Active Galactic Nuclei and their host galaxies

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BCGS weekend seminar 2015, Bad Honnef

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of Physics and Astronomy

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Slightly biased... :)

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Extragalactic astronomy is a young discipline!

Palaeolithic cave paintings Lascaux
→ Plejades???
Japanese: Subaru
Arabic: الثريا

Nebra sky disk
Germany
Bronze Ages (~1600 BC)

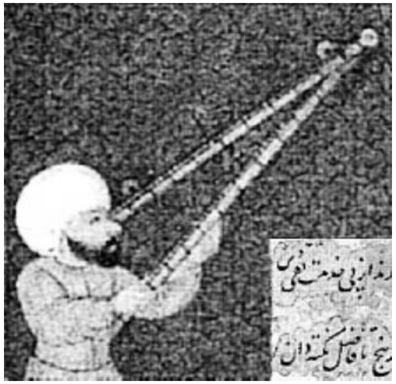
Κλαύδιος Πτολεμαῖος/
Ptolemy (~100-160)

μαθηματική σύνταξις/
المجسطي/
Almagest

Photo credit:
Bbc.co.uk, wikipedia

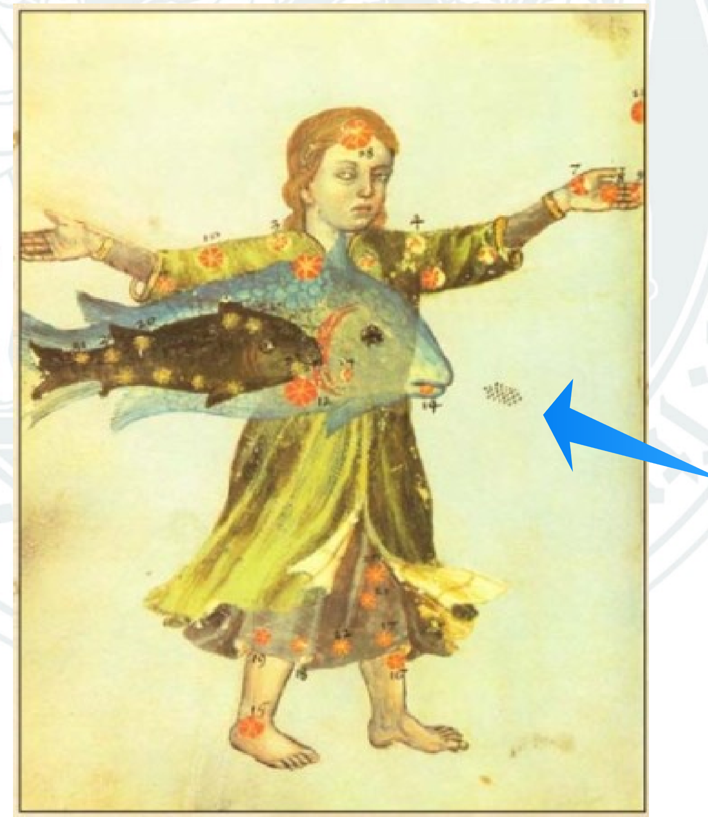
when compared to astronomy in general...

Extragalactic astronomy is a young discipline!



Persian astronomer
Abd Al-Rahman Al-Sufi
عبدالرحمن صوفی
(903-986)

Book of Fixed Stars
كتاب صور الكواكب (~964)
First recorded mention of Large Magellanic Cloud and Andromeda nebula



14th century manuscript depicting Andromeda constellation with Andromeda nebula
Credit: Strohmaier (1984)

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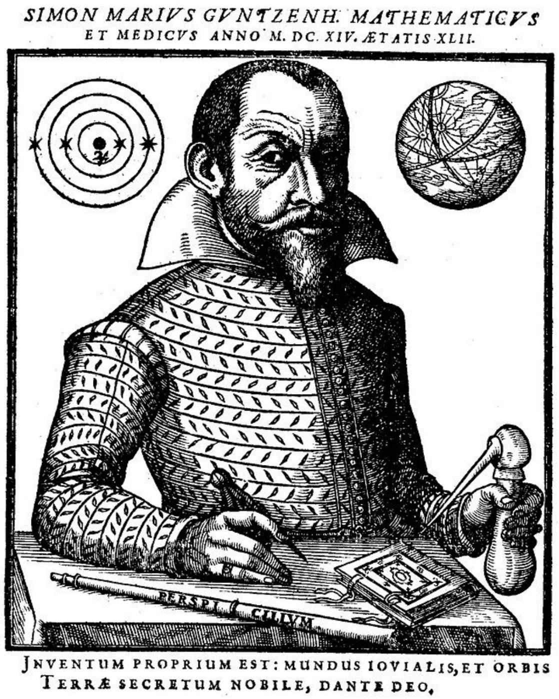
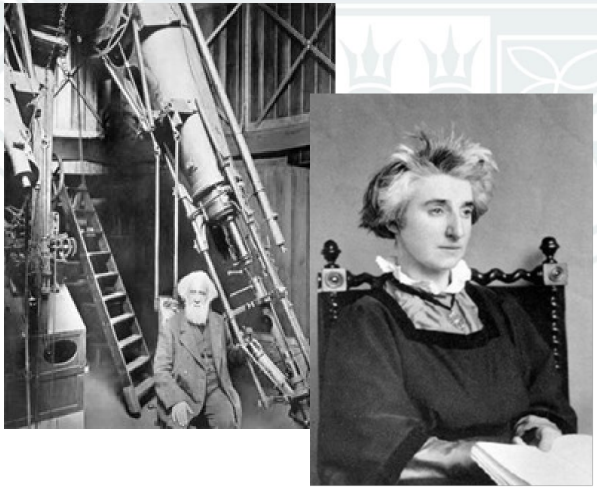


Simon Marius „rediscovered“
Andromeda nebula in 1614

Catalogues of Nebula:
Messier, Herschel, Dreyer
(18th & 19th century)

William Parson (Earl of Rosse):
Sketch of Whirlpool-Galaxy (M51)

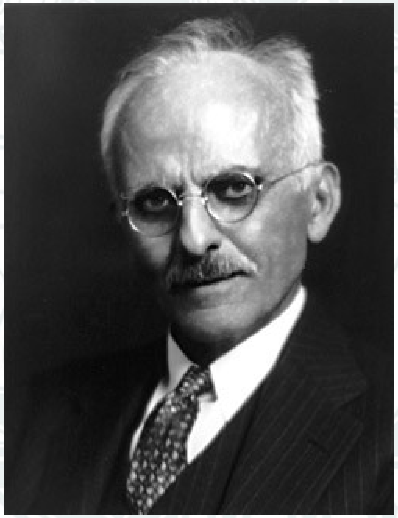


Margaret&William Huggins (1861):
Spectroscopy of stars
→ transition from astronomy to astrophysics

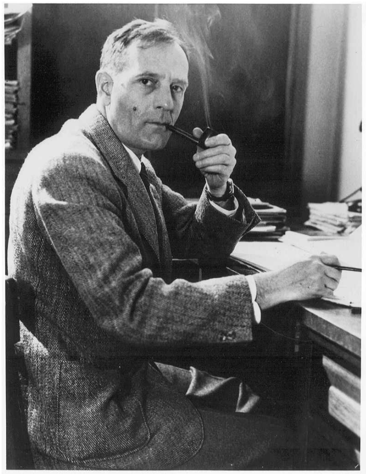
Photo credit: wikipedia, cosmology.carnegiescience.edu

The Great Debate: „The Scale of the Universe“ (1920)

Harlow Shapley (1885-1972):
All celestial objects are part of the Milky Way.



