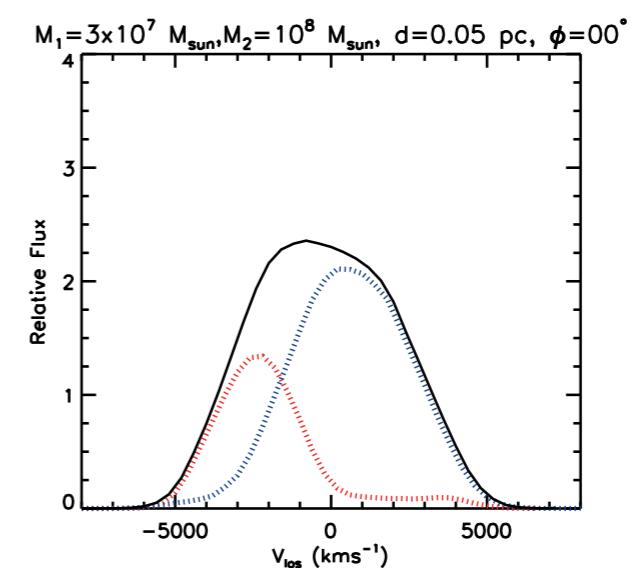
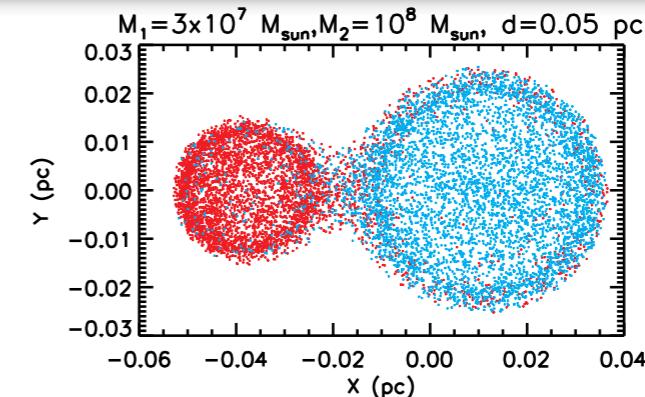
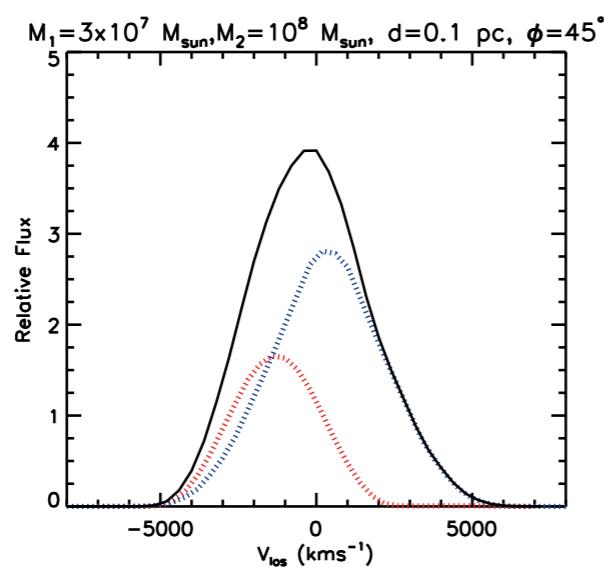
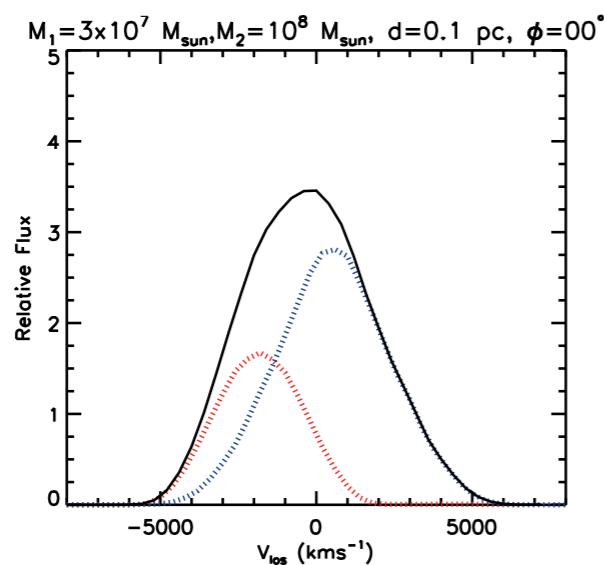
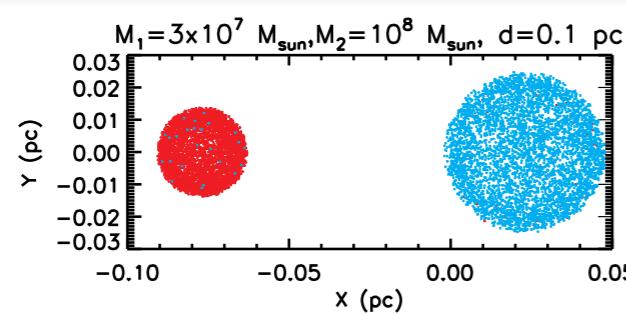
from Shen  
& Loeb (2010)



figures from Eracleous et al. (1997)

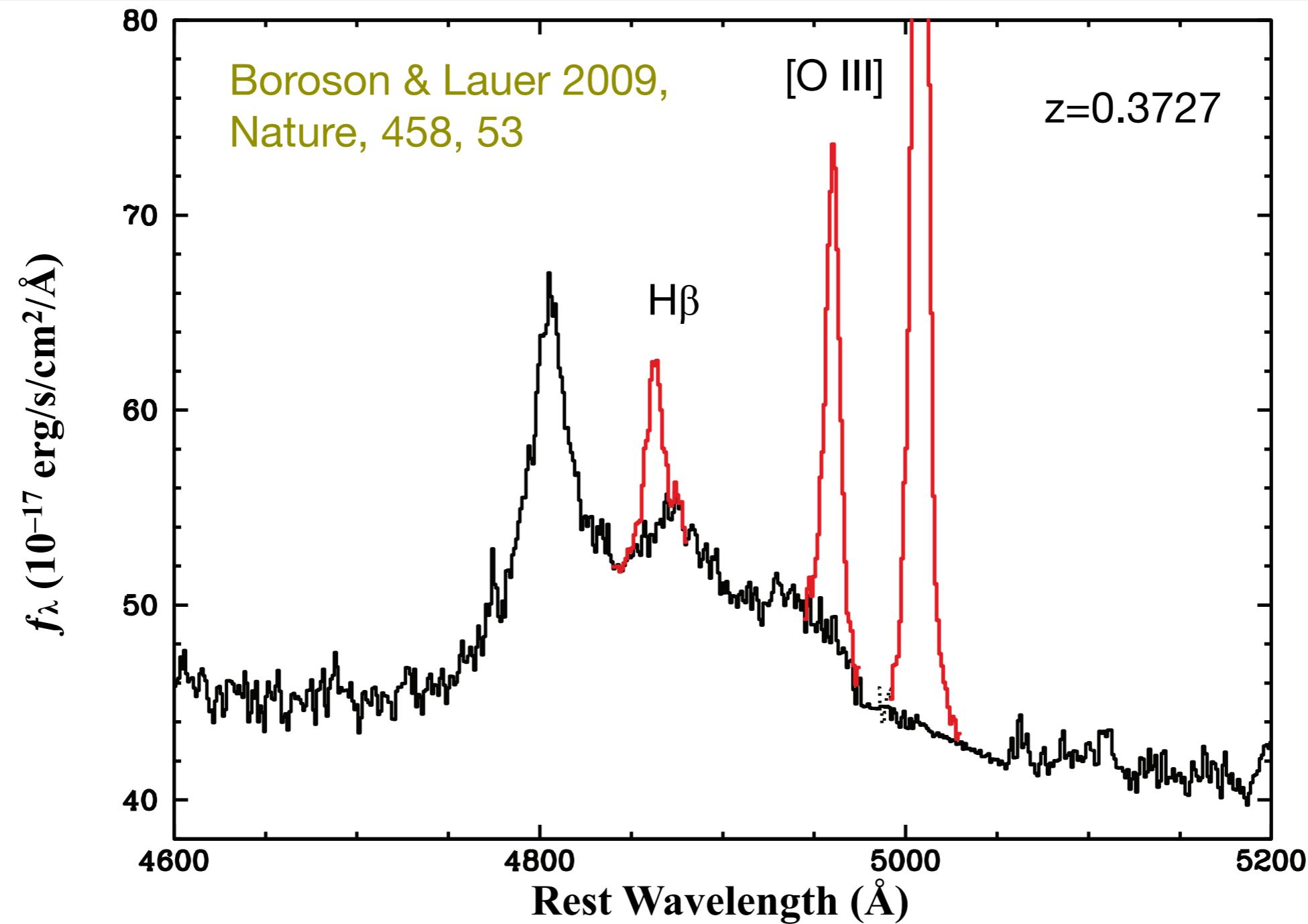


~30 cases now; see Gezari et al. (2007);  
Lewis et al. (2010); Flohic (2009)



figures from Shen & Loeb (2010)

