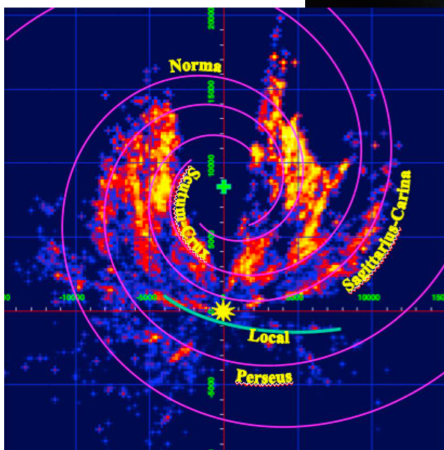
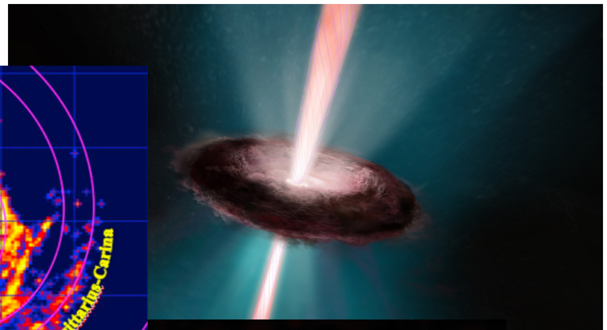
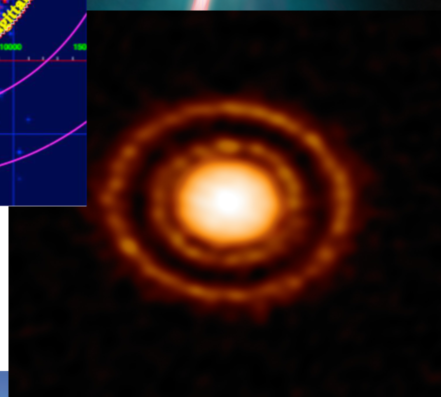
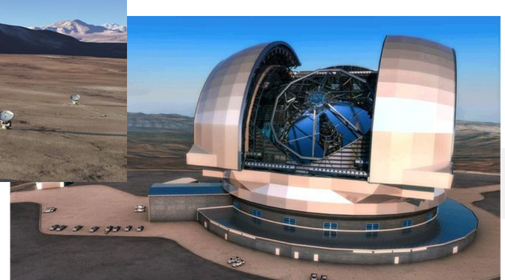
Piano di Visione Strategica INAF

Star Formation









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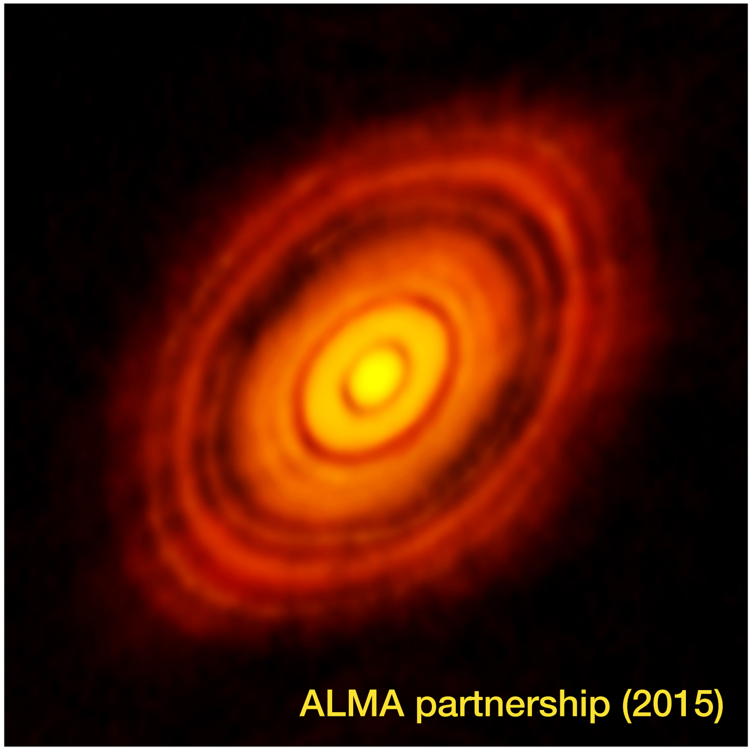
Napoli, 27 Marzo 2019

Motivation



Star formation:

evolution of ordinary matter from its primordial composition to the physical and chemical diversity necessary for the birth of life

interplay of many factors

Gravitation – thermal evolution - angular momentum transport – magnetic effects – turbulence – chemistry ….

..which makes the subject so fascinating !!!

The accretion disk, generated by the conservation of angular momentum is where planets have their origin.

It is crucial to define the disk structure, chemistry and dynamics to correctly set-up the initial conditions of planet formation.

Key Questions

1. Global star formation properties in the Milky Way

2. Physics of individual star formation events

3. Disks : initial conditions for the formation of planets

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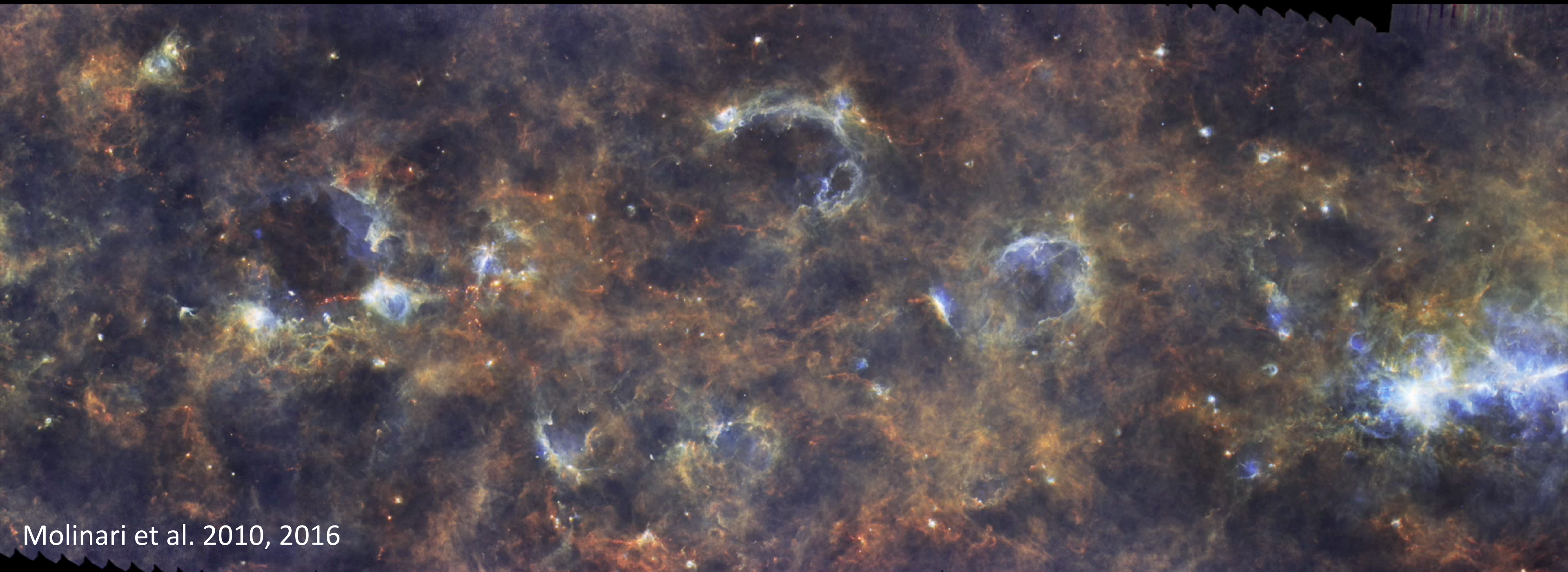
1. Global properties of SF in our Galaxy

