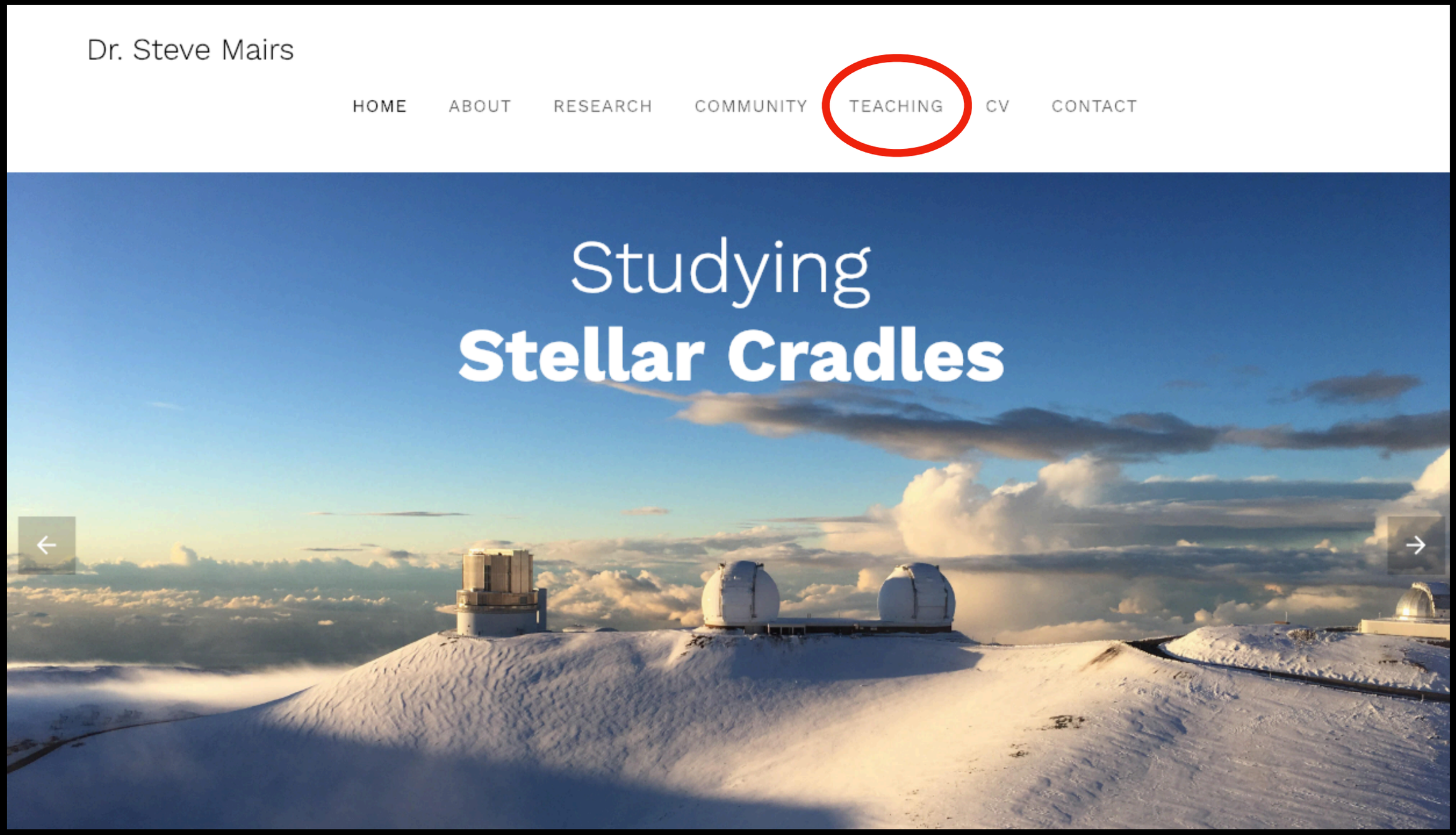
ASTR 351L: Introduction

Dr. Steve Mairs (ASTR351L Spring 2019)

Finding Information

Website: https://www.eaobservatory.org/~s.mairs



Email: s.mairs@eaobservatory.org

Overview

1. **An Introduction to the JCMT**

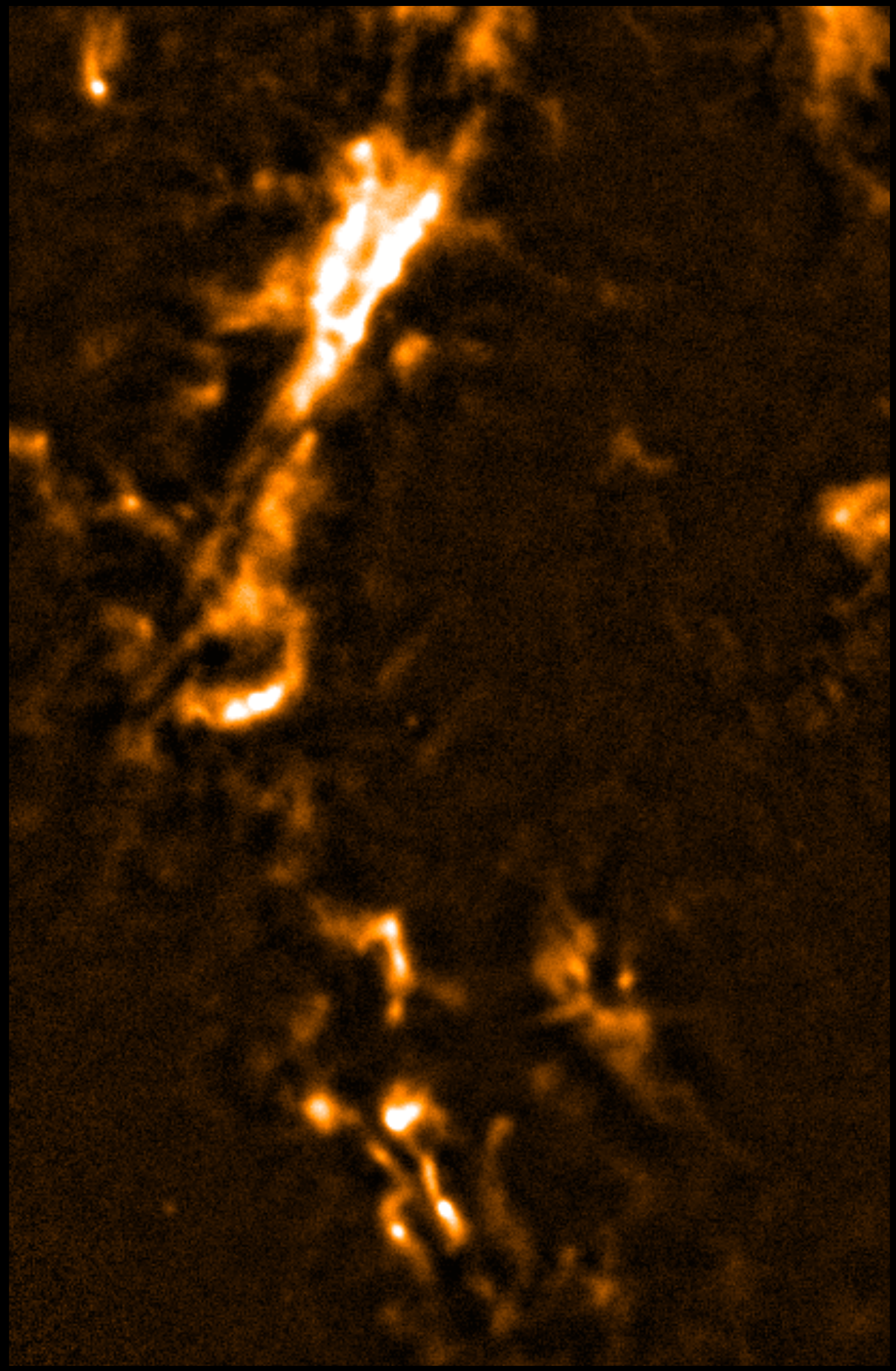
2. **Instruments:**

- ★ **SCUBA-2**
- ★ **POL-2**
- ★ **HARP**
- ★ **Nā maka nui**

3. **Science Highlights:**

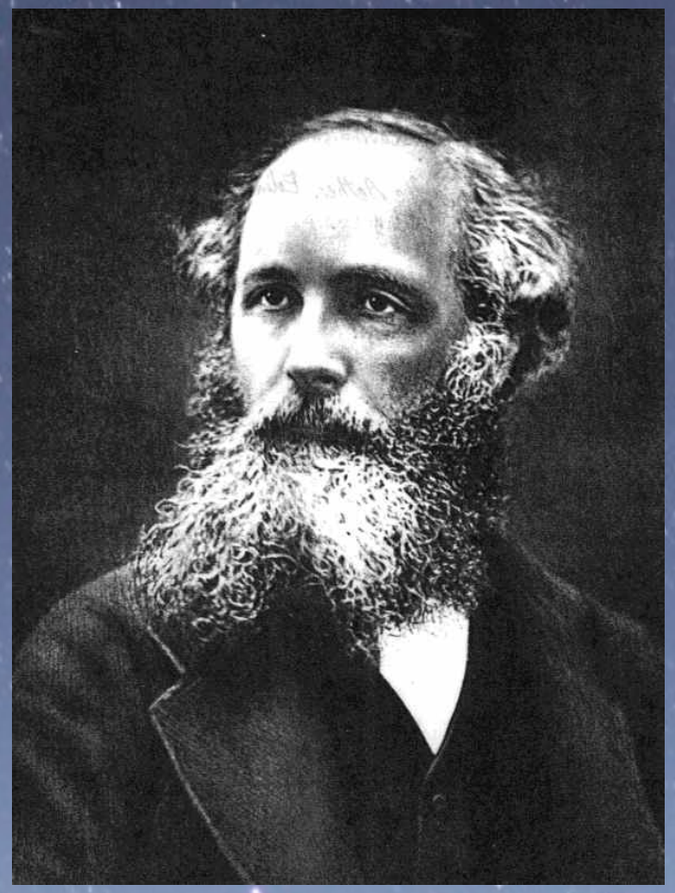
- ★ **Star Formation**
- ★ **Cosmology**
- ★ **Comets/Planets**
- ★ **Event Horizon Telescope**

4. **What the semester will look like**



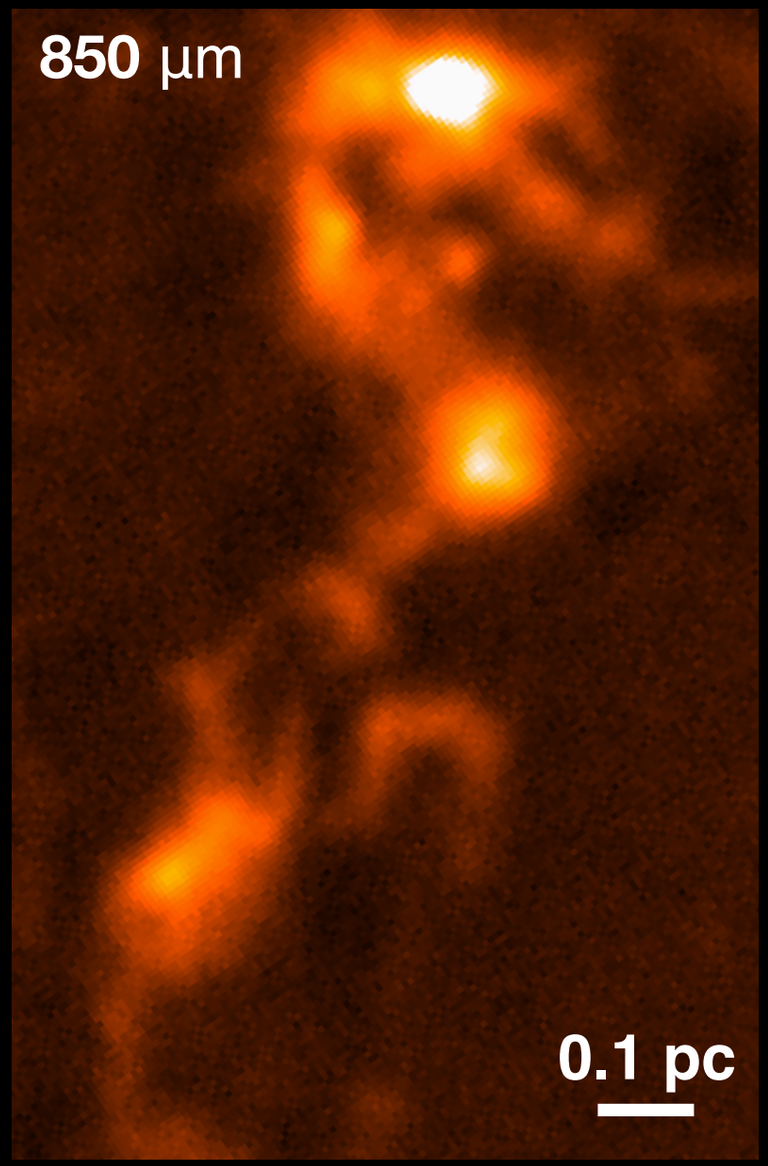
The Telescope

James Clerk Maxwell Telescope



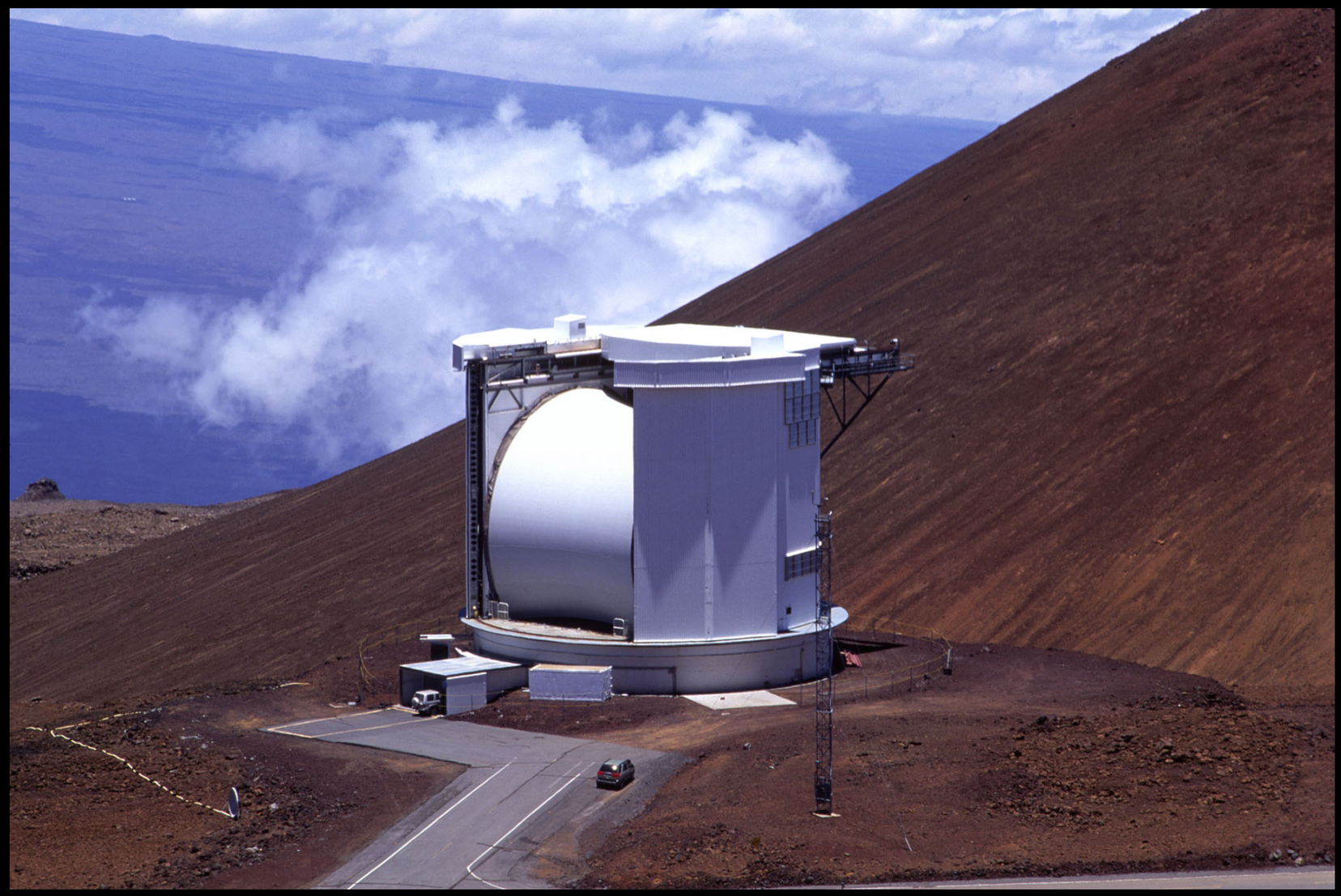
Submillimetre Valley

The James Clerk Maxwell Telescope



The JCMT is the **largest single dish (15 m) submillimetre telescope** on the planet

It is sensitive to cold, interstellar dust:
The birthplace of stars



JAC Observatory

NAOC 国立天文台 NAOJ KASI Korea Astronomy and Space Science Institute ASIAA

Submillimetre Light

Interstellar Dust
Far off Galaxies
Interesting Molecules

10^{-12} meters | 10^{-9} 1 nanometer | 10^{-6} 1000 nanometer | 10^{-3} 1 millimeter | 10^{0} 1 meter | 10^{3} 1 kilometer

Cosmic rays | **Gamma rays** | **X-rays** | **Ultraviolet (UV)** | **Infrared (IR)** | **Microwaves** | **Radar** | **Radio** | **Broadcast band**

Short Wavelenghts — **Long Wavelengths**

Ultraviolet (UV) | **Visible Light** | **Infrared (IR)**

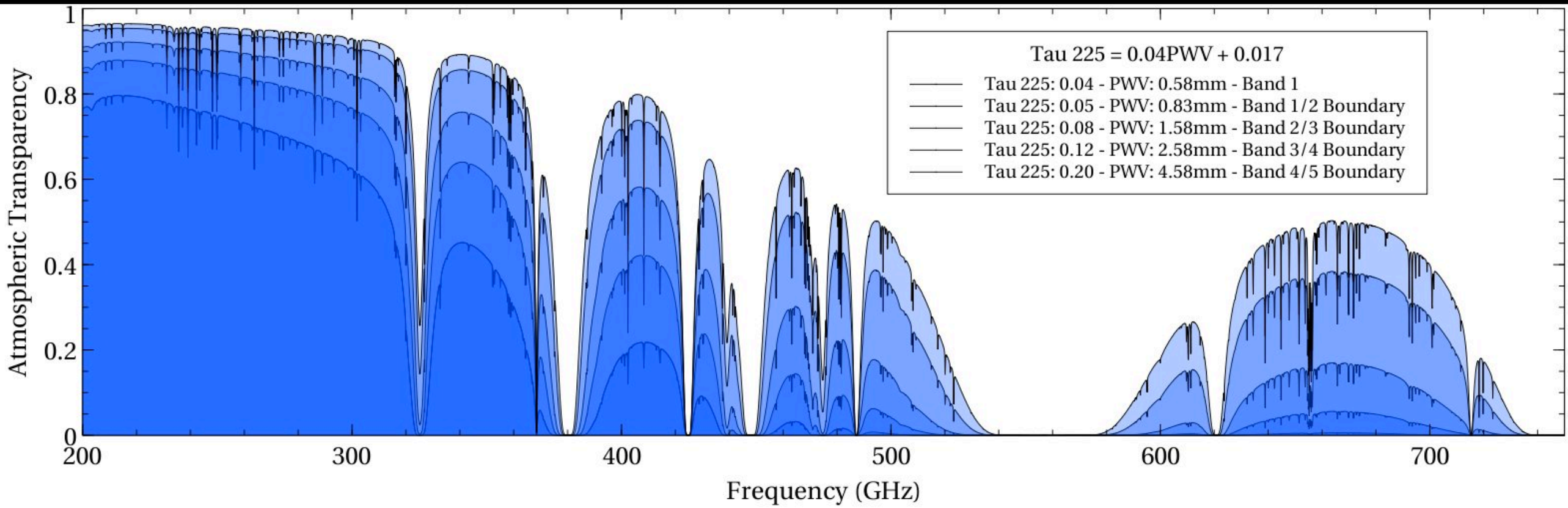
400 nanometers | 500 nanometers | 600 nanometers | 700 nanometers

Submillimetre Specialties

1. **Cold dust & gas in the local universe**
   (Molecular clouds, pre-stellar cores, debris discs…)

2. **Emission from heated dust at High Redshifts**
   (Star formation in the early universe, AGN Activity…)

Why Maunakea? Lack of Water Vapour!



The Surface

15 metre dish

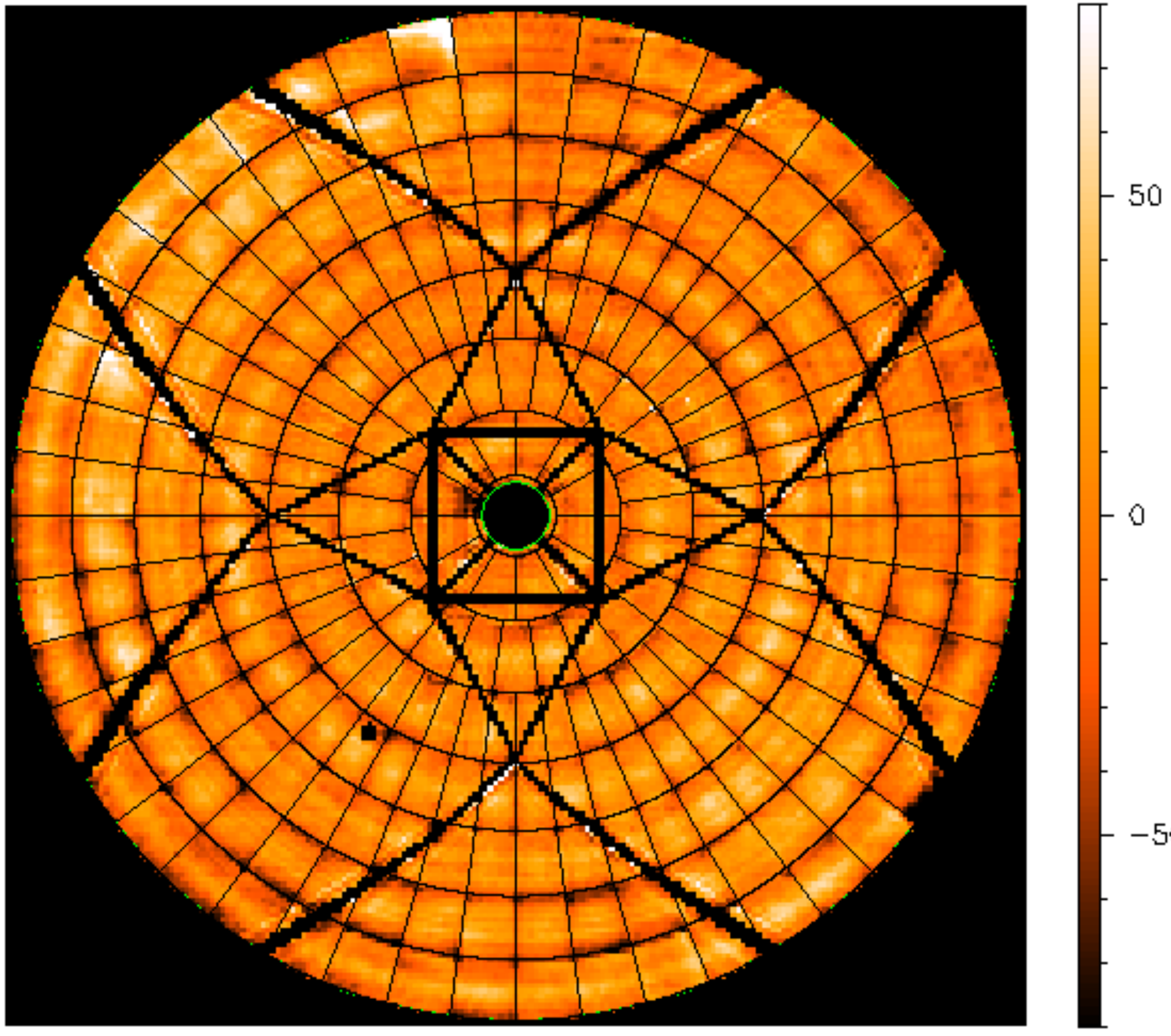
276 Aluminium panels

Each panel connected to 3 motors that make adjustments to dish shape

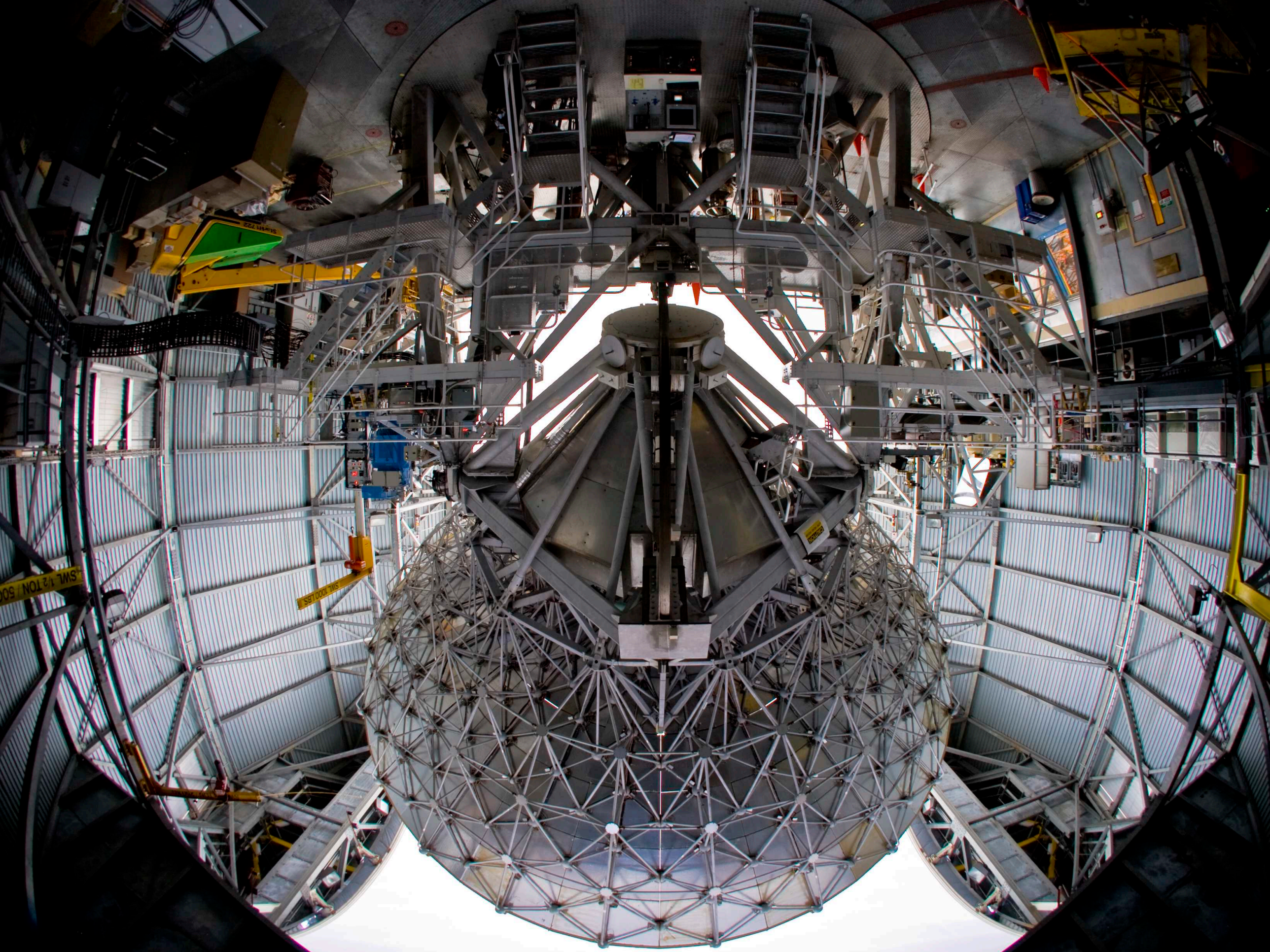
We turn on a signal at the United Kingdom Infrared Telescope (UKIRT) and point to it with the JCMT to measure the uniformity of our dish

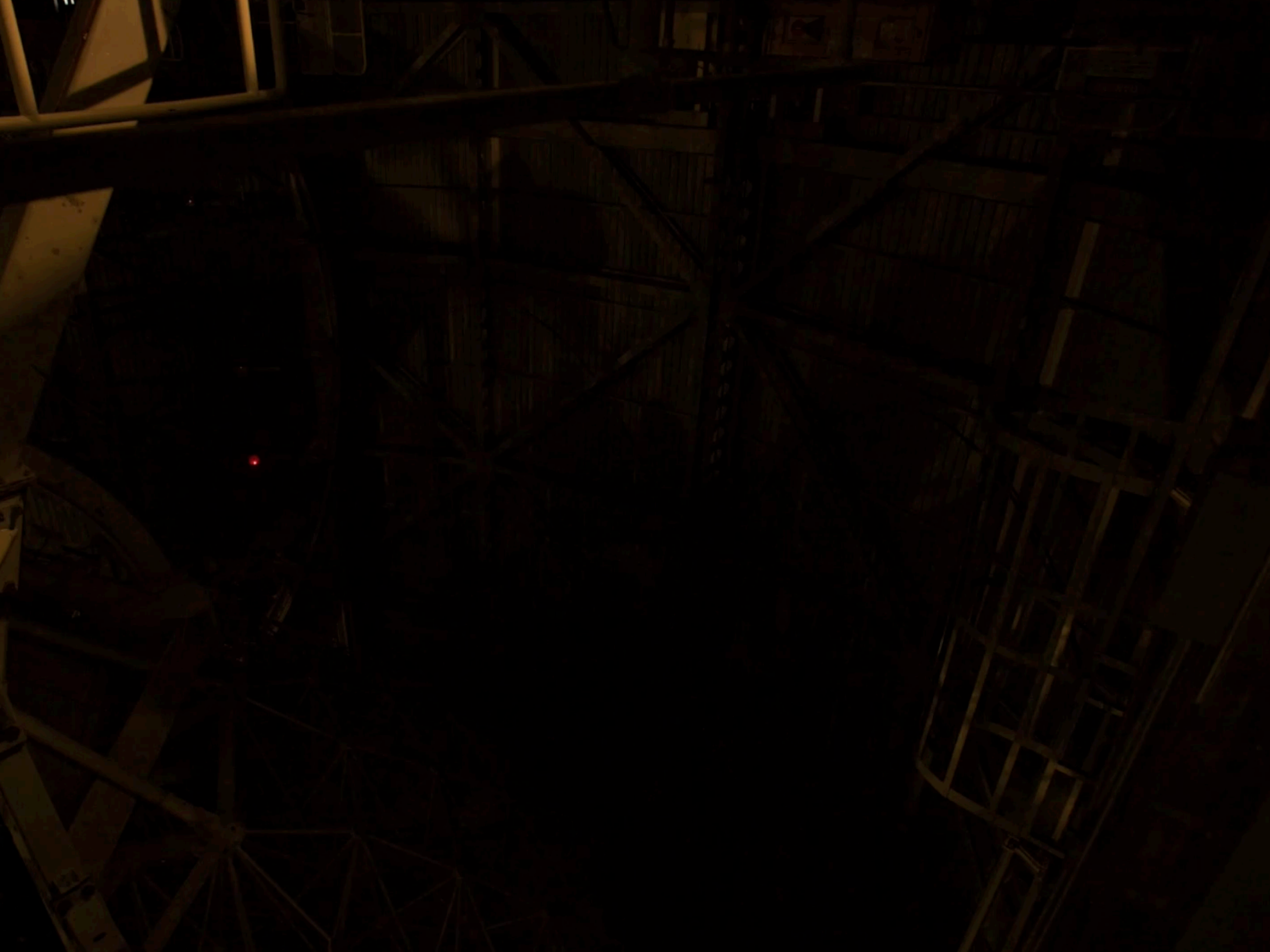
Correct for seasonal variations in temperature