Heber Curtis (1872-1942):
Milky way is just one „Island Universe“ (I. Kant) of many.

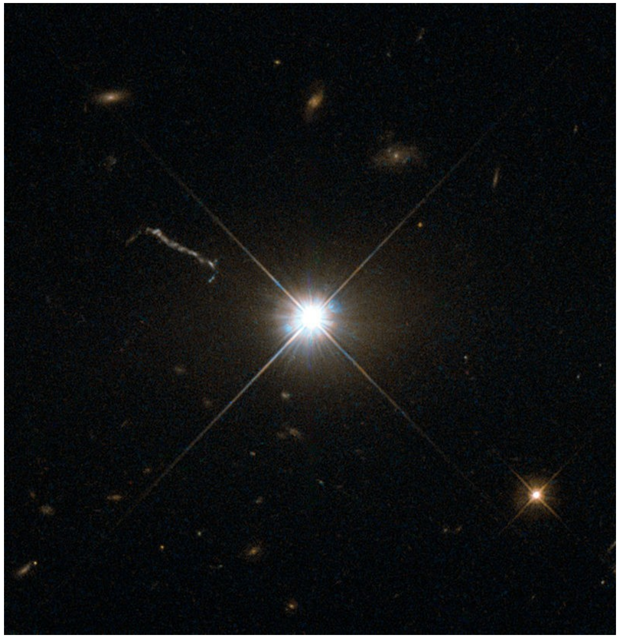


Settled by Edwin Hubble (1889-1953) in 1925:
Determined distances to NGC6822, M33, and M31, they are outside the Milky Way!!

Photo credit: American Institute of Physics Niels Bohr Library, astro.virginia.edu, nmspacemuseum.org

1st Seyfert spectrum: 1908 E.A. Fath, phd thesis (NGC 1068)

C.K. Seyfert discovered class of AGN (1943)



M. Schmidt observes 3C 273 and finds that the redshift is too high for a normal star (1963): first quasar

Photo credit: wikipedia/Hubble space telescopy

Active Galactic Nucleus

Refers to the existence of energetic phenomena in the nuclei, or central regions, of galaxies which cannot be attributed clearly and directly to stars.

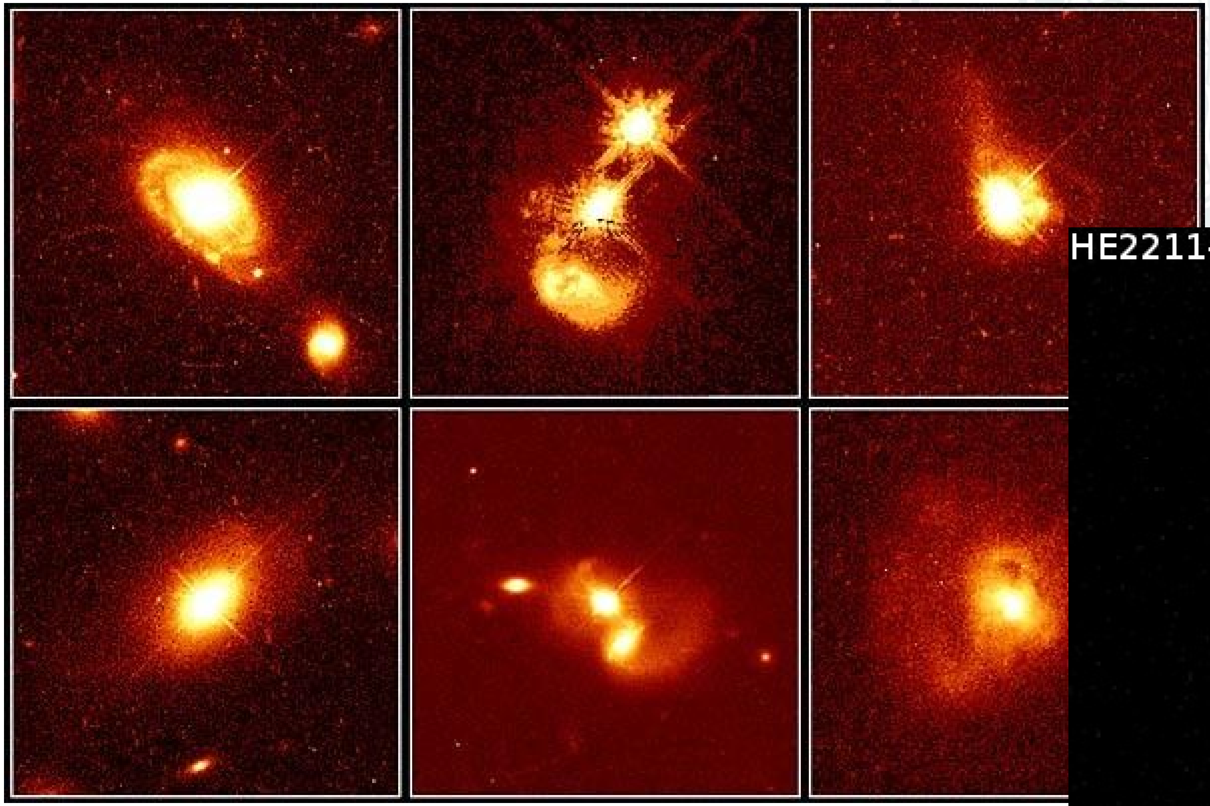
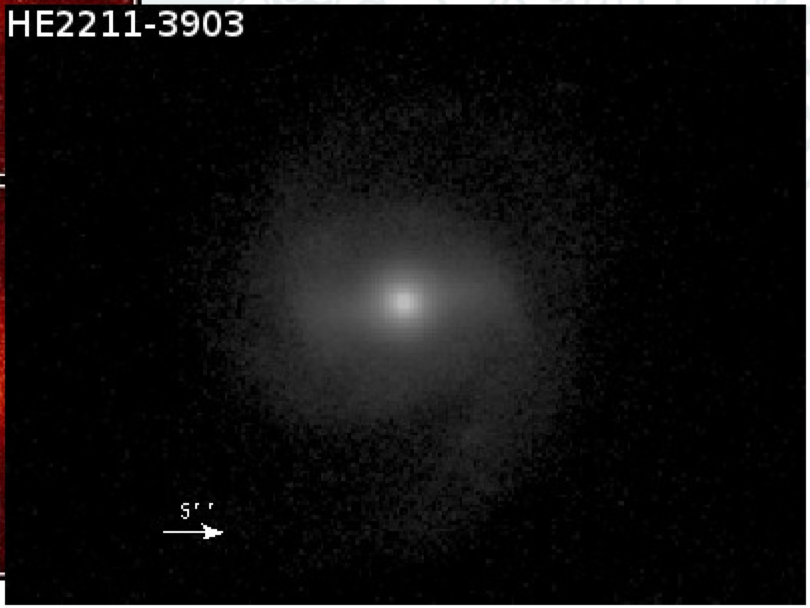


