Energetic processing of complex carbonaceous compounds

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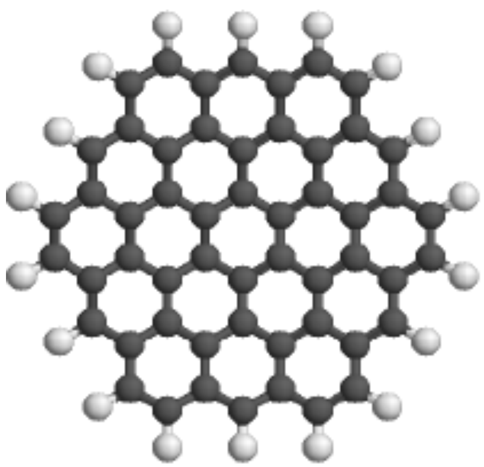
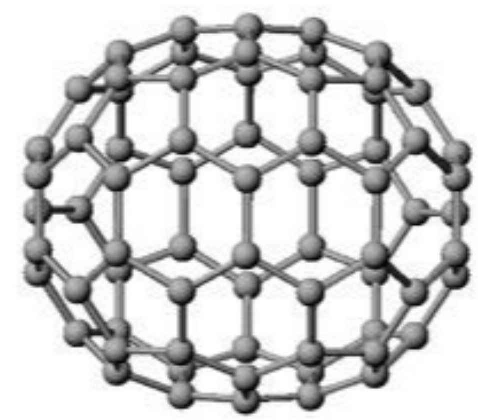
Complex carbon compounds

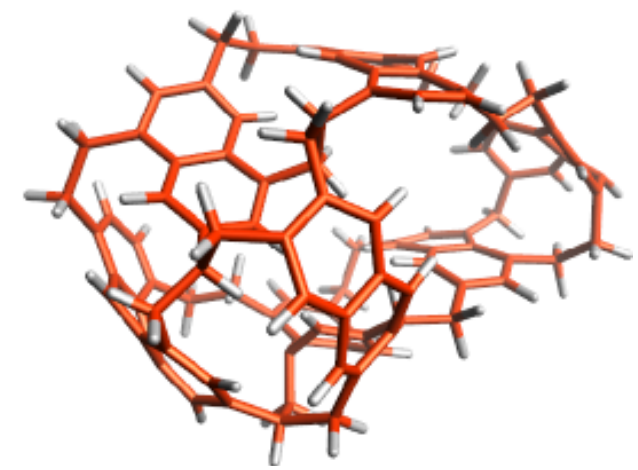


PAHs

C_{60}



C_{70}



a-C:H nanoparticles

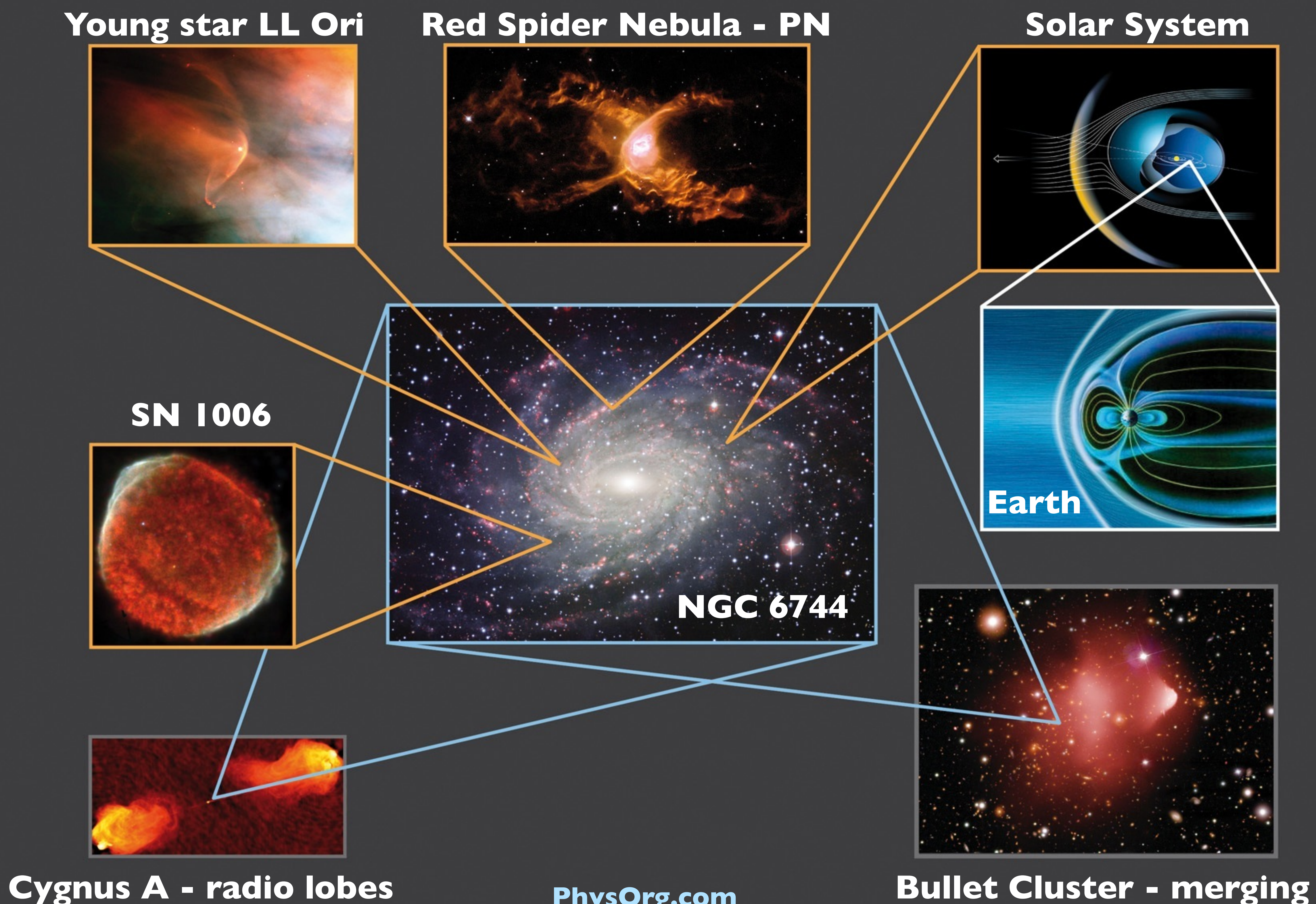
Energetic processing

How? → Processing occurs via **interactions** with these projectiles

Ions & Electrons
(H, He, CNO) →
E = 10 eV - 3 keV
E = 5 - 50 eV
E = 10 eV - 10 keV
E = 5 MeV/nuc - 10 GeV

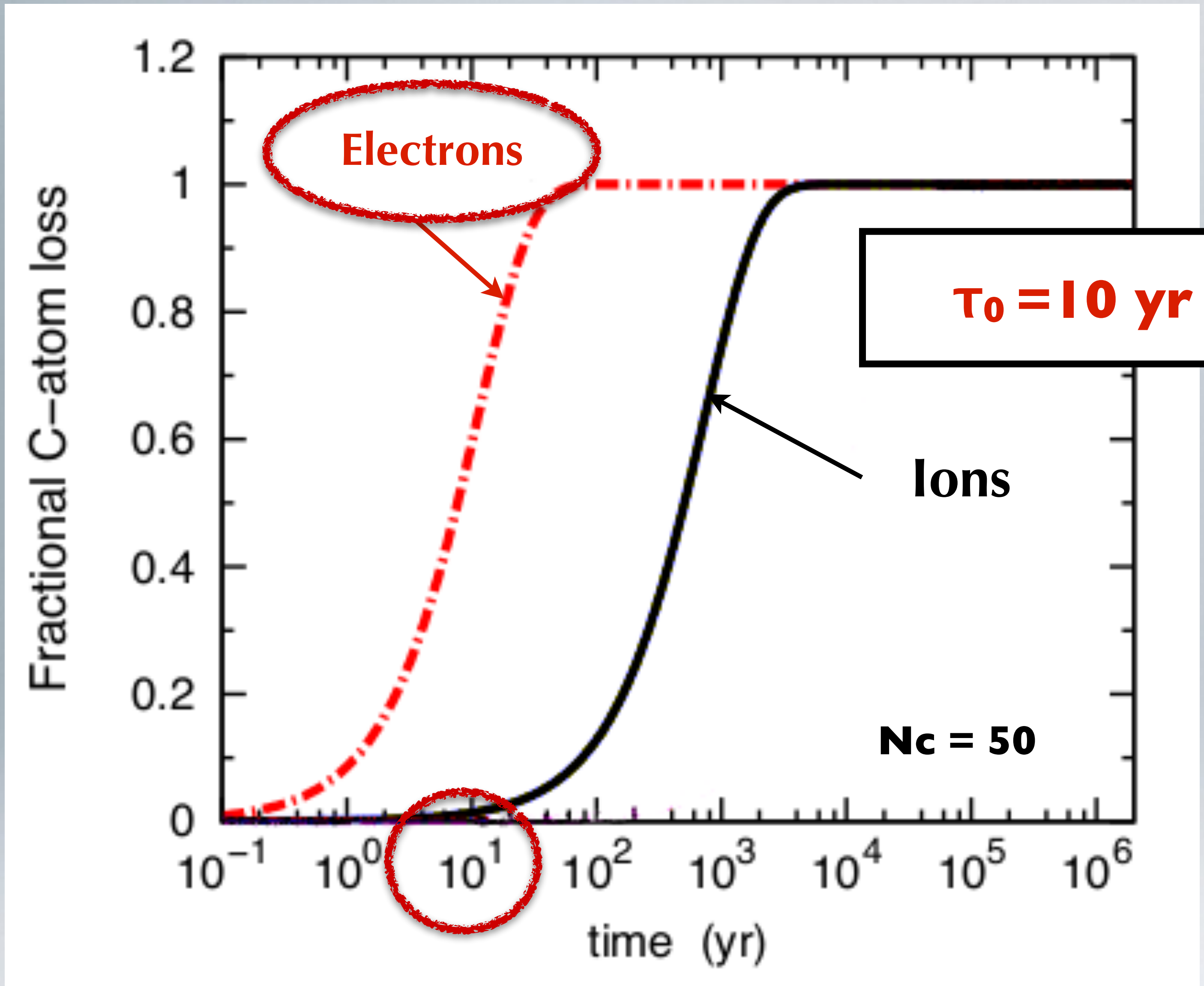
Photons →
UV: **E= 6 - 15 eV**
X-rays: **E = 0.3 - 10 keV**

Where?



