

Herschel/PACS Observation of a Variable Protostar

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Abstract

We present the first complete Herschel/PACS 70 μm and 160 μm light curve of the young variable protostar LRL54361, located in the IC348 cloud at 300 pc. It exhibits periodic variations in luminosity at near- and mid-infrared wavelengths and shows a remarkably stable periodicity of 25.34 days over a time span of several years. Scattered light images at 1.6 μm reveal a light echo propagating through the envelope. Previous studies have attributed the luminosity change to pulsed accretion due to a binary. We have obtained 29 epochs of observations using the PACS instrument on board Herschel during our monitoring campaign of IC348 to get a complete phase coverage of the 25.34 days period. Our observations show unprecedented flux variation at these far infrared wavelengths (factor of six at 70 and factor of two at 160 μm) that are well correlated with the variations seen at shorter wavelengths.

Introduction

YSO evolution takes place over a few million years; however, there is growing evidence that the process is in fact highly dynamic on timescales from centuries to as short as days. Young stars are long known to vary in the optical and near-infrared, due to cold stellar spots related to stellar activity, hot spots associated with accretion flows striking the surface of the star, or variable extinction along the line-of-sight. In the recent years it was recognized that flux changes in the mid-infrared are also common (see e.g. Flaherty et al. 2012, 2013). However strong and periodic flux variation in the far infrared is not yet reported in the literature. The variations discovered so far are either not periodic (Kóspál et al. 2007) or weak, with amplitudes around 10-20% (Billot et al. 2012). At these wavelengths the radiation is dominated by thermal emission of the circumstellar material, which could in principle vary as a consequence of either its changing illumination/accretion heating or a physical restructuring of the density. Our knowledge about the flux variation of class I sources that are still embedded in their envelope material is very limited. Our observations with SPITZER/MIPS suggest that fraction of variability among these sources is different to that of class II sources, however this difference is not seen at the shorter wavelengths (3.6 and 4.5 μm) of IRAC warm mission data. The reason might be that we are only sensitive to the brightest class I sources in the this wavelength domain.

Our target LRL54361 is a young protostar exhibiting periodic increases in luminosity at near- and mid-infrared wavelengths. The luminosity change is attributed to pulsed accretion due to a companion star (Muzerolle et al. 2013). The object shows a remarkably stable periodicity with a period of 25.34 days over a time span of several year. Scattered light HST/NICMOS images reveal a light echo propagating through the envelope.

