Variability of DPELs in AGNs as probe to the structure of the BLR

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Why care about BLR structure?

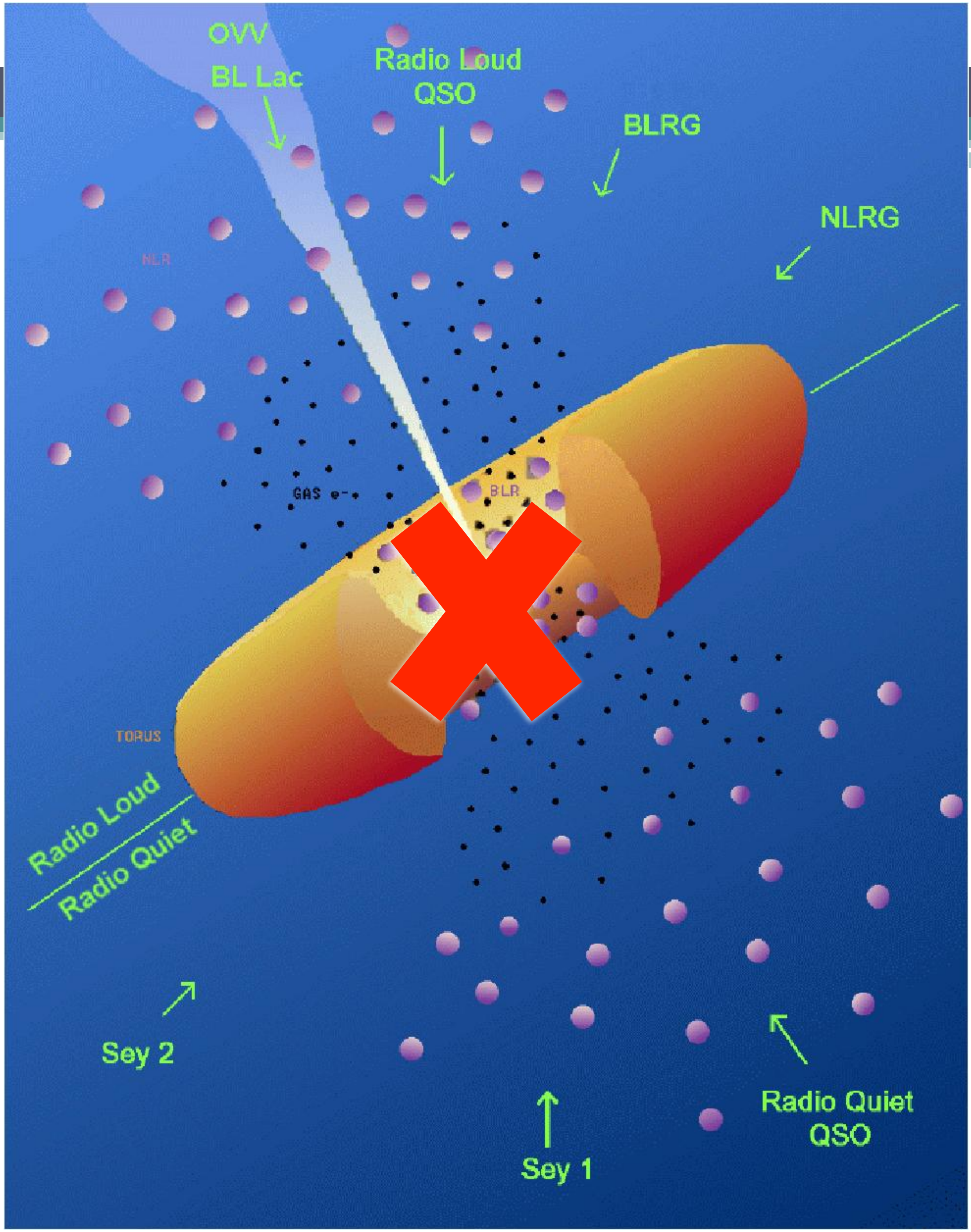
- Used to measure black hole mass:

  Assuming Keplerian motion

$$M_{BH} = f\, R_{BLR}\, v^2$$

  - v = FWHM or line velocity dispersion
  - R obtained from variability delay or empirical relation between R and L
  - f = scaling factor dependent on BLR structure (currently obtained by comparison with other BH mass methods)

