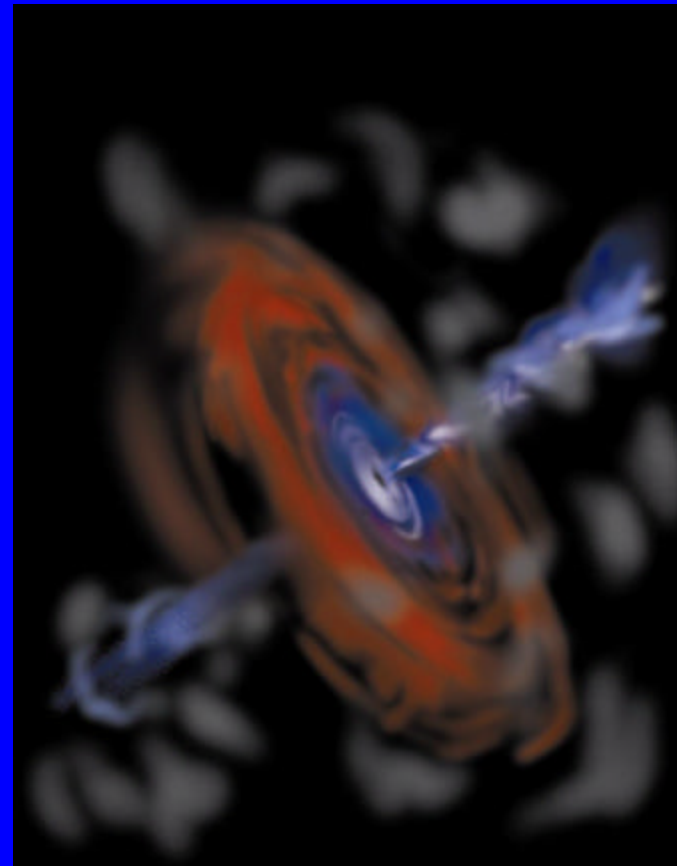


# The Structure and Energetics of Active Galactic Nuclei

Bradley M. Peterson  
The Ohio State University

# The AGN Paradigm

- The black-hole + accretion-disk model is finally fairly secure
  - Black-hole mass measurements have unknown systematic uncertainties
- No generally accepted models for emission and absorption regions, though disk-related outflows seem most promising



# Major AGN Questions

- What are the masses AGN black holes?
- What are the energetics of the accretion process?

- Accretion rate

- Radiative efficiency

- Kinetic energy (jets, absorbing gas)

- How does the AGN mass function evolve over time?

- What is the nature of the line emitting and absorbing gas in AGNs?

