ALMA
Premiers résultats: les (tant) attendus et les inespérés

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Qu’est ce que c’est ?

- Atacama Large (sub-)Mm Array
- 50 antennes de 12-m, dans des configurations de 150-m à 18 km de diamètre.
- + 12 antennes de 7-m et 4 antennes de 12-m pour l’imagerie des zones étendues (ACA: Alma Compact Array)
- Fréquences de 80 (30) à 950 GHz (0.3 à 3 mm)
- Résolutions angulaires de 7’’ à 0.007’’
- Résolutions spectrales jusqu’à 5 kHz (5 m/s…)
- En configuration compacte, équivalent à une antenne de 150-m de diamètre avec un rendement en ouverture de 40 %. (comparez au 30-m, ou au GBT 100-m avec < 50 % de rendement à 3 mm…)
- Un saut majeur en sensibilité (100 en continuum, 5 à 25 en raies)
- Un site exceptionnel (altitude 5000 m, très sec)

Level 1 requirements

ALMA has three level-1 science requirements:

- The ability to detect spectral line emission from CO or C+ in a normal galaxy like the Milky Way at a redshift of z = 3, in less than 24 hours of observation.
- The ability to image the gas kinematics in a solar-mass protostellar/ protoplanetary disk at a distance of 150 pc (roughly, the distance of the star-forming clouds in Ophiuchus or Corona Australis), enabling one to study the physical, chemical, and magnetic field structure of the disk and to detect the tidal gaps created by planets undergoing formation.
- The ability to provide precise images at an angular resolution of 0.1". Here the term *precise image* means accurately representing the sky brightness at all points where the brightness is greater than 0.1% of the peak image brightness. This requirement applies to all sources visible to ALMA that transit at an elevation greater than 20 degrees.

Galaxies

Disques

Imagerie

Caveat: ALMA n'est pas fini…

- 3 appels à propositions + « Science Verification »
- Cycle 0 terminé, mais pas mal de problèmes dans les données à haute résolution spectrale
- Cycle 1 pas complet, données en général très bonnes
- Cycle 2 à peine commencé…
- Pas encore de très haute résolution spatiale (0.25'' au mieux)

Mais ALMA fonctionne !...

High quality imaging: kinematics of dense cores (Tan et al 2013)

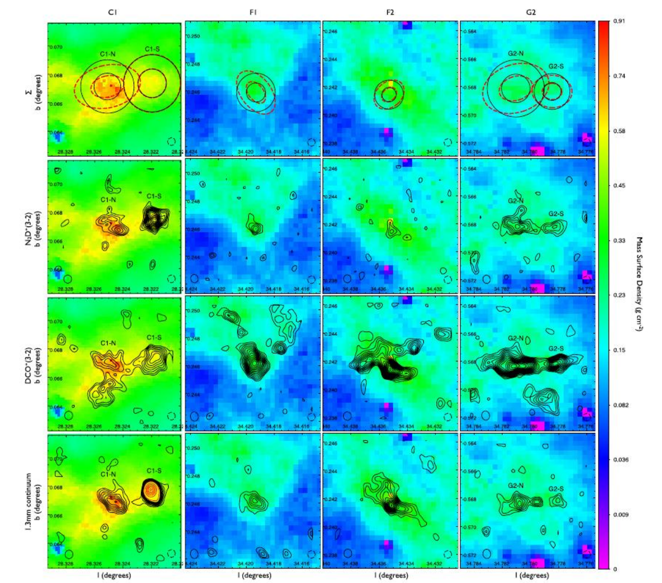


Figure 1. Four massive starless core/clumps observed by ALMA: columns from left to right show C1, F1, F2, G2. The background colors in all rows show MIREX Σ maps in g cm^{-2} (Butler et al. 2013, hereafter BTK for C1; BT12 for F1, F2 and G2). The *Spitzer*-IRAC 2″ beam is shown in the lower right of the panels. (a) First row: analytic regions used to define the cores and their surrounding clump environments. The inner ellipses and equivalent area circles show the deconvolved extent of the N_2D^+ cores identified in row (b), while the outer ellipses and circles have a radius twice as large and define the annuli used to estimate the surrounding clump envelope. (b) Second row: ALMA Cycle 0 observations of N_2D^+ (3–2) integrated intensity, contours shown from $2, 3, 4 \ldots \sigma$. Six cores, C1-N, C1-S, F1, F2, G2-N and G2-S, are defined by their 3σ contours in position–velocity space. The ALMA beam is shown in the lower left of each panel. Note that not all high Σ regions show strong N_2D^+ emission, but N_2D^+ cores do correlate well with structures seen in the MIREX maps. (c) Third row: ALMA observations of DCO^+(3–2) integrated intensity, contours shown from $2, 3, 4 \ldots \sigma$, which is generally more widespread than N_2D^+. (d) Fourth row: ALMA observations of the 1.34 mm dust continuum emission, with contours from $2, 3, 4 \ldots 8\sigma$ (black) then (for C1) $10, 20, 30 \ldots 60\sigma$ (red).

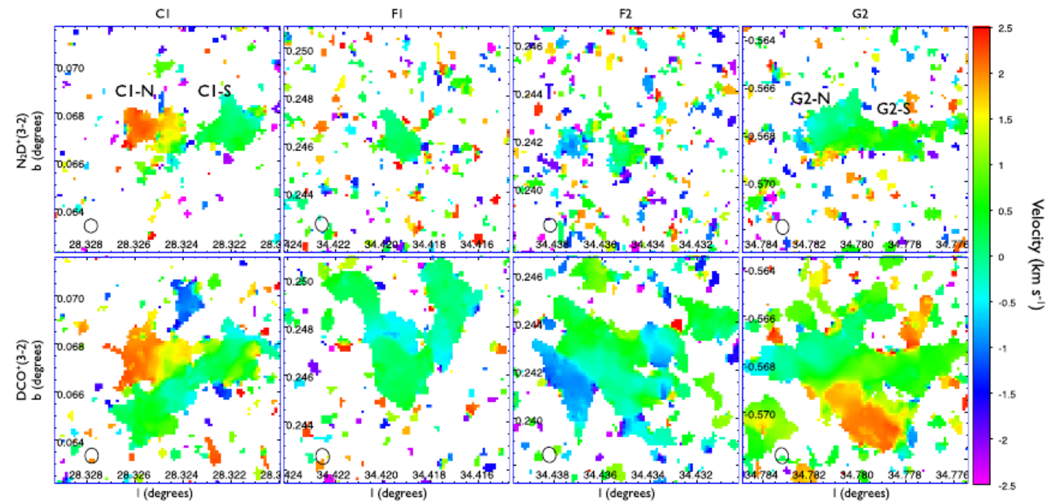
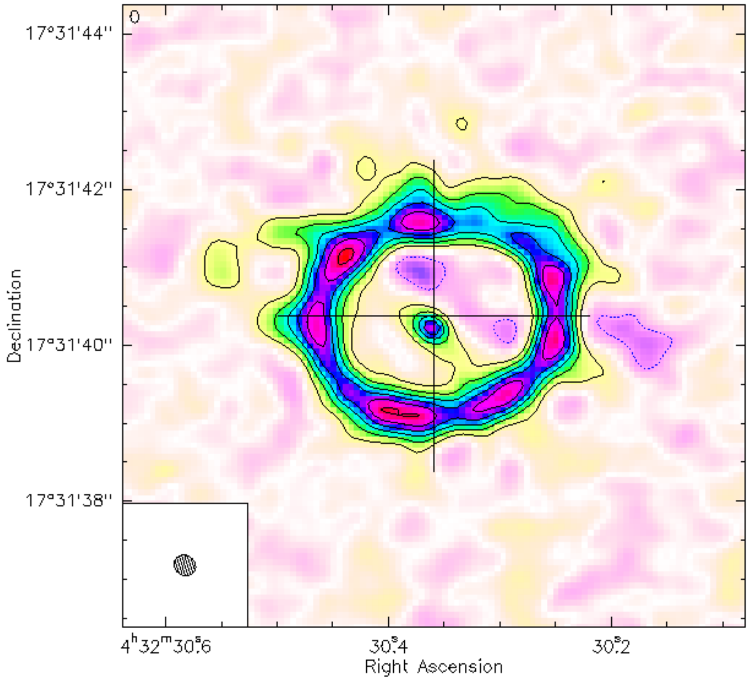
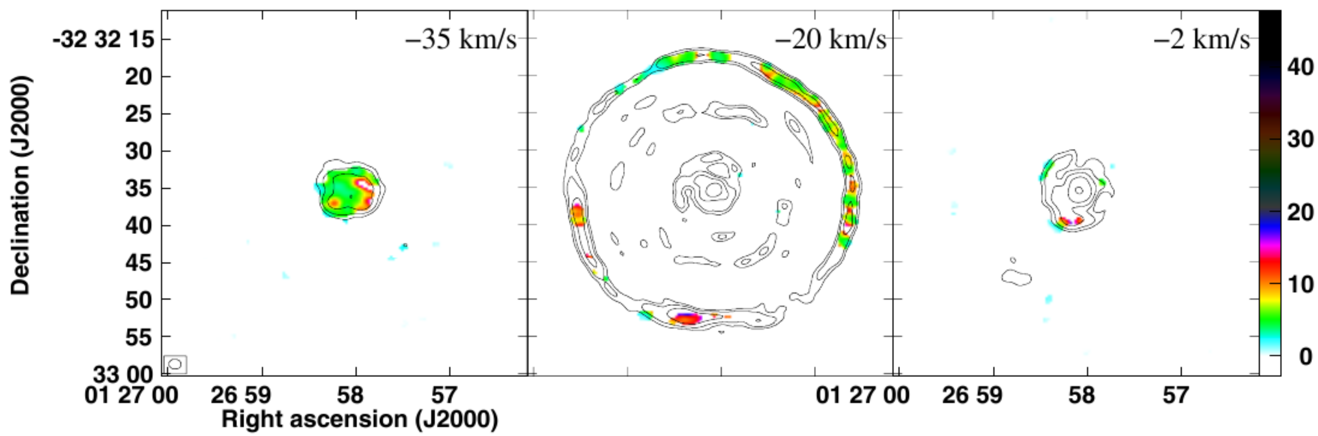


