8 – Host Galaxies of AGN
Figure 8.1. HST images of host galaxies of several type-I AGNs showing clear signs of interaction and disturbed morphology (from Veilleux et al., 2009; reproduced by permission of the AAS). In all objects, (a) is the raw image, and the other frames show the results of the removal of the PSF and various assumed Sérsic profiles with index $n$: (b) $n = 1$, (c) $n = 4$, (d) unconstrained Sérsic index.
Figure 8.2. Example active and nonactive galaxy images arranged into different morphological classes. There is no obvious distinction in the morphology of AGN hosts and inactive galaxies. Black spots at the center of some of the galaxies are residuals from the point source removal (from Cisternas et al., 2011; reproduced by permission of the AAS).
8.3 Stellar mass and black hole mass
Figure 8.3. The $M-\sigma^*$ relationship for galaxies with dynamical measurements (from Gultekin et al., 2009; reproduced by permission of the AAS). The symbol indicates the method of BH mass measurement: stellar dynamical (pentagrams), gas dynamical (circles), masers (asterisks). The color of the error ellipse indicates the Hubble type of the host galaxy: elliptical (red), S0 (green), and spiral (blue). The line is the best fit relation to the full sample. (See color plate)
Figure 8.4. $M_{\text{bulge}}/M_{\text{BH}}$ and $M_*/M_{\text{BH}}$ for two galaxy samples. Large symbols are $M_{\text{bulge}}/M_{\text{BH}}$ from the work of E. Sani and collaborators (courtesy of E. Sani) with two additional points corresponding to the largest known local BHs (as of 2011). Small points represent bulge-dominated ($B/T > 0.85$ in the r-band) red SDSS galaxies where $M_*$ is obtained from SED fitting and $M_{\text{BH}}$ from the $M-\sigma^*$ relationship. The dashed line is a fit to the Sani et al. (2011) data.
\[ r_{\text{BH, sph}} = \frac{G M_{\text{BH}}}{\sigma_*^2} \simeq 10.7 \frac{M_{\text{BH}}}{10^8 M_\odot} \left[ \frac{\sigma_*}{200 \text{ km/s}} \right]^{-2} \text{ pc}, \]

\[ \log \left( \frac{M_{\text{BH}}}{M_\odot} \right) = a_{\text{BH}} + b_{\text{BH}} \log \left( \frac{\sigma_*}{200 \text{ km s}^{-1}} \right). \]

\[ a_{\text{BH}} = 8.29; \quad b_{\text{BH}} = 5.12 \]
\[ \log M_{\text{BH}} = 9.16 + 1.16 \log \frac{L_V}{10^{11} L_\odot} M_\odot. \]

\[ I(r) = I(0) \exp \left[ -b_n \left( \frac{r}{r_e} \right)^{1/n} \right], \]

\[ M_{V, \text{def}} \simeq -18.05 - 2.63 \log \left( \frac{M_{\text{BH}}}{10^9 M_\odot} \right), \]
Figure 8.5. A comparison of two methods of measuring $M_{\text{BH}}$ in 30 low-luminosity AGNs. The virial method mass is based on the combination of $R_{\text{BLR}}(\text{H} \beta)$ and $\text{FWHM}(\text{H} \beta)$ (vertical axis) and The $M-\sigma^*$ method is based on the width of the stellar absorption lines. The line is the 1:1 ratio.
Figure 8.6. BH mass as a function of emission-line velocity dispersion (note that $\sigma$ in this diagram refers to the observed emission lines and not the stellar absorption lines). A clear correlation is evident in all lines, suggesting that line width measurements can be used to estimate BH mass (from Dasyra et al., 2011; reproduced by permission of the AAS).
8.4 – Red and Blue galaxies
Figura 1.1: A distribuição bi-modal de cores das galáxias e sua evolução no diagrama cor-massa. As flechas indicam migração de galáxias para a sequência vermelha, sob a hipótese de ‘fusões mistas’ (Faber et al., 2007). As trajetórias de estrangulamento são mostradas por flechas aproximadamente verticais. Estas fusões serão ricas em gás (‘wet’ - molhadas), dissipativas, pois as duas galáxias em fusão são azuis, formam estrelas e contêm gás. Ao chegar à sequência vermelha, as galáxias se movem mais lentamente através de uma sequência de fusões não-dissipativas, sem gás (‘dry’ - secas), mostradas pelas flechas vazadas. Estas têm ligeira inclinação para cima para indicar o envelhecimento das estrelas ao longo das gradativas fusões não-dissipativas. Fusões dissipativas não são a única forma de transformar galáxias azuis em vermelhas. O suprimento de gás de alguns discos pode ser expulso por choques ou despido sem ocorrer fusão - por efeito de ambiente de aglomerado para produzir galáxias com discos, do tipo S0. Neste caso suas trajetórias seriam verticais (flechas cinzentas); fora isso, suas histórias seriam semelhantes. A amostra analisada nesta tese está localizada na extremidade da direita da sequência vermelha, que correspondem às ETGs mais massivas.
The E-E dichotomy
Figure 8.7. Blue and red galaxies as determined by their UV color at various redshifts. The right panel shows reddening-corrected UV colors. The separation into two groups becomes clearer, suggesting that many green valley sources are highly reddened blue galaxies (from Brammer et al., 2009; reproduced by permission of the AAS).
Figure 8.8. The fraction of AGNs with different $M_{\text{BH}}$ in host galaxies of different types (from Schawinski et al., 2010; reproduced by permission of the AAS).
8.5 – Starforming galaxies

