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Multiple systems observed with ALMA.

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ABSTRACT

Here goes the abstract.

Keywords: wow much keywords

1. INTRODUCTION

Here goes the Introduction.

- Most stars are in binary systems
- However, few binary protoplanetary systems are known.
- And none of them has been studied at high resolution, to understand how companions affect the evolution and substructure of each one.
- Spirals and substructures have been usually assumed to be caused by companions, however, in most cases that is hard to be confirmed.
- In this case, we can safely assume the substructures have been caused by companions, because they are in fact binaries.
- We'll show the results of the first analysis in the binaries detected in our alma large program.
- in section 2 we blablabla...

2. HT LUP

HTLup is a known multiple system, ghez et al, where they identified three point sources. However, because of the unavailability to resolve both closest sources, until now most researches has taken them as a binary (citas citas) instead of triplet. This is not different in the latest data release from GAIA (cite to gaia), where the parallax for the main source is of 6.49 ± 0.06 mas, or a distance of $154\pm ?$ pc, and the farthest source of the system has a parallax of 6.46 ± 0.13 mas. This shows that their proximity in the sky is not only a projection artifact, but they are in fact in the vicinity of each other.

Here I have to write about the physical known parameters, like mass, magnitudes, etc, luminosity class if possible, and cites.

3. AS205

In AS205 system we also have a triple system. The brightest source is AS205 north (AS205N) (citas), a disk with a K5 star of $1.5 M_\odot$ mass, and at $1.3''$ is located the spectroscopic binary AS205 south (AS205S) (citas), where Almeida2018 proved through radial velocities the existence of a binary interaction between a star of $0.9\,\mathrm{M}_\odot$ and a substellar companion with a mass of $19.25 \pm 1.96\,\mathrm{M}_{\mathrm{Jup}}$, with a orbital period of 24.84 ± 0.03 and a semimajor axis of 0.16 ± 0.04 AU.

The distances of each source in the AS205 system were obtained from the last (second) GAIA data release, however, we found a discrepancy between the GAIA distances and previous researches. For AS205N the parallax is 7.82 ± 0.1 mas, which are $127.93 \pm XX$ pc, but for AS205S the parallax is 6.37 ± 0.19 mas, and that puts them at more than 30pc of distance. Even when the proximity in the sky of this sources could be a just projection effect, we know from (Salyk et al 2014) and Andrews2009 that there is a gas flow between disks, extending even to X'' from the main source. As will be shown in section 5, we are able to confirm that this flow is not an artifact of lower resolutions, and therefore distance between disks must allow interaction. Since the luminosity of AS205S is the weaker than AS205N, we

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are using the distance of the later as the true one for this system.

[IN THIS PARAGRAPH I HAVE TO DISCUSS ABOUT THE GAS FLOW, WHAT IS KNOWN, AND ALSO ABOUT THE MOLECULES DETECTED IN PREVIOUS STUDIES, like organic and water lines.]

4. DATA

The datasets presented here are part of the ALMA Large Program number XXX (citar paper) to observe with very high resolution 20 classical disks in band 6, including the molecular line 12CO 2-1 in one of the spectral windows. For AS205, we also used archival data corresponding to observations in band 6 from cycle 0? (PI: Collete Salyk 2014?).

We calibrated the observations following the standard procedure guidelines of this Large Program (cita). Before any treatment, for each source we flagged the channels that were $25 km\, s^{-1}$ around molecular lines, making a total width of $50 km\, s^{-1}$. Using the software CASA5.1 we applied the tasks `imfit`, `fixvis` and `fixplanets` to respectively find the 2D gaussian centroid of each disk, align it to the phase center in each observation, and then correct the coordinates positions of all observations with the centroid position of the longest baseline dataset, because of the highest angular resolution and signal to noise?. For HT Lup, however, we faced the problem that the two closest disks observables in long baselines *** CORRECT USING THE TABLE NAMES *** are unresolved in the short baselines configuration, showing them as if they were just one disk. To solve this, we used the binary component located at 2.8arcsec as a reference to align the observations.

