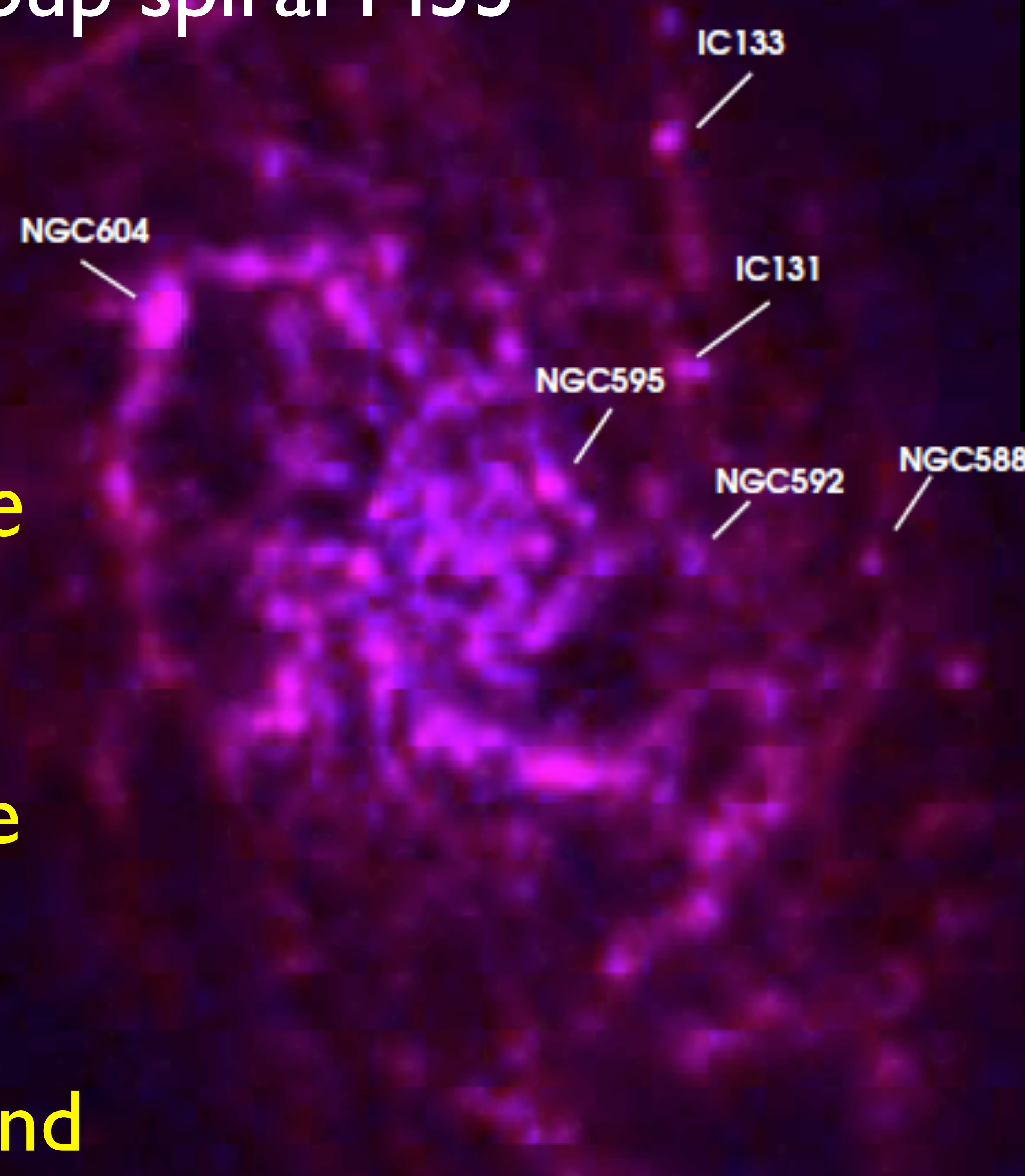
The interstellar medium in the small Local Group spiral M33



Jonathan Braine

Laboratoire d'Astrophysique de Bordeaux

&

The M33-CO and ***HERM33ES*** team

Manolis Xilouris, Fatemeh Tabatabaei

Why M33 ?

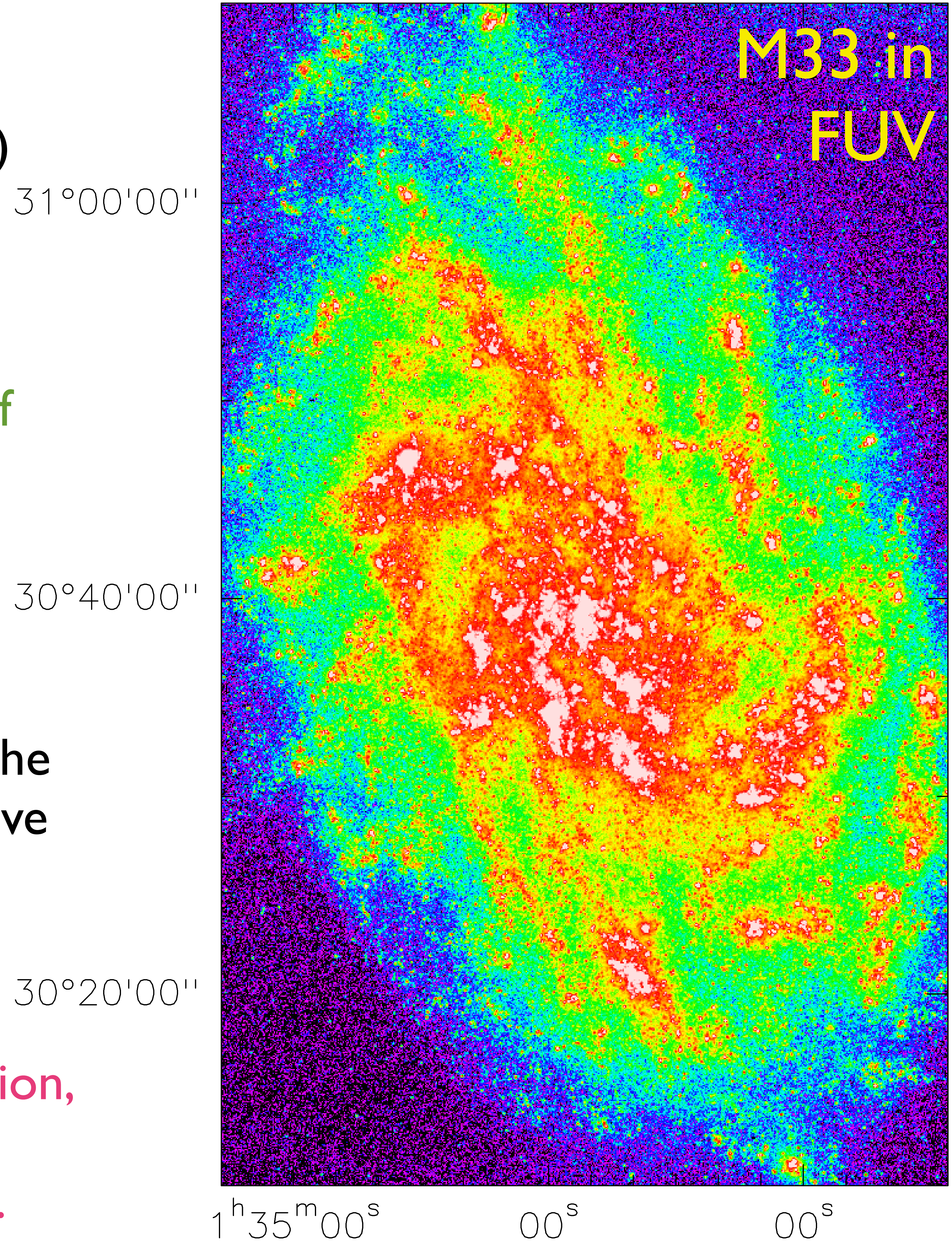
Very nearby (~840 kpc, 1" = 4pc)
==> resolve molecular clouds

True spiral galaxy,
rather average radiation field.
Inclination optimal -- dynamics of disk with clear line of sight.

