Black hole – galaxy co-evolution
Making a case for paradigm change

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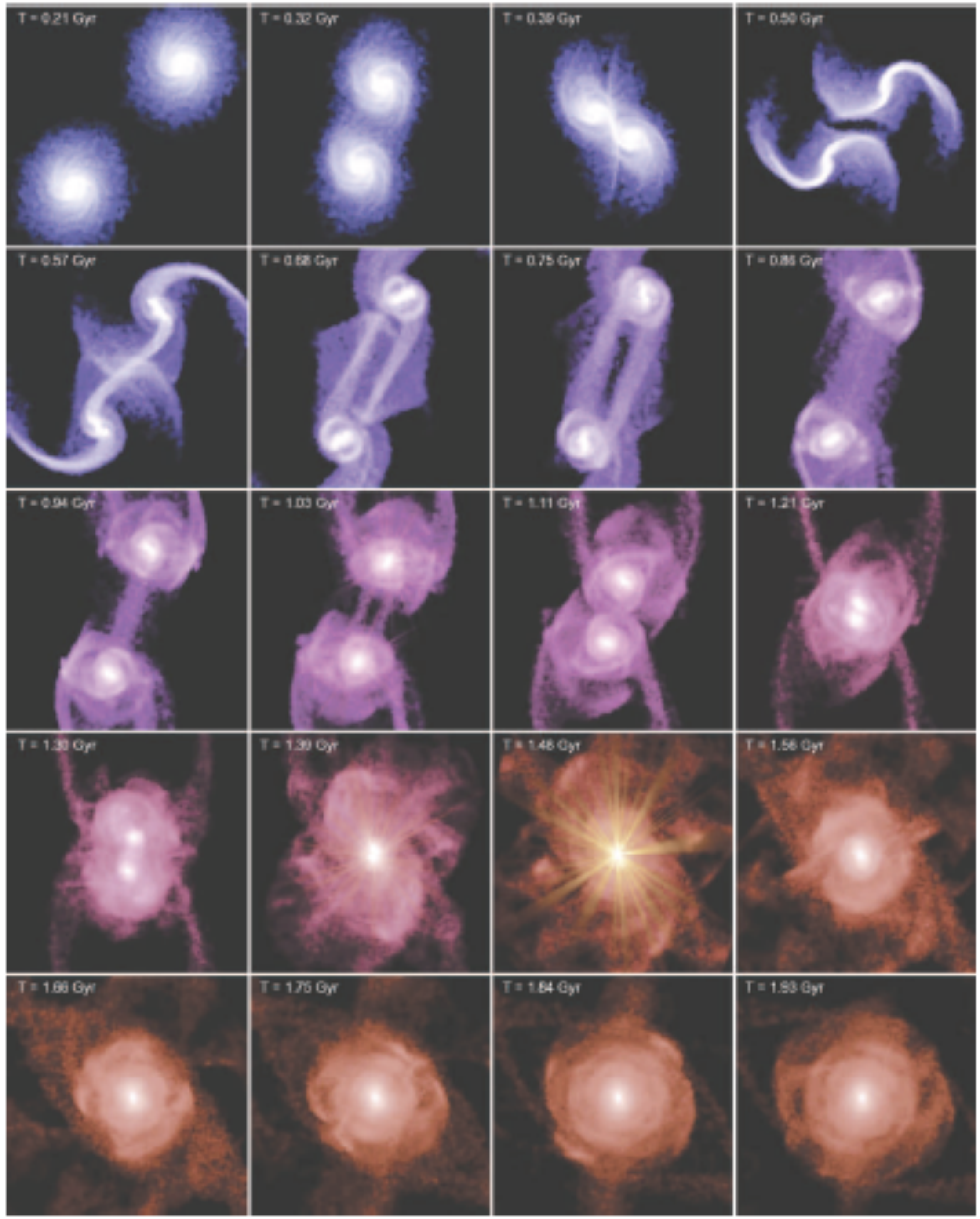
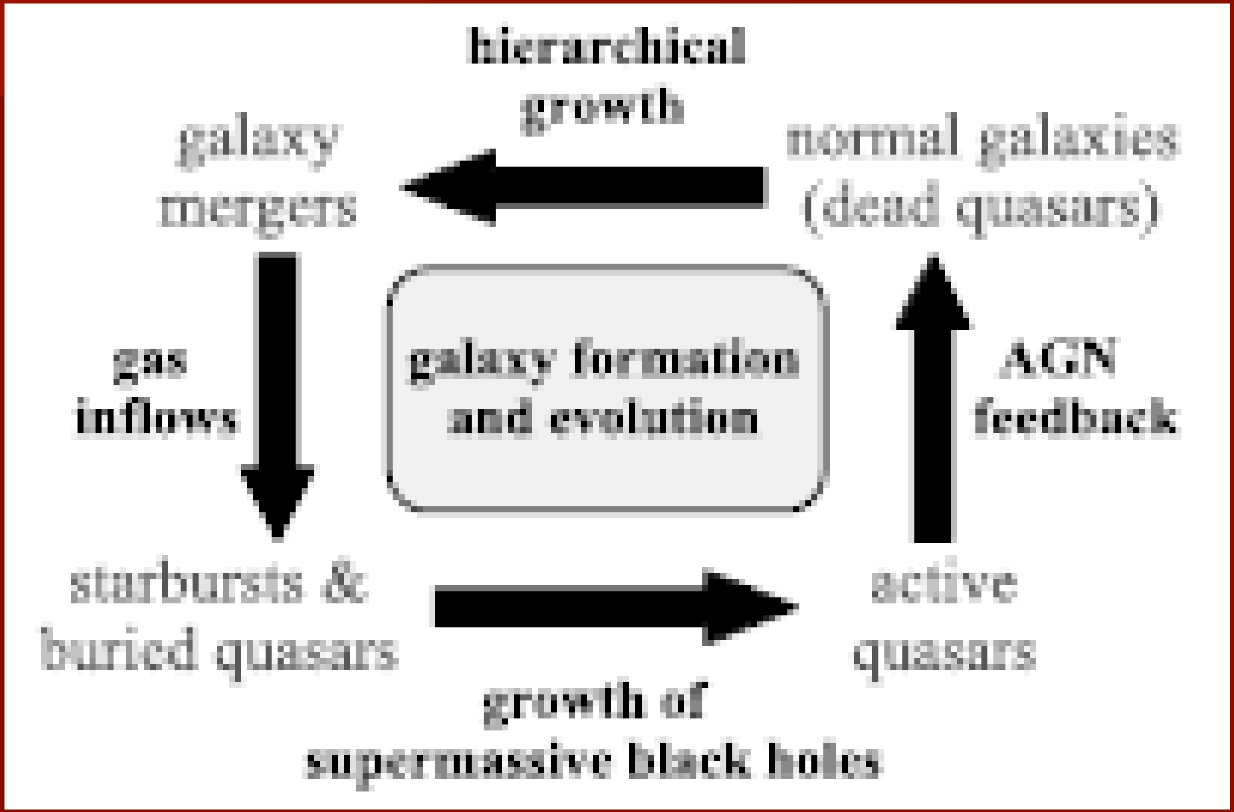
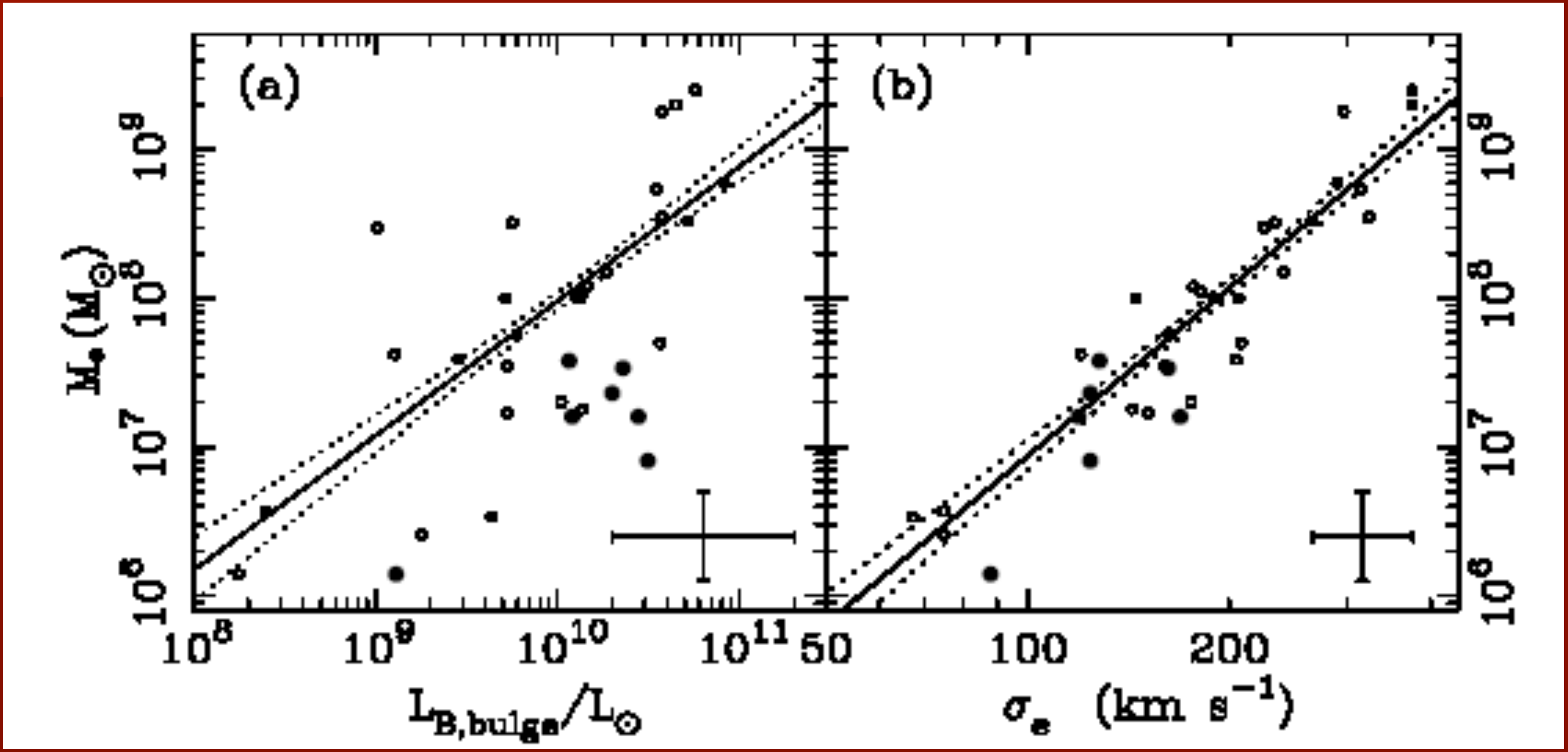

