A review of (sub)mm band science and instruments in the ALMA era

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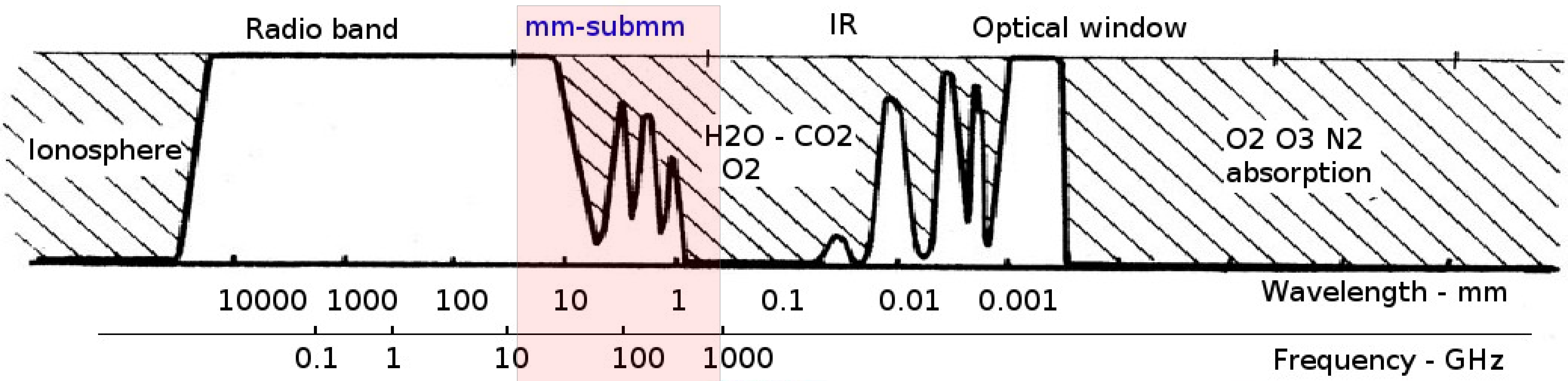
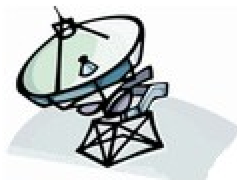
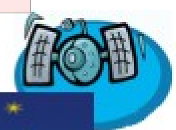
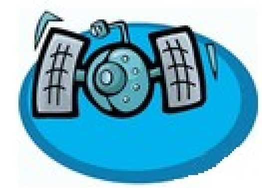
Outline









Signals: Synchrotron
Dust
Molecular lines

Observing instruments: Interferometers (ALMA)

Science cases

Observing processes: Proposals and archives

General words & ALMA pros

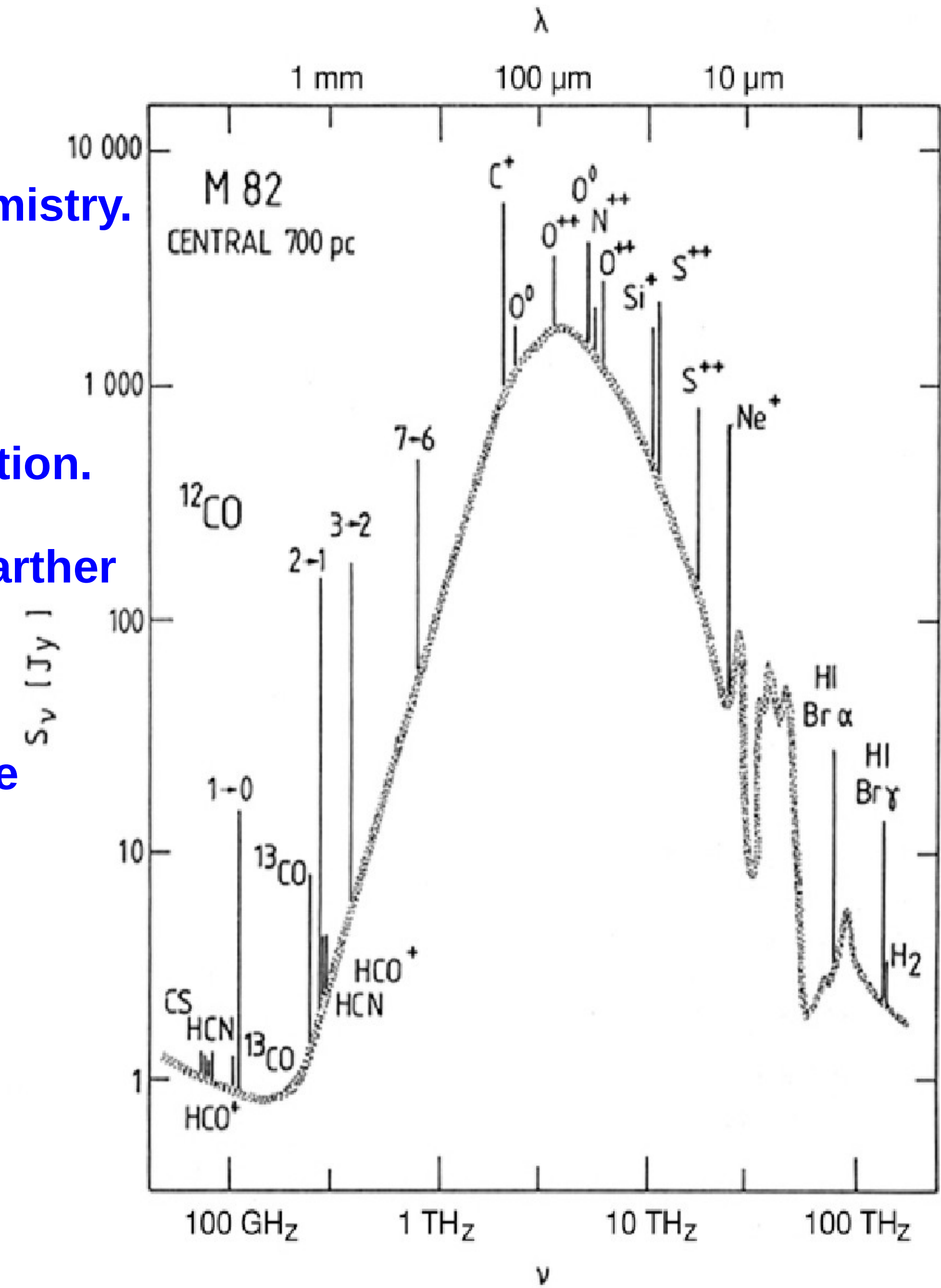
Sub(mm) is characterized by dust and rich chemistry.

Dust and moleculae are mostly (but not only) associated with forming structures.

Hence **sub(mm) helps studying structure formation.**

Higher resolution and sensitivity allows to go farther so to investigate a deeper sky region, getting more sources and more statistics on populations.

Higher spectral resolution allows to detect more narrow lines and more details from broad lines, and hence investigate chemical compositions, source dynamics and pressure and temperature structures.

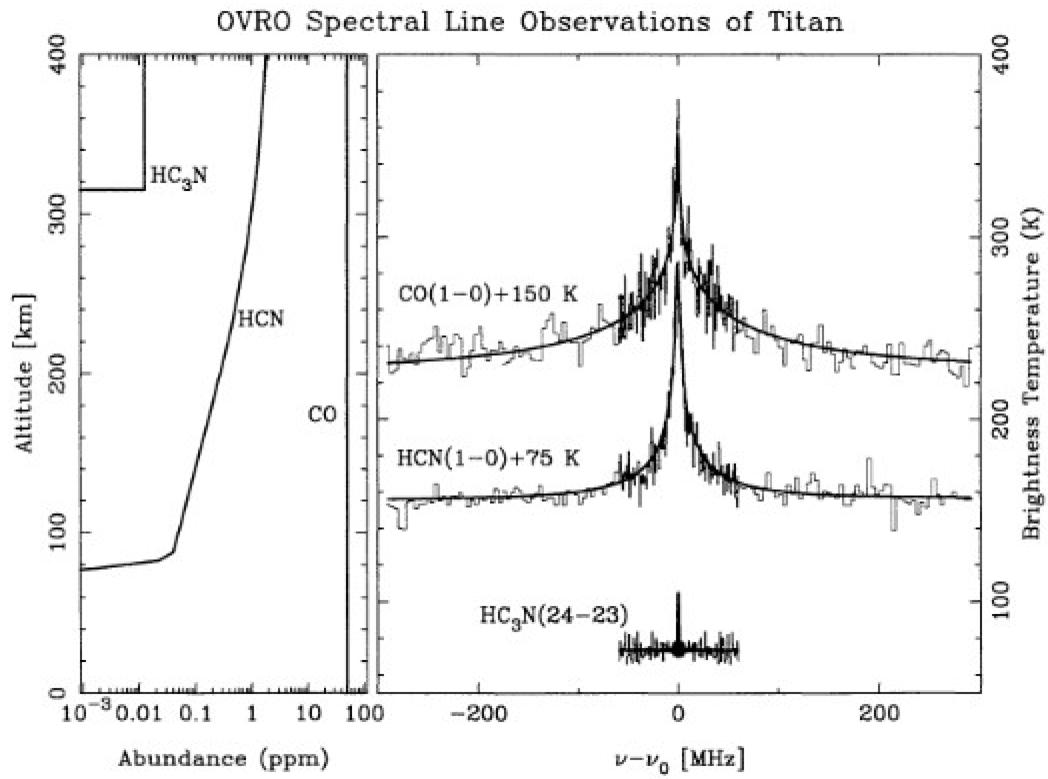


Planets & small bodies

Surface studies

- Mapping regions that may contain ice at mm wavelength can help determining the surface temperatures and hence **if the ice is stable** (e.g. Mars polar caps).

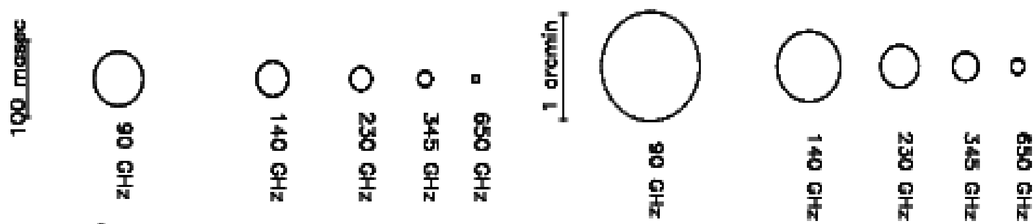
- Mapping the surface temperature as a function of wavelength constrains the properties of the planet heat from the interior, useful to study **the planetary magnetic fields.** (e.g. to determine if Mercury has a molten core)



Atmospheric studies

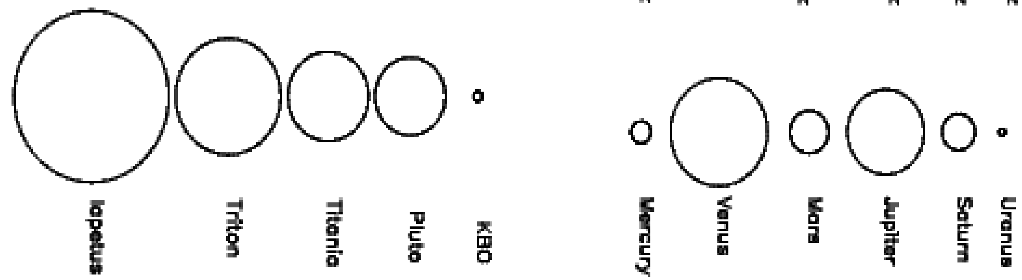
- Since spectral line shape (i.e. Doppler and pressure broaden lines) depends on molecular abundances and temperature profiles they can be used to reconstruct **vertical structures and dynamics of planetary Atmospheres, (seasonal variations and climate models)**

ALMA beam sizes



Calibrations

- Planets & satellites are “relatively” stables, so are often used as **flux calibrators at sub(mm)** Proper models of flux density distribution (they are typically extended wrt to telescope beams) including time variability (e.g. seasonal variations) are crucial also for other science observations.



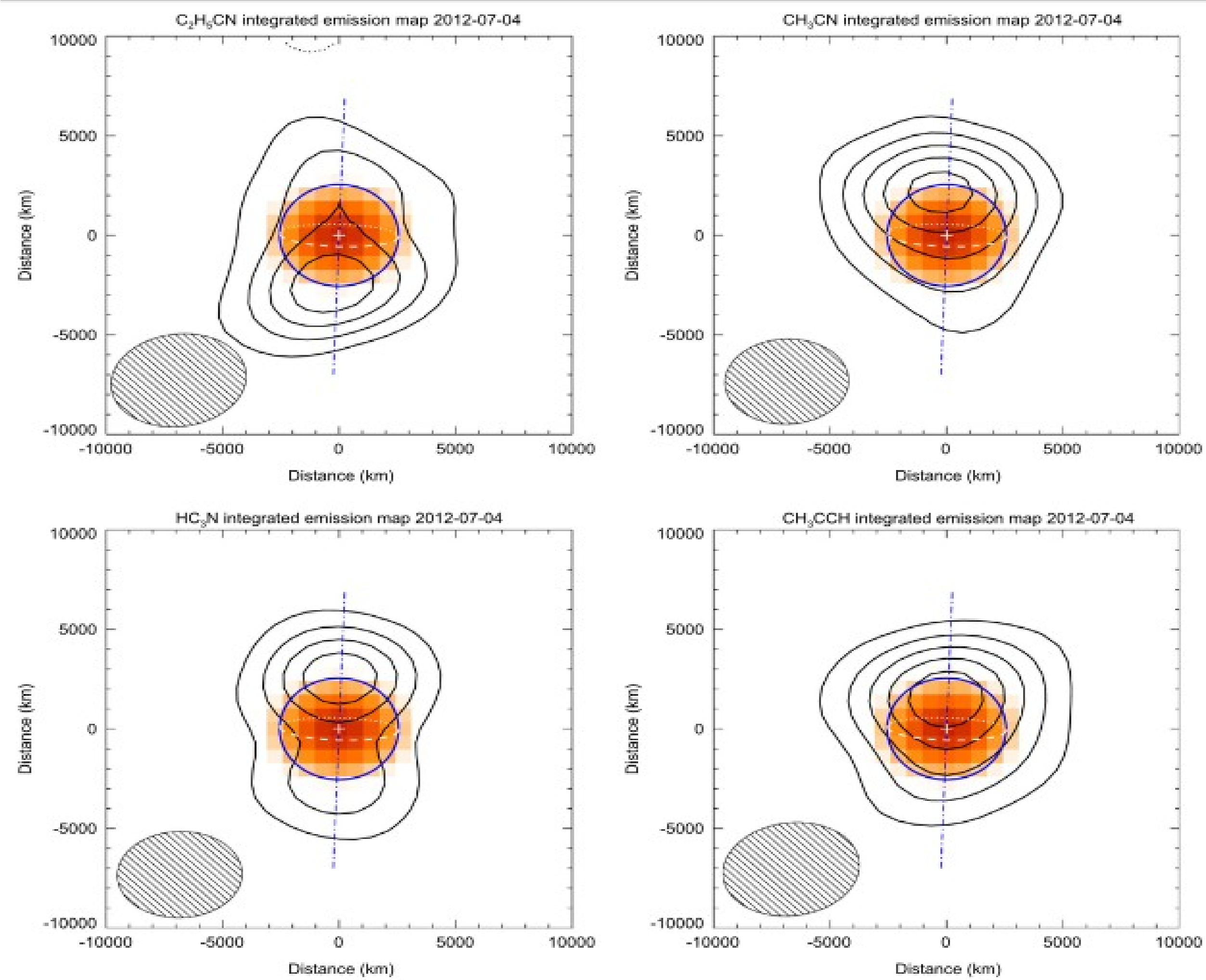
Solar System bodies sizes

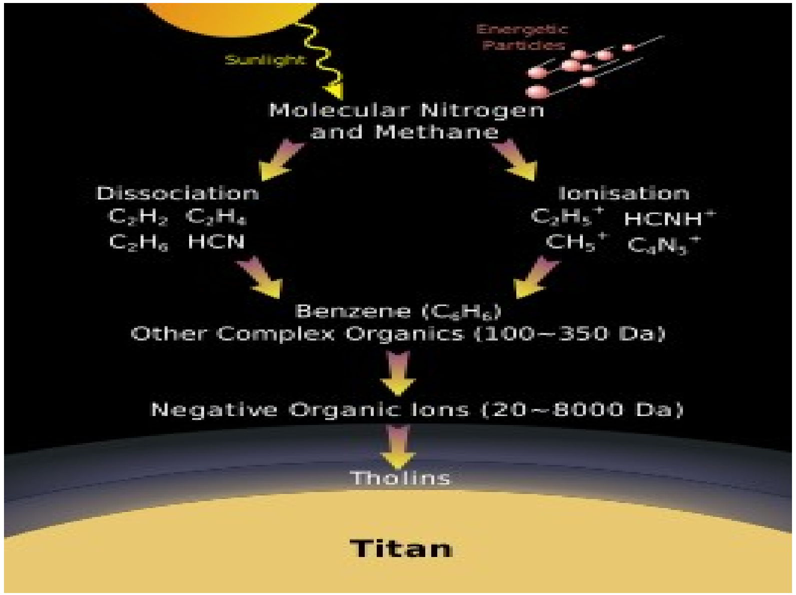
- Cycle 0 -20 antennas
- 8min on-source
- Band 6 (1.7 mm)
- **Spectral res 1.3km/s**
- Angular Res 0.7"(= ~5000km ~Titan diameter)

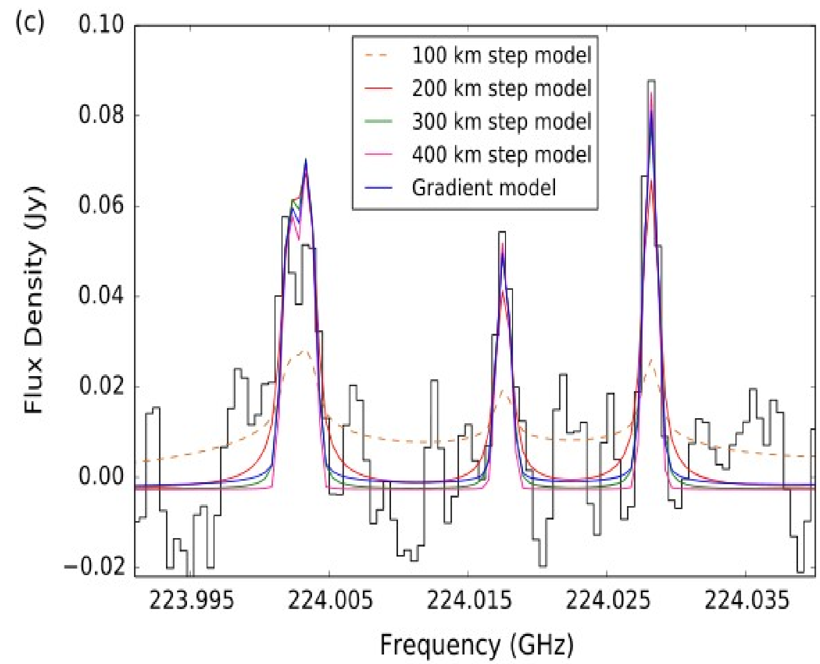
Ethyl Cyanide on Titan

Cordiner et al. 2015

Titan has a thick atmosphere composed primarily of molecular nitrogen (98%) and methane (2%). Organic molecules form at various altitude from ionization and photodissociation processes.







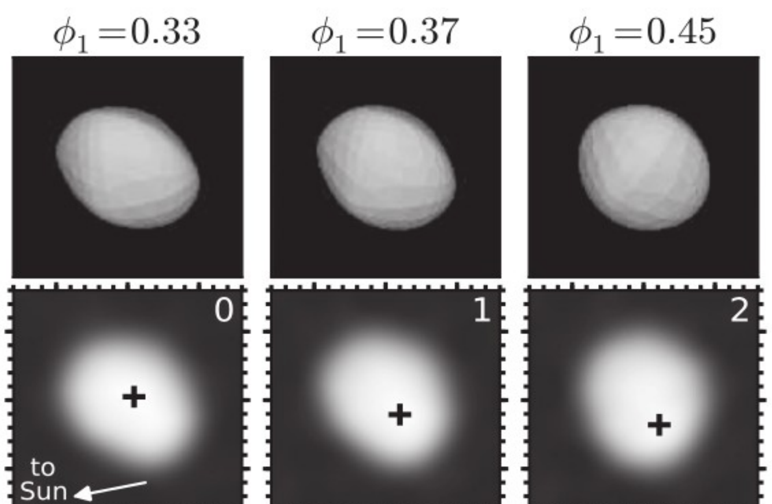
Ethyl Cyanide (C2H5CN) is detected on Southern hemisphere indicating a shorter lifetime (during northern winter-spring transition) than HC3N, CH3CN and CH3CCN which are found to the north. Comparison with models show that C2H5CN is produced in the moon's stratosphere and above 200km.

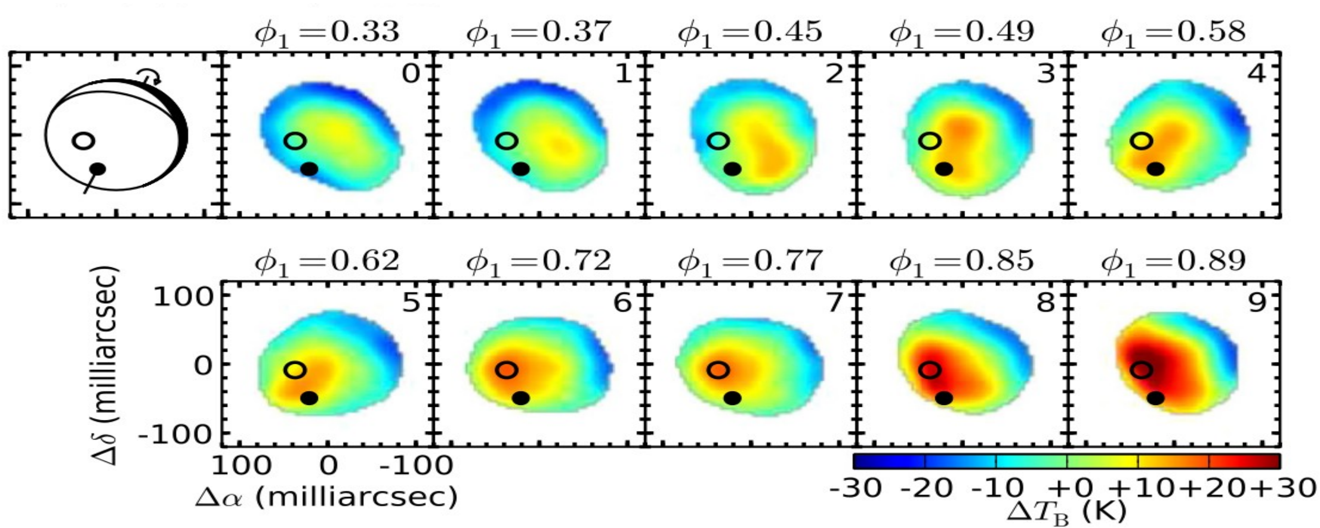
Science Verification 3 Juno at high resolution

PI: M. Cordiner

- Science Verification Cycle 2
- 3x15min on-source
- Band 6
- 10km baselines: res=0.042"=60km @1.97AU

Asteroid 3 Juno was observed with a 60km resolution at 1.3mm covering 60% of the rotation period (ALMA Partnership et al. 2015). Images were taken when Juno was approximately 295 million kilometres from Earth. Diameter measure 259\pm4 km. Brightness excess yields info of the surface.

