Galaxies: Near & Far with CCAT, ALMA, & EVLA (& Spitzer)

Mission Impossible

Kartik Sheth

NRAO – Charlottesville

NAASC CSV Liaison / ALMA

w/ thanks to Schinnerer, Koda, Leroy, Aravena, Munoz-Mateos, Kim

Atacama Large Millimeter/submillimeter Array

Expanded Very Large Array

Robert C. Byrd Green Bank Telescope

Very Long Baseline Array

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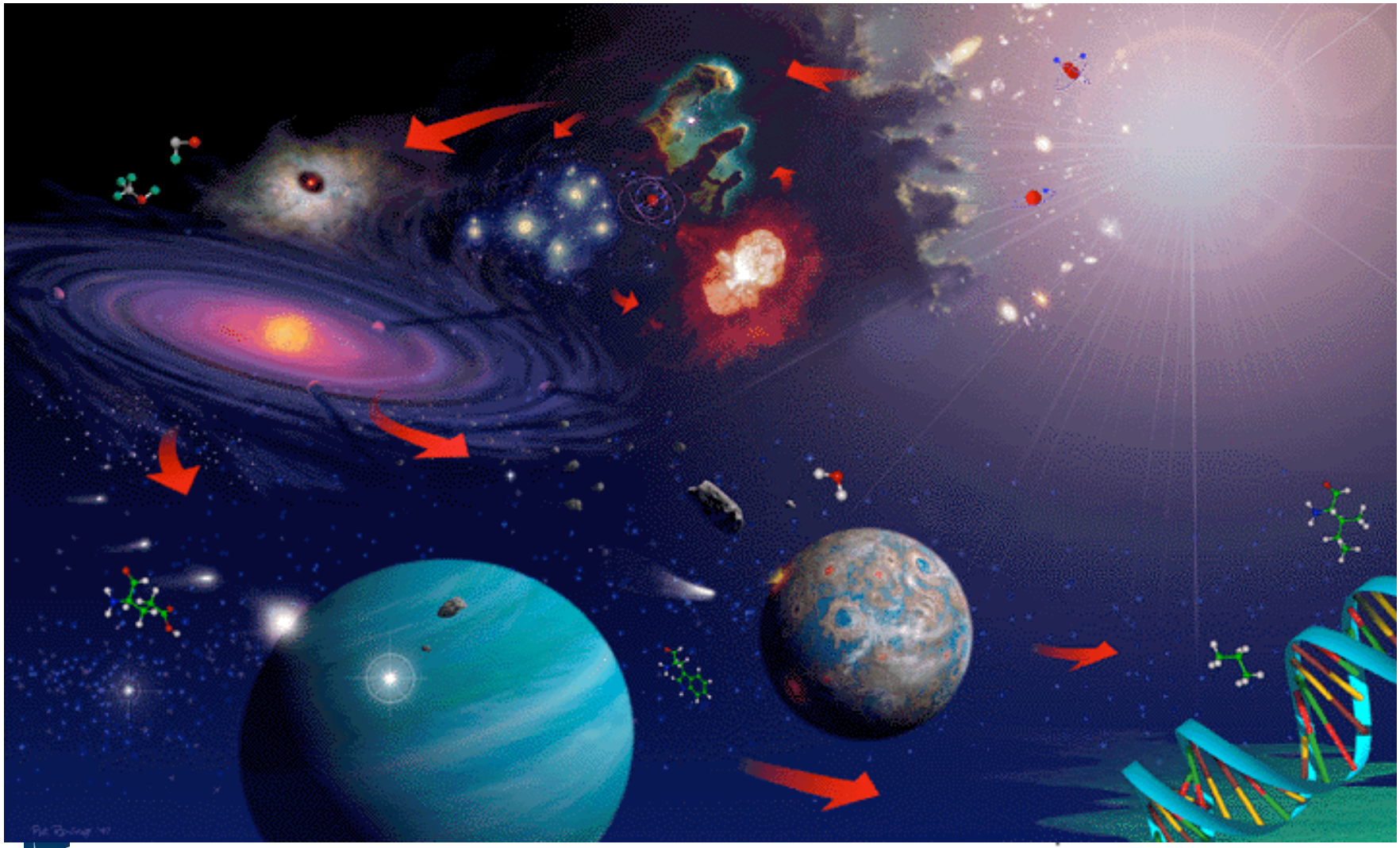
How do Galaxies Form?

ALMA



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Basic Questions (cm/mm/submm)

- What is the distribution of molecular gas and dust?
- What are the gas kinematics?
- How do stars form from their molecular nurseries?
- What is the relation between the ISM, star formation, AGN, feedback?

Recent Millimeter / Submm Studies

Interferometric Surveys:

- ('98-02) SONG (Regan, Helfer, Thornley, KS, Wong, Blitz, Vogel, Bock)
  - BIMA survey of CO (1—0) in **44** galaxies + NRAO 12m OTF Maps / Total Power
  - Central 3 arcminutes @ 3--6" & 10 km/s

- ('97-'99) MAIN (Scoville, Sakamoto, Baker, Jogee)
  - OVRO survey of central arcminute in **20** galaxies

- ('08-..) CARMA + Nobeyama Survey of SINGS Galaxies (Koda et al.)
  - CO (1-0) in **17** galaxies

- ('08-..) CARMA STING (Bolatto, et al. – see previous talk)
  - CO (1-0) in **27** nearby galaxies

Recent Millimeter / Submm Studies

Interferometric Surveys:

- SMA Survey of **14** LIRGs and ULIRGs (Wilson et al.)
  - ^{13}CO (2-1), CO(2-1), HCO+ (4-3), dust @ 1.3mm, 0.88mm

Single – Dish Surveys:

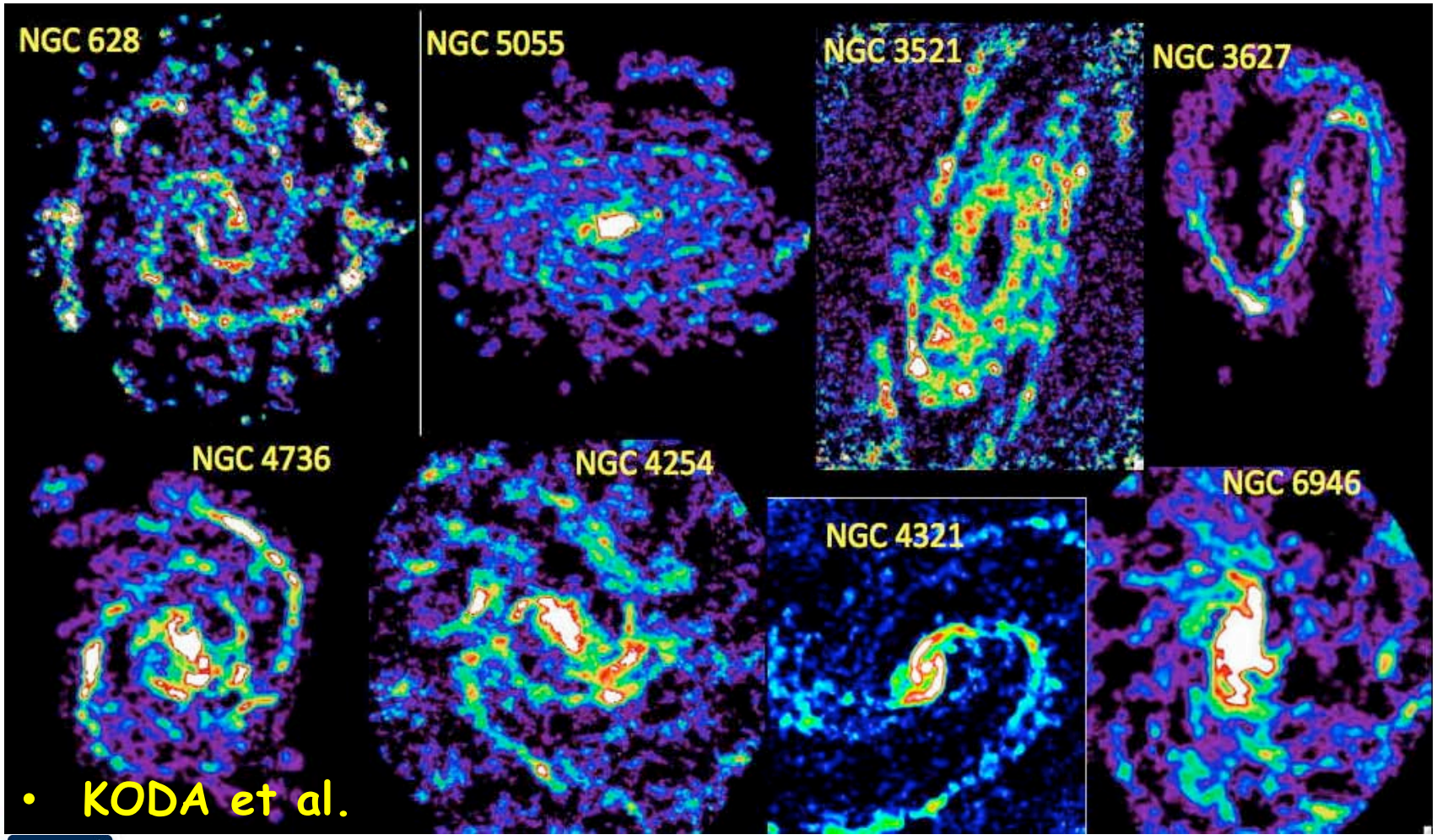
- ('09-..) HERACLES (Leroy, Walter, Bigiel, Usero, Sandstrom, Weiss, Brinks, de Blok, Kennicutt, Roussel, Kramer, Schuster)
  - IRAM 30m HERA survey of CO (2-1) in **18** galaxies
  - 13" resolution maps over D_{25}

- JCMT Nearby Galaxies Legacy Survey (Wilson , Israel, Sarjeant, Warren, Bendo + > 35 co-Is)
  - CO (3-2) in ~**150** galaxies using HARP (12" resolution)

What have we learned so far?

