The First NRAO North American ALMA Science Center (NAASC) Workshop

FROM Z–MACHINES TO ALMA:
(Sub)Millimeter Spectroscopy of Galaxies

January 13–14 2006
NRAO Headquarters/NAASC
520 Edgemont Road
Charlottesville, VA

FROM Z–MACHINES TO ALMA:

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FROM Z–MACHINES TO ALMA:

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FROM Z–MACHINES TO ALMA:

SCIENTIFIC PROGRAM

Thursday January 12th

18:30–20:30 Meeting Registration/Reception
Courtyard Hotel, Main Street.

Friday, January 13th

08:00, 08:30 Bus departs Courtyard Marriott for NRAO

09:00 Fred Lo (NRAO)
Welcome

09:05 Carlton Baugh (Institute for Computational Cosmology)
The nature of (sub)millimetre galaxies in hierarchical models

09:35 David Alexander (University of Cambridge)
The role of accretion in high–redshift submillimeter galaxies

09:55 Linda Tacconi (MPE)
High–resolution millimeter imaging of submillimeter galaxies

10:15 COFFEE

11:00 Pierre Cox (IRAM)
Molecular gas in QSO host galaxies

11:20 Axel Weiss (MPIfR Bonn)
CO line SEDs of high–z QSOs and submillimeter galaxies

11:40 Lin Yan (Spitzer Science Center)
Spitzer mid–IR spectroscopy of $z \sim 2$ ULIRGs

12:00 CONFERENCE PHOTO — Meet in NRAO lobby

12:10 LUNCH

13:30 Françoise Combes (Observatoire de Paris, LERMA)
Predicted molecular excitation at high z

13:50 Michael Kaufman (San Jose State University/NASA Ames)
The dense ISM in (high redshift) starbursts

14:10 Gordon Stacey (Cornell University)
ZEUS: the redshift (z) and early universe spectrometer

14:40 COFFEE

15:25 Jason Glenn (University of Colorado)
Z–Spec: a dispersive millimeter–wave spectrometer

15:55 Neal Erickson (University of Massachusetts)
An ultra–wideband receiver and spectrometer for 74–110 GHz

16:25 Andrew Harris (University of Maryland)
Zpectrometer: an ultra–wideband spectrometer for the Green Bank Telescope

16:55 Karl Menten (MPIfR Bonn)
Z–machine science other than CO

17:15–18:30 Reception with NRAO Director (NRAO lobby)

18:00, 18:30 Bus departs NRAO for Courtyard Marriott

Saturday, January 14th

08:00, 08:30 Bus departs Courtyard Marriott for NRAO

09:00 Andrew Blain (Caltech)
The future of bolometer surveys

09:20 Grant Wilson (University of Massachusetts)
Coordinated instruments for source detection and characterization

09:40 Eva Schinnerer (MPIA)
(Sub)millimeter and radio observations of the COSMOS field

10:00 Scott Chapman (Caltech)
Optical spectroscopy of submillimeter galaxies

10:20 COFFEE

11:05 Itziar Aretxaga (INAOE)
Photometric redshifts for submillimetre galaxies

11:25 Dominik Riechers (MPIA)
CO(1–0) emission from QSO host galaxies beyond redshift 4

11:45 Laura Hainline (Caltech)
Beyond the baselines: detecting high–redshift molecular emission with the GBT

12:05 Nick Scoville (Caltech)
Redshift searches with COBRA and the COSMOS survey

12:25 LUNCH

13:55 Min Yun (University of Massachusetts)
Redshift determination algorithms from broadband spectroscopic data

14:15 Fabian Walter (MPIA)
High resolution CO imaging of high redshift QSO host galaxies

14:35 Al Wootten (NRAO)
ALMA as spectrometer

15:05 COFFEE

15:50 Matt Bradford (NASA JPL)
BLISS on SPICA: charting the history of the far–IR background

16:10 Jeremy Darling (University of Colorado)
Formaldehyde: a high redshift tracer of pre–starburst molecular gas?

16:30 Chris Carilli (NRAO)
Redshifted radio absorption lines: viewing the universe through rose colored glasses

16:50 Adrian Russell (NRAO)
Valedictory

17:45, 18:15 Bus departs NRAO for Courtyard Marriott

FROM Z–MACHINES TO ALMA:
ABSTRACTS OF ORAL PRESENTATIONS

The nature of (sub)millimetre galaxies in hierarchical models

C. M. Baugh (Institute for Computational Cosmology), C. Lacey, C. S. Frenk, G. L. Granato, L. Silva, A. Bressan, A. J. Benson, & S. Cole

We present predictions for the abundance of sub-mm galaxies (SMGs) and Lyman-break galaxies (LBGs) in the ΛCDM cosmology. A key feature of our model is the self-consistent calculation of the absorption and emission of radiation by dust. The new model successfully matches the LBG luminosity function, as well as reproducing the properties of the local galaxy population in the optical and IR. The model can also explain the observed galaxy number counts at 850 μm, but only if we assume a top-heavy IMF for the stars formed in bursts. The predicted redshift distribution of SMGs depends relatively little on their flux over the range 1–10 mJy, with a median value of $z \approx 2.0$ at a flux of 5 mJy, in good agreement with the recent measurement by Chapman et al. The counts of SMGs are predicted to be dominated by ongoing starbursts. However, in the model these bursts are responsible for making only a few per cent of the stellar mass locked up in massive ellipticals at the present day.

The role of accretion in high-redshift submillimeter galaxies

D. M. Alexander (University of Cambridge)

Deep surveys have uncovered a large population of luminous submillimeter emitting galaxies (SMGs) at $z > 1$. Although it is generally believed that these galaxies host intense star-formation activity, there is growing evidence that a substantial fraction also harbor an Active Galactic Nucleus [AGN; i.e., an accreting super-massive black hole (SMBH)]. Using X-ray, optical, and infrared observations I will explore the role of SMBH accretion in the SMG population, including placing constraints on the energetic contribution from AGN activity and the growth of SMBHs.

High-resolution millimeter imaging of submillimeter galaxies

Linda Tacconi (MPE), Roberto Neri, Reinhard Genzel, Scott Chapman, Ian Smail, Rob Ivison, Frank Bertoldi, Andrew Blain, Pierre Cox, Thomas Greve, Alain Omont

I will summarize results from an ongoing study of high resolution ($0.6'' - 1''$) interferometry of $z \sim 2 - 3$ submillimeter galaxies made with the IRAM interferometer at the Plateau de Bure. The redshifted CO 3-2 or 4-3 line profiles often are double-peaked, indicative of orbital motion either in a single rotating disk or of a merger of two galaxies. The millimeter line and continuum emission is compact; we marginally resolve the sources or are able to obtain tight upper limits to their intrinsic sizes in all cases we have studied so far. The measurements show that the submillimeter galaxies we have observed resemble scaled-up and more gas rich versions of the local Universe, ultra-luminous infrared galaxy (ULIRG) population. Their central densities and potential well depths are much greater than in other $z \sim 2-3$ galaxy samples studied so far. We interpret the data in the framework of a maximal starburst, where most of the available initial gas reservoir is converted to stars over a few dynamical timescales.

