Atacama Large Millimeter Array(ALMA)

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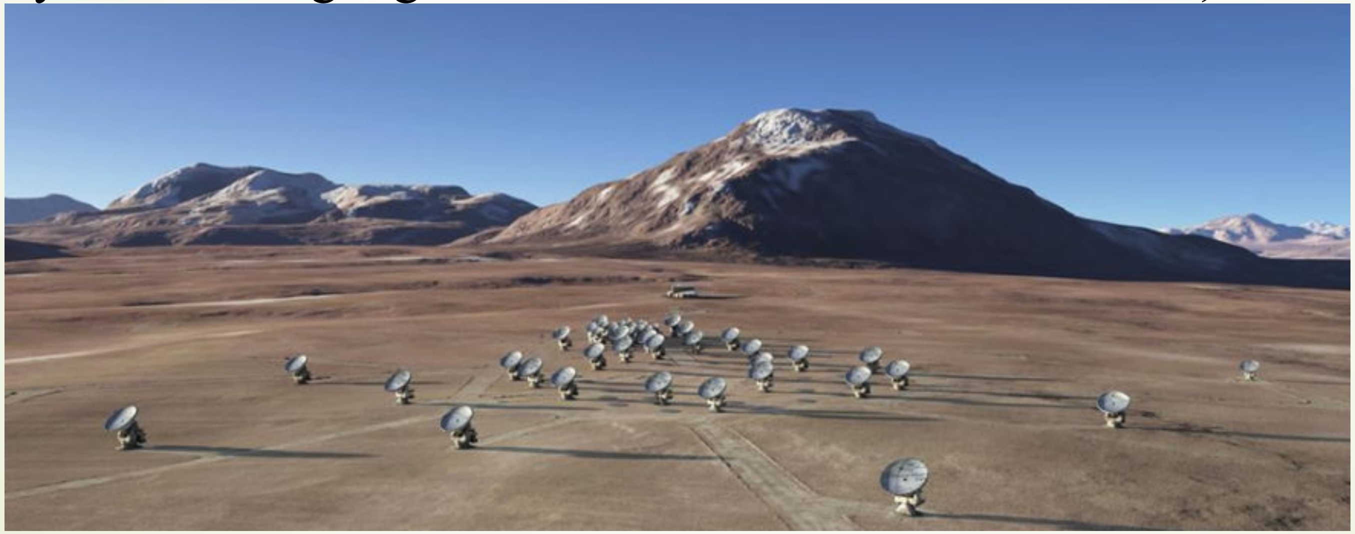
outline

- The origin of ALMA
- How does ALMA work?
- Science Highlights
- Summary

Origins

- National Radio Astronomy Observatory (NRAO) : MMA
- European Southern Observatory(ESO) : LSA
- National Astronomical Observatory of Japan (NAOJ) : LMSA

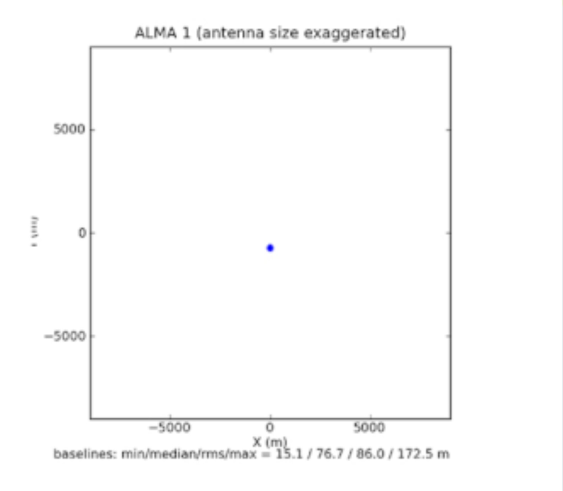
Why not working together? → At the end of 2003, ALMA comes out.

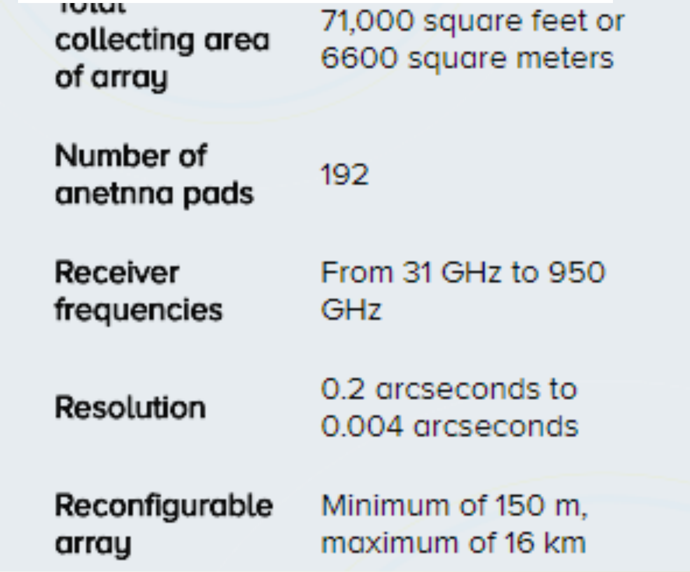


Brief Look

- Fifty 12 meter Dish:
  moveable, so the baseline can be changed from 150m ~ 16km.
- twelve 7-m antennas and four 12-m antennas:
  Atacama Compact Array (ACA)
- In ALMA's most compact configurations, the level of detail it can see ranges from 0.7" at 675 GHz to 4.8" at 110 GHz.
- In its most extended configuration, ALMA's resolutions range from 6 mas at 675 GHz to 37 mas at 110 GHz.

Costing about US$1.4 billion!