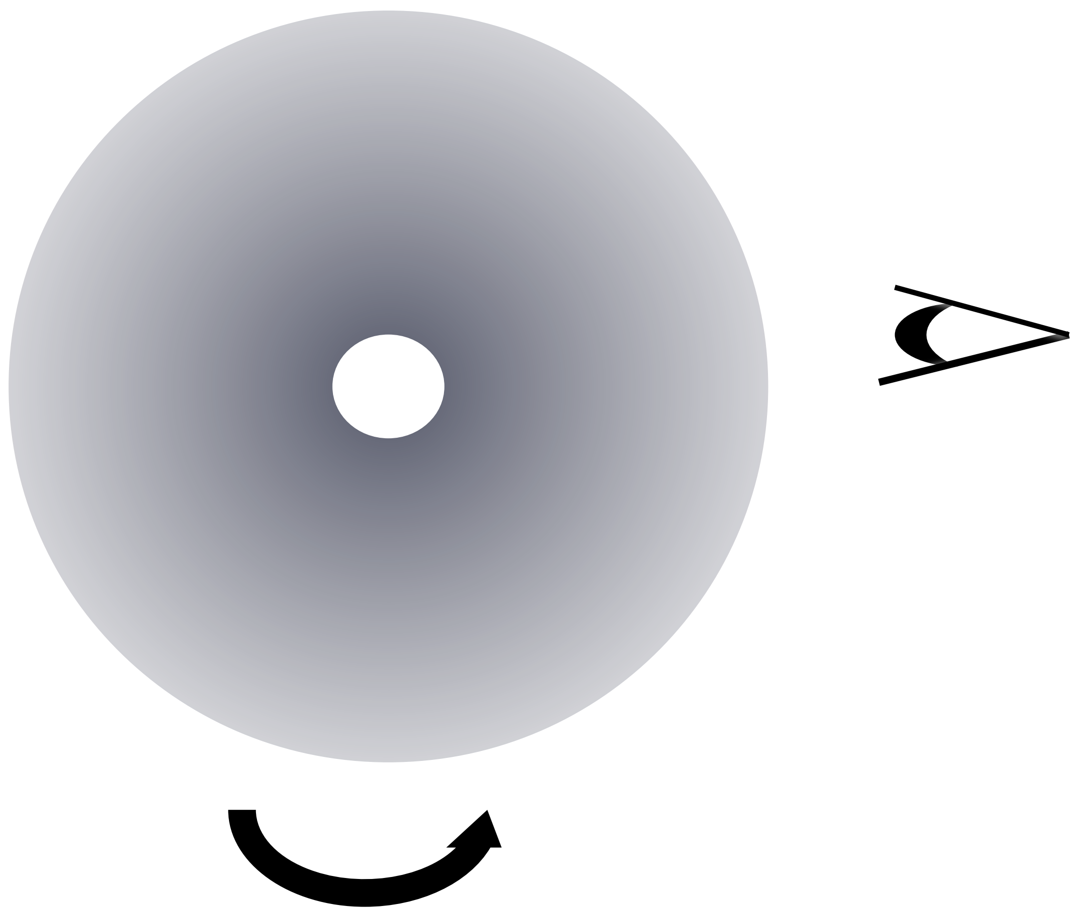
➔ Need to know BLR structure



Urry & Padovani 1995

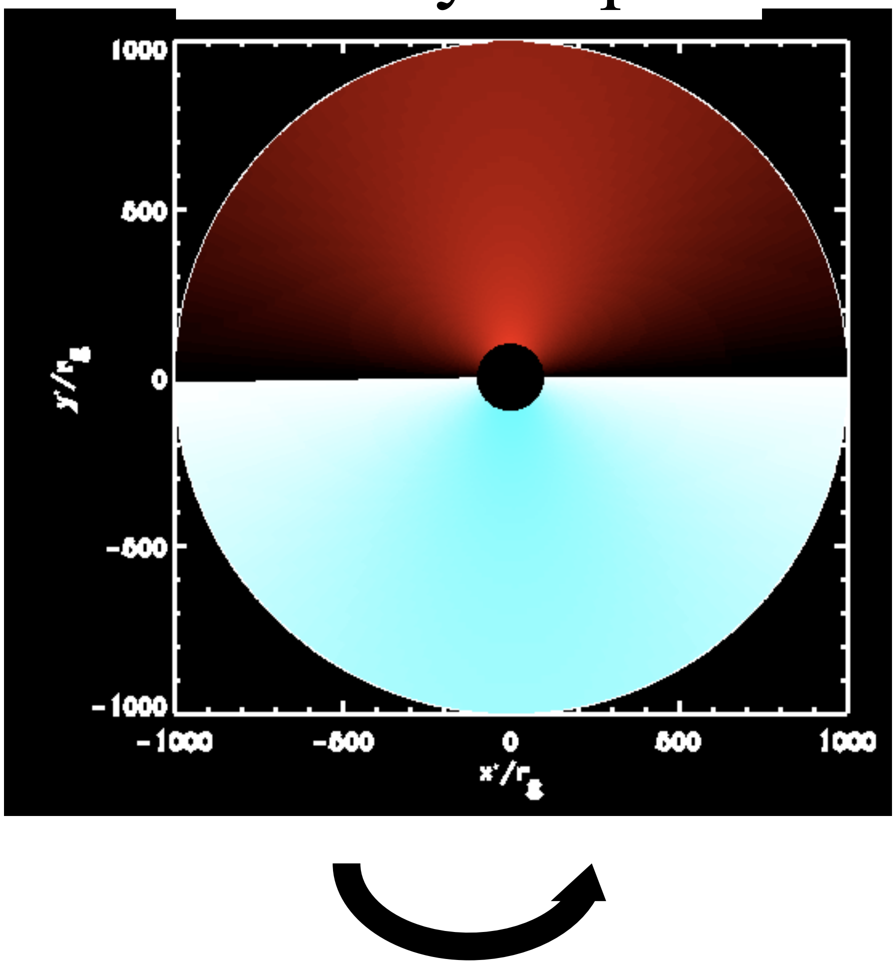
Spectroscopic signature of disk

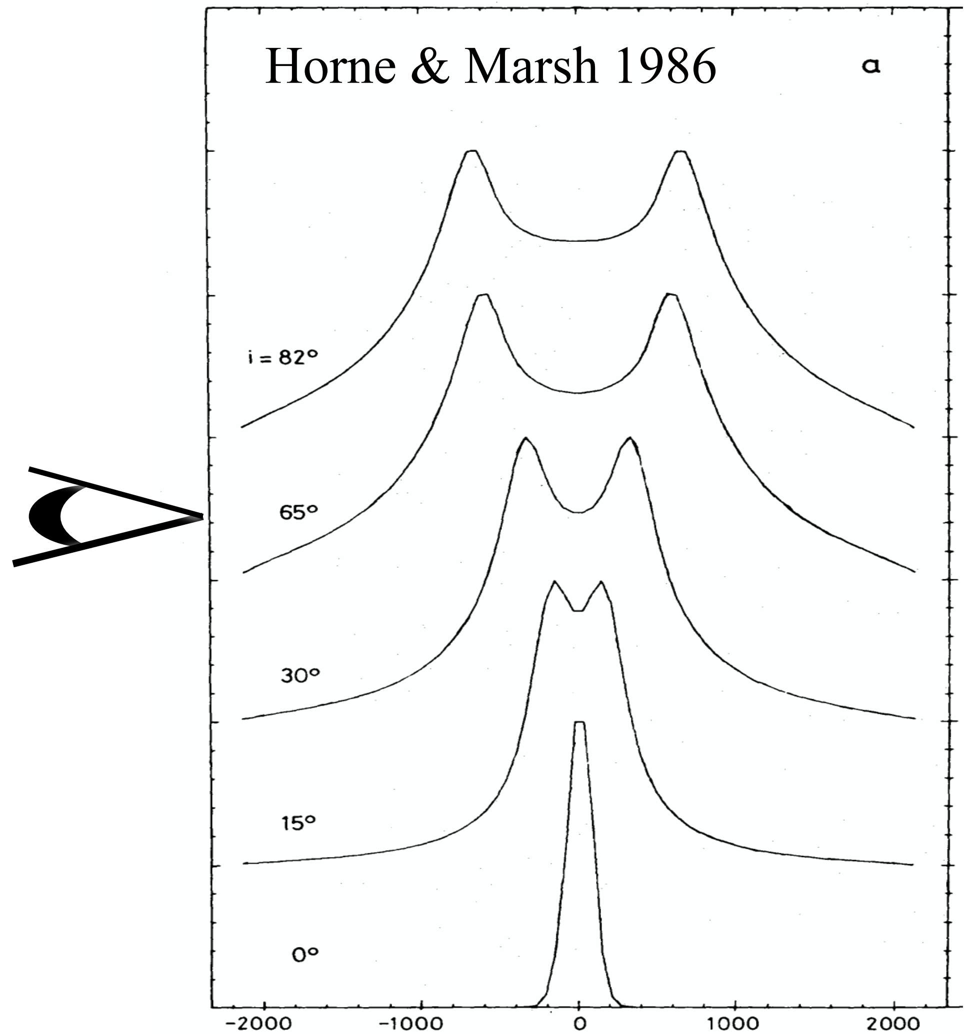
Emissivity map



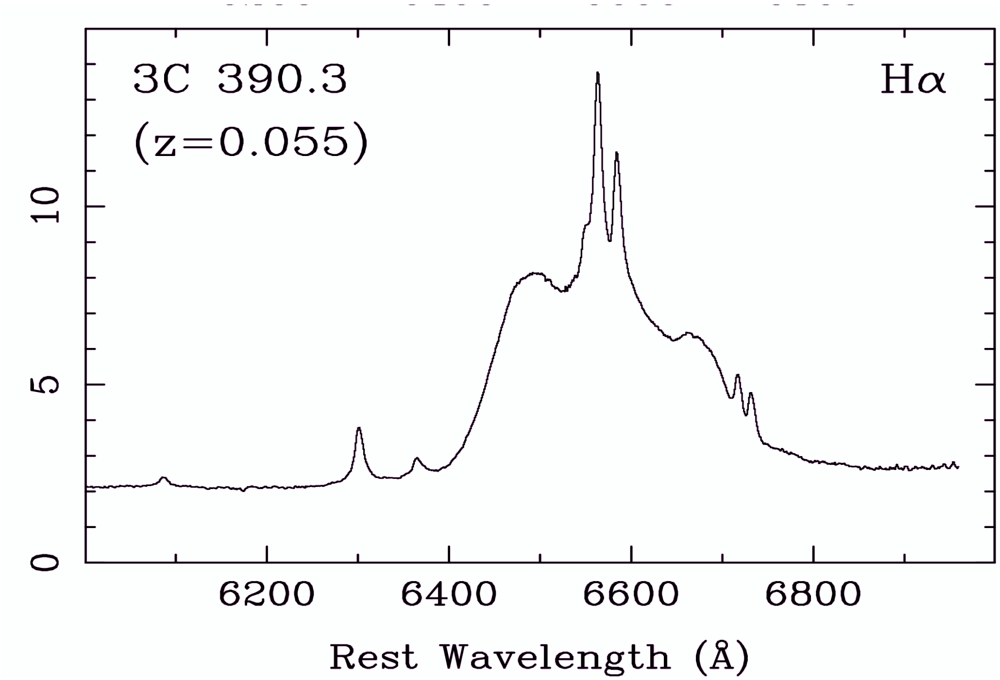
Spectroscopic signature of disk

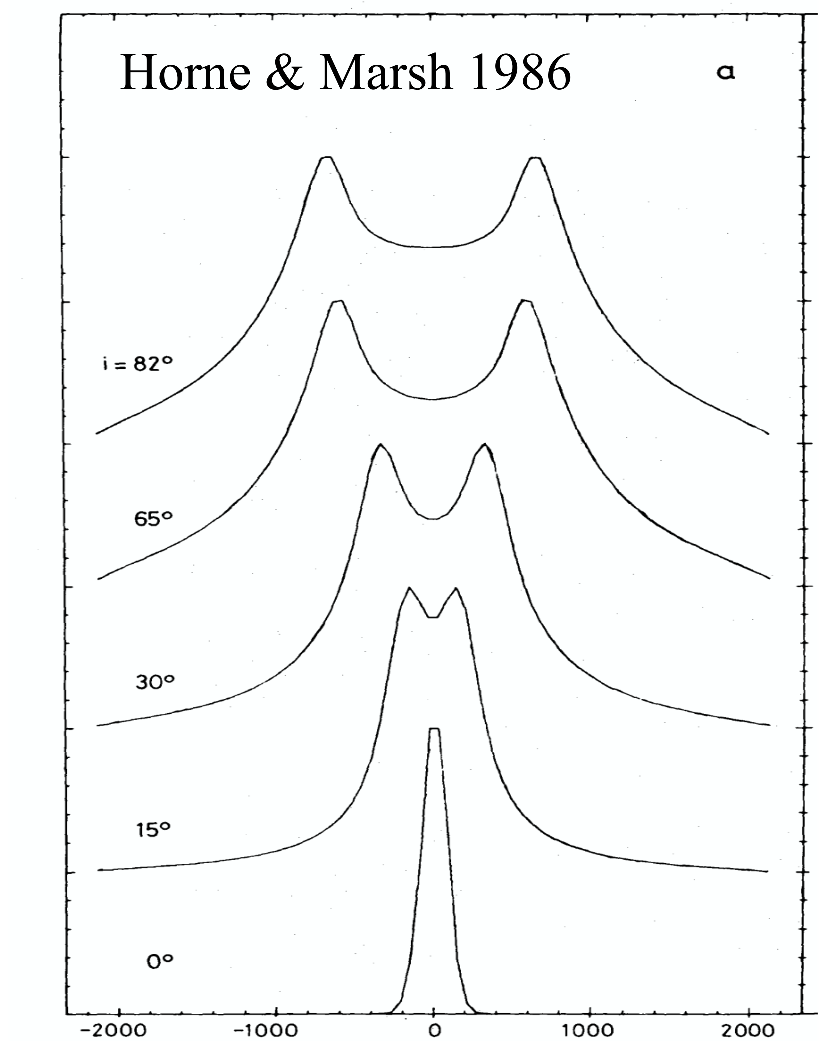
Velocity map



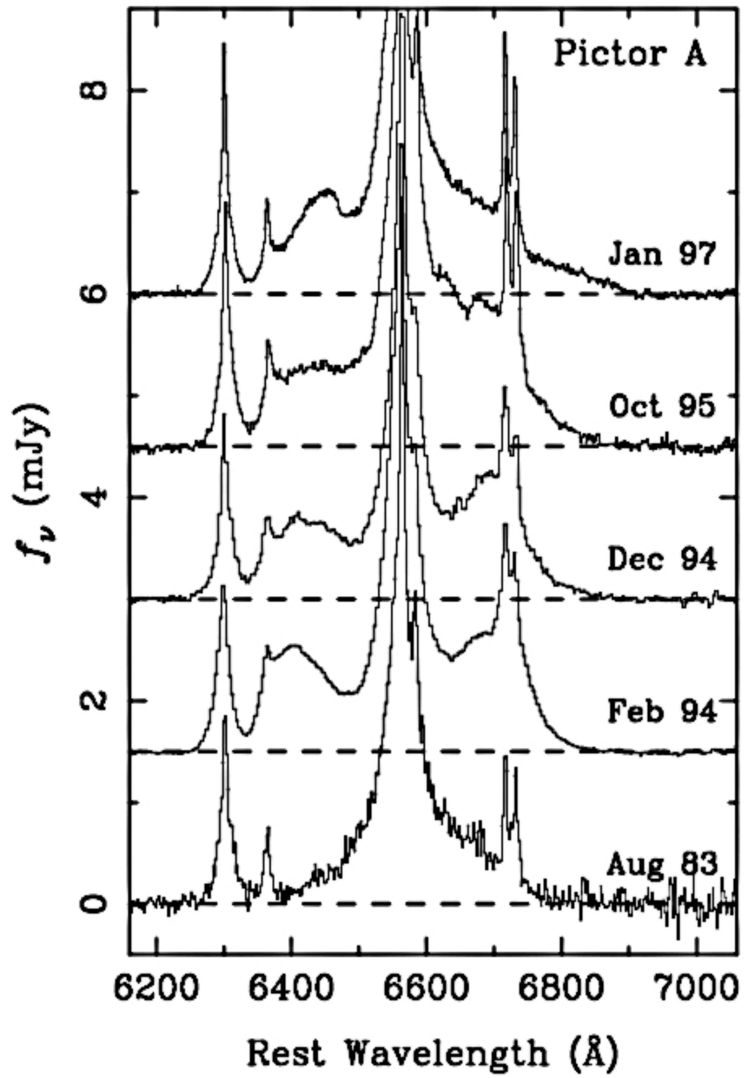


Spectroscopic signature of disk



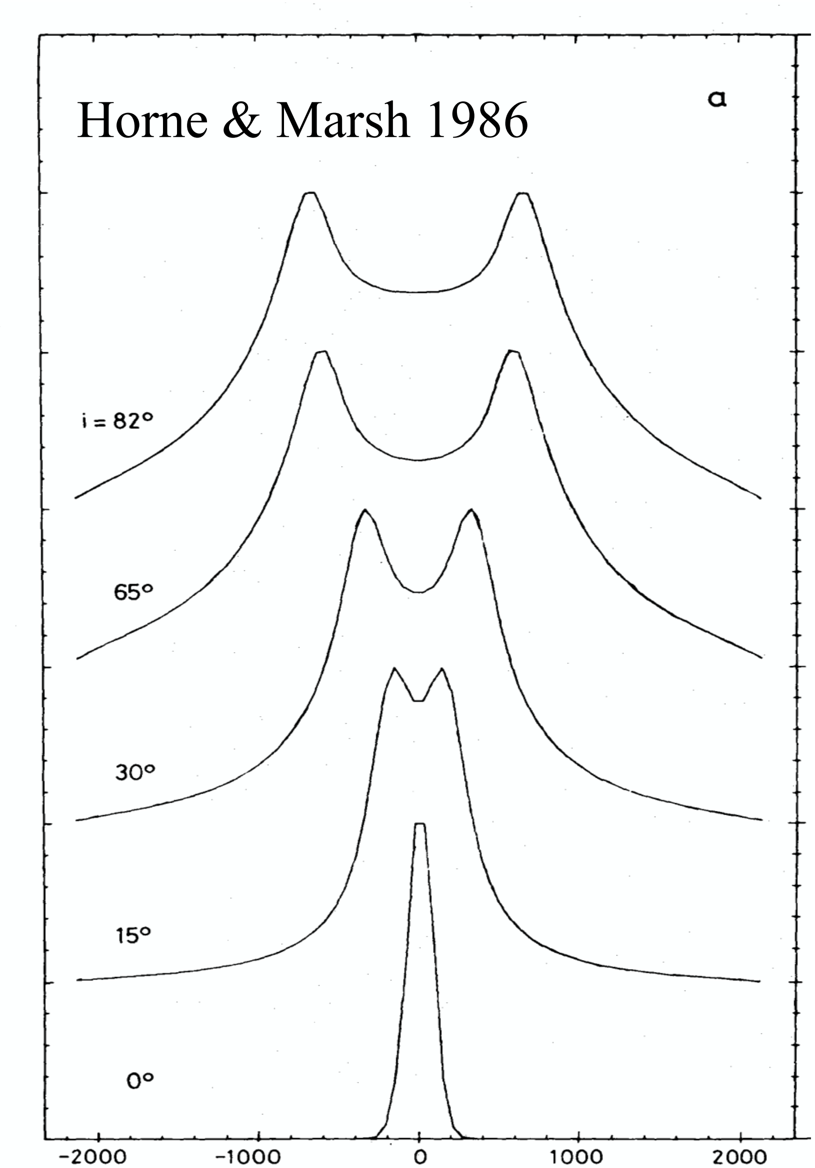


Double-peaked ⇔ Single-peaked

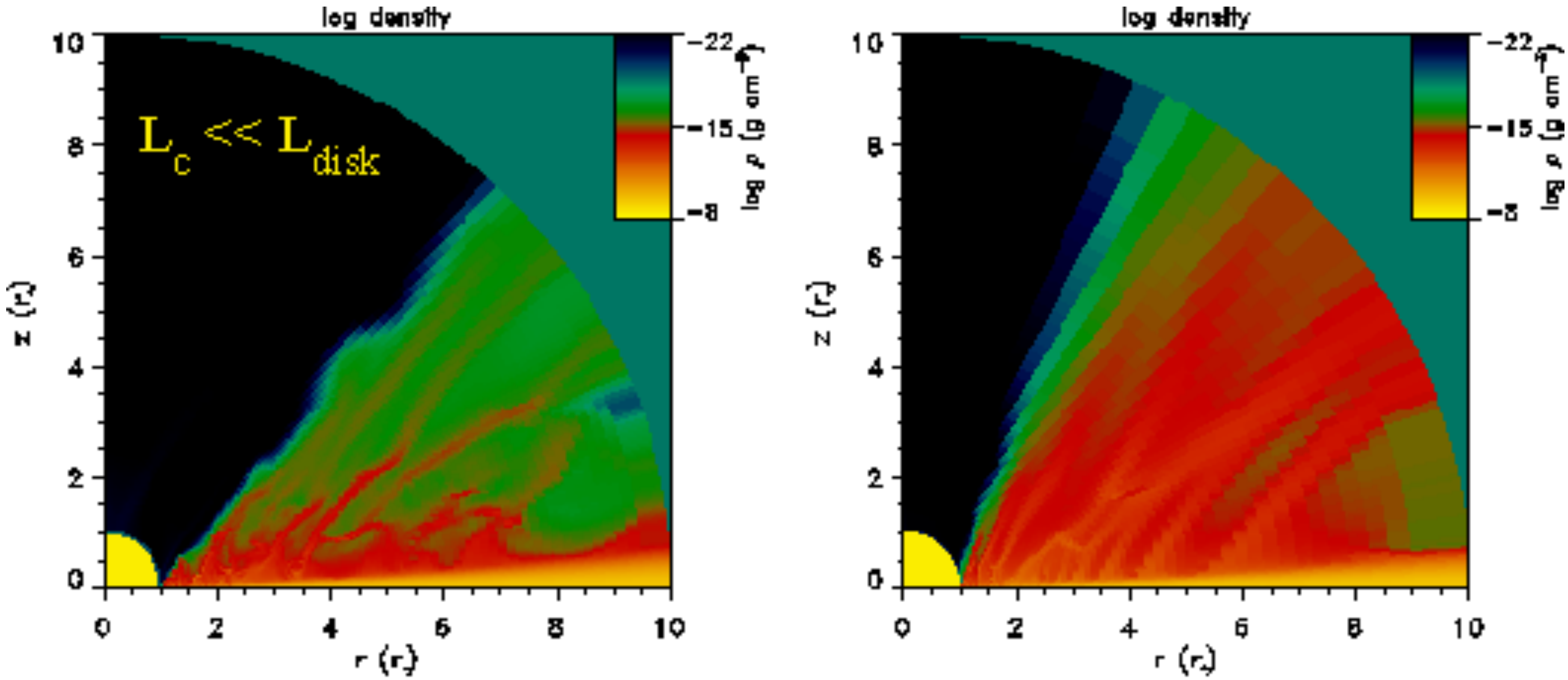


Eracleous & Halpern 1998

Double-peaked ⇔ Single-peaked