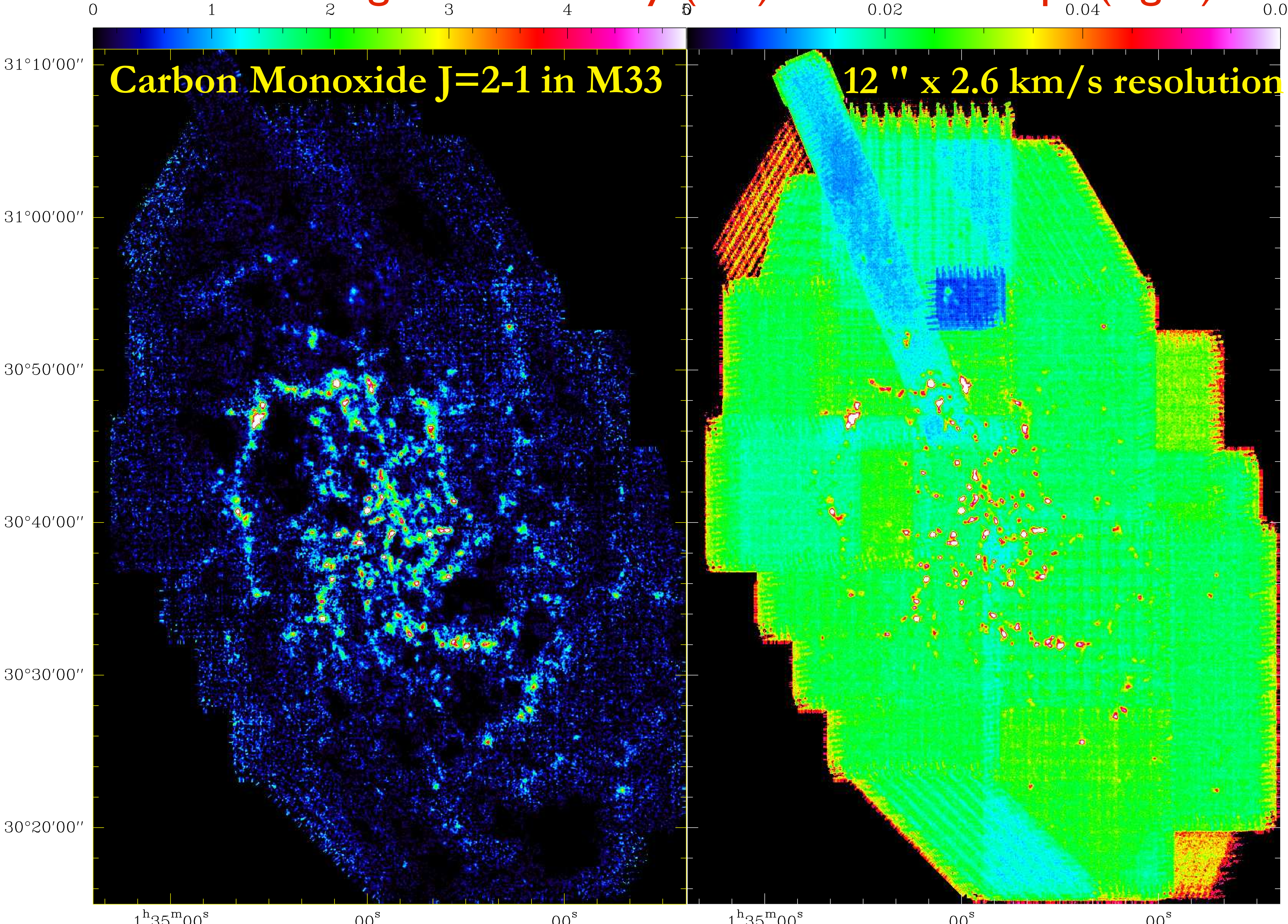
Small, blue, gas-rich, subsolar Z
==> similar to high-z objects?

Stepping-stone towards more extreme objects to understand the ISM and star formation in primitive environments.

GOALS: Identification of GMCs, lifetime, link with star formation, size and luminosity (mass?) function, formation of molecular clouds, N(H2)/Ico factor and "Dark" H2.



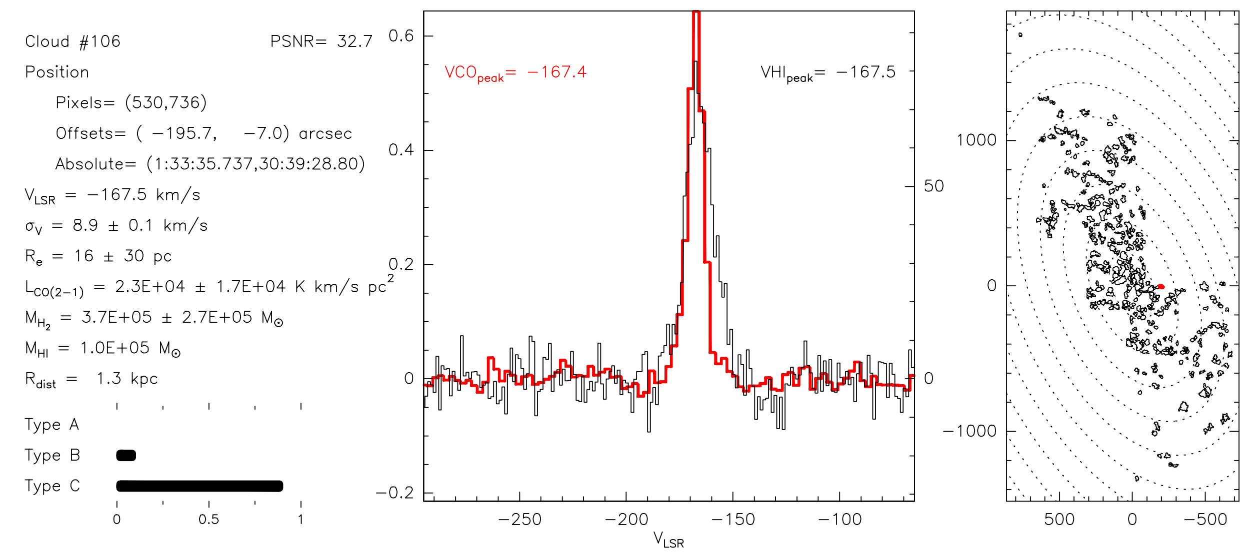
Current CO integrated intensity (left) and noise maps (right)



CO emission decomposed into clouds using CPROPS
(Rosolowsky & Leroy 2006)

yielding sample of GMCs

largest GMC sample to date
(Gratier et al 2012, A&A 542, 108)



cloud contours placed on
FUV, Hα, 8μm et 24μm images

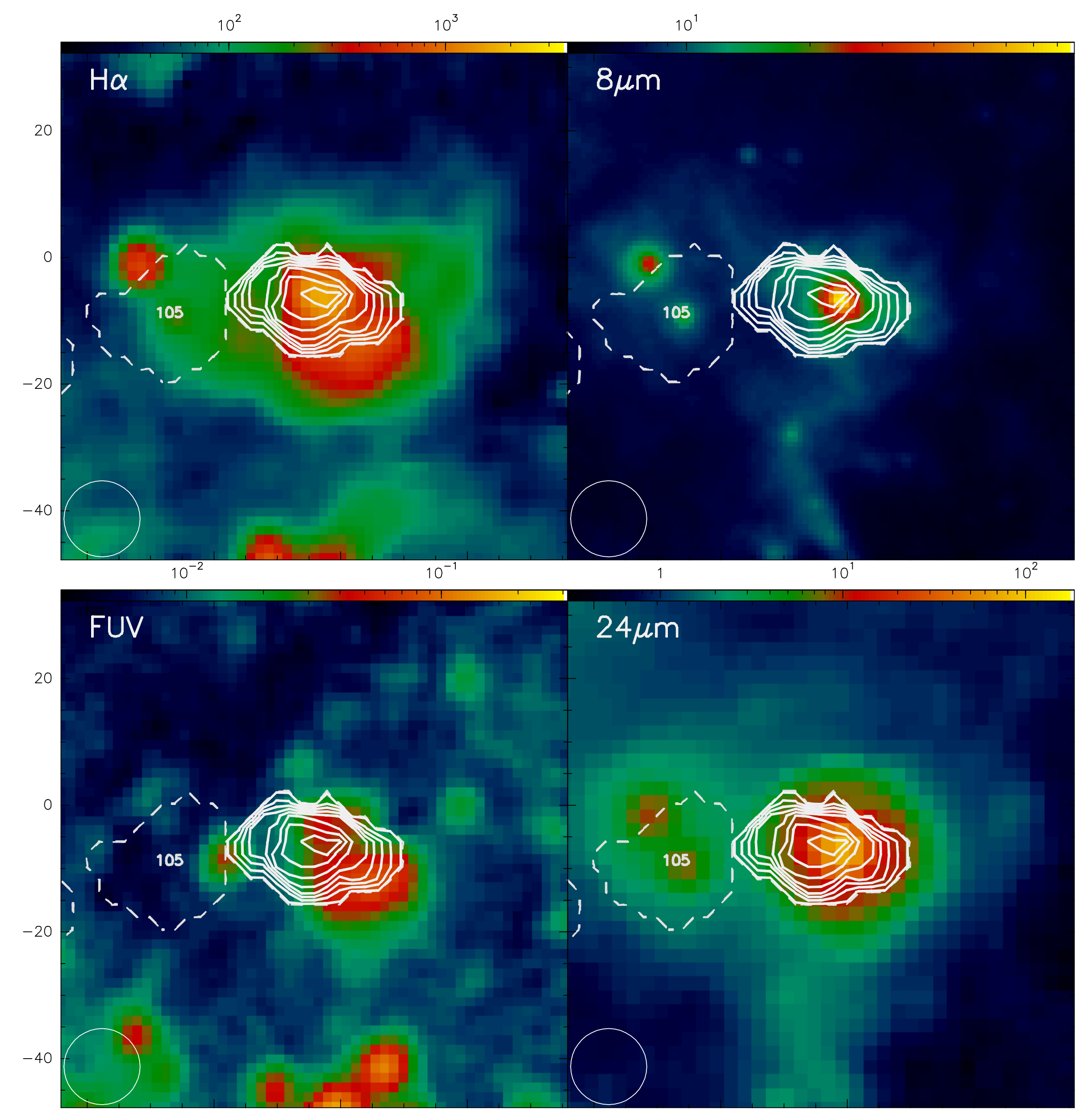
- better spatial resolution than CO

Three categories depending on phase of star formation:

- Type A : no star formation
- Type B : embedded star formation
- Type C : exposed star formation

These types are meant to represent the life cycle of molecular clouds.

A similar classification of LMC clouds was done by Kawamura et al 2009



General procedure for estimating gas masses

$$S_\nu = B_{\nu,T_d}\,(1 - e^{-\tau}) \approx B_{\nu,T_d}\,\tau$$
$$S_\nu = B_{\nu,T_d}\,N_H\,\sigma$$

dust emission optically thin at submm wavelengths

$$\frac{S_{\nu_1}}{S_{\nu_2}} = \frac{B_{\nu_1,T_d}}{B_{\nu_2,T_d}}\,\frac{\sigma_{\nu_1}}{\sigma_{\nu_2}}$$

A flux ratio enables calculation of a "color temperature" for a given grey body emissivity

$$\sigma_\nu = \sigma_{\nu_0}\,(\tfrac{\nu}{\nu_0})^\beta \text{ with } \beta \sim 1.5 - 2$$

Sigma is dust cross-section per H-atom

Then estimate total H column density and H2 column by subtracting HI column

Back to reality (some caveats about dust emission)

Beta remains unknown, probably 1.5 - 2. Dust emission probably not so simple anyway.

Dust is a mixture of chemical compositions with different behaviors. Milky Way dust is generally assumed. Correct for M33 ?

