

# Star Formation

Dr Sarah Jaffa

University of  
Hertfordshire **UH**

School of Physics,  
Astronomy and Mathematics

# OVERVIEW

- 1 Basics of star formation
- 2 Why is star formation important?
- 3 Current challenges in star formation

THEORY

OBSERVATION

SIMULATION

# OVERVIEW

## 1 Basics of star formation

Making a star

Lifetime of a star

Death of a star

## 2 Why is star formation important?

## 3 Current challenges in star formation

## Star Formation

Dr Sarah Jaffa  
(U. Herts)

Overview

Basics of star formation

Making a star

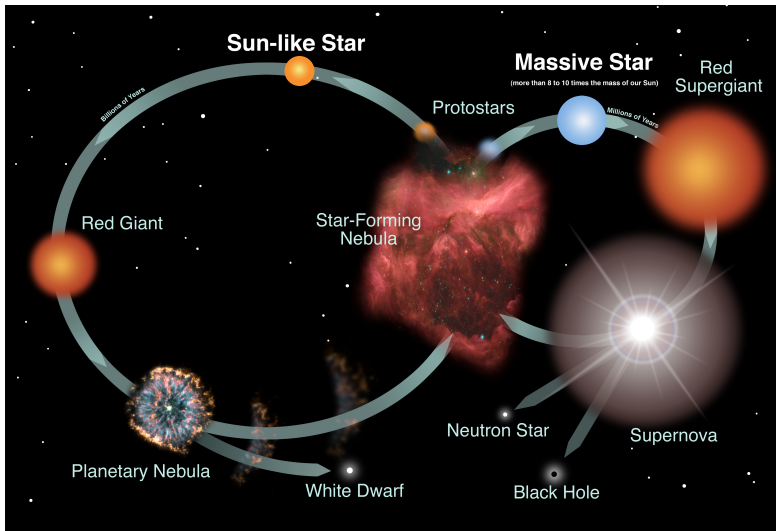
Lifetime of a star

Death of a star

Why is star formation important?

Current challenges in star formation

# MAKING A STAR



Credit: NASA and the Night Sky Network

# Star Formation

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(U. Herts)

## Overview

### Basics of star formation

#### Making a star

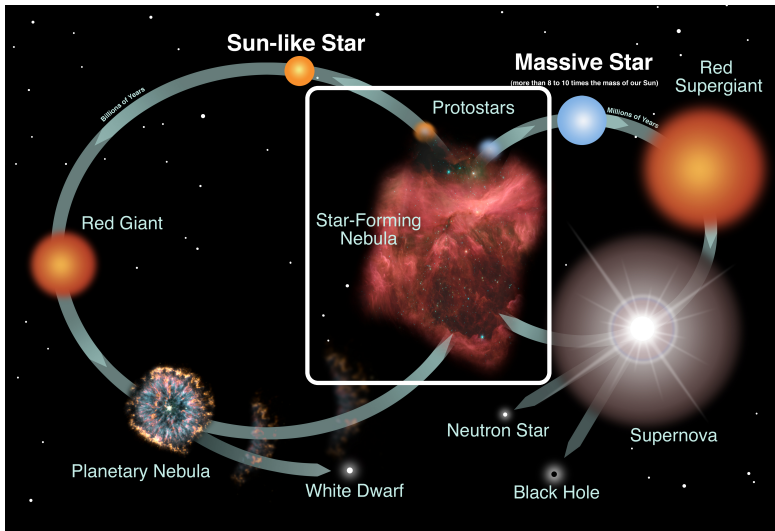
Lifetime of a star

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### Why is star formation important?

### Current challenges in star formation

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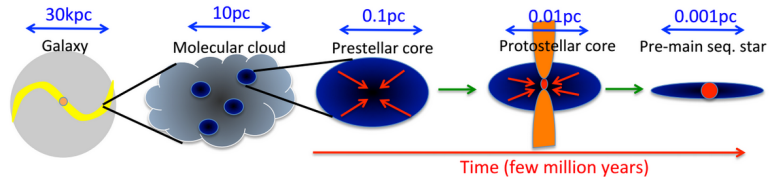


Illustration by N. Peretto, Cardiff

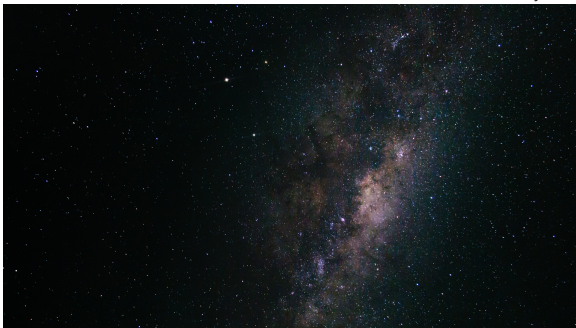


Photo by Thom Schneider on Unsplash

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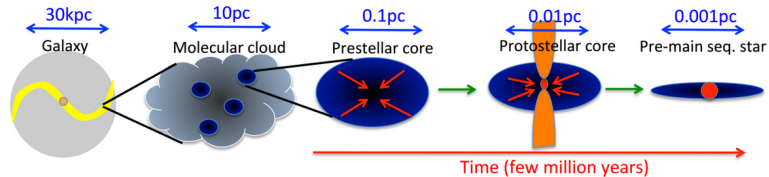


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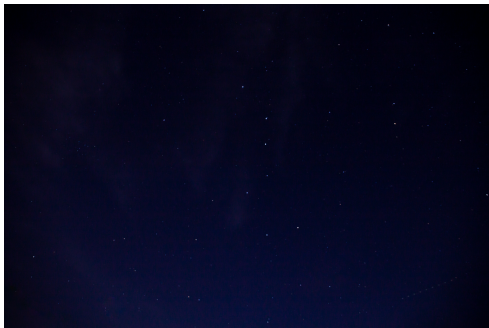


