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

Hélène M.L.G. Flohic
FONDECYT Postdoctoral Fellow
Universidad de Chile

M. Eracleous (Pennsylvania State U.)
T. Bogdanović (U. of Maryland, Einstein Fellow)
D. Grupe (Pennsylvania State U.)
K.T. Lewis (Coll. of Wooster)
C.P. Gutierrez Avendaño (U. de Chile)
Felipe Isaule (U. de Chile)

Why care about BLR structure?

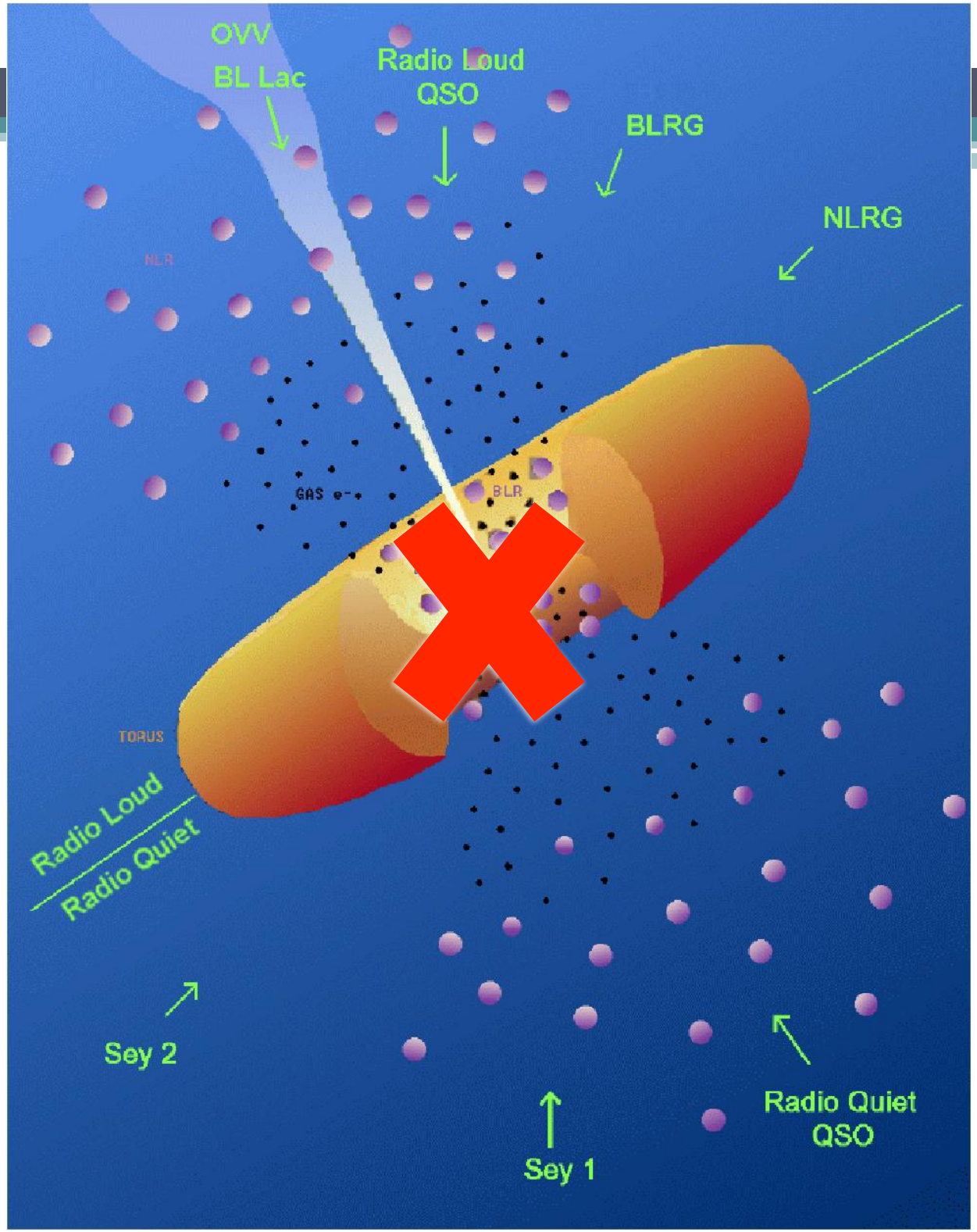
- Used to measure black hole mass:

  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)

