

ALMA, Star Formation, and the SOLA Project



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The Hot Universe - The Realm of Optical Telescopes



Hawaii - Gemini North
and Keck I and II



Earth Orbit - Hubble
Space Telescope



Chile - Gemini South
and the VLT



The Hot Universe - Galaxies, Stars

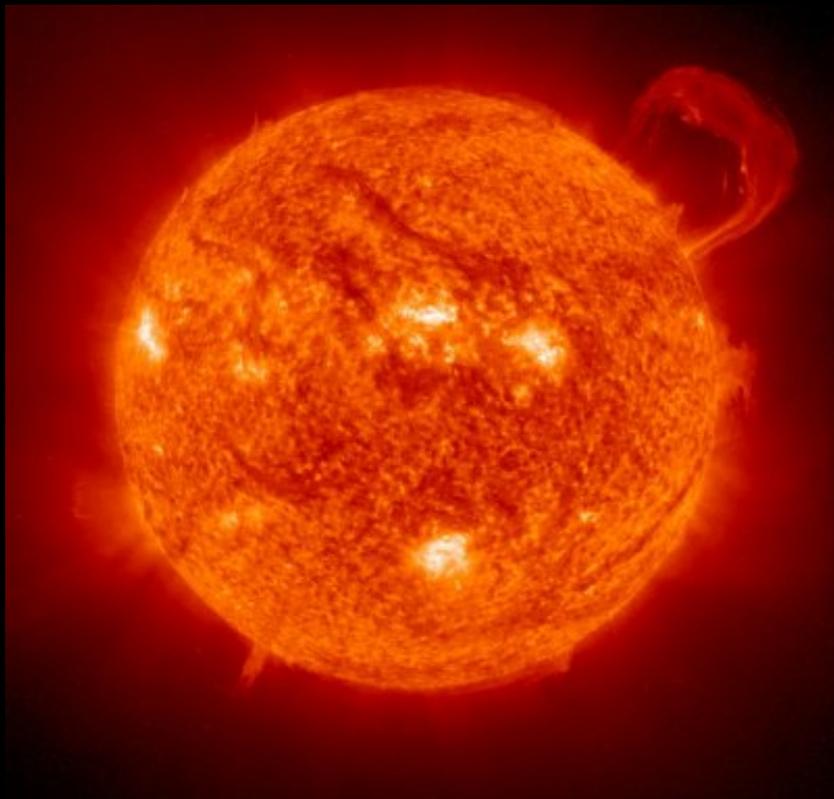
Galaxy NGC 4565



“Jewel Box” star cluster



Sun - ultraviolet



Where does it all come from?

Center of
our Galaxy

Galaxies, stars, and planets form out of vast cold clouds of gas and dust that lie between what we see in the sky

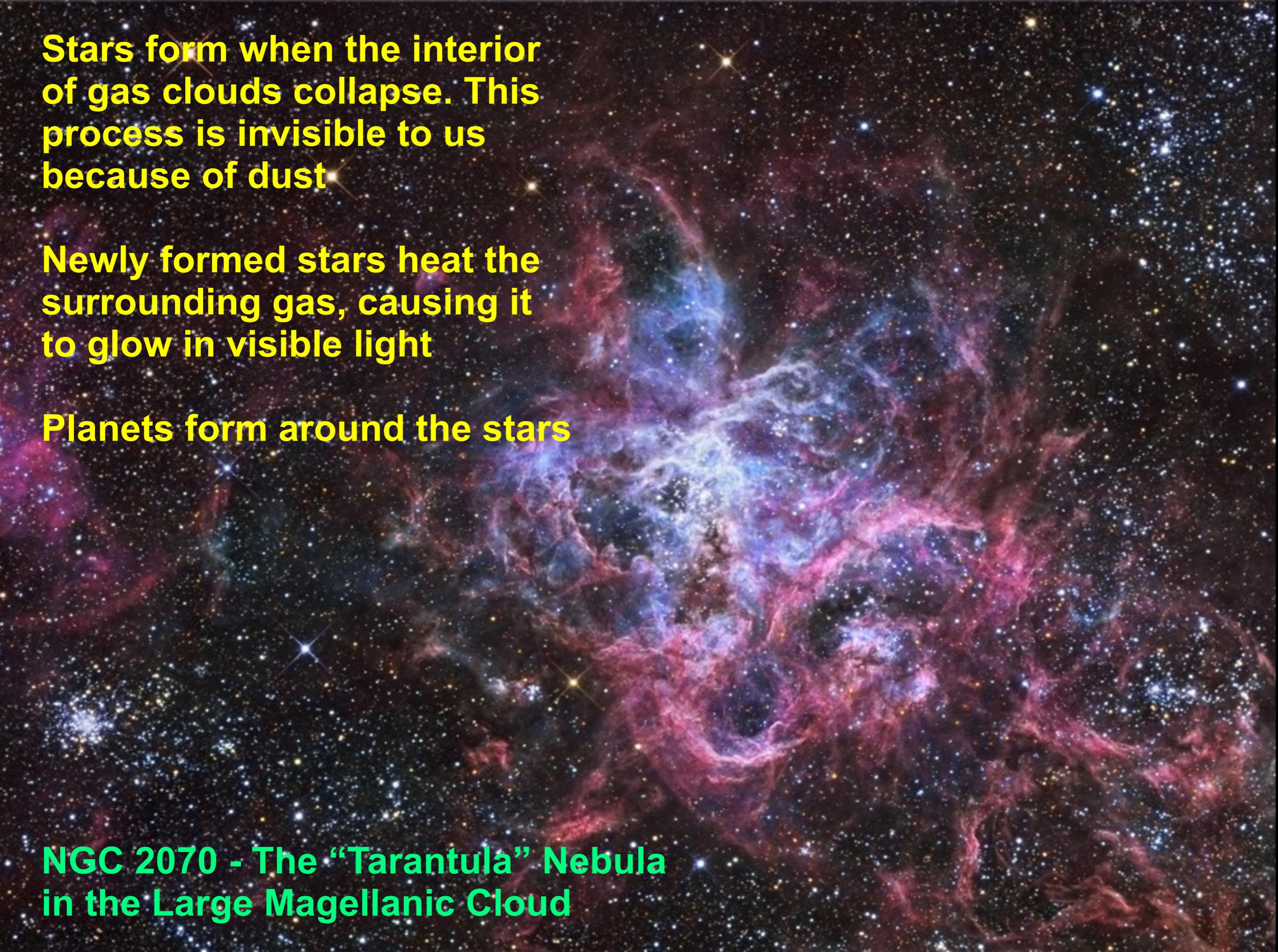
Cold clouds are invisible and opaque to visible light, but the secrets of origins lie within them

Stars form when the interior of gas clouds collapse. This process is invisible to us because of dust

Newly formed stars heat the surrounding gas, causing it to glow in visible light

Planets form around the stars

NGC 2070 - The "Tarantula" Nebula in the Large Magellanic Cloud



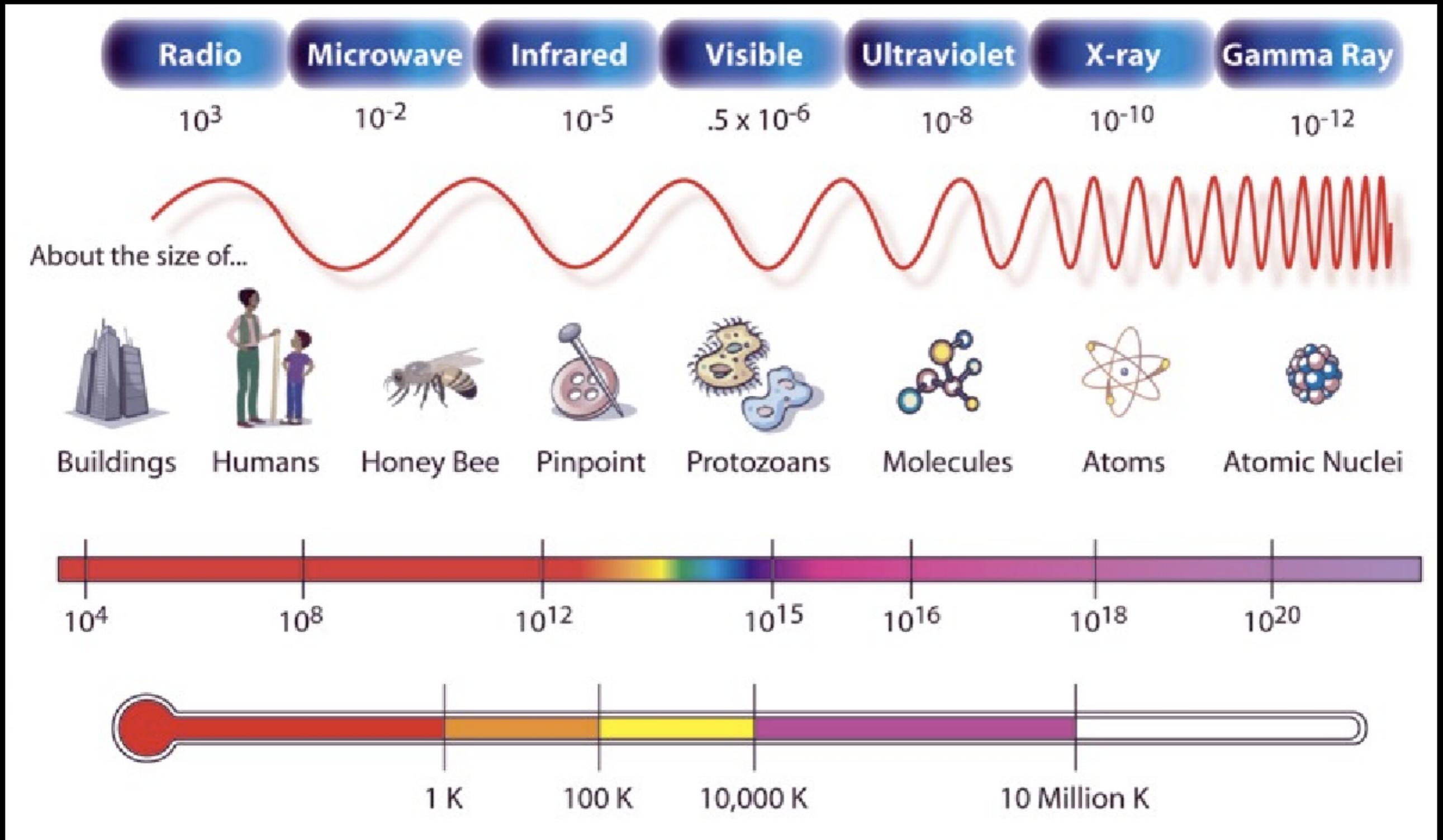
How can we “look” inside?

Barnard 68 - A dusty
molecular cloud



By observing the light which *comes* from the dust and cold gas!