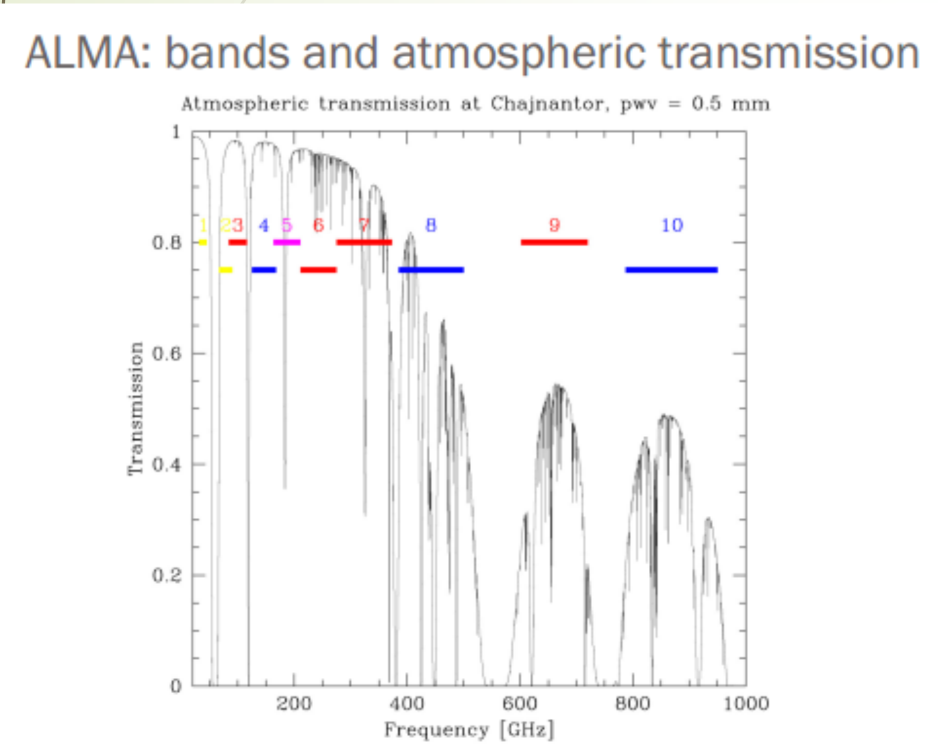




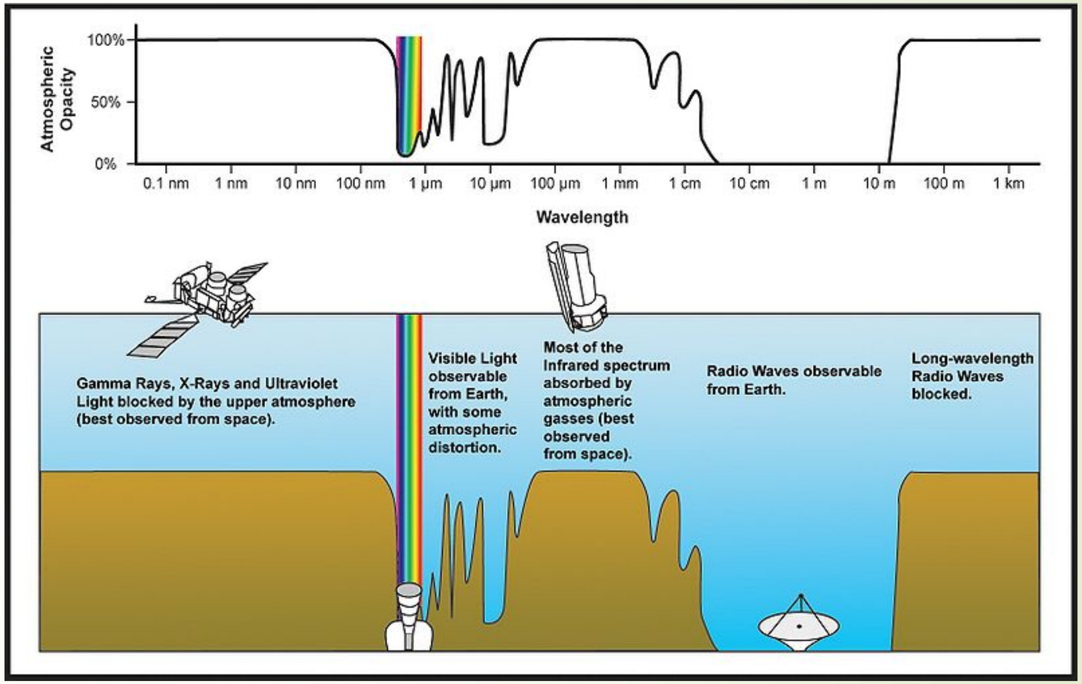
Total collecting area of array	71,000 square feet or 6600 square meters
Number of anetnna pads	192
Receiver frequencies	From 31 GHz to 950 GHz
Resolution	0.2 arcseconds to 0.004 arcseconds
Reconfigurable array	Minimum of 150 m, maximum of 16 km

Location: the Atacama Desert

- dryness and high altitude are necessary.



ALMA: bands and atmospheric transmission



Gamma Rays, X-Rays and Ultraviolet Light blocked by the upper atmosphere (best observed from space).

