Astrophysical Dynamics

VT 2010

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Aims of this Course

- understanding the **role and nature of dynamical processes in a wide range of astrophysical contexts** and how to study such phenomena
- getting familiar with the **basic concepts of gas dynamics** (incl. gravitation) and commonly used approximations
- learning about theoretical and numerical **solutions of the gravitational N-body problem**
- getting introduced to the construction of **models for self-gravitating stellar systems** and characterization of orbits in such models
- studying **examples of astrophysical objects and systems** where dynamical processes play an important role
- learning how to make **simple estimates for dynamical time scales and stability** of astrophysical objects and systems
- understanding how the **effects** of dynamical processes can be measured and **observed in astronomical contexts**
- creating a **basis for more specialized astrophysics courses**

Course Contents and Format

The course consists of a series of **lectures** on the following topics:

- introduction: overview of dynamical processes in astrophysics
- solar system dynamics
- basic gas dynamics (conservation laws, waves, shocks)
- protostellar collapse and star formation
- protoplanetary disks and planet formation
- stellar outflows (winds, supernovae) and their interaction with the ISM
- dynamics of stellar clusters and galactic dynamics
- interacting galaxies

together with **hand-in exercises, computer labs** (discussed in extra sessions) and **short presentations** by each student on topics related to dynamical processes in astrophysics (literature seminars)

Practical Matters

Literature

- lecture notes (will be posted on-line and/or handed out)

Resources

- PC + MATLAB (or equivalent) for computer labs/exercises
- detailed schedule & more information online:
  www.astro.uu.se/~hoefner/astro/teach/apd_vt10.html

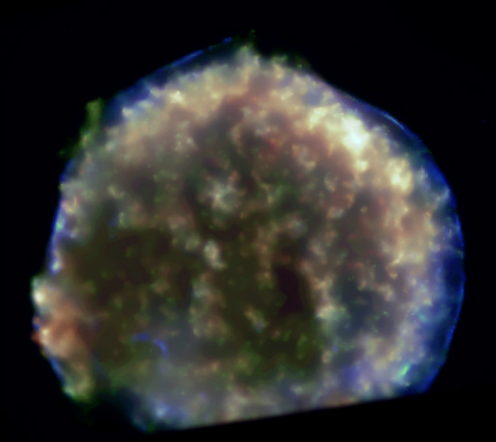
Course Requirements

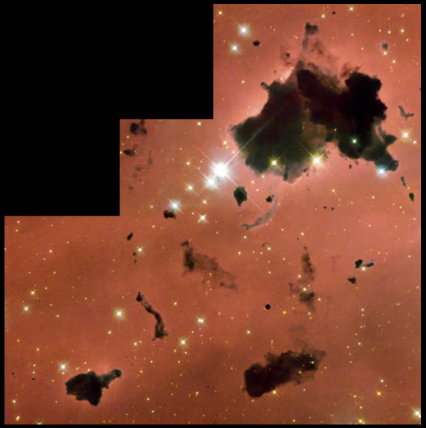
- problem sets handed in during course
- results of computer labs handed in / presented during exercises
- short presentations on selected topic ... more information later ...
- written summaries of presentations handed in by end of course