The last generation of Galactic infrared-millimeter dust and molecular gas surveys:

- ***Dust***: Herschel (Hi-GAL), Spitzer (GLIMPSE & MIPSGAL), APEX (ATLASGAL)
- ***Gas***: GRS, FCRAO-OGS, NANTEN2, SEDIGISM, Mopra-GPS, JCMT-JPS

The Milky Way as a star formation engine:

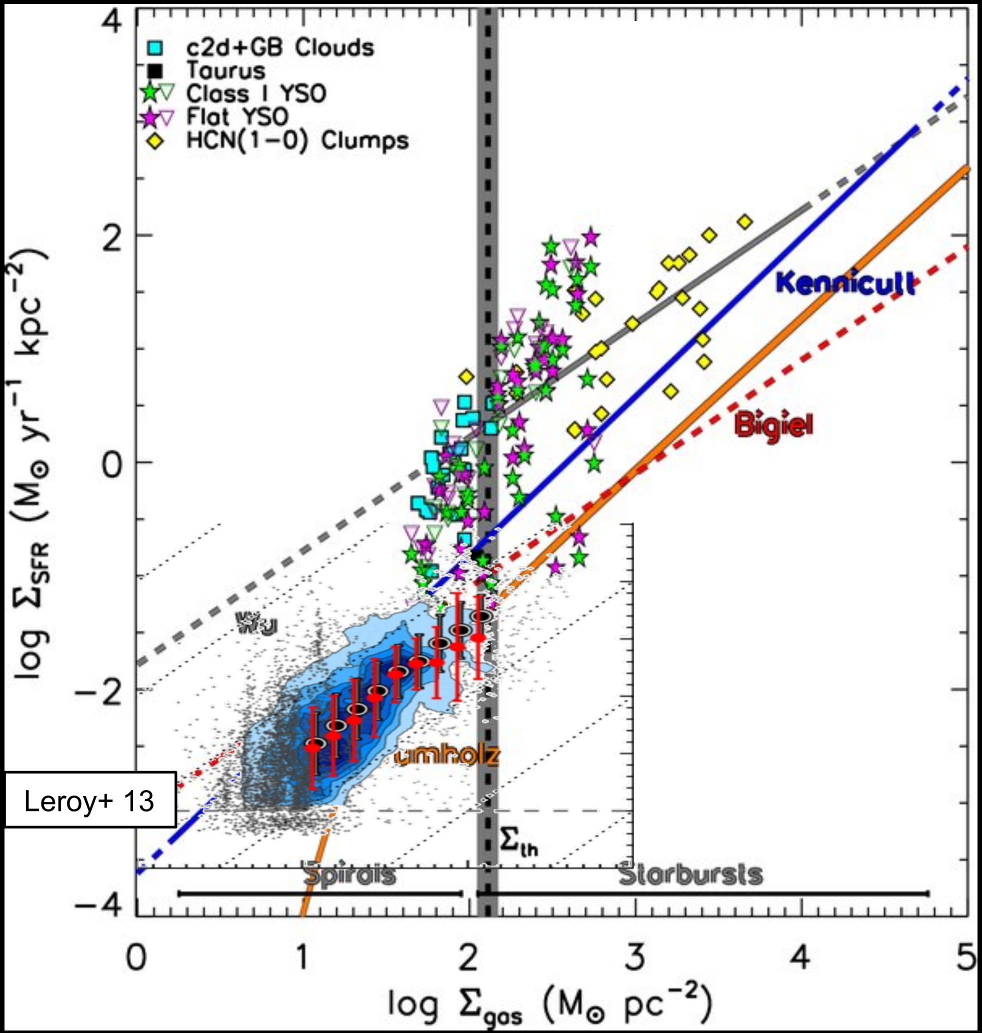
- Census, properties and distribution of Galactic stellar nurseries
- Ubiquity of filamentary structures
- Role of spiral patterns as ISM collectors



Molinari et al. 2010, 2016

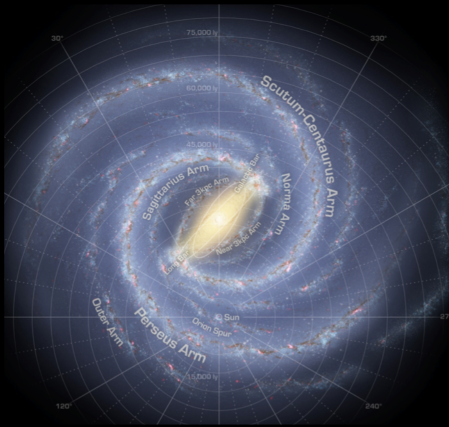
1. Global properties of SF in our Galaxy

Setting the Milky Way in the extra-galactic context



Identify the critical parameters that make star formation different:

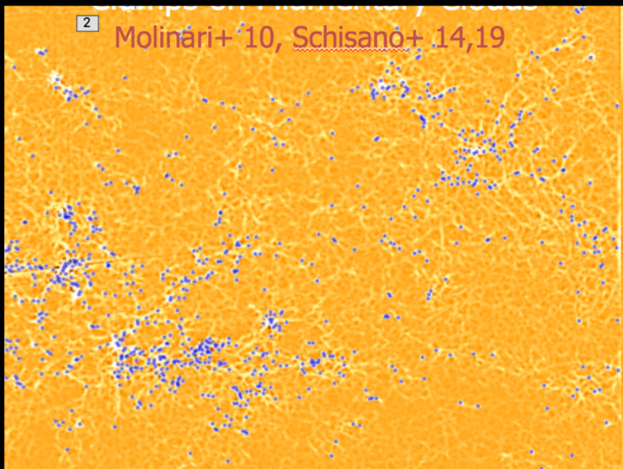
- Spontaneous/triggered
- Star Formation on/off Filaments ?
- Depending on the position in the Galaxy
- w.r.t. Spiral Arms
- etc.



understand if & how the mix of the ingredients conspire to determine a global Star Formation law

1. Global properties of SF in our Galaxy

Massive Clumps on Filamentary Structures: Properties and Evolution

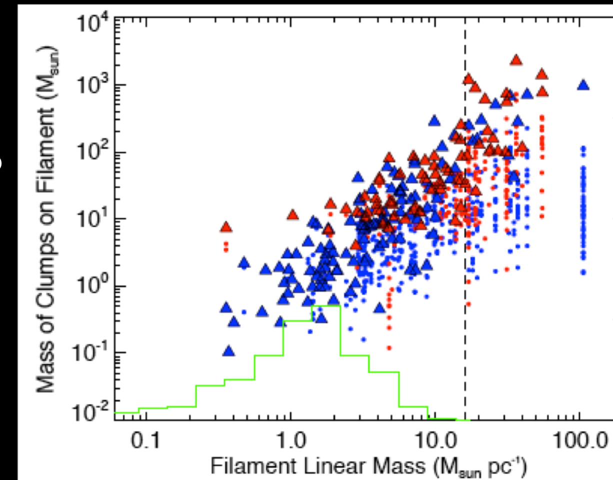


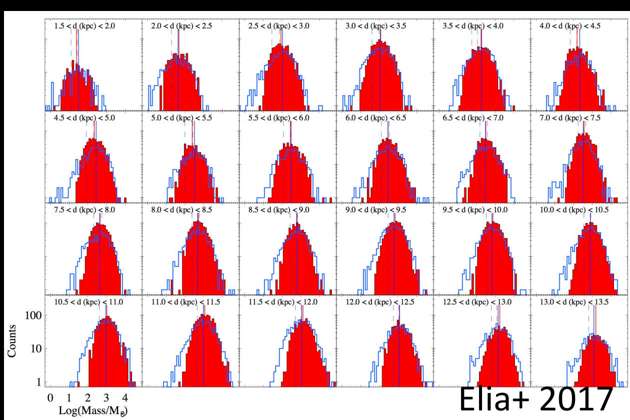
Ubiquitous

Massive and evolved clumps found on massive filaments: co-evolution?