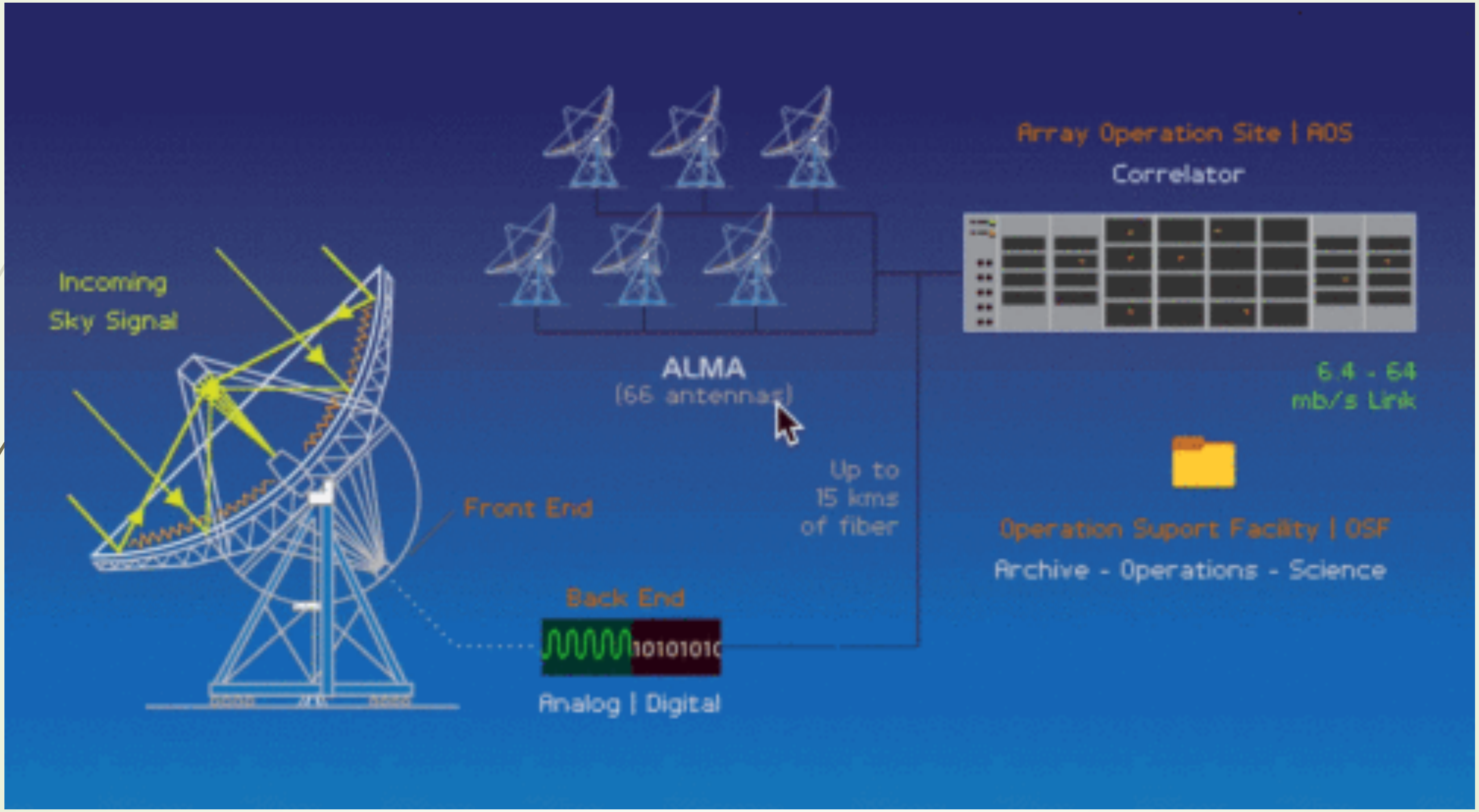
Visible Light observable from Earth, with some atmospheric distortion.

Most of the Infrared spectrum absorbed by atmospheric gasses (best observed from space).

Radio Waves observable from Earth.

Long-wavelength Radio Waves blocked.

How does ALMA work?



Interferometry & Correlator

sky brightness distribution $I_\nu(s)$

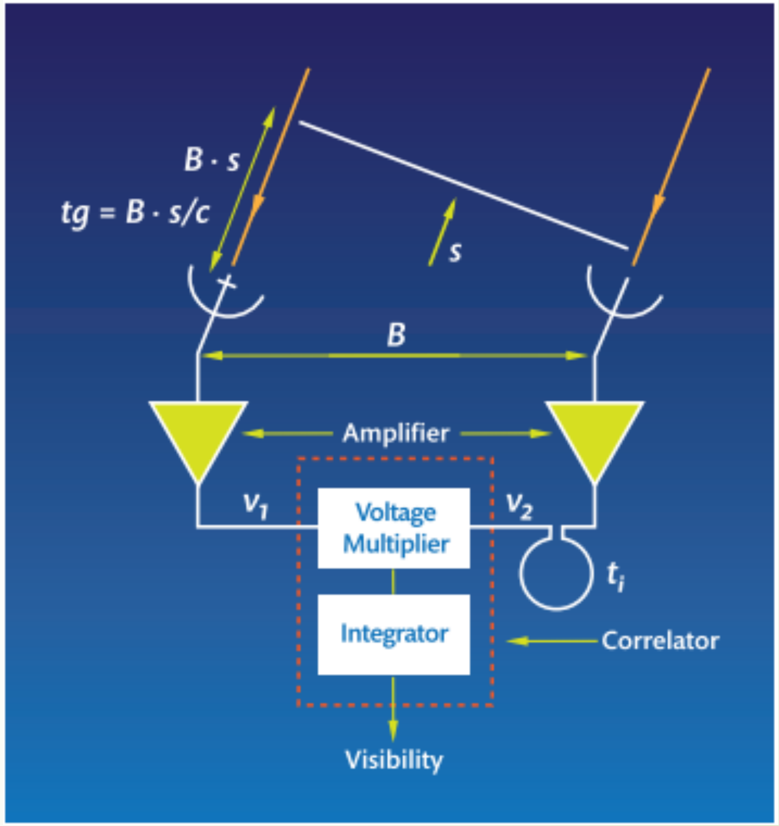
complex visibility:

$$V_\nu = \int I_\nu(\vec{s})\exp\left(-i \cdot 2\pi \vec{B} \cdot \vec{s}/\lambda\right) d\Omega$$

Effects of Finite Bandwidths: $\Delta\nu$ centered on ν_c

$$V = \int I_\nu(\vec{s})\,\mathrm{sinc}\left(\Delta\nu\tau_g\right)\exp\left(-i2\pi\nu_c\tau_g\right) d\Omega$$

