On the dust and gas content of high-redshift galaxies hosting obscured AGN in the CDF–S

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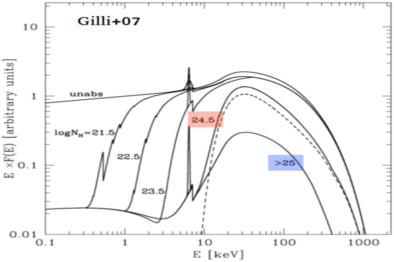
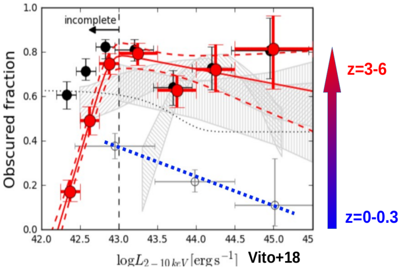
Obscured AGN

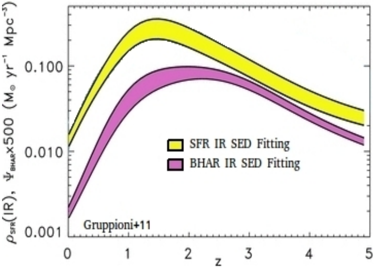


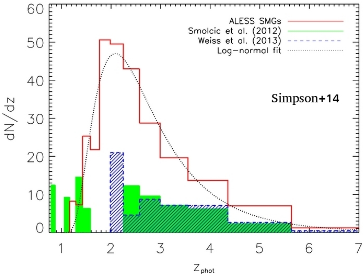


- **Unabsorbed**: $\log N_H < 21$
- **Compton thin**: $21 < \log N_H < 24$
- **Mildly Compton thick**: $\log N_H \sim 24 - 25$
- **Heavily Compton thick**: $\log N_H > 25$

obscured AGN fraction increases at high redshift

Sub–Millimetre Galaxies





SFR density and BH accretion density peak at z ≈ 2

SMGs

- Peak at z ≈ 2
- $M_* \sim 10^{10-11}\ M_\odot$
- $M_d \sim 10^{8}\ M_\odot$
- $M_{H_2} \sim 10^{10}\ M_\odot$
- SFR $\sim 10^{2-3}\ M_\odot/yr$
- $\tau_d \sim 10^{8}\ yr$
- AGN fraction:
  $\sim 0.5\ (L_{IR} < 10^{12}\ L_\odot)$
  $\sim 0.9\ (L_{IR} > 10^{12}\ L_\odot)$
- Size ∼ few kpc

Contribution of the host galaxy to the AGN obscuration?

Objectives and targets

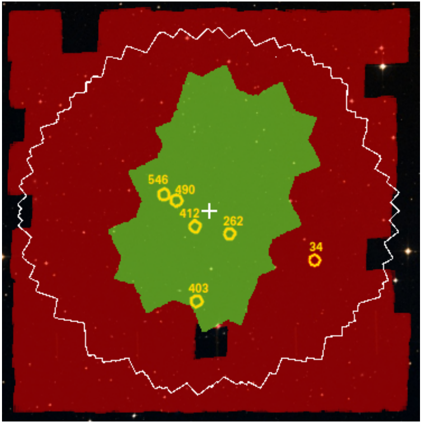
Outline

Scientific rationale and targets

Data analysis

Results

Conclusions and future perspectives



White contour: CDF–S
Red area: GEMS
Green area: CANDELS
$28' \times 28'$

Parent samples

- 34 AGN at z > 3, selected in the 4–Ms CDF–S (Vito+13)
- 8 AGN at z = 1.1–3.7, selected in the 1–Ms CDF–S (Rigopoulou+09)

Selection criteria

- Secure spectroscopic z > 2.5
- Column density log $N_H > 23$
- Detection at $\lambda_{obs} > 100\mu m$