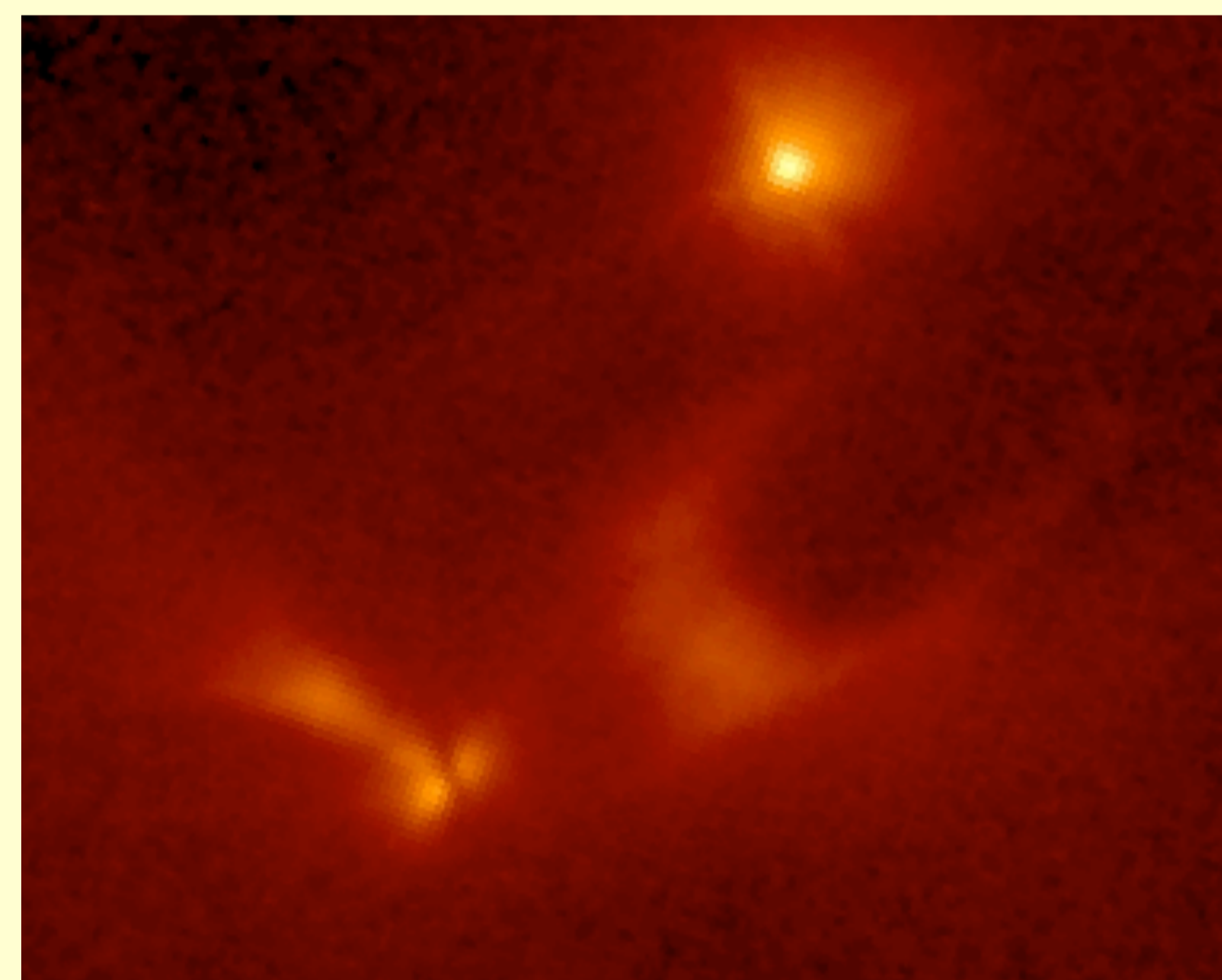