T = 0.21 Gyr
T = 0.32 Gyr
T = 0.39 Gyr
T = 0.50 Gyr
T = 0.57 Gyr
T = 0.68 Gyr
T = 0.75 Gyr
T = 0.86 Gyr
T = 0.94 Gyr
T = 1.03 Gyr
T = 1.11 Gyr
T = 1.21 Gyr
T = 1.30 Gyr
T = 1.39 Gyr
T = 1.48 Gyr
T = 1.56 Gyr
T = 1.66 Gyr
T = 1.75 Gyr
T = 1.84 Gyr
T = 1.93 Gyr

Hopkins+06

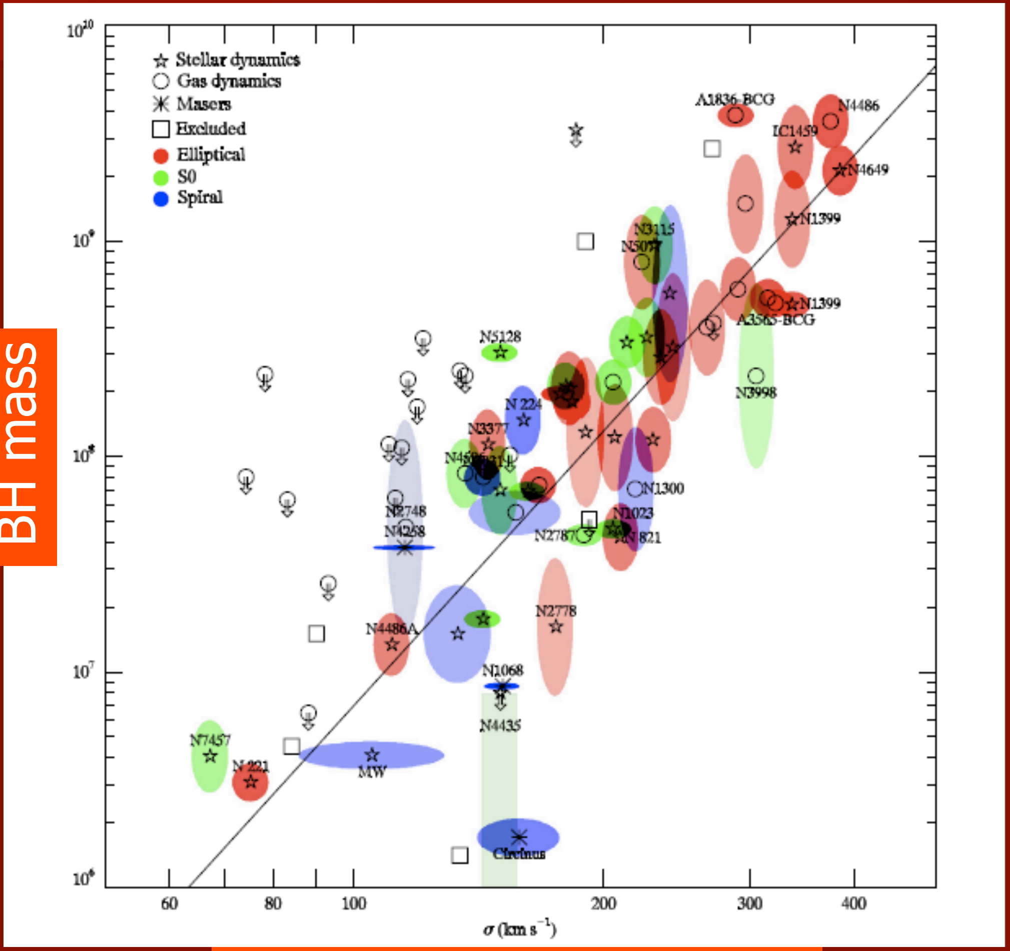

hierarchical
growth
galaxy
mergers
normal galaxies
(dead quasars)
gas
inflows
galaxy formation
and evolution
AGN
feedback
starbursts &
buried quasars
active
quasars
growth of
supermassive black holes

Black hole—Bulge relations



Gebhardt et al 2000, Ferrarese & Merritt 2000

Deviations from the BH—bulge relations



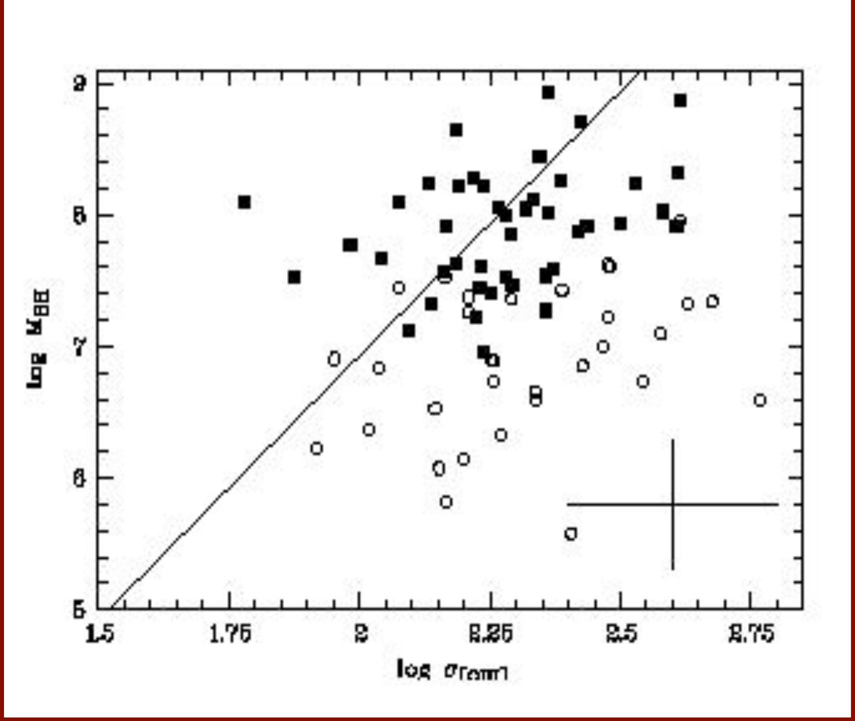
BH mass

Bulge velocity dispersion

Gultekin et al. 2009

Locus of NLS1s on the M_{BH}--σ plane

- The M_{BH}--σ for normal galaxies and broad line Seyfert 1s is <u>not</u> followed by the narrow line Seyfert 1 galaxies.



Mathur et al. 2001

Grupe & Mathur 2004

Mathur & Grupe 2005a,b

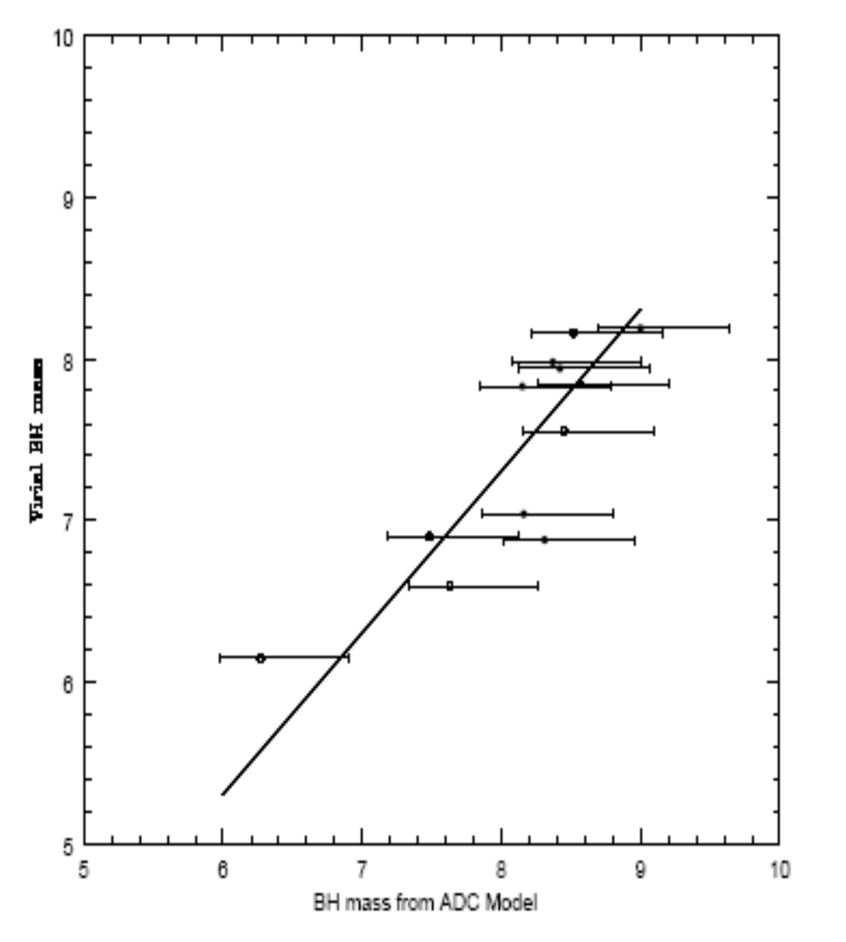
Interpretation

- Black holes grow during accretion phase in well formed bulges.
- Accretion rate highest in the beginning and dwindles as the time goes by.
- BHs approach the M_{BH}--σ relation towards the late stages of active life.