20160430–004301: mean surface minus tilts+defocus



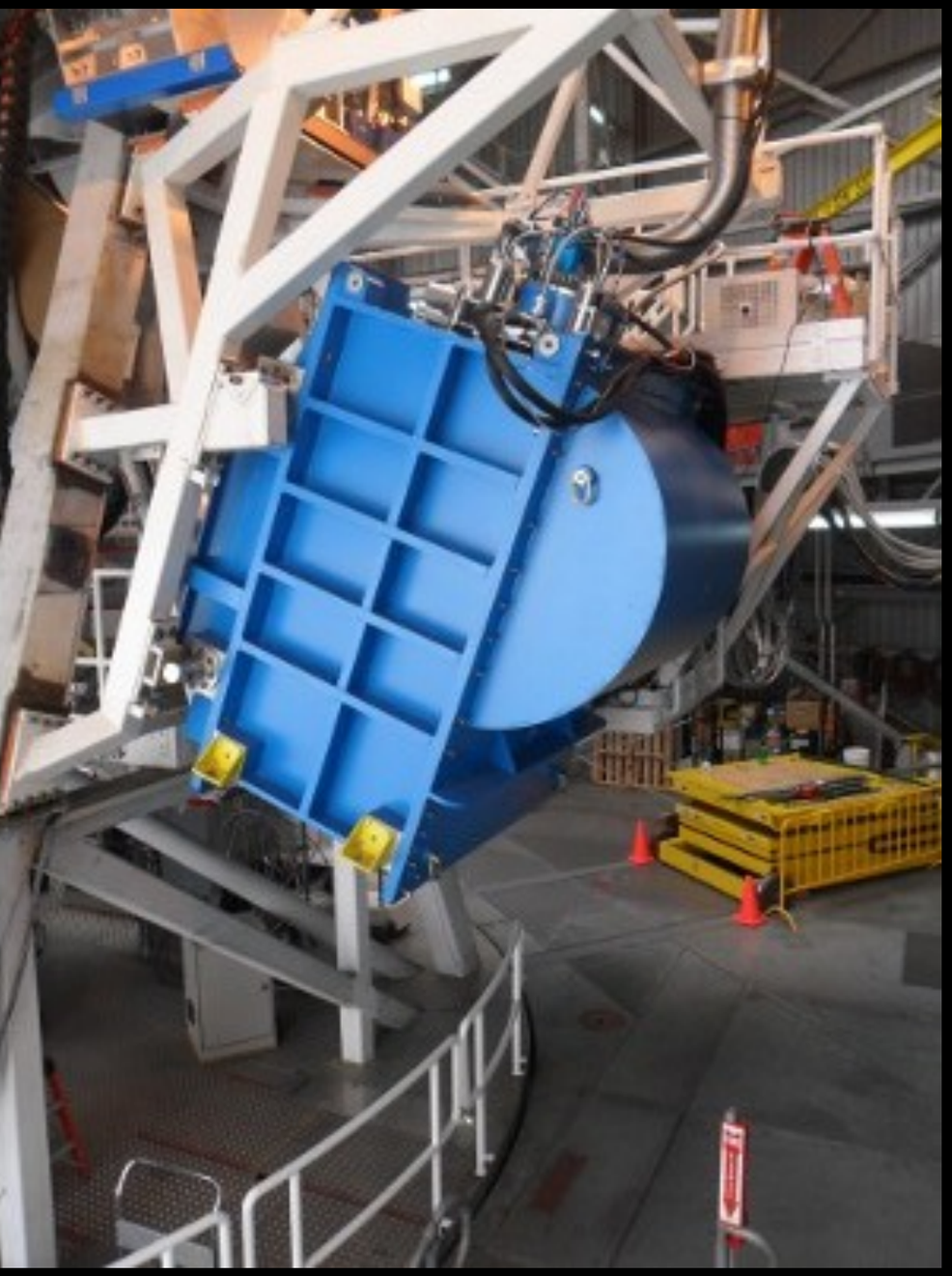
janw 2–May–2016 09:04





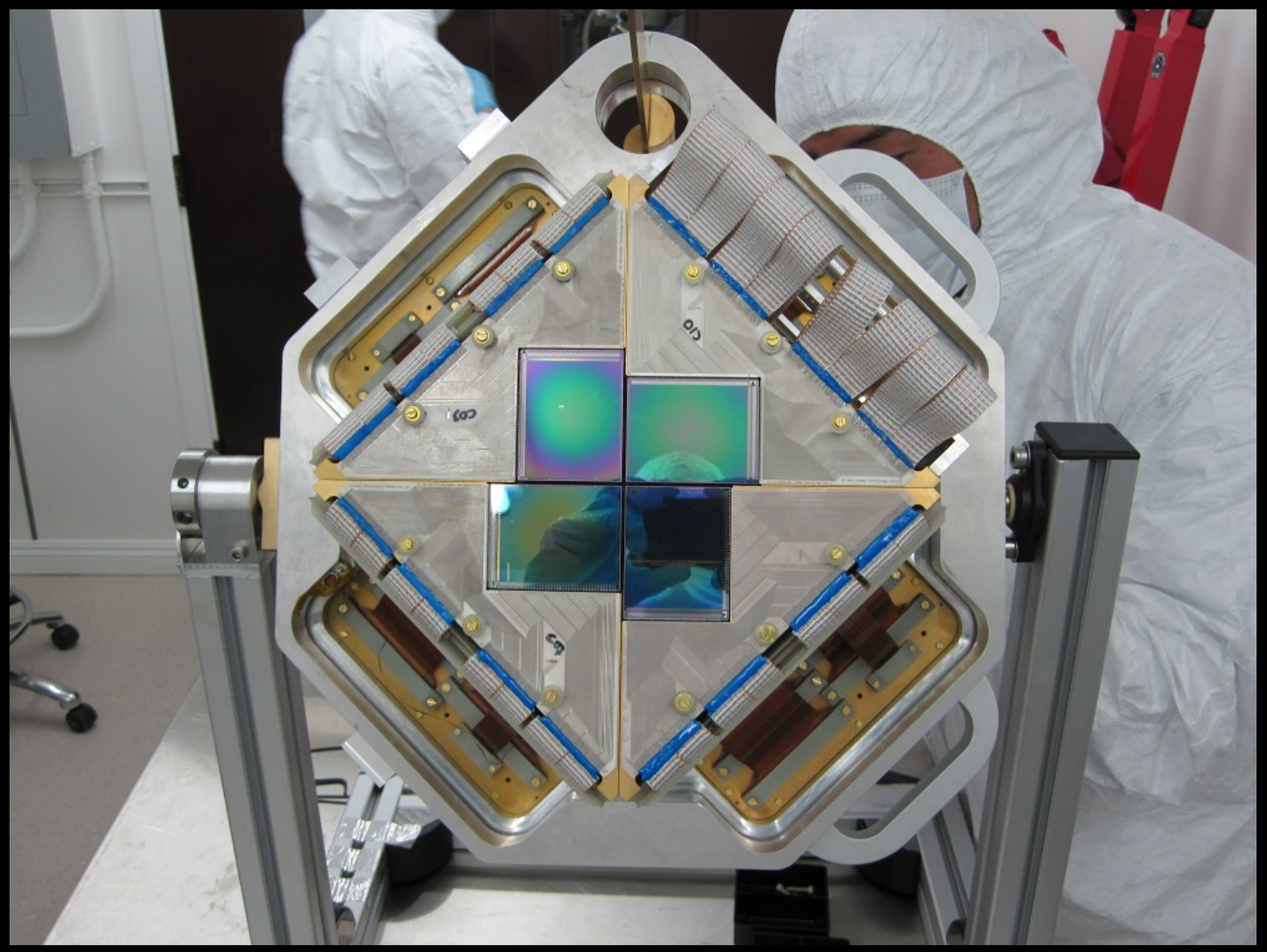
The Instruments: SCUBA-2

SCUBA-2: Instrument Overview



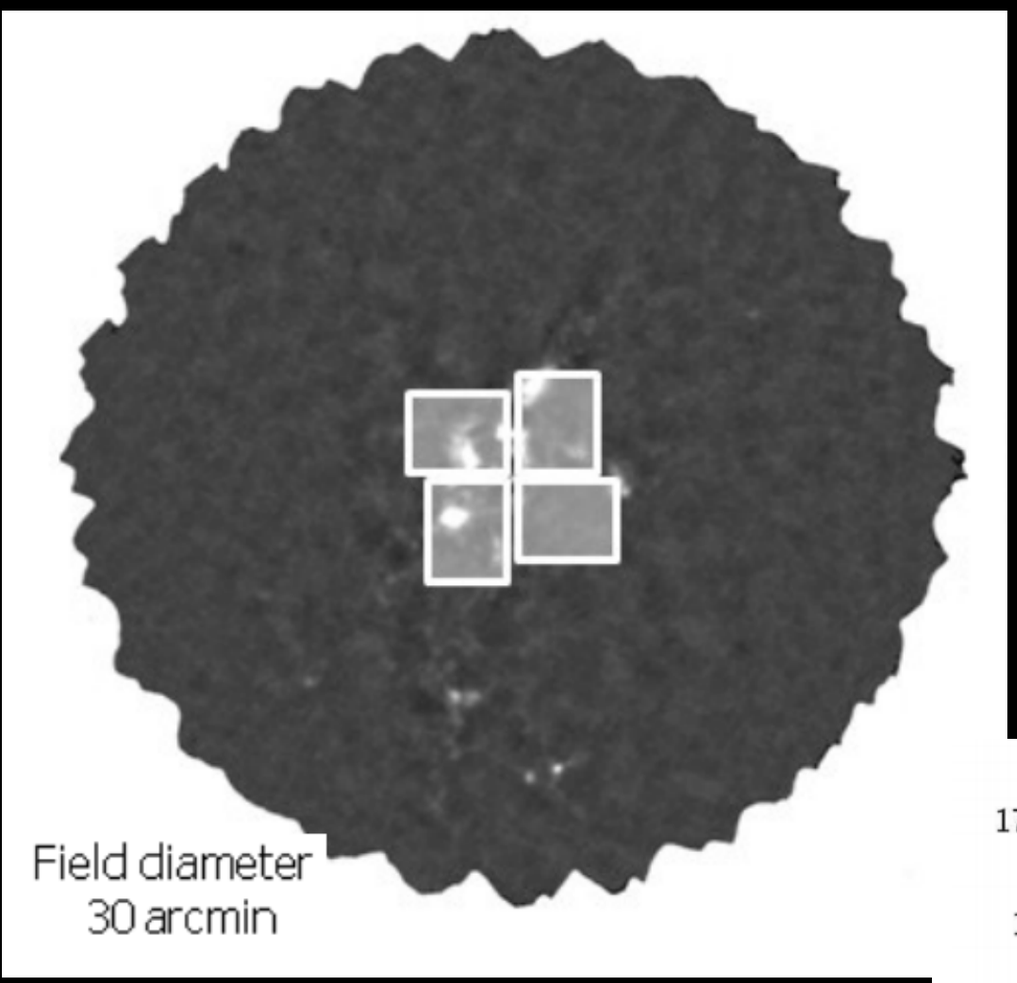
Continuum Imager:
850 μm and 450 μm Simultaneously

4 subarrays each consisting of 40 x 32 =
5120 bolometers at each wavelength



Beam @ 450um = 9.8”
Beam @ 850um = 14.6”

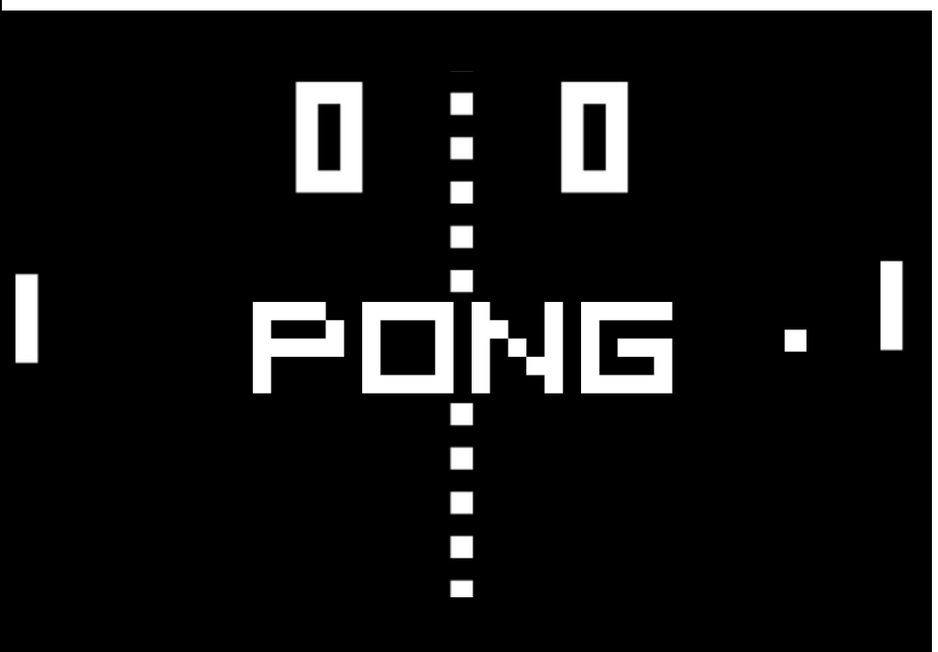
SCUBA-2: PONG Observing Mode

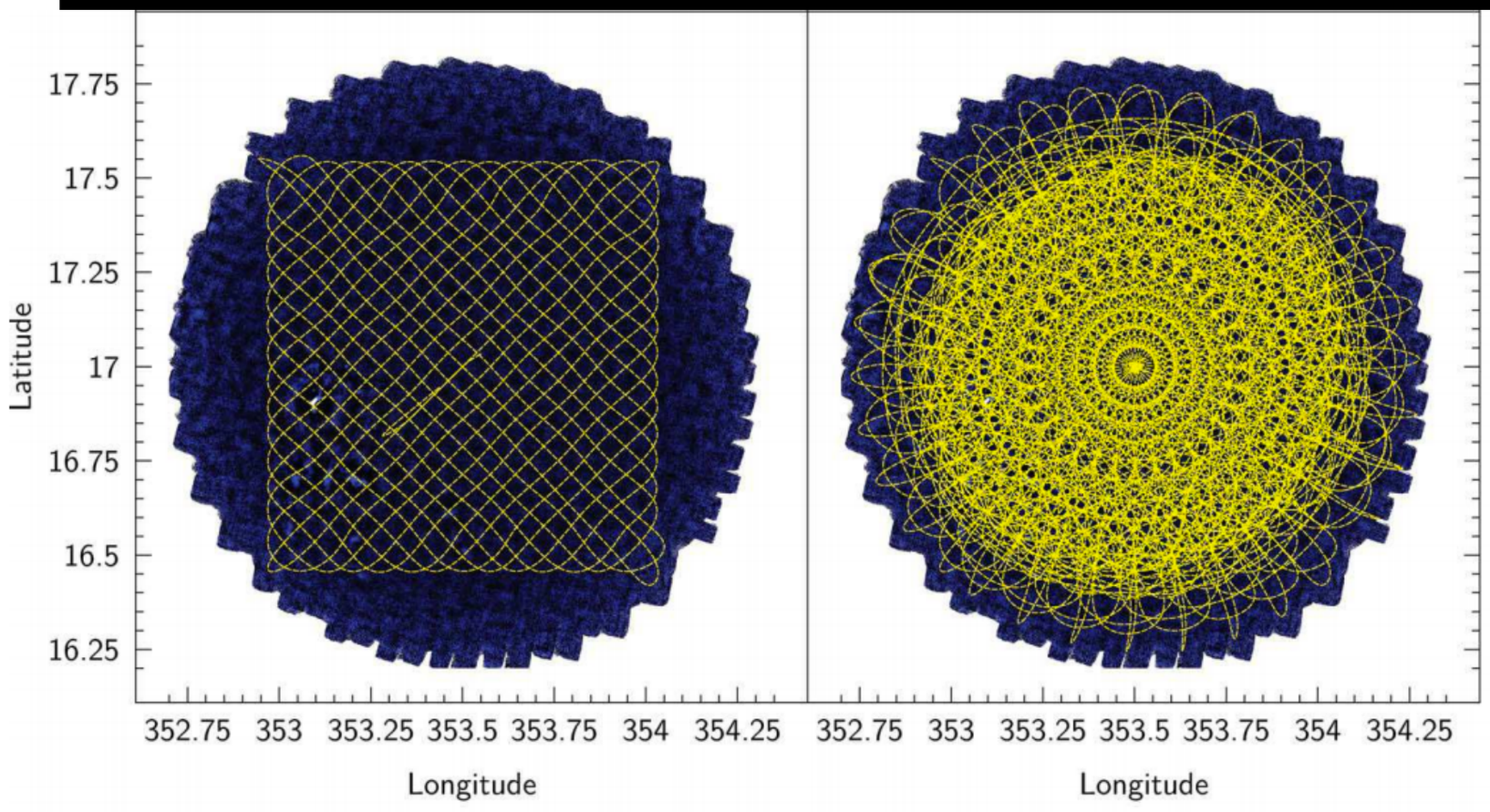


The telescope scans across the sky and across the same region at many different position angles

PONG options of: 15’, 30’, 90’, 1°, and 2°

Figures From: Holland et al. 2013



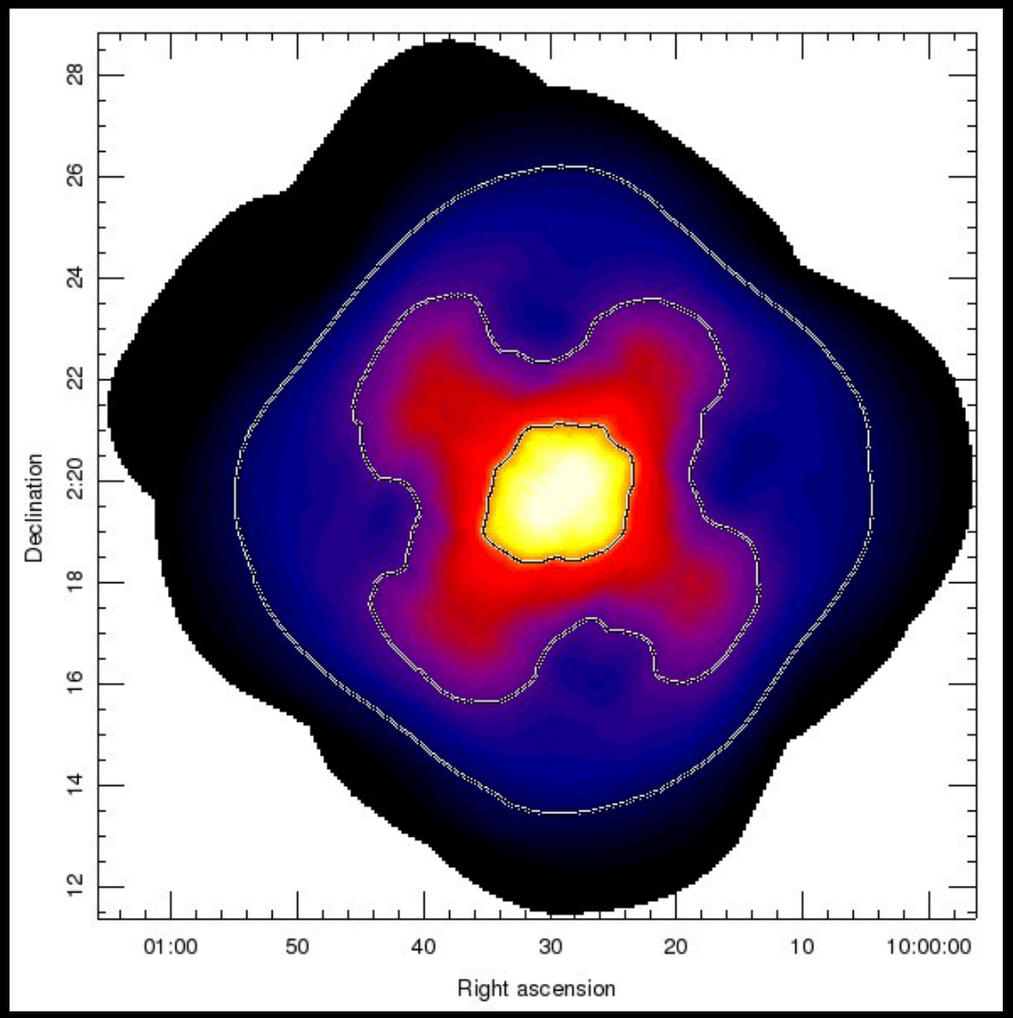


Serpens

Ophiuchus

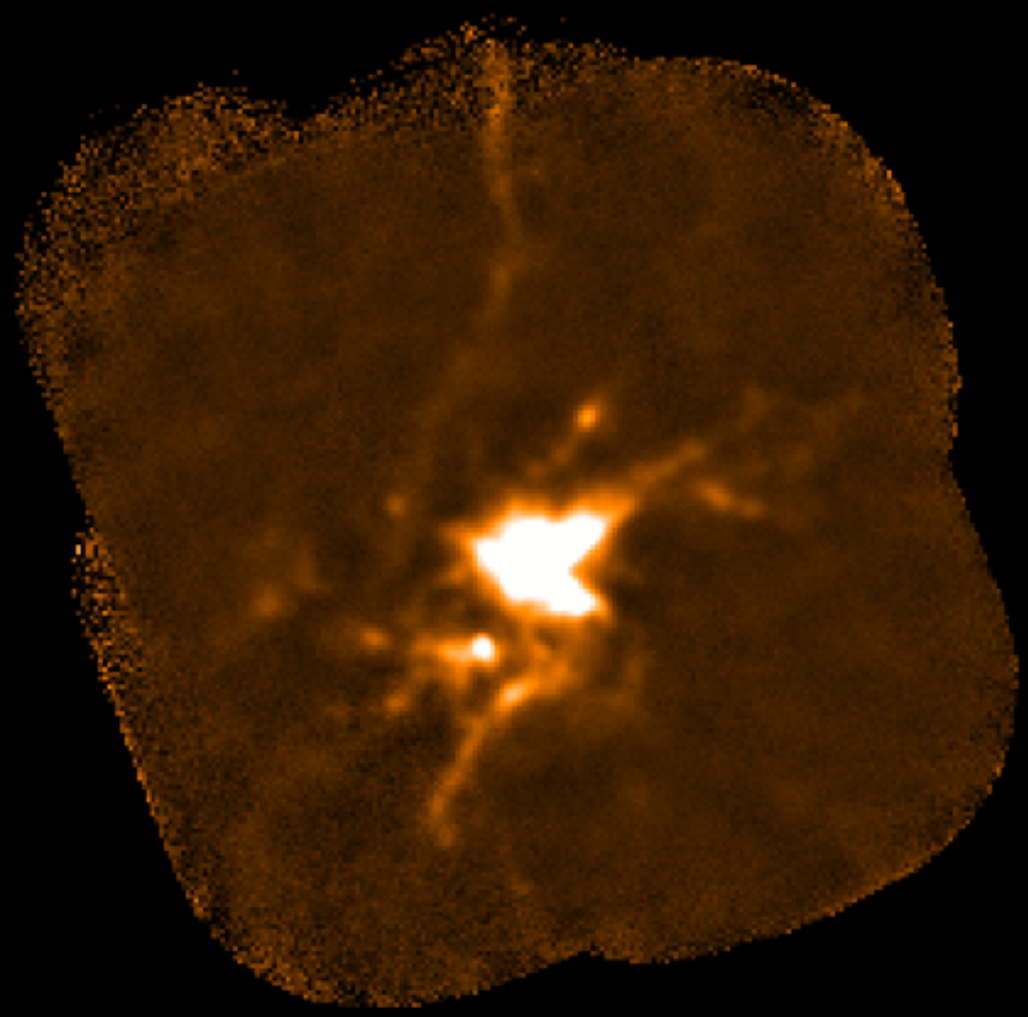
Orion Nebula

SCUBA-2: DAISY Observing Mode



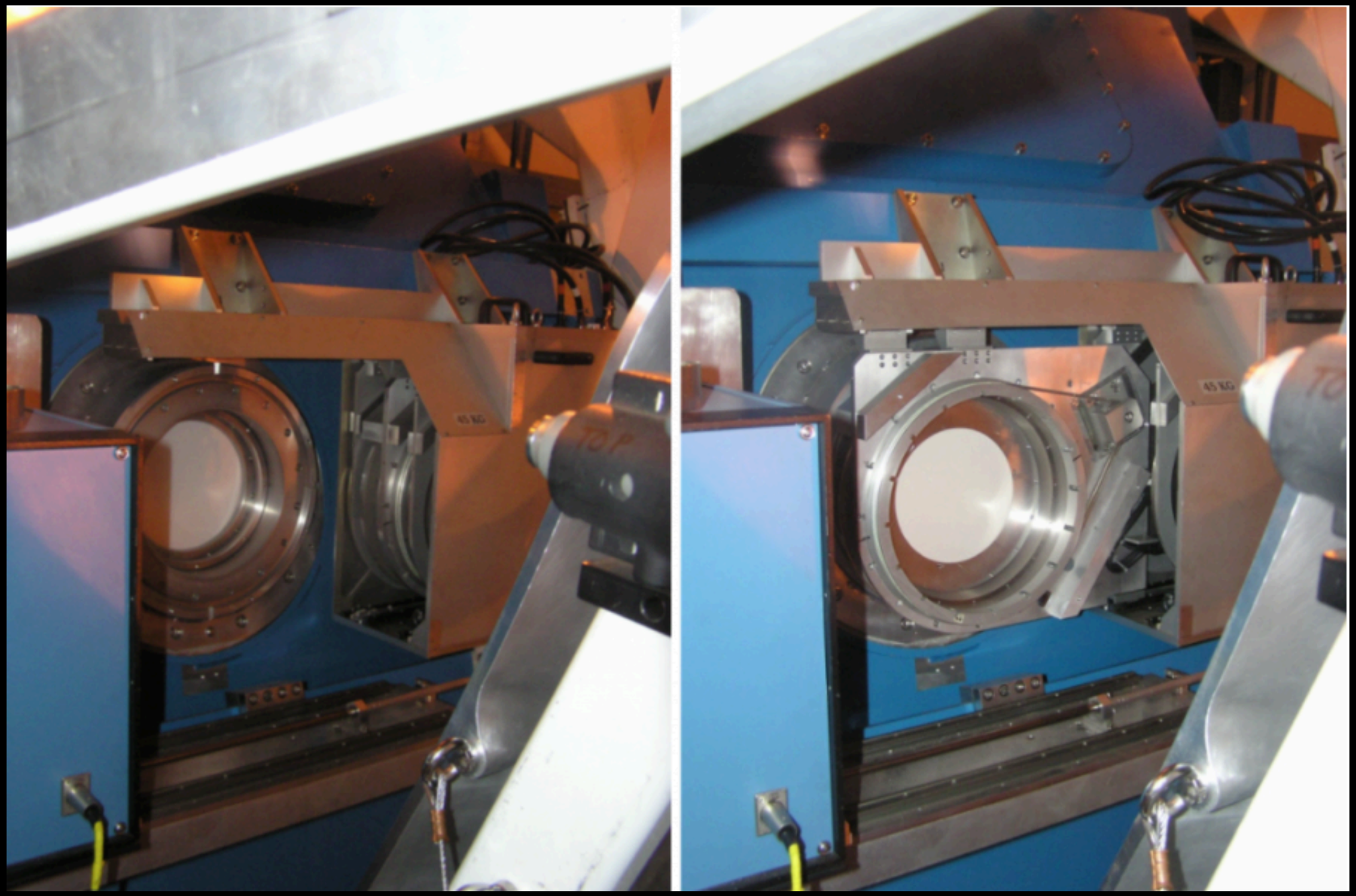
The telescope scans across the sky and across the same region at many different position angles

For smaller scale maps: 3 - 12 arcminutes

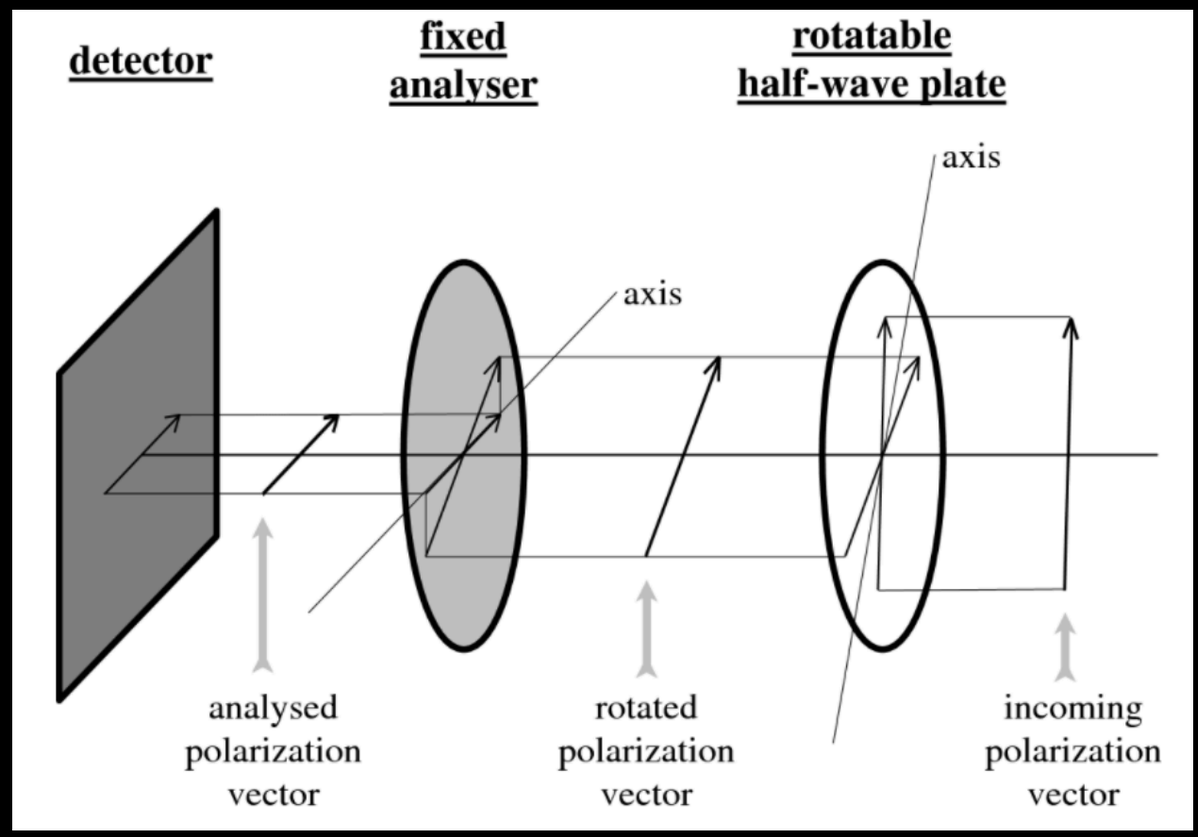


Also used for calibrations
On planets and planetary nebulae!

The Instruments: POL-2

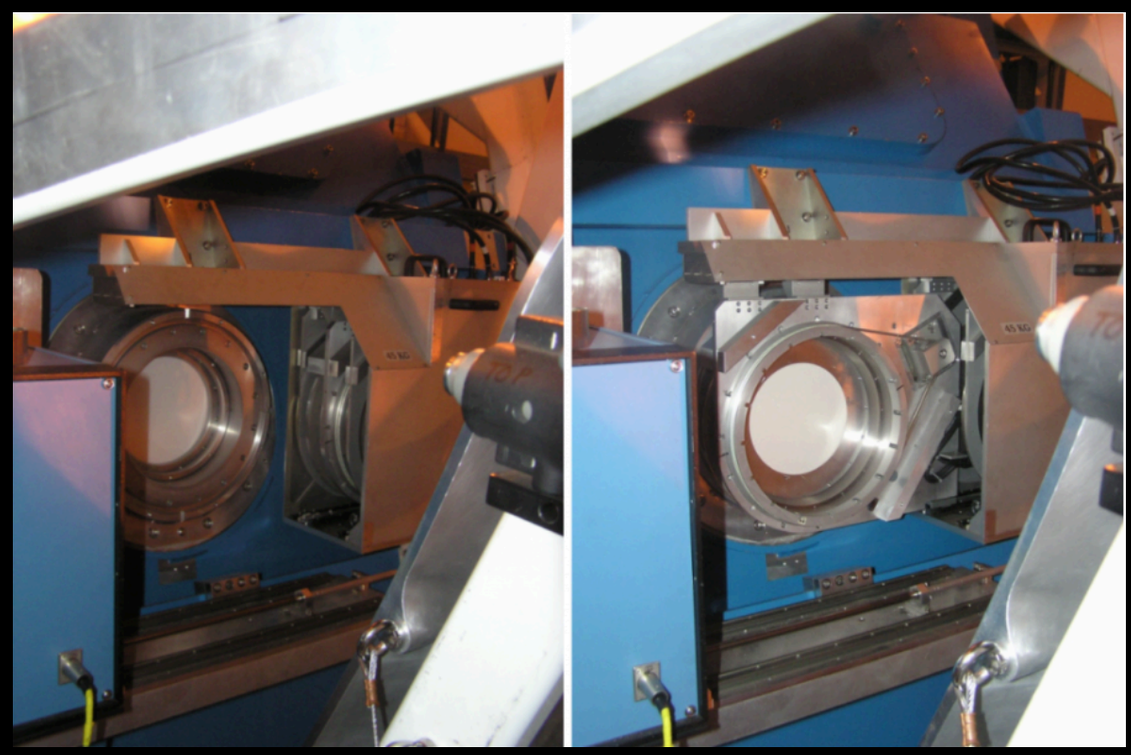


POL-2: Polarimeter



The long axis of dust grains tend towards an alignment perpendicular to B-field lines

POL-2 works
in conjunction with SCUBA-2



POL-2: Polarimeter

The rotating polarizer allows us to measure the **polarisation angle**

Chandrasekhar-Fermi (C-F) method combines POL-2, SCUBA-2, and HARP data to calculate **the B-Field strength**

$$B_{\rm pos} = Q' \sqrt{4\pi\rho}\,\frac{\sigma_v}{\sigma_\theta} \approx 9.3\,\sqrt{n({\rm H}_2)}\,\frac{\Delta v}{\langle\sigma_\theta\rangle}\;\mu{\rm G}$$