For HT Lup we had 4 observations in ALMA band 6. All of them had 4 spectral windows, where 3 were dedicated to observe continuum and 1 contained the 12CO 2-1 line. A summary of the observational setup can be found in Table 1. We applied self-calibration to the [short baselines] datasets before concatenating it with the [large baselines] datasets, and then selfcalibrating again (quick summary, I had to describe with more detail how the self-calibration was done).

For AS205 we had 6 observations, 2 from Colette (agregar cita) and 4 from our ALMA Large Program. Because of climatological conditions, only 1 of our observations were executed in configuration [Long baseline configuration], corresponding to the largest baselines, and the remaining 3 with [Short Baseline configuration]. Similar to HT Lup, we self-calibrated the [short baselines datasets] before concatenating them to the [LB data] to take advantage of the bigger beam and highest signal to noise. After joining all datasets, we performed 4 phase and 2 amplitude self-calibrations (more details in apendix).

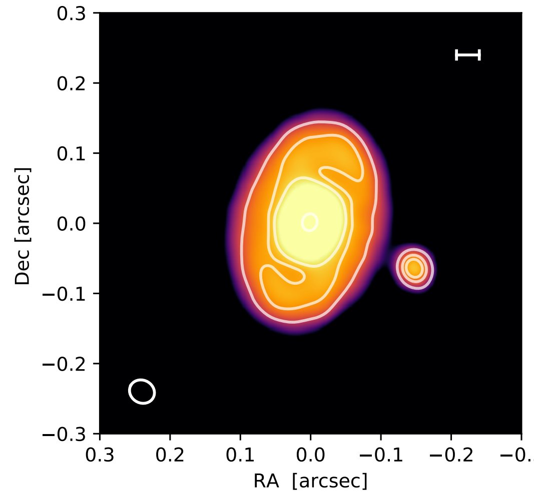

Figure 1. Continuum brightness distribution of the closest sources in the HTLup system, in logarithmic scale. The contour levels come from the unsharp image to help visualize the spiral substructure in the disk. There is still left to add the colorbar. Probably final displaying continuum image.

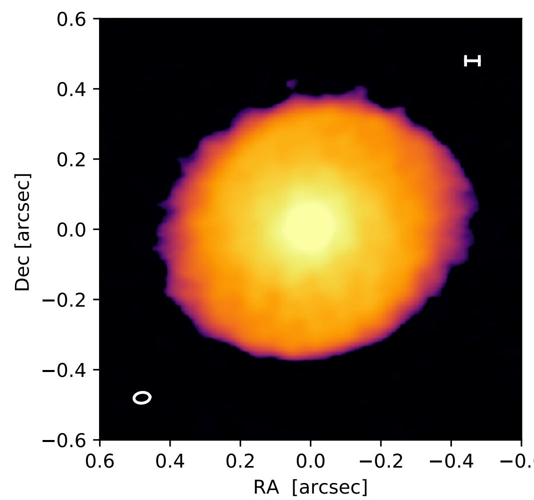

Figure 2. Continuum emission of main AS205 disk in logarithmic scale. ***I have to add the colorbar***.

5. RESULTS

5.1. *HT Lup*

For HT Lup we could spatially resolve the close companion that were first detected with speckle imaging in the K band by (Ghez et al. 1997) using speckle photometry. Figure 1 shows the high resolution continuum

Table 1. Observational setup for both sources. I have to adjust the column width, and fill with the data.

Source	Date	Freq. Range (GHz)	Antennas	Baselines (m)	On Source time (minutes)	Spw
AS 205	2012-03-27	13	$\sim 0.''5$			1 continuum, 12CO 2-1
		56013.944	$0''0$			
		56014.984				
		56016.978				
HTLup						

^{a}At exposure start.

