Outflows and Jets: Theory and Observations

Summer term 2011

Henrik Beuther & Christian Fendt

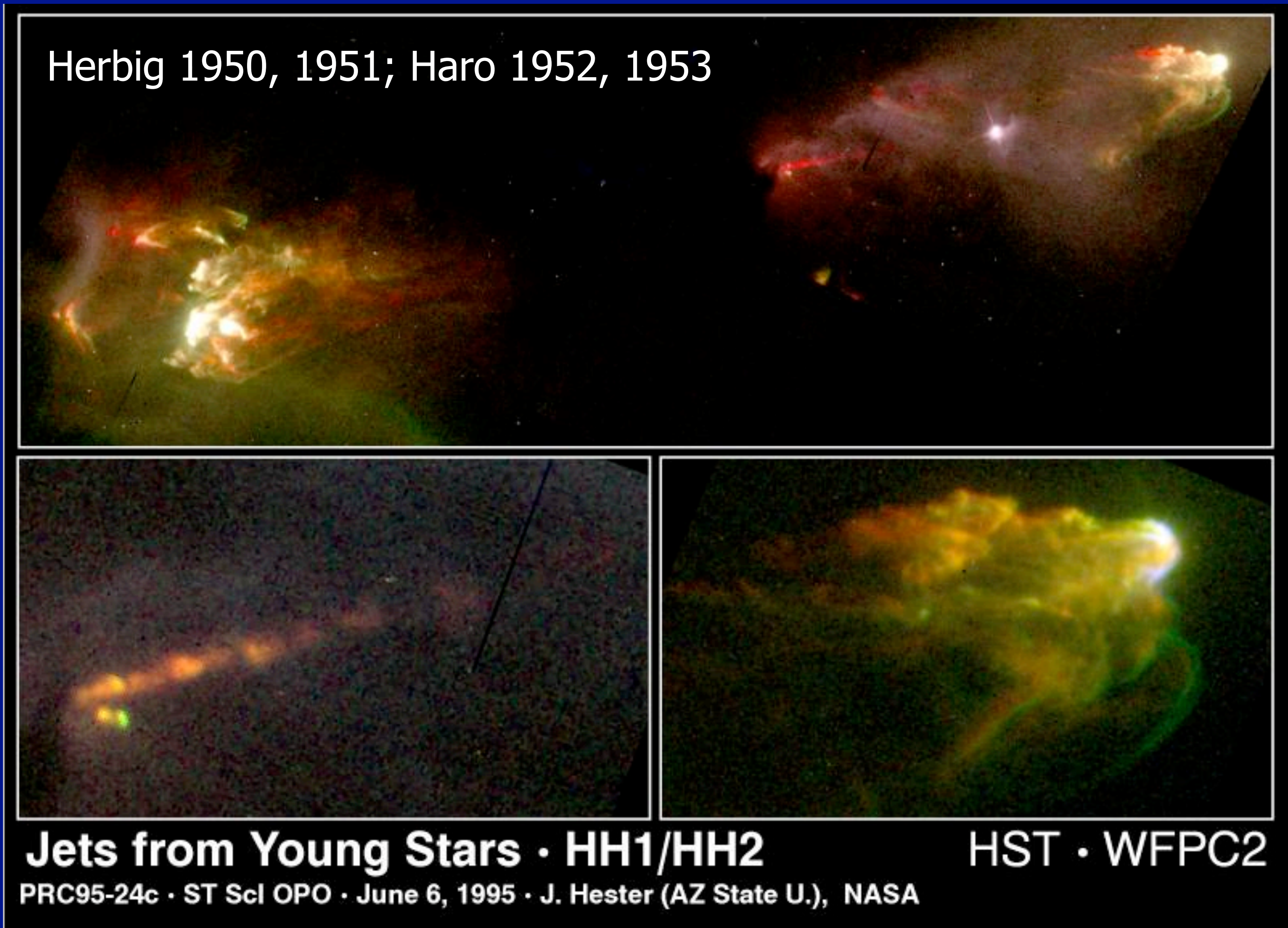
15.04 Today: Introduction & Overview (H.B. & C.F.)

29.04 Definitions, parameters, basic observations (H.B.)
06.05 Basic theoretical concepts & models (C.F.)
13.05 Radiation processes I (C.F.)
20.05 Radiation processes II (H.B.)
27.05 Observational properties of accretion disks (H.B.)
03.06 Basic MHD and plasma physics; applications (C.F.)
10.06 Accretion disk theory and jet launching (C.F.)
17.06 Outflow-disk connection, outflow entrainment (H.B.)
24.06 Outflow-ISM interaction, outflow chemistry (H.B.)
01.07 Outflow interactions: Entrainment, instabilities, shocks (C.F.)
08.07 Outflows from massive star-forming regions (H.B.)
15.07 Observations of extragalactic jets (C.F.)
22.07 Theory of relativistic jets (C.F.) (examination week?)

More Information and the current lecture files: http://www.mpia.de/homes/beuther/lecture_ss11.html

