Probing massive young stellar objects with long-baseline mid-infrared interferometry

Paul Boley
pboley@mpifr-bonn.mpg.de
Max Planck Institute for Radio Astronomy
Bonn

May 5, 2014
Heidelberg
Formation of massive stars

- **Where?** Dense molecular clouds
  => High extinction

- **How long?** ~1 Myr
  => Forming massive stars *extremely* rare

- **How?**
  - Stellar mergers?
  - Competitive accretion?
  - Spherical collapse?
  - *Non-spherical* collapse (accretion disk)?

- What is the role of turbulence, magnetic fields, composition of gas and dust, etc.??
Massive young stellar objects

- Observationally-defined class
- Luminosity: $10^4 - 10^6 \, L_\odot$
  - Progenitors of “massive” stars (>8 M\odot)
- Deeply embedded: $A_V \sim 20 - 100$ mag
  => Generally invisible at optical wavelengths
  => Deep silicate absorption in $N$ band (8-13 $\mu$m)
- Outflows, (compact) H II zones, masers
- Typical distances of 1 - 5 kpc
  - Resolution on VLTI: ~10 mas $\leq$ tens of AU.
- SED is dominated by envelope
  - There are indications of dust disks (e.g. IRAS 13481-6124, AFGL 4176)
SED of AFGL 4176
SED of AFGL 4176
SED of AFGL 4176
Long-baseline infrared interferometric studies of MYSOs

To date, 100% of published works use VLTI

4) de Wit et al. 2010 (A&A 515, A45): W33A
5) Vehoff et al. 2010 (A&A 520, A78): NGC 3603 IRS 9A
6) Follert et al. 2010 (A&A 522, A17): M17 SW IRS1 (KW)
7) Kraus et al. 2010 (Nature 466, 399): IRAS 13481-6124
8) de Wit et al. 2011 (A&A 526, L5): AFGL 2136
Long-baseline infrared interferometric studies of MYSOs

To date, 100% of published works use VLTI

4) de Wit et al. 2010 (A&A 515, A45): W33A
5) Vehoff et al. 2010 (A&A 520, A78): NGC 3603 IRS 9A
6) Follert et al. 2010 (A&A 522, A17): M17 SW IRS1 (KW)
7) Kraus et al. 2010 (Nature 466, 399): IRAS 13481-6124
8) de Wit et al. 2011 (A&A 526, L5): AFGL 2136
MIDI observations of W33A

- Single \textit{uv} point (46 m); 1D rad. tran. modeling
- First \textit{direct confirmation} of warm dust around MYSO at scales of 100-200 AU
MWC 297: a young high-mass star rotating at critical velocity
Acke et al. 2008 (A&A 485, 209)

- AMBER + MIDI (6 and 13 uv points)
- Geometric (Gaussian) modeling of visibilities and SED
MWC 297: a young high-mass star rotating at critical velocity

Acke et al. 2008 (A&A 485, 209)

- AMBER + MIDI (6 and 13 $uv$ points)
- Geometric (Gaussian) modeling of visibilities and SED
- Compact (~1 AU), elongated emission; attributed to circumstellar disk at 40 deg inclination
Evidence for a circumstellar disk surrounding the Kleinmann-Wright object
Follert et al. 2010 (A&A 522, A17)

- Five $uv$ points with MIDI
- Fit SED (only) with Robitaille et al. grid; compare visibilities of best-fitting models
Evidence for a circumstellar disk surrounding the Kleinmann-Wright object
Follert et al. 2010 (A&A 522, A17)

- Five $uv$ points with MIDI
- Fit SED (only) with Robitaille et al. grid; compare visibilities of best-fitting models
baseline: 43.52m; proj. angle: 48°

baseline: 31.70m; proj. angle: 70°

baseline: 15.10m; proj. angle: 65°

- **Obs. Visibility**
  - **3003929** Incl: 76°
  - **3008813** Incl: 63°
  - **3008813** Incl: 70°
  - **3008813** Incl: 76°
  - **3008813** Incl: 81°
Evidence for a circumstellar disk surrounding the Kleinmann-Wright object
Follert et al. 2010 (A&A 522, A17)

- Five $uv$ points with MIDI
- Fit SED (only) with Robitaille et al. grid; compare visibilities of best-fitting models
- Inclined $0.1 \, M_\odot$ disk without envelope consistent with SED and MIDI visibilities
VLTI/MIDI survey of massive young stellar objects
Boley et al. 2013 (A&A 558, A24)

- MIDI observations of 20 MYSOs (1-40 $uv$ points per object)
- Fit visibilities with simple (Gaussian) geometric models
- Fit silicate absorption with lab opacities
VLTI/MIDI survey of massive young stellar objects
Boley et al. 2013 (A&A 558, A24)

- MIDI observations of 20/24 MYSOs (1-40 $uv$ points per object)
- Fit visibilities with simple (Gaussian) geometric models
- Fit silicate absorption with lab opacities
- Warm dust at 10s of AU ubiquitous
- Emission can be aligned with disk or outflow (or neither)
- Absorption occurs at scales larger than those probed by MIDI
Conclusion: MIDI and MYSOs

- Warm circumstellar dust probed at ~10-100 AU scales for the first time by MIDI
  - Critical for testing/constraining massive star formation theories
- 24 MYSOs observed and published in
  - 10 refereed publications
  - 4 PhD theses
- Some idea of what to expect with e.g. MATISSE
- More to come
  - Survey data publically available!
  - P93/P94 observations