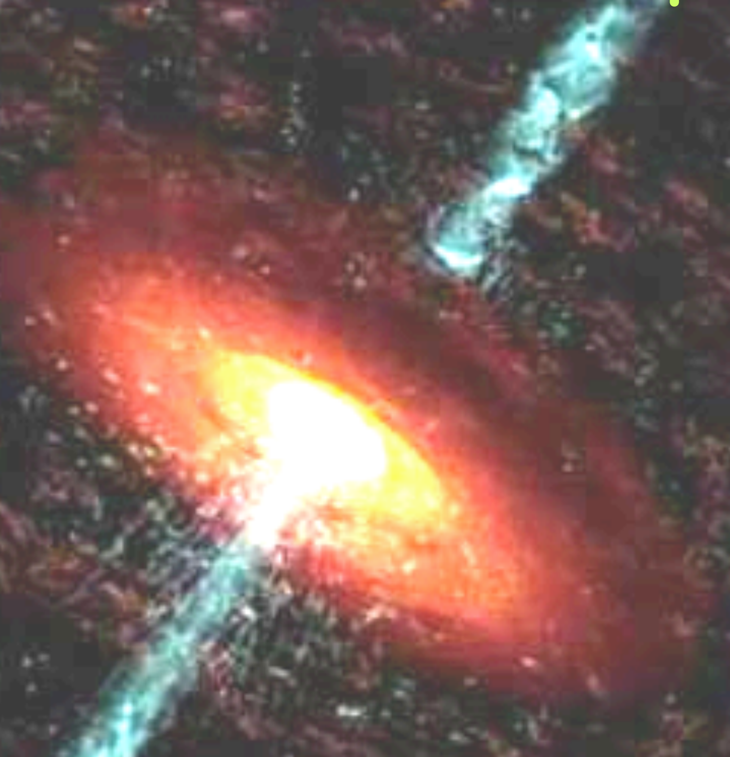
Quasar Science and Cosmic Distances with the NOT Transient Explorer



Main collaborators:
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Dark Cosmology Centre, Copenhagen
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Dark Cosmology Centre

Science with NOT, Aarhus, 25 October 2012

Main Science Drivers

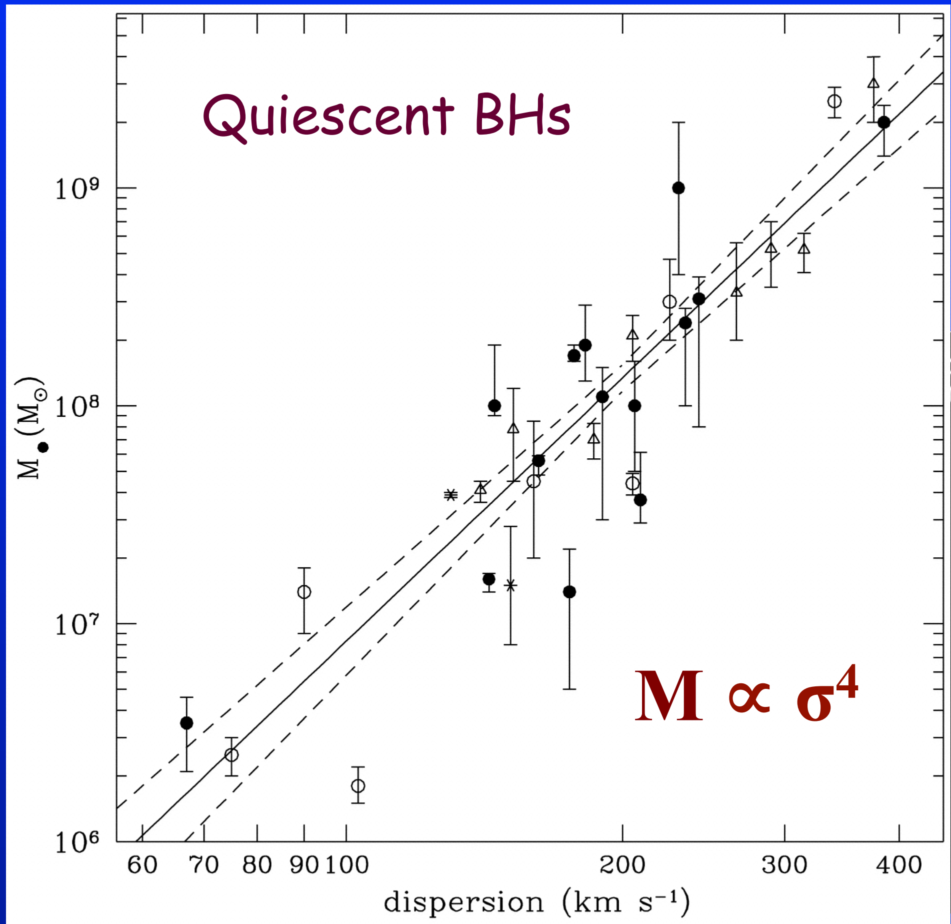
- Supermassive black holes – accurate mass determinations
  - BH demographics and growth
  - BH role for galaxy formation and evolution

- Measure cosmic distances using quasars – a potentially powerful method
  - Constrain Dark Energy Models
  - Complementary to SNe, CMB, BAO

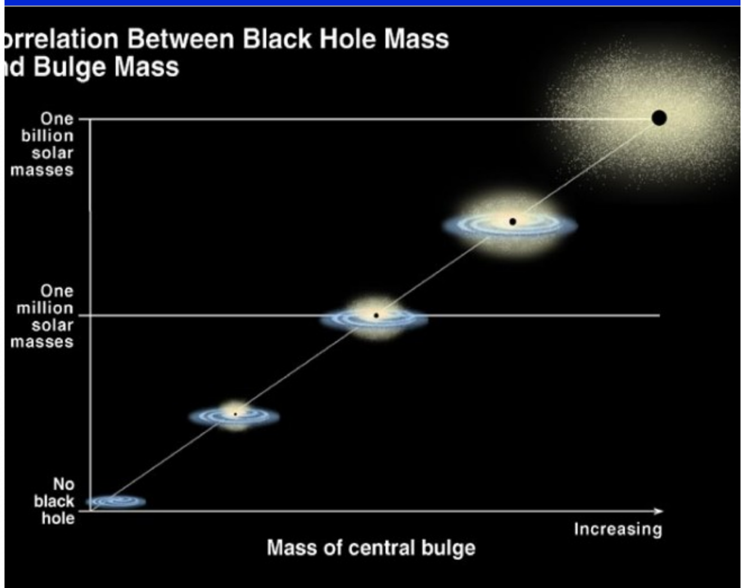
The NOT Transit Explorer can provide significant advances to both issues by providing simultaneous and wide UV-optical wavelength coverage at intermediate spectral resolution.

M - M_{bulge} Relationship: Co-evolution?

Black Hole Mass



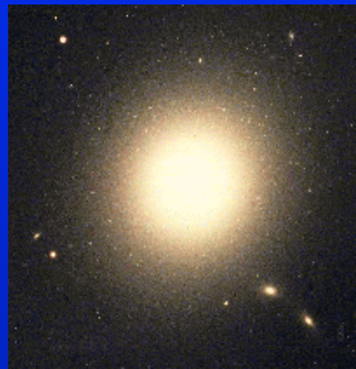
(Tremaine et al. 2002; See also Ferrarese & Merritt 2000; Gebhardt et al. 2000)



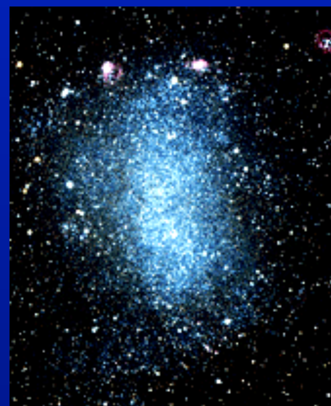
Mass of Galaxy Bulge

Why the interest in supermassive black holes?

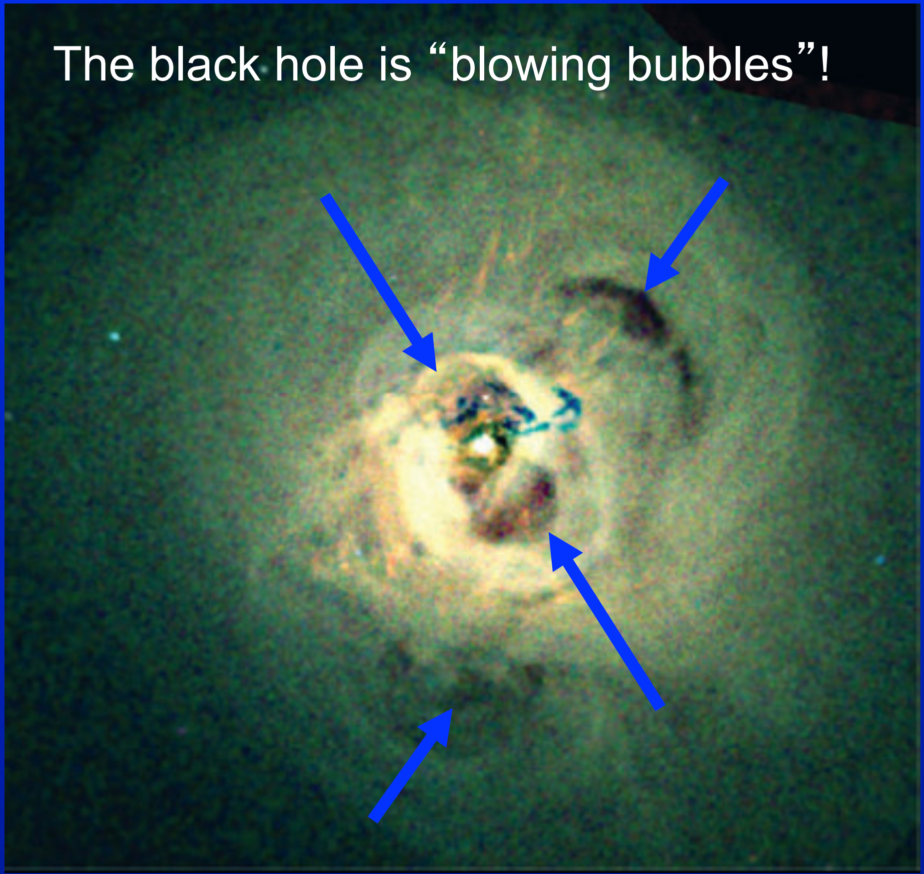
- What stopped star formation in the now red, “dead”, elliptical galaxies?

