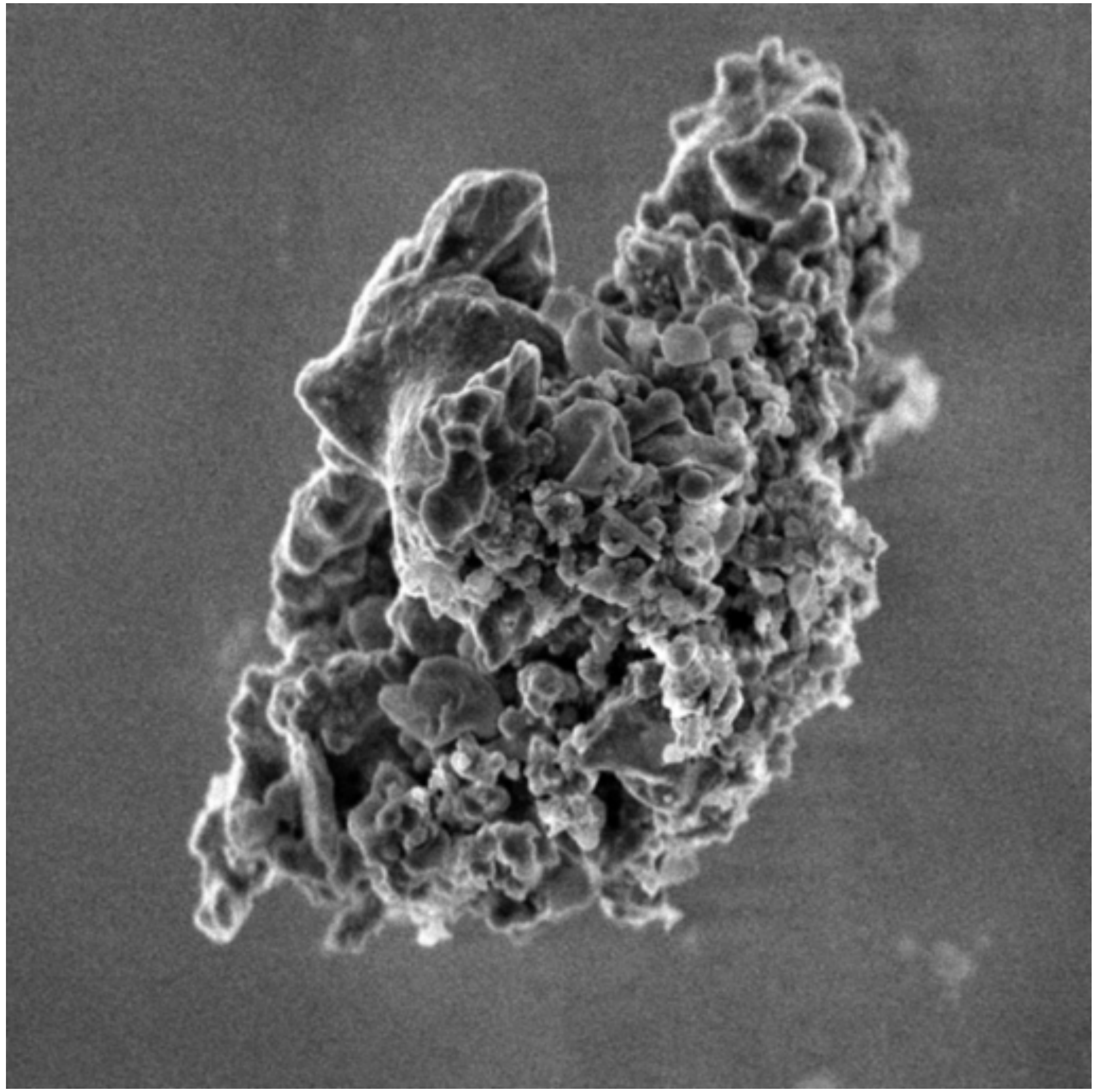


Prašina

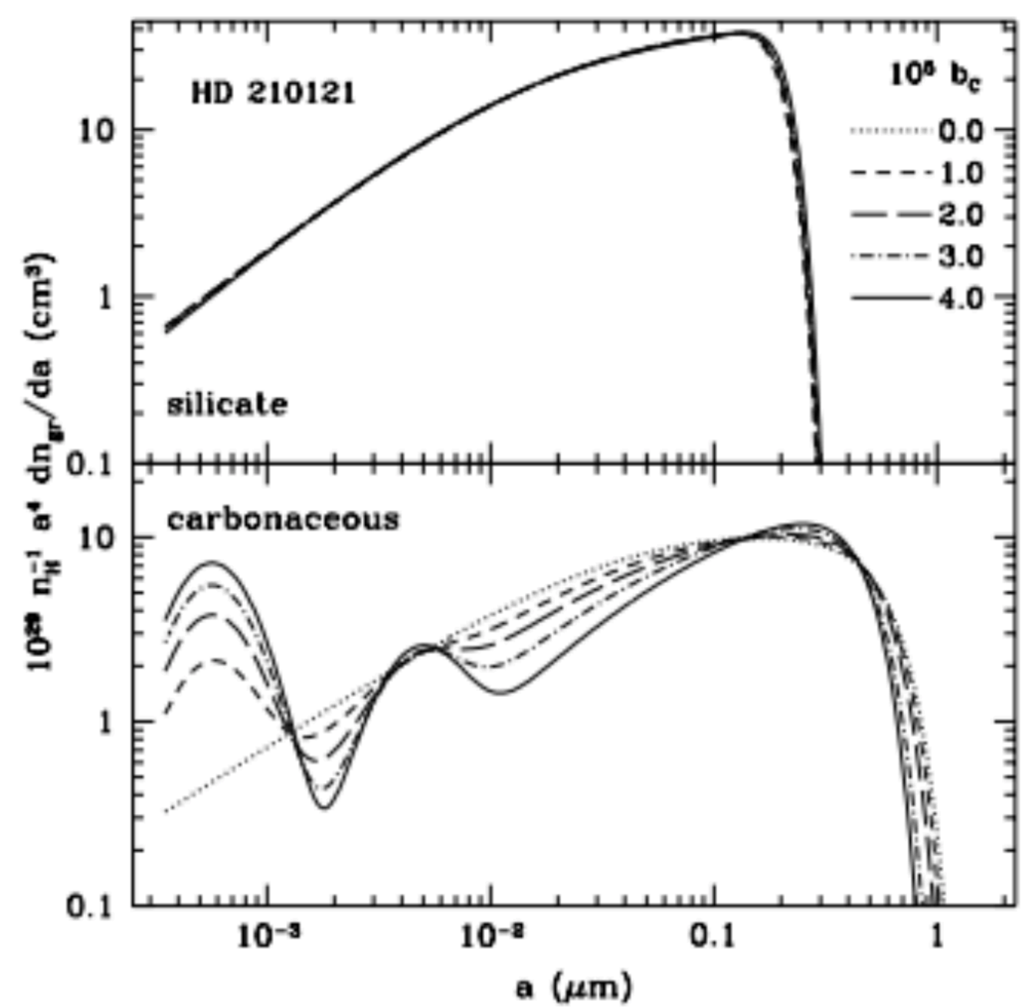
Vanja Šarković
vanja.sarkovic@gmail.com

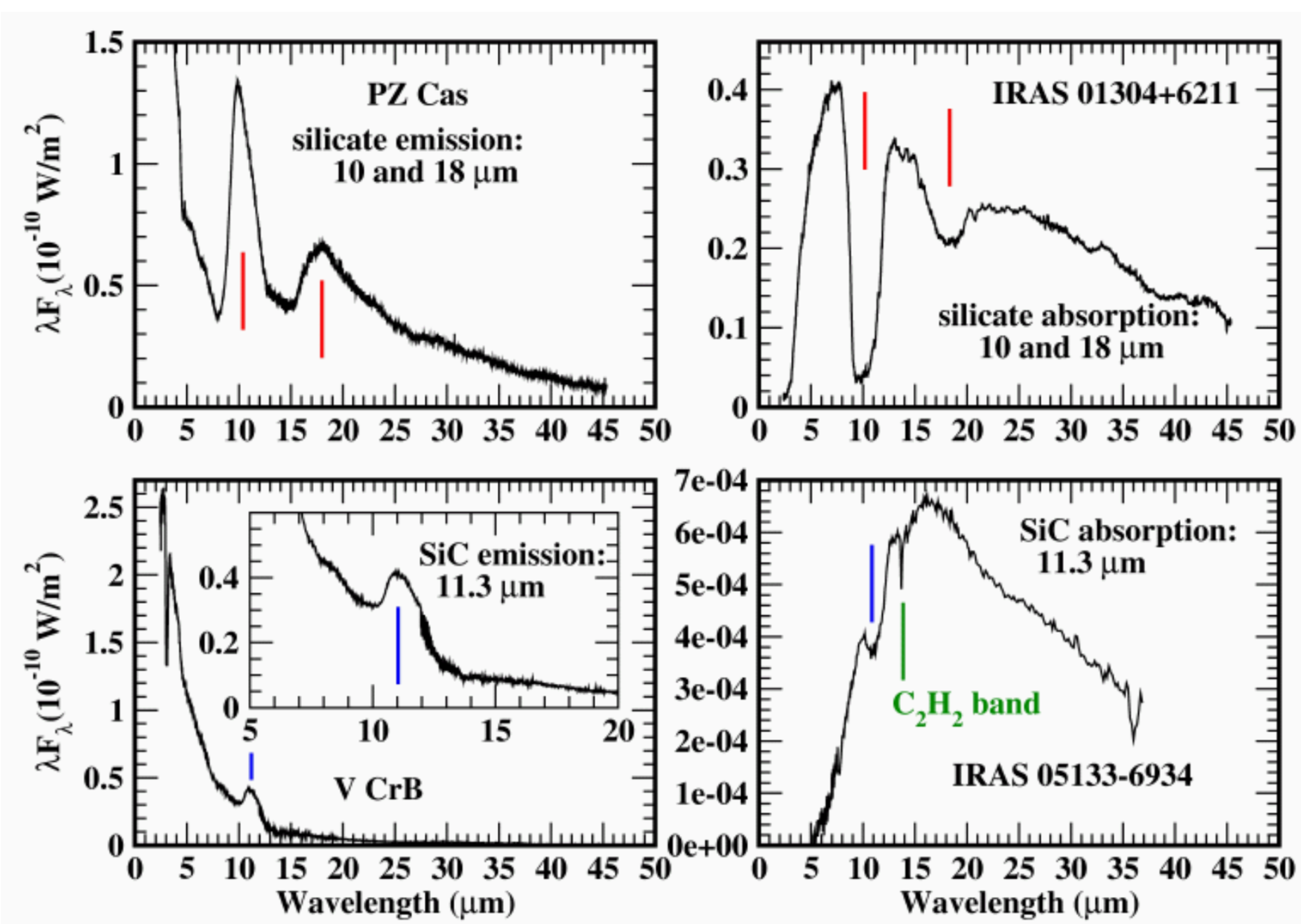
Osobine prašine

- Veličina utiče na:
  - apsorpciju, rasejanje svetlosti
  - emisiju od strane prašine
- Jezgro prašine utiče na
  - raspodelu po veličinama
  - izgled profila emisije/apsorpcije

zrno je optički debelo za:
$a > \lambda$

$dn/da \sim a^{-3.5}$





Weingartner & Draine 2001

Ekstinkcija - zrno prašine

- Efektivni presek pojedinačnog zrna*: $\sigma = \pi a^2$
- Efektivni presek pri absorbciji: $\sigma_{abs} = \sigma Q_{abs}(\lambda)$
- Emitivnost(?) (eng. *Emittance*): $\pi B_\nu(T) Q_\nu$
- Zrno u TRD se opisuje sa T_G
- Ukoliko se nalazi u polju izotropnog zračenja crnog tela na T *(spec. slučaj - stvarnost: razređena svetlost zvezda)*

