Observability of High Density Tracing Molecular Lines in Lensed Galaxies with the Atacama Large Millimeter Array

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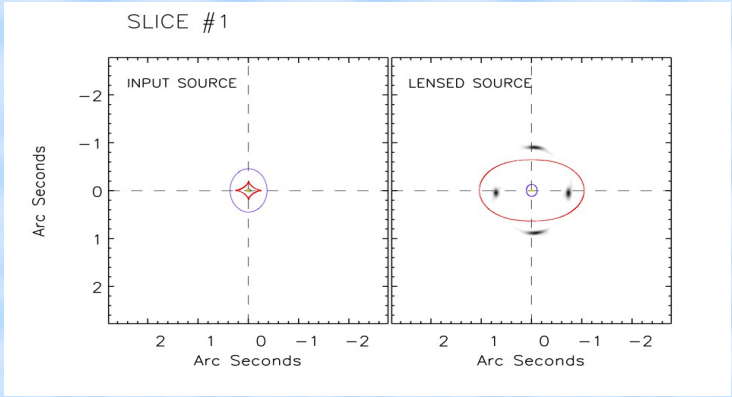

In collaboration with:

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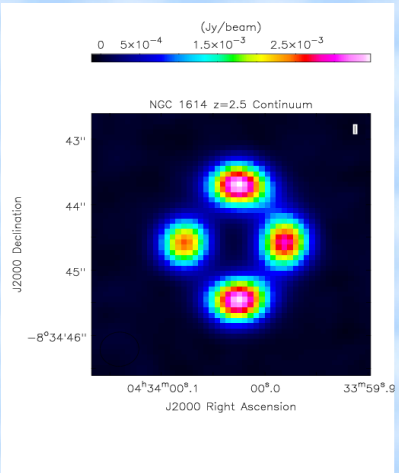
Marcella Massardi
Mattia Negrello (INAF OAPD)
Andrea Lapi (SISSA)
Italian node of the European ALMA Regional Centre

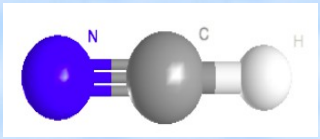


Molecular lines tracing high densities

HCN (Hydrogen cyanide)

(1-0) 88.63 GHz n_{crit}~2×10^{6} cm^{-3}

(4-3) 354.50 GHz n_{crit}~2×10^{7} cm^{-3}



CO

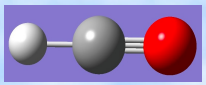
(1-0) 115.27 GHz n_{crit}~10^{3} cm^{-3}

(4-3) 461.04 GHz n_{crit}~10^{5} cm^{-3}

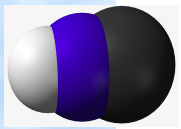
HCO+ (Protonated Carbon Monoxide)

(1-0) 89.19 GHz n_{crit}~10^{5} cm^{-3}

(4-3) 356.73 GHz n_{crit}~10^{7} cm^{-3}

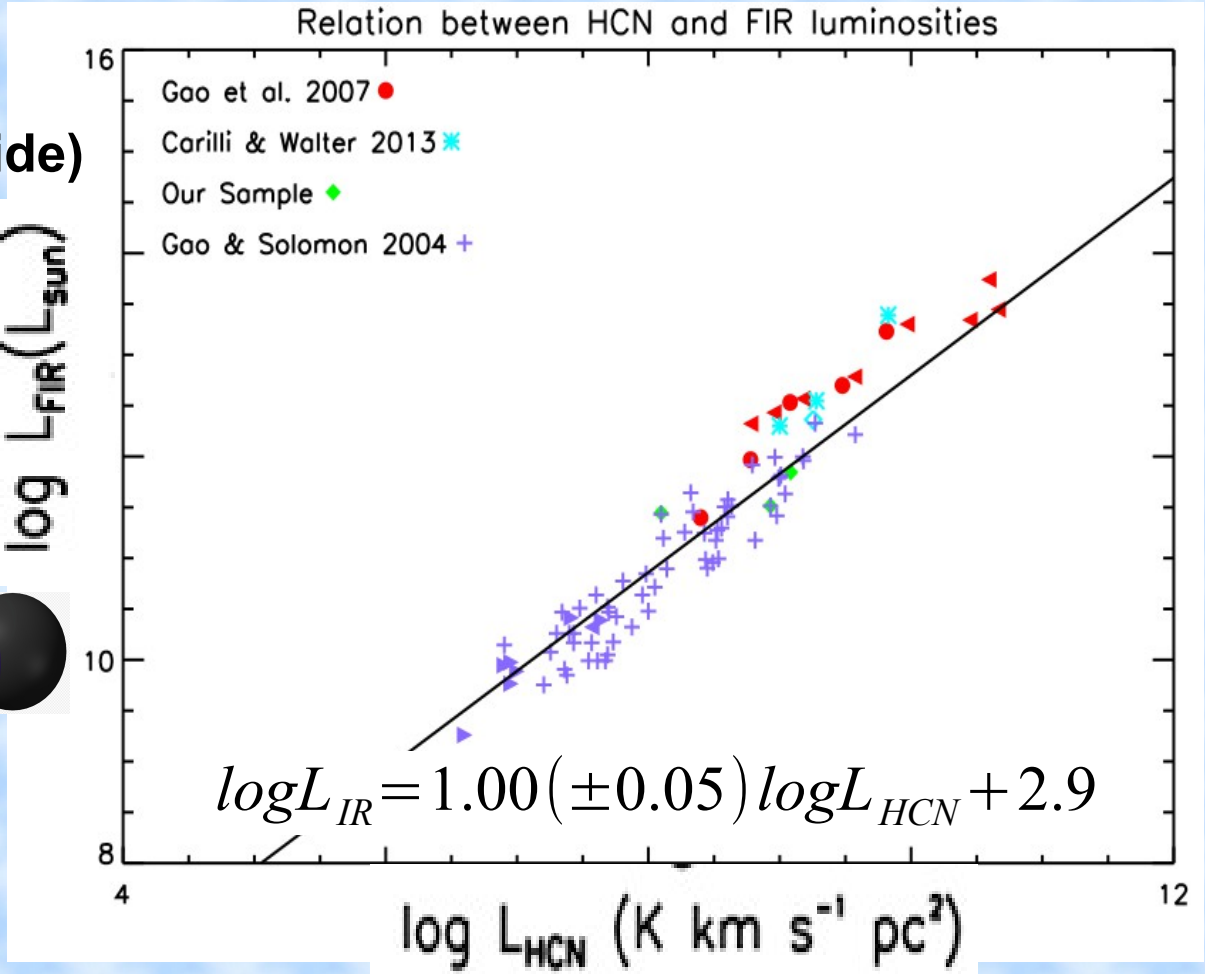


HNC (Hydrogen isocyanide)

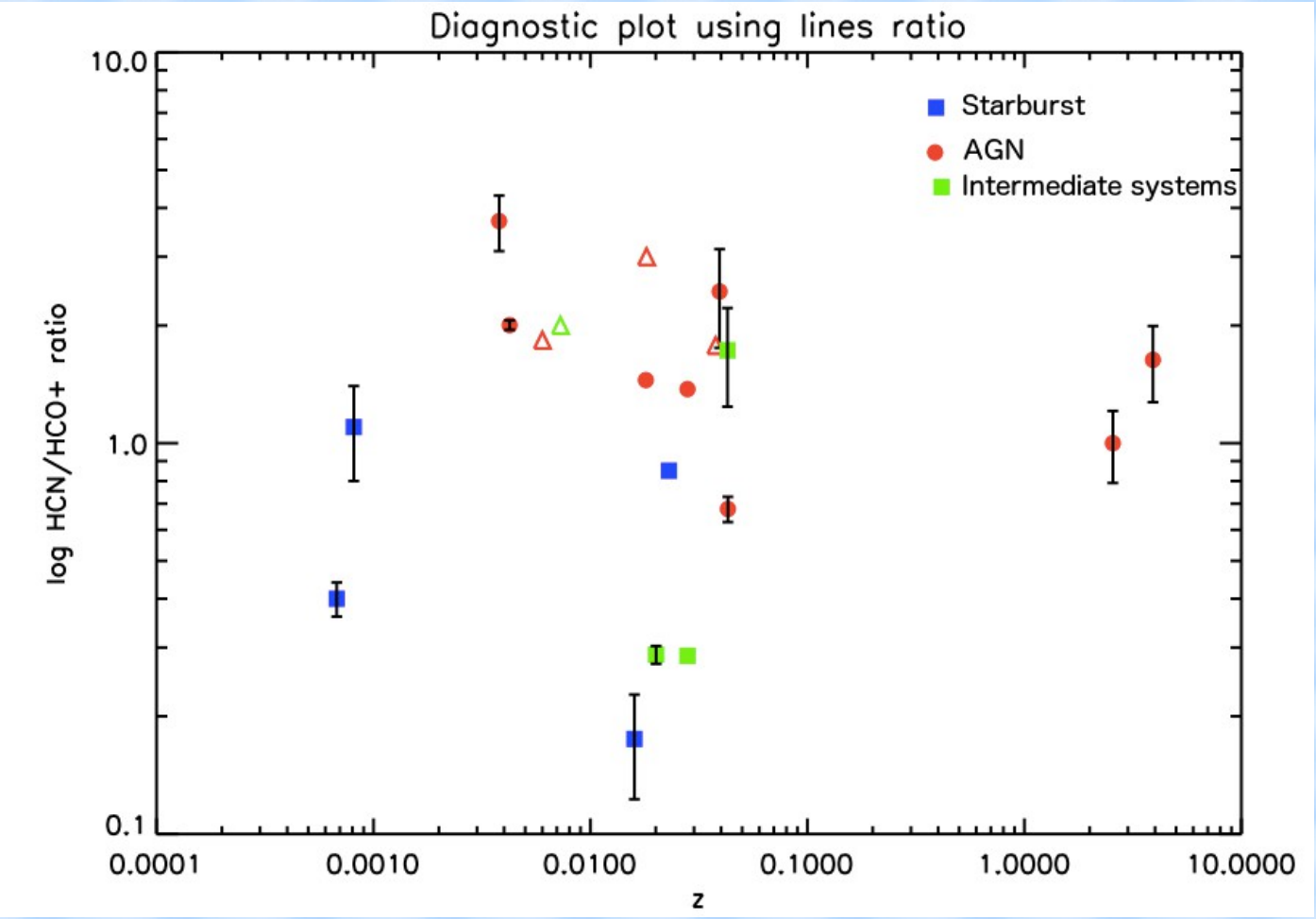


(1-0) 90.66 GHz n_{crit}~10^{6} cm^{-3}

(4-3) 362.63 GHz n_{crit}~10^{7} cm^{-3}



Starburst and AGN



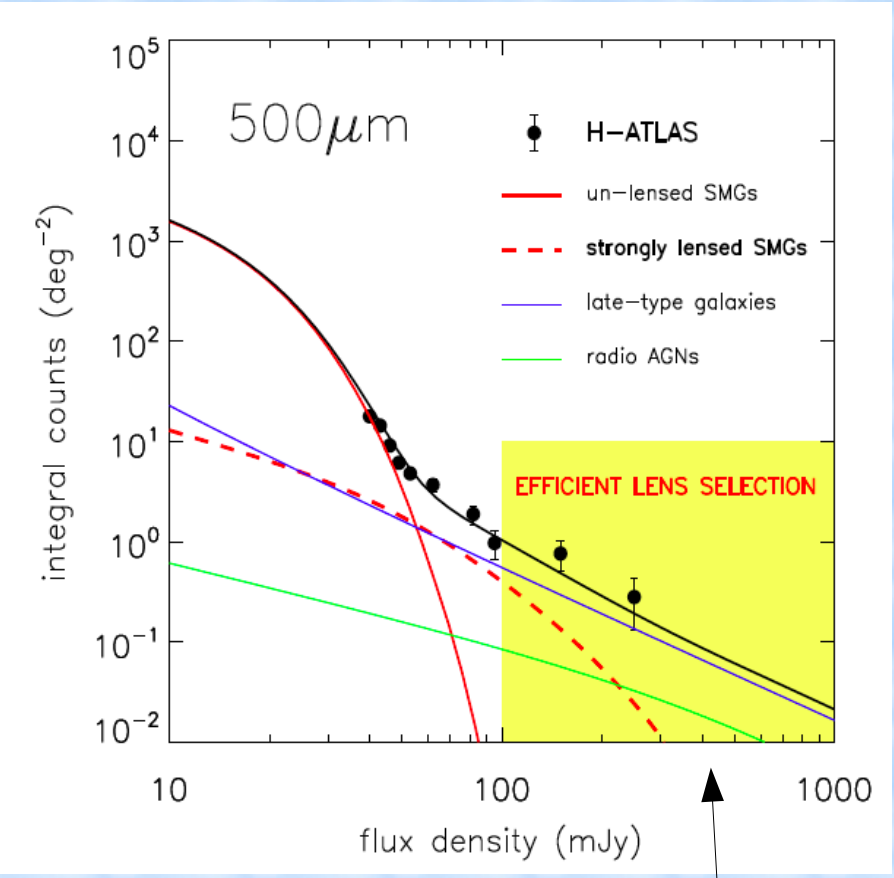
DATA:

