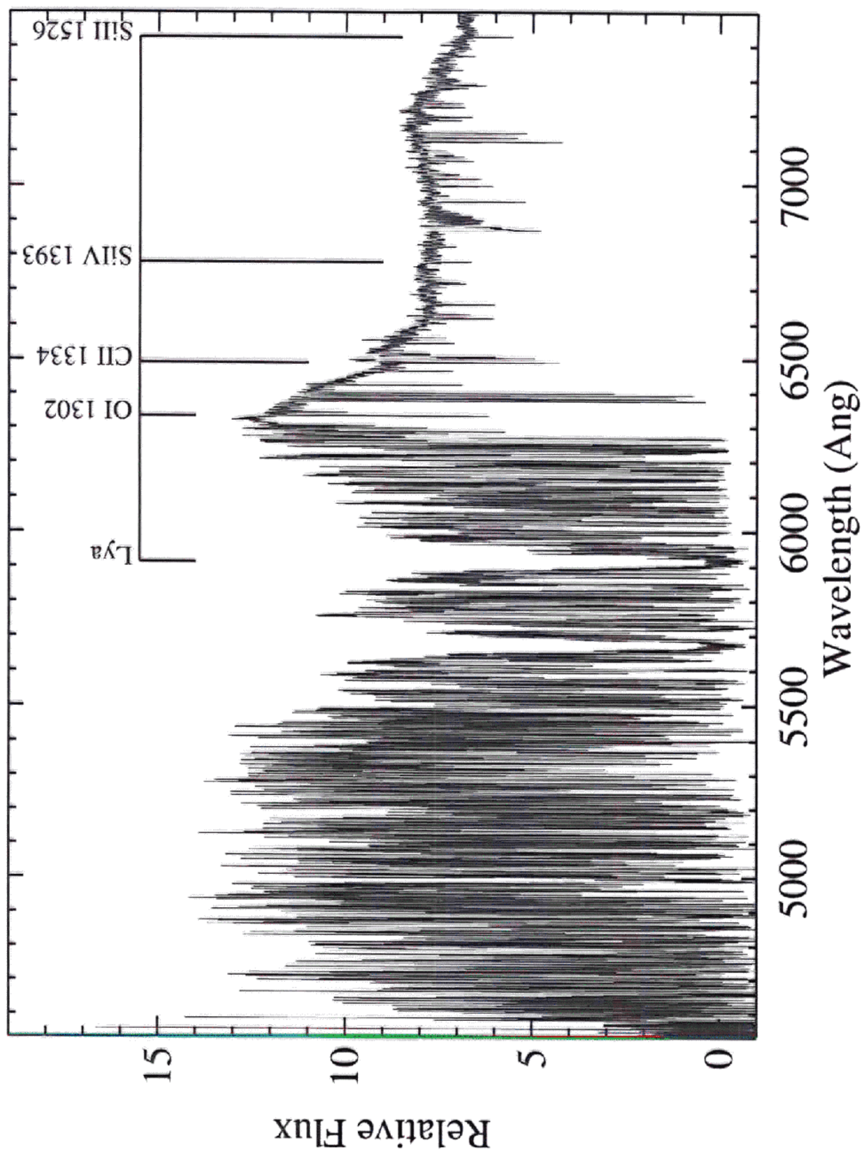
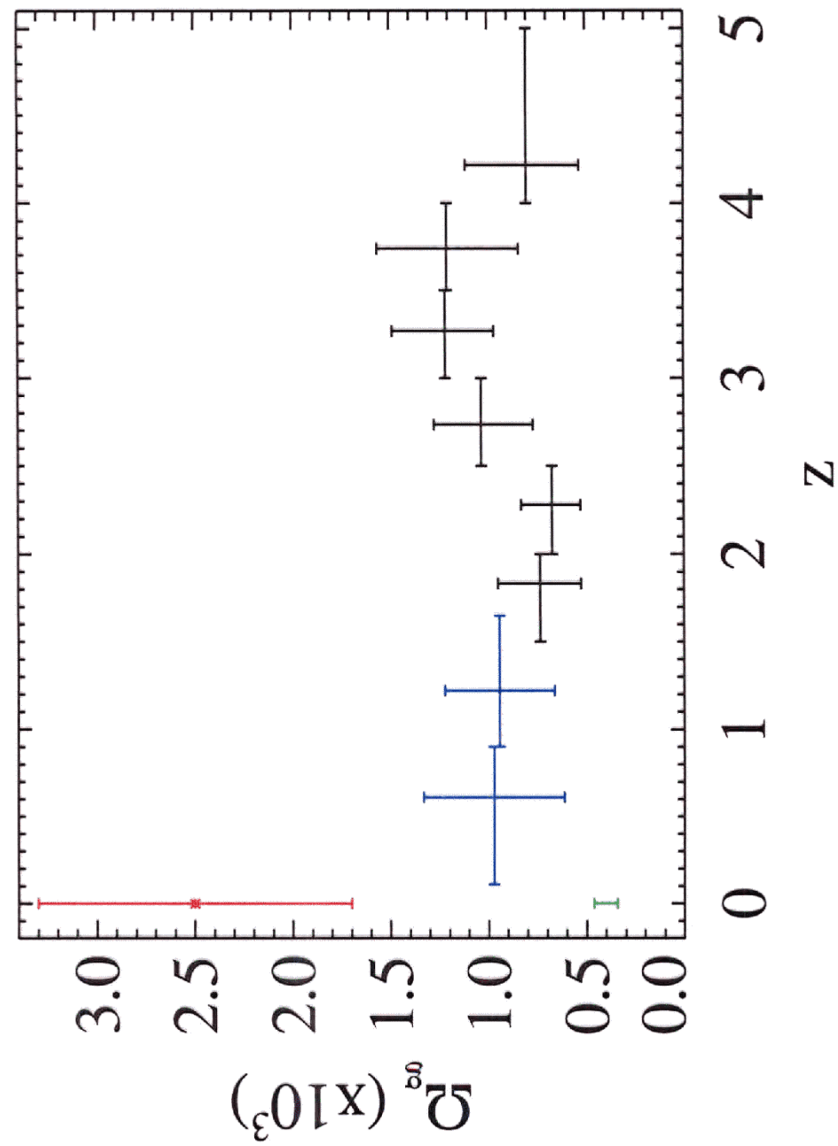
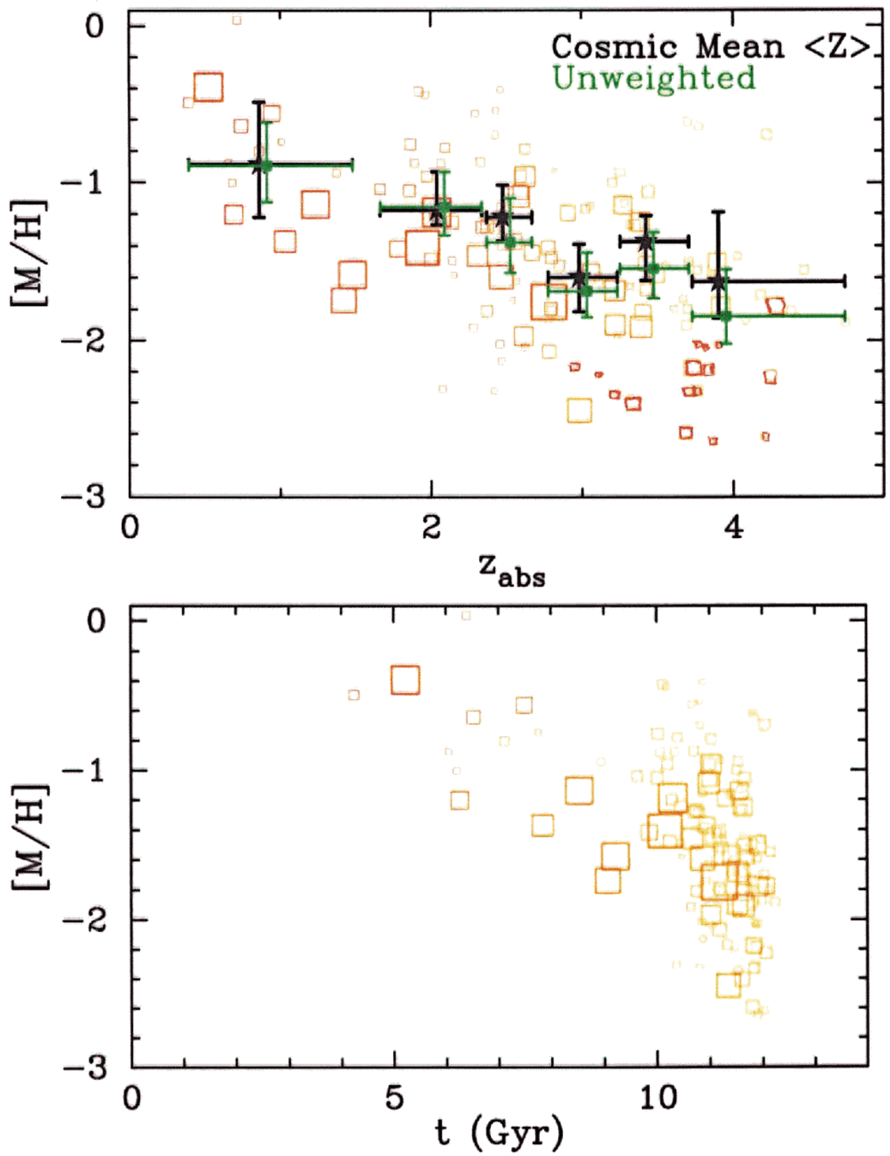
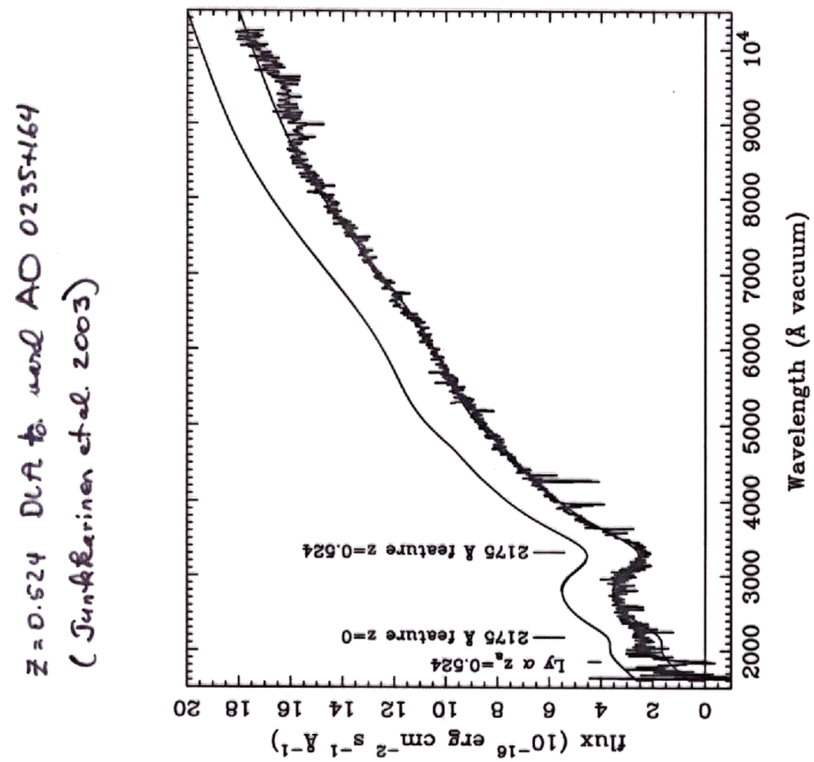
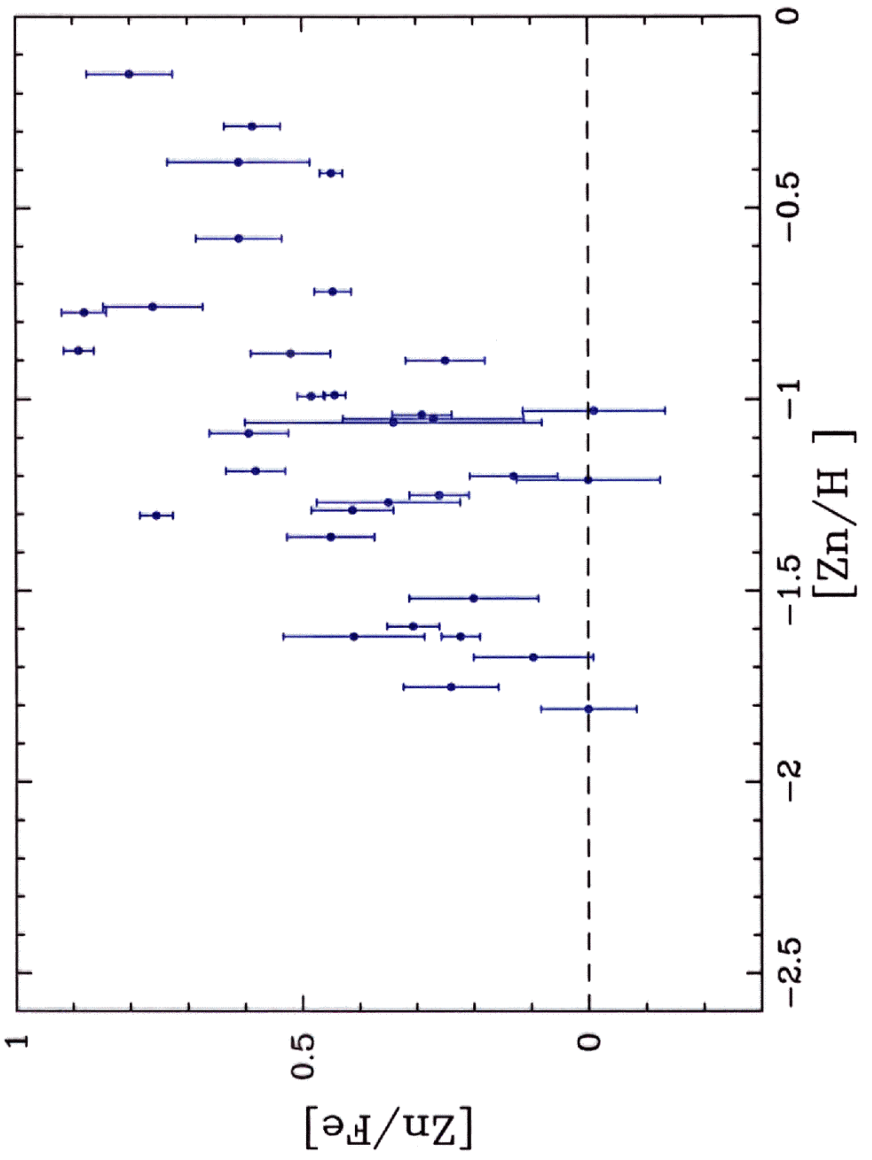
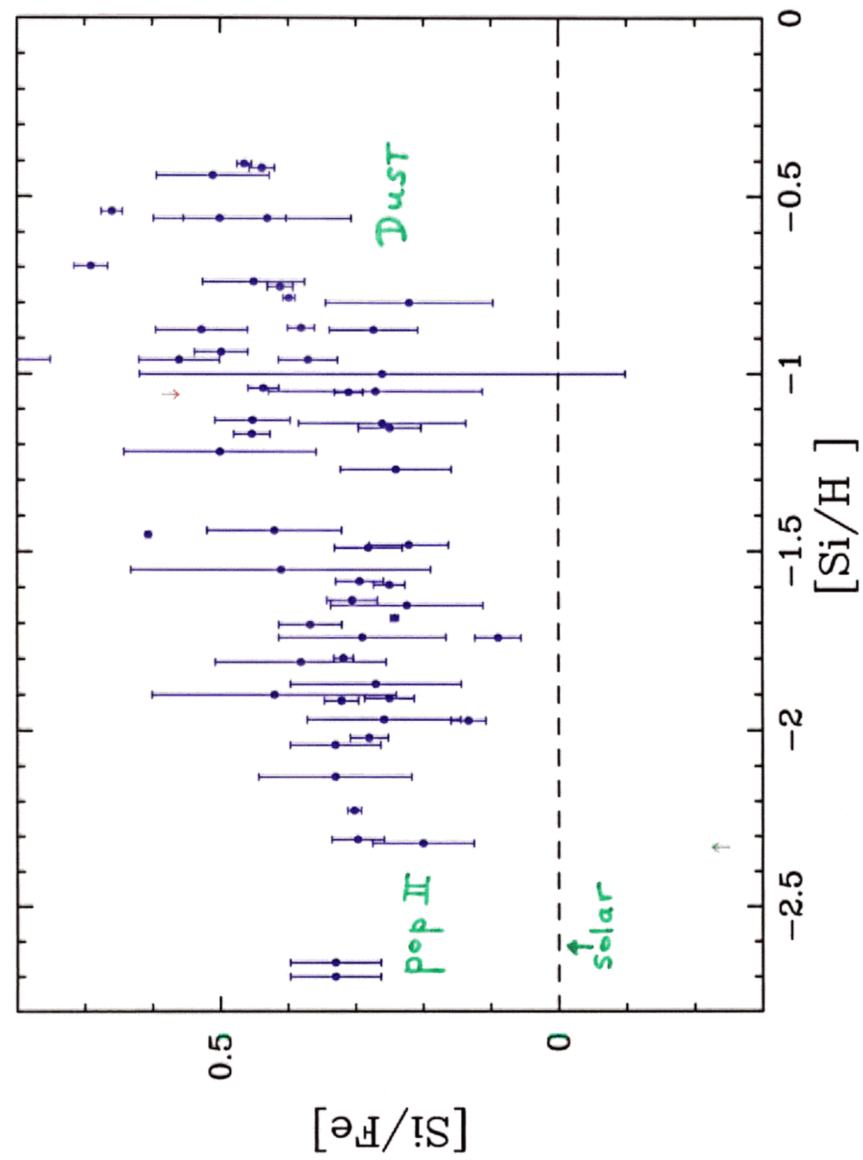