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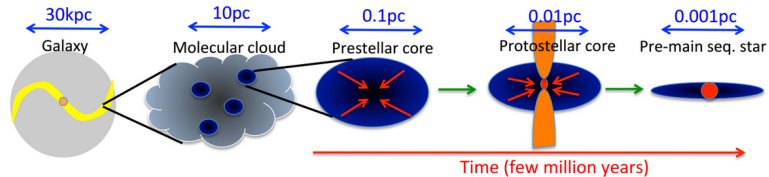


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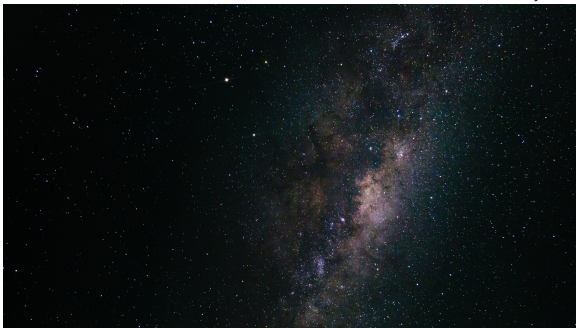


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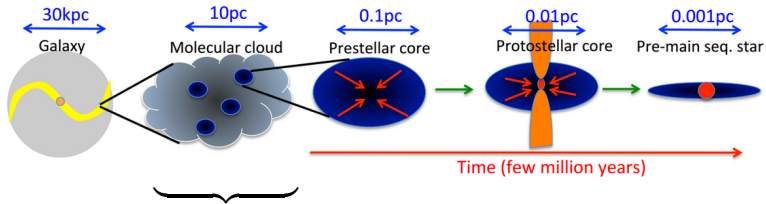


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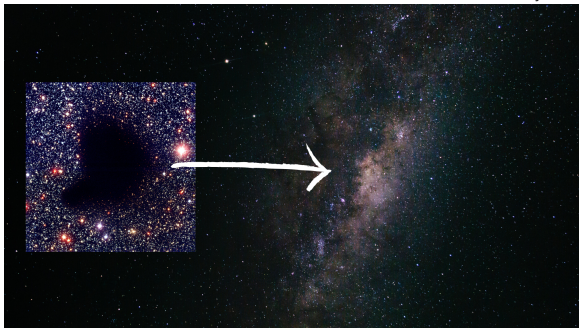


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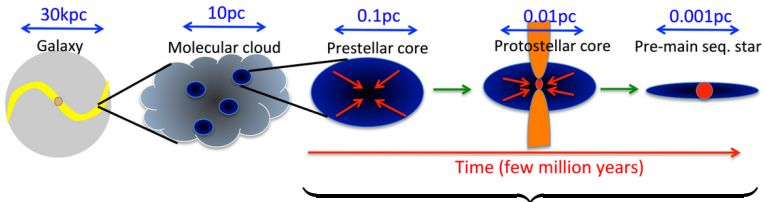
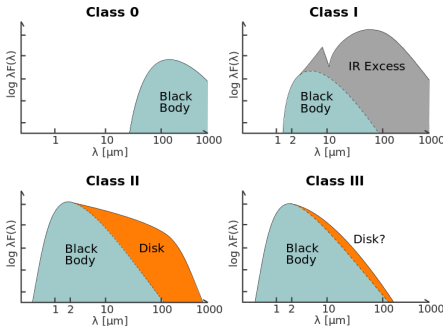
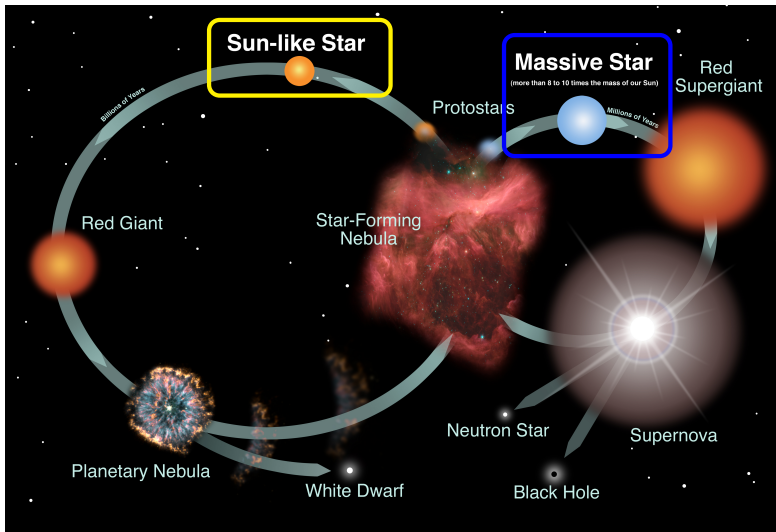


Illustration by N. Peretto, Cardiff



# LIFETIME OF A STAR



Credit: NASA and the Night Sky Network

# LIFETIME OF A STAR

Overview

Basics of star formation

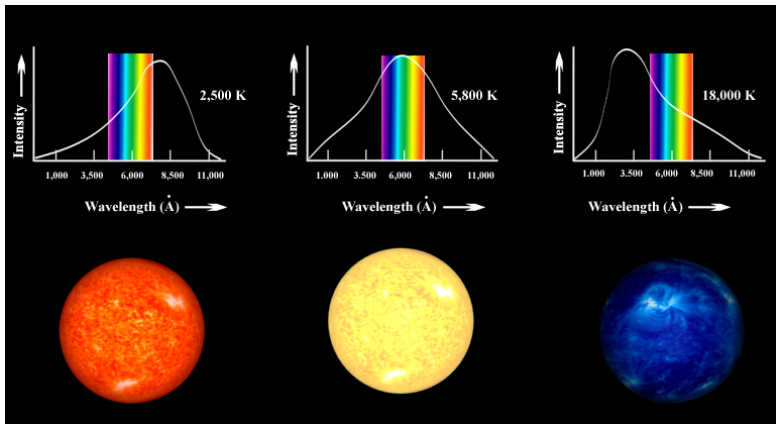
Making a star

Lifetime of a star

Death of a star

Why is star formation important?

