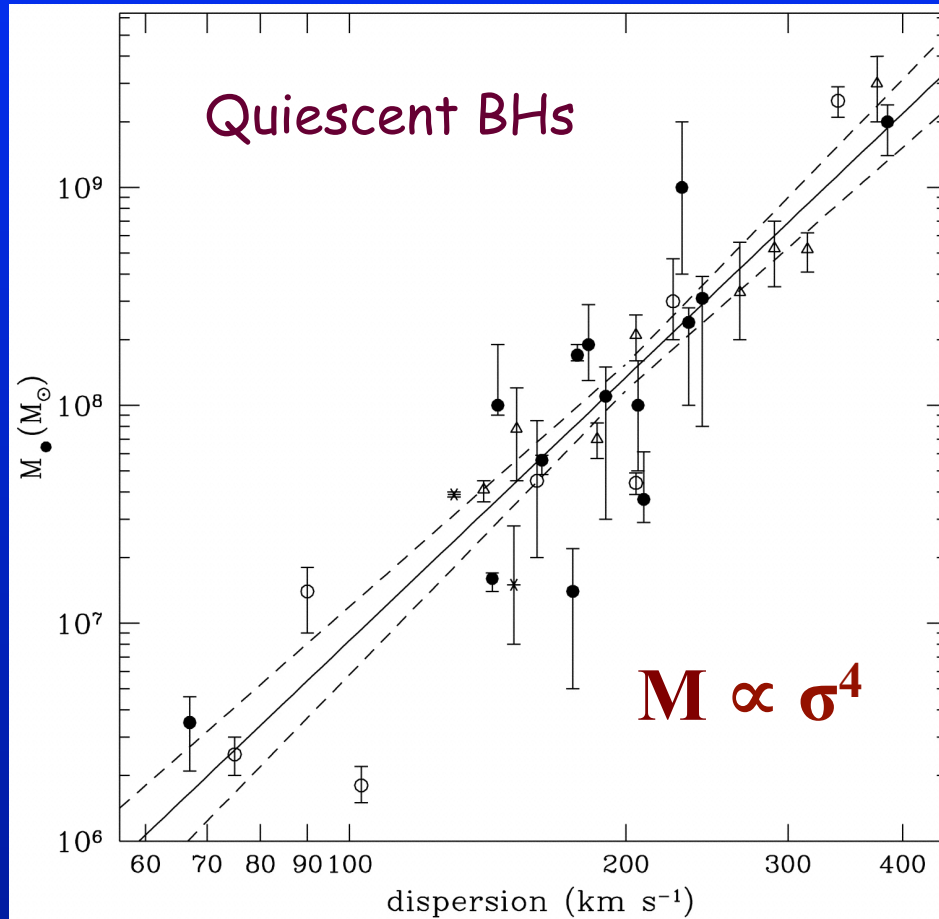


How can polarization studies improve
our understanding of black hole and
quasar physics?

Marianne Vestergaard
Dark Cosmology Centre, Copenhagen
& University of Arizona, USA

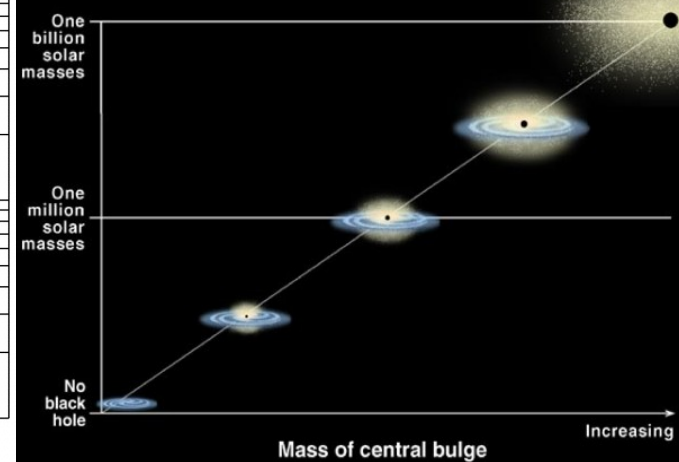
$M - M_{\text{bulge}}$ Relationship: Co-evolution?

Black
Hole
Mass



(Tremaine et al. 2002; See also Ferrarese & Merritt 2000; Gebhardt et al. 2000)

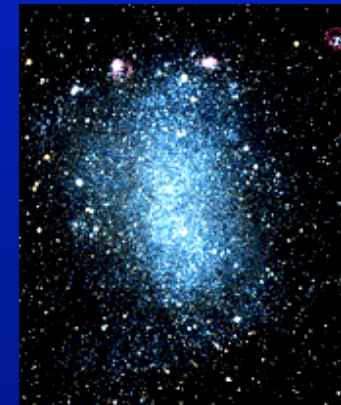
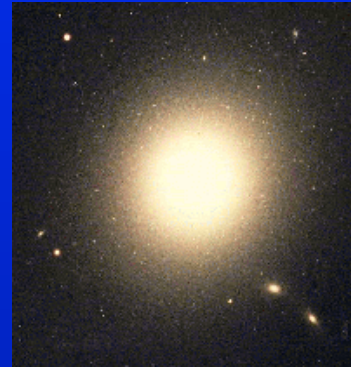
Correlation Between Black Hole Mass and Bulge Mass



Mass of Galaxy Bulge

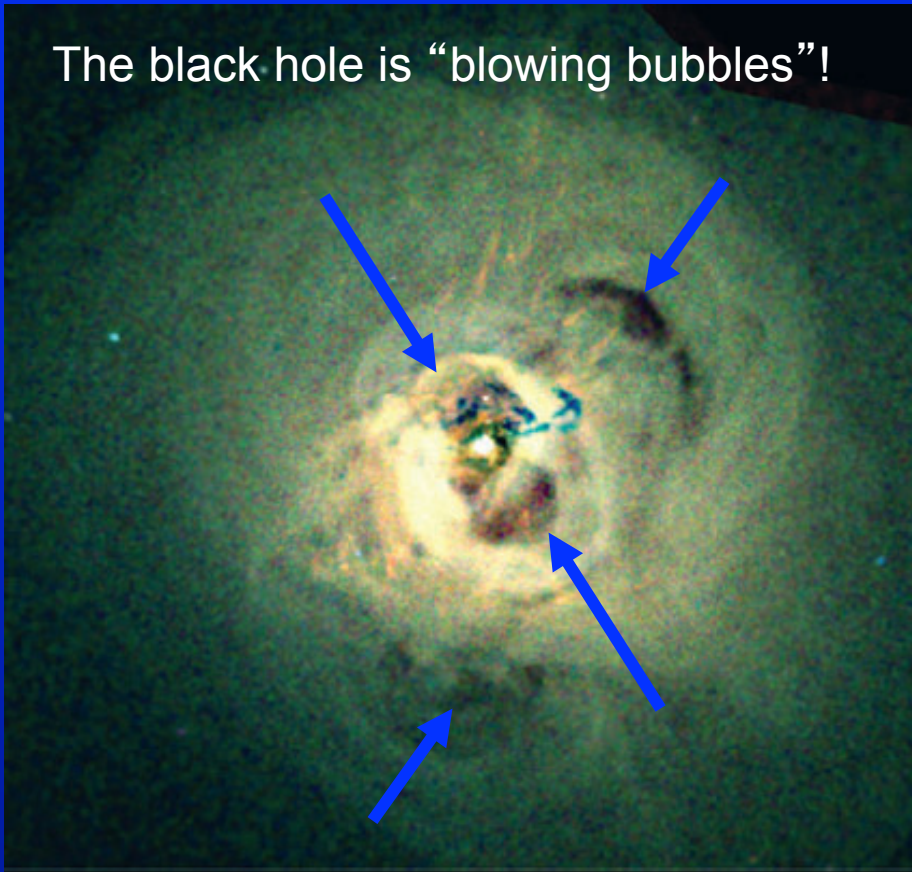
Why the interest in supermassive black holes?

- What stopped star formation in the now red, “dead”, elliptical galaxies?



