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How to find molecular gas (column) densities in luminous galaxies?

Molecular clouds are filamentary

Large surface : volume ratio renders them very susceptible to environment

Simple scaling of H_2 tracers like CO, [CI], [CII] lines, FIR dust continuum potentially (very) large errors

Even in the Milky Way, there are no tracers reliably calibrated for environmental variation

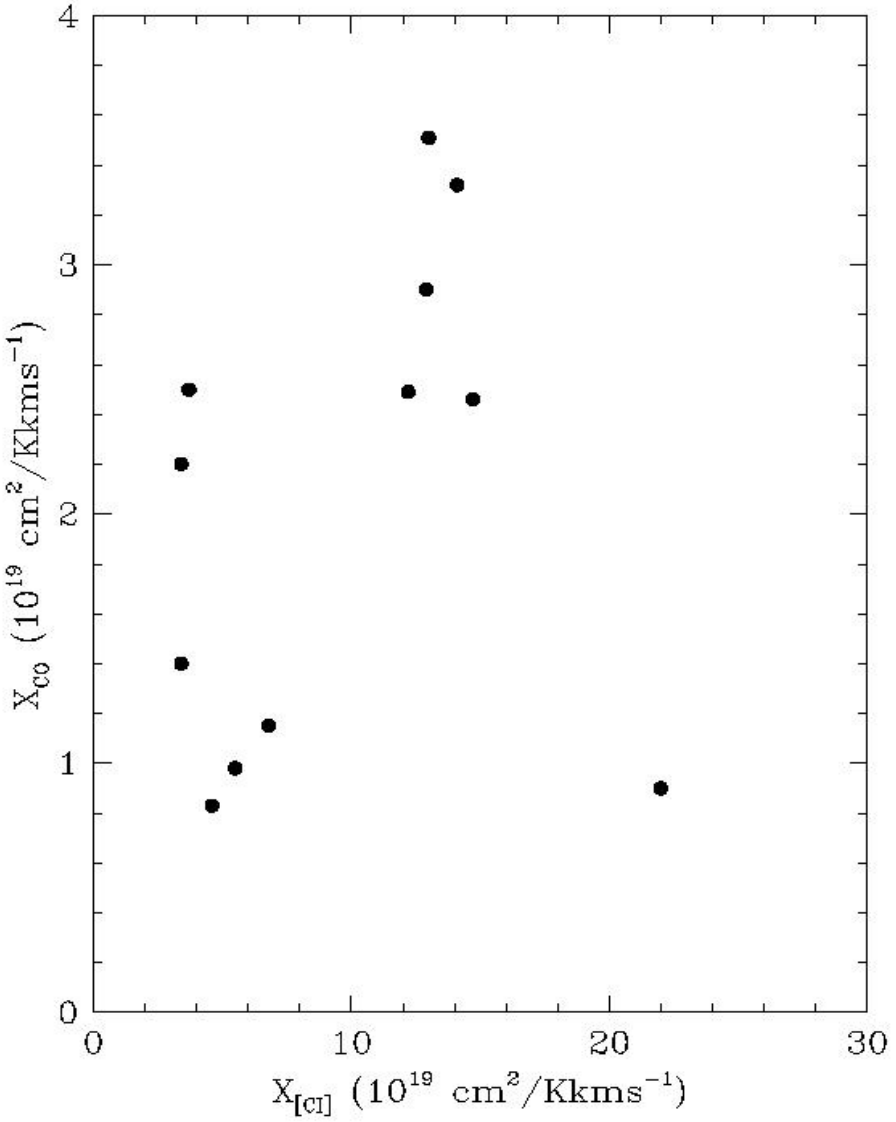
Comparison shows:

Data from detailed modeling

(Israel & Baas, various papers)

X(CI) is no better than X(CO) and neither of the two is very good in luminous galaxies and starburst galaxy centers