# SDSS J1536+0441: old ideas resurrected



# **A Systematic Search for Close, Bound Binaries**

# The hypothesis: only one BH is “active”

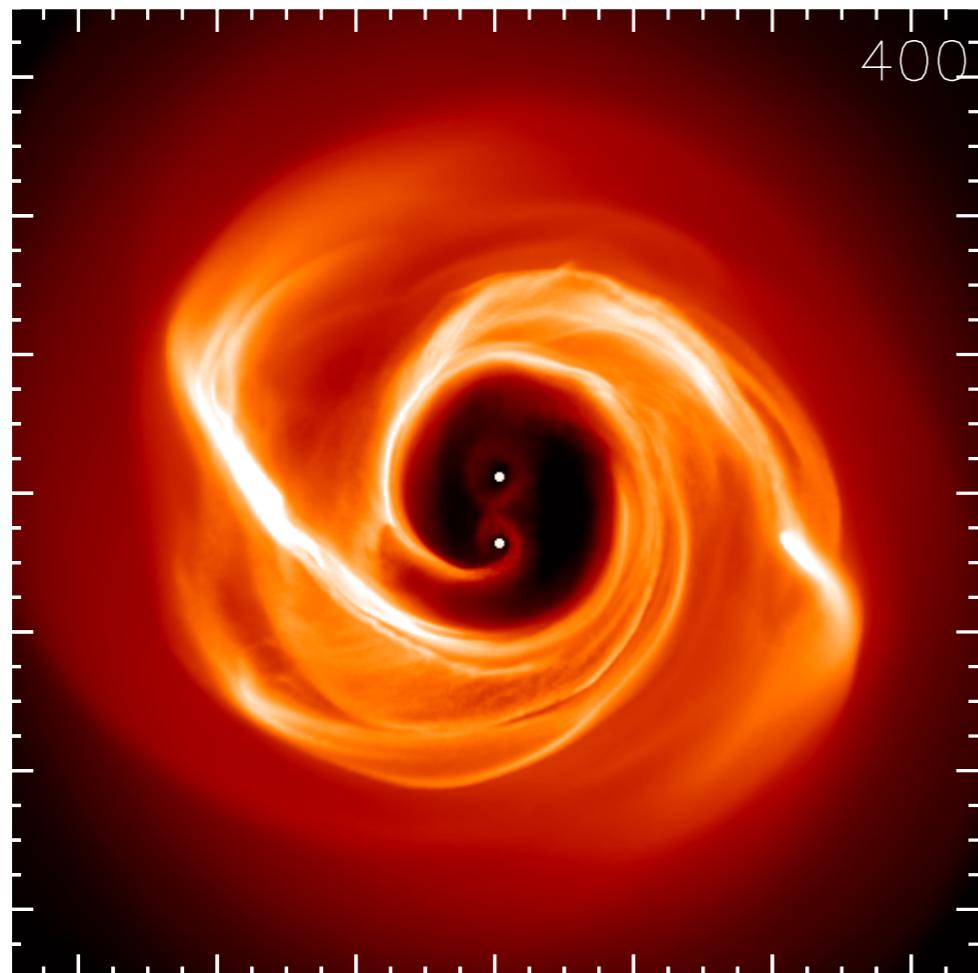


Figure from Cuadra et al. 2009,  
MNRAS, 393, 1423  
see also Hayasaki et al. 2007,  
PASJ, 59, 427

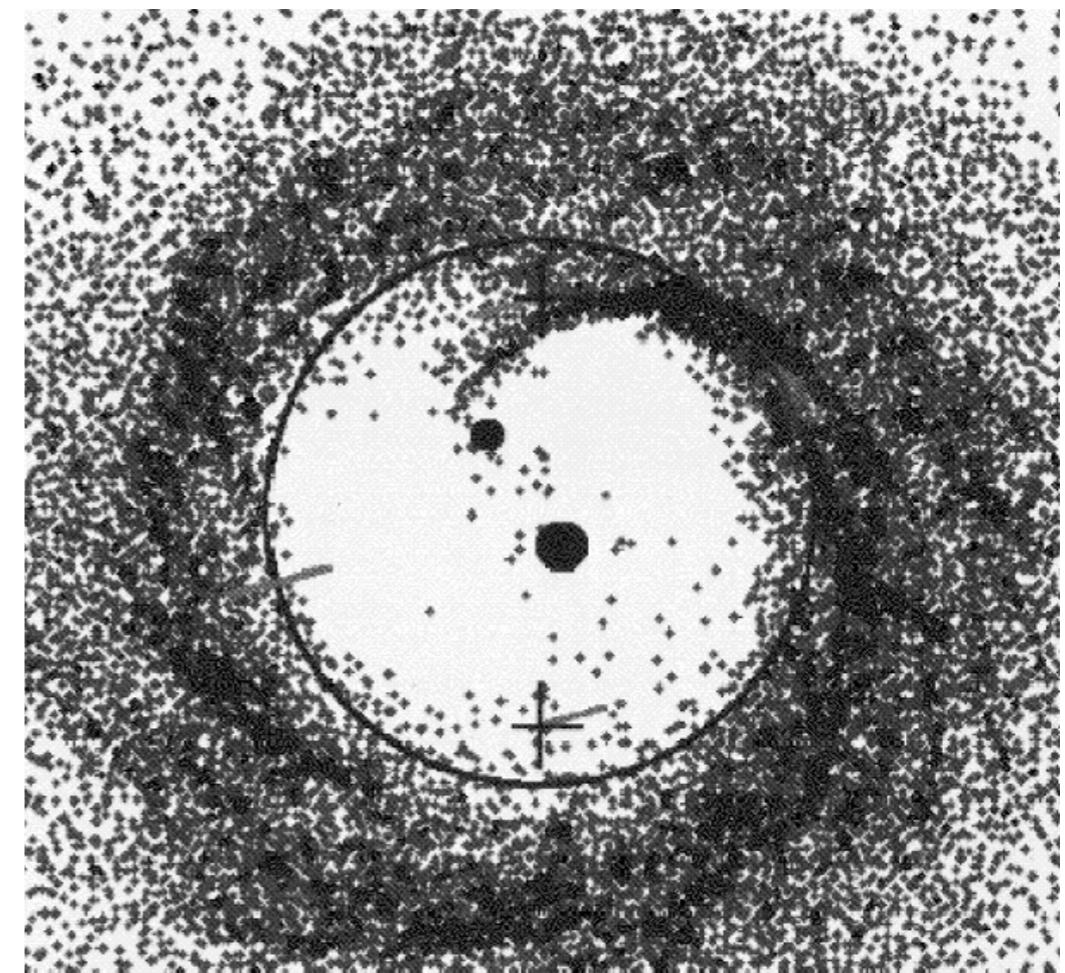
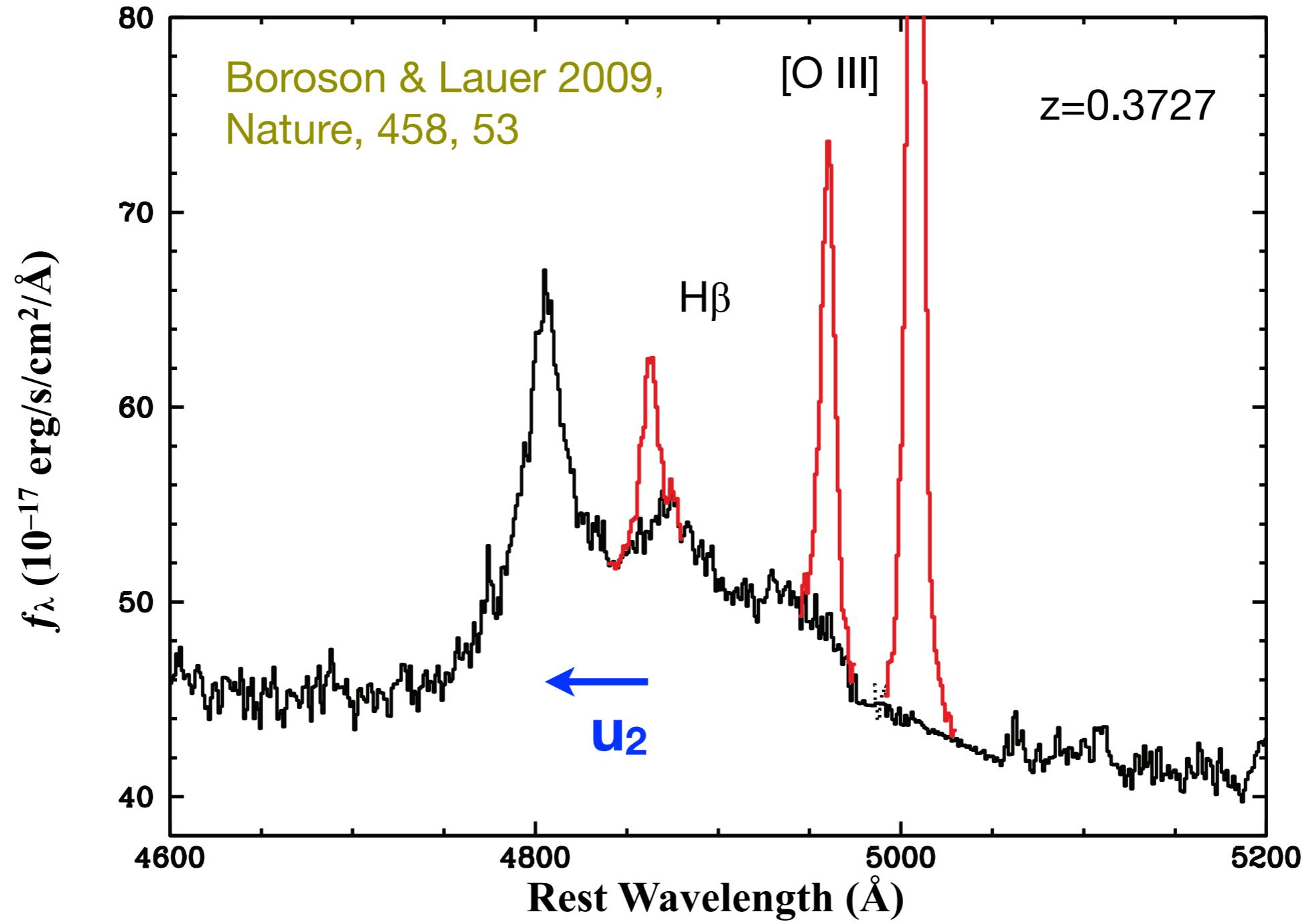
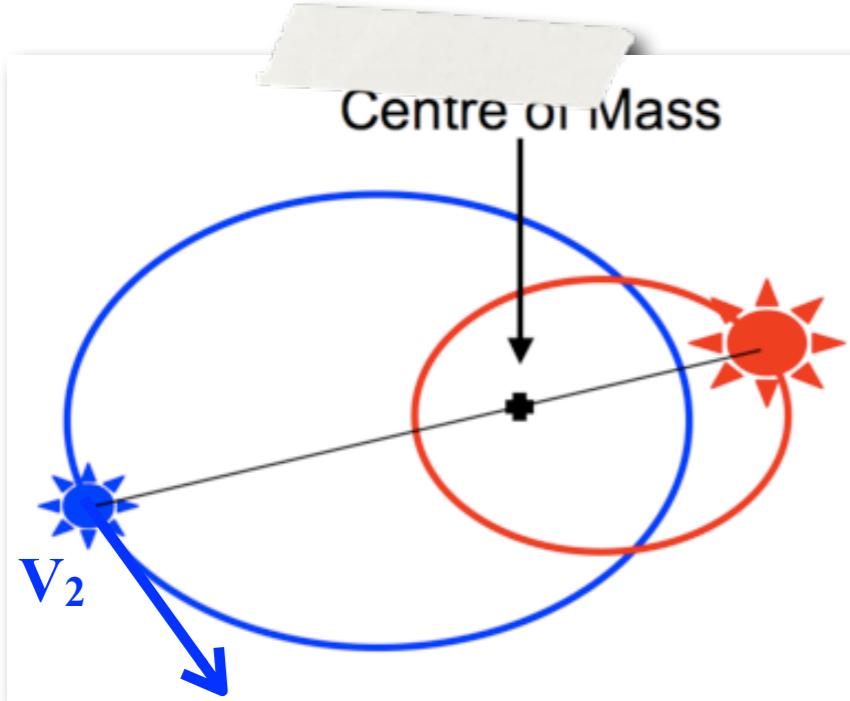


