On Carbon Nanotubes in the Interstellar Medium

Qi Li\(^{1,2,*}\), Aigen Li\(^{2†}\), B.W. Jiang\(^{1‡}\) and Tao Chen\(^{3§}\)

\(^{1}\)Department of Astronomy, Beijing Normal University, Beijing 100875, China
\(^{2}\)Department of Physics and Astronomy, University of Missouri, Columbia, MO 65211, USA
\(^{3}\)Department of Theoretical Chemistry and Biology, Royal Institute of Technology, Stockholm 10691, Sweden

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ABSTRACT
Since their discovery in 1991, carbon nanotubes (CNTs) — a novel one-dimensional carbon allotrope — have attracted considerable interest worldwide because of their potential technological applications such as electric and optical devices. In the astrophysical context, CNTs may be present in the interstellar space since many of the other allotropes of carbon (e.g., amorphous carbon, fullerenes, nanodiamonds, graphite, polycyclic aromatic hydrocarbons, and possibly graphene as well) are known to be widespread in the Universe, as revealed by presolar grains in carbonaceous primitive meteorites and/or by their fingerprint spectral features in astronomical spectra. In addition, there are also experimental and theoretical pathways to the formation of CNTs in the interstellar medium (ISM). In this work, we examine their possible presence in the ISM by comparing the observed interstellar extinction curve with the ultraviolet/optical absorption spectra experimentally obtained for single-walled CNTs of a wide range of diameters and chiralities. Based on the absence in the interstellar extinction curve of the ∼4.5 and 5.25 eV π-plasmon absorption bands which are pronounced in the experimental spectra of CNTs, we place an upper limit of ∼10 ppm of C/H (i.e., ∼4% of the total interstellar C) on the interstellar CNT abundance.

Key words: dust, extinction – infrared: ISM – ISM: lines and bands — ISM: molecules

1 INTRODUCTION
As one of the most abundant elements in the Universe only exceeded by hydrogen, helium and oxygen, carbon (C) is a major player in the evolutionary scheme of the Universe (Henning & Salama 1998). Since C atoms can form strong and stable single, double, and triple covalent bonds, they facilitate the generation of a large variety of allotropic forms, including amorphous carbon, carbon chains, carbon nanotubes (CNTs), carbon onions, diamond, fullerenes (e.g., C\(_{60}\), C\(_{70}\), graphene, graphite, and polycyclic aromatic hydrocarbons (PAHs). While diamond and graphite have been known for at least a few thousand years, the laboratory discoveries of such low-dimensional carbon nanostructures as zero-dimensional (0D) fullerenes, one-dimensional (1D) CNTs, and two-dimensional (2D) graphene were far more recent (see Dinadayalane & Leszczynski 2010).

Thirty five years ago, C\(_{60}\) and C\(_{70}\) were serendipitously discovered by Kroto et al. (1985) — R.F. Curl, H.W. Kroto and R.E. Smalley received the 1996 Nobel Prize in Chemistry because of this spectacular discovery — in the sooty residue experimentally generated by vaporising graphite in a (hydrogen-lacking) helium atmosphere. Six years later, CNTs were discovered and synthesized by Iijima (1991) as spin-off products of fullerenes, using an arc-discharge evaporation method similar to that used by Kroto et al. (1985) for fullerene synthesis. In 2004, the first isolation of a single graphene sheet has been achieved by Andre Geim and Kostya Novoselov who extracted single-atom-thick layers from bulk graphite (see Novoselov et al. 2004). Because of this, they were awarded the 2010 Nobel Prize in Physics.

