LkHα 101 – a Herbig B0e – B1e V star with a disk

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Outline

- Why are early B-stars important?
- Brief summary of what is known until now about LkHα 101
- New data and what we learned from them
- Summary and Conclusions

Why study early B-stars?

- Formation of massive stars still poorly understood
- Optically visible early B-stars (with fairly secure spectral type) and firm evidence for circumstellar disk may tell us what we should expect that a disk around an O-star may look like
- Three clear examples (all very similar): LkHα 101 (nearly face-on), MWC349A (edge on), MWC297 (nearly edge on)
- All very bright (easy to study, but not with *Spitzer* – too bright)
- Here we focus on LkHα 101

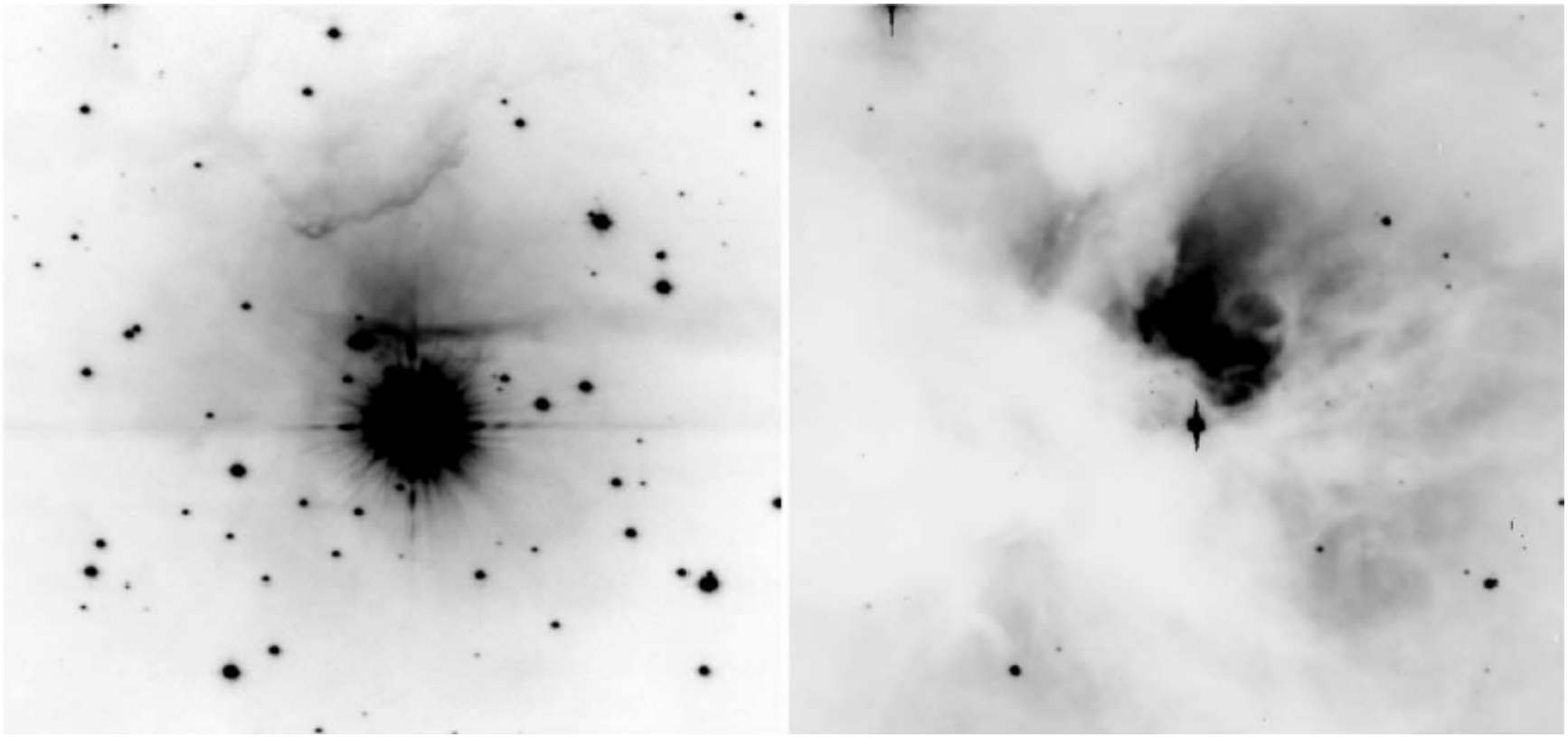
What do we know about LkHα101?

- A few important papers
  - Herbig, Andrews & Dahm 2004, AJ, 128,1233
  - Andrews & Wolk 2008, Handbook of Star Forming Regions, Vol 1, Ed. Reipurth, p390-404
  - Tuthill et al. 2002, ApJ, 577, 826
  - Wolk et al. 2010, ApJ, 2010, 715, 671
  - Thum et al. 2013, A&A, 556, A129
- Illuminating star of a large reflection nebula, NGC 1579
- Ionizes an HII region (S222) ~ 1 arcmin EW (compressed in the North) and drives an ionized (disk)wind
  - Requires a spectral type of B0 – B1, ~ consistent with bolometric luminosity of ~ 1 - 2 104 LSun
- Most massive star in a cluster of more than 200 PMS stars, distance 500 – 700 pc, age 0.5 – 1 Myr
- Spectrum completely dominated by emission lines, strong IR excess, Av ~ 9 - 10 mag

Optical (VRi) image of LkHα 101 ~7′ ×7′

Herbig et al. (2004)