PhysOrg.com
NASA/ESA, Hubble Heritage

PAHs in hot shocked gas: M82



$\tau_0 = 10$ yr

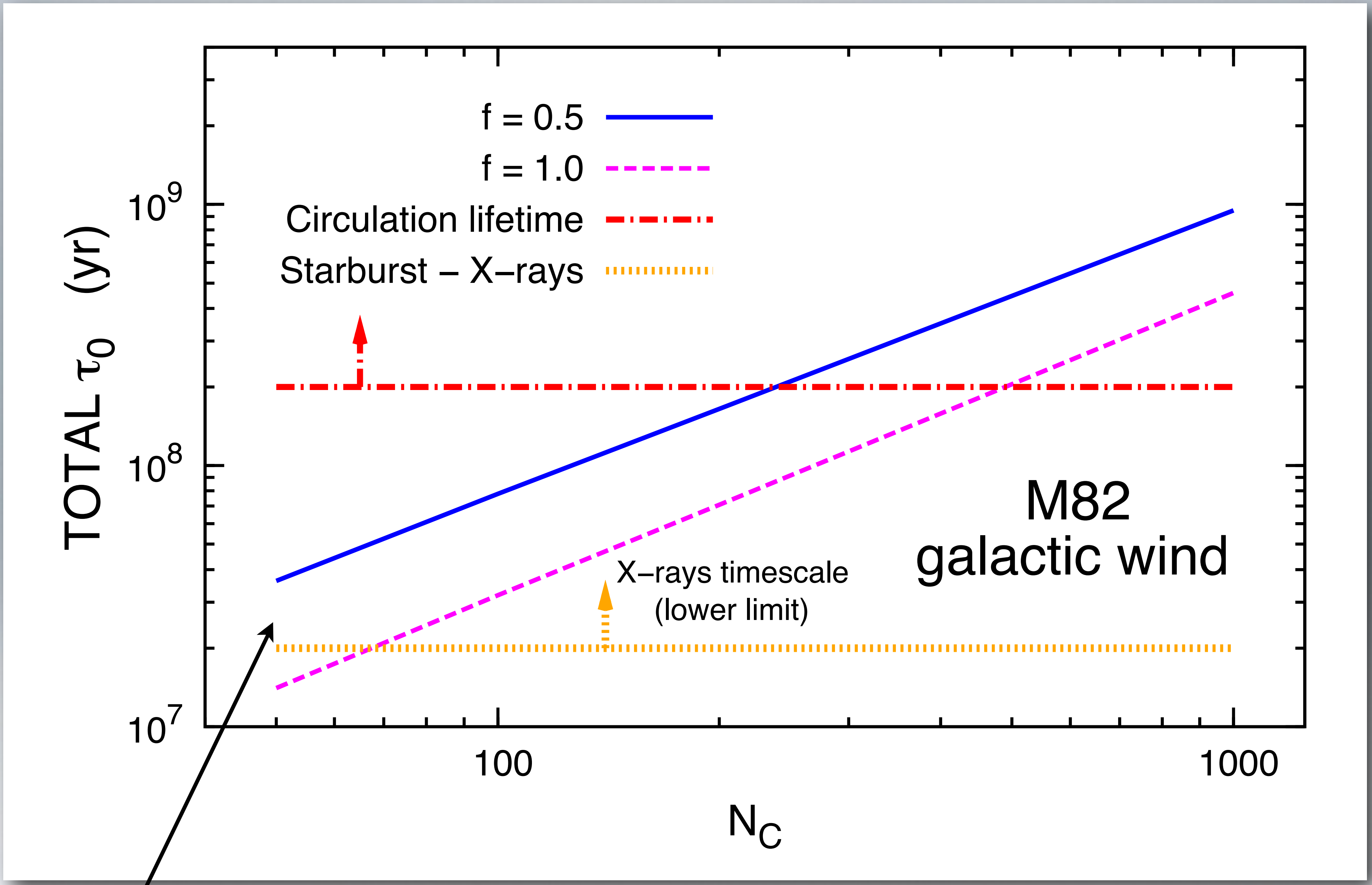
v_{SHOCK} ~ 600 km/s

Temperature of gas**:**
T ~ 5.8x10^6 K
Thermal motion**: E = 500 eV**

*Adapted from **Micelotta** et al. 2010b, A&A, 510, A37*

Destroyed unless protected

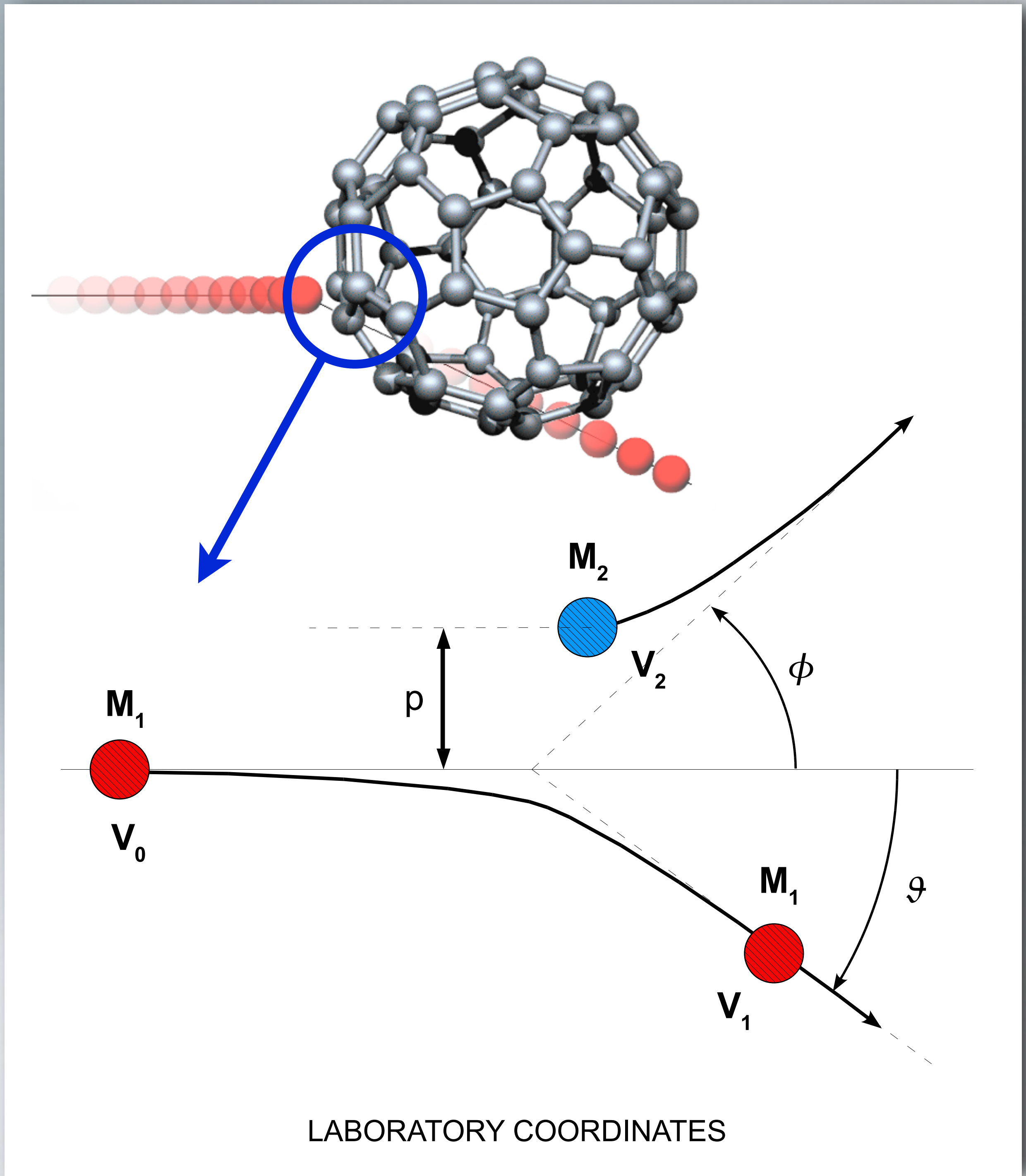
PAHs in M82: add X-rays + CRs

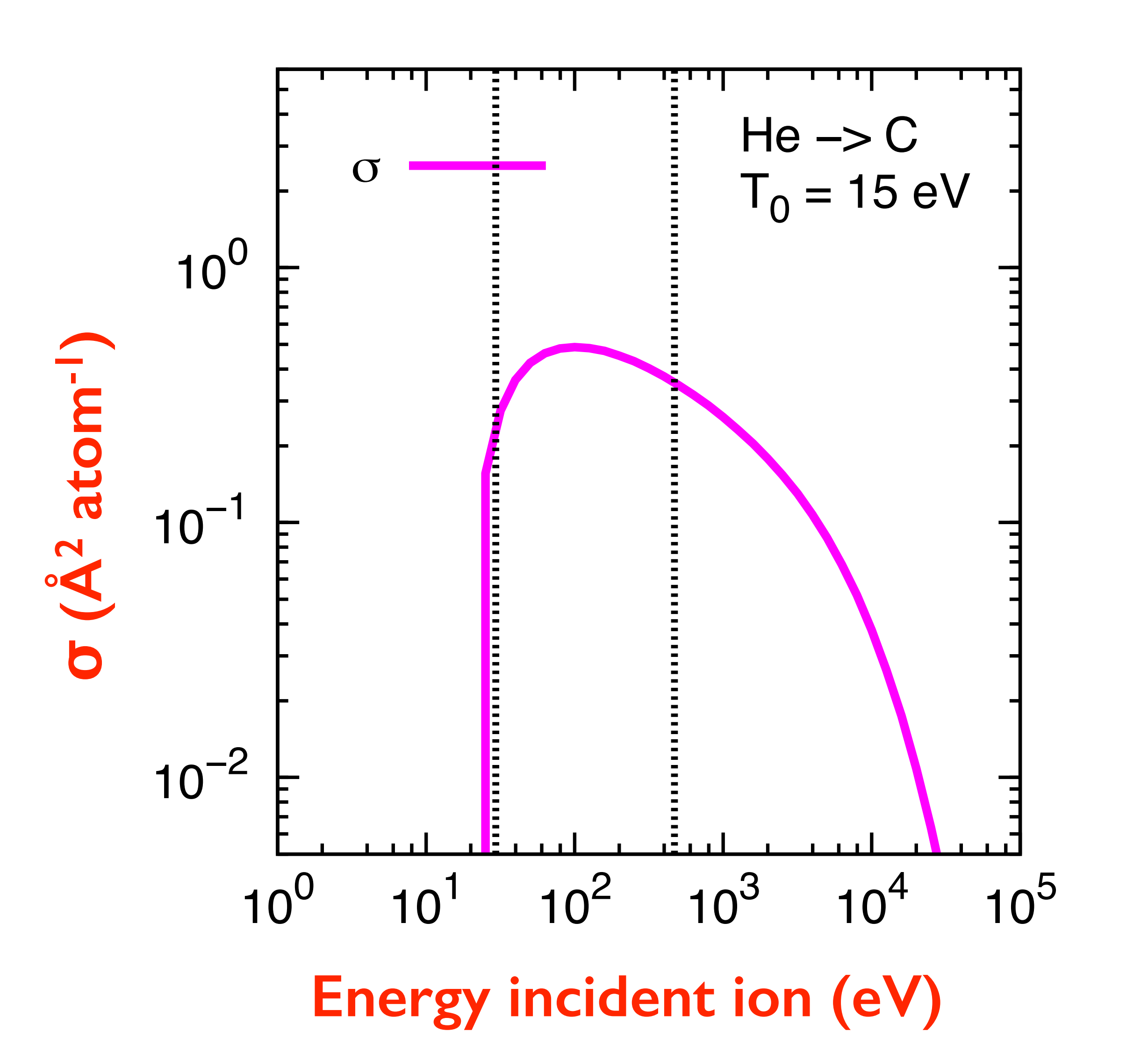


Cosmic Rays: E = 5 MeV - 10 GeV

Micelotta *et al. 2011, A&A, 526, A52*

Ions - C_{60} collisions

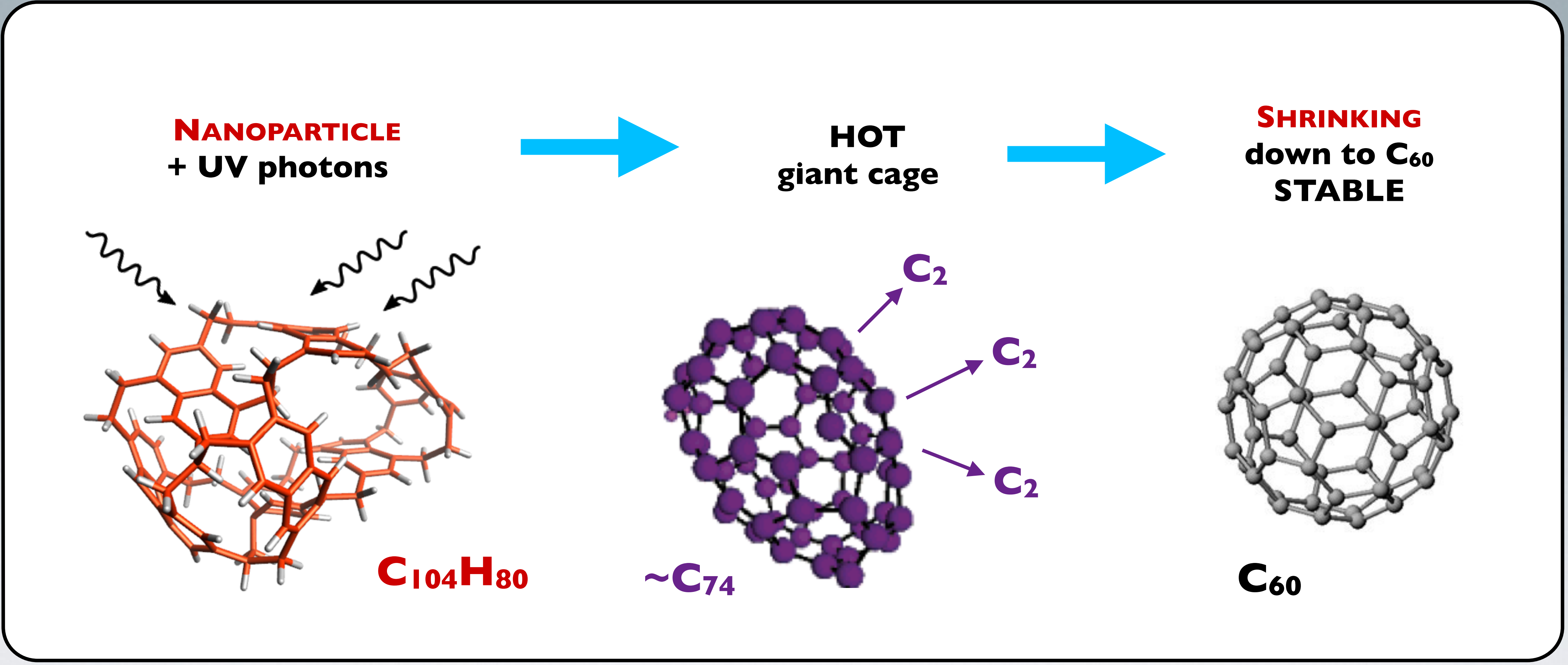




Micelotta *et al. 2013, Proc. IAU Symp. 297, 339*

C_{60} formation in space

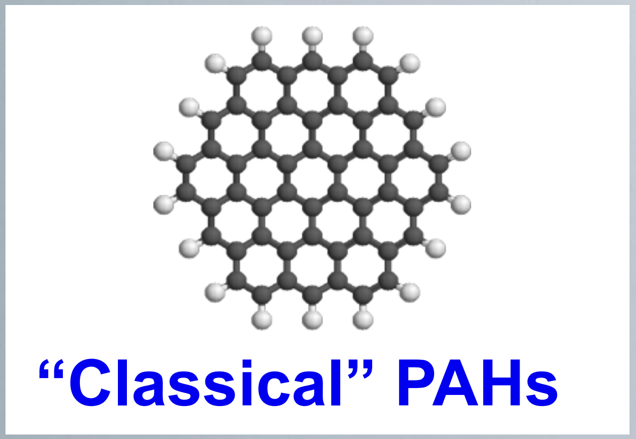
Conventional routes **DO NOT WORK** $\Longrightarrow$ **NEW MECHANISM!**