The presence of many of these C allotropes in the interstellar medium (ISM) has been explicitly revealed or implicitly indicated from presolar grains isolated from carbonaceous primitive meteorites (e.g., nanodiamonds, graphite; see Lewis et al. 1987, Amari et al. 1990), and/or from the observations of molecular and solid-state features in astronomical spectra and the realization that these features are linked to certain carbonaceous materials (e.g., amorphous carbon, graphite, and PAHs; see Stecher & Donn 1965, Léger & Puget 1984, Allamandola et al. 1985, Pendleton & Allamandola 2002, Qi et al. 2018). While fullerenes, CNTs, and graphene are of paramount importance in modern science...
and technology since these carbon nanomaterials provide exciting challenges and opportunities for physicists, chemists, biologists, engineers, and material scientists, in recent years, the astronomical community has also been passionate about their possible presence as well as the role they could have played in the interstellar and circumstellar space. It is worth noting that the initial synthesis of fullerenes was actually astrophysically motivated — the experiments which resulted in the discovery of fullerenes were originally aimed at understanding the mechanisms by which long-chain carbon molecules are formed in the interstellar space and circumstellar shells (Kroto et al. 1985). A quarter of a century later, the detection of C_{60} and C_{70} and their ions in the interstellar and circumstellar space has been reported based on their characteristic vibrational spectral bands in the infrared (IR; Cami et al. 2010, Sellgren et al. 2010, Berné et al. 2011, 2012) — a broad, featureless emission band. Instead, fullerite shows prominent absorption bands at \( \sim 2175 \text{ Å} \) interstellar extinction feature. It has also been proposed that single- and multi-shell fullerenes may be the carrier of the still unidentified 2175 Å interstellar extinction feature (e.g., see Iglesias-Groth 2008, Li et al. 2008). Cataldo (2002) measured the absorption spectra of fullerite (i.e., carbon soot containing fullerenes) and C_{60} fullerene photopolymer in the wavelength range of \( \sim 0.2–1.1 \mu \text{m} \). It was found that neither fullerite nor C_{60} photopolymer exhibits any strong absorption feature around \( \sim 2175 \text{ Å} \). Instead, fullerite shows prominent absorption bands at \( \sim 2520–2670 \text{ Å} \), similar to that seen in some hydrogen-deficient and carbon-rich supergiant R CrB stars (e.g., R CrB, RY Sgr, V348 Sgr) which peaks around \( \sim 2400–2500 \text{ Å} \) (Hecht et al. 1984, Drilling et al. 1997). Unlike fullerite, C_{60} photopolymer exhibits three absorption peaks at \( \sim 2710, 3890 \) and \( 5100 \text{ Å} \) which are not seen in the ISM.

As the basic structural element of fullerenes, graphene is intimately related to fullerenes as demonstrated by Chuvilin et al. (2010) experimentally and by Berné & Tielens (2012) computationally that C_{60} could be formed from a graphene sheet. However, whether graphene is present in the interstellar and circumstellar space is less certain. García-Hernández et al. (2011, 2012) detected a set of unusual IR emission features in several planetary nebulae (PNe), both in the Milky Way and in the Magellanic Clouds, and attributed them to planar C_{24}, a piece of graphene sheet. Based on the absence of the 2755 Å absorption feature in the fullerene extinction curve characteristic of the \( \pi^* \) electronic transition of graphene, Li et al. (2019) argued that in the ISM as much as \( \sim 20 \text{ppm of C/H} \) could be tied up in graphene (also see Chen et al. 2017). In addition, Sarre (2019) attributed the widespread extended red emission (ERE; see Witt & Vijh 2004) — a broad, featureless emission band at \( \sim 5400–9500 \text{ Å} \) — to the photoluminescence of graphene oxide nanoparticles.

Like fullerenes, graphene is also the basic structural element of CNTs: CNTs can be envisioned as the result of rolling up a segment of a graphene sheet to form a seamless tubular structure of high aspect ratio. The possible presence of graphene in space therefore raises the exciting possibility that CNTs may also be present in the Universe. While the electronic UV and optical spectra and vibrational IR spectra of individual CNTs depend on their diameters, lengths, and morphologies (e.g., see Guo et al. 2004, Chen & Li 2019, Weisman & Kono 2019), as will be elaborated below in §2, the UV/optical absorption spectra of CNT mixtures of different sizes and types remain essentially invariant (Murakami et al. 2005). As interstellar CNTs — if present — likely consist of a mixture of many individual CNT species, in this work we examine the possible presence of CNTs in the ISM by confronting the experimentally-measured UV/optical absorption spectra of CNT mixtures with the observed interstellar extinction curve (see §3). The results are discussed in §4 and summarized in §5.

2 UV ABSORPTION OF CARBON NANOTUBES

Experimentally, CNTs exist in a varying number of concentric shells. Whereas the carbon-arc synthesis produces almost entirely multi-shell tubes on the carbon cathode, Iijima & Ichihashi (1993) found that abundant single-walled carbon nanotubes (SWNTs) with diameters of about one nanometer grow in the gas phase. As will be discussed in §41, the possible pathways for the formation of CNTs in the ISM would result in SWNTs, more favorably than multi-walled nanotubes. In this work, we will therefore focus on SWNTs.