What kind of light?



Interstellar dust and gas molecules emit light with wavelengths about 0.1 mm to 10 mm in size - “millimetre or sub-millimetre light” - also known as “microwaves”

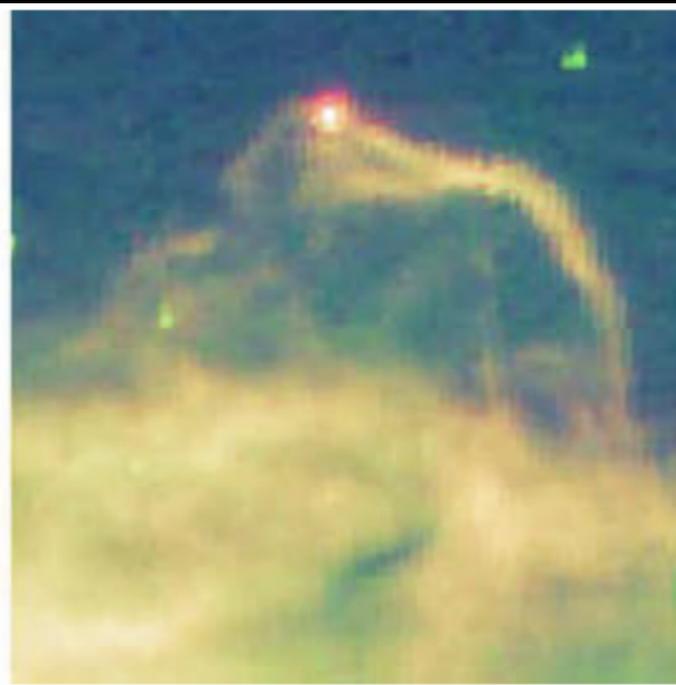
Clouds block optical light and are transparent to infrared light

The millimetre and sub-millimetre light emitted from dust and gas can escape from the clouds, allowing us to see inside

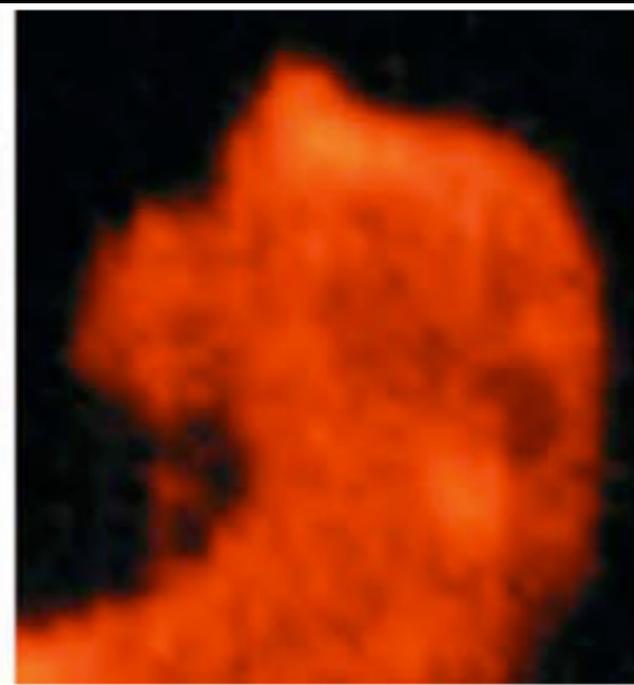
The “Horsehead” nebula seen at four different wavelengths



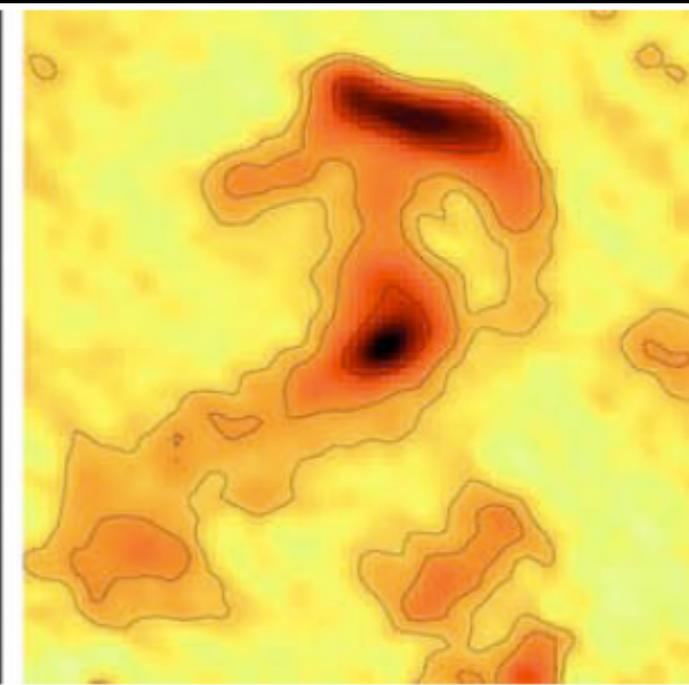
Visible



Infrared



**Sub-millimetre
(molecules)**



**Sub-millimetre
(dust)**

Astronomers can observe sub-millimetre light using radio telescopes designed to operate at high frequencies - about 30 GHz to 1000 GHz

The Earth's atmosphere and water vapour block sub-millimetre light, making observations difficult or impossible at low altitude and wet sites

Sub-millimetre telescopes need to be built where it is *very high* and *very dry*!



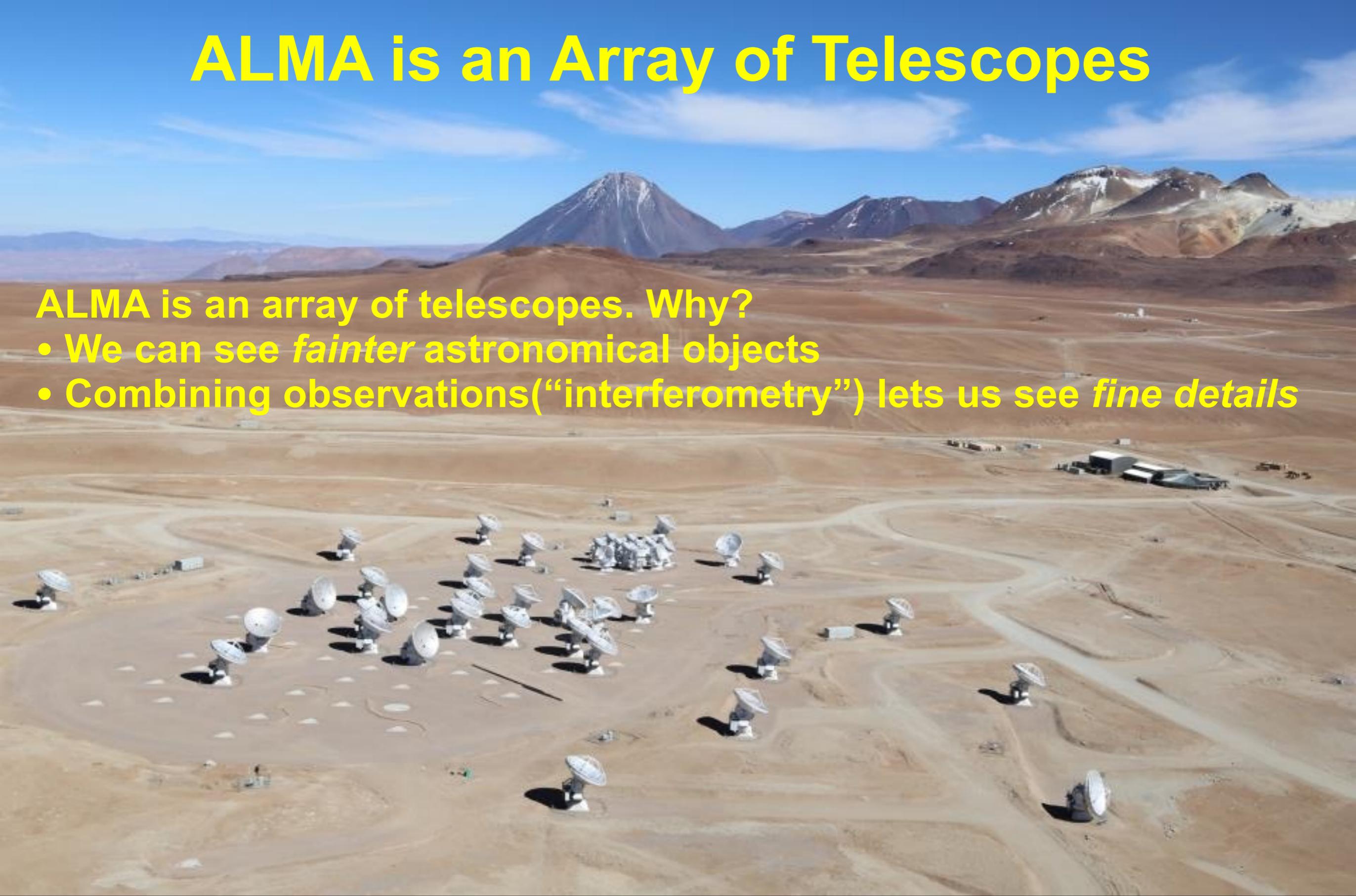
The ALMA site on the Llanos de Chajnantor in Chile

2004/05/19

ALMA is an Array of Telescopes

ALMA is an array of telescopes. Why?

- We can see *fainter* astronomical objects
- Combining observations (“interferometry”) lets us see *fine details*



The Atacama Large Millimetre Array is operated by Europe (ESO), North America (USA, Canada), and East Asia (Japan, Taiwan)



What will ALMA Do?