Figure 2. First moment (mean velocity) maps of the four core/clumps: columns from left to right show C1, F1, F2, G2. (a) First row: first moment map of N_2D^+(3–2) emission, integrated over a 5 km s^{-1} velocity range centered on the mean N_2D^+ core velocities of C1-S, F1, F2 and G2-N. The ALMA beam is shown in the lower left of each panel. Only regions that have some contribution from cells with intensities $\geqslant 3\sigma$ are displayed in color. (b) Second row: first moment map of DCO^+(3–2) emission in the same velocity reference frames as in row (a).

Imagerie à 690 GHz sans auto-calibration
GG Tau (Dutrey et al 2014, Nature sous presse…)



Imagerie grand champ: mosaique de 45 points $^{12}C/^{13}C$ in R Scl (Vlemmings et al 2013)



Une compétition féroce…

- Facteur de pression
  - 2 pour le Chili
  - 4-5 pour l’Asie (Japon, Taiwan)
  - 5-6 pour l’Amérique du Nord (USA, Canada, Taiwan)
  - 8-10 pour l’Europe (ESO)
  - 3 % de temps « ouvert » (via l’open sky policy de NRAO)

ESO data base
(137 articles publiés, de 2012 à Aout 2014)

- Galaxies 43
- AGN 12
- YSOs 16
- Disks 35
- Molecular Clouds 7
- Chemistry 6
- Circum-Stellar Envelopes 6
- Others 12 (GRBs, physics, SN, …)
- Solar System 0

Les plus cités

- A Major Asymmetric Dust Trap in a Transition Disk (van der Marel et al 2013, Science)
- An ALMA survey of submillimetre galaxies in the Extended Chandra Deep Field South: high-resolution 870 µm source counts (Karim et al 2013 MNRAS)
- Constraining the Planetary System of Fomalhaut Using High-resolution ALMA Observations (Boley et al 2012 ApJ)
- Star Formation and Gas Kinematics of Quasar Host Galaxies at z ~ 6: New Insights from ALMA (Wang et al 2013)
- An ALMA Survey of Submillimeter Galaxies in the Extended Chandra Deep Field South: Source Catalog and Multiplicity (Hodge et al 2013, ApJ)

Impact: articles dans « Science »

Molecular Gas Clumps from the Destruction of Icy Bodies in the β Pictoris Debris Disk	Dent et al
Imaging of the CO Snow Line in a Solar Nebula Analog	Qi et al
A Major Asymmetric Dust Trap in a Transition Disk	van der Marel et al.

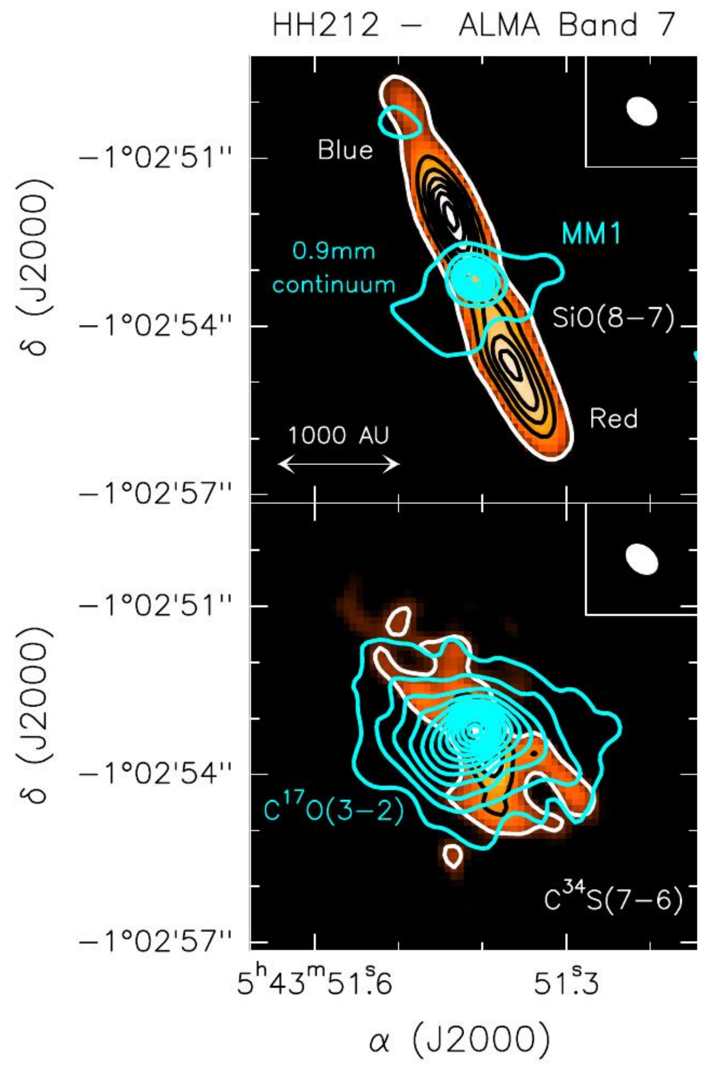
Impact: articles dans « Nature »

Misaligned protoplanetary disks in a young binary star system	Jensen & Akeson
Two γ-ray bursts from dusty regions with little molecular gas	Hatsukade, et al
Change in the chemical composition of infalling gas forming a disk around a protostar	Sakai et al.
Suppression of star formation in the galaxy NGC 253 by a starburst-driven molecular wind	Bolatto et al
Dusty starburst galaxies in the early Universe as revealed by gravitational lensing	Vieira et al
An old disk still capable of forming a planetary system	Bergin, et al
Flows of gas through a protoplanetary gap	Casassus et al

37 articles dans A&A, 79 dans ApJ

Disques, Jets et Flots

- HH212, Codella et al



Choc d’accretion entre enveloppe et disque (Sakai et al Nature 2014)