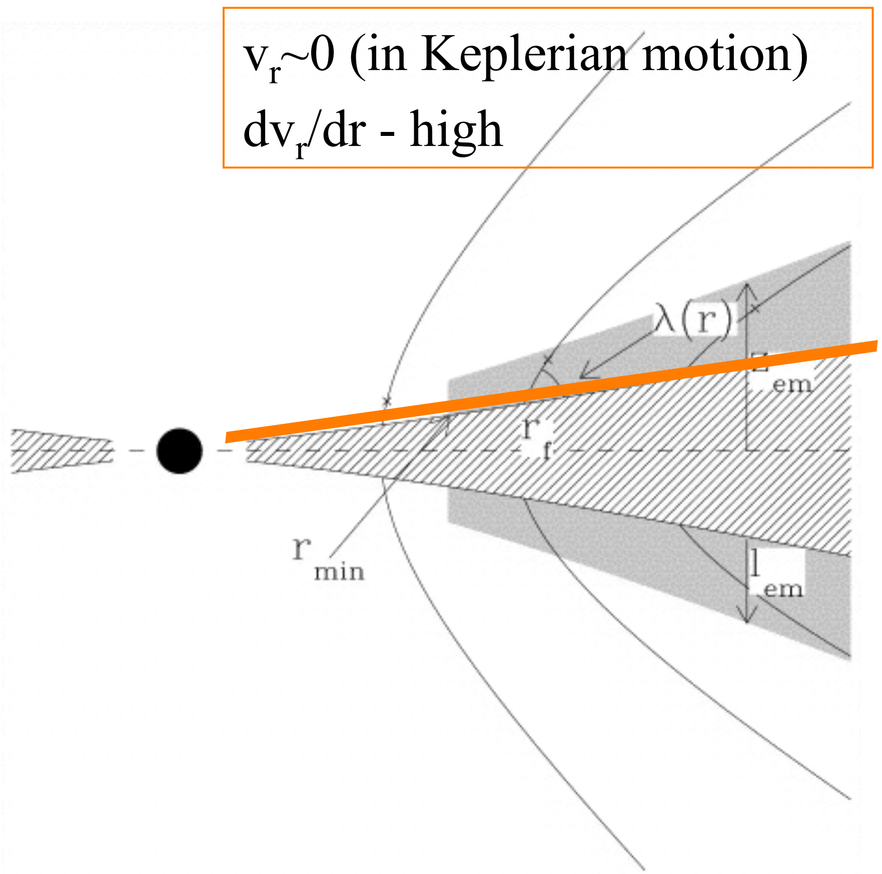


Double-peaked ⇔ Single-peaked



Proga et al. 2000

Effect of disk-wind on line profile



Chiang & Murray 1996

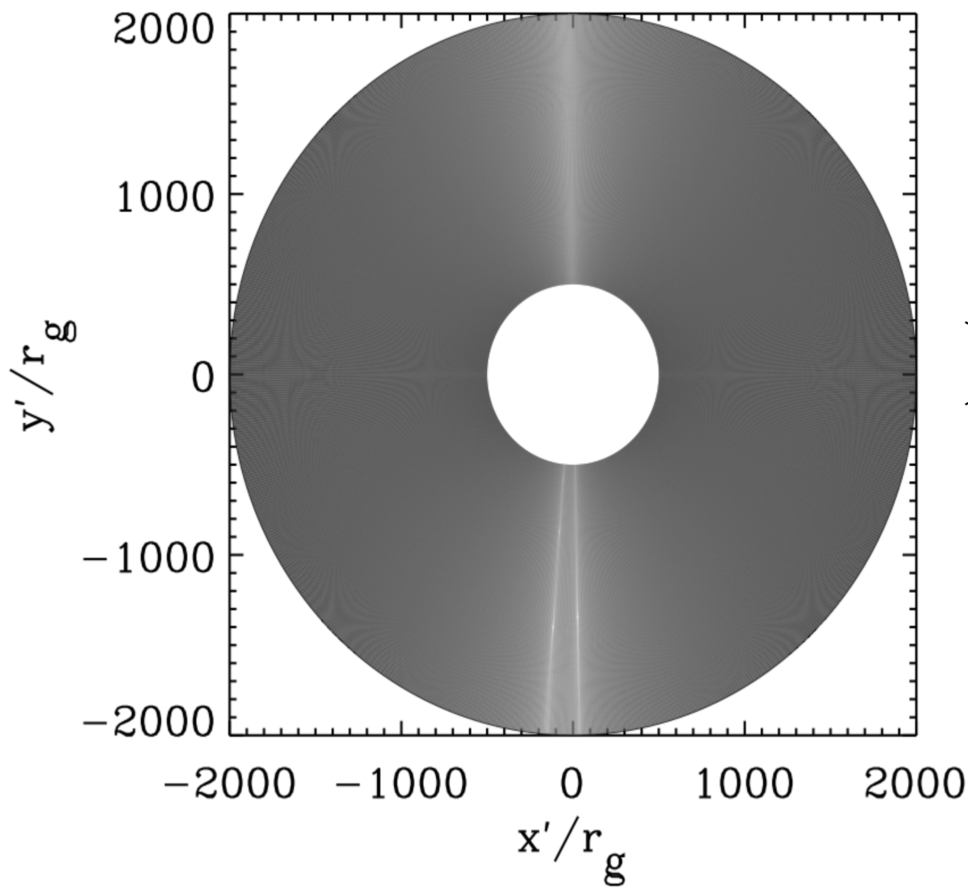
Sobolev approximation:

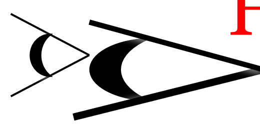
$$\tau \propto \frac{\rho}{|\hat{\mathbf{n}} \cdot \boldsymbol{\Lambda} \cdot \hat{\mathbf{n}}|}$$

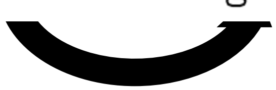
$\sim dv_r/dr$

Effect of disk-wind on line profile

Emissivity map







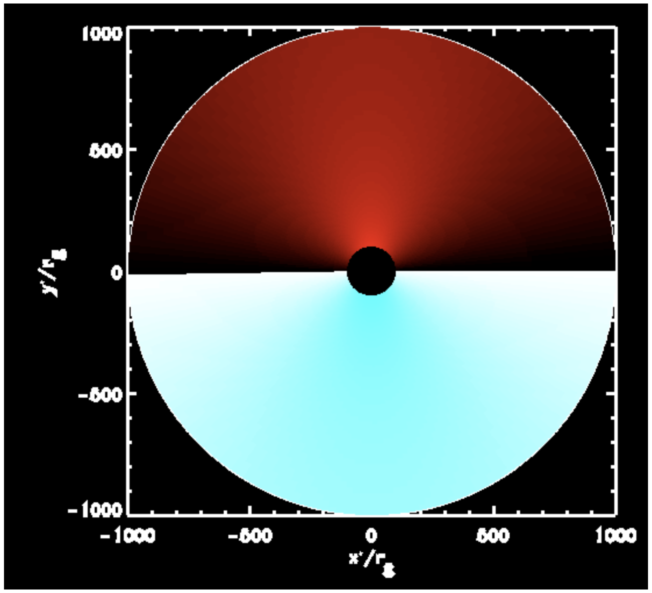
$$\tau \propto \frac{\rho}{|\hat{\mathbf{n}} \cdot \boxed{\mathbf{\Lambda}} \cdot \hat{\mathbf{n}}|}$$

