# Entangled In Cirrus:
# The Star Formation Environment at High Galactic Latitude

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*a co-production of the Planck/Herschel "Cold Cores" and WISE "Taurus" teams*

Drawing on large-area surveys spanning the optical [SDSS] to the millimeter [*Planck*] wavelengths we assess the environment and conditions for star formation at $|\beta| > 20°$. This assessment has the goals of 1) distance determination of features in the Galactic ISM, 2) identification of candidate pre-stellar cores, and 3) selection and spectroscopic verification of young stellar objects.

Results are presented for interstellar clouds located within the Sloan Digital Sky Survey DR9 imaging that are away from the anti-center star formation regions (Orion, Taurus, Perseus). Candidate T Tauri stars are identified on the basis of SDSS+2MASS+WISE multi-band imaging and classified by follow-on observations at the Palomar Observatory Hale Telescope.

### Cold Cores as seen by Planck and Herschel
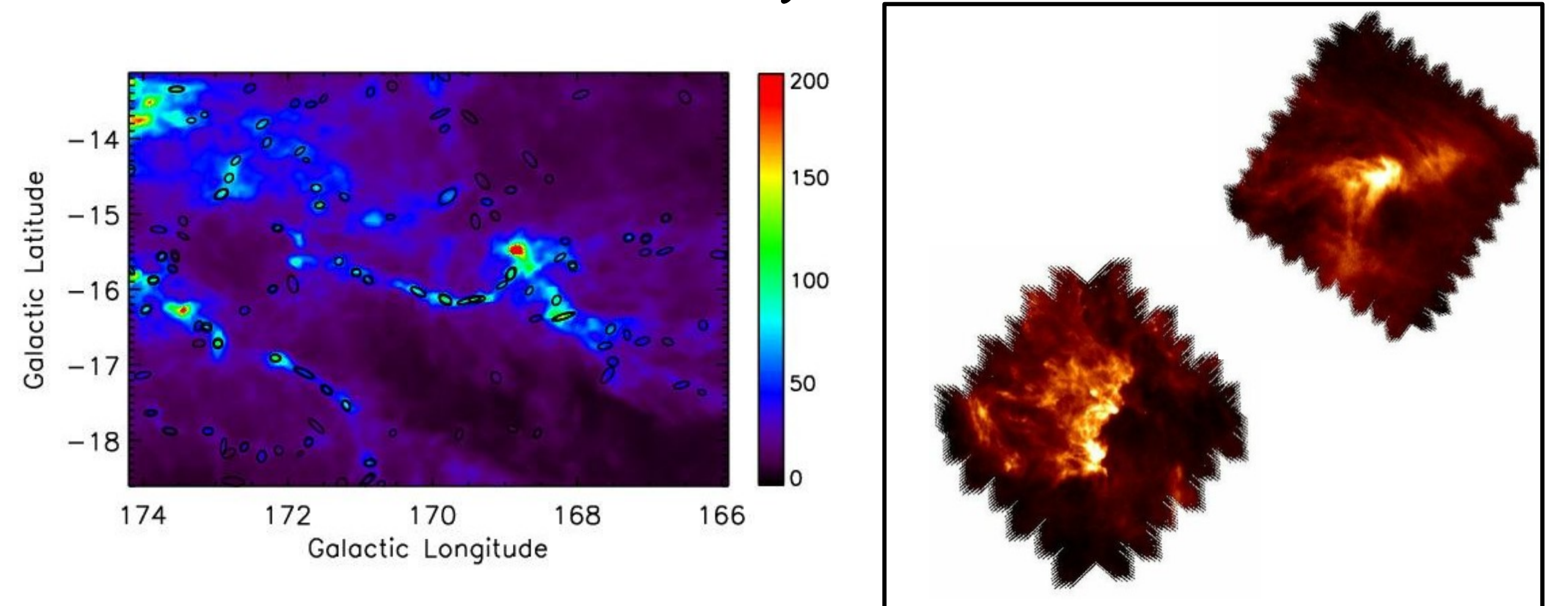


**Cold clumps** are detected on the basis of excess emission in the *Planck* submillimeter bands relative to the IRAS 100 micron traced warm component of the gas **[Planck Collaboration 2011, A&A 536 A23].**

Association with structures in the ISM, including these filaments in Taurus [*Planck* 857 GHz map; **left**], and follow-on observations with *Herschel* [SPIRE 250 microns; **right**], the Caltech Submillimeter Observatory, and other facilities show that these are Galactic cold pre-stellar cores.

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**DISTANCES** are obtained from analysis of SDSS photometry to determine the line-of-sight reddening to individual stars [**Berry et al. 2012 ApJ 757 166; McGehee et al. 2013 (in prep)**].

The Planck Early Release Cold Clumps catalog [ECC] contains 915 sources, 108 of which are at $|\beta| > 20°$. Of these 44 are located within the SDSS DR8 imaging footprint. All of these are found to be within several hundred parsecs of the Sun.