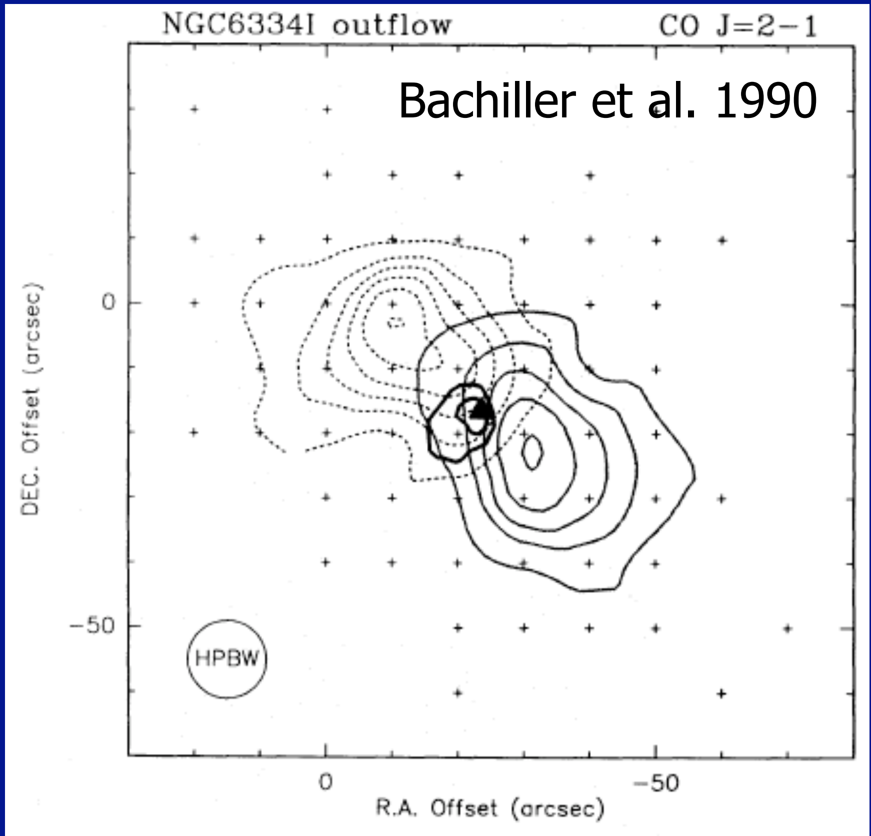
beuther@mpia.de, fendt@mpia.de

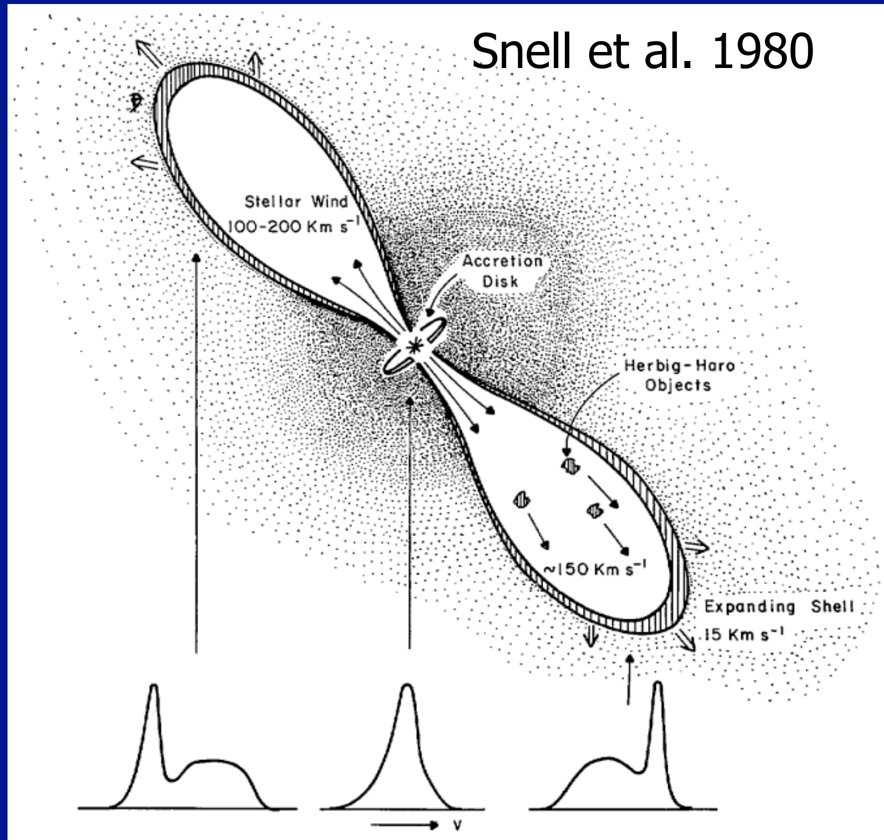
Discovery of outflows I



Initially thought to be embedded protostars but soon spectra were recognized as caused by shock waves → jets and outflows

Discovery of outflows II

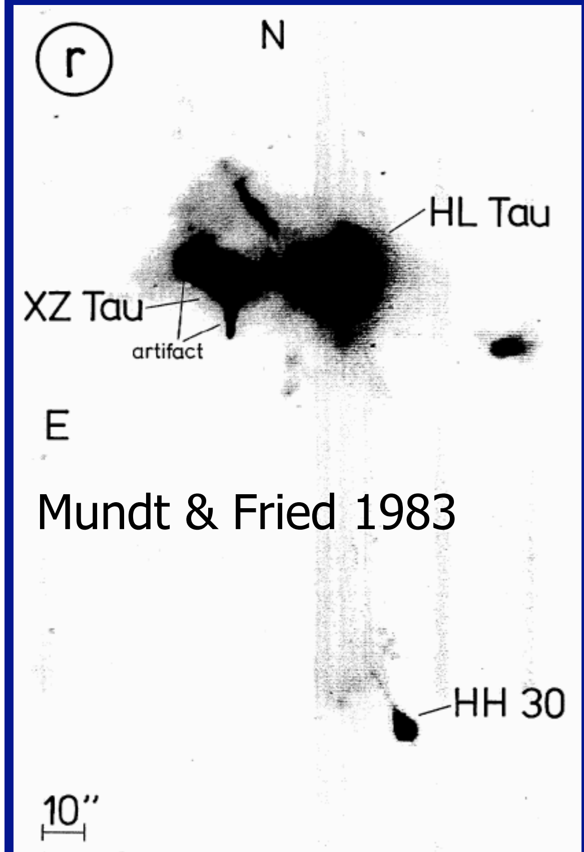




- In the mid to late 70th, first CO non-Gaussian line wing emission detected (Kwan & Scovile 1976).
- Bipolar structures, extremely energetic, often associated with HH objects

