Photospheric backscatter & directivity

Alexander & Brown 02

- Analytic inversion of power-law photon spectrum, $I(\varepsilon)$ vs $I_o(\varepsilon)$
- Error Inferred in the Mean electron spectrum F(E) by ignoring photospheric backscatter.

Importance of Albedo Overlooked?

- Prevailing wisdom: Albedo could not be seen in data
- Therefore not import; Not worth studying

Albedo as a diagnostic tool

- Kontar & Brown – Spectroscopic Technique for determining $F(E, \mu)$ from $I(\varepsilon)$, splitting into direct and backscattered components
- $I(\varepsilon)$

Don't ignore albedo

Greens hemispheric Approach

MZ 95

- Compton reflection from cosmic sources - AGN

Kontar, Green Matrix approach

- Matrix based approach – Kontar et al 06
- Assumes isotropic emission
- Investigated anisotropic effects upon the primary spectrum
- Empirical fit - Leach & Petrosian 83

How does anisotropy affect the observed spectrum

- Changes shape of I(eps), size
- Empirical fit – shape can be obviously seen in R(ε) but size reduced
- effects sensitive to empirical fit chosen

Greens hemispheric Approach

Magdziarz & Zdzairski 95

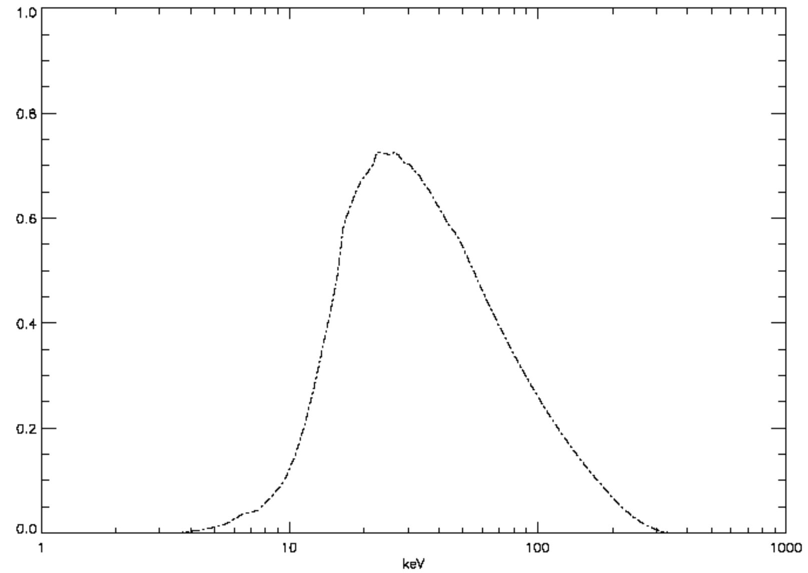
$$I_r(\epsilon) = \int_\epsilon^\infty G(\mu,\ \epsilon,\ \epsilon')I_d(\epsilon')d\epsilon',$$

$$I_{obs} = I_p + \int_\epsilon^\infty \bar{\mathrm{G}}(\mu, \epsilon, \epsilon^{'})I(\epsilon^{'})d\epsilon^{'}$$

Kontar

$$\mathbf{I_{obs}} = \mathbf{I_p} + \hat{\mathbf{G}}\mathbf{I_p}$$

$$(\mathbf{I_{obs}})_i = (\mathbf{I_p})_\mathbf{i} + \Sigma_\mathbf{j}\hat{\mathbf{G}}_\mathbf{ij}(\mathbf{I_p})_\mathbf{j}$$



Isotropic R(ε) (γ=2)

Greens hemispheric Approach

Hemispheric Approach

- $\alpha(\varepsilon)$ – fraction of $I_o(\varepsilon)$ emitted downward
- $(1-\alpha(\varepsilon))$ – fraction of $I_o(\varepsilon)$ emitted upwards

Isotropic

$\alpha(\varepsilon)=0.5$

Anisotropic

$\alpha(\varepsilon)>0.5$ - downward beaming

Greens hemispheric Approach

Anisotropic version

$$I_o(\epsilon) = \alpha I_o^{down}(\epsilon) + (1-\alpha) I_o^{up}(\epsilon)$$

$$(I_{obs})_i = (I_p^{up})_i (1-\alpha) + \Sigma_j \hat{G}_{ij} \alpha (I_{p,i}^{down})_j$$

Anisotropic version – Monoenergetic “beams”

$$I_{obs} = \int_{\epsilon''} \left(I_p(\epsilon'') + \alpha(\epsilon'') \int_{\epsilon}^{\infty} \bar{\mathrm{G}}(\mu, \epsilon, \epsilon') I(\epsilon') d\epsilon' \right) d\epsilon''$$

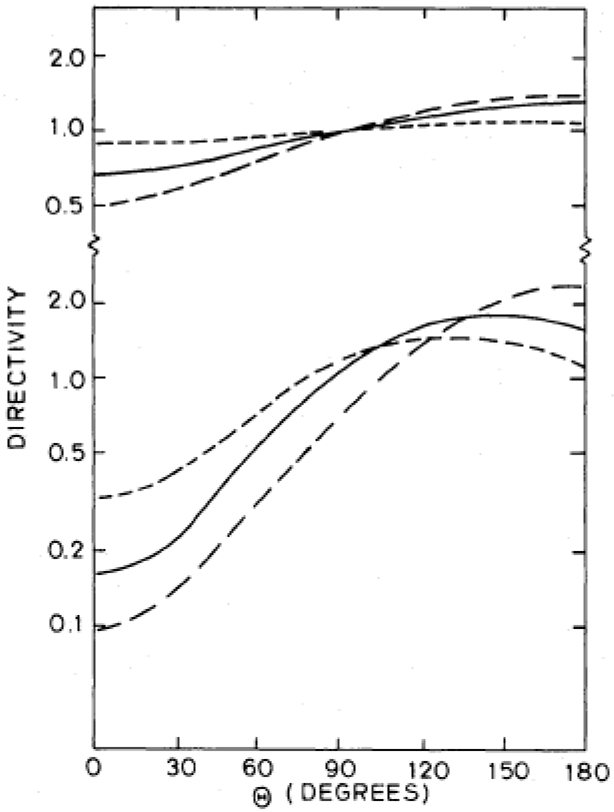
$$(\mathbf{I_{obs}})_k = \Sigma_i \left[(\mathbf{I_p})_\mathbf{i} + \mathbf{\Sigma_j} \alpha_\mathbf{j} \hat{\mathbf{G}}_\mathbf{ij} (\mathbf{I_p})_\mathbf{j} \right]$$

Empirical Fit

Leach & Petrosian 83, figure 4

- Directivity data good with θ but only 2 data points in ε.

