Watching dark matter stars burn

Possible signatures of Dark Stars in the EBL density

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Outline

Dark (matter powered) stars

Ingredients for Dark Stars (DS)

- Self-annihilating dark matter e.g. WIMPs ($m_\chi = 1\,\text{GeV} - 10\,\text{TeV}$, $\langle\sigma v\rangle_{ann} = 3 \cdot 10^{-26}\,\text{cm}^3\,\text{s}^{-1}$)
- High dark matter density inside a star
- $L_{DM} \sim \frac{2}{3} \int \rho_\chi^2 \frac{\langle\sigma v\rangle_{ann}}{m_\chi} \mathrm{d}V > L_{nuclear}$
- $\rightarrow$ First stars are good candidates! (Spolyar *et al.* 2008; Iocco *et al.* 2008)

Two different physical mechanisms of DS formation

- Adiabatic Contraction: DS formation during proto-star collaps due to gravitational pull
- DM Capture: scattering processes enhances DM density
- $\rightarrow$ resulting DS can have similar features regardless of formation process

Overview Dark Stars

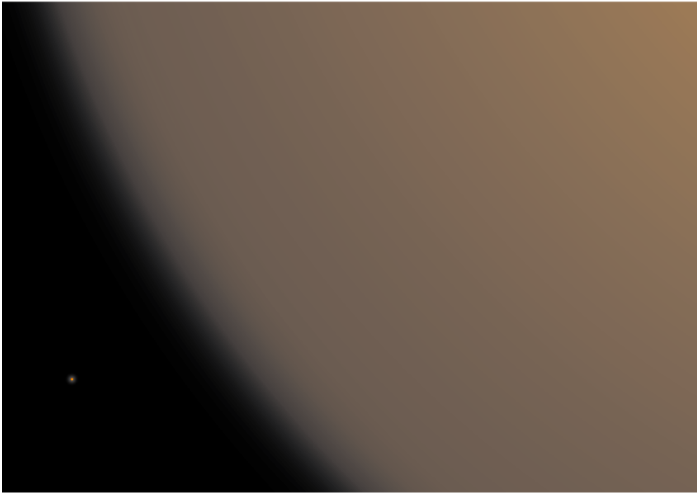


Figure: Sketch of a Dark Star next to a “normal” star (picture by T. Kneiske)

Properties of DS

	Sun	Dark Stars
T	$5778\,\mathrm{K}$	$\sim 5000 - 10000\,\mathrm{K}$
L	$3.8 \cdot 10^{33}\,\mathrm{erg\,s^{-1}}$	$\sim 10^{5-7}\,L_\odot$
R	$7 \cdot 10^{5}\,\mathrm{km}$	$\sim 1 - 10\,\mathrm{AU} \approx 1.5 \cdot 10^{8-9}\,\mathrm{km}$
M	$2 \cdot 10^{30}\,\mathrm{kg}$	$\sim 500 - 1000\,M_\odot$
Δt	$\sim 4.5 \cdot 10^{9}$ years	$\sim 10^{5-9}$ years
$\log_{10}(g)$	$4.44\,\log_{10}(\mathrm{cm\ s^{-2}})$	~ -0.7 to $5.5\,\log_{10}(\mathrm{cm\ s^{-2}})$

Dark Stars in the EBL

Why the extragalactic background light?

- Direct detection can be very difficult (Zackrisson *et al.* 2010a)
- Our approach: extragalatic background light (EBL)
- EBL is isotropic, diffuse radiation field between $\sim 0.1 - 100\,\mu$m containing informations of star formation history
- Signatures of Dark Stars in the EBL density opens new wavelength range for indirect dark matter search
- Advantage: EBL is sensitive to many **faint** sources
- Disadvantage: EBL is sensitive to **many** faint sources

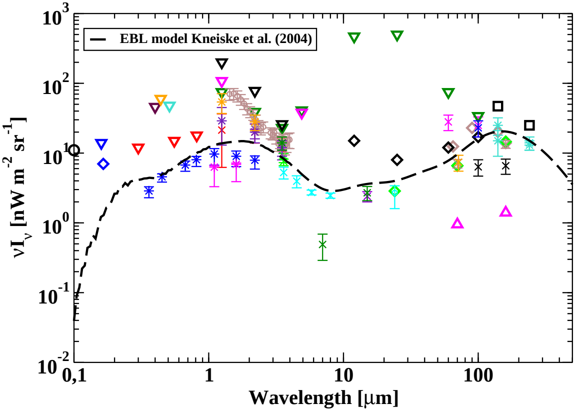


Figure: EBL data based on a collection by Mazin & Raue (2007) updated regularly, EBL model by Kneiske *et al.* (2004)