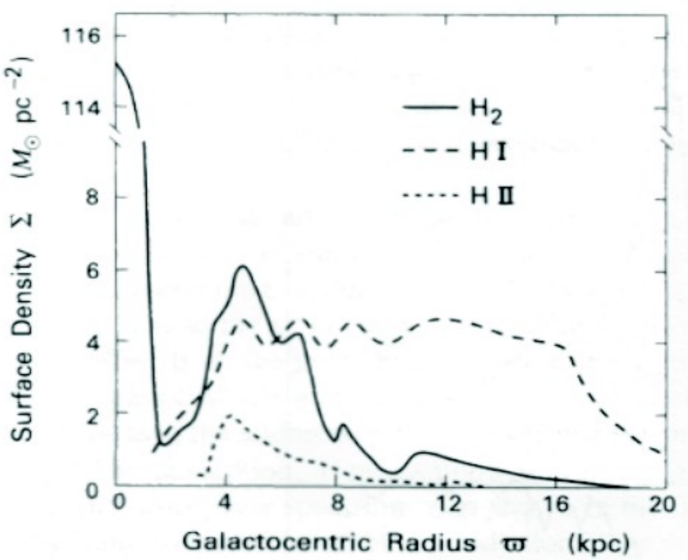


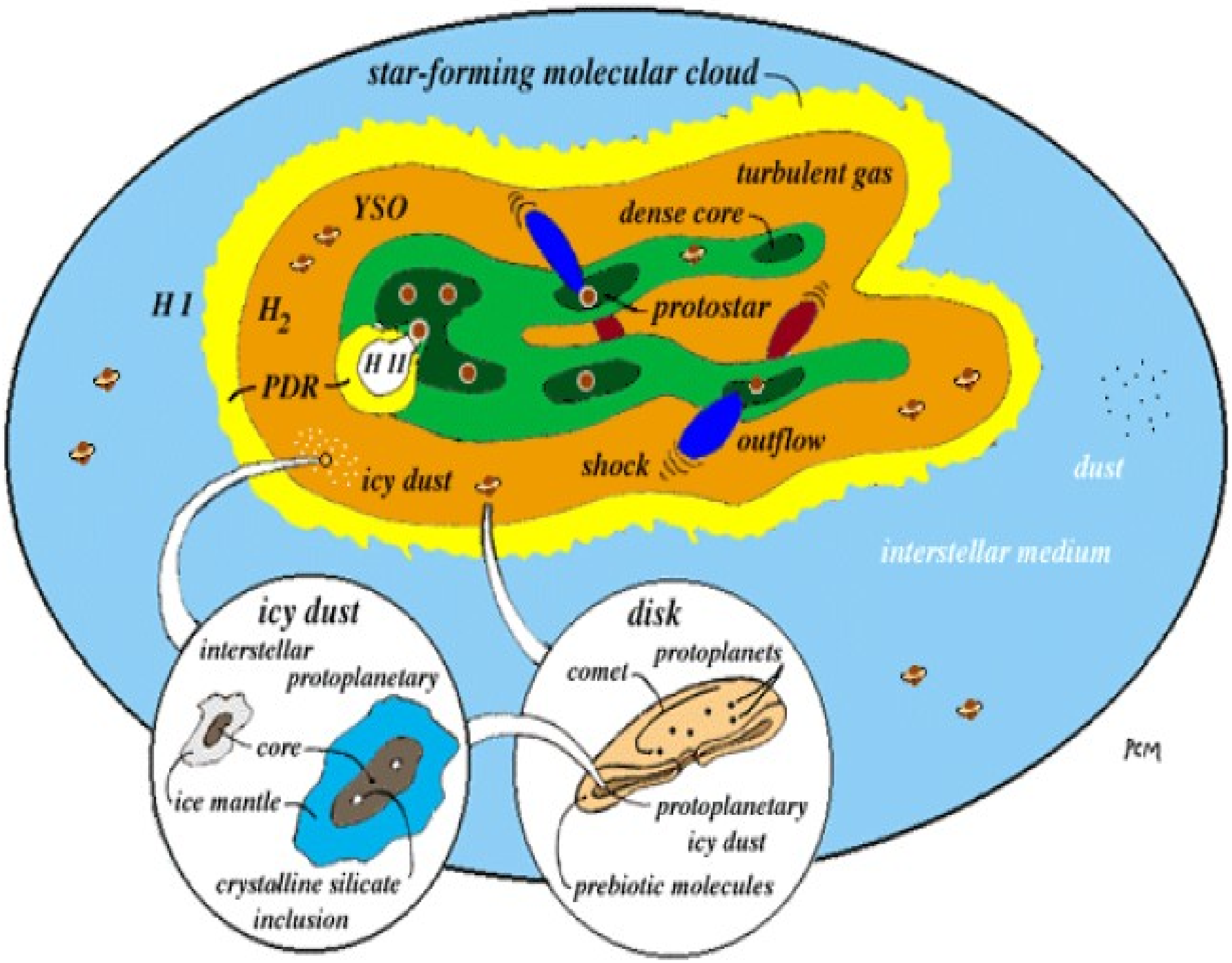


Interstellar medium

The ISM is constituted by 90% of H, 9% of He and traces of other components
H appears in H2, HI and HII.
80% of H2 is in giant molecular clouds, peaking in the Galactic center.

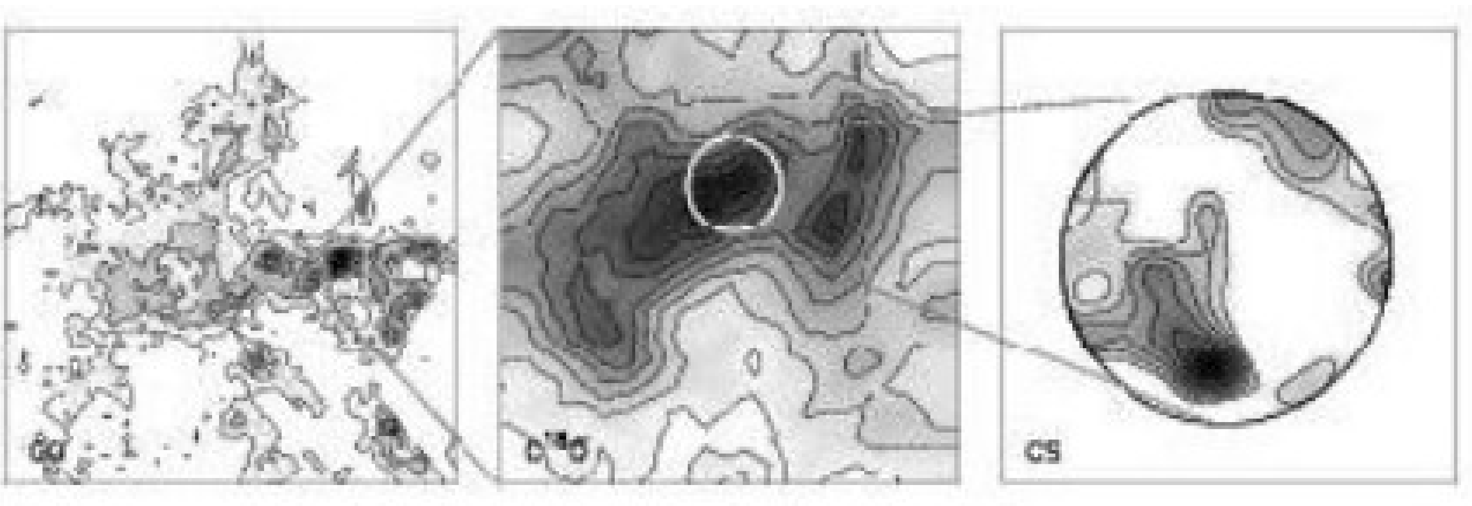
(Stahler & Palla)





Clumps & Cores

Molecular clouds are highly structured complexes made of clumps (where clusters can form) and cores (where a single or binary star form). Objects are typically located along filaments.



Clouds	clumps	cores
$D \geq 10$ pc	$D \approx 1$ pc	$D \approx 0.1$ pc
$n(H_2) \approx 10^2$-10^3 cm^{-3}	$n(H_2) \approx 10^5$ cm^{-3}	$n(H_2) \approx 10^7$ cm^{-3}
$M \geq 10^4\ M_\odot$	$M \approx 10^3\ M_\odot$	$M \approx 10$-$10^3\ M_\odot$
$T \approx 10$ K	$T \approx 50$ K	$T \approx 100$ K
CO, ^{13}CO	CS, C^{34}S	NH_3, CH_3CN
$N(CO)/N(H_2) \approx 10^{-4}$	$N(CS)/N(H_2) \approx 10^{-8}$	$N(CH_3CN)/N(H_2) \approx 10^{-10}$

NOTES on SCALES

SF sites 150-500 pc

0.1 pc @ 200 pc -> 1.7arcmin

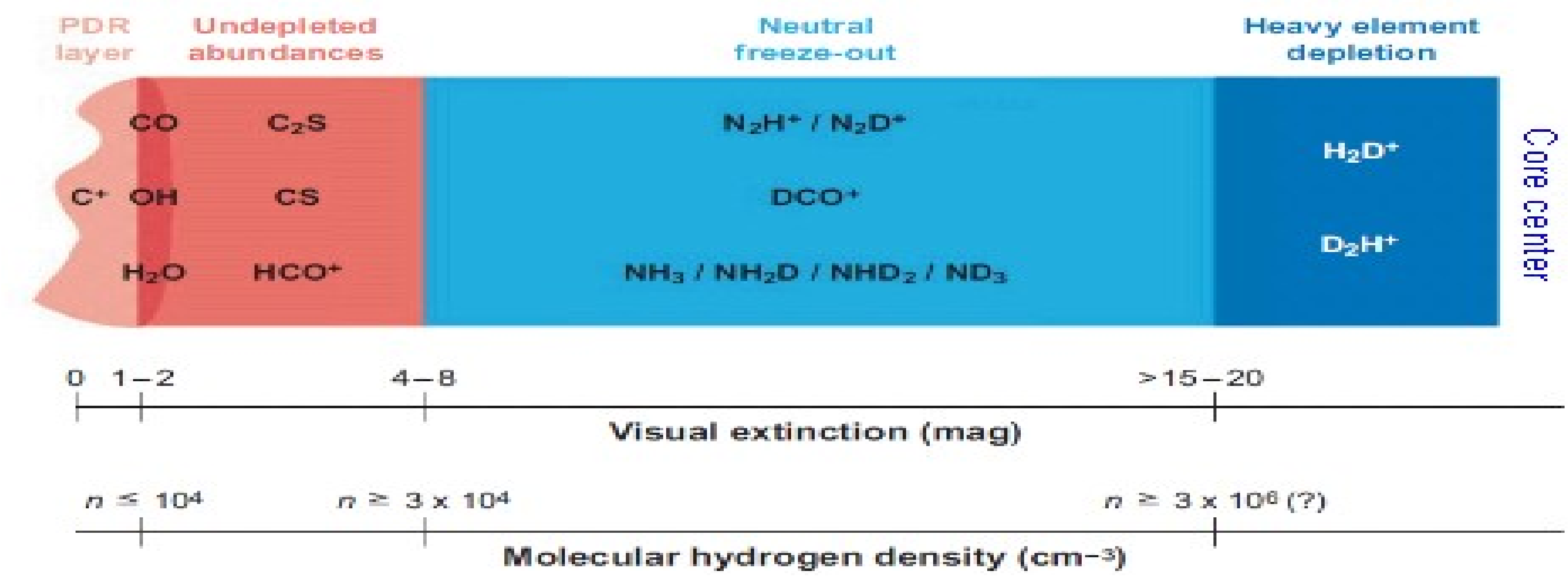
Larger than ALMA beams

Hot Cores

Hot molecular cores represent an early evolutionary stage in massive star formation prior to the formation of an ultracompact H II region (UCH II).

Single-dish line surveys toward hot cores have revealed high abundances of many molecular species and temperatures usually exceeding 100 K.

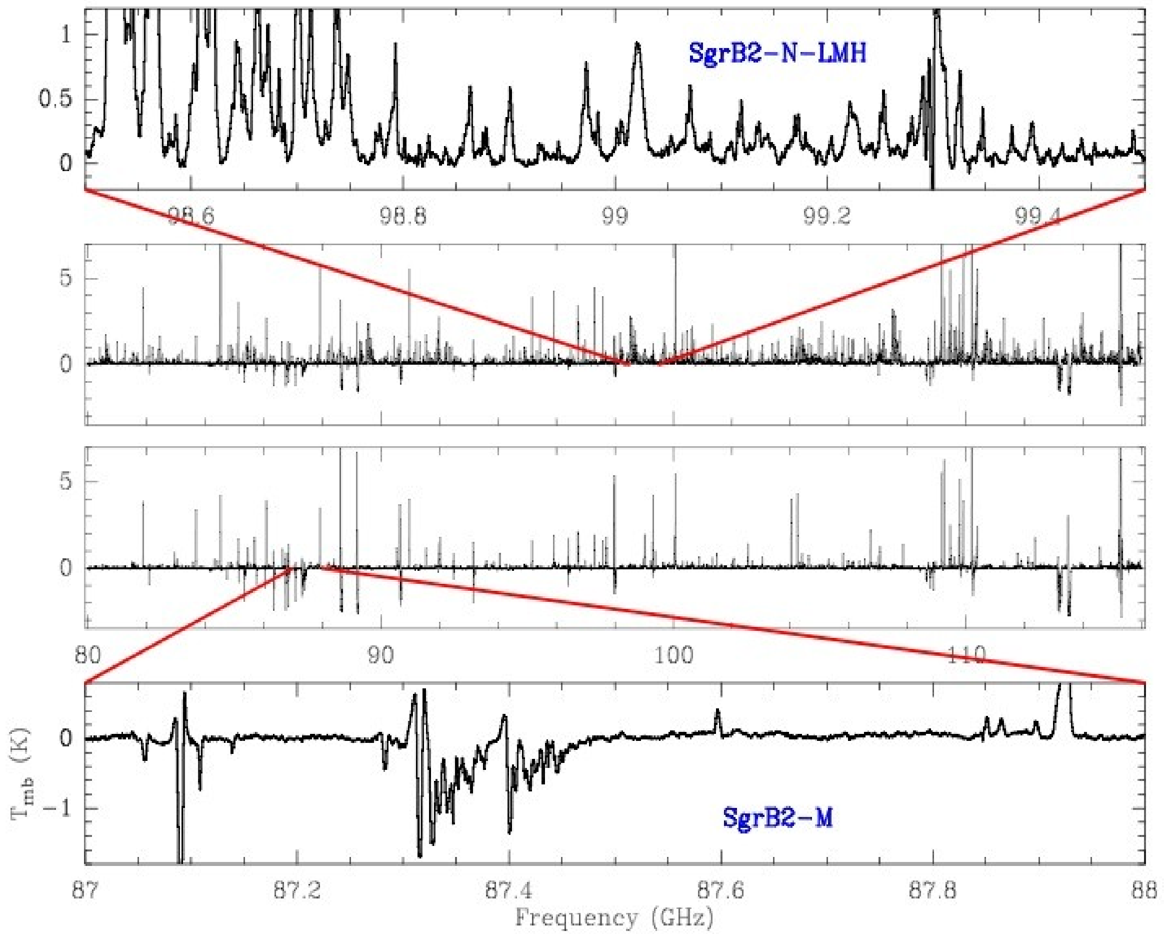
Hot Molecular Cores are usually associated with masers of H2O, CH3OH.



Different chemical species provide information on the different core layers.

Abundances and velocity patterns provide details on composition (including IMF, fragmentation, outflows …) on-going chemical processes.

Complex Molecules in the ISM of hot cores



More than 80 amino acids have been identified in meteorites found on Earth. They are the building blocks of proteins. This suggests that they or their direct precursors have an inter-stellar origin.

ISM chemistry might be capable of producing organic molecules more complex than those detected so far and thus of great importance to astrobiology.

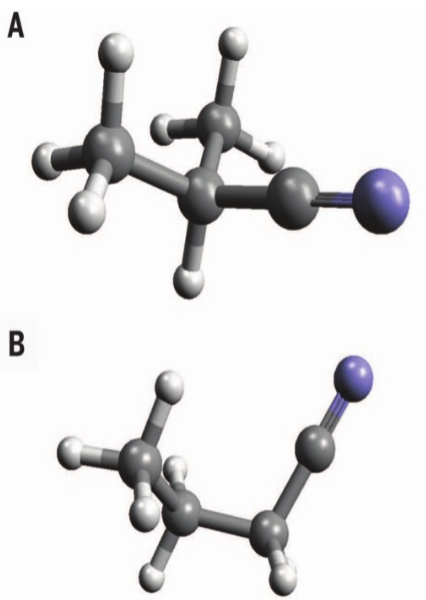
The degree of complexity that may be reached in the ISM is still an open question.

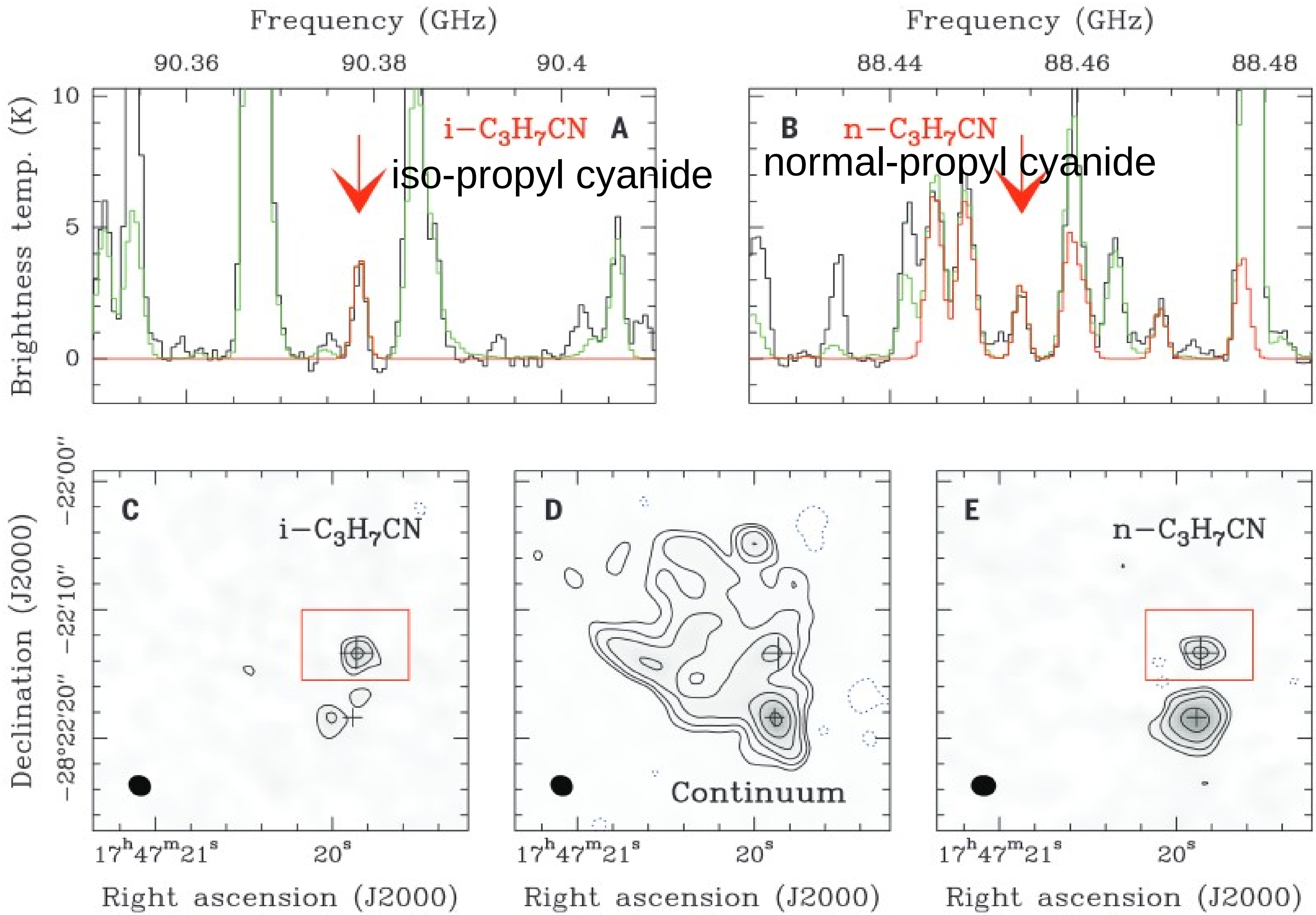
Belloche et al. (2007) IRAM-30m 80-116GHz scan SgrB2(N, M)
These are two hot, dense cores in the most massive star-forming region in our Galaxy close to the Galactic Center. Their immense hydrogen column densities that signify large quantities of gas enable the detection of low-abundance species

SgrB2(N): **ca. 100 features/GHz >3sigma** of emitted/absorbed by 51 molecular species.
40% of the features are yet unidentified (15% of which are at >=10sigma) 1 sigma (TA*) = 15-30mK
SgrB2(M): **25 features/GHz above 3sigma**,
Unidentified ca. 50% of the features (of which 7% are >=10sigma).
The number of features per GHz translates, for the whole 80-116GHz range, into 3700 and 950 lines.

Complex Molecules in the ISM of hot cores

- Cycle 1
- spectral scan
- Band 3 84-111GHz





The detection of a branched molecule, with abundance similar to its straight-chain isomer, shows that less-active regions produce only linear molecules.
This is similar to the molecular composition of meteorites for which branched aminoacids dominate over their straight-chain isomers.
Branched molecules may be prevalent in star-forming regions where chemistry of sufficient complexity is reached.

