Mass Loss Constraints for Massive Stars with the CHARA Array

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Fundamental Mass-loss Physics

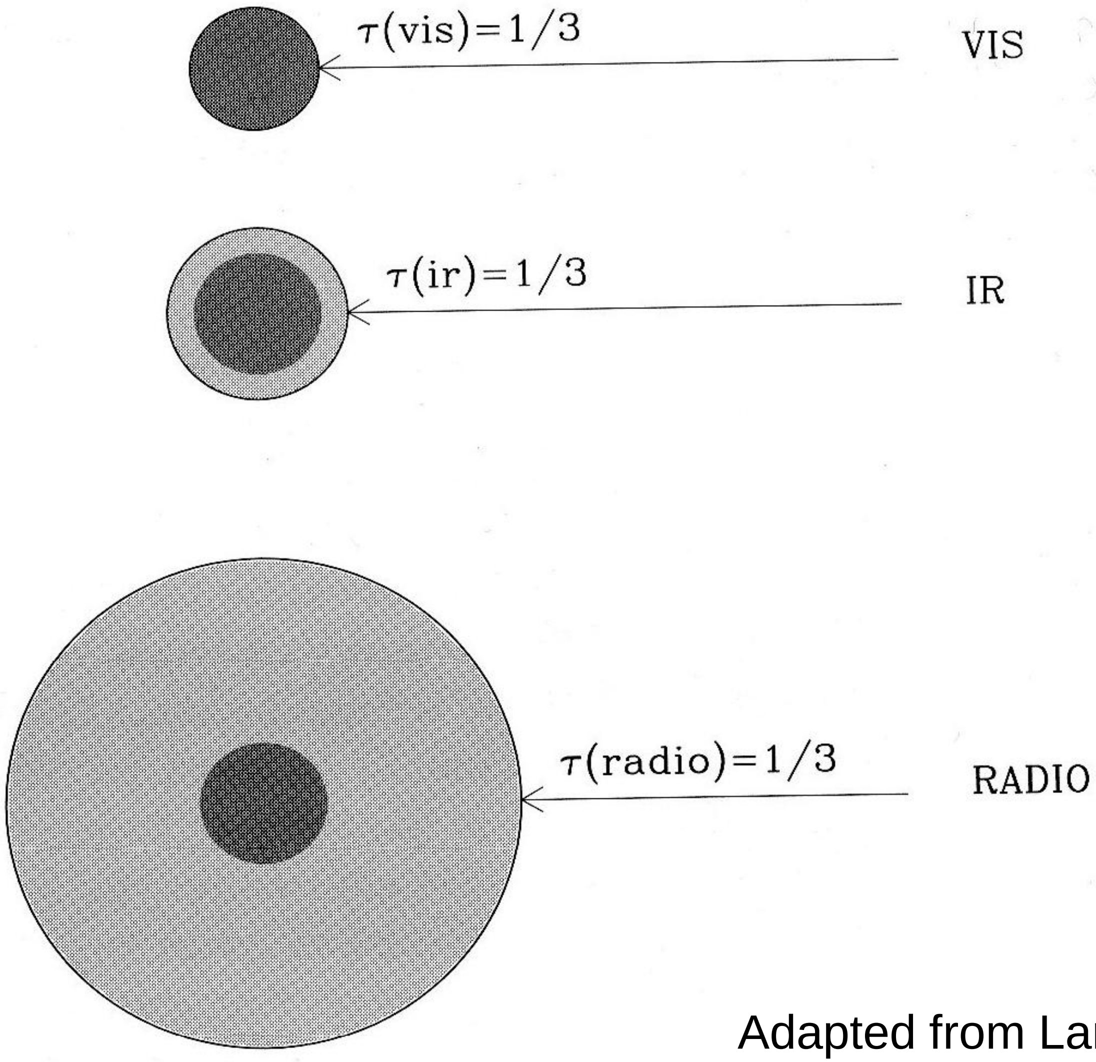
The zero-order solution of the radiative transfer for a star with a wind is

$$L_\nu \simeq 4\pi r^2(\tau_\nu = \tau_{\text{eff}}) \times \pi B_\nu(T(\tau_\nu = \tau_{\text{eff}}))$$