Molecular gas in QSO host galaxies

Pierre Cox (IRAM)

The study of the molecular gas in the host galaxies of quasars at high redshift has significantly progressed during the last few years. From the current detection of CO emission in 38 sources, half are from quasars in the redshift range from $1 < z < 6.4$. In some cases, many CO rotational transitions are measured enabling us to constrain the physical conditions of the massive ($\geq 10^{10}\,M_{\odot}$) reservoirs of gas in the host galaxies. This review will present the current status of the studies of molecular gas in high-z quasars, detail the physical conditions which pertain in these systems which are scaled-up versions of the local ULIRGs, and discuss the searches in high-z sources for species other than CO, including the fine structure lines of neutral carbon and the recent detection of the redshifted [CII] emission line in the $z = 6.4$ quasar J 1148+5251. These results hold great promise for the study of galaxy formation and their evolution with redshift. This review will conclude by outlining the expected progress in the field, in particular when future instruments such as ALMA will be operational which will enable to study the astrochemistry and its evolution in the early Universe.

CO line SEDs of high-z QSOs and submillimeter galaxies

A. Weiss (MPIfR Bonn), D. Downes, C. Henkel, & F. Walter

Observations of multiple CO transitions provide a unique tool to constrain the excitiation conditions of the molecular gas in high redshift objects. We present first results of our ongoing multi CO transitions study in six QSO host galaxies and four submm-galaxies at redshifts between $z = 1.4$ and 4.7 obtained at the IRAM 30 m telescope and the IRAM Plateau de Bure interferometer. Observed CO lines typically include transitions between CO(3-2) and CO(8-7) but range up to the CO(11-10) line in the BAL QSO APM0827 ($z = 3.9$). This unique set of rest frame mm/submm transitions provides, for the first time, information on the full CO ladder in ultra luminous infrared galaxies at any redshift. Using Large Velocity Gradient (LVG) models we conclude that, surprisingly, all CO line SEDs (CO flux density vs. rotational quantum number) can be explained by single temperature/density models. We will discuss variations of the CO line SEDs and of the underlying physical conditions within the massive molecular gas reservoirs found in these high-z objects.

Spitzer mid-IR spectroscopy of $z \sim 2$ ULIRGs

Lin Yan (Spitzer Science Center) et al.

I will present the results from a Spitzer GO program on mid-IR spectroscopy of high redshift infrared luminous galaxies.

Predicted molecular excitation at high z

Françoise Combes (Observatoire de Paris, LERMA)

Galaxies at high redshift are expected to have different excitation than local ones, first because the cosmic background temperature is higher, and because the star formation rate is higher in average, due to the higher rate of galaxy interaction and mergers, the larger gas fraction, and the shorter dynamical time-scale. Some simple predictions will be presented.

The dense ISM in (high redshift) starbursts

Michael Kaufman (San Jose State University/NASA Ames)

Over the past 20 years, PDR models have developed into mature and useful tools for analyzing emission from dense and diffuse interstellar clouds illuminated by FUV radiation. The classic PDR tracers are the OI 63 micron and CII 158 micron fine-structure lines, along with the far-infrared continuum. While these tracers are useful for constraining the physical conditions in nearby individual PDRs, care must be used in applying the models to more distant regions in which both dense star forming regions and diffuse gas lie in the beam. Observations of H_2 and CO in nearby galaxies independently probe the dense gas component and provide a calibration for observations where many components lie in the beam. The implications for ALMA observations of starbursts, particularly of CII and OI in galaxies with low metallicity at high redshift, will be discussed.

ZEUS: The redshift (z) and early universe spectrometer

G. J. Stacey (Cornell University), S. Hailey-Dunsheath, T. Nikola, T. Oberst, S. C. Parshley, D. Benford, S. H. Moseley, & J. G. Staguhn

We will discuss the design, current status, and plans for our submillimeter grating spectrometer, ZEUS. ZEUS is an echelle grating spectrometer designed to study star formation in the early Universe from about 2 billion years after the Big Bang to the present by observing submillimeter and redshifted far-infrared spectral lines from star forming galaxies. ZEUS has a resolving power $\sim$ 1000 and large (up to 6.4%) spectral coverage, optimized for detection of extragalactic point sources in the short submillimeter (350, 450 and 610 μm) windows. When completed, ZEUS will have a 4×64 pixel TES sensed array delivering an instantaneous 64 element spectrum for each of 4 spatial positions on the sky. ZEUS is adaptable for use on the JCMT, the CSO, the SMT, and APEX. Our science goals include (1) observing redshifted far-IR fine-structure lines from distant ($z \sim 1$ to 4) galaxies, (2) measuring the redshift of optically obscured submillimeter galaxies by detecting their bright 158 μm [CII] line emission, and (3) investigating the properties of nearby starburst and ULIG galaxies through studies of their [CI] and mid-J CO line emission.

Z-Spec: a dispersive millimeter-wave spectrometer

J. Glenn (University of Colorado), P. A. R. Ade, J. Aguirre, J. J. Bock, C. M. Bradford, M. Dragovan, L. Duband, L. Earle, H. Matsuhara, B. Naylor, H. Nguyen, C. Wood, & J. Zmuidzinas

Z-Spec is a broadband spectrometer with coverage from 1.0 to 1.5 mm. It utilizes a waveguide diffraction grating coupled to an array of 160 60-millikelvin bolometers. We are building Z-Spec to measure redshifts of submillimeter galaxies using the CO rotational ladder and atomic fine structure lines. We will also undertake a survey of nearby ULIRGs. We had an engineering run with Z-Spec at the Caltech Submillimeter Observatory in June, 2005, and obtained first light.

An ultra-wideband receiver and spectrometer for 74-110 GHz

Neal Erickson (University of Massachusetts), Gopal Narayanan, & Robert Goeller

A receiver system is nearly complete which will cover the widest instantaneous bandwidth ever utilized by an astronomical heterodyne receiver. It is intended for use in searching for the highly redshifted spectral lines from galaxies of unknown redshift. There are four receivers covering 74-110 GHz instantaneously in a dual-beam, dual-polarized system. The receiver uses InP MMIC based low noise amplifiers operated at 20 K, with two receivers combined into one horn using a full band orthomode transition. A switch based on Faraday rotation provides beamswitching at a 1 kHz rate, to overcome the $1/f$ noise in the amplifiers. Two feeds are used to maintain one dual polarized beam on the source at all times. Full band noise temperatures are < 70 K for three pixels and < 80 K for the fourth. The backend spectrometer is a set of 24 analog autocorrelators each covering 1.5-8.0 GHz with a final spectral resolution of 31 MHz. They are built using very low cost microwave and analog/digital components, with 256 lags on each circuit board. A prototype board is complete and is largely tested.