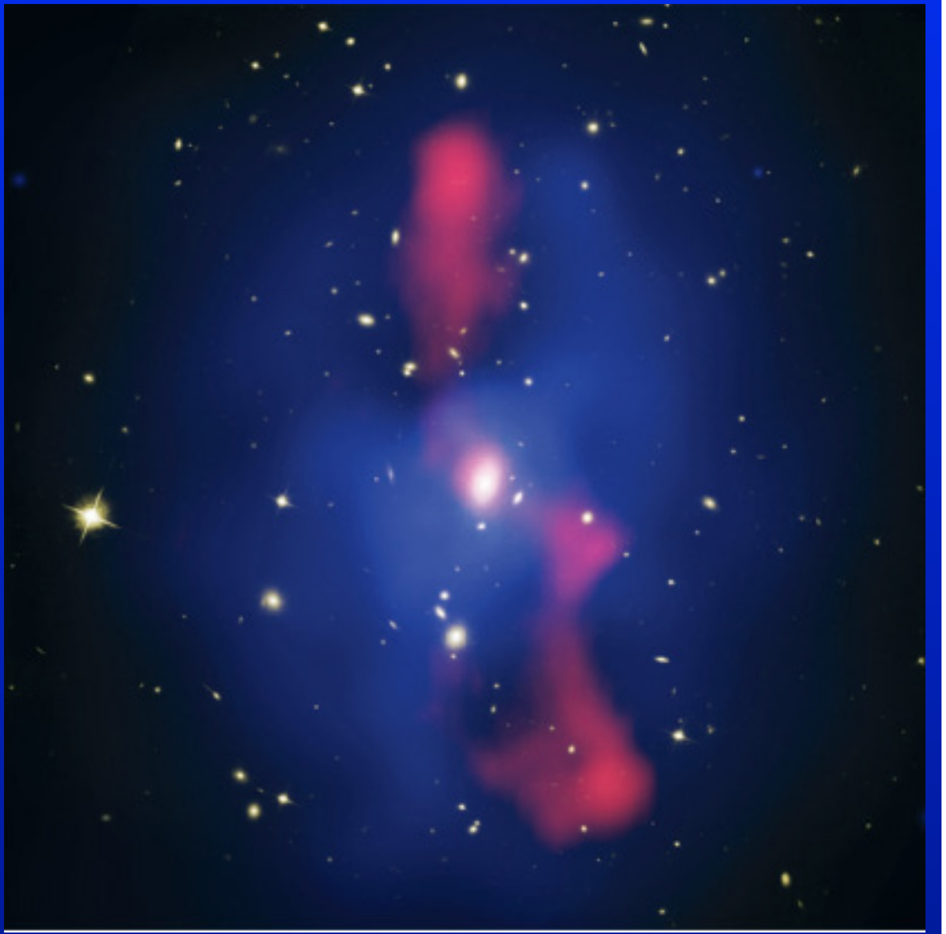




Black Hole Activity Affecting the X-ray Gas in Clusters: outflows + heating

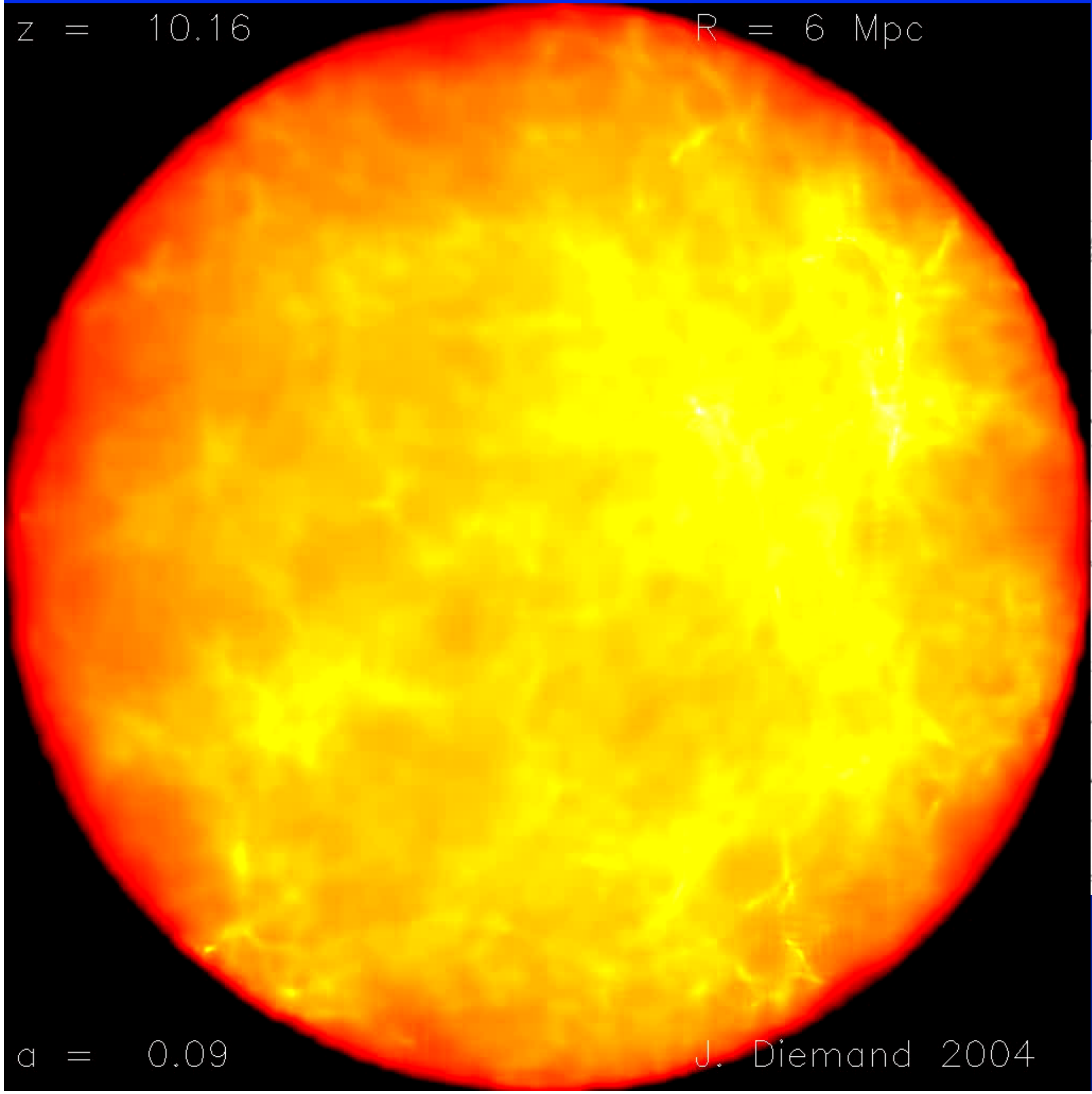


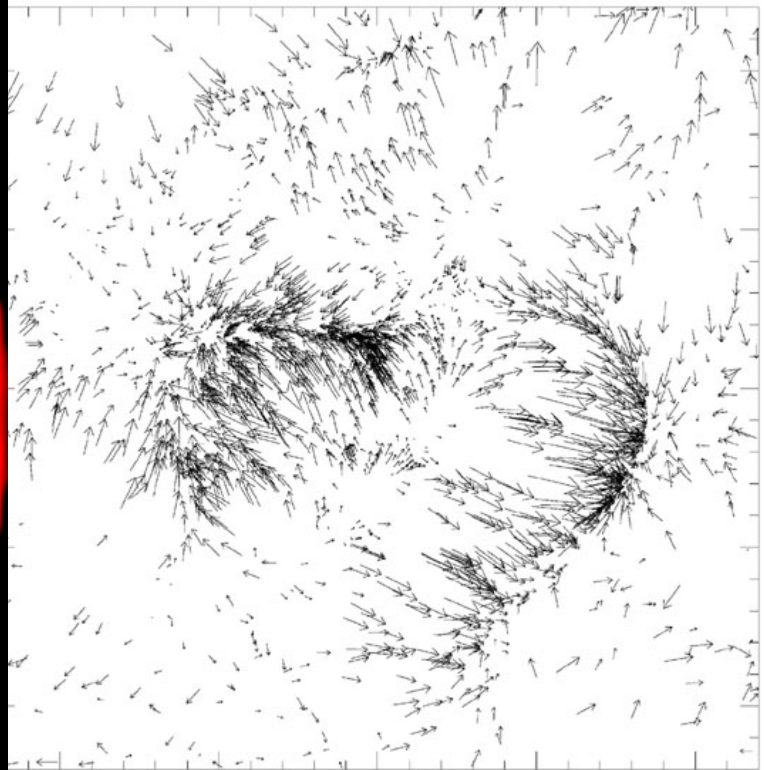


Perseus A
(Fabian et al. 2006)

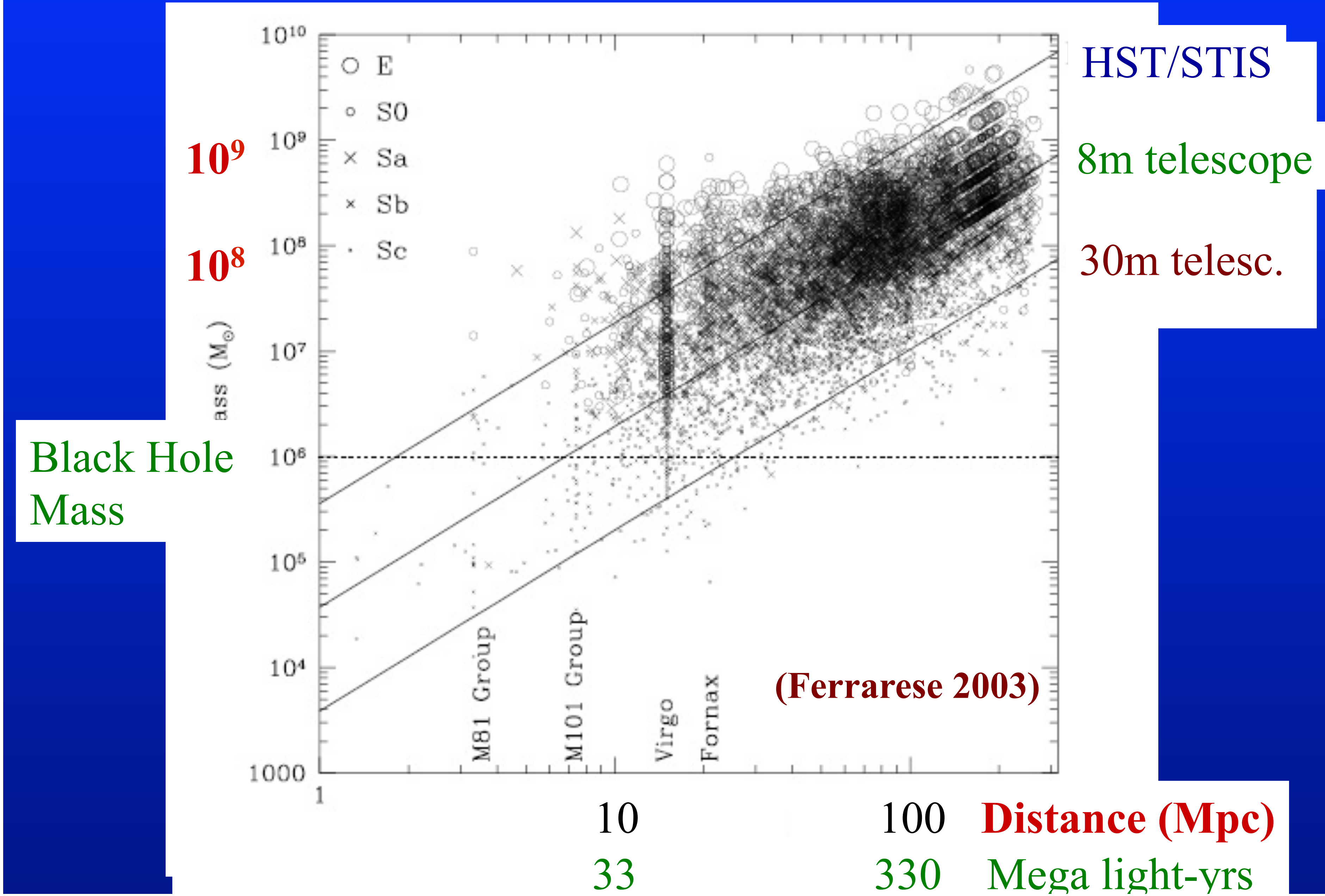
MS0735.6+7421 Cluster
(McNamara & Nulsen 2007)

The Role of Black Holes on Structure Formation and Evolution?