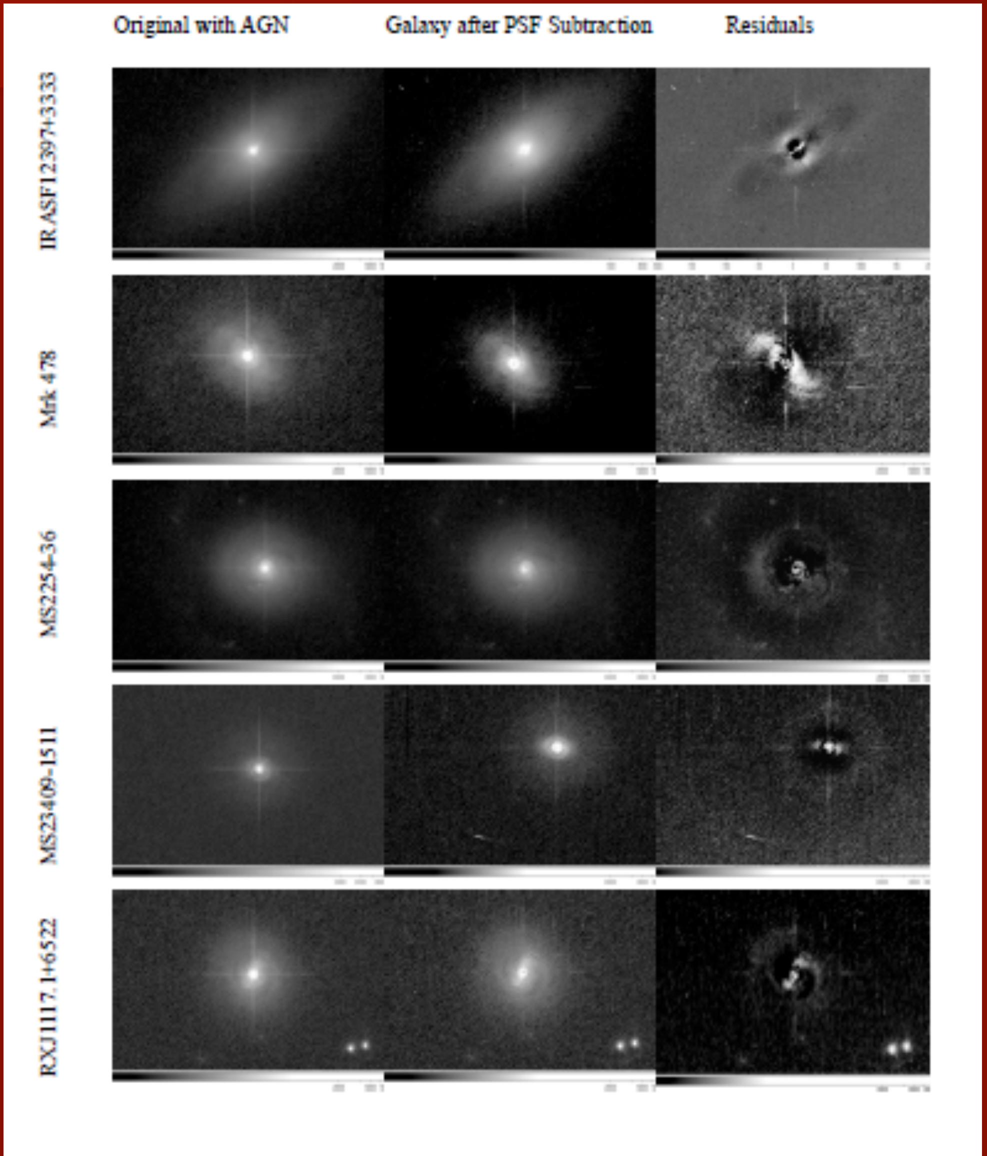
Mathur 2000

Independent methods of BH mass determination give same results

- BH mass from fits to SEDs. (Mathur et al 2001)
- BH mass from power spectrum analysis (Czerny et al 2001)

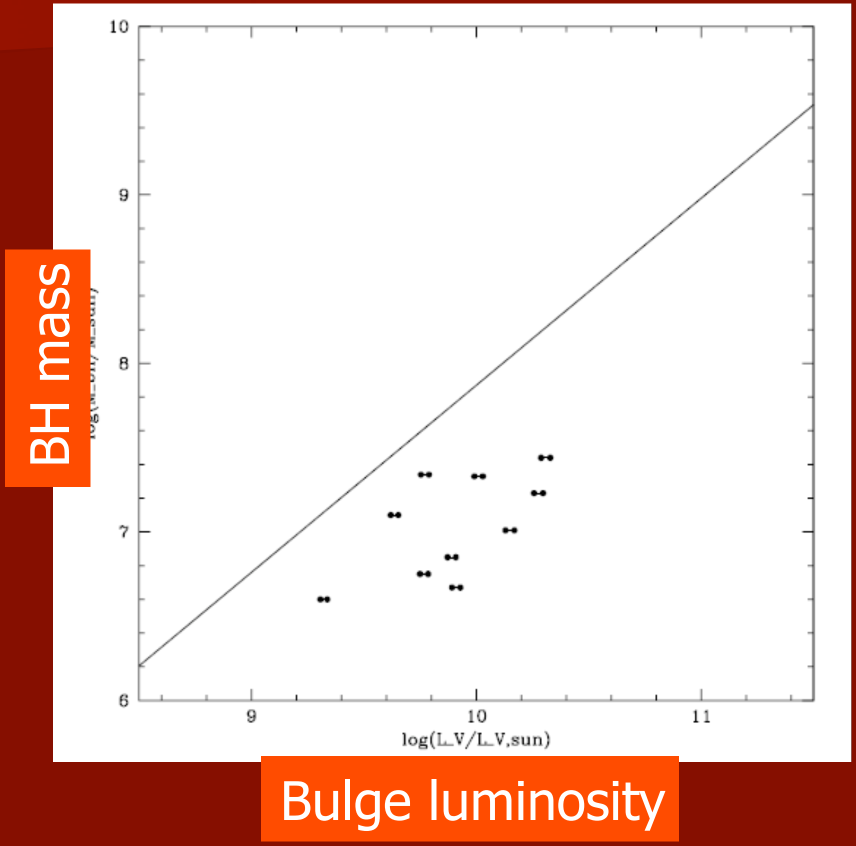


HST/ACS observations of NLS1s



Mathur et al. 2011

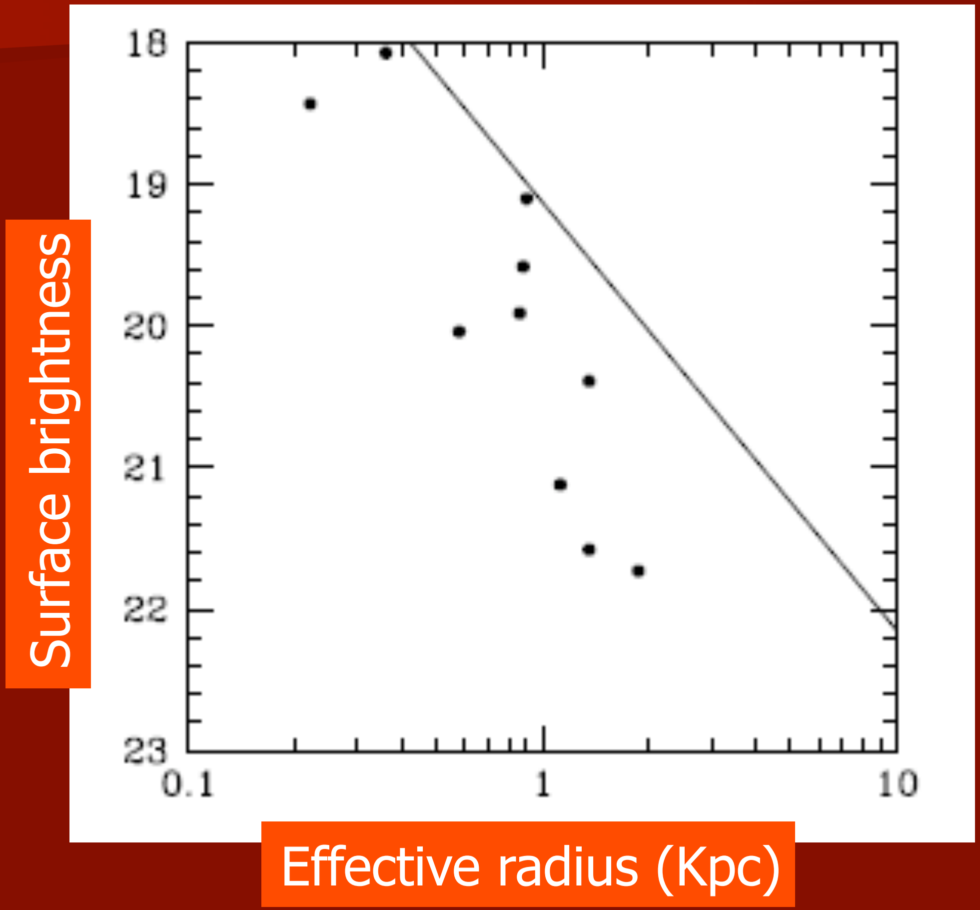
NLS1s lie below the "Magorrian" relation: a robust result



Mathur et al 2011

NLS1s also lie off the fundamental plane of AGNs (Barway & Kembhavi; Graham et al.)