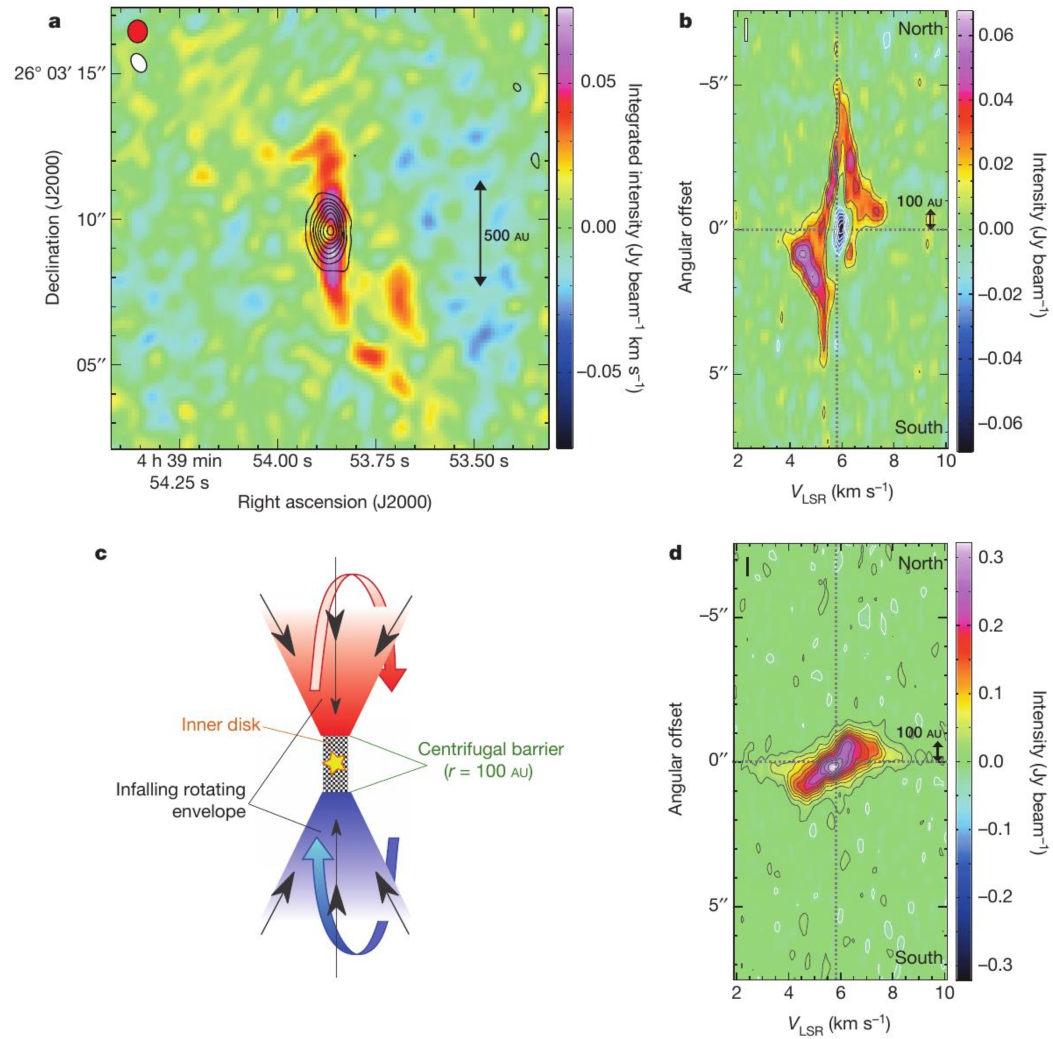


Figure 1 | IRAS 04368+2557 the cyclic-C_3H_2 (5_{23}–4_{32}) and S ($J_N = 7_8$–6_7) lines. **a**, Integrate intensity distributions of cyclic-C_3H_2 (colour) and SO (contours). Contours are every 10σ (90 mJy beam^{-1} km s^{-1}), starting from 5σ (the outermos contour). The red and white ellipses represent the synthesize beam sizes for cyclic-C_3H_2 and SO, respectively. **b**, The PV diagram of cyclic-C_3H_2 along a north–south line passing throug the protostar position. Contour are every 3σ (12 mJy beam^{-1}), starting from 3σ. The white rectangle represents the resolution. **c**, A schematic of th envelope geometry. **d**, The PV diagram of SO along the same line as **b**. Contours are every 4σ (28 mJy beam^{-1}), starting from 2σ. White contours represent negative values. V_{LSR} denotes th velocity with respect to the loca standard of rest. The white rectangle represents the resolution.

Keplerian (?) disks in Class 0
Murillo et al 2013

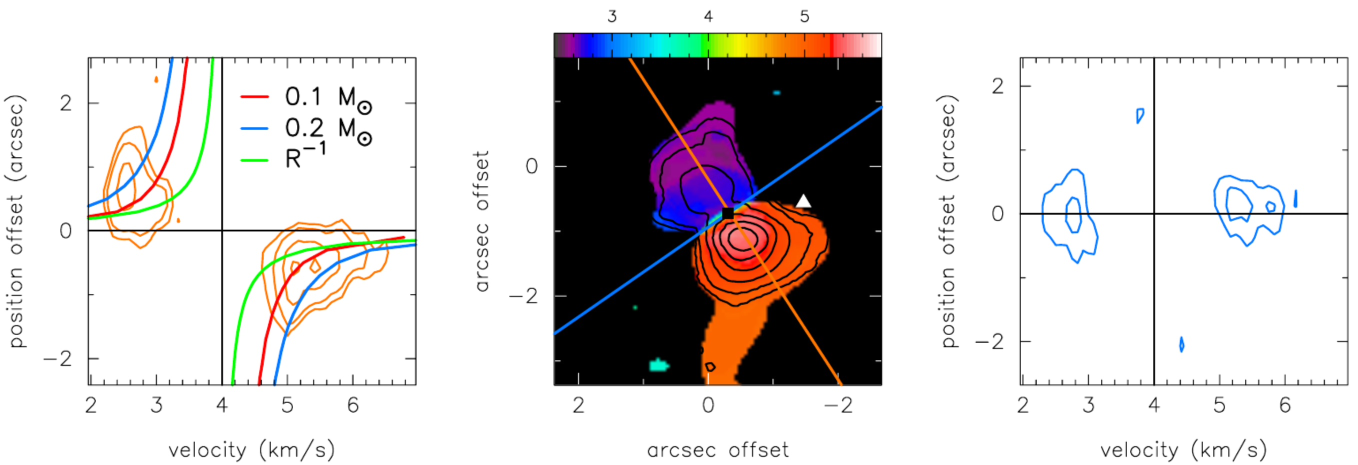


Fig. 2. Observed $C^{18}O$ (2–1). *Left*: pure Keplerian rotation curves ($\upsilon \propto R^{-0.5}$, red and blue) and infall ($\upsilon \propto R^{-1}$, green) are overlaid on the PV diagram. This suggests that the emission may be rotationally supported with $M_* \sim 0.1$–$0.2\ M_\odot$. *Center*: $C^{18}O$ velocity map (moment 1, halftone) and intensity integrated (moment 0, contours) maps. Contours are in steps of 3σ, 5σ, 10σ, 15σ, 20σ and 25σ with $\sigma = 13$ mJy beam^{-1}. VLA1623A and B's positions are marked with a square and triangle, respectively. Orange and blue lines indicate the image-space PV diagram cuts at PA = 35° (*left*) and 125° (*right*), respectively. *Right*: lack of velocity gradient suggests no outflow contamination on the $C^{18}O$ emission. In both PV diagrams contours are in steps of 3σ, 5σ, 10σ and 15σ where $\sigma = 19$ mJy beam^{-1} and the black lines indicate the systemic velocity and position of VLA1623A.

Direct evidence for disk flaring & mid-plane depletion of CO (de Gregorio-Monsalvo et al 2013)

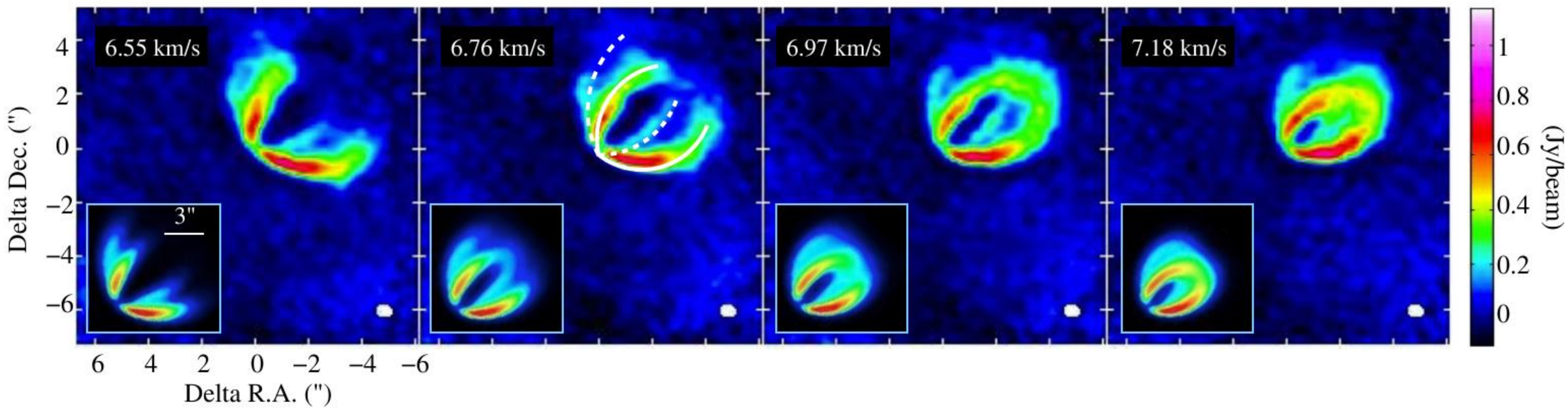


Fig. 4. CO(3–2) representative channel emission maps in HD 163296, primary beam corrected. The spectral resolution is 0.21 km s^{-1} and the rms per channel is 14 mJy $beam^{-1}$. The synthesized beam size is represented in the lower-right in each panel. The white solid and dotted lines represent the front and back surfaces of the gas disk, respectively. The insert at the bottom-left of each panel shows a zoomed-down model at the corresponding velocity (i.e., the size is the same, the scale is different).

