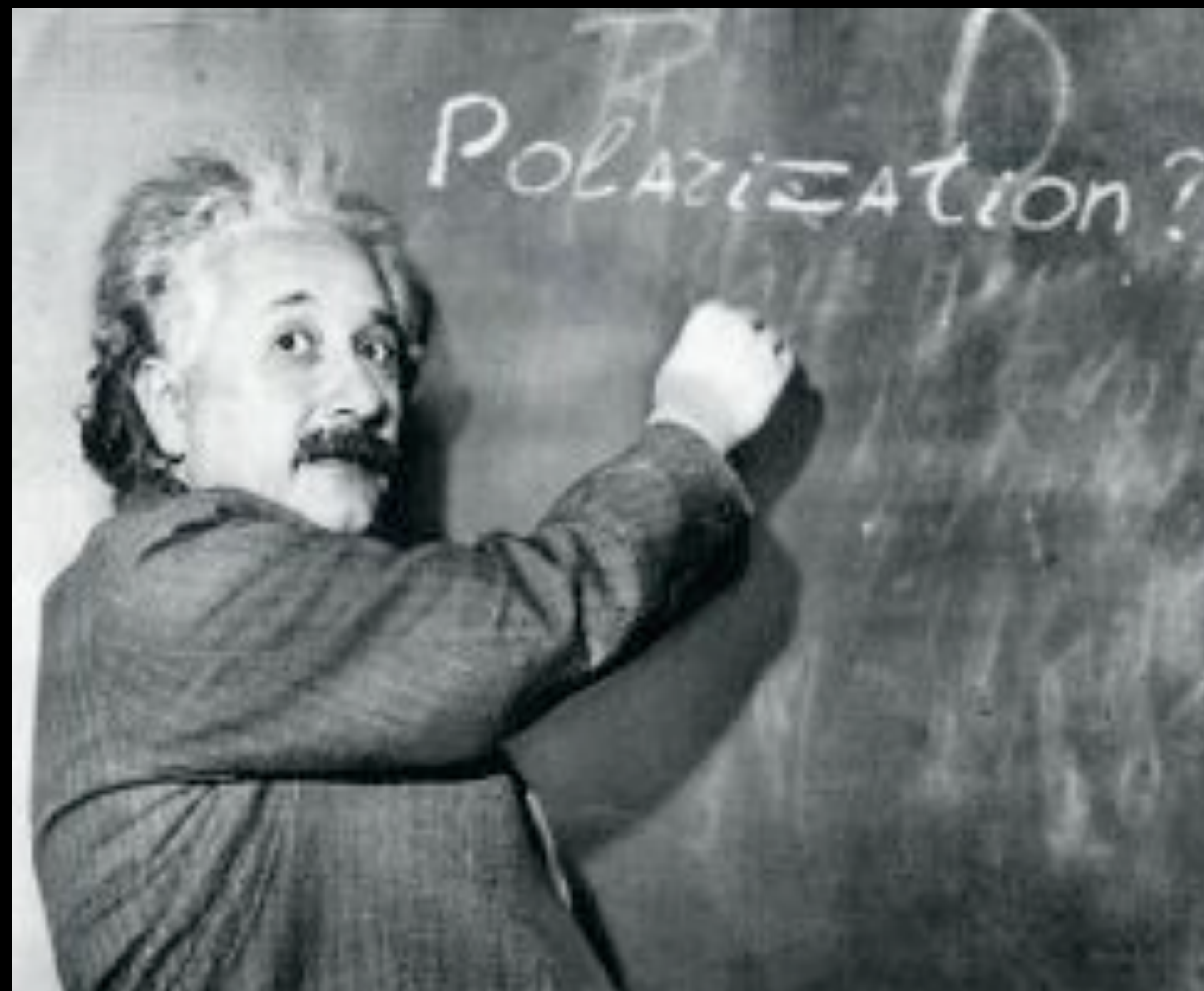
Observations of polarized dust emission in protostars: how to reconstruct magnetic field properties?



Anaëlle MAURY, showcasing work carried out in the framework of the *MagneticYSOs* project
(main contributors: Galametz, Girart, Guillet, Hennebelle, Houde, Rao, Valdivia, Zhang)

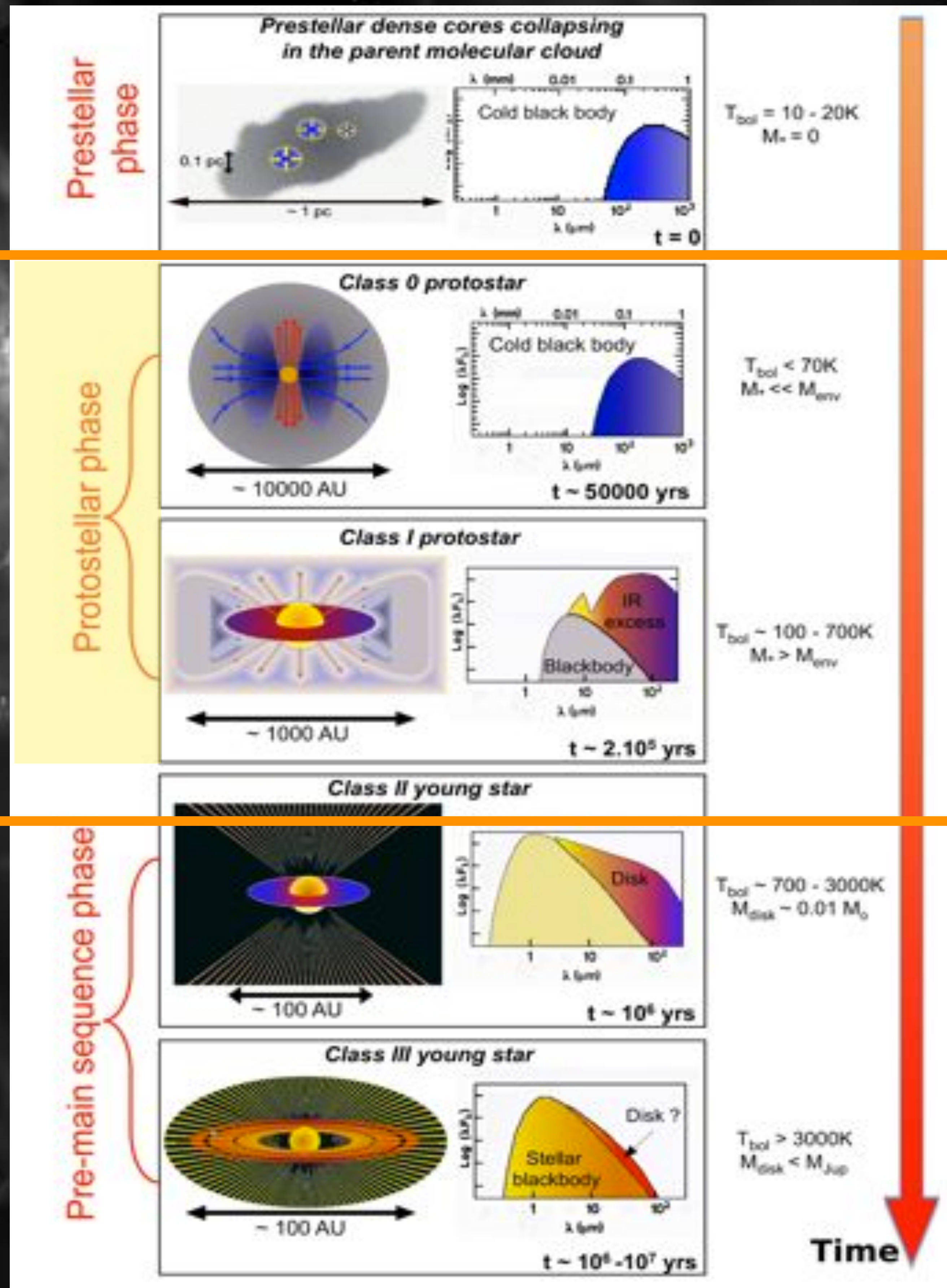
Irfu - CEA Saclay
Institut de recherche sur les lois fondamentales de l'Univers

AIM
Astrophysique Interactions Multi-échelles

erc
European Research Council
Established by the European Commission

MagneticYSOs

Observations of polarized dust emission in protostars: how to reconstruct magnetic field properties?



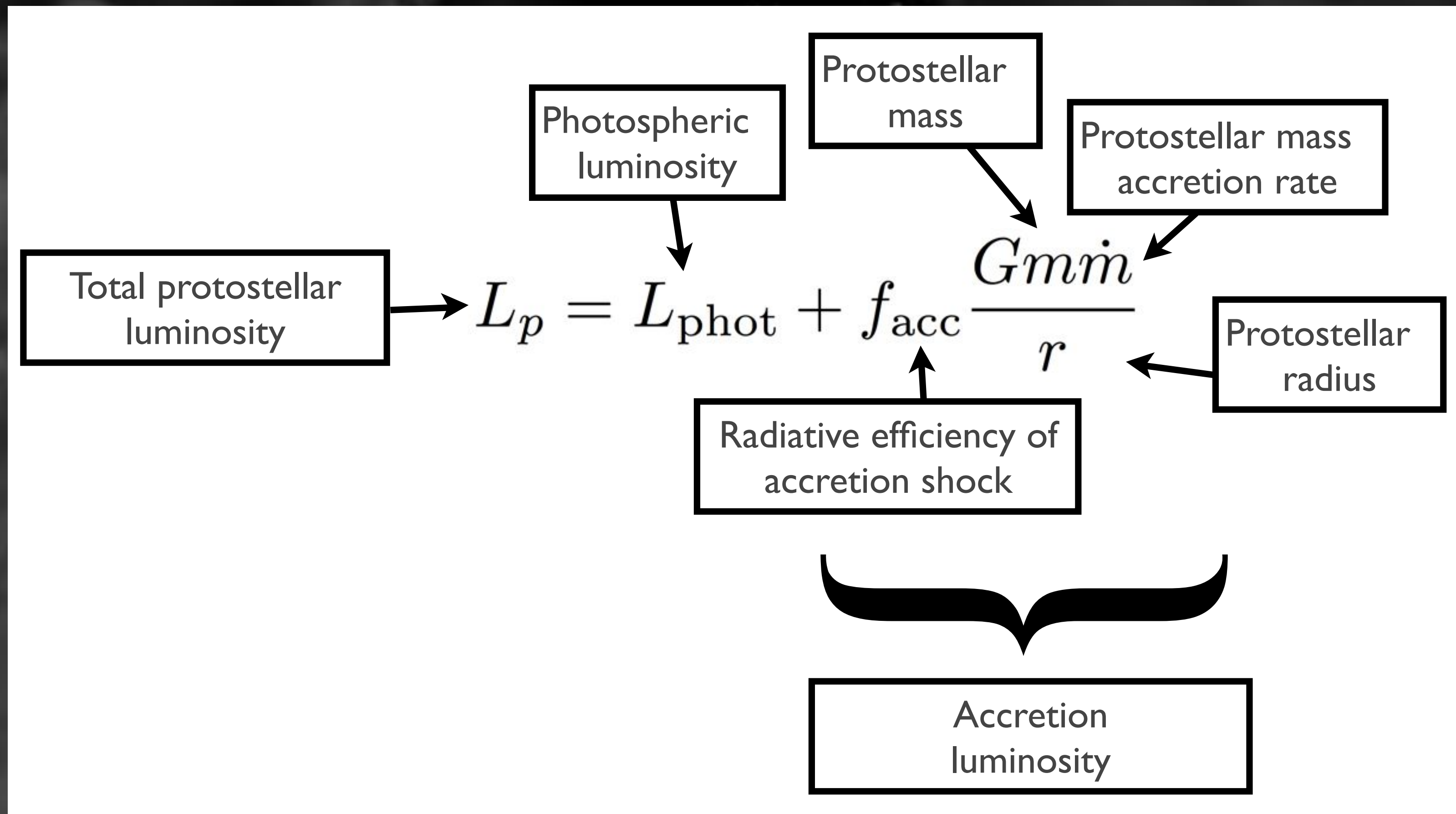
Progenitors of solar-type stars

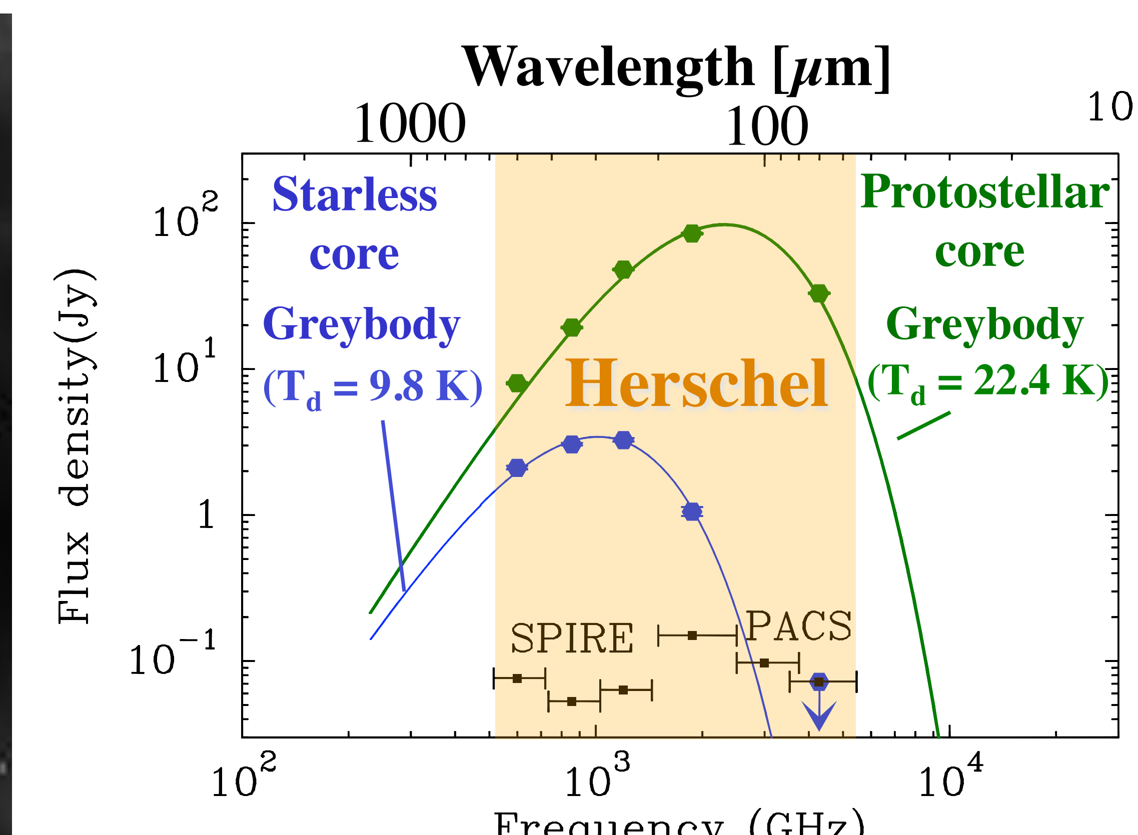
Shu et al. 1987

Lada 1987

André et al. 1993

André et al. 2001

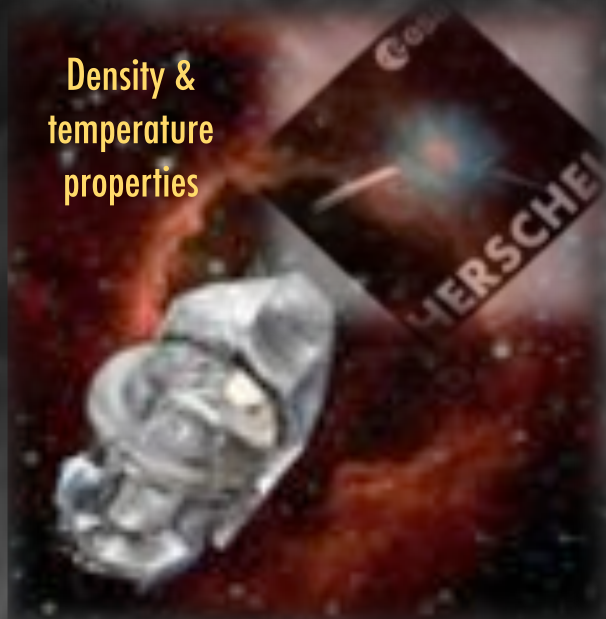


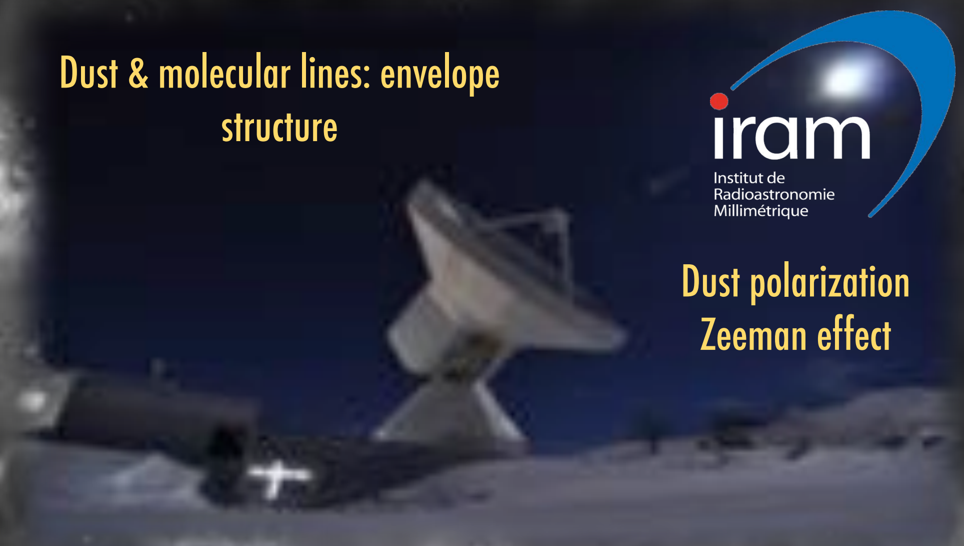


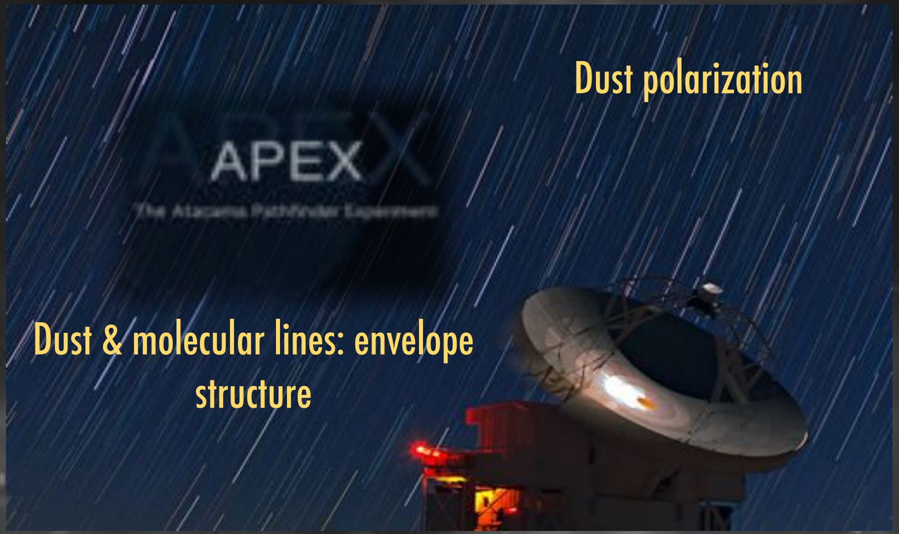
Progenitors of solar-type stars

OBSERVATIONS OF POLARIZED DUST EMISSION IN PROTOSTARS: HOW TO RECONSTRUCT MAGNETIC FIELD PROPERTIES?