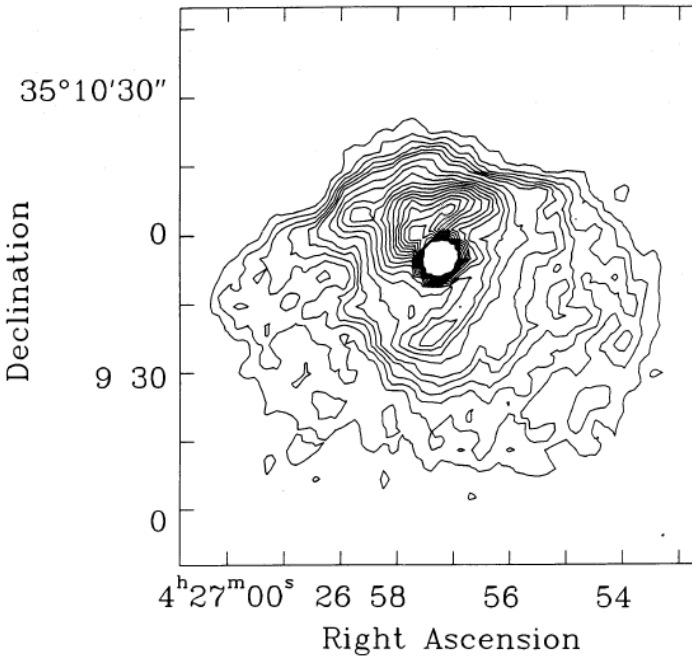
K &R images of LkHα 101 ~2.75′ ×2.75′



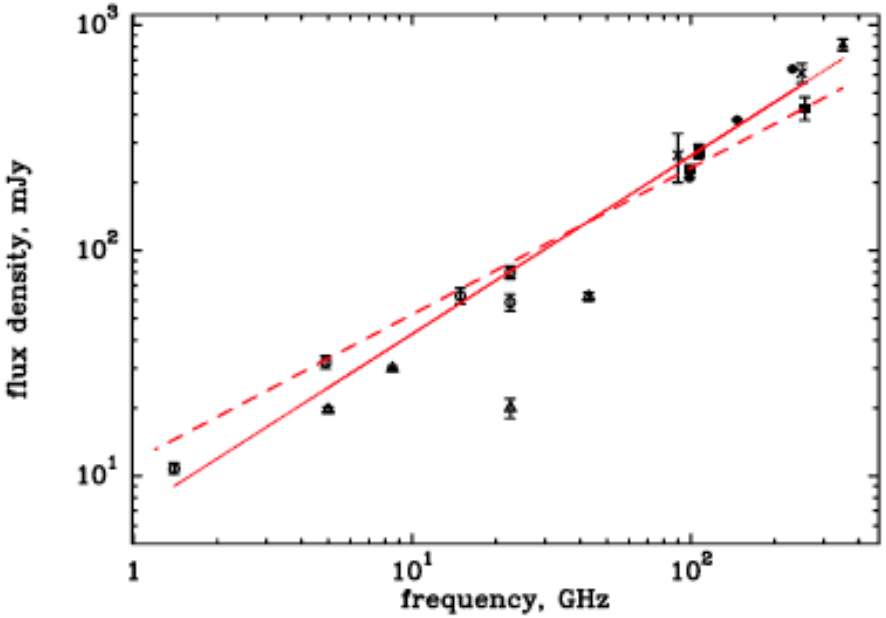
K

R

Radio image of LkHα 101



Becker & White 1988

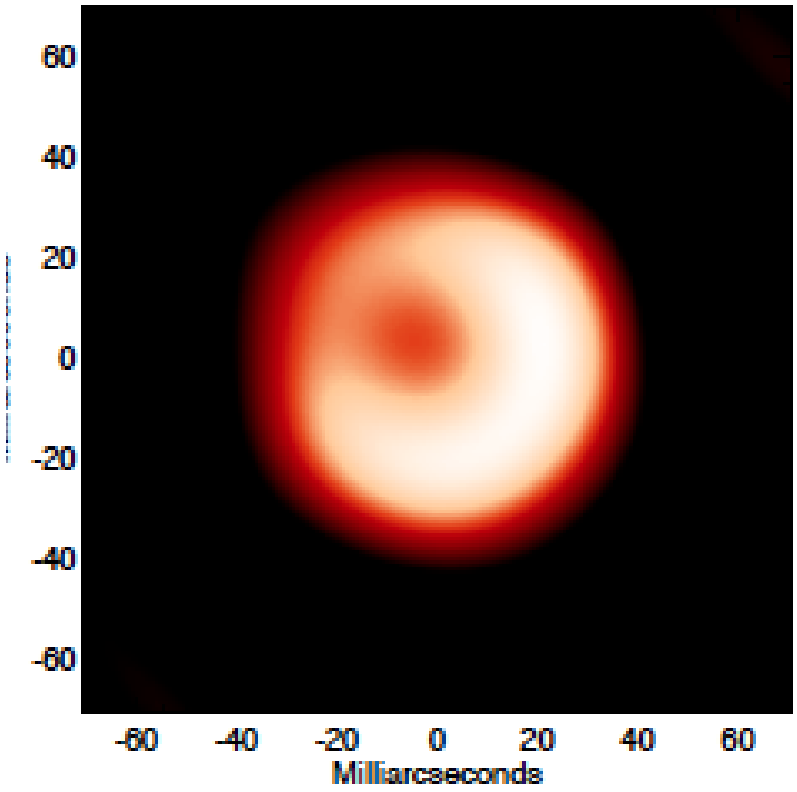


Radio SED of central source from Thum et al. 2013

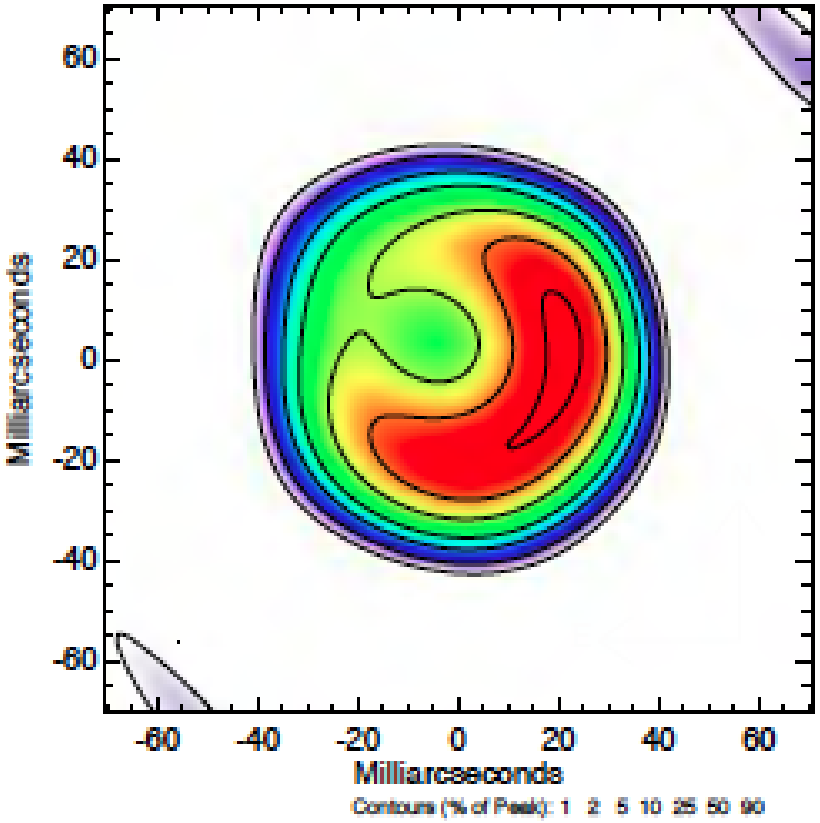
LKHα 101 continued

- Radio SED consistent with thermal wind emission from ionized disk, size 0.55″ ″ @ 5 GHz, ~ 0.03″ ″ (20 au) @ 100 GHz (optically thick part of the wind)
- Interferometric imaging (1.2 – 11 μm) shows a largely face-on (< 35°) dusty disk with a size of 44 mas at 2.27 μm (63 mas at 11 μm) and a faint blue companion at ~ 180 mas from the star
- Emission lines in Fe II (Ni II and Mn II), possibly also [OI] show double split lines consistent with Keplerian rotation around a 15 MSun star

