LINEAR WAVES AND STREAMING INSTABILITY IN HERBIG-HARO OBJECTS

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• Content :

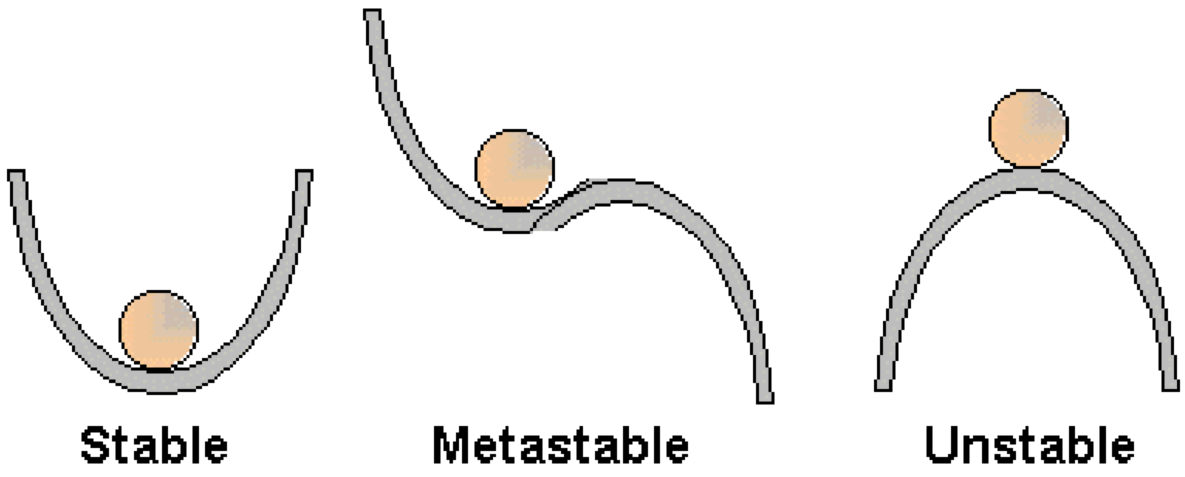
- Instability.
  - Definition of Instability.
  - Types of Instability.
- Herbig-Haro objects.
  - What are Herbig-Haro objects?
  - Historical Overview.
  - Formation and Some Numbers.
- Mathematical Description.
- Simple Curious Conversation.

- # Instability.

- ## Definition of Instability :

A Plasma instability is a region where turbulence occurs due to changes in the characteristics of a plasma (temperature, density, electric fields, magneti fields).

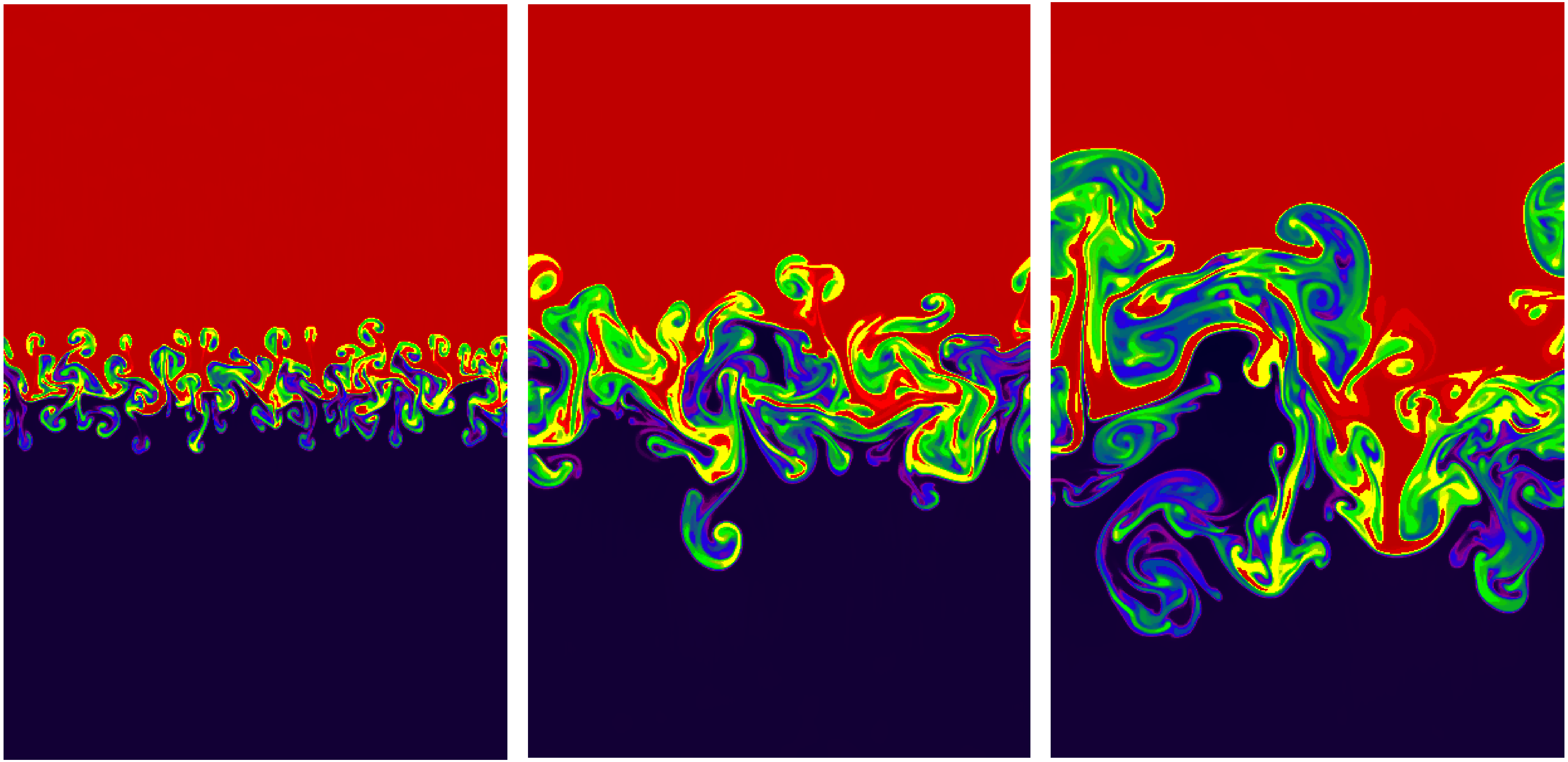
As the name suggests, instabilities are unstable, though they may appear to evolve through different forms (morphology). Similar types of instability are common in fluids (liquids and gases).



