ALMA DOES GALAXIES!

A User's Perspective on Early Science

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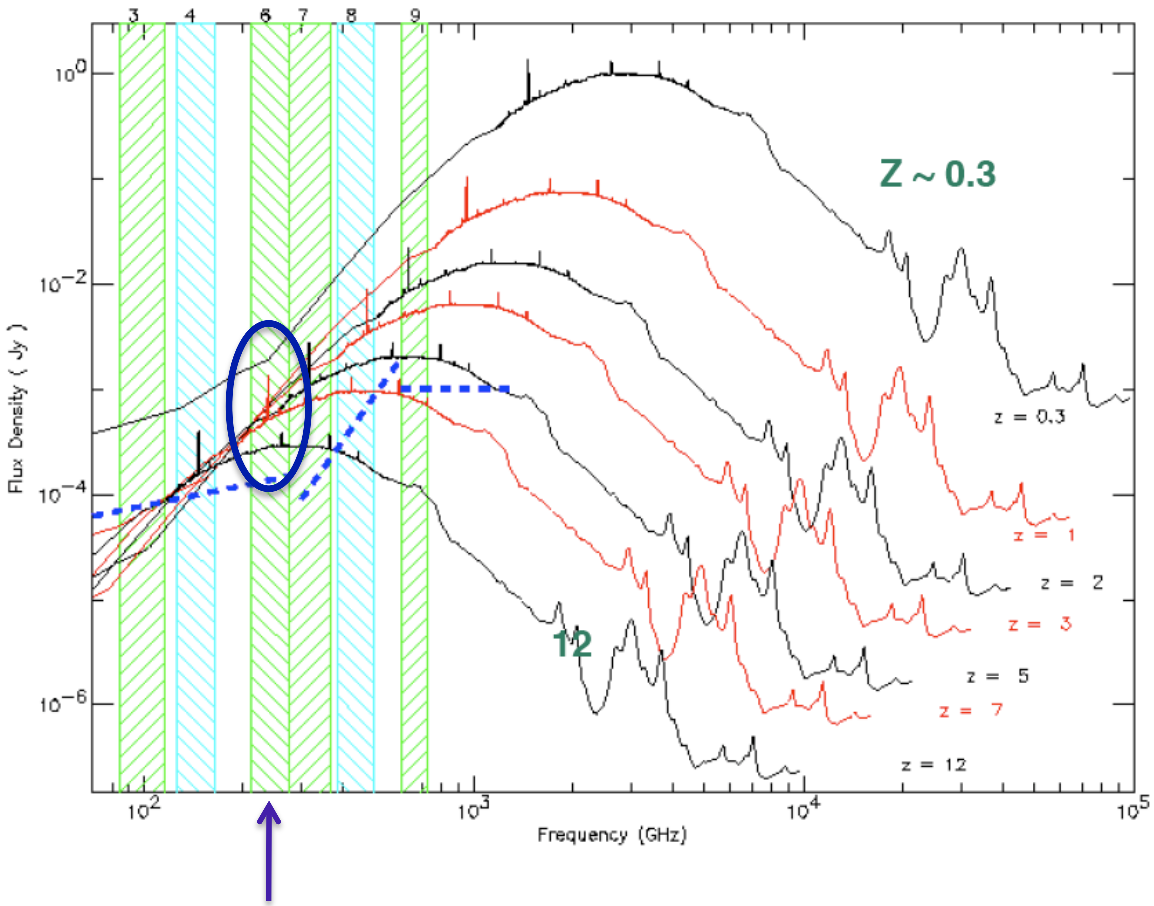
Atacama Large Millimeter/submillimeter Array
Expanded Very Large Array
Robert C. Byrd Green Bank Telescope
Very Long Baseline Array

