

CUME 427, October 6, 2018

The following cume is related to the paper NOEMA Observations of a Molecular Cloud in the Low-Metallicity Galaxy KISO 5639, by Elmegreen et al., ApJ 2018

You may use a calculator but no stored formulae or notes or other materials. Passing grade is expected to be 70%. Total points is 57. While there seem to be many questions, you can keep most answers brief and to the point.

1. (5 pts) In the introduction, the authors have a $1/\sin^2(i)$ dependence for the dynamical mass estimate. The “i” refers to the inclination angle. Explain why that term is there, including why it is squared.

A: Mass scales as velocity squared, true radial velocity differs from observed radial velocity by $1/\sin(i)$.

2. (10 pts) Also in the introduction, they use the H α luminosity as a tracer of star formation rate. Explain the connection between the two. Why is there a direct correlation? In other words, describe the direct link between these two quantities, in terms of physical processes, assumptions that might have been made, etc. I do not need formulae but a physical description with as much detail in the description as you can provide.

A: Full answer would include ionization process, recombination line, connection to counting ionizing photons from massive stars that have short lives and so time scales for the recombination line emission is similar to timescale of massive stars. Mentioning IMF would be good, as an assumption that has to be made.

3. In section 2.1 they describe optical spectroscopy obtained with the 10-m GTC telescope.

- a. (3 pts) Convert the resolution they cite (550) in Section 2.1 to a spectral line width in Ångstrom? Do this for the H α line.

A: Convert $1/R$ to $\Delta\lambda$ at relevant wavelength.

- b. (3 pts) They list a set of spectral lines in the second paragraph in that section. Many of the lines are “forbidden”, as indicated by the “[]” brackets. What are “forbidden” lines? How are these lines excited and how can they be de-excited?
A: Forbidden lines are lines that are not permitted under electric dipole selection rules. All forbidden lines are excited by collisions, then they can de-excite by collisions or by emitting a photon.

- c. (5pts) Select one, or one set, of the forbidden lines and discuss how this line or set of lines might be useful for measuring particular physical properties of an HII

region such as temperature or density. Note: you cannot select [NII]6583 for what the authors use it for, since that is already in the paper. So pick another line(s) or another application for this line. If you do not know the details for particular lines, you may explain in general sense how these lines in HII regions can be used to provide information on temperature, or on density. A rough sketch of an energy level diagram might be helpful in the explanation.

A: Some lines are good for measuring gas density (e.g. [SII] doublet or [OII] doublet, others for temp, e.g. [OIII]4363. Sketching an energy diagram to explain that would be helpful but not required if the answer has the right direction.

4. (18 pts) In the paper the authors also use CO observations to derive the molecular cloud mass. We will explore in this question what makes CO a good tracer of molecular clouds. To do that try to answer each individual question below:
 - (a) Why not directly observe molecular hydrogen?
A: No dipole moment, symmetric molecule, no suitable lines.
 - (b) Why is CO one of the best trace molecules to observe molecular clouds?
A: Most abundance molecule, O and C most abundant elements after He, CO has suitable energy levels that are easily excitable.
 - (c) The CO line in question is excited by collisions with hydrogen molecules. Given the frequency of the line is in the mm range, it is easy to excite this line with collisions at prevailing temperatures. Show this by quantitatively comparing kinetic energy to energy of the photon.
A: Compare kT to $h\nu$, find that $kT \gg h\nu$
 - (d) What type of transition is the “J = 1 – 0” line they observe?
A: rotational transition, falls in mm range.
 - (e) In e.g. Section 3 they talk a lot about the conversion of CO luminosity (or intensity) to molecular cloud mass (or mass surface density). Why might this conversion be dependent on the metallicity of the molecular gas? What metallicity dependency do they assume for the conversion factor and what might motivate that particular dependency?
A: They assume quadratic dependency, since both O and C abundances relative to hydrogen enter.
 - (f) Calculate the “beam size” they provide on page 2, right column, near the middle from the information given in Section 2.2.
A: beam size from maximum baseline and frequency of transition.
5. (3 pts) Below the middle of the right column on page 3 the authors estimate a gas consumption time scale. Show how they get that number from the discussion in this paragraph and the one above.
A: Directly from gas mass divided by SFR.
6. Near the bottom right of that page they estimate a “virial ratio”.
 - a. (5 pts) Explain why they do this, in other words, what point are they trying to make in this paragraph.

