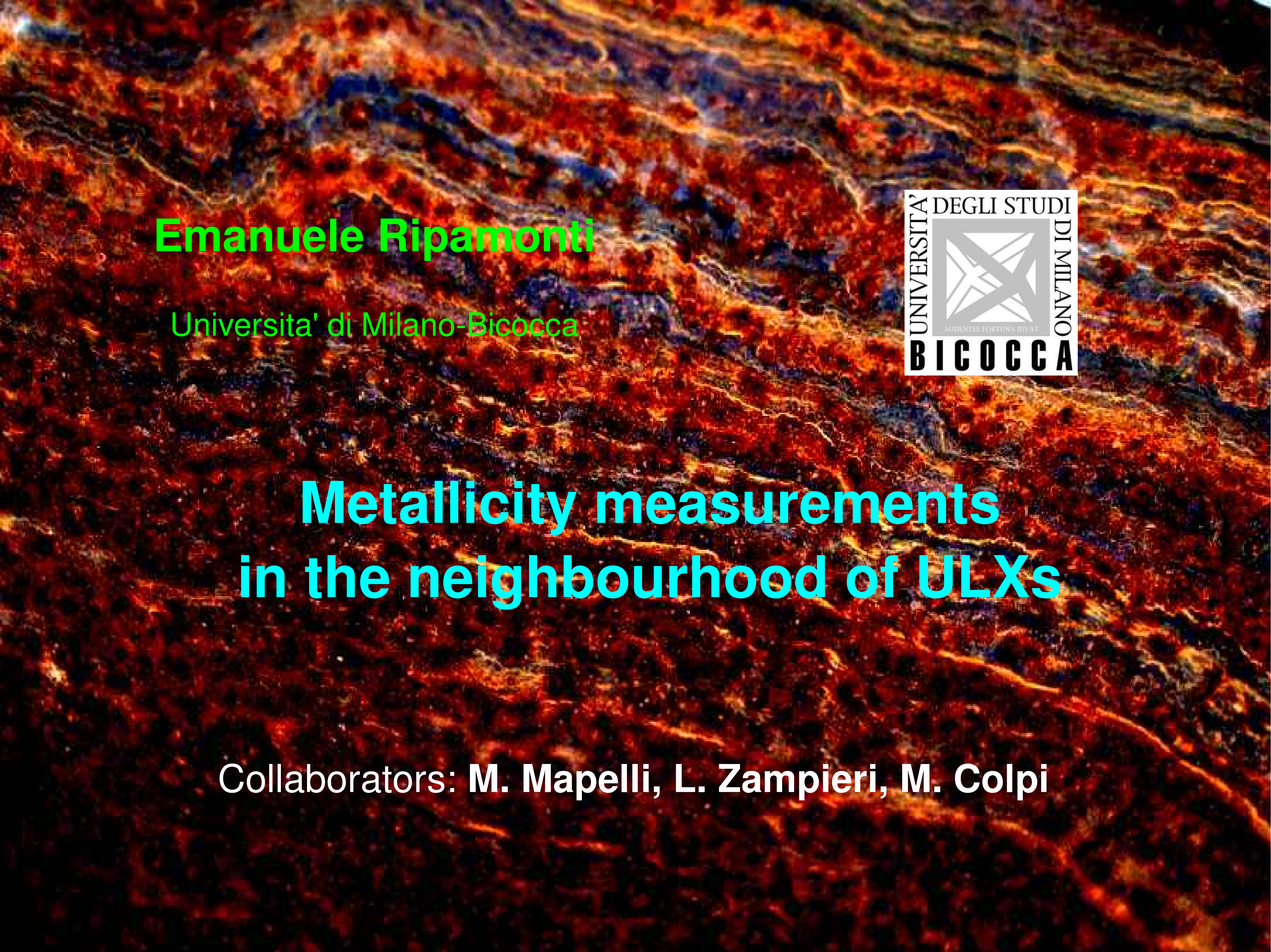


Emanuele Ripamonti

Universita' di Milano-Bicocca

Metallicity measurements in the neighbourhood of ULXs

Collaborators: **M. Mapelli, L. Zampieri, M. Colpi**

Introduction

Models predict metallicity is important for ULX formation

examples

1) Mapelli et al. 2010 (previous talk; arXiv:astro-ph:1005.3548):
   low metallicity reduces stellar mass losses, enhancing the maximum possible M_{BH}