  iz svakog pravca zrno absorbije: $\sigma B_\nu(T) Q_{abs}(\lambda)$

  u slučaju potpune ravnoteže ($T_G = T$) ukupno: $4\pi a^2 \pi Q_\nu B_\nu(T)$
- Važi ravnoteža: $Q_{abs}(\lambda) = Q_\nu$
- Više zrna?

Ekstinkcija zbog prašine

- Po jedinici zapremine:

$$j_\nu \rho = 1/(4\pi)(\text{number of grains per unit volume})(\text{emission per grain})$$
$$= N\, 4\pi a^2 \pi Q_\nu B_\nu(T)/(4\pi) = N\pi a^2 Q_\nu B_\nu(T)$$

- Koeficijent po jedinici zapremine:

$$\kappa_\nu \rho = N\pi a^2 Q_\nu$$

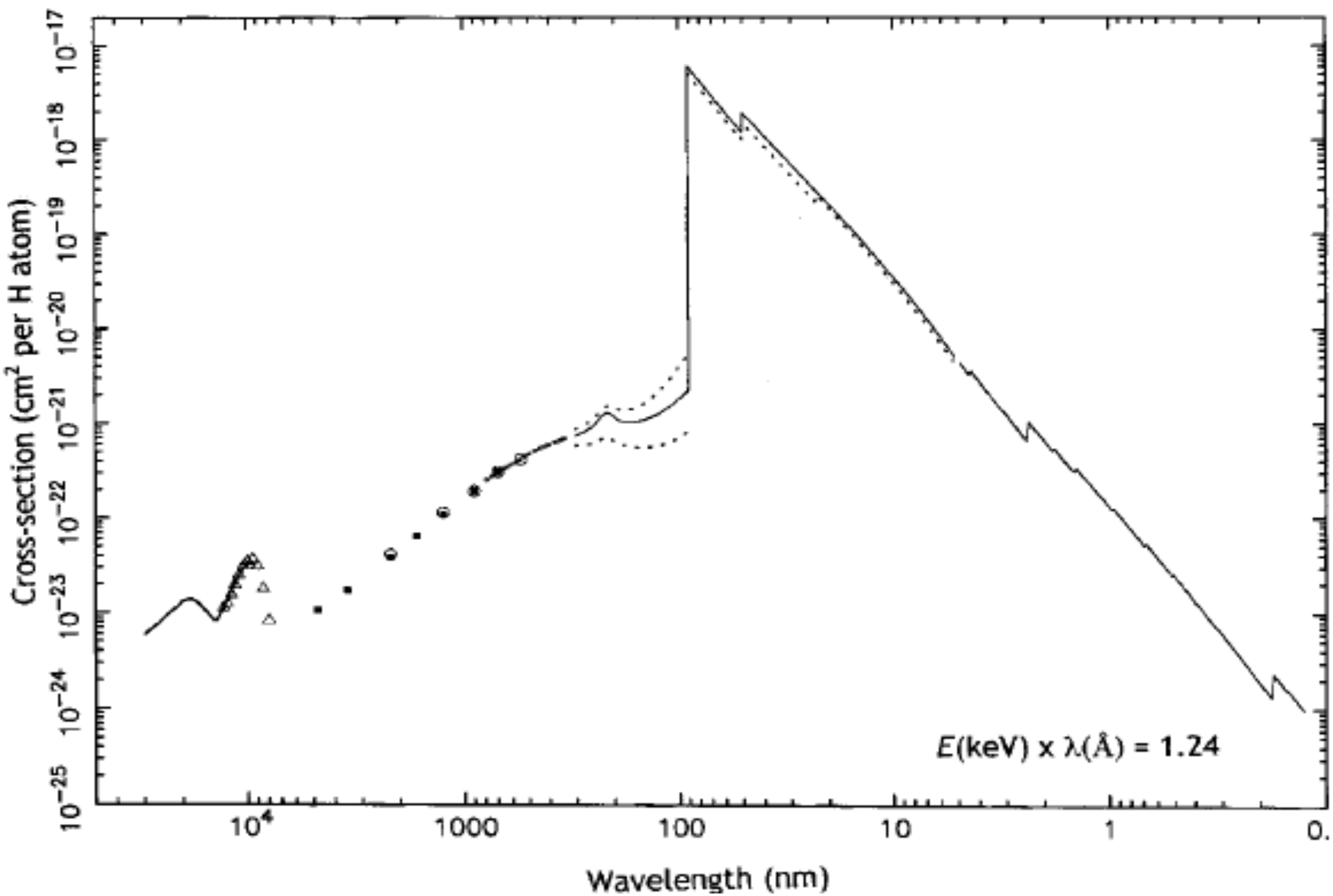
- Maseni koeficijent absorbcije:

$$\kappa_\nu = \frac{N\pi a^2 Q_\nu}{N\frac{4}{3}\pi a^3 \rho_G} = \frac{3Q_\nu}{4a\rho_G}$$

  - efikasnije za kraće talasne dužine ($\propto \lambda^{-1}$)
    - najefikasnije kada su sličnih dimenzija ($a \sim \lambda$)

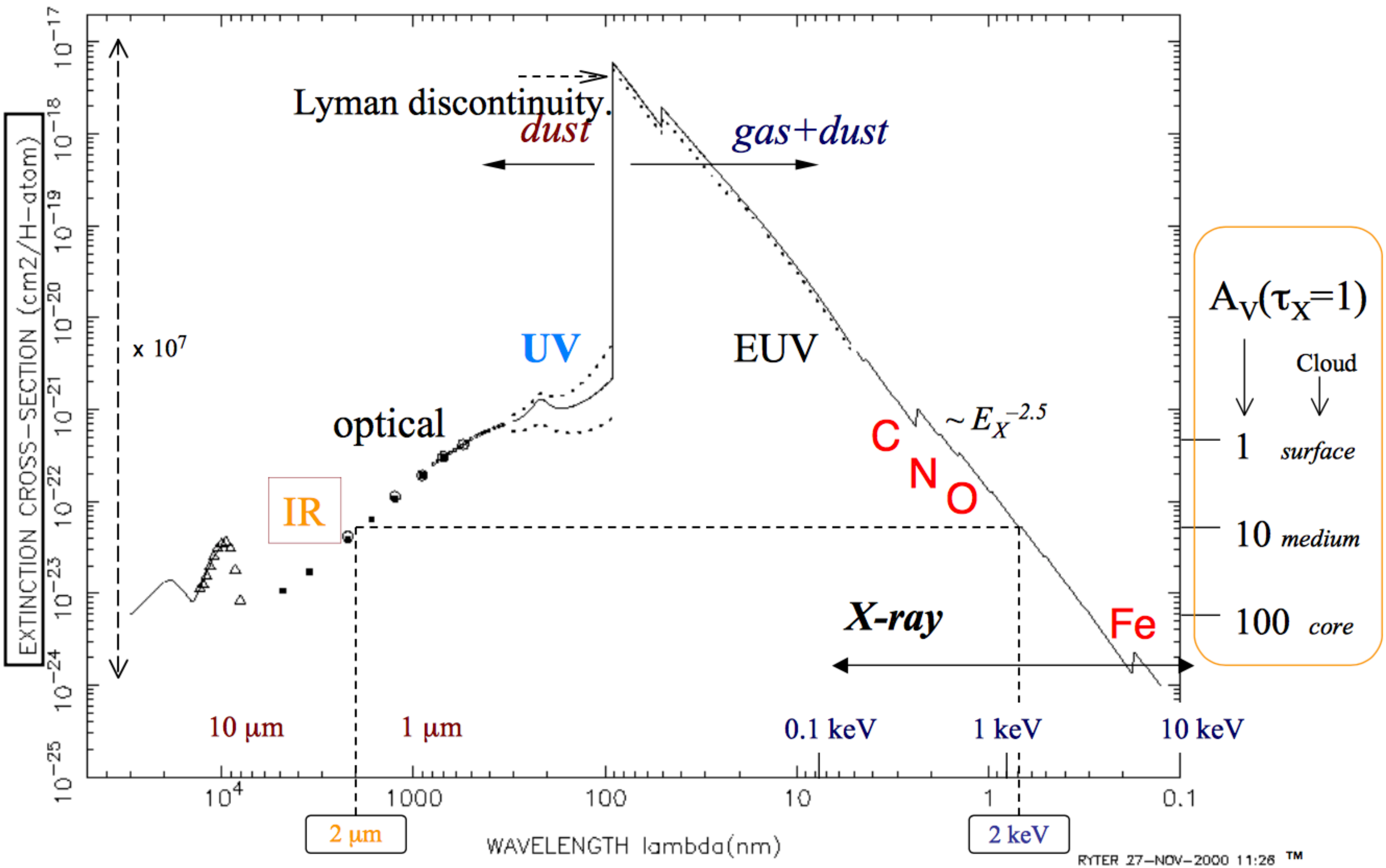
geometrijski poprečni presek ~ efektivni poprečni presek

