Herschel PACS/SPIRE map of Aquila (Gould Belt survey)

Vera Könyves

IAS/Orsay – SAp, CEA/Saclay, France

Ph. André, A. Men'shchikov, N. Schneider, S. Bontemps, D. Arzoumanian, N. Peretto, P. Didelon, P. Palmeirim, F. Motte, A. Maury, and the SPIRE SAG3 cons.

From interstellar filaments to prestellar cores/protostars

Selected results of the Herschel Gould Belt survey and map-making issues

Map-making Workshop, ESAC, Jan., 2013.

OUTLINE OF THE TALK

- Introduction
- The Herschel Gould Belt survey
  - Aquila
  - Orion B
  - IC5146
  - Taurus
  - A coherent star formation scenario

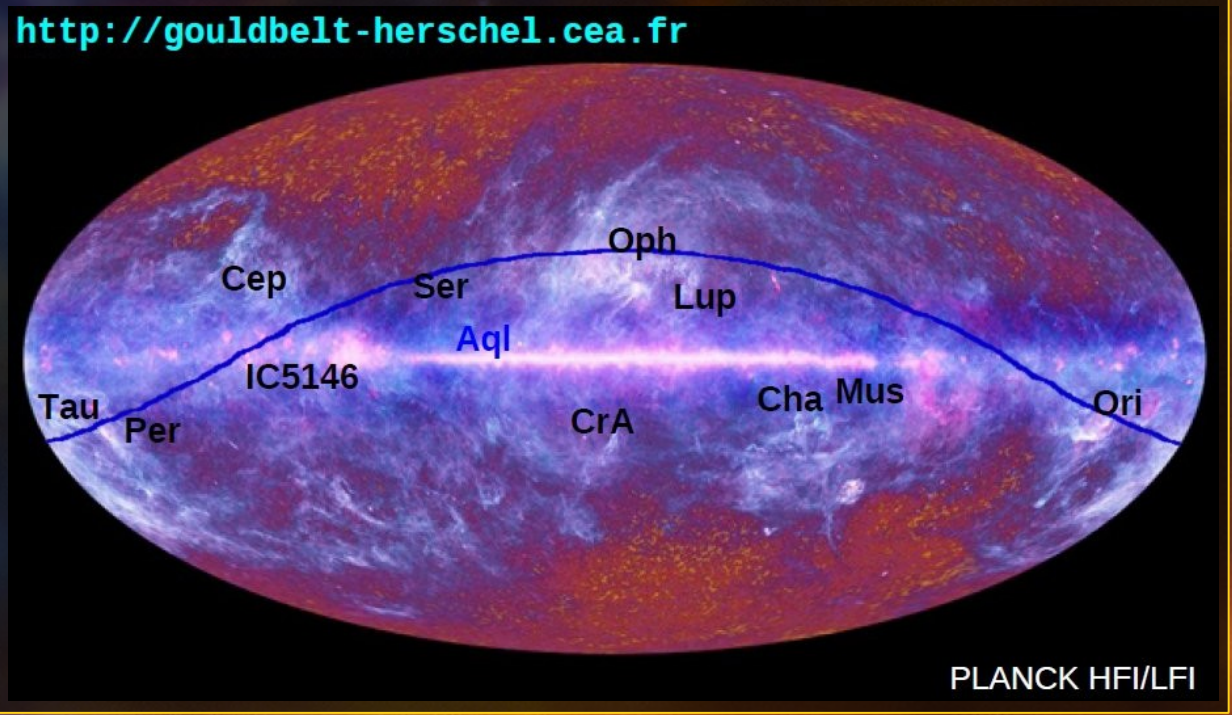
HERSCHEL Gould Belt survey (HGBS)

***Herschel* Gould Belt Key Program** (André et al. 2010)

- wide-field submm continuum survey with SPIRE/PACS
- 461 hrs of GT (SPIRE+PACS Consortia)
- in nearby star-forming cloud complexes ($d \leq 500$ pc) of the Gould Belt
- probes **the origin of the stellar masses**

Scientific motivations, goals:

- ⇨ What is the link between the pre-stellar CMF and the stellar IMF
- ⇨ To provide a complete census of prestellar cores and protostars
- ⇨ To unravel the core formation mechanisms



INTRODUCTION

THE *HERSCHEL* PROMISE

Herschel is ideally suited for **taking a census of resolved cores and protostars** in nearby molecular complexes ($d \leq 0.5$ kpc):

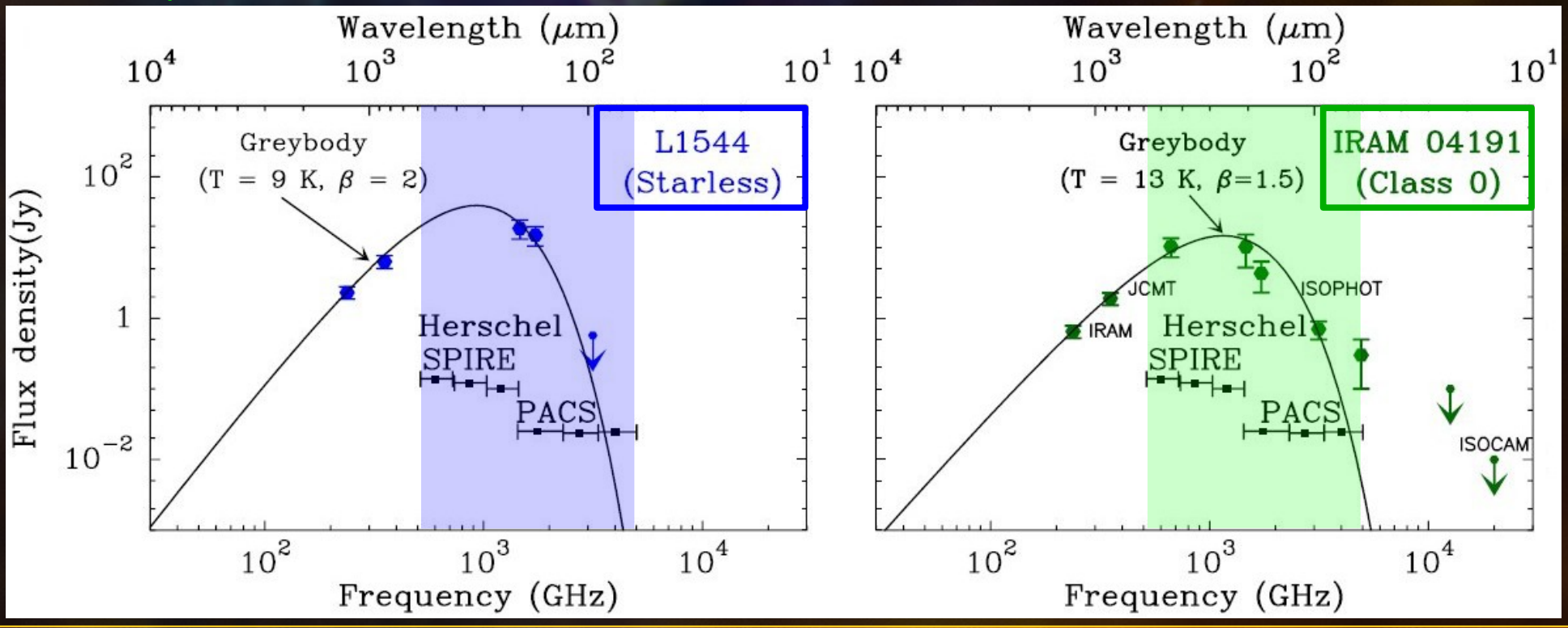
- in the 0.01–0.1 pc size range
- down to $M_{proto} \sim 0.01$–$0.1\ M_{\odot}$

Herschel bands are **essential for luminosity and temperature determinations**

Spectral energy distributions (SEDs)

Ward-Thompson et al. 2002

André at al. 1999



HGBS: SOME „TECHNICAL” DETAILS

OBSERVATIONS, DATA REDUCTION

Observations of HGB survey fields

- **With SPIRE/PACS parallel-mode of Herschel.**
- Large scan maps, taken with 60"sec^{-1} scanning speed
- Several subfields observed in **PACS-only mode** (100/160 μm, 20"sec^{-1} scan. speed.

Data reduction

SPIRE 250/350/500 μm (reduced by N. Schneider):

- Using HIPE for data processing; map making with **HIPE 'naive' method**.

PACS 70/160 μm (reduced by V. Könyves):

- HIPE for data processing; map making with **Scanamorphos** (Roussel 2012, subm.).

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⇨ **destriper**

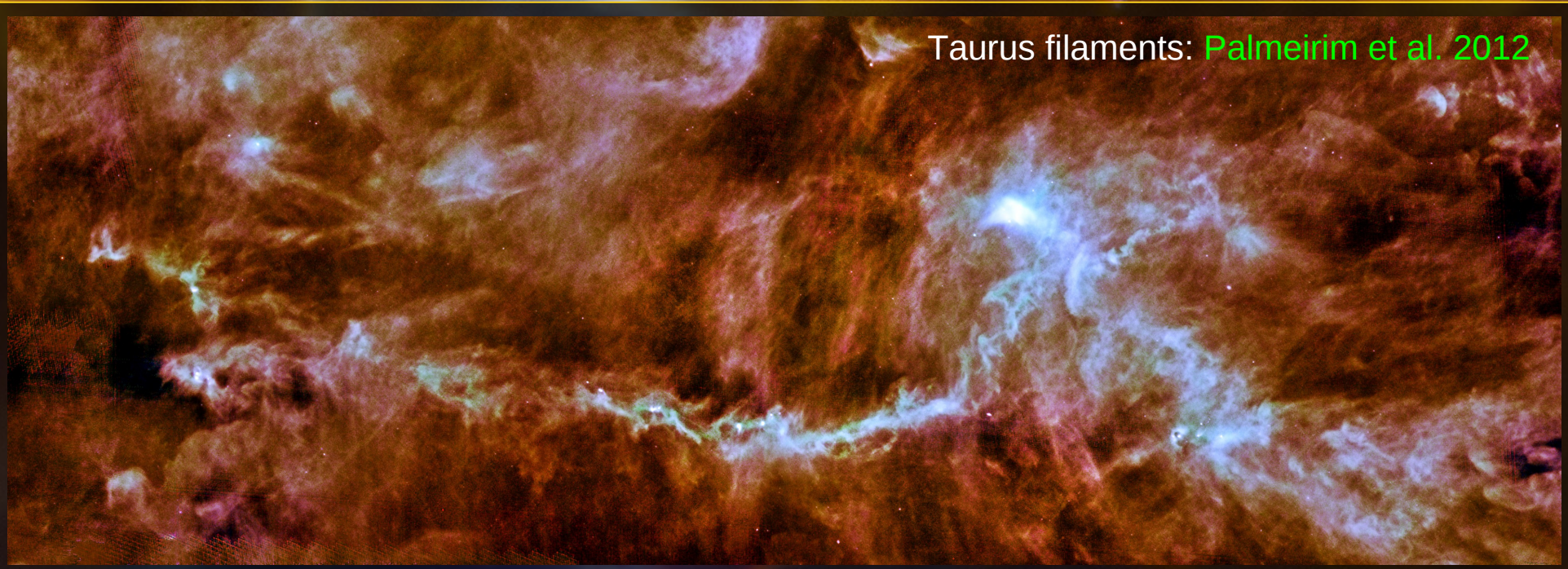
PACS 70/160 μm (reduced by V. Könyves):

- HIPE for data processing; map making with **Scanamorphos** (Roussel 2012, subm.).

(started with photProject and MADmaps ⇨ Scanamorphos v19/v20)

Herschel Gould Belt Survey Archives: *http://gouldbelt-herschel.cea.fr/archives*

SELECTED DATA ANALYSIS STEPS WE START WITH...



