Image:
McCaughrean et al. 2002, in *the ESO Messenger*

# HH212:
# *The Most Beautiful Jet!*

Dr. Jennifer Wiseman
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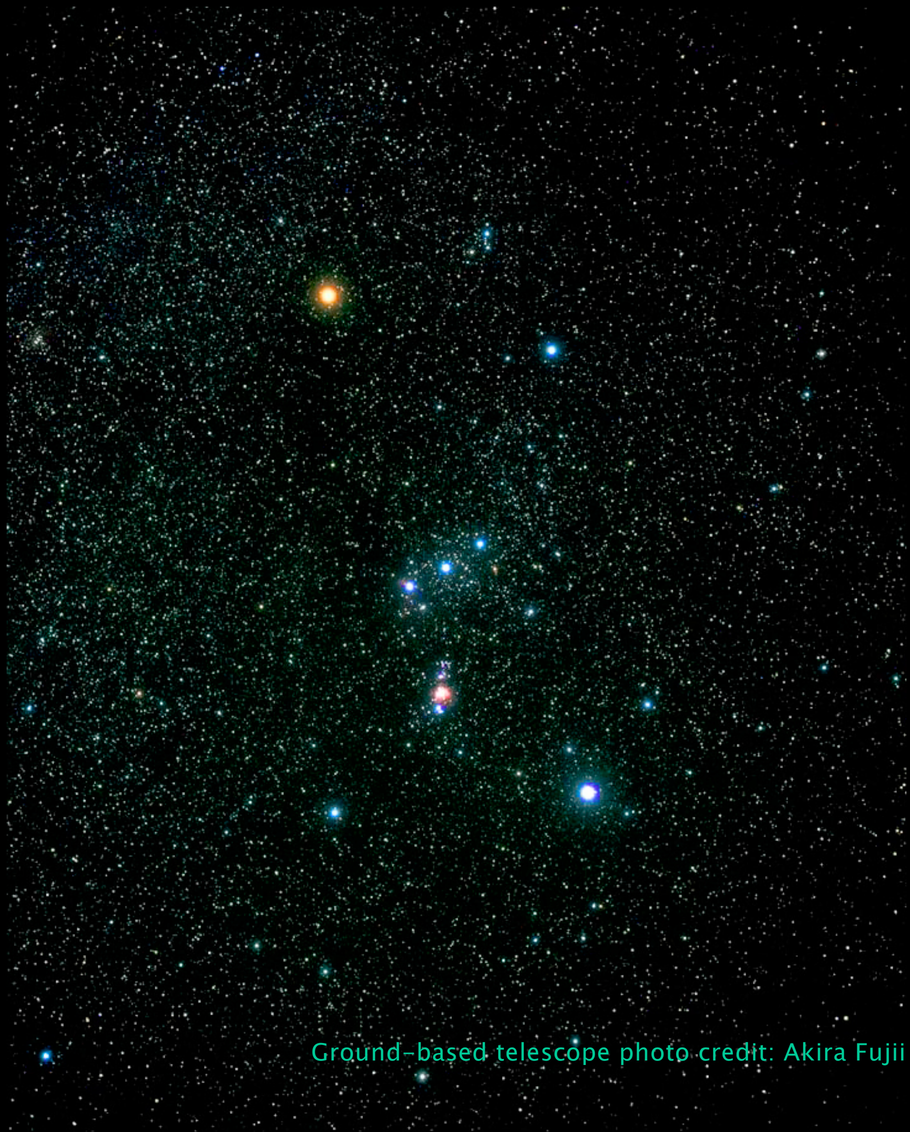
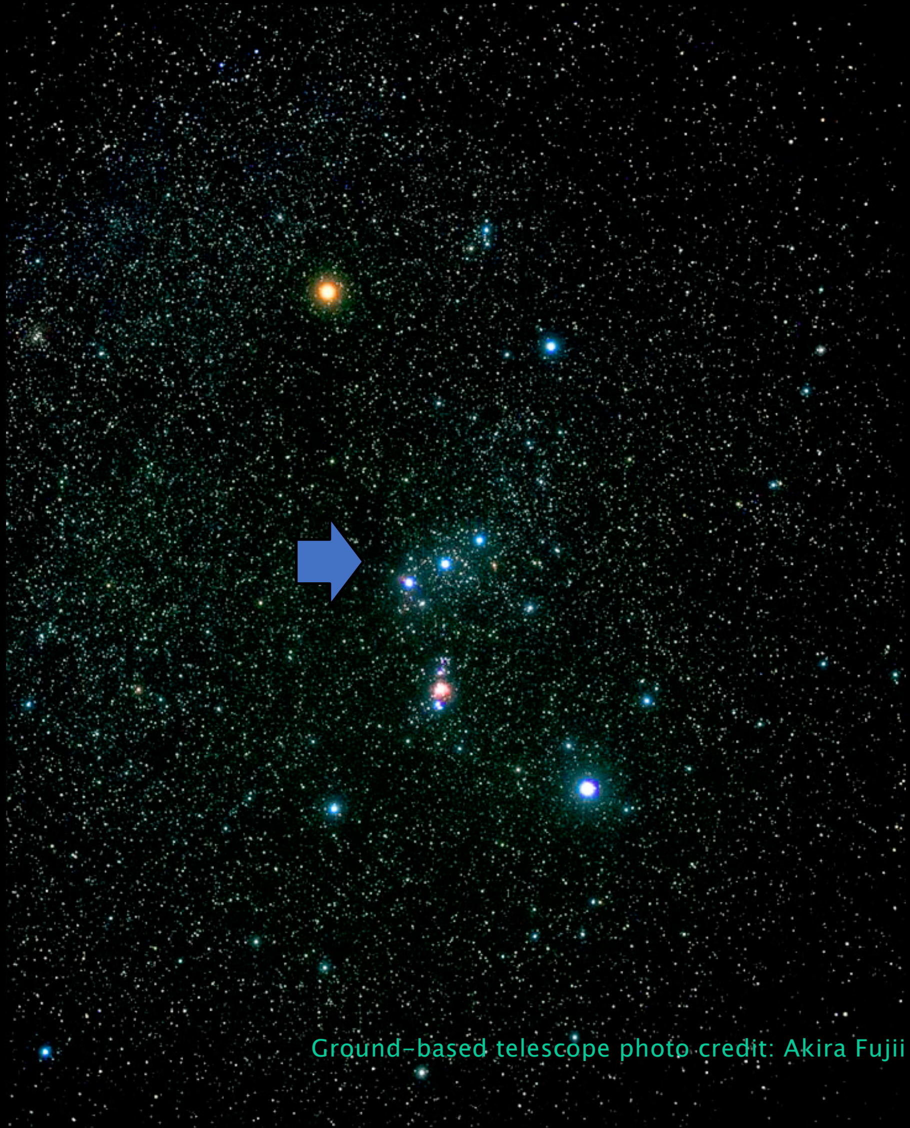
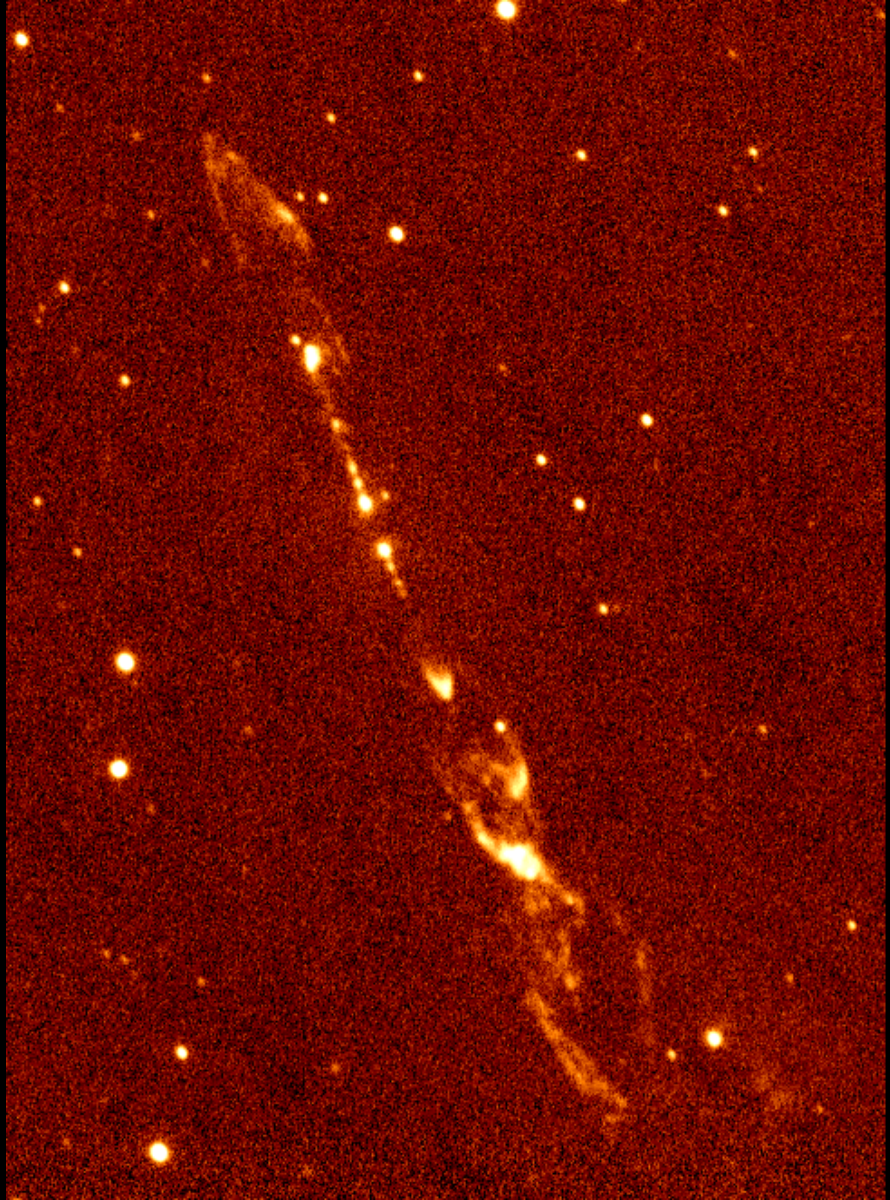

Ground-based telescope photo credit: Akira Fujii



Ground-based telescope photo credit: Akira Fujii



# HH212:
# *The Most Beautiful Jet!*

**DISCOVERED**: 18 December 1993 at the 3-m NASA Infrared Telescope Facility on Mauna Kea, Hawaii.

**More sensitive observations:** Calar Alto 3.5-m telescope on 18 November 1994

$H_2$ $v$ = 1–0 S(1) line at 2.122 μm

YSO: IRAS 05413-0104

# HH 212: The Most Beautiful Protostellar Jet Known to Date

Hans Zinnecker[1], Mark McCaughrean[2], and John Rayner[3]

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[2] Max-Planck-Institute für Astronomie, Königstuhl 17, D-69117 Heidelberg, Germany
[3] Institute for Astronomy, University of Hawaii, 2680 Woodlawn Drive, Honolulu, HI 96822, USA

**Summary.** We report the discovery of the most symmetric embedded twin-exhaust jet known to date. It is located in a dense molecular star forming core in Orion, not far from the famous Horsehead Nebula, and is about 0.3 pc long on either side. Each side contains an inner series of spatially resolved knots (with inter-knot emission) and an outer series of giant bow-shocks, all seen in the v=1–0 S(1) line of shock excited $H_2$ at 2.12 $\mu$m. Each pair of bow-shocks represents a distinct ejection event, lasting of the order of 300 yr. The regular spacing of the inner knots (of order 0.01 pc) which are almost perfectly matched on opposite sides of this bipolar jet, provide the strongest evidence yet for a physical model of a time-variable pulsed jet, with a period of (small) velocity variations as short as 30 yr. The high degree of symmetry also allows us to see that the two opposite halves of the jet are not completely co-linear and that there is a 1–2 degree asymmetry angle. The jet (named HH 212) originates from a very cold infrared and mm-continuum source, *i.e.*, a very young embedded stellar object with a luminosity about 15 $L_\odot$, likely to be powered by accretion from an edge-on disk. Furthermore, the position of the exciting source as inferred from the symmetry of the jet coincides very well with the position of a compact radio $H_20$ maser, this maser being the origin of our initial interest in this cold IRAS source.