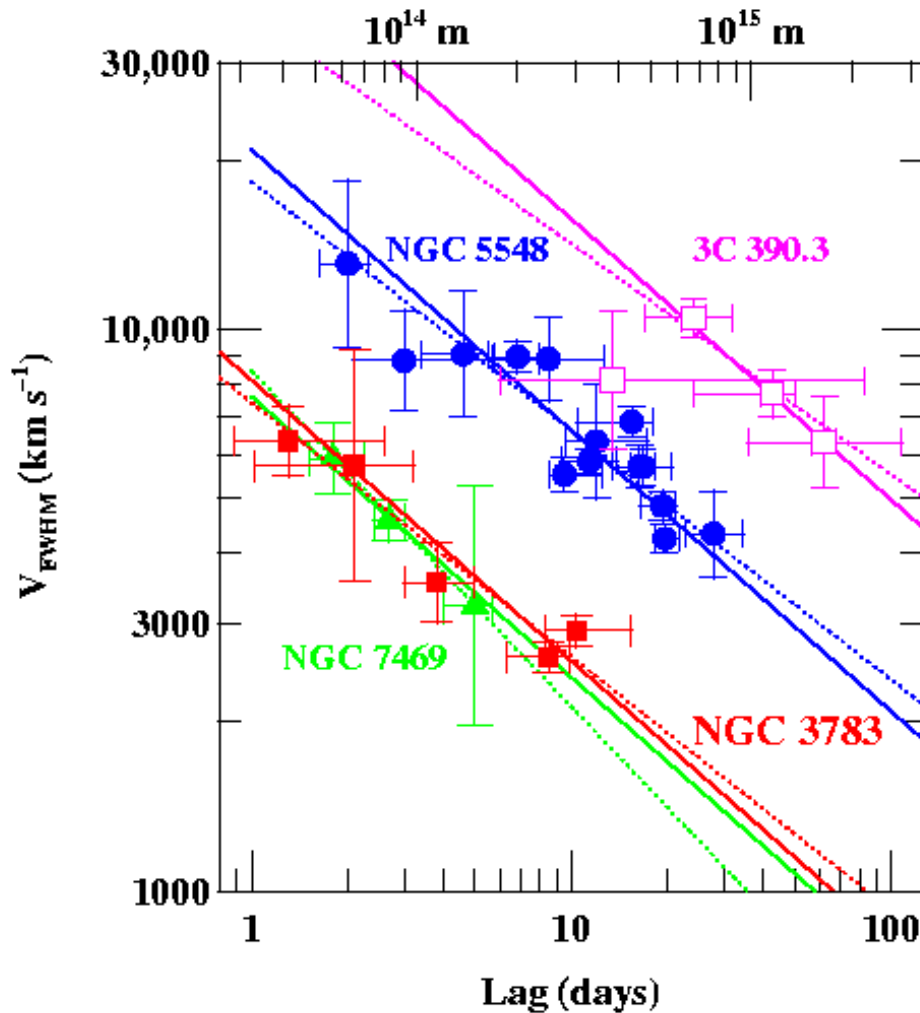
$$L = \eta \dot{M} c^2$$

efficiency

Mass accretion rate

# AGN Black Hole Masses

- Measured for nearly 40 AGNs via reverberation mapping
- Secondary methods are tied to these
- Evidence these are meaningful estimates:
  - Virial relationship between line widths and time delays



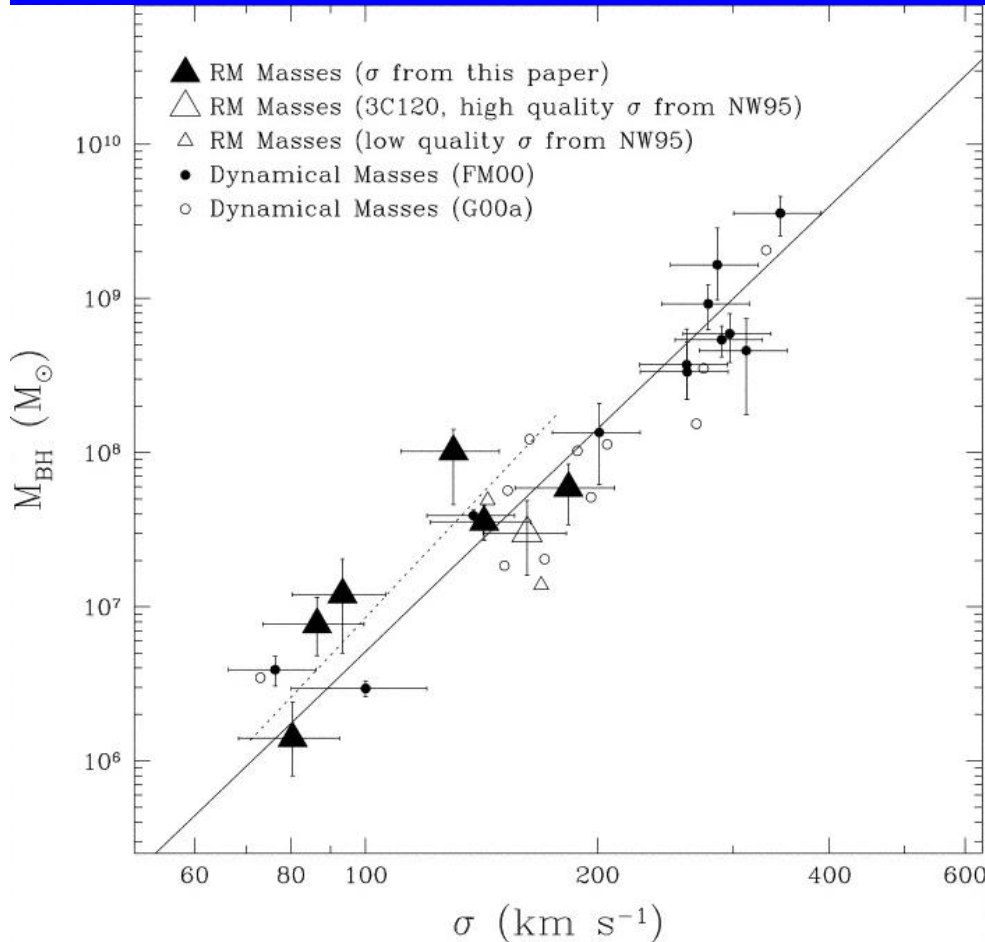
Onken and Peterson 2002  
Peterson and Wandel 2000