Comparison of the flux between a star with a wind and without a wind is

$$\frac{L_\nu}{L_\nu^*} \simeq \frac{r^2(\tau_\nu = \tau_{\text{eff}})}{R_*^2} \times \frac{B_\nu(T(\tau_\nu = \tau_{\text{eff}}))}{B_\nu(T_{\text{eff}})}$$

Adapted from Lamers and Cassinelli “Introduction to Stellar Winds”



Adapted from Lamers and Cassinelli "Introduction to Stellar Winds"

CHARA Observations

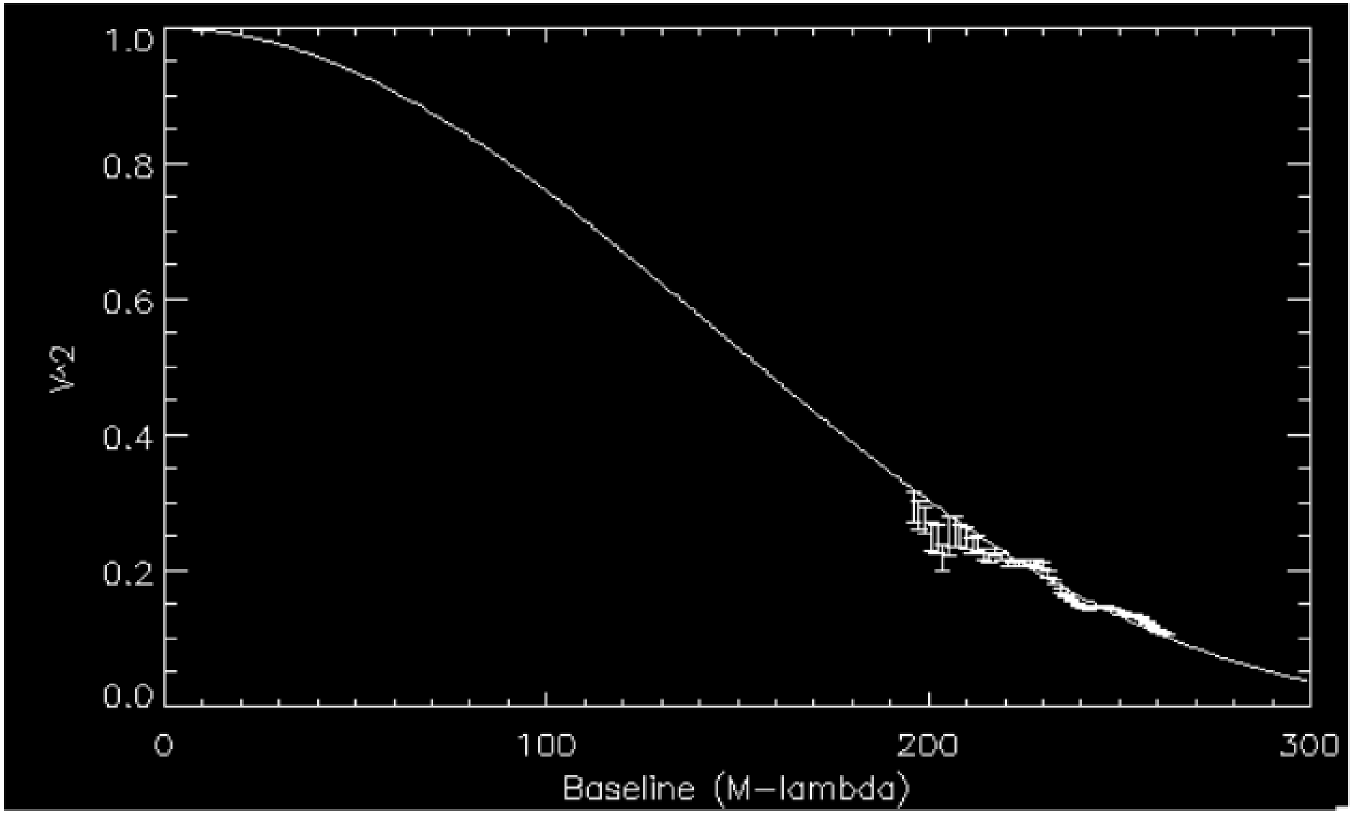
- Find hot stars that are large enough to observe in the optical (PAVO) and NIR (Classic K'-band) and with strong winds
  - Hot supergiants
  - ε Ori, κ Ori, and ζ Ori are the 3 best candidates
  - All observed at Narrabri
- Use the diameters from the different wavelengths to test the physics of the Eddington-Barbier relationship for hot stellar winds

