M66 (10 Mpc away): HST – NASA, Press release, 08.04.2010

What can we learn from Star Clusters?

- There are two point of views which perfectly supplement each other

  1. The Star Cluster as global aggregate
  2. Each member as single stellar object

- We are able to study local and global characteristics simultaneously

- The Star Cluster as global aggregate
  1. Distance, age, reddening and metallicity
  2. Kinematics und dynamics
  3. Initial Mass Function (IMF)
  4. Star formation and evolution
  5. Global characteristics of a Galaxy
- Members as single stars
  1. Special star groups: CP, Blue Stragglers, (Super)giants, Binaries, Wolf-Rayet Stars, Variable stars, post-AGB, HB stars, …
  2. Test of most astrophysical models and theories

Two working examples:

1. Metallicity:

   - From isochrones for the complete cluster
   - From Strömgren uvbyβ photometry for individual members

2. Reddening:

   - From the shift of the Zero-Age-Main-Sequence (ZAMS)
   - From isochrone fitting
   - From photometric calibrations of different filter systems

Definition of Star Clusters

Star clusters are physically related groups of stars held together by mutual gravitational attraction.

The number of all star clusters in the Milky Way is about 10 000 but only 3000 in catalogues. From these, about 170 Globular Clusters ("old").

Working Hypothesis

All members of an individual Star Cluster are born within one Giant Molecular Cloud (GMC) over a time scale of some few Myrs.

What are the immediate conclusions?

All members of an individual star cluster have:

- *Identical distance from the Sun:* +- The volume expansion of the cluster
- *Identical age:* +- Time scale of star formation
- *Identical metallicity:* +- Inhomogeneities of the initial GMC and the chemical evolution of the giant branch
- *Identical kinematical characteristics:*
  +- Intrinsic spread
  - Radial velocity
  - Proper motion
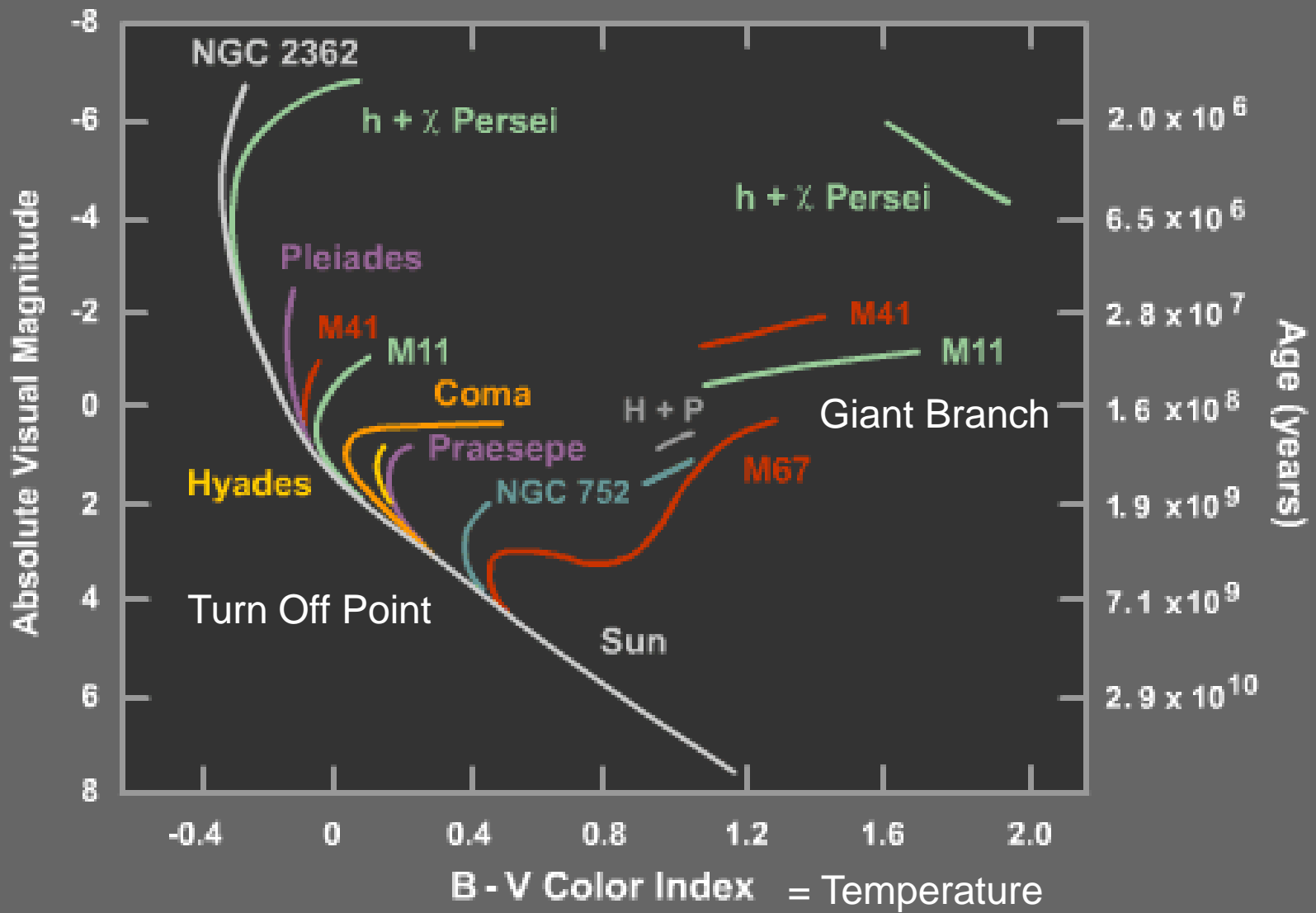
HR Diagrams for Various Open Clusters
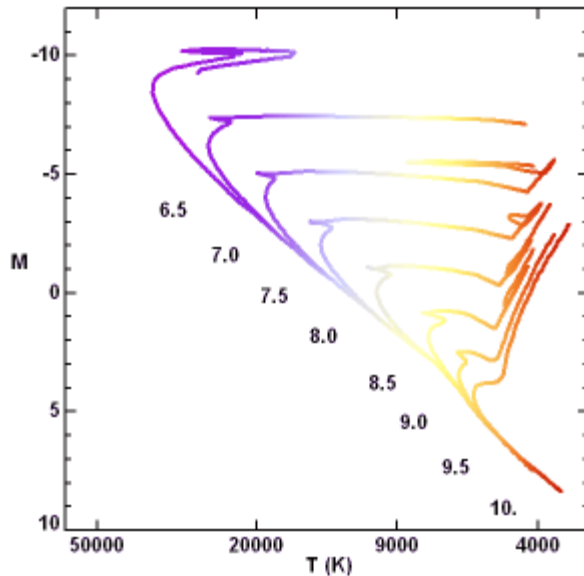
From the Pre-Main Sequence to Globulars clusters
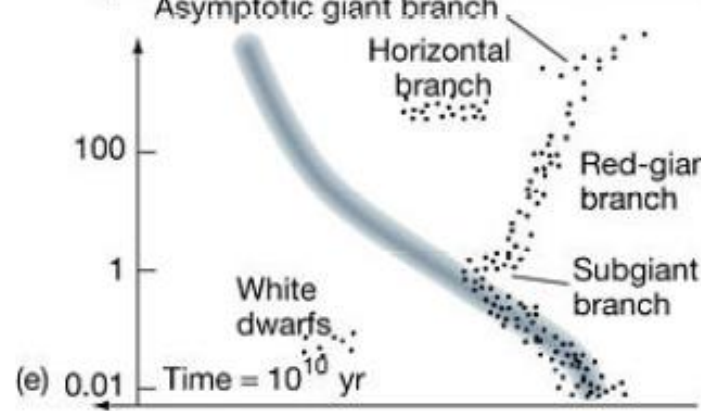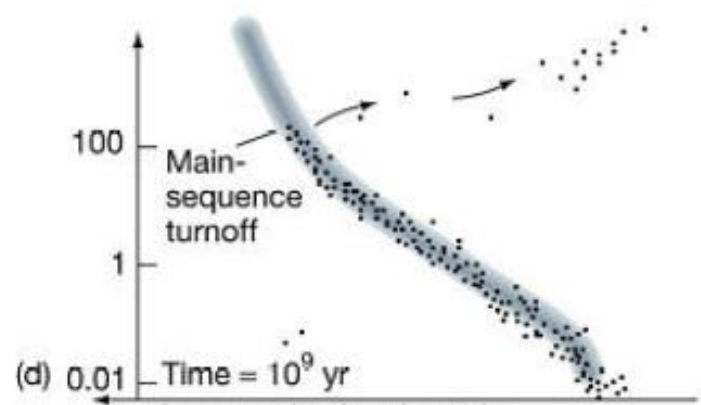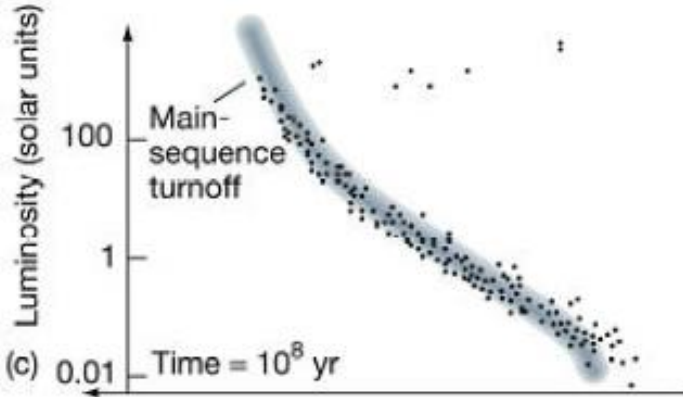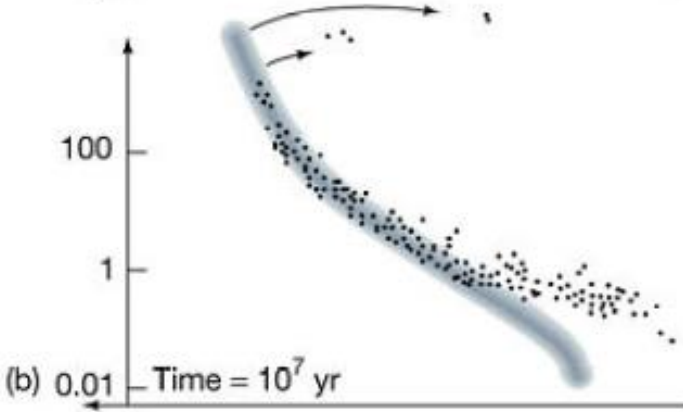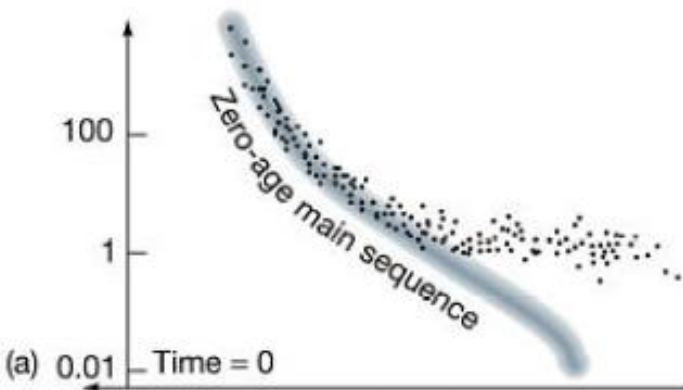
(a) $t = 0$

(b) $t = 10^7$yr

(c) $t = 10^8$yr

(d) $t = 10^9$yr

(e) $t = 10^{10}$yr

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Isochrones

Lines of equal age

Can be calculated

A lot of free parameters and problems

Clusters in Spiral Galaxies

- In Spiral Galaxies as in our Milky Way, we can clearly distinct between

  1. Young clusters in the disk (Open Clusters)
  2. Old clusters in the halo (Globular Clusters)

- For other types of Galaxies, for example the LMC and SMC, this simple classification is **not valid** any more.

Characteristics – Open Clusters

- **Age:** 1 Myr – 5 Gyr

- **Metallicity:** -1.0 to +0.6 dex compared to the Sun

- **Distance from the Sun:** > 45 pc

- **Mass range of the members:** 0.08 to 100 M(sun)

- **Total masses:** up to 40000 M(sun)

- **Absolute linear diameter:** 2 to 20 pc

Characteristics – Globular Clusters

- **Age:** up to the age of the host galaxy
- **Metallicity:** -0.5 to -2.5 dex compared to the Sun
- **Distance from the Sun:** > 2000 pc
- **Mass range of the members:** 0.08 to 20 M(sun)
- **Total masses:** up to 10^6 M(sun)
- **Absolute linear diameter:** up to 100 pc

Star Associations and Moving Groups

Besides classical star clusters according to our definition there are also

- Moving Groups
- Stellar Associations
- Open Cluster remnants
- (Star Forming regions)

There is a continuous transition between star clusters and these four types of stellar aggregates

Stellar Association

- Concentration of specific star groups, for example O, B or T Tauri Sterne, significant higher than in the galactic vicinity
- Overall density equal to surrounding
- Short life time, only about 10 Myrs because not gravitional bound
- Diameters up to 200 pc
- Example: Orion OB1 association

Moving Group

- Simplified: "dissipating star clusters"
- Density as the surrounding
- Still "same motion", weak gravitational bound
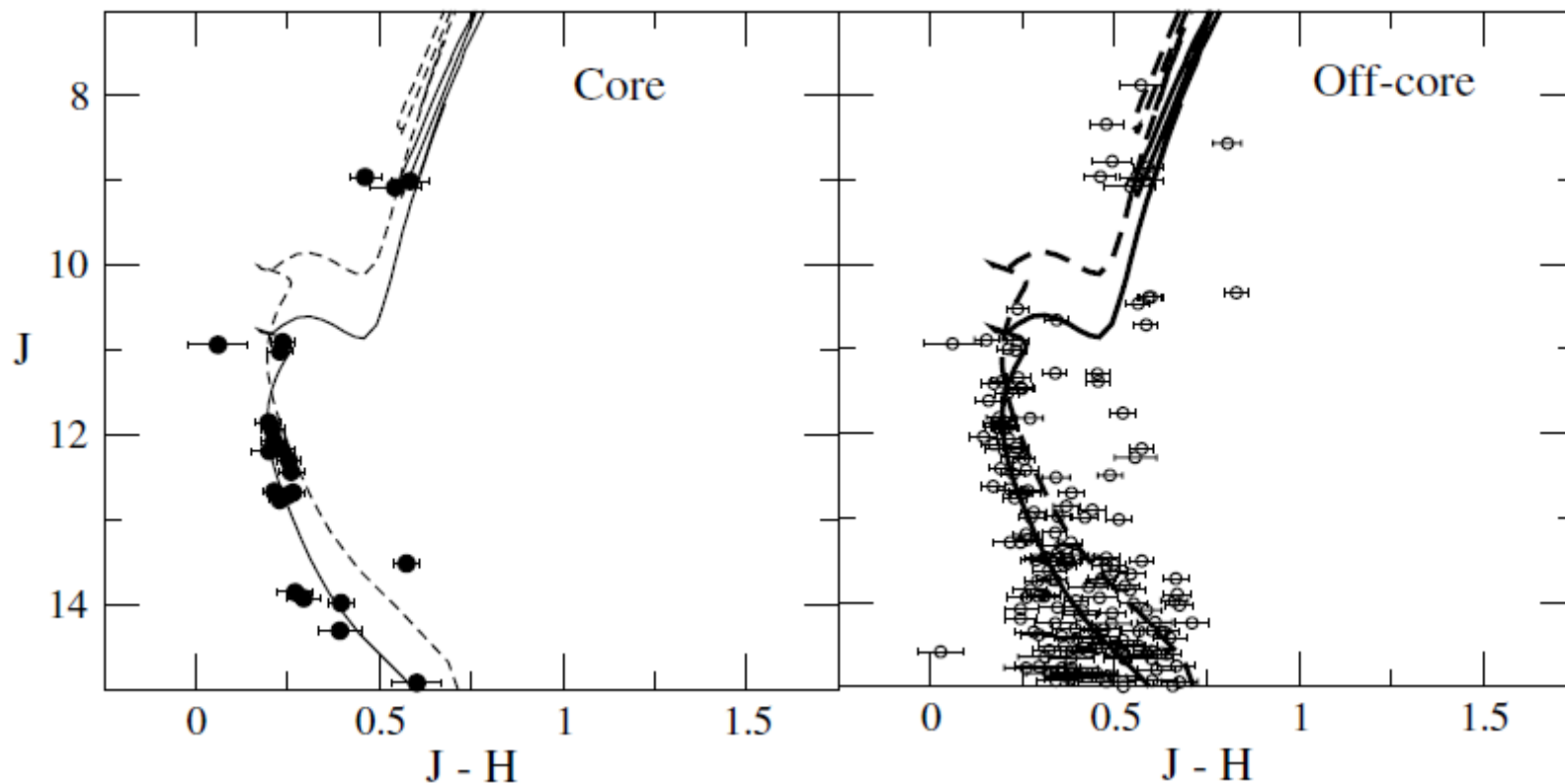- Diameters up to 400 pc

Open Cluster Remnants (OCR)

- Pavani & Bica, 2007, A&A, 468, 139
- Simplified: "dissipated star clusters"
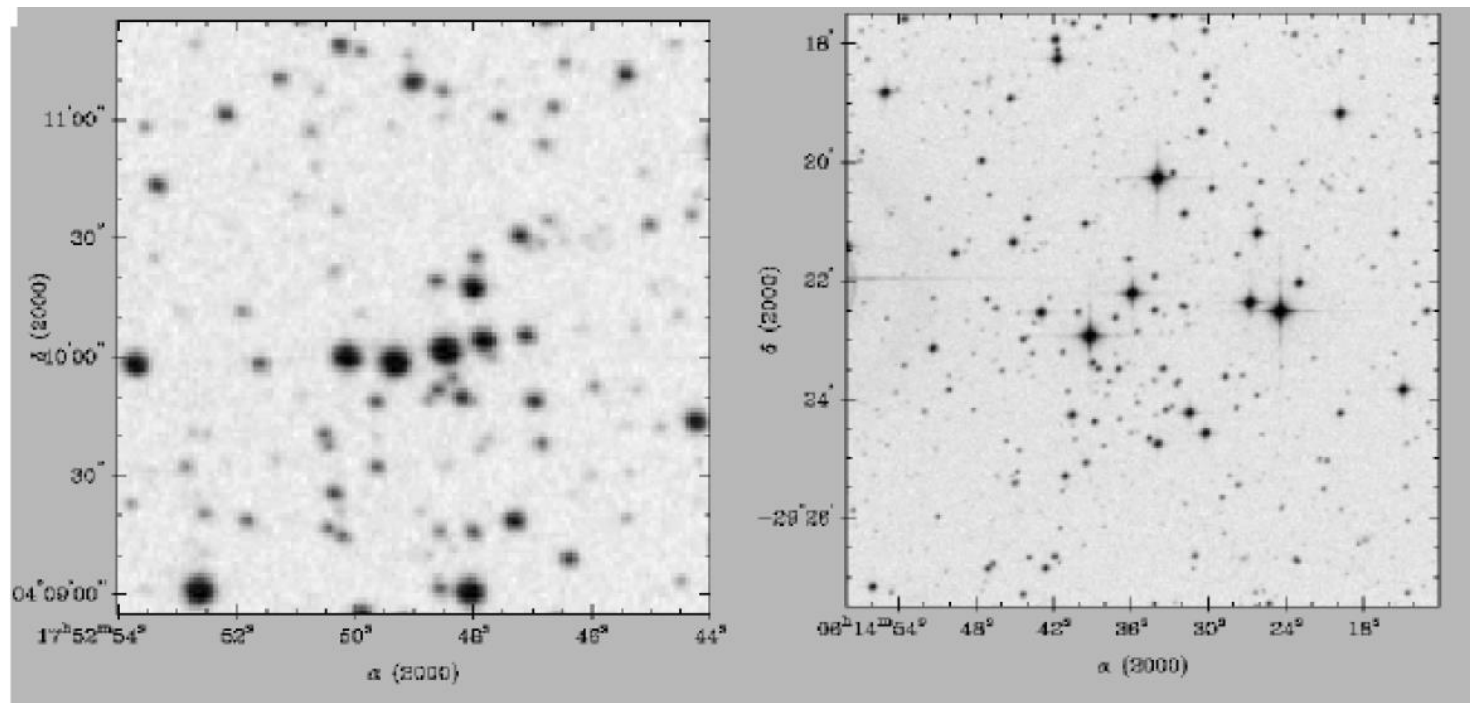
Open Cluster Remnants (OCR)

- Very difficult to distinguish from "true Open Clusters"

M11, NGC 6705: Total Mass About 10000 M(sun), 200 Myr

Orion Nebula, Distance about 450 pc, Total Mass about 5000 M(sun), Diameter about 3 pc

Cluster formation

- Observations versus Models

- Important parameters
  1. Time scale
  2. Total mass
  3. Initial Mass Function
  4. Velocity distribution
  5. Binary fraction
  6. Diameter
  7. Density distribution