CO « snow » line in a protoplanetary disk
Qi et al 2013, Science

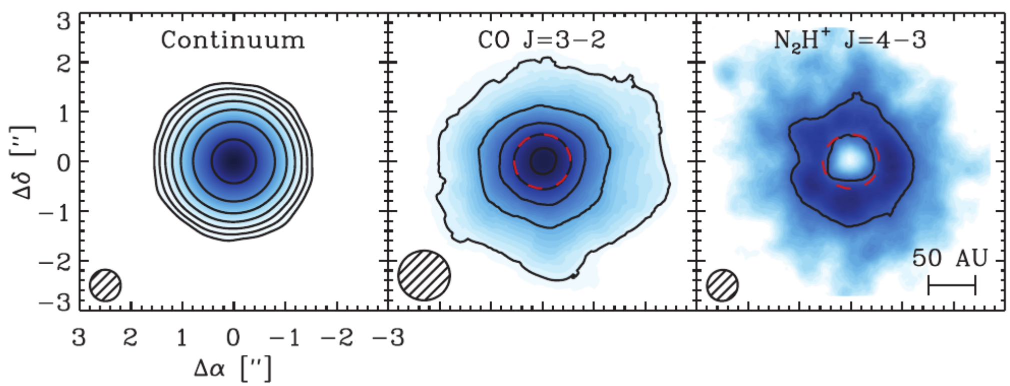
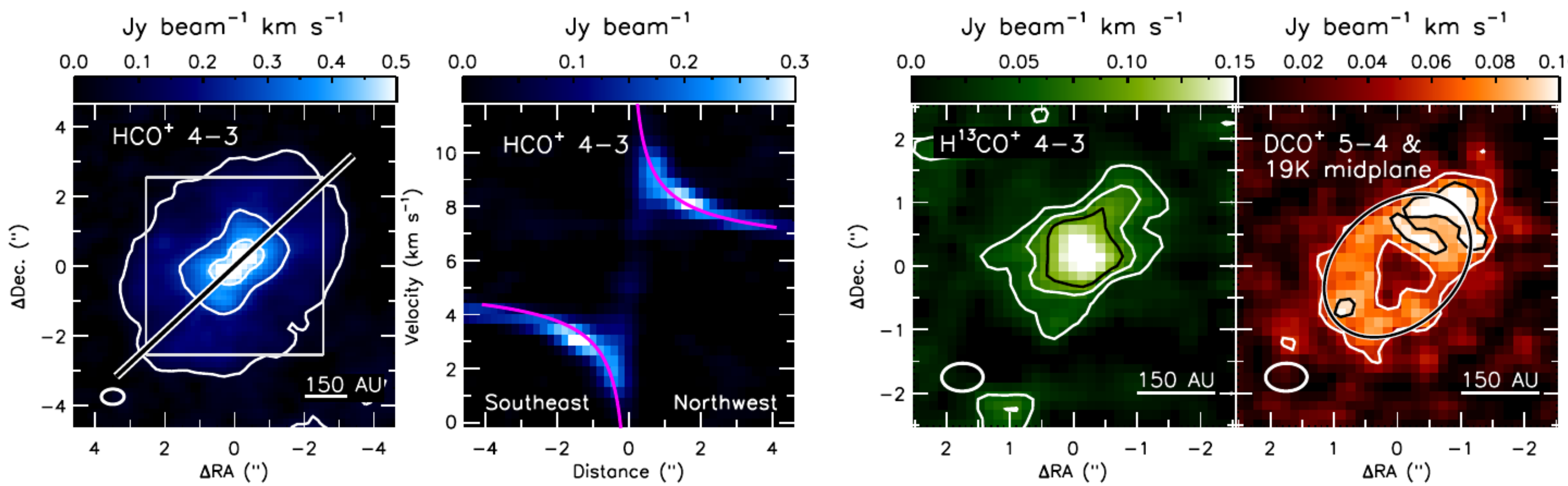
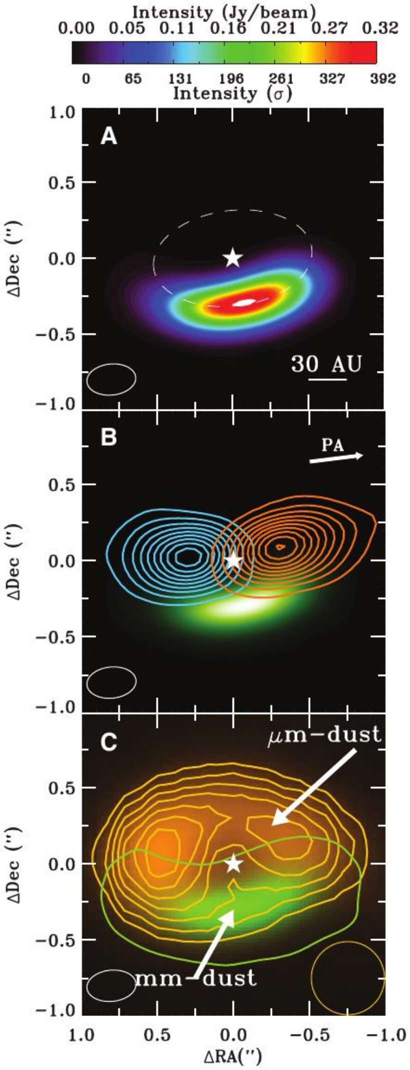


Fig. 1. Observed images of dust, CO, and N_2H^+ emission toward TW Hya. (**Left**) ALMA 372-GHz continuum map, extracted from the line-free channels of the N_2H^+ observations. Contours mark [5, 10, 20, 40, 80, 160, 320] millijansky (mJy) beam^{-1}, and the root mean square (RMS) is 0.2 mJy beam^{-1}. (**Center**) Image of CO J = 3–2 emission acquired with the SMA (*24*). Contours mark (*1*–*5*) Jy km s^{-1} beam^{-1}, and the RMS is 0.1 Jy km s^{-1} beam^{-1}. (**Right**) ALMA image of N_2H^+ J = 4–3 integrated emission with a single contour at 150 mJy km s^{-1} beam^{-1}, and the RMS is 10 mJy km s^{-1} beam^{-1}. The synthesized beam sizes are shown in each bottom left corner. The red dashed circle marks the best-fit inner radius of the N_2H^+ ring from a modeling of the visibilities. This inner edge traces the onset of CO freeze-out according to astrochemical theory and thus marks the CO snow line in the disk midplane.

CO Depletion from DCO+ (Mathews et al 2013)



Asymmetric dust traps van der Marel et al 2013



690 GHz imaging

Most extreme case, but many other ones

Brown Dwarf Disks (Ricci et al 2014)

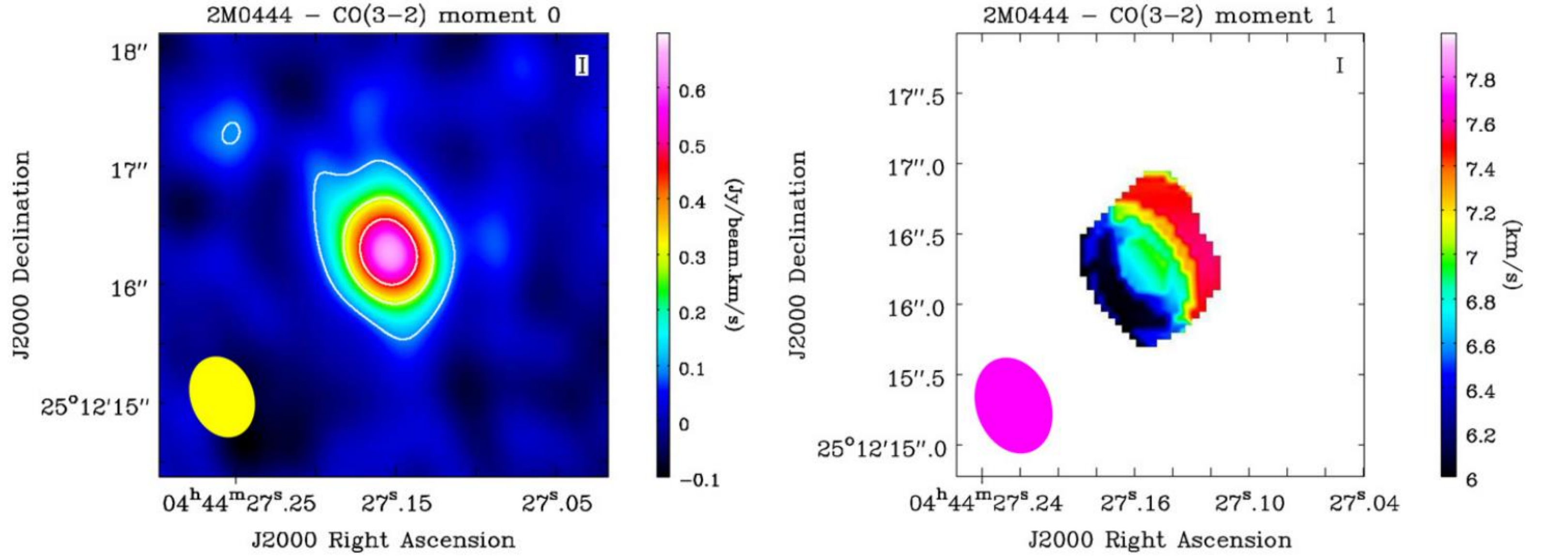
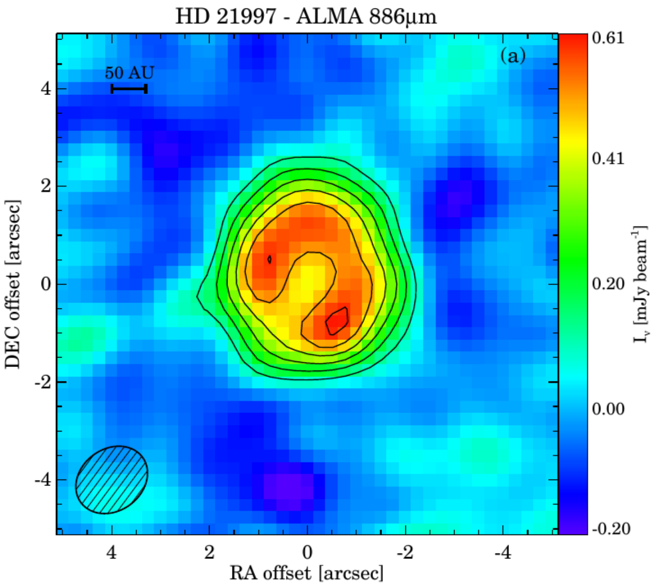
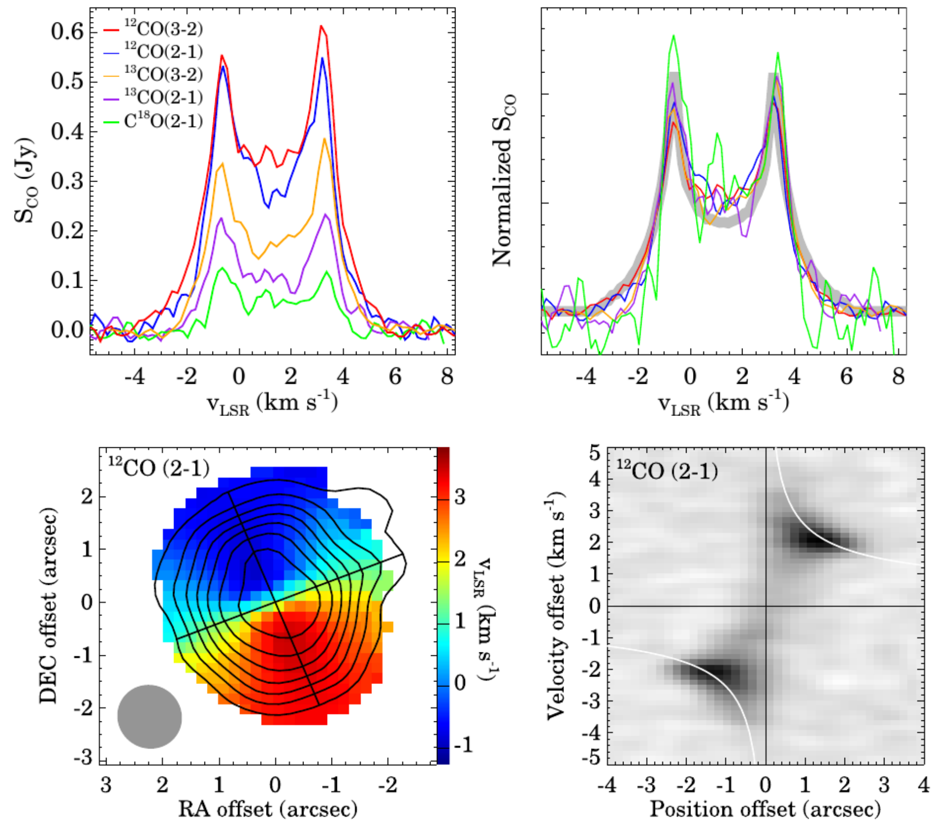