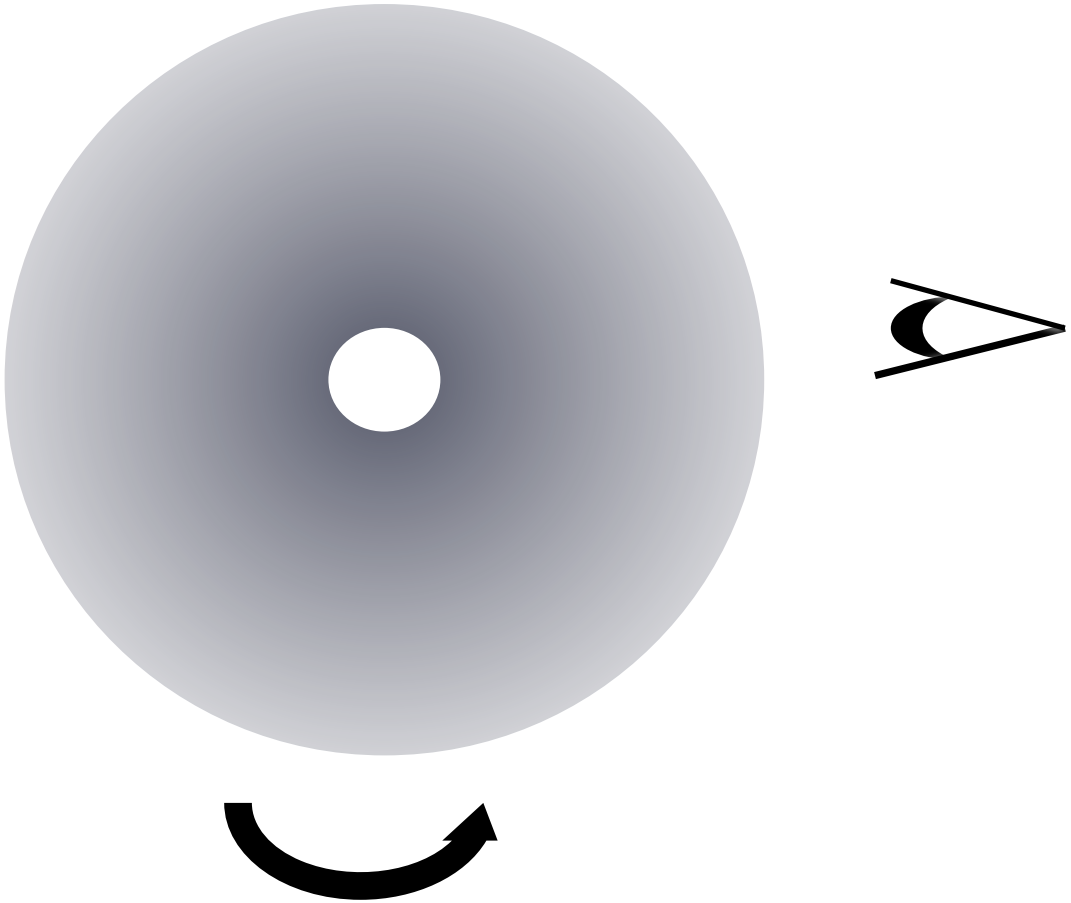
➔ Need to know BLR structure



Urry & Padovani 1995

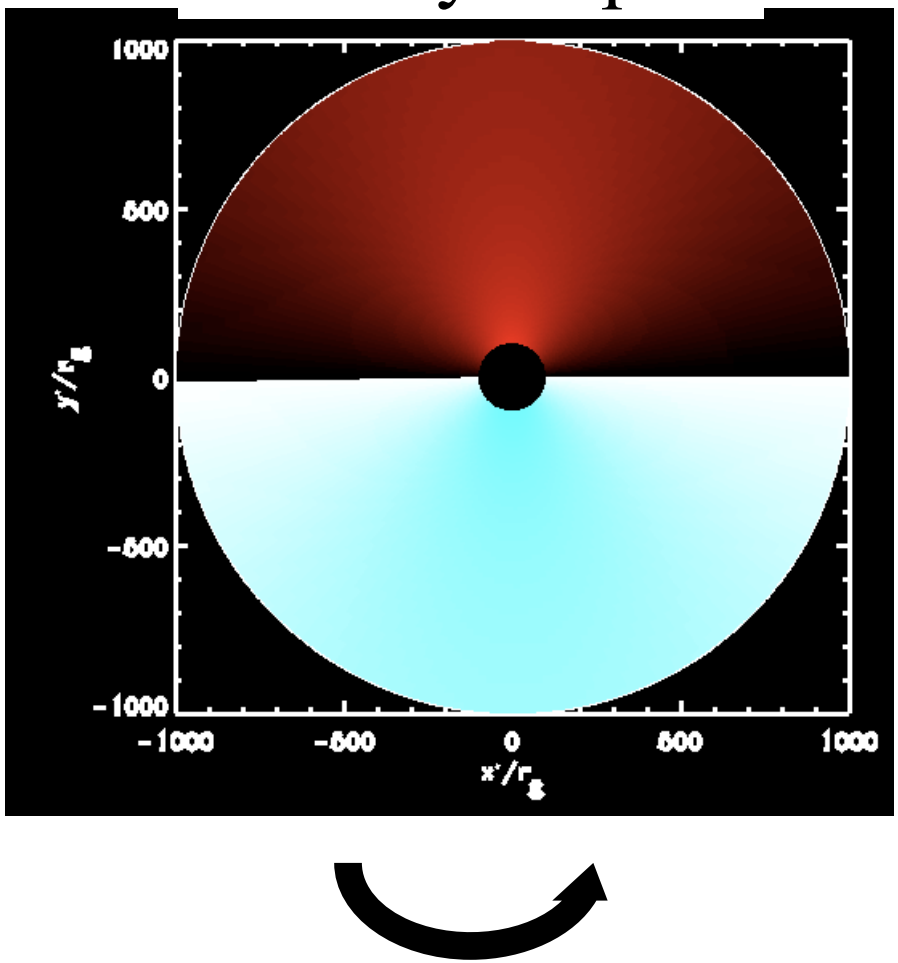
Spectroscopic signature of disk

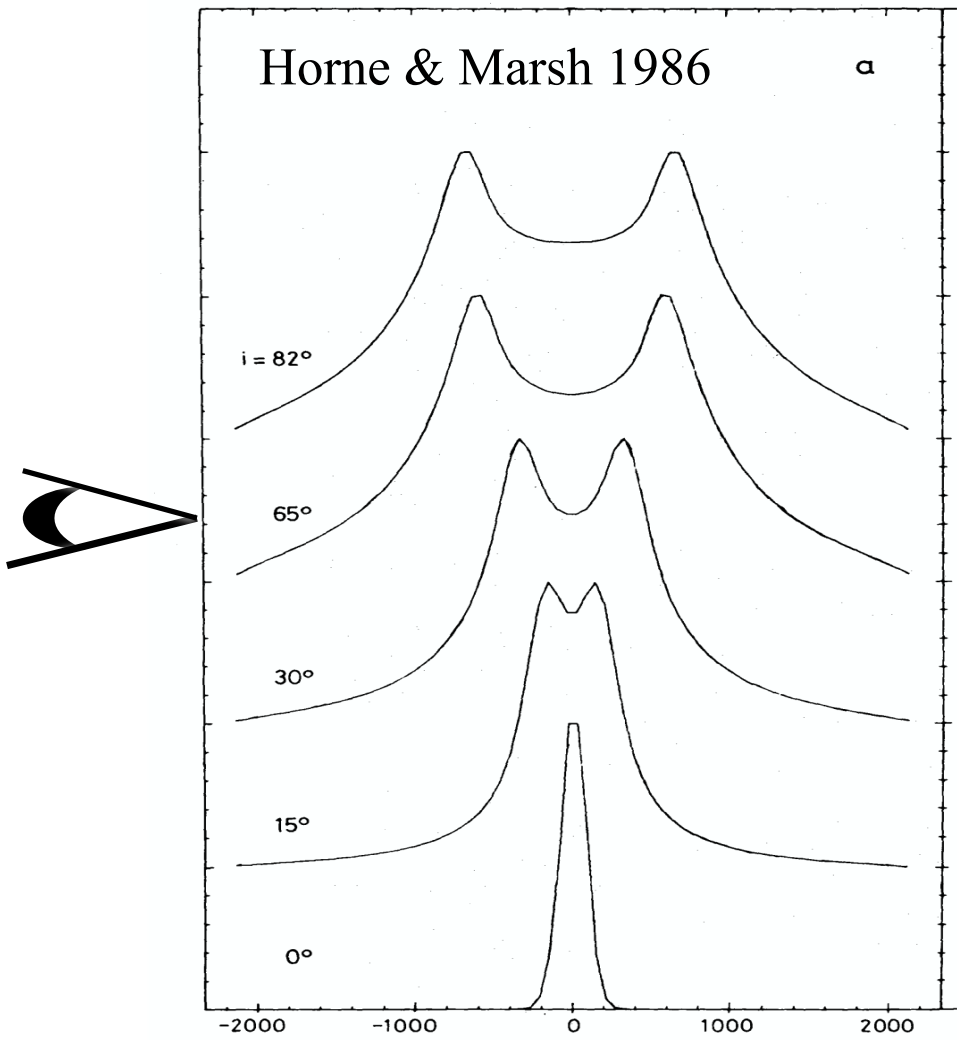
Emissivity map



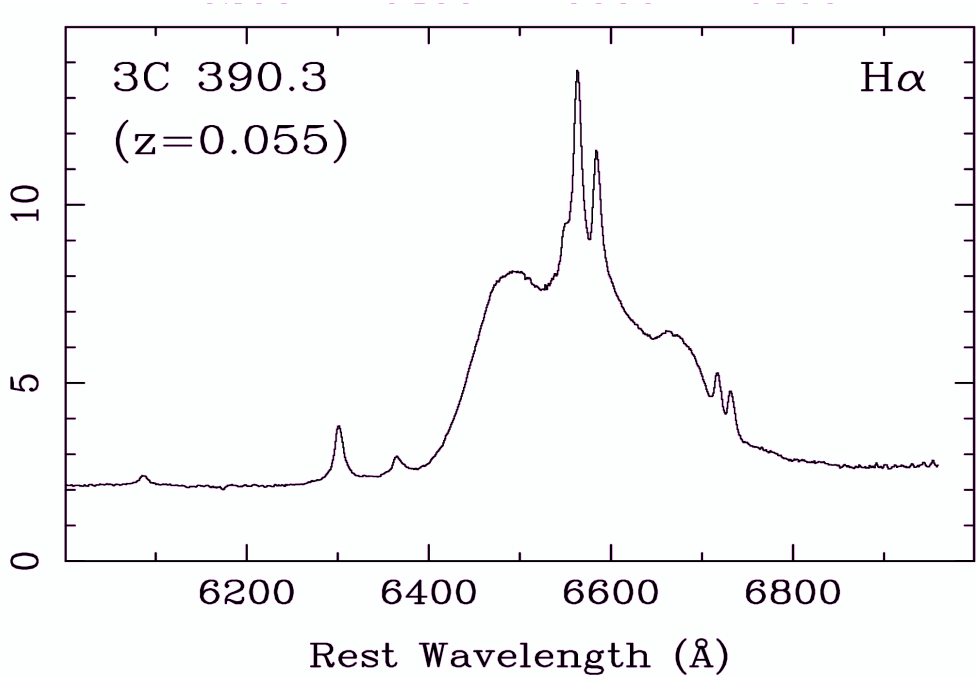
Spectroscopic signature of disk

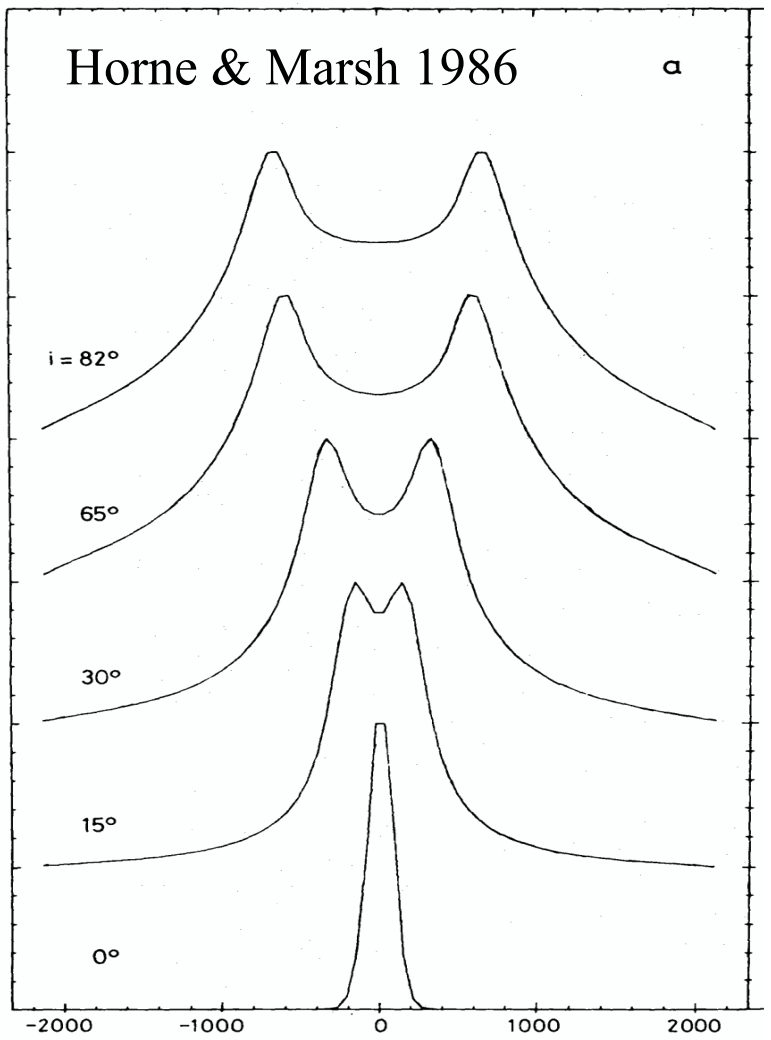
Velocity map



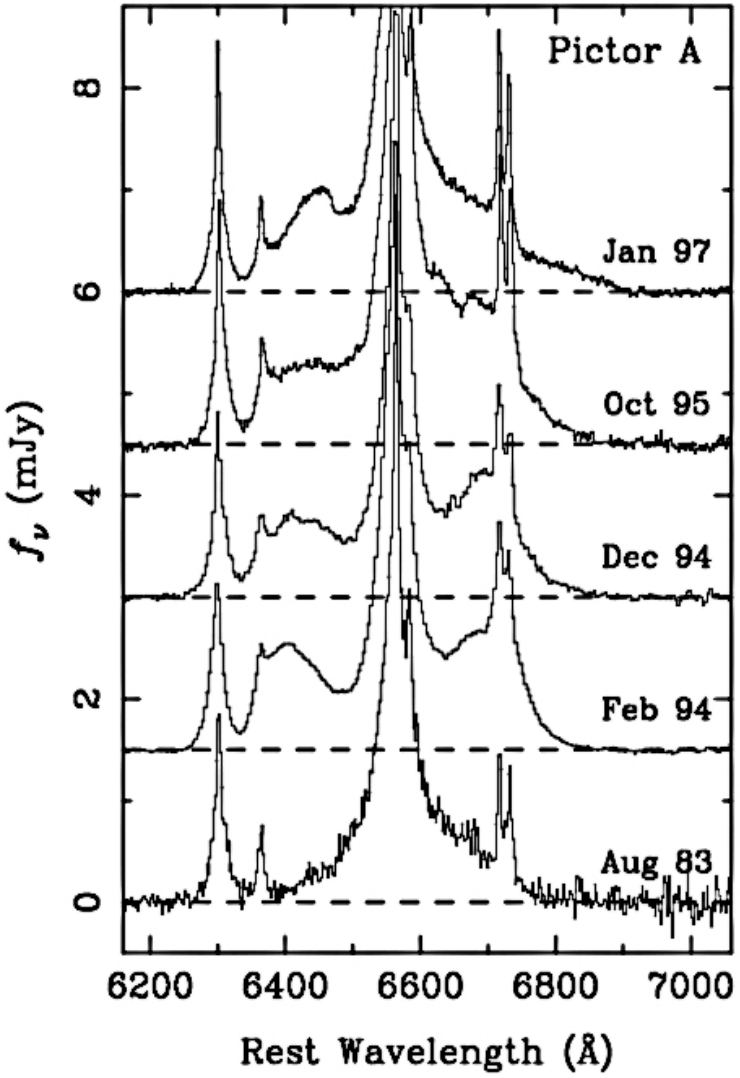


Spectroscopic signature of disk



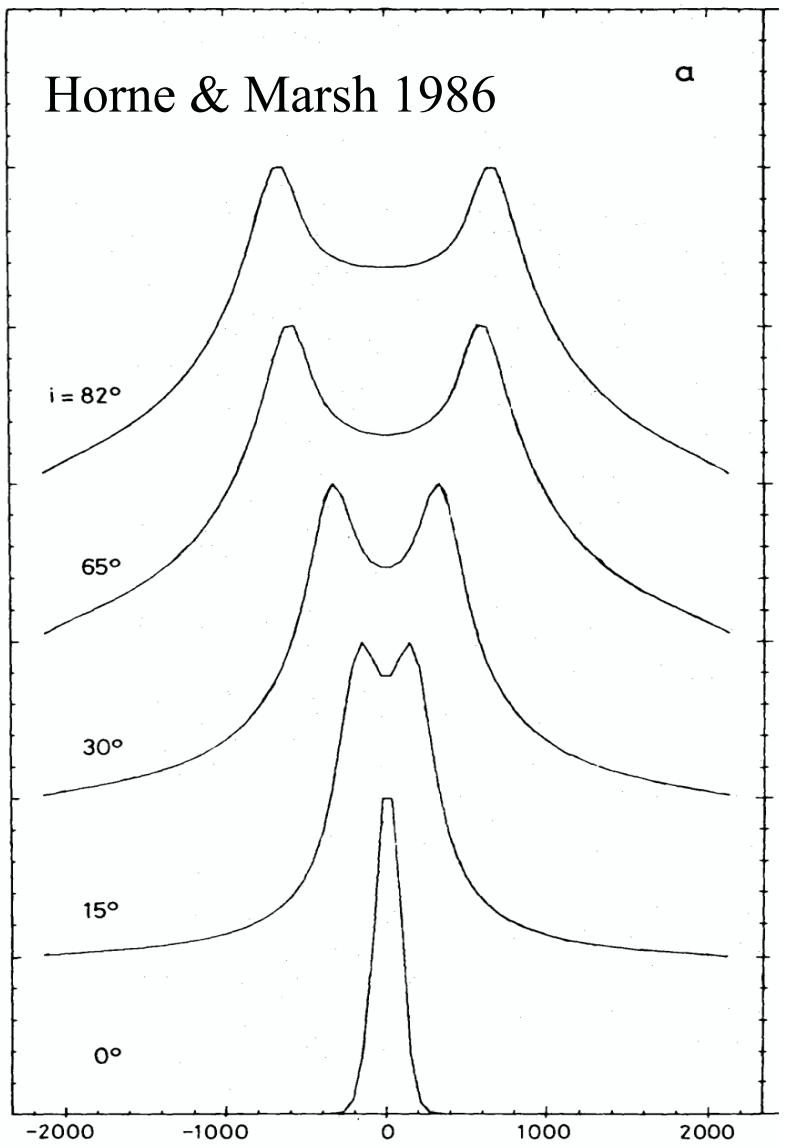


Double-peaked ⇔ Single-peaked

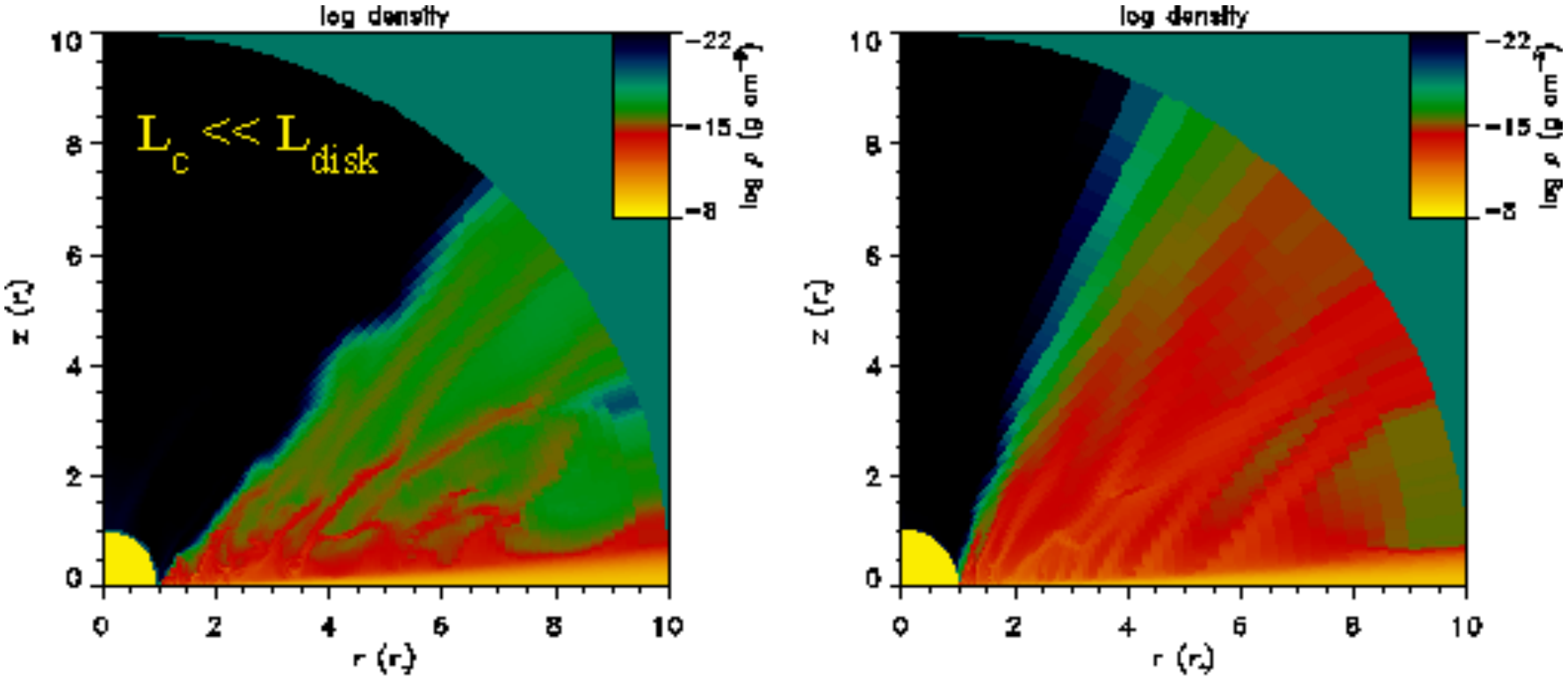


Eracleous & Halpern 1998

Double-peaked ⇔ Single-peaked

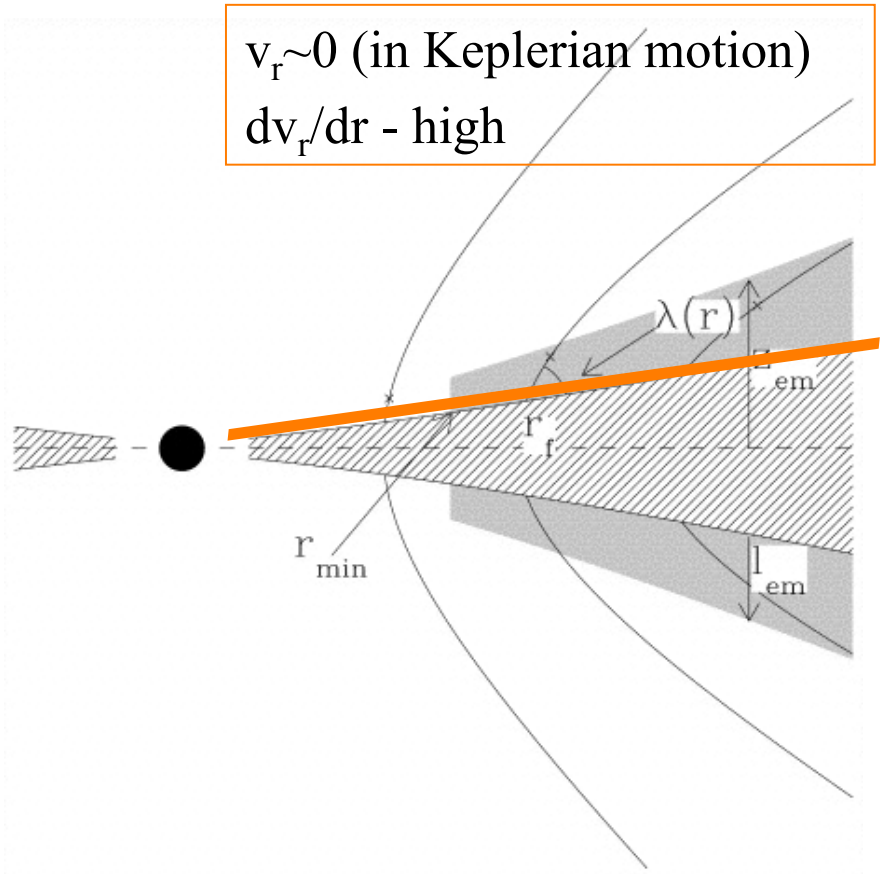


Double-peaked ⇔ Single-peaked



Proga et al. 2000

Effect of disk-wind on line profile