More than 30,000 Filamentary structures extracted: Mass & Size

CO cross-match Kinematics underway

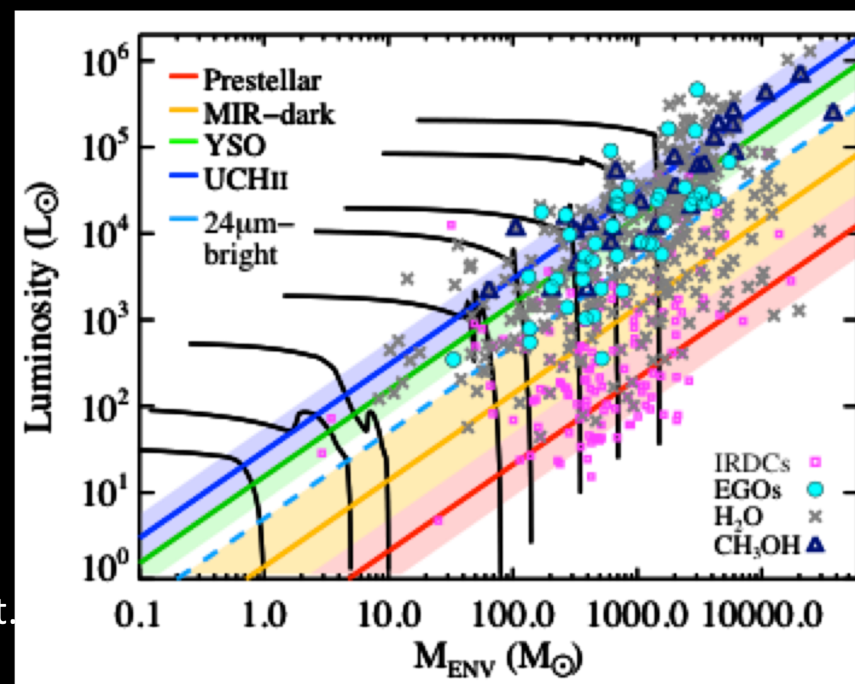




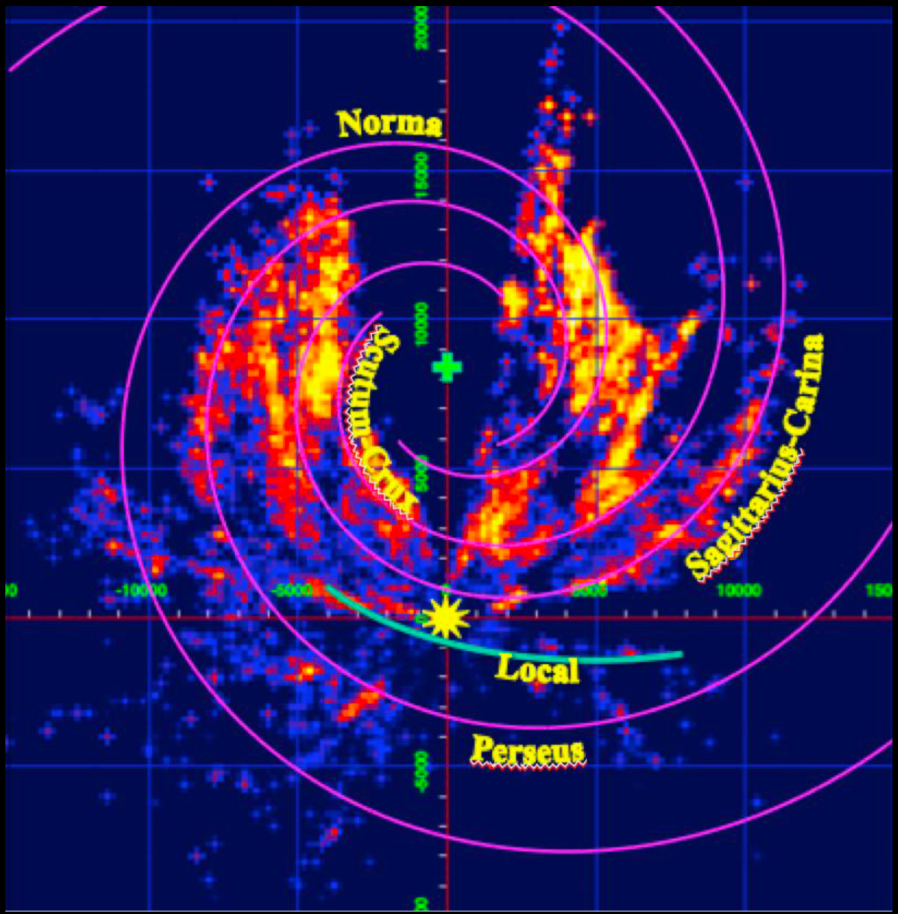
150,000 clumps catalogued with physical properties: size, mass, luminosity, temperature

115,000 clumps have distance determined: CO, HI, dust ext.

Evolutionary classification → Star Formation Rate



1. Global properties of SF in our Galaxy



Map of the Galactic Star Formation Rate (Elia et al. in prep.)

Challenge for the next decade:

Create a fundamental theory for star formation in the Milky Way as a z=0 template for external galaxies.

Tools:

- Spectroscopic follow-up of thousands SF sites: chemistry, kinematics, physical conditions → IRAM, GBT, APEX, SRT…
- Dust Polarization: magnetic field distribution in Filaments and Clumps → SPICA
- Very high angular resolution imaging: resolve clustered SF in Clumps → ALMA, NOEMA, SMA, JWST
- 3D tomography of ISM vs Spiral arms → GAIA
- Radio Galactic Plane surveys: HII regions & triggered SF → ASKAP, MeerKAT, SKA

Imperative to attack science analysis in Galaxy-scale Star Formation within new data science frameworks → Machine-learning, fuzzy logic etc.