Relative Flux
Wavelength (Ang)
Lyα
OI 1302
CII 1334
SiIV 1393
SiII 1526


Ω_g (x10^3)
z


Cosmic Mean <Z>
Unweighted
[M/H]
z_abs
[M/H]
t (Gyr)

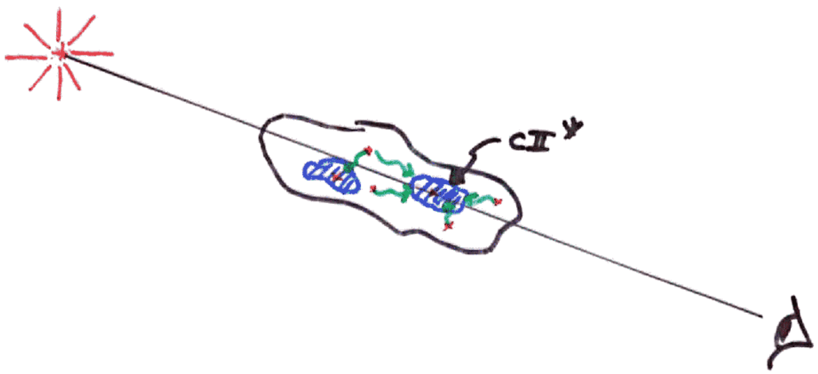

z = 0.524 DLA toward AO 0235+164
(Junkkarinen et al. 2003)
2175 Å feature z=0.524
2175 Å feature z=0
Ly α z_a=0.524
Wavelength (Å vacuum)
flux (10^-16 erg cm^-2 s^-1 Å^-1)


[Zn/H]
[Zn/Fe]


[Si/H]
[Si/Fe]
Dust
Pop II
solar

CII* Method for Measuring Star Formation Rates in DLAs

Collaboration with:
J.X. Prochaska, E. Gawiser, + J.C. Howk

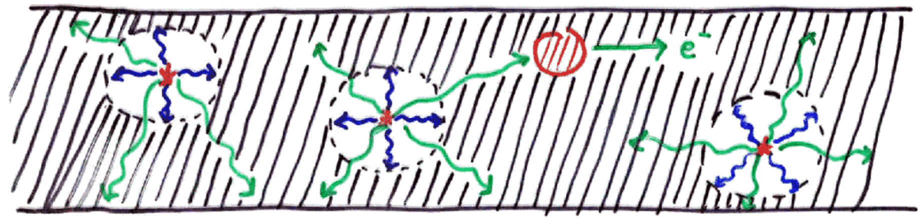


- Goal:

  Infer level of radiative feedback from absorption-line data

Energy Balance in Damped Lyα Systems

- Heating



$$\Gamma_d \propto \kappa \cdot \epsilon \cdot J \qquad \text{ergs s}^{-1}\ \text{H}^{-1}$$

κ: Dust to gas ratio
ϵ: Photoelectric Efficiency
J: FUV mean intensity

- Mean Intensity

  $J(t) \propto \dot{\psi}_*(t)$ ($\dot{\psi}_* \overset{d}{=}$ SFR per area)

- Dust-to-Gas Ratio

  $$\kappa = 10^{[Si/H]_{int}} \left[10^{[Fe/Si]_{int}} - 10^{[Fe/Si]_{gas}} \right]$$