Ekstinkcija (ukupno)



T. Montmerle (2002)

Ekstinkcija (detaljnije)



T. Montmerle (2002)

Ravnoteža?

- U MZM postoji ravnoteža između:
  - *sudara čestica, pritiska gasa, hemijskih reakcija…*
  - presudno: **apsorpcije i emisije**
- **Polje zračenja je opisano:**

$$I_\nu = W B_\nu(T_{is}) \quad I_\nu = c/(4\pi) u_\nu$$

- Ravnoteža je data sa:

$$4\pi\pi a^2 \int B_\nu(T_{is}) W Q_\nu \, d\nu = 4\pi a^2 \pi \int Q_\nu B_\nu(T_G) \, d\nu$$

$$W \int B_\nu(T_{is}) Q_\nu \, d\nu = \int Q_\nu B_\nu(T_G) \, d\nu$$

- Srednja vrednost:

$$\langle Q_\nu(T) \rangle = \frac{\int B_\nu(T) Q_\nu \, d\nu}{\int B_\nu(T) \, d\nu} = \frac{\pi}{\sigma_{SB} T^4} \int B_\nu(T) Q_\nu \, d\nu$$

$$W \frac{\sigma_{SB}}{\pi} T_{is}^4 \langle Q_\nu(T_{is}) \rangle = \frac{\sigma_{SB}}{\pi} T_G^4 \langle Q_\nu(T_G) \rangle$$

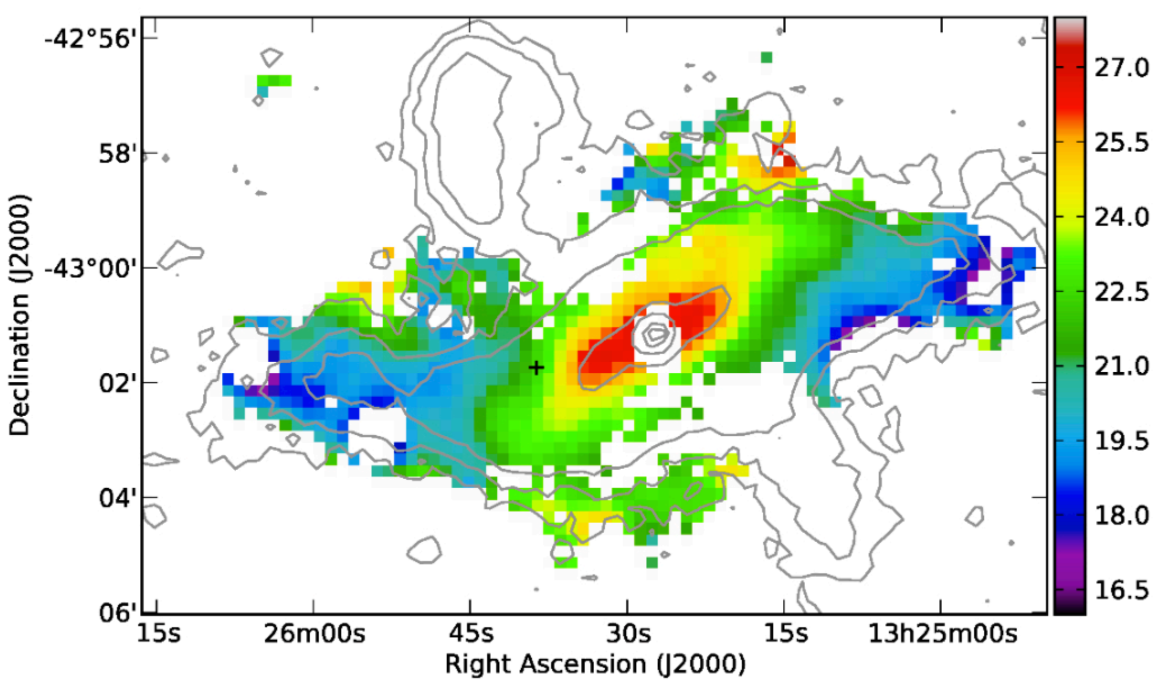
$$T_G = T_{is} W^{1/4} \left(\frac{\langle Q_\nu(T_{is}) \rangle}{\langle Q_\nu(T_G) \rangle} \right)^{1/4}$$

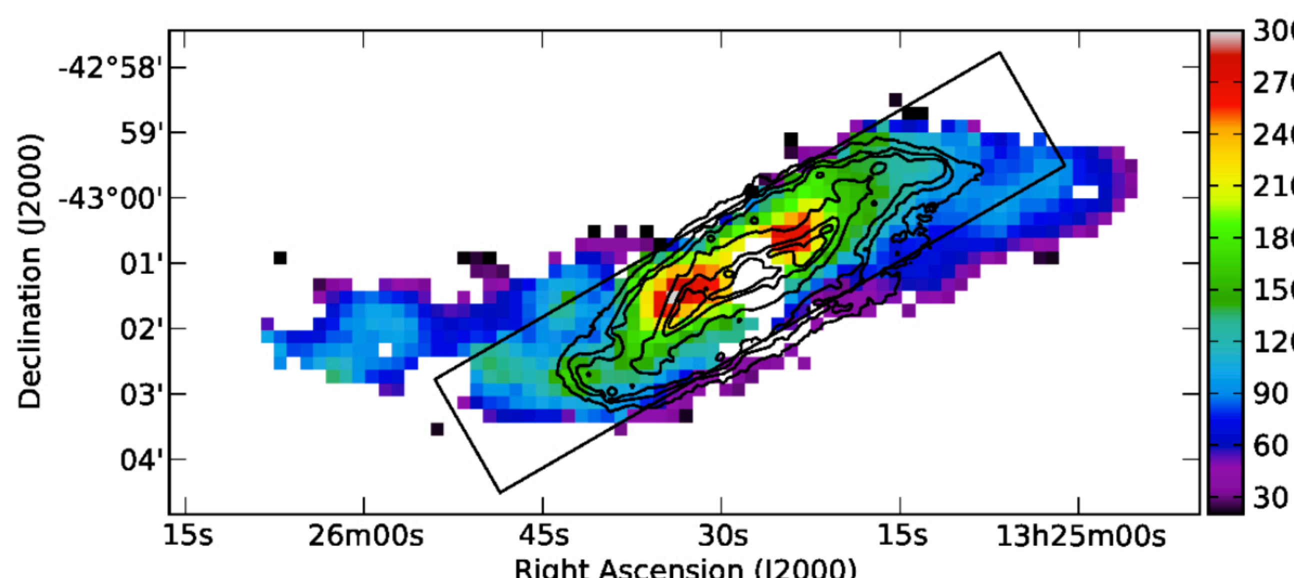
Veza između T_{is} i T_G

- U slučaju ravnoteže važi:

$$T_G \sim T_{is} W^{1/4} \left(\langle Q_{UV} \rangle / \langle Q_{FIR} \rangle \right)^{1/4}$$

- Za W ~ 10^{-14} i odnos između $\langle Q_{UV} \rangle / \langle Q_{FIR} \rangle \sim 1$
    - T_G iznosi oko 3K
    - ✳ ispravnost procene zavisi od:
        - ✳ sastava zrna (menjaju Q)
        - ✳ optičke debljine oblaka





Tara Parkin et al., 2012

Veza između T_{is} i T_G

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➡ Da li je to sve?