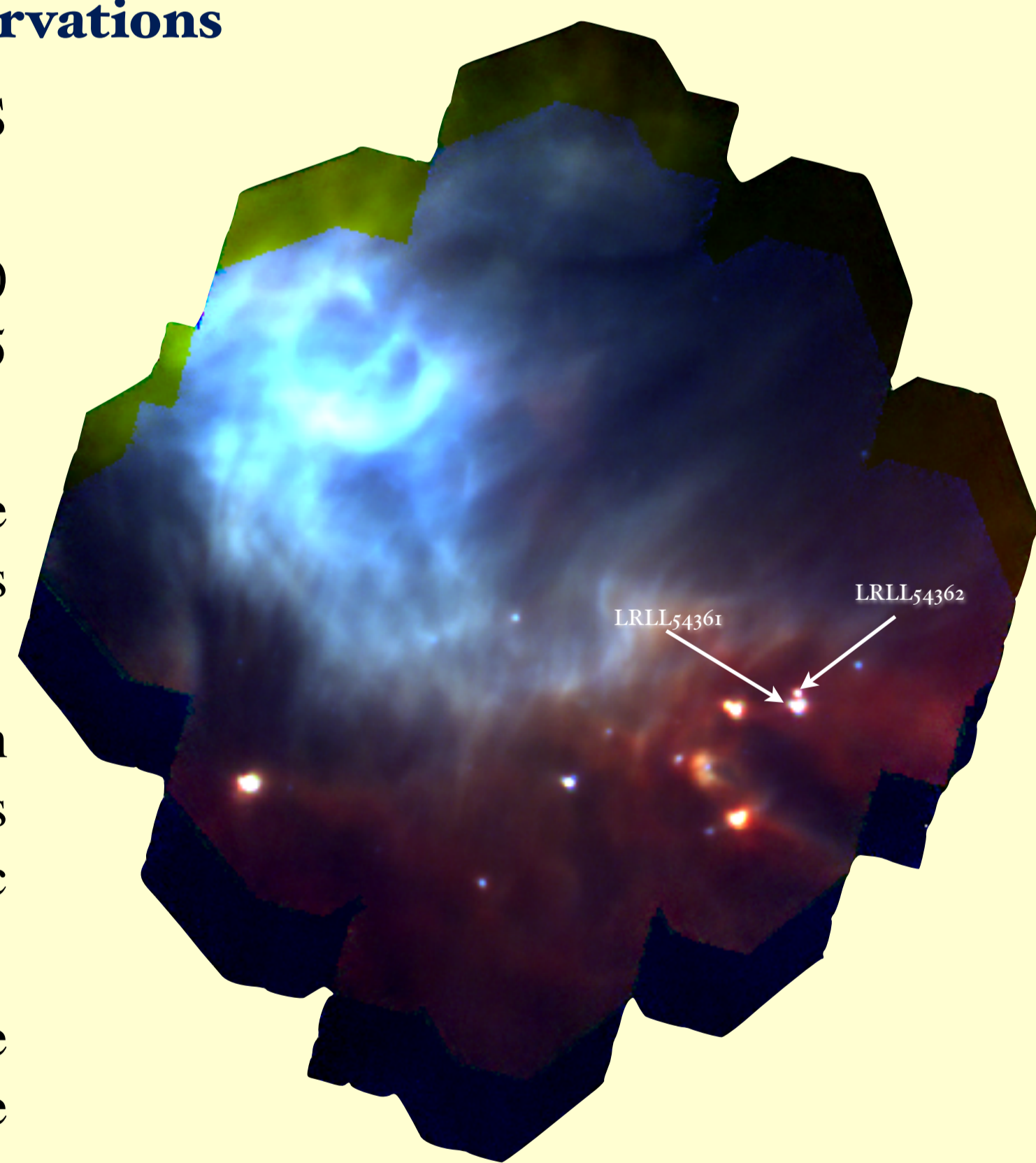


