Long-Term Profile Variability in Double-Peaked Emission Lines in AGNs

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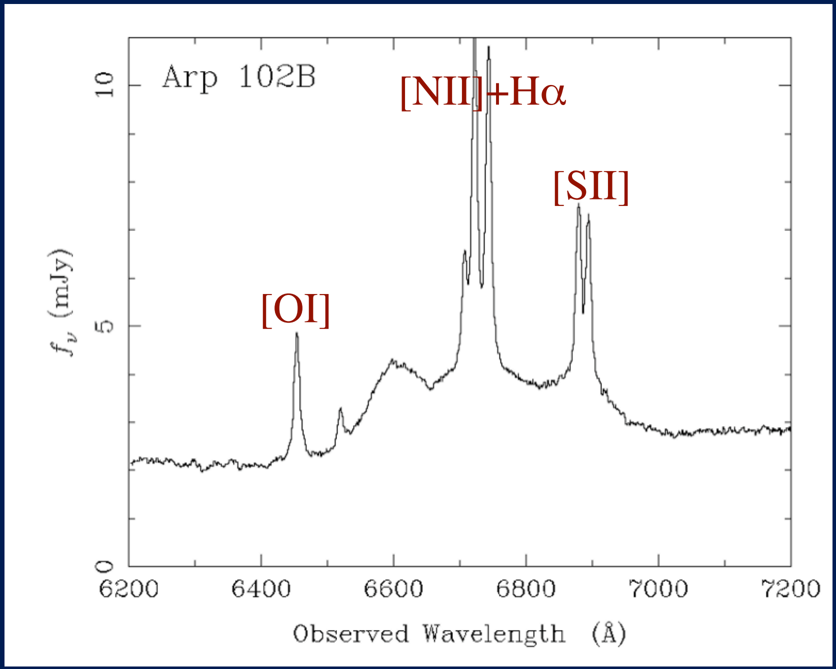
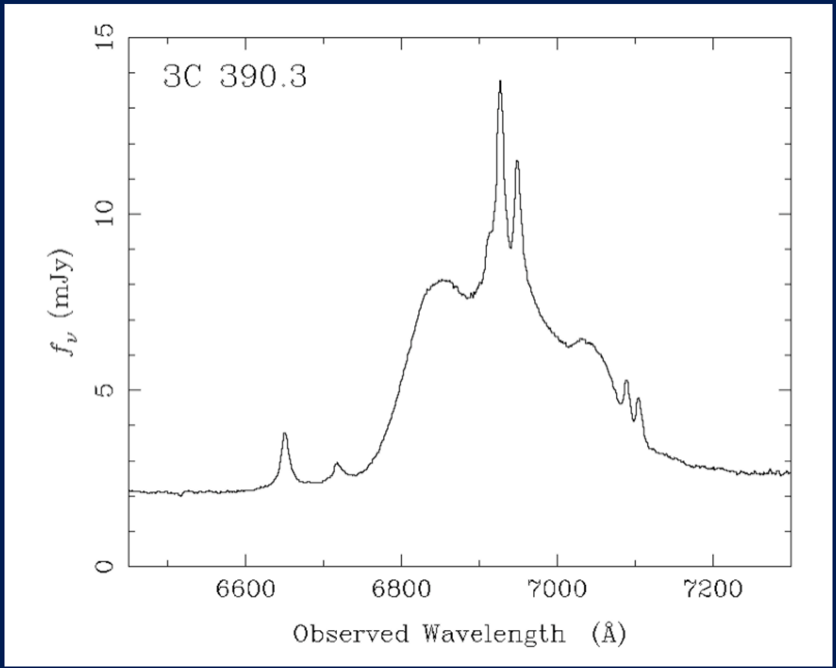
Double-Peaked Balmer Emission Lines

- Reminiscent of disk emission lines in Cataclysmic Variables.
- First observed in Broad Line Radio Galaxies (Arp 102B, 3C 390.3, 3C 332)
- Later found in 20% of z<0.4 BLRGs (Eracleous & Halpern 2003) and 3% of all z<0.3 AGNs in SDSS (Strateva et al. 2003).





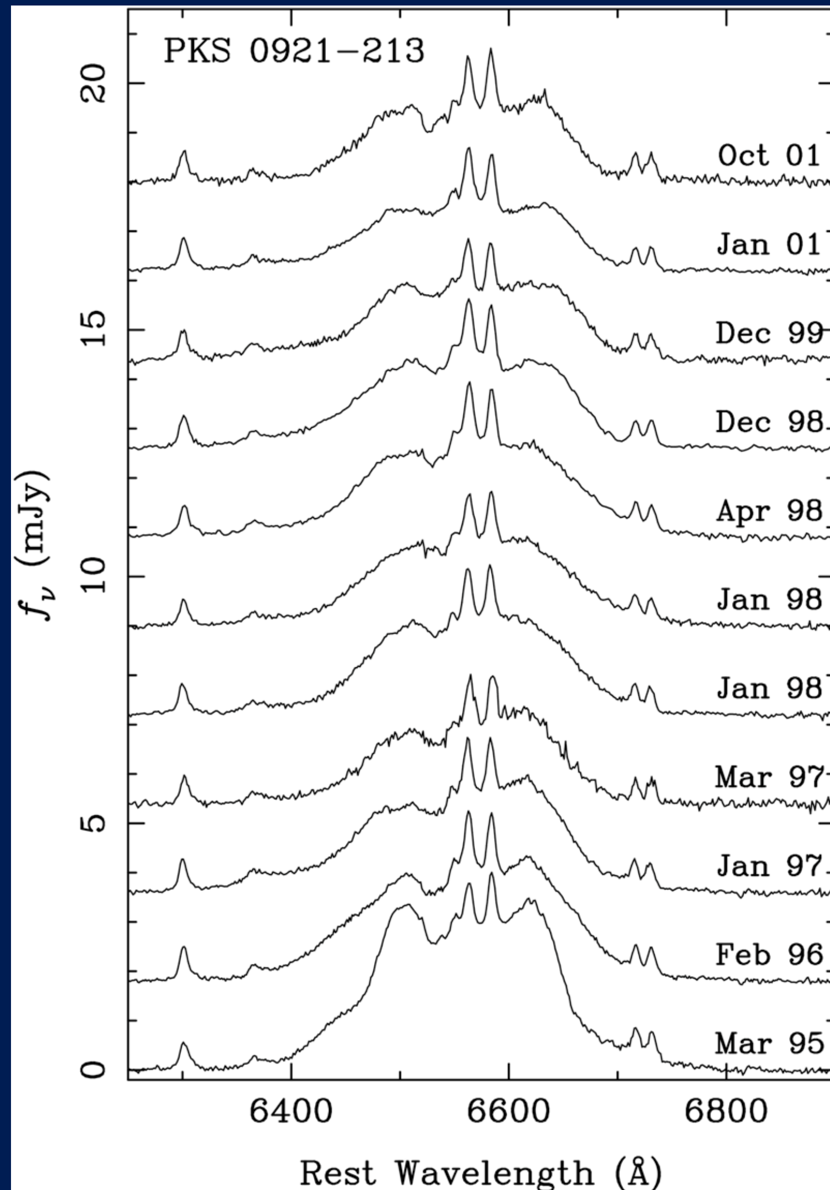
Long-Term Profile Variability

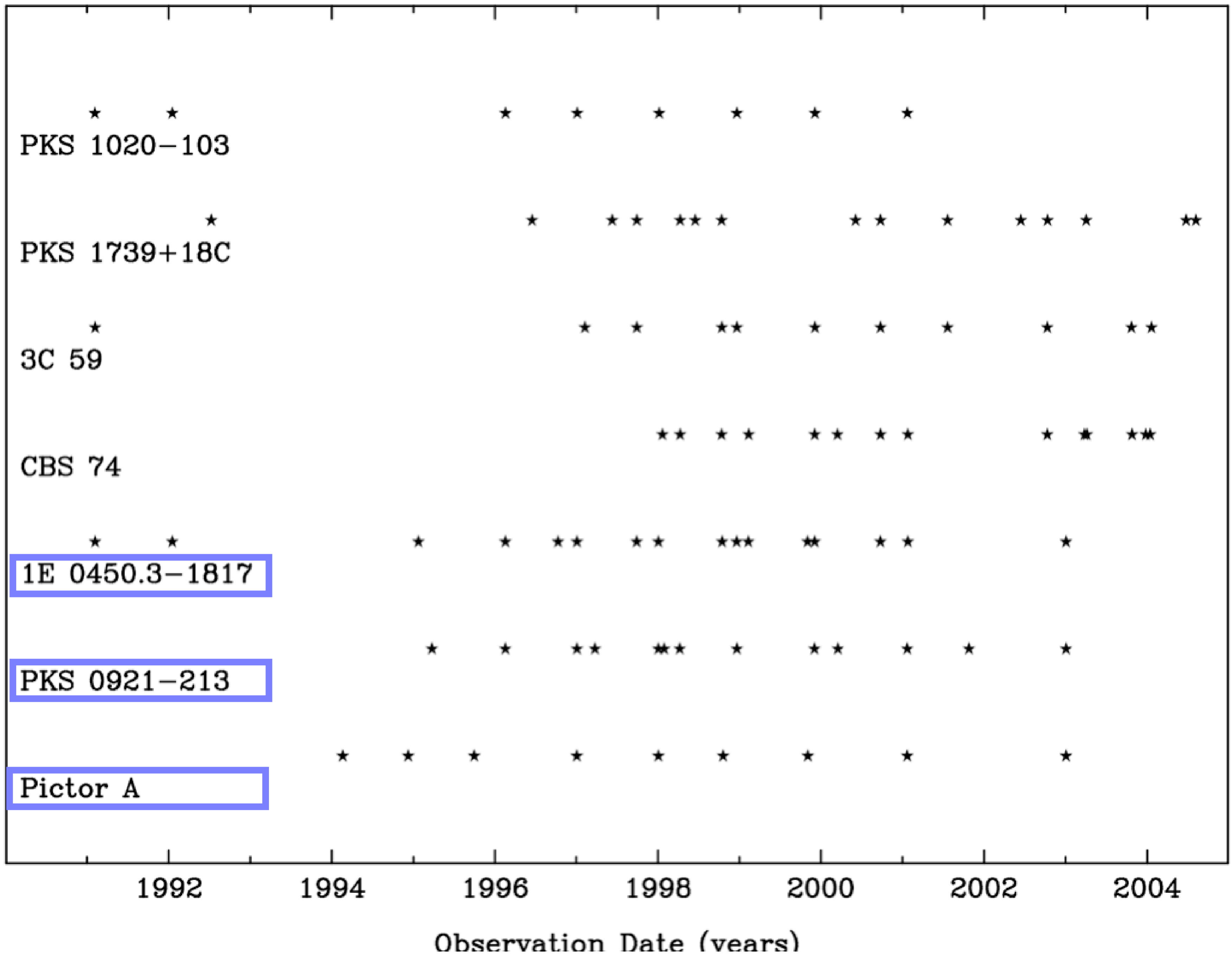
- Profiles vary on timescales of years; *this is much longer than the light crossing time.*

⇒ Variability due to changes in disk structure.

- Disk not axisymmetric!

⇒ Long-term variations probe disk structure.