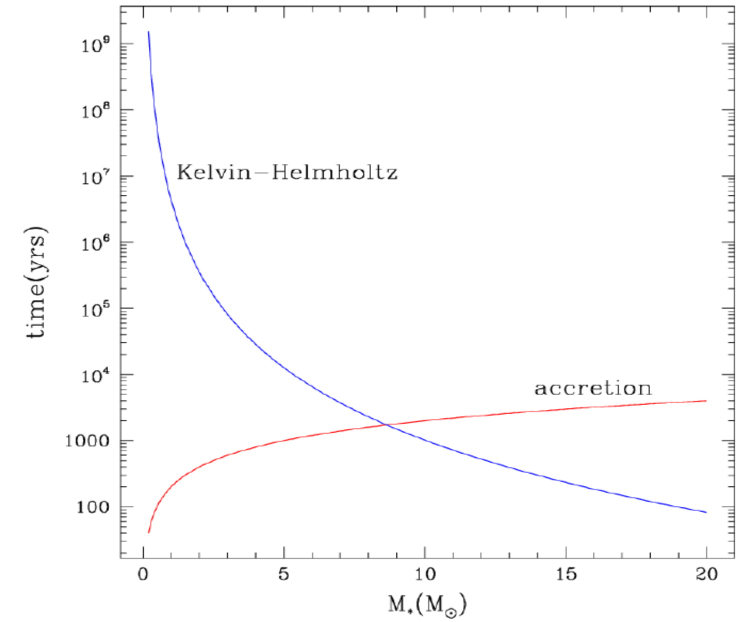
Belloche et al., Science, (2014)

Low mass star formation

Accretion on the protostar
Contraction of the protostar

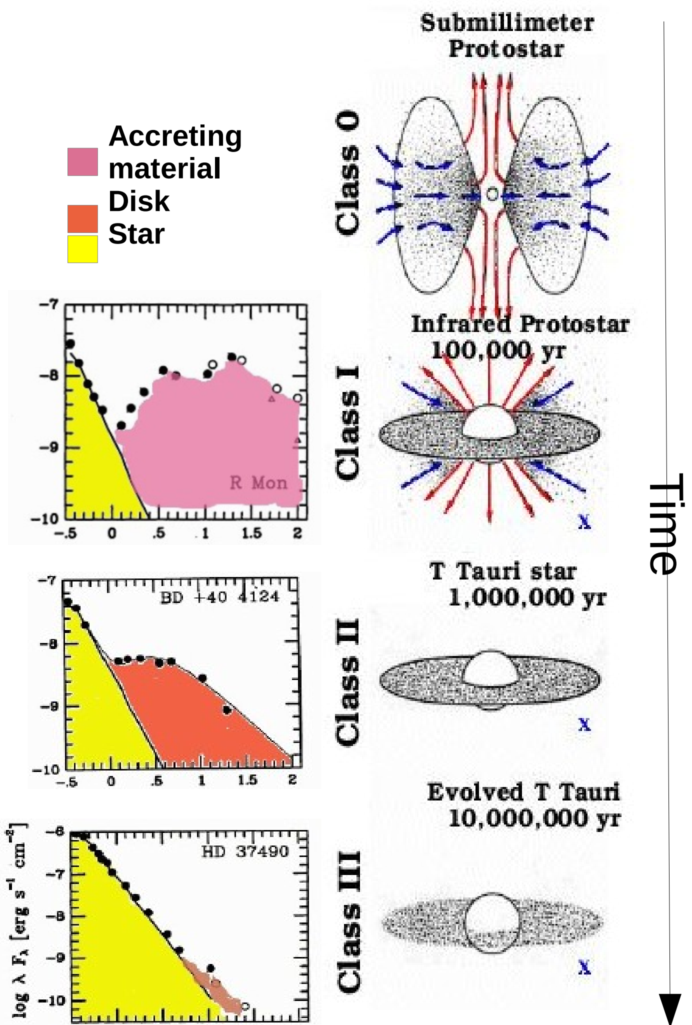
$t_{acc} = M_* / (dM_{acc}/dt)$

$t_{KH} = GM^2 / R_* L_*$



For $M_* < 8M_{sun}$ $t_{acc} < t_{KH}$

Embedded phase **Observables**



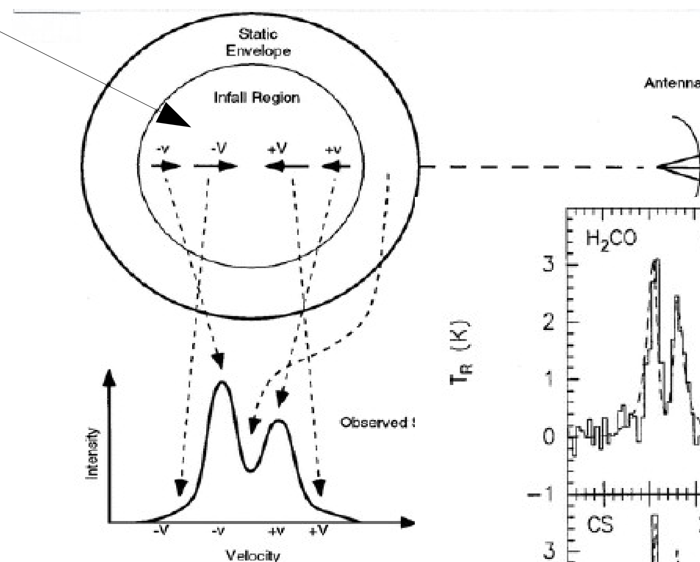
Revealed phase

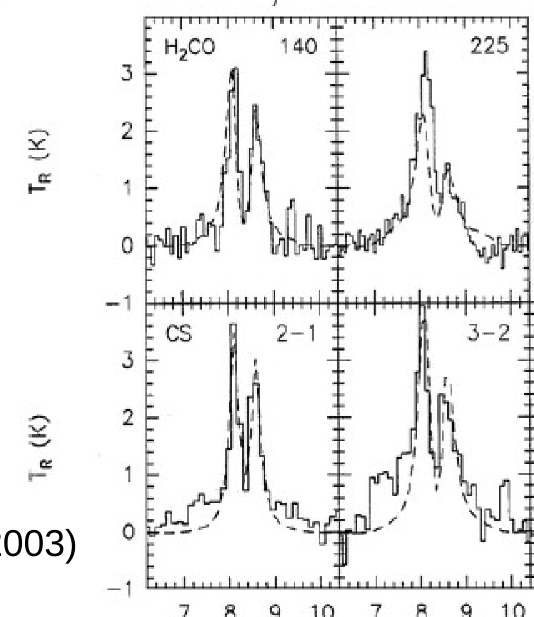
Dusty environment
Infall
Outflows

Disk
Outflows
Infall

Disk without accretion

Protoplanetary disk





(Zhou et al. 2003)

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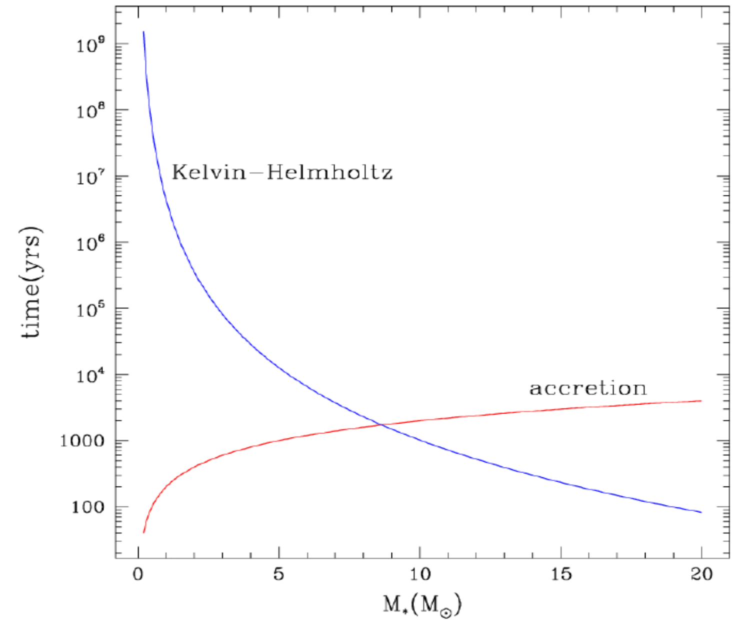

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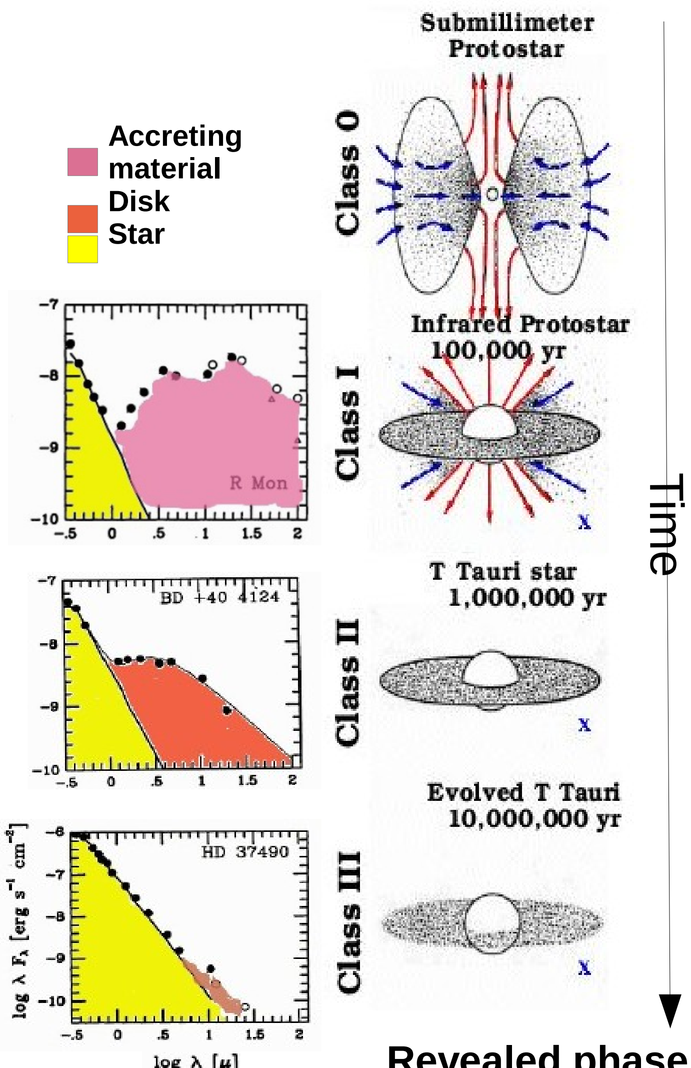

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Protoplanetary disk

Revealed phase

NOTES on SCALES

Jeans scale 10000 AU
Planet formation 1-10 AU
Outflows < 10AU
Protostellar disk = 100 AU
PDR (HII regions) 1000 AU
Nearest Ttauri star 50 pc
Lowmass SF sites 150 pc
High mass SF sites 500 pc

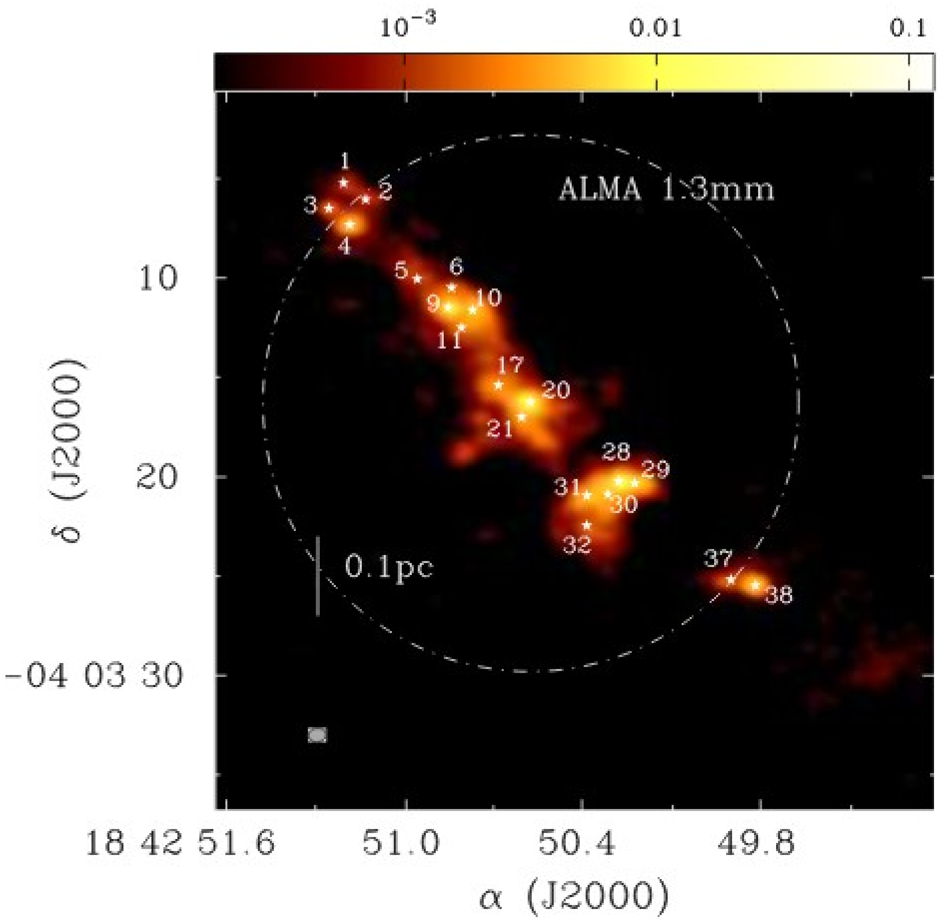
10 AU @ 100 pc -> 0.1arcsec

ALMA reaches 20-100 mas @ 200kpc (LMC) -> Jeans scale

Fragmentation in star-forming filaments

OBSERVATIONS

- Cycle 0 – 29 antennas
- Band 6
- **Angular resolution ~ 0.8''**



G28.34-0.06 is an IR dark cloud arbouring the early stages of massive star and cluster Formation at 4.8kpc.

The earliest stages of star formation should be bound prestellar cores which can be Measured via thermal dust emission.
High angular resolution can measure the dust fragments down to subsolar masses.

In G28.34 ALMA observations found only few solar mass fragments, while the ALMA sensitivity could reach tenth of solar masses. Hence, lower mass stars form at a later stage After the more massive protostars have Already been formed.

Zhang et al. 2015

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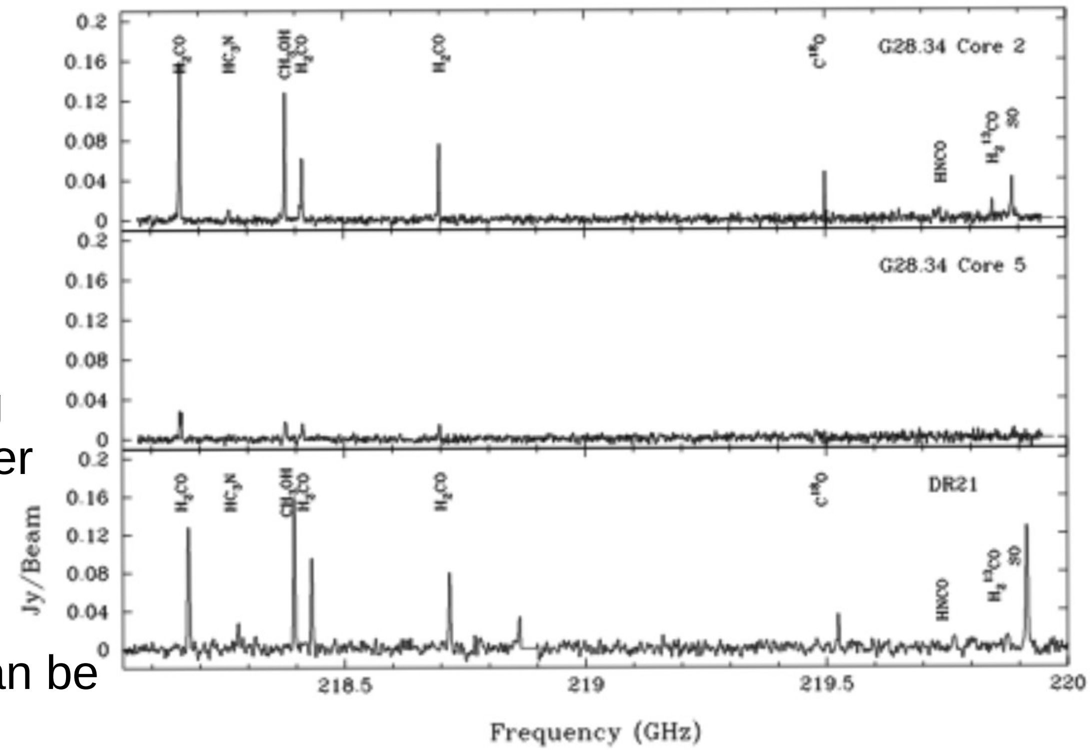

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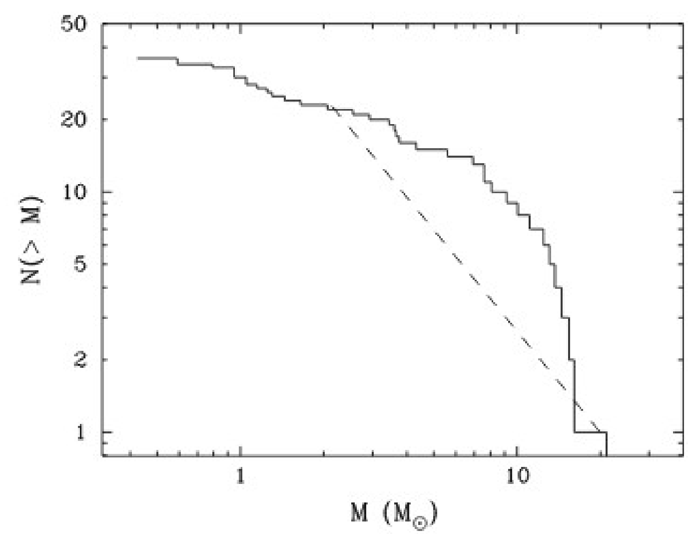
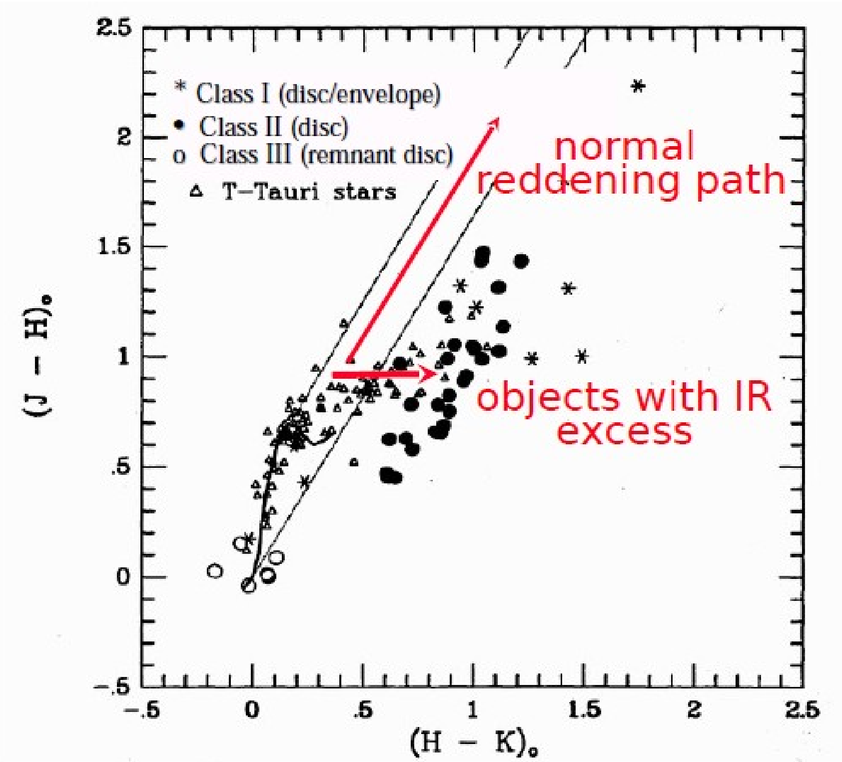
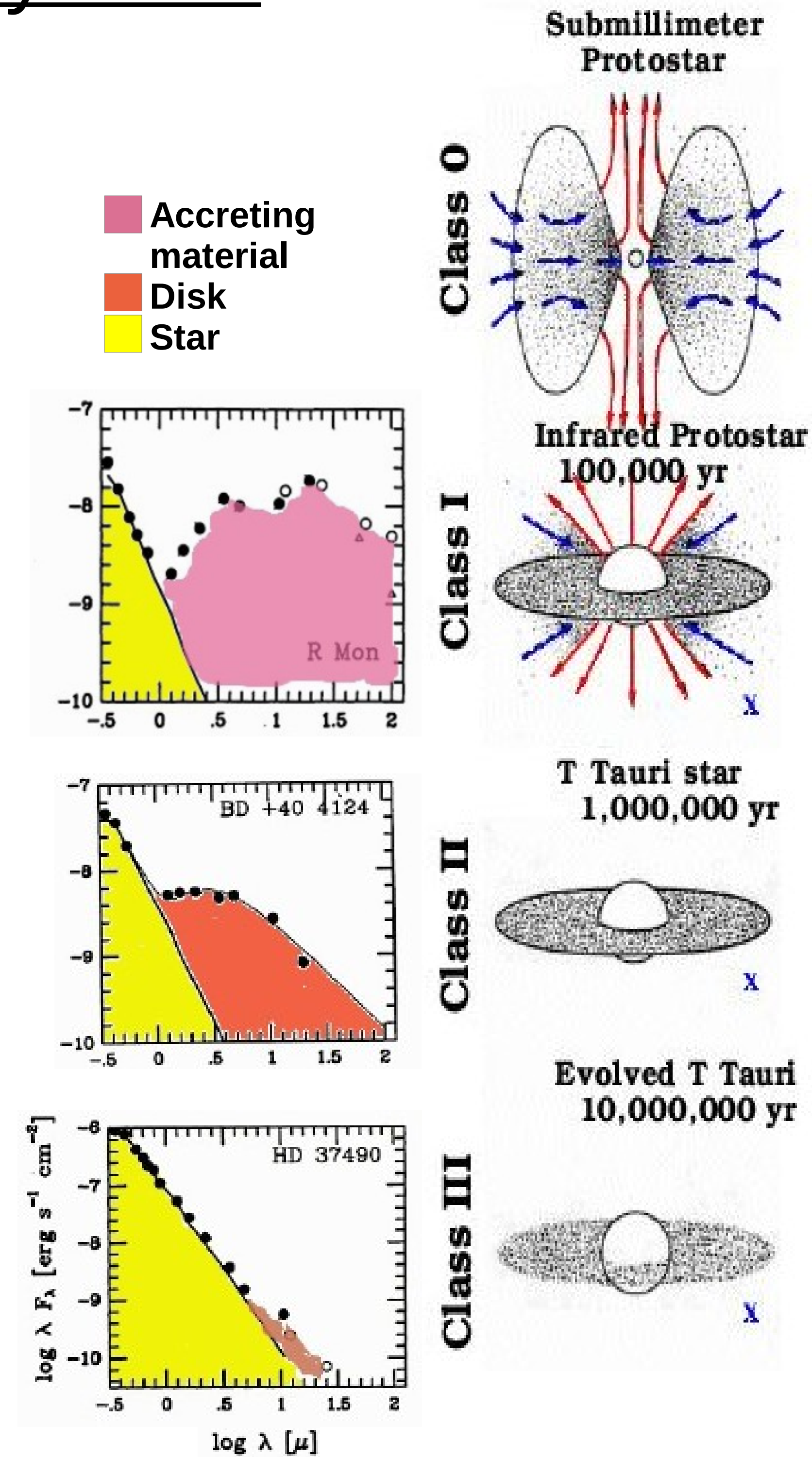


Zhang et al. 2015

Protoplanetary disks





Presence of discs in stars were identified by IR excess and SEDs. Different star-disc classes show different SEDs. In sub(mm) optically thin envelopes of protostars are observable

Ttauri: young star <10-20Myr 0.5<M<2Msun (class 2)

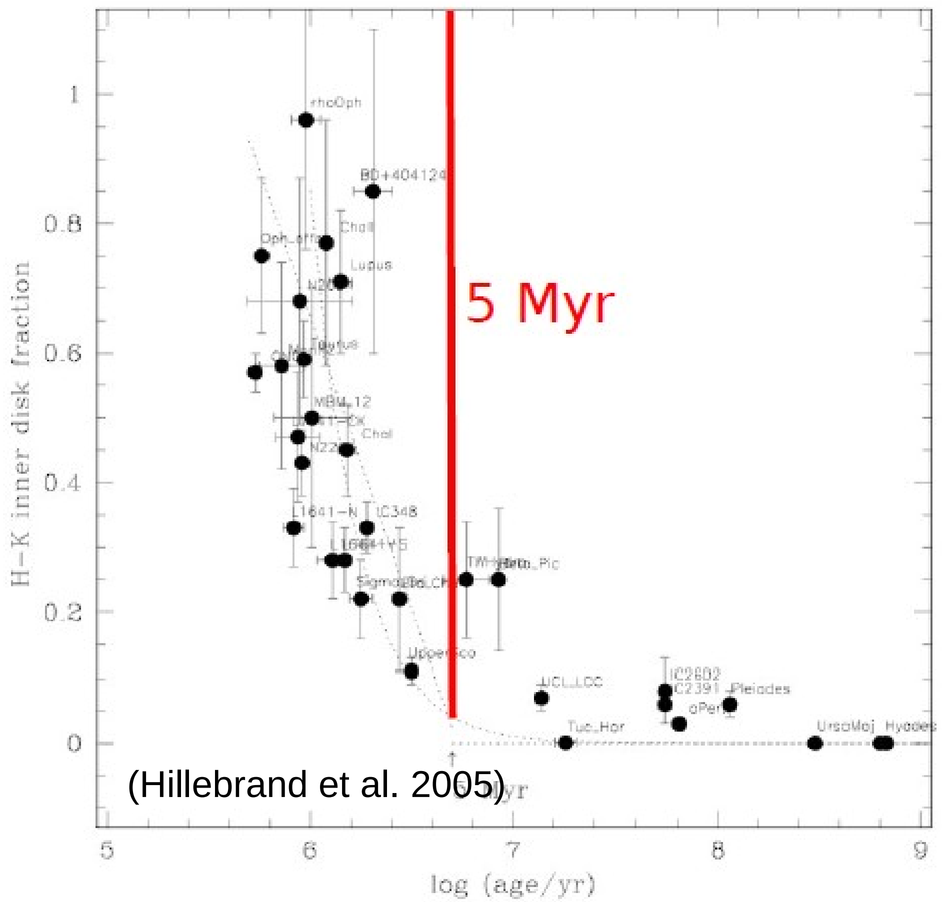
Herbig Ae/Be: <10Myr 2<M<8 MSun (class 3)