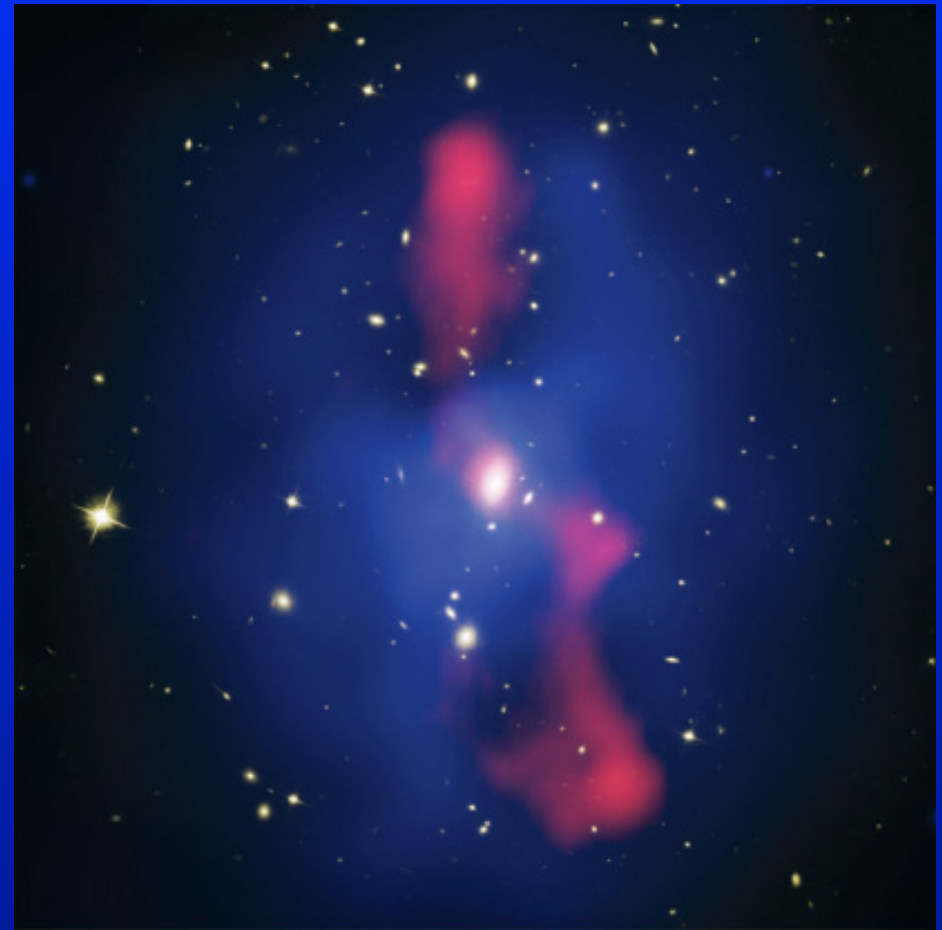
Black Hole Activity Affecting the X-ray Gas in Clusters: outflows + heating

The black hole is “blowing bubbles”!



Perseus A

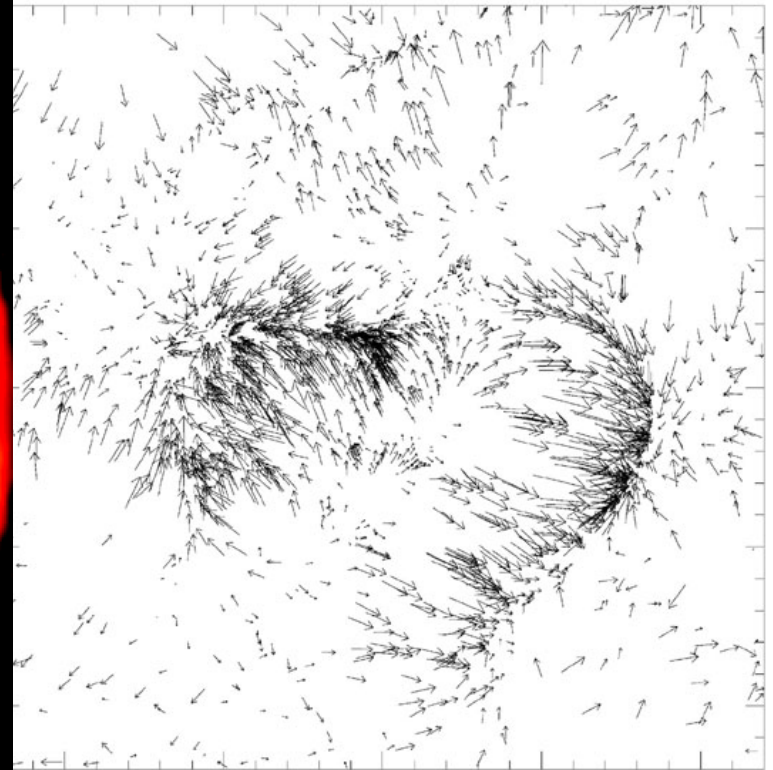
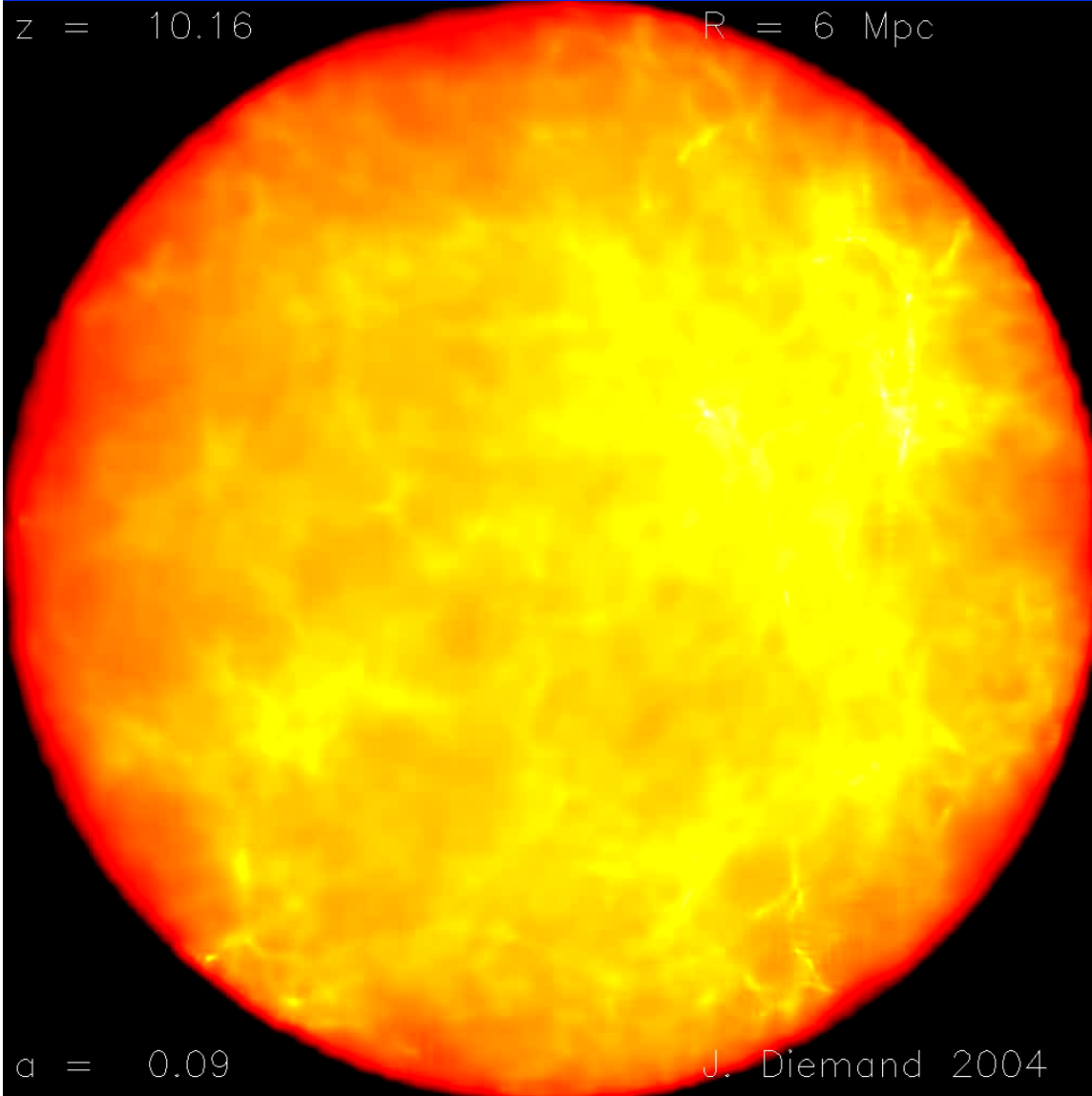
(Fabian et al. 2006)



MS0735.6+7421 Cluster

(McNamara & Nulsen 2007)