LkHα 101 disk (Tuthill et al. 2002)

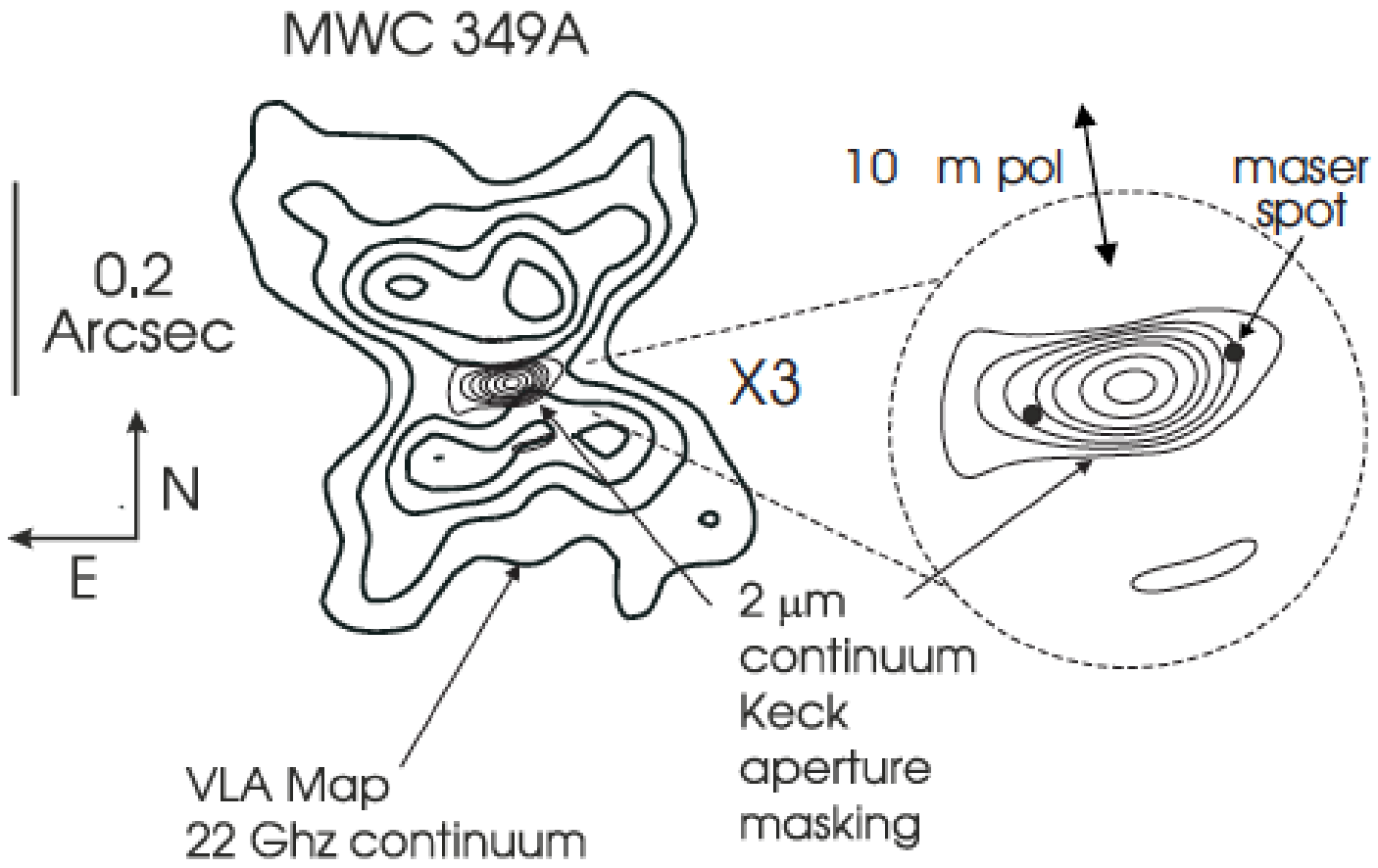


H band



K band

Compare with MWC349A – edge on disk

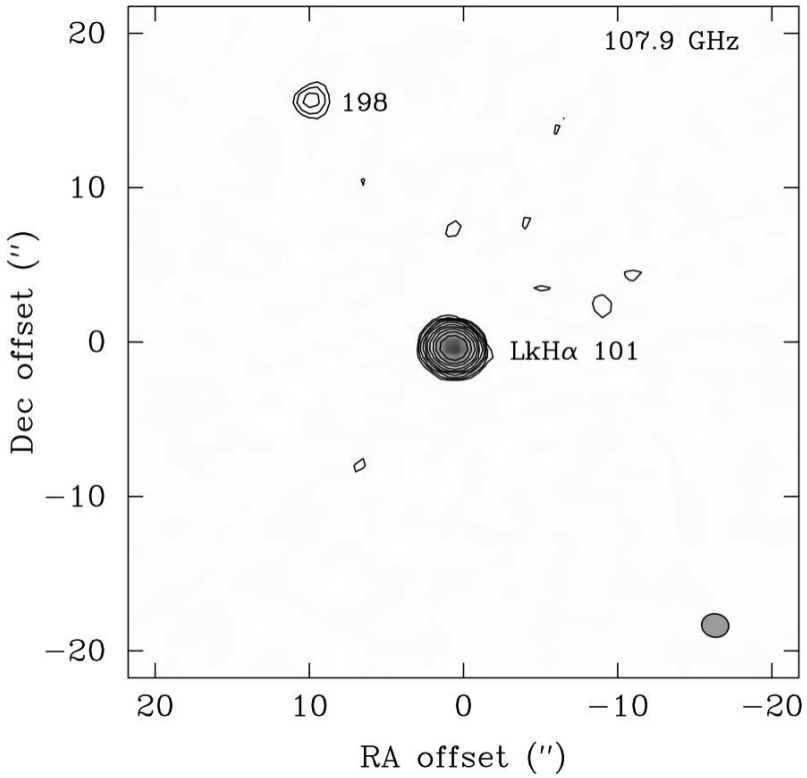


New Data

- CARMA C& D array data
  - Continuum @ 103 – 115 GHz
  - 12CO & 13CO J=1-0
  - Resolution C: 1.76″ ″ ×1.51″ ″ CD: 2.9″ ″ ×2.6″ ″
    D: 3.7″ ″ ×3.2″ ″
- Onsala Space Observatory 13CO J=1-0 map (30″ ″)
- Herschel PACS archive data (P. Harvey)
  - 100 & 160 μm images (~6.7″ ″ @100 μm)
- IRTF SpeX 0.8 – 5.1 μm spectrum (R ~2000)
- SOFIA FORCAST imaging (5-38 μm)
  - Not yet scheduled