Zinnecker H., McCaughrean M., Rayner J. (1996) In: Beckwith S., Staude J., Quetz A., Natta A. (eds) Disks and Outflows Around Young Stars. Lecture Notes in Physics, vol 465. Springer, Berlin, Heidelberg

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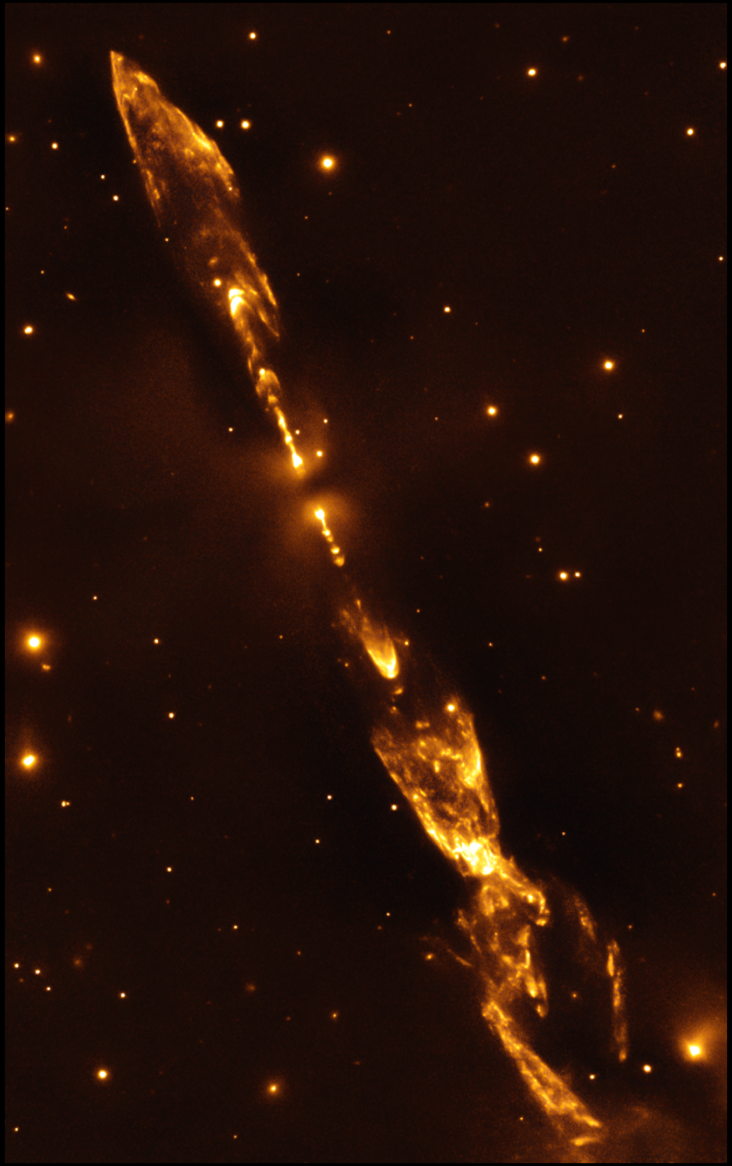


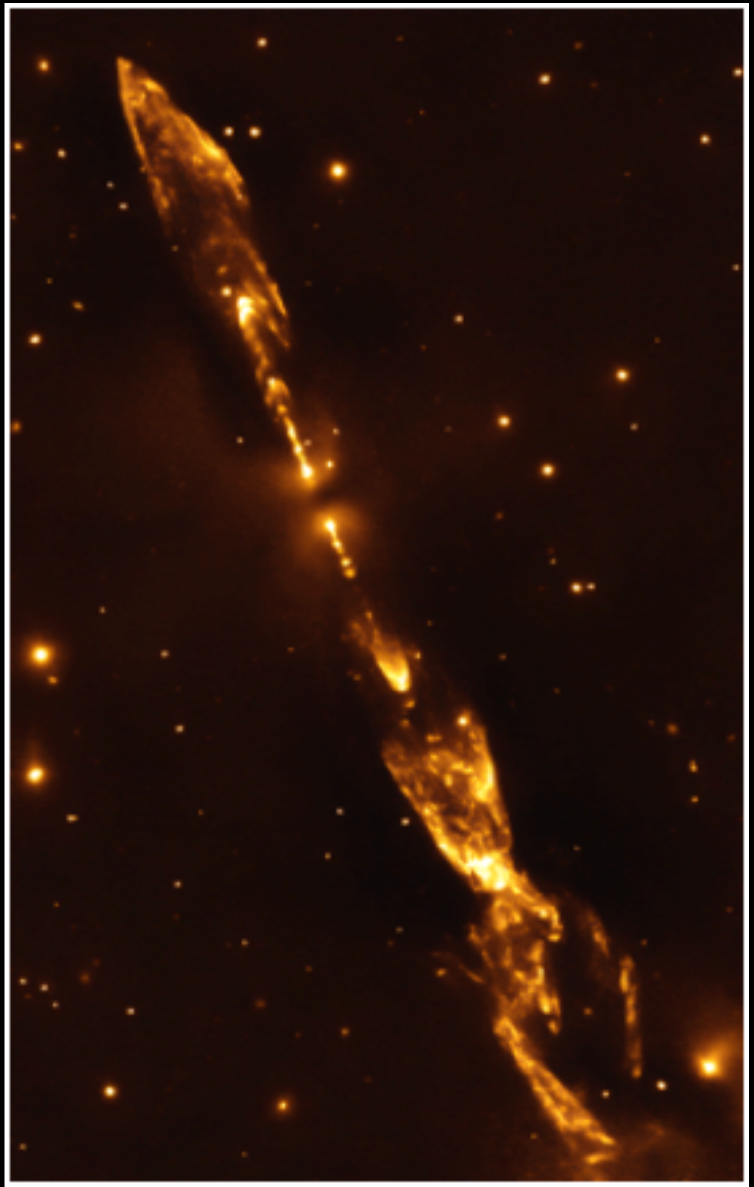
# HH212:
# *The Most Beautiful Jet!*

Beautiful Symmetry:

Hans:  Even the jet's NAME is Symmetric!

Name matches discovery hydrogen line at 2.12 microns!

Credit:ESO/M. McCaughrean



# HH212:
# *The Most Beautiful Jet!*

Beautiful Symmetry:

Hans: Even the jet's NAME is Symmetric!

Name matches discovery hydrogen line at 2.12 microns!

Postulate: Maybe jets that show up at 2.12 microns can be used to "point" to embedded driving protostars.
*Confirmed in HH211*

nature
International journal of science

Letter | Published: 27 August 1998

# A symmetrically pulsed jet of gas from an invisible protostar in Orion

Hans Zinnecker, Mark J. McCaughrean & John T. Rayner

*Nature* **394**, 862–865 (27 August 1998) | Download Citation

## Abstract

Young stars are thought to accumulate most of their mass through an accretion disk, which channels the gas and dust of a collapsing cloud onto the central protostellar object[1]. The rotational and magnetic forces in the star–disk system often produce high-velocity jets of outflowing gas[2,3,4,5,6]. These jets can in principle be used to study the accretion and ejection history of the system, which is hidden from direct view by the dust and dense gas of the parent cloud. But the structures of these jets are often too complex to determine which features arise at the source and which are the result of subsequent interactions with the surrounding gas. Here we present infrared observations of a very young jet driven by an invisible protostar in the vicinity of the Horsehead nebula in Orion. These observations reveal a sequence of geyser-like eruptions occurring at quasi-regular intervals and with near-perfect mirror symmetry either side of the source. This symmetry is strong evidence that such features must be associated with the formation of the jet, probably related to recurrent or even chaotic instabilities in the accretion disk.

**Figure 1: Molecular hydrogen images of HH212.**

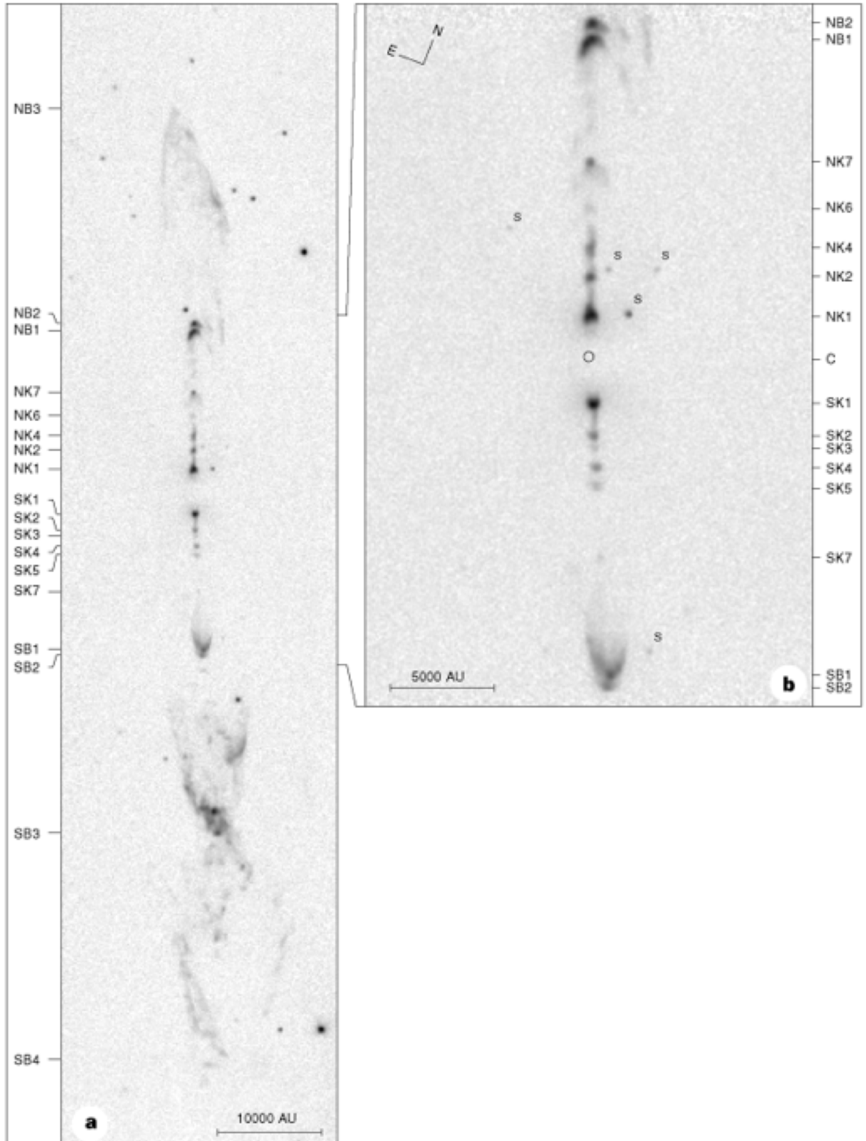
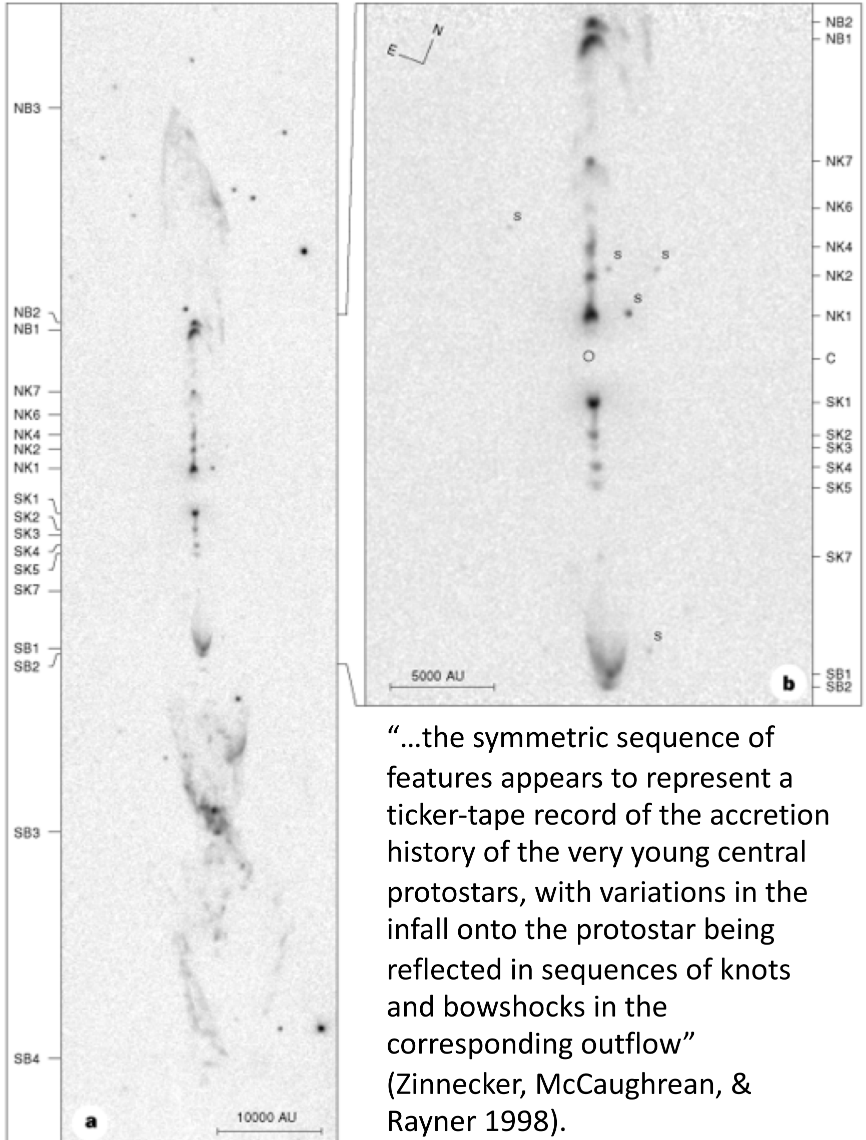


**Figure 1: Molecular hydrogen images of HH212.**

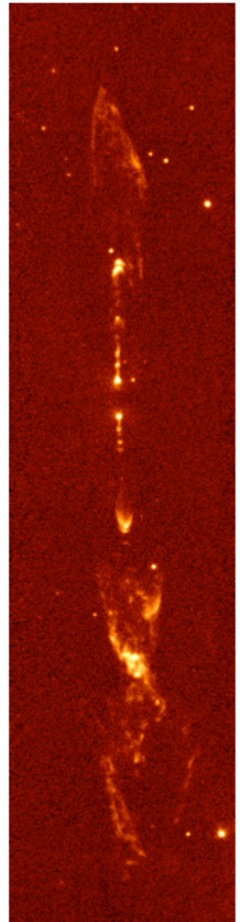



"…the symmetric sequence of features appears to represent a ticker-tape record of the accretion history of the very young central protostars, with variations in the infall onto the protostar being reflected in sequences of knots and bowshocks in the corresponding outflow" (Zinnecker, McCaughrean, & Rayner 1998).

