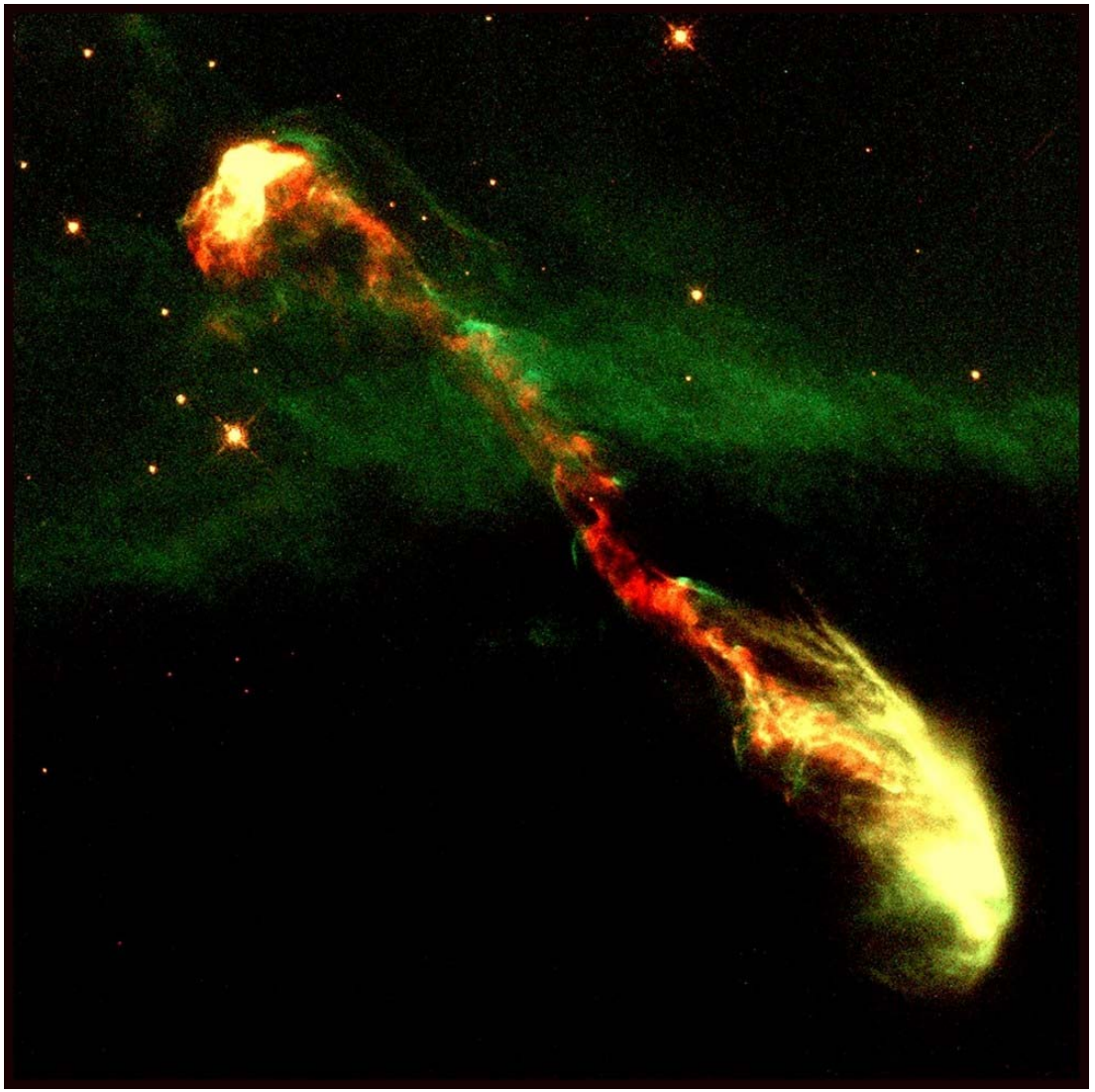