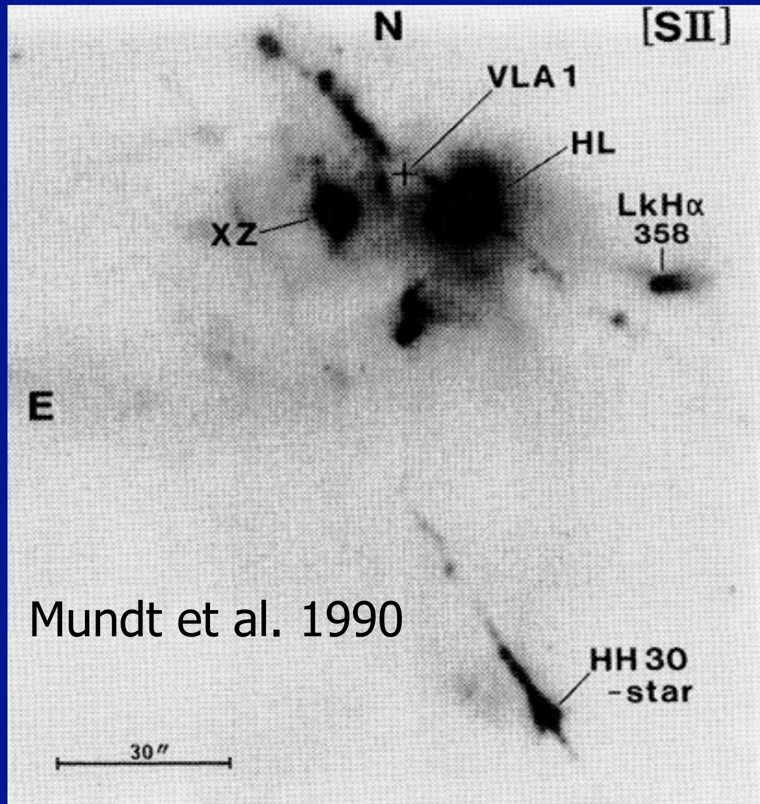
Optical jet observations

1983



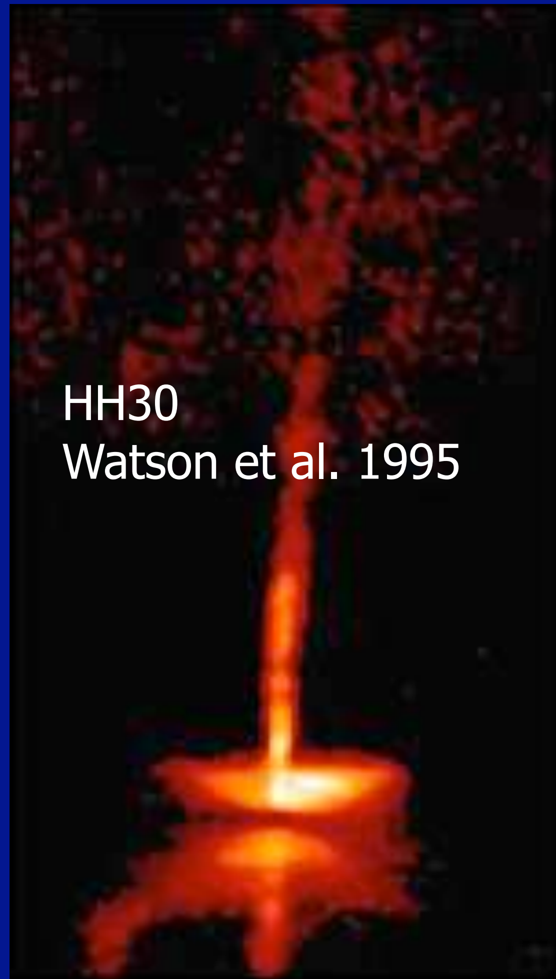
Mundt & Fried 1983

1990 (both ground based)