NRAO

ALMA will map gas & star formation in galaxies across cosmic time

- free-free continuum, [CII], & radio recombination lines: extinction free tracers of star formation
- submillimeter dust emission & dust mass
- star formation history; gas enrichment history
- gas distribution & gas mass: CO, star formation efficiency
- kinematics & dynamical masses of galaxies & galaxy systems
- molecules, chemistry, & gas diagnostics: density, temperature, pressure, radiation fields, shocks, abundances (PDRs, XDRs)
- direct observations of feedback & regulation of star formation through radiation and shock effects on gas

dust emission & the negative K correction



fluxes are nearly distance-independent in the submm

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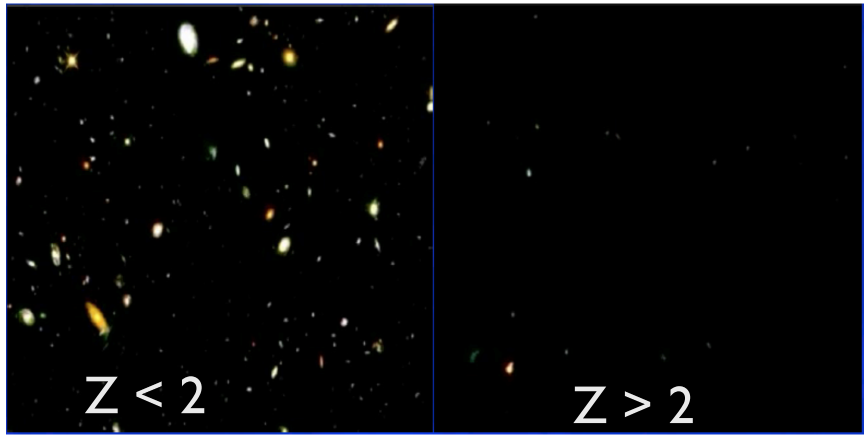
dust emission & the negative K correction

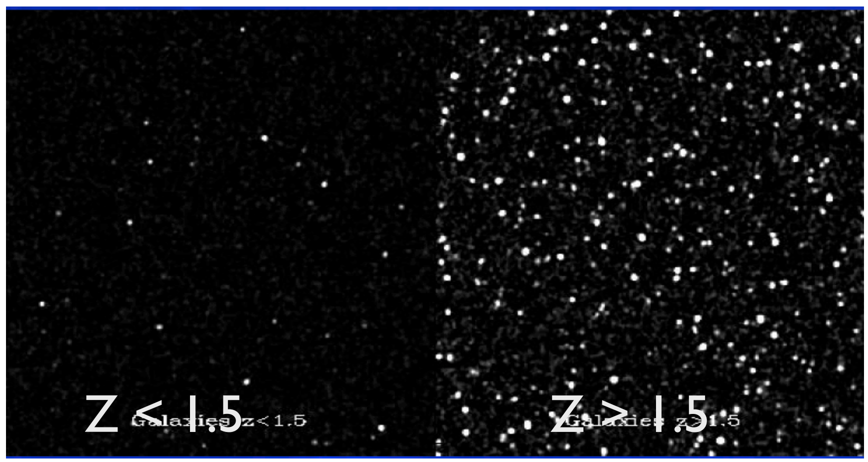
Hubble Deep Field



Lanzetta+97

simulated

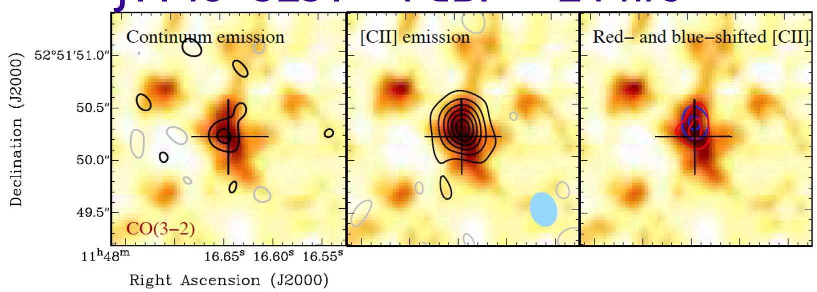
ALMA Deep Field



Wootten & Gallimore 01

CO, [CII], dust across the universe

J1148+5251 PdBI ~24 hrs



dust [CII] [CII]v

z= 6.42; t = 870 Myr

SDSS J1148+5251 QSO Walter et al. 2009

- PdBI → [CII] & dust continuum (contours)
- VLA → CO 3-2 (color), extent 2.5 kpc

M_{dyn}~5-6 x 10^{10} $M_\odot$ M_{gas} ~1 x 10^{10} $M_\odot$

[CII] → SFR ~3000 $M_\odot$/yr (rare!)