Figure from  
Artymowicz & Lubow 1996,  
ApJ, 467 L77



# Expected Binary Properties



We observe:

$$u_2 = V_2 \sin i \sin \phi$$

$$u_{2,3} = \frac{V_2 \sin i \sin \phi}{10^3 \text{ km/s}}$$

$$P = \frac{332 M_8}{(1+q)^3 u_{2,3}^3} \left( \frac{\sin i}{\sin 45^\circ} \frac{|\sin \phi|}{\sin 45^\circ} \right)^3 \text{ yr}$$

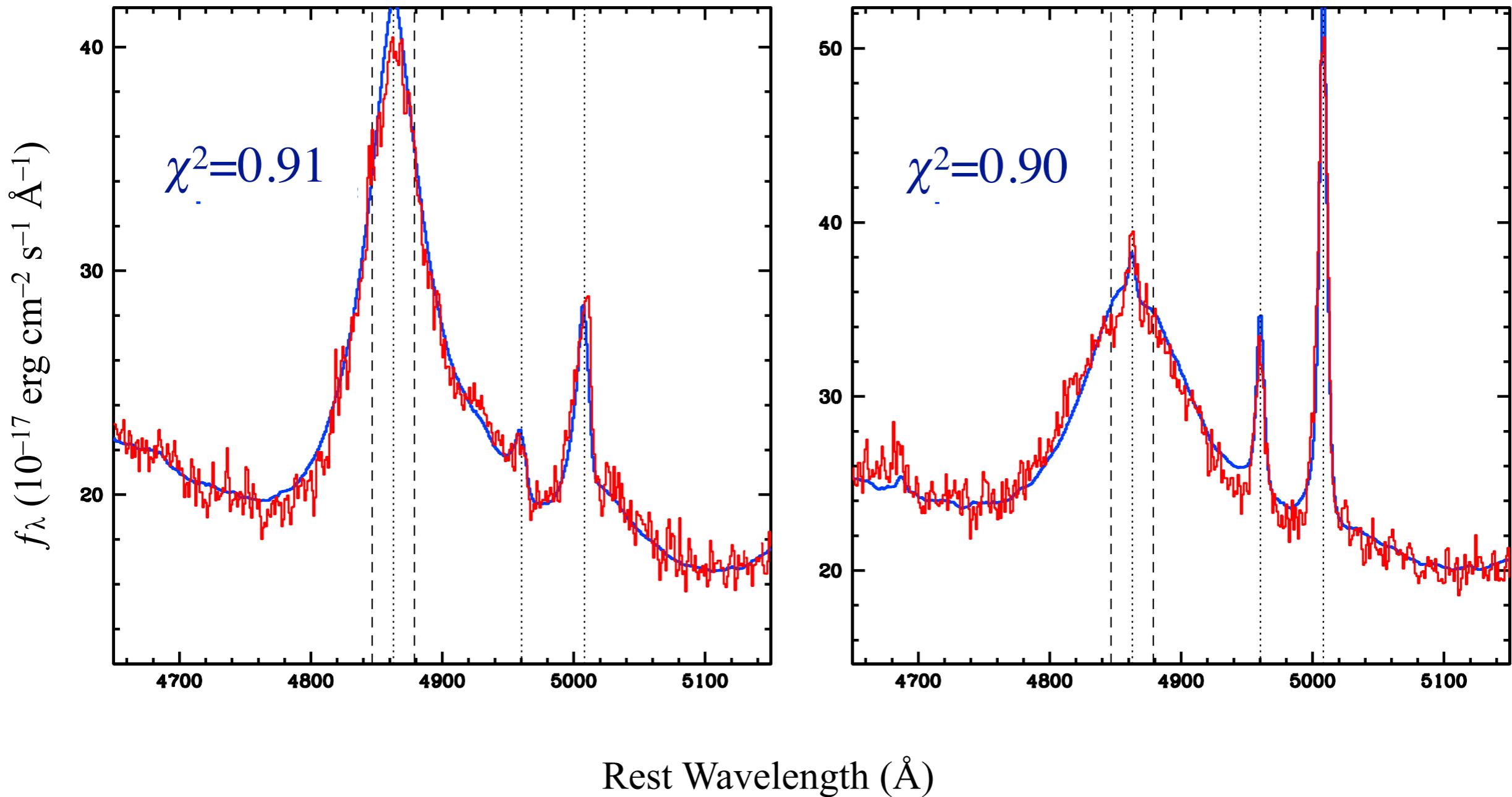
$$a = \frac{0.11 M_8}{(1+q)^2 u_{2,3}^2} \left( \frac{\sin i}{\sin 45^\circ} \frac{|\sin \phi|}{\sin 45^\circ} \right)^2 \text{ pc.}$$

$$\left| \frac{du_2}{dt} \right| = 19 \frac{u_{2,3}^4 (1+q)^3}{M_8} \text{ km/s/yr}$$
$$\left( \frac{\sin 45^\circ}{\sin i} \right)^3 \left( \frac{\sin 45^\circ}{\sin \phi} \right)^4 \frac{|\cos \phi|}{\cos 45^\circ}$$