2) Linden et al. 2010 (arXiv:astro-ph:1005.1639)
   low metallicity enhances the probability of forming bright HMXBs (without really affecting M_{BH})

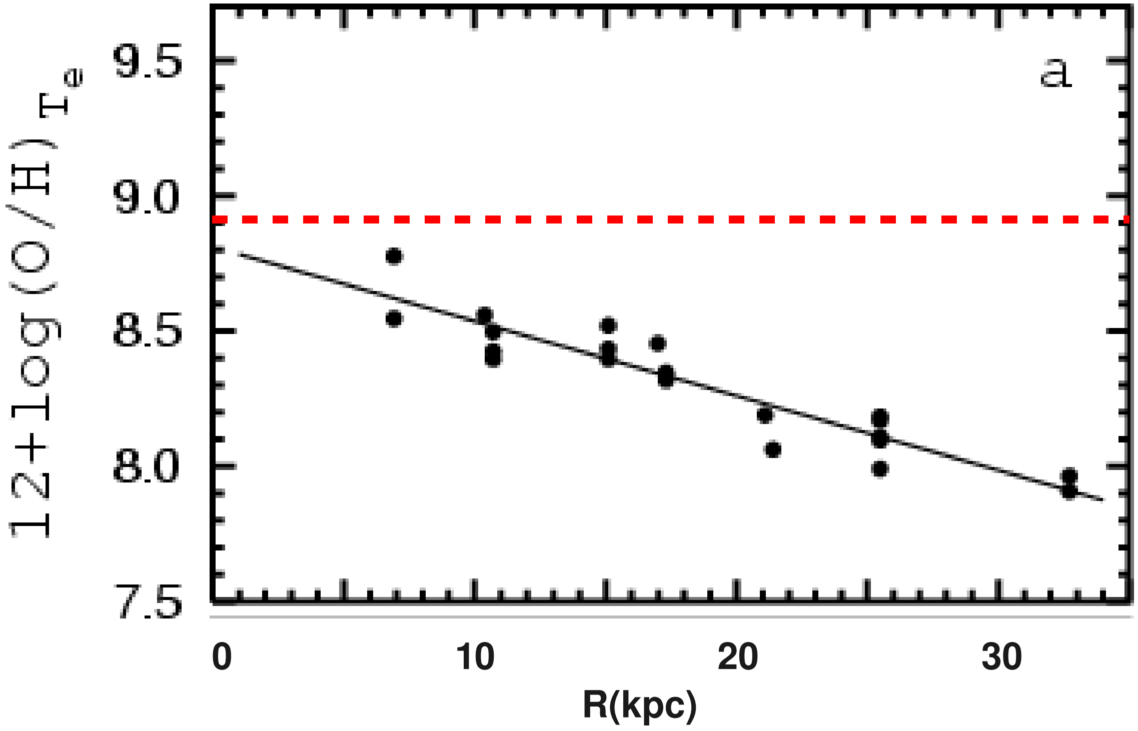
“Galactic” vs “local” metallicity

Average galactic metallicity suffer from metal fluctuations within a galaxy:

giant spirals exhibit metallicity gradients with radius

variations of ±0.1 dex (i.e. ±25%) are possible even at fixed radius

Example: M 101 abundance profile (Pilyugin 2001)