- Imanishi et al. 2010
- Imanishi et al. 2006
- Campione
- Carilli & Walter 2013

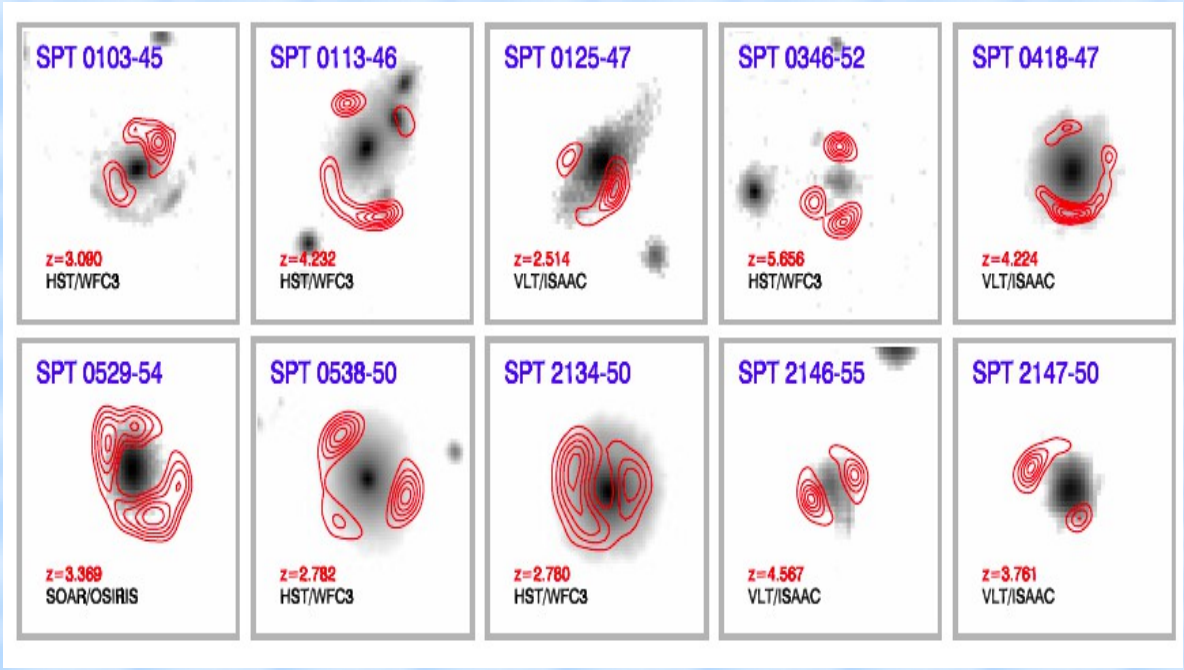
Significant HCO+/HCN variations in starbursts and AGN sources.

HNC indicator of AGN activity.

Lensing



Negrello et al. 2010



Vieira et al. 2013

Flux-selection method efficient to select strongly lensed galaxies at high-z

SUBMM transparent lenses. Near-infrared (NIR) and ALMA submillimeter-wavelength images of SPT targets.

Sample selection

Publicly available **Cycle 0** data:

P.I. M.Imanishi
2011.0.00020.S project

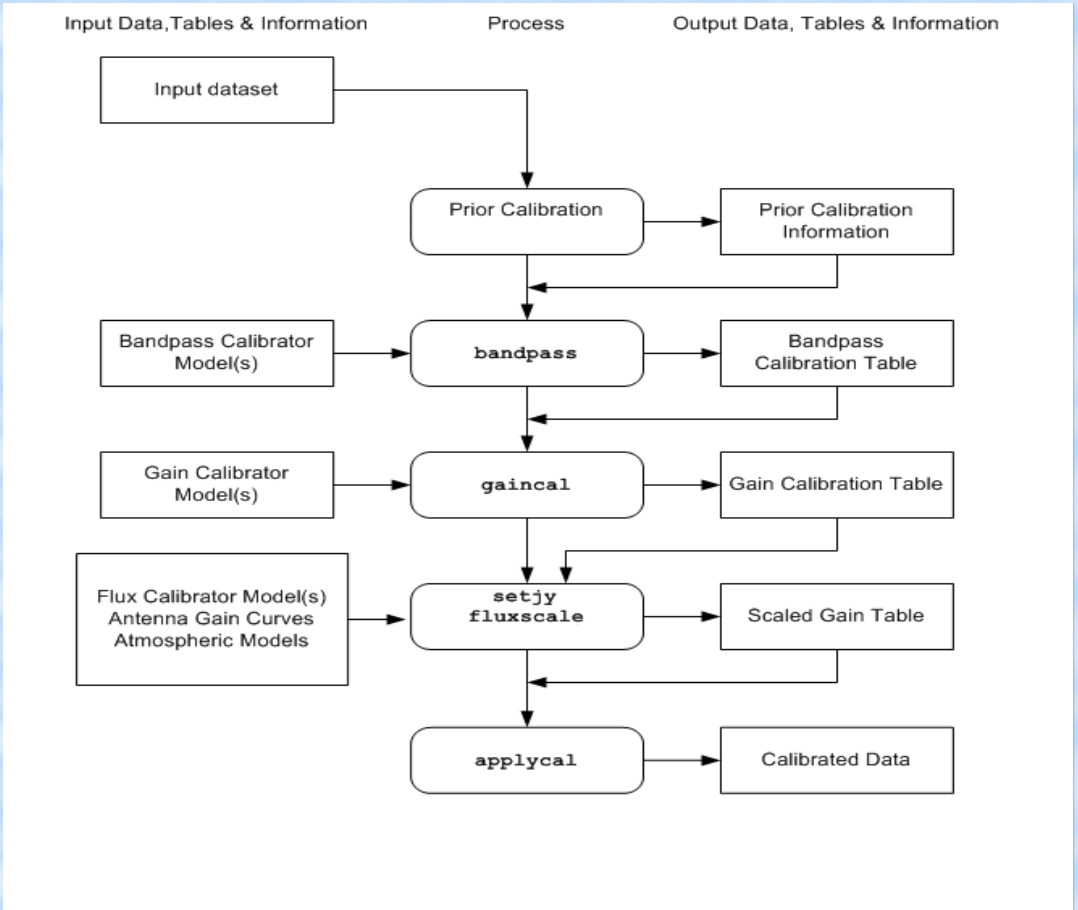
- BANDS 3, 6, 7 ,9.
- ANTENNAs 16
- BASELINES: 18 - 400 m
- MAX RESOLUTION: 1.56" x (100/freq[GHz])
- SENSITIVITY: **0.14mJy @100 GHz in 1 hr**

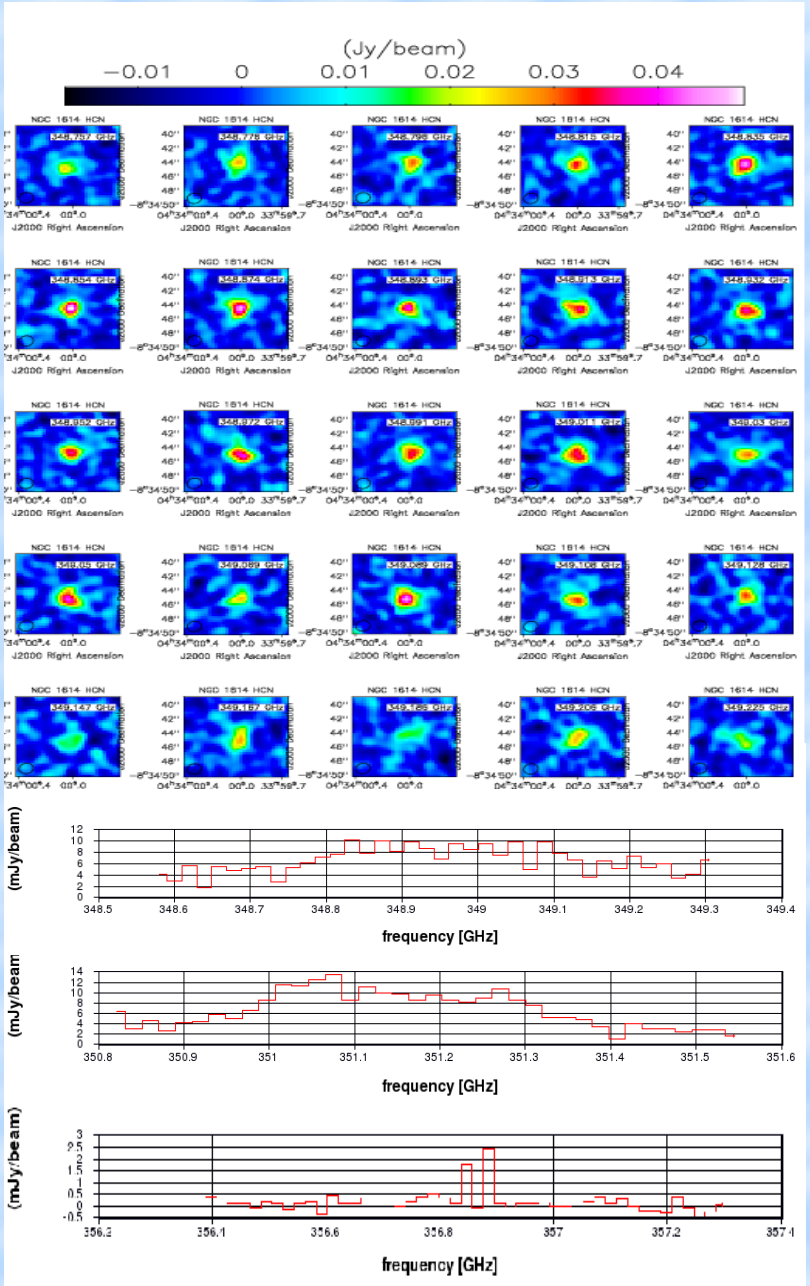
	NGC 1614 z=0.016		**IRAS 20551-4250 z=0.042**	
LINE	**HCN/HCO+(J=4-3)**	**HNC (J=4-3)**	**HCN/HCO+(J=4-3)**	**HNC (J=4-3)**
DATE (UT)	2011 Nov 15	2011 Nov 15	2012 June 1 2012 July 26	2012 June 2 2012 July 26
ANTENNAS	16	16	18 17	19 18
BANDPASS CALIBRATOR	3C454.3	3C454.3	3C454.3	3C454.3
FLUX CALIBRATOR	Callisto	Callisto	Neptune	Neptune
PHASE CALIBRATOR	J0423-013	J0423-013	J2056-472	J2056-472
ON-SOURCE TIME	26 min	25 min	26 min 28 min	25 min 25 min
CENTRAL FREQUENCY	348.922/350.920 GHz	356.920 GHz	347.680/353.589 GHz	347.680 GHz

