Looking into the heart of a young outbursting star: First AU-scale observations of V1647 Ori with VLTI/MIDI

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The outburst of V1647 Ori

January 23 2004: the appearance of a reflection nebula in L1630 was announced (McNeil et al. 2004) - outburst occurred in Nov 2003

Popular target
- optical brightening ~ 4 mag
- L ~ 30-90 $L_{\text{Sun}}$, flat SED
- spectrum: accretion, wind
- the source is embedded in an elongated disk-like structure of size ~6000 AU, i=60° (Kun et al. 2004)
- young stellar object (IRAS 05436-0007)

FUor candidate
  (e.g. Briceno et al. 2004, Abraham et al. 2004, Andrews et al. 2004)
McNeil’s Nebula

Reipurth & Aspin 2004,
Gemini-N 8m (g',r',i')

V1647 Ori

~30”
FU Ori type sources (FUors)

- increased accretion ($\sim 10^{-4} M_{\text{Sun}}$/yr):
  - triggered by the companion
    (e.g. Reipurth & Aspin 2004)
  - thermal instability ($\sim 1$AU)
    (e.g. Hartmann & Kenyon 1996)

- FUor eruptions are repetitive
  and recur in T Tau stars
  after $\sim 10000$ years (?)

- One class, one model?
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- One class, one model?

- Milli-arcsecond scale observations needed
MIDI observations of V1647 Ori

- MID-Infrared interferometric instrument for the VLTI
- Director's Discretionary Time Proposal to ESO (November 2004)
  - investigate the hot inner source structure, compare to models
  - start monitoring the temporal evolution of the inner hot region
  - look for companion (like FU Ori, L1551 IRS5, ...)


MIDI observations of V1647 Ori

- observations from December 2004, successful on March 2, 2005 (UT3-UT4, 56m)
- data reduced with MIA (e.g. Leinert et al. 2004)
MIDI results I.
Spectrally resolved visibilities

- Spectrally resolved visibilities slightly resolved (similar to other obtained YSO data).
- Errors: on this night all other observations were conducted with MACAO - conservative estimation: 10%.
- Fitted Gaussian sizes:
  - 8 μm ~ 6 mas = 2.7 AU
  - 13 μm ~ 16 mas = 7.2 AU

![Graph of calibrated visibility vs. wavelength (μm) with error bars and fitted Gaussian sizes.]
MIDI results II.
Search for companion

- A signature of a companion is the sinusoidal modulation of the spectrally resolved visibilities.
- We determined an upper limit for the brightness of a possible companion, at the measured position angle, with:
  - separation: 50 mas - 200 mas
  - flux ratio: $I_2/I_1 < 0.1$
MIDI results III.
N-band spectrum
MIDI results III. N-band spectrum

- Total flux (whole source)
- Correlated flux (inner regions)
Analysis: model fit

A model of the circumstellar structure (disk, etc.) which fits simultaneously

- the SED,
- the (spectrally resolved) visibilities.

Usually not easy!
Analysis: SED fit

Spitzer: March 2004 (Muzerolle et al. 2004)

- steady accretion disk, rate 
  $\sim 10^{-5} M_{\text{Sun}}/\text{yr}$
- optically thin envelope*, infalling rate $\sim 10^{-6} M_{\text{Sun}}/\text{yr}$

* the featureless N-band spectrum
* RT calculations - optically thick
Analysis: SED fit

Alternative: a simple (spatially flat, optically thick) disk model

- \( R_{in} \sim 5 \text{ AU} \)
- \( T(1\text{AU}) = 680 \text{ K} \)
- \( q = -0.53, T(r) \sim r^q \) (not a simple accretion disk)
- \( p = -1.5, \Sigma(r) \sim r^p \)
- \( M_d = 0.05 \text{ } M_{\text{Sun}} \)
- \( A_v = 10 \text{ mag} \)
- \( i = 60^\circ \)
Simultaneous fit of SED and visibilities

- $R_{in} \sim 5$ AU
- $T(1AU) = 680$ K
- $q = -0.53, T(r) \sim r^q$
  (not a simple accretion disk)
- $p = -1.5, \Sigma(r) \sim r^p$
- $M_d = 0.05 \, M_{\text{Sun}}$
- $A_v = 10$ mag
- $i = 60^\circ$
Comparison with FUors

