C_3 excitation profiles in diffuse interstellar clouds

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astro-ph/0306059
(*ApJ* ~ v595 n1, September 20, 2003)

The Ohio State University International Symposium on
Molecular Spectroscopy
58th Meeting June 19, 2003

C_3 – probe of diffuse cloud density?

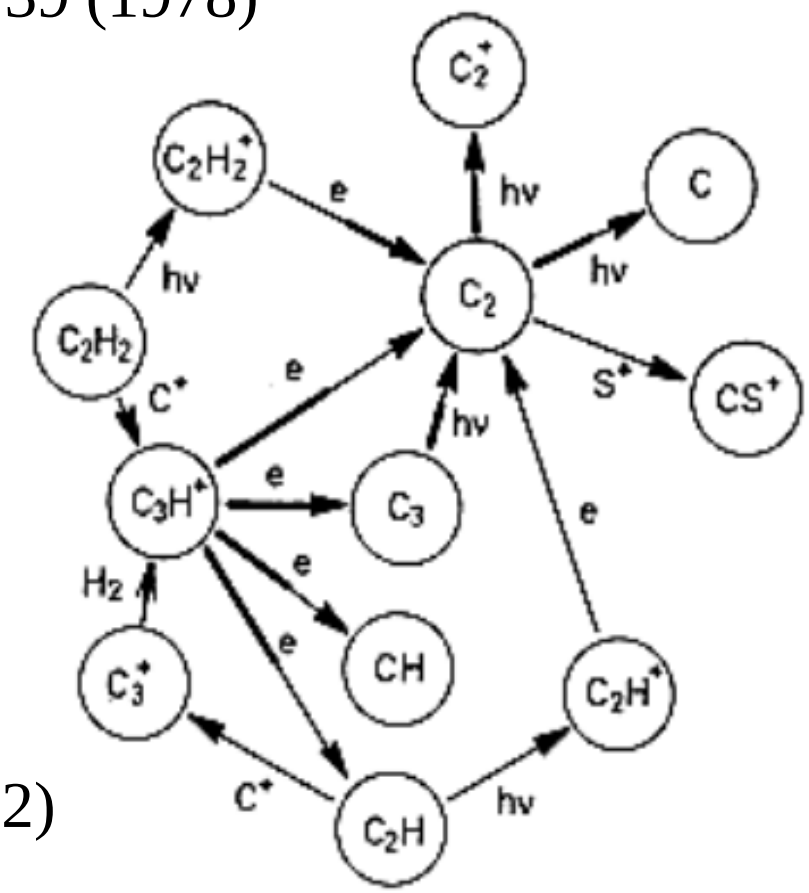
$C_3H^+ + e \rightarrow C_3 + H$

$C_3 + h\nu \rightarrow C_2 + C$ (n~10^3 cm^{-3})

$C_3 + \textit{cosmic ray} \rightarrow C_3^+ + e$ (n~10^4 cm^{-3})

Mitchell, Ginsburg, & Kuntz, *ApJS*, **38**, 39 (1978)

C_3 chemistry expanded, linked to C_2 ?



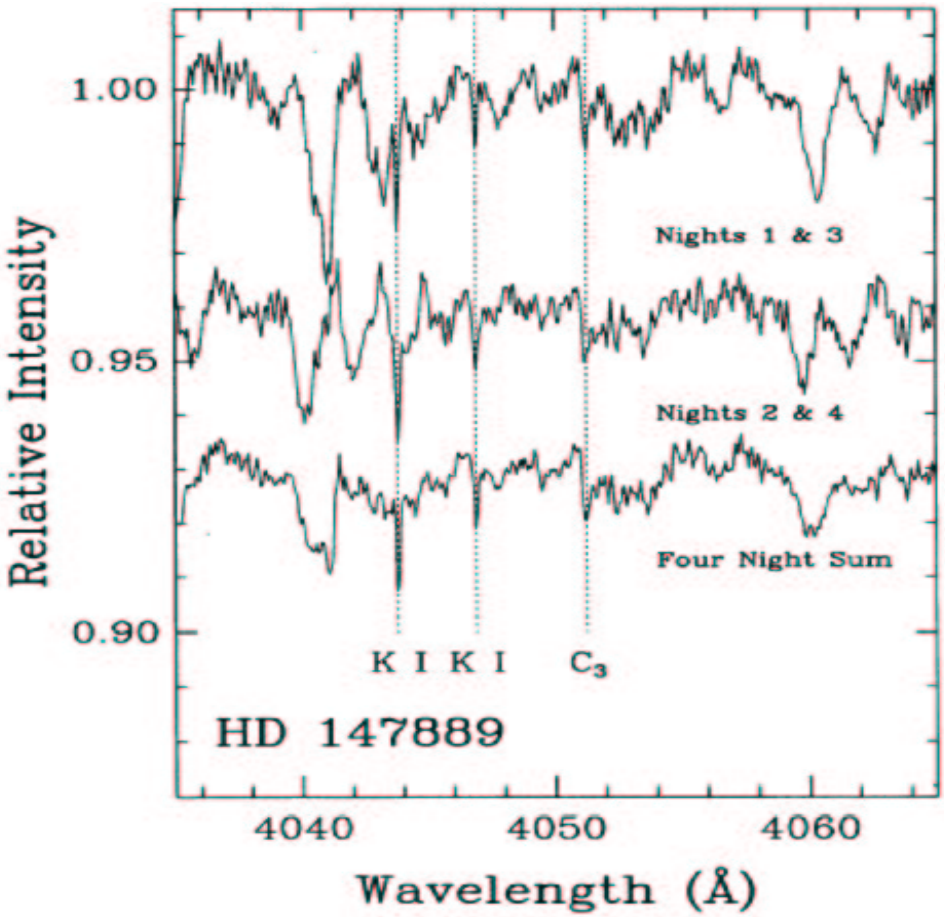
Clegg & Lambert, *MNRAS*, **201**, 723 (1982)

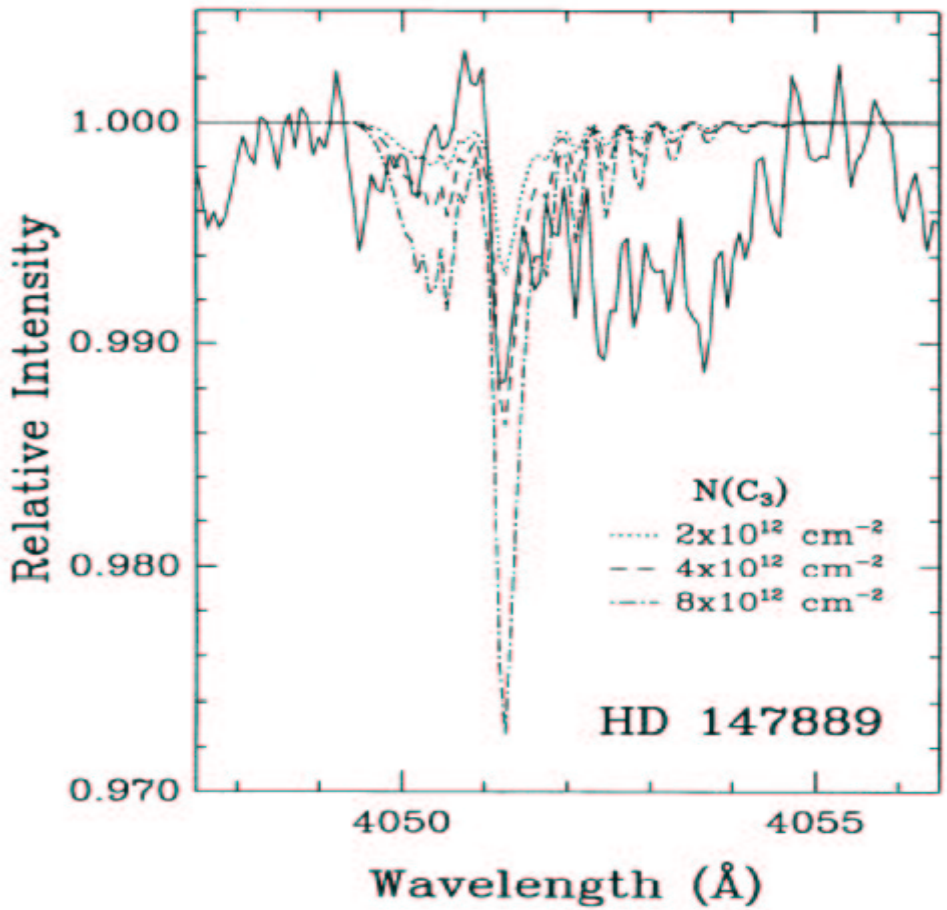
Pioneering efforts

The searches

Clegg and Lambert, *MNRAS*, **201**, 723 (1982)
Snow, Seab, & Joseph, *ApJ*, **335**, 185 (1988)