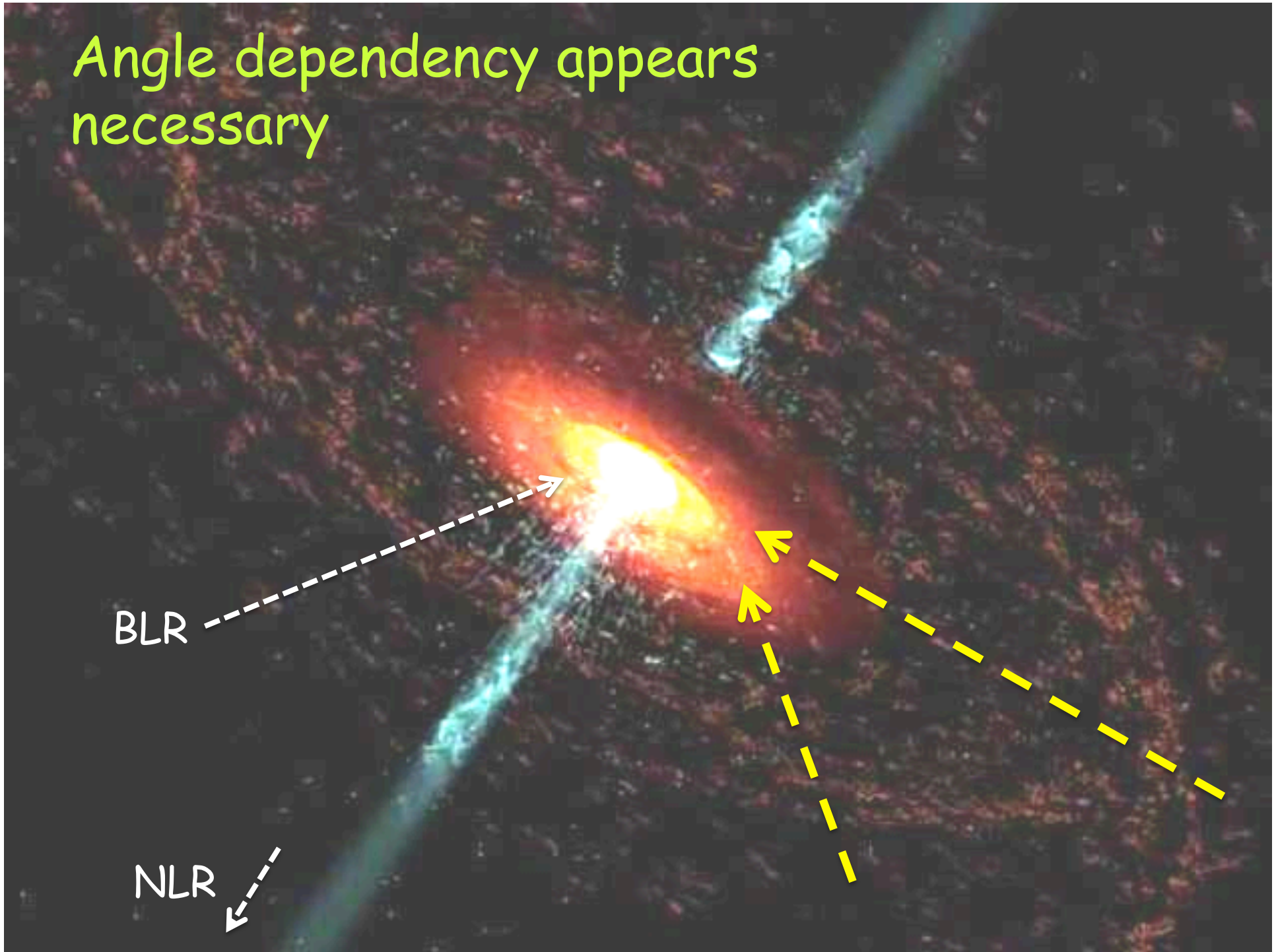
The Role of Black Holes on Structure Formation and Evolution?



Angle dependency appears
necessary

BLR

NLR



Angle dependency appears necessary

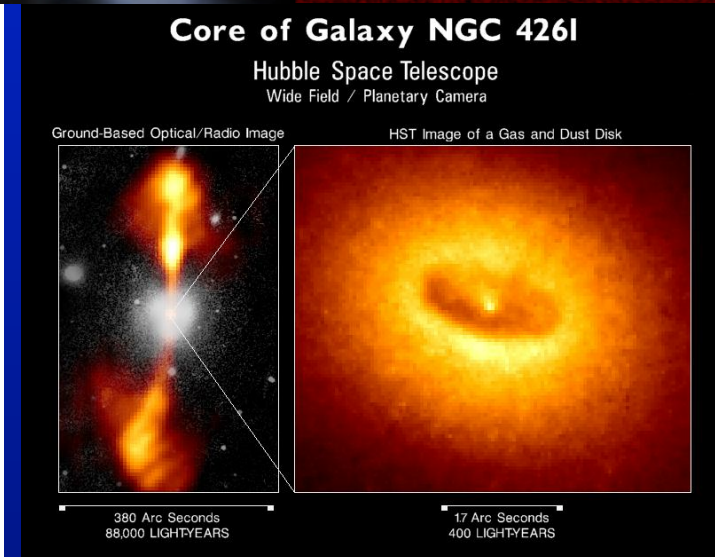
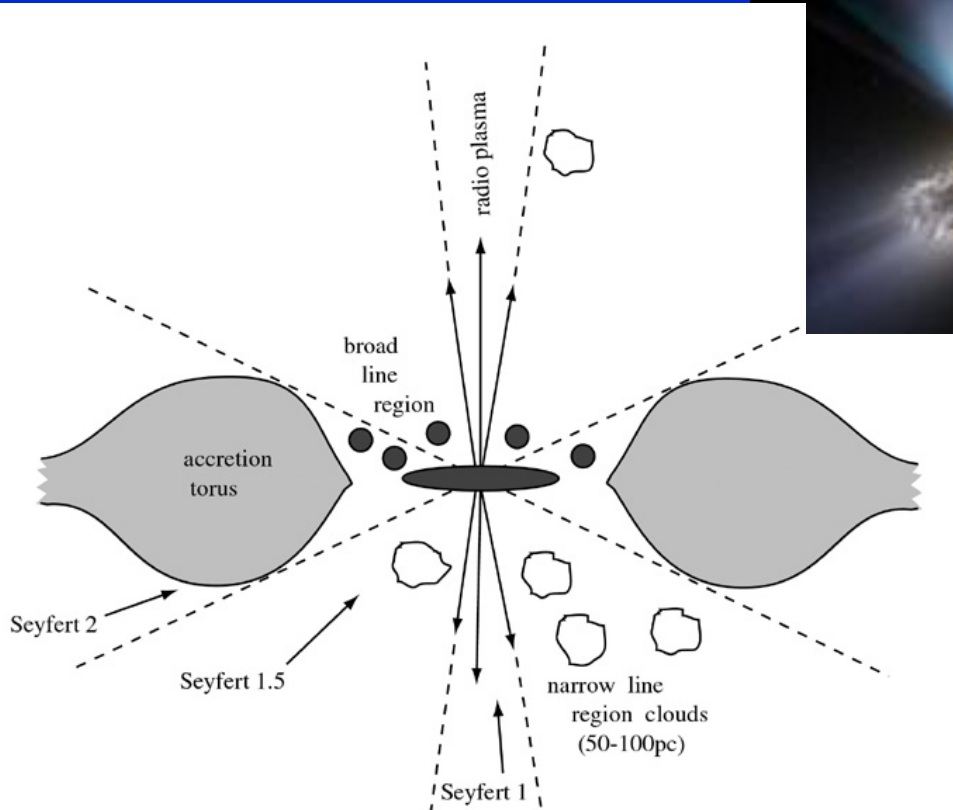
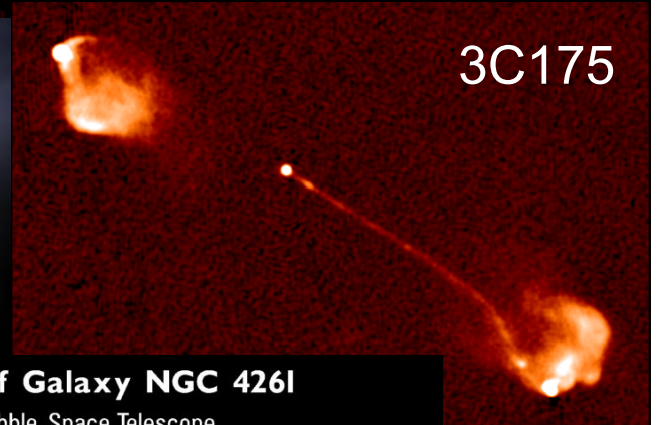
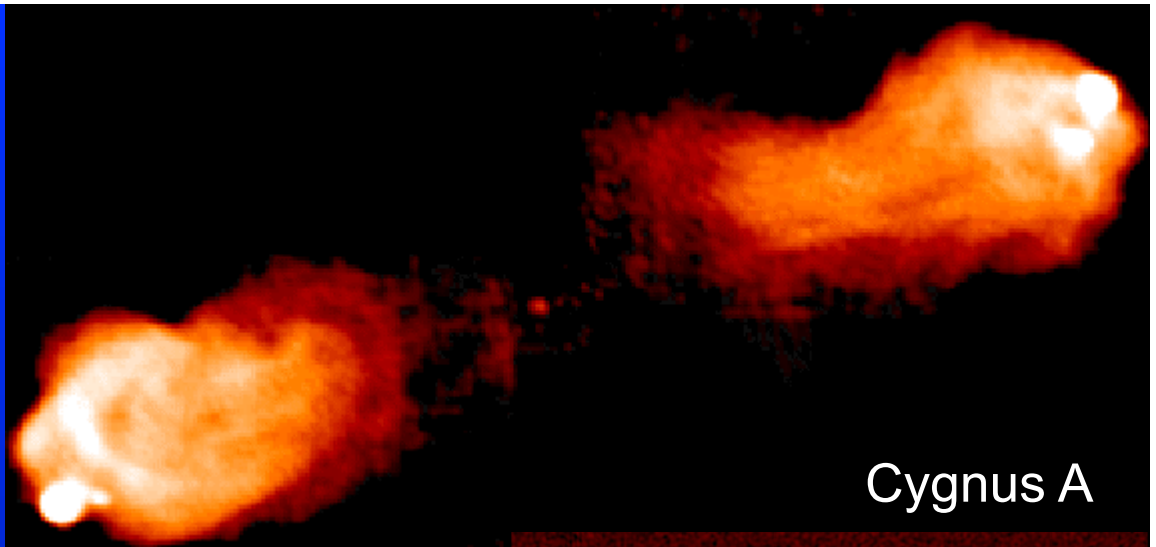


Fig 9.3 'Galaxies in the Universe' Sparke/Gallagher CUP 2007

Understanding viewing angle dependencies is important for:

- Quasar/AGN physics
- BAL quasars - where fit in?
 - Unification - in angle or time?
- Black hole mass determinations