Even with a fixed beta, dust temperatures have significant uncertainties. Distribution of "warm" and "cool" components, calibration.

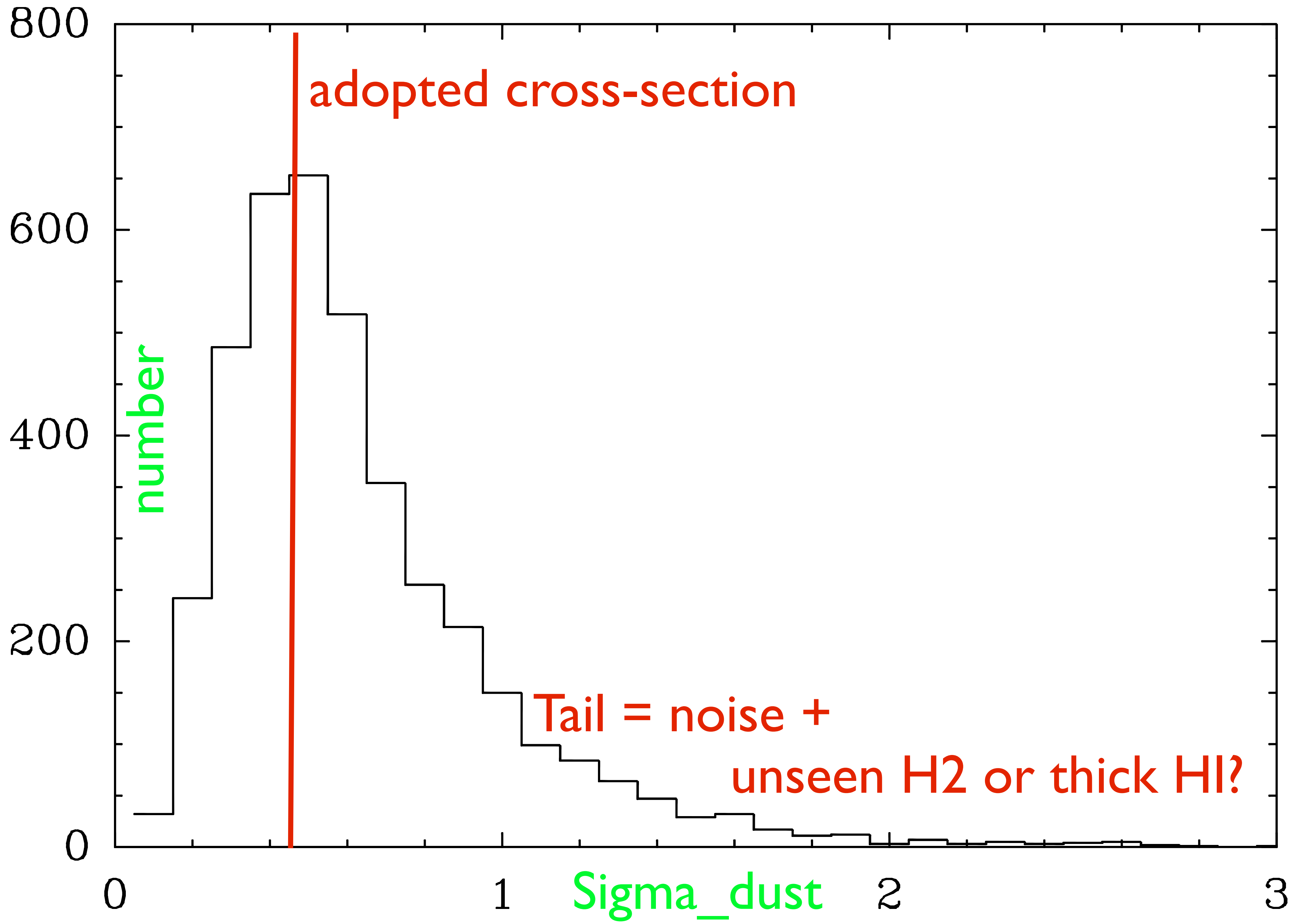
Dust emission cross-section sigma still not known from theory.
==> **Is it the same for HI and H2 ?** <==
(not for very dense gas: mol depletion and fluffy grains but small mass)

Problem of undetected H2 -- where do we really know the Hydrogen column density? M33 should be similar to the Milky Way (moderate ISRF and only slightly subsolar metallicity) and a first step to low-Z and high-z systems.

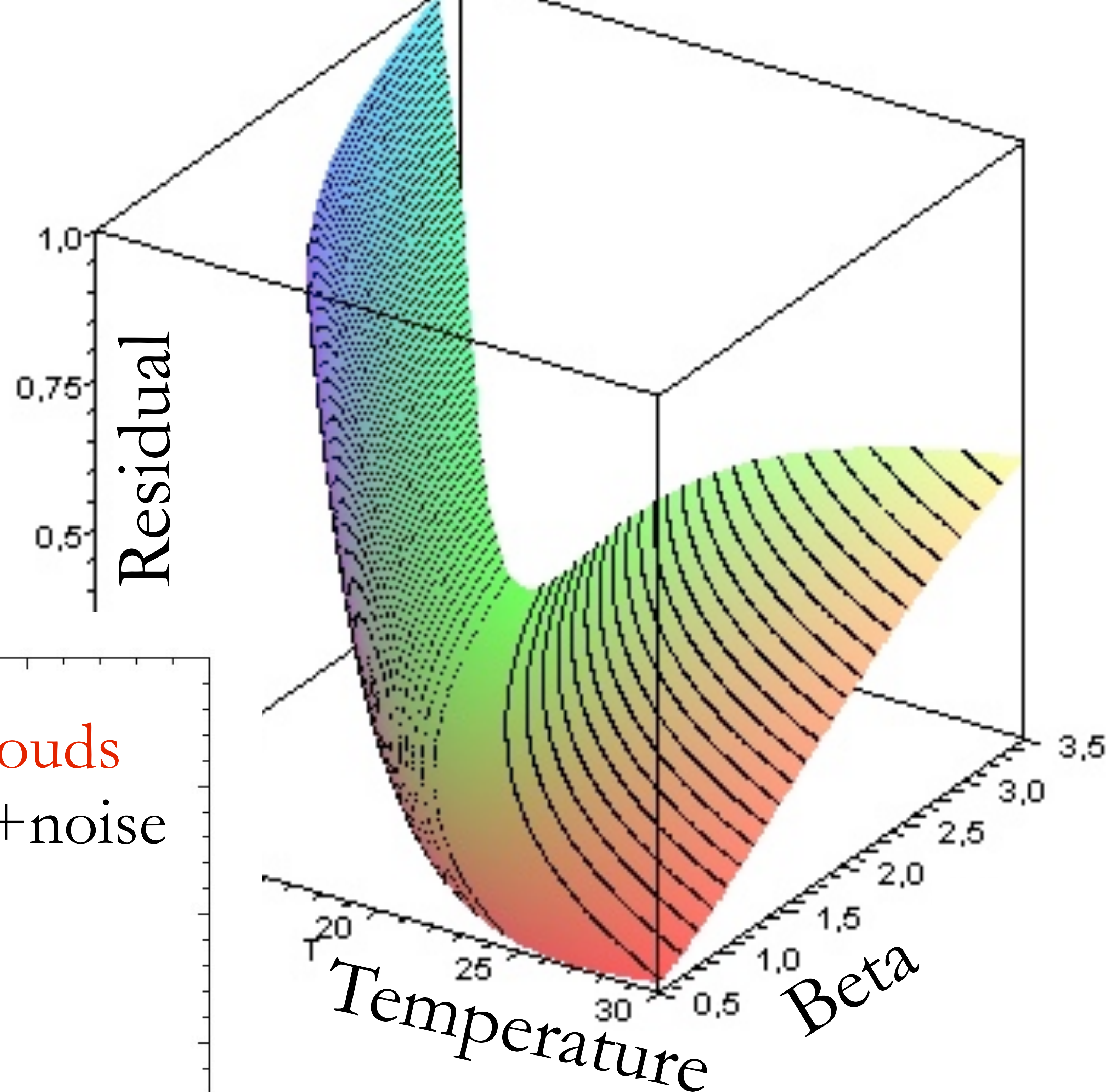
How good is the optically thin approximation for HI?