Photo credit: Hubble

Quasi-stellar object = QSO
Quasar = radioloud QSO



Seyfert galaxy

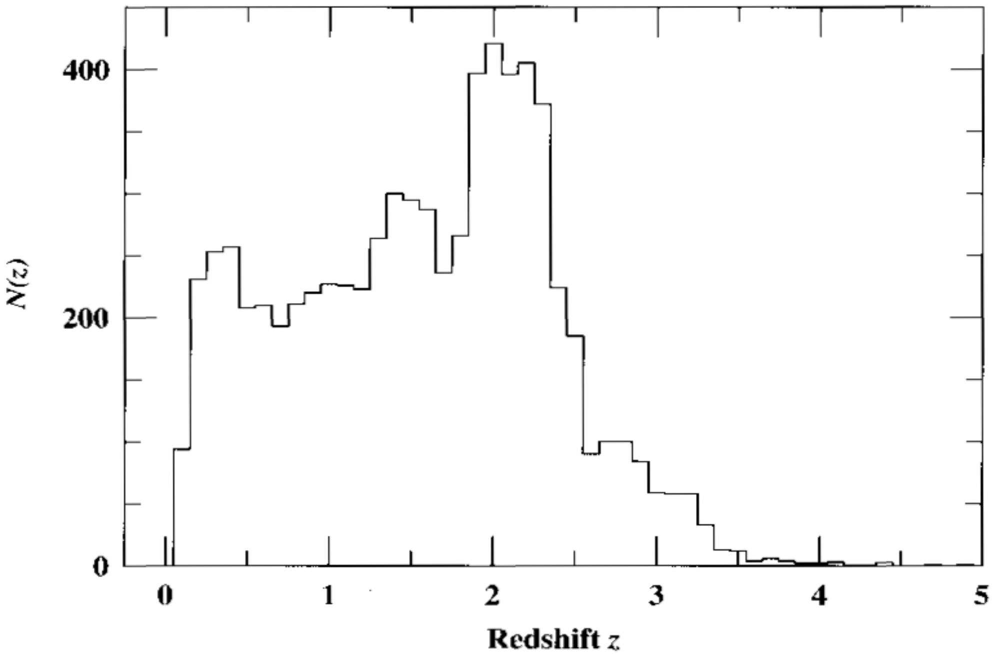
Many quasars are found at high redshift:

$$z = \frac{\lambda - \lambda_0}{\lambda_0} = \frac{\lambda}{\lambda_0} - 1$$

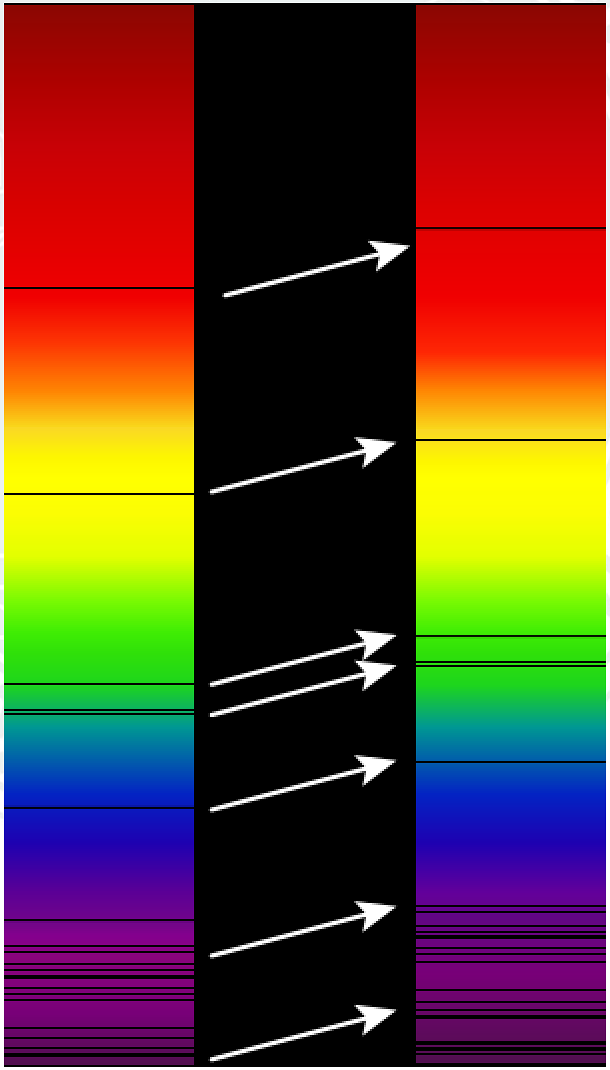
$$d = \frac{cz}{H_0} = 3000\, z h_0^{-1}\, Mpc$$

$$h_0 = H_0 / 100 \;\; km/s/Mpc$$

Higher redshift *z*
= more distant
= at an earlier age of the Universe

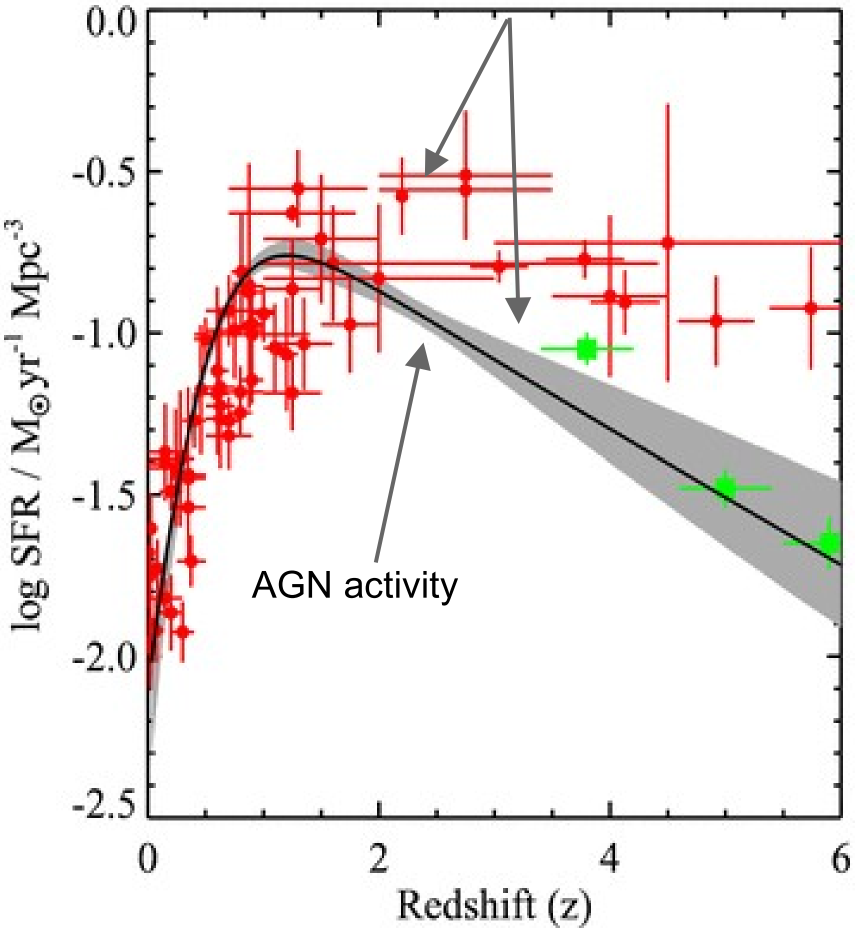


Source: Peterson (1997)



Absorption lines are redshifted compared to those of the Sun.
Source: wikipedia

star formation activity



Aird+ 2010, MNRAS 401, 2531

star formation activity and AGN activity as a function of redshift are correlated!

Both peak at z ~ 1-2!

What powers the AGN???