CASA Calibration

NGC 1614
- Continuum
- HCN (38 slices)
- HCO+ (38 slices)
- HNC (48 slices)

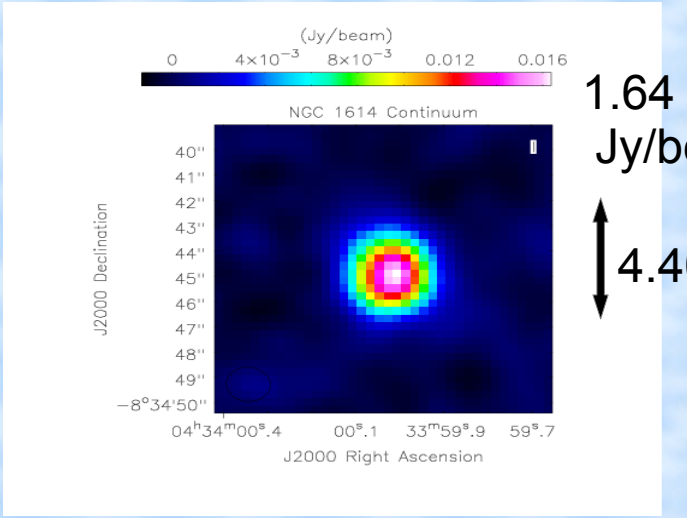
IRAS 20551-4250
- Continuum
- HCN (25 slices)
- HCO+(25 slices)
- HNC (25 slices)





Extrapolation high-z

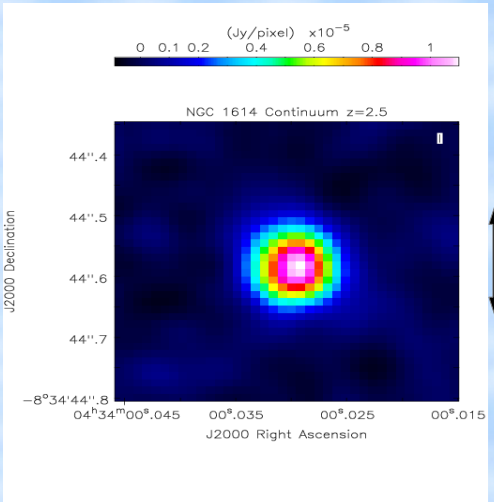
NGC 1614 z = 0.016



1.64 x10^{-2} Jy/beam

4.40"

z = 2.5



1.10 x10^{-5} Jy/beam

0.20"

z = 2.5-3.0 Median redshift for the SMGs population

(Smail et al. 2000, 2002; Eales et al. 2000, Chapman et al. 2005; Hodge et al. 2013; Simpson et al. 2014)

Scale for new redshift:

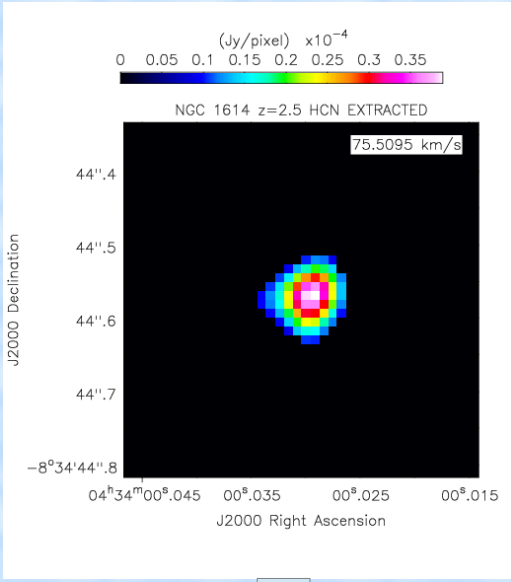
- FLUX DENSITY by $d_{L,old}^{\ 2} / d_{L,new}^{\ 2}$
- ANGULAR SIZE by $d_{A,old} / d_{A,new}$
- FREQUENCY by $(1+z_{old}) / (1+z_{new})$
- CHANNELWIDTH by $(1+z_{old}) / (1+z_{new})$
- TASK **SIMOBSERVE**

Lensing Simulation

Quantity	fiducial value
Halo mass	$M_H = 5 \times 10^{12} M_\odot$
Dark-to-light ratio	$M_H/M_* = 40.0$
Ellipticity	$q = 0.7$
Lens redhift	$z_l = 0.7$

- **NGC 1614 @ z=2.5**
- **NGC 1614 @ z=3.0**
- **IRAS 20551-4250 @ z=2.5**
- **IRAS 20551-4250 @ z=3.0**

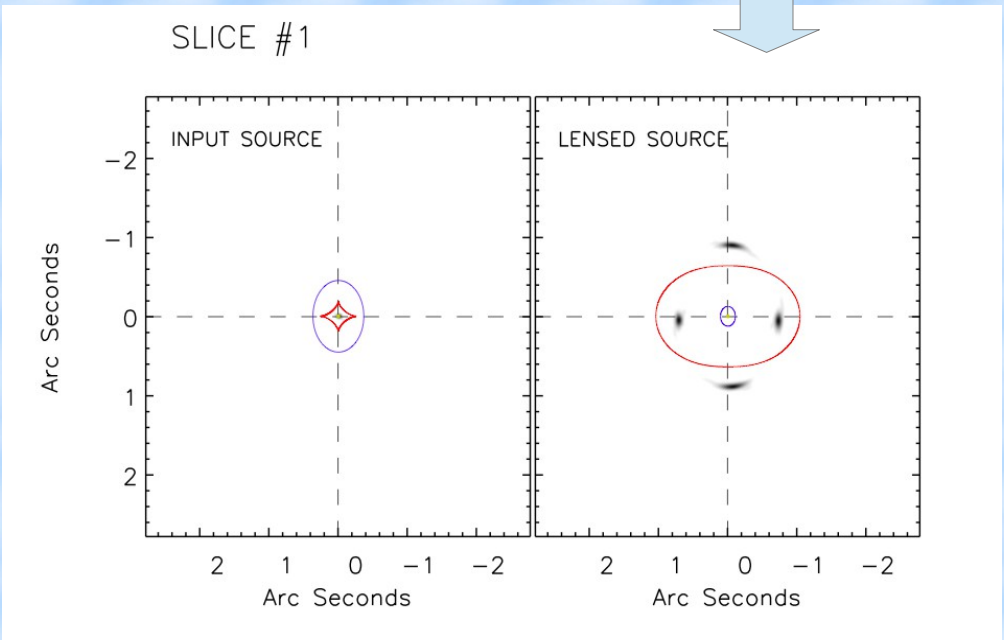
EXTRACTION



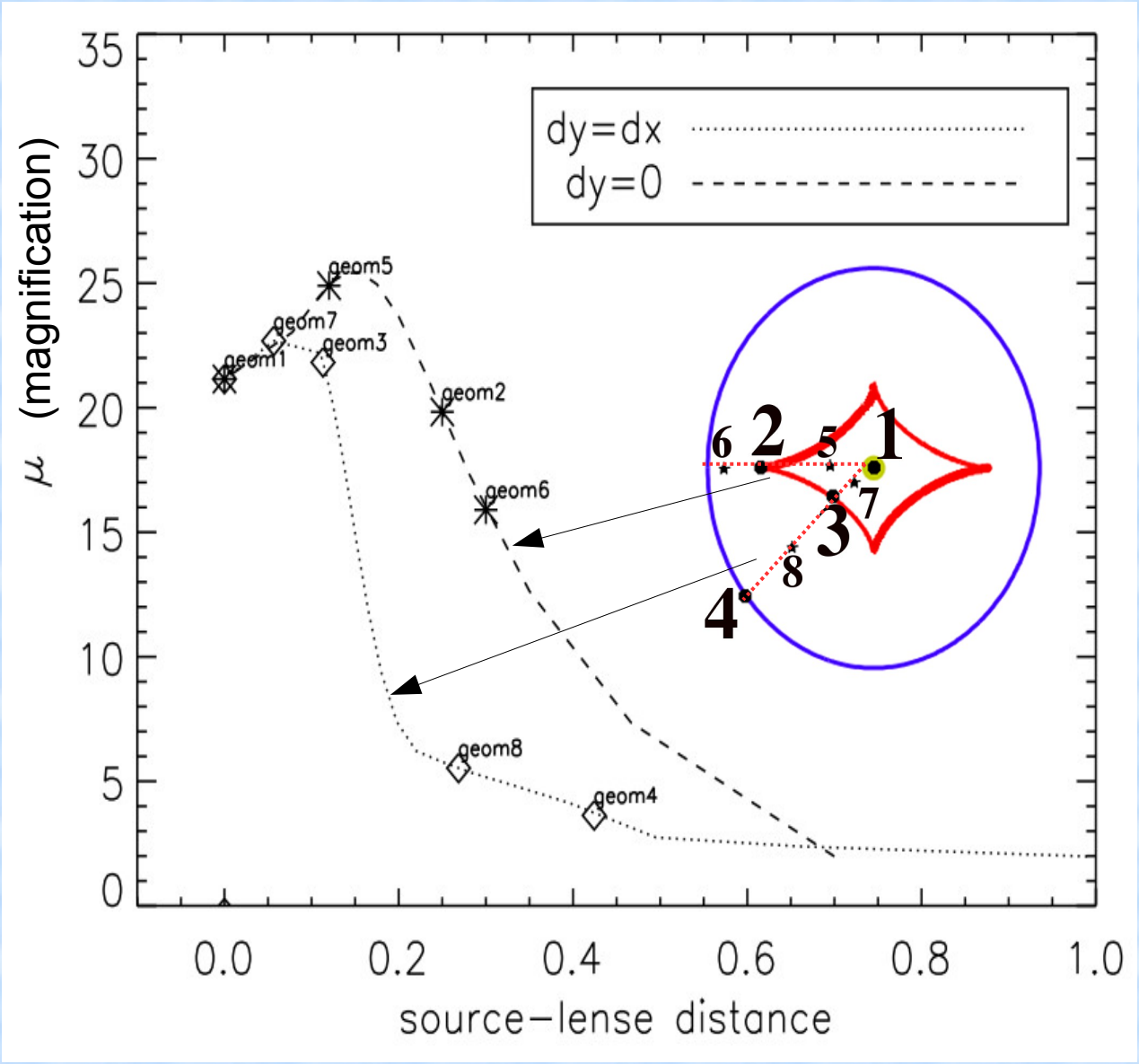
Lensing model based on Lapi et al. 2012

Galaxy-scale gravitational strong lensing events.

