Week 9:
Co-evolution of AGN and galaxies

Introduction by S. Lilly

Key points from last week:

Most of what we know about the distant Universe comes from systematic studies of a small number of intensively studied survey fields: total area a few deg^2, c.f. 40,000 deg^2 of the whole sky.

These have a finite volume, leading for instance to fundamental constraints on, for example, the accuracy with which the number density of objects of a given type is known (much worse than Poisson statistics)

Observations span a wide range of wavelength from X-rays (hn ~ keV) to radio cm-wave studies to get information on components of interest.

There is inevitably a trade-off in the amount of information and the number of objects studied. This leads to the Yin and Yang of studies of the population (large numbers, basic information) and of individual objects (more detailed information on a few objects). This is technically driven (field of view of instruments, resolution etc).

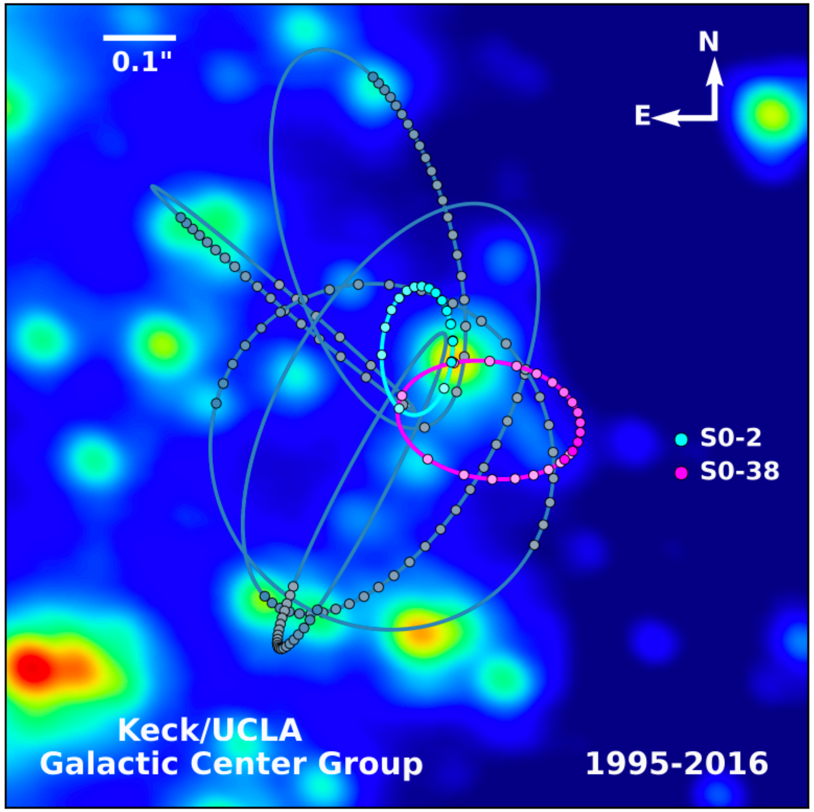
There are some pretty extraordinary pieces of equipment coming down the line (JWST, 39m E-ELT, AKS…) with high price-tags (1-10 G$) which should cpme on line in 2022-2032 decade.

Measuring masses of the black hole at the center of the Milky Way

- There is a "supermassive black hole" (SMBH) at the center of the Galaxy with a mass of $4 \times 10^6 M_\odot$