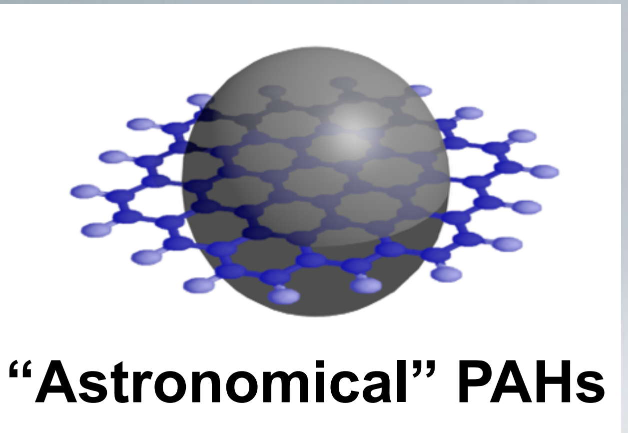


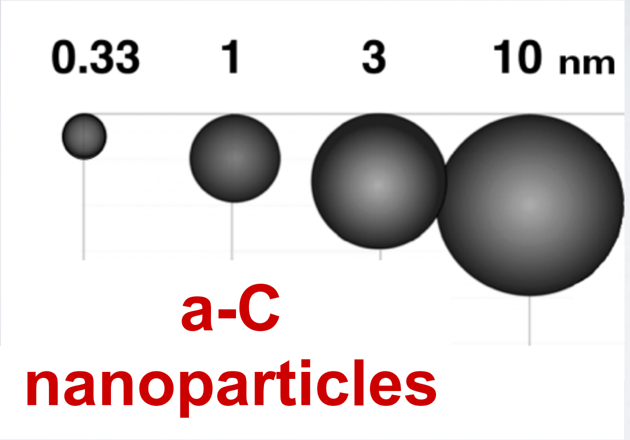
Micelotta *et al.* *2012, ApJ, 761, 35*

Photo-processing

Aromatic **I**nfrared **B**ands - Proposed carriers







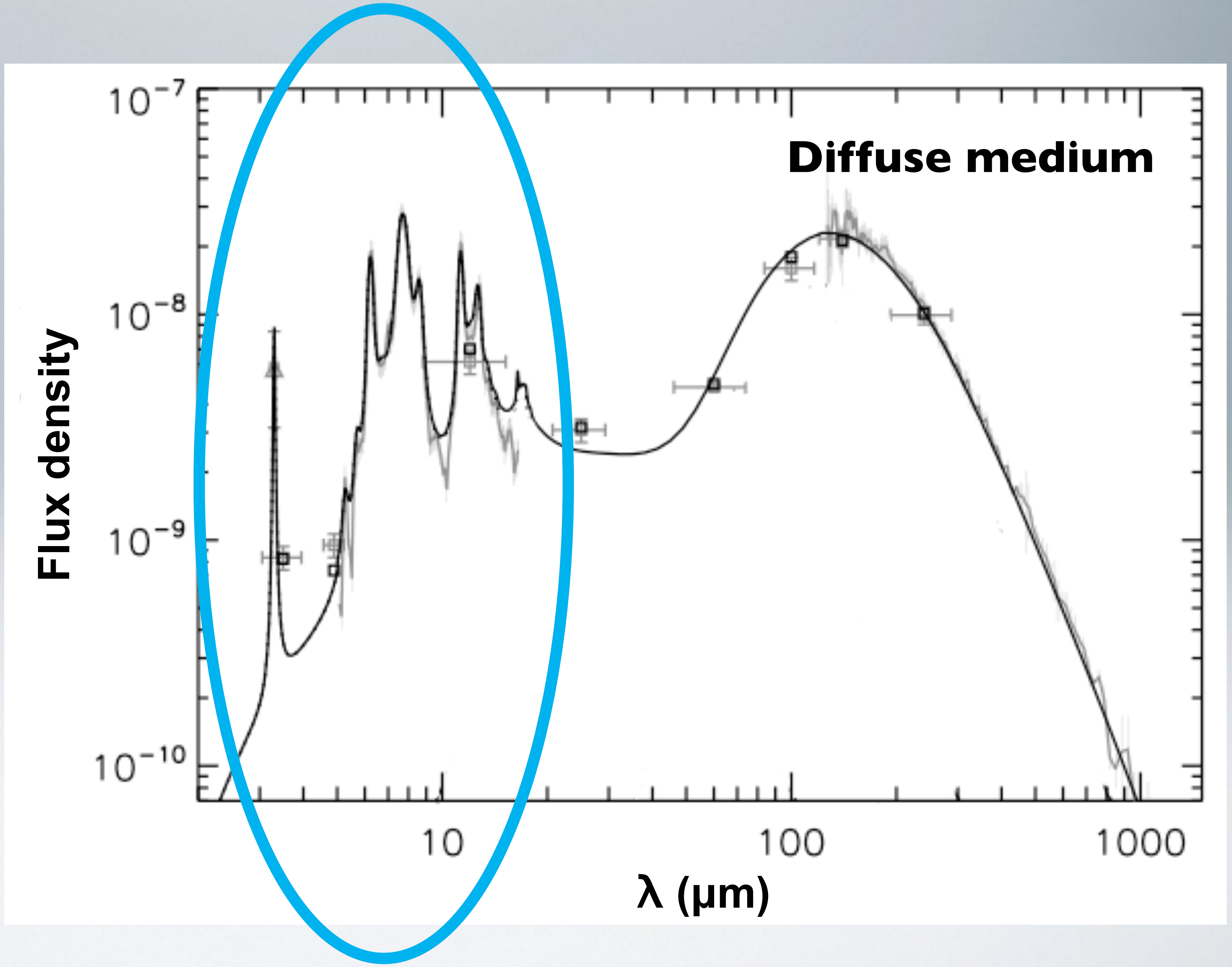


Photo-processing

ISRF

↓

Absorption properties

↓

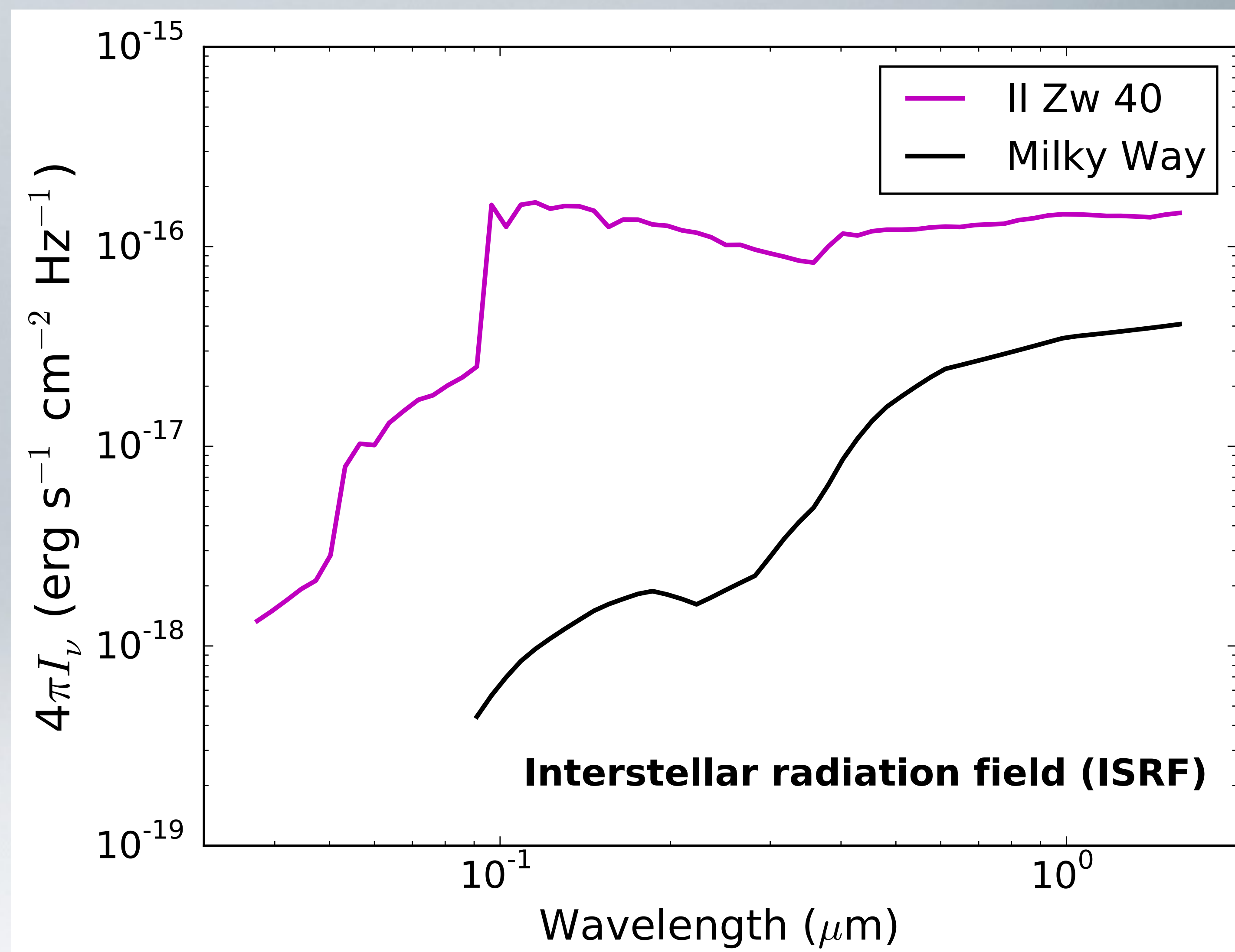
Dissociation

↓

Particle Size modification

↓

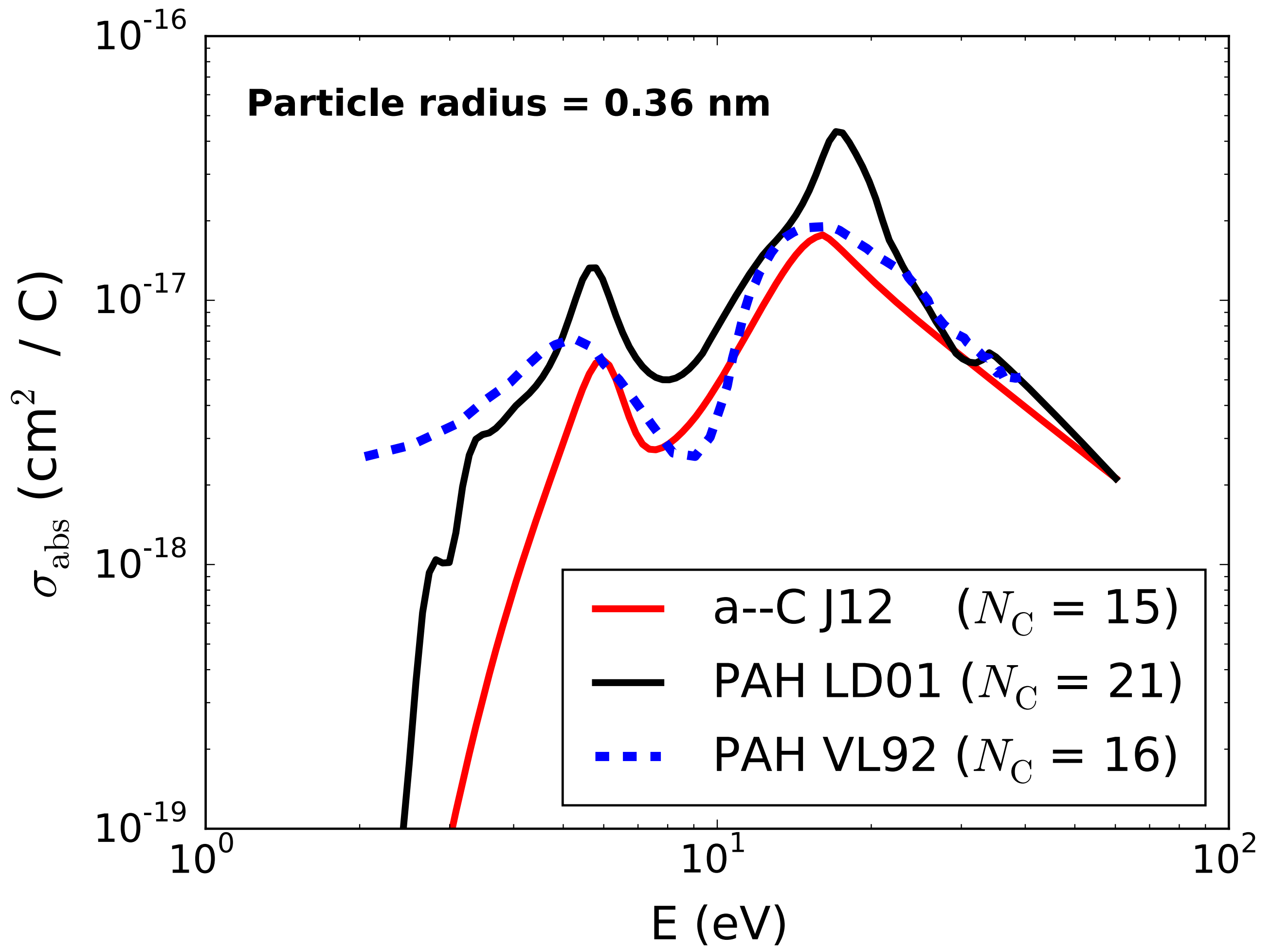
Emission properties

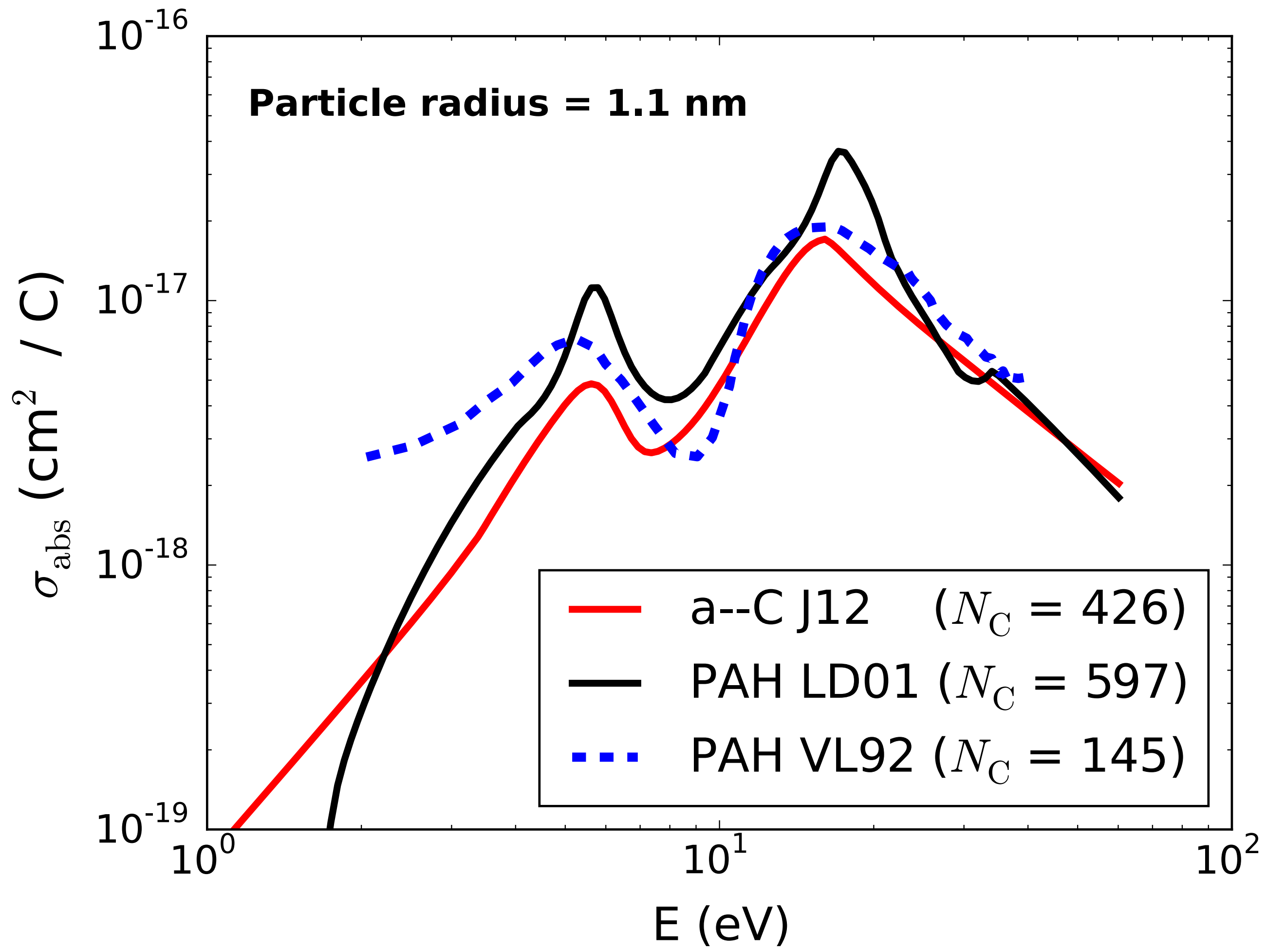


- Mathis, J. S., et al. 1983, A&A, 128, 212
