Interim Report - "How fast do Molecular Clouds grow?"

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# Abstract

*+White space for cover sheet*

# Background

The interstellar medium (ISM) is a collection of gaseous, solid particles and cosmic rays that exist throughout space. The gaseous portion takes up of the mass in the ISM meanwhile the solid particles known as dust take the remaining 1%. The composition of the gases consists of hydrogen and helium with the remaining being heavier elements . The density and chemical composition of the ISM tends to vary however, but can be broadly split into five categories: hot ionised, warm ionised, warm atomic, cold atomic and cold molecular mediums. The cold molecular medium otherwise known as molecular clouds is of particular importance.

The cold nature of the molecular cloud results in a minimal amount of thermal pressure, which decreases the requirements for gravitational collapse. The temperatures required for this to occur is in the range of K. This is substantially lower than the cold atomic medium which has temperatures in the ranges of K. While this may seem to suggest the molecules of the cloud possess a efficient means of cooling, this is not necessarily true. The primary constituent of the molecular cloud, H2, has an relatively high energy requirement for its first excited state of J K] . Unsurprisingly, the emissions from H2 within the molecular cloud is negligible. On the other hand, CO is another molecule commonly found in the molecular clouds with a much lower energy requirement of J [K] for the emission line. Due to the high density of H2, CO can be easily excited through collisions with H2 . This gives a method of tracing the density of H2 in the cloud using the observed intensity of CO. Cooling through CO radiation is significant but is not required to reach range of K. Simulations using cooling from C+ (C II) fine-structure lines with sufficient dust extinction also show they can reach similar temperatures.

*-segue-*

The formation of hydrogen molecules heavily depends on dust. As collisions with gaseous hydrogen atoms usually result in both being repelled, actual rate of reaction is very low. The dust grains can act as a catalyst however and enables hydrogen atoms to attach onto the surface to rid itself of its excess energy . Dust also shields the resulting hydrogen molecule from UV rays to prevent dissociation. Any energy absorbed from the UV ray is then radiated away aiding in cooling.

*-Add more on [Observations] : Atomic lines / radiative processes(Einstein coefficients) / line broadening?*

*STAGE 2: Gravitational collapse (Jeans mass/length) -> turbulence and magnetic field (+ observations and magnetic braking)*

If a isothermal molecular cloud of uniform density is sufficiently large enough, it will become gravitationally unstable and collapse. For a spherical model of the cloud this radius is known as the Jean's length . The mass associated with this length is known as the Jean's mass given as:

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| --- | --- | --- |
| *Probably don't need this here* |  | [1] |

where is the mass density and is the sound speed which has dependence. In the case where the cloud has no outward support mechanism, the time it takes to collapse is given by the free-fall time:

|  |  |  |
| --- | --- | --- |
| *Probably don't need this here* |  | [2] |

which represents the minimum timescale a cloud can collapse in . However, the actual percentage of the cloud that is converted into stars within a free-fall time is much lower than one. It is found that only cloud is converted into stars for a single free-fall time.

Observations of the ISM show large amounts of polarisation in the starlight received. This effect has been accredited to the dust aligning on a large scale to polarise the light for a particular axis. In order to produce such a effect there must be a equally large magnetic field which can be measured from the polarised light using the Zeeman effect . The compression of the ISM into molecular clouds and later into pre-stellar cores also causes the magnetic field lines to compress as well. This increases the magnetic field strength which also increases magnetic pressure that opposes gravitational collapse. The magnetic field also aids in gravitational collapse by removing angular momentum from pre-stellar cores through magnetic braking. This reduces the angular speed of the outer parts of the envelope, allowing it to collapse inwards towards the core.

Observations of a molecular cloud's spectral lines usually possesses some degree of additional line broadening caused by Doppler shifts. A significant amount of this can be explained by the thermal velocity dispersion of the gas in the cloud however there is still a large amount that cannot be explained other broadening methods. This non-thermal velocity dispersion is caused by turbulence . Turbulence within a molecular cloud appears to be a side effect of the various mechanism occurring within it . Turbulence has a been attributed to variety of effects such as creating molecular cloud cores through compressive motions and fragmentation of the cloud .