Zpectrometer: an ultra-wideband spectrometer for the Green Bank Telescope

A. I. Harris(1), A. J. Baker(2,1), P. R. Jewell(2), and K. P. Rauch(1), S. G. Zonak(1), K. O'Neil(2), A. L. Shelton(2), R. D. Norrod(2), J. Ray(2), G. Watts(2) [(1) University of Maryland (2) National Radio Astronomy Observatory]

We discuss astronomical and technical aspects of the Zpectrometer, an ultra-wideband radio spectrometer now under construction for the 100 meter diameter Green Bank Telescope. The Zpectrometer covers the entire Ka-band (26 to 40 GHz) with a set of analog lag cross-correlation spectrometers in a multi-channel correlation radiometer architecture. The instrument is optimized for observations of low to moderately excited carbon monoxide molecules in the lowest energy rotational transitions. With a 14 GHz bandwidth at a center frequency of 33 GHz the Zpectrometer has an unprecedented 42 percent fractional bandwidth, corresponding to redshifts of $1.88 < z < 3.43$ in the carbon monoxide $J = 1 - 0$ transition and $4.76 < z < 7.87$ in the $J = 2 - 1$ line. Probing cool as well as warm molecular material at redshifts near $z = 2.5$ is essential for constraining the physical conditions in young galaxies in the era when most of the stars in the Universe formed and galaxies assembled. The Zpectrometer's bandwidth, coupled with the Green Bank Telescope's sensitive receiver and enormous area, makes the Zpectrometer ideal for blind line searches in targets at positions identified at submillimeter, infrared, and other wavelengths. Its spectral resolution of approximately 150 km/s is sufficient for velocity-resolved spectroscopy to find dynamical masses and test for interactions in the target galaxies.

Z-machine science other than CO

Karl Menten (MPIfR Bonn)

While clearly the main scientific targets of "z-machines" will be redshifted lines of carbon monoxide, there also exist other interesting applications. Here I shall discuss the prospect of oberving lines from species other than CO at high redshift and in the local universe. In particular, I shall address the issue as to what minimum spectral resolution would be required and in which wavebands observations covering very wide frequency ranges would be worthwhile.

The future of bolometer surveys

A. W. Blain (Caltech)

The next generation of wide-field surveys will provide a rich opportunity for investigating key examples of the population of the most luminous galaxies, in order to carry out a full census of their properties. While the results could highlight the most unusual and exotic regions of the high-redshift Universe, it will remain important both to study the objects in detail, and to push deeper to understand the connection with conventional optically-selected galaxies at high redshifts. ALMA will be the key instrument for both goals.

Coordinated instruments for source detection and characterization

Grant Wilson (University of Massachusetts)

In this talk I will describe the projected capabilities of a set of instruments designed to make coordinated measurements of the submm galaxy population. AzTEC is a 144 element bolometer camera designed to survey fields and detect submm galaxies in the 1.1 mm band. In June of 2005 AzTEC completed a successful engineering run at the JCMT. The instrument then returned to the JCMT in October for a series of science programs which should result in a set of catalogs of the submm galaxy population which span a wide range of environments. SPEED is a 4 pixel photometer which uses frequency selective bolometers to observe in four colors simultaneously in each pixel (for a total of 16 detectors). SPEED's band centers are 2.1 mm, 1.4 mm, 1.1 mm, and 0.85 mm. Because each color is observed through the same optics, the relative calibration of the four bands should be excellent. SPEED is under construction now with a planned deployment to the HHT in 2006. These two instruments will eventually be installed at the LMT as facility instruments.

(Sub)millimeter and radio observations of the COSMOS field

E. Schinnerer (MPIA), F. Bertoldi, C. Carilli, A. Blain, N. Scoville, K. Menten, H. Voss, V. Smolčić, & D. Lutz

Deep (sub-)mm imaging of the COSMOS deep field is an integral part of this pan-chromatic survey (X-ray - radio). We will present first results from the MAMBO imaging of the inner $20 \times 20\,\mathrm{arcmin}^2$ at 250 GHz (1.2 mm) to an rms noise level of 1 mJy per $11''$ beam. We detect 23 sources at significance between 3.5 and 7σ, about half of which are also detected at 1.4 GHz with the VLA with a flux density $> 3\sigma = 30\,\mu$Jy. The 250 GHz source areal density in the COSMOS field is comparable to that seen in other deep mm fields. In addition, we discuss the multi-frequency properties of the MAMBO sources (HST/ACS morphologies, XMM X-ray and VLA radio flux densities). Also, we will outline the future efforts on (sub-)millimeter sources in the COSMOS field.

Optical spectroscopy of submillimeter galaxies

S. Chapman (Caltech), A. Blain, I. Smail, & R. Ivison

We present the latest results on the evolution of submm galaxies, exploiting the multiwavelength followup to our spectroscopically identified sample of 100 submm galaxies.

Photometric redshifts for submillimetre galaxies

Itziar Aretxaga (INAOE)

Ground-based submillimetre and millimetre blank-field surveys have identified more than 150 galaxies, the majority of which are believed to be heavily dust-obscured starburst galaxies. Larger numbers of these galaxies still will be discovered in the next generation of (sub-)mm surveys. An efficient photometric redshift technique is clearly needed in order to select subsamples of objects that will enable detailed follow-up experiments to derive the physical and clustering properties of the galaxies and their cosmic evolution.

We will describe three different methods that our group has been developing and using to derive photometric redshifts, and we will discuss their different degrees of success and inherent biases.

We present an updated assessment of the accuracy with which radio-mm-FIR photometric redshifts can be obtained in the light of the mounting optical/IR and CO spectroscopic data, which reconfirm that photometric redshifts can indeed be used as a selection technique to produce (sub)milli– metre galaxy samples in redshift intervals of $dz \sim \pm 0.3$ to 0.7 (i.e., the rms dispersion in the spectroscopic-z – photometric-z plot). This accuracy depends on the combination of currently available photometric bands used within the radio-mm-FIR regime, and ultimately, the true redshift distribution and physical nature of the sub-mm galaxies.

These photometric redshift techniques will be used in combination with the next generation of broad-band spectroscopic receivers at (sub)millimetre wavelengths, not only to identify suitable targets for these spectrometers, but also to guide the tuning of follow-up observations with narrower-band receivers in those cases where the broad-band receivers detect only a single emission-line.