CARMA continuum results

- two continuum sources at 108 GHz:
  - LkHa101 0.258 +/- 0.002 mJy
  - All thermal emission
  - No dust excess
  - #198 Class I object
  - (K 11.3m 8μm 5.7m)
  - 9.0 +/- 0.001 mJy
  - Drives an outflow



Radio/FIR SED

- Flux density Sν ∝ ν0.77 (0.05)
- Size ∝ ν–0.97 (0.10)

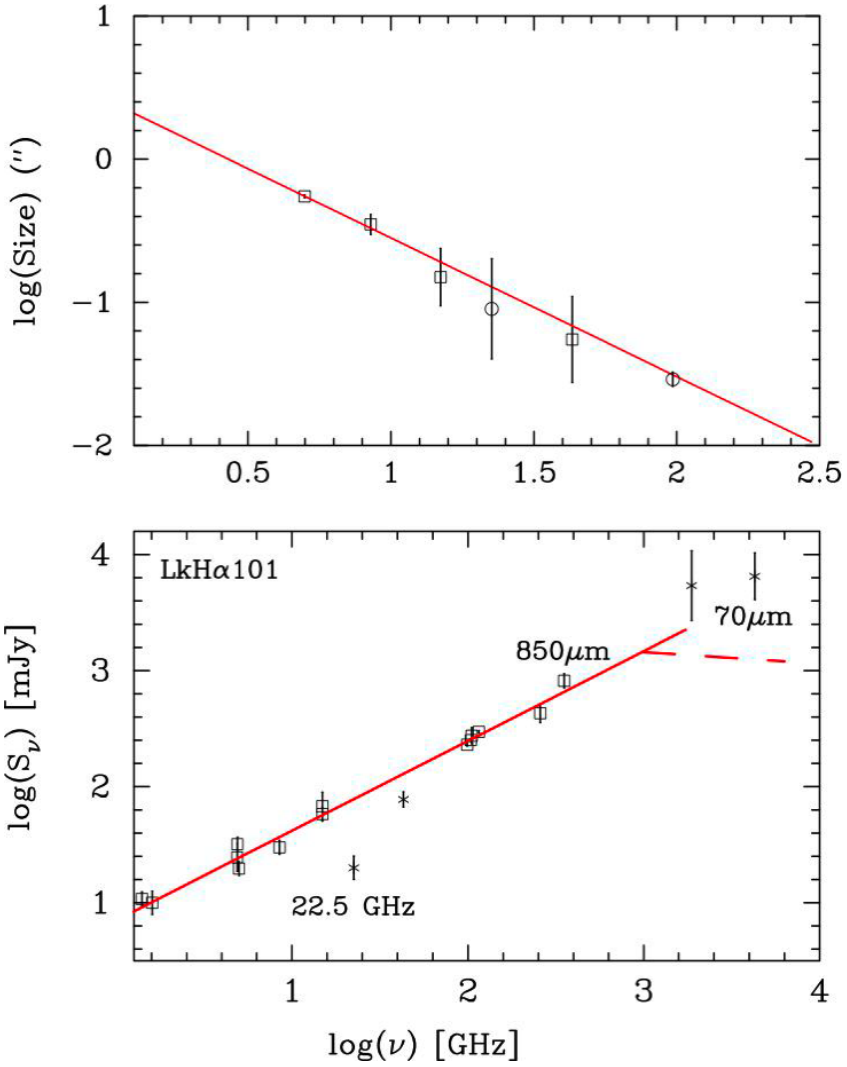
Note:

Wind becomes optically thin around 500 – 300 μm (guess)

160 μm is an upper limit (hardly visible)

Clear excess at 70 μm (~ 7 Jy)

Thum et al (2013) gets spectral index of 0.86 (0.03) using published values and their own PdB data

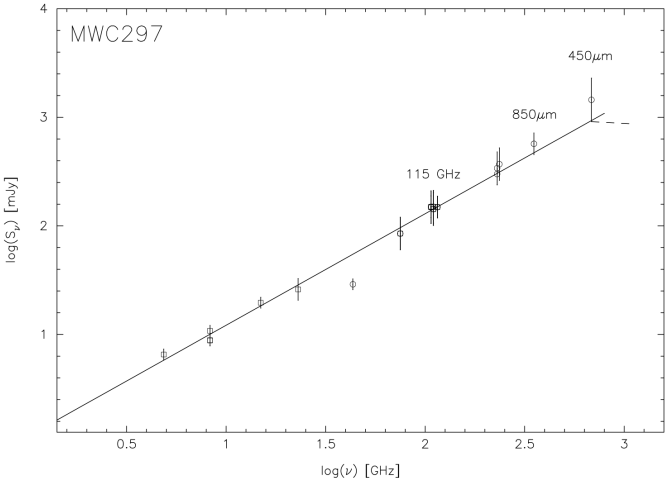


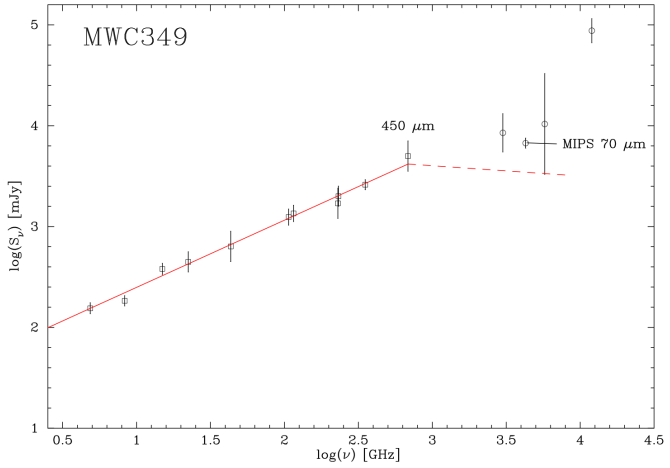
MWC297 & MWC349: very similar

Both are dominated by thermal wind emission into the FIR, but seen more edge on. No cold dust, but clear resolved hot dust disk seen with IR interferometry.