Sobolev approximation:

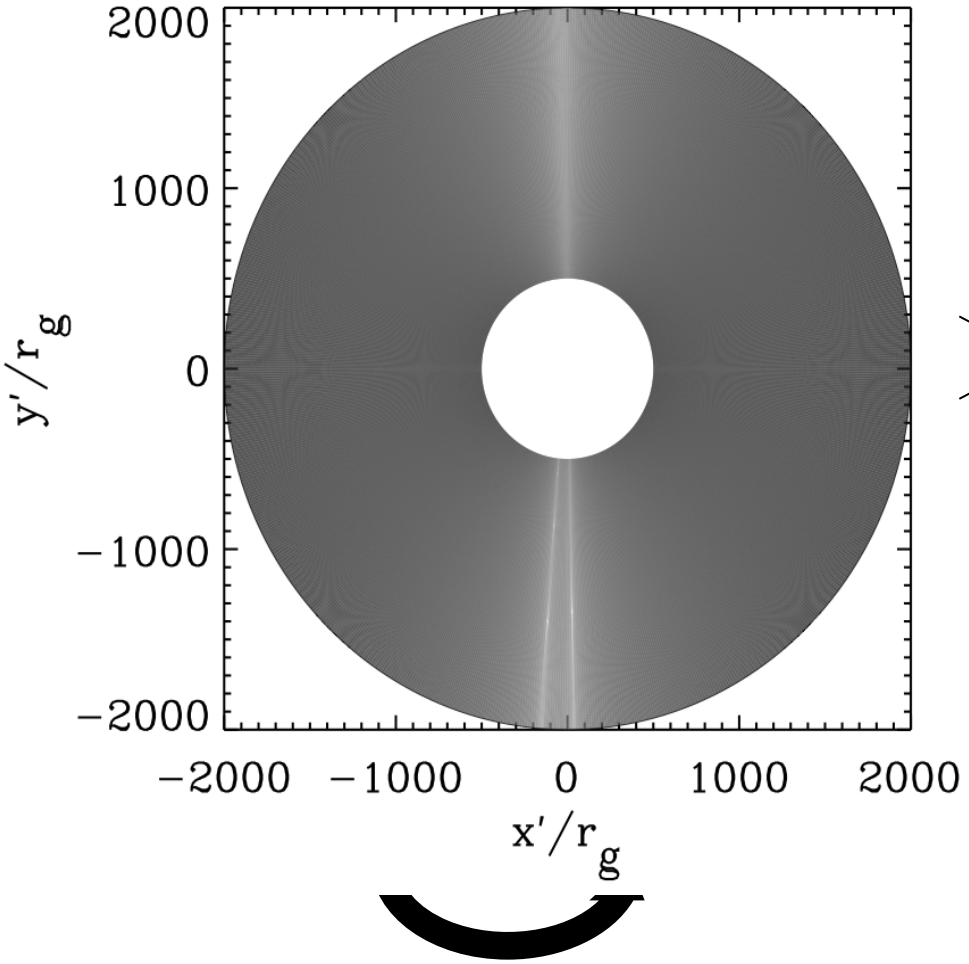
$$\tau \propto \frac{\rho}{|\hat{\mathbf{n}} \cdot \boldsymbol{\Lambda} \cdot \hat{\mathbf{n}}|}$$

~dv_r/dr

Chiang & Murray 1996

Effect of disk-wind on line profile

Emissivity map



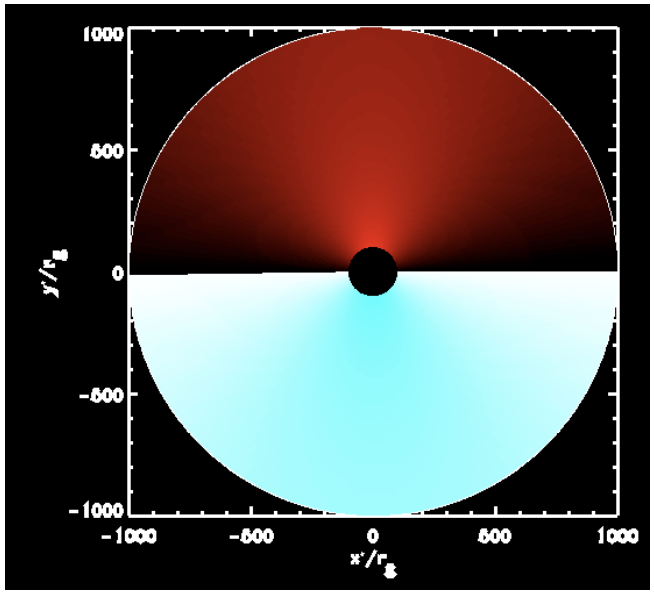
$$\tau \propto \frac{\rho}{|\hat{\mathbf{n}} \cdot \boldsymbol{\Lambda} \cdot \hat{\mathbf{n}}|}$$

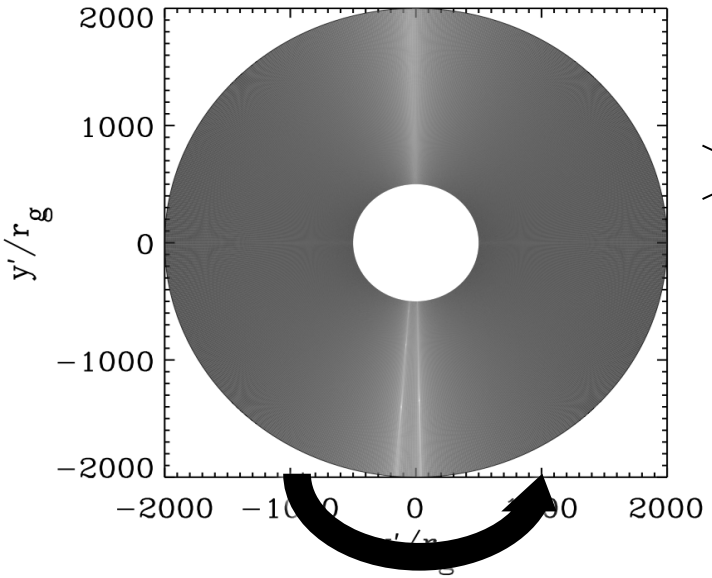
$\sim dv_r/dr$

High projected dv_r/dr – low opacity

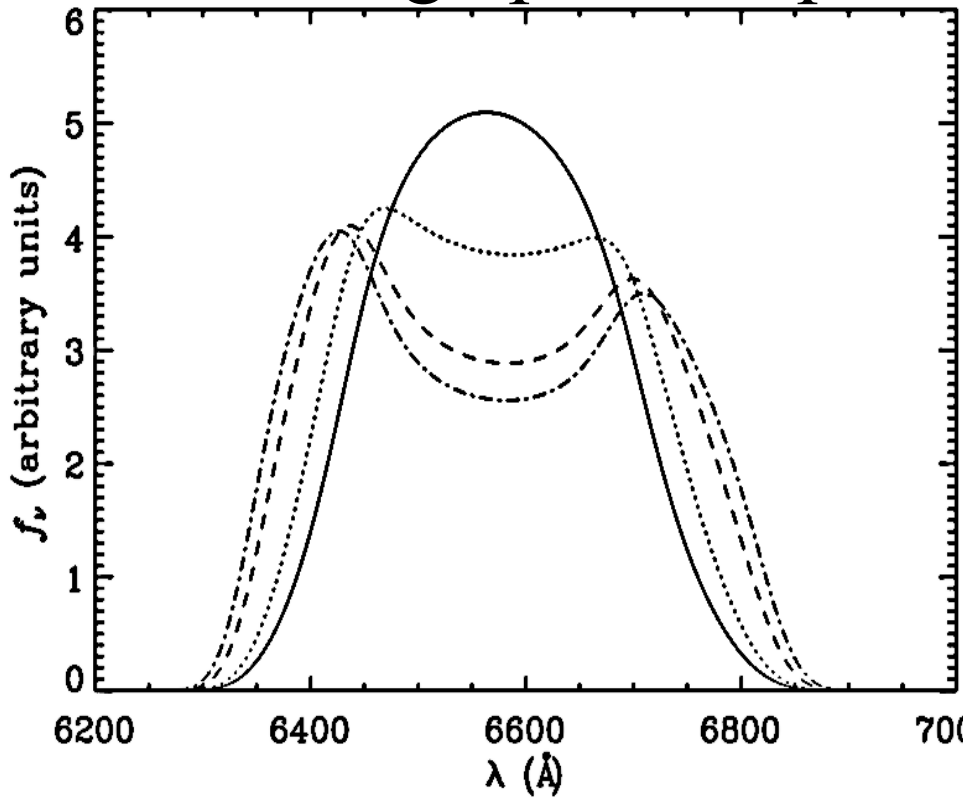
Low projected dv_r/dr – high opacity

Effect of disk-wind on line profile





Increasing optical depth

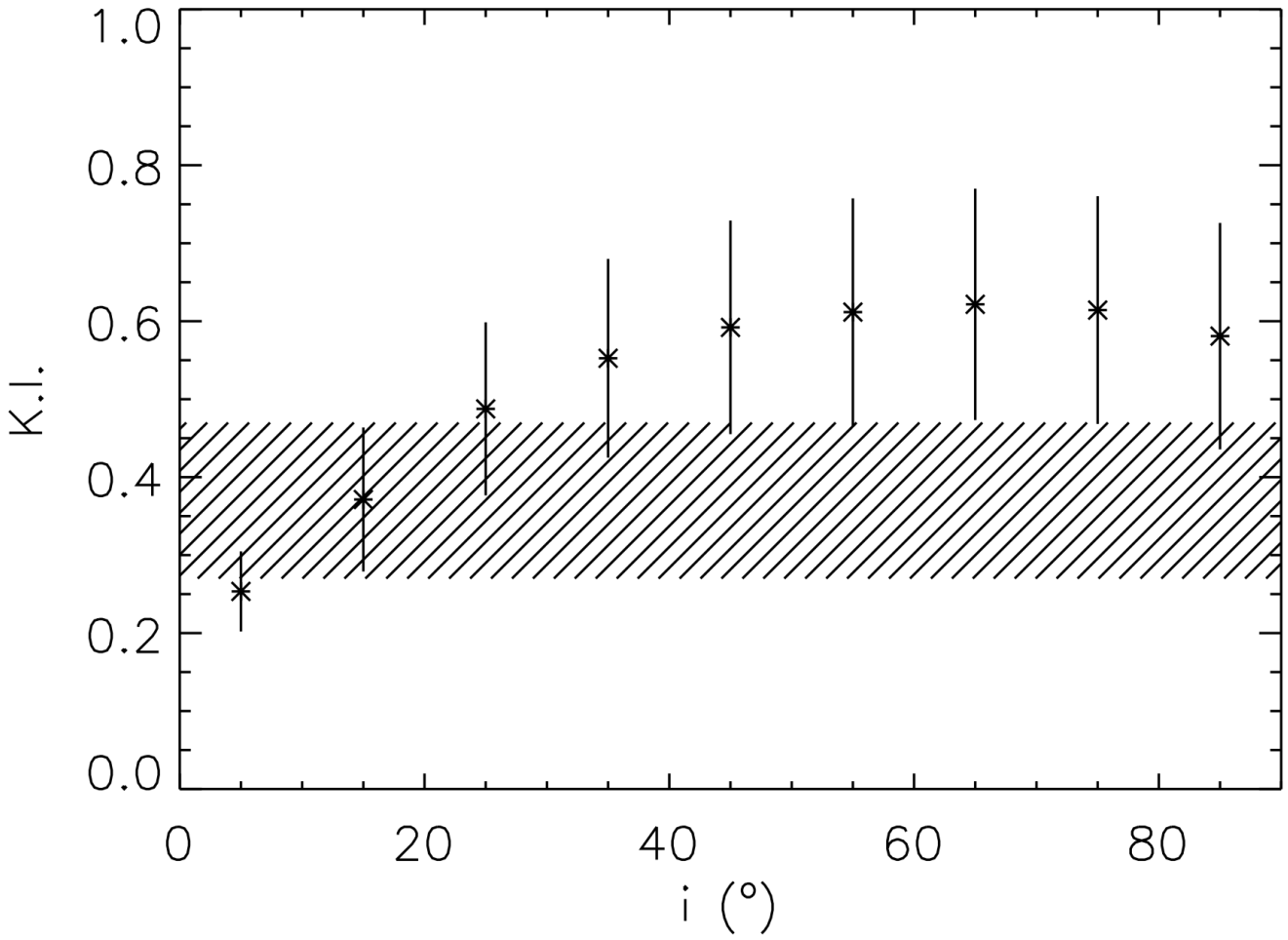


Flohic et al. 2011 (in prep)