Figure 8.9. Model spectrum of a continuous $10 \, M_\odot \, \text{yr}^{-1}$ starburst, with solar metallicity gas and a Kroupa IMF, $10^8$ yrs after the beginning of the burst. The hydrogen Lyman (912 Å), He$^+$ Lyman, and hydrogen Balmer (3646 Å) edges are marked.
PAHs - Polycyclic Aromatic Hydrocarbon
PAHs emission features

Figure 8.10. The NIR–MIR spectrum of the star-forming galaxy M 82 showing the strong PAH emission features. The [NeII] line at 12.8 μm is, in many cases, the strongest IR line in the spectrum of SF galaxies (courtesy of D. Lutz).
Figure 8.11. The MIR spectrum of low-redshift ULIRGs showing the large range of properties, in particular, the large variation in the optical depth of the 9.7 μm silicate absorption feature. The diagram shows two subgroups of ULIRGs and compares their spectra with a mean high-luminosity AGN (QSO) spectrum (courtesy of D. Lutz).
Schmidt-Kennicutt law

\[ \Sigma_{\text{SFR}} = K \Sigma_{\text{gas}}^N, \]

\[ \Sigma_{\text{SFR}} = \epsilon \frac{\Sigma_{\text{gas}}}{\tau_{\text{dyn}}}, \]

N=1.4 +/- 0.15;
K=1.5 \times 10^{-4} \text{ for disks; } x4 \text{ for starbursts}
\[
\frac{dN(m)}{dm} = am^{-\alpha},
\]

where the slope $\alpha$ is of order 2–2.5 for stars with $m > 0.5M_\odot$. The special case of $\alpha = 2.35$ for all stars between 0.1 and 100 $M_\odot$ was considered for many years to be a good approximation for young stellar clusters. This IMF is referred to as the “Salpeter IMF.” Detailed analysis of many field and cluster stars suggests that this IMF overpredicts the number of low-mass stars below about 0.5 $M_\odot$. A more
Kroupa

- $\alpha = 0.3$ for $m<0.08$
- $\alpha = 1.3$ for $0.08<m<0.5$
- $\alpha = 2.3$ for $m>0.5$
SFR efficiency

\[ L_{\text{SF}} \simeq 10^{10} \left[ \frac{\eta_{\text{SF}}}{7 \times 10^{-4}} \right] \text{[SFR]} L_\odot. \]
Estimating SFR from Balmer lines

An expression that is often used in combination with the Kroupa IMF assumes heating and ionization by stars that are less than 30 Myrs old. Under these assumptions,

\[
[SFR] = 5.5 \times 10^{-42} L(H_\alpha) \ M_\odot \ yr^{-1}.
\] (8.13)

For Salpeter IMF, the constant 5.5 is replaced by 7.9. \(L_{\text{SF}}\) can be computed from the same \(L(H_\alpha)\). For example, in a case of a Kroupa IMF,

\[
L_{\text{SF}} \simeq 220 L(H_\alpha)_{\text{corr}} \ \text{ergs s}^{-1},
\] (8.14)

where \(L(H_\alpha)_{\text{corr}}\) is the unattenuated line luminosity.
\[ L(\text{H} \alpha)_{\text{corr}} = L(\text{H} \alpha)_{\text{obs}} + a_\lambda L(\text{IR}), \quad (8.15) \]

where \( a_\lambda \) is a wavelength-dependent correction factor measured for the IR band in question. For example, if \( L(\text{IR}) = L(24 \, \mu\text{m}) \), then \( a_\lambda \simeq 0.02 \). In the important case where \( L(\text{IR}) \) represents the total 8–1000 \( \mu\text{m} \) emission, \( a_\lambda \simeq 0.0024 \). Such expressions have been obtained and verified over the range of \( L(\text{H} \alpha)_{\text{corr}} = 10^{39} - 10^{43} \text{ erg s}^{-1} \).
SFR from forbidden lines

\[ L_{\text{SF}} \sim 218 L([\text{OII}]\lambda3727) \text{ ergs s}^{-1} , \]

