The background of the slide is a dark space filled with numerous small, distant stars. In the center, two galaxies are shown in a head-on collision. Each galaxy has a bright, irregularly shaped core and a diffuse, reddish-purple outer envelope. From the cores of both galaxies, a narrow, bright jet of light extends towards the other galaxy, meeting at a central point. The jets appear to be composed of multiple smaller filaments. The overall scene is symmetric and captures a moment of intense gravitational interaction.

# The Fundamental Plane of Black Hole Activity

David Nisbet

DEX Meeting      January 2016

# Two Types of AGN

Radiative-Mode AGN: Accrete at  $> \sim 1\%$  of Eddington Limit

Jet-Mode AGN: Accrete at  $< \sim 1\%$  of Eddington Limit

# The Fundamental Plane of Black Hole Activity

Accretion Flow: X-ray Luminosity

Black Hole: Mass

Radio Jets: Radio Luminosity

$$L_R = a L_X^\beta M_{BH}^\gamma$$

or

$$\log L_R = \alpha + \beta \log L_X + \gamma \log M_{BH}$$

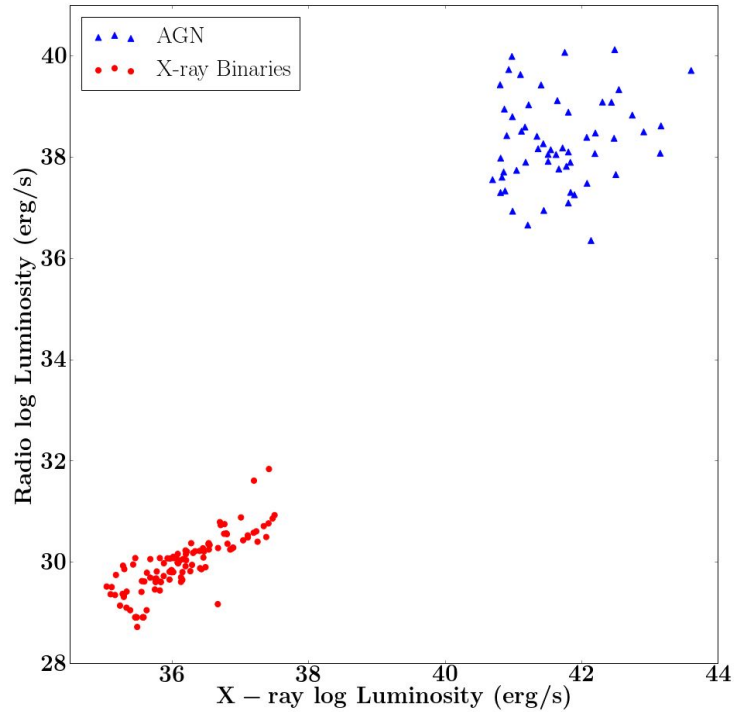
# Data Base

Jet-mode AGN :            3XMM + SDSS + FIRST  
                                  +     quality controls  
                                  +     5 diagnostic tests  
                                  =     **576 LINERs**

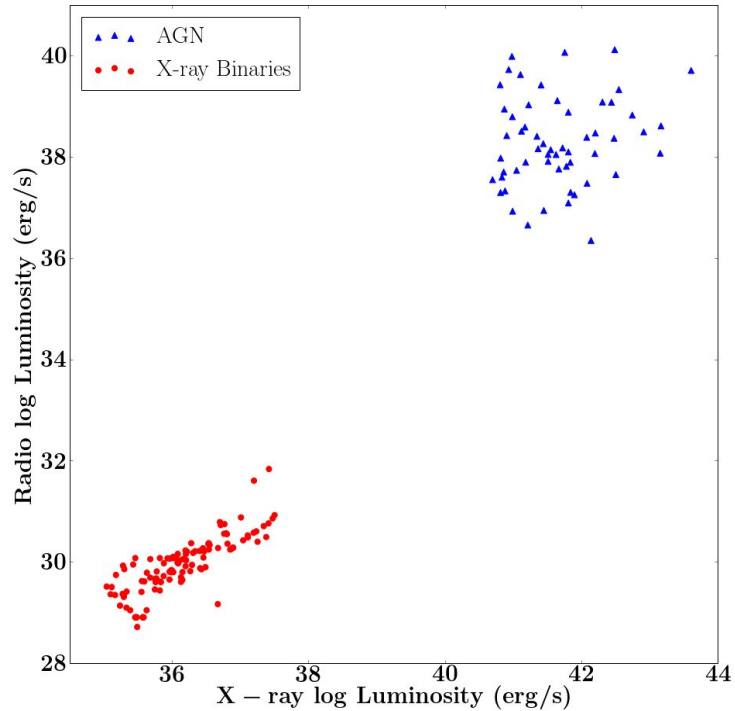
X-ray Binaries :            **130** observations from **7 XRBs**