SCUBA-2

HARP

POL-2

Crutcher et al. 2004, ApJ 600:279

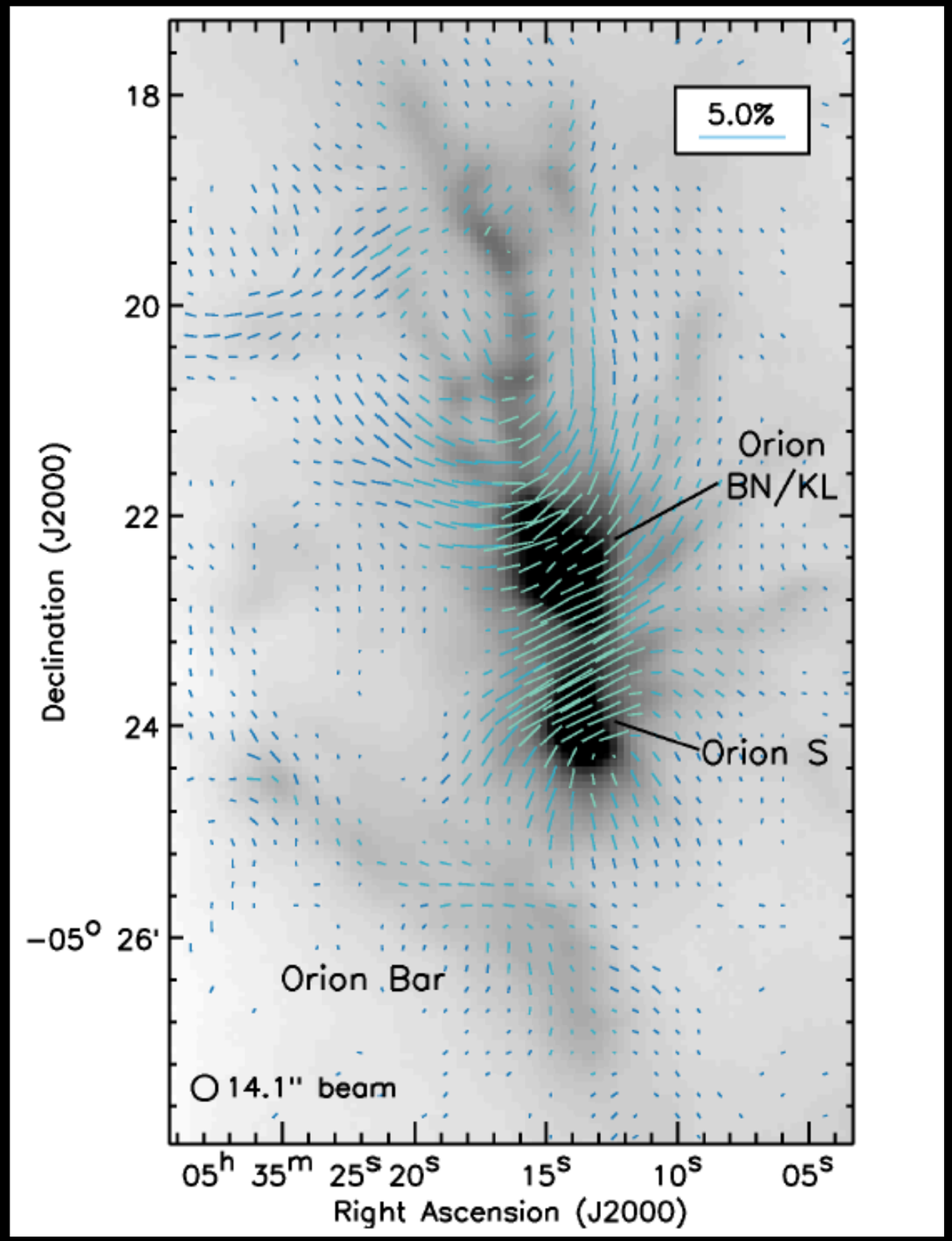
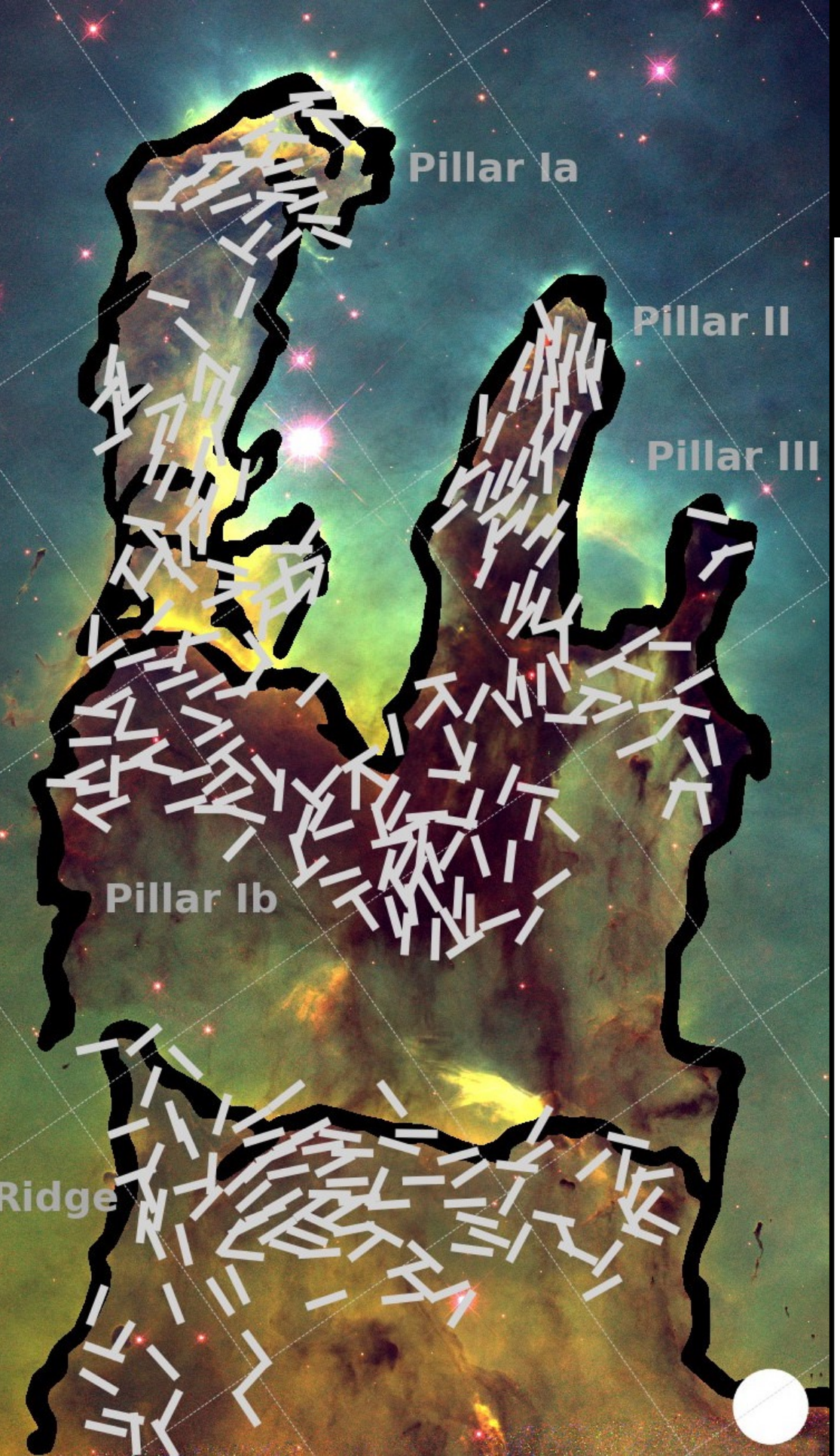
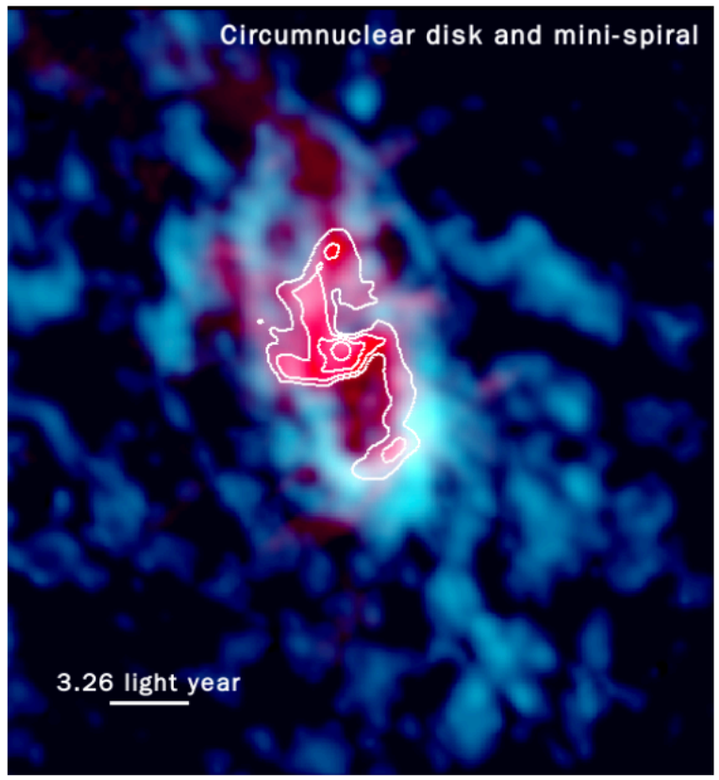
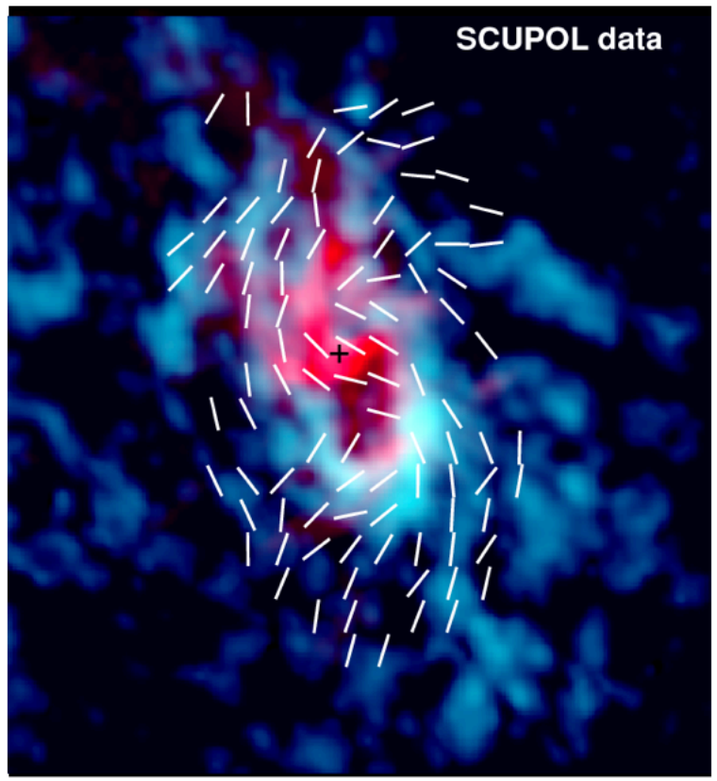


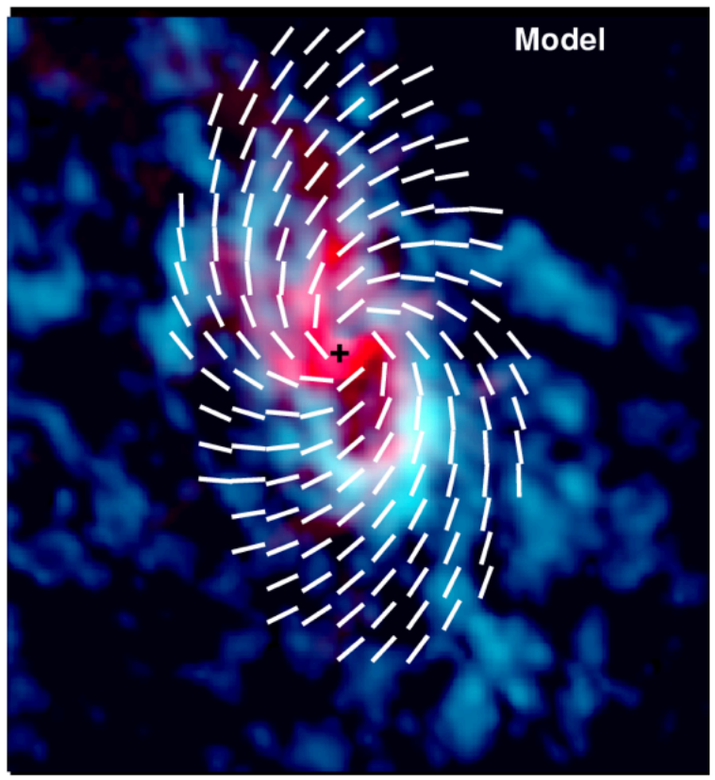
Figure: Pattle et al. 2017, ApJ 846:122

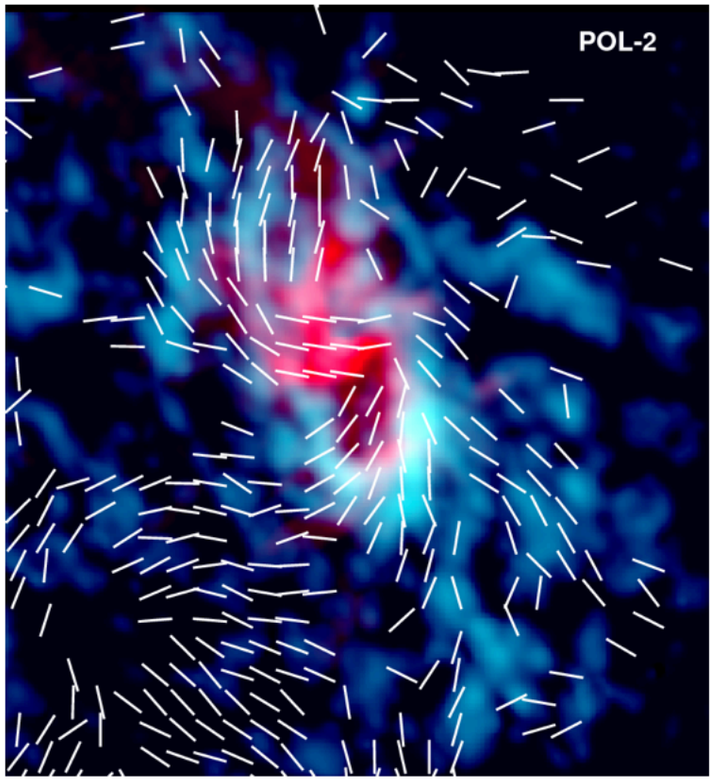
Tracing Magnetic Fields in Space!







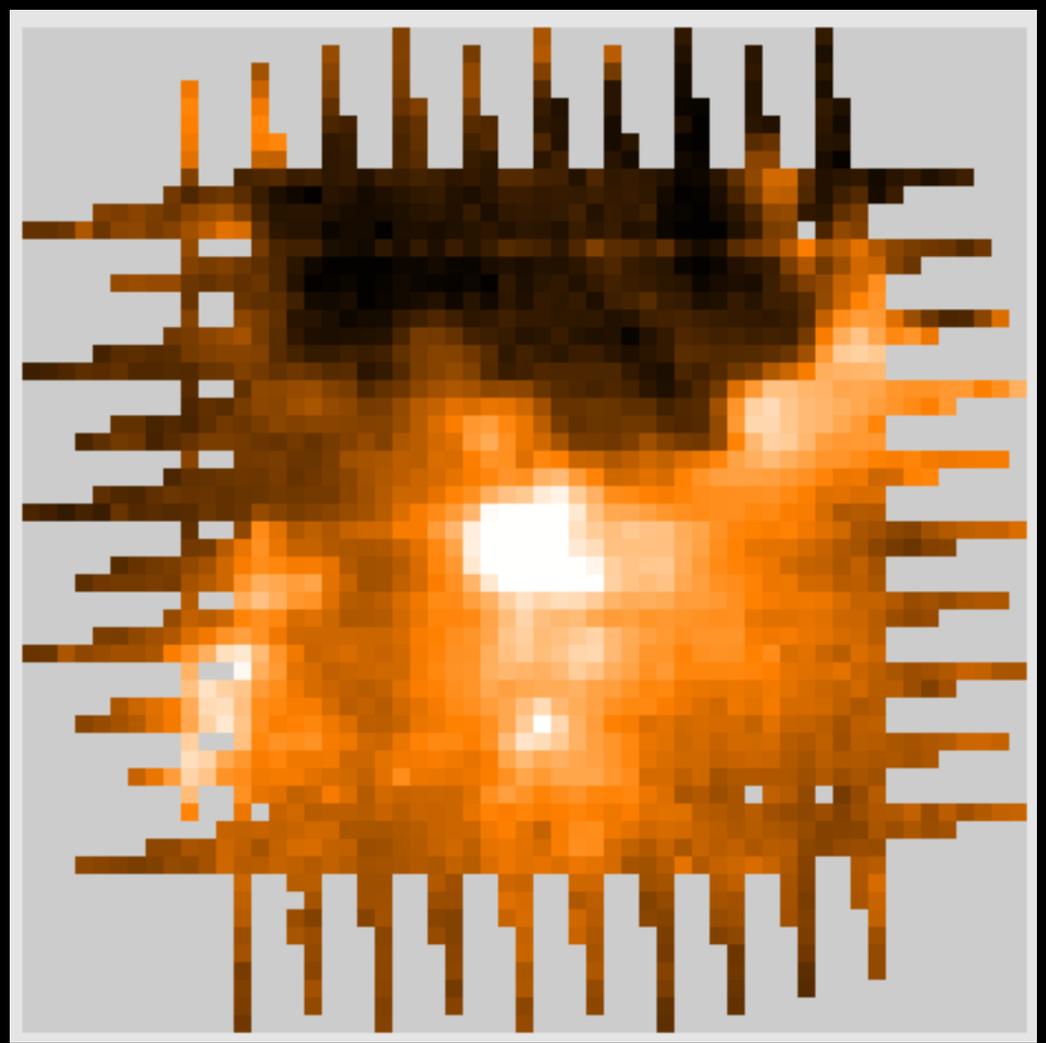




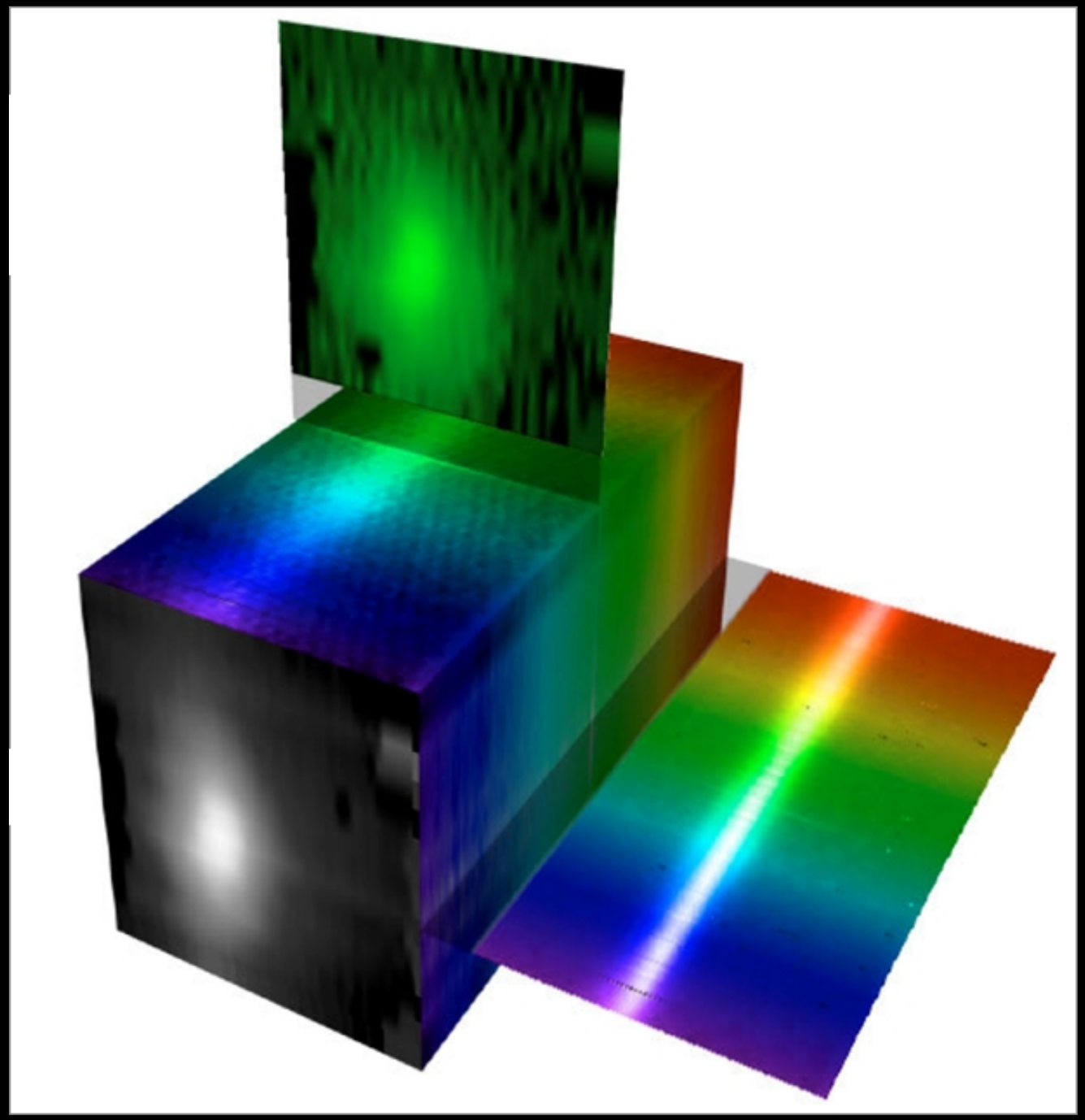
The Instruments: HARP

HARP: 325-375 GHz

Generates Image Cubes
With Velocity Information
For nearly 70 different molecules
(CO, HCN, Formaldehyde…)

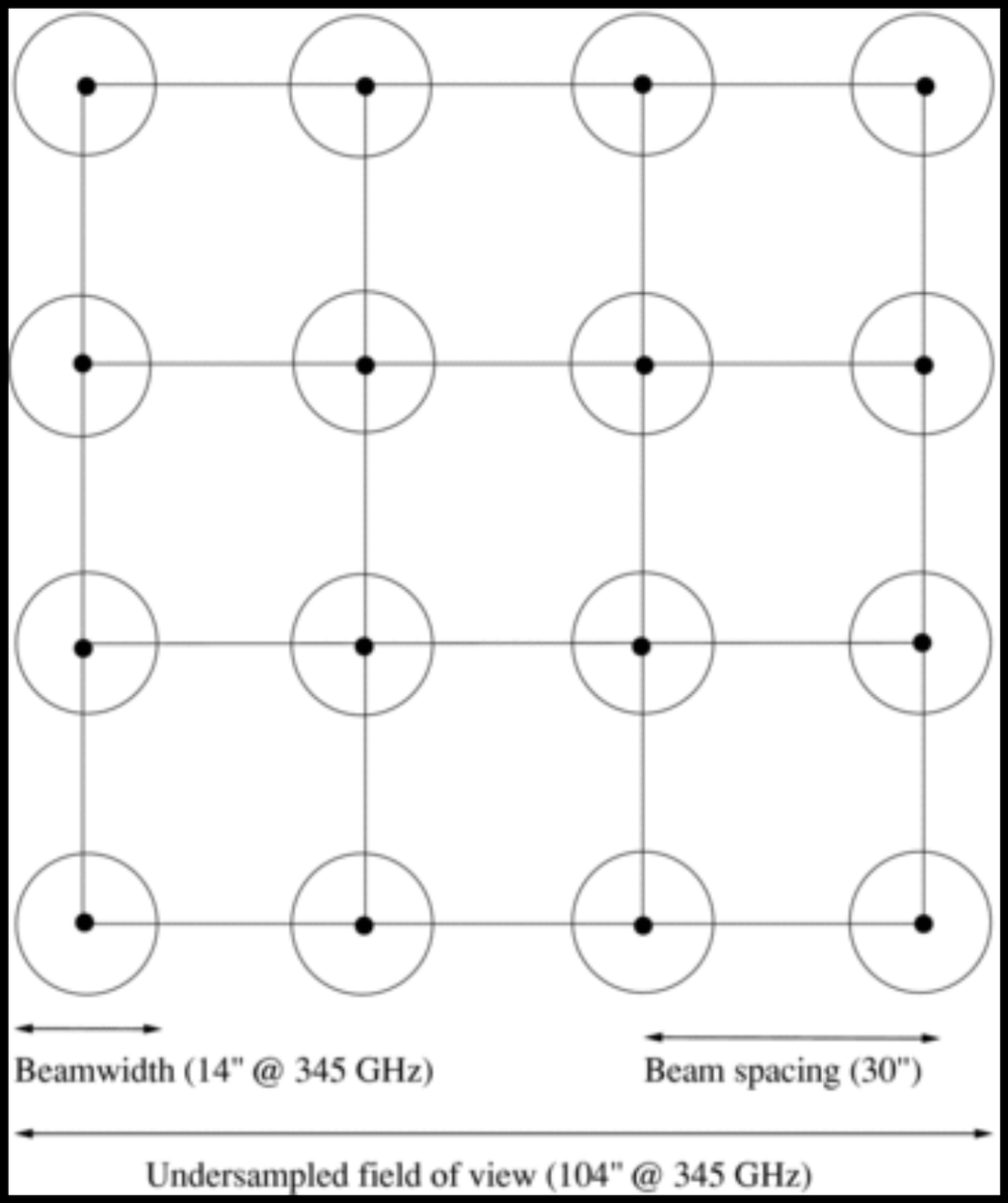


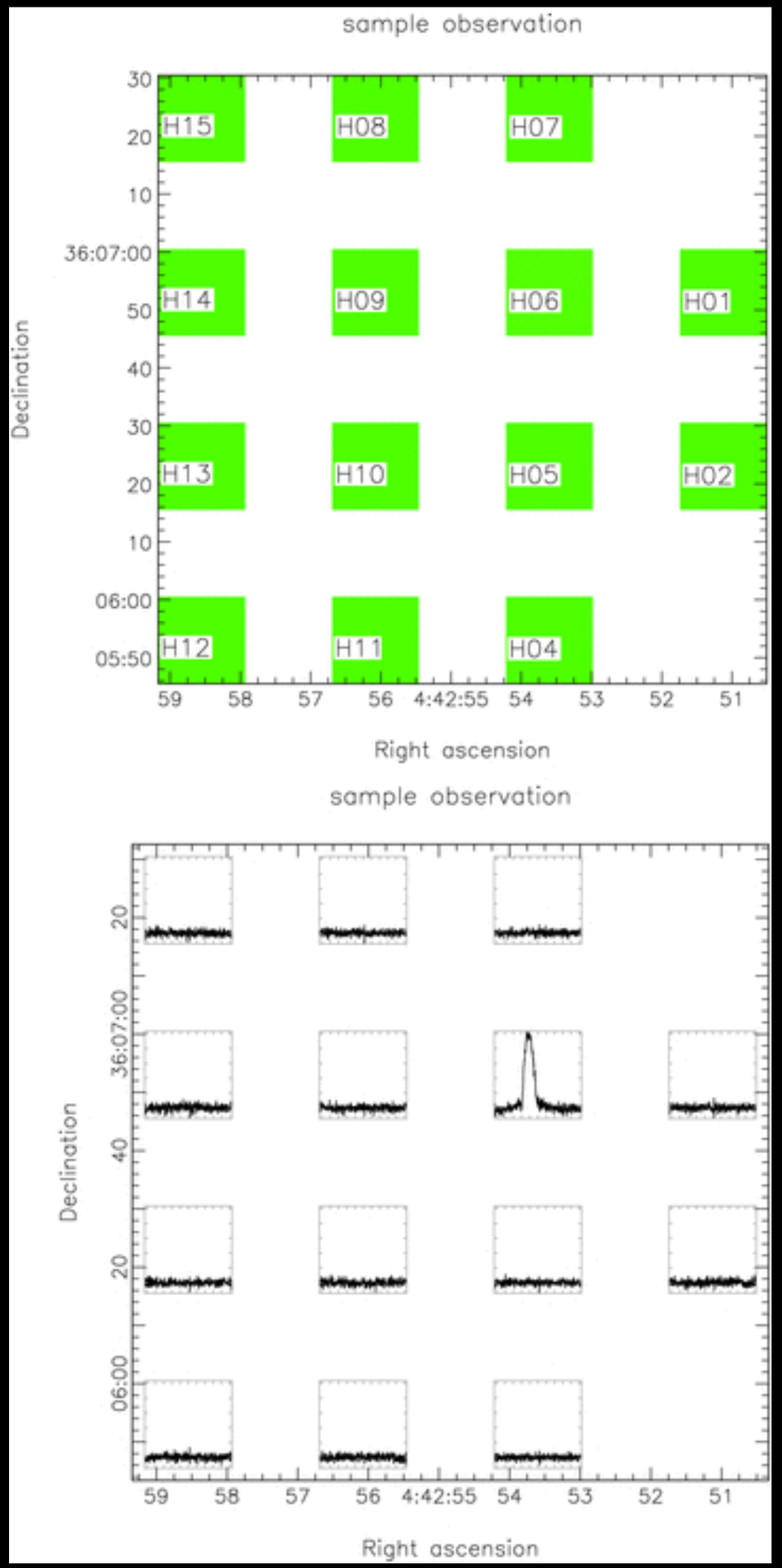
HARP is sensitive to a range of Frequencies/Velocities



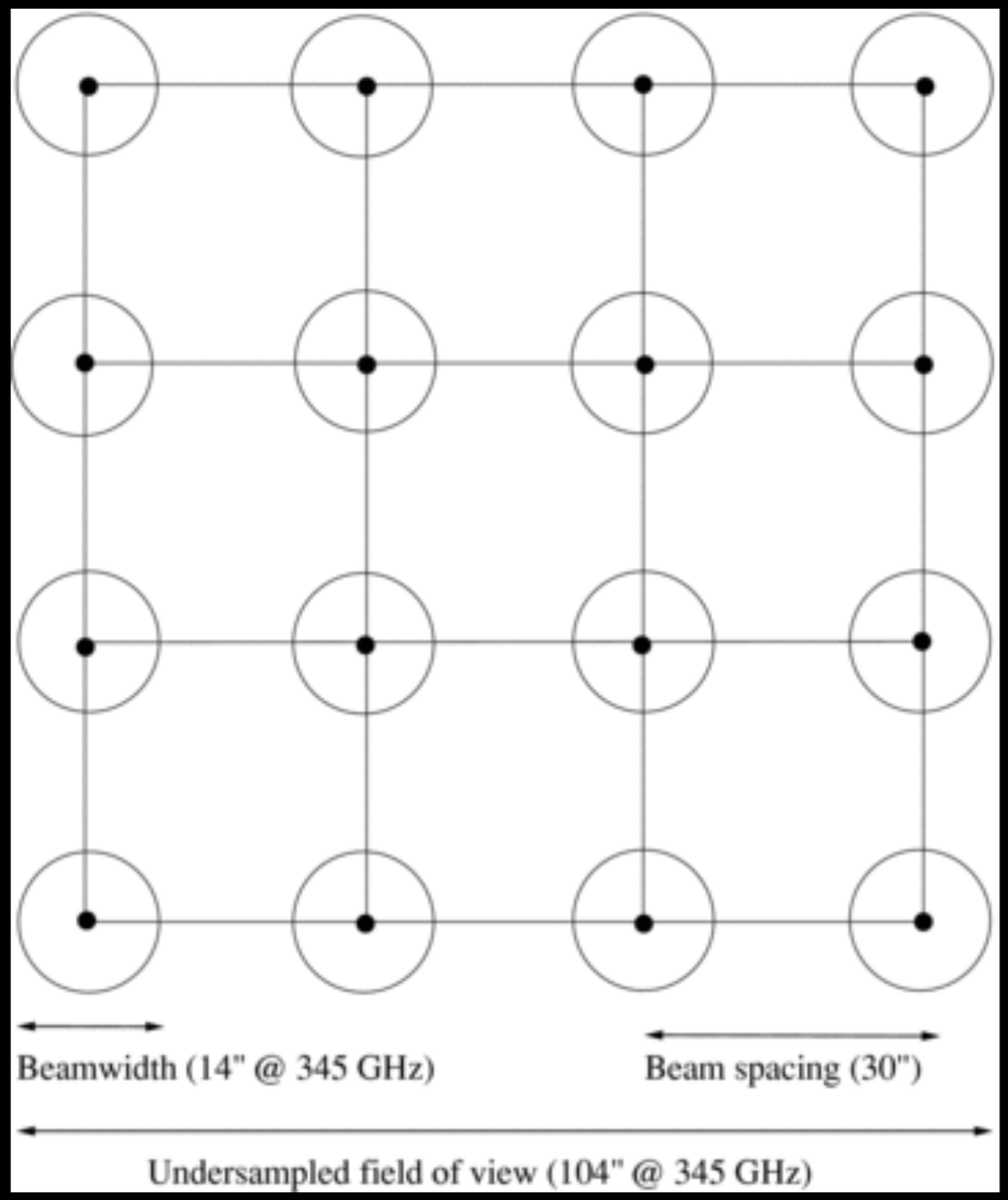
HARP: 325-375 GHz Stare Mode (Point Sources)

16 Receptors that each produce a spectrum!

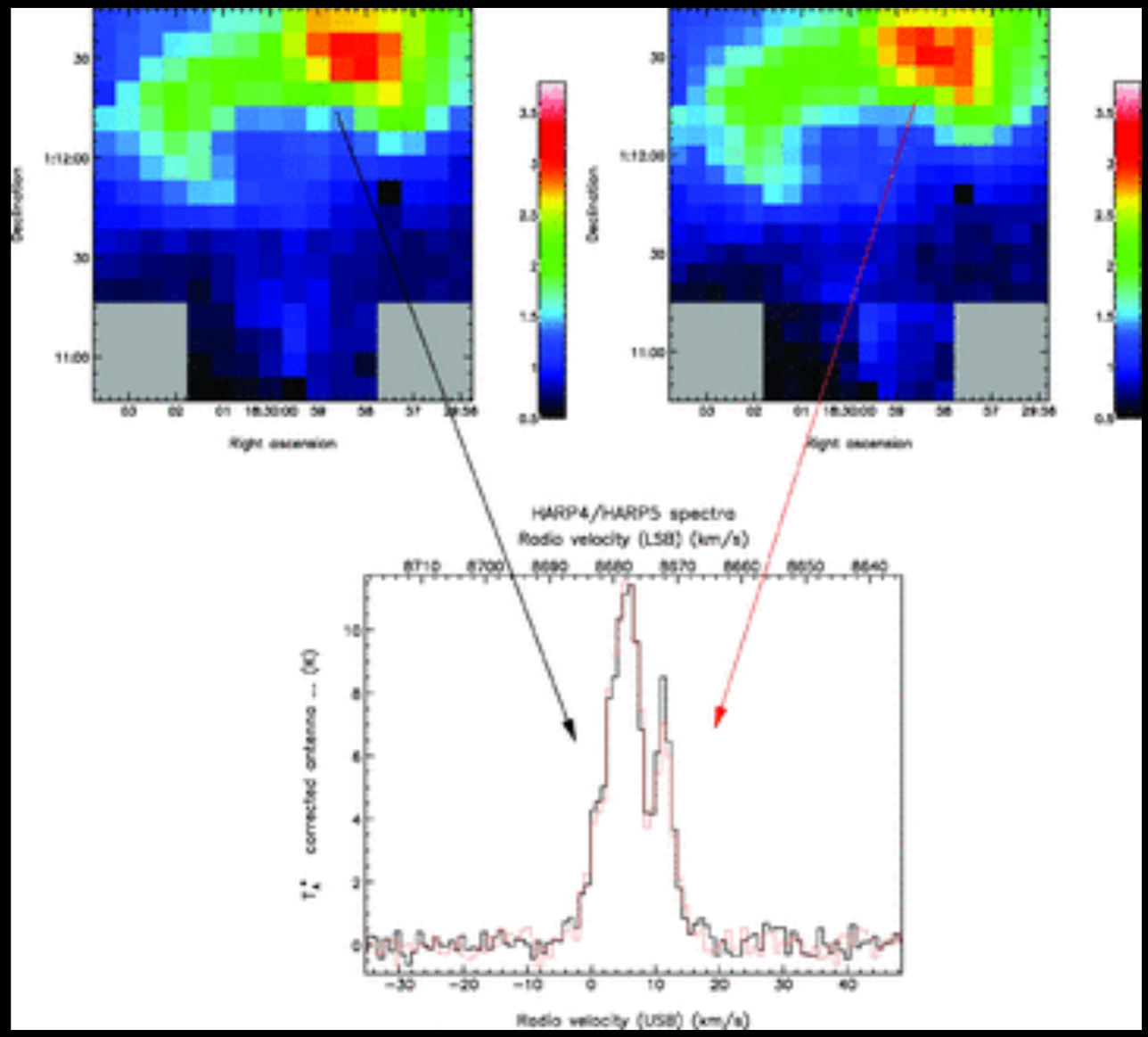




HARP: 325-375 GHz — Jiggle Mode (<2’)