Starless cores, YSO studies

Aquila, Polaris, Lup., Per., Cham.:
André et al. 2010, Könyves et al. 2010, Bontemps et al. 2010, Men'shchikov et al. 2010, Ward-Thompson et al. 2010, Rygl et al. 2013, Pezzuto et al. 2012, Winston 2012

Filamentary studies

Aquila, Polaris, IC5146, Pipe, Tau.:
André et al. 2010, Men'shchikov et al. 2010, Arzoumanian et al. 2011, Peretto et al. 2012, Palmeirim et al. 2012

For data analysis we leave HIPE:

Used tools, for e.g.: `getsources` (Men'shchikov et al. 2012), IDL, GILDAS, DisPerSE (Sousbie 2011), etc...

HGBS: SOME „TECHNICAL" DETAILS

SOURCE DETECTION, IDENTIFICATION, PHYSICAL PROPERTIES

Source extraction

Compact sources were extracted from the SPIRE/PACS images **using `getsources`**, a multi-scale, multi-wavelength source finding algorithm (Men'shchikov et al. 2012).

Within `getsources`, we use **aperture correction** ("new" Encircled Energy Fractions).

Dust temperature (T_d) and column density (Σ) maps

- **Weighted SEDs** for all map pixels from the 5 SPIRE/PACS wavelengths.
- SEDs **fitted by a greybody**, $I_\nu = B_\nu(T_d)(1 - e^{-\tau_\nu})$

  I_ν: observed surface brightness at ν; $\tau_\nu = \kappa_\nu \Sigma$: dust optical dept; κ_ν: dust opacity per unit (dust+gas) mass, $\beta = 2$ (e.g. Hildebrand 1983).
- **T_d and Σ were derived from the fit** to the 5 *Herschel* data points for all pixels.

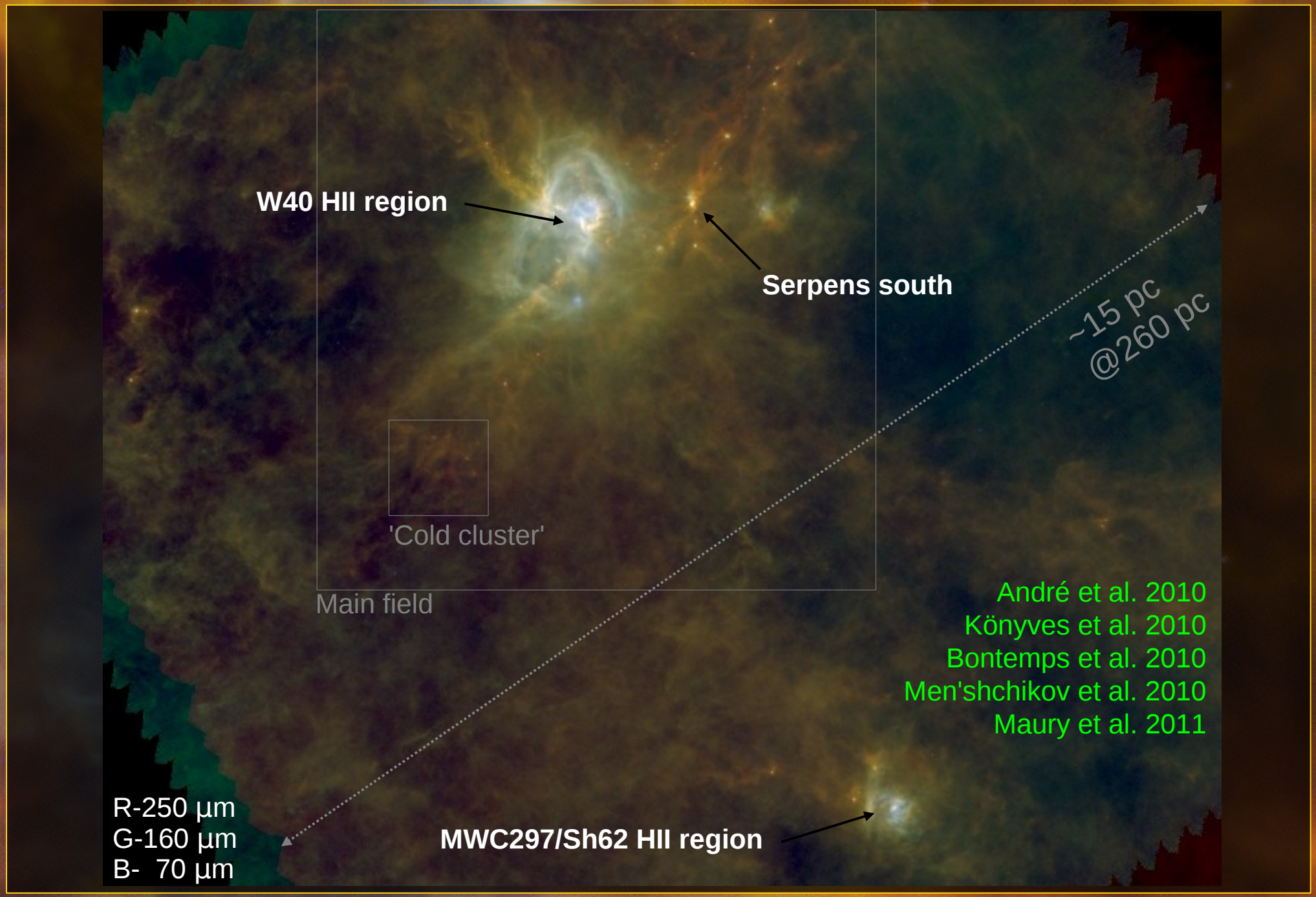
AQUILA

Highlights:

- Prestellar cores
- CMF
- Lifetimes
- Core formation “threshold”, PDF

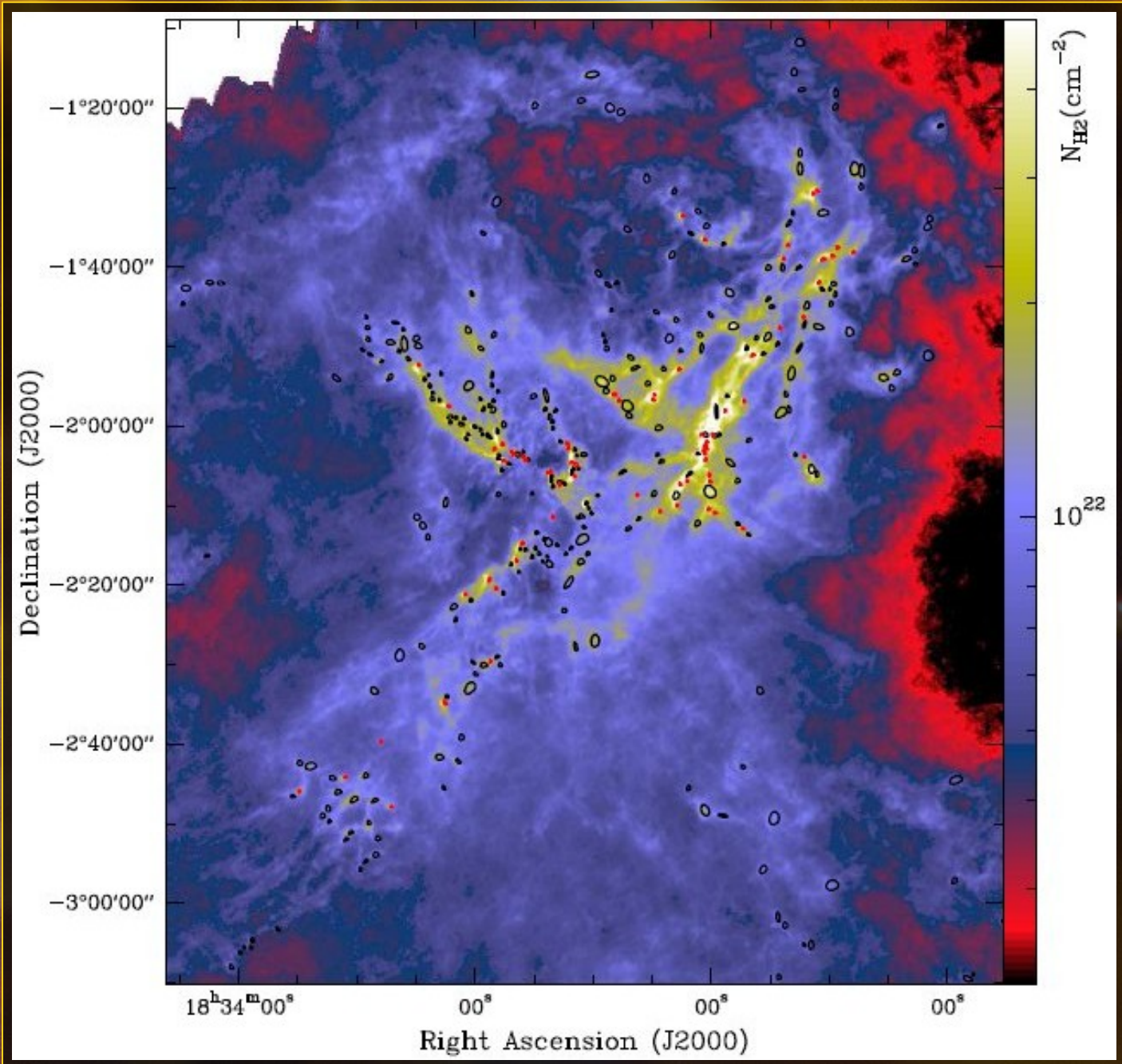
HGBS: THE AQUILA FIELD

RGB COMPOSITE



HGBS: AQUILA

SOURCES IN THE AQUILA MAIN PART



In Aquila -entire- field (~10 deg^2)**:**

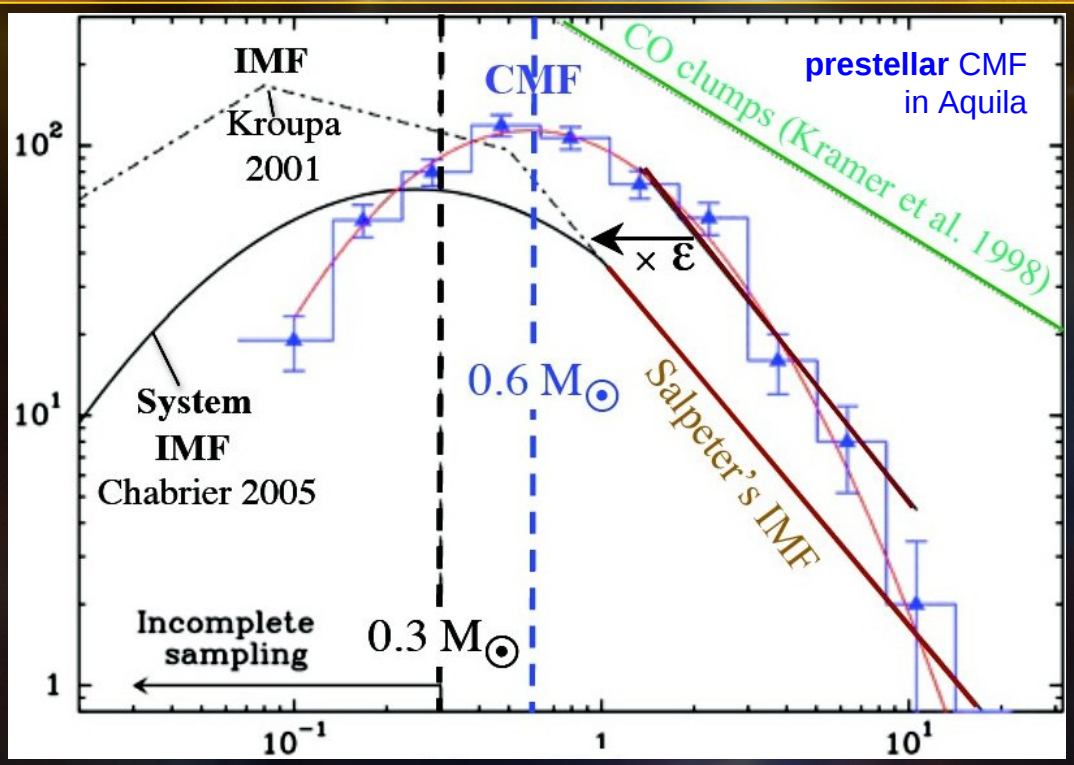
~ 500 starless cores (O)
~ 350 prestellar cores (60 %)
~ 200 protostars (O)
(~ 35 class 0)