ALMA

Greater Variety in Molecular Gas Distribution than in Stellar Disk!



- KODA et al.

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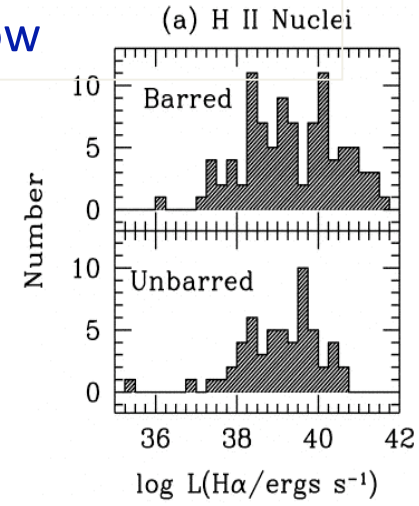
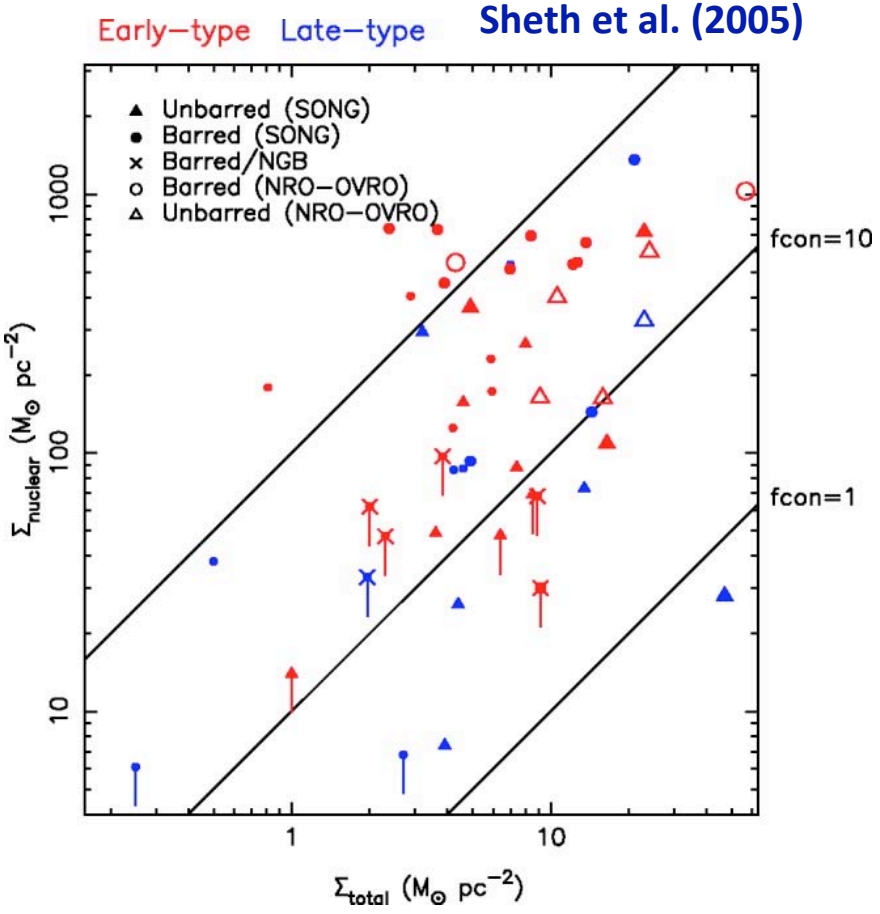
CARMA Studies are starting to push to GMC scales / cloud formation

Bars Feeding Gas to Nuclei

- Bars have higher central concentrations of molecular gas (Sheth et al. 2005; Sakamoto et al. 1999)
- Difference pronounced in early type bars
- Late type -☒-> Early types via bar driven gas inflow



(Ho et al. 1997)



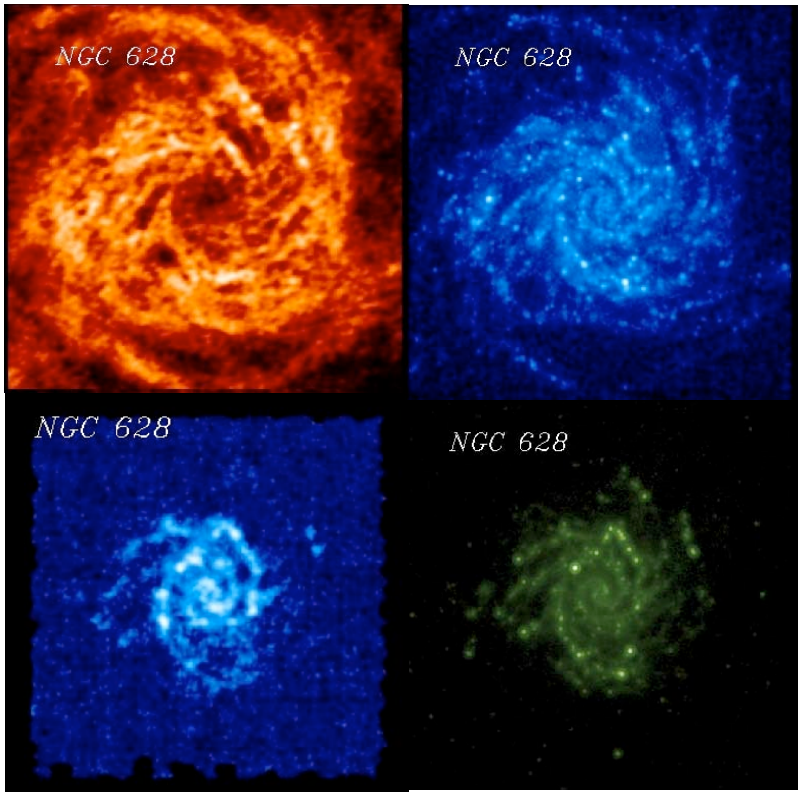
Sheth et al. (2005)

Molecular Gas and Star Formation

- Multi-λ database to understand star formation in galaxies:

THINGS
VLA Large Program
WALTER+ '08

HERACLES
IRAM Large Program
LEROY+ '09



GALEX
Nearby Galaxies Survey
GIL DE PAZ+ '07

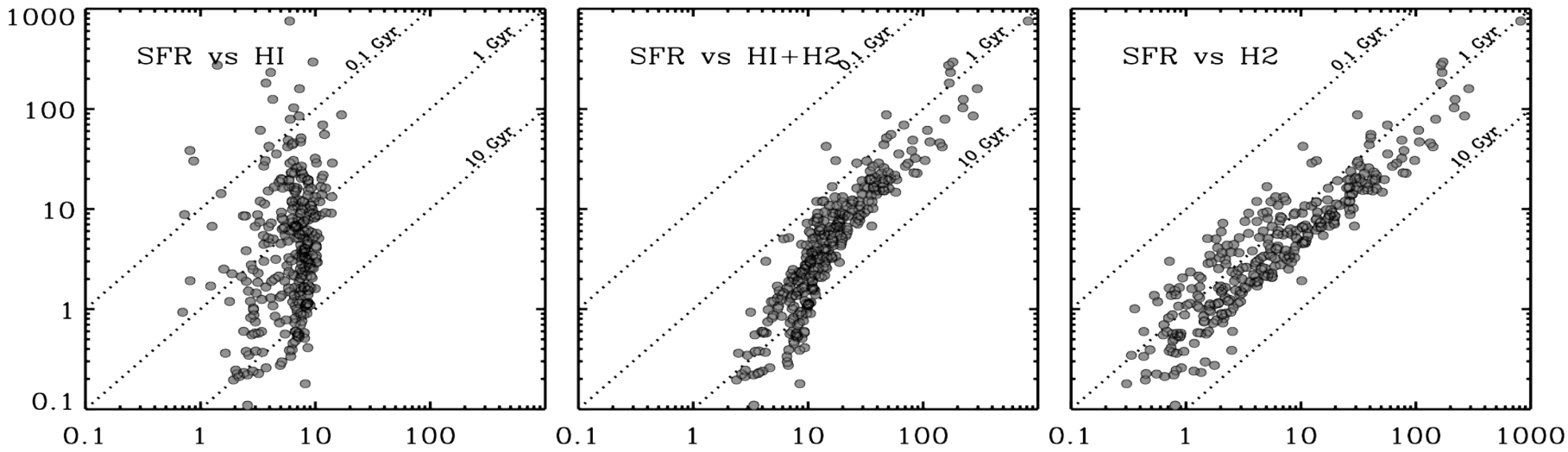
SINGS + LVL
Spitzer Legacy Surveys
KENNICUTT+ '03, DALE+ '0

Currently: data on HI, H_2, star formation, stars, kinematics, dust for **47** galaxies.