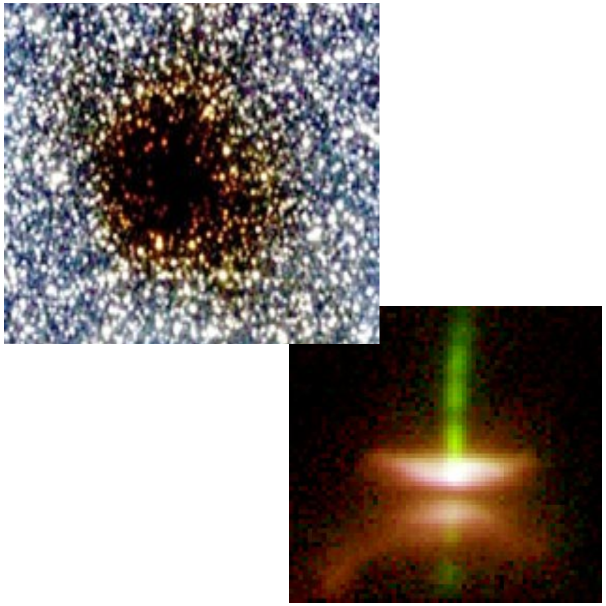
Key Questions

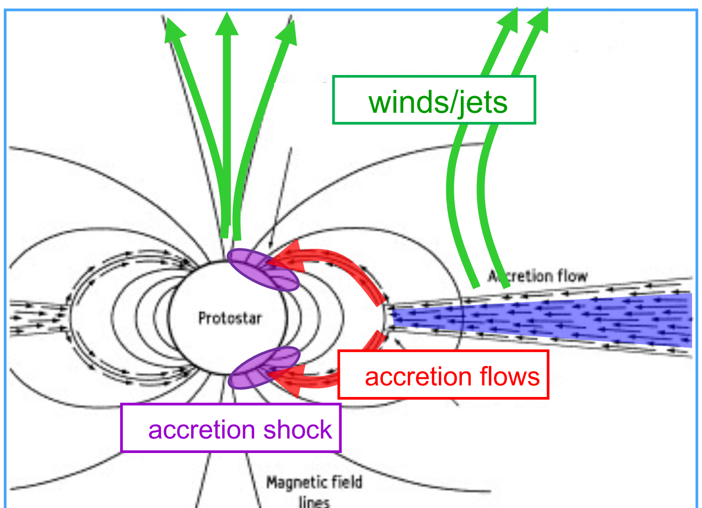
1. Global star formation properties in the Milky Way

2. Physics of individual star formation events

3. Disks : initial conditions for the formation of planets

2. Physics of single object formation





Aim :

Create a unifying picture for the formation of a young system from the pre-stellar to the pre-planetary phase.

→ Chemical properties from dark cores to protostellar disks at all masses

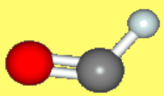
→ Physics of the collapse: magnetic braking, ambipolar diffusion

→ Evolution of angular momentum:
accretion signatures
jets and winds

→properties of the central protostar

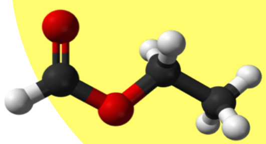
2. Physics and chemistry go hand in hand

astrochemistry: **search of key molecules in the early phases in high and low mass SF regions/objects**



HCO (carbonic acid)

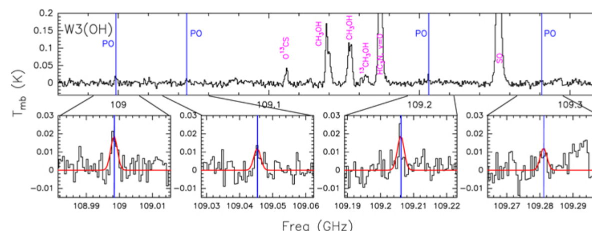
precursor of COMs,
towards IRAS 16293-2422



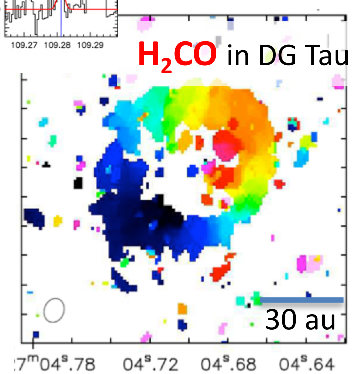
CH_3CH_2OCHO

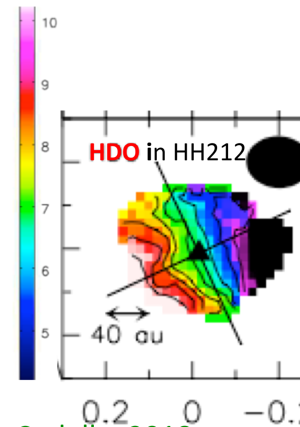
(ethyl formate)

in the W51e2
hot molecular core



PO pre-biotic molecule
in W3(OH) Rivilla+ 2107





Podio+ 2019, Codella+2018

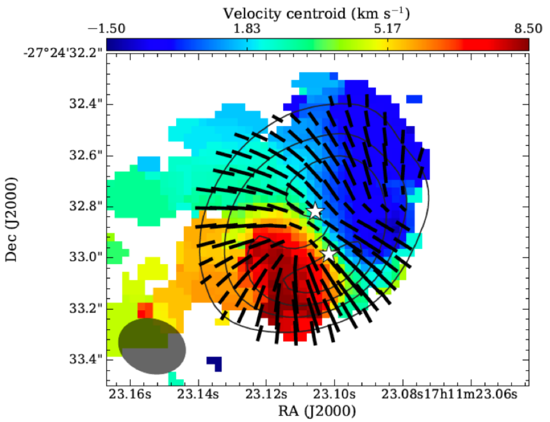
Future directions:

- FIR, sub-mm radio investigations with **JWST, ALMA, NOEMA, SKA**
- Projects as **PRIN-SKA, EU-ACO ..**
- Large programmes as **Calypso, Solis, ASAI, FAUST**
- Chemistry from local **cosmic ray** production in jet shocks **(analytical models + SKA, CTA)**

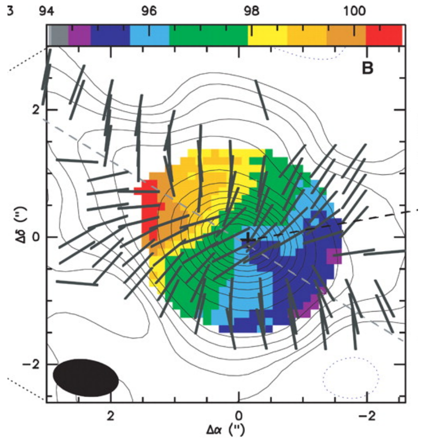
2. Polarimetry and magnetic fields

AIM: define the impact of Magnetic effects

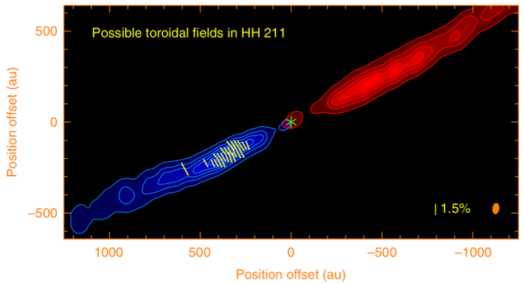
collapse time scales (ambipolar diffusion - magnetic catastrophe)
effective disk viscosity from Magneto-rotational instabilities (MRI)
acceleration of outflows and disk braking



Spiral B in BHB07-11 disk ?
Alves+ 2018



Hourglass B in G31.41+0.31 ?
Girart+ 2009



Toroidal B in the HH 211 jet ?
Lee+ 2018

Future directions:

- Polarimetry of cores and disks with **ALMA, SMA, NOEMA, SPICA**
- Numerical tools to produce synthetic maps **(ARTIST, DUSTPOL)**
- Line polarimetry in jets with **ALMA**