CO(1-0) emission from QSO host galaxies beyond redshift 4

Dominik A. Riechers (MPIA Heidelberg), Fabian Walter (MPIA Heidelberg), Christopher L. Carilli (NRAO Socorro), Kirsten K. Knudsen (MPIA Heidelberg), K. Y. Lo (NRAO Charlottesville), Dominic J. Benford (NASA/GSFC), Johannes G. Staguhn (NASA/GSFC), Todd R. Hunter (CfA Cambridge), Frank Bertoldi (RAIUB Bonn), Christian Henkel (MPIfR Bonn), Karl M. Menten (MPIfR Bonn), Axel Weiss (MPIfR Bonn), Min S. Yun (UMASS), & Nick Z. Scoville (Caltech)

Molecular gas has now been detected in 15 $z > 2$ QSOs through observations of high-J CO transitions using millimeter interferometers. Observations of the CO ground-state transition, CO(1-0), however, have the potential to trace the molecular gas at lower excitations which may give a better estimate of the total molecular gas content in high-z QSOs. Here we present first $z > 4$ CO(1-0) observations obtained with the NRAO Green Bank Telescope (GBT) and the MPIfR Effelsberg telescope. Utilizing the K band receivers of these two 100 m class radio telescopes, we detect the CO(1-0) transition in the high-redshift QSOs BR 1202-0725 ($z = 4.7$), PSS J2322+1944 ($z = 4.1$), and APM 08279+5255 ($z = 3.9$). The spectral capabilities of the GBT (1×200 MHz in high-resolution mode, 2×800 MHz in high-bandwidth mode) allow us to cover velocity ranges of up to 20000 km s^{-1}, or $\Delta z/z = 0.09$ at $z = 4$, which will be imperative for future high-z studies in galaxies with known strong dust continuum, but poorly constrained redshift. This is a first step towards observations with future z machines. From our observations out to $z = 4.7$, we find that the CO/FIR luminosity ratios of our high-z sources follow the same trend as seen for low-z galaxies. We also derive that CO emission from all observed transitions can be described by a single gas component and that all molecular gas appears to be concentrated in a compact nuclear region.

Beneath the baselines: detecting high-redshift molecular emission with the GBT

Laura Hainline (California Institute of Technology) & Andrew Blain

The Robert C. Byrd Green Bank Telescope has opened to the astronomy community exciting new capabilities for the detection of molecular emission from high-redshift galaxies, offering an off-axis feed arm design for an unblocked aperture, active surface control, a large-bandwidth spectrometer, and receivers covering the radio window from below 1 GHz to nearly 100 GHz. These features, together with the ~ 100 m filled aperture of the GBT, have promise for minimizing some difficulties of single-dish radio spectroscopy that hamper attempts to observe the emission from low-J molecular rotational transitions from distant galaxies, such as spectral baseline shapes caused by reflections and scattering of light from more traditional feed structures. However, in attempting to use the K- and Ka-band receivers at the GBT we have found that the reality of the telescope's current performance does not yet match these high expectations. The observatory staff continue to smooth out the wrinkles and debug a complex new facility, putting forth considerable effort in shared-risk mode with the community, to find ways to calibrate GBT data on faint sources that produce useful scientific results. In this conference contribution we present the results of our efforts to calibrate and remove spectral baselines from our GBT observations, in which we use the K- and Ka-band receivers to search for CO(1-0) emission in several submillimeter-selected galaxies. With a likely detection of CO(1-0) emission from SMM J13120+4242 at $z = 3.4$, we show that despite the remaining systematic sources of error, we can still place useful constraints on the properties of interstellar gas in high-redshift systems.

Redshift searches with COBRA and the COSMOS survey

N. Scoville (Caltech)

I will review existing searches for high redshift CO emission using the OVRO 4-GHz COBRA correlator and describe future surveys with CARMA of the COSMOS 2 sq deg survey.

Redshift Determination Algorithms from Broadband Spectroscopy Data

M. Yun & M. Heyer (University of Massachusetts/FCRAO)

Advent of receiver systems with a broad bandwidth and new spectrometers that can take advantage of their full bandwidth have broadened the parameter space for radio/mm/submm spectroscopy to the traditional regime of optical and infrared spectroscopy, and entirely new scientific analysis such as blind redshift searches and multi-transition excitation analysis has become feasible for extragalactic systems even at cosmological distances. Most traditional optical spectroscopy techniques such as emission line identification and cross-correlation techniques may be adopted directly for redshift determination, but there are enough distinct advantages and disadvantages to the radio/mm/submm data to warrant some additional considerations. We will review traditional redshift determination algorithms used in the optical regime and identify special concerns for applying them to broadband radio/mm/submm spectroscopic data. We will discuss some of the specific approaches that might work well for the Redshift Receiver System being constructed by the University of Massachusetts group.

High resolution CO imaging of high redshift QSO host galaxies

F. Walter (Max Planck Institute for Astronomy), D. Riechers, C. Carilli, F. Bertoldi, A. Weiss, & P. Cox

We present new high-resolution CO observations of distant QSOs obtained at the Very Large Array. The aim of these observations is to resolve the molecular gas distribution in these extreme objects both spatially and in velocity space. Such observations provide unique information regarding the small-scale distribution, the extent, and the brightness temperatures of the molecular gas in these early systems. E.g., the structure and dynamics of the molecular gas may reveal whether or not mergers can be the cause of the ongoing starburst activity. The observations also allow for a first estimate of the dynamical gas mass. Currently, only the VLA is able to obtain resolutions in CO of up to $0.15''$ which is needed to resolve typical galactic structures of sizes ~ 1 kpc. We present high-resolution VLA imaging of high-z QSOs (BRI 1335-0417, APM 08279+5255 and J1148+5251). These observations pave the road to future ALMA observations where resolutions of order $0.1''$ will be obtained routinely.

ALMA as spectrometer

Al Wootten (NRAO)

The Atacama Large Millimeter Array (ALMA[1]) is a large international telescope project under construction in northern Chile on a site at Chajnantor of 5 km elevation. The excellent atmospheric transmission at that site in the millimeter and sub-millimeter wavelength ranges will allow ALMA to provide detailed images of the sources of the the Cosmic Microwave Background and the Cosmic Far-Infrared Background radiation, near the wavelengths of the two strongest peaks in the spectral energy distribution of the Universe (ALMA will cover a broad total spectral wavelength range from 10mm to 0.3 mm or shorter wavelengths), For any given receiver on ALMA within this wide band, 16 GHz of spectral information will be processed. This capability gives ALMA sensitive capability for measuring the redshifts of objects of uncertain distance, as well as for serendipitous study of the physical conditions in galaxies owing to the simultaneous measurement of other spectral line diagnostics.

[1]ALMA is an equal partnership between Europe and North America, in cooperation with the Republic of Chile, and is funded in North America by the U.S. National Science Foundation (NSF) in cooperation with the National Research Council of Canada (NRC), and in Europe by the European Southern Observatory (ESO) and Spain. In the bilateral project, ALMA construction and operations are led on behalf of North America by the National Radio Astronomy Observatory (NRAO), which is managed by Associated Universities, Inc. (AUI), and on behalf of Europe by ESO. In addition, Japan has also entered the ALMA project.