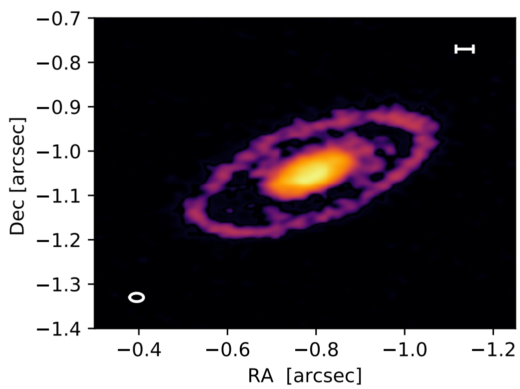

Figure 3. Continuum emission of main AS205 secondary in logarithmic scale. ***I have to add the colorbar***

map obtained from our data calibration, where the spiral structure of the main disk in the continuum is clearly seen with contour levels.

5.1.1. *Spirals*

In the continuum image, we calculated the mean radial profile of the main disk, and substracted it until deprojected 28 AU, that mark the point were the flux between the disk peaks is minimum. The spiral is very low contrast, in fact, the differences for a fixed radius are in the order of [X percent] (as it can be observed in the [figure X]), so the contribution of this substructure in the mean radial profile negligible, and therefore we can substract it from the deprojected continuum image to enhance the assymetries.

The deprojected spirals are displayed in figure X, where the mean radial profile was substracted. The pitch angle of each spiral is ......

5.1.2. *Mass ratio*

[THIS SUBSUBSECTION MUST BE MODIFIED]

The peak of the secondary is located at $0.16''$ from the peak of the main disk, which represent ≈ 35 AU if we deproject using the inclination and position angle of the main disk. We threw a line between the peaks and calculated the luminosity profile along the line, presented in figure X. From the contour levels it can be seen that each object holds its own disk, and they interact surrounded by a cloud of X flux, and the line that separates them is X of the flux. From this, we use the formalism of roche lobes to calculate an approximation of the mass ratio between the disks. (I have to explain that the radiative profile of each disk is decreasing, so the minimum point between them must be related to the L1 point). From this, we obtain a mass ratio of q=13.

Previous photometric studies took HT Lup as if it were just one source (), calculating a photometry of X in the band K. from Ghez1997 we now that, roughly, the flux ratio between the sources is , so we can use it to calculate the corrected magnitudes in K band, which are X for the main source, and X for the secondary. Using as the age X Myr from XX et al, by the position in the HR diagram, the masses of the sources is approximately X and Y, which is in good agreement to the mass ratio calculated from the roche lobes approximation.

5.1.3. *Terciary Component*

The terciary component is found at $2.8''$ from the peak of the main disk. This binary was already known (citas citas citas)

5.1.4. *CO map*

To obtain the CO map, we flagged all the channels around... blablabla, explain how do we obtain the co map.

We found the CO map to be highly contaminated by extended cloud contribution (Adjuntar figura muy contaminada en el anexo) and intense extinction in the low velocity channels. In order to obtain a clean cinematic CO map, we cut the baselines smaller than 150 m, which give the resolution for structures of size $\geq 2''$, so we