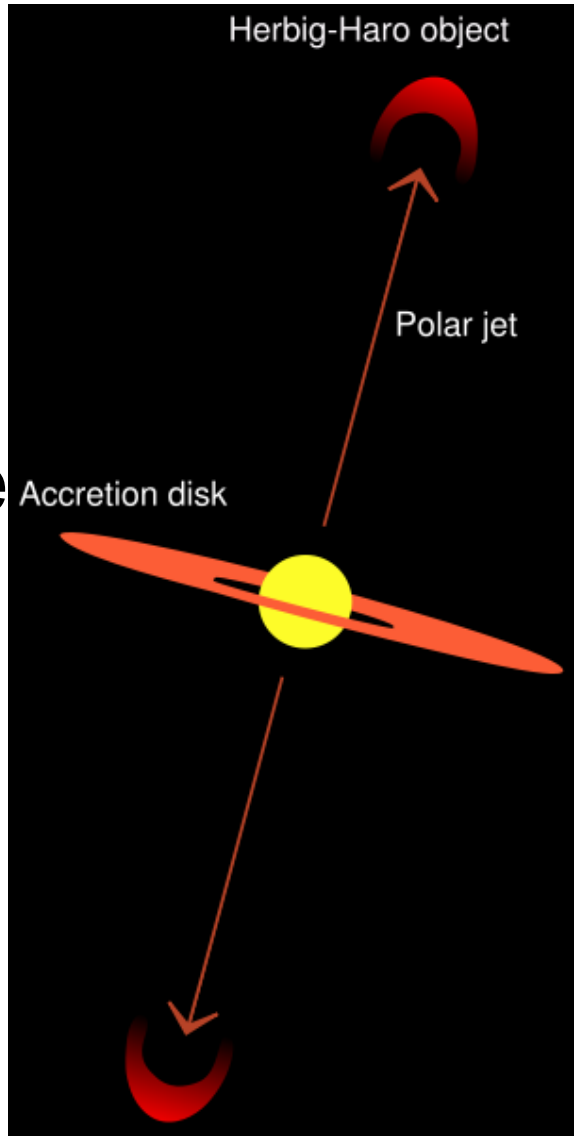
Herbig-Haro Objects