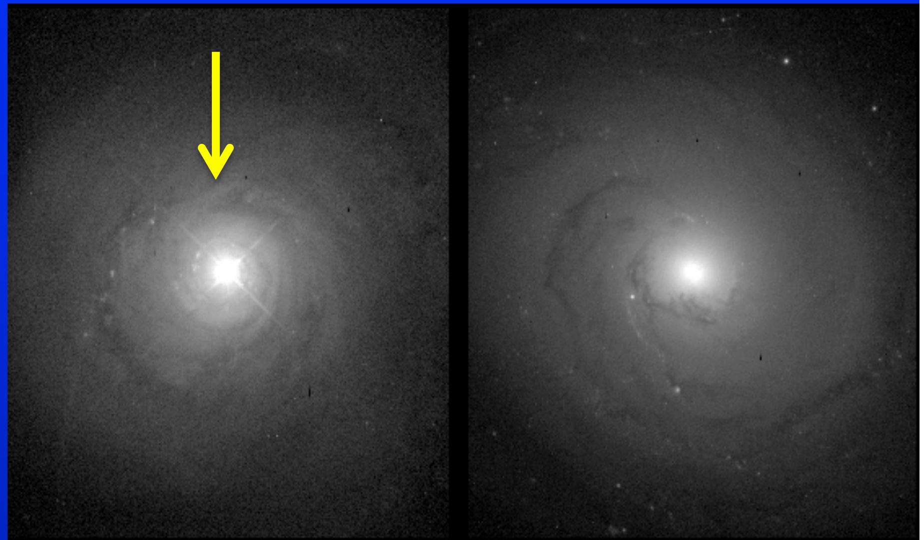


Why Study *Quasar* Black-Holes?



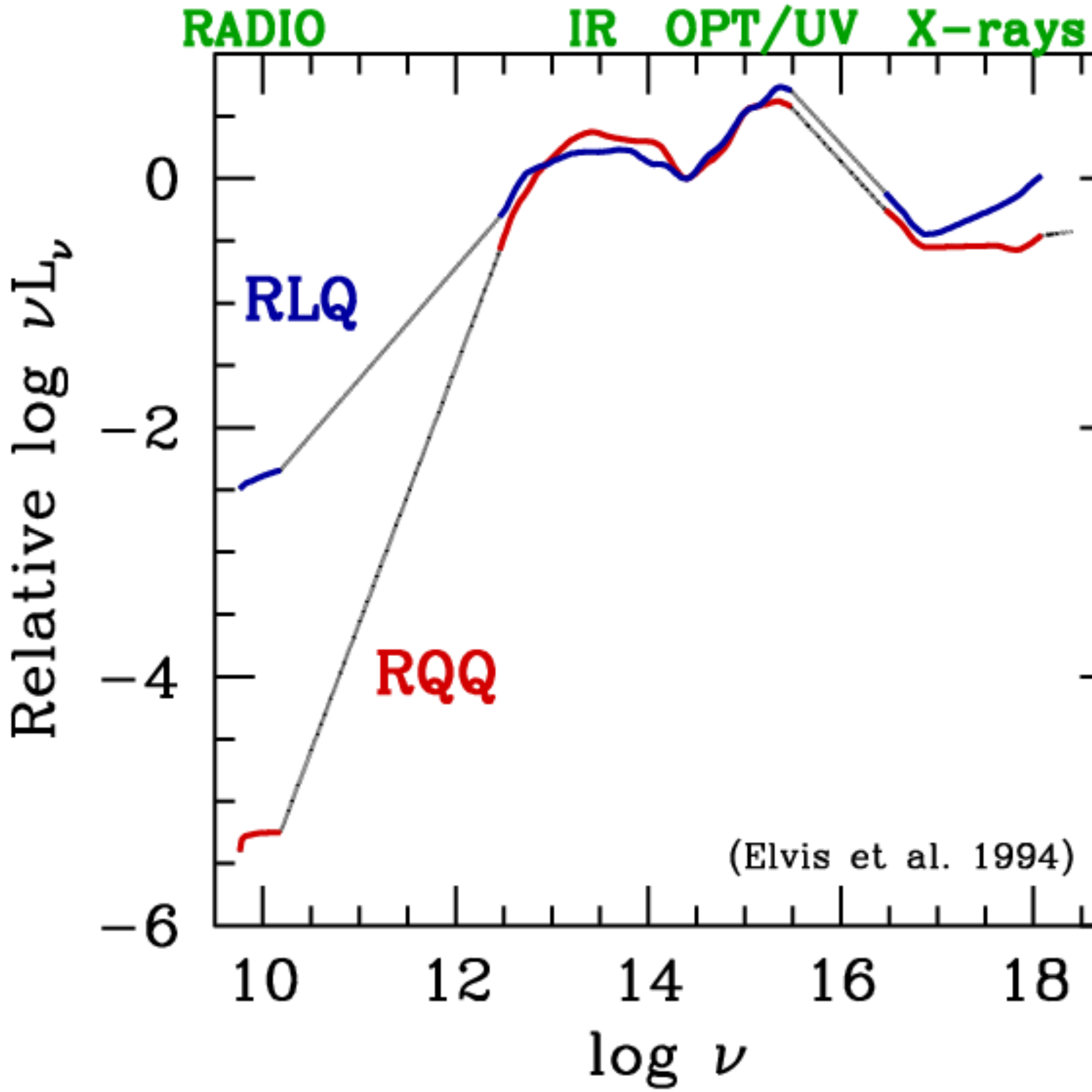
Active Galactic Nuclei

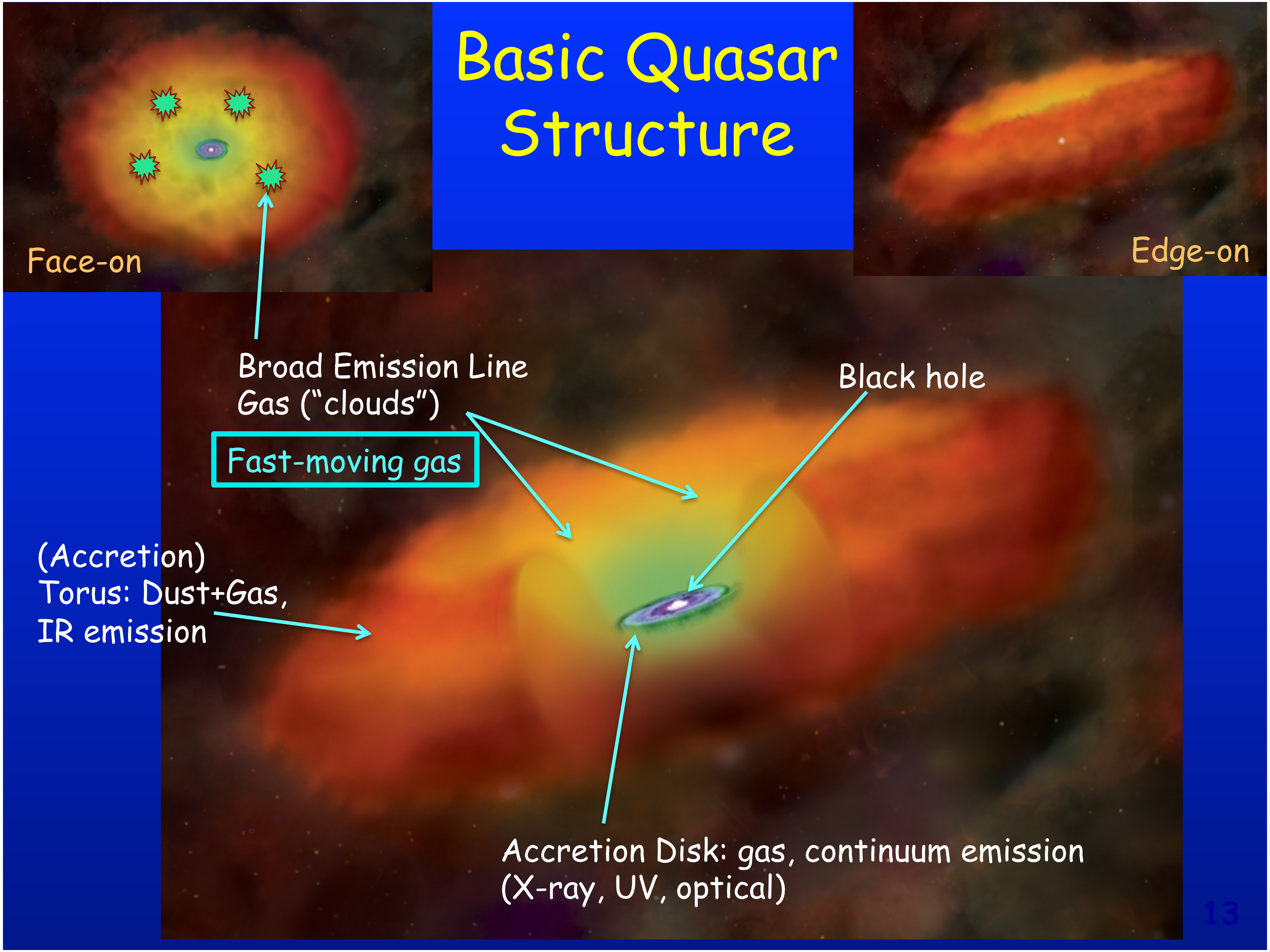
- Bright galaxies with a point-source of non-stellar activity in nuclei - powered by an accreting black hole
- They are rare – comprise only a few percent of ***bright*** galaxies
- The most powerful are called quasars.
- While rare, these are the only massive black holes we can study beyond ~300Mpc