Black Hole Virial Mass

$$M_{\text{BH}} = v^2 R / G$$

Face-on

Edge-on

Broad Emission Line Gas ("clouds")

- photo-ionized by photons from accretion disk

It takes time for light to travel to the BEL gas from the accretion disk

We can measure this time delay (or distance) with variability studies

$$R_{\text{BLR}} = c T$$

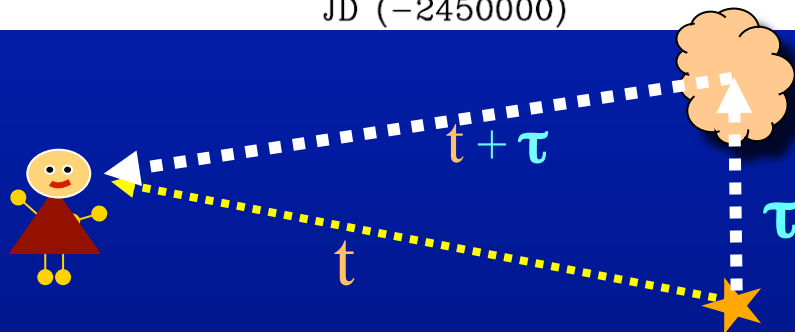
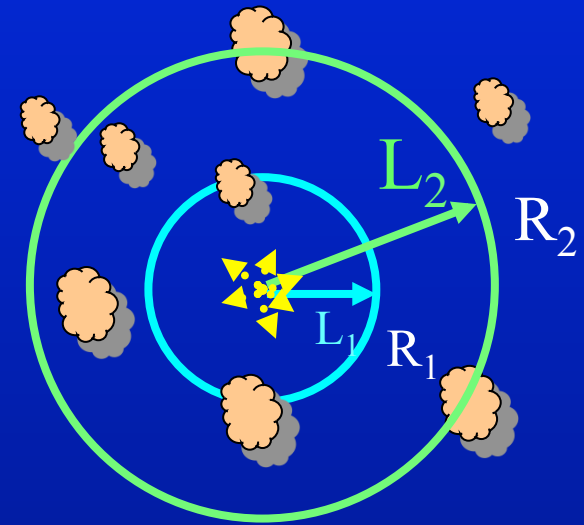
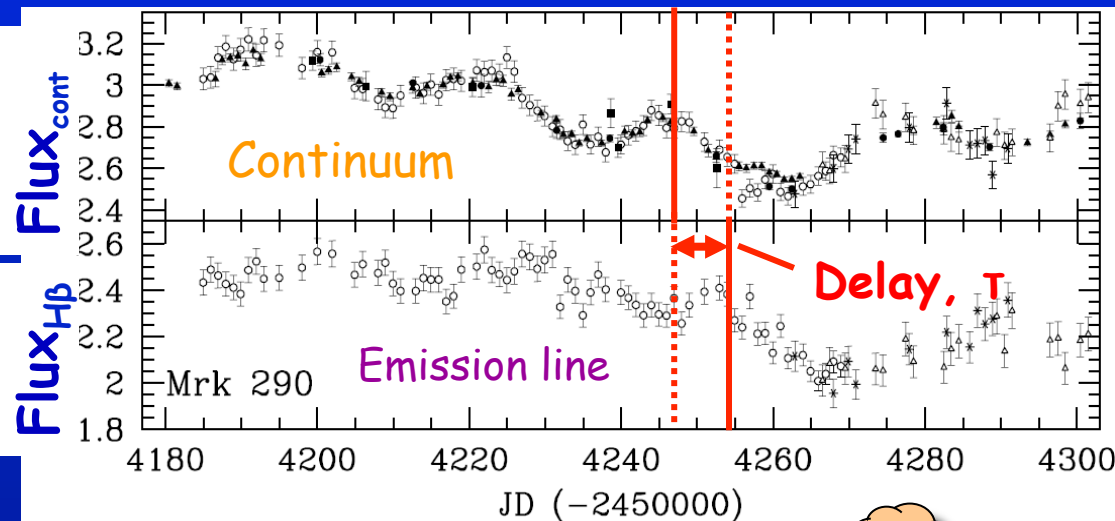
Accretion Disk

AGN Virial Mass Estimates

$$M_{\text{BH}} = v^2 R_{\text{BLR}} / G$$

- Variability Studies: $R_{\text{BLR}} = c\tau$

- Radius - Luminosity Relation:

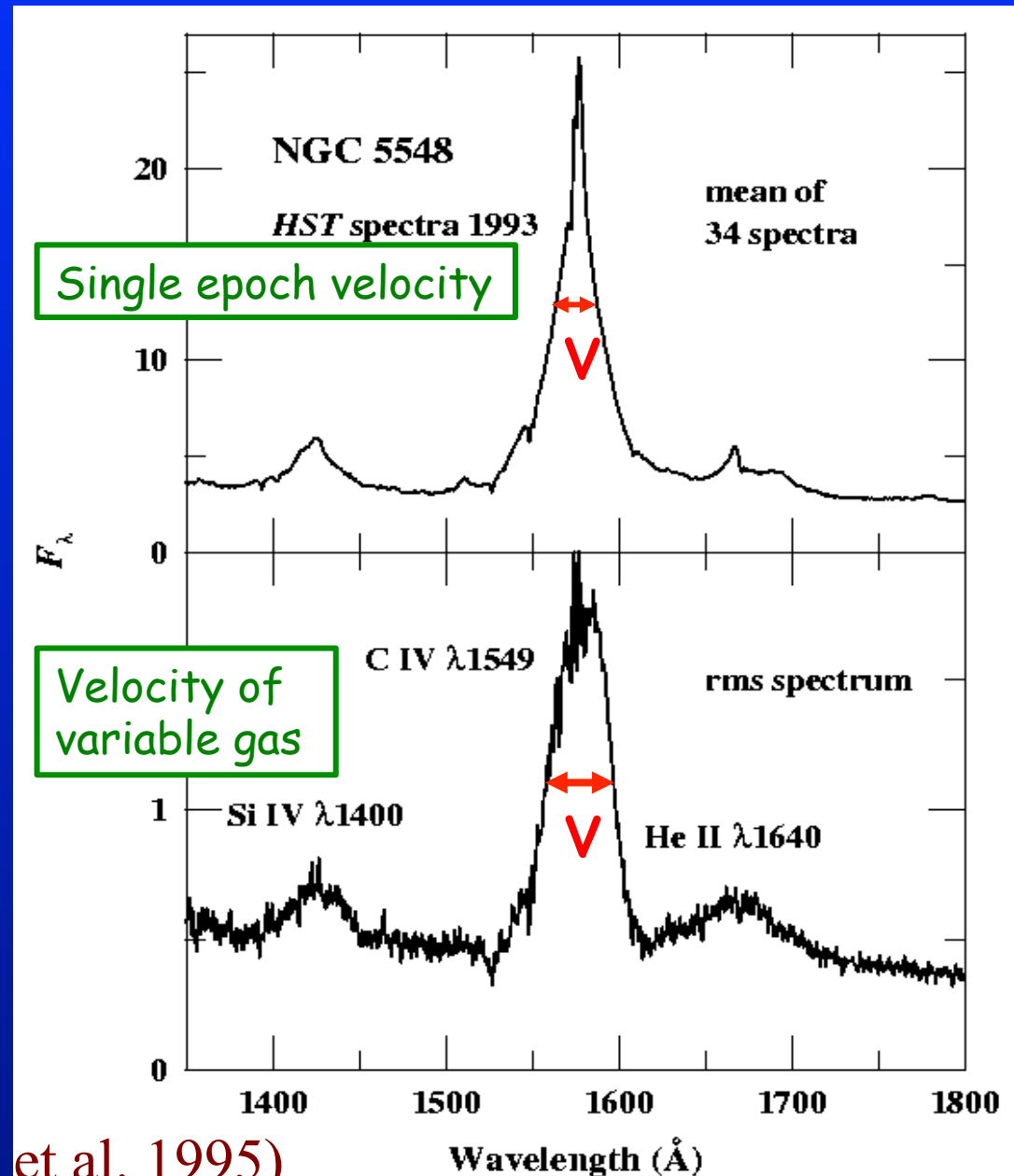


Velocity Dispersion of the Broad Line Region and the Virial Mass

$$M_{\text{BH}} = f v^2 R_{\text{BLR}} / G$$

f depends on structure, geometry, and inclination of broad line region

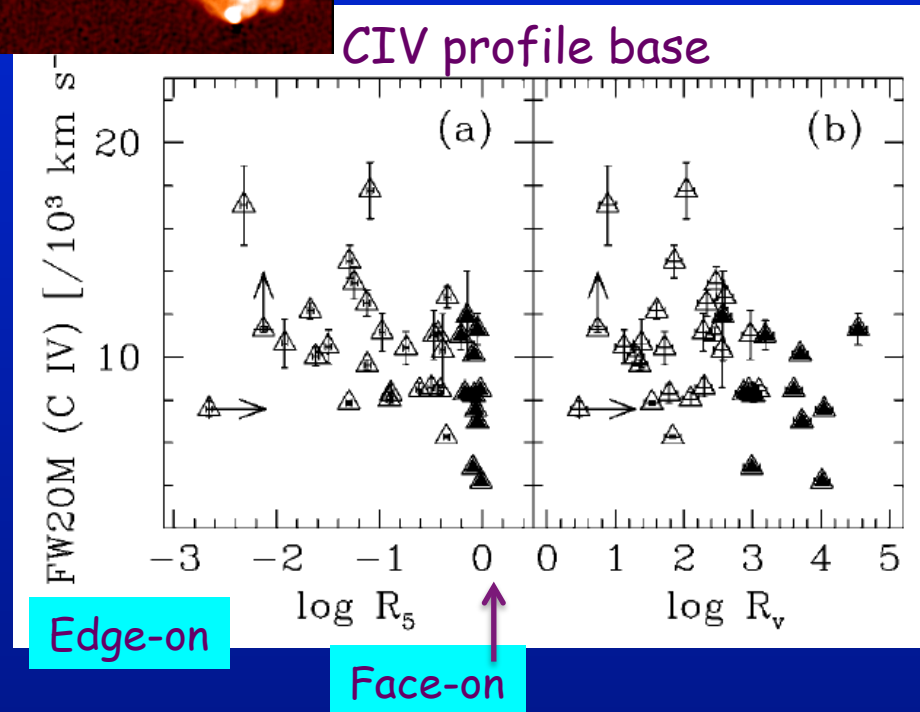
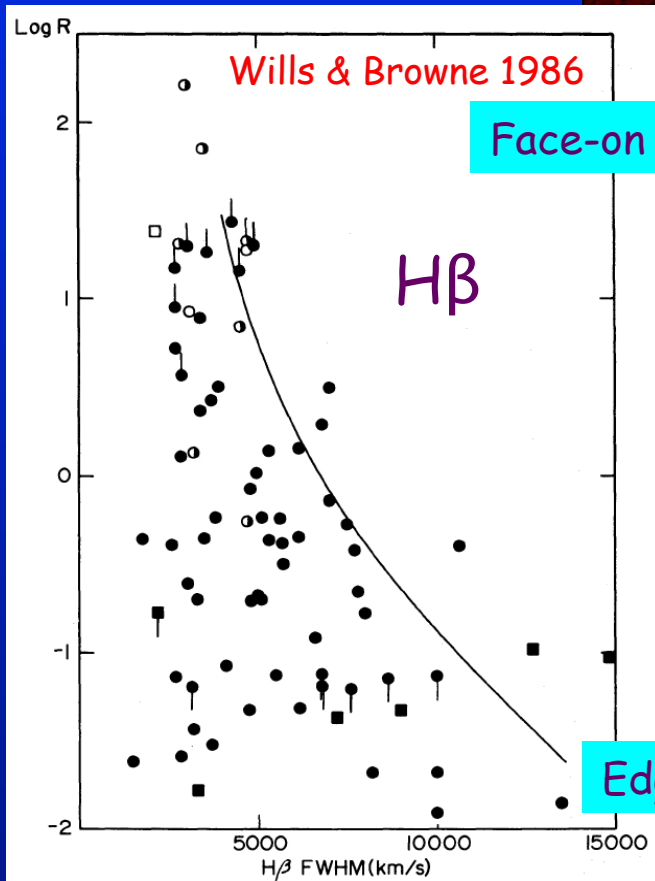
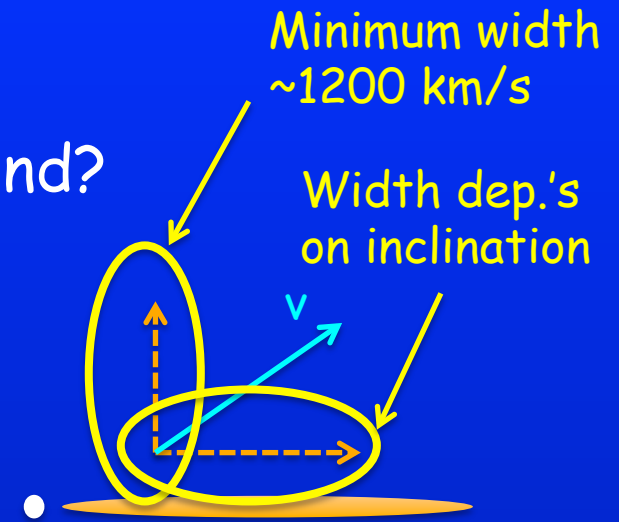
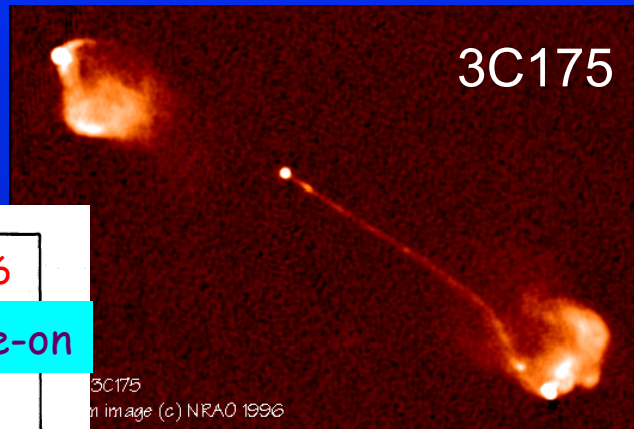
1 σ absolute uncertainty relative to M - σ relation: factor ~ 3



(based on Korista et al. 1995)

BLR velocity field

- Two component velocity field: disk + wind?



BLR velocity field

- Two component velocity field: disk + wind?
- BLR as flared disk ?
- BLR as warped disk ?
- Similar velocity field description:

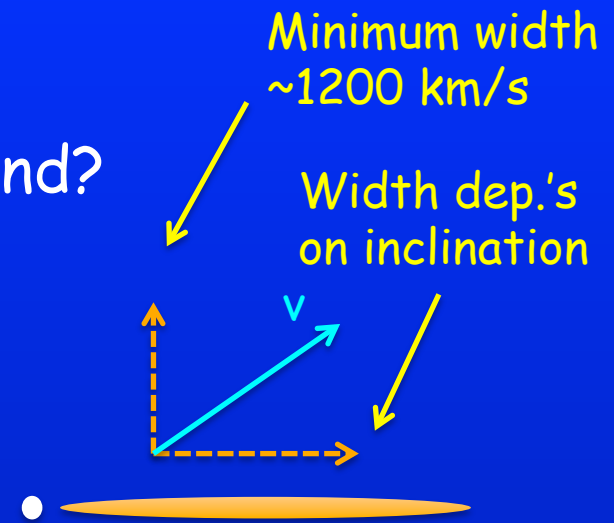
$$\Delta V_{\text{obs}} \approx (a^2 + \sin^2 i)^{1/2} V_{\text{Kep}},$$

$a = H/R$ of disk or

$V(\text{turbulent}) / V(\text{Kepler}): 0.1 - 0.3$

$i =$ inclination of disk normal to LOS

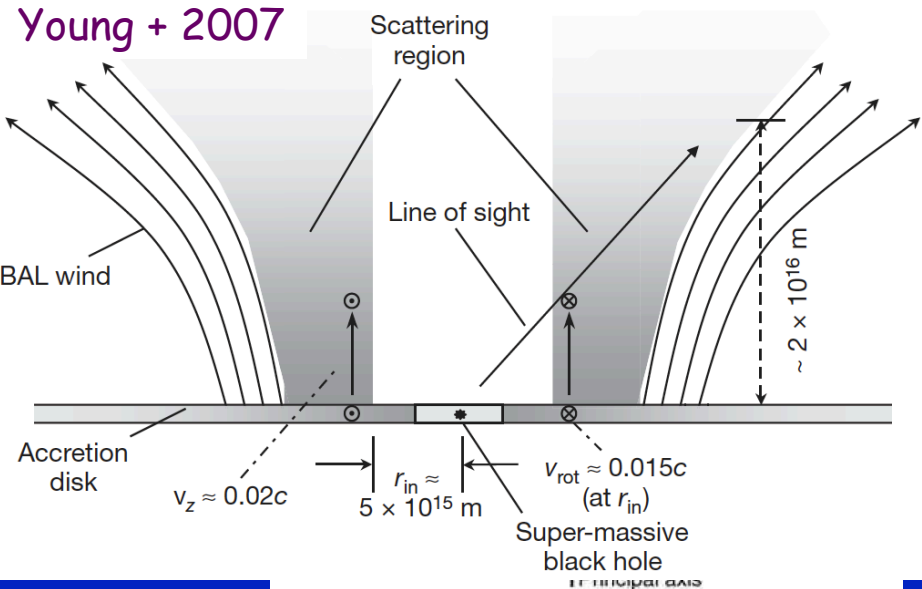
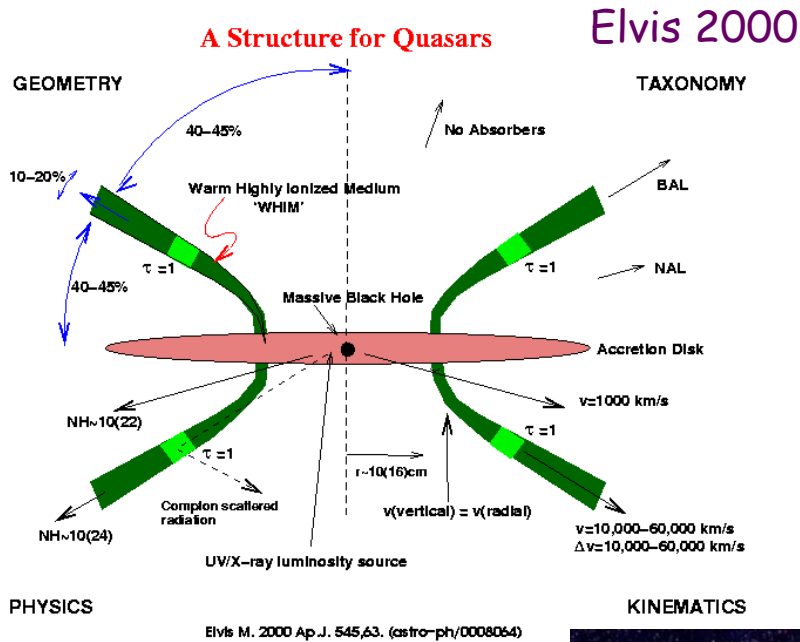
- Both a and i unknown: M_{BH} uncertain by factor 25!
- *Factor 3 Scatter in M - σ relation: a not small - closer to 0.3 than 0.1*
- See talk by Jens Juel Jensen tomorrow