*STAGE 3: Cores + accretion -> Stellar systems (Classes) + observations + high mass stars (+fragmentation & multiplicity)*

When the cloud becomes gravitationally unstable and starts collapsing, multiple processes occur in the cloud that prevents and assists collapse. Initially, the gravitational energy gained from the collapsing gas is radiated away keeping the pre-stellar core isothermal. However the accumulating dust increases the opacity towards the centre of the pre-stellar core (protostar), reducing the ability to radiate away energy. This results in a steady decrease in luminosity with a minor temperature increase known as the Hayashi track. Eventually the centre of the protostar becomes too opaque to radiate effectively causing a rapid increase in temperature.

*-> Classes, higher mass stars*

*-> fragmentation & multiplicity*

While the accretion of the envelope is occurring, the pre-stellar core can also accrete mass from the background ISM as it moves through space. The model used to calculate the rate of accretion as known as Bondi-Hoyle accretion. This model assumes the accreting mass can be approximated as a point mass that moves through a infinite stationary background. As it does so the nearby background mass is pulled towards the point mass in a conical wake behind the direction of motion which is then accreted. This model does ignore a few factors such as the accumulation of momentum and radiative feedback in the wake .

# Project Outline

The purpose of this project is to investigate the differences in mass gain between Bondi-Hoyle accretion and collisions of clouds. This will be done by writing code to produce a computer simulation of a GMC for a time period. The result of the computer simulation will then be analysed to explain the effects that collisions and accretion have on star formation in the GMC.

*Add GMC initial conditions*

# Project Design

*Physics used (Bondi-Hoyle equation, assumptions made, equations/topics used for analysis?), outline code features (Integration methods, Energy calculation, timestep control, box boundary conditions, collision modelling, particle bookkeeping +exploding particles, central z-axis potential(?))*

# Preliminary Results & Future

*Current design of code (Velocity verlet, Box wrapping, Energy calculation, timestep control), tests of current working features , features to still implement (mention c?).*

# References

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| 1. | Ferriere K. The Interstellar Enviroment of our Galaxy. Reviews of Mordern Physics. 2001 June; 73(4). |
| 2. | D.Ward-Thompson APW. An Introduction to Star Formation. 1st ed. Cambridge: Cambridge University Press; 2011. |
| 3. | S.C.O.Glover MMM. SIMULATING THE FORMATION OF MOLECULAR CLOUDS. I. SLOW FORMATION BY GRAVITATIONAL COLLAPSE FROM STATIC INITIAL CONDITIONS. The Astrophysical Journal Supplement Series. 2007 April; 169(2). |
| 4. | N.J.Evans. Physical Conditions in Regions of Star Formation. Annual Reviews. 1999 September; 37. |
| 5. | M.R.Krumholz JCT. Slow Star Formation in Dense Gas: Evidence and Implications. The Astrophysical Journal. 2007 April; 654(1). |
| 6. | J.Ballesteros-Paredes RSKMMLEVS. Molecular Cloud Turbulence and Star Formation. In B. Reipurth DJKK, editor. Protostars and Planets V. Tucson: University of Arizona Press; 2006. p. 63–80. |
| 7. | Edgar R. A Review of Bondi–Hoyle–Lyttleton. New Astronomy Reviews. 2004 June; 48(10). |
| 8. | S.C.O.Glover PCC. Is molecular gas necessary for star formation? Monthly Notices of the Royal Astronomical Society. 2012 March; 421(9). |
| 9. | Padoan P,LT,JM,NÅ,CD,KA,NMaUS. ‘Magnetic Fields in Molecular Clouds’. Proceedings of the International Astronomical Union. 2010 June; 6(271). |

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