Fig 1: Three color image of IC348. red: 160 μm , green: 100 μm , blue 70 μm

Observations

1. a 14'x14' area in IC348 with PACS onboard *Herschel*
2. observed simultaneously at 70 and 160 μm 29 times and at 100 and 160 μm 5 times
3. the field was selected to maximize the coverage of the 70 micron sources detected with *Spitzer*/MIPS
4. two scanmaps of the field with perpendicular scan directions (scan angles = 45 and 135 degree) using 20"/sec scanspeed
5. We processed our PACS maps up to the Level 1 stage using the HIPE. For the final maps and the combination of the different scan angles we used the Scanamorphos software (Roussel 2012)
6. We used a uniform pixel scale in all of our maps (1"/pixel at 70 and 100 μm and 2"/pixel at 160 μm). Photometry was performed on the final map in each epoch using the annularSkyAperturePhotometry task in HIPE.



References

- Billot, N., et al. 2012, ApJ, 753, L35
 Flaherty, K., et al. 2012, ApJ, 748, 71
 Flaherty, K., et al. 2013, AJ, 145, 66
 Kóspál, Á., et al. 2007, A&A., 470, 211
 Muzerolle, J., 2013, Nature, 493, 378

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Light Curves

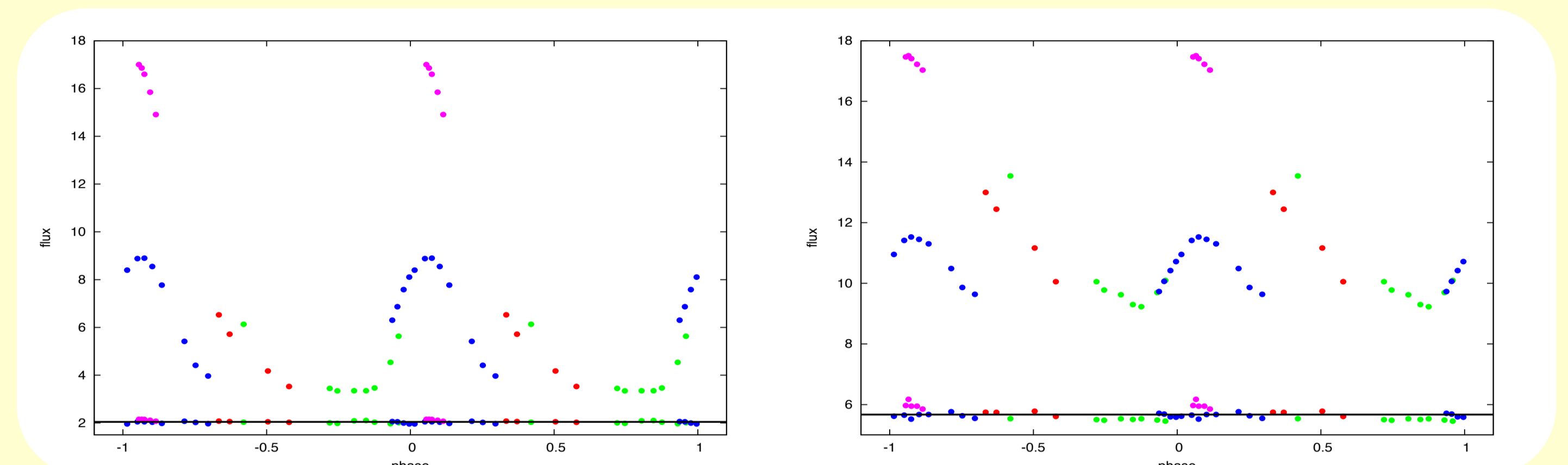


Fig 2: Folded light curve of LRL54361 at 70 (left) and 160 (right) μm . The light curve of LRL54362 is also shown to demonstrate the reliability of the measurements. Different colors designate different cycles.

Fig 2 shows the folded light curve of LRL54361 at 70 μm (left panel) and 160 μm (right panel) of LRL54361. The different symbols represent different observing campaigns (thus different cycles). The light-curve of LRL54362 is also shown for comparison (around 2.0 Jy (left) and 5.7 Jy (right)). From this we calculate that our data processing and photometry are stable within 2-3%.

Phase=0 corresponds to the maximum calculated using the Spitzer /IRAC observations. The scheduling conventions and the time awarded for our variability program did not make it possible to cover an entire cycle so our observation cover one maximum transition and a different minimum transition. The change between the minimum and maximum flux at 70 μm is about a factor of 6 while at 160 μm it is about a factor of 2. Although the flux variation follows nicely the 25.34 days period obtained from the Spitzer/IRAC campaign (Muzerolle et al. 2013), it is obvious that the variation pattern does not repeat exactly. There is a slight shift between the curves of the different cycles implying that the strength and/or the exact time of the outburst changes from cycle to cycle. The plot also implies that the system returns to the same minimum state after each outburst but the timescale of the decline depends on the strength of the maximum.