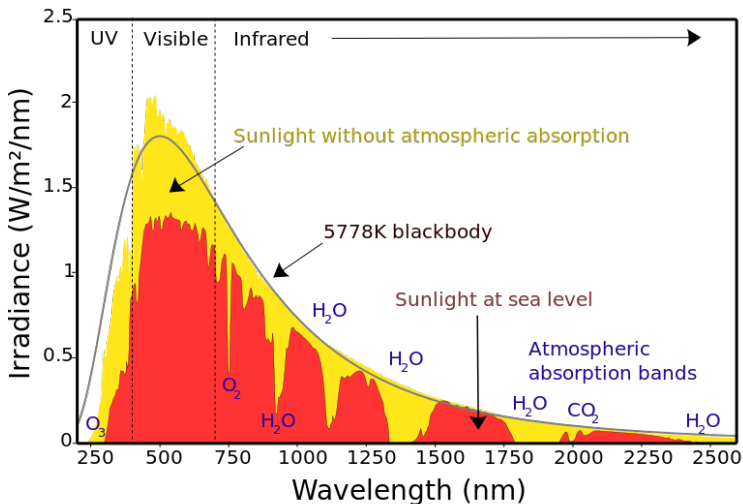
Current challenges in star formation



Copyright 2001-2020 Jason Harris and the KStars Team

# LIFETIME OF A STAR

## Spectrum of Solar Radiation (Earth)



# LIFETIME OF A STAR

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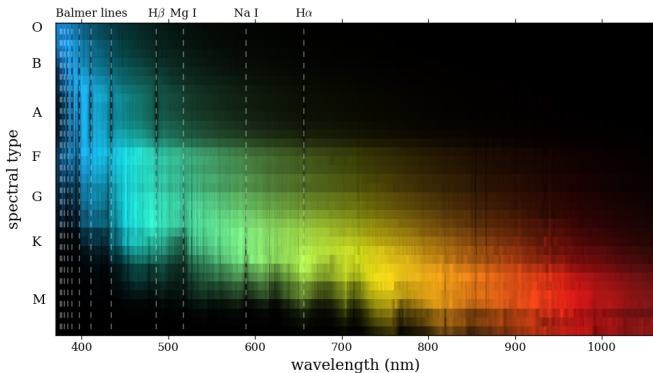


Image from Wikimedia by Warrickball

# LIFETIME OF A STAR

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Basics of star  
formation

Making a star

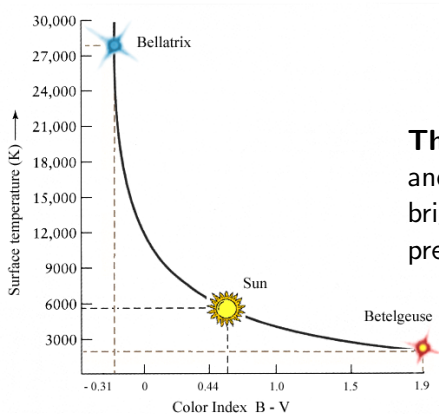
Lifetime of a star

Death of a star

Why is star  
formation  
important?

Current  
challenges in  
star formation

## Hertzsprung-Russell Diagram



**Theory:** Mass dictates radius and central pressure, so brightness and temperature are predictable.

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# LIFETIME OF A STAR

## Hertzsprung-Russell Diagram

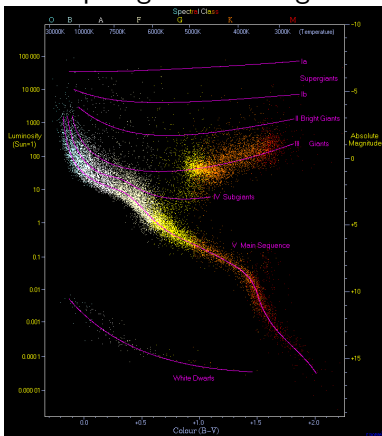


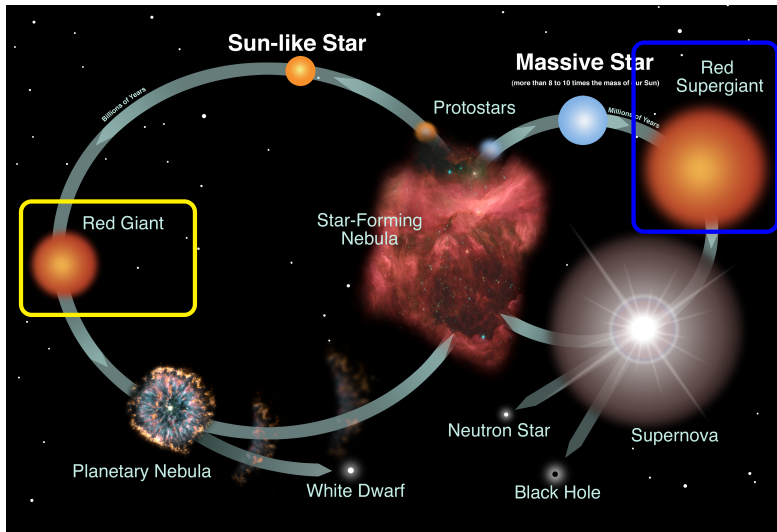
Illustration by Richard Powell WikiMedia Commons