Courtesy A. Leroy

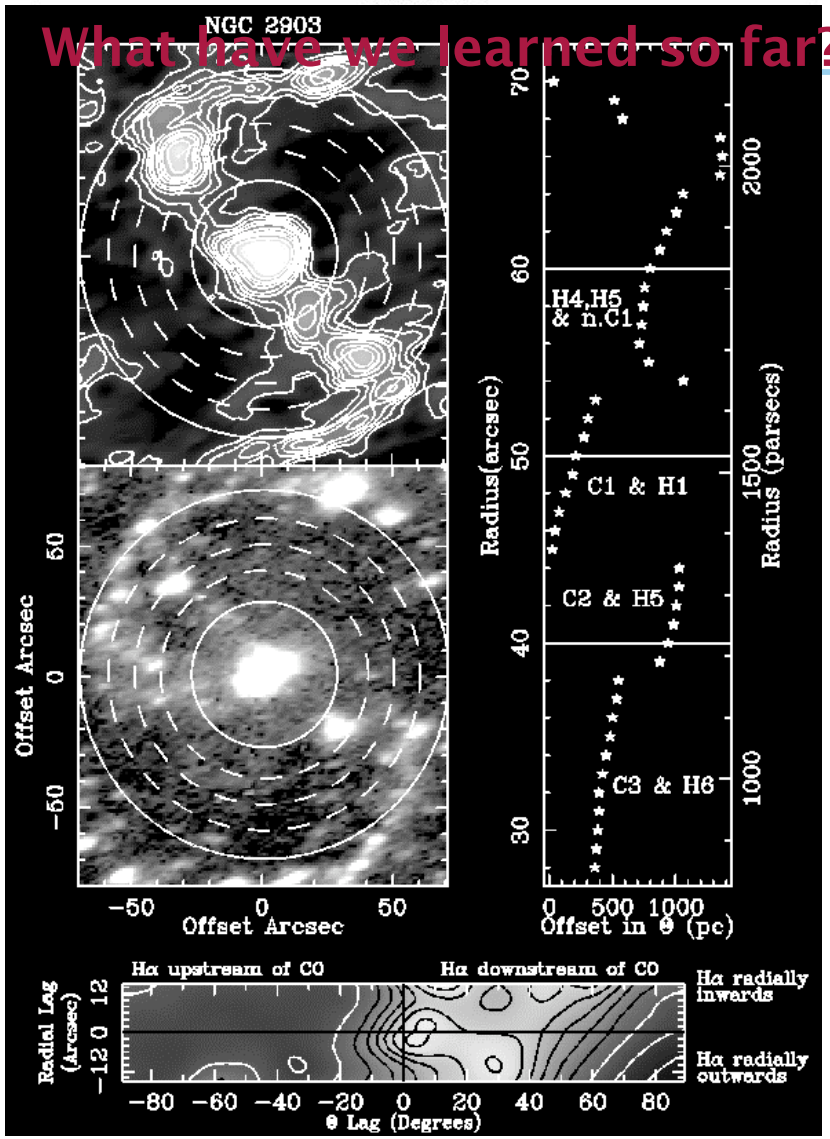
HI, H_2 and SFR Scaling

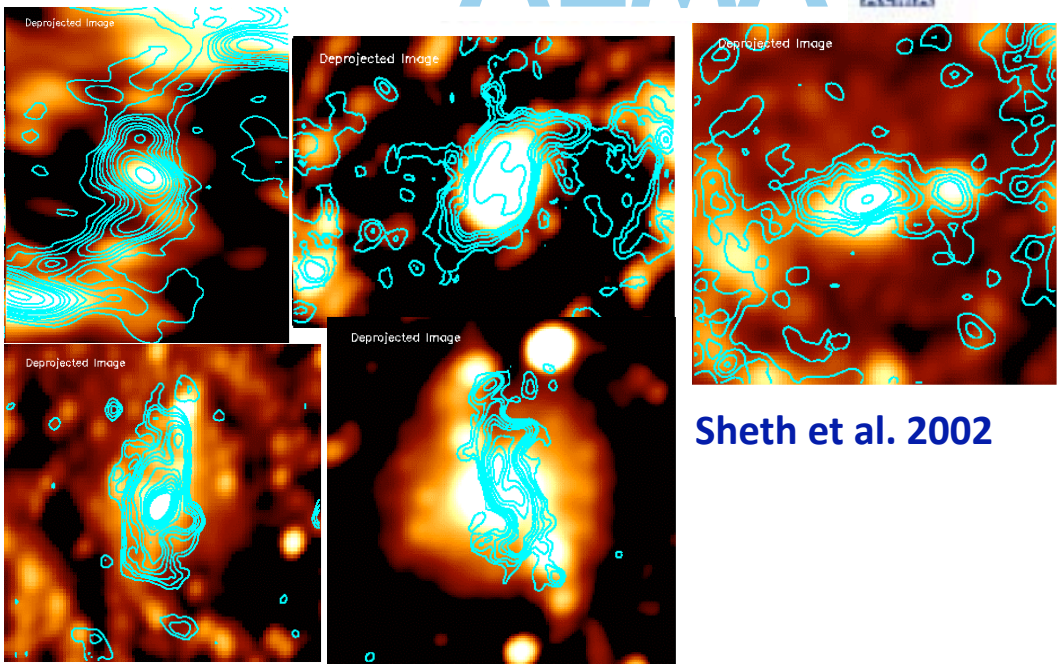
SCHRUBA+ '10



- SFR-H_2 correlation extends to where HI > H_2
- Correlation with total gas depends on regime ("threshold").

What have we learned so far?



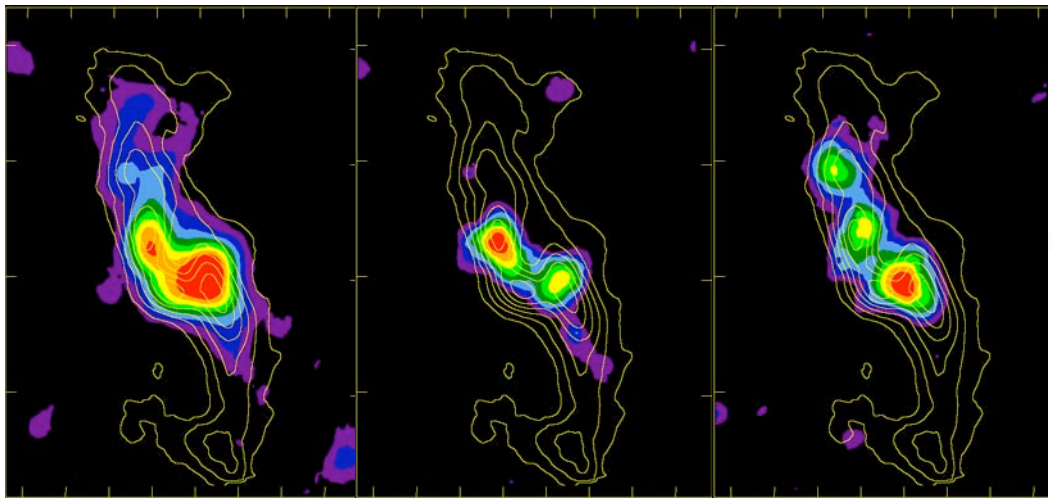


Sheth et al. 2002

- 2-phase molecular gas medium (Sheth et al. 02)
  - Ha offset towards the leading side
  - Kinematics consistent w/ hydrodynamic model
  - Variations in the $^{12}CO/^{13}CO$ line ratios
  - Molecular clouds on leading side

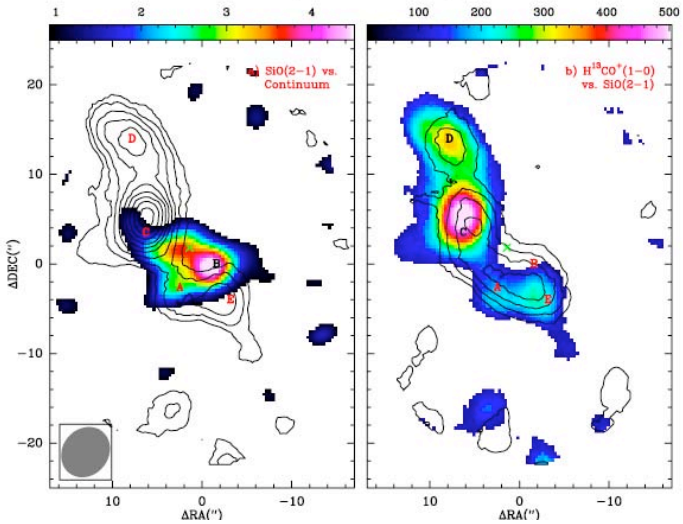
Gas Chemistry

HNC(1-0) >2[-9] HC_3N(10-9) 2[-9] N_2H^+(1-0) 5[-10]



Meier & Turner 2005

SiO (2-1) $H^{13}CO+$ (1-0)