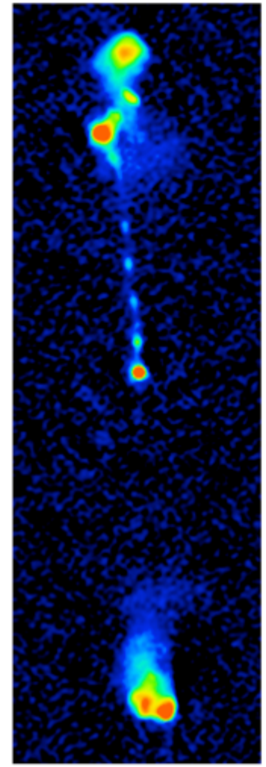
Galactic

Extragalactic

0.5 pc



HH212



160 kpc

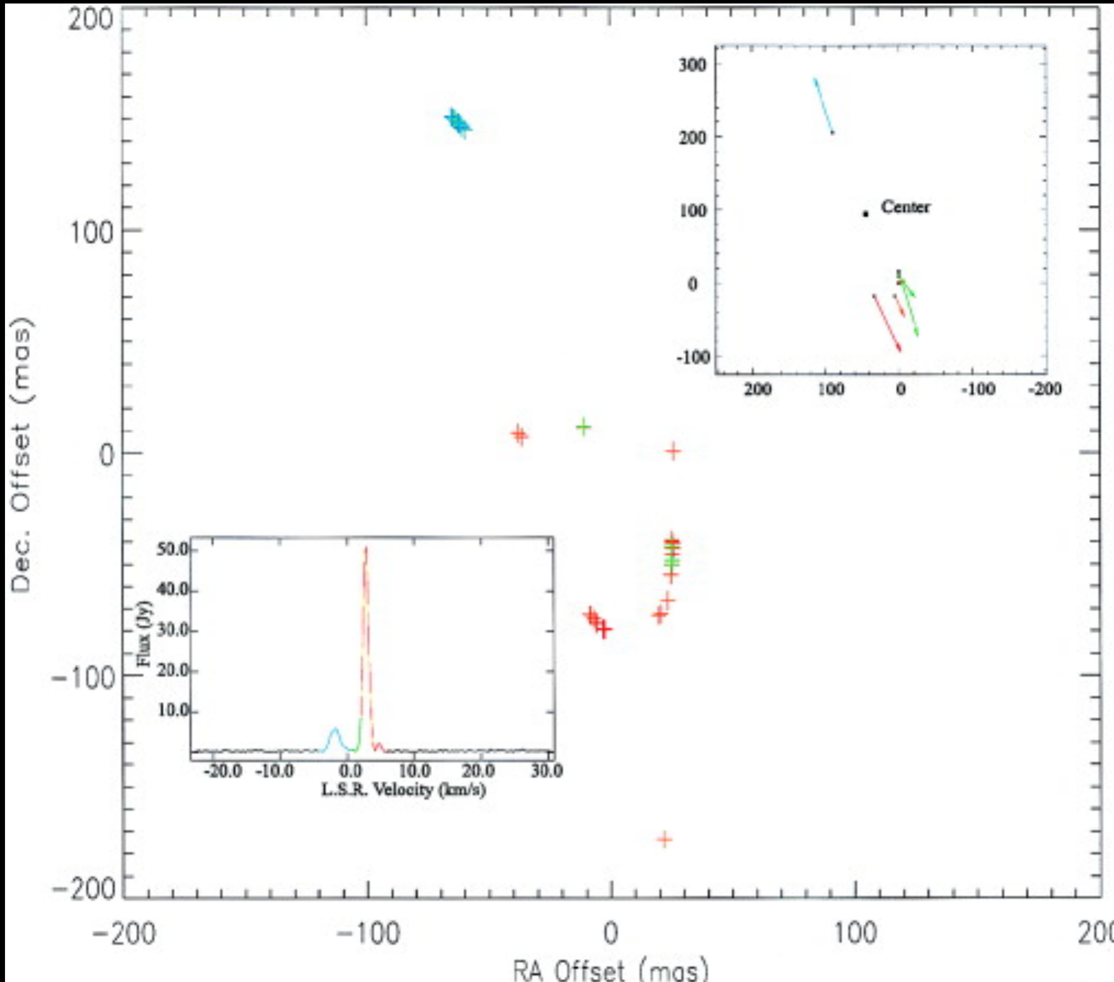
3C204

Wiseman and Biretta, 2002: “What can we learn about extragalactic jets from galactic jets?” New Astronomy Reviews

Image:
McCaughrean et al. 2002, in *the ESO Messenger*

**HH212:**

**Plane of sky aspect makes it perfect for studies of jet, outflows, shocks, disk, envelope, etc.**




# HH212:

**Water masers** detected with VLBA.

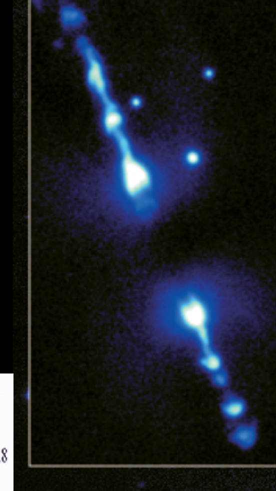
Proper motions consistent with 64 km/s jet within 40-70 AU of central source.

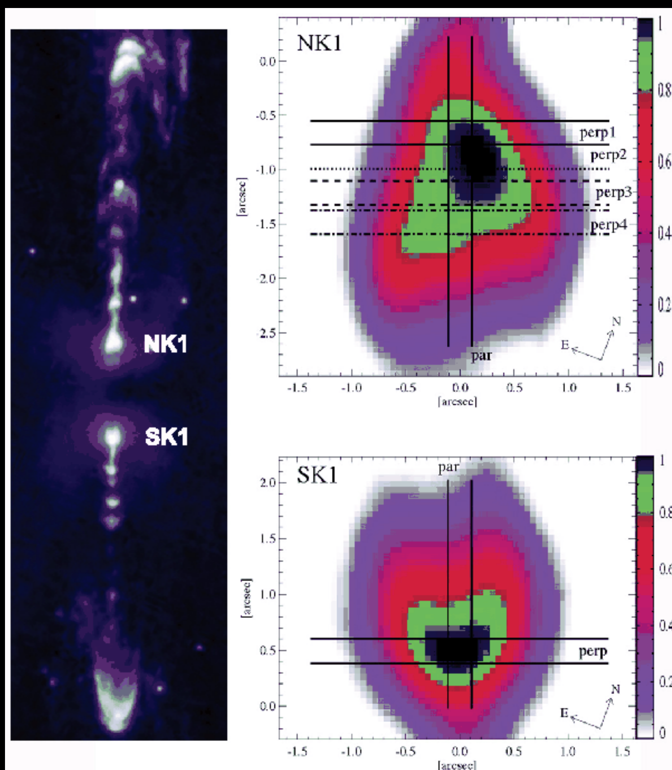
Claussen et al. 1998

Image:
McCaughrean et al. 2002, in *the ESO Messenger*

# Detailed studies of Shock Knots

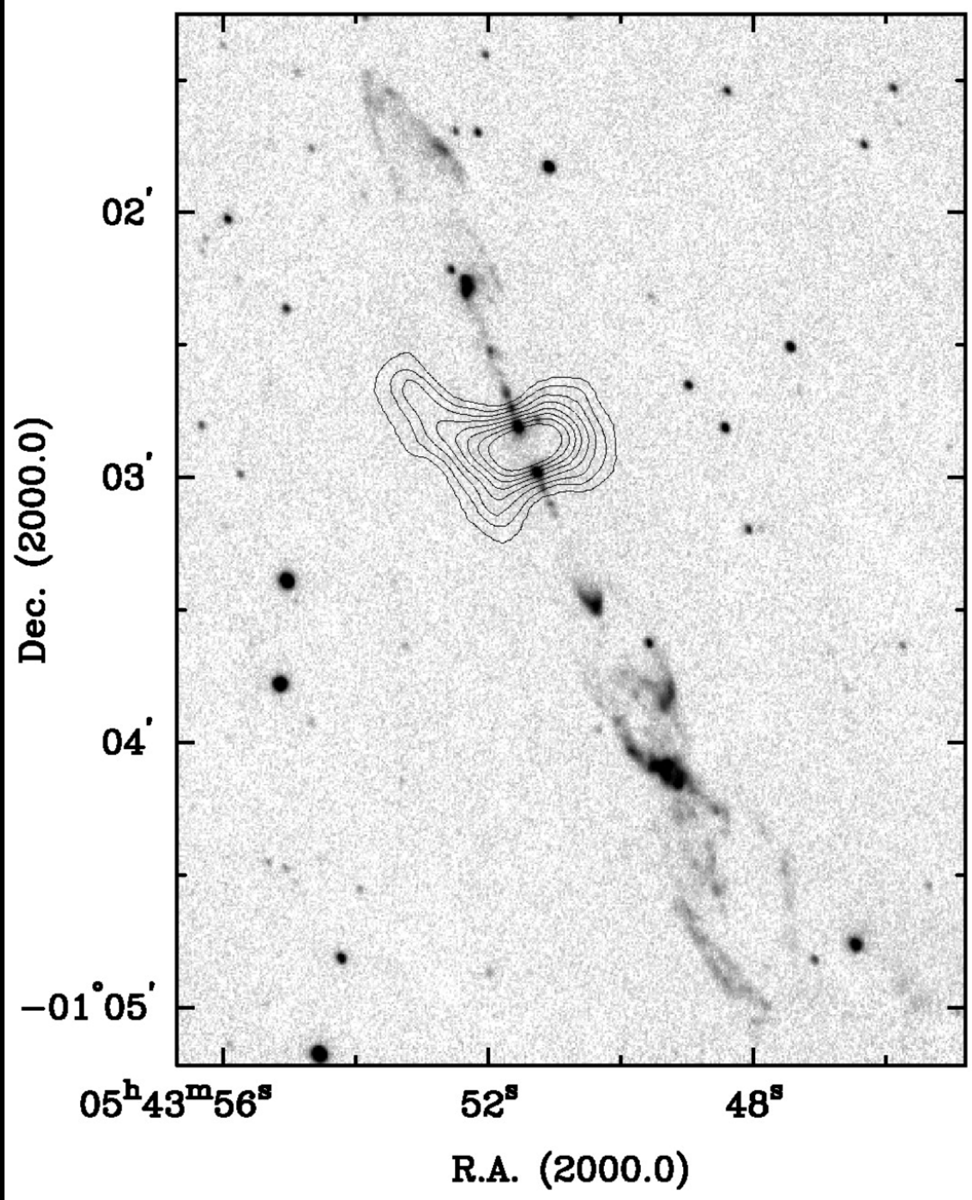
**e.g. integral field spectroscopy, UKIRT (Smith, O'Connell, Davis 2007): some knots may be double bow shocks. Transverse motion of source causing transverse excitation and jet bending?**






# Detailed studies of Shock Knots

**e.g. high-res. long slit spectroscopy from Gemini-S (Correia, Zinnecker, Ridgway, & McCaughrean 2009):**
**Asymmetry in flow?**
**Combination of jet rotation and jet precession in addition to velocity shear?**



