



Star Formation: a Riddle that is Asking to be Solved

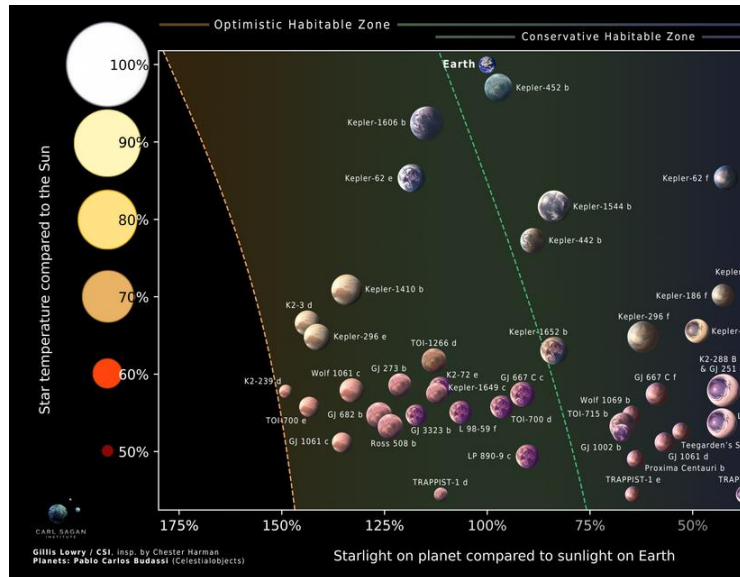
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Ad Astra Workshop
Sep 1 – 3, 2026

Why Star Formation is Still Relevant ?

On one Side:

- Planet Detection
- Planet Demographics
- Planet Atmospheres
- Planet Formation
-

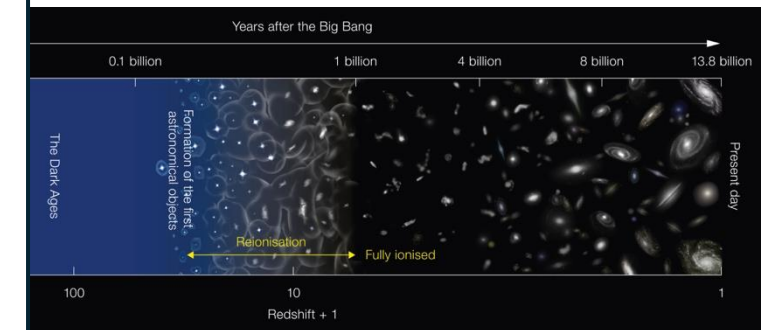


➤ Based on a galaxy physical properties (e.g., mass, metallicity, etc.), can we predict what the average IMF is ?

➤ Based on a proto-star physical property (e.g., mass, luminosity, etc.), can we predict what kind of planetary system (if any) it will form ?

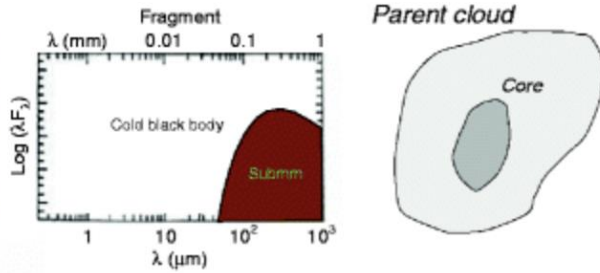
On the Other:

Galaxy Formation
Galaxy Evolution
High-z Galaxies ..
Star Formation across Cosmic time
Star Formation Quenching



Let's Start from the Beginning...