Gilles Otten

Outline

- what are they?
- how were they discovered?
- where do they originate?
- how does their structure look like
- how are they formed?
- other related phenomenons
- 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)
- nebulous 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 nebulous stars (Ambartsumian)
- They originate from YSOs (Schwartz,1975)

Origin

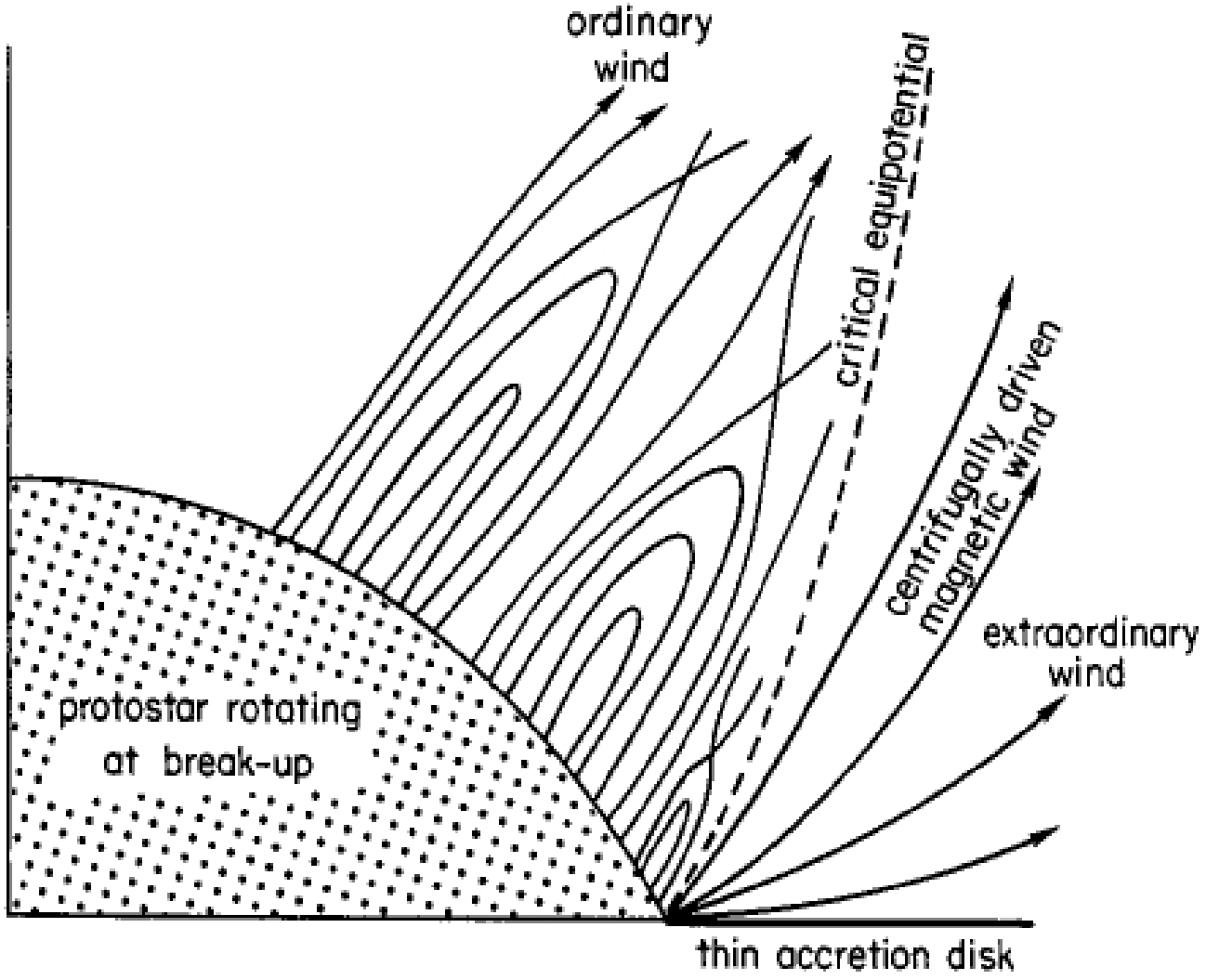
- reflection of light in cloud
- supersonic stellar wind (jet) + ISM -> shocks
- lack of [OIII] + large v -> comoving medium + eruptive source
- HH24 largely polarized
- lines unpolarized - continuum polarizes
- emissionlines formed in shocks