- Photoelectric Heating Efficiency

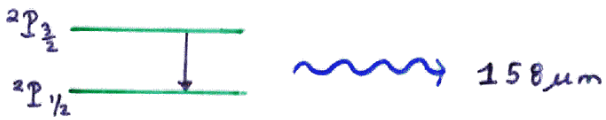
  CNM: $\epsilon \approx 0.05$

  WNM: $\epsilon \ll 0.05$

- **Cooling**

ISM cools by emission of [CII] 158μm

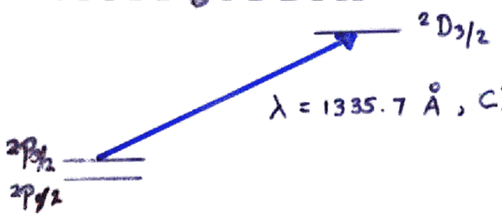
- Fine Structure states



- Cooling rate per H atom

$$\ell_c = \frac{N(CII^*) h\nu_{ul} A_{ul}}{N(HI)} \quad \text{ergs s}^{-1}\ \text{H}^{-1}$$

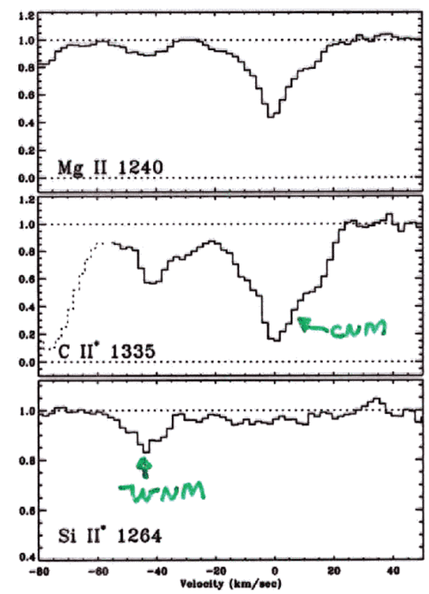
- Measuring $N(CII^*)$



- **Steady State Condition**

$$\Gamma_d = \ell_c$$

Q 0812+32 DLA
z = 2.626

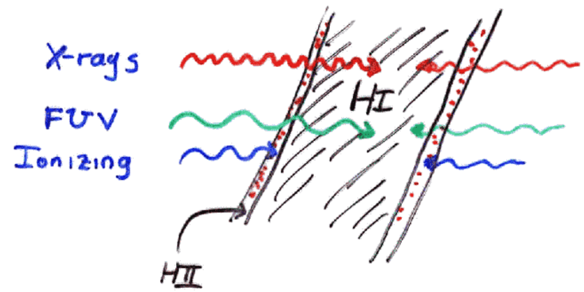


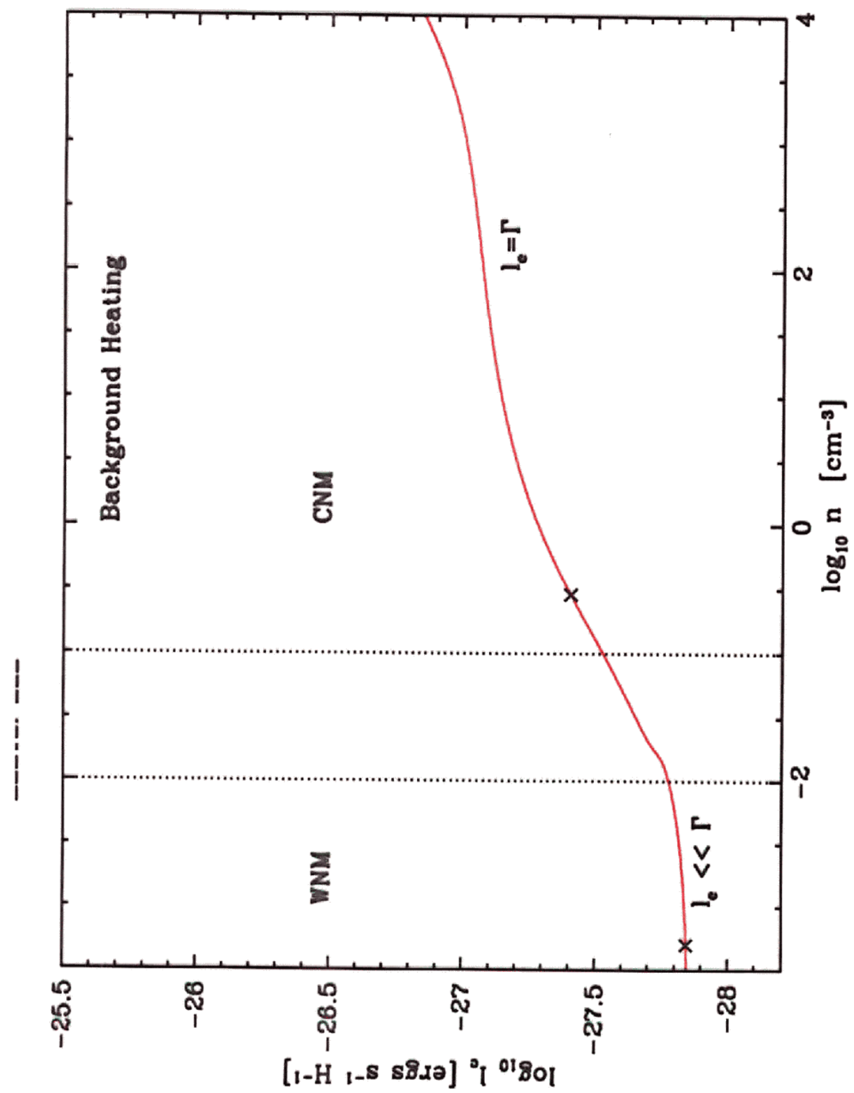
Multi-phase Models (a.la Wolfire et al. 1995)

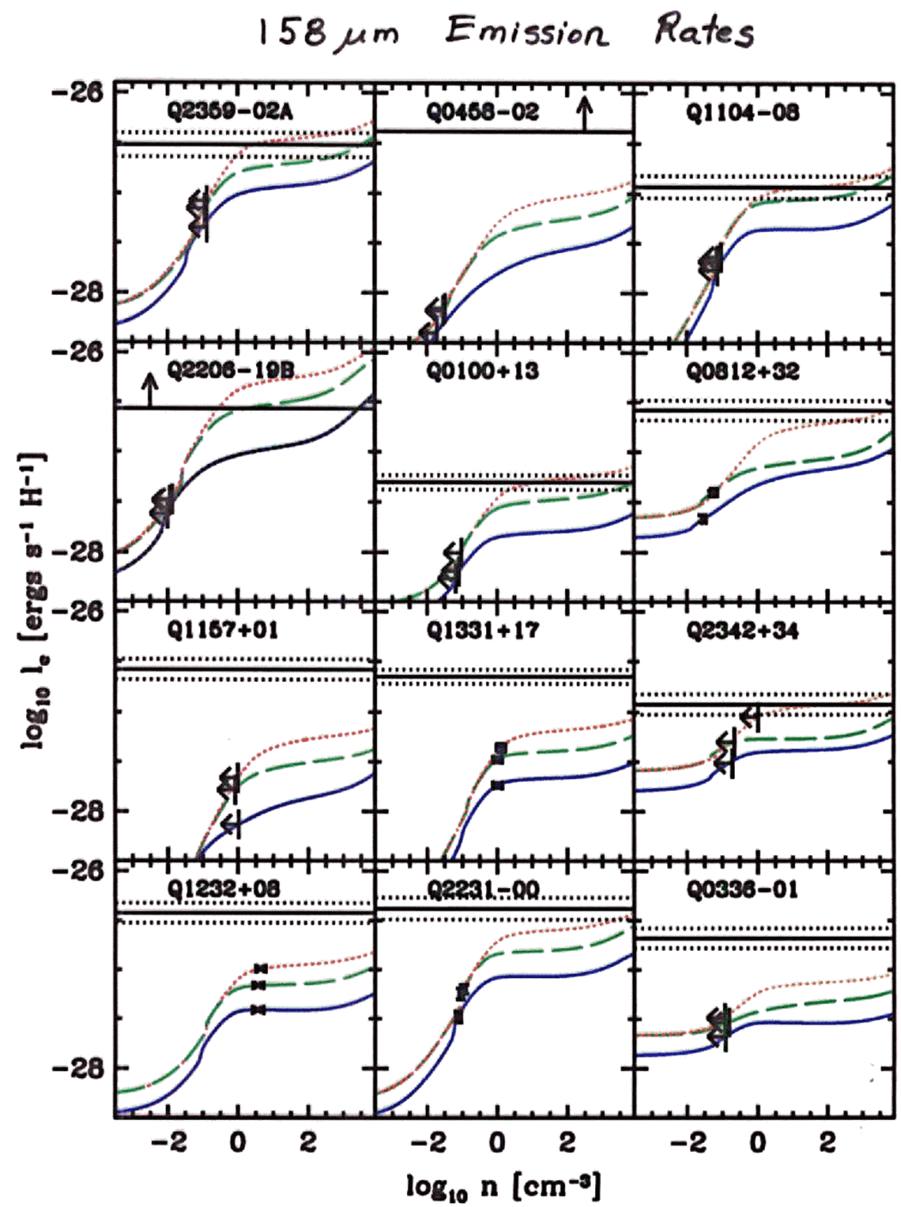
- **Heating**
  - Photoelectric grain heating: Γ_d
  - Cosmic Ray heating: Γ_{CR}
  - X-ray heating: Γ_{XR}
  - CI photoionization heating: Γ_{CI}
  - Total: $\Gamma = \Gamma_d + \Gamma_{CR} + \Gamma_{XR} + \Gamma_{CI}$
- **Cooling.**
  - Fine Structure line emission, [CII], [OI], [FeII], [SiII] : Λ_{FS}
  - Metastable lines: Λ_{MS}
  - Lyα: $\Lambda_{Ly\alpha}$
  - Grain Recombination: Λ_{Rec}
  - Total: $\Lambda = \Lambda_{FS} + \Lambda_{MS} + \Lambda_{Ly\alpha} + \Lambda_{Rec}$
- **Thermal Equilibrium**:

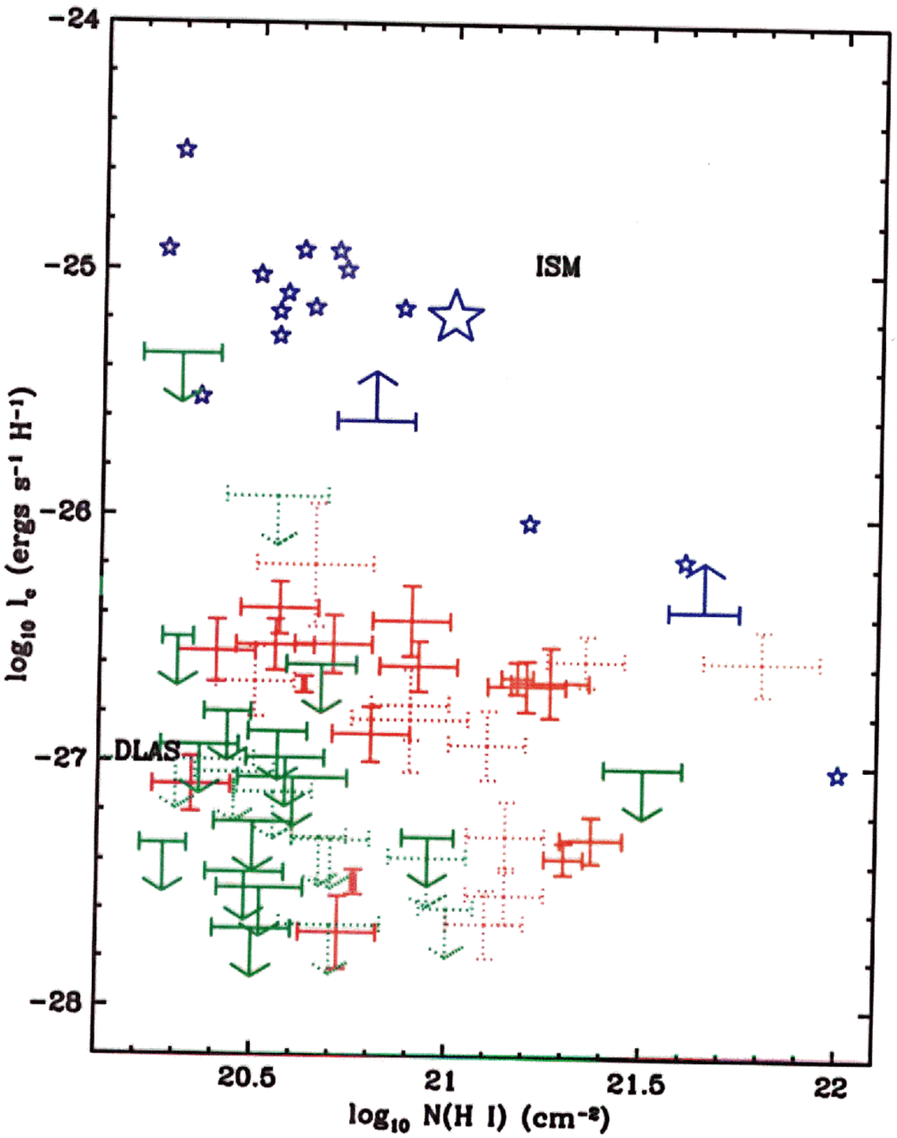
$$\Gamma = n\Lambda$$

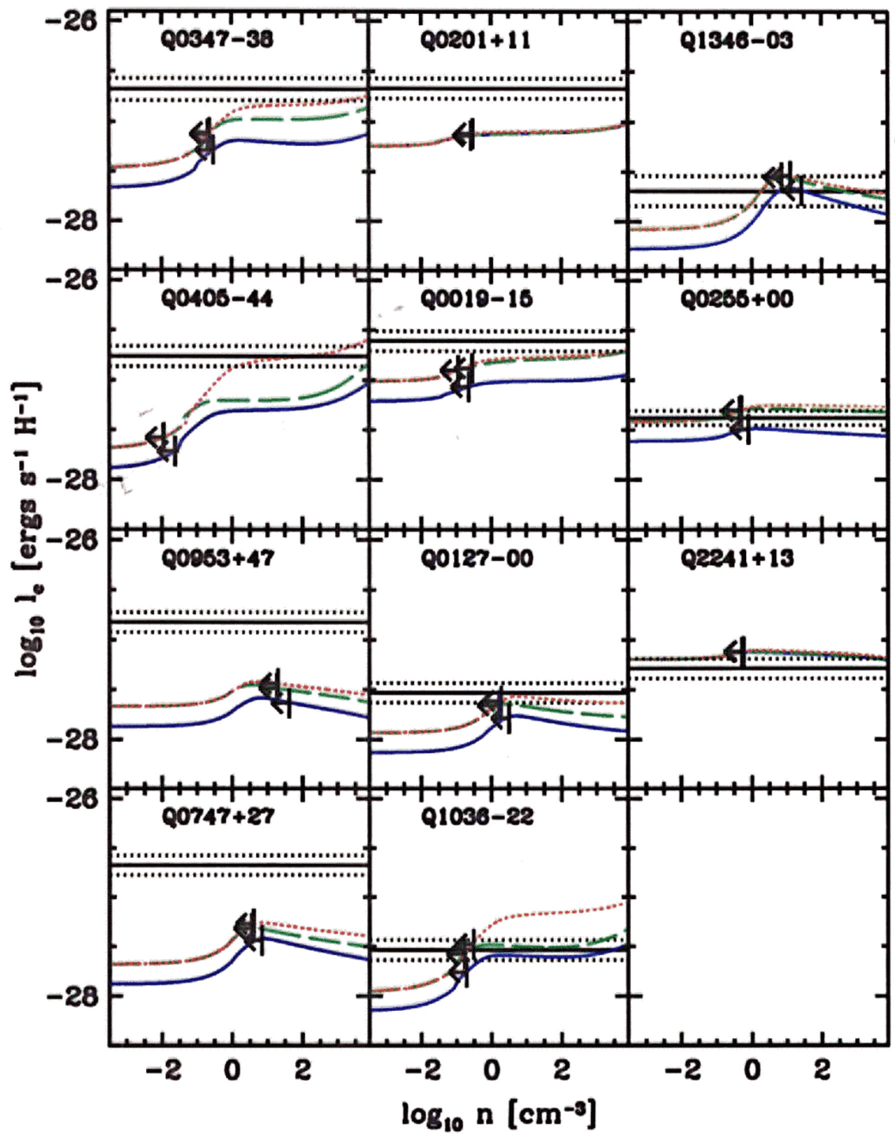
External Heating by Background Radiation

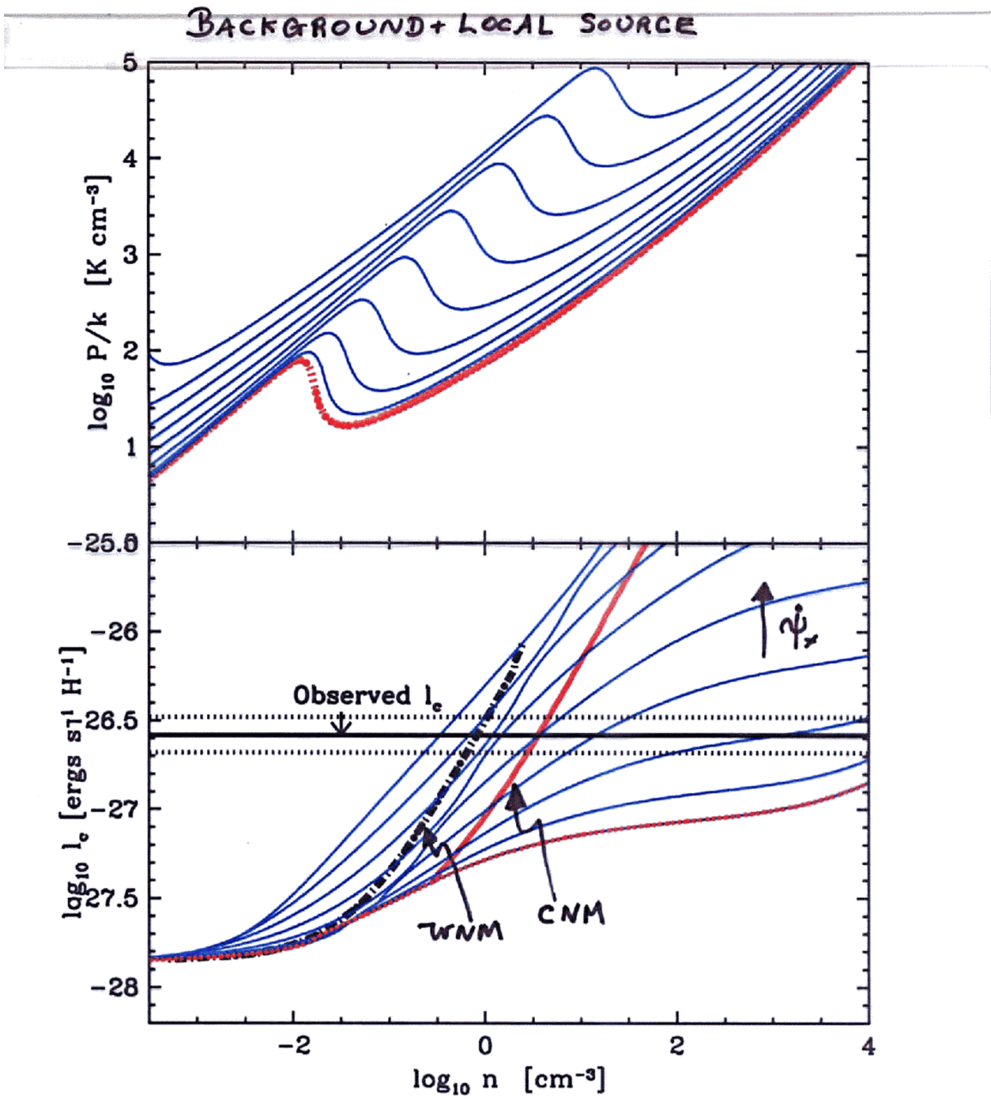



Background Heating
CNM
WNM
l_c=Γ
l_c << Γ
log10 n [cm^-3]
log10 l_c [ergs s^-1 H^-1]
-25.5
-26
-26.5
-27
-27.5
-28
-2
0
2
4