Host galaxies have pseudobulges



---still in formation process

--- blue, starforming

---as such young

- Pseudobulges do not follow the fundamental plane of galaxies
- **Pseudobulges form & grow by secular processes**

Is bulge crucial for the existence of a BH

Supermassive BHs in Bulge-less galaxies

1. NGC 4561, an Sdm galaxy

2. NGC 3184, an Scd galaxy

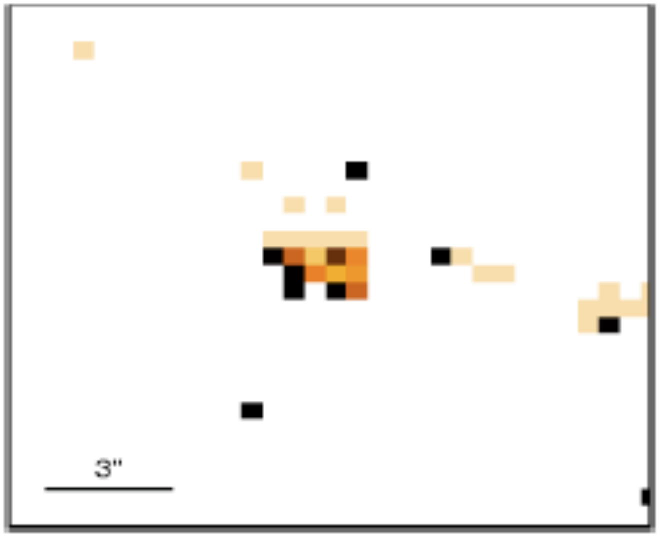
3. NGC 4713, an Sd galaxy

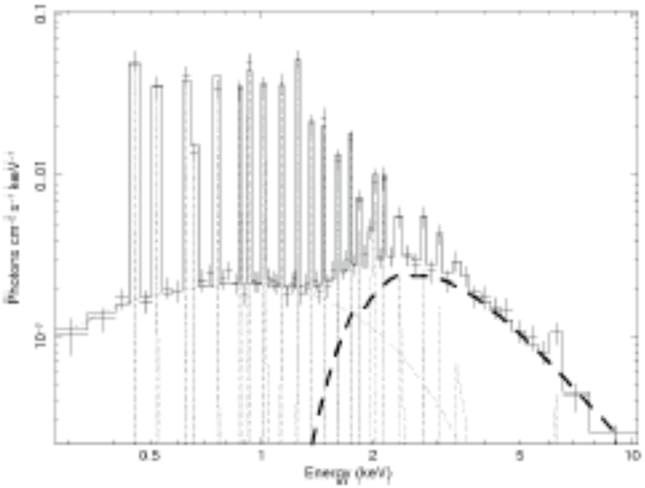
4. M 101, an Scd galaxy

Ghosh, Mathur et al.

Chandra image

XMM spectrum



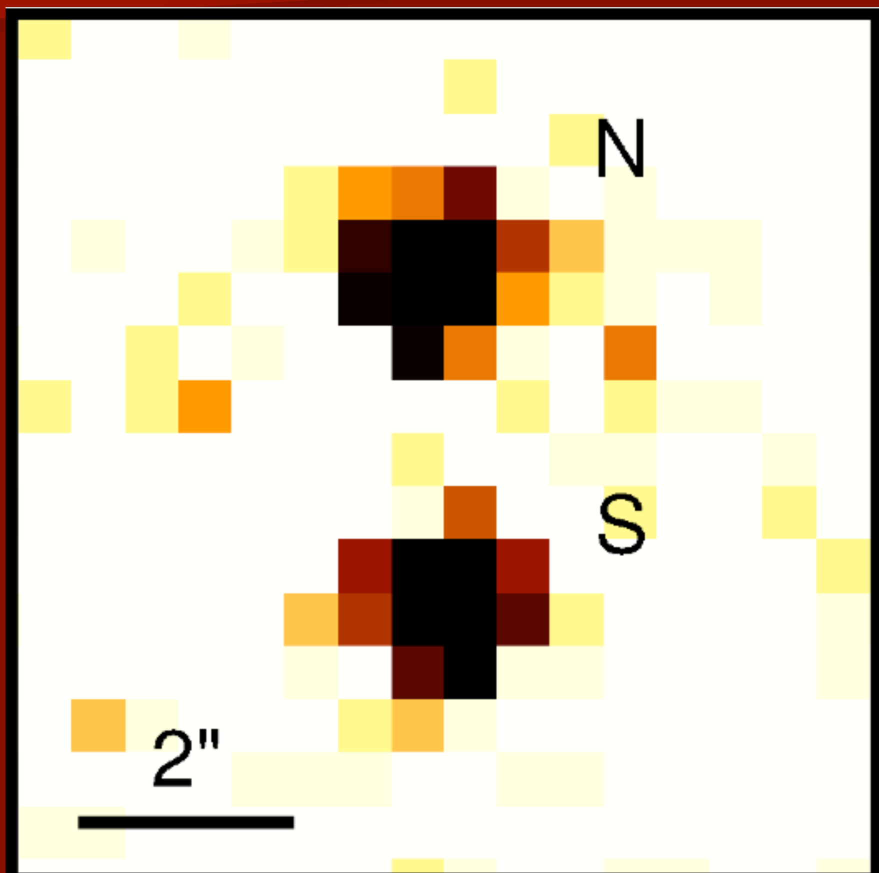


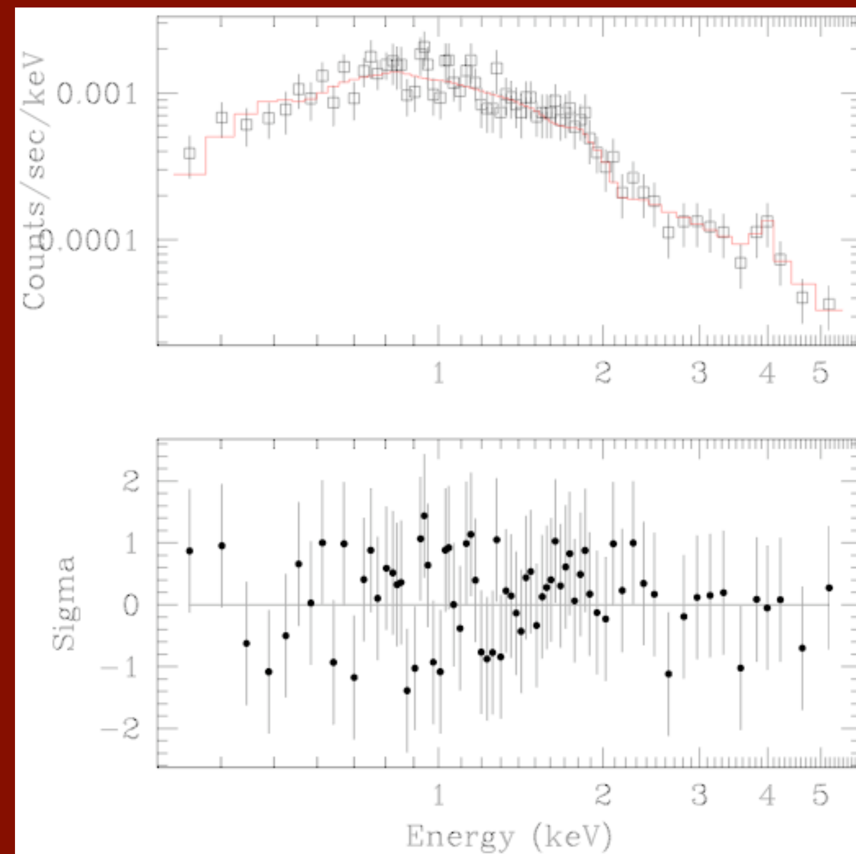
Unabsorbed luminosity
few x 10^42 erg/s

Araya et al 2011

NGC 5457 (M101)