ε Orionis

- V= 1.7
- T_{eff} = 27500±1000
- $Log(L/L_{\odot})$=5.73±0.11
- B0Ia
- $M \sim 40M_{\odot}$
- $R \sim 33R_{\odot}$
- $\dot{M} = 1.9x10^{-6}M_{\odot}/yr$

Searle et al. (2008)

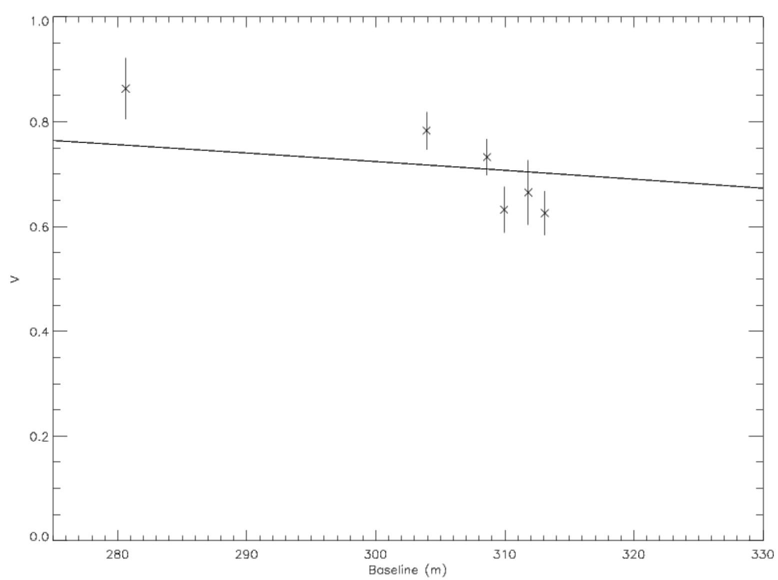
Example V^2 Science

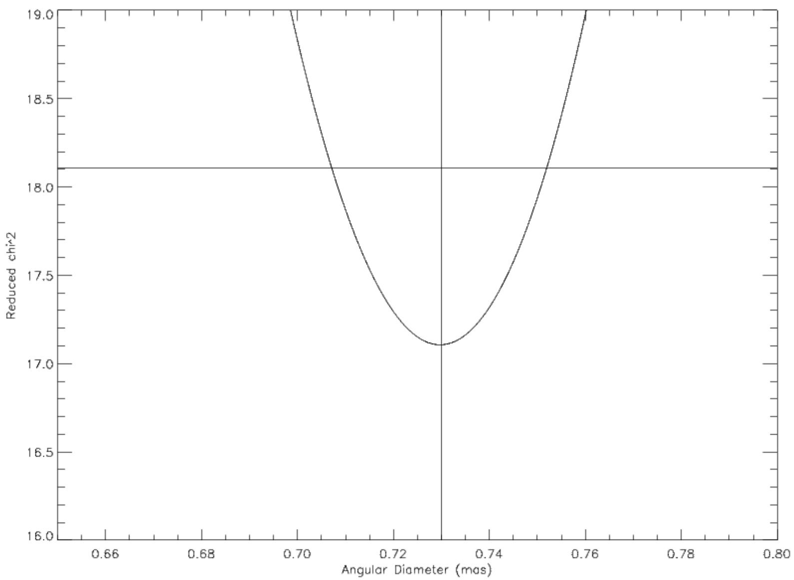


Eps Ori calibrated with HD 35299. 0.68+/-0.005 mas diameter.
We are systematically analyzing all single-baseline data for 2008…