**Theory:** Mass dictates radius and central pressure, so brightness and temperature are predictable.

**Observation:** main sequence (stable middle part of the lifecycle) stars lie on the diagonal

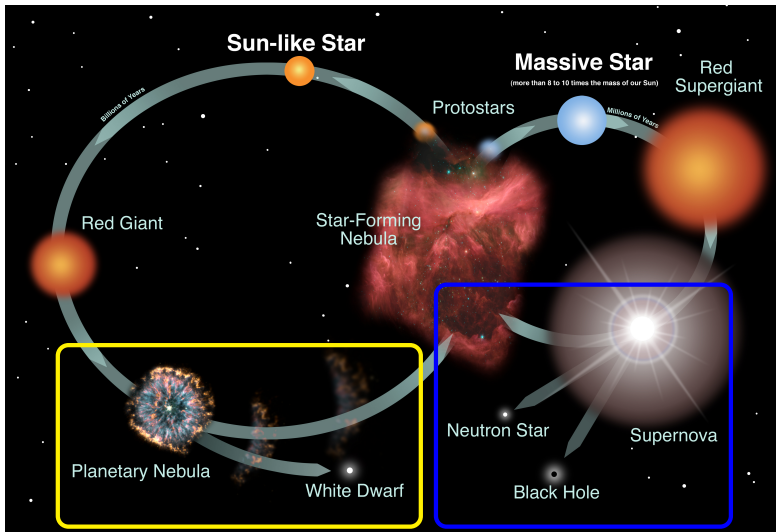


# DEATH OF A STAR



Credit: NASA and the Night Sky Network

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# OVERVIEW

- 1 Basics of star formation
- 2 Why is star formation important?
  - Planets and life
  - Galaxies
  - Cosmology
- 3 Current challenges in star formation

# PLANETS AND LIFE

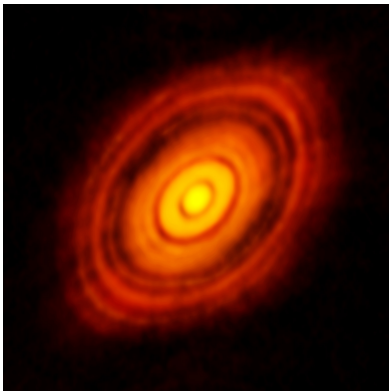


Image from ALMA (ESO/NAOJ/NRAO)

Planet formation:  
How, when and where?

First observation of gaps in a  
protoplanetary disc:  
HL Tau, ALMA, Brogan et al.,  
ApJL, 2015

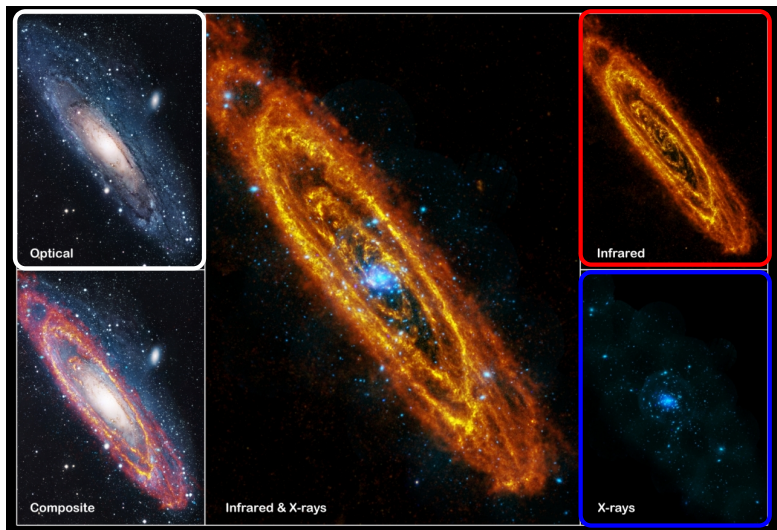
# GALAXIES



**Multiwavelength M31:** infrared: ESA/Herschel/PACS/SPIRE/J. Fritz, U. Gent; X-ray:

ESA/XMM-Newton/EPIC/W. Pietsch, MPE; optical: R. Gendler

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# COSMOLOGY

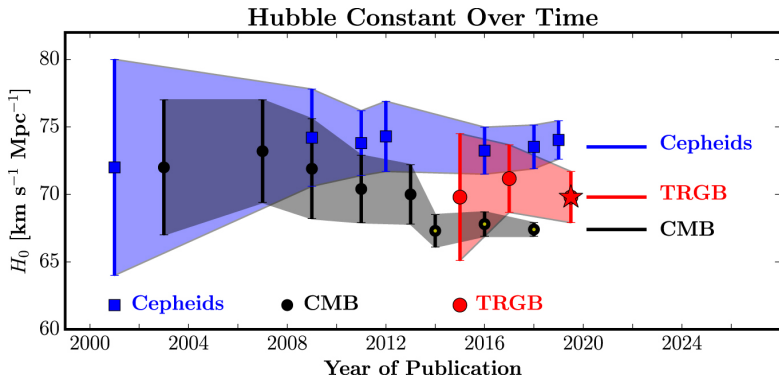


Image from W. Freedman et al., ApJ, 2019

# COSMOLOGY

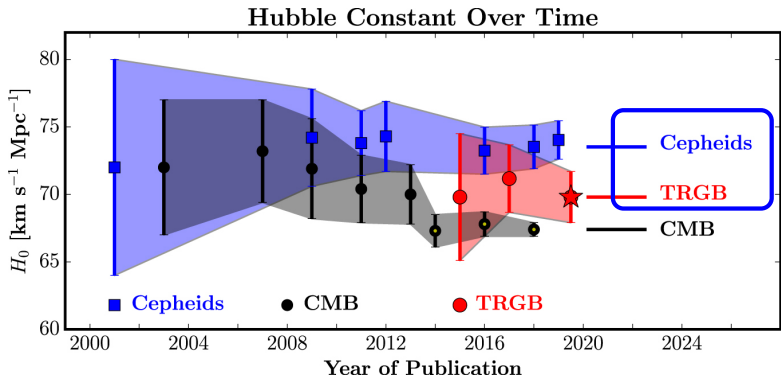


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# OVERVIEW

- 1 Basics of star formation
- 2 Why is star formation important?
- 3 Current challenges in star formation
  - Big questions
  - Big telescopes
  - Big data
  - Big issues