Astrophysical Dynamics

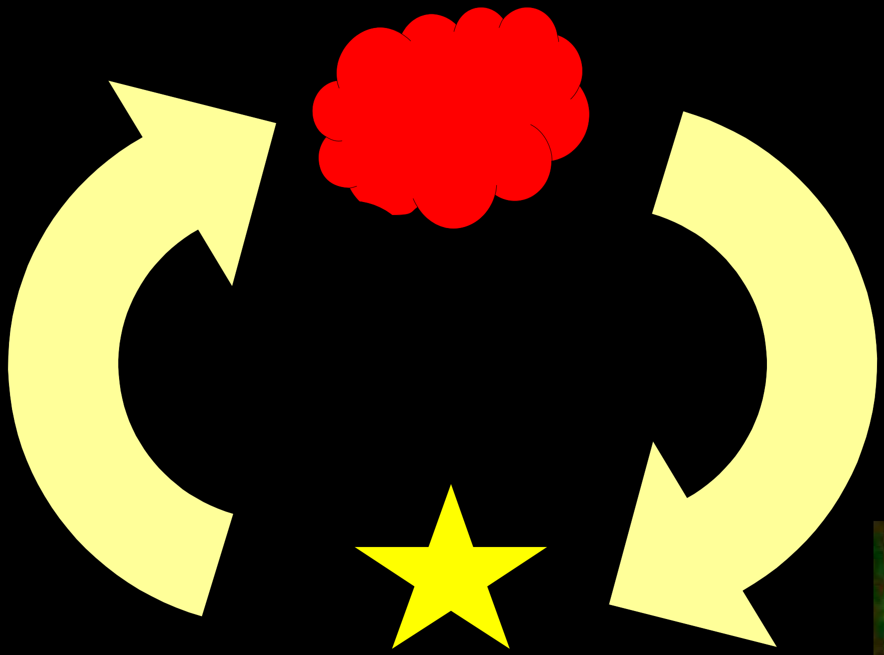
Introduction

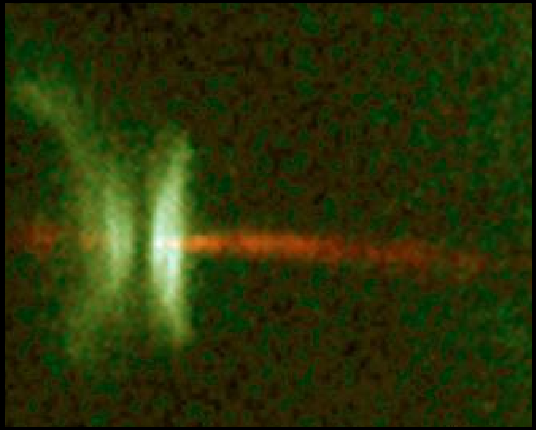
The Cosmic Matter Cycle





Interstellar medium

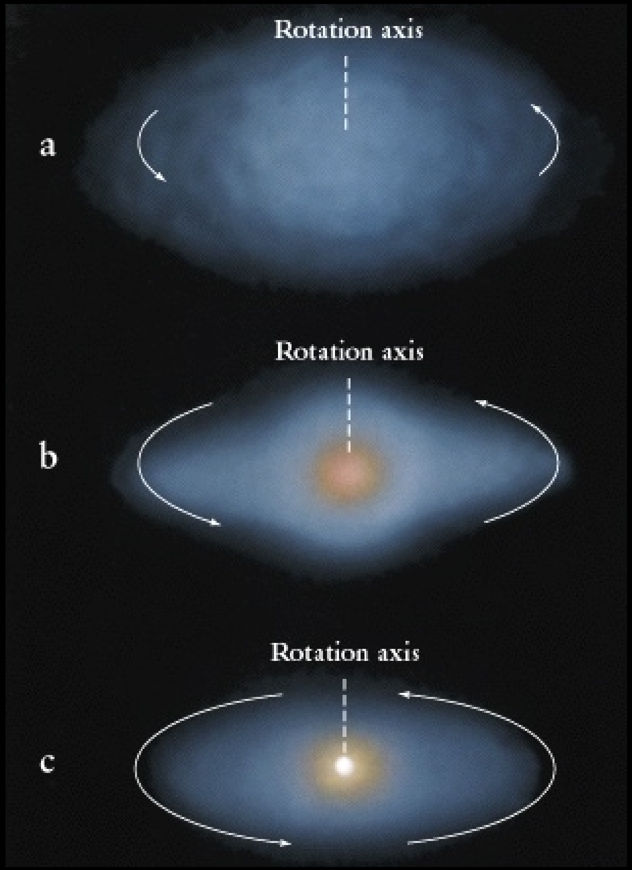


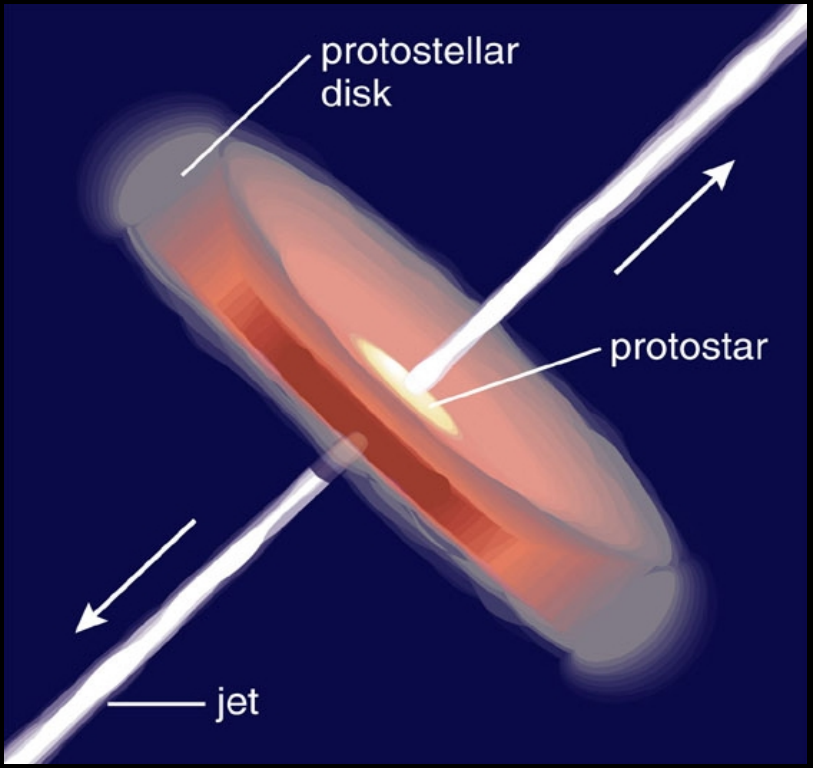


Stars

- form out of interstellar gas
- show convection and pulsation
- return gas to the ISM through winds and SN explosions

