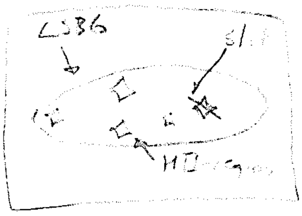
[V] Metallicities

Line ratio analysis → Important information about the gas of a galaxy. Kjell Olofsson is our local expert!

a) Extinction due to dust:



$$I_\lambda = I_{\lambda_0} e^{-\tau_\lambda} \quad (1)$$

$$\tau_\lambda = c f(\lambda) \quad (2)$$

(2) in (1) ⇒

$$I_\lambda = I_{\lambda_0} e^{-c f(\lambda)} \quad (3)$$

$$\Rightarrow \frac{I_{H\alpha}}{I_{H\beta}} = \frac{I_{H\alpha_0} \cdot e^{-c f(H\alpha)}}{I_{H\beta_0} e^{-c f(H\beta)}} =$$

$$= \frac{I_{H\alpha_0}}{I_{H\beta_0}} e^{-c\left(f(H\alpha) - f(H\beta)\right)} \quad (4)$$

$$\Rightarrow \boxed{c = \frac{\ln\left(\frac{I_{H\alpha}}{I_{H\beta}}\right) - \ln\left(\frac{I_{H\alpha_0}}{I_{H\beta_0}}\right)}{-\left(f(H\alpha) - f(H\beta)\right)}} \quad (5)$$

<u>Numerically</u>

$$\left(\frac{I_{H\alpha}}{I_{H\beta}}\right) = \frac{307}{100} = 3.07, \quad \left(\frac{I_{H\alpha_0}}{I_{H\beta_0}}\right) = 2.85$$

$$f(H\alpha) - f(H\beta) = -0.35$$

$\lambda_{H\alpha} = 6563$ Å ⇒

$$\Rightarrow c = 0.2125$$ (a measure of the extinction in this HII-region/galaxy)

<u>Answer</u>: $c = 0.2125$

b) $f(\lambda) - f(H\beta)$ required at $\lambda = 4959$ and 5007 Å !

Plot $f(\lambda) - f(H\beta)$ versus λ ⇒

$f(\lambda) - f(H\beta)$ almost linear in this λ-range.

Show plot!

Linear interpolation of $f(\lambda) - f(H\beta)$ ⇒

$f(4959) - f(H\beta) = 0.0282$

$f(5007) - f(H\beta) = 0.0415$

(3) ⇒ (derived same way as (4))

$$\frac{I_{\lambda 0}}{I_{H\beta 0}} = \left(\frac{I_\lambda}{I_{H\beta}}\right) e^{c\,(f(\lambda) - f(H\beta))} \qquad (6)$$

Numerically:

$$\frac{I_{3727\,0}}{I_{H\beta\,0}} = \left(\frac{127}{100}\right) e^{0.2125 \cdot 0.33} = 1.362$$

$$\frac{I_{4959\,0}}{I_{H\beta\,0}} = \left(\frac{178}{100}\right) e^{0.2125 \cdot 0.0282} = 1.7906$$

$$\frac{I_{5007\,0}}{I_{H\beta\,0}} = \left(\frac{531}{100}\right) e^{0.2125 \cdot 0.0415} = 5.357$$

Answer: Corrected ratios (rel. to $H\beta$) of lines at 3727, 4959, 5007 Å = 1.4, 1.8, 5.4.

[O III] λ = oxygen ionized twice (two electrons missing!)

[O II] λ — " — once (one electron missing!)

Problem set 2

11 Points.

c) $$\log(R_{23}) = \log\left(\frac{I_{3727} + I_{4959} + I_{5007}}{I_{H\beta}}\right) \quad (7)$$

Numerically:

$$\log(R_{23}) = \log(1.362 + 1.7906 + 5.357) = 0.930$$

$(\log(R23), 12+\log(O/H))$-relation $\Rightarrow$ $12+\log(O/H) \sim 7.6-8.3$

Number densities

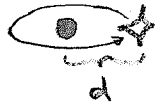
Solar value: 8.93

$$\frac{(O/H)}{(O/H)_\odot} = \frac{10^{(7.6 \text{ to } 8.3)-12}}{10^{8.93-12}} = 0.0468 \text{ to } 0.2344$$

Answer: $12+\log(O/H) \sim 7.6-8.3$ (or 7.95 ± 0.35) ($O/H \sim 5-24\%$ of solar value)

Typical value for LSBGs. Not very accurate method for determining metallicities though.

12 Supermassive black holes



$d = 10$ light minutes $= 3 \cdot 10^8 \, m/s \cdot 60 \cdot 10 = 1.8 \cdot 10^{11} \, m$

$$R_{sch} = \frac{2 G M_{SMBH}}{c^2}$$ (p. 267 in S&G)

<u>Numerically:</u>

$G = 6.6726 \cdot 10^{-11} \, Nm/kg^2$

$M_{SMBH} = 2 \pm 1 \cdot 10^8 M_\odot = 2 \pm 1 \cdot 10^8 \cdot 1.99 \cdot 10^{30} \, kg = 3.98 \pm 2 \cdot 10^{38} \, kg$

$c = 3 \cdot 10^8 \, m/s$

$\Rightarrow R_{sch} = 5.9 \pm 2.9 \cdot 10^{11} \, m$

$\therefore \; d < R_{sch}$ (within to error bars)

If this were true, we would not be able to observe this star!

Either M_{SMBH} has been overestimated or d underestimated!