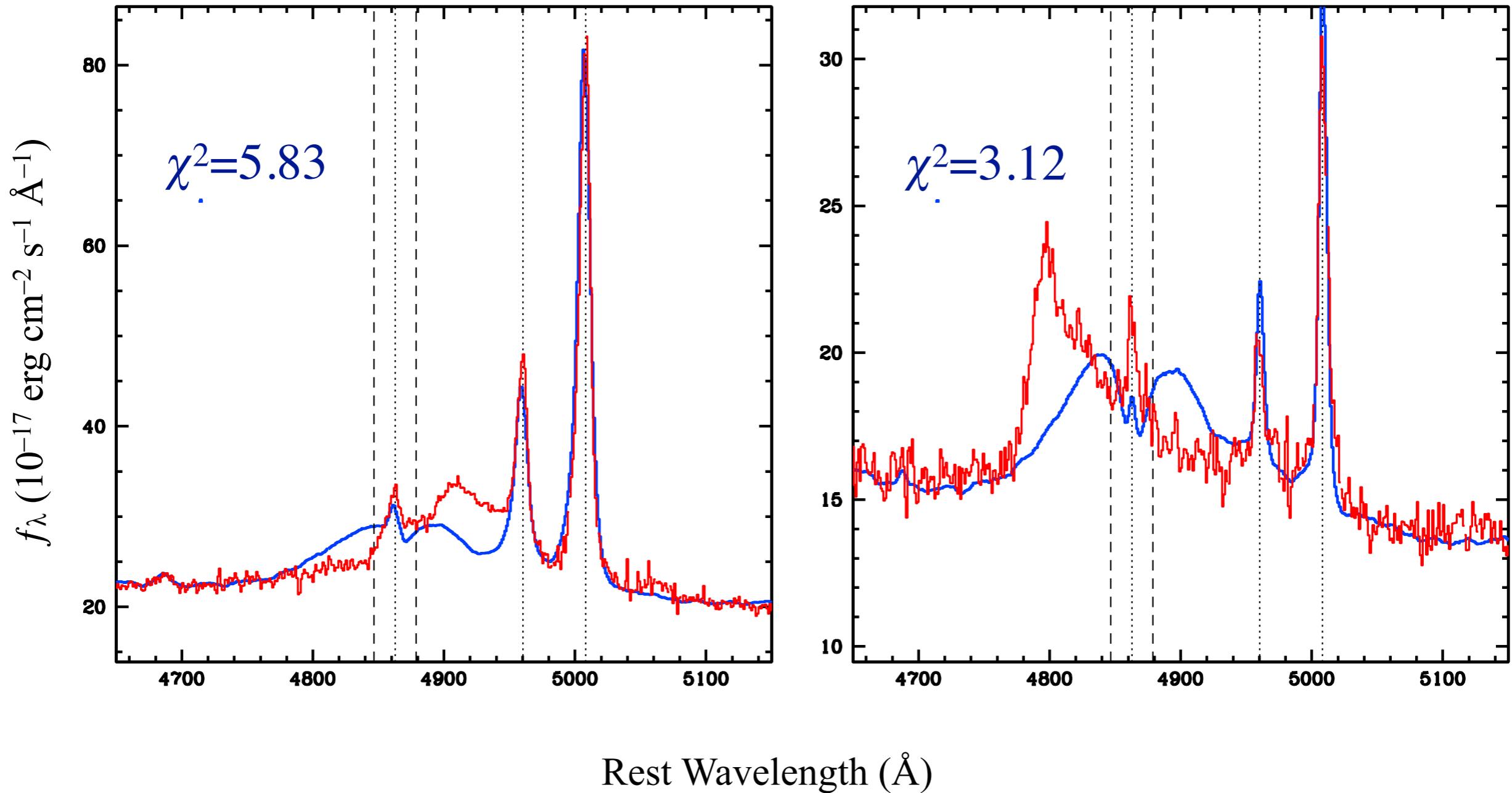
# Selection of Candidates from SDSS

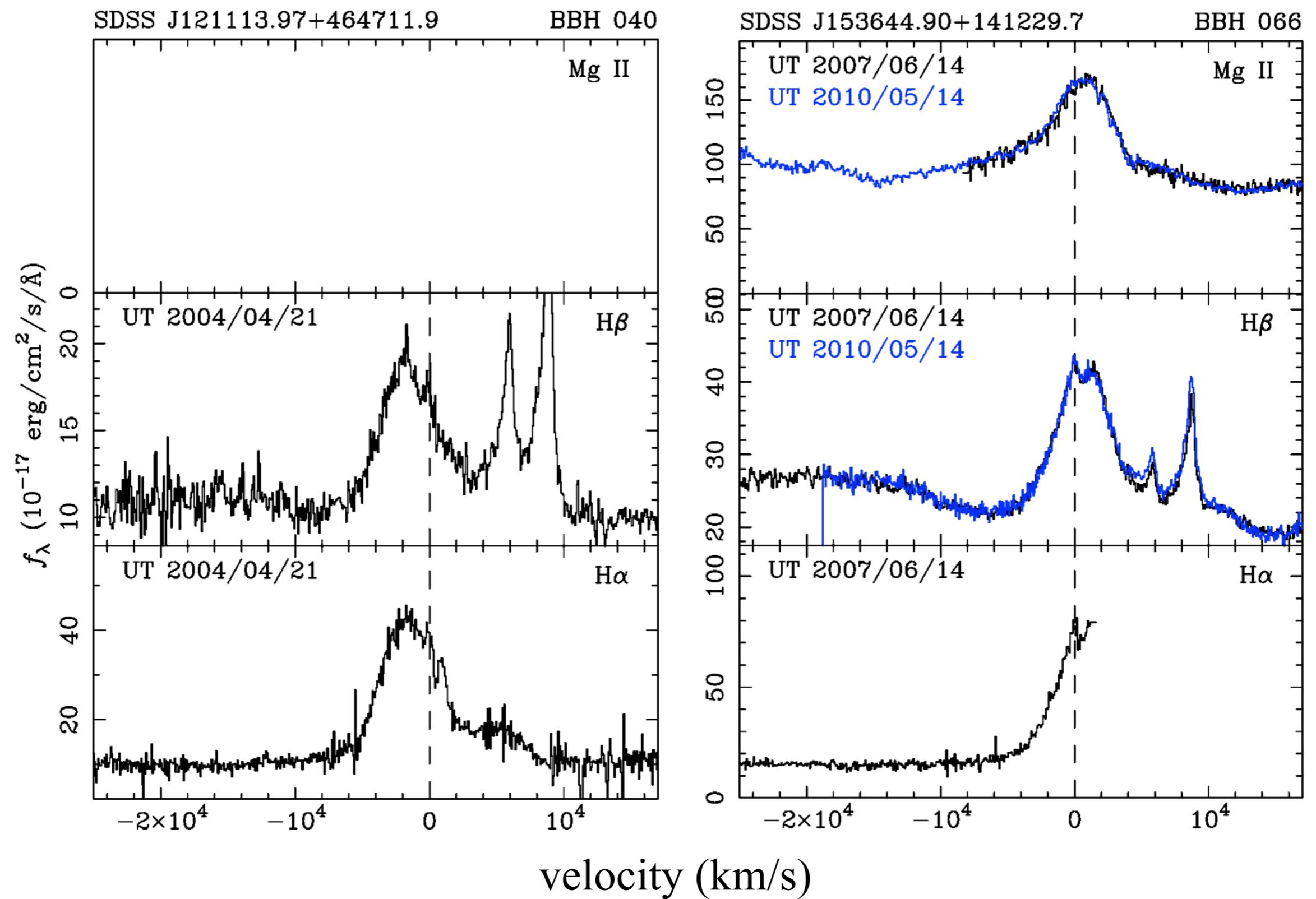
- Spectroscopic PCA used to find quasars with “oddball” H $\beta$  profiles.
  - start with  $z < 0.7$  quasars from SDSS DR7
  - tune of PCA technique to find offset line peaks
  - ~900 candidates  $\Rightarrow$  final filtering by visual inspection
  - at the end of the day: 88 candidates
- Volonteri et al 2009 predict ~130 such binaries in the SDSS DR7 spectroscopic sample (~17,000 quasars)