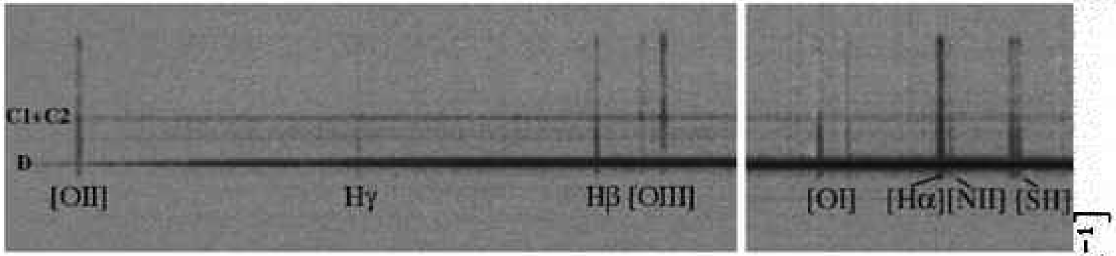


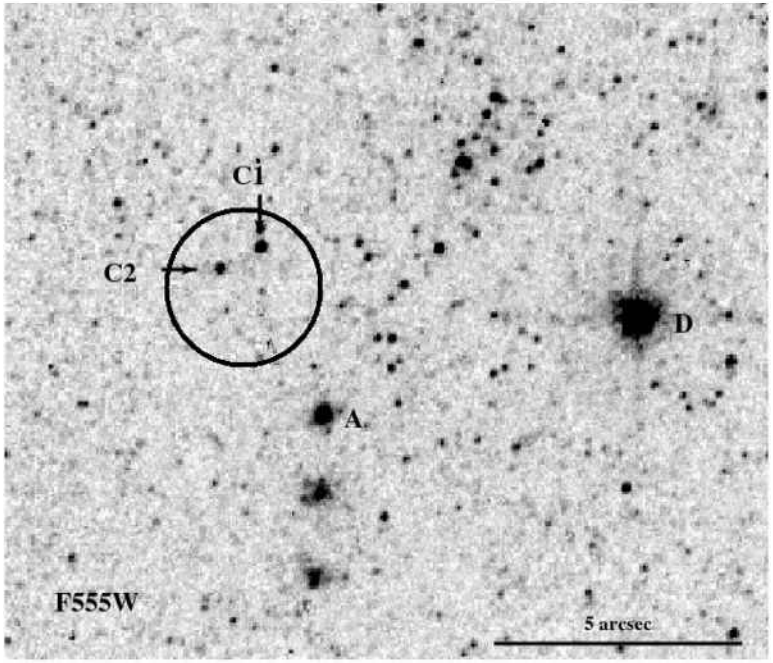
“Solar” metallicity
[Z_{sun}=0.02 → 12+log(O/H)=8.92]