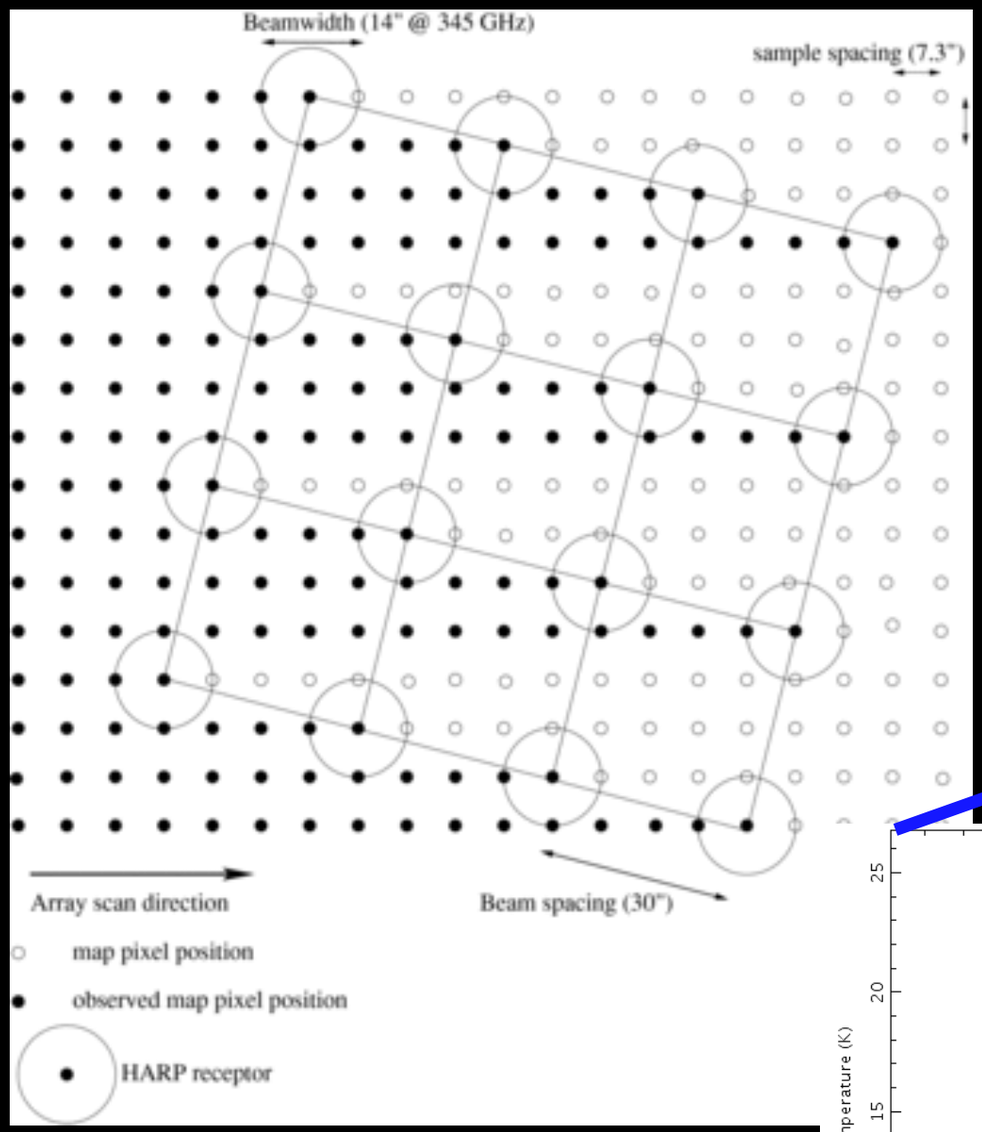


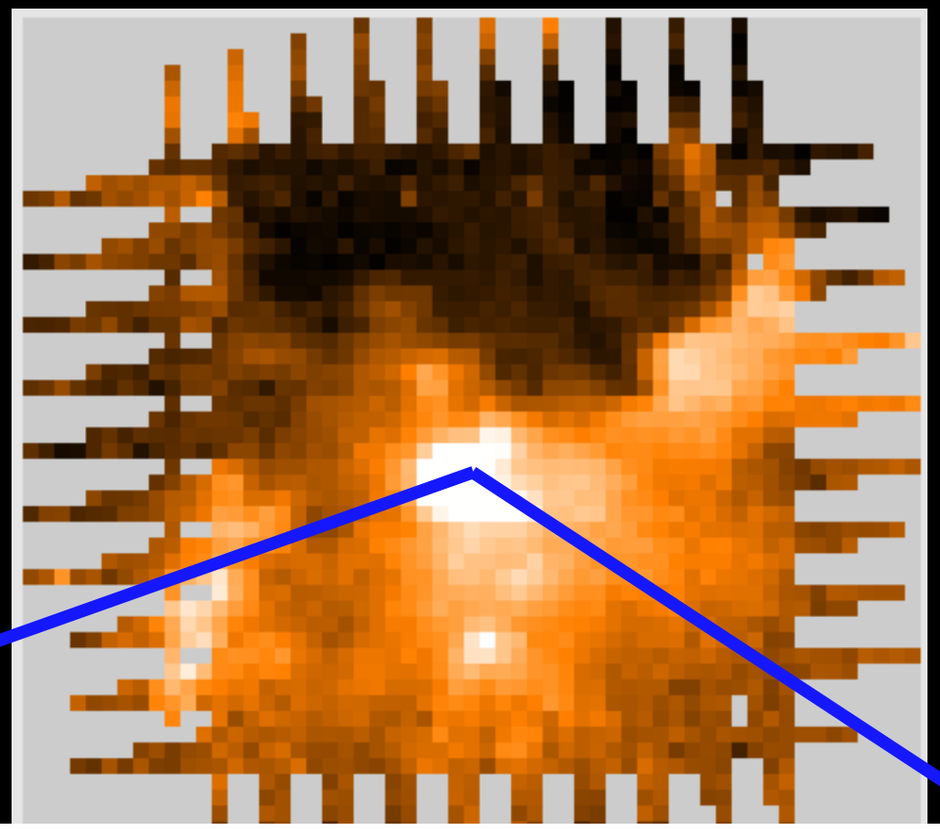
Jiggle those 16 Receptors that each produce a spectrum around the sky in a grid to get a map!

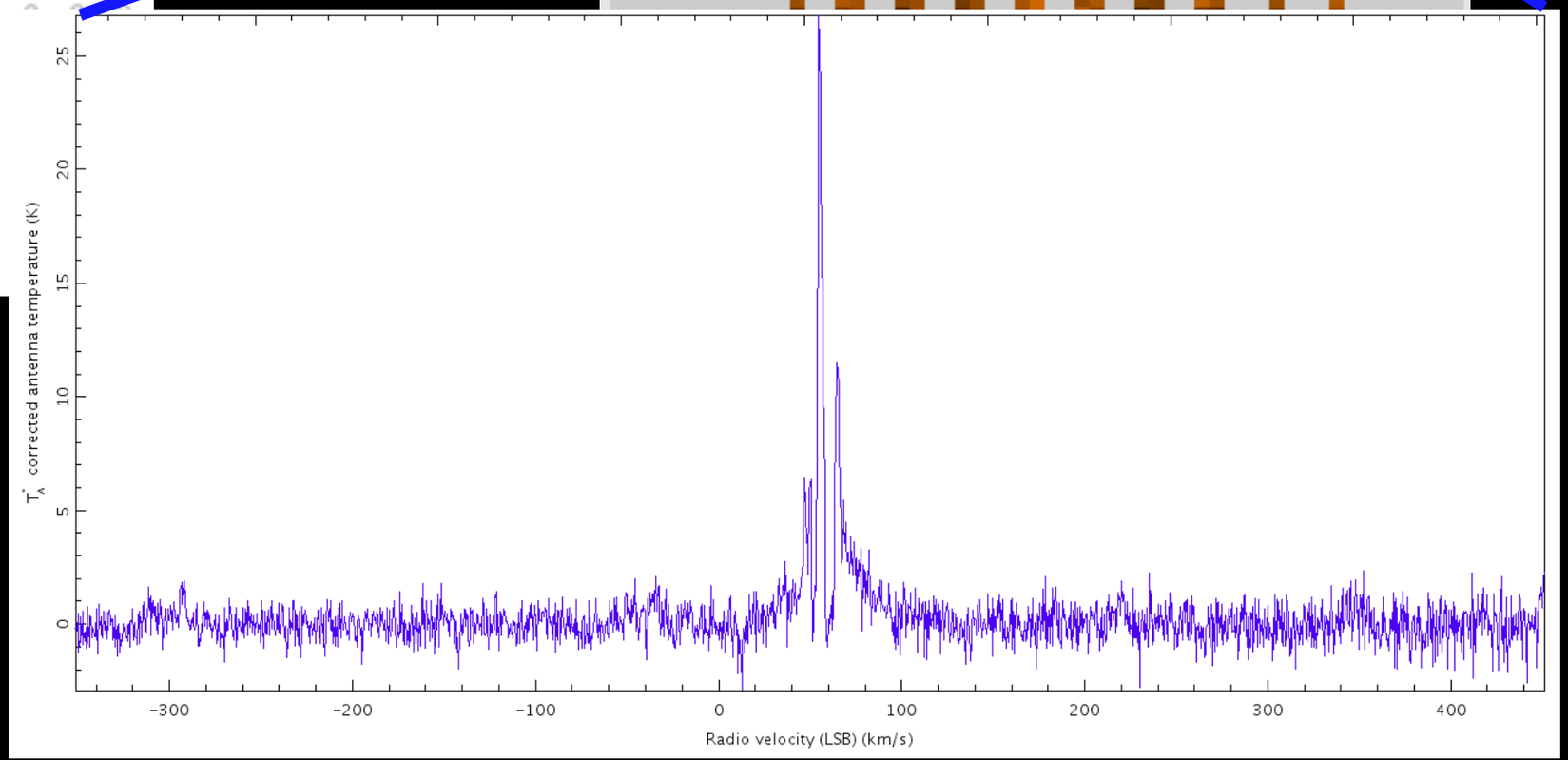


***Jiggles are efficient for small maps**

HARP: 235-275 GHz — Raster Mode (>2')







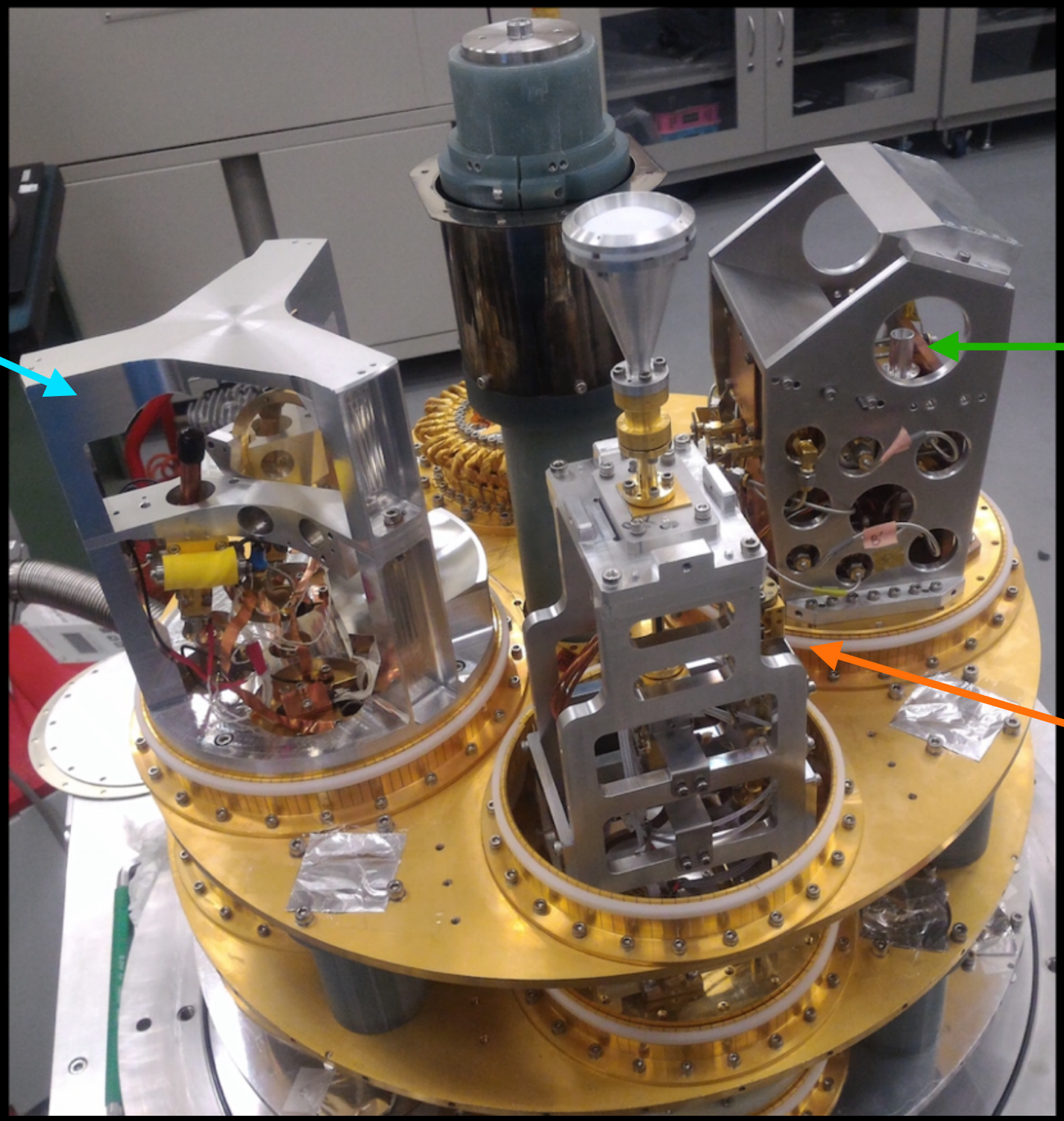
In this way, we measure kinematic information over large areas

Demo of HARP Data!

The Instruments: Nā maka nui

Aweoweo (Big Eye): 345 GHz

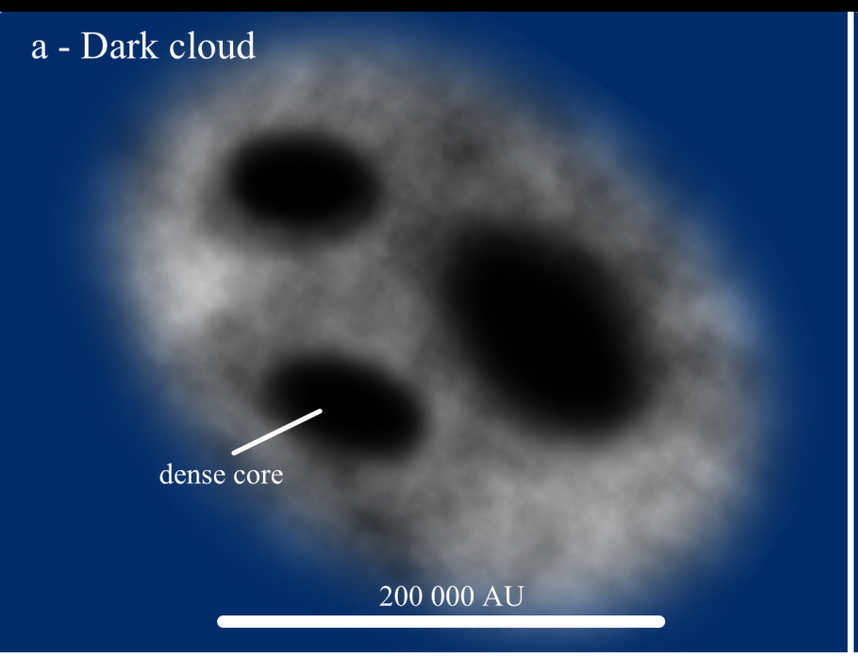
U’u (Soldierfish): 230 GHz

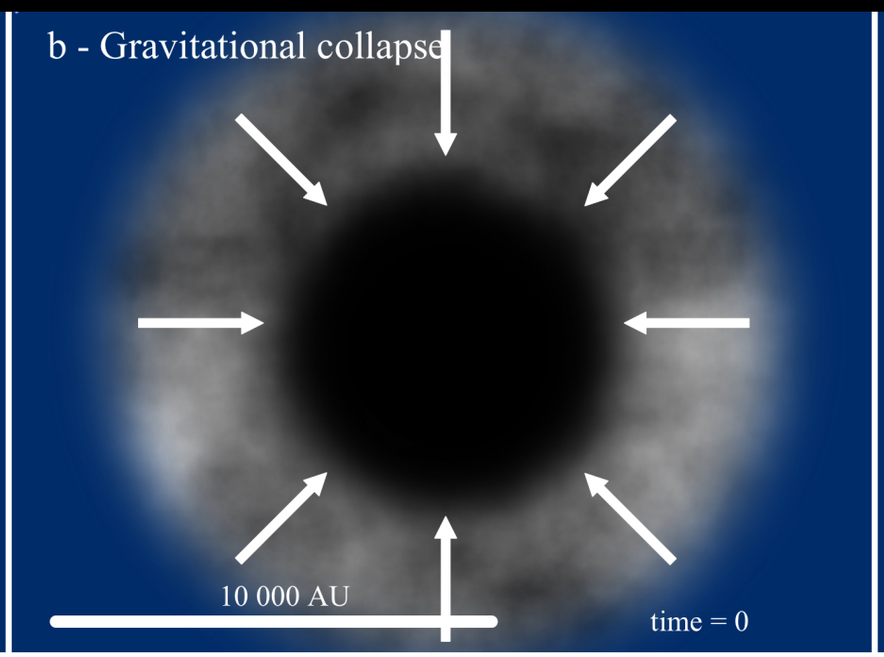


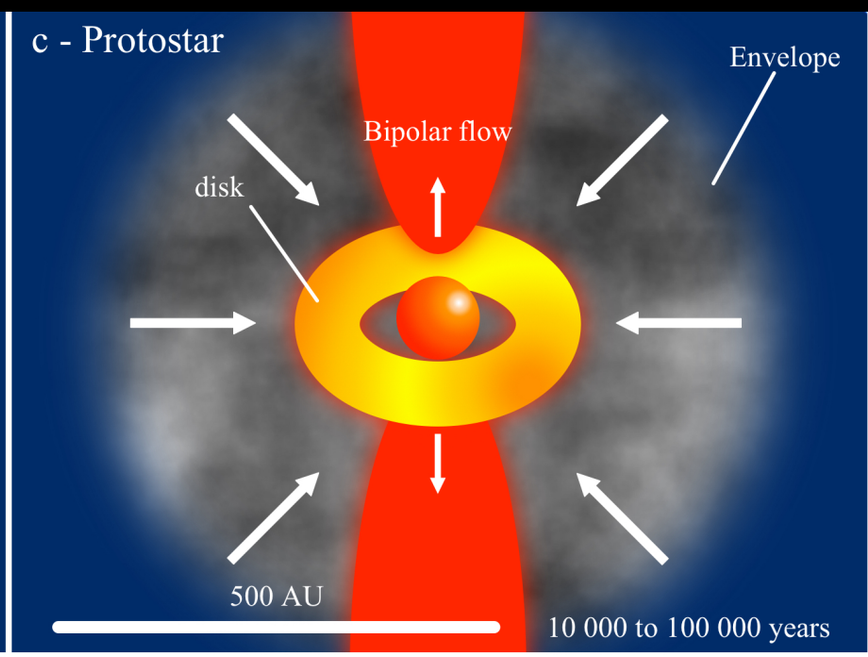
Ala’ihi (Squirrelfish): 86 GHz

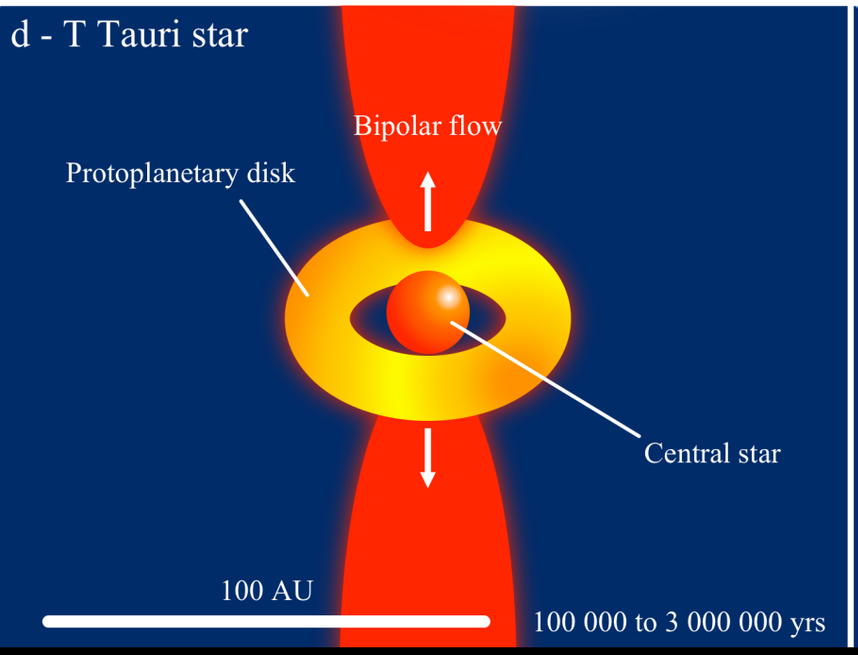
Image Cubes At 3 Different Frequencies!