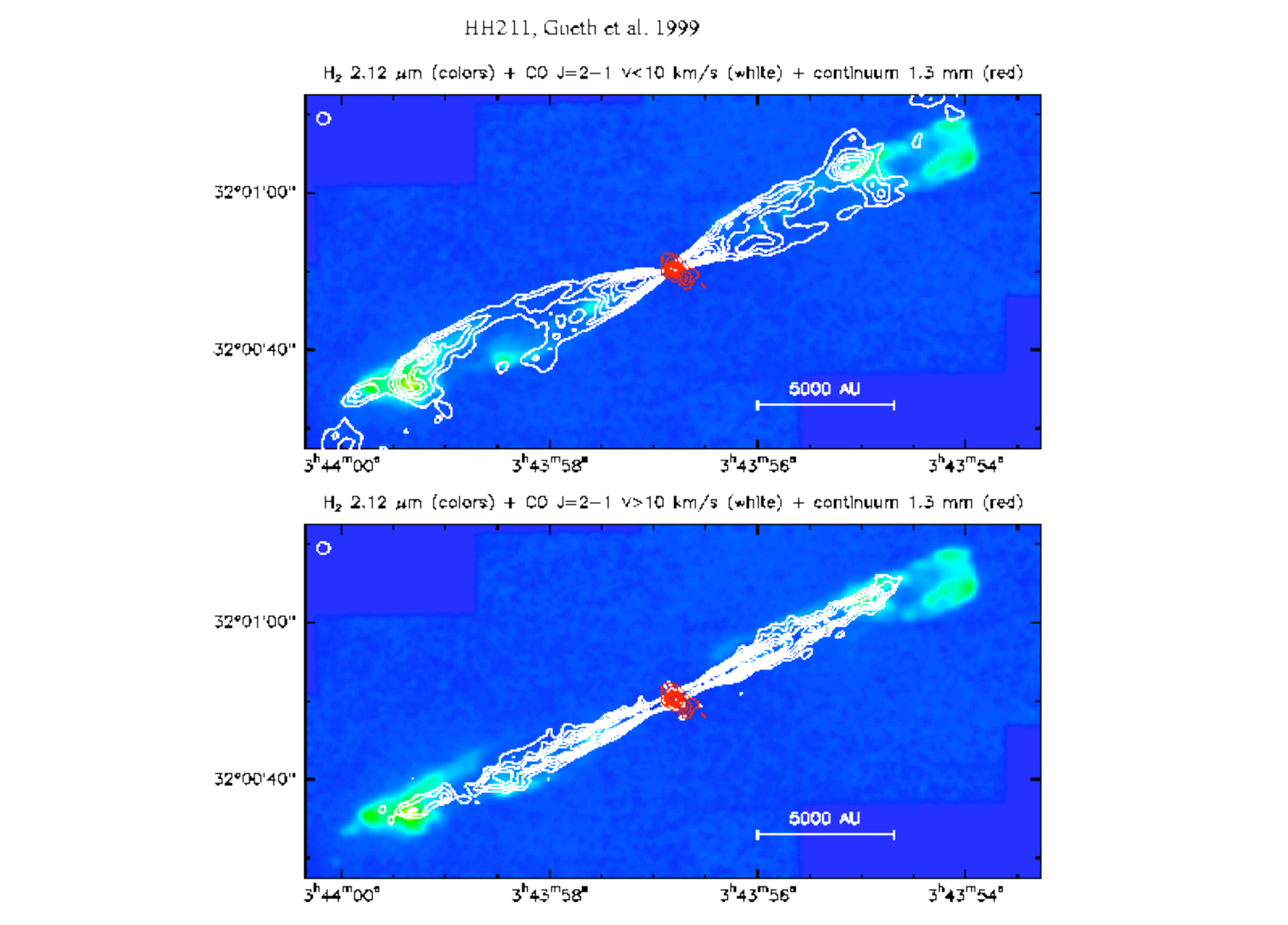


Mundt et al. 1990

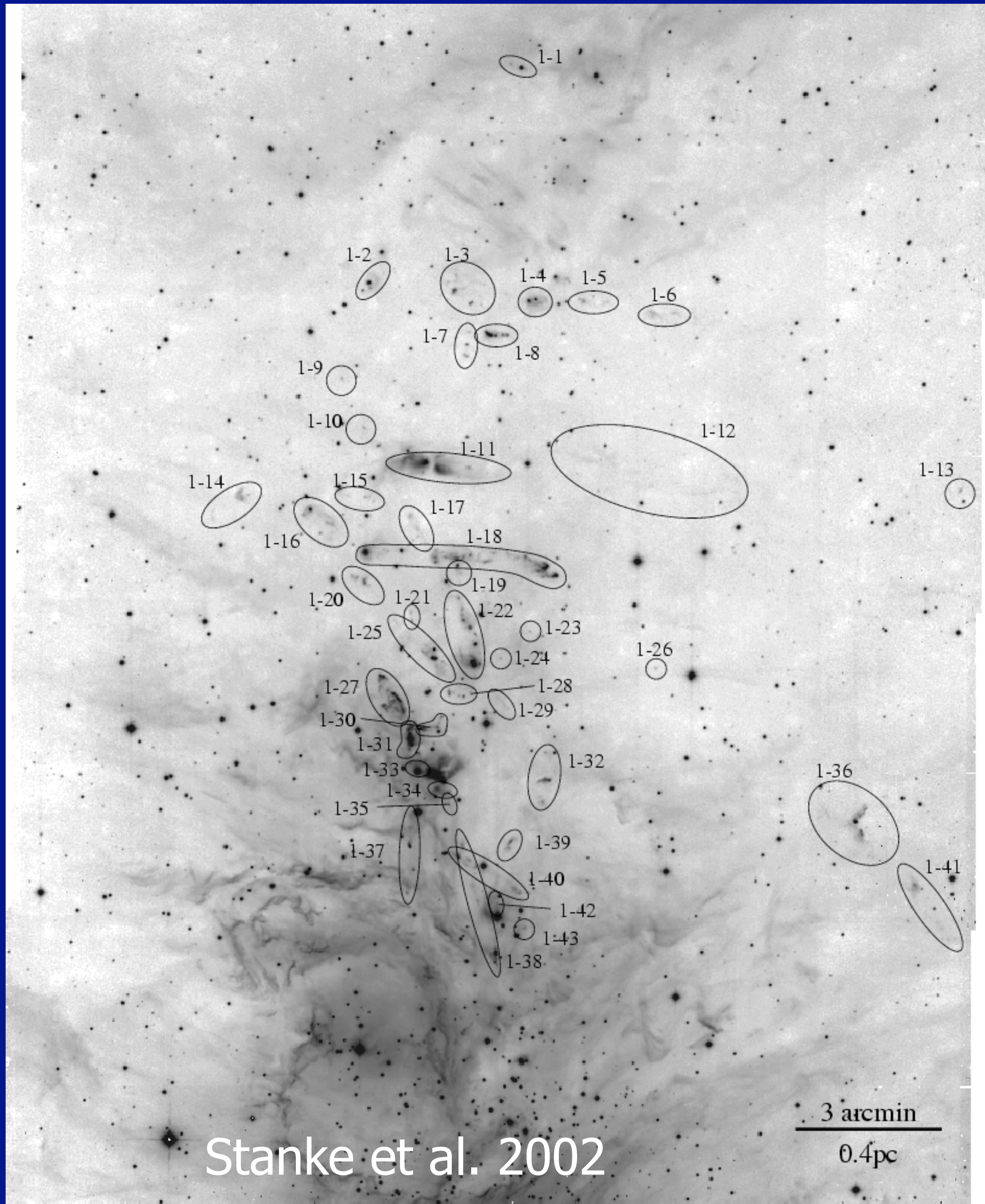
1995 (HST)


HH30
Watson et al. 1995

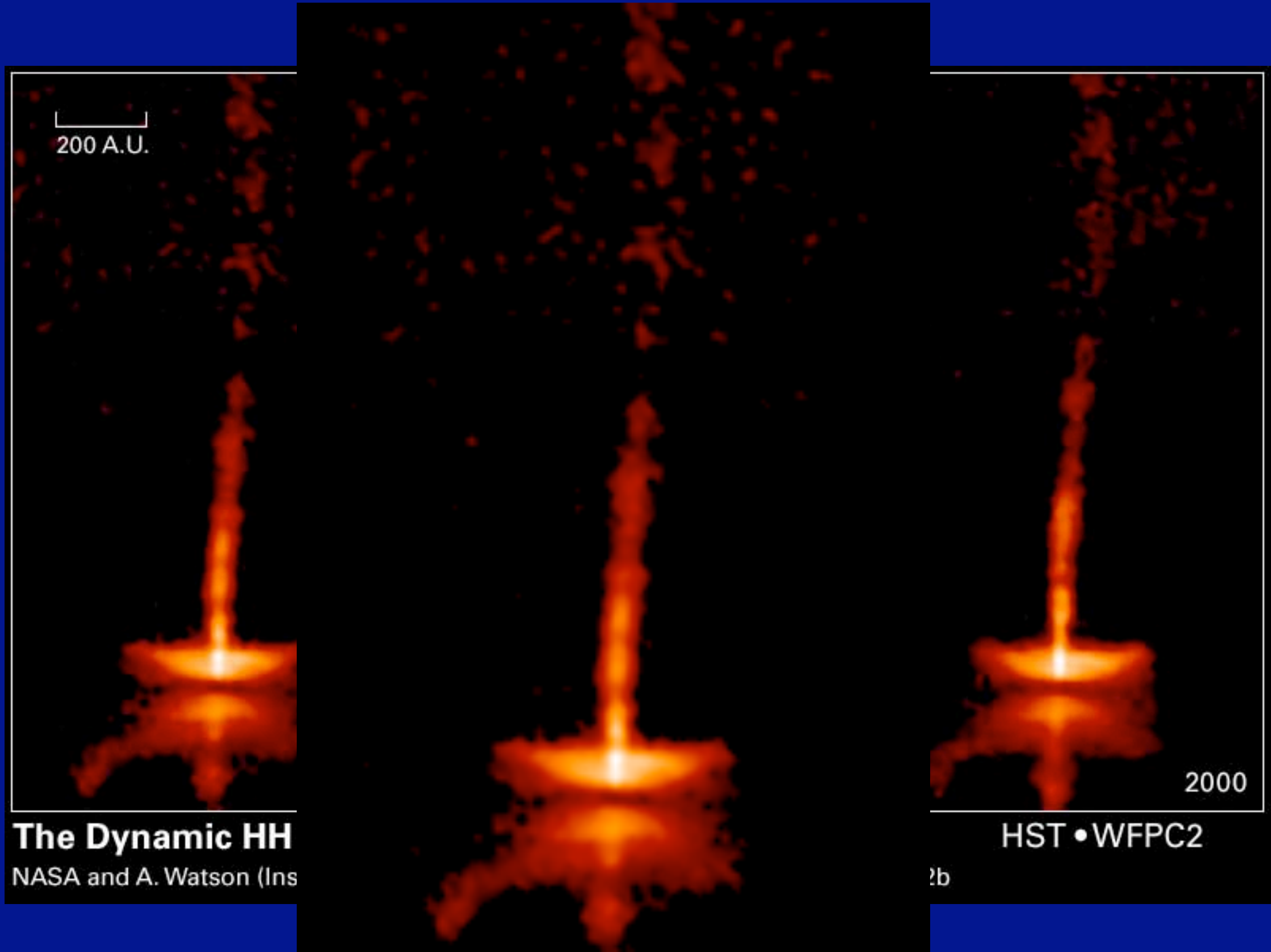
The prototypical molecular outflow HH211