MWC297 Flux density $S\nu \sim \nu 0.97$ Size $\sim \nu -0.8$

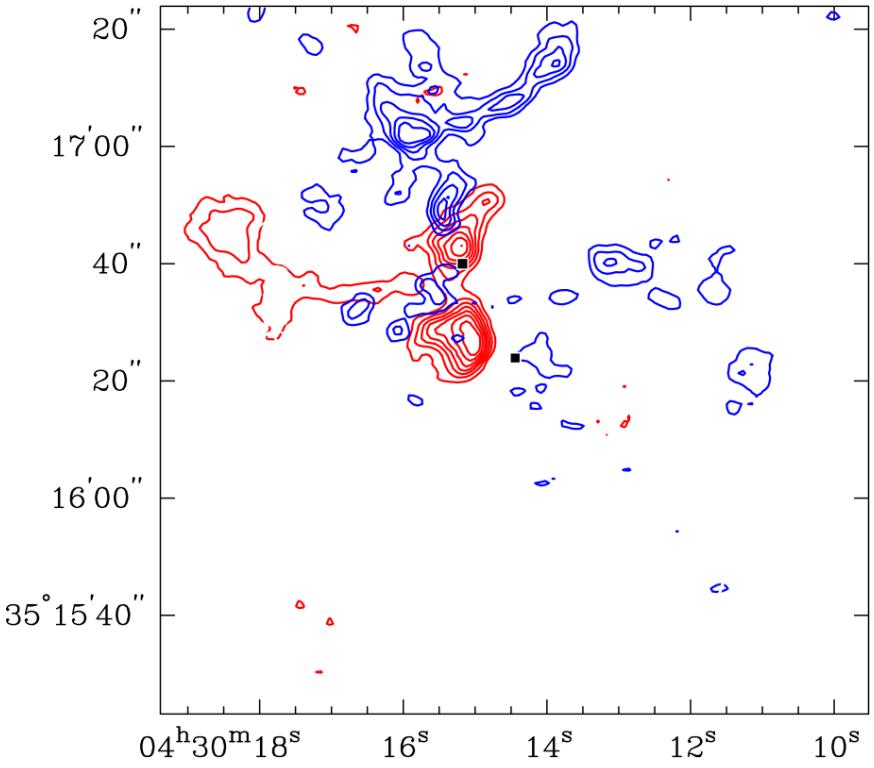
MWC349A Flux density $S\nu \sim \nu 0.67$ Size $\sim \nu -0.74$

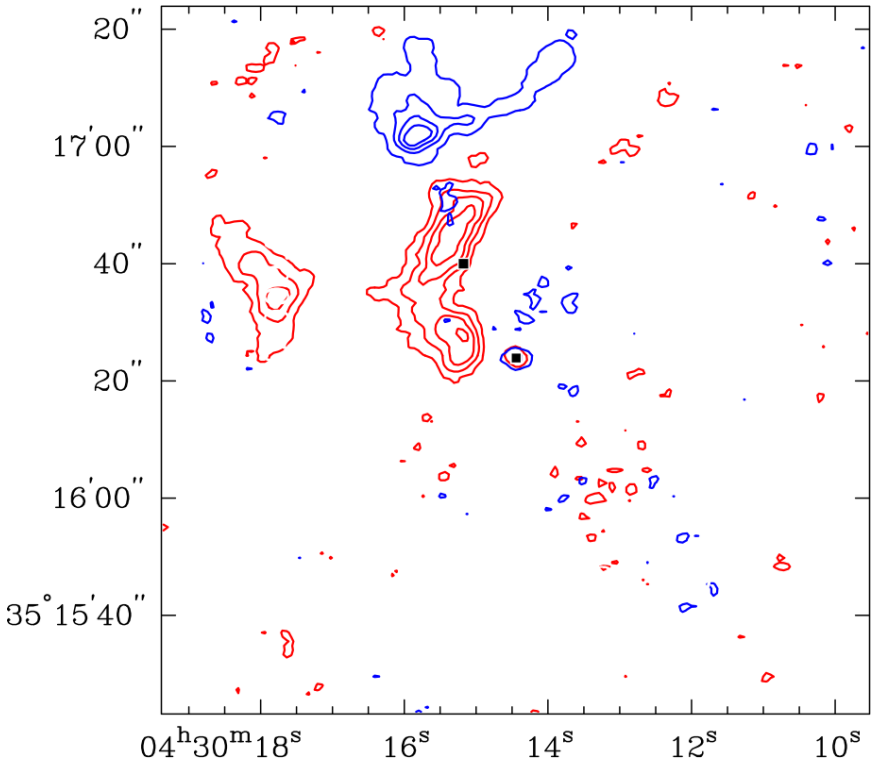




12CO and 13CO J=1-0 imaging

- Shows outflow from the class I source #198
- Interaction with the HII region in the north (blue-shifted)
- Red clump east of LkHα 101 (cometary globule or part of the 198 outflow)