Lynden-Bell (1969)
Formulae from Peterson (1997)

Conversion of mass into enery with efficiency η

I. $E = \eta M c^2$

II. $(L = dE/dt)$

I. and II. result in: $L = \eta \dot{M} c^2,$ with $\dot{M} = dM/dt$

accretion rate

To fule a typical Seyfert type AGN one needs:

$$\dot{M} = \frac{L}{\eta c^2} \approx 1.8 \times 10^{-3} \left(\frac{L_{44}}{\eta} \right) M_{\odot}\ \mathrm{yr}^{-1}.$$

Accretion efficiency

The potential energy of the mass m at a distance r to the central source with mass M is given by:

$$U = GMm/r.$$

From

$$L \approx \frac{dU}{dt} = \frac{GM}{r}\frac{dm}{dt} = \frac{GM\dot{M}}{r}$$

and

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

one finds:

$$\eta \propto M/r$$

The compactness of the mass distribution is essential for the efficieny of the accretion process

Compactness is maximum for black holes.
Fore these objects the efficiency η is also maximum.

Accretion efficiency

Compactness is maximum for black holes.
Fore these objects the efficiency η is also maximum.

Characteristic scale for the object:

$$\eta \propto M/r$$

$$R_S = \frac{2GM}{c^2}$$

$$\approx 3 \times 10^{13} M_8 \text{ cm}$$

$$\approx 10^{-2} M_8 \text{ light days}$$

M_8 is the black hole mass in units of $10^8 M_\odot$.

Typical accretion rate

Variability time scale in the UV indicates that most of the mass m originates from within $5R_S$

$$U = \frac{GMm}{5R_S} = \frac{GMm}{10GM/c^2} = 0.1mc^2$$

$\eta \approx 0.1$ efficiency to produce the observed luminisity through accretion

$\eta = 0.007$ efficiency of nuclearsynthesis processes

$$L_{QSO} \approx 10^{46} \text{ ergs s}^{-1}$$

Angular momentum

Specific angular momentum $|\mathbf{L}|/m = (GMr)^{1/2}$

From an orbit comparable to that of the sun:

$$M = 10^{11}\ M_\odot \text{ and } r = 10\,\text{kpc}.$$

To within:

$$\sim 0.01\,\text{pc of a } 10^7\ M_\odot \text{ central black hole}$$

The angular momentum of an object has to decrease by a factor of

$$(10^7 \times 0.01\,\text{pc}/10^{11} \times 10^4\,\text{pc})^{1/2} \approx 10^{-5}$$

It has to lose 99.999% of its initial angular momentum!!

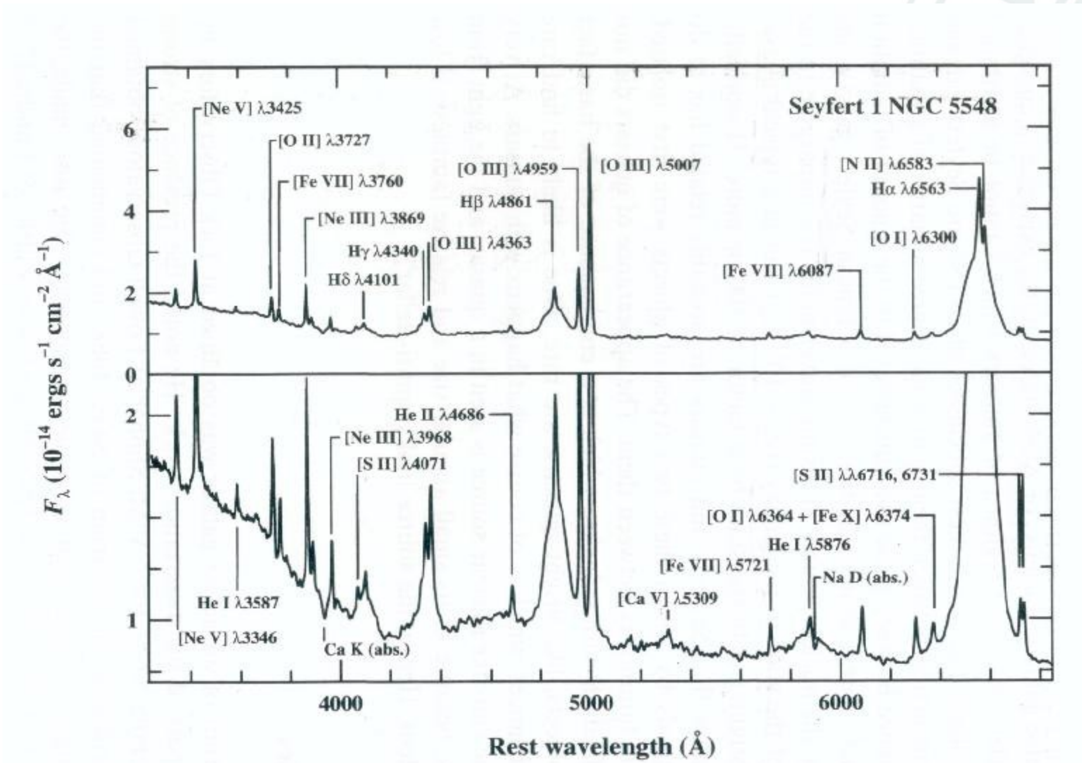
Angular momentum

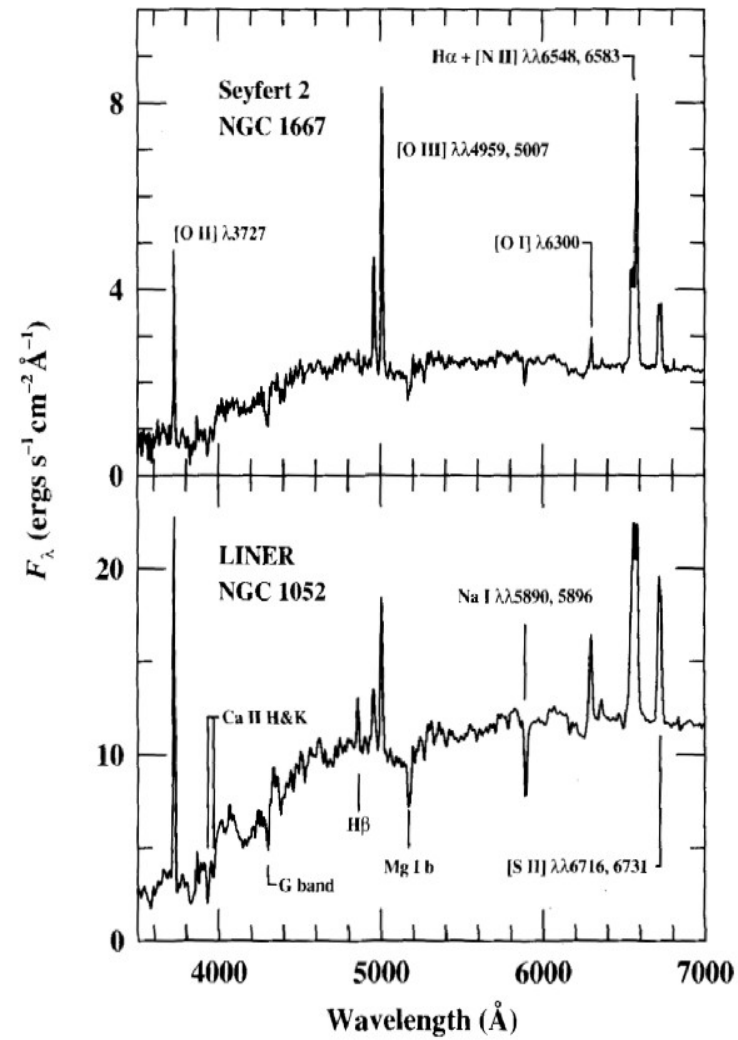
What removes angular momentum???

