2011 UCAT Summer Student Program (USSP 2011)

Freshly Condensed Grains in the Dusty Disks of Evolved Main Sequence Be Stars

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Be star comparisons

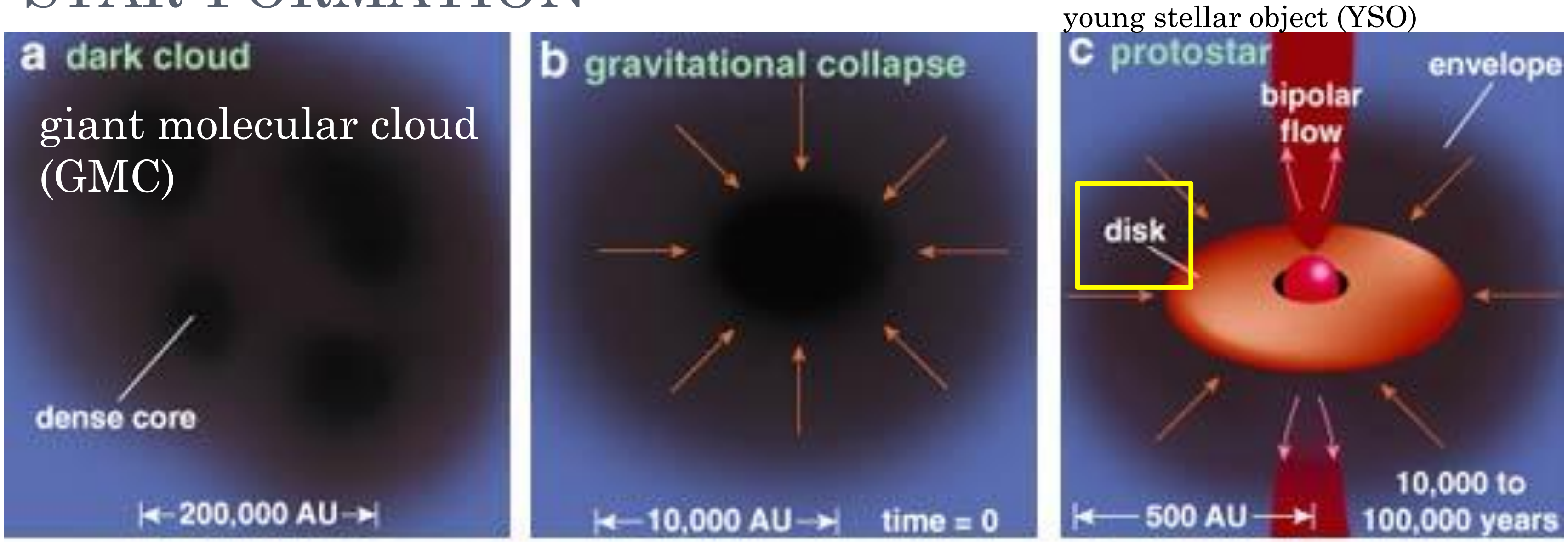
Herbig Ae/Be stars vs. Classical Ae/Be stars

Herbig Ae/Be stars	classical Ae/Be stars
pre–main sequence stars	evolved main sequence stars
in star forming regions	not in star forming regions

Outline

- star formation
- pre-main sequence star comparisons
- Beckwith's model
- HD 259431 introduction
- estimation of disk mass – Beckwith
- estimation of disk mass – SED
- estimation of disk mass – T Tauri vs. Be stars
- discussion and conclusion

STAR FORMATION



Greene, T., "Protostars", 2001, American Scientist, Vol.89, No.4

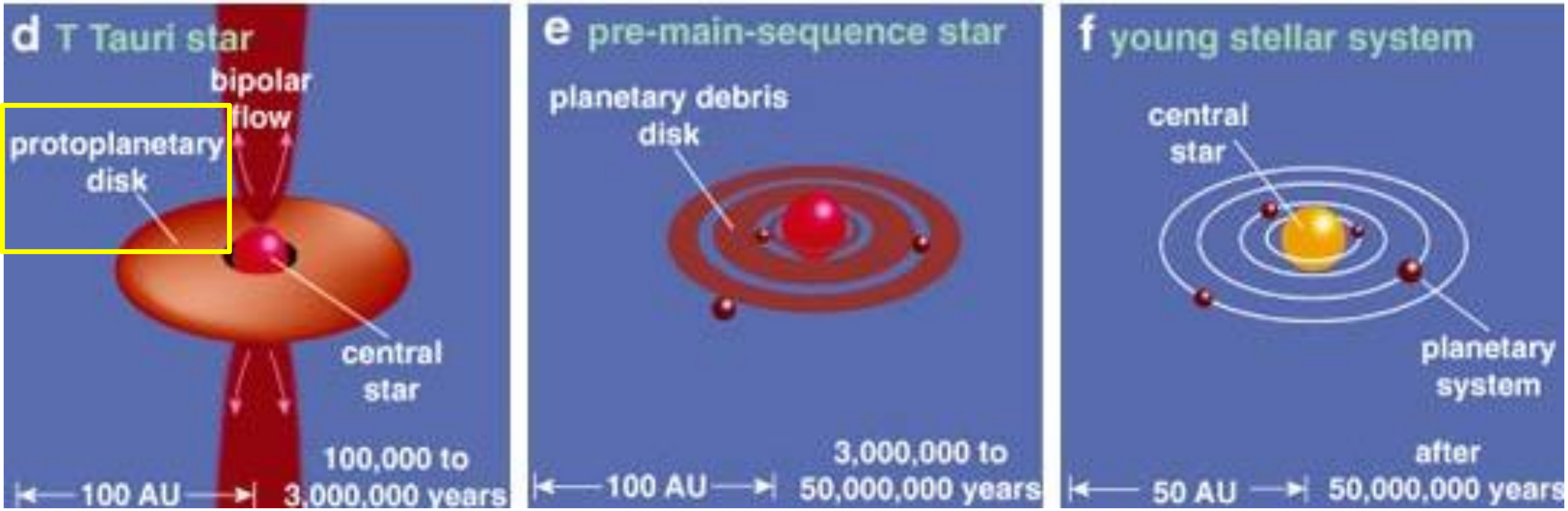
a) Star formation begins inside dark interstellar clouds containing high-density regions that become gravitationally unstable and collapse under their own weight

b) The collapsing core forms a protostar

c) a phase of stellar evolution defined by the rapid accumulation of mass from a circumstellar disk and a surrounding envelope of gas and dust. As the dusty envelope dissipates, the object becomes visible at optical wavelengths for the first time as a T Tauri star

STAR FORMATION

young stellar object (YSO)



Greene, T., "Protostars", 2001, American Scientist, Vol.89, No.4

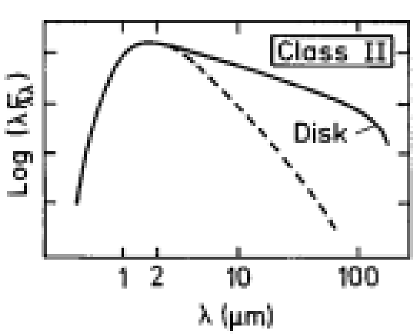
d) These objects can often be recognized in telescopic images by the presence of a protoplanetary disk. After a few million years the dusty disk dissipates, leaving a bare pre-main-sequence star at its center