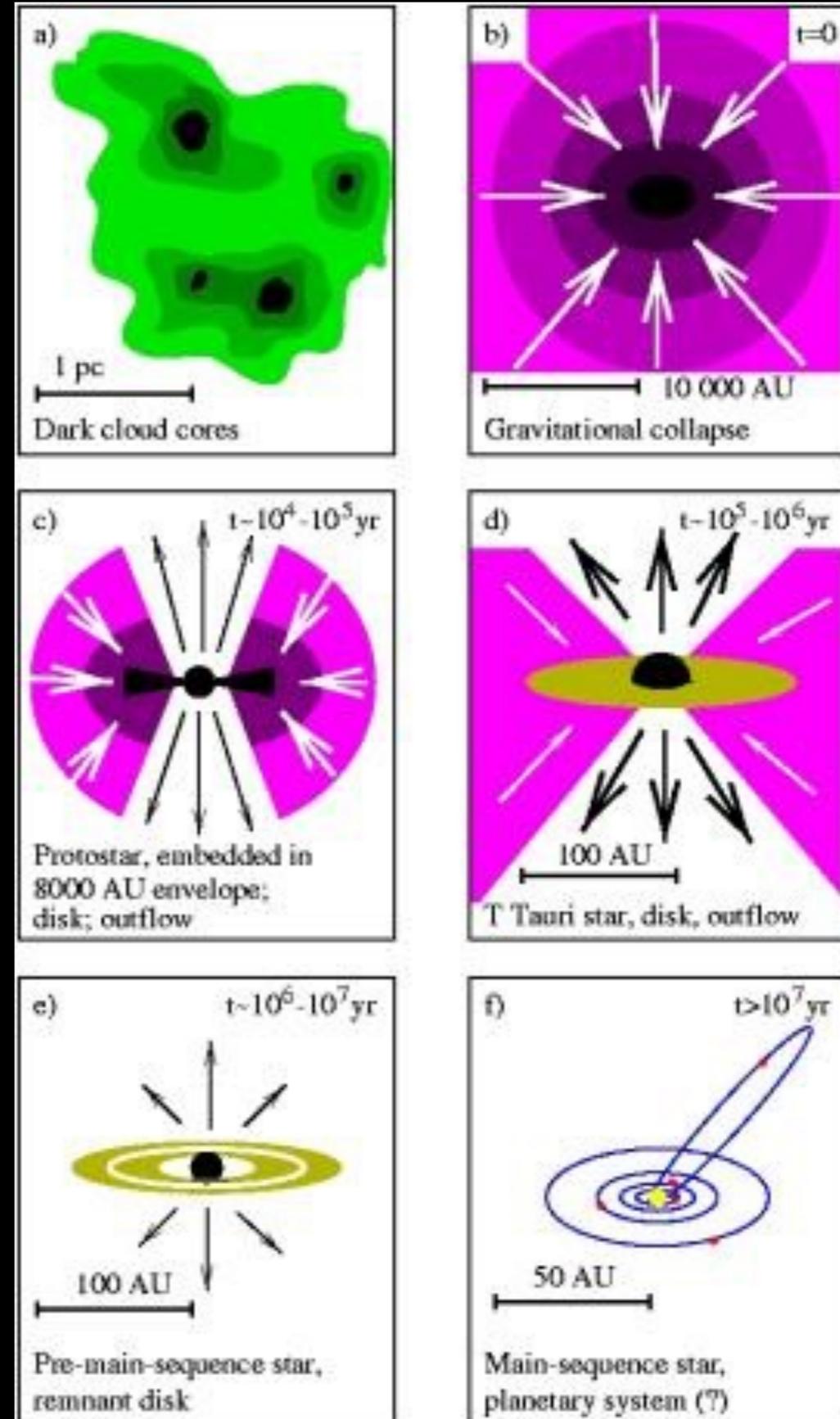
ALMA will study “cosmic origins”

- **Formation of galaxies billions of years ago very far away**
- **Formation of stars in nearby galaxies and in our own galaxy**
- **Formation of planets around stars**
- **Chemistry of clouds and new solar systems**

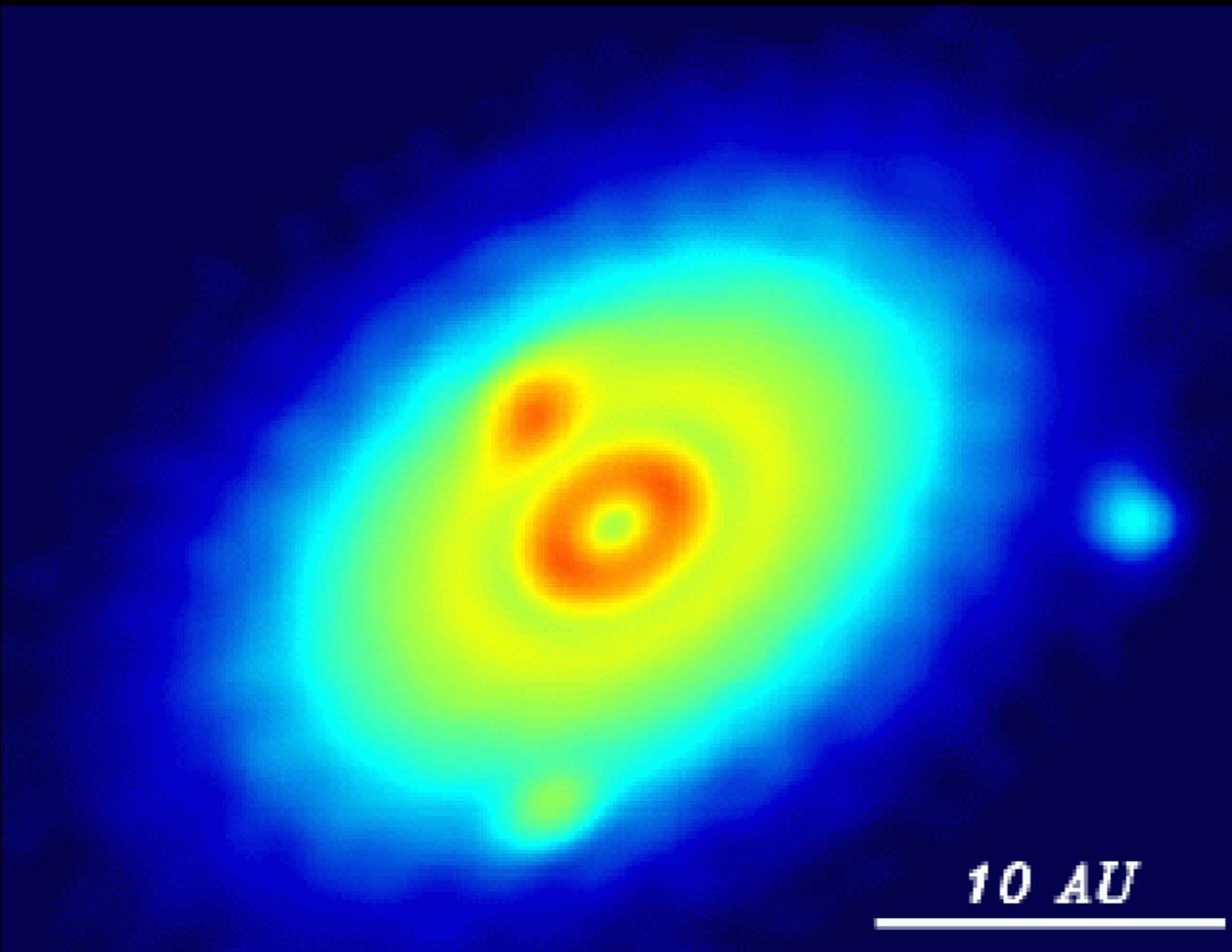
ALMA - Star Formation

With ALMA's exceptional sensitivity and resolution, we will see stars forming in greater detail than ever before - including

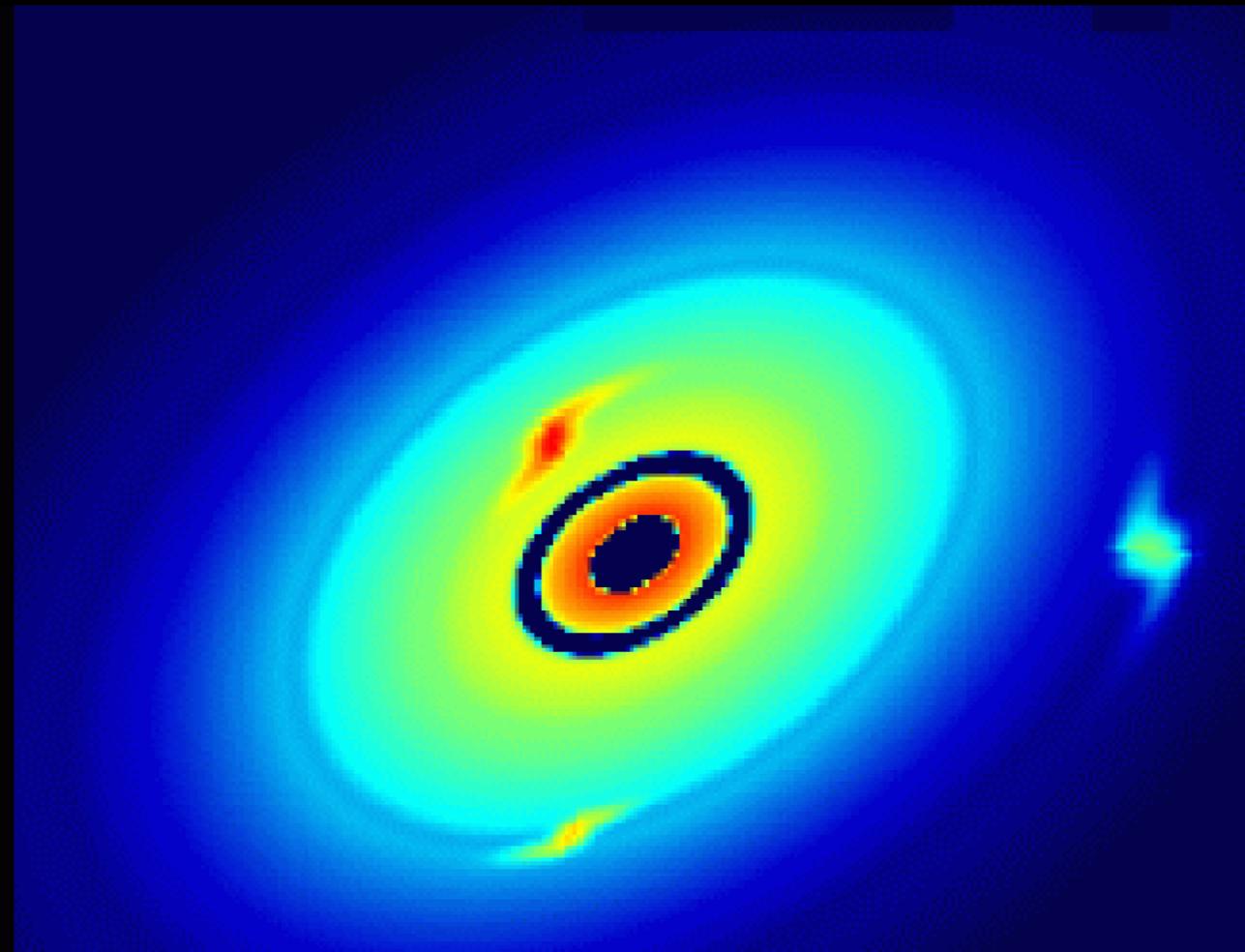
- Inside the disks where planets will form
- The region near the star and disk where streams of gas are ejected by the protostars