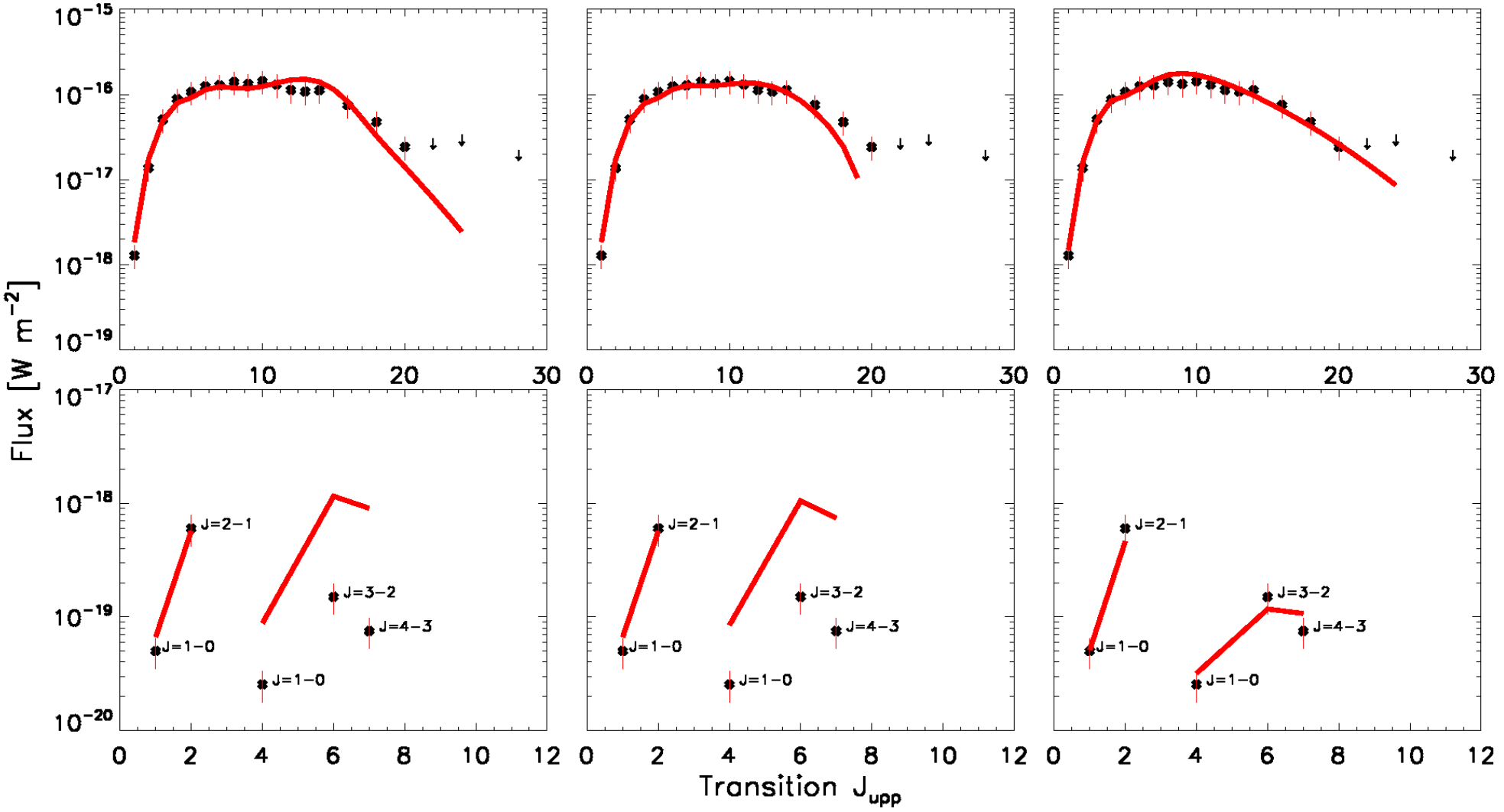
- **Low value X_{CO} = 0.1 X(MW)**
- **Large scatter**
- **Poor correlation X_{CI} - X_{CO}**



Detailed modeling multi-species/multi-transition data (^{12}CO, ^{13}CO, HCN) Example: Arp299 3-phase fits

Rosenberg , Meijerink, Israel, van der Werf, Xilouris & Weiss, 2014, A&A 569, A90