Protoplanetary disks

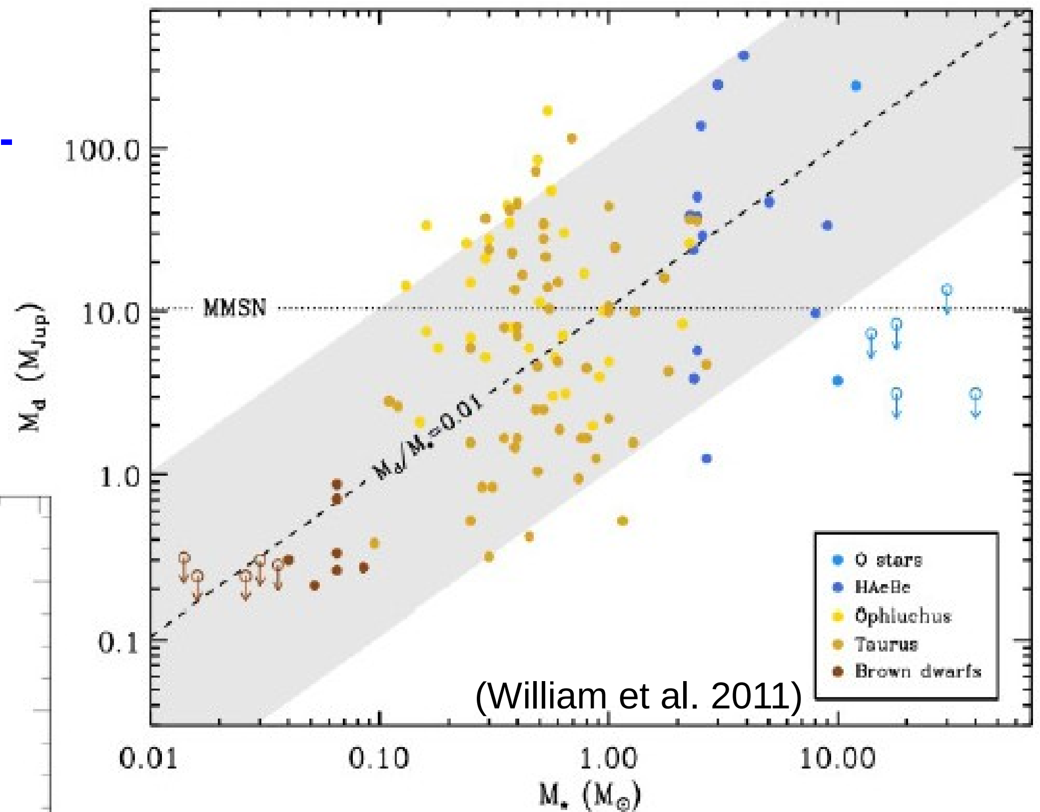
Since discs are optically thin in mm regime, fluxes traces the mass of the disc.

Massive star loose disc more rapidly than low-mass star of same age.
For star masses 0.04<M<10Msun the disk is typically 1% of the star mass.

For O-type star no disk were detected (before ALMA) in submm indicating very short disk life or a different formation scenario.



(Hillebrand et al. 2005)



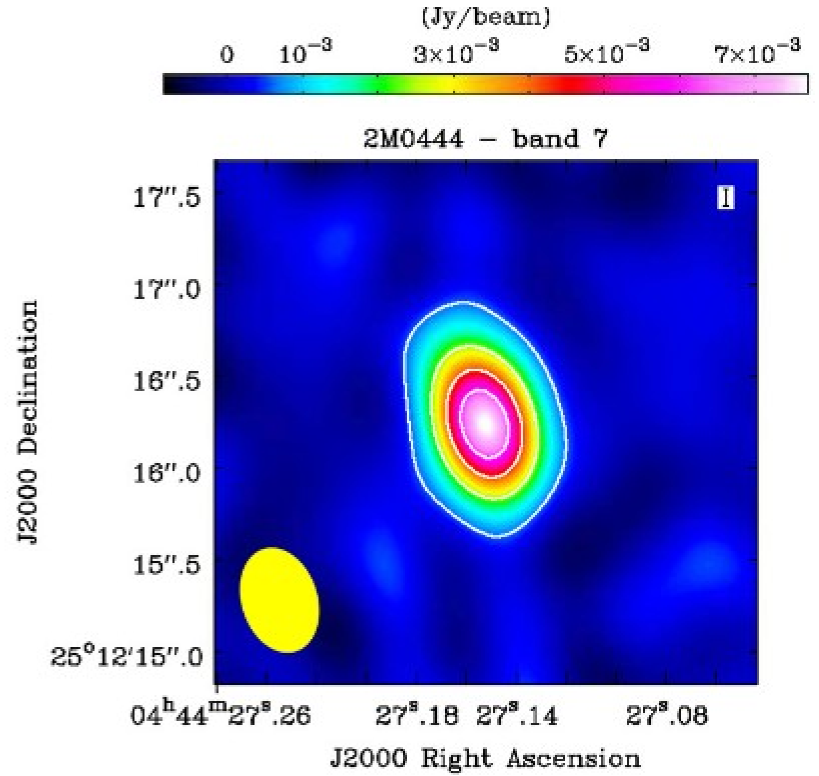
(William et al. 2011)

High mass stars harbour high mass disk (i.e. can form more massive planets)

After 5Myr no disk remain except around low-mass Ttauri stars.
Discs are depleted by UV radiation (stronger in more massive stars), by the presence of a star companion (about 30% of Ttauri are in binary systems), and by grain/planet growth and inner tidal forces.

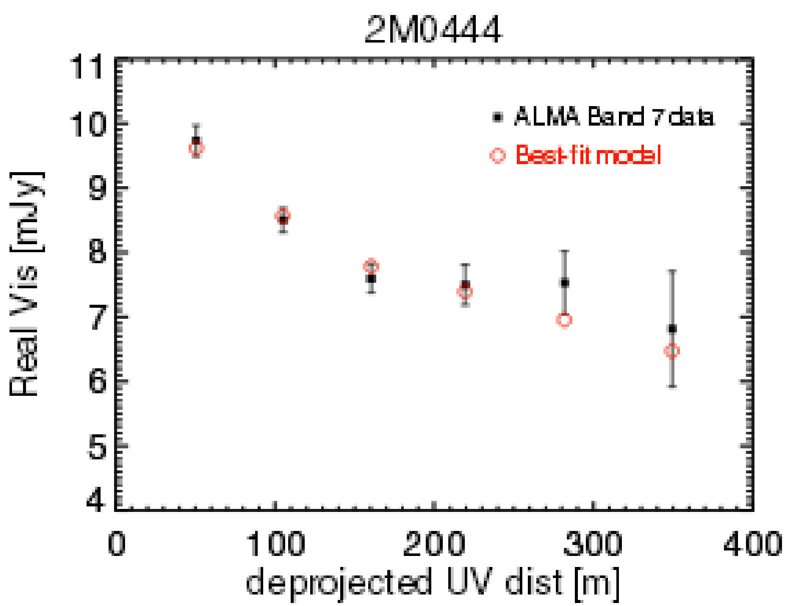
Disks around brown dwarfs

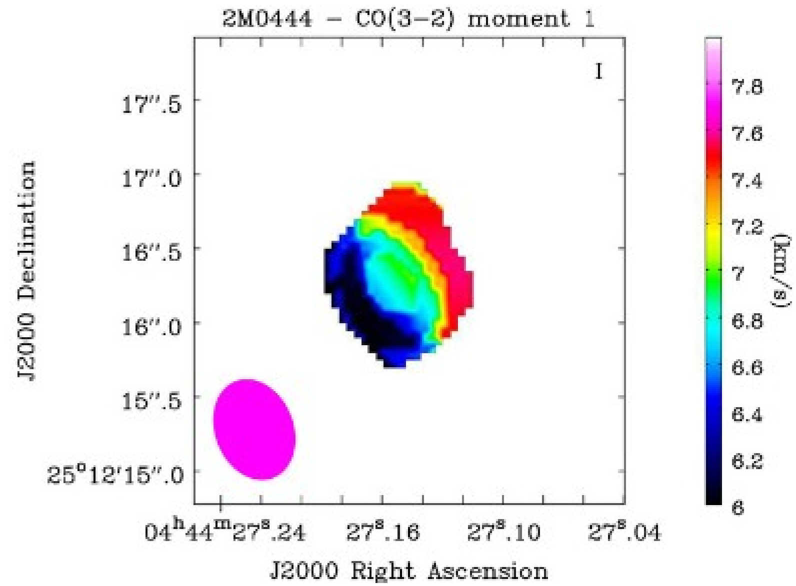
- Cycle 0 – 29 antennas
- Band 6
- **Angular resolution ~ 0.8''**



Brown dwarfs are substellar objects with max
 masses 80Mjup. Their disks contain mm grains
So they can form rocky and gaseous planets

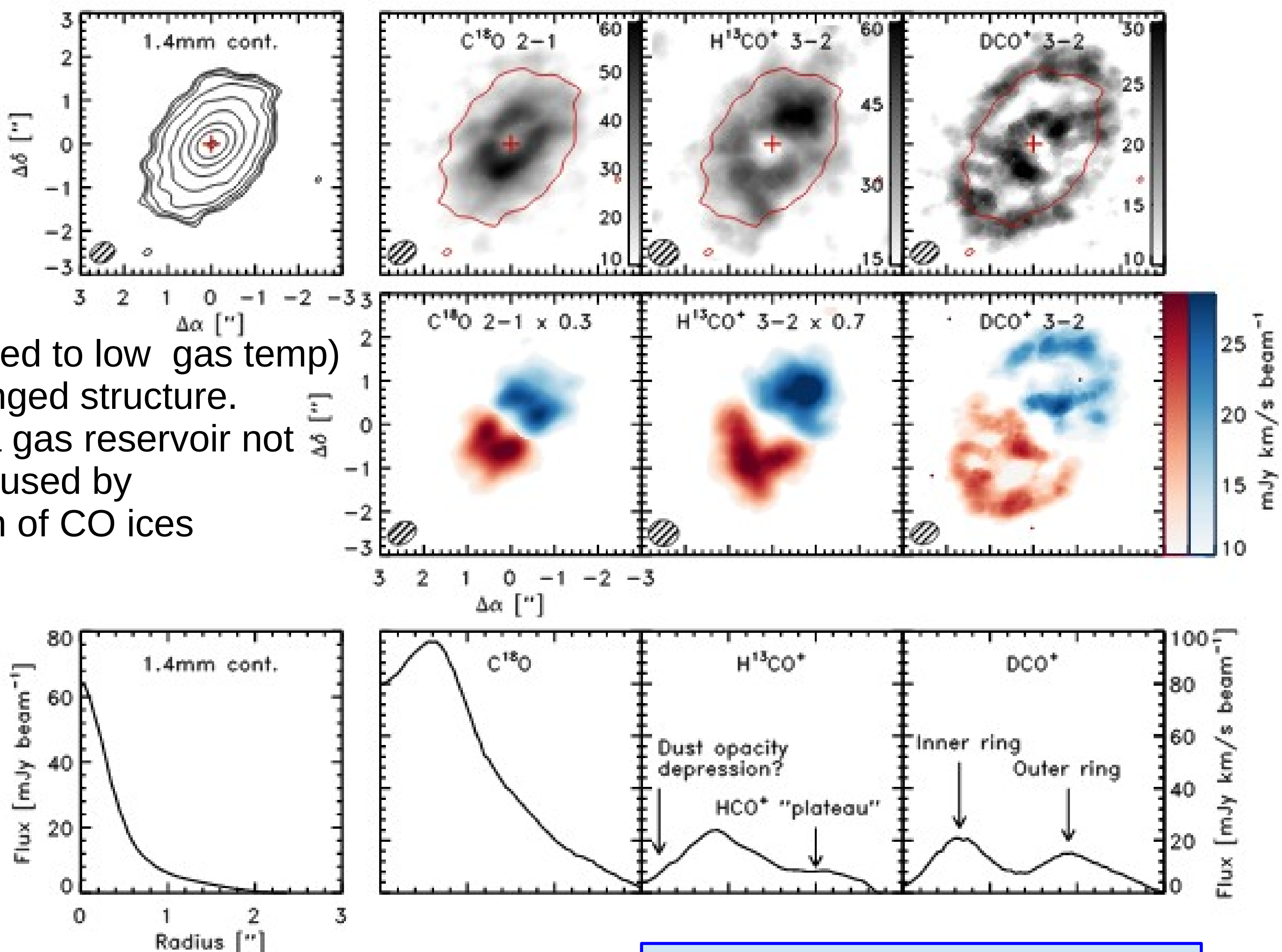
ALMA high angular resolution and sensitivity
Revealed disks in many types of stars





Ricci et al. 2014

Chemistry and kinematics in IM Lup, a T-Tauri disk



DCO+ (associated to low gas temp)
Has a double ringed structure.
DCO+ reveals a gas reservoir not
Visible in CO caused by
Photodesorption of CO ices

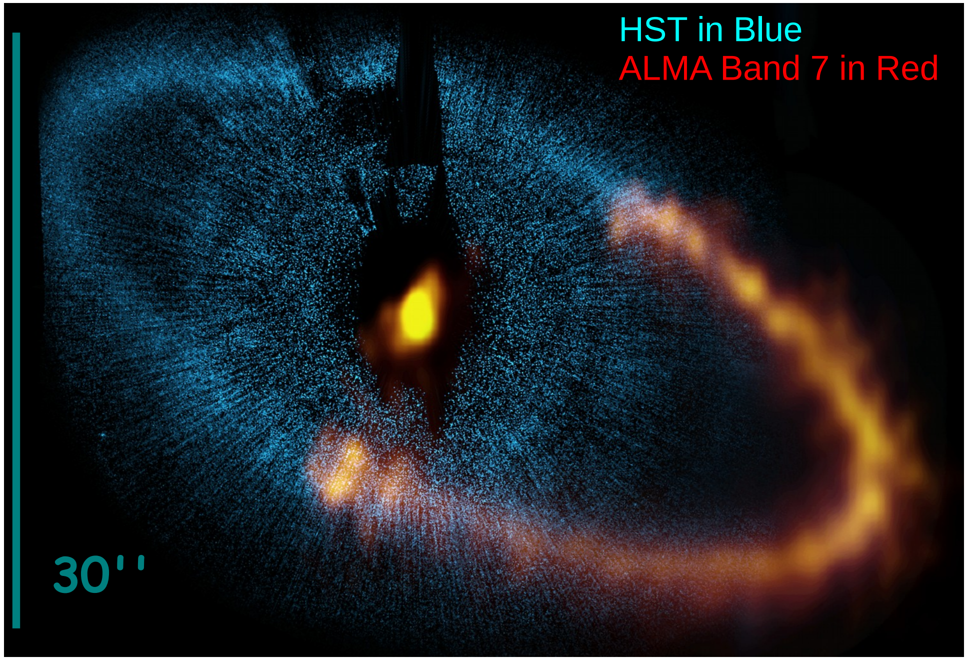
- Cycle 1 – 32 antennas
- Band 6
- **Angular resolution ~ 0.6''**

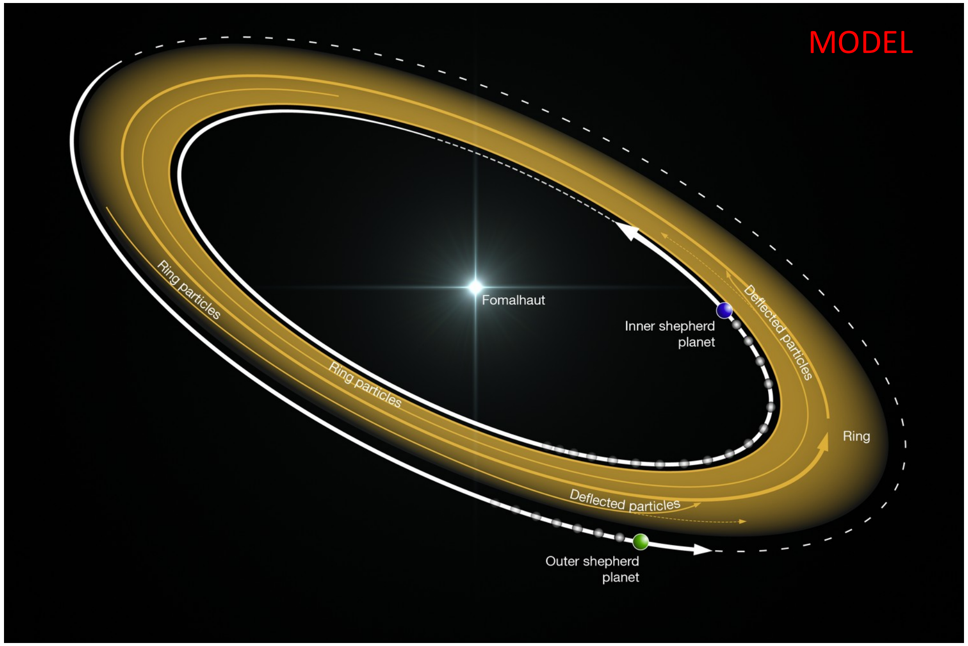
Oeberg et al. 2015

Constraint the planetary system: Fomalhaut

PI: S. Boley

The dynamical evolution of planetary systems leaves observable signatures in debris disks





OBSERVATIONS

- Band 7 – continuum
- 140 min on source
- rms~0.06 mJy/beam
- **Angular resolution ~1.5''**

A3V star with a debris ring at 7.69 pc

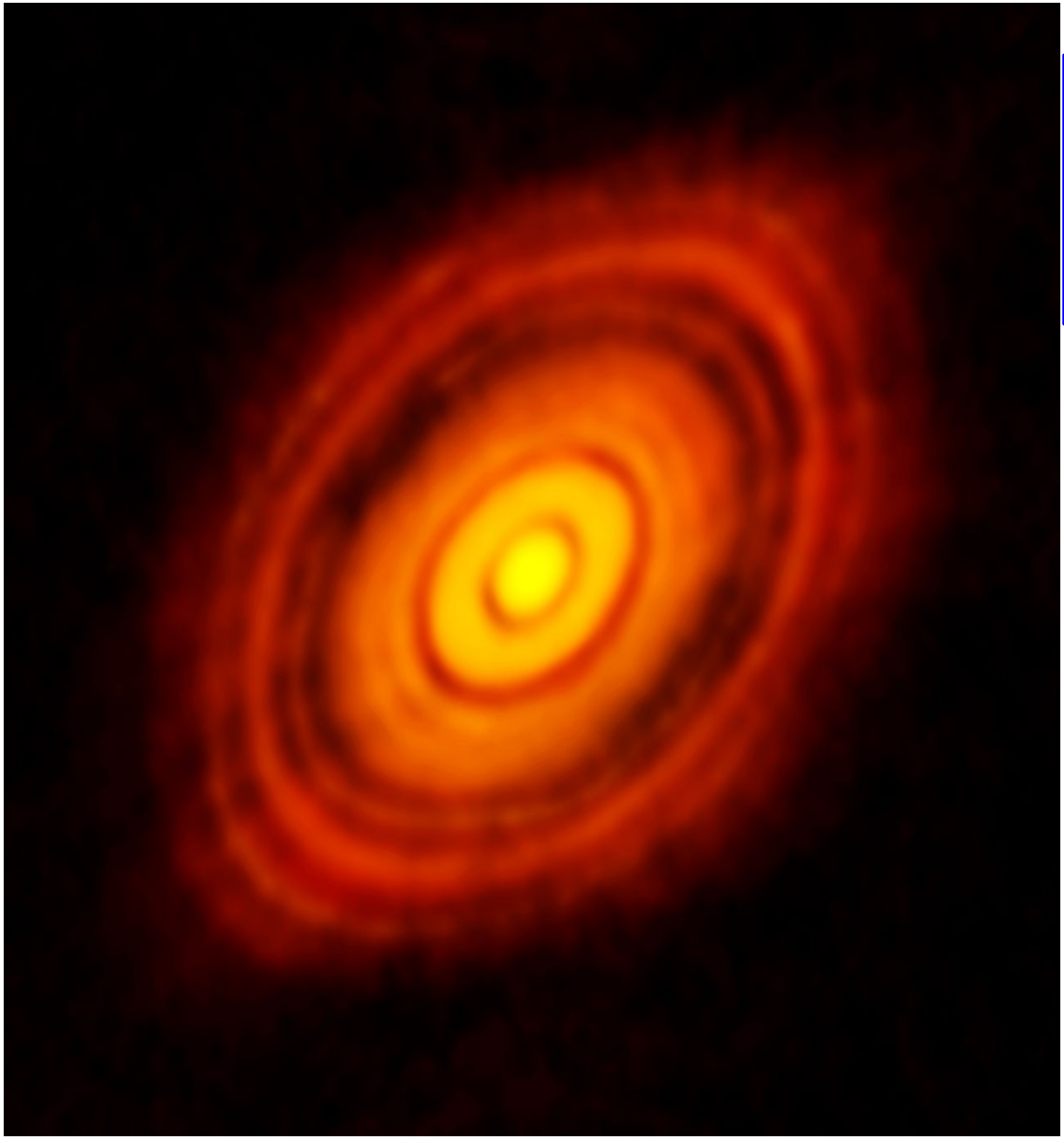
ALMA traces **large grains (1mm), not moved by star radiation**: disk's sharp edges and ring-like structure

Models: **2 planets** in the sharp inner (13AU) and outer (19 AU) boundary

Properties of the profiles allow to estimate masses <3M_Earth

Boley et al 2012

HLTau: ALMA long baseline campaign



OBSERVATIONS

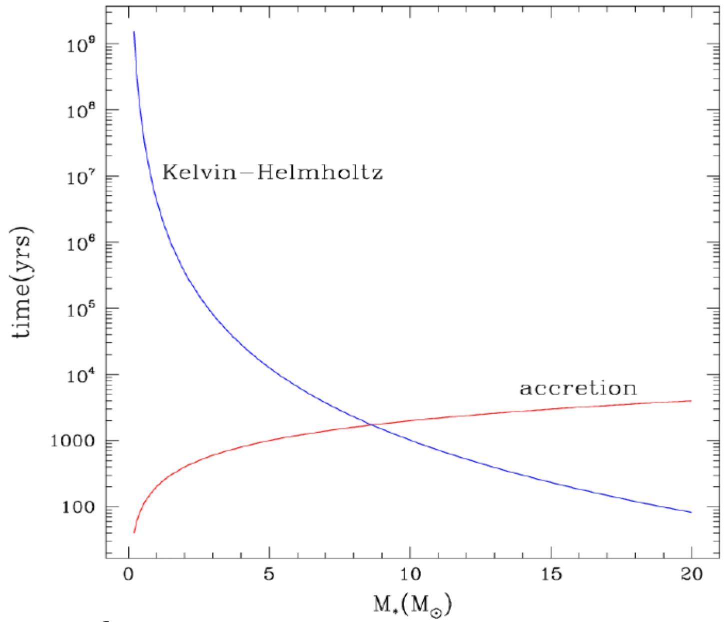
- Long Baseline Campaign SV
- Band 3, 6,7 – continuum
- **Angular resolution ~ 85 x 61 mas, 35 x 22 mas, and 30 x 19 mas**

HL Tauri — a young Ttauri star, about 450 light-years away, which is surrounded by a dusty disc – shows structure indicating that planets are already forming.