- Linear fit between ε=22keV and ε=210keV



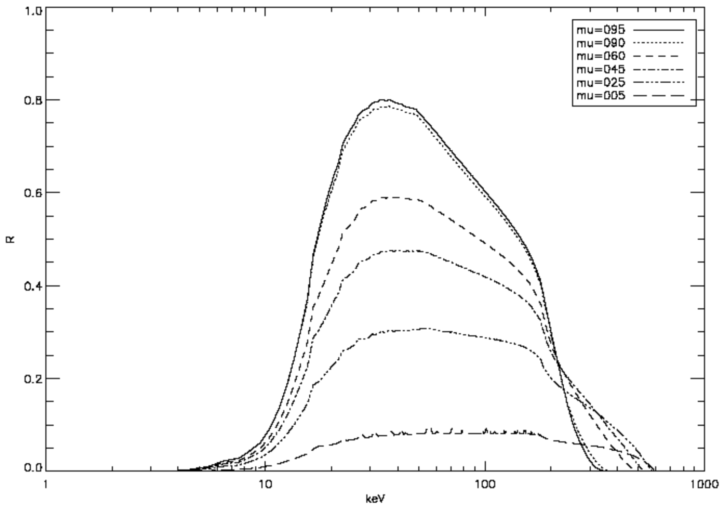
Linear Fit parameters

$D(\varepsilon) = (19/188)*\varepsilon+0.78$

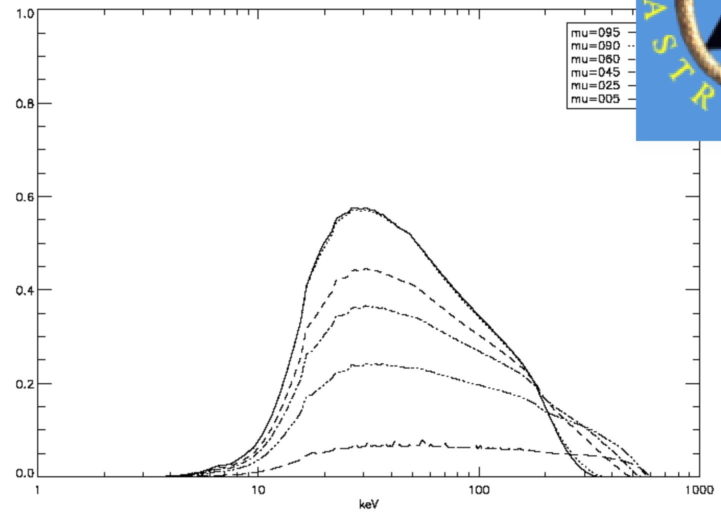
$\alpha(\varepsilon) = 1/(D(\varepsilon)+1)$