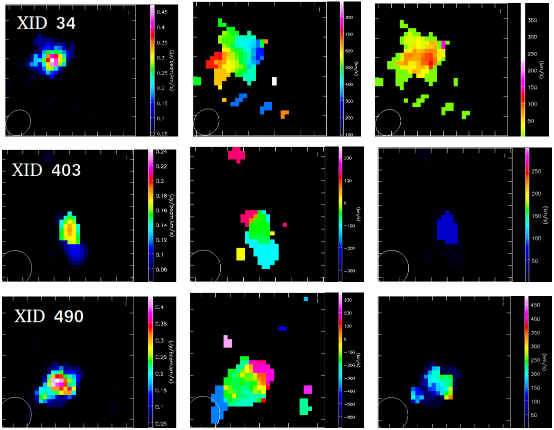
Derived sample: 6 sources

- 2.5 < z < 4.7
- 260–2000 counts in the 7–Ms CDF–S, $(2<L_{2-10keV}<6)\times10^{44}$ erg s^{-1}
- SFR $\sim 10^{2-3} M_{\odot}/yr$
- $M_* \sim 10^{11}\ M_{\odot}$

Moments of the line

Three sources detected in continuum and CO

Flux | Velocity map | Velocity dispersion



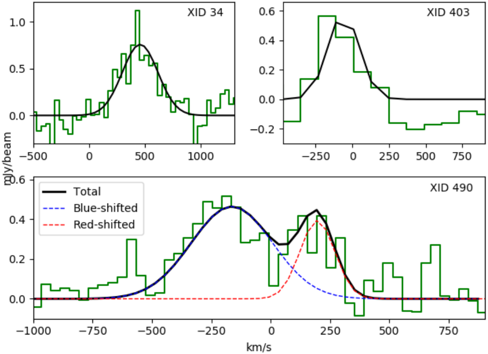
- •XID 34: Chaotic structure
- •XID 403,490: Rotating features
- •Beam size: Poor resolution

Considered channels: $v_0 \pm FWHM$

Image pixels $> 3\sigma$
Image sizes $\sim$ 2.7"

Spectral fitting

Gaussian fitting of the lines

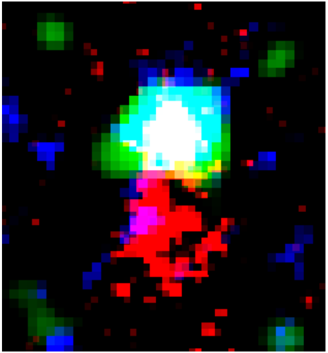


XID	v_0 (km/s)	FWHM (km/s)
34	498 ± 14	368 ± 32
403	-56 ± 33	308 ± 77
490(Blue c.)	-194 ± 26	474 ± 67
490(Red c.)	187 ± 12	162 ± 27

XID 34: the velocity peak is $\sim$ 500 km/s shifted wrt the rest–frame velocity at the spectroscopic redshift

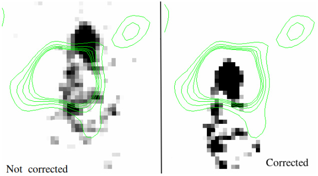
XID 490: double–peaked line, likely Doppler effect

XID 34: Merger?



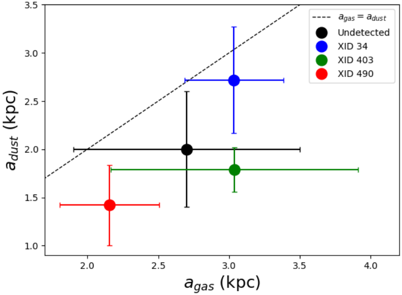
Red: V–band ($\sim$ 600 nm) HST
Green: ALMA continuum @3σ
Blue: ALMA CO @3σ
Image size: 0.6 $\times$ 0.9 arcsec

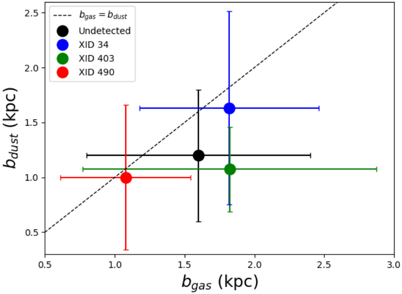
Relative motion between gas and SF component

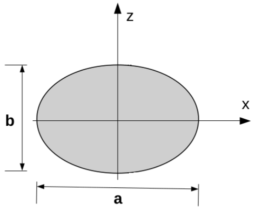


Watchout for astrometry!