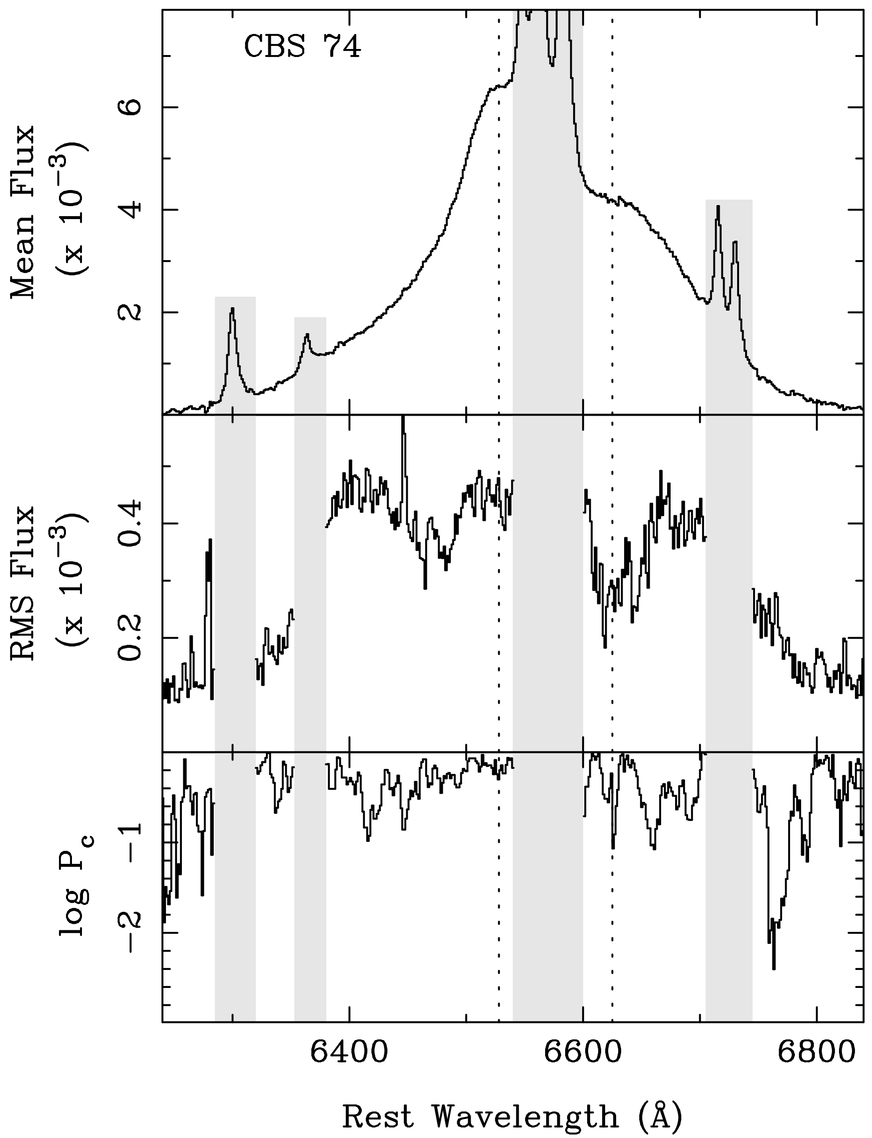


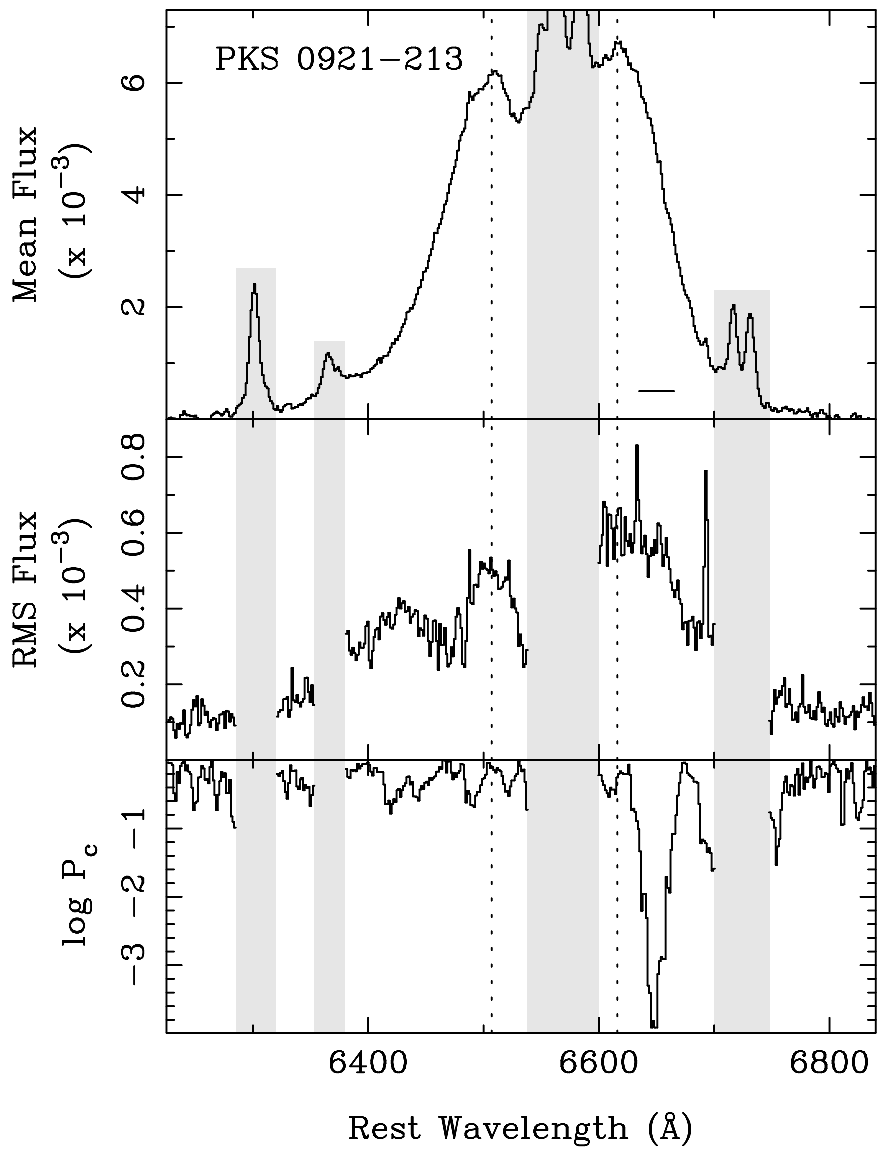
PKS 1020−103
PKS 1739+18C
3C 59
CBS 74
1E 0450.3−1817
PKS 0921−213
Pictor A
1992
1994
1996
1998
2000
2002
2004
Observation Date (years)

Model Independent Characterization

- 1st step is to characterize the data, without reference to any particular model.
  - ✓ What trends are most common?
  - ✓ Common (physical) timescales?
  - ✓ Can any existing models be excluded?
- Current models represent simplest extensions to a circular disk; this characterization will suggest, and be a benchmark for, future models.

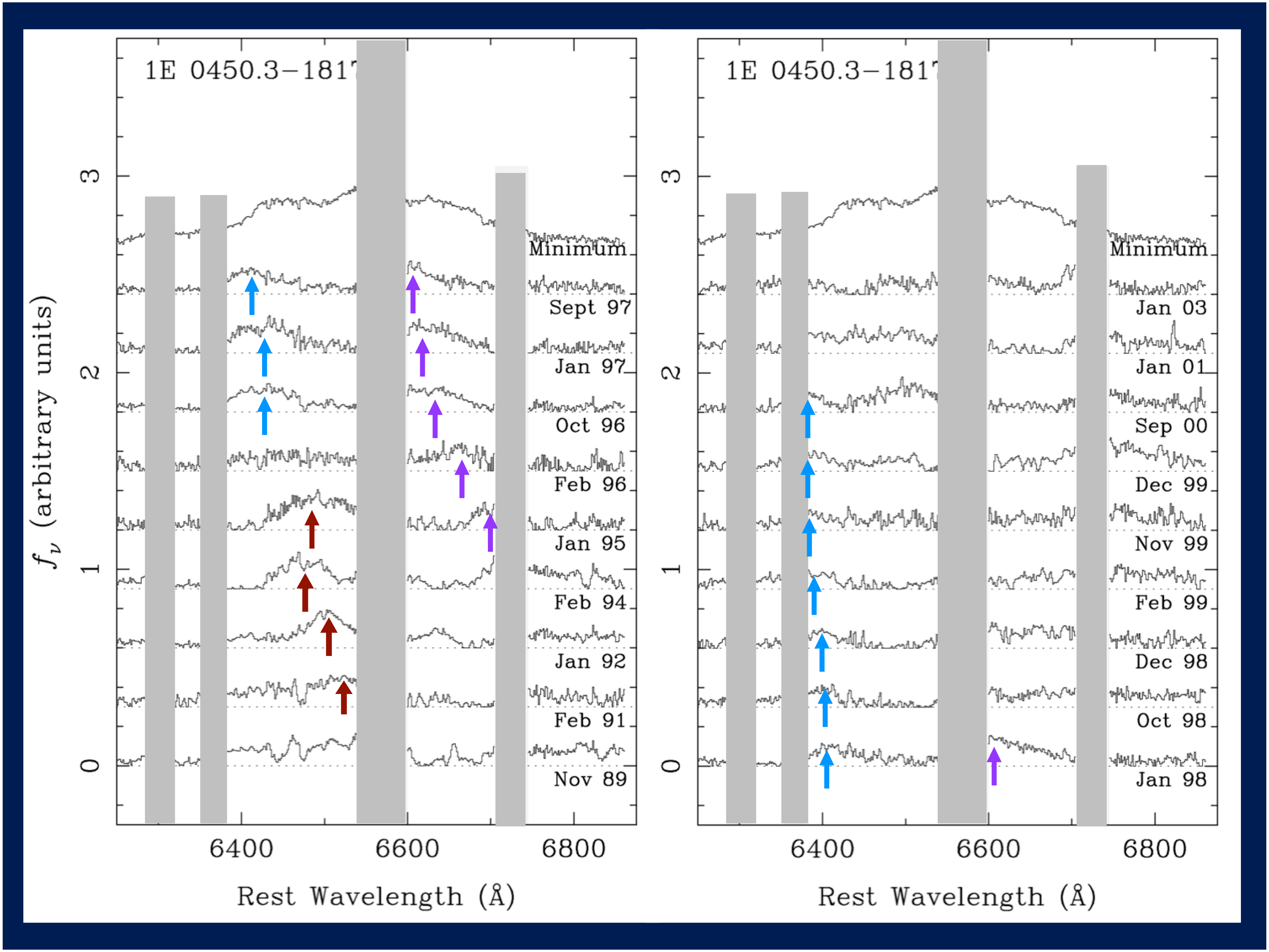
RMS and Correlation Plots





Characterization: Difference Spectra

- Construct average and "minimum" spectra for each object and subtract these from each individual spectrum.
- Minimum spectrum represents a "base" profile that is common to all of the spectra.
- If variability is due to excess emission (spiral arm, bright spot) it will show up clearly.



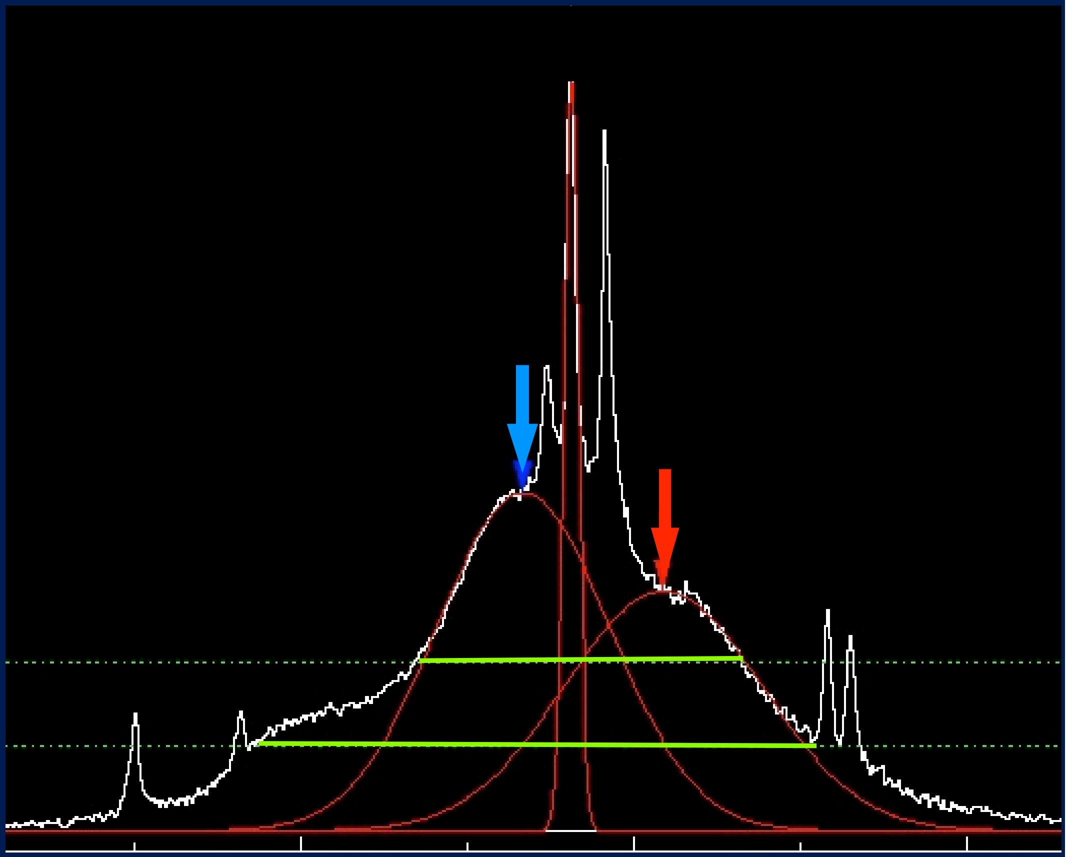
1E 0450.3−1817
1E 0450.3−1817
f_ν (arbitrary units)
Minimum
Sept 97
Jan 97
Oct 96
Feb 96
Jan 95
Feb 94
Jan 92
Feb 91
Nov 89
Minimum
Jan 03
Jan 01
Sep 00
Dec 99
Nov 99
Feb 99
Dec 98
Oct 98
Jan 98
0
1
2
3
6400
6600
6800
Rest Wavelength (Å)
Rest Wavelength (Å)

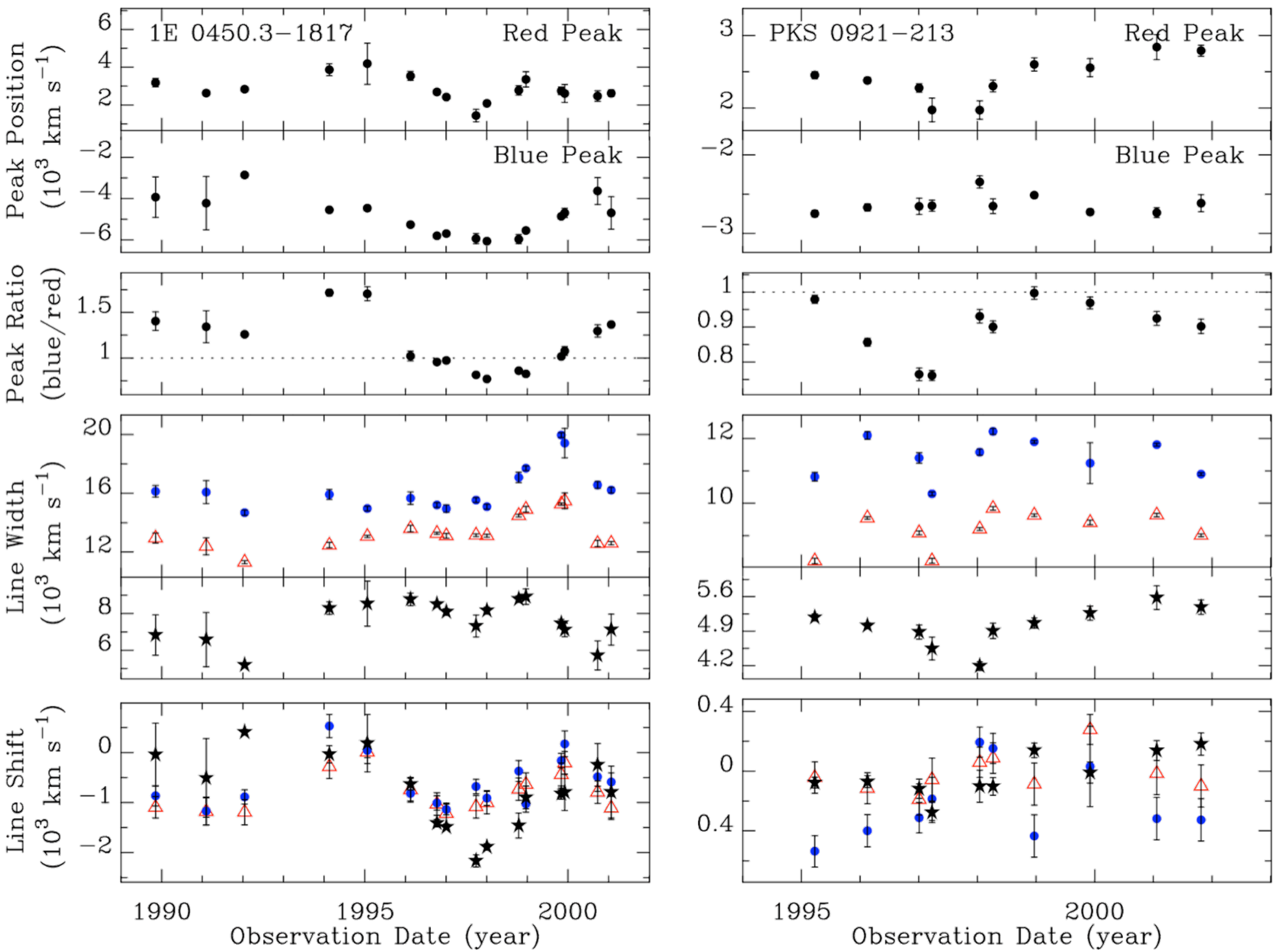
What Does a Lump in the Profile Represent?

- Lumps cannot be bright spots that orbit in the disk.
- Some observations made within a few months (similar to the dynamical timescale), and lumps did not drift significantly.
- Lumps are probably associated with a place in the disk (such as a standing shock that gradually drifts) and not a particular parcel of gas. Fragmented Spiral Arm?

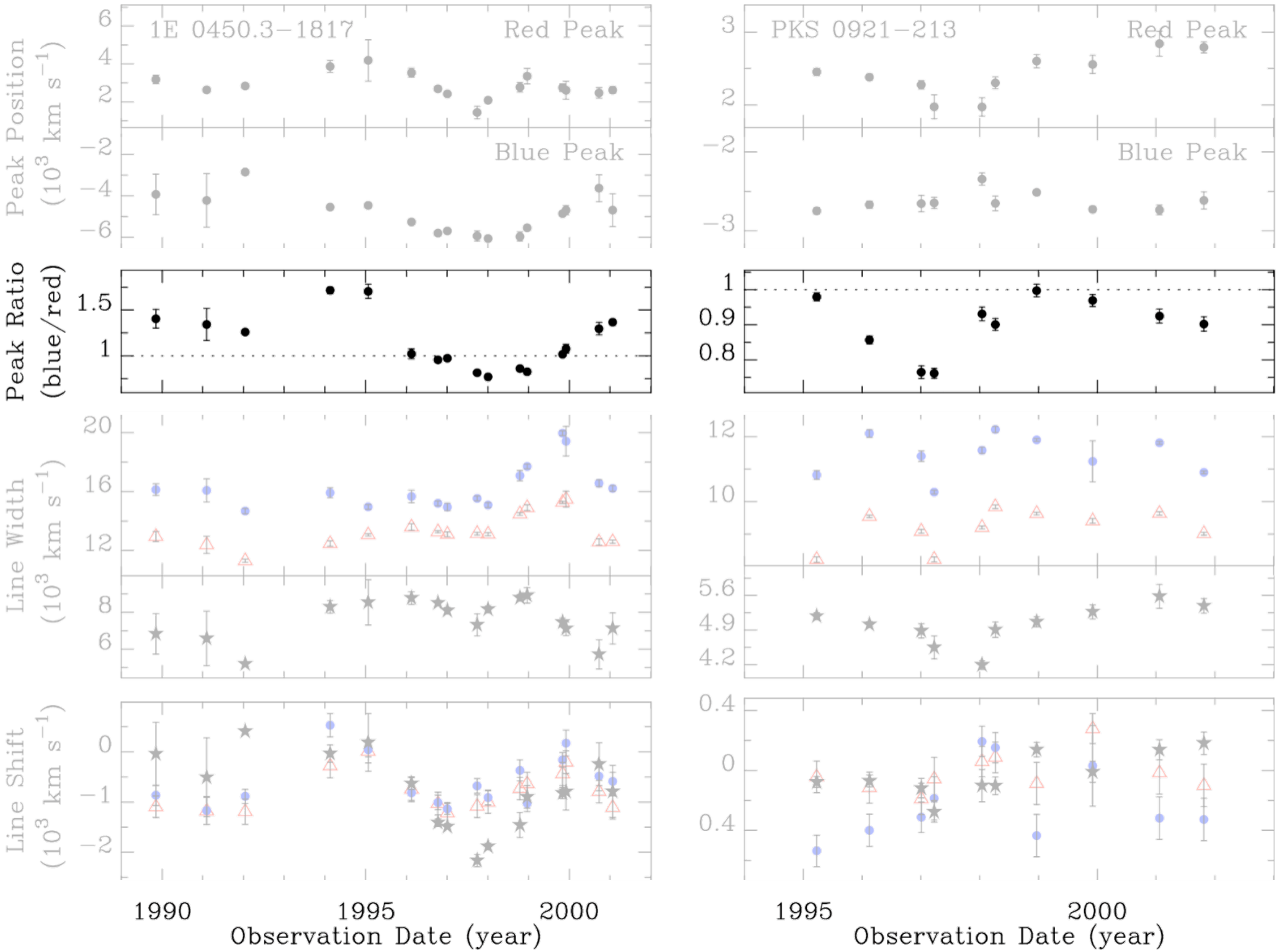
Characterization:
Profile Parameters

- ✓ Peak Velocities
- ✓ Blue/red peak flux
- ✓ Separation of peaks and FWHM/FWQM
- ✓ Velocity shift of the profile centroid at peaks, HM and QM





1E 0450.3−1817
PKS 0921−213
Red Peak
Blue Peak
Peak Position
(10^3 km s^−1)
Peak Ratio
(blue/red)
Line Width
(10^3 km s^−1)
Line Shift
(10^3 km s^−1)
Observation Date (year)
Observation Date (year)