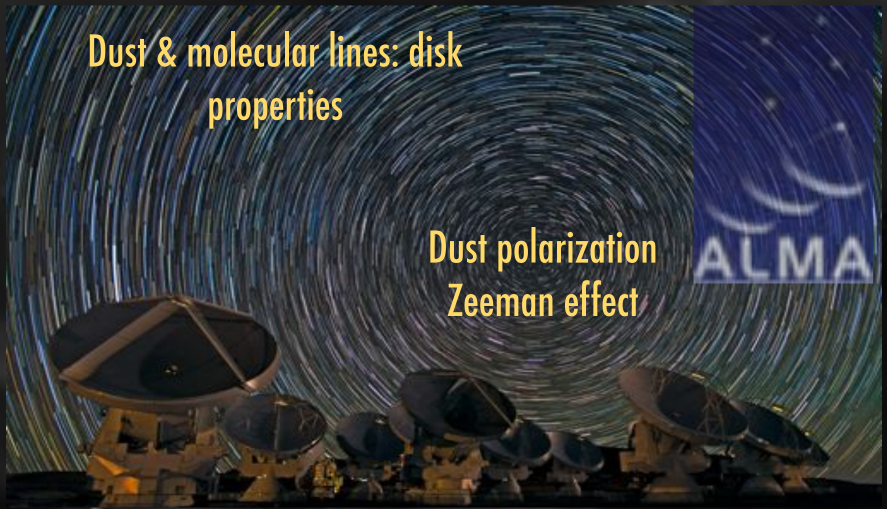
Core scales 1000-10.000 AU

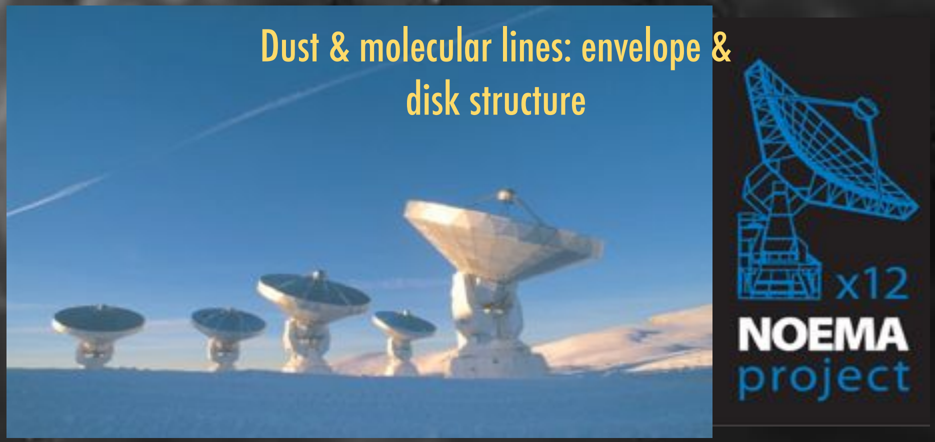


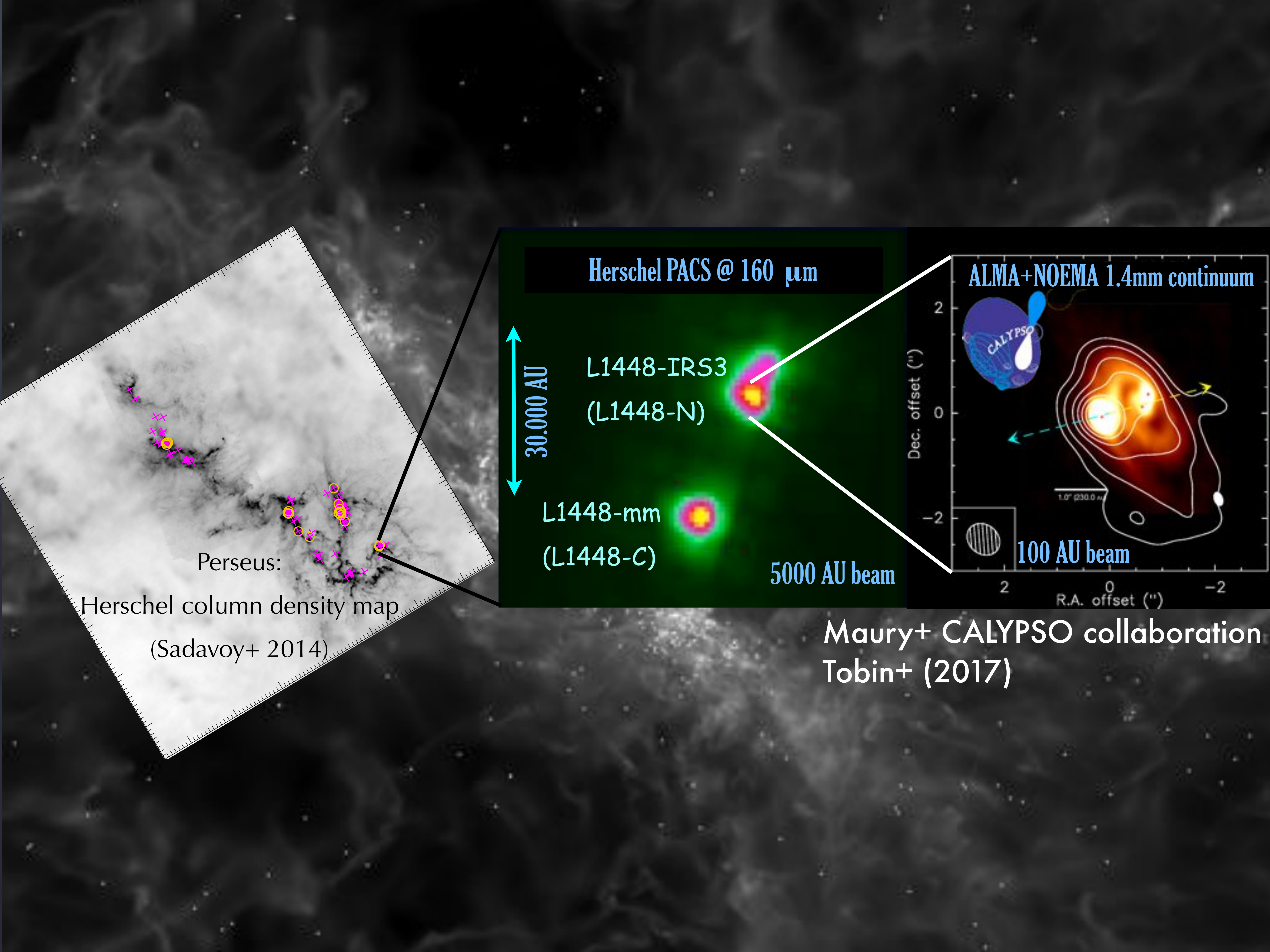




Inner envelope / disk scales 20-1000 AU

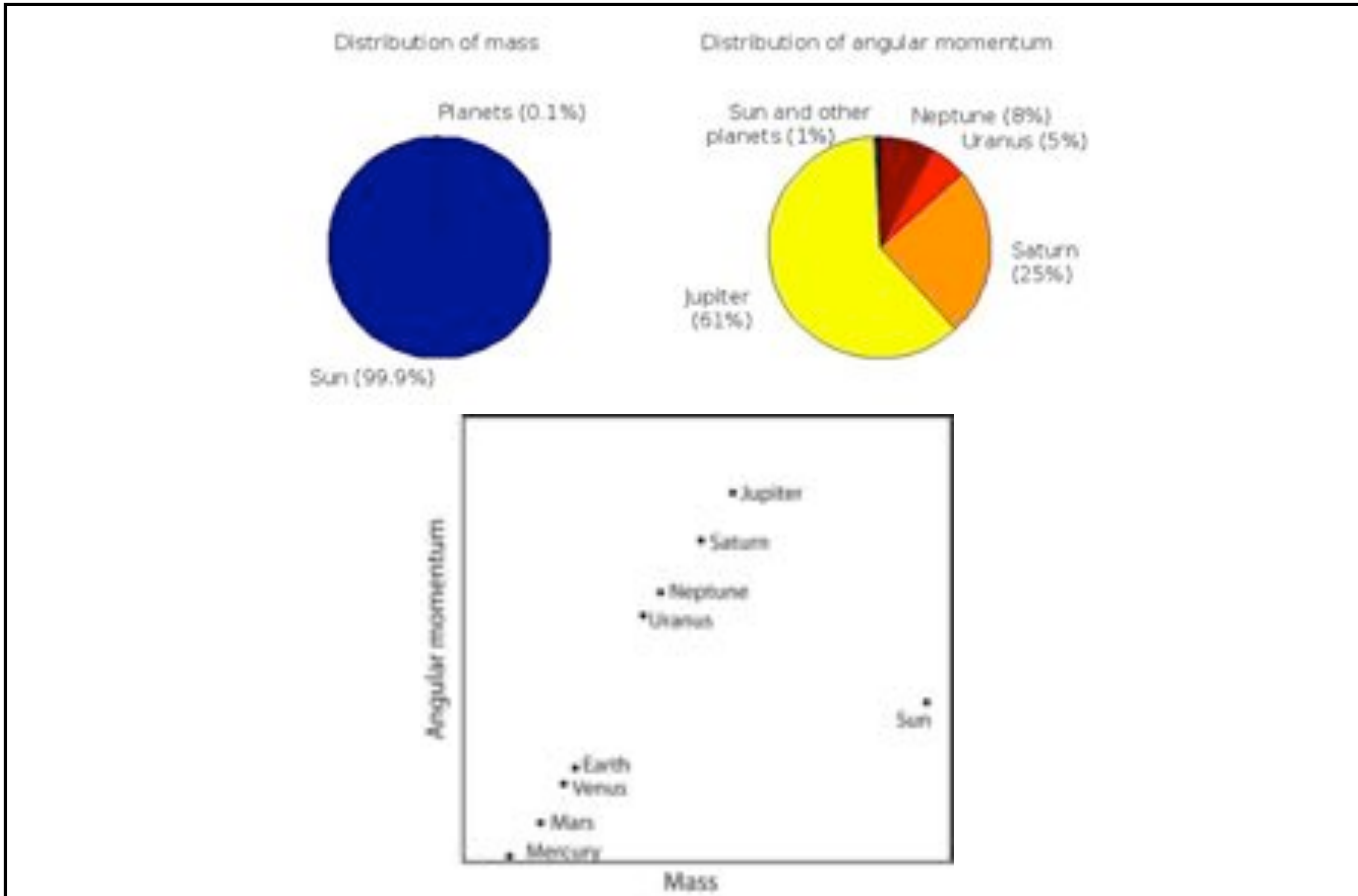





Perseus:
Herschel column density map
(Sadavoy+ 2014)
Herschel PACS @ 160 µm
30.000 AU
L1448-IRS3
(L1448-N)
L1448-mm
(L1448-C)
5000 AU beam
ALMA+NOEMA 1.4mm continuum
CALYPSO
2
0
−2
Dec. offset (")
2
0
−2
R.A. offset (")
100 AU beam
Maury+ CALYPSO collaboration
Tobin+ (2017)

Let's focus on a cornerstone question:

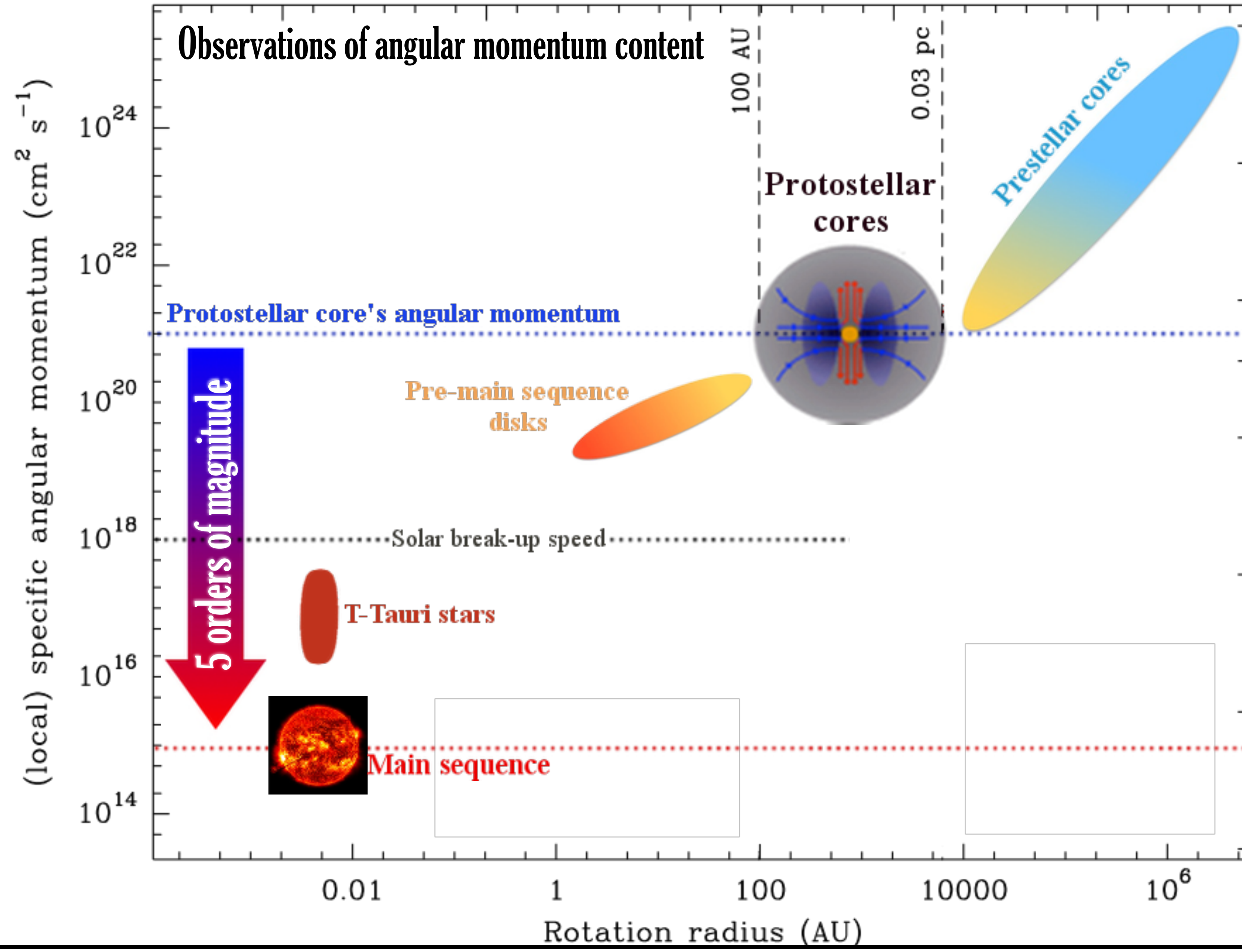
the angular momentum problem



One would naively expect most of the angular momentum contained in the star-forming core would end up in the central star: not in our solar system !