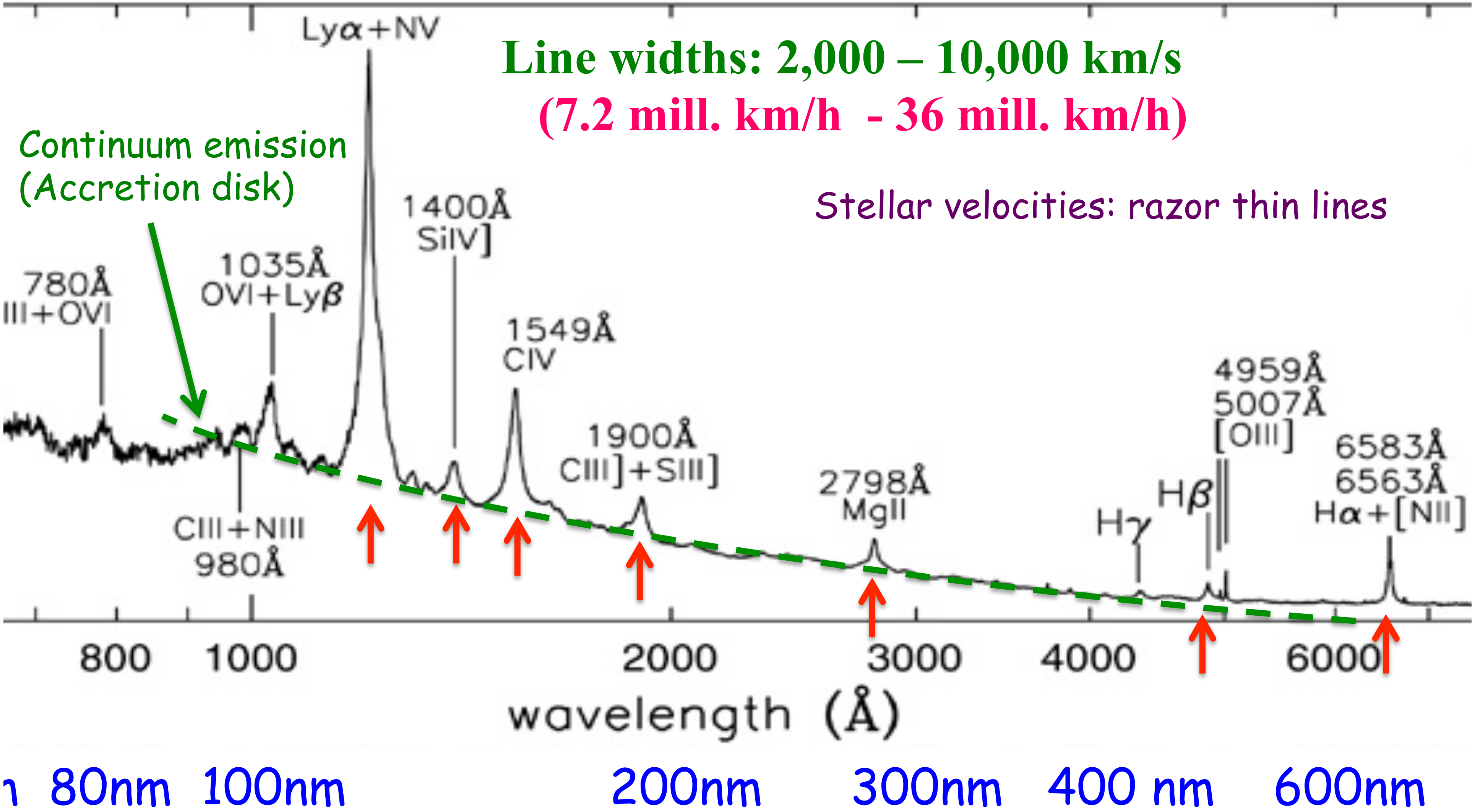
Quasars outshine the host galaxy

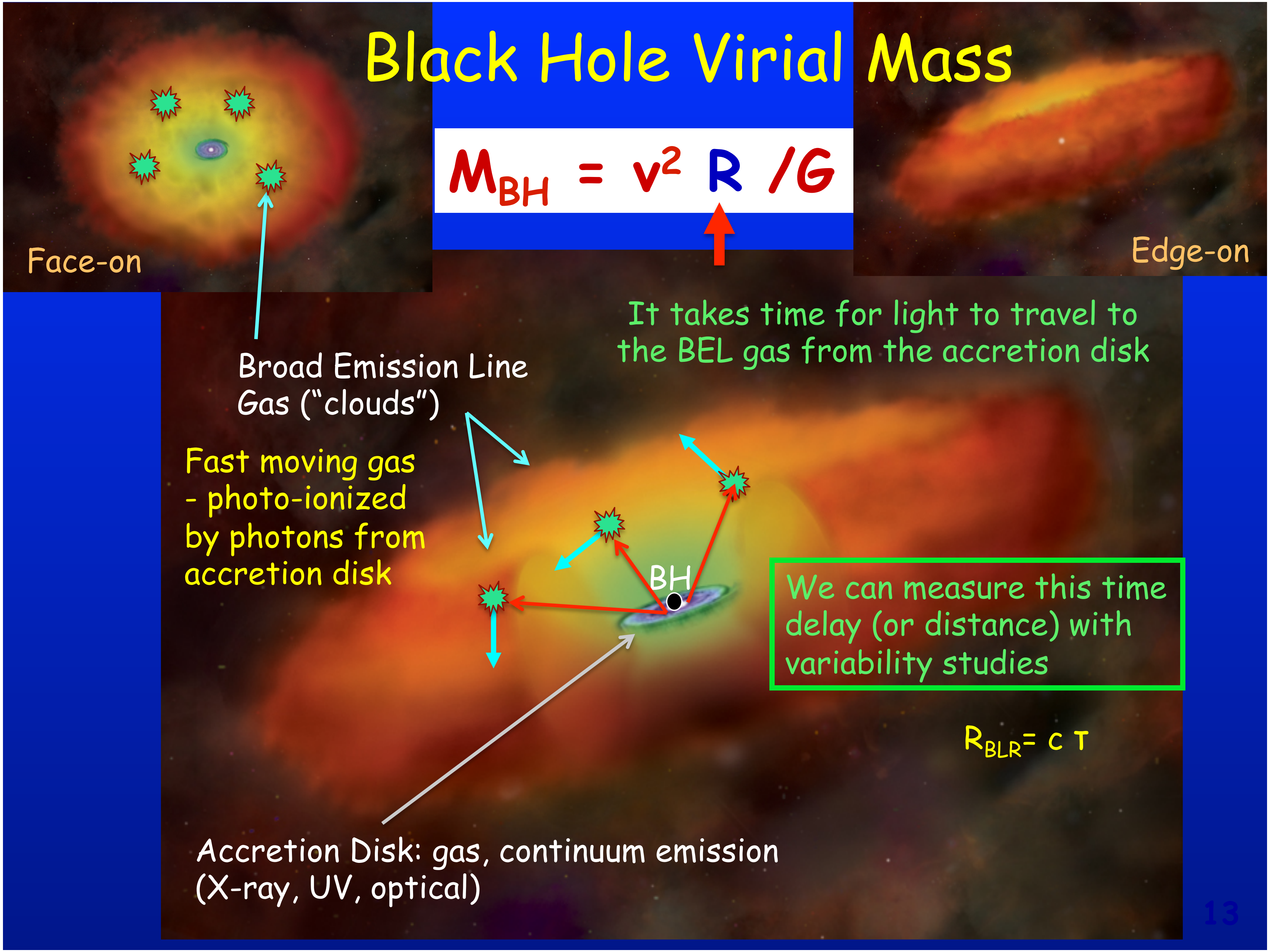
Quasar emit across the entire electromagnetic spectrum




Basic Quasar Structure
Face-on
Edge-on
Broad Emission Line Gas ("clouds")
Fast-moving gas
Black hole
(Accretion) Torus: Dust+Gas, IR emission
Accretion Disk: gas, continuum emission (X-ray, UV, optical)
13

AGN broad emission lines from gas in motion around the black hole



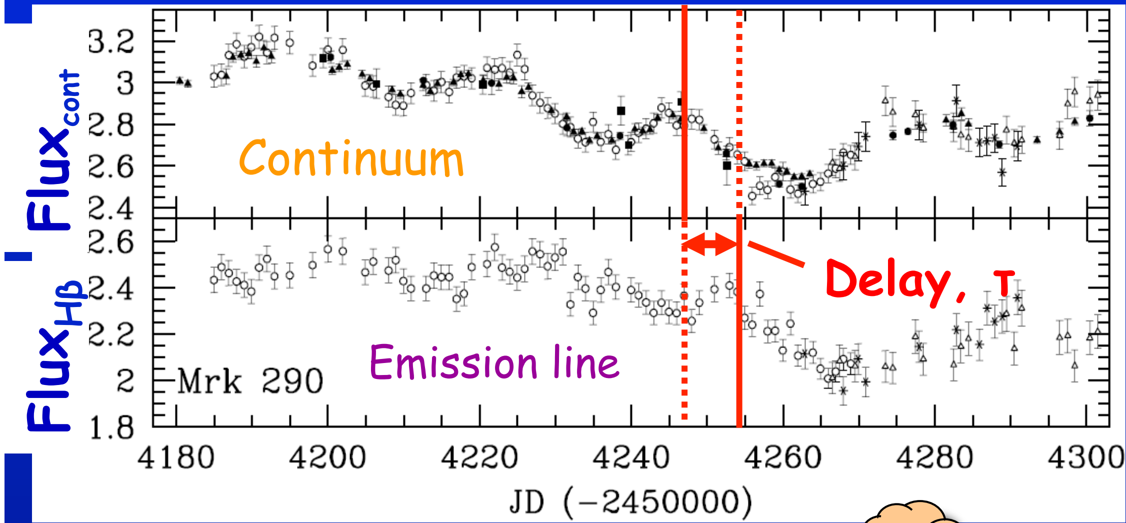


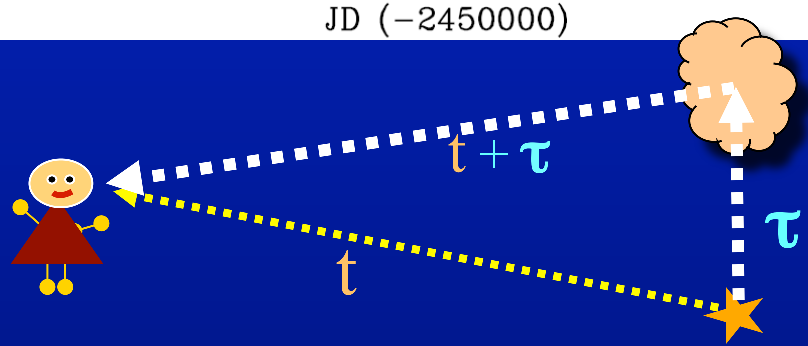
Black Hole Virial Mass
$M_{BH} = v^2 R / G$
Face-on
Edge-on
It takes time for light to travel to the BEL gas from the accretion disk
Broad Emission Line Gas ("clouds")
Fast moving gas - photo-ionized by photons from accretion disk
BH
We can measure this time delay (or distance) with variability studies
$R_{BLR} = c\ T$
Accretion Disk: gas, continuum emission (X-ray, UV, optical)
13