Tentative Detection

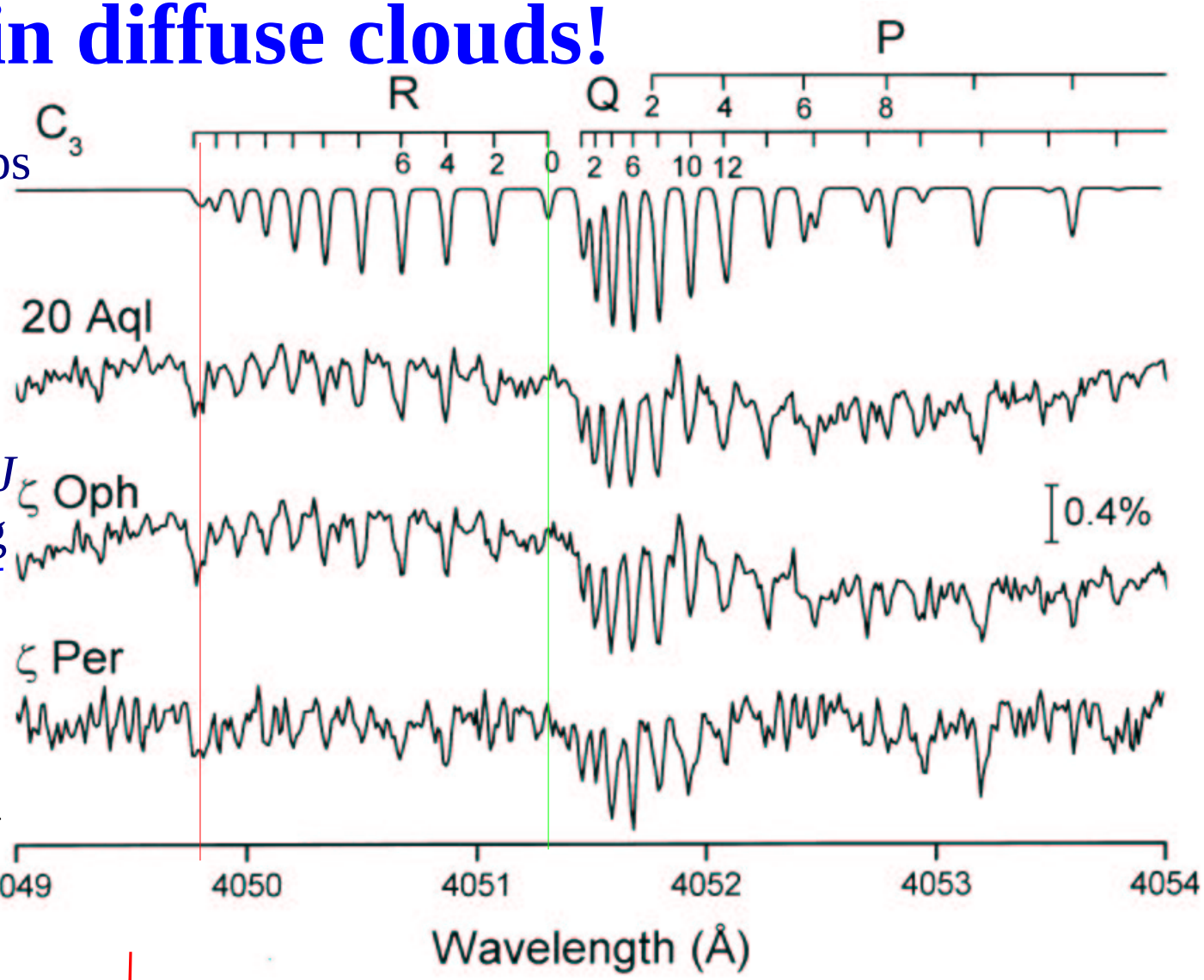


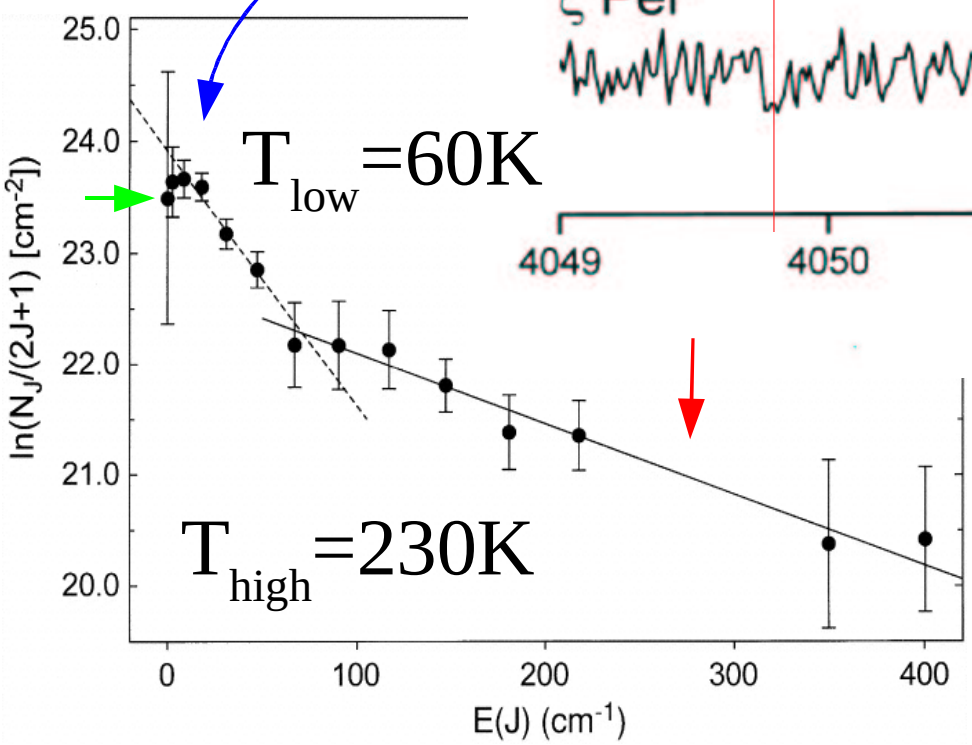


Haffner & Meyer, *ApJ*, **453**, 450 (1995)

C_3 found in diffuse clouds!