SWNTs can be considered as a layer of graphene sheet rolled up into a cylinder. The ends of each nanotube are closed by hemi-fullerene caps, each containing six five-membered rings. In the limit of large aspect (i.e., length-to-diameter) ratios, however, the ends have negligible effects on nanotube electronic structure. SWNTs are novel 1D materials made of an sp²-bonded wall one atom thick and constitute a rich family of structures, with each SWNT structure uniquely defined by the chiral index, a pair of integers \((n,m)\), which describes the length and orientation of the nanotube’s circumference vector within the graphene sheet. SWNTs are classified into three types: (i) armchair \((n,n)\) nanotubes, (ii) zigzag \((n,0)\) nanotubes, and (iii) chiral \((n,m)\) nanotubes with \( n \neq m \). Electrically, SWNTs can be either metallic or semiconducting, depending on their geometry, i.e., on the \((m,n)\) integer-pair, or on the way of the rolling up. Armchair SWNTs are always metallic and exhibit no energy bandgap, as are zigzag SWNTs with \( m = 3q \), where \( q \) is an integer. On a statistical basis, one-third of the nanotubes are metallic, and two-thirds are semiconducting.

Each SWNT species, as labeled by a unique pair of integers \((n,m)\), has well-defined electronic and spectroscopic properties. Because of their distinct physical and chemical properties, different \((n,m)\) structural species may be considered separate chemical substances. However, despite the importance of \((n,m)\)-specific absorption spectra, reliable experimental determination of nanotube absorption cross section at the individual-tube level has been hampered by the difficulty of sorting as-grown mixtures into structurally pure fractions and by the challenge of determining absolute

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1. Armchair and zigzag SWNTs are identical to their images and are therefore classified as achiral. Other SWNTs are chiral since they have distinguishable mirror images (enantiomers) of opposite handedness. Chiral nanotubes can exhibit very large (i.e., long) 1D unit cells compared to achiral tubes of the same diameter.

2. Zigzag tubes can have a small bandgap due to curvature effects.
Experimental UV/optical absorption cross sections (per C atom) of SWNTs along the tube axis \( [C_{ab}^\parallel (\lambda)/N_C; \text{solid magenta line}] \) and perpendicular to the tube axis \( [C_{ab}^\perp (\lambda)/N_C; \text{solid cyan line}] \) obtained by Murakami et al. (2005) for vertically-aligned SWNTs of various diameters and chiralities. The mean absorption cross sections (solid red line) are obtained with the “1/3–2/3” approximation. The measurements were made over an energy range of \( \sim 0.5–6 \text{ eV} \) which corresponds to \( 0.4 \leq \lambda^{-1} \leq 4.8 \mu \text{m}^{-1} \). Extrapolations (dashed blue and green lines) are made for \( \lambda^{-1} < 0.4 \mu \text{m}^{-1} \) and \( \lambda^{-1} > 4.8 \mu \text{m}^{-1} \) by fitting the experimental absorption spectra at \( \sim 0.5–6 \text{ eV} \) with a sum of multiple Drude functions. Also shown are the absorption cross sections of nano graphite calculated from Mie theory using the dielectric function of Draine & Lee (1984).

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SWNT concentrations in suspensions that often also contain surfactants or polymer coatings (see Guo et al. 2004, Murakami & Maruyama 2009, Weisman & Kono 2019). Whereas the interstellar extinction is the strongest in the UV, to the best of our knowledge, existing measurements of the absorption cross sections for individual SWNTs are limited to the visible and near-IR wavelength ranges (e.g., see Liu et al. 2014, Streit et al. 2014, Sanchez et al. 2016, Yao et al. 2018). Also, interstellar SWNTs — if present — see Liu et al. 2014, Streit et al. 2014, Sanchez et al. 2016, Yao et al. 2018. These absorption features correspond to the first \( (\sim 1.45 \text{ eV}) \) and second \( (\sim 3 \text{ eV}) \) subband gaps in semiconducting SWNTs. Due to intersubband absorptions, in the low energy range \((< 3 \text{ eV})\) three weak features at \( \sim 0.63, 0.93 \) and \( 1.45 \text{ eV} \) are also seen in the absorption spectra for light polarized parallel to the SWNT axis. Murakami et al. (2005) found that these two peaks were observed at almost the same positions regardless of the diameter and preparation method of SWNTs. Due to intersubband absorptions, in the low energy region \(< 3 \text{ eV}\) three weak features at \( \sim 0.63, 0.93 \) and \( 1.45 \text{ eV} \) are also seen in the absorption spectra for light polarized parallel to the SWNT axis.