Pre-stellar phase

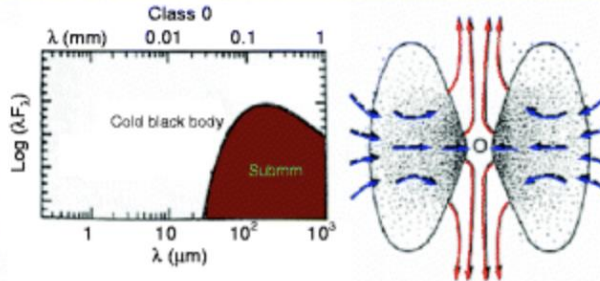


Pre-stellar dense core
 $T_{\text{bol}} \sim 10\text{--}20$ K, $M_* = 0$

$\sim 1,000,000$ yr

Formation of the central protostellar object

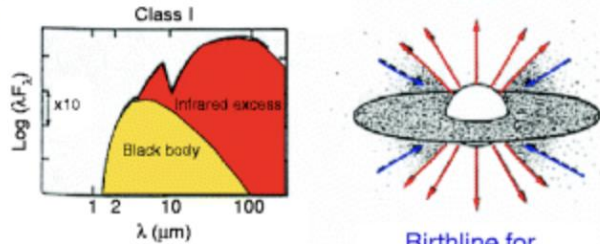
Protostellar phase



$t \sim 0$ yr

Young accreting protostar
 $T_{\text{bol}} < 70$ K, $M_* \ll M_{\text{env}}$

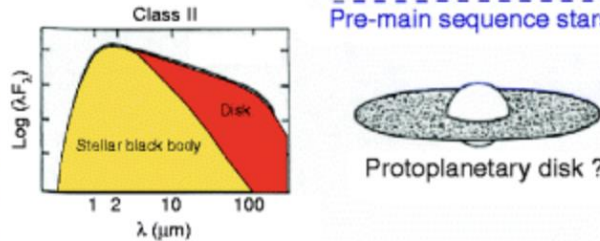
$< 30,000$ yr



Evolved accreting protostar
 $T_{\text{bol}} \sim 70\text{--}650$ K, $M_* > M_{\text{env}}$

$\sim 200,000$ yr

Birthline for
 Pre-main sequence stars

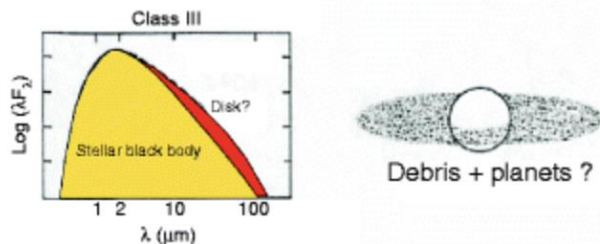


Classical T Tauri star
 $T_{\text{bol}} \sim 650\text{--}2880$ K, $M_{\text{Disk}} \sim 0.01 M_\odot$

$\sim 1,000,000$ yr

Protoplanetary disk ?

Pre-main sequence phase



Weak T Tauri star
 $T_{\text{bol}} > 2880$ K, $M_{\text{Disk}} < M_{\text{Jupiter}}$

$\sim 10,000,000$ yr

Debris + planets ?

Time

Sub-mm /
 FIR

Star Formation
 is
 a Multi-Scale Process

FIR / MIR

The Golden Age of Star Formation: 2003 - 2013

Spitzer (Cold Mission: 2003 – 2009)
3.6 – 160 μm



Herschel (2009 – 2013)
70 – 500 μm



Census of
YSOs



Star Formation in the Rho Ophiuchi Cloud Spitzer Space Telescope • IRAC • MIPS
NASA / JPL-Caltech / L. Allen (Harvard-Smithsonian CfA) & D. Padgett (SSC-Caltech) ssc2008-03a

Ubiquitous Presence
of Filaments



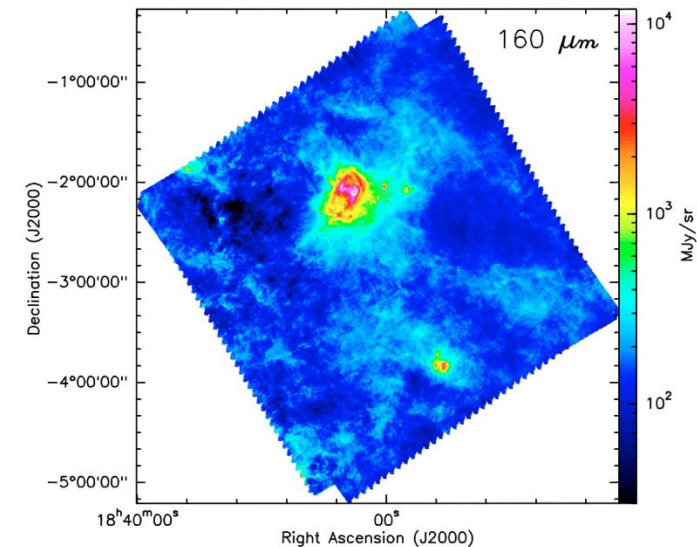
Comprehensive SF Scenarios Are Proposed..