The compensating delay $\tau_0 \approx \tau_g$ to minimize attenuation

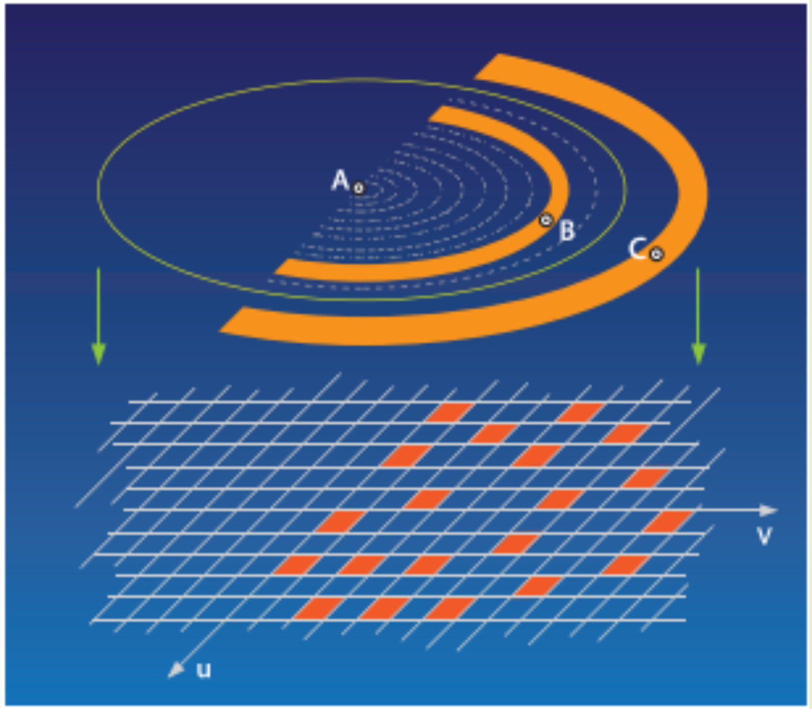


U-V Plane

- The baseline changes as the source moves a function of time

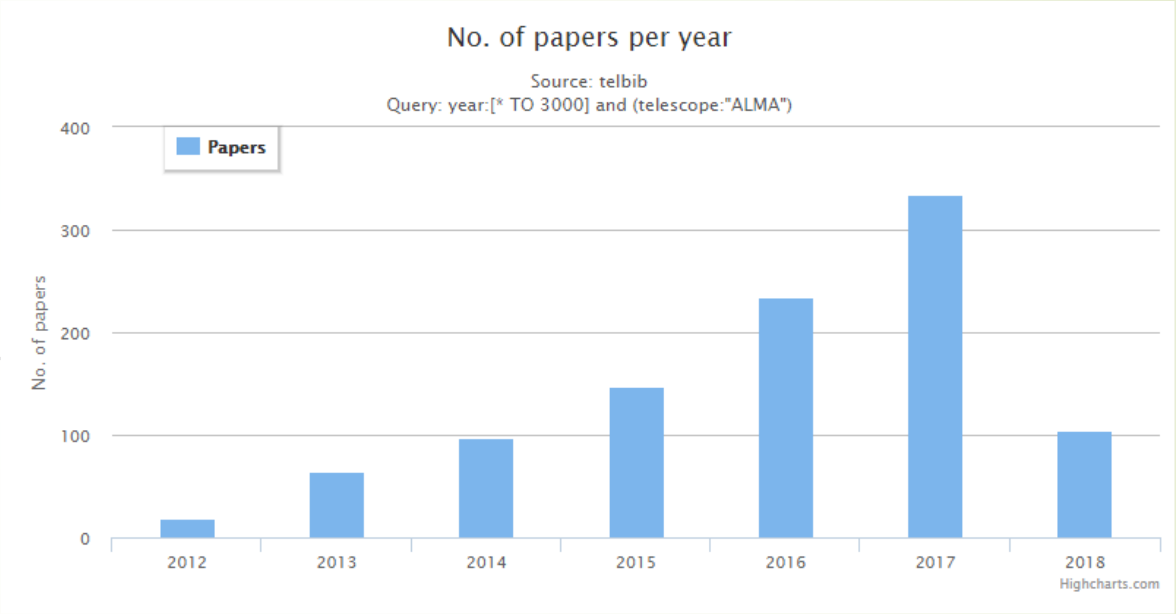
- The baseline length can be separated into two orthogonal directions, referred to as “u” and “v”

- If all of the (u,v) plane can be filled with data, we can obtain almost the same detail as that measured with a filled aperture of the same size