Murakami et al. (2005) grew the vertically-aligned SWNT film on an optically polished quartz substrate, using the alcohol catalytic chemical vapor deposition (AC-CVD) method. The film consists only of SWNTs that are sufficiently clean, i.e., contain virtually no amorphous carbon and no multi-walled carbon nanotubes, as confirmed by resonant Raman scattering and high-resolution transmission electron microscopy (HRTEM). Direct HRTEM imaging measurements of more than 50 SWNTs revealed an average diameter of \( \sim 2.0 \text{ nm} \) with a standard deviation of \( \sim 0.4 \text{ nm} \). Most SWNTs in the film form bundles with a typical diameter of \( \sim 15 \text{ nm} \), while the thickness of the film is typically \( \sim 5–10 \mu \text{m} \).

SWNTs are optically anisotropic. Murakami et al. (2005) used the Shimadzu UV-3150 spectrophotometer combined with a UV-vis-NIR polarizer to determine the polarization-dependent absorption spectra of the vertically-aligned SWNT film in the wavelength range of \( \sim 200–2500 \text{ nm} \) which corresponds to an energy range of \( \sim 0.5–6 \text{ eV} \). As illustrated in Figure 1, most noticeable in the absorption spectra are the broad, polarization-dependent peaks at \( \sim 4.5 \) and \( \sim 5.25 \text{ eV} \), respectively arising from surface and bulk \( \pi \)-plasmon excitations. The absorption feature at \( \sim 4.5 \text{ eV} \) is seen for light polarized parallel to the SWNT axis, while the absorption feature at \( \sim 5.3 \text{ eV} \) is seen for light polarized perpendicular to the axis. Murakami et al. (2005) found that these two peaks were observed at almost the same positions regardless of the diameter and preparation method of SWNTs. Due to intersubband absorptions, in the low energy region \(< 3 \text{ eV}\) three weak features at \( \sim 0.63, 0.93 \) and \( 1.45 \text{ eV} \) are also seen in the absorption spectra for light polarized parallel to the SWNT axis.

Let \( C_{ab} (\lambda)/N_C \) be the mean absorption cross section per C atom of a SWNT of \( N_C \) C atoms. Let \( C_{ab}^\parallel (\lambda)/N_C \) and \( C_{ab}^\perp (\lambda)/N_C \) respectively be the absorption cross section per
C atom of a SWNT of $N_C$ C atoms along or perpendicular to the tube axis. The “1/3–2/3” approximation (Draine 1988, 2016) leads to

$$C_{abs}(\lambda)/N_C \approx \frac{1}{3} C_{abs}^{\parallel}(\lambda)/N_C + \frac{2}{3} C_{abs}^{\perp}(\lambda)/N_C .$$

In Figure 1 we show the polarization-dependent absorption cross sections $C_{abs}^{\parallel}(\lambda)/N_C$ and $C_{abs}^{\perp}(\lambda)/N_C$ measured by Murakami et al. (2005) as well as the mean absorption cross section $C_{abs}(\lambda)/N_C$ determined from the “1/3–2/3” approximation. Also shown in Figure 1 is the extinction cross section of a graphite nanoparticle of $N_C = 40$ calculated from Mie theory (Bohren & Huffman 1983) using the dielectric functions of “astronomical graphite” of Draine & Lee (1984). While the absorption cross sections of SWNTs show two distinct peaks at $\sim 4.5$ eV (i.e., $\sim 2759 \text{ Å}$ or $\sim 3.62 \mu m^{-1}$) and $\sim 5.25$ eV (i.e., $\sim 2365 \text{ Å}$ or $\sim 4.23 \mu m^{-1}$), graphite exhibits a more pronounced absorption peak at $\sim 5.7$ eV (i.e., $\sim 2175 \text{ Å}$ or $\sim 4.60 \mu m^{-1}$).

### 3 EXTINCTION

The interstellar extinction curve, often expressed as the variation of the extinction $A_\lambda$ with the inverse wavelength $\lambda^{-1}$, generally rises from the near-IR to the near-UV, with a broad absorption bump at $\lambda \approx 2175 \text{ Å}$ or $\lambda^{-1} \approx 4.6 \mu m^{-1}$, followed by a steep rise into the far-UV at $\lambda^{-1} \approx 10 \mu m^{-1}$, the shortest wavelength at which the extinction has commonly been measured (see Figure 2).