Fitting model: 2–D Gaussian in the visibilities space





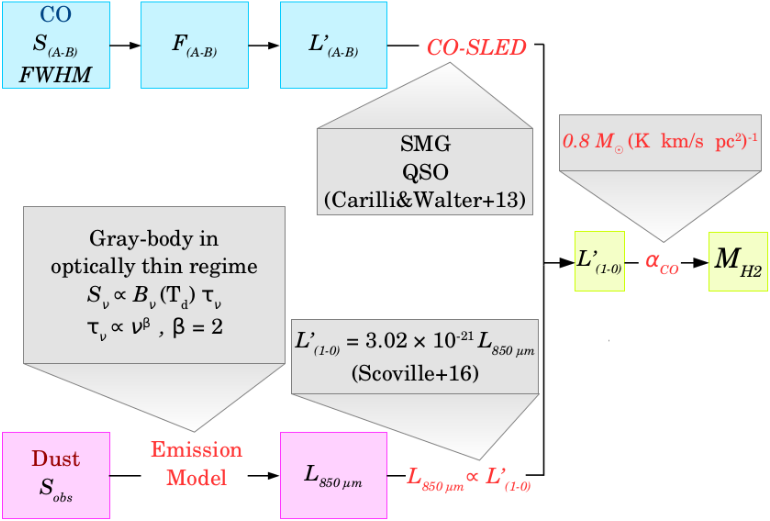


Assumptions

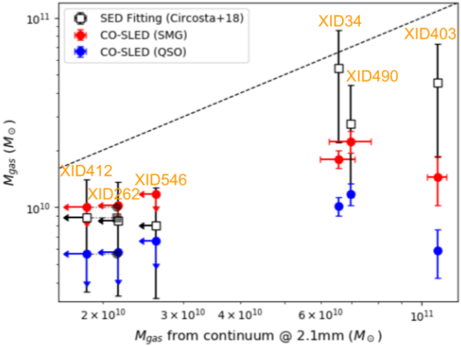
- **Undetected sources**: Size = mean of the detected sources, Error on a = 30%, Error on b = 50%
- **XID 490 dust** b: XID 490 dust b: Unconstrained by the fitting, assuming R= 0.8 (from the non–deconvolved image fitting), Error on R = 50%

Size gas > Size dust

Gas mass - Different approaches



Gas mass



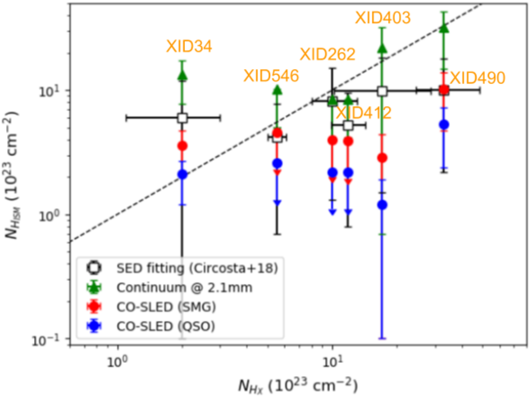
$$M_{H_2}^{DUST} > M_{H_2}^{CO-SLED}$$

$$M_{H_2}^{SMG} > M_{H_2}^{QSO}$$

Undetected sources

Upper limits at the 3σ level measured on the images for both the line and continuum emissions.

Column density – Uniform sphere



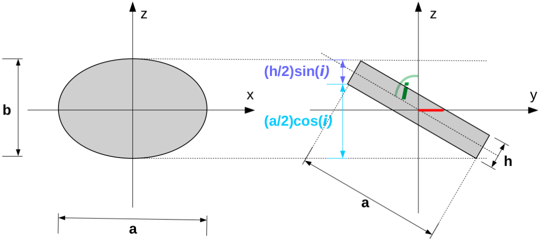
Notes

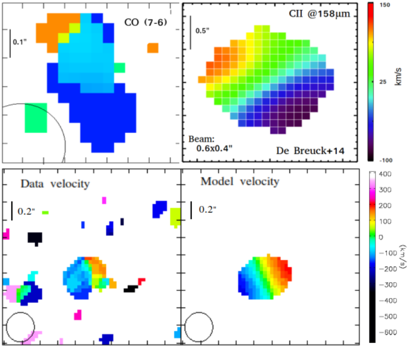
- N_{H_X} from X–ray spectral fitting
- Upper limits at the 3σ level