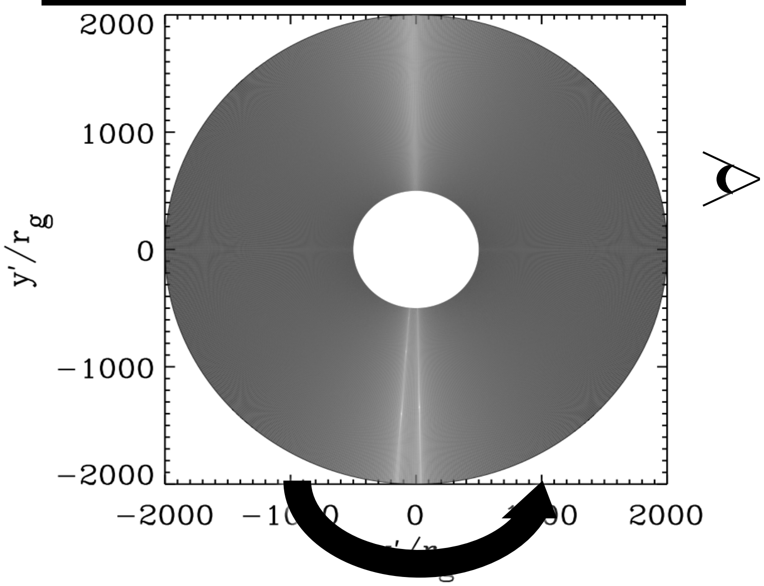
$\sim dv_r/dr$

High projected dv_r/dr – low opacity

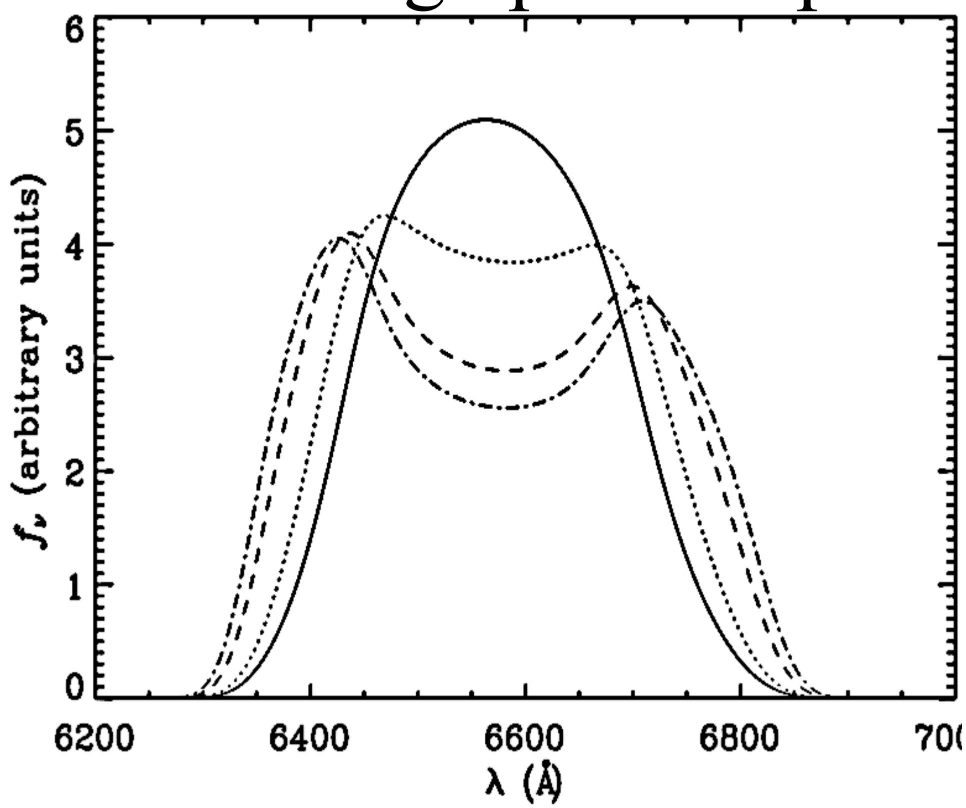
Low projected dv_r/dr – high opacity

Effect of disk-wind on line profile





Increasing optical depth

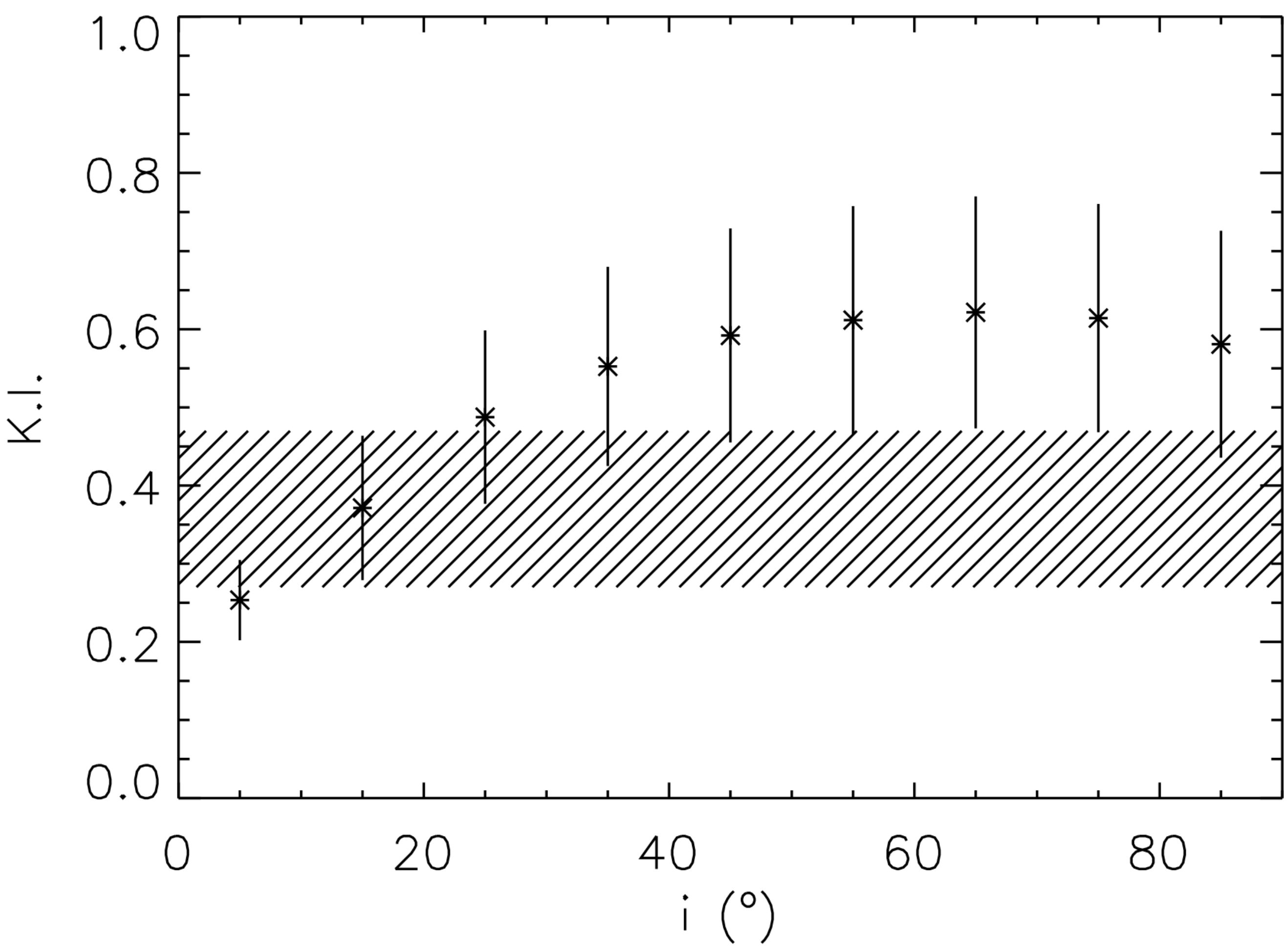


Flohic et al. 2011 (in prep)

Realistic line profiles?

- Database of modeled line profiles with range of model parameters:
  - Inclination
  - Optical depth
  - Disk size
  - Radial density profile of wind (powerlaw index)
- Measured line profile parameters (Marziani et al. 1996):
  - Asymmetry Index (AI)
  - Kurtosis Index (KI)
  - Centroid shift (c1/4, c1/2)
  - FWHM
- Zamfir et al. (2010) – 470 Hβ profiles from SDSS quasars

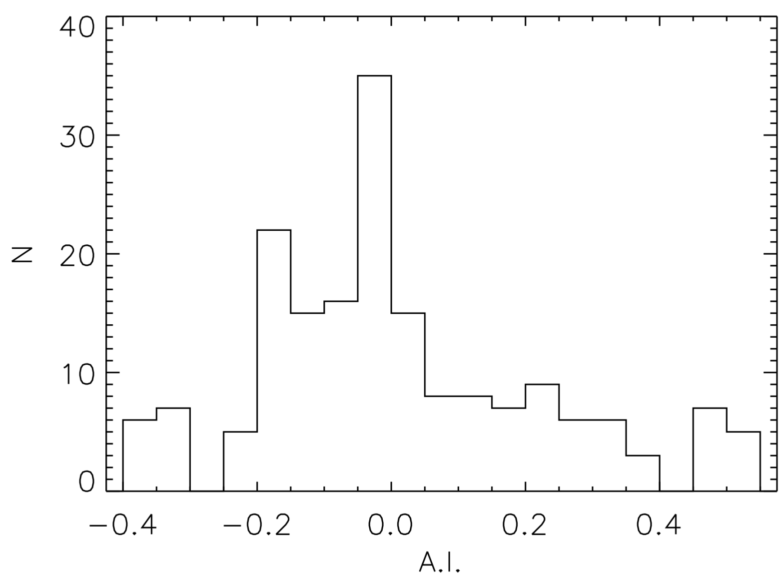
Flohic et al. 2011 (in prep)



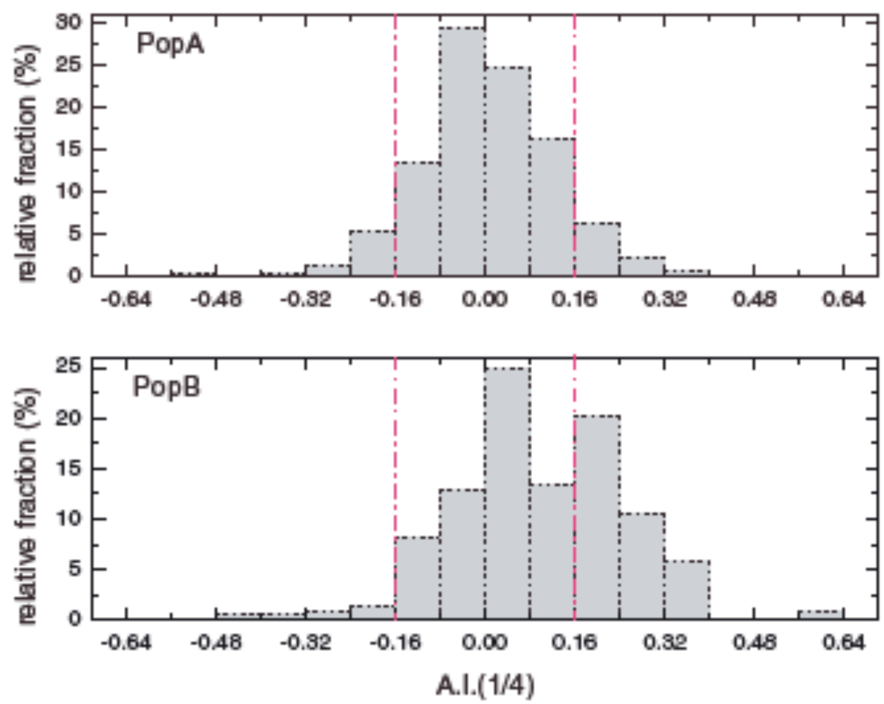
Flohic et al. 2011 (in prep)

Realistic line profiles?

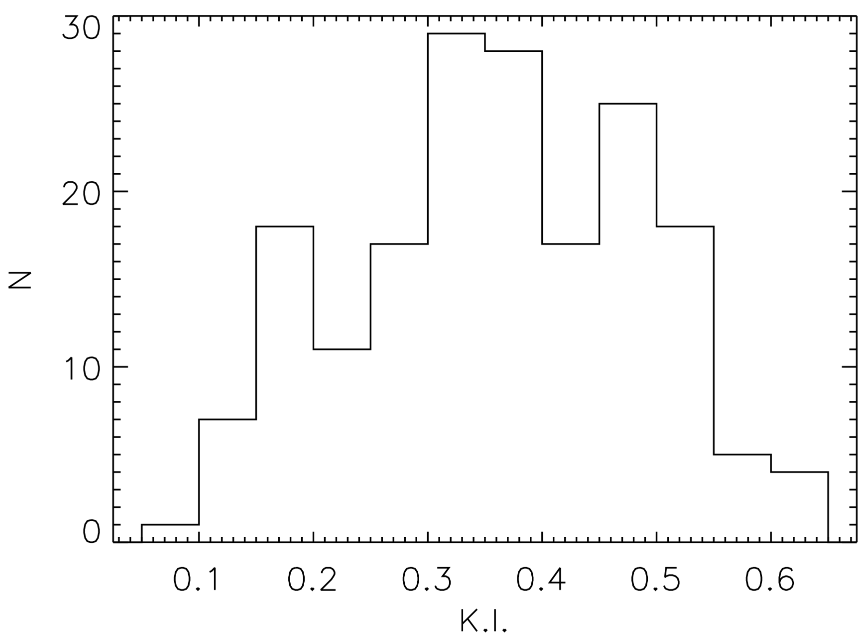
- Inclination < 45 d
- $R_{in} < 2000\ r_g$
- $R_{out} > 5000\ r_g$
- $n \propto r^{-\eta}$ – $\eta > 0.5$
- High optically depth



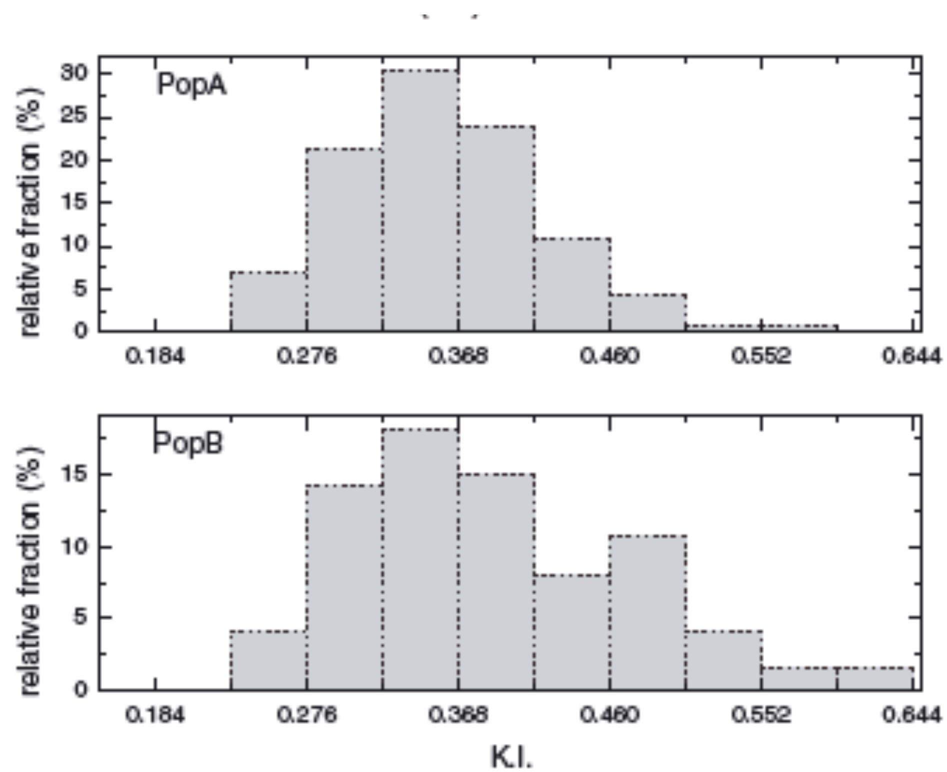
Flohic et al. 2011 (in prep)



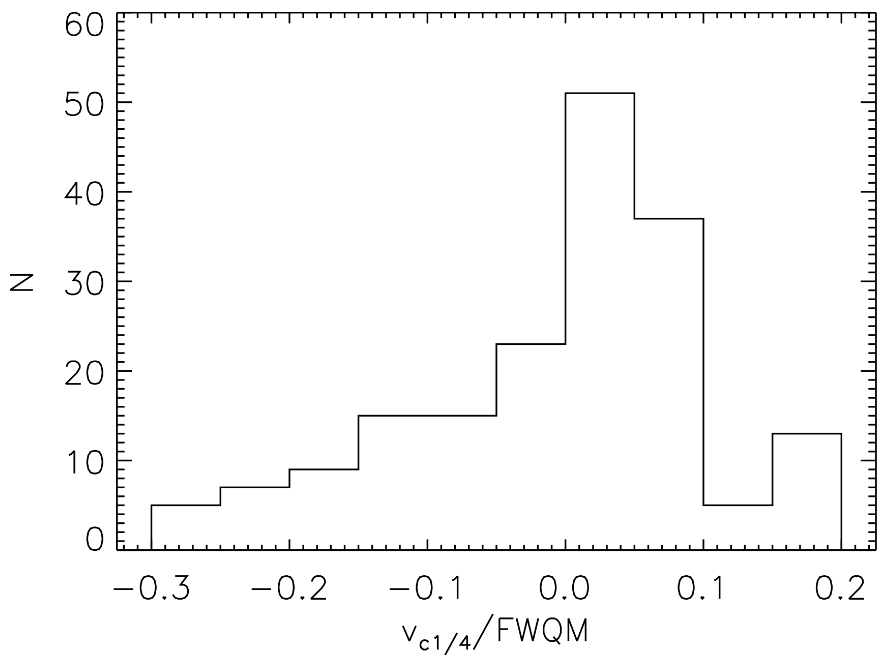
Zamfir et al. 2010



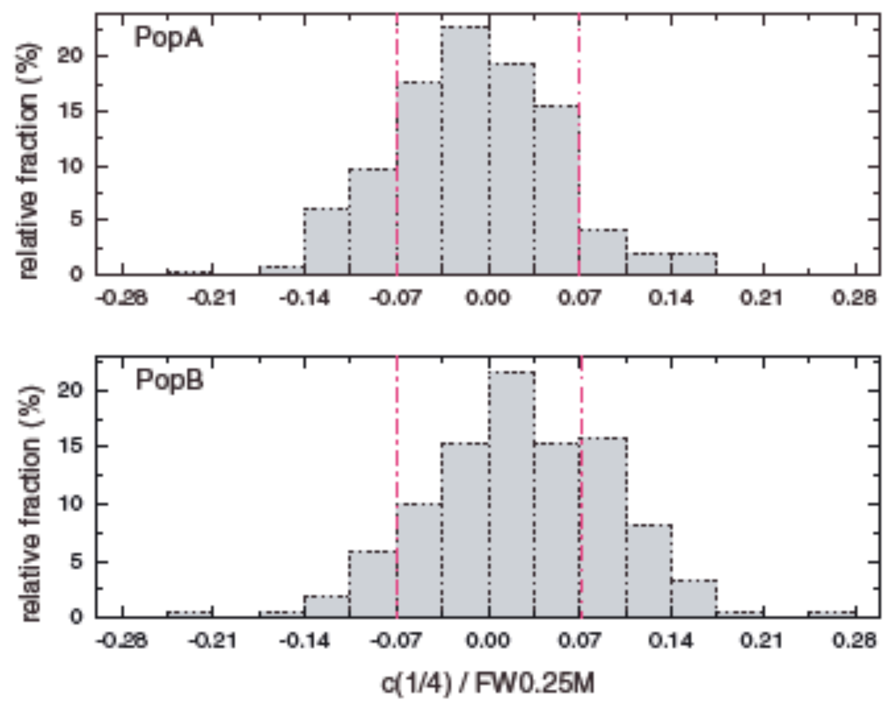
30
20
10
0
N
0.1
0.2
0.3
0.4
0.5
0.6
K.I.