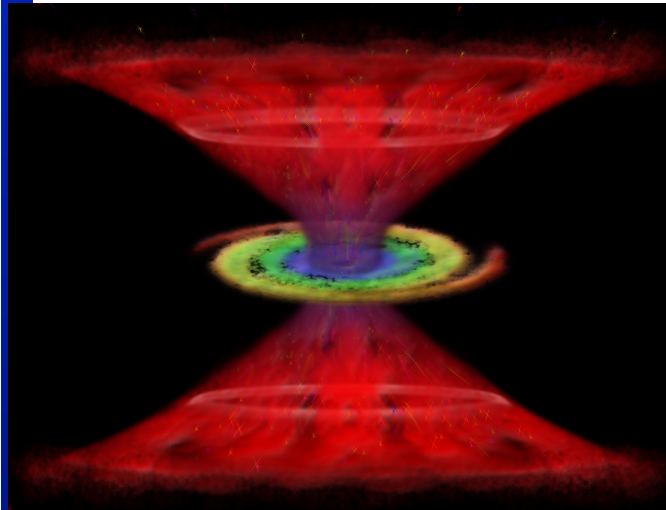
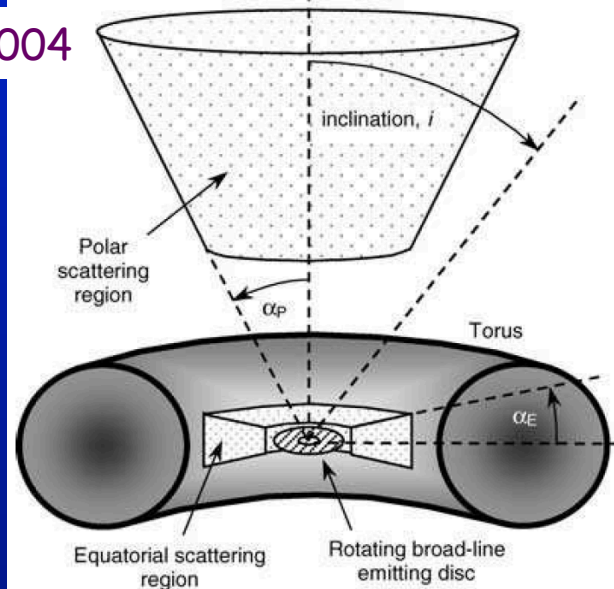
$$V_{\text{Kepler}} = \frac{V_{\text{Obs}}}{\sqrt{(a^2 + \sin^2 i)}};$$
$$M_{\text{BH}} = f \times R V_{\text{Kepl}}^2 / G$$

Structure & geometry for Quasar physics

- What is typical?

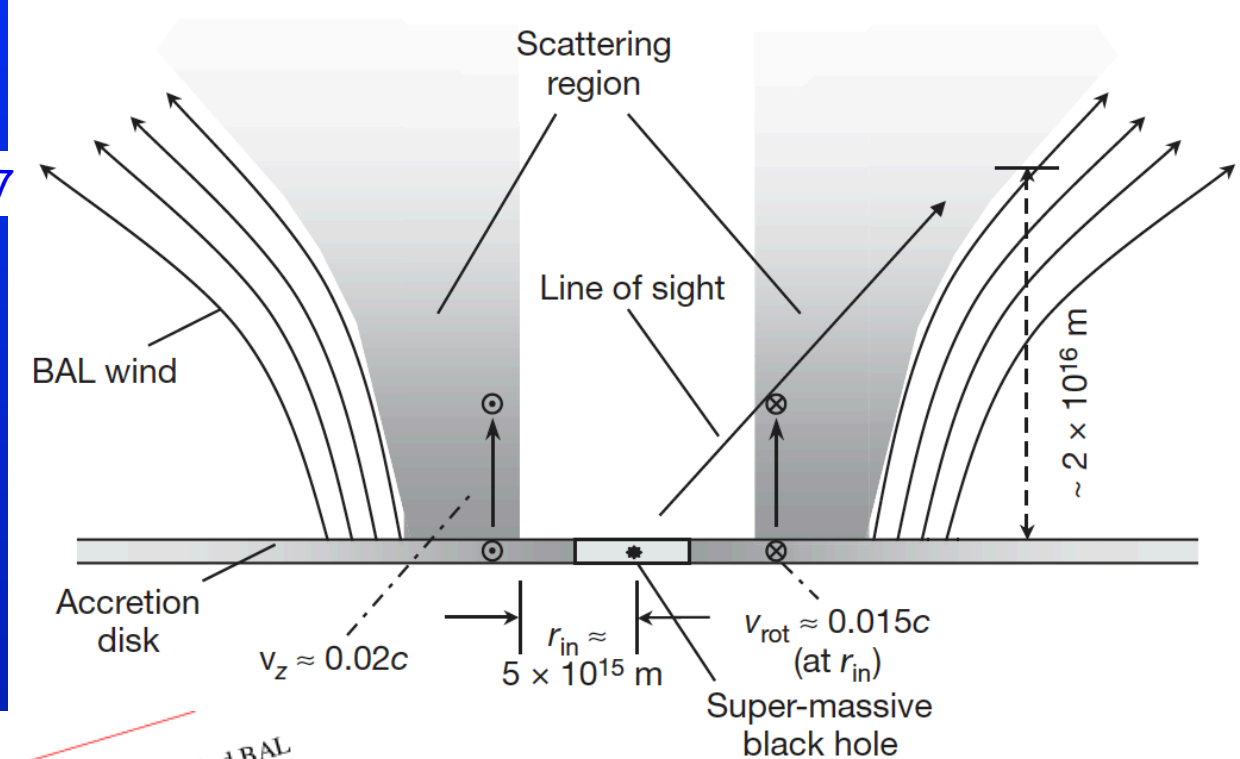
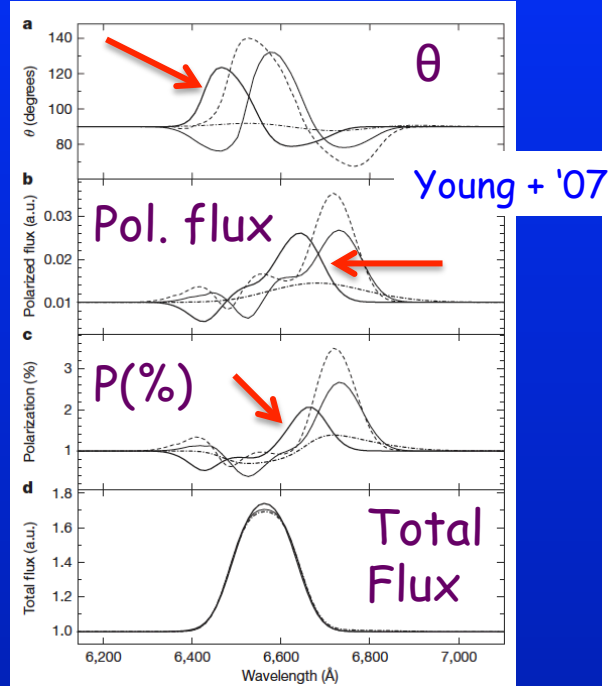