LENS = isolated early-type elliptical galaxy associated to a DM halo



Lensing configurations



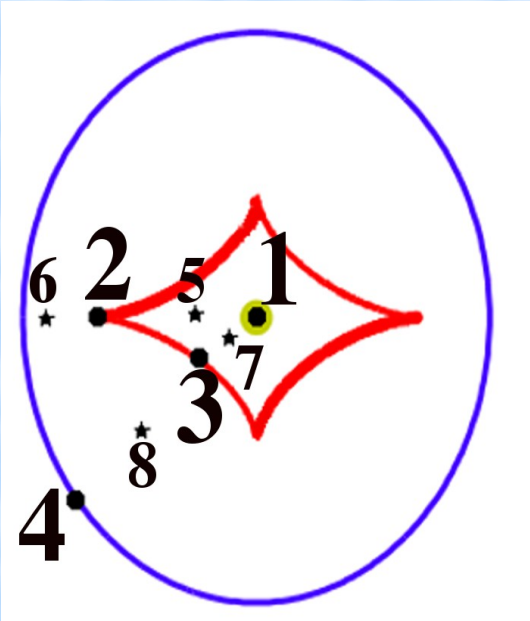
Configuration	dx	dy
1	0.00	0.00
2	0.25	0.00
3	0.08	0.08
4	0.30	0.30
5	0.12	0.00
6	0.30	0.00
7	0.04	0.04
8	0.19	0.19

NGC 1614 @ z=2.5
Continuum 8 conf
HCN, HCO+, HNC 4 conf

NGC 1614 @ z=3.0
Continuum, HCN, HCO+, HNC 2 conf

IRAS 20551-4250 @ z=2.5
Continuum, HCN, HCO+, HNC 4 conf

IRAS 20551-4250 @ z=3.0
Continuum, HCN, HCO+, HNC 2 conf

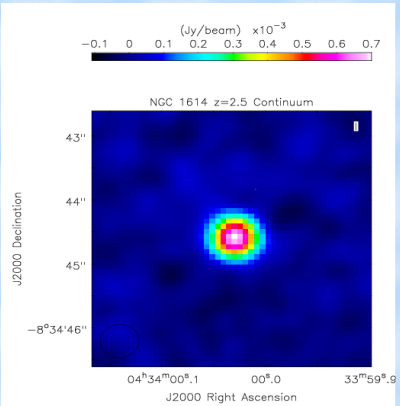


CASA Simulations

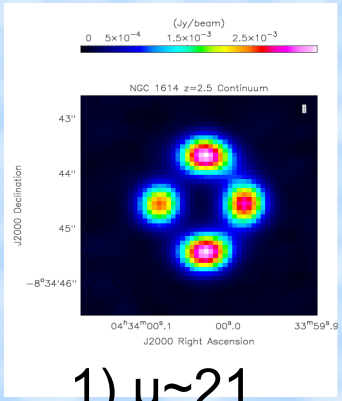
- ***SIMOBSERVE***
  ALMA Full Array configuration 14
  (intermediate resolution 0.5" @ 100 GHz)
  Integration time 10 min
  Thermal noise

- ***CLEAN*** 0.08" pixel^{-1}

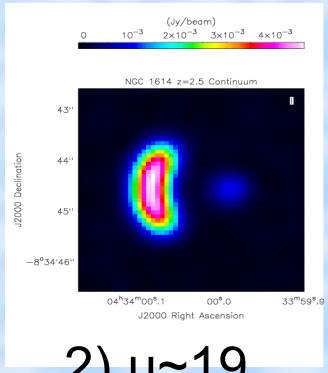
UNLENSED



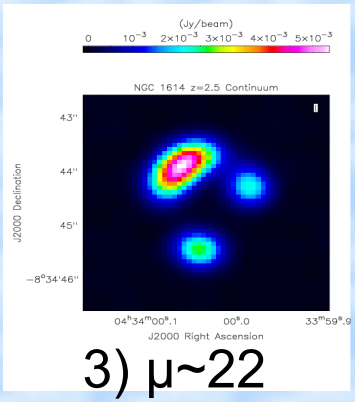
NGC 1614 z=2.5 Continuum



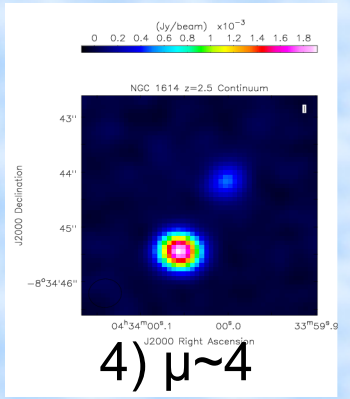
1) μ~21



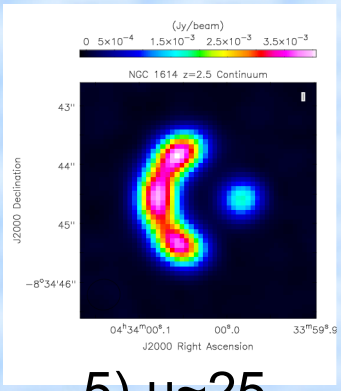
2) μ~19



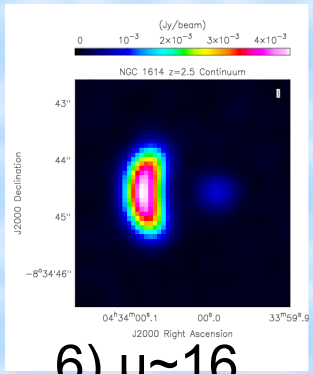
3) μ~22



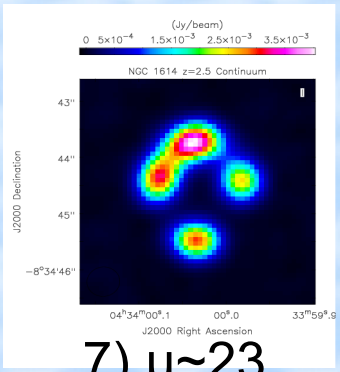
4) μ~4



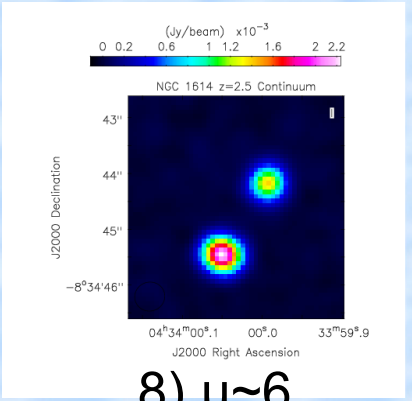
5) μ~25



6) μ~16



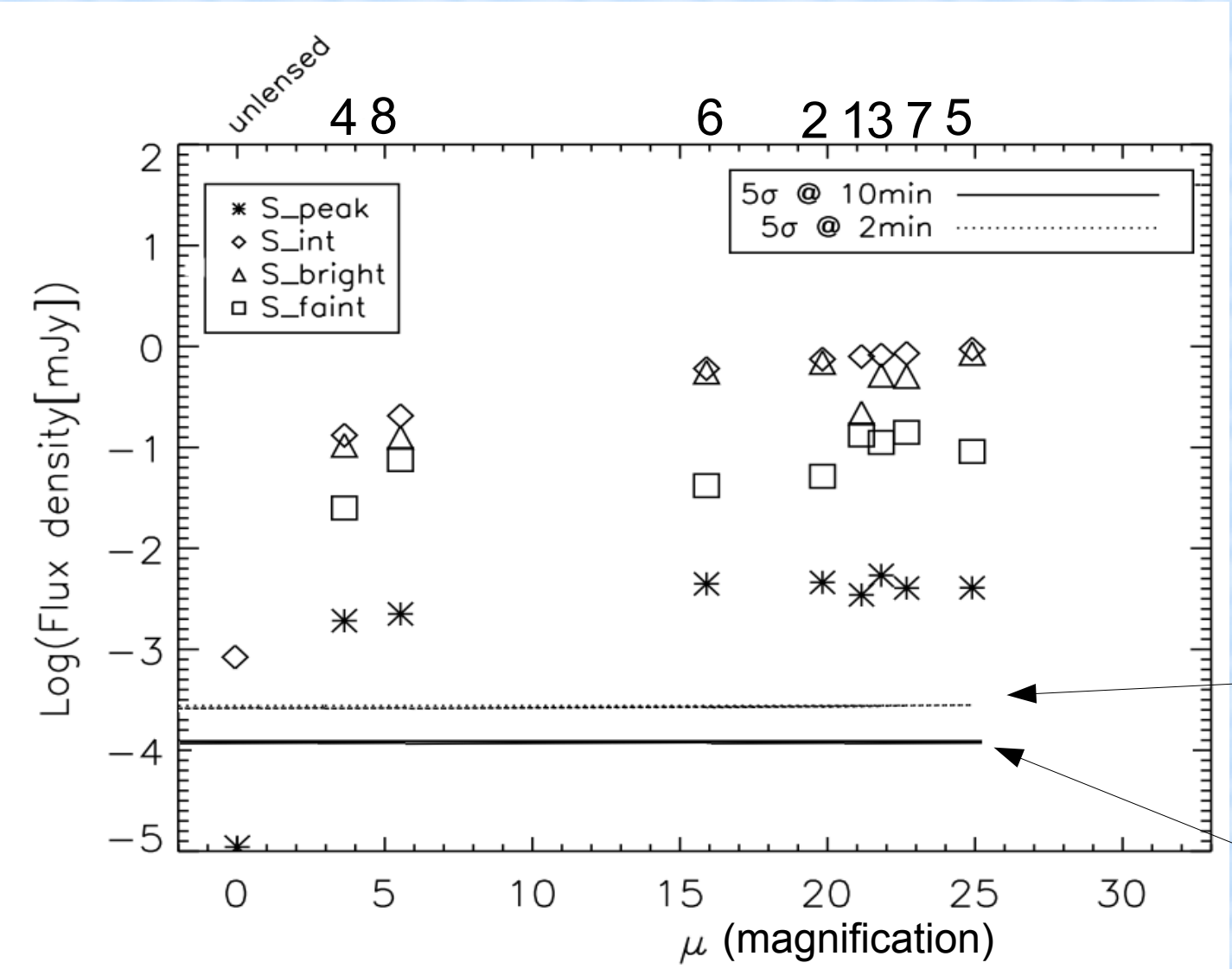
7) μ~23



8) μ~6

Simulation results

NGC 1614 z=2.5 Continuum



* **S_peak**: peak flux

◇ **S_int**: integrated flux

△ **S_bright**: integrated flux of the brightest component

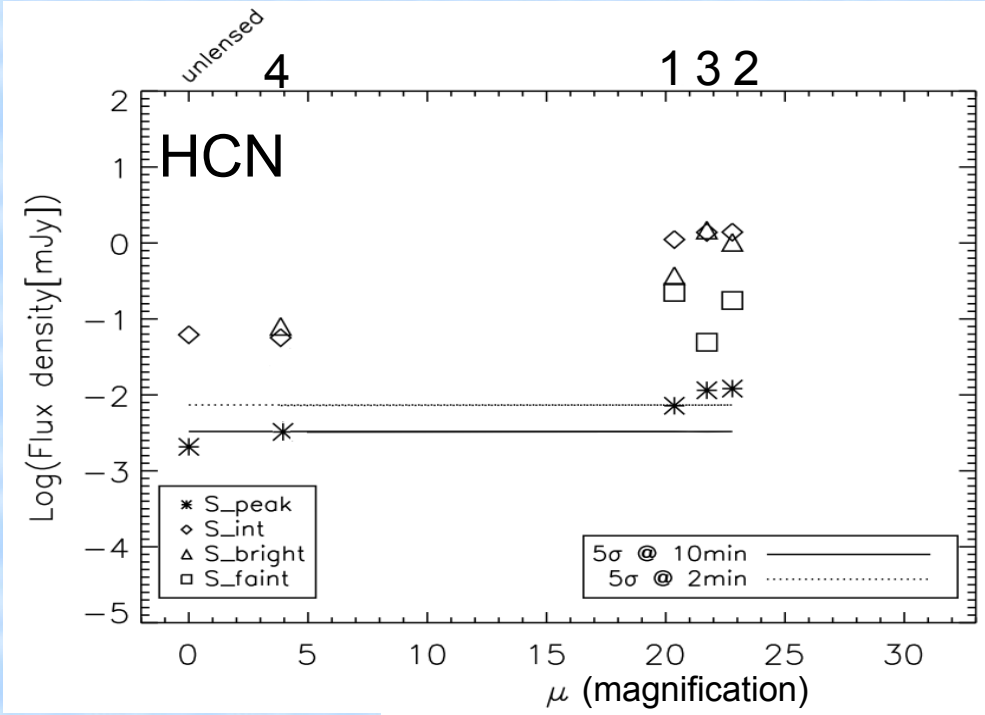
□ **S_faint**: integrated flux of the faintest component