2002 April 4

Hubble Science Legacy

4

# AGN Black Hole Masses



- Evidence these are meaningful estimates:
  - $M_{\text{BH}} - \sigma$  relationship same in AGNs and quiescent galaxies
- What we need:
  - Direct comparison of reverberation and stellar dynamical masses
  - Two-dimensional reverberation-mapping to understand kinematics and geometry of line-emitting region

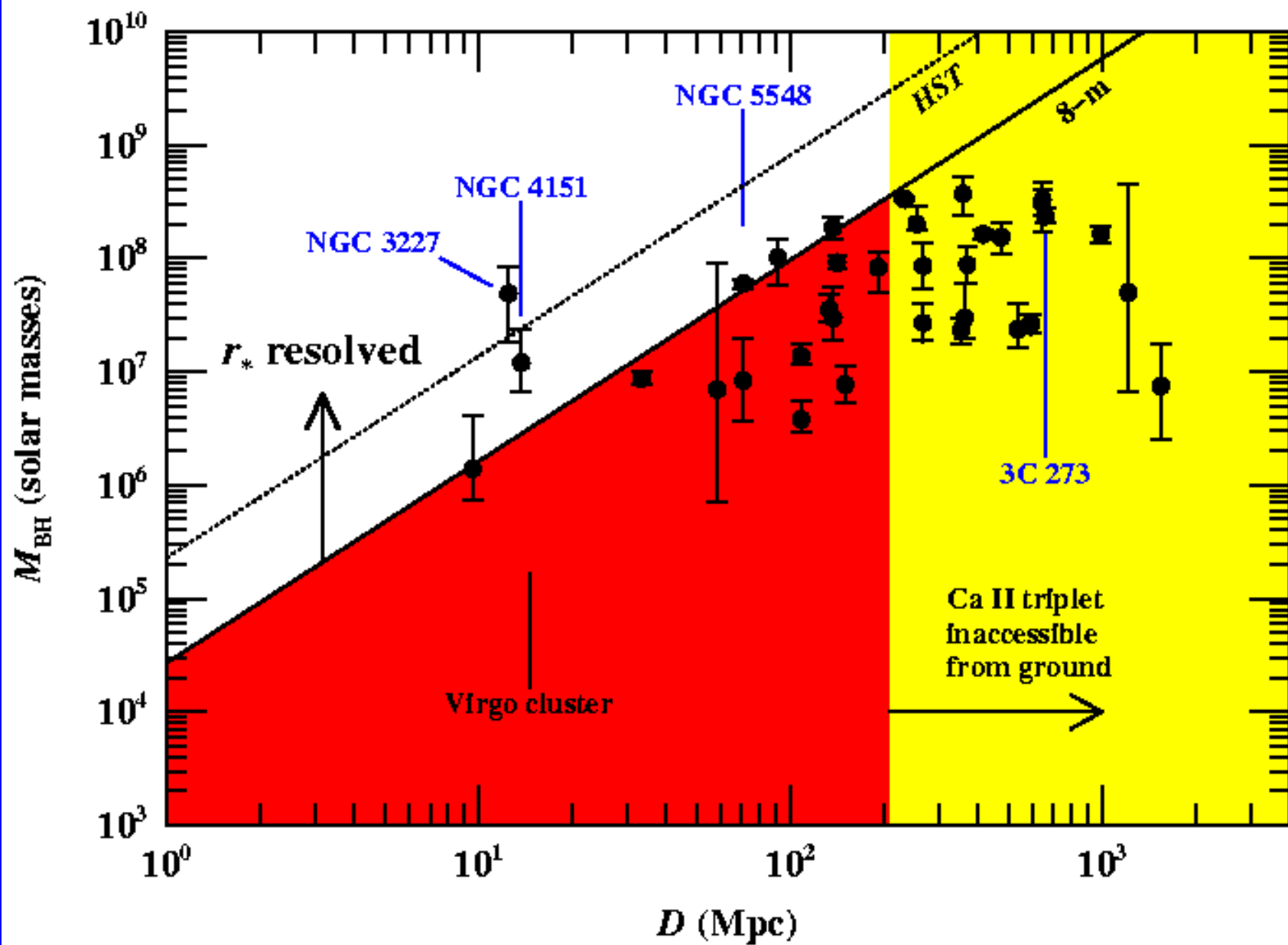
Ferrarese et al. 2001

# Direct Comparison of Reverberation and Stellar Dynamical Masses

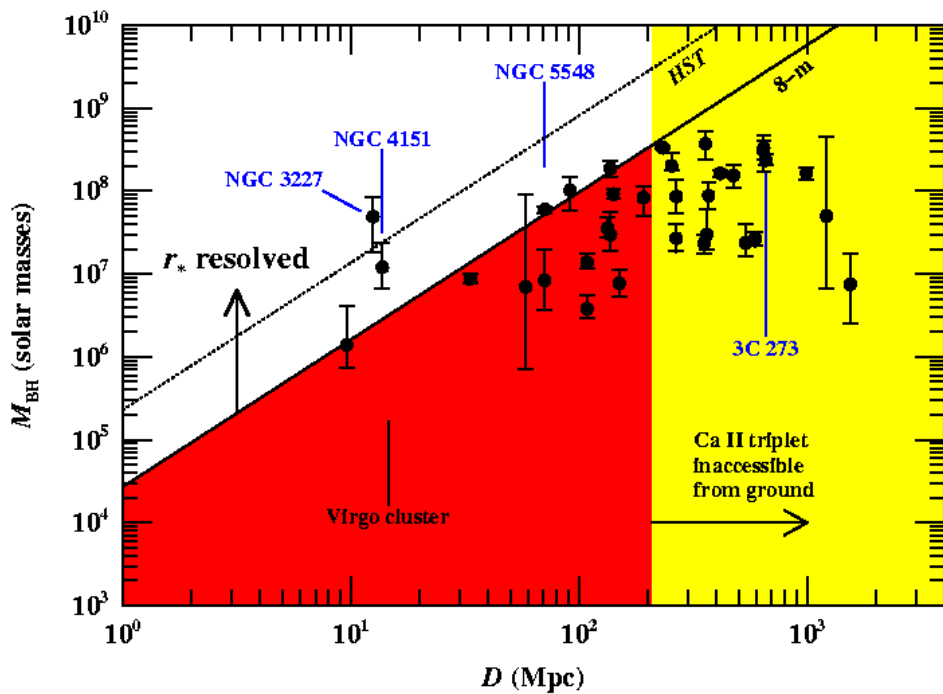
- Requires spatially resolving the black-hole radius of influence  $r_* = GM_{\text{BH}} / \sigma^2$ .
  - Impose criterion on diffraction limit and use  $M_{\text{BH}} - \sigma$  relationship ( $\sigma \propto M_{\text{BH}}^{2/9}$ ):

$$\phi_{\text{diff}} < \frac{r_*}{D} \propto \frac{M_{\text{BH}}}{\sigma^2 D} \propto \frac{M_{\text{BH}}^{5/9}}{D}$$

- This gives minimum dynamically measurable  $M_{\text{BH}}$  as a function of distance.