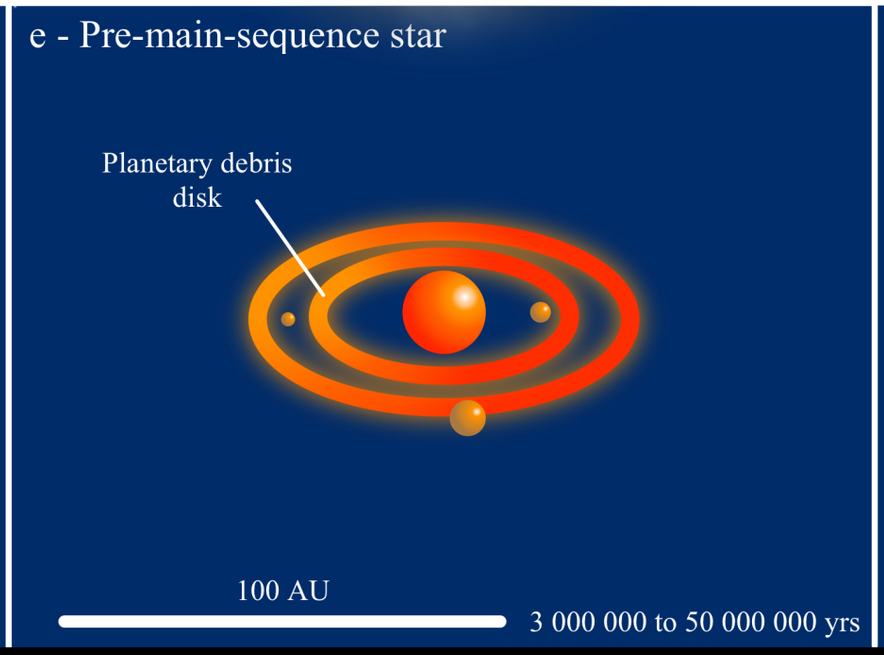
The Science: Star Formation

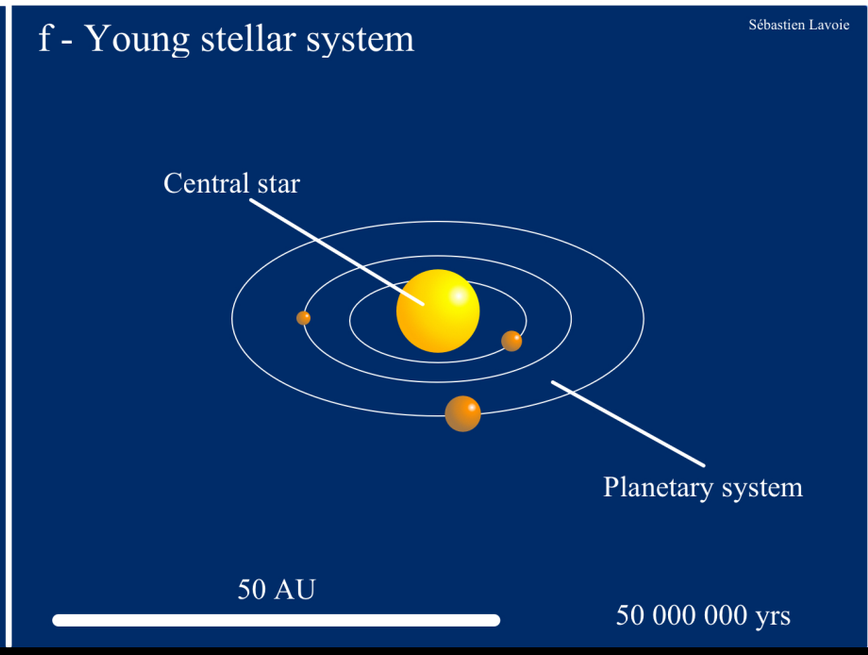




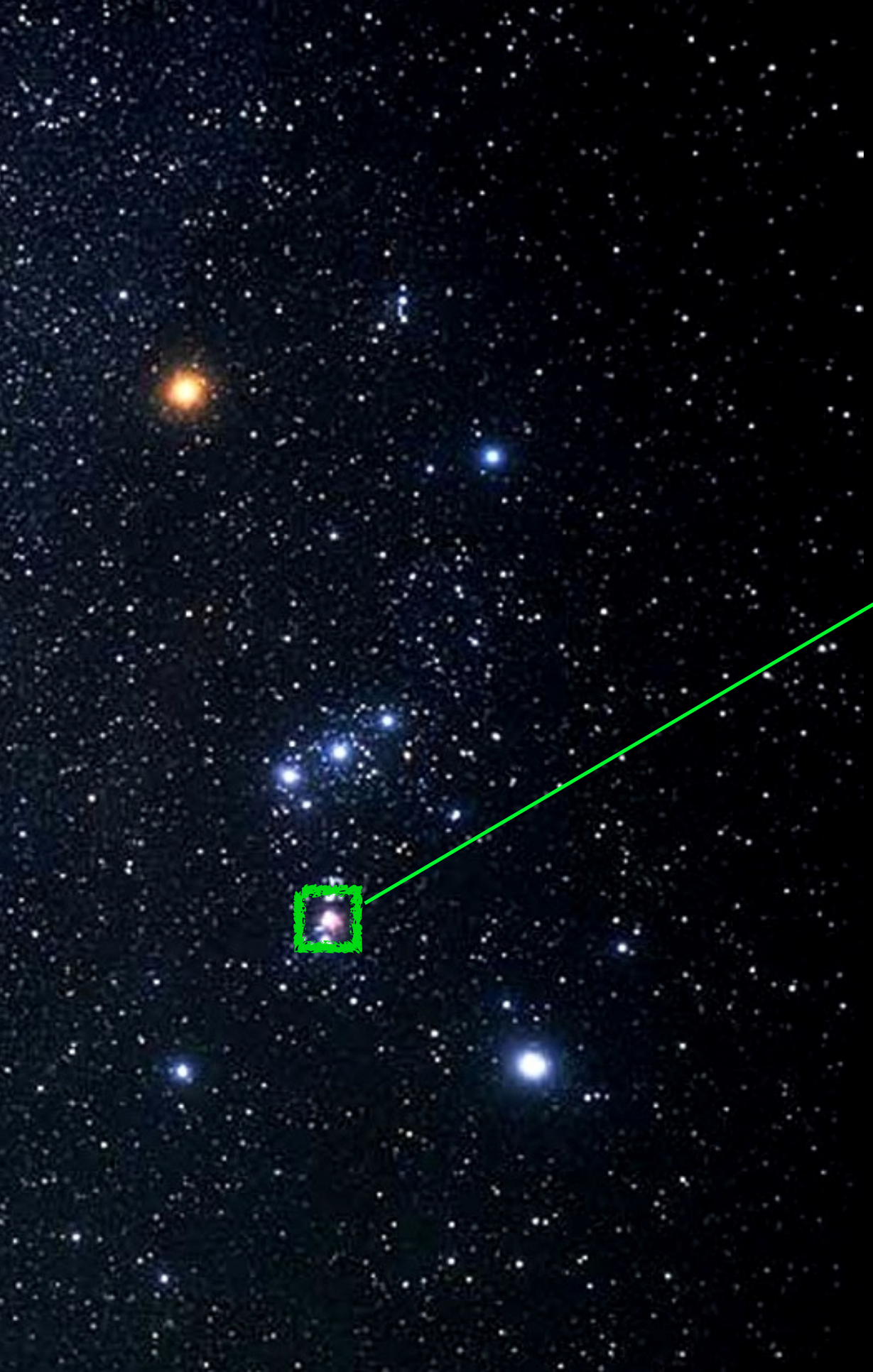


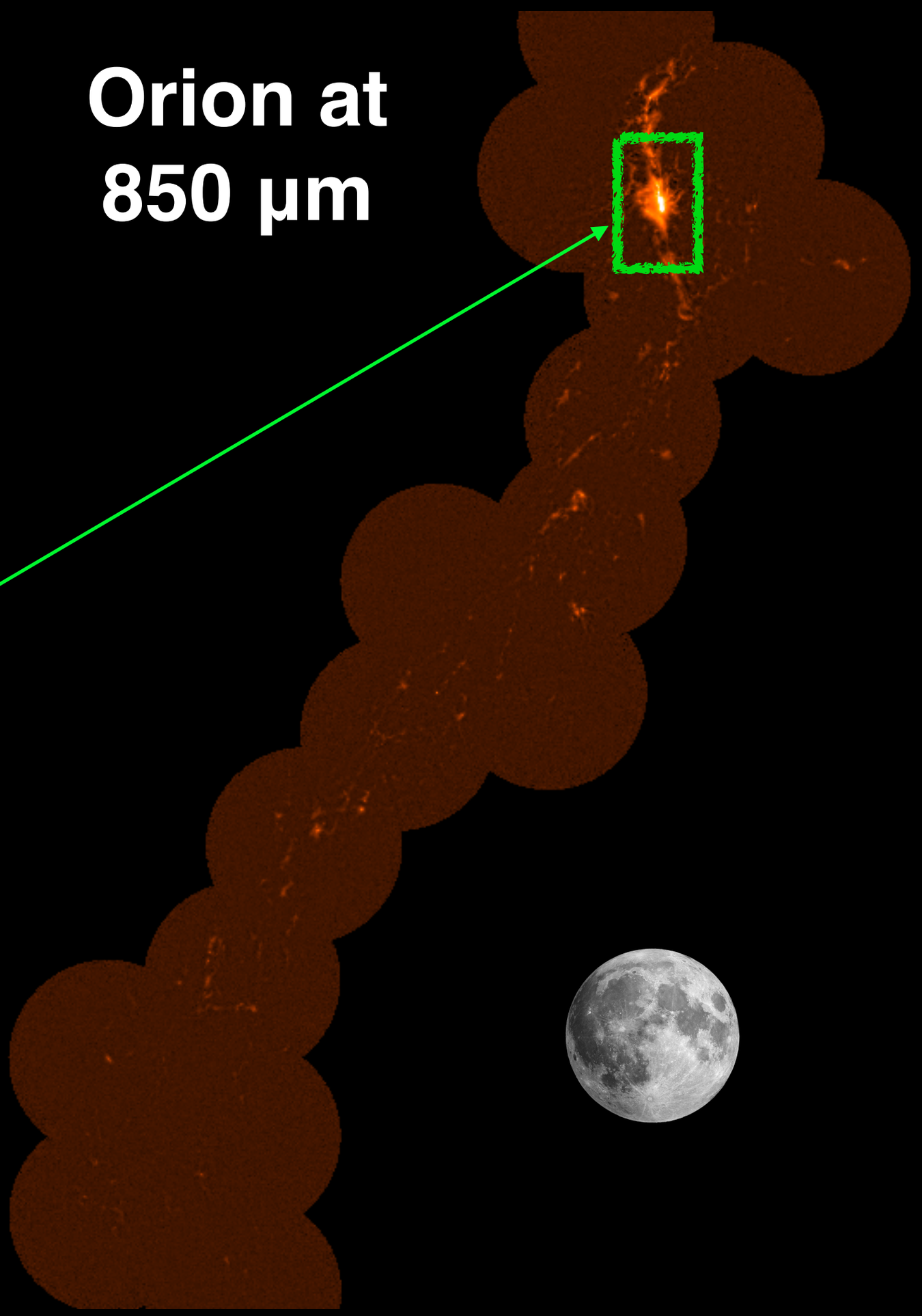




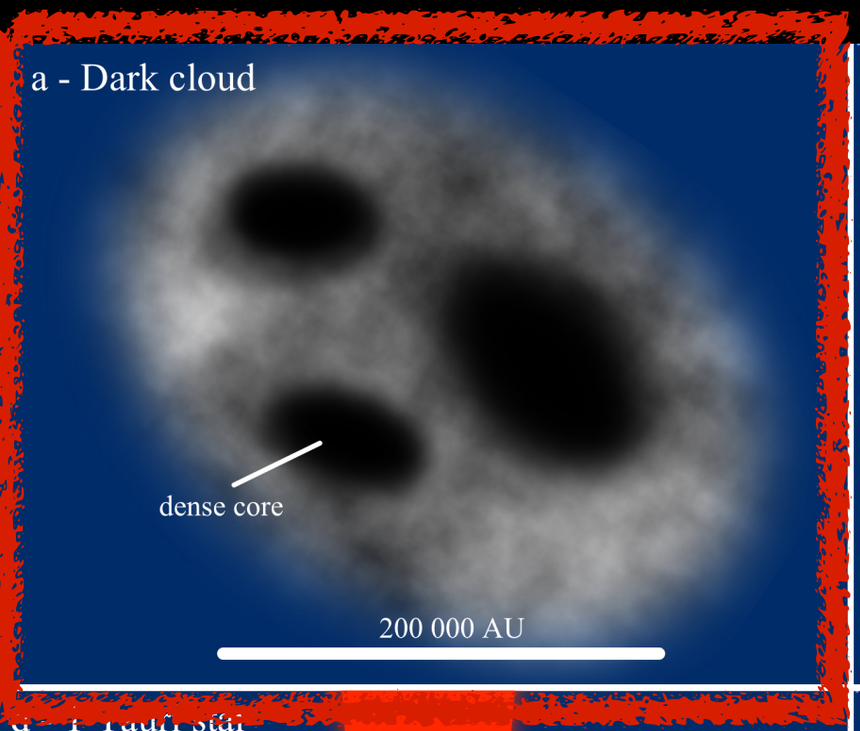


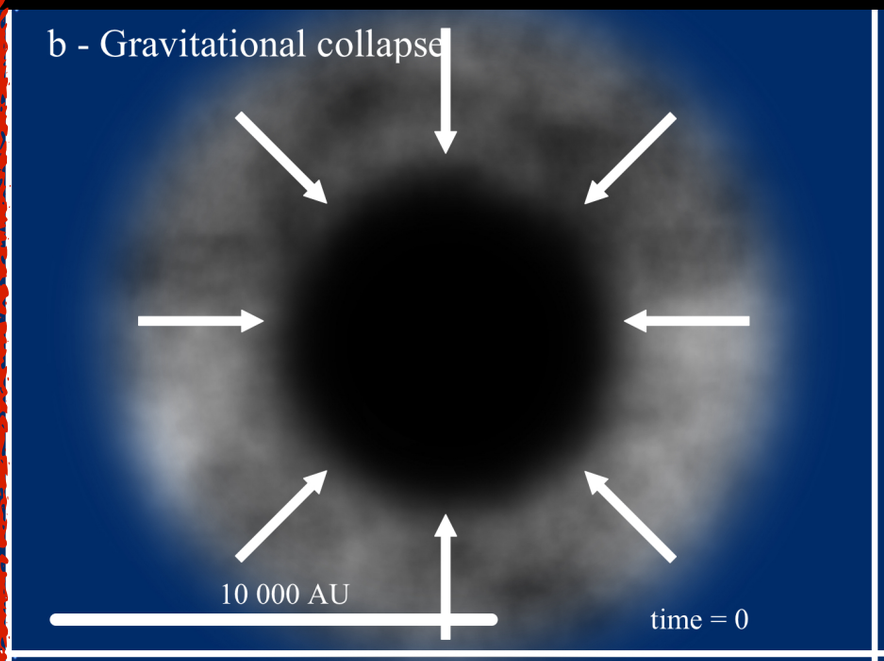
Orion at 850 μm

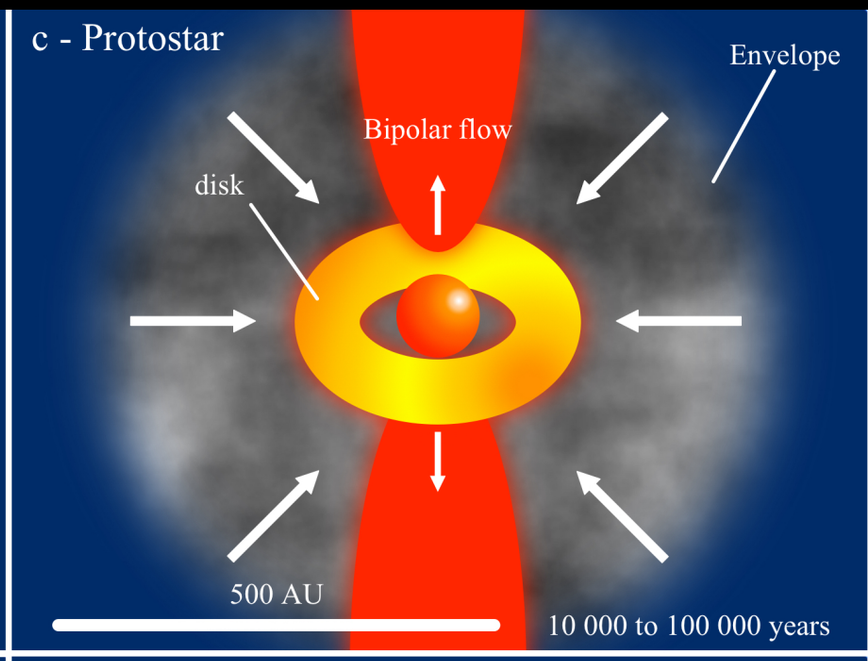


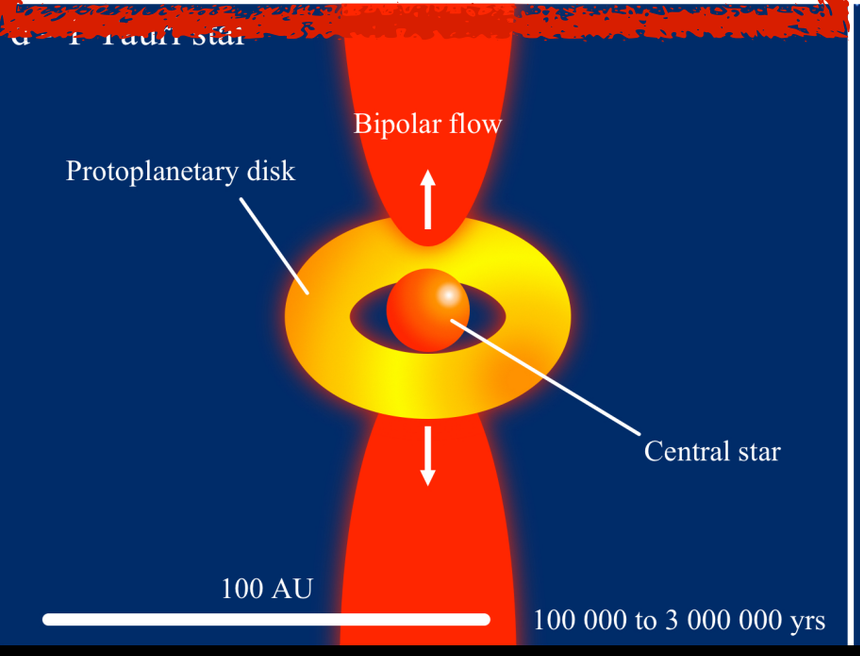


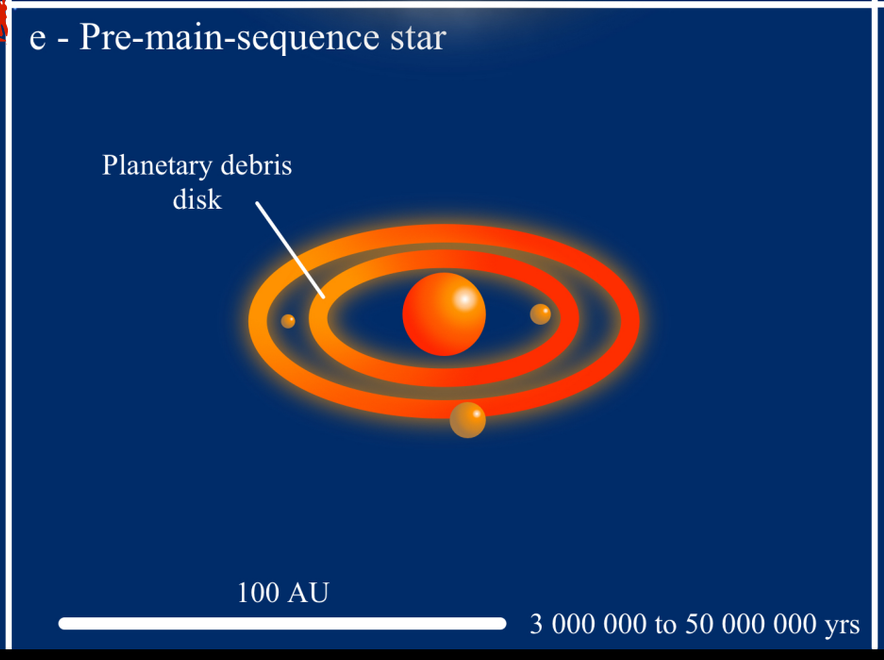
Star Formation in a Nutshell

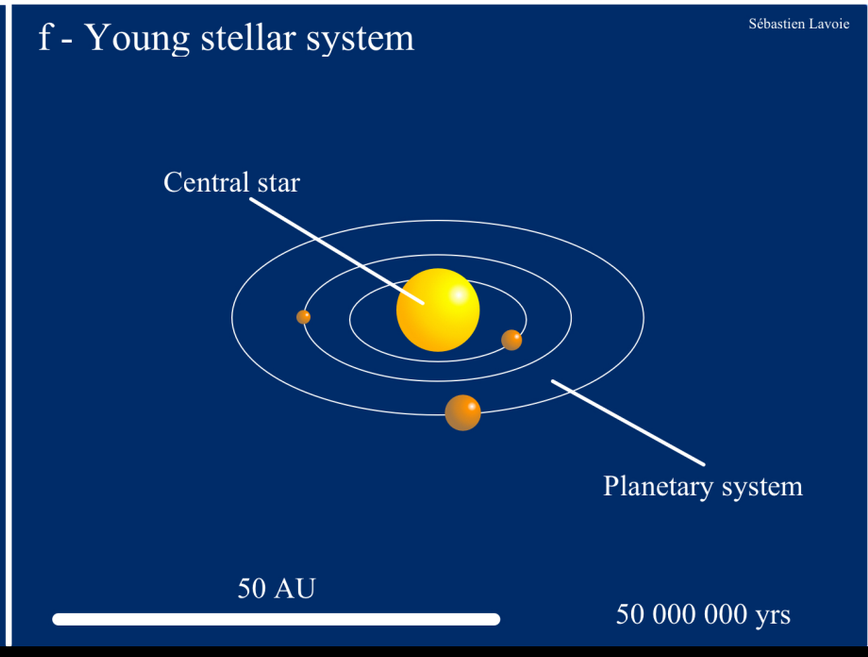




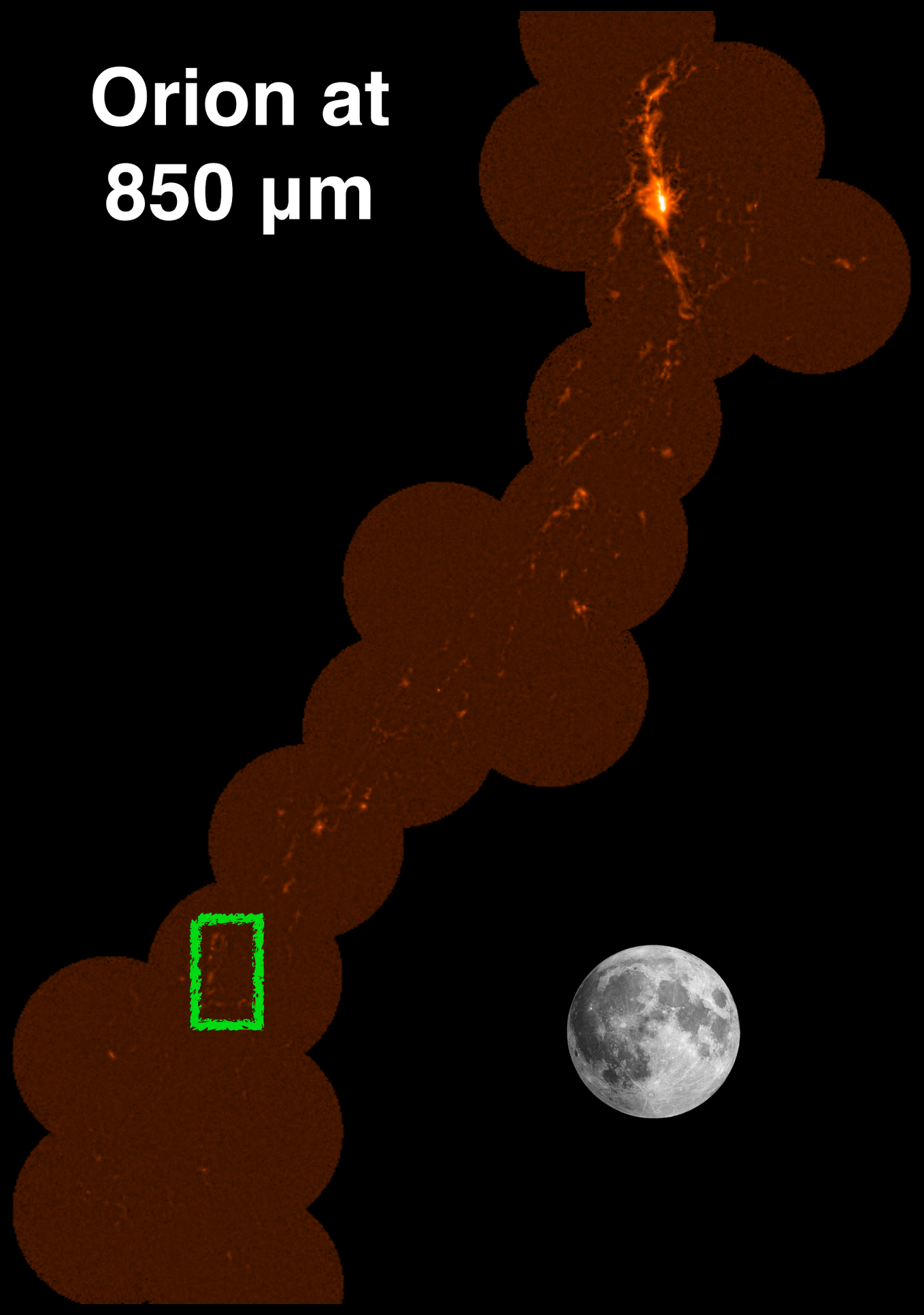






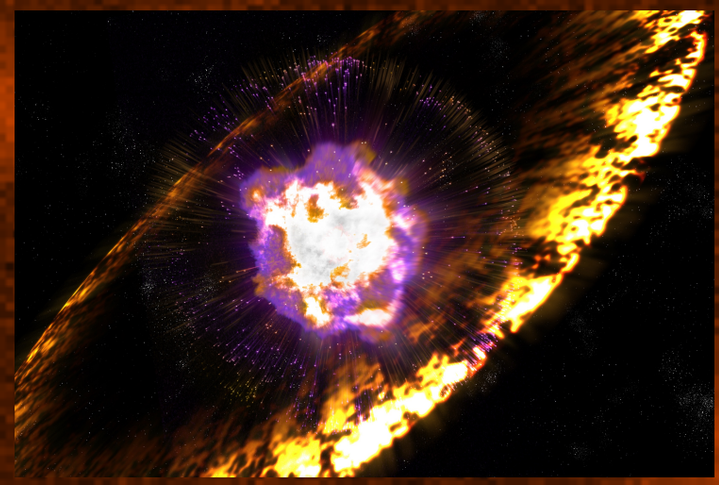


Orion at 850 μm



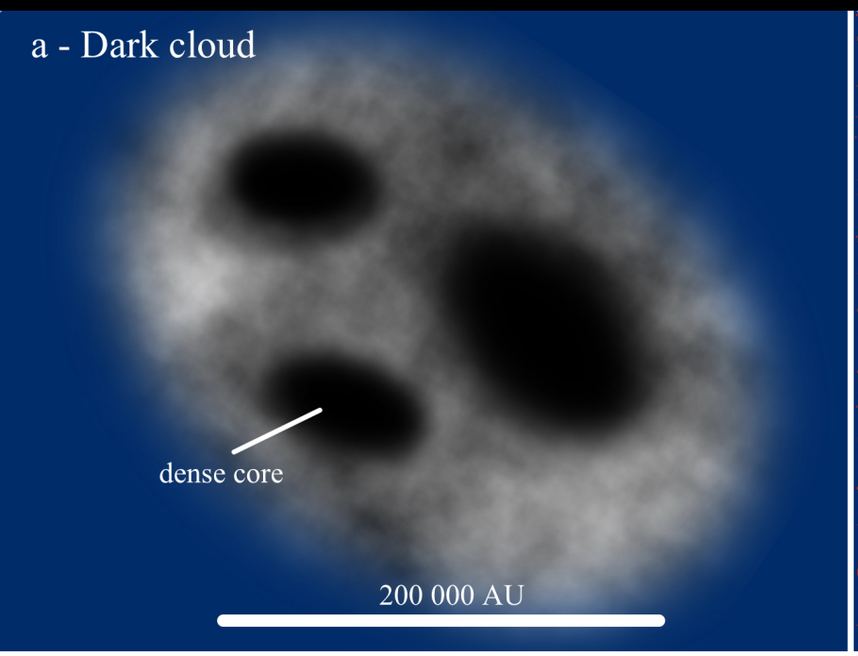
Dense Gas/Dust Conglomerates

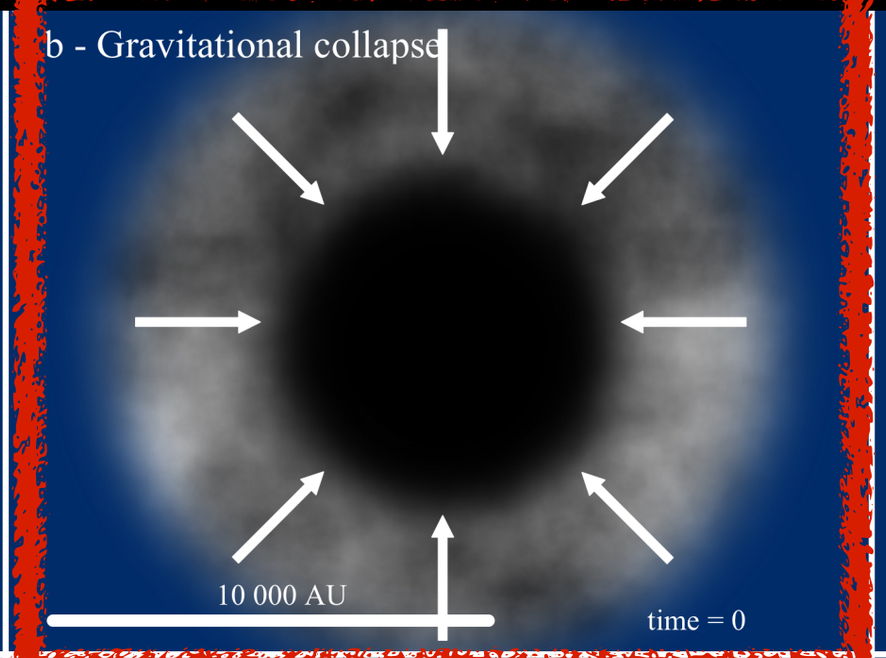
Ring-like Structures

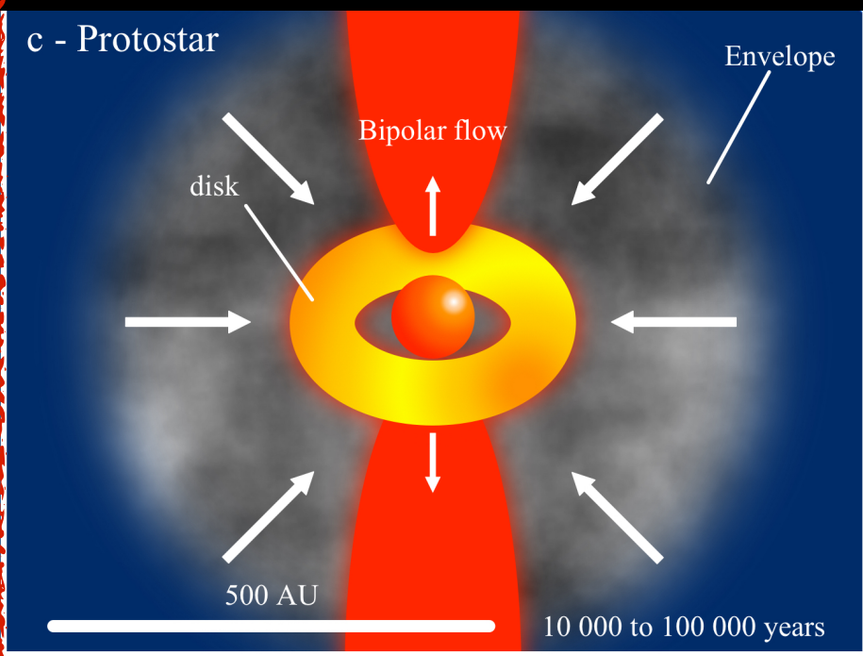


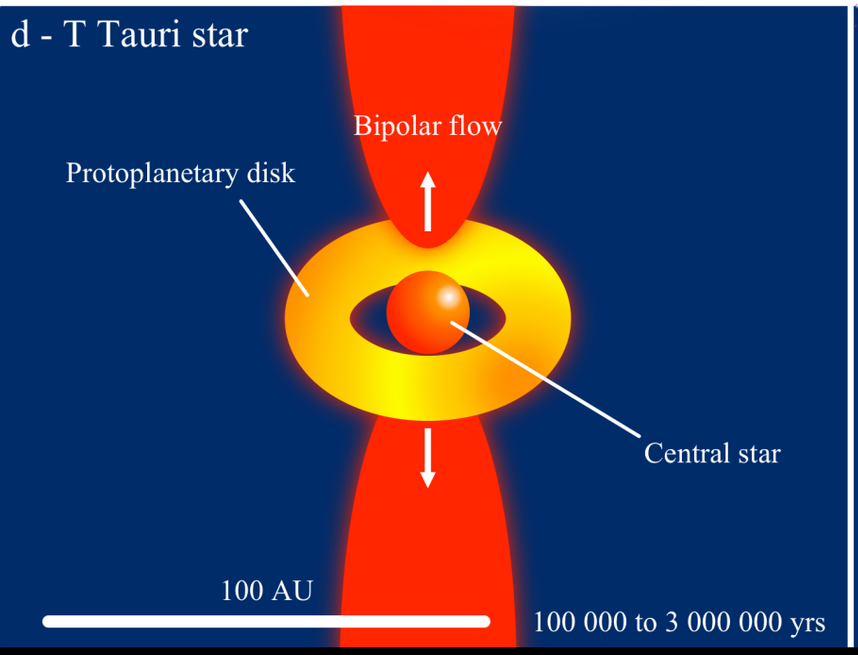
?

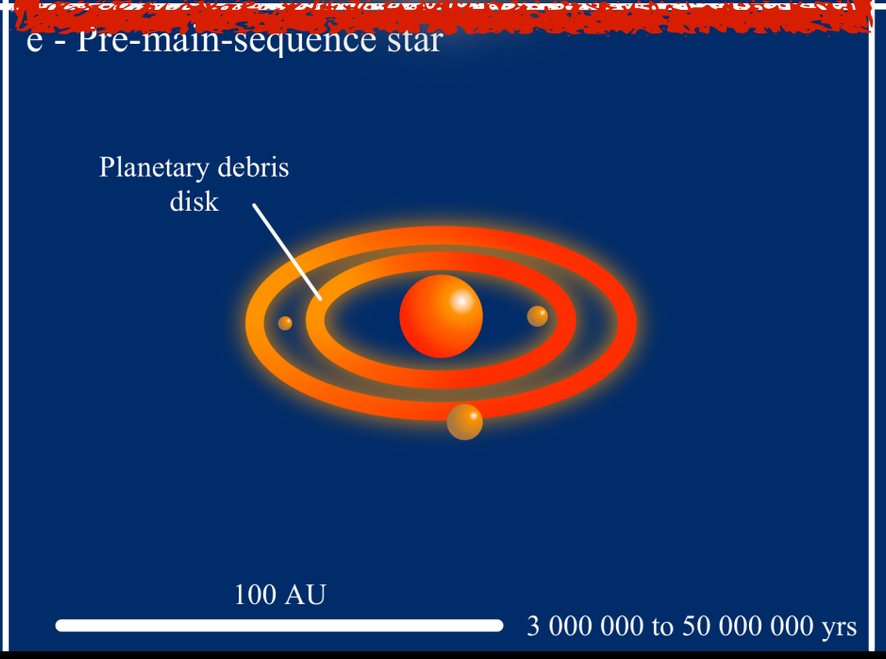
Star Formation in a Nutshell

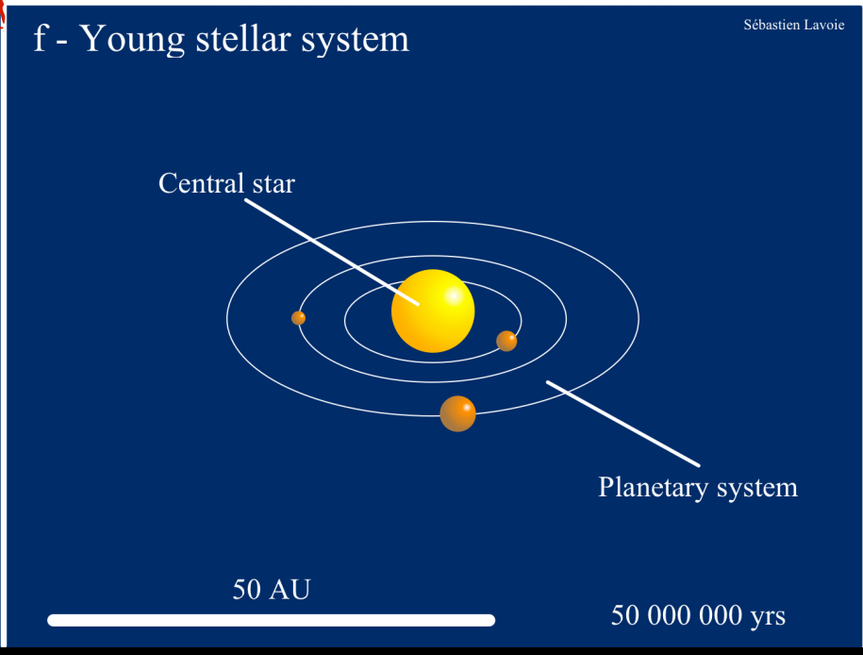












Stronger Pressure

=

Expansion

=

No star formation

Stronger Gravity

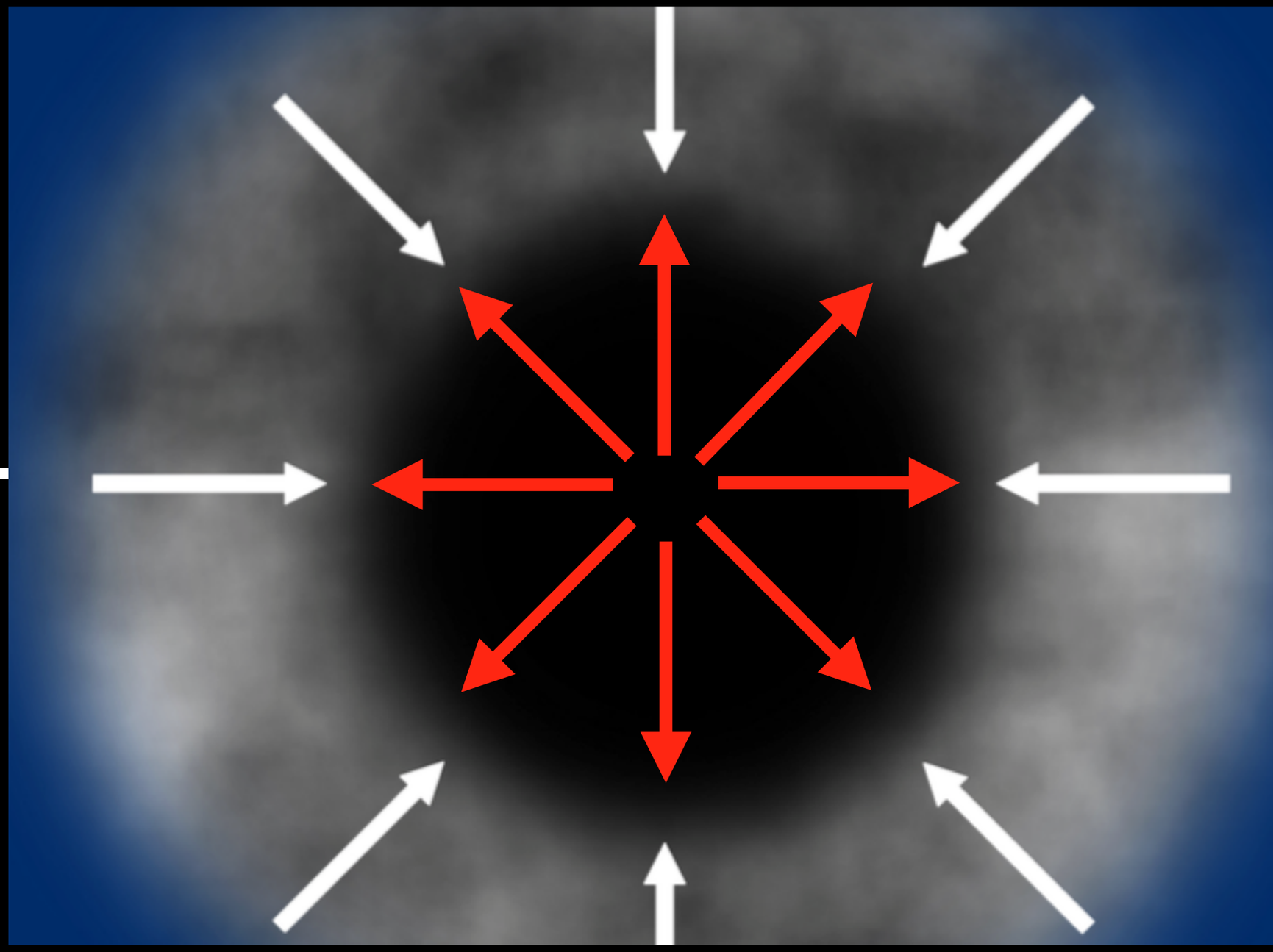
=

Collapse

=

Star Formation

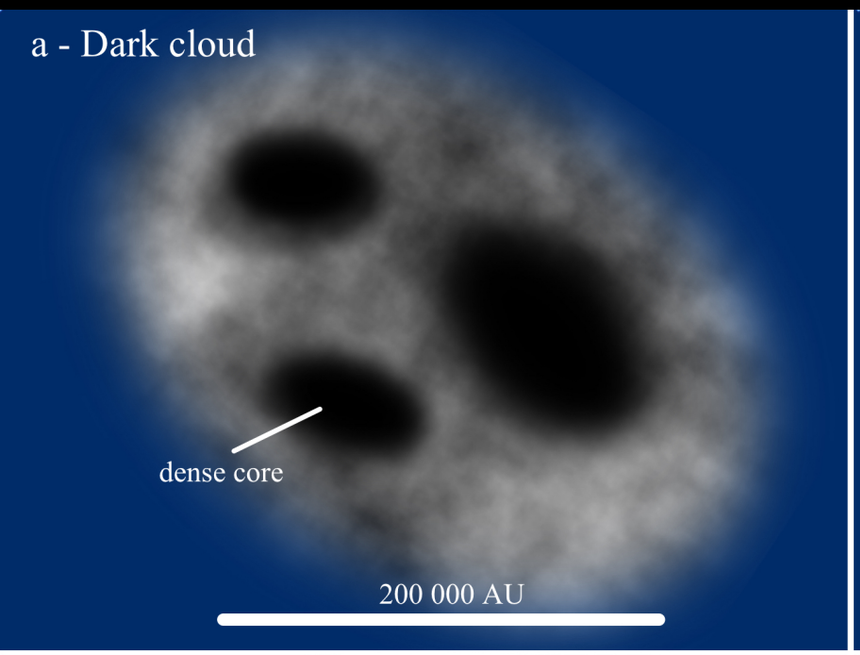
Gravity

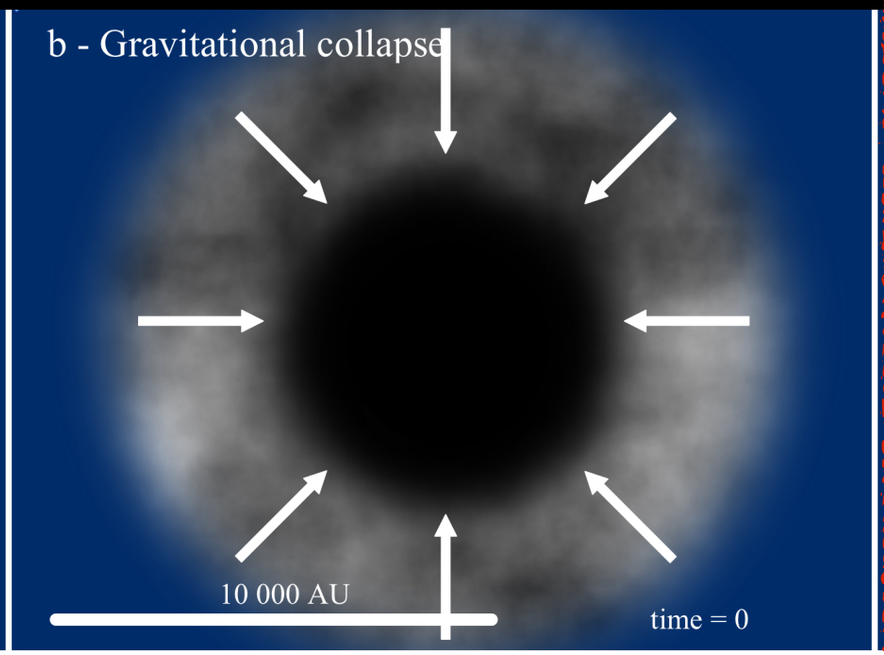


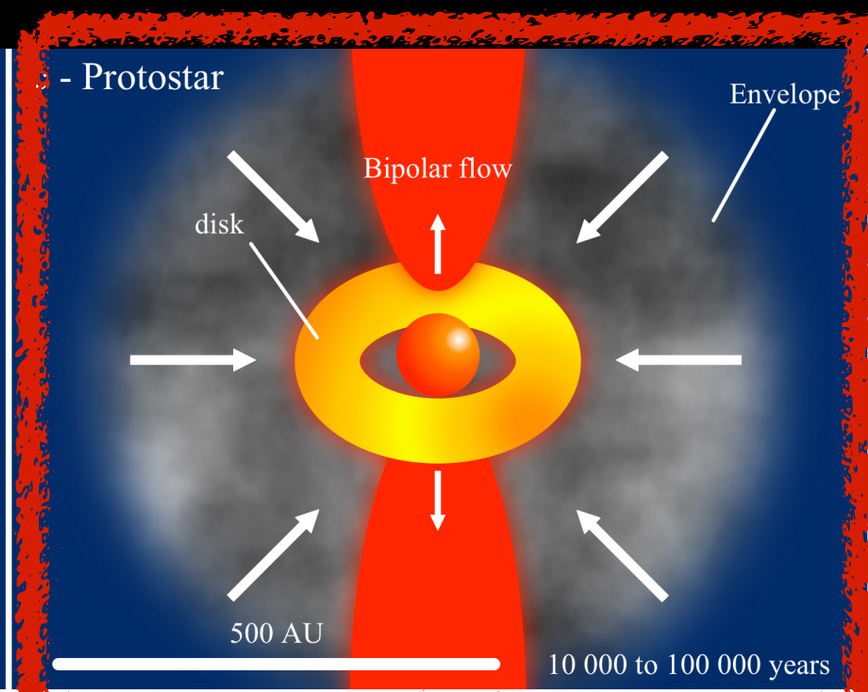
Thermal Pressure

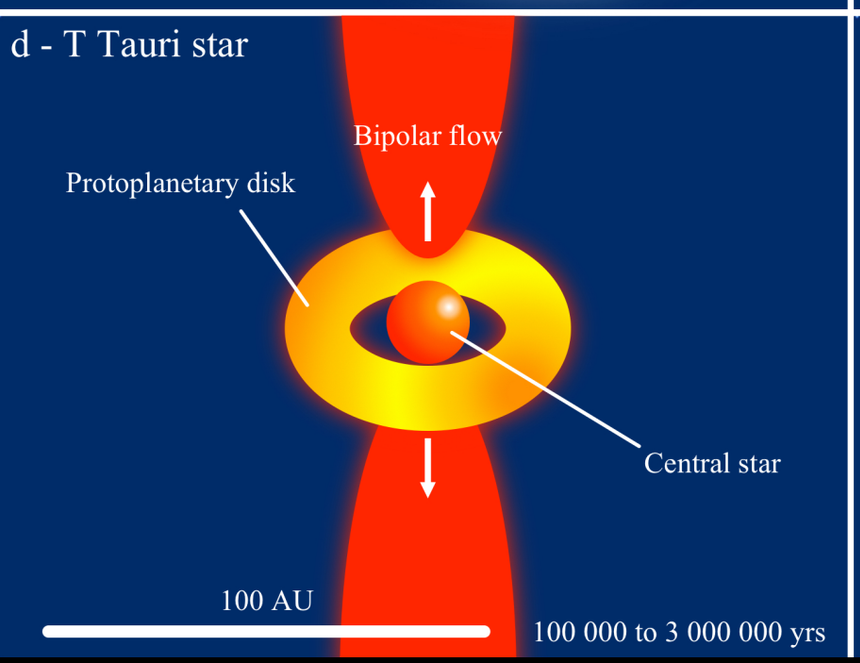
A constant struggle!