Scd, 7 Mpc, HII





M 101

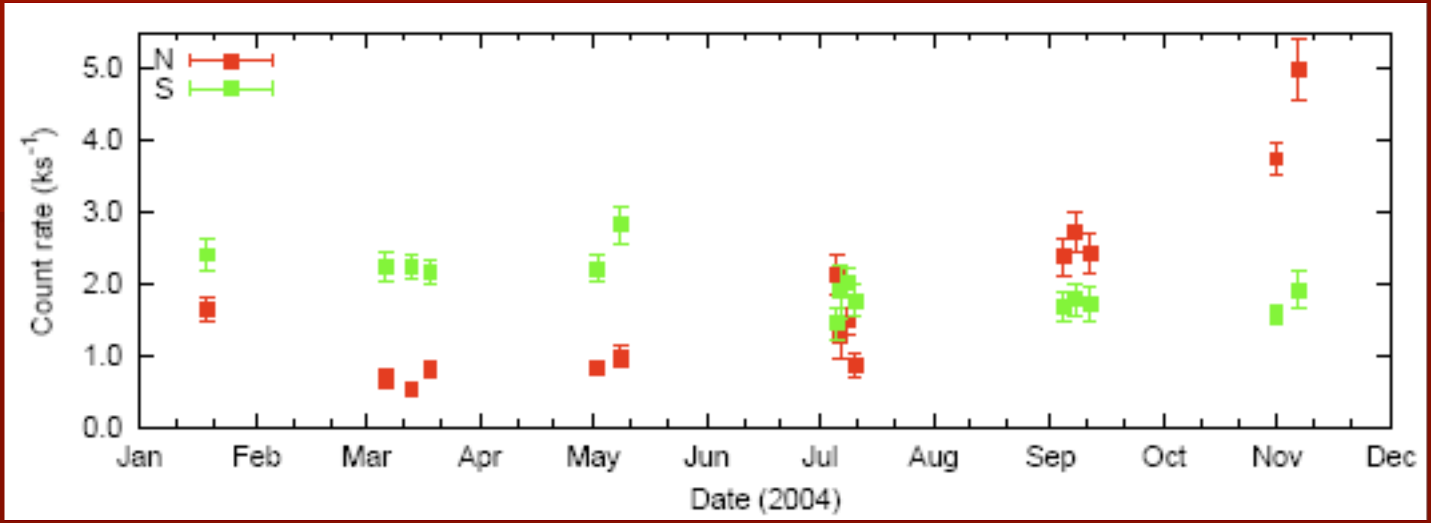
- AGN
- X-rays
  - Low luminosity (3×10^{38} erg/s) but varies by factor of 9 in 8 months
- Optical (HST)

  α_{ox} = 1.4 similar to AGN
- IR (2MASS)

  $\nu L_\nu \sim 10^{41}$ erg/s difficult to produce without AGN

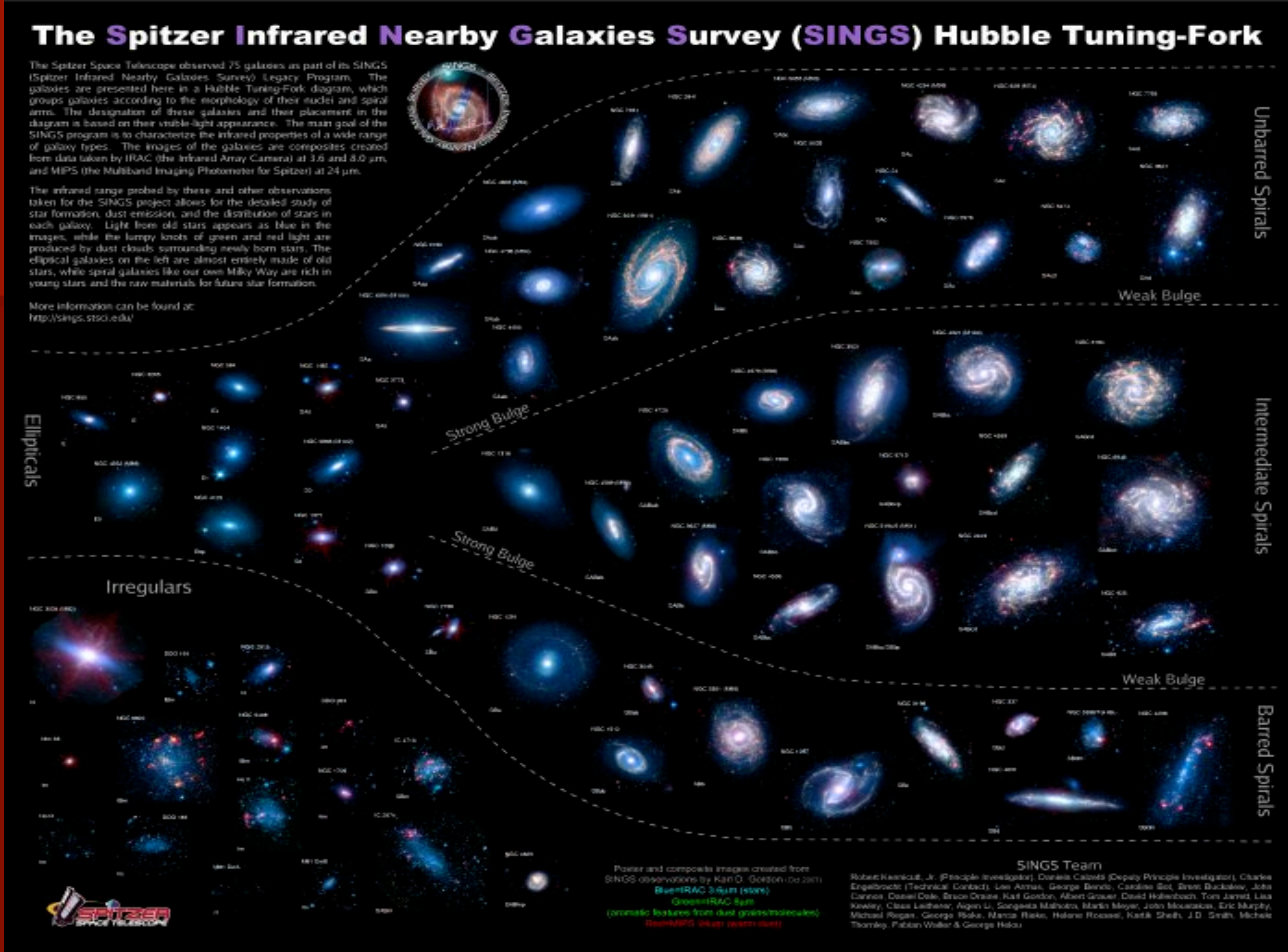
  α_{KX} = 1.9 similar to x-ray faint AGN (Laor et al. 1997)
- Radio
  - Upper limit $\nu L_\nu < 6\times10^{35}$ erg/s (Heckman 1980)

- X-ray binary?
  - X-ray luminosity like XRB
  - BUT, bolometric luminosity implied by IR, $\sim 10^{41}$ erg/s, would require implausibly high number of XRBs (10^3 - 10^4)

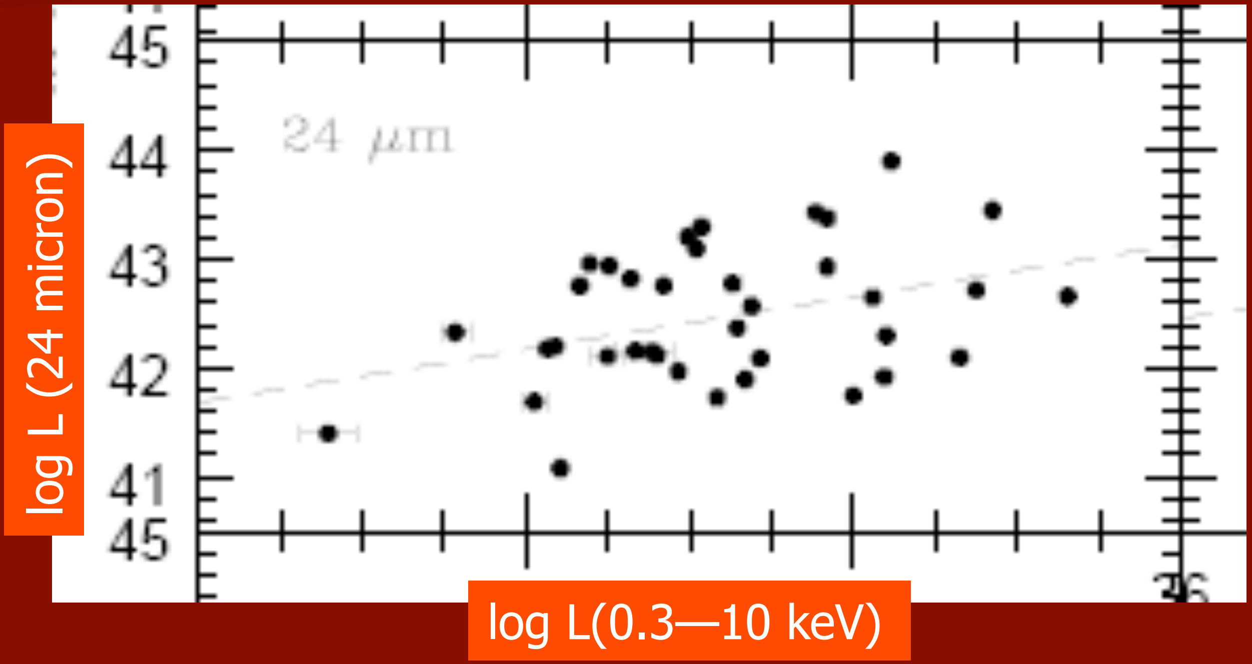


The nucleus of M 101 (the N source) varied by a factor of ~9 between March and November 2004.