- Integrated, redshifted em-radiation from all epochs
- Direct measurements, lower limits, upper limits
- Peaks: $\sim 1\,\mu$m (stars) and $\sim 100\,\mu$m (dust)

EBL contribution model: Emissivity

Method

- Calculating the (possible) contribution from Dark Stars to the EBL density
- using a Forward evolution model (see e.g. Hauser & Dwek 2001), assuming minimal radiative transfer (e.g. no reprocessing)
- Concordance ΛCDM cosmological model

Emissivity - comoving luminosity density

$$\begin{aligned}
\varepsilon_\nu(z) &= \int_{z}^{z_{max}} L_\nu(t(z) - t(z'))\dot{\rho}_*(z') \left| \frac{\mathrm{d}t}{\mathrm{d}z'} \right| \mathrm{d}z' \\
L_\nu(t(z) - t(z')) &= L_\nu = \text{constant for } t(z) - t(z') \leq \Delta t_{DS} \\
\dot{\rho}_*(z) &= \mathrm{SFR}_{Norm}[\Theta(z - z_{min}) - \Theta(z - z_{max})]
\end{aligned}$$

Dark Star spectra calculated with PHOENIX (Hauschildt *et al.* 1997)

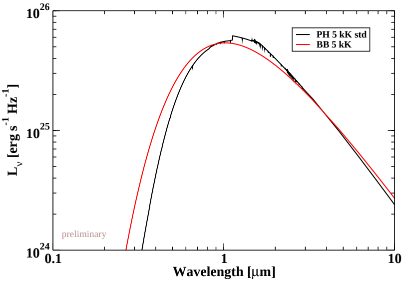


Figure: Dark Star spectrum calculated with PHOENIX vs blackbody with $T_{DS} = 5000\,\mathrm{K}$, $M_{DS} = 106\,\mathrm{M}_\odot$, $R_{DS} = 2.4 \times 10^{12}\,\mathrm{m}$

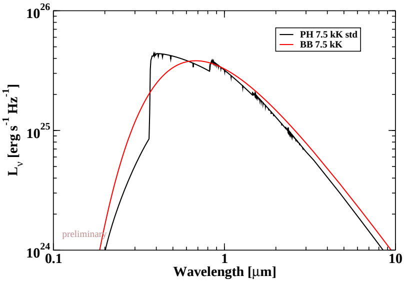


Figure: Dark Star spectrum calculated with PHOENIX vs blackbody with $T_{DS} = 7500\,\mathrm{K}$, $M_{DS} = 690\,\mathrm{M}_\odot$, $R_{DS} = 1.1 \times 10^{12}\,\mathrm{m}$

DS parameters from Spolyar *et al.* (2009)

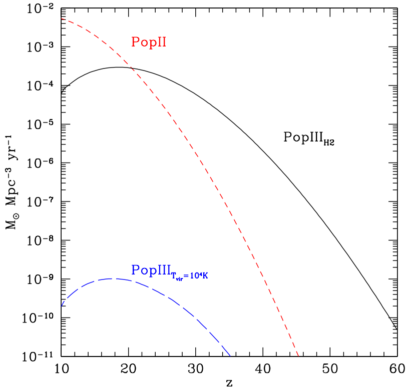


Figure: POP III SFR from Trenti & Stiavelli (2009)

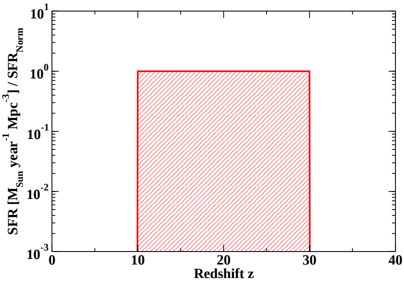
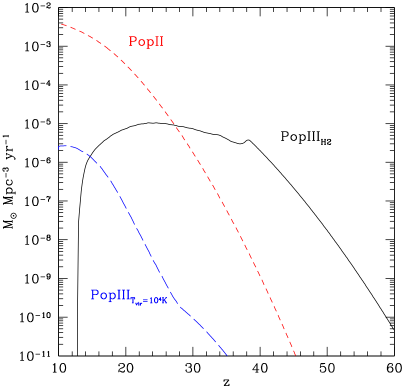