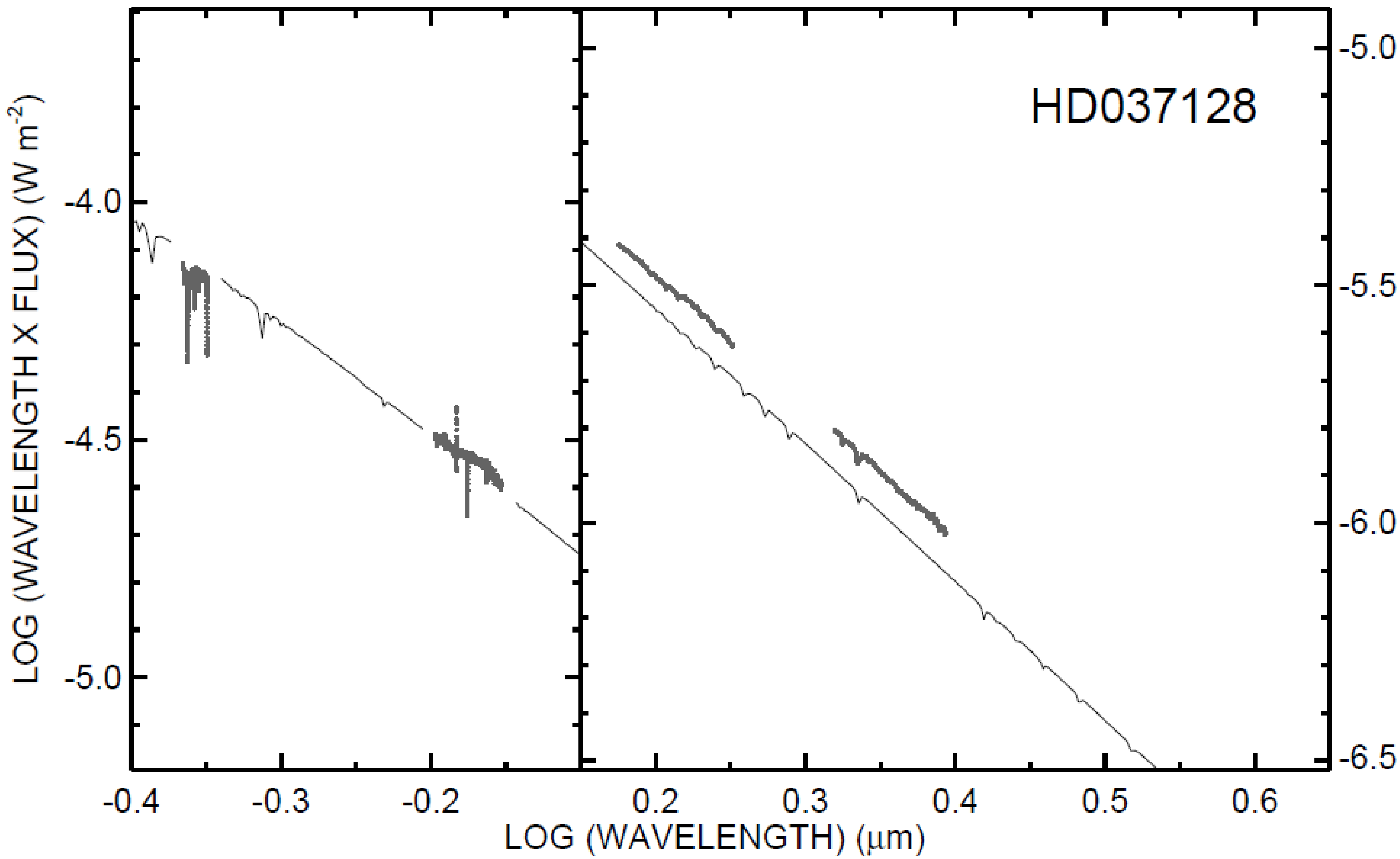
ε Ori – K'-band (Classic)