anisotropic, hemispheric approximation

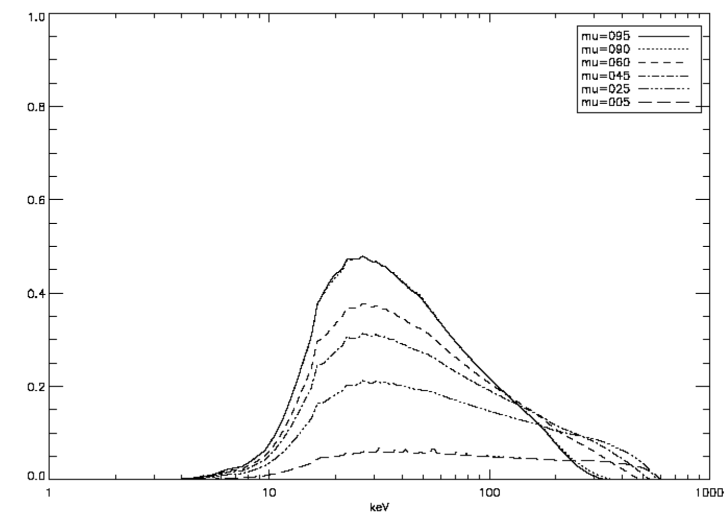
Greens hemispheric Approach



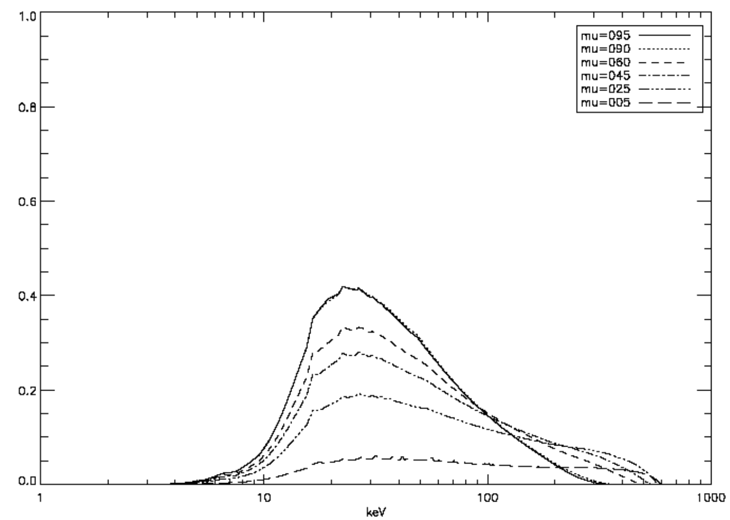
$\gamma=2$



$\gamma=3$



$\gamma=4$

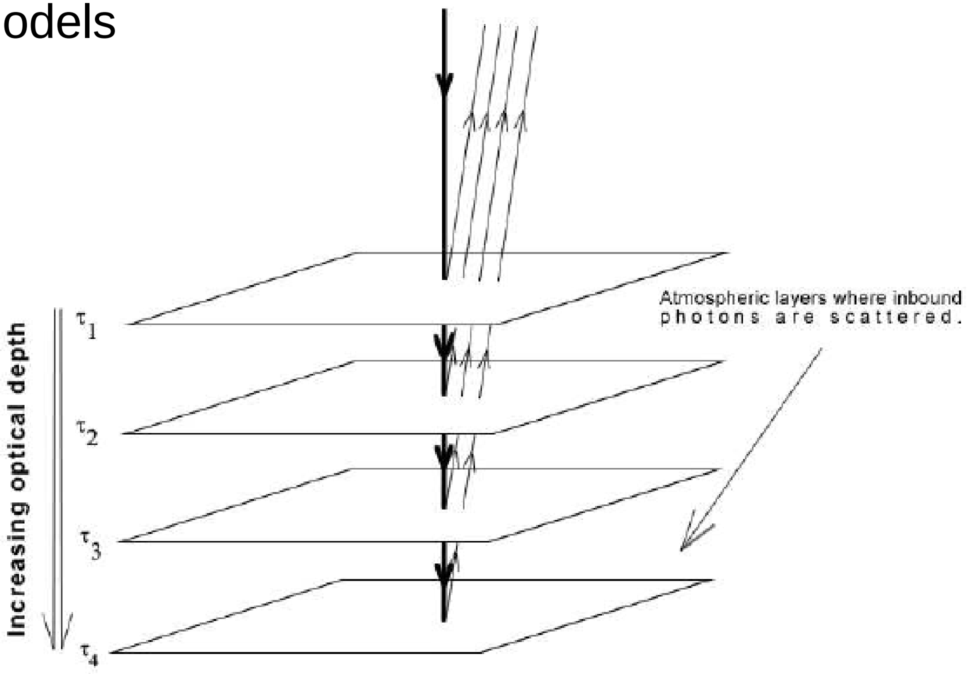


$\gamma=5$

Radiative Transfer Approach

Radiative Transfer Solution

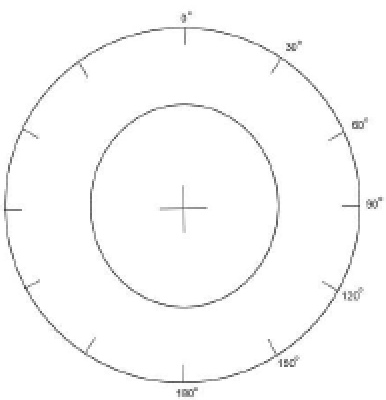
- Again developed for cosmic sources – Black holes
- Independent Greens function method
- Agrees with MZ95 in isotropic limit.
- Original assumption of isotropic emission but allows for anisotropic emission models



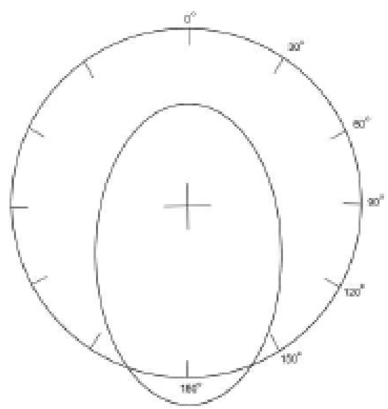
Radiative Transfer Approach

Photon emission model

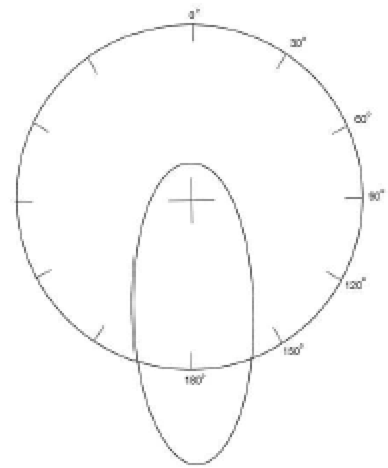
- I(ε) ⟹ I(ε,θ)



Isotropic emission (low ϵ)



anisotropic emission



Highly anisotropic emission (high ϵ)

Radiative Transfer Approach

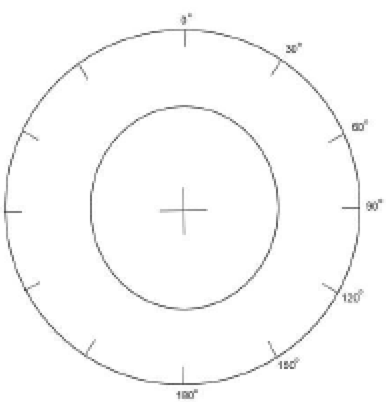
Empirical fit model

- $I(\theta)_\varepsilon = A_o\, \varepsilon^{-\gamma}\, (a_\varepsilon + b_\varepsilon \theta)^{\eta\varepsilon}$ at ε=22keV, ε=210keV

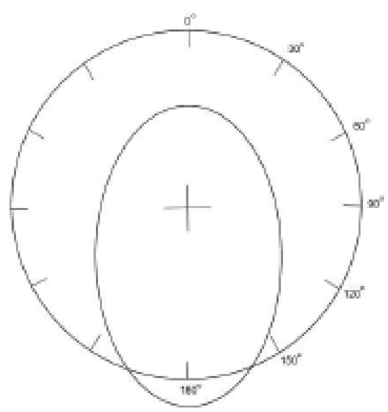
- Chi square fit – a_ε, b_ε & η_ε

$a(\varepsilon) = -(0.1/188)*\varepsilon+0.9$
$b(\varepsilon) = -(0.3/188)*\varepsilon-0.2$
$\eta(\varepsilon)=1.95$

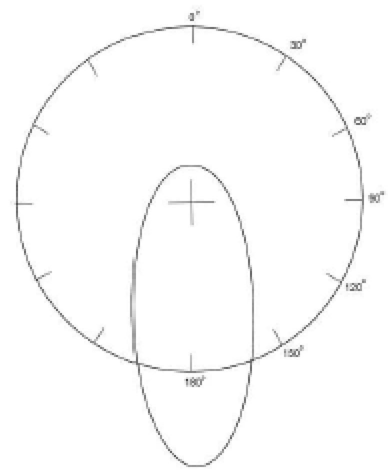
- $I(\theta)_\varepsilon$ -> $I(\varepsilon, \theta) = A_o\, \varepsilon^{-\gamma}\, (a(\varepsilon)+b(\varepsilon)\theta)^{\eta(\varepsilon)}$



Isotropic emission (low ϵ)