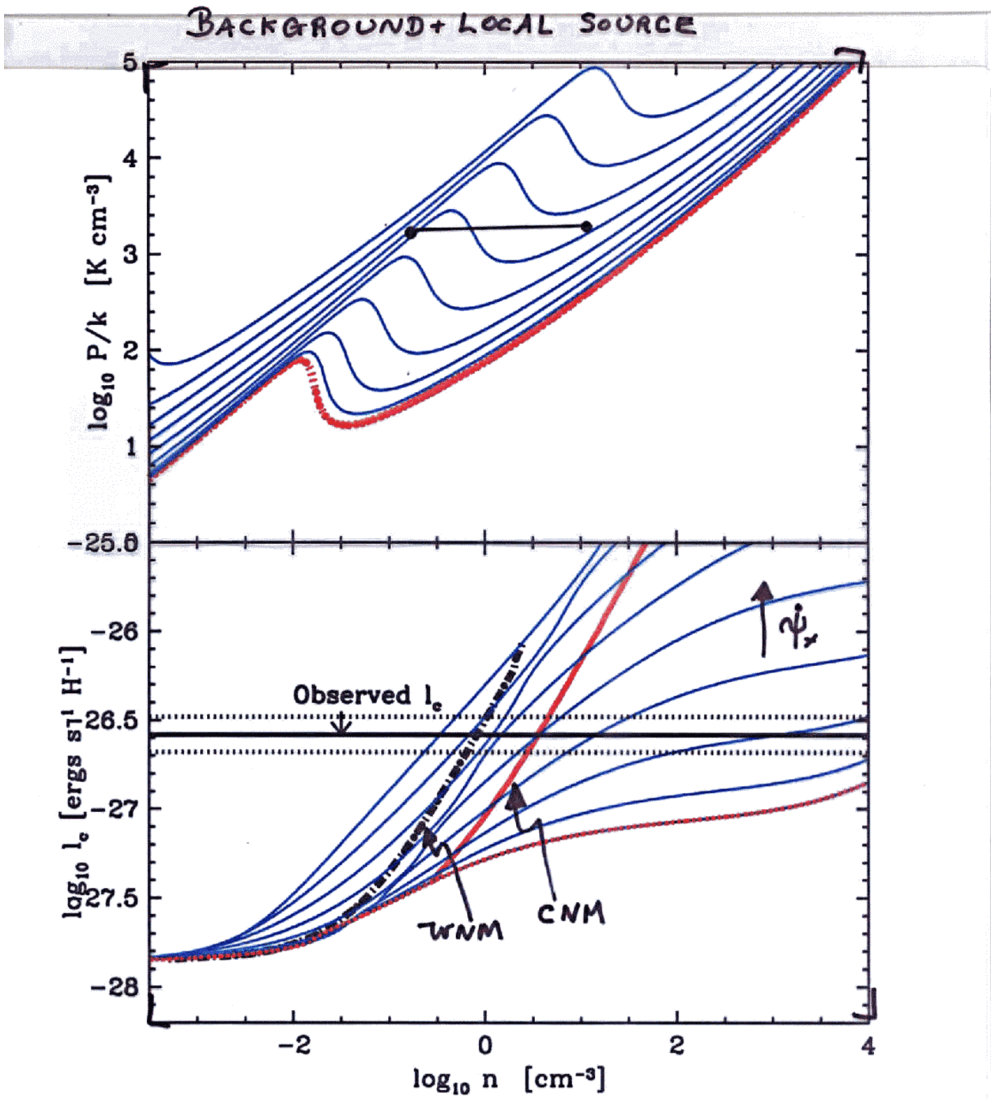

158 μm Emission Rates
Q2359-02A
Q0458-02
Q1104-08
Q2206-19B
Q0100+13
Q0812+32
Q1157+01
Q1331+17
Q2342+34
Q1232+08
Q2231-00
Q0336-01
log10 l_c [ergs s^-1 H^-1]
log10 n [cm^-3]
-26
-28
-2
0
2


ISM
DLAS
log10 lc (ergs s-1 H-1)
log10 N(H I) (cm-2)


Q0347-38
Q0201+11
Q1346-03
Q0405-44
Q0019-15
Q0255+00
Q0953+47
Q0127-00
Q2241+13
Q0747+27
Q1036-22
log10 lc [ergs s-1 H-1]
log10 n [cm-3]



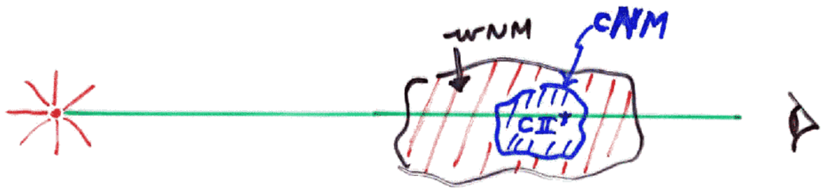
BACKGROUND + LOCAL SOURCE
log10 P/k [K cm^-3]
log10 lc [ergs s^-1 H^-1]
Observed lc
WNM
CNM
log10 n [cm^-3]



BACKGROUND + LOCAL SOURCE
log10 P/k [K cm^-3]
log10 lc [ergs s^-1 H^-1]
Observed lc
WNM
CNM
log10 n [cm^-3]

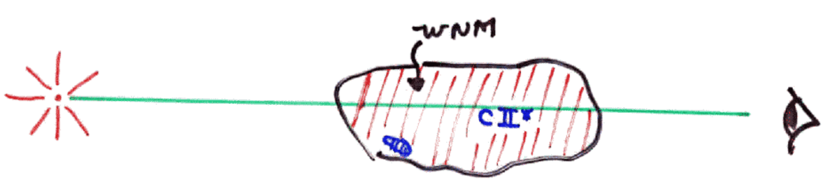
Two Phase Models for Positive Detections