- Data from 2007 and 2009 (E1-W1 and S1-E1)
- K' diameter: 0.723+-0.022 mas





Optical and NIR SED



Touhami, Richardson, et al. (in press)

Parameters from the Different Diameters of ε Ori

4430 Angstroms	PAVO	Classic (2.15 microns)
0.69±0.04 mas	0.68±0.005 mas	0.723±0.022 mas

From the SED, ϵ Ori has a K' excess of 0.1 dex, meaning

$$\frac{L_{\lambda,\mathrm{star+wind}}}{L_{\lambda,\mathrm{star}}} \approx 1.25$$

$$F_\lambda \approx (\mathrm{SurfaceArea}) \times F_\lambda(K'\mathrm{-band}, T)$$

$$1.25 \approx \frac{\theta_{K'}}{\theta_{\mathrm{star}}} \times \frac{F_{\lambda,\mathrm{star+wind}}}{F_{\lambda,\mathrm{star}}}$$

$$\frac{F_{\lambda,\mathrm{wind}}}{F_{\lambda,\mathrm{star}}} = 1.1 \approx \frac{B_{\lambda,\mathrm{wind}}(T_{\mathrm{wind}})}{B_{\lambda,\mathrm{star}}(T_{\mathrm{star}})} \approx 1$$

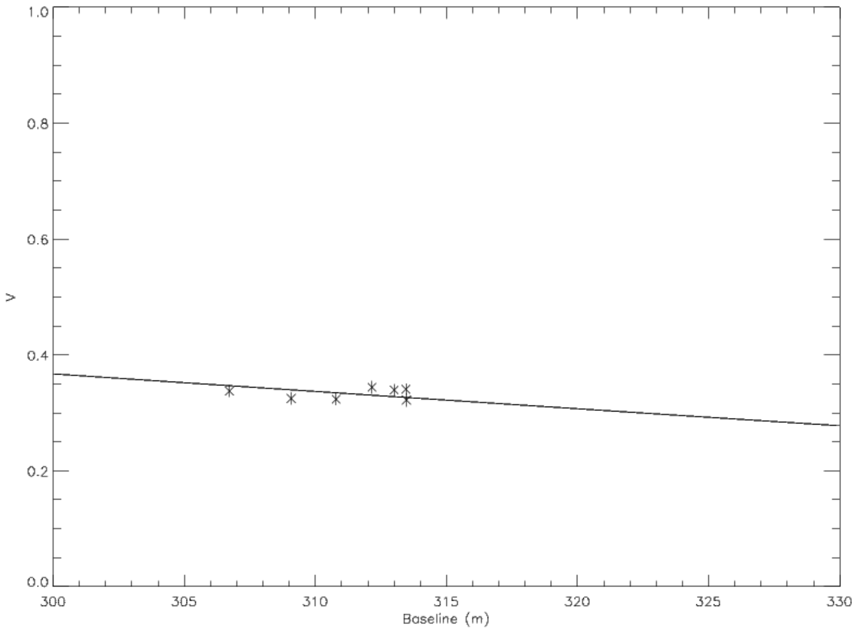
κ Orionis

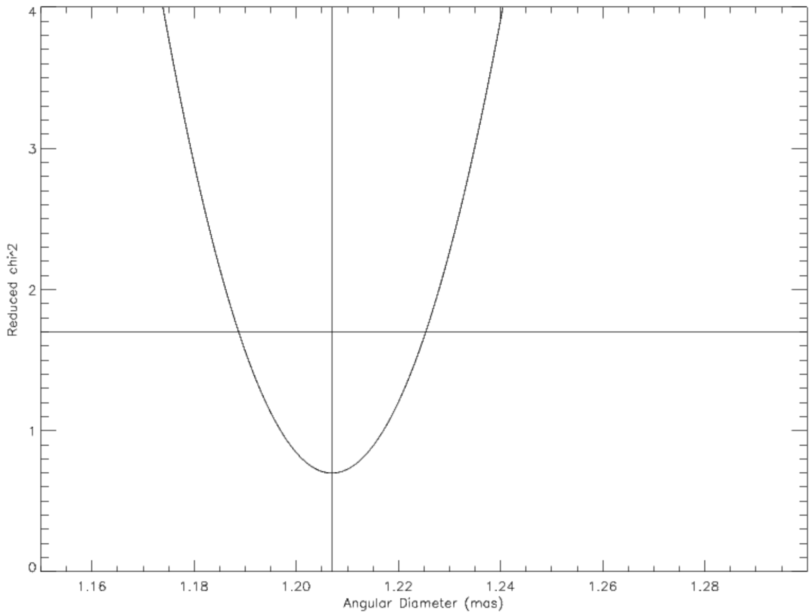
- V= 2.04
- T_{eff} = 26000±1000
- $\log(L/L_{\odot})$=5.48±0.14
- B0.5Ia
- $M \sim 33 M_{\odot}$
- $R \sim 27 R_{\odot}$
- $\dot{M} = 1.2 \times 10^{-6} M_{\odot}/yr$