## Reconstruction of Line Profiles Using First 5 Eigenspectra

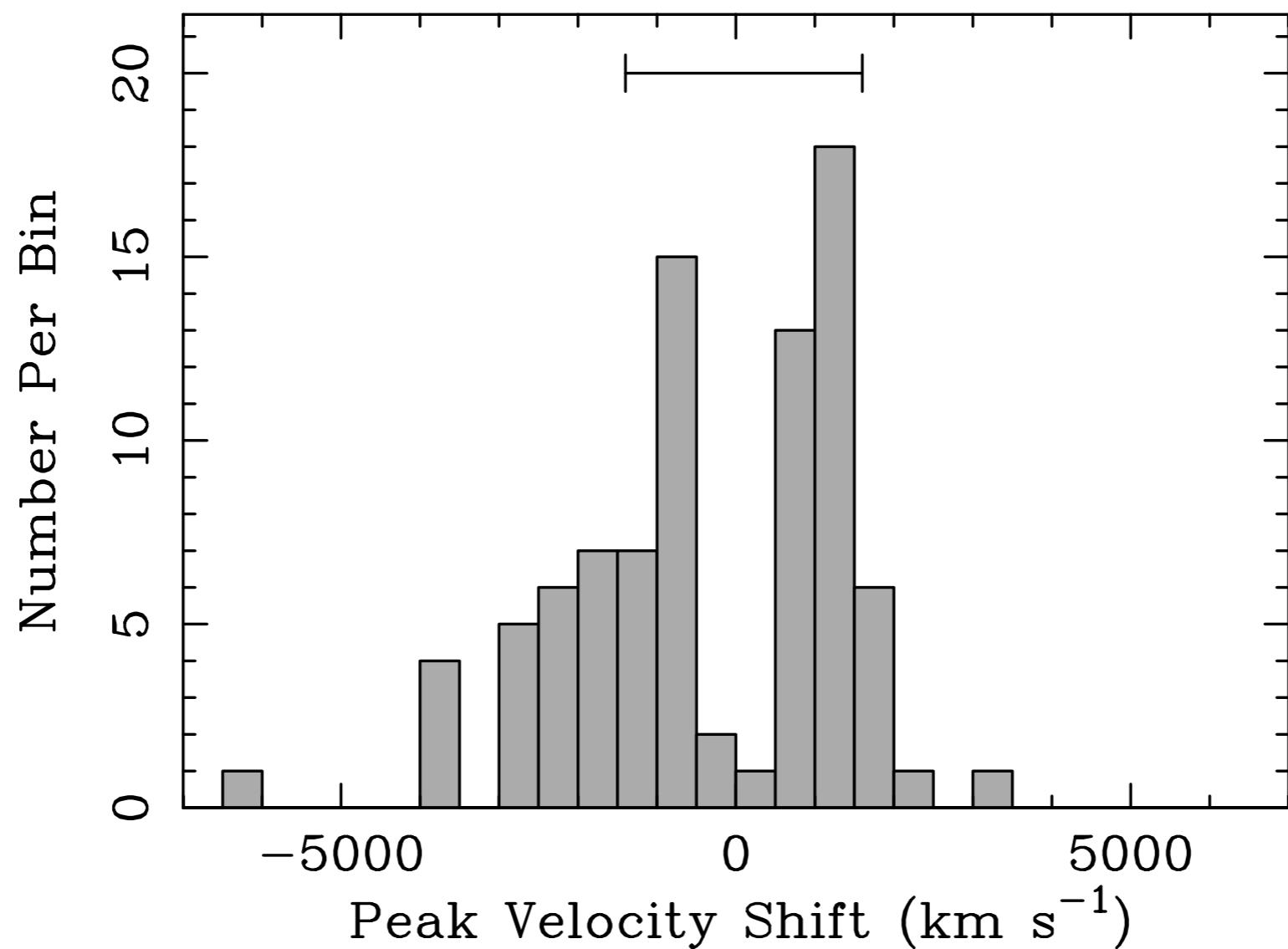


## Reconstruction of Line Profiles Using First 5 Eigenspectra

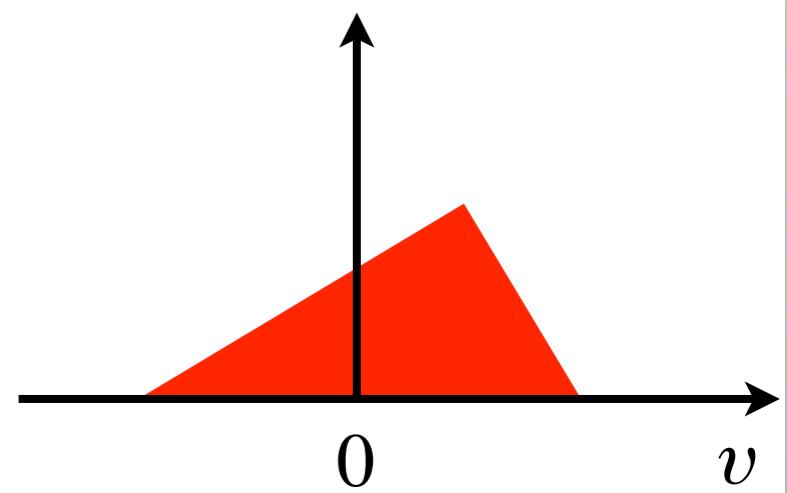
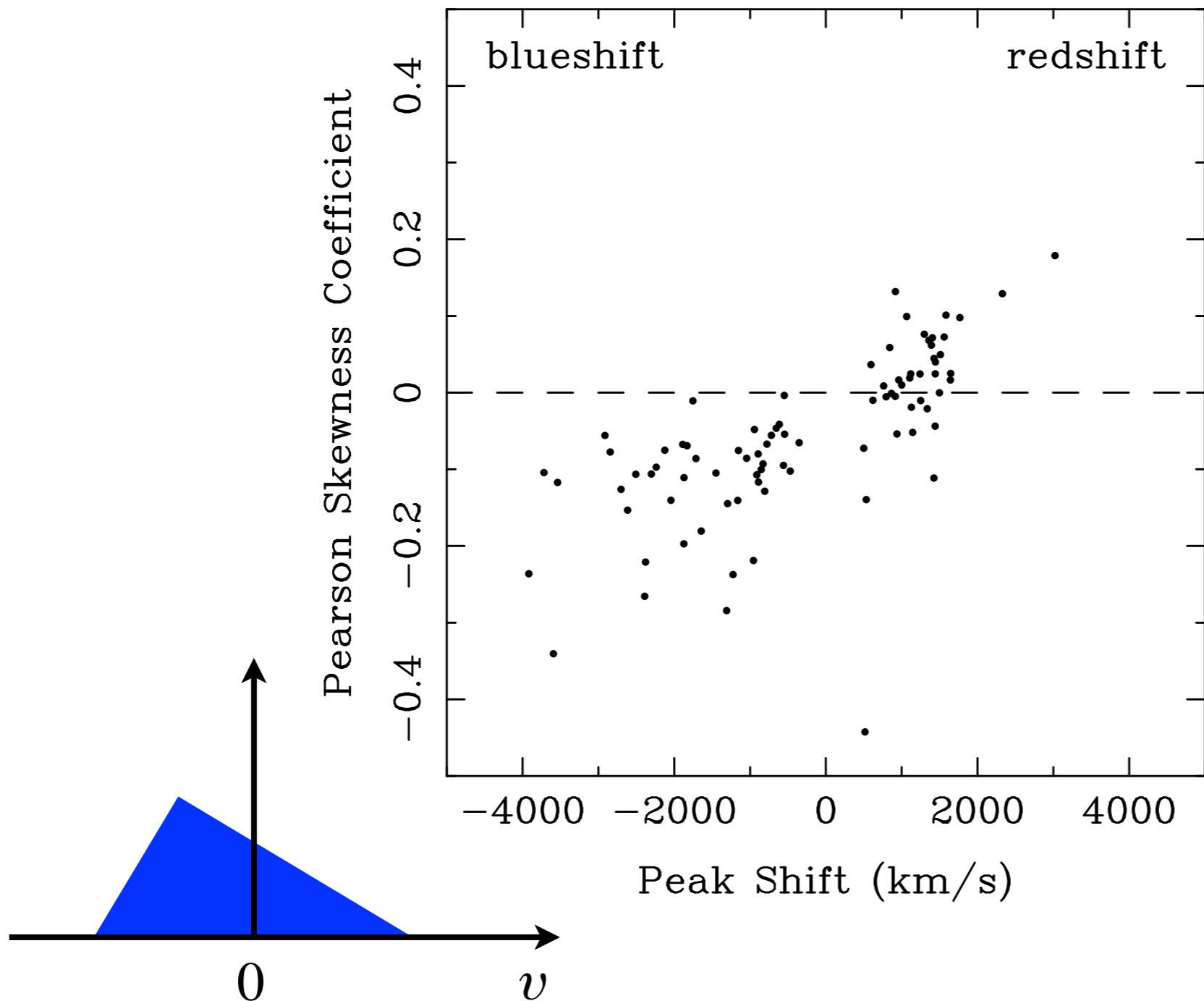