BLISS on SPICA: charting the history of the far-IR background

C. M. Bradford (JPL), T. Nakagawa, the BLISS team, & the SPICA team

We present the scientific motivation, point designs and plans for a background-limited Infrared-Submillimeter Spectrograph (BLISS) for the Japanese SPICA mission. SPICA will be a 3.5-meter telescope cooled to below 5 K, and offers the potential for far-IR observations limited only by the zodiacal dust emission and other diffuse foregrounds. BLISS on SPICA will provide moderate-resolution ($R \sim 1000$) spectroscopy from 40-600 microns at this background limit, achieving sensitivities below $10^{-20}\,\mathrm{W\,m^{-2}}$ in modest integrations. This huge advance will enable the first routine survey spectroscopy of the redshift 0.5 to 5 galaxies which produce the cosmic far-IR background. The far-IR fine-structure and molecular transitions are immune to dust extinction, and will unambiguously reveal these galaxies' redshifts, stellar and AGN content, gas properties, and metallicities – in aggregate the history of the population.

Formaldehyde: a high redshift tracer of pre-starburst molecular gas?

Jeremy Darling (University of Colorado)

Formaldehyde (H_2CO) has been observed in absorption against the cosmic microwave background (CMB) in dark clouds in the Galaxy, indicating an anti-inversion of level populations most likely induced by collisions with H_2. In an extragalactic setting, H_2CO may provide a unique tracer of the cold molecular ISM in pre-star-forming molecular clouds. Because the CMB scales as $T_{\rm CMB} = 2.73(1+z)$ and lies behind every galaxy, the detectability of H_2CO likely increases with redshift as $(1+z)$ and does not rely on the fortuitous alignment of flat- or inverted-spectrum continuum sources with molecular clouds that has traditionally frustrated cold molecular ISM studies. Since the "cooling" of formaldehyde is collisional, line ratios can indicate molecular hydrogen density as well as excitation temperatures, providing new insight into the cold molecular gas input to star formation. ALMA can detect the $\Delta J = \pm 1$ rotation transitions of H_2CO to arbitrary redshift, both in emission and absorption, potentially providing redshifts for systems undetectable in CO or CII lines. Combined with cm-wave observations of H_2CO $\Delta J = 0$ rotation transitions, ALMA can characterize the physical state of the cold molecular ISM in galaxies from the present to the early universe.

Redshifted radio absorption lines: viewing the universe through rose colored glasses

Chris Carilli (NRAO)

Observations of absorption lines towards high redshift radio loud quasars provide a distance independent method to study baryonic matter throughout the universe. I will discuss mm and cm observations of the highest column density quasar absorption line systems, which arise in gas associated with primeval disk galaxies. Redshifted radio absorption lines provide the most direct probes of physical conditions in the absorbing gas, such as temperatures, densities, and sizes of the absorbing clouds, as well as exquisitely detailed astrochemistry across the cosmos. Moreover, the high precision of these measurements provide stringent constraints on the evolution of fundamental physical parameters, such as the fine structure constant, the electron-to-proton mass ratio, and the temperature of the CMB. I will summarize what is currently known, and derived, from the few high z molecular absorption line systems known. I will then discuss the Z-spectrometer specifications dictated by the study of these systems.

FROM Z–MACHINES TO ALMA:

ABSTRACTS OF POSTER PRESENTATIONS

(1)
Superconducting bolometers for submillimeter spectroscopy from ground-based, airborne, and space platforms

D. J. Benford (NASA / GSFC), J. G. Staguhn (NASA / GSFC & SSAI), S. H. Moseley (NASA / GSFC), C. A. Allen (NASA / GSFC), J. A. Chervenak (NASA / GSFC), S. D. Dicker (U. Penn), M. J. Devlin (U. Penn), K. D. Irwin (NIST - Boulder), T. E. Oberst (Cornell), & G. J. Stacey (Cornell)

The far-infrared and submillimeter regimes harbor significant numbers of strong lines useful as diagnostics of processes in the interstellar medium, regions of intense star formation, and AGN activity. We all know how hard it is to detect these lines: covering a decade or more in wavelength, many of them are emitted or redshifted to wavelengths where they are obscured by atmospheric absorption. Instrumentation for spectroscopy across the submillimeter is lacking both in instantaneous bandwidth and tunable range. To realize the potential of this rich portion of the spectrum, grating or Fabry-Perot spectrometers coupled to broadband bolometers seem a logical solution, albeit one with technological difficulties.

First of all, the reduced bandwidth of these spectrometers as compared to photometric spectrometers requires significantly greater sensitivity in the bolometer and greater care in instrument design. For ground-based instruments, the atmosphere dominates the instrument noise and so simultaneous coverage in both spatial and spectral directions will be essential in controlling this foreground. Once airborne - SOFIA being the most obvious example - conditions are better but observing speed is at a premium. For both these examples, the enabling technology is the availability of large-format (hundreds to thousands) of pixel bolometer arrays with high sensitivity. We have been developing such detector arrays based on multiplexed superconducting bolometers. At the present level of maturity, we have fielded a submillimeter spectrometer containing around ten detectors of the requisite sensitivity. In the coming months, new instruments will demonstrate up to of order 100 bolometers (e.g., 8×16). The path to several hundred is established, and we are working to implement over a thousand pixels in a single detector package. One application for such large arrays is the 100 μm - 655 μm spectrometer SAFIRE on SOFIA. We present results on individual bolometers and arrays of bolometers, the above-mentioned instruments, and future directions for space-based observatories such as SAFIR.

(2)
A Submillimeter interferometer for the Large Binocular Telescope

R. S. Bussmann (Steward Observatory), C. Y. Drouet d'Aubigny, & C. K. Walker

The Large Binocular Telescope (LBT) will consist of two 8.4 m optical quality primary mirrors on a common azimuth-elevation mount with a center-to-center distance between the primaries of 14.4 m. We describe a unique 350 μm heterodyne receiver system designed for use on the LBT. The instrument will have an angular resolution of $\sim 2'' \times 6''$. Unlike the case of traditional radio interferometers, here the beams are combined quasi-optically without the need of a digital correlator (a design using waveguide detectors at the LBT prime focus is shown). This will allow us to achieve instantaneous bandwidths which are limited by the capabilities of a modern SIS mixer, ~ 10 GHz. The large instantaneous bandwidth will make this a unique heterodyne instrument for probing galaxies at high redshift.