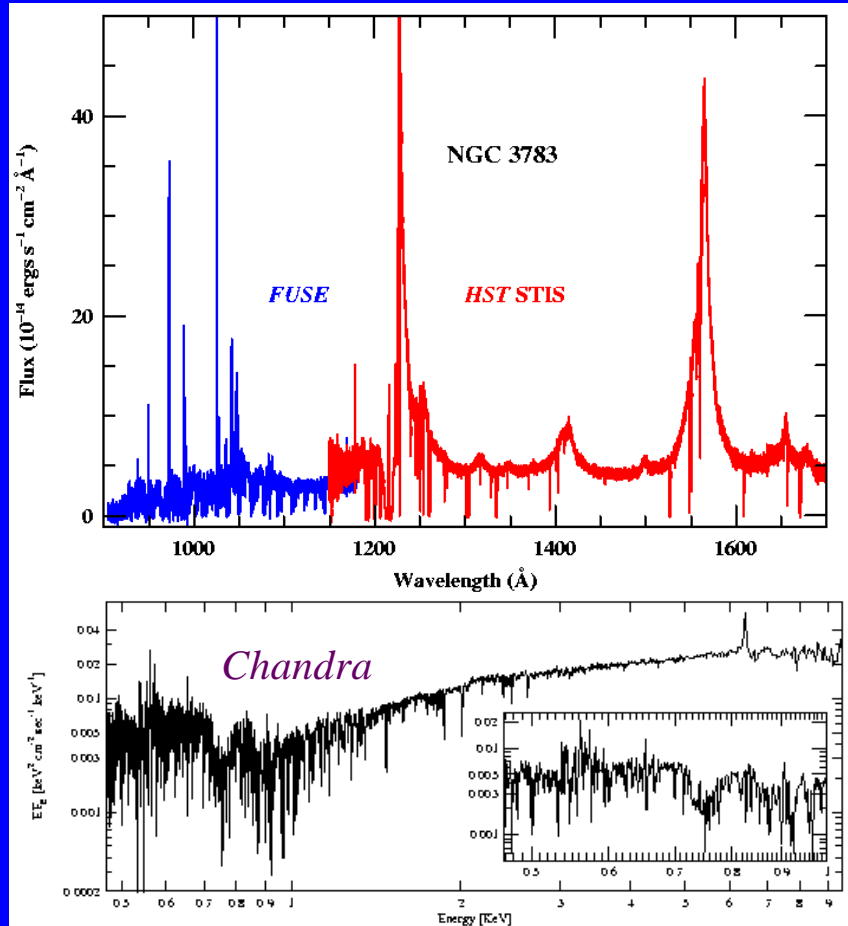


# Why Must This Be Done From Space?



- A ground-based large telescope should be able to attain comparable resolution with adaptive optics (AO)
- However, AO Strehl ratios are still too small: the faint stellar absorption features are swamped by scattered nuclear light

# X-ray/UV Absorption

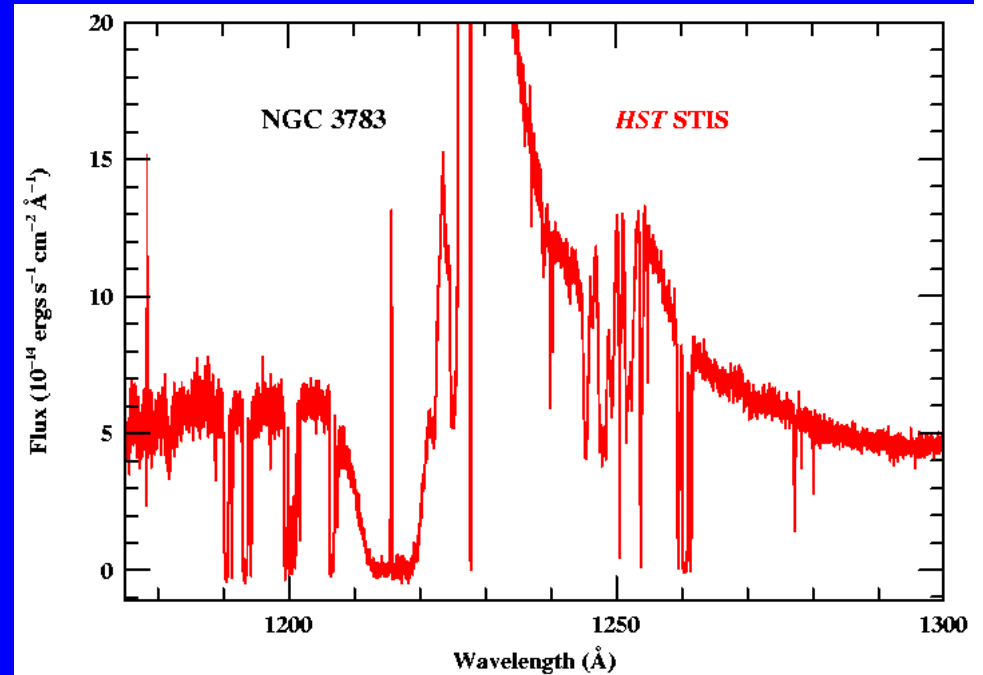


*Chandra*: Kaspi et al. 2002  
*HST*: Crenshaw et al. 2002  
*FUSE*: Gabel et al. 2002

- Ubiquitous property of AGNs
- Large column densities, multiple velocity components, massive outflows
- Analogs to outflows in young stars?
- Connection to BALs in luminous QSOs?
- How much mass and kinetic energy is involved?
- How do these vary with AGN properties?

