Formation of Molecular Clouds and Global Conditions for Star Formation

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MVSem: Star Formation
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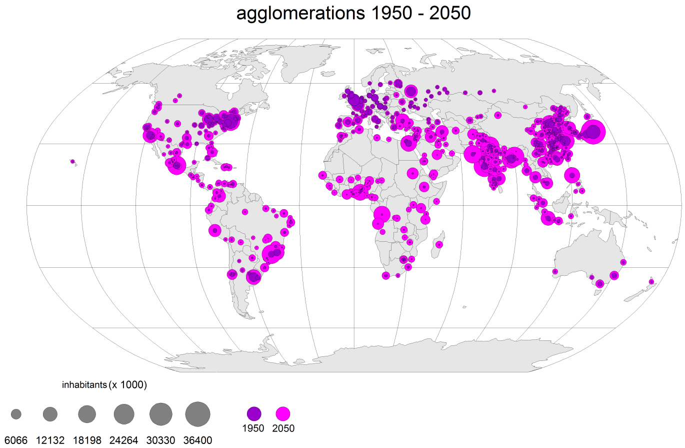
Motivation



Reference: https://de.wikipedia.org/wiki/Urbanisierung, 2016

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Credit: NASA, ESA, S. Beckwith (STScI), and the Hubble Heritage Team (STScI/AURA))

1. Introduction - Observed Properties of GMCs
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2. Formation of GMCs

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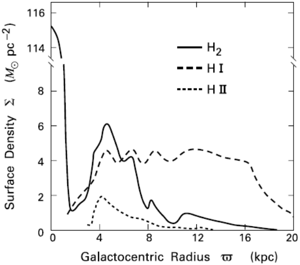
What are Giant Molecular Clouds (GMCs)?

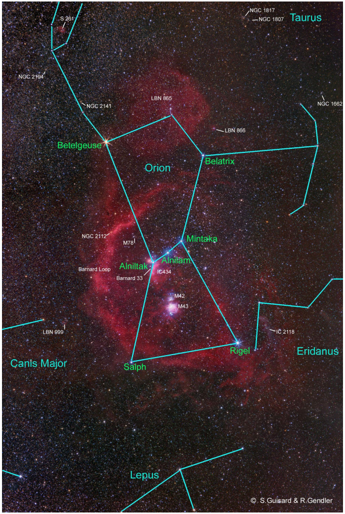
Credit: NASA, ESA, S. Beckwith (STScI), and the Hubble Heritage Team (STScI/AURA))



Reference: Stahler and Palla, 2005

- densest, coldest, highest column density, highest extinction, molecular component
- coherent, localized volumes or clouds in Milky-Way like galaxies
- mass contribution: 70% H_2, 26 % He
- radial H-distribution within spiral galaxy

What are Giant Molecular Clouds (GMCs)?

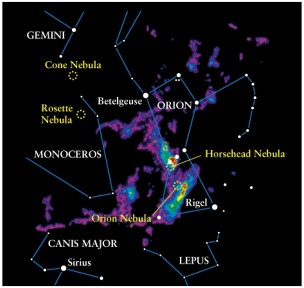


Credit: S. Guisard and R. Gendler

- $T \sim 10$ K
- $n > 300$ cm^{-3}
- environment dependent $M \sim 10^2$ - 10^9 $M_\odot$
- $M_{mol}/M_{stellar}$ increases with galaxy colors

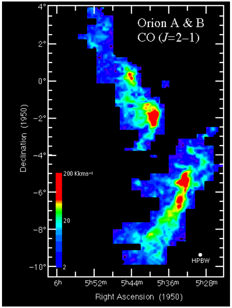
Identification of GMCs

- crucial H_2 is not detectable
- tracers as CO line emission and dust extinction



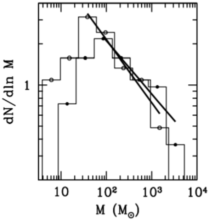
Credit: NRAO

- definition of cloud: contiguous voxels in PPV cube of CO emission above surface brightness threshold