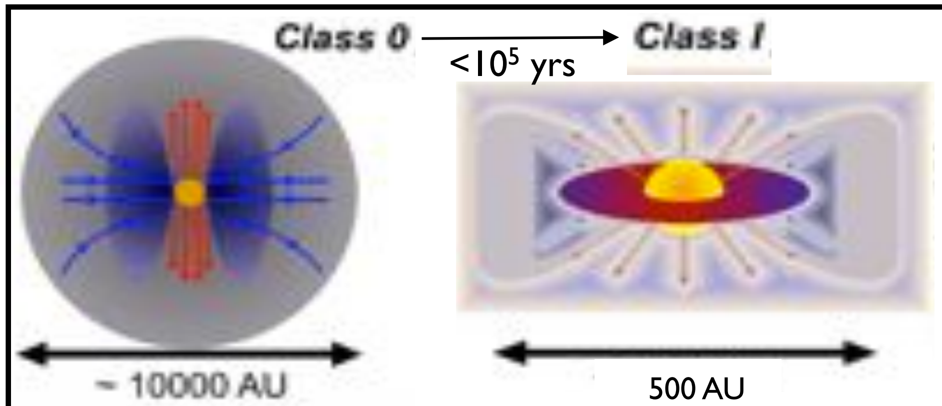
The angular momentum problem

Protostars must lose >99.99% of their angular momentum prior to entering the T Tauri stage



Based on Belloche (2013)
See also Li et al. review for PPVI (2014)

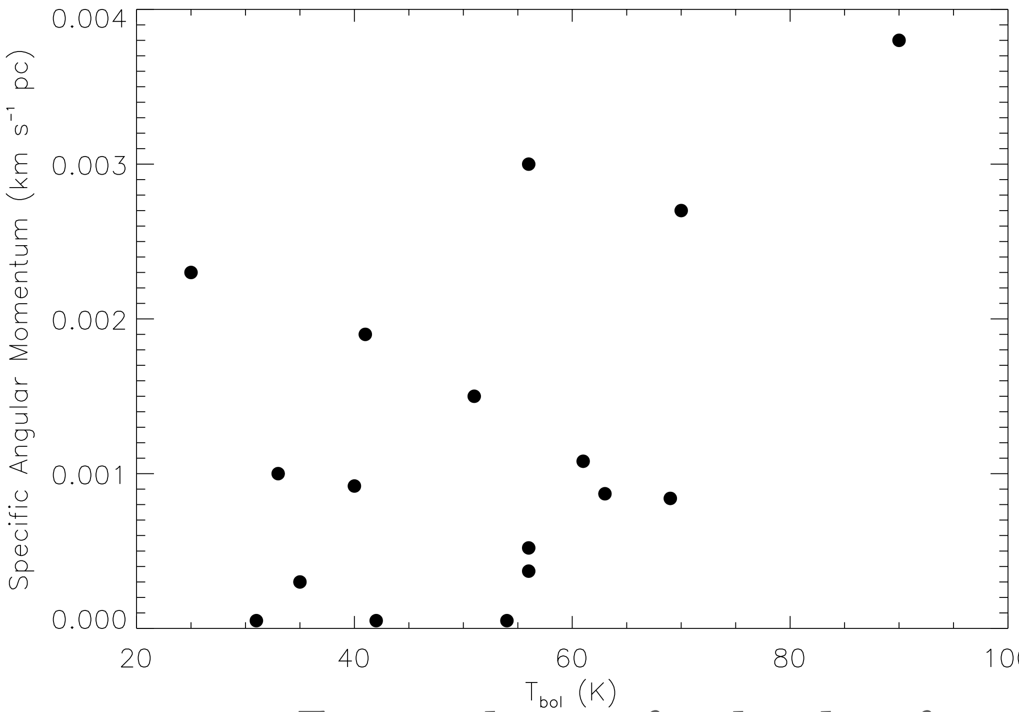
Class 0 protostars: a key stage for solving the AM problem

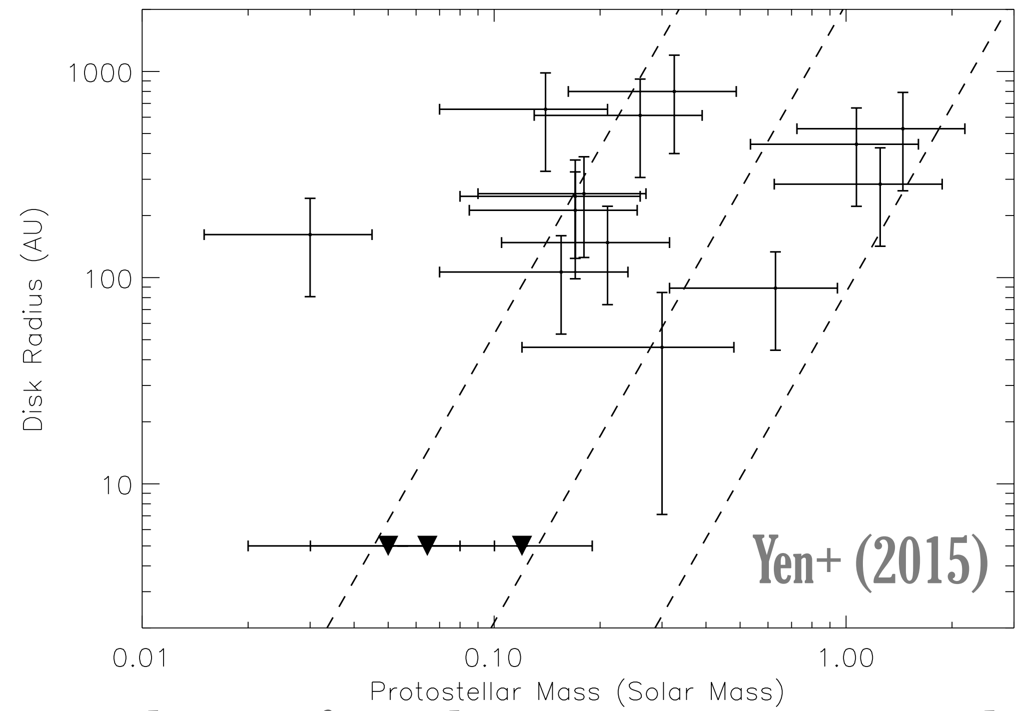


Class 0 phase = main accretion phase

>50% of the final stellar mass is assembled: need to get rid of the 10.000 AU envelope's AM during its accretion on 0.1 AU protostellar embryo

Disks as a solution to the angular momentum problem ?





Source	R_d (AU)
L1448 IRS 2	130–390
L1448 IRS 3B	330–720
L1448-mm	140–160
NGC 1333 IRAS 4A	630–720
NGC 1333 IRAS 4B	<5
L1527 IRS	70–150
B335	<5
L1157	<5

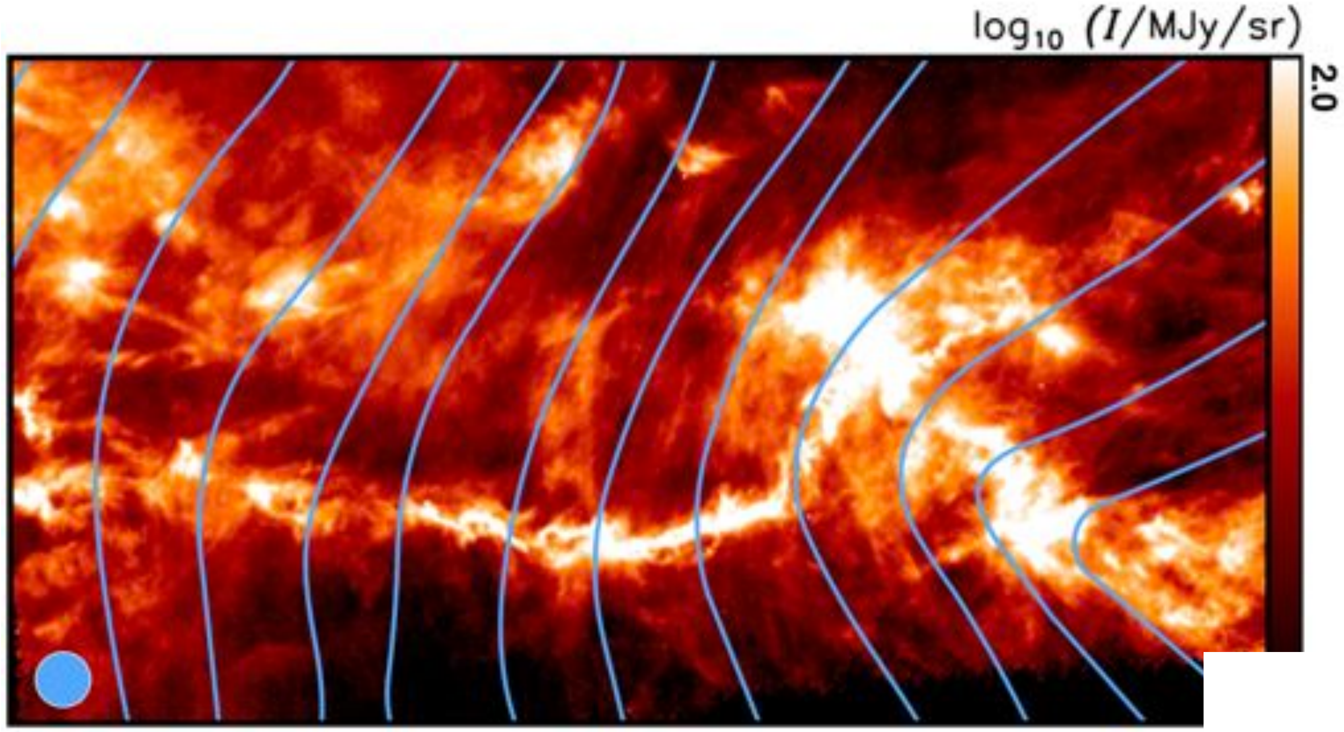
Expected centrifugal radius from extrapolation of angular momentum measured at 1000 AU radius

Upper-limits on Class 0 disk radii
as measured from CALYPSO PdBI continuum observations are
smaller by at least 50 %
than disk sizes expected from angular momentum conservation

Hydro disks are excluded in >75% of the CALYPSO sample (16 protostars)
Hybrid sample with literature (VANDAM VLA, ALMA): 80% of Class 0 protostars have disks <100 au

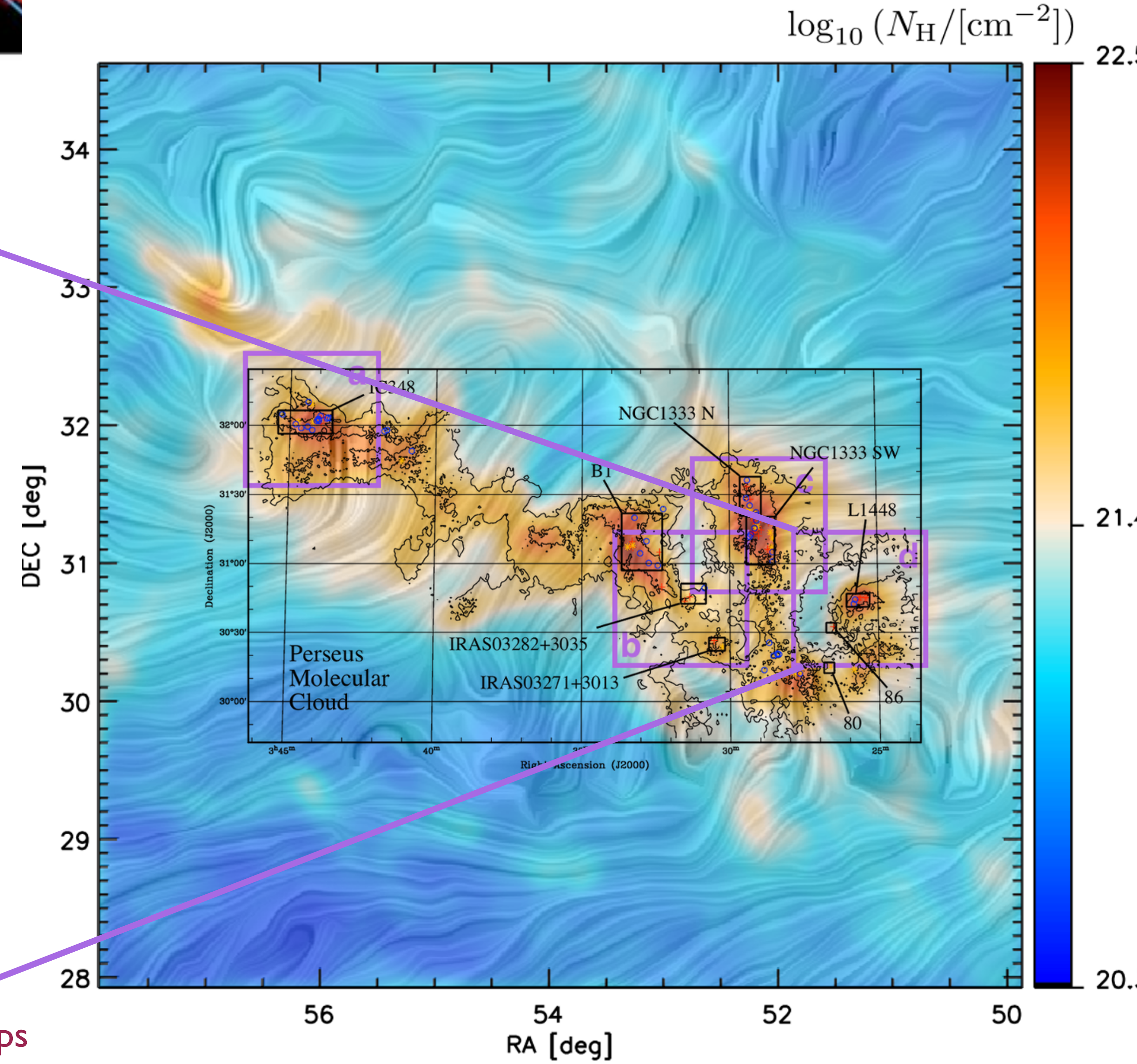
Maury+ (2010, 2014, 2018)

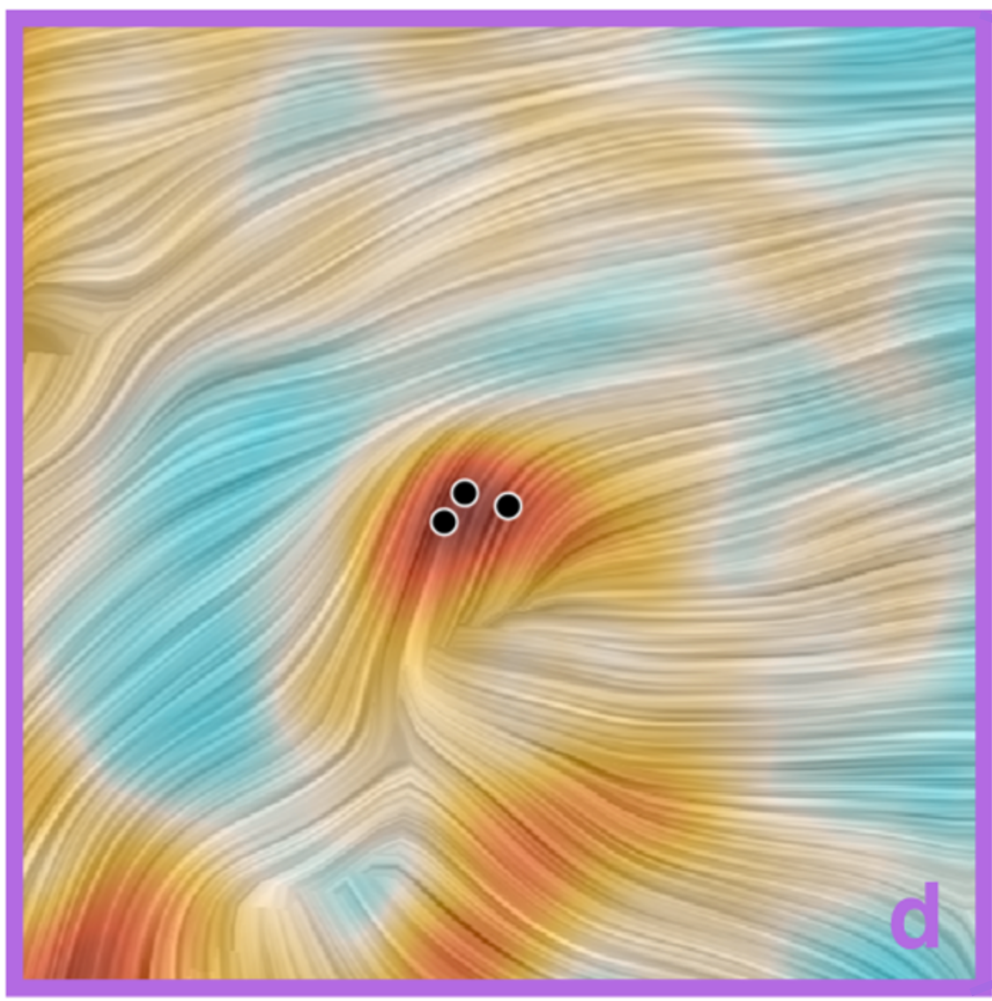
Challenging the long-standing solution for AM problem
& the standard star/disk formation scenario



B211 in ***Taurus*** *(Herschel Gould belt survey 250 μm)*
Blue : Magnetic Field from Planck polarizatin data

Perseus *cloud: Magnetic Field from Planck polarization data*
Contours; 13CO emission from the COMPLETE survey