Young Stellar Objects: Disks & Jets





The Cosmic Matter Cycle

The stellar life cycle ...
in real life:

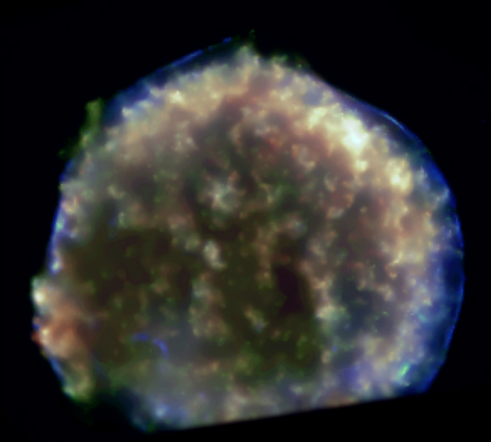
stars of different mass born from the same cloud evolve on different time scales

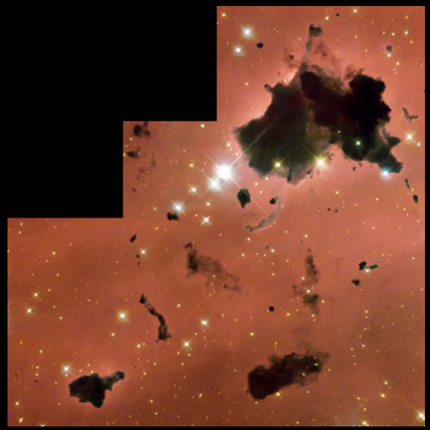
stars influence the surrounding interstellar medium, triggering or prohibiting further star formation in a certain region

material ejected from stars is mixed in the ISM

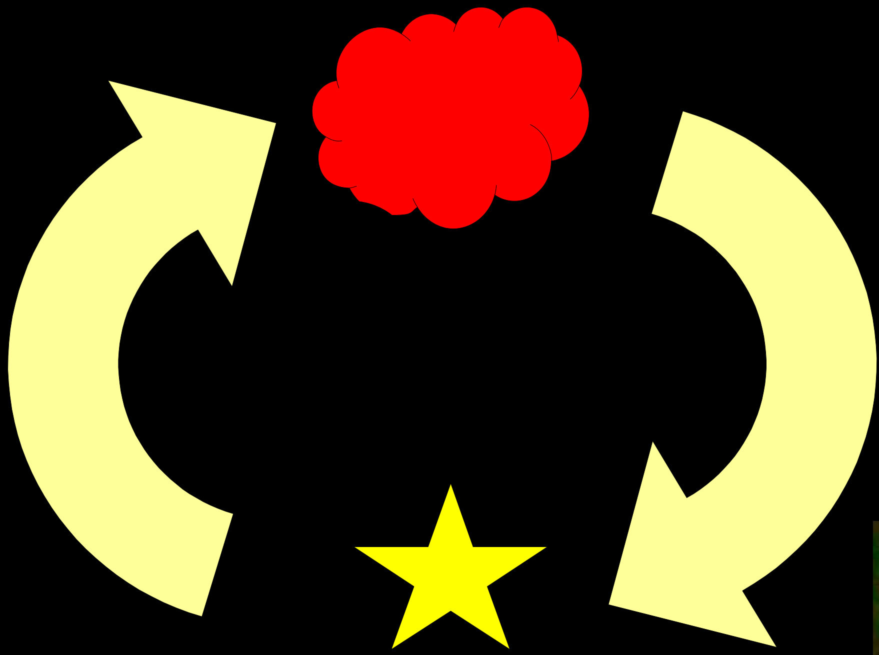
The galactic nebula NGC 3603 (source: hubblesite.org)