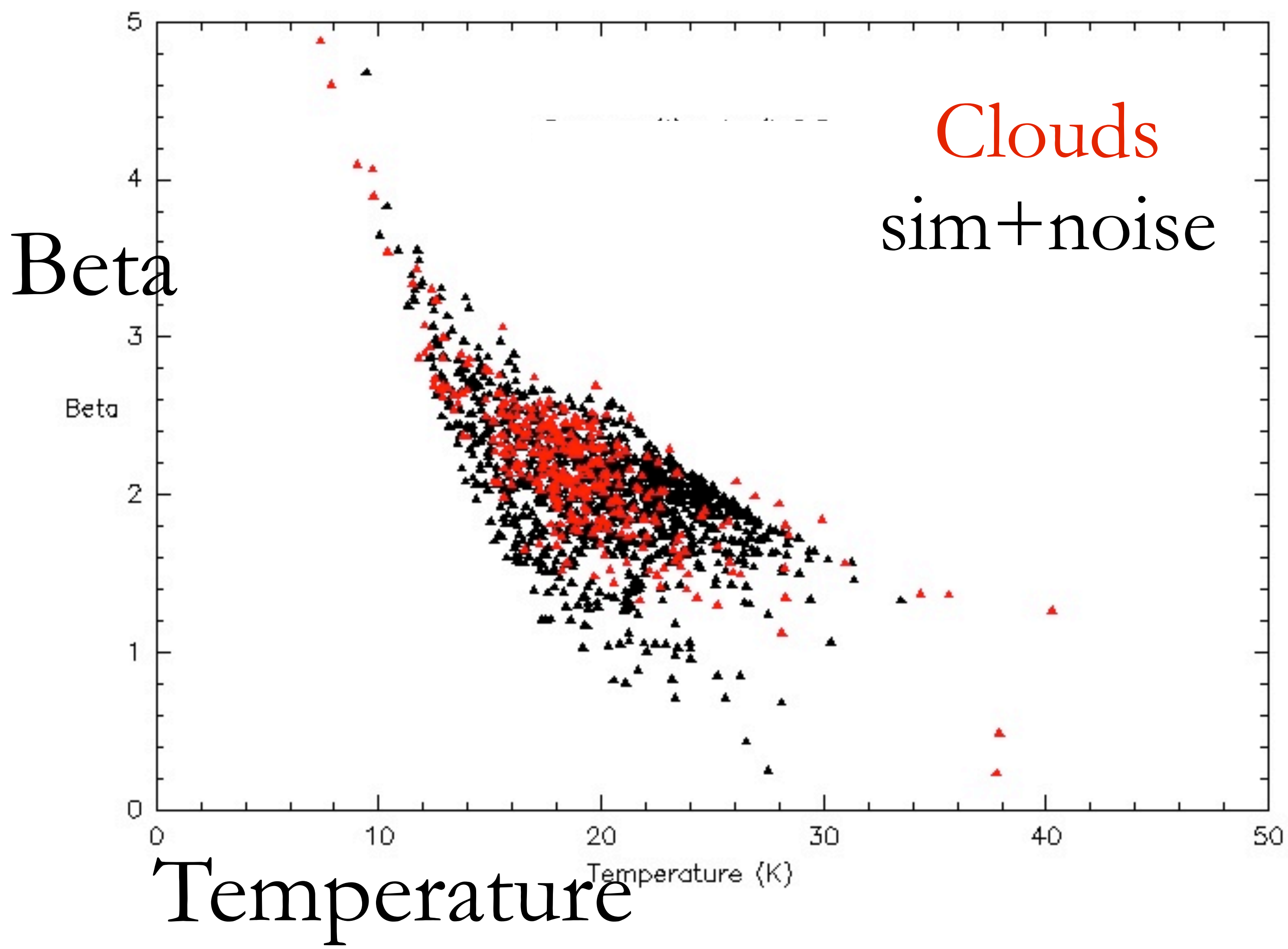
How can we measure the dust cross-section in the HI?

For regions over the disk, test regions with (a) a well-defined dust temperature (b) reasonably high S/N HI (c) no detected CO.
Make histogram of values and do *NOT* take average but peak of distribution just in case undetected H2 or HI is present. sigma=S/B(T)N_{HI}.

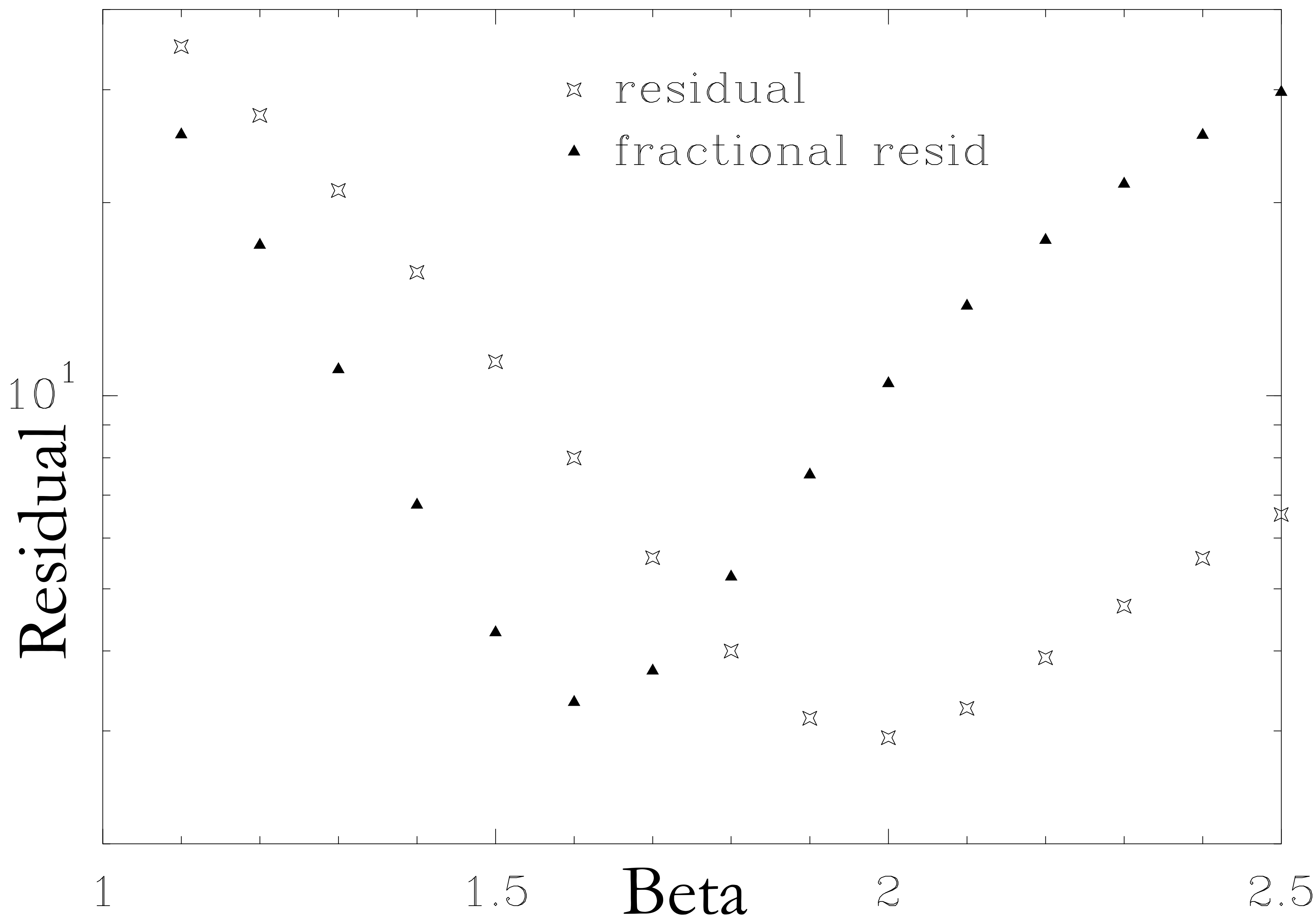


EXTREMELY strong Beta-Temperature degeneracy when fitting FIR data.