Sagittarius A\* :            Black Hole at the centre of the Milky Way

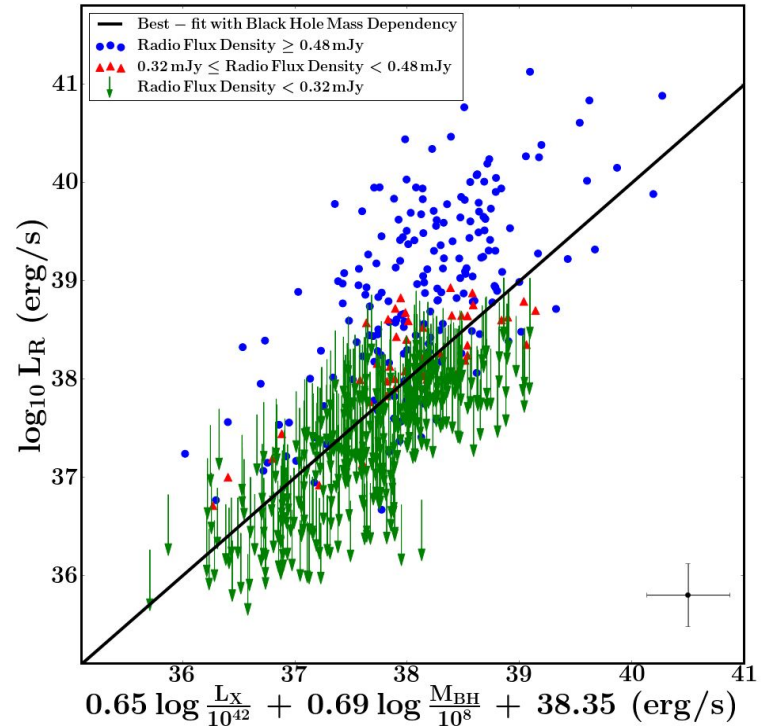
# One Approach ....



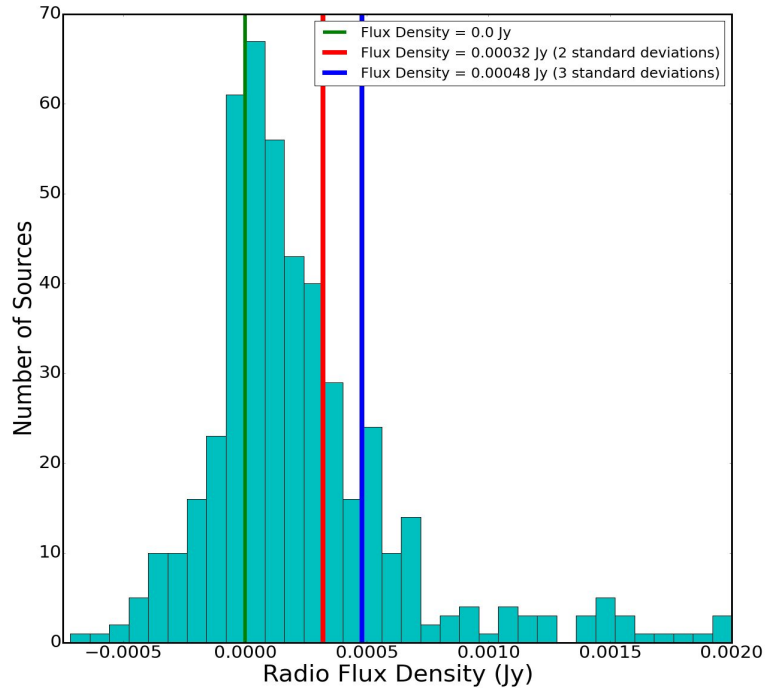
# One Approach ....



