Structure and Kinematics of the central BLR in AGN

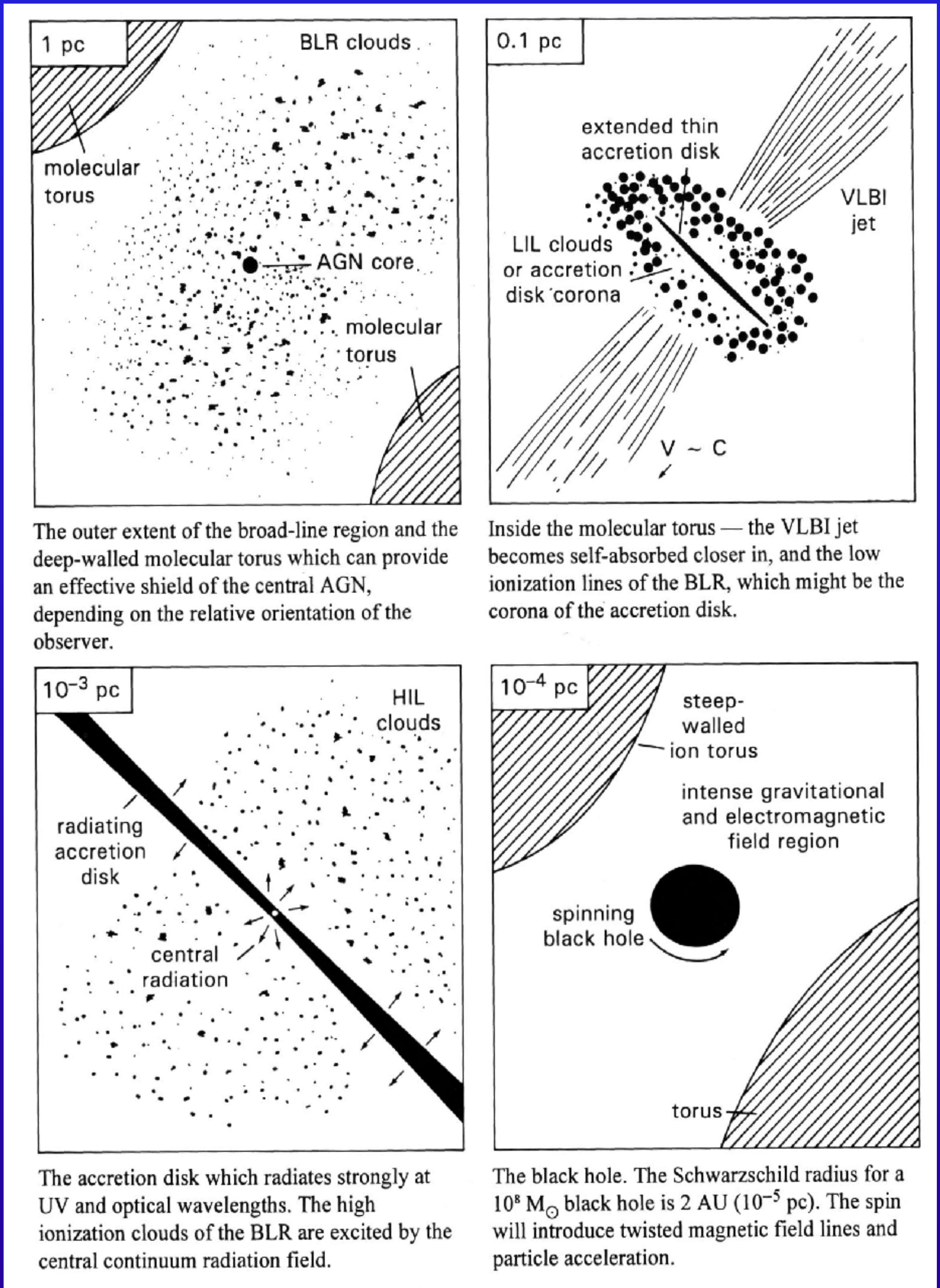
Wolfram Kollatschny, Göttingen

Divcibare, 2011

University Observatory

Institute for Astrophysics

Broad Line Region Size?



The outer extent of the broad-line region and the deep-walled molecular torus which can provide an effective shield of the central AGN, depending on the relative orientation of the observer.

Inside the molecular torus — the VLBI jet becomes self-absorbed closer in, and the low ionization lines of the BLR, which might be the corona of the accretion disk.

The accretion disk which radiates strongly at UV and optical wavelengths. The high ionization clouds of the BLR are excited by the central continuum radiation field.

The black hole. The Schwarzschild radius for a $10^8\ M_\odot$ black hole is 2 AU (10^{-5} pc). The spin will introduce twisted magnetic field lines and particle acceleration.

radius:
- 10^{-4} ...10^{-1} pc
- 1 .... 100 light days

at a dist. of 50 Mpc (Virgo):
spatial resolution

4×10^{-5} ... 4×10^{-3} ''
(0.04 ... 4. mas)

unresolved

R. Blandford

Broad Line Region Structure?

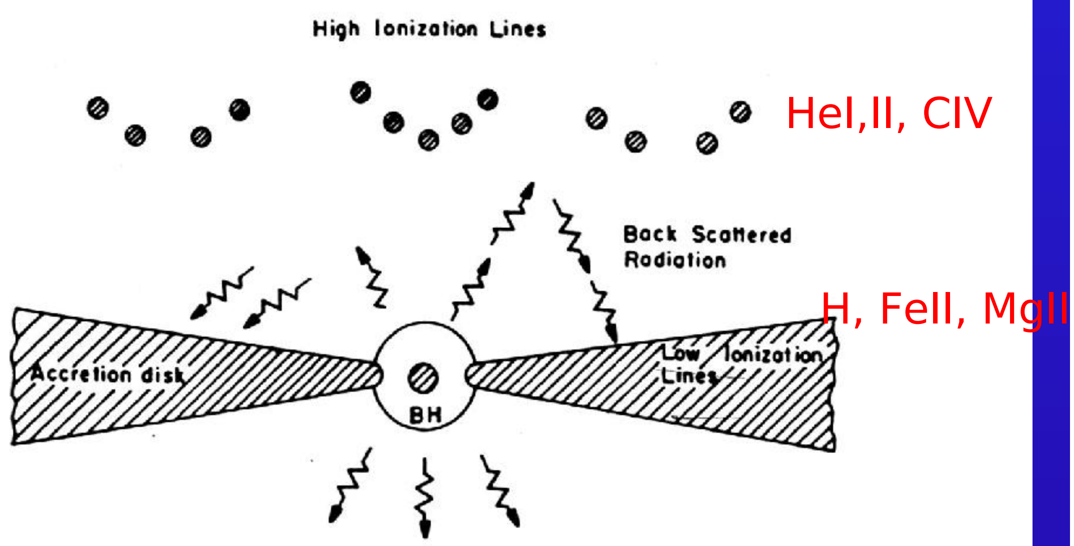


Fig. 13. A schematic two-component model for the BLR. The high ionization lines are emitted in a spherical system of clouds, and are excited by the direct ultraviolet radiation of the central source. The low ionization lines come mainly from the outer regions of the central disk, where most of the line excitation is due to back-scattered, hard ionizing photons. (After Collin-Souffrin, Perry and Dyson(1987), Collin-Souffrin (1987) and Dumont and Collin-Souffrin (1990))

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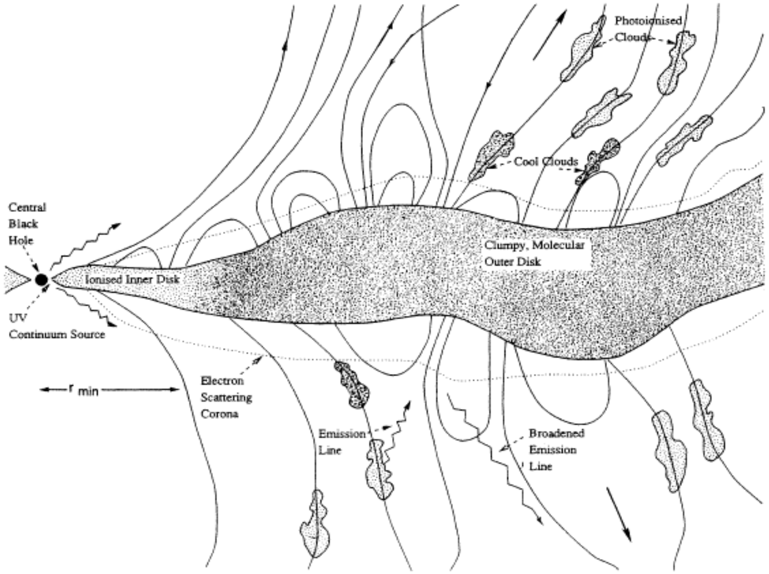


FIG. 1.—Schematic representation of magnetic accretion disk model for broad emission-line region. The accretion disk is ionized in the inner parts but neutral and probably molecular at large radius. Small dense clouds of molecular gas can be radiatively accelerated away from the surface of the disk and flung centrifugally outward along the magnetic field to attain speeds several times the initial Keplerian velocities. When these clouds are exposed to the full UV photoionizing flux, they are heated to temperatures $T \sim 10^4$ K and produce the emission lines. It is possible that these line photons are subsequently scattered by $\sim 10^6$ K electrons, either within a corona or at the disk.

Two component BLR?

Collin-Souffrin et al., 1990

Radiatively accelerated clouds in hydromagnetic wind?

Emmering, Blandford, Shlosman,1992

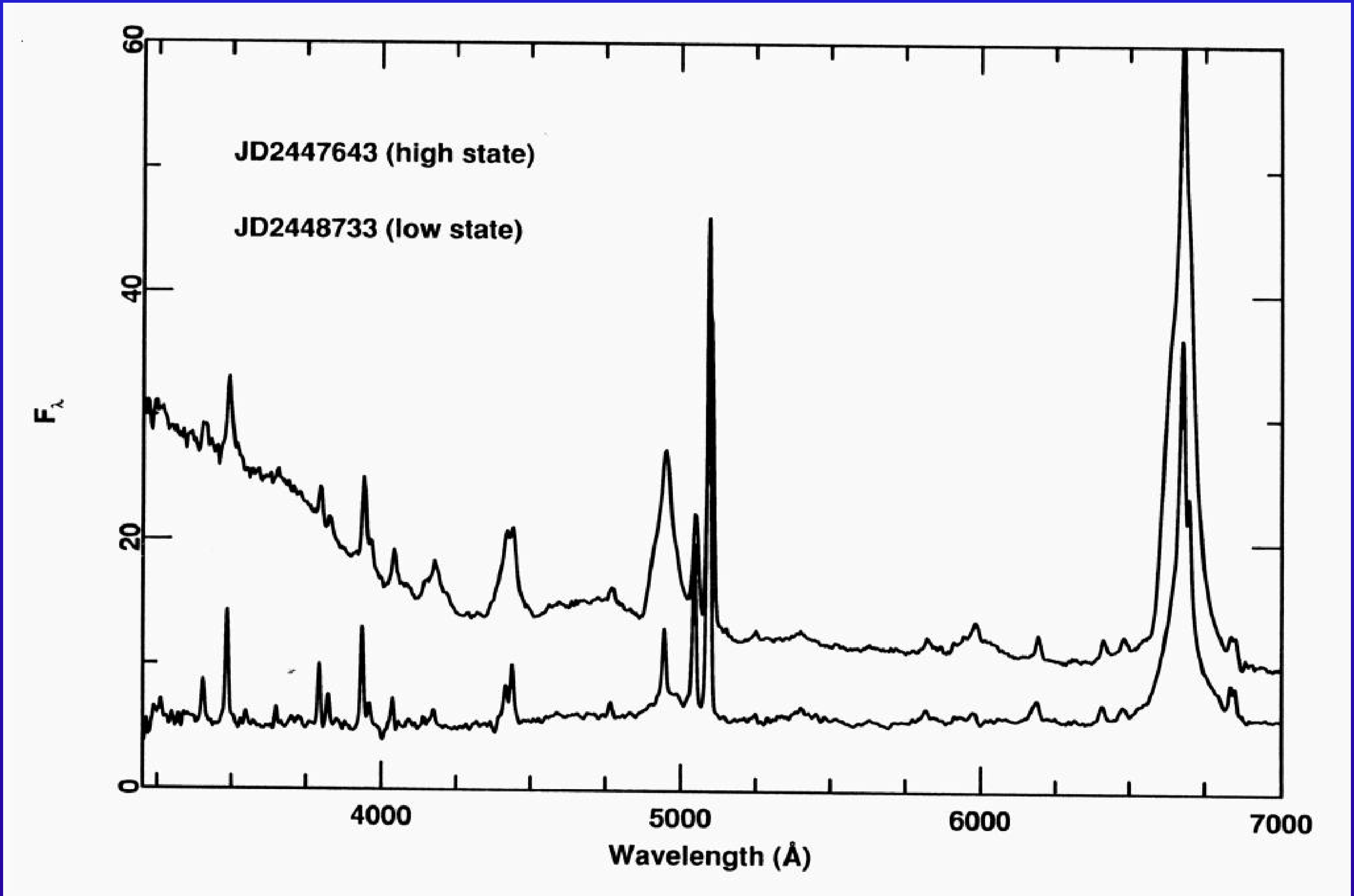
Study of Variability:

-Extension, Structure
-*Geometry*
-*and Kinematics* of the central
Broad Line Region in AGN

- *Black Hole Mass*

in NGC5548, Mrk110

High and low state spectra of NGC5548

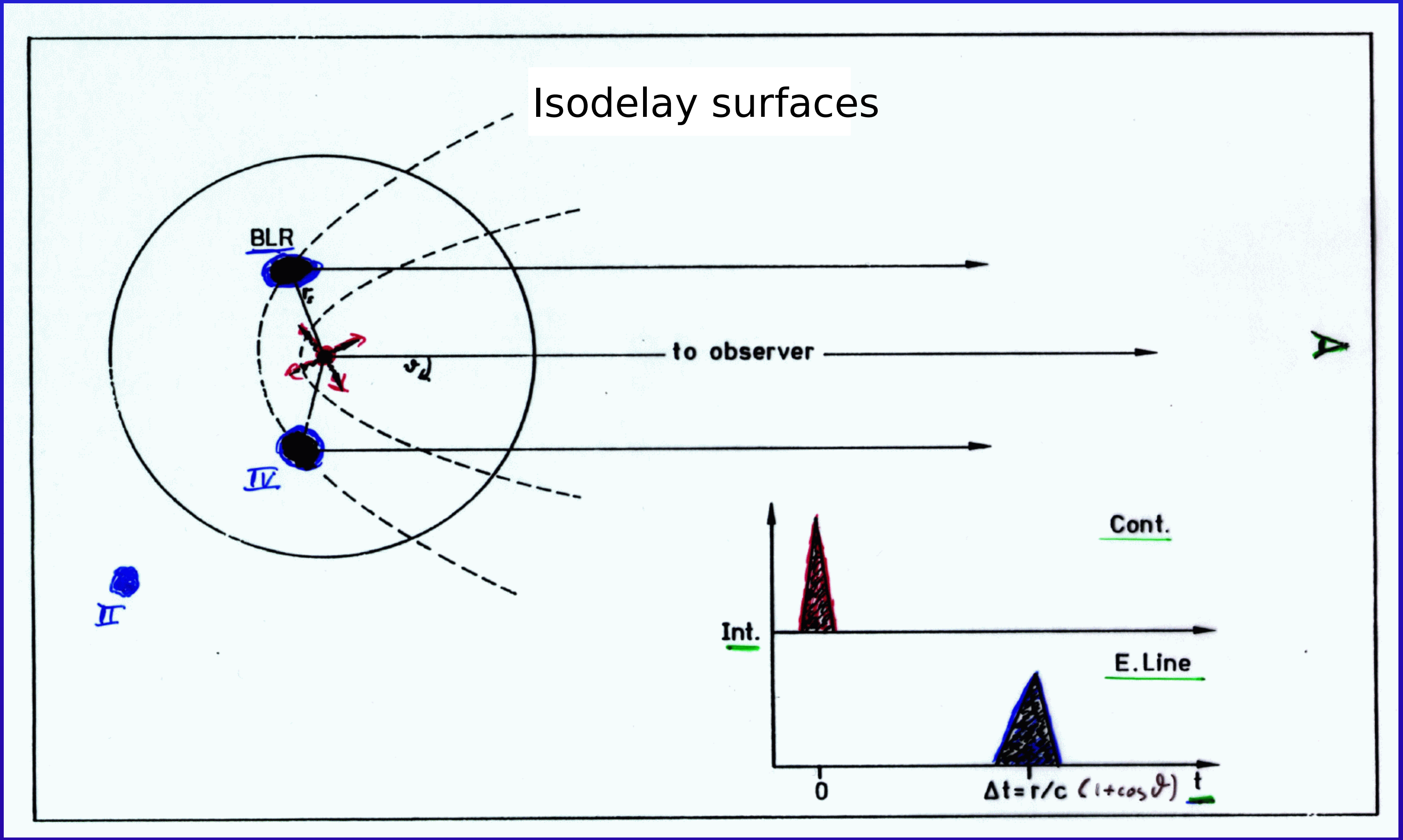


1989

1993

BLR: Idealized Model

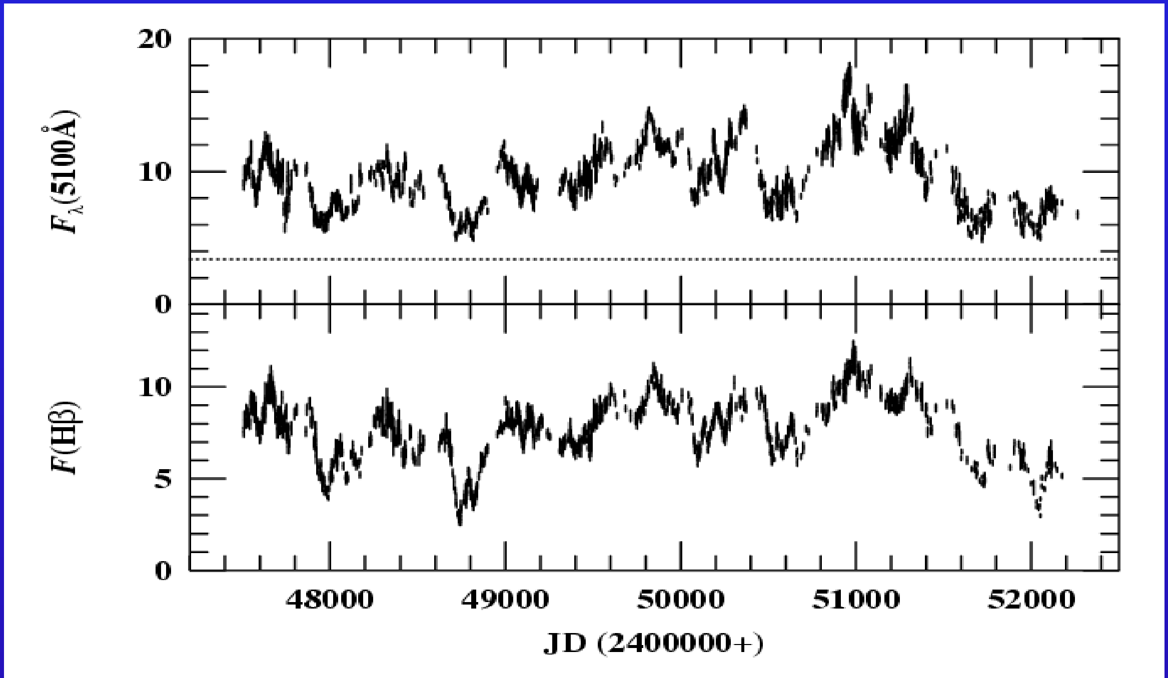
Response of BLR clouds on continuum flashes



BLR stratification

Delay by light travel time effects

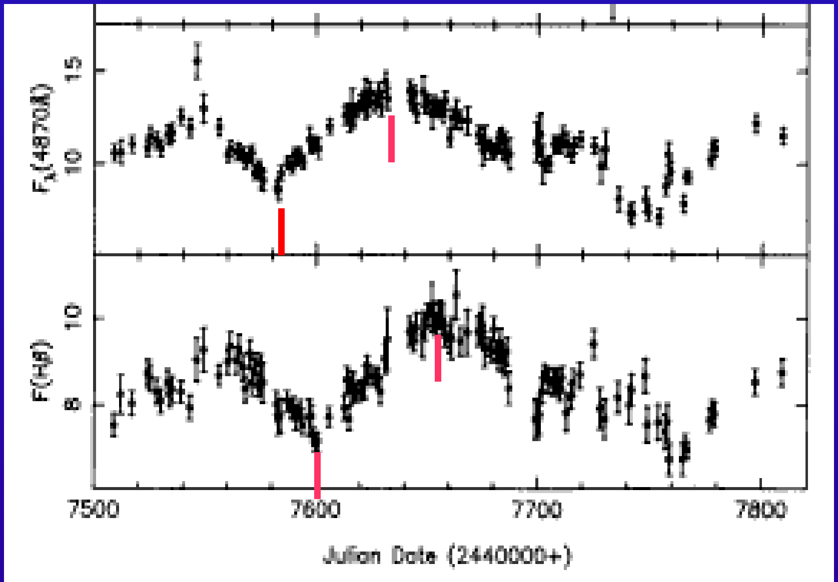
BLR: Continuum & integ. Hβ line variability



1989 - 2001

NGC 5548

B. Peterson et al., 2002

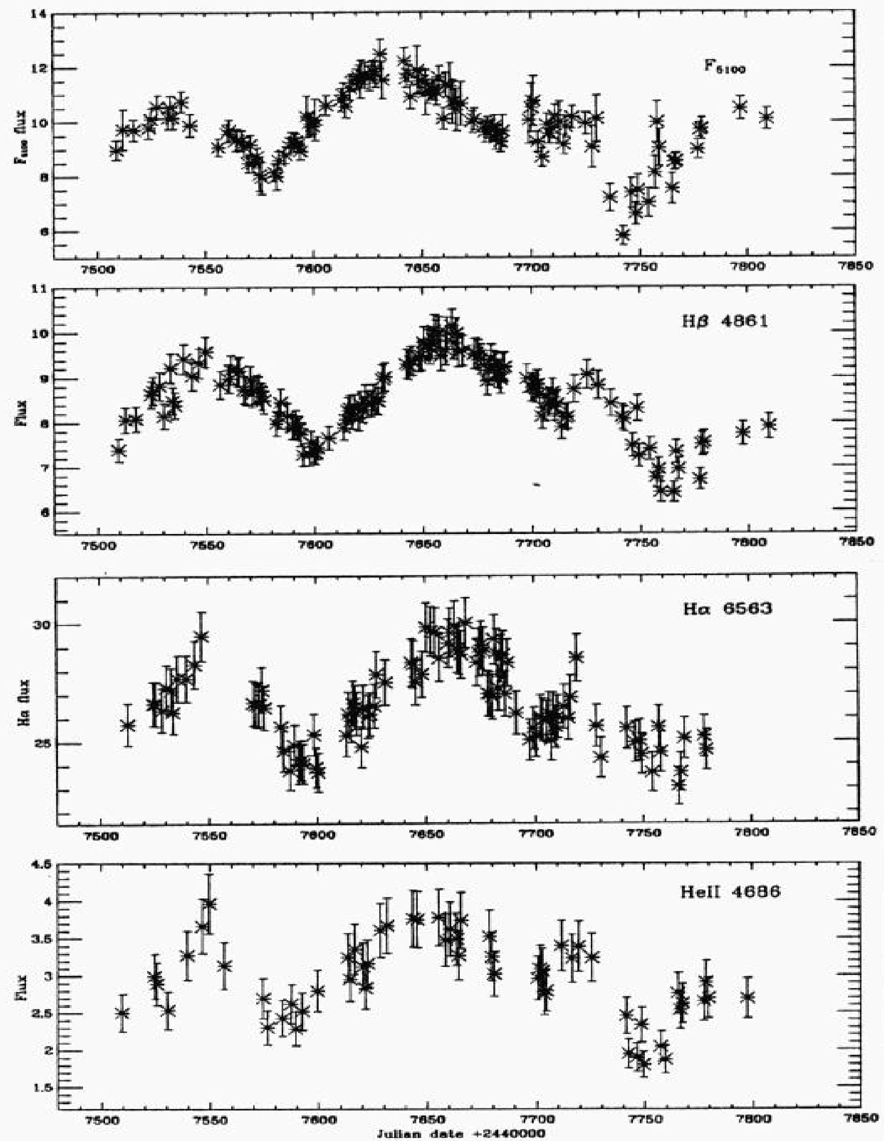


Hβ delay ~ 20 light days

1989

BLR size and stratification in NGC5548

peak to peak var. ampl. | lightcurves (1989) | ACF, CCF



delay

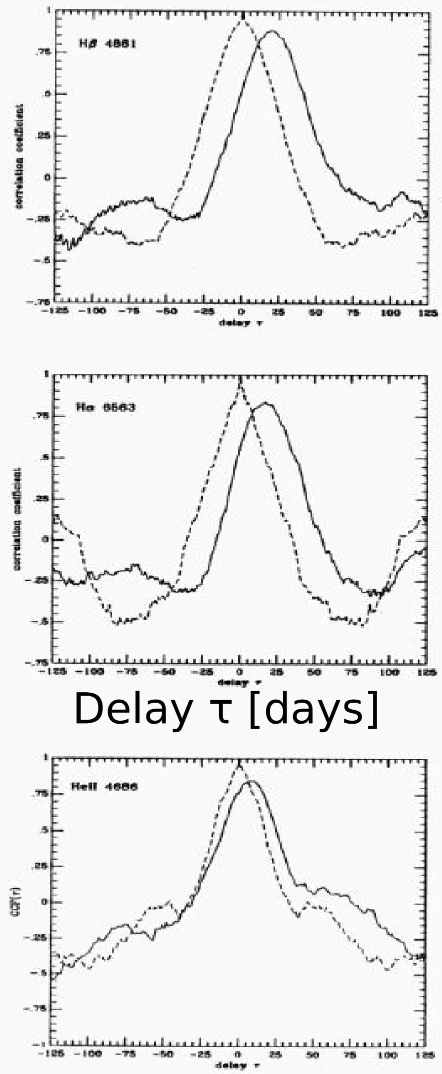
opt. Cont. 0.56

Hβ 0.29 — Hβ 19.

Hα (0.17) — Hα (18.)