# Why Is A Large Space Telescope Needed?

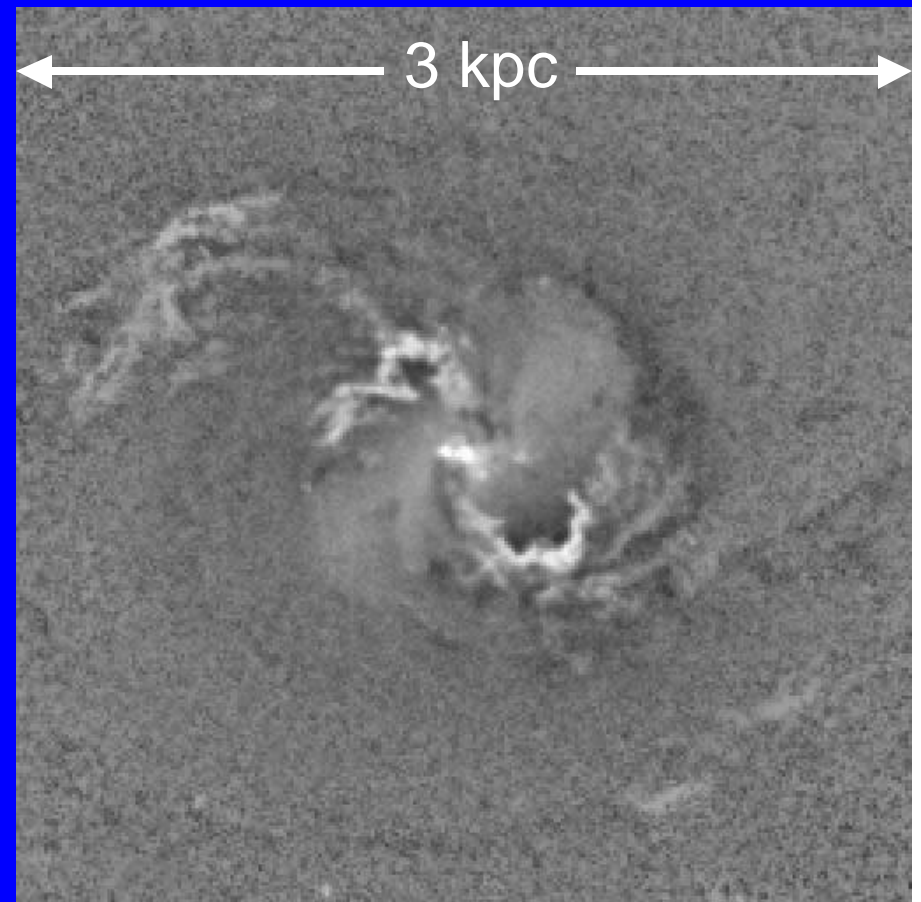
- Resolution needs to reach thermal width ( $\sim 10 \text{ km s}^{-1}$ , or  $R = 30,000$ ) to resolve velocity components
- Large collecting area since these are faint sources
- Must be done in the UV (resonance lines), must be done at low redshift (complex absorption structures in lower luminosity objects)



- Variability and weak fine structure lines probe physical conditions in absorbing gas

# Extended Structures

- AGNs show small-scale structures at the highest spatial resolution
- 8-m diffraction limit yields spatial resolution on scales of several parsecs, where outflow and fueling structures might become apparent
- Evolution of AGN host galaxies out to  $z \approx 1$  can also be probed in rest-frame optical



NGC 3393  
WFPC2 F606W  
Spatial resolution  $\sim 30$  pc

# Formation and Evolution of Galaxies

- Bulges and supermassive black holes are intimately related
- A small percentage of current SMBHs are active, but these are important as tracers and as examples of how the accretion process works
- We need to understand the energetics of the process, both the radiative and kinetic output, to understand galaxy evolution
- ***Understanding galaxy evolution requires understanding black-hole evolution***

# Comment on Space Astronomy Infrastructure

- To make efficient use of very large telescopes, we must off-load essential work that can be done with smaller telescopes
  - A generally recognized principle in ground-based astronomy
  - UV data are too critical to do without
  - We need smaller workhorse facilities as part of the space astronomy infrastructure
  - A 1-m class UV spectroscopic telescope fits into a MDEX funding envelope (~\$200M) and ELV (e.g., Delta II with 10-ft fairing)