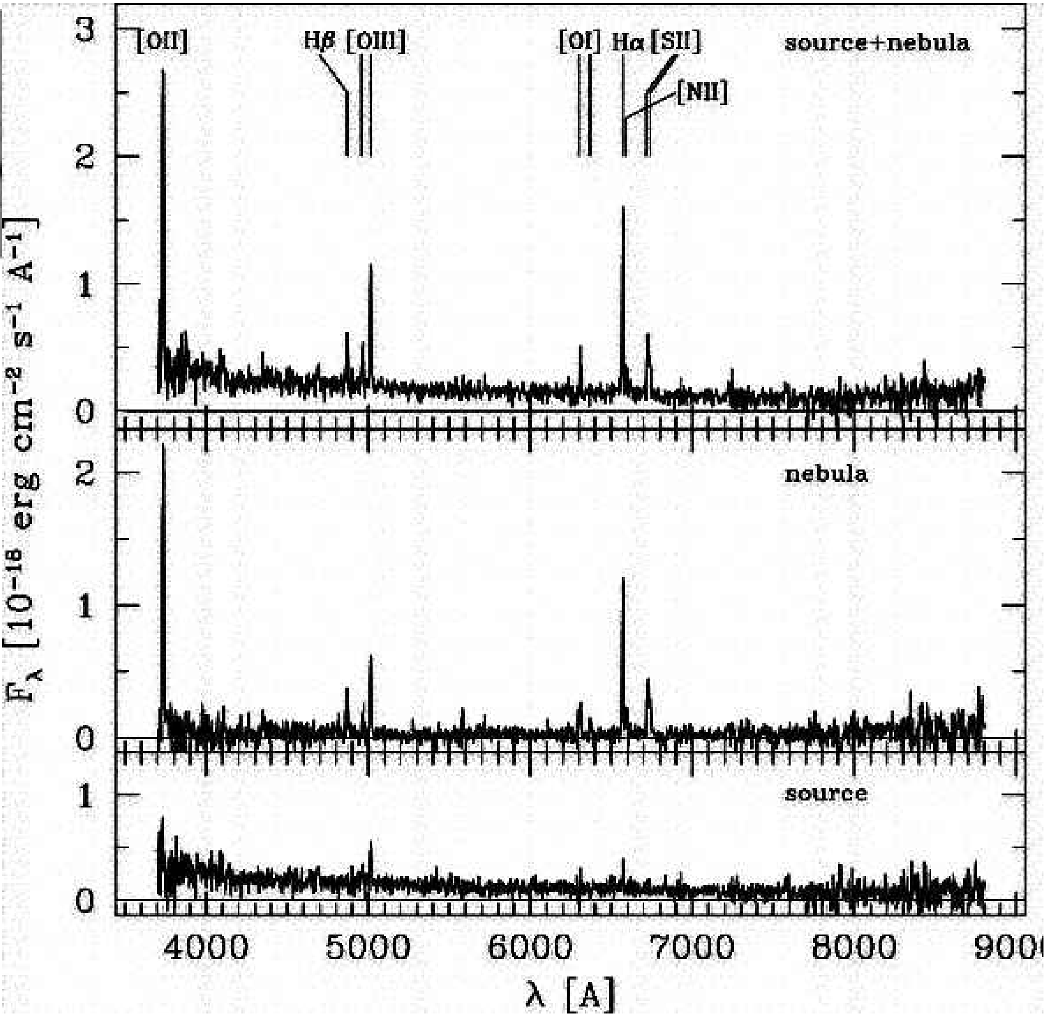
Measuring the local metallicity

Main tool: spectroscopic observations of the ionized nebulae around known ULXs

looked at data available for NGC 1313 X-2 (Mucciarelli et al. 2005, 2007)







NGC 1313 X-2: summary

Host galaxy properties

distance: 3.7 Mpc metallicity: 2 HII regions with Z=0.2-0.3 Z_{sun}

X-ray properties (at least 2 states)

luminosity(0.3-10 keV): ~2-30 $\times 10^{39}$ erg s^{-1}

spectrum: MCD + PL

kT: 0.13-0.25 keV Γ : 1.7-2.5

F_{MCD}/F_{PL}: 0.45-0.94

N_H: 2-4 x 10^{21} cm^{-2} ($N_{H,gal}$ = 4 $\times 10^{20}$ cm^{-2})

Optical Counterpart

object C1, E(B-V)~0.1 (0.3?), M_V~-4.6±0.2,

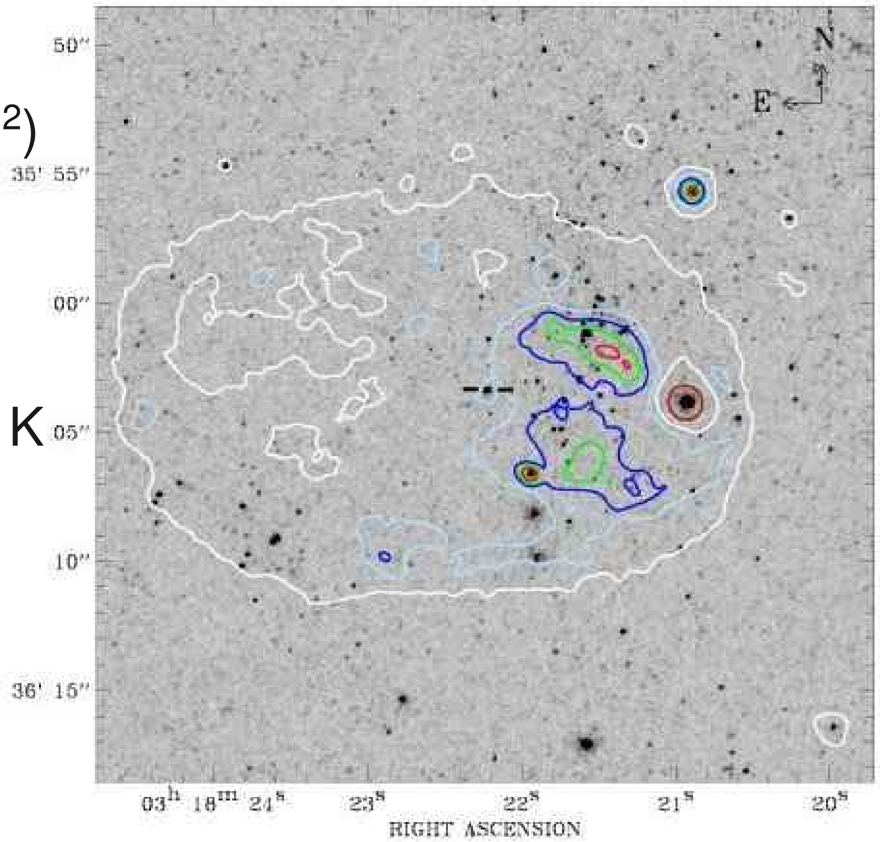
B-V~-0.13±0.06, 20000 K <~ T_{eff} <~ 30000 K

Optical nebula

~ 500x300 pc

blue population with age ~20 Myr

From Grise' et al. 2008



Line intensities & Metallicity calibrations

Main observed metal lines [dereddened imposing I(Hα)/I(Hβ)=3.1]