Figure: Model assumption used here

Star formation rates: Our model vs. simulations



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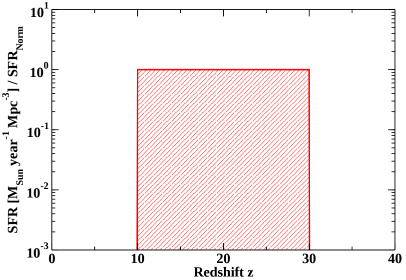

Figure: Model assumption used here

EBL density - redshifted integrated luminosity density

$$
\begin{aligned}
P_\nu(z) &= \nu I_\nu(z) = \nu \frac{c}{4\pi} \int_z^{z_{max}} \varepsilon_{\nu'}(z') \left| \frac{\mathrm{d}t}{\mathrm{d}z'} \right| \mathrm{d}z' \\
\nu' &= \nu \left(\frac{1+z'}{1+z} \right)
\end{aligned}
$$

Cosmological parameters

$$
\begin{aligned}
\left| \frac{dt}{dz} \right| &= \frac{1}{H_0(1+z)E(z)} \\
E(z)^2 &= \Omega_r(1+z)^4 + \Omega_m(1+z)^3 + \Omega_k(1+z)^2 + \Omega_\Lambda
\end{aligned}
$$

$H_0\,[\mathrm{km\,s^{-1}\,Mpc^{-1}}]$	Ω_r	Ω_m	Ω_k	Ω_Λ
70	0	0.3	0	0.7

Calculation of the EBL signatures of Dark Stars

Method

- Calculate the EBL density $P_\nu(z)$ for $z = 0$ (today's universe)
- Choose parameters and determine their contribution to the EBL density
- Build some minimum/maximum scenarios and compare them to the data
- Exclude extreme sets of parameters

Dark Star parameter space

Parameters

- DS Lifetime = $10^5 - 10^9$ years
- Minimum redshift $z_{min} = 5 - 15$ (see e.g. Trenti *et al.* 2009; Maio *et al.* 2010)
- (D)SFR$_{Norm}$ = $10^{-7} - 10^{-3} \times$ M$_\odot$ year^{-1} Mpc^{-3} (obtained by using POP III SFR from Trenti & Stiavelli 2009)
- Luminosity to mass ratio = $10^2 - 10^5 \times$ L$_\odot$ / M$_\odot$ (calculated from different DS models by Iocco *et al.* 2008; Spolyar *et al.* 2009; Freese *et al.* 2010)
- More spectra of DS to be calculated with PHOENIX $\rightarrow$ work in progress
- $\rightarrow$ Delivers huge parameter space volume for input parameters

Effect of different DS formation rates

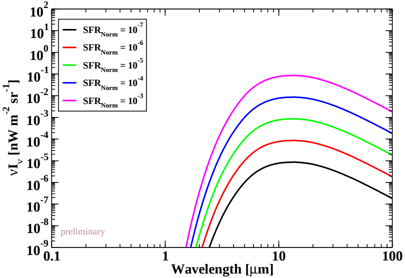

Figure: Dark Star EBL contribution for DS:

$T_{DS} = 5000\,\mathrm{K}$, $M_{DS} = 106\,\mathrm{M}_\odot$, $R_{DS} = 2.4 \times 10^{12}\,\mathrm{m}$

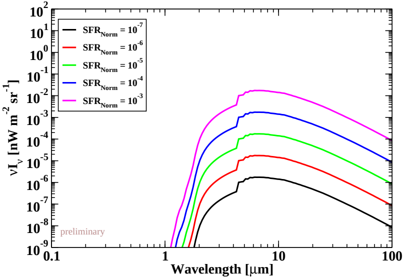

Figure: Dark Star EBL contribution for DS:

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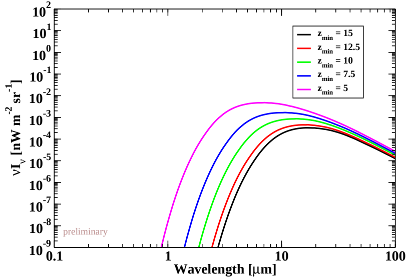