Smith + 2004

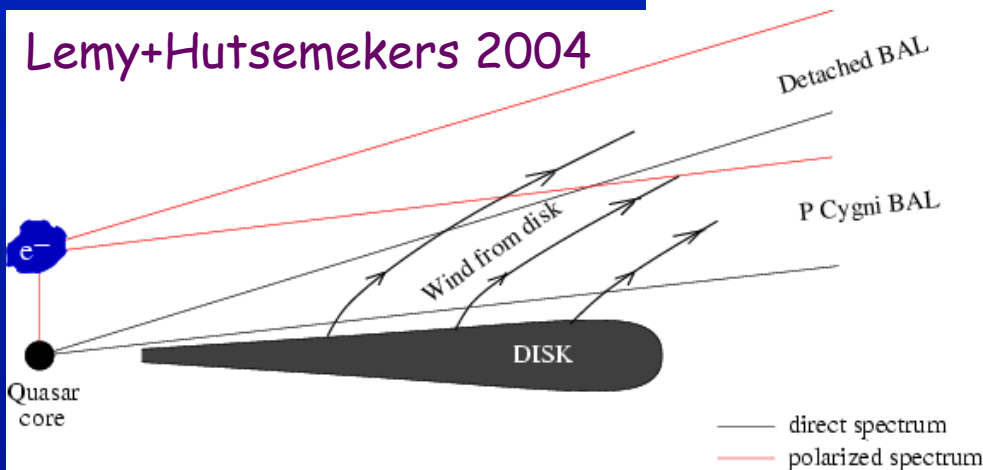


Geometry for BAL Q PG1700+518

Strong constraints from polarization data



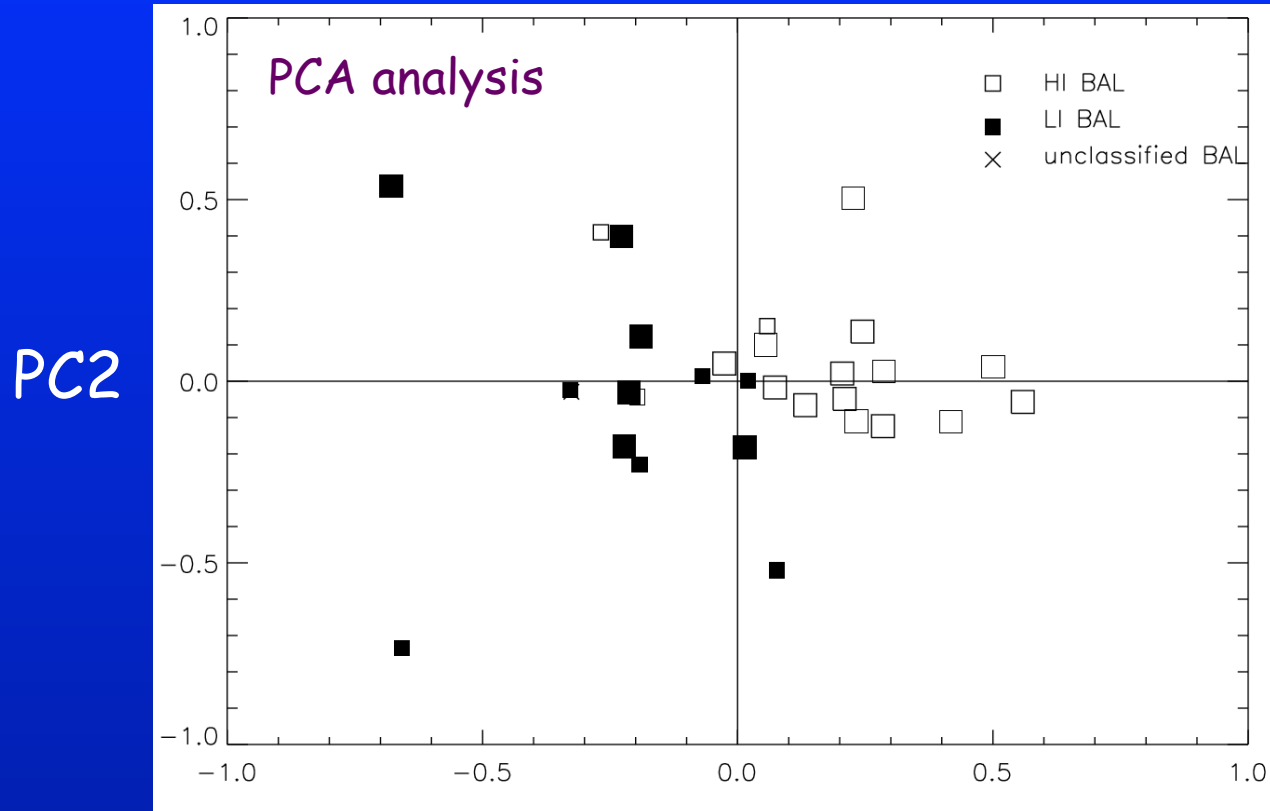
Lemy+Hutsemekers 2004



Young et al. 2007, Nature
- PG1700+518 BAL quasar

- Typical for BALs?
- - for all quasars?

Further support for outflow geometry



↑ Orientation driven?

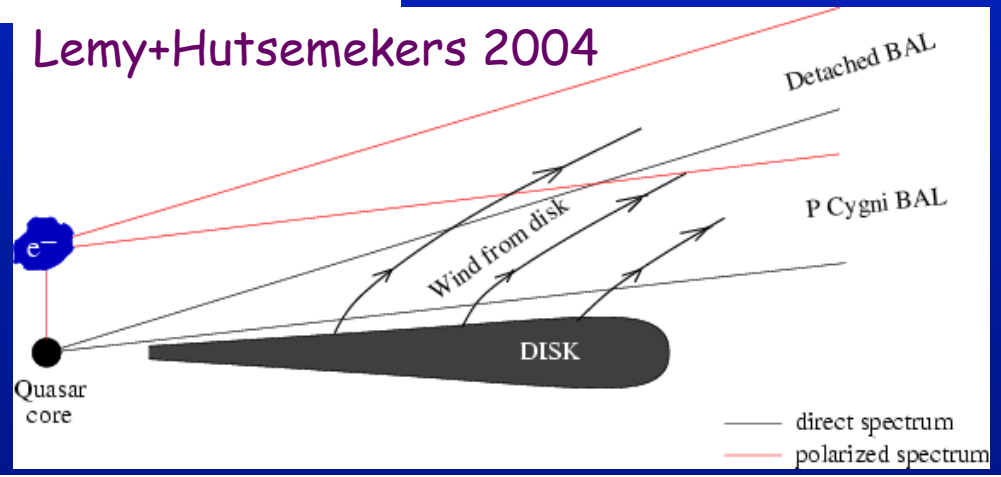
Balnicity index,
 FeII λ 2400,
 (slope?)

→ \dot{M} driven?

P_0 , Detachment index, CIV EW

PC1

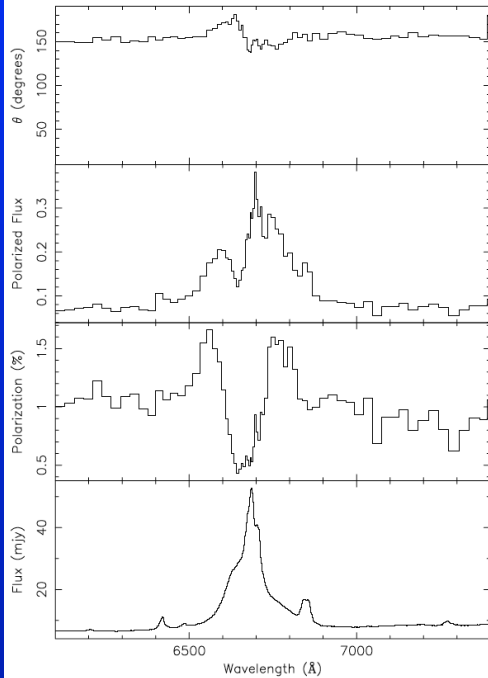
Lemy+Hutsemekers 2004



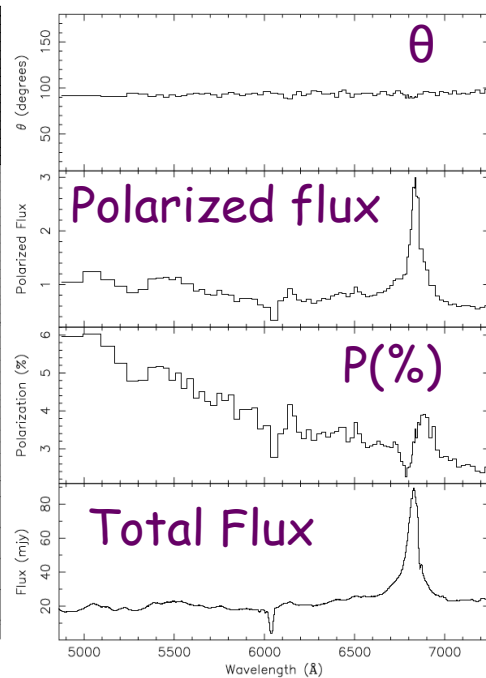
Polarization changes across Ha

Mark 6

Epoch 2

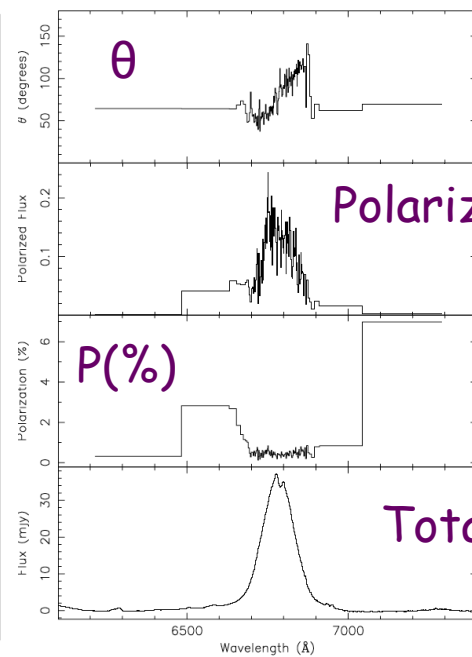


Mark 231



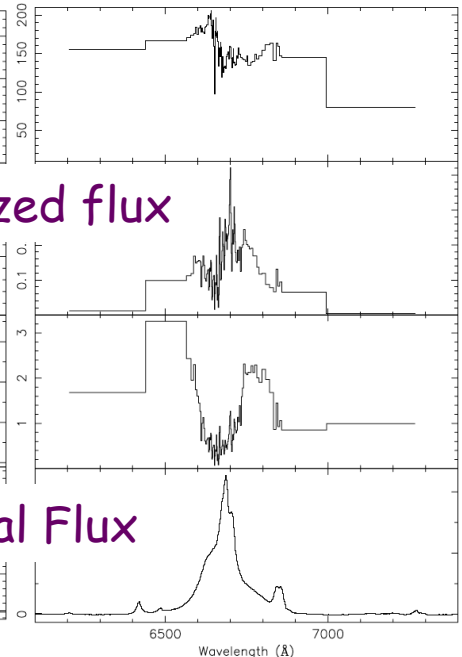
Ark 120

Akr ted



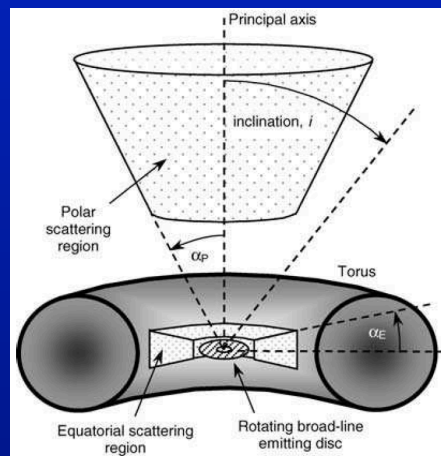
Mark 6

tracted



Clue to inclination?