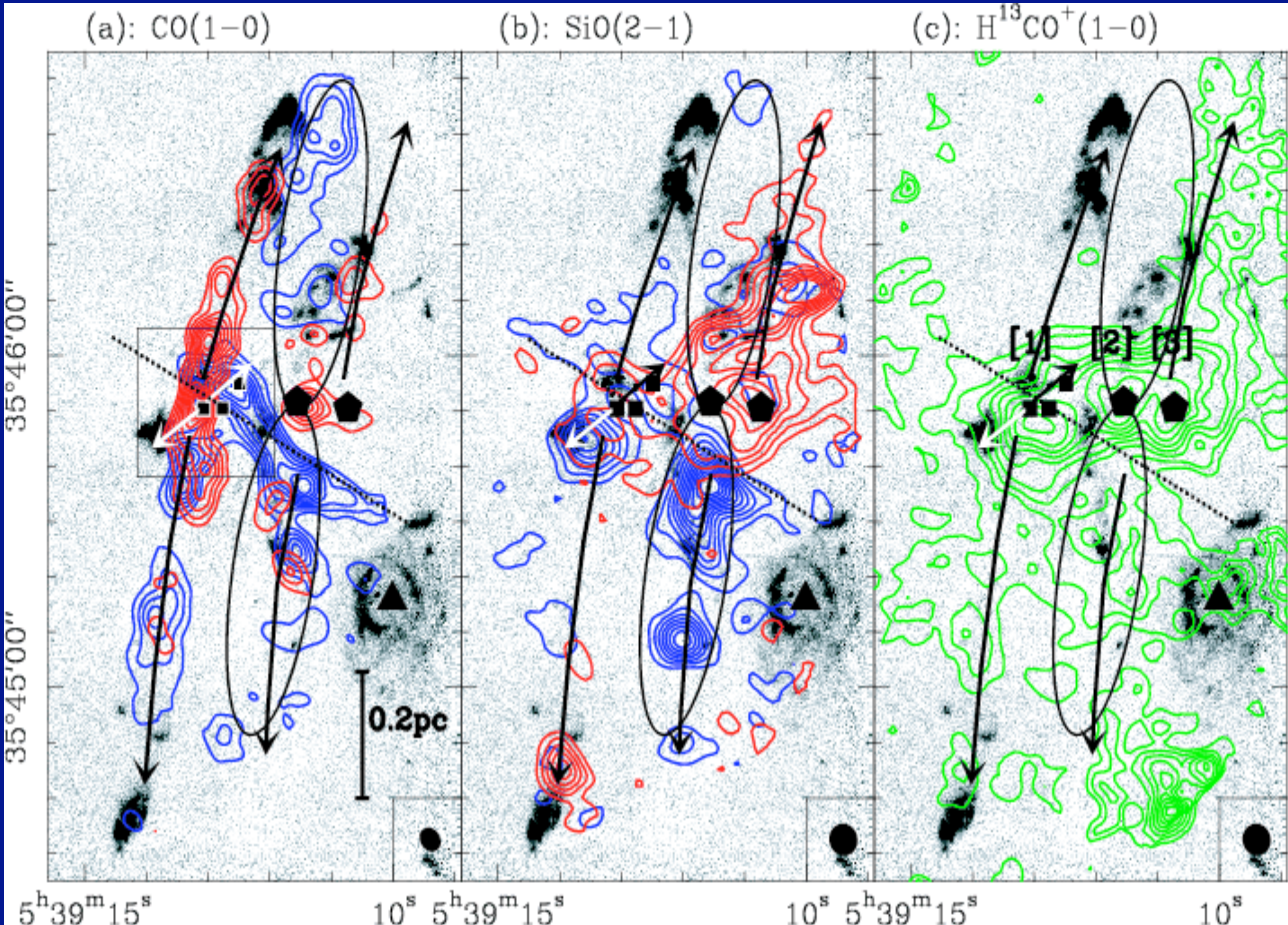
Outflow multiplicities in Orion



HH30, a disk-outflow system



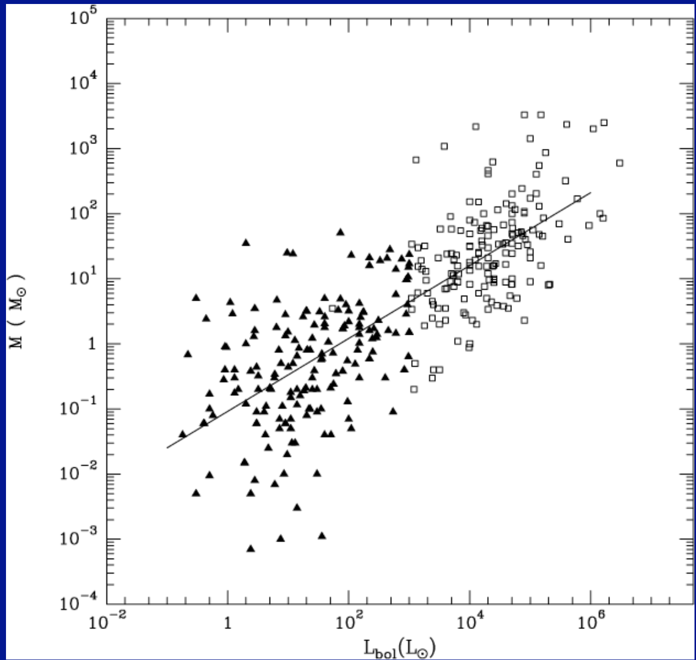
Outflows from massive star-forming regions