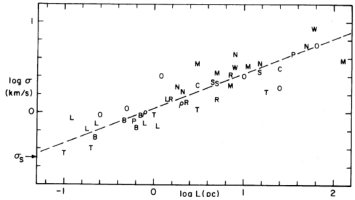


Credit: IOA/S/U-TOKYO/VST

Statistical Properties of GMCs



Reference: Williams et al., 2000



Reference: Larson, 1981

mass:

- mass spectrum powerlaw: $\frac{dN}{dM} = M^{-\gamma}$ with $\gamma < 2$

size and area:

- $\sum_{GMC}$ environment-variation
- Larson (1981) M $\propto$ A relation

velocity dispersion:

- $\sigma_V = 0.7\sqrt{\frac{\sum_{GMC}}{100 M_\odot pc^{-2}}}\sqrt{\frac{R}{1pc}}\frac{km}{s}$
- processes driving velocity structure operate on scales $\geq$ cloud

GMCs Parameter

Virial Theorem Analysis:

$$\rho(\frac{d\vec{u}}{dt} + (\vec{u}\nabla)\vec{u}) = -\nabla\vec{P} - \rho\nabla\vec{\phi_G} + \frac{1}{c}\vec{j} \times \vec{B}$$
$$2T = 2U - W + M$$

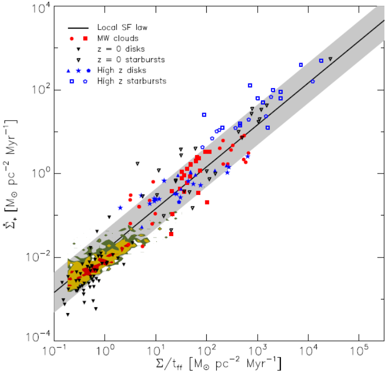
virial parameter: $\alpha_G = \frac{M_{virial}}{M_{GMC}} \sim 1$

virial mass: $M_{virial} = \frac{5\sigma^2 R}{G}$

mass to flux ratio: $\frac{M_{GMC}}{M_{cr}} \sim 2$ - 3

critical mass: $M_{cr} = \frac{\phi}{\sqrt{4\pi^2 G}}$

GMCs Parameter



Reference: Krumholz et al., 2012

- free-fall time:

$$t_{ff} = \sqrt{\frac{3 * \pi}{32 G\rho}} = 3.4 \sqrt{\frac{100}{n_{H_2}}} Myr$$

$$= 1 - 8 Myr$$

- lifetime:
  $t_{lifetime} \sim 100$ Myr
- depletion time:
  $t_{dep}(\mathrm{H_2}) = \frac{M(H_2)}{SFR} \sim 2.2$ Gyr

$$\rightarrow \mathbf{t_{ff} \ll t_{lifetime} < t_{dep}}$$

1. Introduction - Observed Properties of GMCs
2. Formation of GMCs
   - Localized Converging Flows
   - Spiral Arm Induced Collisions
   - Gravitational Instability
   - Magneto-Jeans Instability
   - Parker Instability
3. Evolution and Destruction of GMCs
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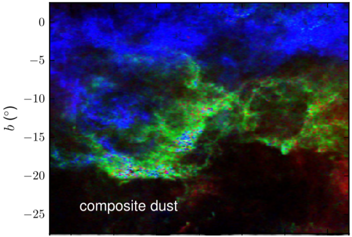
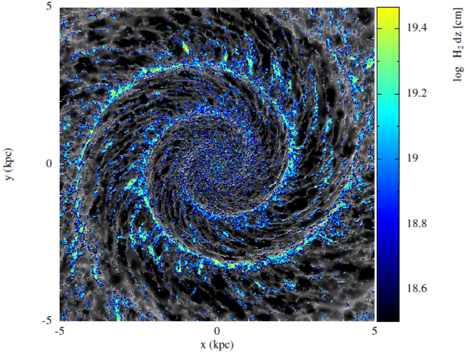
Localized Converging Flows



Reference: Schlafly et al., 2015

- stellar feedback processes drive converging flows
- HII region expansion and SNe blast waves
- scale of $\sim$ 100 pc
- simultaneous:
  mass accumulation
  $+$
  molecular phase development
  $+$
  transition from sub- to supercritical magnetic state