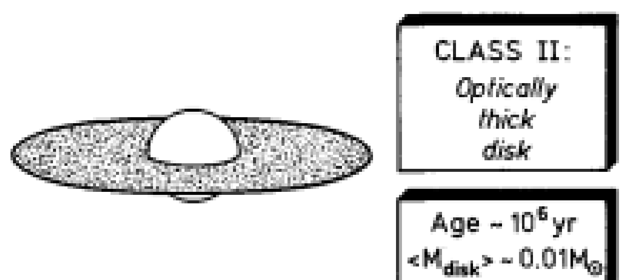
e) In some instances, a debris disk with newly formed planets may continue to orbit the star. The star continues its gravitational collapse to the point where its core temperature becomes hot enough for nuclear fusion, and the object becomes a main-sequence star

PRE-MAIN SEQUENCE STAR COMPARISONS

T Tauri stars vs. Herbig Ae/Be stars

T Tauri stars	Herbig Ae/Be stars
pre–main sequence stars	
variable stars	
<2 Solar masses	2-8 Solar masses
F, G, K, M spectral type	spectral type earlier than F0





類日恆星誕生過程，《時空》第三十一期

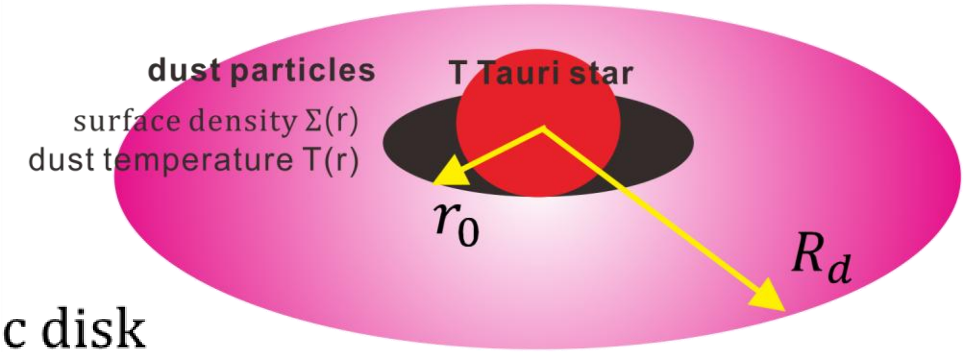
Be star comparisons

Herbig Ae/Be stars vs. Classical Ae/Be stars

Herbig Ae/Be stars	classical Ae/Be stars
pre–main sequence stars	evolved main sequence stars
infrared radiation excess due to circumstellar dust	infrared excess due to free-free emission
in star forming regions	not in star forming regions
	fast rotation
spectral type earlier than F0	
Balmer emission lines	

BECKWITH'S MODEL

Beckwith *et al.*, 1990



- spatially thin, axisymmetric disk
- disk

$$T(r) = T_0\left(\frac{r}{r_0}\right)^{-q}, \Sigma(r) = \Sigma_0\left(\frac{r}{r_0}\right)^{-p}$$

- $L_\lambda = 4\pi\delta A B_\lambda(T)(1 - e^{-\tau_\lambda})$

L_λ: luminosity density, F_λ: flux density

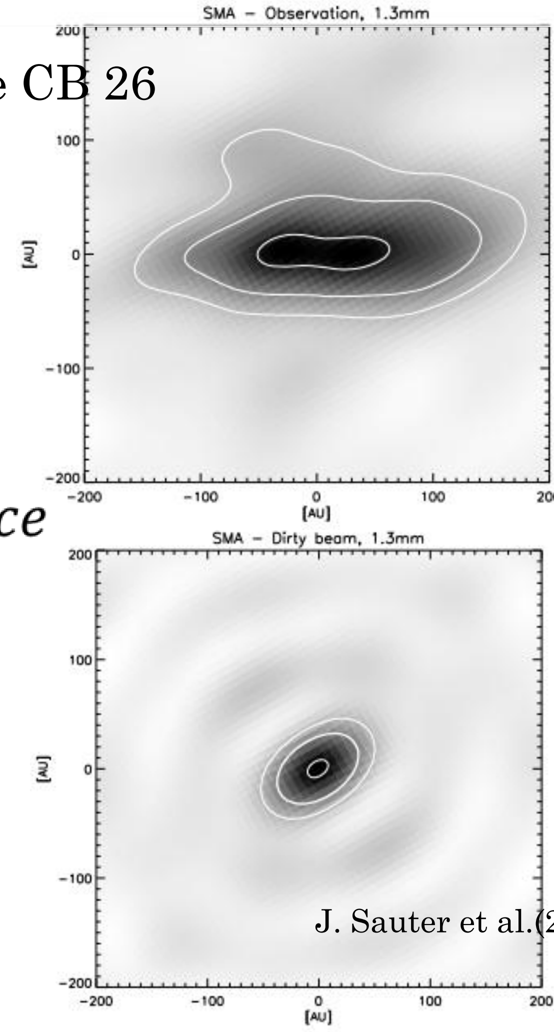
δA: projected area, $B_\lambda(T)$: Planck function

- $L_\lambda \equiv 4\pi d^2 F_\lambda,\ \ d: distance\ from\ the\ source$

$$F_\lambda = \frac{\delta A}{4\pi d^2} \cdot 4\pi B_\lambda(T)\tau_\lambda$$

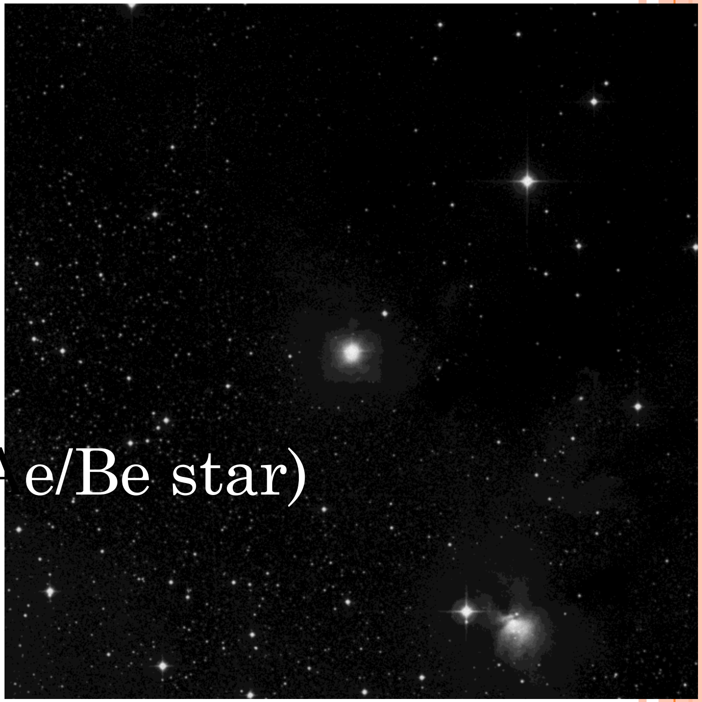
- $\tau_\lambda: optical\ depth, \tau_\lambda = \kappa_\lambda \Sigma \approx \kappa_\lambda \cdot \frac{M}{\delta A}$
- $M = \frac{F_\lambda d^2}{\kappa_\lambda B_\lambda(T)}$, 1.3mm