Source morphology

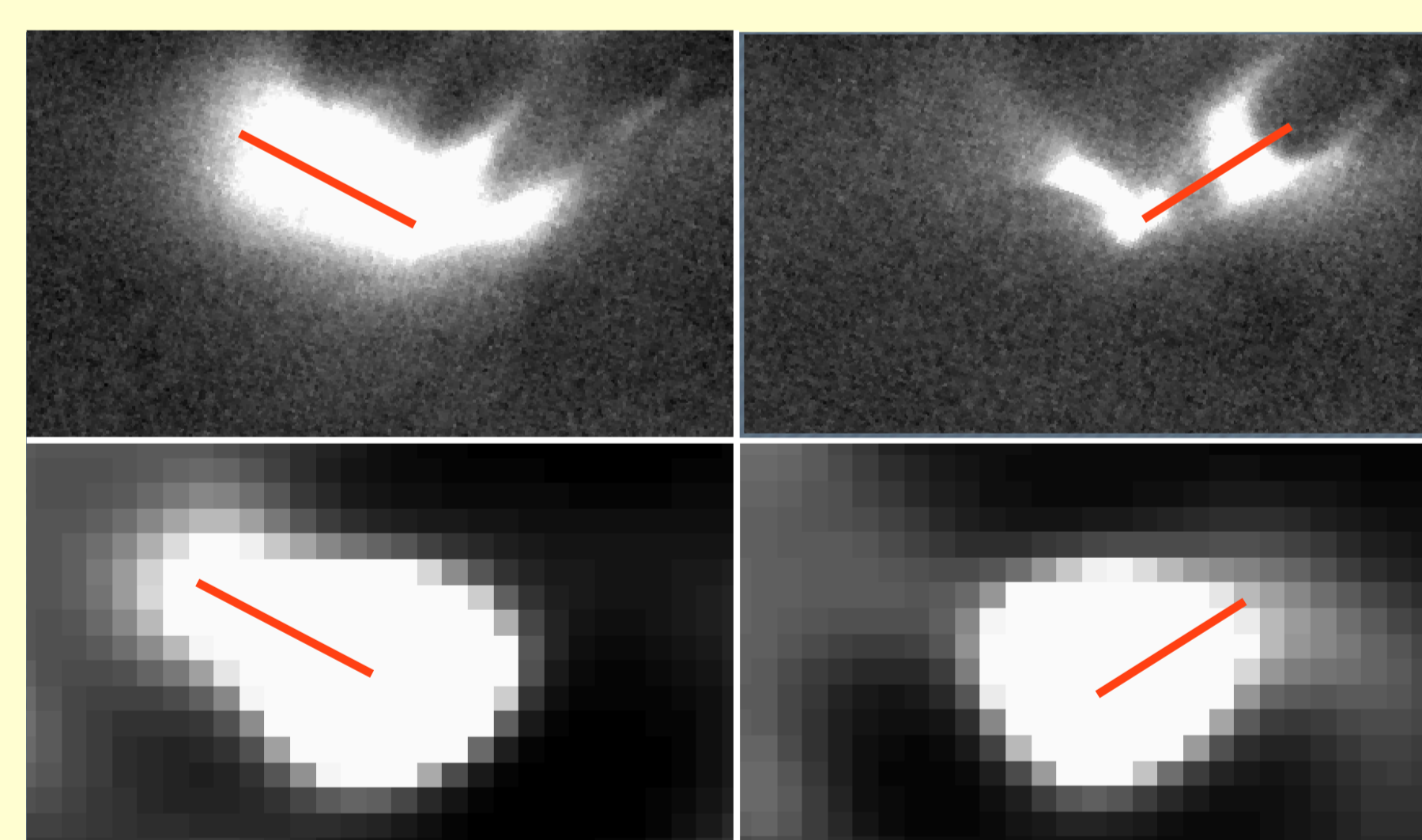


Fig 3: comparing the HST/WFC3 1.6 μm (upper) and the Herschel/PACS 70 μm image (lower). The left panel shows the source 8 days after the maximum (largest spatial extent) while the right panel shows it during minimum.

The red lines in the left panel show the A-F line while the one in the right panel shows the A-D line from Fig S4 of Muzerolle et al. (2013) (see Fig 4.). In both cases an elongated structure appears next to the source indicating the light echo propagating outwards after the outburst. The appearance of the elongated structure 8 days after the outburst is in good agreement with the findings of Muzerolle et al. (2013); the light echo reaches point F (approximately at the end of the red line) about 6 days after the outburst.

During the 29 epochs of observations the shape of the source changed with the period of the photometric changes. Fig 3 shows the image of LRL54361 at 70 μm (deconvolved with the HERSCHEL/PACS 70 μm PSF to recover the spatial structure) together with the HST/WFC3 image from Muzerolle et al.(2013).