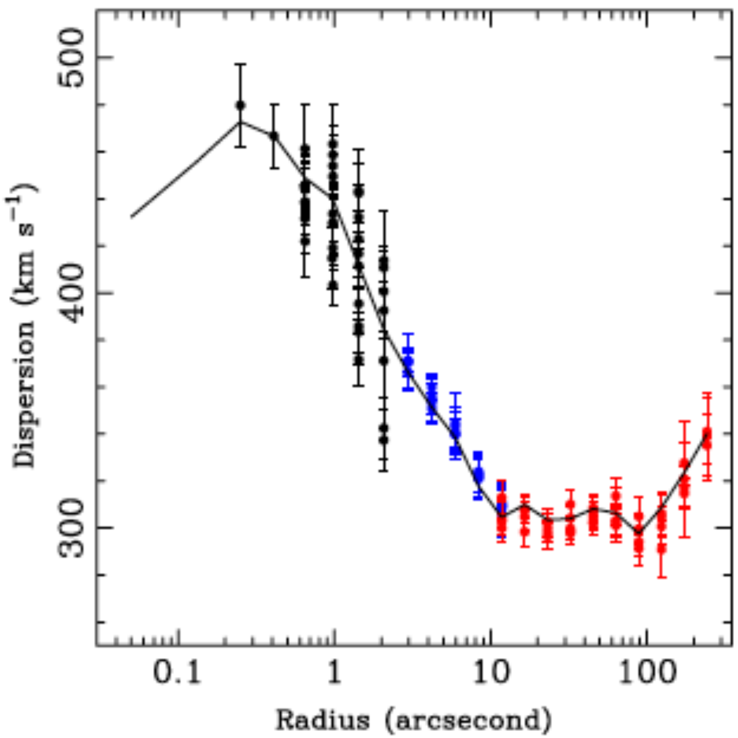
CourtesyKeck/UCLA group

Stellar orbits around SMBH Sagittarius A*

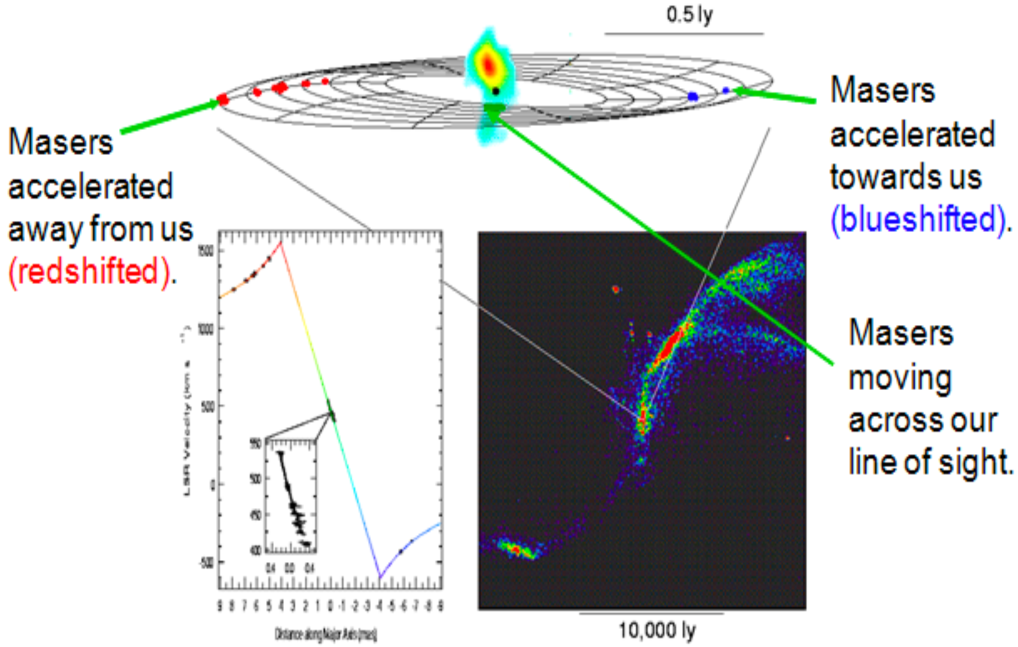


Measuring masses of other black holes

- Stellar dynamics in the center of nearby galaxies
- OH masers in gas disks around the BH



M87: $m_{BH} \sim 6 \times 10^9 M_\odot$



NGC 4258: $m_{BH} \sim 4 \times 10^7 M_\odot$

Indirect measures: e.g. reverberation mapping

Basic idea:

- Broad (emission) lines are produced by high velocity gas clouds, with velocity dispersion σ, around the black hole, in the "Broad Line Region".
- Changes in the brightness of the central accretion disk produce changes in the brightness of emission lines after some time delay, indicating distance to the clouds R_{BLR}
- This then gives M_{BH} (f is an uncertain geometric factor of order unity)

$$M_{BH} = f\frac{R_{BLR}\sigma^2}{G}$$

Needs intensive spectral monitoring (months to years for quasars)

Of order 40 AGN have been measured in this way. Broadly consistent with scaling relations from dynamical measurements (but these generally not in AGN).

Then get "single epoch" scaling relations between M_{BH}, σ and L used on any quasar

$$\log\left(\frac{M_{BH}}{M_{sun}}\right) = 0.38 + 0.43\log\left(\frac{L_{H\alpha}}{10^{42}\,\mathrm{erg.s^{-1}}}\right) + 2.1\log\left(\frac{FWHM_{H\alpha}}{\mathrm{km.s^{-1}}}\right)$$

Questions for today

1. What are the connections between the growth of supermassive black holes in the centers of galaxies ($m_{BH} \sim 10^9\ M_{\odot}$, $r \sim 3\times10^{12}$ m) and the growth of the rest of the galaxy ($m_{star} \sim 10^{11}\ M_{\odot}$, $r \sim 3\text{x}10^{19}$ m)?

2. What are the observed scaling relations in present-day galaxies between m_{BH} and the properties of the surrounding galaxy (such as velocity dispersion σ and stellar mass)?

3. What are the similarities/differences between the overall cosmic evolution of the star-formation history (SFRD) and the history of black hole accretion (BHARD)?

4. What can we learn by comparing the evolution of the galaxy stellar mass function and the AGN luminosity function?