Background: column density map (Planck offsets added)

André et al. 2010
Könyves et al. 2010
Bontemps et al. 2010
Maury et al. 2011

HGBS: AQUILA

CORE MASS FUNCTION (CMF)



André et al. 2010
Könyves et al. 2010

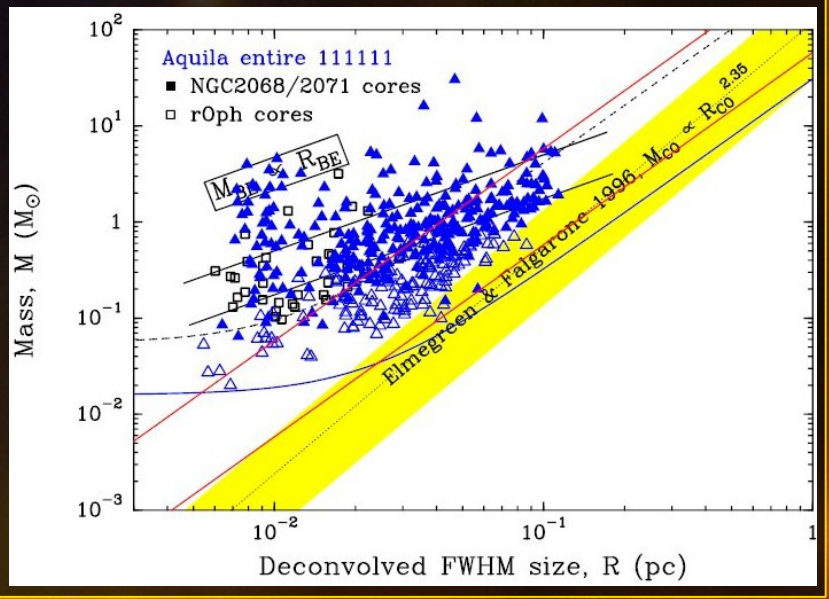
Mass vs. size diagram comparing the locations of ~300 candidate prestellar cores (▲), and the rest starless cores (△), to both models of critical isothermal BE spheres (at T=7K, T=20K) and observed prestellar cores (Motte et al. 1998, 2001).

Differential mass function of >400 starless cores in the entire Aquila field. ~60% of them is bound, a.k.a., prestellar cores.

Lognormal fit peaks at ~ 0.6 $M_\odot$

fitted power-law: $dN/d\log M \propto M^{-1.5\pm0.2}$

The fitted properties are robust



In the end the whole survey will be used to fully characterize the nature of the CMF-IMF link

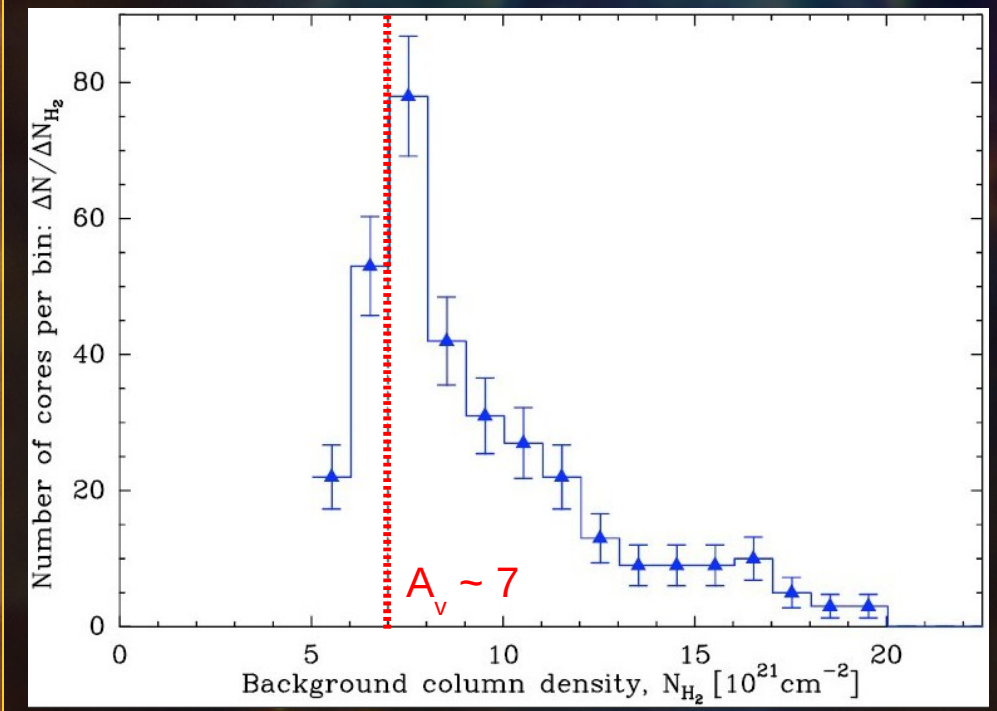
HGBS: AQUILA

STAR FORMATION THRESHOLD?

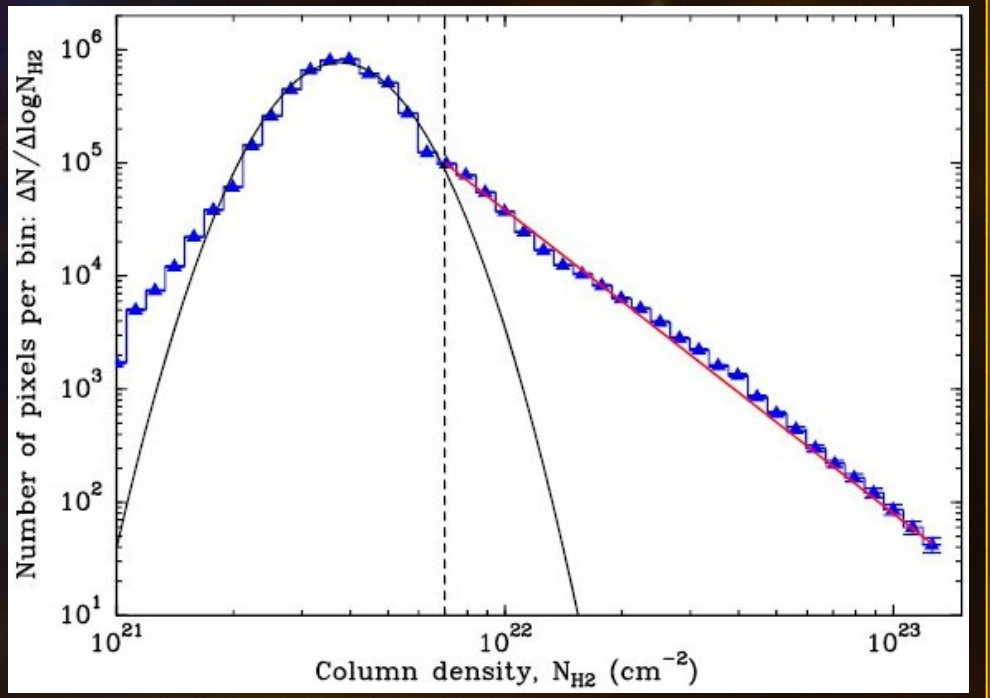
Strong evidence of a **column density "threshold" for the formation of prestellar cores** in Aquila

In Aquila, ~ 90% of the Herschel prestellar cores are found above $A_v \sim 7 \Leftrightarrow \Sigma \sim 150\ M_\odot\ pc^{-2}$

Distribution of bg cloud column densities 'behind' the prestellar cores.



PDF of column densities in Aquila



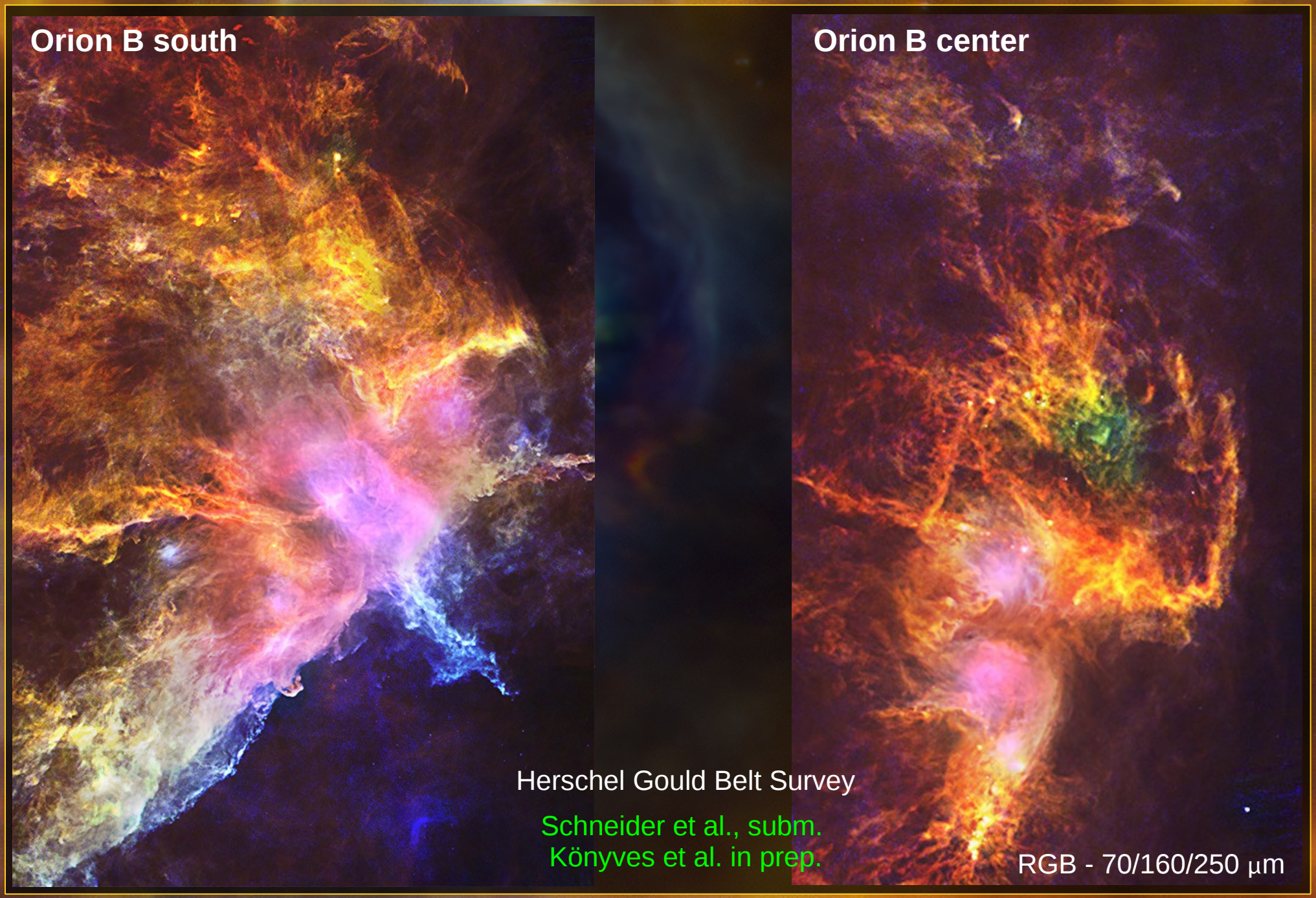
André et al. IAU270
Könyves et al. in prep