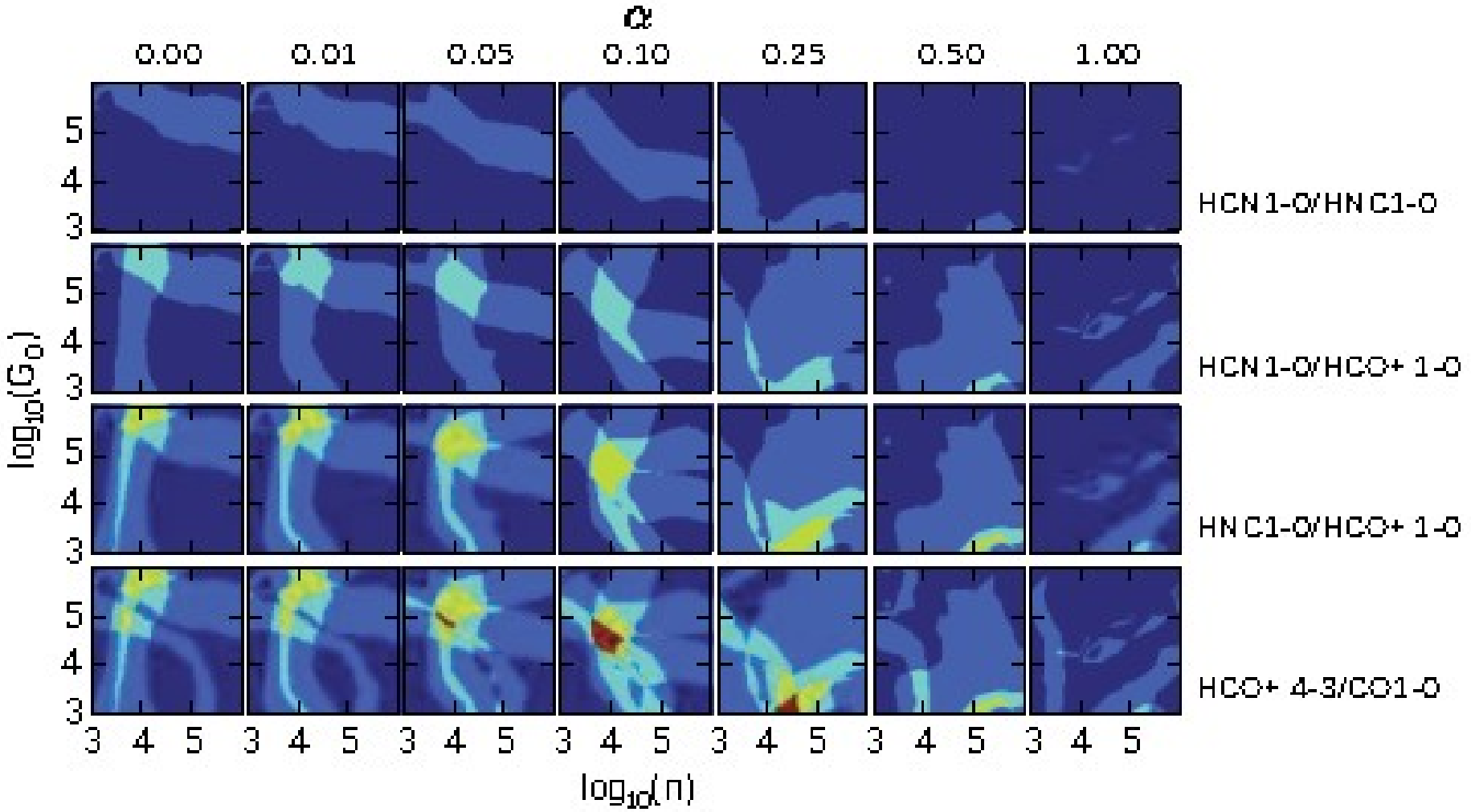
UV (PDR) XDR PDR+Turbulence



Other example: find degree of Turbulent Excitation from intersecting line ratios (Kazandjian 2014 Leiden Ph.D. thesis)

ULIRG example from:

Kazandjian, Meijerink, Pelupessy, Israel & Spaans, 2015 A&A 574, A127 (arXiv 1403.7000)



Are there simpler methods requiring fewer lines?