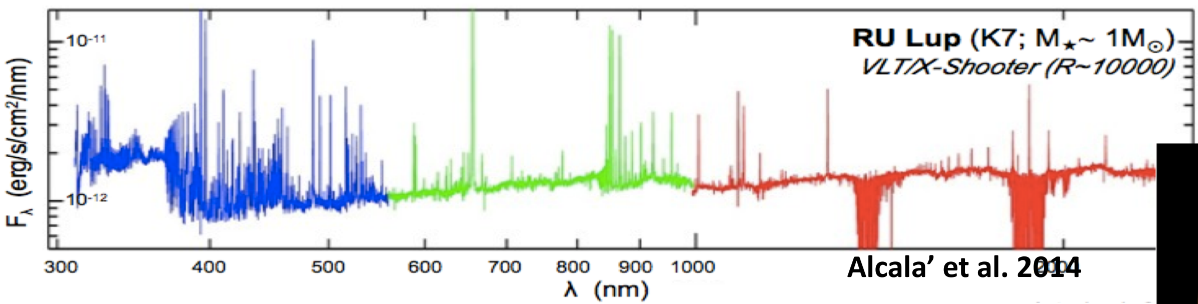
2. Surveys of Young Stellar Objects

AIM: Probe inner disk evolution due to accretion and ejection of matter

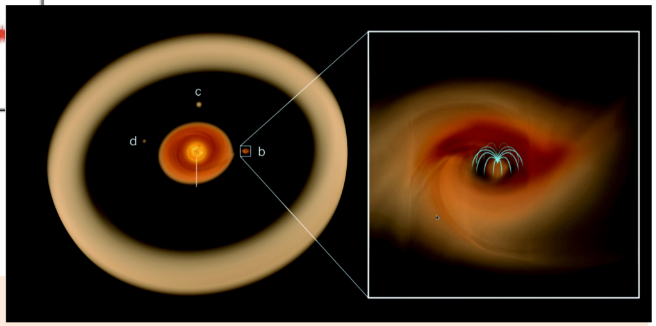
- Observations of large samples of YSOs in different environments (e.g. ages, metallicity, masses, T and OB associations, accretion signatures, jet frequency)

Ongoing Projects of the JEDI (Jets & Disks @ INAF) community:

- The **X-shooter** spectral surveys of YSOs (GTO+GO programs)
- The **TNG-GHOST** project (High-res Observations of T Tauri star



Alcala' et al. 2014



Future directions:

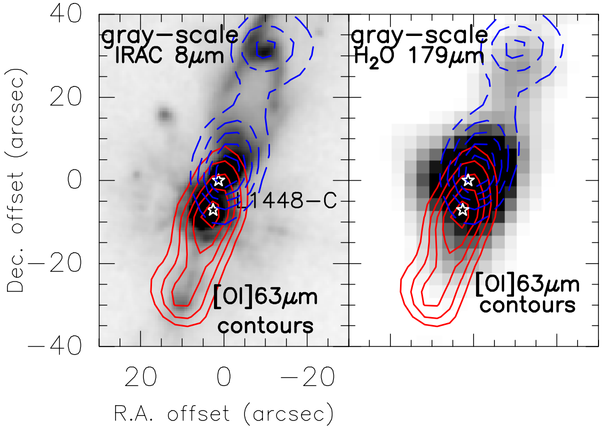
- *ULLYSES HST Legacy survey*: 500 orbits next 3 cycles (Library of UV young star templates)
- *VLT/MOONS* surveys of young clusters (P.I. Sofia Randich)
- *LBT/SHARK* search for young accreting planets in YSOs
- *VLT/MAVIS - ELT/MAORY*: low-metallicity YSOs, jets occurrence (P.I.s: Alcala', Antoniucci, Podio)
- *ELT/HIRES*: gas kinematics in the inner disk structure (participation to the relevant WG)

2. Role of jets and slow winds

Jet from embedded source in [OI] 63 μm (main coolant)

Nisini+ 2015

L2448, Herschel



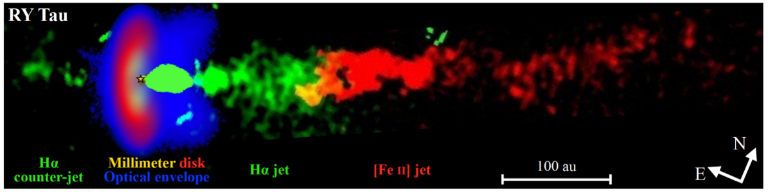
Jets : extraction of angular momentum
disk/envelope clearing
feedback on planet formation

HIGH SPATIAL RESOLUTION needed Goal : 1 au

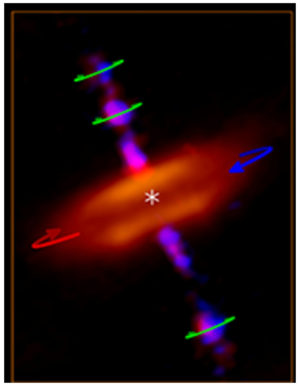
Jets imaged with AO (SPHERE)

, (shocks, source properties)

Antoniucci+2016, Garufi+ subm.



HH 212, ALMA



Jet rotation

HST and ALMA

(acceleration and origin)

Bacciotti+ 2002, Coffey+ 2012, Lee+ 2017, Tabone Codella+ 2018, Louvet 2018, Erkal+ in prep ..

Future directions:

- ***ALMA, NOEMA***: surveys at combined high spectral **and** spatial resolution
- ***LBT/SHARK*** **:** high contrast AO imaging in the NIR and VIS
- ***HST – JWST - SPICA*** **:** UV, VIS and MIR/FIR studies of jets from embedded protostars
- ***ELT/HIRES***: diagnostics of physical quantities and rotation kinematics in the VIS/NIR at high res

Key Questions

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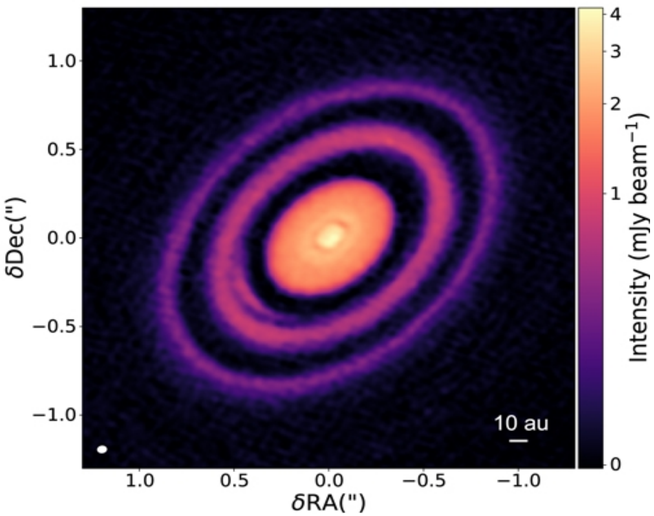
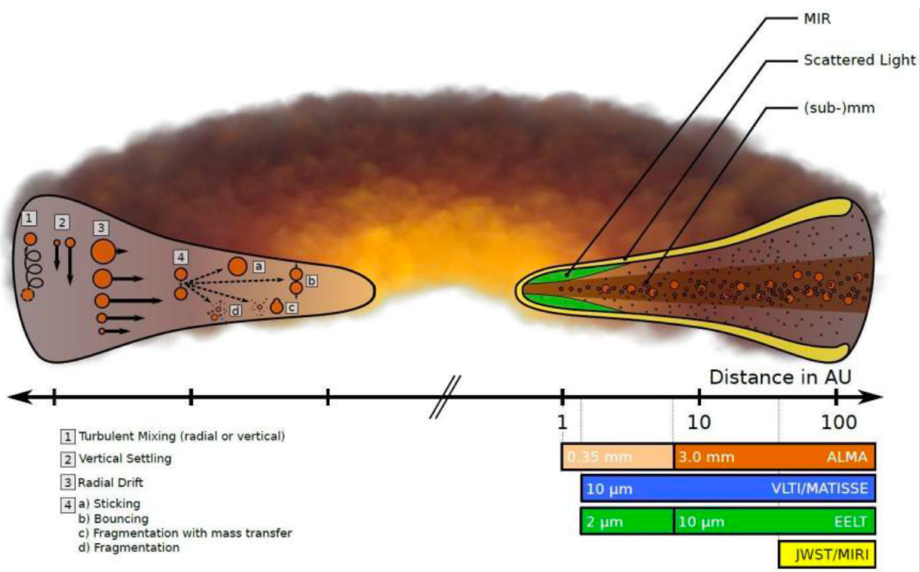
3. Planet – forming disks