Searle et al. (2008)

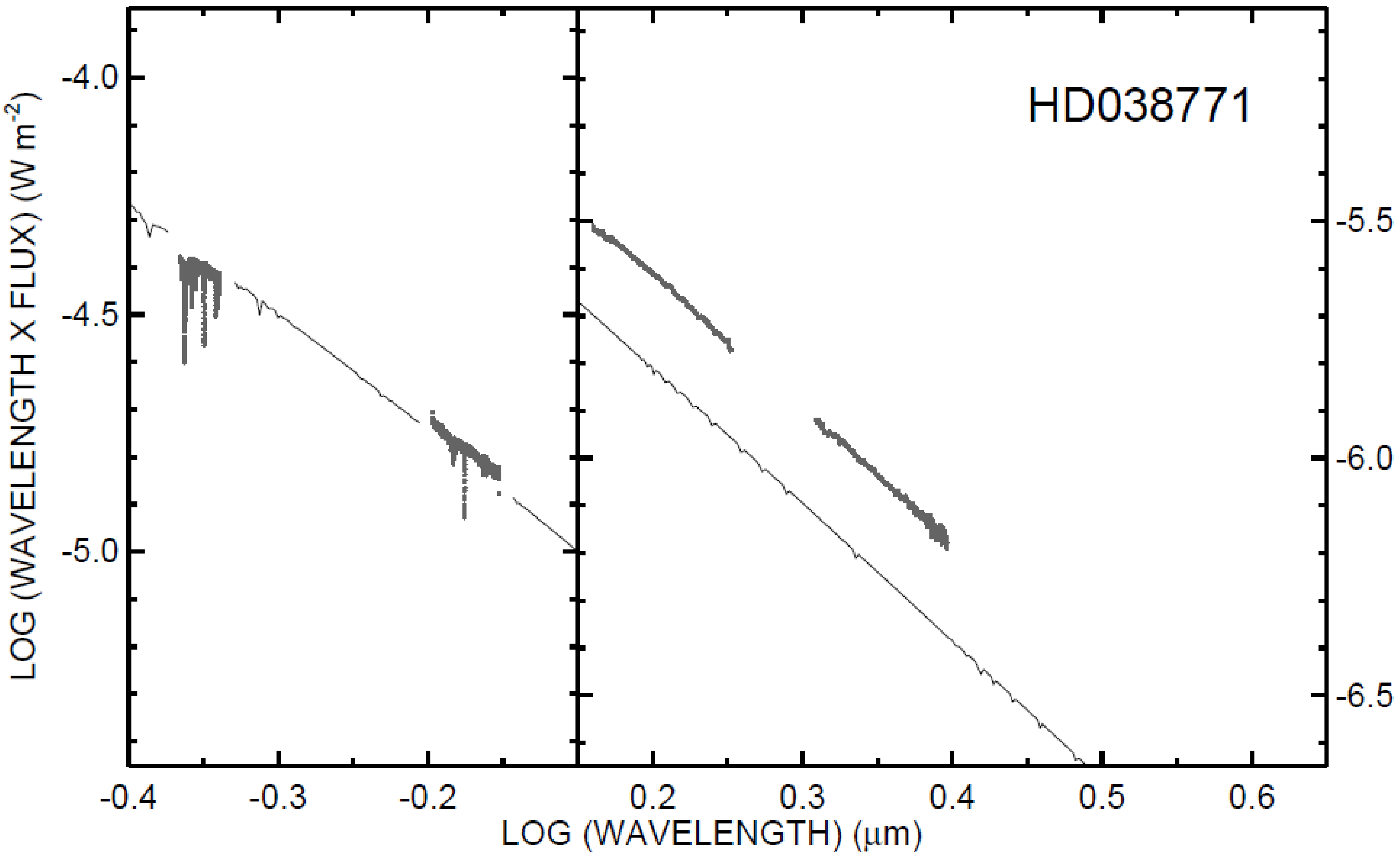
Classic Observations

- Data from 2009 (E1-W1)
- K’ diameter: 1.207±0.018 mas





Optical and NIR SED



Touhami, Richardson, et al. (in press)

Parameters from the Different Diameters of κ Ori

4430 Angstroms	PAVO	Classic (2.15 microns)
0.45±0.03 mas	(not finished)	1.207±0.018 mas