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

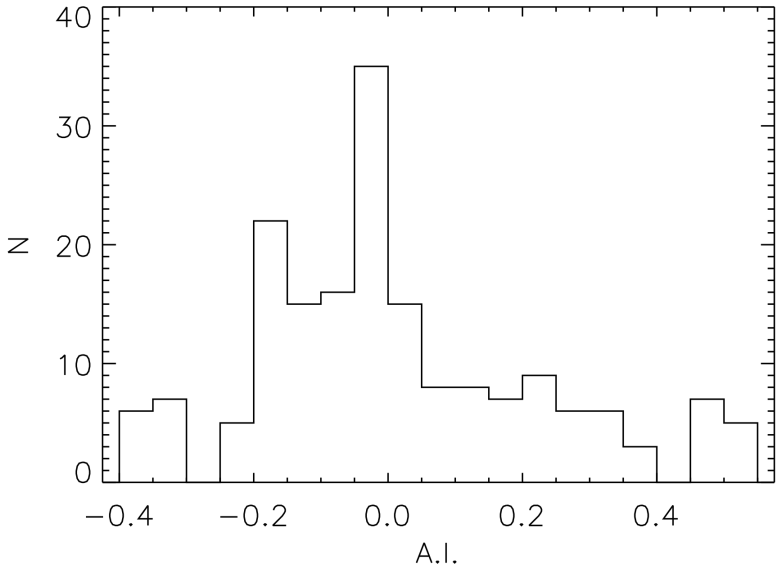
Flohic et al. 2011 (in prep)



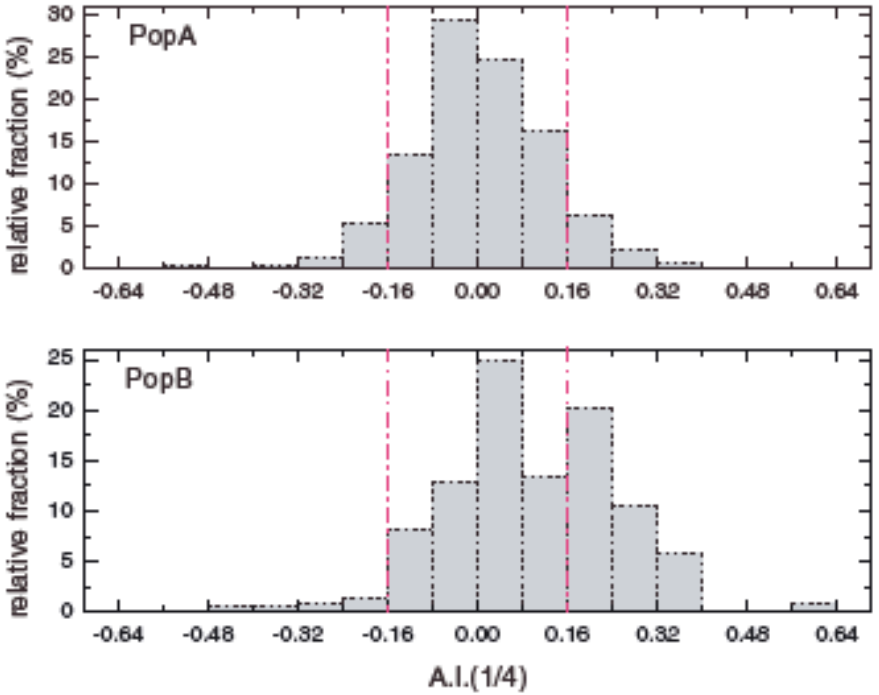
Flohic et al. 2011 (in prep)

Realistic line profiles?

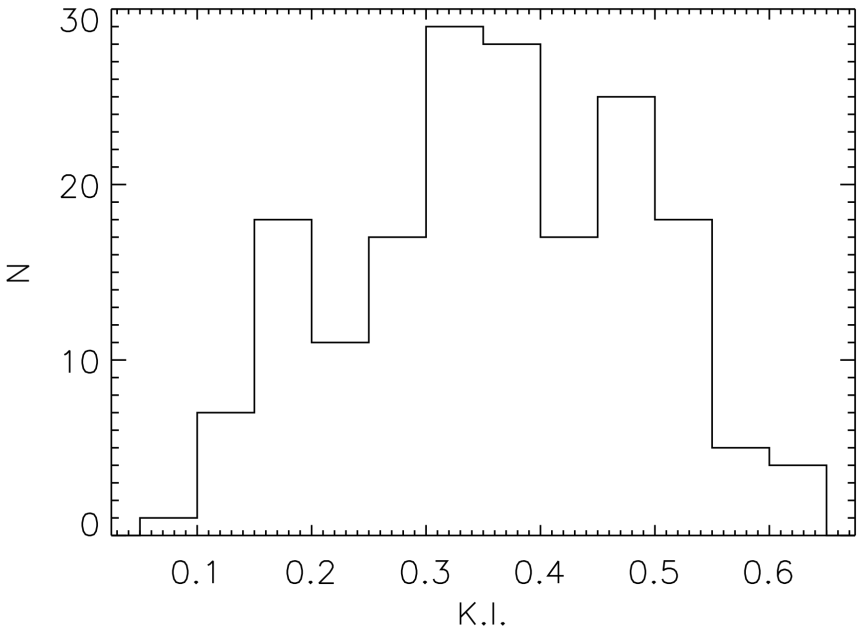
- Inclination < 45 d
- $R_{in} < 2000\ r_g$
- $R_{out} > 5000\ r_g$
- $n \propto r^{-\eta} - \eta > 0.5$
- High optically depth

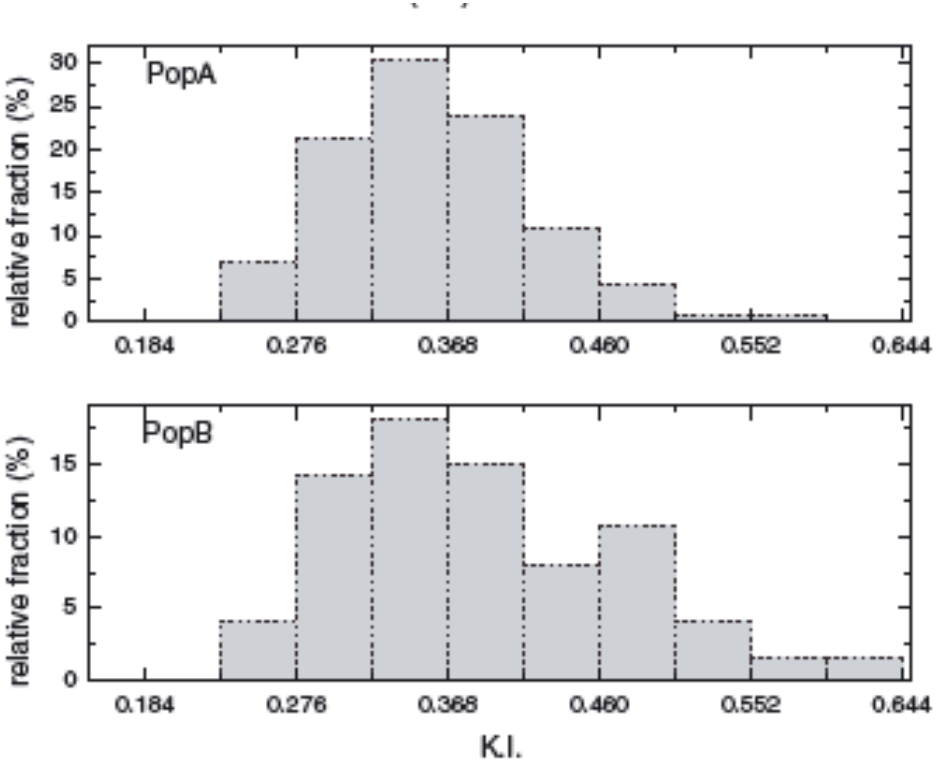


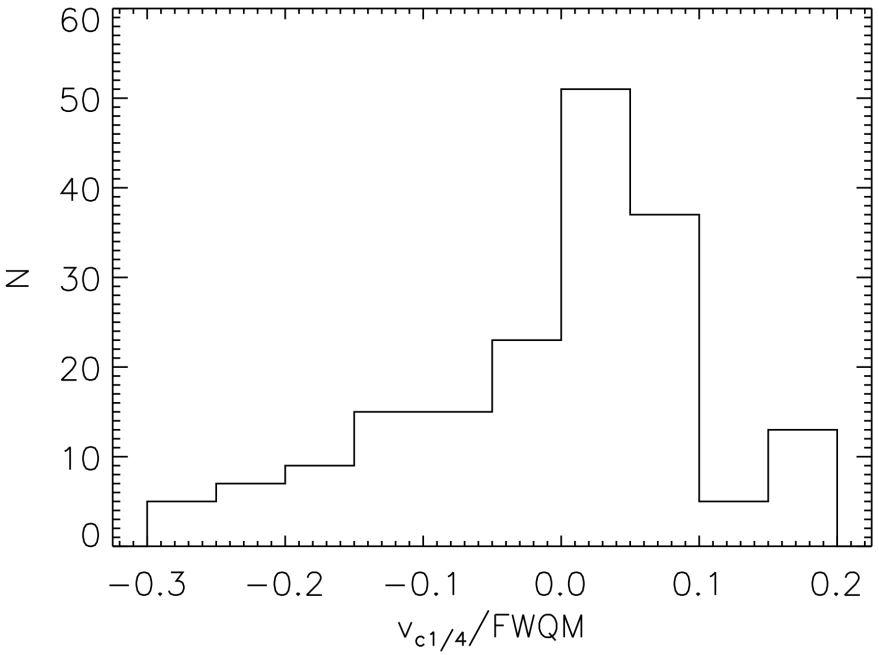
Flohic et al. 2011 (in prep)

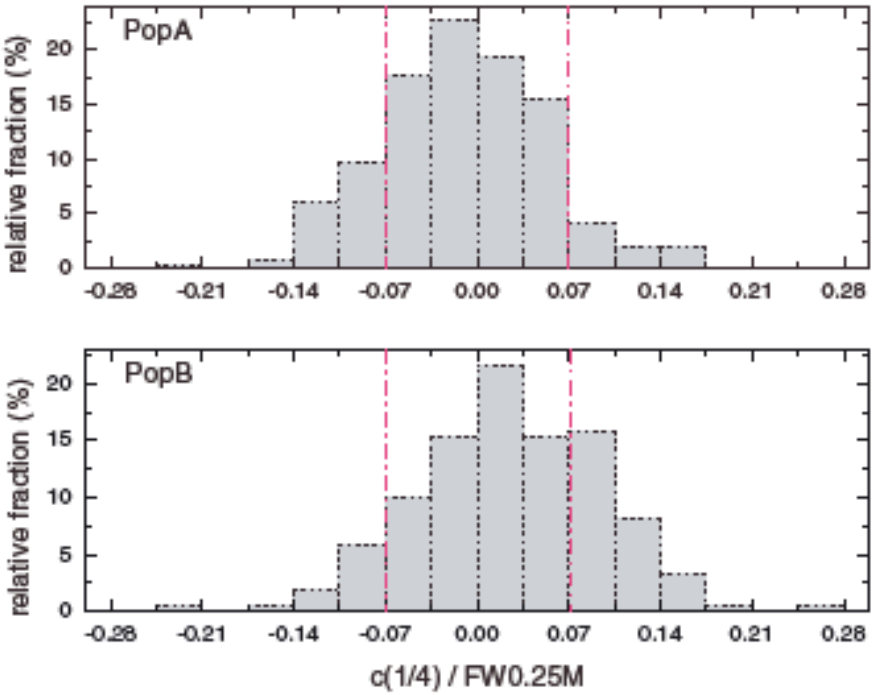


Zamfir et al. 2010

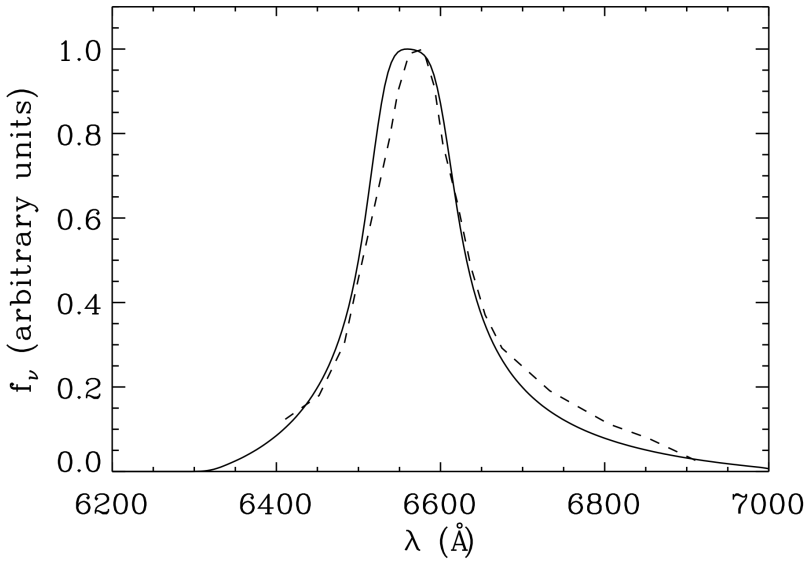

30
20
10
0
N
0.1
0.2
0.3
0.4
0.5
0.6
K.I.