- Galaxy-galaxy interaction (major merger/minor merger)
- Disk instabilities (e.g. stellar bars)
- Star formation/Stellar winds??

→ Relation of AGN activity and host galaxy morphology!!!

How do the spectra look like?

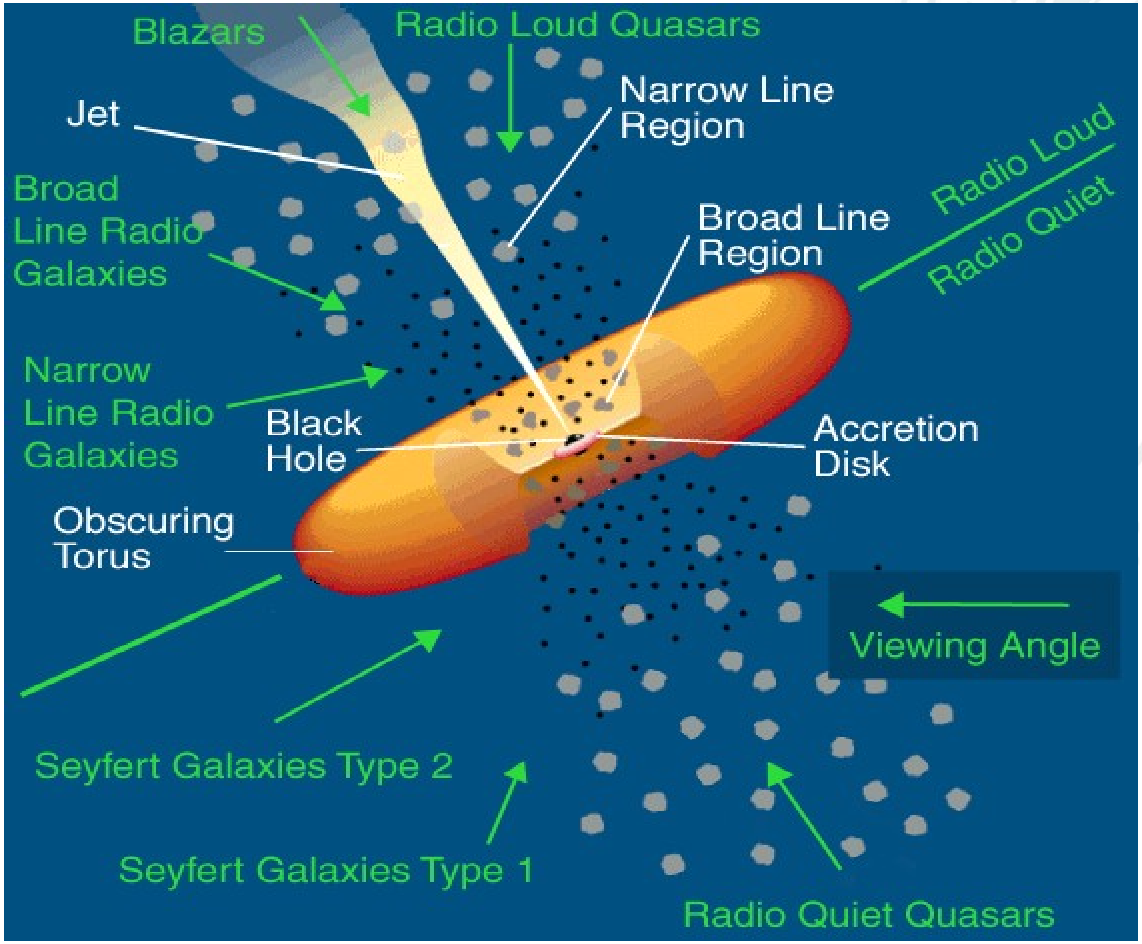




Spectral classification:
Seyfert 2: only „narrow“ components (200-900km/s)
Seyfert 1: additional „broad“ components (1000-10000km/s of permitted lines

Credit: Peterson (1997)

The Unified Model of AGN



Urry&Padovani (1995)

BLR:
r ~ 10 light days
FWHM ~ 5000 km/s
M ~ 10^{-3} M_{sun}

$M_{BH}=rv^2/G=10^7$-10^8 M_{sun}

Broad H-recombination lines
CIII], CIV, HeII
density: $n=10^{11}$ cm^{-3}

NLR:
r ~ 10-100 pc
FWHM ~ 200 - 900 km/s
M ~ 10^5 M_{sun}

forbidden lines
[OII], [OIII],[NII] ...
ionization cones
density: $n=10^3$-10^6 cm^{-3}

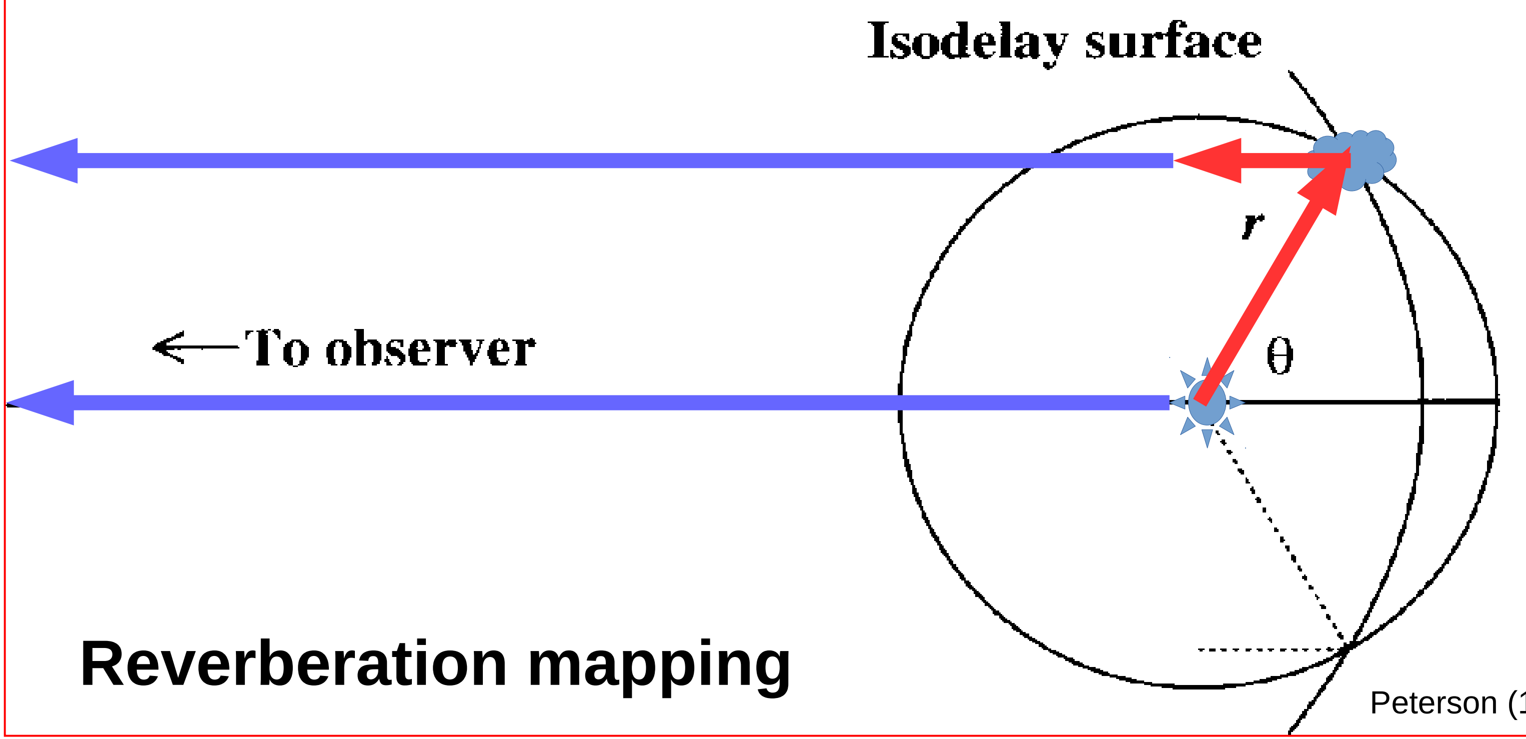
How to determine black hole mass?