(3)
MUSYC: A Deep Square Degree Survey of the Formation and Evolution of Galaxies and Supermassive Black Holes

E. Gawiser (Yale), MUSYC Collaboration

The Multiwavelength Survey by Yale-Chile (MUSYC) consists of deep optical ($UBVRIz$) and near-infrared (JHK) imaging of four quarter-square-degree fields on the sky, to AB limiting depths of $U, B, V, R = 26$ and $K = 22$. Our optical catalog contains 277,341 objects detected in BVR images with median seeing of $0.9''$. Satellite coverage of our fields includes Chandra, XMM, GALEX, HST-ACS, and Spitzer, with the Extended Chandra Deep Field South imaged at all of these wavelengths plus the radio. Extensive follow-up spectroscopy is being performed with VLT+VIMOS, Magellan+IMACS and Gemini+GNIRS. Hence, MUSYC provides ideal supporting data for a survey with the Z-Machine and rich target lists for spectroscopy with ALMA. We are conducting a census of protogalaxies at redshift three in order to separate physical properties from selection effects. These protogalaxies include Lyman break galaxies, Lyman alpha emitters, Damped Lyman alpha absorption systems, Distant red galaxies, Sub-millimeter galaxies and AGN. I will present measurements of the dark matter halo masses and overlap fractions of these populations and of the total cosmic star formation rate and stellar mass densities at $z = 3$. MUSYC publications and data releases are available at `http://www.astro.yale.edu/MUSYC`.

(4)
A search for dense gas in luminous submillimeter galaxies using the GBT

T. R. Greve (Caltech)

The first two detections of CO emission towards submillimeter galaxies (SMGs) revealed the presence of vast amounts of molecular gas in these systems (Frayer et al. 1998, 1999). However, while the $J > 2$ CO lines typically used at high redshifts are good indicators of the total metal-rich H_2 gas reservoir, they do not trace the dense ($n > 10^5\,\mathrm{cm}^{-3}$), starforming gas well. The latter could be particularly true in the tidally disrupted giant molecular clouds (GMCs) expected in starbursts where a diffuse phase may dominate the CO emission but has little to do with star formation (Downes & Solomon 1998; Sakamoto et al. 1999). Here we present results from a search for HCN(1-0) emission towards two bright SMGs using the Green Bank Telescope.

(5)
Providing catalogues of high-z (sub)millimetre targets for ALMA

David Hughes (INAOE), on behalf of the LMT and BLAST collaborations

The determination of the redshift distribution of dusty, high-redshift starburst galaxies, identified in (sub)millimetre surveys, is an essential measurement in the effort to understand the evolutionary history of this optically-obscured population that dominates the extragalactic sub-mm background light. Extensive radio, optical and IR follow-up observations of (sub)millimetre galaxies have led to spectroscopic redshifts for < 100 of the brightest sub-mm galaxies, some of which have been confirmed by CO molecular-line observations.

Alternatively, measurements of the rest-frame FIR to mm-wavelength SEDs of (sub)millimetre galaxies can efficiently provide many thousands of photometric-redshifts for this population. Although less precise ($dz \sim \pm 0.4$) than spectroscopic-redshifts for an individual galaxy, the significantly larger size of the photometric-redshift samples still provides a robust measurement of the overall redshift distribution, and a powerful method to identify high-redshift sources.

In the next few years extragalactic (sub)millimetre surveys with larger-format cameras and larger-aperture telescopes will routinely cover many sq. degrees, as well as pushing fainter into the luminosity function of this high-redshift (sub)millimetre population, which together prohibits the follow-up of optical, IR and radio follow-up observations to the necessary depth to identify counterparts.

In this presentation I will summarise the large-area confusion-limited blank-field extragalactic surveys that will be conducted by the Balloon-borne Large-Aperture Submillimetre Telescope (BLAST) and the Large Millimetre Telescope (LMT). I will describe how the combined data-sets, providing SEDs between 250 microns and 3 mm, and complemented in some instances with Spizter observations, will efficiently select those high-redshift galaxies (via photometric-redshifts) that can be expected to have molecular CO-lines that will fall within the tuning-ranges of the next generation of wide-band (sub)millimetre spectrometers ("z-machines"). Finally I will present specific examples of how the LMT and BLAST surveys, with follow-up using the LMT "z-machine", will provide a significant catalogue of ALMA targets that will maximise the efficiency of the higher-resolution (spatially and spectrally) ALMA observations in the future.

(6)
The significance of the ACA in imaging high-z sources

Daisuke Iono (SAO), Ryohei Kawabe, Shigehisa Takakuwa, Baltasar Vila Vilaro, Masao Saito & Yoichi Tamura

We present imaging simulations of line and dust emission in high-z sources using the proposed array configuration of the combined ACA + 12-meter system. In order to check the image fidelity and detectablility, we use various galaxy models, from a normal spiral galaxy like our own, to morphologically disturbed galaxies similar to the mergers seen in the local Universe. It is suggested from simple size scale arguments that the higher ALMA bands benefit most from the short spatial frequencies obtained using the ACA, but assessing the true impact of the ACA to the final image quality requires extensive simulation studies using fairly realistic observing conditions. The results obtained here could be used to tailor the observing strategies for the much anticipated deep and wide field ALMA submm observations.

(7)
A detection of [CII] line emission in the z=4.7 QSO BR1202-0725

Daisuke Iono (SAO), Min S. Yun, Martin Elvis, Alison B. Peck, Paul T. P. Ho, David J. Wilner, Todd R. Hunter, Satoki Matsushita, & Sebastien Muller

We present $\sim 3''$ resolution imaging of the $z = 4.7$ QSO BR1202-0725 at 900 micron from the Submillimeter Array. The two submillimeter continuum components are clearly resolved, and the positions are consistent with previous lower frequency images. In addition, we detect [CII] line emission, predominantly from the northern component. The ratio of [CII] to far-infrared luminosity

is 0.03%, similar to the low values found in local ultraluminous galaxies, indicating that the excitation conditions are different from those found in local field galaxies. X-ray emission is detected by Chandra in both submillimeter continuum components, supporting the idea that BR1202-0725 is pair of interacting galaxies at $z = 4.7$ that each harbor an active nucleus.

(8)
The nature of 350 μM-selected galaxies

Sophia A. Khan (Imperial College London/GSFC), Matthew L. N. Ashby (Harvard / Smithsonian Center for Astrophysics), Dominic J. Benford (NASA/GSFC), David L. Clements (Imperial College London), Eli Dwek (NASA/GSFC), S. Harvey Moseley (NASA/GSFC), Richard A. Shafer (NASA/GSFC), Timothy J. Sumner (Imperial College London), & Steven P. Willner (Harvard / Smithsonian Center for Astrophysics)

As part of an ongoing blank deep field extragalactic survey, using the 350 μm-optimised second generation Submillimeter High Angular Resolution Camera (SHARC II) at the Caltech Submillimeter Observatory, we have imaged a 6 square arcminute region in the Boötes Deep Field to a 1σ sensitivity of 6 mJy. Our survey is expected to be dominated by luminous and ultraluminous infrared galaxies (LIRGs and ULIRGs), around the peak of their spectral energy distribution, at $1 < z < 3$, the epoch of peak cosmic star formation rate. Our most significant source (3.6σ, designated SSG 1) is also detected by *Spitzer* (IRAC and MIPS-24 μm), with additional optical/NIR photometry from the NOAO-NDWFS and FLAMEX surveys. SSG 1 is a ULIRG with a warmer dust temperature than ULIRGs selected at 850 μm, a photometric redshift of ~ 1, and a predicted 850 μm flux density near the SCUBA detection threshold. We also characterise the submillimetre properties of IRAC-selected sources in the Boötes field via a stacking analysis, finding a 3σ detection of sources at $z \sim 1$. By selecting sources at 350 μm we can begin to address the parameter space of shorter-wavelength submillimetre galaxies (e.g., redshift, luminosity, dust temperature, mergers, AGN), their evolution and their relation to locally selected *IRAS* and high redshift 850 μm SCUBA galaxies. These considerations are necessary for planning future surveys in this waveband (e.g., with *Herschel*) and to characterise the submillimetre population as a whole.