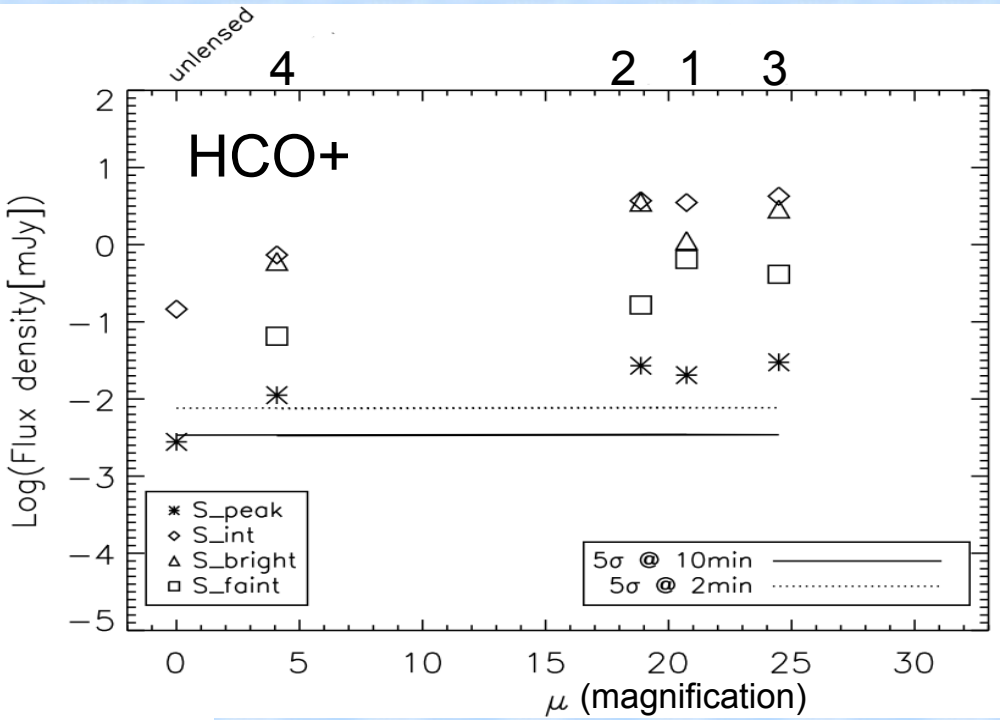
5 σ @ 2 min

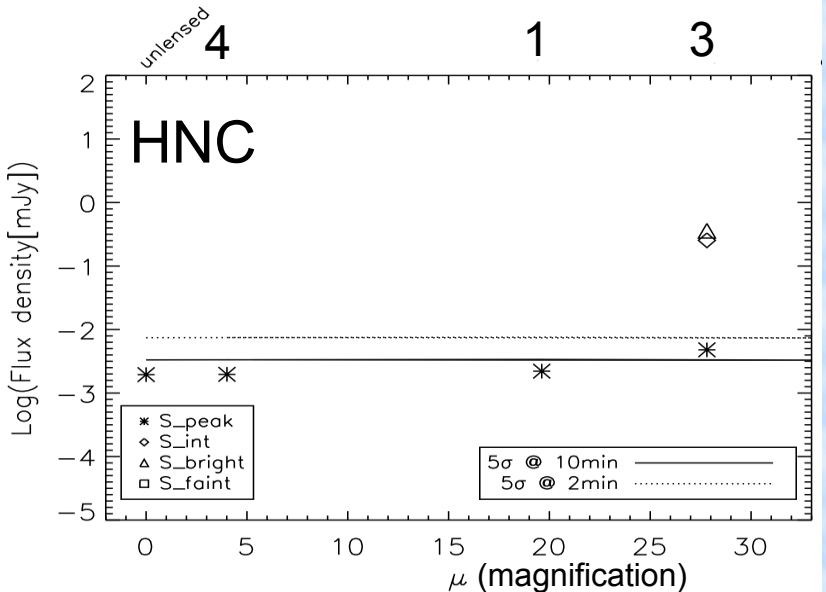
5 σ @ 10 min

Simulation Results

NGC 1614 z = 2.5



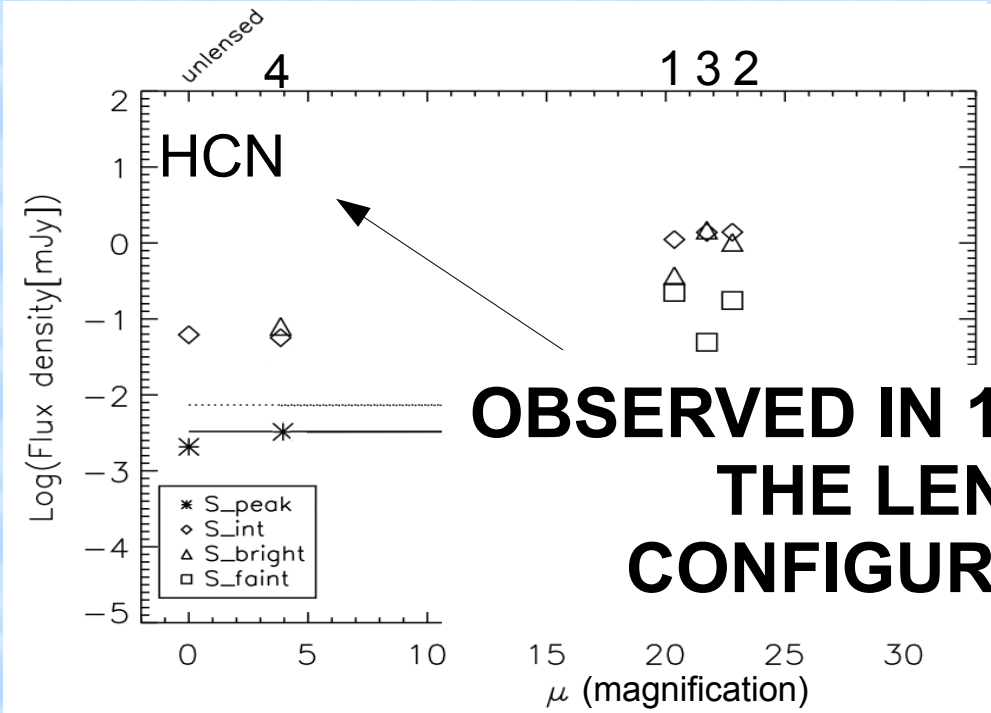


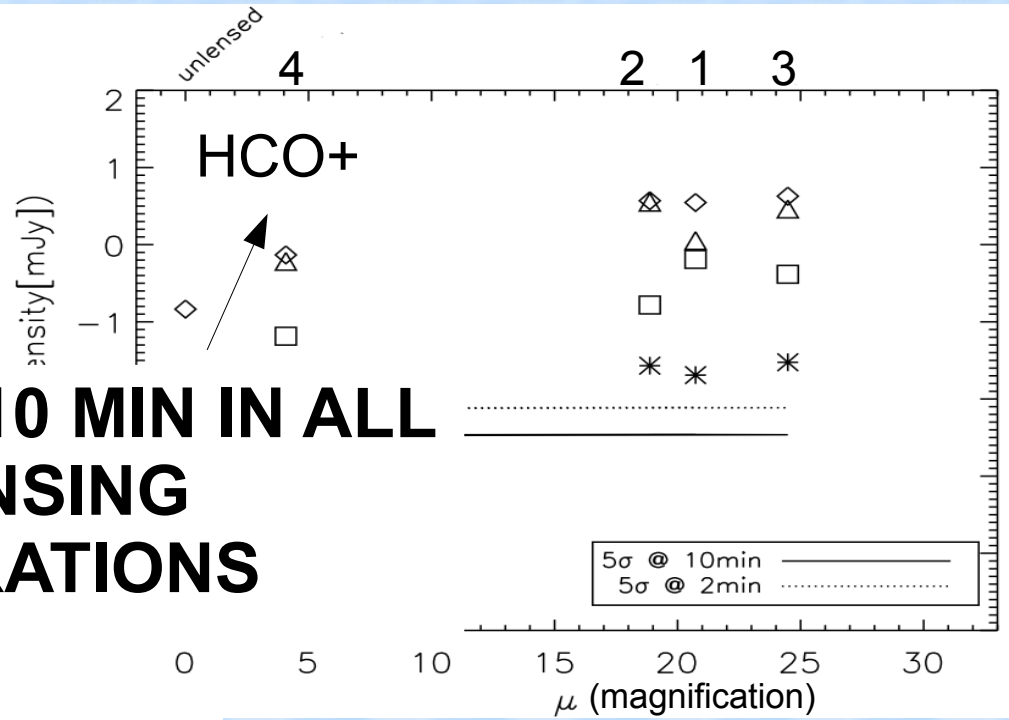


- HCO+ observability referred to HCN
- Lensing effects
- HNC only in favourites configurations

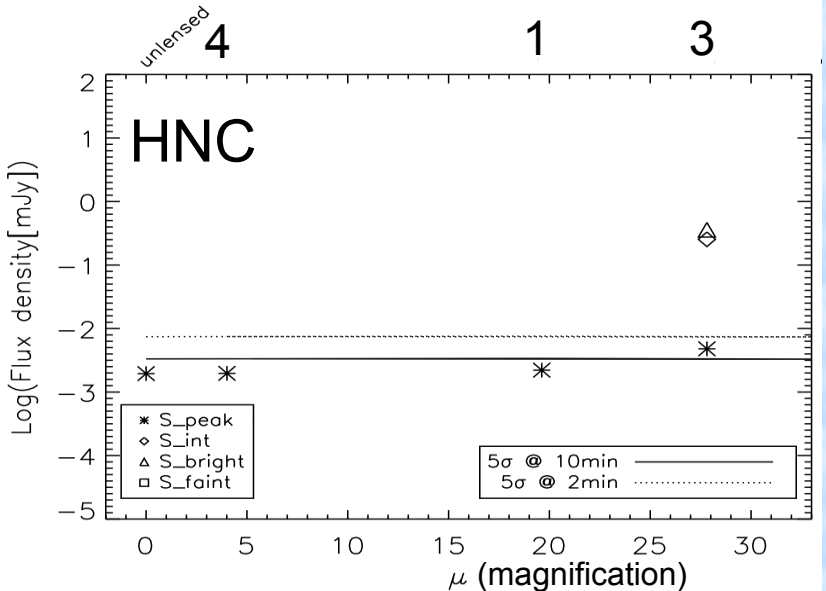
Simulation Results

NGC 1614 z = 2.5





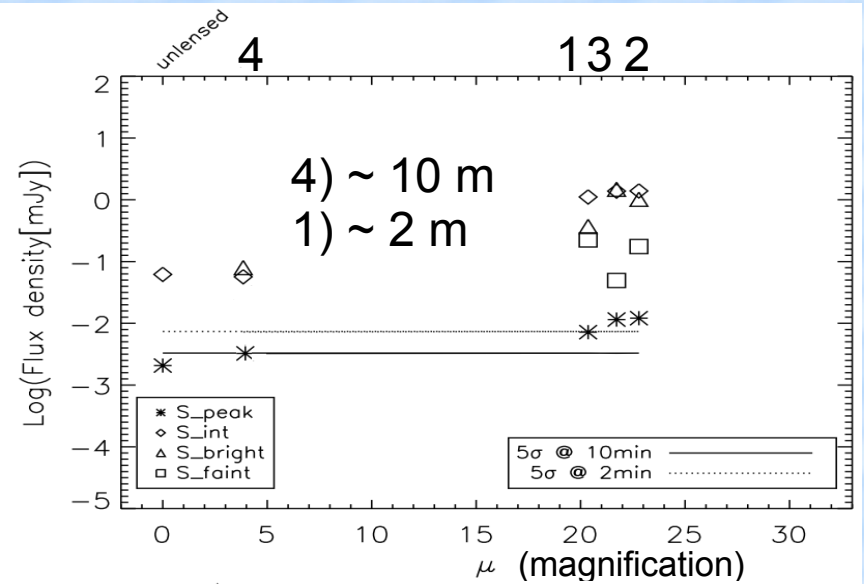
OBSERVED IN 10 MIN IN ALL THE LENSING CONFIGURATIONS



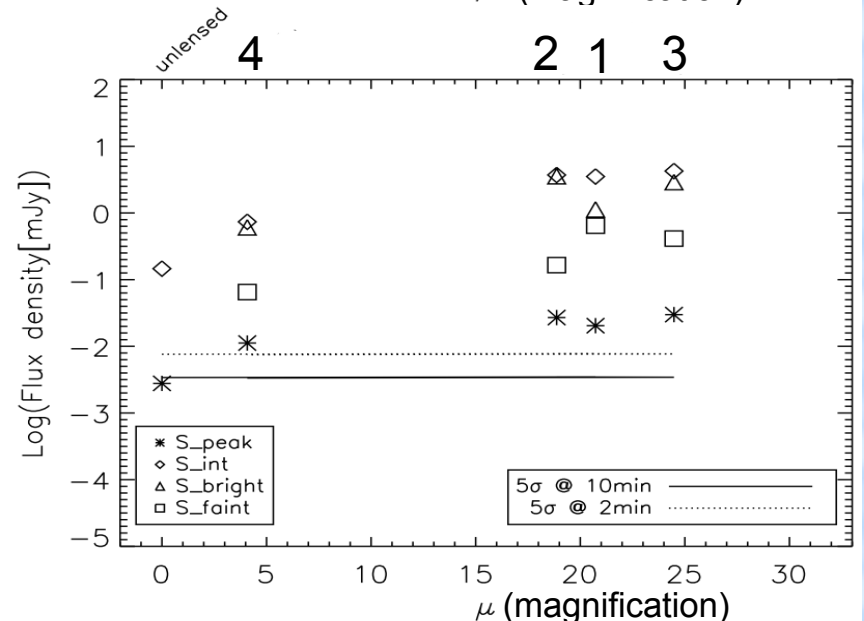
- HCO+ observability referred to HCN
- Lensing effects
- HNC only in favourites configurations