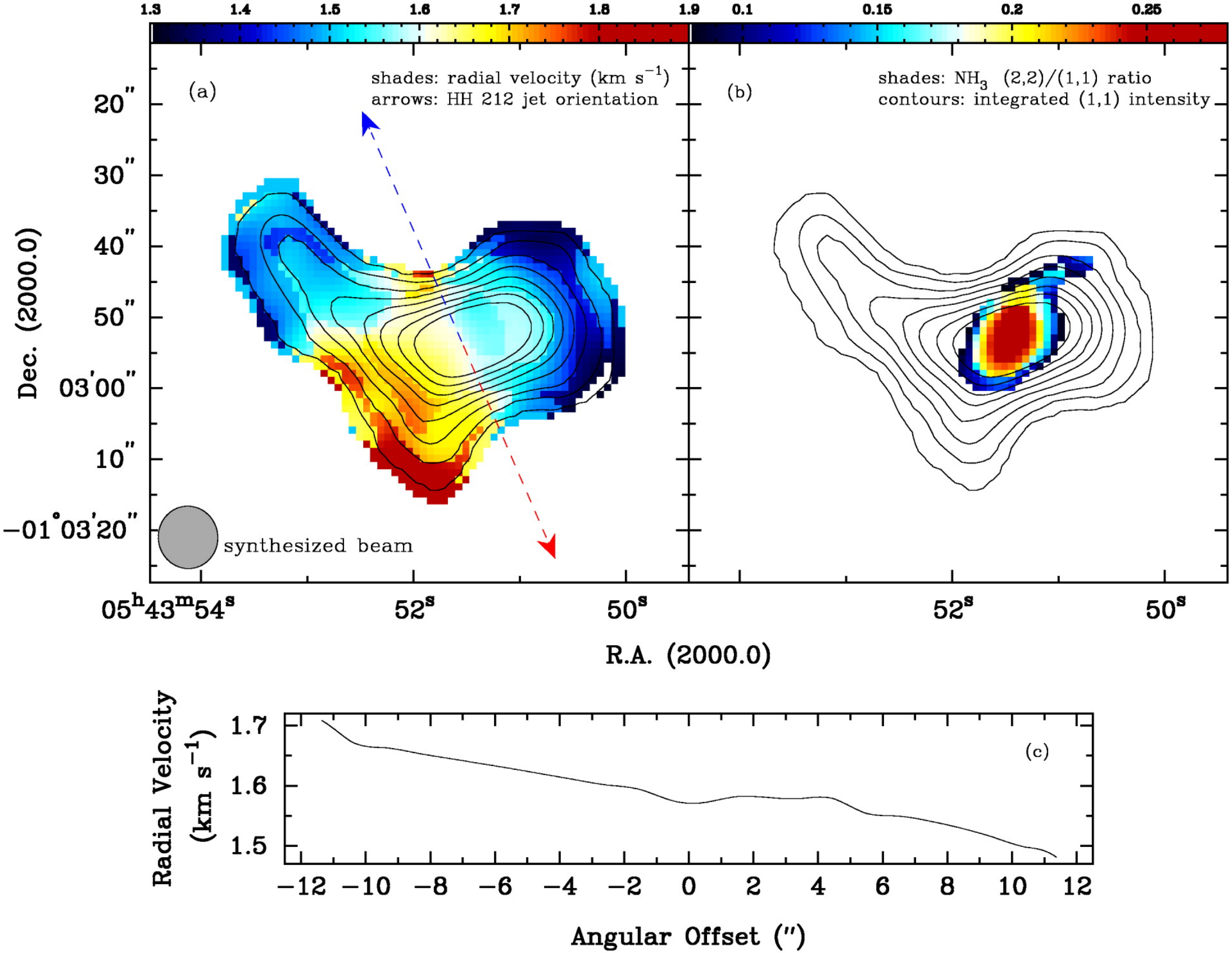

# The Envelope

Contours: VLA NH3 (1,1) integrated emission.

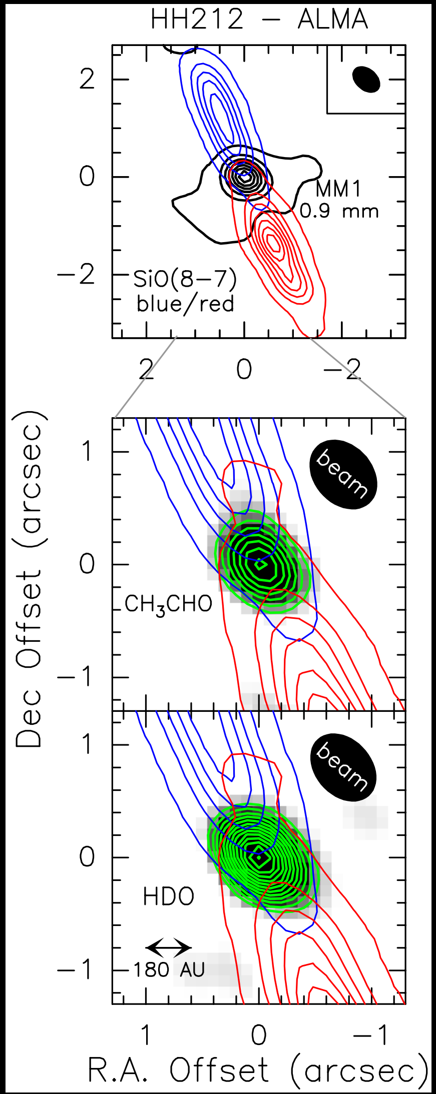
12,000 AU diameter flattened envelope
of molecular gas.

(from Wiseman, Wootten, Zinnecker, & McCaughrean 2001)

Flattened core also seen by Lee et al. 2006, 2014




Wiseman, Wootten, Zinnecker, & McCaughrean 2001




# Complex Organic Molecules (COMs) in HH212!

"Water and **acetaldehyde** in HH212: The first hot corino in Orion"

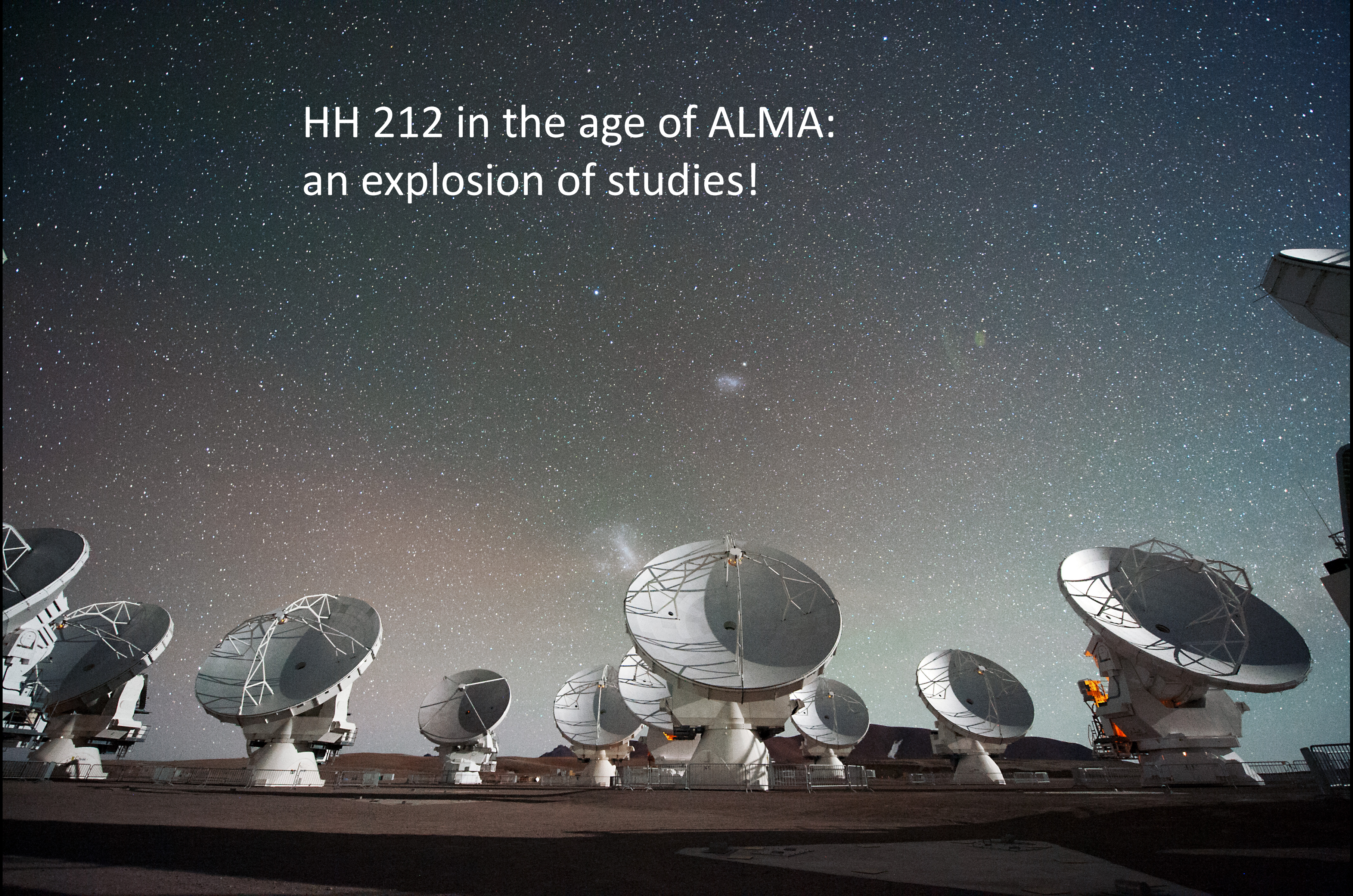
Codella et al. 2014

See also Leurini et al. 2016 (**methanol**); Bianchi et al. 2017 (**deuterated methanol** on solar system scale)

Larger envelope and core very cold (15 K), but inner disk must be very hot! (115 K)

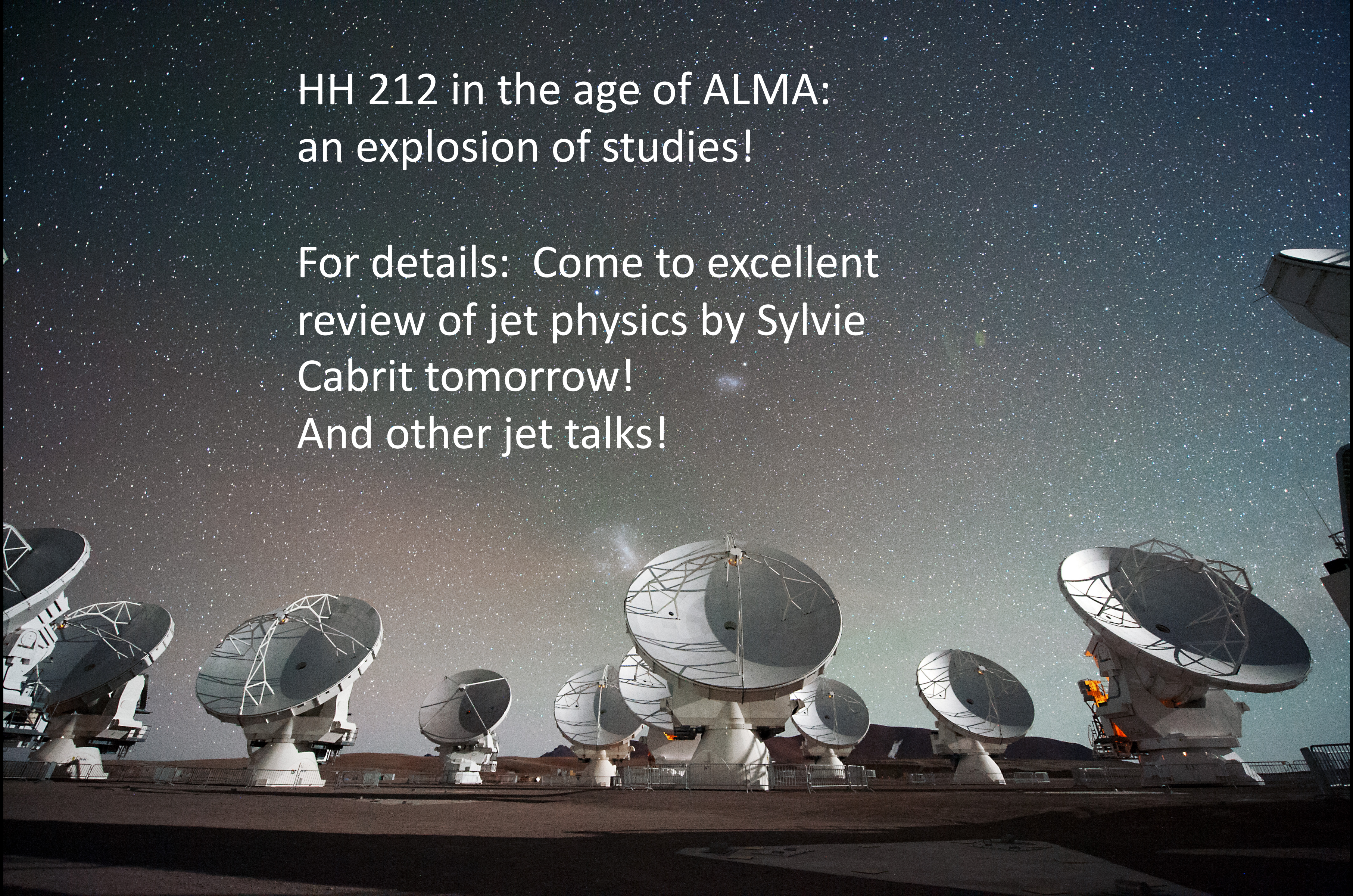
See also Poster 4A– Sewilo et al., first detection of COMs in LMC!

