Formation of high mass stars with the HSO

Studying the earliest phases of massive-star formation

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Formation of high mass stars

	Instruments used (and GT consortium)	Program	Main goals
Henning et al.	PACS (GT)	Imaging & Spectroscopy	Pointed obs. of selected sources
Motte, Zavagno, Bontemps et al.	PACS (GT) and SPIRE (GT)	Imaging (PACS+SPIRE) and spectroscopy (PACS)	• Unbiaised survey of nearby molecular clouds + • Pointed obs. of triggered star forming regions (hot PDRs)
Abergel, Baluteau, Zavagno et al.	SPIRE (GT) and PACS	Imaging and spectroscopy (PACS+SPIRE)	• Dust cycle in the ISM + • SPIRE imaging and FTS spectro. of hot PDRs
Van Dishoeck et al.	HIFI	Spectroscopy	Time sequence evolution using water as tracer

The birth of high-mass stars: An *Herschel* imaging survey of nearby giant molecular cloud complexes

Program

1) **Wide-field photometric imaging** of nearby molecular complexes with both SPIRE & PACS

+

2) **a detailed spectroscopic & photometric study** of hot PDRs with PACS

- 125 hours = 85h SPIRE GT from SAG3
  + 20h PACS GT from OAMP
  + 20h GT from HSC

- Coordinators: Motte, Zavagno, Bontemps

Background and aims of present proposal

Science context

How do OB star form?

Radiation pressure is expected to stop the accretion when $M_* \sim 8\ M_?$

What physical mechanism forms high-mass stars (HMS)?

Open questions related to the earliest phases of HMS formation

- Initial conditions and evolutionary sequence for HMS formation?
- Role of external triggers in massive star formation?

Main goals of our GT *Herschel* project

- Discover the precursors of OB stars (protostars & prestellar cores)
- Derive their mass and luminosity
- Assess the importance of triggering

Seeking the precursors of high-mass stars

Criteria used to search for the progenitors of HII regions

High-luminosity sources	> 10^3 $L_?$
Embedded in massive envelopes	"red" FIR colors, dense gas
Associated with hot dust & gas	hot core and masers
Without a developed HII region	no or weak cm free-free

Galaxy-wide selections of *IRAS* sources

Heterogeneous samples (d = 1-10 kpc) tracing 0.1-1 pc objects (e.g. Molinari et al.1996; Beuther et al. 2002)

• Biased against "IR-quiet" sources

• Bad spatial resolution at the SED peak (~100 μm)

***Herschel* uniqueness**

Wide-field imaging

Spectro-imaging capabilities (60-670 mm)

Unprecedented spatial resolution at FIR wavelengths

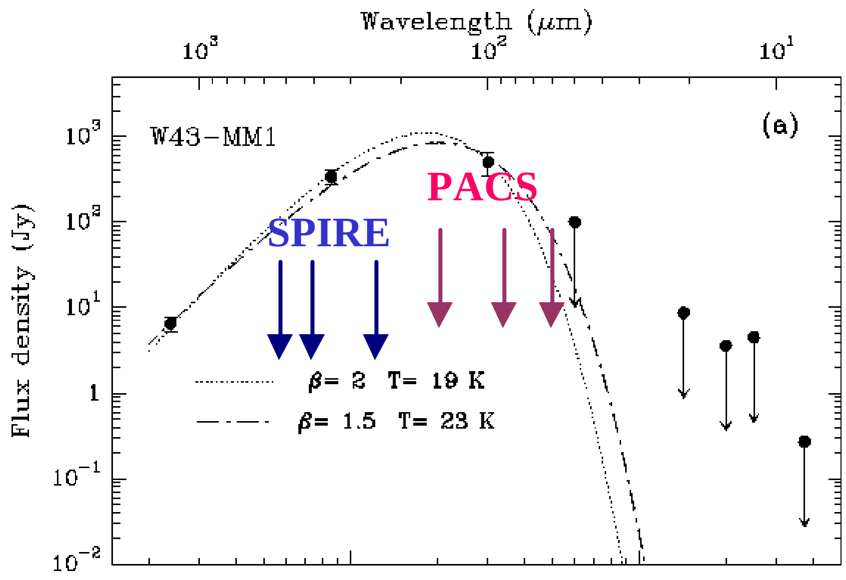
Uniqueness of *Herschel* to study the precursors of high-mass stars

• Spatial resolution
~ 0.1 pc @ 1.7 kpc (unmatched at FIR wavelengths – 10” @ 140 μm)

• Spectral coverage of PACS and SPIRE
- Ideally suited to detect high-mass starless cores and protostars
- Provide **robust measurements** of their basic properties (bolometric luminosity and mass)

• Imaging speed for the photometry
Unbiased survey of molecular complexes

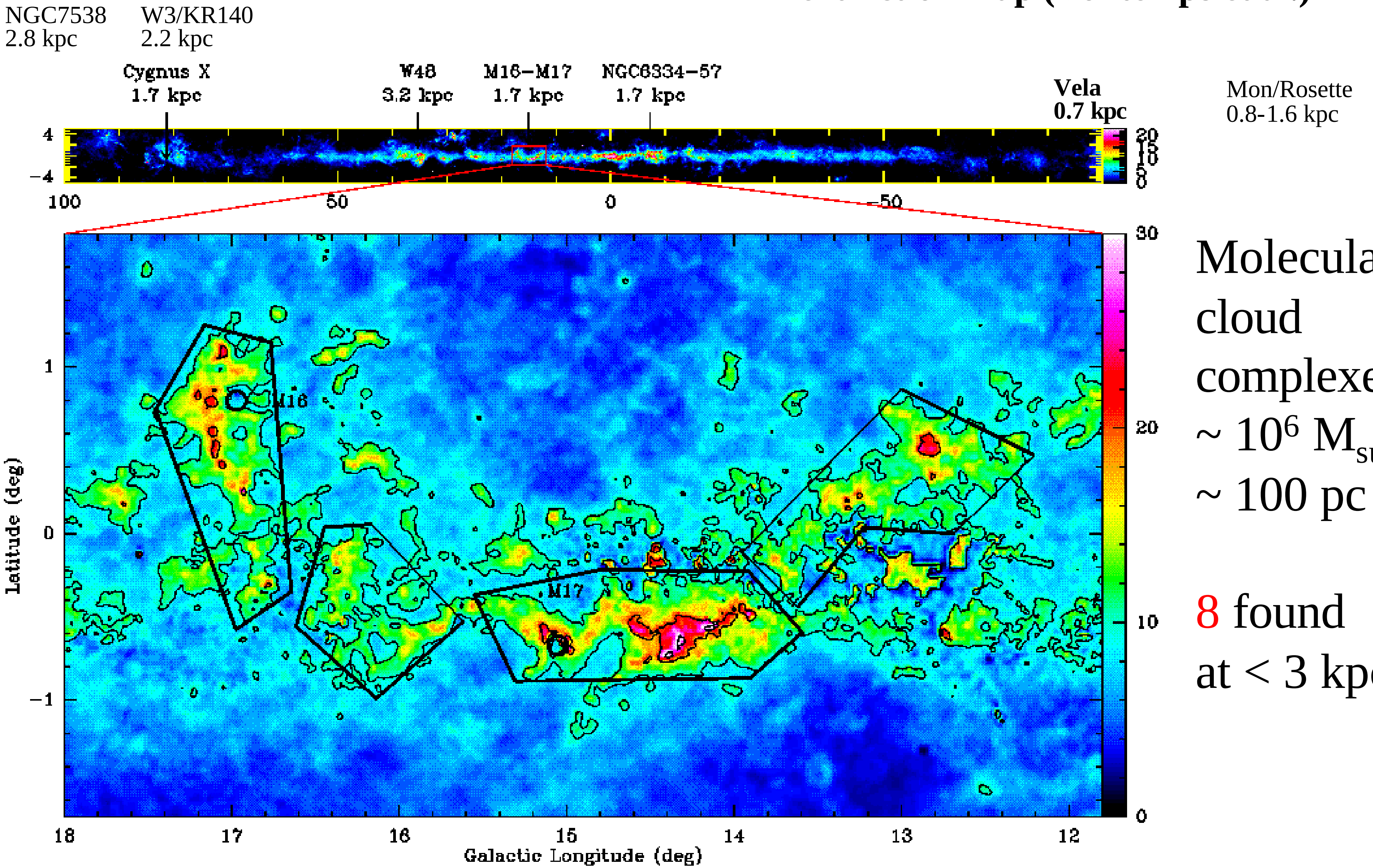
• Important lines
traced by the spectroscopic cameras
e.g. [OI], [CII], [NII], [NIII], [OIII]
→ Physical diagnostics (T, n)



T_{dust} ~ 20 K (Motte et al. 2003)

1.Wide-field photometric imagings of all the molecular cloud complexes at < 3 kpc

NIR extinction map (Bontemps et al.)



Molecular cloud complexes:
~ 10^6 M_{sun}
~ 100 pc

8 found at < 3 kpc

Molecular complexes to survey with *Herschel*

Molecular complexes	D (kpc)	Gas mass ($M_\odot$)	$A_V > 10$ area (deg^2)	$\sigma_{250\mu m}$[a] (mJy)	Ref.[b]	ALMA vis.	Notes
Vela	0.7	$> 5 \times 10^5$	3.1	40	(1)	Y	Intermediate-mass SFR near a supernova bubble.
MonR1/R2 /NGC2264	0.8	2.5×10^5	3.5	30	(2),(3)	Y	Two concentrated intermediate-mass SFRs.
/Rosette	1.6	3.5×10^5			(9)	Y	An isolated high-mass SFR.
Cygnus X	1.7	4×10^6	6	100	(4),(5)	N	The richest nearby high-mass SFR, triggered by Cyg OB2.
M16/M17 /Sh40	1.7	1.5×10^6	2.5	< 1000	(5)	Y	Rich part of the Sagitarius arm with 2 reference SFRs.
NGC 6334 /6357/6231	1.7	1.3×10^6	3.5	< 1000	(5)	Y	Network of 3 high-mass SFRs in the Carina-Sagitarius arm.
W3/W5 /KR140	2.2	2×10^5	1.5	10	(6),(7)	N	Reference high-mass SFR in the Perseus arm.
NGC 7538	2.8	1×10^6	0.6	25	(8)	N	Reference high-mass SFR in the Perseus arm.
W48	3.0	5×10^6	3.9	< 400	(5)	Y	Extremely massive complex in the Galactic molecular ring.

SPIRE 250, 360, 520 μm and **PACS** 110, 170 μm survey of intermediate-distance clouds down to $A_v >$ 10 mag (~ 25 deg^2)

The « 3 kpc opportunity » to study OB star formation

Within 3 kpc, the star formation rate is 1/20th that of our Galaxy

$SFR_{<3kpc}$ = 0.2 M_{sun} yr^{-1} (McKee & Williams 1997)

➡ Enough statistics for precursors of stars with 8-50 M?

Table 3: Predicted numbers of OB-like YSOs in the targetted complexes of Table 2.

Source	Spectral type / Final mass	B3–B1 $8-20\ M_\odot$	O9–O7 $20-50\ M_\odot$	O6–O3 $50-100\ M_\odot$	O3–O1 $>100\ M_\odot$	Total $>8\ M_\odot$
Pre-stellar core		480	150	40	30	700
Class 0-like protostar		48	15	4	3	70
Infrared protostar		480	150	40	30	700
UCH II region		160	50	15	10	235

Intermediate-distance complexes have d_{sun} from 0.7 to 3 kpc

➡ Enough resolution with *Herschel* to identify high-mass sub-clusters (~ 0.1 pc)

Mapping strategy and time estimate

Fast photometric imaging with SPIRE

250 µm, 360 µm, 520 µm

Scanning at 30-60''/sec (cross-linked scans, no chopping)

⇒ rms $_{250\mu m}$ ~ 15-20 mJy (5 σ detection of 0.2-0.3 M_o sources)

⇒ 35 hours for 24 deg^2

Fast photometric imaging with PACS

110 µm, 170 µm

Scanning at 24''/sec (cross-linked scans, no chopping)

⇒ angular resolution preserved (Billot et al.)

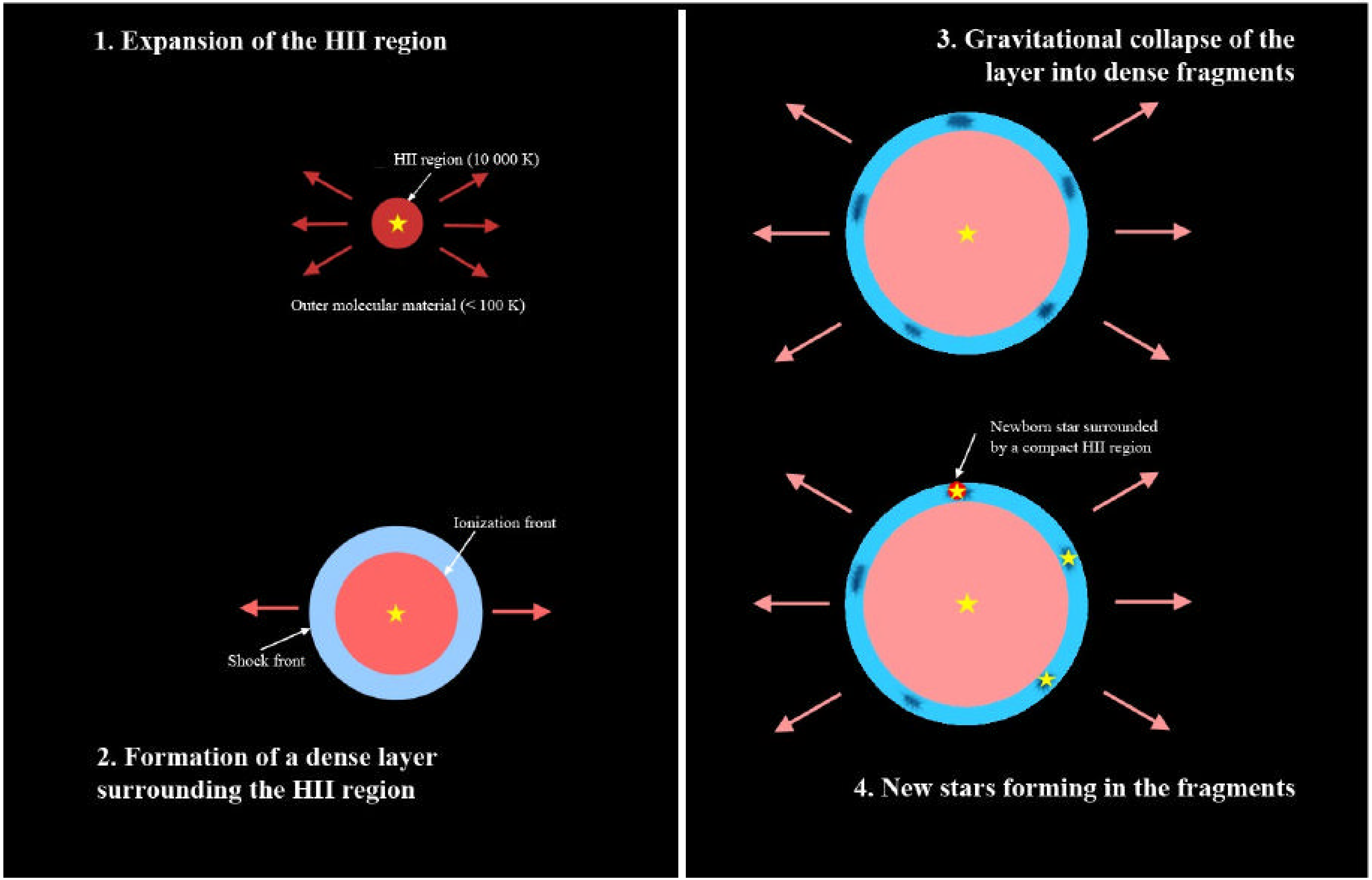
⇒ rms $_{170\mu m}$ ~ 13 mJy (5 σ detection of 0.1 $M_?$ sources)

⇒ 65 hours for 24 deg^2

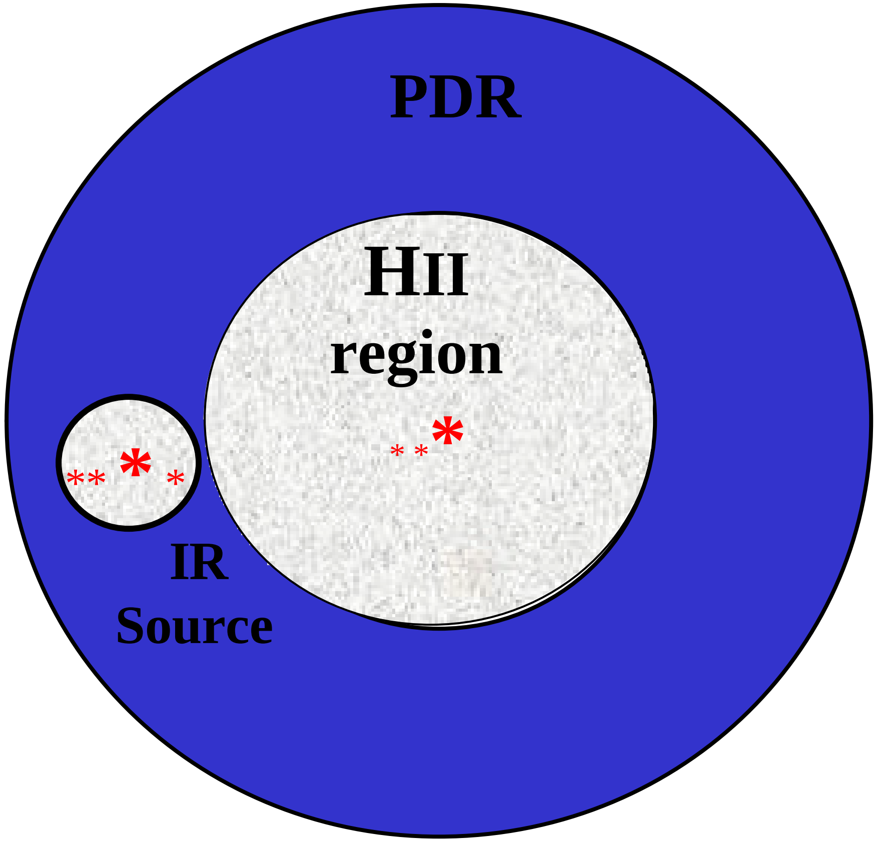
100 hours for wide-field photometric imaging with SPIRE & PACS

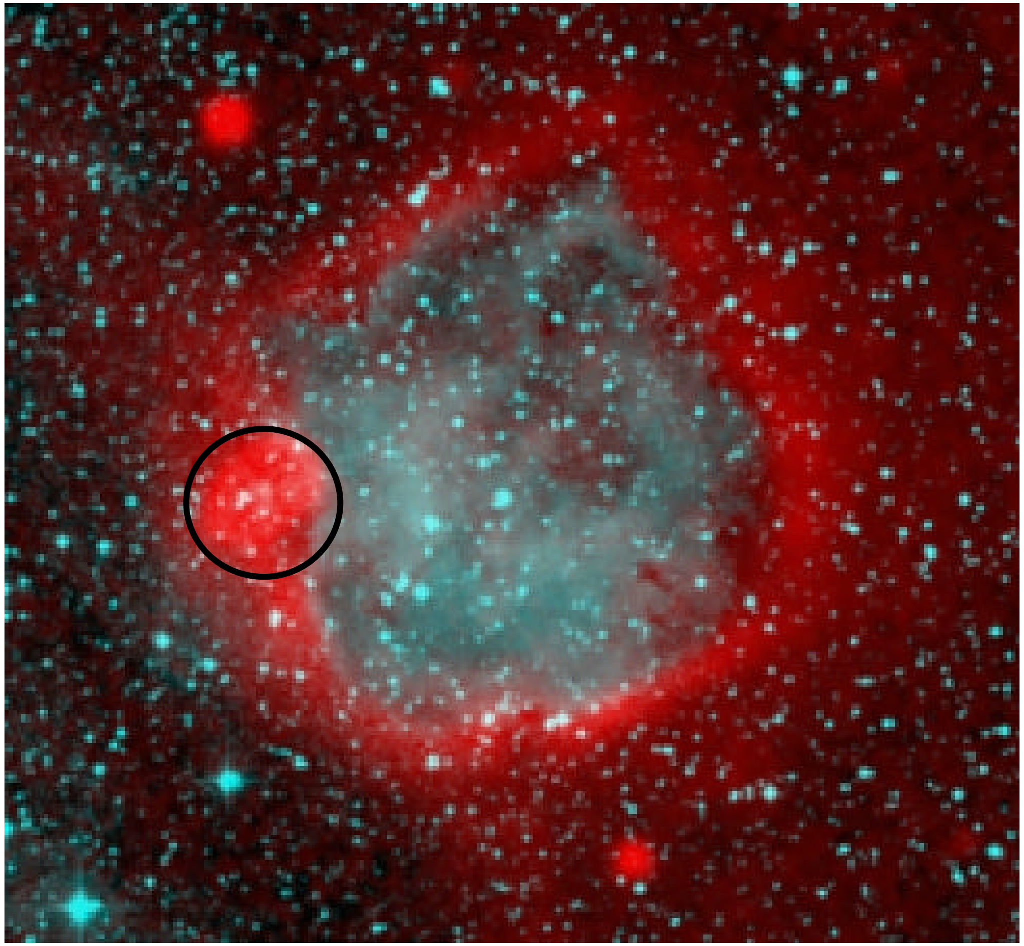
2. Spectroscopic & photometric study of triggered star formation

The « collect and collapse » model: Elmegreen & Lada (1977)



Hot PDRs potentiel site of triggered massive star formation





Sh 104 **DSS - *R*** + **MSX - *A*** (6-11µm)

Circular HII region
Annular PDR
Signposts of massive-star formation
(maser, ultracompact HII region, bright IR sources)

Simple geometry

Proposed observations and time estimate

Photometric imaging with PACS

110 μm, 170 μm. 10'x10' areas covered @ 6''/sec

⇒ rms $_{250\mu m}$ ~ 13 mJy (S/N > 50 for a source with a 1 Jy flux)

⇒ 8 hours for 5 sources

Spectroscopic pointings with PACS

• PDR diagnostics: [OI] 63 and 146 μm, [CII] 158 μm

• Ionized region diagnostics: [NII] 122 and 205 μm, [NIII] 57 μm, and [OIII] 88 μm

• Molecular absorptions: OH 119.23 and 119.44 μm, CH 149.09 and 149.39 μm, and H_2O 179.53 μm

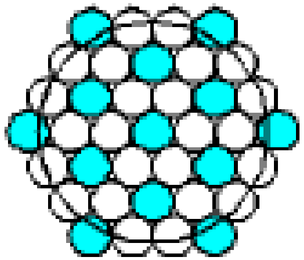
⇒ 13 hours for 25 pointings (5 positions x 5 sources)

20 hours for detailed photometric and spectroscopic pointings with PACS (Zavagno et al.)

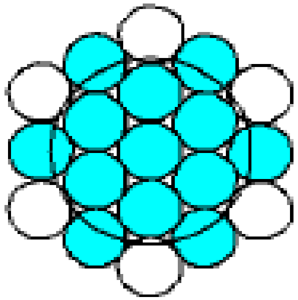
Hot PDRs SPIRE-FTS observations (in SAG4 GT)

Physical conditions in massive star forming regions (gas and dust)

- High resolution mode
- Spectrum: lines + continuum 230 – 670 μm
- 3 pointings/source and 4 sources = **12 hours**
- Spectro imaging on a 2.6’ FoV

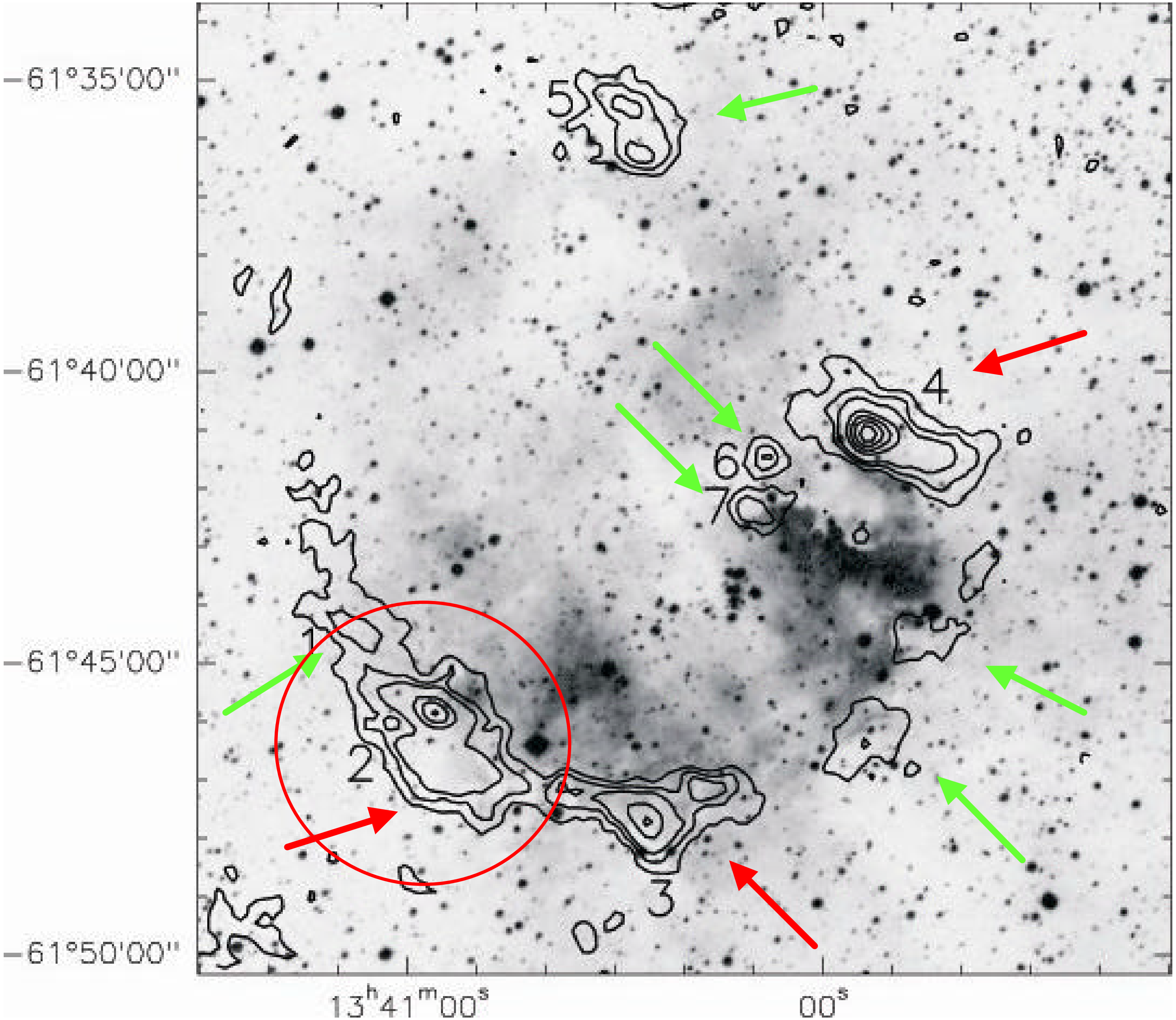


SW (190-325 μm)



LW (300-670 μm)

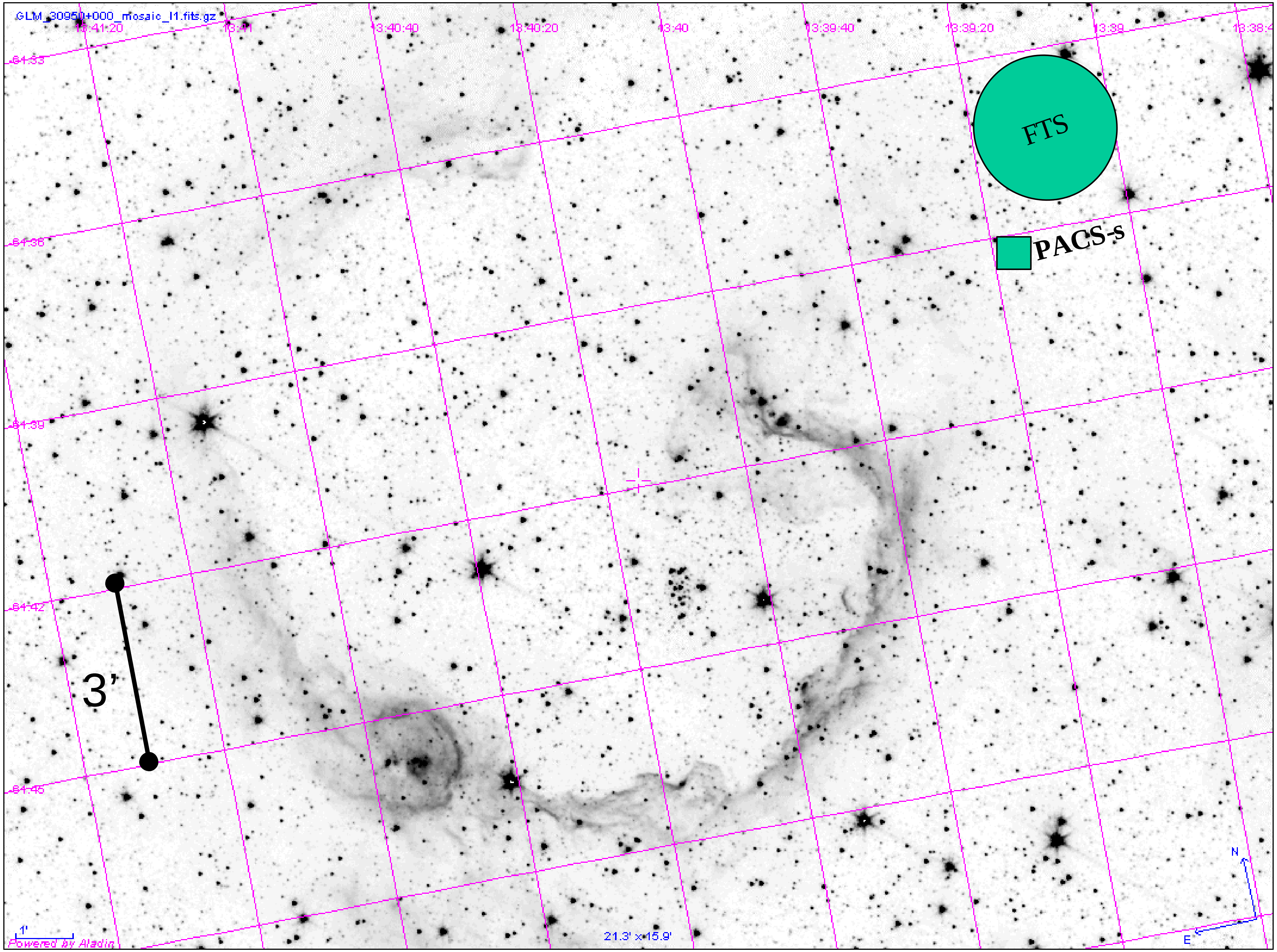
RCW 79 1.2-mm continuum emission (ESO-SEST - contours) and Hα image (SuperCosmos Hα survey – grey scale)



SPITZER 8 microns and Halpha

RCW 79

Zavagno et al.
2006



RCW 79 Image: 3 μm (GLIMPSE)

Hot PDRs potentiel site of triggered massive star formation

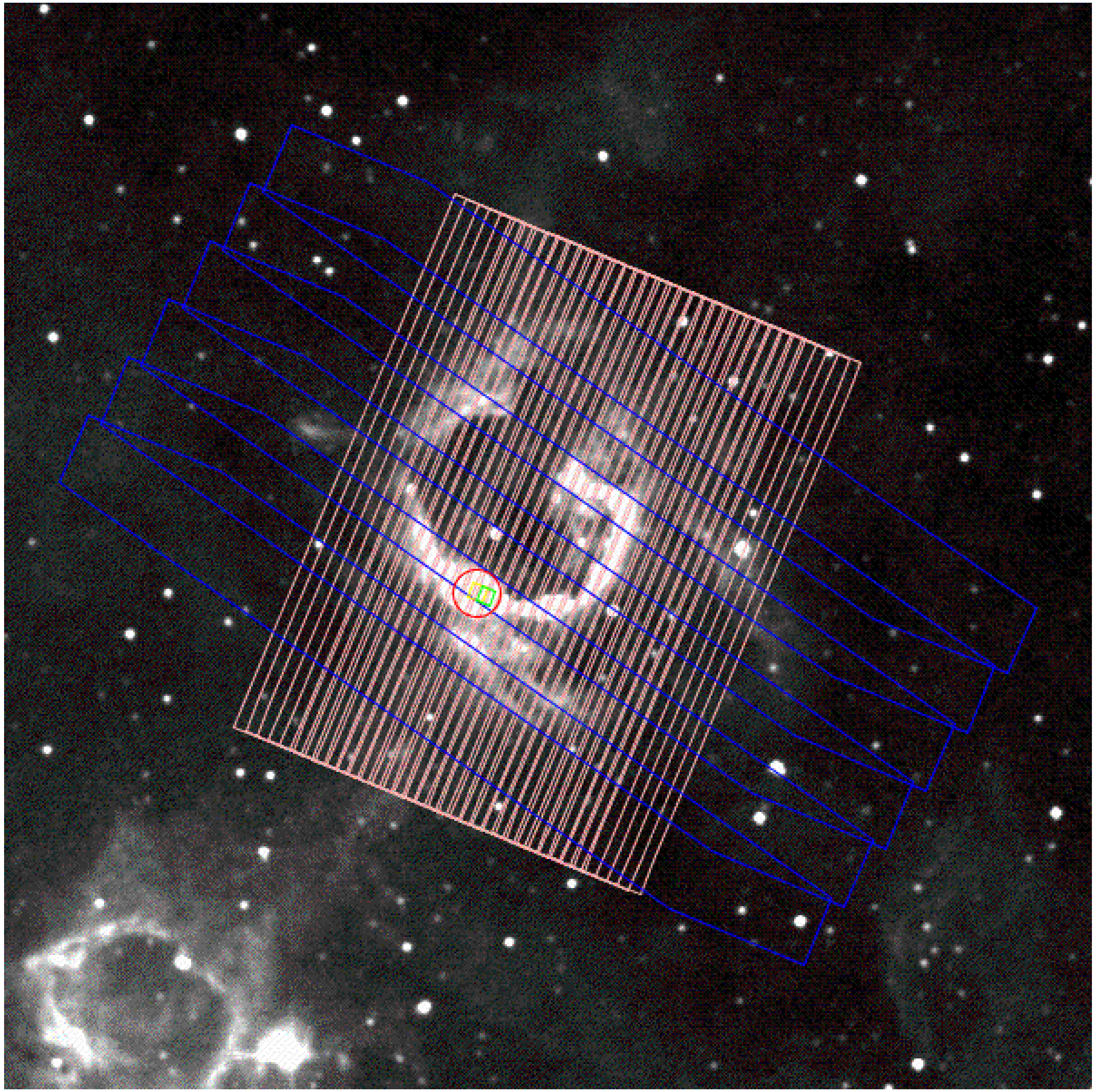
HSPOT

SPIRE-i

PACS-i

FST

PACS-s



Exploitation Plan

Team focus

- Complete catalogs of high-mass starless cores and protostar

  Basic characteristics (mass, luminosity, density, SED…)

  Lifetimes of the various phases

  Luminosity & mass functions of massive YSOs

- Relationship of clouds with YSOs clusters, OB associations to search for triggering.

Legacy value

- Long-lasting databases
- Dust properties in OB star-forming regions
- Templates for extragalactic star forming regions

Preliminary Distribution of Responsible Subteams for the 'OB Star Formation' SPIRE/PACS Survey

Cloud complex	Area (deg^2)	Dist (kpc)	Cirrus Noise$_{250m}$ (mJy/b)	Required rms$_{250m}$ (mJy/beam)	Required SPIRE+PACS Time (hr)	Responsible Team(s)
Vela	3.1	0.7	40	20	13	Rome/**Saclay**
Mon R1-R2 **Rosette**	2.0 1.5	0.8 1.5	30	20	15	Cardiff/**Saclay** **Saclay**/Canada
Cygnus X	6	1.7	100	20	25.5	**Saclay**/HSC
M16/M17/Sh40	2.5	1.7	< 1000	20	10.5	HSC/RAL
NGC 6334 **NGC 6357**	1.7 1.7	1.7	< 1000	20	7 7	**Marseille**/Rome RAL/**Marseille**
W3/KR140	1.5	2.2	10	20	6.5	Canada/Rome
NGC 7538	0.6	2.8	25	20	2.5	Canada/Cardiff
W48	3.9	3.0	10	20	16.5	**Saclay**/Rome

Preparatory studies for the SPIRE/PACS Survey

- Ongoing multi-wavelengths analysis for the selected complexes
  Existing IR databases (2MASS, UKIDSS, Spitzer, MSX, IRAS and **AKARI** – to come)

- Proposal preparation to ask for missing data
  * CO and molecular tracers
  * mm and radio continuum
  * dynamical studies
  * masers
  * ….

- *Herschel* observations preparation
  Use of HSPOT
  Better strategy depending on results of the latest tests