# BIG QUESTIONS

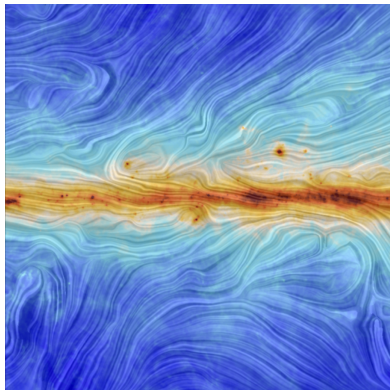
- 1 Magnetic fields
- 2 Structure and lifetime of clouds
- 3 Initial Mass Function and massive stars
- 4 Planets
- 5 Comparing simulations and observation

## MAGNETIC FIELDS

### Very hard to detect!

**Direction:** Elongated dust grains align with the magnetic field producing polarised light, but dust formation/growth theory is quite uncertain, lots of dust along the line of sight, measurements change with scale.

**Strength:** Zeeman splitting of  $H\alpha$  line visible against very bright background sources.



ESA/Planck Collaboration/Miville-Deschênes

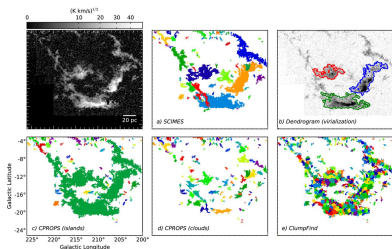
# STRUCTURE AND LIFETIME OF CLOUDS

## What is a cloud?

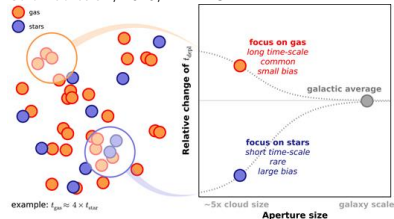
Each tracer detects different density/temperature.  
'Cloud identifying' algorithms are highly inconsistent and tuneable.

## How long do they live?

What percentage is turned into stars vs. dispersed by feedback?  
Are they static or dynamic?

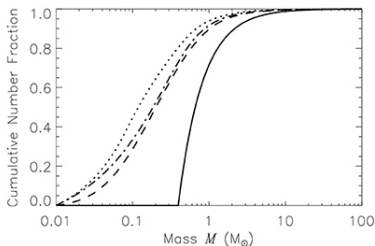
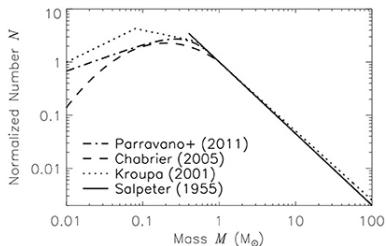


Colombo et al., 2015, MNRAS



Kruijssen et al., 2018, MNRAS

# INITIAL MASS FUNCTION AND MASSIVE STARS



Krumholz et al., 2019, FrASS

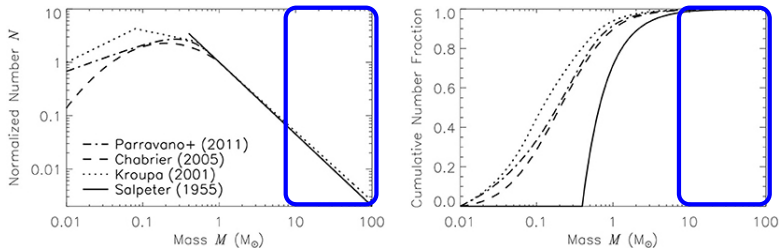
## What is the mass of a star when it is born?

Observed distribution of masses in clusters is universal?

Larger stars have shorter lifespans so may not be observed at all. Smaller stars are faint and hard to observe.

Is it the same in all galaxies/clusters, or varies with environment?

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# PLANETS

At what stage of the star formation process do planets start to form?

How long do disks last and how are they affected by the forming star or others nearby?

Which type of stars are likely to sustain life?

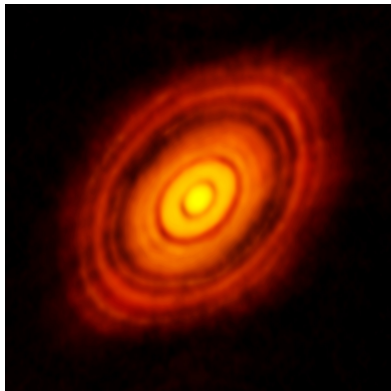


Image from ALMA (ESO/NAOJ/NRAO)

## Is the Solar System special?

Image from NASA/Kepler/Dan Fabricky

Overview

Basics of star  
formation

Why is star  
formation  
important?