Representative derived E(B-V) reddening profiles are shown for ECC sources in a cirrus field [**left**] and the MBM 12 molecular cloud [**right**]. The mean SFD98 [**Schlegel et al. 2008 ApJ 500 525**] reddening in each 15 arcmin radius field is marked for reference, and the mean and standard error is overplotted for 100 pc bins.



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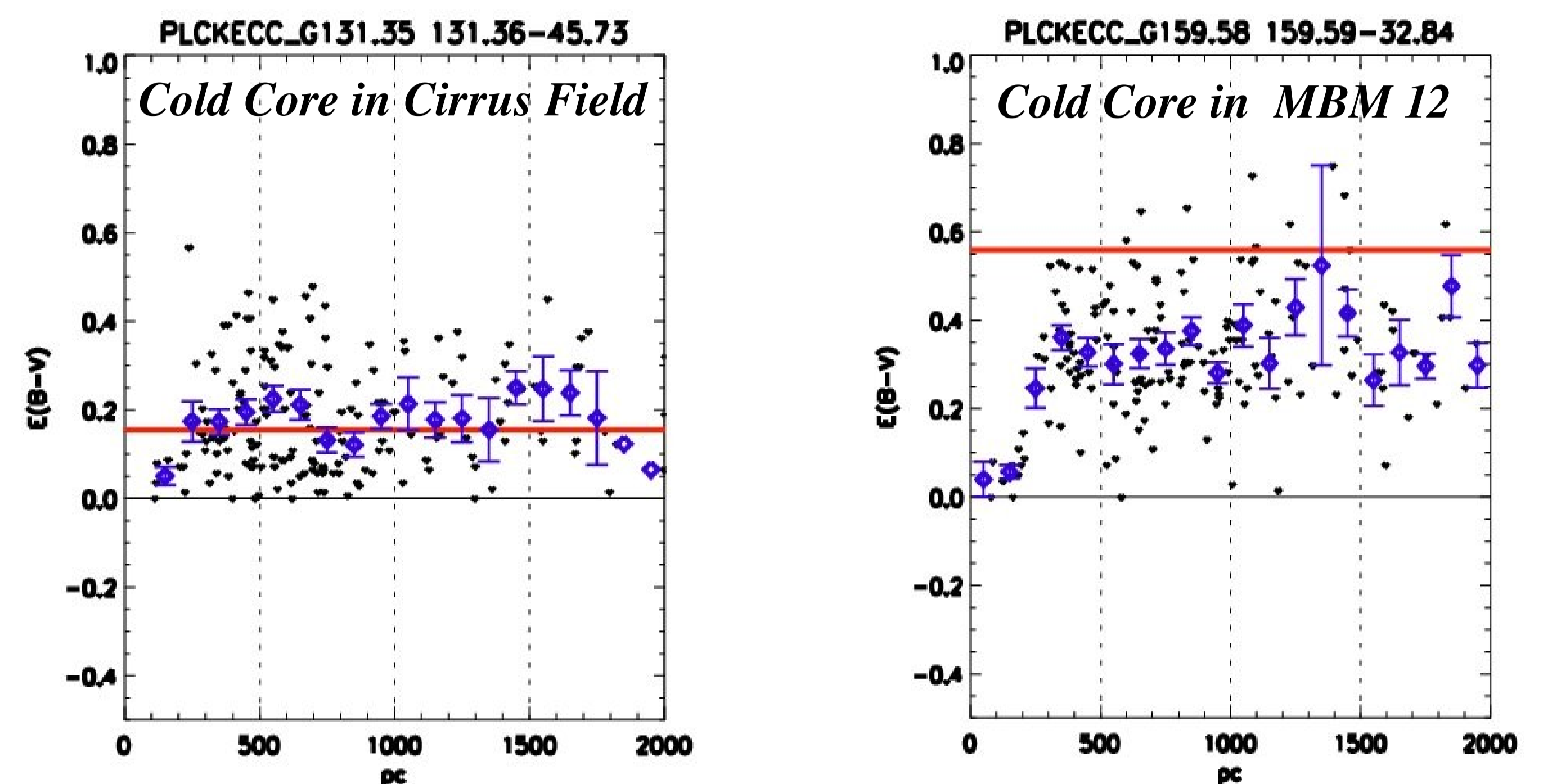