Veza između T_{is} i T_G

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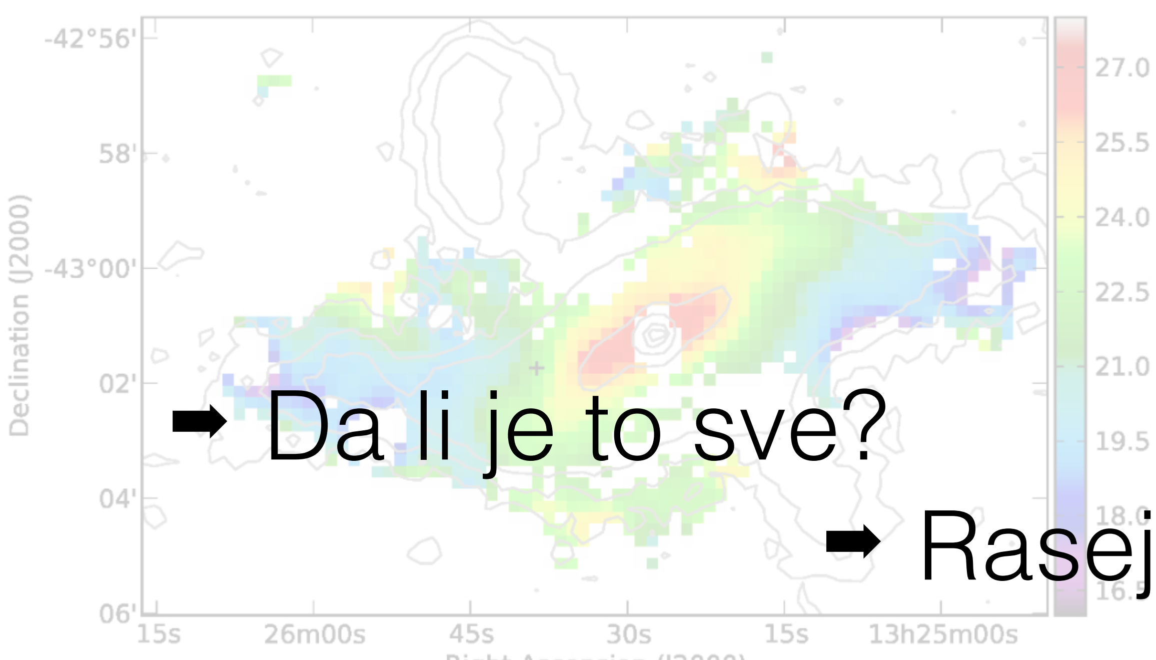
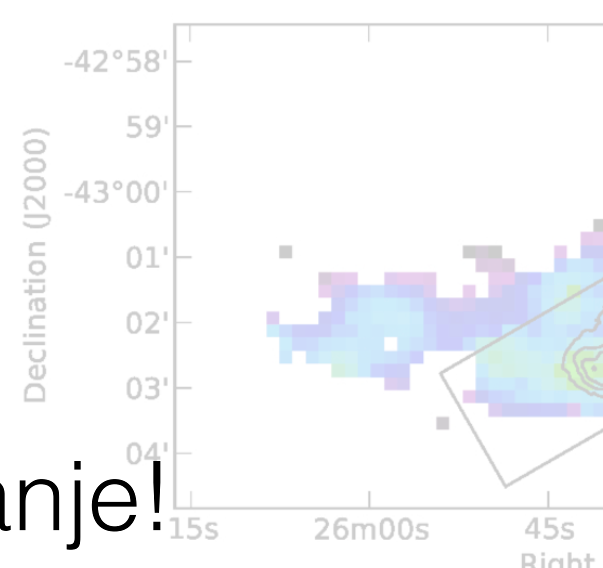




➡ Da li je to sve?

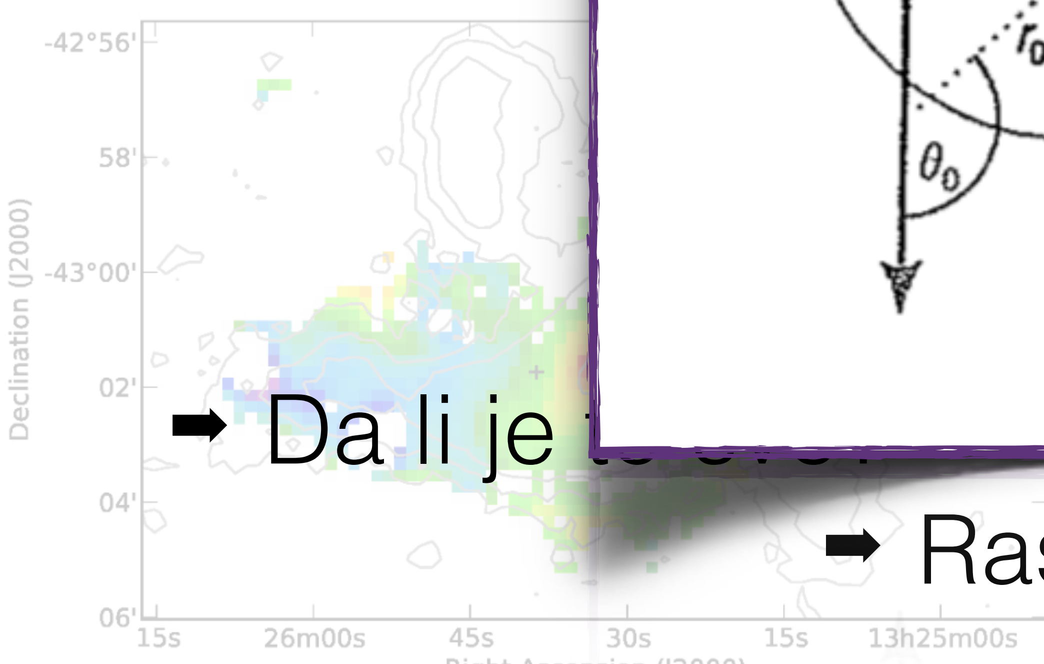
➡ Rasejanje!

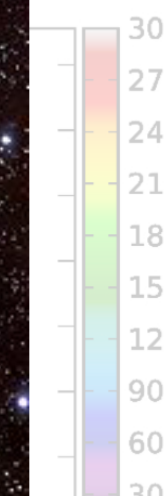
Vez ... s i T_G

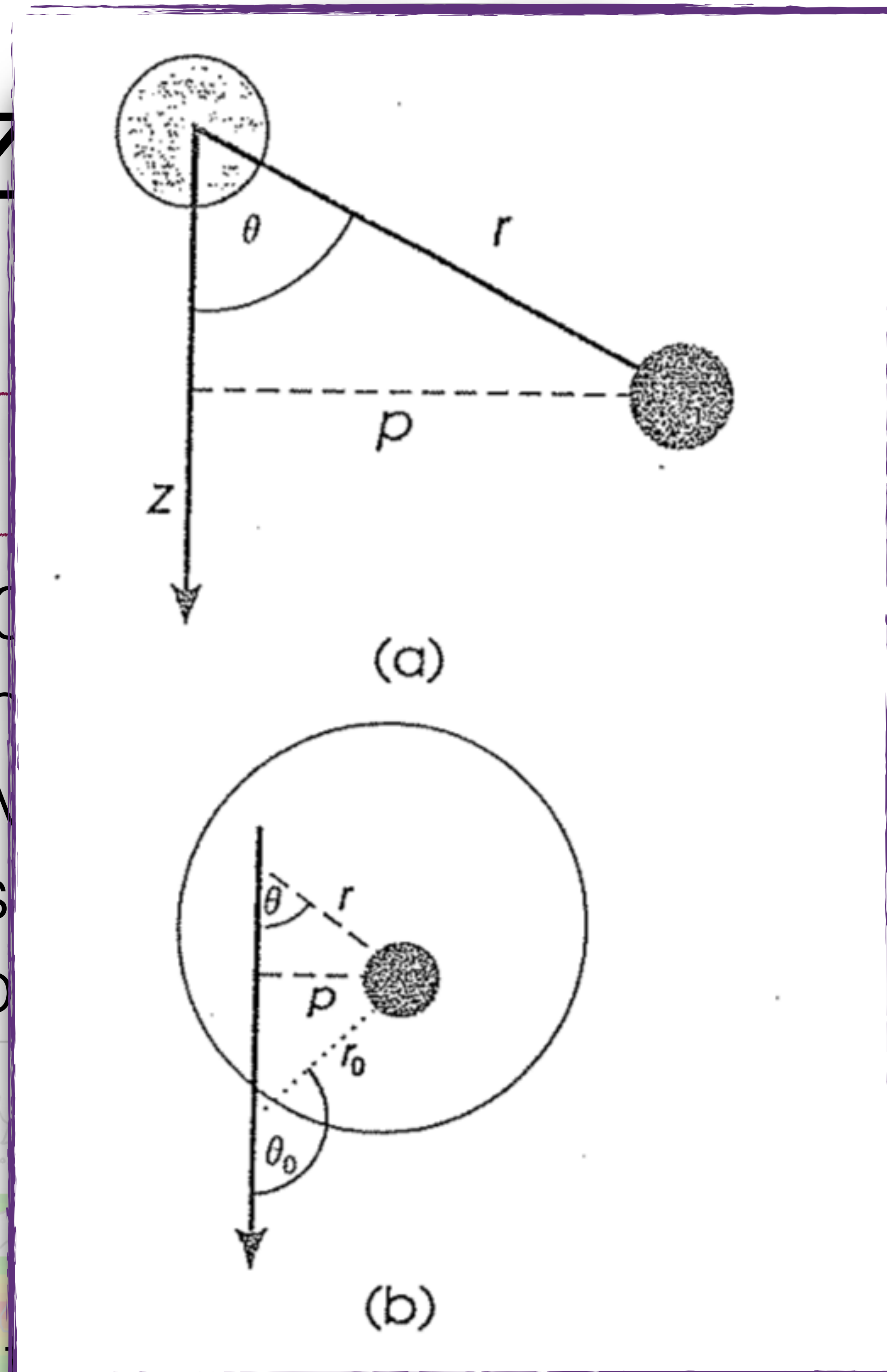
- U slučaju ...