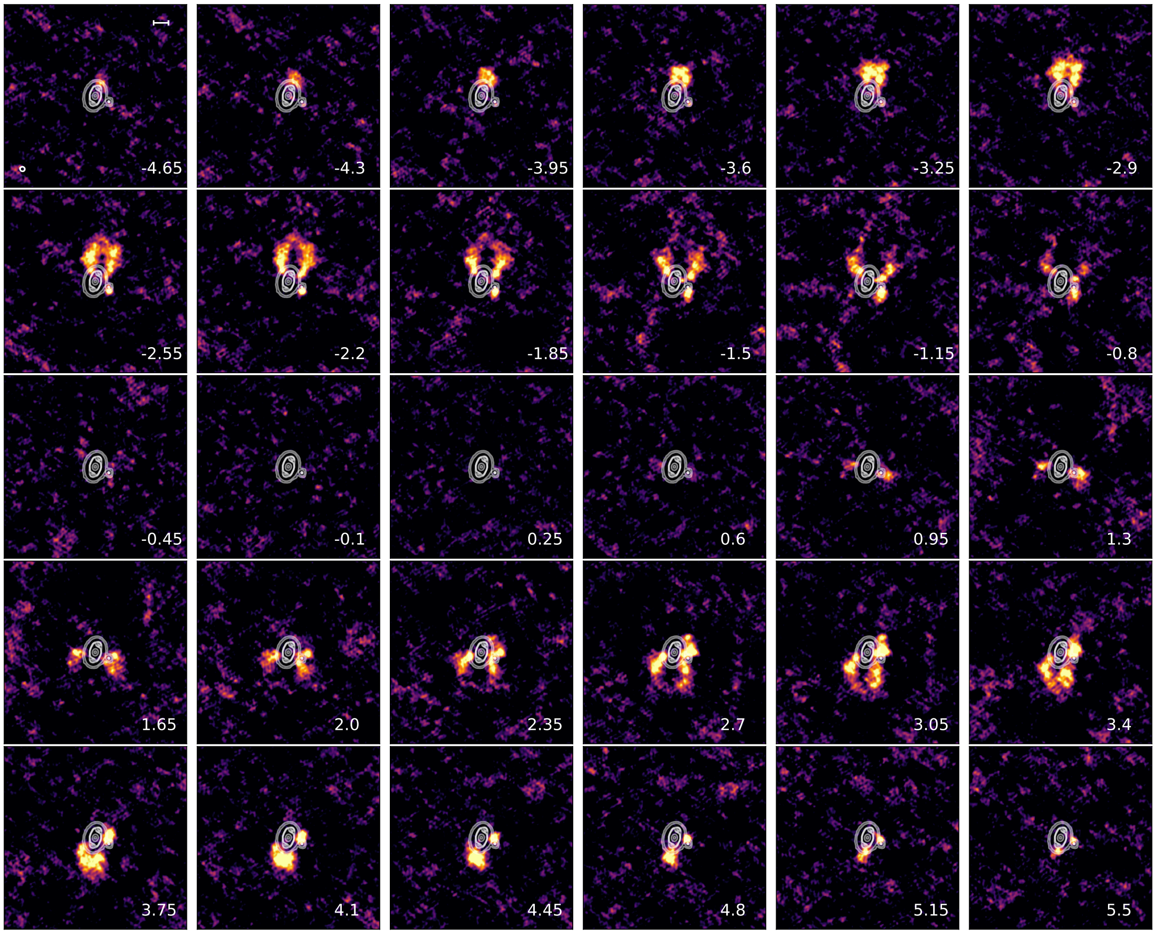

Figure 4. CO 2-1 emission in HTLup closest sources. The LSRK? velocity is printed at the lower right corner of each frame, while the beam size and a 25AU projected bar are printed in the first image at the upper left frame. The image was generated cutting all baselines with less than 150 m in length, losing sensitivity

lose sensitivity in large extended scales, emphasizing the compact ones.

From (weaver2018) we know that... (continuum substraction shouldn't be used in this cases, and In fact we didn't use it.)

5.2. *AS205*

In AS205 we are able to resolve at a scale of 5 projected AU two disks, with peaks located at a distance of 1.31″. Their continuum maps are shown in Figures 2 and 3, and in the apendix can be found a figure of both disks together.

5.2.1. *Main disk*

For the main disk we applied a 2D gaussian fit using `imfit` in CASA5.1 to find the inclination and position angle, and we found the values $i = 16.24° \pm x$ and PA $= 11.6° \pm x$ measured from north to west. Similar to the main disk in HT Lup, we also found here a spiral structure of low contrast, that can be seen deprojected in polar coordinates in figure X.

To calculate the pitch angle of the spirals, we started by subtracting the average azimuthal profile, which was computed using the inclination and position angle previously obtained, from the continuum image. Then, we calculated the maximums in the radial luminosity profile of 10° width regions, measured from the center of flux in the continuum. The results can be found in Figure 5, where the peaks trace the spiral structure, with extension between 32 and 58 AU. (This has to be written better).

In order to characterize each spiral, we used as a model the logarithmic spiral equation $\log(r) = r_0 + b\phi$, with a r_0 and b for each spiral, and also letting free to be adjust the center of the spirals and the observed inclination and position angle. This results are summarized in Table 3. From b parameter we obtain the pitch angle of each spiral: $14.9° \pm 1.1$ and $8.0° \pm 0.9$ for the northern and southern spiral respectively.