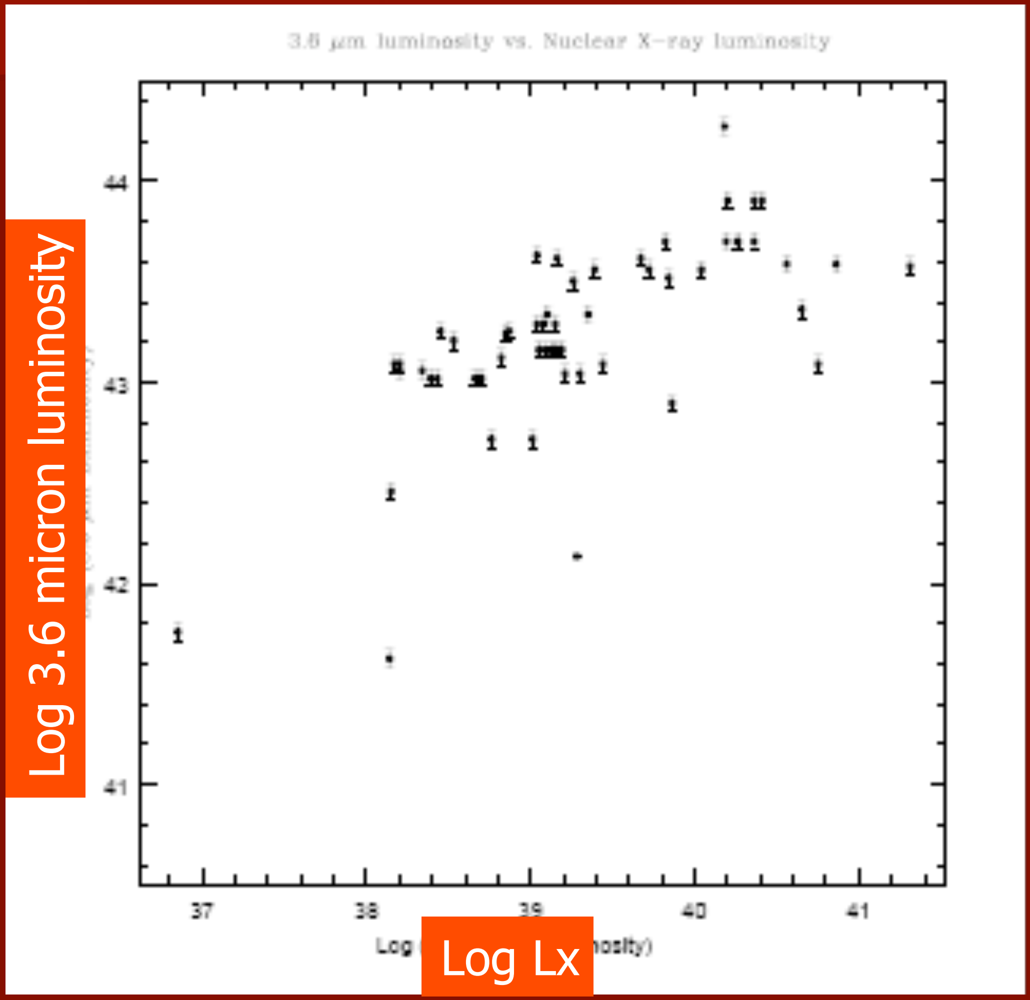
AGN activity – Star-formation


The Spitzer Infrared Nearby Galaxies Survey (SINGS) Hubble Tuning-Fork
The Spitzer Space Telescope observed 75 galaxies as part of its SINGS (Spitzer Infrared Nearby Galaxies Survey) Legacy Program. The galaxies are presented here in a Hubble Tuning-Fork diagram, which groups galaxies according to the morphology of their nuclei and spiral arms. The designation of these galaxies and their placement in the diagram is based on their visible-light appearance. The main goal of the SINGS program is to characterize the infrared properties of a wide range of galaxy types. The images of the galaxies are composites created from data taken by IRAC (the Infrared Array Camera) at 3.6 and 8.0 μm, and MIPS (the Multiband Imaging Photometer for Spitzer) at 24 μm.
The infrared range probed by these and other observations taken for the SINGS project allows for the detailed study of star formation, dust emission, and the distribution of stars in each galaxy. Light from old stars appears as blue in the images, while the lumpy knots of green and red light are produced by dust clouds surrounding newly born stars. The elliptical galaxies on the left are almost entirely made of old stars, while spiral galaxies like our own Milky Way are rich in young stars and the raw materials for future star formation.
More information can be found at:
http://sings.stsci.edu/
Unbarred Spirals
Weak Bulge
Strong Bulge
Intermediate Spirals
Ellipticals
Strong Bulge
Irregulars
Weak Bulge
Barred Spirals
Poster and composite images created from SINGS observations by Karl D. Gordon
Blue=IRAC 3.6μm (stars)
Green=IRAC 8μm
(aromatic features from dust grains/molecules)
Red=MIPS 24μm (warm dust)
SINGS Team
Robert Kennicutt, Jr. (Principle Investigator), Daniela Calzetti (Deputy Principle Investigator), Charles Engelbracht (Technical Contact), Lee Armus, George Bendo, Caroline Bot, Brent Buckalew, John Cannon, Daniel Dale, Bruce Draine, Karl Gordon, Albert Grauer, David Hollenbach, Tom Jarrett, Lisa Kewley, Claus Leitherer, Aigen Li, Sangeeta Malhotra, Martin Meyer, John Moustakas, Eric Murphy, Michael Regan, George Rieke, Marcia Rieke, Helene Roussel, Kartik Sheth, J.D. Smith, Michele Thornley, Fabian Walter & George Helou
SPITZER SPACE TELESCOPE