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.

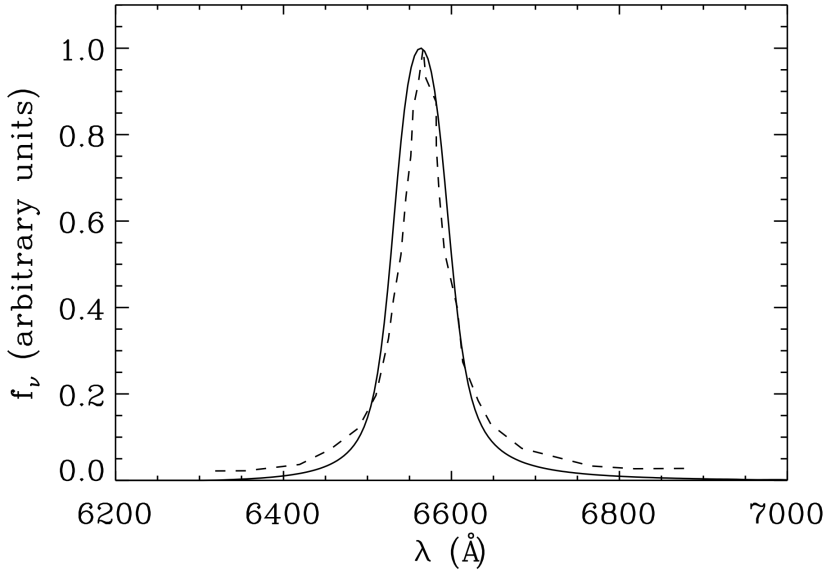

N
60
50
40
30
20
10
0
−0.3
−0.2
−0.1
0.0
0.1
0.2
$v_{c1/4}$/FWQM


PopA
PopB
relative fraction (%)
20
15
10
5
0
-0.28
-0.21
-0.14
-0.07
0.00
0.07
0.14
0.21
0.28
c(1/4) / FW0.25M

Double Gaussian (pop B)

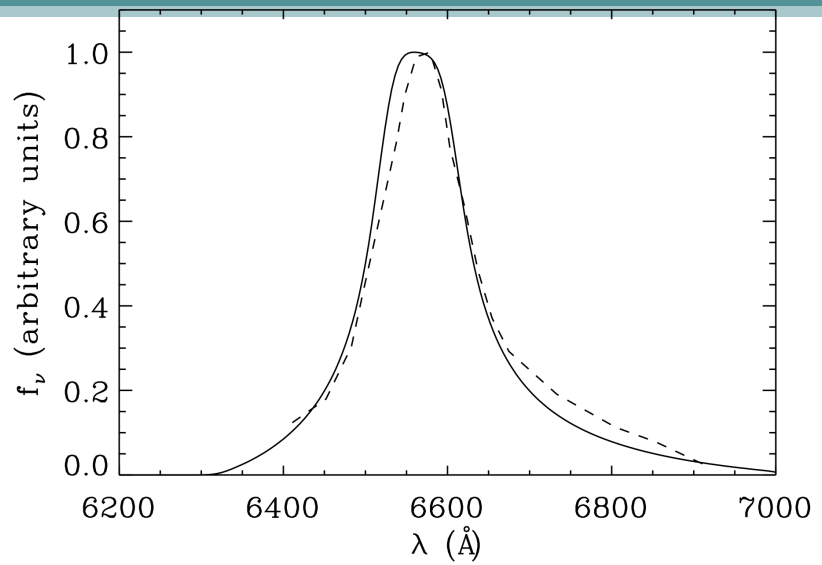


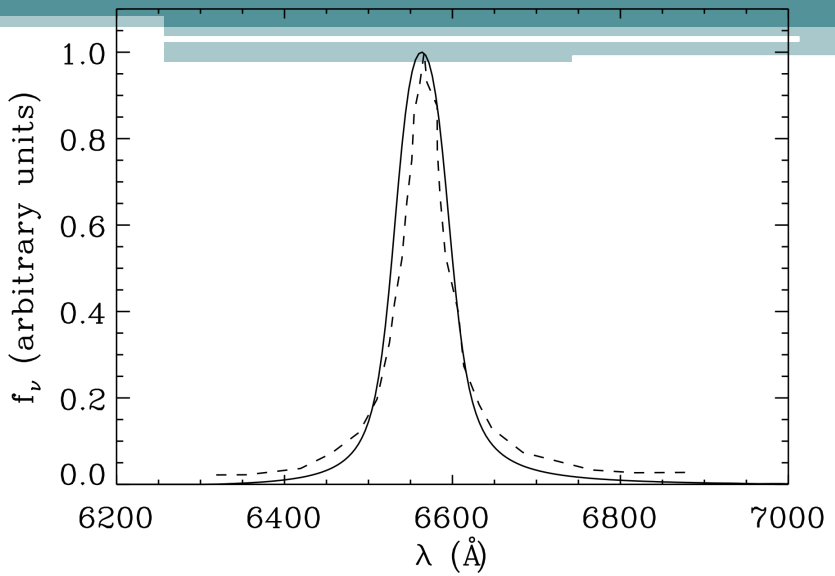
Lorentzian (pop A)

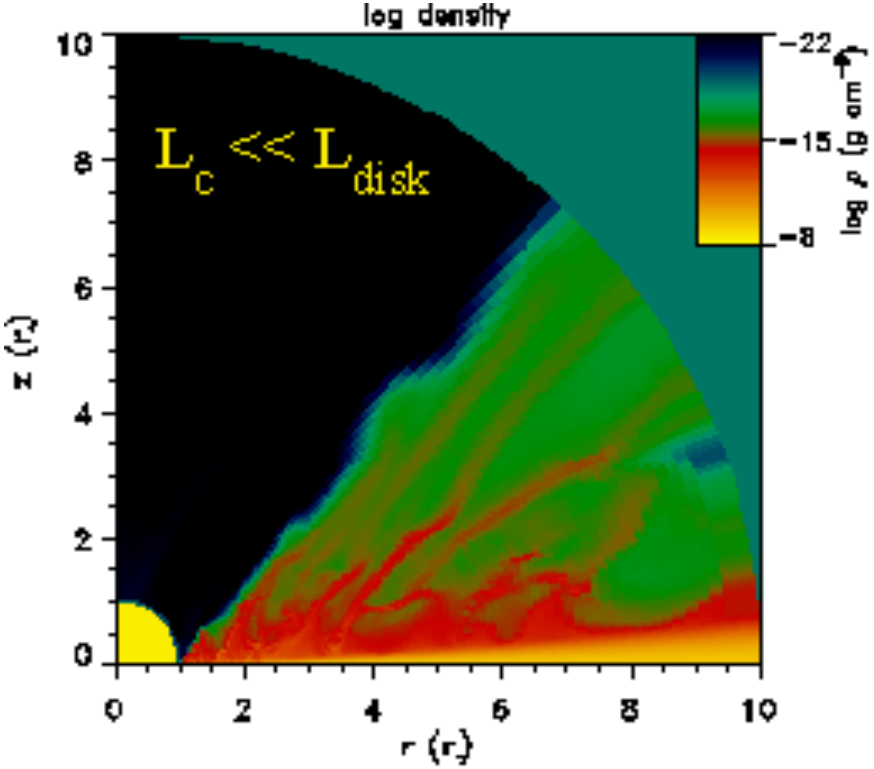


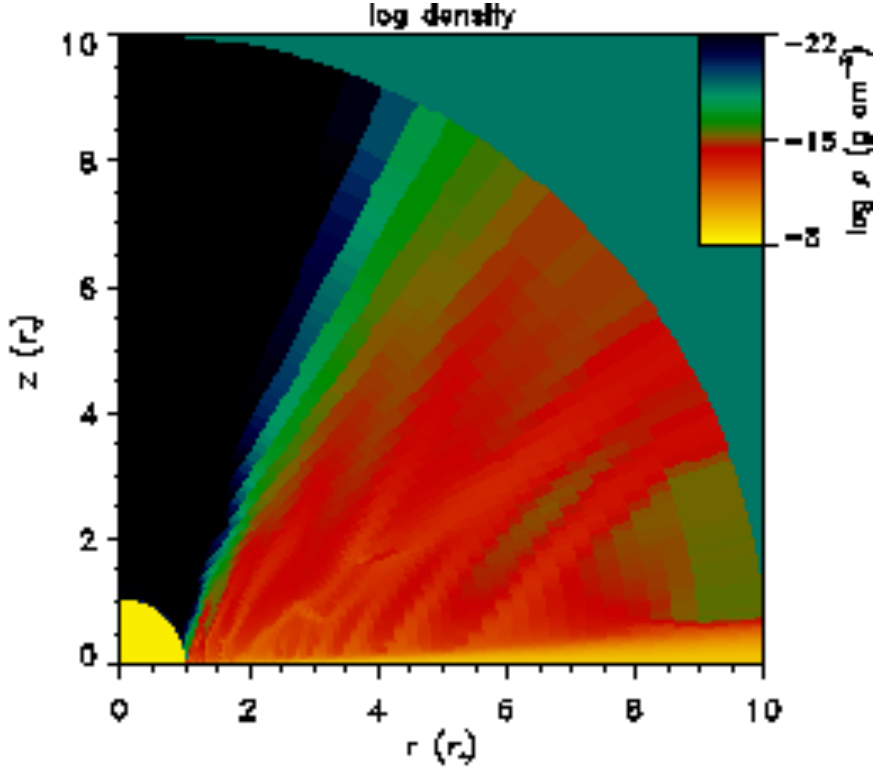
Sulentic et al. 2009

Flohic et al. 2011 (in prep)


1.0
0.8
0.6
0.4
0.2
0.0
f_ν (arbitrary units)
6200
6400
6600
6800
7000
λ (Å)

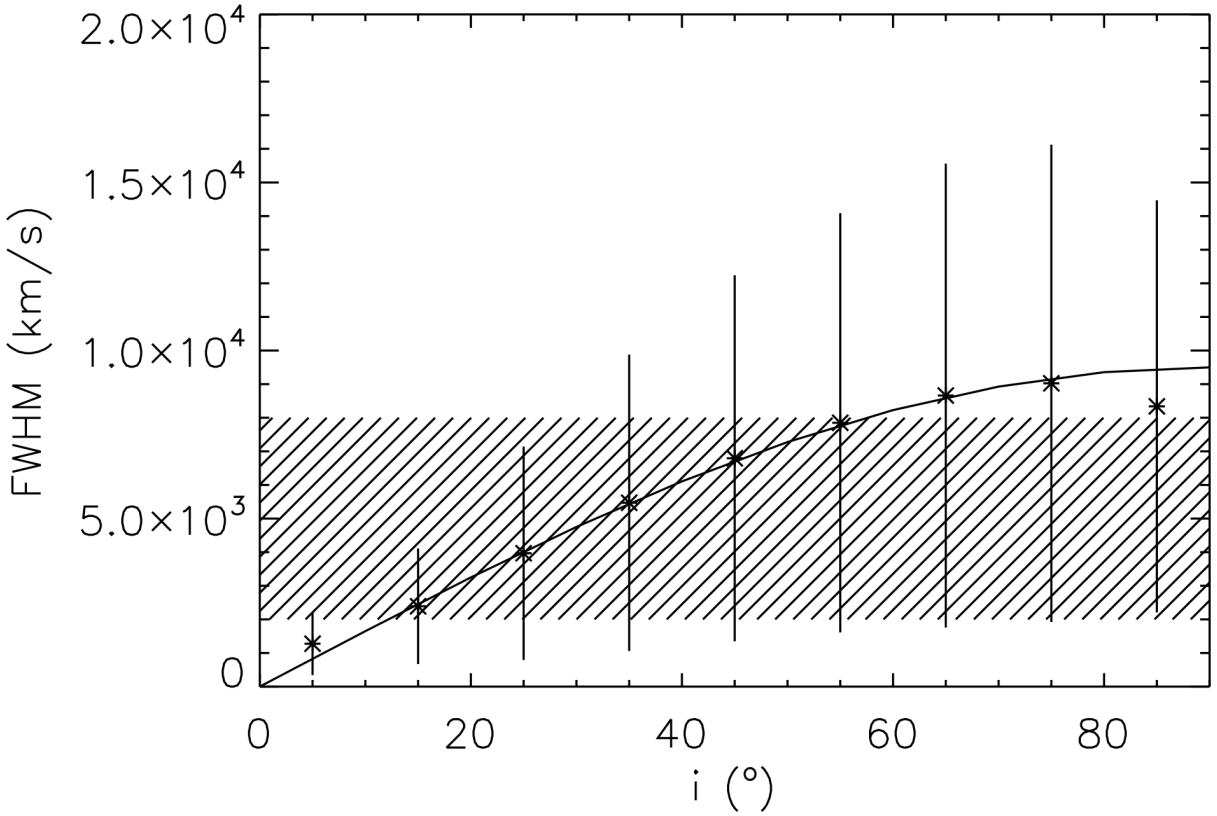

1.0
0.8
0.6
0.4
0.2
0.0
f_ν (arbitrary units)
6200
6400
6600
6800
7000
λ (Å)


log density
$L_c \ll L_{disk}$
−22
−15
−8
log ρ (g cm⁻³)
z (r_s)
r (r_s)
0
2
4
6
8
10