High mass star formation

Accretion on the protostar $t_{acc} = M_* / (dM_{acc}/dt)$
Contraction of the protostar $t_{KH} = GM^2/R_* L_*$

For $M_* < 8M_{sun}$ $t_{acc} < t_{KH}$
For $M_* > 8M_{sun}$ $t_{acc} > t_{KH}$
Hence massive stars enter MS while still accreting.



However they are crucial for ISM enrichment
(via winds and supernovae explosions)
and UV radiation.

High-mass stars are **rare**
- For each 1000 stars of 1 Msun, only a single 10 Msun star forms
- The nearest star with M > 10 Msun is at d ~ 400 pc

High-mass stars **evolve fast**
- The most massive stars go supernova in 3 Myr
- Fast evolution means there are only very few objects in each phase!

=> Observing each stage of evolution is difficult (resolution, distance, time...)

High-mass stars are frequently **obscured** or in dense clusters
- Need high-resolution observations to disentangle dense cluster cores
- Need deep infrared observations to penetrate the dust

High mass star formation

Proposed models:

- **Monolithic collapse (non-spherical collapse through disks)**
  * A protostellar core forms by core collapse
  * Accretion occurs through a disc
  * A massive outflow develops very early during the accretion phase

  Evidences:
  - **presence of disk and outflows**
  - **possible isolated star formation** (no need of dense clusters)
  - formation at cluster center together with the other cluster members

- **Competitive accretion (many low-mass star merge to form one massive)**
  * Densest area of the cloud: gravitational collapse leads to a protocluster
  * Fragments/protostars/cores in the center have
    - higher accretion rates
    - more material available to accrete from

  Evidences:
  - **unlikely presence of disk and outflows**
  - possible stellar collision
  - **unlikely isolated star formation**
  - formation at cluster center after the other cluster members

- **Stellar mergers scenario (massive stars are formed in the collision of lower-mass sources).**
  * Stellar mergers are rare, and mostly in the densest regions of tightly-packed clusters

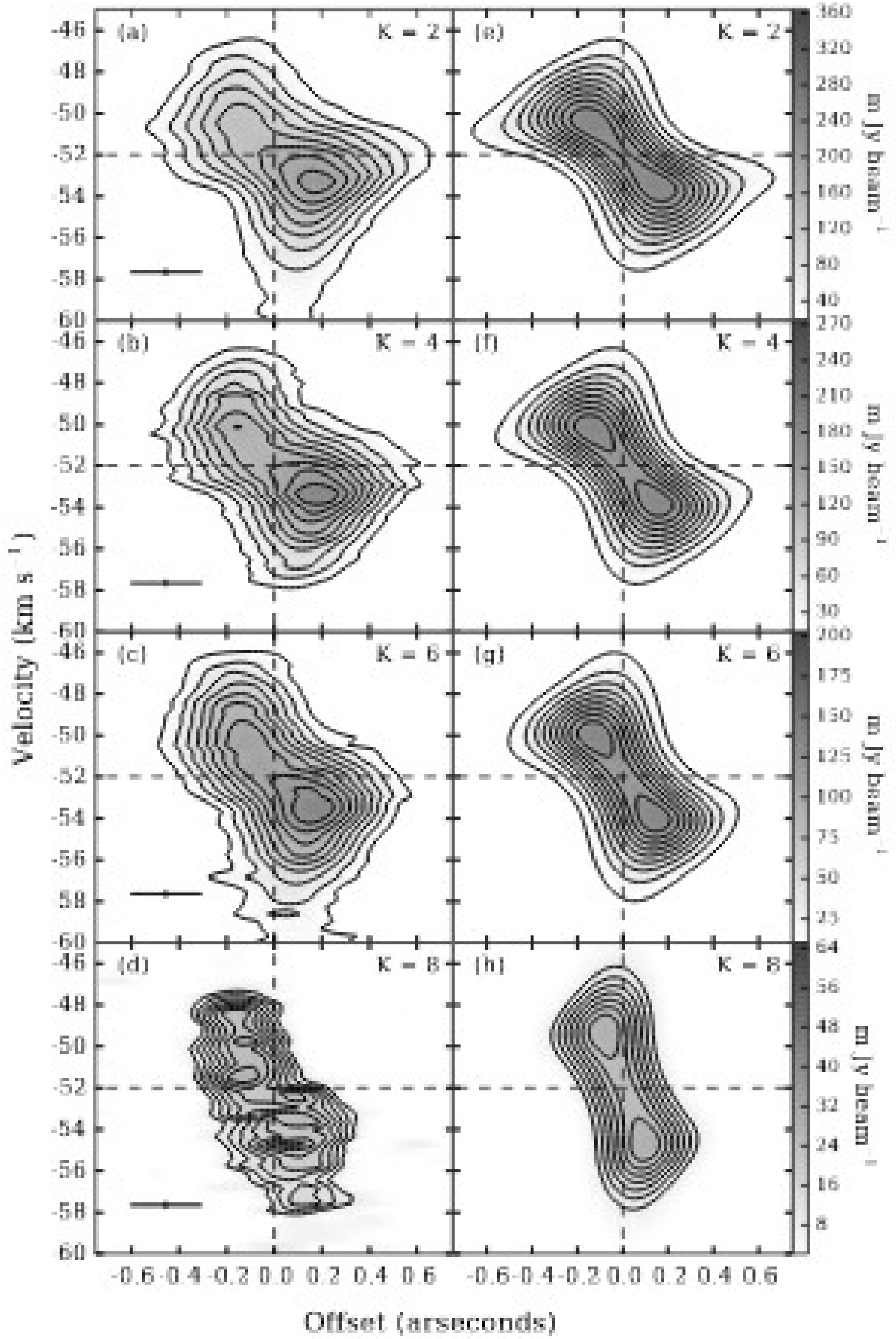
  Evidences:
  - **unlikely presence of disk and outflows**
  - stellar collision
  - **unlikely isolated star formation**

Disk around high-mass stars

- Cycle 1 – 29 antennas
- Band 6
- **Angular resolution ~ 0.3''**

Keplerian disk around a O type galaxy
Observed both in coninuum and in methanol

The position velocity diagrams of the
Various K levels are in very good agreement
With a Keplerian disk model
Higher K levels have higher excitation
temperatures, thus trace hotter gas,
Nearer to the central star, which in
Concordance with kepler laws have
Higher velocities

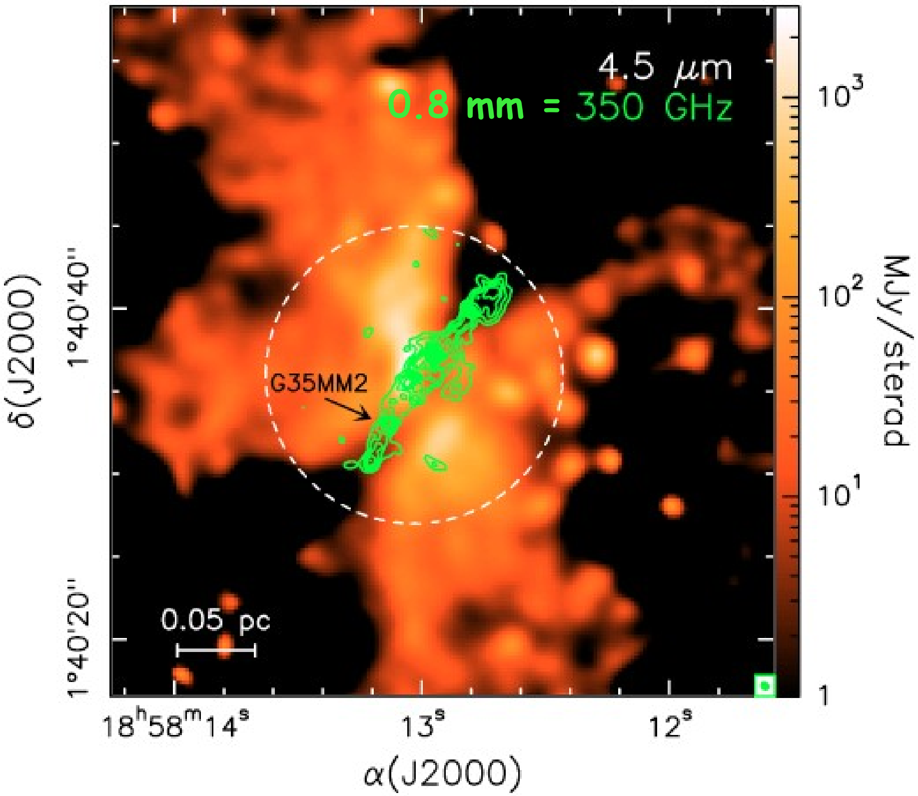


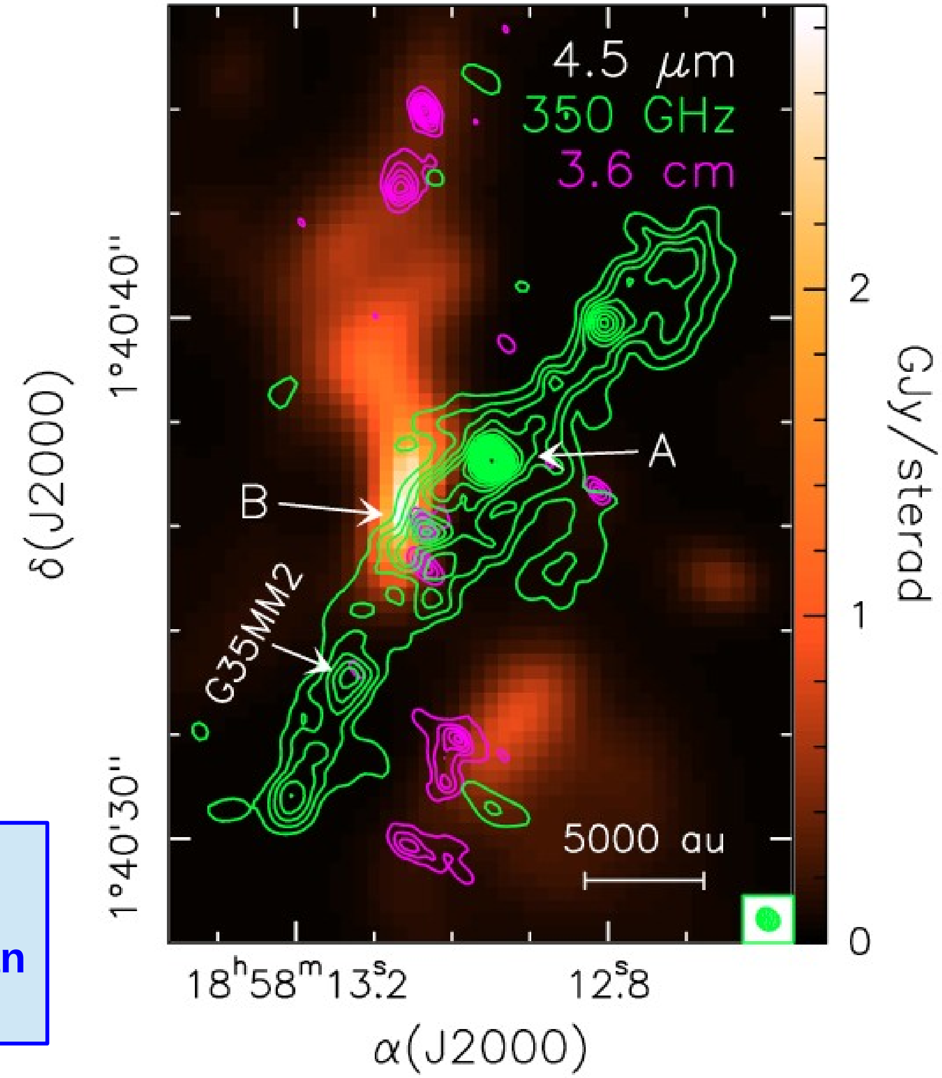
Johnston et al. 2015

A candidate circumbinary Keplerian disk in G35.20-0.74 N

A detailed investigation of the disk properties around high-mass star (OB-type) was missing to limited previous angular resolution in (sub)mm

PI: R. Cesaroni





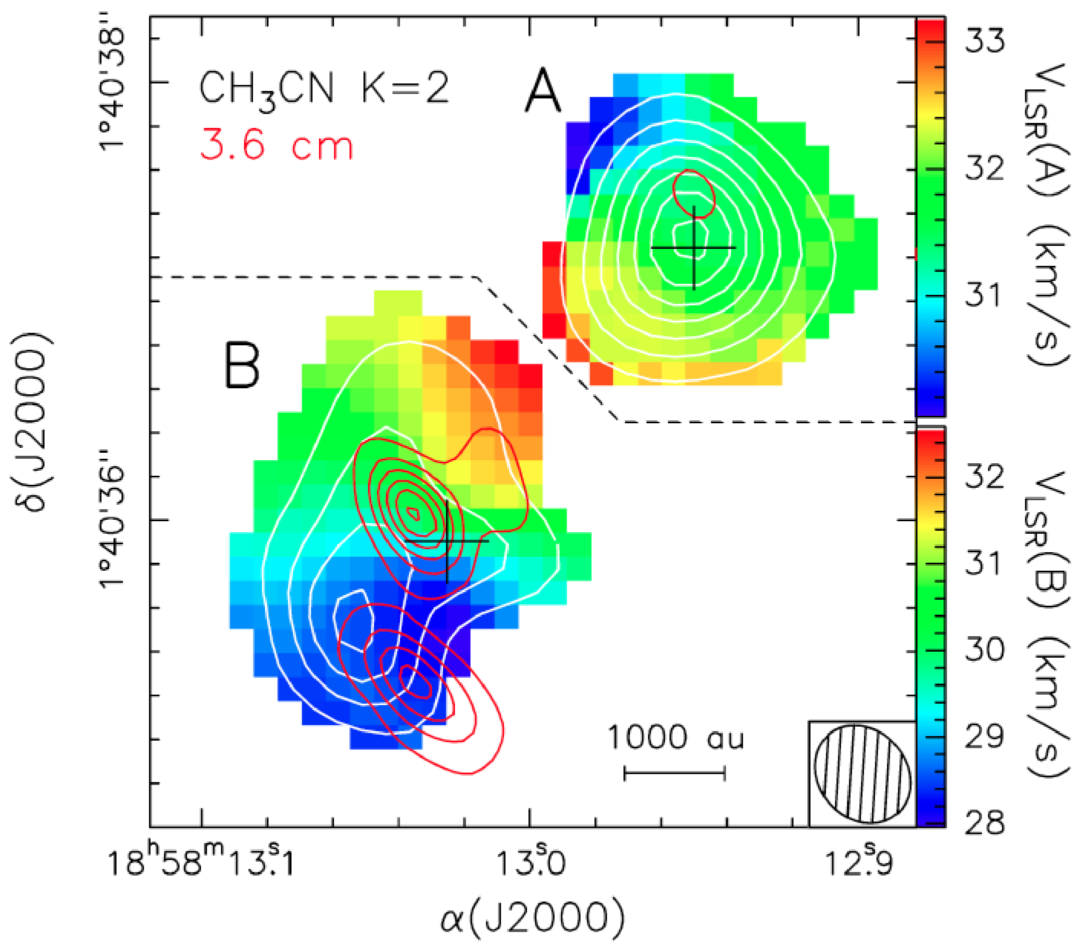
- Band 7 (350 GHz): continuum + CH_3CN
- **Angular resolution ~0.4'', 7 times better than previous mm observations**

Star forming region at 2.19 kpc. YSOs are powering outflows in A and B cores

Sanchez-Monge et al 2013

A candidate circumbinary Keplerian disk in G35.20-0.74 N

PI: R. Cesaroni



The 2 dense cores are detected also in CH_3CN (hot-core tracer) with velocity gradient

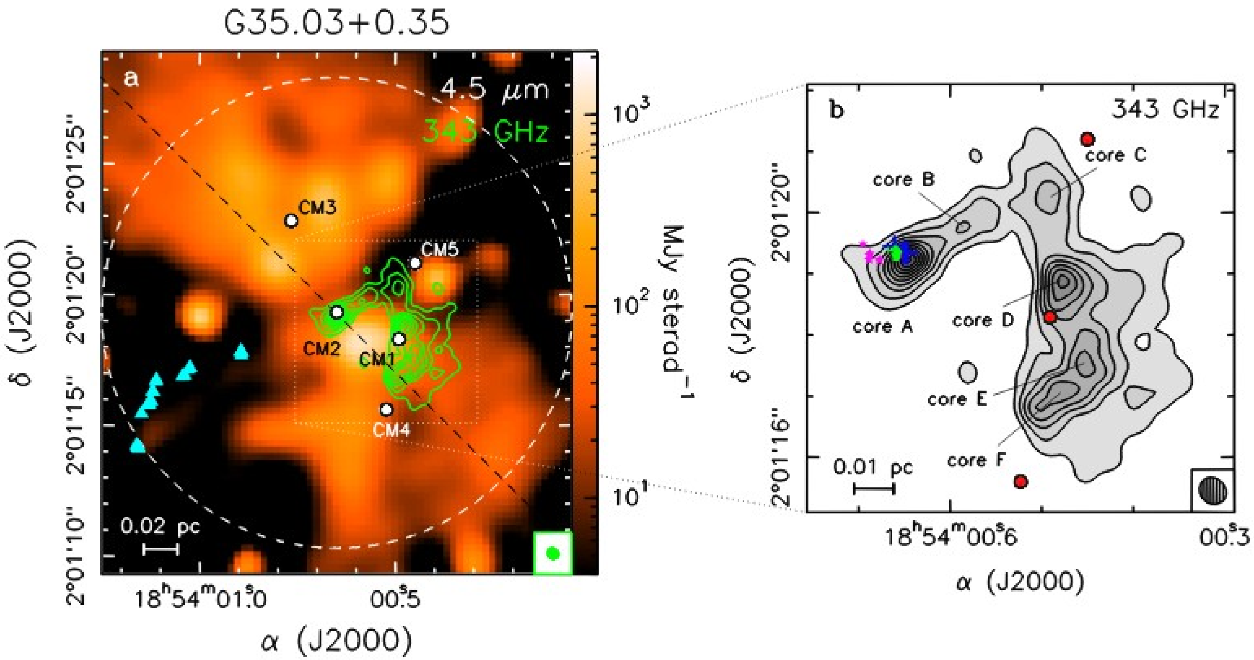
Core B: edge-on Keplerian disk rotating about a central mass of ~18 $M_\odot$

Disk radius ≥2500 AU, disk mass ~3 $M_\odot$

Evidence of binary system of stars comparing bolometric luminosity and estimated stellar mass