Virial theorem:

$$M_{\rm BH} = f\,\frac{RV^2}{G}$$

R – radius of the BLR
V – characteristic velocity
(e.g. vel dispersion)

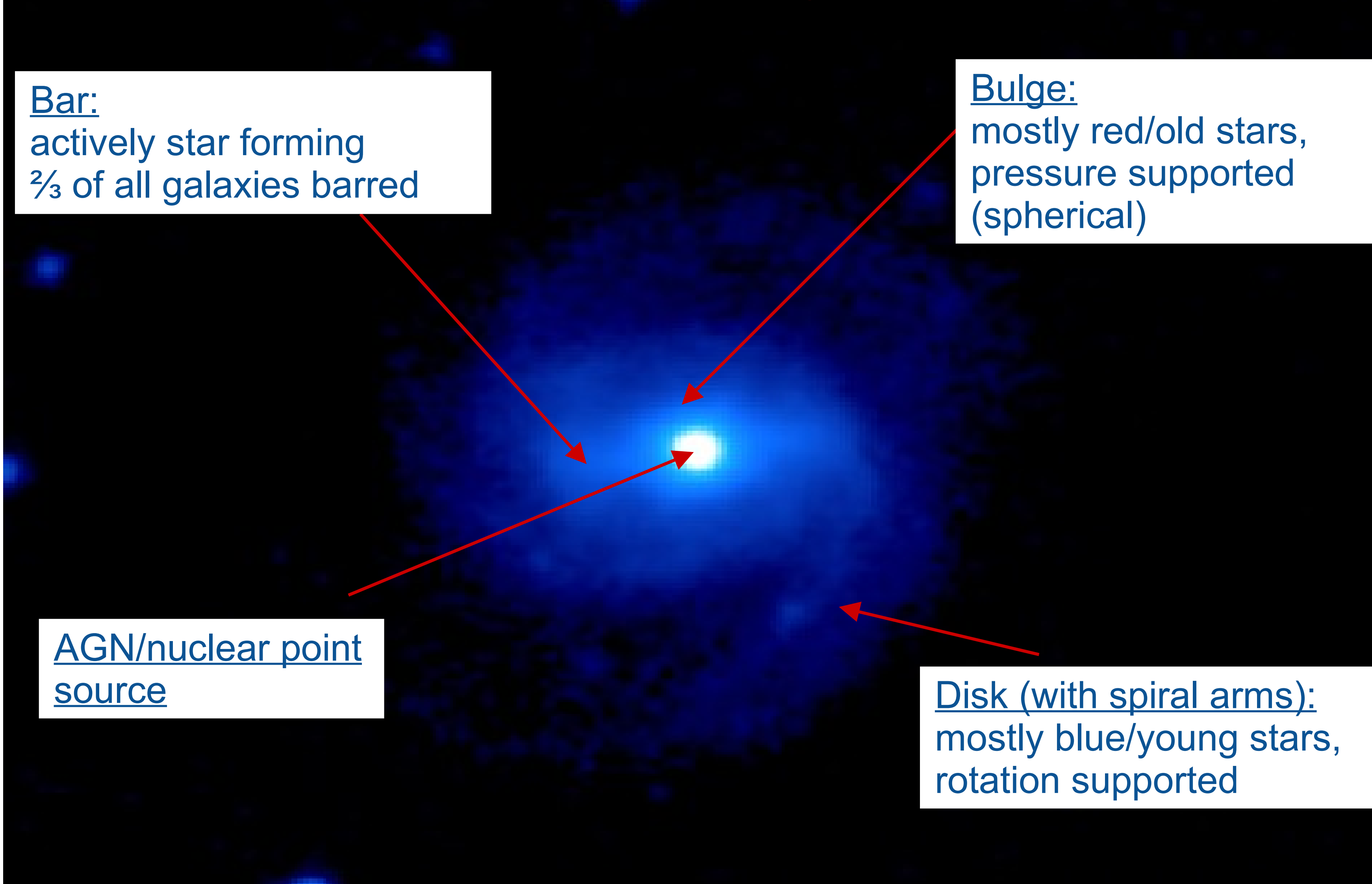
G – gravitational constant
f – scale factor (geometry of BLR)



Reverberation mapping

Peterson (1997)

Components of galaxies

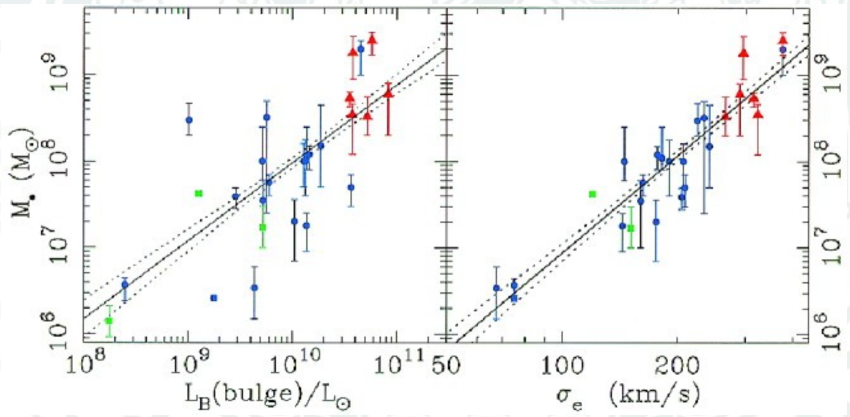


K-band image of the low-luminosity QSO (LLQSO) HE 2211-3903

BH - host galaxy (bulge) relations

Relations between BH mass and *bulge* properties have been found in the last 15 years:

- mass M_*
- velocity dispersion
- luminosity (optical, NIR)



Gebhardt et al. 2000

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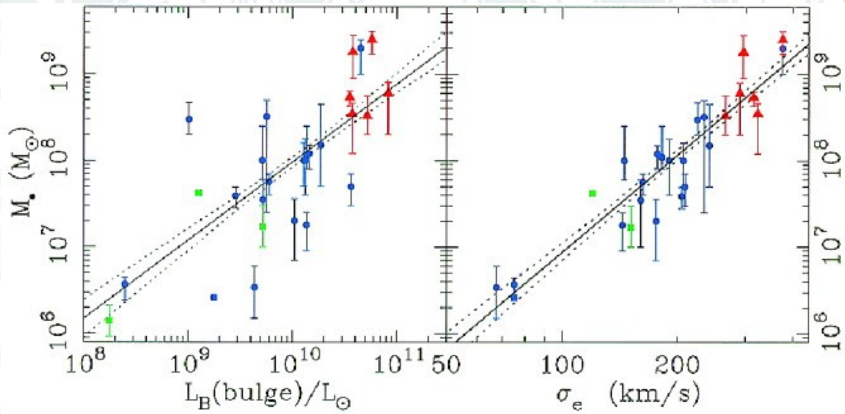