To calculate the contrast between the spiral and inter-spiral region, we rotate 90° each arm from the spirals center, and then used bilinear interpolation in the con-

Parameter	Value.
r_1	49.8 ± 4.1 AU
r_2	52.7 ± 5.6 AU
b_1	0.266 ± 0.021
b_2	0.141 ± 0.016
i	$19.5^\circ \pm 2.3$
pa	$123.0^\circ \pm 5.4$

Table 3. Results from the MCMC search for best parameters in AS205 north spirals. Parameters r_1, r_2, b_1 and b_2 correspond to spiral north and south respectively. Inclination i and position angle pa were also variables of this model. (PROBABLY I'LL CHANGE THIS TABLE TO BE THE SUMMARY OF RING AND SPIRALS, AND NOT ONLY THE SPIRAL FIT)

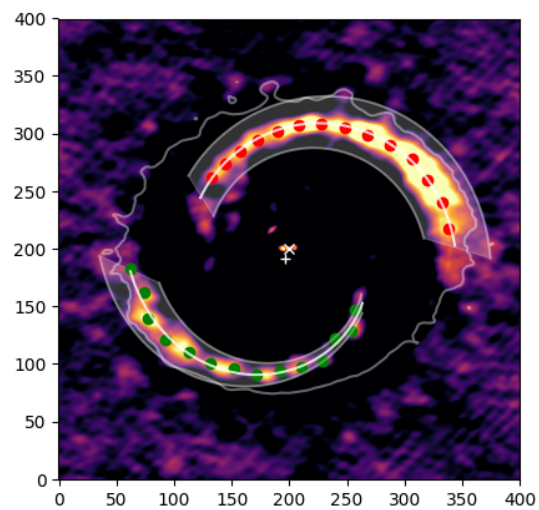

Figure 5. Continuum emission of AS205N, with the azimuthal average profile substracted. Triangles show the spiral trail of both arms, while the contour level marks the 3σ level of the not substracted image.

tinuum image to calculate the luminosity profiles, that are shown in figure 6. We found a 2.5% difference in contrast between regions, and also a 1% (HAVE TO CORRECT THIS VALUE) difference in luminosity between spirals, which is above the 3σ level of this observation.

In the left paragraph I have to finish the results of contrast.

5.2.2. *AS205 South*

Even when the secondary disk AS205S is well resolved, it luminosity peak is only 29% of the main disk peak, and the rings has luminosities around 5% *** Rewrite using sigma values, probably there are better ways to explain this disk is very faint***. Differently from the previous disk, this one shows a central disk and a ring-like structure, separated by a cavity that is not empty in

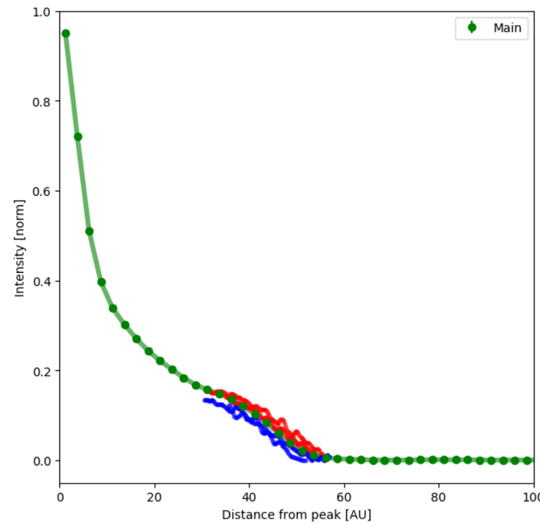

Figure 6. Azimuthal continuum profile of AS205 north.

continuum emission. The mean radial profile, calculated from the image, is shown in figure 7, where it can also be seen the luminosity dispersion inside the cavity.