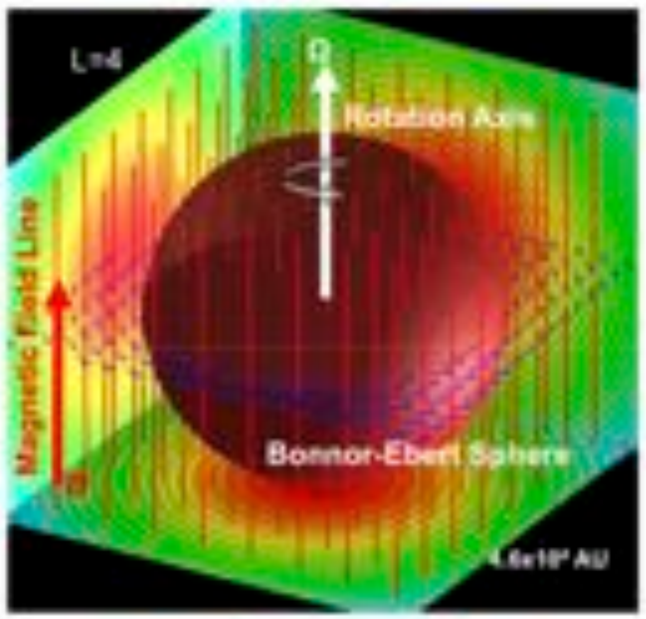


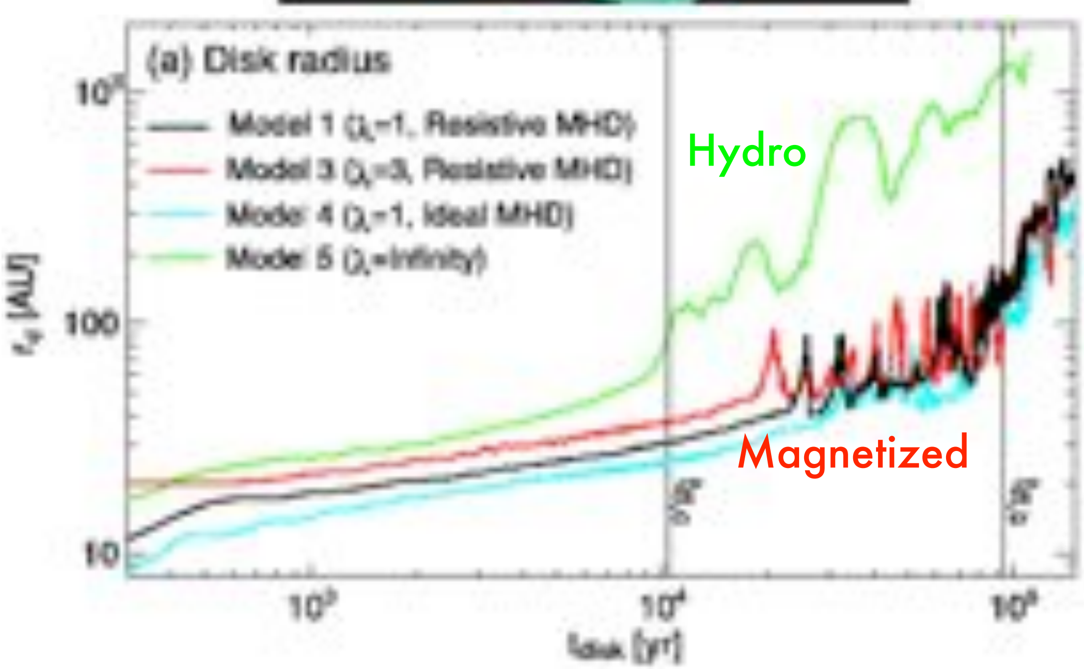


Thanks to A. Bracco for producing optimum Planck B maps

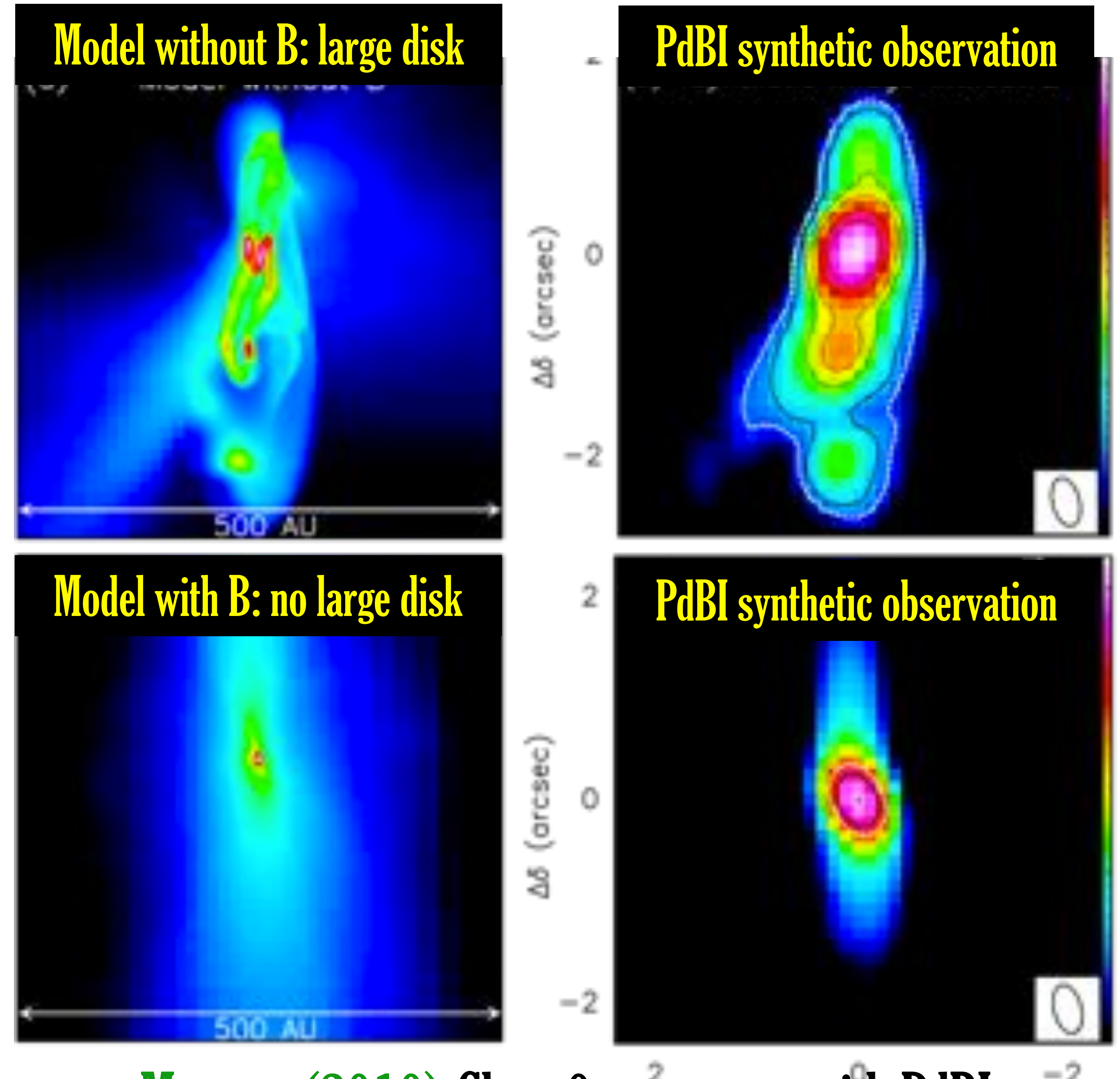
What do magnetic fields do ?

Magnetic braking:
a key process affecting angular momentum transport





Hennebelle & Teyssier (2008), Machida et al. (2010)



Maury+ (2010) Class 0 protostars with PdBI:
synthetic observations of a variety of numerical models

→ magnetized models fit best the observations of inner Class 0 envelopes ?

Why do we (think we) need magnetic fields ?

Launching Jets ?

Angular Momentum /Disks ?

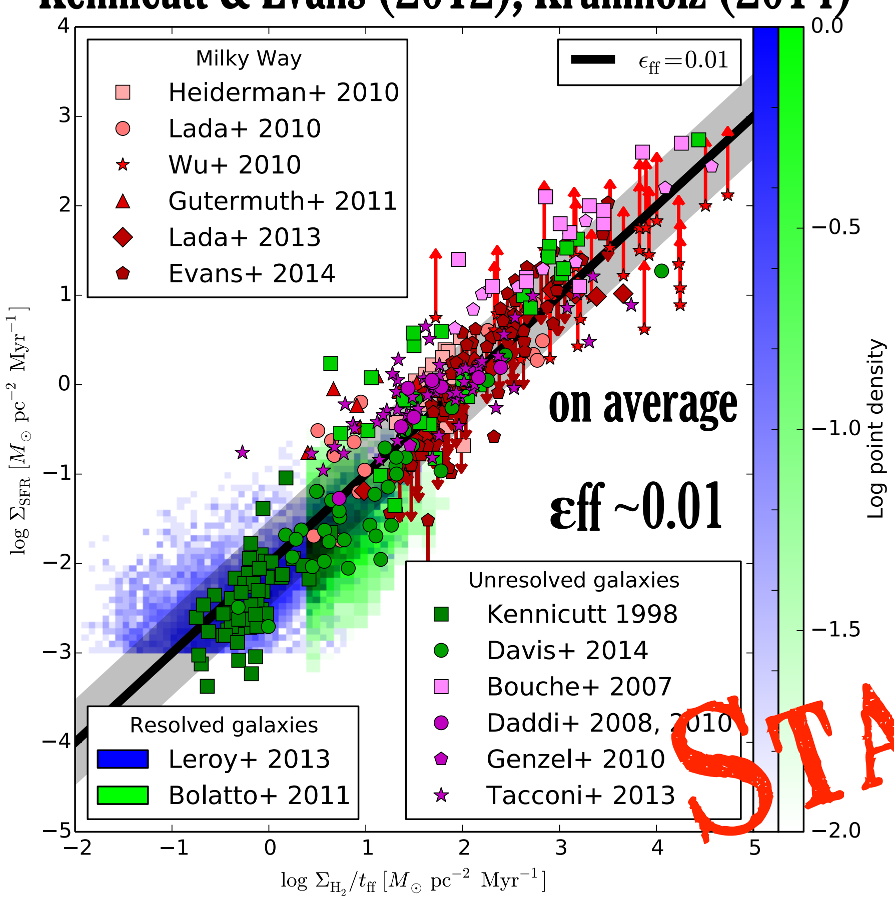
Luminosity problem ?

$$L_p = L_{\rm phot} + f_{\rm acc}\frac{Gm\dot{m}}{r}$$

- Total protostellar luminosity → L_p
- Photospheric luminosity → $L_{\rm phot}$
- 0.25 MSUN → m
- 10^{-5} MSUN yr^{-1} → $\dot{m}$
- 3 RSUN → r
- $\lesssim 1$ → $f_{\rm acc}$

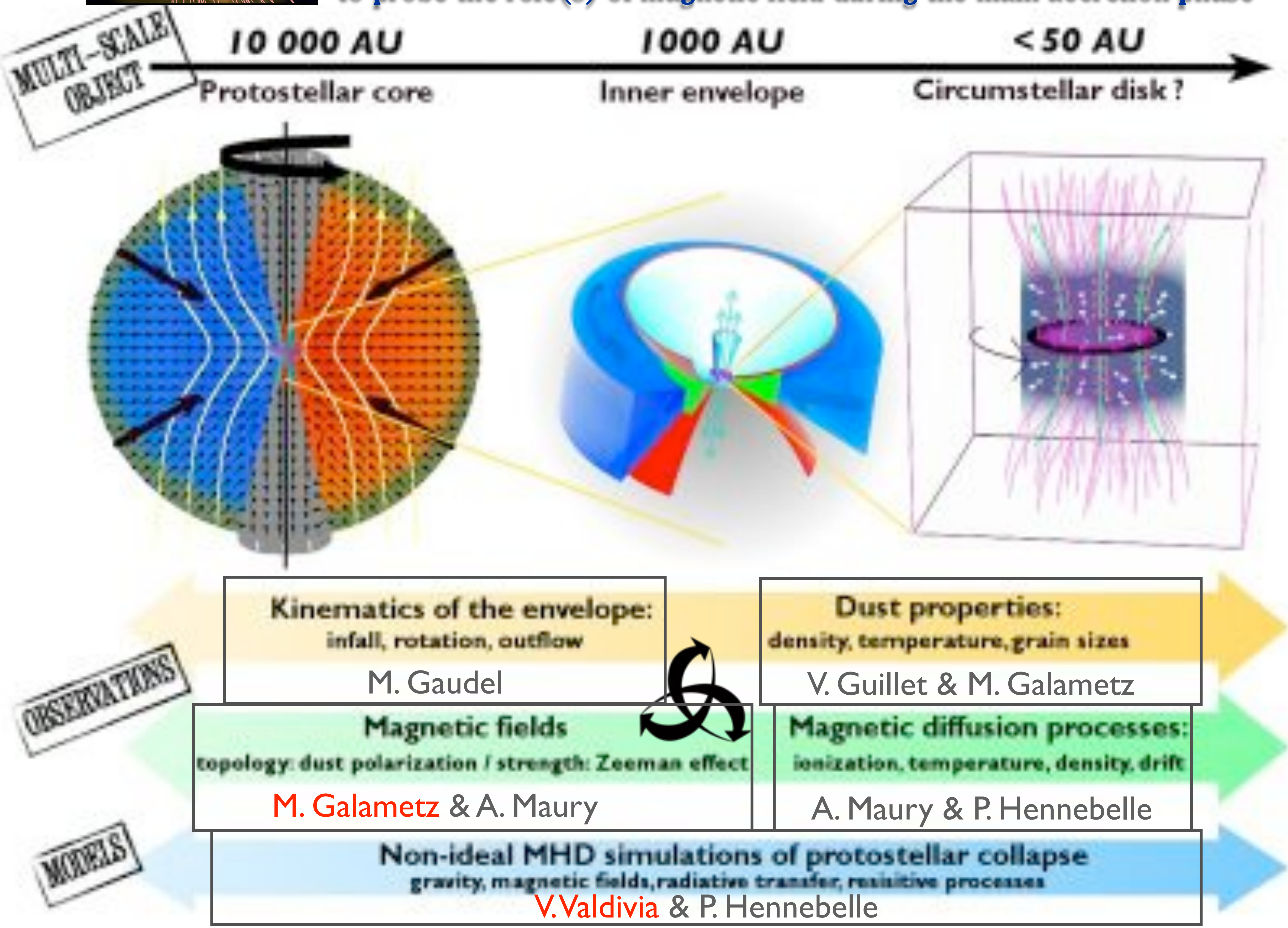
LACC ~ 25 LSUN ↔ Median observed luminosity = 1.2 - 1.3 LSUN

Kennicutt & Evans (2012), Krumholz (2014)

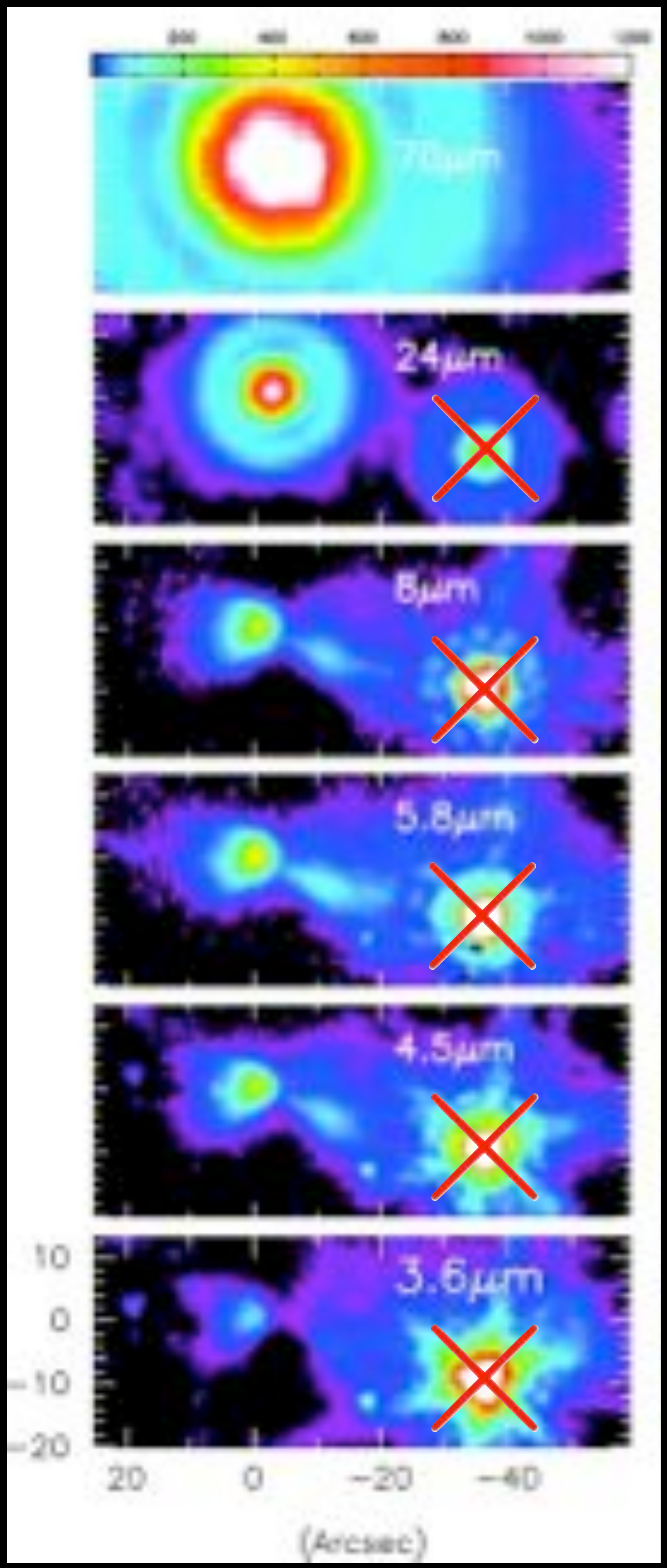


Star Formation Rates ?