Source of jets

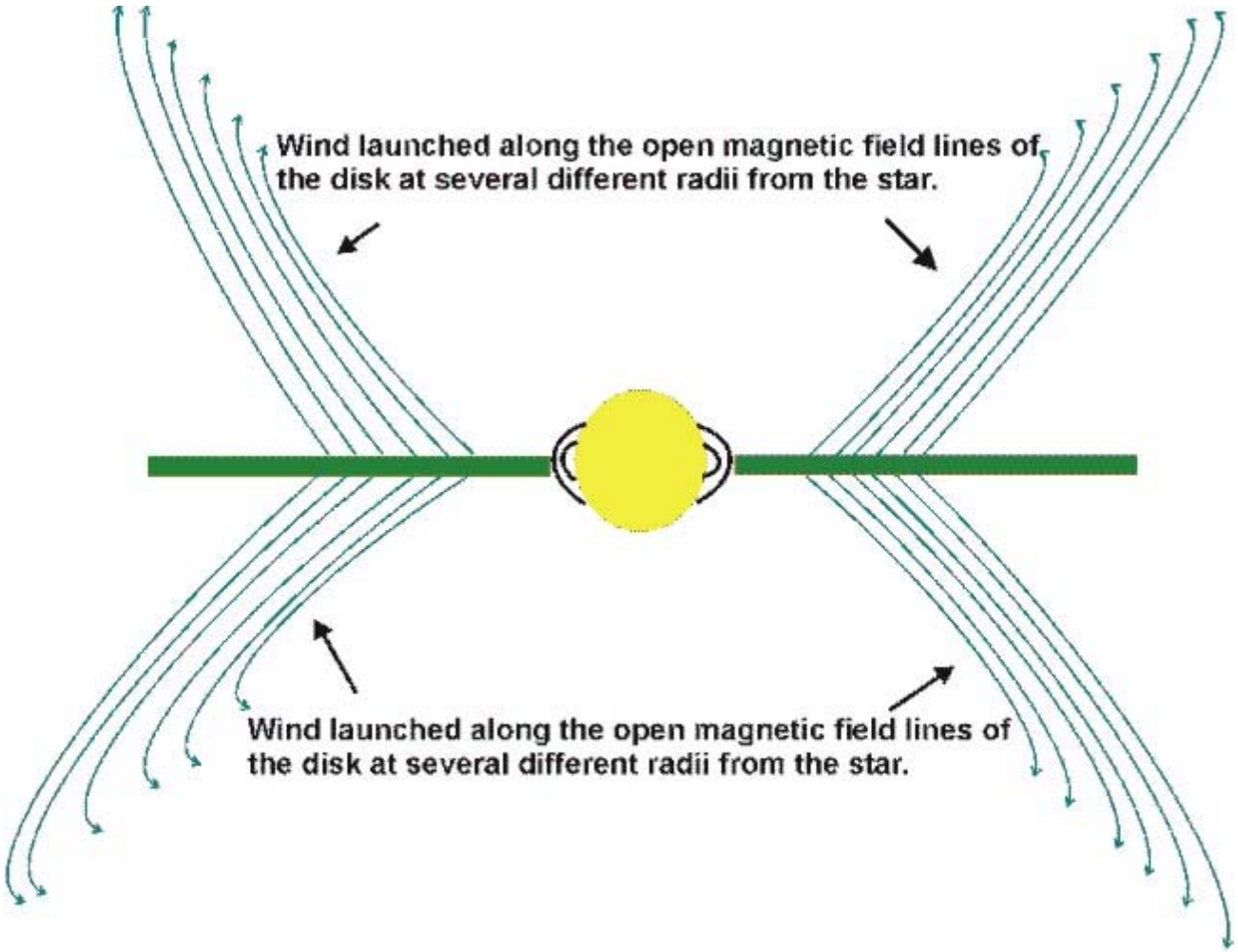
- convection + advection

  create poloidal fields
- x-wind at edge accretiondisk
- diskwinds from lots of radii
- driven by rotation and magnetism
- 10% of the accreting material gets ejected

X-wind model


ordinary
wind
critical equipotential
centrifugally driven
magnetic wind
extraordinary
wind
protostar rotating
at break-up
thin accretion disk