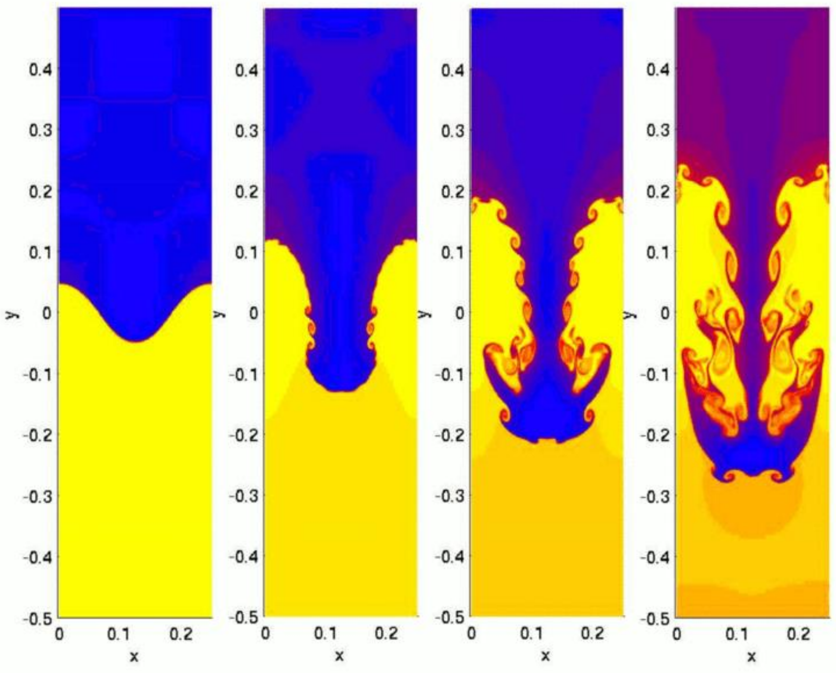
Types of Instability.

- Coalescence instability
  - Non-linear coalescence instability
- Cyclotron instabilities, including:
  - Alfven cyclotron instability
  - Cyclotron maser instability
  - Electron cyclotron instability
  - Electrostatic ion cyclotron Instability
  - Ion cyclotron instability
  - Magnetoacoustic cyclotron instability
  - Proton cyclotron instability

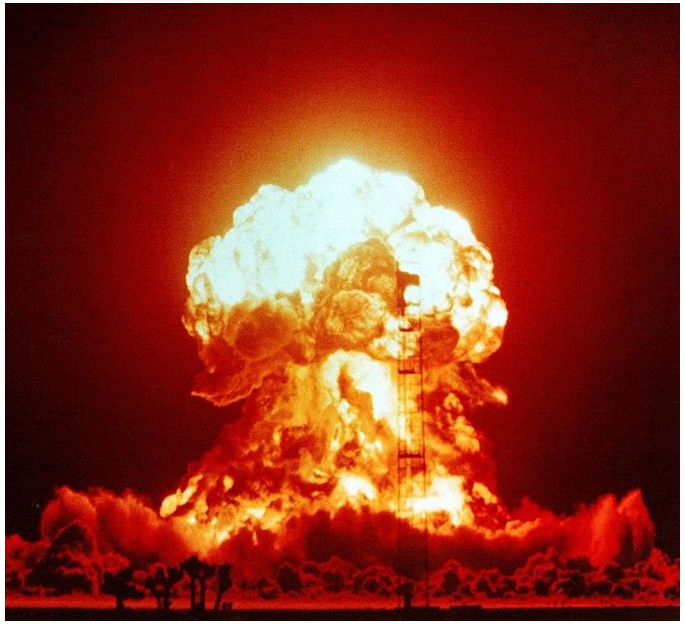
- **Rayleigh-Taylor Instability**



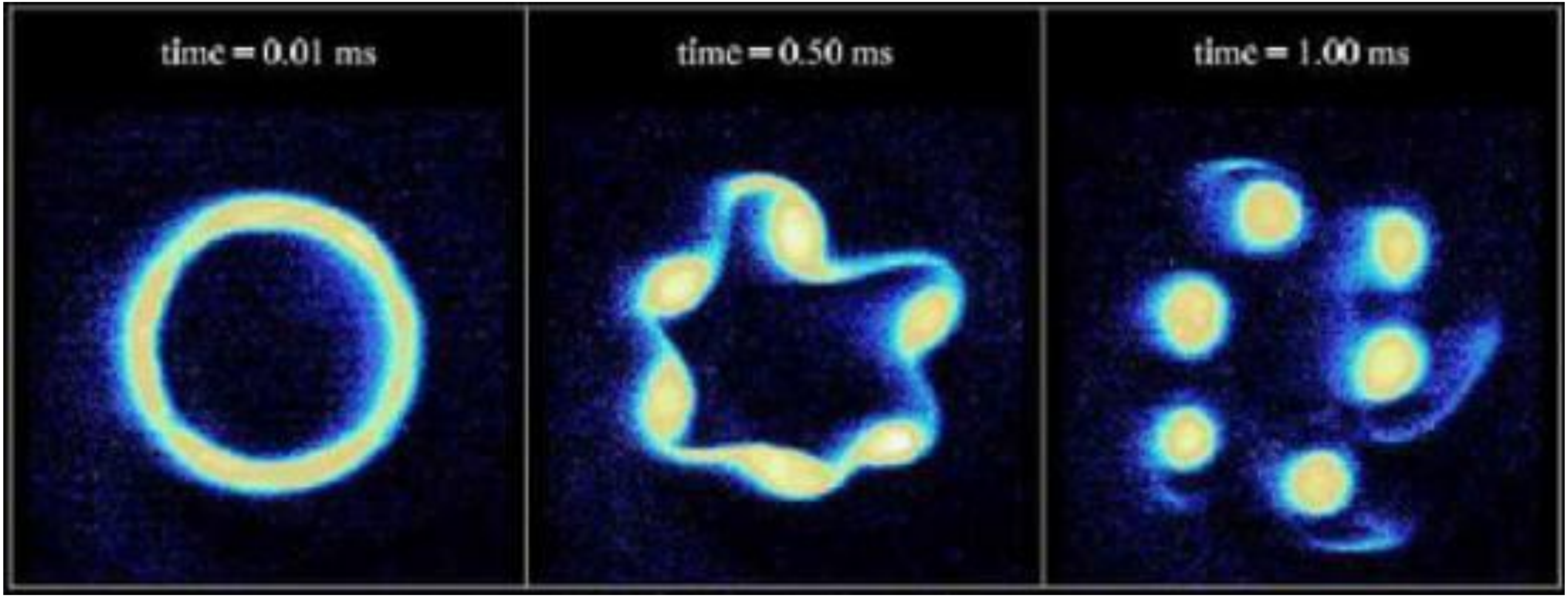
- **The Rayleigh–Taylor instability, or RT instability is an instability of an interface between two fluids of different densities which occurs when the lighter fluid is pushing the heavier fluid.**