ALMA Science

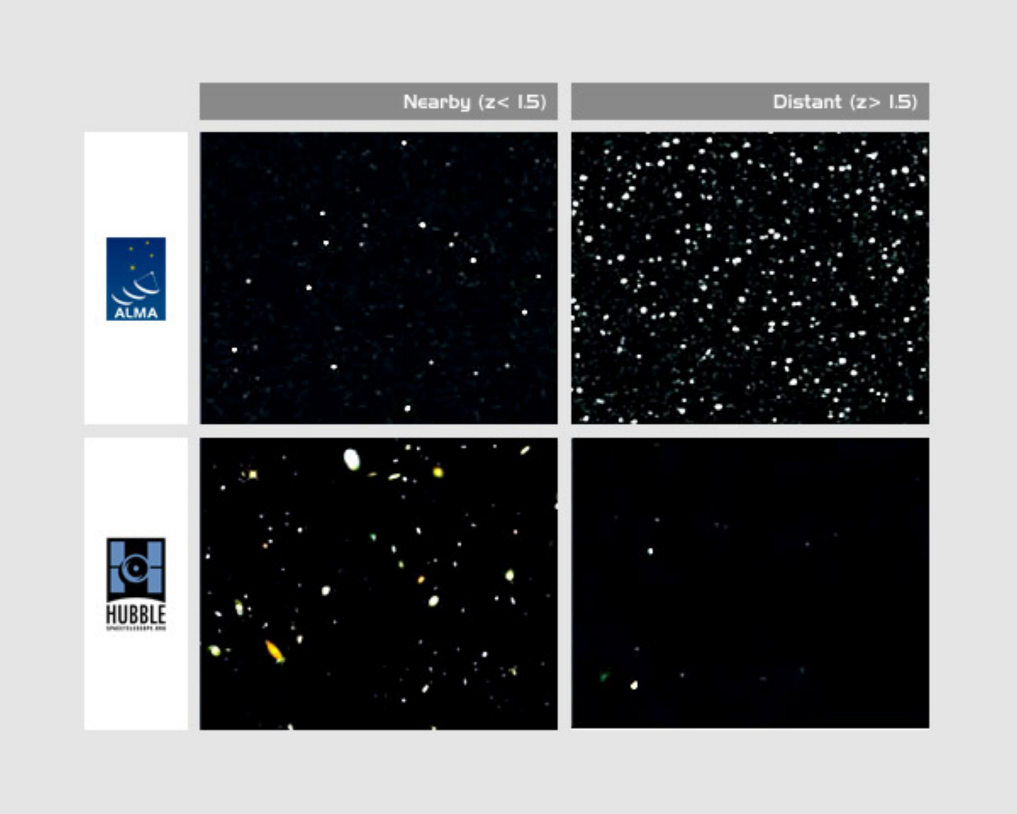
- ALMA Deep Field
- Early Galaxy Formation
- Star and planet formation
- Detecting extrasolar planets under formation
- …



Over 1000 paper since 2012!

ALMA deep field

- It shows the number of low redshift (z<1.5) and high redshift (z>1.5) galaxies expected from a simulated deep ALMA observation

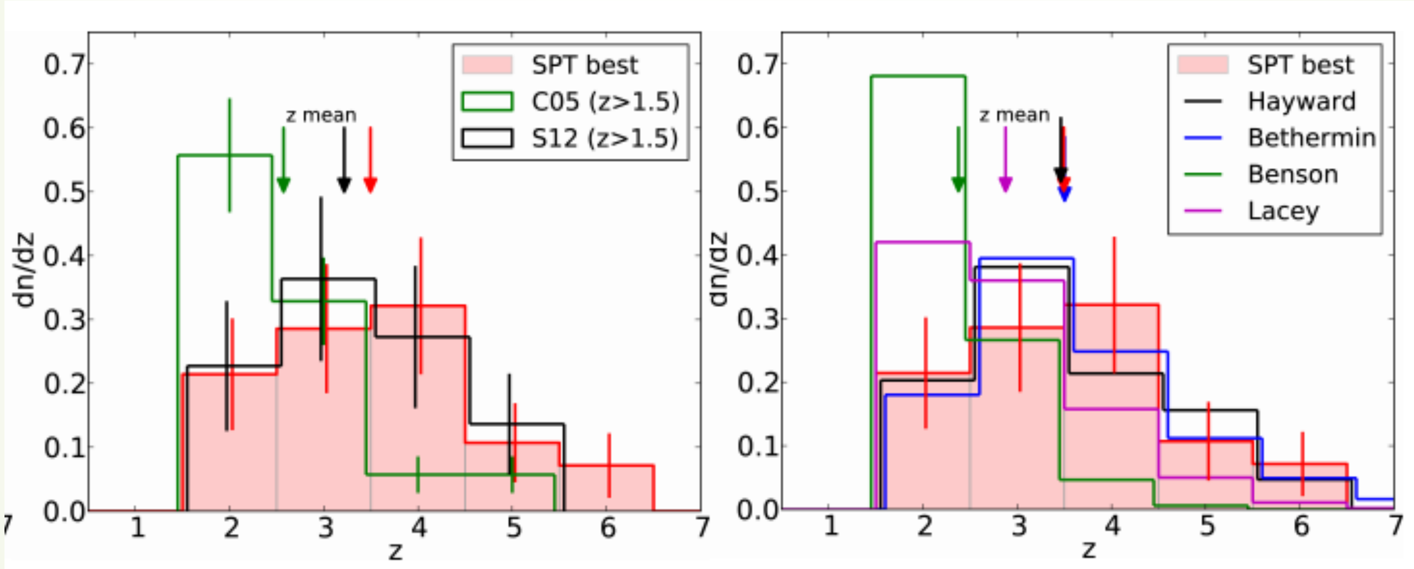


Early Galaxy Formation

- How could we get information about the first generation of galaxies?
  - Space telescopes : registering the huge light issued by the explosion of this type of stars
  - More realistic method: detecting the DUST. The first appearance of dust is our best evidence of the life and death of the first stars

Dusty Star-Forming Galaxies at High redshift!

“Rewrites History of Universe’s Stellar Baby Boom”



Mean redshift of our sample is z=3.5. This finding is in contrast to the redshift distribution of radio-identified DSFGs, which have a significantly lower mean redshift of z=2.3 and for which only 10-15% of the population is expected to be at z>3.