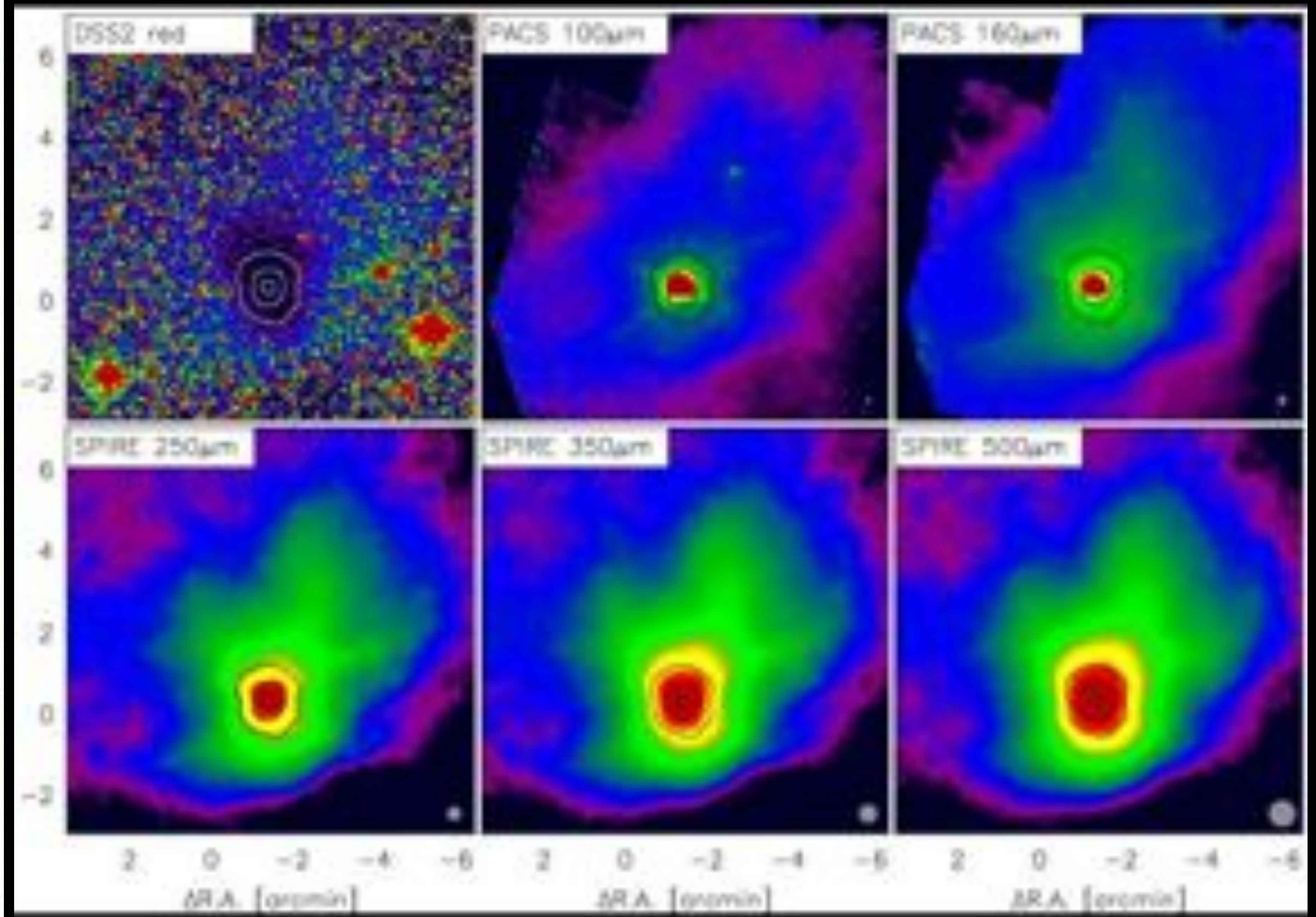
MagneticYSOs: a multi-scale multi-diagnostic approach to probe the role(s) of magnetic field during the main accretion phase



B335: a non - prototypical but good testbed case for low-mass star formation

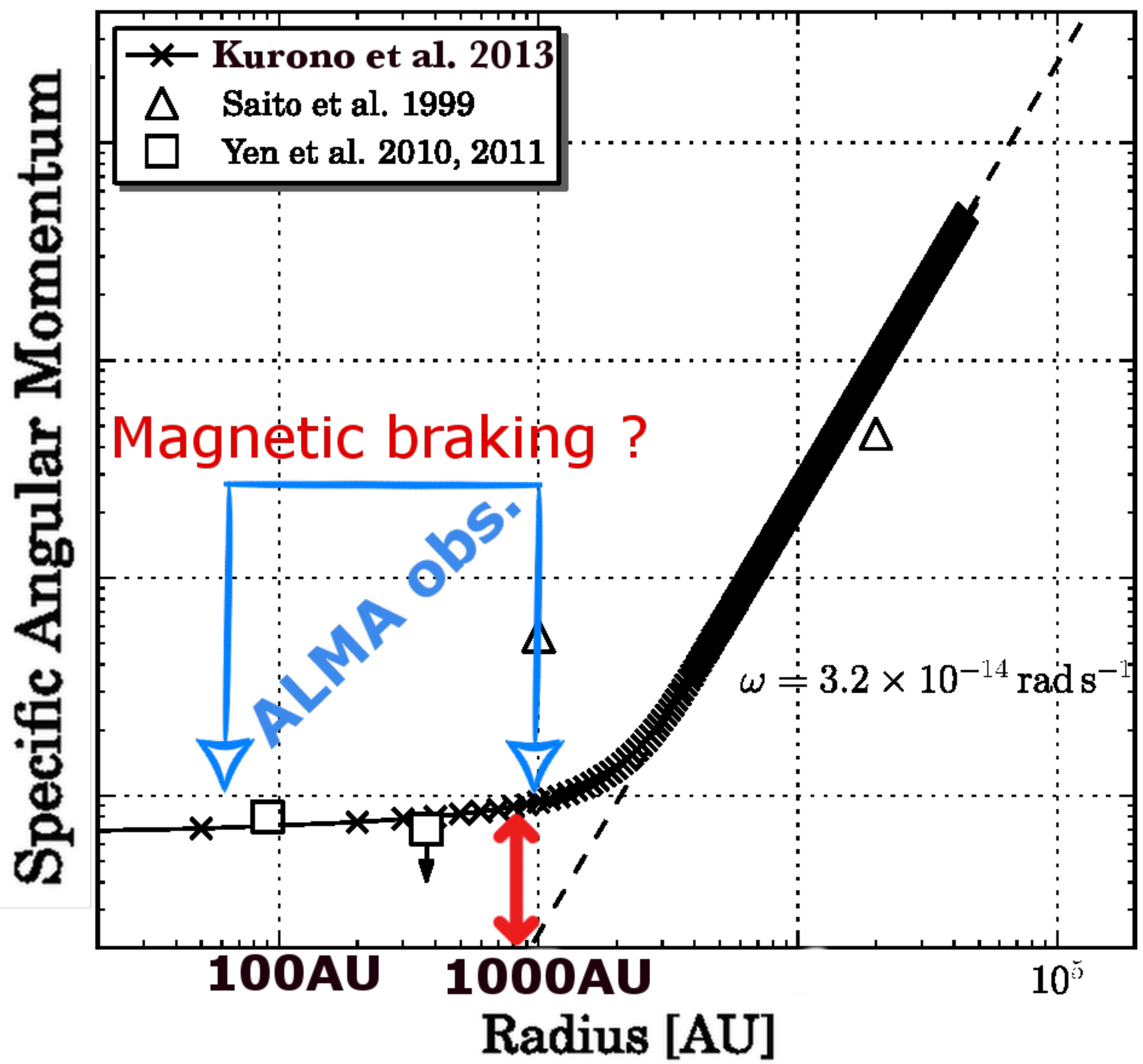


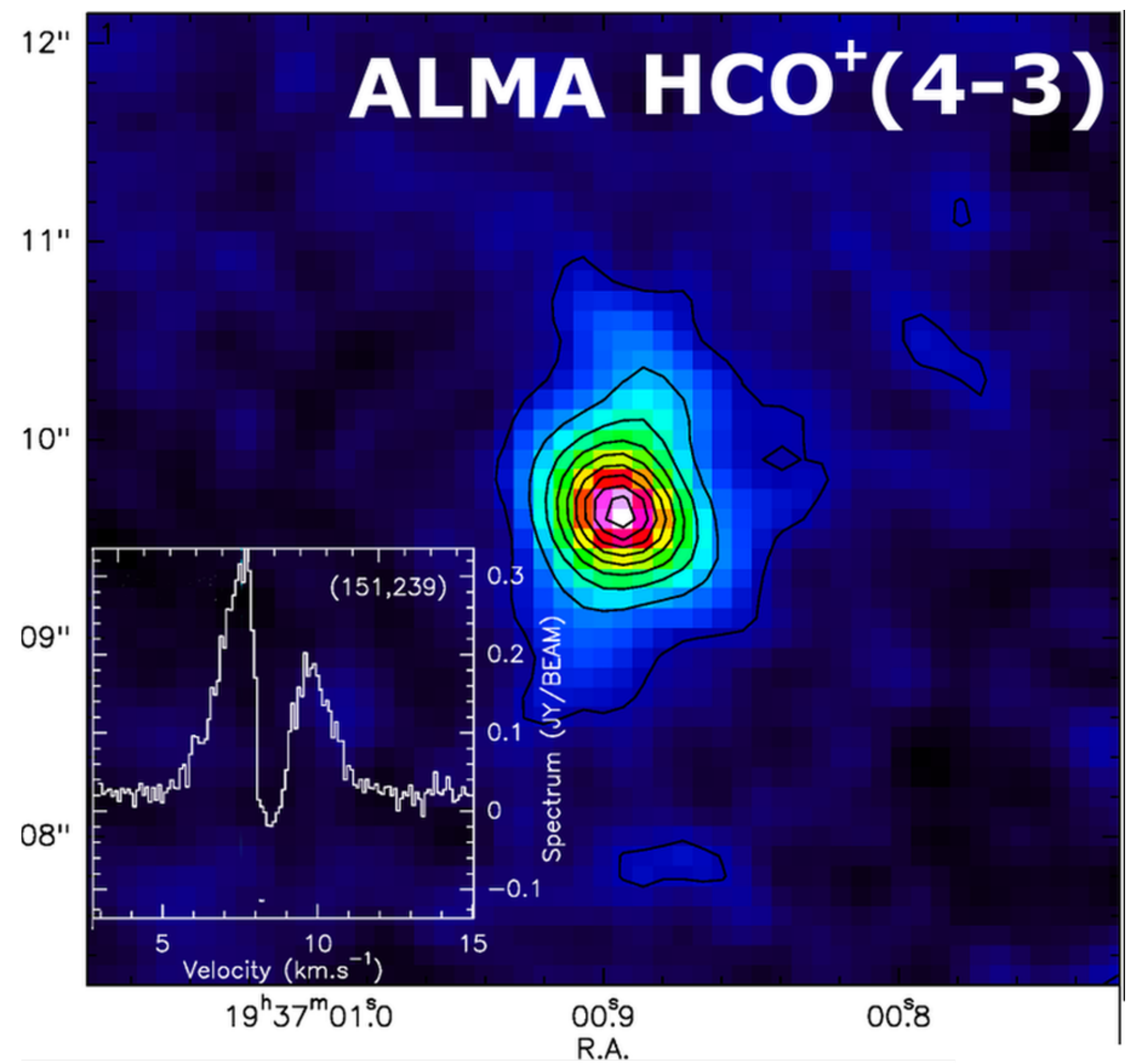
Stutz+ (2008)



Launhardt+ (2013)

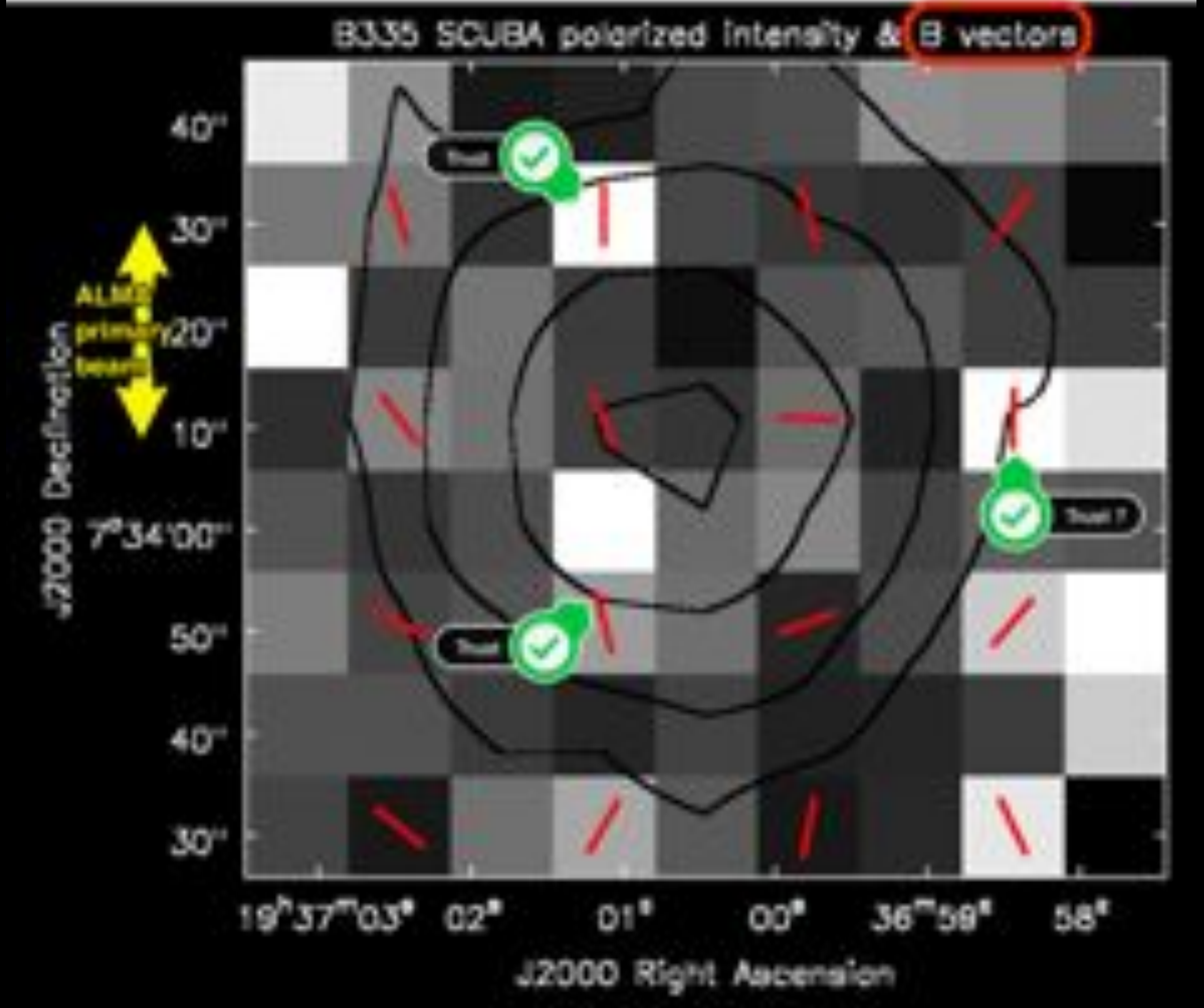
B335: a prototype of magnetic braking ?