log density
−22
−15
−8
log ρ (g cm⁻³)
z (r_s)
r (r_s)
0
2
4
6
8
10

Possible problems for mass estimate

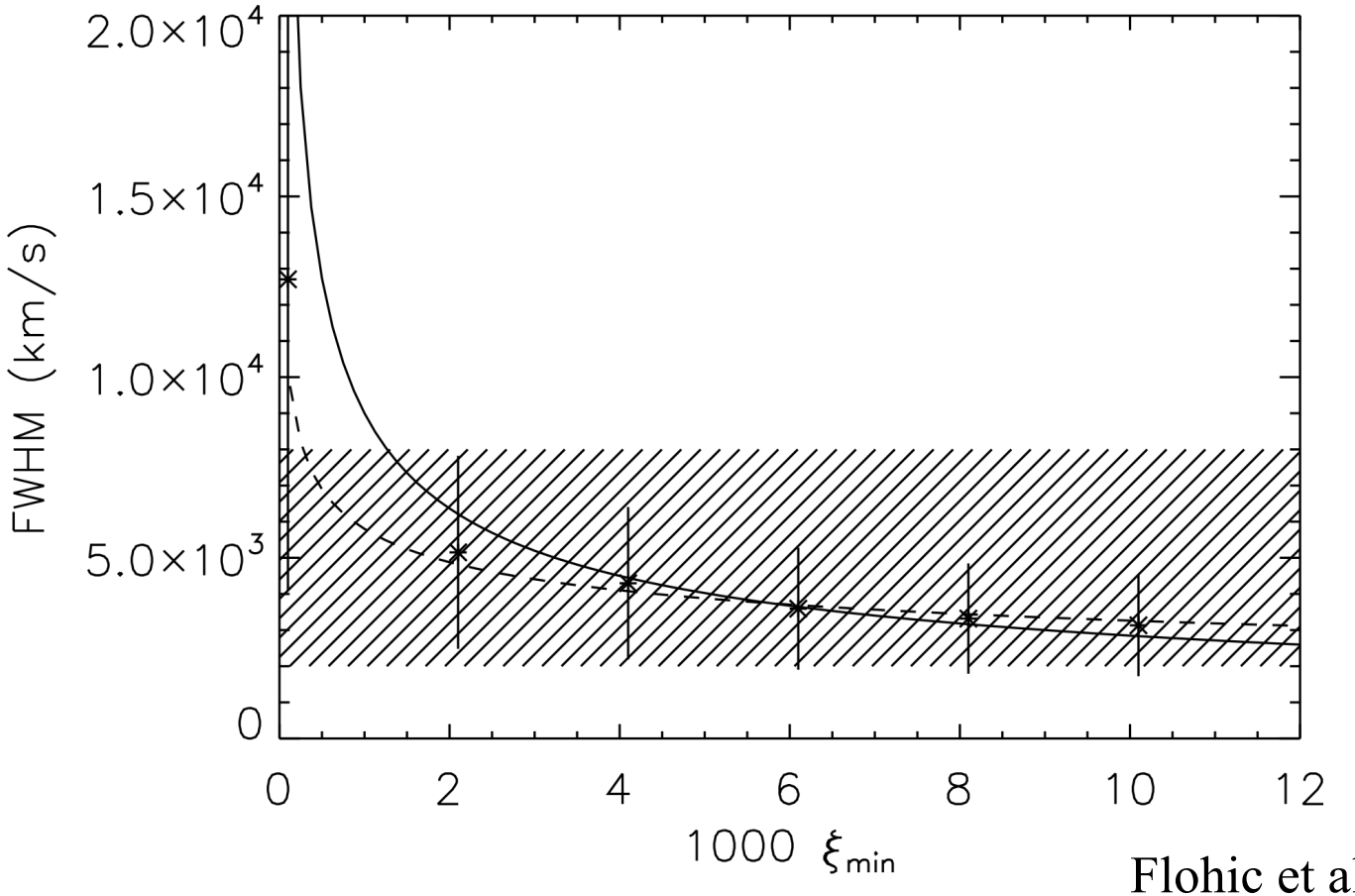
$$M_{BH} = f\, R_{BLR}\, v^2$$



Flohic et al. 2011 (in prep)

Possible problems for mass estimate

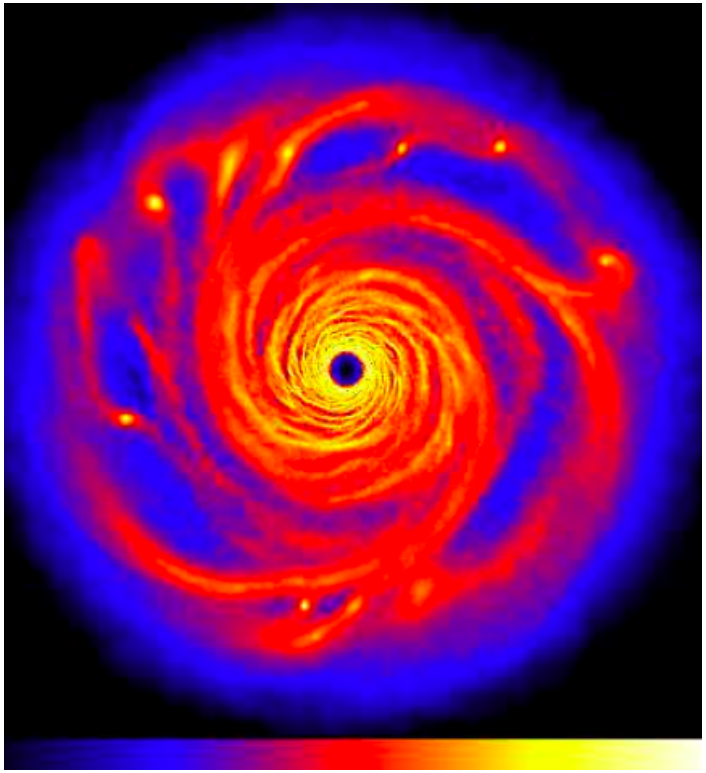
$$M_{BH} = f\, R_{BLR}\, v^2$$



Flohic et al. 2011 (in prep)

So…

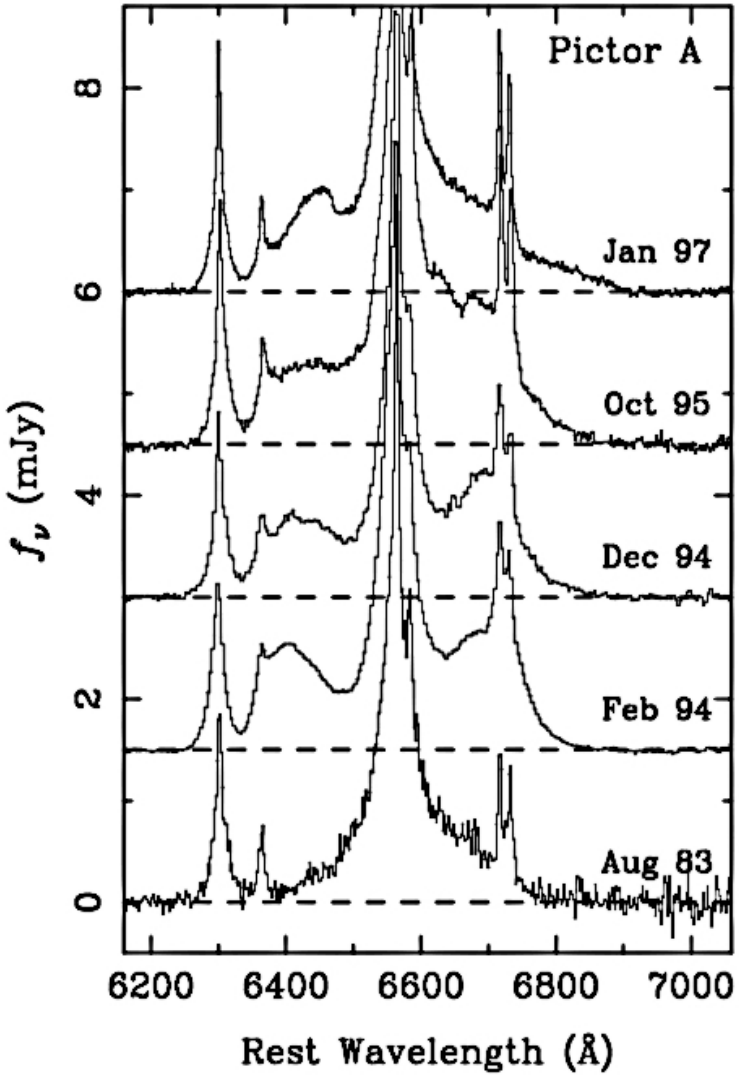
- Accretion disk + wind produces realistic line profiles
- But does the accretion disk have structure? Clumps, spiral…



Rice et al. 2005

Variable double-peaked profile

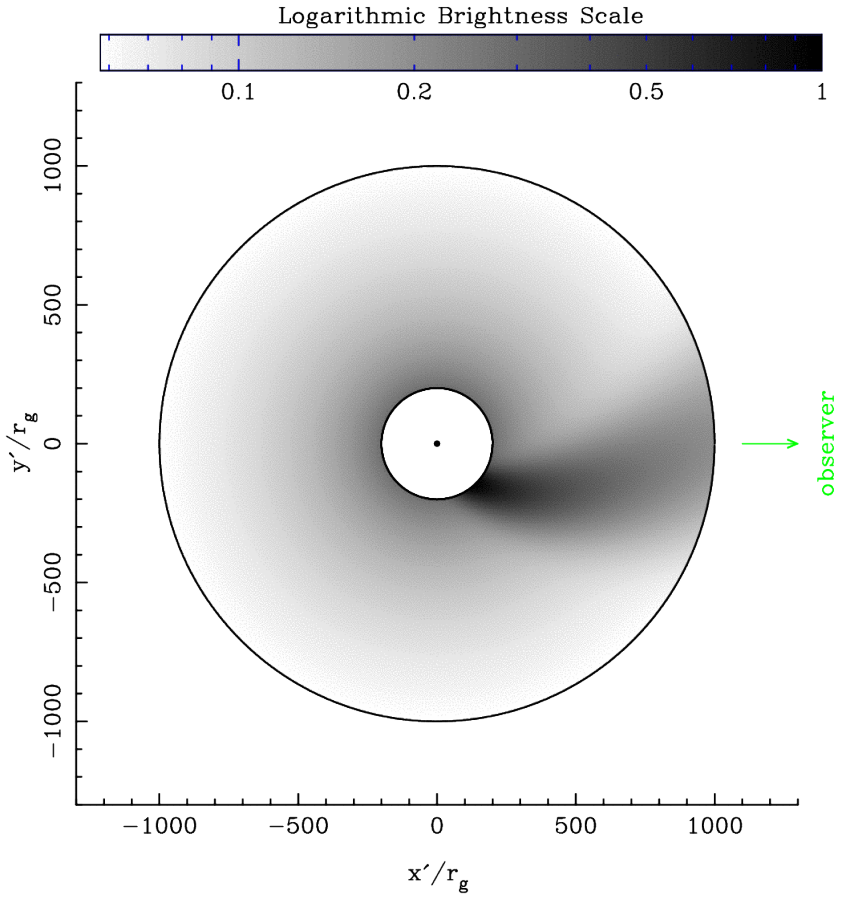
- Variability of profile uncorrelated with variability of line and/or continuum flux
- Likely traces changes in accretion disk structure
- DPELs give us a ‘direct’ view of the accretion disk