No clear correlation with star formation rate

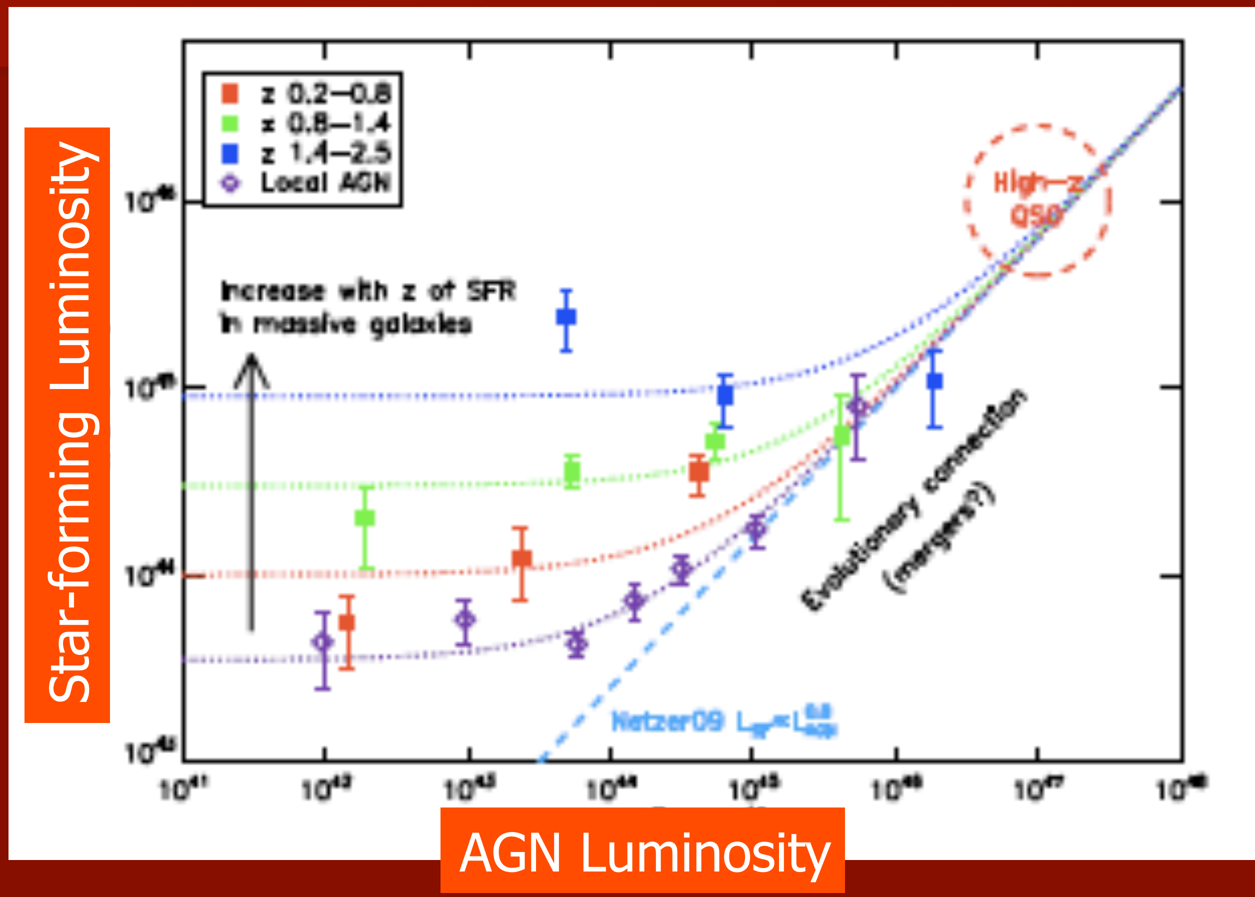


AGNs in SINGS galaxies



Grier, Mathur et al 2011

Hershel observations of GOODS

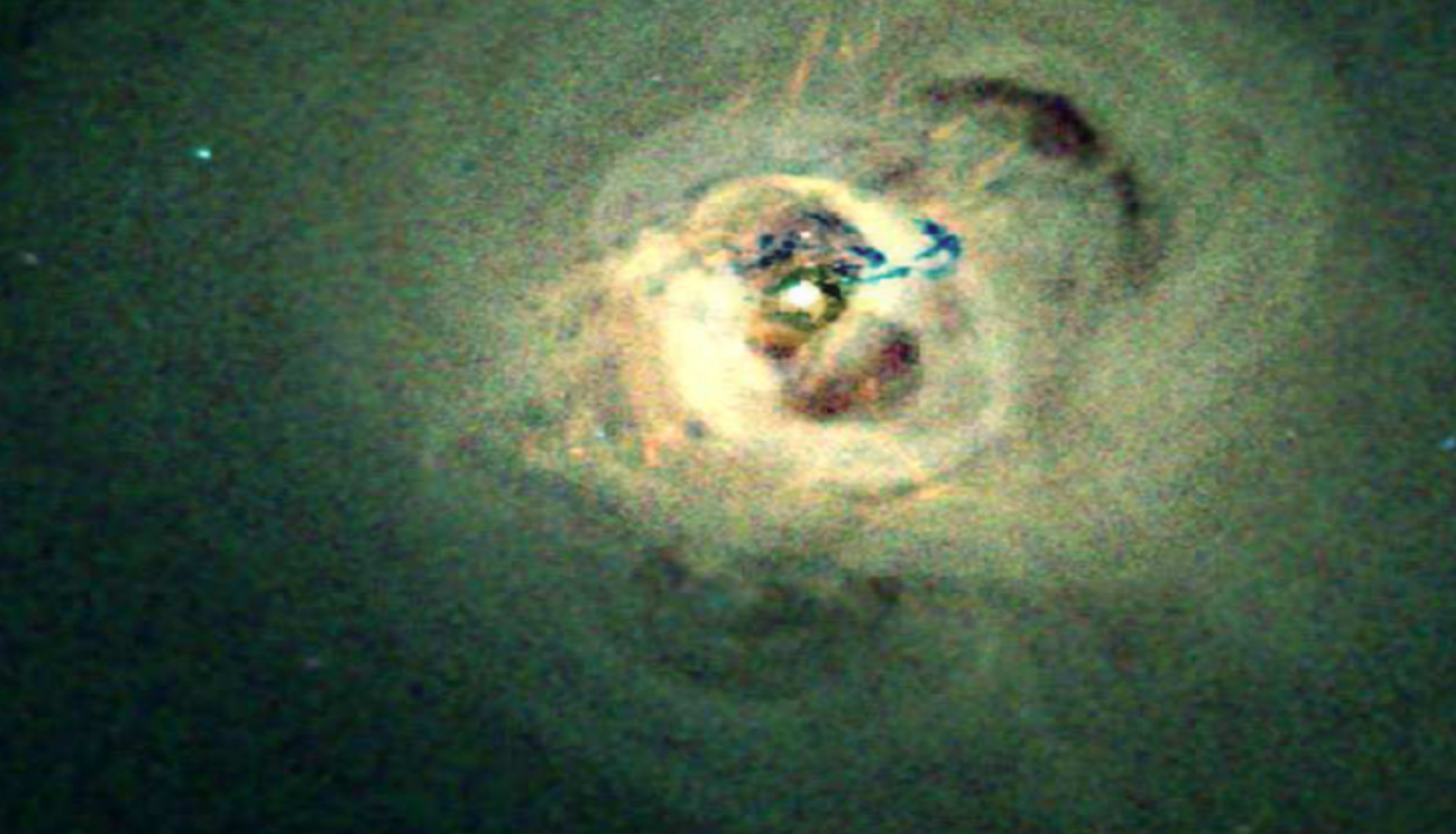


Shao, Lutz et al 2010

AGN feedback

Methods of Feedback

Jets : accepted for cluster cooling flows.

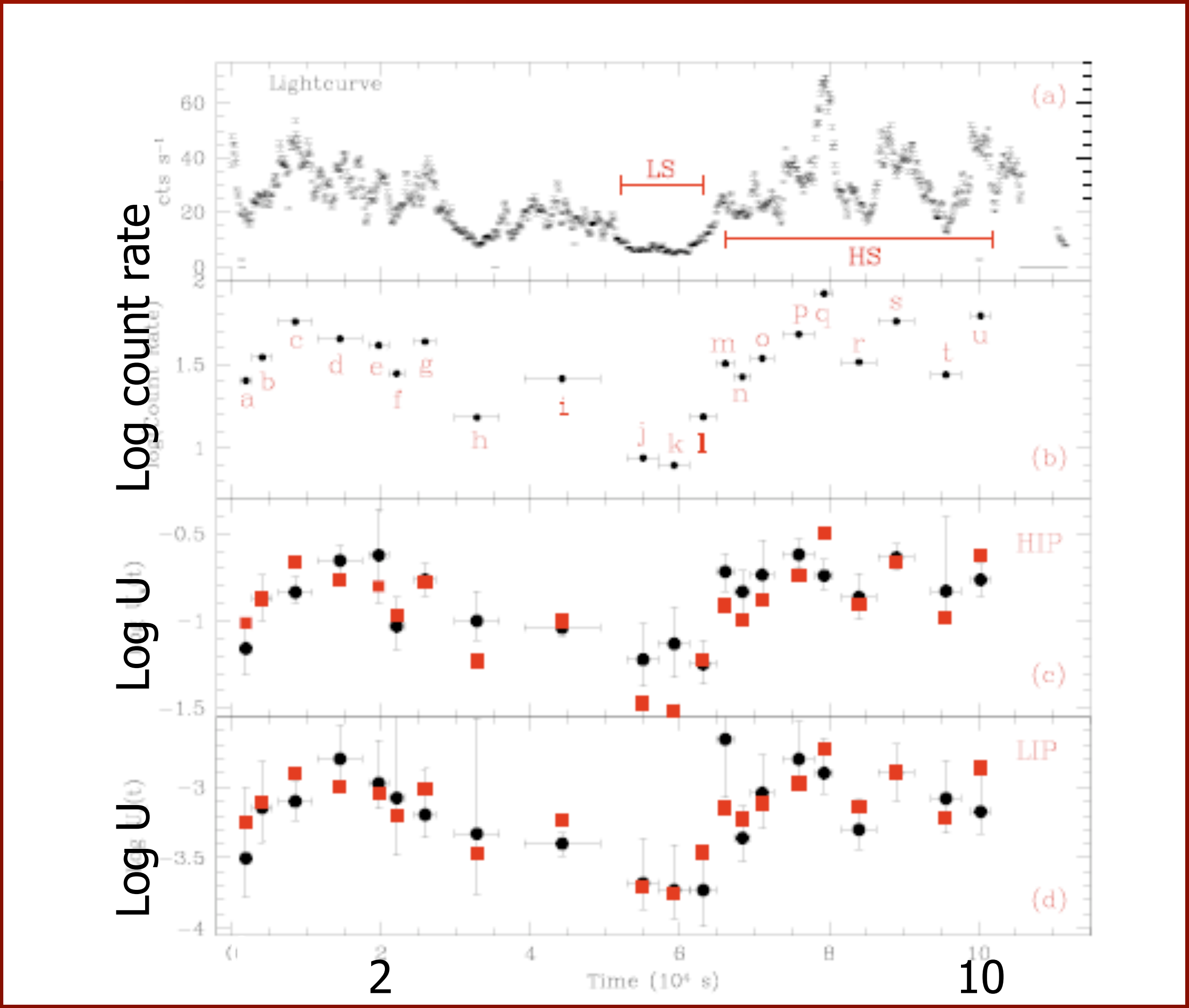


Do outflows carry sufficient energy and momentum to be effective agents of feedback?

What is the distance of the absorber from the nucleus?

Proposals span a factor of > 10^6 from accretion disk to Kpc scale narrow line region

$n R^2$



Time 10^4 s

Krongold et al. 2007

Kinetic power released: ~10^{38} erg/s

c.f. bolometric luminosity: 2.5 x 10^{43} erg/s

Energy injection rate in the surrounding medium is significantly smaller than that in feedback models

Scannapieco
Silk

Several nails in the present paradigm

- Bulge crucial for BH formation & evolution: NO, we discovered BHs in bulge-less galaxies
- BH—bulge correlations tight: NO, we observe significant scatter/ offset
- Correlation of AGN activity with star formation rate: NO, not seen in local galaxies OR at high redshift