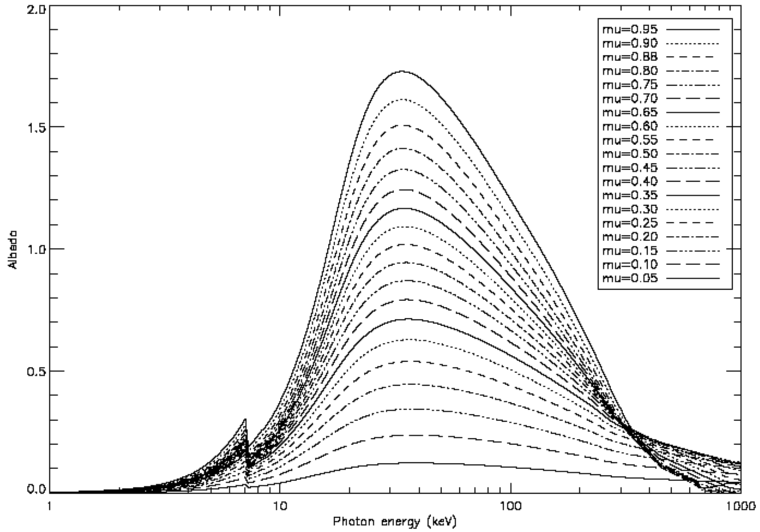
anisotropic emission

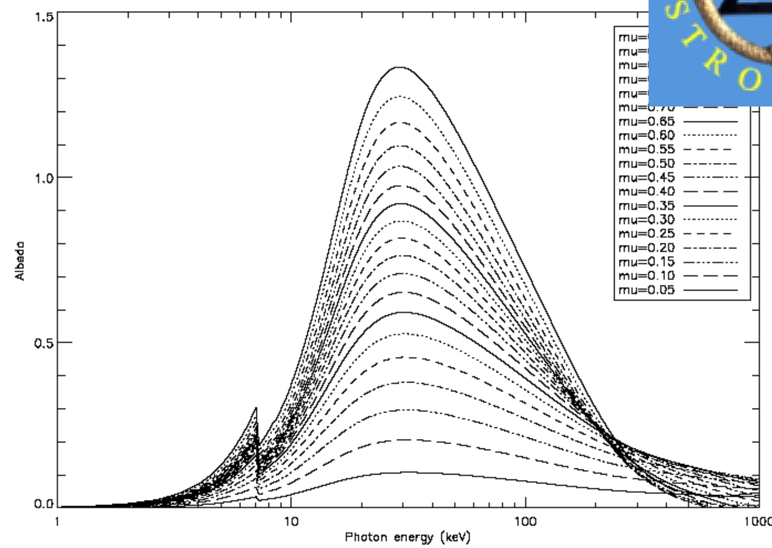


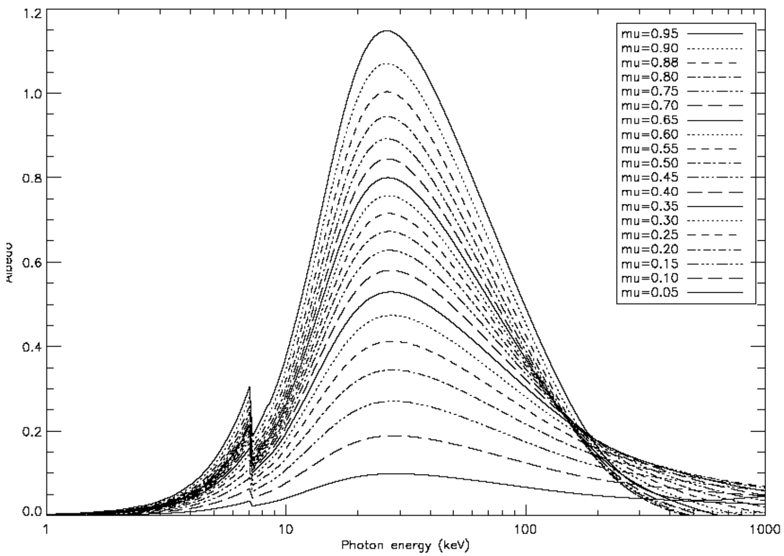
Highly anisotropic emission (high ϵ)

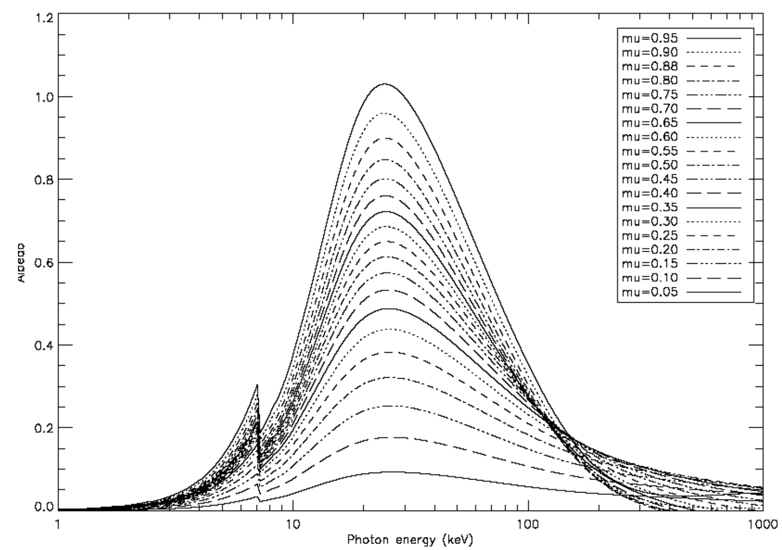
Radiative Transfer Approach

9th RHESSI Workshop, Genova, September 2009









http://www.astro.gla.ac.uk/calum/albedo

Radiative Transfer Approach

Gold Standard for Compton reflection?

- Full anistropic treatment
- Equivalent empirical fit – Leach & Petrosian data
- Anisotropic influence on albedo most noticeable for hard spectral indexes

Bivariate Inversion – Kontar & Brown 06

Stereoscopic Technique

- I(eps) observed at earth, in terms of a direct upward and backscattered downwards component at the flare source.

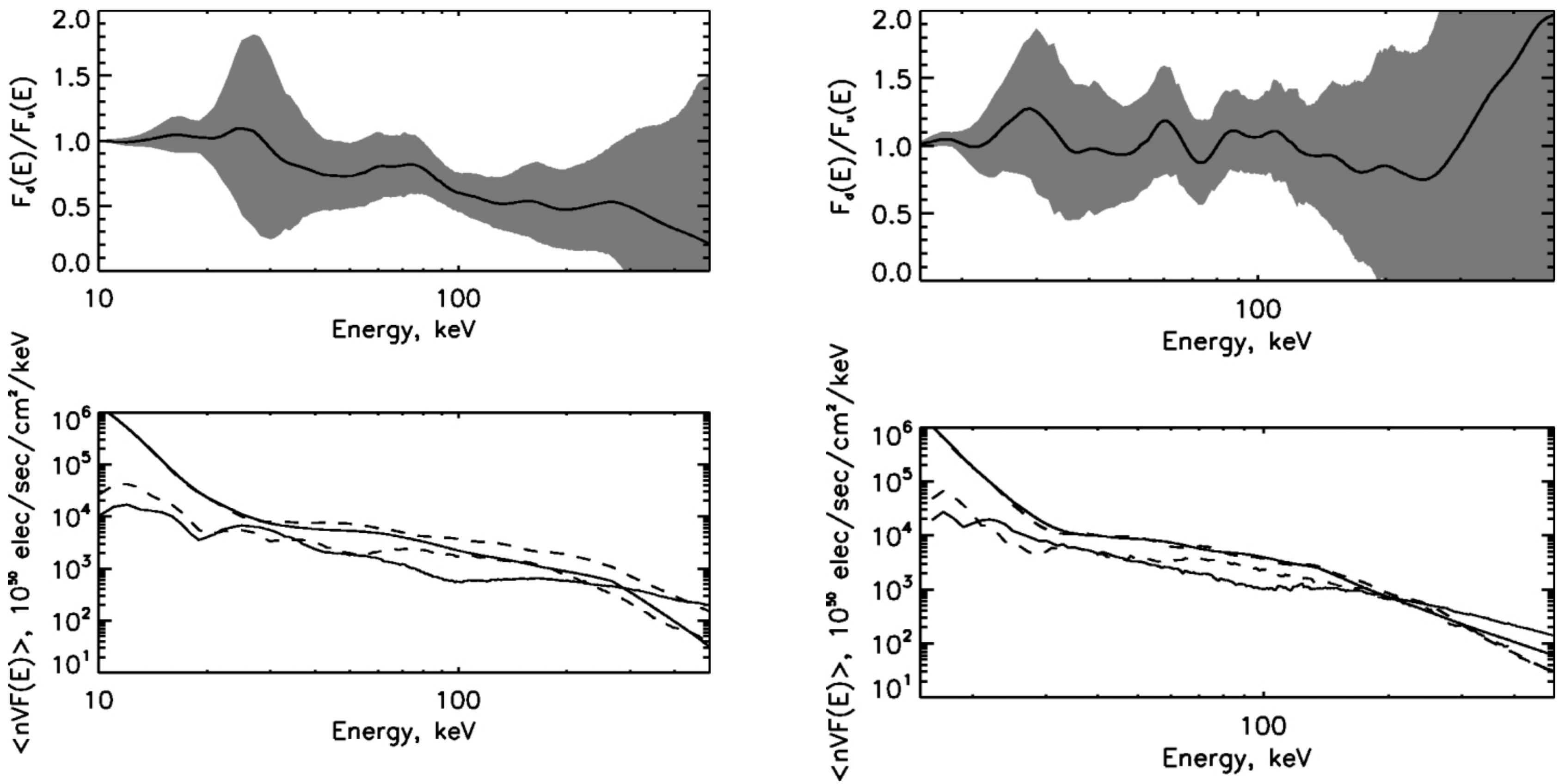
$$I_o(\epsilon) = \frac{\bar{n}V}{4\pi R^2}\int_{\epsilon}^{\infty}\left[Q_F(\epsilon, E)\bar{F}_u(E) + Q_B(\epsilon, E)\bar{F}_d(E)\right] dE$$