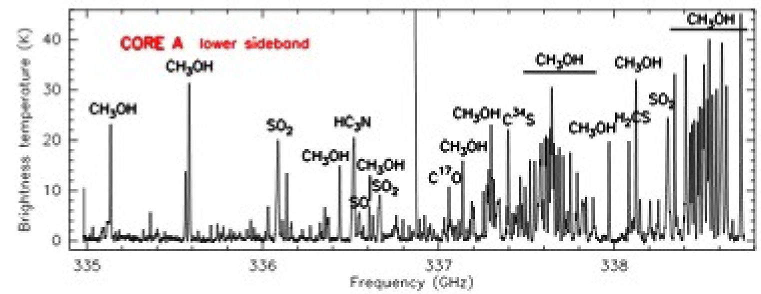
Sanchez-Monge et al 2013

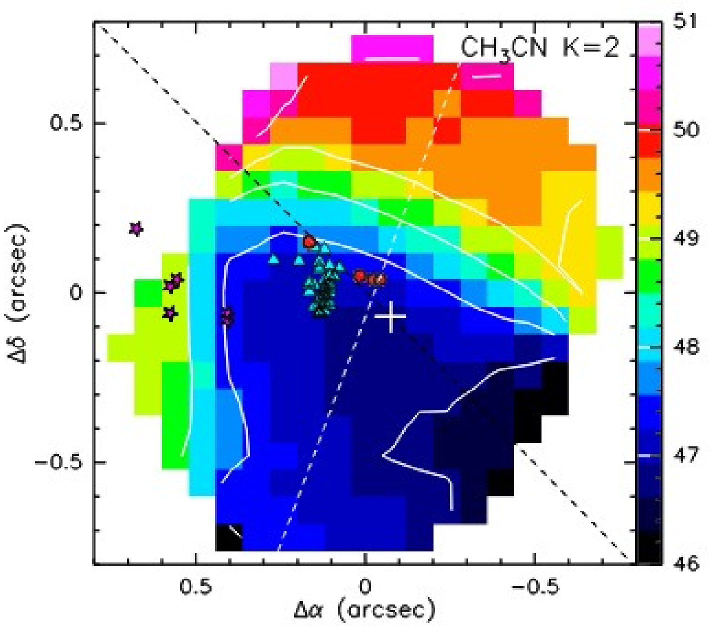
Disk around high-mass stars

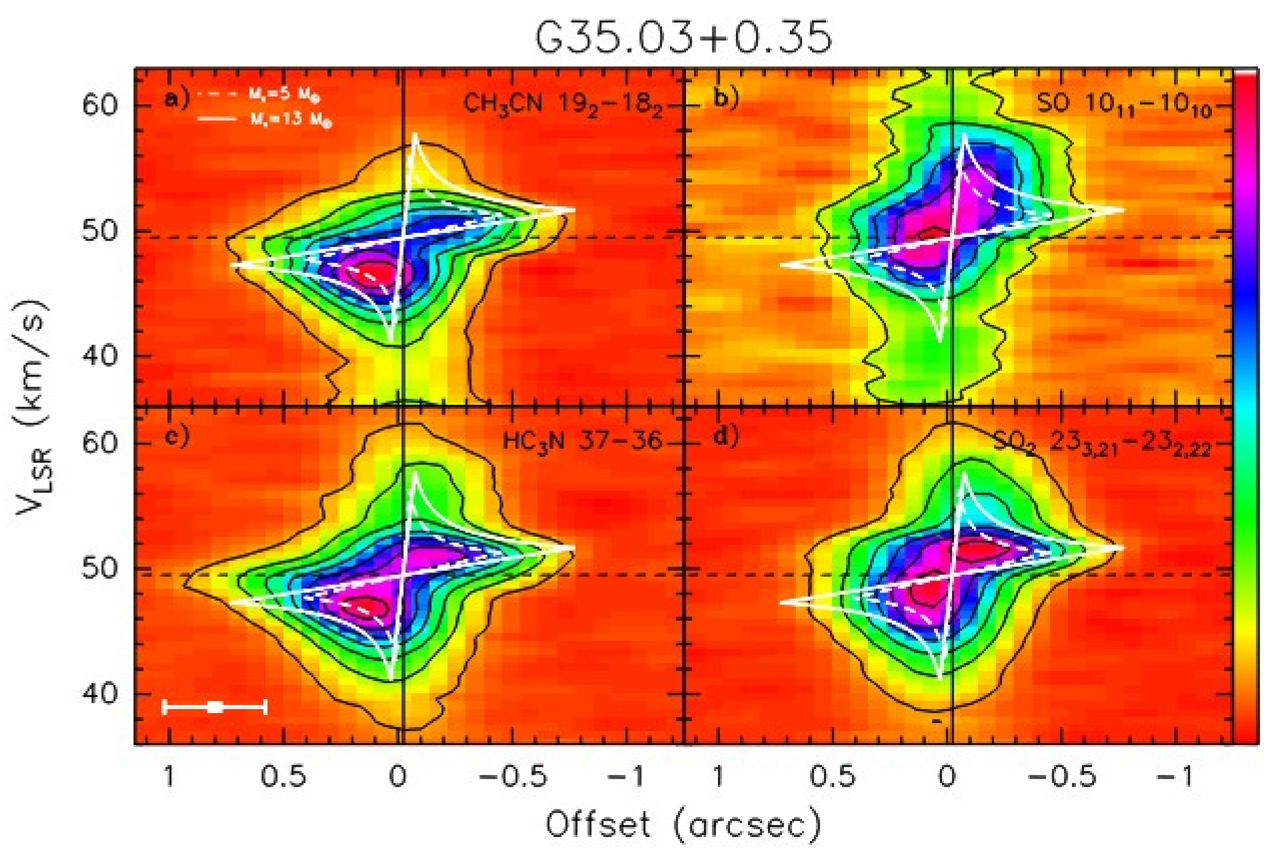


G35.03+0.35 harbors a disk candidate around a B-type protostar

Identified fragmentation in 6 cores of 1-5Msun



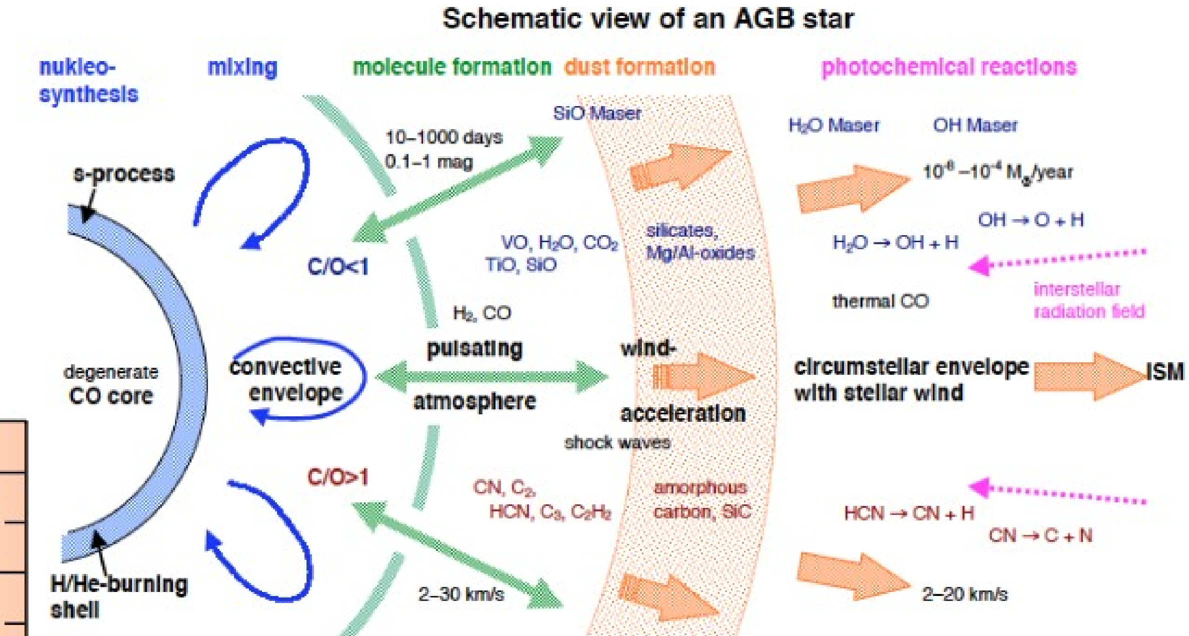


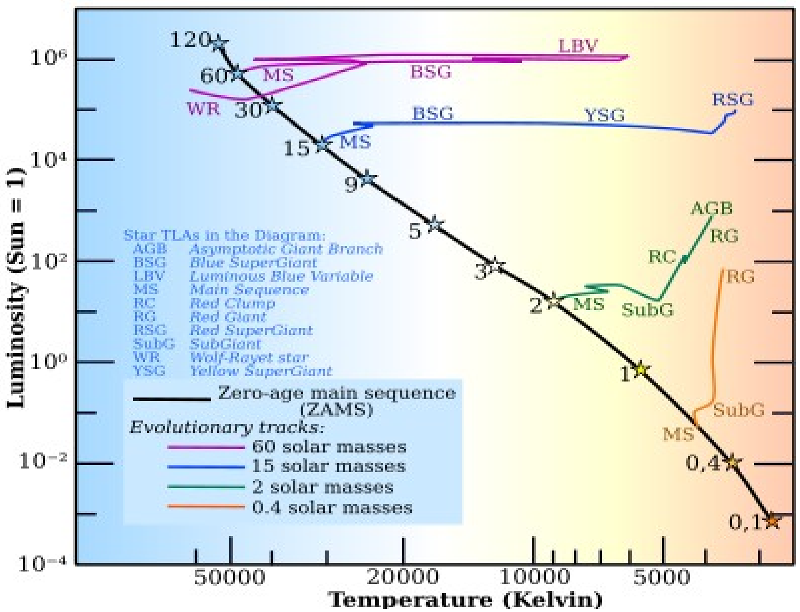


Beltran et al. 2014

AGB stars

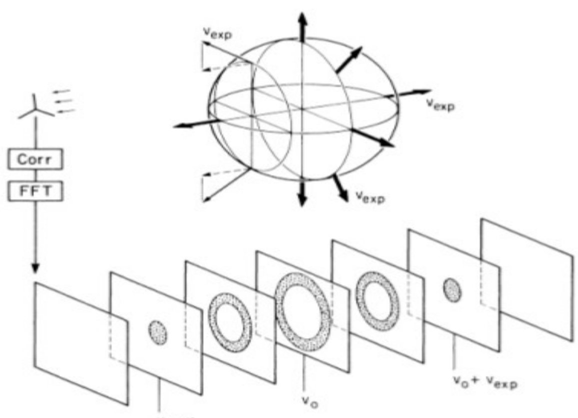
The asymptotic giant branch is the region of the Hertzsprung–Russell diagram populated by evolving low- to medium-mass stars. This is a period of stellar evolution undertaken by all low- to intermediate-mass stars (0.6–10 solar masses) late in their lives





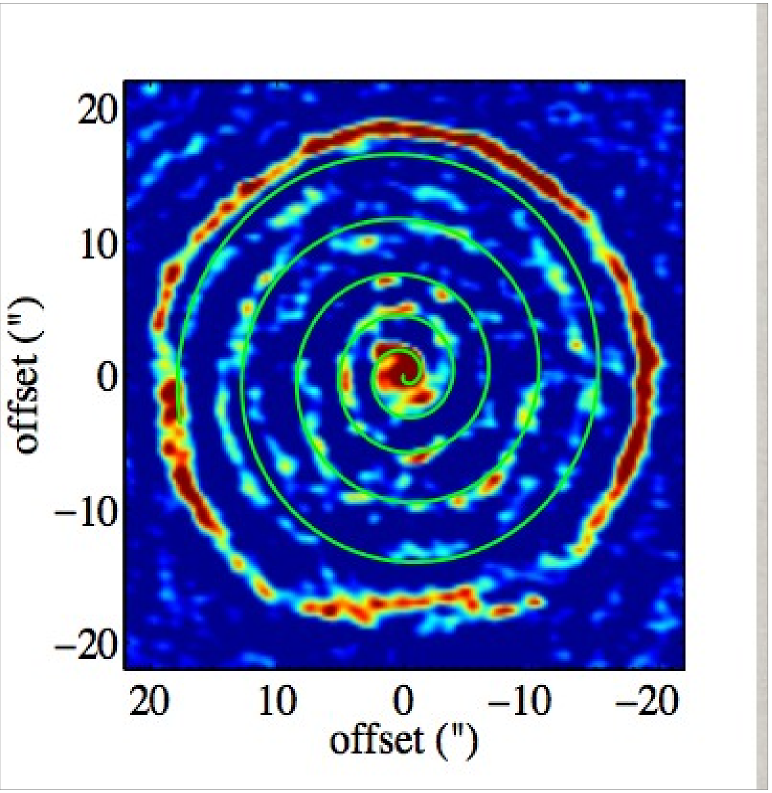
AGB stars are typically long-period variables, and suffer mass loss in the form of a stellar wind. **Thermal pulses produce periods of even higher mass loss and may result in detached shells of circumstellar material.**
During the thermal pulses, which last only a few hundred years, material from the core region may be mixed into the outer layers.

After these stars have lost nearly all of their envelopes, and only the core regions remain, they evolve further into short-lived preplanetary nebulae.



For an envelope expanding with constant velocity the iso-velocity curves are circles

ALMA Observations of AGB Stars – R Sculptoris



CO(3-2) Velocity Channel Movie

PI: M. Maercker

- ~15 antennas, ~4 hrs
- Band 7: CO(3-2),
- **resolution = 1.3"**
- 45 pointed mosaics
  (50" x 50" field)

Spiral structure in shell: an unseen shepard companion that modulates the loss of mass from the star?

Observations + hydrodynamic simulations: a binary system, a thermal pulse about 1800 yr ago lasting ~200 yr

~3×10^{-3} $M_{\odot}$ of material ejected at v = 14.3km/s, a **mass-loss rate 30 times higher than pre-pulse**

~3 times more mass into ISM than previously thought

Maercker et al. 2012;
Vlemmings et al. 2013

Summary

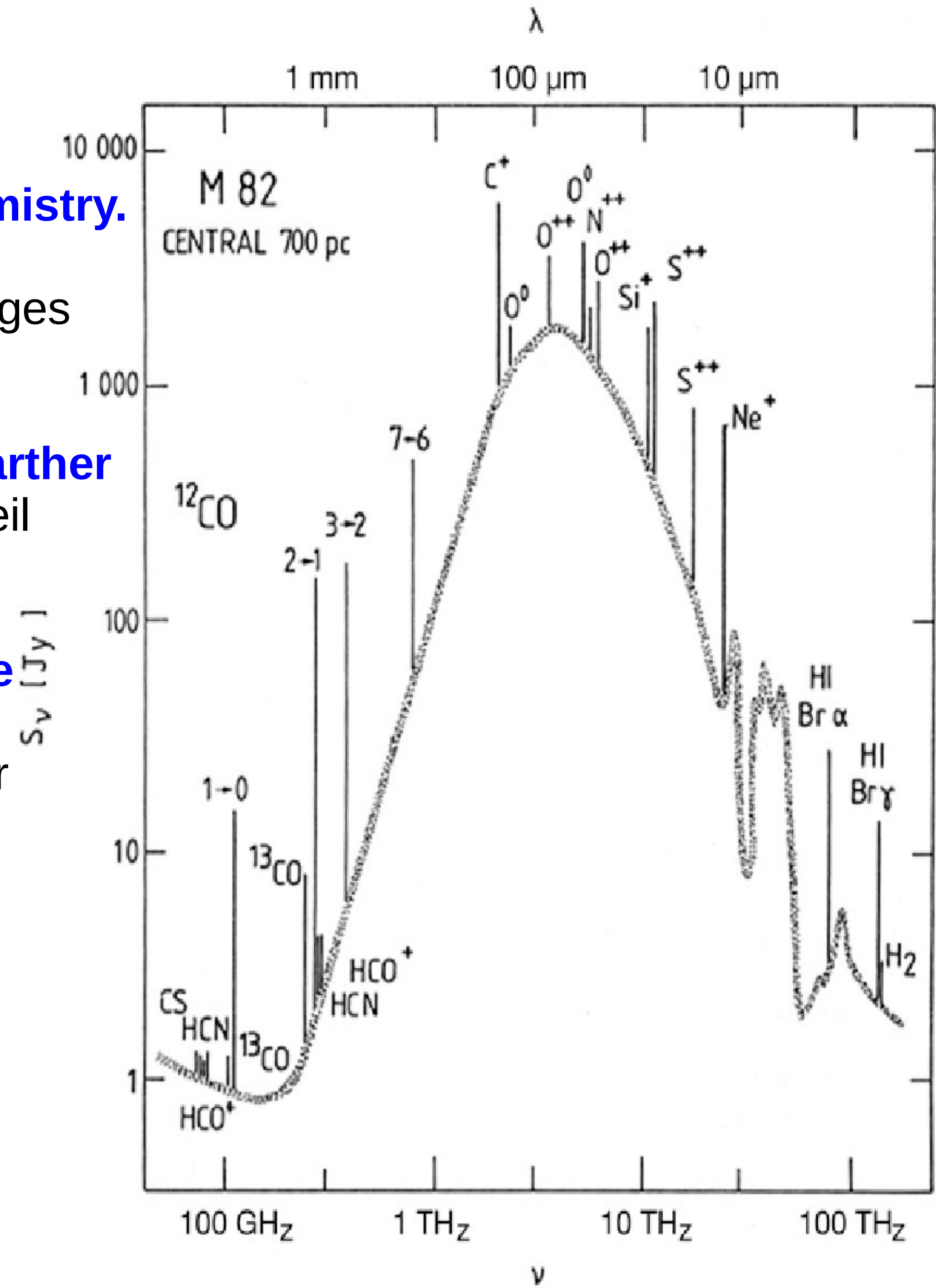
Sub(mm) is characterized by dust and rich chemistry.

Dust allows the investigation of earlier and later stages of stellar formation.

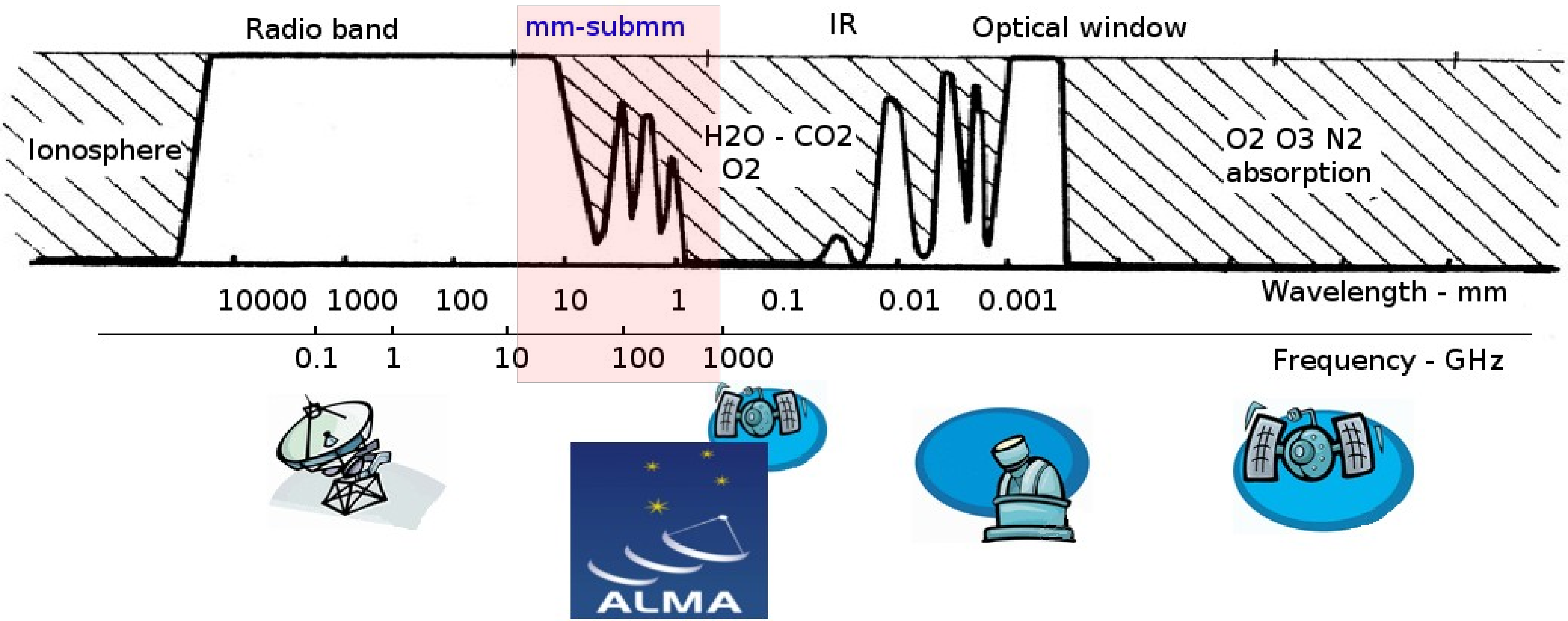
Higher resolution and sensitivity allows to go farther reaching the sites of massive star formation to unveil the underlying mechanism.

Higher spectral resolution allows to detect more narrow lines and more details from broad lines, allowing for dynamical and chemical details in Solar System objects, in protoplanetary disks, in star forming regions.

Missing topic: Solar science



Outline



Observing instruments: **Interferometers (ALMA)**

Science topics

Science cases

Observing processes: **Proposals and archives**

Mining an archive

Early Science Cycles

Early Science observations are conducted on a best effort basis
to allows community to observe with incomplete, but already superior array,
with priority given to the completion of the full ALMA capabilities

Past & current ALMA Early Science cycles:

	Cycle 0 Sep. 2011 – Jan. 2013	Cycle 1 Jan. 2013 - May. 2014	Cycle 2 Jun. 2014 – Oct. 2015	Cicle 3 Oct 2015 - Oct 2016
Telescope				
Hours dedicated to Science	**800**	**800**	**2000**	2100
Antennas	**> 12x12-m**	**> 32x12m +9x7m+2TP**	**> 34x12m +9x7m+2TP**	**> 36x12m +10x7m+2TP**
Receiver bands	3, 6, 7, 9	3, 6, 7, 9	**+4, 8**	**+10**
Wavelengths [mm]	3, 1.3, 0.8, 0.45	3, 1.3, 0.8 0.45	+2, 0.7	
Baselines	up to 400 m	**up to 1000 m**	**up to 1500m**	**up to 10km**
Polarisation	single-dual	single dual	**full**	**full**
Proposal outcome				
Submitted	917	1133	1381	1578
Highest priority	112	198	354	402
Filler	51	93	159	236
Success rate	12% (18%)	17% (25%)	26% (37%)	25% (40%)

Pressure factors (highest priority projects)

- Cycle 1: Europe: 9.1 (global ALMA: 5.8)
- Cycle 2: Europe: 4.9 (global ALMA: 3.9)
- Cycle 3: Europe: 6.2 (global ALMA: 3.9)

Reasons to use archived data

- Check if data are already available for a target
- Check the feasibility of a project looking for similar targets
- Retrieving information on a large sample of objects (e.g. statistics of populations, stacking, …)
- Retrieving information on a single object but with different configuration (e.g. multifrequency studies) or in different epochs (e.g. variability studies)
- Extracting unpublished information from existing data (e.g. finding additional spectral lines, targets in the same region/time of other observations,)
- **For ALMA in particular avoid the stress of competition and oversubscription**

	Proposal submission	**Archive mining**
Time to get data	✖	✚
Amount of data	✖	✚
Data homogeneity	✚	✖
Adherence to idea	✚	✖

A project lifetime: phase 2 Observing process

PHASE II – Observing process

Scheduling Block

Each SG is converted into a **Scheduling Block, an observational unit including targets in the same sky region and their Calibrators to be observed with the same instrumental setup.** They are the minimum set of instructions to perform an observation.

Observations

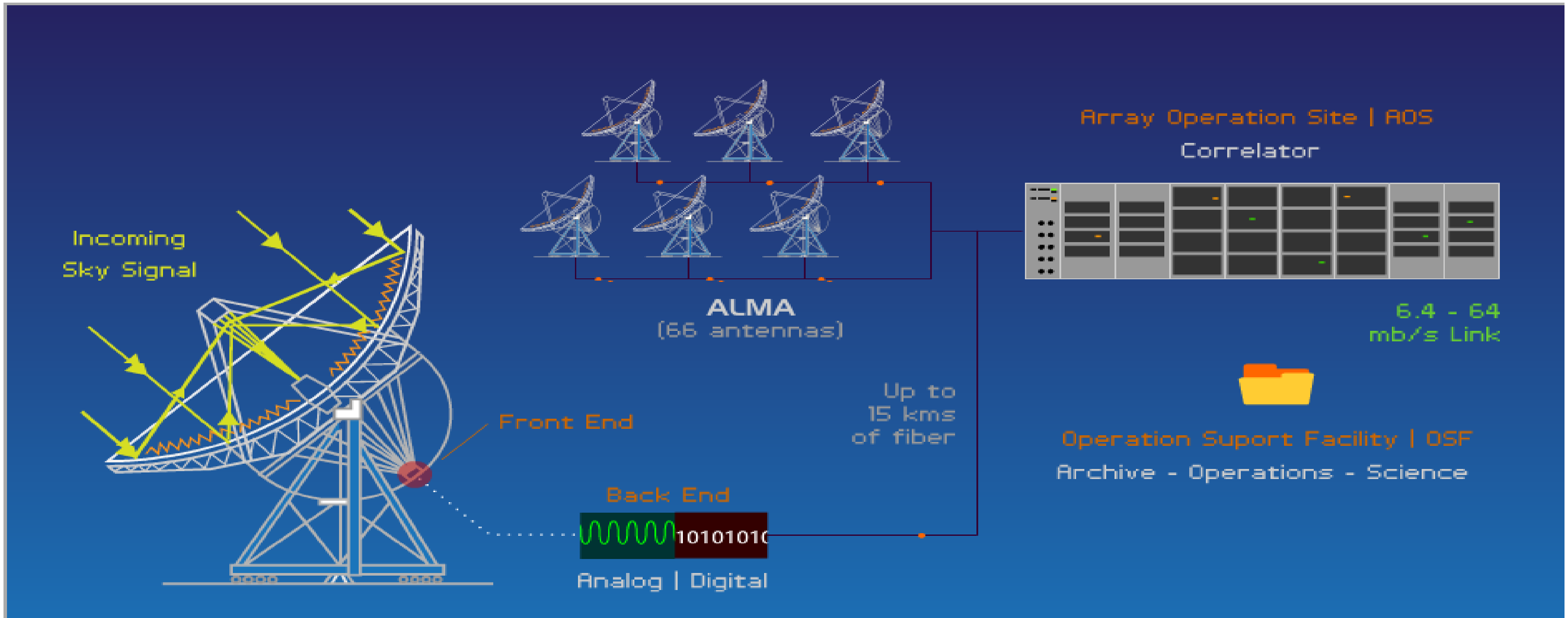
Projects are dynamically scheduled according to telescope configuration, weather, ranking, project status...