HD 163296 *Isella+ 2018*





Testi+ 2014

Aim :

Understand disk dynamics and chemistry to set the conditions for planet formation and emergence of life

Dust and gas evolution

Rings, gaps, spirals

Magnetic fields

Chemical properties

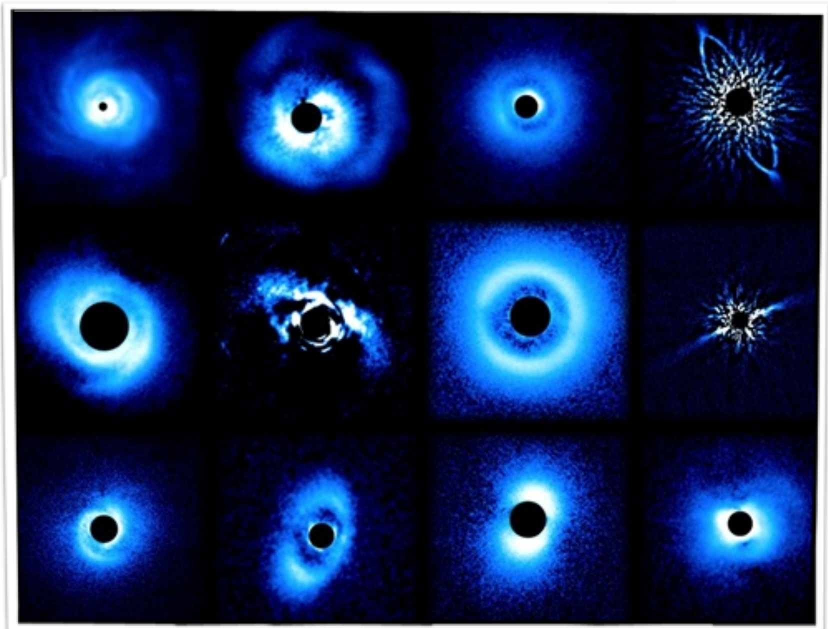
Disk – planet interaction

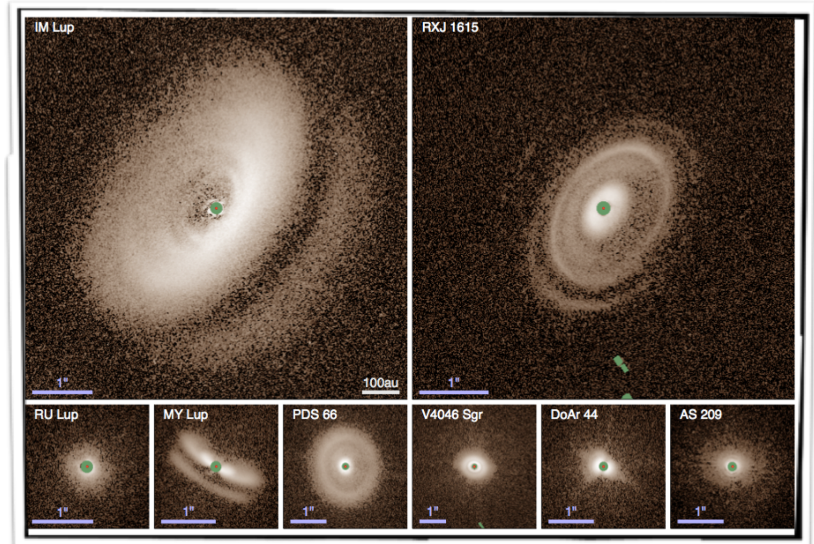
Jet feedback

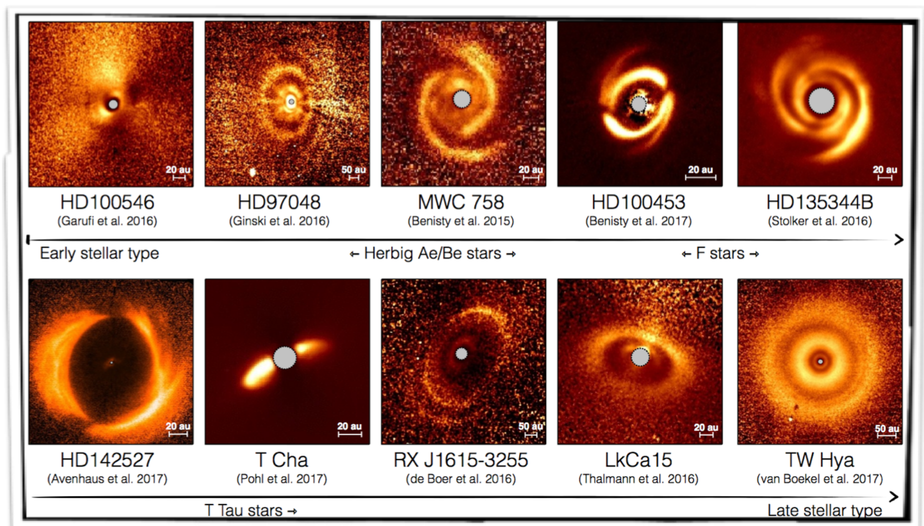
Disk dispersal

Young planet detection

3. disks imaged in the NIR with AO



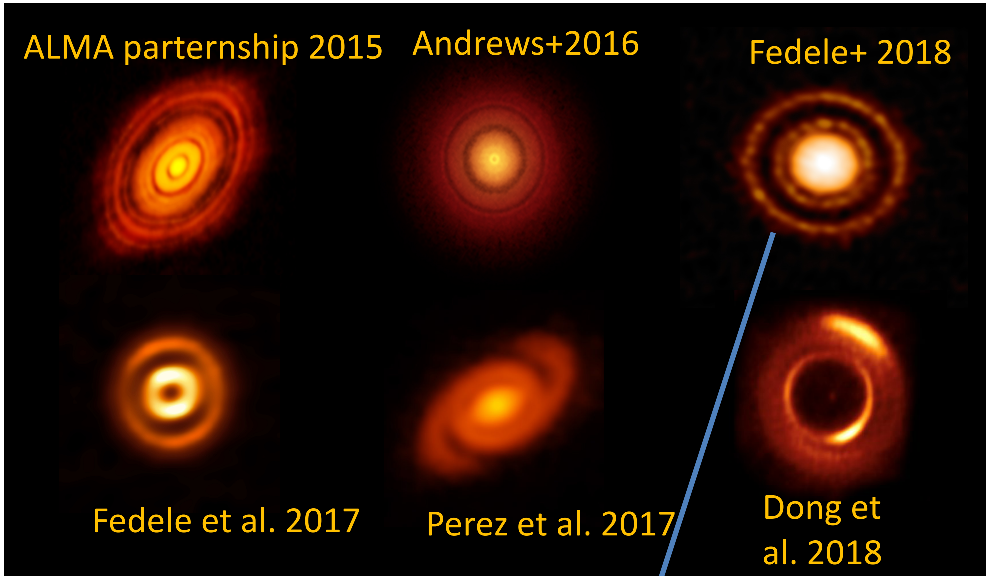


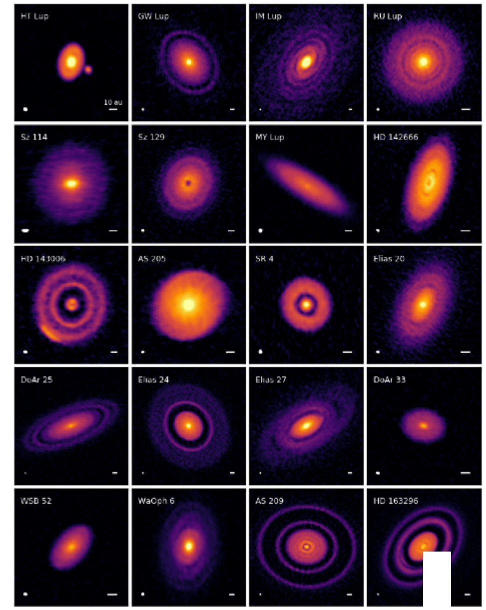