$$\bar{F}_{u,d} = (\bar{n}V)^{-1}\int F_{u,d}(E,r)n(r)dV$$

$$I_r(\epsilon) = \int_{\epsilon}^{\infty} G(\mu,\ \epsilon,\ \epsilon')I_d(\epsilon')d\epsilon', \quad I_r(\epsilon,\ \mu) = \frac{\bar{n}V}{4\pi R^2}\int_{\epsilon}^{\infty} G(\mu,\ \epsilon,\ \epsilon')\, d\epsilon' \int_{\epsilon'}^{\infty} [Q^F(\epsilon',\ E)\bar{F}_d(E) + Q^B(\epsilon',\ E)\bar{F}_u(E)]dE,$$

$$\boldsymbol{I} = \boldsymbol{I}_o + \boldsymbol{I}_r = (\boldsymbol{Q}^F + \boldsymbol{G}(\mu)\boldsymbol{Q}^B \quad \boldsymbol{Q}^B + \boldsymbol{G}(\mu)\boldsymbol{Q}^F)\begin{pmatrix}\bar{\boldsymbol{F}}_d \\ \bar{\boldsymbol{F}}_u\end{pmatrix}$$

Stereoscopic Approach

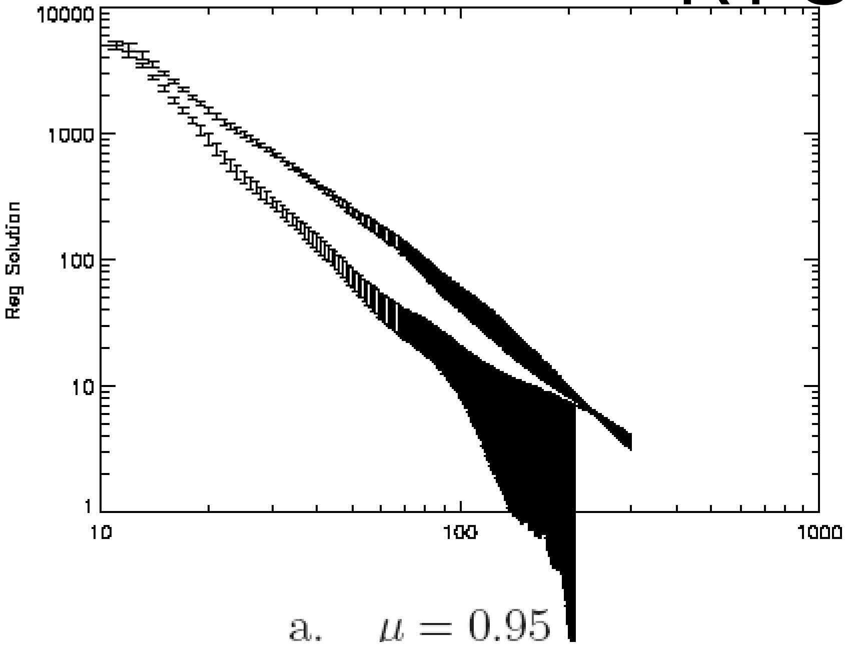


Results

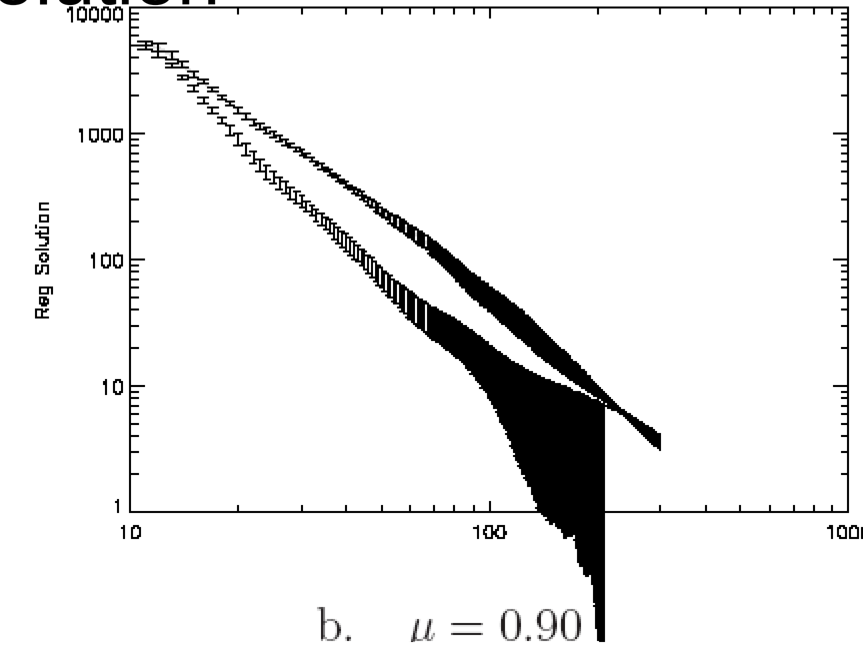
Stereoscopic Technique

- KB technique used as a black box, for $I(\varepsilon,\mu)_{radiative}$ vs $I(\varepsilon,\mu)_{hemisphere}$