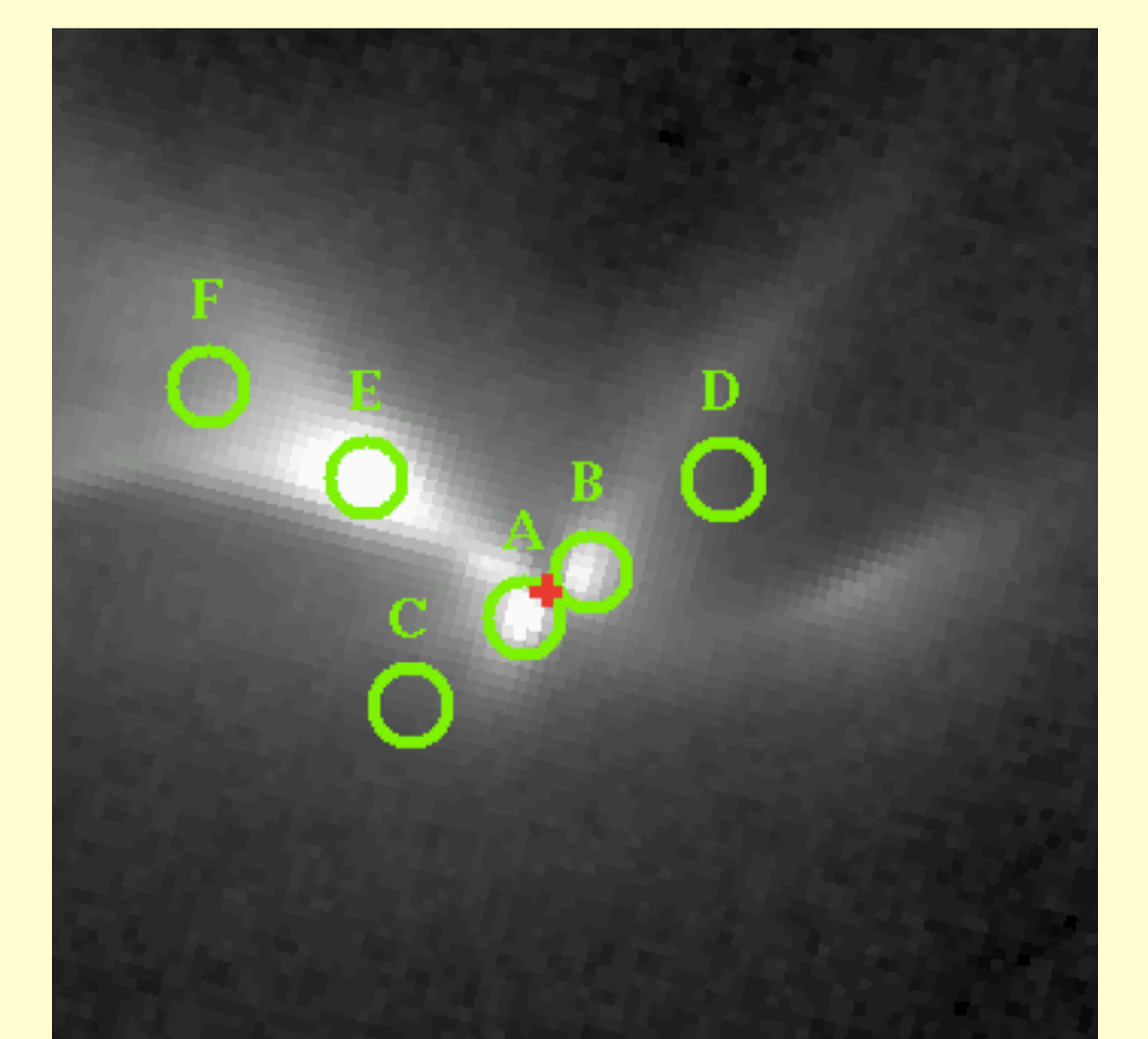


Fig 4: Close-up of the HST/WFC3 image. The red cross marks the centroid position of the Spitzer source. (Fig S4; Muzerolle et al. (2013))