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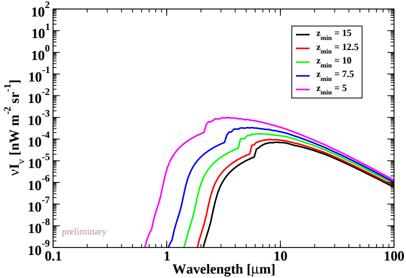

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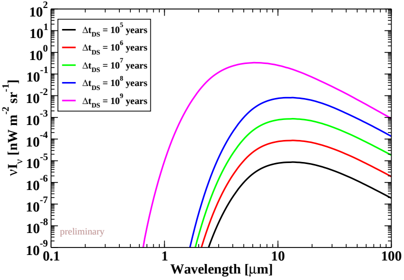
Effect of different DS lifetimes



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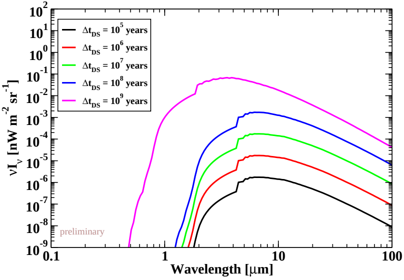

Figure: Dark Star EBL contribution for DS:

$T_{DS} = 7500\,\text{K}$, $M_{DS} = 690\,\text{M}_\odot$, $R_{DS} = 1.1 \times 10^{12}\,\text{m}$

Calculated EBL density

Maximum EBL density [$\mathrm{nW\,m^{-2}\,sr^{-1}}$]

	5 kK DS	7.5 kK DS
Minimal $z_{min} = 15,\ \mathrm{SFR}_{Norm} = 10^{-7},\ \Delta t_{DS} = 10^5\,years$	$\sim 3.5 \times 10^{-8}$	$\sim 7.2 \times 10^{-9}$
Medium $z_{min} = 10,\ \mathrm{SFR}_{Norm} = 10^{-5},\ \Delta t_{DS} = 10^7\,years$	$\sim 8.2 \times 10^{-4}$	$\sim 1.7 \times 10^{-4}$
Maximum $z_{min} = 5,\ \mathrm{SFR}_{Norm} = 10^{-3},\ \Delta t_{DS} = 10^9\,years$	~ 63	~ 13

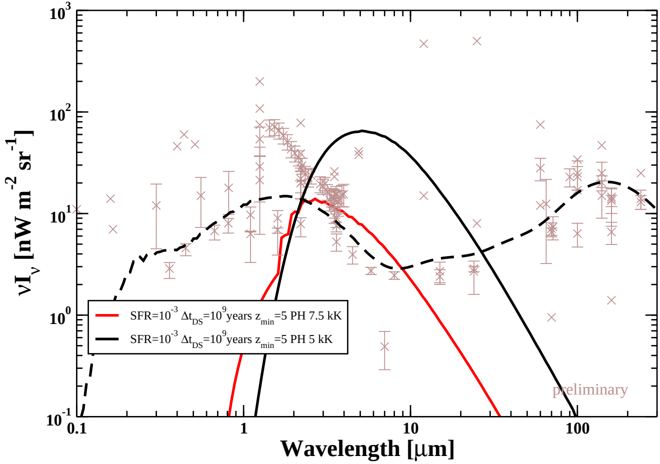

Figure: Maximum EBL contribution scenarios of DS parameters, EBL model by Kneiske *et al.* 2004 (black dashed line)

Supermassive Dark Stars (SMDS)

Extreme SMDS

- Recently SMDS ($10^5 - 10^7\,M_\odot$)were proposed by Freese *et al.* (2010)
- Calculate EBL density of SMDS
  - DSFR = Halo formation rate ($10^8\,M_\odot\,DM - halo$) $\times\,M_{DS}$ (see Zackrisson *et al.* 2010b)
  - Halo formation rate = $\sim 10^{-8}$ halos year^{-1} Mpc^{-3}
  - $\rightarrow$ DSFR = 0.1 $M_\odot$ year^{-1} Mpc^{-3}
- $\Delta t_{DS} = 10^9 years$
- Assumption: SMDS formed at $z = 30$, accrete mass till $z = 15$ ($\sim 10^8$ years)
- Zackrisson *et al.* (2010b) put constraints on SMDS from direct detections