... $)^{1/4}$

- Za W ~ 1(... $_{FIR}\rangle \sim 1$
    - T_G izr ...
    - ✳ ispra ...
        - ✳ s ...
        - ✳ o ...



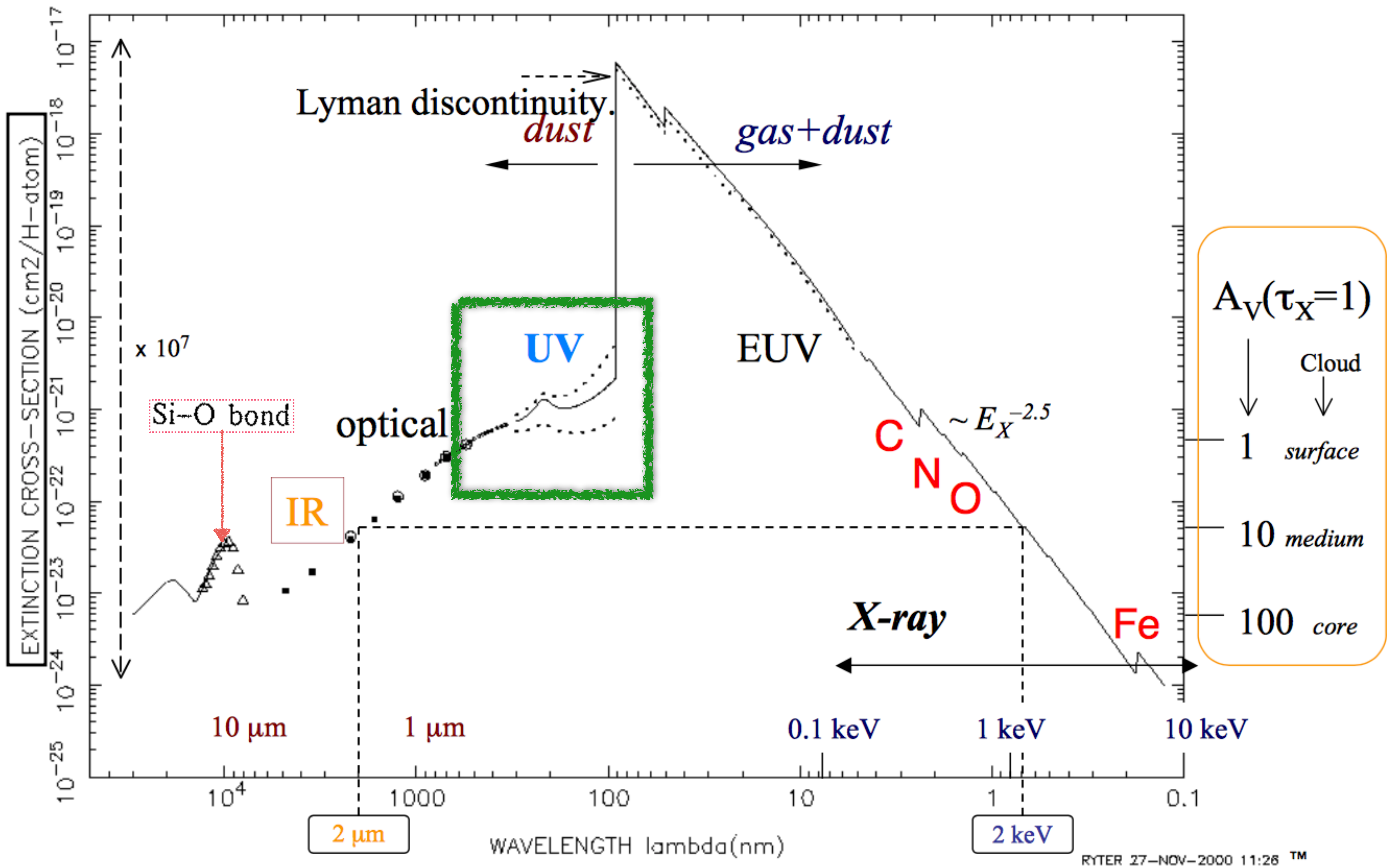




➡ Da li je t...

➡ Rasejanje!

Ekstinkcija (detaljnije)



T. Montmerle (2002)

I rasejanje?

- Ukupan koeficijent

$$\kappa_{ext}\rho = \kappa_{abs}\rho + \kappa_{sca}\rho = N\sigma Q_{ext}(\lambda) = N\sigma[(Q_{sca}(\lambda) + Q_{abs}(\lambda)]$$

$$\sigma_{sca} = \sigma Q_{sca}(\lambda)$$

- Albedo: $Q_{sca}/Q_{ext} = 1 - Q_{abs}/Q_{ext}$
- Koeficijenti $Q_{sca}(x)$ i $Q_{abs}(x)$ zavise od talasne dužine različito, ali po zakonu $Q = \text{constant } \nu^{\beta}$ gde $1<\beta<2$
- Bitan parametar je odnos između dimenzije zrna i tal. dužine $x = 2\pi a/\lambda$
- Mieva teorija - prašina opisana preko $m = n - ik$ (rasejanje: n, apsorpcija: ik)

$$Q_{abs} \simeq 4x\Re\left[\frac{m^2-1}{m^2+1}\right] \qquad Q_{sca} \simeq \frac{8}{3}x^4\left|\frac{m^2-1}{m^2+1}\right|^2$$

slabo-apsorbujući $m \sim n$.

Koeficijent ekstinkcije

- Ukupan uticaj usled rasejanja i apsorpscije

- metod parova (dve zvezde iste klase)

$$\Delta m_\lambda = m_\lambda^{(1)} - m_\lambda^{(2)} = 5\log\frac{r_1}{r_2} + \mathcal{A}_\lambda^{(1)} - \mathcal{A}_\lambda^{(2)}$$

$$\mathcal{A}_\lambda^{(i)} = 1.086\,\tau_\lambda^{(i)} = 1.086\int_0^{r_i}\kappa_\lambda\,\rho_{\rm ms}(r_i';l_i,b_i)\,dr_i'.$$

$$\Delta m(\lambda) = c_1 + c_2\,\kappa(\lambda),$$

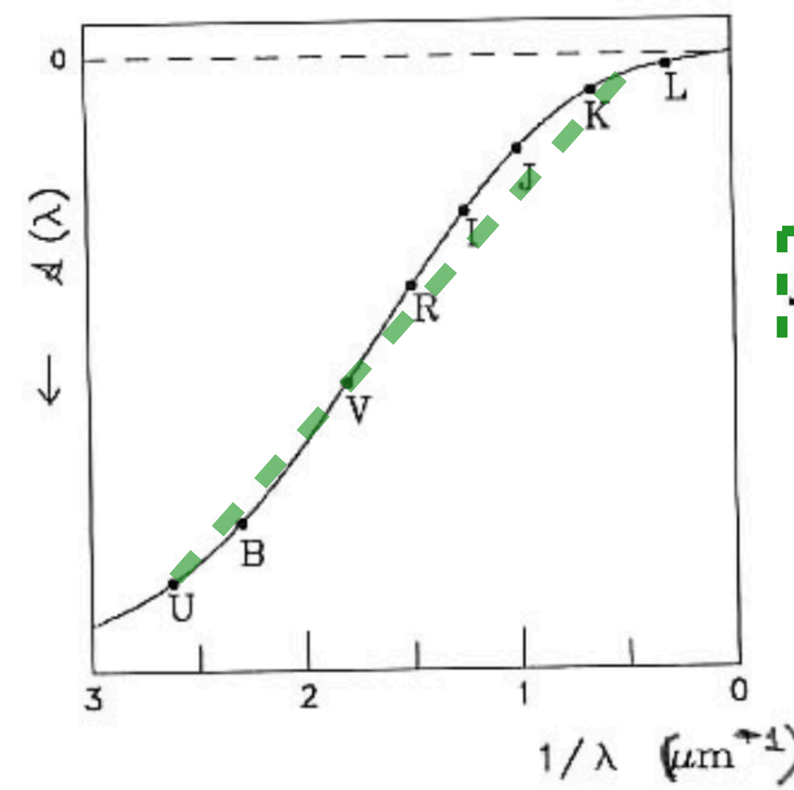
$$\Gamma(\lambda) = \frac{\Delta m(\lambda)-\Delta m(\lambda_2)}{\Delta m(\lambda_1)-\Delta m(\lambda_2)} = \frac{\kappa(\lambda)-\kappa(\lambda_2)}{\kappa(\lambda_1)-\kappa(\lambda_2)}$$

$\mathcal{A}^{(2)}=0$ i $\mathcal{A}^{(1)}\equiv\mathcal{A}$

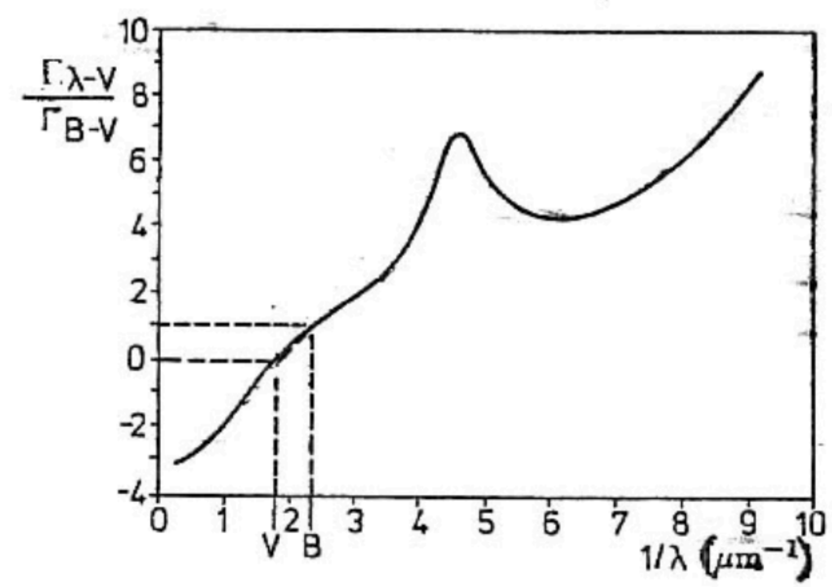
$$E(\lambda_1,\lambda_2) = [m(\lambda_1)-m^0(\lambda_1)] - [m(\lambda_2)-m^0(\lambda_2)] = \mathcal{A}(\lambda_1)-\mathcal{A}(\lambda_2).$$

$$\Gamma(\lambda) = \frac{\mathcal{A}(\lambda)-\mathcal{A}(\lambda_2)}{\mathcal{A}(\lambda_1)-\mathcal{A}(\lambda_2)} = \frac{E(\lambda,\lambda_2)}{E(\lambda_1,\lambda_2)},$$