Figure 6. ALMA moment 0 and 1 maps of CO(J = 3–2) from 2M0444 in Band 7. Left: moment 0 map. Contours are drawn at 3, 9, 15σ, with $1\sigma = 0.030$ Jy beam^{-1} km s^{-1}. Right: moment 1 map. Only pixels with values greater than about 5σ were used for the map. In both panels, the ellipse in the lower left corner shows the synthesized beam, with sizes of 0″.70 × 0″.52 and P.A. = 21°.2.

Primary CO and secondary dust in a disk around a 30 Myr old star (Kospal et al 2013)





High Redshift business

- Scoville et al 2014
  - Un échantillon de 107 galaxies pour des redshift de 0.3 à 2, observé à 850 µm en continuum, montrant l'évolution de la poussière 1 à 4 min d'integration par source, + stacking

- H_2O and C^+ in high redshift galaxies
  - Images of lensed objects
  - South Pole Telescope survey

- Surveys of high redshift galaxies
  - Chandra deep field, CANDLES, SPT

Simpson et al, Hodge et al, Karim et al

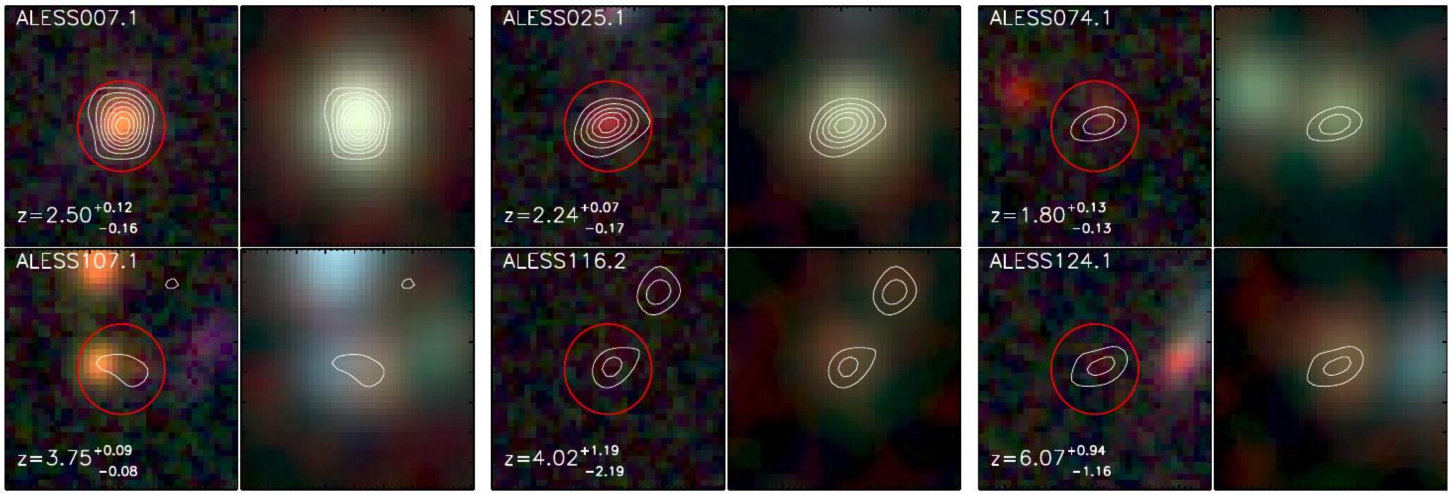
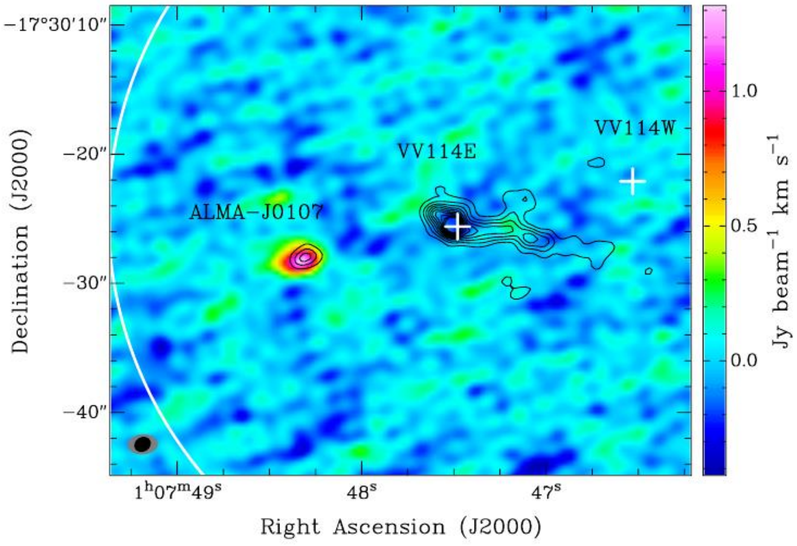
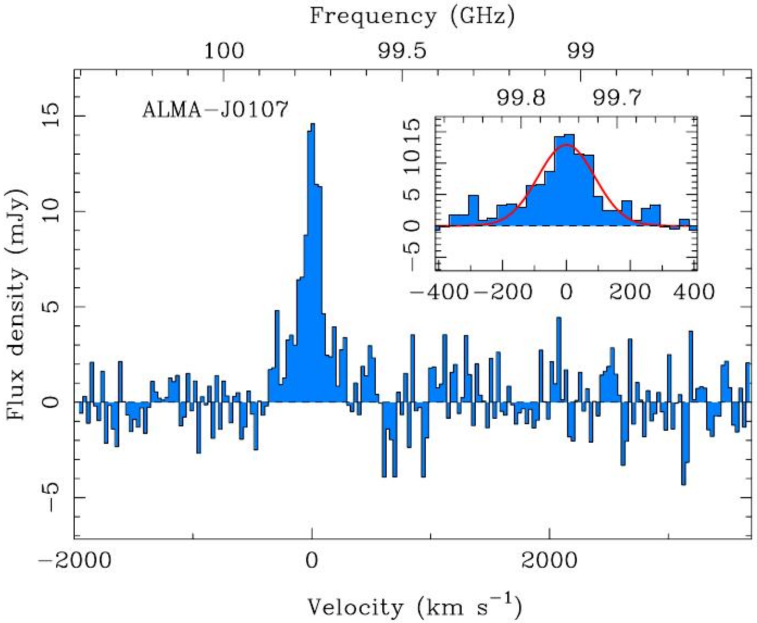


Figure 1. In our analysis we make use of extensive archival imaging of the Extended Chandra Deep Field South (ECDFS), covering 19 optical through NIR wavebands (see Table 1). Here we present $8'' \times 8''$ optical (co-added B, I, and K_S; left) and NIR (co-added 3.6, 4.5, and 8.0 μm; right) false-color images for six example SMGs, from our sample of 96 SMGs, which span the full range of 870 μm flux (thumbnails of all sources are shown in Appendix B). Contours represent ALMA 870 μm detections at $3, 5, 7 \ldots \times\sigma$. The ALMA observations pinpoint the 870 μm emission to $<0\farcs3$ precision, identifying the optical/NIR counterpart without the requirement for indirect statistical associations. Using the precise locations, we measure aperture photometry for each SMG (the size of the aperture is indicated with a red circle) and derive photometric redshifts using the SED-fitting code HYPERZ; see Section 3.