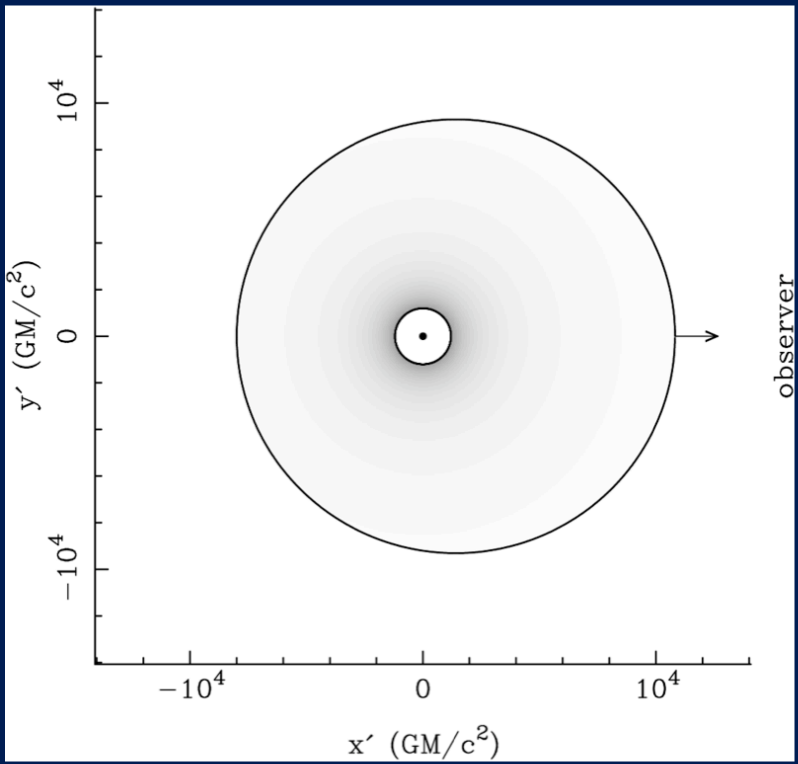

1E 0450.3−1817
PKS 0921−213
Red Peak
Blue Peak
Peak Position (10^3 km s^{-1})
Peak Ratio (blue/red)
Line Width (10^3 km s^{-1})
Line Shift (10^3 km s^{-1})
Observation Date (year)
1990
1995
2000

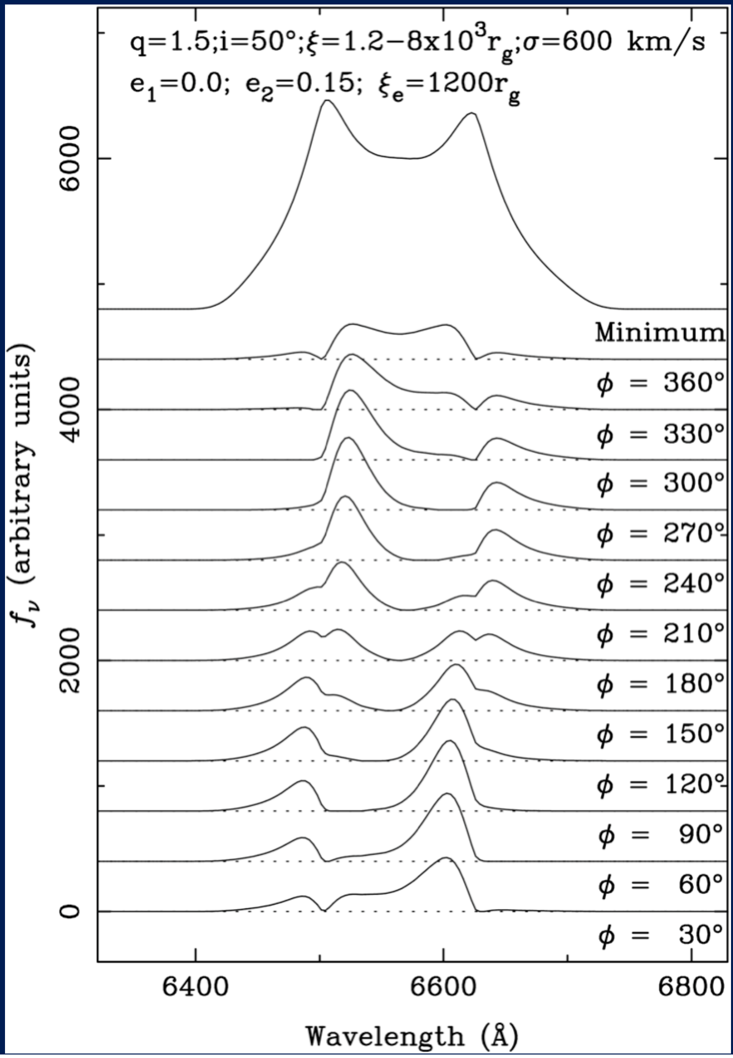
Comparison with Simple Models

- Elliptical Accretion Disk
  - ✓ Forms through perturbation by a massive object or tidal disruption of a star.
  - ✓ The latter inspired by the sudden appearance of double-peaked lines in some objects.
- One-Armed Spiral
  - ✓ Circular accretion disk with a one-armed spiral emissivity pattern.
  - ✓ Can arise in the self-gravitating outer disk or by perturbation by a massive object.
  - ✓ Provides way to shed angular momentum

Common Trends: Elliptical

- Multiple lumps of emission at most times.
- Profile parameters vary smoothly, symmetrically, and in concert.





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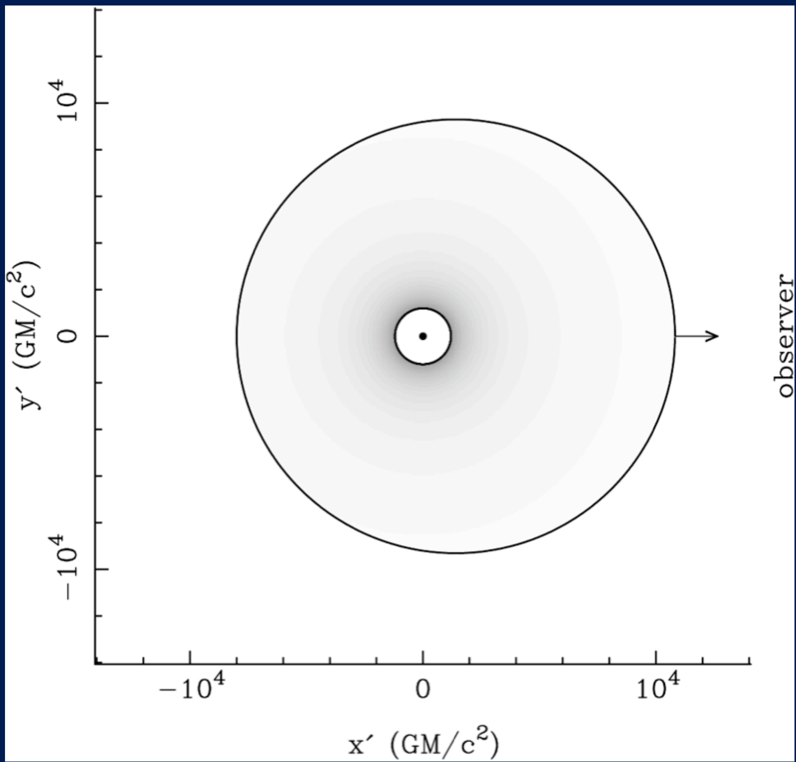
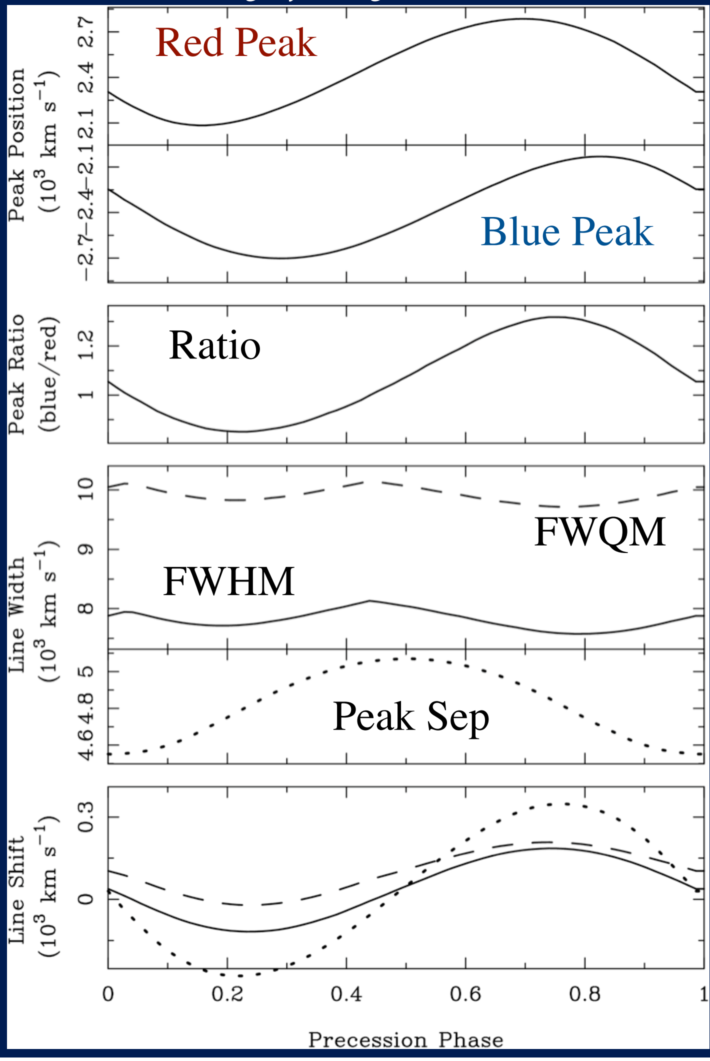
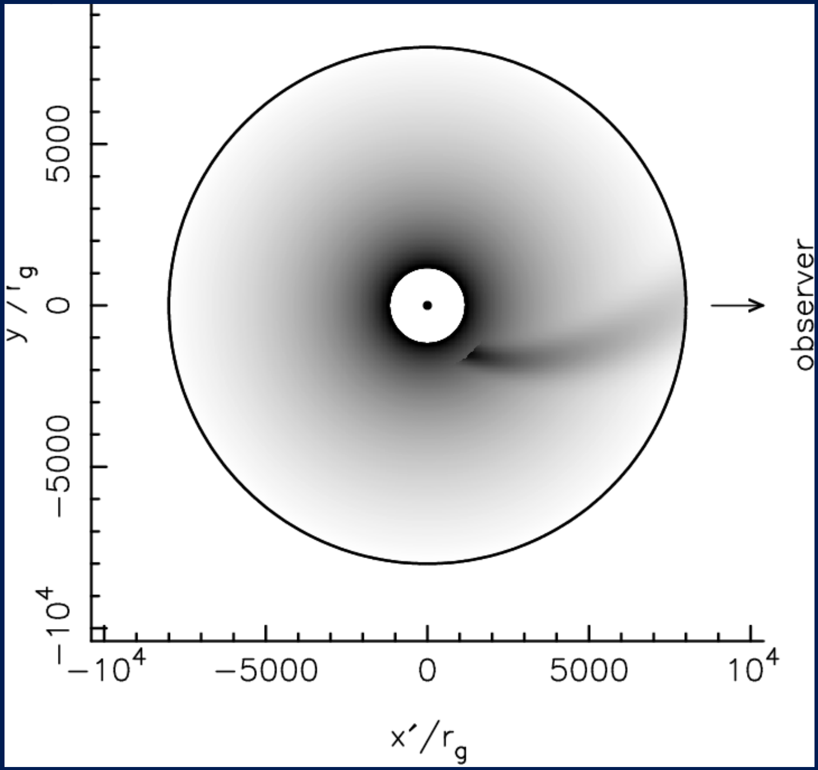
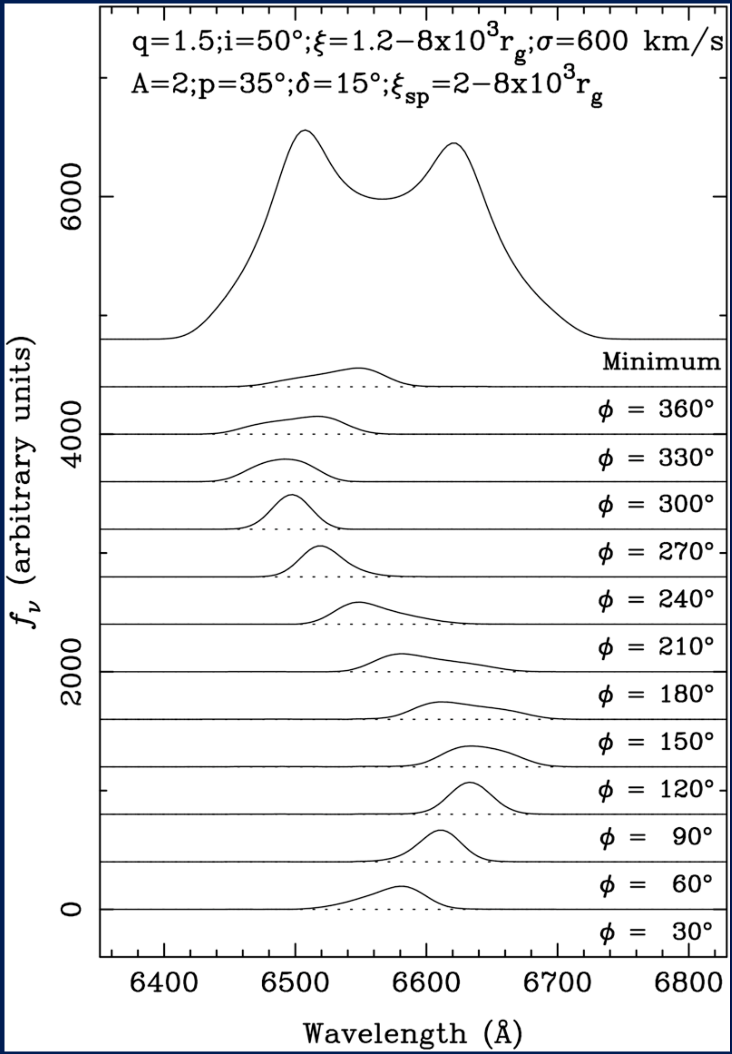




Common Trends: Spiral

- Multiple lumps of emission difficult to obtain
- Variations in profile parameters more complex, less smooth and symmetric.





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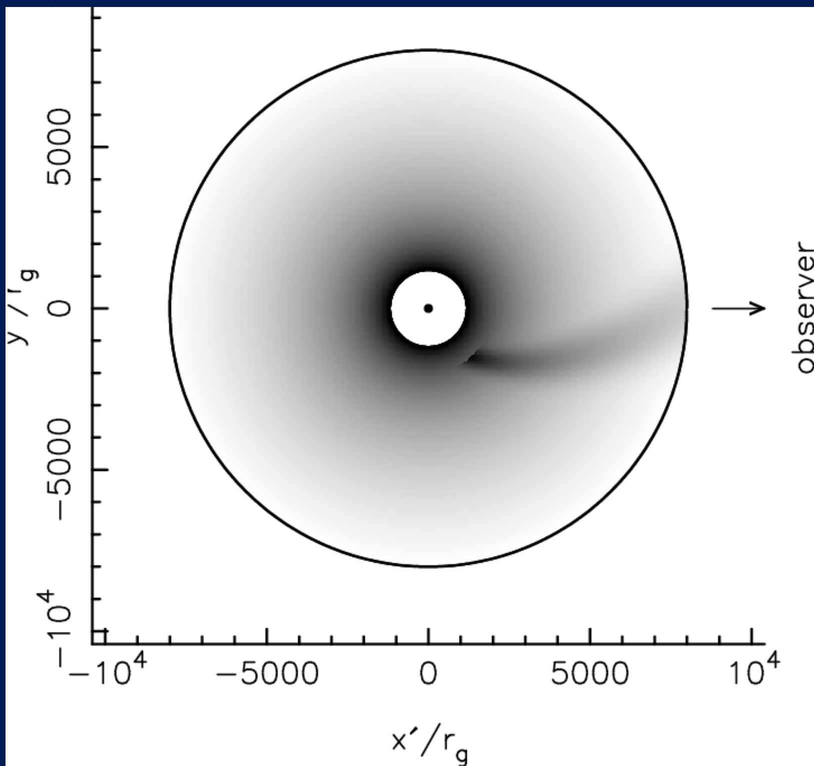
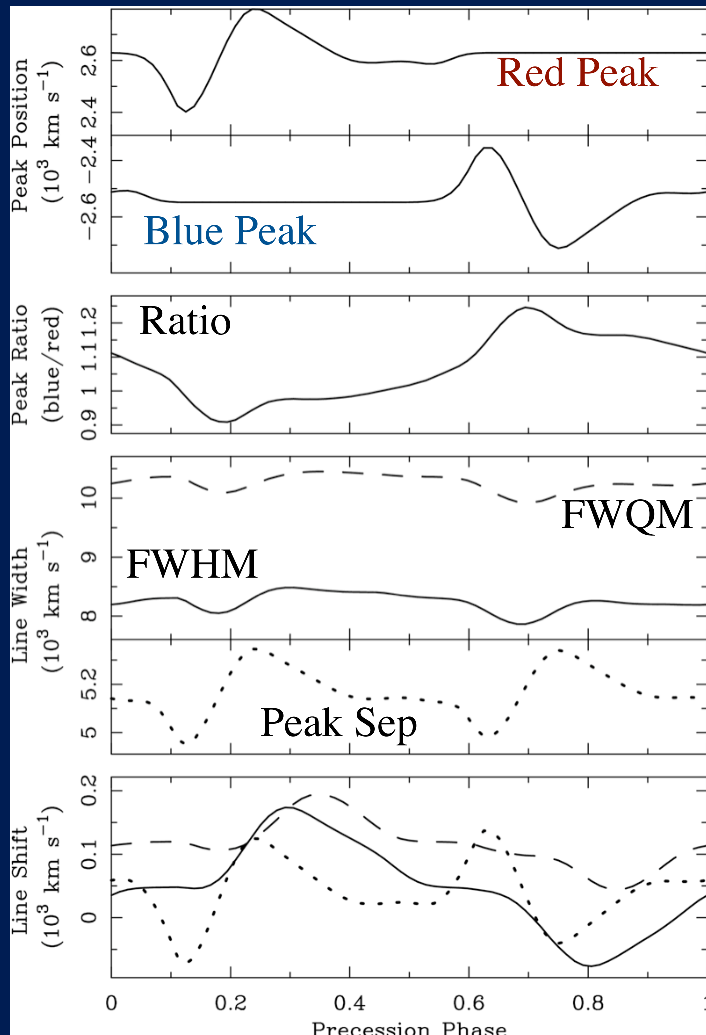




Variability Timescales

- Both of these models lead to profile variability due to precession.
- Three objects in my study have known black hole masses ($\sim 4 \times 10^7\ M_\odot$). Lewis & Eracleous 2006
  - ✓ Spiral arm: order of magnitude longer than dynamical timescale, up to sound crossing time -> ~3–30 years.
  - ✓ Elliptical disk: 100s of years!
- Elliptical disk model can be ruled out for many objects, and seems unlikely to be generally applicable.

Much more has been been done . . . and much more is to come!

- See the poster by Helene Flohic!
  "Interpreting the variability of double-peaked emission lines using models for accretion disk structures"
- Talk to Suvi Gezari, who worked on seven other double-peaked emitters, esp. 3C 390.3, Arp 102B, and 3C 332!
- Watch out for papers by Suvi Gezari and Karen Lewis!

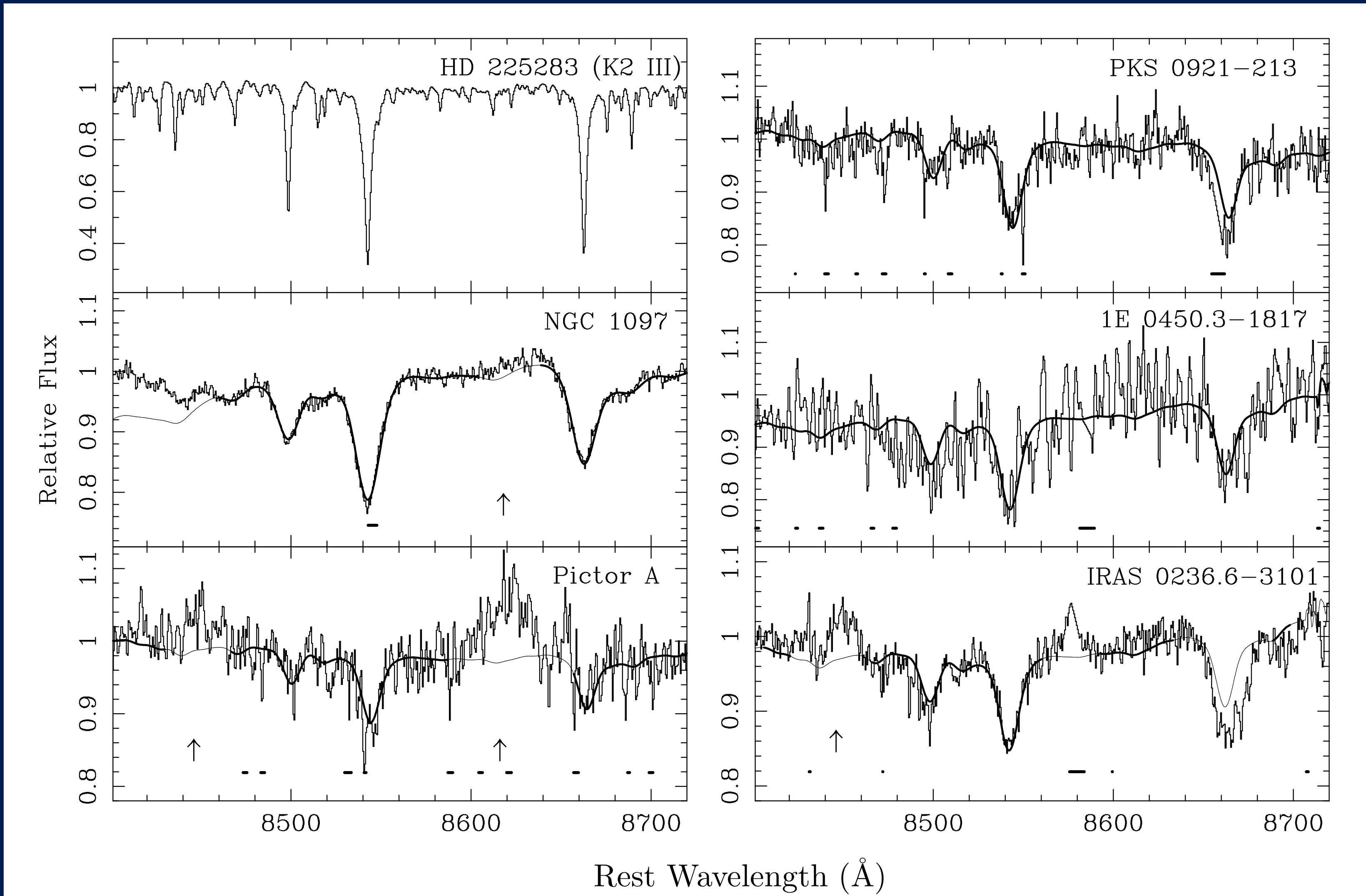
Future Work

- Dynamical timescale shorter than expected, some objects should be monitored more frequently to determine whether variability takes place on this timescale.
- Test fragmented spiral arm model (with observations and with simulations)
- Many models to test! This model-independent characterization offers a way to quickly assess the viability of any model.
- Determine more black hole masses via M–σ

Conclusions

- Profile variability is very common and comprises lumps of excess emission that change in amplitude, position etc.
- Modulation of peak flux ratio is most obvious variation, but other properties vary as well.
- Elliptical disk model not generally applicable (wrong timescale and variability patterns)
- A fragmented spiral arm might produce better agreement with the observations.