The interstellar extinction curve contains important information about the interstellar dust size distribution and composition. While SWNTs exhibit two prominent peaks at $\sim 4.5$ eV and $\sim 5.25$ eV in their absorption spectra (see Figure 1 and 2), the interstellar extinction curve is rather smooth in these energy ranges. The International Ultraviolet Explorer (IUE) obtained the extinction curves in the wavelength range of $\sim 115$–$330$ nm along the lines of sight toward hundreds of stars and none of these extinction curves exhibit a more pronounced absorption peak at $\sim 5.7$ eV (i.e., $\sim 2175 \text{ Å}$ or $\sim 4.60 \mu m^{-1}$).

#### 4 DISCUSSION

As fullerenes and CNTs are intimately related (e.g., nanotubes are often known as cylindrical fullerenes), the ubiquitous detection of fullerenes in various astrophysical environments (see Zhang & Kwok 2013), together with the remarkable stability of CNTs against intense radiation, reinforces the idea that CNTs may also be widespread in the ISM. Although the formation processes of fullerenes and CNTs in space are still unclear to date, they may both be related to PAHs which are ubiquitously seen in a wide variety of astrophysical regions as revealed by the distinct set of IR emission features at $3.3, 6.2, 7.7, 8.6, 11.3$ and $12.7 \mu m$ (see Peeters 2014). Berné & Tielens (2012) proposed that fullerenes could be made in space through graphene from the complete dehydrogenation of PAHs. Based on molecular dynamic simulations, Chen et al. (2020) demonstrated that zig-zag SWNTs could be formed from linear, catacondensed PAHs. Using pentacene ($C_{22}H_{16}$; a linear, five-ring PAH molecule) as a case study, Chen et al. (2020) found that vibrationally-excited linear PAHs could bend significantly without breaking the C-C bonds, with a bending barrier easily surmountable by absorbing a single stellar photon. Following such a bending, a closed, stereospecific 3D nanostructure forms and could subsequently grow longer to zig-zag SWNTs via the conventional hydrogen-abstraction and acetylene-addition (HACA; Frenklach & Fiegelman 1989) process which involves repetitive hydrogen losses from the 3D structure followed by the addition of one or two acetylene ($C_2H_2$) molecule(s).

Chen & Li (2019) have also shown that armchair SWNTs could form in the ISM from benzene ($C_6H_6$) and phenyl ($C_6H_5$) through the HACA process. This formation pathway starts with a benzene combining with a phenyl radical to form a biphenyl radical ($C_{12}H_{10}•$) through hydrogen abstraction. Then, the biphenyl radical loses a hydrogen atom and reacts with another phenyl radical to form a triphenyl radical ($C_{18}H_{14}•$). The triphenyl radical, with the loss of a hydrogen atom, isomerizes to a closed 3D structure. Subsequently, the HACA process leads to the continual growth of the 3D structure to more complex armchair SWNTs. Also, it has been experimentally shown that SWNTs could be catalytically formed on the surface of Fe nanoparticles of $\sim 1$–$10$ nm from any C-rich feedstock, including CH$_4$, C$_2$H$_2$, benzene, and PAHs (see Zhou et al. 2006 and references therein). Nanotube length would depend on the local Fe/C ratio, and detailed chemical kinetics, and is expected to show environmental variations. In principle, a 1 nm-diameter SWNT could grow to lengths of hundreds of microns if gaseous reagents are continuously supplied.
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Figure 2. Comparison of the average Galactic interstellar extinction curve (dotted line; Fitzpatrick 1999) with the model extinction curve (solid red line) obtained by adding the contribution from CNTs with [C/H]_{CNT} = 10 ppm (thin red line) to the best-fit model of Weingartner & Draine (2001). Also plotted are the contributions (see Li & Draine 2001) from “BSil” (a ∼ 250 Å silicate); “SSil” (a < 250 Å silicate); “Bcarb” (a ∼ 250 Å carbonaceous); “Scarb” (a < 250 Å carbonaceous, including PAHs). The vertical bars superposed on the extinction curve of Fitzpatrick (1999) represent the observational uncertainties.

(Hafner et al. 1998, Kong et al. 1998). In the ISM, shock processing could detach the formed SWNTs from the catalytic Fe nanoparticles and break long nanotubes into shorter ones.

