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Comparison of [CII] 158μm line widths to luminosities

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Abstract

A comparison of [CII] 158μm emission line widths to different luminosities is presented to decide if any luminosity relates to velocity dispersion. [CII] 158 μm emission lines are observed with Herschel PACS for 379 galaxies and the archival data for [CII] line widths are taken from http://cassis.sirtf.com/herschel/. Emission line widths are compared to [CII] luminosities, to near-infrared 1.6μm luminosities and to infrared 22μm luminosities. H magnitudes are taken from 2MASS catalogue, and 22μm fluxes from the WISE catalogue.

Keywords: *infrared:galaxies - galaxies:starburst - galaxies:active - galaxies: distances and redshifts*

1. Introduction

Investigation of early galaxies is crucial for understanding galaxy formation and evolution. A particularly important new capability is the study of the far infrared [CII] 158 μm emission line. Especially in dusty, obscured sources it may be the only line observable with currently available techniques. This [CII] line is the strongest far-infrared line in most sources (Brauher et al., 2008, Luhman et al., 2003, Malhotra et al., 1997, Nikola et al., 1998, Stacey et al., 1991) and is associated with star formation because it arises within the photodissociation region (PDR) surrounding starbursts (Helou et al., 2001, Malhotra et al., 2001, Meijerink et al., 2007, Tielens & Hollenbach, 1985). Numerous observations of the [CII] line have been made (De Looze et al., 2014, Díaz-Santos et al., 2013, 2014, Farrah et al., 2013, Sargsyan et al., 2012, 2014) using the Photodetector Array Camera and Spectrometer (PACS) instrument (Poglitsch et al., 2010) on the *Herschel* Space Observatory (Pilbratt et al., 2010). The [CII] line profiles are often of very high quality, with velocity resolution <250 km s^{-1}, so the line profiles themselves potentially contain diagnostic information. In previous papers (Sargsyan et al., 2011, 2014), we compared the [CII] line with mid-infrared emission lines and with the Polycyclic Aromatic Hydrocarbon (PAH) feature observed with the Infrared Spectrograph ((IRS; Houck et al., 2004) on the *Spitzer* Space Telescope (Werner et al., 2004). These comparisons led to our calibration of the star formation rate (SFR) based on [CII] luminosities such that log(SFR) = log(L[CII])-7.0 for SFR in solar masses/year and L([CII]) in solar luminosities. For those sources also observed at high resolution with the IRS, we compared line widths for various emission lines and confirmed the association of [CII] with the starburst component of 379 sources ((Samsonyan et al., 2016, hereafter S16)). The [CII] line profiles were published in S16. In this paper our primary new result is the comparison of the line widths with various other properties of the galaxies to search for astrophysical mechanisms that control the line widths.

2. Sample selection and data

For the analysis in this paper, the [CII] profiles shown in S16 are used. These profiles arise from the 8" x 8" spaxel of the PACS observation which is most closely aligned with the position of the *Spitzer* IRS observations used for comparisons in S16. All data used for the analysis in section 3 are available in VizieR Online Data Catalog. The full list of the FWHM of the profile from the Gaussian fits illustrated in http://cassis.sirtf.com/herschel/. The FWHM-s listed are intrinsic widths, after correcting for instrumental resolution of 236 km s^{-1}. The FWHM errors are also given in the webpage, the errors are so small, that they can be neglected. Archival data for H band fluxes and luminosities from the Two Micron All Sky Survey (2MASS; Skrutskie et al., 2006) and for 22 μm fluxes and luminosities from the Wide-Field Infrared Survey Explorer (WISE; Wright et al., 2010) are also given.

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3. Analysis and discussion

The objective of this study is to search for what physical characteristic of the galaxies is primarily responsible for determining the observed [CII] profile widths. Much of the analysis in S16 was designed to compare the [CII] line to mid-infrared forbidden lines observed with the *Spitzer* IRS, with the goal of seeking differences between AGN and starburst sources. As described and reviewed in that paper, the mid-infrared AGN/starburst classification is made using the strength relative to continuum (equivalent width - EW) of the 6.2μm PAH emission feature.