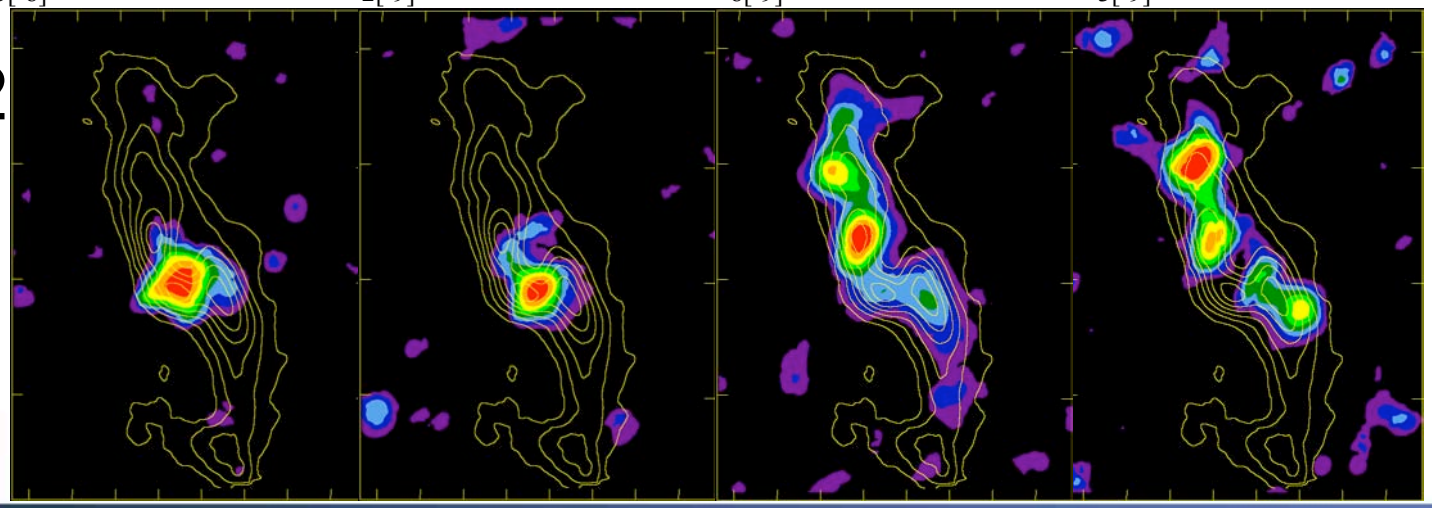


Usero et al. 2006

IC 342

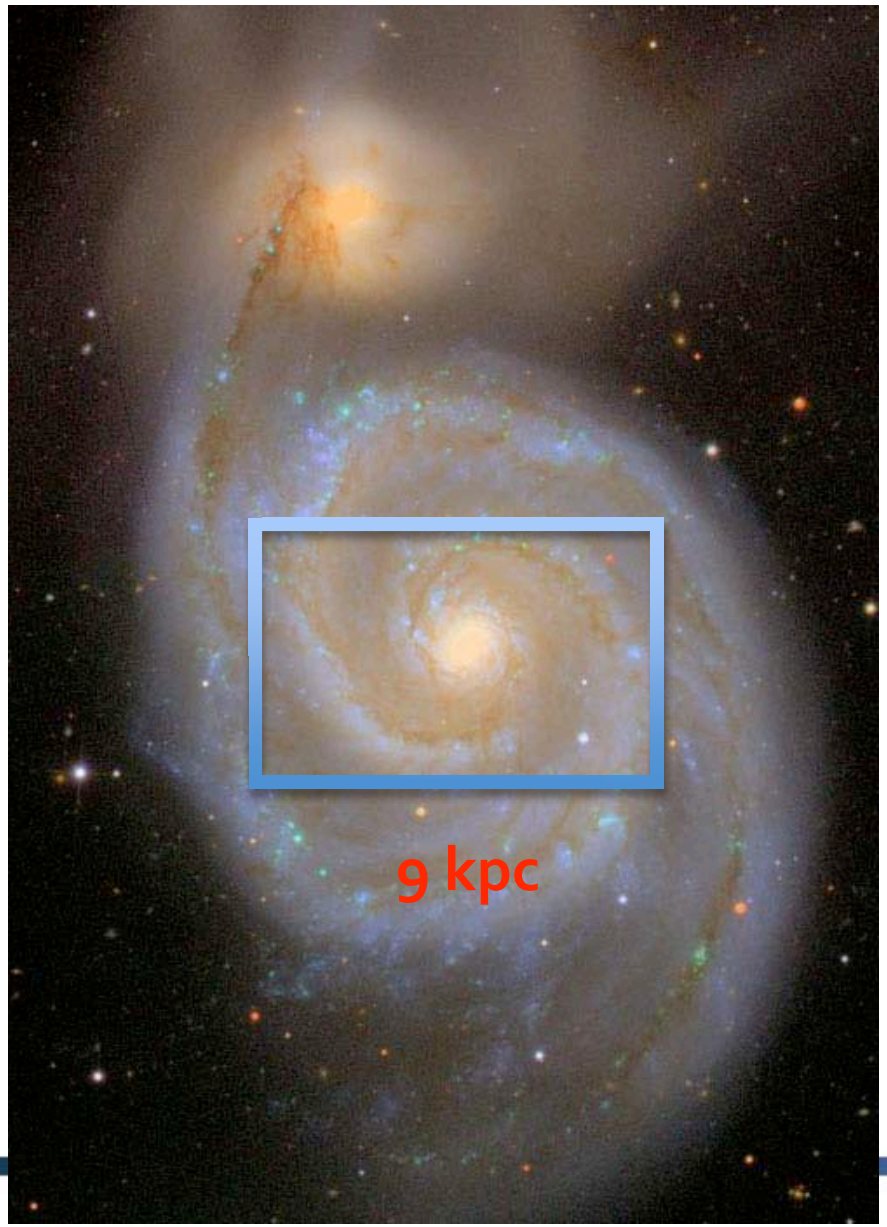
contours: ^{13}CO

3[-8] 2[-9] 8[-9] 3[-9]



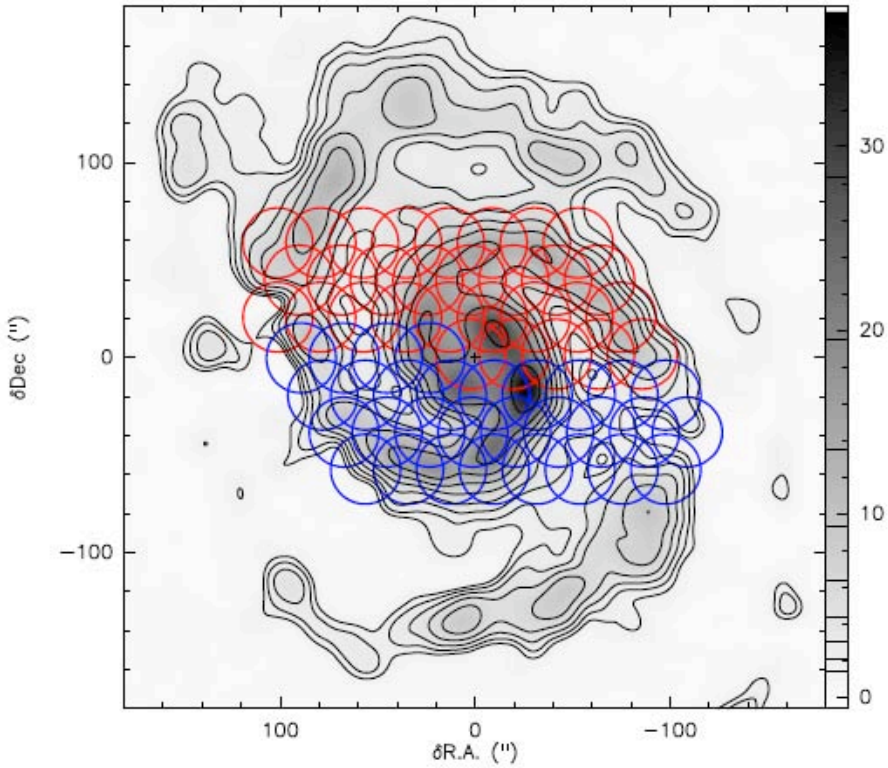
C_2H(1-0;3/2-1/2) $C^{34}S$(2-1) $CH_3OH(2_k\text{-}1_k)$ $HNCO(4_{04}\text{-}3_{03})$