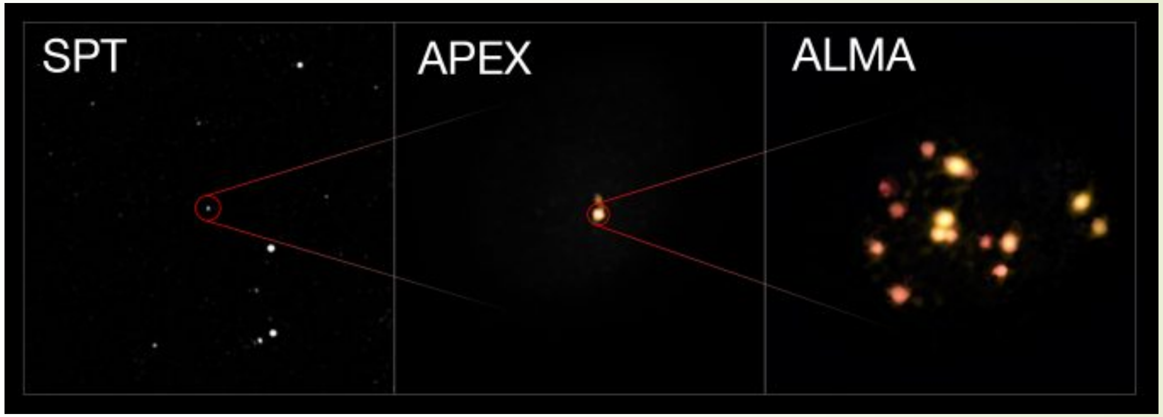
A. Weiss et al. 2013

Ancient Galaxy Megamergers

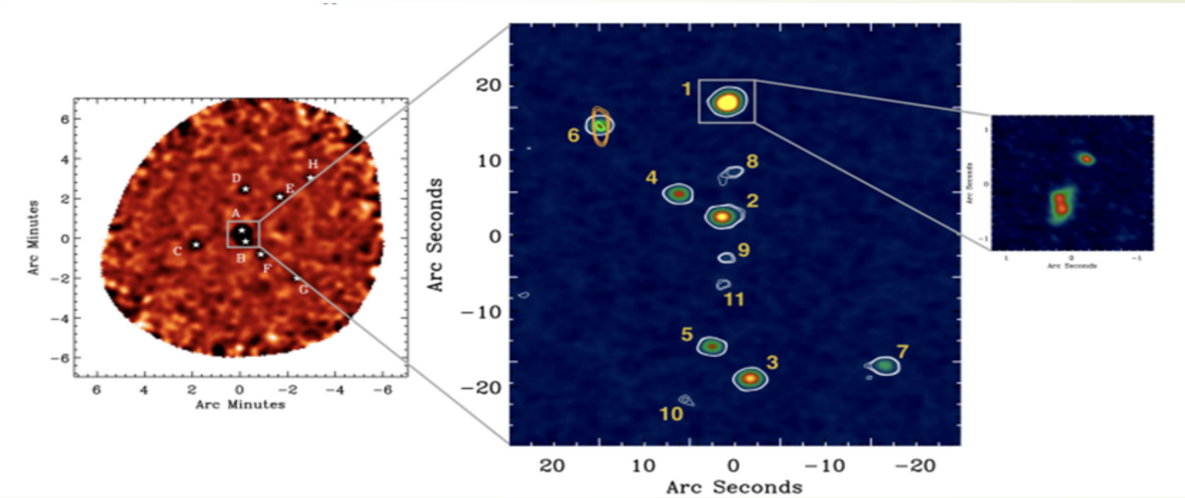
SPT: a bright spot

APEX: a little more details

ALMA: a group of 14 merging galaxies

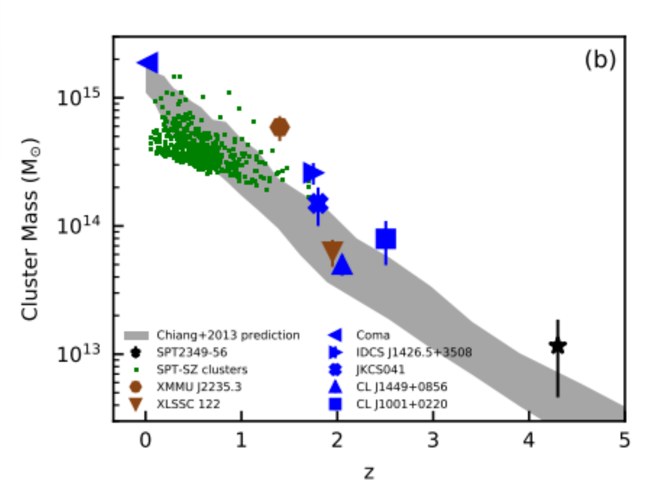


SPT 2349-56



SPT 2349-56(Distant Red Core,DRC)

- Slightly more massive than models predict for the most massive progenitor halos and could suggest that DRC may evolve into a cluster at z = 0 with a total mass>10^15 *solar mass.*