- **Examples:**



- **diocotron instabilities**



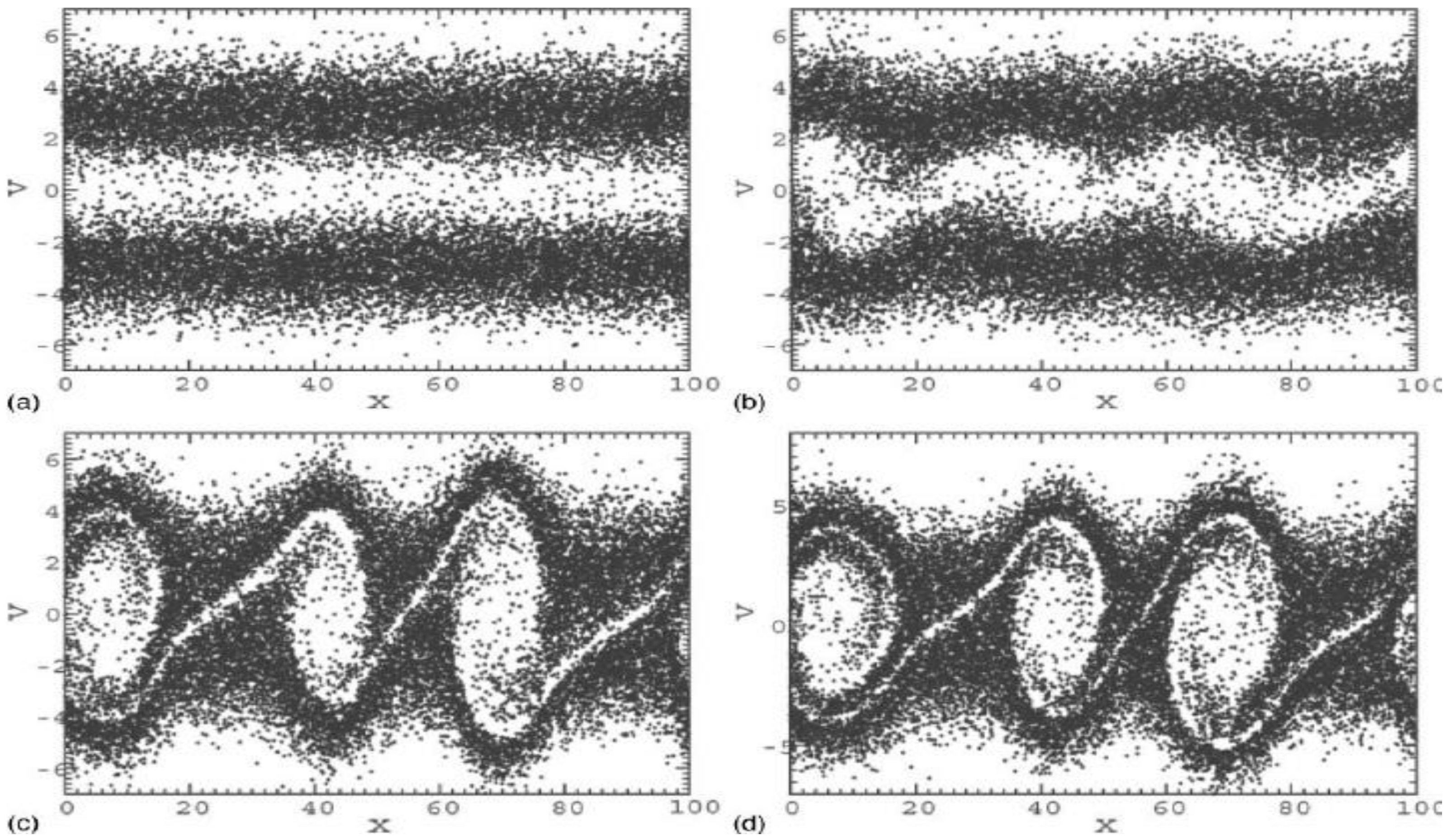
• Two-stream instability

- The two-stream instability is a very common instability in plasma physics. It can be induced by an energetic particle stream injected in a plasma, or setting a current along the plasma so different species (ions and electrons) can have different drift velocities. The energy from the particles can lead to plasma wave excitation.

- Two-stream instability can arise from the case of two cold beams, in which no particles are resonant with the wave, or from two hot beams, in which there exist particles from one or both beams which are resonant with the wave.