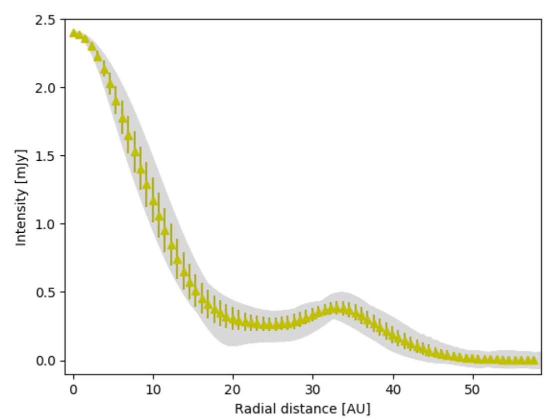

Figure 7. Mean azimuthal profile of the secondary disk in AS205 system. In gray are shown the raw points directly deprojected from the image.

*** THE NEXT PARAGRAPHS MUST BE MERGED IN ONE***

To obtain the mean radius of the ring, we calculated the mean radial profile in the continuum image in regions of 18° (which are approximately 10AU in the deprojected ring), and searched for the position of the maximum emission in the ring. The points were then fitted with an ellipse using an MCMC routine, letting the center, major and minor axis, and position angle free to vary. We found a mean radius of which resulted in a radius of 32.5 ± 1.4 AU *** THIS MEAN VALUE MUST BE UPDATED FROM MCMC*** from the peak emis-

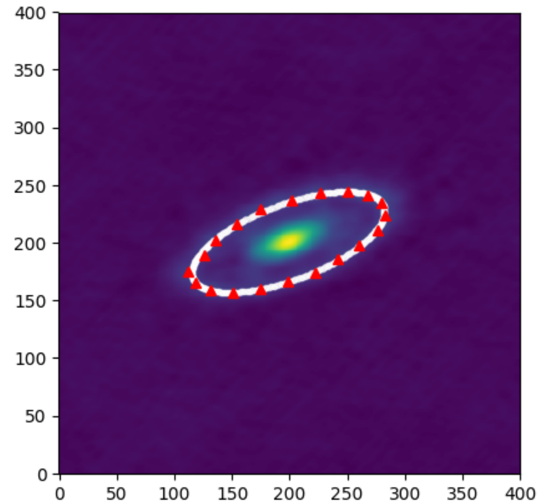

Figure 8. Mean azimuthal profile of the secondary disk in AS205 system. In gray are shown the raw points directly deprojected from the image.

sion, with a center that the peak luminosity and center of the central disk.

To confirm that the ring was aligned with the central cavity, we used the peaks previously identified to fit an ellipse through them, results that are shown in figure X. The ellipse has a position angle of X, which is in agreement with the 2d gaussian we perform previously. The center of this ellipse matches the peak luminosity position of the central disk within ¡1 mili arcsec. (I NEED TO GET THE RESULTS FROM THE MCMC FIT, TO COMMENT THEM HERE).

5.3. *CO map*

In the Figure 9 it can be seen the high resolution CO map of AS205 system, which shows interaction between the disks, and gas can be detected traveling between the two continuum sources at velocities between X km/s and Y km/s.

Here I have to explain something about the central velocity of each disk

The discussion for the explanation of this spirals will be in the next section

6. DISCUSSION

- GAIA distances.
- AS205 Secondary disk, binary component. high CO speeds around them.
- Interactive closest disks in HTLup: discuss about the orbit plane.
- Spirals origin, compare with other known spirals.
- HTLup CO, compare with simulations.
- Next steps: Hydrodynamic simulations, other lines observations.

7. CONCLUSION

8. ANEXOS

REFERENCES

Astropy Collaboration, Robitaille, T. P., Tollerud, E. J., et al. 2013, A&A, 558, A33