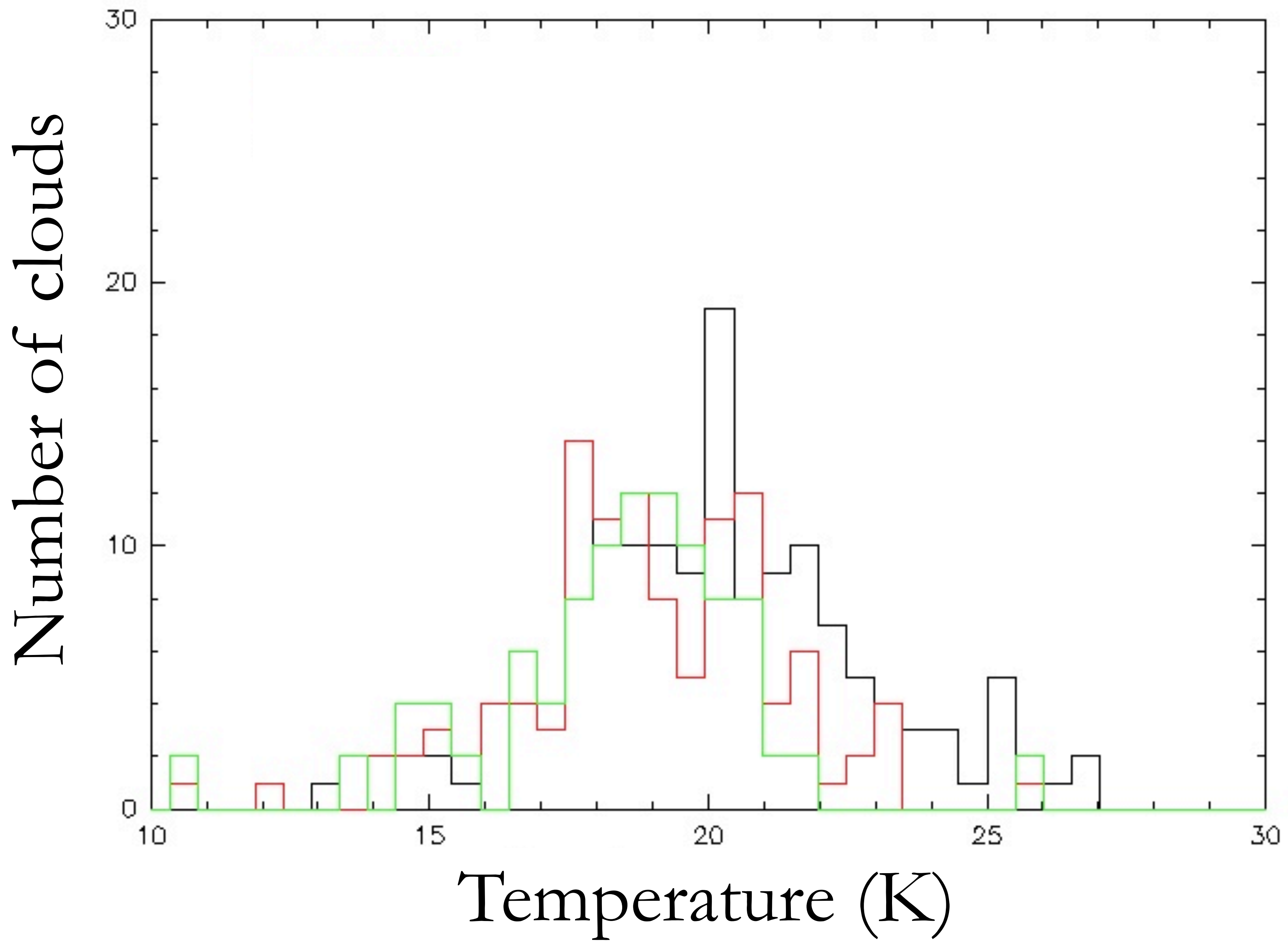


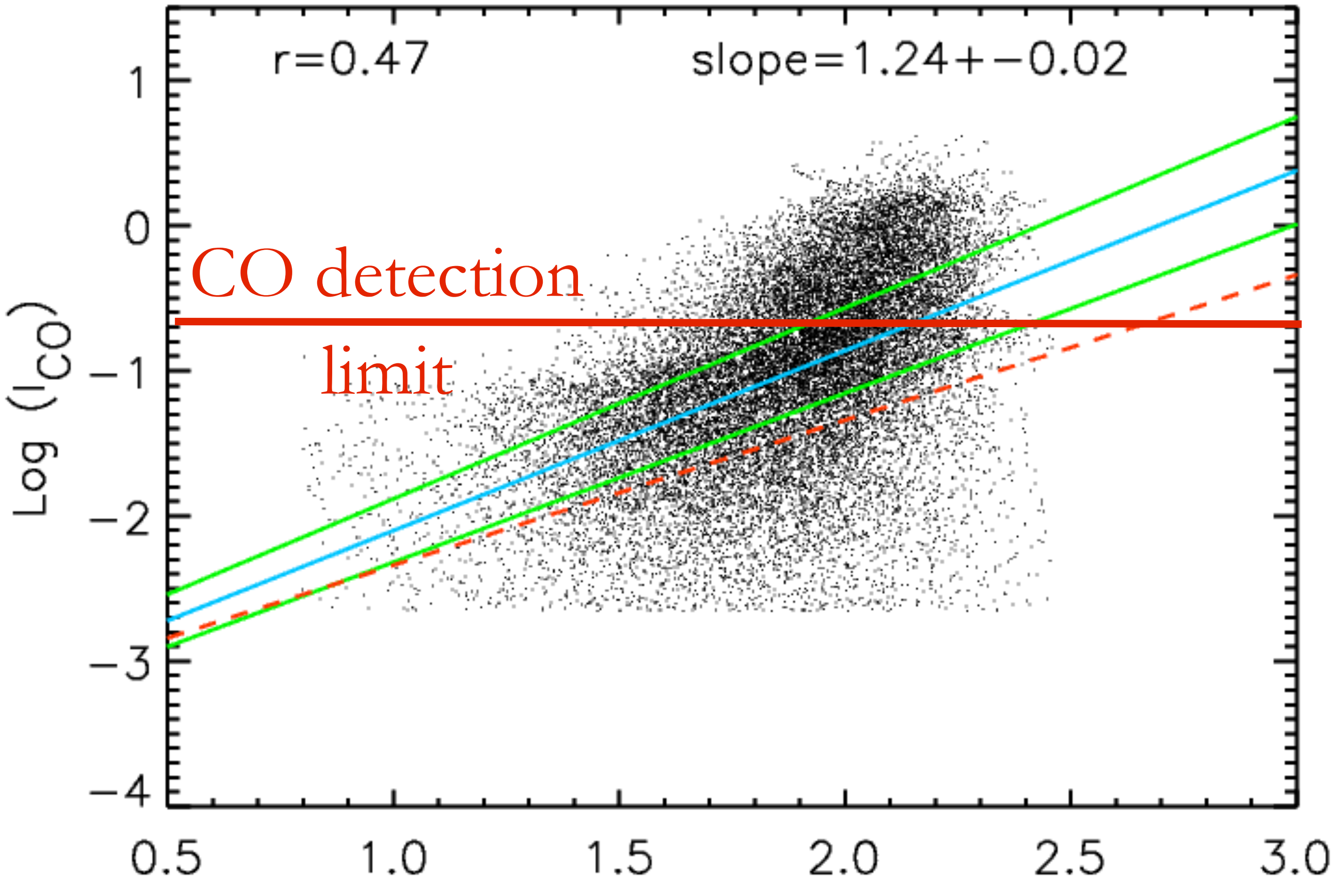


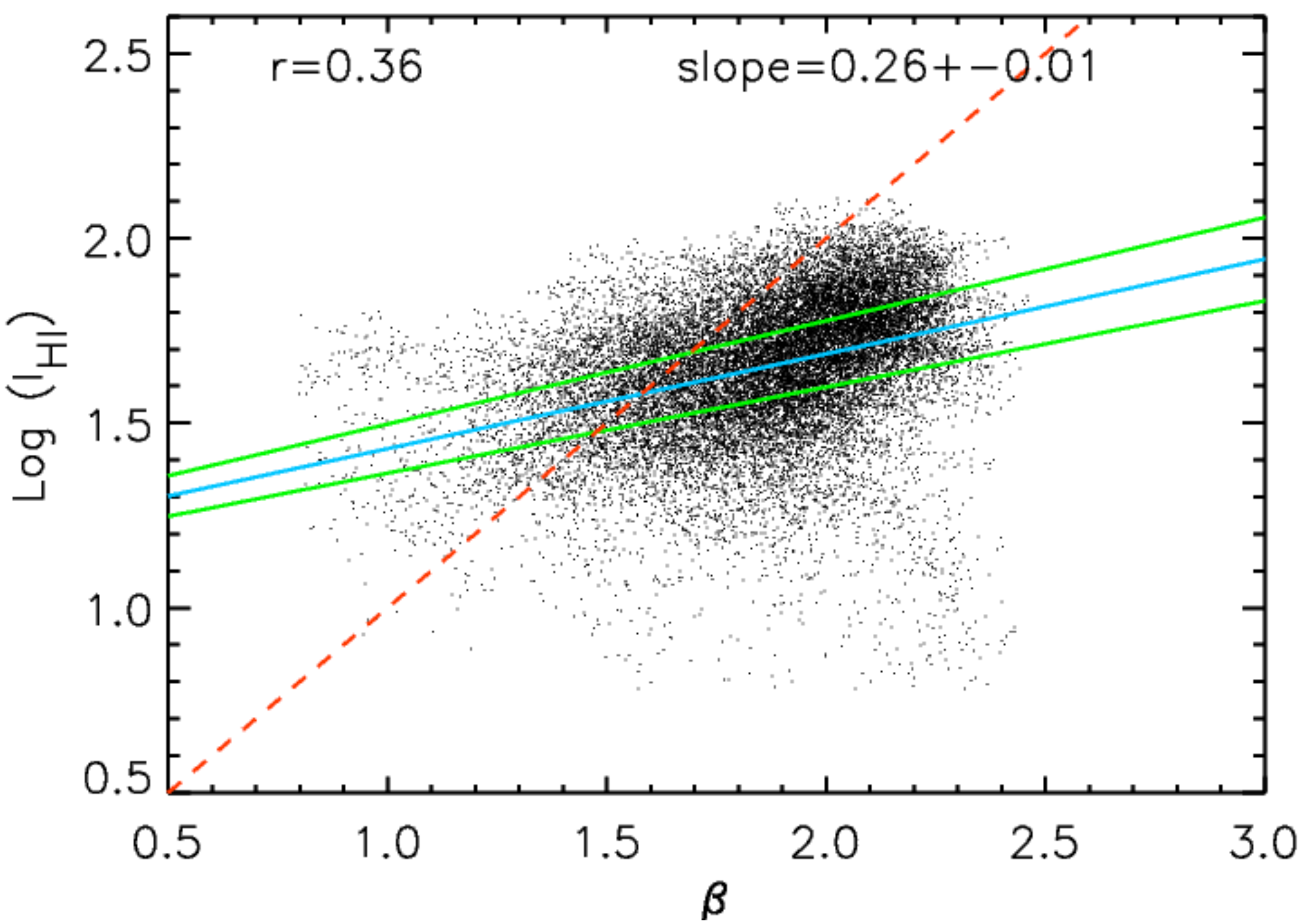
PROCEDURE: For the 337 clouds, fit 160 - 500 micron data with grey-body with beta taking values ranging from 1 - 2.5. If the flux predicted at 100 microns is higher than the observed flux, then refit using the 5 fluxes. Then calculate residuals (sum of $(\text{fit-flux})^2$) and fractional residuals $((\text{fit-flux})/\text{flux})^2$.



Clouds divided into 3 categories:
without star formation (A), embedded SF (B), exposed SF (C)
Temperature difference but no detectable difference in beta.