- Galliano, F., et al. 2005, A&A, 434, 867

Photo-absorption cross section

Optical - UV



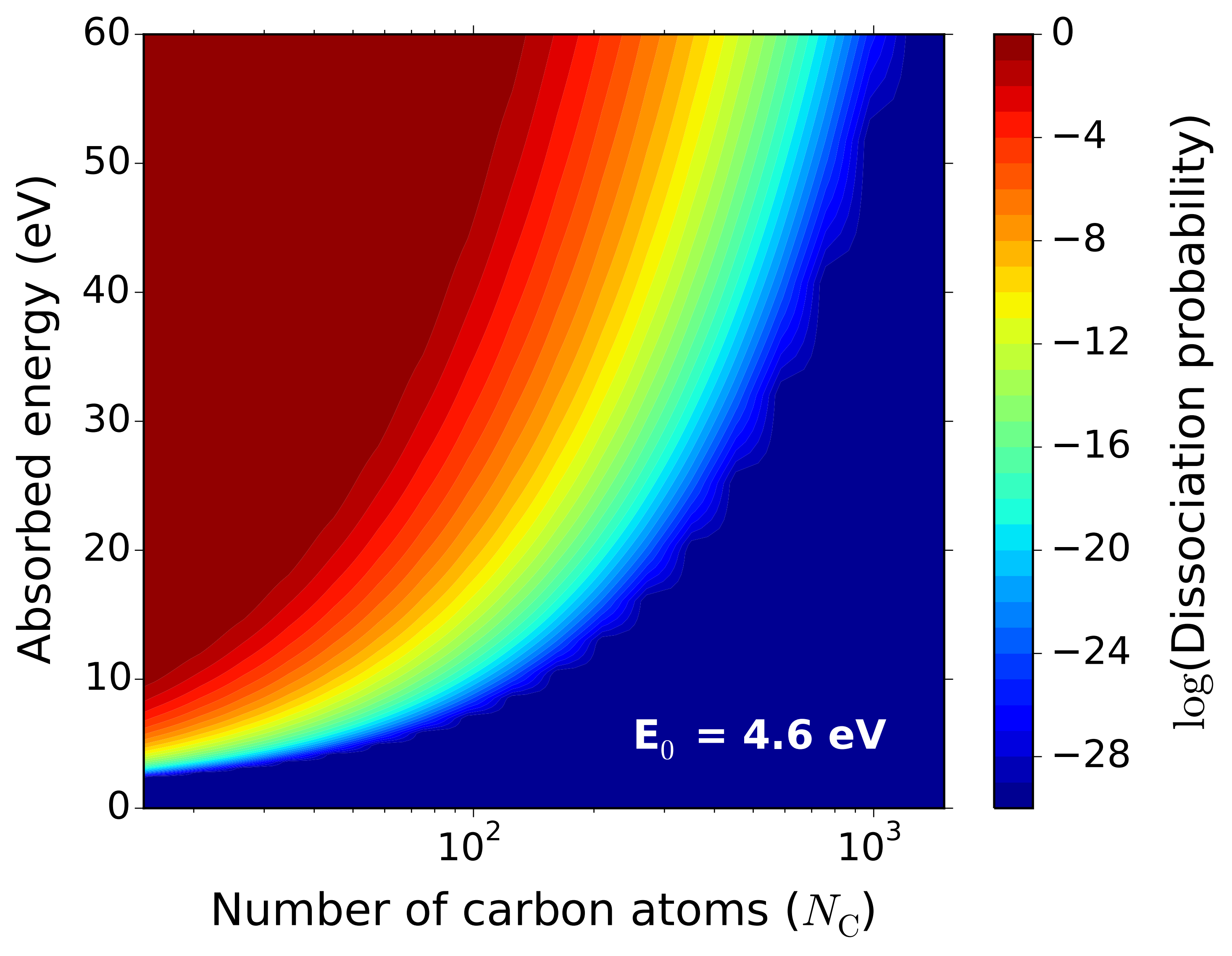


- Verstraete, L. & Léger, A. 1992, A&A, 266, 513
- Li, A. & Draine, B. T. 2001, ApJ, 554, 778
- Jones, A. P. 2012, A&A, 542, A98

***Micelotta**, Jones & Juvela 2016, in prep.*

Dissociation probability

- **STATISTICAL** fragmentation instead of IR emission
- All particles treated as **PAHs**
- Use of **FORMALISM** developed for **PAHs** to treat dissociation induced by **ELECTRON COLLISIONS** in shocks/hot gas (Micelotta et al. 2010a,b)