ALMA - Planet Formation



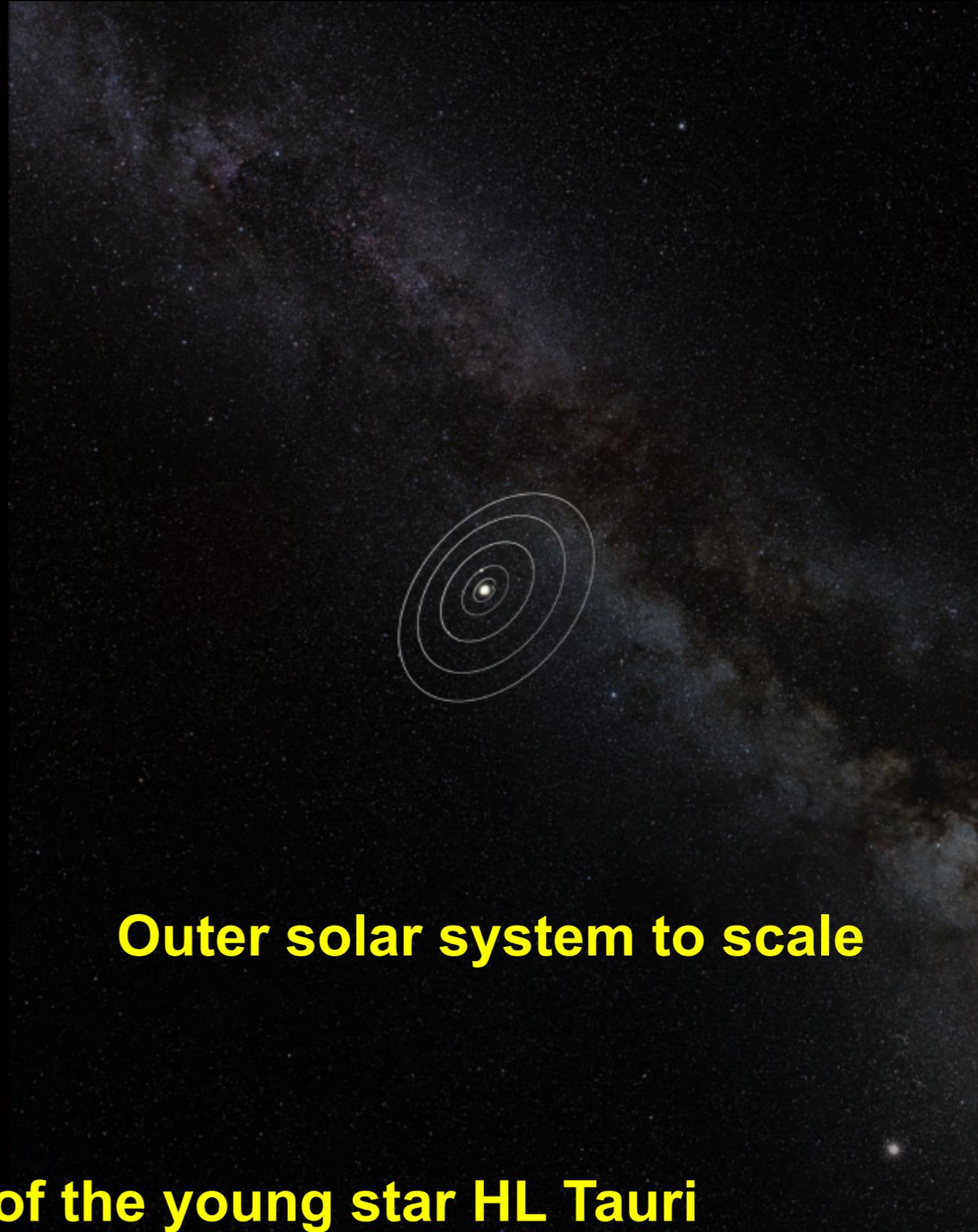
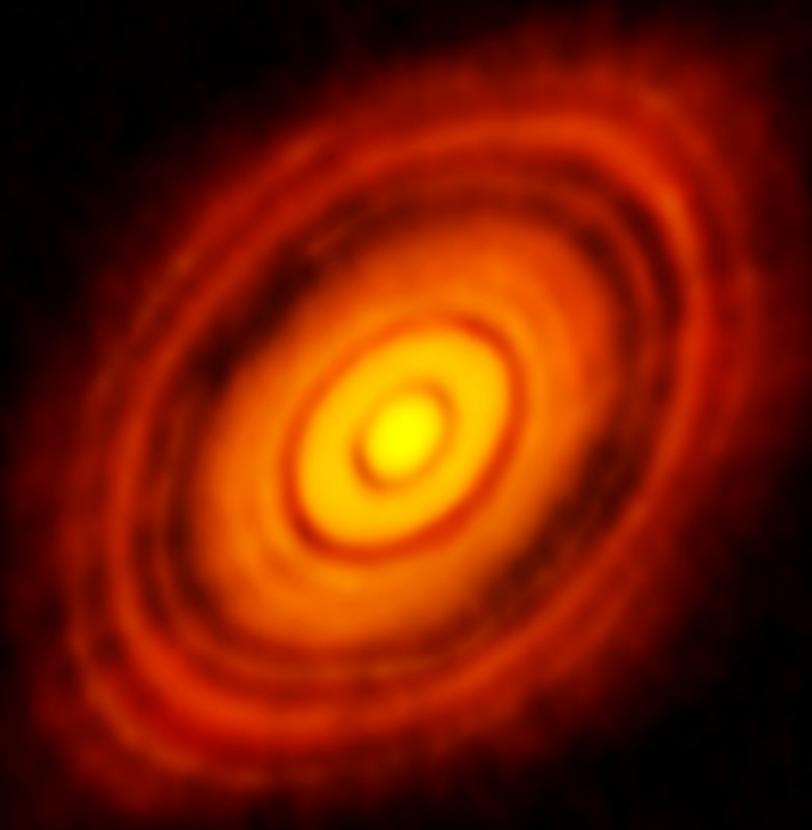
Simulated high-resolution ALMA observation - structures in the disk and proto-planets are detected



Computer simulation of a dusty disk around a newly-formed star with planets forming

These are simulations...

ALMA - Actual Observations!



Outer solar system to scale

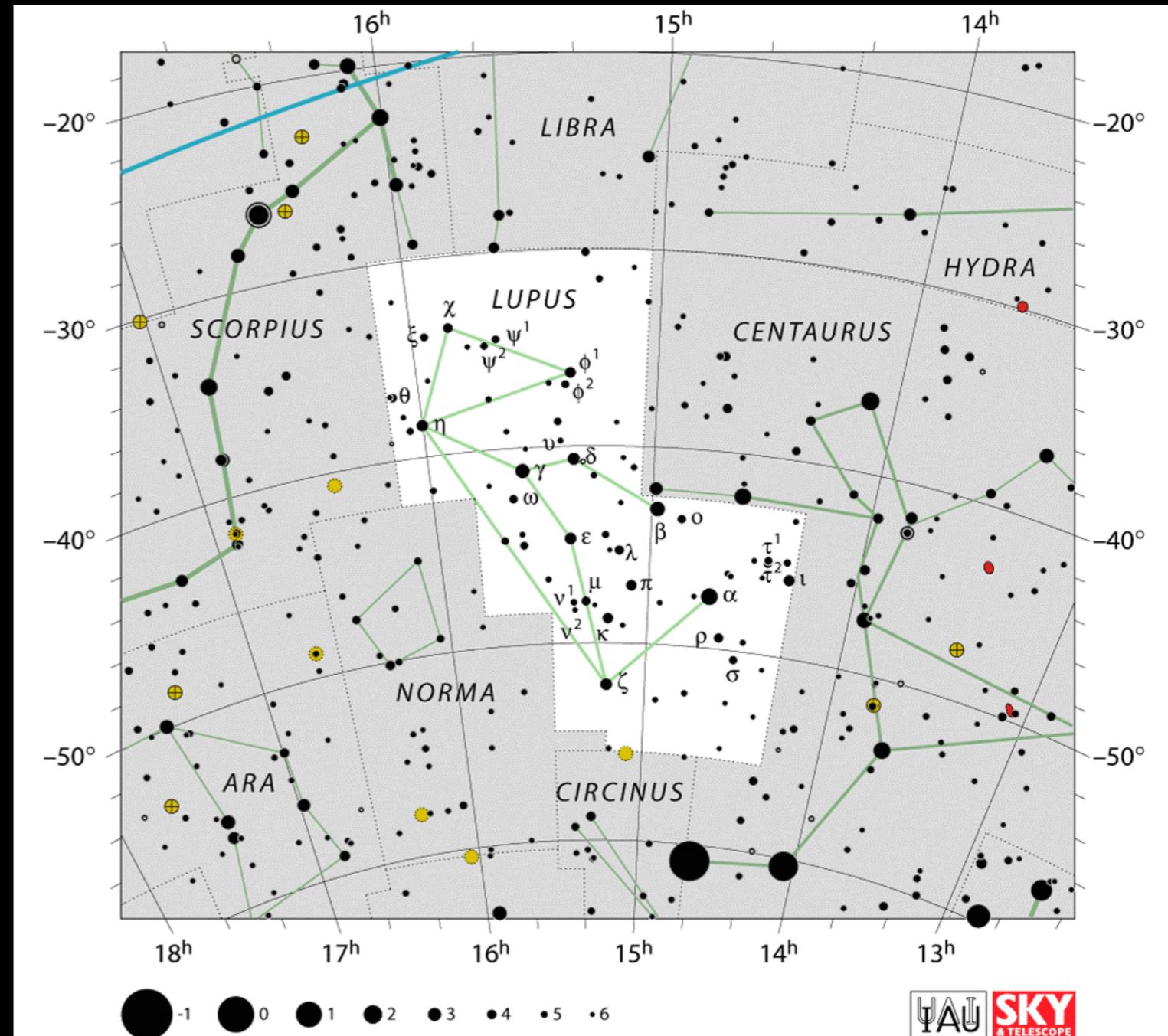
Planets forming in the dusty disk of the young star HL Tauri