Model Fits



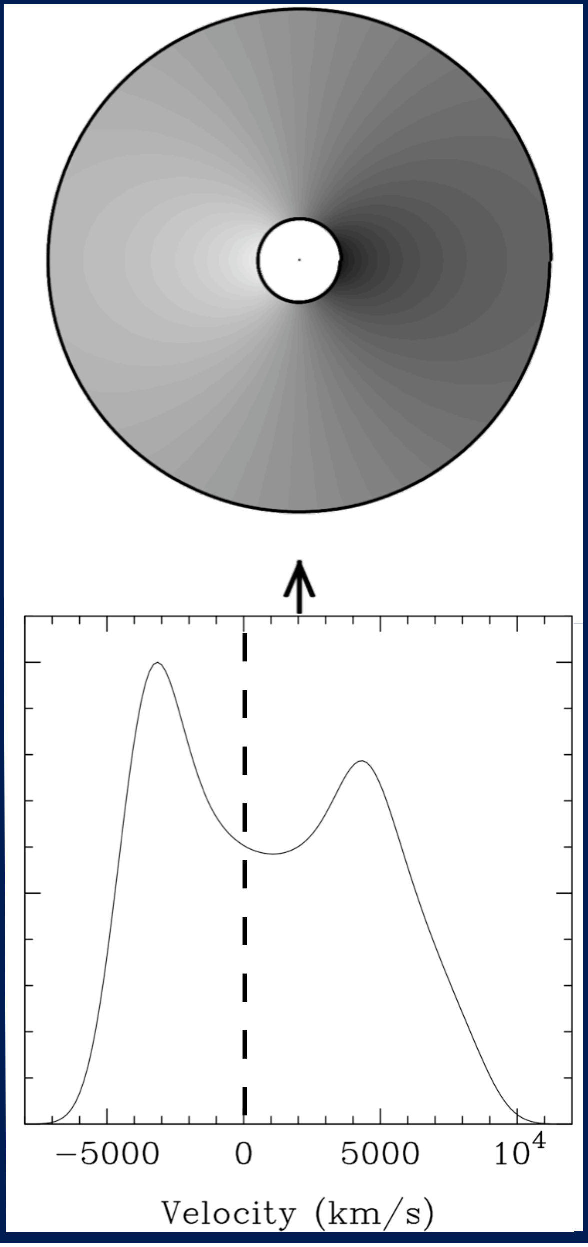
$$M(\lambda;f,\sigma) = f \times S(\lambda) \otimes G(\lambda;\sigma) + P(\lambda)$$

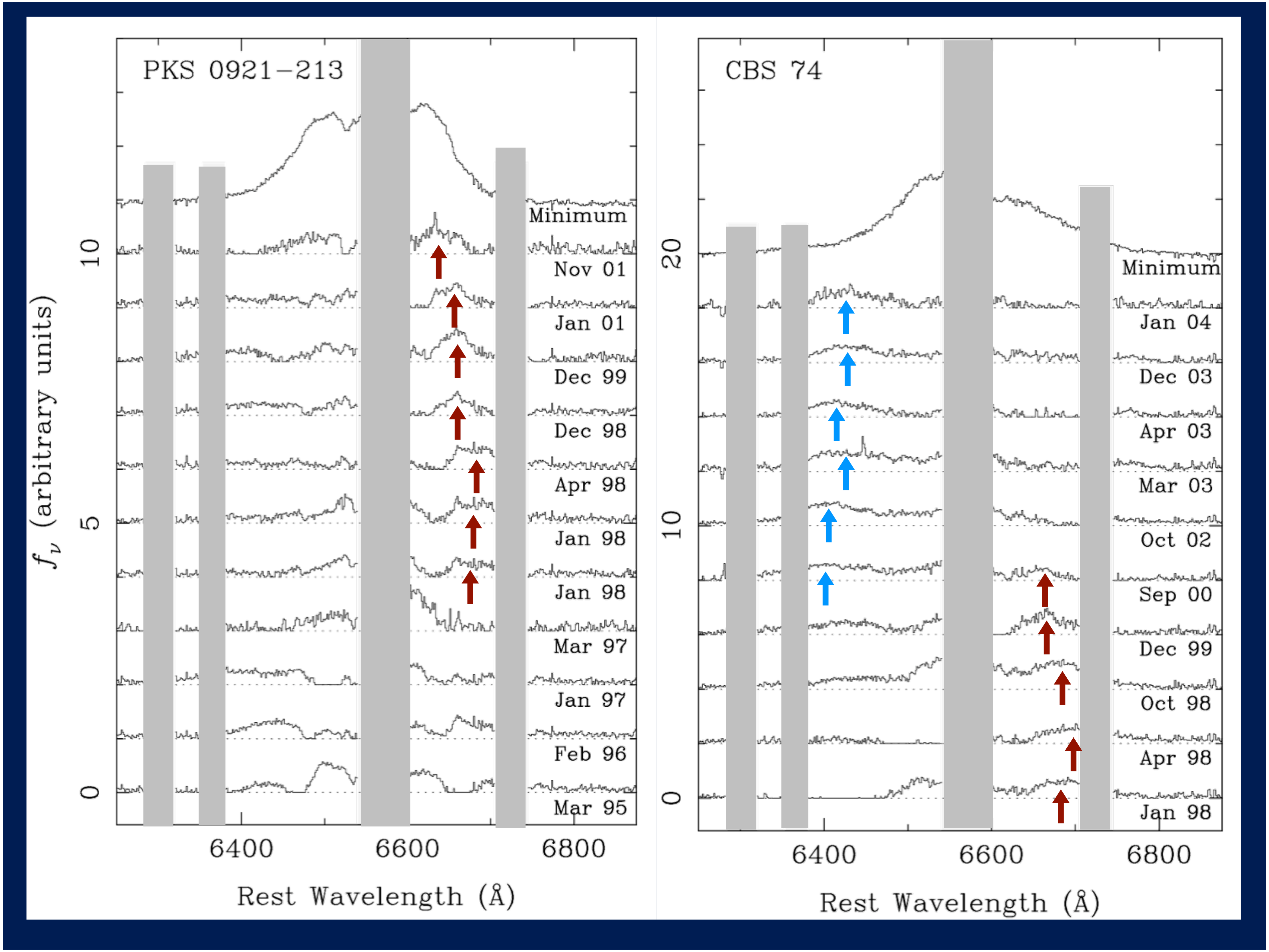
Formation of Double-Peaked Lines

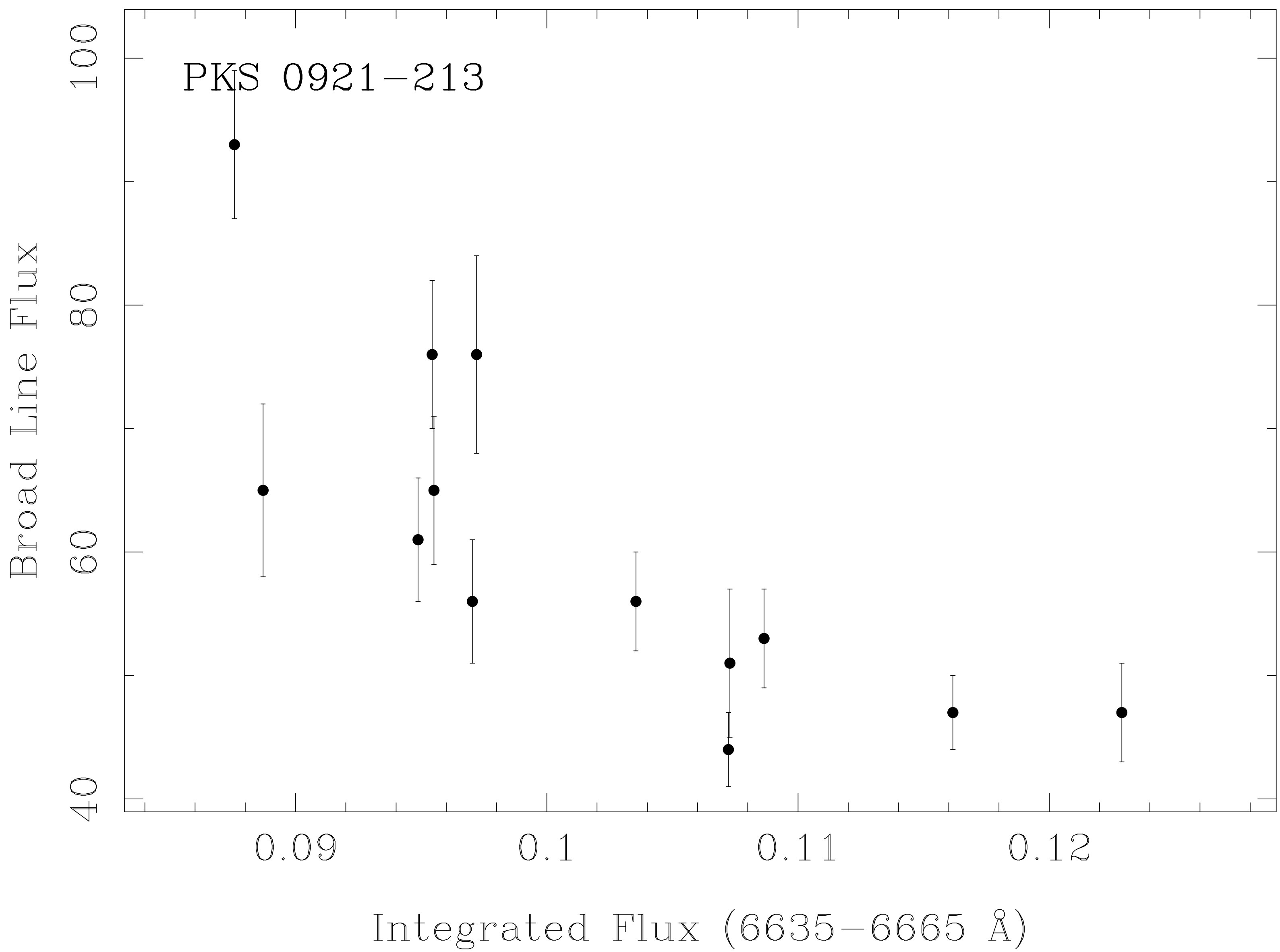
- Line forms at distances of a few 10^2 – a few 10^3 r_g

$$r_g = GM_{BH}/c^2$$

- General and special relativistic effects distort the line profile.
  - ✓ Doppler boosting of the blue peak
  - ✓ redshifting of entire line profile
  - ✓ red wing becomes distorted