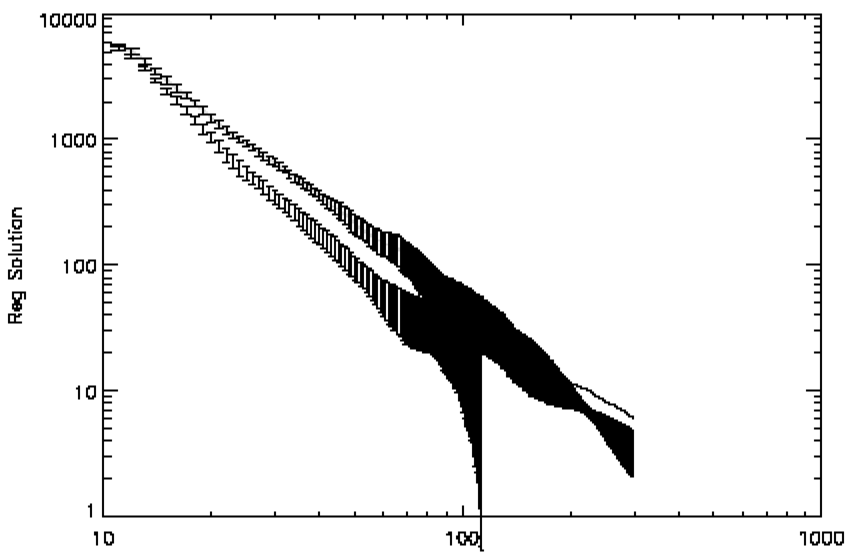
RT Solution



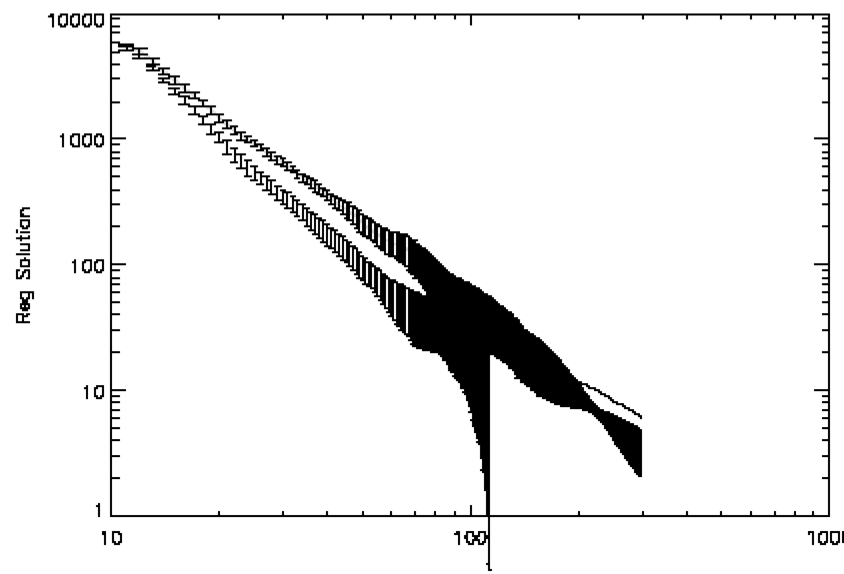
a. $\mu = 0.95$



b. $\mu = 0.90$

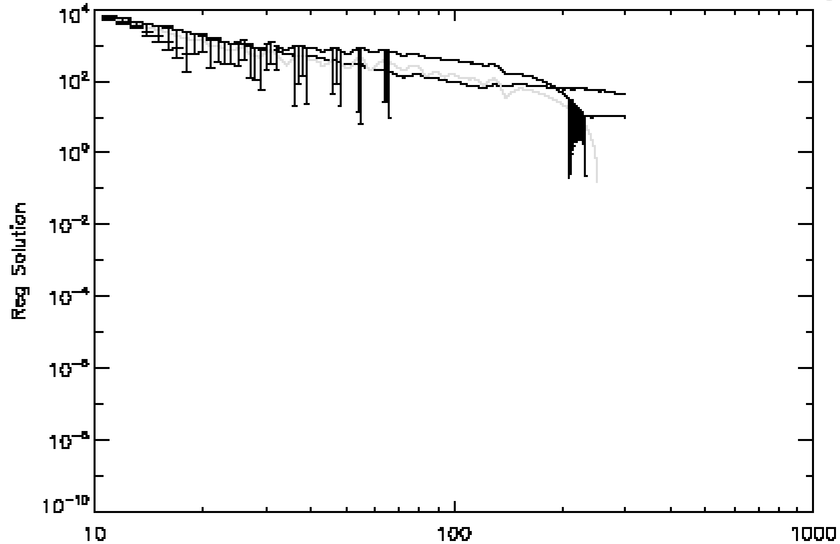


a. $\mu = 0.95$

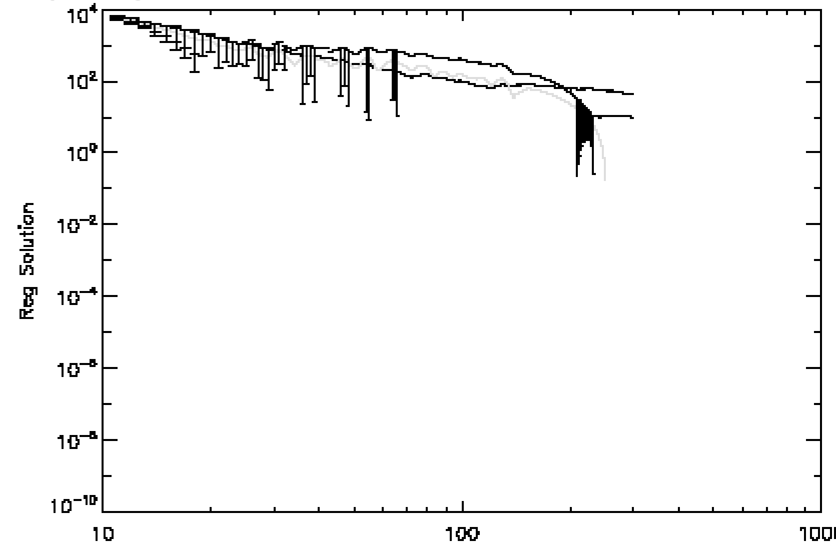


b. $\mu = 0.90$

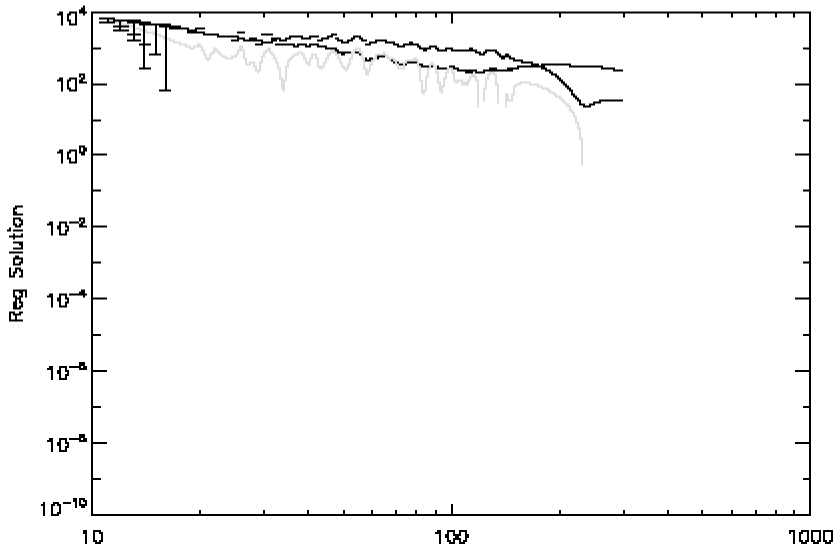
RT Solution



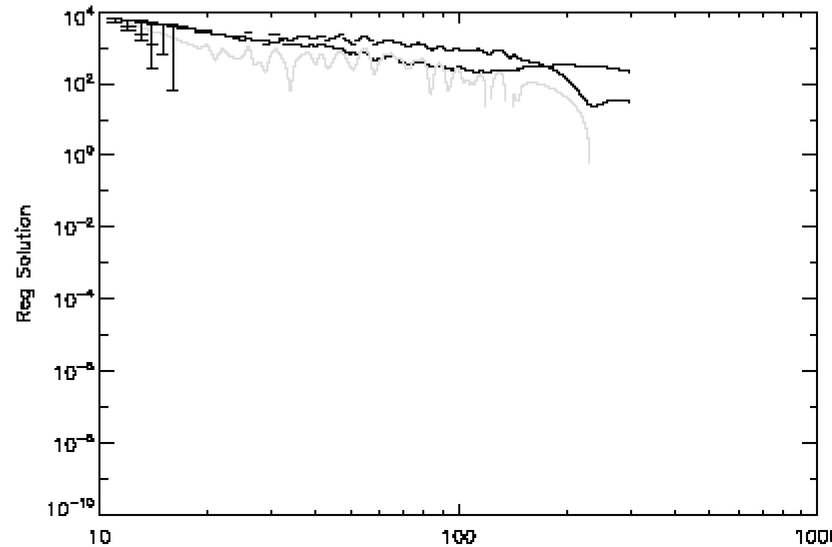
a. $\mu = 0.95$