From the SED, κ Ori has a K' excess of 0.2 dex, meaning

$$\frac{L_{\lambda,\mathrm{star+wind}}}{L_{\lambda,\mathrm{star}}} \approx 1.5$$

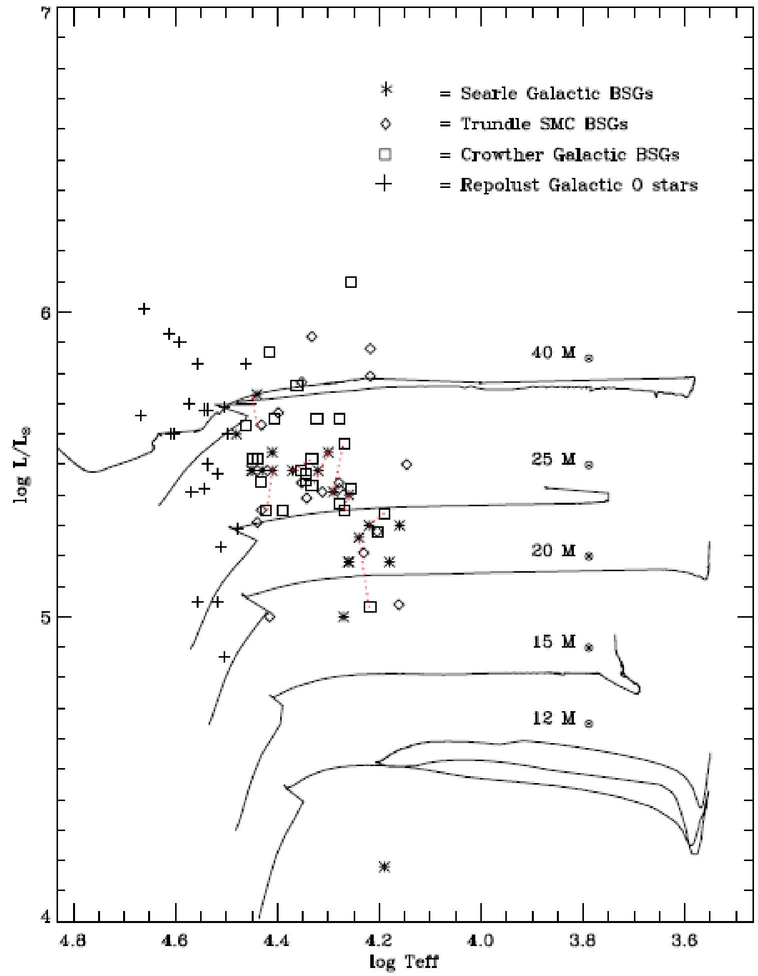
$$F_\lambda \approx (\mathrm{SurfaceArea}) \times F_\lambda(K'{-}\mathrm{band}, T)$$

$$1.5 \approx \frac{(\theta_{K'}}{\theta_{\mathrm{star}})^2} \times \frac{F_{\lambda,\mathrm{star+wind}}}{F_{\lambda,\mathrm{star}}}$$