13 The luminosity function of galaxies I

$L > 0.1 L_*$ often used to distinguish dwarf galaxies from large ones

The luminosity function:

$$\Phi(L_R)\, d\left(\frac{L_R}{L_{R*}}\right) = n_* \left(\frac{L_R}{L_{R*}}\right)^{\alpha} \exp\left(-\frac{L_R}{L_{R*}}\right) d\left(\frac{L_R}{L_{R*}}\right) \quad (1,\ 1.18 \text{ in S\&G})$$

← Nr of objects

Mass density:

$$\rho_{M,gal} = \left(\frac{M}{L_R}\right) \int_0^{\infty} \Phi(L_R) \left(\frac{L_R}{L_{R*}}\right) d\left(\frac{L_R}{L_{R*}}\right) \quad (2)$$

(1) in (2) ⇒

$$\rho_{M,gal} = \left(\frac{M}{L_R}\right) n_* \int_0^{\infty} \left(\frac{L_R}{L_{R*}}\right)^{\alpha+1} \exp\left(-\frac{L_R}{L_{R*}}\right) d\left(\frac{L_R}{L_{R*}}\right) =$$

[Math. Handbuch p. 173, formula 40] $= \left(\frac{M}{L_R}\right) n_* L_{R*} \Gamma(\alpha+2) \quad (3)$

To convert from unit of L_{R*}/Mpc^3 to $L_\odot/Mpc^3$

↑ gamma function, if j is integer $\Gamma(j+1) = j!$

$$\Omega_{M,gal} = \frac{\rho_{M,gal}}{\rho_c} \quad (4)$$

(3) in (4) ⇒

$$\Omega_{M,gal} = \frac{\left(\frac{M}{L_R}\right) n_* L_{R*} \Gamma(\alpha+2)}{\rho_c} \quad (5)$$

<u>Numerically:</u>

$\left(\frac{M}{L_R}\right) = 20 \frac{M_\odot}{L_{R\odot}}$

$\alpha = -0.7$

$h = 0.72$

$L_{R*} = 8 \cdot 10^9 h^{-2} L_{R\odot}$

$n_* = 0.019 h^3 Mpc^{-3}$

$\rho_c = 2.8 \cdot 10^{11} h^2 M_\odot Mpc^{-3}$

$\Gamma(\alpha+2) = 0.8975$?

$\Gamma(n+1) = n\Gamma(n)$

$\Gamma(1) = 1$

⇒ $\Omega_{M,gal} = 0.0135 \approx 0.01$ (S&G derives 0.02 on p. 200)

$\Omega_{baryons} \approx 0.05$

$\Omega_{lum} \approx 0.005$

$\Omega_M \approx 0.3$

⇒ All of the DM in galaxies could in principle be baryonic

16 Taxonomy of AGN

Visa egenskapslista från föreläsning

Quasars: point sources
$M_B < -23$
Broad and narrow lines

Seyferts: disk galaxies
$M_B > -23$

Sey I: Broad and narrow lines
High optical lum

Sey II: Narrow lines only
Low optical lum

Blazars: often featureless spectrum
emission lines weak or absent
Rapid and violent variability

Images:

A : E? Point source with structure / nebulosity

B : Point source (starlike) → likely QSO!

C : S/SB/S0 galaxy

D S/SB galaxy

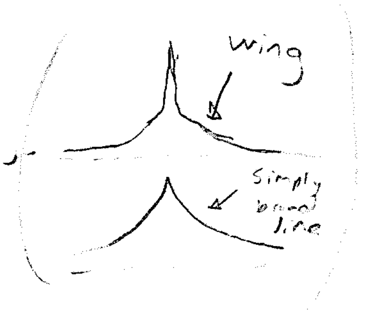
Spectra:

A : No obvious emission lines, flat continuum

B : Strong, broad emission lines

C : Strong, broad & narrow lines

D: Strong, narrow lines, no wings



Luminosities

A : $M_V = -21.8$ ($M_V > -23$ → Not QSO)

B : $M_V = -24.6$ ($M_V < -23$ + point like image → QSO!)

C : $M_V = -22.1$ ($M_V > -23$ → Not QSO

D: $M_V = -21.2$ ($M_V > -23$ → Not QSO)

Classification:

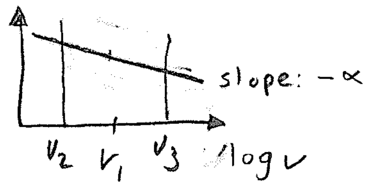
A: Almost point source, but too faint to be a quasar, lacks emission lines → <u>Blazar</u>?
Possible test: Monitoring should show rapid (≤1 day) variability

B: Point source + very luminous + broad lines →
Quasar

C: Disk-like galaxy with low optical luminosity → Likely Seyfert
Broad ~~and~~ narrow lines with wings → **Seyfert type I**
Higher lum than D

D: Disk-like galaxy with low optical luminosity → Likely Seyfert
Narrow lines only → **Seyfert type II**
Lower lum than C

18) The spectral energy distribution of quasars I



$L_\nu \propto \nu^{-\alpha} \Rightarrow$

$$L_\nu = \left(\frac{\nu}{\nu_1}\right)^{-\alpha} L_{\nu_1} \qquad (1)$$

$$L_{[\nu_2,\nu_3]} = \int_{\nu_2}^{\nu_3} L_\nu \, d\nu \qquad (2)$$

(1) in (2) $\Rightarrow$

$$L_{[\nu_2,\nu_3]} = L_{\nu_1} \nu_1^{\alpha} \int_{\nu_2}^{\nu_3} \nu^{-\alpha} d\nu = L_{\nu_1} \nu_1^{\alpha} \left[\frac{\nu^{-\alpha+1}}{-\alpha+1}\right]_{\nu_2}^{\nu_3} =$$

$$= \frac{L_{\nu_1} \cdot \nu_1^{\alpha}}{-\alpha+1} \left(\nu_3^{-\alpha+1} - \nu_2^{-\alpha+1}\right) \quad \square$$