(9)
Differential lensing effects in high-z sources: constraining the size and shape of the emitting regions

M. Krips (CfA), R. Neri, A. Eckart, R. Barvainis, A. Peck, D. Downes, P. Planesas, J. Martin-Pintado, D. Iono, & G. Petitpas

One of the largest obstacles in determining the physical parameters of galaxies in the early universe is our inability to accurately constrain the size of the sources detected. Current cutting-edge mm/submm interferometers, such as the Submillimeter Array (SMA) and the Plateau de Bure Interferometer (PdBI), yield angular resolutions of the order of $1''$, which is in most cases not sufficient to resolve the observed emission at high-z. However, if the high redshift source is gravitationally lensed by an intervening galaxy, the angular resolution can be improved by up to two orders of magnitude, as demonstrated in the case of the Cloverleaf galaxy. Light from extended regions is deflected in a different way than from compact ones, so that the lensed images set tight constraints on their true size and shape. We will discuss the use of such differential lensing effects for

three gravitationally lensed high redshift quasars: Q 0957+561 ($z = 1.41$), SBS 1520+530 ($z = 1.86$) and APM 08279+5255 ($z = 3.9$). We have recently detected molecular gas emission traced by CO in the first two sources, doubling the number of CO detections at this mostly unexplored redshift range of $z = 1 - 2$. We will be able to use this technique as well to place even tighter constraints on the size of the dust emission in APM 08279+5255 using the new very extended configuration of the SMA with its angular resolution of $0.4''$ at 345 GHz.

(10)
Understanding sub-mm radio emission in our own backyard

Christopher L. Martin (Oberlin College), Wilfred M. Walsh, Kecheng Xiao, Adair P. Lane, Christopher K. Walker, & Antony A. Stark

As we look for red-shifted mm and sub-mm radio emission in distant galaxies, we need to understand our own galaxy's emission to serve as a comparison. To aid in this effort, the Antarctic Sub-mm Telescope / Remote Observatory (AST/RO) has completed a survey of CO (4-3), CO (7-6), and [CI] 3P1-3P0 over a three square degree area around the Galactic Center (Martin et al., ApJS, 150, 239 (2004)). In addition to this dataset, AST/RO has recently completed a survey area around Clump 1 and 2, thus covering the bulk of strongly excited gas near the center of the galaxy.

Using an interactive movie to tour through the data, we'll explain the variety of features in our own galaxy and how they can be used discern what it would look like were we to observe the Milky Way from a great distance.

(11)
From 20 cm - 1 micron: measuring the gas and dust in massive low surface brightness galaxies

K. O'Neil (NRAO) & E. Kearsley

Archival data from the IRAS, 2MASS, NVSS, and FIRST catalogs, supplemented with new measurements of HI, are used to analyze the relationship between the relative mass of the various components of galaxies (stars, atomic hydrogen, dust, and molecular gas) using a small sample of nearby ($z < 0.1$), massive low surface brightness galaxies. The sample is compared to three sets of published data: a large collection of radio sources from the UGC having a radio continuum intensity > 2.5 mJy (Condon, Cotton, & Broderick 2002 AJ 124, 675) ; a smaller sample of low surface brightness galaxies (Galaz et al. 2002 2002 AJ 124, 1360); and a collection of NIR low surface brightness galaxies (Monnier-Ragaigne et al. 2002 Ap&SS 281, 145). Overall, our sample properties are similar to the comparison samples in regard to NIR color, gas, stellar, and dynamic mass ratios, etc. Based off the galaxies' q-value (determined from the FIR/1.4 GHz ratio), it appears likely that at least two of the 28 galaxies studied harbor AGN. Notably, we also find that if we naively assume the ratio of the dust and molecular gas mass relative to the mass of HI is a constant we are unable to predict the observed ratio of stellar mass to HI mass, indicating that the HI mass ratio is a poor indicator of the total baryonic mass in the studied galaxies.

(12)
Astrometric imaging of high redshift galaxies at 345 GHz

A. B. Peck (CfA/SMA Project), D. Iono, G. R. Petitpas, A. Pope, C. Borys, J. S. Dunlop, M. Krips, & D. J. Wilner

Recent single-dish submillimeter wavelength surveys have revolutionized observational cosmology by uncovering a substantial new population of dust-enshrouded starburst galaxies at high redshift. A tremendous amount can be learned about the star formation history of the universe by comparing the characteristics of these early sources at a range of wavelengths, from radio to X-ray. Unfortunately, the positions of these sources are not well enough determined in the parent surveys to justify devoting large amounts of time using higher resolution instruments without first performing high precision astrometry. The Submillimeter Array on Mauna Kea is now the ideal instrument for this, as it can observe at the same frequency as the original survey, but with substantially better angular resolution. We present images of the distant galaxies detected to date using the Submillimeter Array at 345 GHz.

The Submillimeter Array is a joint project between the Smithsonian Astrophysical Observatory and the Academia Sinica Institute of Astronomy and Astrophysics, and is funded by the Smithsonian Institution and the Academia Sinica.

(13)
Monitoring Phase Calibrators at Submillimeter Wavelengths

A. B. Peck (CfA/SMA Project), M. A. Gurwell (CfA), S. R. Hostler (CfA), M. R. Darrah (UHH) & the SMA team

One of the biggest challenges facing submillimeter wavelength interferometry is correcting for short timescale atmospheric phase fluctuations during the observations. Quasars sufficiently bright to use as calibrators are scarce, particularly at frequencies higher than 300 GHz. We present results of an ongoing monitoring program to determine the fluxes and variability of quasars at 230 and 345 GHz. The data is being collected at the Submillimeter Array (SMA) on Mauna Kea and reduced using MIR data reduction software. Results are updated regularly and are available in a searchable format at: *http://sma1.sma.hawaii.edu/callist.html*.