Bok globule CB 26



J. Sauter et al.(2009)

INTRODUCE HD 259431



- HD 259431

variable star of Orion Type (Herbig Ae/Be star)

may be a classical Be star

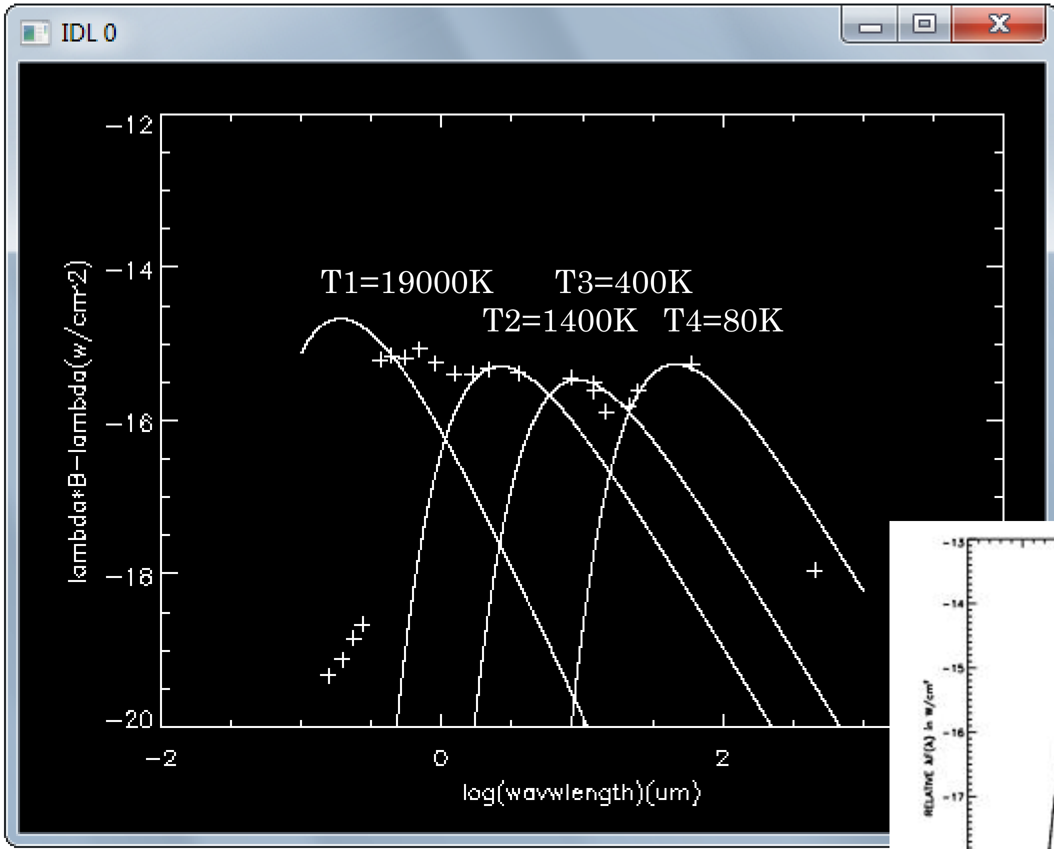
spectral type: B3 (Swings & Struve, 1943)

distance: 800pc

star	RA(2000)			Dec(2000)			SpT	V	J-H	H-K
	h	m	s	°	′	″		mag.	mag.	mag.
HD 259431	06	33	05.20	+10	19	19.9	B6	8.71	0.788	0.940

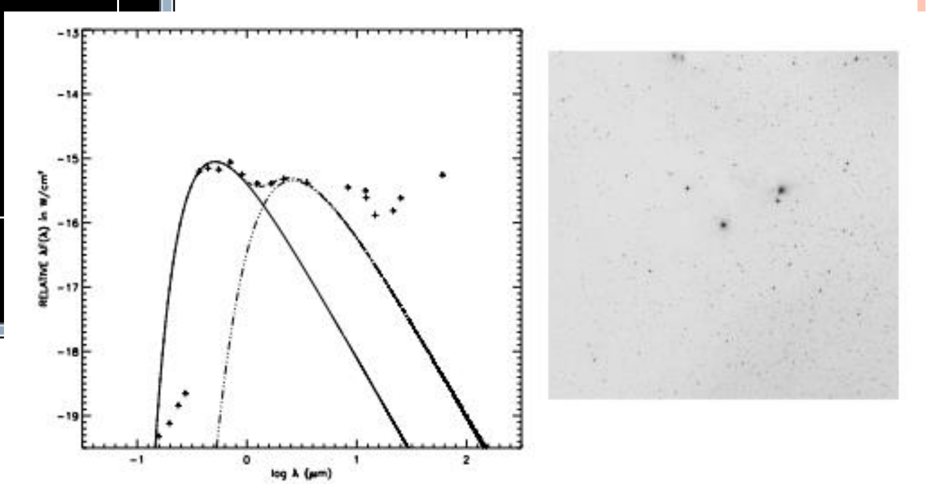
Near-Infrared Excess of Classical Be stars, 李建德(2009)

ESTIMATION OF DISK MASS



B3 star, Teff=19000K

(Swings & Struve, 1943)



Near-Infrared Excess of Classical Be stars, 李建德(2009)

ESTIMATION OF DISK MASS – BECKWITH

- flux density in 1.3mm(use blackbody, T4=80K)

when $\lambda = 1300\mu m$, $\lambda F_\lambda = 2.81 \times 10^{-19}\, {}^{W}/_{cm^2}$

$F_\lambda = 2.16 \times 10^{-18}\, {}^{W}/_{cm^3}$

$d = 800 \times 3.0857 \times 10^{16} \times 10^2 = 2.47 \times 10^{21} cm$

$B_\lambda(80) = 2.16 \times 10^{-7}\, {}^{W}/_{cm^3}$

$$M_d = \frac{F_\lambda \times d^2}{\kappa_\lambda \times B_\lambda(T)} = 6.09 \times 10^{28} \times {\kappa_\lambda}^{-1}$$

- $\kappa_\lambda = \kappa_0 \, (\frac{\lambda_0}{\lambda})^\beta$, while $\lambda_0 = 0.25mm, \kappa_0 = 0.1\, {}^{cm^2}/_{g}$ (Hildebrand, 1983)
- then get $\kappa_\lambda = 0.019\, {}^{cm^2}/_{g}$,