PAWS – PdBI Arcsecond Whirlpool Survey



ALMA

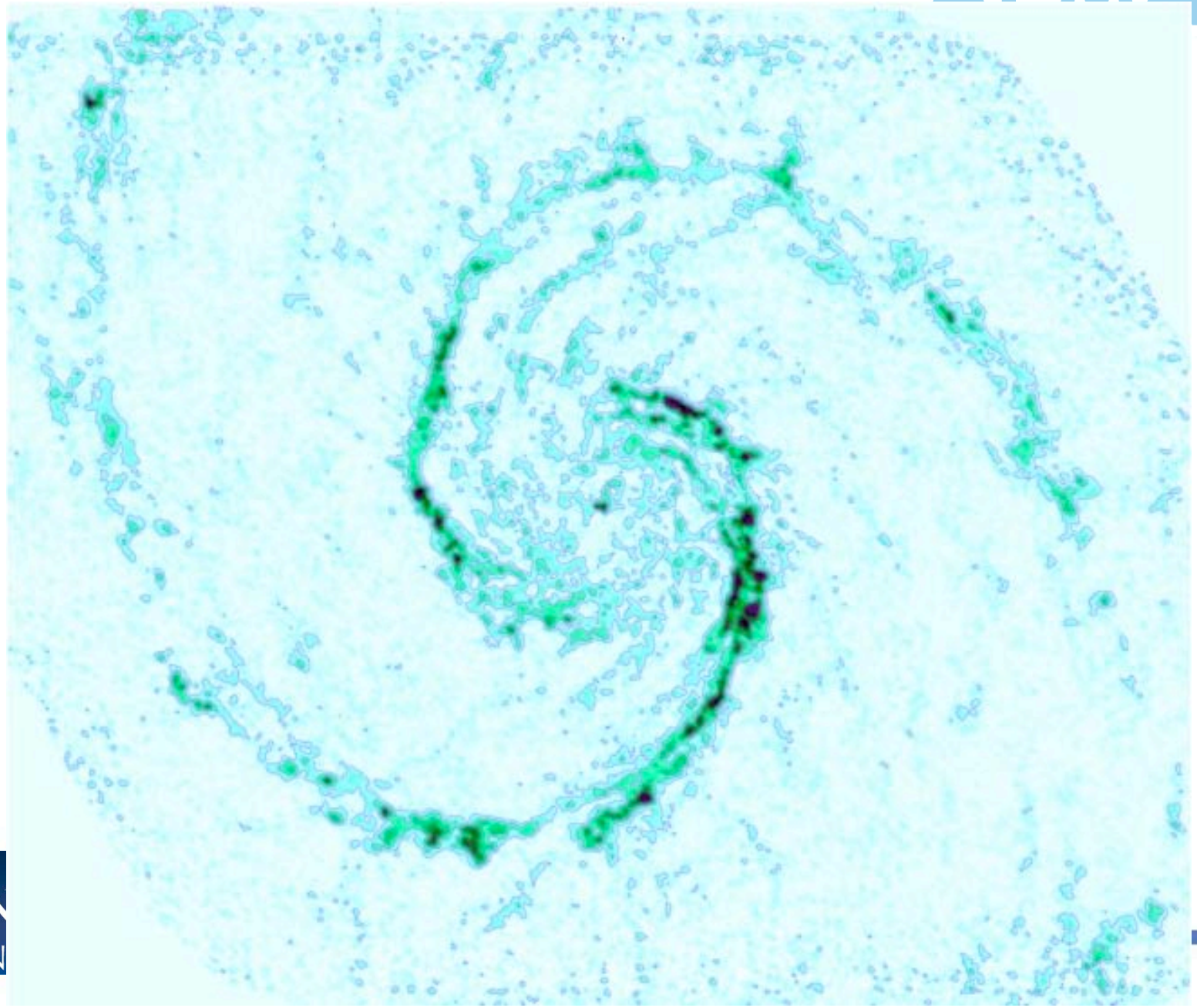
PI Schinnerer,
data acquisitions finished
in June2010

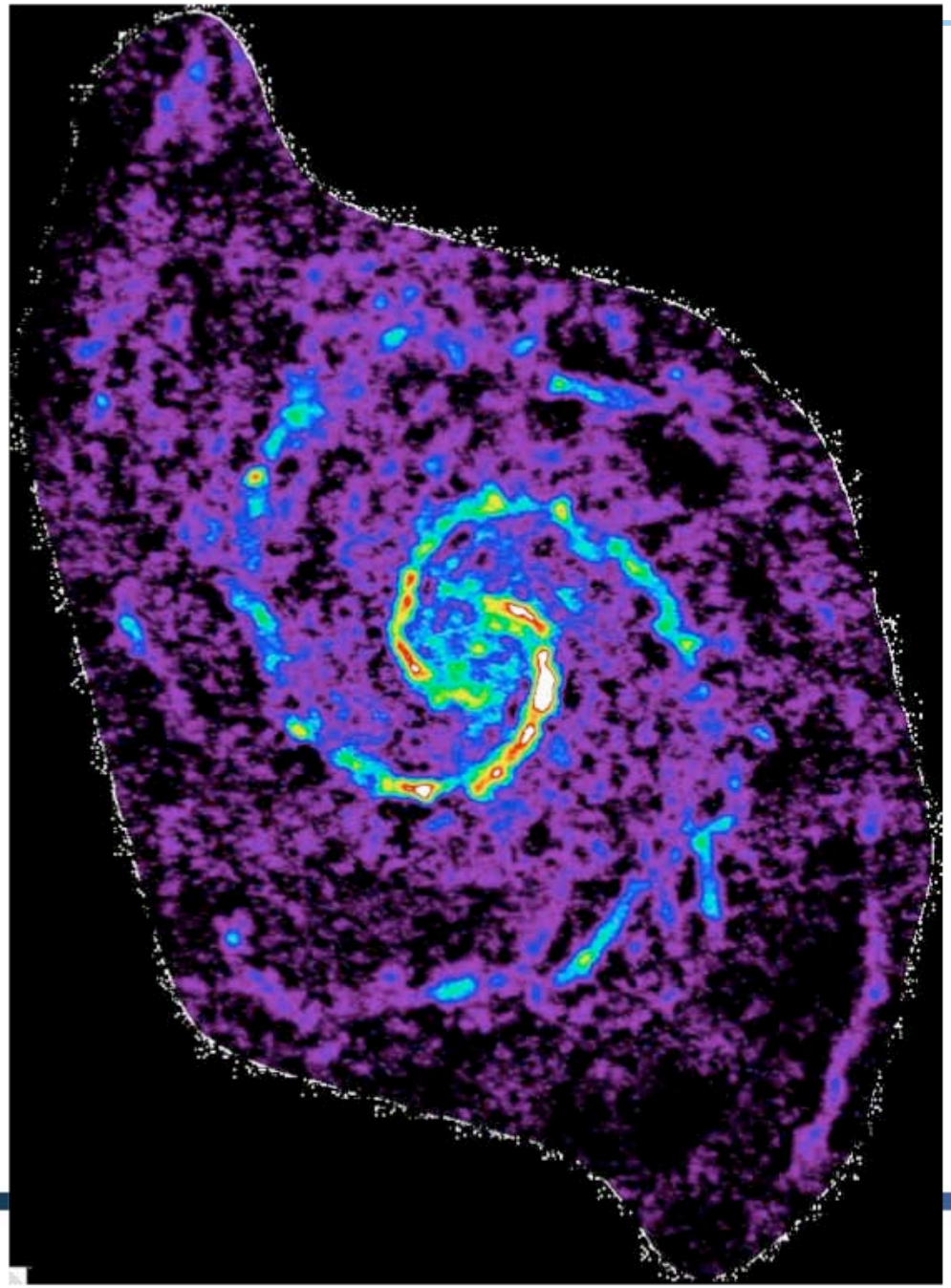


5σ = 1 GMC

1.2×10^5 M_{sun} at 45 pc resolution

PAWS – ^{12}CO(1-0) map





ALMA

CO(1-0)
Nobeyama
+CARMA map

PI: Jin Koda,

Jennifer Donovan Meyer, Fumi Egusa, Rieko Momose, Masayuki Fukuhara, Misty La Vigne

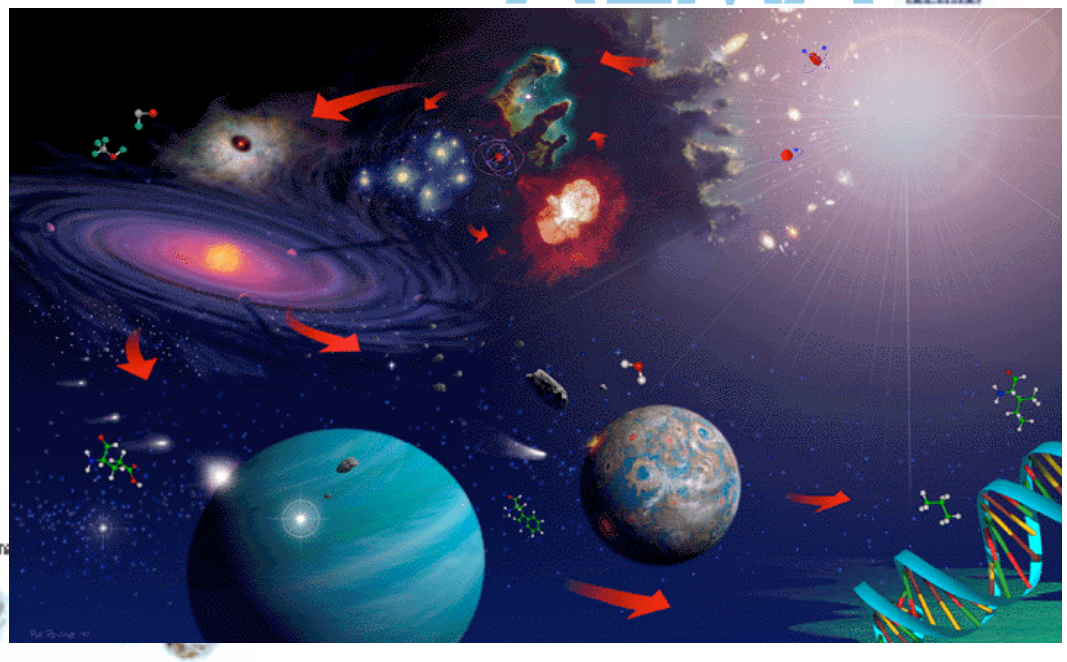
- A Rosetta Stone but we need more Rosetta Stones!