N_{H_X} and $N_{H_{ISM}}$: same order of magnitude

Host ISM can significantly contribute to the obscuration of the central AGN

Column density – Rotating "coin" disk





$$b_G = a_G \cos(i) + h_G \sin(i)$$

XID 403: $i = 53^\circ$

XID 490: $i = 40.5^\circ$

$$N_{H_{ISM}}^{disk} \approx 10 N_{H_{ISM}}^{sphere}$$

POORLY CONSTRAINED

Dust mass and temperature

XID	T (K)	M_d (10^8 $M_\odot$)
262	71	< 1.0
412	80	< 0.9
34	55	4.9 ± 0.7
403	65	4.8 ± 0.5
546	65	< 1.5
490	69	4.2 ± 0.5

Temperature

Single temperature (error $\approx \pm 5$ K), gray body IR–SED fitting:

$$S_\nu \propto B_\nu(T_d)\tau$$

$$\tau \propto \nu^\beta \ , \ \beta = 2$$

Mass

$$M_d = \frac{D_L^2 S_{obs}}{k_\nu B_\nu(T_d)(1+z)}$$

$$k_\nu \propto \nu^\beta \ , \ \beta = 2$$

Dynamical mass

$M_{dyn} \sin^2 i = 6.5 \cdot 10^4 \left(\frac{FWHM}{\mathrm{km\ s^{-1}}}\right)^2 \left(\frac{a}{\mathrm{kpc}}\right) M_\odot$ (Wang+13, Calura+14)
Assuming $v_{c,max} = 0.75 FWHM$

XID 403: $M_{dyn} \sin^2 i = 1.8^{+1.7}_{-0.9} \times 10^{10}\ M_\odot$ (Coppin+10 , De Breuk+14)

XID 490: $M_{dyn} \sin^2 i = 1.4^{+0.3}_{-0.3} \times 10^{10}\ M_\odot$

$M_{bar} = M_* + M_{H_2} + M_{HI} \approx 10^{11}\ M_\odot$, $\sim 10\ M_{dyn} \sin^2 i$
M_* from SED fitting , $M_{HI} \sim M_{H_2}/5$ (Calura+14)

For $M_{dyn} \approx M_{bar} \longrightarrow |i| \lesssim 10^\circ$, $h \gtrsim 6$ kpc UNREALISTIC

Possible causes

- Underestimate $M_{dyn} \sin^2 i$ conversion factor
- Different CANDELS/HST emitting region size wrt ALMA
- Uncertainty on position of $v_{c,max}$, underestimate a due to low sensitivity

Conclusions and future perspectives

- Sources have $M_{H_2} \sim 10^{10}\ M_\odot$ and $M_d \sim 10^8\ M_\odot$ confined in few kpc scale.
- The host galaxy ISM can significantly contribute to the obscuration of the central AGN for both spherical and disk model. $N_{H_{ISM}}^{SMG}$ is more consistent with N_{H_X} than $N_{H_{ISM}}^{QSO}$.
- Rotating systems and one possible merger.

- Future observations at better resolution ($< 0.1"$) and higher sensitivity ($\sim$6 h exposure to halve the current sensitivity) would drastically reduce the uncertainties on the physical quantities derived in this work.
- XID 403: CO–SLED coupling measured CO(7–6) with CO(2–1) by Coppin+2010 and CO(12–11) by Nagao+12 (upper limit).


THANKS FOR YOUR ATTENTION!