$and\ M_d = 3.21 \times 10^{33} g = 1.61 M_\odot$

ESTIMATION OF DUST MASS – T TAURI VS. BE STARS

- **T Tau**

distance: 140pc
flux density: 280mJy
M_d: $0.016 M_{\odot}$

- **HD 259431**

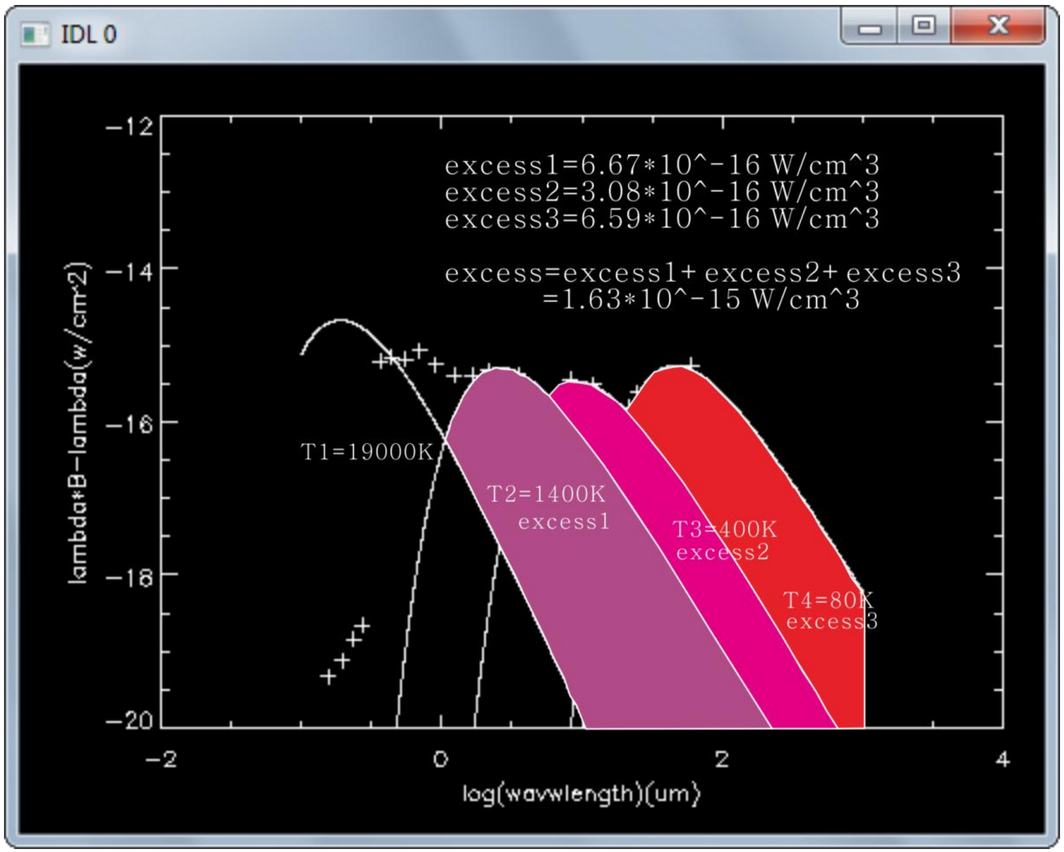
distance: 800pc
flux density: $2.16 \times 10^{-18}\, {}^{W}/_{cm^3} = 1210 mJy$
M_d: $1.61 M_{\odot}$

- use $\boldsymbol{M} = \frac{\boldsymbol{F_\lambda} \times \boldsymbol{d^2}}{\boldsymbol{\kappa_\lambda} \times \boldsymbol{B_\lambda(T)}}$

$$left = \frac{M_{d,HD\ 259431}}{M_{d,T\ Tau}} = 100.50$$

$$right = \frac{1210}{280} \times \left(\frac{800}{140}\right)^2 = 141.11$$

ESTIMATION OF DISK MASS – SED




```
主控台
% Compiled module: $MAIN$.
excess1=   6.6684123e-016
excess2=   3.0771061e-016
excess3=   6.5871561e-016
excess=  1.6332675e-015
```

T2=1400K	purple	1400K particles
T3=400K	pink	400K particles
T4=80K	red	80K particles

ESTIMATION OF DISK MASS – SED

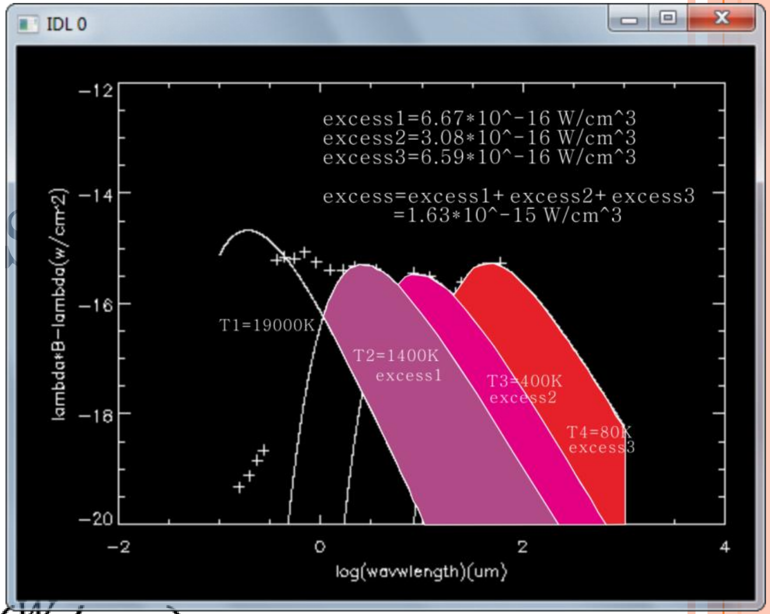
- assume dust particles are silicate, a perfect sphere and an ideal black body
- radius: $r_s = 0.1\mu m$, volume: $V_s = 4.19 \times 10^{-21} (m^3)$

density: $d_s = 2\, {}^{g}/_{cm^3} (2000\, {}^{kg}/_{m^3})$,

temperature: 80K(excess3), 400K(excess2), 1400K(excess1)

distance: d=800pc=$2.47 \times 10^{19} m$ Brian Donehew and Sean Brittain(2011)

ESTIMATION OF DISK MASS –



- one particle:

$$L=4\pi r_s^2\sigma T_e{}^4,\ F_\lambda = \frac{L}{4\pi d^2}$$

80K, $L=2.92\times10^{-13}(W)$,
$F_\lambda = 3.80\times10^{-53}\left({}^{W}/_{m^2}\right)=3.80\times10^{-57}\left({}^{W}/_{cm^2}\right)$
400K, $L=1.82\times10^{-10}(W)$,
$F_\lambda = 2.37\times10^{-50}\left({}^{W}/_{m^2}\right)=2.37\times10^{-54}\left({}^{W}/_{cm^2}\right)$
1400K, $L=2.74\times10^{-8}(W)$,
$F_\lambda = 3.57\times10^{-48}\left({}^{W}/_{m^2}\right)=3.57\times10^{-52}\left({}^{W}/_{cm^2}\right)$

- we have

excess3(80K) $F_\lambda = 6.59\times10^{-16}\left({}^{W}/_{cm^2}\right)$
excess2(400K) $F_\lambda = 3.08\times10^{-16}\left({}^{W}/_{cm^2}\right)$
excess1(1400K) $F_\lambda = 6.67\times10^{-16}\left({}^{W}/_{cm^2}\right)$