**CANDIDATE YOUNG STELLAR OBJECTS** are selected using basis of the WISE photometry [**Koenig et al. 2012 ApJ 744 130**] for one degree square fields centered on each high latitude cold clump. SDSS imaging and star/galaxy separation [**center**], WISE W3 [12 micron] and W4 [22 micron] background characterization [**left**], and SDSS+2MASS+WISE spectral energy distributions [**right**] are used to remove likely contaminants and sources lacking robust infrared excesses.
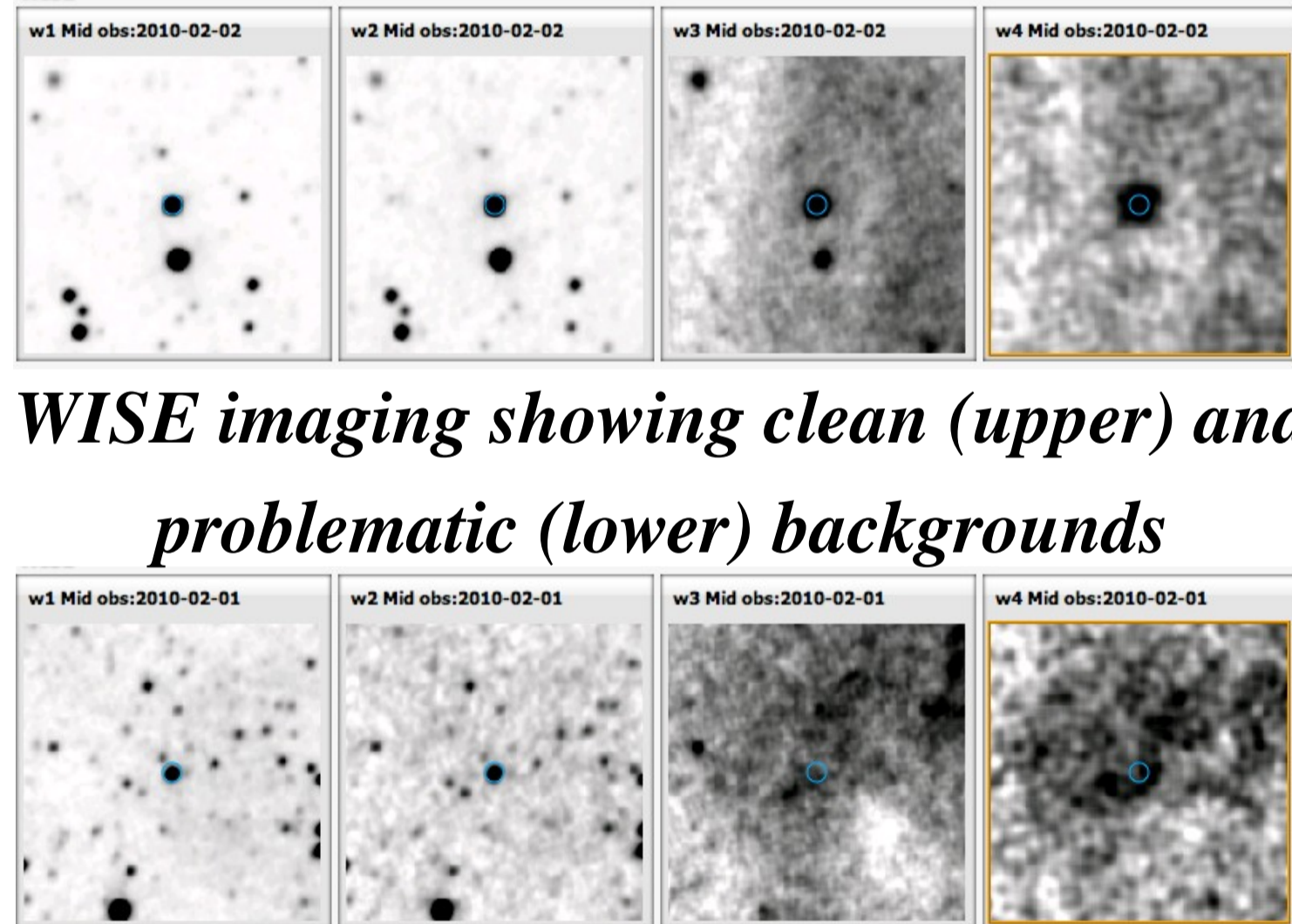


