Observational astrophysics

Final exam

05-feb-2019 // 9h-11h

Useful constants:

Constant	Symbol	Standard Value (S.I.)	Standard Value (cgs)
Solar mass	$M_\odot$	1.981(30) kg	1.981(33) g
Solar radius	$R_\odot$	6.9551(8) m	6.9551(10) cm
Solar luminosity	$L_\odot$	3.838(26)	3.838e+33 erg/s
Stefan	σ	5.6696(-8) W m^{-2} K^{-4}	5.6696(-5) erg s^{-1} cm^{-2} K^{-4}

1 Ground-based Infrared astronomy (3pt)

1. What is the photon flux at 10micr from a point-like 1Jy source ? Put the result in photon s^{-1} m^{-2} μm^{-1}.
2. The telescope has a diameter D=2m. Compare the previous value with the photon flux from the atmosphere (which you will treat as a black-body at 273 K)
3. Conclusion ? What is the typical observing mode in ground-based IR astronomy ? What is the real problem of ground-based IR astronomy ?

2 The K-correction (8pt)

When observing distant sources at a significant redshift z, one needs to correct for the so-called K-correction, because the photometric filter in the observatory rest frame is shifted and expanded with respect to the source rest frame.

Suppose we observe a Type Ia supernova located at a distance D_L, called the *luminous distance*, which is defined by

(Bolometric Flux) = (Bolometric Luminosity)/(4π D_L^2)

The supernova is observed with a CCD and we will assume that the quantum efficiency η is constant and does not depend on λ. All magnitudes are measured in a given photometric system defined by an idealized source, the spectral energy distribution of which is such that, at z=0, all magnitudes are zero in any photometric band. We note F_0 the flux density of this fictitious source. In the following, the flux density of the supernova is noted F(λ) or F(ν). The luminosity of the source is noted L(λ) or L(ν). Important: we implicitely assume that L(λ) means $L_\lambda(\lambda)$, etc.

We consider that the observations are performed in band R and we want to know the absolute magnitude M_Q in the bandpass Q in the source rest frame (because, for instance, we want to compare with stellar evolution models which predict the flux that is emitted by the source, in the source restframe).

1. What is the definition of the redshift in terms of the emitted and observed wavelength, which are noted λ_e and λ_o respectively ? What would this be in terms of frequency ν_e and ν_o?

2. Give the apparent magnitude m_R of the source in terms of R, F, and F_0. It would be wise to make it explicit which wavelength (λ_e or λ_o) you use in your expression.

3. We define the K-correction term K_{QR} by: $m_R = M_Q + \mu + K_{QR}$. What is μ ? Give the expression of μ in terms of D_L.

4. Recall the definition of the absolute magnitude and give an expression of M_Q, in terms of F, F_0, Q, and D_L.

5. From the three previous expressions, show that:

   $K_{QR} = -2.5 \log \left(\frac{\int_0^\infty S_R(\lambda_o) F(\lambda_o) d\lambda_o}{\int_0^\infty S_R(\lambda_o) F_0(\lambda_o) d\lambda_o} \frac{\int_0^\infty S_Q(\lambda_e) F_0(\lambda_e) d\lambda_e}{\int_0^\infty S_Q(\lambda_e) L(\lambda_e) d\lambda_e} 4\pi D_L^2 \right)$

   where we have noted $S_R(\lambda)=\lambda\ R(\lambda)$, and similarly for S_Q, to simplify the expression.

6. To derive the so-called *classical* K-correction, we now assume that $S_Q=S_R=S$. Show that

   $F(\lambda_o) = L(\lambda_e)/[4\pi\ D_L^2\ (1+z)]$

   and obtain the desired expression:

   $K = 2.5 \log(1+z) + 2.5 \log \left(\frac{\int S(\lambda) L(\lambda) d\lambda}{\int S(\lambda) L(\lambda/(1+z)) d\lambda} \right)$

3 Integration time estimate (4 pt)

We wish to observe the ground-state rotational lines emitted by the ortho-H_2D^+ ion at 372.421GHz, towards a young protostar located at a distance d=400 pc. We anticipate that the emission will come from the very inner region of the core and would be confined in a radius R=2000 au. The telescope is APEX-12m.

1. Assuming pure thermal broadening and a temperature of 10K, and considering that 5 spectral channels per FWHM are needed to resolve the line, what spectral resolution (in kHz) will you chose ?

2. The APEX webpage reports an HPBW of 17". Can you comment ?

3. Radiative transfer calculations predict a line intensity of 0.3 K (T_A*). The typical system temperature of the observatory at this frequency and period of the year is 600K. Observations will be performed in position-switching mode. What is the integration time needed to reach a 5σ detection on the peak intensity ?

4 Observing a protoplanetary disk with ALMA (3pt)

A Keplerian protoplanetary disk located at 50 pc will be observed with ALMA with an angular resolution of 1". The disk is seen almost edge-on (par la tranche). What is the expected order of magnitude of the FWHM of spectral lines from this protoplanetary disk at radii R=1, 10, and 100 au ? What spectral resolution would you chose to resolve the CN(3-2) line at 340 GHz ?

5 X-ray detectors (2pt)

1. Recall the definition of the quantum efficiency of a detector

2. Show that the quantum efficiency of a proportional counter X-ray detector can be written

   $Q = e^{-d\mu_w}\ (1-e^{-g\mu_g})$

   with d and g the window and gas column densities in g cm^{-2}; what are the μ_w and μ_g coefficients ?