The Cosmic Matter Cycle



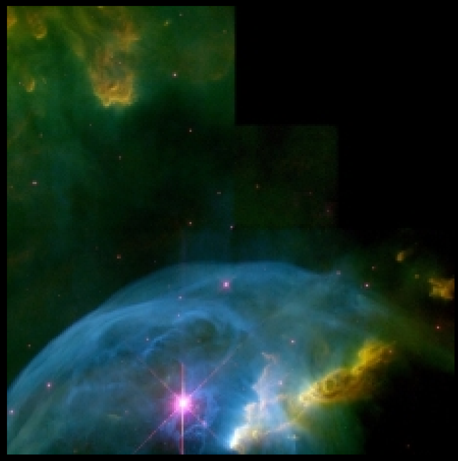


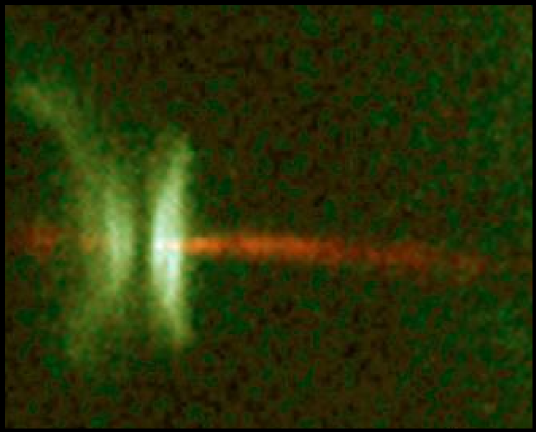
Interstellar medium



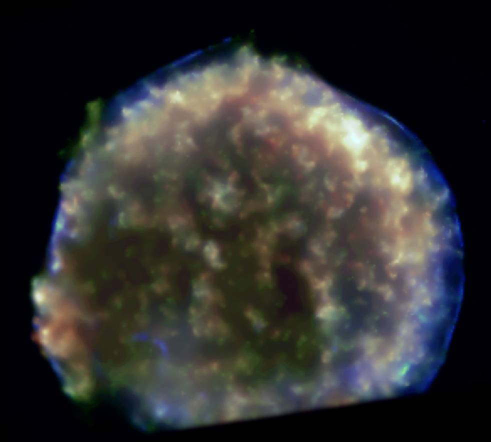
Stars

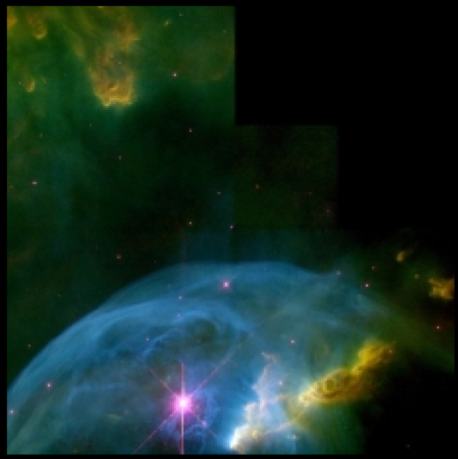
enrich the interstellar medium
with newly-produced elements
heavier than H and He



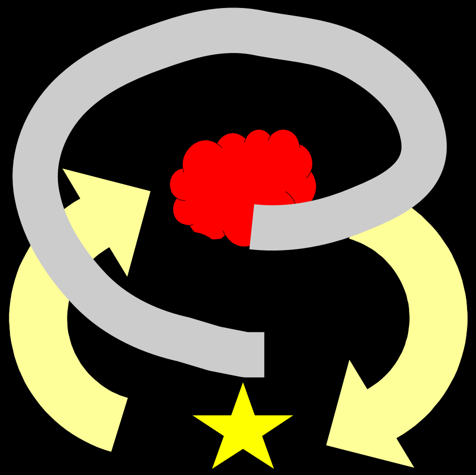


The Cosmic Matter Cycle





Interstellar medium



Stars

enrich the interstellar medium with newly-produced elements heavier than H and He

Fraction of elements heavier than H and He (metallicity) increases in the ISM with every generation of stars

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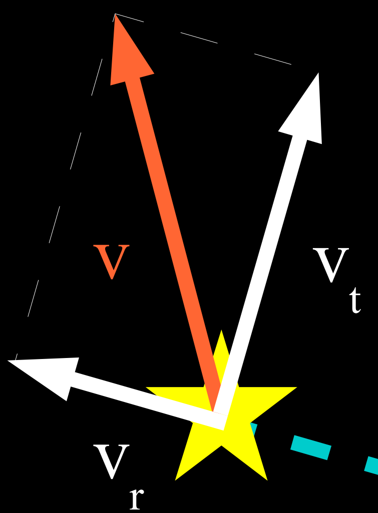
Dynamical processes in stars and the ISM play a crucial role for the chemical evolution of galaxies!