*WISE imaging showing clean (upper) and problematic (lower) backgrounds*
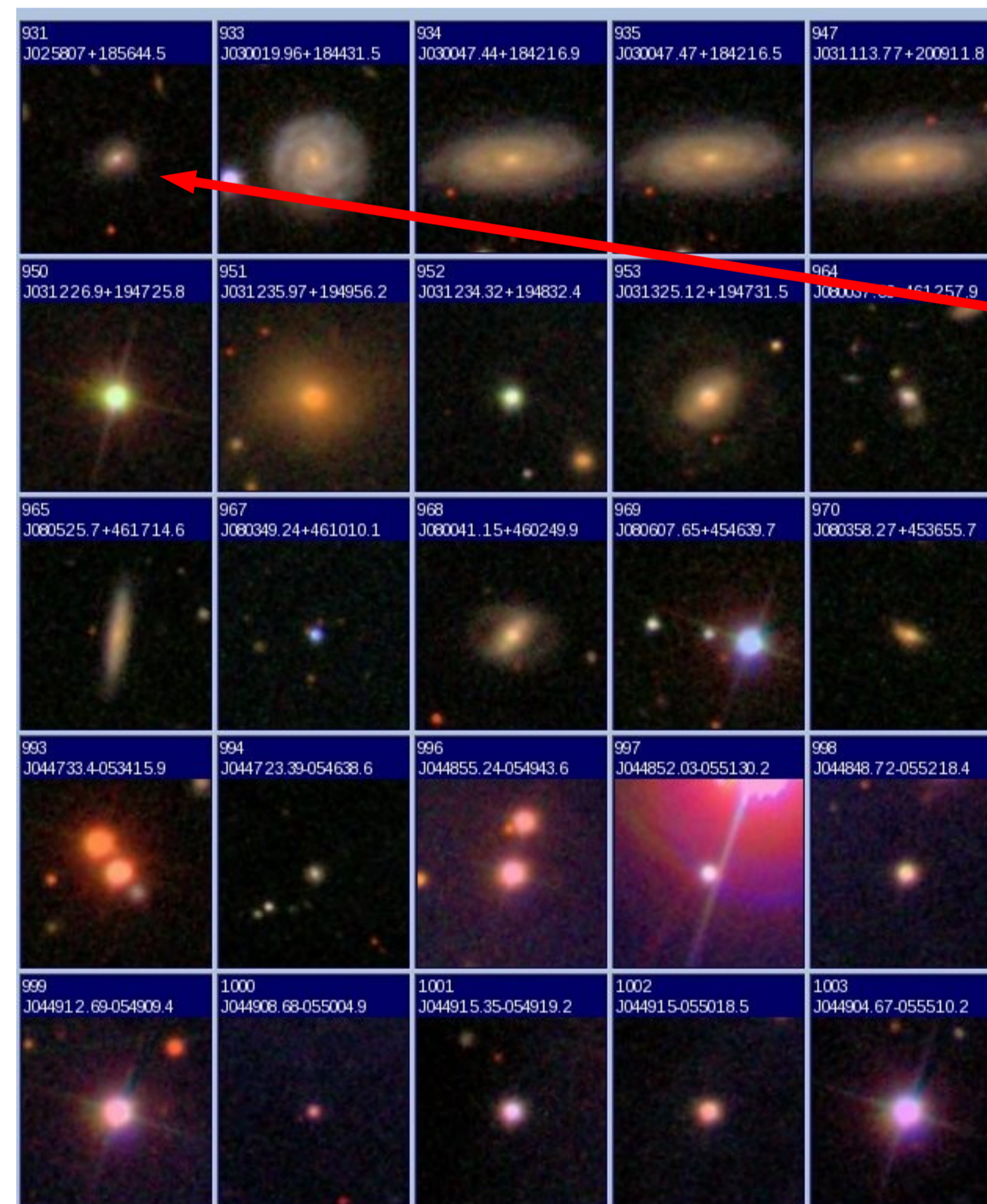
### SDSS Imaging and Corresponding SDSS+2MASS+WISE Spectral Energy Distributions