HeII 0.61 — HeII 7.

Correlation coeff.

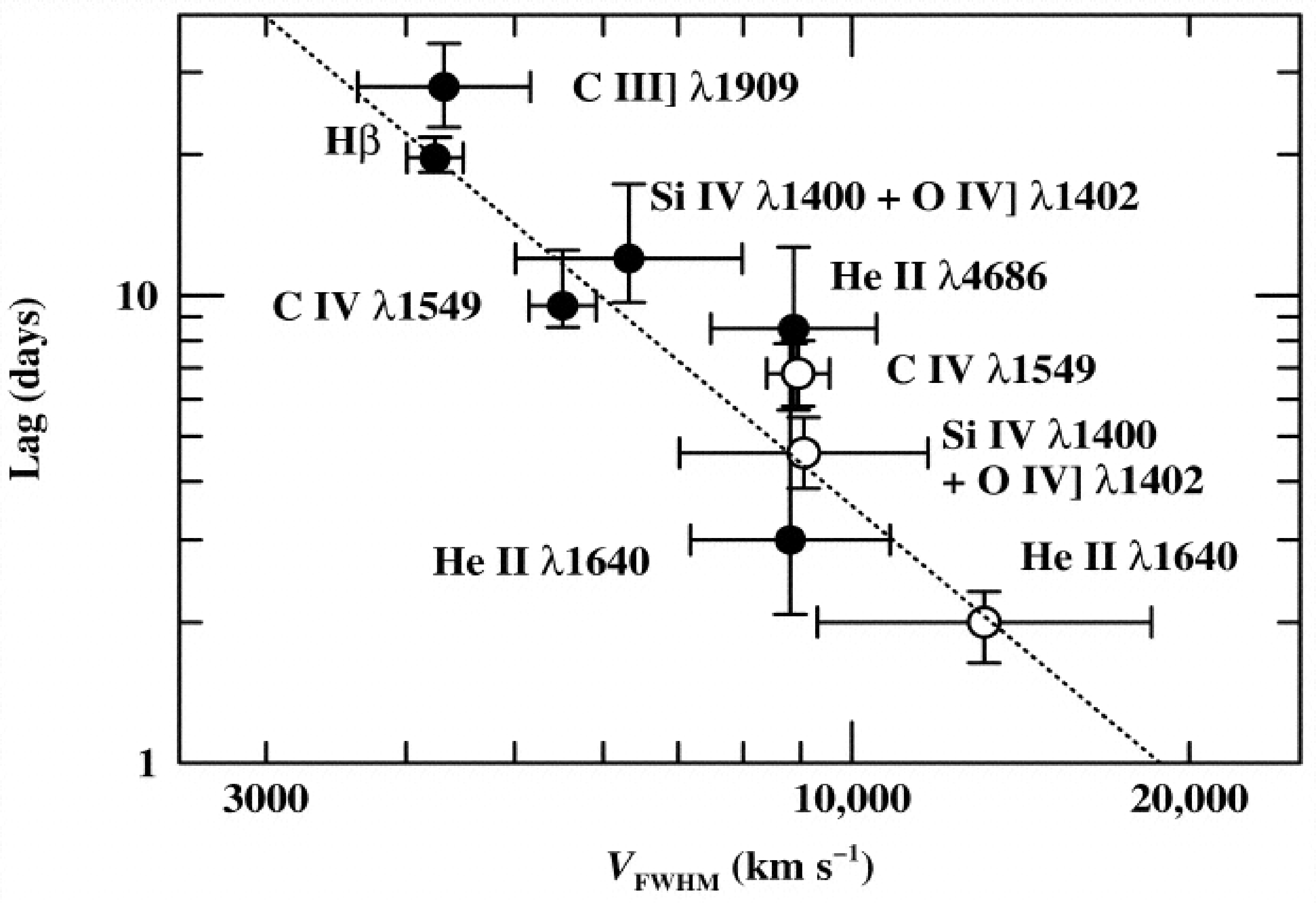


Delay τ [days]

Dietrich, Kollatschny et al., 1994

BLR size and stratification in NGC5548

higher ionized lines: - broader line widths
- faster response

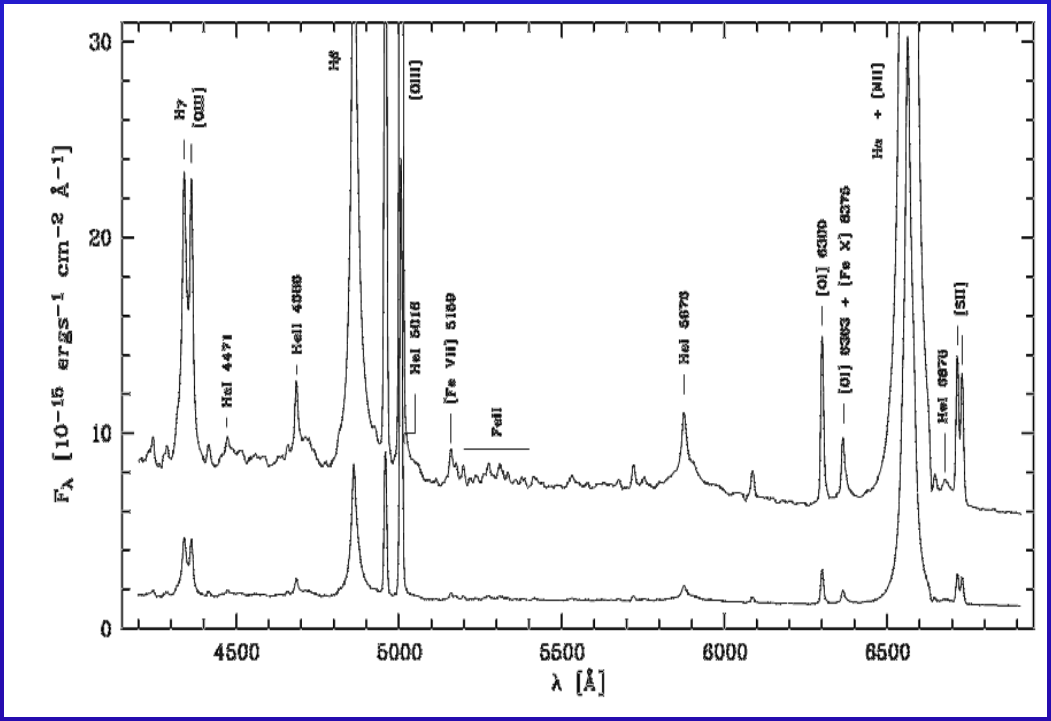


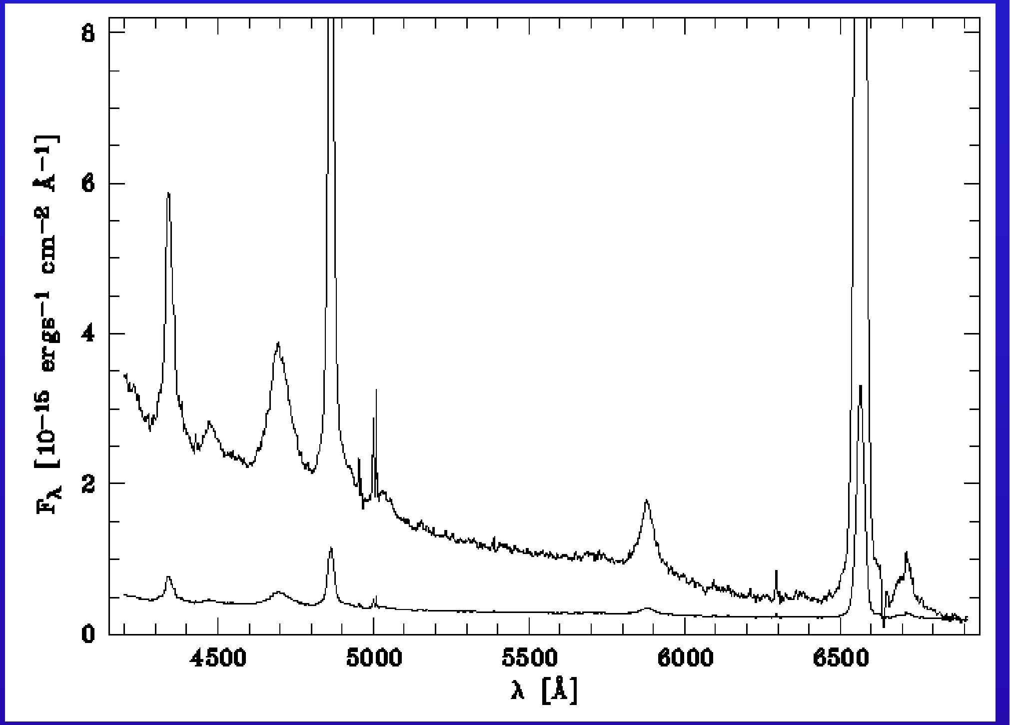
Time lag (CCFs centroids) for various emission lines

Peterson, Wandel, 1999

HET variability campaign of Mrk110

9.2m Hobby-Eberly Telescope at McDonald Observatory
S/N >100





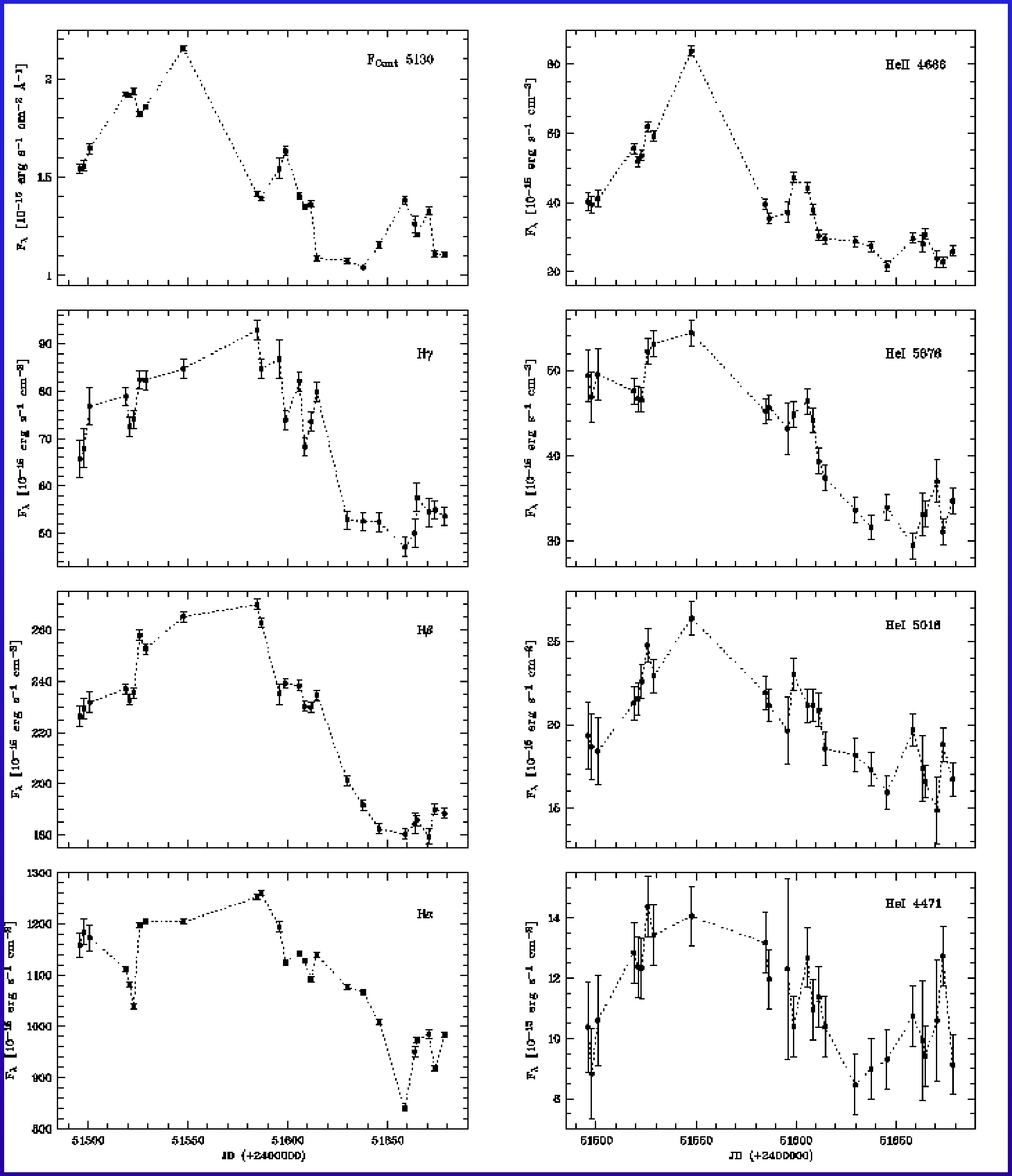
Mean spectrum of Mrk110
for 24 epochs from Nov. 1999 through
May 2000

Rms spectrum

- the rms spectrum shows the variable part of the spectrum

Kollatschny et al., 2001

HET variability campaign of Mrk110

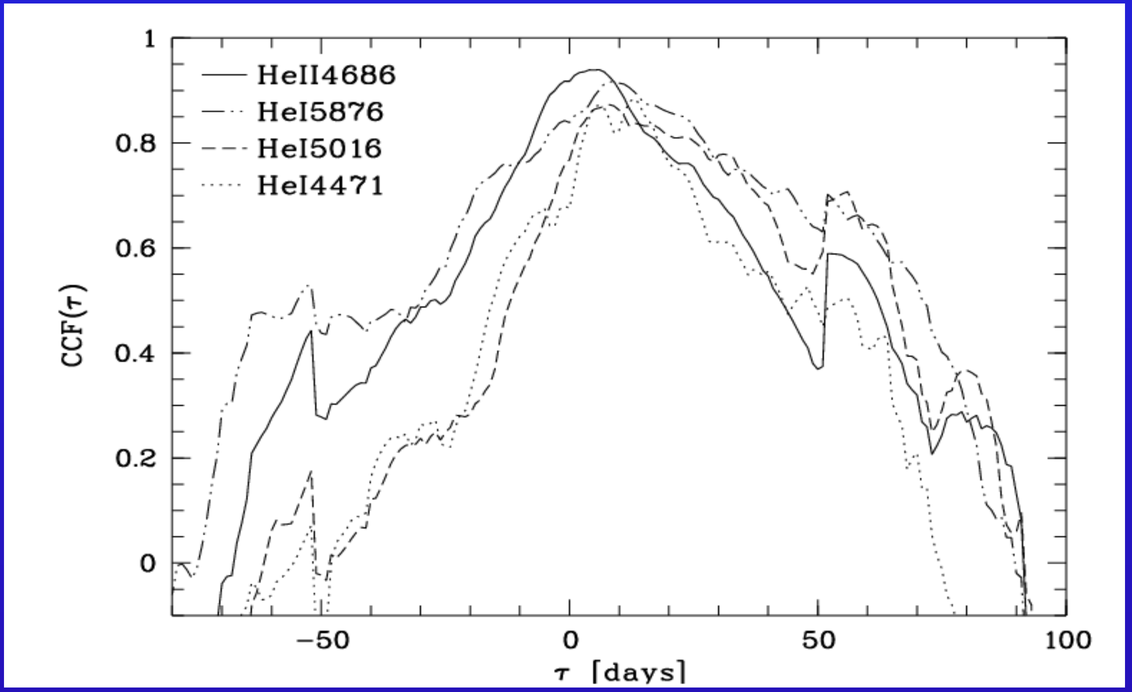


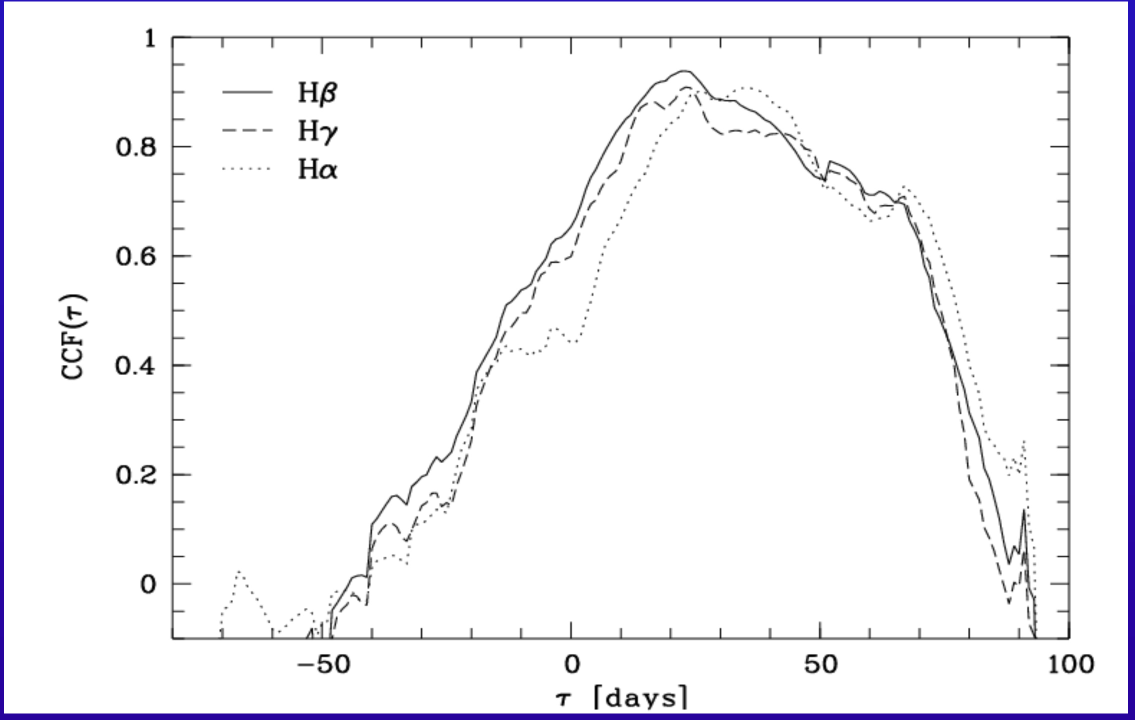
Continuum and integrated emission line (Balmer, HeII and HeI) light curves

1999 Nov. - 2000 May

Kollatschny et al., 2001

BLR size and structure - HET variab. campaign





Mkn110

CCF functions of HeII, HeI and Balmer line light curves with continuum light curve.

Line (1)	τ_{cent} [days] (2)
HeIIλ4686	$3.9^{+2.8}_{-0.7}$
HeIλ4471	$11.1^{+6.0}_{-6.0}$
HeIλ5016	$14.3^{+7.0}_{-7.0}$
HeIλ5876	$10.7^{+8.0}_{-6.0}$
Hγ	$26.5^{+4.5}_{-4.7}$
Hβ	$24.2^{+3.7}_{-3.3}$
Hα	$32.3^{+4.3}_{-4.9}$

stratification

Central Black Hole Mass in Mrk110

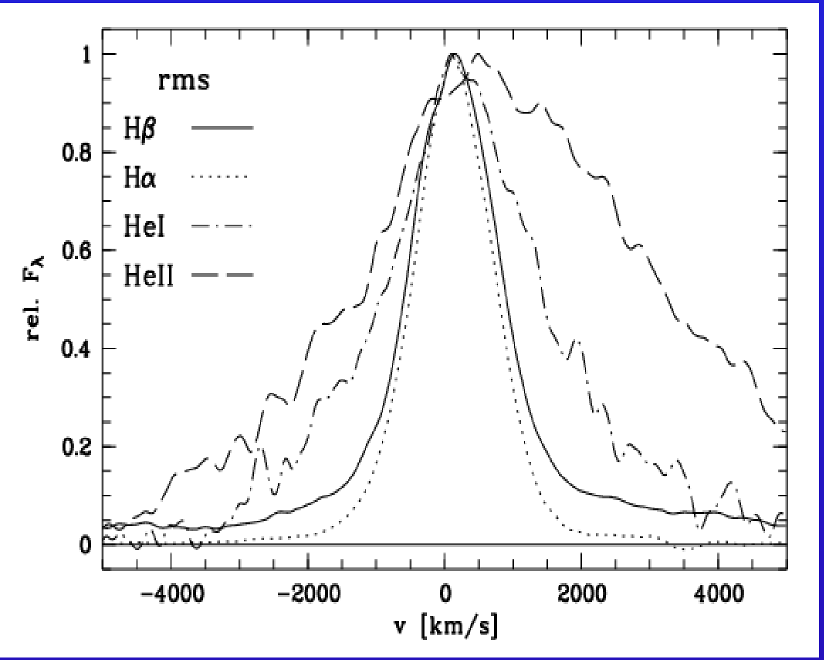
Assumption:
emission line clouds
are gravitationally bound by
central object

$$M = \frac{f V_{\mathrm{FWHM}}^2 c\tau}{G}$$

$c\tau$ = mean dist. of
line em. clouds

V = vel.disp. of clouds
(from rms line width)

f = factor (½ - 5.5)
(unknown geometry



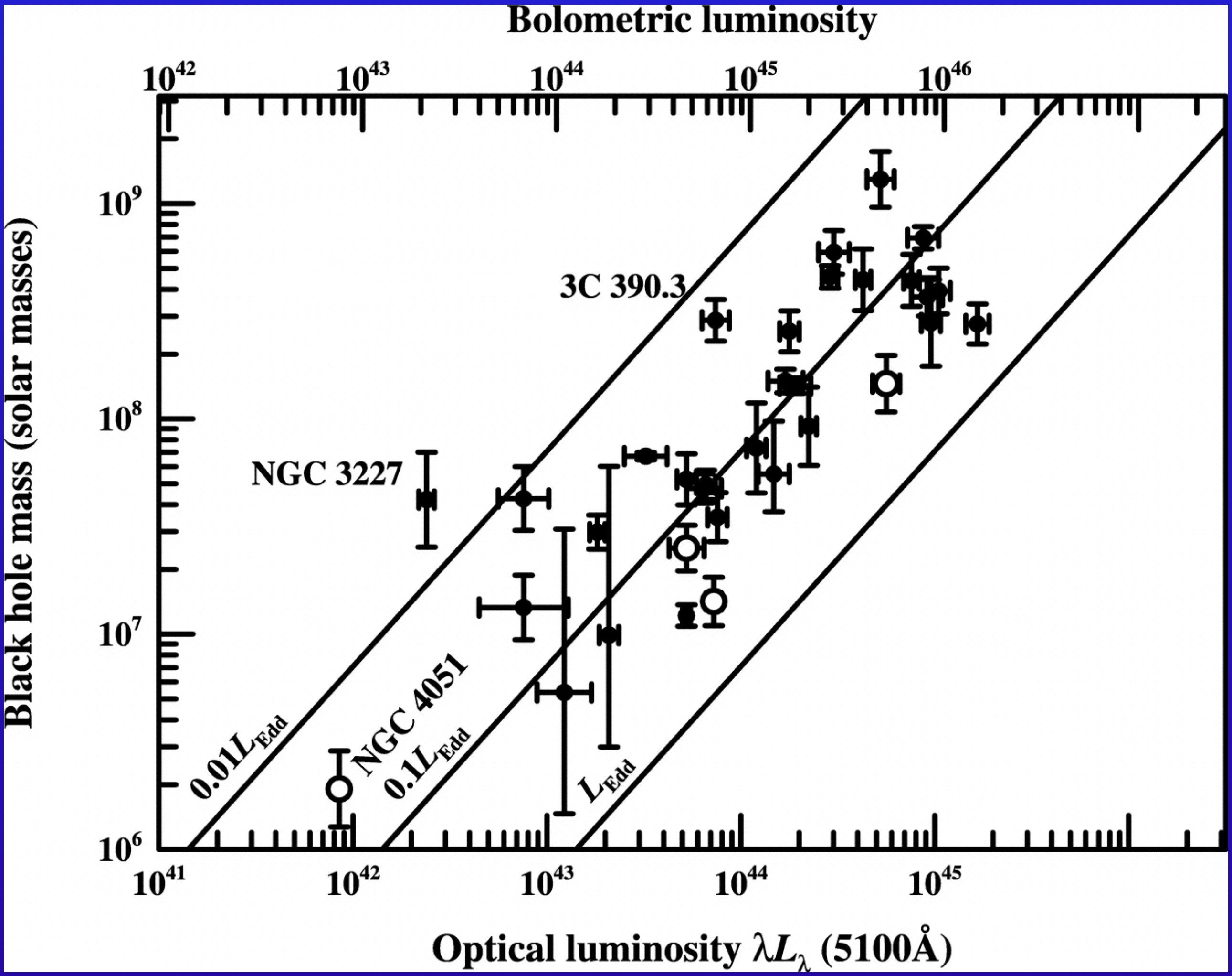
Normalized rms line profiles in velocity space

Line (1)	FWHM(rms) [km s^{-1}] (2)	τ_{cent} [days] (3)	M [$10^7 M_\odot$] (4)
HeIIλ4686	4444. ± 200	$3.5^{+2.}_{-2.}$	$2.25^{+1.63}_{-0.45}$
HeIλ5876	2404. ± 100	$10.8^{+4.}_{-4.}$	$1.81^{+1.36}_{-0.33}$
Hβ	1515. ± 100	$23.5^{+4.}_{-4.}$	$1.63^{+0.33}_{-0.31}$
Hα	1315. ± 100	$32.5^{+4.}_{-4.}$	$1.64^{+0.33}_{-0.35}$

Kollatschny et al., 2001, 2003

Central Black Hole Masses in AGN

Black hole mass vs. luminosity for AGN

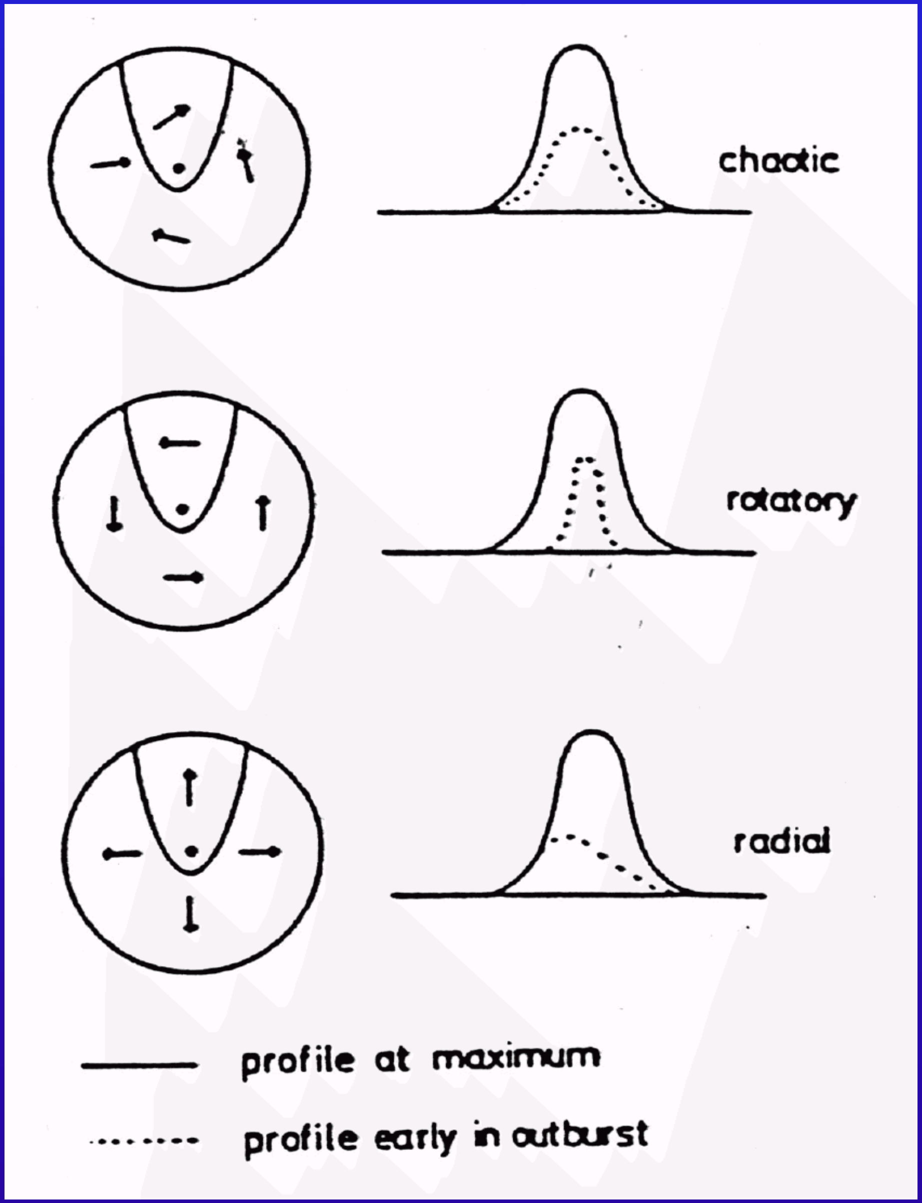


BH mass for 35 reverberation mapped AGN.