PopA
relative fraction (%)
30
25
20
15
10
5
0
0.184
0.276
0.368
0.460
0.552
0.644
PopB
relative fraction (%)
15
10
5
0
0.184
0.276
0.368
0.460
0.552
0.644
K.I.

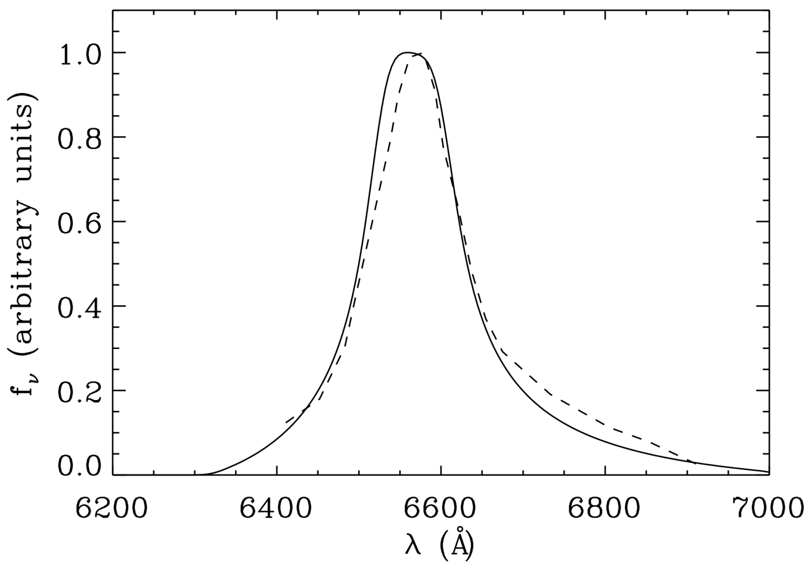


N
v_{c1/4}/FWQM

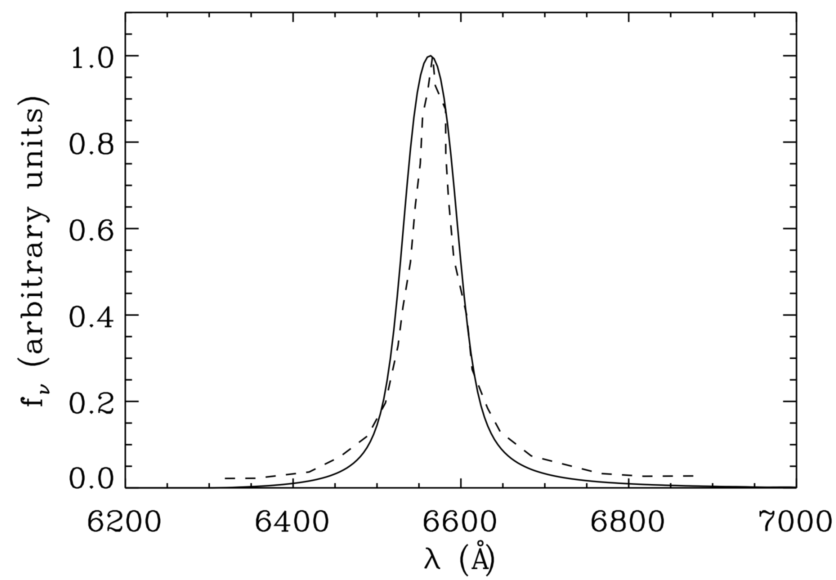


PopA
PopB
relative fraction (%)
c(1/4) / FW0.25M

Double Gaussian (pop B)

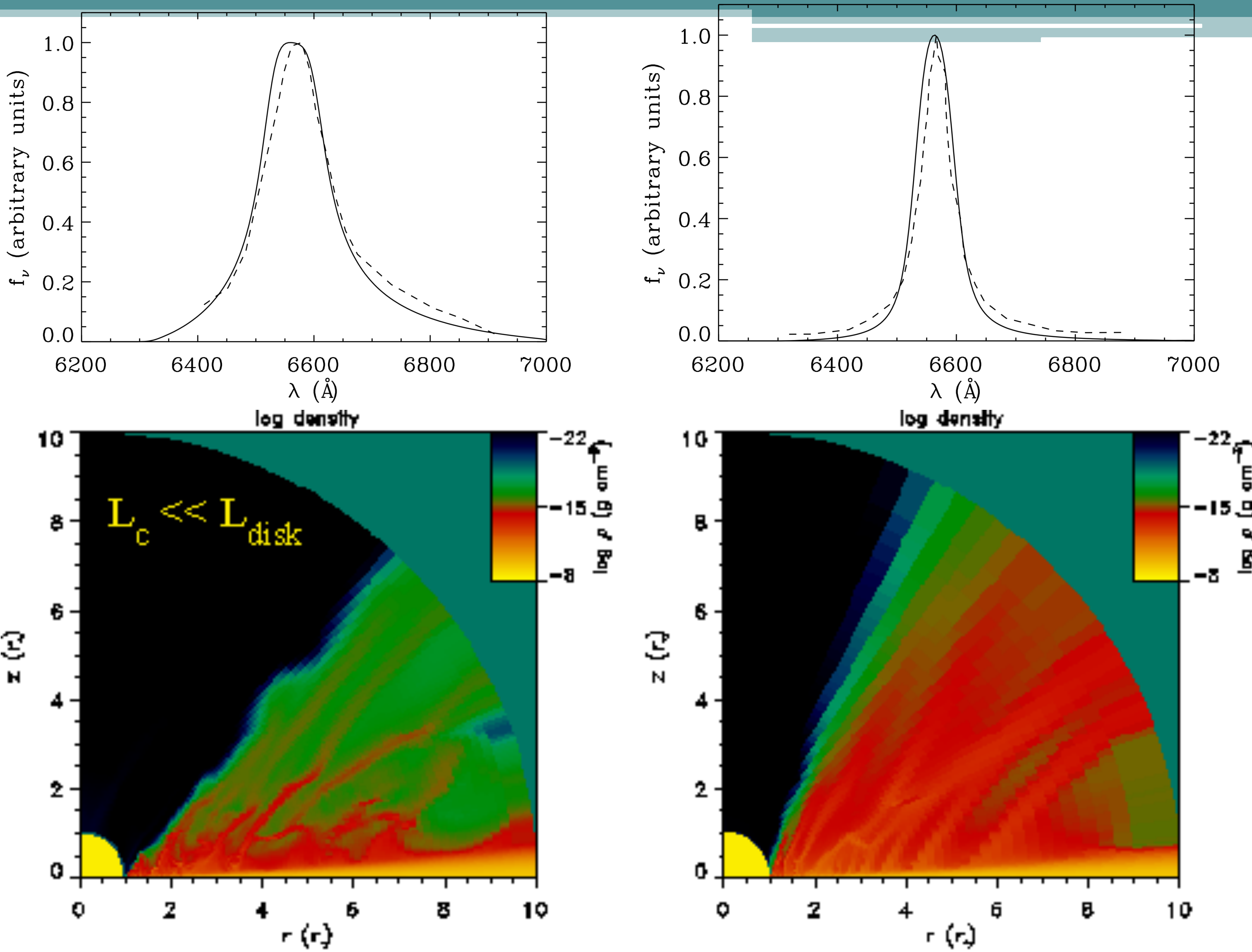


Lorentzian (pop A)



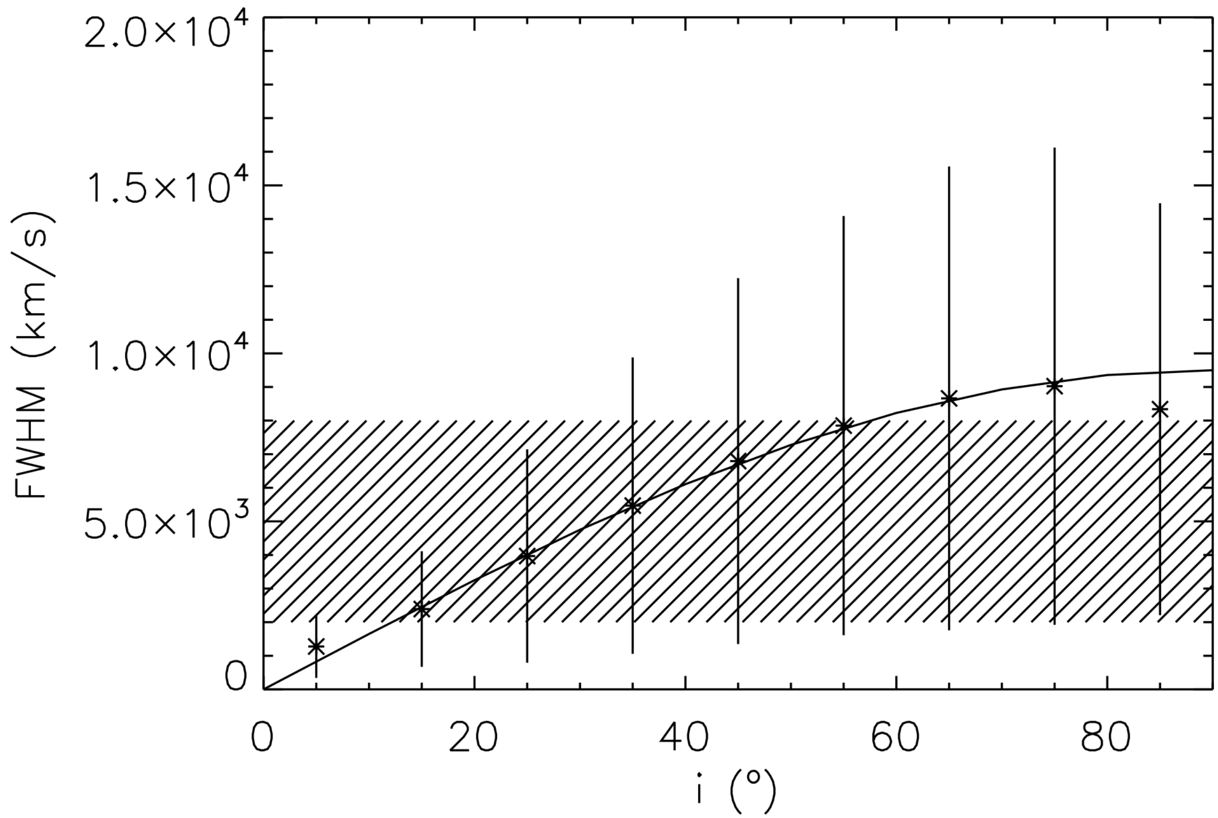
Sulentic et al. 2009

Flohic et al. 2011 (in prep)


f_ν (arbitrary units)
λ (Å)
log density
z (r_i)
r (r_i)
log ρ (g cm⁻³)
L_c << L_disk