# ... and Ours



# Noisy Radio Data



S / N

Number of Sources

> 3

194

2 - 3

45

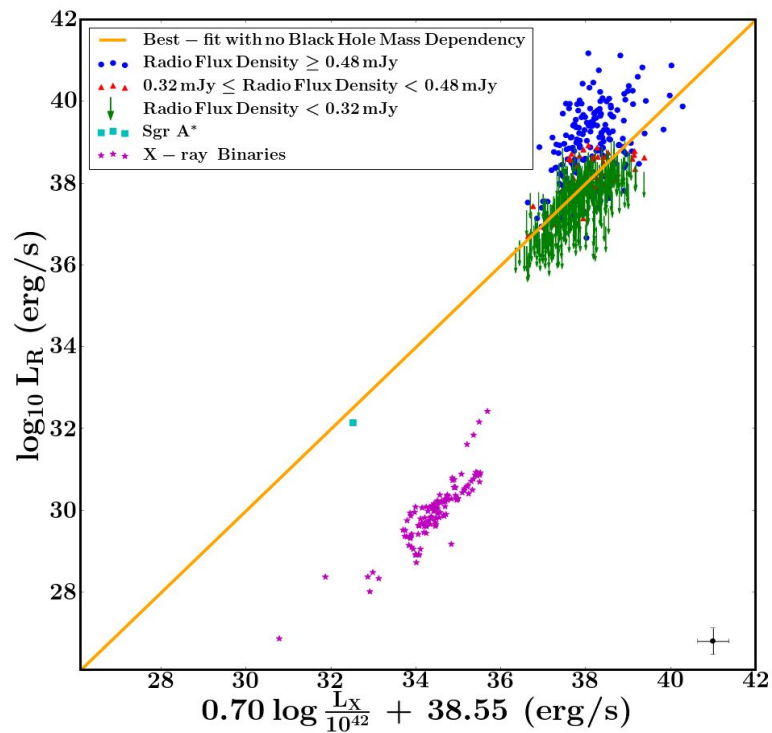
0 - 2

208

< 0

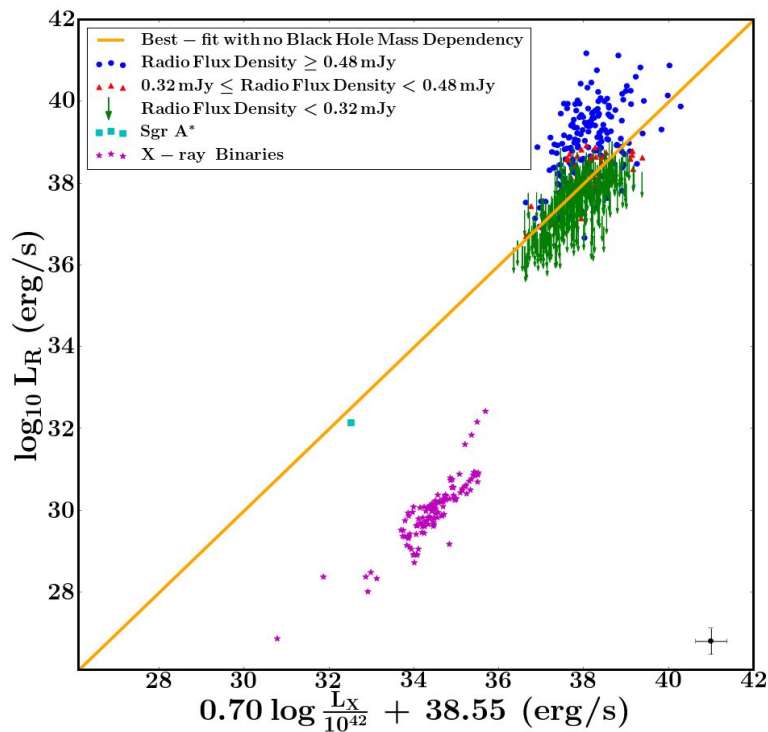
129

# Without $M_{\text{BH}}$ Dependency

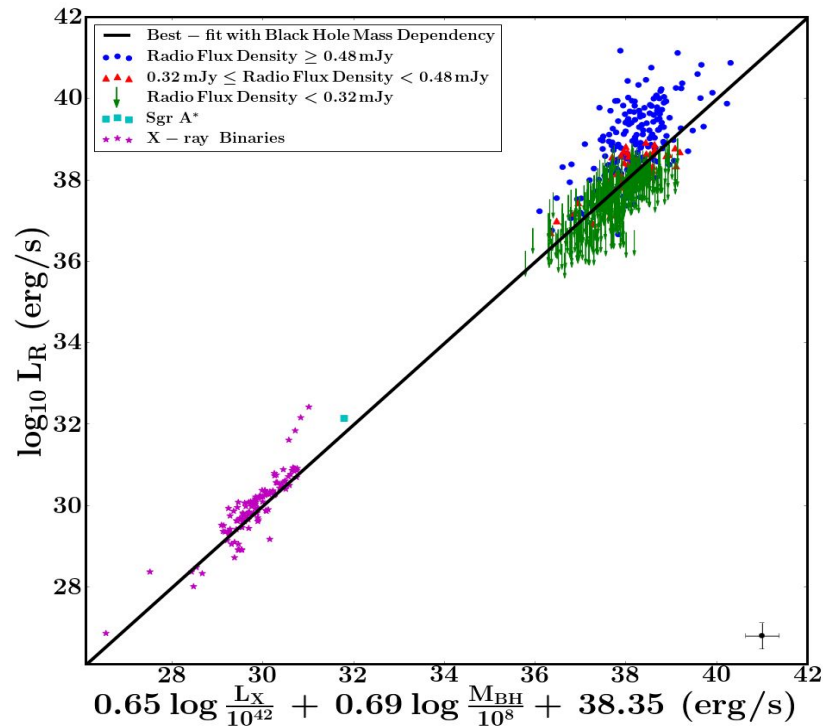




## Without $M_{\text{BH}}$ Dependency



## With $M_{\text{BH}}$ Dependency



# $M_{\text{BH}}$ - sigma Relationship

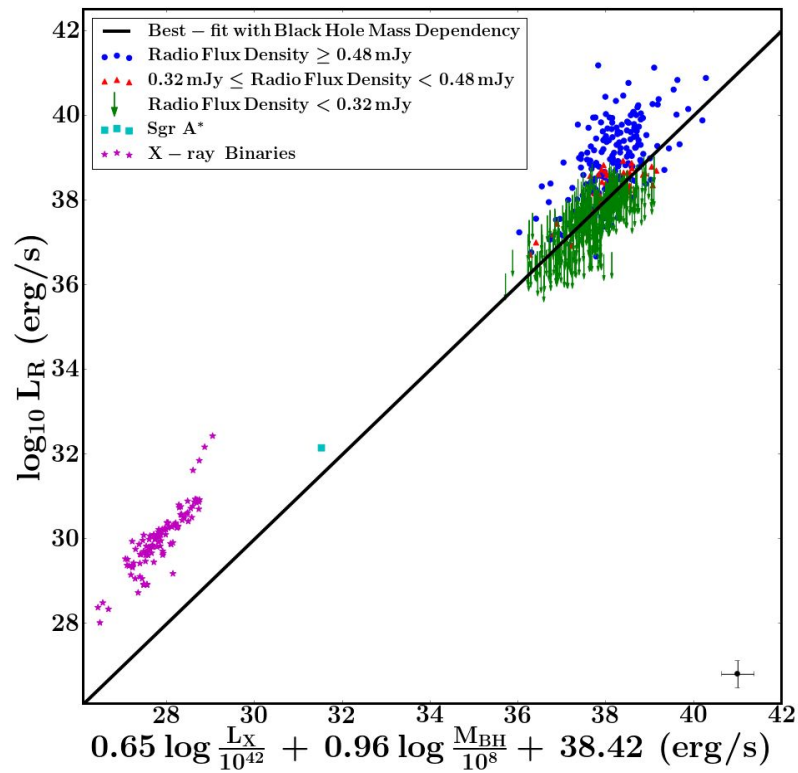
$$M_{\text{BH}} = \alpha \sigma^\beta$$

Tremaine et al (2002):  $\beta = 4.02 \pm 0.32$

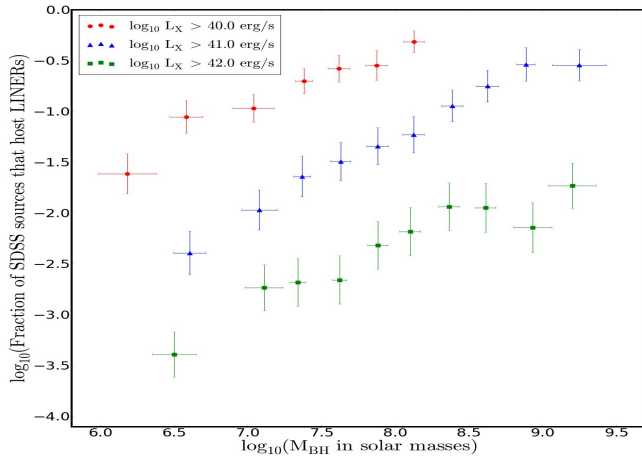
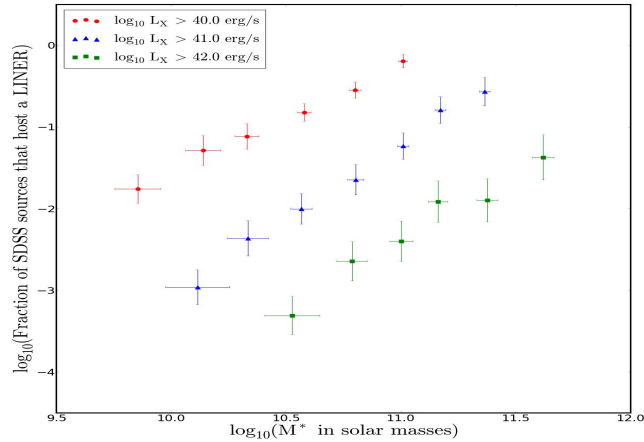
Novak et al (2006):  $\beta = 4.59 \pm 0.34$

McConnell et al (2011):  $\beta = 5.12$

McConnell & Ma (2013):  $\beta = 5.64 \pm 0.32$



# Other Results



1. Fraction of galaxies hosting a LINER is a strong function of both stellar mass and black hole mass.
2. A significant proportion (> 50% on average) of the LINERs' energy is released in the jets.