AGN Virial Mass Estimates

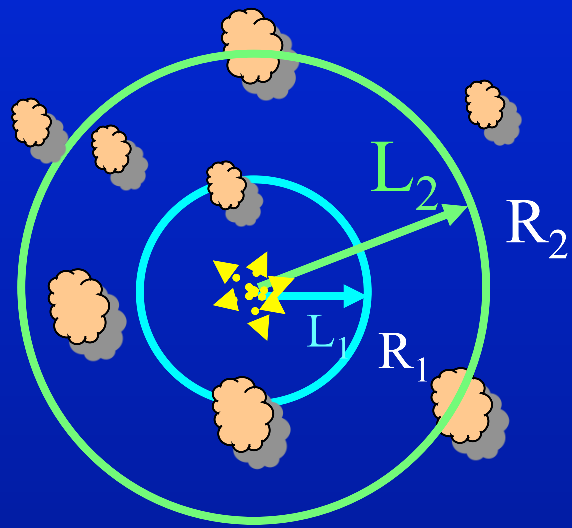
$$M_{BH} = v^2 R_{BLR}/G$$

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





- Radius – Luminosity Relation:



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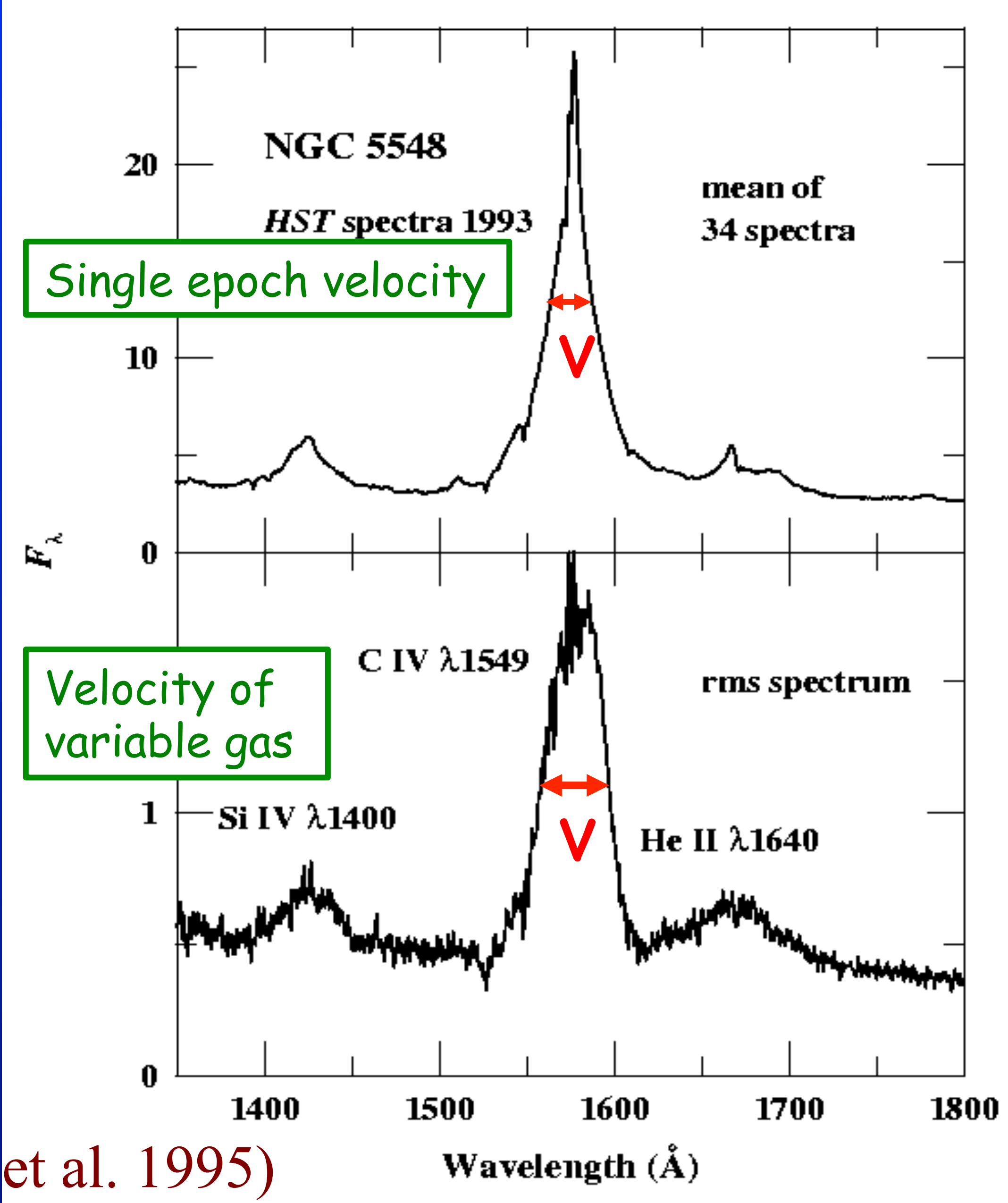
Velocity Dispersion of the Broad Line Region and the Virial Mass

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

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

1σ absolute uncertainty relative to M-σ relation: factor ~3-4



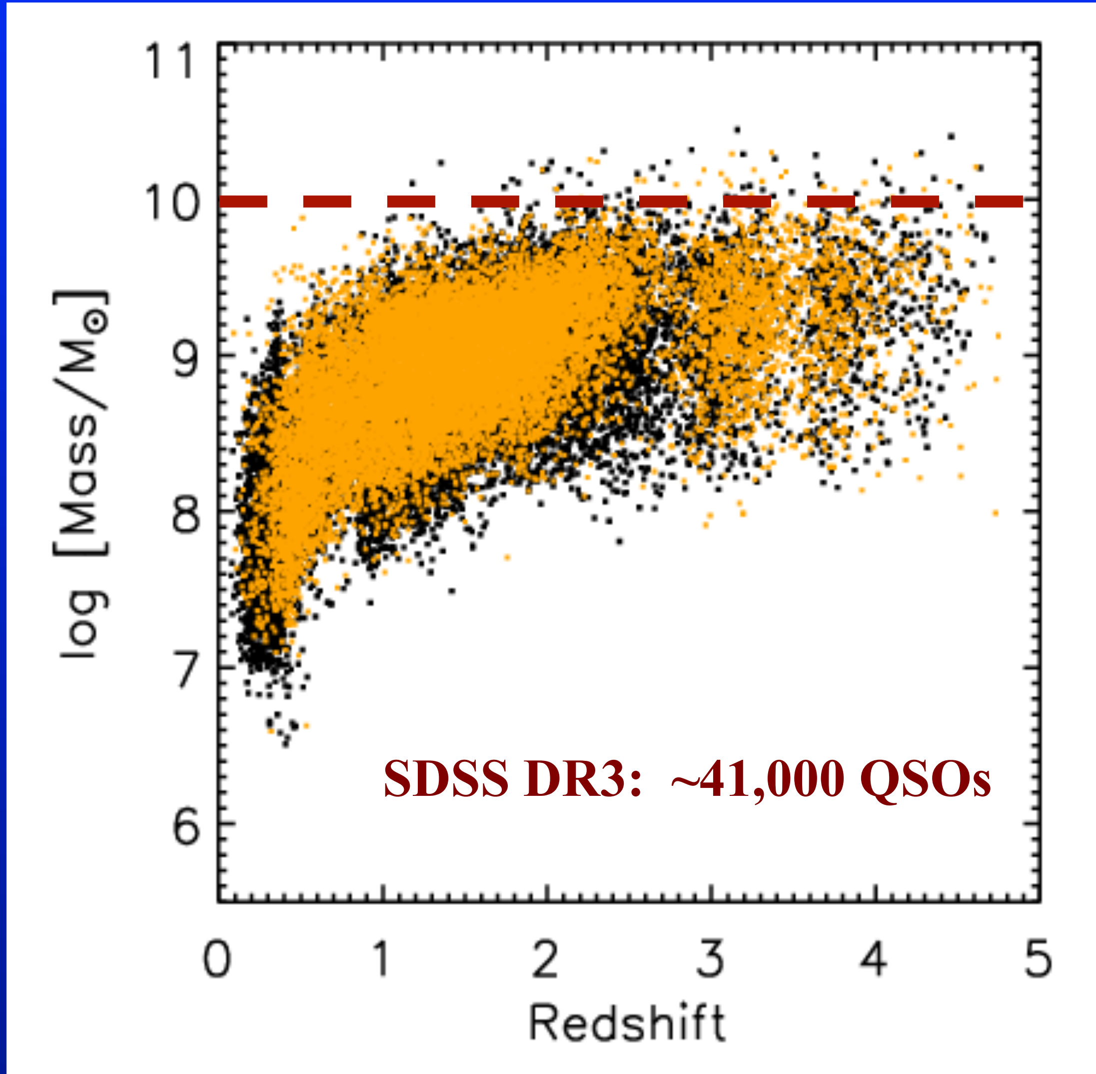
(based on Korista et al. 1995)

Masses of Distant Quasars

Distant active black holes are very massive:
M_{BH}: 10^{8} – 10^{10} $M_{\odot}$
and very luminous:
L_{BOL}: 10^{38} – 10^{41} W
= 10^{45} – 10^{48} erg/s

- $M_{BH} \approx 10^{9}$ $M_{\odot}$ - even beyond space density drop at $z \approx 3$