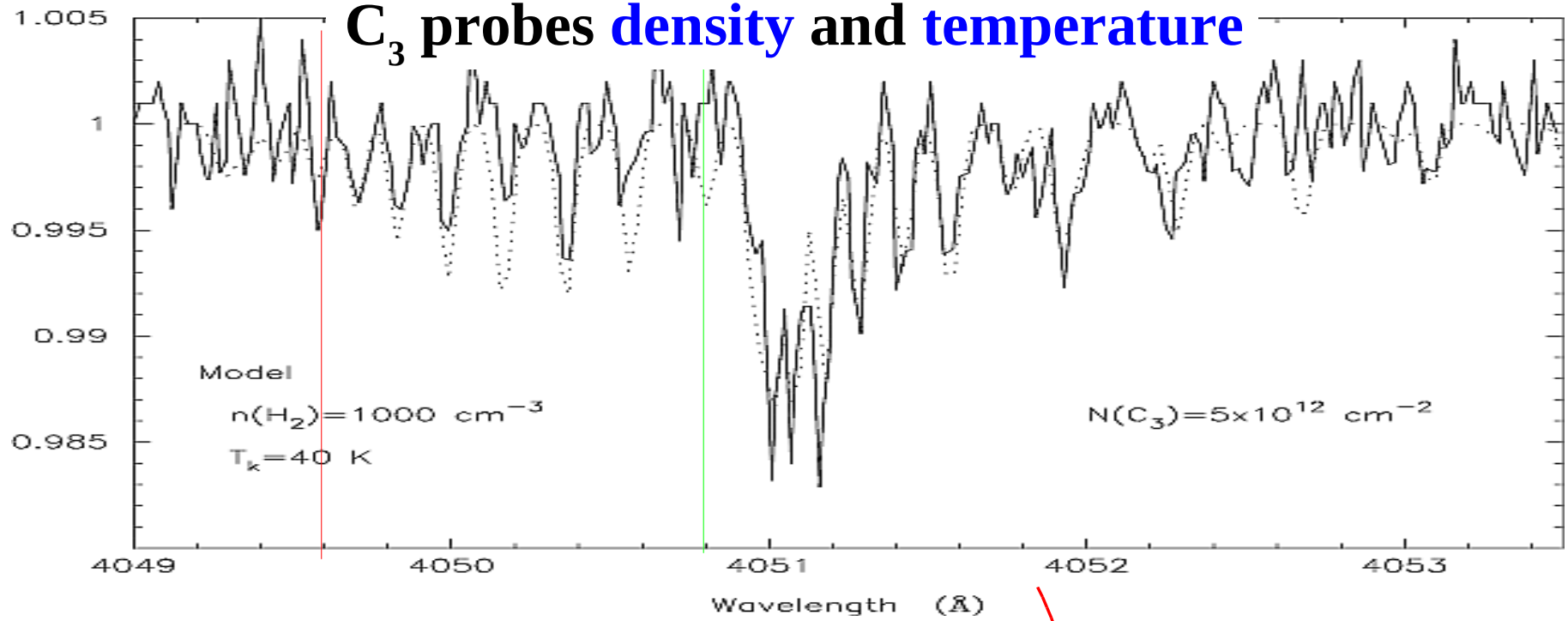
- Two excitation temps analogous to C_2
  - $T_{low} = T_{kinetic}$
- population of high J by radiative pumping

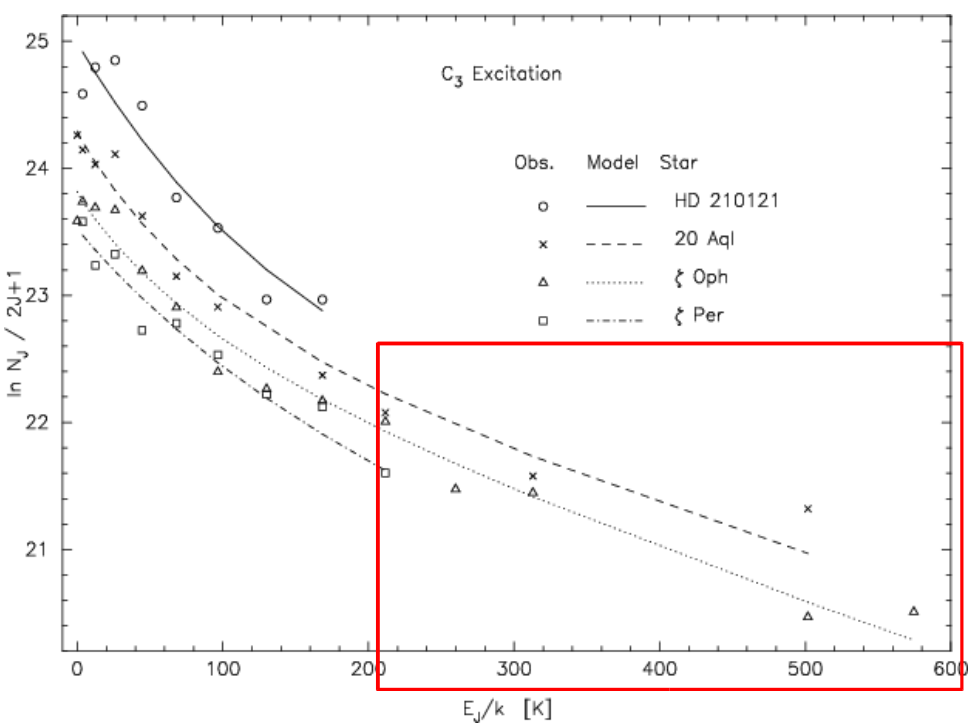




Maier, Lakin, Walker, & Bohlender, *ApJ*, **553**, 267 (2001)

Another detection and *detailed excitation model*: C_3 probes density and temperature



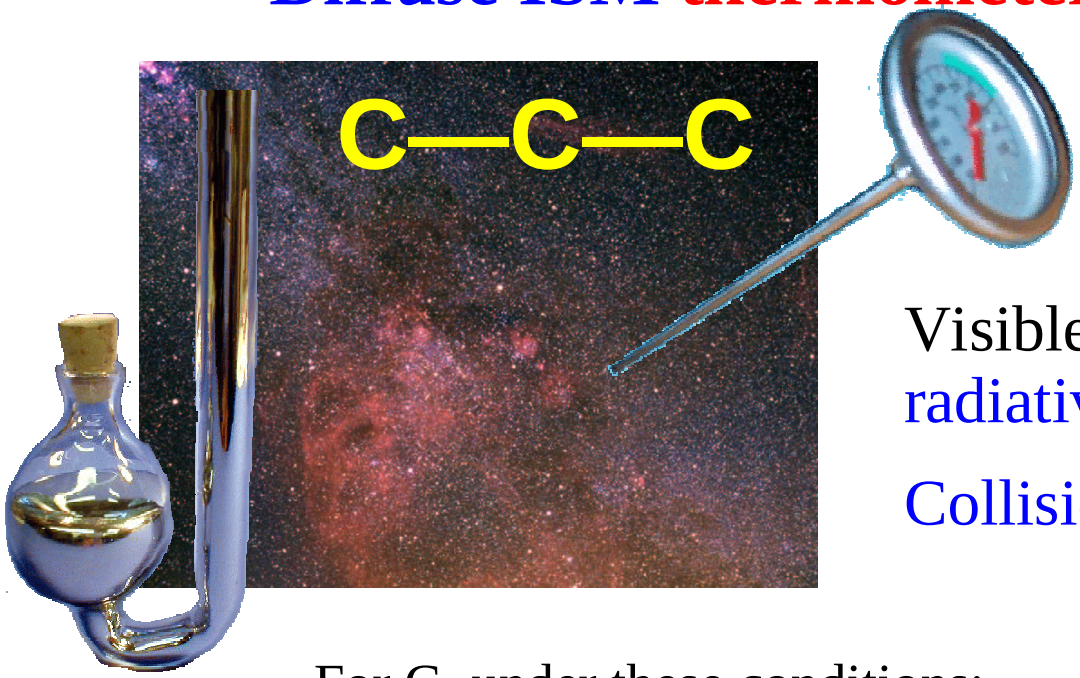


need more data here

Observations of high *J* levels *do not* constrain model

Roueff, Felenbok, Black, & Gry, *A&A*, **384**, 629 (2002)

Diffuse ISM thermometer and 'barometer'



No permanent dipole,
no rotational transitions
(only rare electric quadrupole transitions)

Visible, IR (2040cm^{-1}) and FIR (63cm^{-1})
radiative pumping

Collisional (de-)excitations

For C_3 under these conditions:

$J < 12$ thermalize to kinetic temperature

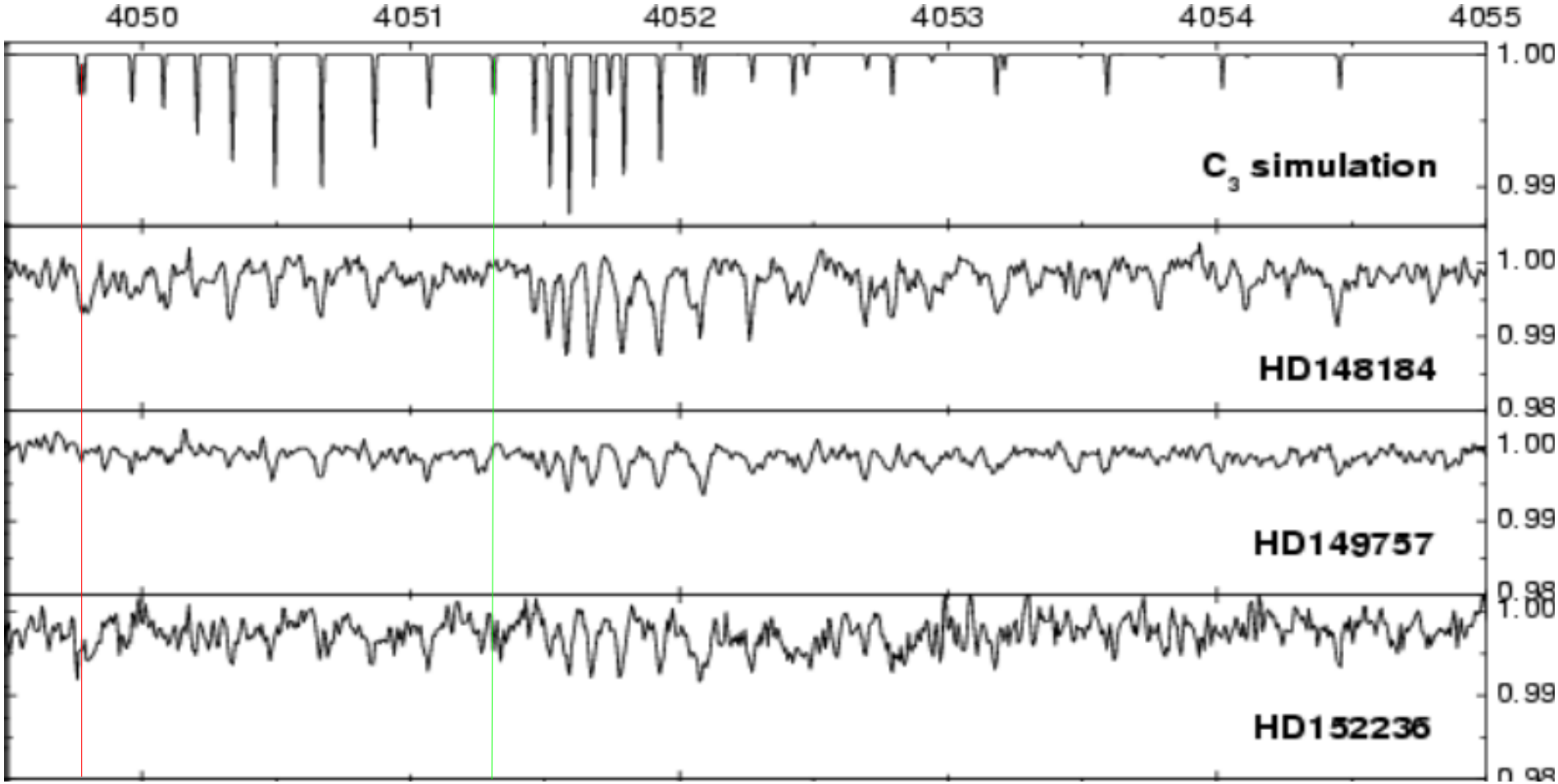
$J > 14$ only thermalize at $n \sim 10^3$ cm^{-3} so
high J excitation very sensitive to density

Chemically related, unidentified species

★ Big question: C_2, C_3 → C_2 DIB or C_2 DIB → C_2, C_3?

Oka RA04

...two more very nice detections (that's 6 so far)



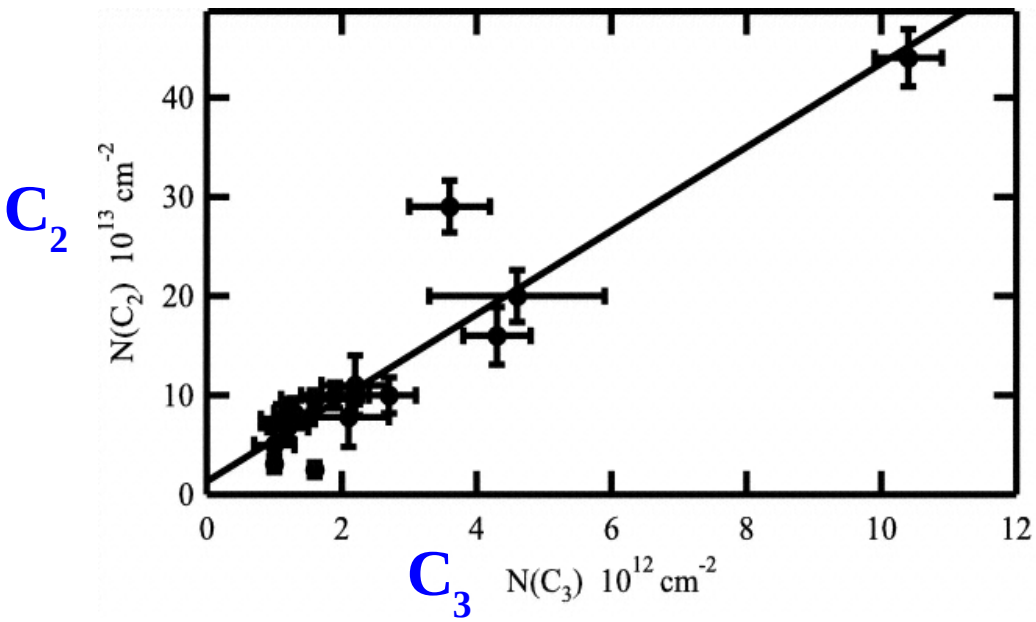
Unfortunately no excitation analysis

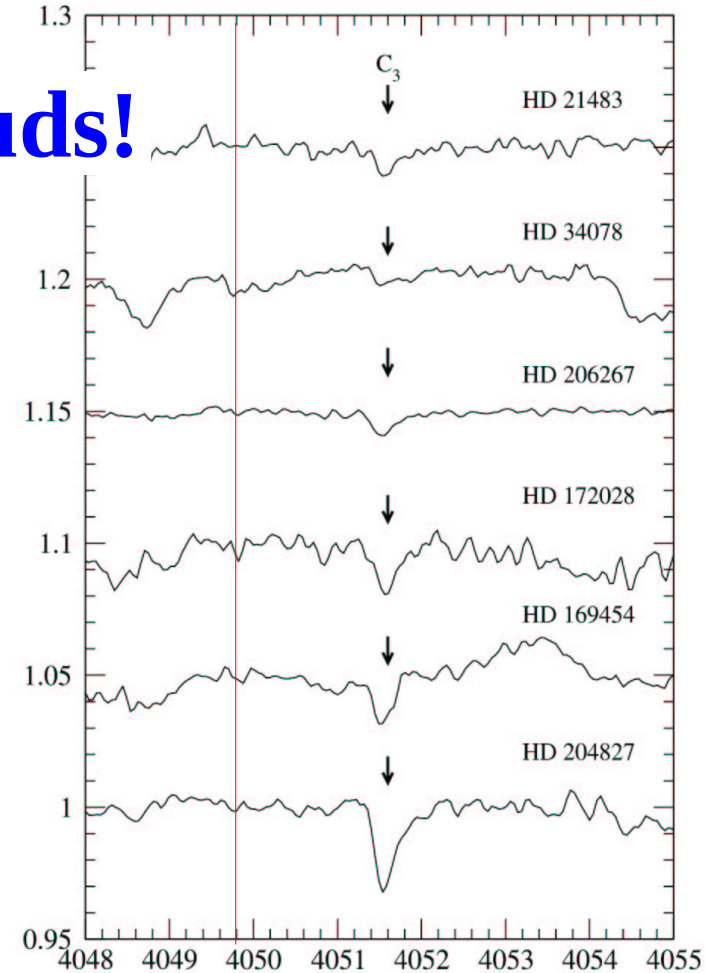
Galazutdinov, Petlewski, Musaev, Montou, Lo Curto, & Krełowski, *A&A*, **395**, 969 (2002)