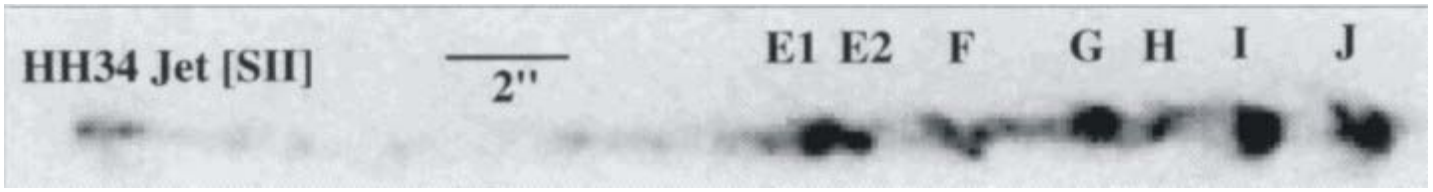
Diskwinds



Emma Whelan

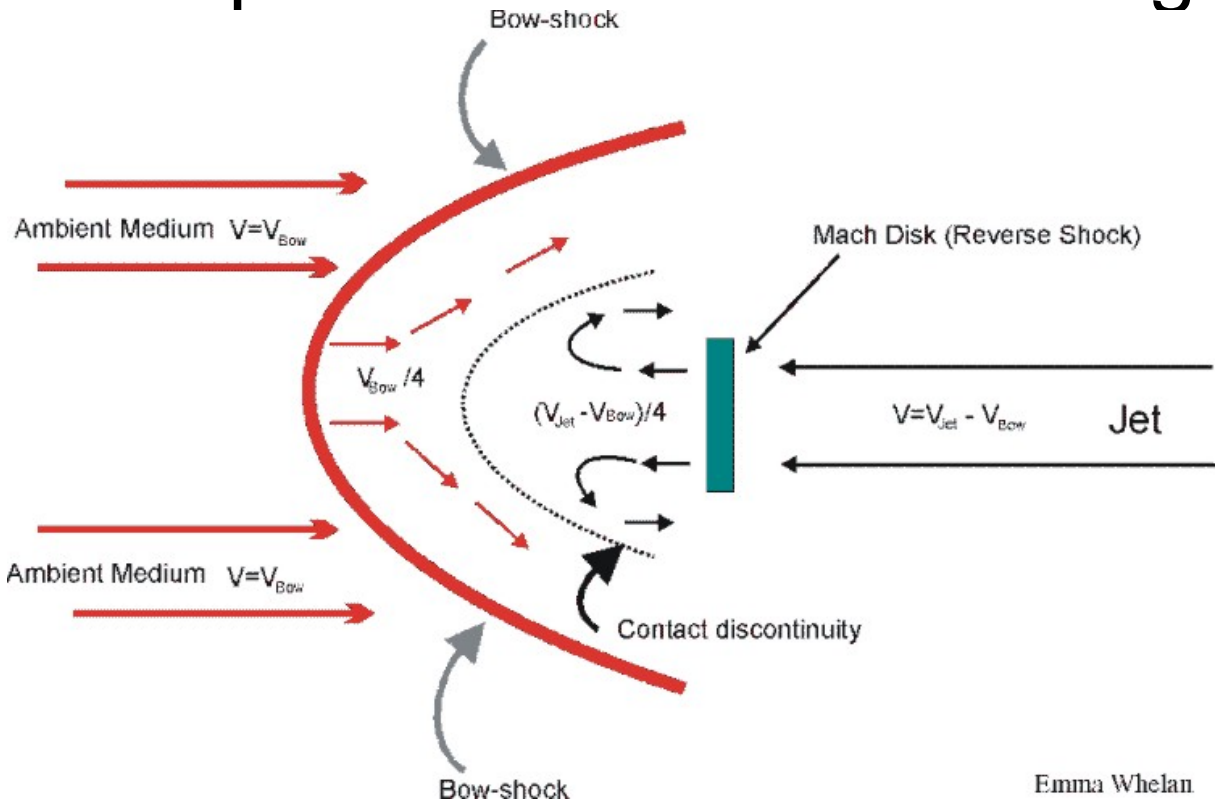
Structure of jets

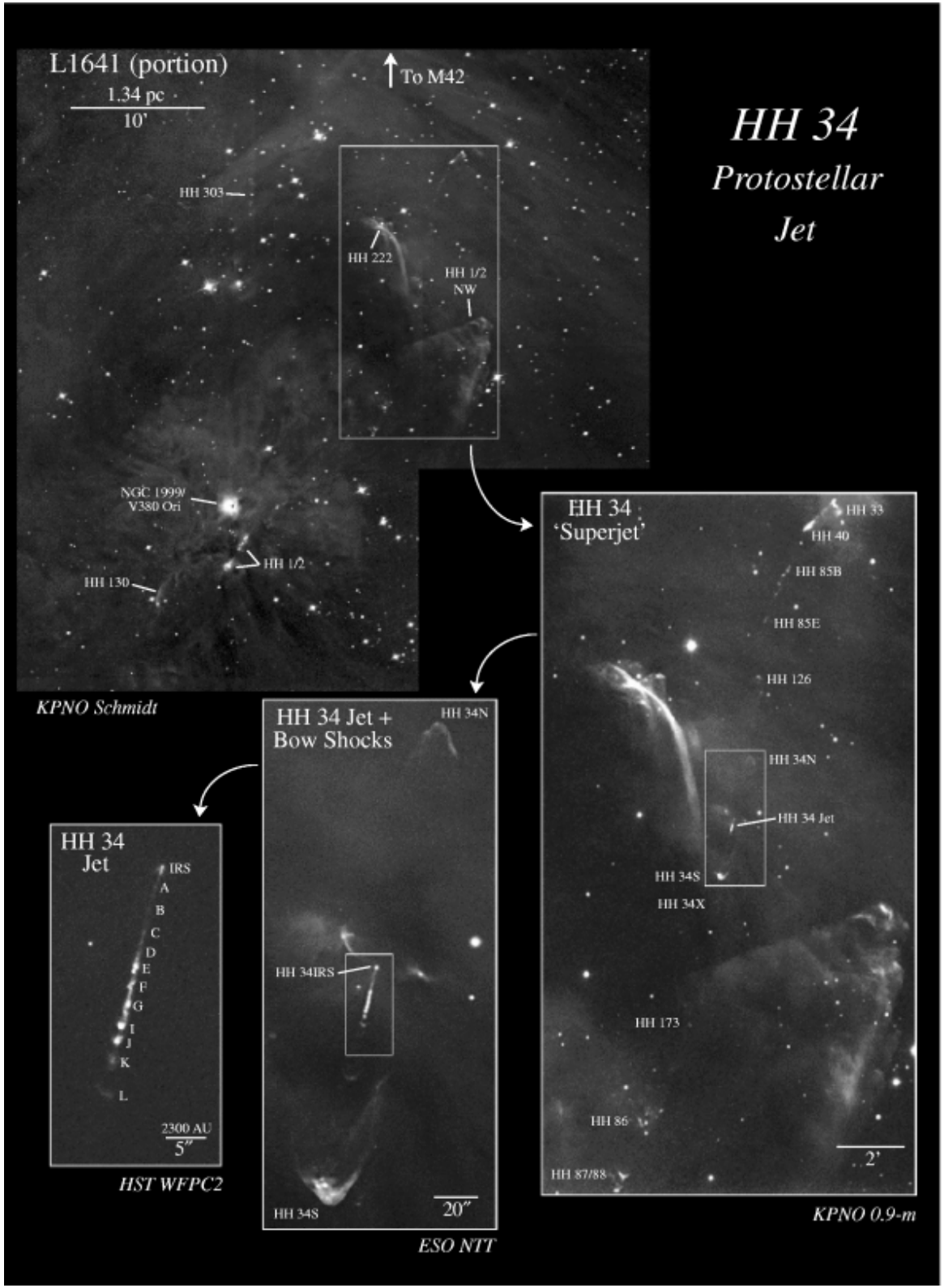
- starts off as ionized (20-30%) but decreases
- have multiple working surfaces
- high H/SII ratio near edges, low near center
- faster in center, slower near edges
- Hubblelike velocity dependancy
- jets remove angular momentum