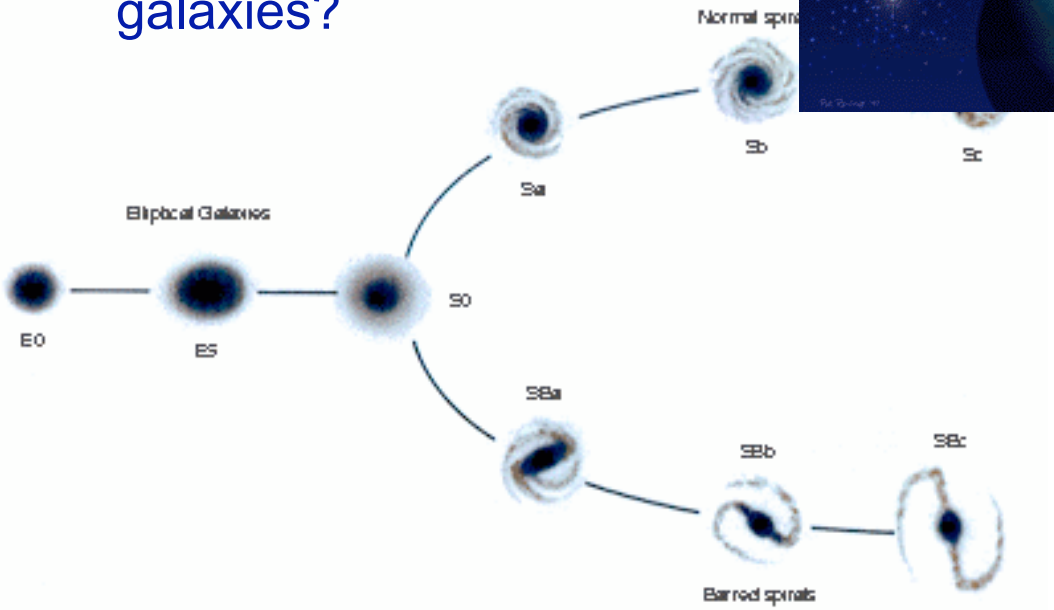
How do Galaxies Form?

ALMA

CCAT, ALMA, EVLA – gas and dust & star formation

- What about the stellar endoskeleton and evolutionary history of galaxies?





Nearby Galaxies at other wavelengths!

ALMA

The Spitzer Survey of Stellar Structure in Galaxies (S^4G)

29 original co-Is (now > 45 members)

Sheth et al. 2010

Representative sample of spiral, elliptical and dwarf galaxies
Galaxies with

$v_{rad} < 3000$ km/s (d < 40 Mpc)
$m_B < 15.5$,
$D_{25} > 1.0'$
$|b| > 30^\circ$

2,331 galaxies (1,733 new targets) **@ 3.6μm and 4.5μm**
Mosaicked or mapped to 1.5 x D_{25} w/ 240s per pixel ->

Image all galaxies to $\Sigma_* << 1\ M_\odot\ pc^{-2}m$

637.2 hrs (1/2 of the data are taken so far)

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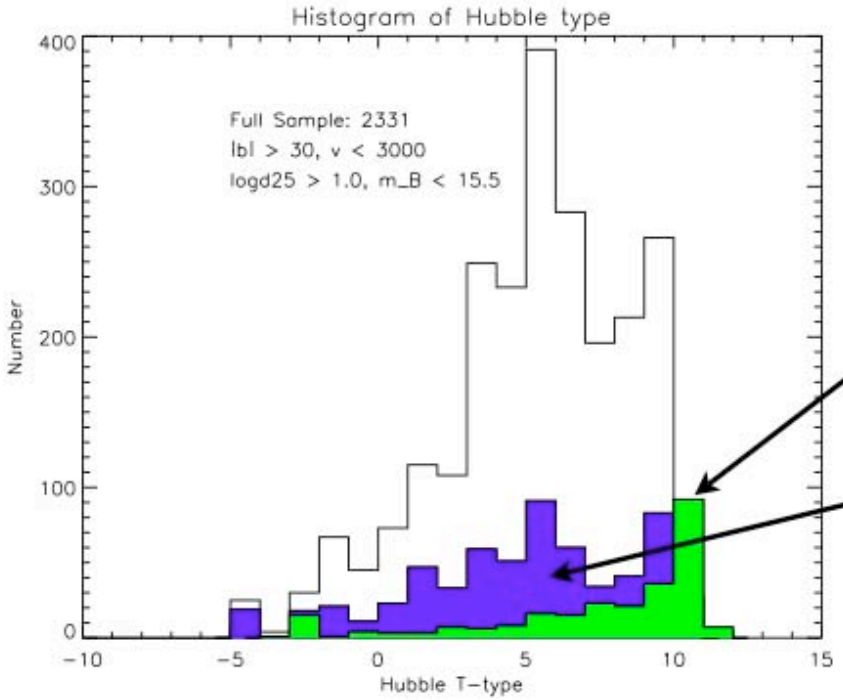
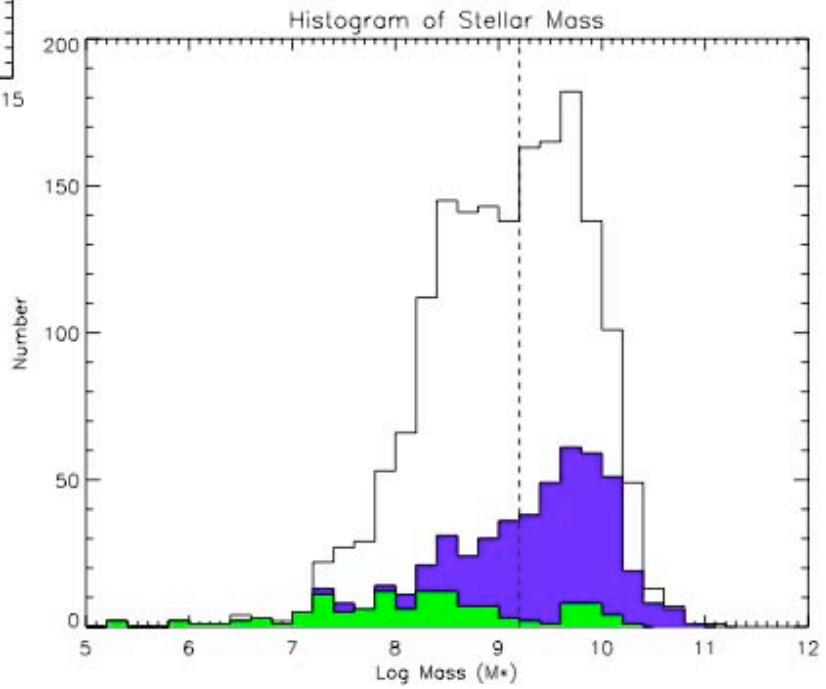
Create the ultimate survey of the distribution of stellar structures, their masses and properties in the nearby Universe.



Local Galaxy Volume (3 Mpc) survey (258 galaxies)

SINGS + GO + GTO (339 galaxies)



★ S^{4}G is needed to explore the full mass and T-type space.

Sheth et al. 2010

Science Goals for the S^{4}G Legacy Survey

Sheth et al. 2010; Buta et al. 2010

- Formation of disks, bulges, bars, rings
- Outer disk structures, debris, tidal tails,
- Thick vs. thin disks (over 800 edge-on disks)
- Detailed structure of bulges
- **Structural properties of each component**
- **A mass and structure inventory of the Local Universe (~ 2014)!**
- Old disks in dwarfs (87 DDOs)
- Merger history / evolution history
- Tully-Fisher & FP in the MIR

We need an equally large & homogenous database with CCAT, ALMA, EVLA!

CCAT Wish List: (~2x 1000 hr proposals):

CCAT ~ 7x resolution of Herschel, 3—4 times more sensitive?