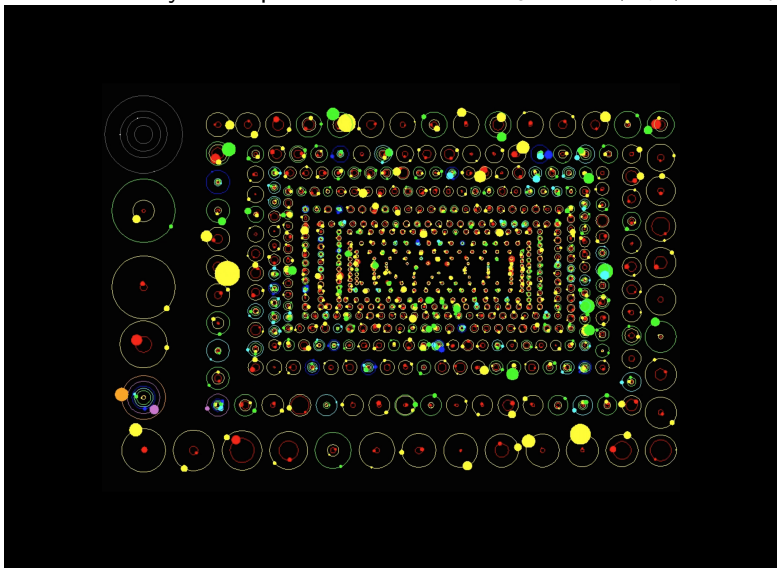
Current  
challenges in  
star formation

Big questions

Big telescopes

Big data

Big issues





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Big issues

Explains Travel Bureau

PLANET HOP FROM TRAPPIST-1e

VOTED BEST "HAB ZONE" VACATION WITHIN 15 PRICES OF EARTH

Small text at the bottom: Based on information from NASA's planet-hunting mission TRAPPIST-1, which is now being studied in detail by the European Space Agency and other researchers. The poster is not intended to be a travel brochure for the TRAPPIST-1 system. It is a work of fiction. The poster is not intended to be a travel brochure for the TRAPPIST-1 system. It is a work of fiction. The poster is not intended to be a travel brochure for the TRAPPIST-1 system. It is a work of fiction.

Explains Travel Bureau

EXPERIENCE THE GRAVITY OF HD 40307g A SUPER EARTH

Small text at the bottom: Based on information from NASA's planet-hunting mission HD 40307, which is now being studied in detail by the European Space Agency and other researchers. The poster is not intended to be a travel brochure for the HD 40307 system. It is a work of fiction. The poster is not intended to be a travel brochure for the HD 40307 system. It is a work of fiction.

<https://exoplanets.nasa.gov/alien-worlds/exoplanet-travel-bureau/>

# COMPARING SIMULATIONS AND OBSERVATION

## Simulations:

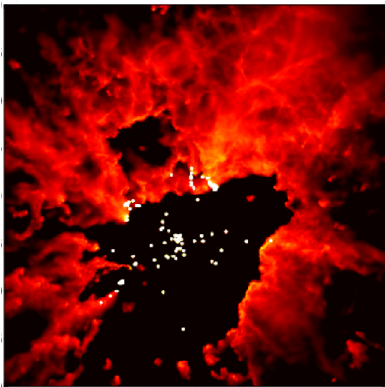


Image from Dale, 2014, MNRAS

## Observations:

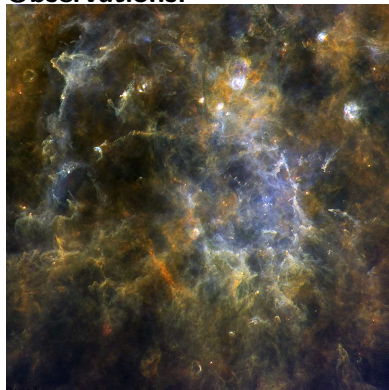


Image from ESA/Hi-GAL Project

# COMPARING SIMULATIONS AND OBSERVATION

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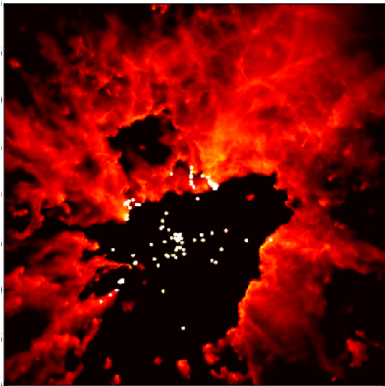


Image from Dale, 2014, MNRAS

Density

## Observations:



Image from ESA/Hi-GAL Project

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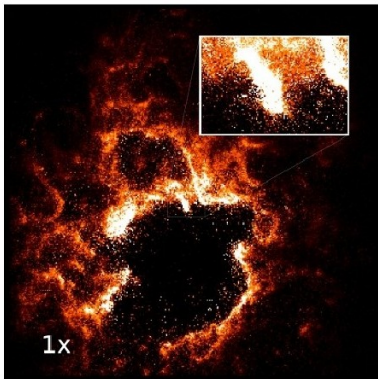


Image from Haworth et al., 2018, NewAR

Density  $\rightarrow$  emission

## Observations:

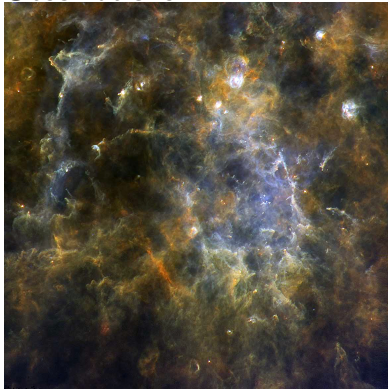


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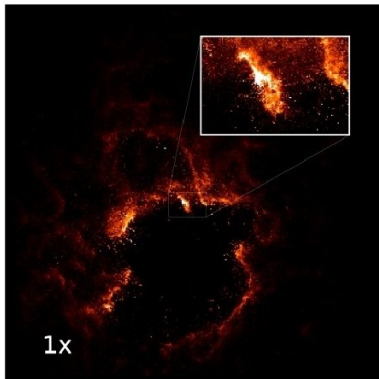