Spiral Arm Induced Collisions

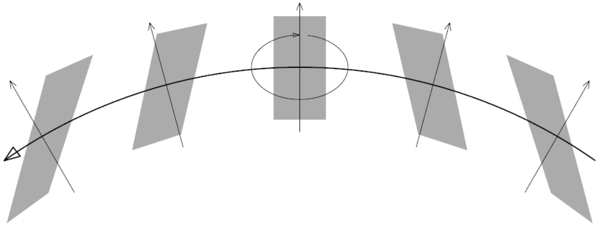


Reference: Dobbs and Pringle, 2013

- spiral arm induced small cloud collisions
- quasi-periodic spacing along arms: set by epicyclic frequency
- counter-rotating GMCs are possible

black-white: $\sum_{gas}$
colorful: integrated H_2

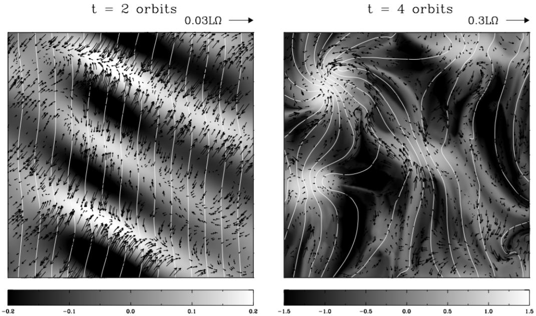
Gravitational Instability



Reference: Barnes, 2005

- axissymmetric perturbations: Toomre parameter = $\frac{kc_{eff}}{\pi G \sum} < 1$
- linear perturbation theory
- analoguous to swing-amplifiaction
- calculated M too high $\rightarrow$ multiphase medium

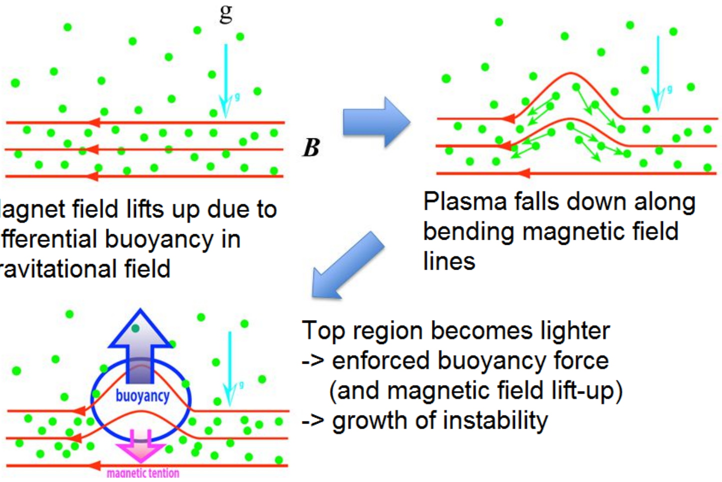
Magneto-Jeans Instability



Reference: Kim and Ostriker, 2001

- magnetized gas disk
- low-shear disk
- linear perturbation theory
- magnetic tension counteracts $F_{coreolis}$

Parker Instability



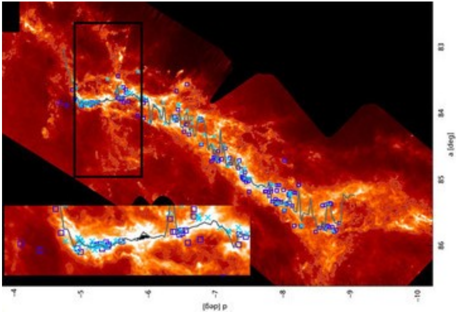
Magnet field lifts up due to differential buoyancy in gravitational field

Plasma falls down along bending magnetic field lines

Top region becomes lighter
-> enforced buoyancy force
(and magnetic field lift-up)
-> growth of instability