- c_1 i c_2 ne zavise od λ, ali zavise od r
- Γ(λ) ne zavisi od r



$\mathcal{A}_\lambda \propto \lambda^{-1}$



Procena površinske gustine prašine

- Ukoliko *N* zrna veličine a izvrši ekstinkciju $Q_{ext}(\lambda)a^2N$,
- Ukoliko je linijska gustina za zrna ove veličine $n_{col}(a)\,\mathrm{d}$
- Na osnovu posmatranja je poznato da u IC delu spektra važi $A(\lambda) \sim 1/\lambda^{1.84}$
- Integracijom $\Delta m = A(\lambda) = 2.5\log_{10}[\exp(-\tau_D)] = 1.086\,\tau_D = 1.086 < \pi a^2 Q_{ext}(a,\lambda) > N_{coll}$
- Dobija se: $\int A(\lambda)\,\mathrm{d}\lambda = 1.086 \int \pi a^2 n_{col}(a) \int Q_{ext}(a,\lambda)\,\mathrm{d}\lambda\,\mathrm{d}a$
- Primenom Mieve teorije rasejanja imamo: $\int Q_{ext}(a,\lambda)\,\mathrm{d}\lambda = 4\pi^2 a \frac{m^2-1}{m^2+2}$
- Što dalje daje: $\int A(\lambda)\,\mathrm{d}\lambda = 1.086 * 4\pi^3 \frac{m^2-1}{m^2+2} \int a^3 n_{col}(a)\,\mathrm{d}a$

$$= 1.086 \times \frac{3\pi^2}{\rho_G}\frac{m^2-1}{m^2+2}\int m_G(a) n_{col}(a)\,\mathrm{d}a, \quad \text{where } m_G = \frac{4}{3}\pi a^3 \rho_G$$

$$= 1.086 \times \frac{3\pi^2}{\rho_G}\frac{m^2-1}{m^2+2} M_{dust}$$

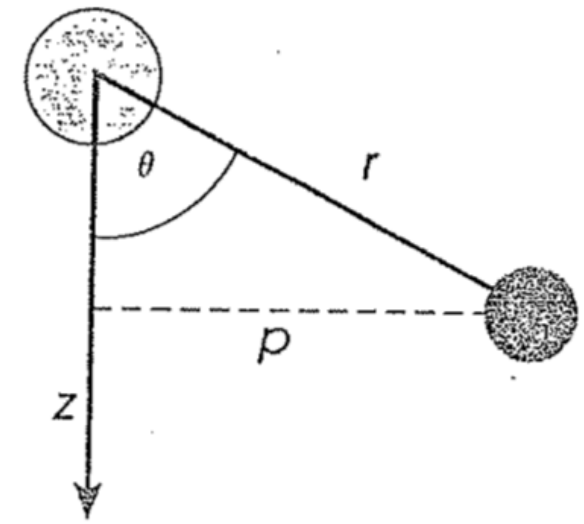
$$M_{dust} = \frac{A_V \int \frac{A(\lambda)}{A_V}\,\mathrm{d}\lambda}{1.086 \times 3\pi^2}\,\rho_G\,\frac{m^2+2}{m^2-1}$$

+ posmatranja vodonika
  -> Dust to Gas ratio

Posmatranja prašnjavih oblaka

$L_{sca}(UV)$ $L_{abs}(FIR)$

- Odnos UV i FIR posmatranja može se iskoristiti kao mera albeda $w = L_{sca}/(L_{sca} + L_{abs})$



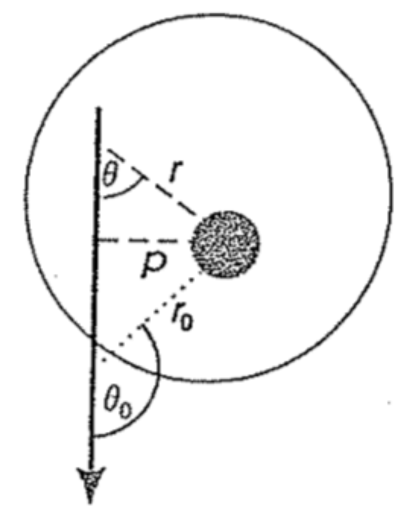
(a)

- Na pojedinačnm zrnu se raseje:

$$Q_{sca}\pi a^2 L_\nu/(4\pi r^2)\exp[-\tau_{ext}(r)] \qquad L_\nu \sim \pi B_\nu(T^*)4\pi R^2$$

- Za izotropno* rasejanje:

$$I_{sca}\mathrm{d}\Omega = \frac{L_\nu}{4\pi r^2} e^{-\tau_{ext}} Q_{sca}\pi a^2 N f(\theta)\,\mathrm{d}V\mathrm{d}\Omega$$



(b)

- Na rastojanju p posmatramo:

$$I(p) = \int Q_{sca}\pi a^2 \frac{L_\nu}{4\pi r^2} N e^{-\tau_{ext}(r)} e^{-\tau_{ext}(z,p)} f(\theta)\,\mathrm{d}z$$

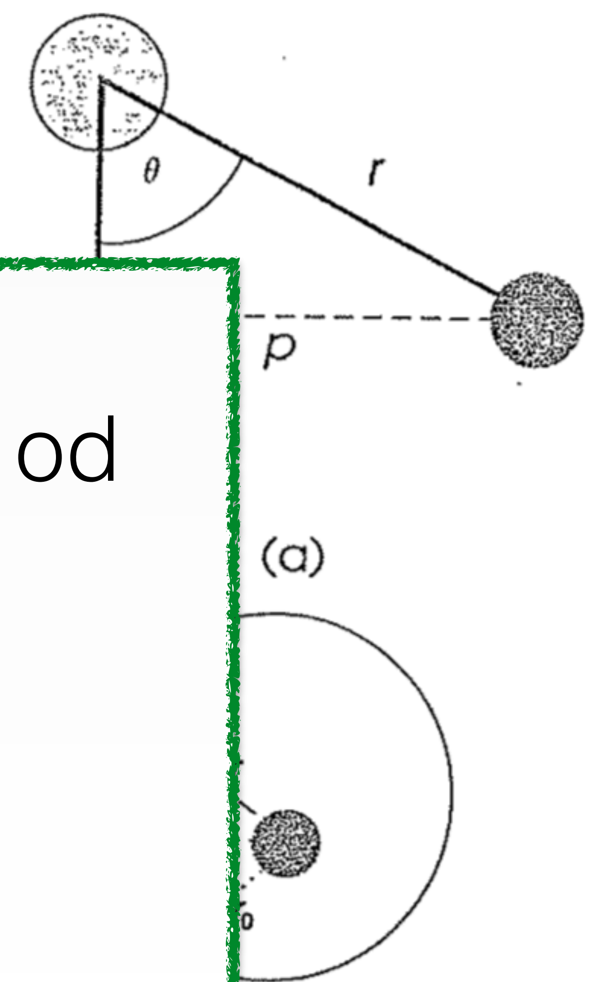
$$= \omega \int \frac{L_\nu}{4\pi r^2} e^{-\tau_{ext}(r)} e^{-\tau_{ext}(z,p)} f(\theta)\,\mathrm{d}\tau_{ext}(z)$$

$$\mathrm{d}\tau_{ext}(z) = 1/\omega\,\mathrm{d}\tau_{sca} = 1/\omega\, N\, Q_{sca}\pi a^2\,\mathrm{d}z$$

Posmatranja prašnjavih oblaka

$L_{sca}(UV)$ $L_{abs}(FIR)$

- Odnos UV i FIR posmatranja može se iskoristiti kao mera albeda $L_{sca}/(L_{sca}+L_{abs})$



- N

$Q_{sca}\pi$

- Za

- N

Kako je oblak daleko manjih dimenzija od rastojanja do njega (*r ~ const*)

$$I(p) = \omega \frac{L_\nu}{16\pi^2 r^2} e^{-\tau_{ext}(r)}(1 - e^{\tau_{ext}})$$

$$F_\nu(*) = L_\nu/(4\pi d^2)\exp[-\tau_{ext}(SO)]$$

$$I(p) = \int Q_{sca}\pi a \ldots \frac{}{4\pi r^2} N e \ldots e \ldots f(\theta)\,dz$$