- **CNM+WNM Model**

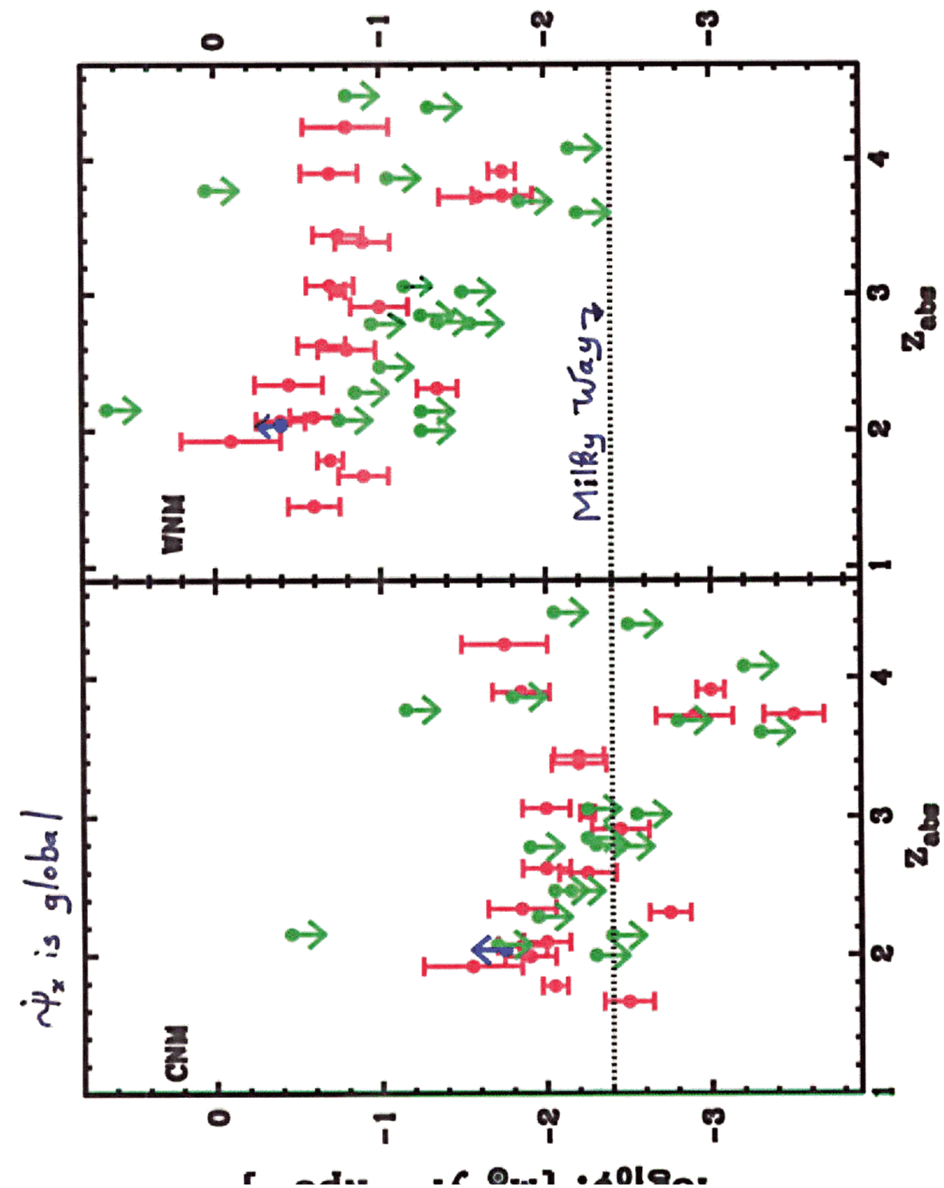


$J_{FUV} \gtrsim (J_{FUV})_{Milky\ Way}$

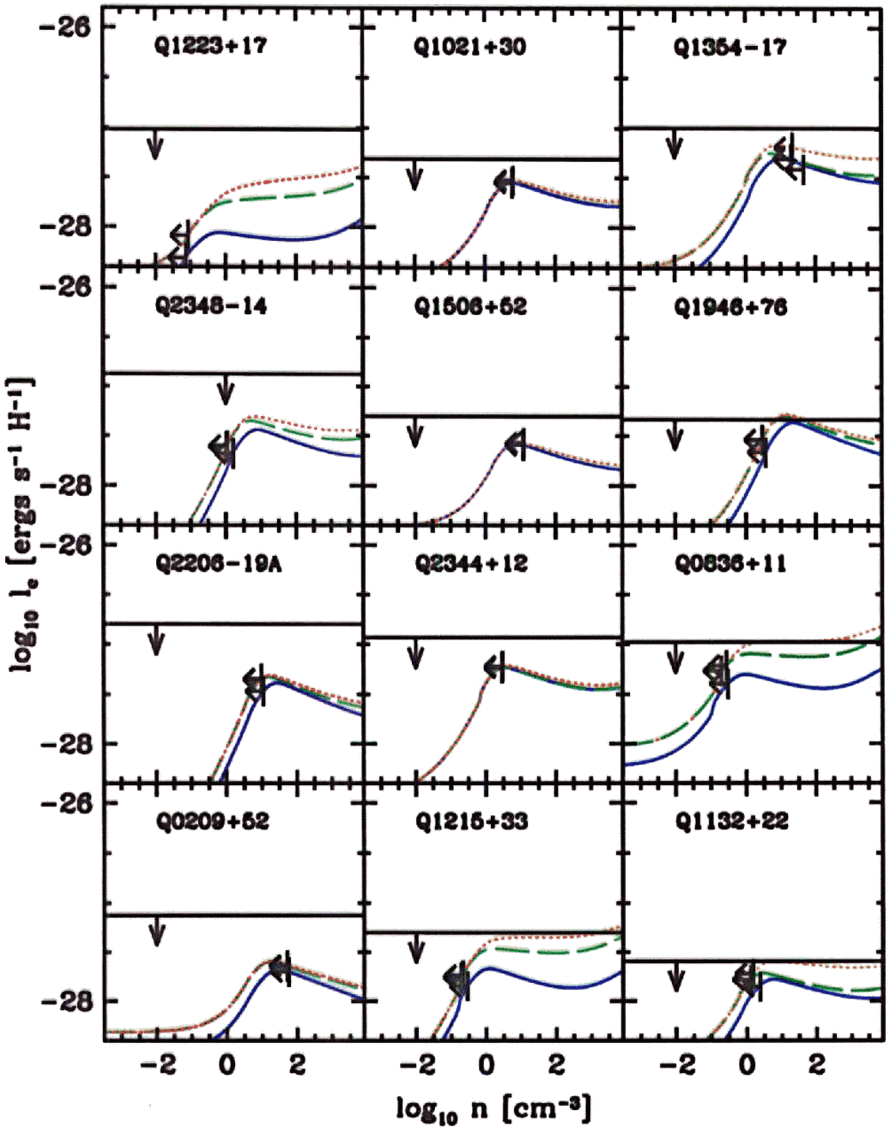
- **WNM Model**

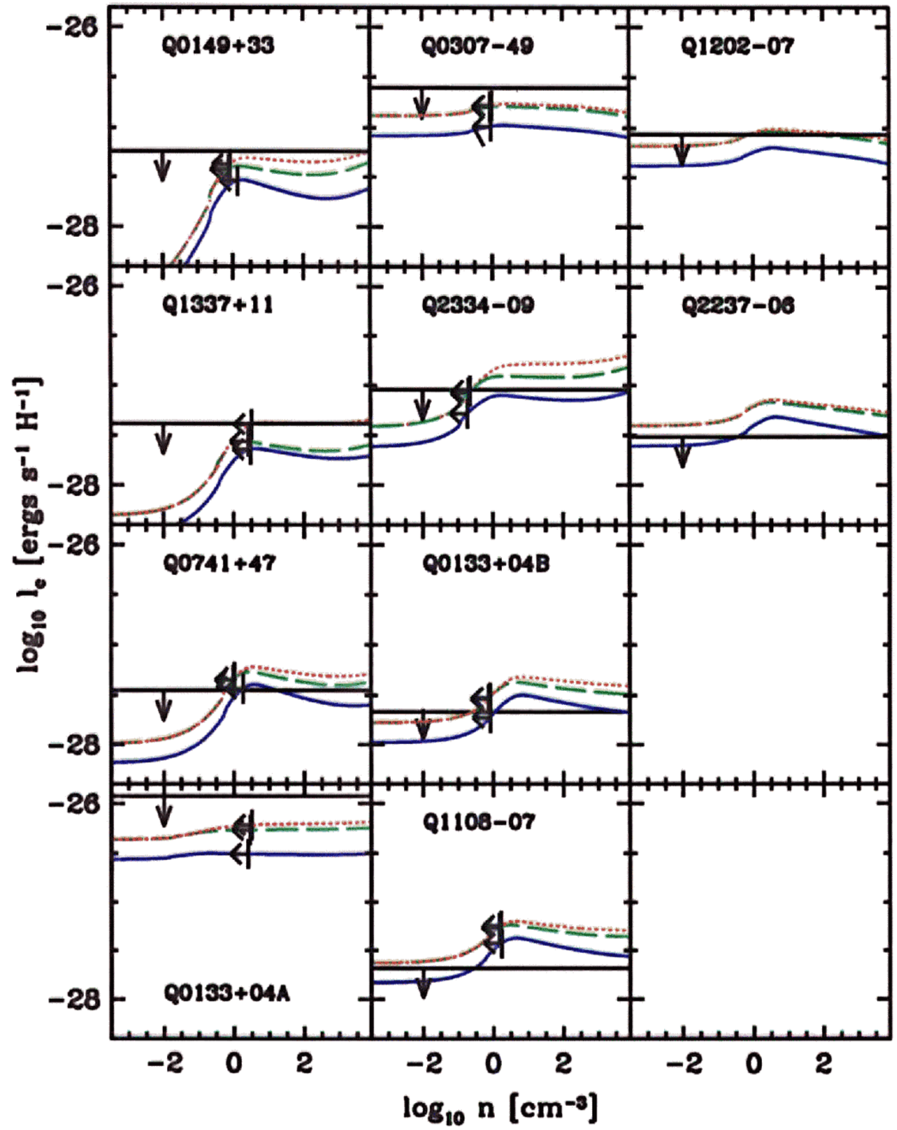


$J_{FUV} > 10 (J_{FUV})_{Milky\ Way}$



UPPER LIMITS





MODEL FOR UPPER LIMITS

$J^{DLA} << J^{BKD}$

COSMOLOGY

Comoving Star Formation Rates

- SFR per unit comoving volume

$$\dot{\rho}_* = n_{co} \dot{M}_*$$

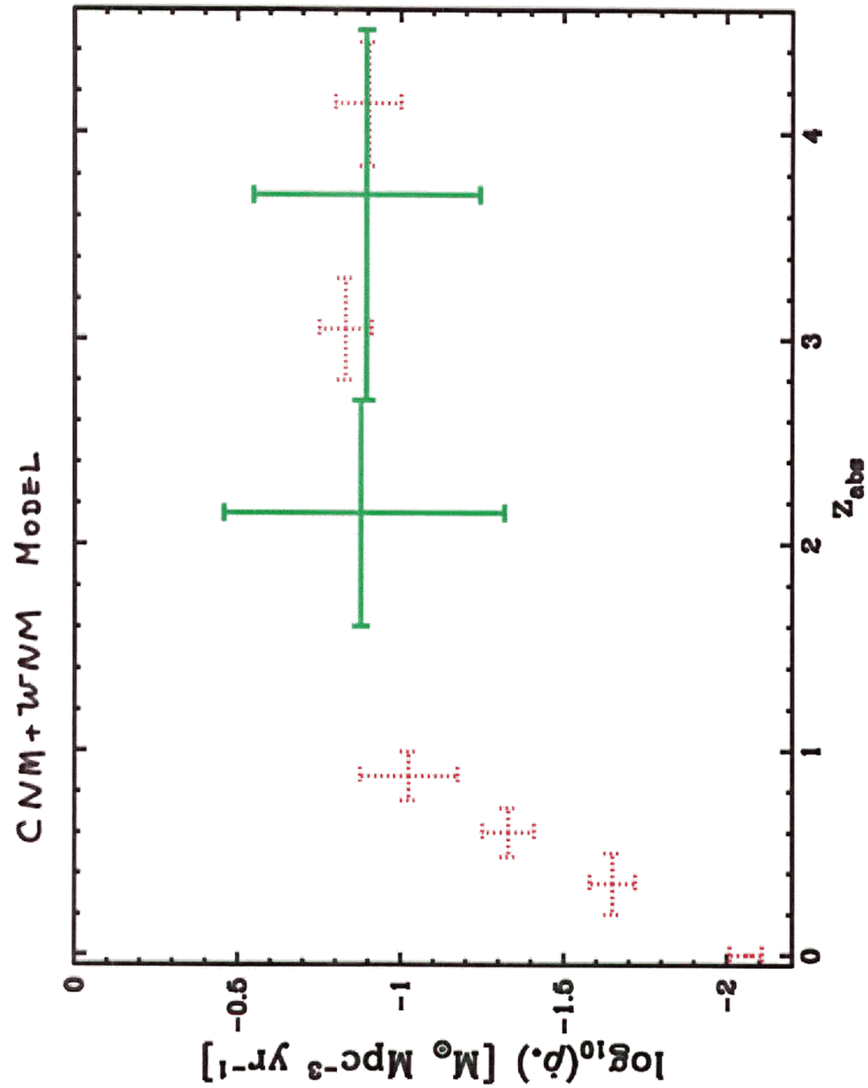
- DLA Incidence

$$\frac{d\mathcal{N}}{dX} = n_{co} \cdot A_{HI} \; ; \quad \frac{dX}{dz} = (1+z)^3 c \left| \frac{dt}{dz} \right|$$