- Unknown mechanism to trigger extreme star formation

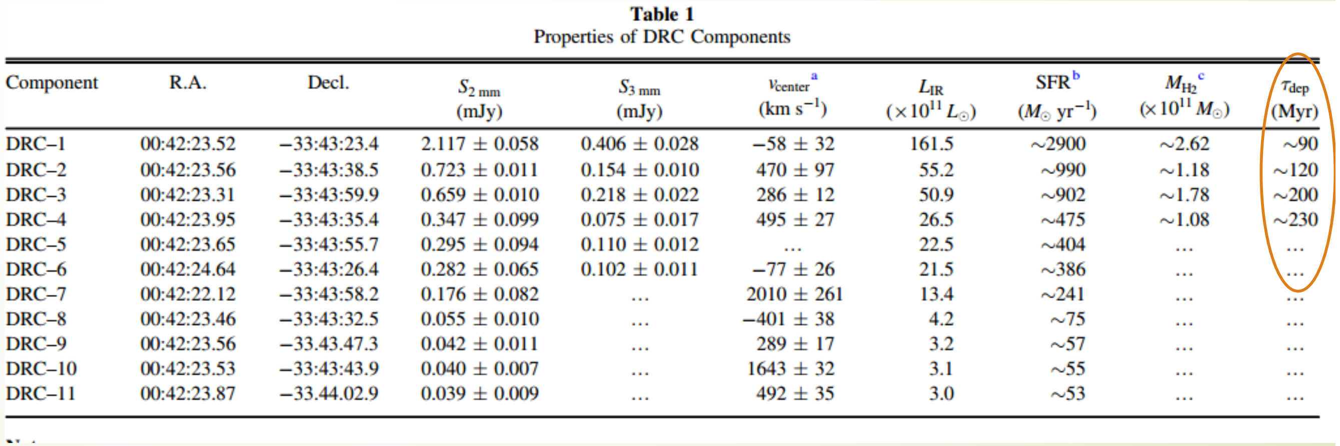


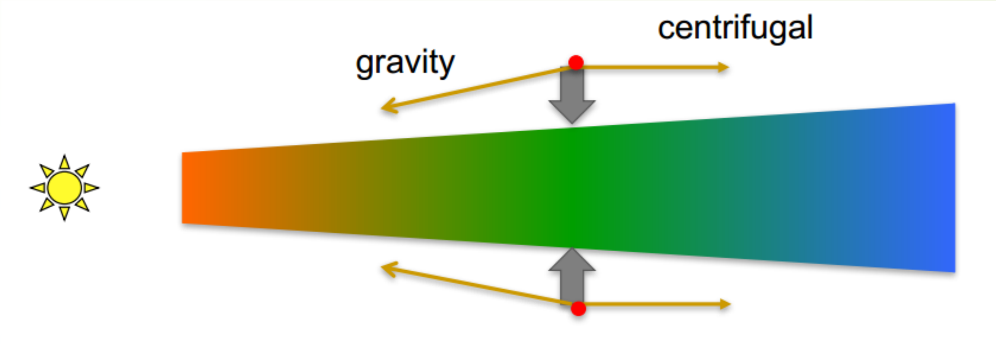
Table 1
Properties of DRC Components

Component	R.A.	Decl.	$S_{2\,\mathrm{mm}}$ (mJy)	$S_{3\,\mathrm{mm}}$ (mJy)	v_{center}[a] (km s^{-1})	L_{IR} ($\times 10^{11} L_\odot$)	SFR[b] ($M_\odot\ \mathrm{yr}^{-1}$)	$M_{\mathrm{H_2}}$[c] ($\times 10^{11} M_\odot$)	τ_{dep} (Myr)
DRC–1	00:42:23.52	−33:43:23.4	2.117 ± 0.058	0.406 ± 0.028	−58 ± 32	161.5	~2900	~2.62	~90
DRC–2	00:42:23.56	−33:43:38.5	0.723 ± 0.011	0.154 ± 0.010	470 ± 97	55.2	~990	~1.18	~120
DRC–3	00:42:23.31	−33:43:59.9	0.659 ± 0.010	0.218 ± 0.022	286 ± 12	50.9	~902	~1.78	~200
DRC–4	00:42:23.95	−33:43:35.4	0.347 ± 0.099	0.075 ± 0.017	495 ± 27	26.5	~475	~1.08	~230
DRC–5	00:42:23.65	−33:43:55.7	0.295 ± 0.094	0.110 ± 0.012	…	22.5	~404	…	…
DRC–6	00:42:24.64	−33:43:26.4	0.282 ± 0.065	0.102 ± 0.011	−77 ± 26	21.5	~386	…	…
DRC–7	00:42:22.12	−33:43:58.2	0.176 ± 0.082	…	2010 ± 261	13.4	~241	…	…
DRC–8	00:42:23.46	−33:43:32.5	0.055 ± 0.010	…	−401 ± 38	4.2	~75	…	…
DRC–9	00:42:23.56	−33.43.47.3	0.042 ± 0.011	…	289 ± 17	3.2	~57	…	…
DRC–10	00:42:23.53	−33:43:43.9	0.040 ± 0.007	…	1643 ± 32	3.1	~55	…	…
DRC–11	00:42:23.87	−33.44.02.9	0.039 ± 0.009	…	492 ± 35	3.0	~53	…	…

T. B. Miller et al. 2018
I. Oteo et al. 2018

Star and planet formation

- Protoplanetary disks:
  - dusty gaseous disk surrounding newly born stars with lifetime of a few Myrs
  - To zeroth order, the disk can be understood as being in Keplerian rotation with vertical hydrostatic equilibrium
  - Disk evolution is driven by angular momentum transport(turbulence and magnetic field).



Vertical gravity:

$$g_z = -\frac{GM_*}{(R+z)^2}\frac{z}{(R^2+z^2)^{1/2}} \overset{(z<<R)}{\approx} -\Omega^2 z$$

Pressure support (assuming isothermal EoS $P=\rho c_s^2$):