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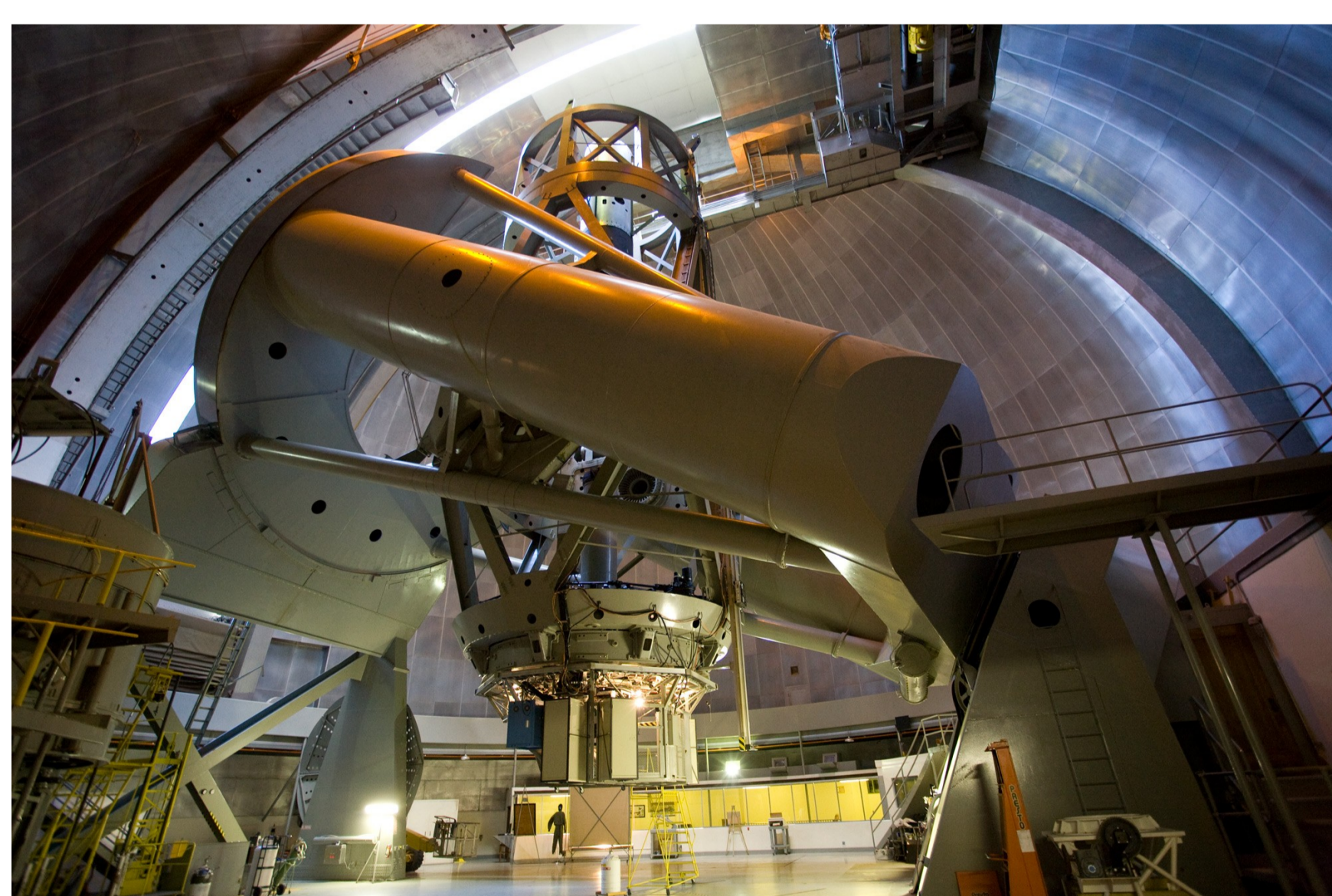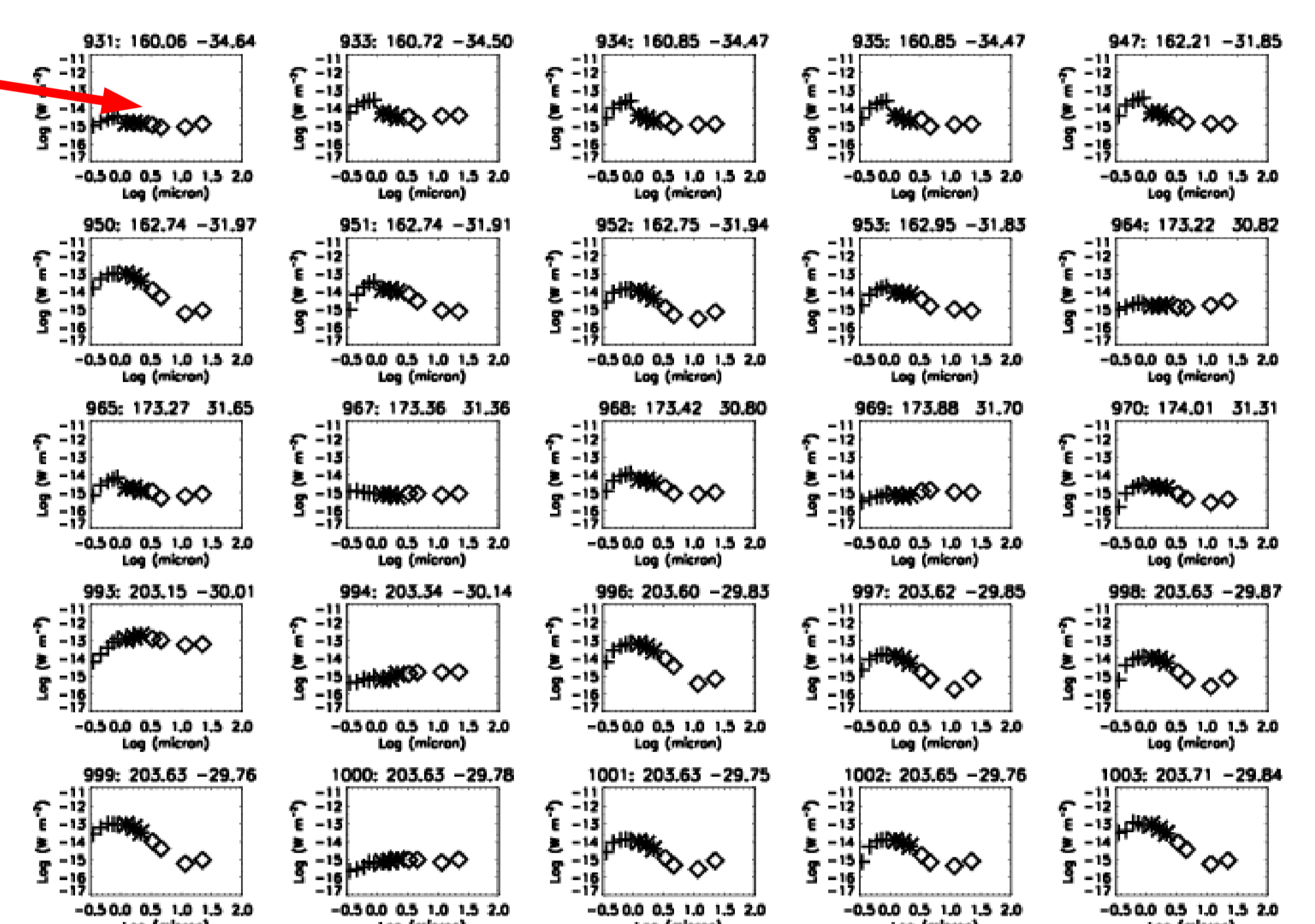
**THE INITIAL PALOMAR SPECTROSCOPIC SURVEY** conducted in May 2013 of targets with RA between 8 and 22 hours and having r < 18 uncovered no high-latitude YSOs apart from several Classical T Tauri candidates in the Cepheus Flare [**left - green: emission-line stars, blue: other objects, red: r > 18 (not observed)**] The other regions studied in this DoubleSpec run were Ophiuchus North, the Bok Globule CB 77, and the MBM 40 cloud.