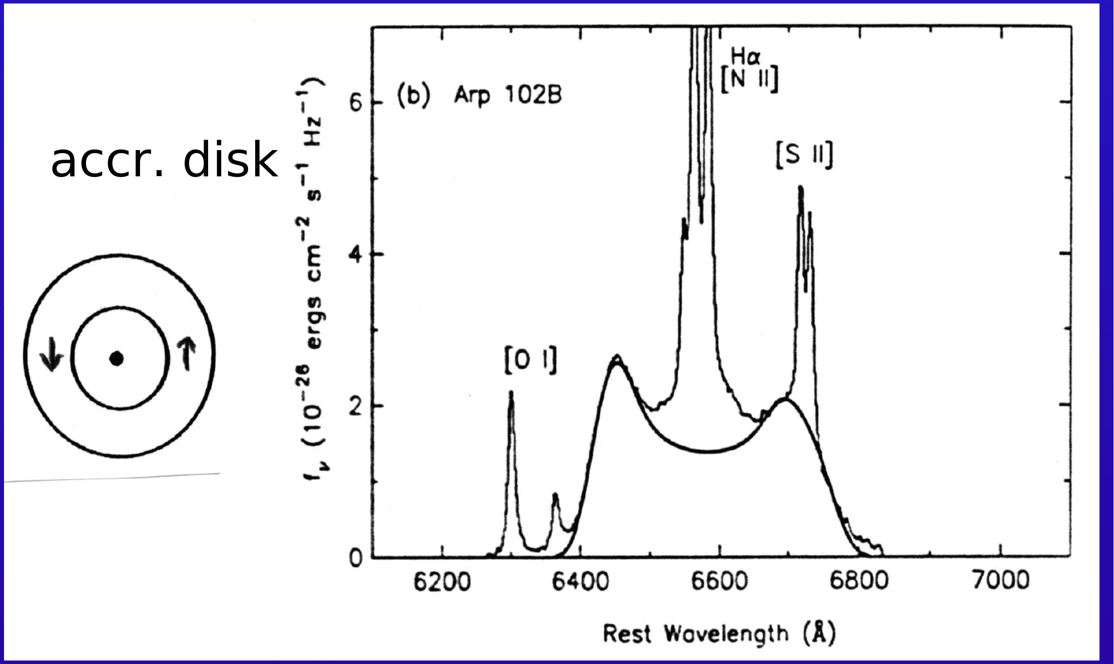
--- : lines of constant mass to luminosity ratio
open circles: NLSy1

Peterson et al., 2004

BLR kinematics - line profile variations



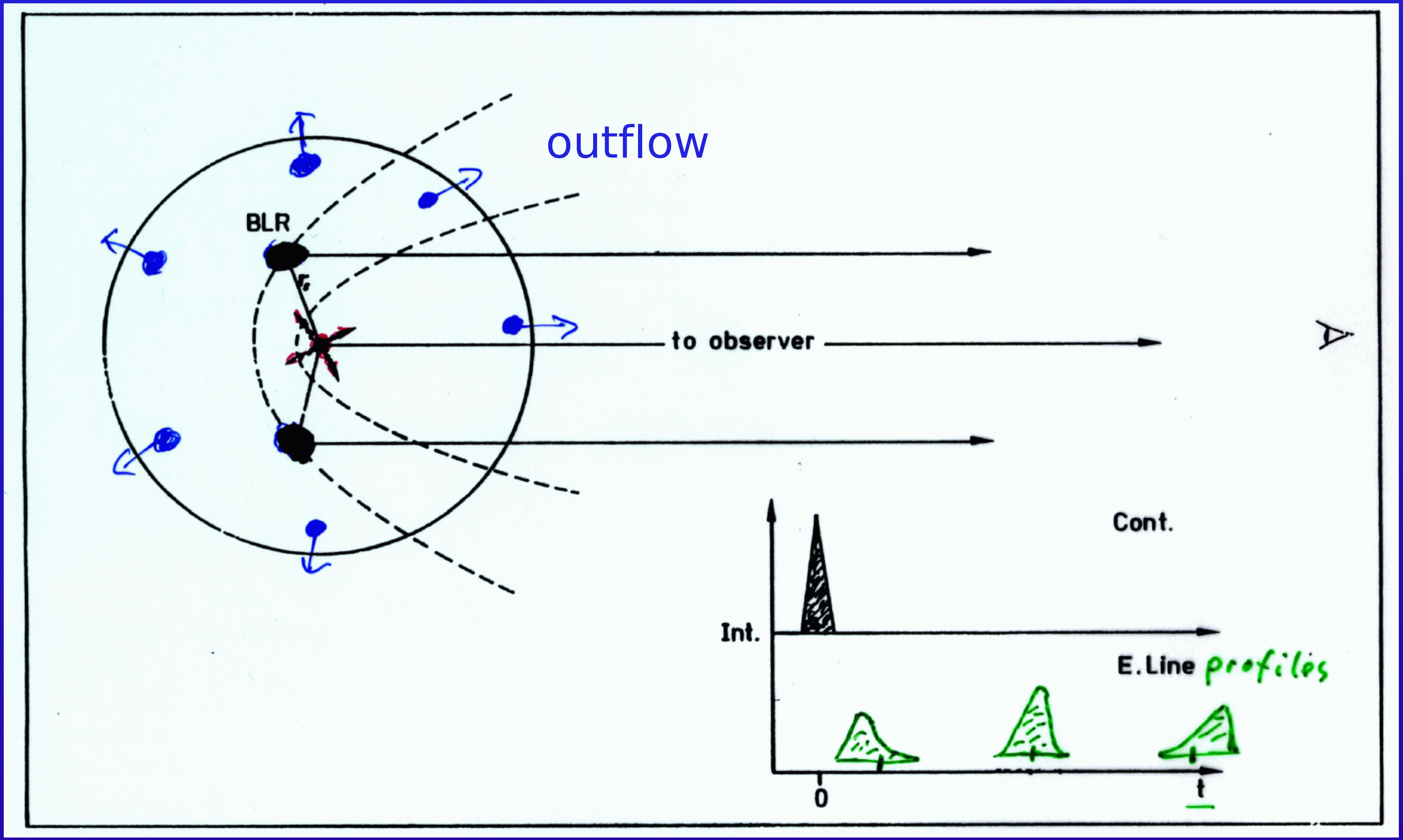
Information about kinematics:
- from emission line profile variations
- from line profiles



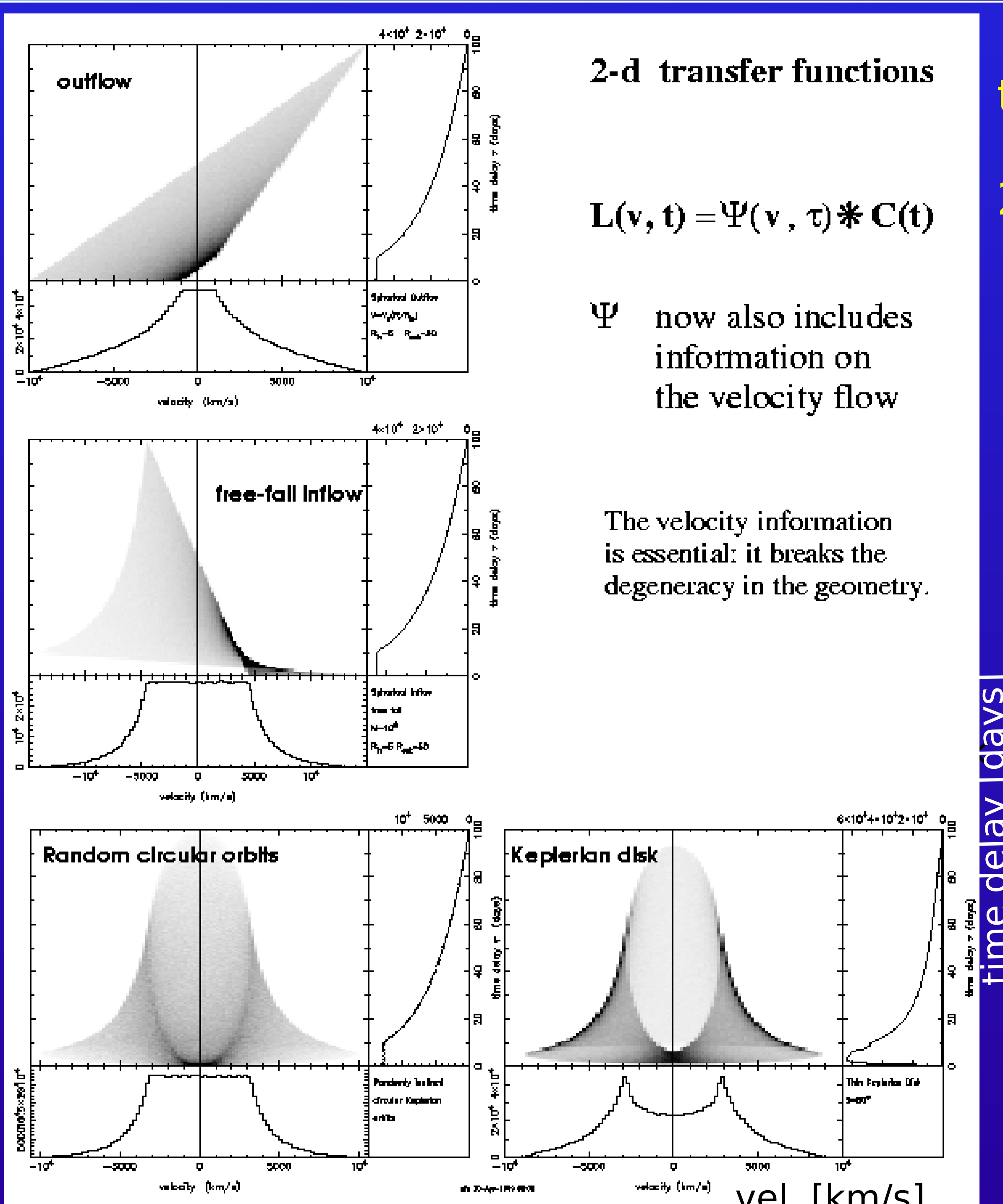
Ulrich et al., 1984

BLR Kinematics: Idealized Model

Influence of BLR motions on line profile variations



Theory : BLR kinematics - line profile variations



theoretical emission line profile variations to derive 2-dim. velocity-delay maps Ψ

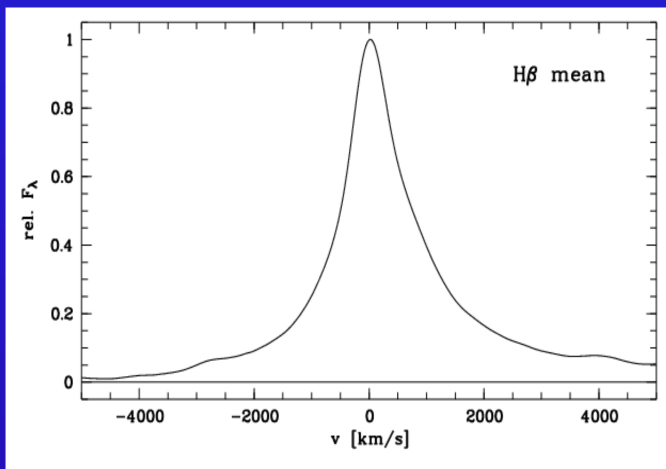
velocity-delay maps for different flows

Welsh & Horne, 1991

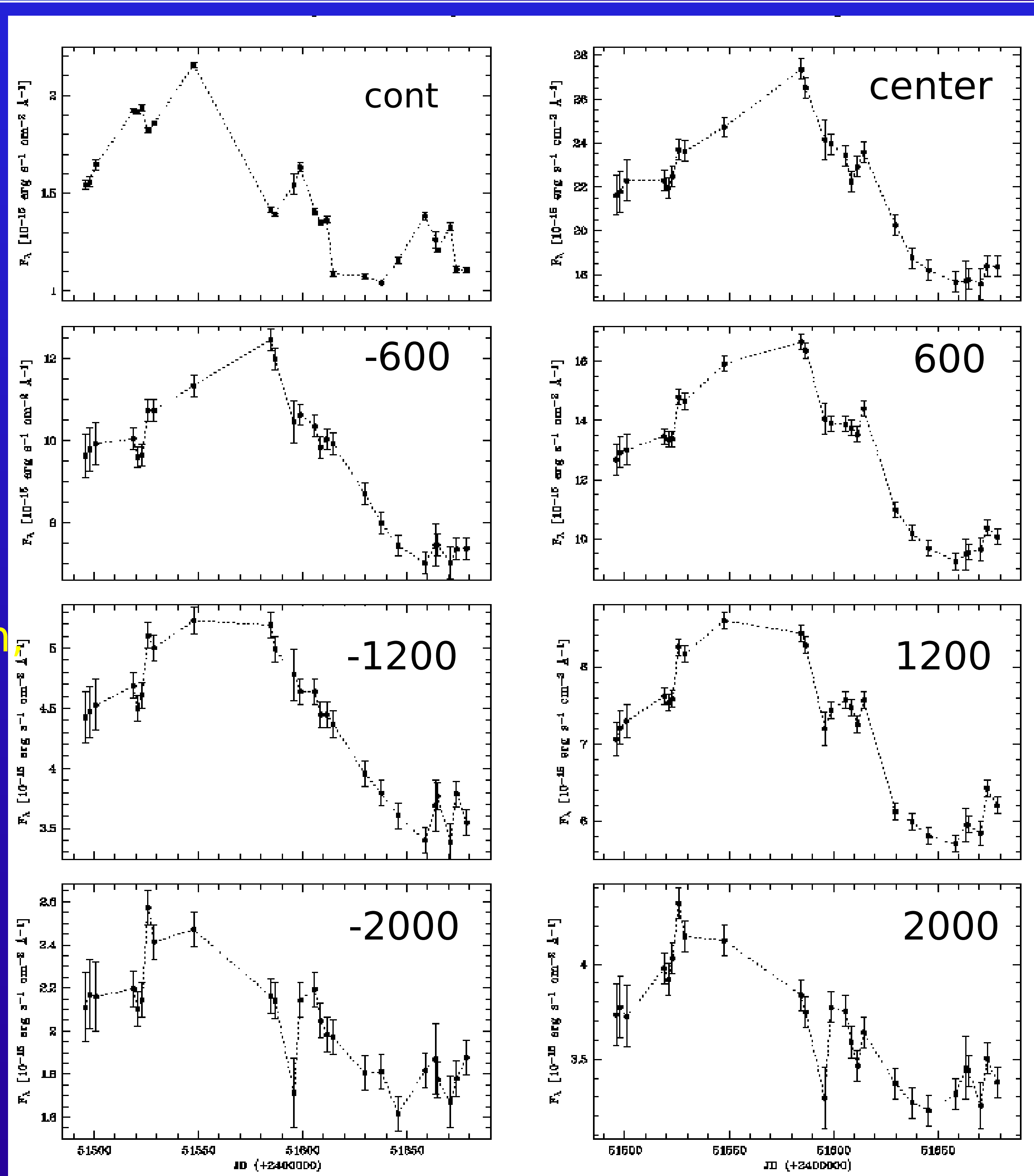
Horne et al., 2004

BLR kinematics and accretion disk structure

Mean Hβ line profile of Mrk110 in
velocity space



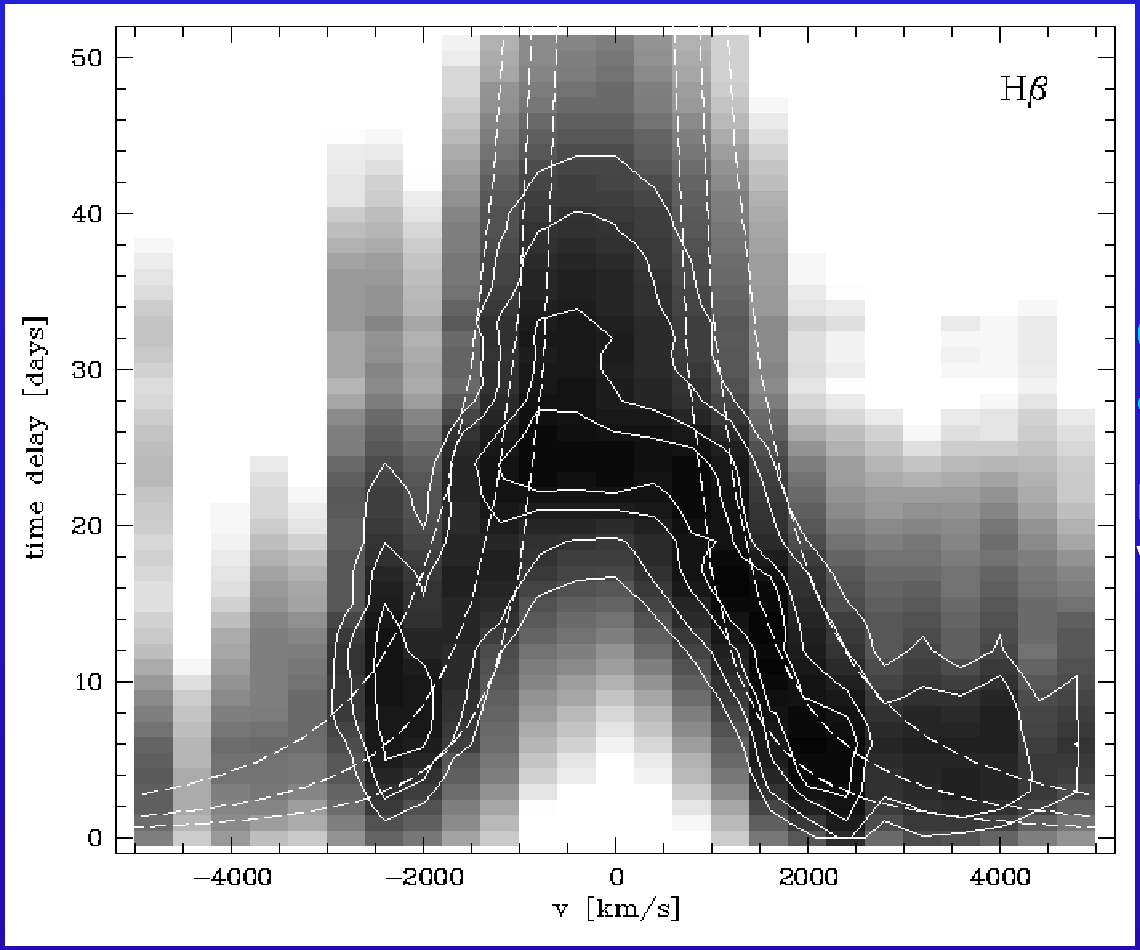
Light curves of the continuum, of the Hβ line center, and of different blue and red line wing segments



Δv = 400 km/s

Kollatschny & Bischoff 2002

BLR: Accretion disk structure in Mrk110



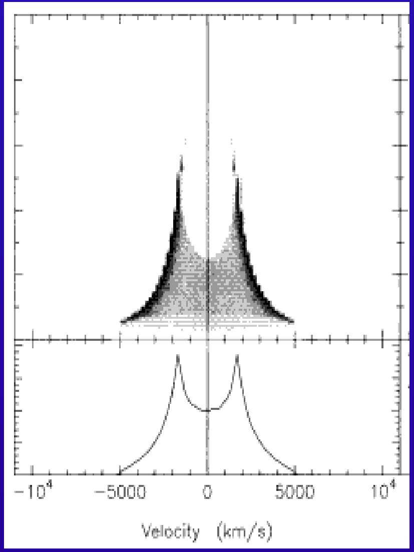
2-D CCF : correlation of Hβ line profile segments with cont. variations (grey scale)

Contours of correlation coefficient at levels of .85 to .925 (solid lines).

Dashed curves: theoretical escape velocity envelopes for masses of 0.5, 1., 2. 10^7 M_o (from bottom to top).

Velocity-delay map Kollatschny 2003a

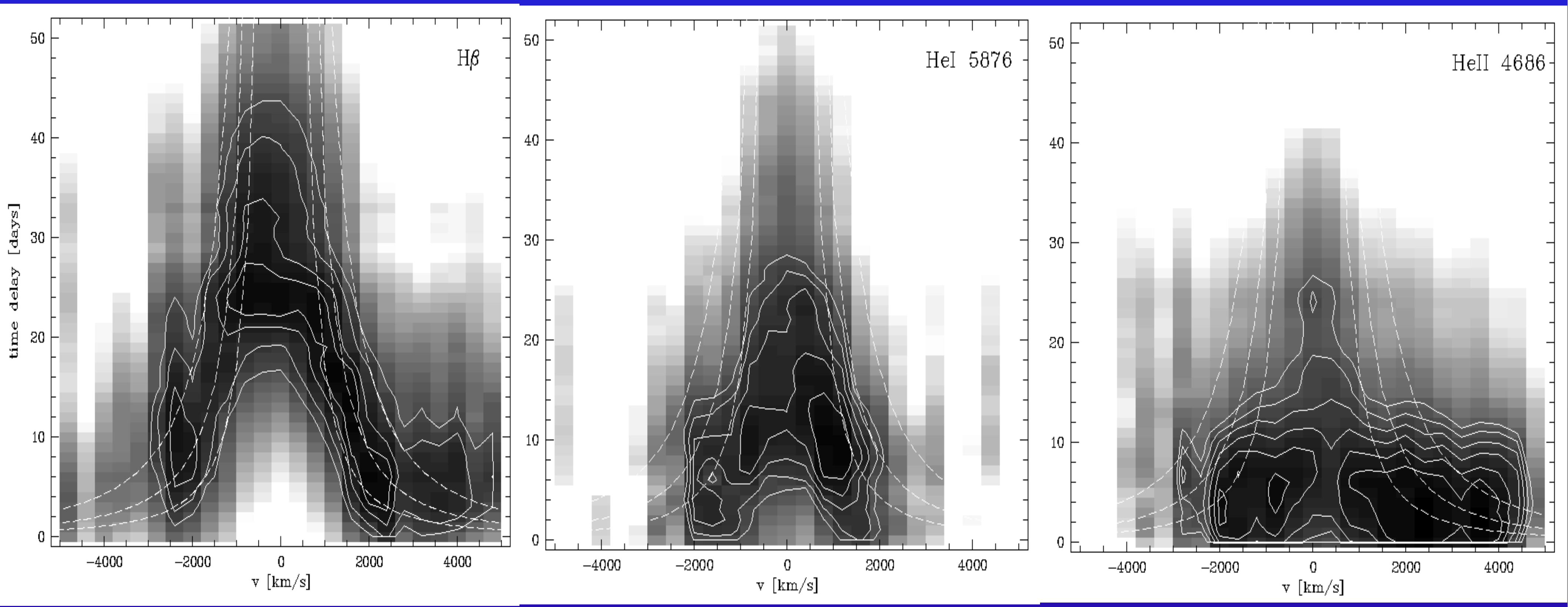
Echo image



Theoretical velocity-delay maps for different flows:
Keplerian disk BLR model: fast response of both outer line wings

Welsh & Horne 1991, Horne et al. 2004

Velocity-delay maps: accretion disk structure

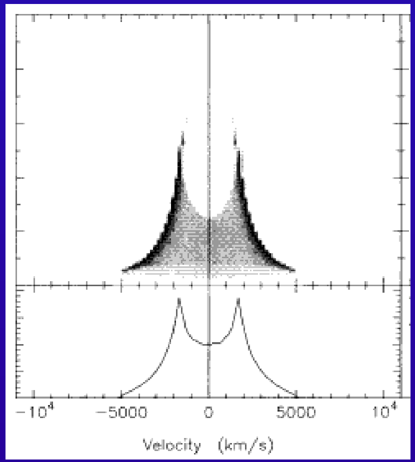


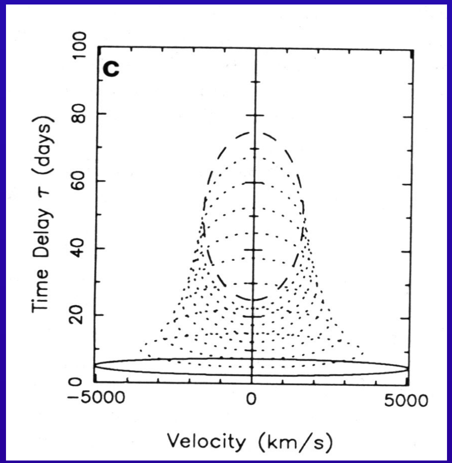
2-D CCF : correlation of Hβ, HeI, HeII line profile segments with continuum variations (grey scale).