[CII] offset from dust & CO by ~600 pc

early universe star formation and gas enrichment

presence of CO suggests metallicities of 0.1 solar in significant quantities of gas at z = 6.42 → a rich SF history by 870 Myr

is this true for more "typical" galaxies of the era? SFR ~100 $M_\odot$/yr

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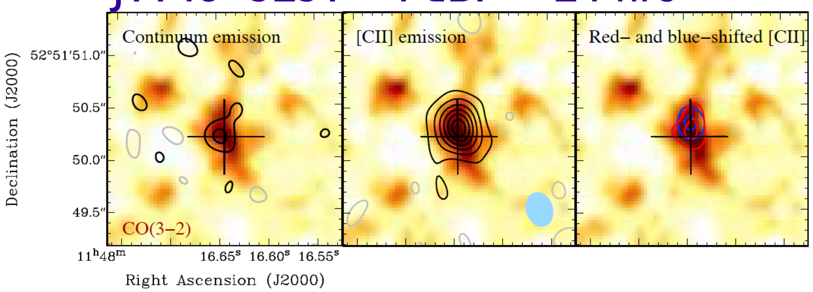

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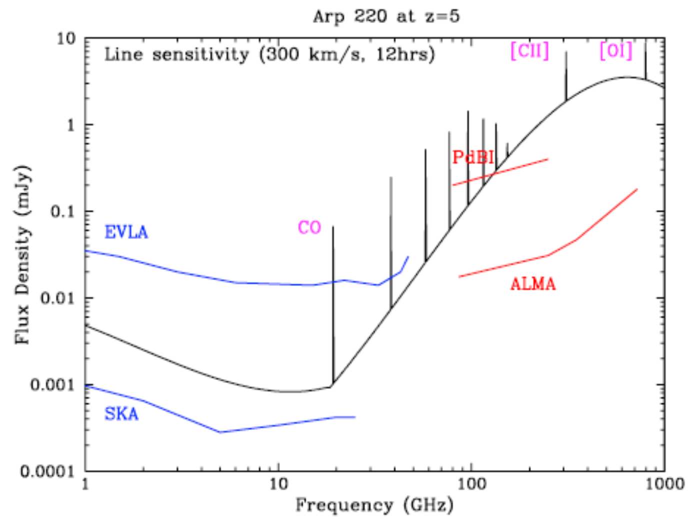


z=5; 12 hrs Carilli +07

[CII], CO, & dust in early galaxies ALMA can detect:

dust in galaxies with SFR ~100 $M_\odot$/yr at z = 5 in ~a minute

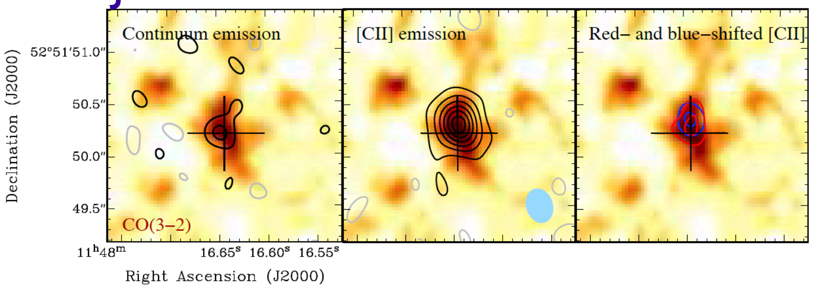
CO in galaxies with SFR ~100 $M_\odot$/yr at z = 5 in ~ a hour