# HH 212 in the age of ALMA: an explosion of studies!

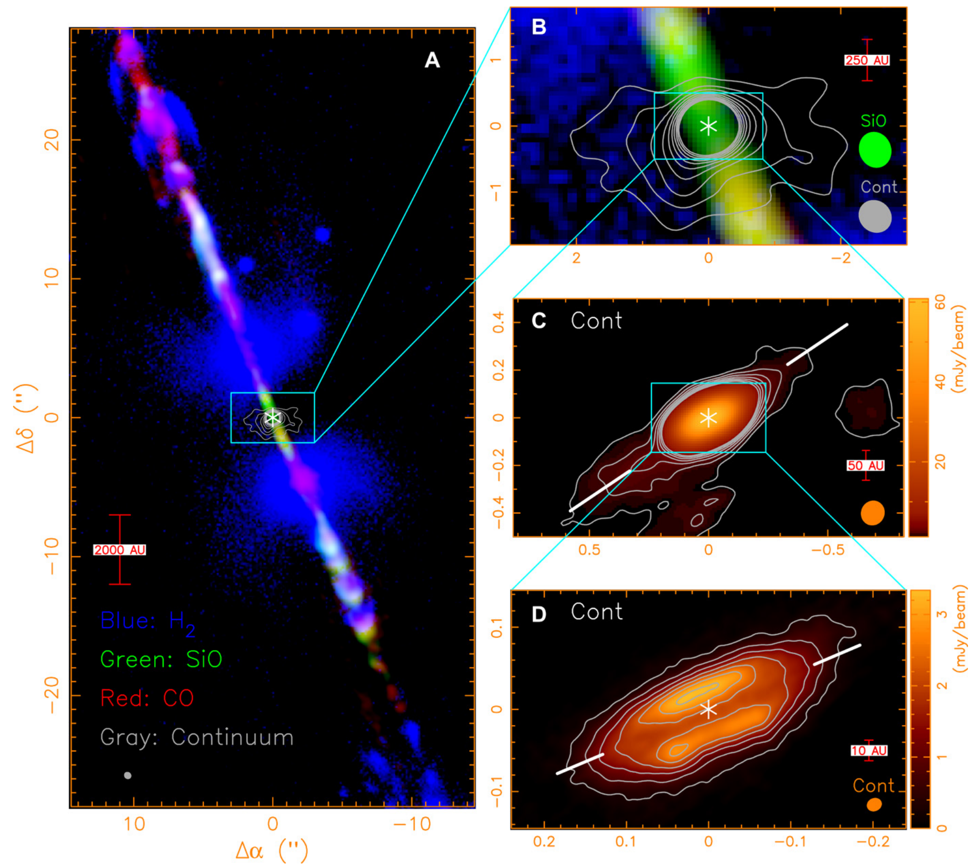


HH 212 in the age of ALMA:
an explosion of studies!

For details: Come to excellent review of jet physics by Sylvie Cabrit tomorrow!
And other jet talks!



## ALMA maps of the jet, envelope, and disk (R=60 AU) in the HH 212 system.




Chin-Fei Lee et al. Sci Adv 2017;3:e1602935

Science Advances

Published by AAAS

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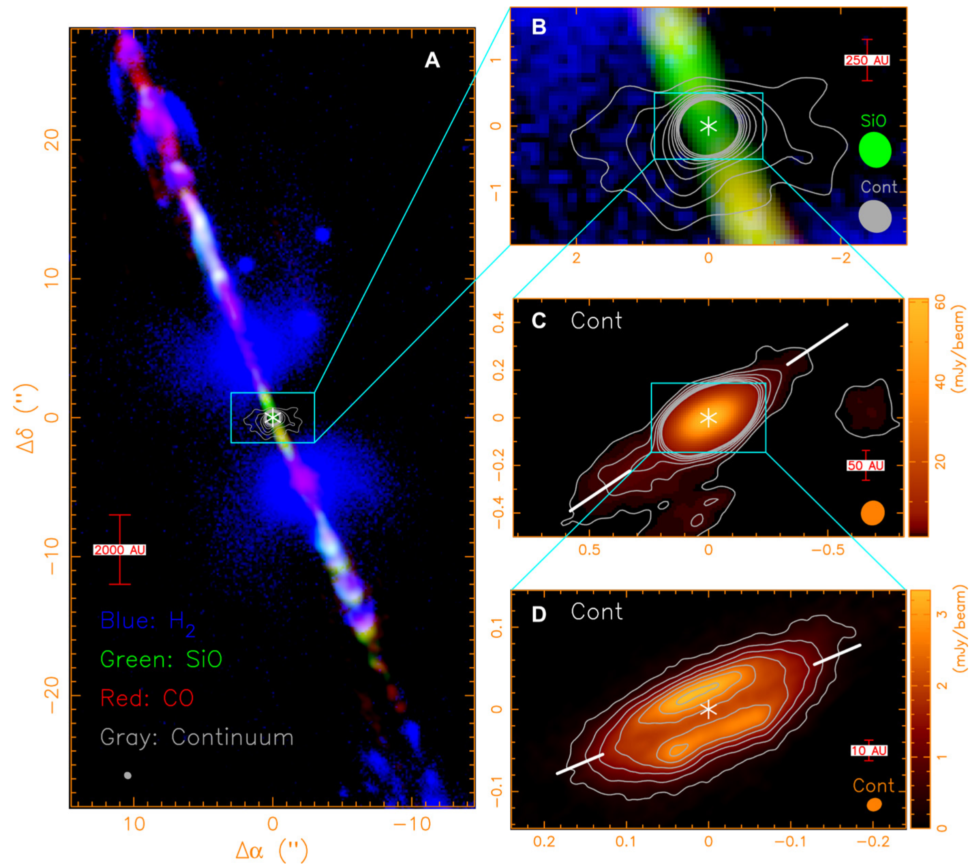



“Hamburger” disk with dark lane !

Chin-Fei Lee et al. Sci Adv 2017;3:e1602935

Science Advances
AAAS

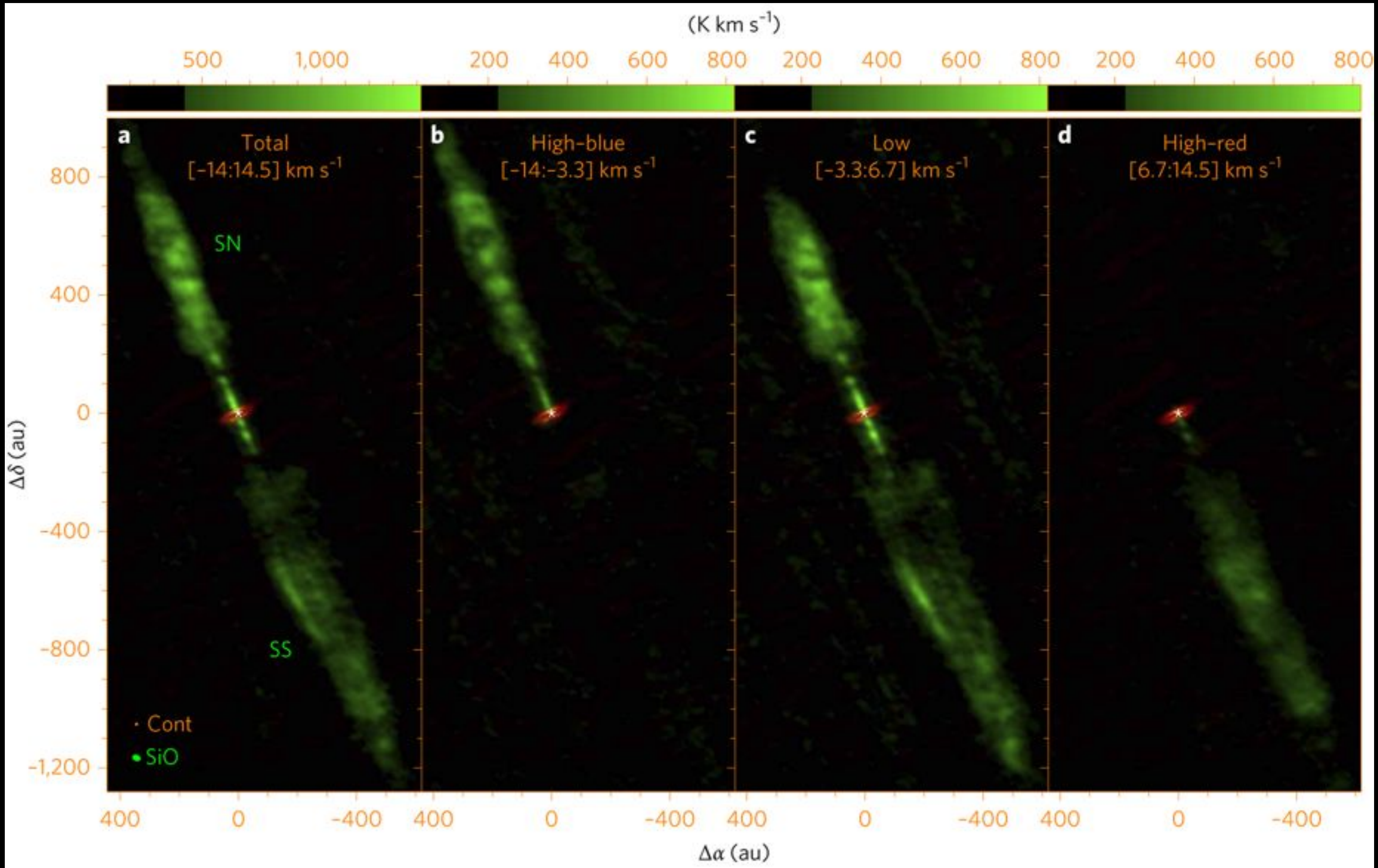
Video on HH212 with ALMA:

**First detection of equatorial dark dust lane in a protostellar disk at submillimeter wavelength**

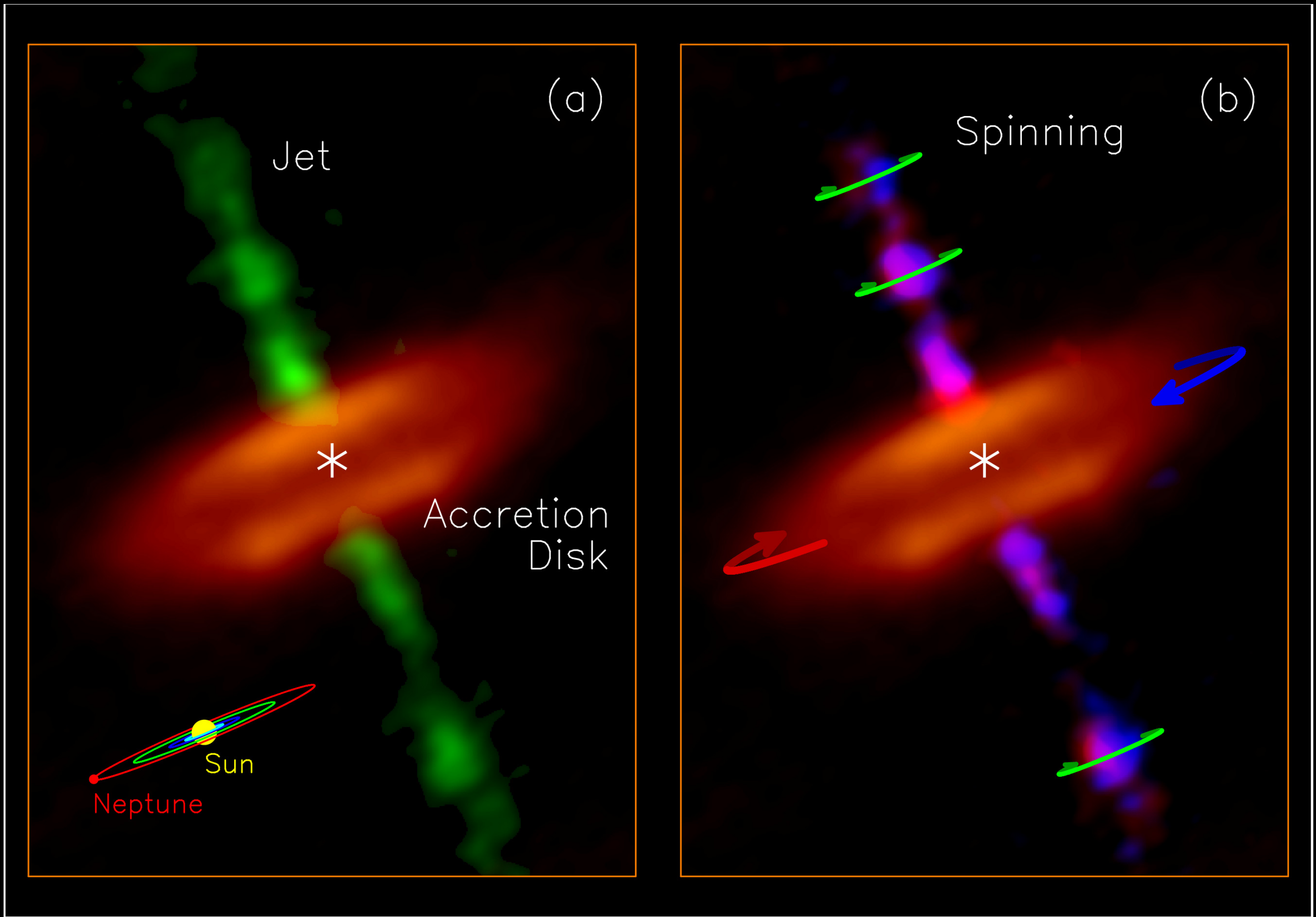
https://vimeo.com/213738858

# ALMA SiO Imaging of Jet

SiO 8-7 Jet (green) on top of dust continuum map (orange, 352 GHz). Lee et al. 2017