Continuum images

Outline

Scientific rationale and targets

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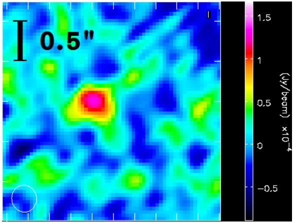
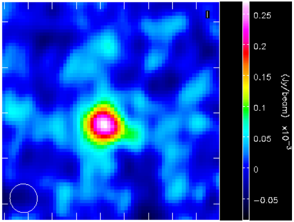
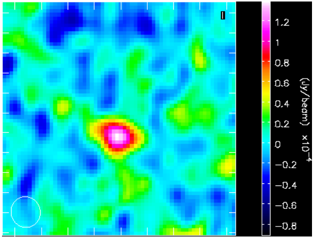
XID 34



XID 403

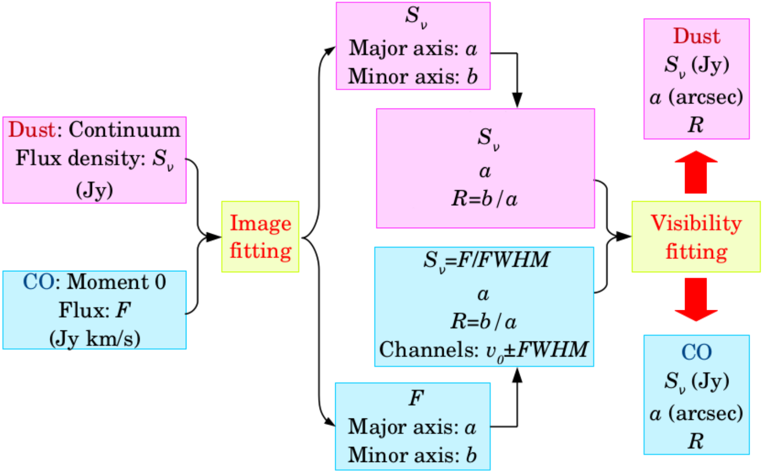


XID 490



Data fitting – Procedure

Fitting model: 2–D Gaussian



Fitting Results

CO line

XID	Flux density (mJy)	Major axis (arcsec)	Axial ratio
34	1.5 ± 0.1	0.38 ± 0.04	0.6 ± 0.2
403	0.7 ± 0.1	0.46 ± 0.13	0.6 ± 0.3
490	1.01 ± 0.07	0.26 ± 0.04	0.5 ± 0.2

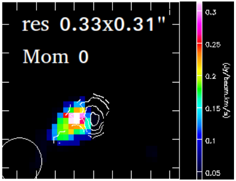
Dust Continuum

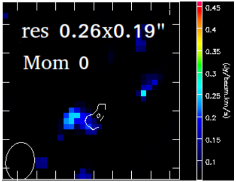
XID	Flux density (mJy)	Major axis (arcsec)	axial ratio
34	0.23 ± 0.02	0.34 ± 0.07	0.6 ± 0.3
403	0.41 ± 0.02	0.27 ± 0.03	0.6 ± 0.2
490	0.19 ± 0.02	0.17 ± 0.05	–