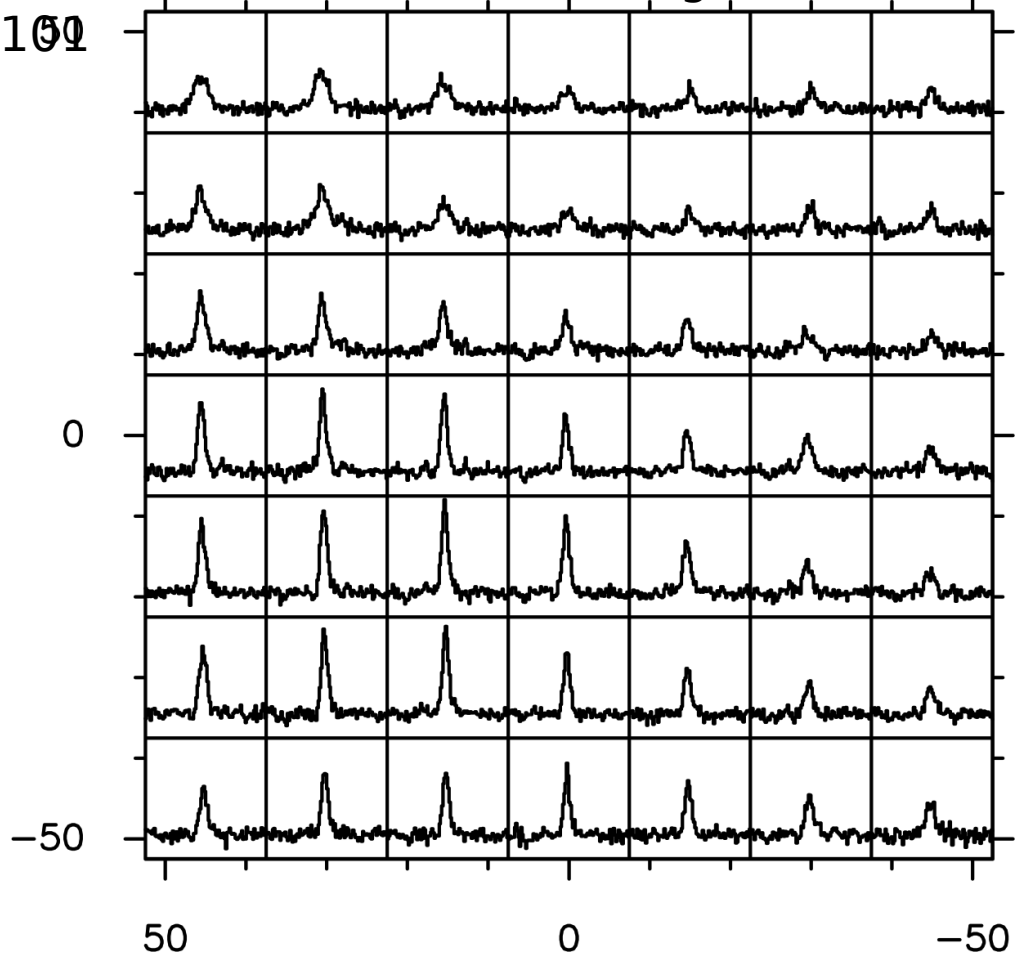




13CO OSO map

The cloud to the N and NE (Vlsr = -2.6 km/s) interacts with LkHα 101

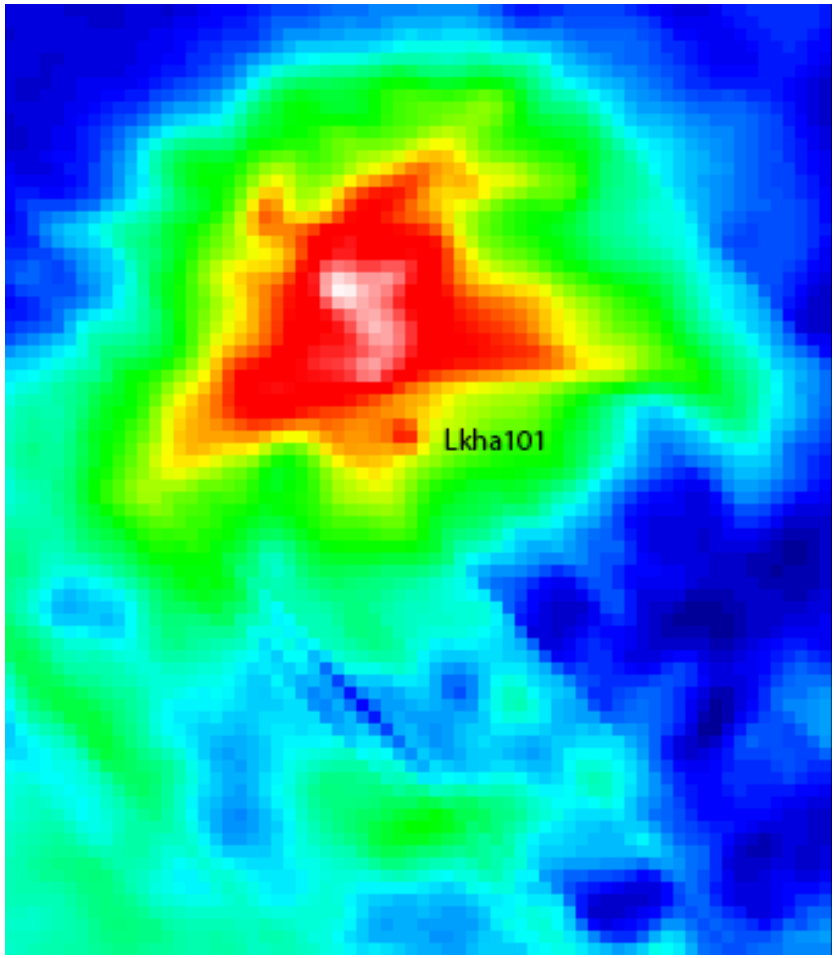
The cloud at Vlsr = -0.5 km/s is foreground, i.e. on and SW of LkHα 101



PACS archive data (PI P. Harvey)

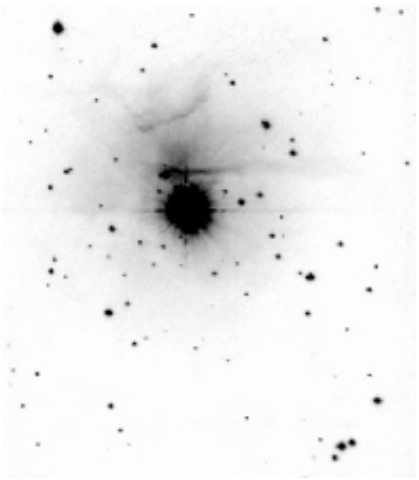
LkHα 101 faint at 100 μm. No other radio and FIR source seen except the Class I source #198, suggesting that the FIR emission we see is heated by LkHα 101.

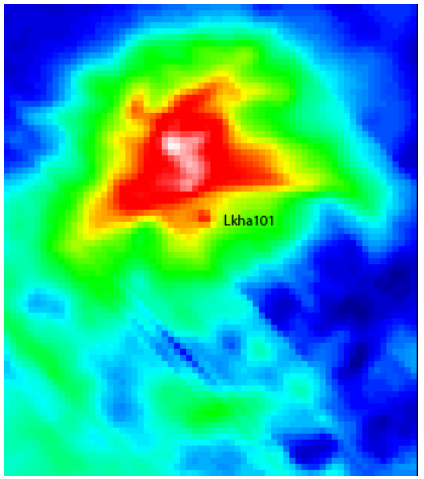
At 160 μm the emission is completely dominated by the cloud and no flux density can be derived for LkHα 101