Image from Haworth et al., 2018, NewAR

Density  $\rightarrow$  emission + dust

## Observations:

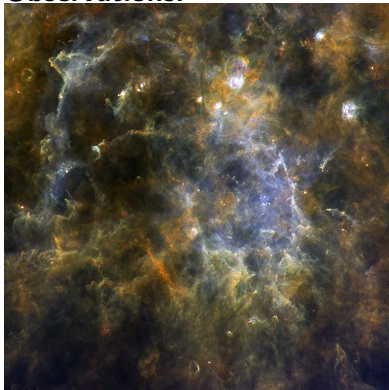


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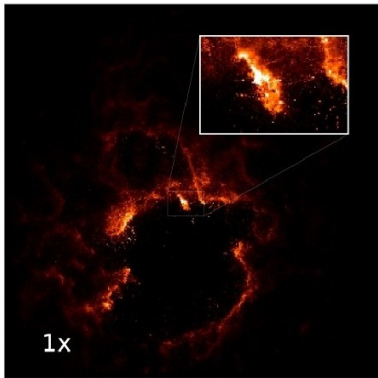


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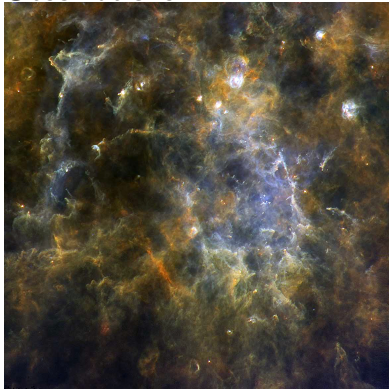


Image from ESA/Hi-GAL Project

Density  $\rightarrow$  emission + dust + pixelation

# COMPARING SIMULATIONS AND OBSERVATION

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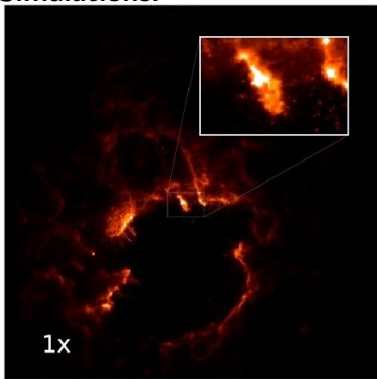


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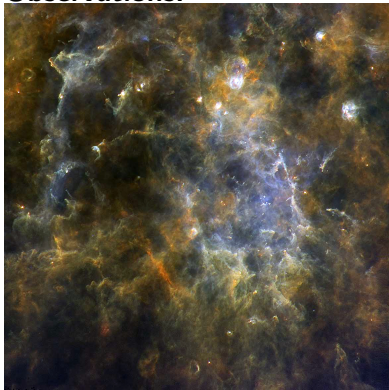


Image from ESA/Hi-GAL Project

Density  $\rightarrow$  emission + dust + pixelation + point spread  
function

# COMPARING SIMULATIONS AND OBSERVATION

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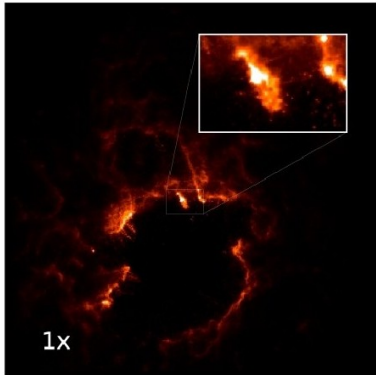


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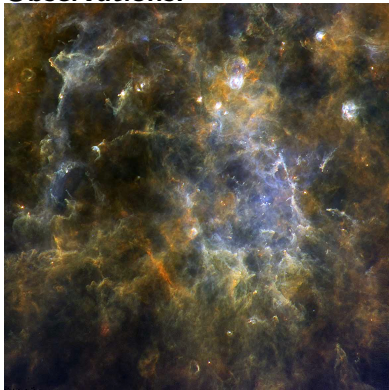


Image from ESA/Hi-GAL Project

Density  $\rightarrow$  emission + dust + pixelation + point spread  
function + thermal noise



# COMPARING SIMULATIONS AND OBSERVATION

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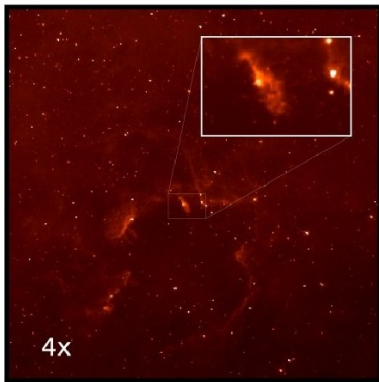


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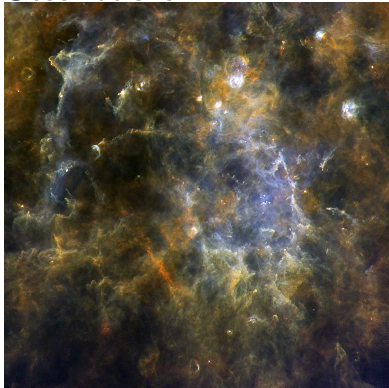


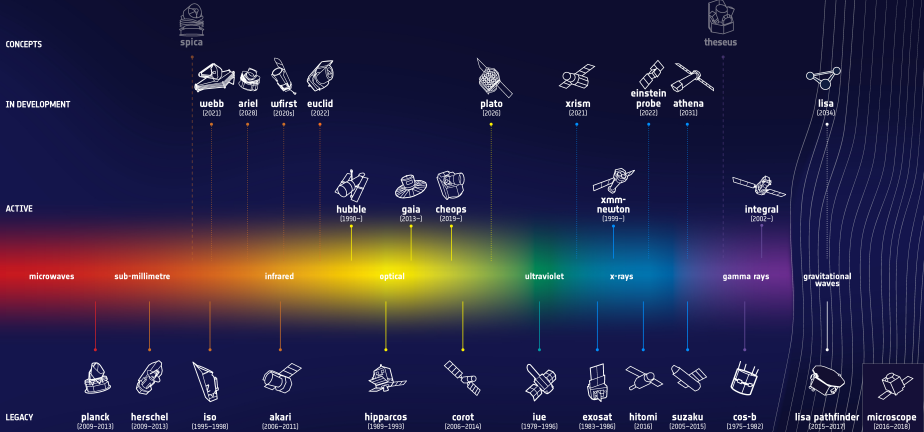
Image from ESA/Hi-GAL Project

Density  $\rightarrow$  emission + dust + pixelation + point spread  
function + thermal noise + background...