Geometrical models – Rotating disk

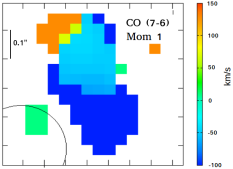
XID 490

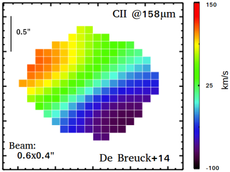
Double peak, velocity maps



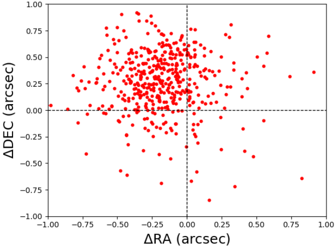


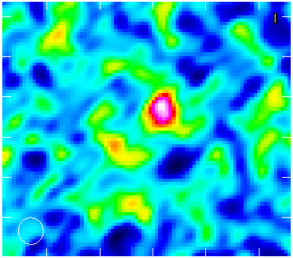
XID 403

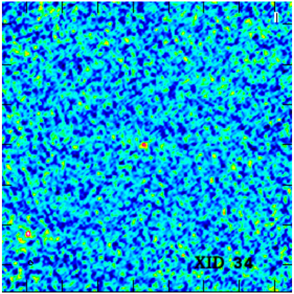


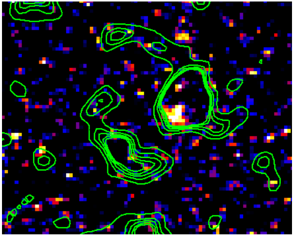


Displacement

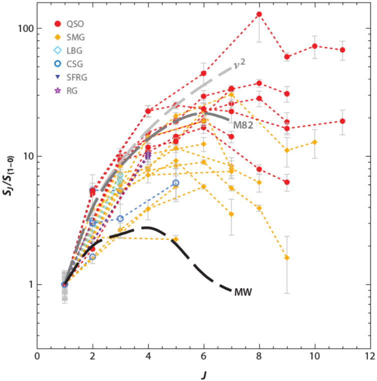


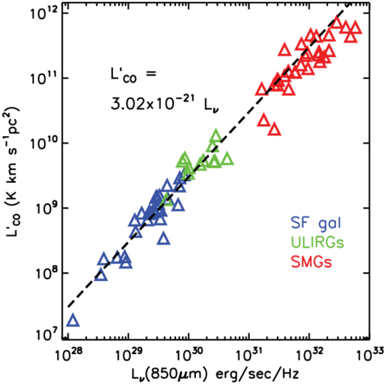




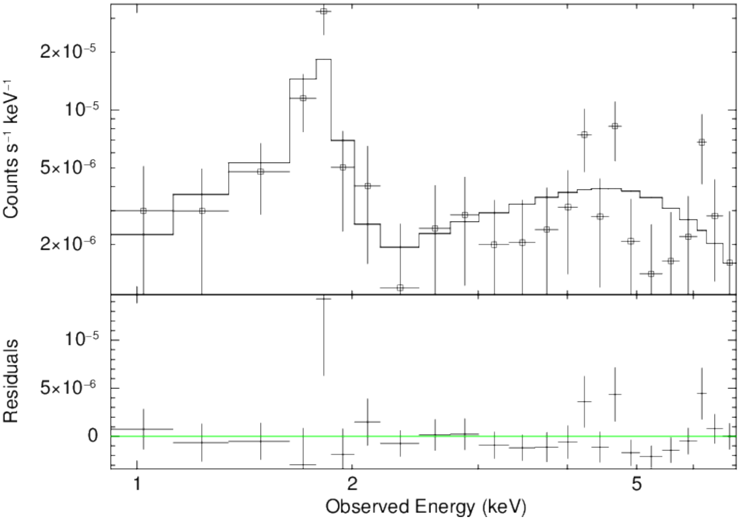


CO–SLEDs and Scoville relation

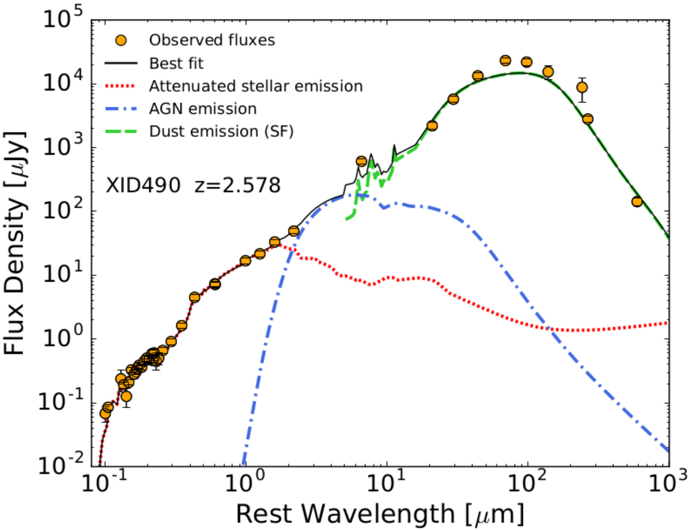




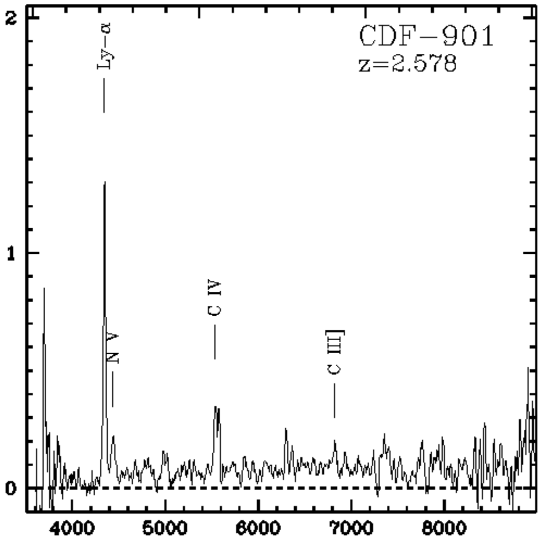
XID 490 – X–ray spectral fitting



XID 490 – IR SED

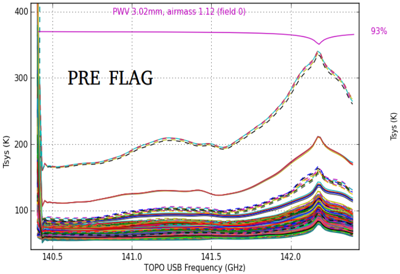