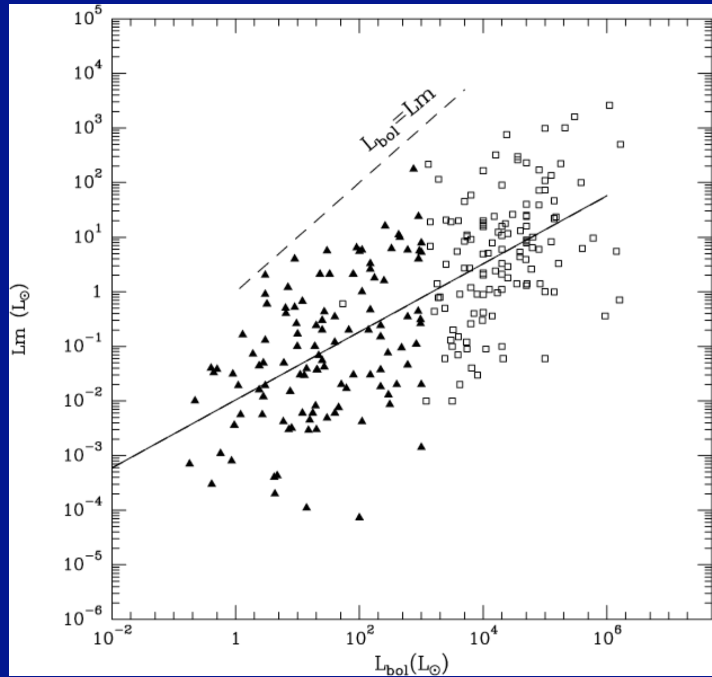
Beuther et al. 2002

Outflow properties

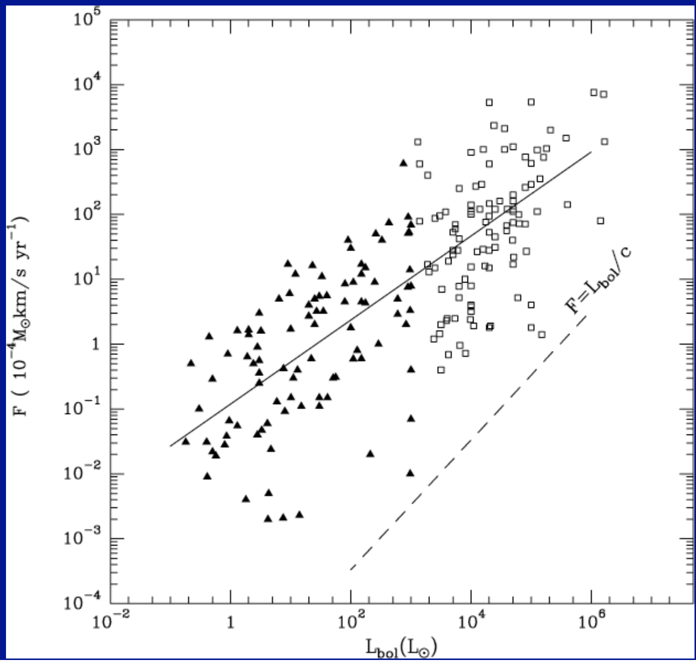
Mass



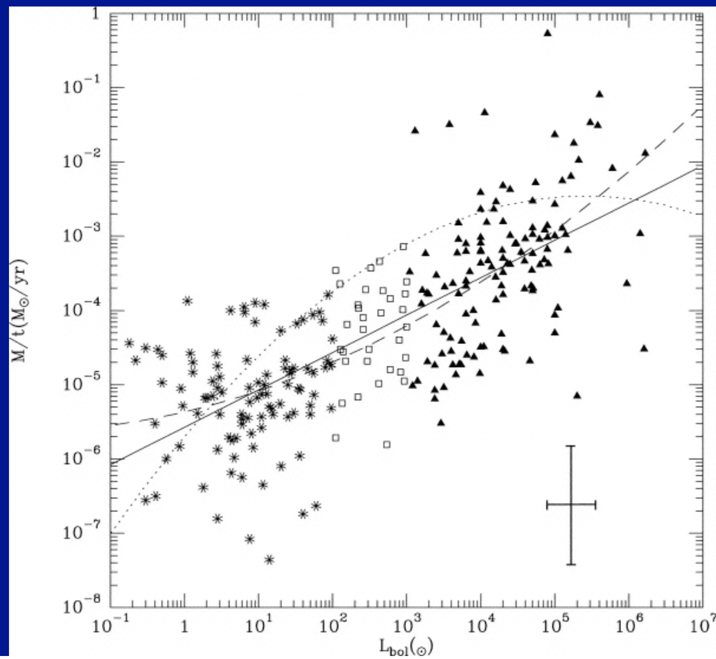
Mechanical L



Mechanical Force



Outflow rate



General jet/outflow parameters

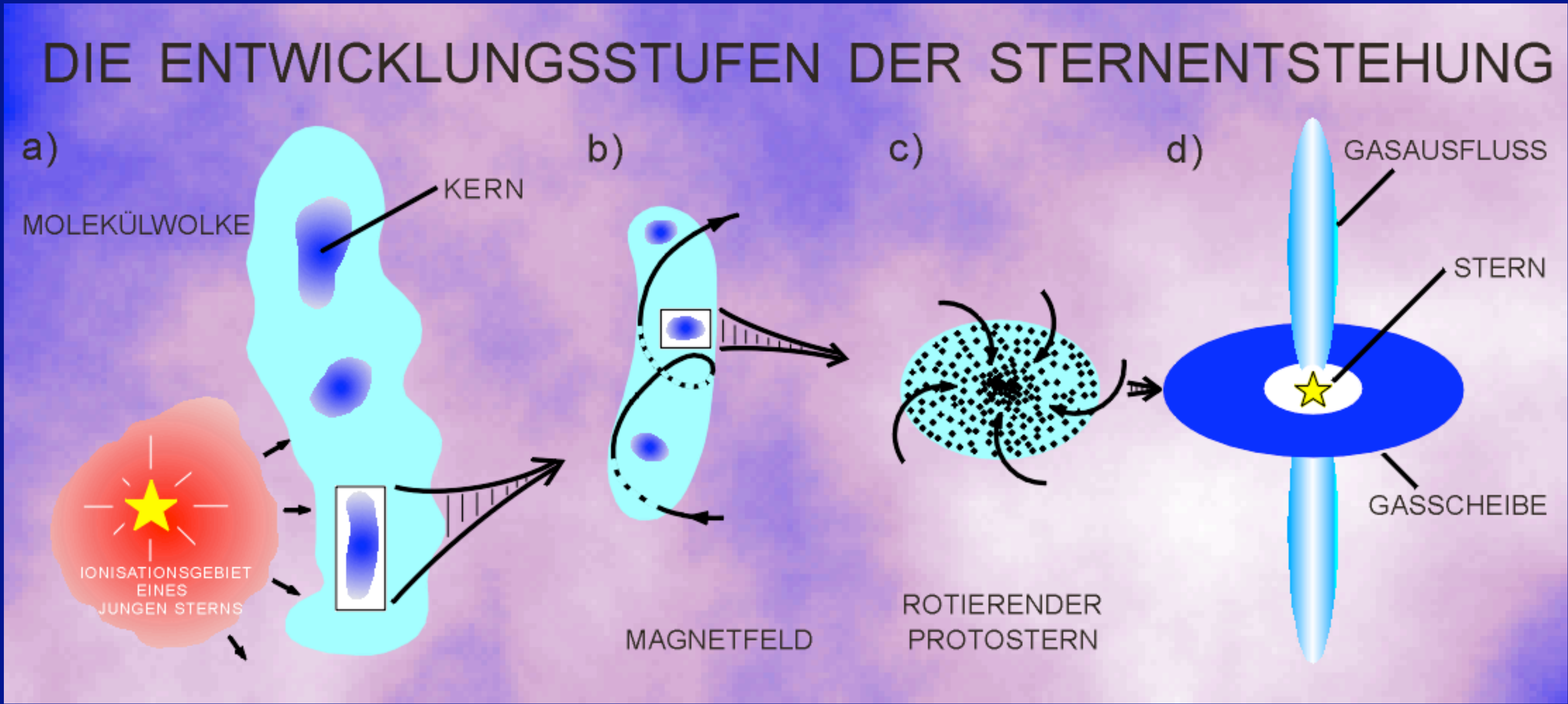
- Initial jet-velocities > 150km/s, can be a few 100km/s jets even >500km/s
- Entrained outflow gas velocities usually a few 10km/s

- Jets extremely collimated with opening angles of a few degrees, molecular outflows can be less collimated with opening angles up to 90 degrees.