Gebhardt et al. 2000

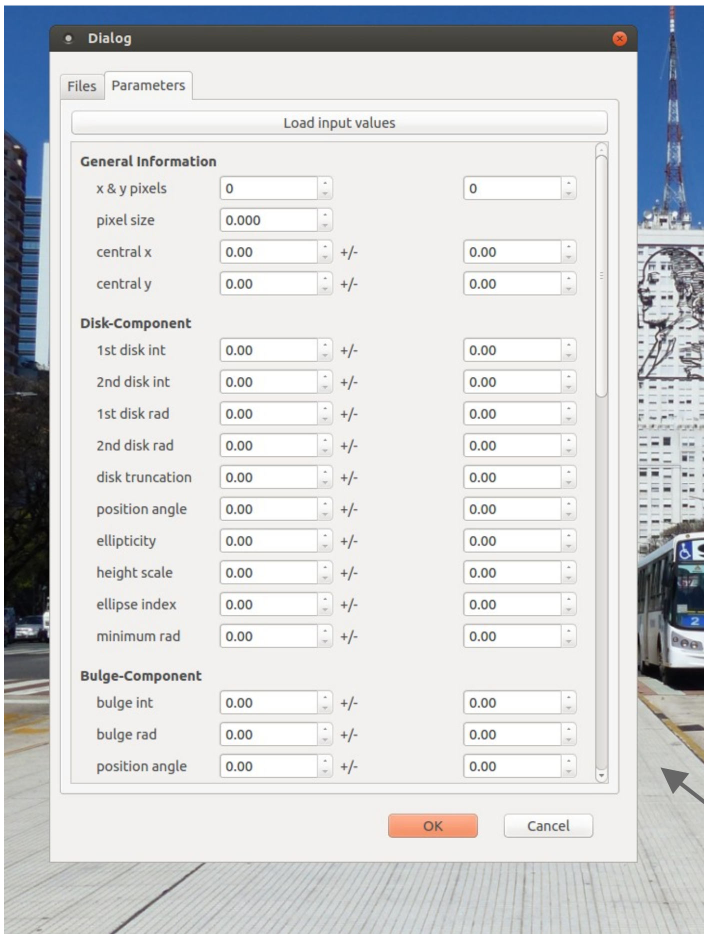
But: $M_{BH}/M_{bulge} \sim 0.1\%$

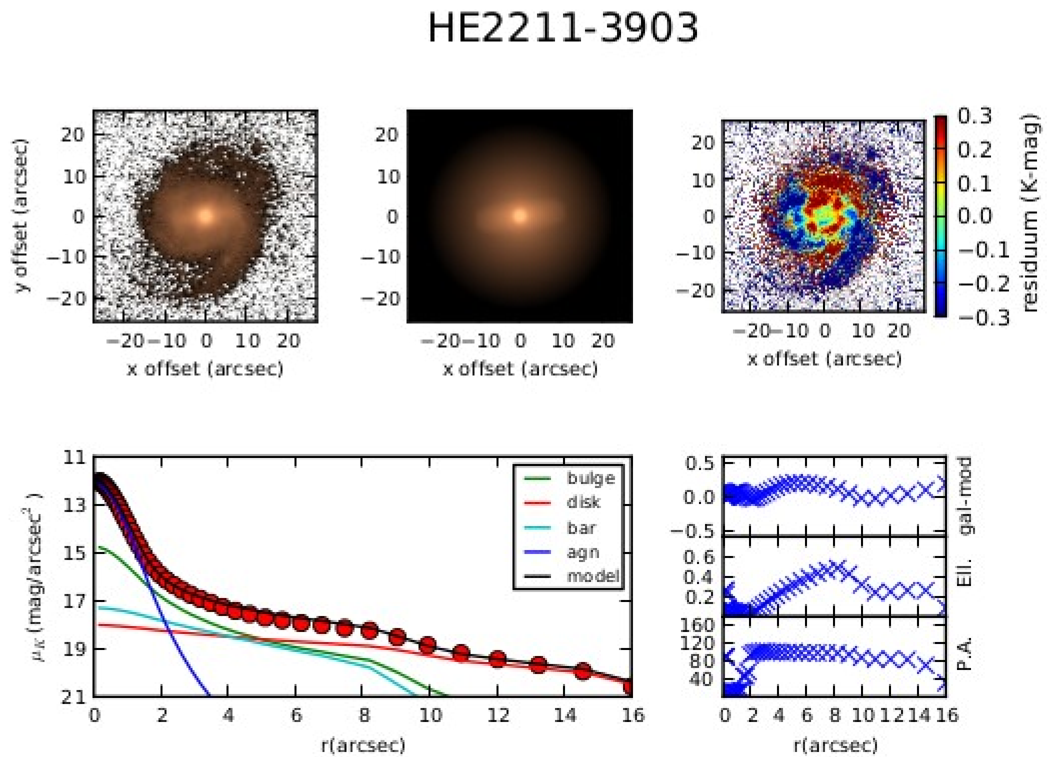
This relation has not been expected!

→ SMBH - host galaxy coevolution ?!

Decomposition of galaxies

- We use “BUlge/Disk Decomposition Analysis (BUDDA)” by Dimitri Gadotti (ESO)
- Decomposition into Bulge, Disk, Bar, AGN according to their light profiles
- Results in scaling parameters and fluxes/luminosities of the components (particularly: bulge luminosity!)





BUDDA fit of HE 2211-3903

graphical interface of the BUDDA wrapper
(BUDDA: D. Gadotti, wrapper: G. Busch/J. Zuther)

Near-infrared astronomy

Near-infrared (NIR): 0.78 - 3μm

Advantages:

- ❖ traces stellar mass better (less affected by young stars)
- ❖ less affected by extinction

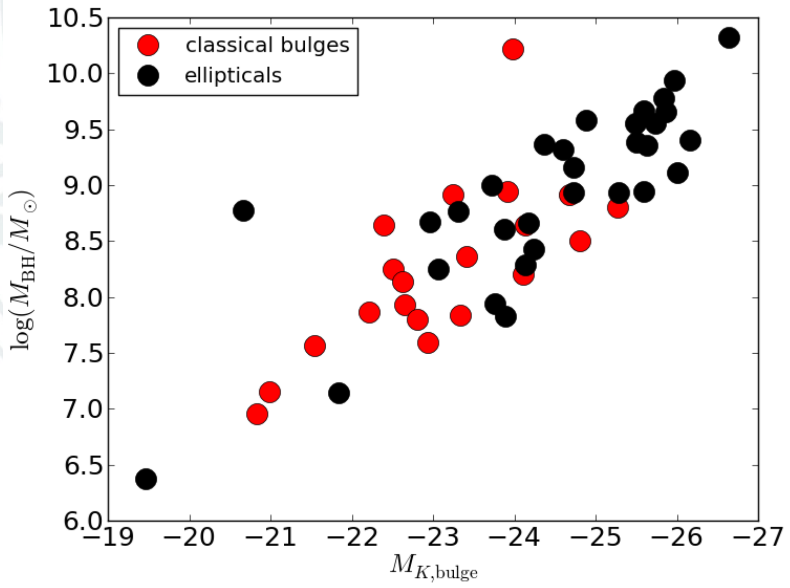
Example: Galactic Center

optical: 30 mag extinction (factor of ~5×10^{10})

NIR *K*-band: 2-3 mag extinction (factor of ~10)

The M_{BH}-L_{bulge} relation of active galaxies

bulge magnitude and black hole mass are correlated!



Data collected by:
Kormendy&Ho 2013, ARA&A 51, 511.