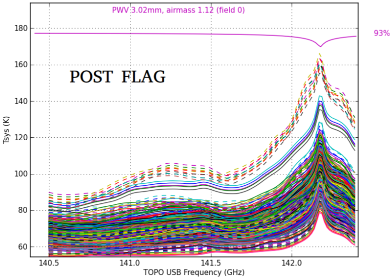
XID 490 – optical spectrum



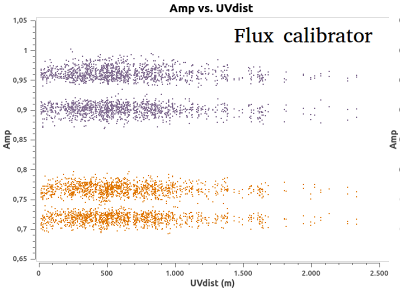
T_{SYS}

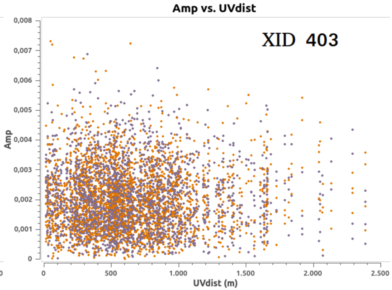
- Outline
- Scientific rationale and targets
- Data analysis
- Results
- **Conclusions and future perspectives**



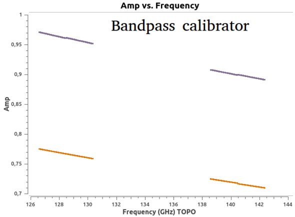


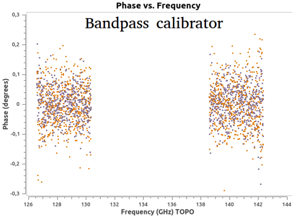
UV distance

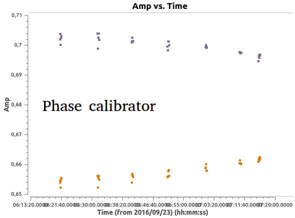

Amp vs. UVdist
Flux calibrator
Amp
1,05
1
0,95
0,9
0,85
0,8
0,75
0,7
0,65
0
500
1.000
1.500
2.000
2.500
UVdist (m)

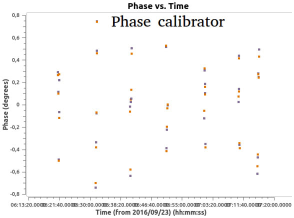

Amp vs. UVdist
XID 403
Amp
0,008
0,007
0,006
0,005
0,004
0,003
0,002
0,001
0
0
500
1.000
1.500
2.000
2.500
UVdist (m)