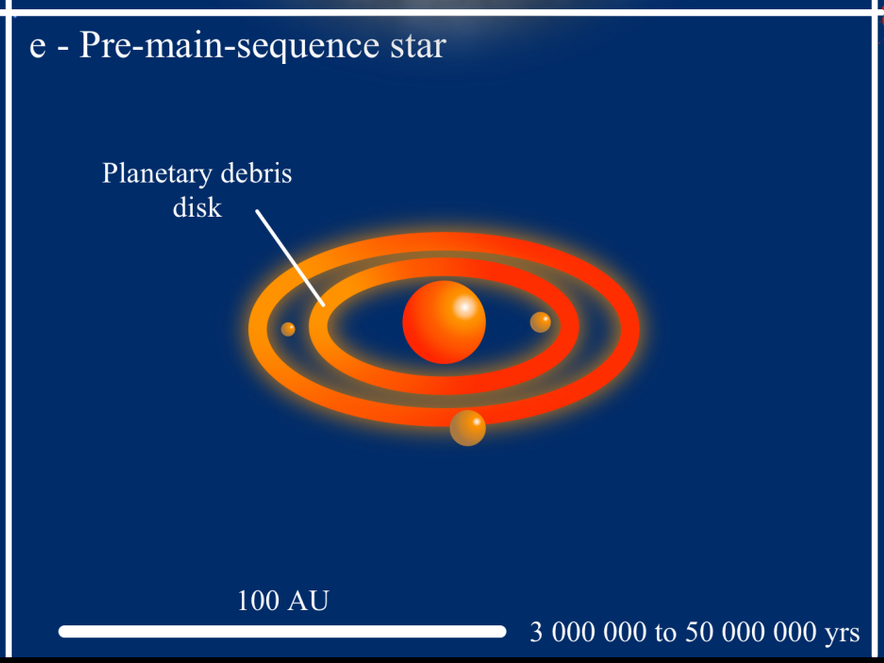
Star Formation in a Nutshell

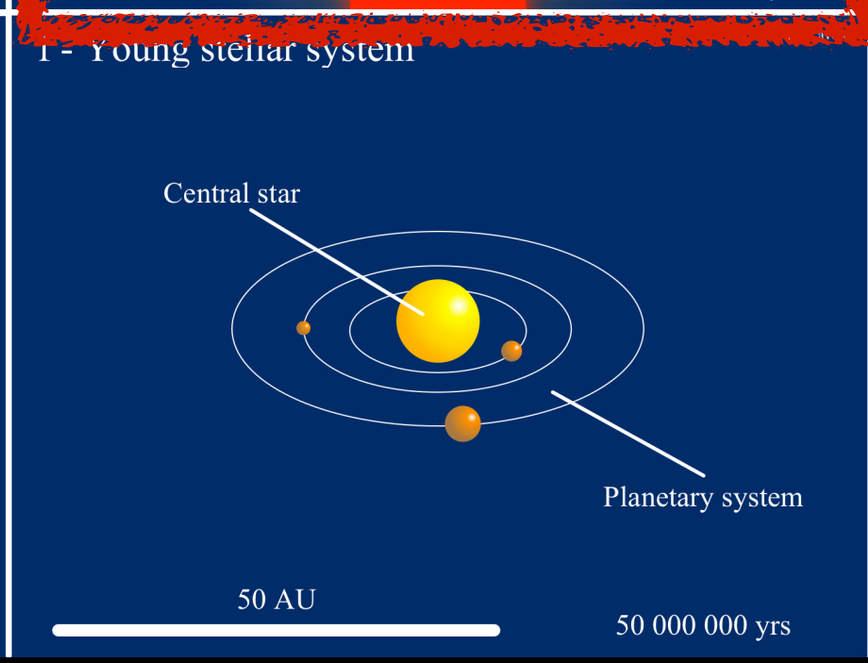




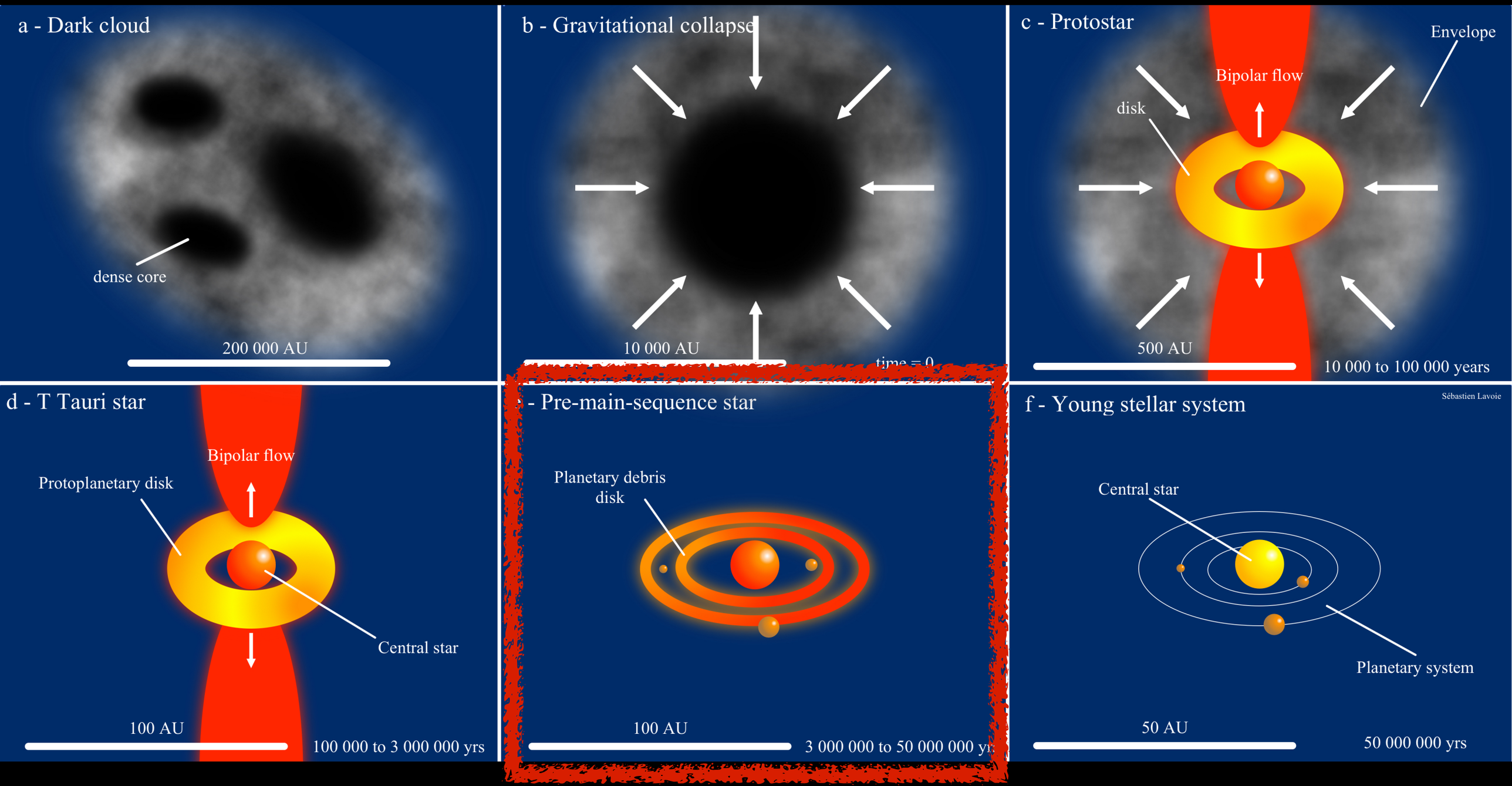








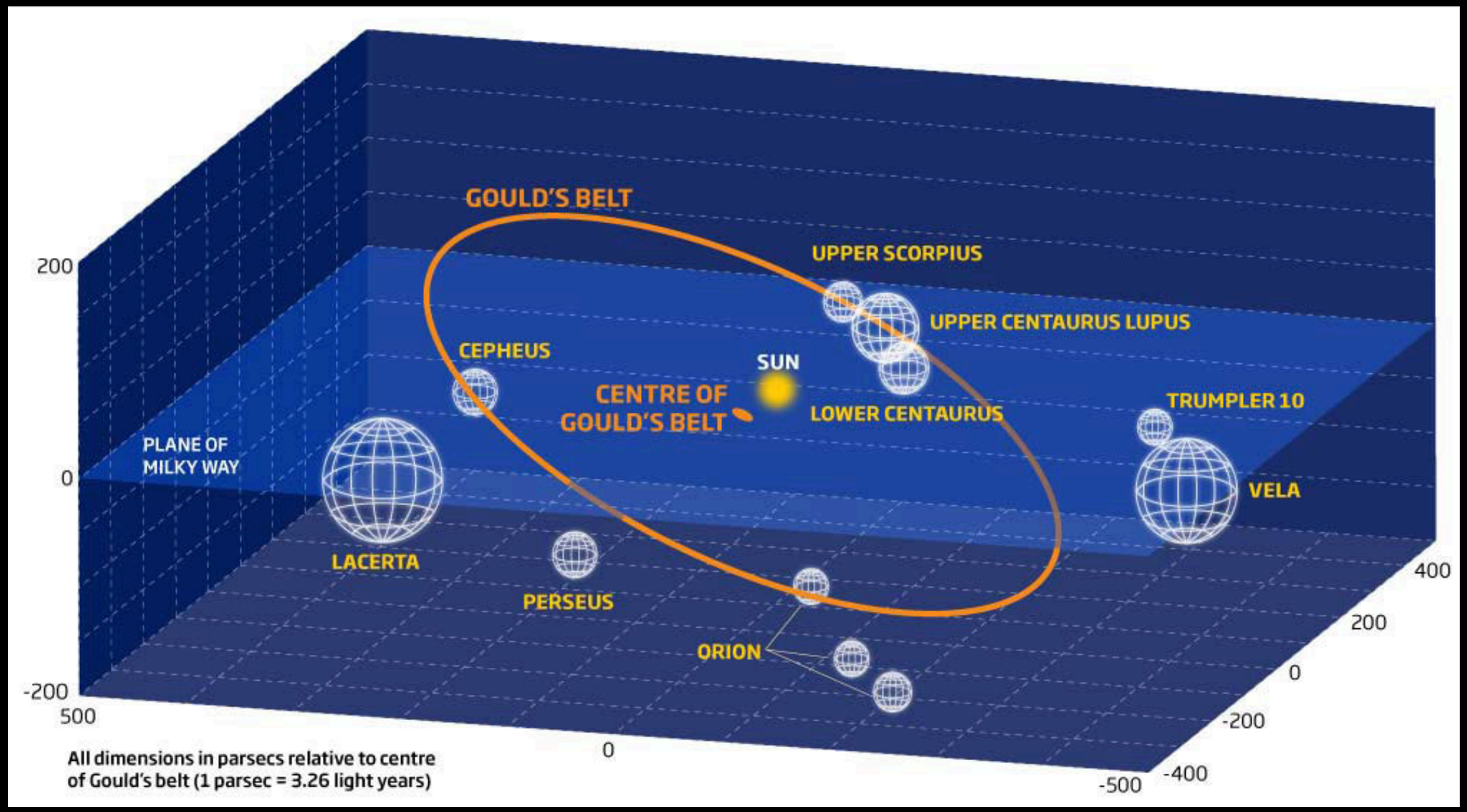
Star Formation in a Nutshell



HL Tauri
ALMA

The Gould Belt

The Gould Belt is a **ring-like region of dense interstellar gas** tilted at ~20° with respect to the plane of our solar system



It is home to many well known star-forming regions such as:

Orion, Perseus, Taurus, Serpens, and Ophiuchus

Molecular Clouds in the Local Universe

Star forming regions are complex and dynamic. A full understanding will require investigating the connection between **many different size scales.**

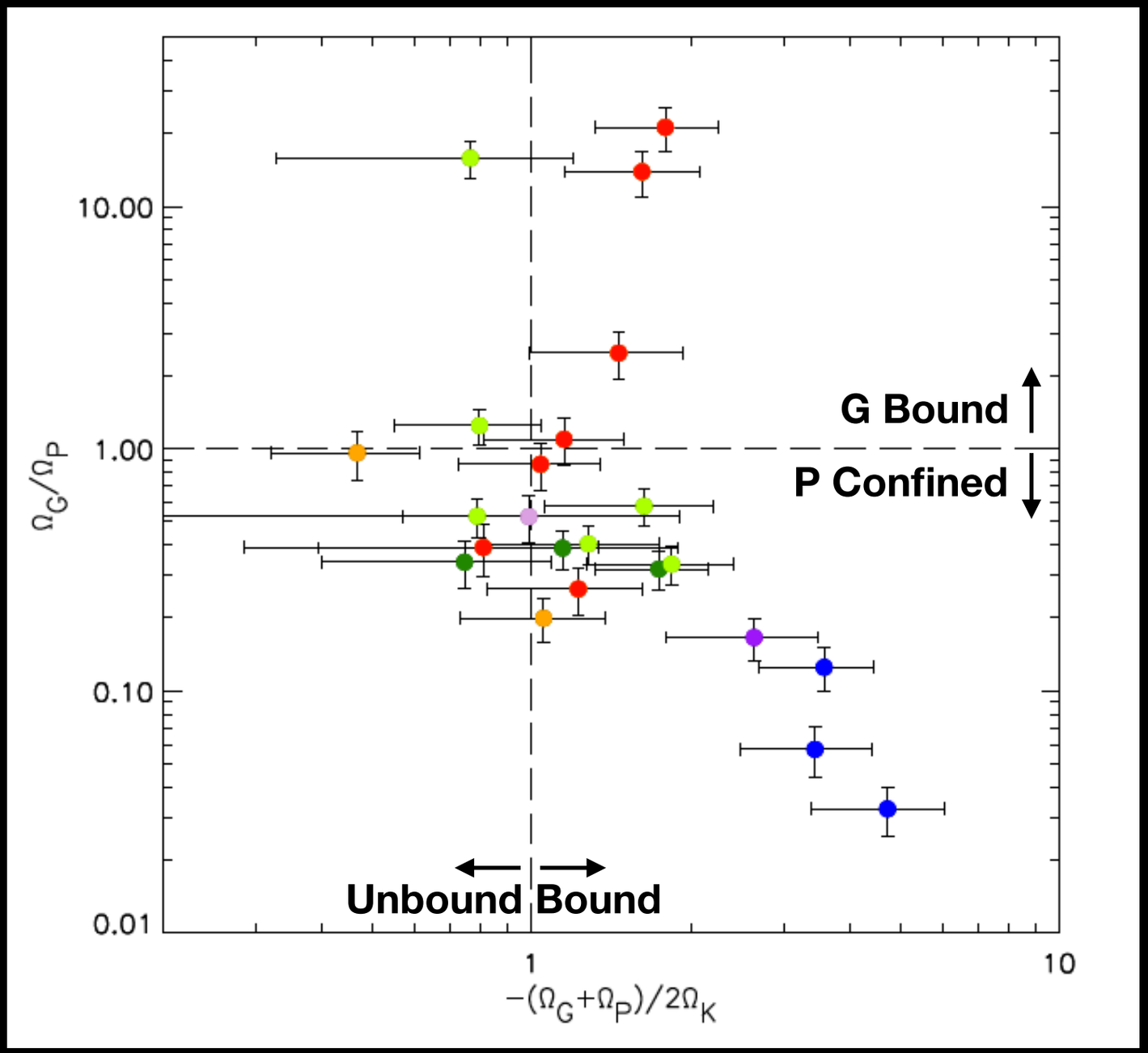
SCUBA-2 provides the **imperative, intermediate observing regime** between the large-scale cloud and the small-scale protostellar physics

The **JCMT Gould Belt Survey** is a consortium dedicated to studying **~20 nearby (<500 pc) star forming regions** at submillimetre wavelengths

Orion, Perseus, Taurus, Ophiuchus, IC5146, Lupus, Cepheus, Auriga, Serpens…

Selected First Look Papers

2015 MNRAS 450:1094. Pattle, K. et al. *Ophiuchus*



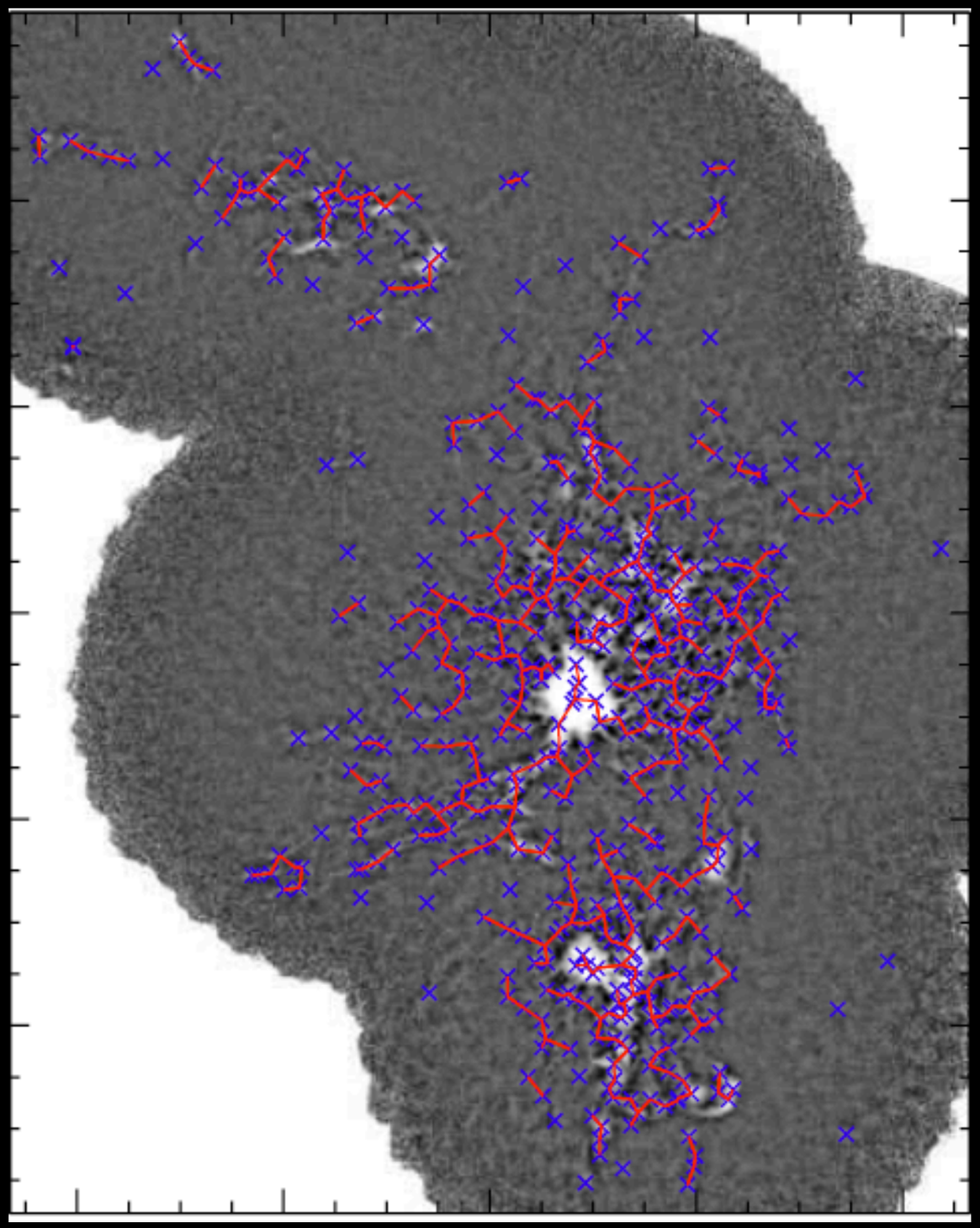
Colours represent different areas of the Ophiuchus Cloud

Can test what types of observations are good for determining if a core will go on to form a star

Can compare different geometries of star forming cores to try to update our theory of star formation

Selected First Look Papers

2016 ApJ 817:167. Kirk, H. et al. *Orion B*



An analysis of **dense core clusters** using minimal spanning trees

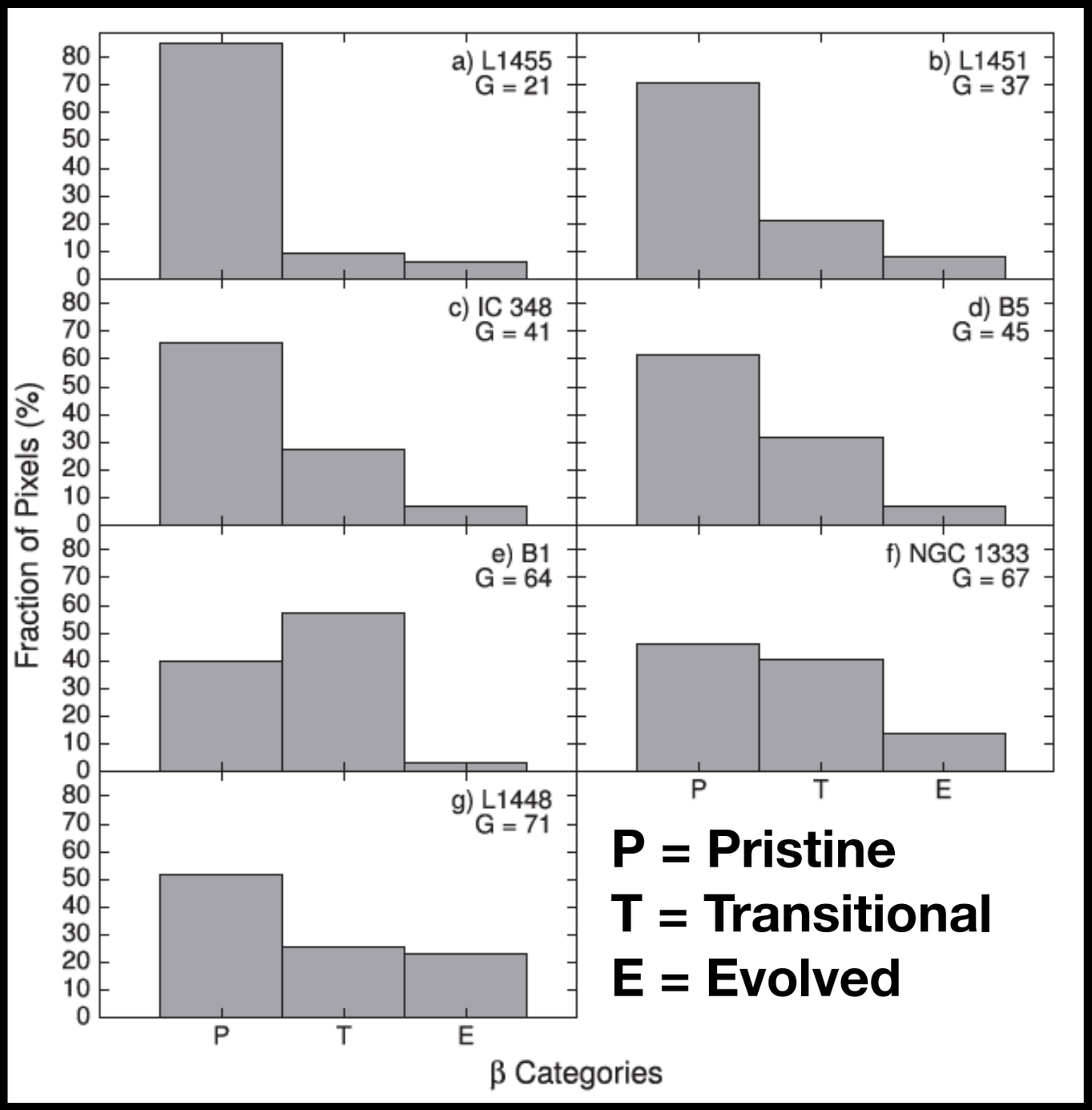
In each cluster, the **most massive cores tend to be centrally located**

Strong **correlation between core mass and the local surface density** of cores

Some amount of **mass segregation in clusters has happened already at the dense core stage**

Selected First Look Papers

2016 ApJ 826:95. Chen, M. C.-Y. et al. *Perseus*



Presents **Spectral Index (β)**, **dust temperature**, and **optical depth** maps

Derived from *Herschel+JCMT* SEDs

Presents evidence of **dust grain growth (G)** and orders regions of Perseus in **relative evolutionary stages**

Mairs et al. 2016.
MNRAS. 461:4022

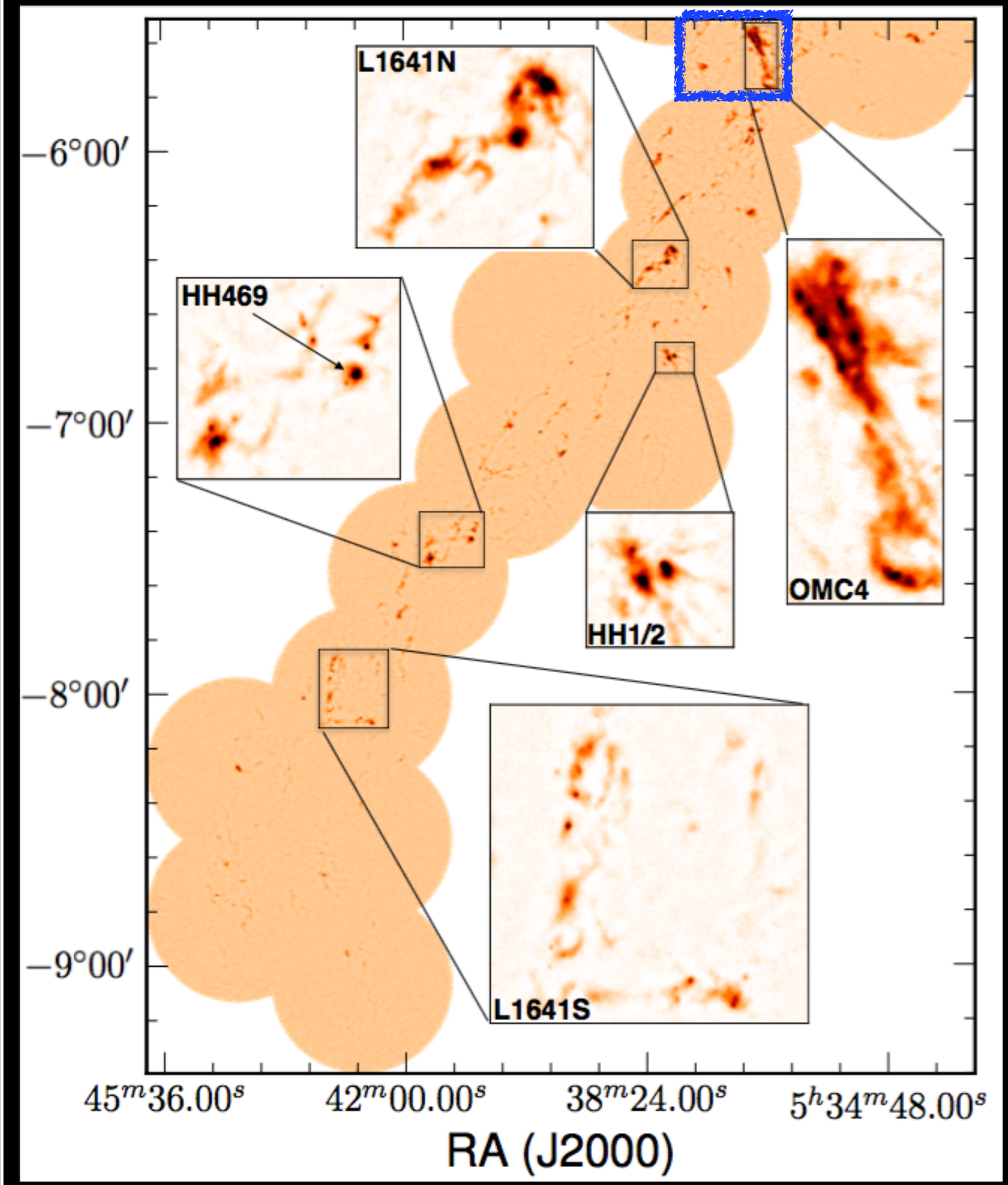
Two Step Source Extraction:

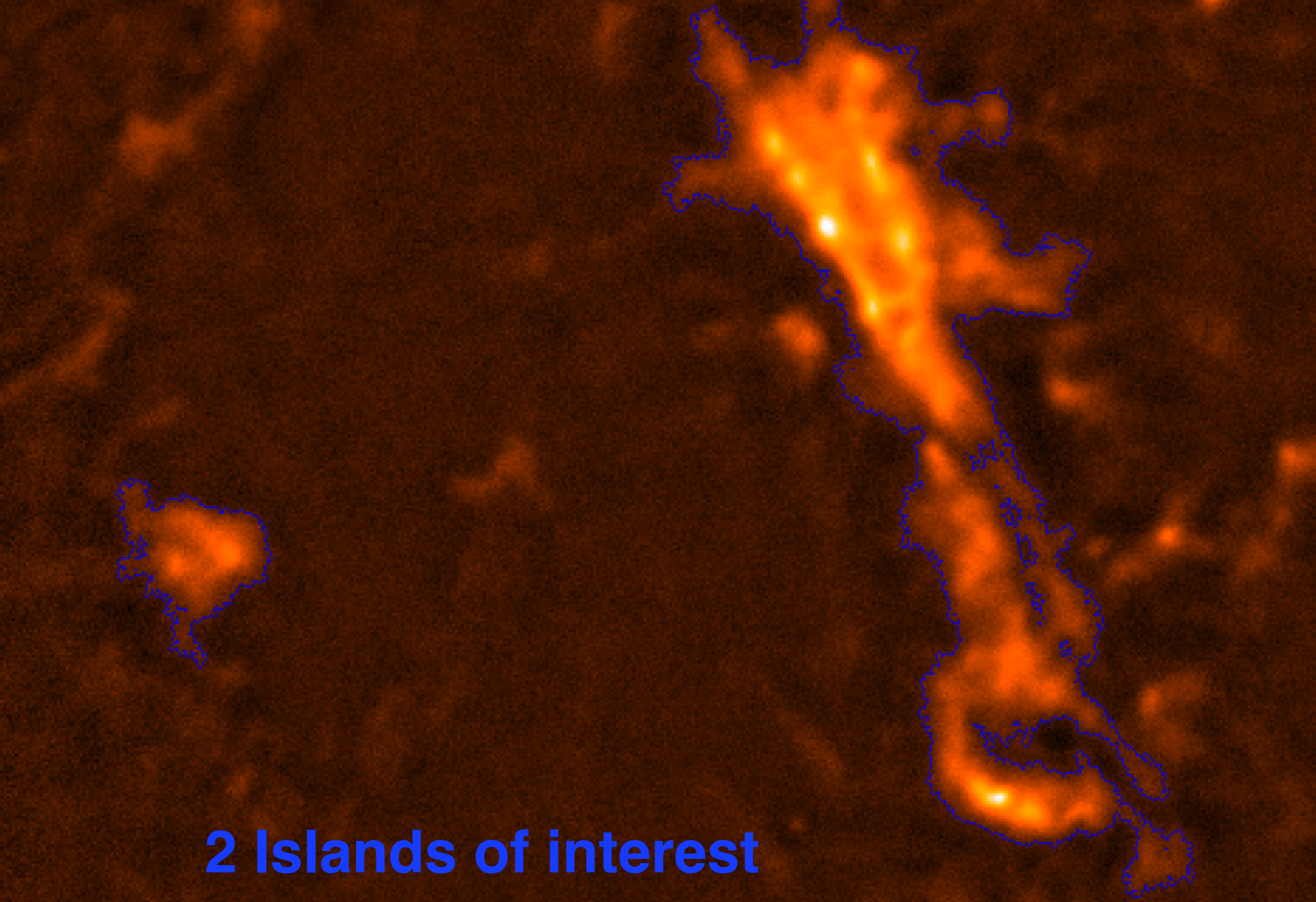
Islands: 3σ contours larger than one beam (~15")

Fragments: Identified using *FellWalker* (Berry 2015 A&C 10:22)

Fragments are often smaller than islands. They highlight substructures within larger sources

Southern Orion A (850 μm; SCUBA-2)