CO in Milky Way-like galaxies at z=3 in ~24 hours

*with EVLA

CO, [CII], dust across the universe

J1148+5251 PdBI ~24 hrs



dust [CII] [CII]v

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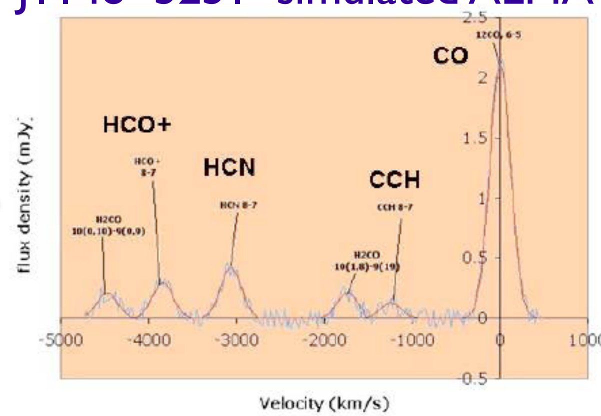
J1148+5251 simulated ALMA data



Carilli et al. 2007

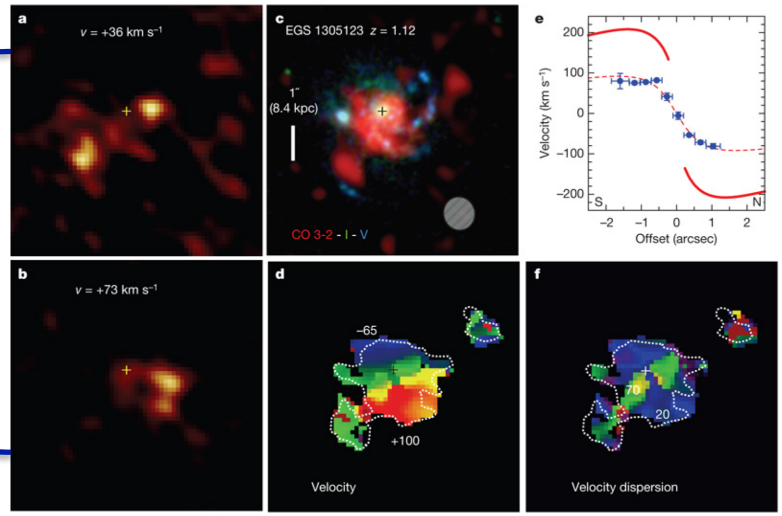
high z chemistry? J1148+5251 with ALMA in 24 hrs

CO, [CII], dust across the universe

CO maps in EGS 1305123, z = 1.12, 20 hrs on PdBI

channel maps:

9 km/s



LJ Tacconi *et al. Nature* **463**, 781-784 (2010) doi:10.1038/nature08773

10^9 $M_\odot$ clumps of gas, 1-2 kpc across

SFR ~ 100 $M_\odot$/yr

total M_{dyn} = 2 x 10^{11} $M_\odot$

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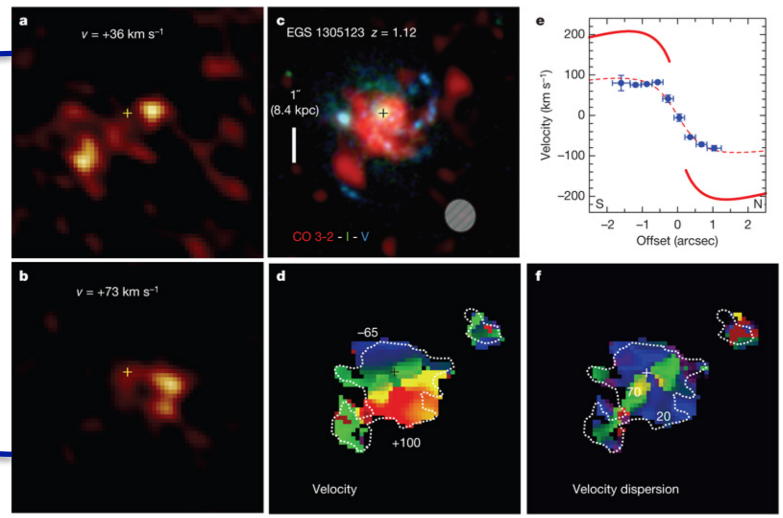