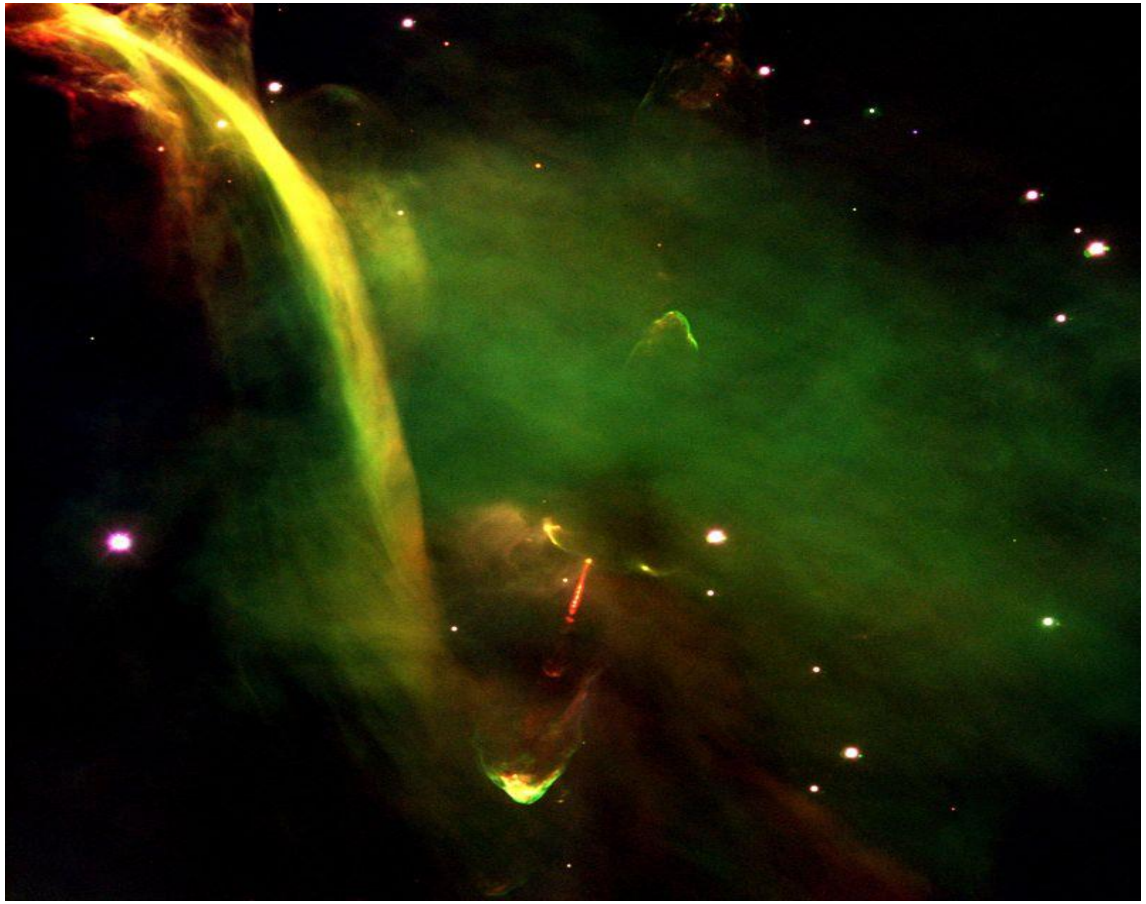
- Two-stream instability is known in various limiting cases as beam-plasma instability, beam instability, or bump-on-tail instability.

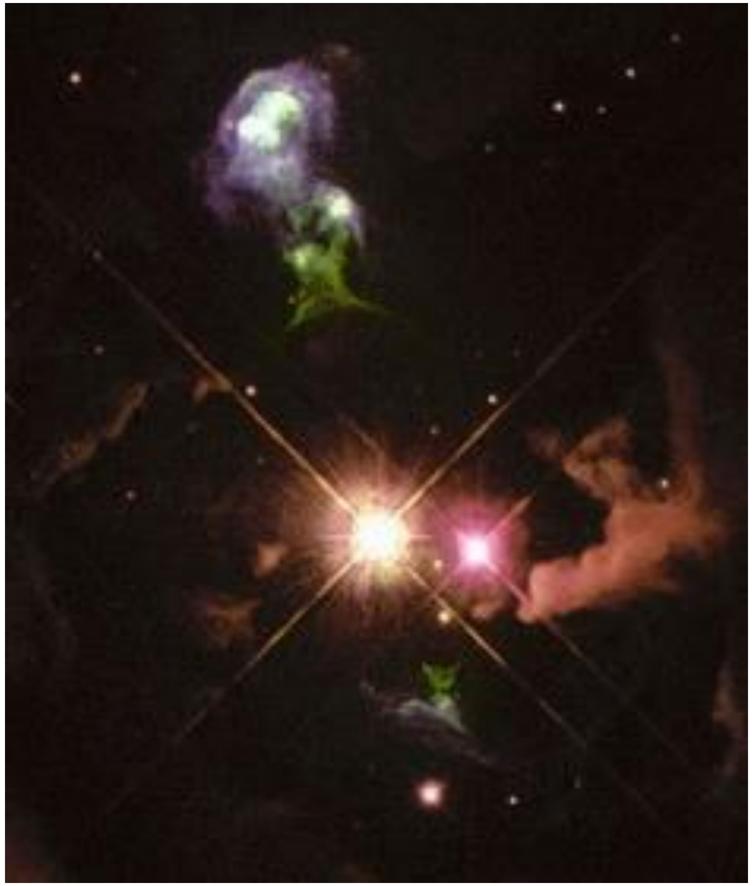
- **Two-stream instability**



What are Herbig-Haro Objects?

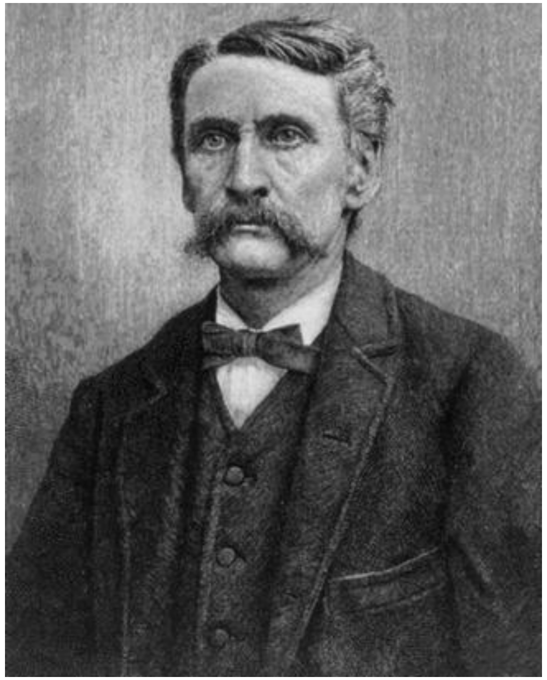
- Herbig–Haro (HH) objects are bright patches of nebulosity associated with newborn stars.





• Historical overview

- The first HH object was observed in the late 19th century by Sherburne Wesley Burnham, when he observed the star T Tauri with refracting telescope at Lick Observatory and noted a small patch of nebulosity nearby.



- T Tauri was found to be a very young and variable star, and is the prototype of the class of similar objects known as T Tauri stars.

• Historical overview

- Both Haro and Herbig made independent observations of several of these objects in the Orion Nebula during the 1940s.