- ~1000 galaxies fully imaged (to > 1.5 D_{25}) at all submm bands on scales of ~100 pc
  - Dust distribution across a galaxy
  - Outer disks & cold dust, gas/dust distribution, heating and cooling budget of the ISM
  - Dust / submm emission and stellar structure (Benson talk)

- ***CCAT (SW-CAM)*** will ideal for this
  - 1 hr /galaxy? (all but 200 μm band)

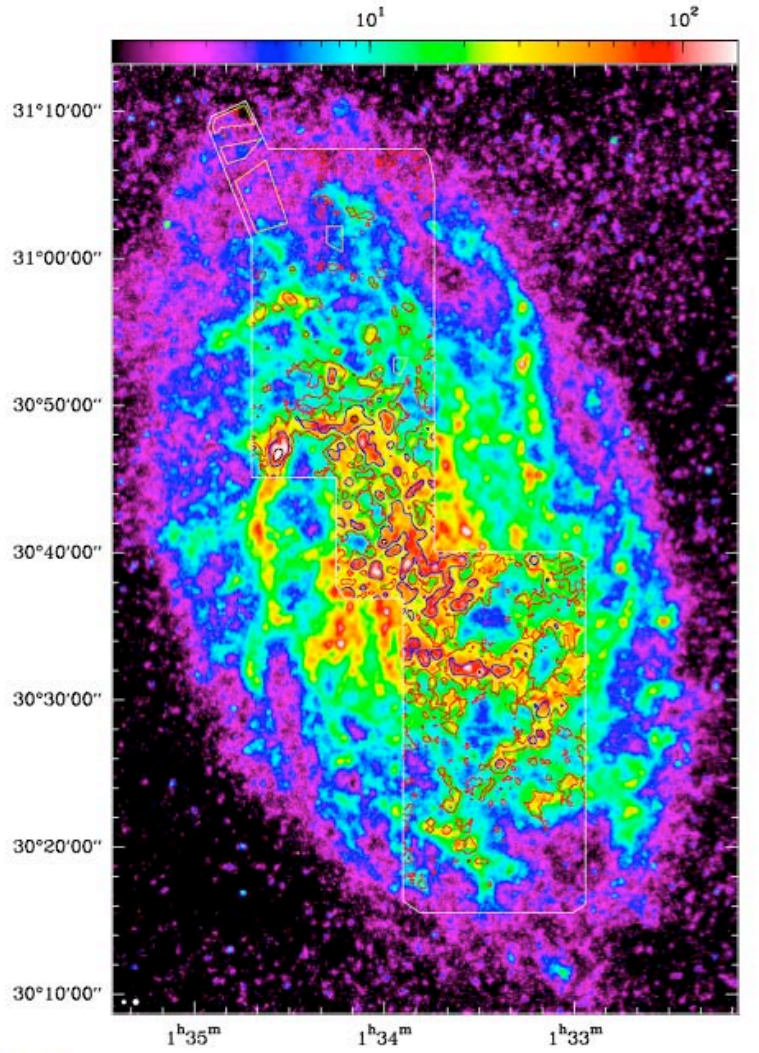


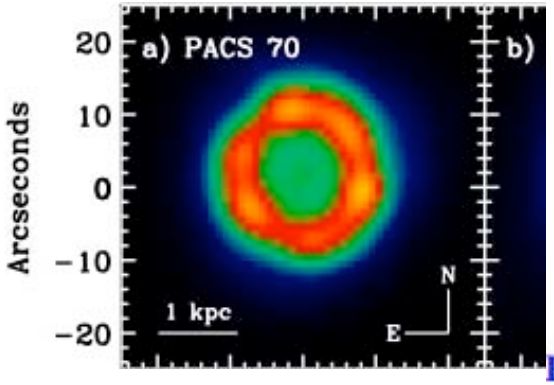
Fig. 3. SPIRE 250 μm emission with the IRAM CO(2–1) emission at 25″ resolution superposed as contours and with the polygons to the up-

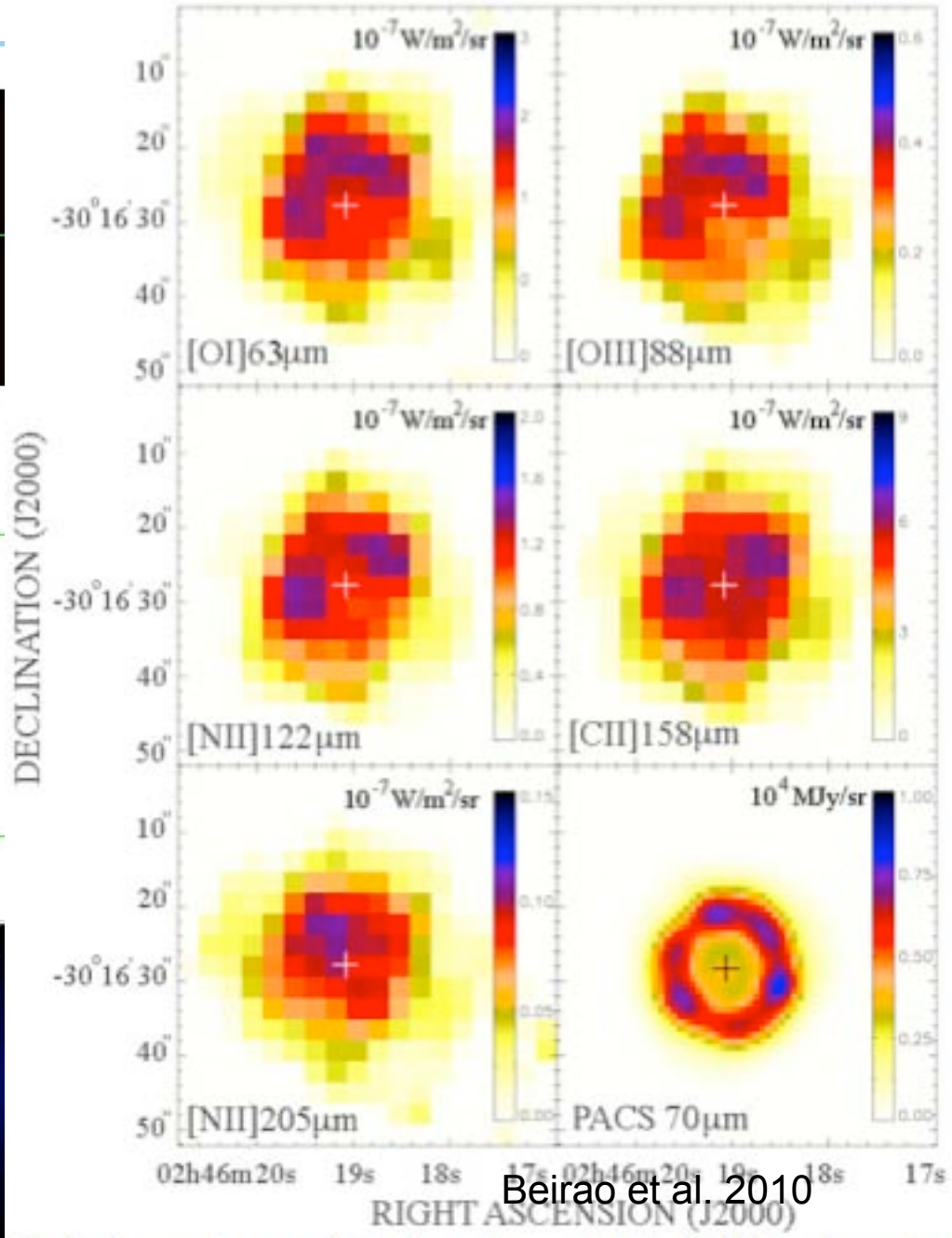
CCAT Wish List: (~2x 1000 hr proposals):

- ~ few 100 galaxies in submm line emission @ high resolution (e.g., CII, NII, high-J CO lines)
  - Gas distribution / excitation / kinematics / chemistry as a function of galaxy host properties!

- Need long-slit, array or FP to resolve and map galaxies (MOS – Jonas overview)

Sandstrom et al. 2010





Beirao et al. 2010

Fig. 2. Spectral maps of the lines observed with PACS at the nuclear

EVLA / SKA Pre-Cursors Wish List (Super THINGS):

- EVLA already in Early Science mode!
- Several thousand hour proposals with EVLA and MeerKAT could get us ~500-1000 galaxies
  - **MeerKAT MHONGOOSE (30 galaxies ultra-deep with 5000 hrs)**
    - MeerKAT first light in 2015
  - THINGS ~500 hrs for 34 galaxies in HI / Little THINGS ~ 400 hrs for 20
  - LVHIS, WALLABY, THINGS, Little THINGS, ANGST, FIGGS, WHISP

- Line emission surveys of molecules with EVLA
  - Radio recombination lines H92a, H230a

ALMA Wish List
(KS, Koda, Regan, Schinnerer, Egusa, others welcome…):

- Early Science (CfP ~ scheduled for Dec / likely first quarter of 2011)
  - UV coverage will be limited, mosaicking unlikely
  - Cannot do a large survey of nearby galaxies nor complete disks of galaxies.

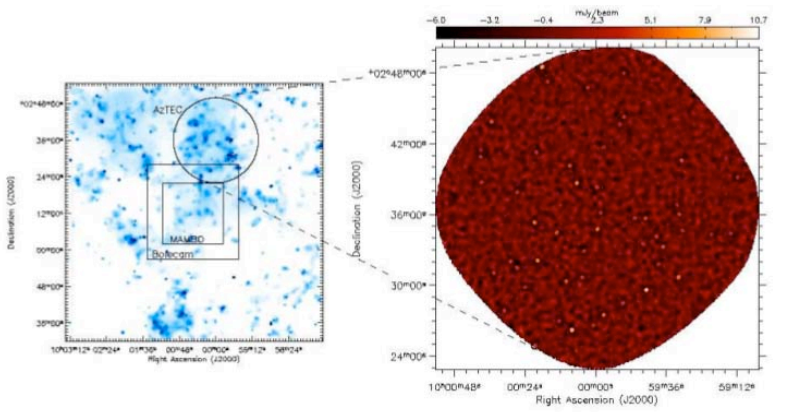
- Full Science possible to do thousands of galaxies but time required may be prohibitively large (> 1 hr per galaxy)!