➤ The "*Paradigm*" of Star Formation

(Herschel Gould Belt Survey, e.g., Andre' et al. 2015)

- Filaments have a universal width (0.1 pc)
- Filaments become gravitationally unstable for $M_{\text{lin}} > M_{\text{lin, crit}}$
- Gravitationally bound cores form only at a universal threshold of $\sim 10 A_V$
- The Core Mass Function (CMF) maps into the IMF
- Overall scenario backed-up by some simulations (Inutzuka & Miyama, 1992, 1997)

Aquila Rift, 225 +/- 55 pc



Bontemps et al. 2010

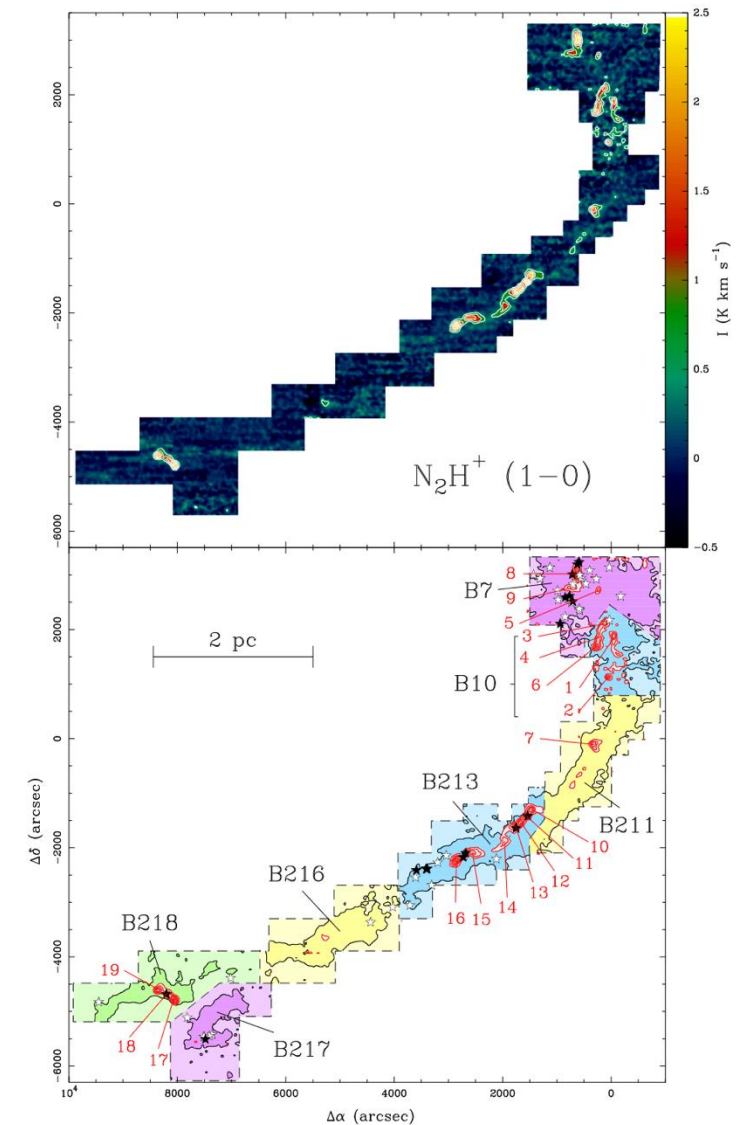
This picture has been strongly challenged: e.g., at odd with observations of variations of SF with environment (metallicity, RF, etc.)

Filaments do play a crucial role

- Discovery of velocity-coherent filamentary structures, called *bundles*
- *Bundles* seem to fragment into cores in a quasi-static fashion
- Based on $\text{C}^{18}\text{O}(1-0)$ and $\text{N}_2\text{H}^+(1-0)$ observations

NB: Gas (radio/spectroscopic) and dust (FIR-submm/imaging) observations of filaments are complementary, e.g. gas kinematics vs. dust grains properties and evolution (grain size, chemistry).