- the particle number may be

$N_3 = 1.73 \times 10^{41}$

$N_2 = 1.30 \times 10^{38}$

$N_1 = 1.87 \times 10^{36}$

$N_t = N_1 + N_2 + N_3 = 1.73 \times 10^{41}$

- total mass of dust should be

$M = N \times V_s \times d_s = 1.45 \times 10^{27}(g)$

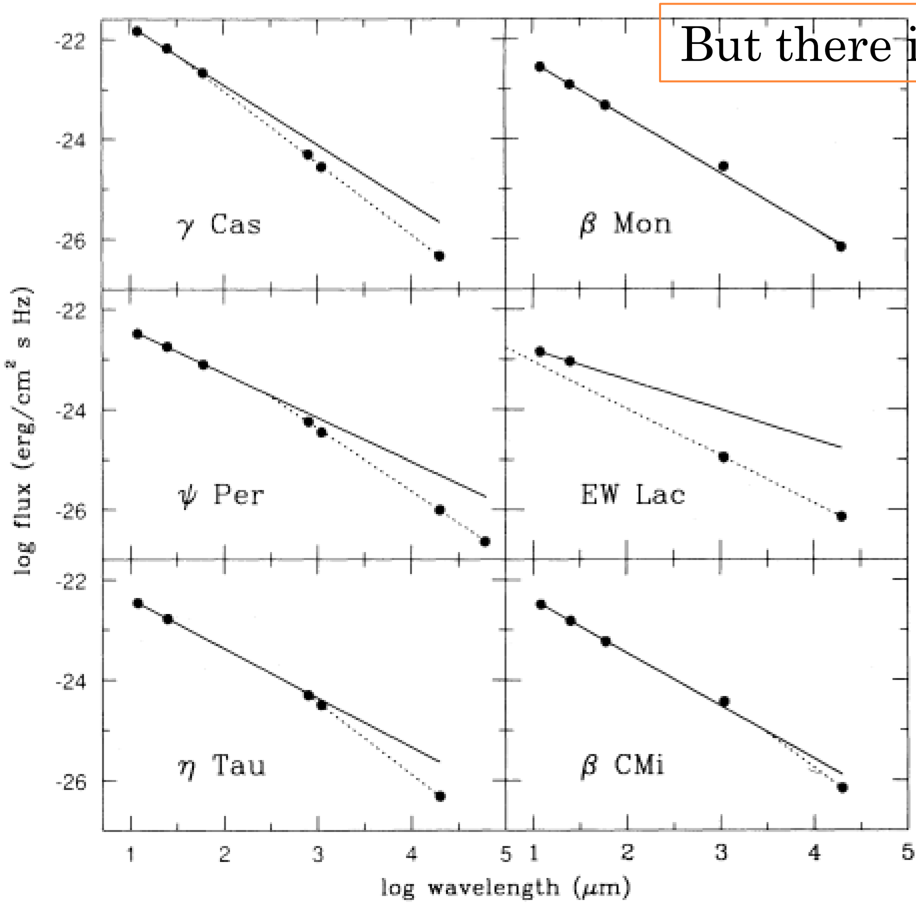
- typical ISM, gas to dust ratio is 100,

$M_d = 1.45 \times 10^{29}(g) = 7.29 \times 10^{-5}\ M_{\odot}$

DISCUSSION

- Beckwith model vs. SED

But there is turn over must be considered…



L.B.F.M Waters et al., 1991

DISCUSSION

- T Tau(T Tauri) $M_* = 1.91 M_\odot$ $M_d = 0.016 M_\odot$

  HD 259431(Be star) $M_* = 6.4 M_\odot$ $M_d = 7.29 \times 10^{-5}\ M_\odot$
- typical ISM: $M_{gas} \approx 100 M_{dust}$

Be stars was thought to have lower mass of disk because it is hotter

CONCLUSION

- opacity, κ_λ
- use a T Tauri star model
- use SED
- submillimeter and millimeter observation is a tool needed

ALMA!

Thanks for your listening!

- κ_λ: opacity, $\kappa_\lambda = \kappa_0 \left(\frac{\lambda_0}{\lambda}\right)^\beta$

$0.002\ to\ 0.10\ cm^2 g^{-1}$(Draine, 1989)

in $30\mu m$, can be determined, but in long wavelengths…

shape, fractal dimentions

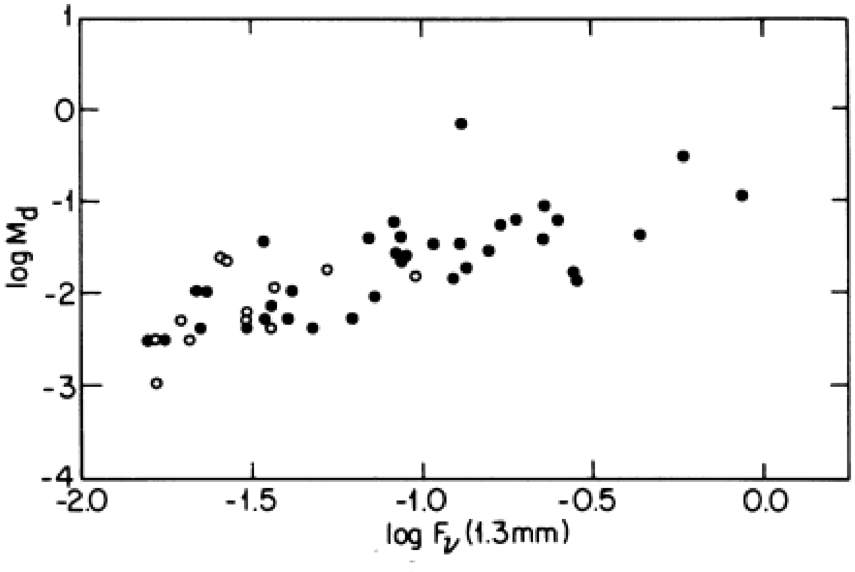


FIG. 5. Logarithm of derived disk mass M_d vs the 1.3 mm flux density F_ν shows the correlation of F_ν with total amount of emitting material; the scatter indicates variation in the disk temperatures that must be taken into account for an accurate derivation of M_d.

Beckwith *et al.*, 1990

ESTIMATION OF DISK MASS – SED

- assume dust particles are silicate, a perfect sphere and an ideal black body
- radius: $r_s = 0.1\mu m$, volume: $V_s = 4.1888 \times 10^{-21}(m^3)$

  density: $d_s = 2\, {}^{g}/_{cm^3}(2000\, {}^{kg}/_{m^3})$,

  temperature: 400K~1400K, 400K in average,

  distance: d=800pc

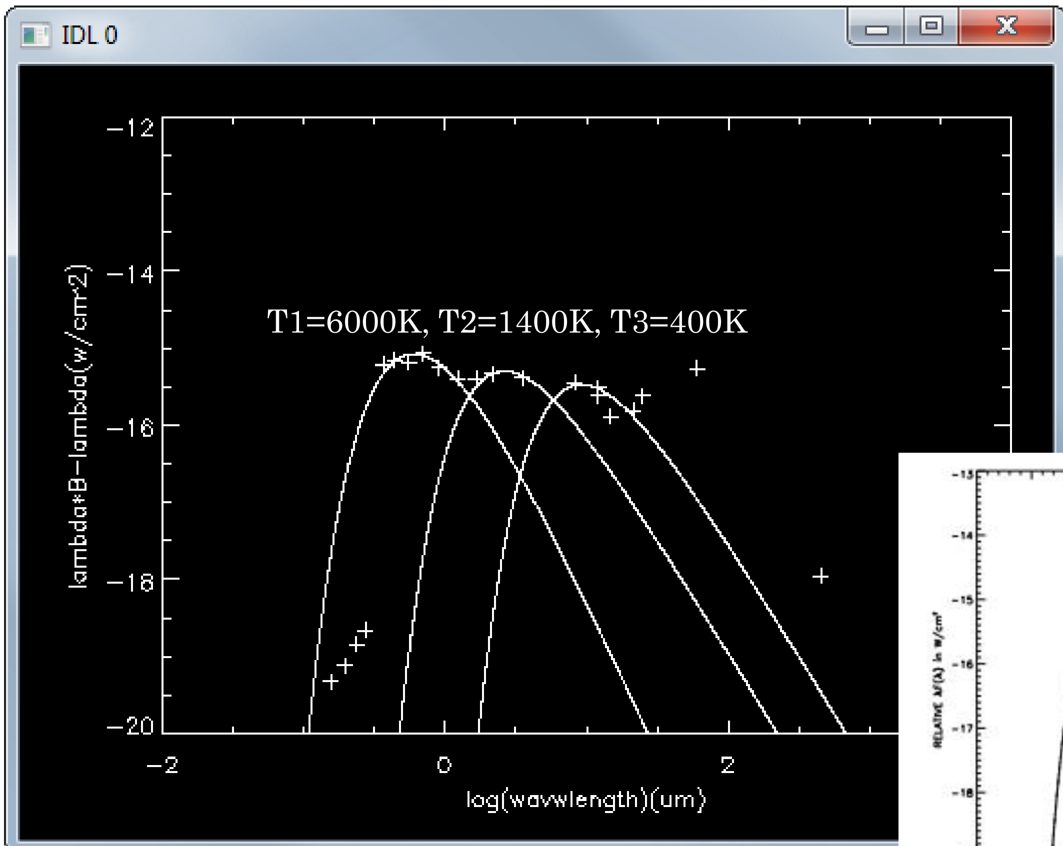
  Brian Donehew and Sean Brittain(2011)
- one particle:

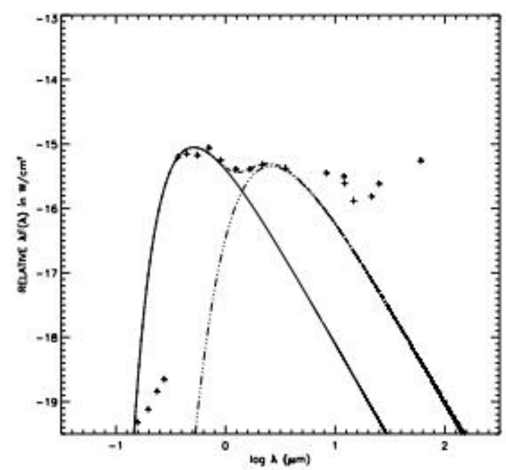
  $L = 4\pi r_s^2 \sigma {T_e}^4 = 4.6751 \times 10^{-9}(W)$

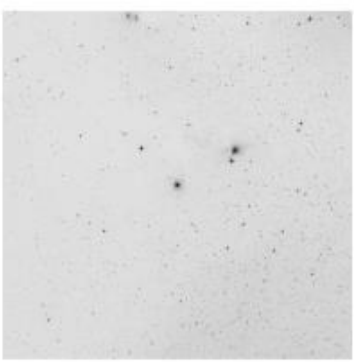
  $F_\lambda = \frac{L}{4\pi d^2} = 6.1052 \times 10^{-49}\left({}^{W}/_{m^2}\right) = 6.1052 \times 10^{-53}({}^{W}/_{cm^2})$

- we have total $F_\lambda = 8.5724 \times 10^{-16}\left({}^{W}/_{cm^2}\right)$
- the particle number may be $N = 1.4041 \times 10^{37}$
- total mass of dust should be $M = N \times V_s \times d_s = 1.1763 \times 10^{23}(g)$
- typical ISM, gas to dust ratio is 100, $M_d = 1.1763 \times 10^{25}(g)$

ESTIMATION OF DISK MASS







Near-Infrared Excess of Classical Be stars, 李建德(2009)

Estimation of Disk Mass – Beckwith

- flux density in 1.3mm(use blackbody(T=400K))

$$\text{when } \lambda = 1300\mu m, \lambda F_\lambda = 4.0634 \times 10^{-23}\, {}^{W}/_{cm^2}$$

$$F_\lambda = 3.1257 \times 10^{-22}\, {}^{W}/_{cm^3}$$

$$d = 800 \times 3.0857 \times 10^{16} \times 10^2 = 2.4686 \times 10^{21} cm$$

$$B_\lambda(400) = 3.1260 \times 10^{-8}\, {}^{W}/_{cm^3}$$

$$M_d = \frac{F_\lambda \times d^2}{\kappa_\lambda \times B_\lambda(T)} = 6.0934 \times 10^{28} \times \kappa_\lambda{}^{-1}$$

- $\kappa_\lambda = \kappa_0\, (\frac{\lambda_0}{\lambda})^\beta$, while $\lambda_0 = 0.25mm, \kappa_0 = 0.1\, {}^{cm^2}/_{g}$ (Hildebrand, 1983)
- then get $\kappa_\lambda = 0.019\, {}^{cm^2}/_{g}, and\ M_d = 3.2071 \times 10^{30} g$

ESTIMATION OF DUST MASS – T TAURI VS. BE STARS

- **T Tau**

distance: 140pc
flux density: 280mJy
M_d: $0.016 M_\odot$

- **HD 259431**

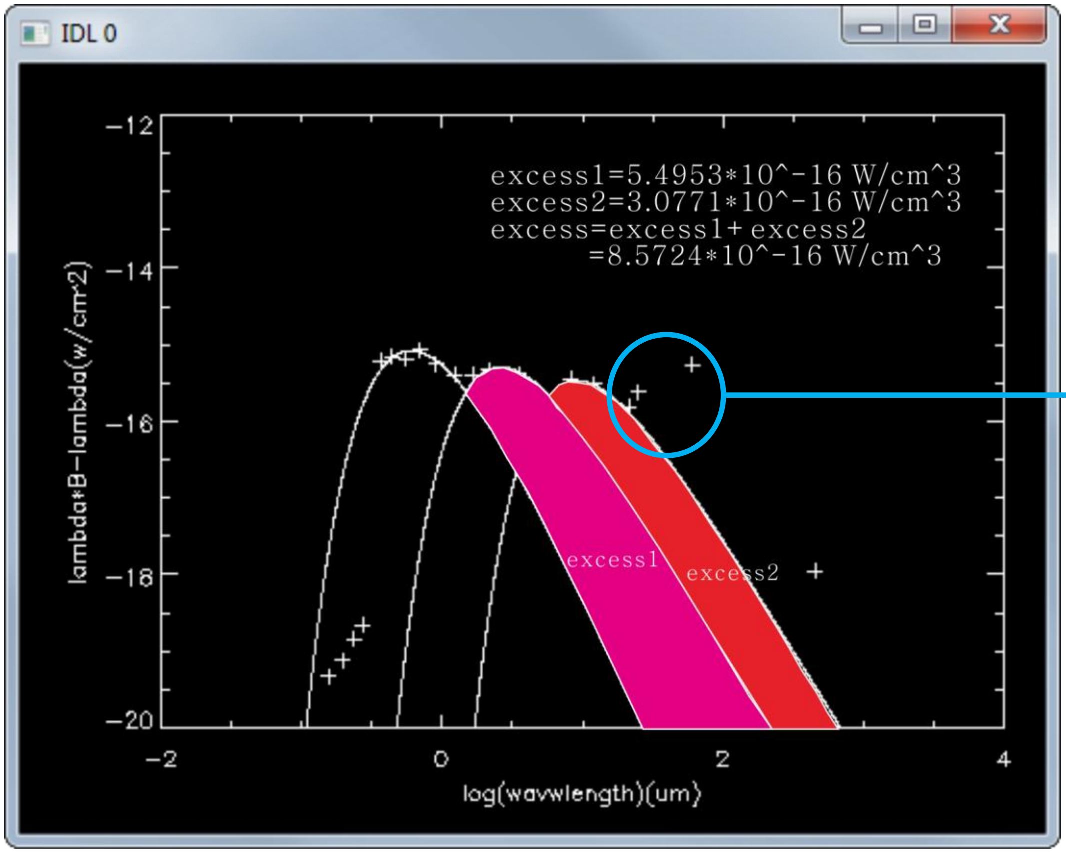
distance: 800pc
flux density: $3.1257 \times 10^{-22} \, {}^{W}/_{cm^3} = 0.17608 mJy$
M_d: $0.0016 M_\odot$