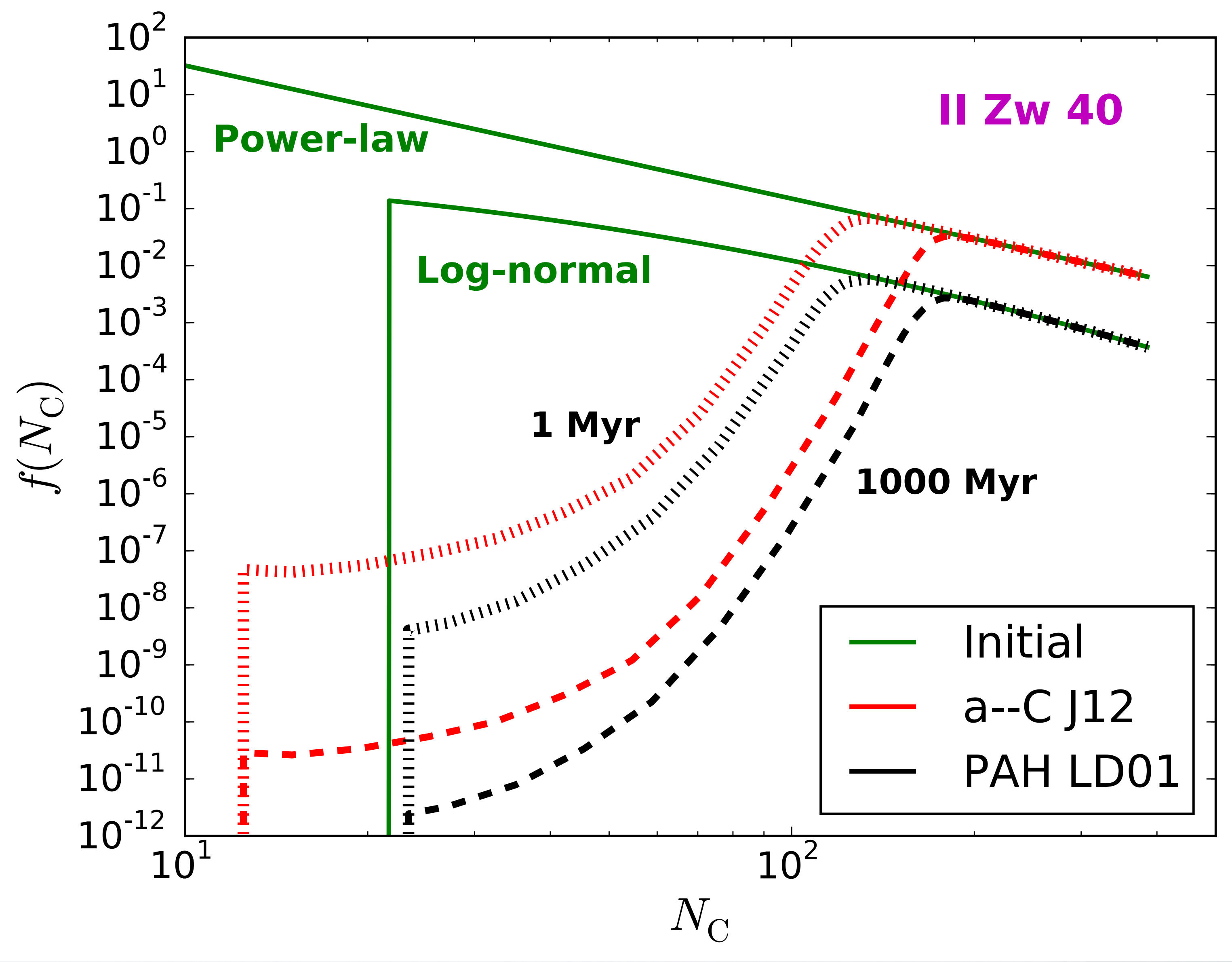


***Micelotta**, Jones & Juvela 2016, in prep.*

Modified size distributions

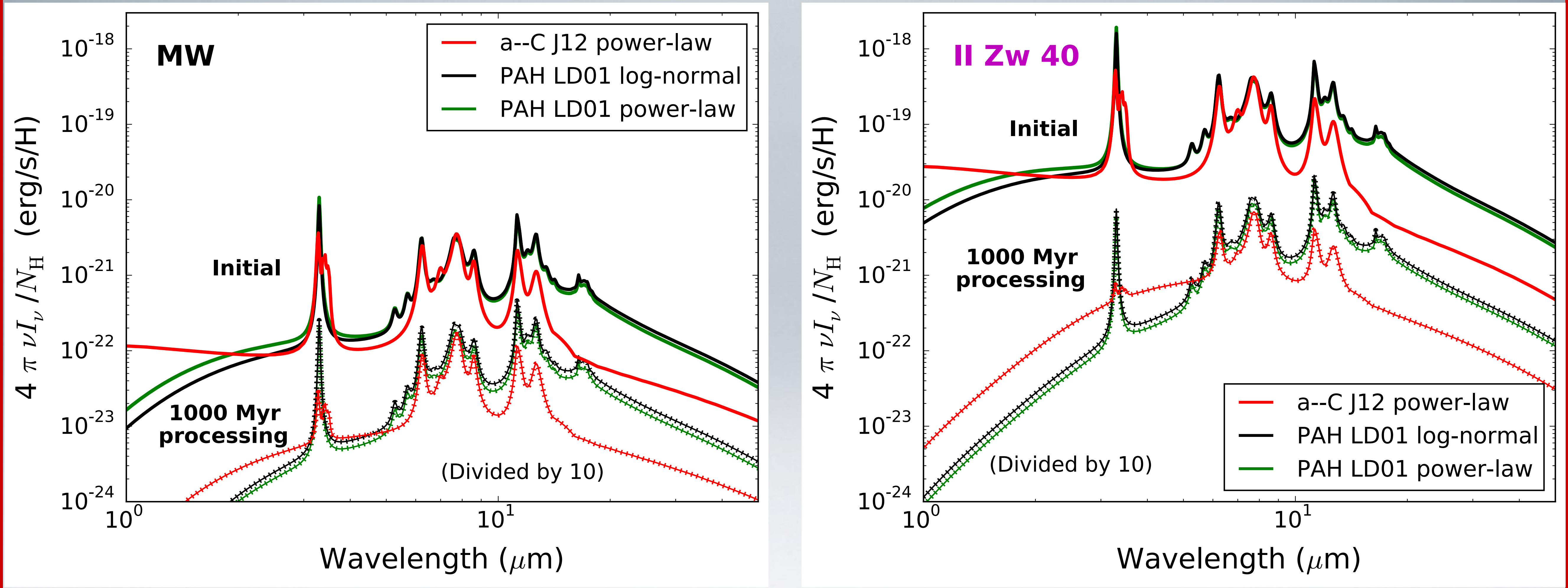
The effect of photo-dissociation & initial grain size distribution

EACH KIND of particle with its **"NATIVE"** initial distribution



Infrared emission

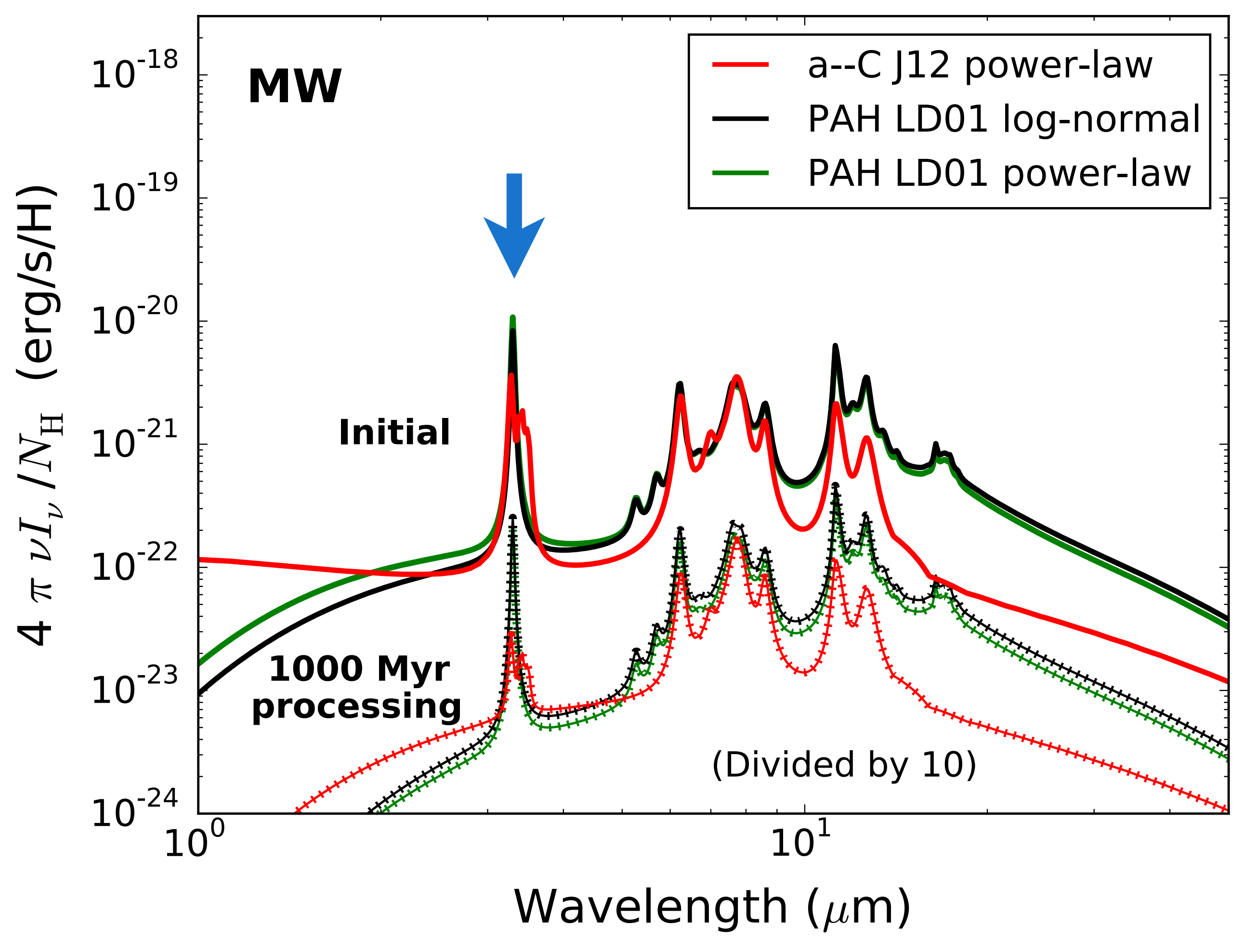
From photo-processed species and size distributions

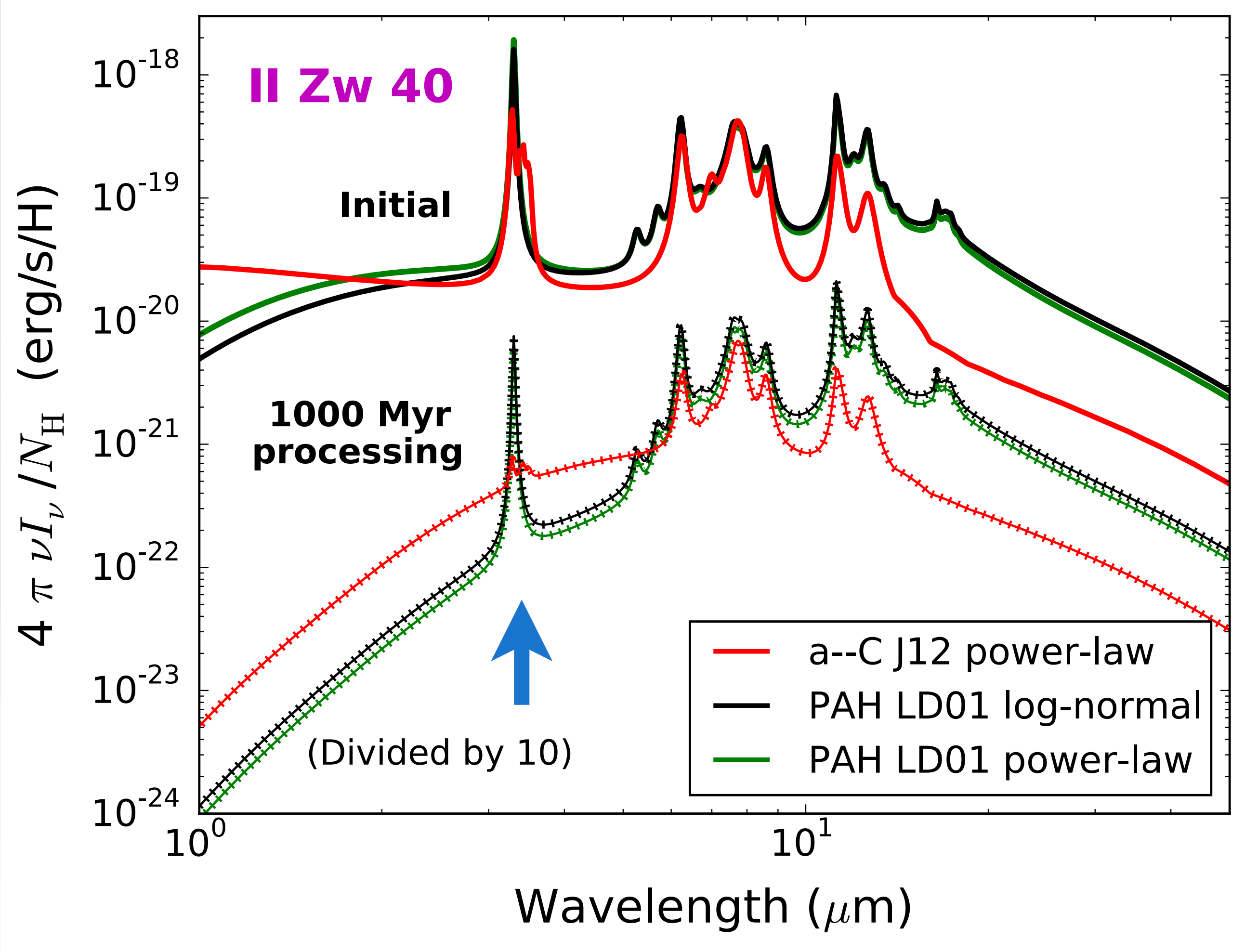


DustEM implementation (Compiègne et al. 2011)

Infrared emission

From photo-processed species and size distributions





Note the SUPPRESSION of the 3.3 - 3.4 µm complex in NANOPARTICLES emission

Conclusions & Perspectives

- Energetic processing has multiple implications and needs detailed analysis.
- Analytical models important for astrophysics.
- Interconnection PAHs - fullerenes - nanoparticles.
- Theory & Experiments & Observations.
- New experimental facilities + telescopes (JWST).