I(OII 3727)/I(Hβ) = 6.03±1.34

I(OIII 4949)I(Hβ) = 0.47±0.15 **I(OIII 5007)]/I(Hβ) = 1.69±0.36**

I(OI 6300)/I(Hβ) = $0.93^{+0.23}_{-0.46}$

I(NII 6548)/I(Hβ) = 0.12±0.10 I(NII 6584)]/I(Hβ) = 0.53±0.30

I(SII 6725)/I(Hβ) = 1.95±0.42

I(Other lines) <~ 0.2 I(Hβ)

Metallicity calibrations

Pilyugin & Thuan (2005) and Pilyugin (2001) provide an empirical calibration of the metallicity proxy 12+log(O/H) in terms of the indexes

$R_2 = I(\mathrm{OII}\ 3727)/I(H\beta)$ $R_3 = [I(\mathrm{OIII}\ 4949) + I(\mathrm{OIII}\ 5007)]/I(H\beta)$

$R_{23} = R_2 + R_3$ $P = R_3 / R_{23}$

CAVEAT: disagreements up to a factor ~3 are possible between various R_{23} calibrations (e.g. with Edmunds & Pagel 1984) and grids of model HII regions (e.g. Kewley & Dopita 2002)

If we apply the PT05 calibration, we obtain
12+log(O/H)~8.2, i.e **$Z \sim 0.2\ Z_{sun}$**

BUT: standard empirical calibrations cannot be used because of the effects of the ULX X-ray emission

THEN: must build ionization models accounting for the ULX+companion star (and possibly other stars in the vicinity)

Modelling - 1

We use the photoionization code Cloudy (Ferland et al. 1998; www.nublado.org)

alternative: MAPPINGS (accounting for shocks)

however, collisional ionization due to the X-ray emission leads to similar features (e.g. strong OI 6300 and SII 6725 emission lines), especially if shocks are weak (v<200 km/s, Russell's talk)

Model parameters

Incident spectrum:Companion star

T_{star}: 8 values, 26200 → 48000 K,

appropriate Q(H); detailed spectra from model atmosphere library; same metallicity as the nebula

X-ray source

MCD(0.2 keV) + PL (Γ=2),

$F_{MCD}=0.8F_{PL}$, L(0.3-10 keV)=6×10^{39} erg s^{-1},

intrinsic N_H: 6 values, $N_{H,intr}=10^{19} \rightarrow 2\times10^{21}$ cm^{-2}

assumed to drop below 54.4 eV

Modelling - 2

Model parameters

Nebula composition:

Overall metallicity: 13 values, $Z = 1/40\ Z_{sun} \rightarrow 2\ Z_{sun}$

N/O ratio: 2 values, solar (Orion) or 1/3 solar

dust/metal ratio: 2 values, Orion or 1/10 Orion

Nebula geometry:

density: 5 values: $n = 1 \rightarrow 100$ cm^{-3}

filling factor: 1/3

internal radius R_i = 1 pc (arbitrary)

external radius R_e such that

$$(R_e - R_i) \times n \times ff \times (Z/Z_{sun}) = N_{H,tot} - N_{H,gal} - N_{H,intr}$$

$$[N_{H,gal} = 4\times10^{20}\ \mathrm{cm}^{-2},\ N_{H,tot} = 3\times10^{21}\ \mathrm{cm}^{-2}]$$

Cloudy (raw) results - 1

grid of (8 T_{star}) x (6 $N_{H,intr}$) x (13 Z) x (2 N/O) x (2 dust/metal) x (5 n)
→ about 12000 models

sorted according to “score” (similar to a χ^2) given by comparison with observational constraints about line intensities and about the size of the nebula

Best score model

$Z=0.2\ Z_{sun}$ N/O=1/3 solar dust/metal=1/10 solar,

$T_{star}=40000$ K $N_{H,intr}=10^{20}$ cm^{-2} n=1 cm^{-3}

→ O2: 5.76(-0.20σ) O3: 2.60($+0.99\sigma$) O1:0.87(-0.12σ)
N2: 0.59(-0.21σ) S2: 1.45(-1.19σ) R(HII)=405 pc

looks pretty good.....