Kollatschny 2003

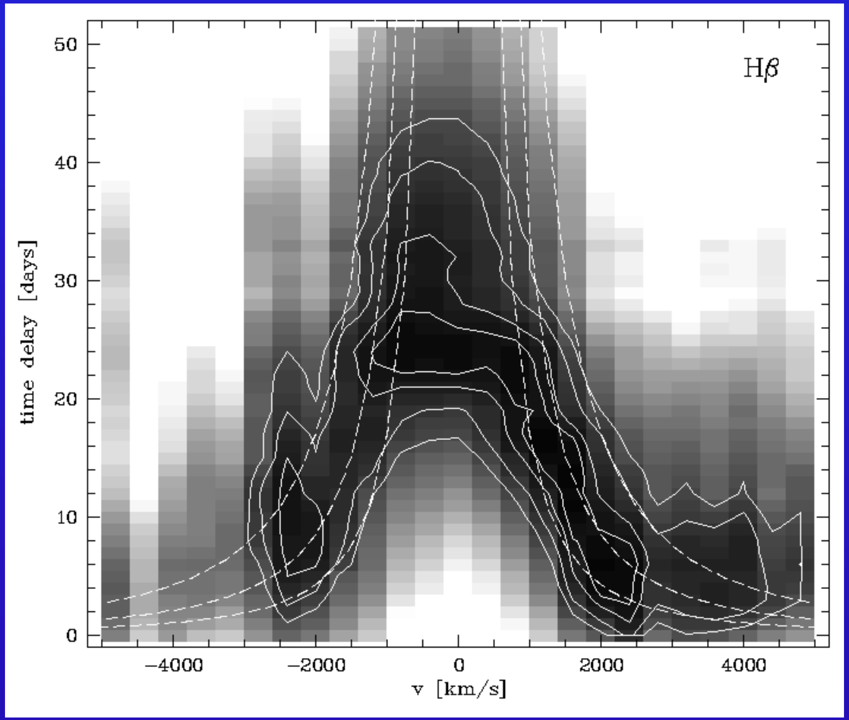
Keplerian disk BLR model: fast response of both outer line wings

Solid line: innermost radius at 5 ld

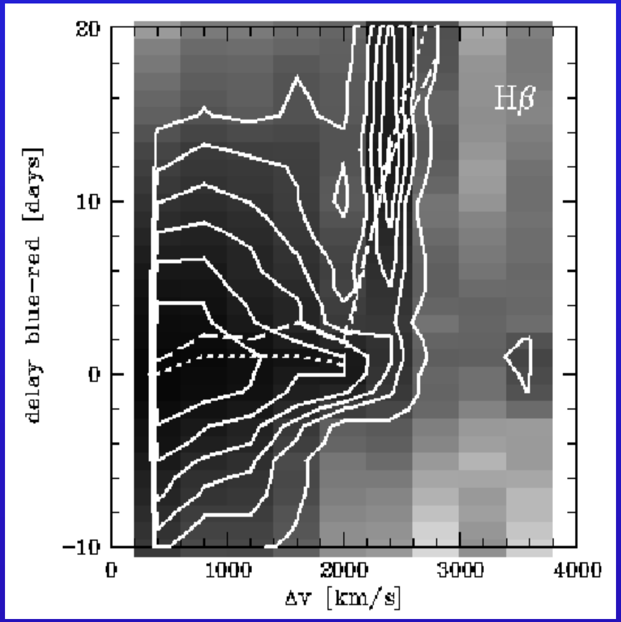




BLR: Accretion disk wind in Mrk110



2-D CCF: velocity-delay map



Time delay of blue line wing to red line wing as function of dist. to line center

Outer line wings: inner BLR

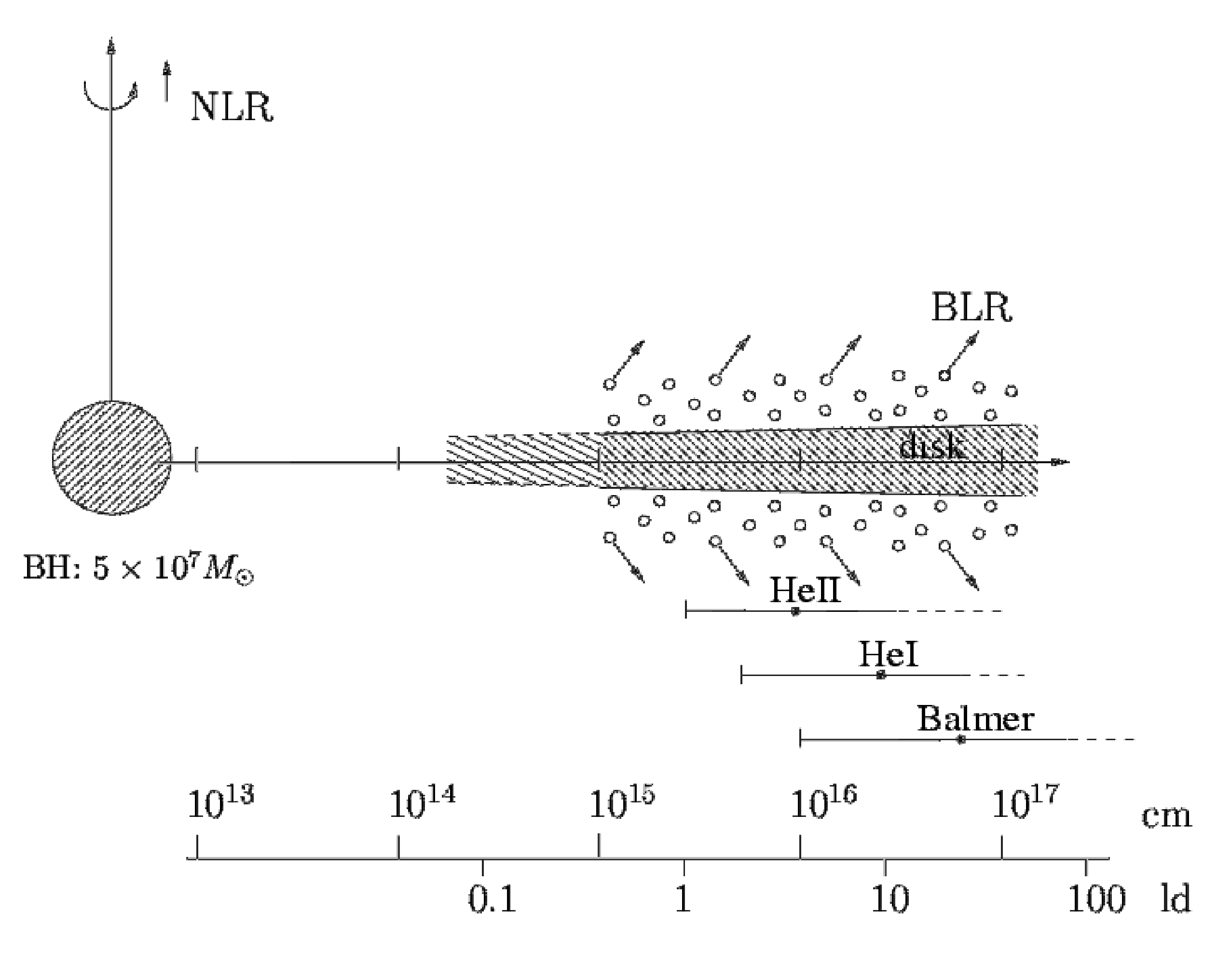
Disk wind model of BLR: Slightly faster and stronger resonse of red wing

Chiang & Murray, 1996

Disk driven outflow models compared to spherical wind models:
velocity decreases with radius (rather than the other way around)

Koenigl & Kartje, 1994

BLR Structure and Kinematics in Mrk110



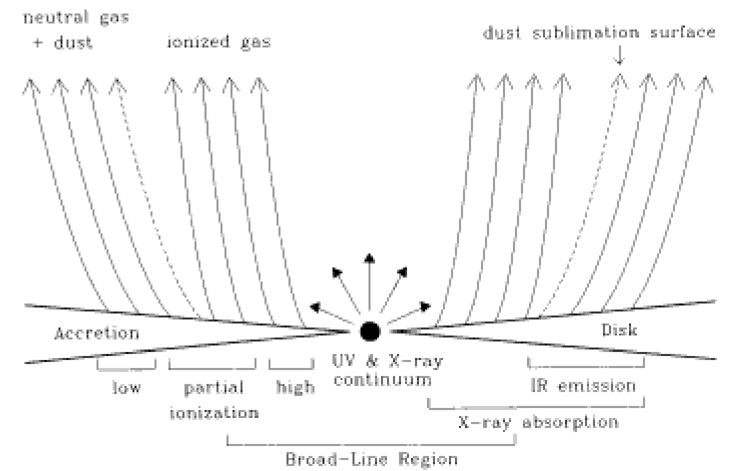


FIG. 13.—Schematic representation of how a disk-driven hydromagnetic wind, which is characterized by a highly stratified density distribution, interacts with the active galactic nucleus (AGN) continuum emission. The innermost regions are heated and ionized by the powerful radiation field, with the temperature and degree of ionization varying both with distance and with the polar angle, whereas the outer regions (beyond the dust sublimination radius) are cooler and contain dust. The radiation pressure force on the dust causes the outer streamlines to have a larger opening angle.

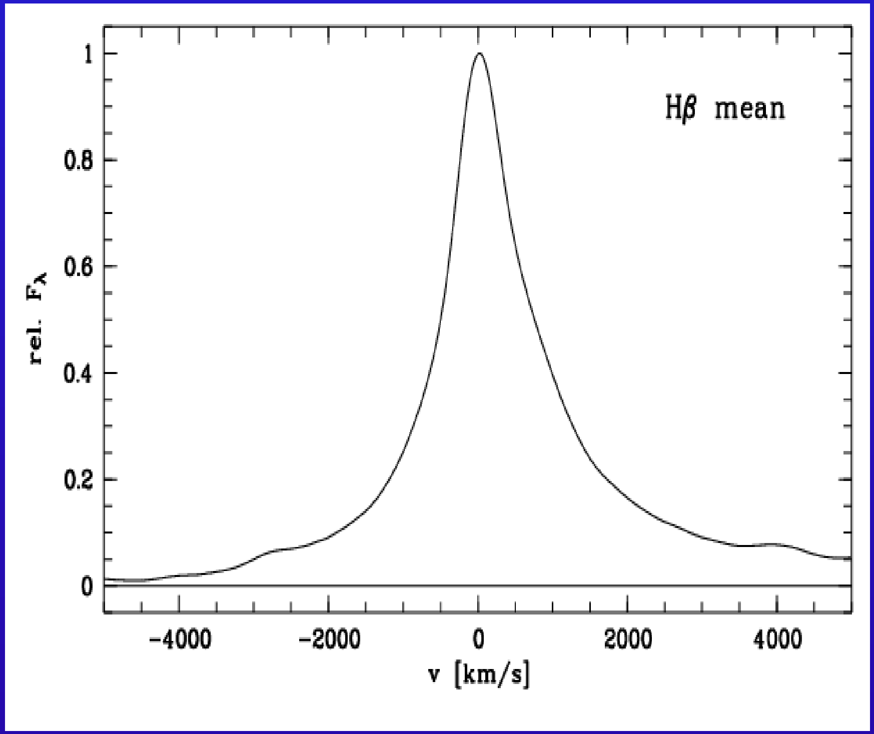
Koenigl & Kartje 1994

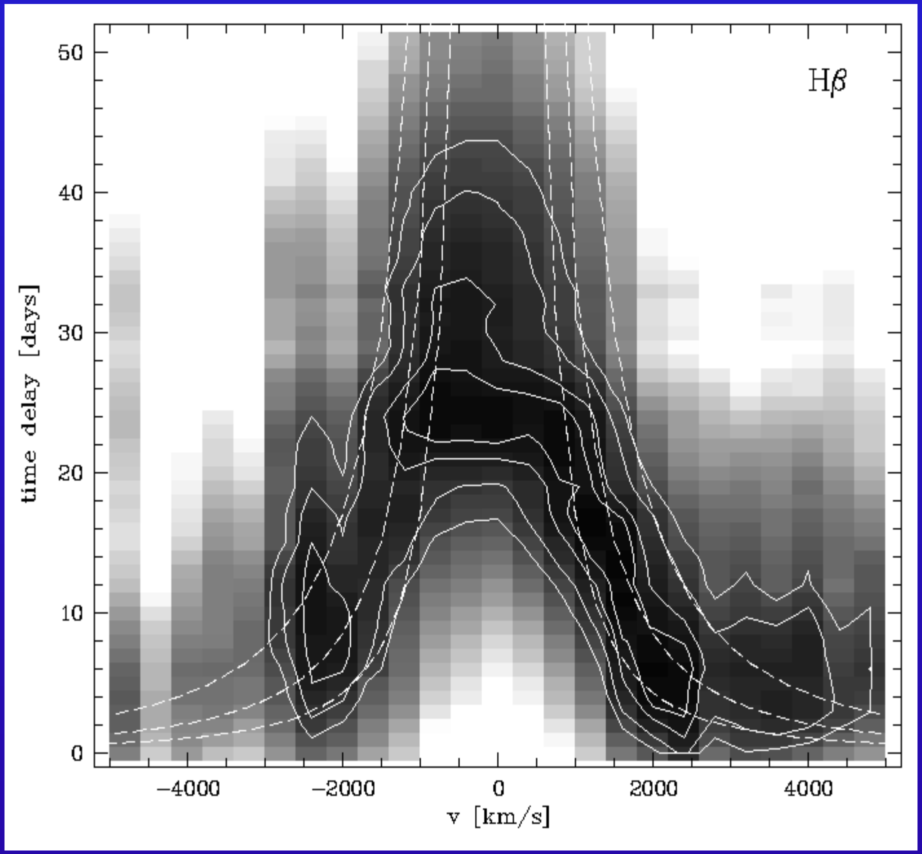
accretion disk wind in Mrk110

Kollatschny 2003a

BLR: Accretion disk structure in Mrk110

Information about accretion disk structure in Mrk110:
from line profile variations (not from line profiles)





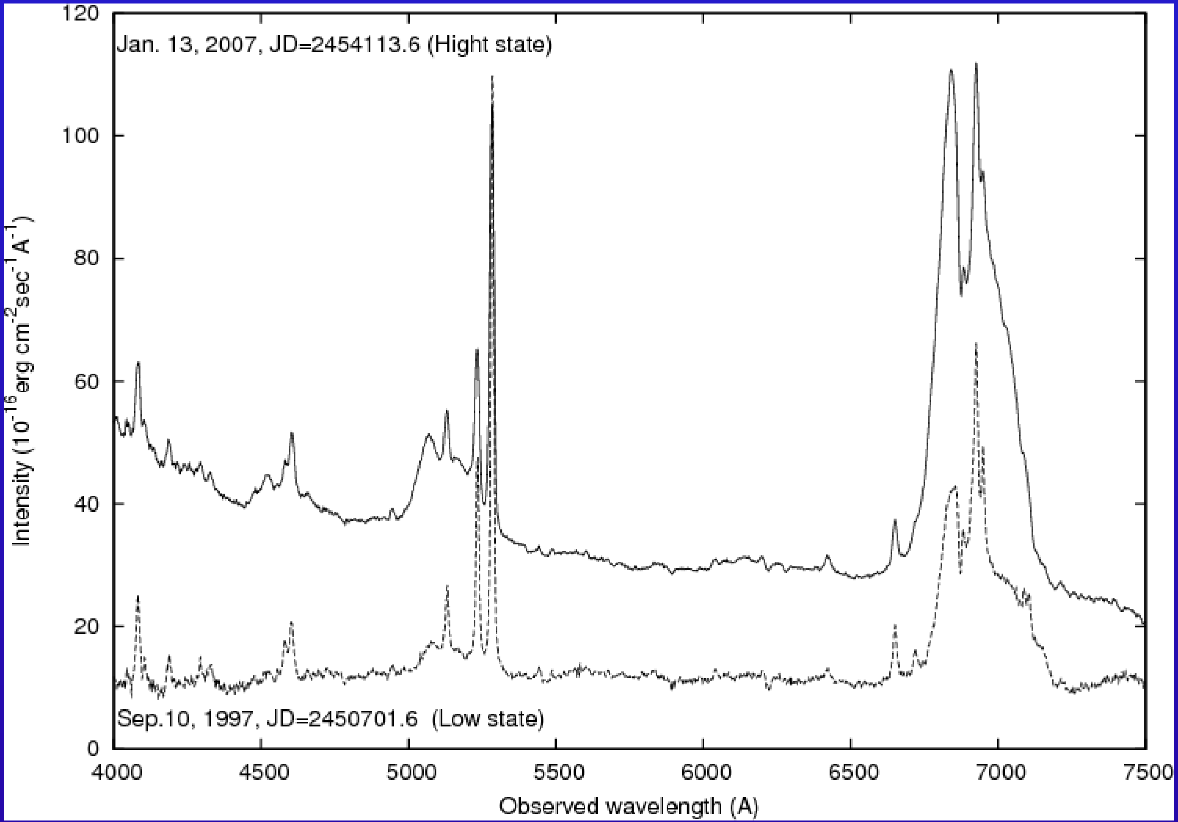
Mean Hβ line profile of Mrk110 in velocity space
(no indication for accretion disk from line profile)

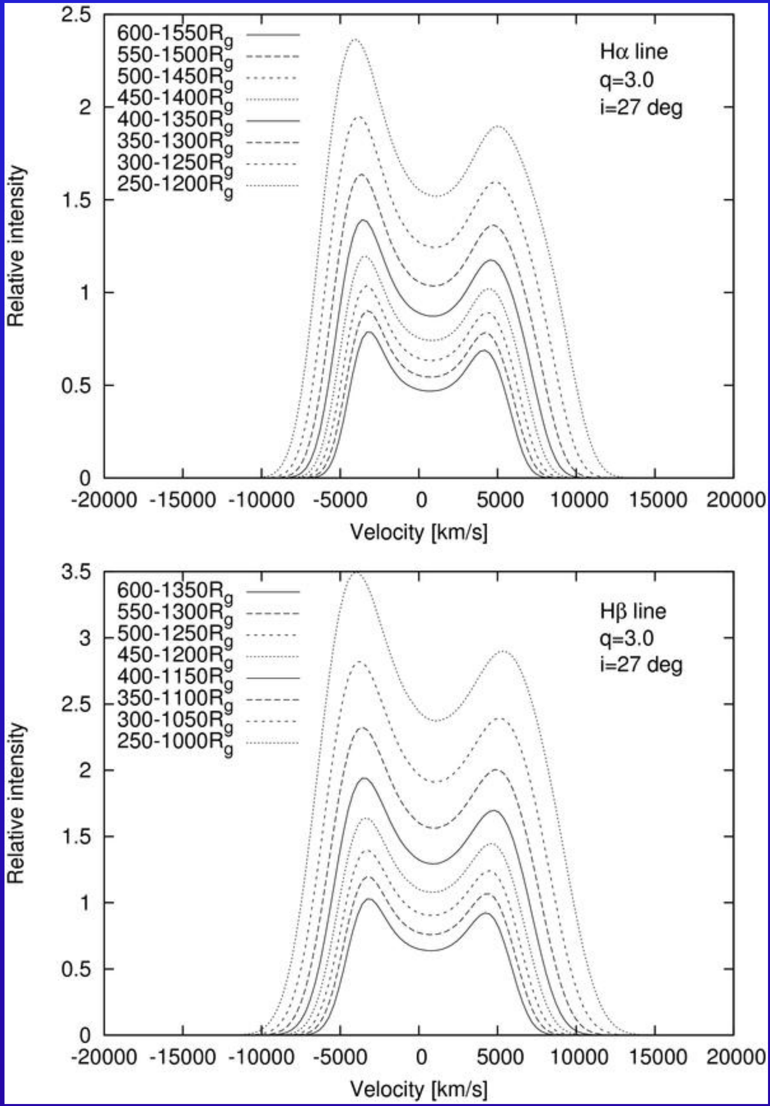
Velocity-delay map

Kollatschny 2003a

BLR: Accretion disk structure in 3C390.3

Information about accretion disk structure in 3C390.3 from shape of line profiles





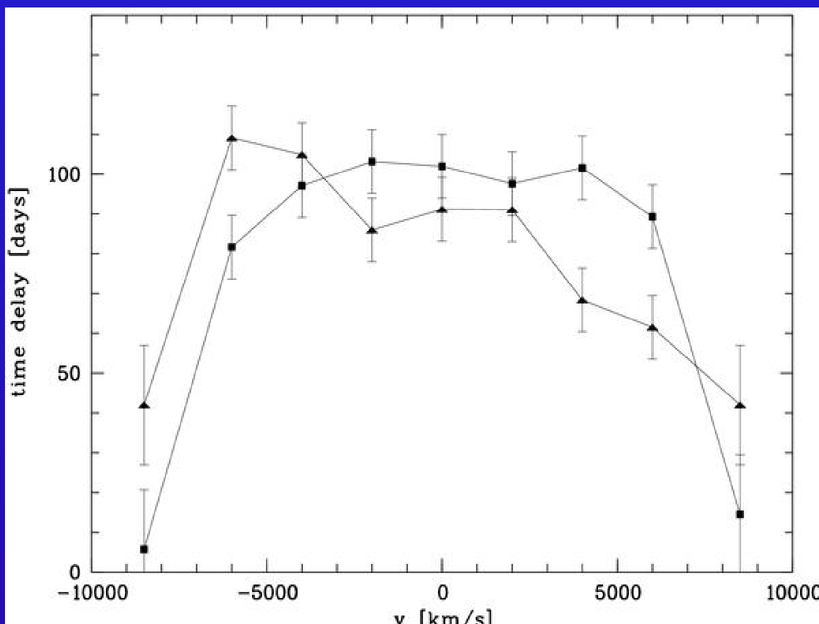
Spectra of 3C390.3 close to maximum (2007) and minimum (1997)

Modeled Hα ,Hβ line profiles for different disk parameters

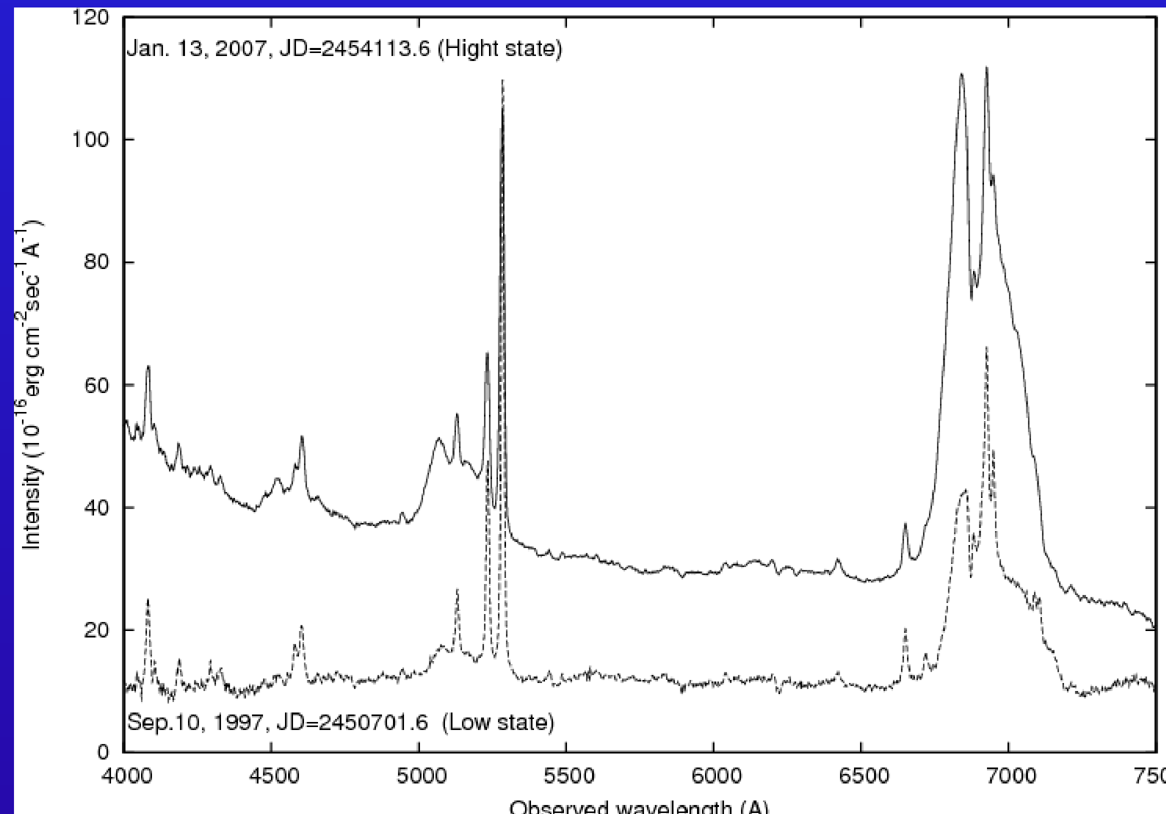
Shapovalova et al. 2010, Popovic et al. 2011

BLR: Accretion disk structure in 3C390.3

Information about accretion disk structure in 3C390.3 also from line profile variations



Time delay of individual Hβ line segments with respect to continuum light curve (1995-2002: squares, 2003-2007: triangles)



Spectra of 3C390.3 close to maximum (2007) and minimum (1997)