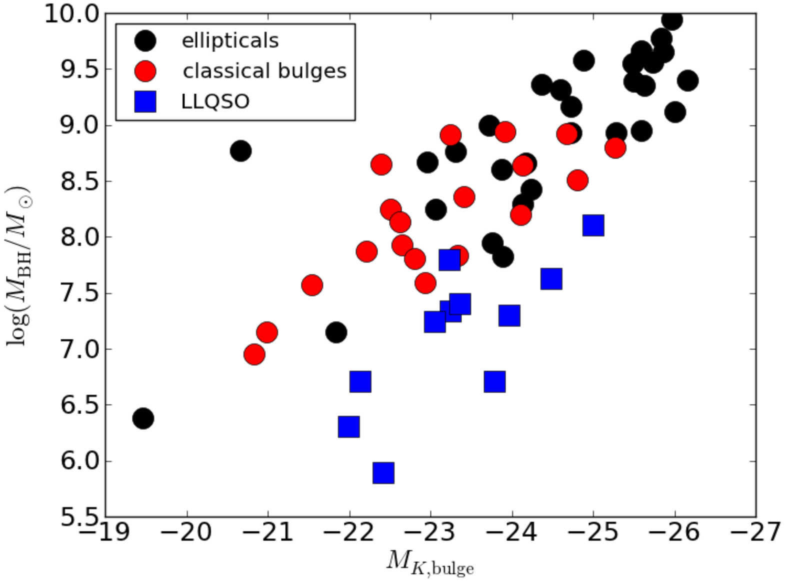
The M_{BH}-L_{bulge} relation of active galaxies

bulge magnitude and black hole mass are correlated!

LLQSOs are under the relation!

In agreement with studies in the optical:
e.g. Nelson+04, Kim+08, Bennert+11

But first time observed in the near-infrared.



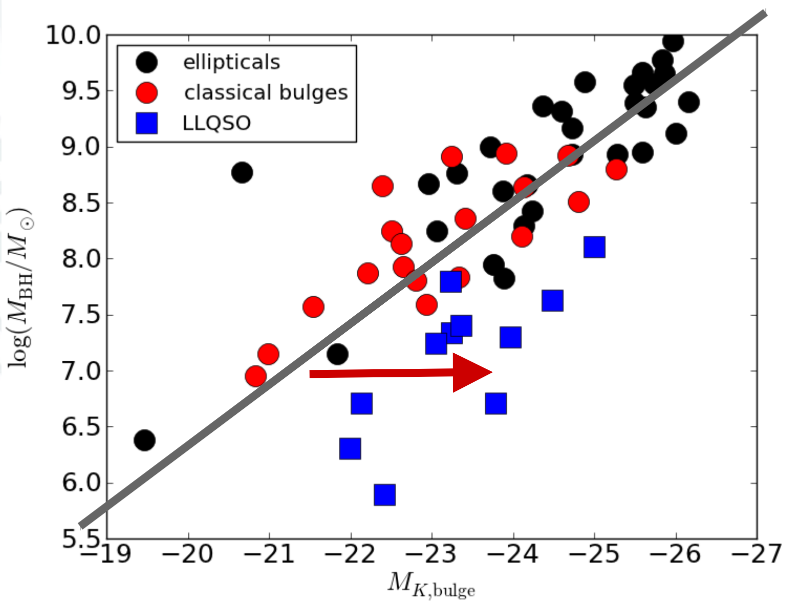
Busch et al. 2014, A&A 561, A140

The M_{BH}-L_{bulge} relation of active galaxies

LLQSOs are under the relation!

Possible reasons:

- ❖ Overluminous bulges (through star formation?)



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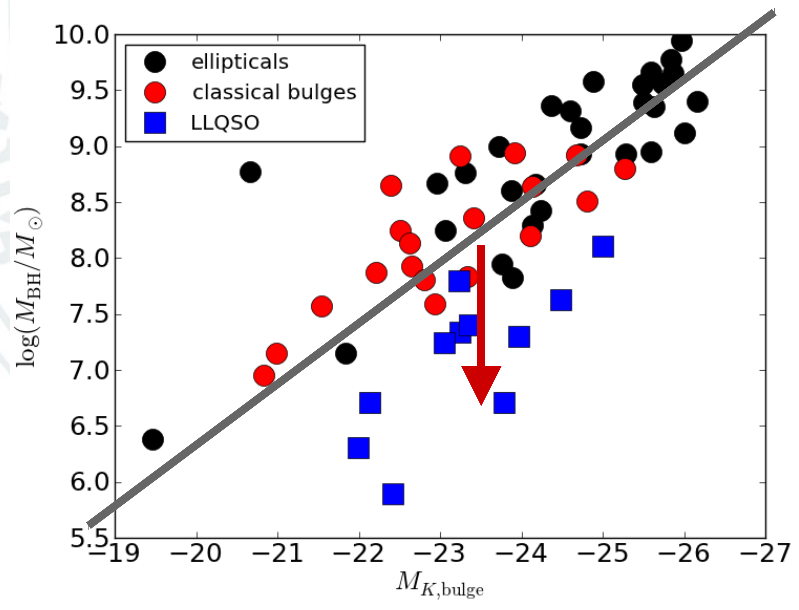

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The M_{BH}-L_{bulge} relation of active galaxies

LLQSOs are under the relation!

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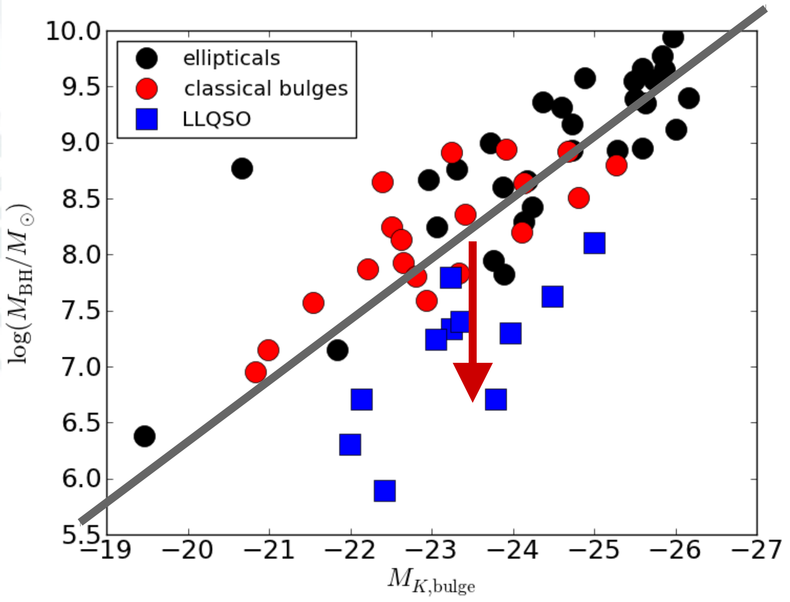
Implications for understanding of black hole - bulge coevolution!!



Busch et al. 2014, A&A 561, A140

Summary and open questions

AGN belong to the most extreme objects in the Universe

Accretion onto supermassive black hole produces vast amount of energy!

→ Where does the mass come from??

→ How does it lose angular momentum??

AGN play an important role in galaxy evolution

There exist strong correlations between BH mass and host galaxy properties!

→ What drives the co-evolution of BH and host galaxy??

→ What was first: BH or host galaxy??

Nuclear activity influences host also today

Central regions of active galaxies contain younger stars than inactive counterparts!

→ What are conditions of circumnuclear star formation??

→ Does/How does the AGN quench star formation??