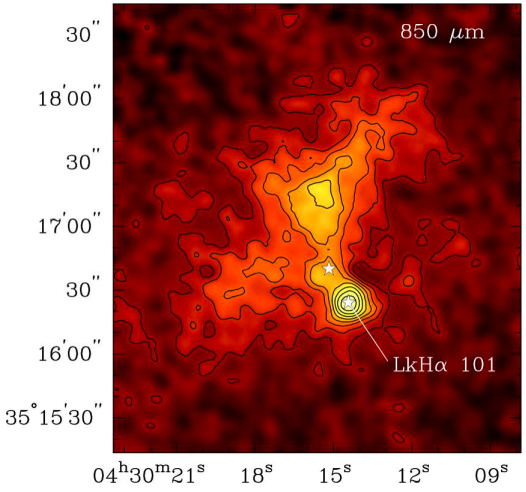


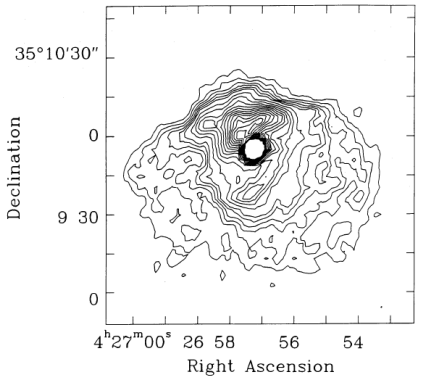
100 μm

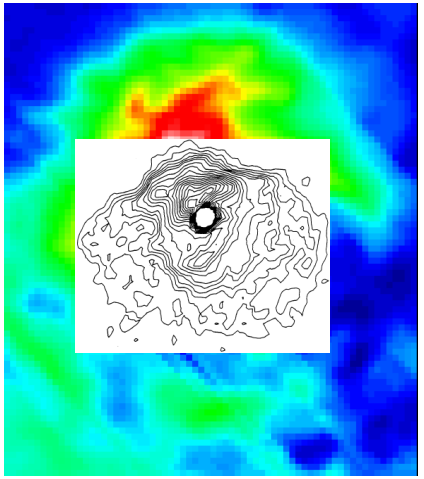
The environment of LkHα 101: Optical - radio