A: They want to determine if the clouds are self-gravitating, i.e. if there is enough molecular gas mass to keep the cloud bound.

- b. (5 pts) Why do they need to use a “deconvolved radius” in their estimate? Describe what deconvolution is and what is the specific correction made here is for.

A: Deconvolution to correct for the beam size width. This is necessary to get a better estimate of the actual cloud radius.

CUME 427, October 6, 2018

The following cume is related to the paper NOEMA Observations of a Molecular Cloud in the Low-Metallicity Galaxy KISO 5639, by Elmegreen et al., ApJ 2018

You may use a calculator but no stored formulae or notes or other materials. Passing grade is expected to be 70%. Total points is 57. While there seem to be many questions, you can keep most answers brief and to the point.

1. (5 pts) In the introduction, the authors have a $1/\sin^2(i)$ dependence for the dynamical mass estimate. The “i” refers to the inclination angle. Explain why that term is there, including why it is squared.
2. (10 pts) Also in the introduction, they use the $H\alpha$ luminosity as a tracer of star formation rate. Explain the connection between the two. Why is there a direct correlation? In other words, describe the direct link between these two quantities, in terms of physical processes, assumptions that might have been made, etc. I do not need formulae but a physical description with as much detail in the description as you can provide.
3. In section 2.1 they describe optical spectroscopy obtained with the 10-m GTC telescope.
 - a. (3 pts) Convert the resolution they cite (550) in Section 2.1 to a spectral line width in Ångstrom? Do this for the $H\alpha$ line.
 - b. (3 pts) They list a set of spectral lines in the second paragraph in that section. Many of the lines are “forbidden”, as indicated by the “[]” brackets. What are “forbidden” lines? How are these lines excited and how can they be de-excited?
 - c. (5pts) Select one, or one set, of the forbidden lines and discuss how this line or set of lines might be useful for measuring particular physical properties of an HII region such as temperature or density. Note: you cannot select [NII]6583 for what the authors use it for, since that is already in the paper. So pick another line(s) or another application for this line. If you do not know the details for particular lines, you may explain in general sense how these lines in HII regions can be used to provide information on temperature, or on density. A rough sketch of an energy level diagram might be helpful in the explanation.
4. (18 pts) In the paper the authors also use CO observations to derive the molecular cloud mass. We will explore in this question what makes CO a good tracer of molecular clouds. To do that try to answer each individual question below:

- (a) Why not directly observe molecular hydrogen?
 - (b) Why is CO one of the best trace molecules to observe molecular clouds?
 - (c) The CO line in question is excited by collisions with hydrogen molecules. Given the frequency of the line is in the mm range, it is easy to excite this line with collisions at prevailing temperatures. Show this by quantitatively comparing kinetic energy to energy of the photon.
 - (d) What type of transition is the " $J = 1 - 0$ " line they observe?
 - (e) In e.g. Section 3 they talk a lot about the conversion of CO luminosity (or intensity) to molecular cloud mass (or mass surface density). Why might this conversion be dependent on the metallicity of the molecular gas? What metallicity dependency do they assume for the conversion factor and what might motivate that particular dependency?
 - (f) Calculate the "beam size" they provide on page 2, right column, near the middle from the information given in Section 2.2.
5. (3 pts) Below the middle of the left column on page 3 the authors estimate a gas consumption time scale. Show how they get that number from the discussion in this paragraph and the one above.
6. Near the top right of that page they estimate a "virial ratio".
- a. (5 pts) Explain why they do this, in other words, what point are they trying to make in this paragraph.
 - b. (5 pts) Why do they need to use a "deconvolved radius" in their estimate? Describe what deconvolution is and what is the specific correction made here is for.