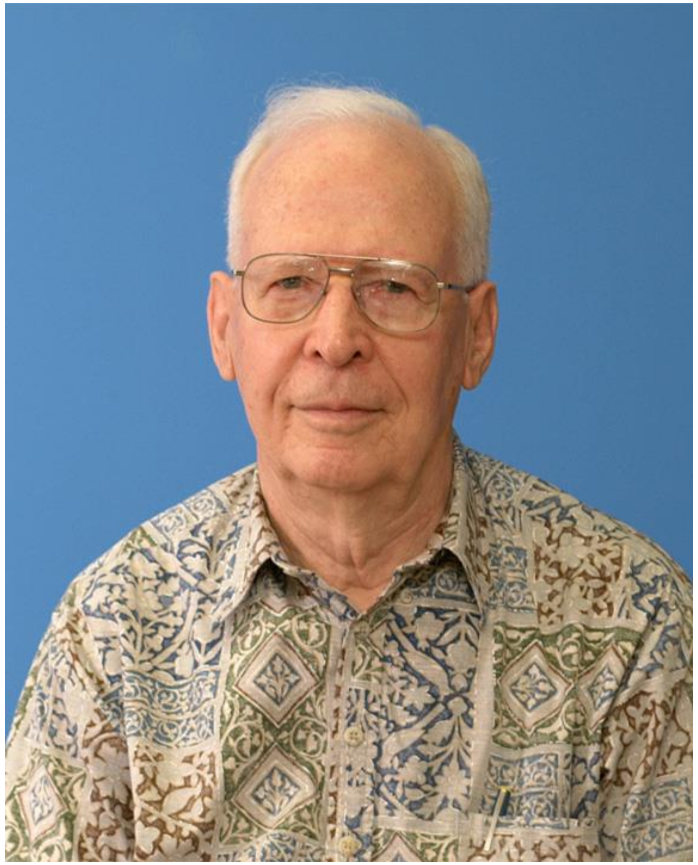
- Herbig also looked at Burnham's Nebula and found it displayed an unusual electromagnetic spectrum, with prominent emission
lines of hydrogen, sulfur and oxygen.

- Haro found that all the objects of this type were invisible in infrared light.

• Historical overview

- Following their independent discoveries, Herbig and Haro met at an astronomy conference in Tucson, Arizona in December 1949.

- Herbig had initially paid little attention to the objects he had discovered, being primarily concerned with the nearby stars, but on hearing Haro's findings he carried out more detailed studies of them



• Historical overview

- The Soviet astronomer Viktor Ambartsumian gave the objects their name (Herbig–Haro objects, normally shortened to HH objects)

- and based on their occurrence near young stars (a few hundred thousand years old), suggested they might represent an early stage in the formation of T Tauri stars. Studies of the HH objects showed they were highly ionised, and early theorists speculated that they were reflection nebulae containing low-luminosity hot stars deep inside.

- **Historical overview**

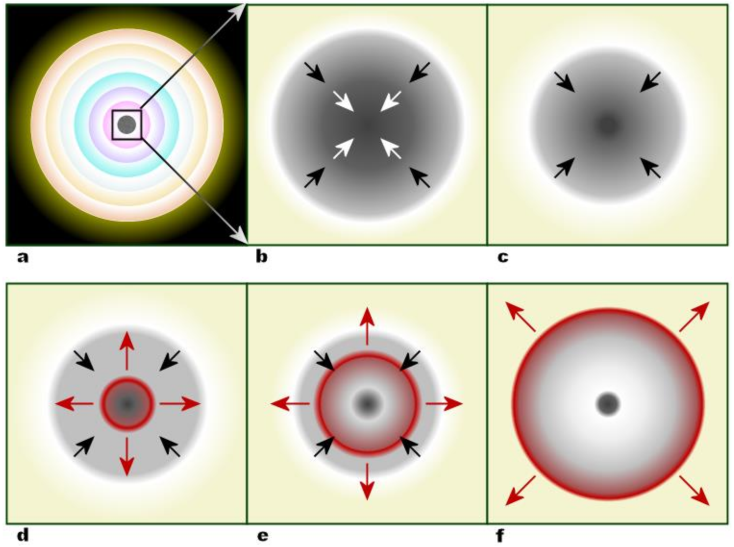
- **Confusing question ....**

Why H-H doesn't radiate infrared?

• Formation

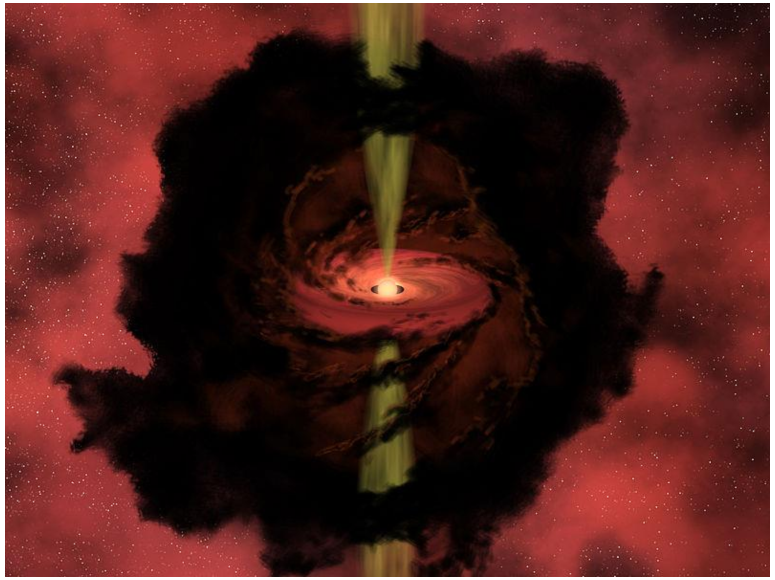
• T Tauri stars : (protostar)

T Tauri was found to be a very young and variable star, and is the prototype of the class of similar objects known as T Tauri stars which have yet to reach a state of hydrostatic equilibrium between gravitational collapse and energy generation through nuclear fusion at their centres.