b. $\mu = 0.90$

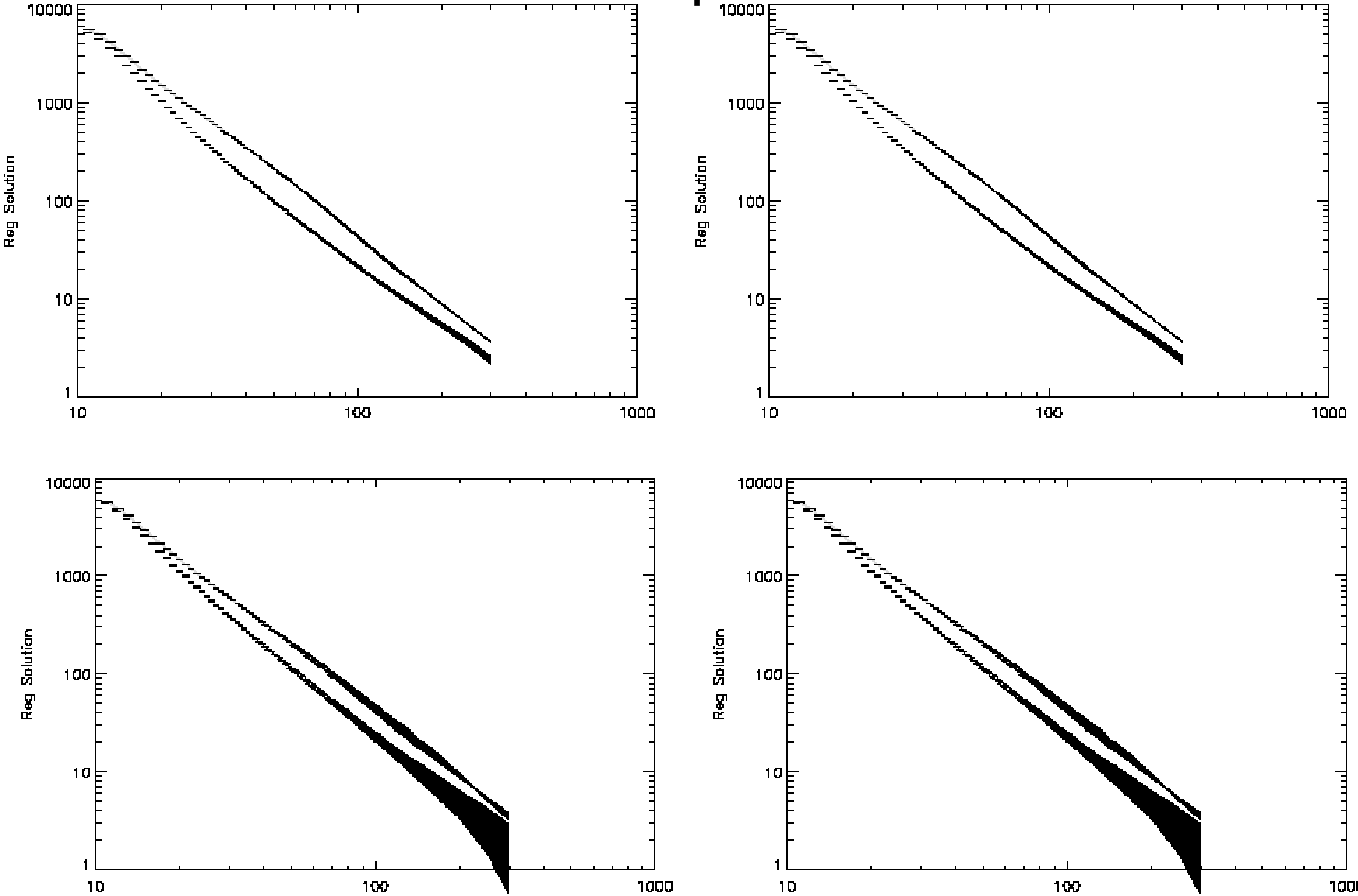


a. $\mu = 0.95$



b. $\mu = 0.90$

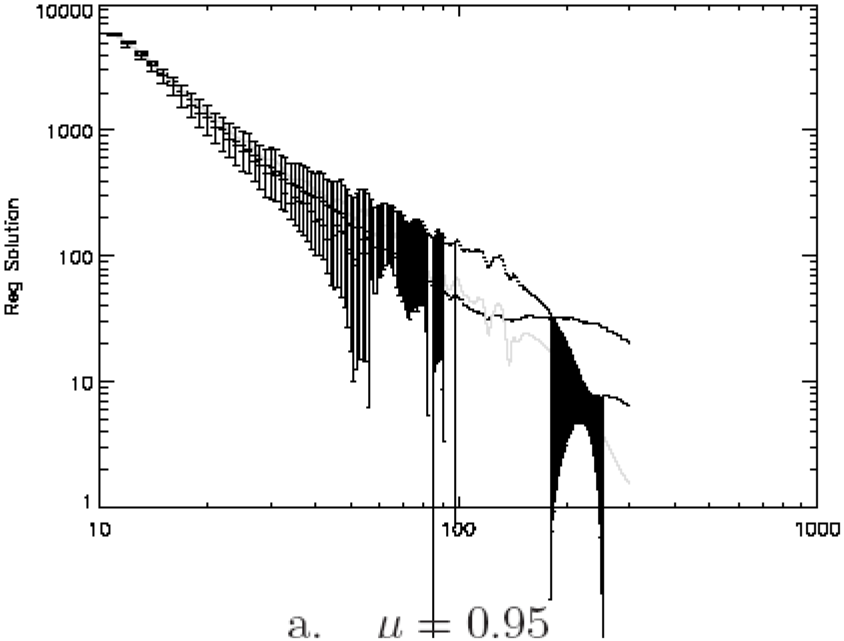
Hemispheric



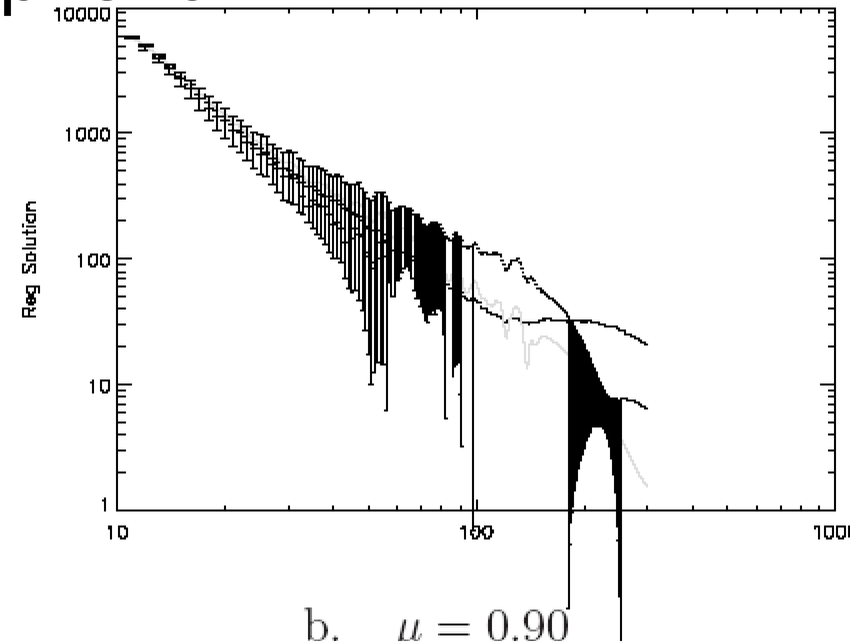
a. $\mu = 0.95$

b. $\mu = 0.90$

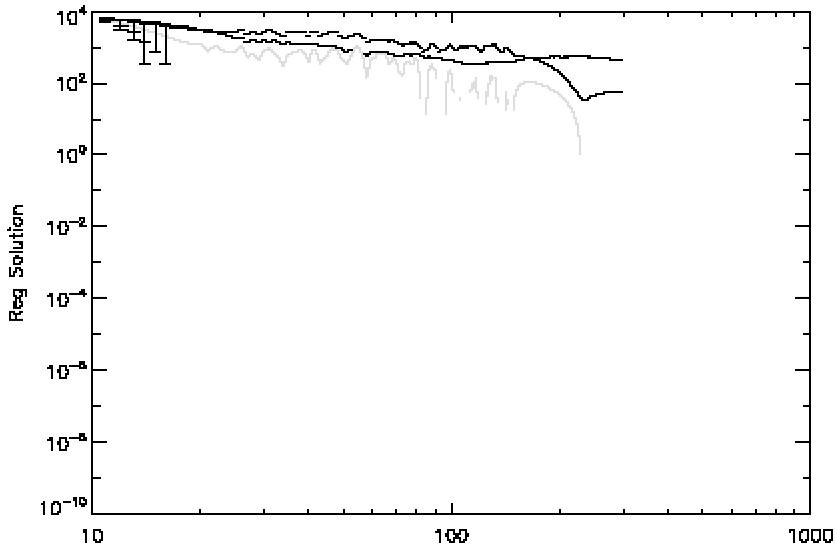
Hemispheric



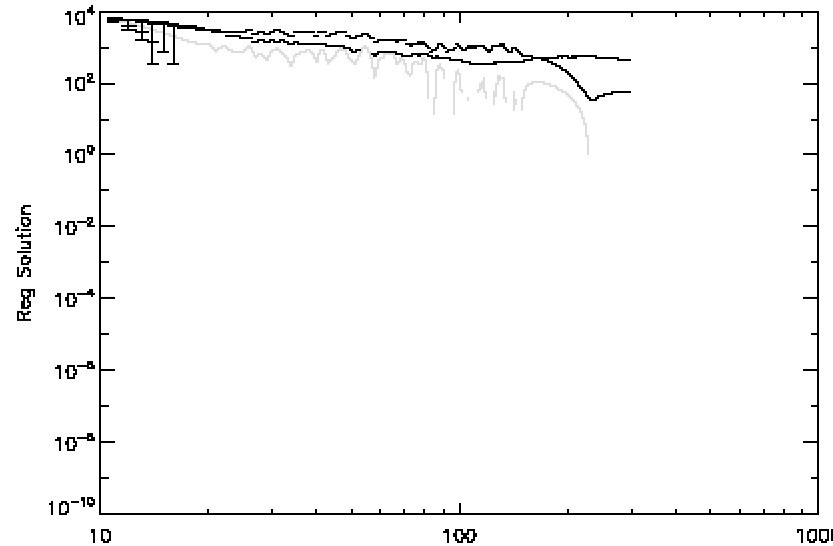
a. $u = 0.95$



b. $u = 0.90$



a. $\mu = 0.95$



b. $\mu = 0.90$

Results & Conclusions

Results

- Results are similar between methods
- solutions worsen with increasing γ
- Errors in RT poorer than hemispheric method

What does this tell us?

- Using a full radiative transfer approach does not alter the conclusions of Kontar & Brown 06

Comparison – Hemispheric vs Full Radiative Transfer solutions

Isotropic, mu=0.95