Exclusion of SMDS

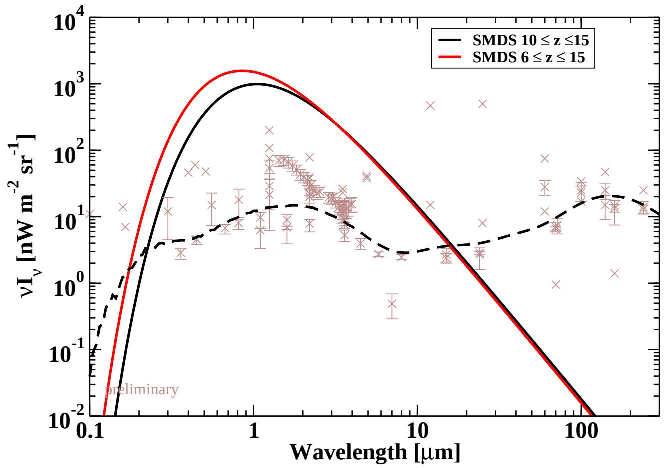

Figure: EBL contribution of SMDS: $T_{DS} = 27000\,\mathrm{K}$, $M_{DS} = 10^7\,\mathrm{M}_\odot$, $R_{DS} = 1.5 \times 10^{13}\,\mathrm{m}$ (Freese *et al.* 2010)

Results and summary

Summary & Outlook

- EBL offers a new possibility to search for DS / constrain DS paramter space
- Calculated contributions from DS to the EBL density range from $\sim 10^{-9}$ to $\sim 60\,\mathrm{nW\,m^{-2}\,sr^{-1}}$
- Advantage: faint DS can contribute to EBL density
- Disadvantage: enough DS are required
- Some (extreme) parameter sets of DS can be excluded
- New data of the EBL density (e.g. JWST, CIBER) will provide further constraints
- Paper is coming soon!

Workshop announcement

International workshop on
"Cosmic Radiation Fields: Sources in the early Universe"

Date: November 9 - 12, 2010
Location: DESY research center, Hamburg, Germany
Website: http://www.desy.de/crf2010

Thank you for your attention!

References I

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Backup slides I

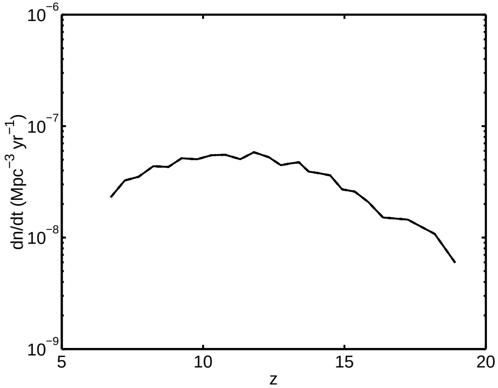


Figure: Comoving halo formation rate for 1-2 $\times 10^8$ DM-halos (Zackrisson *et al.* 2010b)

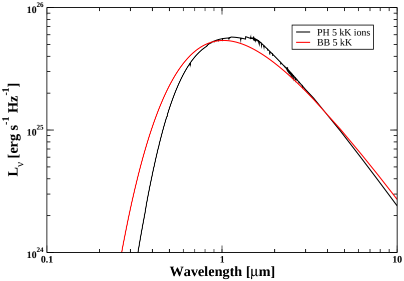
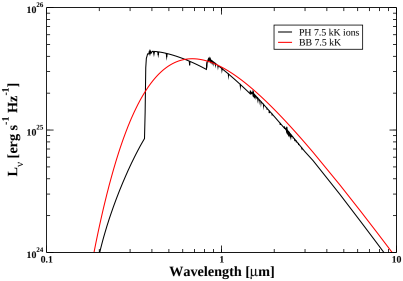


Figure: Dark Star spectrum calculated with PHOENIX vs blackbody with $T_{DS} = 5000\,\mathrm{K}$, $M_{DS} = 106\,\mathrm{M}_\odot$, $R_{DS} = 2.4 \times 10^{12}\,\mathrm{m}$



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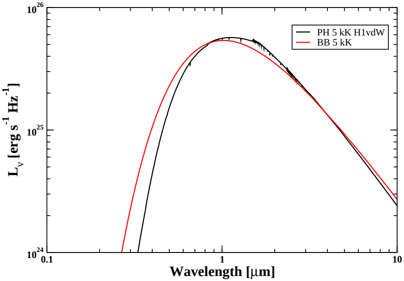
Backup slides III