Collaborators

- X. Tielens (STRW Leiden)
- A. Jones (IAS Orsay)
- M. Juvela (University of Helsinki)
- E. Peeters, J. Cami, G. Fanchini (U. of Western Ontario)
- J. Bernard-Salas (Open University)
- H. Zettergren, H. Cederquist, H. Schmidt (Stockholm University)

Thank you!

Stopping power ← $$\frac{\mathrm{d}E}{\mathrm{d}R} = N\,S_{\mathrm{n}}(E)$$ → **Nuclear stopping cross section**

N → **Atomic number density**

Cross section $C_m\,E^{-m}\,T^{-1-m}\,\mathrm{d}T \qquad 0 \lesssim T \lesssim T_{\mathrm{m}}$

$$V(r) \propto r^{-1/m}$$

$$S_{\mathrm{n}}(E) = \int_{T_0}^{T_{\mathrm{m}}} \mathrm{d}\sigma(E,T)\cdot T$$

T → **Transferred energy**

$$= 4\pi\,a_{\mathrm{U}}\,Z_1 Z_2\,e^2\,\frac{M_1}{M_1+M_2}\,s_{\mathrm{n}}^{\mathrm{U}}(\varepsilon)\left[1-\left(\frac{E_{0\mathrm{n}}}{E}\right)^{1-m}\right]$$

a_{U} ↓ **ZBL Universal screening length**

$s_{\mathrm{n}}^{\mathrm{U}}(\varepsilon)$ ↓ **ZBL Universal reduced stopping cross section**

└── $S^0_{\mathrm{n}}(E)$ **NO threshold** ──┘ └ **Threshold effect** ┘

Micelotta *et al.* *2010a, A&A, 510, A36*

Total cross section

$$\sigma(E) = \int_{T_0}^{T_\mathrm{m}} \mathrm{d}\sigma(E,T)$$

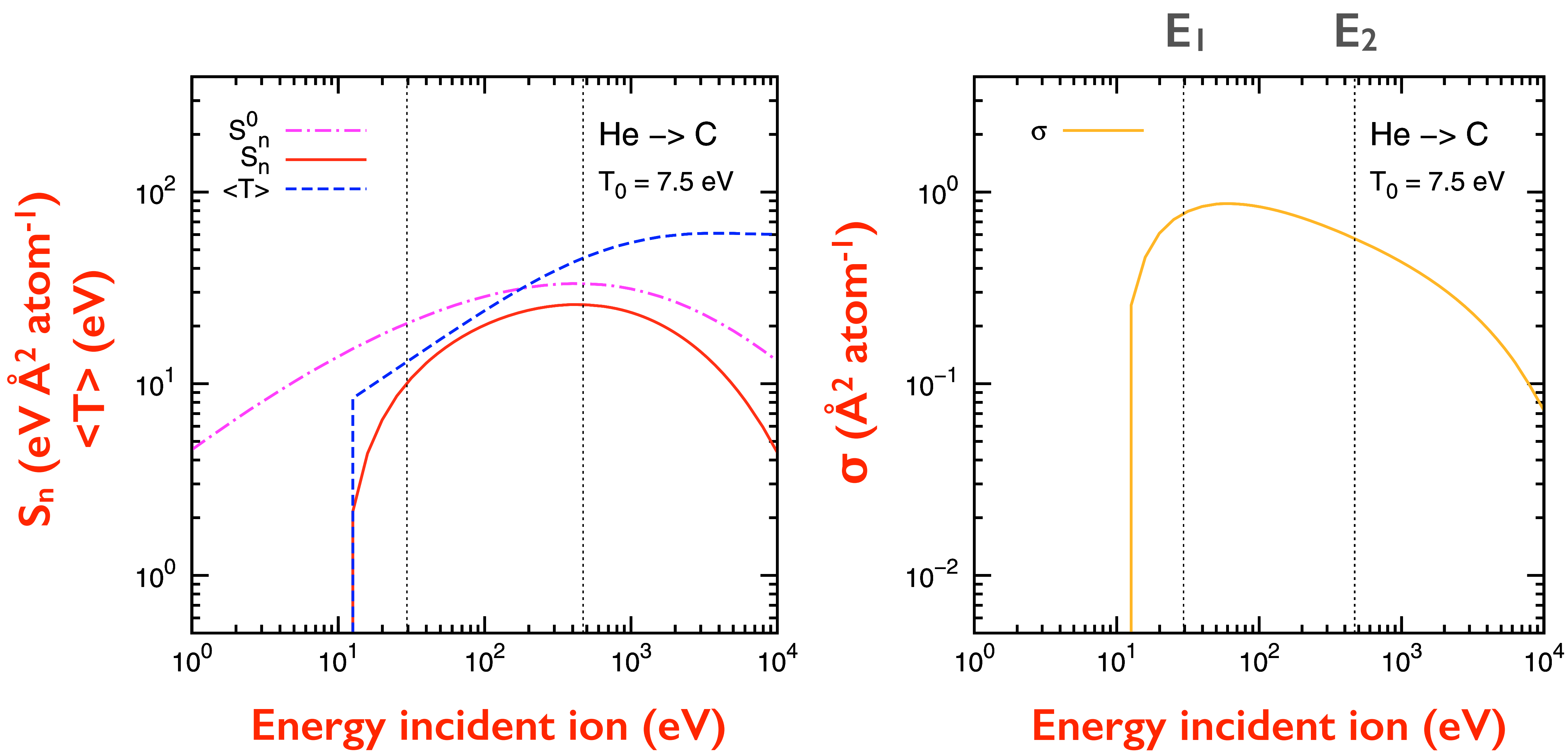
$$= 4\pi\, a_\mathrm{U}\, Z_1 Z_2\, e^2 \frac{M_1}{M_1+M_2}\, s_\mathrm{n}^\mathrm{U}(\varepsilon)\, \frac{1-m}{m}\, \frac{1}{\gamma\, E} \left[\left(\frac{E_{0\mathrm{n}}}{E} \right)^{-m} - 1 \right]$$

$S^0{}_n(E)$ **NO threshold**

$$\langle T(E)\rangle = \frac{S_\mathrm{n}(E)}{\sigma(E)} = \langle T(E)\rangle = \frac{m}{1-m}\,\gamma\, \frac{E^{1-m} - E_{0\mathrm{n}}^{1-m}}{E_{0\mathrm{n}}^{-m} - E^{-m}}$$

Average transferred energy

Micelotta *et al. 2010a, A&A, 510, A36*



Micelotta *et al. 2010a, A&A, 510, A36*

$$T_{\mathrm{e}}(\vartheta) = 27.2116 \int_{-R/\sin\vartheta}^{R/\sin\vartheta} v\,\gamma(r_{\mathrm{s}})\,\mathrm{d}s$$

Transferred energy electronic interaction

$$S(E) = \frac{h\,\log(1 + a\,E)}{f\,E^{g} + b\,E^{d} + c\,E^{e}}$$

Fit to stopping power electrons interaction

$$T_{\mathrm{eff}} \simeq 2000 \left(\frac{T_{\mathrm{e}}(\mathrm{eV})}{N_{\mathrm{C}}}\right)^{0.4} \left(1 - 0.2\,\frac{E_0(\mathrm{eV})}{T_{\mathrm{e}}(\mathrm{eV})}\right)$$

Effective temperature after energy transfer

$$P(n_{\max}) = \frac{k_0\,\exp\left[-E_0/k\,T_{\mathrm{av}}\right]}{k_{\mathrm{IR}}/(n_{\max}+1)}$$

Dissociation probability

Stopping of high-energy ions

E = 5 MeV/nuc. - 10 GeV → Electronic interaction **only**

Bethe - Bloch equation

$$\kappa \equiv 4\pi\, r_0^2\, m_e c^2$$

Shell correction

Mean ionisation

Density effect

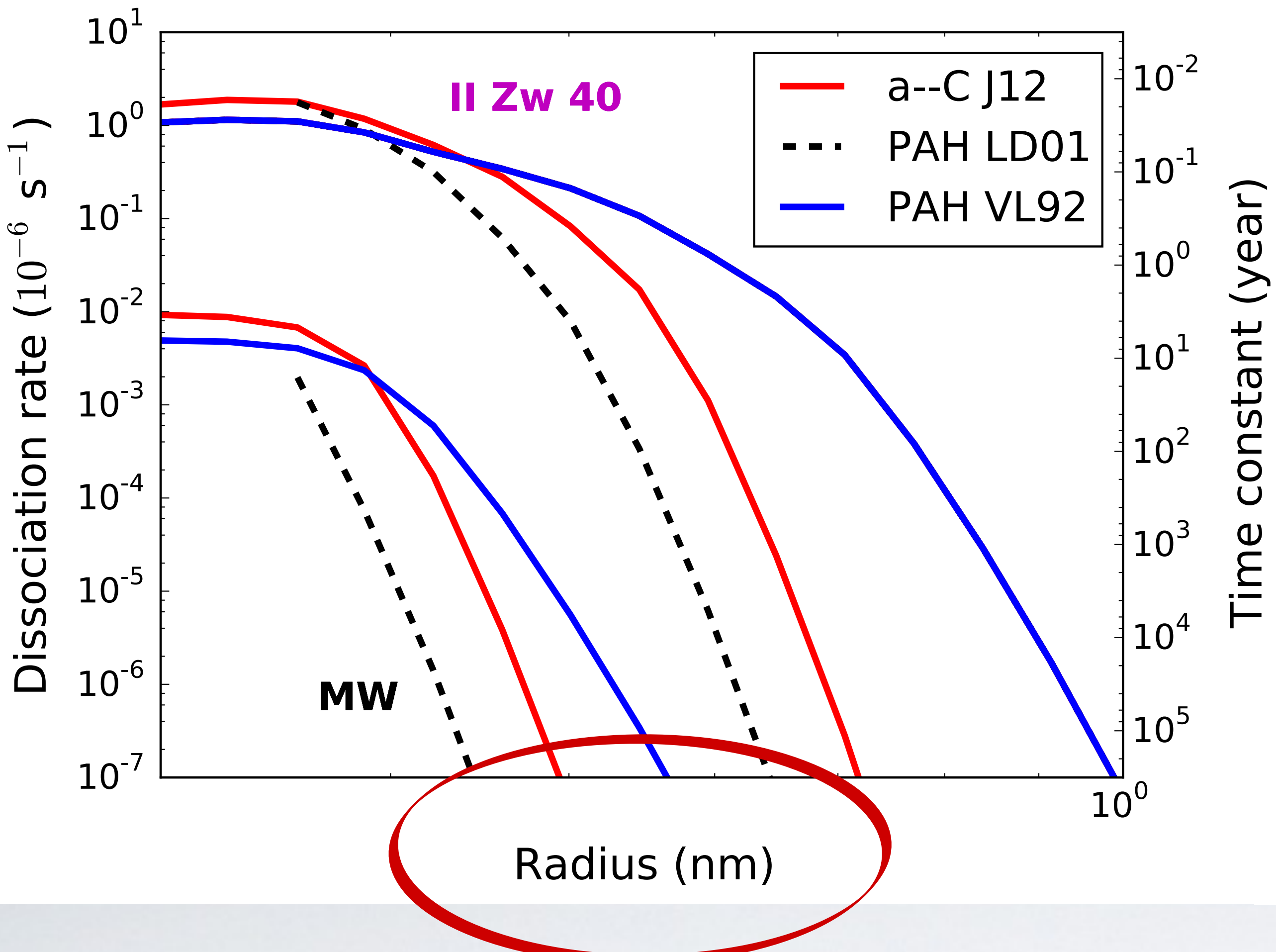
$$S = \frac{\kappa\, Z_2}{\beta^2}\, Z_1^2 \left\{ \left[f(\beta) - \frac{C}{Z_2} - \ln\langle I \rangle - \frac{\delta}{2} \right] + Z_1\, L_1(\,\mathrm{Barkas}\,) + Z_1^2\, L_2(\,\mathrm{Bloch}\,) \right\}$$