Measuring Velocities of Astrophysical Objects



$v_t = 4.74\ \mu\ d$ [km/s]

μ: proper motion [arcseconds/year]

d: distance [parsec]

velocities: observed as

- movements on the sky: tangential velocities v_t
- Doppler shift in light: radial velocities v_r

$v_r/c = (\lambda - \lambda_0) / \lambda_0$

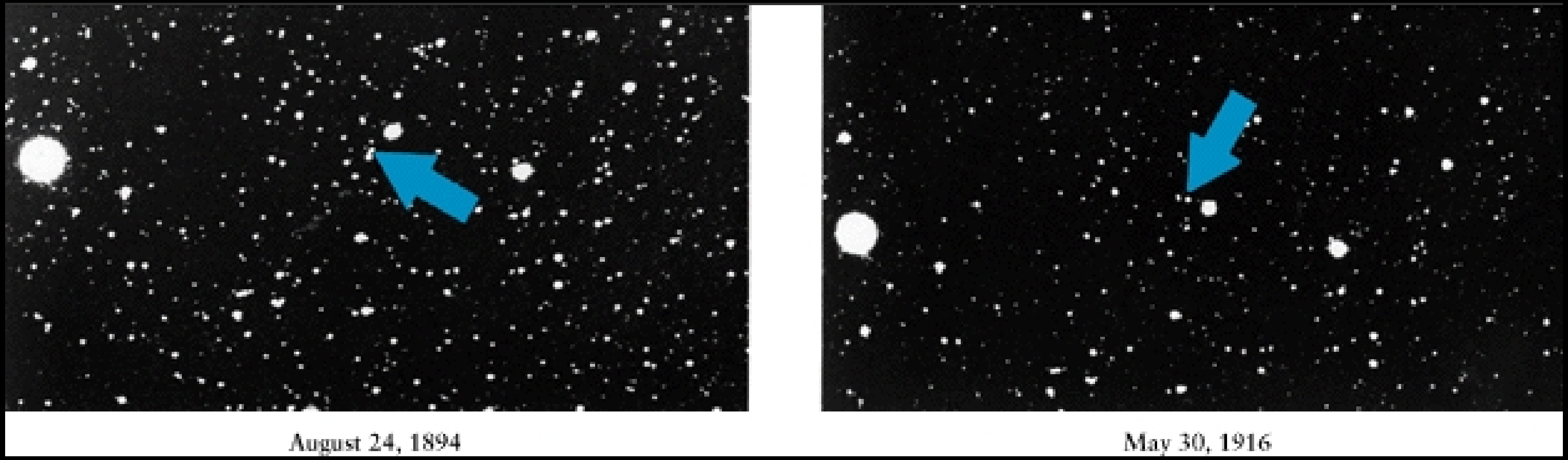
λ: observed wavelength

λ_0: rest wavelength (lab)

c: speed of light

Measuring Velocities of Astrophysical Objects

Example: Barnard's star



$v_t = 4.74\ \mu\ d$ [km/s] = 89.4 km/s

$\mu = 10.358$ [arcseconds/year]

d = 1.82 [parsec]

$v_r = c\ (\lambda - \lambda_0) / \lambda_0 = -\ 111$ km/s

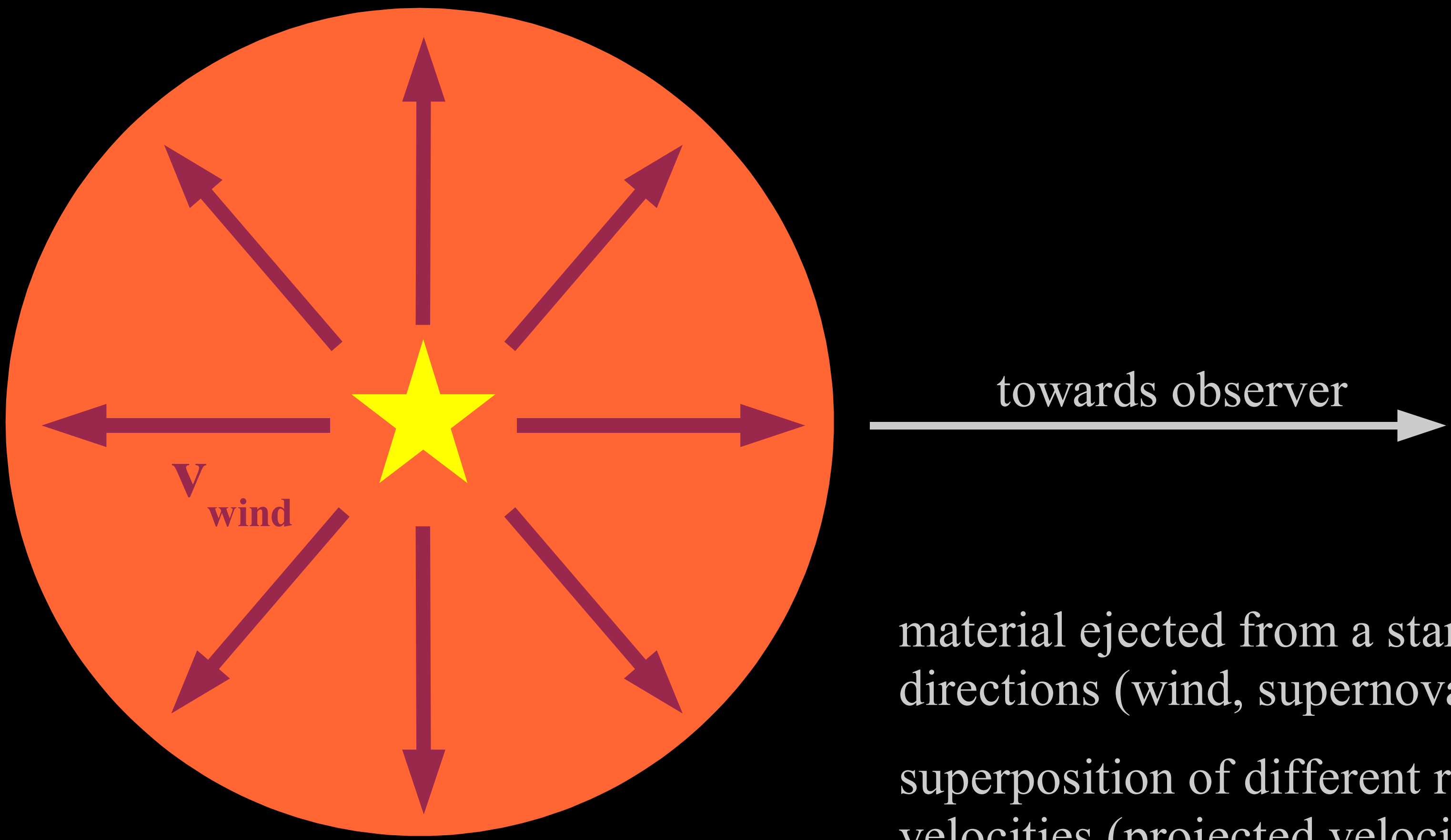
$\lambda = 516.438$ nm

$\lambda_0 = 516.629$ nm (iron line)

$c = 3\ 10^5$ km/s

$v^2 = v_t^{\,2} + v_r^{\,2}$ v = 143 km/s

Measuring Velocities of Astrophysical Objects

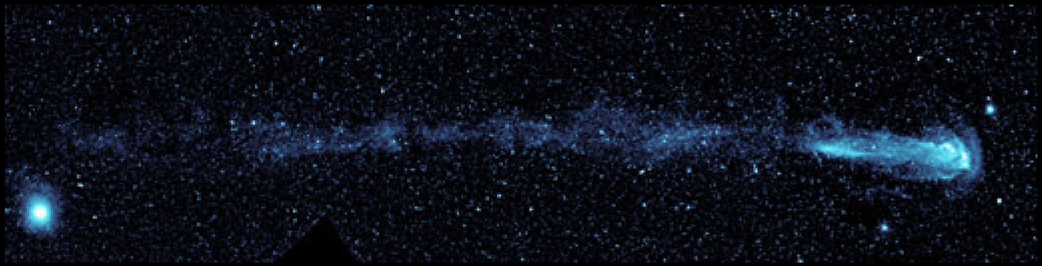


material ejected from a star in all directions (wind, supernova remnant):

superposition of different radial velocities (projected velocity components towards observer) from different parts of the envelope leads to complicated line profiles (e.g. P Cygni profiles for stellar winds)

Measuring Velocities of Astrophysical Objects

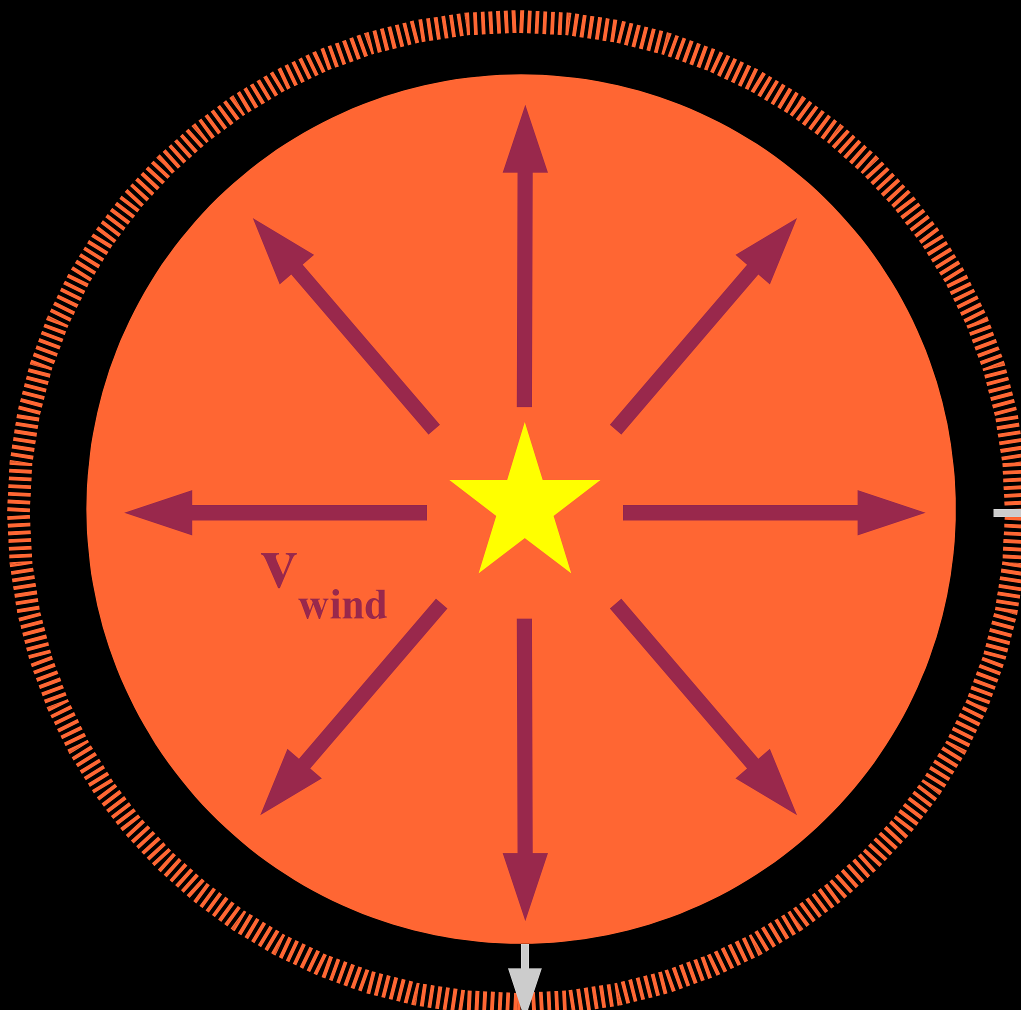
Example: Wind of fast moving star interacting with ISM



NASA's Galaxy Evolution Explorer (Galex) discovered an exceptionally long (13 light years) tail of material trailing behind the cool giant star Mira (o Ceti). The tail is only visible in ultraviolet light (top left), and does not show up in visible light (bottom left).

www.nasa.gov/mission_pages/galex/20070815/a.html

Measuring Velocities of Astrophysical Objects



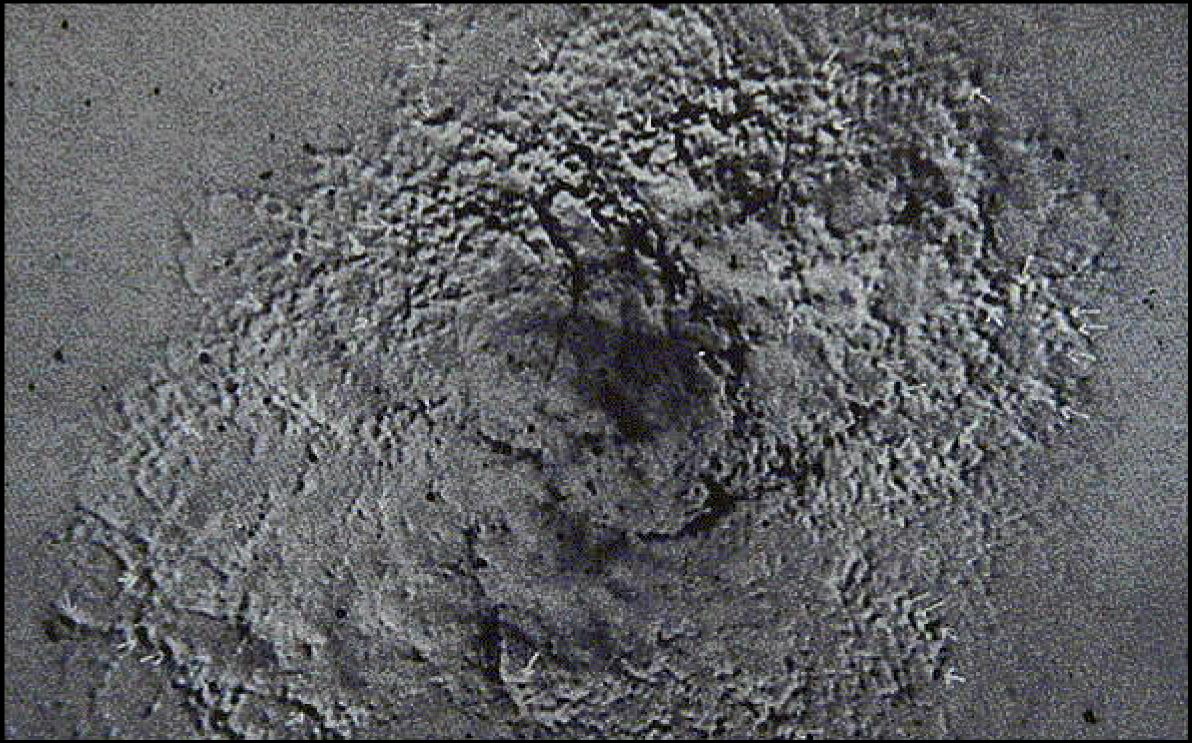
towards observer

material ejected from a star in all directions (wind, supernova remnant)

fast expanding envelopes: change of size in tangential direction may be measurable

Measuring Velocities of Astrophysical Objects

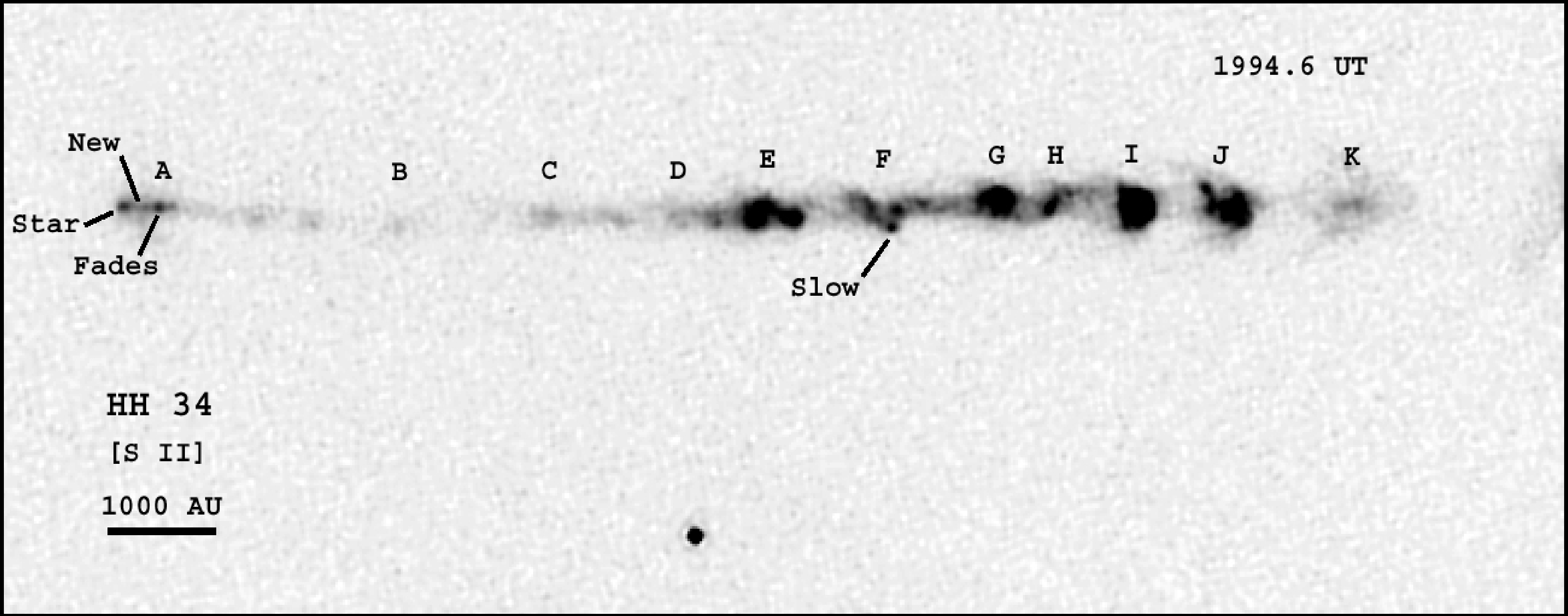
Example: Expansion of the Crab Nebula



Positive and negative photographs of the Crab Nebula taken 14 years apart (by Walter Baade) do not superimpose exactly, indicating that the gaseous filaments are still moving away from the site of the explosion.

Measuring Velocities of Astrophysical Objects

Example: Jet produced by a young stellar object



jet movie obtained with HST

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Dynamics of Stellar Systems

Individual stars
- form, evolve, and die
- modify the interstellar gas

... but they are also parts of stellar systems ...

Stellar systems:

stellar orbits determined by
- gravitation
- kinetic/potential energy
- angular momentum