Serendipity: distant galaxy by chance… Tamura et al 2014





High sensitivity: no dust in a UV bright galaxy at z = 6.6 (Ouchi et al 2013)

1 sigma

17 µJy/lobe

10 fois plus sensible que les meilleures images obtenues au Plateau de Bure

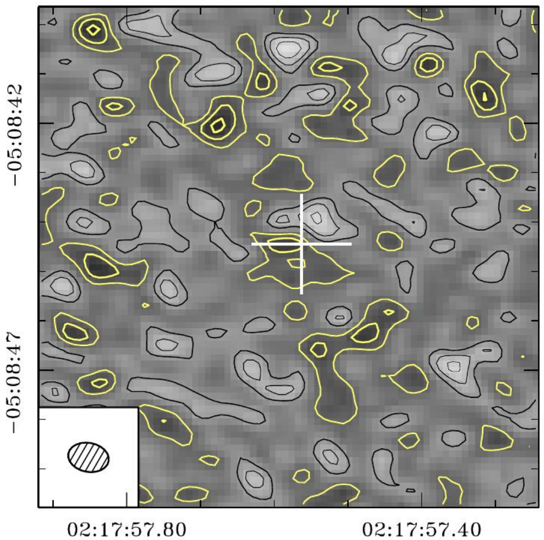


Figure 1. ALMA continuum data for Himiko at 259 GHz (1.16 mm). The gray scale indicates the intensity at each position where darker regions imply higher intensities. The black contours denote -3σ, -2σ, and -1σ levels, while yellow contours show $+1\sigma$, $+2\sigma$, and $+3\sigma$ significance levels where the 1σ flux corresponds to 17.4 μJy beam^{-1}. The white cross indicates the position of Himiko. The ellipse in the lower corner denotes the beam size.

Dust in Arp 220 (Wilson et al 2014)

690 GHz

High resolution

S/N > 100:1

Mesure directe de la Température (brillance résolue spatialement)

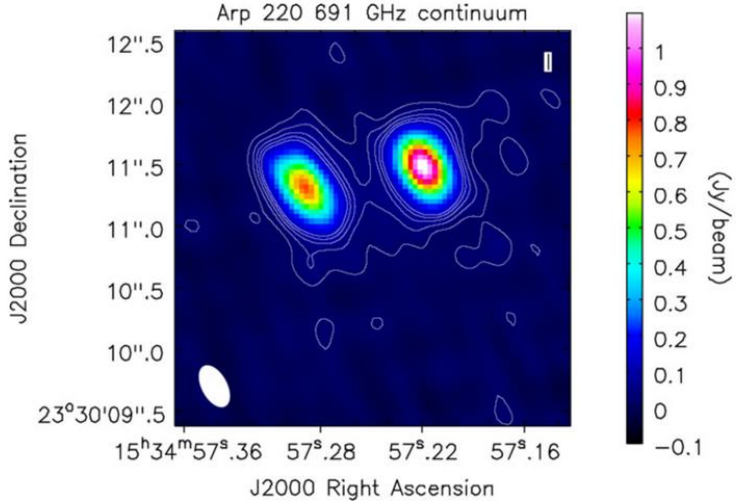
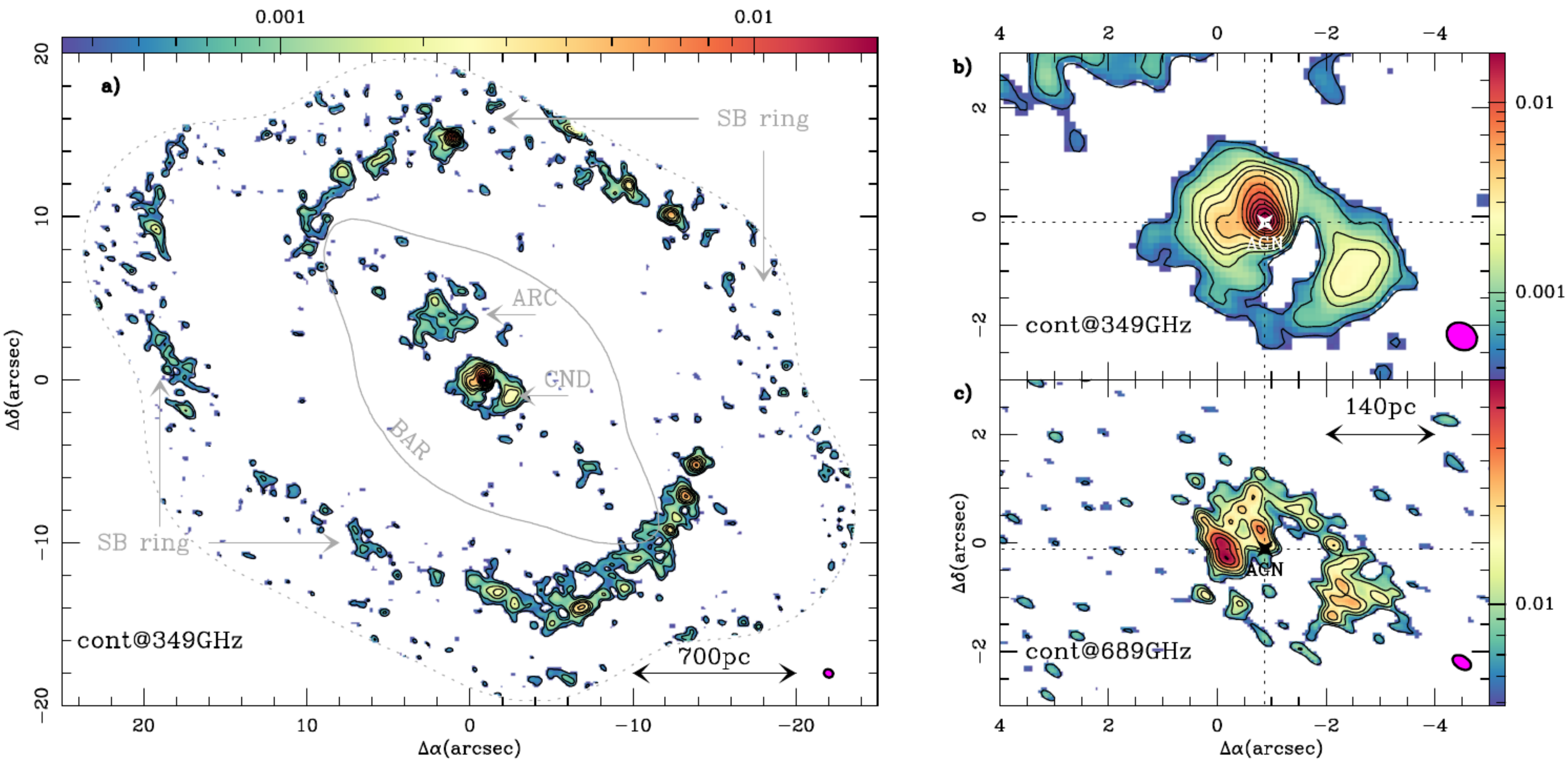
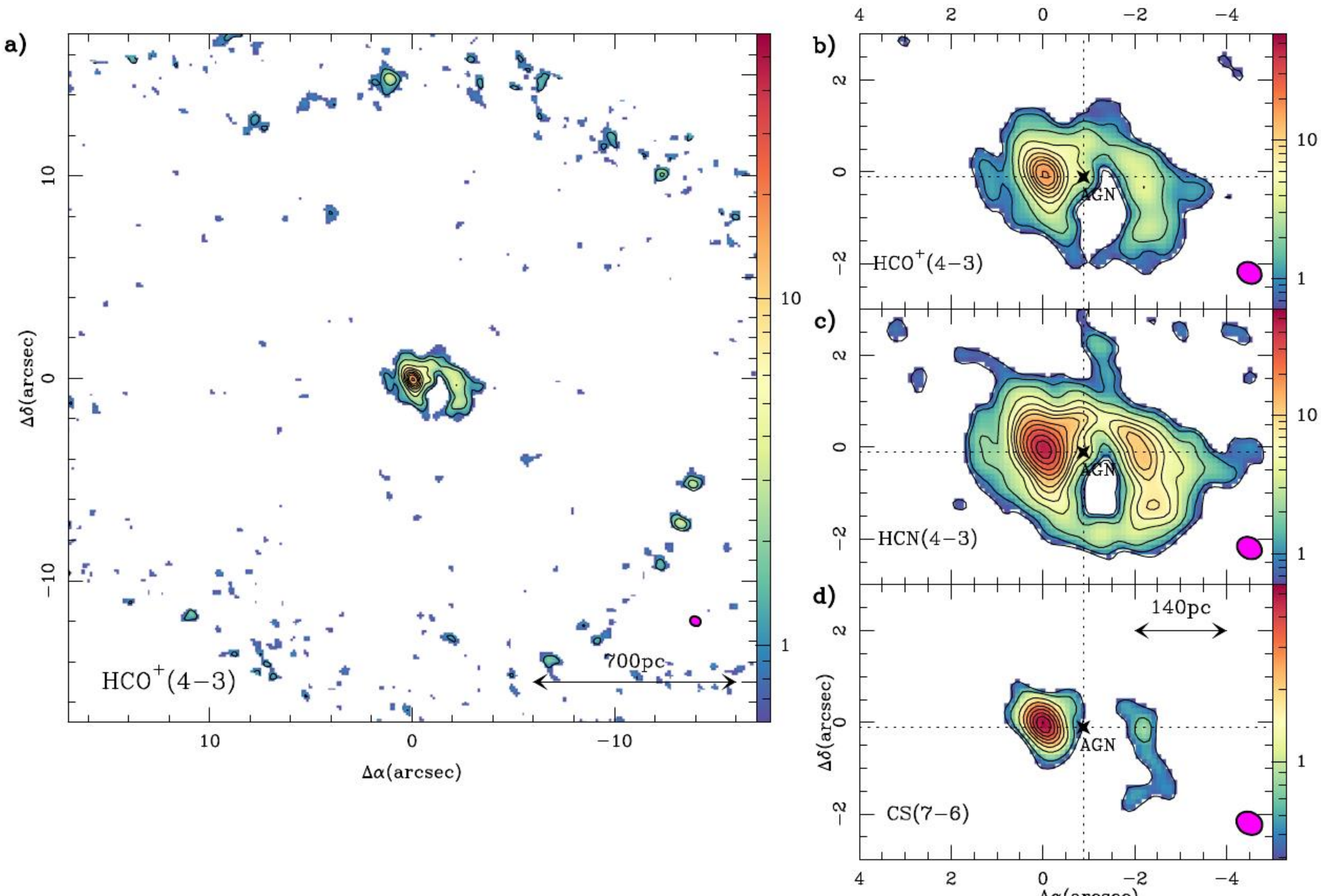


