Plan of Lecture

Stellar Clusters and Star Formation

How can we infer the evolution of stars?

Observations of star clusters.

The collapse of molecular clouds.

The birth of stars.

Challenge Questions

Current challenge questions:

1. How far is the most distant individually detected star?

2. What star has the greatest measured proper motion?

3. How does metallicity correspond to location in our Galaxy?

4. How are mass measurements used to identify black hole candidates?

5. What evidence is there for a high-mass cutoff in stars?

6. How does the ISM differ between types of galaxies?

Observations of Stellar Evolution

We have observed stars closely for $\sim$100 yr.

Lifetime of Sun: $\sim 10^{10}$ yr.

Like humans for 20 seconds!

How, then, do we infer lifetimes of stars?

Combination of theory, observation.

Earth: age $\sim 4.5 \times 10^9$ yr.

Suggests Sun is roughly steady.

Nuclear fusion is power source of stars.

Stars have limited time on MS.

Bigger stars burn faster.

From binaries, spectral types, infer mass-lifetime relation.

Stellar Clusters

What we really need is *uniformity* in our observations.

Consider a stellar cluster.

All stars at $\sim$same distance.

All stars have $\sim$ same age.

Several types of clusters in our Galaxy.

Open clusters: few hundred stars, found in disk of Galaxy, young (e.g., Pleiades).

Globular clusters: spherical groups of 10^{5-6} stars, out of disk, old (e.g., Hercules, M13).

OB associations: loose groups of hot stars (O and B), very weakly bound (dissolving), recently formed.

Use of Stellar Clusters

Construct an H-R diagram of a cluster.

Apparent magnitude vs. color index.

Shift in vertical scale gives distance.

Don't know age of individual star on main sequence.

But, know age it evolves off.

Hot stars evolve off first.

Older clusters $\Rightarrow$ cooler turnoff stars.

This, plus stellar evolution, gives age.

Lessons From Stellar Clusters

From looking at extremely young to very old clusters, get qualitative idea of stellar evolution.

Very young: only MS stars.

Slightly older, get red giants.

Older still, white dwarfs.

No evidence for evolution *along* main sequence.

Suggests MS→red giant→white dwarf. True for most stars, but not all...

Still need theory to get *absolute* ages.

Use Sun for calibration!

Young Clusters and Molecular Clouds

OB associations are usually found near giant molecular clouds.

No time to move from formation site.

Thus, stars form from mol. clouds!

Orion has one of the best-studied GMCs.

OB association: Trapezium.

In IR, see 10^{4-5} stars.

Many low-mass stars in gas.

Low-mass stars have outflows, inflows, very complicated.

Star formation is apparently very inefficient: only $\sim 10\%$ of gas turns into stars.

Regions of single star formation are small, highly extincted, tough to observe.

Steps in Star Formation

A star forming from a molecular cloud is a big change!

Enormous range in density.

How does it get so much denser?

But there are many other questions we could ask.

Why many stars, not one big one?

How does fusion start?

Do all stars form the same way?

Why are there so many binaries?

Not all these questions have been answered!

But, we can start with some basic questions.

Right Now, Your Main Problem is Gravity

Many astrophysical processes can be characterized as gravity vs. everything else.

Gravity is always attractive.

What *stops* things from collapsing?

What allows others to contract?

Imagine isolating a tiny patch of a GMC.

Drift apart (thermal motion).

Now, larger region.

Gravity slows drift.

Big enough $\Rightarrow$ contraction!

For given density, temperature: Jeans mass M_J; larger masses collapse.

Typically $\sim 10^6\, M_\odot$ for GMC.

Why no $10^6\, M_\odot$ stars?

Start of the Collapse

As cloud collapses and cools, density increases.

Jeans mass drops.

Subclumps form.

These collapse independently.

This is one reason why ultramassive ($10^6\,M_\odot$!!) stars aren't forming now.

If cloud can't cool easily, might get very massive stars.

This might have happened in the very early universe.

Only H, He present.

Fewer cooling pathways.

Putting a Spin on Clouds

What happens as the clumps contract?

They had to have *some* initial spin.

Angular momentum is conserved.

Spin rate increases during collapse.

But the amount of collapse is enormous!

1 pc cloud $\rightarrow \sim 10^{-7}$**pc star.**

Spin rate exceeds orbital rate; can't collapse any more.

Must get rid of angular momentum to form star.

Main way: form disk.

Also, binaries help.

What About Magnetic Fields?

Spin isn't the only thing that can delay collapse.

The clouds are permeated by weak magnetic fields ($\sim 10^{-7}$ of a refrigerator magnet!).

But, collapsing clouds squeeze the fields, and the fields provide pressure.

If this halts collapse, fields will eventually diffuse out and collapse will resume.

Slows, but doesn't stop collapse.

If mass of clump is big enough, might collapse right through the fields.

Some have suggested this is a difference between high-mass and low-mass star formation.

Protostars

If gas contracts enough (say, $\sim 1\ M_\odot$ in a ~ 1 AU radius), energy is released.

Gravitational contraction.

Like Jupiter.

Luminous, but predicted to be reddish because very large.

Upper right on H-R diagram.

***Not* red giants!**

Not observed; too obscured.

Contraction in core, protostar grows as material flows on.

Infalling material forms a disk (angular momentum).

Planetary growth?

Towards the Main Sequence

As gas settles towards center, central density and temperature increase.

At some point, “nuclear ignition”: fusion of H to He starts.

Still infalling gas.

Luminosity creates a wind from the star.

Drives off gas, forms outflow.

Eventually settles to main sequence.

High-mass stars do all of this much faster than low-mass!

Summary

Star clusters are important for understanding of evolution.

Stars form from molecular clouds.

Collapse due to gravity.

Angular momentum issues.

Magnetic fields, too.

Protostar powered by gravitational contraction.

Nuclear ignition starts the main sequence.

Big stars live fast!

Challenge: why is star formation common in colliding galaxies?