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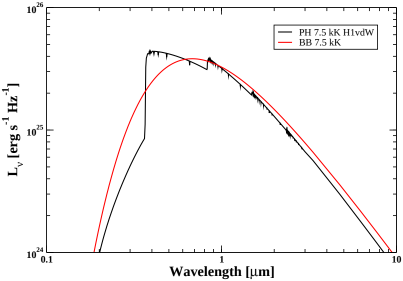

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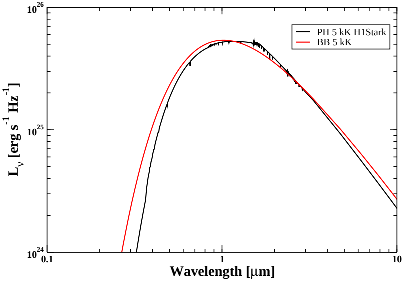
Backup slides IV



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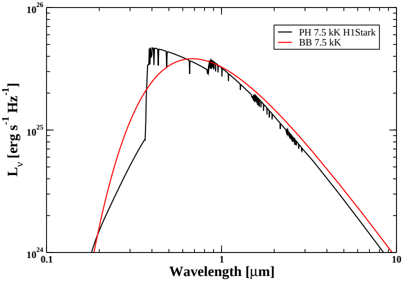

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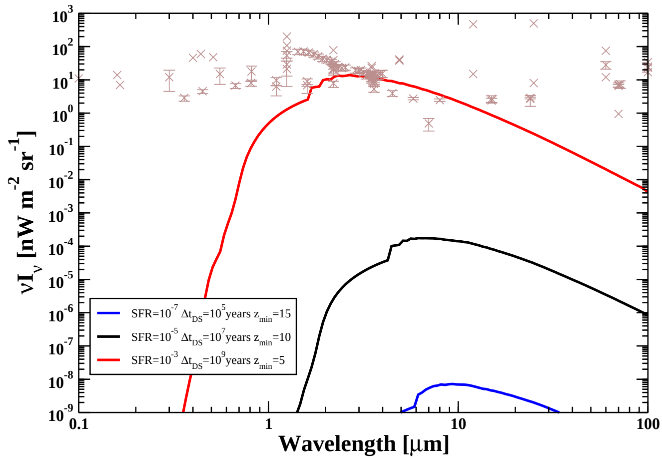

Figure: PH 7.5 kK EBL vs. data

Backup slides VI

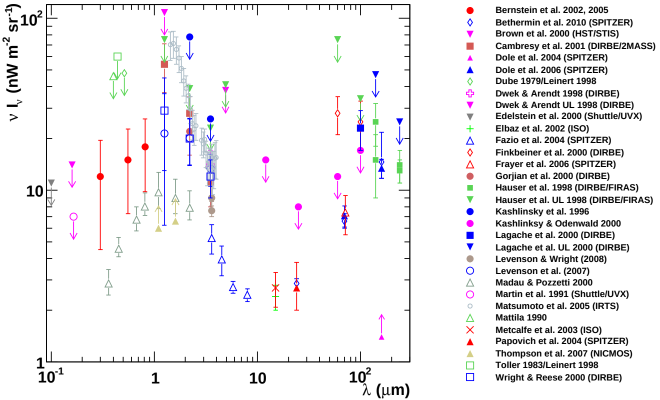

Figure: taken from Mazin & Raue (2007), updated regularly

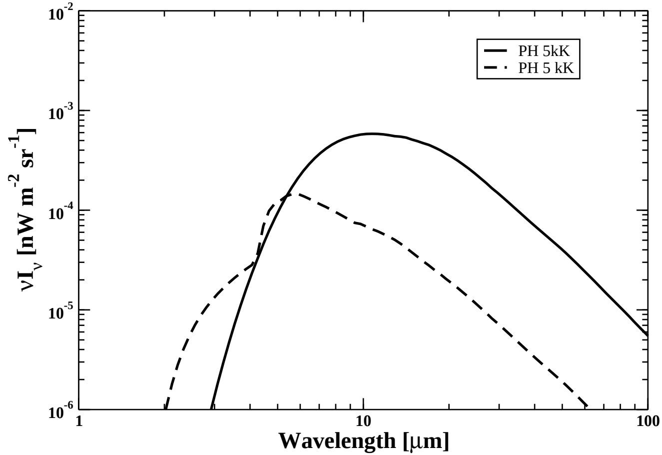

Figure: EBL density: PH 5kK vs. PH7.5 kK