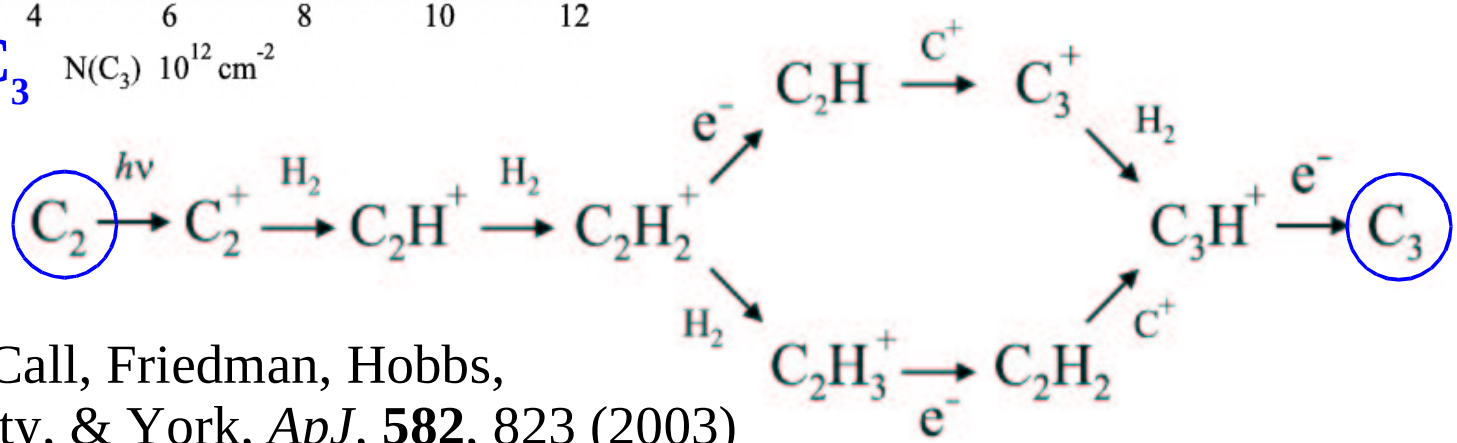
The APO DIB survey by-product:

C_3 measured in 15 diffuse clouds!

- C_2, C_3 abundance correlation confirmed
- chemical formation *mechanism expanded*
- band unresolved







Oka, Thorburn, McCall, Friedman, Hobbs, Sonnentrucker, Welty, & York, *ApJ*, **582**, 823 (2003)

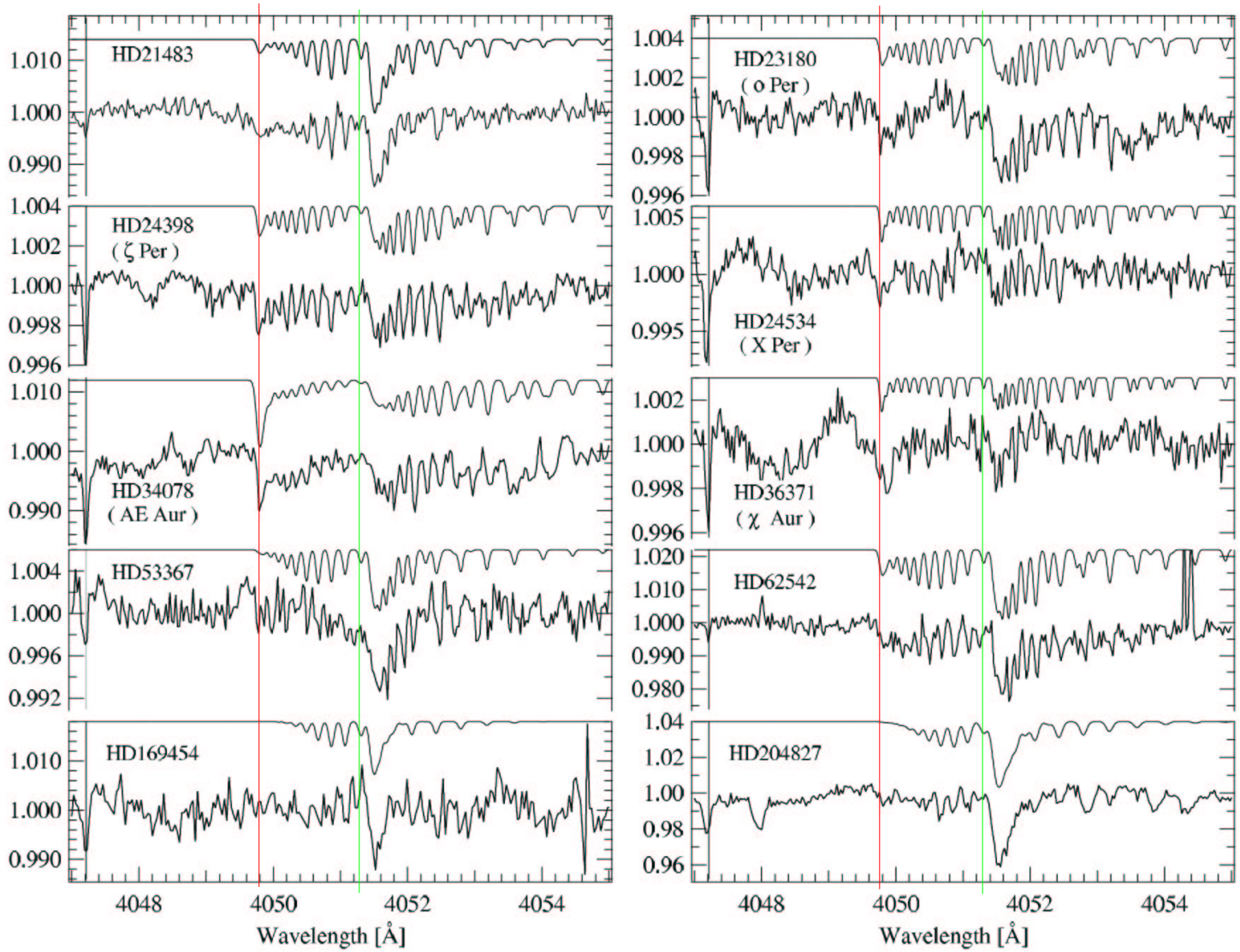
10 Adequately Resolved Detections

3 nights at Lick (3m)
2 nights at Keck (10m)

***R* ~ 60,000** (still some *Q*-,*R*-branch overlap)

Thermal distribution model

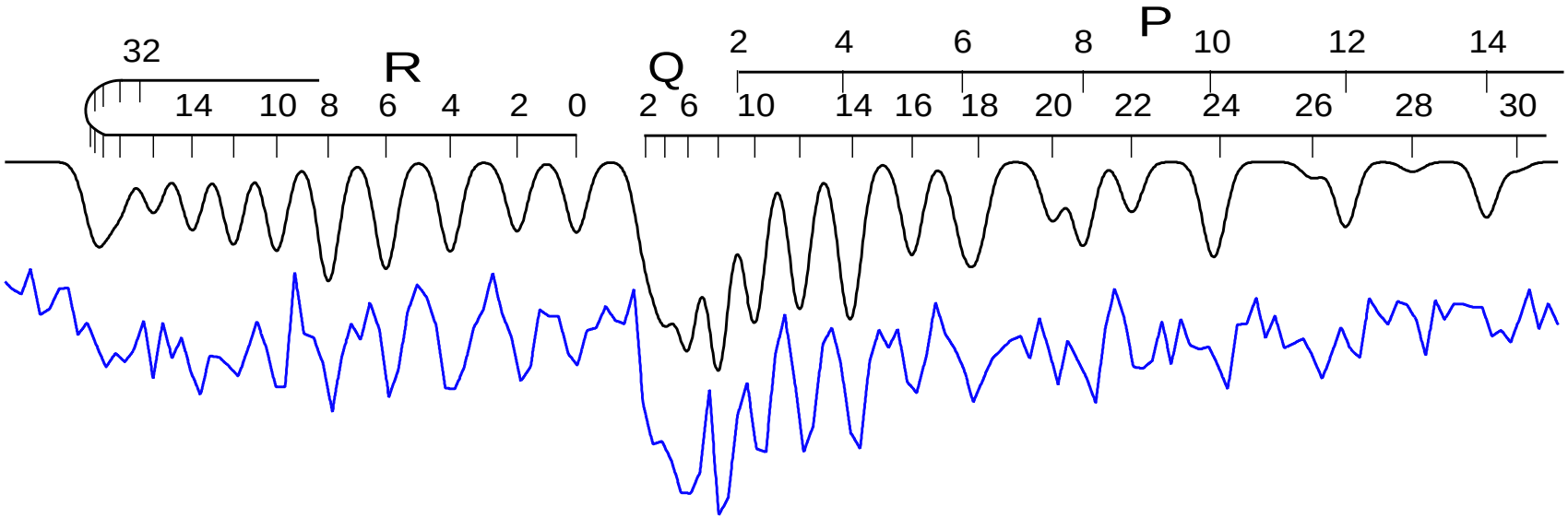
Simulate *entire* spectrum, fit *model* to observations



