1. Introduction

P. Hily-Blant

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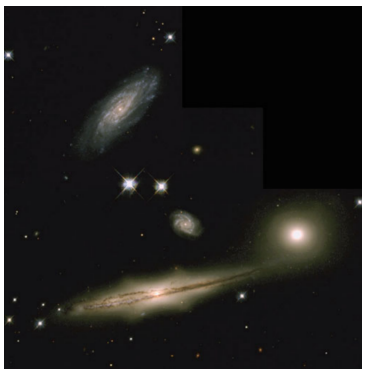
1 Evolution of the universe



"Compact galaxy group HCG87 imaged by HST"

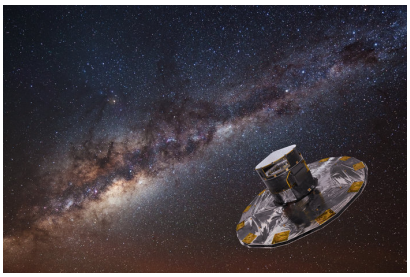
- ▷ Group = galaxies in gravitational interaction
  - bottom and top: edge-on spiral galaxies; on-going star formation
    - bottom is an active galaxy (AGN)
  - right: old, elliptical galaxy; no star formation
  - center: background elliptical, not related to the group
- ▷ Gas streams between the three galaxies in this group

Interacting galaxies and mergers

- ▷ Gravitational interaction and gas streams trigger star formation and active galactic nucleus
- ▷ Interactions play an important role in the evolution of galaxies
  - Interactions lead to merging events
- ▷ They were more common 10 billion years ago

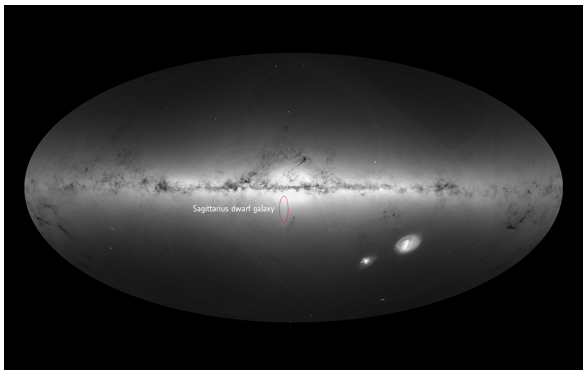
"A group of four interacting galaxies (mistakenly) called Stephan's quintet (Hickson Compact Group 92, HCG 92) discovered by the French astronomer Édouard Stephan in 1877. Image: JWST. See here for more details."

Recent discovery: Gaia-Sausage-Enceladus



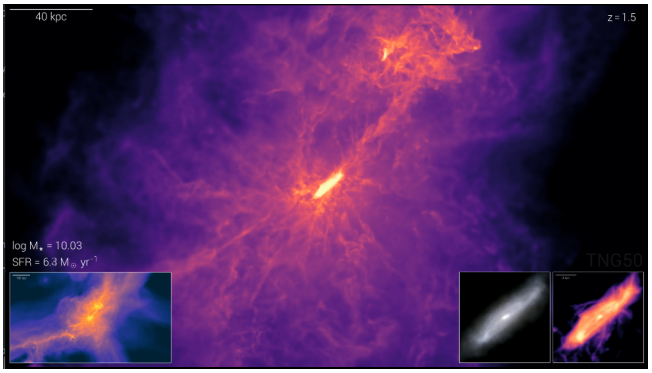
- Gaia-Enceladus: a major merger, 10 Gyr ago, that contributes ~40% of halo stars; could explain the origin of the thick disk (Helmi et al 2018)
- Movie and more information

Milky Way assembly history



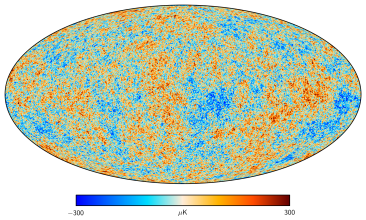
- Disruption of satellite galaxies
- Sagittarius dwarf spheroidal: galaxy discovered in 1994, at d=20kpc from Earth
- Contains the M54 globular cluster

Numerical simulations of galaxy formation and evolution



- Main panel: gas density, transitioning to gas metallicity during the brief pause and rotation.
- Lower left: large-scale dark matter and then gas
- Lower right: small-scale stellar and gaseous distributions
- Movie and another movie

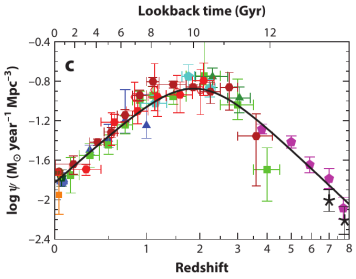
From homogeneous to inhomogeneous universe



"Cosmic Microwave Background (CMB) measured by Planck satellite"

- Map of the temperature of the first propagating light of the universe: T_{CMB} = 2.73 K
- Isotropic (same from all directions) with very small inhomogeneities: Δ T/T ~ 10^{-5} (max 300μ/3)
- These small fluctuations have been amplified by gravity
  - overdense regions expand more slowly
  - density contrasts increase
  - gravitational instability leads to star formation and galaxy formation
  - purely baryonic models require Δ T/T ~ 10^{-3} $\gg$ observed: solution involves non-baryonic (dark) matter
  - See Lecture by Jean-Louis Monin