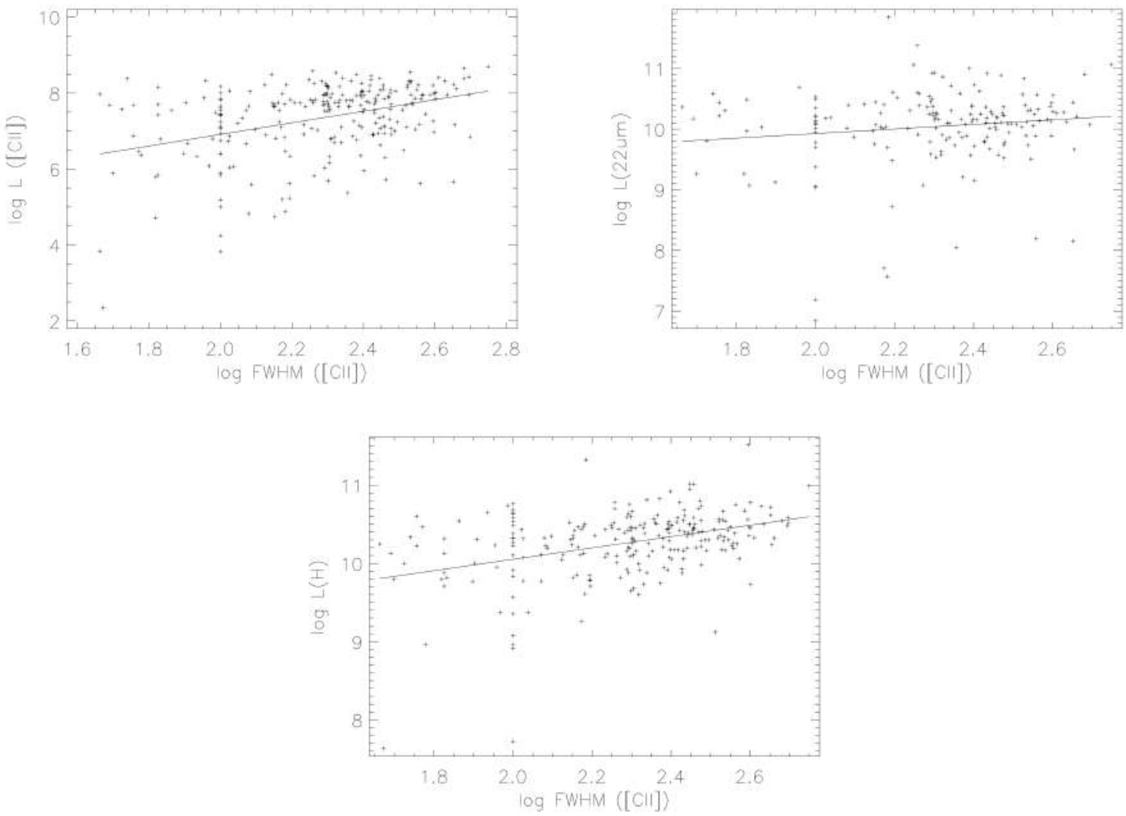

Figure 1. Luminosities in solar luminosities compared to [CII] FWHM in km/s. Top left figure shows [CII] luminosity and line fit is logL([CII]) = 1.52(±0.24)log(FWHM)+3.86. Top right figure shows 22 μm luminosity and line fit is log L(22 μm) = 0.38(±0.20)log(FWHM)+9.17. Lower figure shows H luminosity and line fit is log(L(H)) = 0.73(±0.11)log(FWHM)+8.60.

The objective of this paper is to compare [CII] FWHM to other galactic parameters in search of correlations. It has long been known that stellar velocity dispersions within galactic bulges relate to bulge luminosity with a form $L \propto \sigma^n$ for σ the stellar line of sight velocity dispersion. This relates to the FWHM by FWHM = 2.35 σ, and FWHM is normally used as the measure of velocity dispersion when using optical emission lines (e.g. Feldman et al., 1982, Shields et al., 2003, Whittle, 1992). The initial study (Faber & Jackson, 1976) found that $3 < n < 4$. In a reevaluation of a large sample of galactic bulges, Whittle (1992) found $n = 3.2$. When using the [OIII] optical emission line, primarily for Seyfert galaxies, he found $n = 2.2$. Subsequent studies by Nelson & Whittle (1996) and Shields et al. (2003) determined that even the [OIII] widths from the narrow line region of AGN are controlled primarily by bulge gravity rather than by other sources inputing kinetic energy to the gas. More recent studies of relations between velocity dispersions and bulge gravity emphasized the use of sigma to determine relations among the masses of central black holes, bulge velocity dispersions, and bulge luminosities. The comprehensive summary of Kormendy & Ho (2013) studies yields $n = 3.7$, and that of McConnell & Ma (2013) gives $n = 5.1$. Based on this extensive previous work, it would be expected that any integrated measure of velocity dispersion for a galaxy should show a meaningful correlation with the mass of that galaxy. This is my motive for comparing the FWHM of the [CII] lines with three different measures of galaxy luminosity, each of which measures a different mass. The three parameters are: 1. the luminosity of the [CII] line itself, which scales primarily with the photodissociation regions surrounding starbursts and so scales with the gas mass connected to star formation; 2.