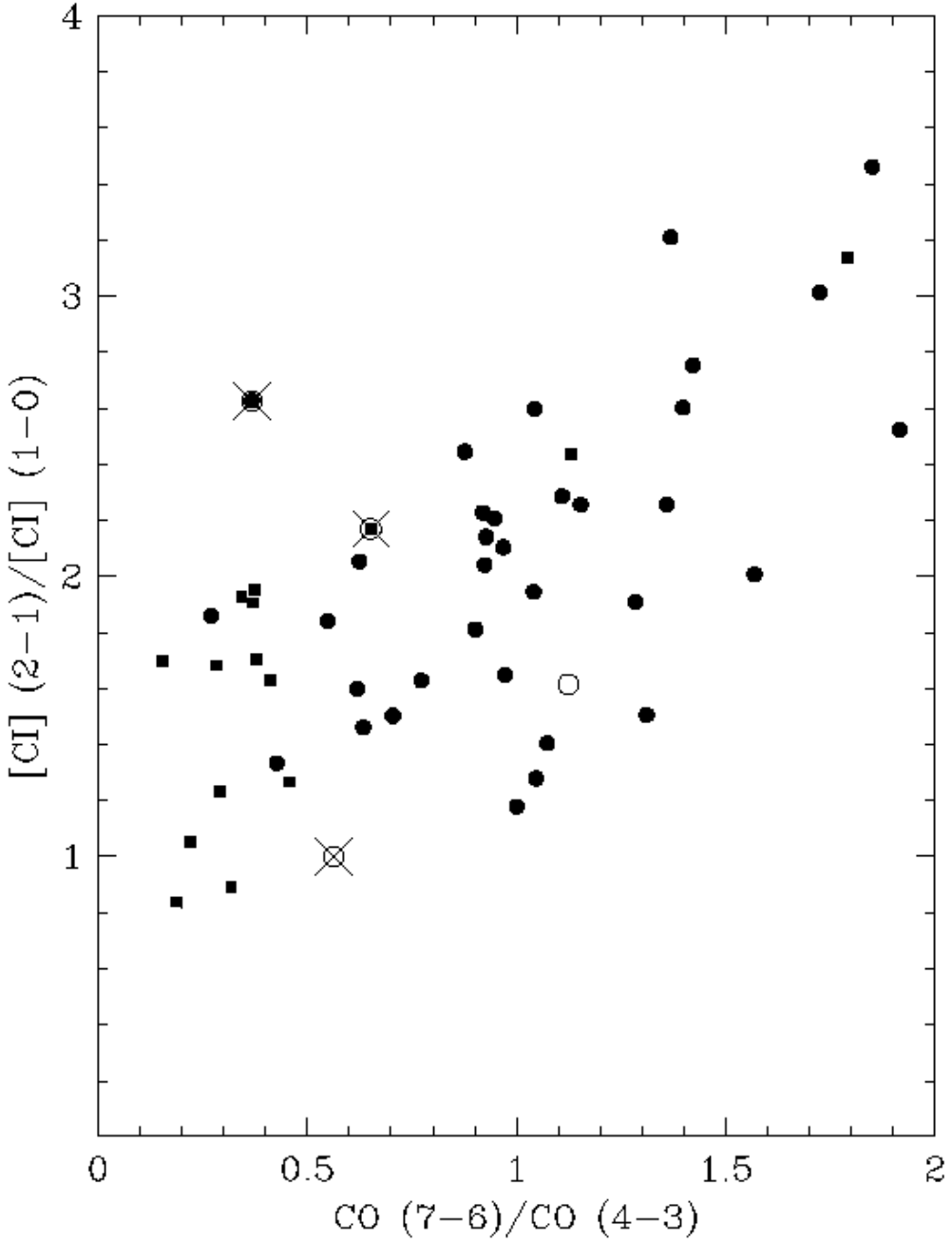
- no guessing at X
- no time-consuming number-crunching

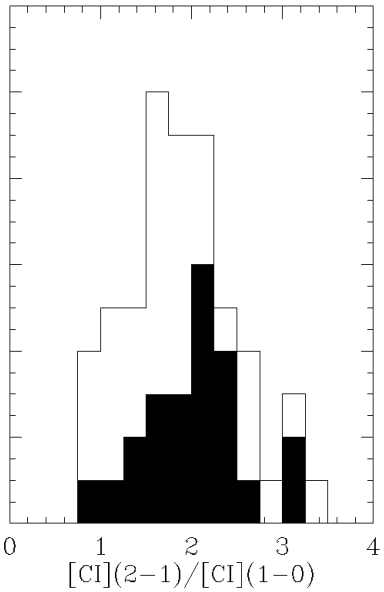
Database Herschel-SPIRE line fluxes

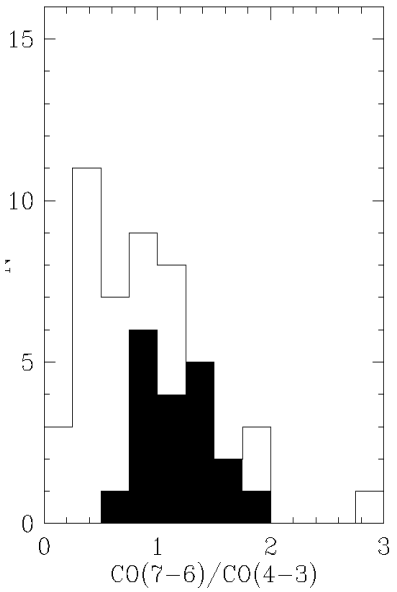
^{12}CO 806 GHz + [CI] 809 GHz
^{12}CO 461 GHz + [CI] 492 GHz
^{12}CO 230 GHz + ^{13}CO 220 GHz

48 Starburst
22 LIRG
6 ULIRG

Israel et al. 2015 A&A 578, A95 (ArXiv 1504.08005)