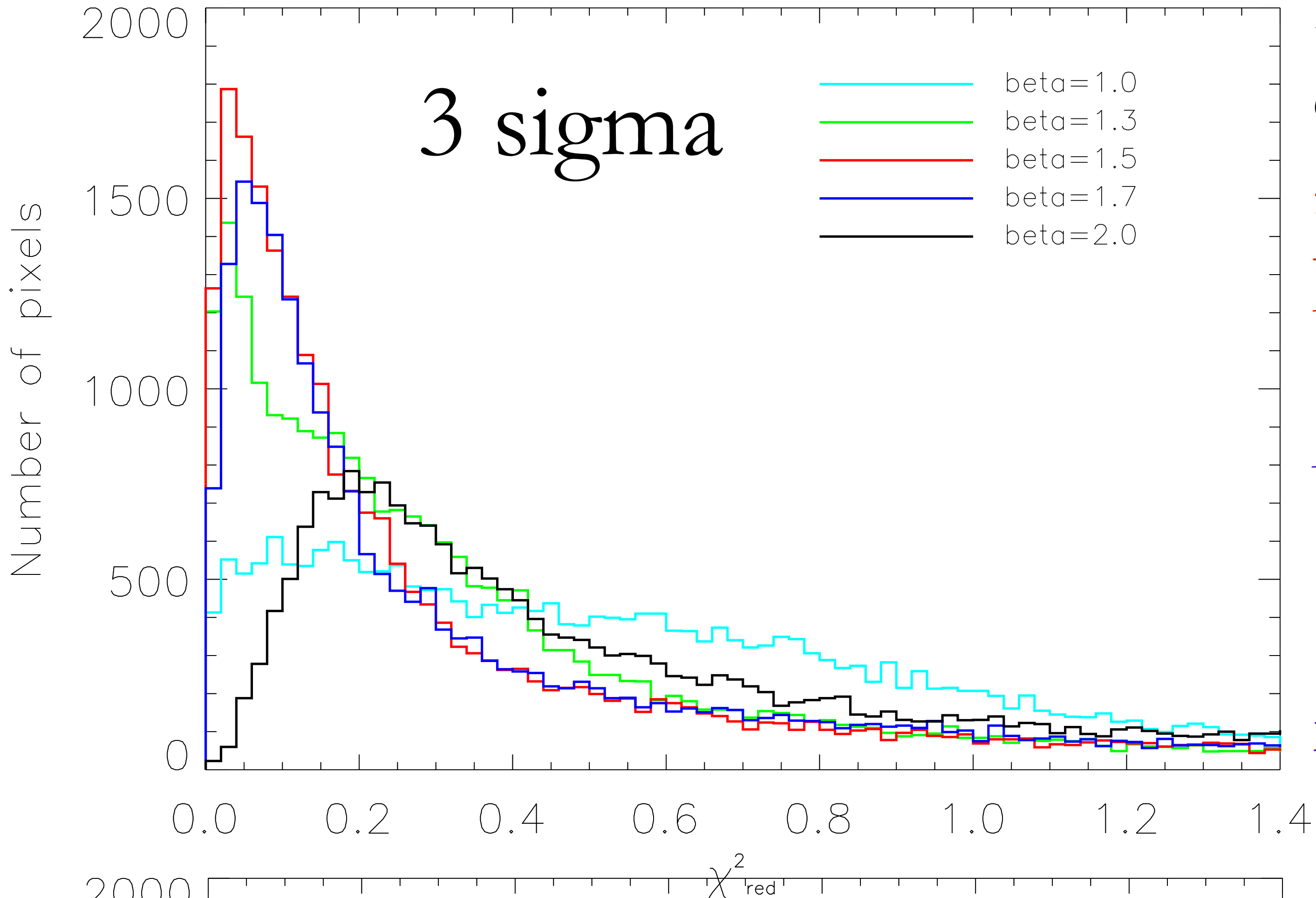


PROCEDURE:

Fit double grey-body (2 temperatures but one beta) to the data from 24 to 500 microns for each pixel.

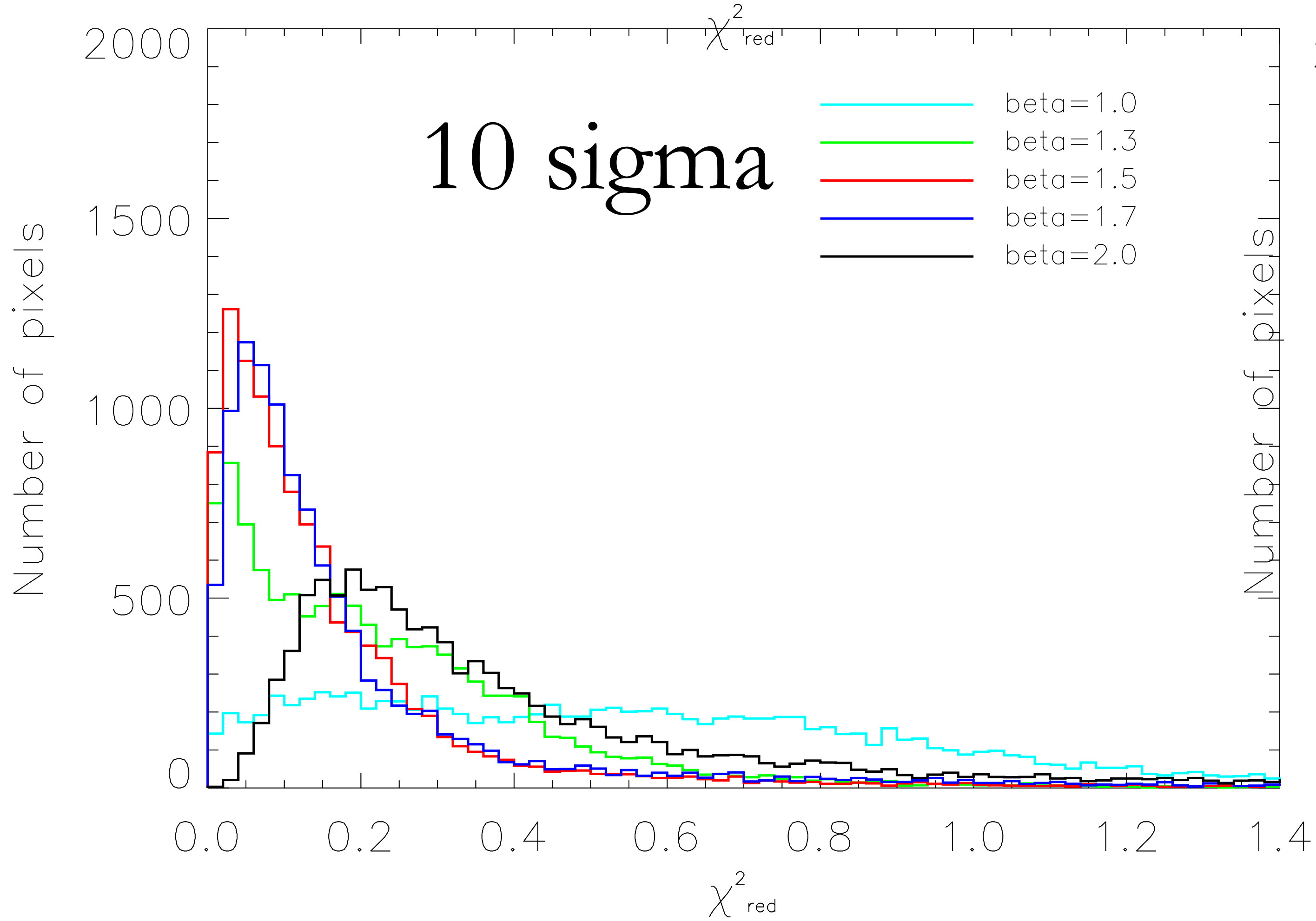
Then compare with CO and HI as in figures. Comparison beta-Halpha resembles CO.