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full ALMA can do this type of map in ~ an hour or two

finely (up to 500 pc) resolved gas kinematics & mass distributions in CO, [CII]

ability to see the development of galactic structure over Gyr

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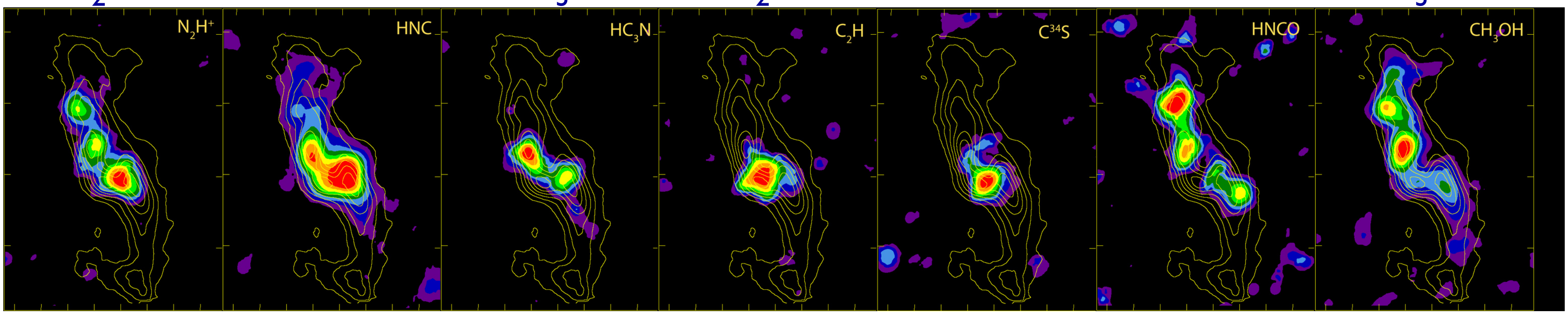
extragalactic chemistry

IC 342 central 300 pc λ=3mm

N_2H^+ HNC HC_3N C_2H $C^{34}S$ HNCO CH_3OH



CO is not the whole story! molecular abundances are sensitive tracers of galactic environment

OVRO, Meier & Turner 2005

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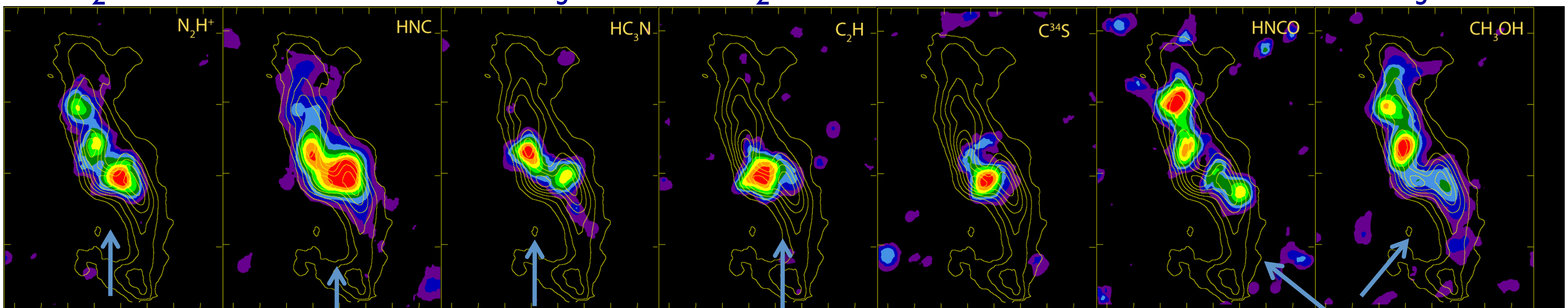

quiescent gas

star formation tracer

dense gas

PDR molecule:
high radiation fields

grain chemistry; tracers
of gentle shocks?