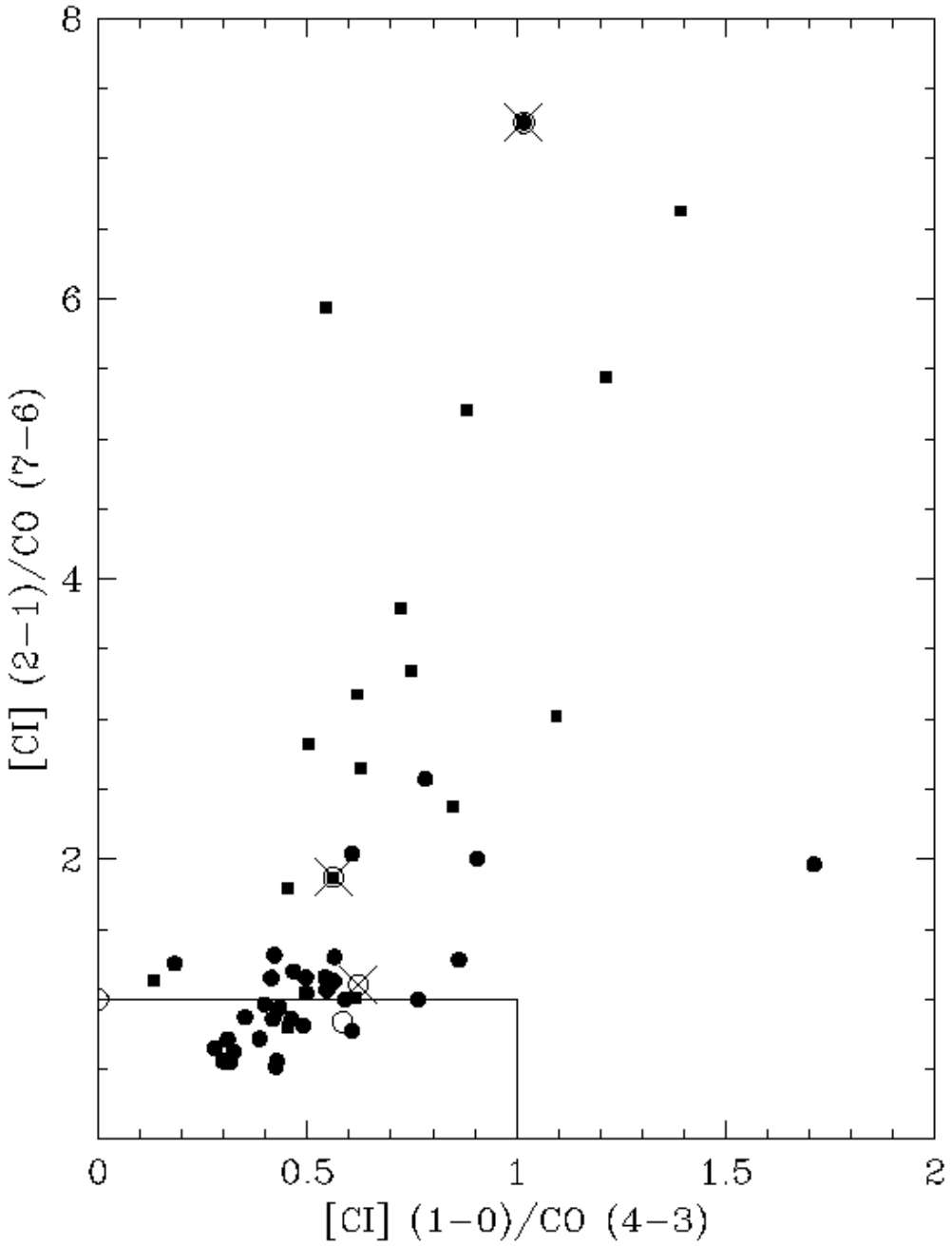


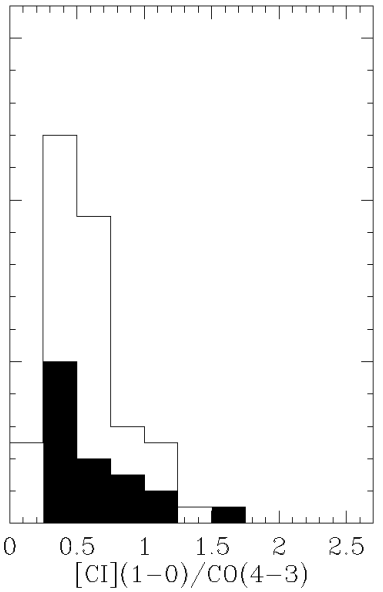


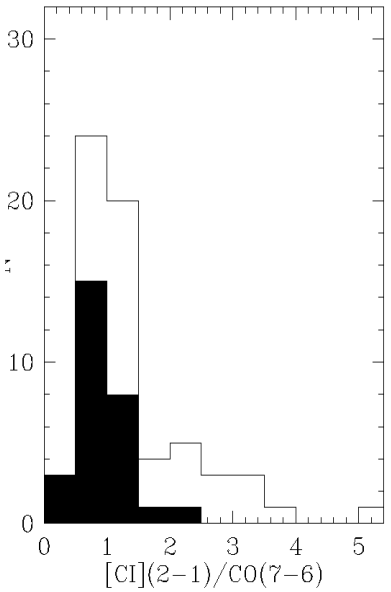
Histogram
Same-species ratios
[CI]/[CI] and CO/CO
distinguish:

Star-burst : low ratios
(U)LIRG : high ratios

X = AGN



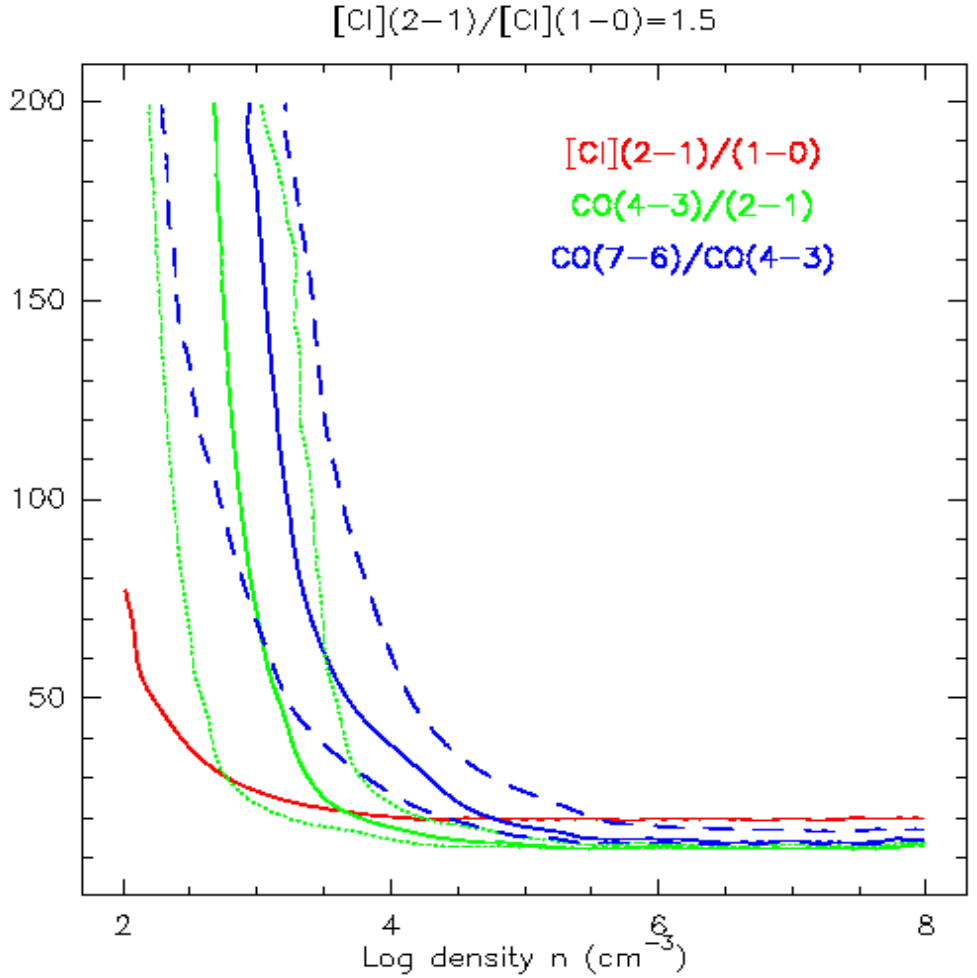


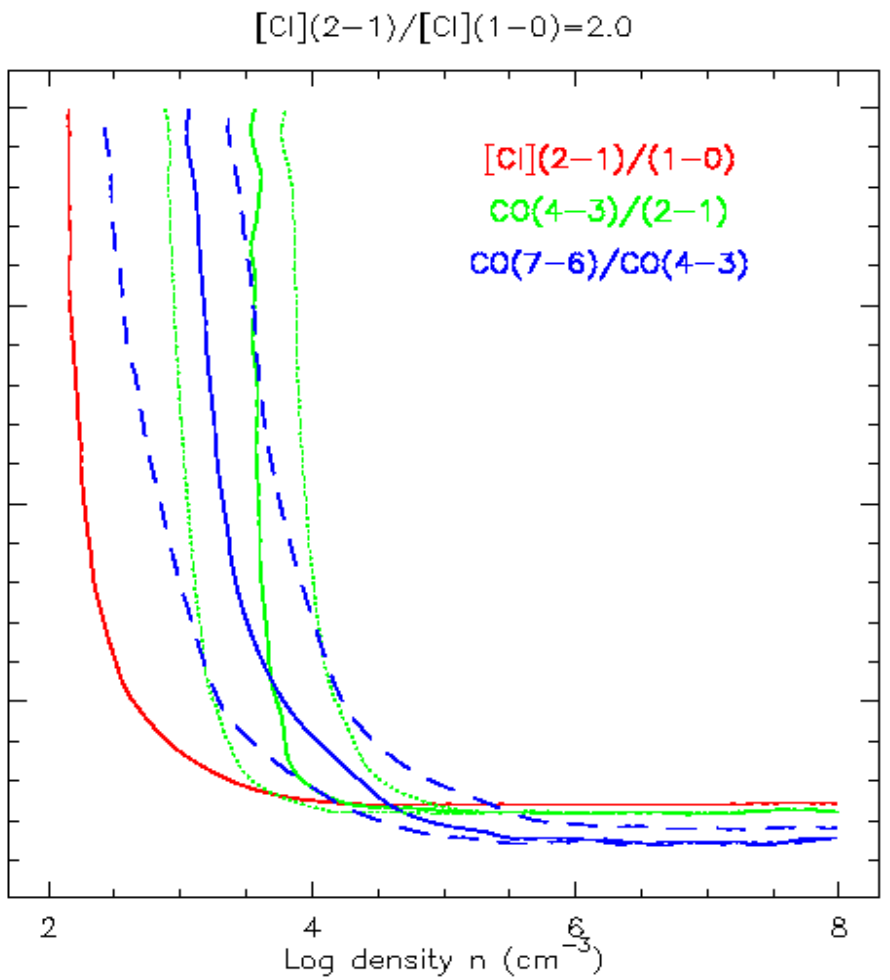


Histogram interspecies ratios [CI]/CO

Star-burst and (U)LIRG: same distribution, no difference

X = AGN





C(2-1)/CI(1-0) < 1.75

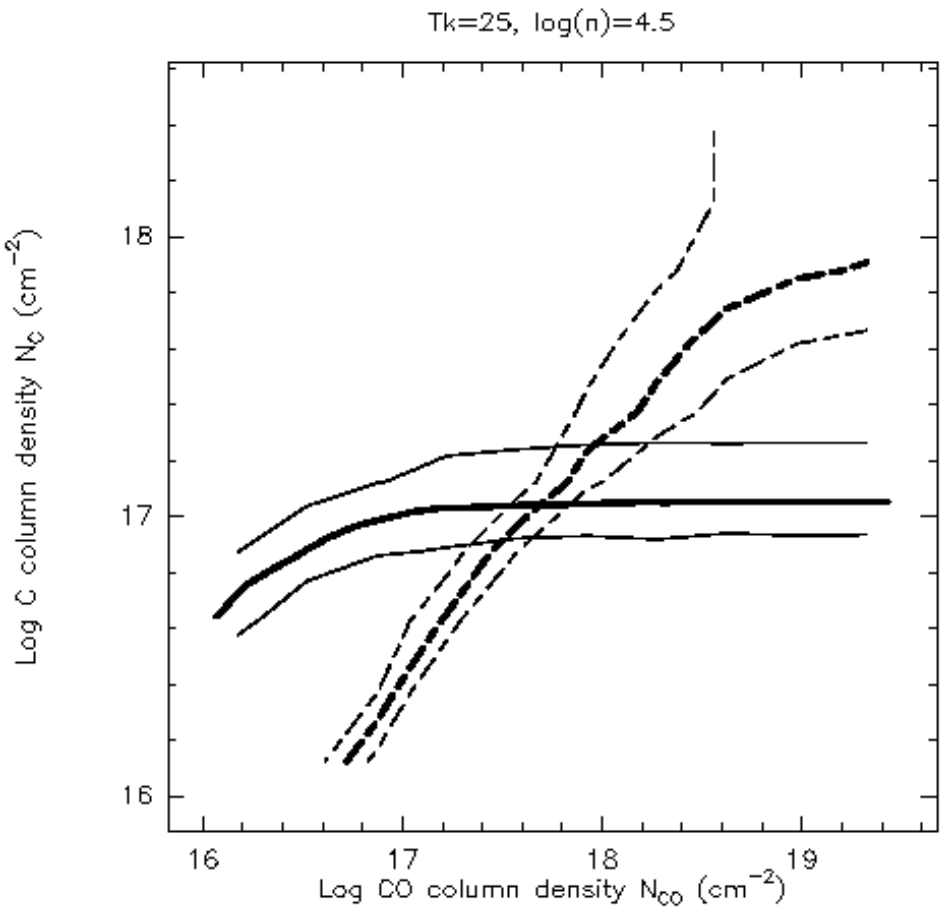
Starburst galaxies

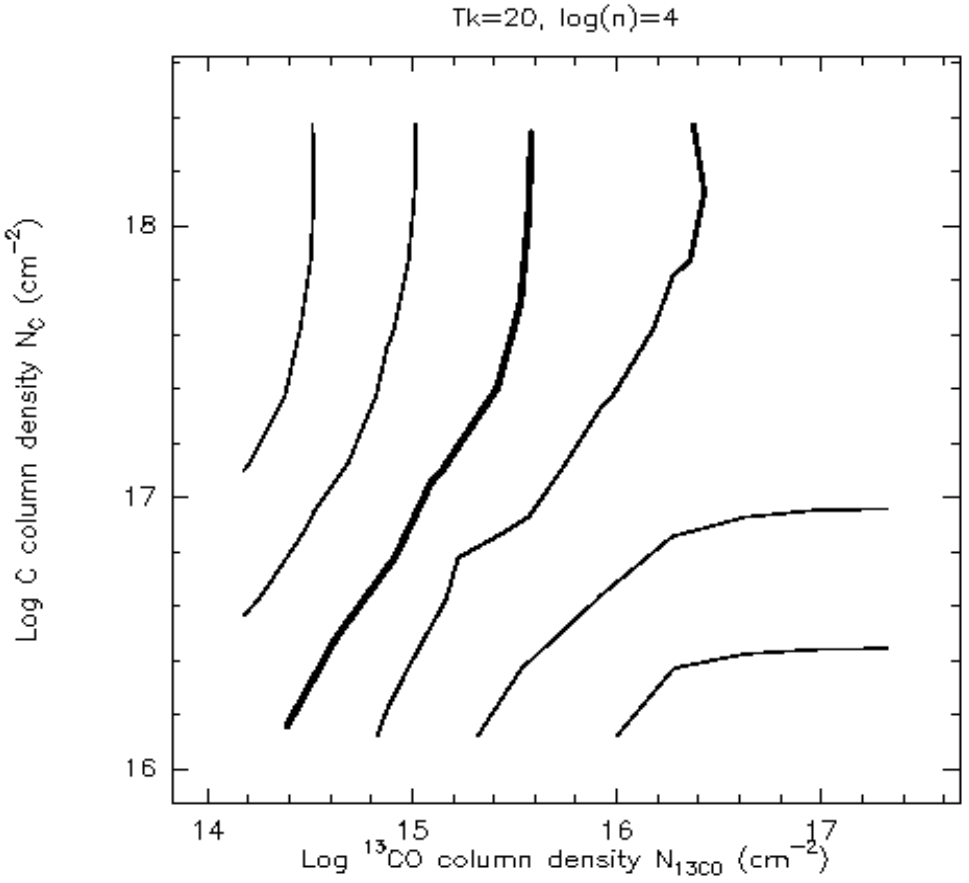
Single-phase fits increasingly poor

CI(2-1)/CI(1-0) > 1.75

(U)LIRGs

Single high-pressure phase dominant





Intersection CI(1-0)/CO(4-3), CI(2-1)/CO(7-6)

N(CO)/N(C) = 5 +/- 3

Constant CI(1-0)/^{13}CO(2-1) ratio (1, 3, 10, 30, 100, 300)

N(^{12}CO)/N(^{13}CO) = 100 - 500

CONCLUSION 1

- **Luminous galaxies can be modeled with a single phase to yield (column) density, temperature and C/CO abundances**

- **Only 5 lines are required:**

CO(2-1)
CO(4-3) + CI(1-0)
CO(7-6) + CI(2-1)

CONCLUSION 2

- **All distant galaxies are luminous galaxies**

- **Simple fits provide excellent estimates of molecular ISM density, temperature and abundance in high redshift galaxies**

- **Required lines are available in intervals up to z = 5**

z(1) = 0.15-0.18
z(2) = 0.9-1.1
z(3) = 1.2-1.4
z(4) = 1.8-2.2
z5 = 3.1-3.2
z6 = 3.7-5.2