The SOLA Project

A project by ALMA astronomers to study star formation in the southern sky

30 scientists from all the ALMA regions

Our target is star forming molecular clouds in the Lupus constellation



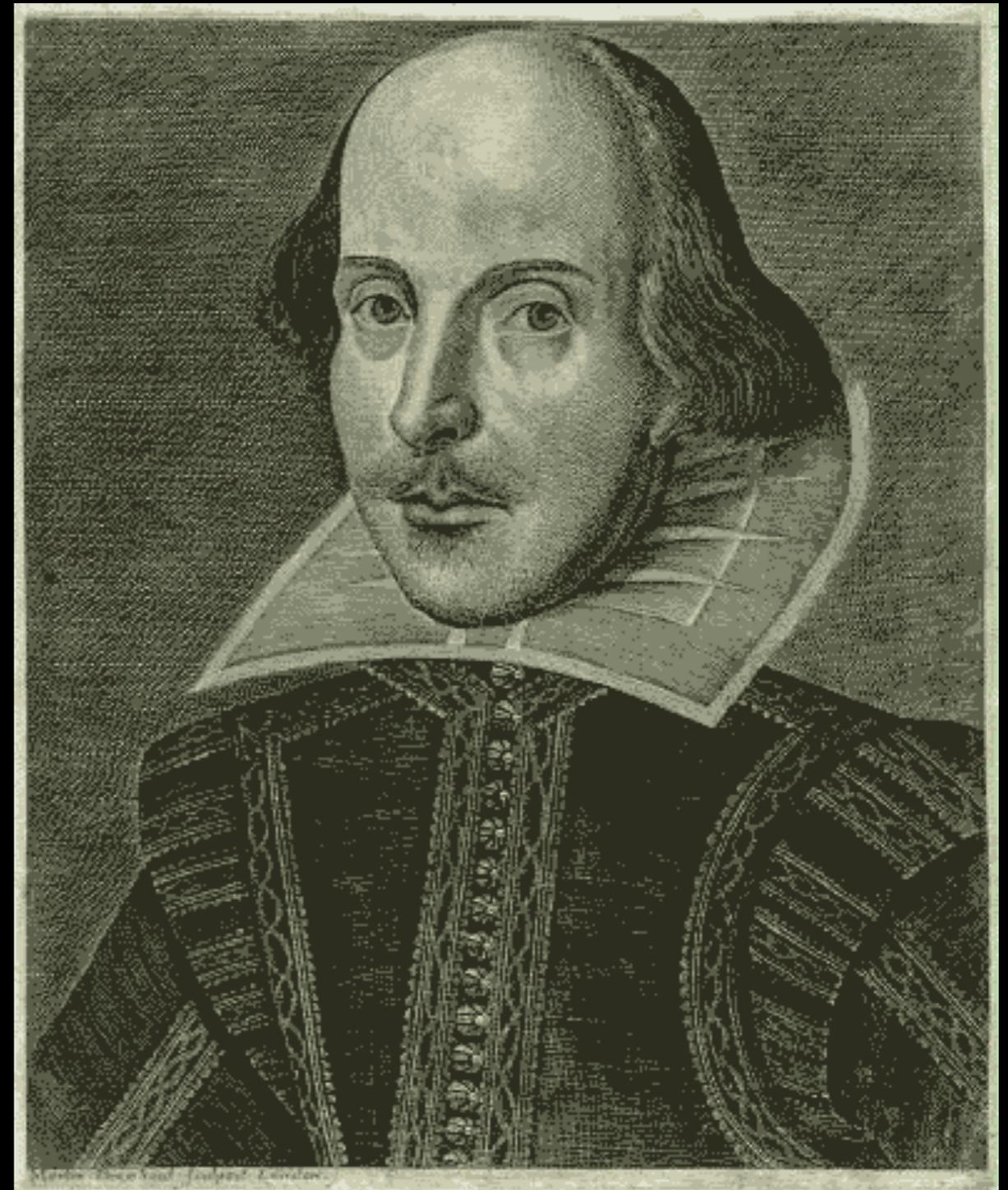
What's in a Name?

Professional astronomers *love* clever acronyms for their research projects

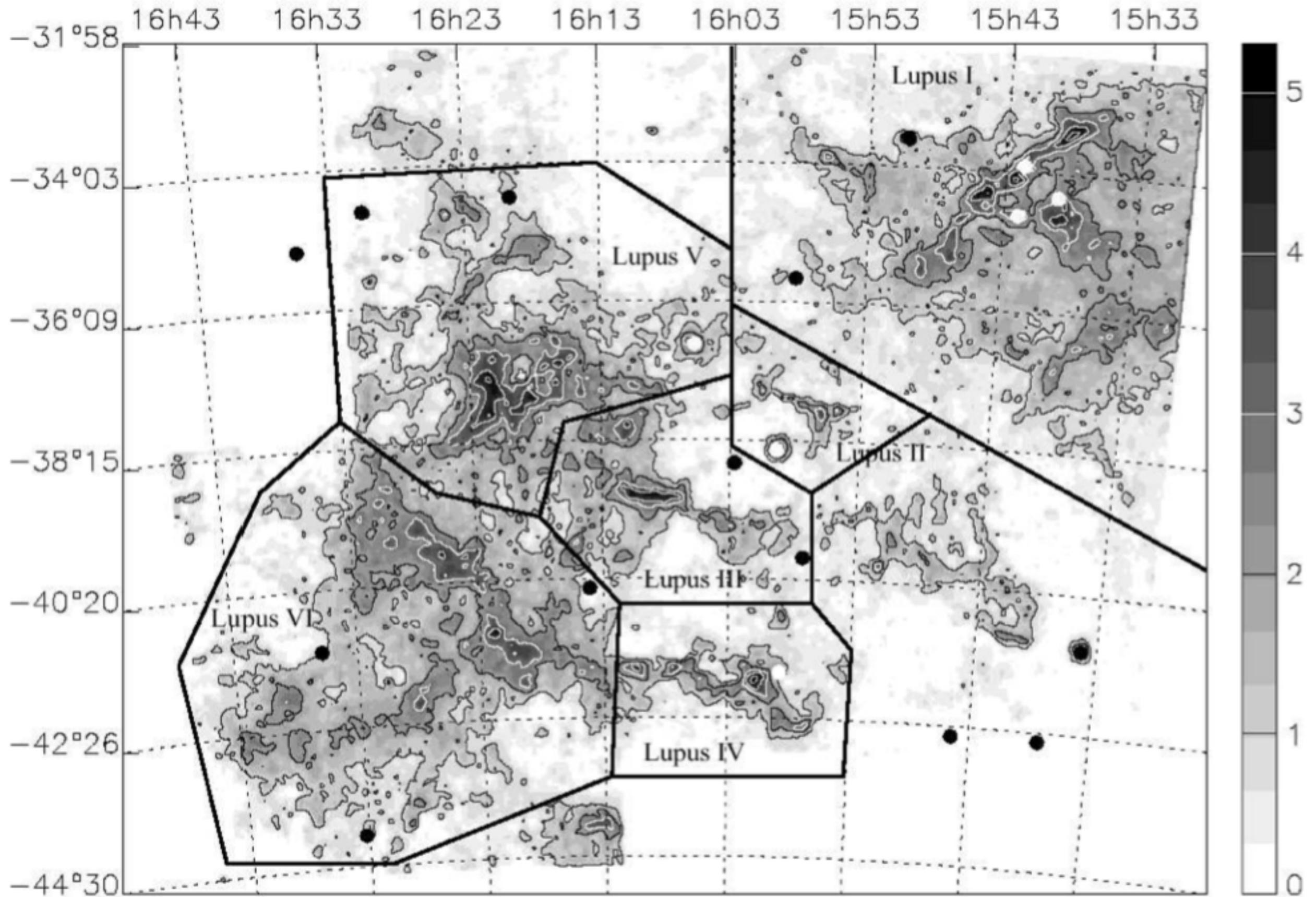
SOLA - “Soul of Lupus with **ALMA**”

“sola” means “sky” in Japanese and “solitary, alone, or unique” in Spanish

“alma” means “soul” in Spanish



Lupus Molecular Clouds

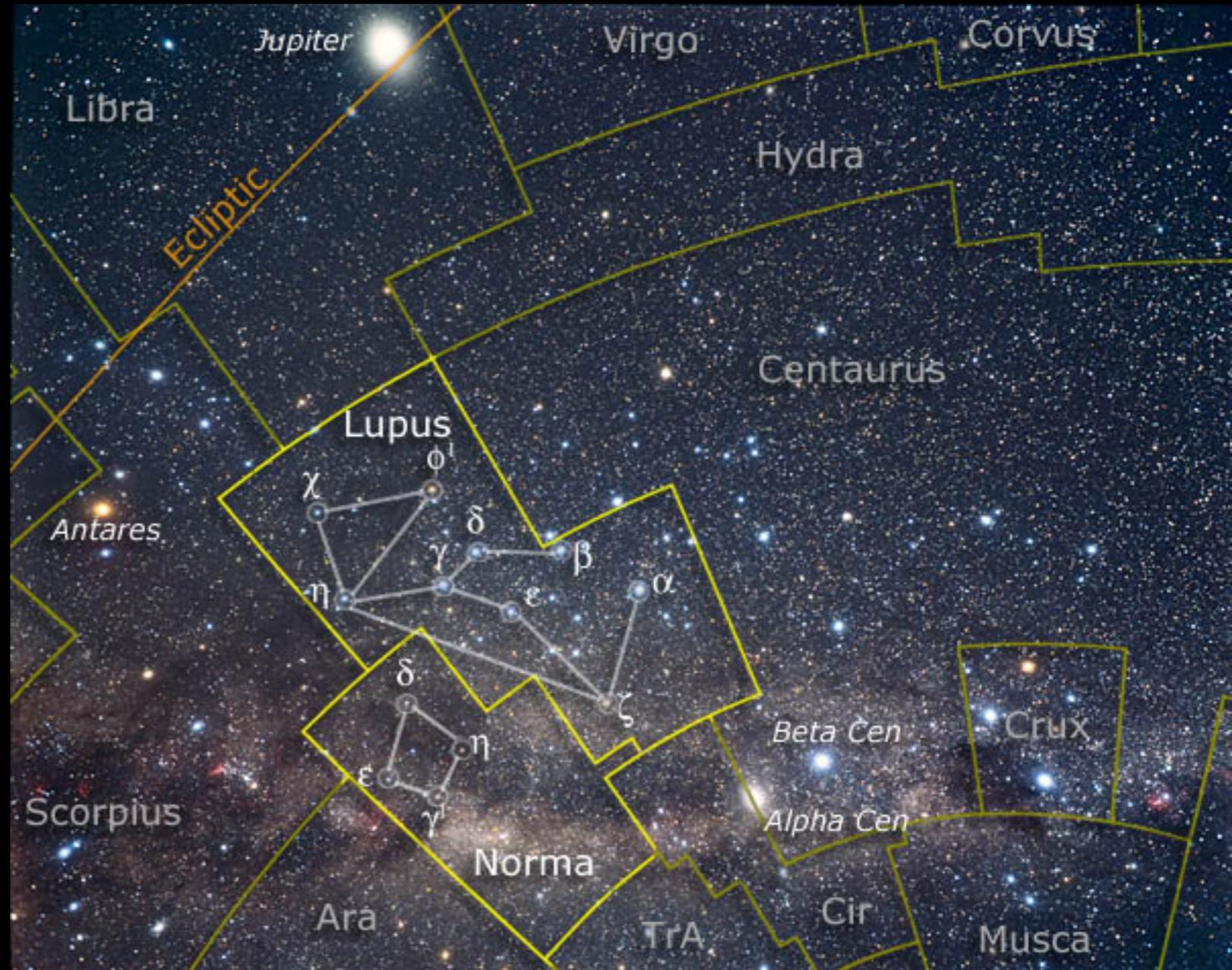


Why Lupus?