# Distribution of Velocity Offsets



## Correlation between skewness and shift



# Followup Observations

- “2nd epoch”  
Dec 2009 - Mar 2011

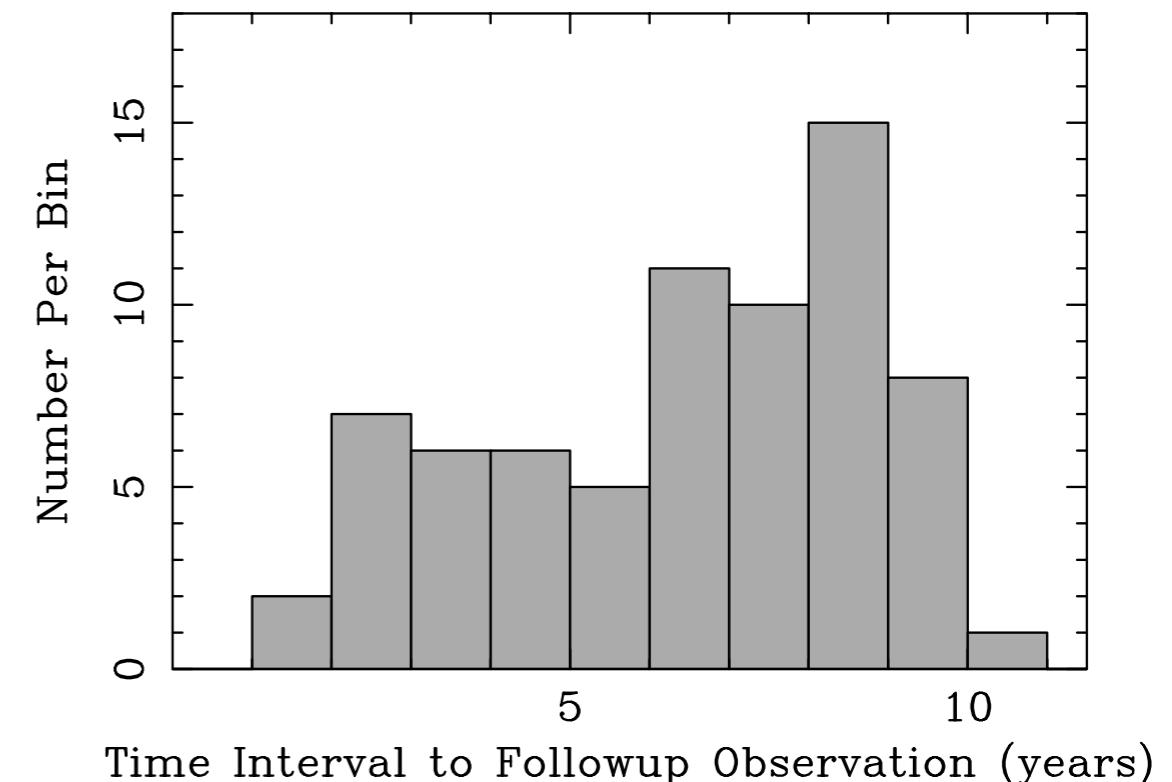
MDM 2.4m Hiltner

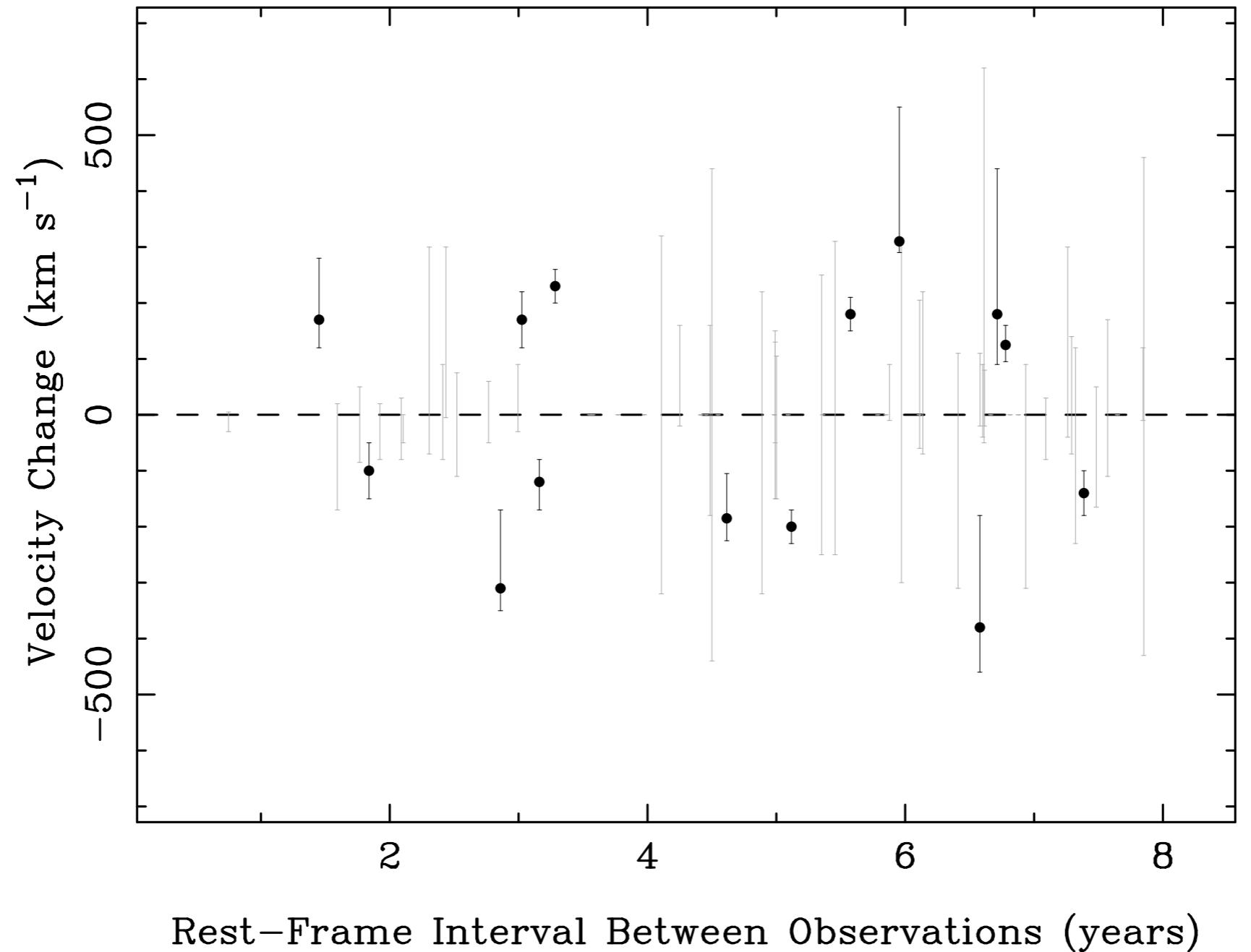
KPNO 4m Mayall

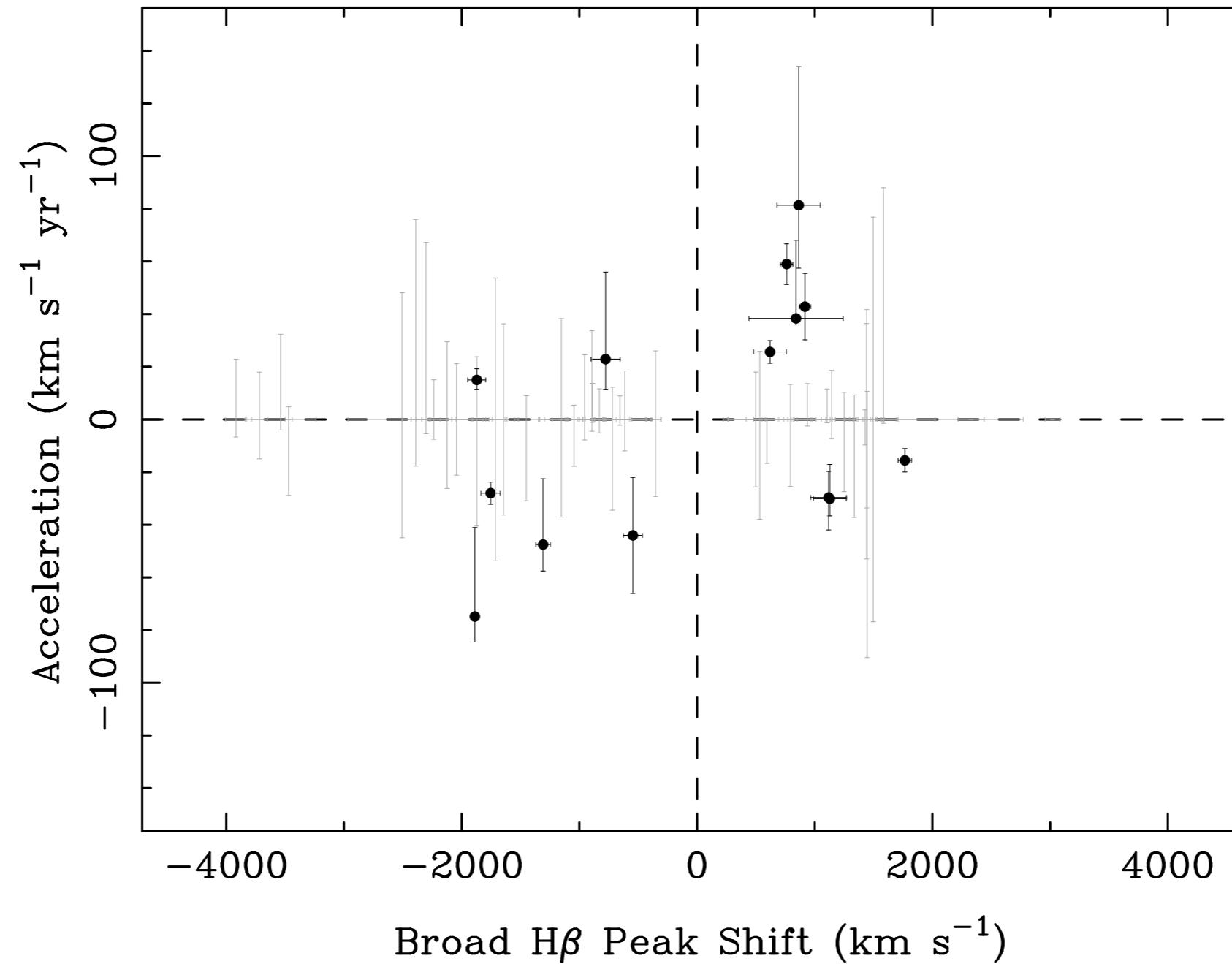
Palomar 5m Hale

9.2m Hobby-Eberly

- “3rd epoch”  
just completed