Ghez, A. M., McCarthy, D. W., et al., 1997. MNRAS

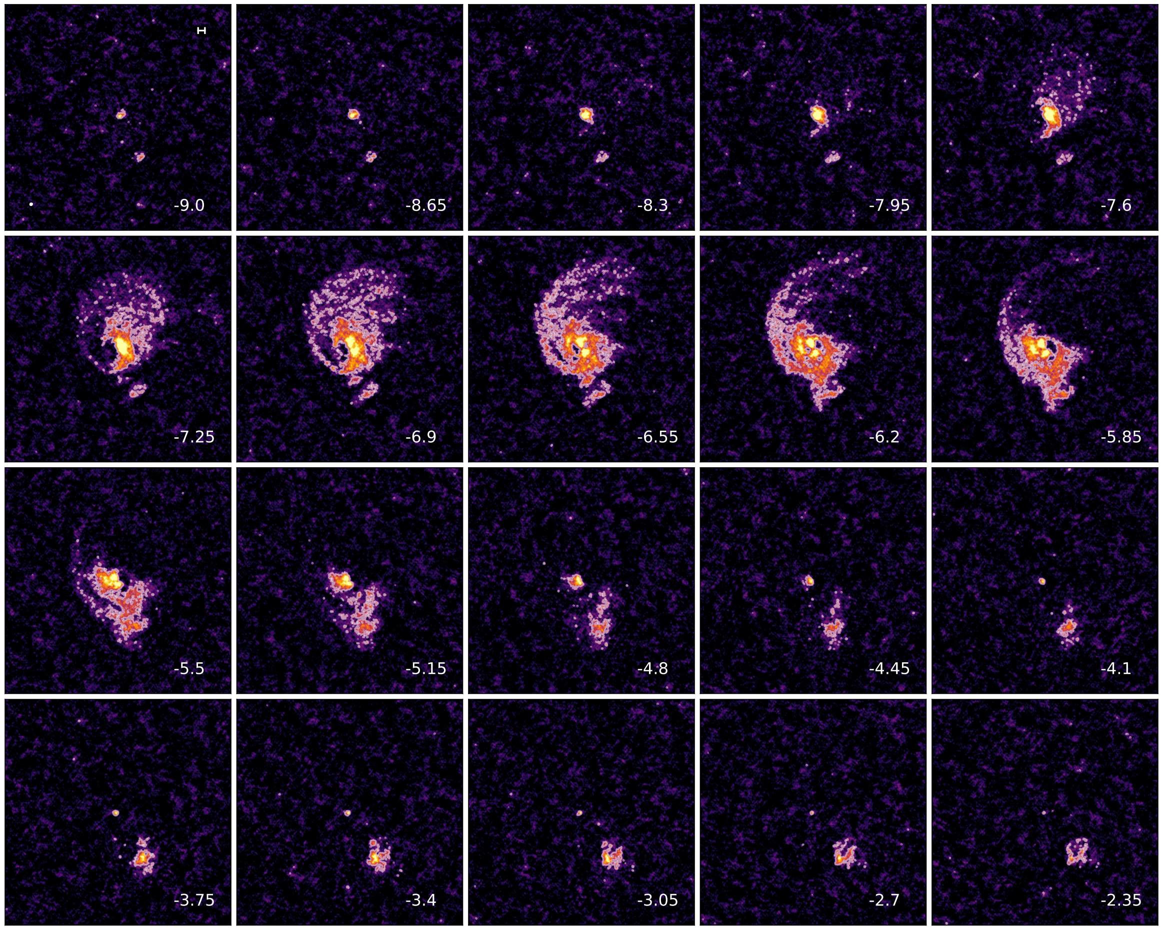

Figure 9. CO 2-1 emission in AS205 system. The LSRK? velocity is printed at the lower right corner of each frame, while the beam size and a 25AU projected bar are printed in the first image at the upper left frame.

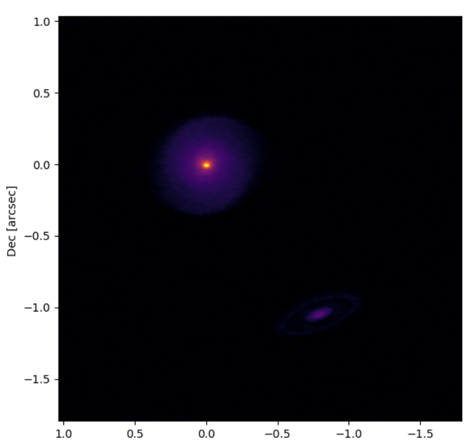

Figure 10. AS205 system.