Quality assessment

QA0 and 1 = telescope conditions
QA2 = Check for PI sensitivity requests performed by ARC staff

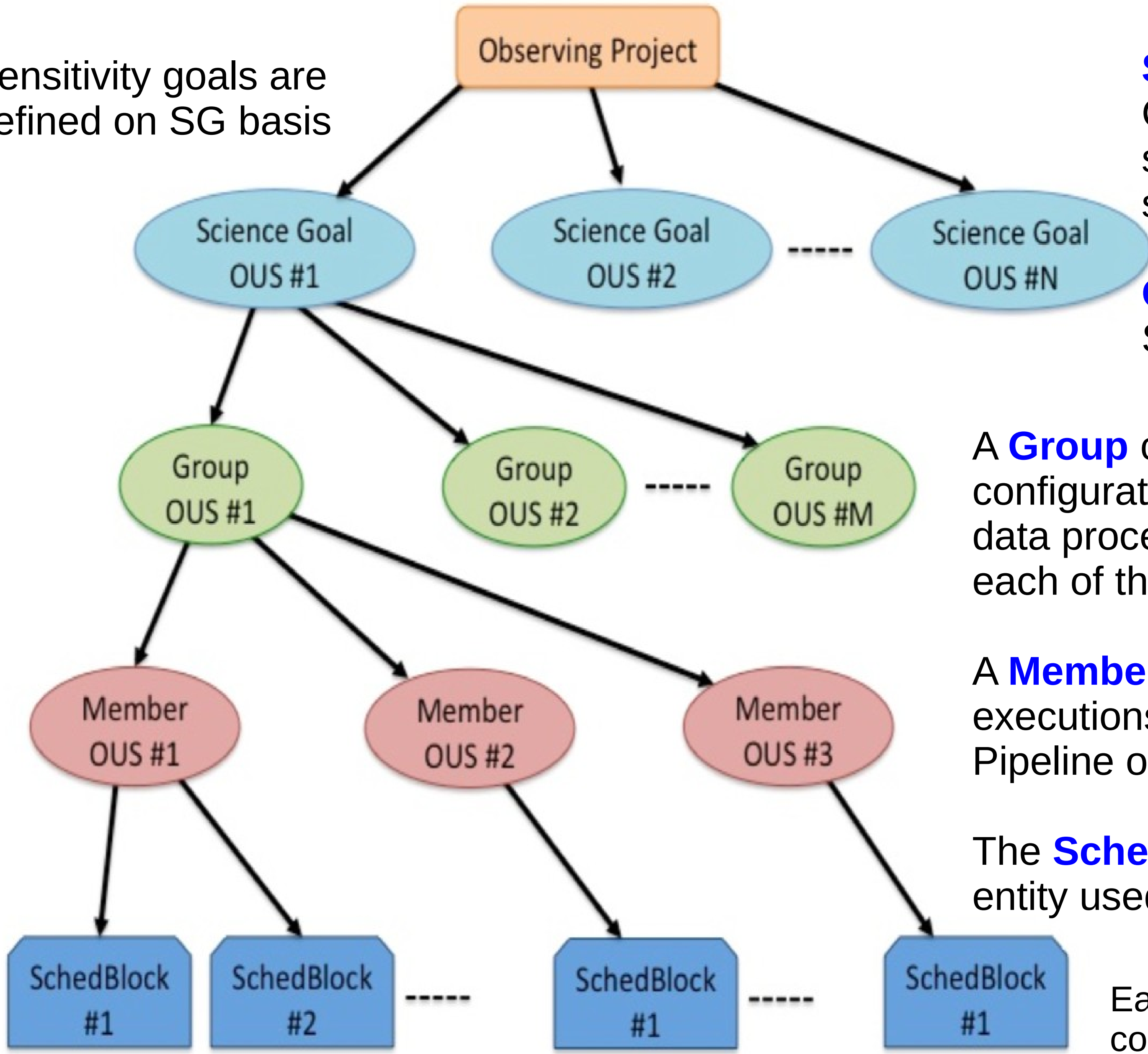
Data archival and delivery

1 yr of proprietary period before data are public through the archive



Data structure

Sensitivity goals are defined on SG basis



Science goal:
Group of sources in the same sky region that share the same spectral setup

OUS= Observing Unit Set
Smallest unit for data processing

A **Group** can contain several configurations to be combined in data processing (e.g. several arrays), each of them is a Member.

A **Member** can contain multiple executions of a Scheduling Block. Pipeline operates at this level.

The **Scheduling Block** is the smallest entity used for observing

Each repetition of a Scheduling Block constitutes an **Execution Block**

Data Quality Assessment

The goal of ALMA Quality Assurance (QA) is to deliver to the PI a reliable final data product that has reached the desired control parameters outlined in the science goals, that is calibrated to the desired accuracy and free of calibration or imaging artifacts i.e. ALMA performs **science-goal-oriented service data analysis**

ALMA QA happens on 4 levels:

QA0: near-real time verification of weather and hardware issues carried out on each execution block immediately after the observation.

QA1: verification of longer-term observatory health issues like absolute pointing and flux calibration.

QA2: offline calibration and imaging (using CASA) of a completely observed MOUS. Performed by expert analysts distributed at the JAO and the ARCs with the help of a semi-automatic CASA pipeline. **Results are archived and given to the PI.**

QA3: (optional) PIs may request rereduction, problem fixes, possibly reobservation

CASA

CASA (Common Astronomy Software Applications) is the designated data analysis package for ALMA and the JVLA.

Used for all offline processing of ALMA data.

CASA is developed by NRAO, ESO, and NAOJ (under NRAO management);
for details see http://casa.nrao.edu
and e.g., Petry et al., 2012, "Analysing ALMA data with CASA", ADASS XXI, ASP conf., 461, 849

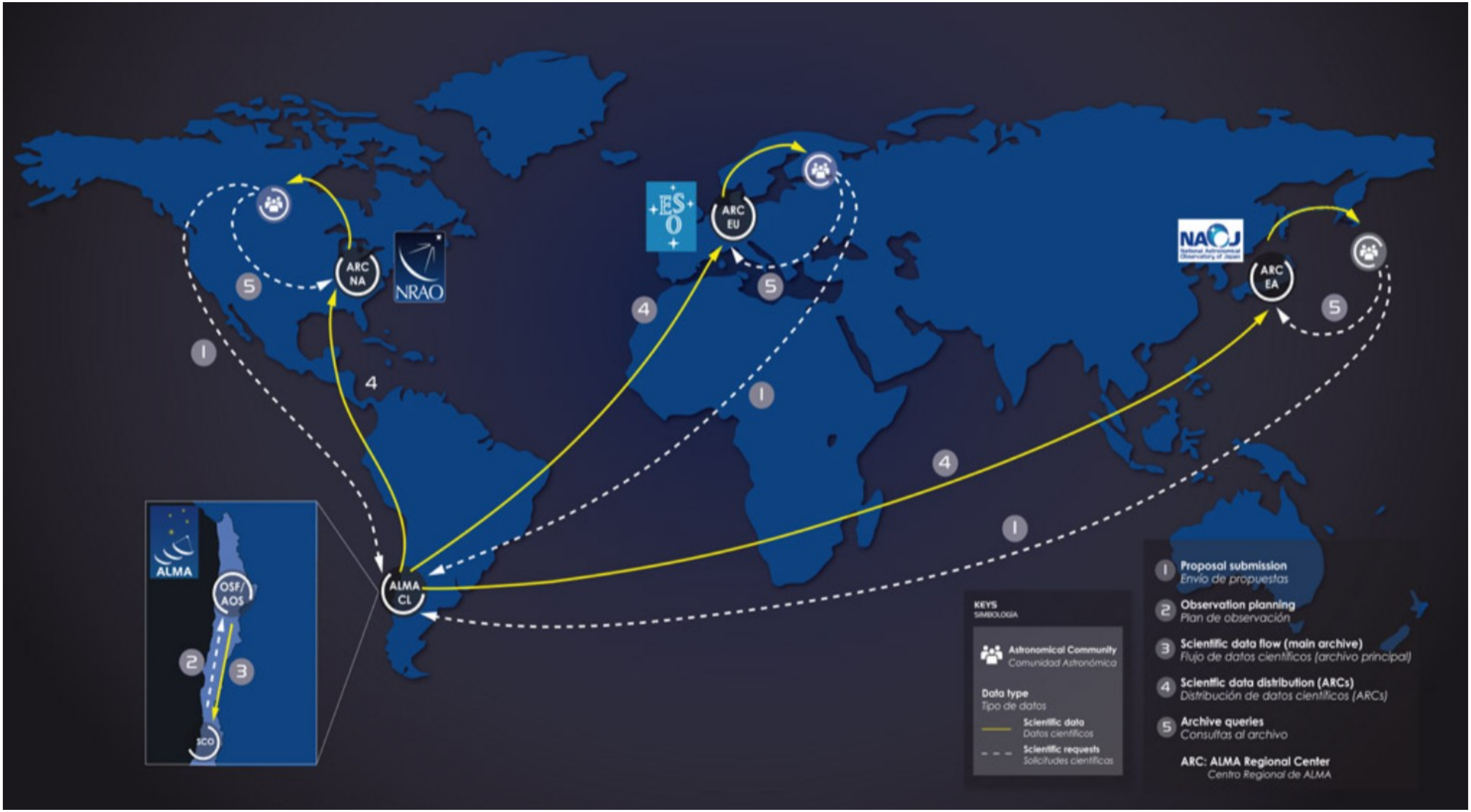
Latest release is CASA 4.3.1 .

The ALMA pipeline is an optional add-on of CASA.

Latest release with ALMA pipeline is CASA 4.2.2 .

CASA deals with data files in the Measurement Set (MS) structure.

ALMA data flow

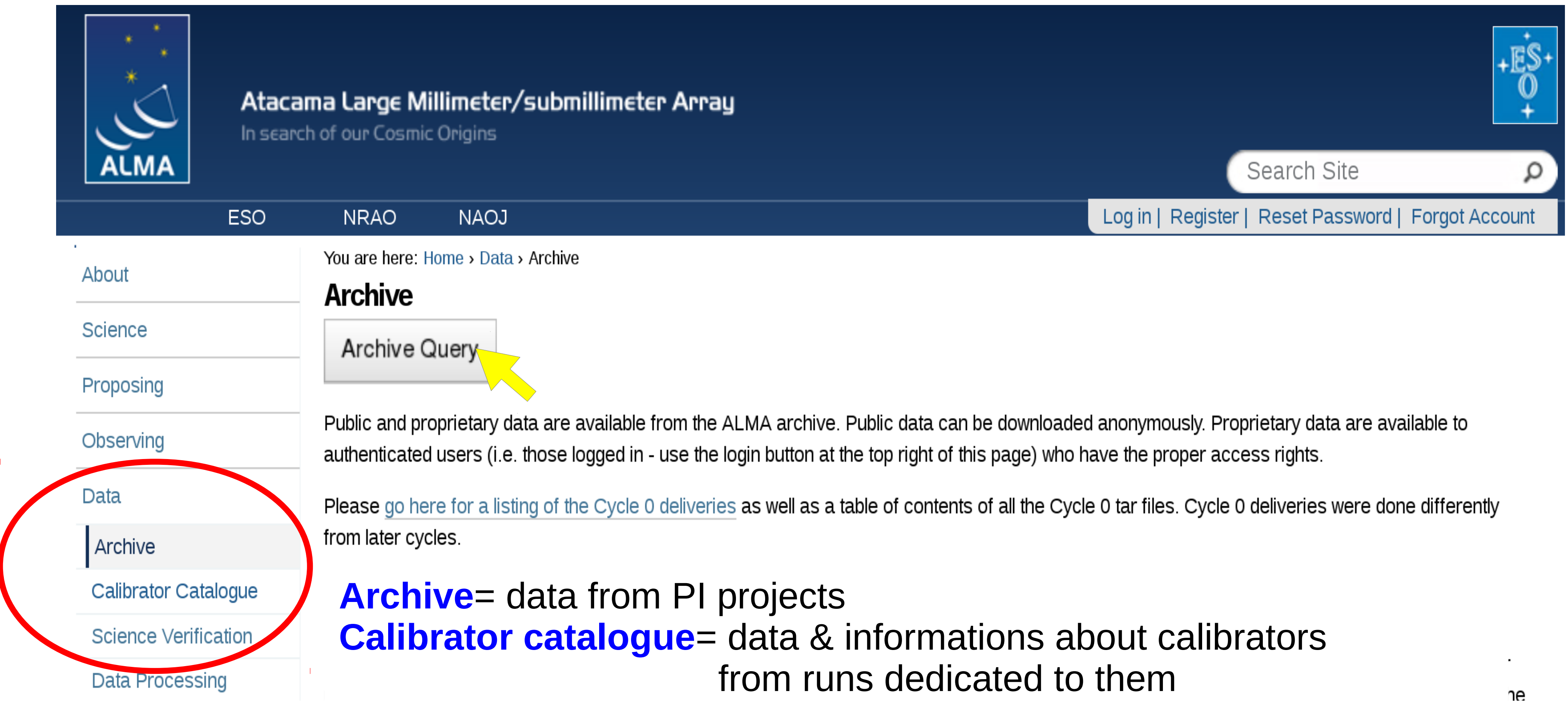


Data is collected, reduced and archived.
All the “almost” raw data is archived.

Each ARC hosts an archive mirror.

The ALMA archive

https://almascience.eso.org/alma-data/archive



Archive= data from PI projects

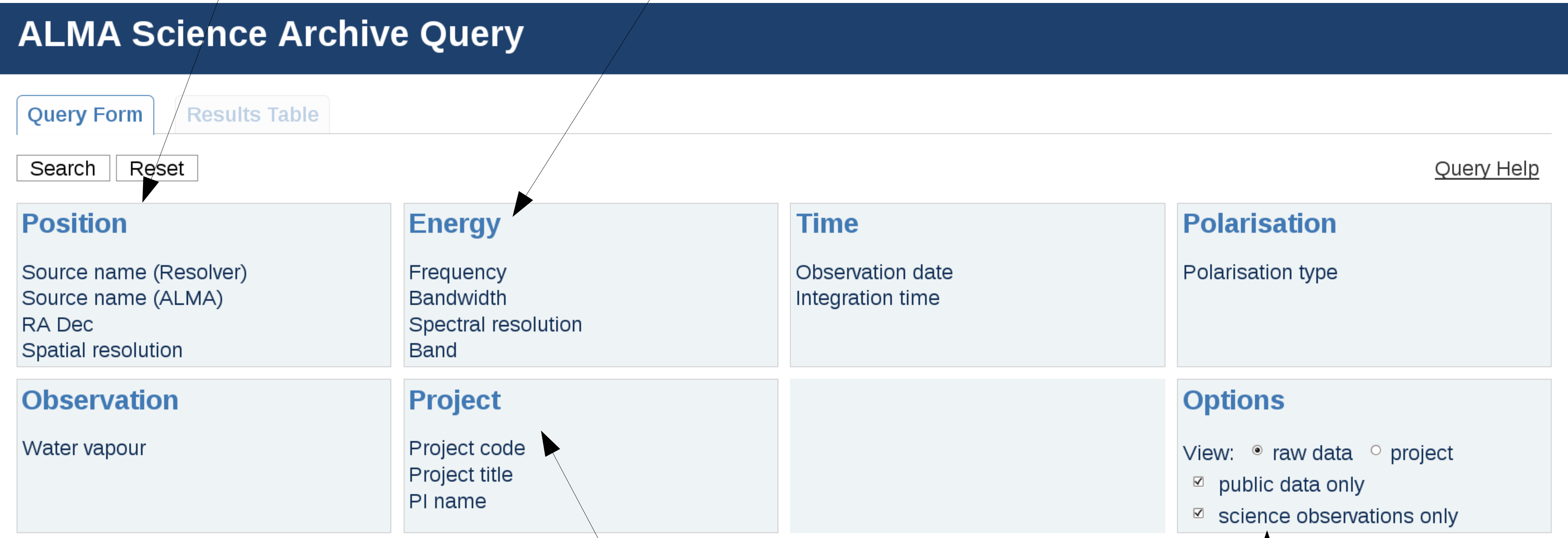
Calibrator catalogue= data & informations about calibrators from runs dedicated to them

Science Verification= data from observations dedicated to the telescope assessment of capabilities for science

The ALMA archive: query

Search per name or position or within a radius

Search the spectral setup



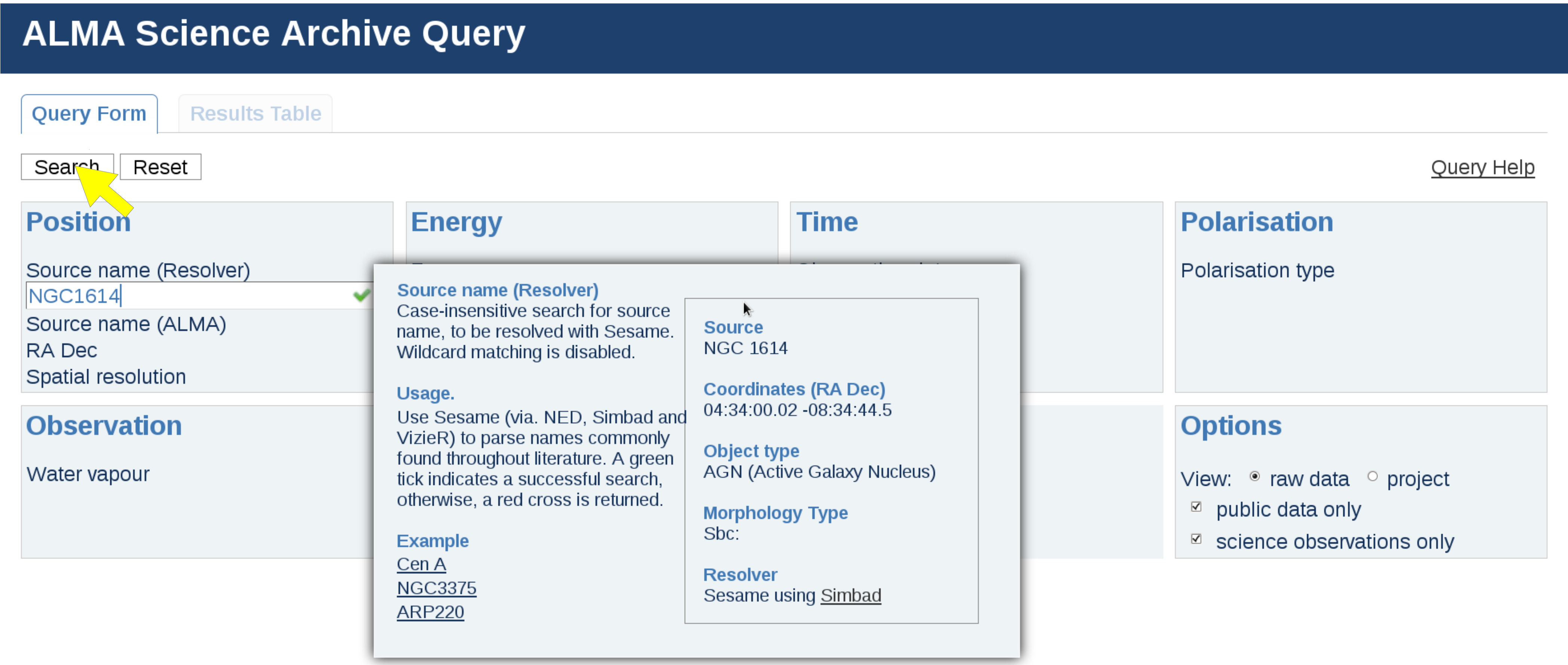
Search the project

Visualization options

The query display will change to allow more criteria!!!

The ALMA archive: help

1) Search with the criteria you need and click Search



Contextual help for each tab

The ALMA archive: result table

2) Select the project/execution blocks you need and click "Submit the download request"

ALMA Science Archive Query

Query Form | Results Table

Submit download request

Results Bookmark Export Table Results Help

Showing 7 rows (7 before filtering).

More columns

■	Project code	Source name	RA	Dec	Band	Integration	*Release date* ▲	Velocity resolution	Frequency support
Filter:								m/s	
☐	2011.0.00020.S	NGC 1614	04:34:00.03	-08:34:44.6	7	484.557	2013-01-12	834.09	344.15..357.85GHz
☐	2011.0.00020.S	NGC 1614	04:34:00.03	-08:34:44.6	7	382.854	2013-01-12	851.55	336.17..351.86GHz
☐	2011.0.00768.S	NGC1614	04:34:00.03	-08:34:44.6	7	463.612	2013-10-15	846.76	337.97..353.59GHz
☐	2011.0.00768.S	NGC1614	04:34:00.03	-08:34:44.6	7	464.391	2013-10-15	846.76	337.97..353.59GHz
☐	2011.0.00768.S	NGC1614	04:34:00.03	-08:34:44.6	7	463.991	2013-10-15	846.76	337.97..353.59GHz
☑	2011.0.00182.S	NGC 1614	04:34:00.03	-08:34:45.2	9	697.859	2013-12-21	13784.20	675.83..683.30GHz
☑	2011.0.00182.S	NGC 1614	04:34:00.03	-08:34:45.2	9	702.437	2013-12-21	13784.20	675.83..683.30GHz

The result table will soon show more details!

The ALMA archive: download manager

So far, this works only for Cycle>0

3) Select the data you want

Atacama Large Millimeter/Submillimeter Array
In search of our Cosmic Origins

ALMA

Request Handler **Login**

Archive Requests Req #855,169,791

Request #855169791 by Anonymous User

Click to edit

☐ *Include raw* Select All Deselect All Download Selected

Requested Projects / OUSets / Executionblocks

Data entities 1-3 of 3

Project / OUSet / Executionblock	File	Size	Access
☑ Project 2011.0.00182.S			
⊟ ☑ Member OUS uid://A001/X74/X1bb			
	☑ 2011.0.00182.S_2012-12-20_001_of_004.tar	4.4GB	✔
	☑ 2011.0.00182.S_2012-12-20_002_of_004.tar	215.0MB	✔
	☑ 2011.0.00182.S_2012-12-20_003_of_004.tar	725.4MB	✔
	☑ 2011.0.00182.S_2012-12-20_004_of_004.tar	176.1MB	✔
⊟ ☑ Member OUS uid://A001/X74/X1bf			
	☑ 2011.0.00182.S_2012-10-29_001_of_001.tar	9.1GB	✔

