Jets and Outbursts in the BHR 71 Class 0 outflows

Tyler Bourke
Square Kilometre Array

Olympian Symposium 29/5/2018
Talk Outline

• Why protostellar jets/outbursts are important
• Introduction to BHR 71
• Evidence for Jets
• Infrared Outburst
• Future Directions

Main Collaborators (past and present, and future):
Protostellar Jets and Outbursts

• Provide a record of the accretion history
  ➢ knots, structure, proper motions
• Provide an estimation of the accretion efficiency
  ➢ mass loss rate, accretion rate
• Reveal interactions with companions (seen or unseen)
  ➢ jet precession modelling
• Jet rotation constrains launch radius
  ➢ specific angular momentum, velocity
• Outbursts reveal recent accretion events
  ➢ duration, magnitude  (next talk by Todd)

Talk Outline

• Why protostellar jets/outbursts are important
• Introduction to BHR 71
• Evidence for Jets
• Infrared Outburst
• Future Directions

Main Collaborators (past and present, and future):
ω Centauri

η Carina

Coalsack

BHR 71

Musca

ω Cen by Joaquin Polleri & Ezequiel Etcheverry
Well Collimated Large-scale Outflow

Images are approximately on the same scale

Red/Blue Contours = CO 1-0 (SEST)
Black Contours = 1.3 mm continuum (SEST)

Bourke+ 1997
Wide Low-mass Binary (~3400 au)

Luminosity ratio ~10

CO 2-1 over Spitzer 8 μm

Bourke 2001
Parise+ 2006
Wide Binary (~3400 au)

Luminosity ratio ~10 (~10 Lsun v. ~1 Lsun)

T_{bol} (IRS2) < T_{bol} (IRS1) (32 cf. 45 K) - Both Class 0

Not yet known if they are bound

CO 3-2 over Spitzer 8 μm
Chemically Active Outflow

Abundance relative to quiescent:

\[ X[\text{SiO}] \sim 350 \]

\[ X[\text{CH}_3\text{OH}] \sim 50 \]

\[ X[\text{HCO}^+] \sim 1/20 \]
Chemically Active Outflow

SiO extended

Garay 1998
Garay 2000
Bourke 2002
Talk Outline

• Why protostellar jets/outbursts are important
• Introduction to BHR 71
• Evidence for Jets
• Infrared Outburst
• Future Directions

Main Collaborators (past and present, and future):
(Indirect) Evidence for Jets

H$_2$ 2.12 $\mu$m + continuum

H$_2$ 2.12 $\mu$m - continuum
Spitzer
Blue = 3.8 µm
Green = 4.5 µm ("H$_2$ band")
Red = 8.0 µm (PAHs and H$_2$)
(Indirect) Evidence for Jets

Neufeld+ 2009
Gusdorf+ 2011
Nisini+ 2015
Benedettini+ 2017
(Indirect) Evidence for Jets

Kristensen+ 2012, 2017
Yildiz+ 2013
Mottram+ 2014
(Indirect) Evidence for Jets

CO (6-5) Spectra

Greyscale = Total emission

[-60, -19.5] km/s  [-19.5, -4.5] km/s
[10.5, 60] km/s [-4.5, 10.5] km/s
Evidence for Jets - ALMA

CO 2-1 & SiO 5-4
1.5” resolution
12m + ACA
PI J.Tobin (Envelope Kinematics)
Evidence for Jets - ALMA

CO 2-1

[-40, -6] km/s

[-3, 29] km/s

emission seen

-80 to 80 km/s

or more

(previous slides)
Evidence for Jets - ALMA

SiO 5-4  +/- 80 km/s  (blue & red)
CO 2-1 all velocities

Jet axes not aligned with large-scale outflow axes

CO 2-1 highest velocities
[-40, -30] km/s
[17, 29] km/s
Evidence for Jets - ALMA

SiO 5-4 velocity resolution ~22 km/s
Evidence for Jets

$T_{MB} (K)$
(for CO and H$_2$O)