HH-objects

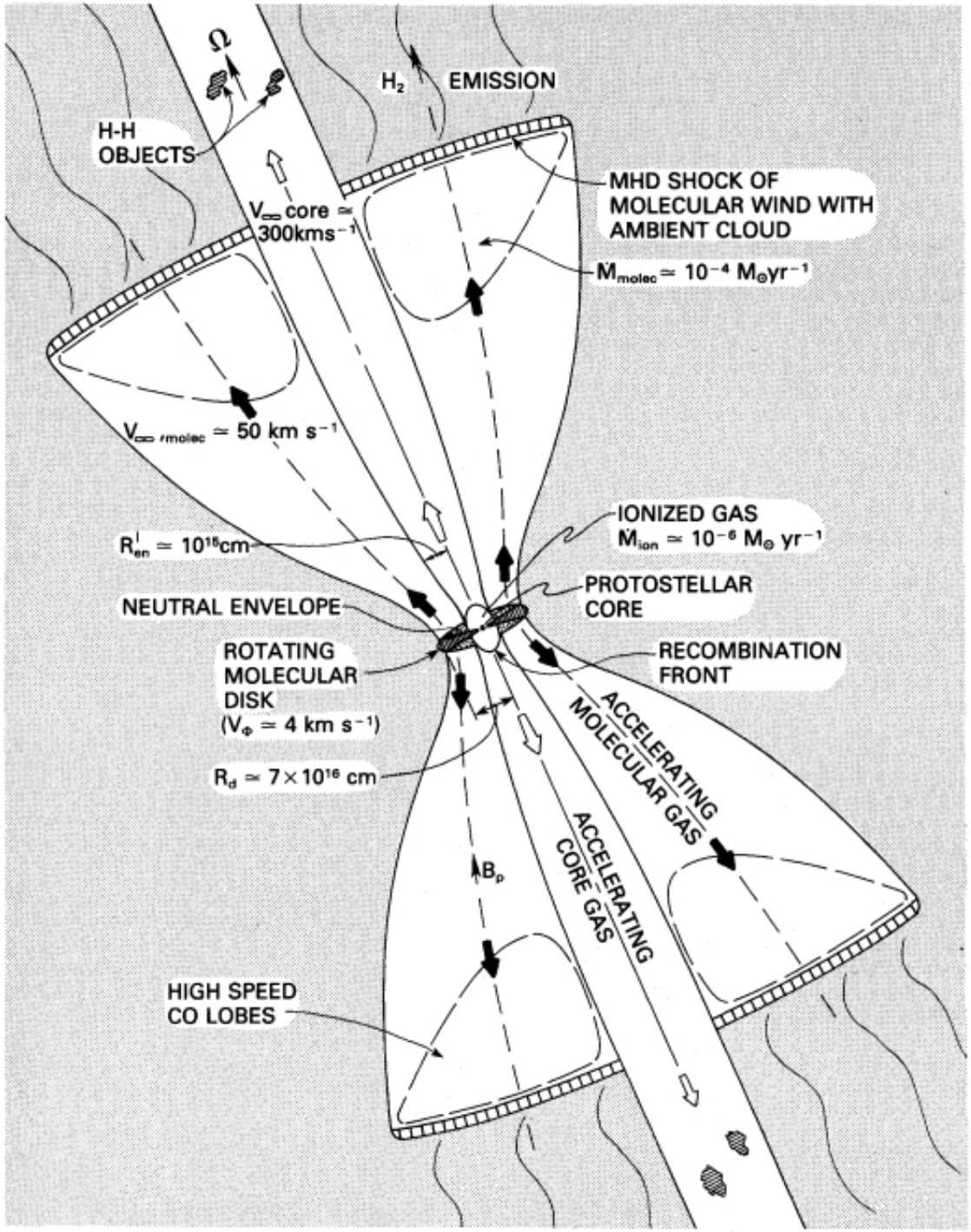
- each HH or working surface has 2 shocks
- jet decelerates in a mach disk
- ambient material accelerates in bow shock
- to maintain pressure radiative cooling occurs




L1641 (portion)
1.34 pc
10'
To M42
HH 303
HH 222
HH 1/2 NW
NGC 1999/ V380 Ori
HH 1/2
HH 130
KPNO Schmidt
HH 34 'Superjet'
HH 33
HH 40
HH 85B
HH 85E
HH 126
HH 34N
HH 34 Jet
HH 34S
HH 34X
HH 173
HH 86
HH 87/88
2'
KPNO 0.9-m
HH 34 Jet + Bow Shocks
HH 34N
HH 34IRS
HH 34S
20"
ESO NTT
HH 34 Jet
IRS
A
B
C
D
E
F
G
I
J
K
L
2300 AU
5"
HST WFPC2
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


Ω
H-H OBJECTS
H_2 EMISSION
V_{∞} core ≃ 300kms^{-1}
MHD SHOCK OF MOLECULAR WIND WITH AMBIENT CLOUD
$\dot{M}_{molec} \simeq 10^{-4}\ M_{\odot} yr^{-1}$
$V_{\infty\ rmolec} \simeq 50\ km\ s^{-1}$
$R_{en}^{I} \simeq 10^{15} cm$
IONIZED GAS
$\dot{M}_{ion} \simeq 10^{-6}\ M_{\odot}\ yr^{-1}$
NEUTRAL ENVELOPE
PROTOSTELLAR CORE
ROTATING MOLECULAR DISK ($V_{\phi} = 4\ km\ s^{-1}$)
RECOMBINATION FRONT
$R_d \simeq 7 \times 10^{16}$ cm
ACCELERATING MOLECULAR GAS
ACCELERATING CORE GAS
B_p
HIGH SPEED CO LOBES

Summary

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

Articles

- Herbig-Haro Flows and the Birth of Stars; IAU Symposium No. 182 ISBN 0-7923-4660-2
- Resistive MHD Accretion and jets
- Ideal MHD jet launching from resistive accretion disks
- http://www.jetsets.org/
- http://www.strw.leidenuniv.nl/~vcgeers/sfcourse/