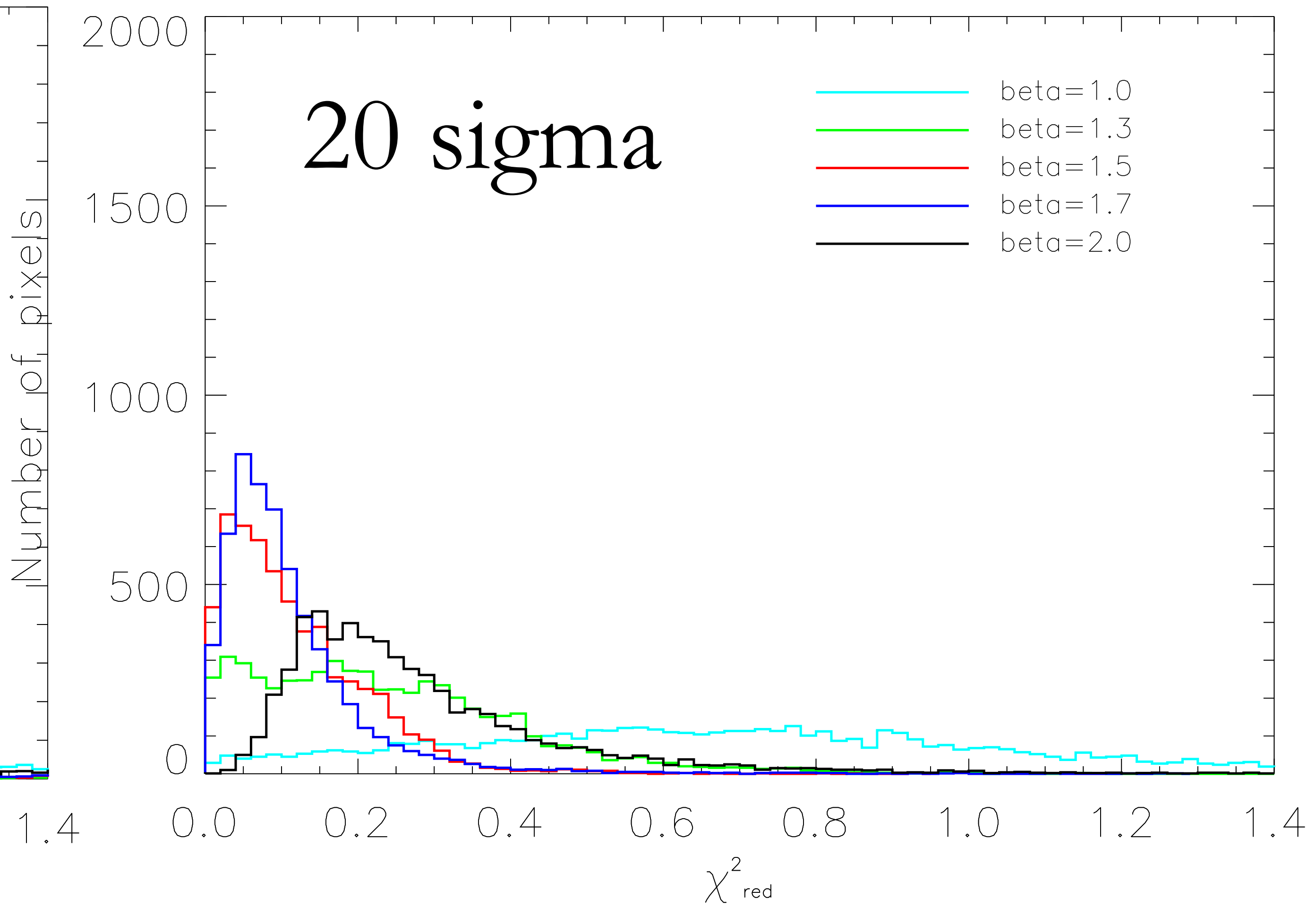
Figures by
Fatemeh Tabatabaei

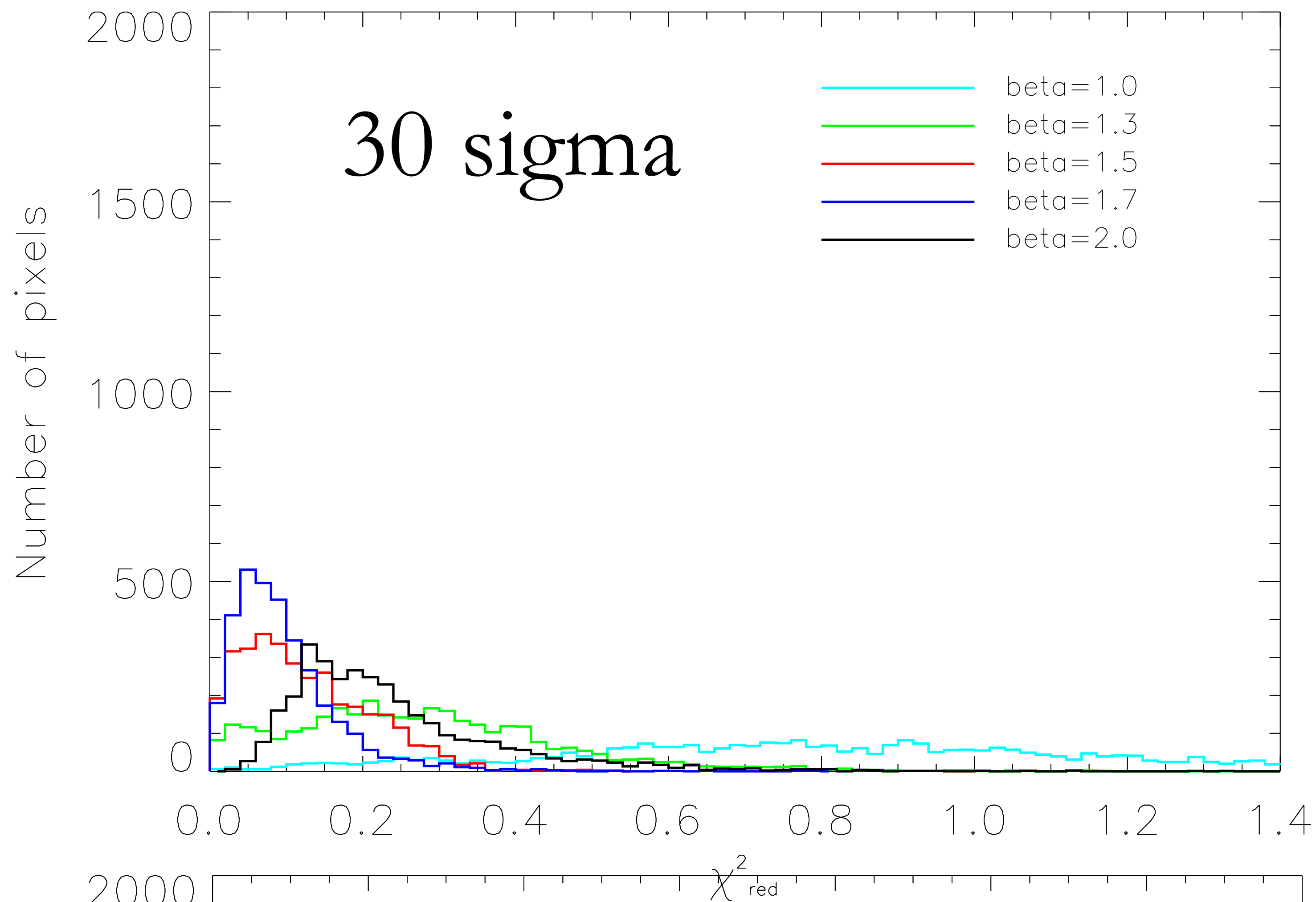


Procedure similar to first step except done pixel by pixel. When all pixels above 3 sigma are used, beta ~ 1.5. Xilouris+ 2012

As the threshold is increased to 20 sigma, beta moves to 1.7. The stronger regions have more molecular gas.