2 Islands of interest
0.2 pc

2 Islands of interest

Fragment Finding Algorithm

0.2 pc

An Example of an interesting follow-up candidate

Protostar
Class 0/I

Disk

Protostar
Candidate

M ~ 4M_J

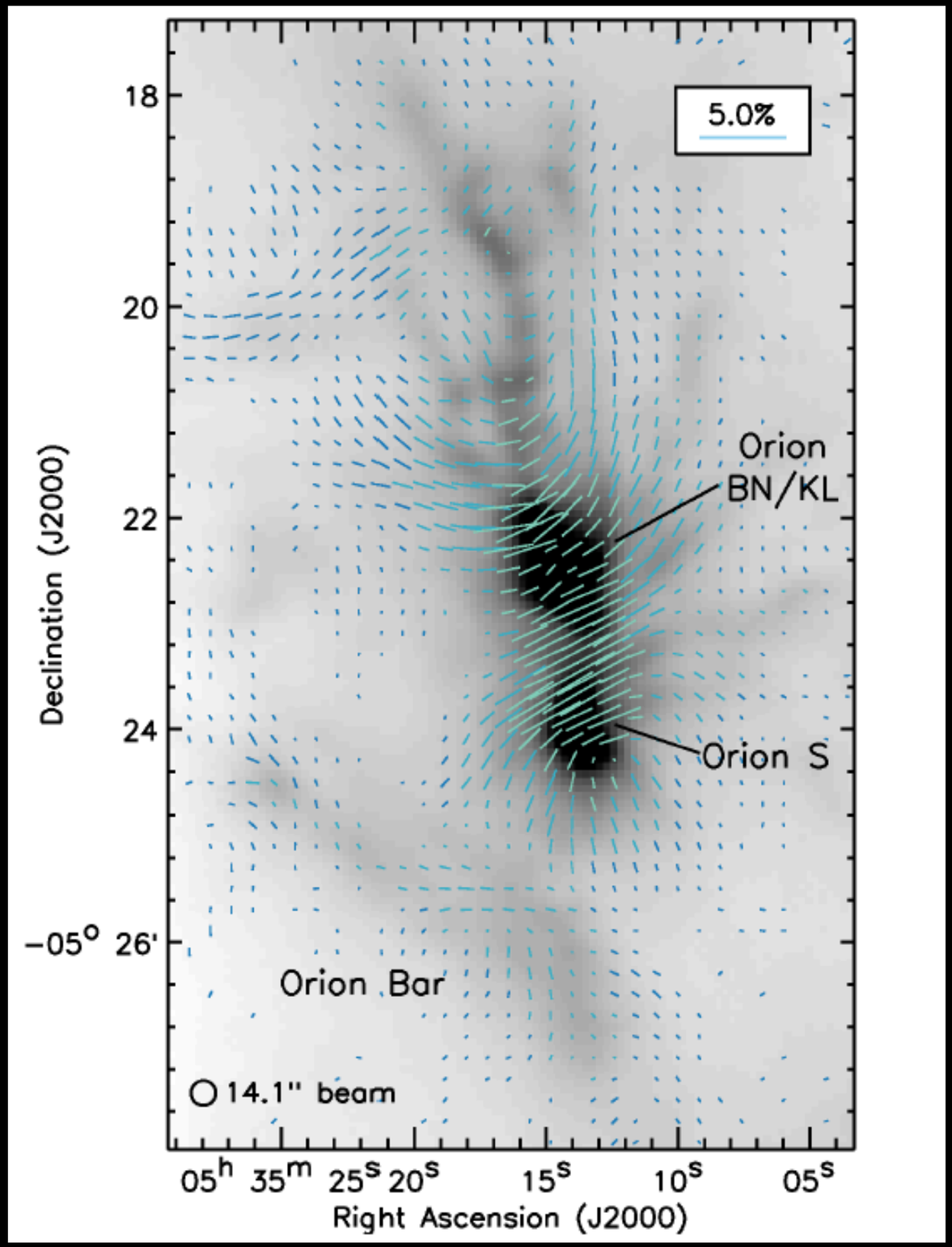
M~ 3M_J

Radius = 0.1 pc
Mass = 16.5 M⊙

YSO Catalogue From:
Megeath et al 2012
Stutz et al 2013

Starless 1

Continuing Work: BISTRO/BISTRO2



2017 ApJ 842:66. Ward-Thompson, D. et al.

The BISTRO and BISTRO2 Large Programs are **extending the GBS data by using POL-2**

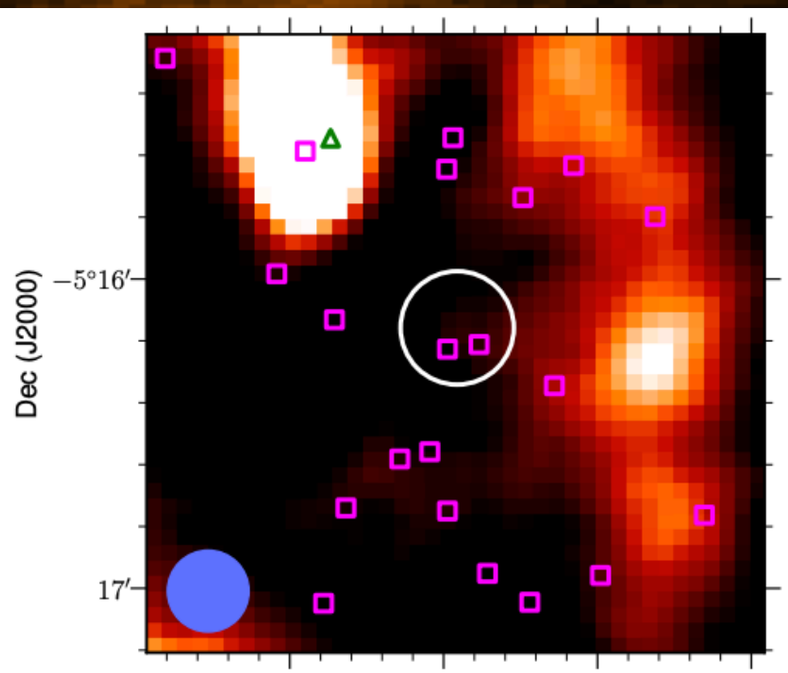
Hoping to answer open questions such as the **relative importance of magnetic fields and turbulence to star formation**

Will allow us to test current models such as the *Herschel* result of **magnetic funneling onto filaments**

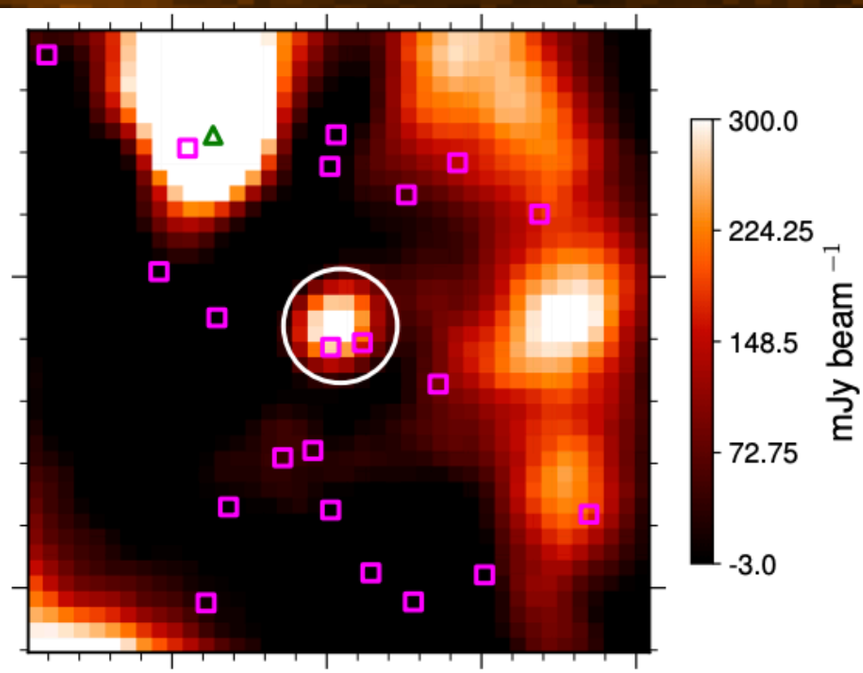
The JCMT Transient Survey

A **Protostar** Being Born!

Brightest Stellar Flare Ever Discovered!



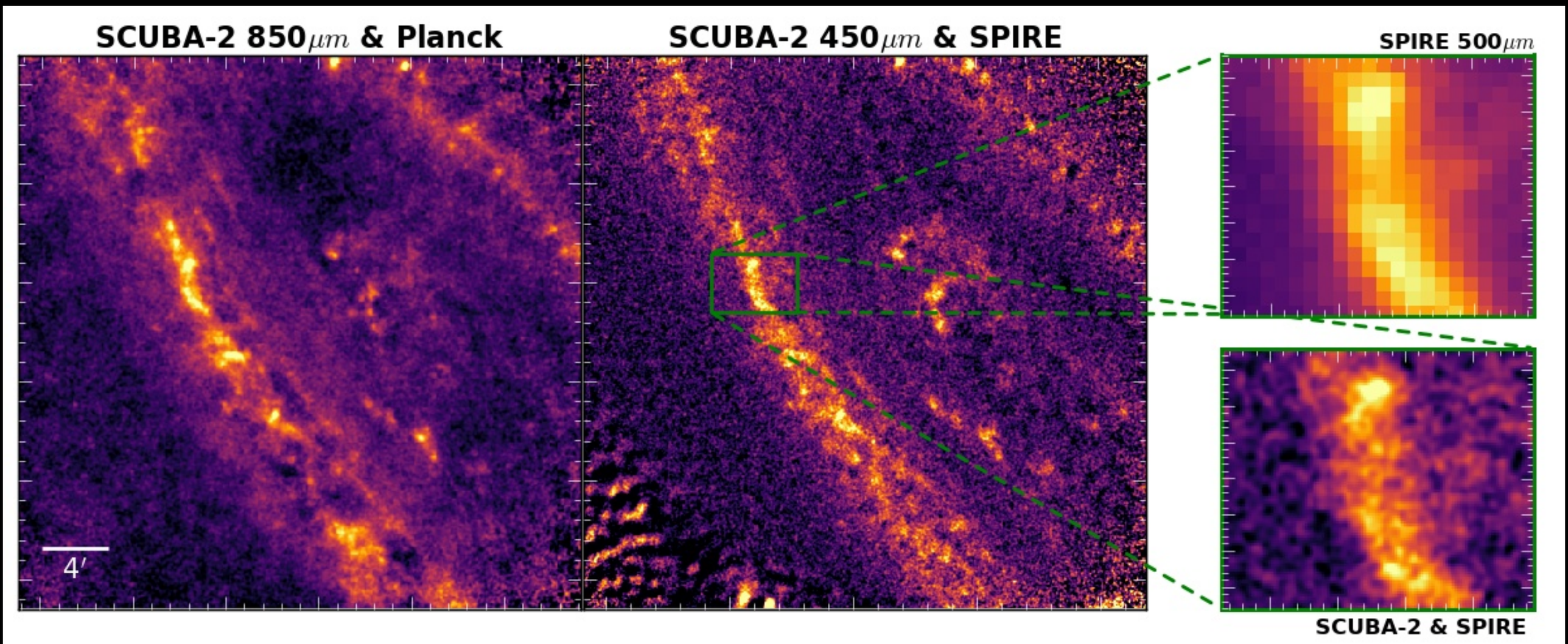
(a) 850 μm 2016-11-20 (UT).



(b) 850 μm 2016-11-26 (UT).

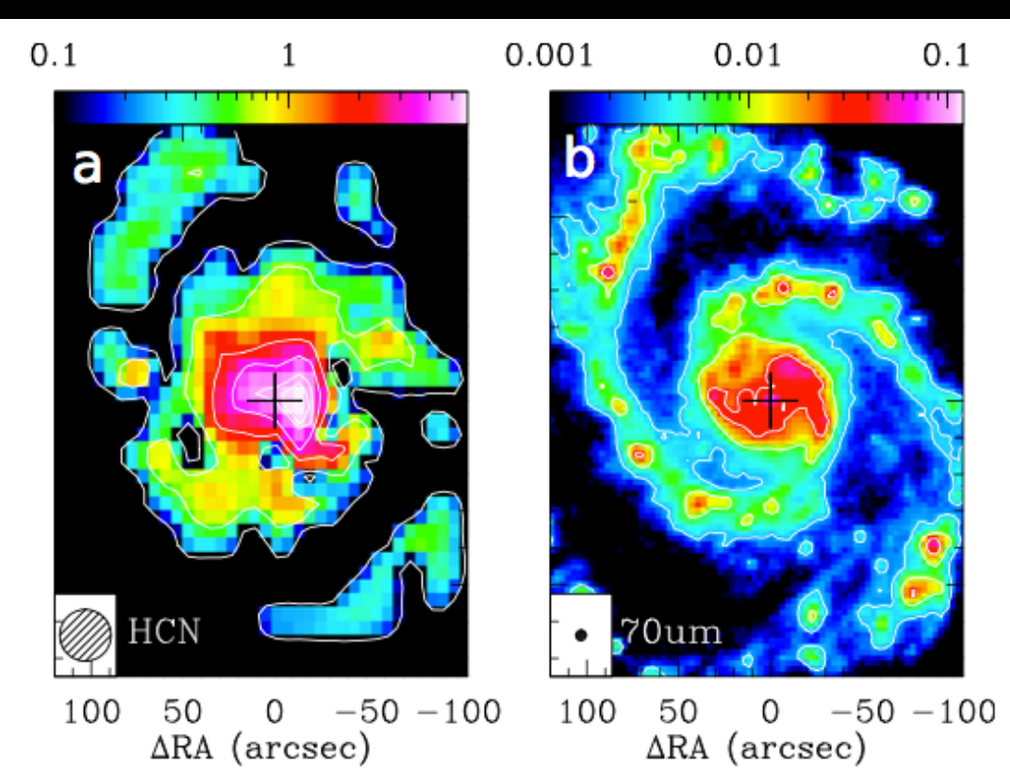
Extragalactic Star Formation Too!

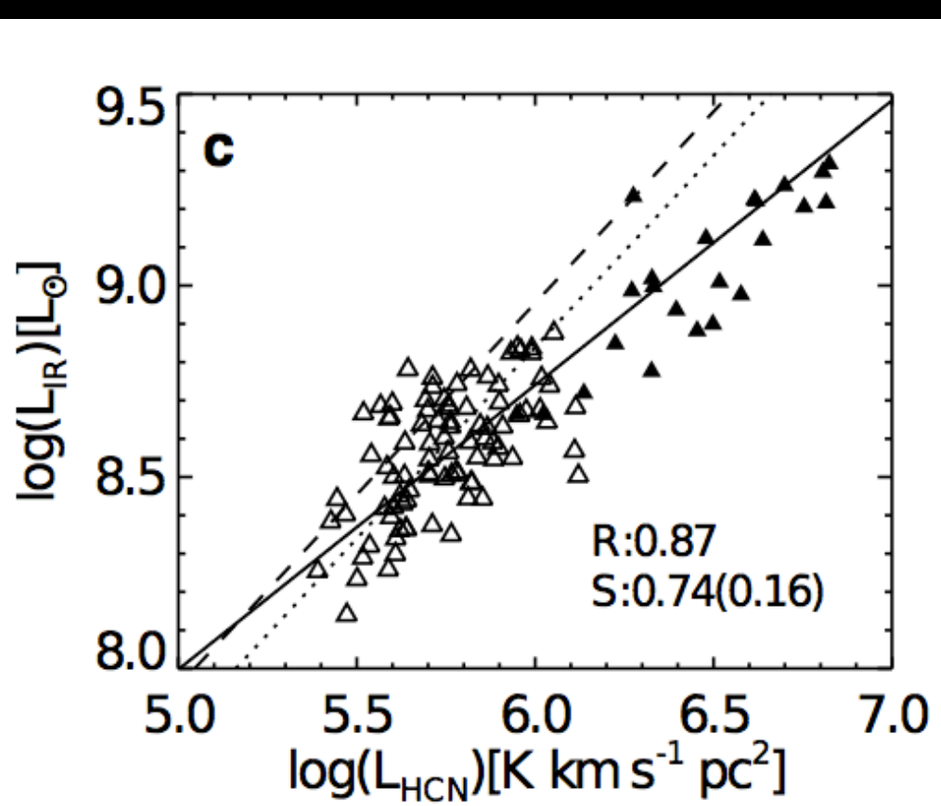
HASHTAG: HARP and SCUBA-2 High Resolution Terahertz Andromeda Galaxy Survey

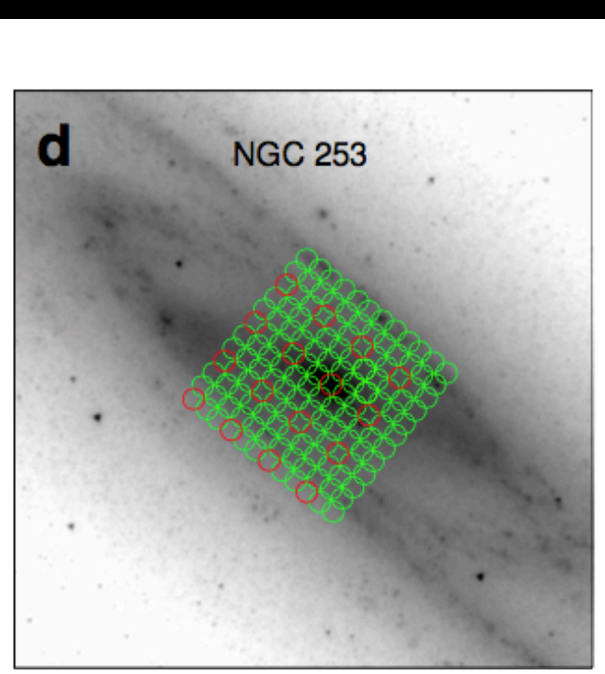


Extragalactic Star Formation Too!

MALATANG: MApping the dense moLecular gAs in the sTrongest stAr-formiNg Galaxies

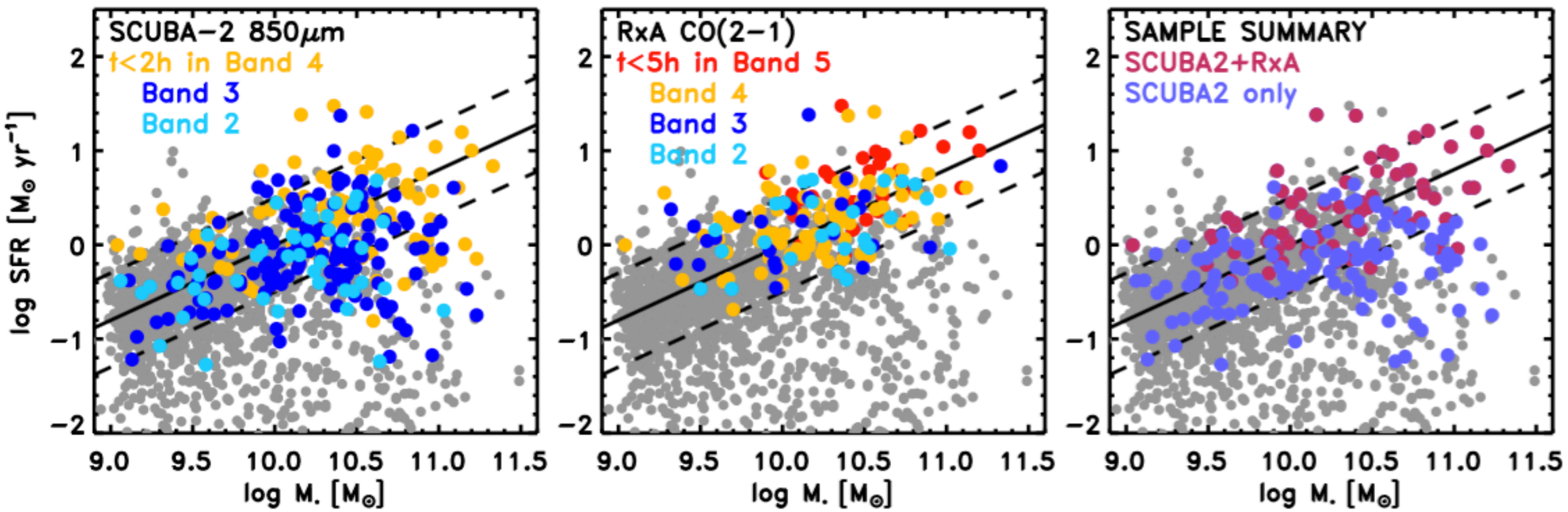




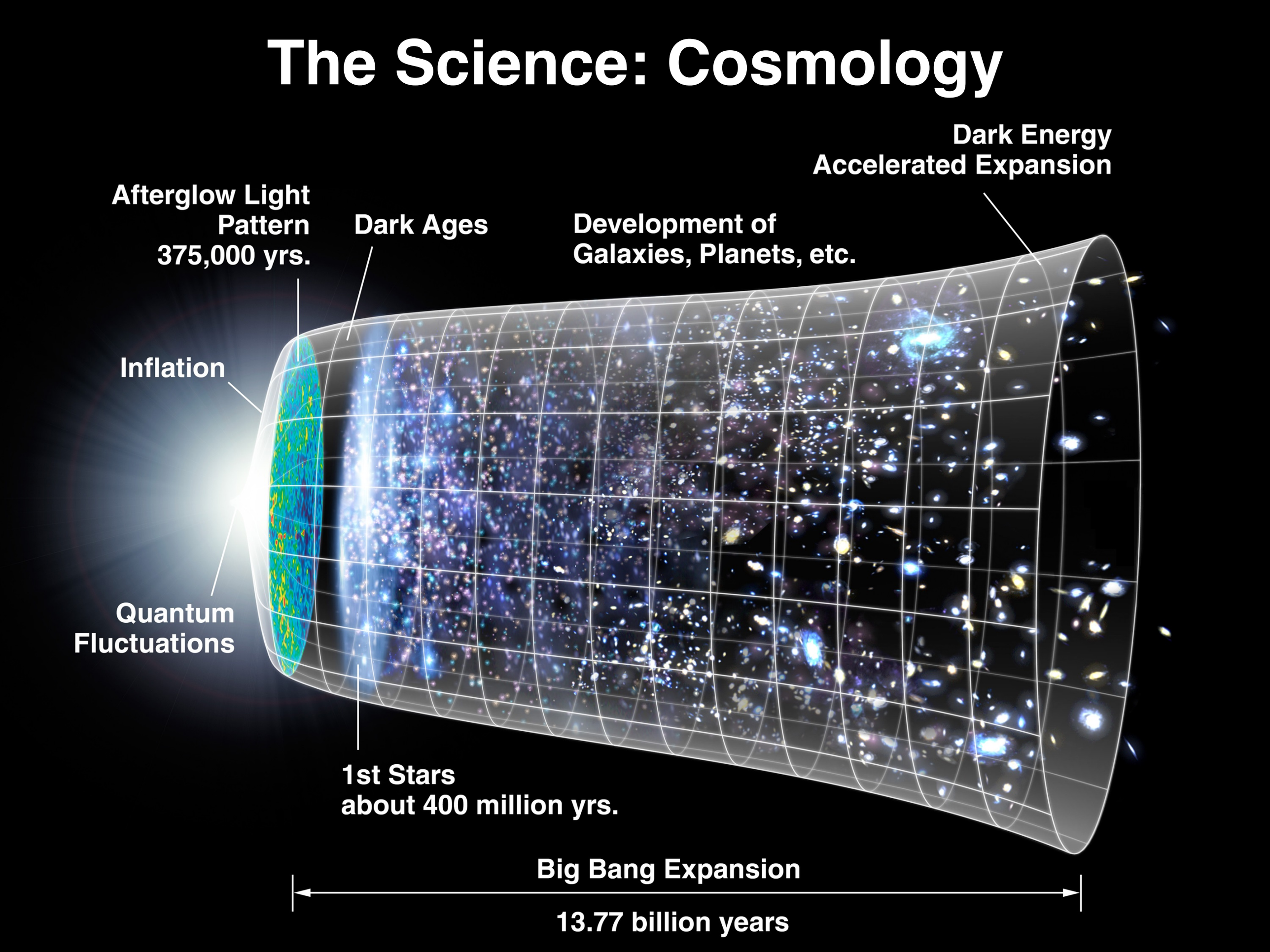


Extragalactic Star Formation Too!

JINGLE: The JCMT dust and gas In Nearby Galaxies Legacy Exploration



The Science: Cosmology

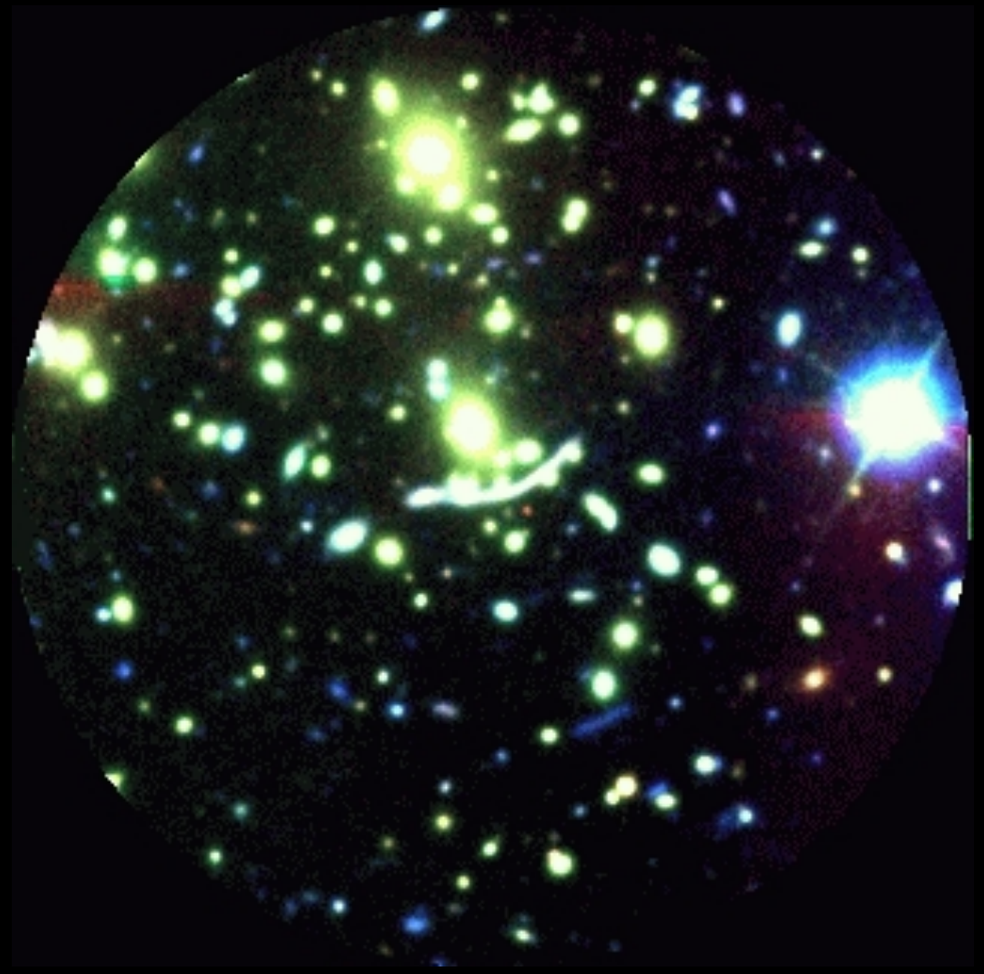


SCUBA Galaxies

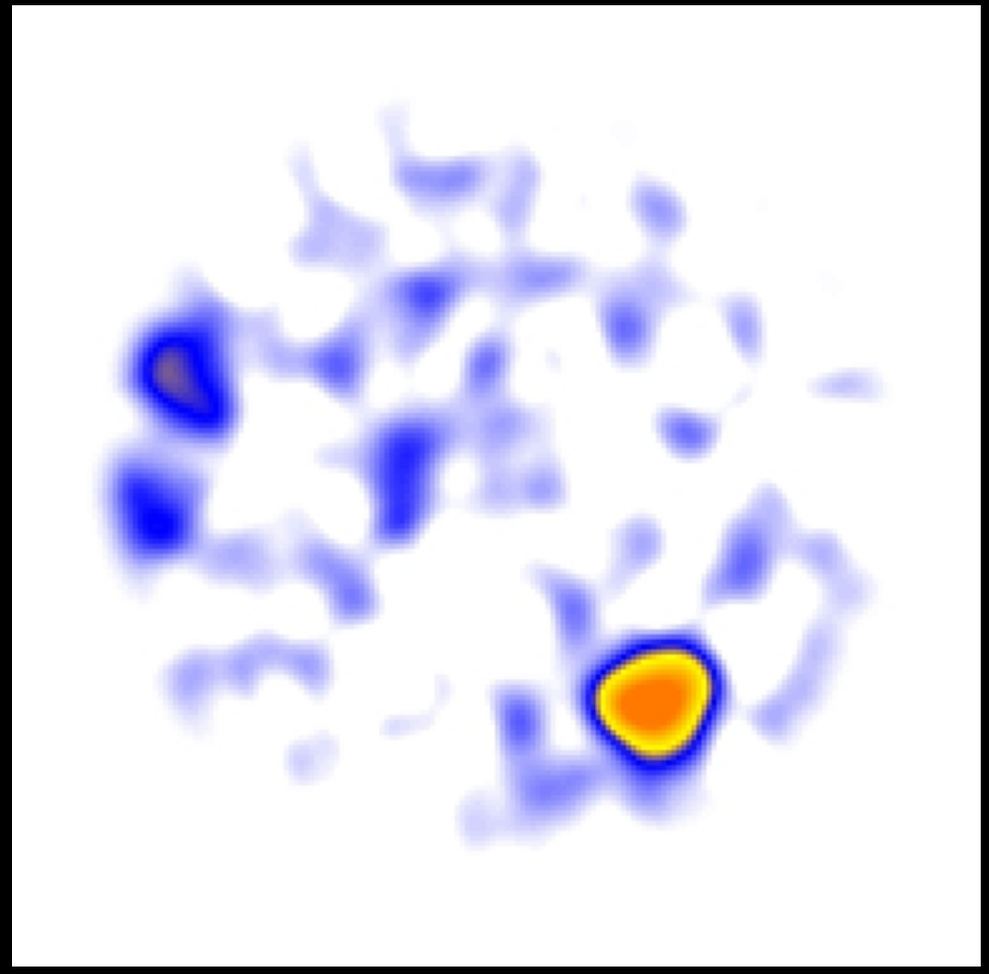
High Energy UV/Optical Starlight is reprocessed by the galactic dust into Infrared Wavelengths

For the earliest (farthest) Galaxies, in some cases, still forming themselves,
The Infrared is then redshifted to Submillimetre Wavelengths to which
the JCMT is sensitive

Optical/Infrared



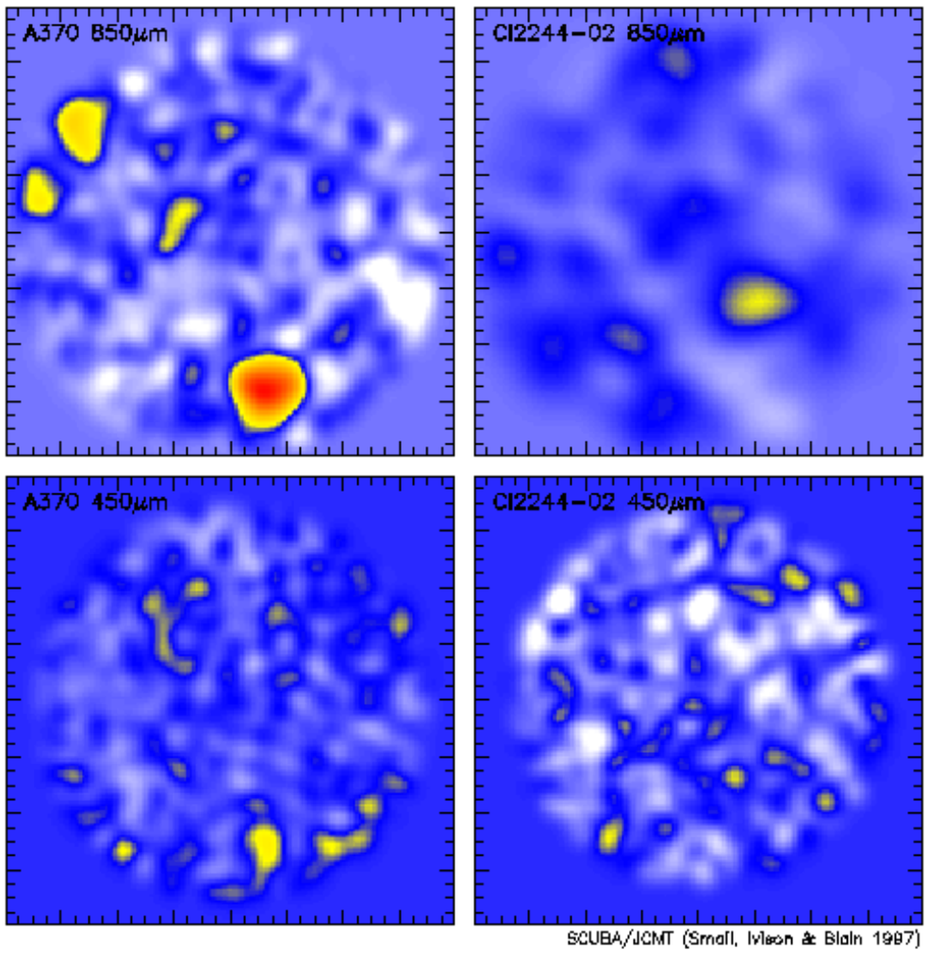
Submillimetre (JCMT)

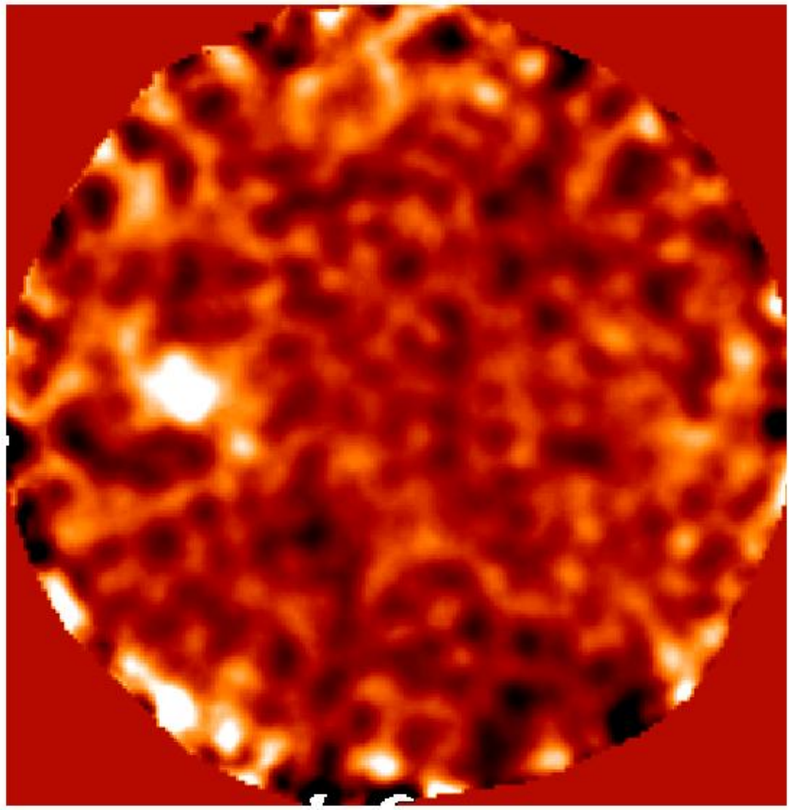


SCUBA Galaxies

(Information from Dr. Ian Smail: http://star-www.dur.ac.uk/~irs/images_misc.html#scuba)

These are the first deep sub-millimeter maps of the distant Universe ever taken and they show a number of sub-mm sources detected at 850um.