- FU Ori (Malbet et al. 2005, NIR): $q=-0.71$
- V1057 Cyg, V1515 Cyg (Millan-Gabet et al. 2006, NIR): $q \sim -0.45$
  Z CMa: $q=-0.75$, ~60% of the flux resolved out
- The inhomogeneous group of young outbursting objects

$q=-0.53$
Monitoring program at Konkoly Observatory

- K-band: LIRIS at William Herschel Telescope (Kun et al., in prep)
- optical light curve: Feb 2004 - :
  Kóspál et al. (2005) +
  Briceno et al. 2004 (open)

Parsamian 21

Á. Kóspál et al.

OO Ser

Á. Kóspál et al.
Analysis: geometry

- more refined models (radiative transfer)
- compare to Herbig Ae/Be stars (Leinert et al 2004):
  - visibilities
  - disks

Meeus et al. 2001
Thank you
Notes
FU Ori type sources - One class? One model?

- thermal instability (~ 1AU):
  - Hartmann & Kenyon 1996
  - triggered by the companion (Reipurth & Aspin 2004)
  - flare of a rapidly rotating G supergiant with quasi-permanent winds + absorbing shell (optical spectrum, Herbig et al. 2003)
V1647 Ori was detected in 1966 (Messier Album) and 1995 (Eislöffel & Mundt 1997) but not in 1951, 1964, 1979, 1990 (POSS, Konkoly Archive plates): EX Lupi type?

V1647 Ori and OO Ser (Kóspál et al.): a new intermediate class?
Analysis: SED fit

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- $T(1AU) = 680\ K$
- $q = -0.53, T(r) \sim r^q$
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- $A_v = 10\ \text{mag}$
- $i = 60^\circ$
Analysis: Model visibilities

- Fourier transformation

\[ I(\alpha, \beta) = \int_{-\infty}^{\infty} \int_{-\infty}^{\infty} \nu(u, v) \exp(2\pi i (\alpha u + \beta v)) \, du \, dv \]

- Hankel transformation: simplified Fourier transformation for circularly symmetric source structure (Berger 2002)

\[ \nu(r) = 2\pi \int_{0}^{\infty} I(\rho) J_0(2\pi \rho r) \rho \, d\rho \]

tools soon @ http://www.mpia-hd.mpg.de/MIDISOFT
MIDI results I.

- Spectrally resolved visibilities
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MIDI results

- Spectrally resolved visibilities
  - slightly resolved
  - fitted Gaussian sizes: $8\mu\text{m} - 7.2\text{ mas} = 3.3\text{ AU}$
  - $12\mu\text{m} - 12.9\text{ mas} = 5.9\text{ AU}$

all other observations were conducted with MACAO - conservative estimation: 10%
measured position of the companion at the measured position.
SED 204 vs MIDI 2005

- optical fading till 2005 spring is small (Kóspál et al. 2005)
- MIDI sp. ~ Spitzer IRAC (2004 March, Muzerolle et al. 2005)
- Andrews data not considered in our fit
- no “fading factors” - overinterpretation
Analysis: SED fit

Simple unphysical model (spatially flat, optically thick disk)

SED

- optical - NIR: our data and Reipurth & Aspin 2004
- 3.6 - 70 μm (Spitzer/IRAC): Muzerolle et al. 2005
- submm: Lis et al. (1999), Mitchell et al. (2001), Andrews et al. (2005) March 10, 2004
SED fit

q=-3/4
  • spatially flat disk or
  • accretion in the disk with Keplerian velocity

q=-1/2
  • flared disk or
  • accretion in the disk with non-Keplerian velocity or
  • Keplerian, but nonviscous: energy transported from inside to outside heating the outer parts and so decreasing the temperature gradient
McNeil’s Nebula

spectral features ~ accretion
colors: visual extinction diminished

Reipurth & Aspin 2004,
Gemini-N 8m
g', r', i'
MIDI results III.
Temporal evolution

![Graph showing temporal evolution of MIDI results for different wavelengths and dates](image.png)
MIDI results III.
Temporal evolution

Spitzer/IRS
#pid 228
PI: J. Muzerolle
MIDI results III.
Temporal evolution