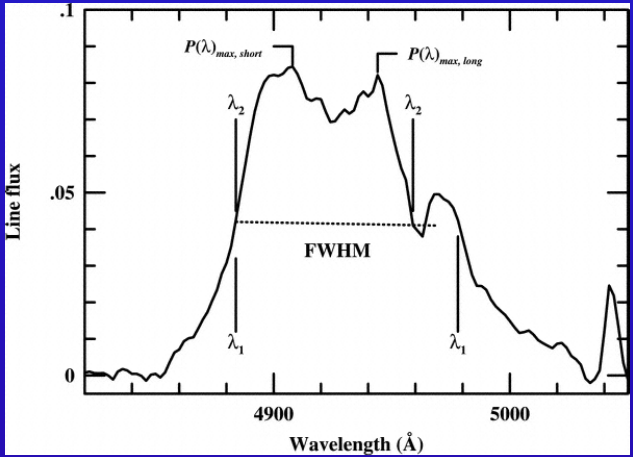
Shapovalova et al. 2010, Popovic et al. 2011

Line profile studies: BLR structure & kinematics

Black hole mass estimations for 35 AGNs based on improved line-width measurements (FWHM, line dispersion σ) of the mean and rms line profiles of Hβ

Given an emission-line profile $P(\lambda)$ (i.e., flux per unit wavelength above a continuum interpolated underneath the line), we parameterized the line width in two separate ways:

FWHM.—How this quantity is measured depends on whether the line is single- or double-peaked. In the case of



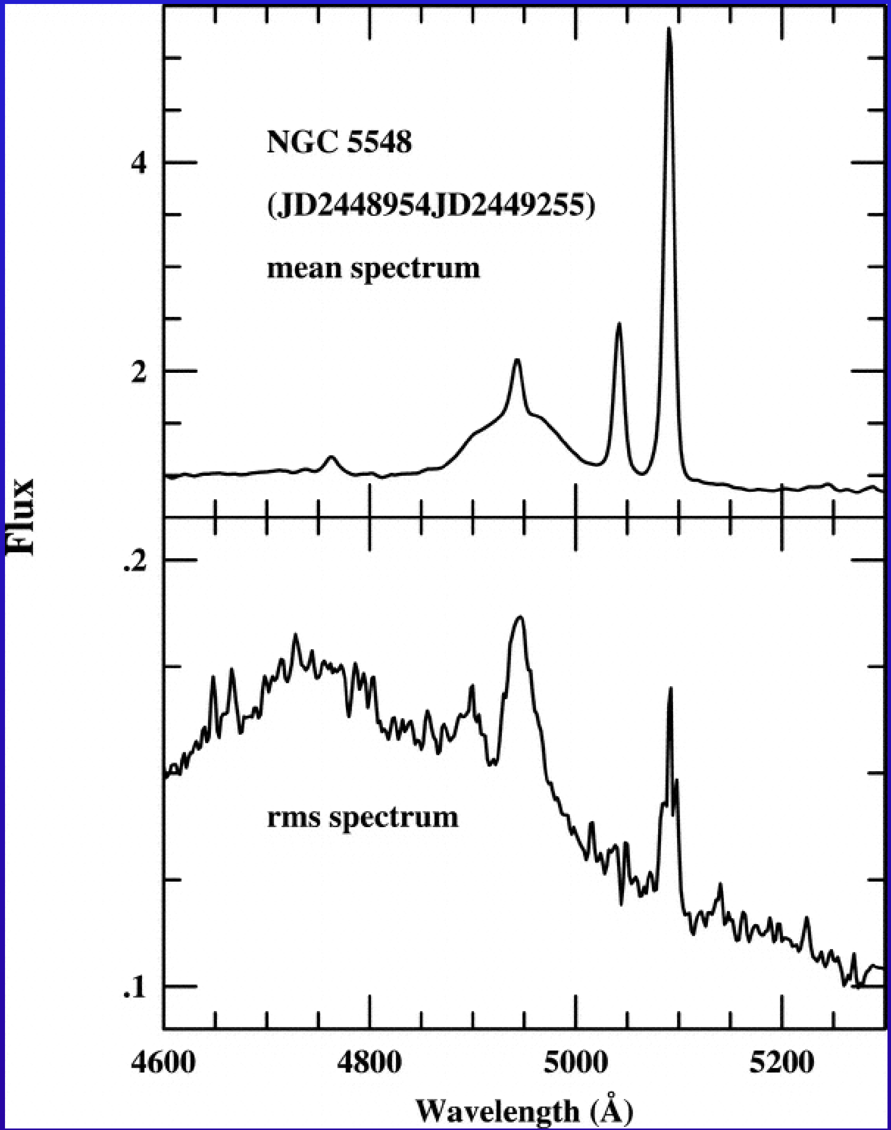
Line dispersion.—The first moment of the line profile is

$$\lambda_0 = \int \lambda P(\lambda) d\lambda \Big/ \int P(\lambda) d\lambda. \qquad (4)$$

We use the second moment of the profile to define the variance or mean square dispersion

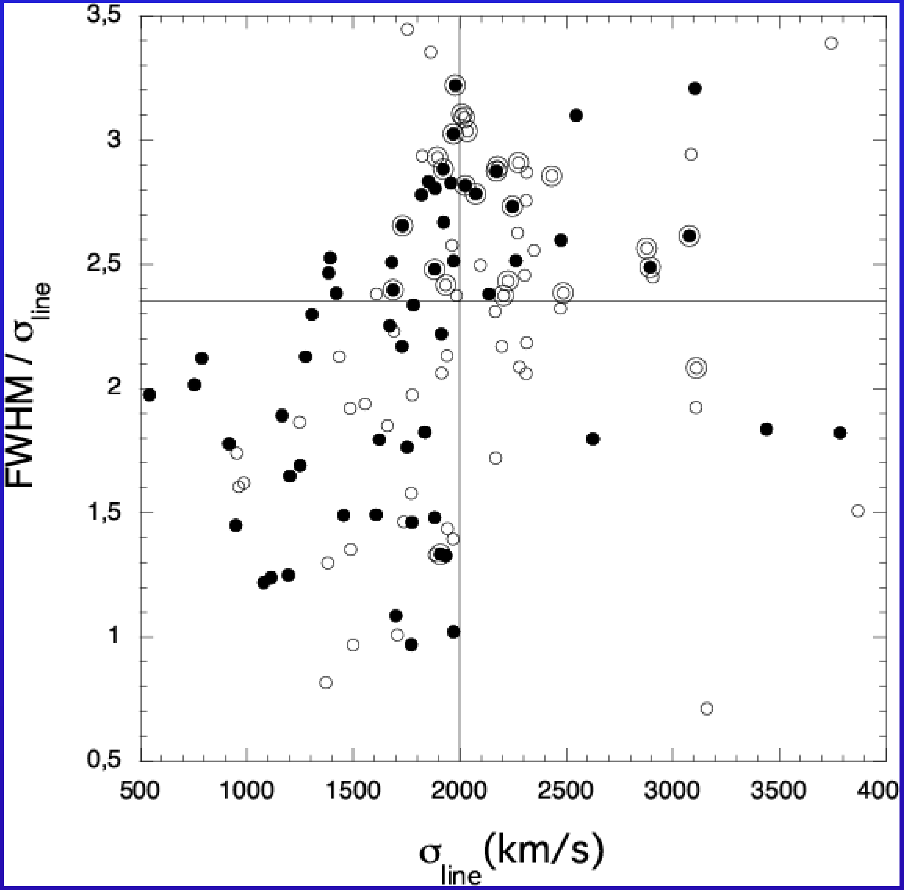
$$\sigma^2_{\rm line}(\lambda) = \langle \lambda^2 \rangle - \lambda_0^2 = \left[\int \lambda^2 P(\lambda) d\lambda \Big/ \int P(\lambda) d\lambda \right] - \lambda_0^2. \quad (5)$$

The square root of this equation is the line dispersion $\sigma_{\rm line}$ or rms width of the line.



Peterson et al., 2004

Hβ line-width ratio FWHM/σ versus σ



Peterson, 2004, data set

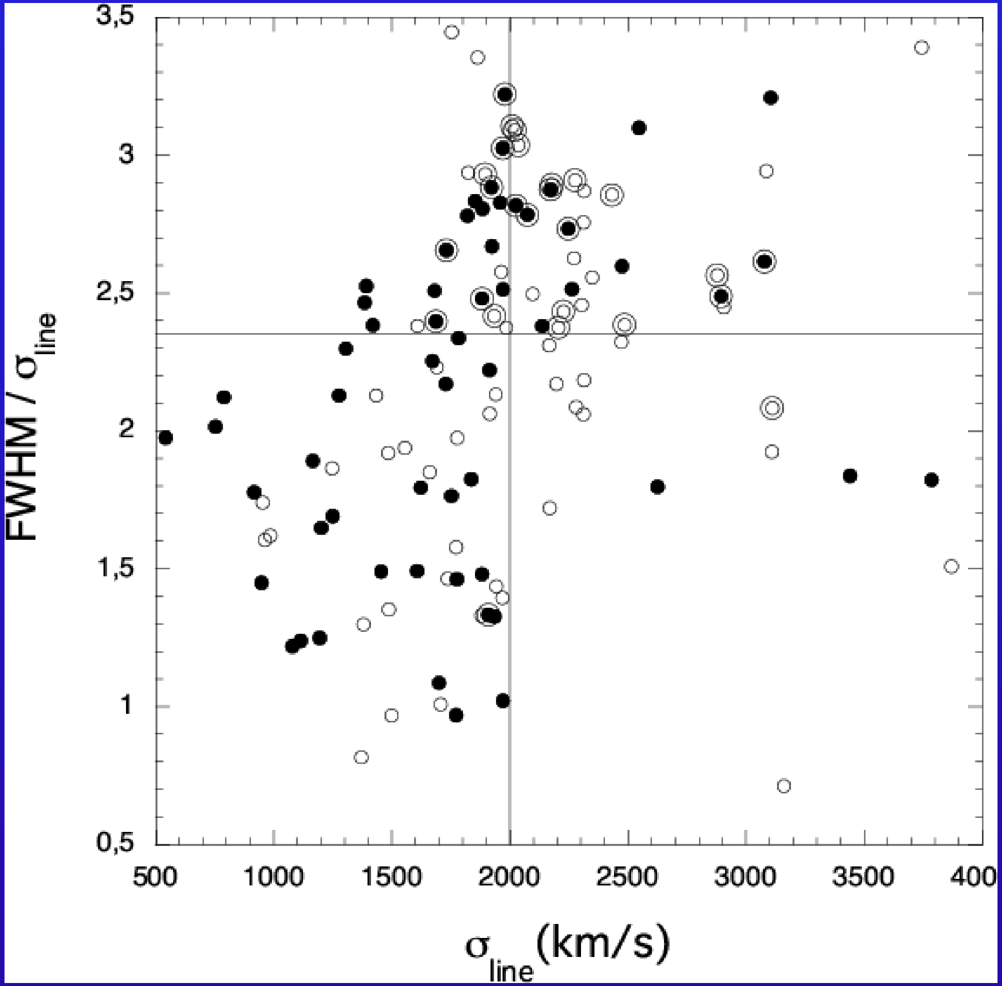
The horizontal line at 2.35 is the value of the ratio for a Gaussian profile.

The open and filled circles correspond respectively to values based on mean and rms spectra.

The vertical line at σ = 2000 km/s approximates the division of Sulentic et al. (2000) into Populations A (left) and B (right).

The horizontal line at 2.35 divides the samples into Populations 1 (lower) and 2 (upper) (Collin et al., 2006).

Hβ line-width ratio FWHM/σ versus σ



The Hβ line-width ratio FWHM/σ versus σ (mean & rms spectra).

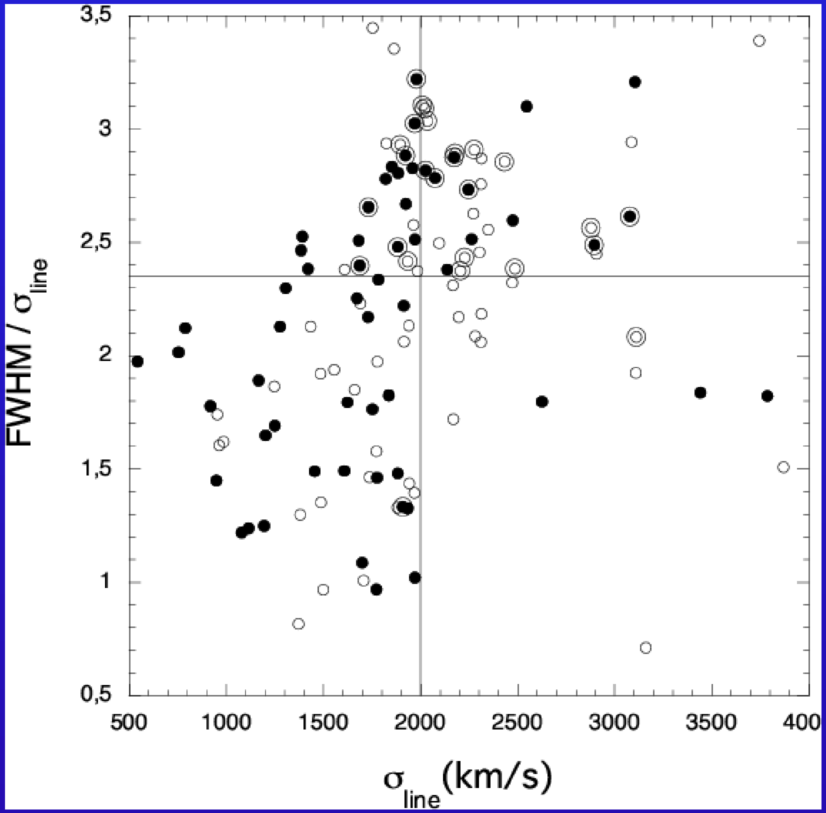
Relationship between FWHM and σ depends on the line profile:

	FWHM/σ
- rectangular fct.	3.46
- edge-on rotat. ring	2.83
- triangular fct.	2.45
- Gaussian profile	2.35
- Lorentzian profile	→ 0.

Collin et al., 2006

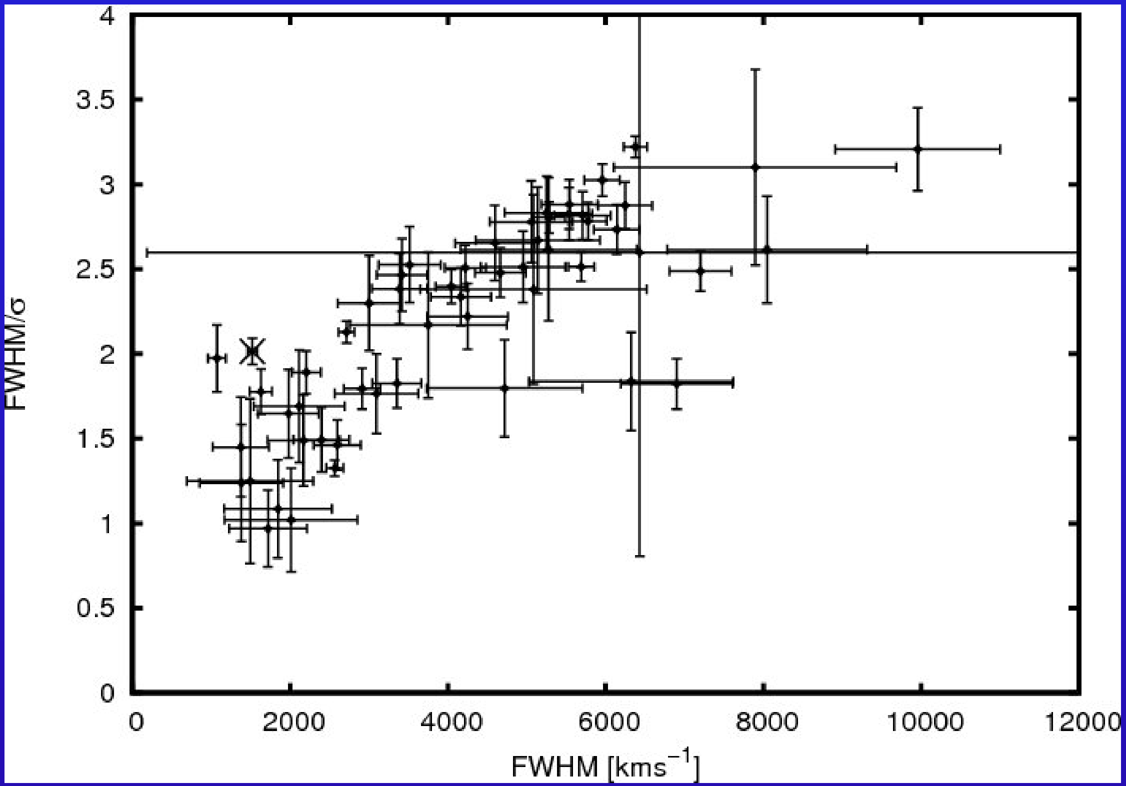
Hβ line-width ratio FWHM/σ versus σ as well as FWHM

Peterson et al., 2004, data set



The Hβ line-width ratio FWHM/σ versus σ (mean & rms profiles).

Collin et al., 2006



The Hβ line-width ratio FWHM/σ versus FWHM (rms profiles) – more continuos.

Mean profiles contaminated by narrow line components.

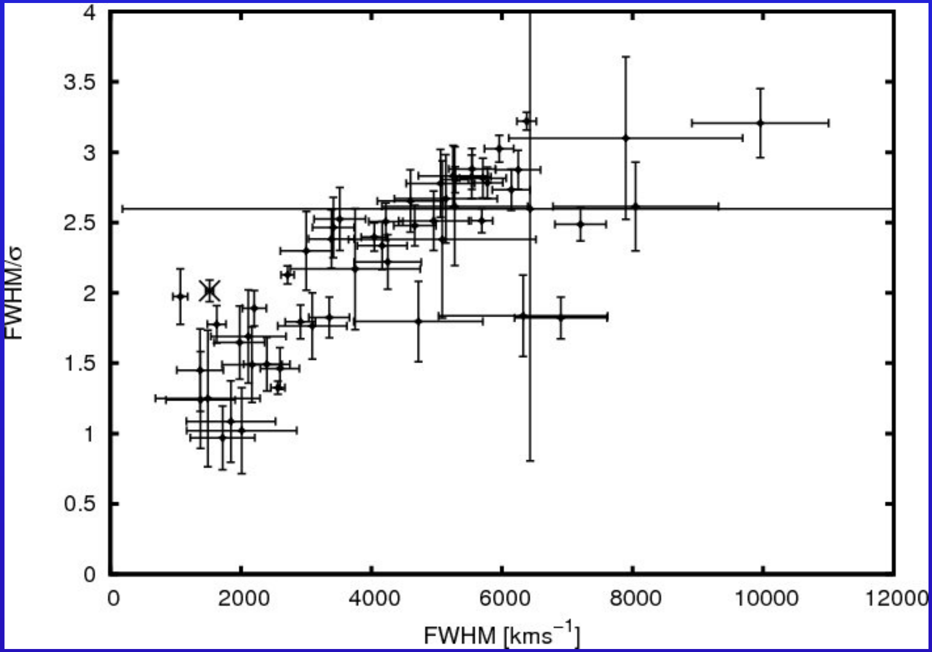
Kollatschny & Zetzl, 2011, Nature 470

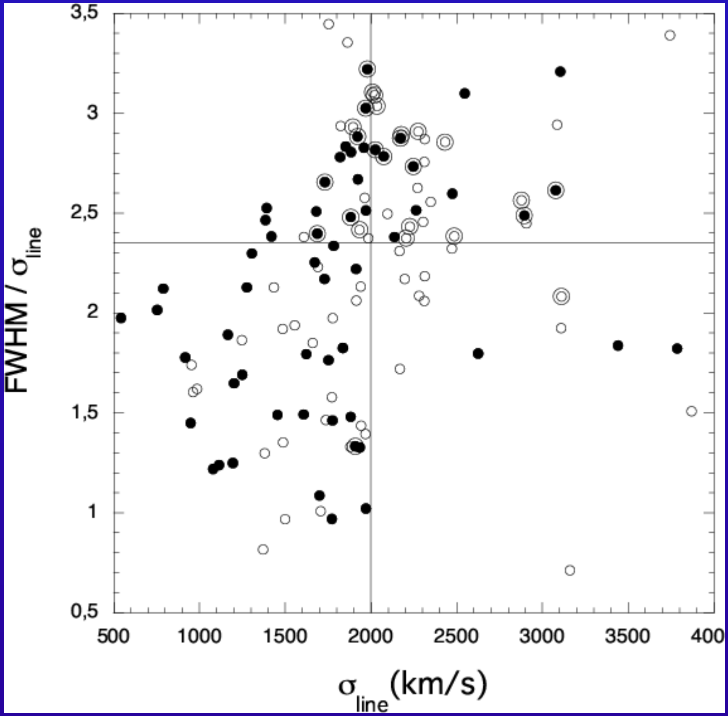
Hβ line-width ratio FWHM/σ versus σ as well as FWHM

Table 1 | Line profile versus linewidth correlations

	r_p	r_s	r_k	P_p	P_s	P_k
Hβ FWHM/σ_{line} versus FWHM	0.792	0.823	0.649	6.4×10^{-15}	6.4×10^{-11}	3.5×10^{-14}
Hβ FWHM/σ_{line} versus σ_{line}	0.364	0.513	0.350	0.003	4.7×10^{-5}	4.4×10^{-5}
He II FWHM/σ_{line} versus FWHM	0.803	0.786	0.571	0.016	0.041	0.048
He II FWHM/σ_{line} versus σ_{line}	0.464	0.357	0.214	0.247	0.361	0.458
C IV FWHM/σ_{line} versus FWHM	0.821	0.821	0.619	0.023	0.049	0.051
C IV FWHM/σ_{line} versus σ_{line}	0.599	0.643	0.429	0.155	0.126	0.176

Given are the Pearson correlation coefficient r_p, the Spearman's rank-correlation coefficient r_s, as well as the Kendall correlation coefficient r_k for Hβ, He II $\lambda = 4,686$ Å and C IV $\lambda = 1,550$ Å linewidth ratios FWHM/σ_{line} versus FWHM as well as FWHM/σ_{line} versus σ_{line}. P_p, P_s and P_k are the associated percentage probabilities for random correlations[15,16]. The Pearson correlation coefficient tests a linear relation only, while the other correlation coefficients test for a general monotonic relation.



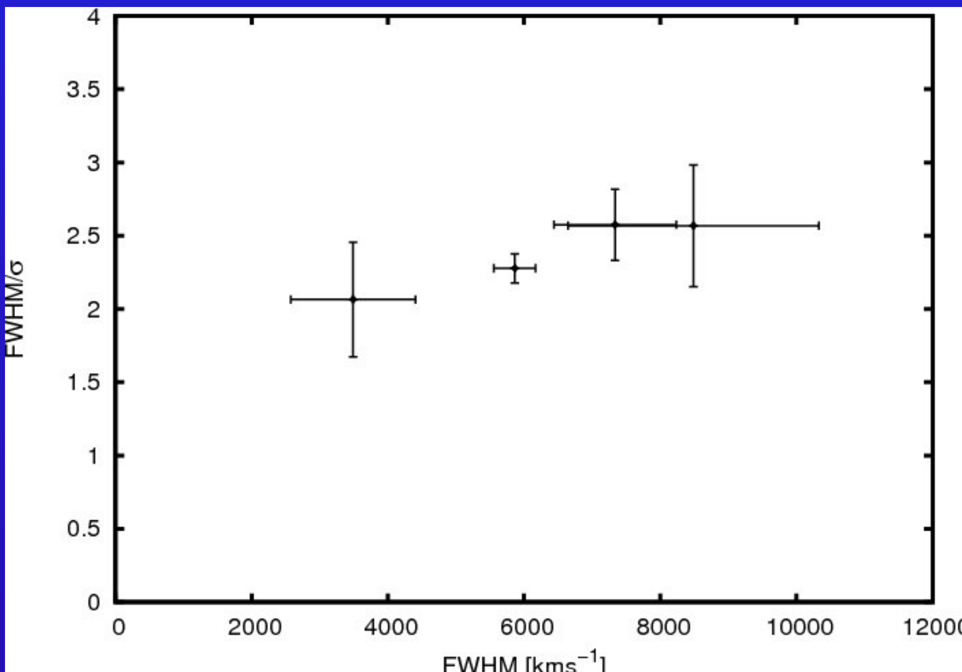


Line profile FWHM/σ versus linewidth (FWHM as well as σ) correlations.

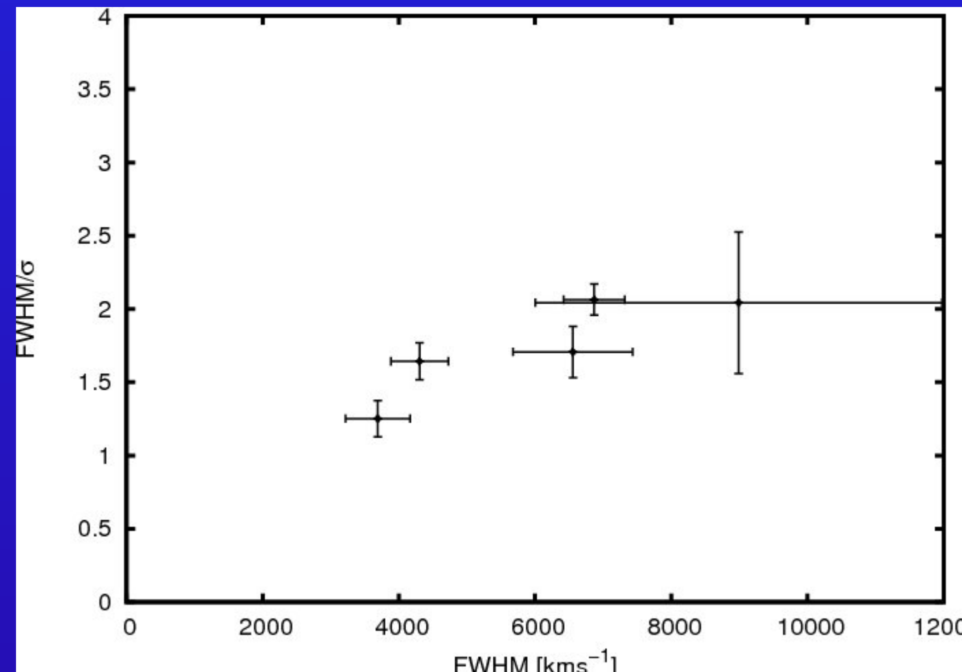
Kollatschny & Zetzl, 2011, Nature 470

HeII and CIV line-width ratios FWHM/σ versus FWHM

Peterson, 2004, data set:



The HeIIλ4686 line-width ratio FWHM/σ versus FWHM (rms profiles).



The CIVλ1550 line-width ratio FWHM/σ versus FWHM (rms profiles).