- $M_{\odot} = 2 \times 10^{30}$ kg

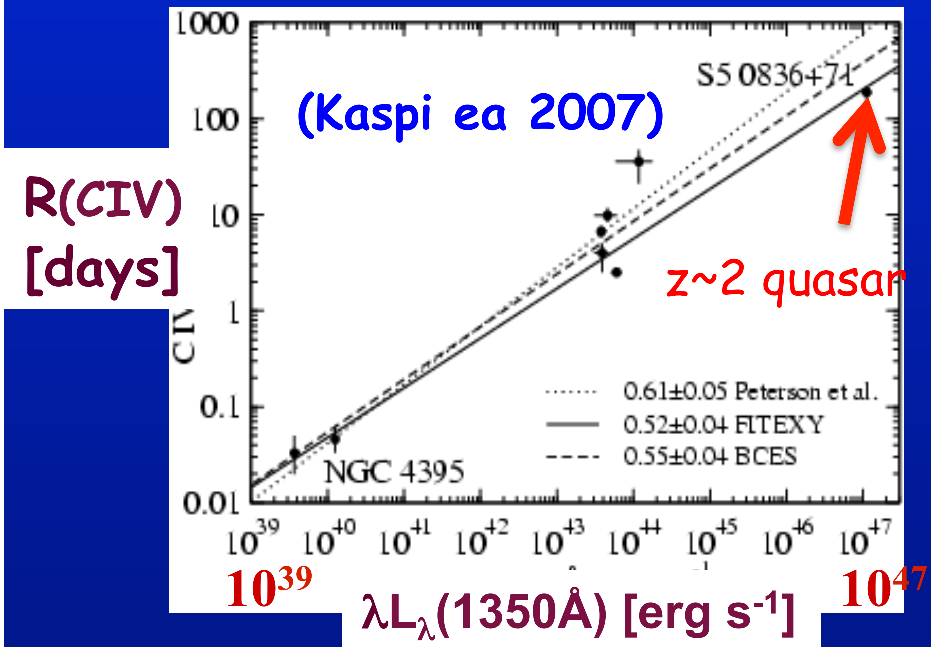


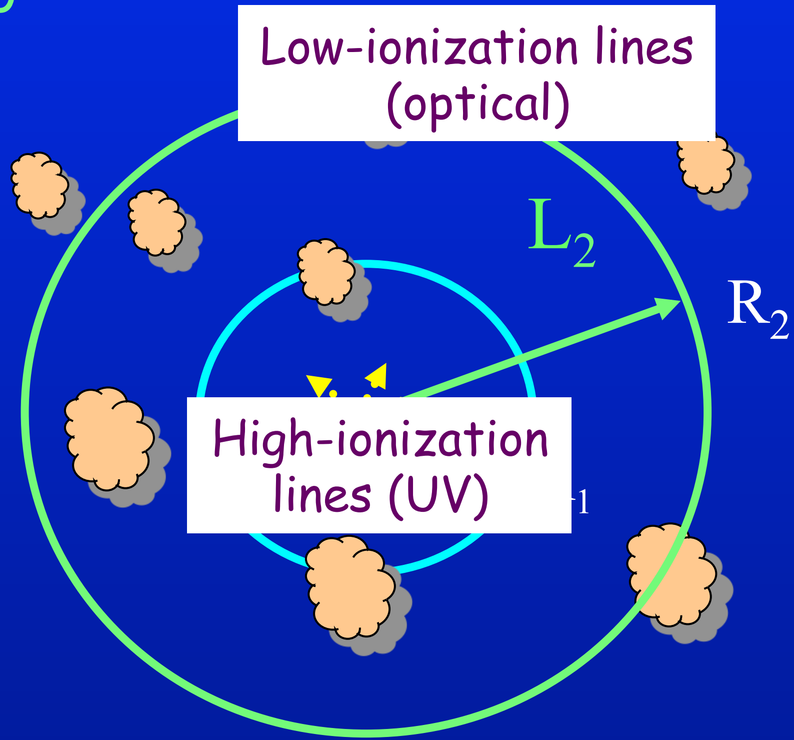
(DR3 Qcat: Schneider et al. 2005)

(MV et al. in prep)

Masses of distant black holes: rest-UV lines

- Rest-frame UV shifts into optical bands accessible from ground (Balmer lines shift out)
- Need calibration of R – L_{UV} relation for the strong UV lines, CIV λ1549 & MgII λ 2800
- UV lines = shorter lags
- Need both UV and optical lines!





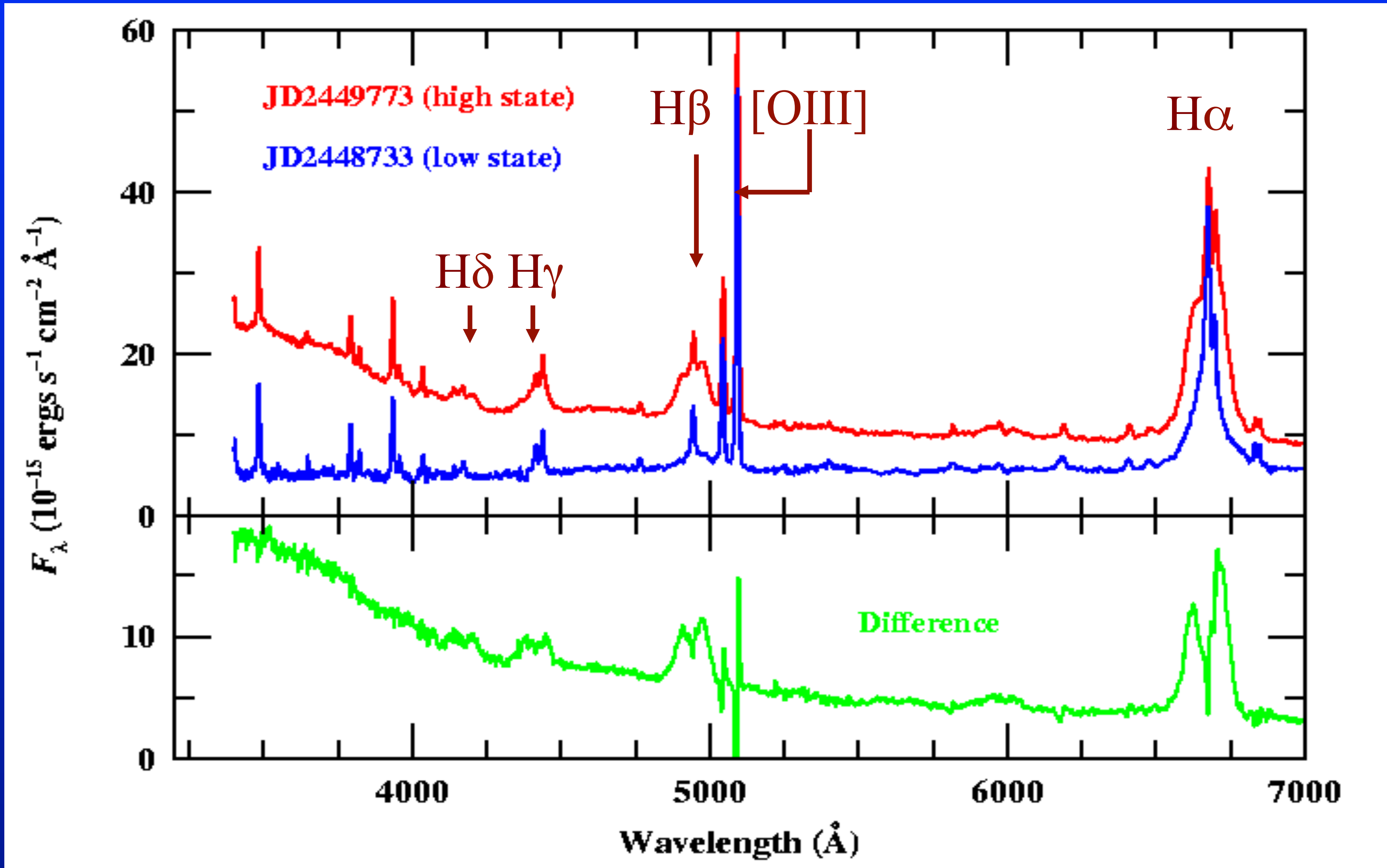
Each line has its own R-L relation: different origin

How the NOT Transient Explorer can help improve accuracy of mass measurements

Simultaneous 3500Å – 1.75μm spectroscopy covering the CIV, MgII, Hβ, and (Hα) lines at range of redshifts provide:

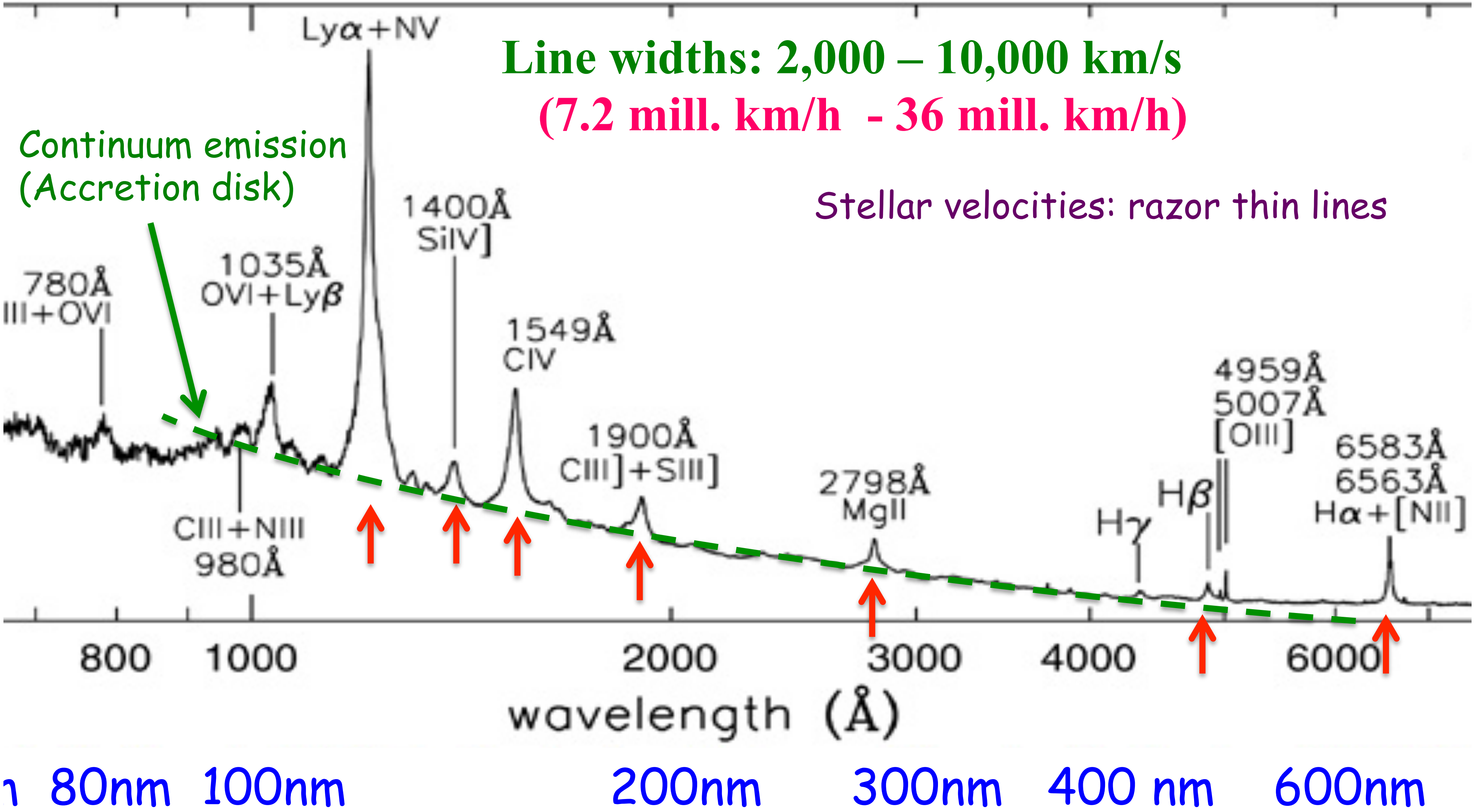
- Monitoring for calibration of R-L relations
  - Short intense campaigns for low-L objects (few months)
  - Longer term (> 6months – years) for high-L objects
- Insight on profile variations with time and quasar properties for different lines
  - physics and dynamics of BLR
  - Hβ actually best line for mass determination?
  - uncertainties in mass
- Extinction/reddening diagnostic lines otherwise accessible (H and He Balmer decrements)