Possible problems for mass estimate

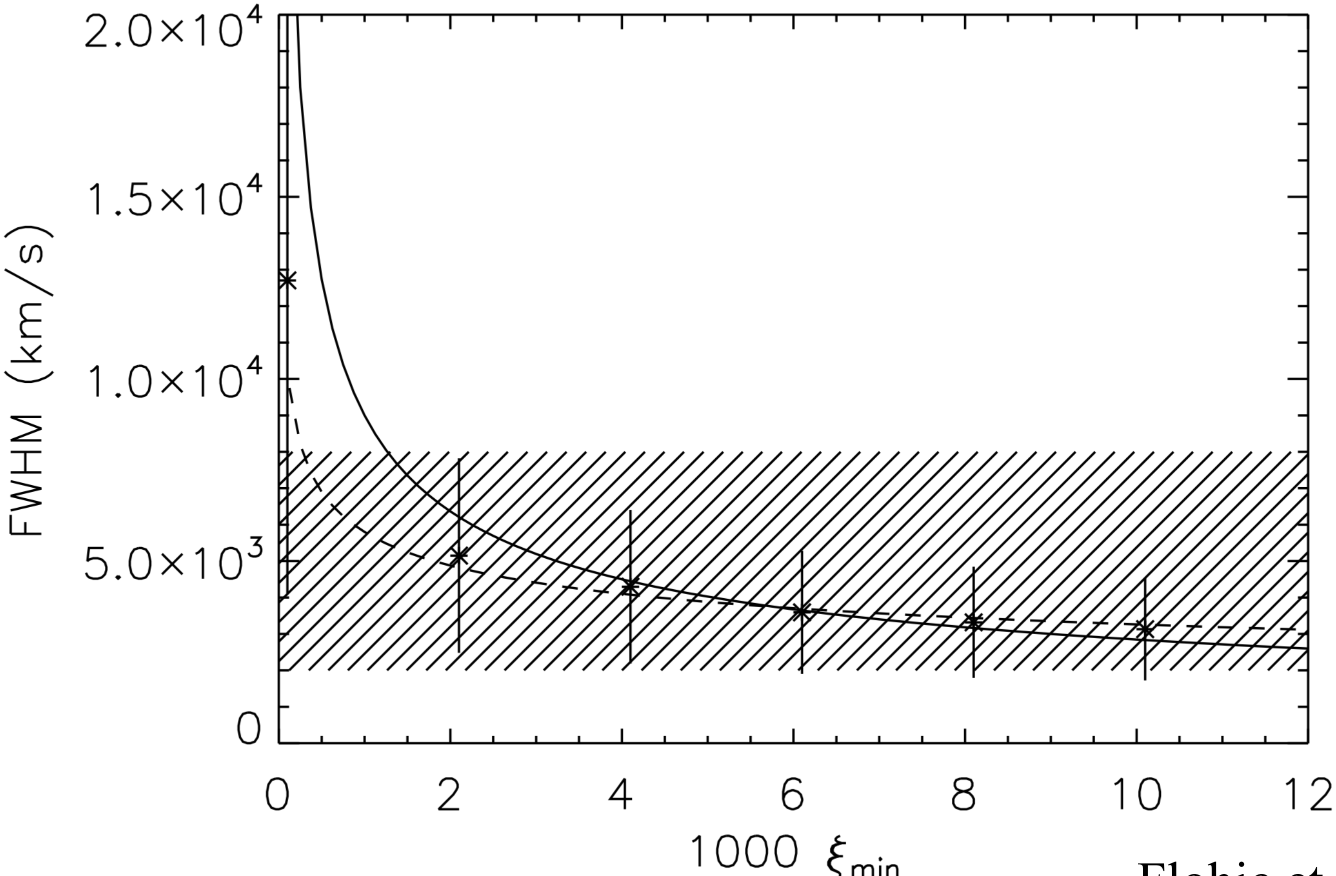
$$M_{BH} = f\, R_{BLR}\, v^2$$



Flohic et al. 2011 (in prep)

Possible problems for mass estimate

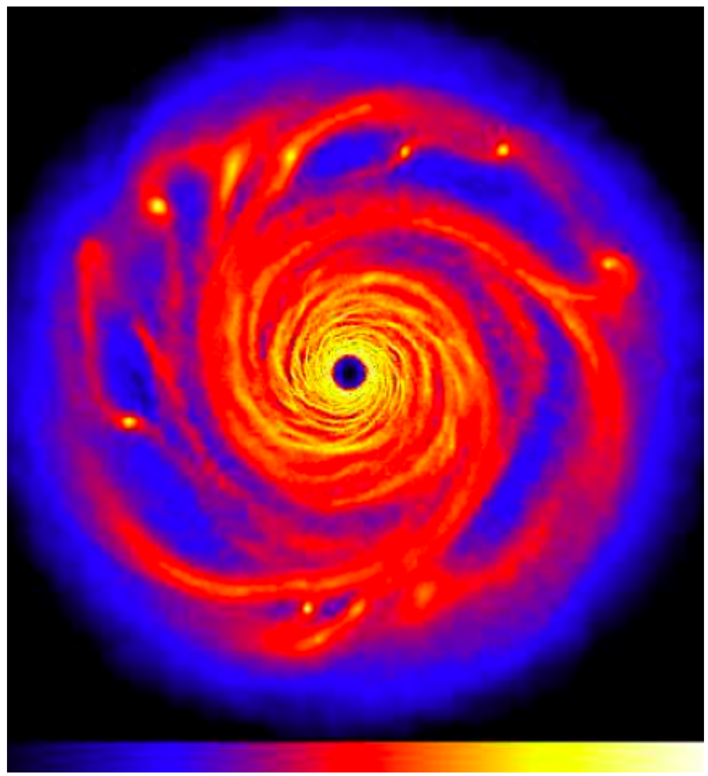
$$M_{BH} = f\, R_{BLR}\, v^2$$



Flohic et al. 2011 (in prep)

So…

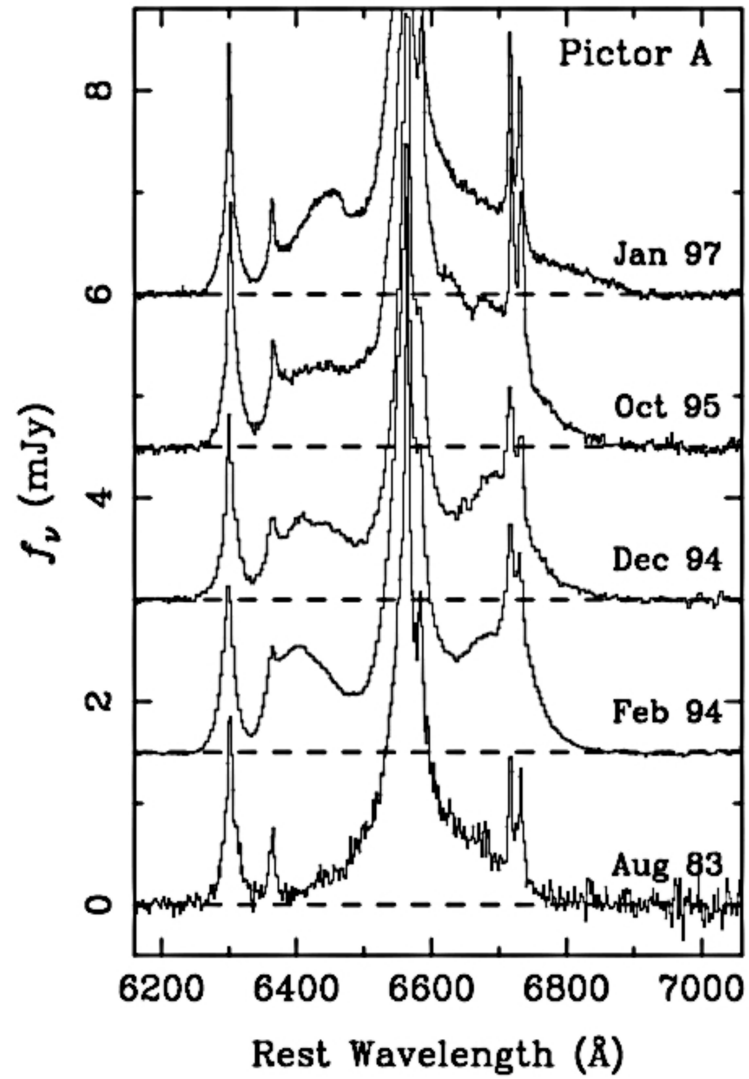
- Accretion disk + wind produces realistic line profiles
- But does the accretion disk have structure? Clumps, spiral…



Rice et al. 2005

Variable double-peaked profile

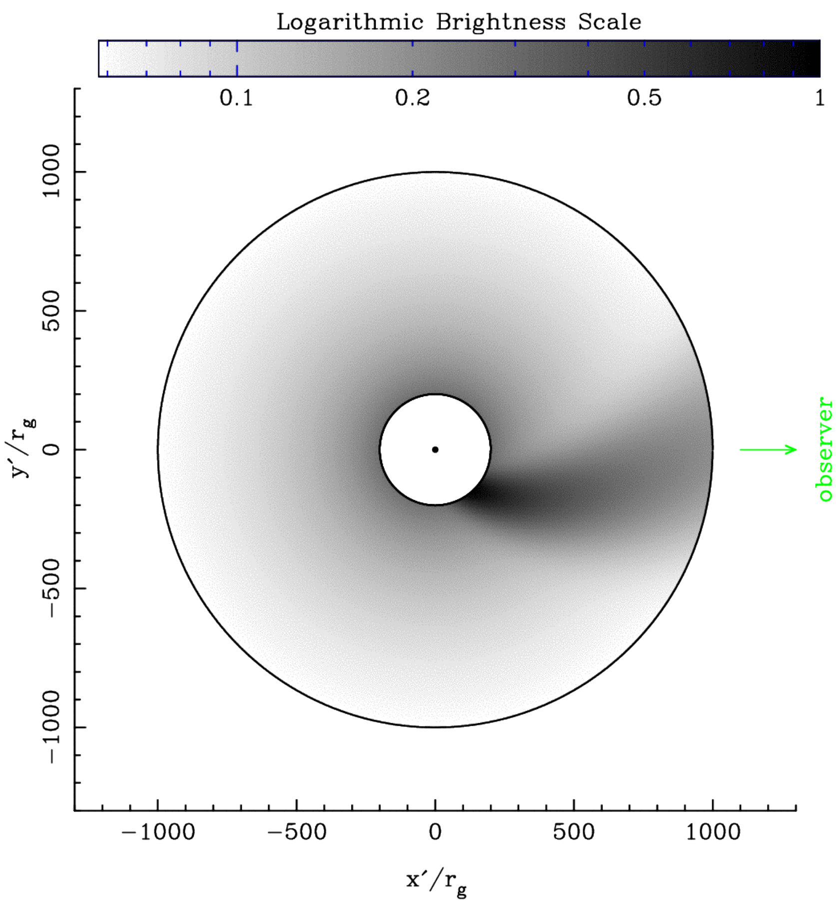
- Variability of profile uncorrelated with variability of line and/or continuum flux
- Likely traces changes in accretion disk structure
- DPELs give us a ‘direct’ view of the accretion disk



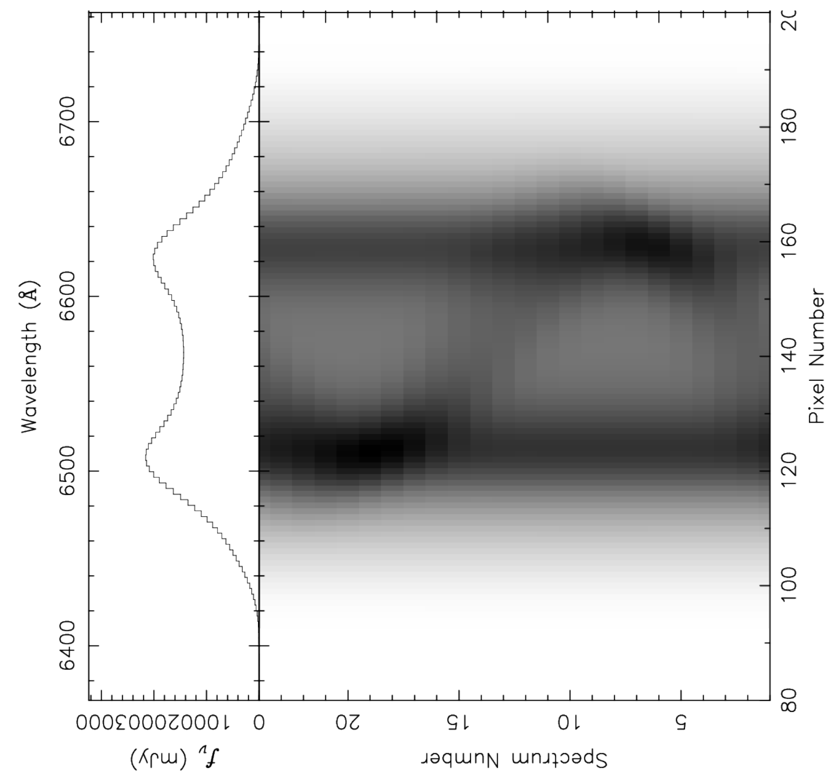
Eracleous & Halpern 1998

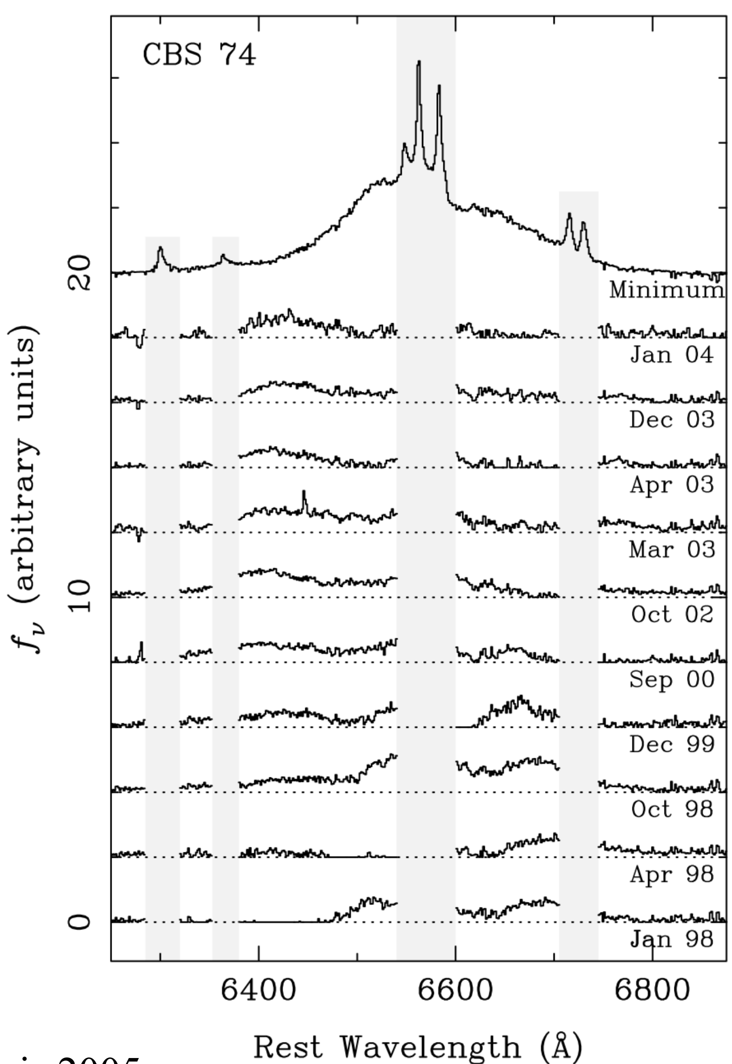
If there is structure in the accretion disk…

