The Near Infrared Continuum Emission of Visual Reflection Nebulae

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Background/Overview

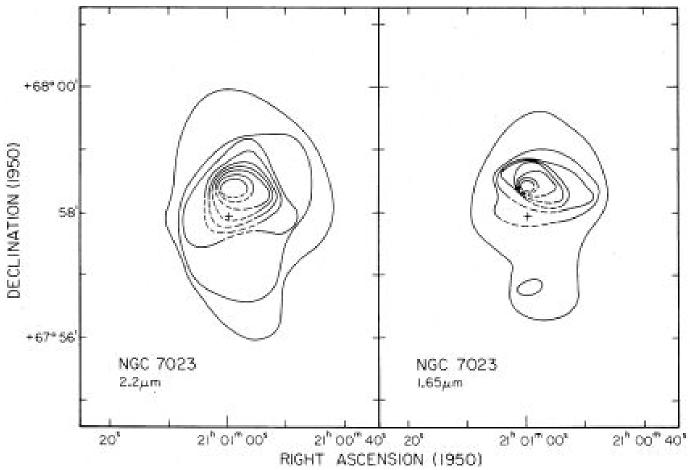
- Reflection nebulae are regions of non-emitting gas and dust.
- By early 1980s, these had been well-studied in visible and UV wavelength ranges.
- Subsequent IR measurements show:
  - Different nebulae have similar colors, despite different central stars.
  - Color temperature is oddly high.
  - NIR brightness higher than reflection predicts.
  - Unidentified narrow emission features at 3.3 and 3.4 microns.
- Goal: Expand on these measurements and account for this emission.

Observations

- Broad-band photometry obtained at 1.25 (J), 1.65 (H), 2.2 (K), 3.5 (L), 3.8 (L’), and 4.8 (M) microns for various positions in objects NGC 7023, 2023, and 2068 and their central stars.
- Spectra obtained between 1.9 and 3.7 microns in the same objects and their central stars.
- Data taken from Mt. Wilson and IRTF. Diaphragm size between 12” and 60”. (NGC 7023 is about 16’ by 16’.)
- “To date no satisfactory explanation of all the observations is available.”

Photometry by Position

- Multiple location photometry yields maps of surface brightness.
- Distinct trend with distance from central star.
- The trend matches observations in visible band.
- This suggests an emission source related to the central star.



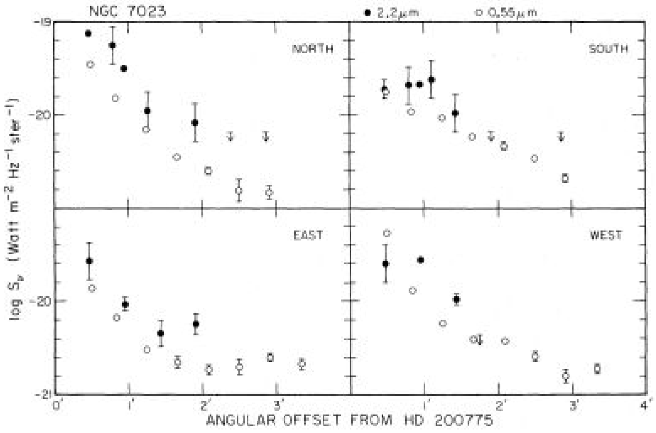
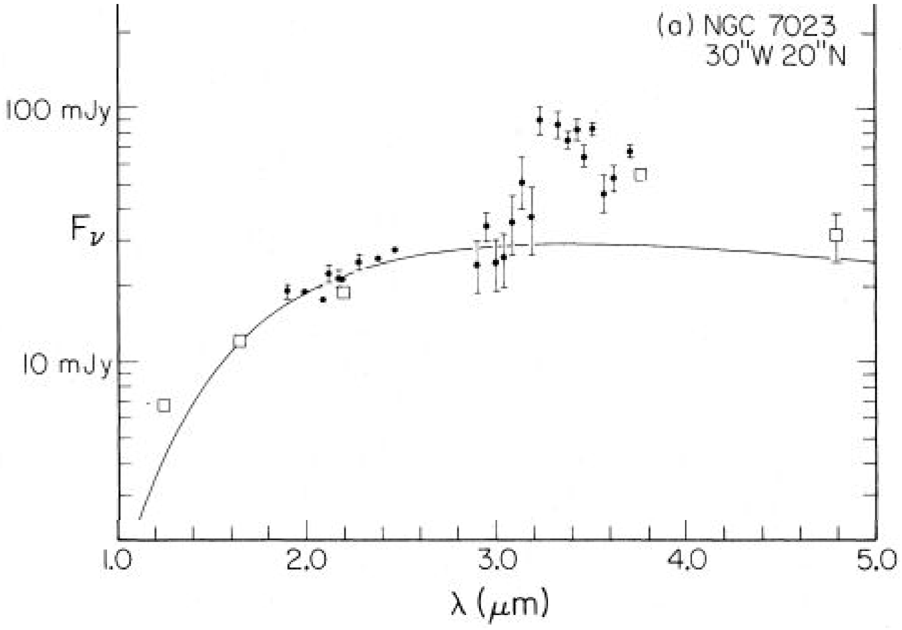


Image credit [1]

Nebular Spectra

- Very little spatial variation
- Emission features at 3.3 and 3.4 microns.
- Color temperature of about 1500 K.