OVRO, Meier & Turner 2005

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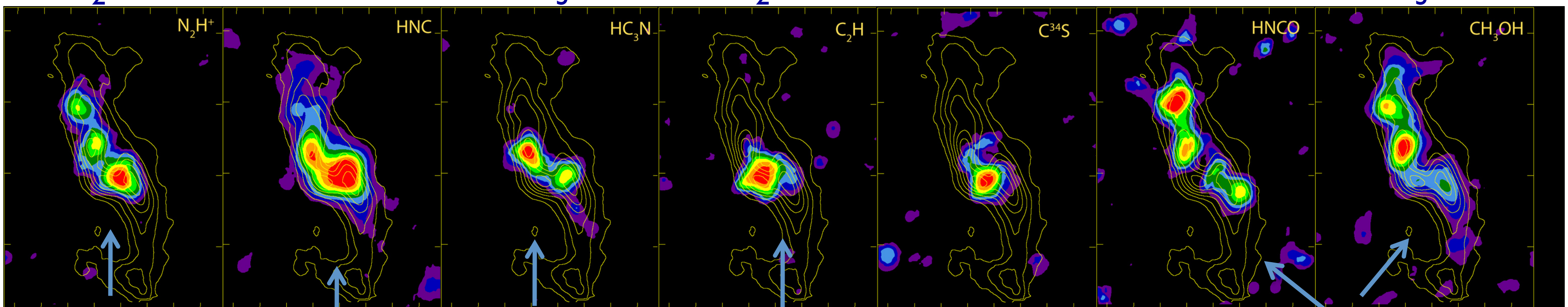

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star formation tracer

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PDR molecule:
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spatial correlations suggest groupings:

quiescent gas tracers (CO, ^{13}CO, $C^{18}O$, N_2H^+)

radiation field tracers (HCN, HNC, C_2H, CN)

grain chemistry tracers, shocks? (HNCO, CH_3OH)

OVRO, Meier & Turner 2005

extragalactic chemistry

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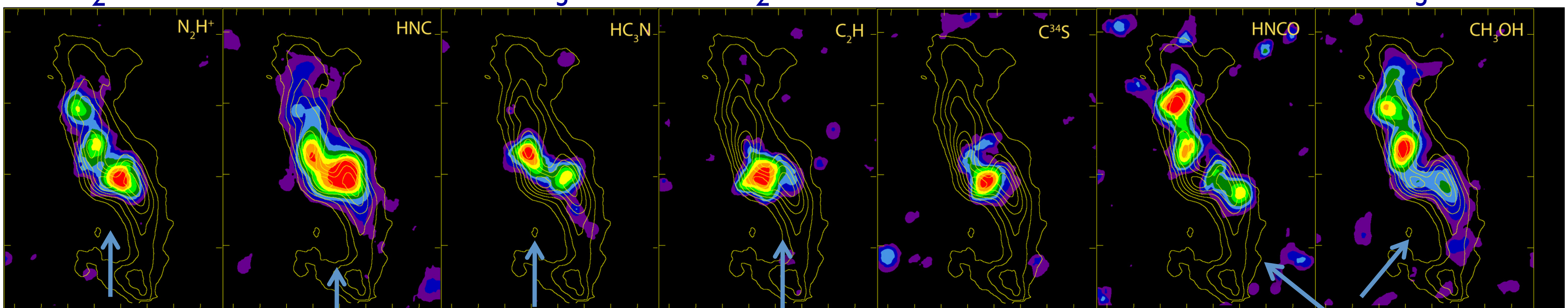