Reference: Mizuno, 2015

Structure of GMCs



Credit: A. M. Stutz / MPIA

Formation → Structure → Evolution → Destruction

→ clumpy

→ filamentary

1 Introduction - Observed Properties of GMCs

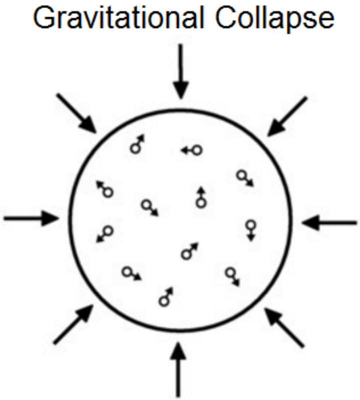
2 Formation of GMCs

3 Evolution and Destruction of GMCs
- Global Collapse Scenario
- External and Internal Driving Scenario
- Mass Loss and Disruption

4 Star Formation Rate of GMCs

5 Conclusion

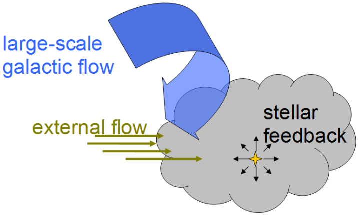
Global Collapse Scenario



Reference: Lang, 2016

- collision between 2 warm, diffuse gas streams
  $\rightarrow$ cold cloud formation
  $\rightarrow$ M_J decreases
  $\rightarrow$ fragmentation into clumps
  $\rightarrow$ formation of sheets and filaments
- SFR too high
- smaller lifetimes

External and Internal Driving Scenario



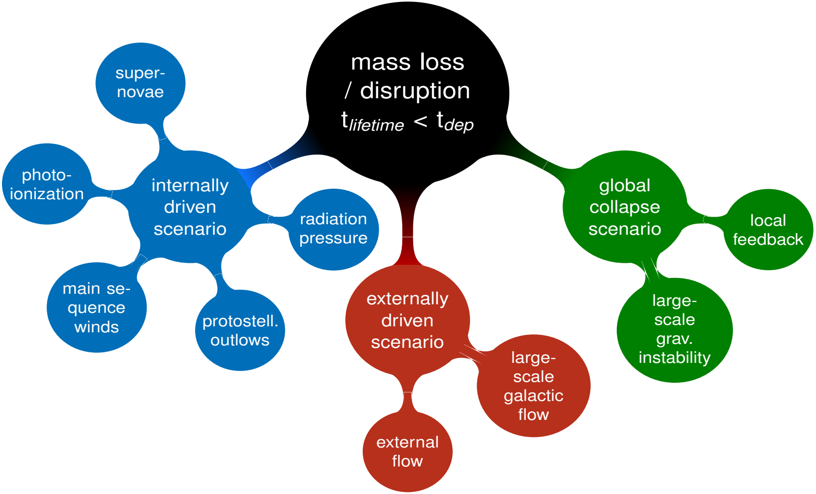
External:

- injection of energy by external flow
- large-scale galactic flow $\rightarrow$ subject of continuous external buffeting

Internal by stellar feedback:

- HII regions
- radiation pressure
- stellar winds
- protostellar outflows

Mass Loss and Disruption



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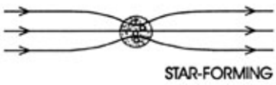
How do Stars form in the frame of evolution?

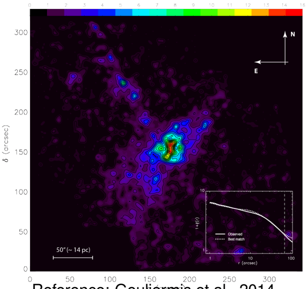
$t_{ff} \ll t_{lifetime} < t_{dep} <$ quasi-steady state
star formation regulation required

magnetic theory:



Reference: Vallee, 2016

supersonic turbulent motions:



Reference: Gouliermis et al., 2014

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localized coverging flows,
spiral arm induced collisions,
gravitational, magneto-jeans, and parker instability
produce GMCs

$\downarrow$

gravitational collapse, externally or internally driven scenarios control cloud evolution

$\downarrow$

magnetic or turbulent supports regulate SFR