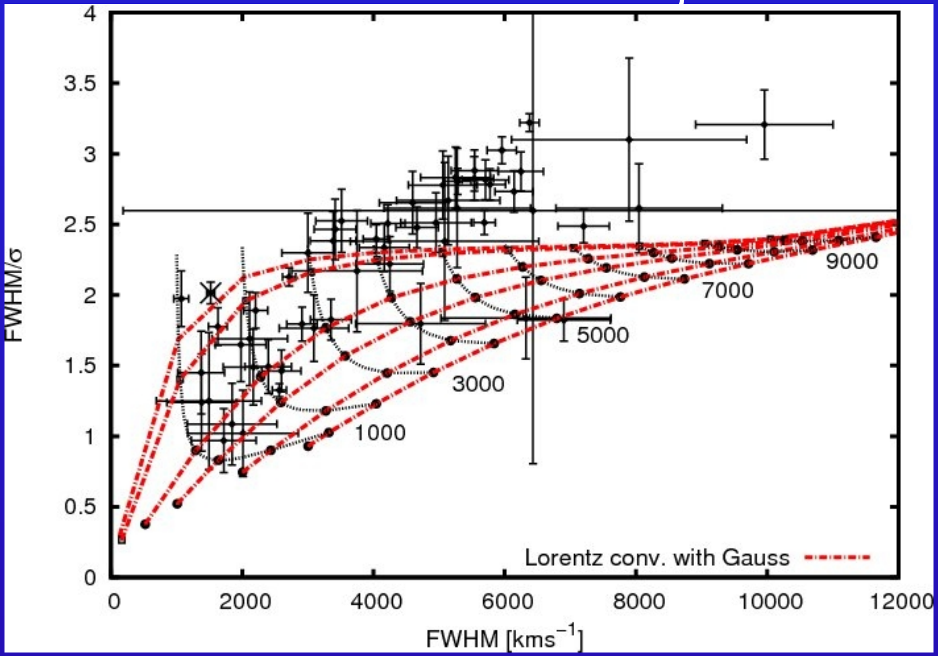
Kollatschny & Zetzl, 2011, Nature 470

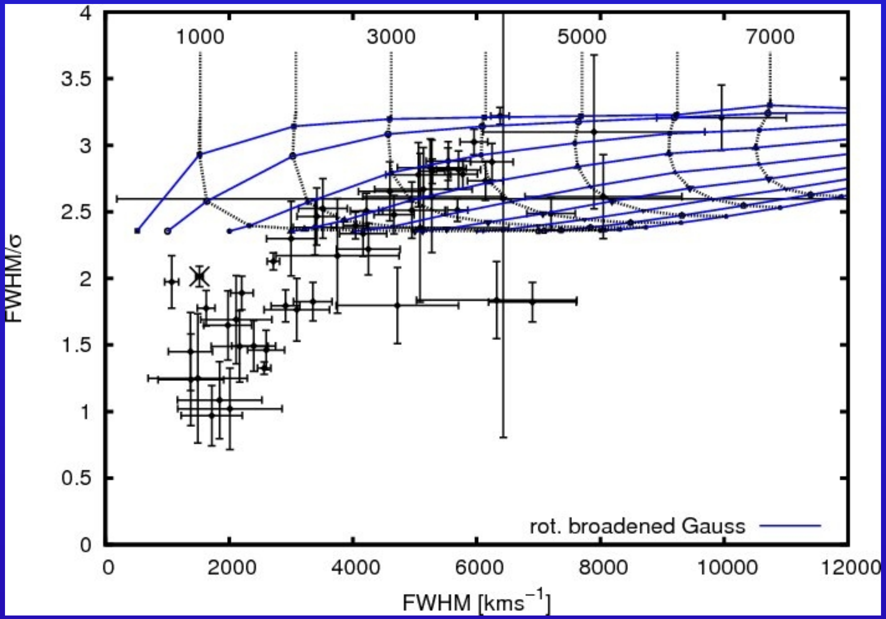
Different emission lines show similar – however unequal – line profile relations.

Modeling of observed line profile relations

in simple way by multiple combinations of profiles.

Observed and theoretical Hβ line-width ratios FWHM/σ versus FWHM





Lorentzian profiles convolved with Gaussian profiles.

The line widths of the Lorentzian profiles (FWHM) correspond to 50, 100, 500, 1000, 2000, 3000 km/s (from top to bottom). The widths of the Gaussian profiles correspond to 1000 to 9000 km/s (from left to right).

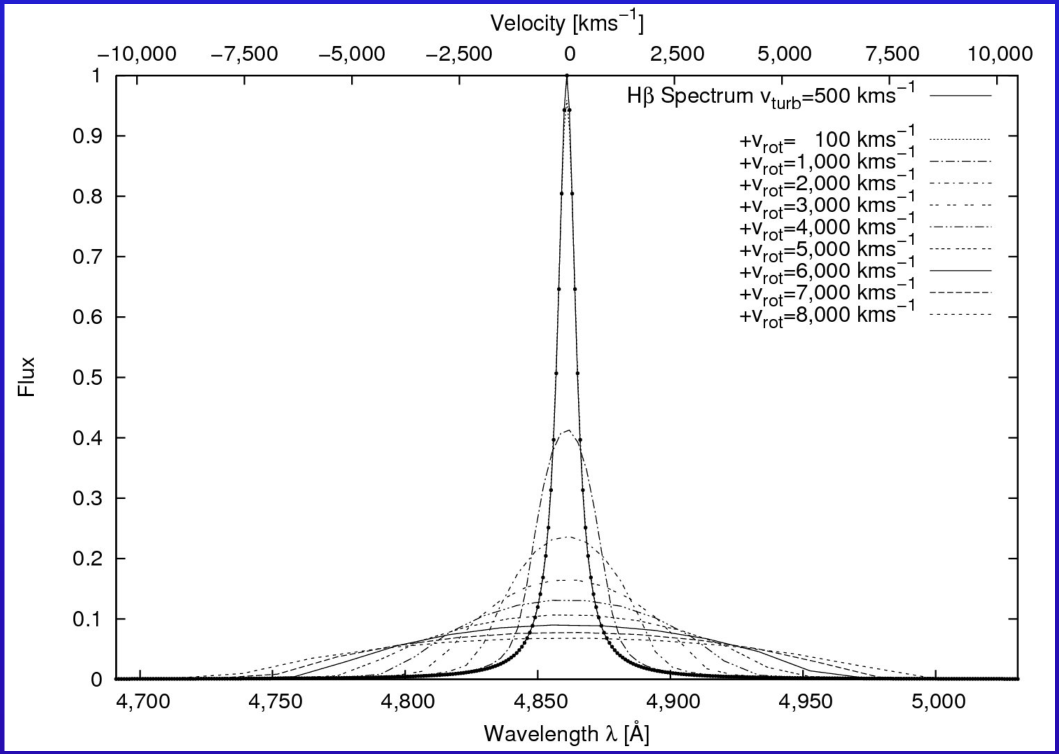
Rotational broadening of Gaussian profiles.

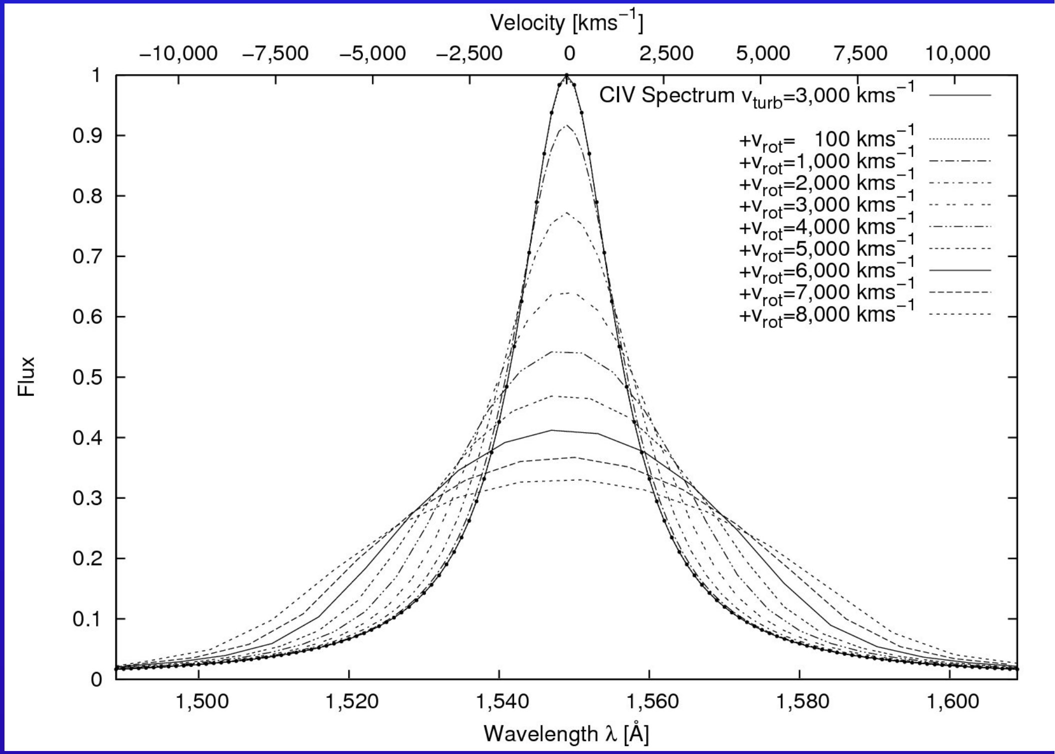
The line widths of the Gaussian profiles (FWHM) correspond to 500, 1000,..., 8000 km/s (from top to bottom). The associated rotational velocities range from 1000 to 7000 km/s (from left to right). FWHM/σ always larger than 2.35.

Kollatschny & Zetzl, 2011, Nature 470

Modeling of observed line profile relations

Tests: *Theoretical line broadening of Lorentzian profiles due to rotation.*



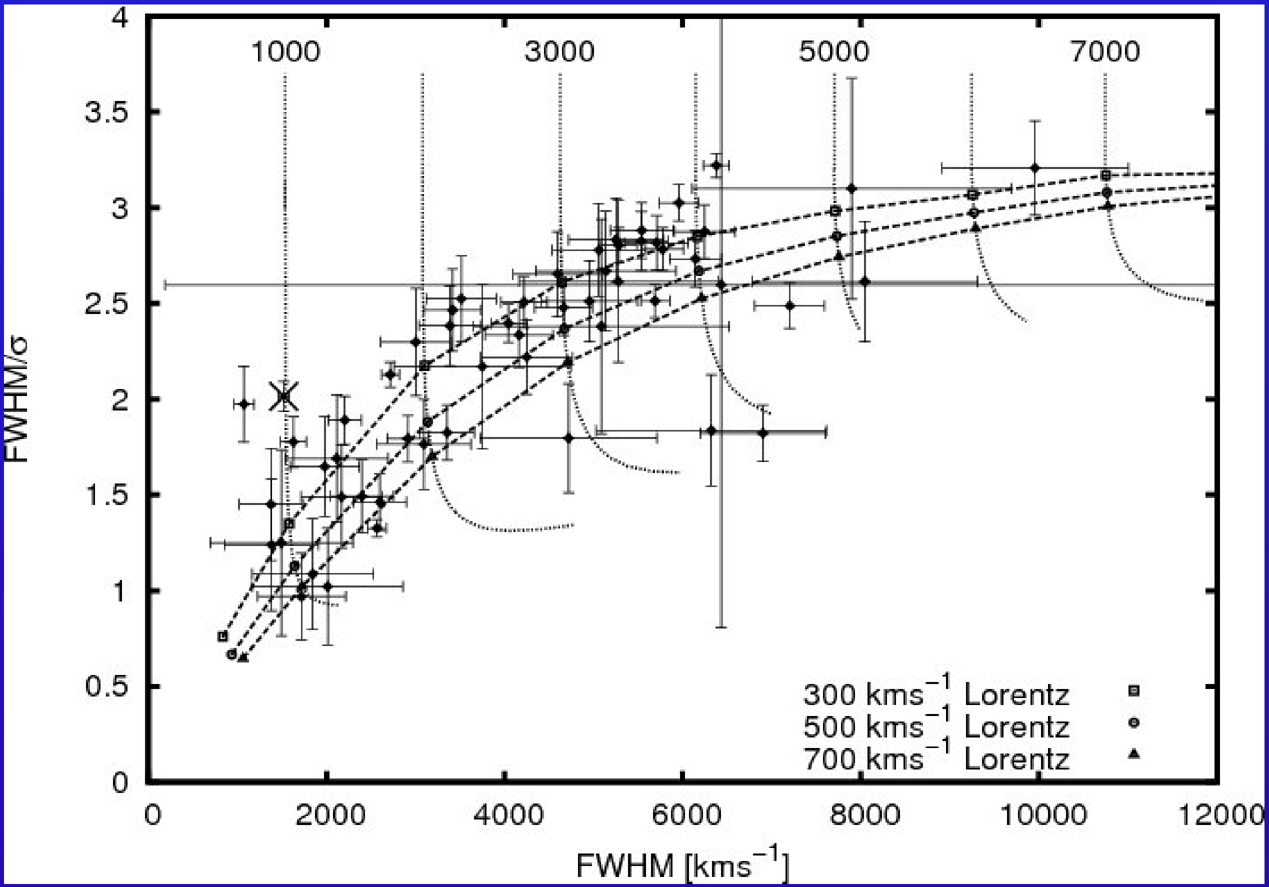


Rotational broadening of Lorentzian Hβ line profile (v_{turb} = 500 km/s).

Rotational broadening of Lorentzian CIVλ1550 line profile (v_{turb} = 3000 km/s).

Observed and modeled Hβ line widths ratios

FWHM/σ versus linewidth FWHM



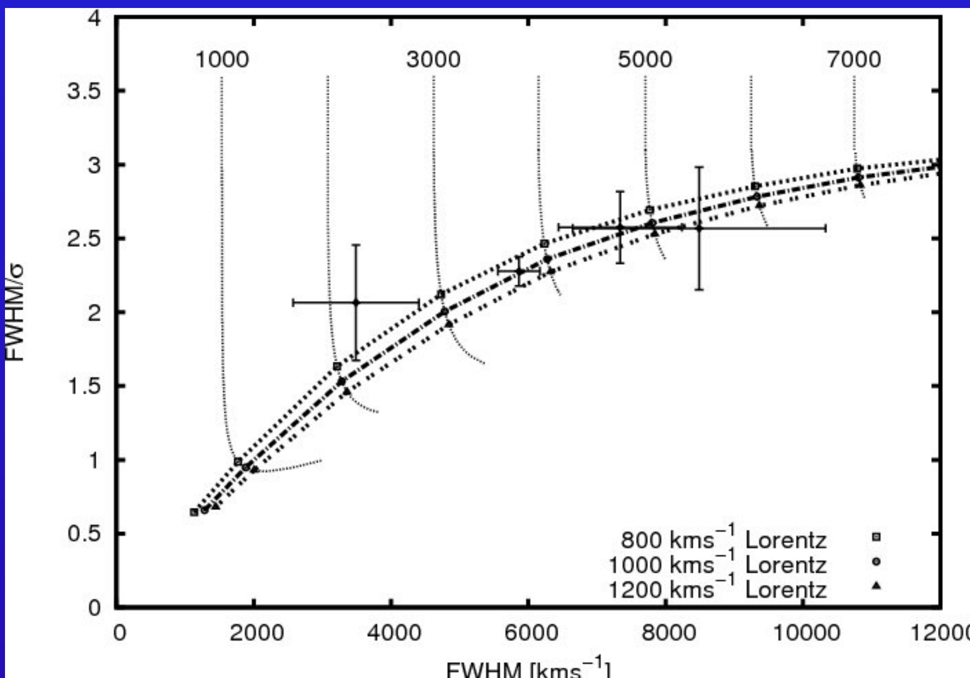
Dashed curves: rotational line broadened Lorentzian profiles (FWHM = 300, 500, 700 km/s). Rotational velocities range from 1000 to 7000 km/s.

Kollatschny & Zetzl, 2011, Nature 470

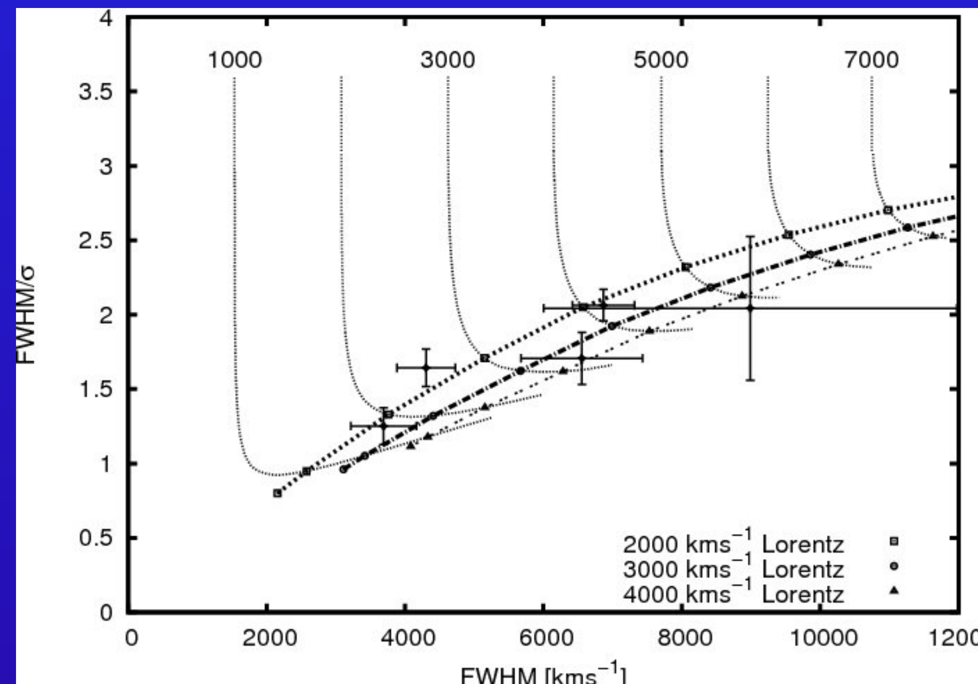
Observed and modeled HeII and CIV line widths ratios

FWHM/σ versus linewidth FWHM

HeIIλ4686



CIVλ1550

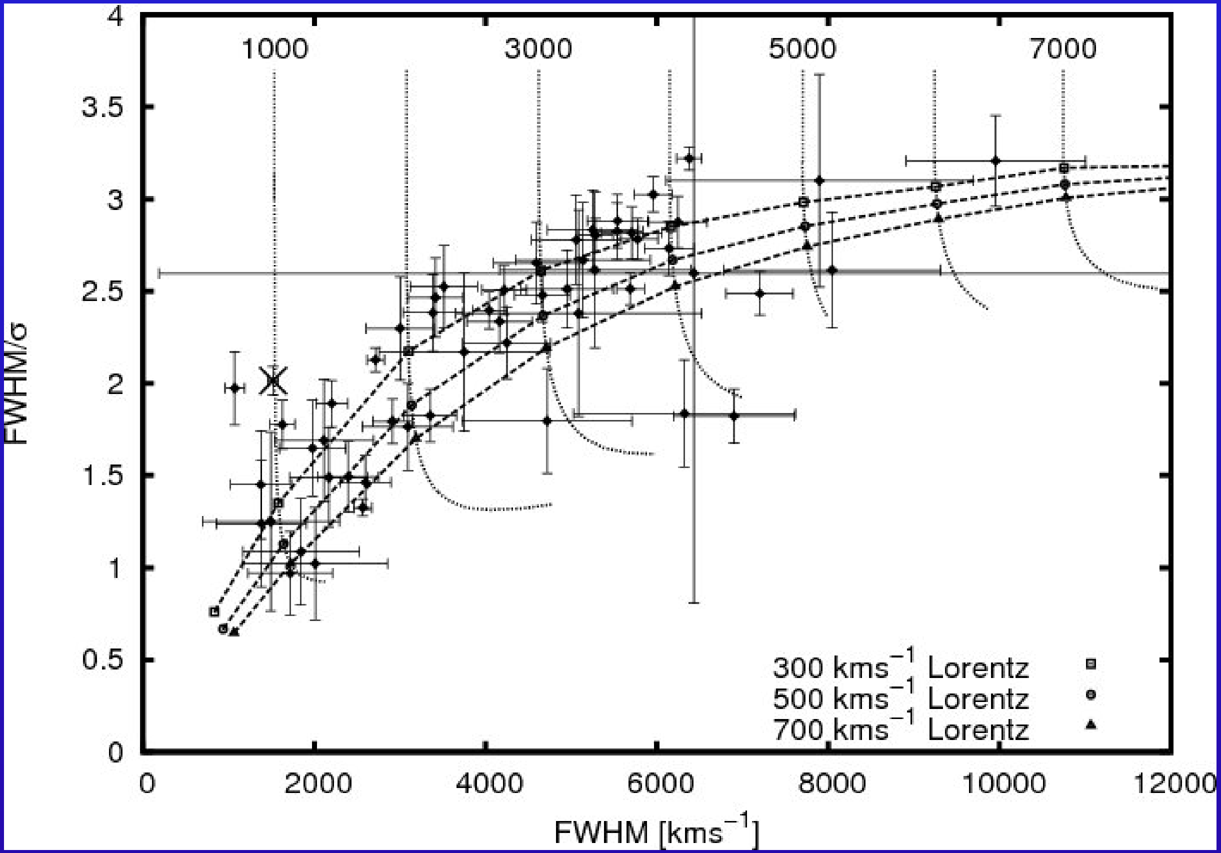


Dashed curves: theoretical linewidth ratios of rotational line broadened Lorentzian profiles (FWHM = 800, 1000, 1200 km/s). Rotational velocities range from 1000 to 7000 km/s.

Dashed curves: theoretical linewidth ratios of rotational line broadened Lorentzian profiles (FWHM = 2000, 3000, 4000 km/s). Rotational velocities range from 1000 to 7000 km/s.

Line profile studies: BLR structure & kinematics

Observed and modeled Hβ line-width ratios FWHM/σ versus linewidth FWHM.



Deviations from general trend: by e.g. orientation effects of line-emitting accretion disk:
an incliened accretion disk leads to smaller linewidths owing to projection effects while the FWHM/σ remains constant (e.g. Mrk110 marked by a cross (i ~ 21°)).

Line profile studies: BLR structure & kinematics

Characteristic turbulent velocities belong to individual emission lines in BLR of all AGN:

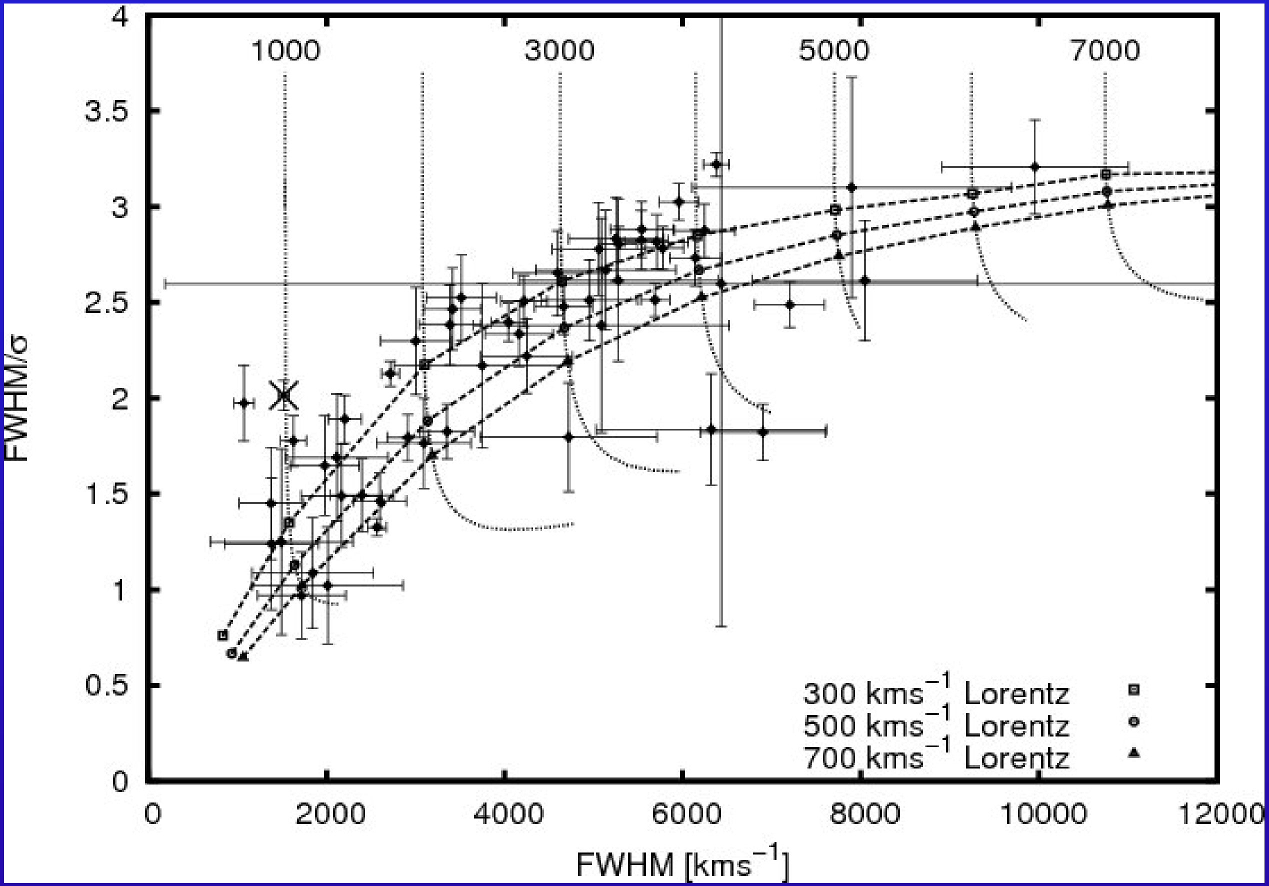
- Hβ : 500 ± 200 km/s
- HeIIλ4686 : 1000 ± 200 km/s
- CIVλ1550 : 3000 ± 1000 km/s

Individual emission lines originate at different distances from center (rev. mapping): →

Turbulent velocity varies as function of distance to center.