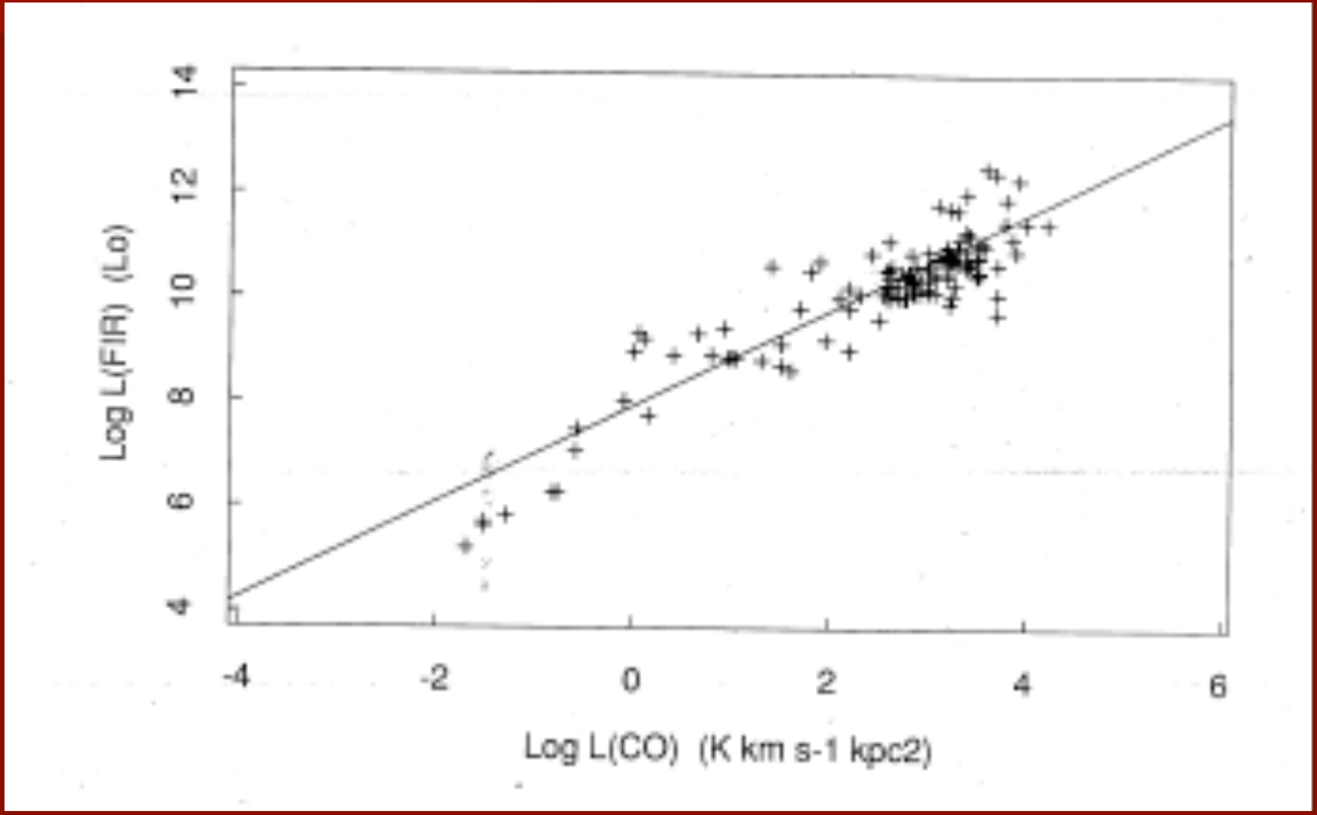
- Feedback regulates BH/Bulge growth: NO, measured feedback orders of magnitude smaller.
- Hierarchical growth is the driver: NO, pseudobulges host AGNs; secular processes important

….and these are not pathological cases

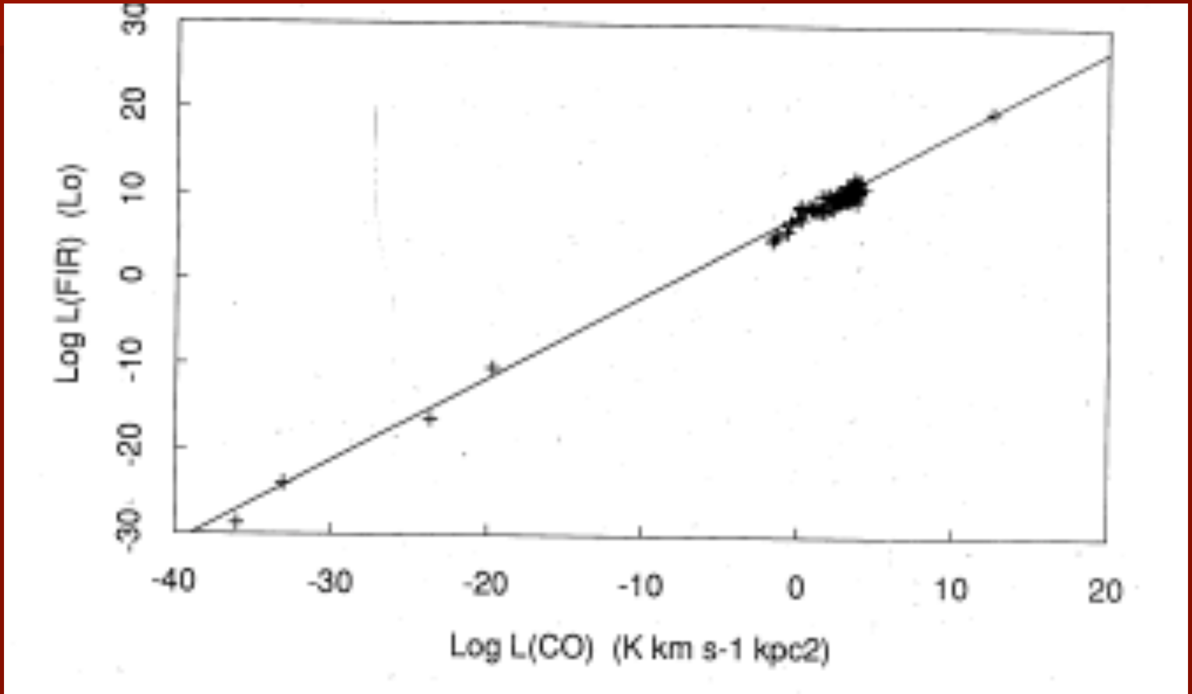
- About 2/3 of all bright spirals host pseudobulges ($n \leq 2$) ($B/T \leq 0.2$)
- About 65% of these also host a bar

Weinzerl et al 2009

A strong correlation……

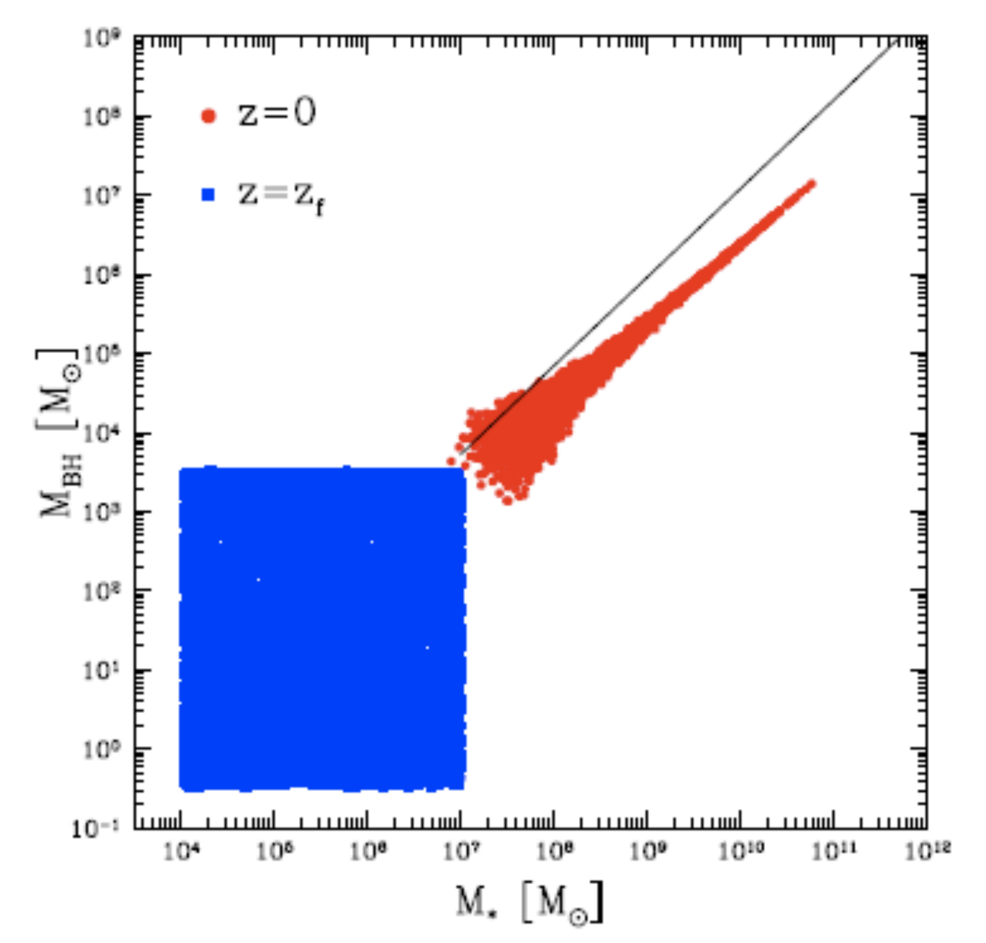


......does not mean causation



Kennicutt 1990

Non-causal origin of the black hole-- galaxy scaling relations



Janhke & Maccio 2010

Conclusions

- All galaxies host a supermassive BH
- Bigger galaxies, bigger BHs
- Total mass, not just the bulge mass
- Non-causal relation
- Secular processes dominate

ASTROSAT

- Broad-band X-ray: BH finding factory
- UVIT: Star-formation
- SSM: trigger alert

.....so what’s the new paradigm?

…..so what's the new paradigm?

Keep our eyes open

…..so what's the new paradigm?

Keep our eyes open

Keep our mind open