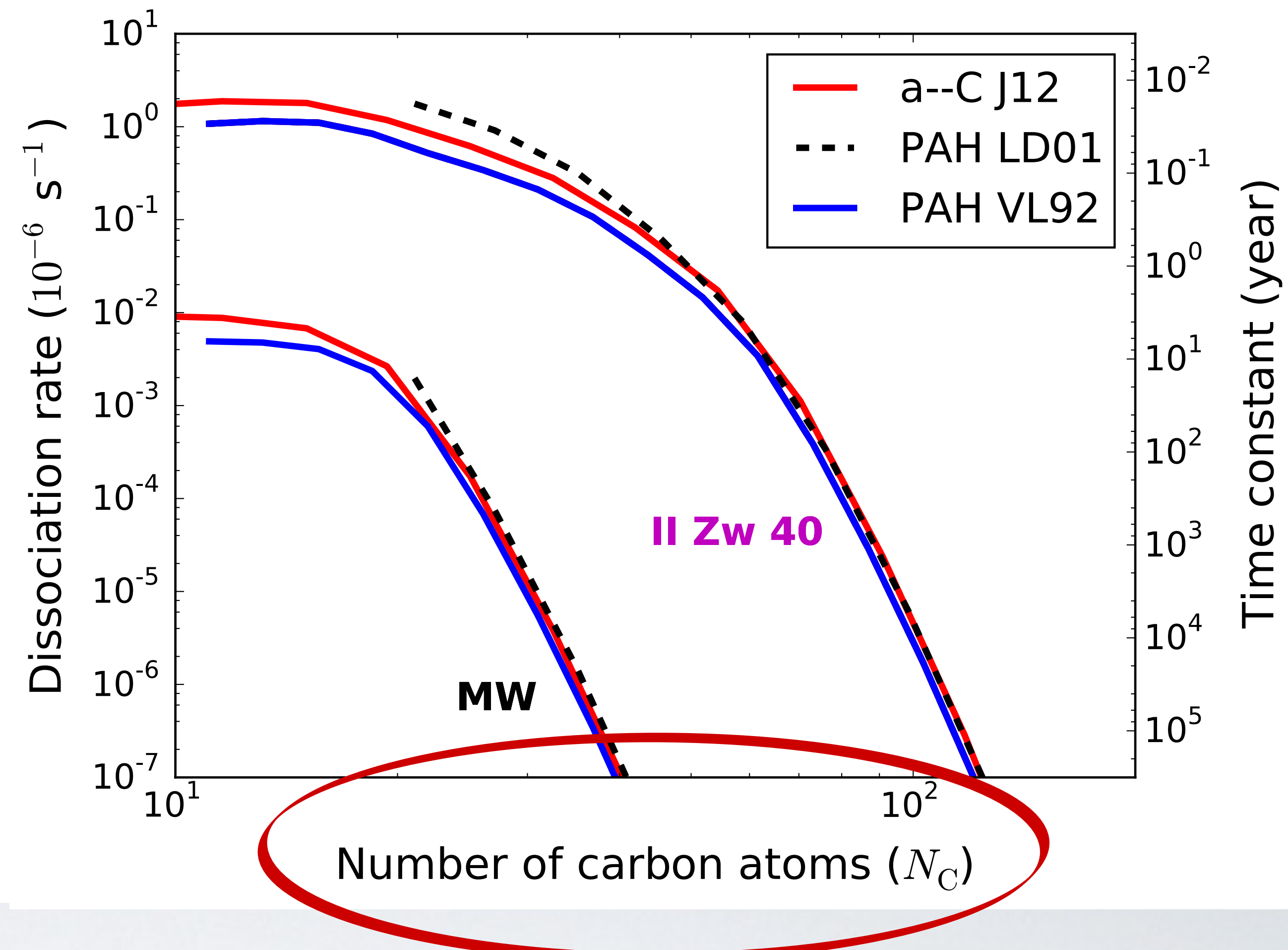
Stopping power

Ziegler et al. 1999

Photo-dissociation rate

Following Vis-UV absorption

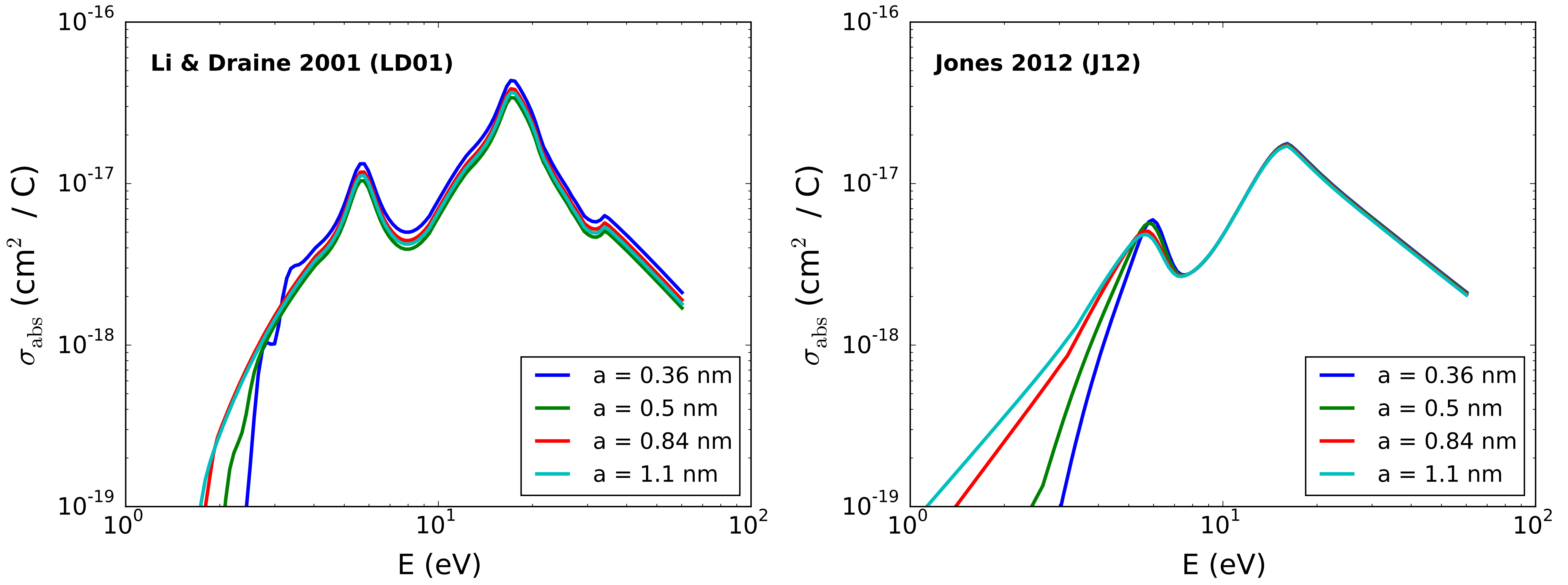




vs.

Photo-absorption cross section II

Optical - UV



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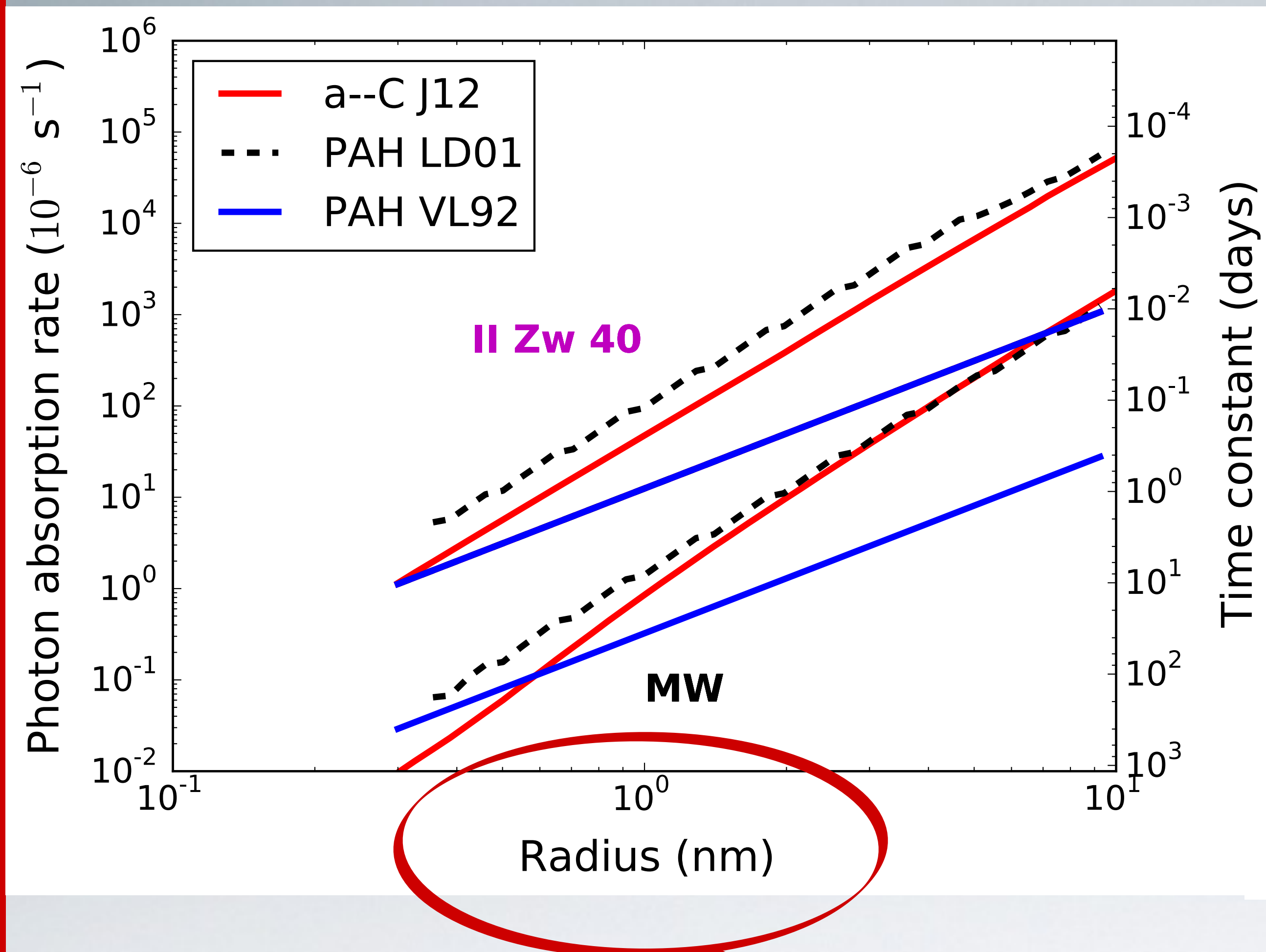
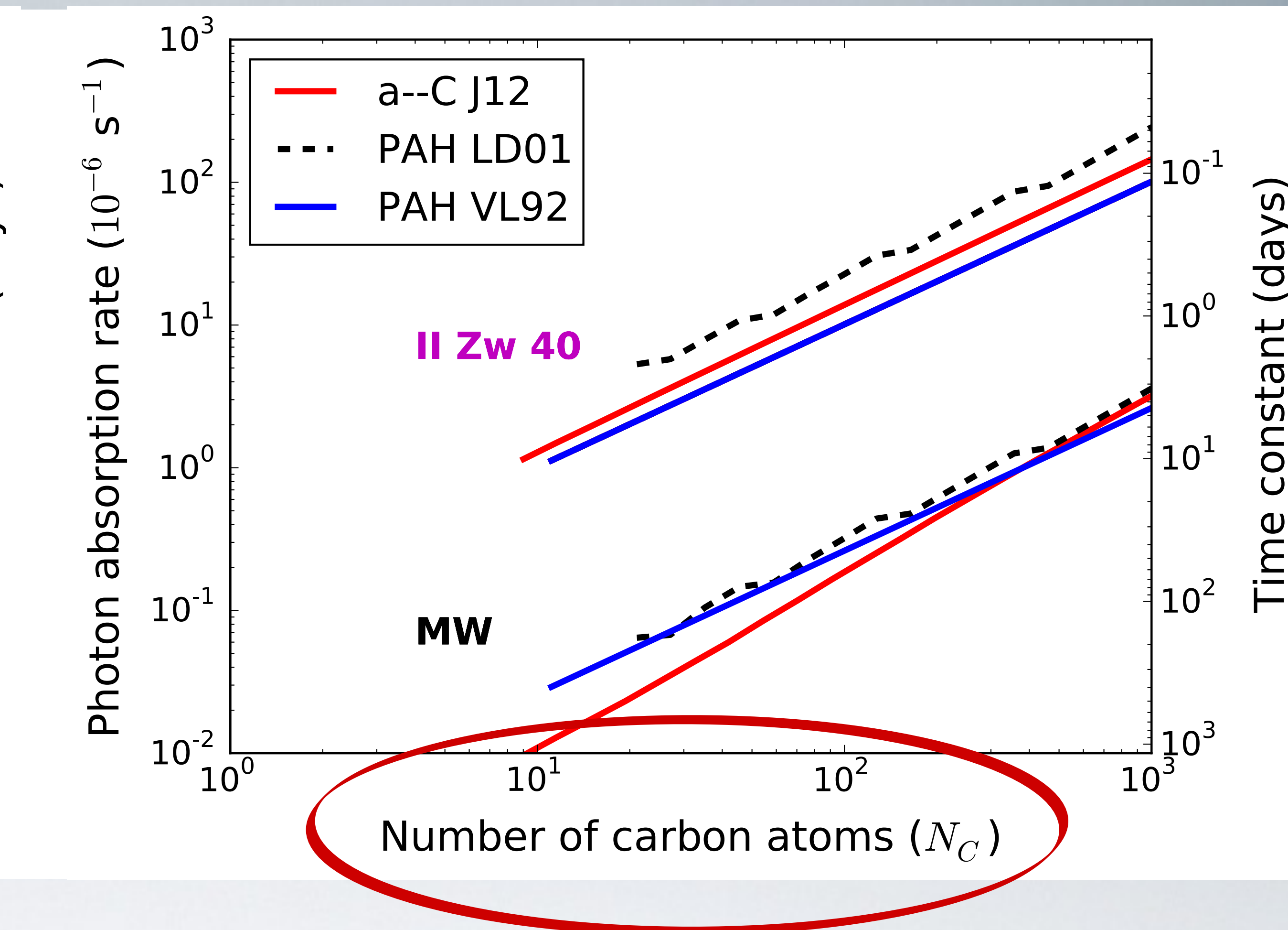
Photon absorption rate