SFR from UV (1200 – 2500 Å)

\[ L_{\text{SF}} = 3.4 \times 10^{44} \left[ \frac{L_{\nu}}{10^{29}} \right] \text{ ergs s}^{-1} , \]
SFR from IR

\[ \log L_{\text{SF}} \simeq 1.16 + 0.92 \log L(70 \, \mu m) \]

\[ \log L_{\text{SF}} \simeq 1.5 + 0.9 \log L(160 \, \mu m) , \]

\[ [\text{SFR}] \simeq 2.5 \times 10^{-43} L(24 \, \mu m) \, M_\odot \, \text{yr}^{-1} \]

\[ [\text{SFR}] \simeq 1.5 \times 10^{-43} L(8 \, \mu m) \, M_\odot \, \text{yr}^{-1} \]
SFR from radio

\[ [\text{SFR}] \simeq 4 \times 10^{-38} L(1.4 \text{ GHz}) \, M_\odot \, \text{yr}^{-1}, \]

where \( L(1.4 \text{ GHz}) \) is \( \lambda L_\lambda \) in units of erg s\(^{-1}\).
Types of SF galaxies

• **LIRGS** – Luminous infrared galaxies
  
  SFR: $10-100 \, \text{M}_\odot/\text{yr} >> \log L = 11$

• **ULIRGS** - Ultraluminous infrared galaxies
  
  SFR$>100 \, \text{M}_\odot/\text{yr} >> \log L > 12$

• **SMGs** - Submillimeter galaxies (HyLIRGs)
  
  SFR$>1000 \, \text{M}_\odot/\text{yr}; z=2-3; \log T (\text{yr}) \sim 8; >>> \text{most massive galaxies}$
[SFR] = a(z) \left( \frac{M_*}{10^{11} M_\odot} \right)^b,
Figure 8.12. SFRs for $z = 2$ galaxies (points with a solid line) measured by two different methods as indicated on the vertical axes (from Daddi et al., 2007; reproduced by permission of the AAS) illustrating the SF sequence, which is the crowded band going from the bottom left to the top right of the diagram. The best-fit SF sequences for $z = 0.1$ and $z = 1$ galaxies are also shown with different colors. The theoretical prediction for $z = 2$ galaxies obtained from the millennium simulation is shown as a dashed line.
Figure 8.14. The metallicity indicator, N(O)/N(H), as a function of the total stellar mass at various redshifts, as marked. The horizontal dashed line marks the solar N(O)/N(H) (based on data presented in Maiolino et al., 2008).
8.6 – The AGN-staburst connection

Figure 8.15. Classification of AGN hosts and other galaxies in a color absolute magnitude diagram. The maps were obtained by combining SDSS spectroscopy and photometry with GALEX NUV photometry. The classification into groups is based on diagnostic diagrams, and the AGNs are type-II low-redshift AGNs. Note that many AGNs hosts are located in the green valley between the red and blue galaxies (from Salim et al., 2007; reproduced by permission of the AAS).
Figure 8.16. The MIR spectra of two AGNs, PG 1613+658 ($z = 0.129$) and PG 1440+356 ($z = 0.079$), showing strong PAH features in the spectrum. These are similar to the features observed in the spectrum of M82 (Figure 8.10) and other SF galaxies. They are thought to be due to intense SF activity in the host galaxies of these objects in regions shielded from the hard AGN radiation field.
Figure 8.17. A comparison of the 60 μm luminosity and $L(\text{PAH 7.7 μm})$ in a sample of luminous AGNs and ULIRGs. Open squares are low-redshift ULIRGs. Triangles are PG-QSOs where open symbols are upper limits and closed symbols are detections.
• MW > SFR = 1Msun/yr
• Lbol(AGN) = 0
• dM/dt(BH) = 0.003 dM/dt)(SF)
• Delay of 100 – 500 million yr
Figure 8.18. A comparison of $L_{\text{SF}}$ versus $L_{\text{bol}}$ for several AGN samples in the redshift range 0–3. The diagram is adapted from Netzer (2009) and includes only AGN-dominated systems where $L_{\text{bol}} > L_{\text{SF}}$. The solid line is drawn by hand and goes through the points with a logarithmic slope of 0.7. The dashed line shows the 1:1 relationship.
8.7-The combined AGN-galaxy SED

Figure 8.20. The combined AGN–galaxy SED. The observations (solid points) are modeled with a combination of a typical AGN (top light color line) and a host galaxy (bottom line with a peak around 1 μm). For very luminous AGNs, the galaxy contribution is negligible. For intermediate-luminosity AGNs, like the one shown here, the host galaxy can contribute significantly, especially around 1 μm, where the AGN SED has a local minimum (courtesy of Angela Bongiorno).
Figure 8.19. Same as Figure 8.18, except that all AGNs, including those where $L_{\text{SF}}$ exceeds $L_{\text{bol}}$, are included. The points represent X-ray-selected AGNs whose SF luminosity was obtained by Herschel. The different redshift groups are marked with different colors, and the horizontal lines illustrate specific evolutionary scenarios leading to the correlation line on the right (adapted from Rosario et al., 2012). (See color plate)