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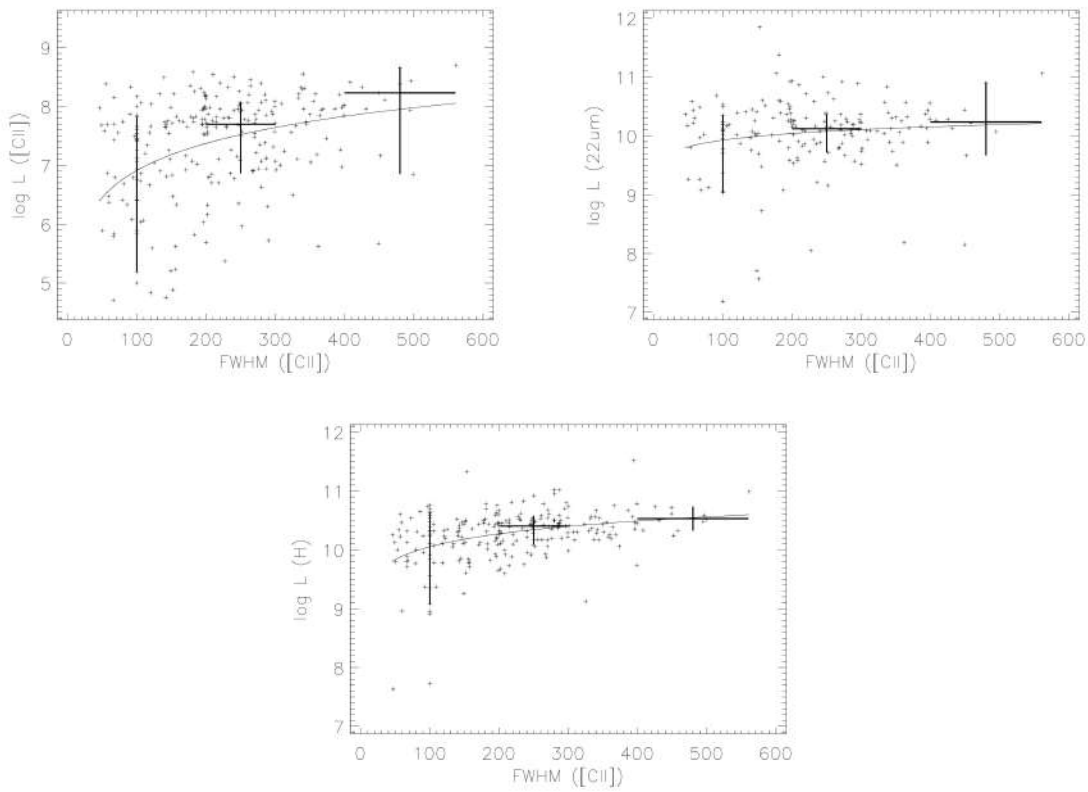

Figure 2. Luminosities compared to FWHM (linear scale). Fits are as in Fig.1. Vertical lines show 1 dispersions for velocities 100 km/s, 200-300 km/s and > 400 km/s.

The luminosity of dust reradiation, taken as 22μm dust luminosity, which scales with the total luminosity of younger, hotter stars that are heating the dust; 3. The near infrared (H band) luminosity of the galaxy, which scales with the total luminosity of the evolved stars. Comparisons of [CII] FWHM with these three measures of luminosity are shown in Fig.1 and 2.

Fig.1 illustrates the results using the conventional comparison of logL with logFWHM. In all cases, the value of n is much smaller than previous studies using stellar velocity dispersions or optical emission lines. For [CII] luminosities, $n = 1.52 \pm 0.24$; for 22 μm luminosities, $n = 0.38 \pm 0.20$; for H luminosities, $n = 0.73 \pm 0.11$. In Fig.2, the fits are shown using linear values for FWHM to compare scatter among the comparisons using the different parameters. These plots show the scatter in the luminosity distributions above and below the formal fits (1 for logL) within three different ranges of FWHM. In all cases, the scatter is extreme. The range of luminosities at a given value of FWHM is comparable in all cases to the full range of FWHM over all luminosities. There can be a factor of 5 range in gas velocities for the same value of luminosity. It does not appear, therefore, that FWHM for [CII] can be used in a meaningful way to predict any kind of galaxy luminosity. Despite the large scatters, the results do imply a meaningful conclusion. The luminosity dispersions are smallest for the H band luminosities, next for the dust luminosities, and largest for the [CII] luminosities. This scaling of luminosity dispersions also progresses the same as the uncertainties in the slopes of the line fits in Fig.1 (smallest uncertainty for H luminosity). In both cases, therefore, the correlation of FWHM with H band luminosity is better than with either other parameter. I conclude from this that the gravity associated with the mass of evolved stars is a factor controlling the widths of the [CII] line. Nevertheless, the large range in gas velocities that can be found at the same value of luminosity remains puzzling. It seems that some unidentified process other than straightforward gravitational forces within the galactic bulge is the primary controller of [CII] gas velocities.