- Length between 1000AU and a couple of parsec

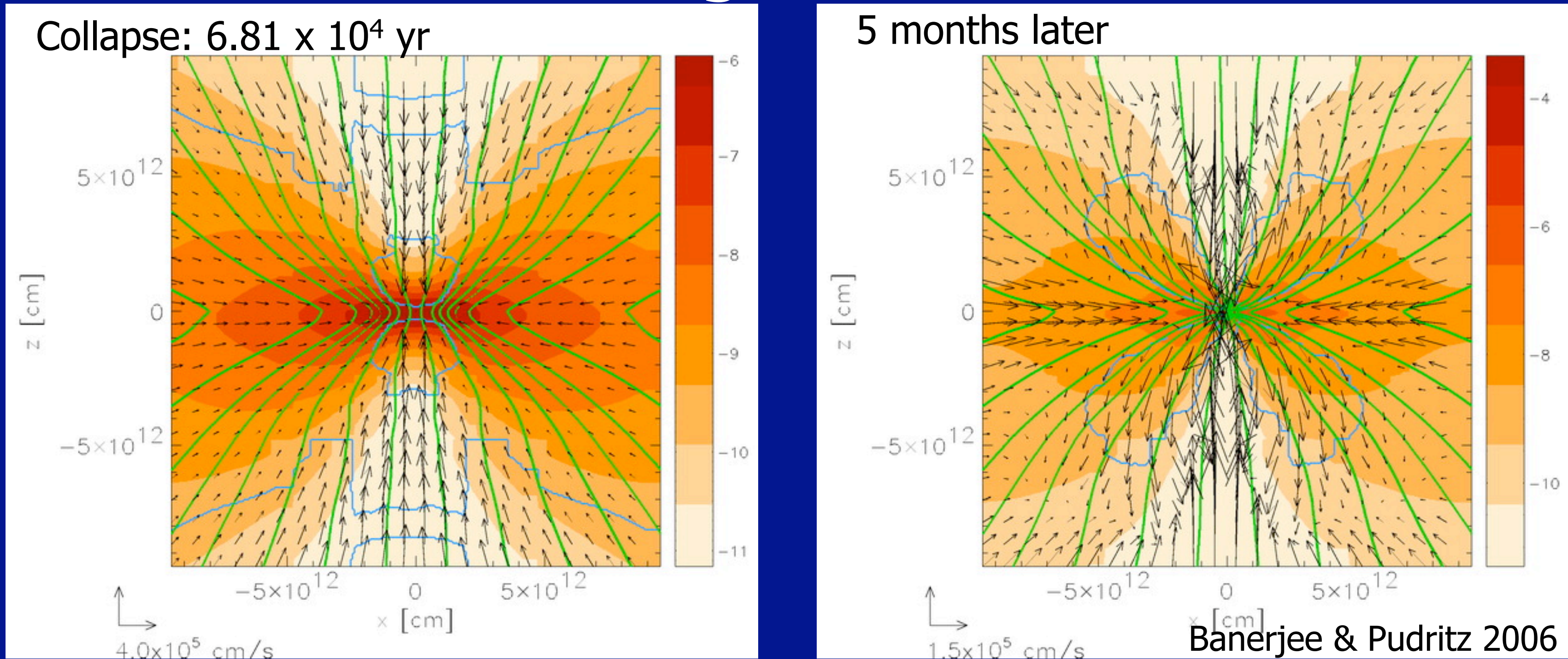
- Outflow masses between sub-solar to ~100M_{sun}.
- Outflow rates from a few times $10^{-8}M_{sun}$/yr for low-mass TTauri stars to a few times $10^{-3}M_{sun}$/yr for high-mass star-forming regions.
- Outflow luminosities between 10^{-3} and several 100 L_{sun}

- Jets largely neutral with ionization degrees between 10^{-1} and 10^{-8}.
- Magnetic fields are observed and jets are MHD driven.
- Momentum conservation between primary jet and entrained outflow gas.