L1495/B213 Taurus region, 140 pc



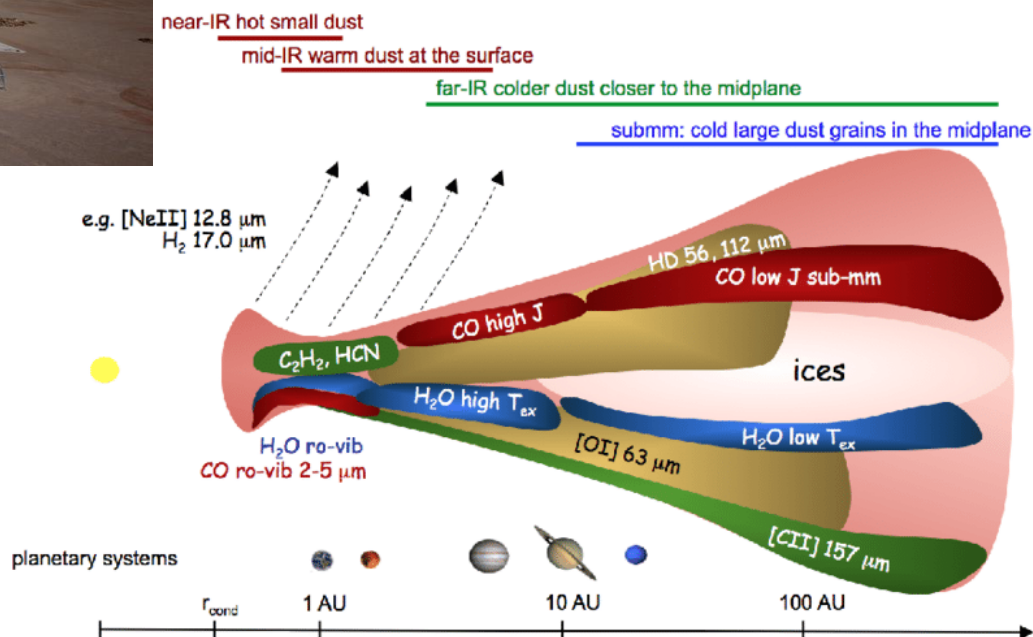
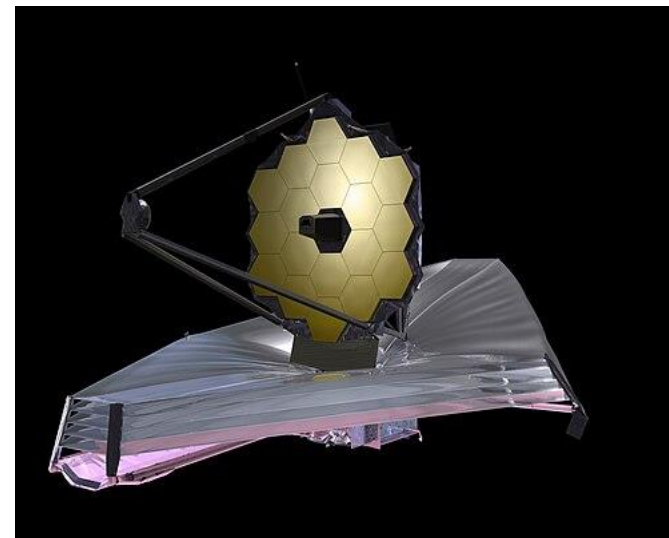
Hacar et al. 2013