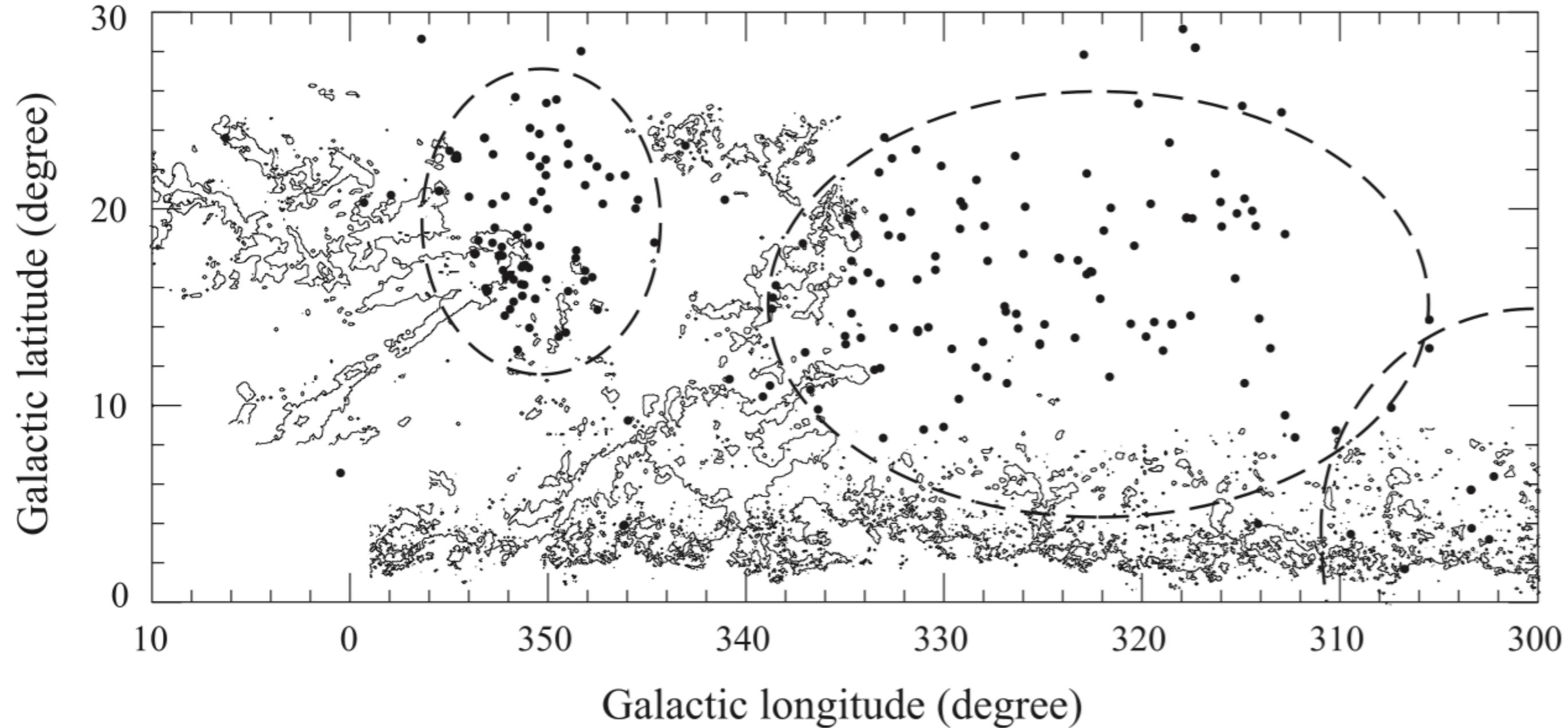
Southern - not well studied
Very well placed for ALMA observations

Nearby - 450 light years away

Rich in low mass young stars, especially low mass M dwarfs - an ideal laboratory to study very low mass star formation



Lupus lives in a rough neighbourhood...



Noisy neighbours - ionizing ultraviolet radiation, strong stellar winds, supernova explosions

Doing our homework



Observing time on ALMA is very hard to get (10% chance!). Already about 200 papers published since 2012.

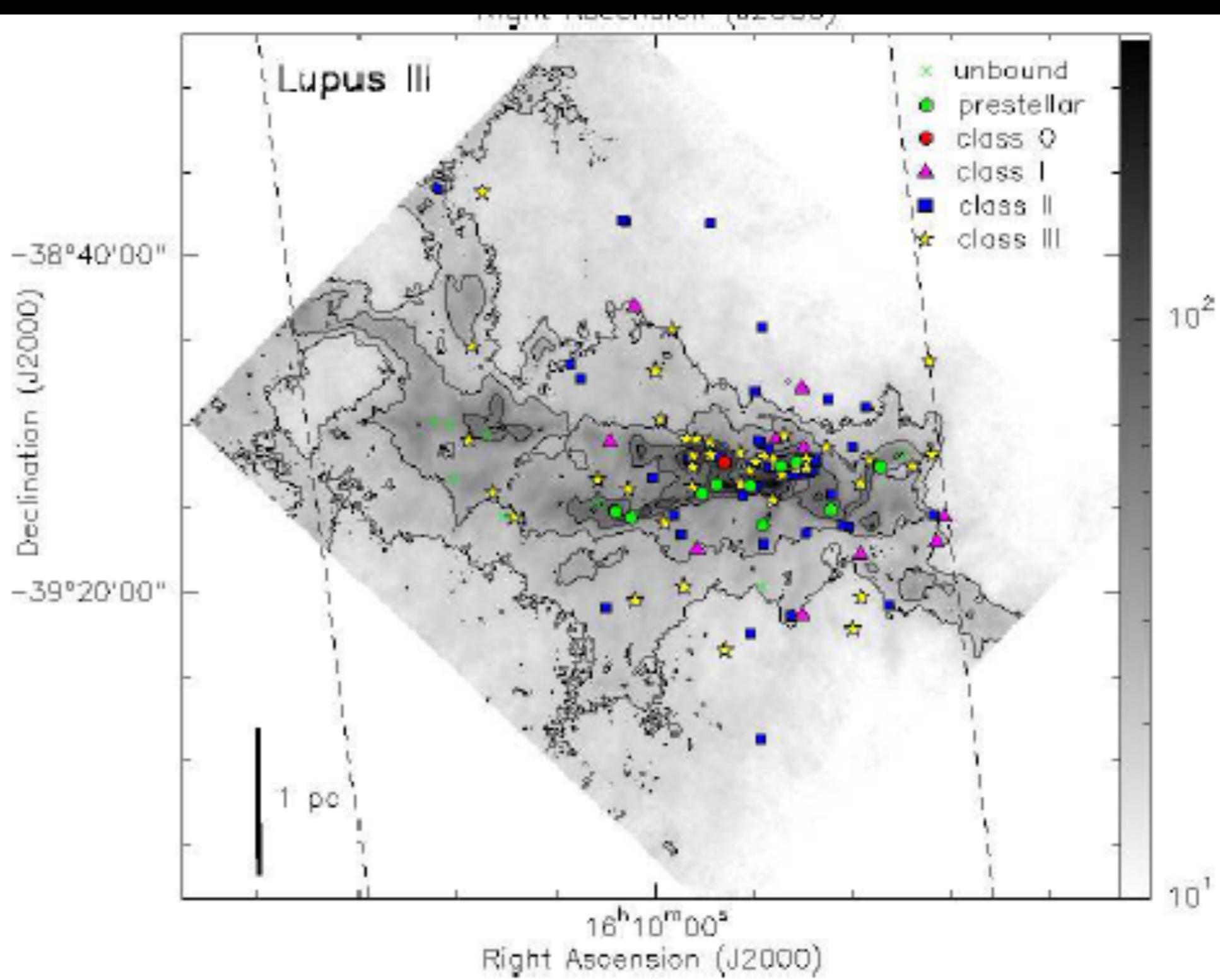
Critical to prepare carefully

- Survey what is known about Lupus
- Preparatory observations from other telescopes



ESA's Herschel Space Telescope (far-infrared and sub millimetre)

**Lupus III
Pre-protostellar
cores,
protostars, and
young stellar
objects**

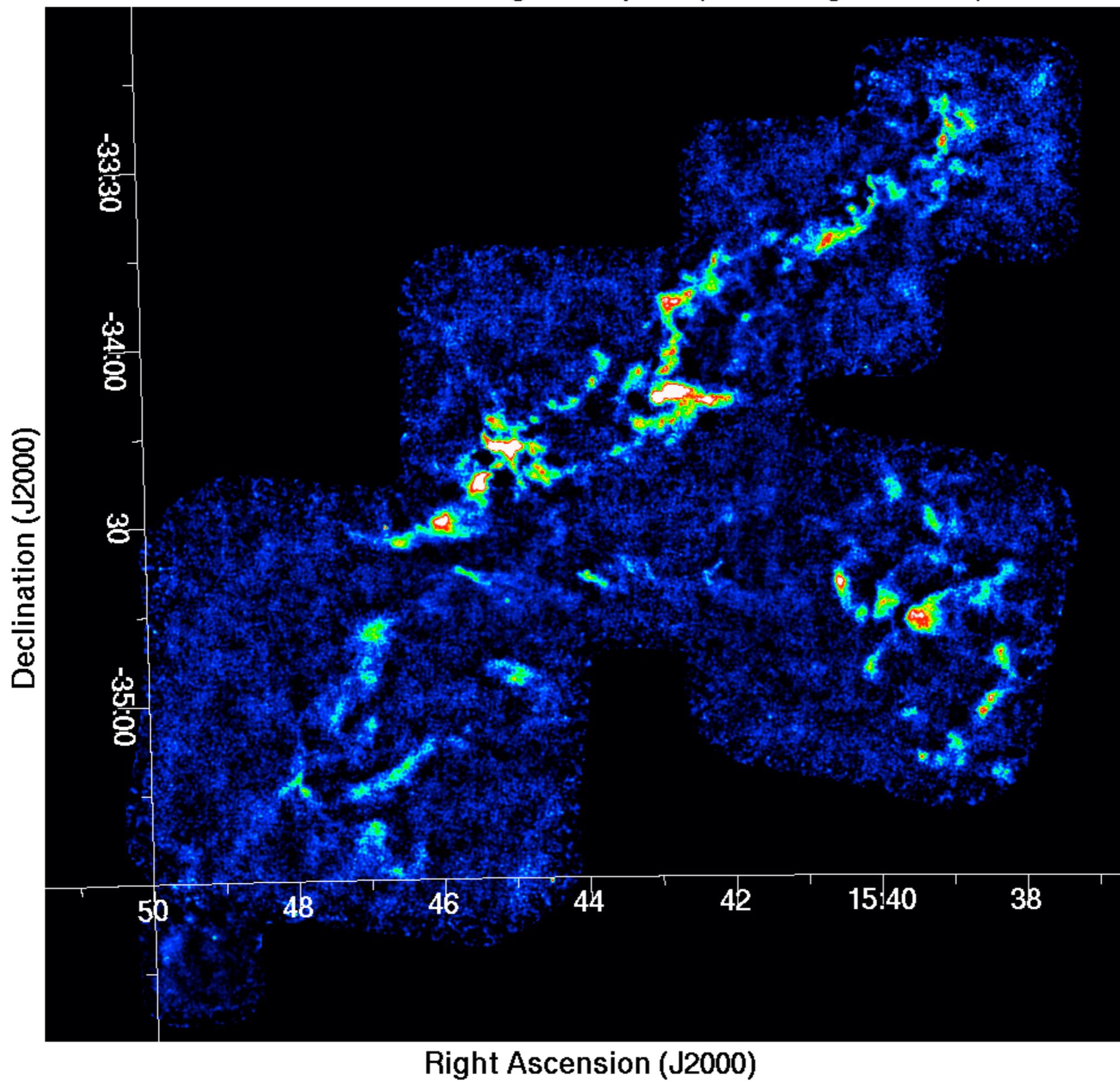


ASTE - Atacama Submillimetre Telescope Experiment



High resolution imaging of dust in the Lupus clouds to identify interesting molecular cores for further study with ALMA using the AzTEC 144-pixel millimetre-wave “camera”

ASTE/AzTEC Dust Image of Lupus I (Wavelength 1.1 mm)



ALMA - Taking the plunge...