5 parameters (at most): T_l, T_h, $N_l(C_3)$, $N_h(C_3)$, w

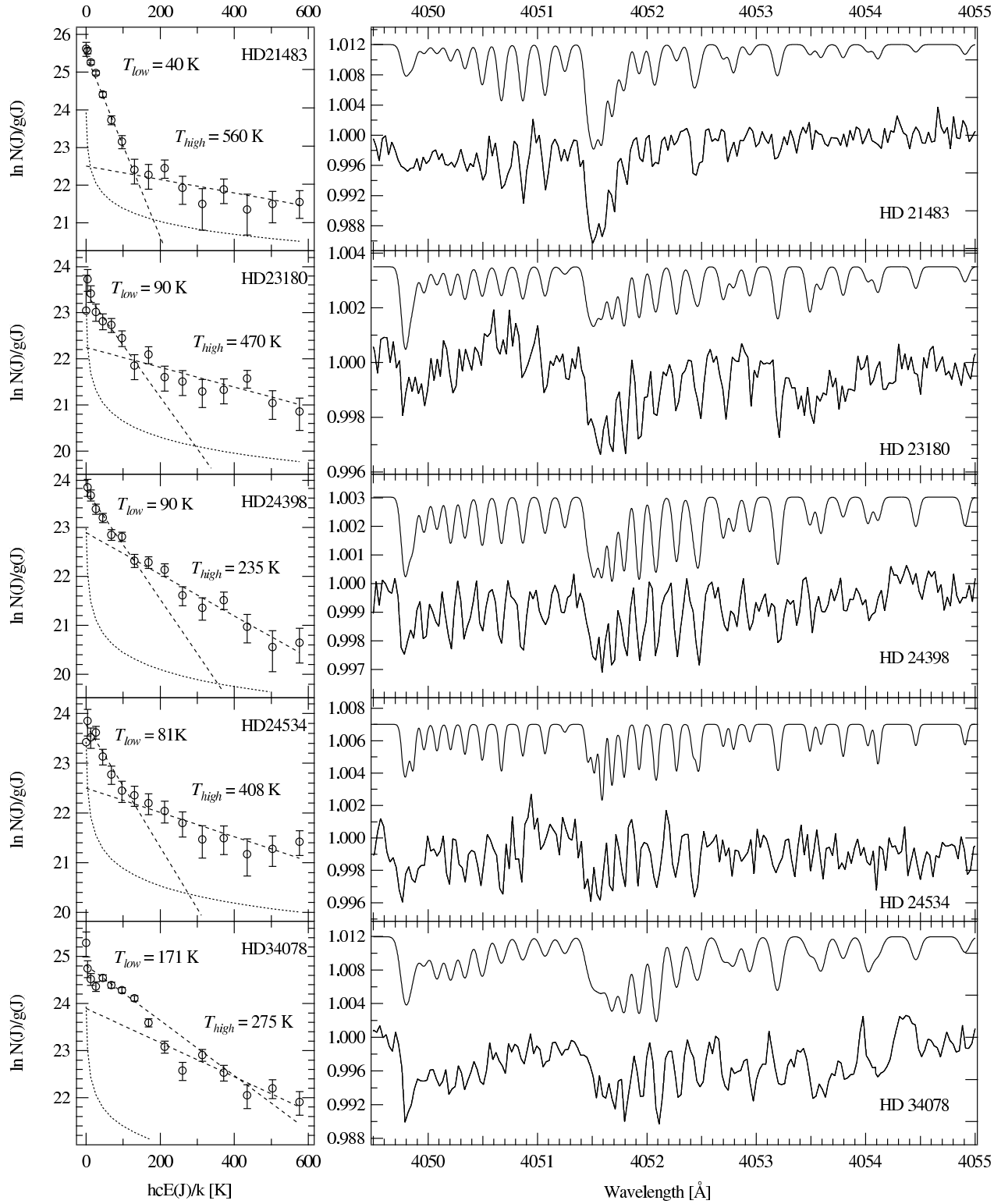
The rotational level fit:

Use entire spectra and presuppose *nothing* about the excitation

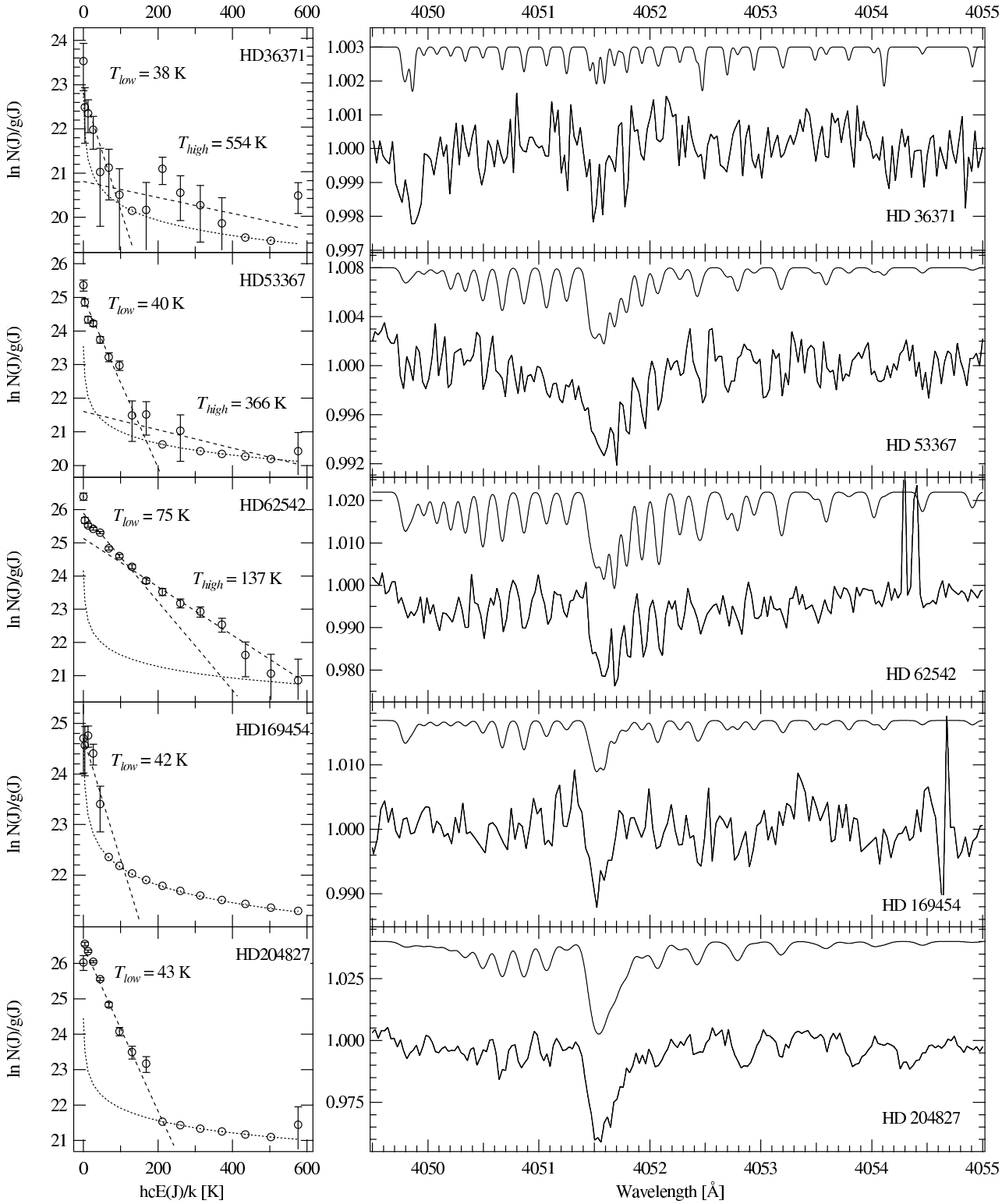


- Fit *J* level populations *not* individual transitions
- Use all observed datapoints, not just unblended features
- Make no assumption about the excitation profile
- Low *J* well resolved in *R*-branch
- High *J* well resolved in *Q*-, *P*-branches
- Optically thin lines fit by Gaussian transition profiles