Reverberation Mapping



(Peterson et al. 1999)

AGN broad emission lines from gas in motion around the black hole

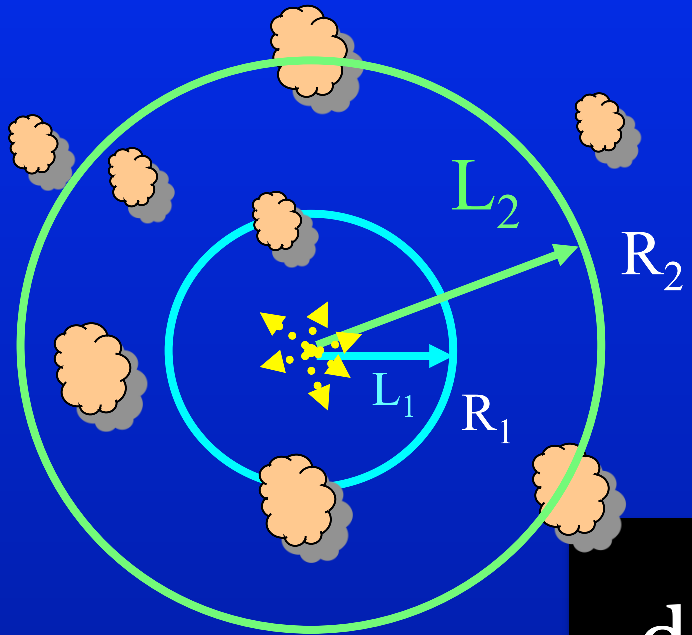


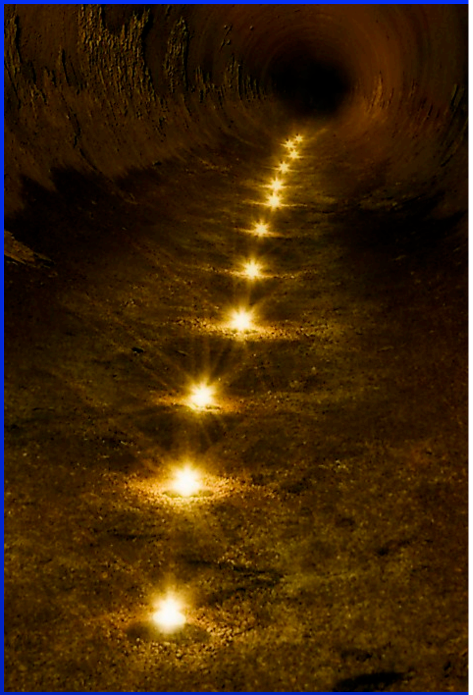
Quasars as Cosmic Distance Indicators

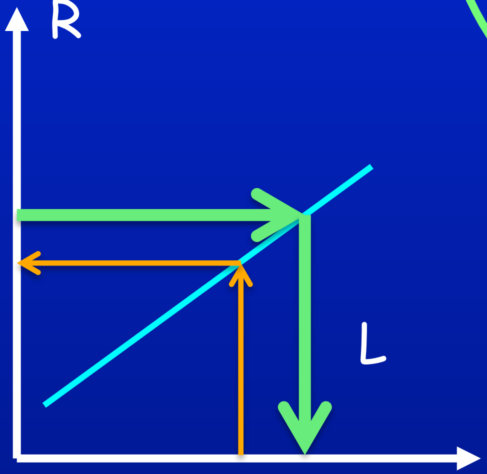
A *well-established* UV R - L relation is key to obtain distances of high-z quasars:

- Accessible from ground
- Time-delay (*R*) is shorter

$R_{BLR} = c\tau$







$$d \sim \tau / F^{1/2}$$

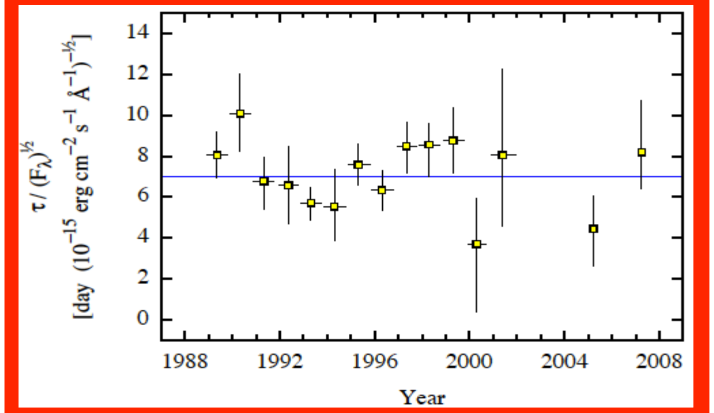
$$L(\lambda) = F(\lambda)\, 4\pi\, d^2$$

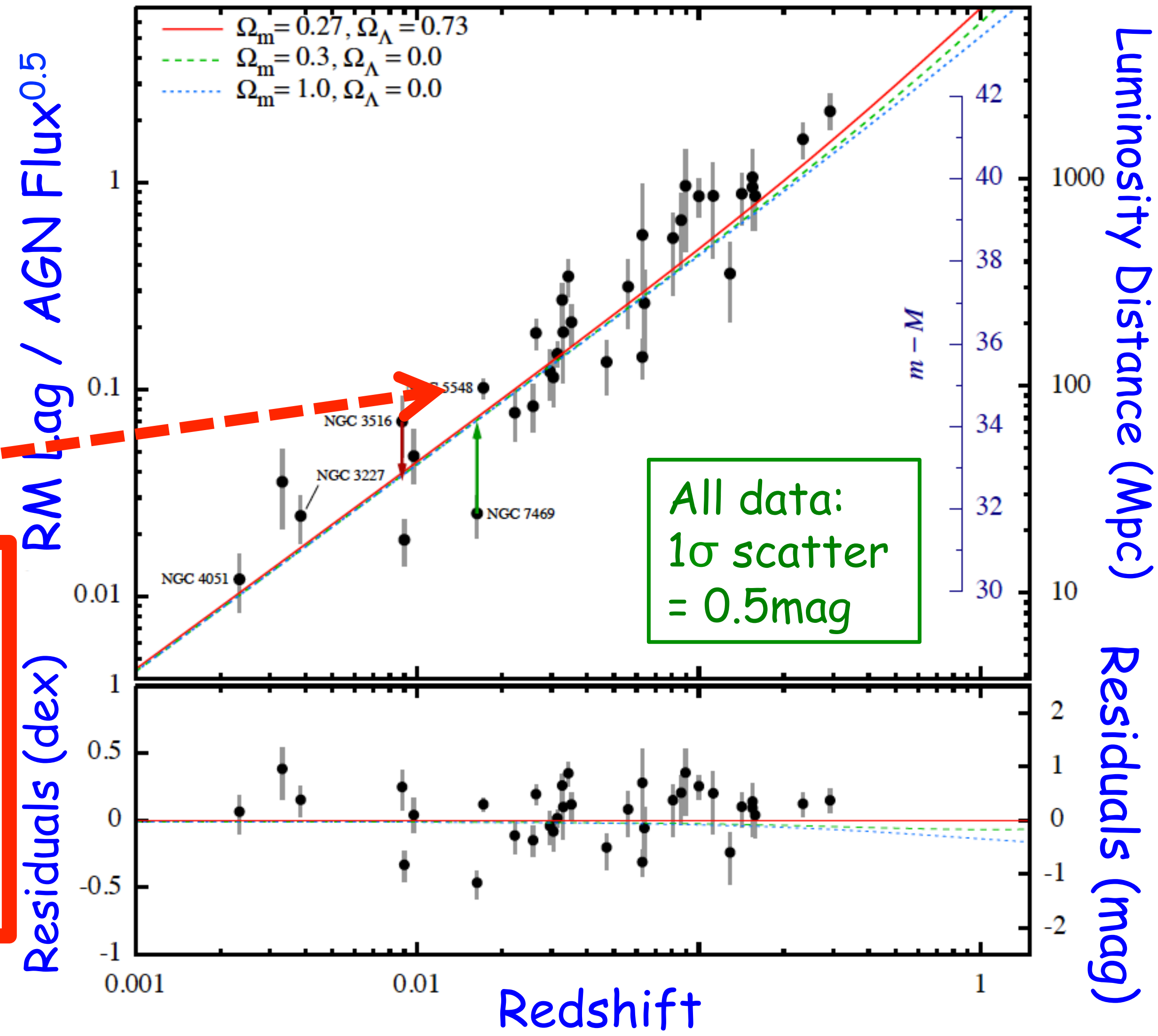
(Watson, Denney, Vestergaard, Davis, 2011, ApJ, 740, L49)

The AGN Hubble Diagram

Reduce the Scatter:

- Misidentified Lags
- Reddening/dust Corrections (e.g. Crenshaw '01)
- Multiple measurements of individual objects