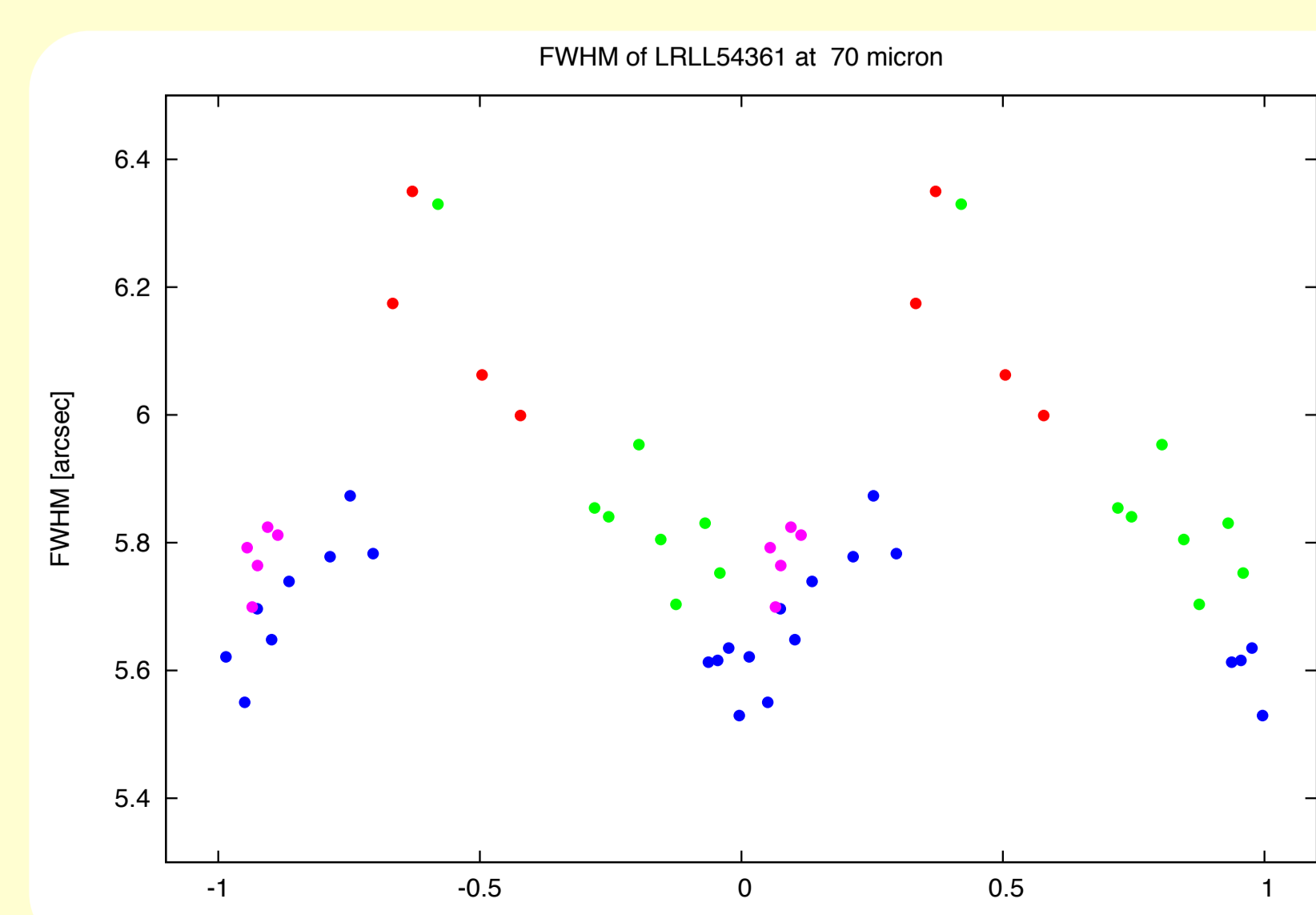


Fig 5: The FWHM of LRL54361 at 70 μm . The meaning of the colors are the same as in Fig. 2

Fig 5. shows the change of the FWHMs of LRL54361. There is a clear anti-correlation between the size and brightness of LRL54361 also indicating the far-IR light echo propagating outwards on the cavity wall as revealed by the HST WFC3 observations.