The success rate of the selection algorithm was much lower in these high latitude regions than for previous applications in Taurus and Lambda Orionis.

### YSOs in the Cepheus Flare



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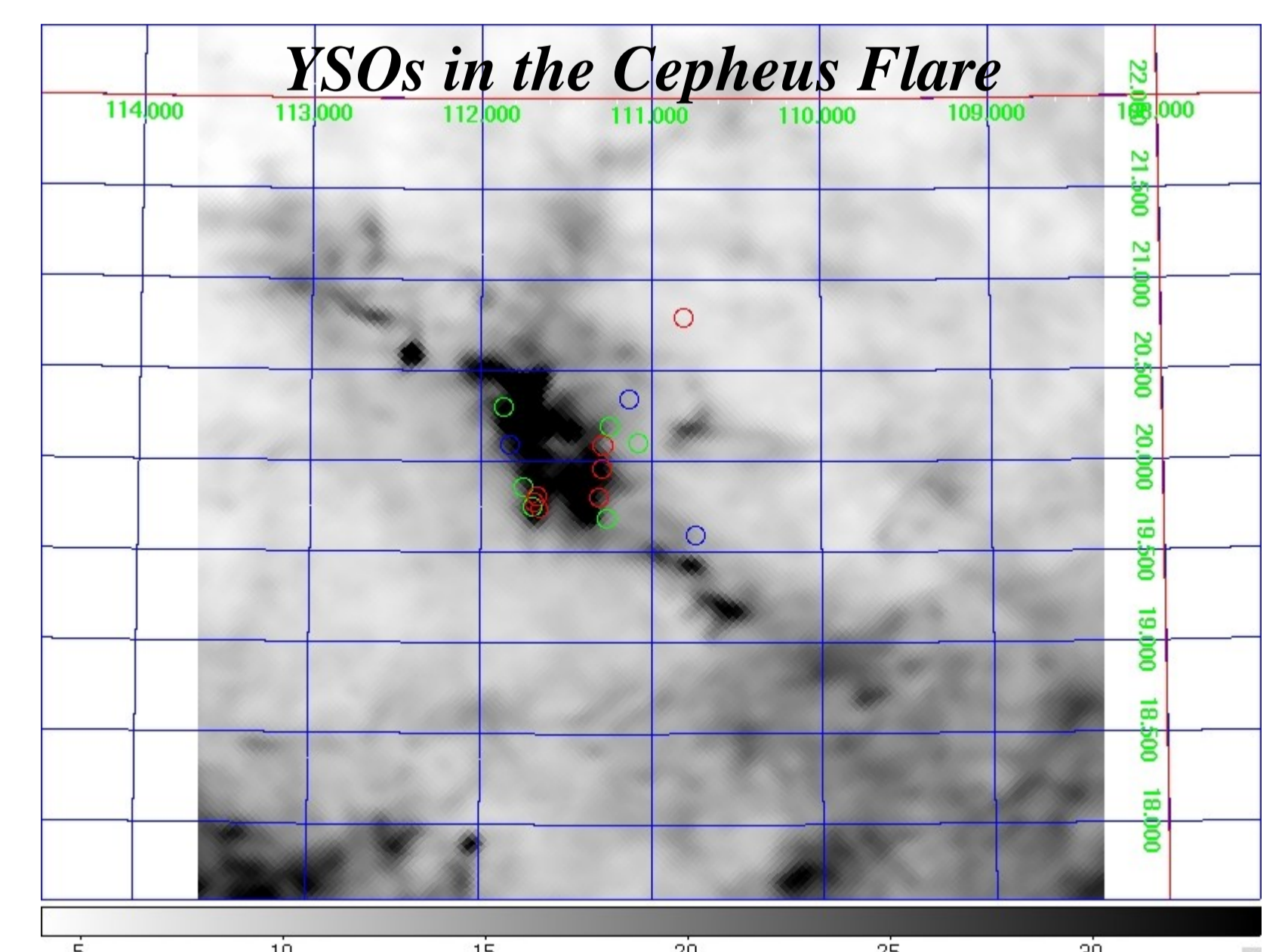
**IMPLICATIONS** for star formation in high latitude environments are that while cold pre-stellar cores are found in even cirrus structures [**left - Herschel observations of cores in the Polaris Flare from Ward-Thompson et al. 2010 A&A 518L 93**], active star formation is so far only seen in the densest