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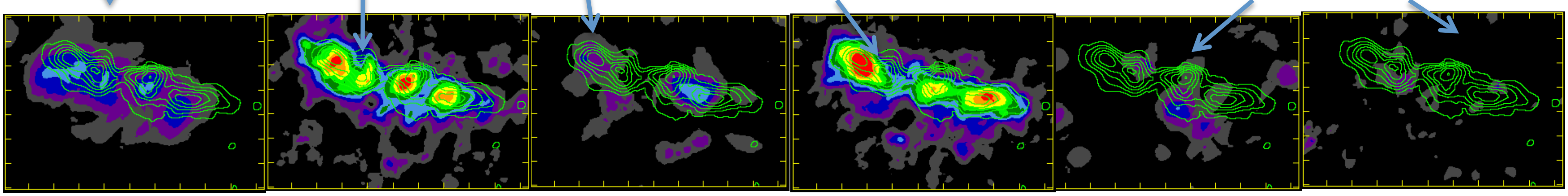


M82 is a "giant PDR"

OVRO, BIMA Meier & Turner 2005, 2010

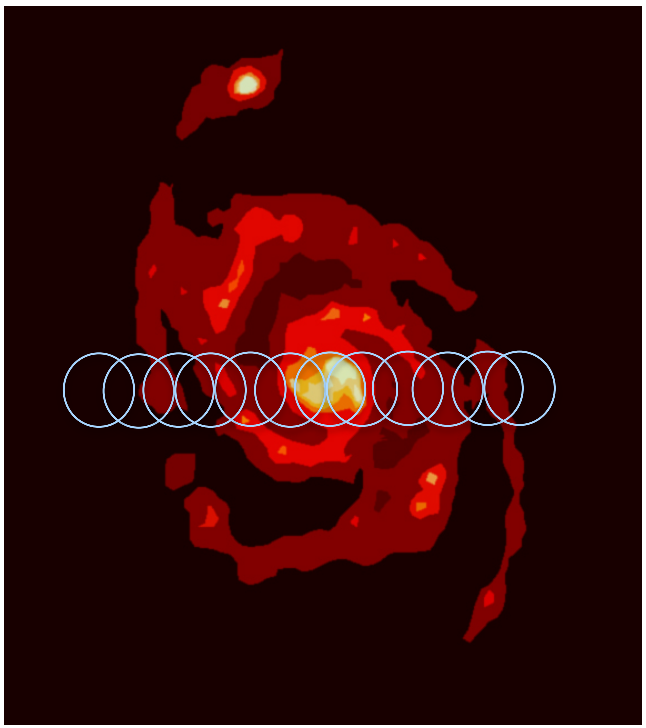
Garcia-Burillo +02, Mauersberger & Henkel 1991, Henkel et al. 1991

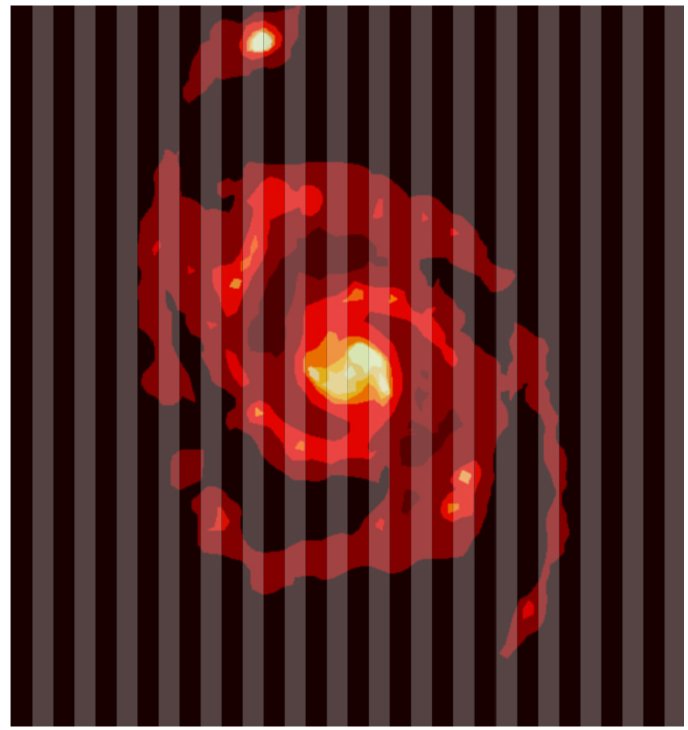
ALMA Early Science: sensitivity

object	*source*	*t*	*ALMA*	*ESALMA*
"W49"	free-free 3mm continuum	1 hr	12 Mpc	20 Mpc
"Milky Way"	dust continuum	1 hr	z=1.5	z=2.5
"Milky Way"	CO	24 hrs	—	z=3
"Arp 220"	CO	12 hrs	z=5	z=8
"Arp 220"	HCN	24 hrs?	—	z=3