$I$ (Jy/beam)
(for SiO)

Velocity (km/s)

CO (6–5), APEX/CHAMP+, 9"

10*o–H$_2$O $1_{10}-1_{01}$ HSO/HIFI, 38.1"

100*SiO (5–4), ALMA, 1.5"

100*SiO (5–4), ALMA, 1.5"

At IRS1
Evidence for Jets

ALMA single pointings, CO 2-1, 0.15”, Vel. +/- 75 km/s
(Pi M.Dunham: Search for close binaries in isolated systems)
Shallow observations; no SiO

CO 2-1 + 1.3 mm
1.5”, Vel +/-35 km/s

IRS1

SiO 5-4

1.3mm
CO 2-1

400 au

100 au
Evidence for Jets

ALMA single pointings, CO 2-1, 0.15”, Vel. +/- 75 km/s
(PI M.Dunham: Search for close binaries in isolated systems)
Shallow observations; no SiO

CO 2-1 + 1.3 mm
1.5”, Vel +/-35 km/s
Talk Outline

- Why protostellar jets/outbursts are important
- Introduction to BHR 71
- Evidence for Jets
- Infrared Outburst
- Future Directions

Main Collaborators (past and present, and future):
An Infrared Outburst

Disk-mediated accretion burst in a high-mass young stellar object

S255IR NIRS 3 (aka S255IR-SMA1)

ΔH ≈ 3.5 mag and ΔK ≈ 2.5 mag

“first light echo ever observed from the outburst of a high-mass young star”

Outflow cavity irradiated by accreting source

Low mass examples incl. McNeill’s Nebula
An Infrared Outburst

BHR 71 IRS1 over the years
An Infrared Outburst

BHR 71 IRS1 over the years – an accretion event (circa 1998)?

Duration ~10 years
Proper Motions

PMs in 50 yrs

IRS1

IRS2

10,000 au

29/05/2018

Olympian Symposium
Proper Motions

SiO 5-4
CO 2-1
Accretion Events

Recent ejection, ~10 yr ago
(100 km/s ➔ 200 au (10 yrs))

Past event, ~50 yr ago
(from proper motions, or assuming 100 km/s)
Talk Outline

• Why protostellar jets/outbursts are important
• Introduction to BHR 71
• Evidence for Jets
• Infrared Outburst
• Future Directions

Main Collaborators (past and present, and future):
Future Directions

• CO with 1.5” resolution only +/- 35 km/s
  ➢ Obtain maps with coverage at least +/- 100 km/s (ALMA)
• SiO with 1.5” resolution only $\Delta v \sim 22$ km/s
  ➢ Obtain maps with $\Delta v \sim 1$ km/s (ALMA)
• Full outflow map is only $\sim 10”$ (20,000 au) resolution
  ➢ Map with 1” (200 au) resolution (ALMA)
• CO with 0.2” resolution is shallow, no SiO
  ➢ Deep CO and SiO with 0.1” (20 au) resolution (ALMA)
• Continue infrared monitoring of IRS1
  ➢ Follow-up Spitzer proposal (14 yrs post c2d) and NIR
• Publish what we have!
• Atomic Jets – SKA (HI); Ionised Jets – SKA, IR
Summary

• Previous indirect evidence for jets
  - infrared $\text{H}_2$ emission; high velocity CO, H$_2$O, [OI]

• ALMA observations 0.2″-1.5″, CO 2-1 and SiO 5-4
  - IRS1 very compact SiO with high V [+/-80 km/s]
  - IRS1 extended CO with compact component
  - plus brightening of IR cavity
    - recent accretion/ejection event (20 yrs)
  - IRS2 extended SiO “looks like a jet!”, also in CO
    - IRS2 similar high velocities +/- 80 km/s

• Is IRS2 younger (or less evolved)?
  - IRS1 resolved with 0.2″ (40au), but IRS2 is not
  - IRS2 shorter outflow, jet-like component, lower $T_{\text{bol}}$