Some possible topics we are considering:

- Centers vs. Disks / GMC population across all environment
- X- factor changes / quantitative analysis
- Star formation / gas efficiency / triggering and inhibition
- Resolved CO ladder -> feedback
- Gas kinematics – bars, spiral arms, bulges, AGN feeding

High-z Galaxies

CCAT will be an ideal machine for high-redshift surveys which can then be followed up with ALMA & EVLA!



COSMOS ES Survey example:

- 0.7” / Band 7 (0.8mm) of individual sources in the COSMOS field
  - Early Science ~ 50 sources in 2.6 hrs at 10 sigma (1σ = 0.5 mJy)
- 2.5” / Band 3 (3mm) blind redshift survey of typical SMGs
  - Early Science ~ 50 minutes per galaxy / FS (~ 10 minutes)
  - CCAT line identification with wideband spectrometers an ideal complement

Take-Home Points (Nearby Galaxies)

- No more than a few 100 galaxies in HI, CO, atomic & molecular lines, dust exist!
- While thousands of galaxy images exist in broad optical bands
  - Only a few hundred avail in UV, Ha, NIR, Fabry-perot or IFUs
  - Homogenous data at these wavelengths now becoming available

Summary

- Time will be ripe for an ambitious CCAT Survey of nearby galaxies
  - Good synergy with on-going large programs + possible large programs in the future (S4G, MeerKAT, ASKAP, EVLA, MEGARA, TYPHOON)
  - ALMA – ideal for detailed study of clouds / gas kinematics in selected objects.

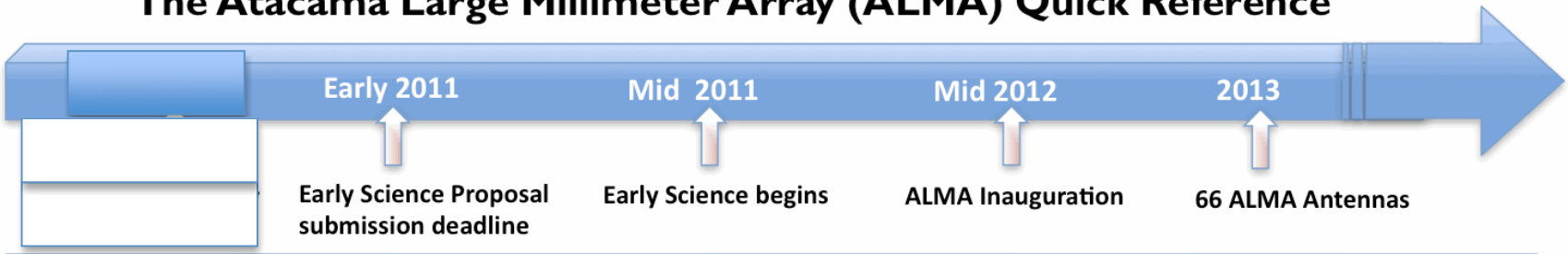
- Please see the NAASC ALMA POSTER
- NAASC / NRAO - ALMA personnel here: Sheth, Corder, Kimball, Mangum, Kent, Wiklind, Hardy, Pilleaux, Donoso
- Watch for NRAO e-NEWS / AAS special session + splinter session
- **ALMA COMMUNITY DAYS announcement – organize & Invite us!** ☺

ALMA

- Current status: 8 antennae on the high site observing!
- Already the most powerful mm-interferometer in the world!
- Call for proposals for Early Science likely in the first quarter of 2011

NRAO

The Atacama Large Millimeter Array (ALMA) Quick Reference



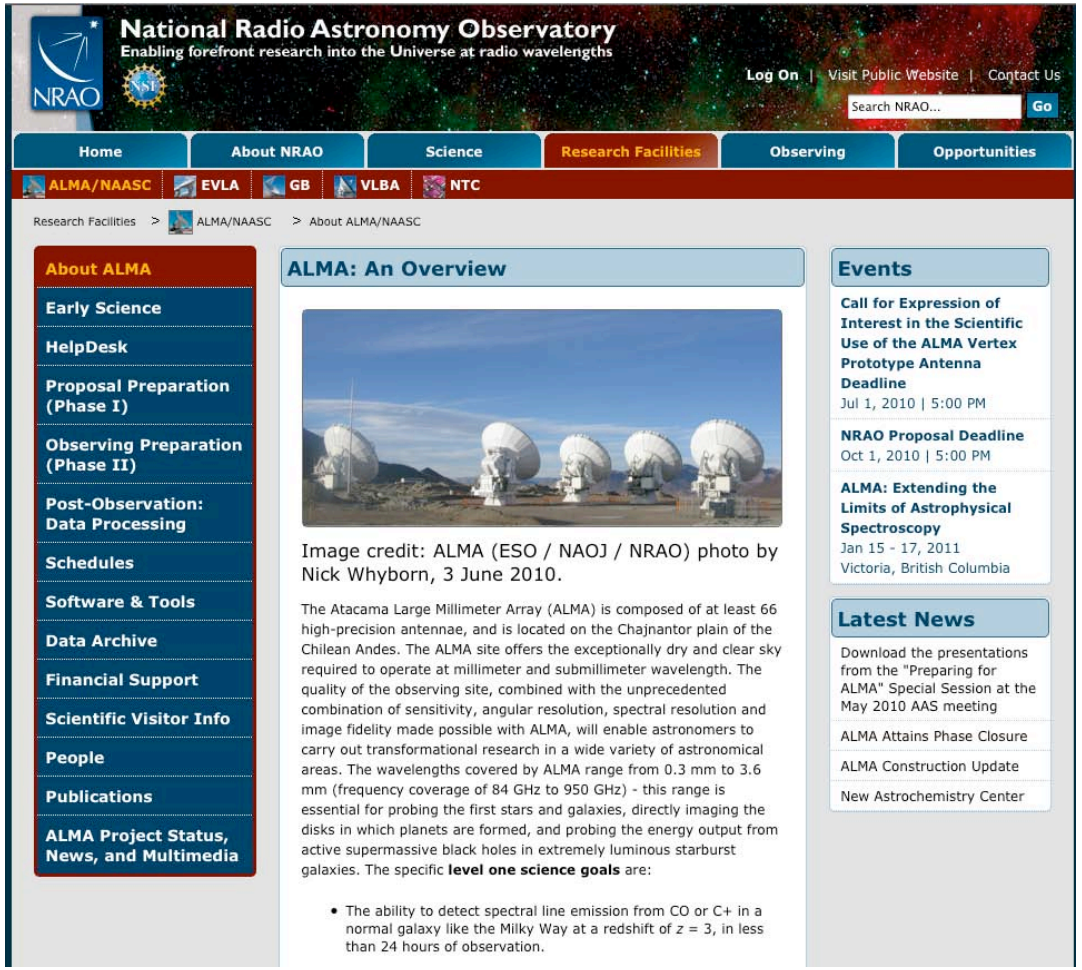
Bands:	3	4	5	6	7	8	9	10
Frequency (GHz)	84-116	125-163	163-211	211-275	275-373	385-500	602-720	787-950
Wavelength (mm)	3.57-2.59	2.40-1.84	1.84-1.42	1.42-1.09	1.09-0.80	0.78-0.60	0.50-0.42	0.38-0.32

	Early Science	ALMA Inauguration
Antennas	≥ 16 x 12m	≥ 50 (12m & 7m)
Bands	≥ 3 bands (Bands 3,6,7,9 likely)	Bands 3,6,7,9 (+ 4,8 & 10 on some)
Maximum Bandwidth	16 GHz (2 polarizations × 8 GHz)	
Correlator Configurations	≥ 5	0.01 - 40 km/sec, 71 configurations
Maximum Angular Resolution	$0.02'' \left(\frac{\lambda}{1\ \text{mm}}\right)$	$\left(\frac{10\ \text{km}}{\text{max baseline}}\right)$
Maximum Baseline	At least 250m (may reach 1km)	15.3 km
Continuum Sensitivity (60 sec, Bands 3—9)	~0.2 — 4.2 mJy	~0.05 — 1 mJy
Spectral Line Sensitivity (60 sec, 1 km/sec, Bands 3—9)	~30 — 250 mJy	~ 7 — 62 mJy

Sensitivity Calculator: http://science.nrao.edu/alma/tools.shtml

The North American ALMA Science Center (NAASC)

- Your one-stop shop for all your ALMA needs!
- http://science.nrao.edu/alma
- ALMA Primer
- ALMA Observing Tool
- CASA Simulator
- The Helpdesk



ALMA ES Preparation Events

- Jan AAS Meeting (Seattle, WA):
  - ALMA Special Session (Tuesday)
  - ALMA Splinter Session Tutorial (Wednesday)
  - NRAO Booth – Hands-on demos
- Jan 14-18, Astrophysical Spectroscopy –Workshop + Tutorial (Victoria, CA)
- Feb, Apr (& May*?)1—2 day in-house tutorials in Charlottesville
- Mar 11 (tentative) - 1-day tutorial in Santa Fe following New Horizons
- Jun AAS Meeting Splinter Session (Boston, MA)

- **ALMA Community Day – Community-sponsored event supported by NAASC Staff members.**