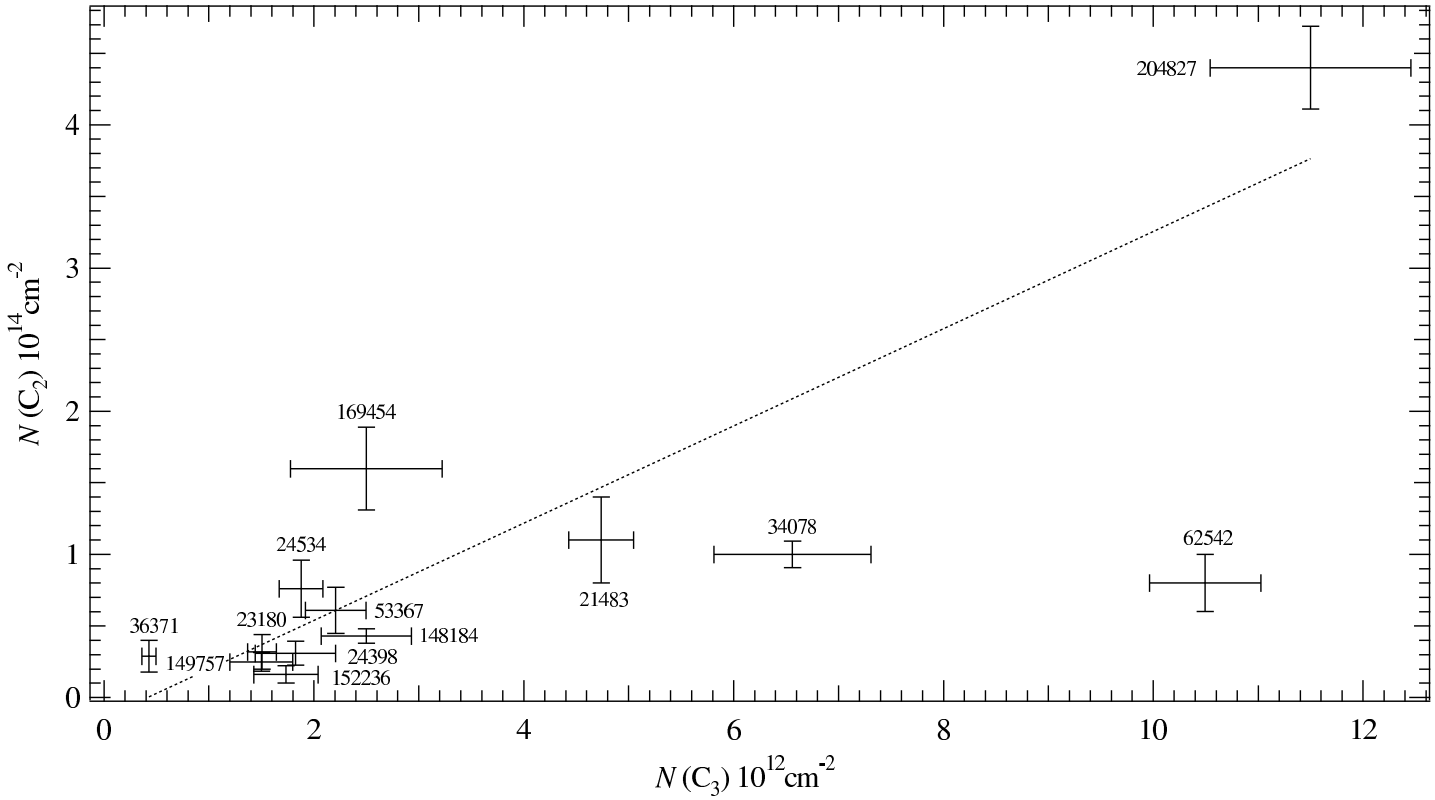
Rotational level fits and Boltzmann plots



Rotational level fits and Boltzmann plots



Correlations



Tight correlation between C_2 and C_3

(with notable outliers: HD 62542 and HD34078)

‹ $N(C_2)/N(C_3)$ › = 28.5 ± 19

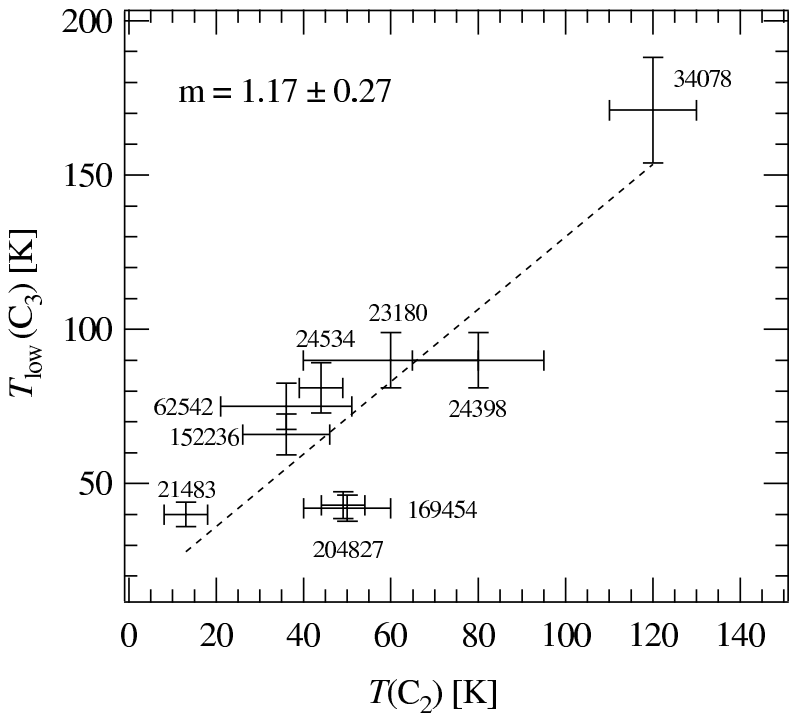
excluding extrema:

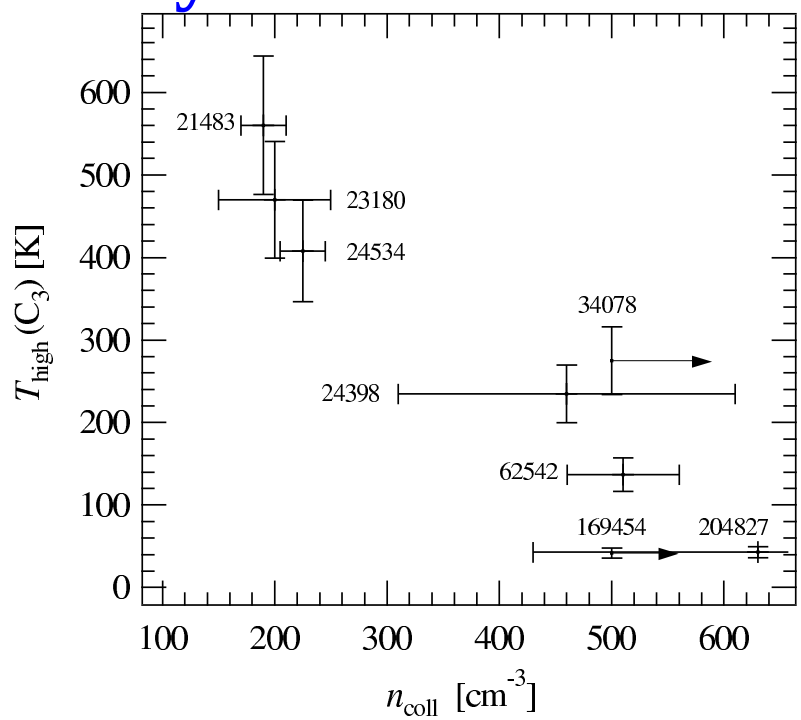
‹ $N(C_2)/N(C_3)$› = 20.9 ± 11)

‹ $N(C_2H)/N(o\text{-}C_3H_2)$ › = 27.7 ± 8

Lucas & Liszt, *A&A*, **358**, 1069 (2000)

Excitation analysis





$J \leq 14$ excitation temperature for C_3 corresponds to kinetic temperature (15-140K) determined* from C_2

$J > 14$ excitation temperature for C_3 ~ 500 K at n < 200 cm^{-3} (determined by full C_2 excitation model*) and approaches kinetic temperature as n → 600 cm^{-3}