3. That proportion rises with increasing black hole mass.
4. The Eddington ratio is inversely correlated with black hole mass.
5. Mechanical luminosity becomes progressively more dominant at lower Eddington ratios.
6. Hints that the properties of a black hole (or of its accretion flow) change at a mass of around  $10^8$  solar masses.

The image shows a galaxy with a complex structure. A large, irregularly shaped region in the upper left and lower right is colored in shades of blue, green, and yellow, indicating high activity or density. These two regions are connected by a narrow, elongated bridge of similar color. The rest of the galaxy is mostly black, with some faint, diffuse blue and green patches. The overall appearance is that of a galaxy with a central or near-central region of intense activity, possibly a black hole or a star-forming region.

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# Problem 2 : Unknown Scatter

Radio Flux

Known

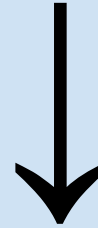
X-ray Flux

Black Hole Mass

Timing Differences, beaming effects, absorption etc

Intrinsic Scatter

Unknown



# Procedure to find the Best Fit

1. Make : initial estimates of  $\alpha$ ,  $\beta$ ,  $\gamma$ , and  $\sigma$ .
2. Calculate:  $\log L_R = \alpha + \beta \log L_X + \gamma \log M_{\text{BH}} + N_1 \sigma$ .
3. Allow :  $N_1$  to vary in small steps from -10 to +10.
4. Convert : each radio luminosity to the equivalent radio flux density.
5. Calculate : how many standard deviations,  $N_2$ , between each predicted radio flux density and the observed radio flux density.
6. Calculate :  $N_{\text{min},i} = (N_1^2 + N_2^2)^{1/2}$ , the minimum value for each source,  $i$ .
7. Calculate:  $\ln L = -0.5 \sum_i (N_{\text{min},i}^2 + \ln (2\pi\sigma^2))$ .
8. Determine: the values of  $\alpha$ ,  $\beta$ ,  $\gamma$ , and  $\sigma$  that maximise the log likelihood function.