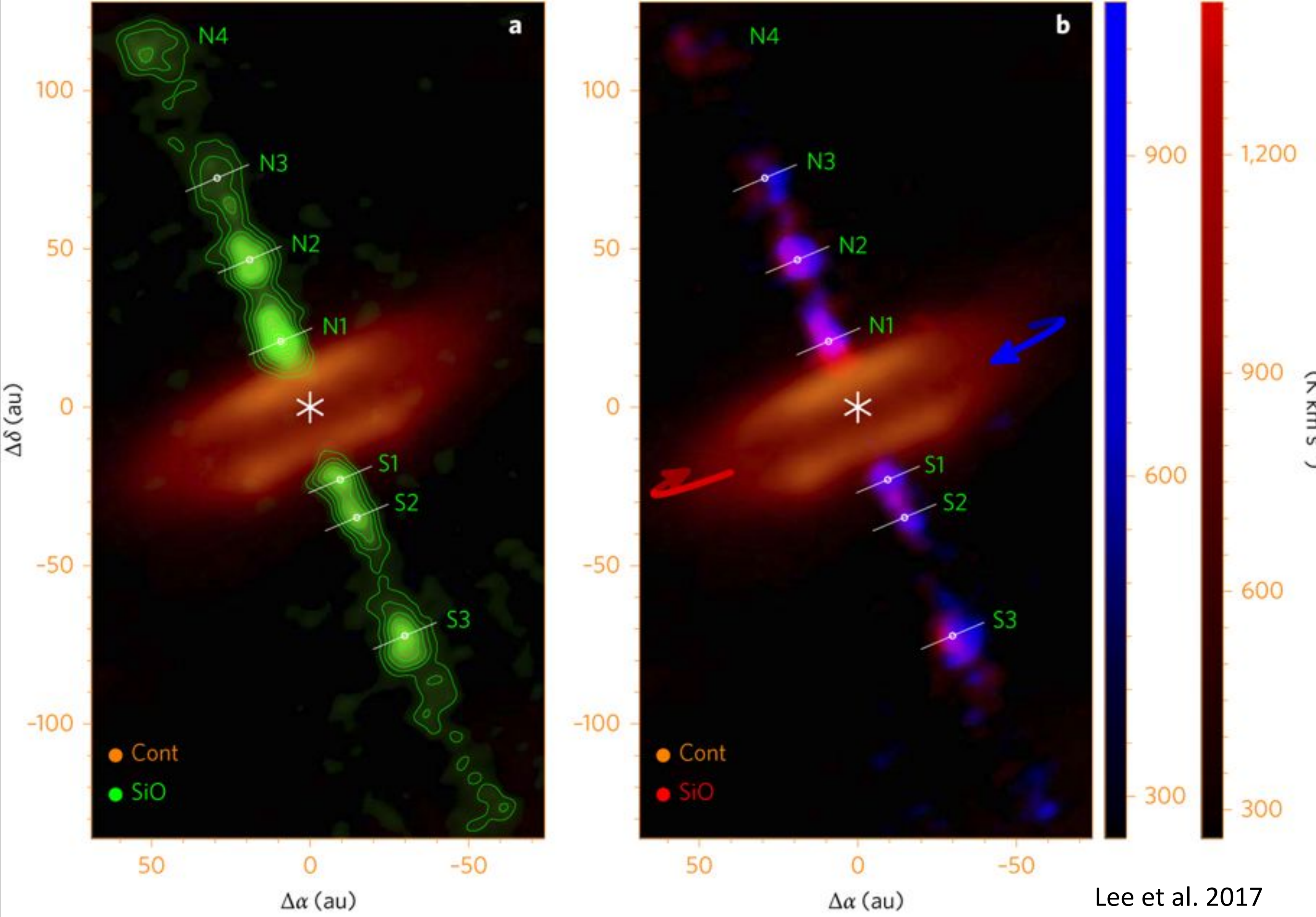


# **Rotating Jet!** Lee et al. 2017

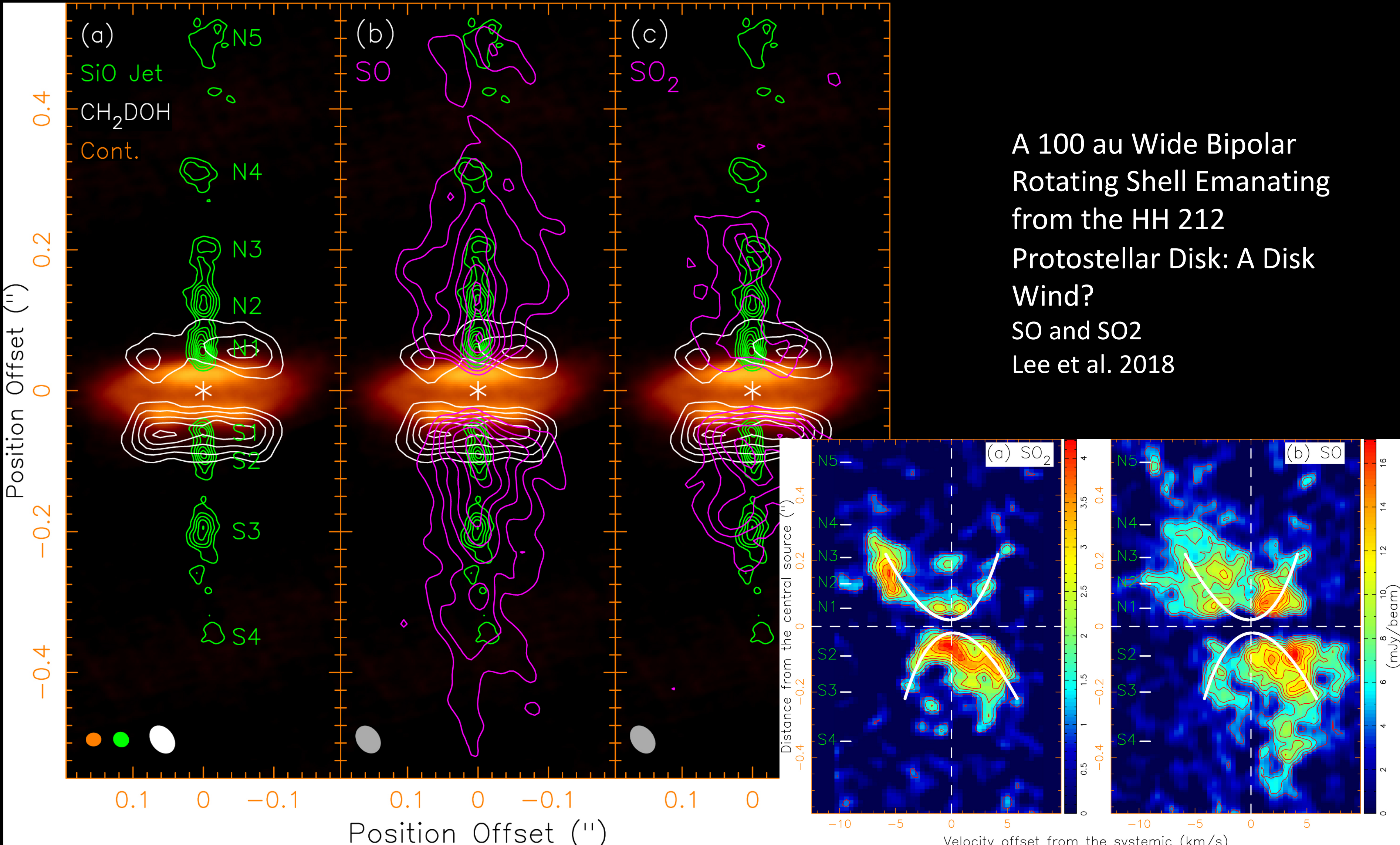



Rotation measured to 10 AU from protostar; implies launching radius of ~0.05 AU

angular resolution of ~8 au (0.02″)



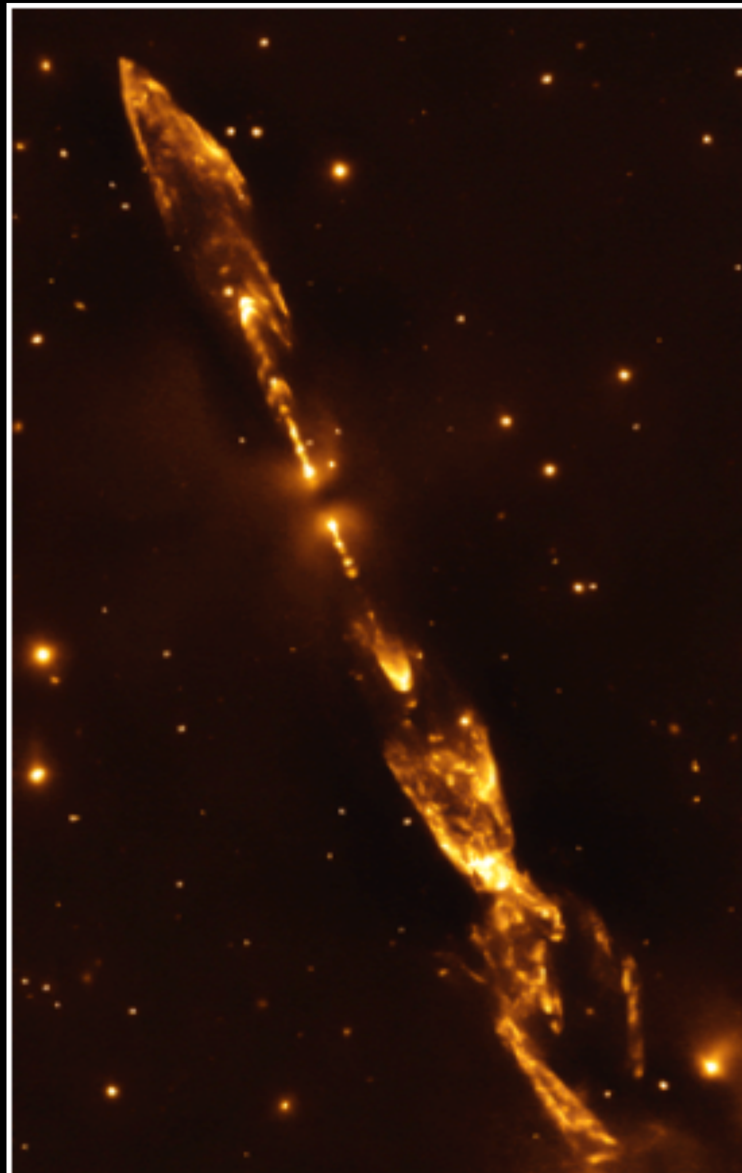

Lee et al. 2017




A 100 au Wide Bipolar Rotating Shell Emanating from the HH 212 Protostellar Disk: A Disk Wind?

SO and SO2

Lee et al. 2018



# What's next for HH212?

Ongoing Questions and Future Study:

Is the source a binary? (or multiple?)

Is it truly isolated?