Phase and bandpass calibration

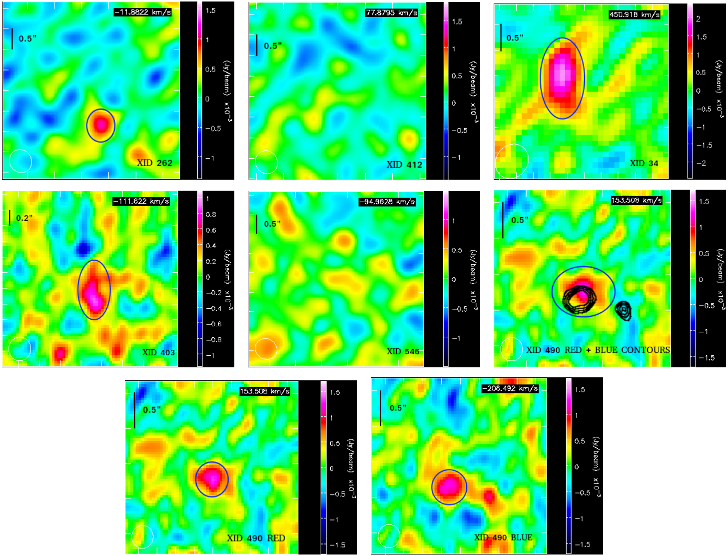




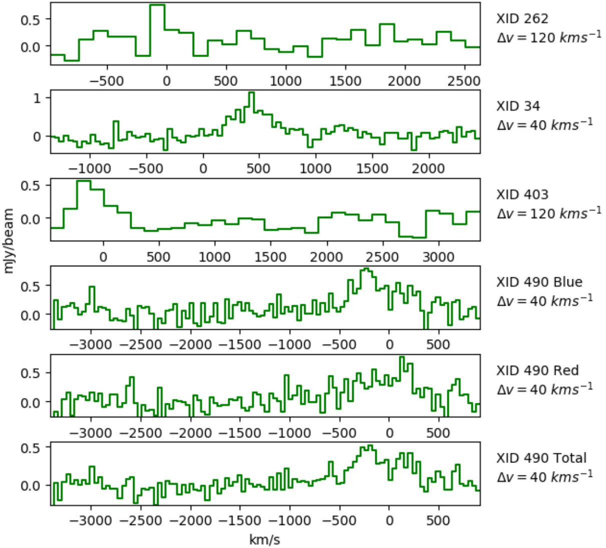




CO peak channels



Total Spectra



Dust mass

$$\begin{cases} L_\nu = \frac{4\pi D_L^2 S_{obs}}{1+z} \\ L_\nu = 4\pi j_\nu V \end{cases}$$

where z is the redshift, D_L is the luminosity distance, S_{obs} is the flux density at the observed frequency ν_{obs}, V is the volume of the source and j_ν is the specific emissivity per unit volume ($\mathrm{erg\ s^{-1}\ Hz^{-1}\ ster^{-1}\ cm^{-3}}$) that is equal to

$$j_\nu = \alpha_\nu B_\nu(T_d) = k_\nu \rho B_\nu(T_d)$$

$\alpha_\nu = k_\nu \rho$ is the opacity per unit of path length ($\mathrm{cm^{-1}}$), k_ν is the opacity per mass unit ($\mathrm{g^{-1}\ cm^2}$) and $\rho = M_d/V$ is the density of the source ($\mathrm{g\ cm^{-3}}$). M_d is the total mass of the dust.
The opacity per mass unit is assumed to scale with the frequency as $k_\nu = 4(\nu/1.2\ THz)^\beta$ (draine+07). The index β is set equal to 2.0 (e.g., magnelli+12,gilli+14).
Equalizing the two expressions of L_ν leads to the formula for the mass of the dust in the optically thin regime:

$$\frac{4\pi D_L^2 S_{obs}}{1+z} = 4\pi k_\nu \frac{M_d}{V} B_\nu(T_d) V$$

$$M_d = \frac{D_L^2 S_{obs}}{k_\nu B_\nu(T_d)(1+z)}$$

Interferometry

T_{SYS}: Temperature of a resistor emitting (as black body) a signal equal to the sum of all the contributions to the noise, placed above the atmosphere.

$$T_{SYS} = T_{atm}(e^{\tau} - 1) + T_{rx} e^{\tau}$$

T_{atm}: atmosphere, T_{rx}: instrument, τ: optical depth. Neglecting cosmic background ($\sim$ 3 K).

$$rms = \frac{2k_B \; T_{SYS}}{A_{eff}\sqrt{\Delta t \; \Delta\nu \; n_p \; N_{ant}(N_{ant} - 1)}}$$