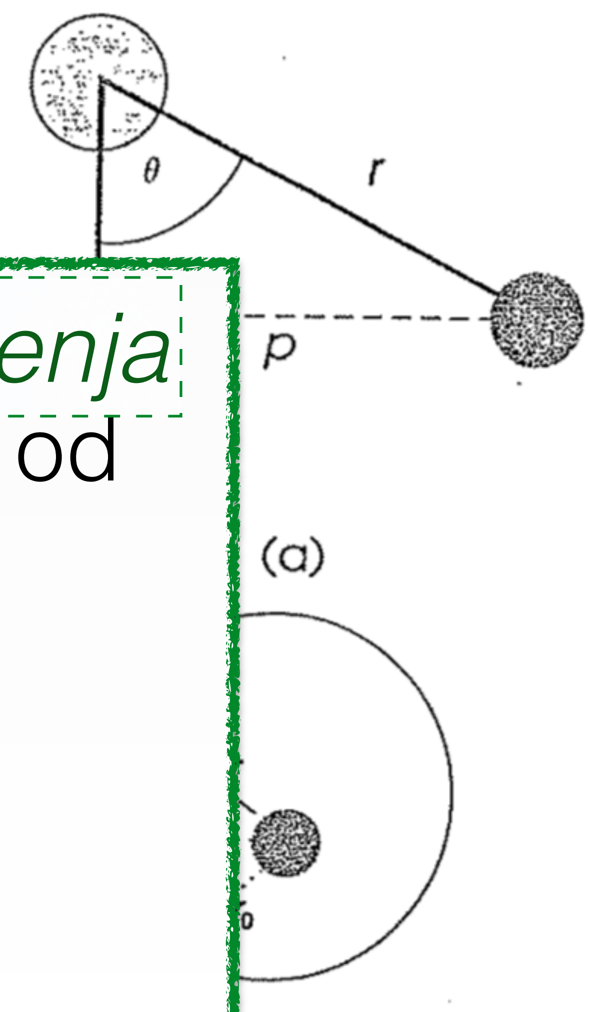
$$= \omega \int \frac{L_\nu}{4\pi r^2} e^{-\tau_{ext}(r)} e^{-\tau_{ext}(z,p)} f(\theta)\,d\tau_{ext}(z)$$

$$d\tau_{ext}(z) = 1/\omega\, d\tau_{sca} = 1/\omega\, N\, Q_{sca}\pi a^2\, dz$$

Posmatranja prašnjavih oblaka

$L_{sca}(\mathrm{UV})$ $L_{abs}(\mathrm{FIR})$

- Odnos UV i FIR posmatranja može se iskoristiti kao mera albeda $L_{sca}/(L_{sca} + L_{abs})$



(a)

(b)

- N
- Za
- N

+ ima još rešenja

Kako je oblak daleko manjih dimenzija od rastojanja do njega ($r \sim const$)

$$I(p) = \omega \frac{L_\nu}{16\pi^2 r^2} e^{-\tau_{ext}(r)}(1 - e^{\tau_{ext}})$$

$$F_\nu(*) = L_\nu/(4\pi d^2)\exp[-\tau_{ext}(SO)]$$

$$I(p) = \int Q_{sca}\pi a^2 \frac{\ldots}{4\pi r^2} N e^{\ldots} e^{\ldots} f(\theta)\,dz$$

$$= \omega \int \frac{L_\nu}{4\pi r^2} e^{-\tau_{ext}(r)} e^{-\tau_{ext}(z,p)} f(\theta)\, d\tau_{ext}(z)$$

$$d\tau_{ext}(z) = 1/\omega\, d\tau_{sca} = 1/\omega\, N\, Q_{sca}\pi a^2\, dz$$

Ostala rešenja

- U slučaju sfernog oblaka sa zvezdom u sredini:
  - ka centru oblaka $\tau_{ext}(r) = \kappa\rho\, p/\sin\theta$
  - prema obodu oblaka $\tau_{ext}(z,p) = \kappa\rho[\sqrt{(r_0^2 - p^2)} + p\cot\theta]$.

$$I(p) = \frac{\omega\kappa_{ext}\rho L_\nu}{4\pi}\int_{\theta_0}^{\pi-\theta_0}\frac{1}{r^2}f(\theta)\exp\left\{-\kappa_{ext}\rho\left[\frac{p}{\sin\theta} + \sqrt{r_0^2 - p^2} + p\cot\theta\right]\right\}\mathrm{d}(p\cot\theta)$$

$$= \frac{\omega\tau_0 L_\nu}{4\pi r_0}\int_{\theta_0}^{\pi-\theta_0} f(\theta)\frac{\sin^2\theta}{p^2}\exp\left\{-\kappa_{ext}\rho\left[\frac{p}{\sin\theta} + \sqrt{r_0^2 - p^2} + p\cot\theta\right]\right\}\frac{-p}{\sin^2\theta}\mathrm{d}\theta$$

… dalje, ukoliko uzmemo $\mathrm{d}z = \mathrm{d}(p\cot\theta)$ i $\tau_0 = \kappa_{ext}\rho r_0$,

\+ uz pps optički retke sredine važi:

$$\frac{\mathrm{d}[pI(p)]}{\mathrm{d}p} = \frac{\omega\tau_0 L_\nu}{4\pi r_0^2\cos\theta_0}\frac{\mathrm{d}}{\mathrm{d}\theta_0}\int_{\theta_0}^{\pi-\theta_0} f(\theta)\,\mathrm{d}\theta, \quad \text{since } \mathrm{d}p = r_0\cos\theta$$

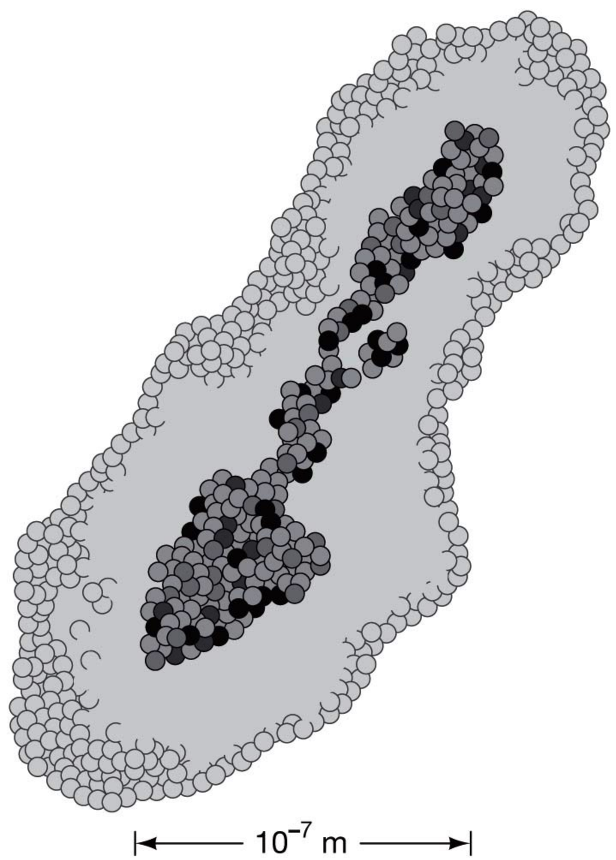
$$= \frac{\omega\tau_0 L_\nu}{4\pi r_0^2}\frac{f(\theta_0) + f(\pi-\theta_0)}{\cos\theta_0}$$