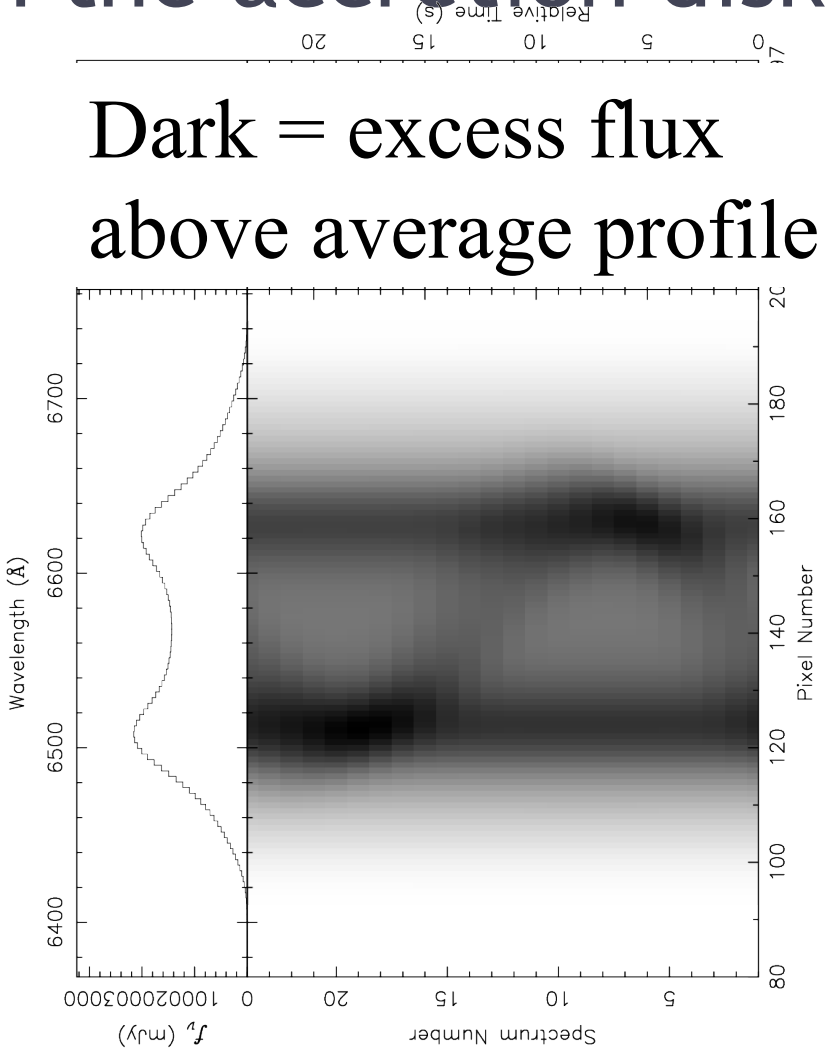
Eracleous & Halpern 1998

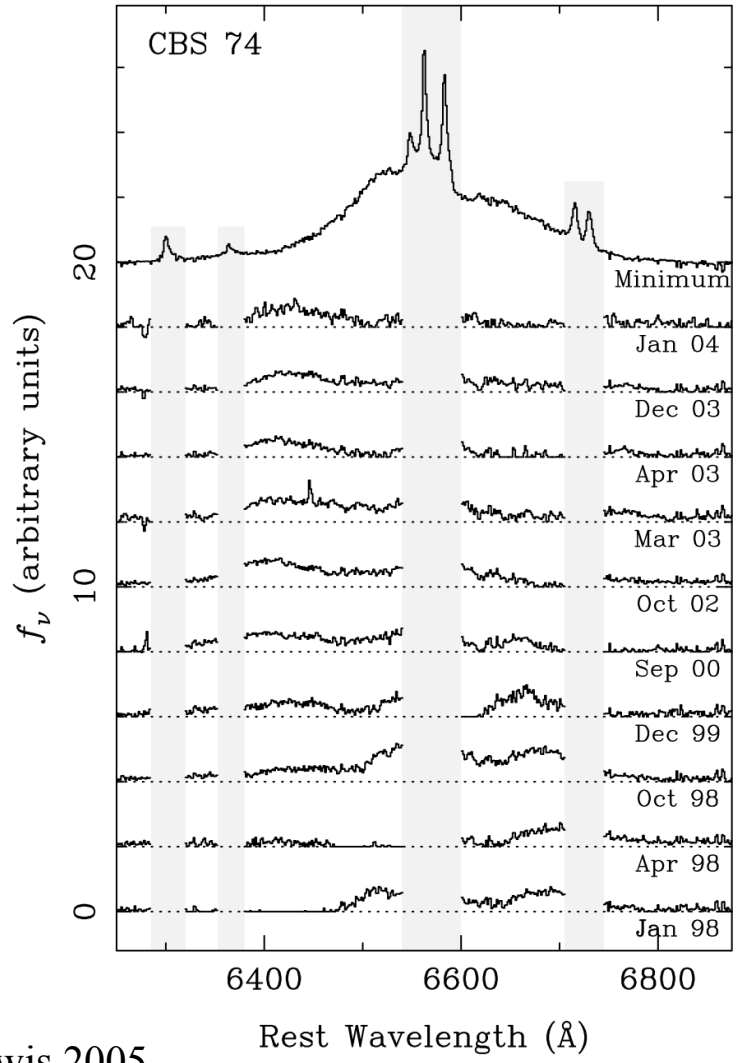
If there is structure in the accretion disk…

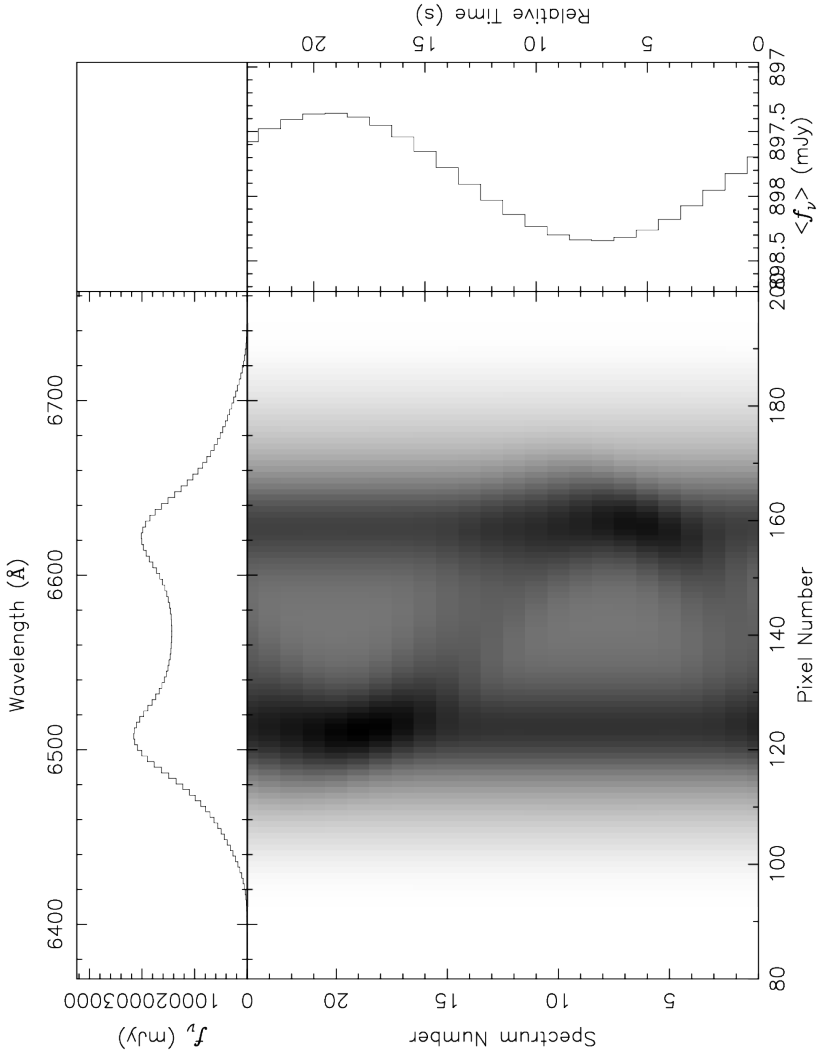
Emissivity map



Dark = excess flux above average profile

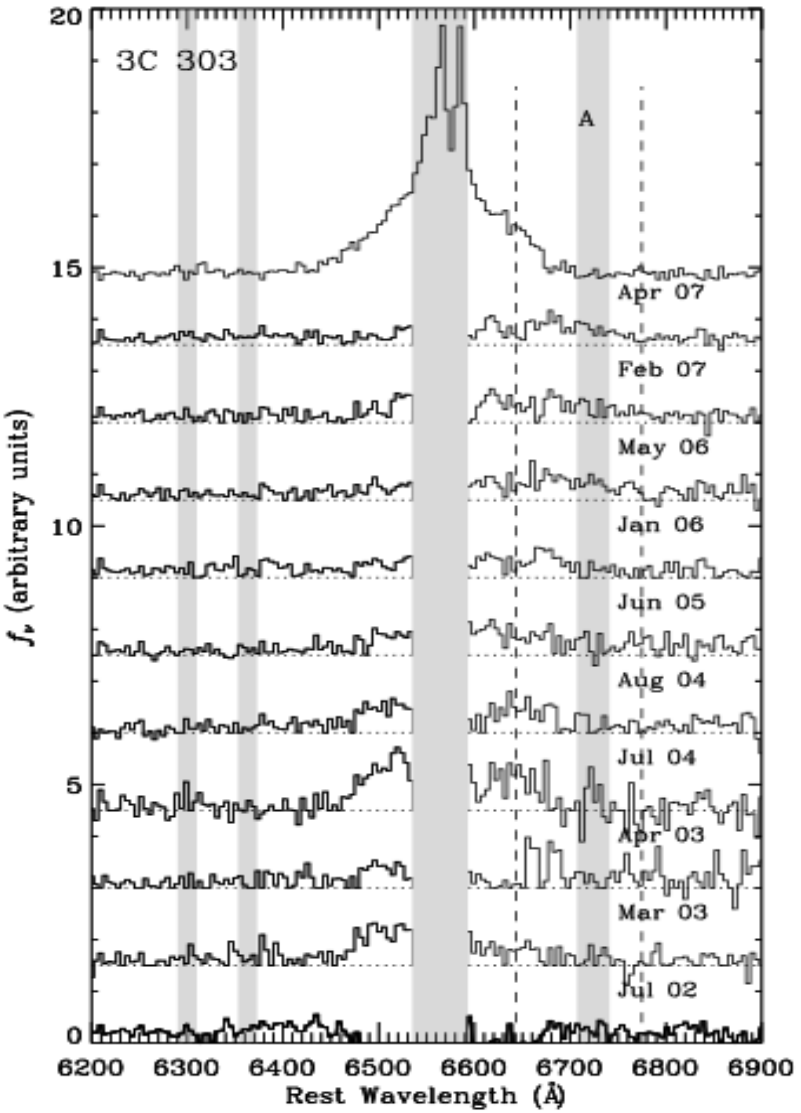



CBS 74
Minimum
Jan 04
Dec 03
Apr 03
Mar 03
Oct 02
Sep 00
Dec 99
Oct 98
Apr 98
Jan 98
f_ν (arbitrary units)
Rest Wavelength (Å)
0
10
20
6400
6600
6800


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

Lewis 2005

Long-term monitoring

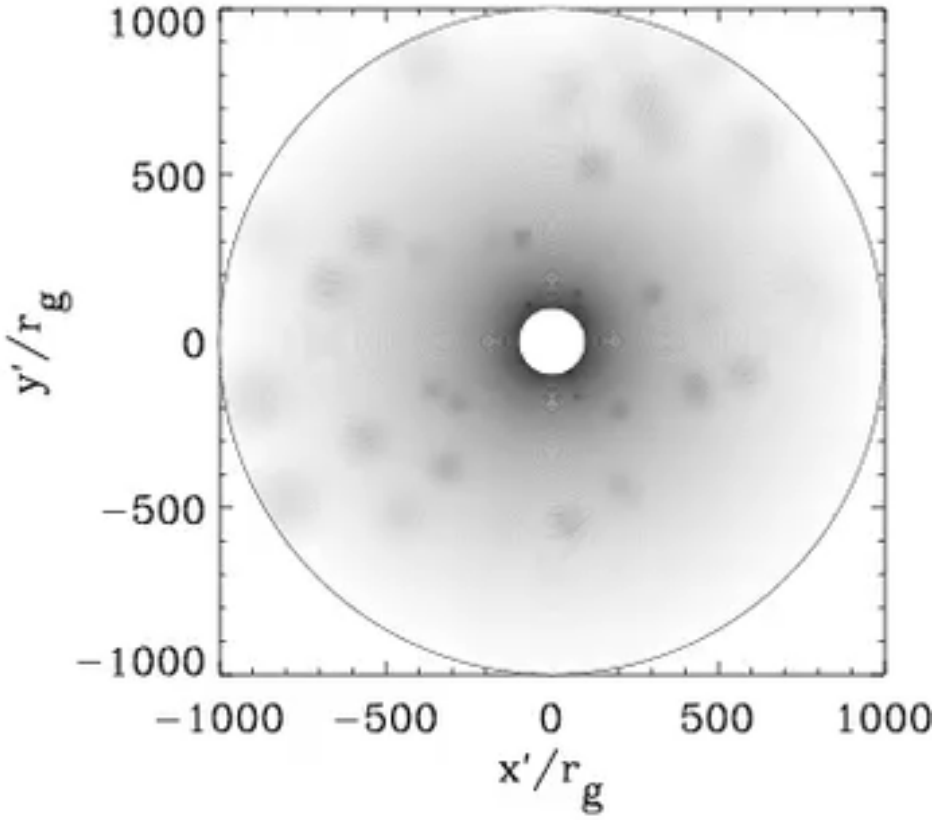


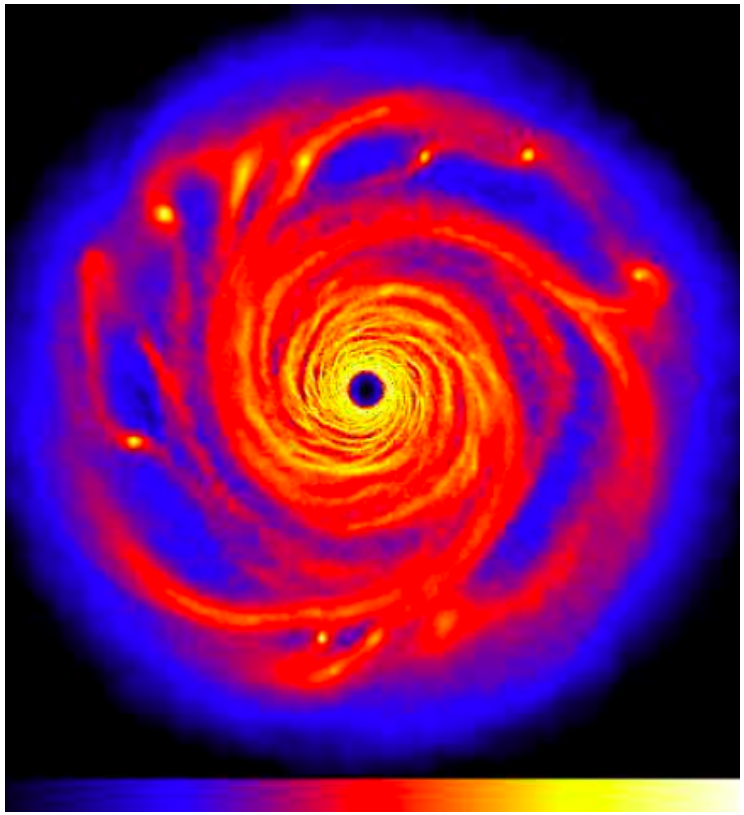
Flohic & Eracleous 2011 (in prep)