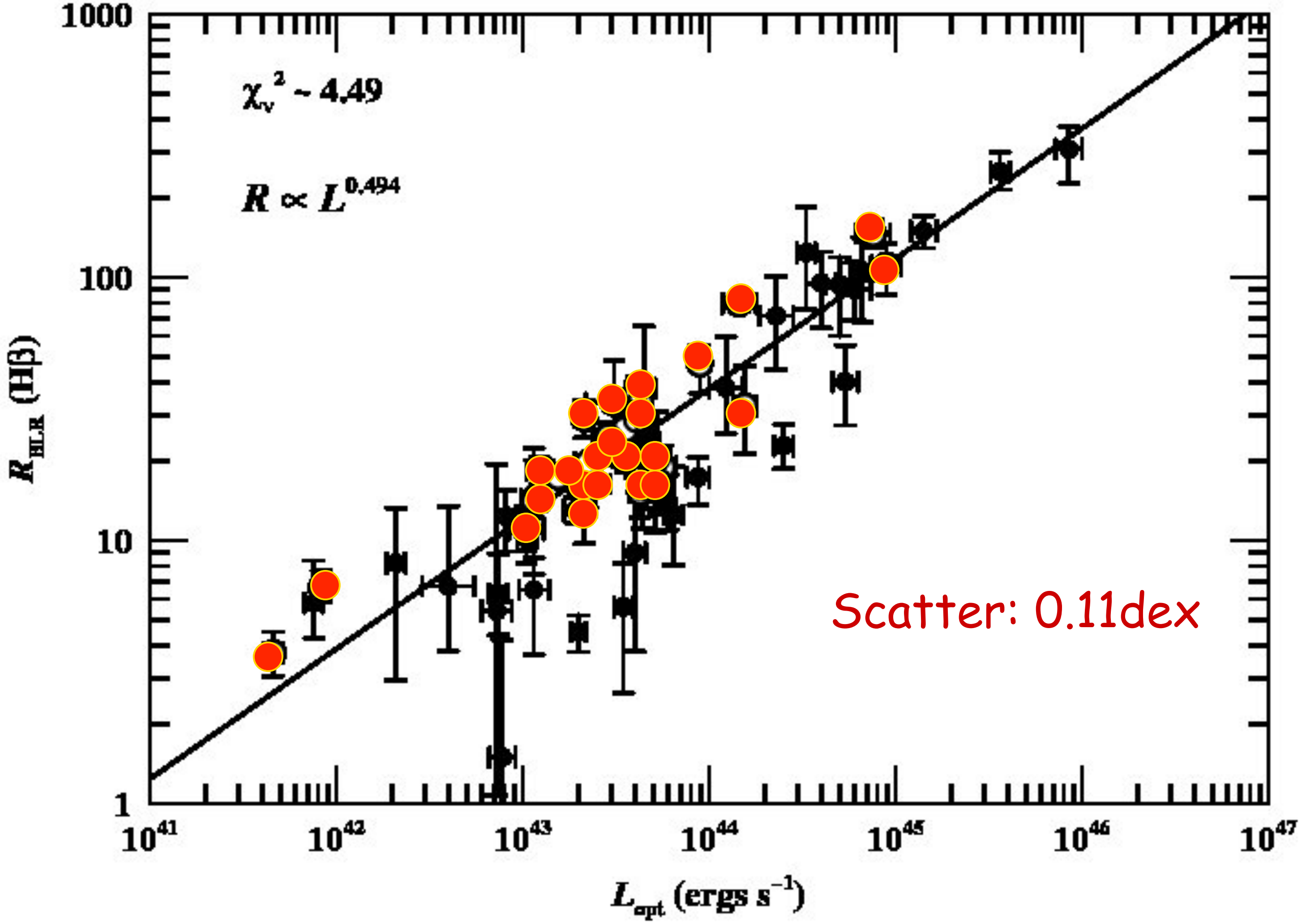


SNe: 1σ = 0.2 mag;
Best data: 0.12 mag

(Watson, Denney, Vestergaard, Davis, 2011, ApJ, 740, L49)

Radius - Luminosity Relation

- Using the highest quality data only!



(Peterson 2010)

Radius - Luminosity Relation

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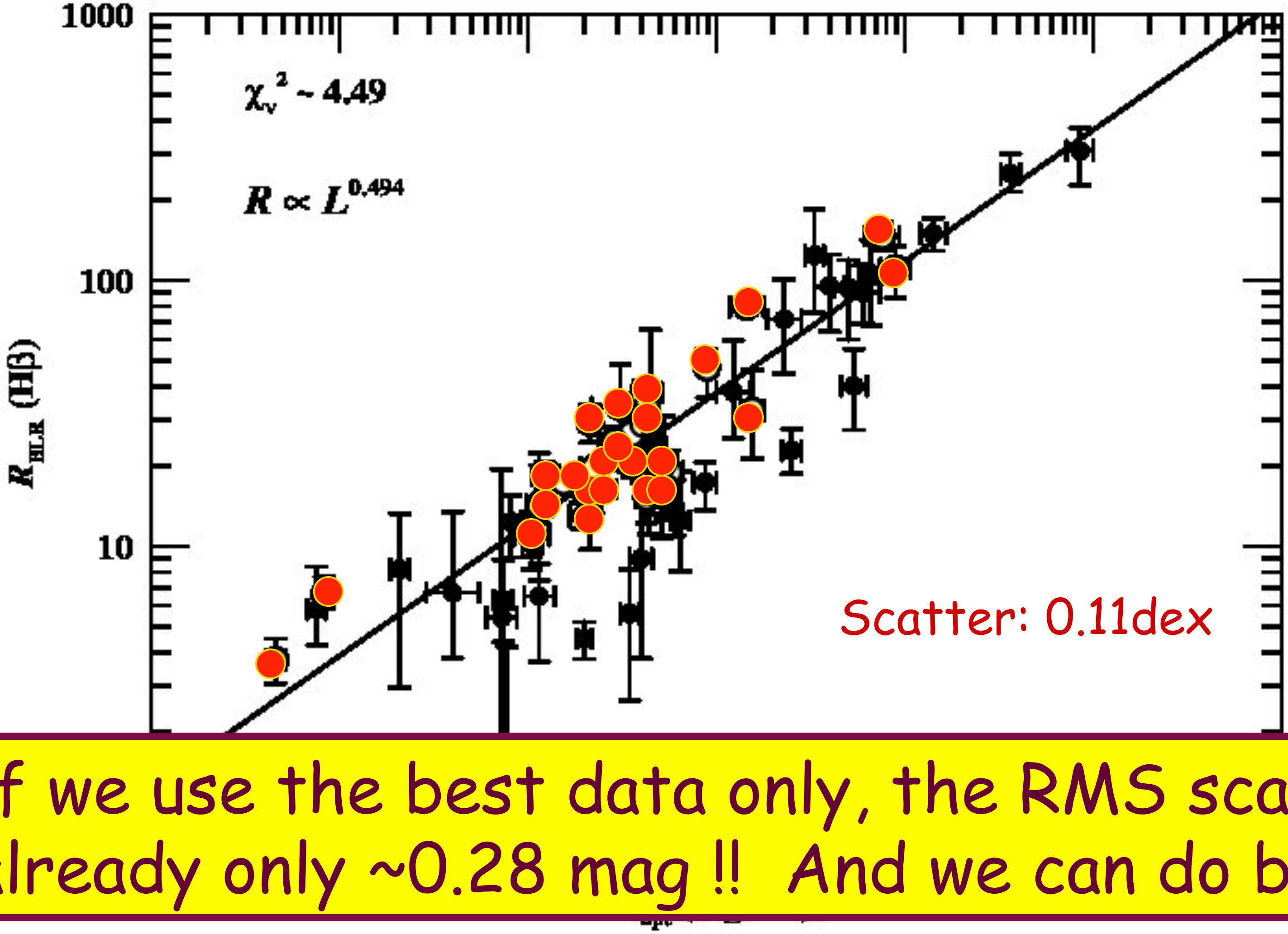
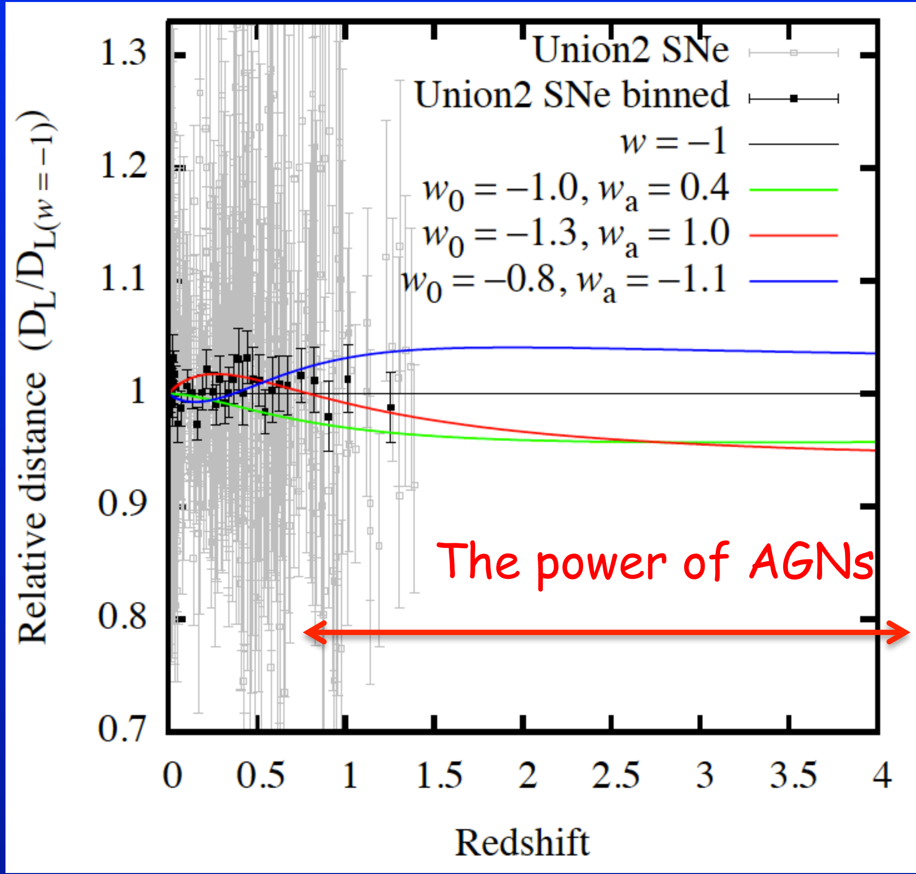


If we use the best data only, the RMS scatter is already only ~0.28 mag !! And we can do better.

(Peterson 2010)

Is the Cosmological Constant "constant"?

- Time dependence of *w*, $w(z) = w_0 + w_a(1 - (1+z)^{-1})$
- Best probed at high z
- AGNs have the clear advantage here:
  - Exist at all z
  - Do not dim with time
  - Can be re-observed
  - Targets can be selected:
    - ✓ At certain redshifts
    - ✓ With minimal reddening
    - ✓ With favorable properties (variability amplitude, strong lines)



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How the NOT Transient Explorer can help prepare for future campaigns to measure cosmic distances with quasars

Long λ-range spectroscopy covering the CIV, MgII, Hβ, and (Hα) lines provide:

- Monitoring for calibration of R-L relations
  - Short intense campaigns for low-L objects (few months)
  - Longer term (> 6months – years) for high-L objects

- Multiple random epochs of candidate objects for reddening measurements

The NOT Transient Explorer to the rescue:

- Accurate black hole masses => help advance precision cosmology
- Prepare for cosmic distances measures using quasars

By means of:

- Long λ-range spectroscopy covering the CIV, MgII, Hβ, and (Hα) lines:
- Monitoring campaigns (calibrations)
- Catalogs of candidate sources for distance measurements
- extinction curves/measurements
- Profile studies and uncertainties in black hole mass