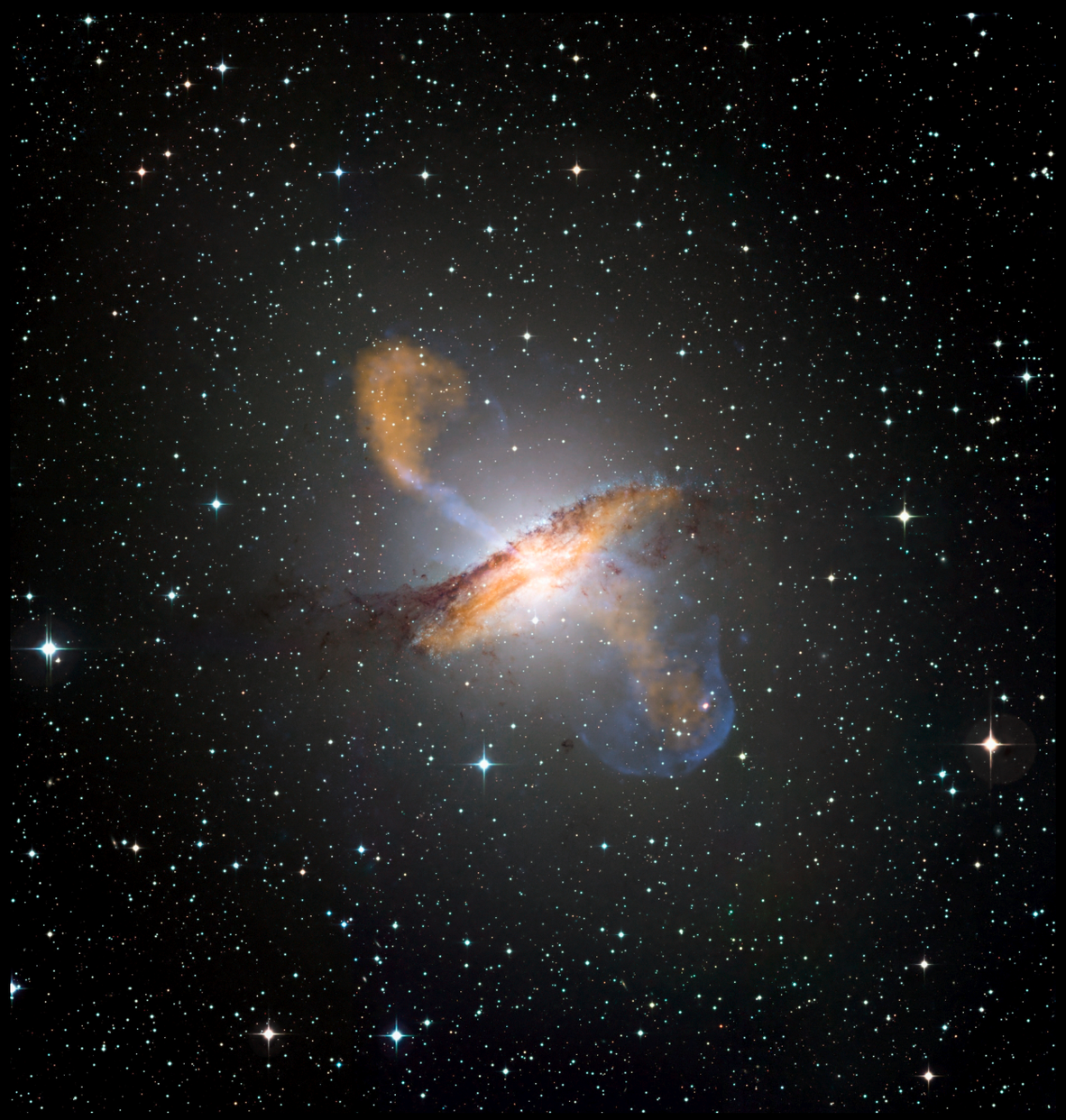


The high surface density of the sub-mm sources indicates that the population being missed by the optical surveys could account for over half the star-formation in the distant Universe.

Active Galactic Nuclei

Most (maybe all!) galaxies contain a supermassive black hole.

In some of these galaxies, infalling material gets too close to the black hole and it heats up to millions of degrees

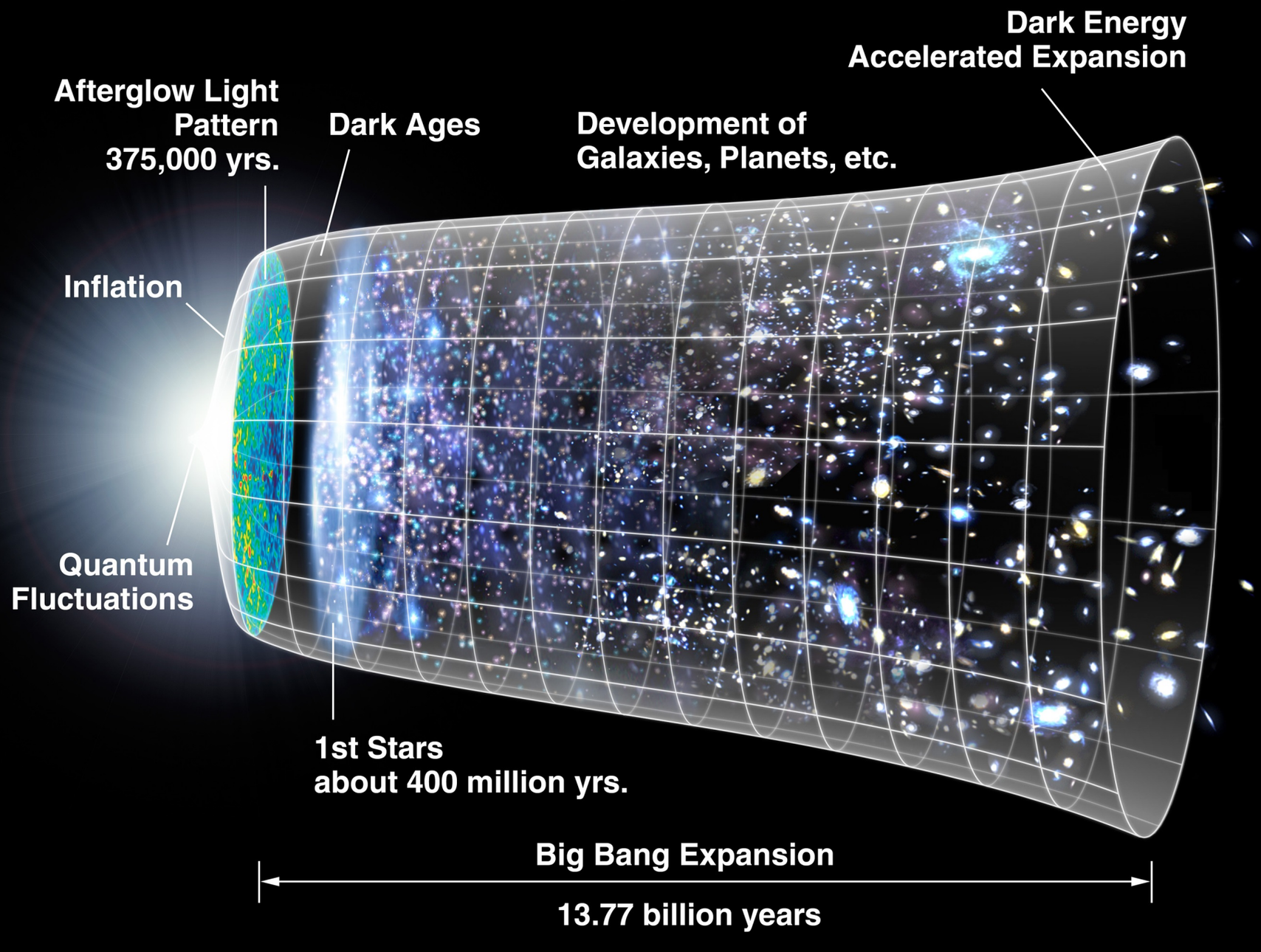


This causes a high energy release exploding outward

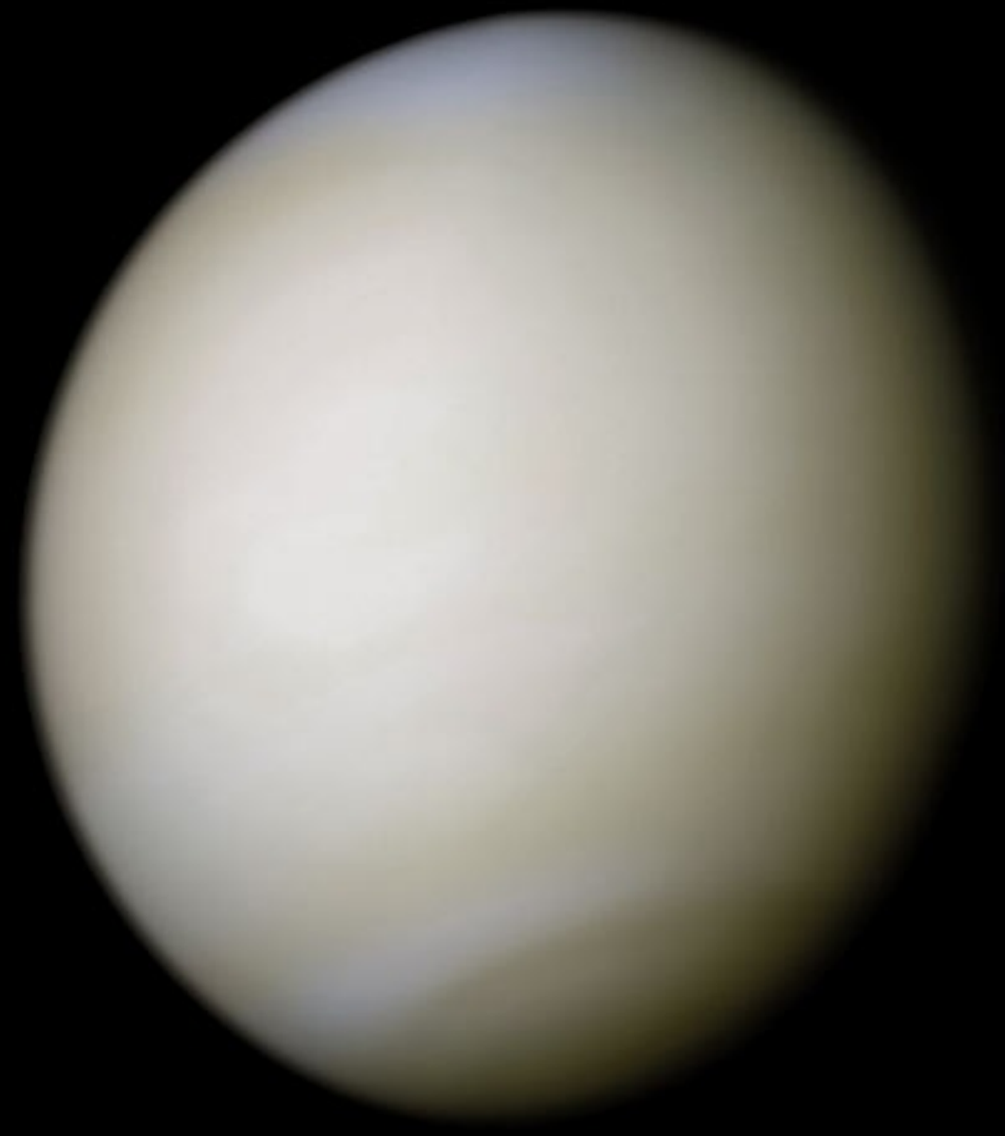
That high energy released is also Reprocessed by dust - allowing us to study far off Quasars formed near the light horizon of the Observable Universe

Galactic Building Blocks

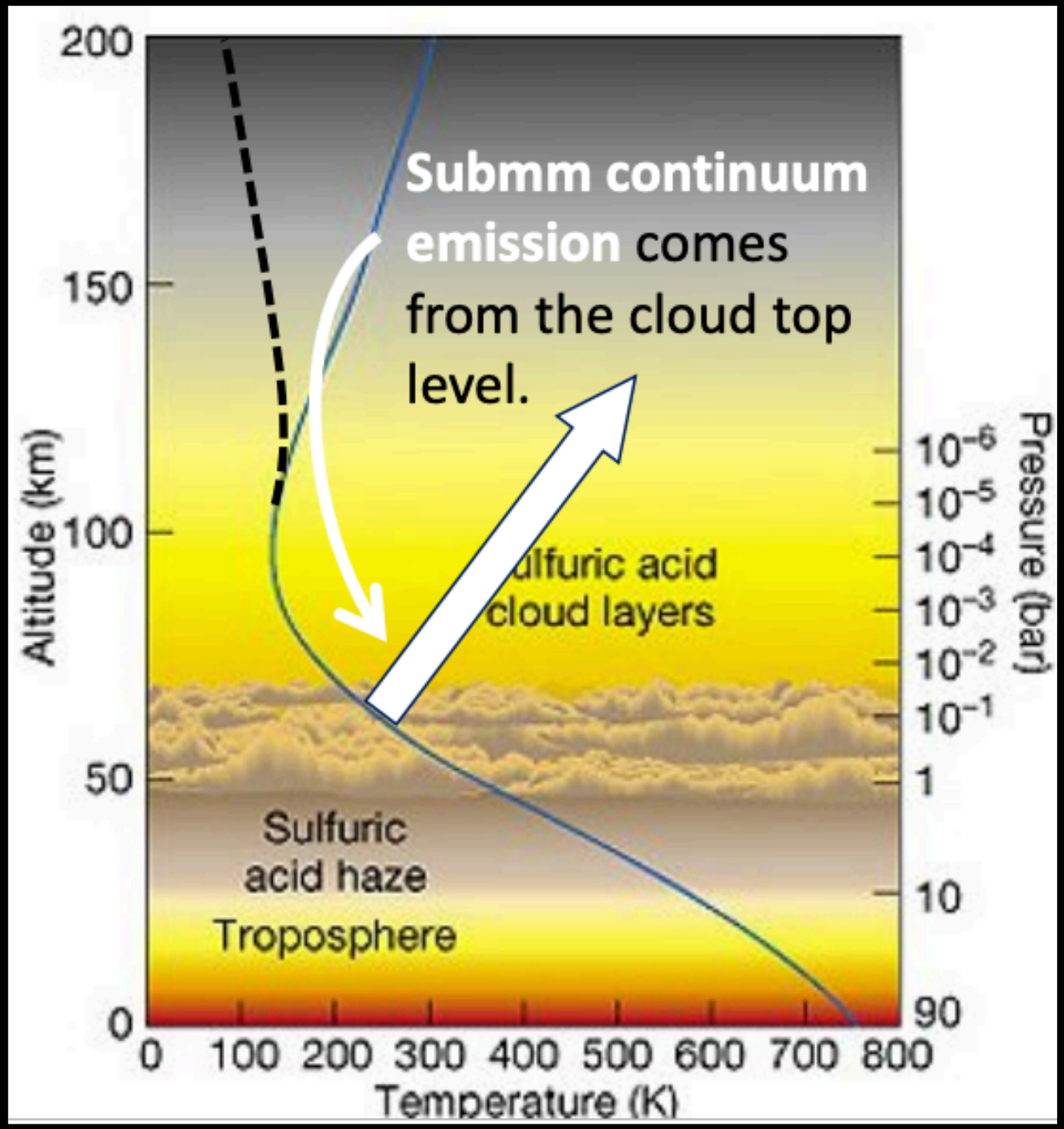
We are using the JCMT to study the star formation history of the universe!



The Science: Comets/Planets



Venus Observations



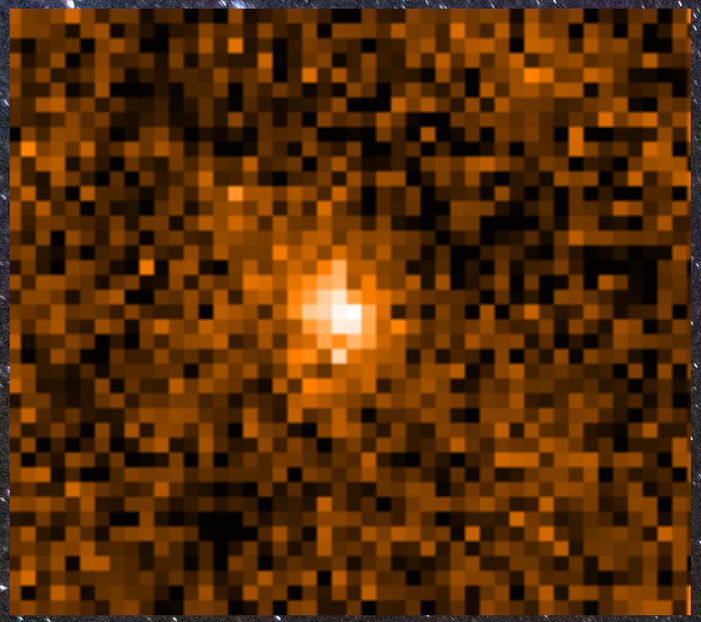
Led by Dr. Hideo Sagawa (Kyoto Sangyo University)

Studying the photochemistry and dynamics of Venus' atmosphere at an altitude of 70-100 Km

Finding correlations in variations among many chemical species (temperature, wind, day/night)

All observations performed in the light of day!

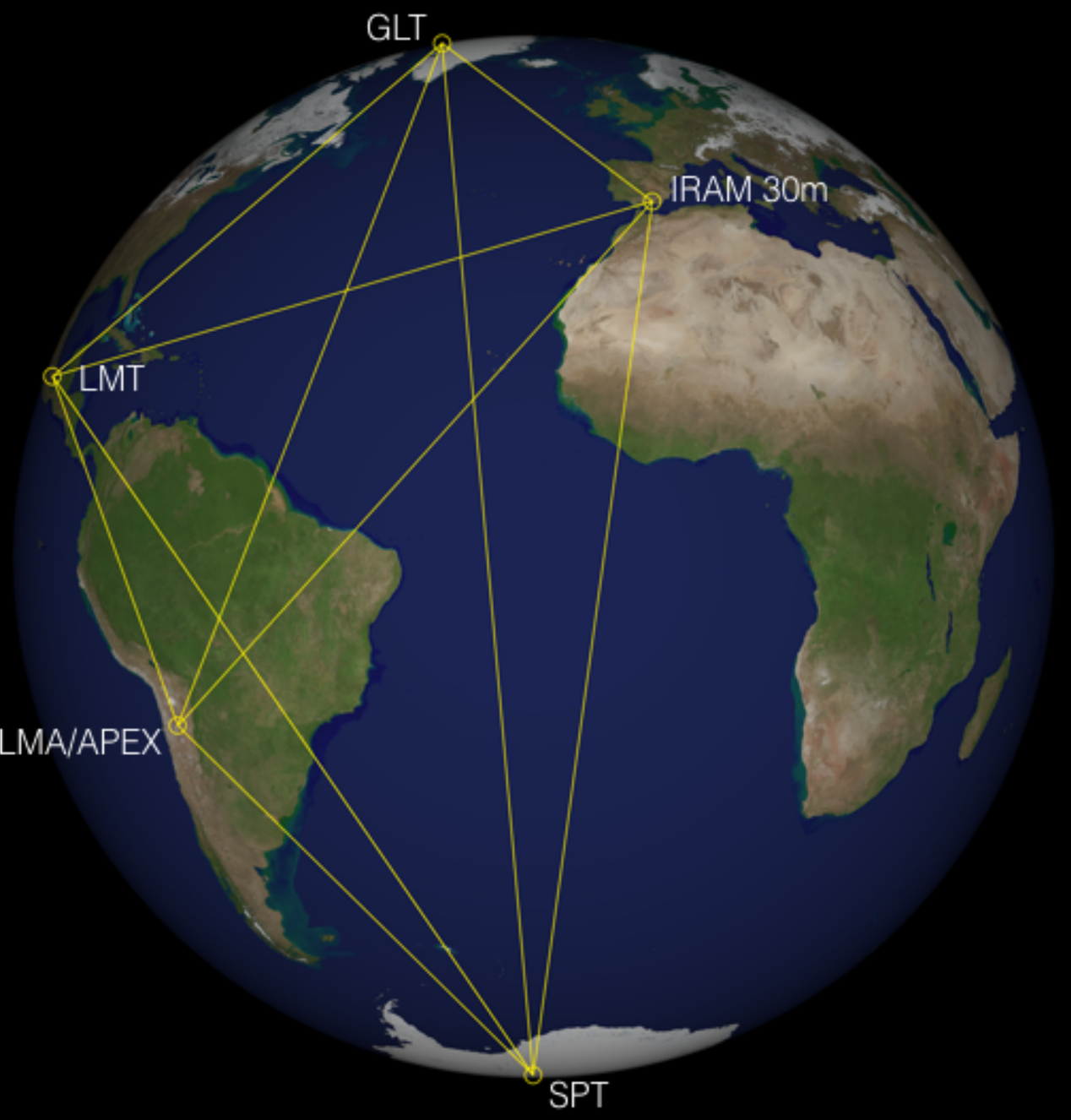
Comet/ToO Observations



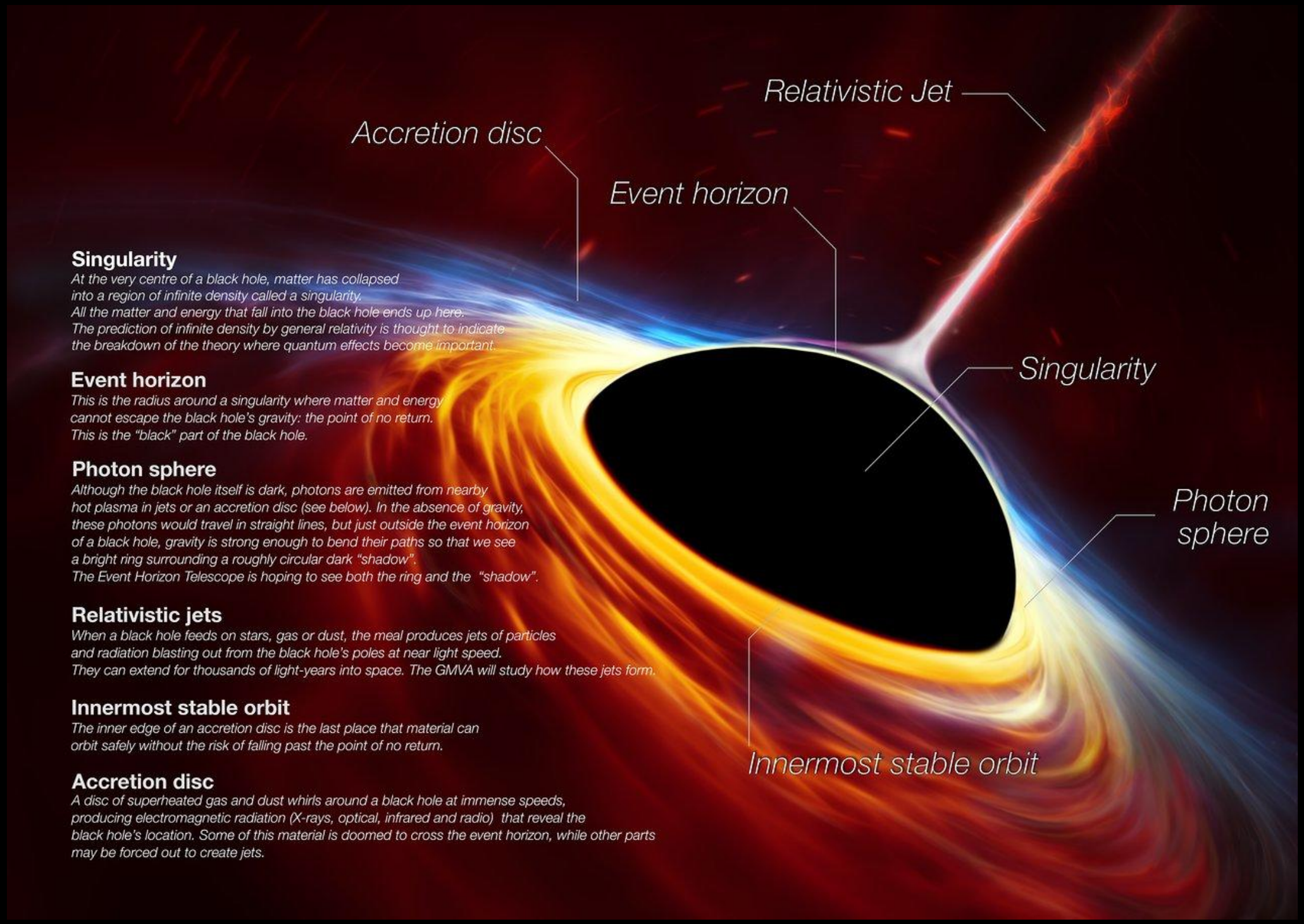
“Target of Opportunity” Observations

- ★ Calculate the mass of the comet
- ★ Find interesting molecular Species
- ★ Track changes as it gets closer to the Sun

The Science: Event Horizon Telescope



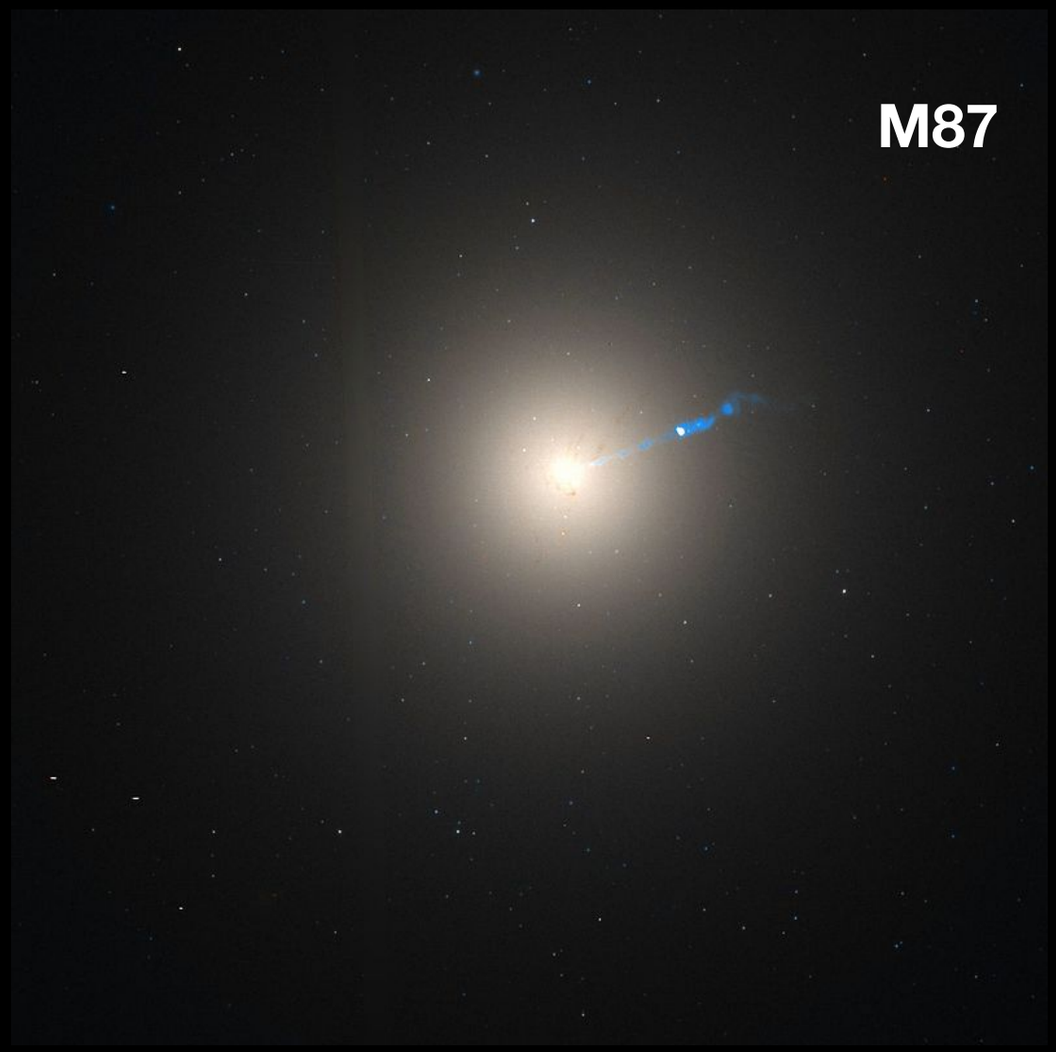
Seeking to Capture the First Image of a Supermassive Black Hole



Seeking to Capture the First Image of a Supermassive Black Hole

From the Event Horizon Telescope "About" Page https://eventhorizontelescope.org/:

"Such observations could lead to images of strong gravity effects that are expected near a black hole, and to the direct detection of dynamics near the black hole as matter orbits at near light speeds.



This capability would open a new window on the study of general relativity in the strong field regime, accretion and outflow processes at the edge of a black hole, the existence of event horizons, and fundamental black hole physics."

What This Lab Course Will Look Like

1. A Smorgasbord of Observational Astronomy Techniques with data obtained by the JCMT

~10 Reports To Submit for Grading (Subject to Change)

SCUBA-2

1. SCUBA-2 Data Reduction - A Simple Map (Feb 15th)
2. Clumpfinding and Additional Data Sets (Feb 22nd)
3. Variability Studies (Dr. Tetarenko - March 1st)
4. Dr. Tetarenko II (March 8th)

HARP

5. Polarisation and Magnetic Fields (March 15th)
6. HARP Data Reduction - Dealing with Spectra (Mar 29th)
7. The JCMT Observing Tool - Proposals and MSBs (Apr 5)

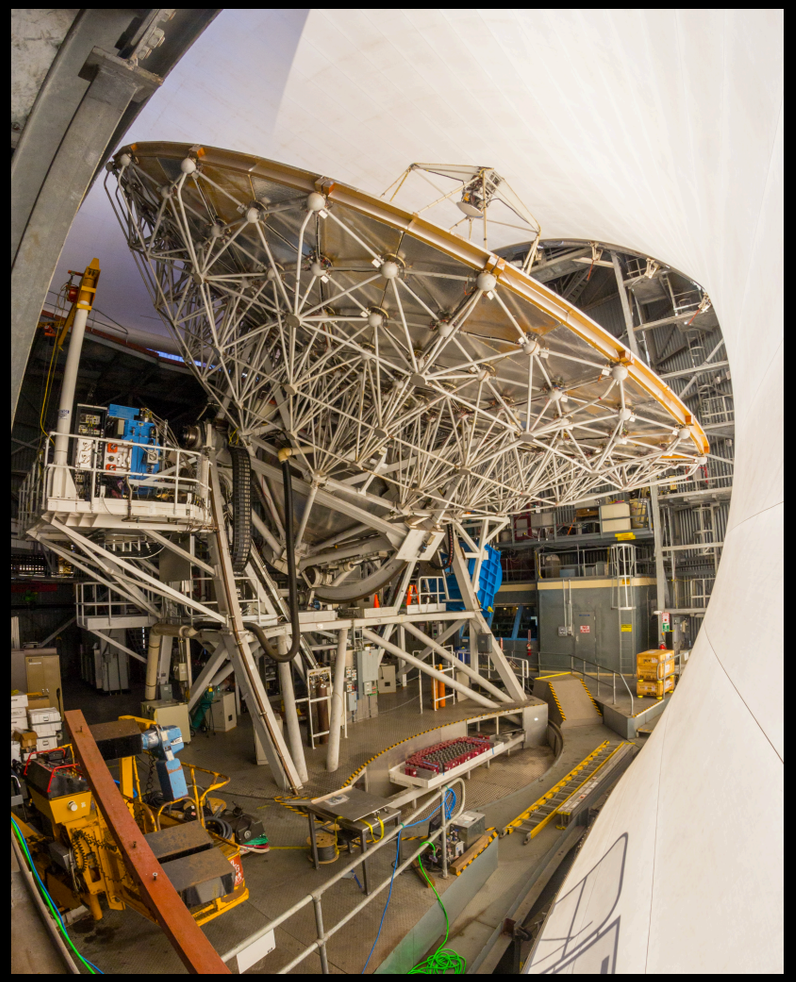
Free-Form

8. Your Night at the JCMT (Apr 11-15)
9. Design a SCUBA-2 Program (Due Apr 26)
10. Design a HARP Program (Due May 3)

What This Lab Course Will Look Like

2. Spending a night at the JCMT performing observations

UH has a 4 night observing block in April. Each of you will staff one night to get practical experience at a telescope and to see how everything works



Dates: April 12th, 13th, 14th, 15th
PLUS AT LEAST ONE ACCLIMATION NIGHT! (April 11th, 12th, 13th, 14th)

Links

Main website:
https://www.eaobservatory.org/~s.mairs

Links to slides and project details
(project links become available throughout the semester):
https://www.eaobservatory.org/~s.mairs/teaching.html

Information on writing a good lab report and how the reports will be graded:
https://www.eaobservatory.org/~s.mairs/ASTR351/logistics/ASTR351_guidelines.pdf

Homework

1. You will need access to the JCMT Archive of Data for this course!

To access the data, please sign up for a CADC (Canadian Astronomy Data Centre) account:

http://www.cadc-ccda.hia-iha.nrc-cnrc.gc.ca/

2. (Optional) You will be using Starlink Software for DR and Analysis!

Starlink Software is available in this lab and you will have access to these computers

If you have a Linux Machine or a Mac, you can also download the software here:

http://starlink.eao.hawaii.edu/starlink/2018ADownload

See you next week!