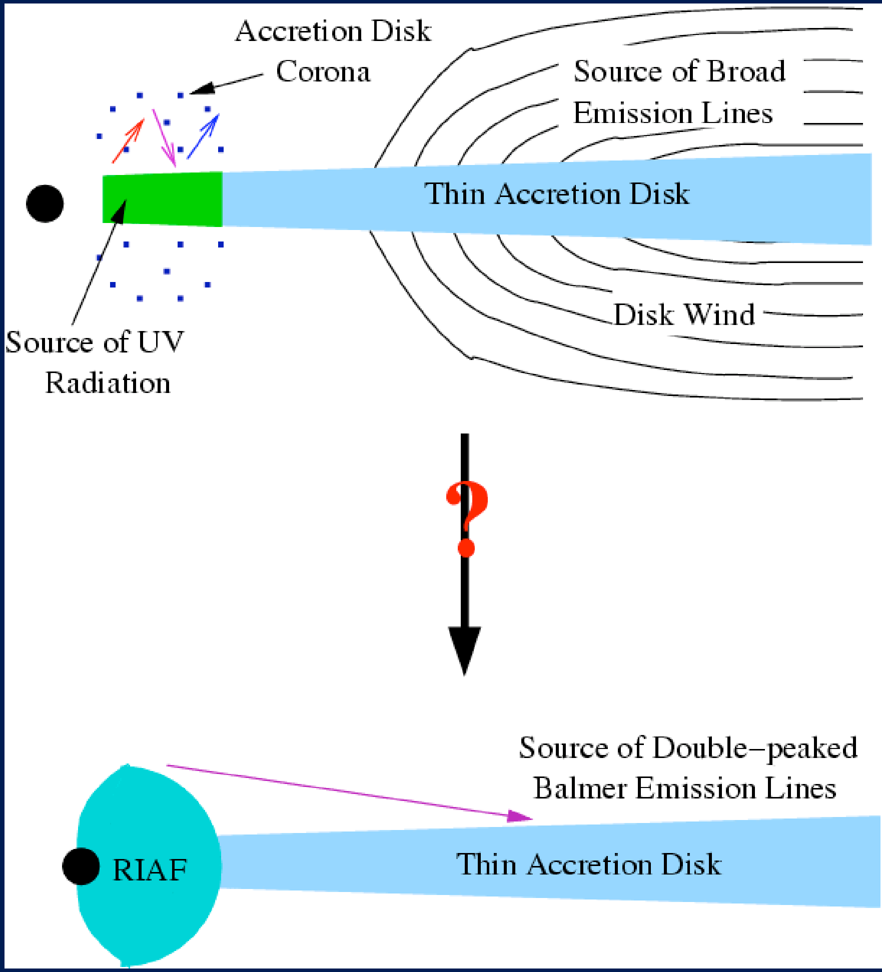


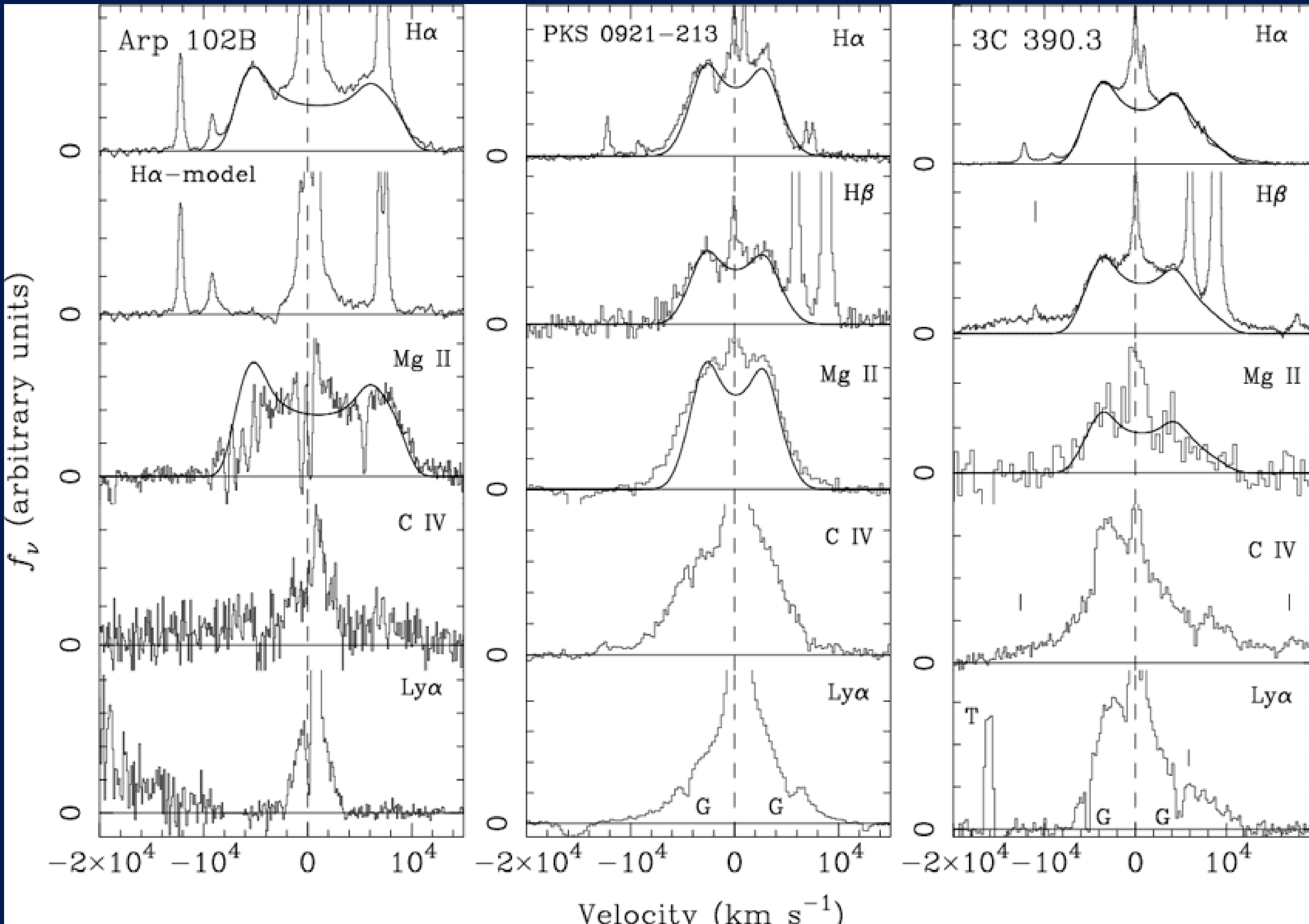

PKS 0921−213
CBS 74
Minimum
Nov 01
Jan 01
Dec 99
Dec 98
Apr 98
Jan 98
Jan 98
Mar 97
Jan 97
Feb 96
Mar 95
Jan 04
Dec 03
Apr 03
Mar 03
Oct 02
Sep 00
Dec 99
Oct 98
Apr 98
Jan 98
f_ν (arbitrary units)
Rest Wavelength (Å)
6400
6600
6800
0
5
10
20


PKS 0921−213
Broad Line Flux
40
60
80
100
0.09
0.1
0.11
0.12
Integrated Flux (6635−6665 Å)

Why are These Lines so Rare?

- Wind effectively masks the disk.
- Do double-peaked emitters have a "stripped down" disk?
- I need to remake this slide! Will show some UV stuff on next slide.
- I will leave this for end if I have time.



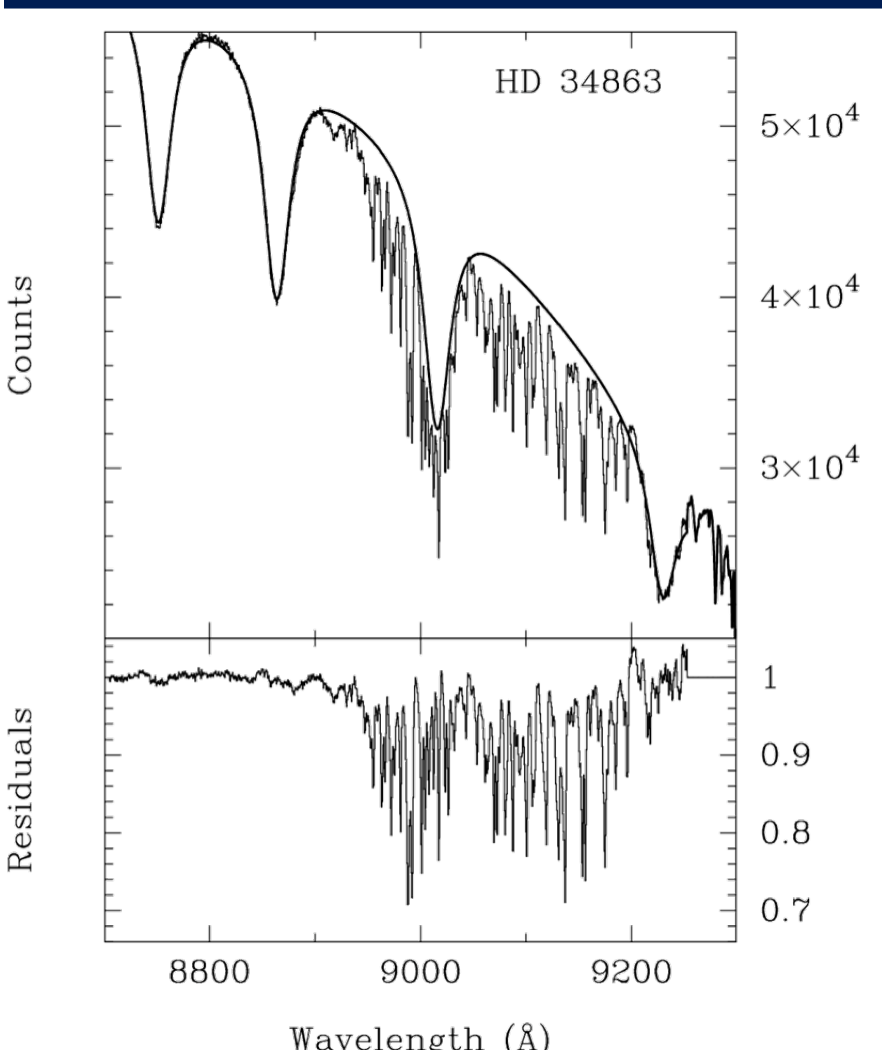


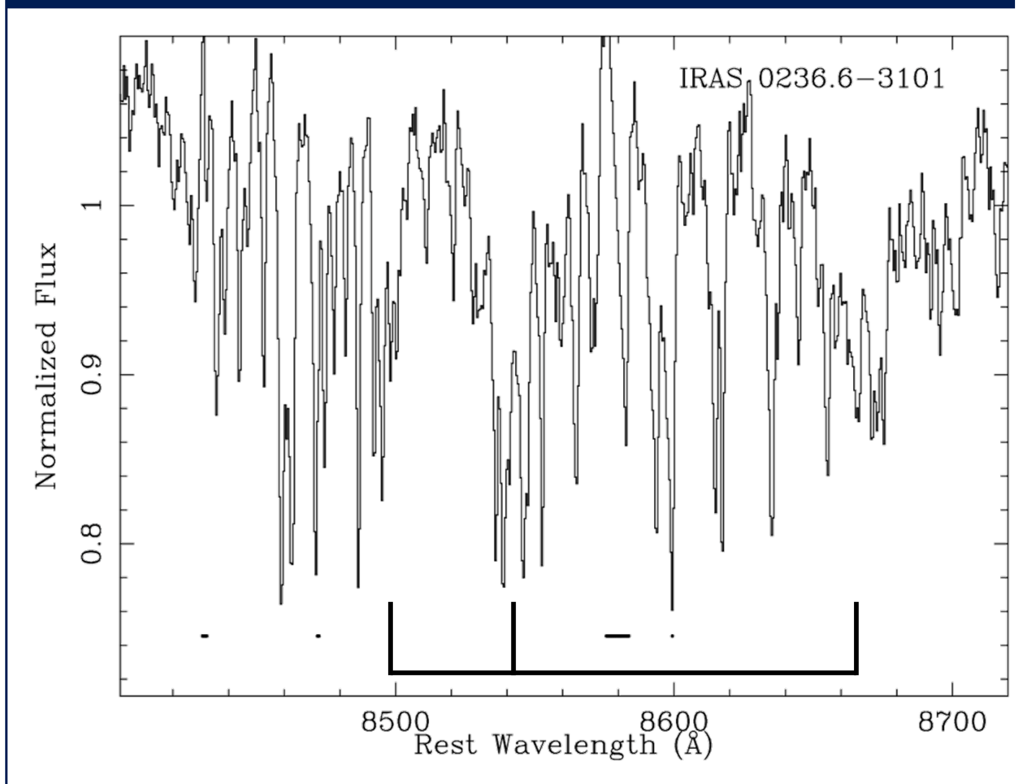
Arp 102B
Hα
Hα−model
Mg II
C IV
Lyα
PKS 0921−213
Hα
Hβ
Mg II
C IV
Lyα
G
G
3C 390.3
Hα
Hβ
Mg II
C IV
Lyα
T
G
G
f_ν (arbitrary units)
Velocity (km s^{-1})

Why is it Important to Study Double-peaked Emitters?