4. Summary

Emission line widths are compared to [CII] luminosities, to near-infrared 1.6 m luminosities and to infrared 22 m luminosities to decide if any luminosity accurately relates to velocity dispersion. The luminosity dispersions are smallest for H band luminosities and the slope uncertainty for the line fit is the smallest for

H luminosities. I conclude from this that the gravity associated with the mass of evolved stars is a weak factor controlling the widths of the [CII] line, but line widths are primarily determined by a mechanism that is still unknown.

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References

Brauher J. R., Dale D. A., Helou G., 2008, Astrophys. J. Suppl. Ser. , 178, 280

De Looze I., et al., 2014, Astron. Astrophys. , 568, A62

Díaz-Santos T., et al., 2013, Astrophys. J. , 774, 68

Díaz-Santos T., et al., 2014, Astrophys. J. Lett. , 788, L17

Faber S. M., Jackson R. E., 1976, Astrophys. J. , 204, 668

Farrah D., et al., 2013, Astrophys. J. , 776, 38

Feldman F. R., Weedman D. W., Balzano V. A., Ramsey L. W., 1982, Astrophys. J. , 256, 427

Gallerani S., Fan X., Maiolino R., Pacucci F., 2017, , 34, e022

Helou G., Malhotra S., Hollenbach D. J., Dale D. A., Contursi A., 2001, Astrophys. J. Lett. , 548, L73

Houck J. R., et al., 2004, Astrophys. J. Suppl. Ser. , 154, 18

Kormendy J., Ho L. C., 2013, Ann. Rev. Astron. Astrophys. , 51, 511

Luhman M. L., Satyapal S., Fischer J., Wolfire M. G., Sturm E., Dudley C. C., Lutz D., Genzel R., 2003, Astrophys. J. , 594, 758

Malhotra S., et al., 1997, Astrophys. J. Lett. , 491, L27

Malhotra S., et al., 2001, Astrophys. J. , 561, 766

McConnell N. J., Ma C.-P., 2013, Astrophys. J. , 764, 184

Meijerink R., Spaans M., Israel F. P., 2007, Astron. Astrophys. , 461, 793

Nelson C. H., Whittle M., 1996, Astrophys. J. , 465, 96

Nikola T., Genzel R., Herrmann F., Madden S. C., Poglitsch A., Geis N., Townes C. H., Stacey G. J., 1998, Astrophys. J. , 504, 749

Pilbratt G. L., et al., 2010, Astron. Astrophys. , 518, L1

Poglitsch A., et al., 2010, Astron. Astrophys. , 518, L2

Samsonyan A., Weedman D., Lebouteiller V., Barry D., Sargsyan L., 2016, Astrophys. J. Suppl. Ser. , 226, 11

Sargsyan L., Weedman D., Lebouteiller V., Houck J., Barry D., Hovhannisyan A., Mickaelian A., 2011, Astrophys. J. , 730, 19

Sargsyan L., et al., 2012, Astrophys. J. , 755, 171

Sargsyan L., Samsonyan A., Lebouteiller V., Weedman D., Barry D., Bernard-Salas J., Houck J., Spoon H., 2014, Astrophys. J. , 790, 15

Shields G. A., Gebhardt K., Salviander S., Wills B. J., Xie B., Brotherton M. S., Yuan J., Dietrich M., 2003, Astrophys. J. , 583, 124

Skrutskie M. F., et al., 2006, Astron. J. , 131, 1163

Stacey G. J., Geis N., Genzel R., Lugten J. B., Poglitsch A., Sternberg A., Townes C. H., 1991, Astrophys. J. , 373, 423

Tielens A. G. G. M., Hollenbach D., 1985, Astrophys. J. , 291, 722

Werner M. W., et al., 2004, Astrophys. J. Suppl. Ser. , 154, 1

Whittle M., 1992, Astrophys. J. , 387, 121

Wright E. L., 2006, Publ. Astron. Soc. Pac. , 118, 1711

Wright E. L., et al., 2010, Astron. J. , 140, 1868