Can these data also be understood in the PCA picture by Lamy & Hutsemekers 2004?

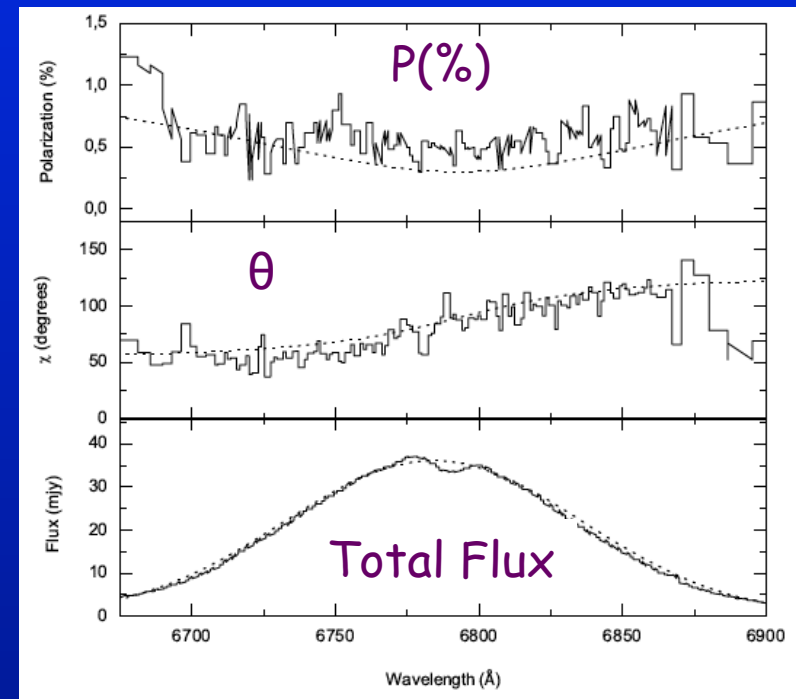


Continuum subtracted

Smith+ 2002

Alternative scenario: Depolarization by Faraday Rotation?

- Emission intrinsically polarized as take origin in magnetized optically thick accretion disk (Milne problem)
- Depolarization due to presence of magnetic fields
- Can explain low polarization degree and angle changes, incl. minimum at line center.

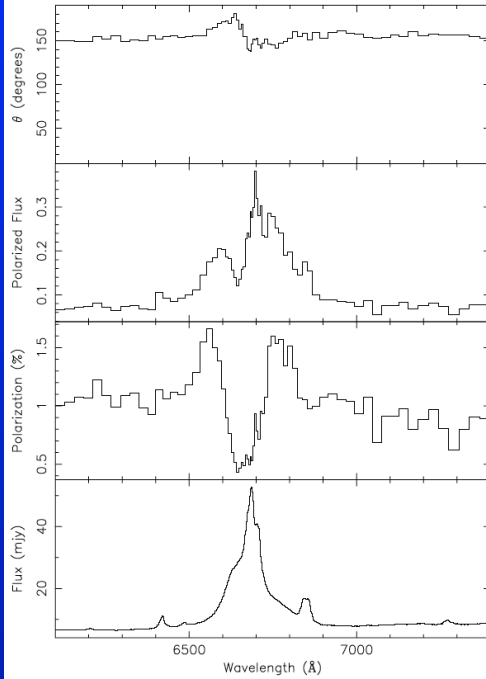


Akn 120 Data - Smith + 2002

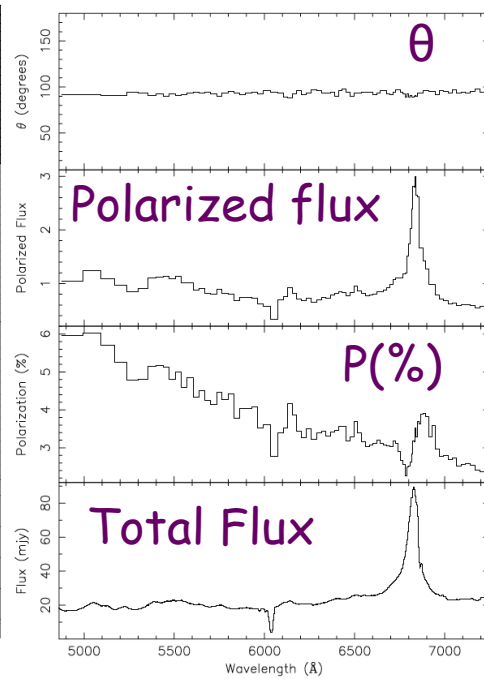
Polarization changes across H α

Mark 6

Epoch 2

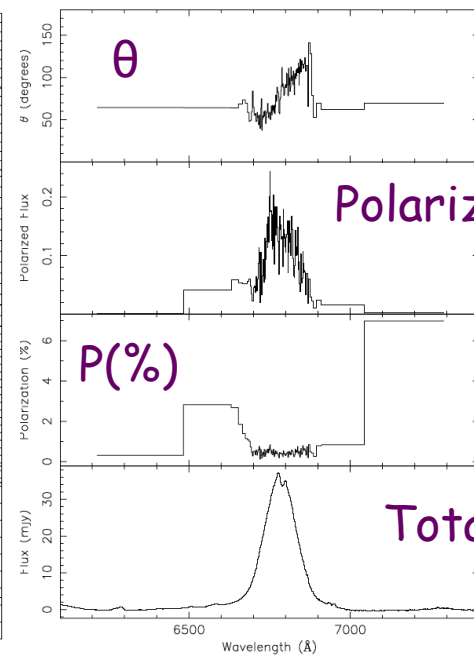


Mark 231



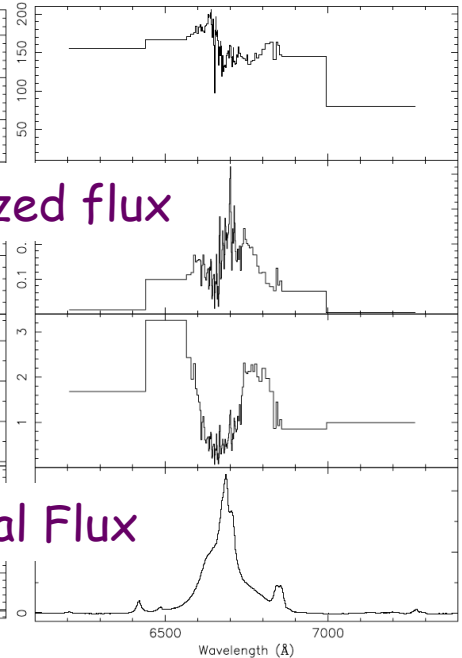
Ark 120

Akr ted

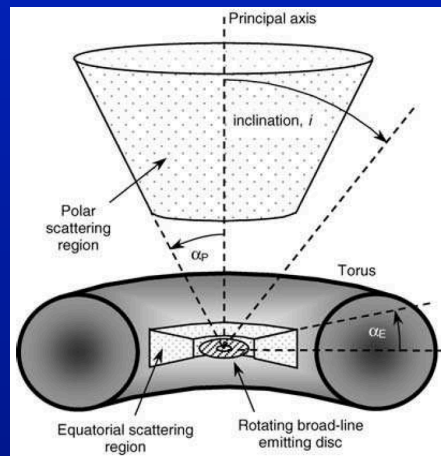


Mark 6

tracted



Can Faraday rotation and depolarization explain all data?



Continuum subtracted

Smith+ 2002

Summary

- Central geometry and velocity structure poorly known/ constrained
- Structure + inclination critical for quasar physics - understanding BALs, FeLoBALs, etc. ; Lawther talk
- Accurate M_{BH} needed for understanding BH role for galaxy evolution
- Source inclination wrt LOS critical for mass estimates
 - Constraints on $a = H/R$, a significant improvement
 - Some constraints on i strongly decrease uncertainties (factor 25 to factor of a few); Juel Jensen talk
- More statistical and detailed studies needed
- Can we do this with polarization data? How?
- What data are needed?
- Basis for collaboration?