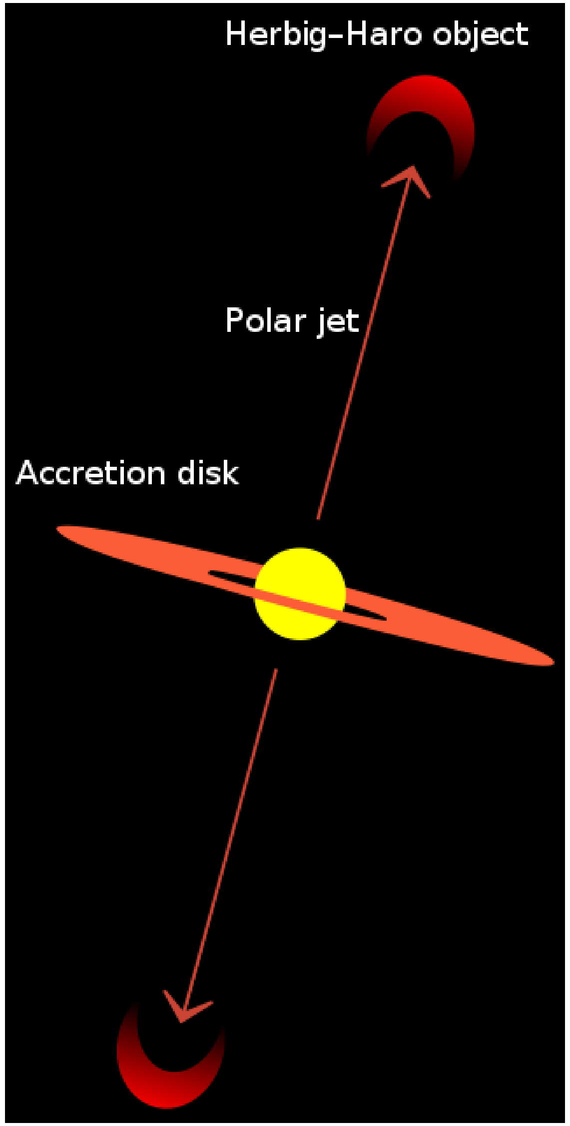


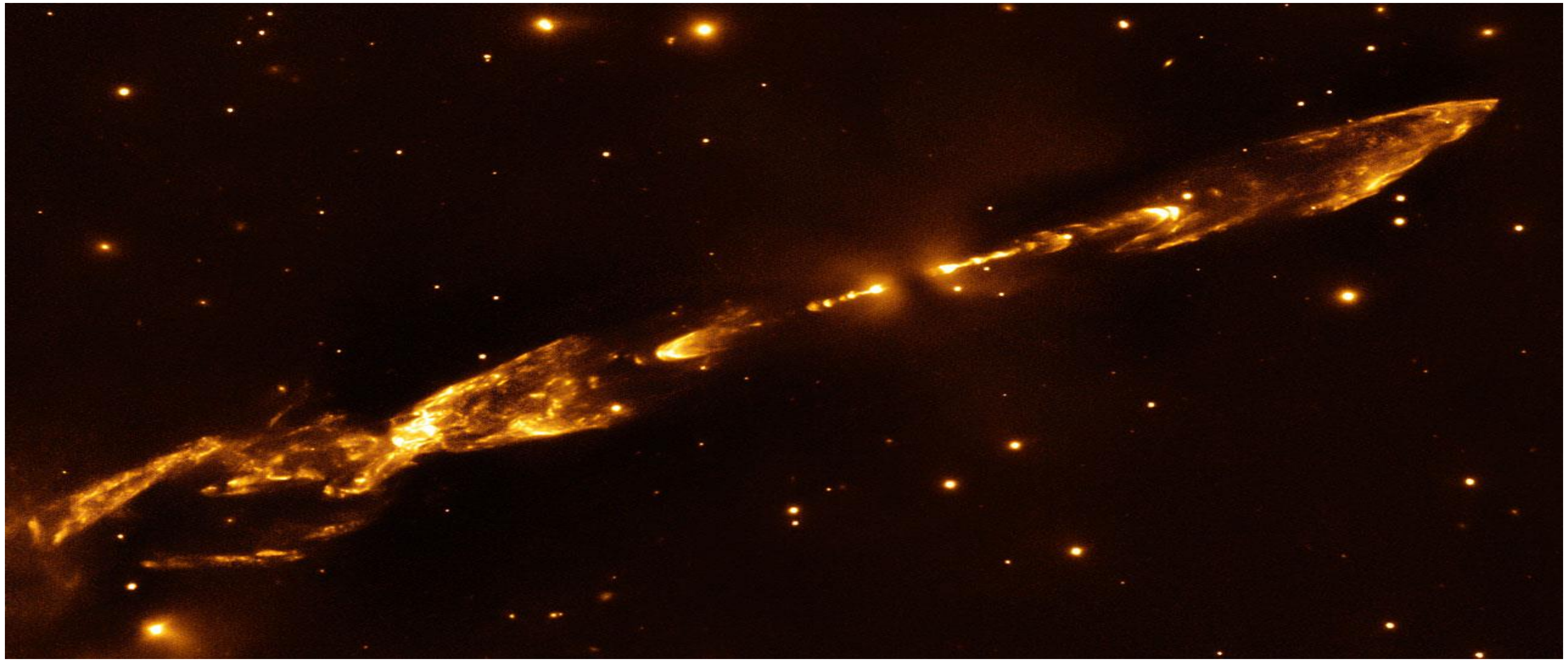
Protostar.

Hydrostatic equilibrium between gravitational collapse and energy generation through nuclear fusion.



Formation of H-H objects.