Where Do We Stand Now ? Focus on Small Scales

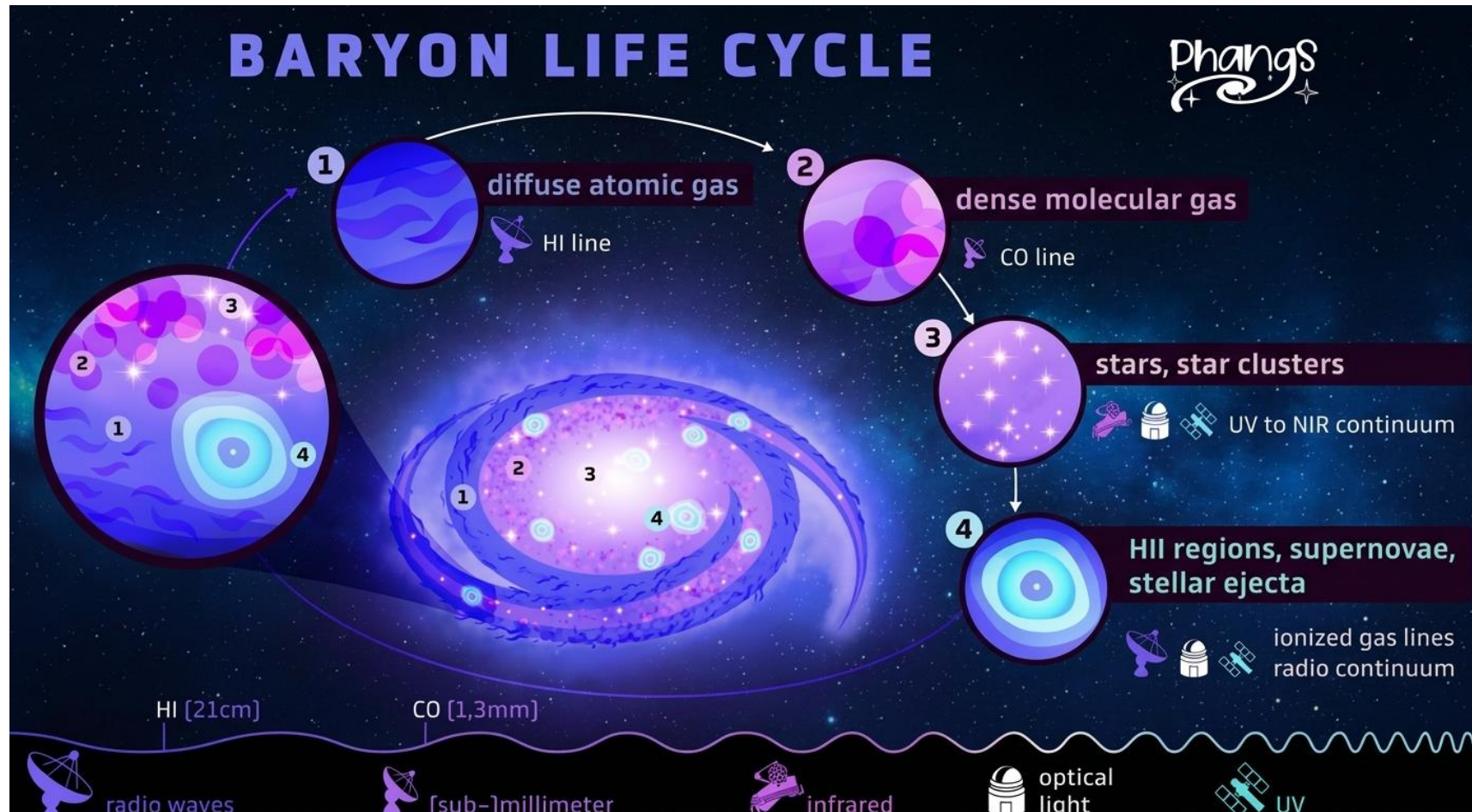
ALMA (2013 -)
0.3 – 9.6 mm

+

JWST (2021 -)
1 – 28 μm



Self-Regulation of Star Formation: Cooling & Heating Budget



Credit: PHANGS Collaboration

Ad Astra Workshop, Sep 1 - 3, 2026

- ❑ To fully understand the baryon cycle, we need to measure heating and cooling on similar physical scales
- ❑ Recent (HST, JWST) and future (ELT, HST) focus on measuring heating on small scales (MS stars, SNe), with no equivalent for cooling