Simulation Results

NGC 1614 z = 2.5

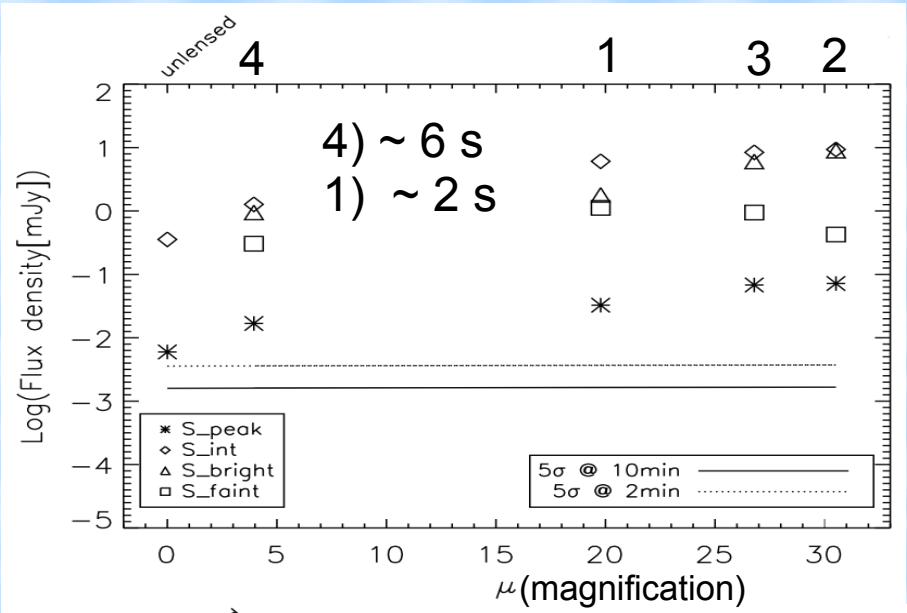


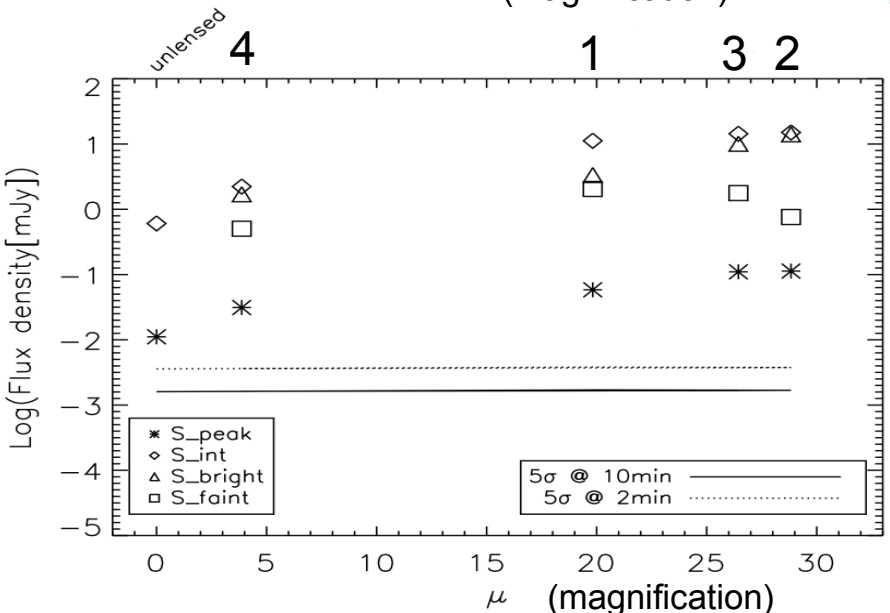
HCN



HCO+

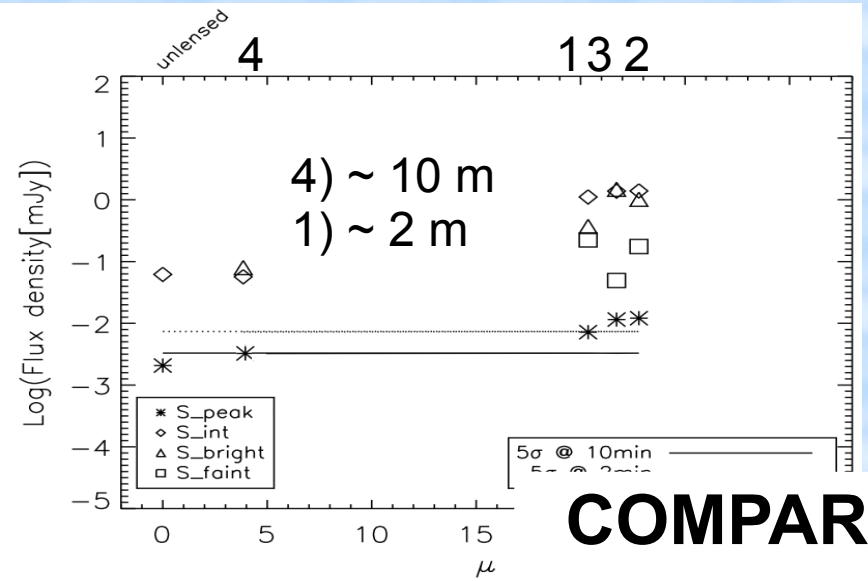
IRAS 20551-4250 z = 2.5





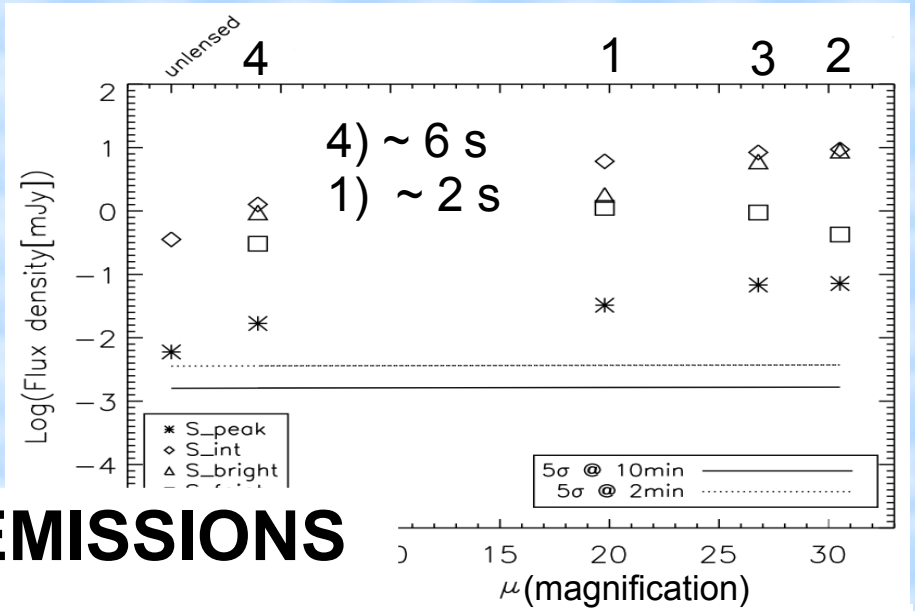
Simulation Results

NGC 1614 z = 2.5

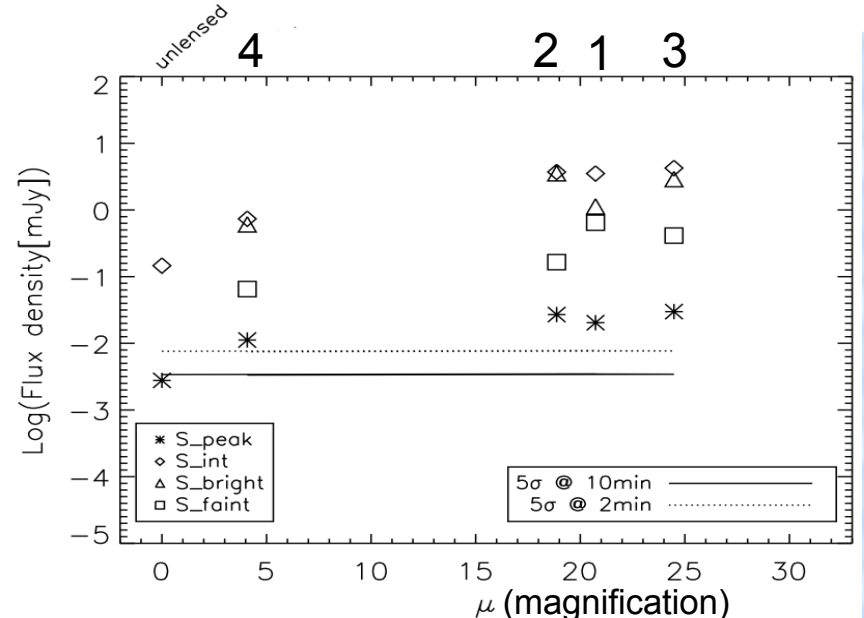


HCN

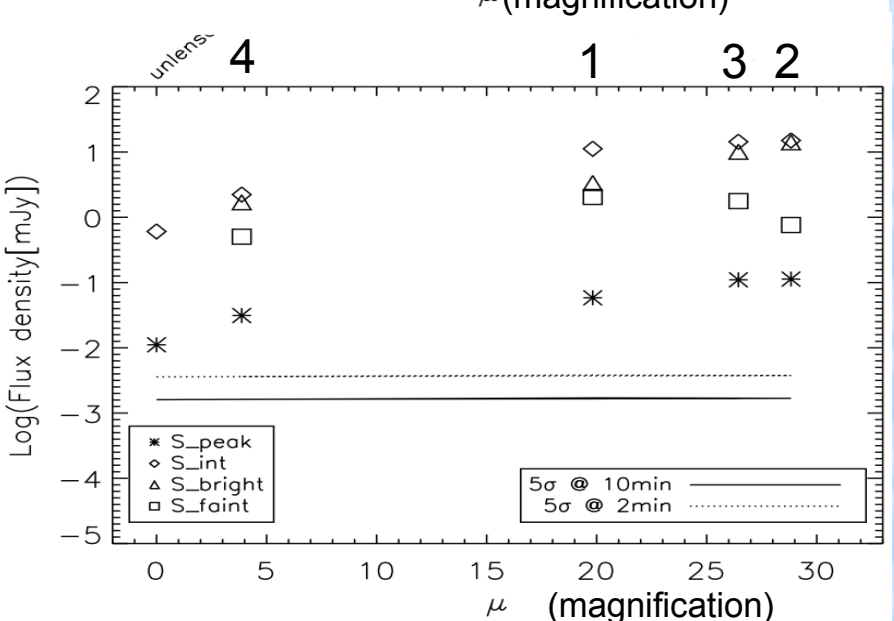
IRAS 20551-4250 z = 2.5



COMPARABLE EMISSIONS

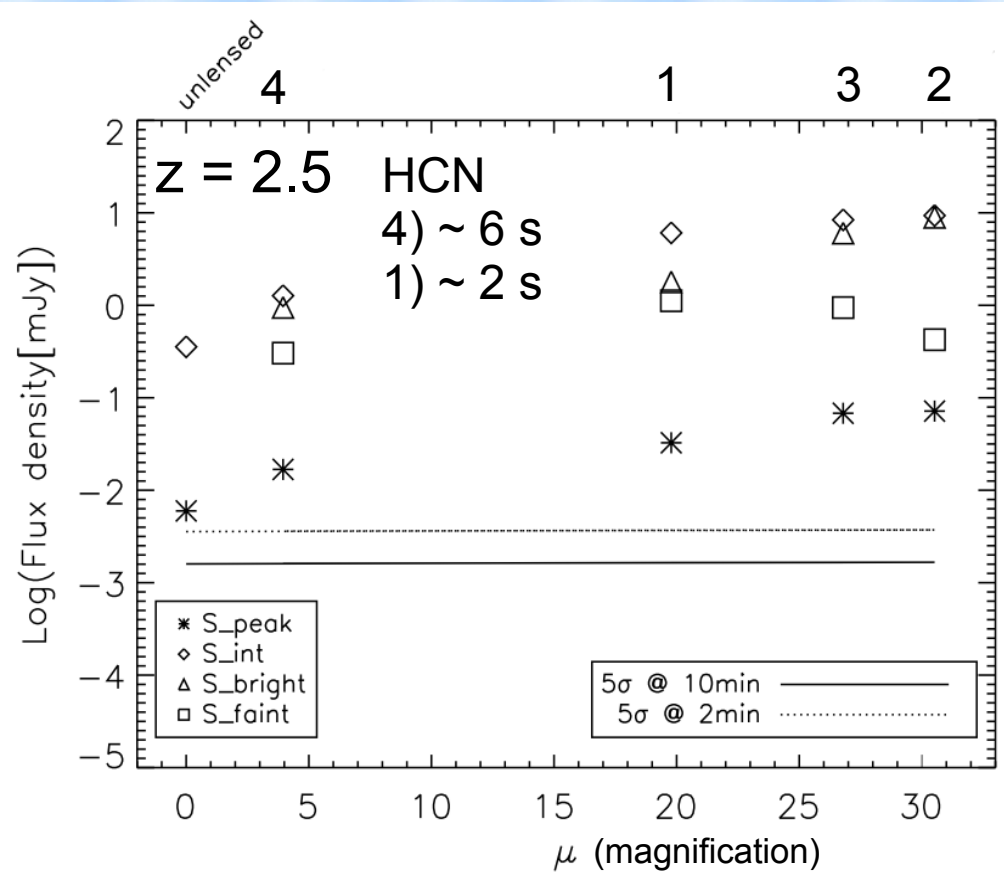