ALMA Early Science vs full ALMA: imaging

CO in Messier objects best done with full ALMA and ACA

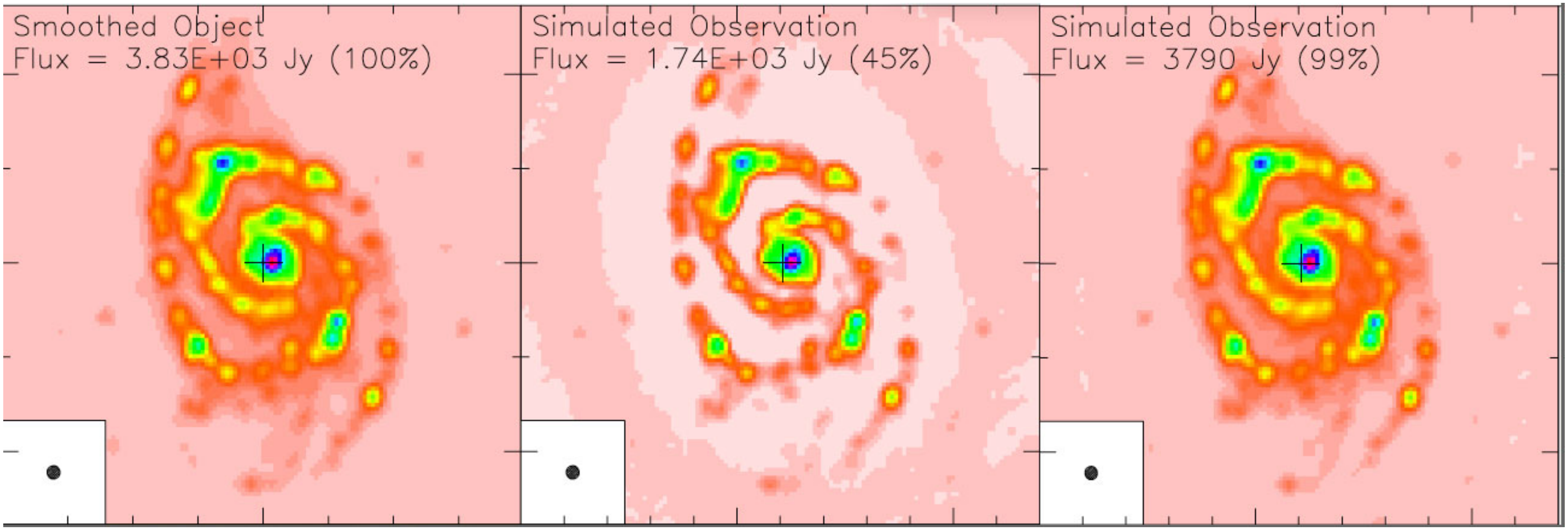




M51 Herschel PACS 70+160 microns combined (ESA, PACS team, + JT Photoshop)

ALMA Early Science vs full ALMA: imaging

CO in Messier objects best done with full ALMA and ACA



model　　12m only　　12m + ACA

Pety, Gueth, & Guilloteau 2001

ALMA does galaxies

expect breakthrough science starting with early ALMA in:

- gas and star formation
- structure & star formation history of high & intermediate z galaxies
- what are submillimeter galaxies
- extragalactic chemistry & direct diagnostics of feedback

full ALMA will give high resolution & sensitivity for

- pc-scale gas structures in starburst galaxies and AGN
- "normal" galaxies in dust, and up to z~3 in CO
- chemistry at z=3 and beyond

imaging of extended obejcts will come with full ALMA, including the capability of mapping large nearby galaxies with ACA

NRAO