The Scales Involved

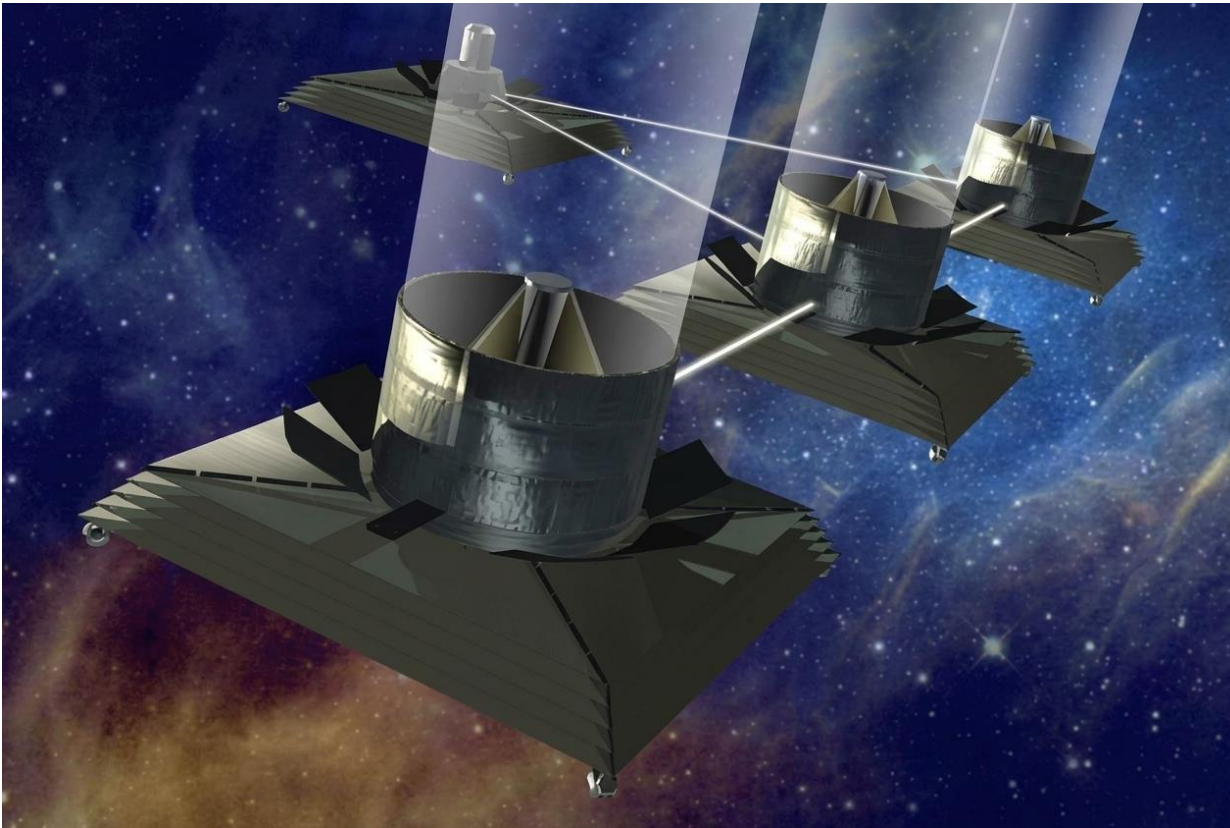
- ❑ Filamentary structures range in length from < 1 pc to > 10 pc
 - a 10-pc filament subtends an angle of $\sim 40''$ at 50 kpc ($\sim$ distance of the LMC)
- ❑ Pre-stellar and Proto-stellar Cores range in size from 0.01 pc to 0.2 pc
 - a 0.01 pc core subtends an angle of $\sim 0.2''$ at 10 kpc
- ❑ Proto-planetary disks range in size from ~ 30 AU to 200 AU
 - A 30-AU diameter disk subtends an angle of $0.1''$ at 300 pc

What Do We Need to Solve the SF Riddle ?

- FIR/MIR wavelengths: to probe **all** the stages of SF, i.e., from filaments to proto-planetary disks & beyond
- An angular Resolution from arcmin to sub-arcsec: to probe **all** the physical scales involved in the SF process
- Large FOV: to observe large swaths of the sky
- Imaging
- Moderate Resolution ($R \sim 3,000$) Spectroscopy (e.g., enough to resolve, e.g., CII 158 μm line)
- Polarization

A FIR to MIR Interferometer in Space

(e.g., CALIGO, U & Paladini)



- 20 – 300 μm
- Imaging & Spectroscopy ($R \sim 3,000$)
- Polarization
- Each interferometer element has a small diameter ($\sim 0.5 - 1.1 \text{ m}$) to allow for a large FOV (at least 1°) and collecting area. Such a configuration would allow for an excellent UV coverage, significantly reducing the “*missing flux*” problem.