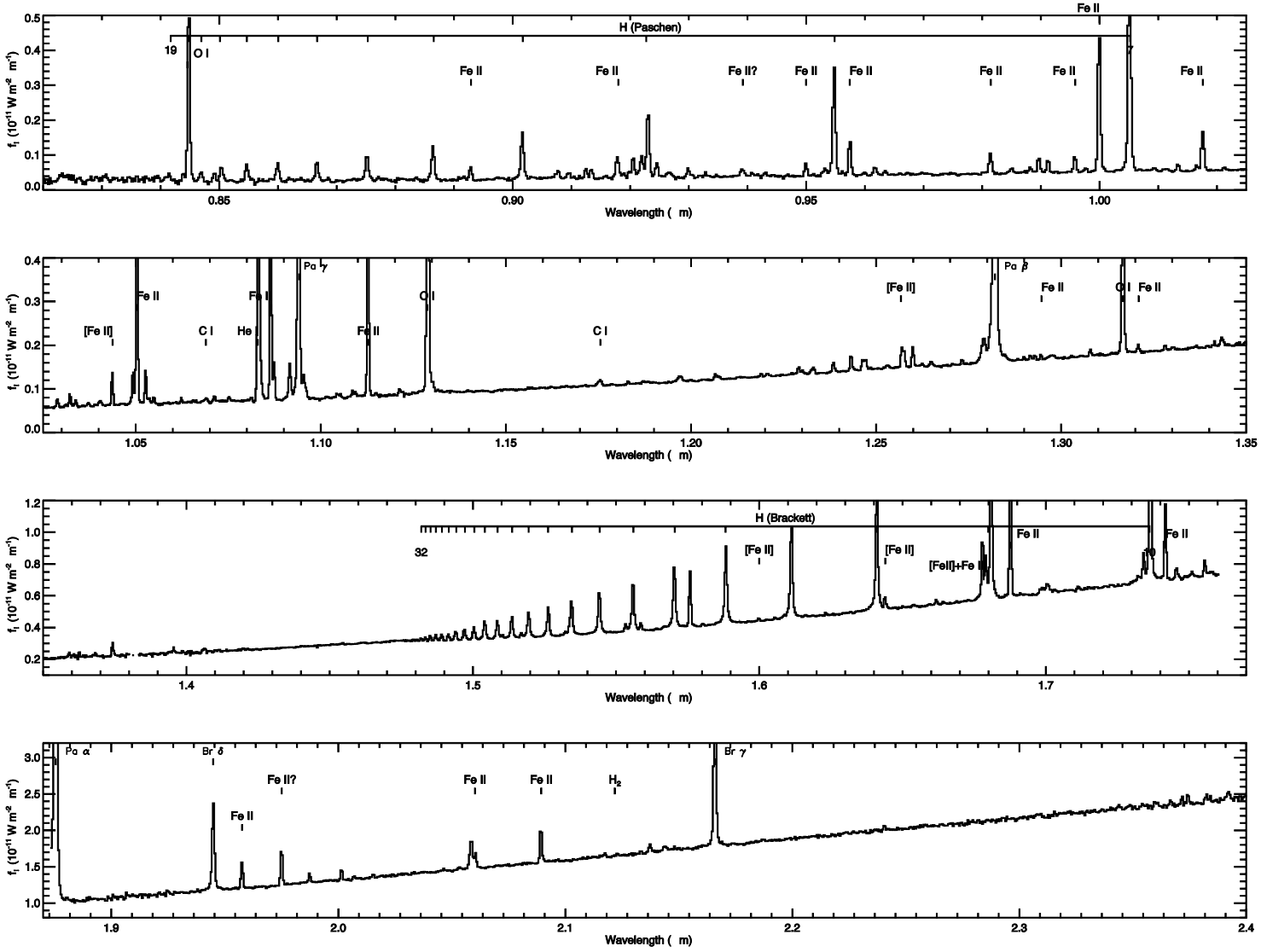




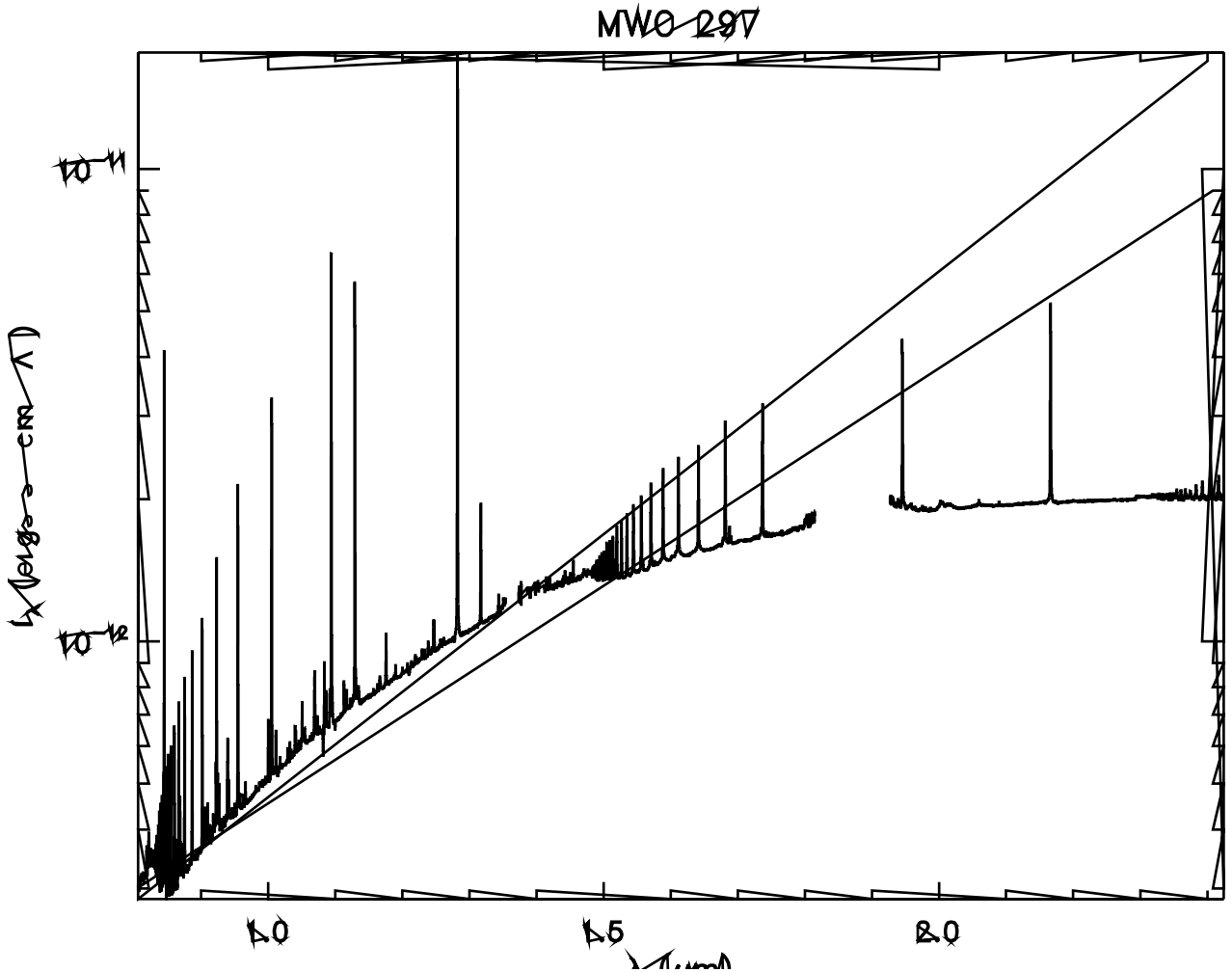




SpeX spectrum of LkHa 101

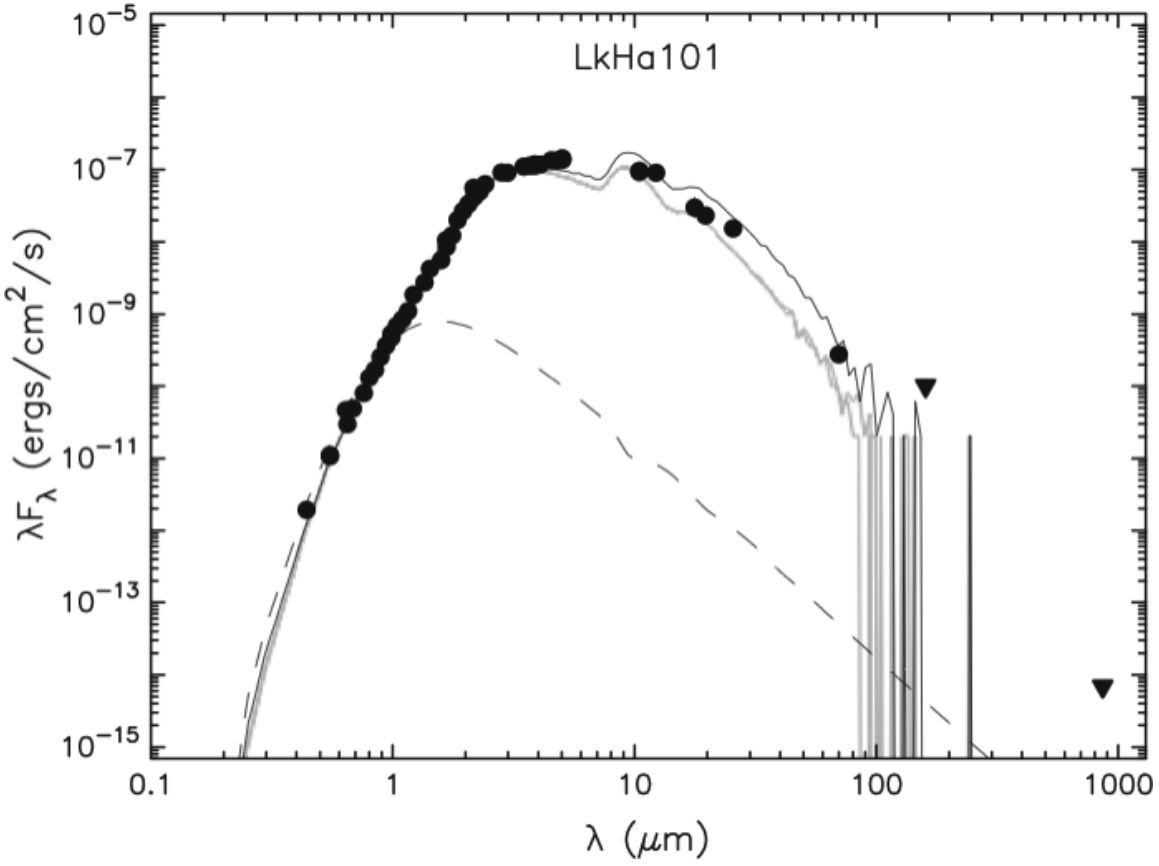


MWC297 (B1.5e) looks very similar



SED modeling (Robitaille)

Even with the low FIR flux the bolometric luminosity still consistent with a B0 – B1 star (1 – 2 104 Lsun, and an effective temperature ~ 30,000 K.



Summary and future work

- LkHα 101 is an early B-star with a circumstellar disk
- We find:
  - Radio SED completely dominated by thermal wind emission
  - No cold dust. No molecular emission from the disk.
  - No molecular outflow
  - Strong interaction between the HII region and the surrounding molecular cloud (at Vlsr = -2.6 km/s)

Future work

- Find out where the free-free emission becomes optically thin (ALMA)
- Look for hot molecular gas (challenging because of face-on disk)
  - With EXES (HCN & H2C2)
- Characterize the hot dust
  - SOFIA FORCAST imaging and spectroscopy
  - HAWC+ at 53, 89. 155 (and 216 μm)