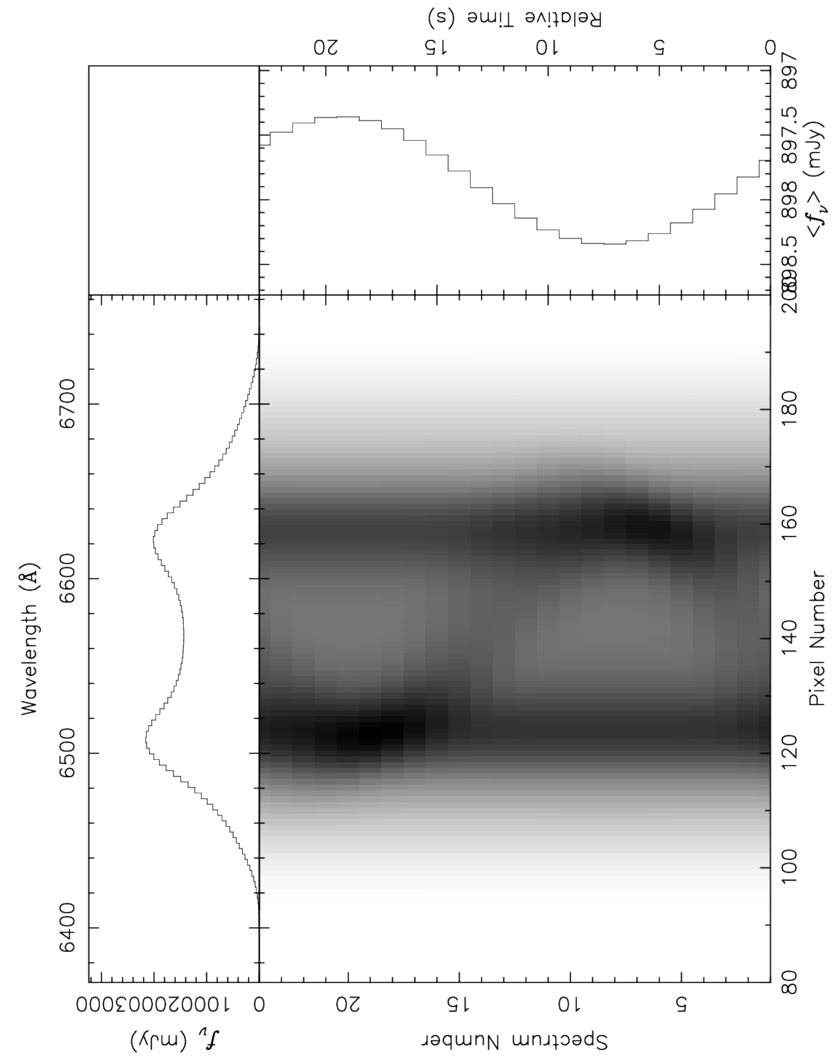
Emissivity map



Dark = excess flux above average profile

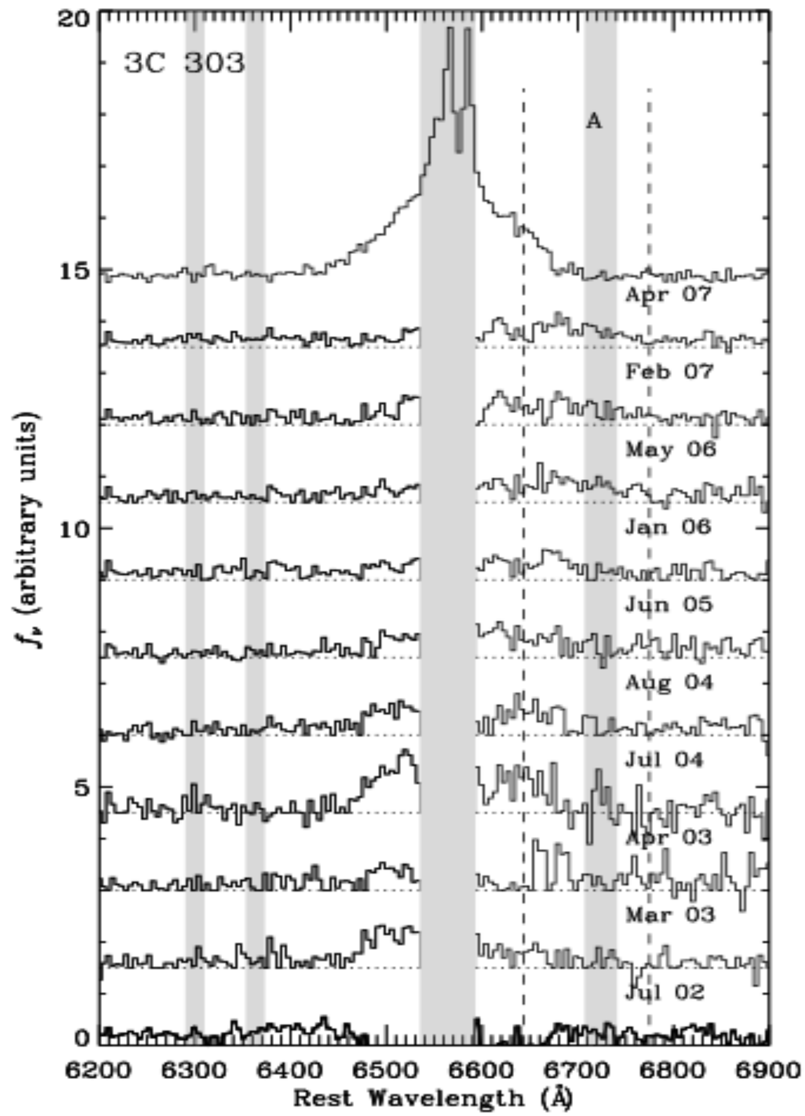



CBS 74
Minimum
Jan 04
Dec 03
Apr 03
Mar 03
Oct 02
Sep 00
Dec 99
Oct 98
Apr 98
Jan 98
0
10
20
f_ν (arbitrary units)
6400
6600
6800
Rest Wavelength (Å)


Relative Time (s)
$\langle f_\nu \rangle$ (mJy)
Pixel Number
Spectrum Number
Wavelength (Å)
f_ν (mJy)

Lewis 2005

Long-term monitoring

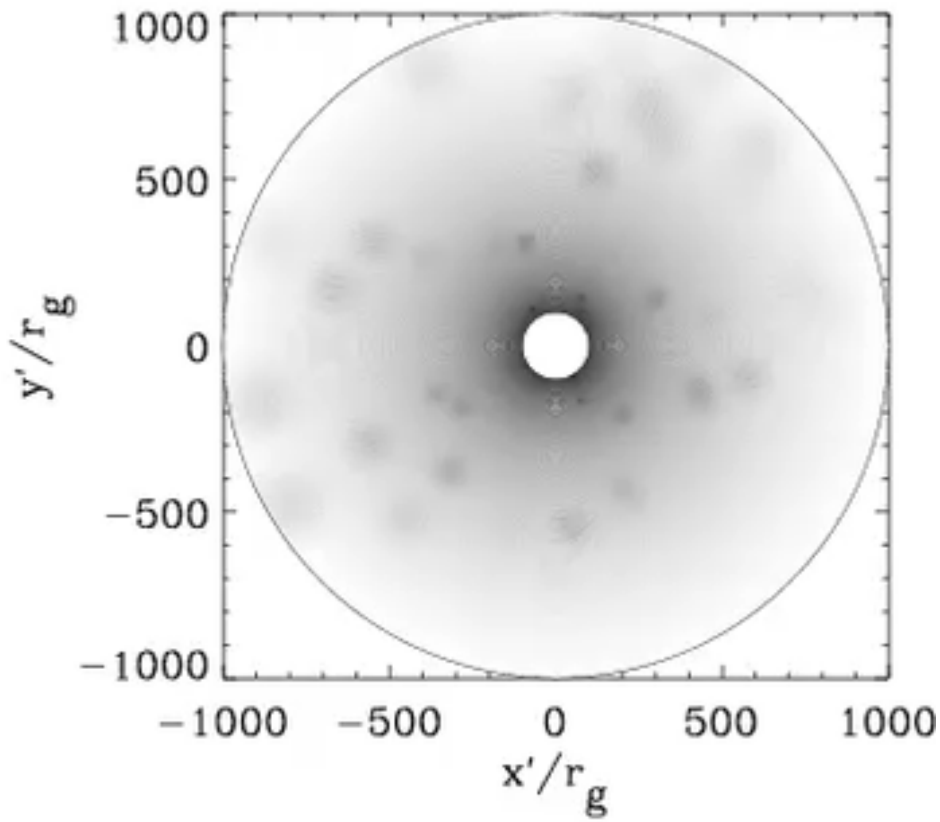


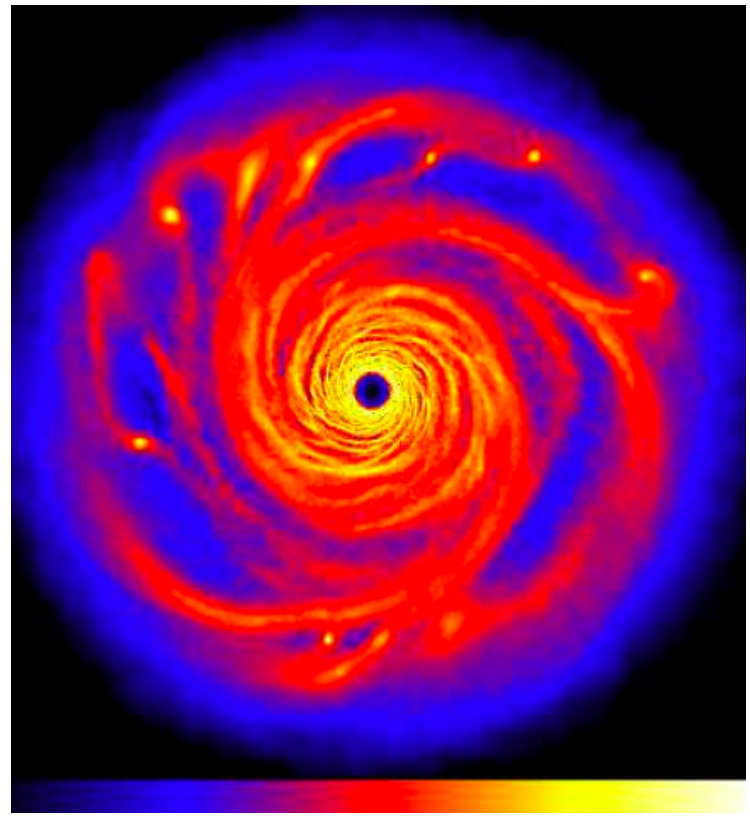
Flohic & Eracleous 2011 (in prep)

- ~ 40 objects
- ~ twice a year
- ~ 10 years
- up to 30 years

- Some large amplitude, long timescale variations
- Mostly small amplitude, short timescale variations

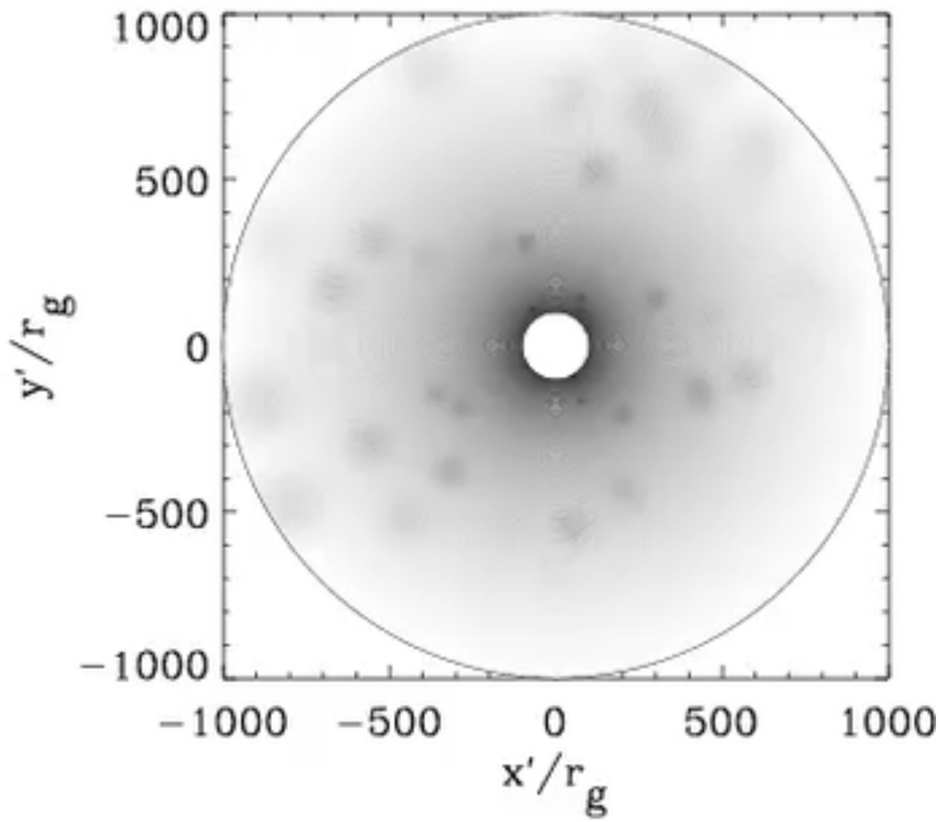
Stochastically perturbed disk





Flohic & Eracleous 2008

Stochastically perturbed disk



- Number of spots
- Size of spots
- Contrast
- Shearing properties
- Radial distribution