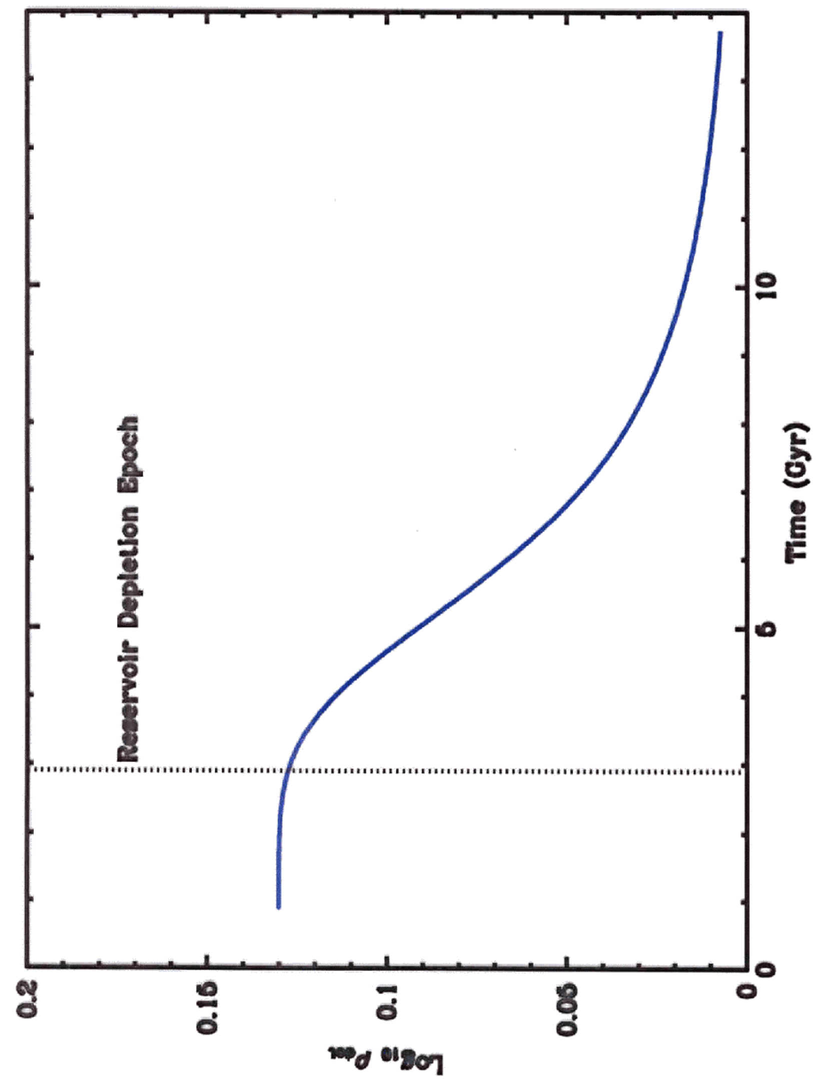
- Combined Expression

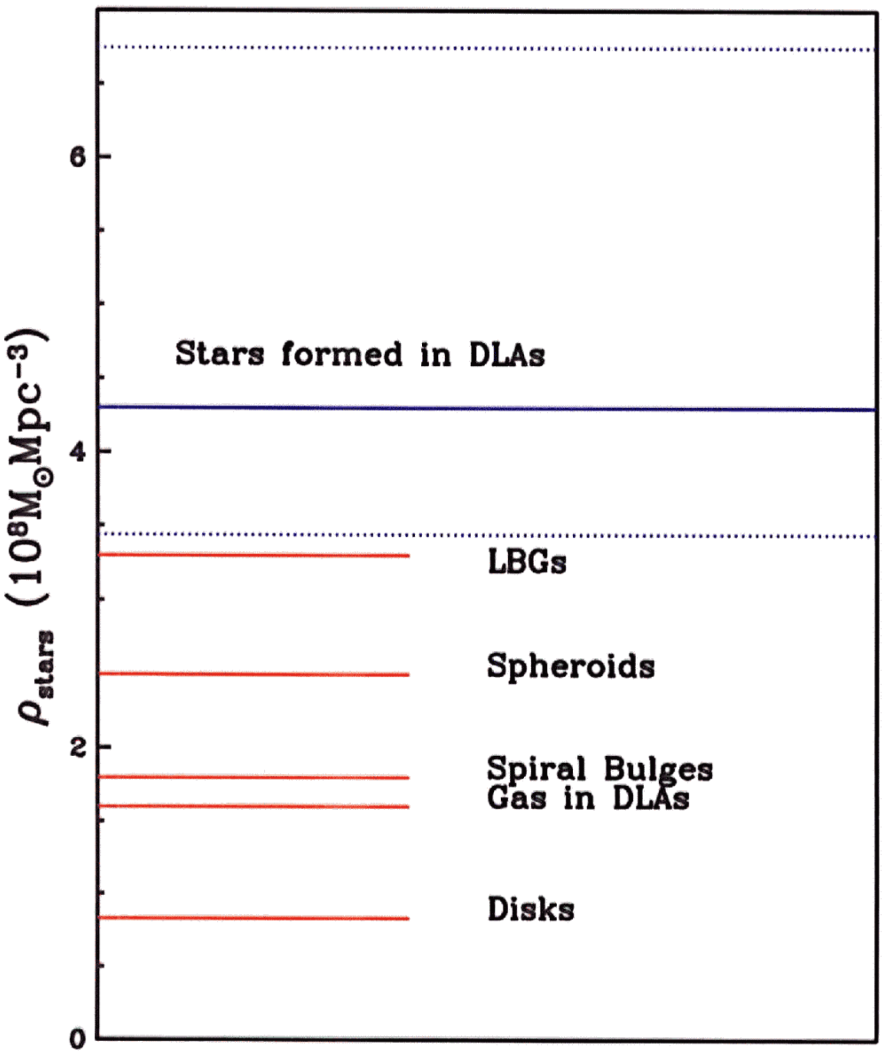
$$\dot{\rho}_* = \frac{\dot{M}_*}{A_{HI}} \cdot \frac{d\mathcal{N}}{dX}$$

$$\boxed{\dot{\rho}_* = \langle \dot{\psi}_* \rangle \frac{A_*}{A_{HI}} \cdot \frac{d\mathcal{N}}{dX}}$$

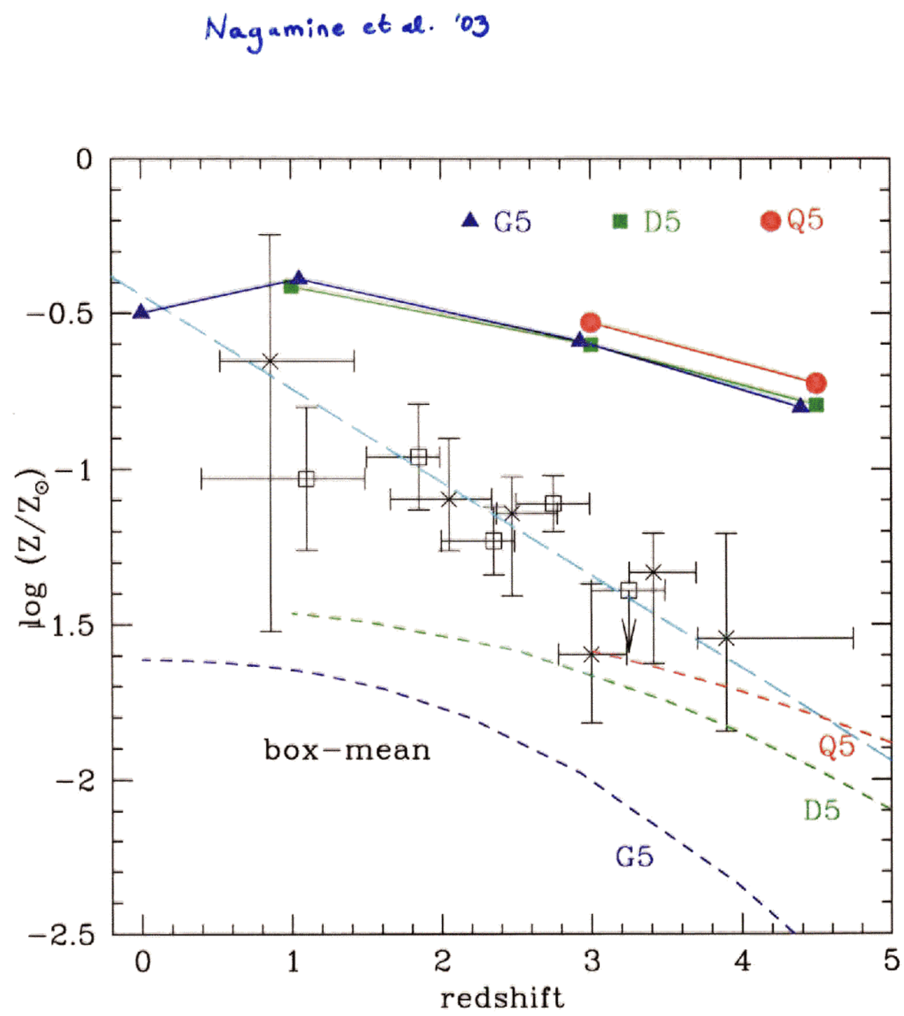


I mplications



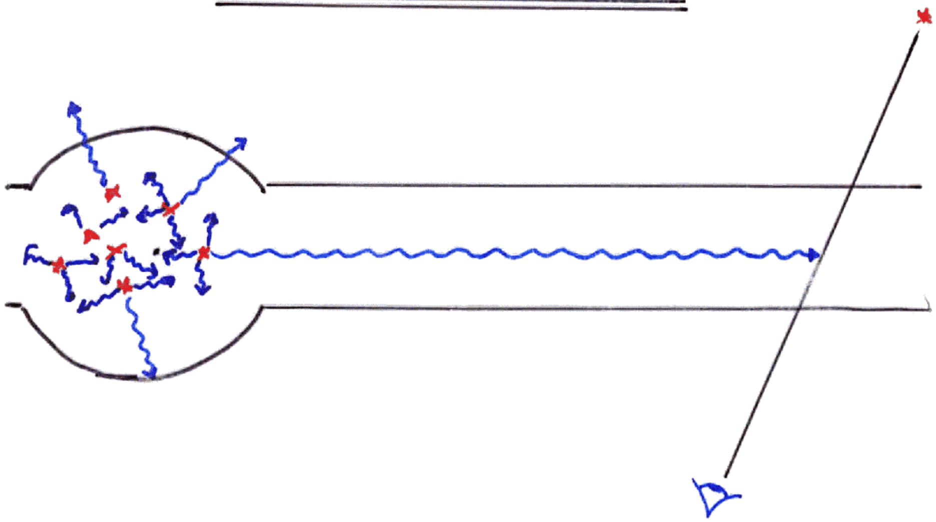


ρ_{stars} ($10^8 M_\odot Mpc^{-3}$)
Stars formed in DLAs
LBGs
Spheroids
Spiral Bulges
Gas in DLAs
Disks
0
2
4
6



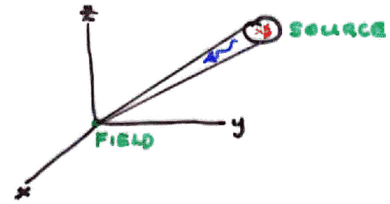
Nagamine et al. '03
G5
D5
Q5
box−mean
log (Z/Z$_\odot$)
redshift
0
−0.5
−1
−1.5
−2
−2.5
0
1
2
3
4
5