For the catalytic formation of SWNTs on nanometer-sized Fe particles to be a feasible pathway in the ISM, a prerequisite is the presence of interstellar Fe nanoparticles. In the Galactic ISM, typically 90% or more of the Fe is missing from the gas phase (Jenkins 2009), suggesting that Fe is the largest elemental contributor to the interstellar dust mass after O and C and accounts for ∼25% of the dust mass in diffuse interstellar regions. However, as yet we know little about the nature of the Fe-containing material. Silicate grains provide a possible reservoir for Fe in the form of interstellar pyroxene (Mg_{2x}Fe_{1−x}SiO_{3}) or olivine (Mg_{2x}Fe_{2−x}SiO_{4}). However, the shape and strength of the 9.7 μm silicate feature in extinction suggest that the silicate material is Mg-rich rather than Fe-rich (Potteet et al. 2015) and therefore a substantial fraction (∼70%) of the interstellar Fe could be in metallic iron or iron oxides (see Draine & Hensley 2013). Thermodynamic computations have shown that Fe nanoparticles are stable against sublimation in the interstellar radiation field and can persist down to a radius of ∼4.5 Å, and perhaps smaller (see Hensley & Draine 2017). Therefore, interstellar Fe in the form of metallic Fe nanoparticles may indeed constitute a component of the interstellar dust.

In principle, the presence of CNTs in the ISM could be revealed through their C–C vibrational modes in the IR. CNTs are actually more IR-active than graphene due to their cylindrical boundary condition. However, as mentioned earlier, the vibrational spectra of CNTs depend on their diameters and chiralities (e.g., see Chen & Li 2019). For SWNTs of diameters less than 2 nm, over 100 different structures are topologically possible. Each different structural SWNT is a unique, ordered, molecular species having its own characteristic vibrational spectra. Therefore, a specific comparison of the vibrational spectra of individual SWNTs and the astronomical spectra is difficult because of the wide range of SWNT diameters and chiralities expected to be present in the ISM. We hence call for experimental measurements of the IR vibrational spectra of ensemble nanotube samples of a wide range of diameters, lengths, and morphologies. Kim et al. (2005) obtained the IR vibrational modes of SWNTs based on the transmission spectra of thin films of purified, freestanding SWNT bundles of typically ∼100 or more species with tube diameters in the ∼1.2–1.6 nm range grown by the electric arc method. However, no information was provided on the strengths of the SWNT vibrational bands. This prevents us from any detailed modeling of the IR emission of SWNTs in astronomical environments.

Electronic structure calculations have shown that
SWNTs exhibit intense electronic transitions in the visible and near-IR, which vary systematically with length. Zhou et al. (2006) suggested that SWNTs might be responsible for some of the mysterious diffuse interstellar bands (DIBs). The DIBs are a set of over 600 interstellar absorption spectral features first detected in 1919 (see Sarre 2006). The identity of the species responsible for most of these bands remains as one of the most enigmatic mysteries in astrophysics. Both experimental and computational studies are needed to explore the electronic properties of individual SWNTs of various diameters and chiralities. Also, due to the strong quantum-confinement (∼1 nm) effect of charge carriers in SWNTs, SWNTs luminesce efficiently over a broad wavelength region, ranging from the optical (Lin et al. 2005) to the near-IR (O’Connell et al. 2002). It would be interesting to explore whether SWNTs could account for the unidentified ERE, an interstellar photoluminescence phenomenon (Witt & Vĳh 2004). Witt (2014) suggested that the ERE carriers and the carriers of DIBs may be connected. Very recently, Lai et al. (2020) detected strong DIBs along the line of sight toward a background star seen through the reflection nebula IC 63, where the most intense ERE is detected. The detection of strong DIBs in association with ERE is consistent with the hypothesis of a common carrier for both DIBs and ERE (Witt 2014).

5 SUMMARY

Motivated by the widespread of many allotropes of carbon (e.g., amorphous carbon, fullerenes, graphite, nanodiamonds, and PAHs) in the interstellar and circumstellar medium, we have explored the possible presence of CNTs, another allotrope of carbon, in the diffuse ISM by comparing the experimentally-measured UV/optical absorption spectra of SWNT mixtures with the observed interstellar extinction curve. While the experimental absorption spectra of SWNTs exhibit two prominent peaks at ∼4.5 and 5.25 eV attributed to σ-plasmon excitations, the interstellar extinction curve is rather smooth in this energy range. Based on the absence of the ∼4.5 and 5.25 eV absorption peaks in the interstellar extinction curve, we have placed an upper limit of ∼10 ppm of C/H (i.e., ∼4% of the total interstellar C) on the interstellar CNT abundance. We call for further experimental measurements and quantum-chemical computations of the UV/optical electronic and IR vibrational transitions of CNTs of a wide range of sizes and chiralities.

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