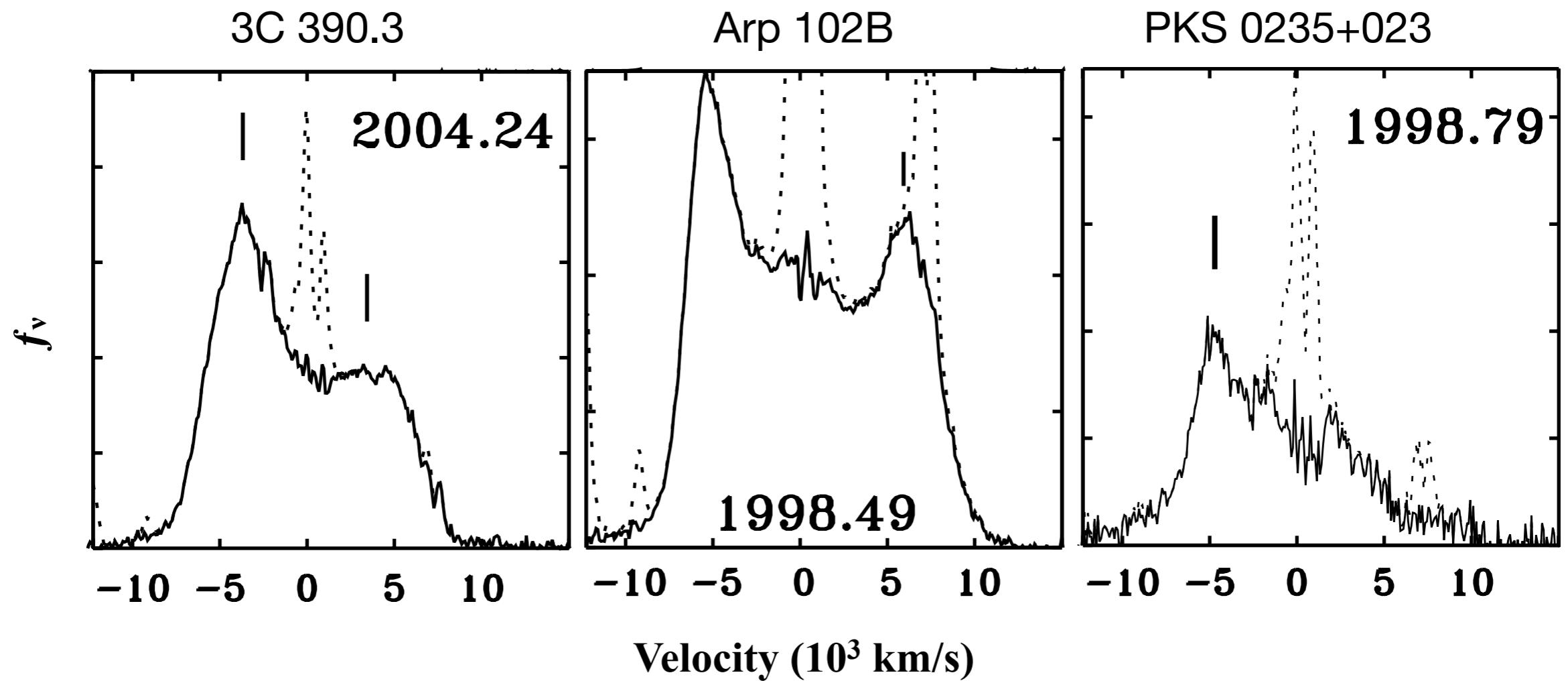




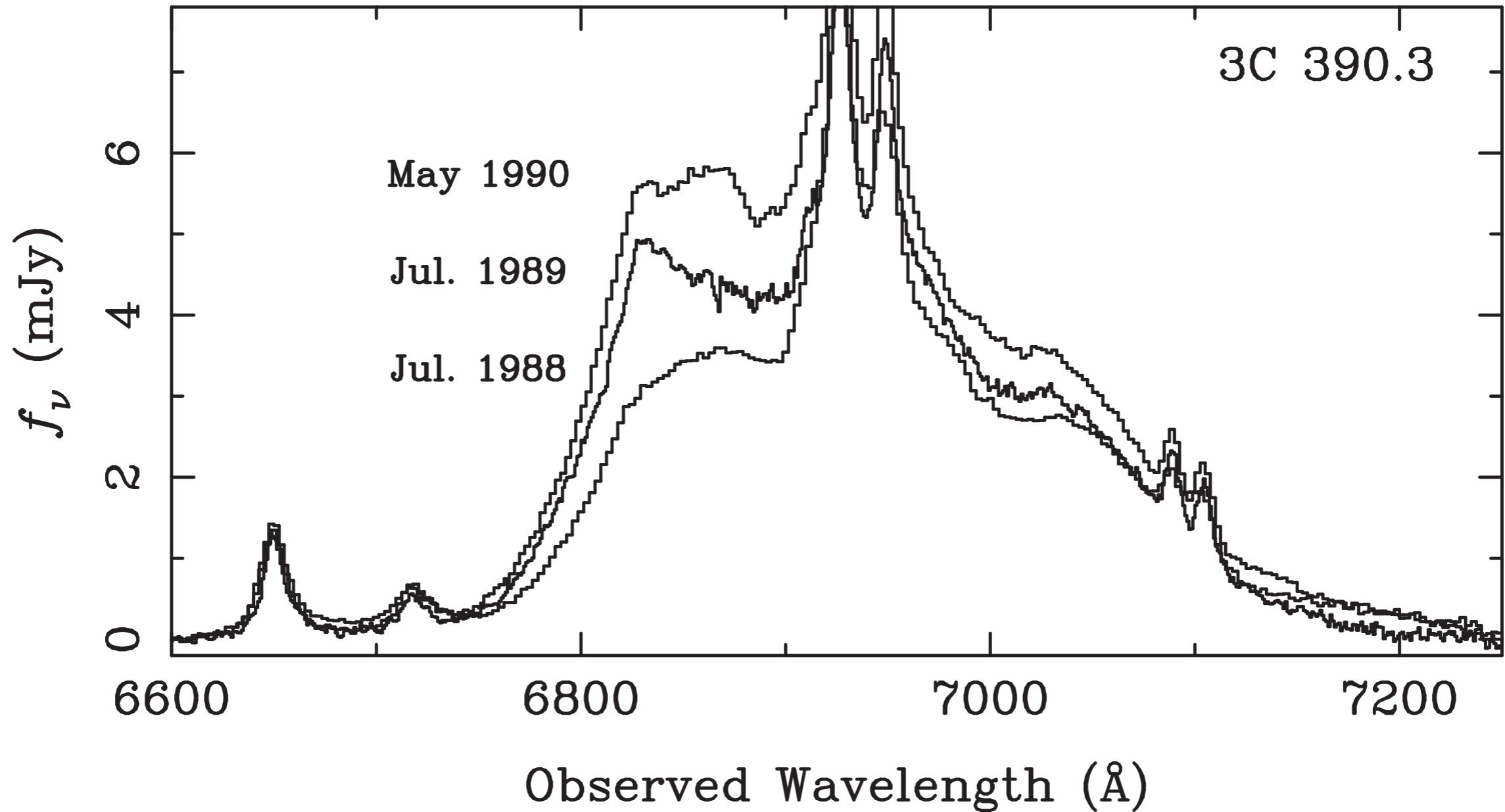


# **Caveats: Pandora's Box**

# Displaced Peaks Do NOT Always Mean Binaries!

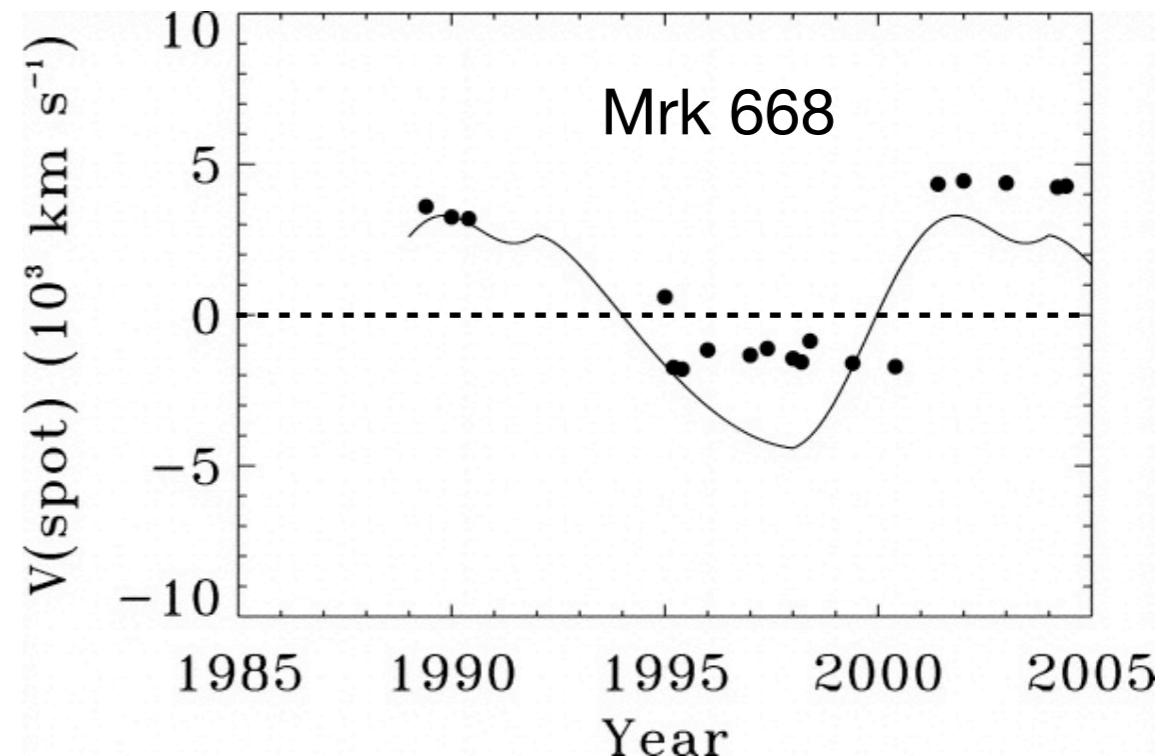
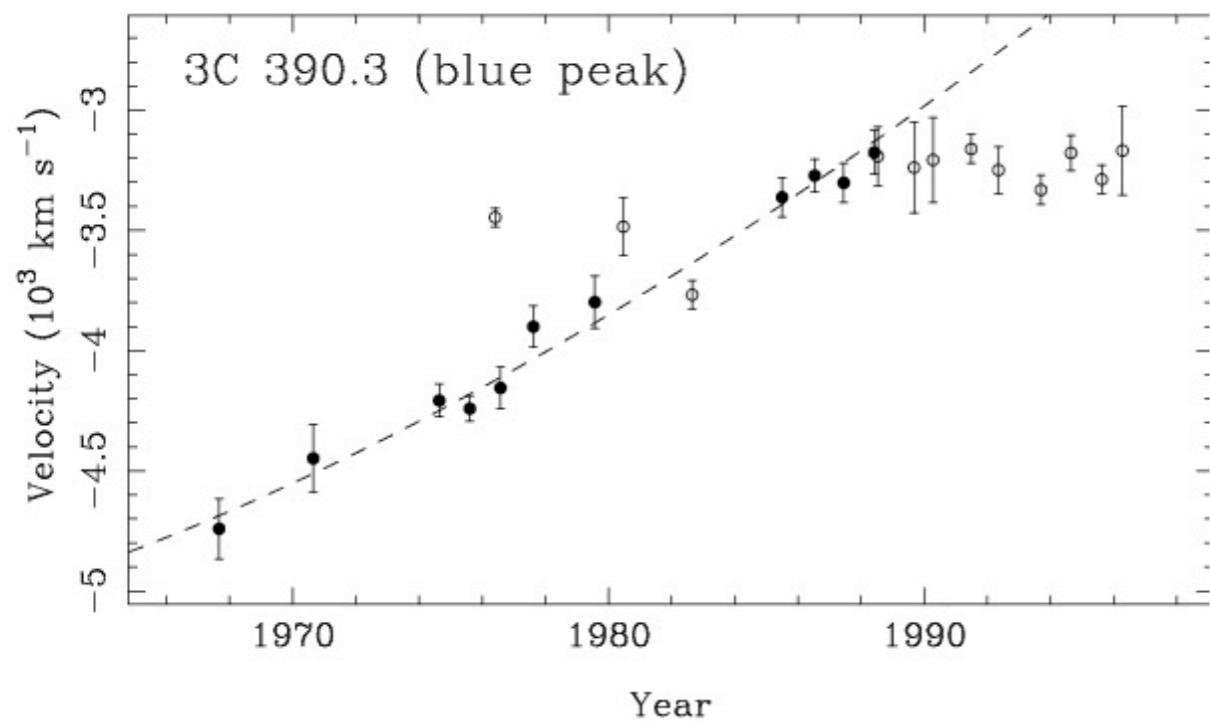


from Gezari, Halpern & Eracleous (2007)



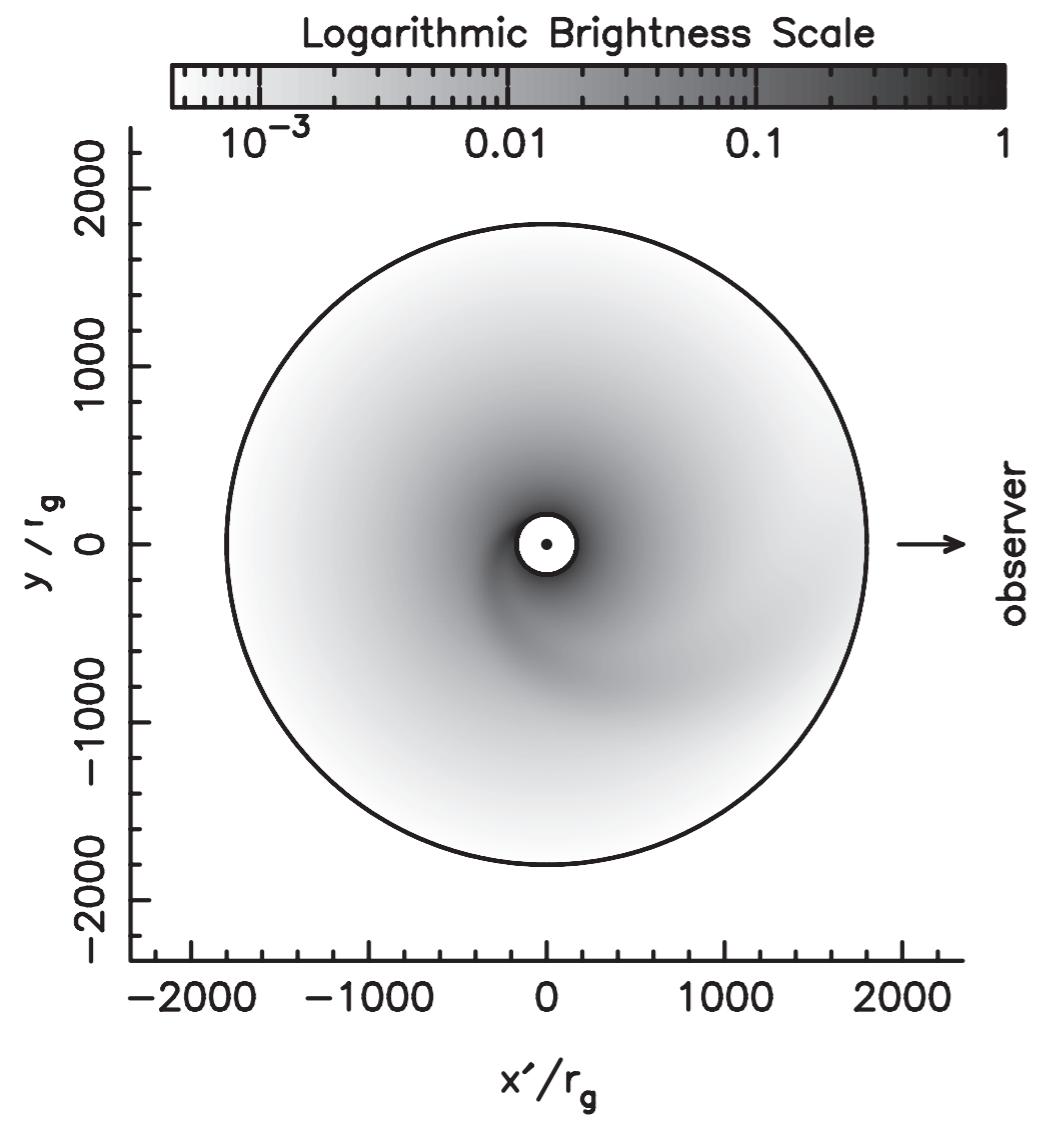
from Eracleous et al. (1997)