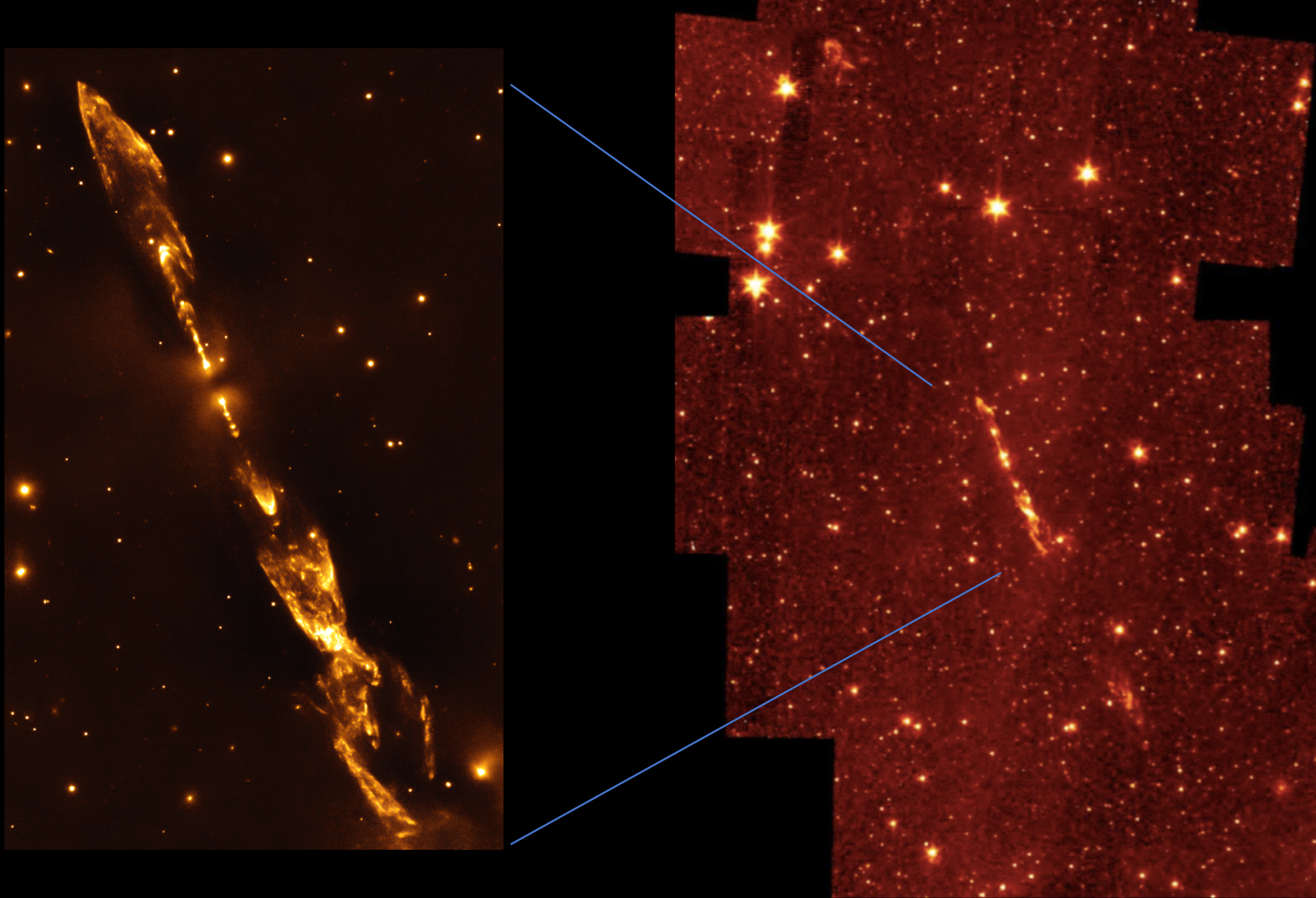
Is the jet bending? Precessing?
Proper motion of jet/knots?
(Don't miss McCaughrean/Rayner talk on Friday!!)

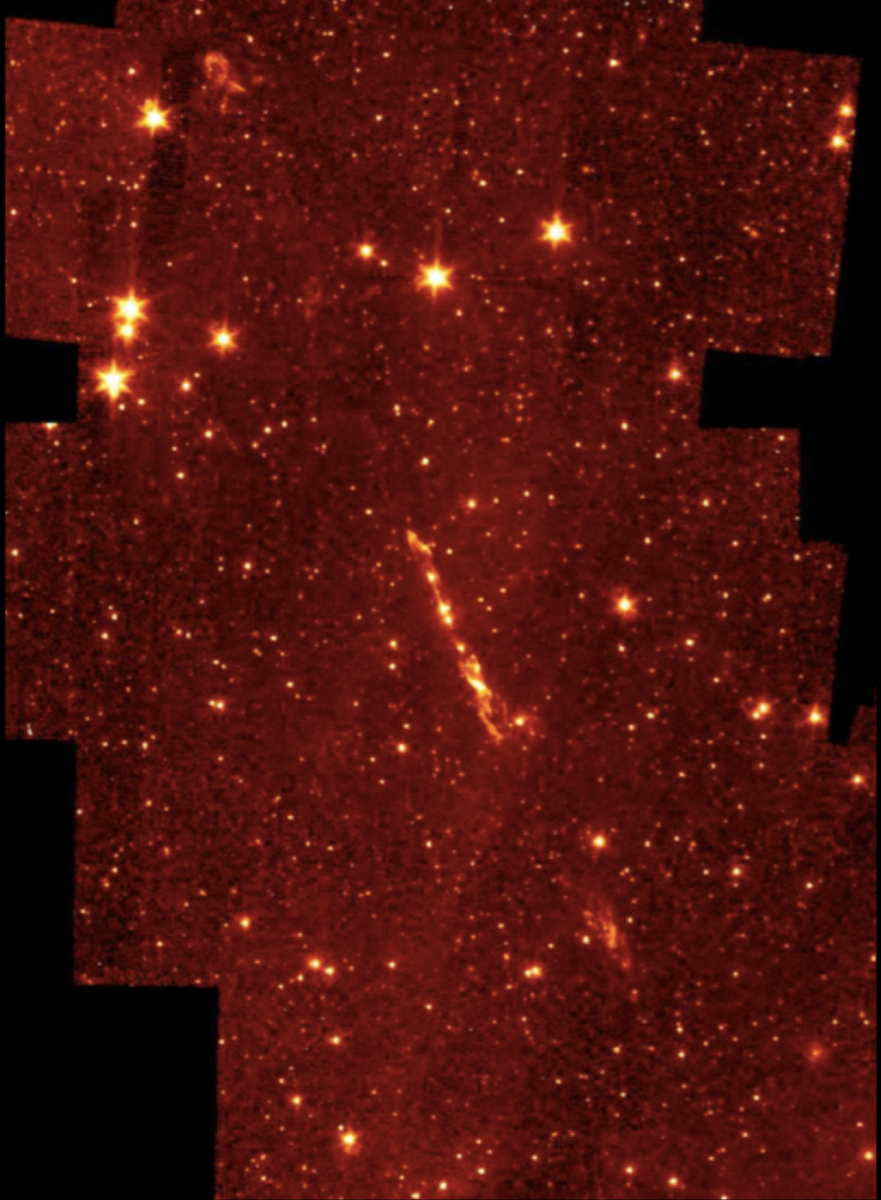
Angular momentum budget: relate angular momentum throughout the system: envelope, disk, jet, winds/outflow

How can the jet appear so spatially symmetric when the velocities on each side are so different?

How big is it, really? How old?

more…??





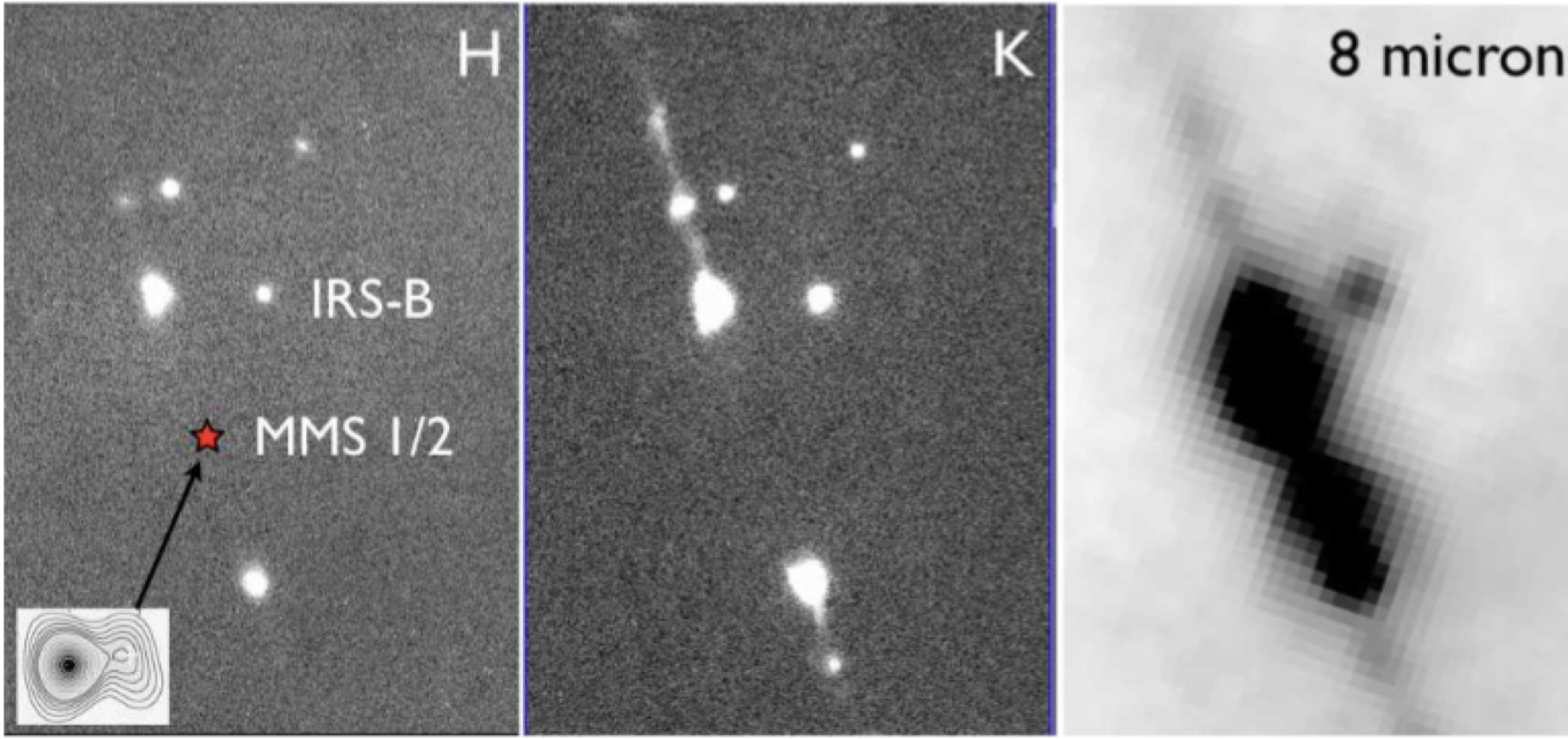
SURPRISE!

HH212 is a lot BIGGER than we thought…

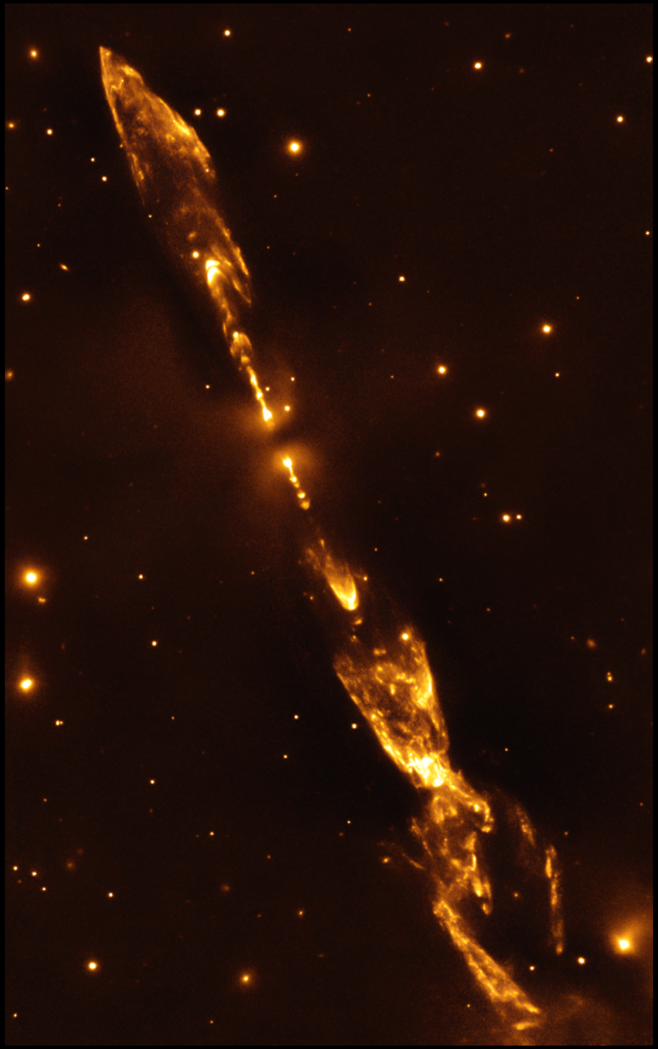
Spitzer wide-field 4.5 micron image.
Total extent 1050”,
or ~2 pc !
(Increases dynamical age of jet!)