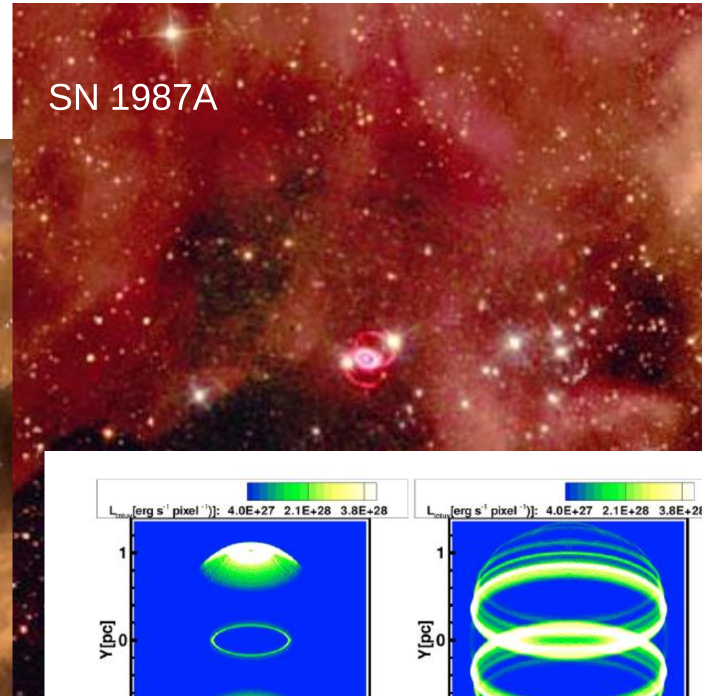
$$\frac{F_{\lambda,\mathrm{wind}}}{F_{\lambda,\mathrm{star}}} = 0.22 \approx \frac{B_{\lambda,\mathrm{wind}}(T_{\mathrm{wind}})}{B_{\lambda,\mathrm{star}}(T_{\mathrm{star}})}$$

κ Ori possibilities

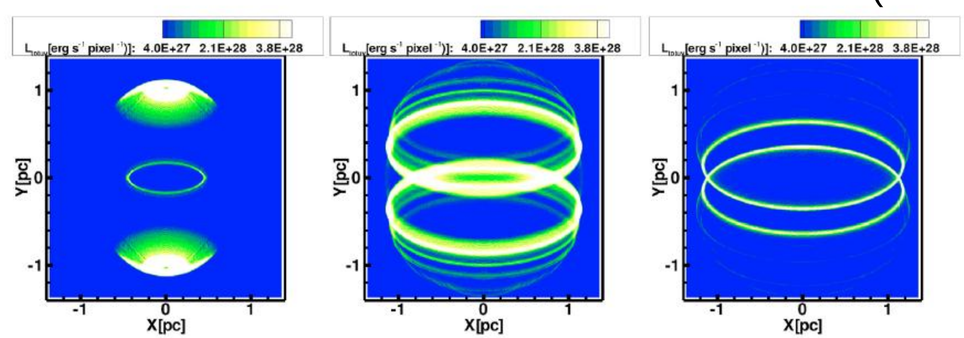
- Bad data in K'-band
  - Only one night of good data collected thus far
- Binary
  - Why wasn't it picked up by Narrabri?
- Evolution
  - RSG shell and evolution back to BSG (like SN 1987A) (note that this star is slightly more enriched than ε Ori) or BSG nebula



Is this the beginning of a blue supergiant nebula?



Chita et al. (2008)



- I need clear nights for this!

Future directions/needs

- More Classic data, for κ Ori as well as more to confirm nature of ε Ori (winter); also analyze ζ Ori in same way (but ζ Ori is a binary)
- Reduction of PAVO data (after workshop tomorrow morning)
  - Finish this project on mass-loss (possible paper this year).
  - Fundamental properties of normal hot stars with PAVO
  - β Cephei pulsations (PAVO diameters, echelle spectroscopy, and photoelectric photometry all simultaneous, paper this winter?)
  - These data are collected, plus some more to be collected this year.