ORION B

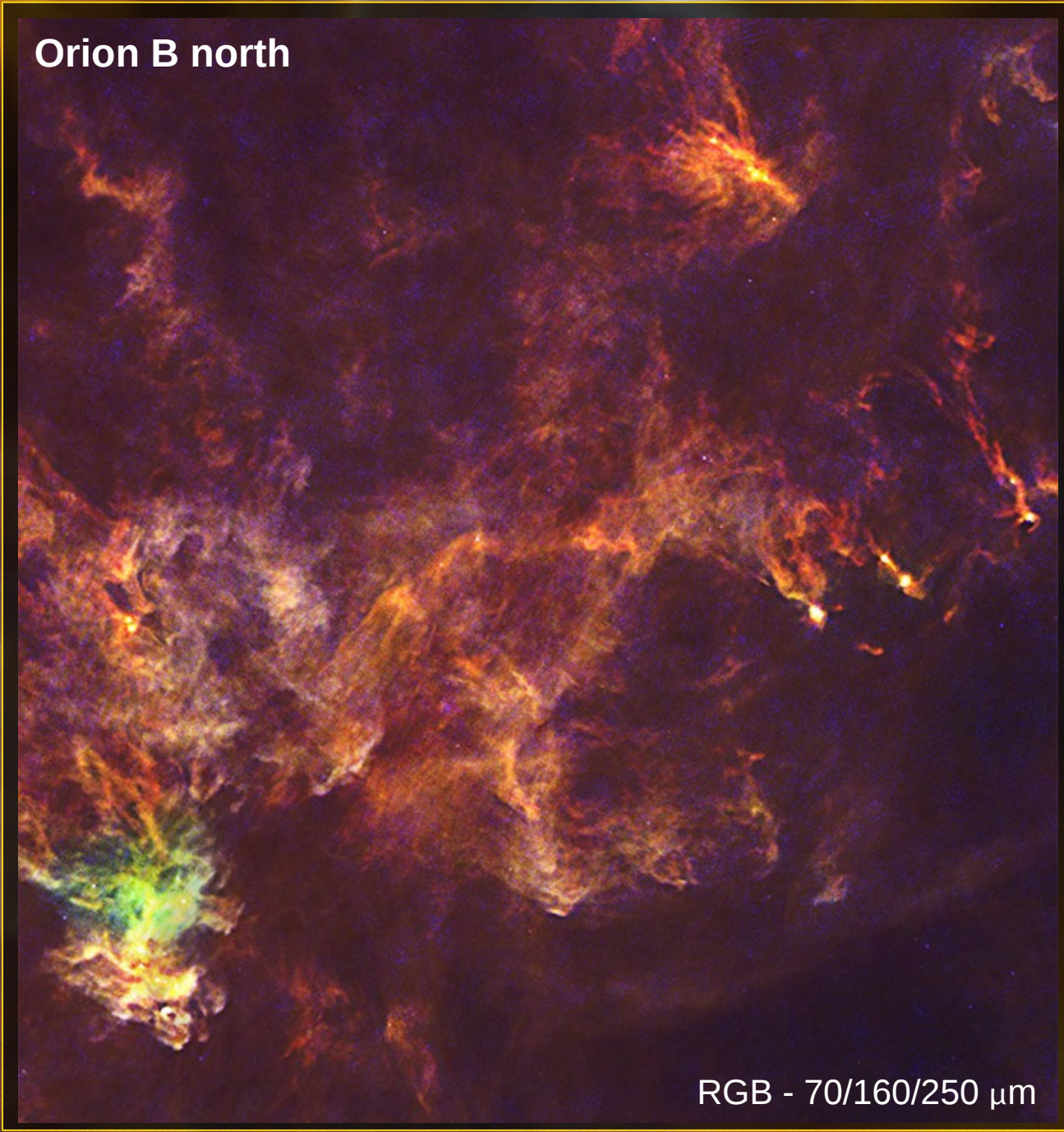
Highlights:

- Cores, potostars
- Core formation “threshold”
- PDFs

ORION B


Orion B south
Orion B center
Herschel Gould Belt Survey
Schneider et al., subm.
Könyves et al. in prep.
RGB - 70/160/250 μm

ORION B

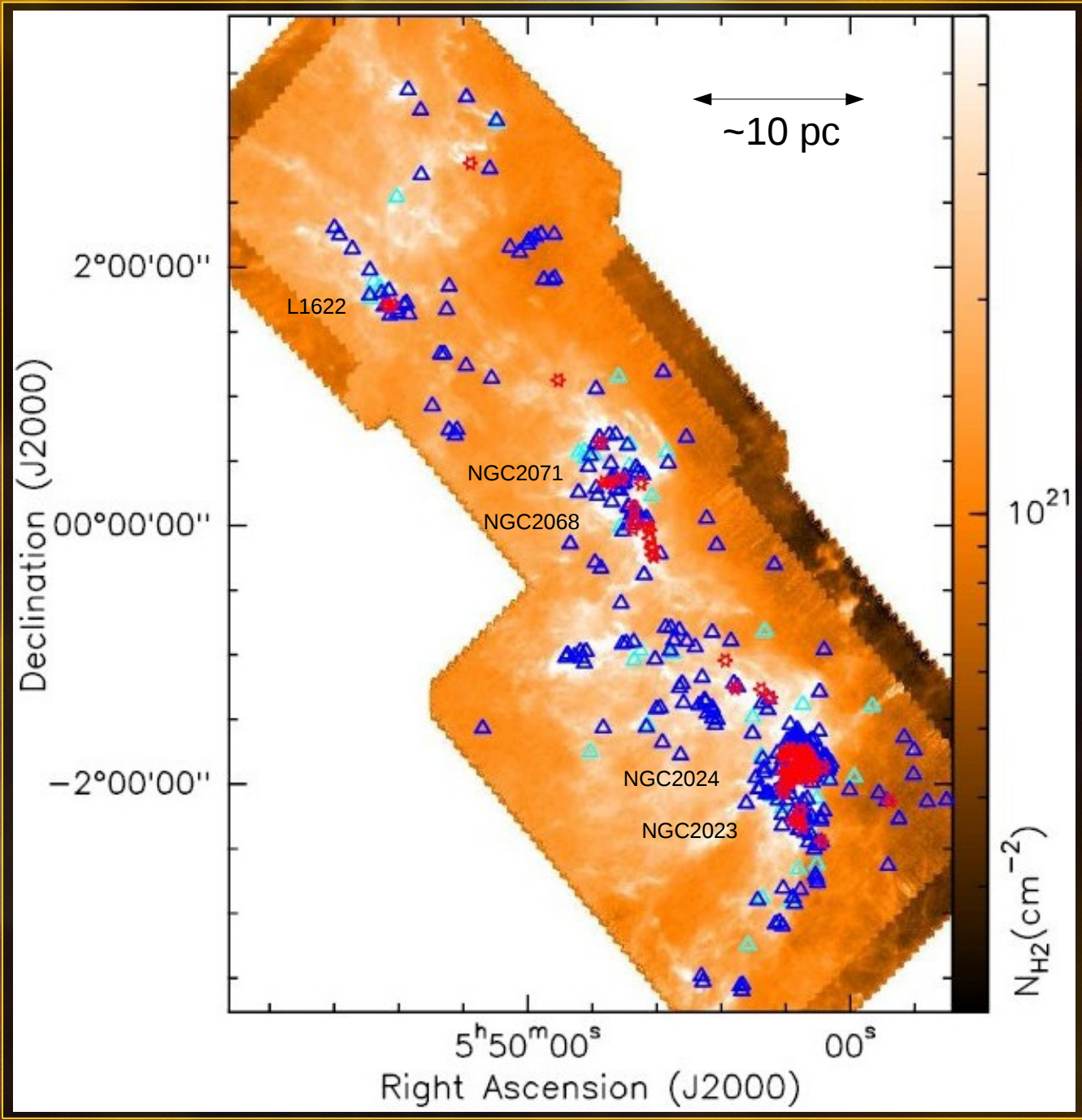


Herschel Gould Belt Survey

Könyves et al. in prep.
Schneider et al. in prep.

ORION B

SOURCES IN ORION B



In Orion B, entire field (~15 deg^2):

~ 400 starless
~ 350 prestellar (> 80 %, △)
~ 60 protostars (✡)
(~ 20 class 0)

Preliminary numbers!

Background: column density map (Planck offsets added)

Könyves et al. in prep.

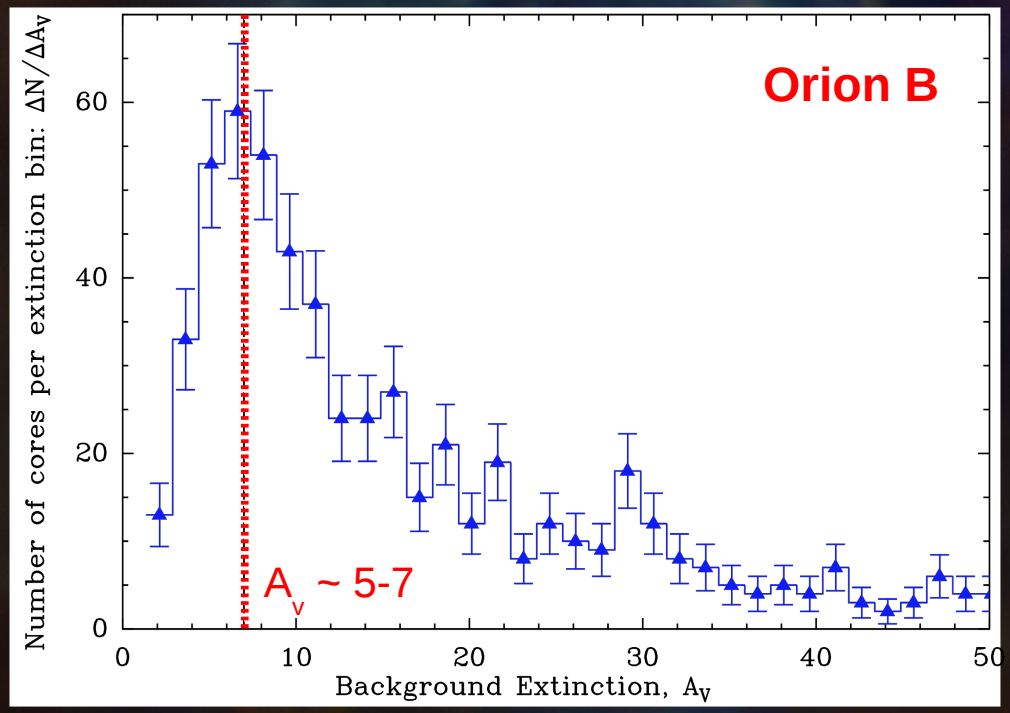
ORION B

STAR FORMATION THRESHOLD?