BULGE SCENARIO

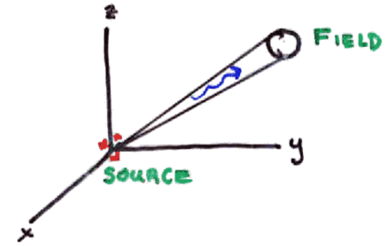


Equivalence Between Bulge and Disk Scenarios

- Disk Scenario



- Bulge Scenario

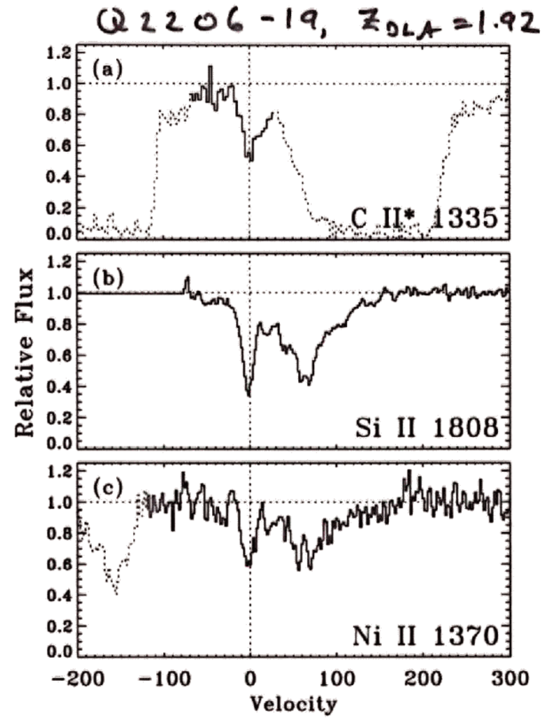


- SFRs per unit Comoving Volume
  - If $L_\nu/(\pi R^2 \cdot 2h)$ same, then

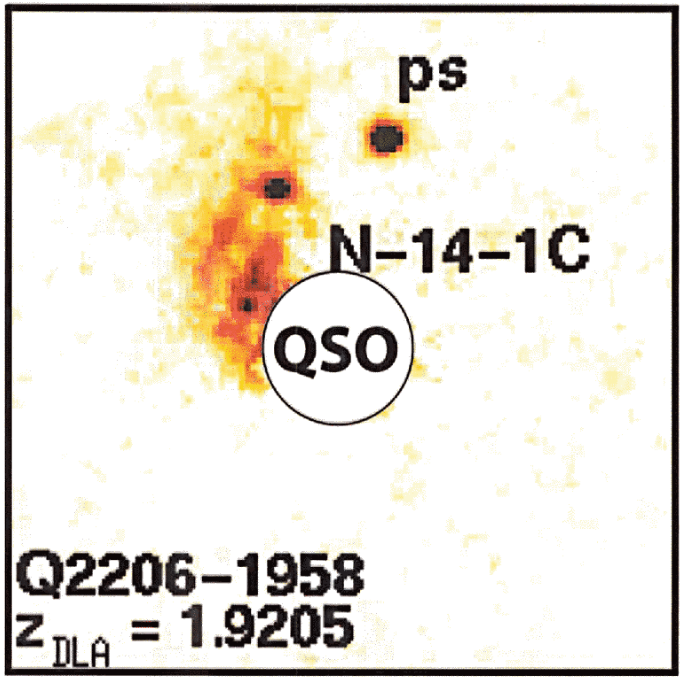
    $\langle J_\nu^B \rangle \approx J_\nu^D$
  - $(\dot{\rho}_*)_B \approx (\dot{\rho}_*)_D$

TEST CASE: DLA 2206−19

- Compare $J_\nu^{CII^*}$ with J_ν^{phot}

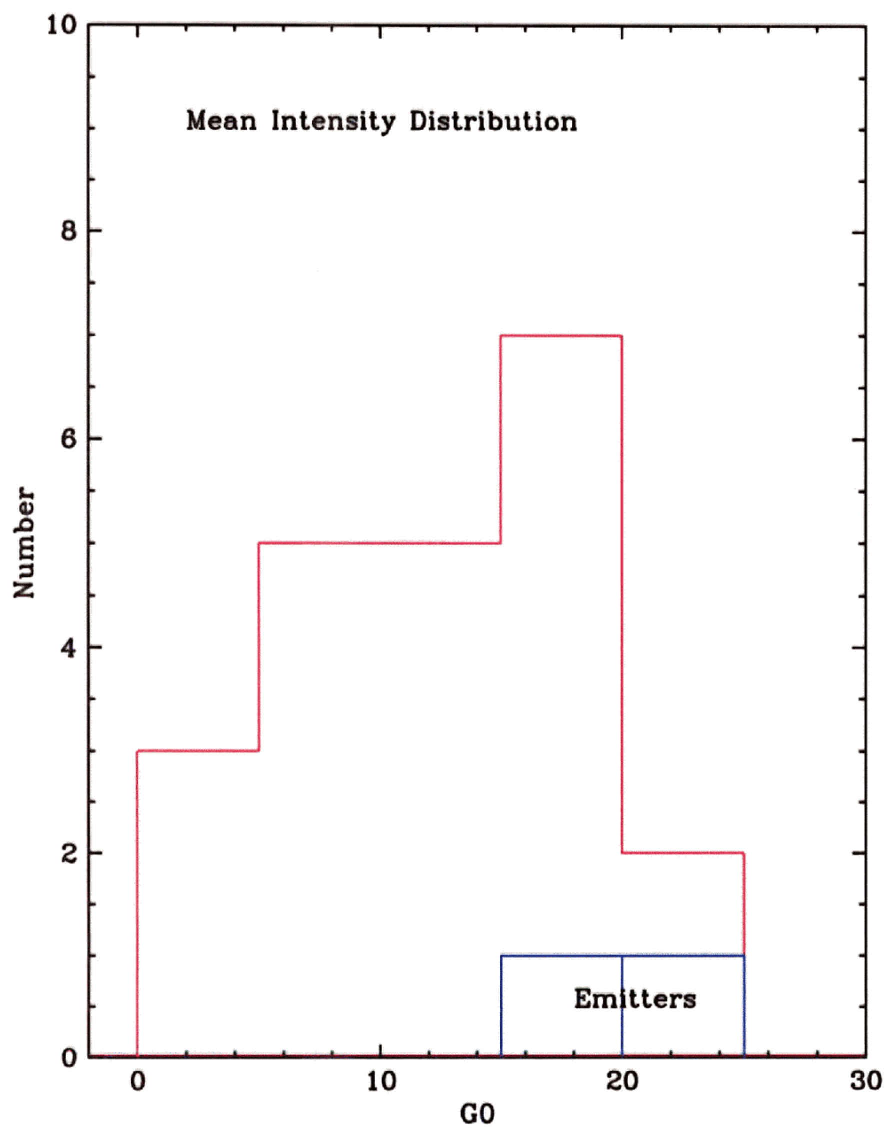


Møller et al. (2002)



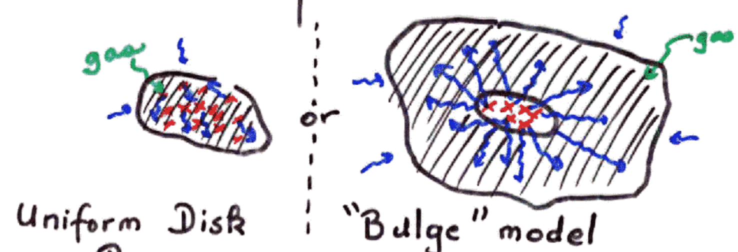
J_ν^{stars} from Photometric and CII* Techniques

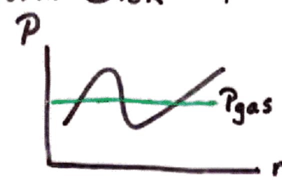
Technique	J_ν^{stars} (10^{-18} cgs)	Notation
Photometry	< 7.0	J_ν^{phot}
CII* : CNM	$1.7^{+2.7}_{-1.0}$	$J_\nu^{CII^*}$
CII* : WNM	38^{+52}_{-23}	$J_\nu^{CII^*}$



Two classes of DLA

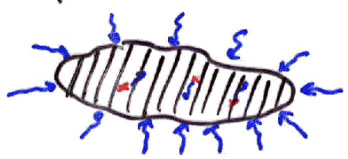
- $\ell_c > 10^{-27}$ ergs s^{-1} H^{-1}
  - Moderate density gas heated by local starlight ⇒ 2 phase medium
  - CII* Absorption arises in CNM



  - 

    $P_{gas} > P_{min}$
  - Massive Galaxy ?

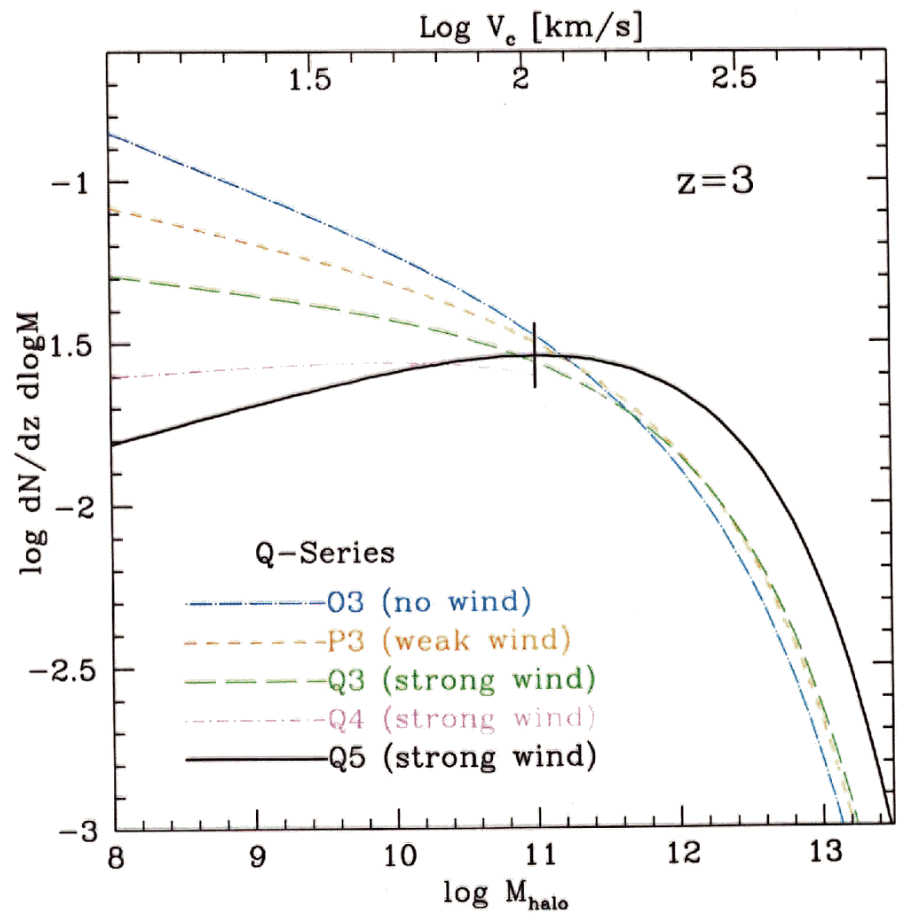
- $\ell_c < 10^{-27}$ ergs s^{-1} H^{-1}
  - Low Density gas heated by external background radiation
  - Single phase WNM



  - 

    $P_{gas} < P_{min}$
  - Lower Mass Galaxy ?

Nagamine, Springel, and Hernquist '03



Summary

- DLA Properties
  - Neutral gas Reservoirs for star formation at high redshifts
  - $[\langle M/H \rangle] \simeq -1.3$
- CII* Technique
  - $\tau(\text{CII}^*) \propto$ Heating Rate in CNM
  - Heating Rate $\propto \dot{M}_* / A_{HI}$
  - $\left\langle \frac{\dot{M}_*}{A_{HI}} \right\rangle \approx 4 \left(\frac{\dot{M}_*}{A_{vis}} \right)_{Galaxy}$
- Cosmology
  - $(\dot{\rho}_*)_{DLA} \approx (\dot{\rho}_*)_{LBG}$
  - Two Types of DLA
  - DLAs drawn from LBG LF
- [CII] 158 μm Emission
  - Detectable with ALMA!