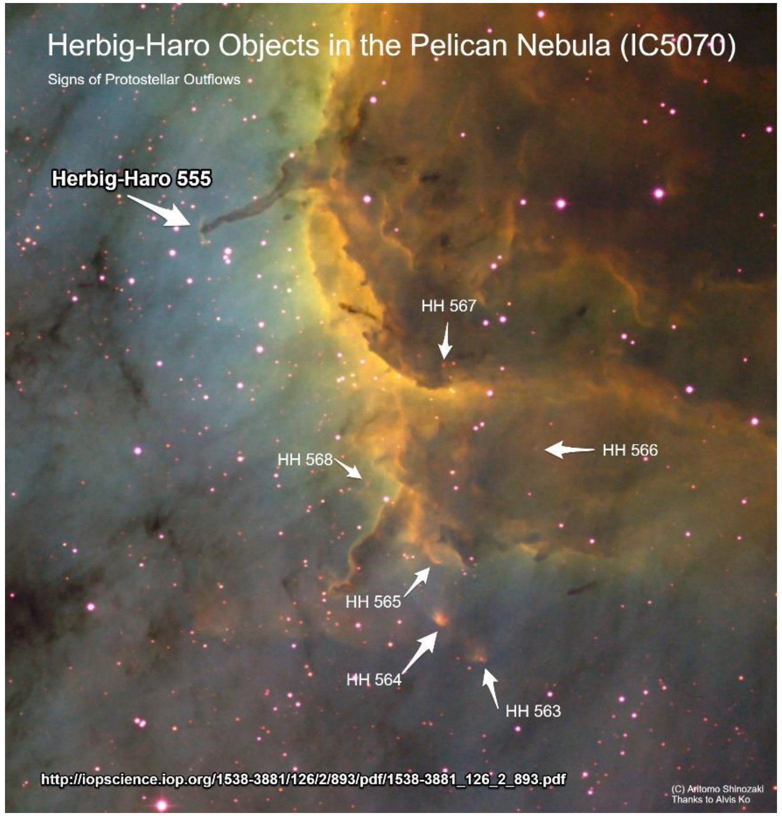


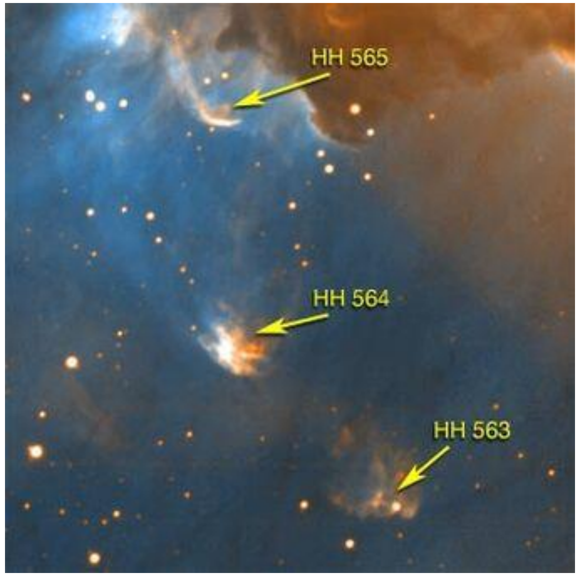


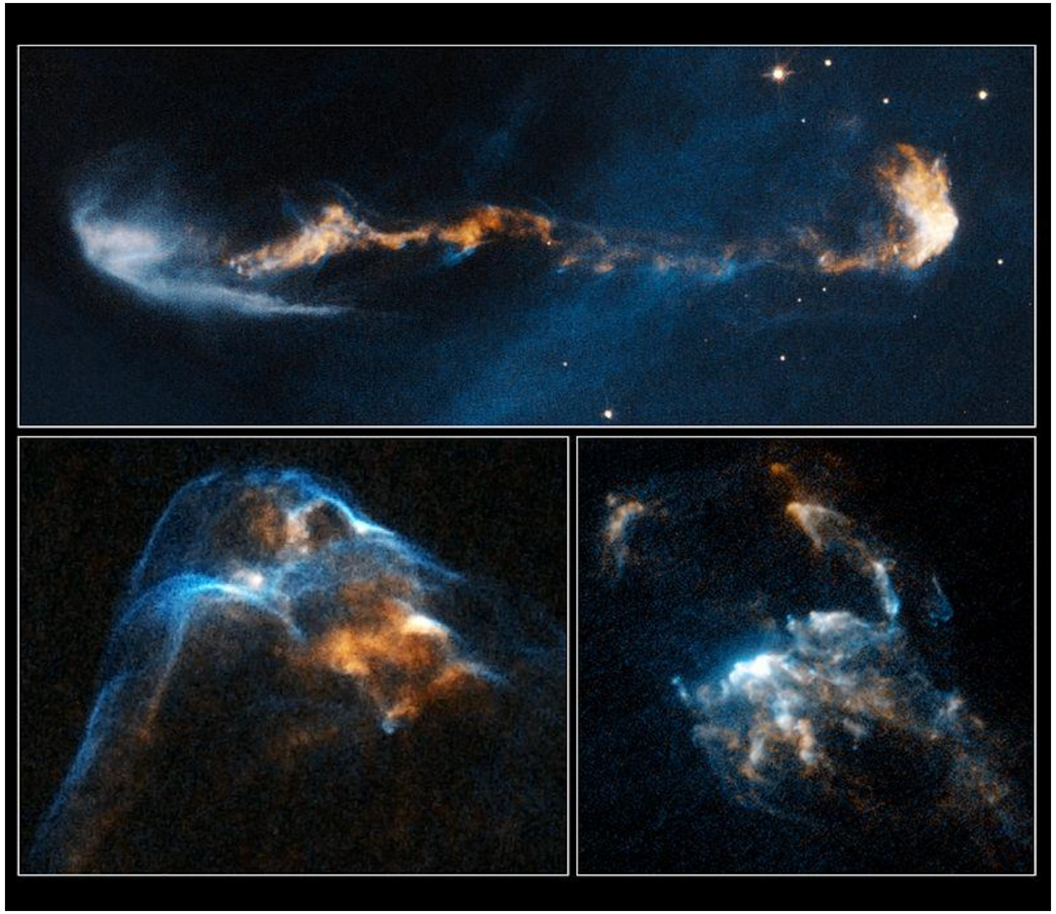
- HH objects are formed when accreted material is ejected by a protostar as ionized gas along the star's axis of rotation.

• Some Numbers and Inforations.

- HH objects are named approximately in order of their identification HH1 being the earliest such objects to be identified. More than a thousand individual objects are now known.







HH2 (lower right), HH34 (lower left), and HH47 (top)

• Some Numbers and Inforations.

- Electromagnetic emission from HH objects is caused when their associated shock waves collide with the interstellar medium
- The spectrum is continuous.
- The total mass being ejected by stars to form typical HH objects is estimated to be of the order of 10^{-8} to 10^{-6} $M_{\odot}$ per year.
- The above mass is about 332946 times the mass of Earth ($M_{\oplus}$), or 1047 times the mass of Jupiter (M_J).
- The solar mass ($M_{\odot}$) is a standard unit of mass in astronomy, equal to approximately 2×10^{30} kg
- The temperatures observed in HH objects are typically about 9,000–12,000 K
- HH objects consist mostly of hydrogen and helium, which account for about 75% and 24% of their mass respectively. Around 1% of the mass of HH objects is made up of heavier chemical elements.