Observed and modeled Hβ line widths ratios

FWHM/σ versus linewidth FWHM



In all AGN: Hβ turbulent velocity ~ 500 km/s
Rotation velocity different in individual galaxies: 500 – 7000 km/s

Line profile studies: BLR structure & kinematics

From accretion disk theory (e.g. Pringle, 1981):

$$H(eight) / R(adius) = 1/\alpha * v_{turb} / v_{rot}$$

α = (const.) viscosity parameter

→ fast rotating broad line AGN: *geometrically thin accretion disk*

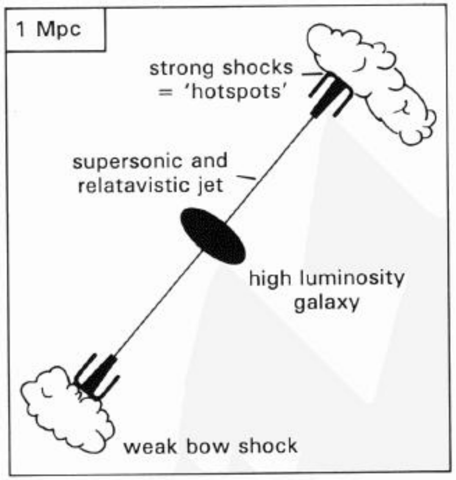
→ slow rotating narrow line AGN: *geometrically thick accretion disk*

Different Hβ line widths → different rotational vel. → different BLR geometries:

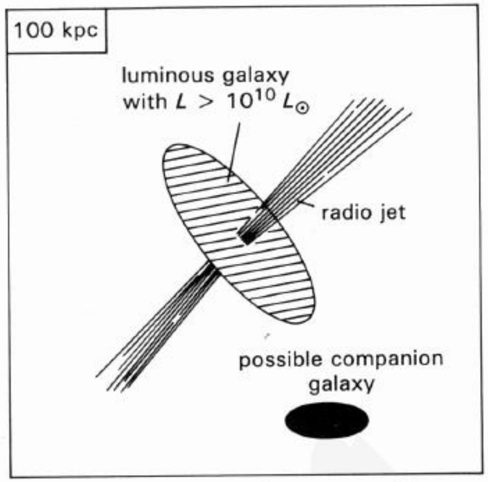
Eigenvector 1 correlation between linewidth, strong FeII emision, soft X-ray excess: due to different BLR/disk geometries

Kollatschny & Zetzl, 2011, Nature 470

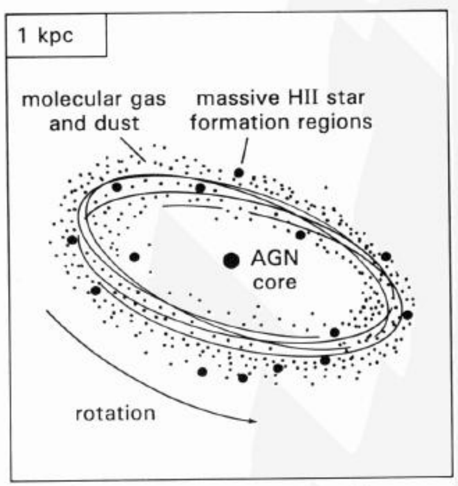
Scale Sizes of an AGN



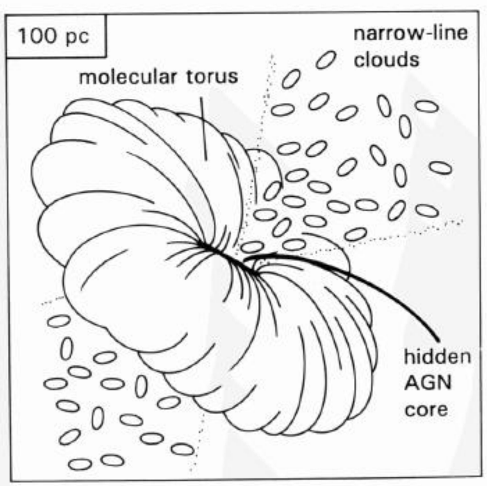
Extended radio sources — shown is an FRII source with an edge-brightened structure. The FRIs have lower jet velocities and fade-out to the ends.



The host galaxy. Although shown as an early type galaxy with a smooth profile, it could also be highly irregular with multiple nuclei as a result of merging.

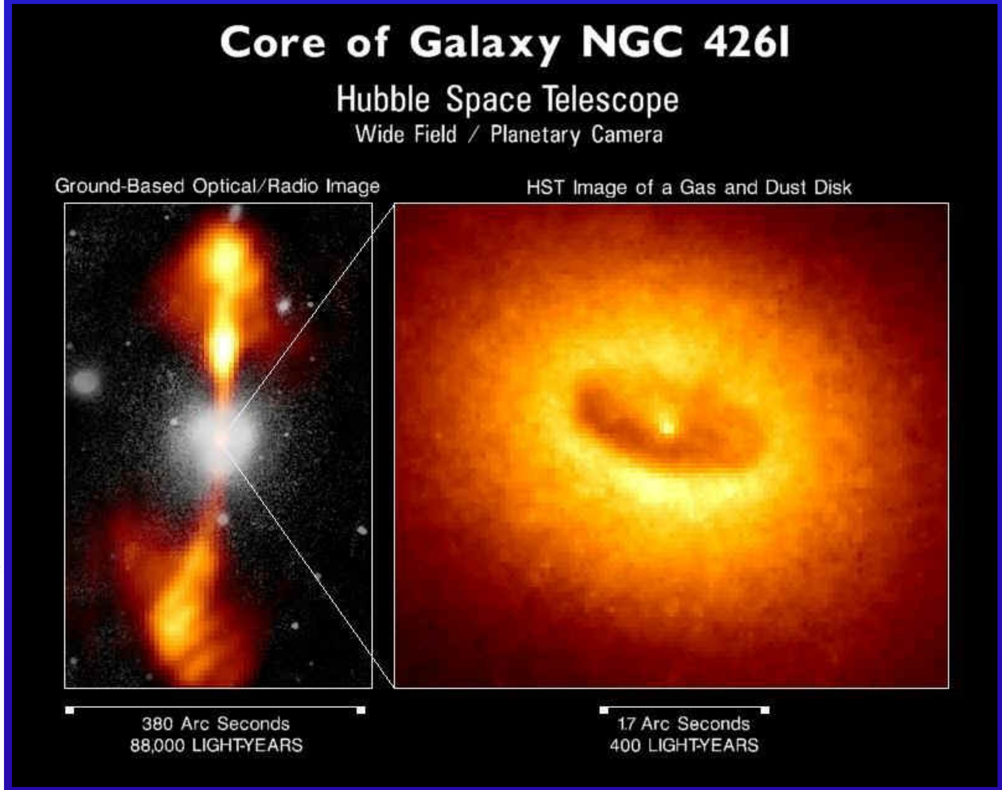


The central kpc star formation disk. This strong far infrared emitting zone might be fed by a bar structure, as seems to be the case for NGC1068.



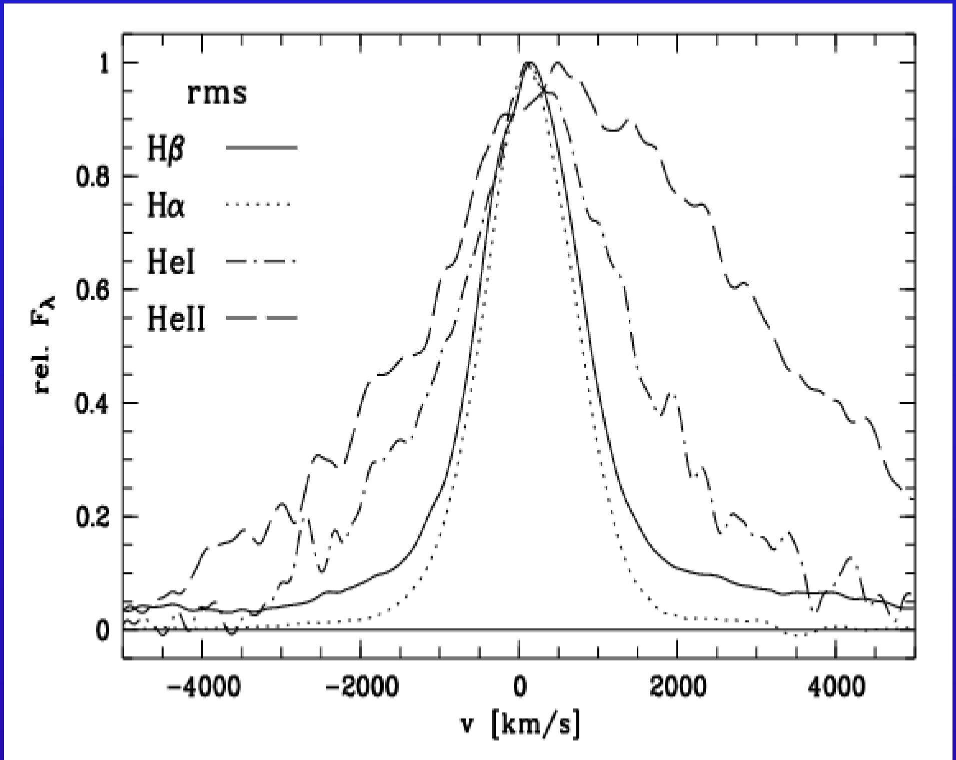
The narrow-line region comprising small but numerous clouds of the interstellar medium ionized by the central AGN core.

Fig. 9.9 Cartoon of the representative scale sizes of an AGN. How we eventually see the object depends on a number of parameters, the main one being the orientation of the obscuring torus with respect to the observer. (Adapted from Blandford, *Active Galactic Nuclei*, Saas-Fee Advanced Course 20, Springer–Verlag, 1990.)

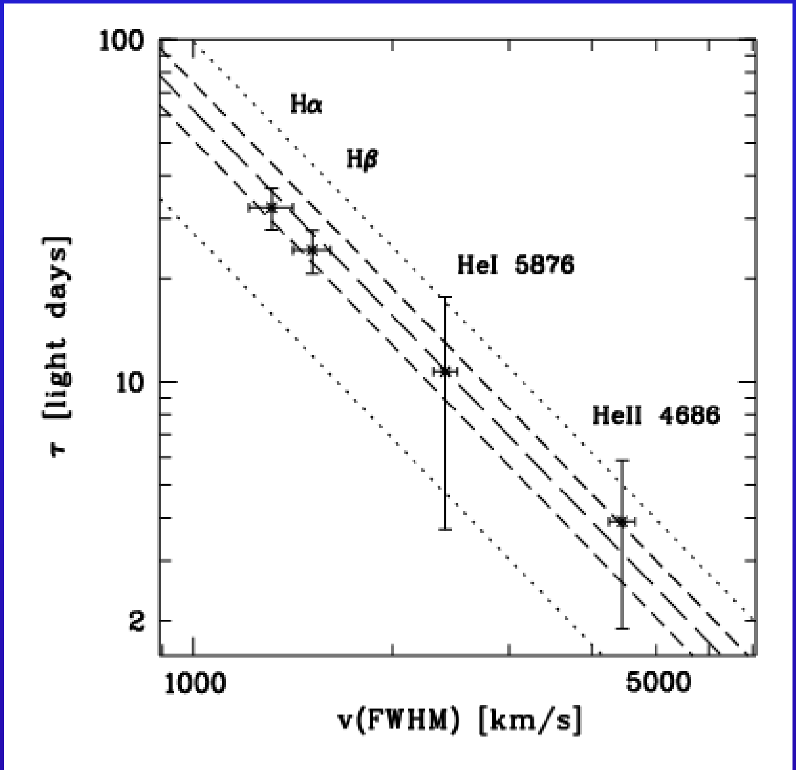


R. Blandford

BLR size and stratification in Mrk110



Normalized rms line profiles in velocity space

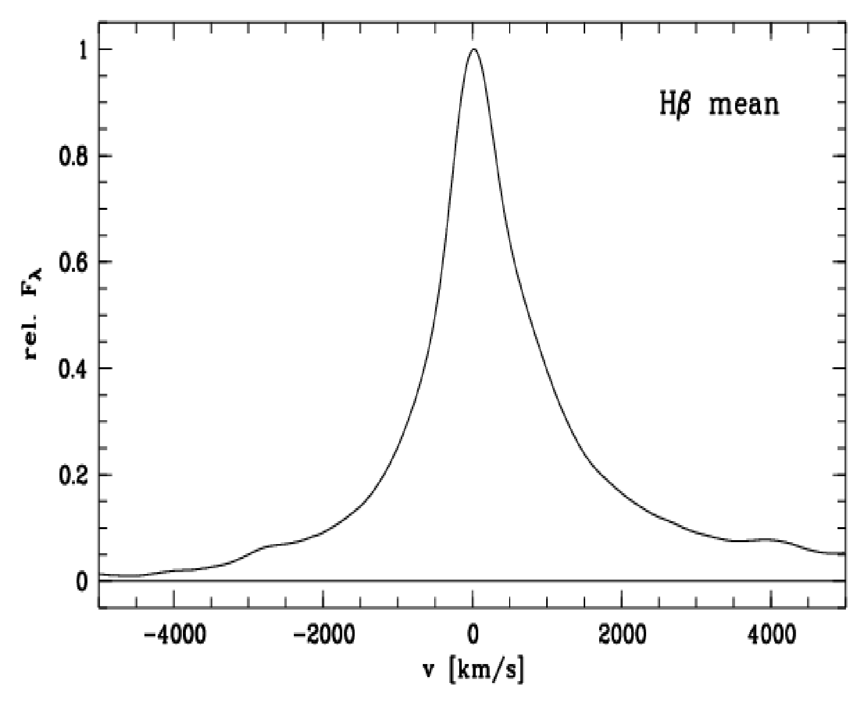


Mean distances of the line emitting regions from central ionizing source as function of FWHM in rms profiles.

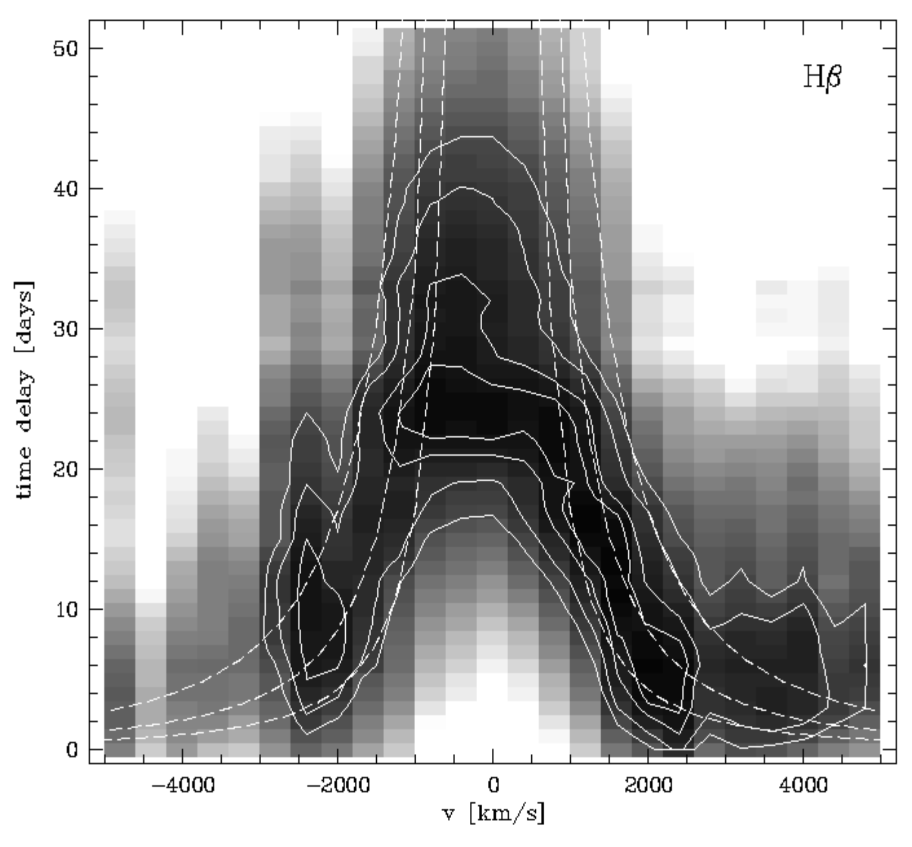
The rms spectrum shows the variable part of the spectrum

The dotted and dashed lines correspond to virial masses of .8 - 2.9 $10^7 M_O$ (from bottom to top).

BLR: Accretion disk structure in Mrk110



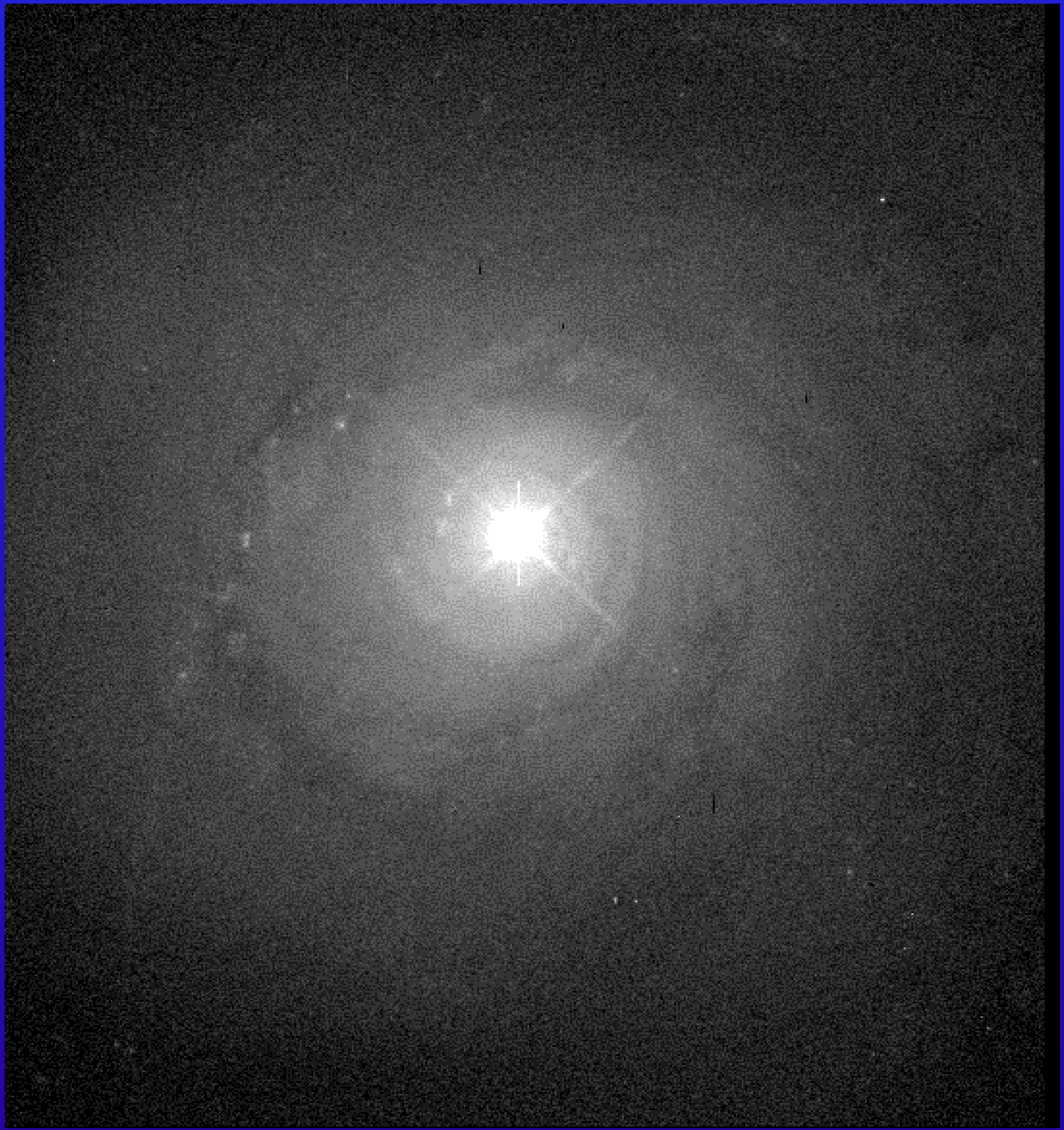
Mean Hβ line profile of Mrk110 in velocity space



Velocity-delay map

Kollatschny 2003a

HST Image of NGC5548

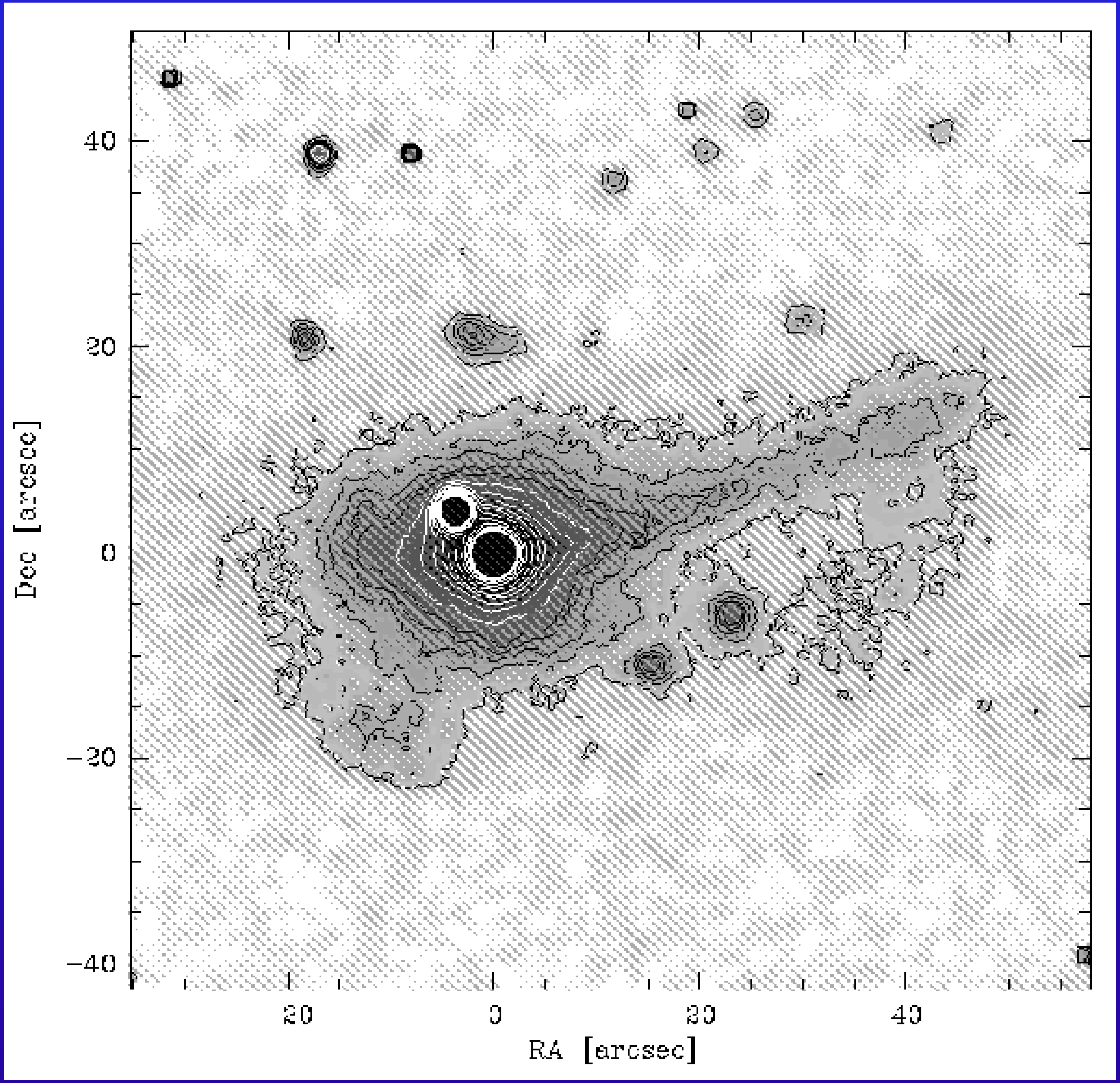


NGC5548

V = 13.7
M_V = -20.7
z = 0.017
FWHM(Hβ)=4400 km s^{-1}

25 x 30 arcsec

BLR size and stratification in Mrk110



Mrk110

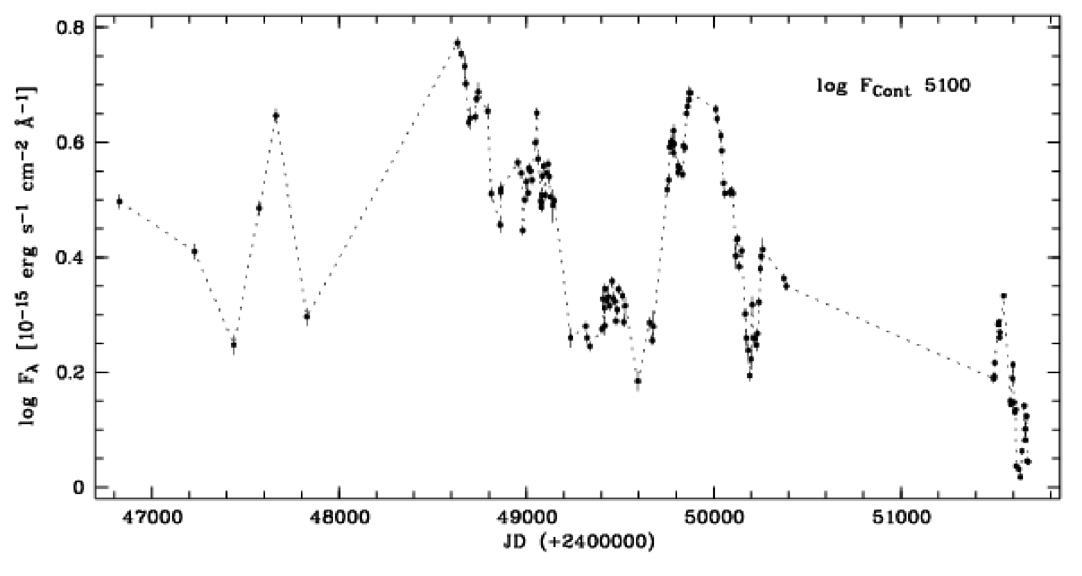
V = 15.4
M_V= -20.6
z = 0.036
FWHM(Hβ)=1680 km s^{-1}