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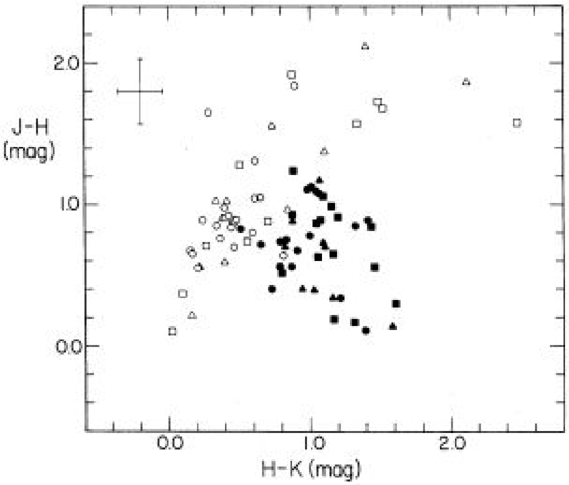
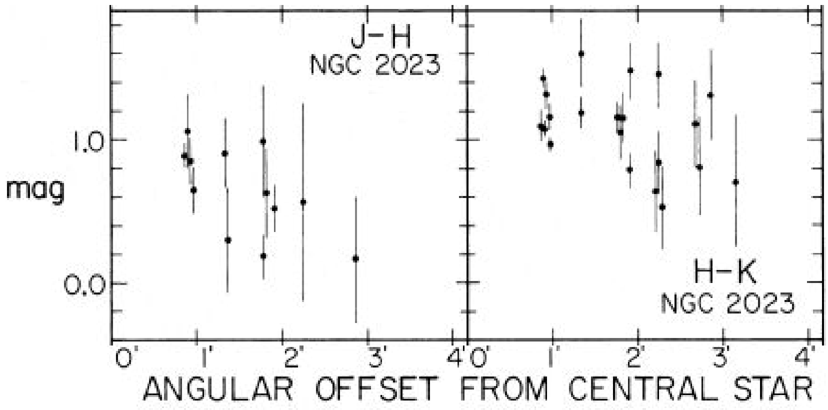
Colors

- Color of nebulae is uncorrelated to color of nearby stars.



- Color of nebulae is uncorrelated to position.
- These data suggest emission is not reflection.



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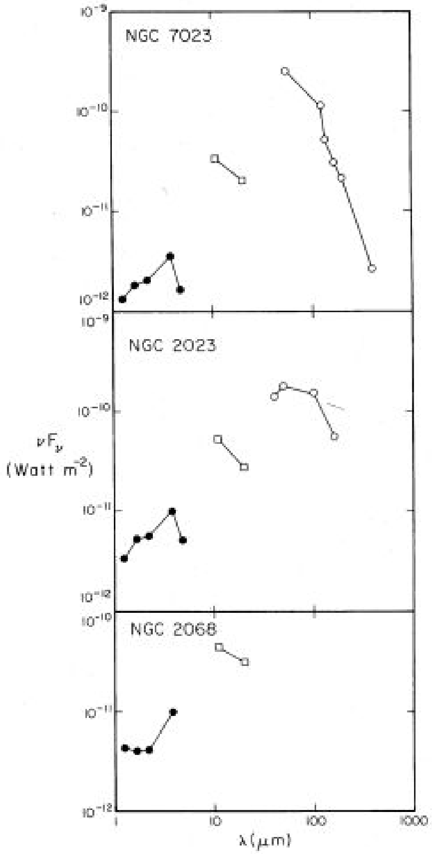
Total Energy Contribution

- The near IR component measured accounts for very little of the total energy.
- Far IR is 30-50x more significant as a total energy fraction.
- Most of the nebular energy is due to thermal radiation at about 50 K.

- Additionally, stellar spectra are not similar to nebular spectra.



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Results

What mechanism can explain these trends?

- Equilibrium emission?
  - Temperature is too high far from the central stars.
- Fluorescence?
  - Continuum emission is too wide a range.
- Pure reflection?
  - There is too much total flux.
- Maybe there are more stars?
  - The colors and surface brightnesses do not work.
- Free-free emission?
  - There is not enough radio emission.

Proposed Model

- Apply Debye theory to dust grains:
  - C_V goes as T^3 at low T.
  - C_V is constant 3Nk at high T.
- Low C_V means high temperature fluctuation.
- Heating can occur absorption of UV photons, chemical reactions on grain surfaces, and collisions with other particles.
- Observations yield minimum required event rate of 7×10^{-8} to 7×10^{-6} s^{-1} for densities involved.
- Rule out all but UV absorption as main contribution.

Proposed Model Continued

- Solve for grain size based on measured parameters.
    - 30 (70) molecules per grain→radius of about 10 angstroms. (This is really small!)
- Are there enough small grains to produce this emission?
- Required fraction of total dust mass in such small grains is not outlandish.
    - Mass fraction closely matches MRN distribution (with some reasonable assumptions).
    - Luminosity fraction also roughly matches.

Model Advantages/Disadvantages

- Emission flux distribution is readily explained.
- Color distribution is readily explained.
- Narrow emission features are <u>not</u> readily explained.
    - Fluorescence?
    - Thermal fluctuation?

Follow-up

- Subsequent surveys of more nebulae and wider wavelength ranges show similar continuum temperature with more narrow features.
- Modeling of particular dust grains matches emission successfully.
- Favored explanation of narrow features is PAH grains.

References

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