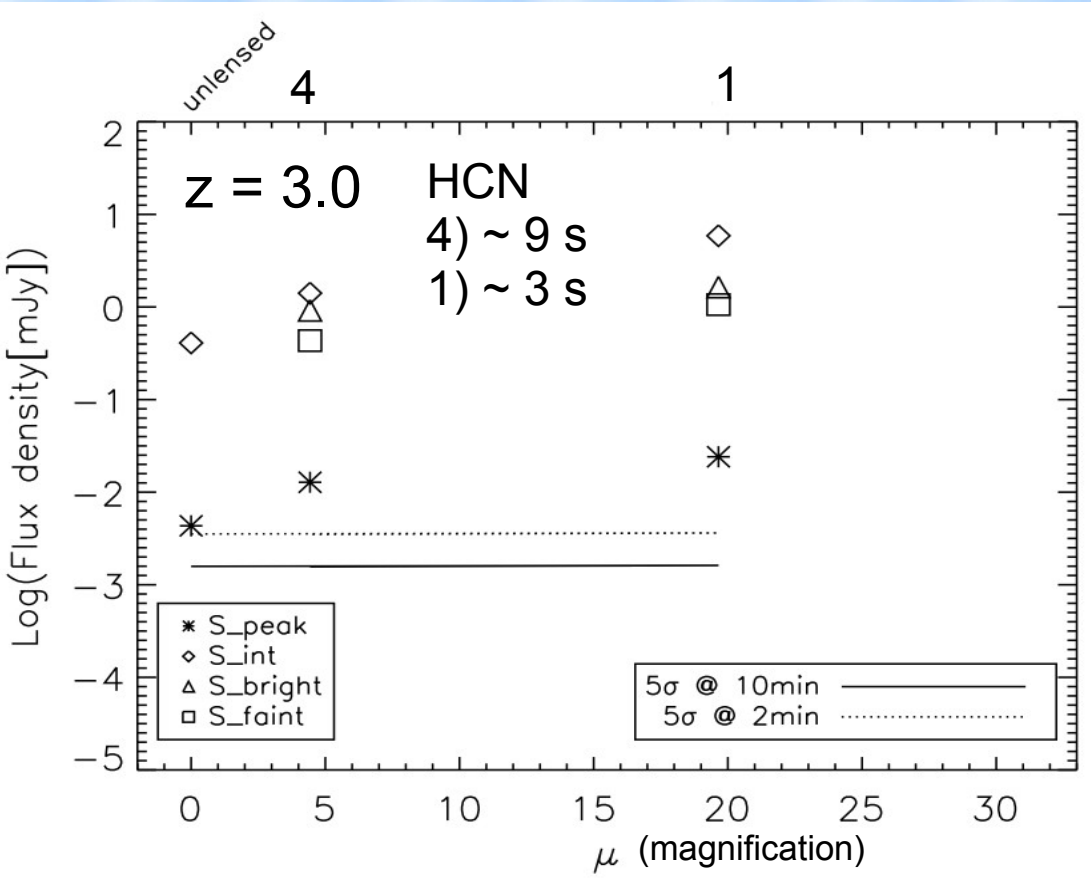
HCO+



Simulation Results

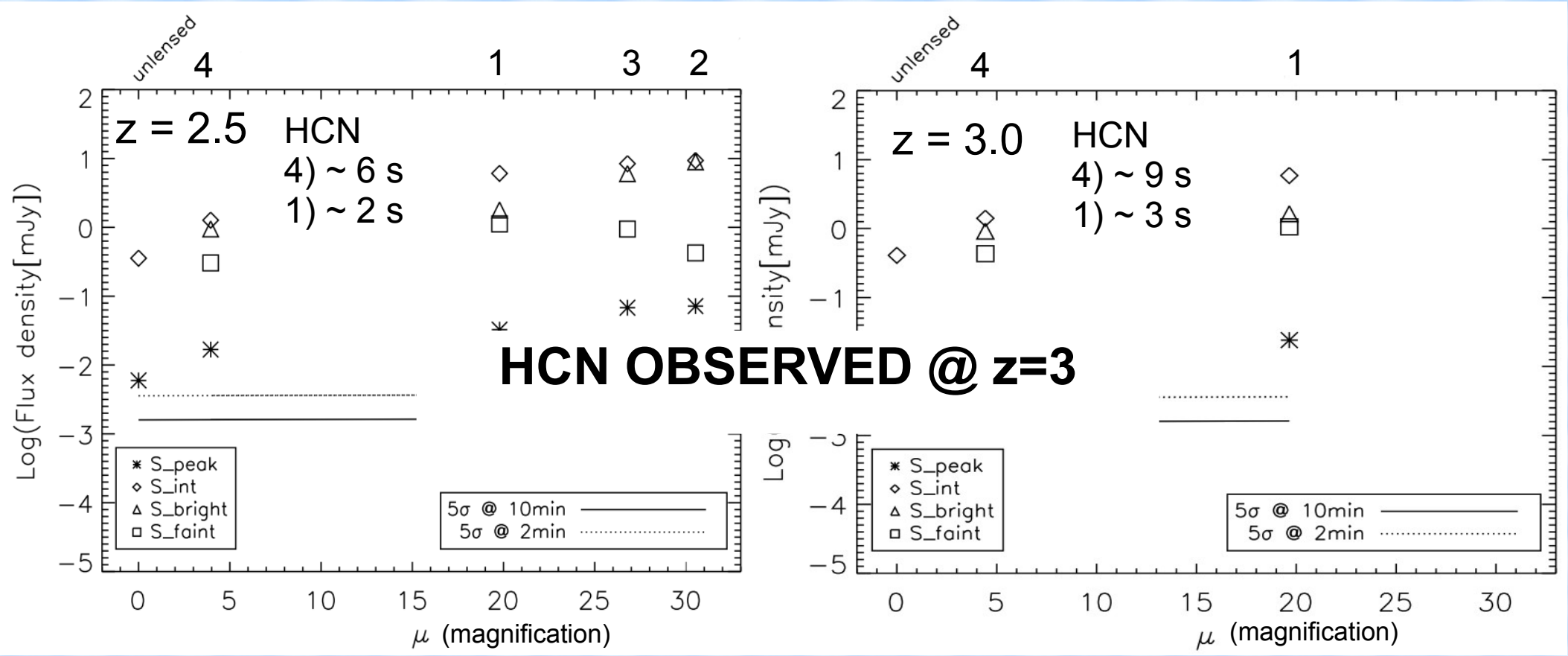
IRAS 20551-4250





Simulation Results

IRAS 20551-4250



HCN OBSERVED @ z=3

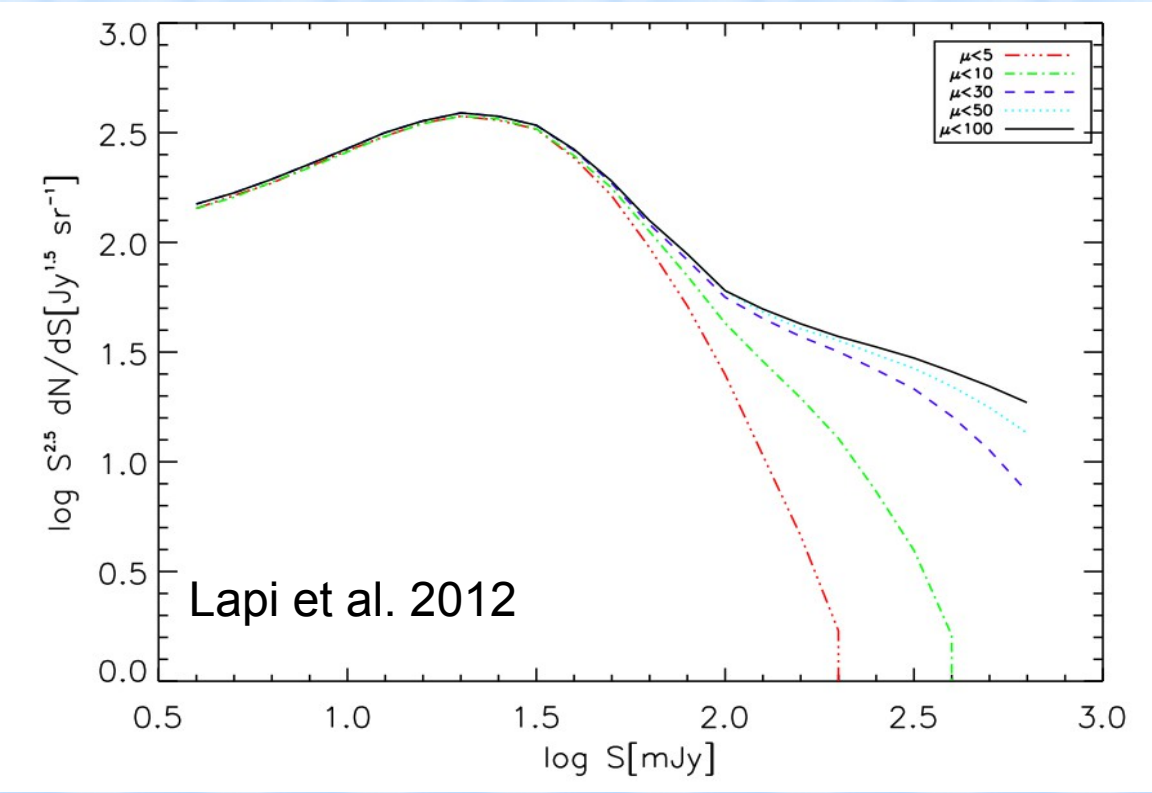
Observing strategies

Herschel surveys ≈ 1000 deg^2
H-ATLAS ≈ 550 deg^2

- 260 selected sources in 21 hr
- 70 sources in half of H-ATLAS in 6 hr

Determination of redshift with HCN (4-3) and HCO+(4-3) and HNC (4-3) for the most magnified ones.