During the last years, more than 100 ‘protoplanetary’ disks (1-10 Myr) have been imaged with high resolution (ALMA and NIR scattered-light).

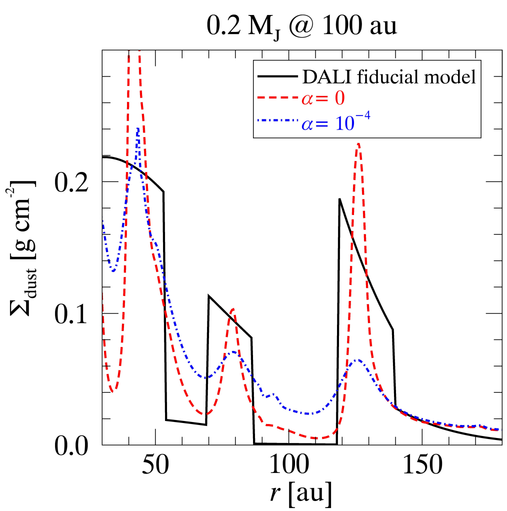
SEEDS from Subaru/HiCiao, Hashimoto et al., www.nao.ac.jp; DISK GTO from VLT/SPHERE, Garufi et al. 2017b +references therein; DARTTS-S from VLT/SPHERE, Avenhaus et al. 2018

3. disks imaged in the mm domain with ALMA

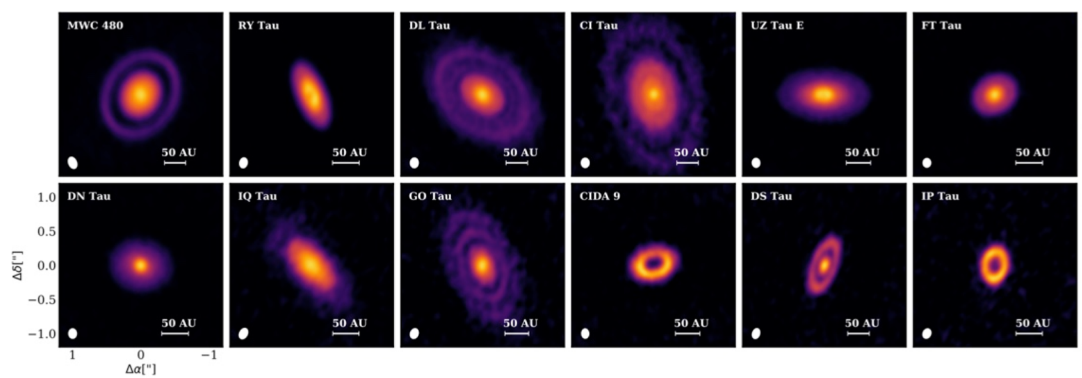




DSHARP collab. Andrews+ 2018



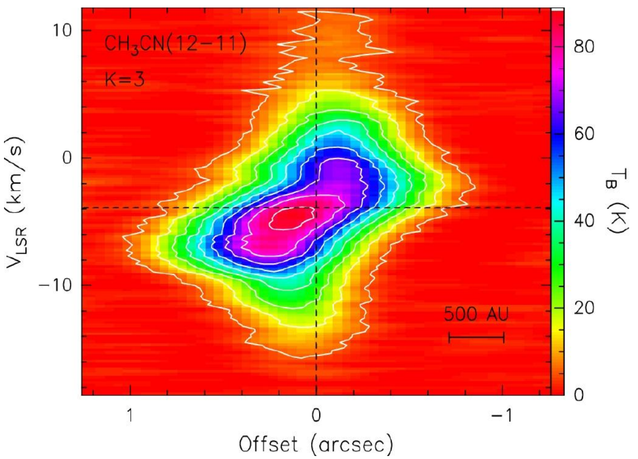
Multiple rings formed by a single 0.2-0.3 M_{Jup} planet at 100 au Fedele+2018