**Reipurth, Davis, Bally, et al., in prep;**
(also Stanke et al.; UKIRT)

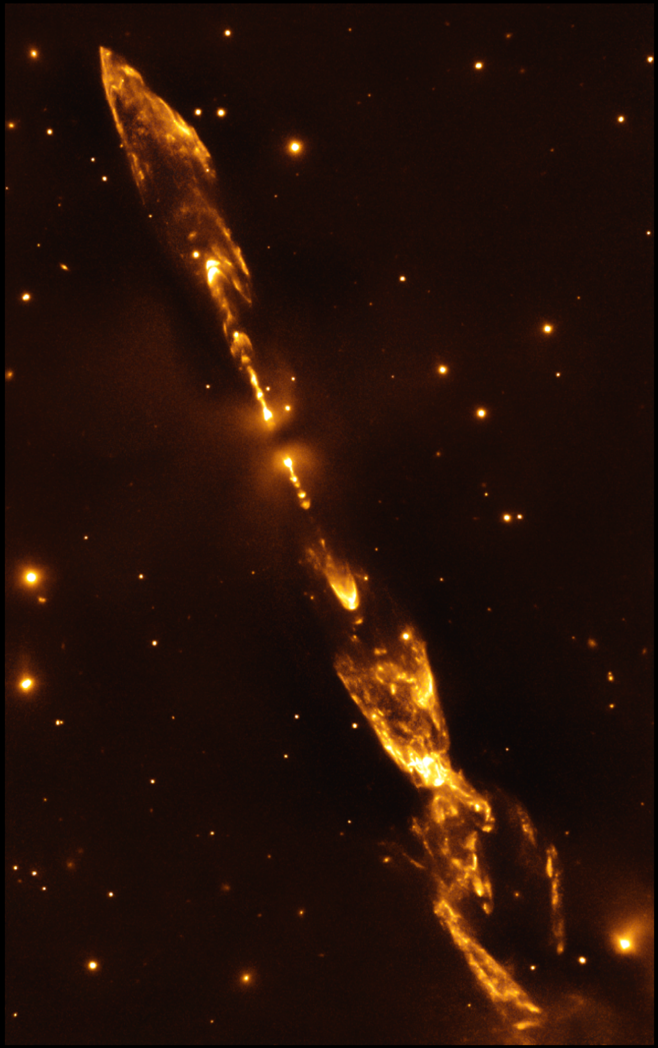
# Multiple interacting objects near the source of HH 212?




Images from Subaru, Spitzer (inset SMA continuum from Chen et al. 2013) . Reipurth, Davis, Bally, et al., in prep 2018

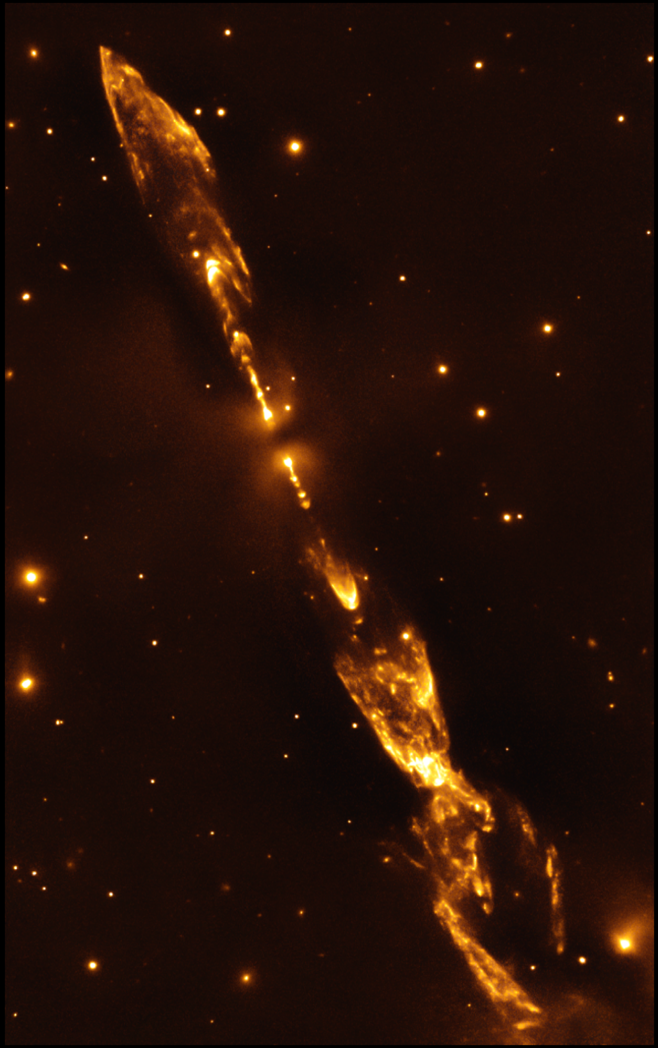


**HH212:**
***The Most Beautiful Jet!***



HH212:

Thank you, Hans!
and Mark and John,
for discovering and
sharing with us
*This Most Beautiful Jet!*



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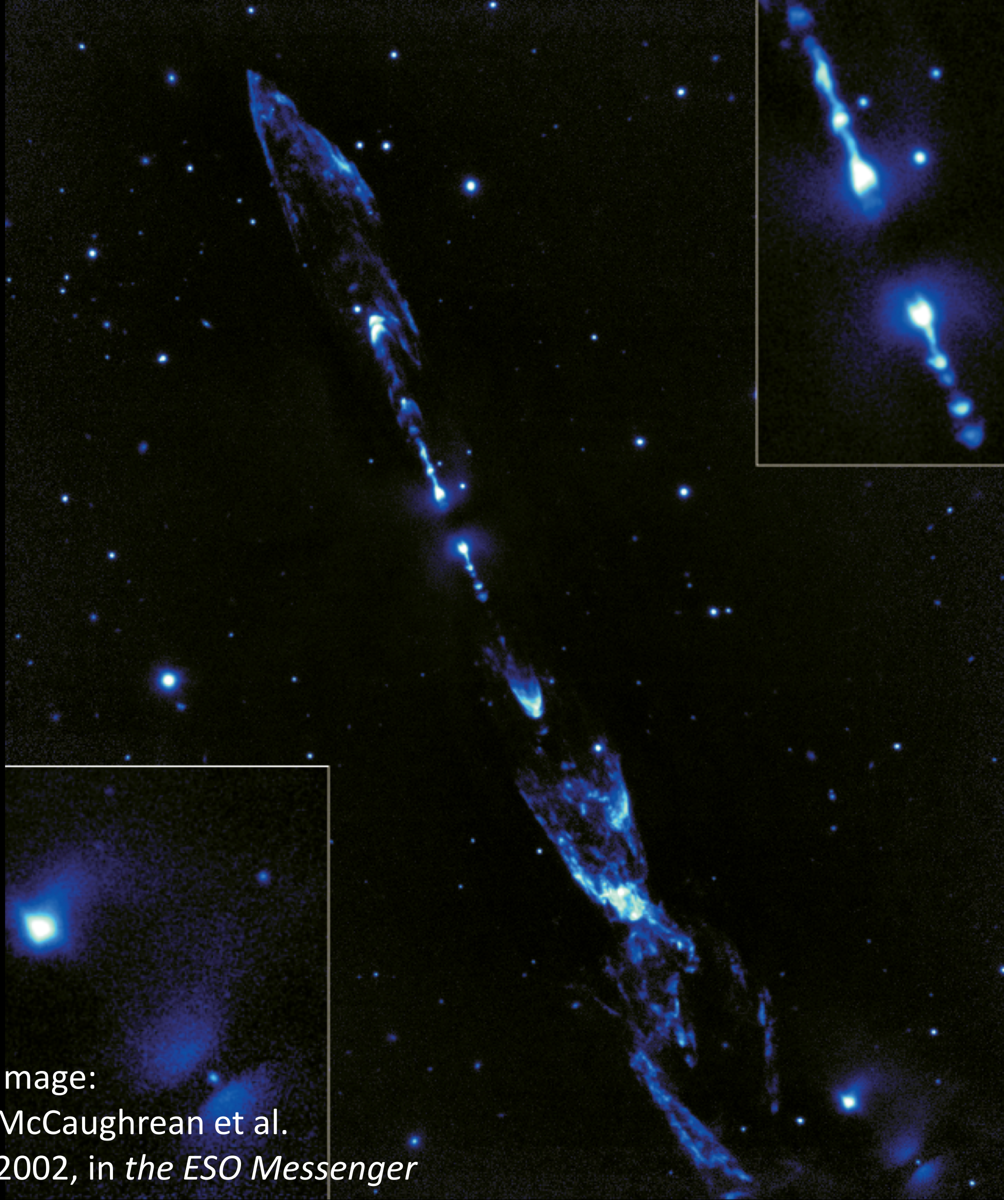

Image:
McCaughrean et al.
2002, in *the ESO Messenger*

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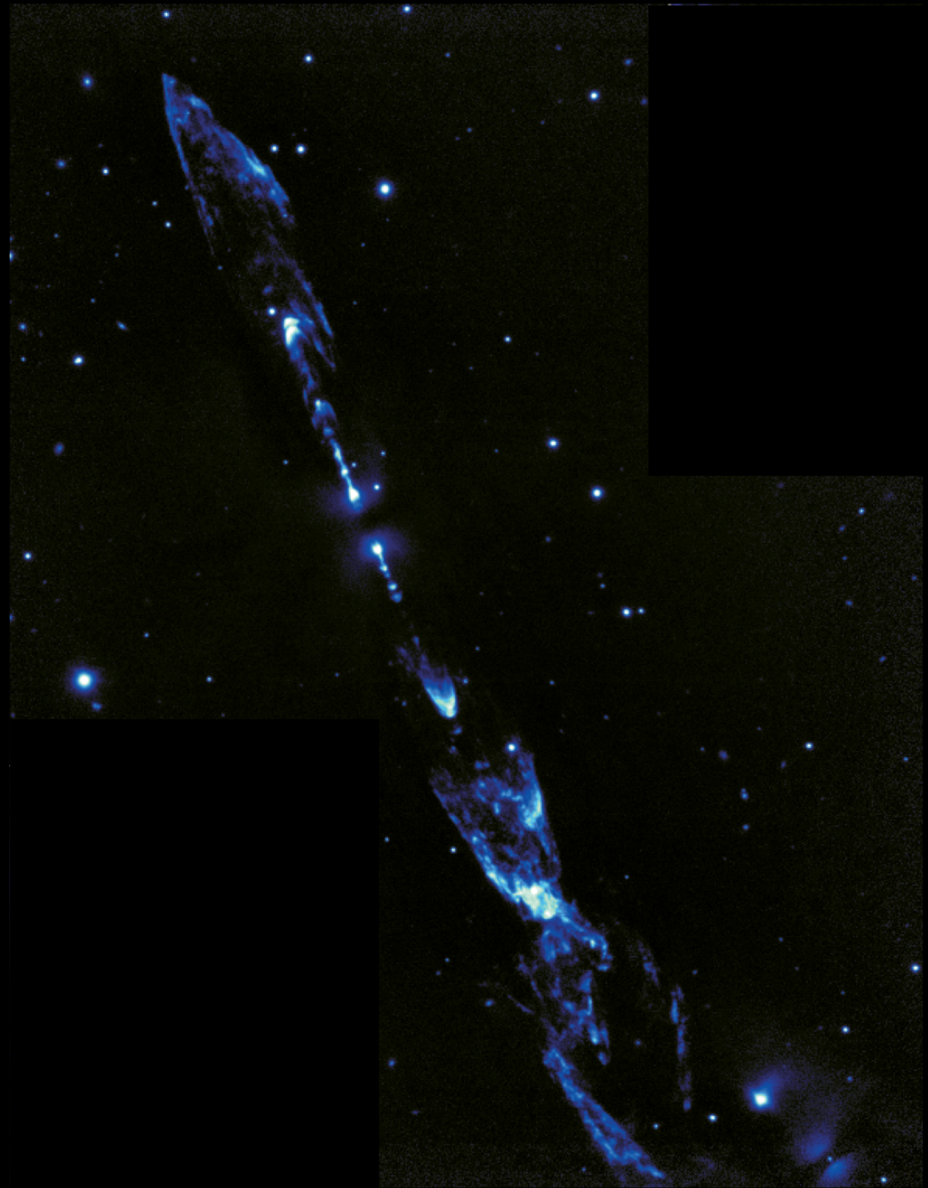

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McCaughrean et al.
2002, in *the ESO Messenger*