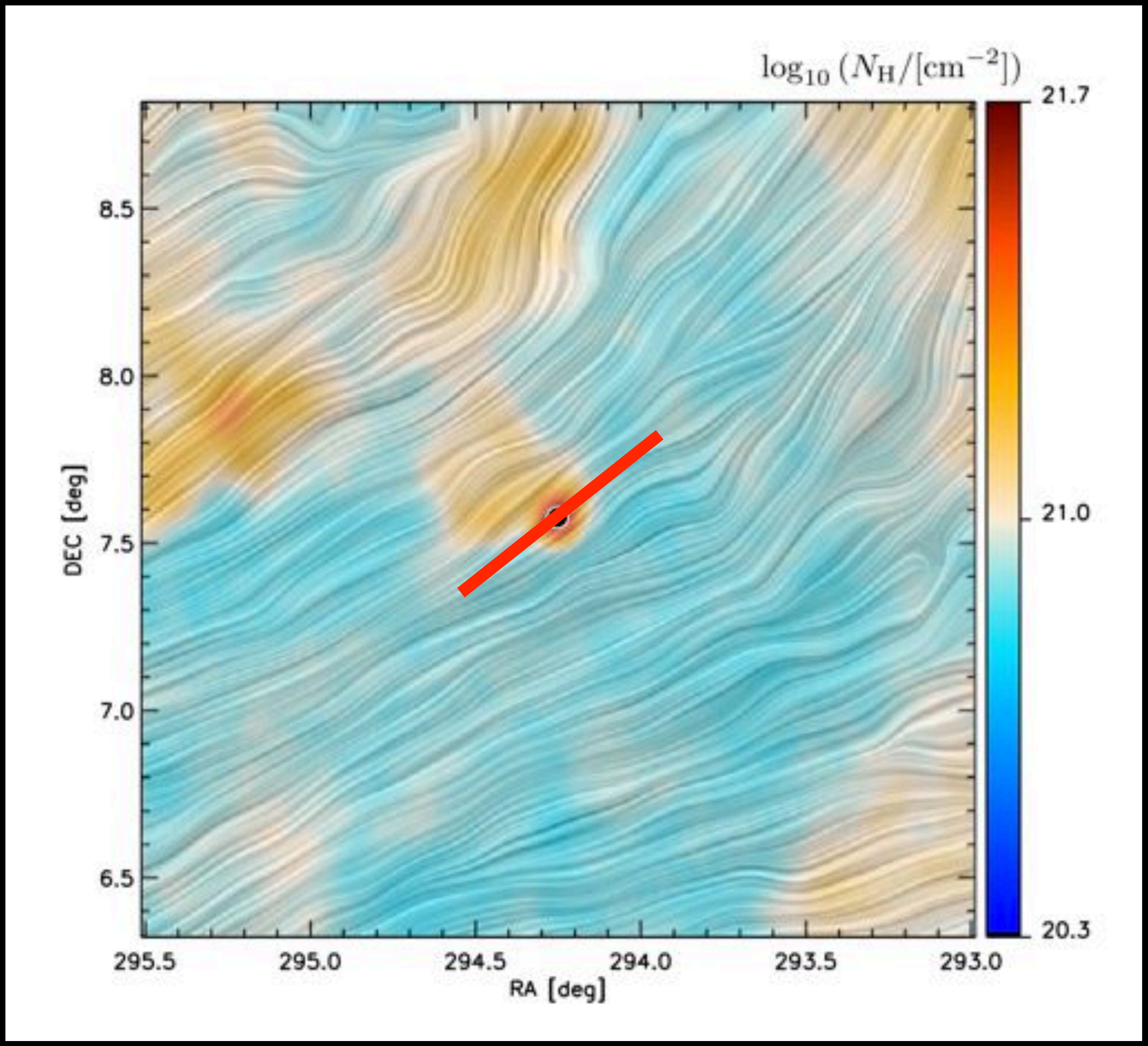


See work by Evans+ (2015), Yen+ (2013, 2015, 2017) and Kurono+ (2013)

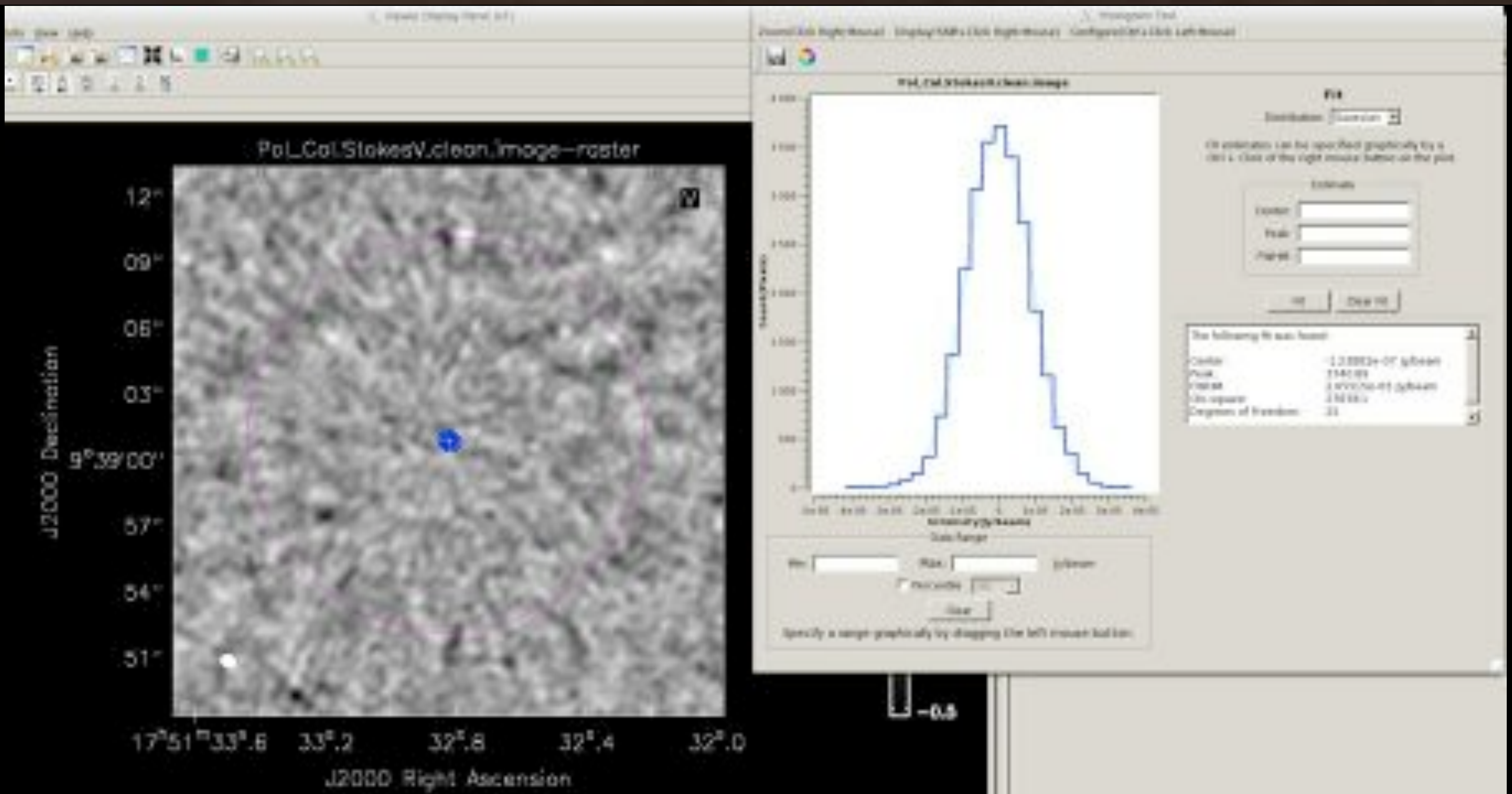
2009 / SCUBA magnetic fields @ 5000 au



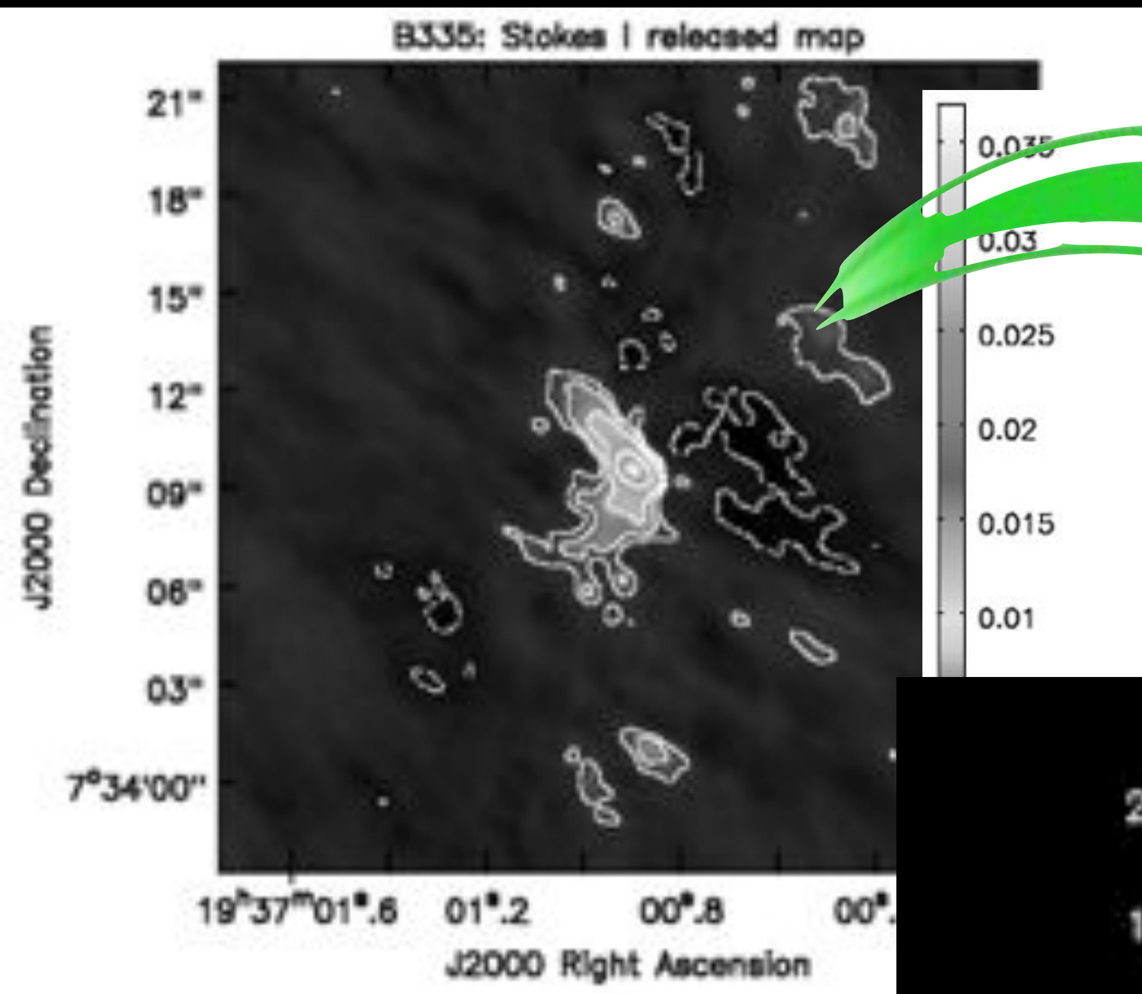
2013 / Planck magnetic fields @ 0.2 pc



2015 / SMA detection of 350GHz polarized emission @ 700 au: see talk by M. Galametz

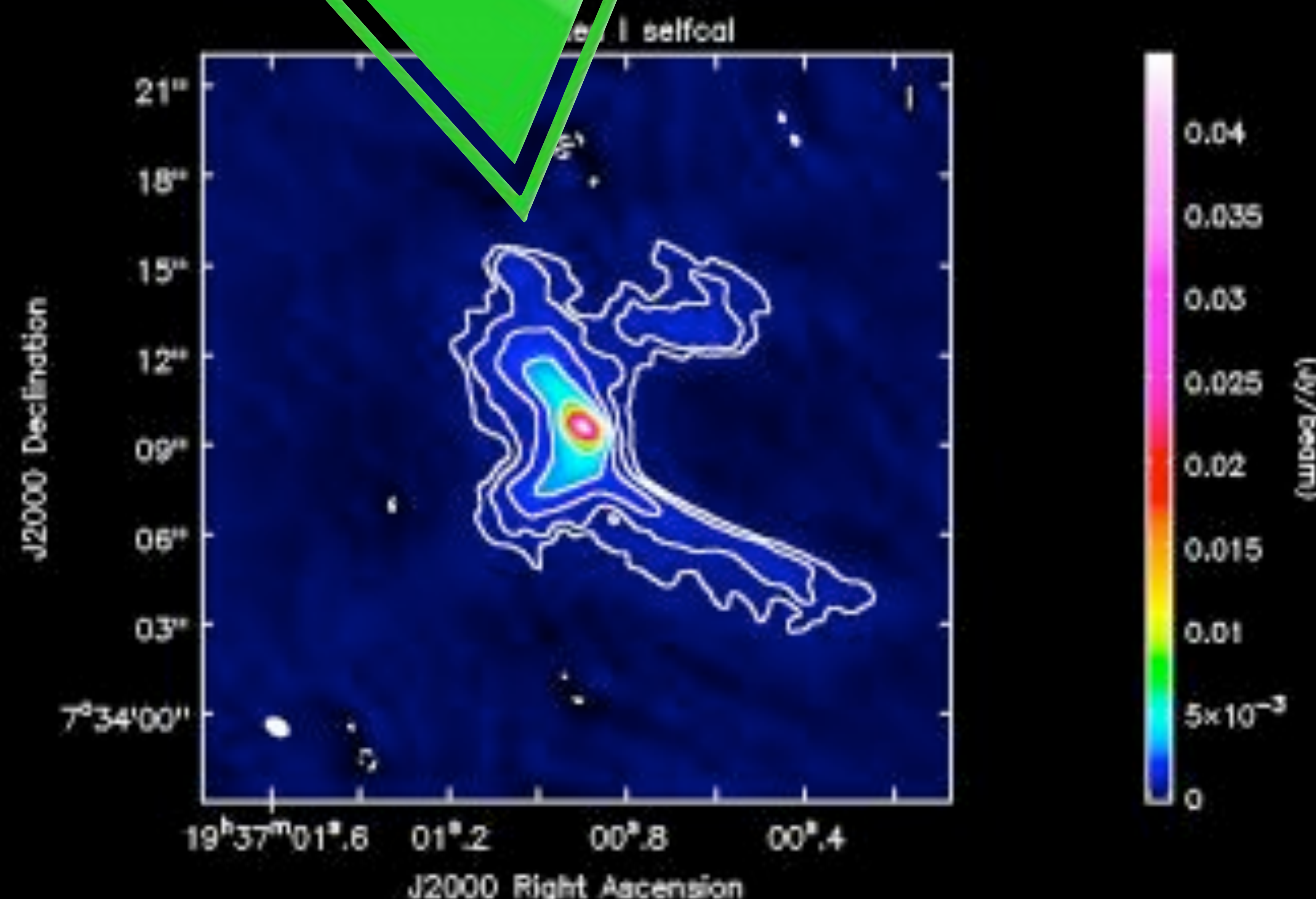


Stokes I rms 0.3 mJy/beam ---- Stokes Q / U rms noise ~0.02 mJy/beam
instrumental polarization < 0.5%, measured to an accuracy of 0.05% (V calibrator)



Phases self calibration

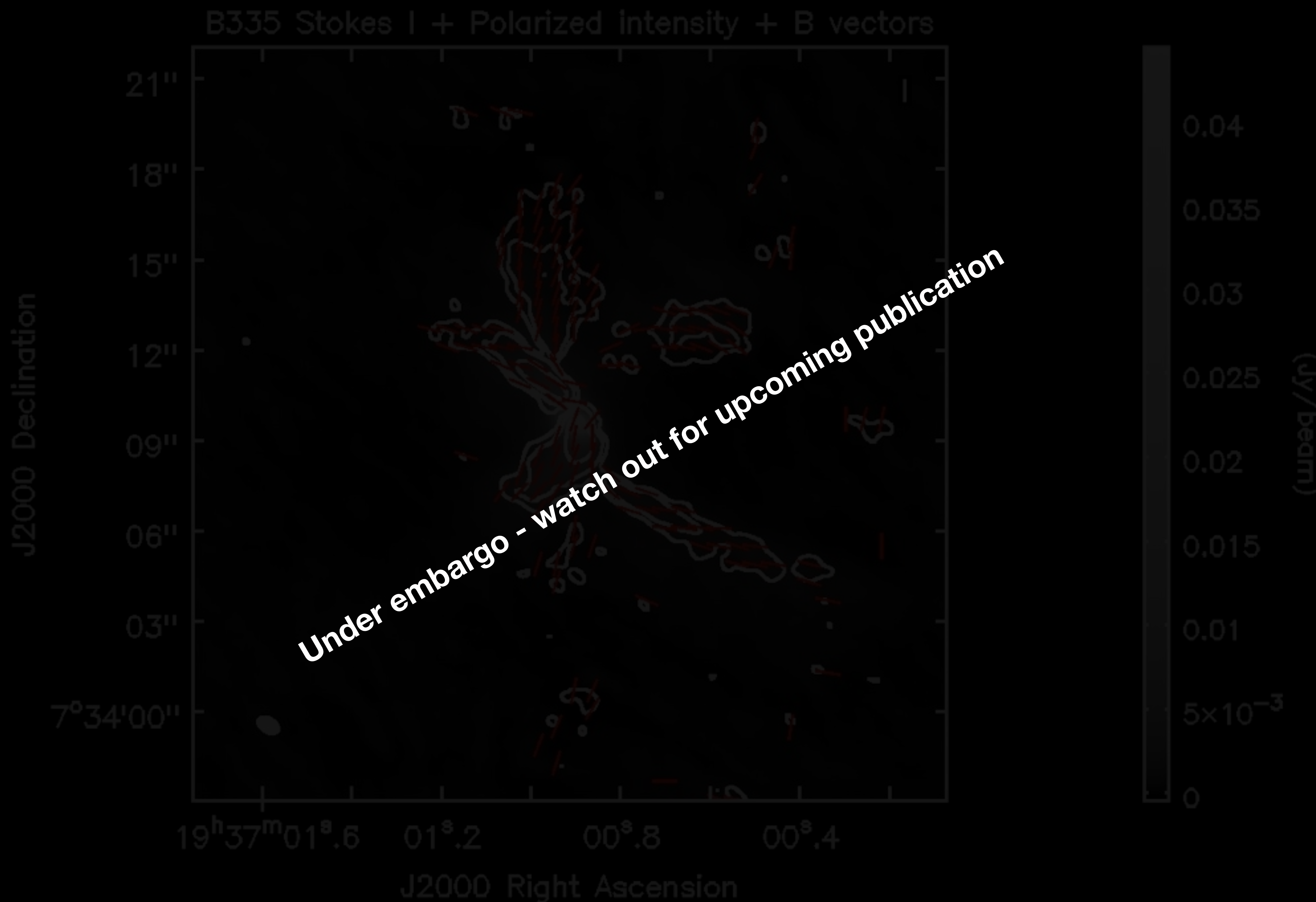
Maury, Girart, Rao, Zhang + (in prep)