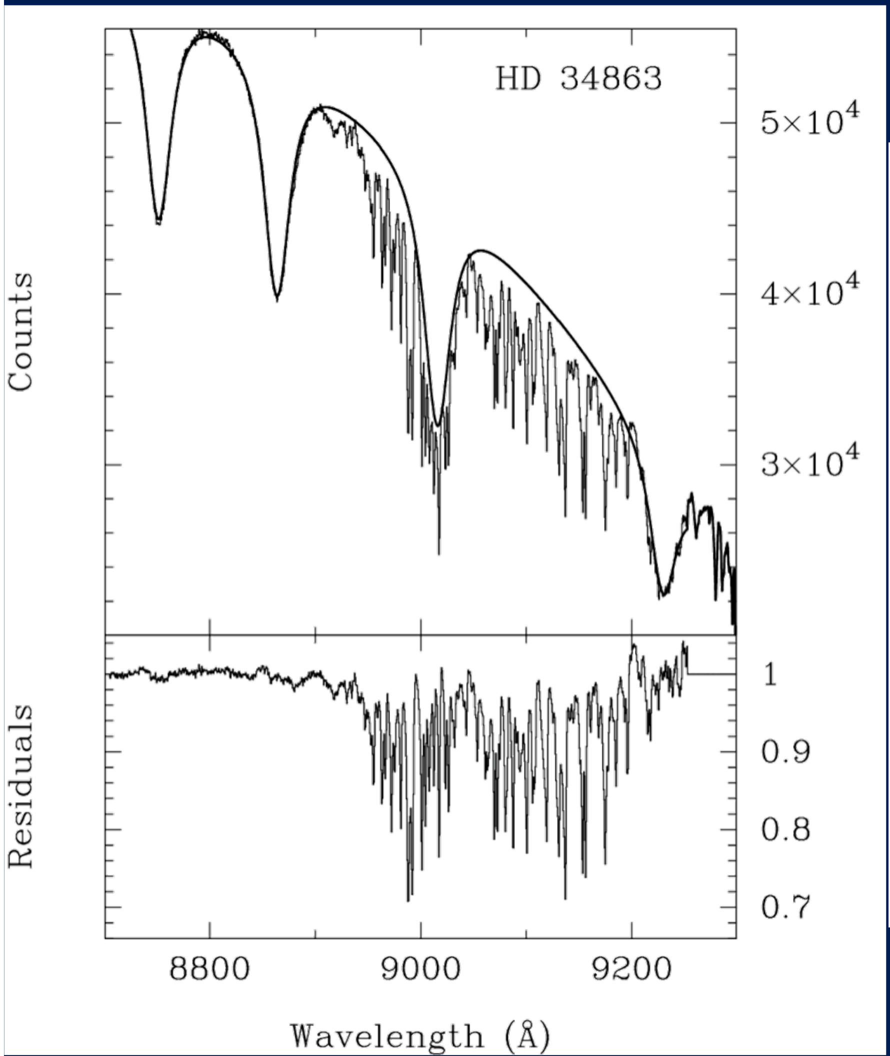
- Disk probably contributes to broad lines in most AGNs, but it's not obvious.
- Studying extreme objects is a good way to test universal theories of AGN broad line regions.
- Many AGNs exhibit profile variability on similar timescales $\Rightarrow$ similar causes?
- Rare systems in which we can observe AGN disk directly $\Rightarrow$ chance to study disk physics.

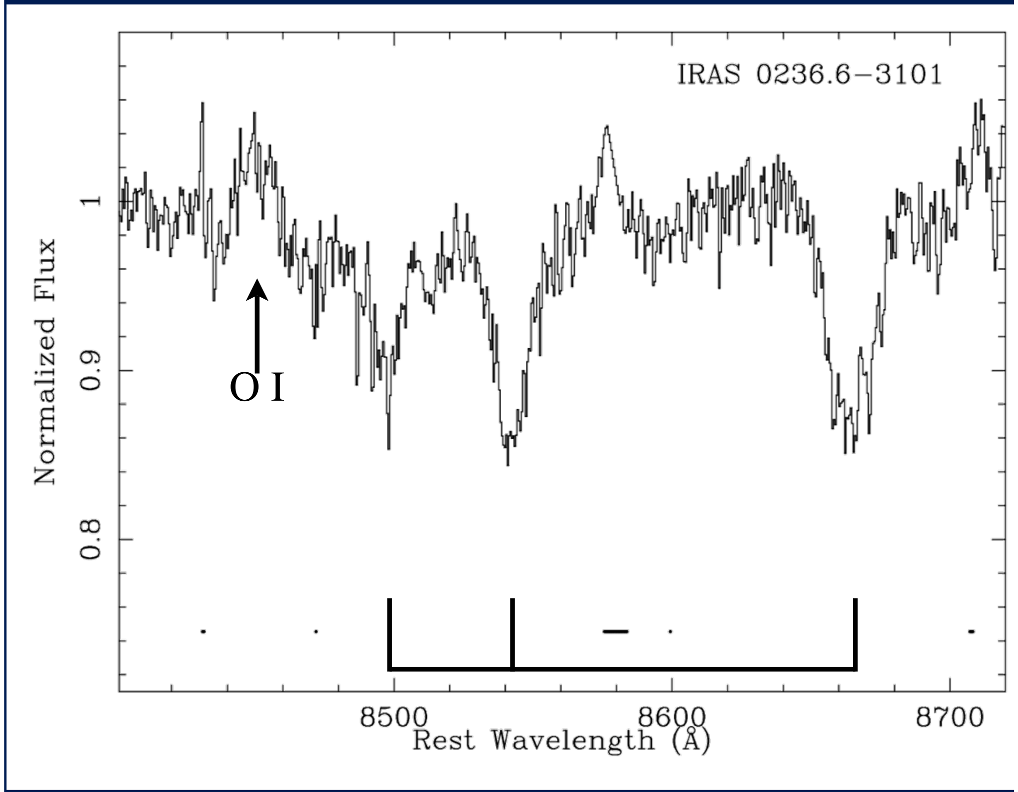
Telluric Correction





Telluric Correction





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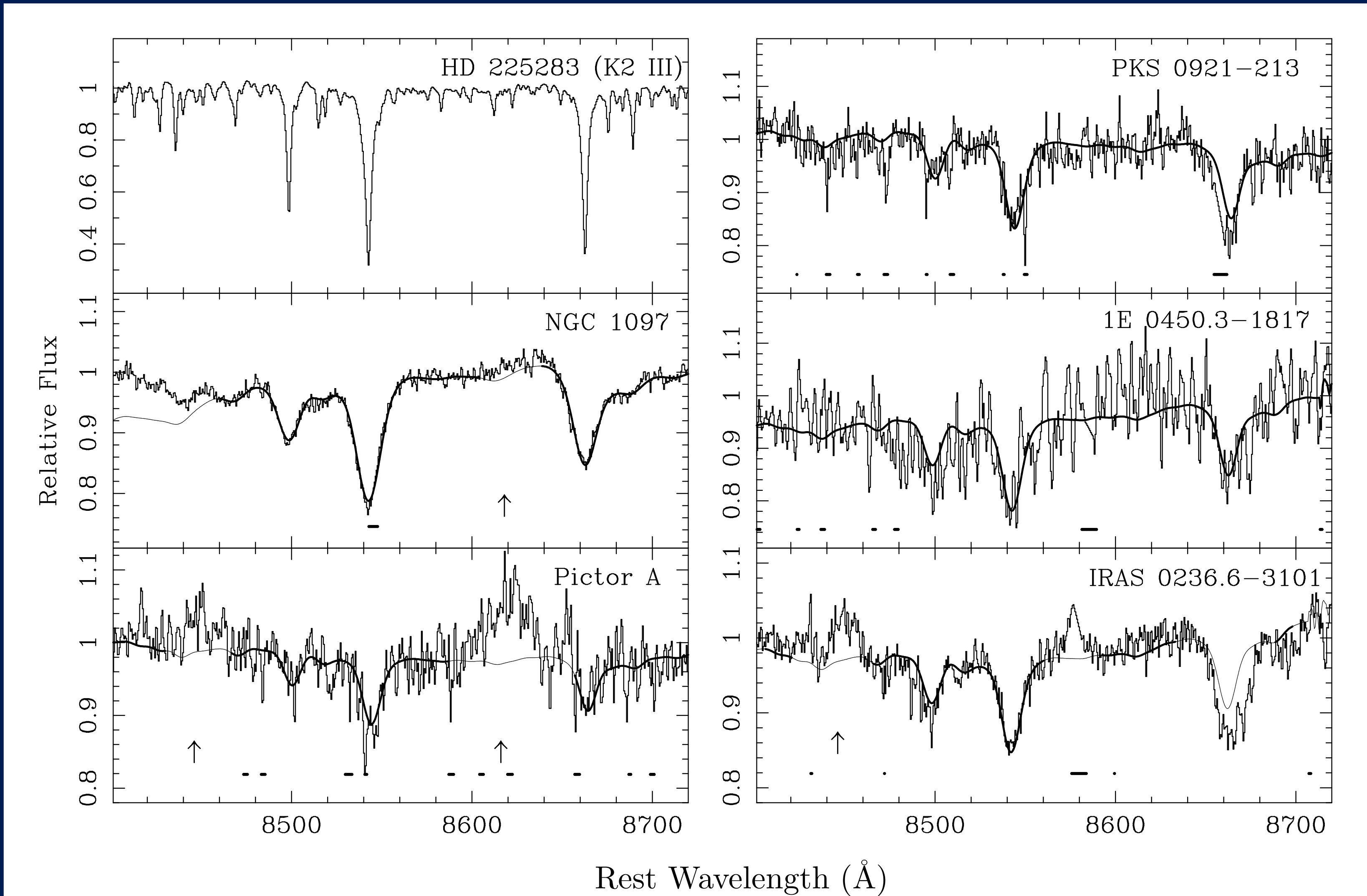

$$M(\lambda;f,\sigma) = f \times S(\lambda) \otimes G(\lambda;\sigma) + P(\lambda)$$

Physical Timescales

There are several relevant physical timescales to consider

$$\text{Dynamical: } \tau_{dyn} \sim 6\, M_8\, \xi_3^{3/2} \text{ months}$$

$$\text{Thermal: } \tau_{th} \sim \tau_{dyn}/\alpha$$

$$\text{Sound Crossing: } \tau_s \sim 70\, M_8\, \xi_3\, T_5^{-1/2} \text{ years}$$

$M_8 = M_\bullet/10^8\, M_\odot$; $\xi_3 = \xi/10^3$ (ξ is the radius in units of $GM_\bullet/c^2$); $\alpha \sim 0.1$ (the viscosity parameter); and $T_5 = T/10^5$K. In constrast the light crossing time is $\tau_l \sim 6\,\xi_3\, M_8$ days.

Mass perturbations orbit over τ_{dyn} *; thermal instabilities dissipate over* τ_{th} *; and density perturbations will precess on time scales of a few* τ_{dyn} *to a few* τ_s *.*