Cloudy (raw) results - 2

grid of (8 T_{star}) x (6 $N_{H,intr}$) x (13 Z) x (2 N/O) x (2 dust/metal) x (5 n)
→ about 12000 models

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N2: 0.59(-0.21σ) S2: 1.45(-1.19σ) R(HII)=405 pc

NOT SO FAST: many acceptable models. Remarkably,

$Z=1.0\ Z_{sun}$ N/O=1/3 solar dust/metal=1/10 solar

$T_{star}=35000$ K $N_{H,intr}=3\text{x}10^{20}$ cm^{-2} n=1 cm^{-3}

→ O2: 5.77(-0.20σ) O3: 2.04(-0.27σ) O1:0.60(-0.71σ)

N2: 1.27($+2.39\sigma$) S2: 1.90(-0.12σ) R(HII)=148 pc

Results: interpretation

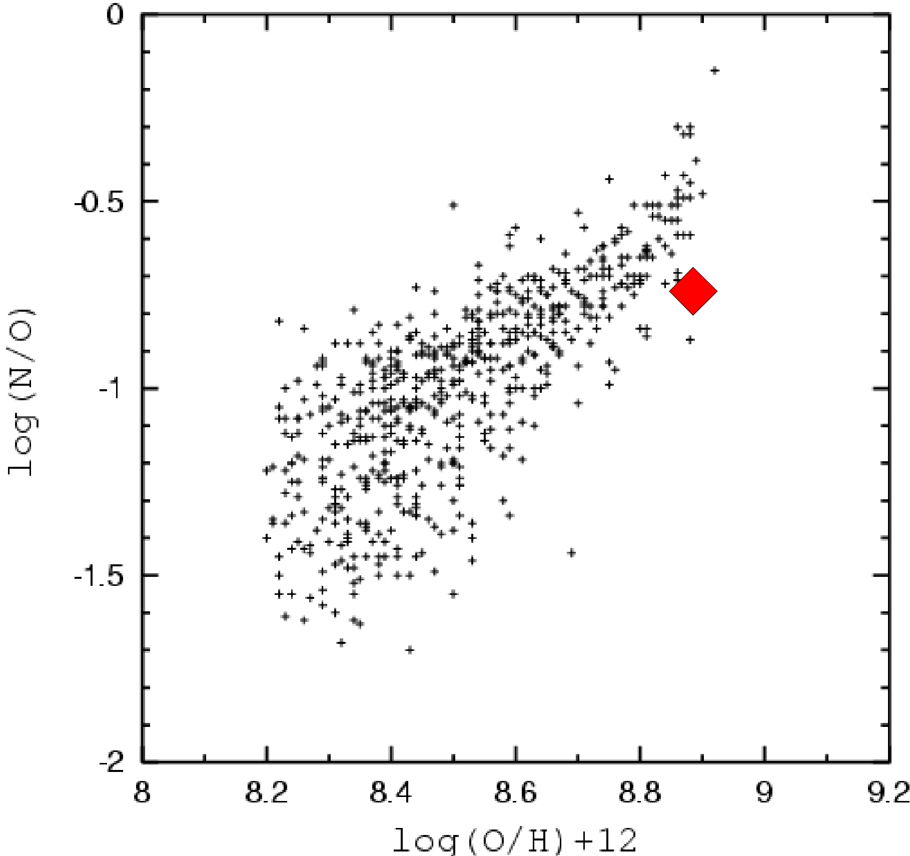
Robust results

- low N/O (<1/3 solar)
- moderate $N_{H,intr}$ = 10^{20}-$10^{20.5}$ cm^{-2} → low dust/metals is favoured
- low number density = 1-10 cm^{-3}
- moderately high T_{star} = 35000-40000 K

METALLICITY IS THE LEAST-CONSTRAINED PARAMETER:
reasonably good agreement for
$0.15\ Z_{sun} < Z < 1.0\ Z_{sun}$

However, high metallicity ($Z>0.5\ Z_{sun}$) models require very low N/O ratios (<1/5 solar), which are empirically (theoretically?) possible only for low Z → **Z<0.5 Zsun**

From Pilyugin, Thuan, Vilchez 2003



Conclusions & future work

Ionization models alone provide only weak constraints ($1/6\ Z_{sun} < Z < Z_{sun}$)

on the metallicity in the nebula around NGC 1313 X-2;
however, high metallicity models require a very low N/O ratio,
inconsistent with the abundance patterns of other HII regions.
Then

$$1/6\ Z_{sun} < Z < 1/2\ Z_{sun}$$

Improve modelling

include UV spectrum of accretion disc
include reprocessed radiation
compare with models including shocks

Extend to other sources

suitable optical data is available for other sources, such as
IC 342 X-1, Holmberg II X-1, Holmberg IX X-1 (see e.g. Grise' et al.)