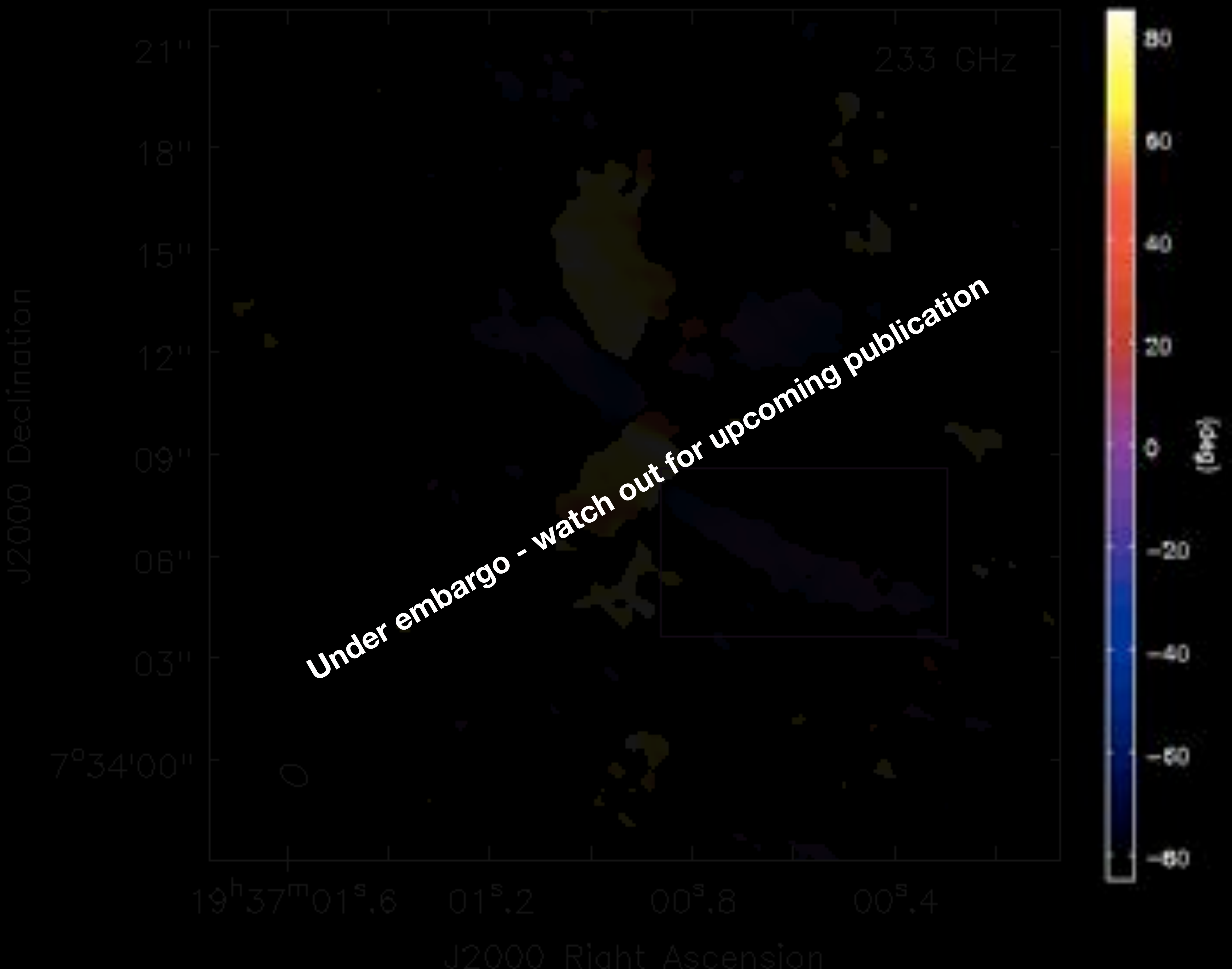


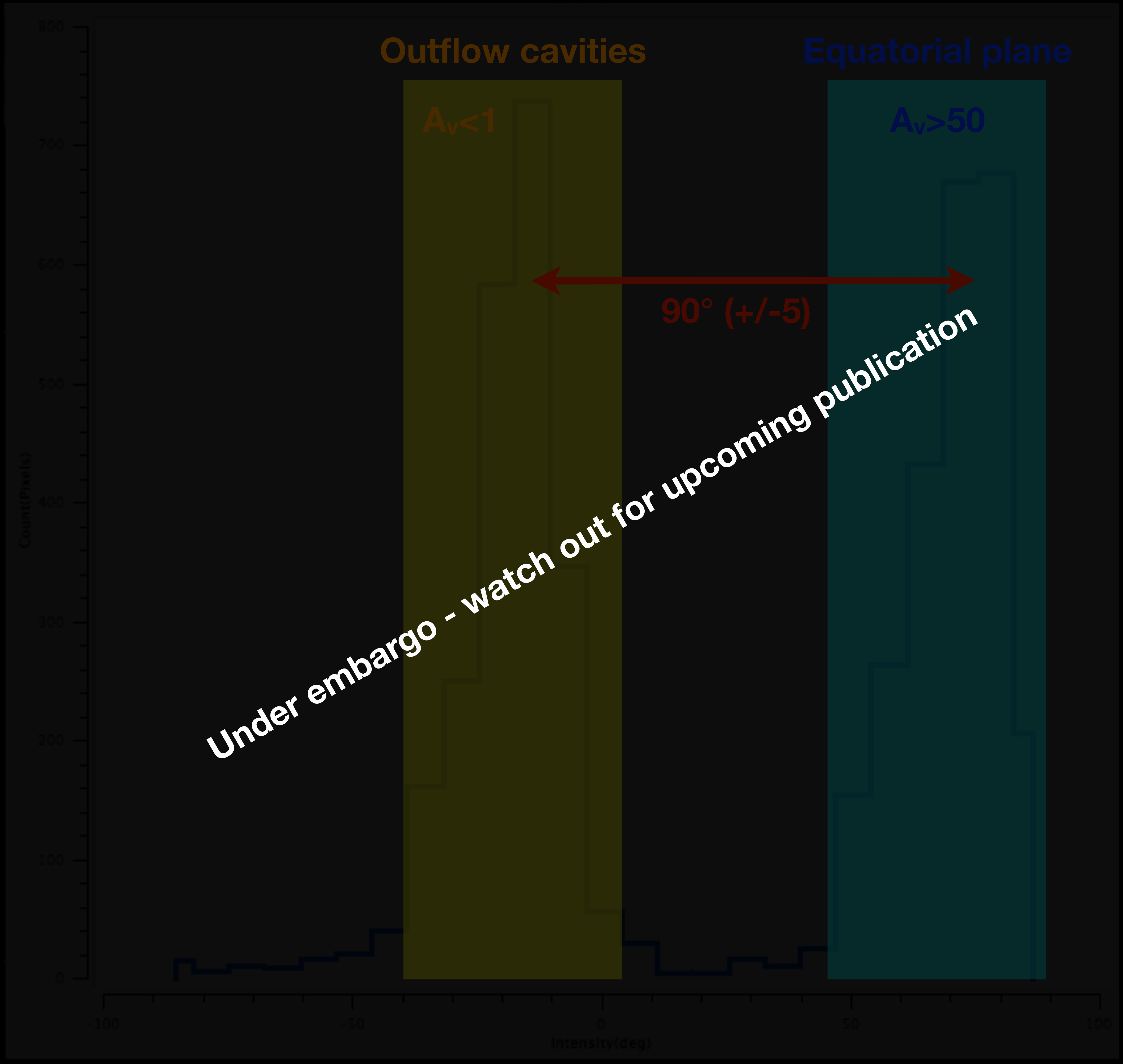
Synthesized beam
0.6"
~100 au @ B335 distance

rms noise Stokes I ~ 0.12 mJy/beam

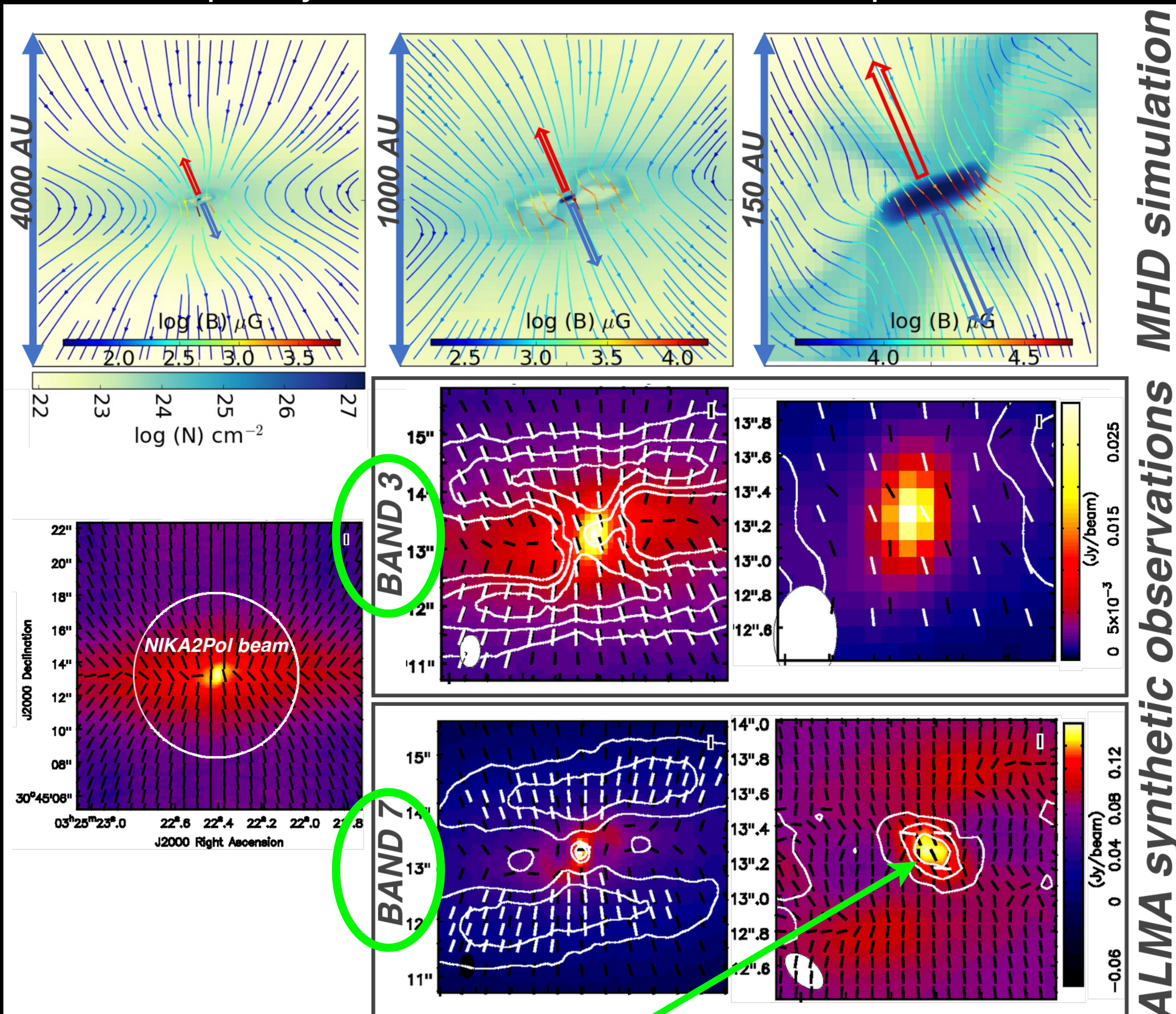
Dynamic range limited + spatial filtering
(recover 0.2 Jy total)


B335 Stokes I + Polarized intensity + B vectors
J2000 Declination
21''
18''
15''
12''
09''
06''
03''
7°34'00''
J2000 Right Ascension
19h37m01s.6
01s.2
00s.8
00s.4
0.04
0.035
0.03
0.025
0.02
0.015
0.01
5×10−3
0
(Jy/beam)
Under embargo - watch out for upcoming publication

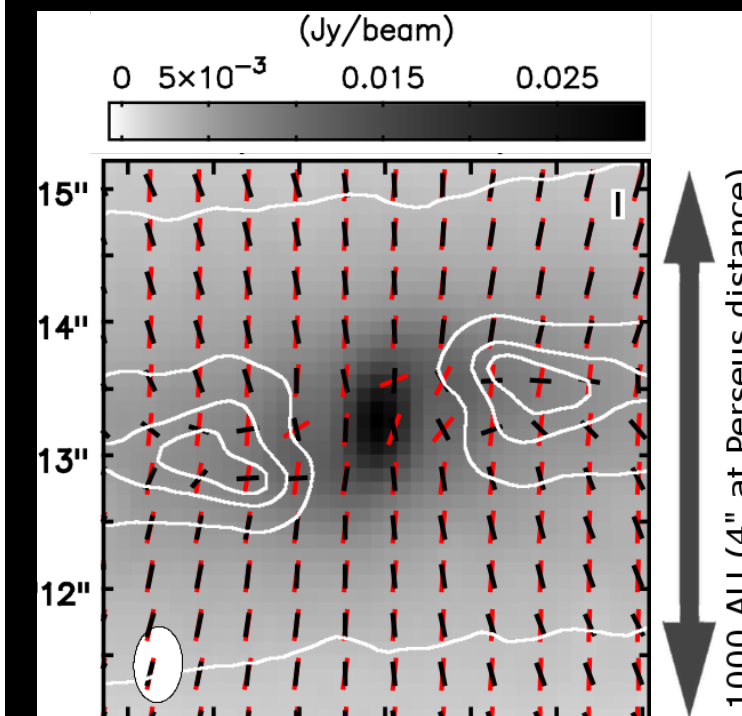

233 GHz
Under embargo - watch out for upcoming publication
J2000 Declination
J2000 Right Ascension
21''
18''
15''
12''
09''
06''
03''
7°34'00''
19h37m01s.6
01s.2
00s.8
00s.4
80
60
40
20
0
-20
-40
-60
-80
(deg)


Outflow cavities
Equatorial plane
Av<1
Av>50
90° (+/-5)
Under embargo - watch out for upcoming publication

Frequency of dust continuum emission: important ?



Physics of grain alignment:
Radiative torques
vs
perfect (density)



Optical depth is devil !

See talk by V. Valdivia

Beyond ALMA .... some advertisement !

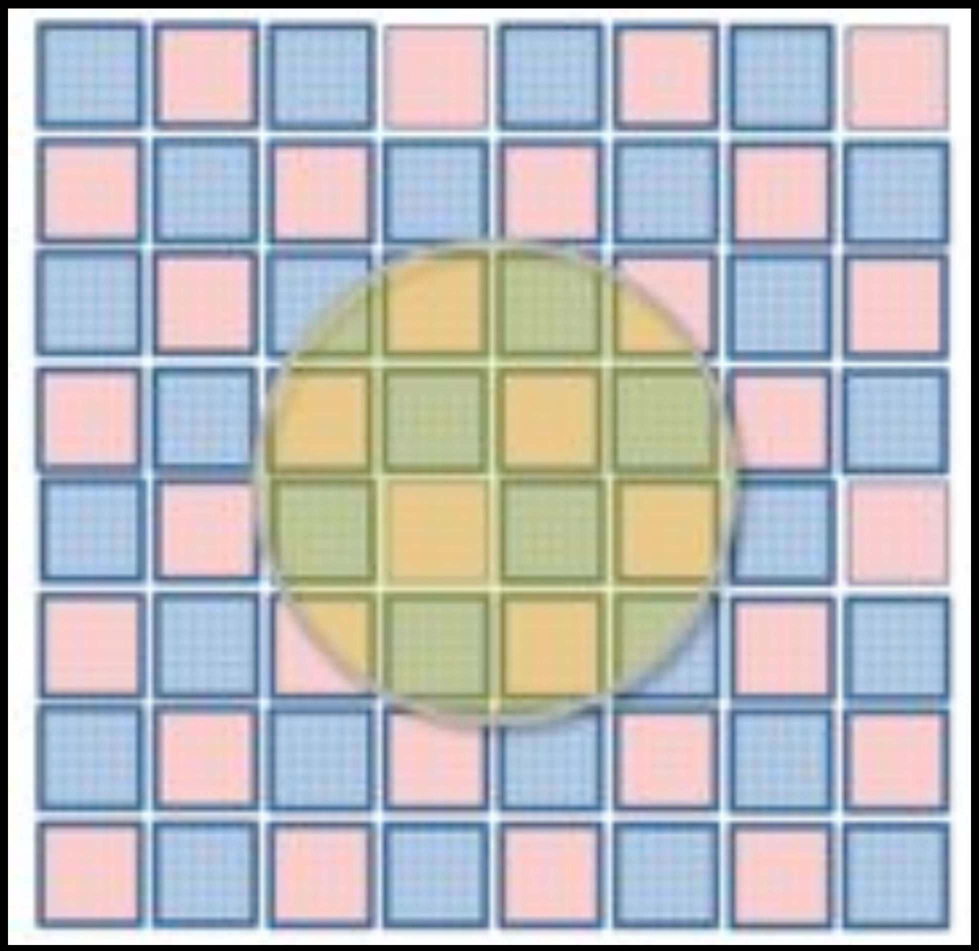
Three BANDS [100 200 350 μm]