# BIG TELESCOPES



## → COSMIC OBSERVERS



# BIG TELESCOPES

Better sensitivity

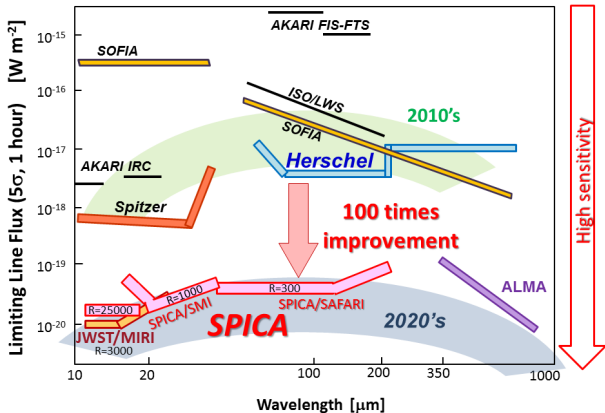
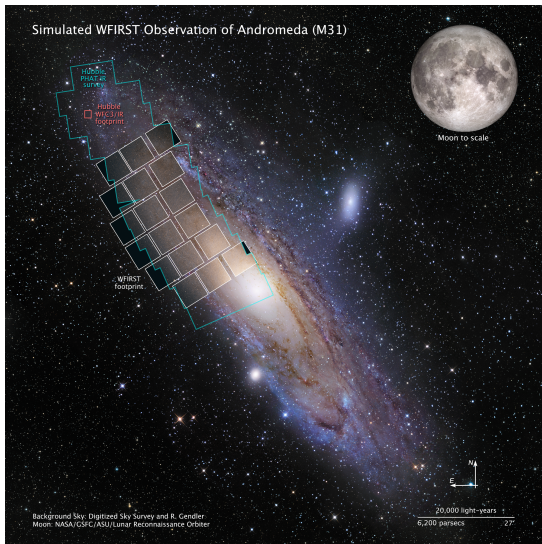


Image from JAXA/SPICA

# BIG TELESCOPES

## Bigger field of view



# BIG DATA

The ALMA array records a terabyte per night

Image by ESO/B. Tafreshi



First image of a black hole:  
5 petabytes of data



Image: EHT Collab.

Simulations can take months  
or years to run

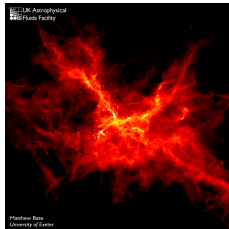


Image from Bate, 2009, MNRAS

## Storing

- Every institute has their own computing facilities.
- ECRs moving jobs abandon data
- Who monitors responsible usage?

## Analysing

- OPEN SOURCE CODE
- Data processing requirements - memory? GPUs?

## Sharing and communicating

- Plots in papers
- Data shared on request?
- Statistical and graphical skills to effectively summarise and communicate data

# BIG DATA



# BIG ISSUES

- Publishing and Plan S
- Covid-19 and lockdown
- Brexit and international science
- Climate change and conferences





# BLACK ASTRONOMERS MATTER

**BLACK LIVES MATTER**

The logo for Black Lives Matter, featuring the text "BLACK LIVES MATTER" in a bold, white, sans-serif font. Below the text are three horizontal yellow lines of varying lengths, with the longest line at the bottom.

**STEPHEN  
LAWRENCE  
CHARITABLE  
TRUST**

# Thank you!

Slides of this talk with full references will be available on my website:

[sjaffa.github.io](https://sjaffa.github.io)

Email: [s.jaffa@herts.ac.uk](mailto:s.jaffa@herts.ac.uk)

Twitter: [@astro\\_biscuit](https://twitter.com/astro_biscuit)

Dr Sarah Jaffa, AMInstP, FRAS  
University of Hertfordshire

**University of  
Hertfordshire UH**

School of Physics,  
Astronomy and Mathematics

## Image sources

**Carina:** [http://www.esa.int/ESA\\_Multimedia/Images/2018/03/Chaotic\\_web\\_of\\_filaments\\_in\\_a\\_Milky\\_Way\\_stellar\\_nursery](http://www.esa.int/ESA_Multimedia/Images/2018/03/Chaotic_web_of_filaments_in_a_Milky_Way_stellar_nursery)

**Protostar SEDs:** Persson, Magnus Vilhelm (2014): SEDs of the different protostellar evolutionary stages. figshare. Figure. <https://doi.org/10.6084/m9.figshare.1121574.v2>

**Star lifecycle:** <https://imagine.gsfc.nasa.gov/science/objects/stars1.html>

**Star colours:** <https://docs.kde.org/trunk5/en/extragear-edu/kstars/ai-colorandtemp.html>

**Spectra:** By User:Warrickball, CC BY-SA 4.0,

<https://commons.wikimedia.org/w/index.php?curid=52451585>

**Sun spectrum:** By Nick84 - File:Solar\_spectrum\_ita.svg, CC BY-SA 3.0,

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