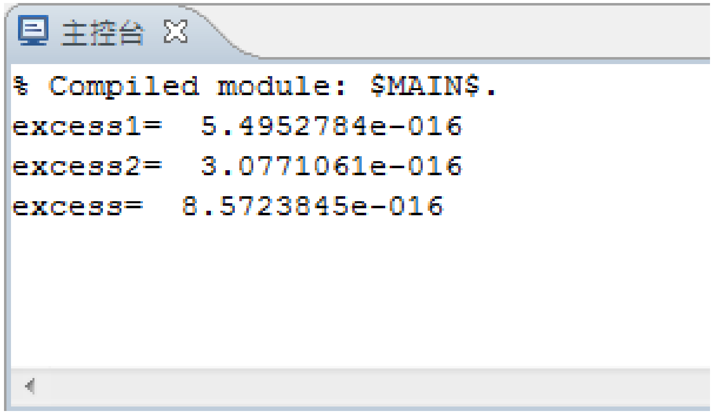
- use $\boldsymbol{M} = \frac{\boldsymbol{F_\lambda} \times \boldsymbol{d^2}}{\boldsymbol{\kappa_\lambda} \times \boldsymbol{B_\lambda}(\boldsymbol{T})}$

$$left = \frac{M_{d,HD\,259431}}{M_{d,T\,Tau}} = 0.1$$

$$right = \frac{0.17608}{280} \times (\frac{800}{140})^2 = 0.021$$

ESTIMATION OF DISK MASS – SED





There is not enough points to find another blackbody, indicating there is more IR excess. The disk mass estimated below is only the minimum

ESTIMATION OF DISK MASS – SED

- assume dust particles are silicate, a perfect sphere and an ideal black body
- radius: $r_s = 0.1\mu m$, volume: $V_s = 4.1888 \times 10^{-21}(m^3)$

  density: $d_s = 2\,{}^{g}/_{cm^3}(2000\,{}^{kg}/_{m^3})$,

  temperature: 400K~1400K, 900K in average,

  distance: d=800pc

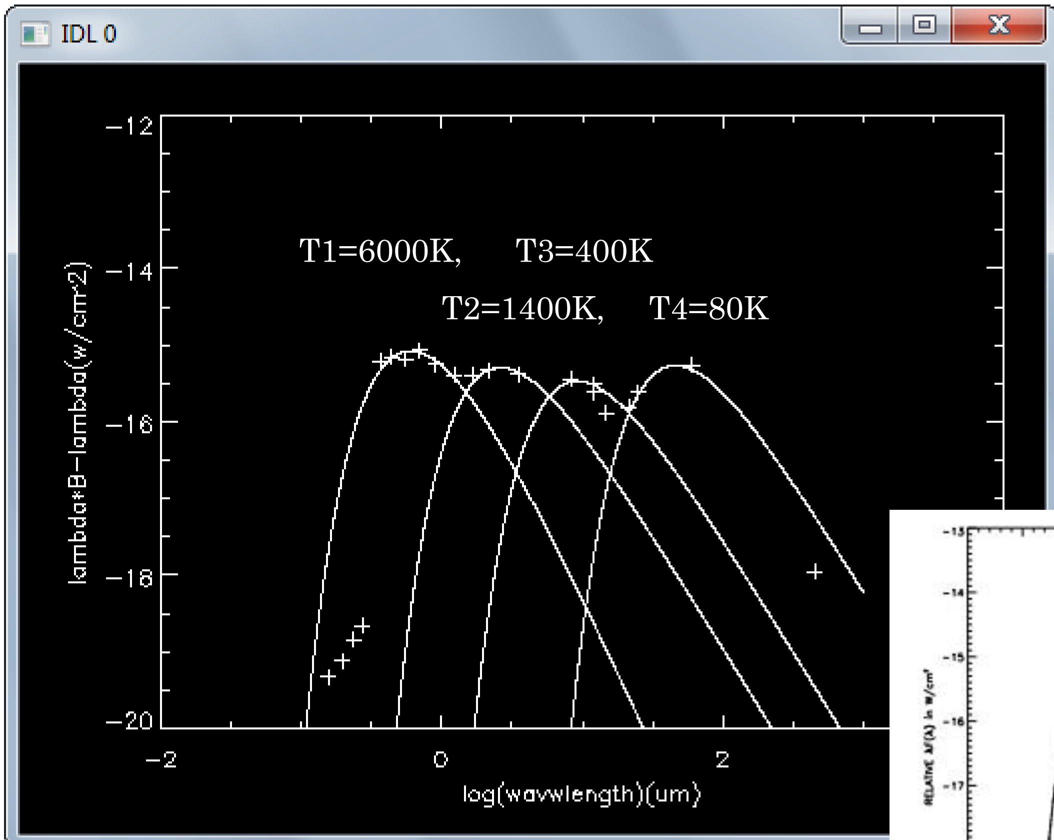
  Brian Donehew and Sean Brittain(2011)
- one particle:

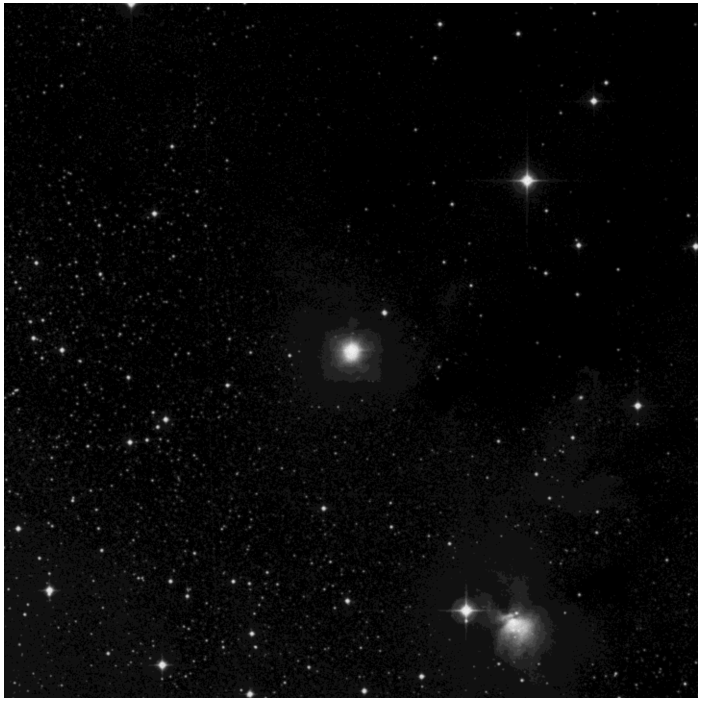
  L=$4\pi r_s^2 \sigma {T_e}^4 = 4.6751 \times 10^{-9}(W)$

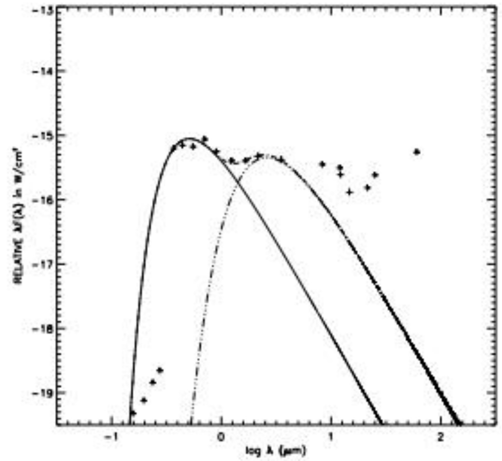
  $$F_\lambda = \frac{L}{4\pi d^2} = 6.1052 \times 10^{-49}\left({}^{W}/_{m^2}\right) = 6.1052 \times 10^{-53}({}^{W}/_{cm^2})$$