Figure 1. The 691 GHz continuum image of Arp 220 obtained with ALMA with a resolution of 0.″363 × 0.″199 and 1σ sensitivity 11 mJy beam^{-1}. Contours at (2, 4, 6, 8, 10)σ show the extended low-level emission; the peak in the western nucleus is 1.15 Jy beam^{-1}. The two nuclei appear as compact continuum sources and dominate the total flux; however, low-level emission on scales of 1″–2″ contributes up to 24% of the total flux in this map.

Galaxies: NGC 1068 (Garcia-Burillo, Combes et al)



Galaxies: NGC 1068



30 Doradus

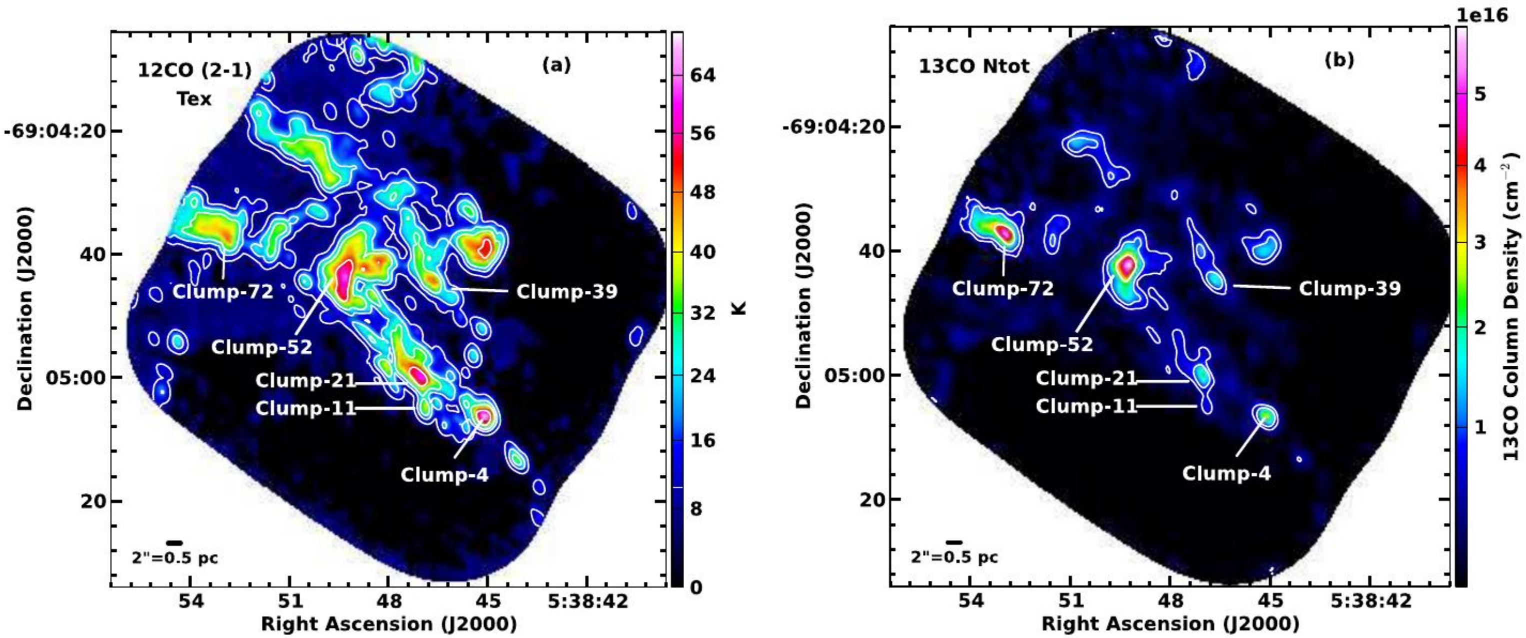
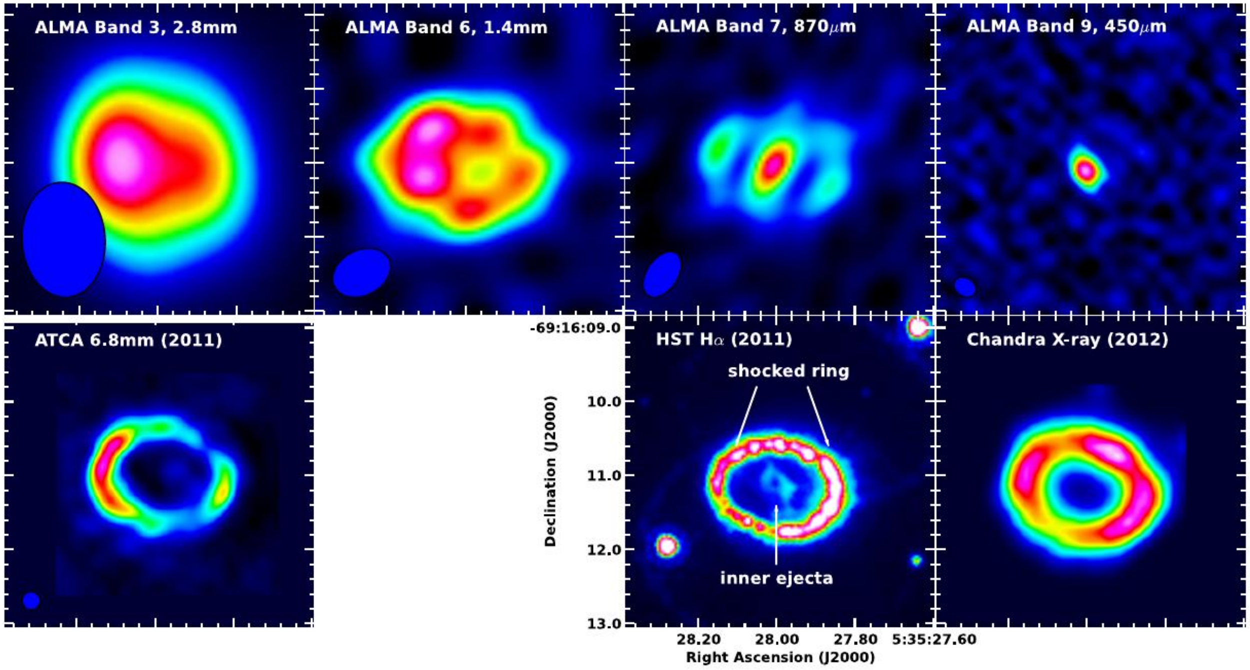


Figure 10. T_{ex} calculated from the ^{12}CO 2–1 brightness temperature and the ^{13}CO column density calculated from that T_{ex} and the ^{13}CO 2–1 intensity.