Fourth round of ALMA proposals submitted by the international astronomical community

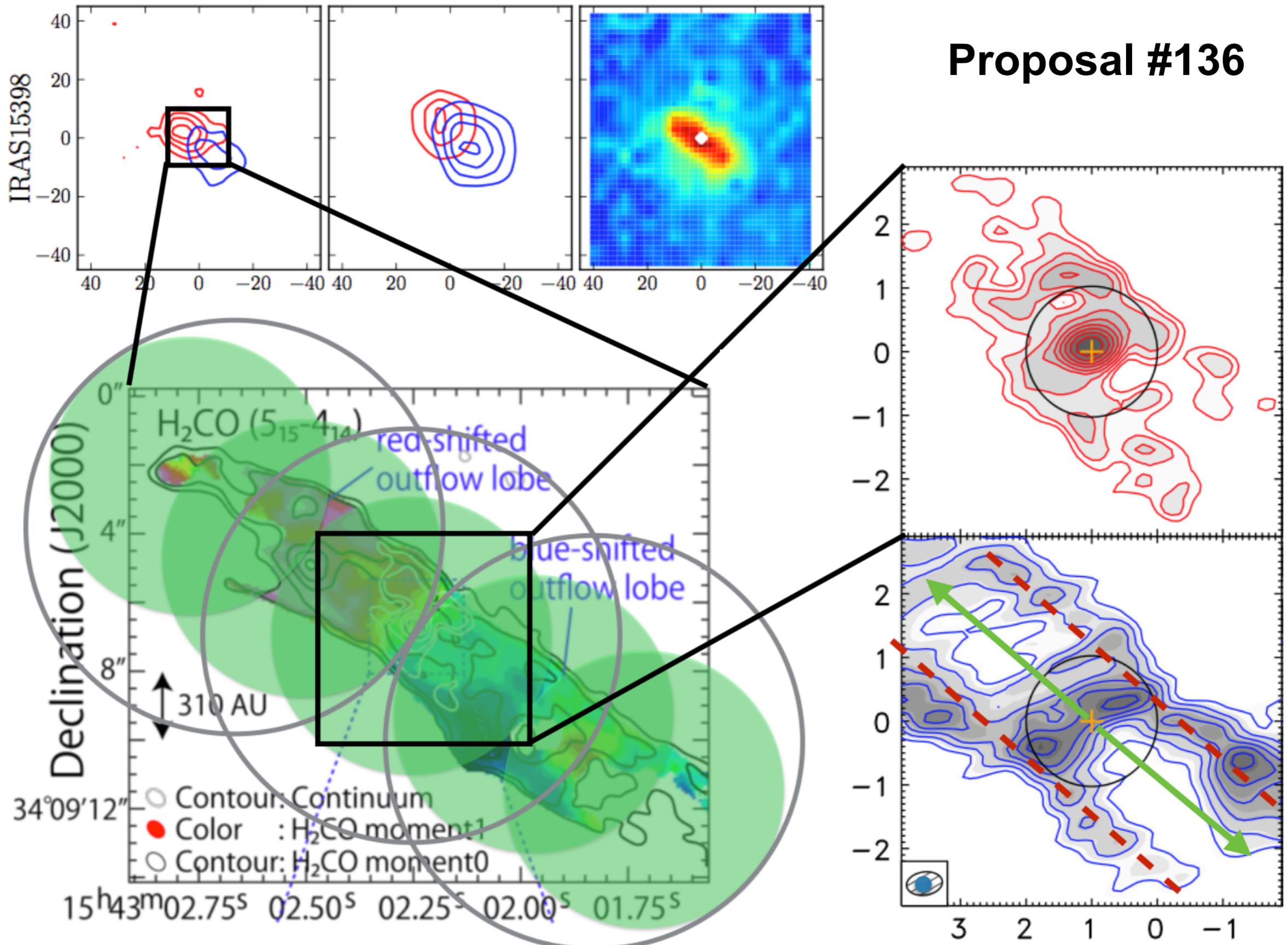
1582 proposals received. A new record...

The SOLA consortium submitted 5 proposals to ALMA



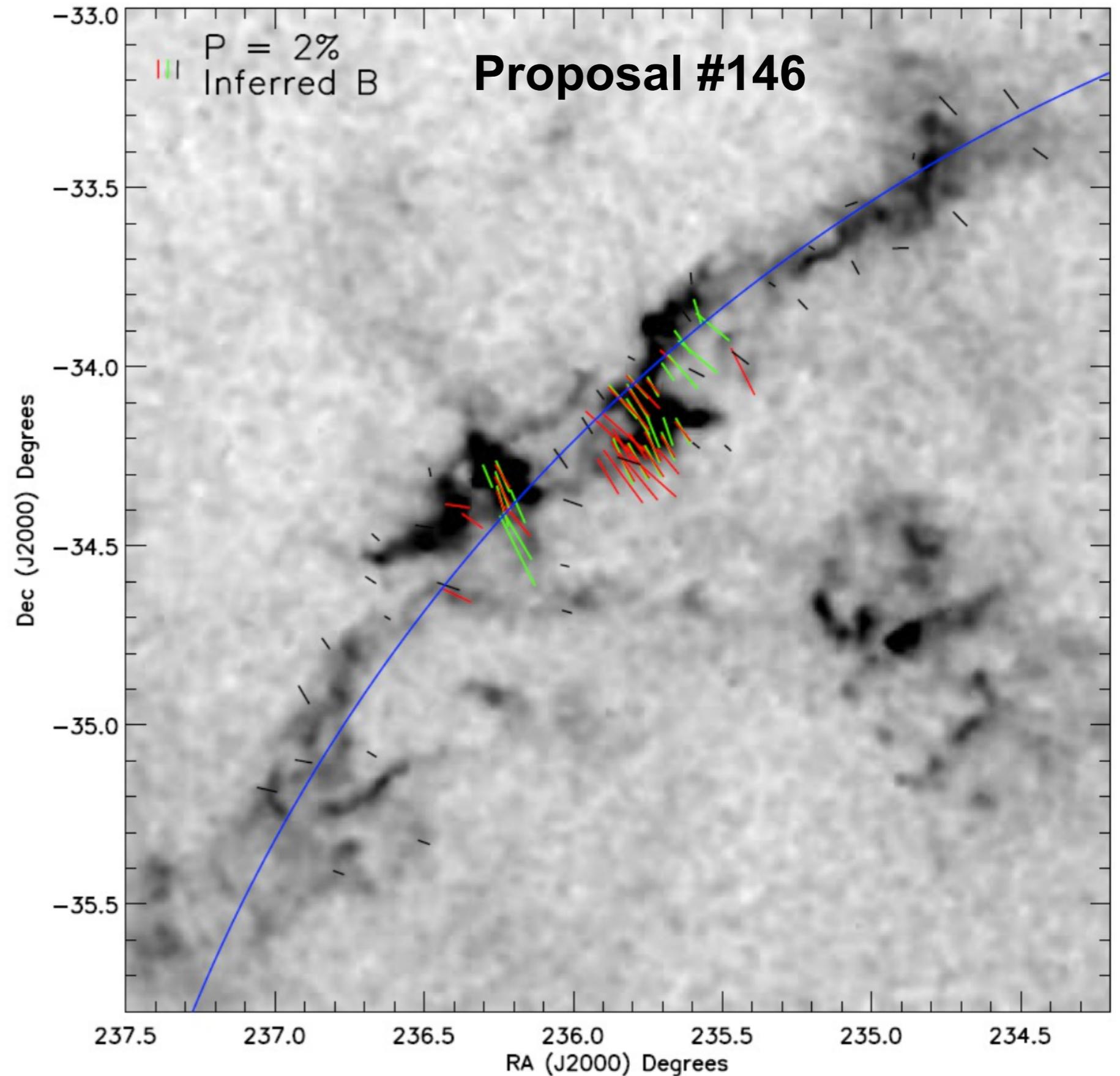
Searching for the protostellar jet in IRAS15398 in atomic carbon at 809 GHz

Proposal #136



Mapping magnetic fields around protostars in Lupus I

Do magnetic fields in protostars stay aligned with the field in the surrounding cloud?