Optical - UV

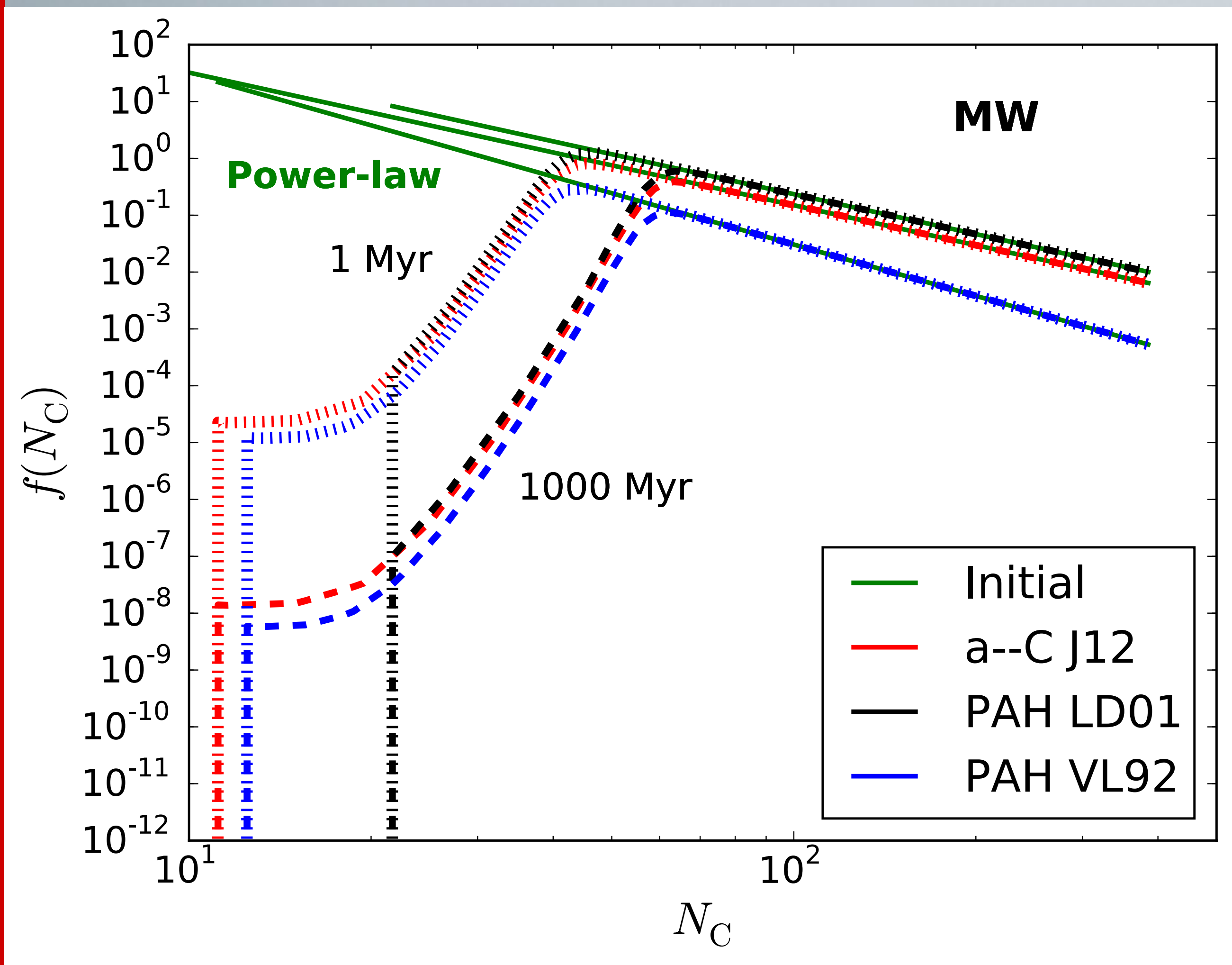


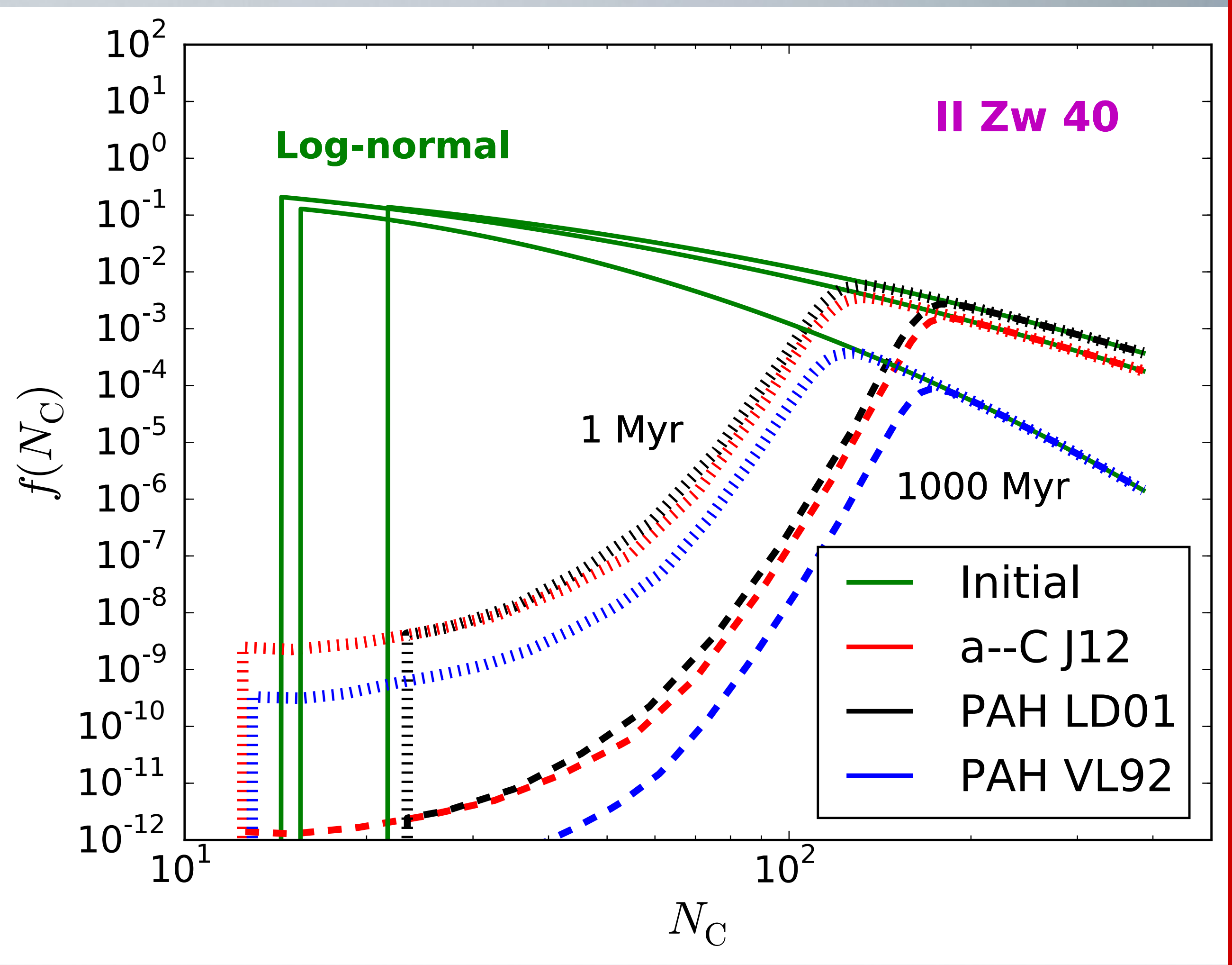


vs.

Modified size distributions I

The effect of photo-dissociation



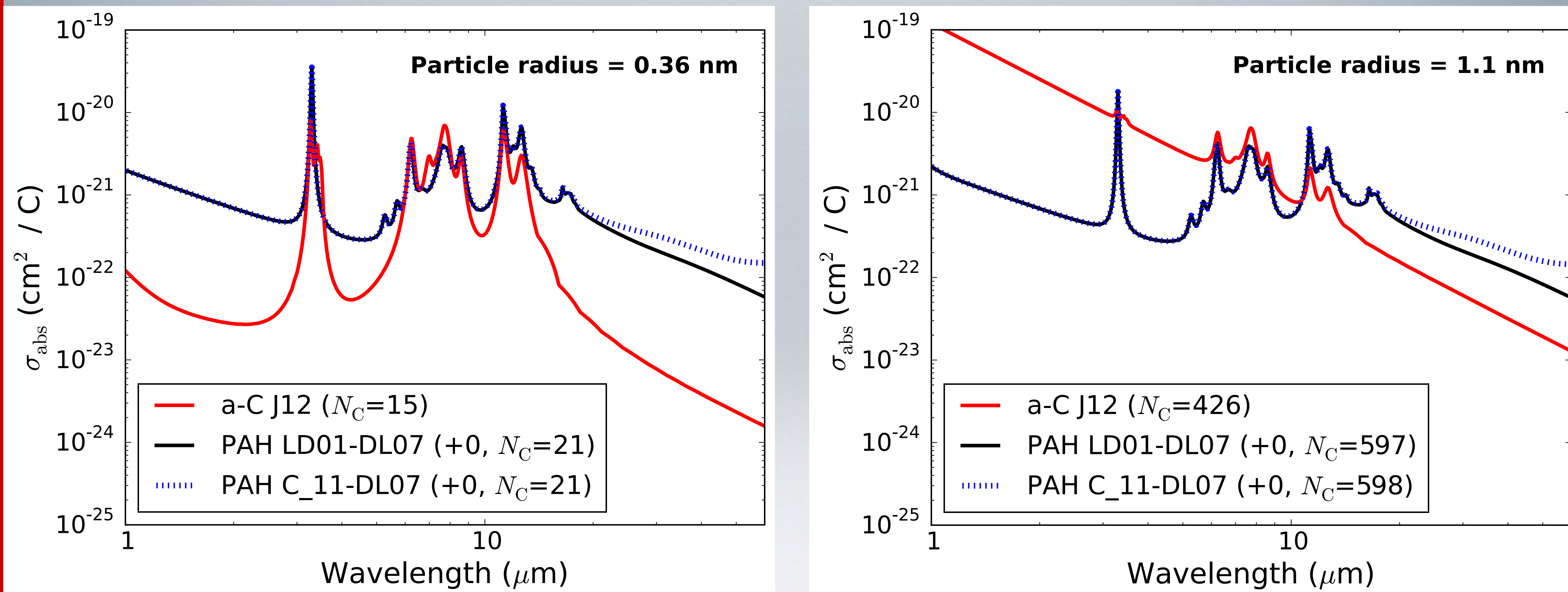


Power-law for all:
the "native" distribution of
nanoparticles - J12

Log-normal for all:
the "native" distribution of
astronomical PAHs - LD01

Photo-absorption cross section III

Infrared



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