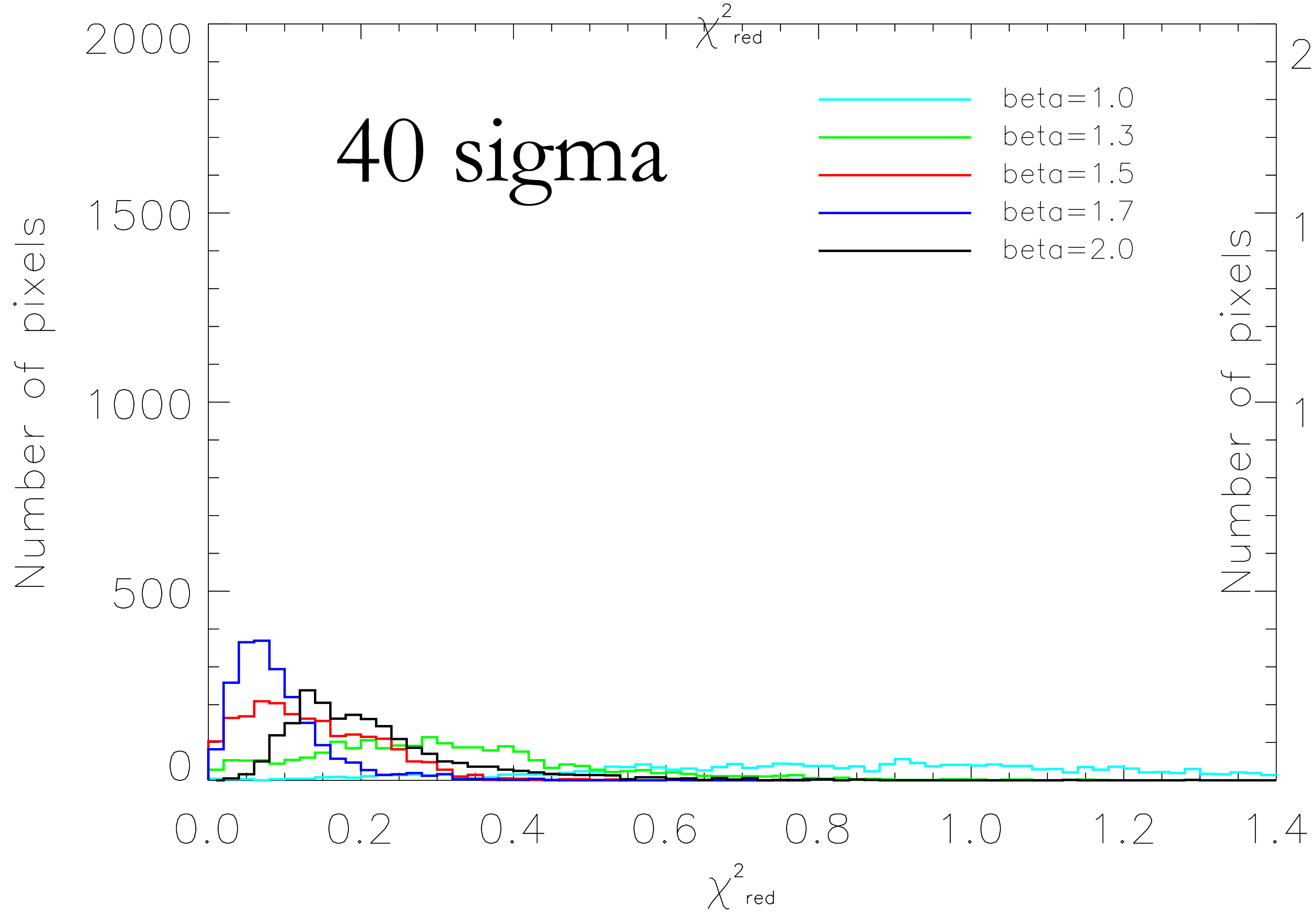


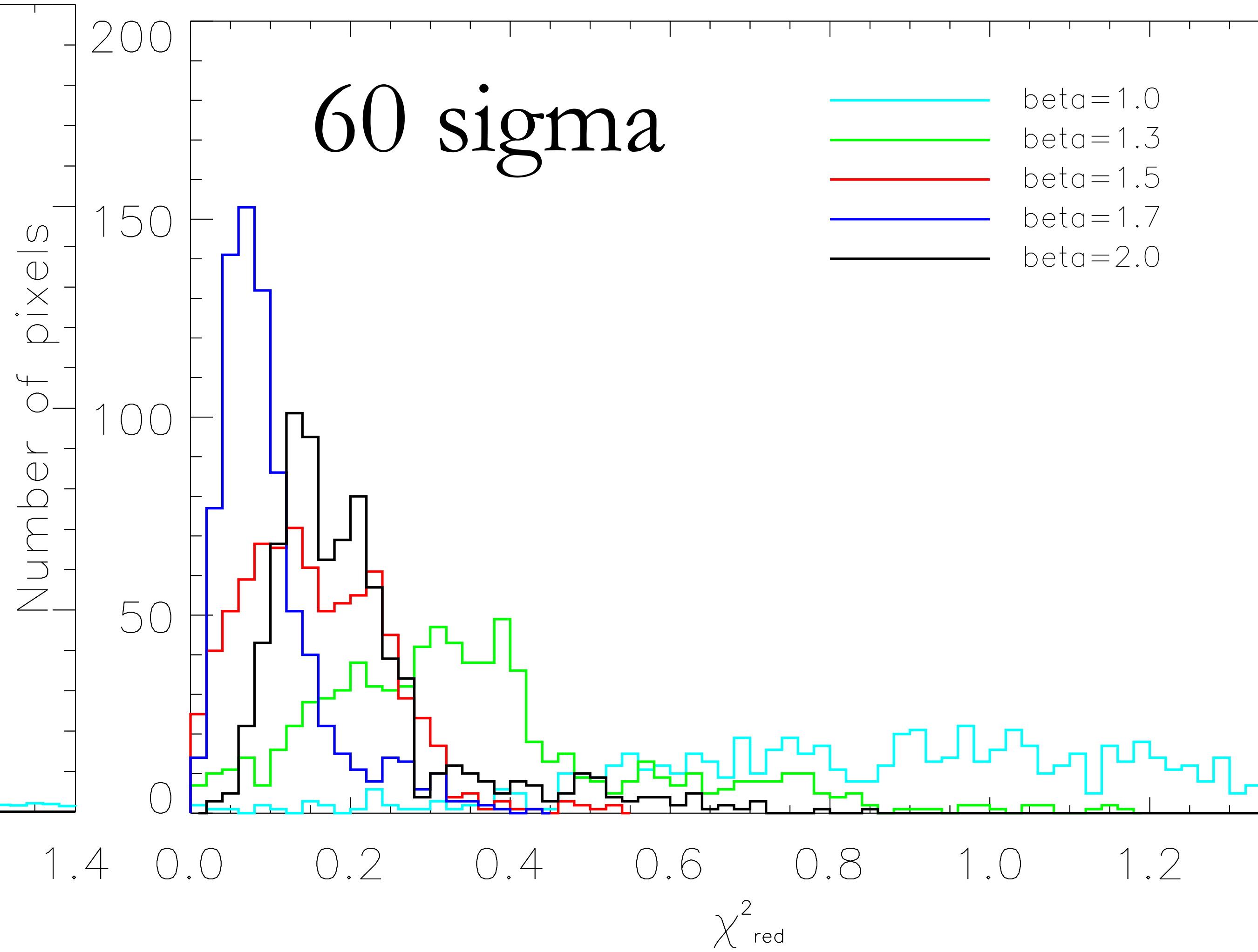




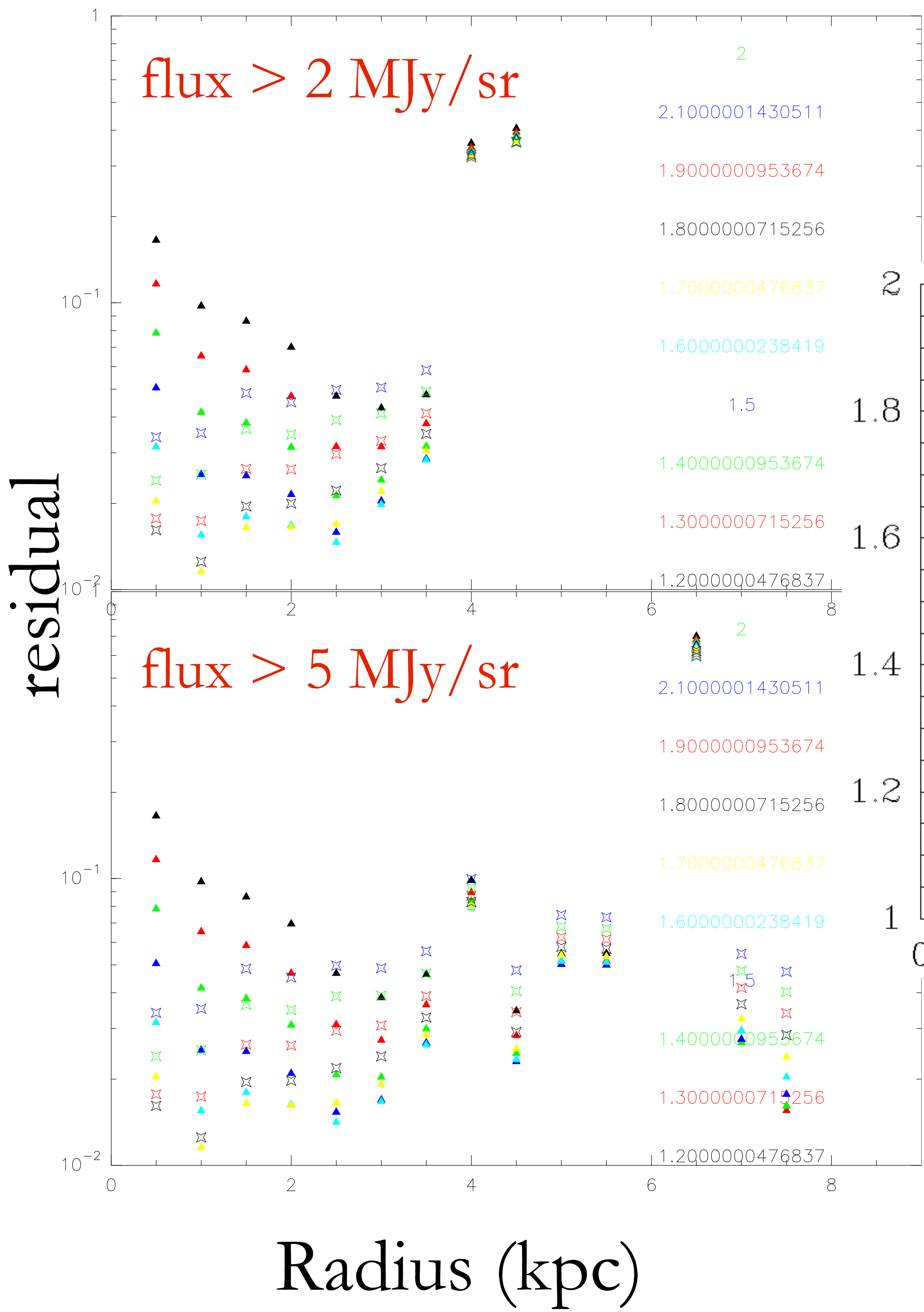
And between 30 and 60 sigma thresholds, the beta=2 fits become as good as beta=1.5. Residuals are fractional.

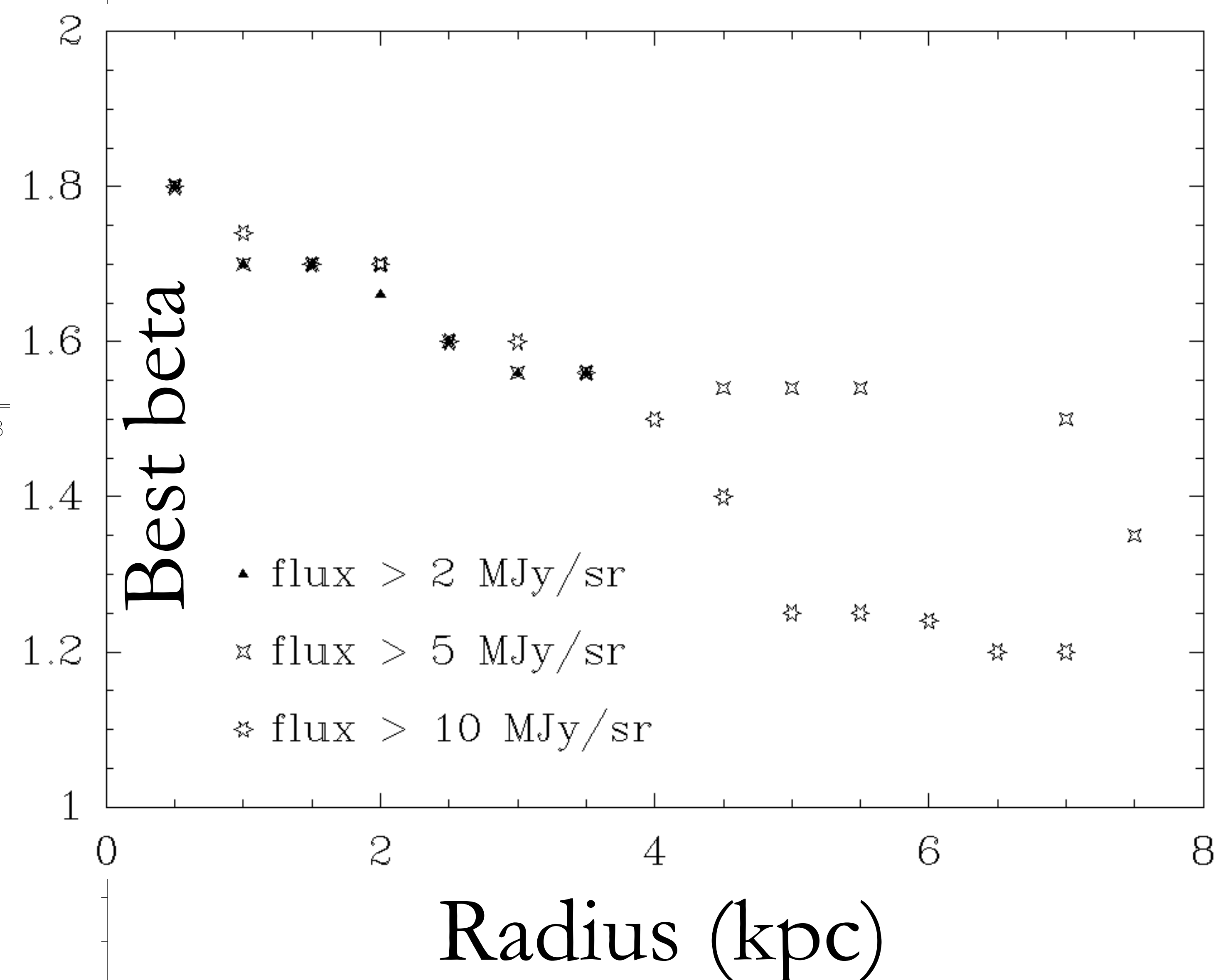
Figures by Manolis Xilouris





Look for radial trends, as the appropriate breakdown may not be HI vs H2. Use first procedure pixel by pixel.





Radial gradient is present, possibly due to the radial HI/H2 gradient.


Thank you for your attention