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

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

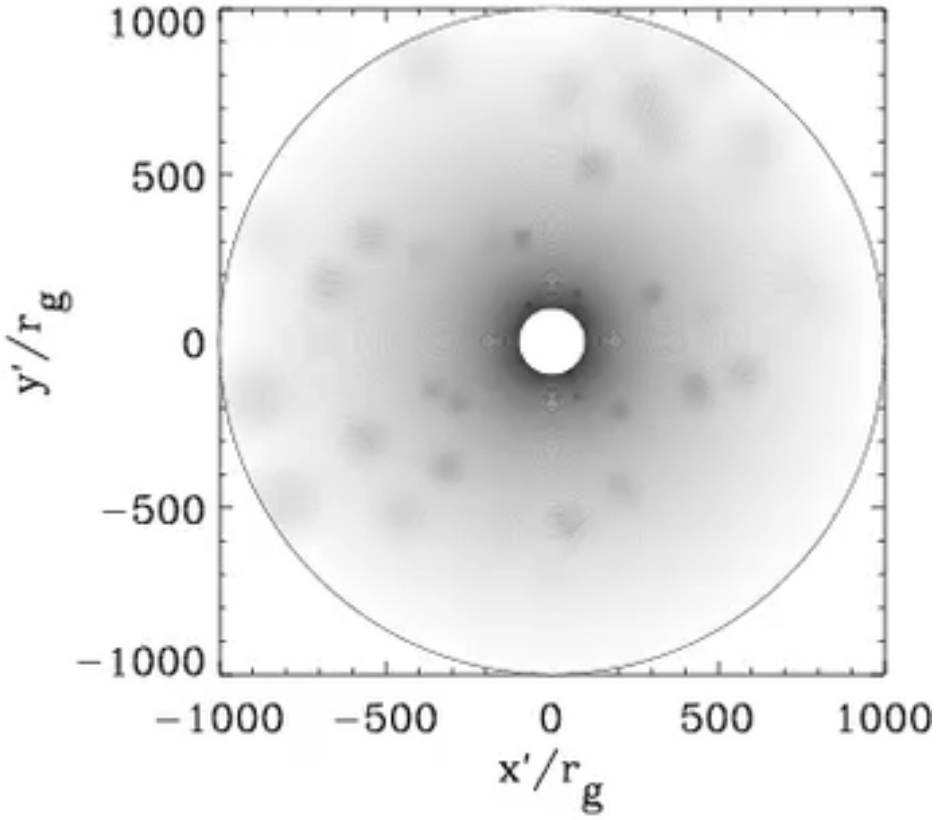
Stochastically perturbed disk





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

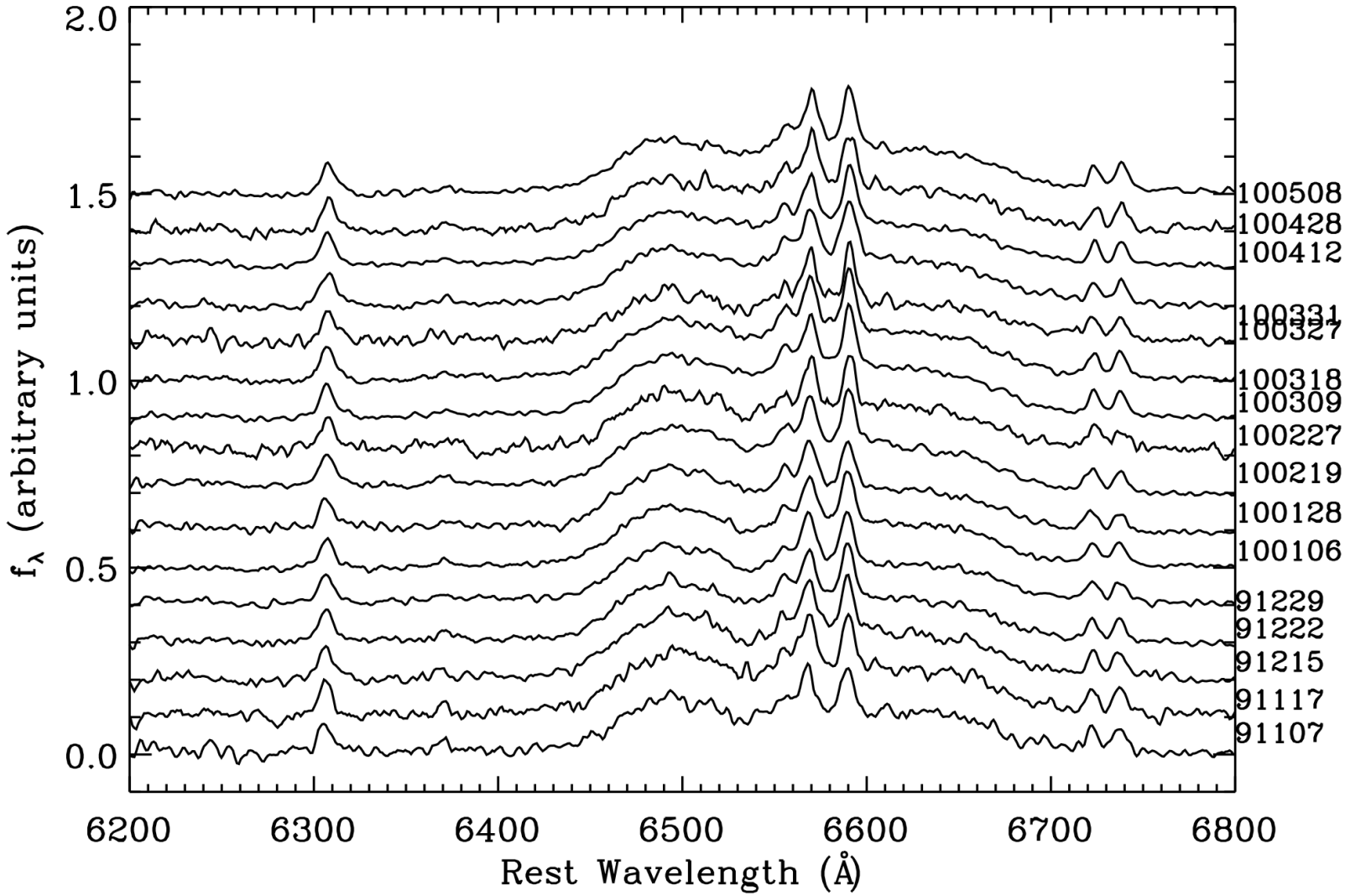
Obtaining more observations

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

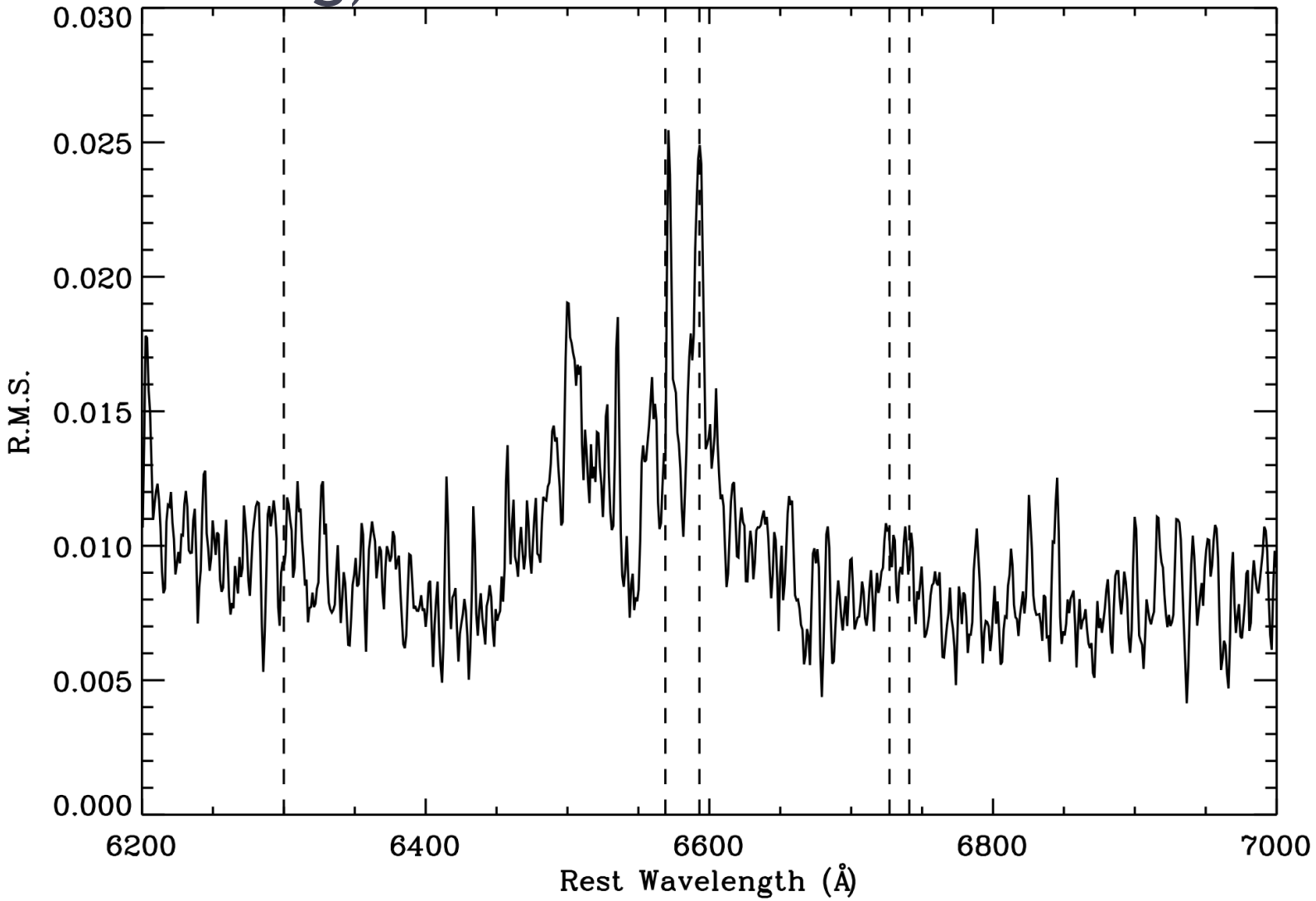
→Target DP AGNs with low mass BH (and reange of Eddington ratios)

- 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

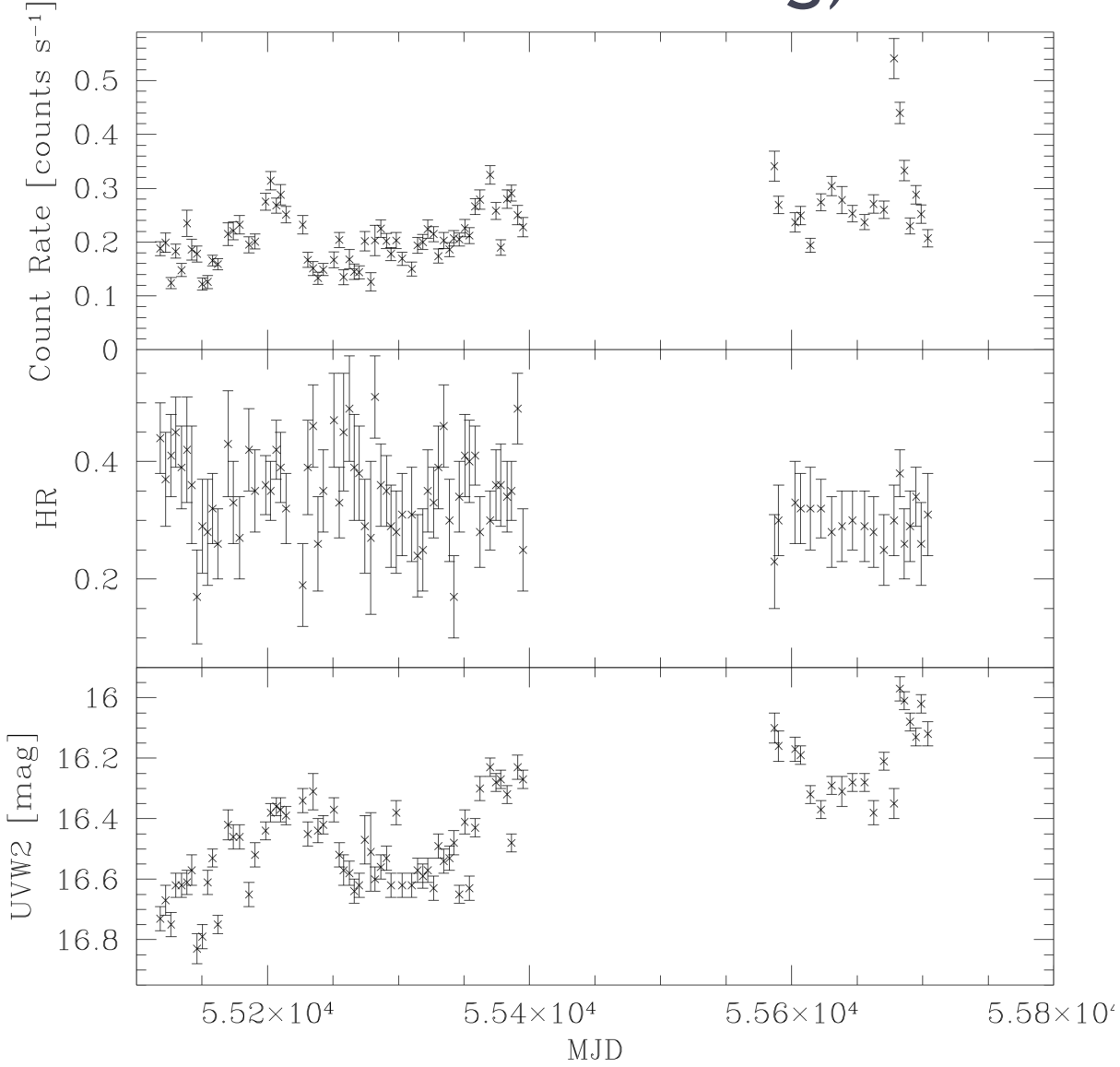
Preliminary results (one year of optical monitoring)



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