Star Formation Paradigm



Jet-launching: Disk winds



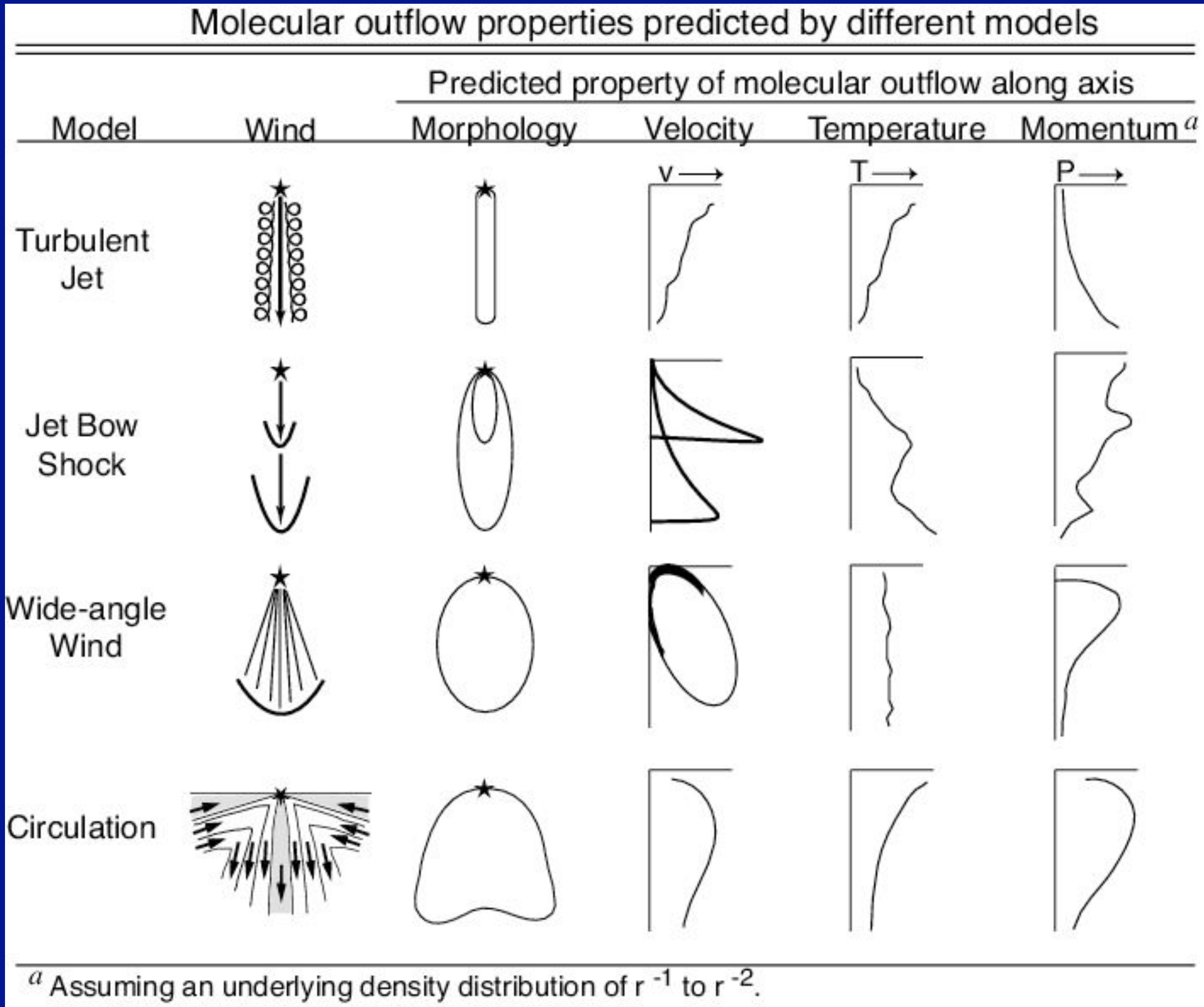
- Infalling core pinches magnetic field.

- If poloidal magnetic field component has angle larger 30° from vertical, centrifugal forces can launch matter-loaded wind along field lines from disk surface.

- Wind transports away from 60 to 100% of disk angular momentum.

Recent review: Pudritz et al. 2006

Outflow entrainment models



Arce et al. 2007

Why studying outflows/jets?

Interesting astrophysical phenomena in itself.

Important for angular momentum removal.

Impact on ISM.

Driving Turbulence.

Potentially triggering other star formation.

Shock chemistry.

…

Outflows and Jets: Theory and Observations

Summer term 2011

Henrik Beuther & Christian Fendt

15.04 Today: Introduction & Overview (H.B. & C.F.)

29.04 Definitions, parameters, basic observations (H.B.)

06.05 Basic theoretical concepts & models (C.F.)

13.05 Radiation processes I (C.F.)

20.05 Radiation processes II (H.B.)

27.05 Observational properties of accretion disks (H.B.)

03.06 Basic MHD and plasma physics; applications (C.F.)

10.06 Accretion disk theory and jet launching (C.F.)

17.06 Outflow-disk connection, outflow entrainment (H.B.)

24.06 Outflow-ISM interaction, outflow chemistry (H.B.)

01.07 Outflow interactions: Entrainment, instabilities, shocks (C.F.)

08.07 Outflows from massive star-forming regions (H.B.)

15.07 Observations of extragalactic jets (C.F.)

22.07 Theory of relativistic jets (C.F.) (examination week?)

More Information and the current lecture files: http://www.mpia.de/homes/beuther/lecture_ss11.html

beuther@mpia.de, fendt@mpia.de