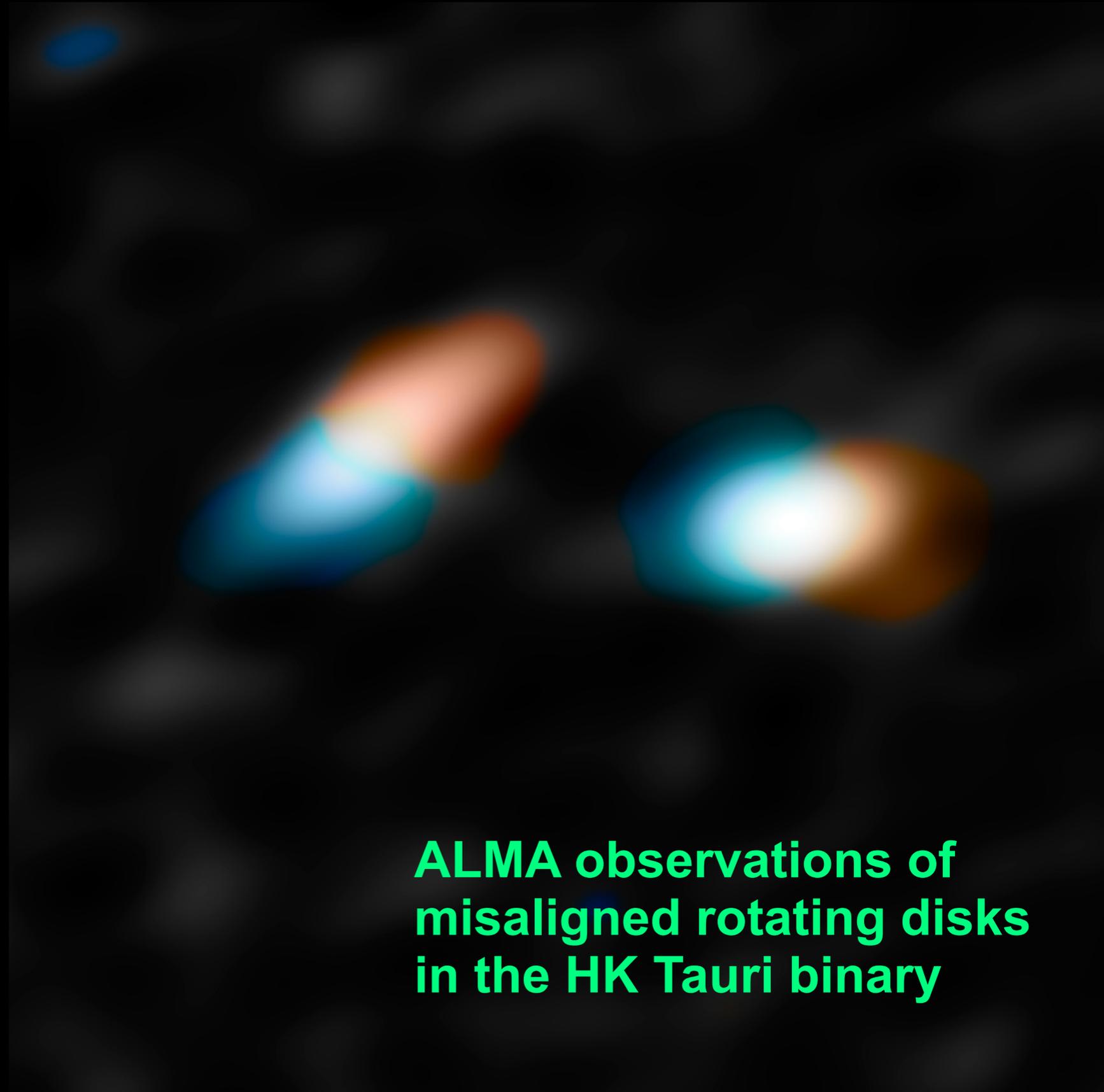
Searching for disks around young binary stars

Do disks always form around both stars in a binary?

Does the more massive star always have the more massive disk?

Do the disks interact?

Proposal #197



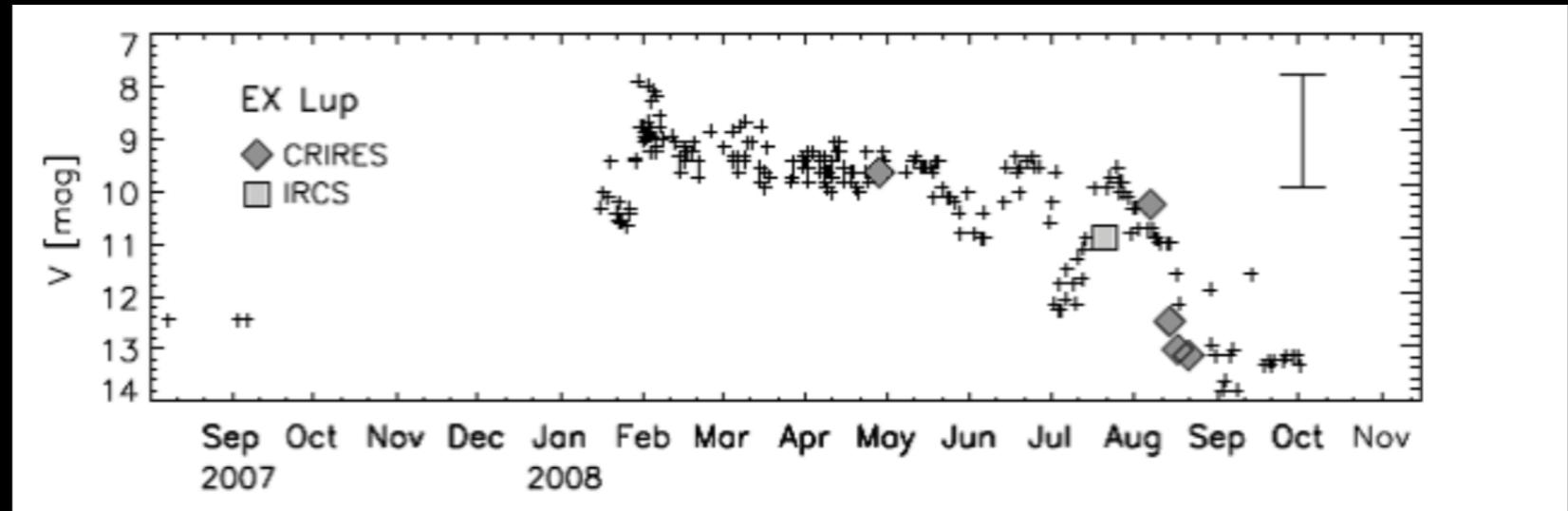
ALMA observations of misaligned rotating disks in the HK Tauri binary

Probing the envelope and disk of the outburst young variable EX Lupi

Prototype of the “EXor”
young stellar object
irregular variables

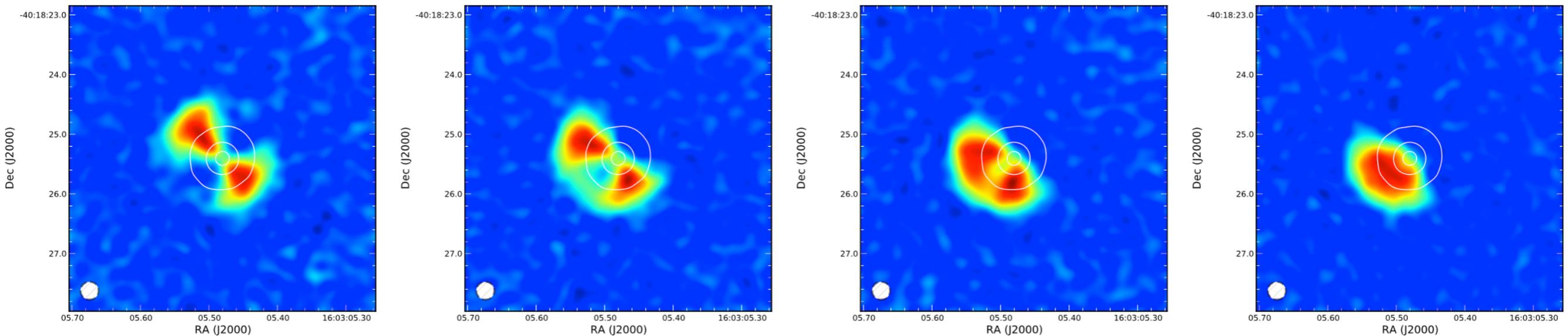
Outbursts thought to be
triggered by accretion
events from the
surrounding envelope to
the star via the disk

Proposal #200



Optical variability - outburst in 2008

Model prediction for disk in CO gas

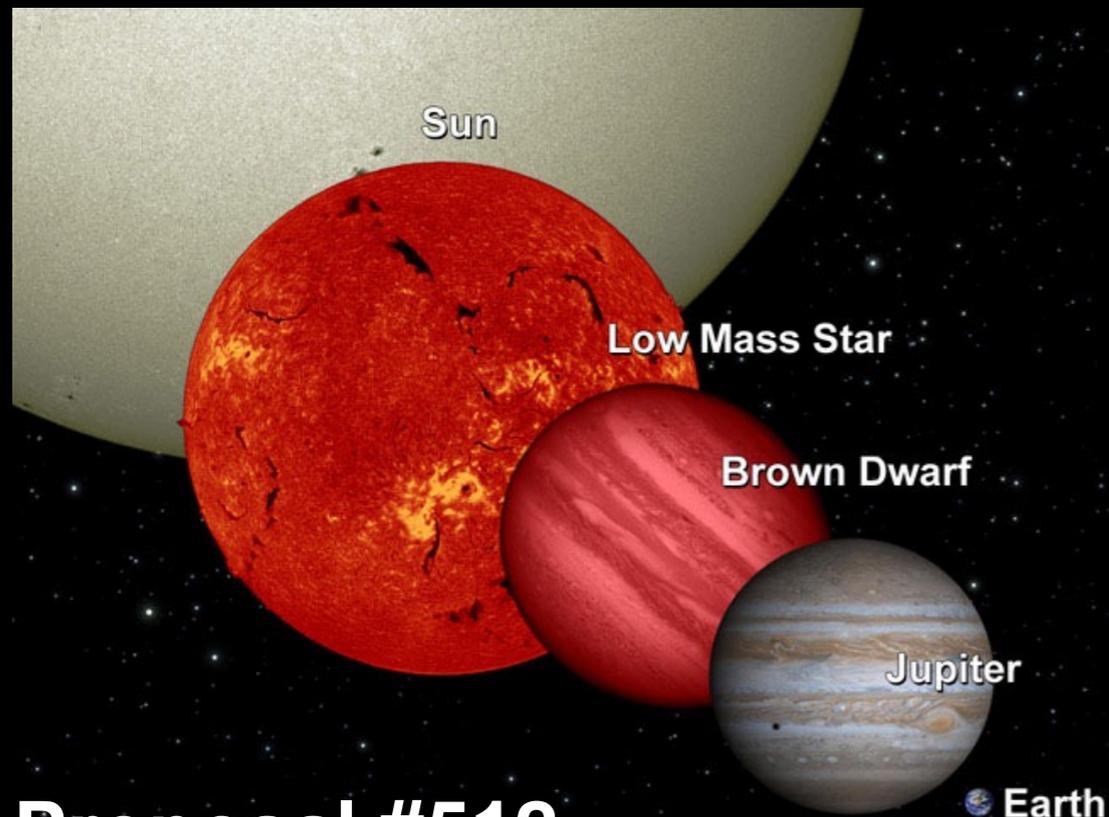


Searching for young brown dwarfs and proto-brown dwarfs

How do brown dwarfs form?

Do they have disks and thus maybe their own planets?

Do they also drive protostellar outflows?



Proposal #512



Our goal is to make Lupus as important a region for understanding low mass star formation as any of the traditional clouds in the north such as Perseus and Taurus. ALMA is the tool to achieve that.



**Thank you!
Gracias!
ありがとうございます**