Une science variée

- Physique fondamentale:
  - **Robust Constraint on a Drifting Proton-to-Electron Mass Ratio at z=0.89 from Methanol Observation at Three Radio Telescopes.** Bagdonaite, J. et al 2013 2013PhRvL.111w1101B
- Restes de supernova
- Enveloppes Circumstellaires (le chaud et le froid…)
- Gamma Ray bursts

Indebetouw et al 2014
Dust in SN1987A



Hot HNC in IRC+10216: 1300 K, dust forming region (Cernicharo et al 2014)

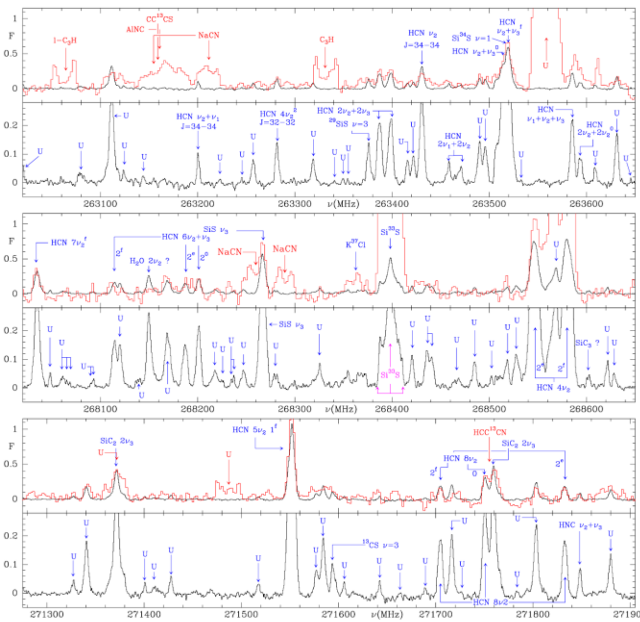
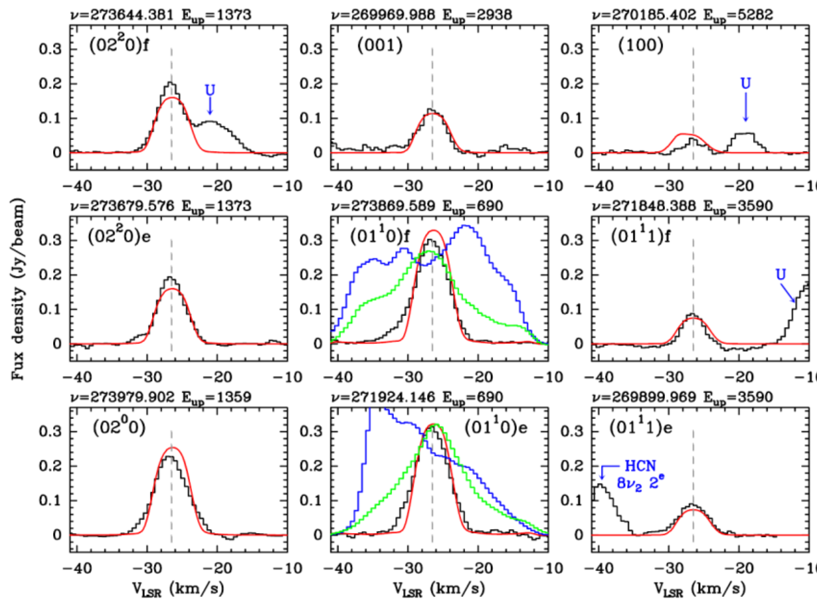
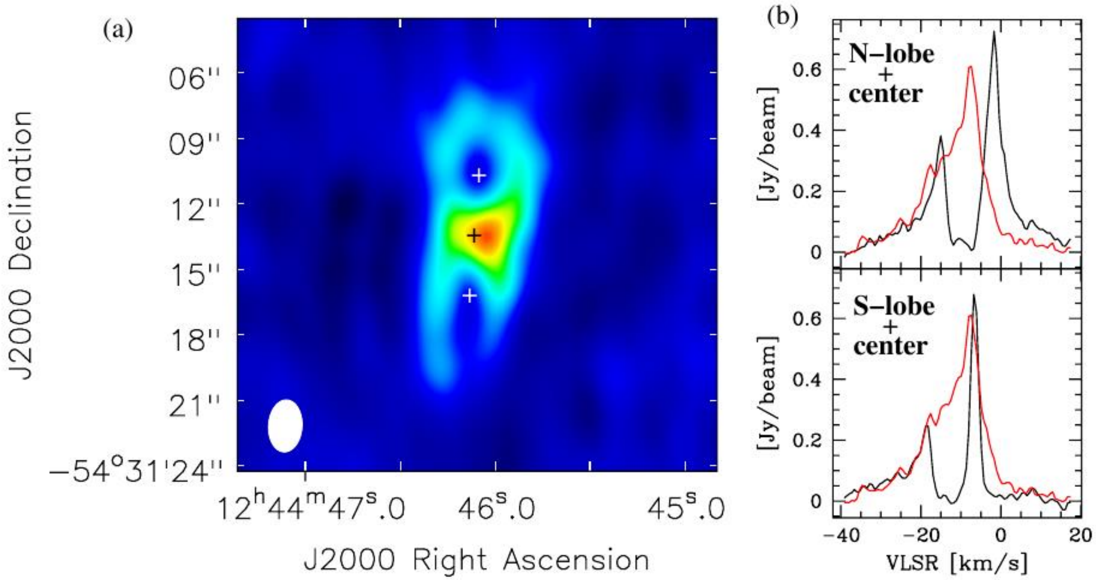


Figure 1. ALMA spectrum (black) of IRC+10216 in three selected frequency ranges of the 20 GHz bandwidth covered by our data. For each selected frequency the ALMA spectrum is compared to the data obtained with the 30-m IRAM telescope (red) at the same frequency (Cernicharo et al. 2011). Intensity scale is in units of Jy Beam^{-1}. Spectral resolution is ~1 MHz for both datasets. The bottom panel of each selected frequency shows a close-up view of the ALMA data. Interestingly, a forest of narrow and unidentified lines are evidenced thanks to the extreme sensitivity, and much higher angular resolution, of ALMA. Note the good calibration agreement for lines spatially unresolved by both instruments. Labels in red correspond to lines detected with the 30-m telescope and filtered by the interferometer.



Le coin le plus « cool » de l'Univers (2K)
La nébuleuse du Boomerang (Sahai et al)



Serendipity (again)

- Probing the jet base of the blazar PKS 1830-211 from the chromatic variability of its lensed images. Serendipitous ALMA observations of a strong gamma-ray flare

Quelques leçons

- Une révolution: ALMA permet des grands échantillons
  - Galaxies
  - Disques autour de binaires
- Une autre révolution: la sensibilité autour de 350 GHz
  - Traceurs de haute densité & température
- Une 3ième révolution: l’imagerie robuste à 0.25’’
- Une 4ième révolution: les découvertes « annexes »
  - Liées à la sensibilité
  - Mais aussi à la flexibilité du corrélateur
- L’hémisphère Sud
- La capacité à « aller plus loin »
  - Orion
  - 30 Doradus

Un peu de pot, ça compte…

- Oph IRS48 : l’asymétrie n’était pas prévue … (van der Marel, Science)
- Le choc d’accrétion dans L1527 : un phénomène cherché par beaucoup, trouvé par hasard … (Sakai et al, Nature)
- La chance de l’Hémisphère sud
  - Disques: la chance d’avoir les bons objets dans l’hémisphere Sud
  - Objets jeunes: la aussi !...
  - Même pour la physique (PKS1830-211)
  - Ou les objets exotiques: Boomerang, SN1987A

L’hémisphère Sud: la grande chance d’ALMA

- HD 163296 (le disque le plus massif près de nous ?)
- TW Hya (le disque jeune le plus proche de nous)
- Cavités, asymétries et pièges à poussières
  - Oph IRS 48 , HD141567
- Disques « hybrides » (HD21999)
- Disques de Débris
  - Fomalhaut
  - B Pictoris: le CO venant des comètes…
- « Young Stellar Objects »
  - HH 212
  - IRAS 16293-2422
  - VLA 1623A

Ce qui aurait pu être fait ailleurs…

- Orientation des disques dans HK Tau (Jensen & Akeson, Nature 2014): faisable au Plateau de Bure depuis > 10 ans…

- Si le Plateau de Bure avait été dans l'hémisphère Sud
  - Pas mal de choses sur HD163296 (à l'exception des raies les plus faibles, comme c-C_3H_2)
  - Encore plus de TW Hya

- Donc, en pratique, pas grand-chose… ALMA était vraiment indispensable !...

ALMA fonctionne…

- Mais le meilleur est encore à venir

- ACA
- Longues lignes de base
- Polarisation

Le système solaire: