Initial conditions for habitability: the triggered star formation phase

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Habitability ?

eccentricity obliquity tidal-lock circumstellar temperature magnetism interaction tides planet star flare ice water heat brown-dwarf sun moon venus mars atmosphere climate aquability exoplanet super-habitable world magnetosphere stellar wind astrosphere dynamo sun-cycle solar-luminosity solar-analogs effective-stellar-flux liquid-water dense-atmosphere IHZ OHZ greenhouse

Habitability ?

- Habiter → Habitare (latin, 1050) → to get used to, to live in, to stay and live somewhere… (cf: habere, habitum: to have got, habit) → to become populated (1400-1600).
- Habitat → area occupied by a plant, an animal or living species (1800-1900), human organisation (urban habitat) (1925).
- Habitable → Habilitis (latin) → « where we can live in », suitable or fit to live in
- Habitabilité / Habitability: what is habitable, what offers space to live in… (source: S. Tirard)

➔ Habitability ⇔ Living conditions (to live *in* = to inhabit = habiter and to live = vivre)

Habitability in astrophysics ?

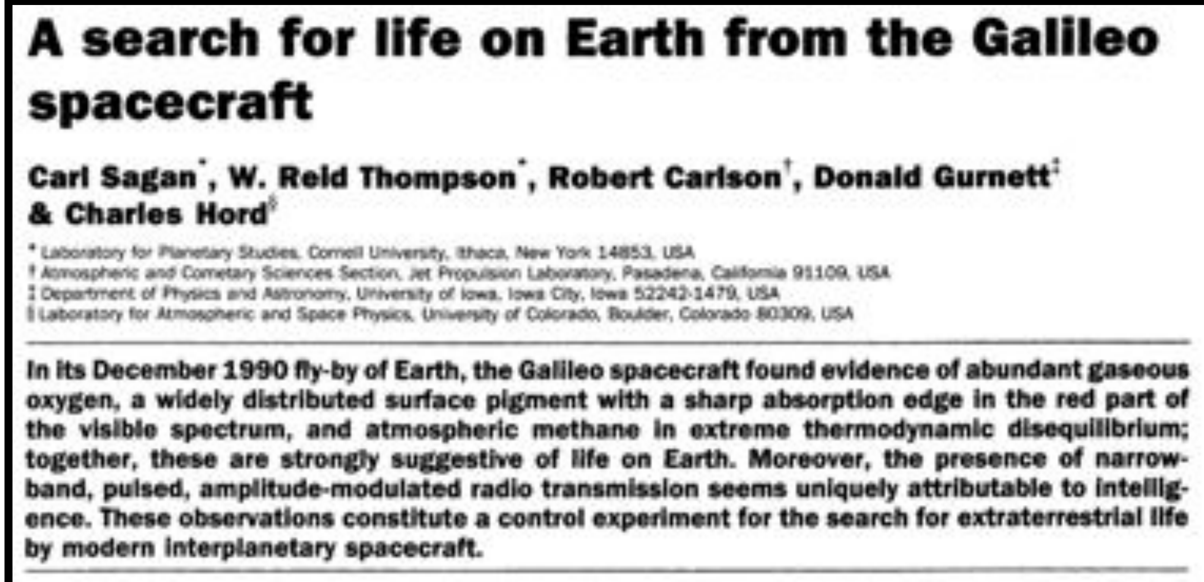
- Habitability is a concept structuring comparative studies between Earth and other zones in the universe.

- Comparable habitable conditions → comparable evolution

- Habitability, two ways of using this concept as:
  - Description of the conditions for life on Earth and survey of comparable regions.
  - Observation of signatures allowing to assume the potential presence or sustainability of life.

➔ Habitability ⇔ Anthropo/geo-morphic conditions

Habitability ⇔ Earth



A search for life on Earth from the Galileo spacecraft

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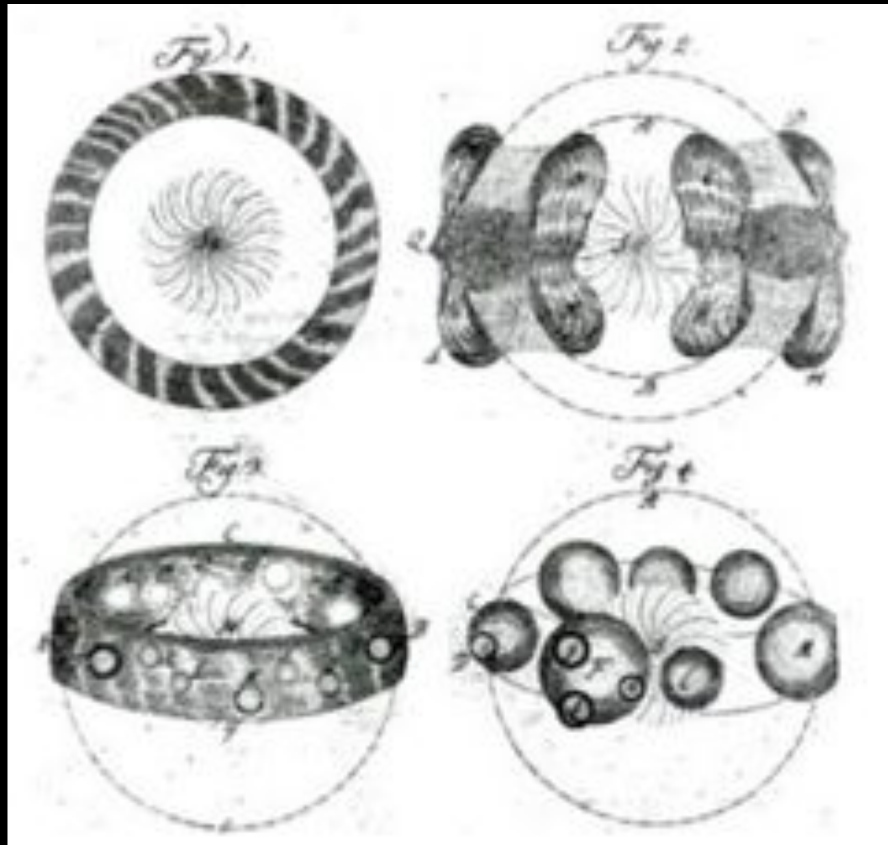
In its December 1990 fly-by of Earth, the Galileo spacecraft found evidence of abundant gaseous oxygen, a widely distributed surface pigment with a sharp absorption edge in the red part of the visible spectrum, and atmospheric methane in extreme thermodynamic disequilibrium; together, these are strongly suggestive of life on Earth. Moreover, the presence of narrow-band, pulsed, amplitude-modulated radio transmission seems uniquely attributable to intelligence. These observations constitute a control experiment for the search for extraterrestrial life by modern interplanetary spacecraft.

Sagan et al. 1993, Nature

Habiter désigne déjà le séjour de l'homme sur la terre, sur "cette" terre, à laquelle tout mortel se sait confié et livré. Habiter est la manière dont les mortels sont sur terre.
Heidegger, 1951
Already « living in » means the stay of man on Earth, « this » land in which any mortal knows himself confided and forsaken. Living (in) is the way mortals are on earth.

Sun formation scenario ?

- Scientific theories of the solar system formation:
  - Emanuel Swedenborg in 1734,
  - Compte de Buffon in 1749,
  - Immanuel Kant in 1755,
  - Pierre- Simon Laplace in 1796.



Perryman 2001,
The origin of the solar system

➔ Isolated solar nebula

Birth environment of the solar system = GMC and star cluster

Adams 2010

- Birth cluster dynamical processes affect star and planet formation (orbit pertubation, disk truncation…)
- Birth cluster provides strong background radiation (photoevaporation, gas removal…)
- Presence of short-lived radioactive species (^{26}Al, ^{60}Fe) inferred from decay species in meteorites (^{26}Mg) ➔ presence of supernovae, but preferential location.

Birth environment of the solar system = GMC and star cluster

Adams 2010

Table II: Summary of Constraints

Solar System Property	Implication	Fraction
Mass of Sun	$M_* \geq 1 M_\odot$	0.12
Solar Metallicity	$Z \geq Z_\odot$	0.25
Single Star	(not binary)	0.30
Giant Planets	(successfully formed)	0.20
Ordered Planetary Orbits	$N \leq 10^4$	0.67
Supernova Enrichment	$N \geq 10^3$	0.50
Sedna-Producing Encounter	$10^3 \leq N \leq 10^4$	0.16
Sufficient Supernova Ejecta	$d \leq 0.3$ pc	0.14
Solar Nebula Survives Supernova	$d \geq 0.1$ pc	0.95
Supernova Ejecta and Survival	0.1 pc $\leq d \leq 0.3$ pc	0.09
FUV Radiation Affects Solar Nebula	$G_0 \geq 2000$	0.50
Solar Nebula Survives Radiation	$G_0 \leq 10^4$	0.80

Sun formation scenario ?

Cameron & Truran 1977

Supernova ejecta containing the short-lived species (^{26}Al) could be incorporated in the dense core that formed the Solar System.

Cameron 1990

From interstellar gas to Earth-Moon system

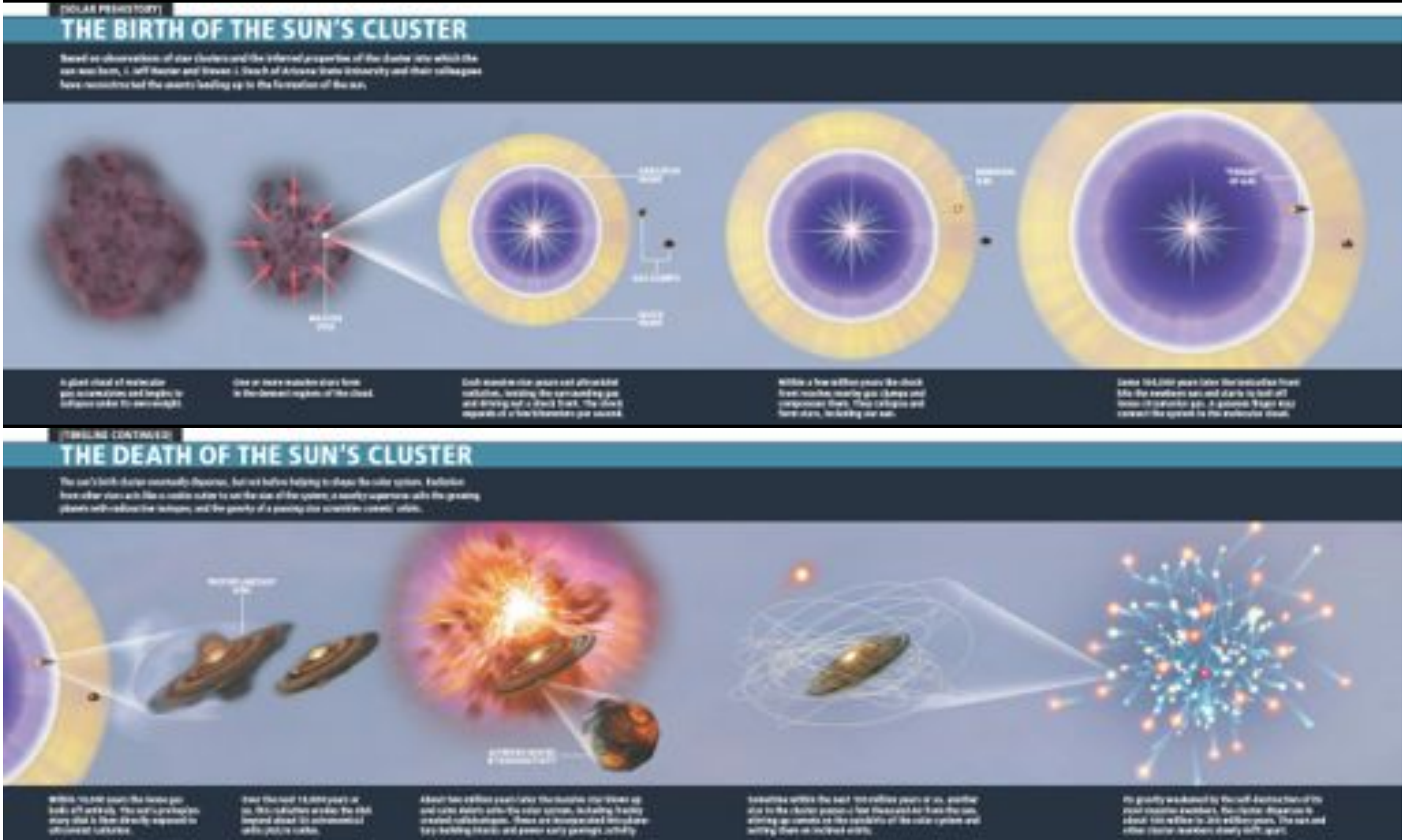
Cameron et al. 1995

Massive supernovae, orion gamma rays and the formation of the solar system

Cameron 1996

The supernova trigger revisited

Sun formation scenario ?

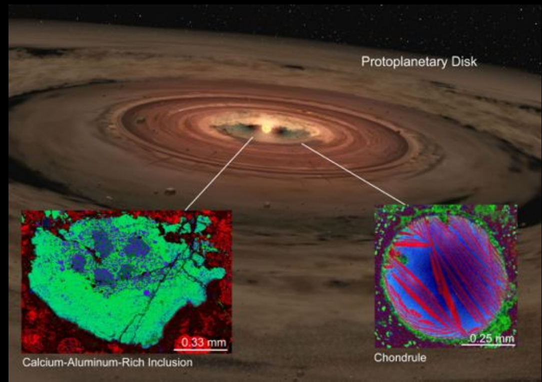


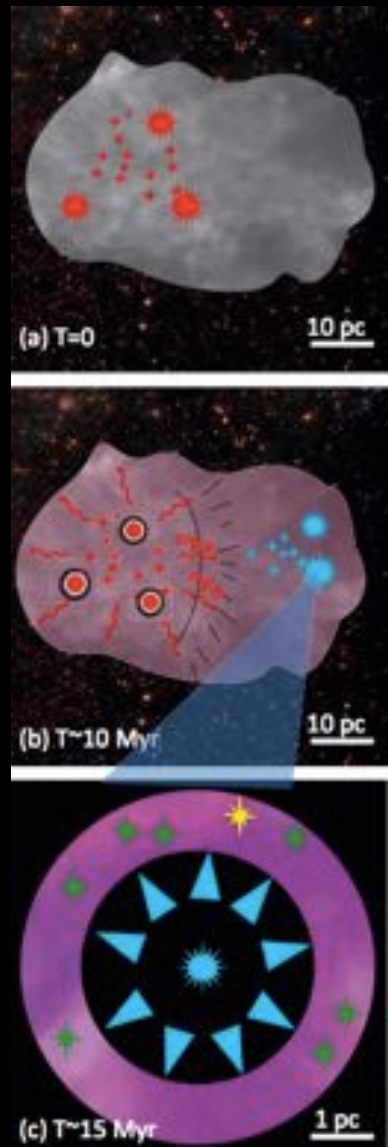
2 generations of stars: Hester & Desch 2005

Sun formation scenario ?

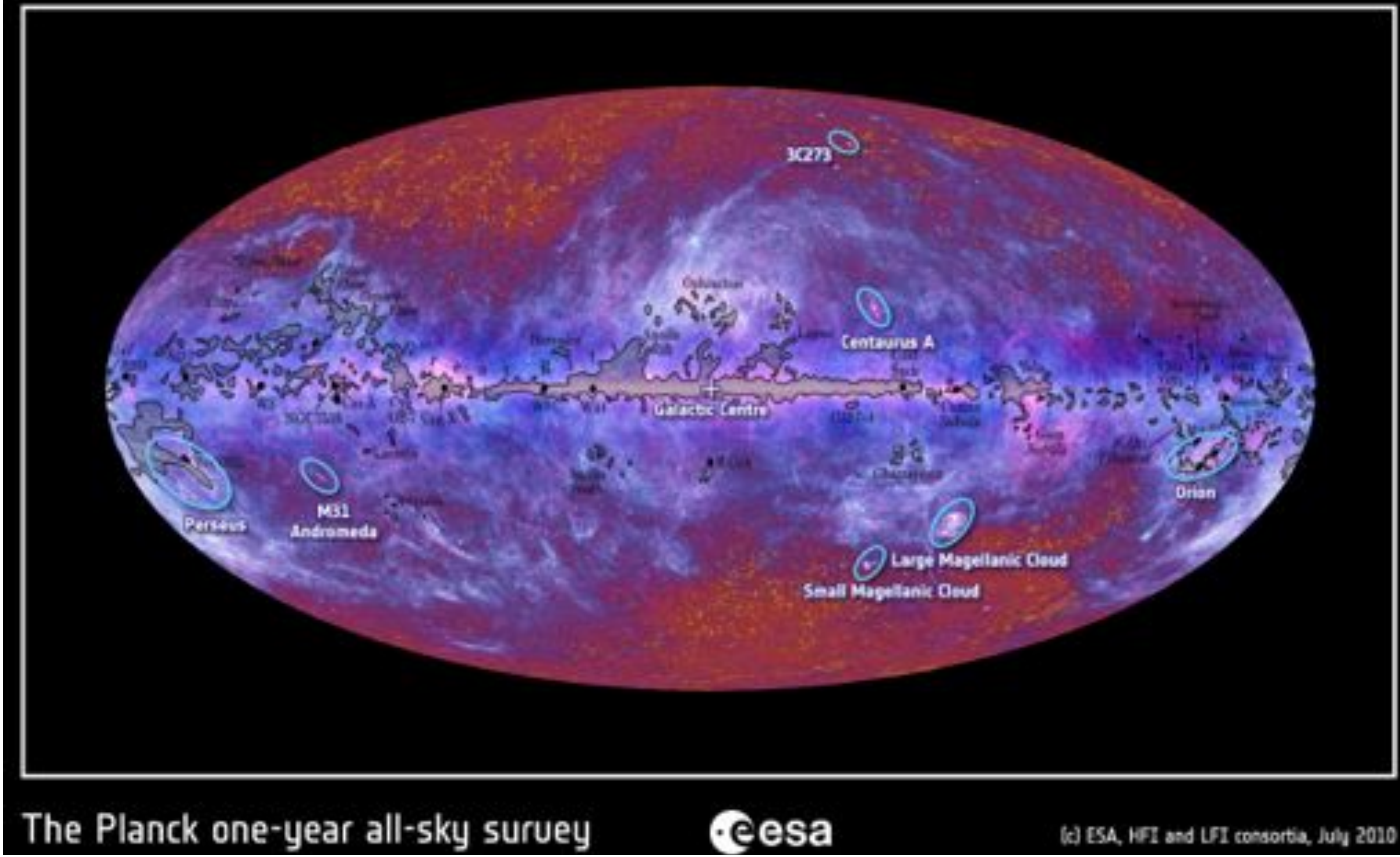
Gounelle et al. 2012: 3 generations of stars

- Time 0 is that of the formation of a first generation (#1) of N_1 stars in a region #1 of the GMC (see panel *a* of Fig. 1).
- After a few Myr, massive stars from generation #1 explode as SNe and start to deliver ^{60}Fe into a neighboring region #2.
- Five Myr after time 0 (see in Sect. 4.1 how this time is estimated), an ^{60}Fe steady-state abundance (due to the balance between decay and production by SNe from generation #1) is established in region #2.
- At $t \sim 10$ Myr, a second star generation (#2, containing a total of N_2 stars) forms in region #2, partly due to the compressive action of the generation #1 SNe shockwaves onto the molecular cloud gas (Preibisch & Zinnecker 2007) (see panel *b* of Fig. 1).
- From $t \sim 10$ Myr and for some Myr, the wind of one or two massive stars from generation #2 will collect ISM gas to build a dense shell surrounding an HII region of radius 5–10 pc (Deharveng et al. 2010). That collected shell, which contains ^{60}Fe originating in the SNe of the first generation, will be wind-enriched in ^{26}Al via efficient turbulent mixing (Koyama & Inutsuka 2002) during a time t_* lasting a few Myr (see Fig. 2).
- At $t \sim 10$ Myr + t_*, aluminum-26 delivery ends when the dense shell fragments and collapses via a diversity of gravito-turbulent mechanisms, such as gravitational instabilities and ionization of a turbulent medium (Deharveng et al. 2010), to form a third generation star cluster (#3). The collapse phase lasts $\Delta_C \sim 10^5$ yr. Our Sun belongs to that third generation of stars (see panel *c* of Fig. 1). CAIs formed in the protoplanetary disk surrounding the protoSun on a timescale of a few 10^4 yr (Jacobsen et al. 2008) contains ^{26}Al from the wind of the generation #2 massive star and ^{60}Fe from the generation #1 SNe (Fig. 2).





Do we observe such scenarios in the Milky Way ?

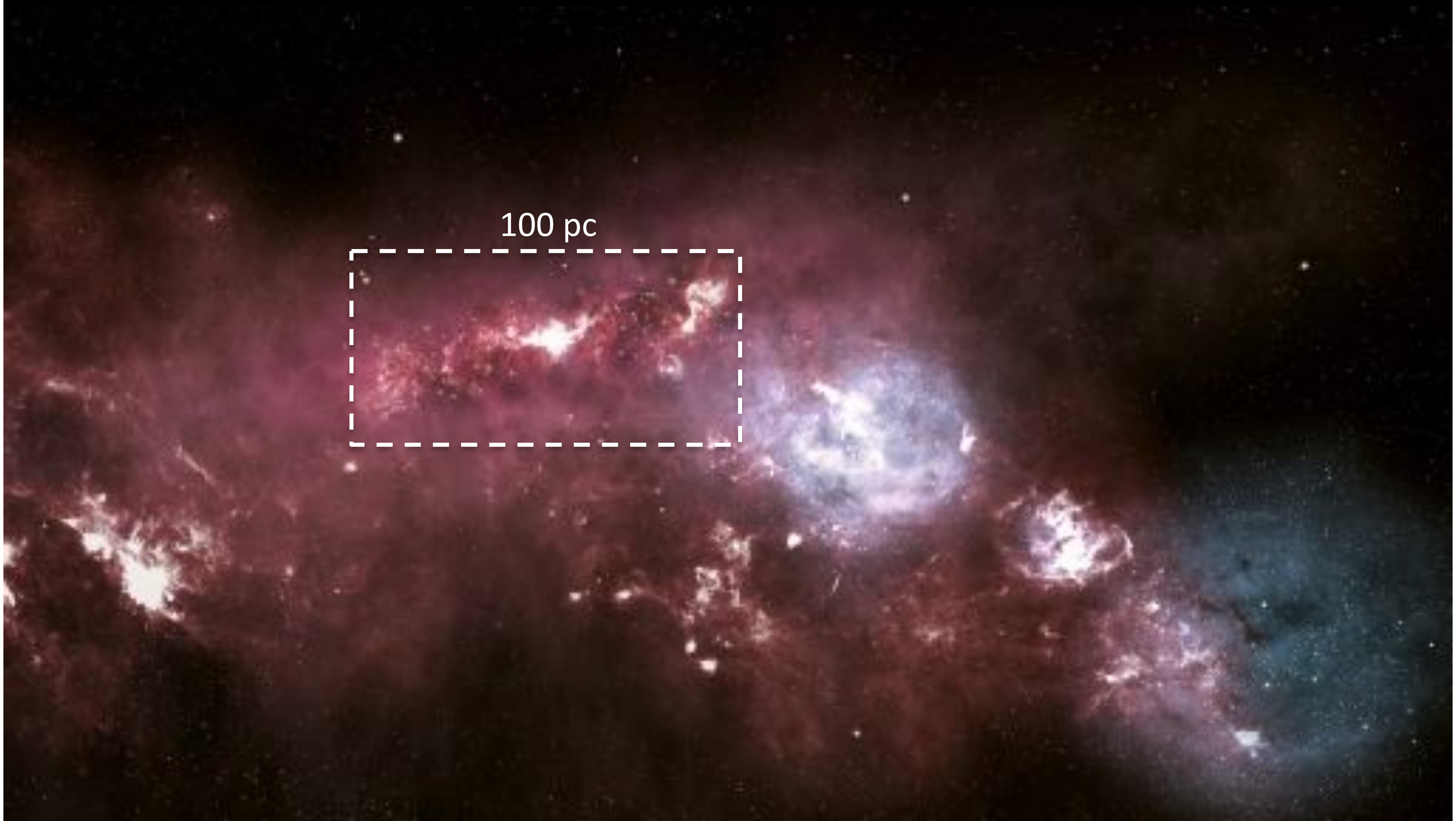


Vela Molecular Ridge

2 generations of stars

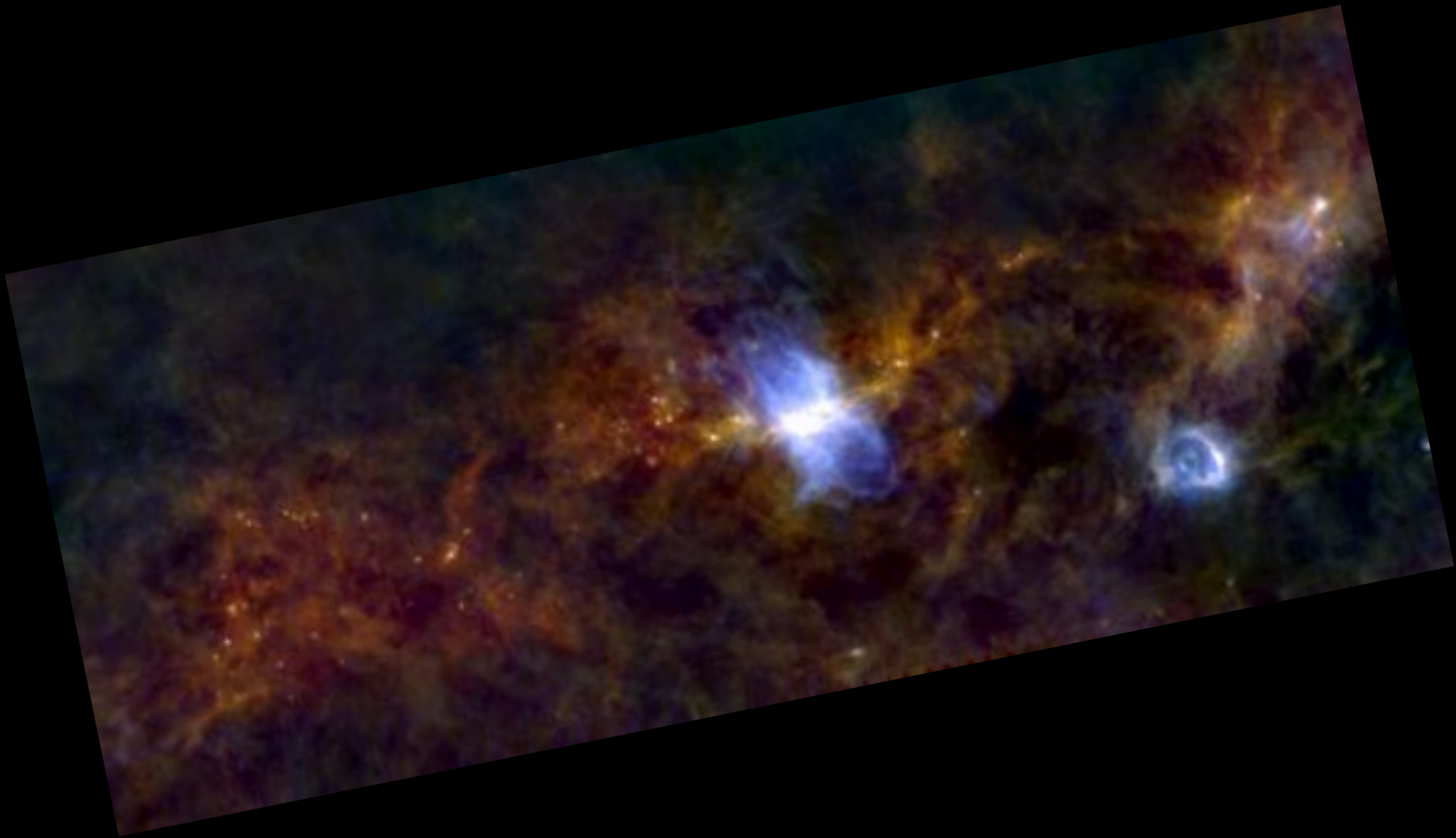
Combined image: Herschel + BLAST + Hα (V. Minier)

Vela C : distance ≈ 700 pc



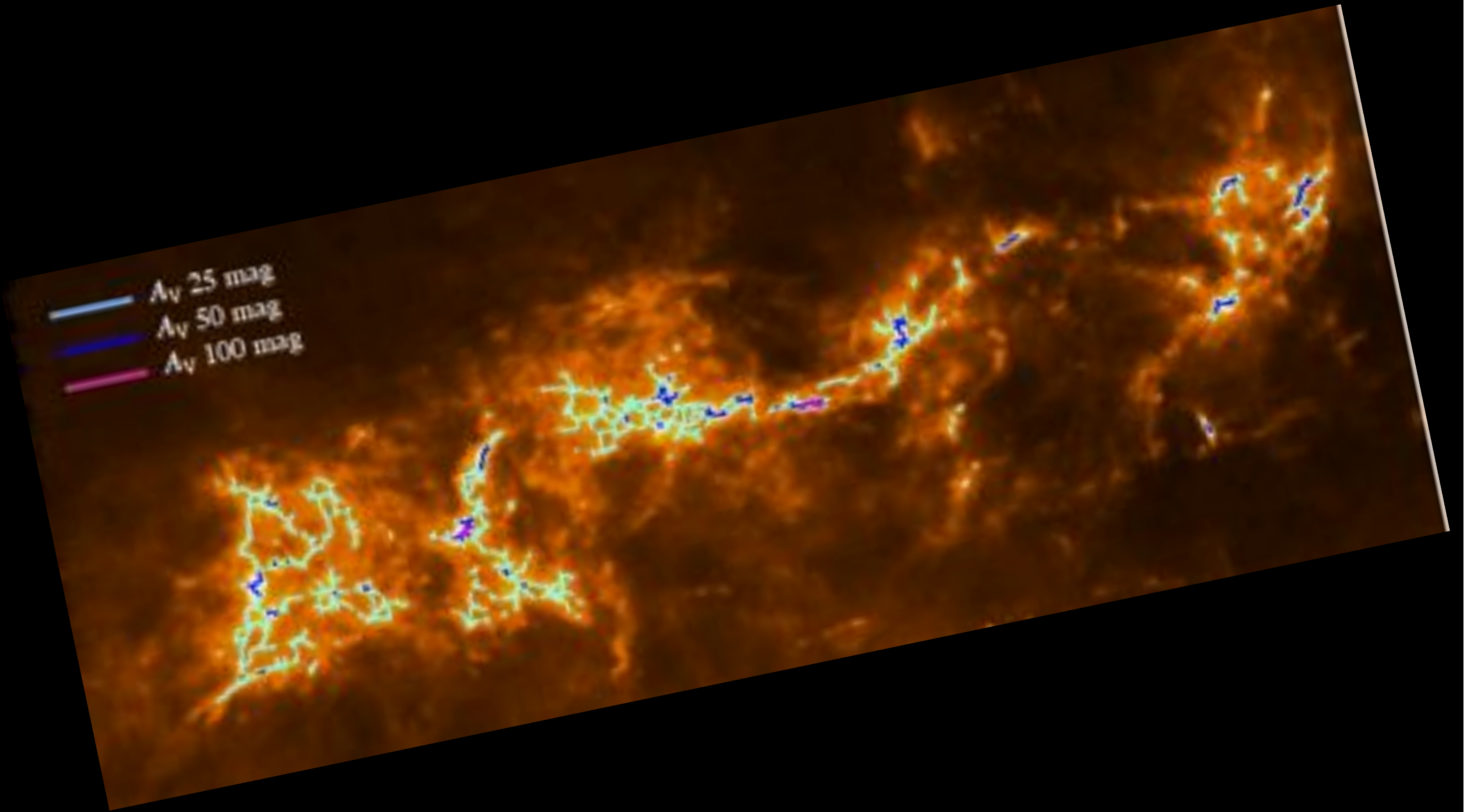
Combined image: Herschel + BLAST + Hα (V. Minier)

Vela C



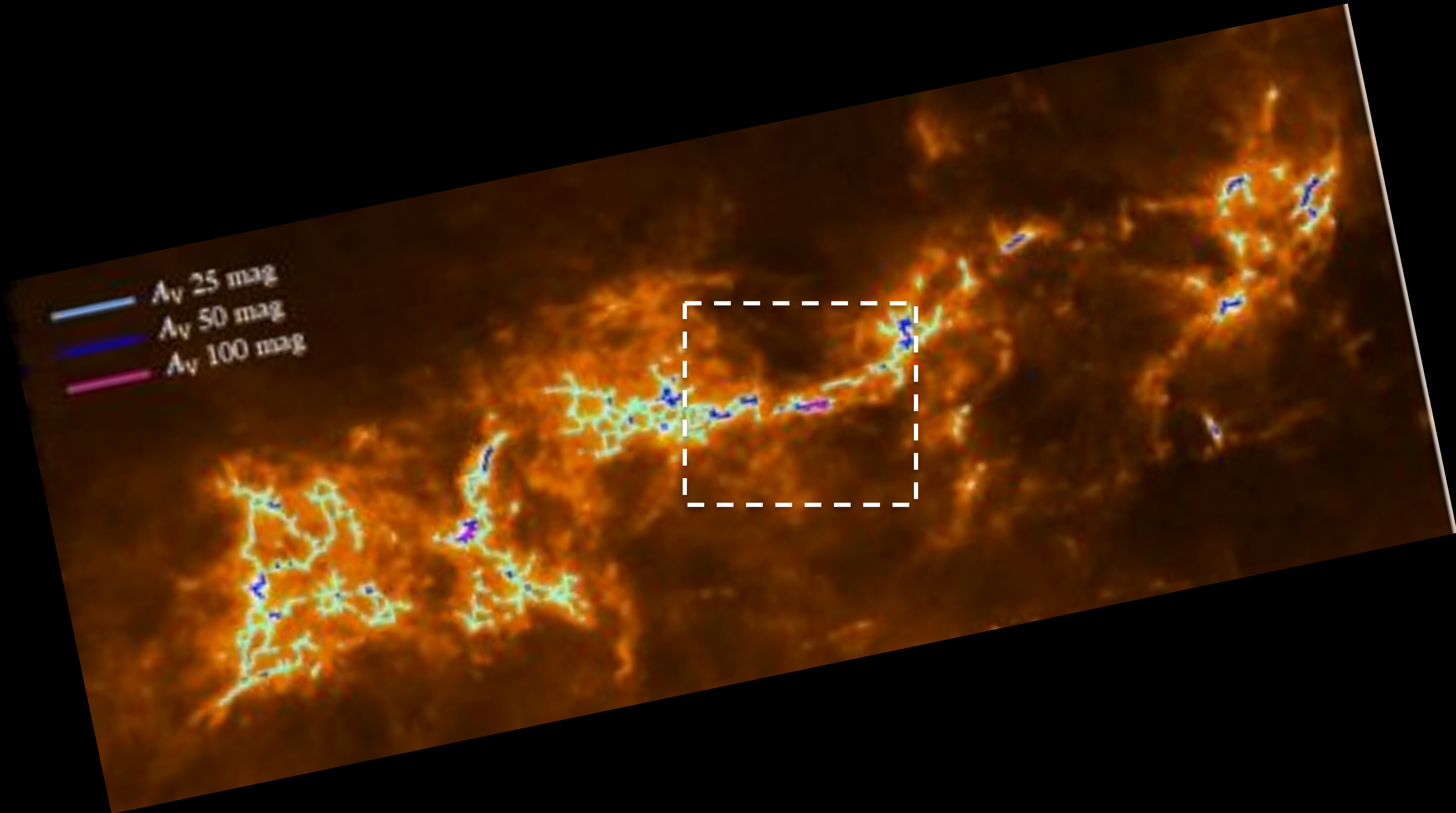
Combined Herschel image (Hill et al. 2011)

Vela C: filamentary structures in column density



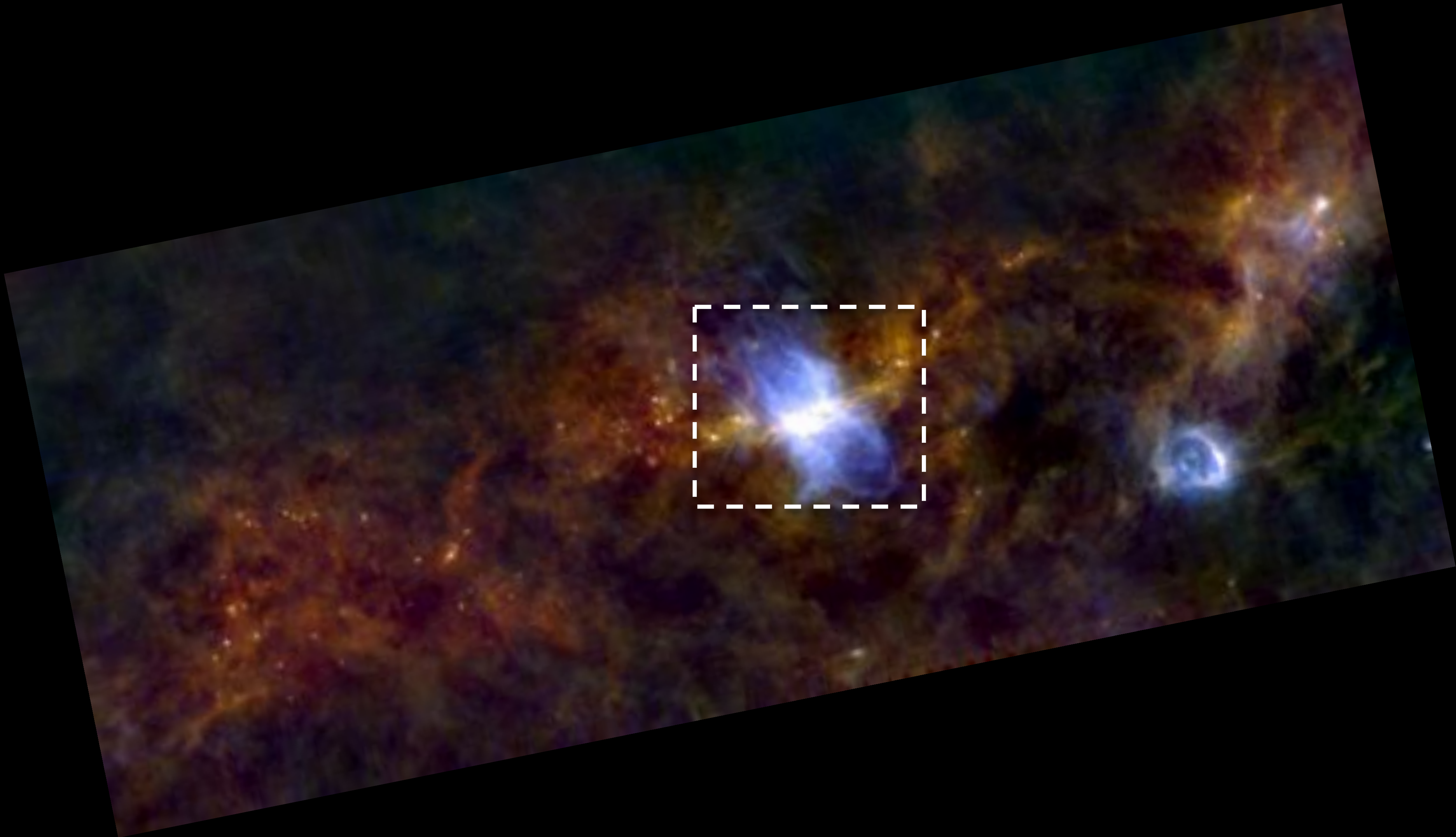
Herschel column density image (Hill et al. 2011)

RCW 36 in Vela C: a filament with 2 cavities on each side



Herschel column density image (Hill et al. 2011)

RCW 36 in Vela C: bipolar HII region

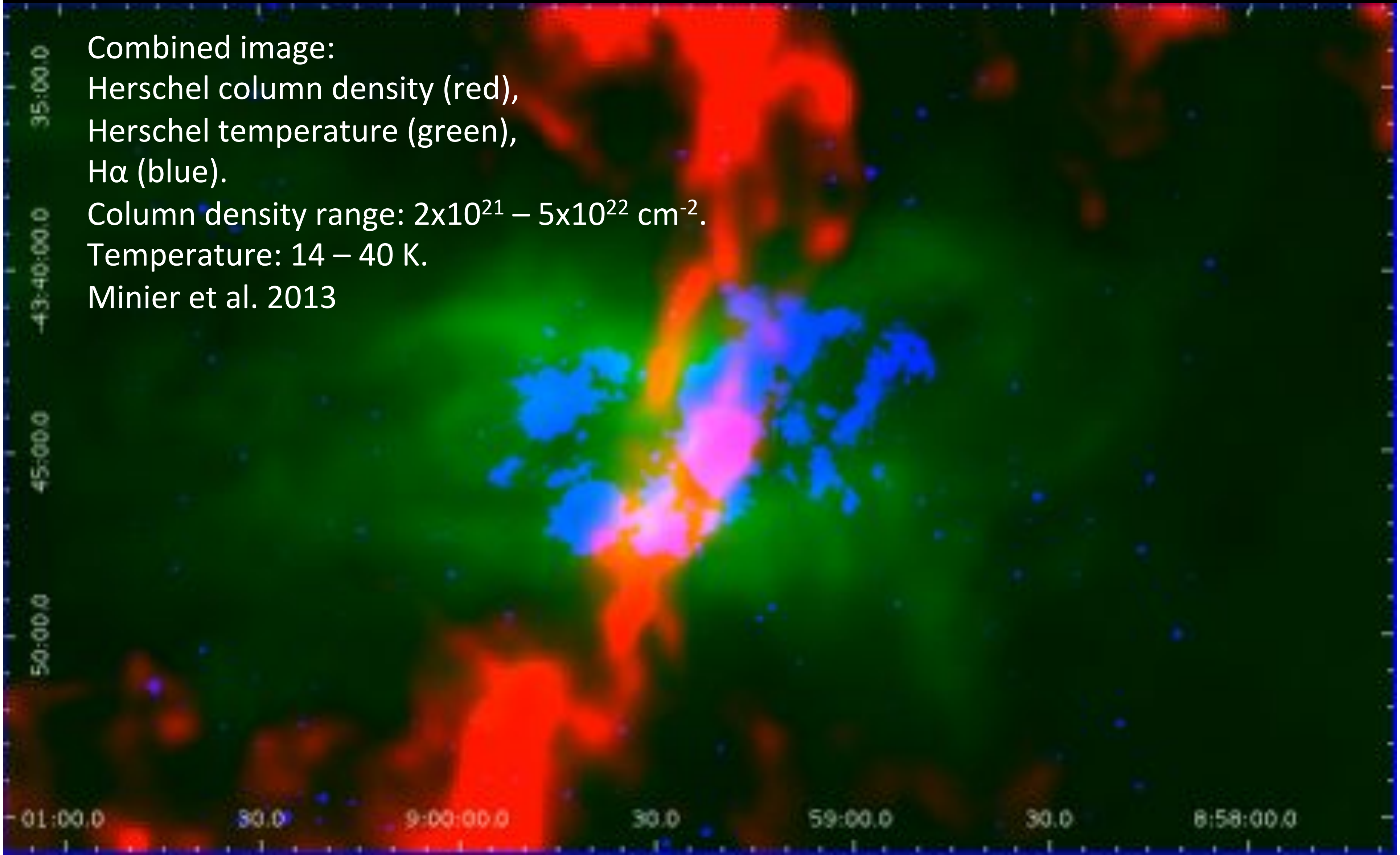


Combined Herschel image (Hill et al. 2011)

RCW 36 in Vela C: bipolar HII region

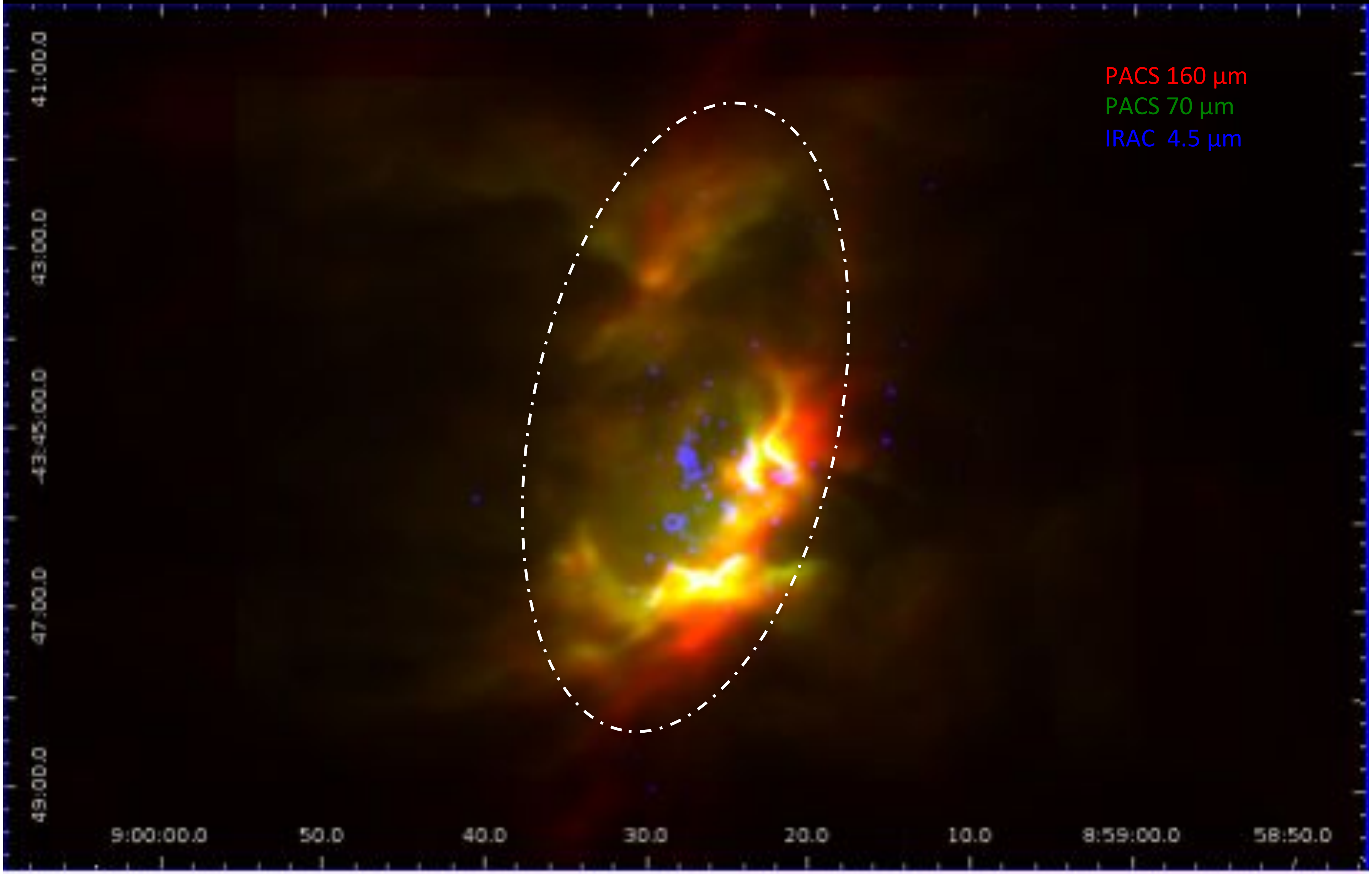
Combined Herschel image (Hill et al. 2011)

RCW 36 in Vela C: bipolar HII region



Combined image:
Herschel column density (red),
Herschel temperature (green),
Hα (blue).
Column density range: $2 \times 10^{21} - 5 \times 10^{22}$ cm^{-2}.
Temperature: 14 – 40 K.
Minier et al. 2013

RCW 36 in Vela C: ring of matter



The RCW 36 cavity in Vela C: bright rims, pillars and clumps

Star cluster:
350 stars
3000 stars.pc^{-2}
2-3 Myr old
One O9.5 star
$6x10^{47}$ ph.s^{-1}

Image: Spitzer/IRAC (Minier et al. 2013). Star cluster has been reproduced using 2MASS and Spitzer data.

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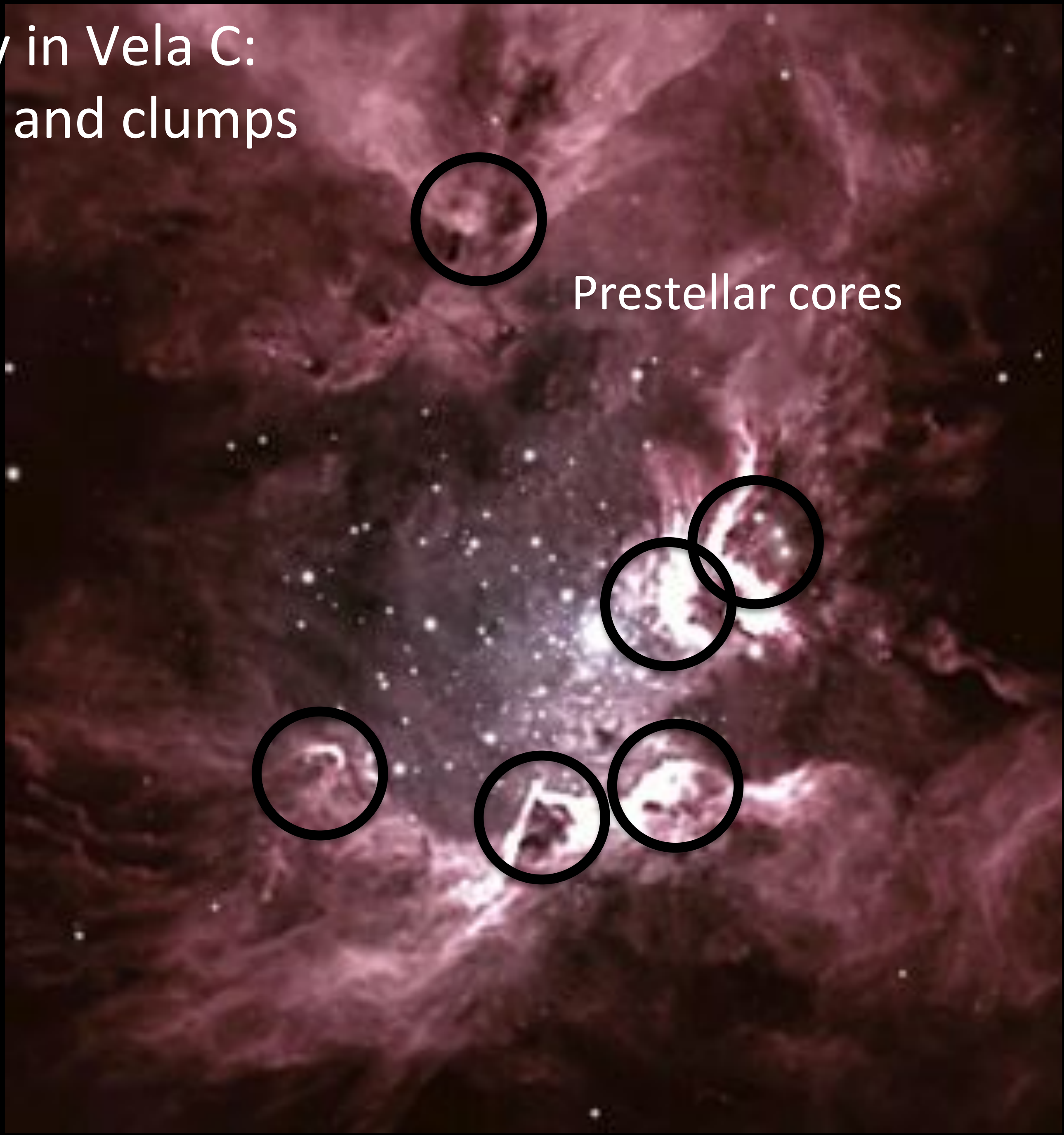

Image: Spitzer/IRAC (Minier et al. 2013). Star cluster has been reproduced using 2MASS and Spitzer data.

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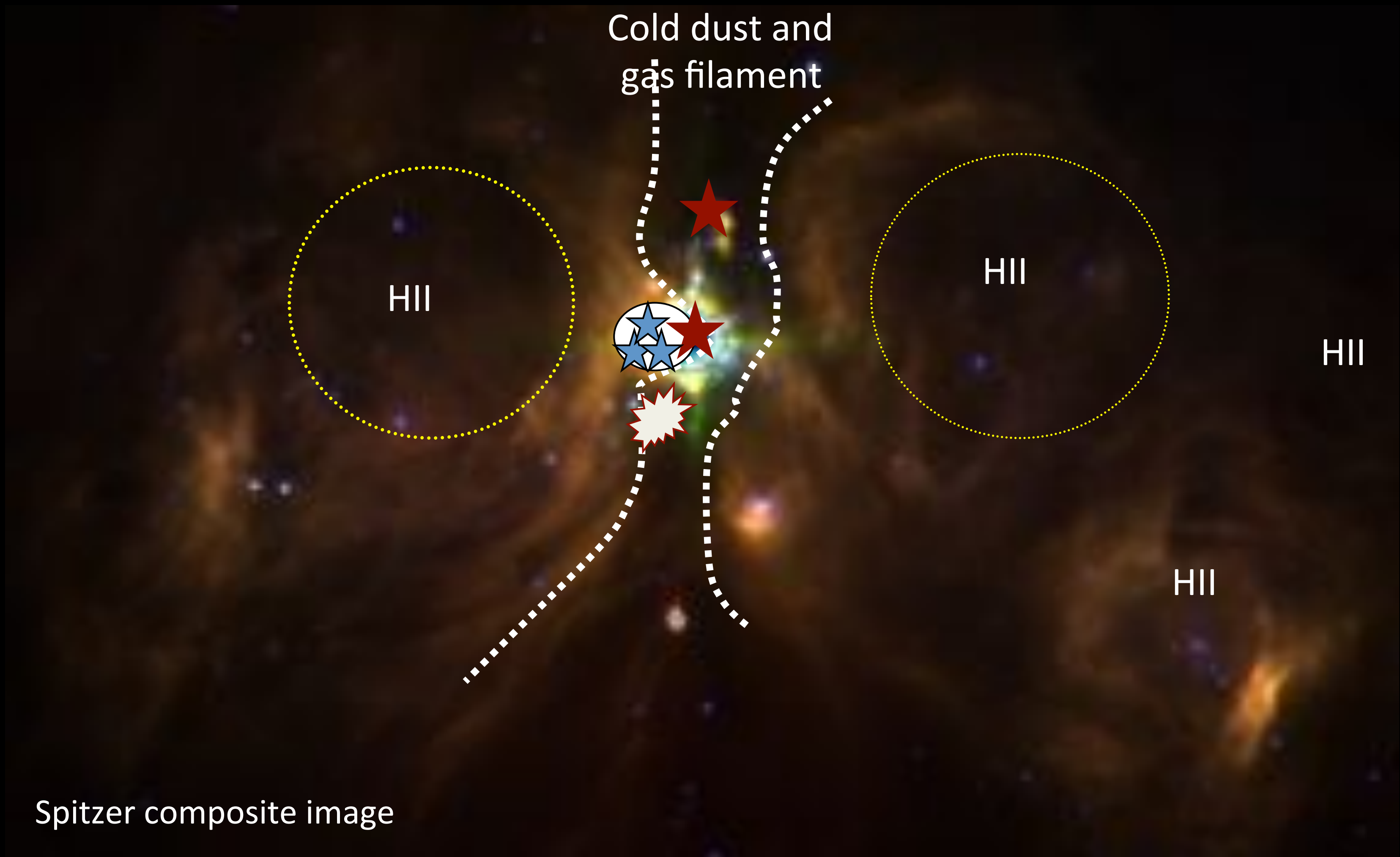
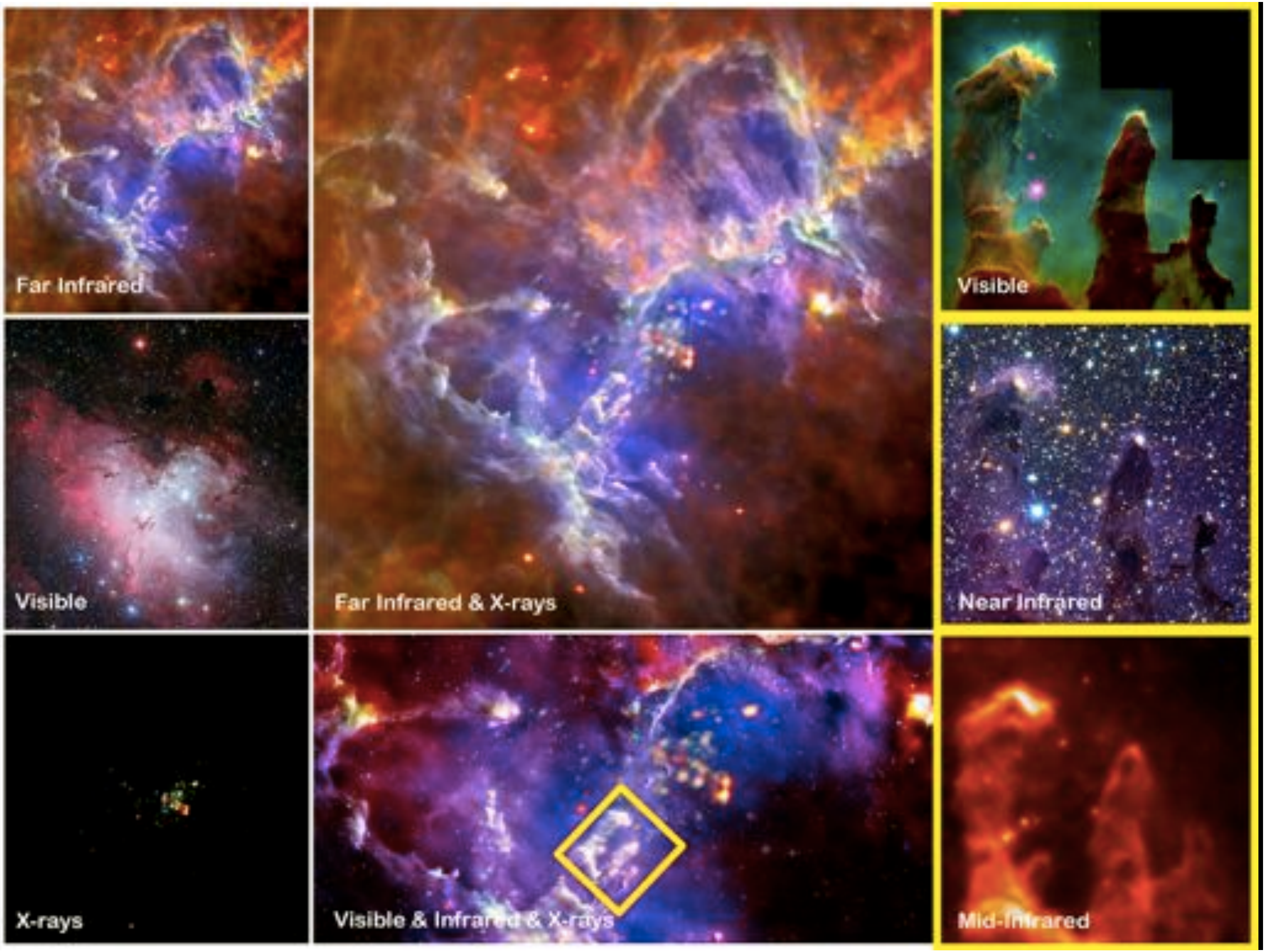
Complex S 255 – S 257

3 generations of stars




Far Infrared
Visible
X-rays
Far Infrared & X-rays
Visible & Infrared & X-rays
Visible
Near Infrared
Mid-Infrared

Conclusions

Habitability is related to Earth conditions (including Sun) and appears as a rare combination of constraints.

Looking for analogs of solar nebula formation

Our results suggest that the RCW36 environment is the scene of

- the ionisation of a molecular filament by a star cluster ;
- the expansion of a HII region ;
- the triggered formation of potentially new stars.

confirming that Sun formation scenario may still happen.

However: timescale seems more rapid (1-5 Myr) than what is proposed by Gounelle et al.

Circumstellar Habitable Zone > Triggered star formation phase > Galactic Habitable Zone