clouds and perhaps requiring external triggering, as in the case for MBM 12 [**right – from McGehee 2008 Handbook of Star Forming Regions Vol II 813**].
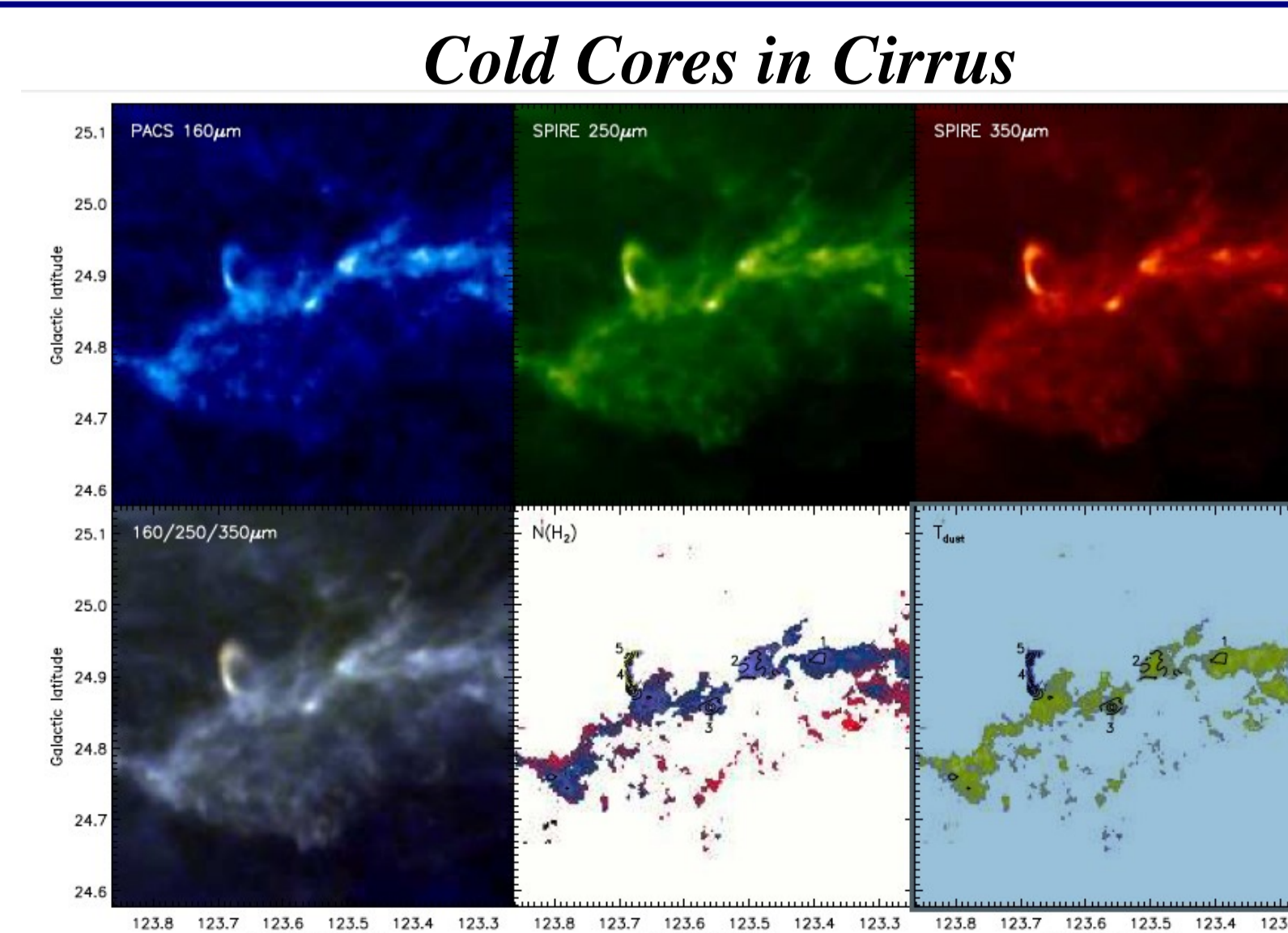
### Cold Cores in Cirrus
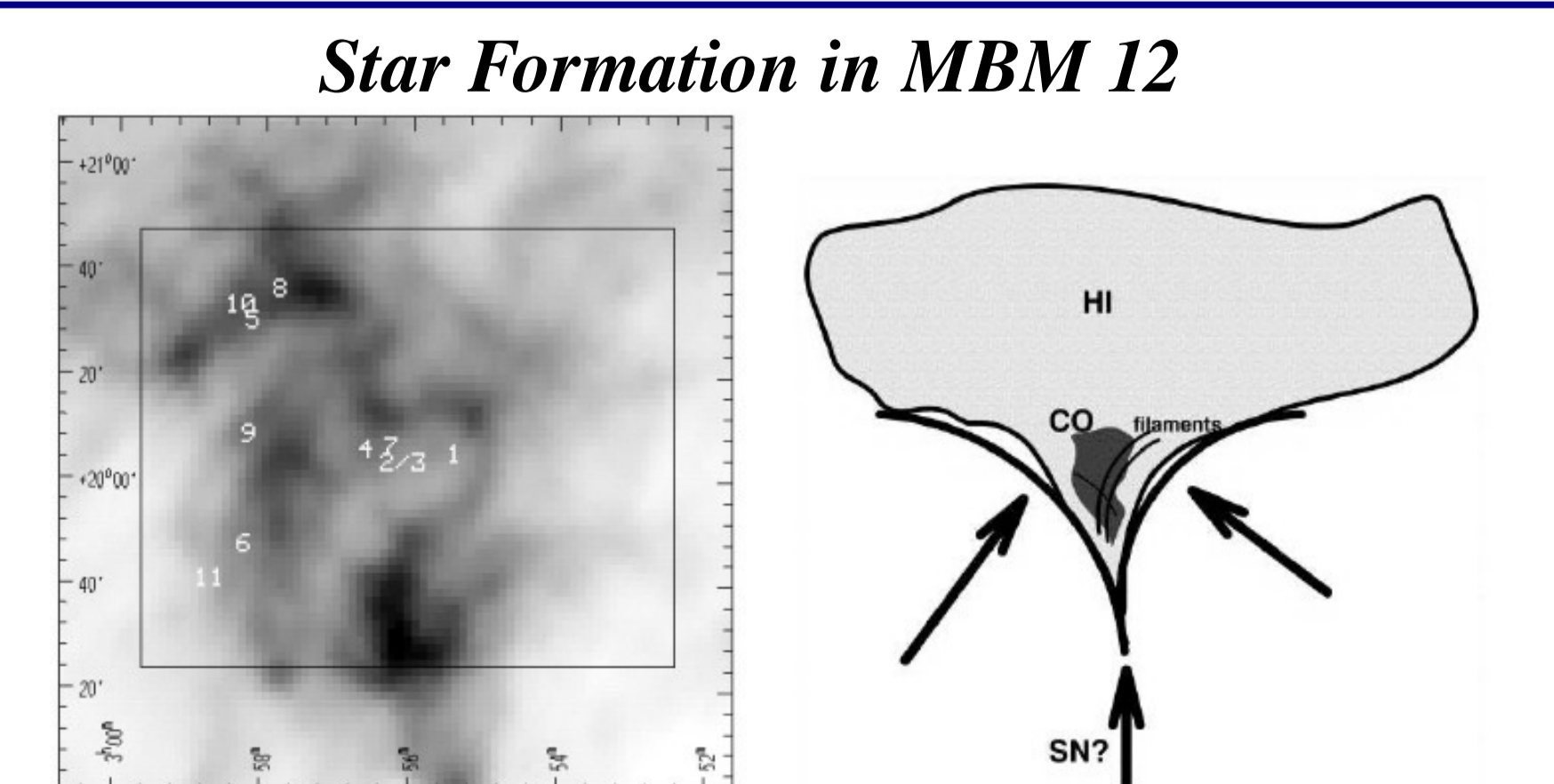


### Star Formation in MBM 12



Figure 5. The left panel shows the locations of MBM 12A 1–11 marked on an IRAS 100 $\mu m$ image of the MBM 12 cloud (from Luhman 2001). On the right (from Moriarty-Schieven, Andersson, & Wannier 1997) is a depiction of a possible triggered star formation scenario due to an external supernova.