The star formation history



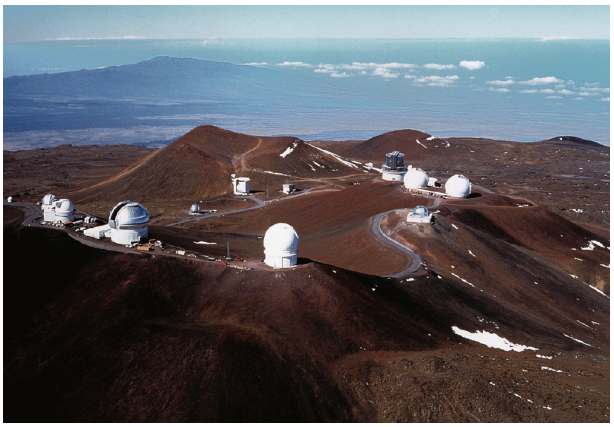
- Star formation began ~ 300 million years after Big Bang
  - the first stars are called Population III stars (Pop I is the current population)
  - Pop III stars are responsible for the re-ionization of the universe after the dark (opaque) ages
- Today, star formation is low: 1 solar mass per year per Mpc^3 (1pc = 3.1 $\times 10^{16}$m = 3.26 ly)
- SF reached a maximum 10 Gyr ago: strong interactions between galaxies (streams of matter)

One of the major question in astrophysics is to understand star formation to explain this plot and the history of the universe

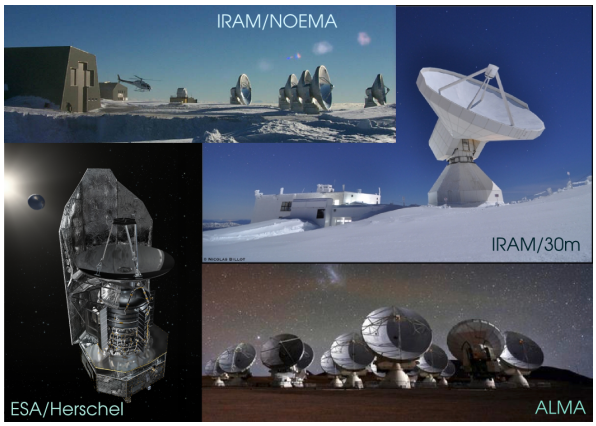
2 Science = theory + observations

- Observe the Universe and use Physical laws to understand the formation and evolution of the Universe and the objects within
- Establish the Physical laws, confront their consequences to observations, etc
- Science is 'true until it can be shown it fails'; in some sense, science is always wrong, but true until some observations show it is wrong;
- You must understand the basics of observational techniques and you must master the underlying fundamental physical laws
- Astrophysics is very specific
  - sample return is out of range (in most instances)
  - remote sensing: electromagnetic and gravitational waves
    - radiative transfer: use photons to know about the source, and about the traversed medium;
    - multi-wavelength observations

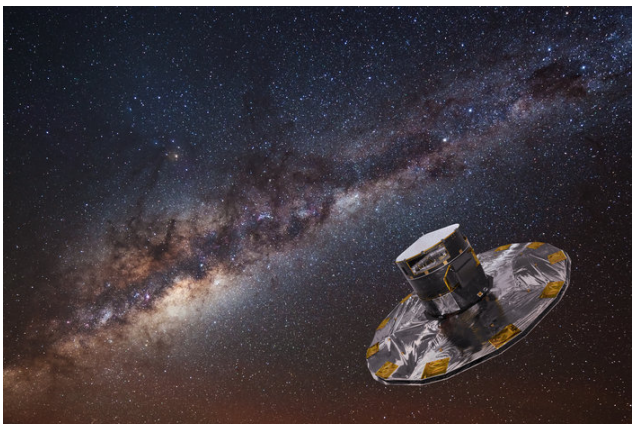
Optical telescopes: Visible light from stars



Radiotelescopes: the birth of stars and planets



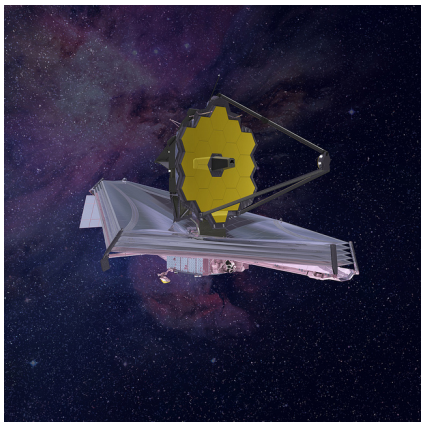
The ESA/Gaia telescope: stars



The Hubble Space Telescope: the local Universe

Hubble Against Earth's Horizon
Image Credit: NASA, 1997

The James Webb Space Telescope: the early Universe



- Main aims: 1/ The first stars of the Universe and 2/ the value of H_0

3 Our Lecture

1. Evolution of the universe
   (a) Galaxy interactions
   (b) From homogeneous to inhomogeneous universe
   (c) The Star formation history
2. Stellar evolution
   (a) The Mass-Luminosity relation
   (b) The Hertzprung-Russell Diagram
   (c) Overview of stellar evolution
3. Astronomical tools of astrophysics
   (a) Spectroscopy
   (b) Standard candles: Cepheids and Supernovae
   (c) Distance ladder
4. Physical principles
   (a) Thermodynamics of the perfect gas
   (b) Equilibrium and stability of gaseous configurations
   (c) Thermodynamics of black-body radiation
   (d) Pressure of the degenerate gas of electrons
5. Compact stars: white dwarfs, neutron stars

6. Overview of star formation
   (a) Virial theorem
   (b) Jeans mass and hierarchical formation
   (c) Open questions: IMF

Organisation

1. No lecture notes; slides on Moodle webpage
2. Written language: english; spoken=français
3. Evaluation pour cette partie: Examen terminal
4. Contact
   (a) My office: at IPAG (next to JL Monin); please visit us!
   (b) e-mail: pierre.hily-blant@univ-grenoble-alpes.fr
   (c) use exclusively your UGA e-mail adress