$$c_s^2 \frac{d\rho}{dz} = \rho g_z$$

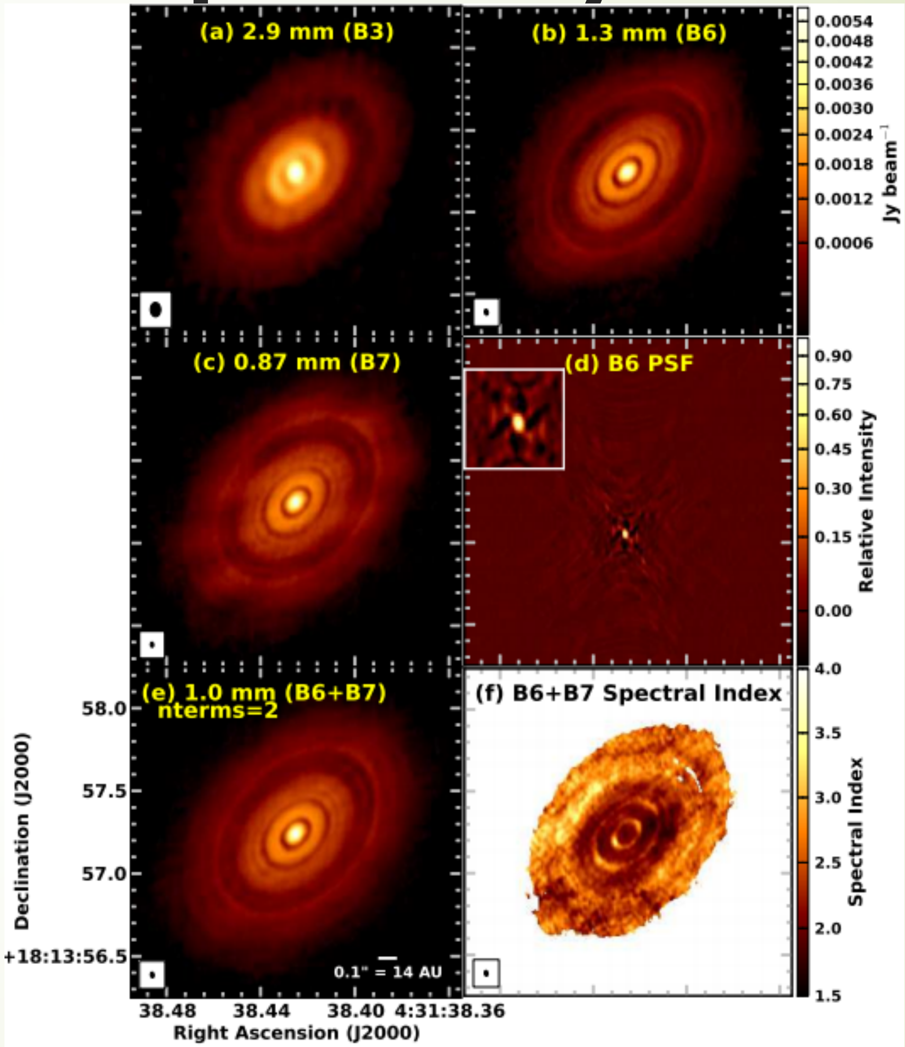
The structure of protoplanetary disk

- remarkable pattern of bright and dark circumstellar rings in the continuum images and spectral index.
- An increase in eccentricity with radius and numerous resonances.

the dark rings are gaps arising from the process of planet formation?

What are causing them is currently under hot debate…

C. L. BROGAN et al. 2015



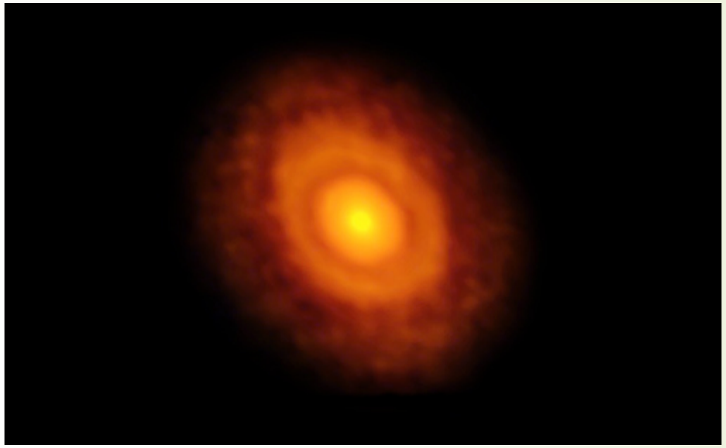
First Protoplanetary Water Snow Line

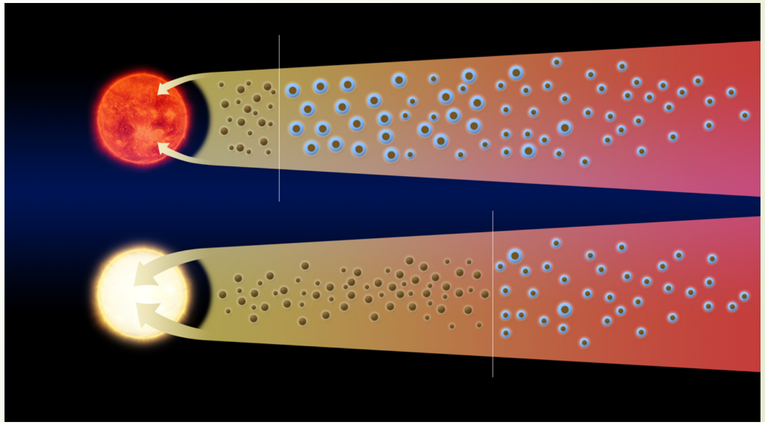
- Snow lines are the regions in those disks where the temperature reaches the sublimation point for most of the volatile molecules.

- A dramatic increase in the brightness of the young star heated the inner portion of the disk

Lucas A. Cieza et al. 2016

V883 Ori





ALMA Sounds

Summary

- ALMA’s antennas can be configured in different ways, spacing them at distances from 150 meters to 16 kilometers
- ALMA is currently the largest radio telescope in the world and has much higher sensitivity and higher resolution than earlier submillimeter telescopes
- The purpose of ALMA is to study star formation, molecular clouds and the early Universe, closing in on its main objective: discovering our cosmic origins

Reference

[1] A. Weiss et al. 2013, ALMA redshifts of millimeter-selected galaxies from the SPT survey: The redshift distribution of dusty star-forming galaxies

[2] T. B. Miller et al. 2018, The formation of a massive galaxy cluster core at z=4.3

[3] I. Oteo et al. 2018, An extreme protocluster of luminous dusty starbursts in the early universe

[4] C. L. BROGAN et al. 2015, First results from angular resolution ALMA observations toward the HL Tau region

[5] Lucas A. Cieza et al. 2016, Imaging the water snow-line during a protostellar outburst

[6] https://public.nrao.edu/telescopes/alma/

[7] http://www.almaobservatory.org

[8] https://en.wikipedia.org/wiki/Atacama_Large_Millimeter_Array