Herbig-Haro Objects

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Outline

- what are they?
- how were they discovered?
- where do they originate?
- how does their structure look like?
- how are they formed?
- other related phenomena
- summary
What are HH-objects?

- small patches of nebulosity
- form when gas from YSO hit ISM at high v
- disappear when time progresses
- by-product of stellar formation
- perpendicular to accretion disk
Properties of HH objects

- 1–20 Earth-masses
- 100-1000 km/s
- 8.000–12.000 K (Like HII regions and PN)
- 2.000-20.000 particles/cm$^3$
- ~75% Hydrogen ~25% Helium ~1% rest
- 400+ known, 150,000 in our galaxy
History

- Sherburne Wesley Burnham
- Lick Observatory 36 inch refractor (1890, 1894)
- nebuluous patch near T-Tauri (Burnham's Nebula - HH255)
- similar objects found (Herbig & Haro, 1940s)
- IR invisible
- odd combination spectral lines ([SII], [OII], H)
- coexist with nebuluous stars (Ambartsumian)
- They originate from YSOs (Schwartz, 1975)
Origin

- reflection of light in cloud
- supersonic stellar wind (jet) + ISM -> shocks
- lack of \([\text{OIII}]\) + large \(v\) -> comoving medium + eruptive source
- \(\text{HH24}\) largely polarized
- lines unpolarized - continuum polarizes
- emission lines formed in shocks
Source of jets

- convection + advection
  create poloidal fields
- x-wind at edge accretion disk
- disk winds from lots of radii
- driven by rotation and magnetism
- 10% of the accreting material gets ejected
X-wind model

protostar rotating at break-up

ordinary wind

critical equipotential

centrifugally driven magnetic wind

extraordinary wind

thin accretion disk
Diskwinds

Wind launched along the open magnetic field lines of the disk at several different radii from the star.

Emma Whelan
Structure of jets

- starts off as ionized (20-30%) but decreases
- have multiple working surfaces
- high H/SII ratio near edges, low near center
- faster in center, slower near edges
- Hubblelike velocity dependancy
- jets remove angular momentum
HH-objects

- each HH or working surface has 2 shocks
- jet decelerates in a mach disk
- ambient material accelerates in bow shock
- to maintain pressure radiative cooling occurs
HH 34
Protostellar Jet
Molecular outflows

- detected in the CO molecule (mm-wave)
- influenced by jet
- lobes terminate in H2 shock
- thin J-shockfront (non-radiative) in apex
- continuous C-shockfront in wake
Summary

- found near YSOs
- jets originate from accretion disk
- jets powered by rotation and magnetic field
- caused by cooling process due to bowshock
- disappears into ISM after cooling
Articles

- Resistive MHD Accretion and jets
- Ideal MHD jet launching from resistive accretion disks
- http://www.jetsets.org/
- http://www.strw.leidenuniv.nl/~vcgeers/sfcourse/