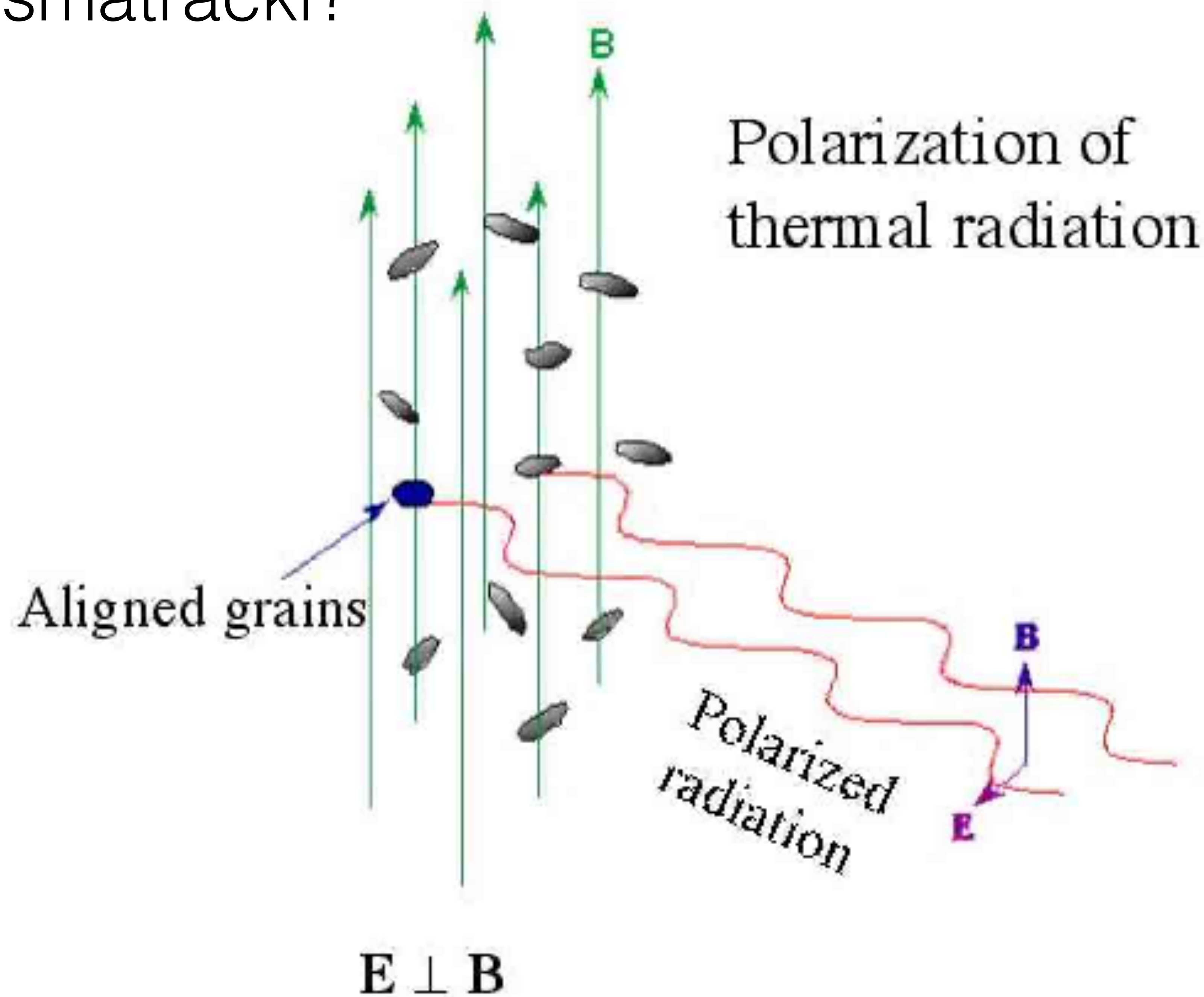
aproksimativno

$$I(p) = \frac{\omega L_\nu \tau_0}{4\pi r_0 p}\int_{\theta_0}^{\pi-\theta_0} f(\theta)\mathrm{d}\theta$$

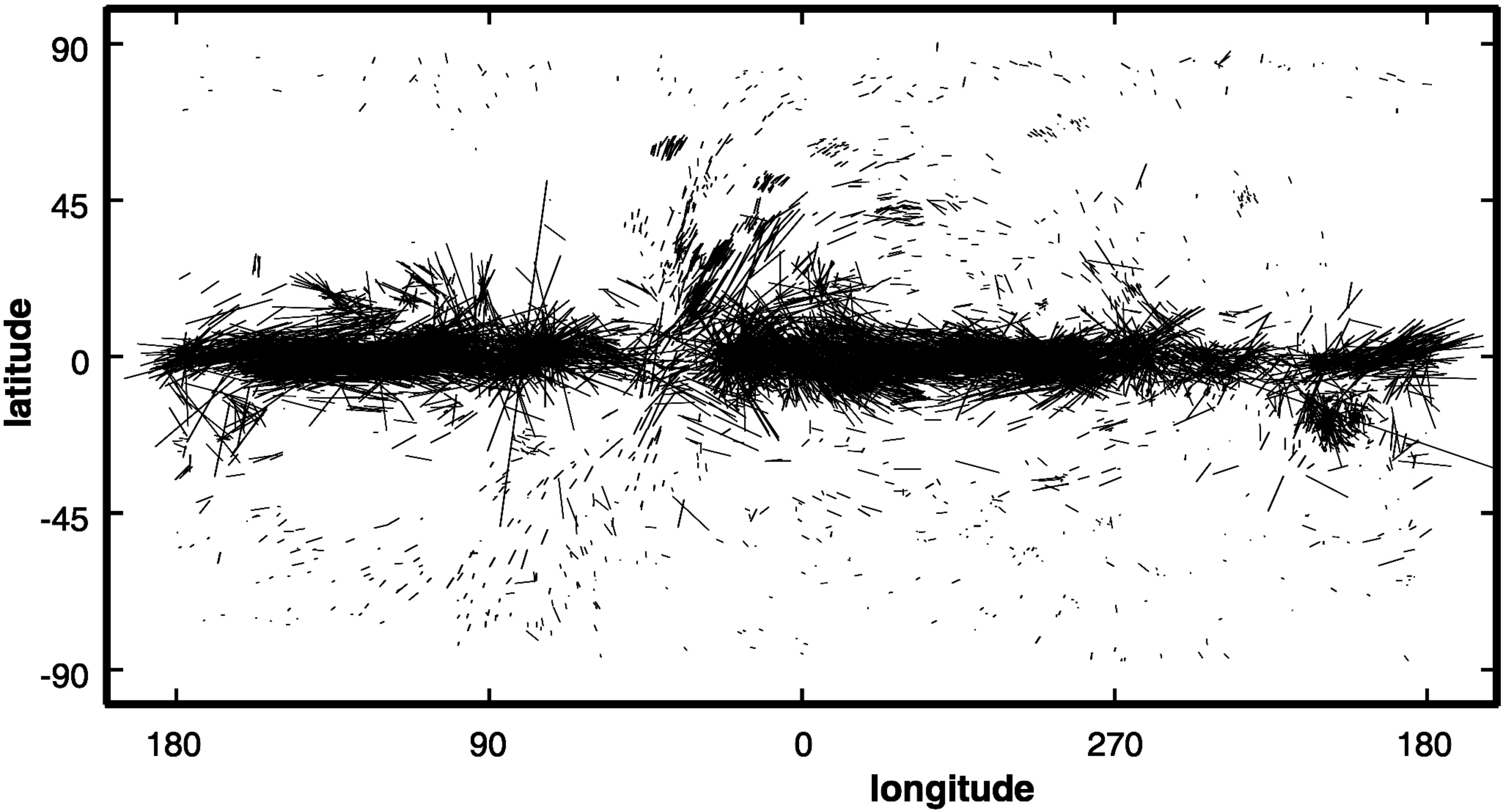
Polarizacija reflektovane svetlosti

- Sferna simetrija zrna ≠ dobra pretpostavka
- Kako ovo izgleda posmatrački?



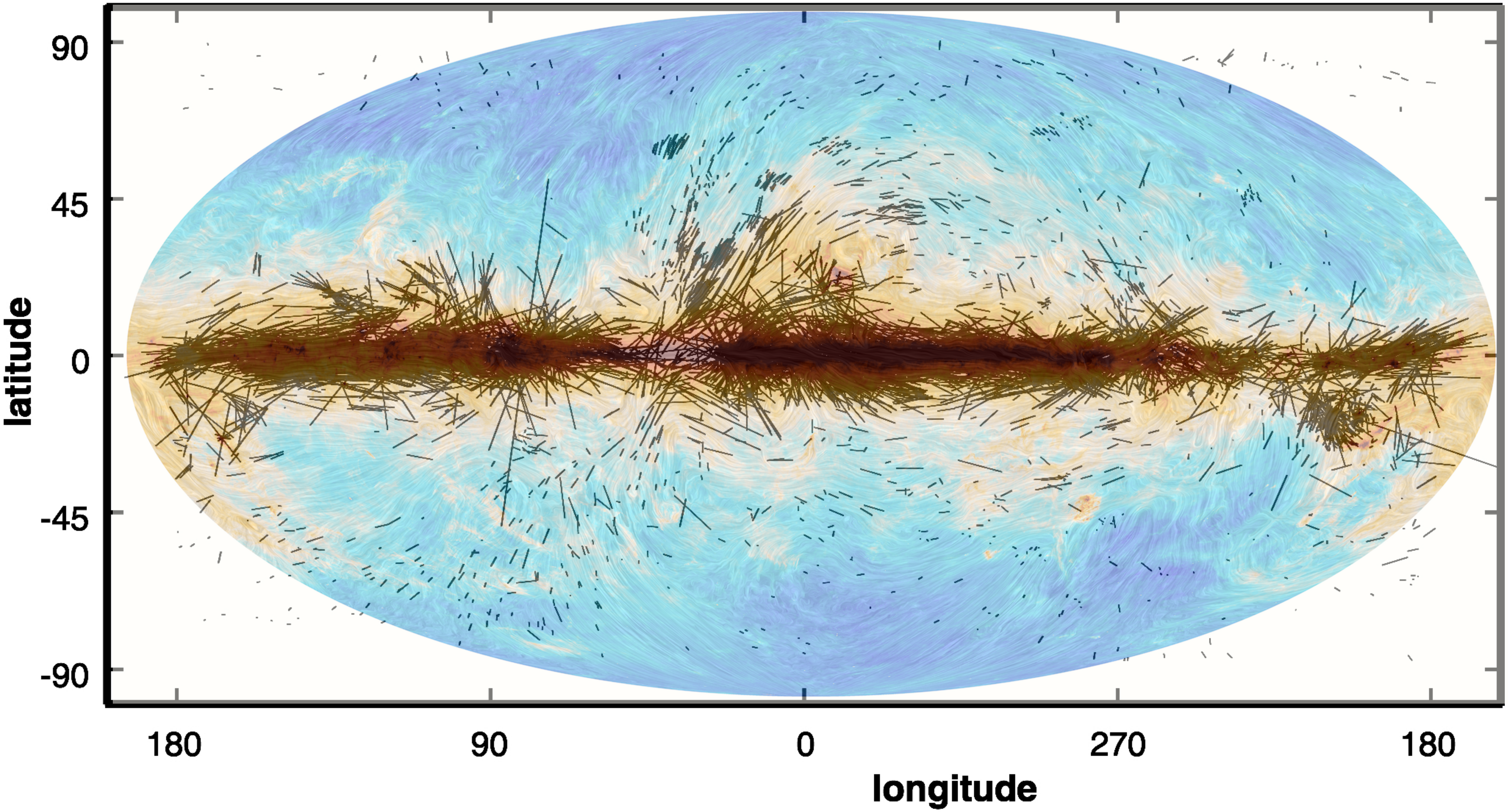


Polarizacija reflektovane svetlosti



(Berdyugin et al. 2014)

Polarizacija reflektovane svetlosti



(Planck collaboration 2016)

(Berdyugin et al. 2014)

Hvala na pažnji!