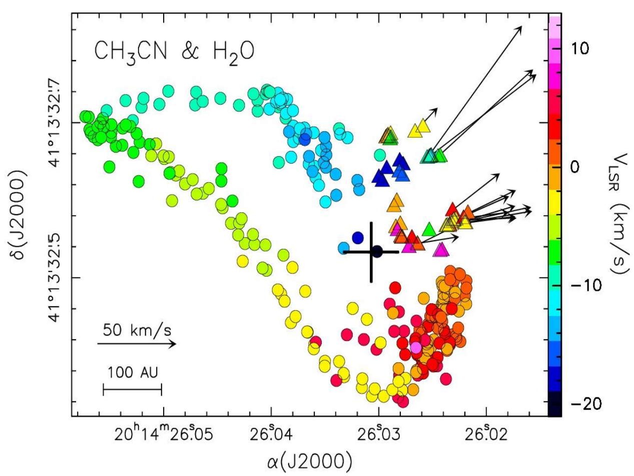


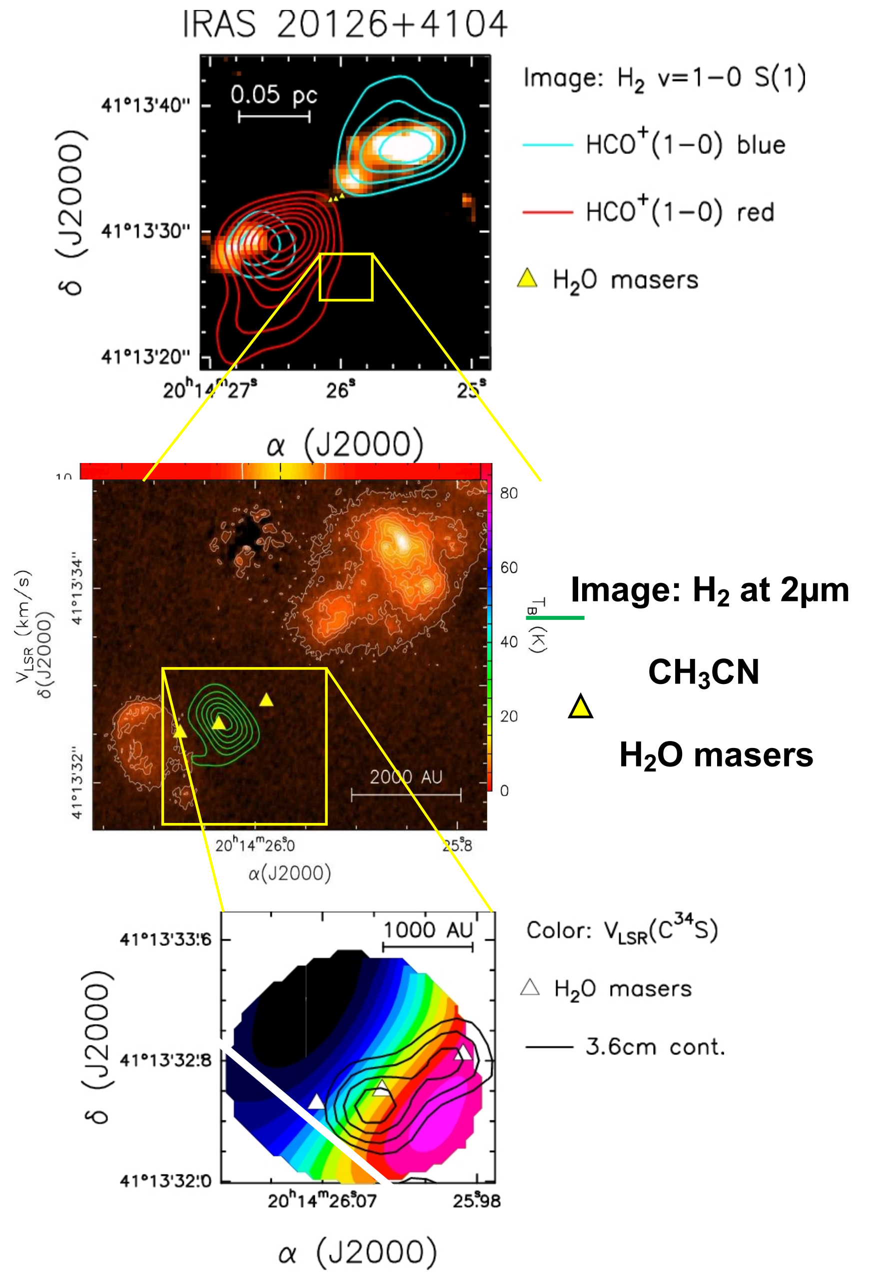
ALMA survey in Taurus at 0."15 Long+ 2018
(see MEDIA INAF 06-12 2018)

3. disks in high mass stars

IRAS 20126+4104
Cesaroni et al. (1997, 1999, 2005, 2013, 2014)
Hofner et al. (1999, 2007)
Moscadelli et al. (2005, 2010)

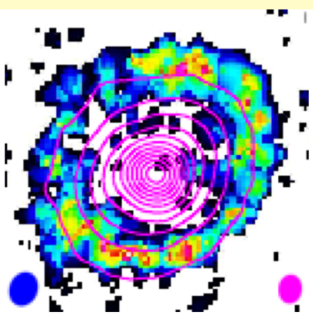




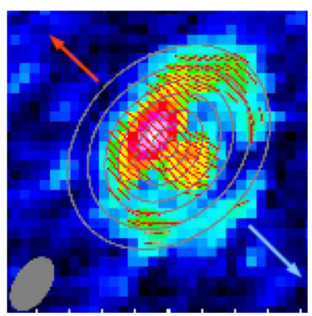


3. Prospects for disk studies

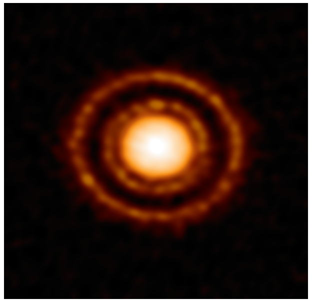
- Statistical occurrence of discs in large samples of YSOs : **ALMA, NOEMA, JWST**
- Robust determination of disk gas/mass ratio : **ALMA, NOEMA**
- Dynamics : fragmentation, migration of large grains, formation of dust traps
- Effective viscosity : MRI instabilities, dead zoned, role of cosmic rays
- Origin of disk substructures **ALMA VLT/SPHERE, LBT/LUCI, LBT/SHARK, VLTI**
- Imaging of inner disk at high res, jet acceleration **LBT/SHARK, ALMA, ELT/MAORY**
- Detection of forming planets **LBT/SHARK, ALMA, SPHERE, ELT/ HIRES**
- Detection of the magnetic configuration **ALMA, SMA, VLA**
- Astrochemistry , detection of complex molecules **ALMA, NOEMA, SKA**

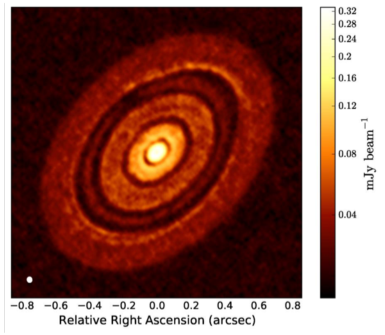


Molecular gas (H_2CO)
e.g. Podio et al. 2019



Grain size (polarization)
e.g. Bacciotti et al. 2018





Instabilites and substructures
(Obs. + num. simulations)
e.g. Fedele+ 2018, DiPierro et al. 2015

Summary

	Key Question	Method	Project
1.	Global star formation properties in the MilkyWay Galaxy : Molecular clouds & dense gas.	Star formation rate, star formation efficiency. Physical mechanism responsible for the onset of star formation in very different places of the Galaxy. Creation of a 'fundamental theory' of a galaxy-scale predictive model for star formation that can serve as a "z=0 template" for external galaxies.	IRAM, APEX, SRT, GBT, ARO, LOFAR, EVLA, ASKAP SKA, ALMA + ACA, NOEMA, SMA, JWST, MeerKAT
2.	Physics of individual star formation events and stellar clusters.	Fragmentation of dense clumps and evolution to dense cores. Monolithic collapse vs dynamic competitive accretion and potential mergers. Core migration in clumps. Origin of the IMF, also in low metallicity environments, and of the stellar binary fraction. From the core to the protostar and formation of the circumstellar disk. Theory of dissipative processes tested with polarimetric studies of dust thermal emission. Morphology and excitation conditions in the disk gas phase and its role in protostellar evolution. Modelling of the jet launching mechanisms and link with the angular momentum evolution. Feedback of jets and outflows on the properties of the disk. Chemistry of the disk material and formation of complex molecules. Determine IMF in low-metallicity environments.	ALMA, IRAM, GIANO, GIARPS , CRIRES+, HIRES, HST, JWST, SPHERE, LUCI, LBTI, GAIA, GES SHARK-NIR, V-SHARK, MICADO, MAORY
3.	Proto-planetary discs: initial conditions for the formation of planets	Robust determination of dust-to-gas mass ratio in disks. The mechanisms to counteract the fragmentation and the migration toward the star of mm/cm-sized dust grains. The measurement of the fraction of discs actively accreting matter on the star. The identification of the mechanisms generating the rich disc structures observed (gaps, rings, spirals, etc.), and their relation with the presence of newly formed planets. Mass accretion and ejection as a function of stellar parameters, in solar and low-metallicity environments.	IRAM, ALMA, SPHERE, LBTI, LUCI GIANO, GIARPS, CRIRES+, SHARK, ERIS, AMBER, GRAVITY, MATISSE, JWST, MAORY, HIGHRES,