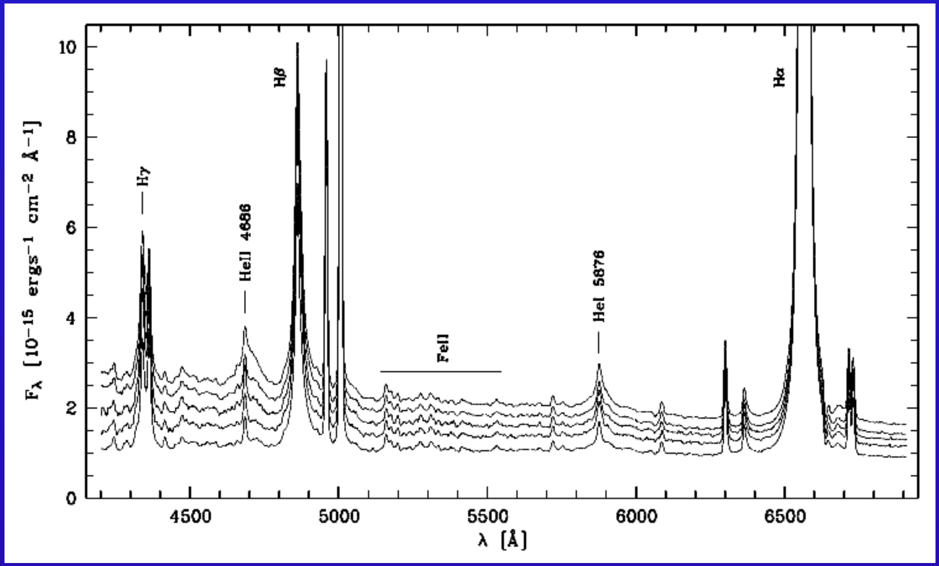
tidal arm: 35kpc

HET variability campaign of Mrk110

long-term continuum light curve

Mrk110 spectra taken between 1999 Nov. and





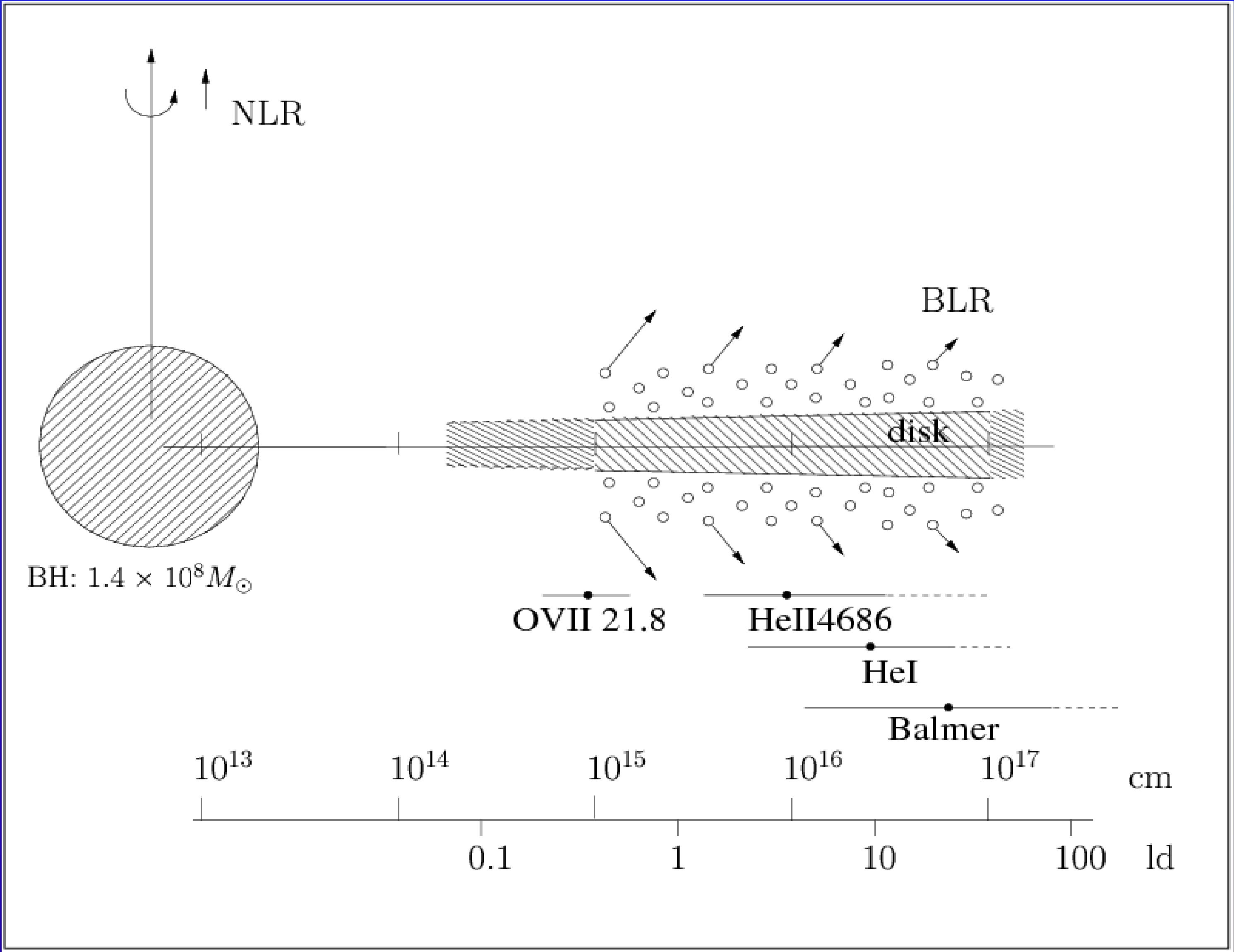
1987

2000

9.2m Hobby-Eberly Telescope at McDonald Ob

S/N >100

The inner BLR structure in Mrk110



i = 21°±10

opt.: 3.9 light-days ($\hat{=}$ 9.8 · 10^{15} cm) = 230 Schwarzschild radii r_s

X-ray: 0.34 ld = 21 r_s

$(r_s = 2GM_{grav}/c^2)$

Theory : BLR kinematics - line profile variations

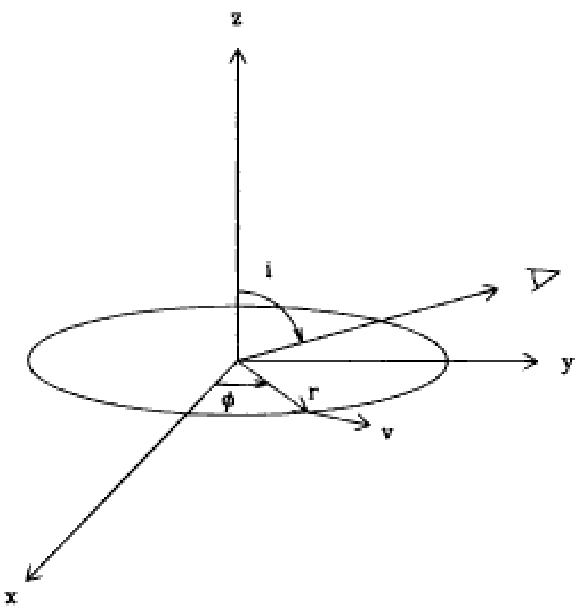


FIG. 1.—Geometry of the disk broad-line region. The angle, i, is the disk inclination relative to the observer. The quantities (r, ϕ) label locations on the disk.

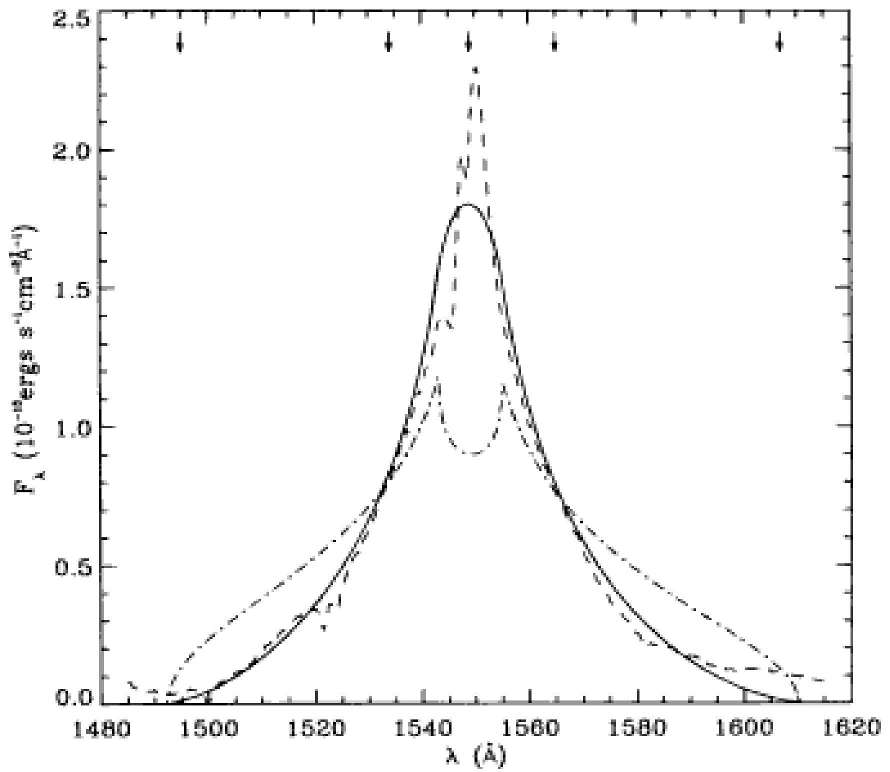
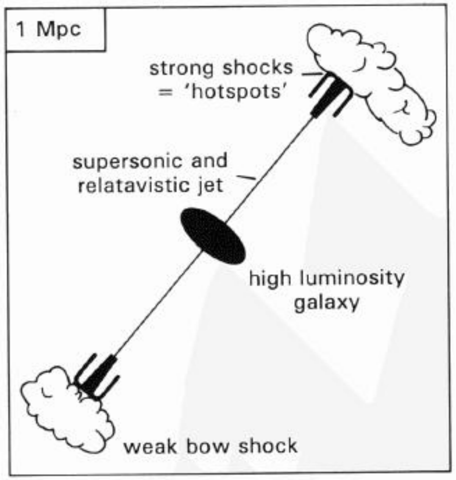


FIG. 2.—Data and model line profiles for the C IV line of NGC 5548. The solid line is the model calculation including the effects of the anisotropic emission. The dashed line is the data from the 1994 *HST* observations described by Korista et al. (1995). Also shown is the double-peaked profile (*dot-dashed line*) of a model line calculation that assumes isotropic emission. The arrows indicate the boundaries of the various wing and core components.

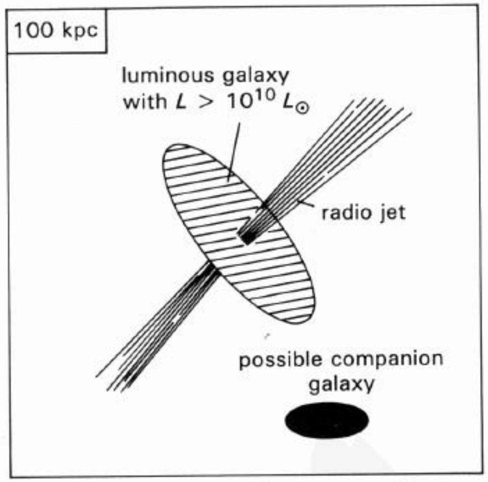
optically thick accretion disk models: single lined profiles

Chiang & Murray, 1996

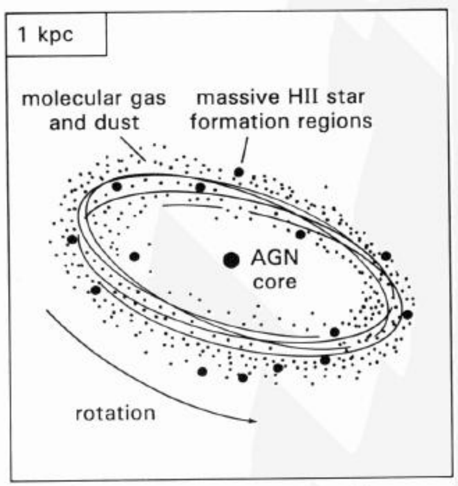
Scale Sizes of an AGN



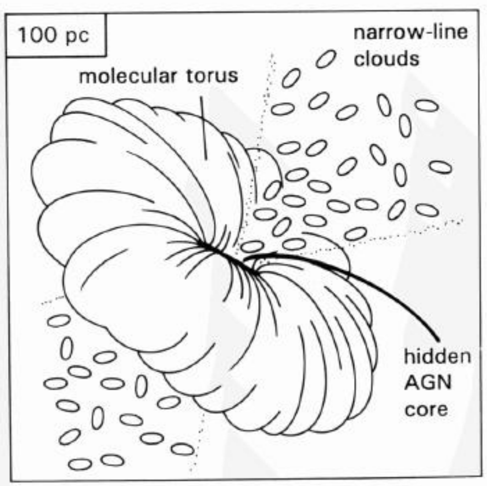
Extended radio sources — shown is an FRII source with an edge-brightened structure. The FRIs have lower jet velocities and fade-out to the ends.



The host galaxy. Although shown as an early type galaxy with a smooth profile, it could also be highly irregular with multiple nuclei as a result of merging.

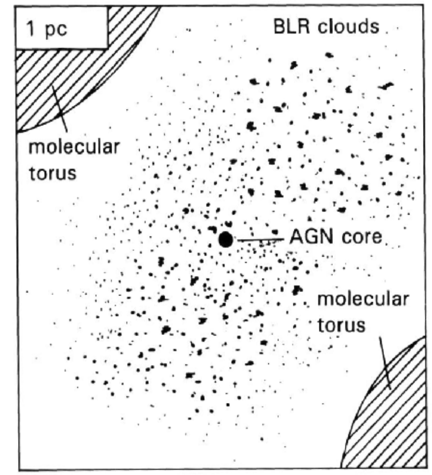


The central kpc star formation disk. This strong far infrared emitting zone might be fed by a bar structure, as seems to be the case for NGC1068.

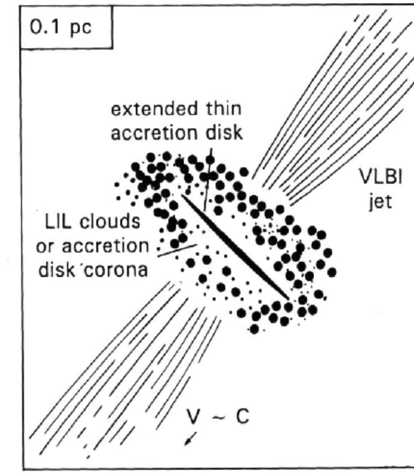


The narrow-line region comprising small but numerous clouds of the interstellar medium ionized by the central AGN core.

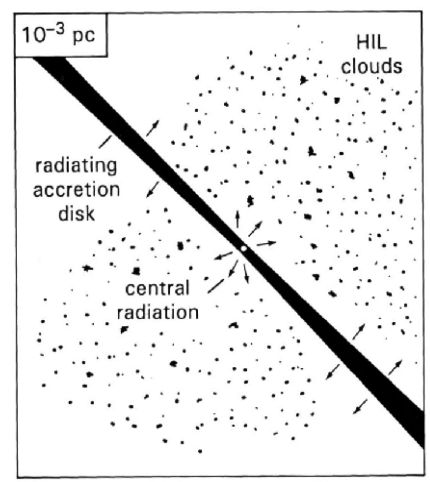
Fig. 9.9 Cartoon of the representative scale sizes of an AGN. How we eventually see the object depends on a number of parameters, the main one being the orientation of the obscuring torus with respect to the observer. (Adapted from Blandford, *Active Galactic Nuclei*, Saas-Fee Advanced Course 20, Springer–Verlag, 1990.)



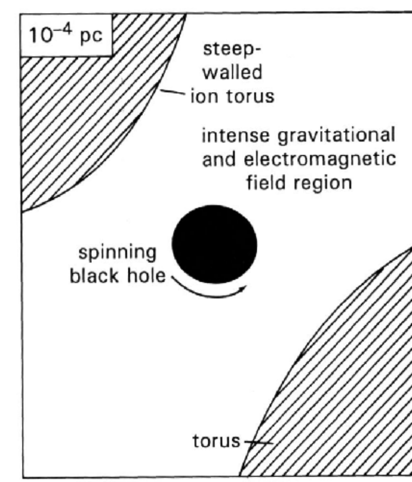
The outer extent of the broad-line region and the deep-walled molecular torus which can provide an effective shield of the central AGN, depending on the relative orientation of the observer.



Inside the molecular torus — the VLBI jet becomes self-absorbed closer in, and the low ionization lines of the BLR, which might be the corona of the accretion disk.



The accretion disk which radiates strongly at UV and optical wavelengths. The high ionization clouds of the BLR are excited by the central continuum radiation field.



The black hole. The Schwarzschild radius for a $10^8 M_\odot$ black hole is 2 AU (10^{-5} pc). The spin will introduce twisted magnetic field lines and particle acceleration.

HST : 0.1" ≅ 2pc

R. Blandford

1pc = 3.3 ly = 1190. ld = $3 \cdot 10^{18}$ cm

Central Black Hole Mass M(grav) in Mrk110

tral black hole mass in Mrk110 derived from gravitational redshift.

Observed shifts of rms profiles identified as gravitational redshift:

$$M_{grav} = c^2 G^{-1} R \Delta z.$$

R = cτ τ= mean dist. of line em. clouds

Line	FWHM(rms) [km s^{-1}]	Δv_{cent}(rms) [km s^{-1}]	τ [days]	M_{grav} [$10^7 M_\odot$]
(1)	(2)	(3)	(4)	(5)
HeII	4444. ± 200	541. ± 60	3.9 ± 2.	13. ± 3.
HeI	2404. ± 100	186. ± 60	10.7 ± 6.	12. ± 4.
Hβ	1515. ± 100	118. ± 50	24.2 ± 4.	17. ± 4.
Hα	1315. ± 100	74. ± 50	32.3 ± 5.	14. ± 5.

$$M_{grav} = 14. \pm 3 \cdot 10^7 M_\odot.$$

Theory : BLR kinematics - line profile variations

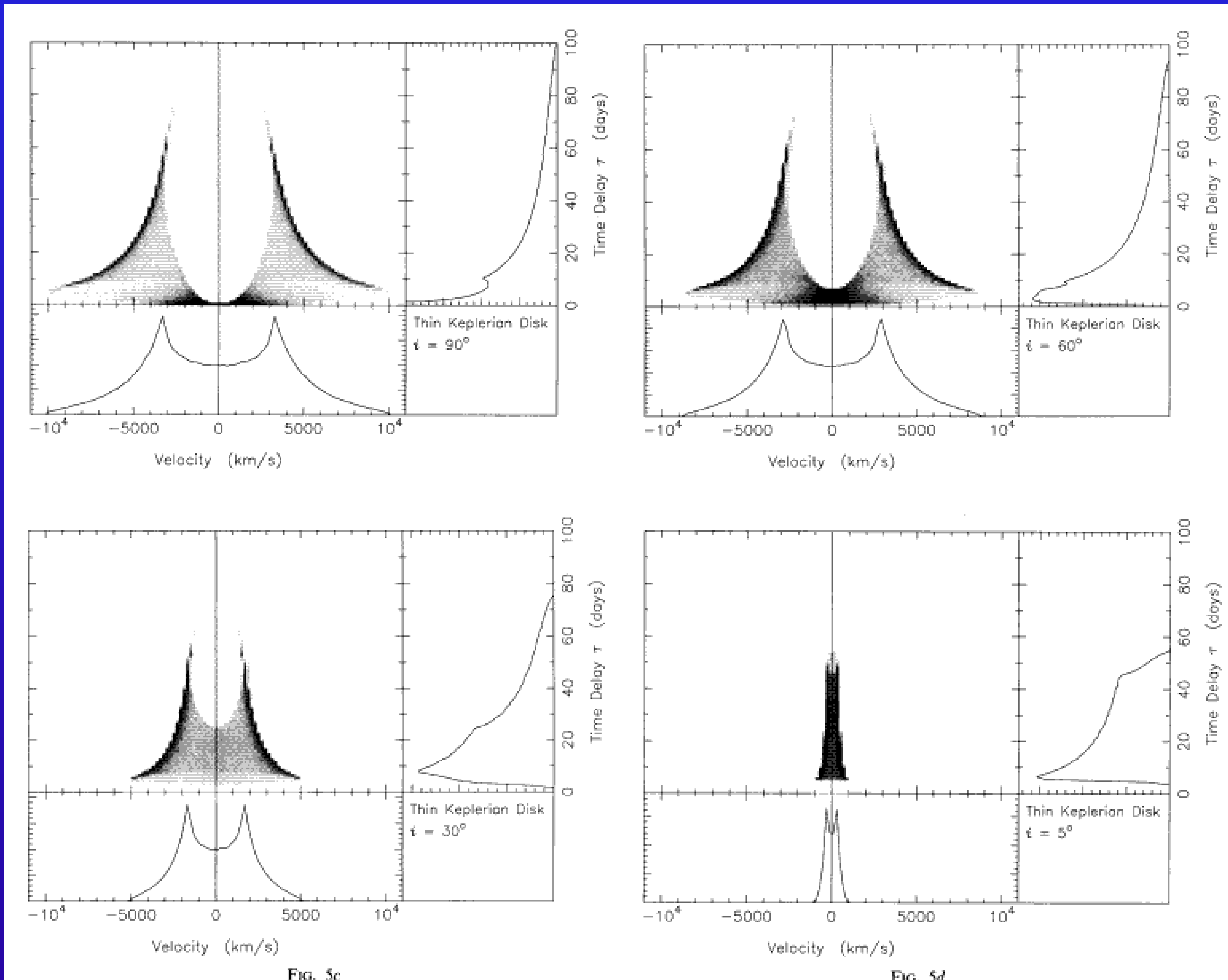
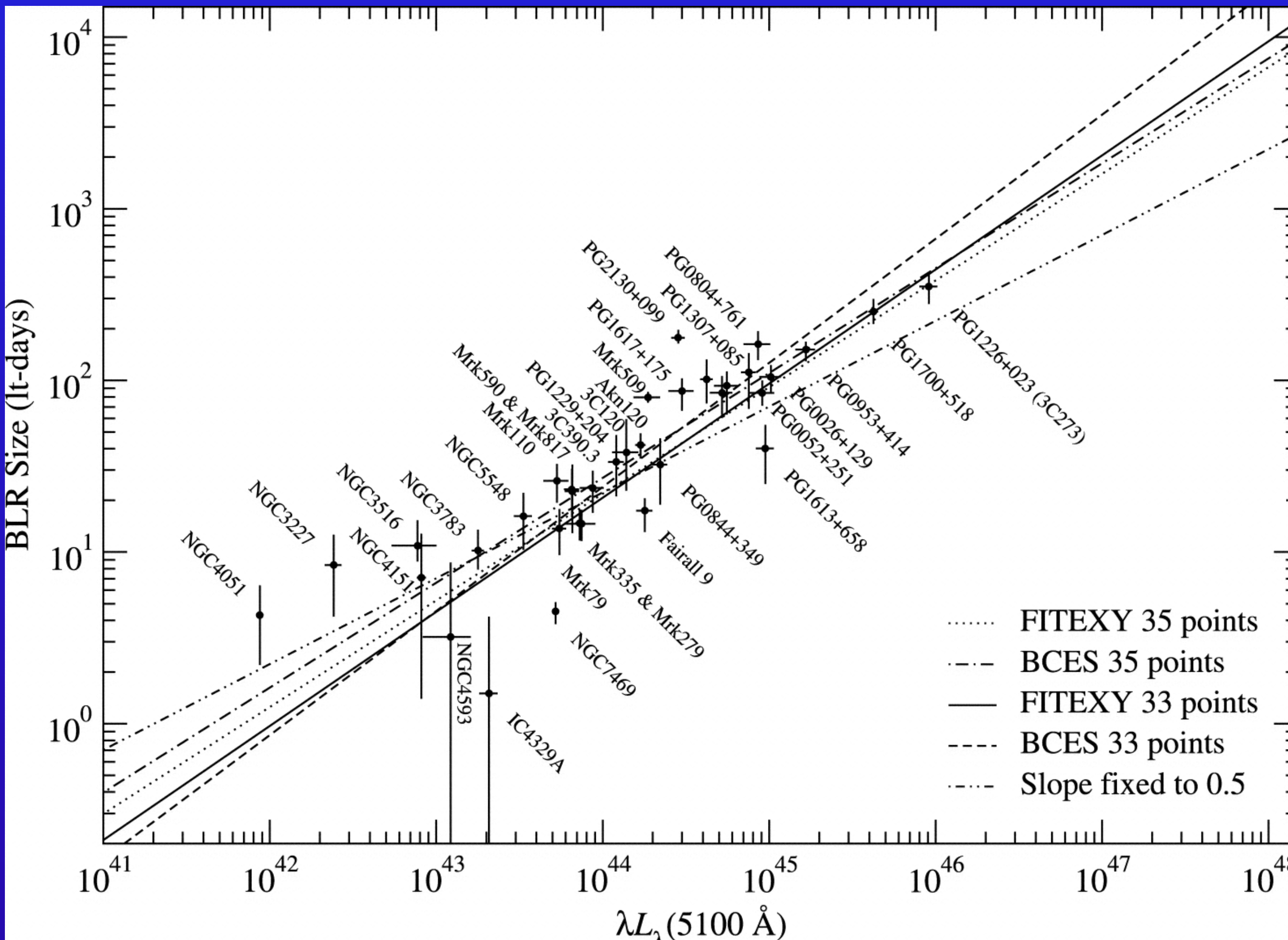


Fig. 5.—Echo image for a thin Keplerian disk BLR model viewed at an inclination of (*a*) 90° (edge on), (*b*) 60°, (*c*) 30°, (*d*) 5°.

Velsh & Horne, 1991

velocity-delay maps (echo images) for thin Keplerian disk BLR mod. viewed at inclination angles of 90 deg (edge on), 60, 30, 5 deg.

Balmer line averaged BLR size in AGN



photoion. theory:

$$r = \left(\frac{Q(\mathrm{H})}{4\pi c n_{\mathrm{e}}}\right)^{1/2} \propto L^{1/2}$$

rogen-ionizing photons emi

between luminosity and broad-line region size

scatter due to: BLR density, column density, ionizing spectral energy dis

Kaspi et al. 2004