- # Mathematical Description.
- **Basic Equations ..**
  - For Ion Fe++:

    Equation of motion.

$$m_{fe}n_{fe}\frac{\partial v_{fe}}{\partial t} = n_{fe}q_{fe}E - \nabla P$$

$$n_{fe} = n_{fe0} + n_{fe1} + \cdots$$
$$v_{fe} = 0 + v_{fe1} + \cdots$$
$$P = n_{fe}K_B T_{fe}$$
$$E = -\nabla \emptyset$$
$$q_{fe} = eZ_{fe}$$

$$m_{fe}n_{fe0}\frac{\partial v_{fe1}}{\partial t} = -n_{fe0}eZ_{fe}\frac{\partial \emptyset}{\partial x} - K_B T_{fe}\frac{\partial n_{fe1}}{\partial x}$$

From Taylor exchanges:

$$n = \tilde{n}\, e^{i(kx-\omega t)}$$
$$v = \tilde{v}\ e^{i(kx-\omega t)}$$
$$\emptyset = \tilde{\emptyset}\, e^{i(kx-\omega t)}$$

$$-i\omega m_{fe}n_{fe0}v_{fe1} = -ikn_{fe0}eZ_{fe}\emptyset - ikK_B T_{fe}n_{fe1}$$

$$v_{fe1} = \frac{keZ_{fe}\emptyset}{m_{fe}\omega} + \frac{kK_B T_{fe}}{m_{fe}n_{fe0}\omega}n_{fe1} \qquad (1)$$

From continuity equation:

$$\frac{\partial n_{fe1}}{\partial t} + n_{fe}\frac{\partial v_{fe1}}{\partial x} = 0$$

$$-i\omega n_{fe1} = -ikn_{fe0}v_{fe1}$$

$$n_{fe1} = \frac{kn_{fe0}}{\omega}v_{fe1}$$

From (1)

$$n_{fe1} = \frac{k^2 n_{fe0} e Z_{fe} \emptyset}{m_{fe}\omega^2} + \frac{k^2 K_B T_{fe}}{m_{fe}\omega^2} n_{fe1}$$

$$n_{fe1} = \frac{k^2 n_{fe0} e Z_{fe} \emptyset}{(m_{fe} n_{fe0} \omega^2 - k^2 K_B T_{fe} n_{fe0})}$$

Basic equation for O++ :

$$n_{o1} = \frac{k^2 n_{o0} e Z_o \emptyset}{(m_o n_{o0} \omega^2 - k^2 K_B T_o n_o)}$$

Basic equation for Electrons :

$$n_e = \widetilde{n_e} \exp\left(\frac{e\emptyset}{K_B T_e}\right)$$

Maxwell–Boltzmann distribution..

$$e^{\frac{e\emptyset}{K_B T_e}} = \frac{\emptyset e}{K_B T_e} + \frac{(\frac{\emptyset e}{K_B T_e})^2}{2!} + \frac{(\frac{\emptyset e}{K_B T_e})^3}{3!} + \cdots, \qquad e\emptyset \ll K_B T_e$$

$$n_e = \widetilde{n_e}\ \frac{e\emptyset}{K_B T_e}$$

Basic equation for Ion beam :

Equation of motion..

$$m_b n_b \frac{\partial v_b}{\partial t} = n_b e E - \nabla P$$

$$v_b = v_{b0} + v_{b1} + \cdots$$

$$m_b n_{b0} \left(\frac{\partial v_{b1}}{\partial t} + v_{b0} \frac{\partial v_{b1}}{\partial x} \right) = -e n_{b0} \frac{\partial \emptyset}{\partial x} - K_B T_b \frac{\partial n_{b1}}{\partial x}$$

$$-i m_b n_{b0} v_{b1} (\omega - v_{b0} k) = -i e n_{b0} \emptyset - i k K_B T_b n_{b1}$$

$$v_{b1} = \frac{k e \emptyset}{m_b (\omega - k v_{b0})} + \frac{k K_B T_b}{m_b n_{b0} (\omega - k v_{b0})} n_{b1}$$

Countinuity equation..

$$\frac{\partial n_{b1}}{\partial t} + n_{b0}\frac{\partial v_{b1}}{\partial x} + v_{b0}\frac{\partial n_{b1}}{\partial x} = 0$$

$$n_{b1} = \frac{k n_{b0}}{(\omega - k v_{b0})} v_{b1}$$

$$n_{b1} n_{b0} m_b (\omega - k v_{bo})^2 = k^2 e n_{b0} \emptyset + K_B T_b k^2 n_{b0} n_{b1}$$

$$n_{b1} = \frac{k^2 e {n_{b0}}^2 \emptyset}{(m_b n_{b0}(\omega - k v_{b0})^2 - K_B T_b k^2 n_{b0})}$$

Poisson's equation..

$$-\varepsilon \nabla^2 \emptyset = e(Z_{fe} n_{fe} + Z_o n_o + n_b + n_e)$$

$$\frac{\varepsilon m_b(\omega - kv_{b0})^2}{n_{b0}e^2} - \frac{\varepsilon k^2 K_B T_b}{n_{b0}e^2} + \frac{\varepsilon m_{fe}\omega^2}{n_{fe}{Z_{fe}}^2 e^2} - \frac{\varepsilon k^2 K_B T_{fe}}{n_{fe0}{Z_{fe}}^2 e^2} + \frac{\varepsilon m_o \omega^2}{n_{o0}{Z_o}^2 e^2} - \frac{\varepsilon k^2 K_B T_o}{n_{o0}{Z_o}^2 e^2} - \frac{\varepsilon k^2 K_B T_e}{n_{e0}e^2} = 1$$

$$(\widetilde{\omega} - \tilde{k}\tilde{v}_b\widetilde{m}_{bfe}\tilde{T}_{bfe})^2 - \tilde{k}^2 + \widetilde{\omega}^2\widetilde{m}_{bfe}\tilde{n}_{bfe} + \widetilde{\omega}^2\widetilde{m}_{bo}\tilde{n}_{bo} - \tilde{k}^2\tilde{n}_{bfe}\tilde{T}_{bfe} - \tilde{k}^2\tilde{n}_{bo}\tilde{T}_{bo} - \tilde{k}^2\tilde{n}_{be}\tilde{T}_{be} = 1$$

Simple Curious Conversation.

- Many new papers and Astronomical observations led to some HH objects move away with change and several velosities.