→ MC simulations

Flohic & Eracleous 2008

Comparing simulations and observations…

- Can only be compared with AGNs with ~40 or more spectra

- Arp 102B - spots have to be in outer region of disk, non-shearing, non-decaying, high contrast
- 3C 390.3 – spots unconstrained

→ consistent with self-gravitating clumps in the outer accretion disk

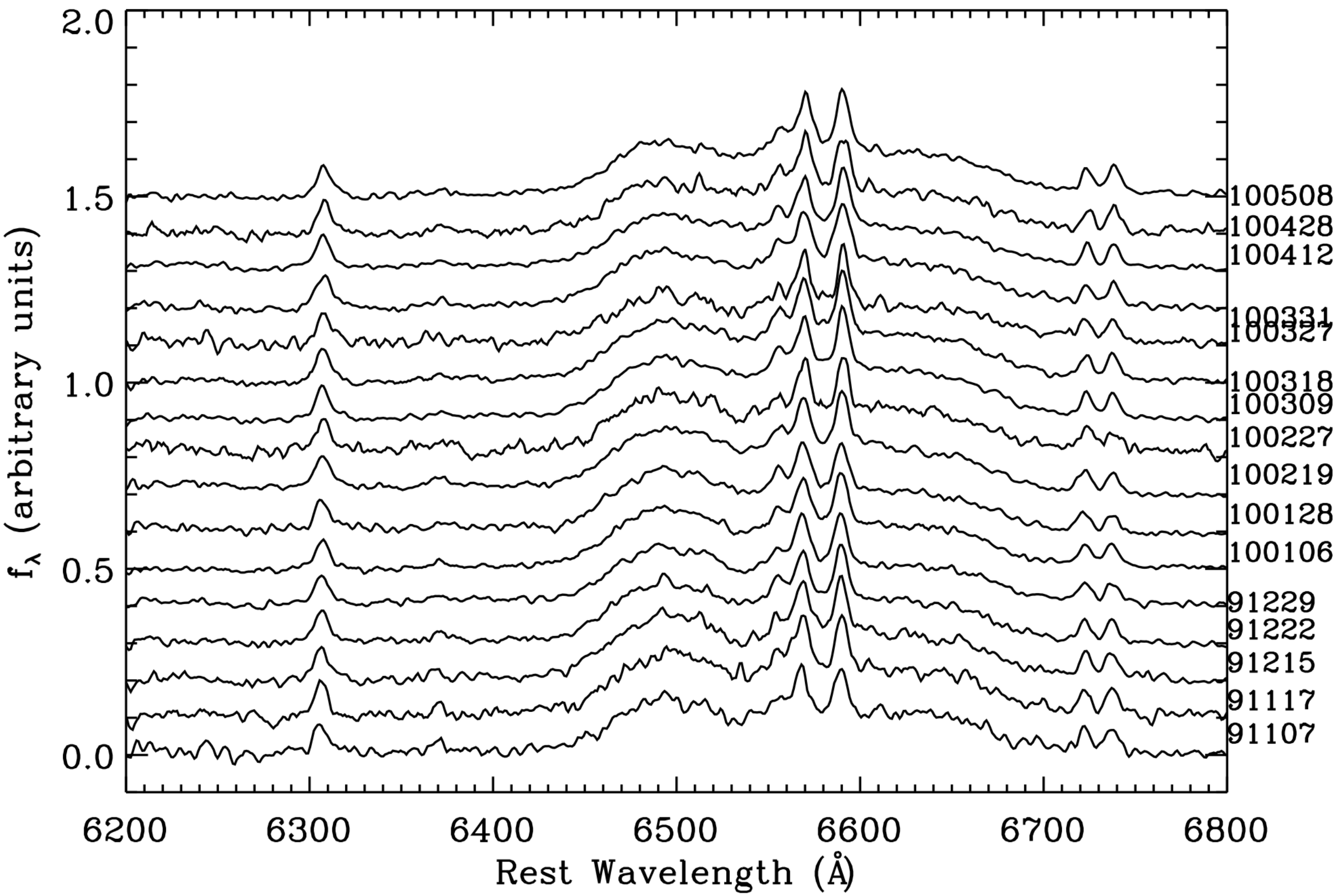
Obtaining more observations

- Ongoing long-term monitoring
- Careful target selection:
  dynamical timescale ~ 6 $M_{BH,8}$ $r_{g,3}$ months

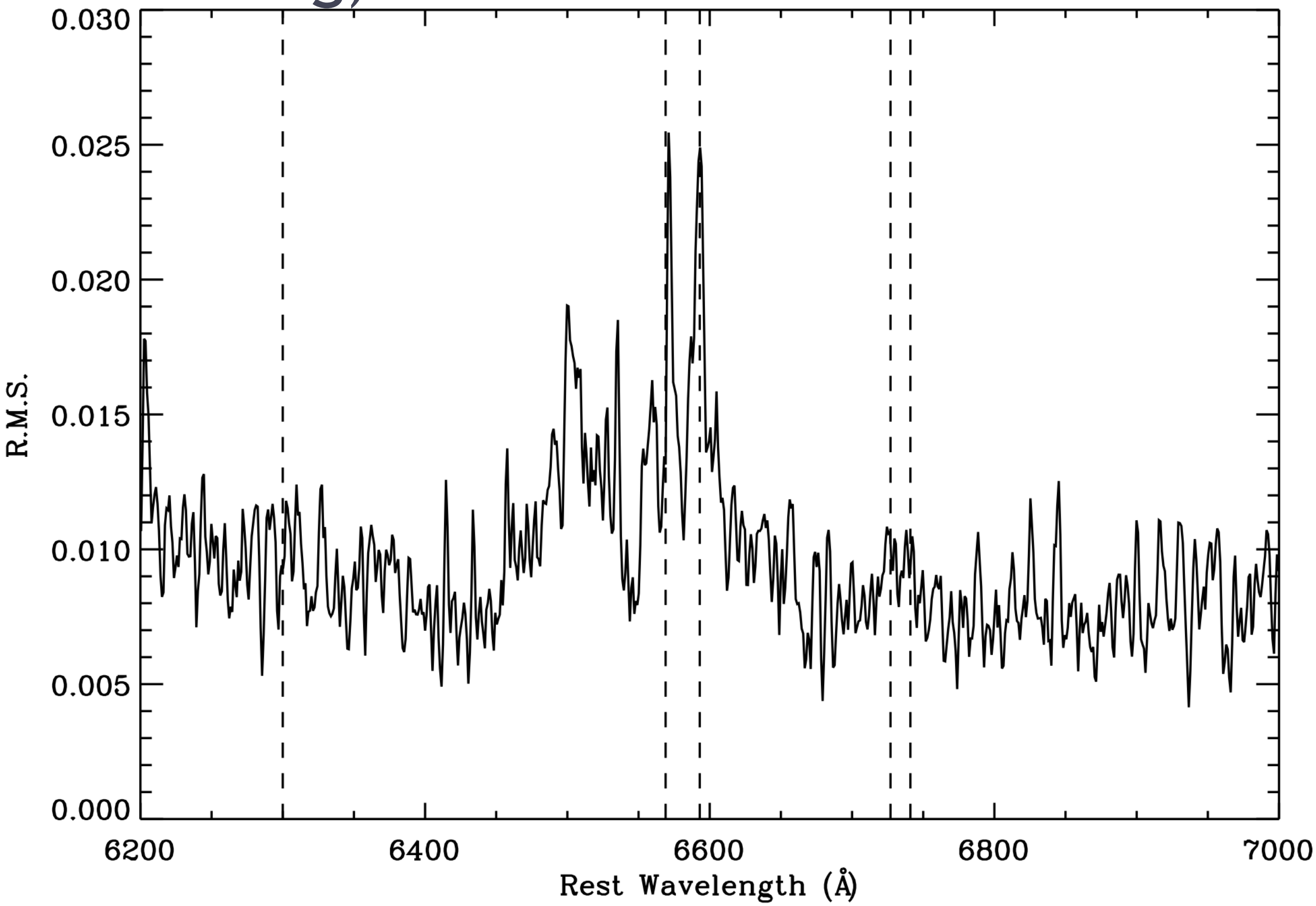
→Target DP AGNs with low mass BH (and reange of Eddington ratios)

- Accepted program to measure BH mass of AGNs with DPELs
- Ongoing 2 year program – one AGN with $M_{BH}=10^7$ M_{sun}:
  - weekly CTIO 1.5m + existing observations
  - biweekly Swift

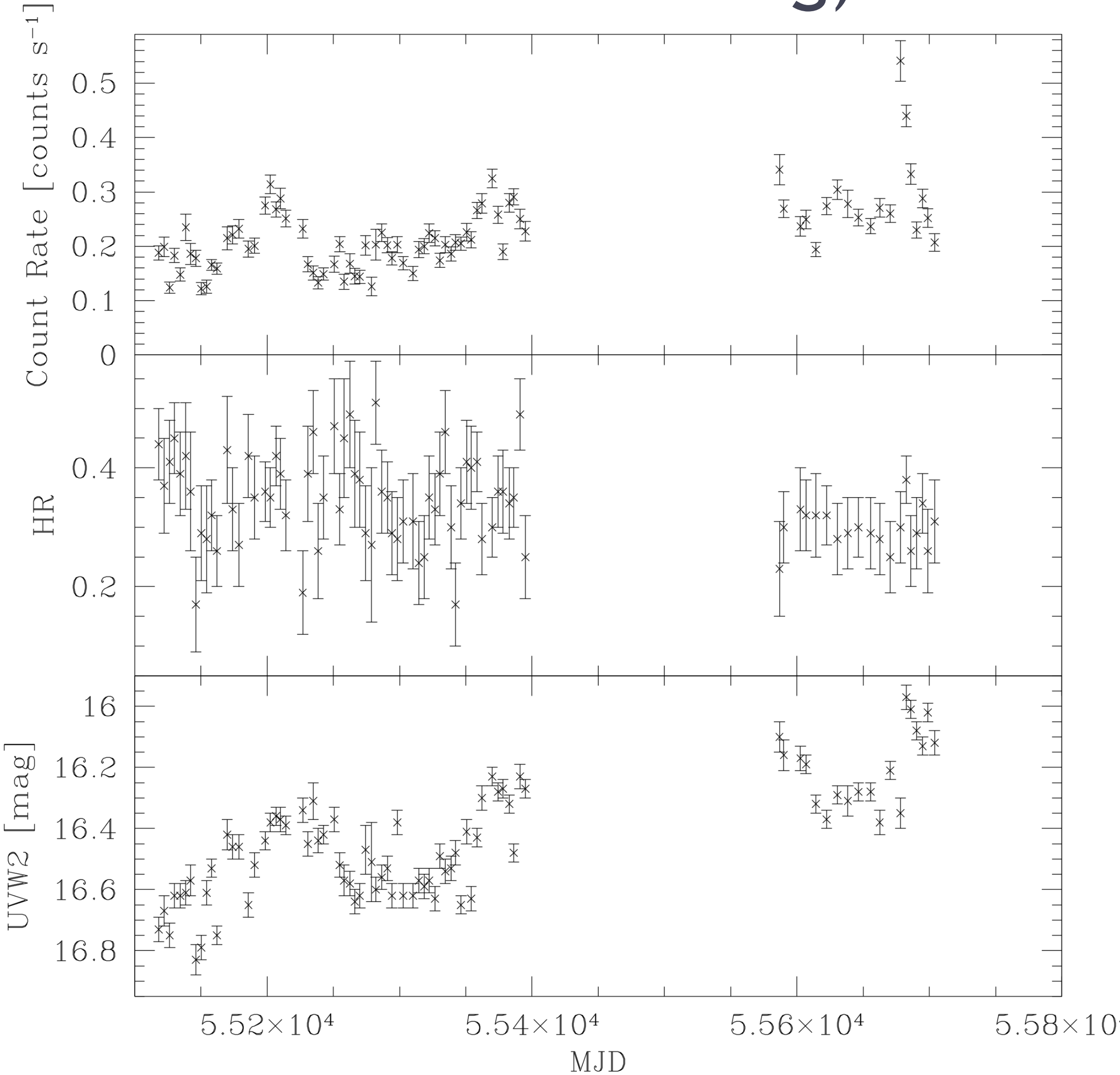
Preliminary results
(one year of optical monitoring)



Preliminary Results (one year of optical monitoring)



Preliminary results
(2 years of SWIFT monitoring)



We have …

- … connected single-peaked and double-peaked emitters
- … demonstrated that the disk+wind model is produces realistic line profiles
- … used DPEL profile variability to learn that the accretion disk might be partially or totally unstable to self-gravity
- … ongoing observations and projects to explore this further