μ range	Number density $[deg^{-2}]$
$\mu < 5$	0.08
$\mu < 10$	0.18
$\mu < 30$	0.29
$\mu < 50$	0.32
$\mu < 100$	0.33



Follow-up spectral line observations

Sources with 10 < μ < 30
87 in the full *Herschel* survey area
24 in half of the H-ATLAS area

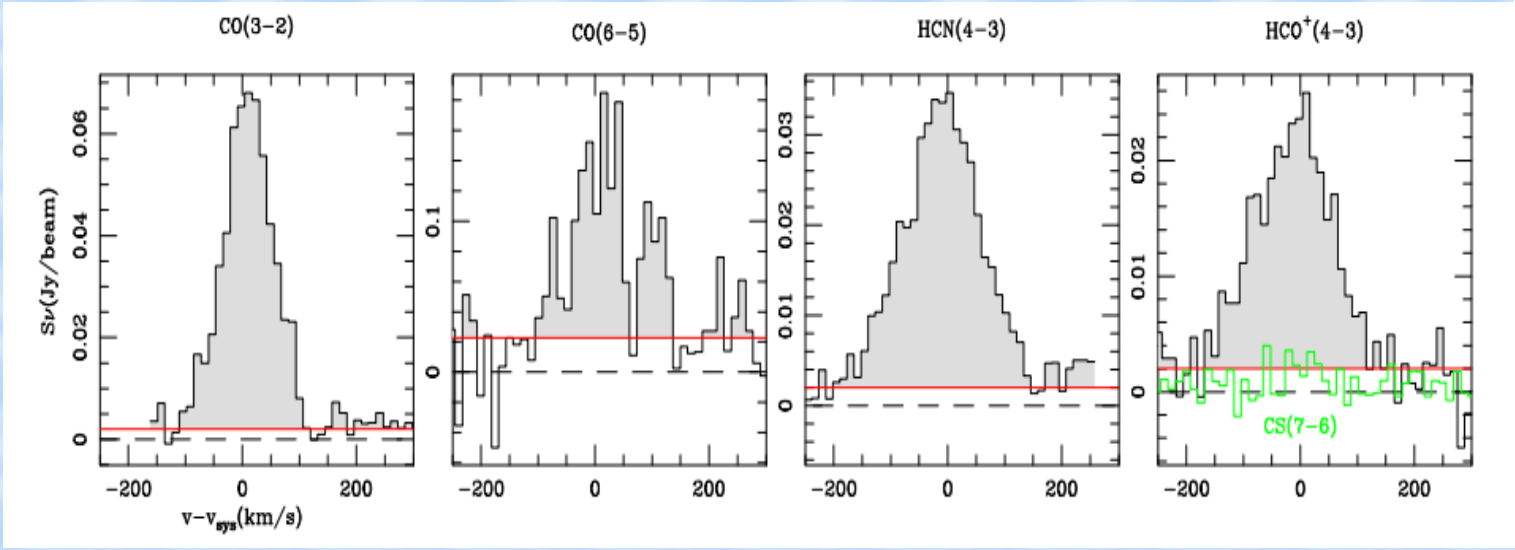
3 hr observations of HCN and HCO+

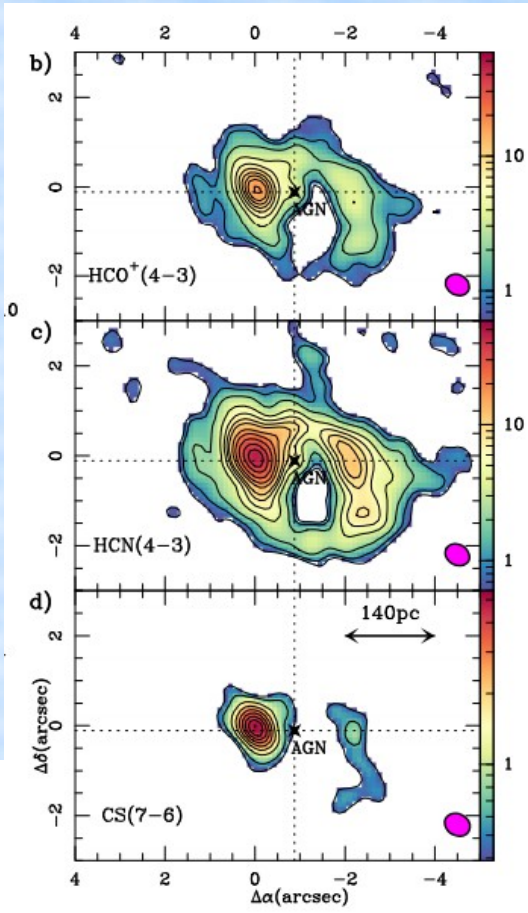
4.30 hr addictional HNC observations

Work in progress

NGC 1068 z = 0.004

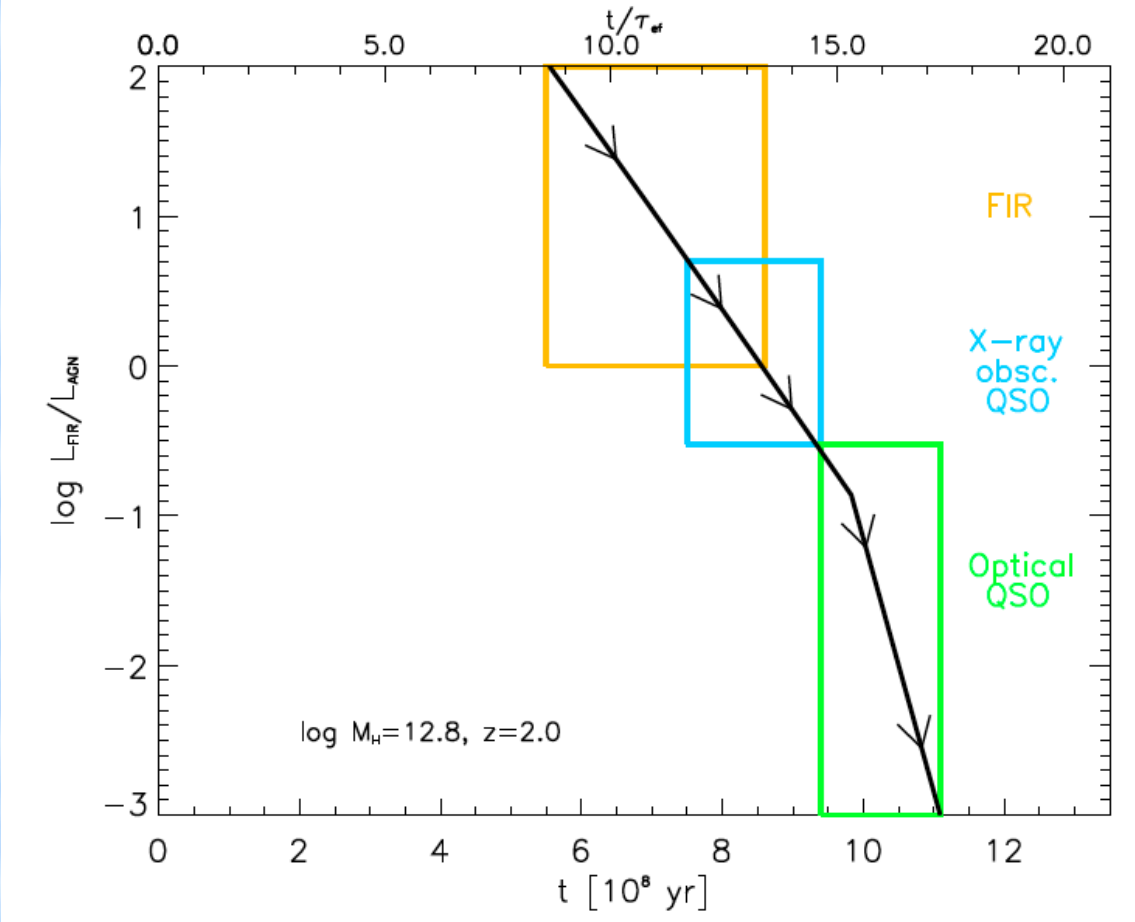
- Prototypical nearby D ~ 14 Mpc Seyfert 2 galaxy
- Composite starburst/AGN galaxy
- Well studied
- Model of buried AGN (observation r ~ 2 kpc)





S. García-Burillo et al. 2014

Future Perspectives



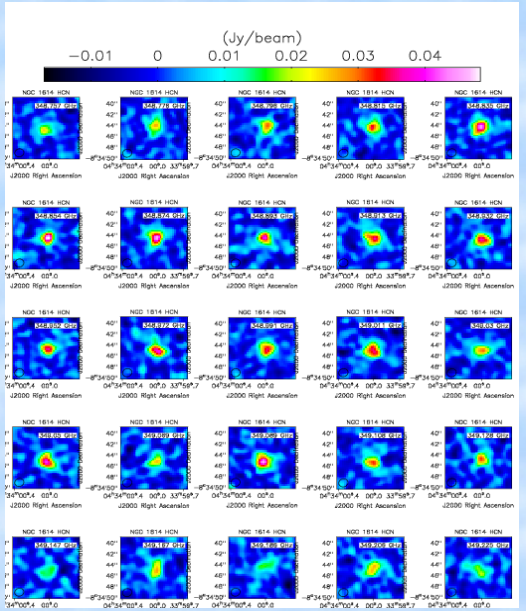
- Upgrade models
- ALMA Cycle 3 Proposal
- ALMA imaging of galaxies central regions and analysis on the visibility plane

Lapi et al. 2014

Summary

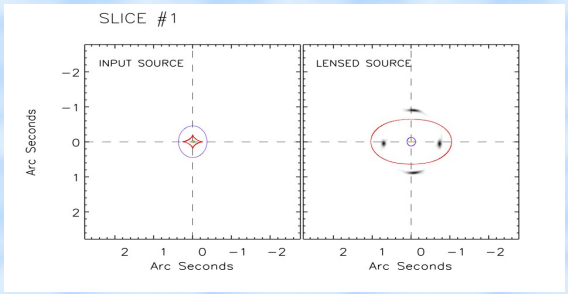
- **SET OF PROCEDURES:**

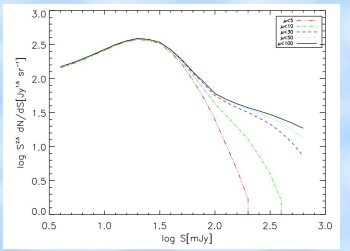
  From real images of local galaxies to simulated high-z lensed objects.



- **OBSERVABILITY**

  HCN, HCO+, HNC in lensed galaxies with ALMA.





- **OBSERVING STRATEGIES**

  Follow-up spectral line observations of lensed sources selected by *Herschel* surveys.