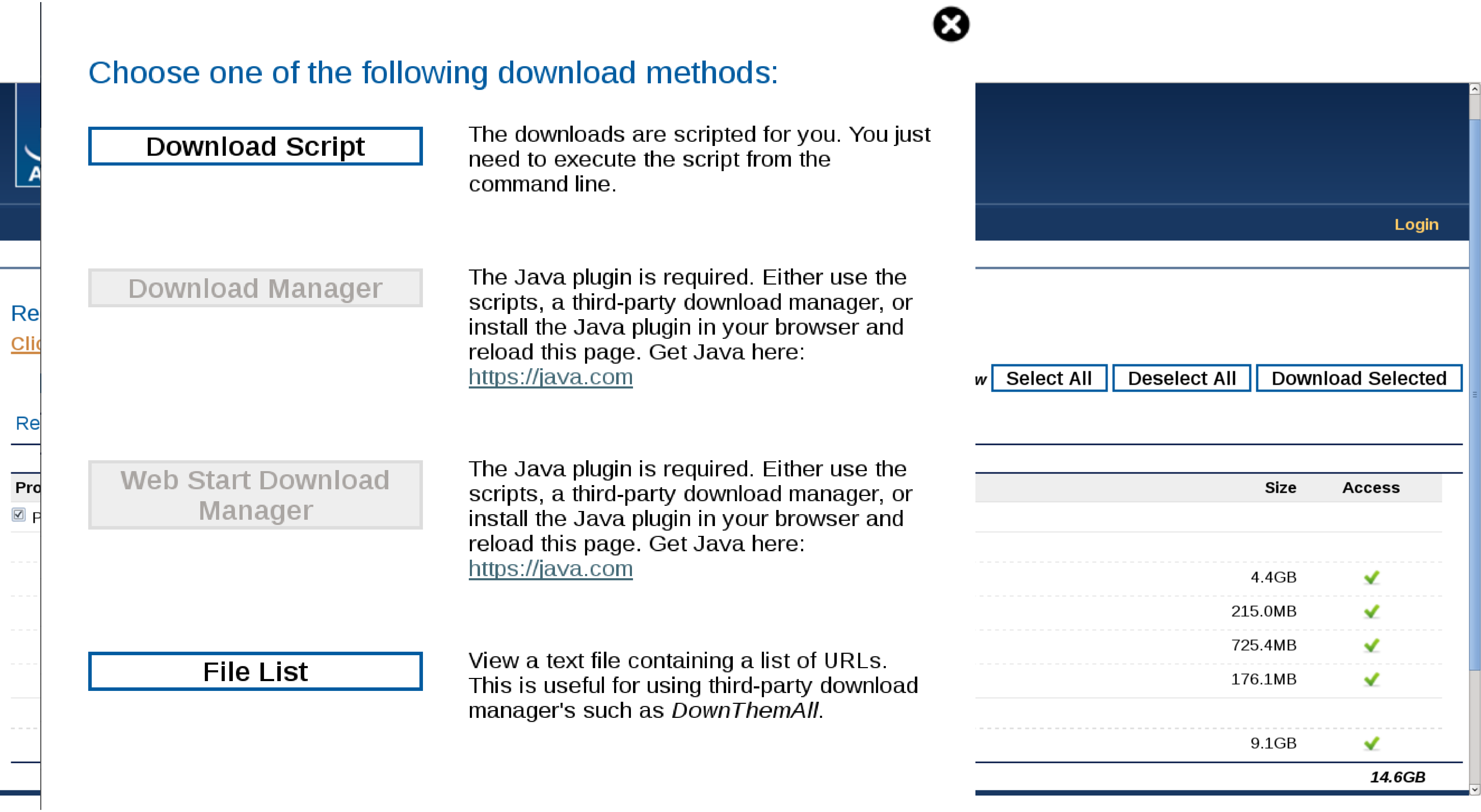
Data entities 1-3 of 3 ***14.6GB***

Remember that a Member OUS
is the smaller data processing unit

Raw data for whole projects are typically >10GB

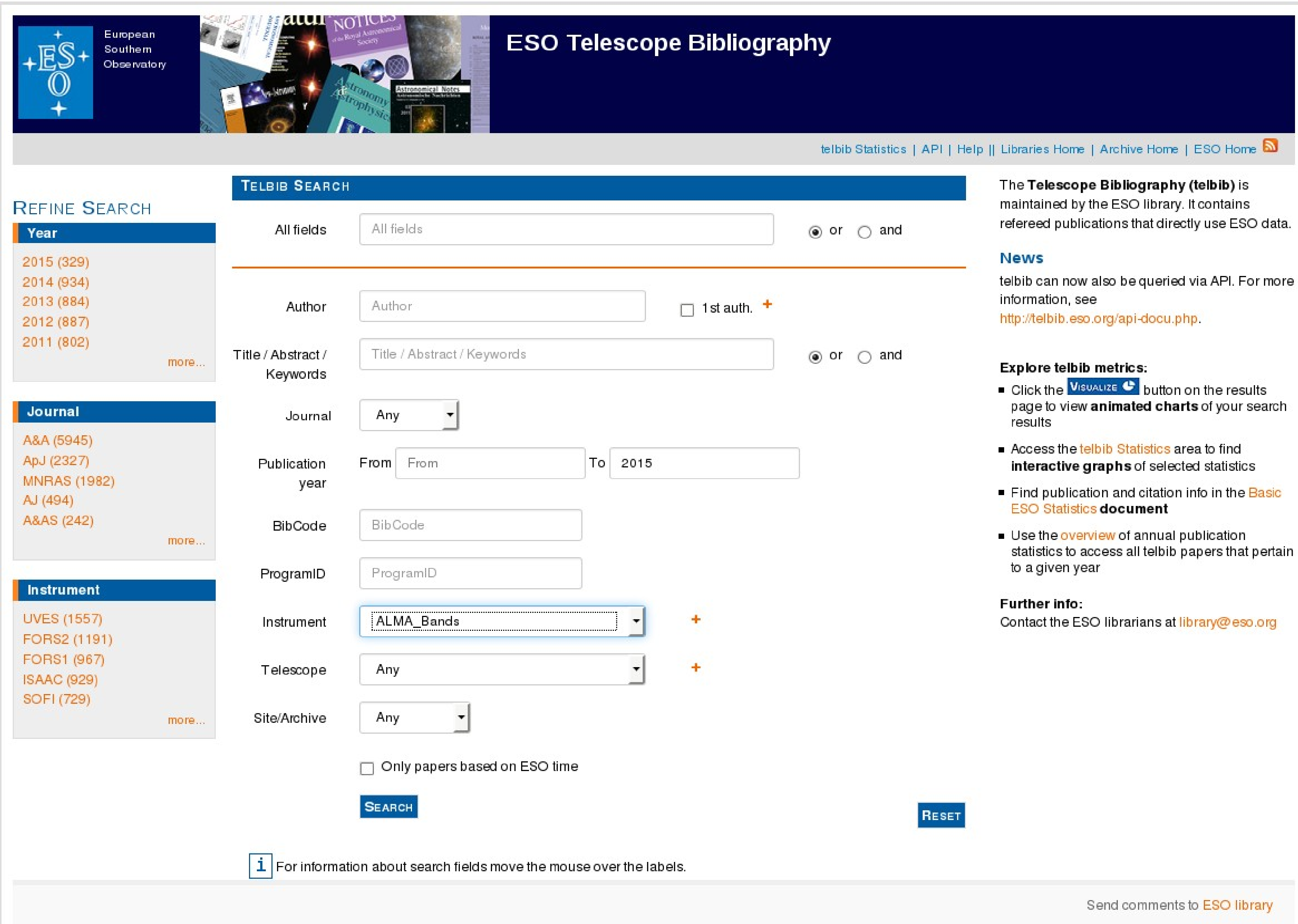
The ALMA archive: download manager

4) Choose the download method



The ESO telbib

http://telbib.eso.org/



The ESO telbib

European Southern Observatory

ESO Telescope Bibliography

telbib Statistics | API | Help || Libraries Home | Archive Home | ESO Home

Refine Search

Year

- 2015 (40)
- 2014 (97)
- 2013 (65)
- 2012 (20)

Journal

- ApJ (121)
- A&A (54)
- MNRAS (16)
- Nature (11)
- PASJ (6)

more...

Instrument

- ALMA_Bands (222)
- LABOCA (14)
- XSHOOTER (6)
- FORS2 (5)
- SHFI (5)

more...

New Search | Edit Search | Visualize | Export

Results **1 - 25** of **222** found for (instrument:ALMA_Bands)

« Previous Next »

Year ▼	Author	Title	Instruments	Access to data	Fulltext ADS
2015	Sakai, Yusuke et al.	An ALMA Imaging Study of Methyl Formate (HCOOCH3) in Torsionally Excited States toward Orion KL	***ALMA_Bands***	2011.0.00009.SV	2015ApJ...803...97S
2015	Brouillet, N. et al.	Antifreeze in the hot core of Orion. First detection of ethylene glycol in Orion-KL	***ALMA_Bands***	2011.0.00009.SV	2015A&A...576A.129B
2015	Saito, Toshiki et al.	ALMA Multi-line Observations of the IR-bright Merger VV 114	***ALMA_Bands***	2011.0.00467.S	2015ApJ...803...60S
2015	Olofsson, H. et al.	ALMA view of the circumstellar environment of the post-common-envelope-evolution binary system HD 101584	***ALMA_Bands***	2012.1.00248.S	2015A&A...576L..15O
2015	Sakai, Takeshi et al.	ALMA Observations of the IRDC Clump G34.43+00.24 MM3: DNC/HNC Ratio	***ALMA_Bands***	2011.0.00656.S	2015ApJ...803...70S
2015	Gullberg, B. et al.	The nature of the [C II] emission in dusty star-forming galaxies from the SPT survey	***ALMA_Bands***	2011.0.00957.S, 2011.0.00958.S, 2012.1.00844.S	2015MNRAS.449.2883G
2015	Rathborne, J. M. et al.	A Cluster in the Making: ALMA Reveals the Initial Conditions for High-mass Cluster Formation	***ALMA_Bands***	2011.0.00217.S	2015ApJ...802..125R

What is in the archive?

For each project the main deliverables are

Raw Data (in CASA readable MS), Calibration Scripts and Tables

Users need to run CASA to generate the Calibrated Data.
The resulting calibrated data is considered science-ready.

Some Imaging Products are delivered too, as result of QA2 processing
(in Early Science provided on a best effort basis, not necessarily science-ready)
a) for Line Observations:
- continuum-subtracted (where needed) image cubes at the requested resolution
- a continuum image for all line-free channels (where possible)

b) for Continuum Observations:
- continuum image combining all SPWs

The main purpose is to measure the rms and verify the achievement of PI requests.

Images in the archive are provided as starting point on the way to obtain the final images and a valuable basis for archive researchers (i.e. they are not considered science-ready!!!)

What is in the archive?

When untarred, the Product Package standard directory structure contains

```
|-- project_id/
| |-- sg_ouss_id/
| | |-- group_ouss_id/
| | | |-- member_ouss_id/
| | | | |-- README .......................important summary of the contents
| | | | |-- product/ .........................all the imaging products
| | | | |-- calibration/ ....................calibration and flagging tables
| | | | |-- qa/ ................................diagnostic plots generated during calibration
| | | | |-- script/ ...........................the scripts necessary to regenerate the cal. MS
| | | | |-- log/ ..............................CASA log files from QA2 calibration and imaging
| | | | |-- raw/ .............................only present when you have unpacked the raw data
```

In publications with ALMA data!

Acknoweledgement Statement:

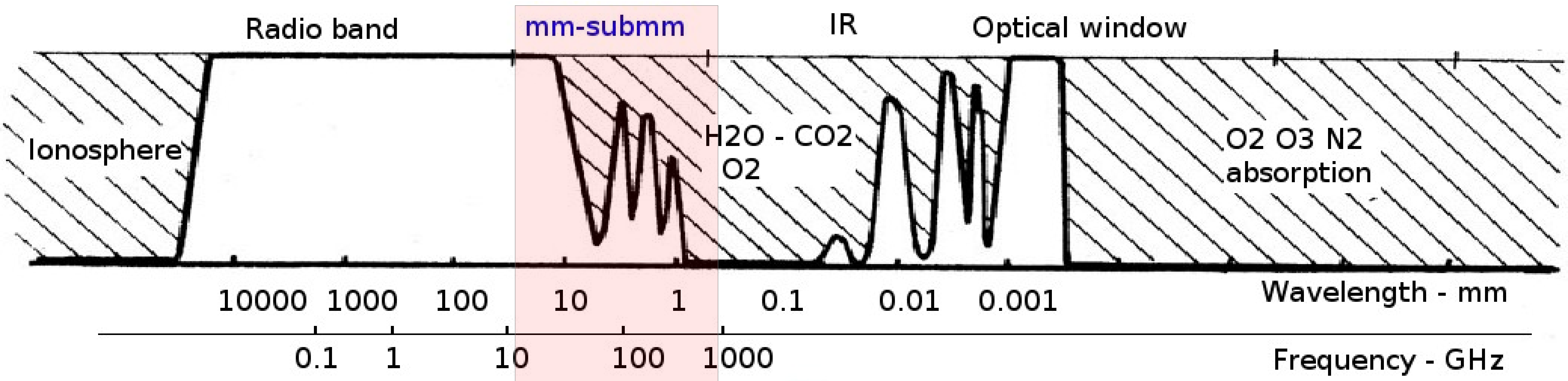
"This paper makes use of the following ALMA data: ADS/JAO.ALMA#2011.0.01234.S. ALMA is a partnership of ESO (representing its member states), NSF (USA) and NINS (Japan), together with NRC (Canada), NSC and ASIAA (Taiwan), and KASI (Republic of Korea), in cooperation with the Republic of Chile. The Joint ALMA Observatory is operated by ESO, AUI/NRAO and NAOJ."

(Can be found in the SP, on the 'ALMA-Data' page)

•

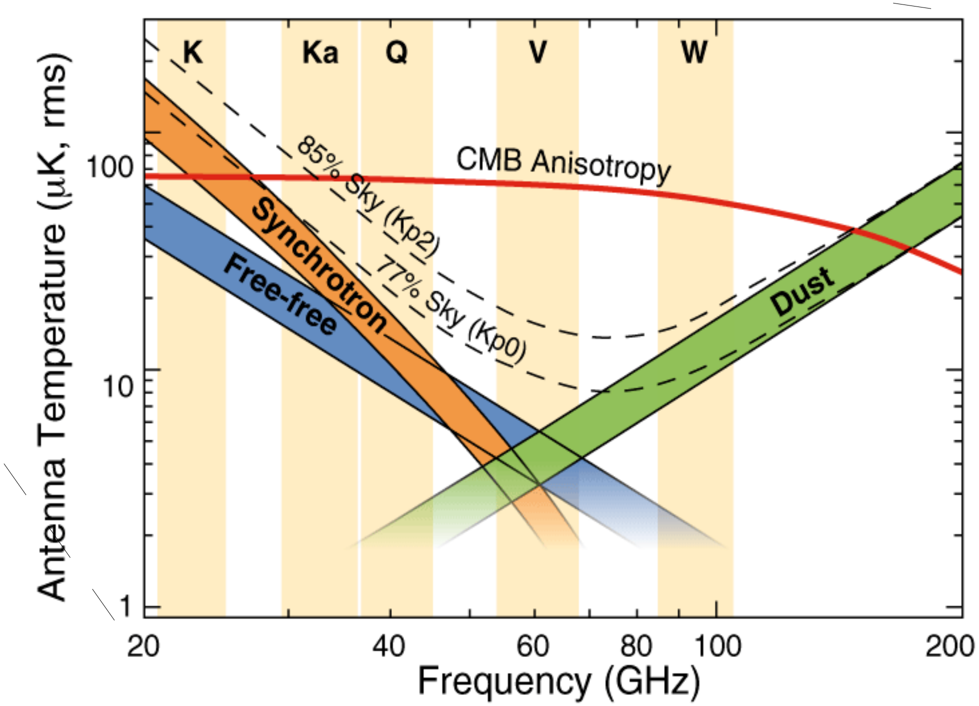
Summary

The signals



The (sub)mm band ranges between 30-1000 GHz

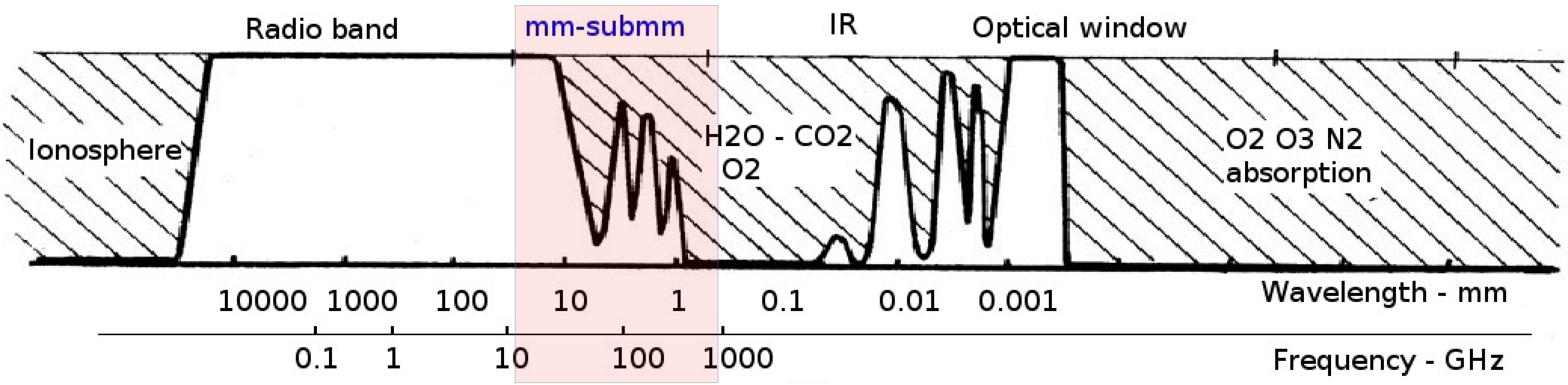
(Sub)mm signals: **synchrotron, dust emission, molecular lines, CMB**

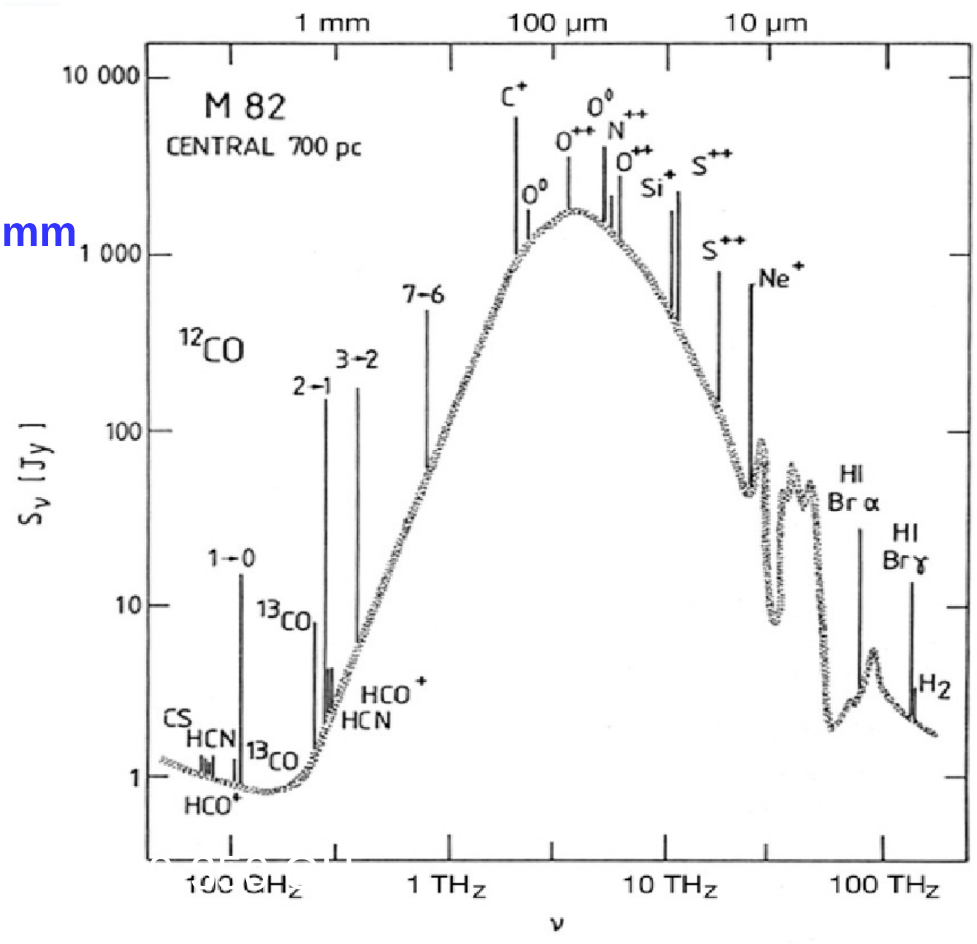


The warm dust emitting at far–IR wavelengths is mostly heated by the UV-radiation field of young massive stars in star forming regions.

The far infrared luminosity is considered good tracer of star formation in galaxies.

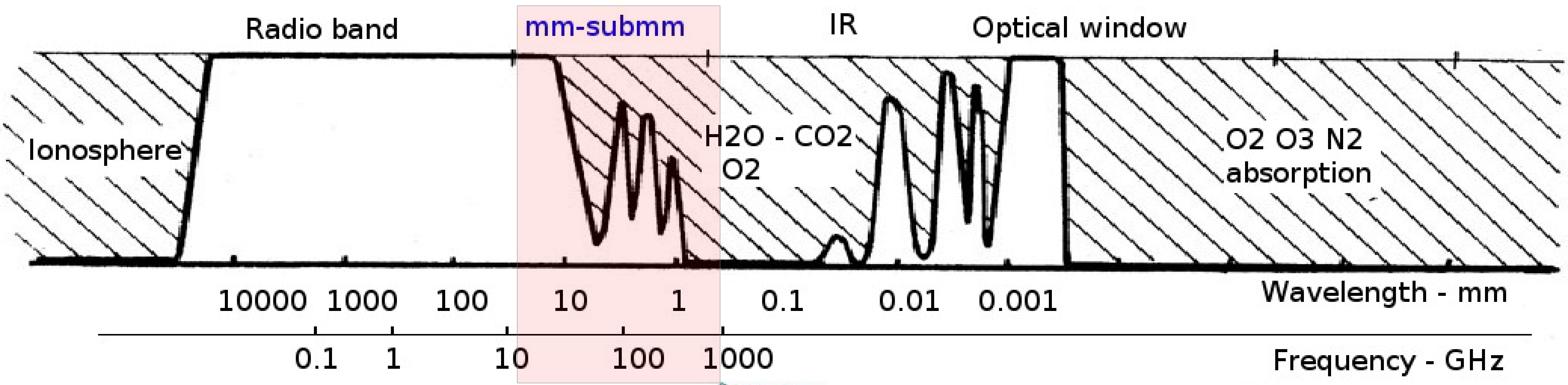
The signals

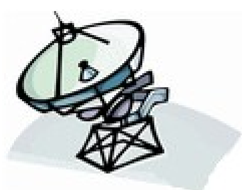


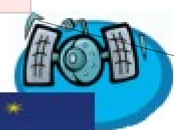


The spectrum of each molecular cloud in the submm is rich of rotational molecular transition ladders and atomic fine structure lines, which shapes and relative abundances can be used to trace physical and dynamical properties of the ISM and the mechanisms of SF and AGN activity in the local and high-z Universe.

The instruments



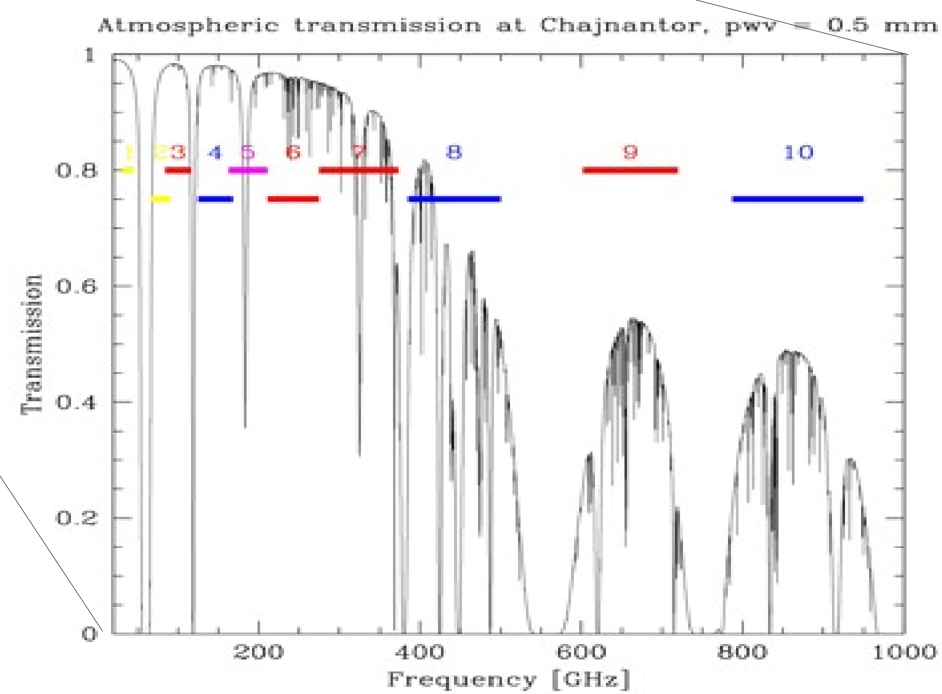




Requirements: Excellent weather
Accurate antennas
Sensitive receivers

ALMA is a 50x12m + 12x7m+ 4x12m array operating in 10 bands between 30 and 1000 GHz in extremely dry site, reconfigurable to cover baselines up to 16km (and in the future mm-VLBI)

Reaches encompassed sensitivity and resolution thanks to the instrumental properties



ALMA science portal: www.almascience.eso.org/

ALMA proposal submission procedures: https://almascience.eso.org/proposing

ALMA documents and tools: https://almascience.eso.org/documents-and-tools

Italian ARC node: www.alma.inaf.it

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Enjoy the new ALMA era!

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