# Nor Do Displaced Peaks that Move!

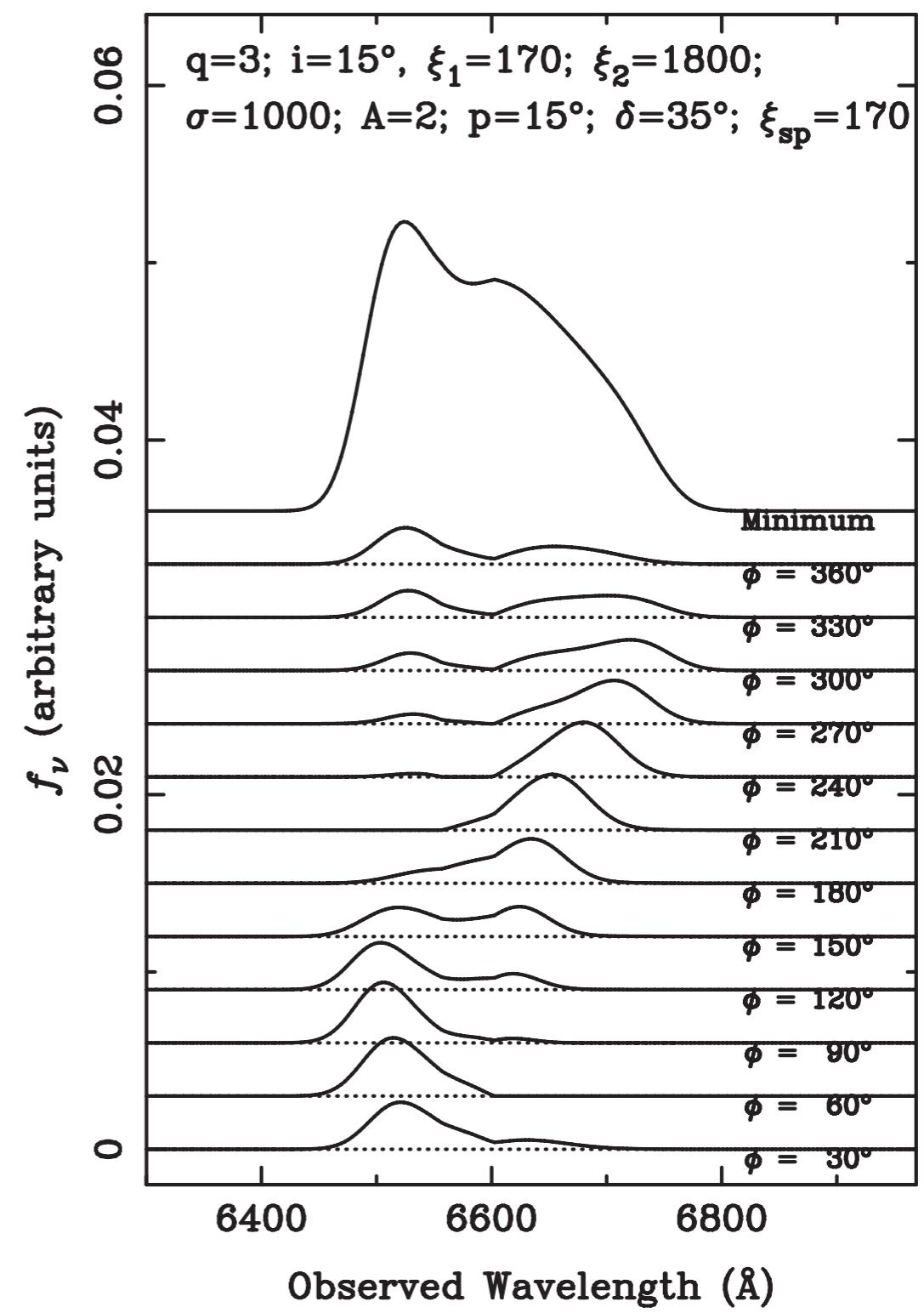


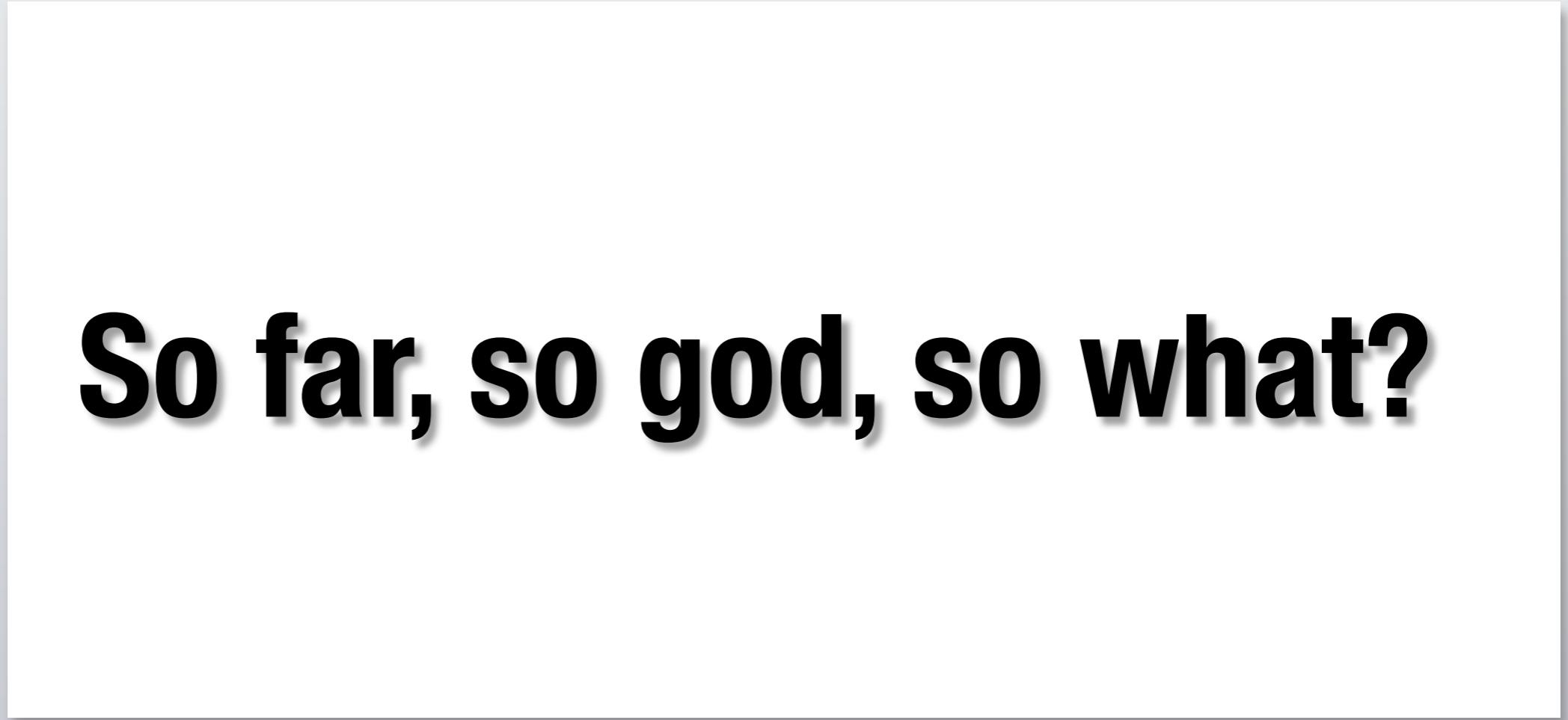
from Eracleous et al. (1997)  
including data from Gaskell (1996)

Gezari, Halpern & Eracleous (2006)  
see also Marziani et al. (1996)



from Lewis, Eracleous, &  
Storchi-Bergmann (2010)





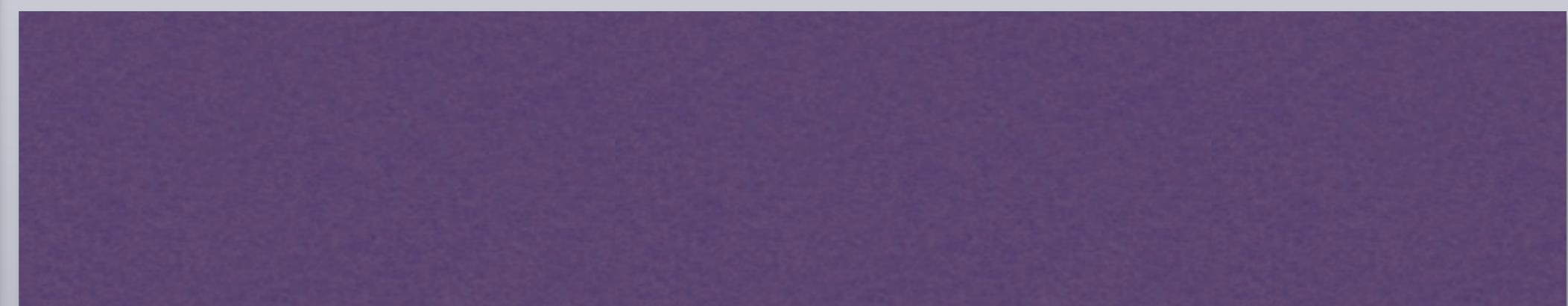
**So far, so god, so what?**

## Reasons to be (cautiously) optimistic...

- Theoretical predictions of population size in broad agreement with observed numbers.
- We can pick out the short-period binaries ( $P \sim 10\text{--}20$  yr) from repeating patterns, even though these will be short-lived.
- We will learn a lot about the dynamics of the gas in the broad-line region in the process.

**Therefore, we push on...**

- Continue monitoring observations
  - verify velocity variations
  - check for monotonic velocity changes: 3 epochs can constrain a sinusoid  $\Rightarrow$  lower bound on the mass
- Simulations of the population properties and assessment of impostors
- Optical and radio imaging: test for recoiling BHs
  - HST and EVLA + VLBI
- Spectroscopic Test for Perturbed Accretion Disks
  - Involves comparison of Balmer and Lyman line profiles.



**End of story**

**for now...**