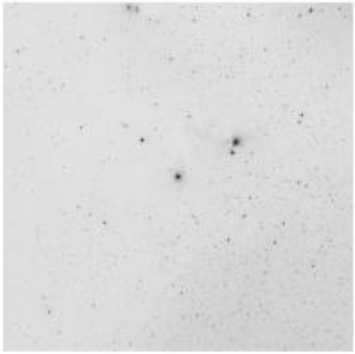
- we have total $F_\lambda = 8.5724 \times 10^{-16}\left({}^{W}/_{cm^2}\right)$
- the particle number may be $N = 1.4041 \times 10^{37}$
- total mass of dust should be $M = N \times V_s \times d_s = 1.1763 \times 10^{23}(g)$
- typical ISM, gas to dust ratio is 100, $M_d = 1.1763 \times 10^{25}(g)$

ESTIMATION OF DISK MASS









Near-Infrared Excess of Classical Be stars, 李建德(2009)

Estimation of Disk Mass – Beckwith

- flux density in 1.3mm(use blackbody(T=400K))

  when $\lambda = 1300\mu m$, $\lambda F_{\lambda} = 2.8119 \times 10^{-19}\, {}^{W}\!/_{cm^2}$

  $F_{\lambda} = 2.1632 \times 10^{-18}\, {}^{W}\!/_{cm^3}$

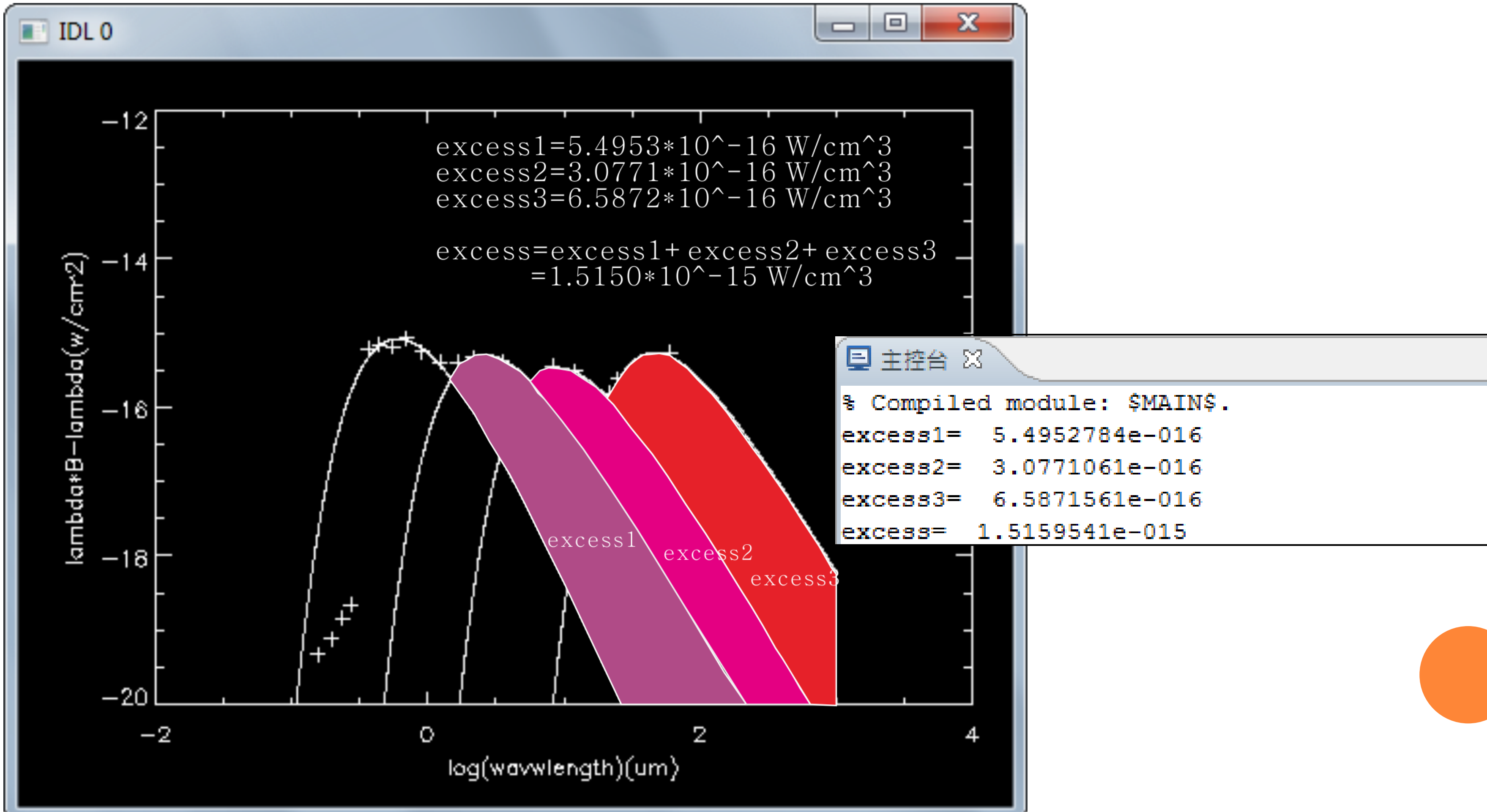
  $d = 800 \times 3.0857 \times 10^{16} \times 10^{2} = 2.4686 \times 10^{21} cm$

  $B_{\lambda}(80) = 2.1634 \times 10^{-7}\, {}^{W}\!/_{cm^3}$

  $$M_d = \frac{F_{\lambda} \times d^2}{\kappa_{\lambda} \times B_{\lambda}(T)} = 6.0934 \times 10^{28} \times {\kappa_{\lambda}}^{-1}$$

- $\kappa_{\lambda} = \kappa_0 \left(\frac{\lambda_0}{\lambda}\right)^{\beta}$, while $\lambda_0 = 0.25mm, \kappa_0 = 0.1\, {}^{cm^2}\!/_{g}$ (Hildebrand, 1983)
- then get $\kappa_{\lambda} = 0.019\, {}^{cm^2}\!/_{g}$, *and* $M_d = 3.2071 \times 10^{33} g$

ESTIMATION OF DISK MASS – SED



ESTIMATION OF DISK MASS – SED

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  density: $d_s = 2\, {}^{g}/_{cm^3} (2000\, {}^{kg}/_{m^3})$,

  temperature: 80K~1400K, 740K in average,

  distance: d=800pc   Brian Donehew and Sean Brittain(2011)
- one particle:

  $L = 4\pi r_s^2 \sigma T_e{}^4 = 2.1367 \times 10^{-9}(W)$

  $$F_\lambda = \frac{L}{4\pi d^2} = 2.7903 \times 10^{-49}\left({}^{W}/_{m^2}\right) = 2.7903 \times 10^{-53}({}^{W}/_{cm^2})$$

- we have total $F_\lambda = 1.5160 \times 10^{-15}\left({}^{W}/_{cm^2}\right)$
- the particle number may be $N = 5.4331 \times 10^{37}$
- total mass of dust should be $M = N \times V_s \times d_s = 4.5516 \times 10^{23}(g)$
- typical ISM, dust to gas ratio is 100, $M_d = 4.5516 \times 10^{25}(g)$