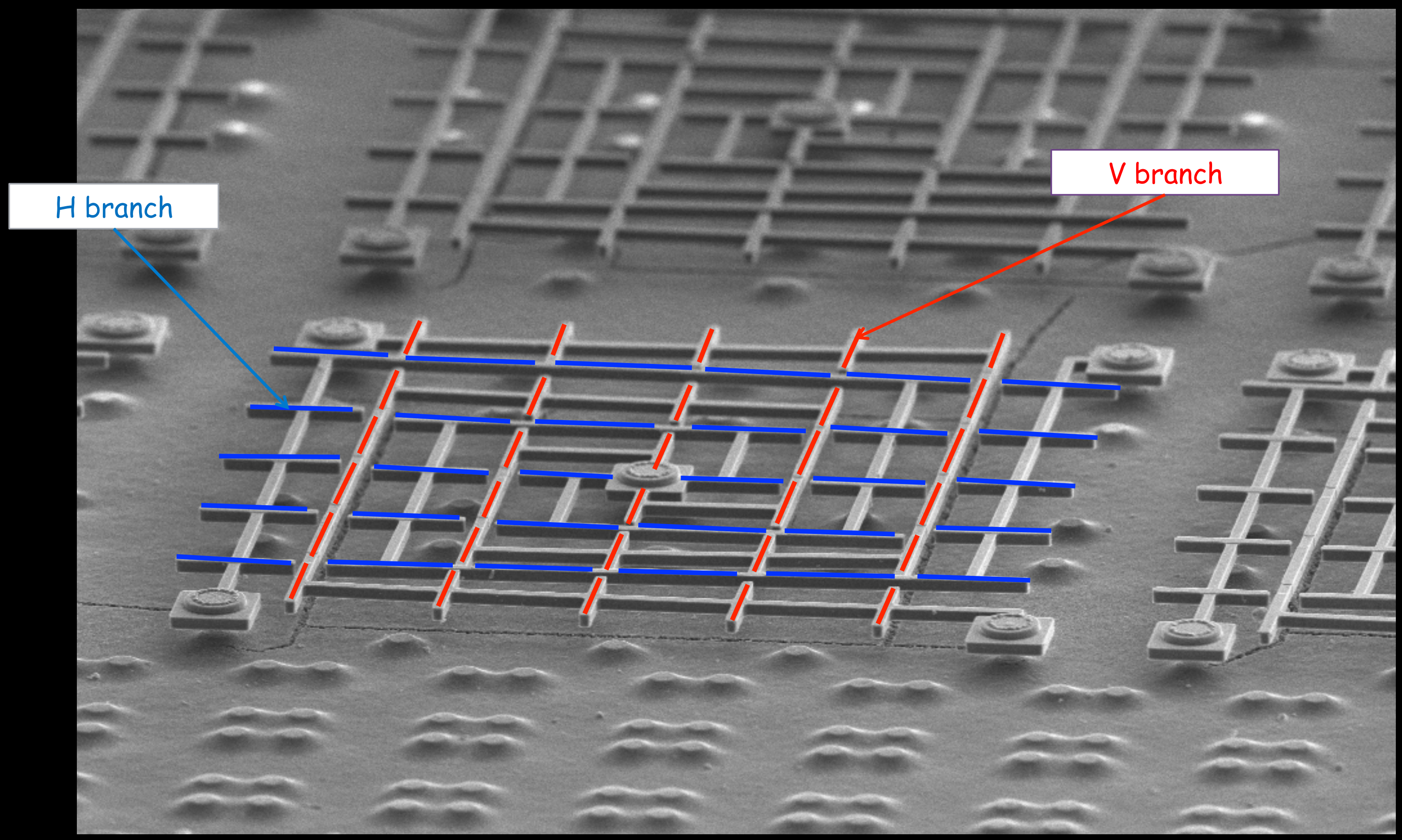
SAFARI-POL

SPICA

The three spectral bands cover the same 2,6' x 2,6' FoV simultaneously, **on the same Focal Plane Assembly**

Stokes (I,Q,U) obtained simultaneously





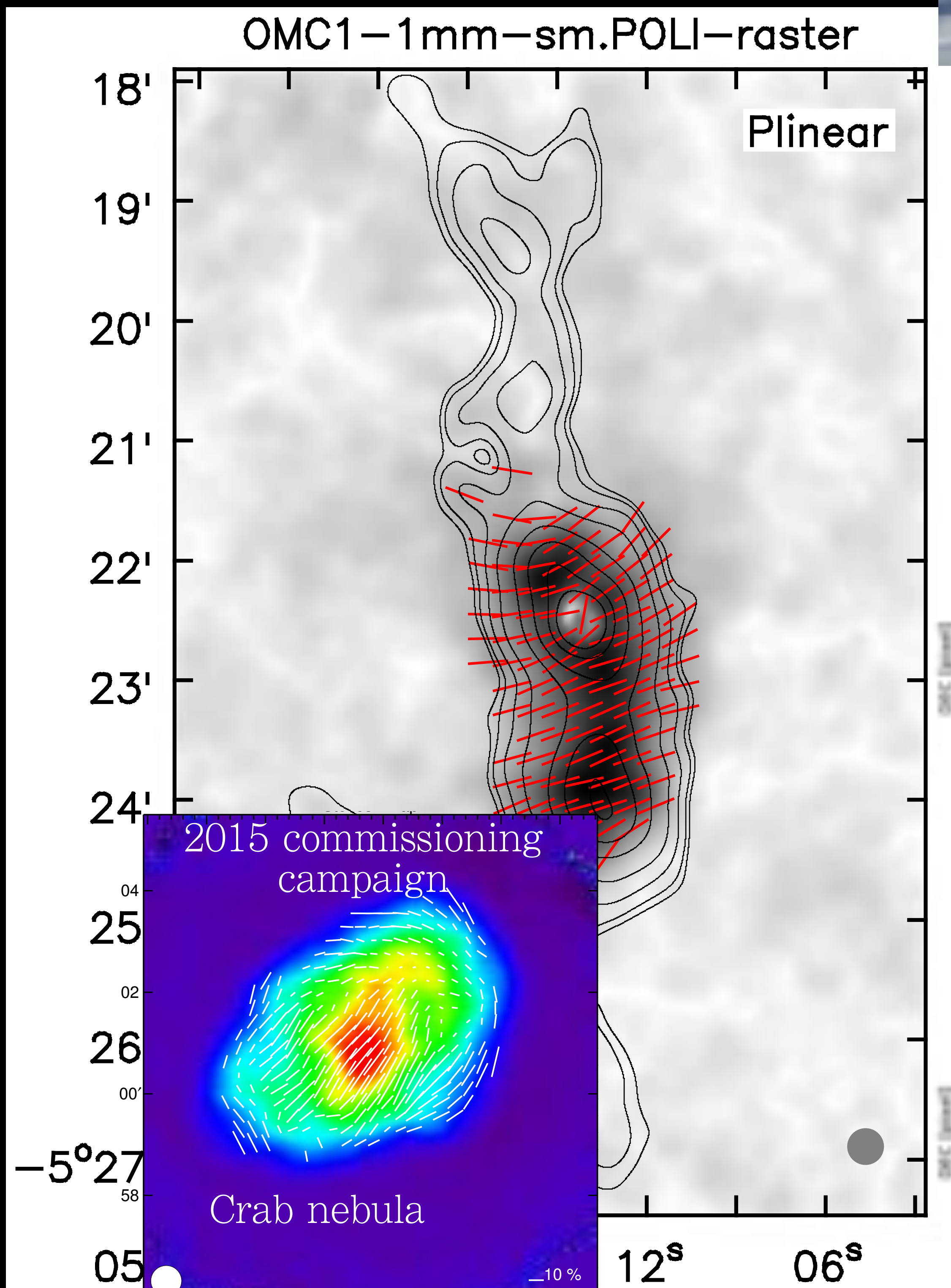
Required sensitivity: 3E-18 W/√Hz by polarisation / pixel

Goal : 1,5E-18 W/√Hz

Technology will be adapted for a ground based instrument (ATLAST?)

NIKA2 POL

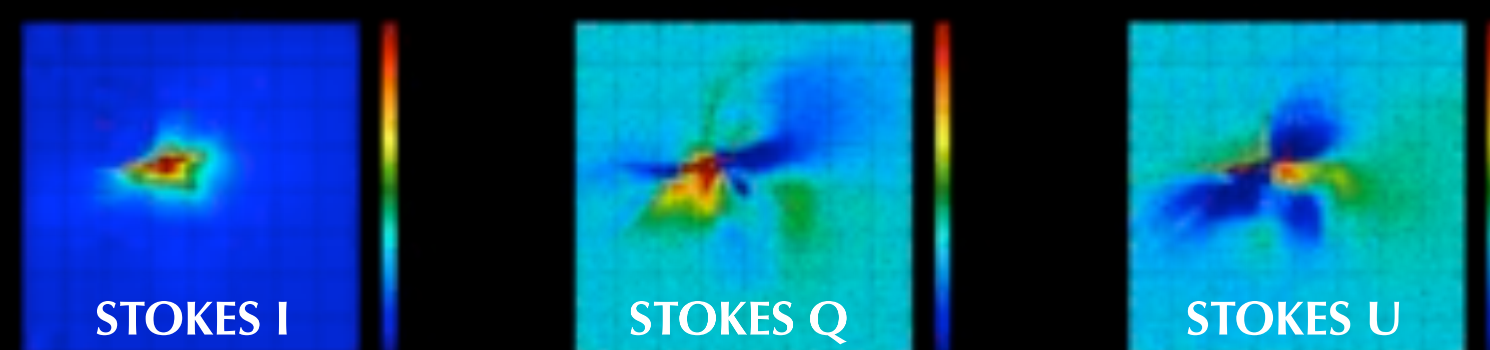
Orion with the NIKA prototype:
Ritacco+NIKA collaboration (2016)



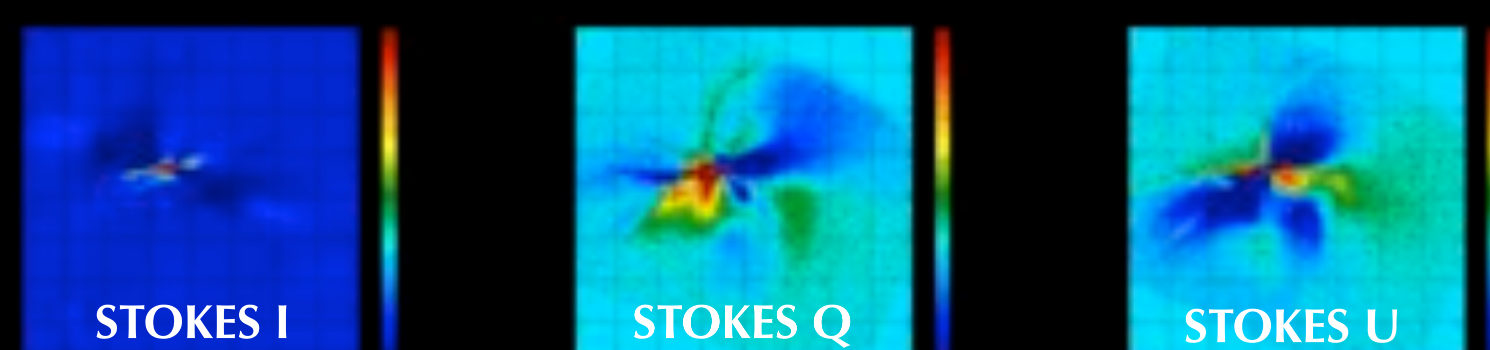
Winter 2017: commissioning of NIKA2pol

simulations of synthetic sky to characterize the leakages

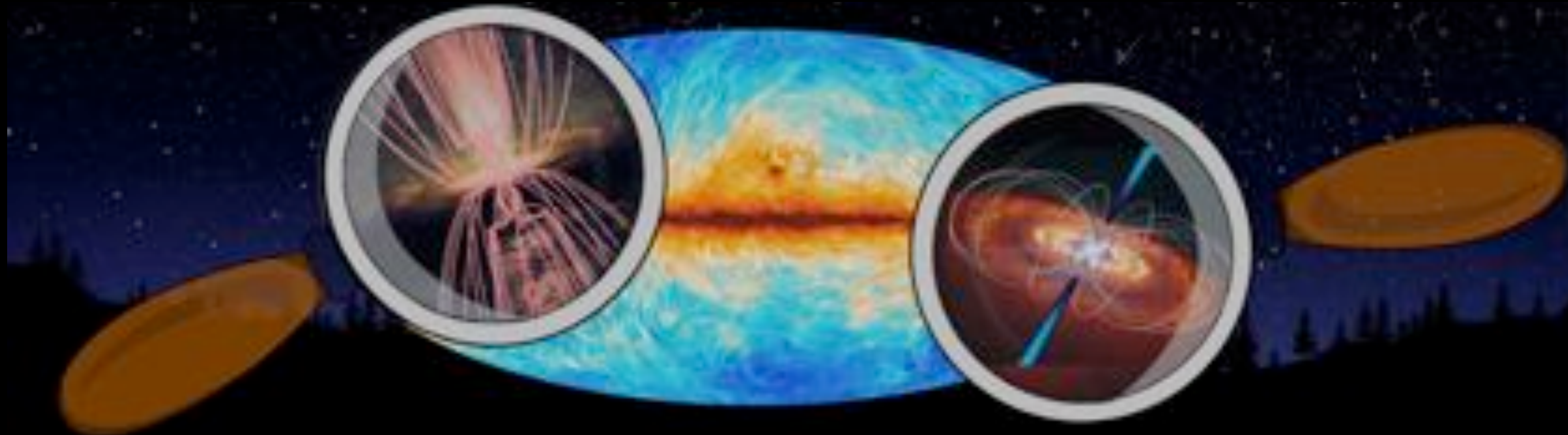
INPUT SKY



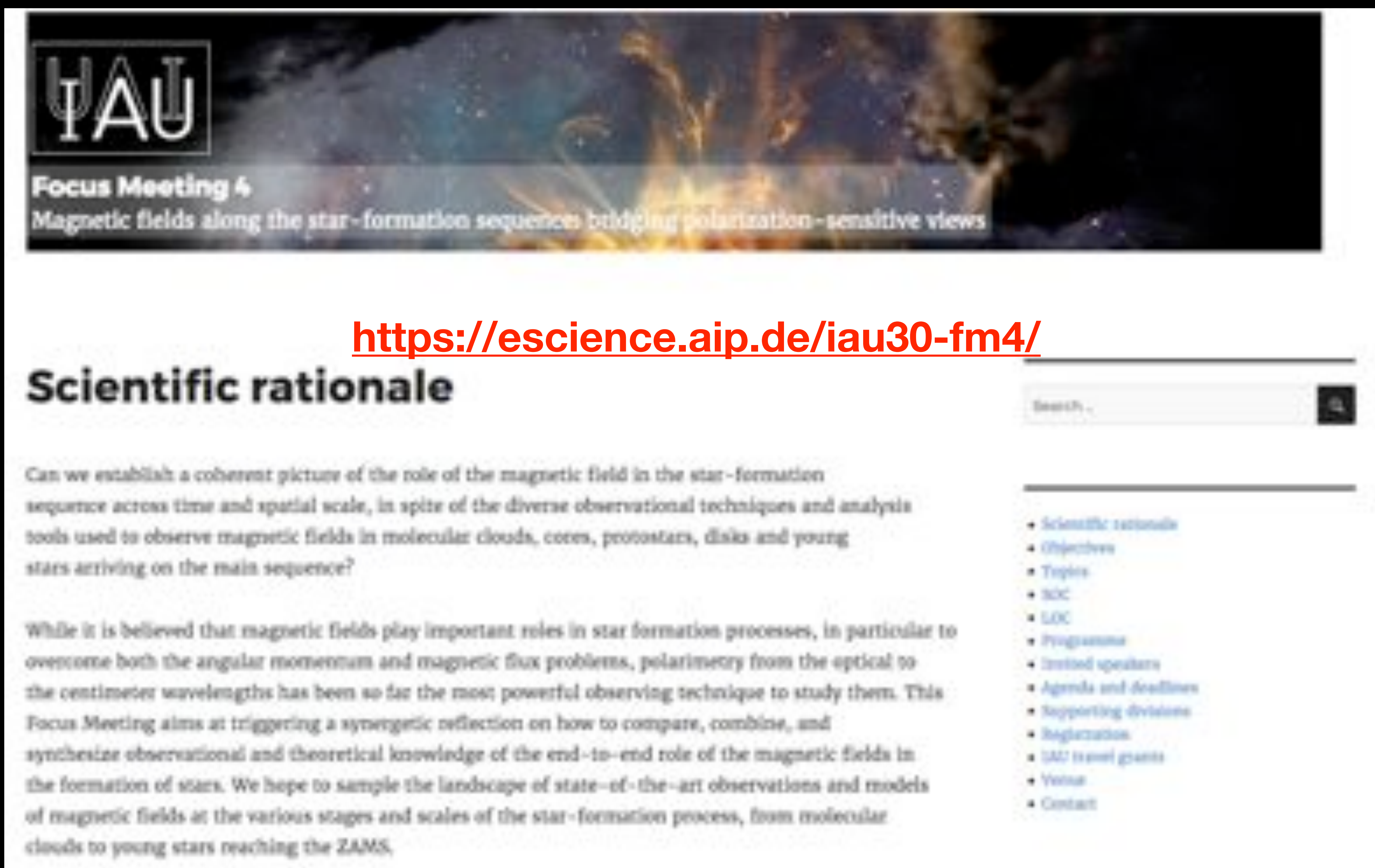
OUTPUT NIKA2 MAPS



Magnetic fields along the star-formation sequence: bridging polarization-sensitive views



Focus Meeting 4 @ 30th IAU General Assembly in Vienna, on August 30-31 2018



https://escience.aip.de/iau30-fm4/