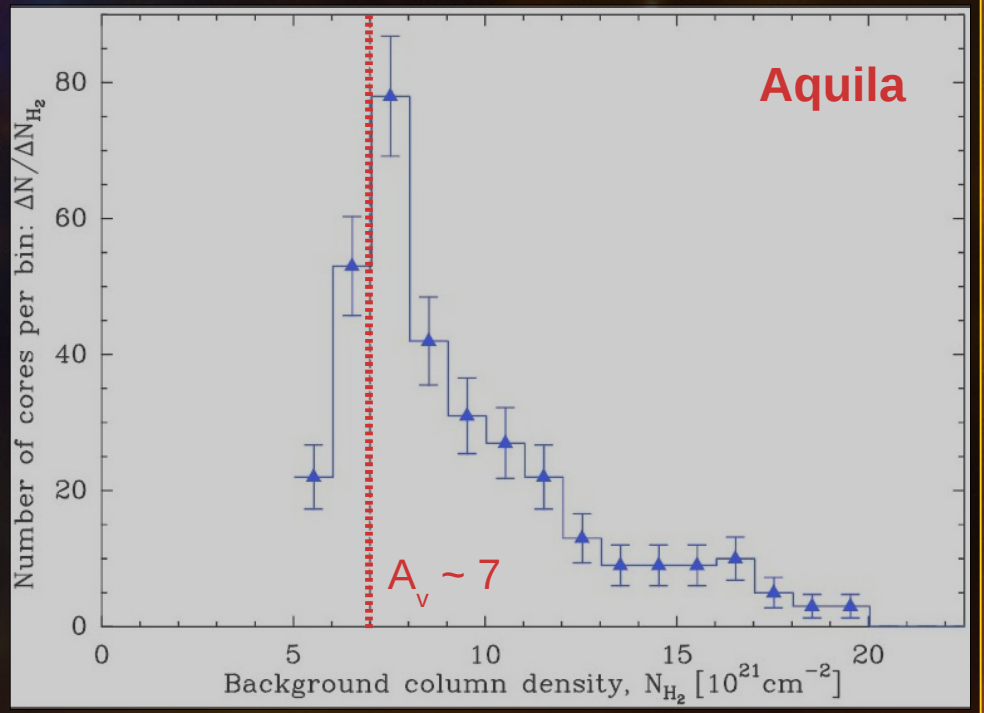
Strong evidence of a **background extinction / column density "threshold" for the formation of prestellar cores** in Orion B

In Orion B, > 75% of the Herschel prestellar cores are found above $A_v \sim 7 \Leftrightarrow \Sigma \sim 150\ M_\odot\ pc^{-2}$

Distribution of background extinction 'behind' the prestellar cores.



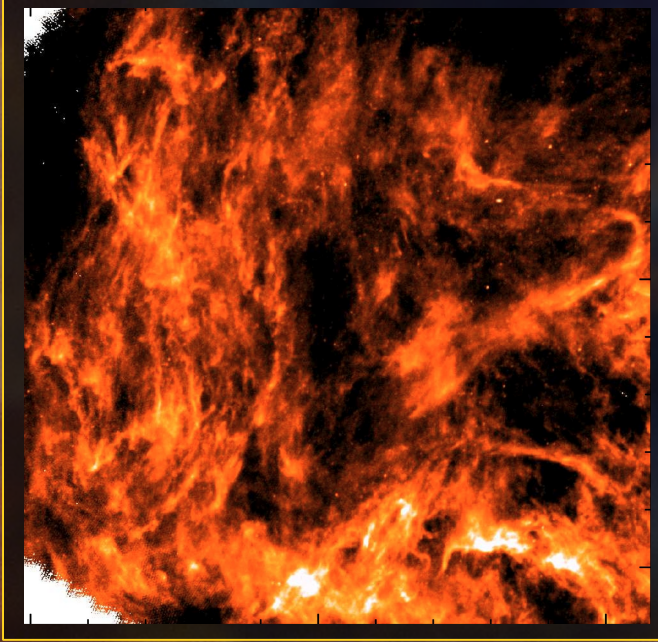
Könyves et al. in prep.

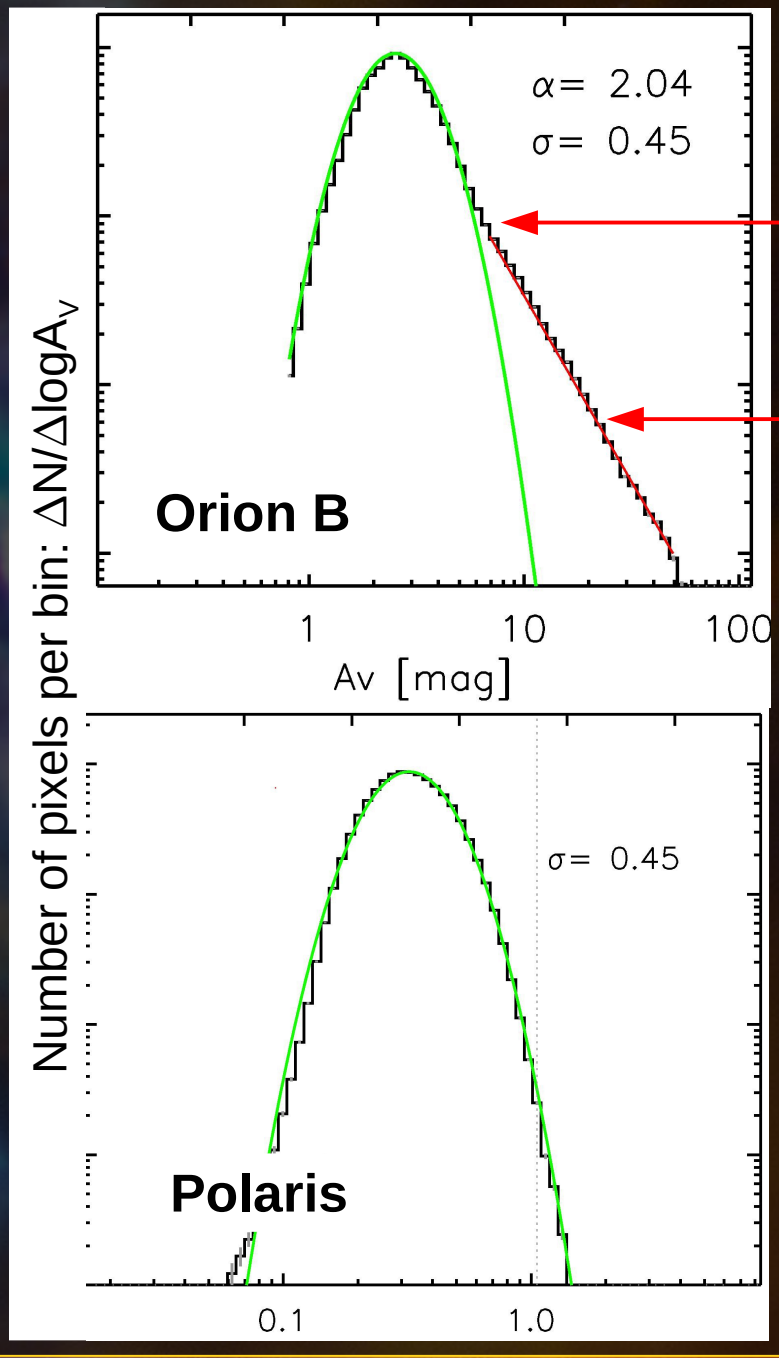


André et al. IAU270
Könyves et al. in prep

ORION B

COLUMN DENSITY PDFs





deviation at A_v ~ 5-7

- power-law tail
- gravity?

- log-normal PDF
- turbulence?

Schneider et al., subm.

IC5146

Highlights:

- Filaments with uniform inner widths
- Connection of cores with filaments

„Filamentary" background and definitions

Interstellar filamentary structures:

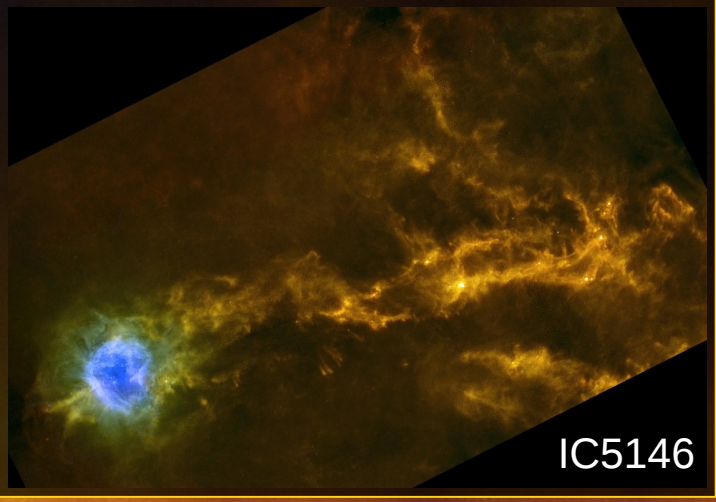
- Everything which is elongated (aspect ratio > 2) in column density maps
- exhibits a central ridge
- no characteristic mass, nor size

Hydrostatic equilibrium solutions of isothermal infinite cylinders are given by Ostriker (1964):

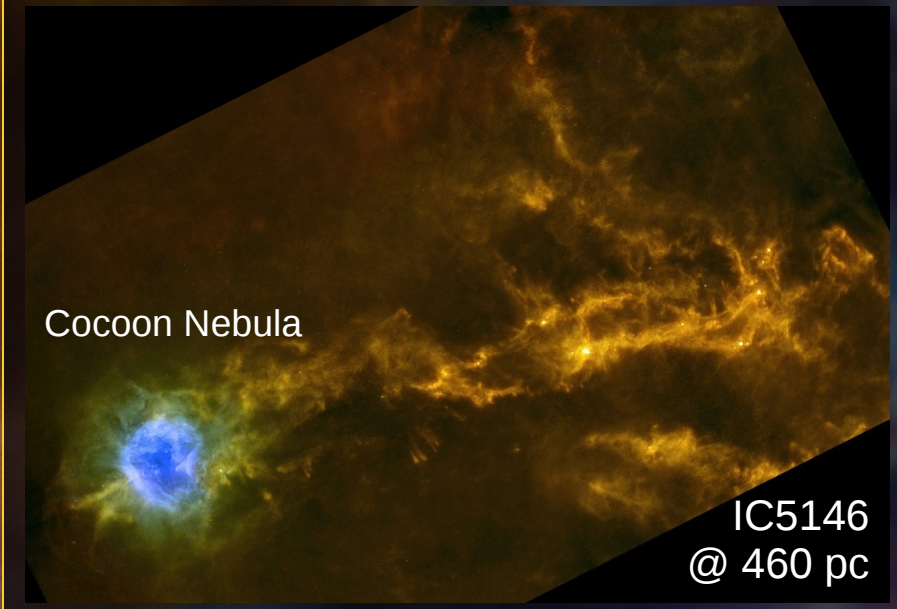
- density profile $\rho \propto r^{-4}$, and
- critical mass per unit length $M_{line,crit} = 2c_s^2/G$

Criterium for fragmenting filaments (Inutsuka & Miyama1997):

- If $M_{line} > M_{line,crit}$, filaments fragment ⇨ **supercritical**
- If $M_{line} < M_{line,crit}$, filaments are unbound ⇨ **subcritical**



Filament width as measured with Herschel

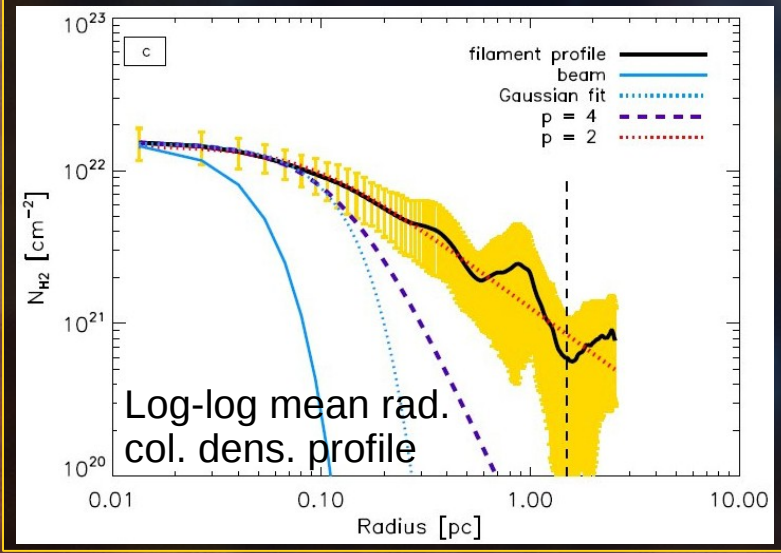


Skeleton of the filamentary network **traced with DisPerSE** algorithm (Sousbie 2011)

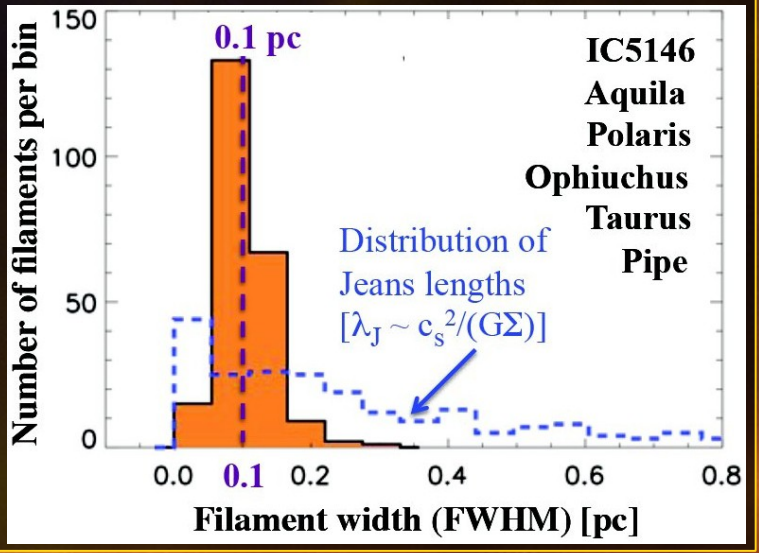
Filament width distribution peaks at **~ 0.1pc** (independent of length or column density)

⇨ sonic scale below which interstellar **turbulence becomes subsonic** (Federrath et al. 2010)

⇨ filaments may form via the dissipation of large-scale turbulence (Padoan et al. 2001)



Arzoumanian et al. (2011)

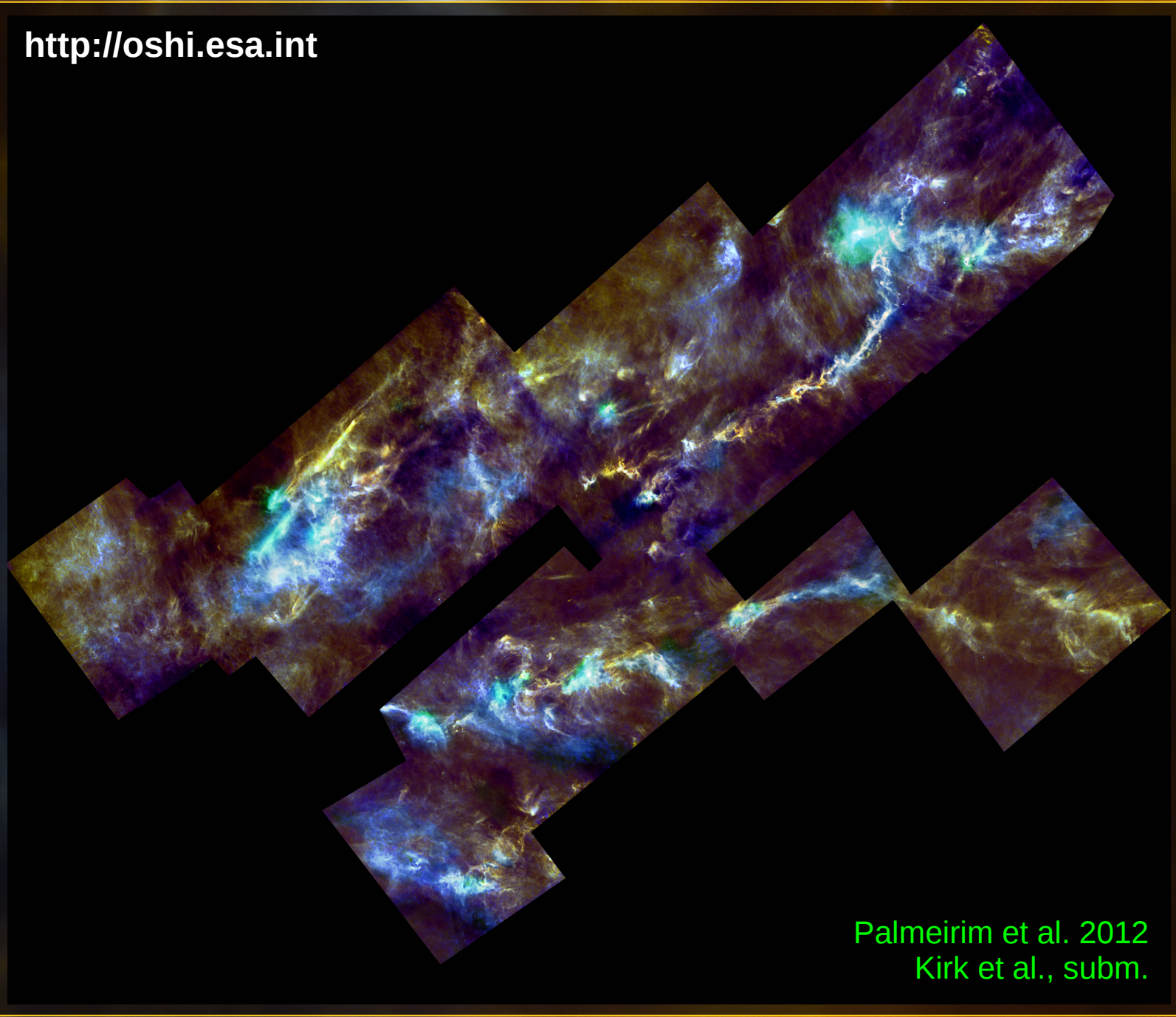


TAURUS

Highlights:

- Filaments and striations

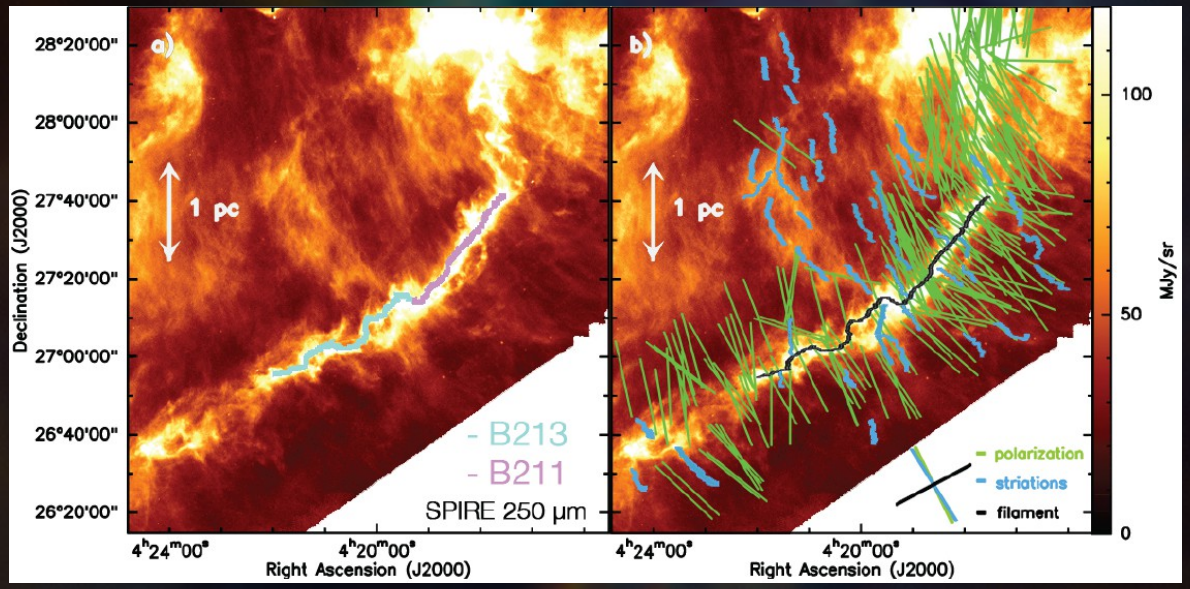
HGBS: TAURUS



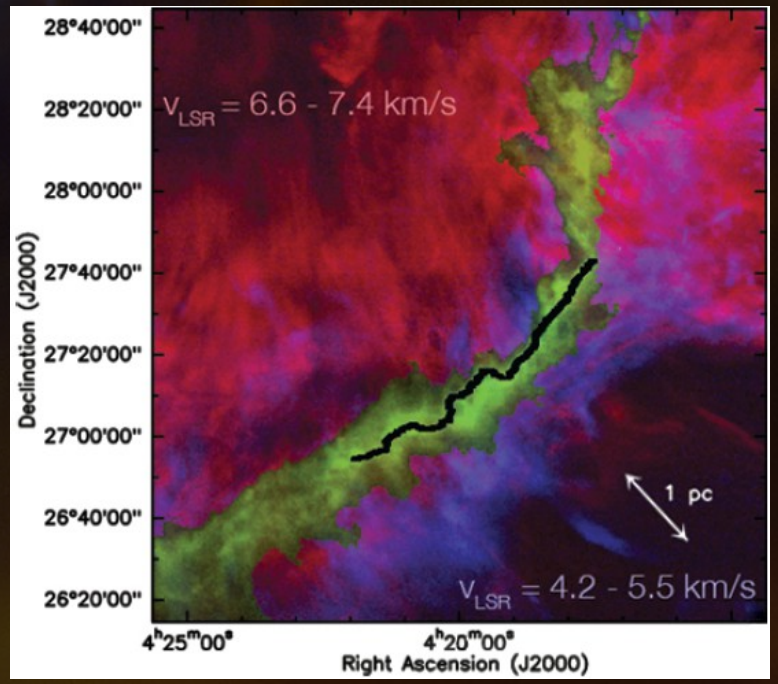
Accretion onto filaments?

Evolution of velocity dispersion with column density (supercritical filaments)

⇨ suggests mass accretion from surrounding material (Arzoumanian et al., subm.; Palmeirim et al. 2013; Palmeirim et al., in prep.)



Red- and blueshifted ^{12}CO(1–0) emission from Goldsmith et al. 2008 (Palmeirim et al., 2012)



Taurus B211/B213 filament

Magnetic field is perpendicular to the main filaments (black) and parallel with the subcritical striations (blue)

Palmeirim et al., 2012

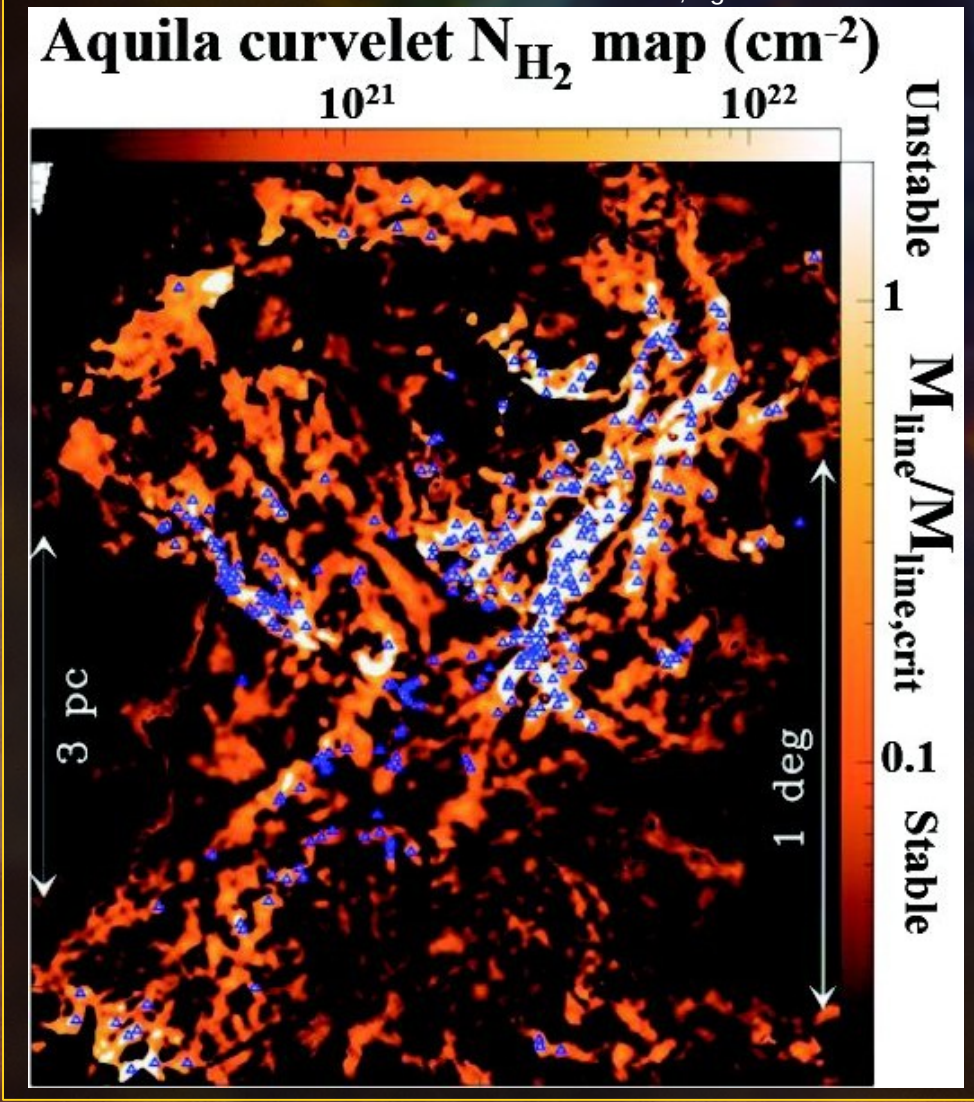
Early results of the Herschel Gould Belt survey:
a coherent star formation scenario

HGBS: SF SCENARIO FROM ORIONB, AQUILA, POLARIS DATA

CORES SITTING IN DENSE FILAMENTS

Prestellar cores are preferentially found within the densest filaments

90% of prestellar cores (△) found at $N_{H2} > 7 \times 10^{21}$ cm^{-2} ⇔ $A_{v,\,bg} > 7$



The gravitational instability of filaments is controlled by the mass per unit length M_{line}

(Ostriker 1964, Inutsuka & Miyama 1997):

- **unstable if $M_{line} > M_{line,\,crit}$**
- unbound if $M_{line} < M_{line,\,crit}$

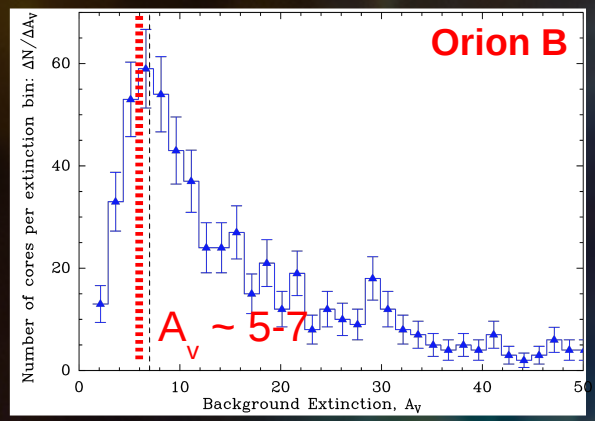
$M_{line,\,crit} = 2c_s^2/G \sim 15\ M_\odot pc^{-1}$, with $c_s \sim 0.2$ km/s at $T \sim 10$K

⇔ $\Sigma_{th} \sim 150\ M_\odot pc^{-2}$

⇔ $A_V \sim 7$, given the filament width of ~ 0.1pc

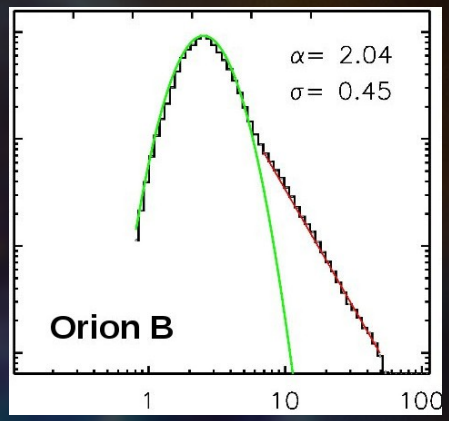
Unstable filaments highlighted in white in the N_{H2} map (André at al. 2010)

HGBS: SF SCENARIO FROM ORIONB, AQUILA, POLARIS DATA



Bg extinction of cores
André et al. 2011
Könyves et al., in prep.

+



N_{H2} PDF
Schneider et al., subm.

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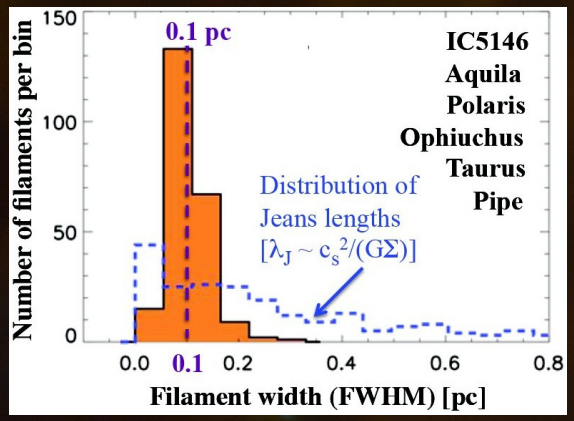


Filament width (0.1pc)
Arzoumanian et al. 2011

Suggested prestellar core formation scenario: in 2 main steps (André et al. 2010, 2011):

1) Filaments form first in the cold ISM, probably as a result of the dissipation of **MHD turbulence** (reflected in the 0.1 pc filament width)

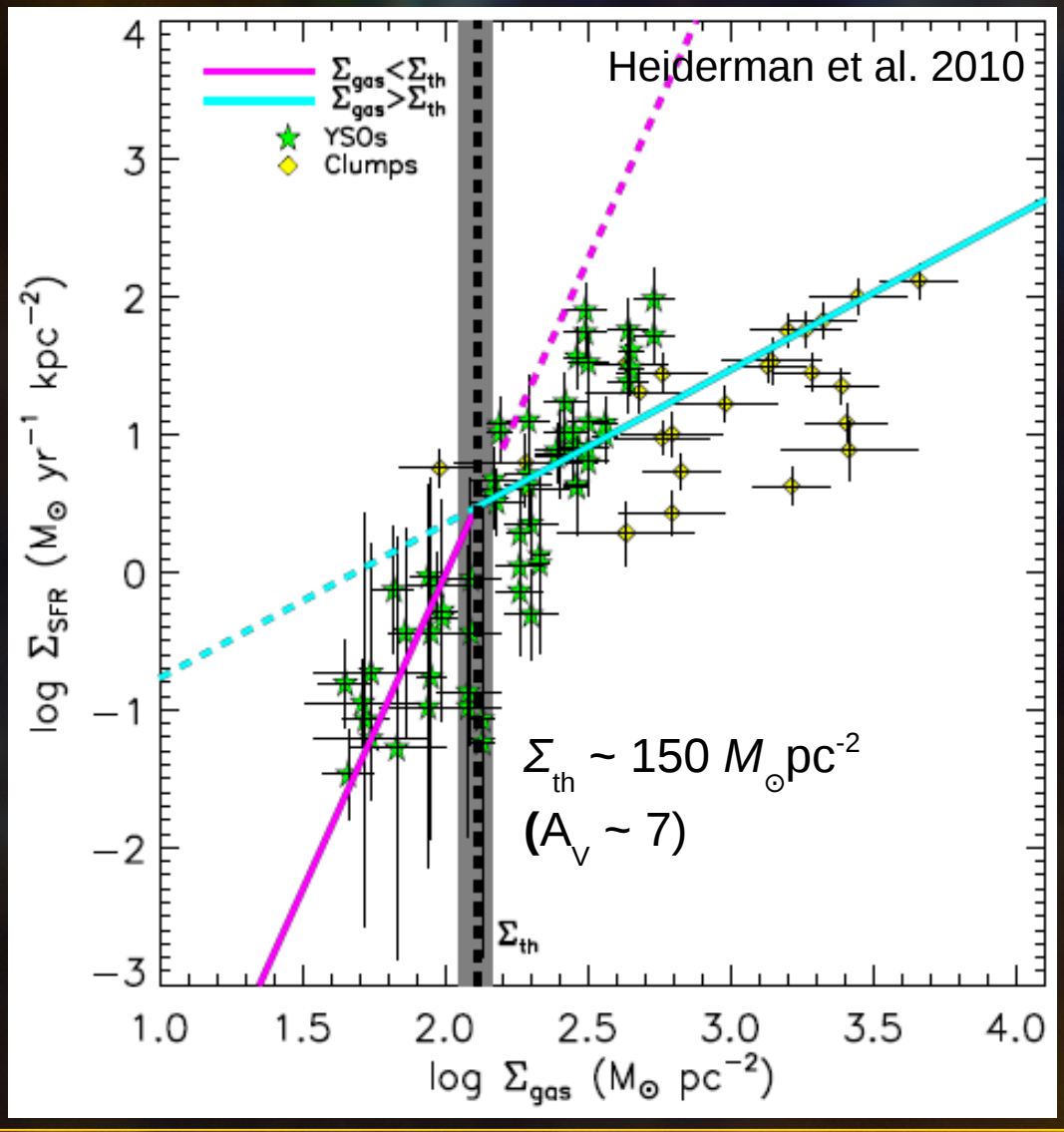
2) The densest filaments then fragment into prestellar cores via **gravitational instability** above the approximately corresponding $A_{V,crit}$ ~ 5–7 and $M_{line,crit}$ ~ 15 $M_\odot$/pc (T ~ 10K) thresholds.

Spectroscopic and polarimetric **follow-up observations** are planned to clarify the roles of turbulence, magnetic fields, gravity in forming the filaments.

HGBS: SF THRESHOLD FURTHER AWAY...

Importance of star formation threshold on (extra)galactic scales

Star formation rate vs. gas surface density



$\Sigma_{SFR} \propto \Sigma_{gas}$ (for $\Sigma_{gas} > \Sigma_{th}$)

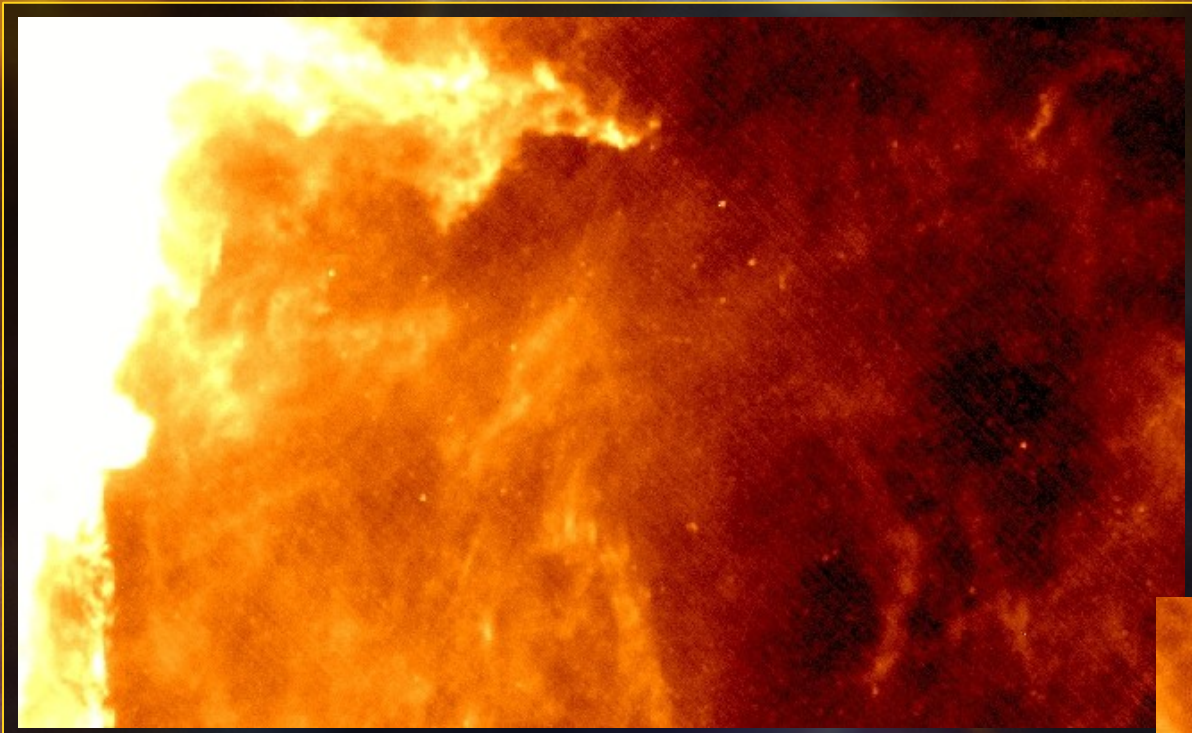
Heiderman et al. 2010,
Lada et al. 2010

For external galaxies:

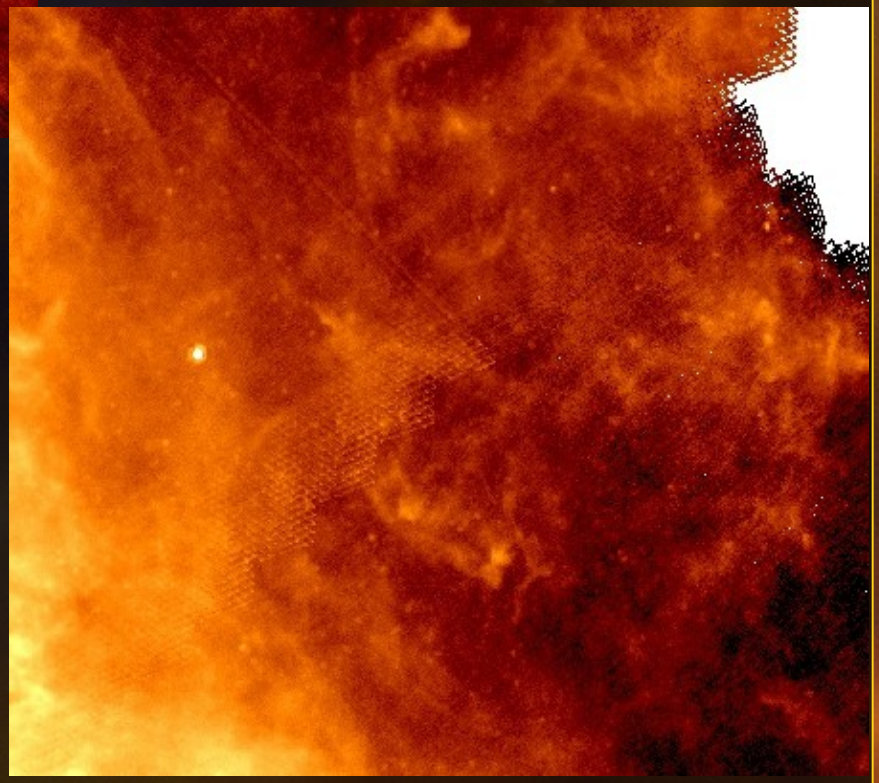
Gao and Solomon 2004

MAP-MAKING ISSUES

HGBS: MAP-MAKING ISSUES



Parallel-mode SPIRE maps (destriper, naive)

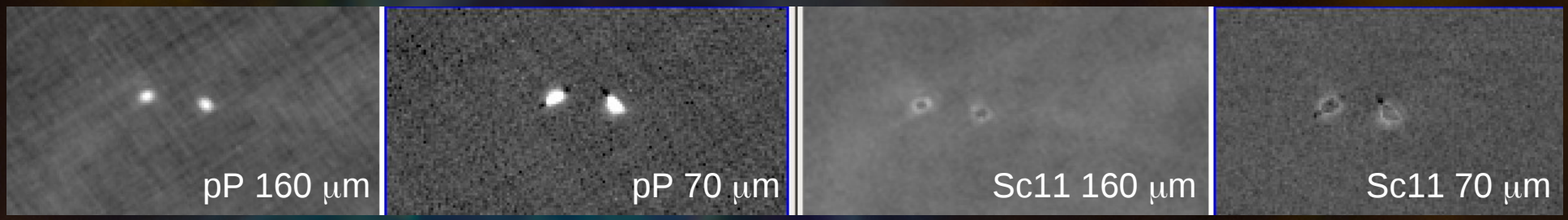


- SPIRE stripes (enhanced with convolving maps)
  - ⇨ gone with latest destriper
- Spire pixel resolution...
- Combination of fields, mosaicking

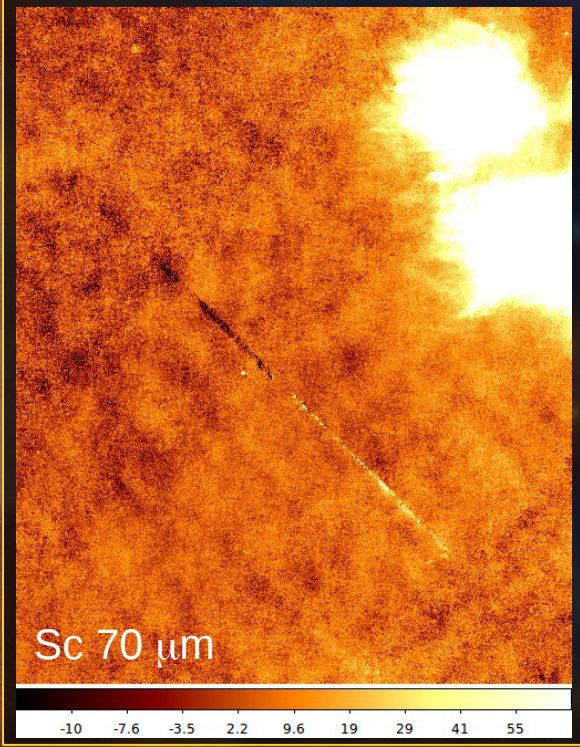
HGBS: MAP-MAKING ISSUES

Parallel/prime-mode PACS maps (HIPE-level1, Scanamorphos)

- Asteroids in Taurus



⇨ _transient.fits maps created in Scanamorphos v12+ (not only for asteroids...)



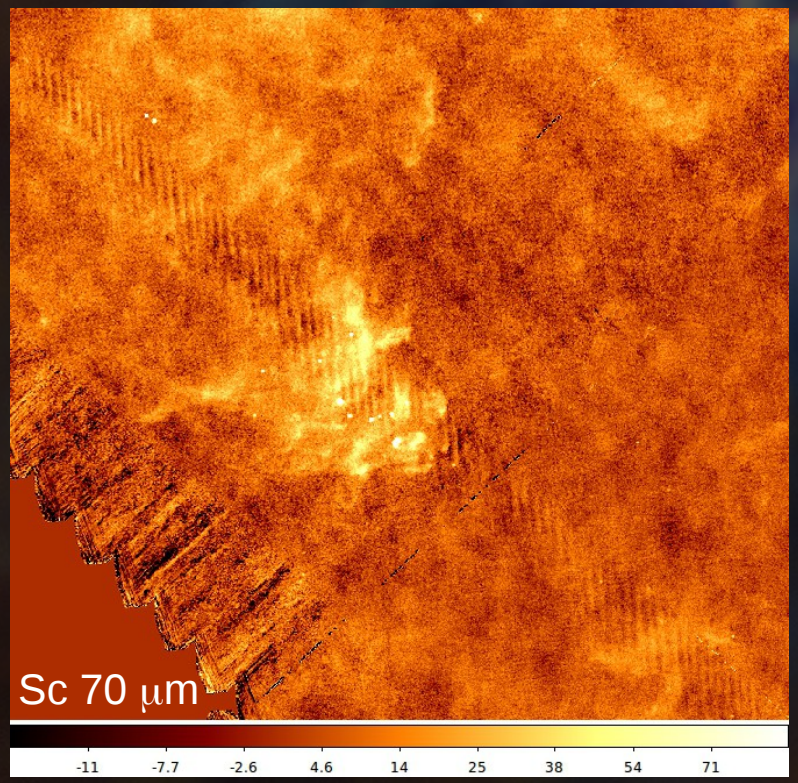
- Artifacts from glitches
  - ⇨ If /jumps_pacs is not the solution, a trick: using Scanamorphos's clean map to replace only this small region.

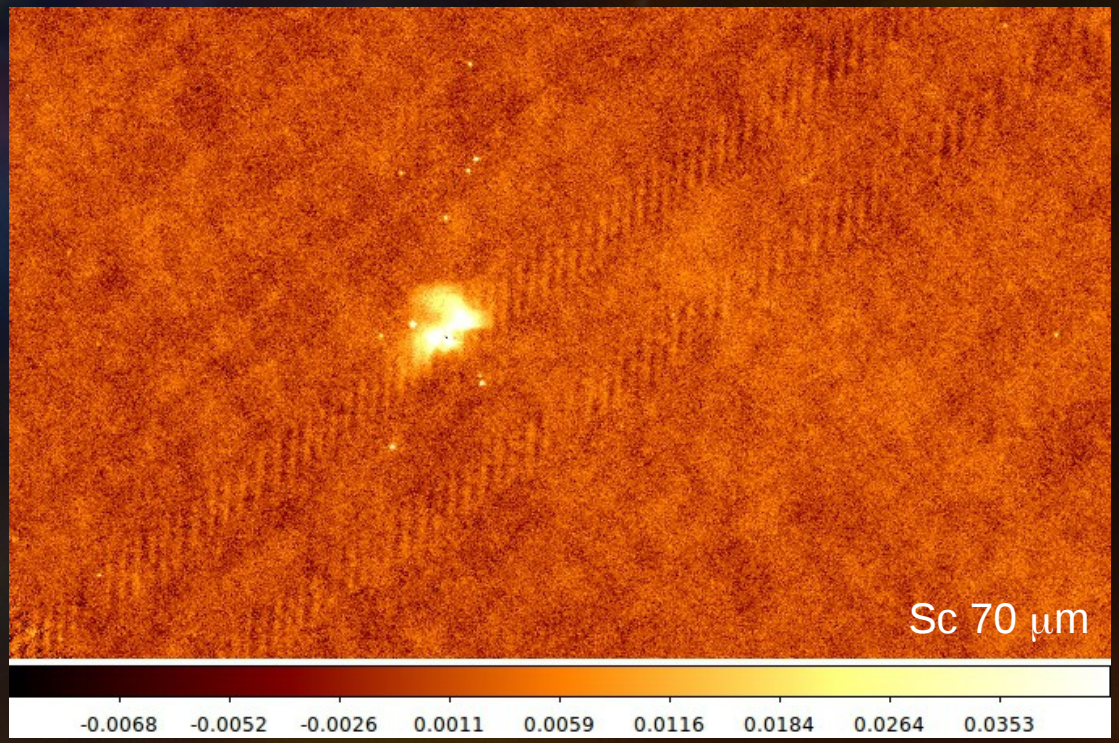
HGBS: MAP-MAKING ISSUES

Parallel/prime-mode PACS maps (HIPE-level1, Scanamorphos)

- PACS: Mainly, if the field is big, I'm not applying 2nd order deglitching in HIPE, but in Scanamorphos.

- Car track pattern (Parasitic electrical interference?)





Thank You!