*van Dishoeck & Black, *ApJ*, **258**, 533 (1982)

Summary

10 rotationally resolved spectra of C_3 in diffuse clouds observing high *J* transitions

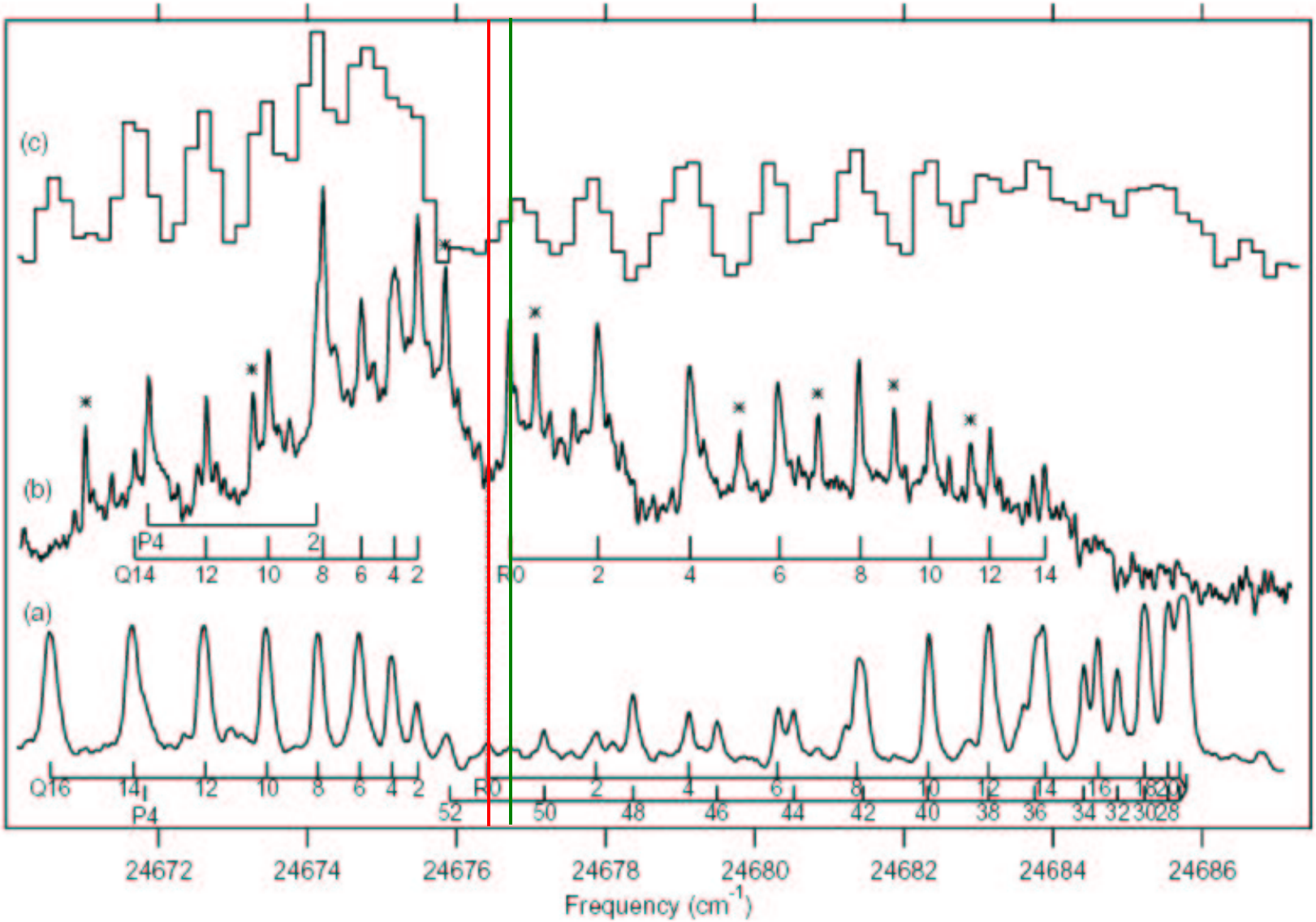
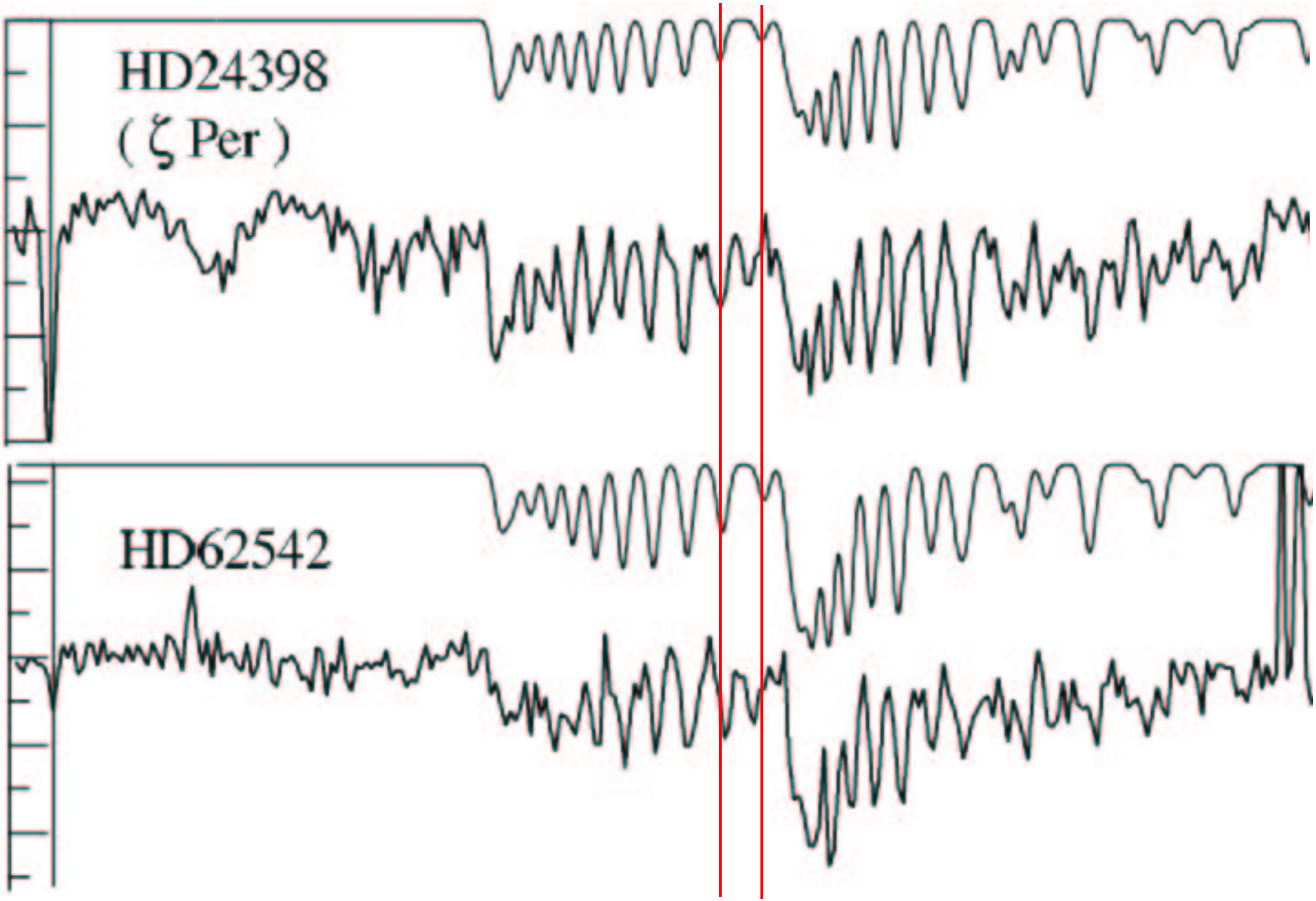
new fitting method for determining rotational level populations (excitation profiles)

full excitation model of C_3 may now be tested against observations

possible chemical link between C_2, C_3 and C_2H, C_3H_2

Clouds with large $N(C_3)$ are good candidates for C_4 and C_5 searches

Laboratory re-examination of the λ4050 group of C_3



The *R*(0) Discrepancy