(14)
SMA observations of warm molecular gas in the Antennae merger

G. R. Petitpas (Harvard-Smithsonian CfA), D. Iono, C. D. Wilson, A. B. Peck, S. Matsushita, K. Sakamoto, J. Wang, P. T. P. Ho, Q. Zhang, A. Rots, Z. Wang, M. Yun, J. Surace, & R.-Q. Mao

The Submillimeter Array (SMA) is currently the only interferometer capable of studying molecular gas warmer than ~ 30 K in nearby and high redshift sources. We present high angular resolution 12CO J=3-2 observations of the Antennae merging galaxy system made with the SMA. We find that the peaks in the warm molecular gas emission do not necessarily correspond to the peaks seen in the cooler CO J=1-0 gas. This suggests the existence of temperature and/or density gradients in the molecular gas in this interacting system. To study this effect in more detail we have created a data cube comprised of the CO J=3-2/J=1-0 line ratio for every 20 km/s channel in this galaxy.

With this cube we can trace the temperature gradients across the spatial and dynamical range of this system. We find excellent spatial agreement between elevated CO J=3-2/J=1-0 ratio and bright spots in the Spitzer 8 μm map suggesting the star formation that is heating the dust is also actively heating the molecular gas. With this correlation, it is possible to trace the dynamics of the warm and cold dust in this system using the CO line ratio, whereas it is not possible to do this with dust measurements alone.

The techniques used in this study of a nearby interacting system have strong implications and analogies to future studies of higher redshift galaxies that will be studied when ALMA comes on-line.

The Submillimeter Array is a joint project between the Smithsonian Astrophysical Observatory and the Academia Sinica Institute of Astronomy and Astrophysics, and is funded by the Smithsonian Institution and the Academia Sinica.

(15)
A search for molecular gas in low-luminosity radio galaxies

I. Prandoni (INAF – Istituto di Radioastronomia), R. Laing, P. Parma, H. de Ruiter, & T. Wilson

We are performing a detection experiment for CO in low luminosity radio galaxies. We extracted a complete sample of 16 low redshift objects ($z < 0.03$), selected from the B2 sample, with available HST imaging. Our aim is to establish the distribution of molecular gas masses and confirm the suggestion that the CO is in ordered rotation. We also want to determine the relation between CO and the dust disks observed in these objects with HST. Detected objects will be targets for future interferometric imaging. We present here preliminary results from the first set of observations.

(16)
Observations of H53α and H92α RRLs toward the starburst galaxy NGC 253

Carlos Alanias Rodriguez-Rico (CRyA, UNAM)

We present new H53α radio recombination line (RRL) observations (at 1.2″) and re-analyzed H92α line observations (at 1.2″ and 0.3″) toward NGC 253. Based on the line flux densities in the H53α and H92α lines the electron density of the ionized gas in the center of NGC 253 has been estimated. Two ionized gas components are necessary to reproduce the RRL observations. One component has an electron density of about 10^3 cm^{-3} and a second component has an electron density of about 10^5 cm^{-3}. The kinematics of the ionized gas observed in the H53α and H92α lines (at 1.2″) reveals a massive compact object in the nuclear regions of this galaxy and the H92α line observations at 0.3″ supports the existence of the massive compact object (about 7×10^6 M$_\odot$). We interpret these RRL observations, based on a comparison between the velocity fields of the ionized and the CO gas, as an accreted object into the nuclear region of NGC 253.

(17)
Tracing the evolution of disk galaxies with galactic structures & gas kinematics

Kartik Sheth (Caltech)

Current evidence suggests that the epoch of disk formation occurred between $1 < z < 3$. When and how did galaxies cool and become sufficiently massive to host structures? What were their properties and how did they evolve to ultimately end up on the Hubble sequence? Although large and comprehensive datasets such as COSMOS, GEMS and GOODS are now becoming available it is possible that these questions will remain unanswered because of the difficulty in obtaining redshifts from optical spectroscopy as emission lines are redshifted into the infrared. This historical shortcoming has also affected millimeter and submillimeter studies; at these wavelengths, the limited bandwidth and sensitivity of current telescopes have restricted studies to only a handful of bright galaxies with good redshifts. I will discuss how with the future generation of Z-machines we can overcome the current obstacles and combine optical, infrared, millimeter and submillimeter observations to trace the evolution of disk galaxies.

(18)
A 2-millimeter bolometer camera for the IRAM 30 m telescope

Johannes Staguhn (NASA / GSFC), Dominic Benford, Christine Allen, S. Harvey Moseley, Troy Ames, Walter Brunswig, David Chuss, Steven Maher, Cathy Marx, Timothy Miller, Santiago Navarro, Elmer Sharp, & Edward Wollack

We are building a bolometer camera for operation in the 2 mm atmospheric window to be used at the IRAM 30 m telescope. The major scientific driver for this instrument is to provide the IRAM 30 m telescope with the capability to observe rapidly galactic and extragalactic dust emission, in particular from high-z ULIRGs and quasars even in the summer season. The 2 mm spectral range provides a unique window to observe the earliest active dusty galaxies in the universe and will be well suited to better confine the star formation in these objects. The instrument will fill in the SEDs of high redshift galaxies at the Rayleigh-Jeans part of the dust emission spectrum, even at the highest redshifts. The observational efficiency of a 2 mm camera with respect to bolometer cameras operating at shorter wavelength increases for objects at redshifts beyond $z \sim 1$.

The instrument uses a 8×16 planar array of multiplexed TES bolometers which incorporates our newly designed "Backshort Under Grid" (BUG) architecture. SQUID multiplexers built at NIST/Boulder are used for the detector readout. Due to the size and sensitivity of the detector array (the NEP of the detectors is 3×10^{-17} W/Hz), this instrument will be unique in that it will be capable of providing significantly greater imaging sensitivity and mapping speed at this wavelength than has previously been possible. The instrument will perform at close to the sky background limit under the best weather conditions at the Pico Veleta site of the IRAM 30 m telescope in Spain. In order to optimize the efficiency of the instrument for survey observations, without compromising the achievable point source signal-to-noise, the close-packed detector array will sample the focal plane with λ/D pixel spacing. Dithering will be used to recover the full angular resolution provided by the telescope. The instrument uses ^{4}He and ^{3}He evaporative coolers to provide a 0.275 K base temperature to cool the bolometer array. The BUG array design allows a flexible choice of backshort-absorber distance. Therefore this prototype array can be considered a pathfinder not only for a 2 mm-optimized array, but for a broad range of wavelengths.

(19)
NIR PHOTOMETRY OF THE HIGH-z QUASAR RDJ 030117+002025: EVIDENCE FOR A MASSIVE STARBURST AT $z = 5.5$

J. G. Staguhn, D. Stern, D. J. Benford, F. Bertoldi, S. G. Djorgovski, & D. Thompson

With a redshift of $z = 5.5$ and an optical blue magnitude $M_B \sim -24.2$ mag ($\sim 4.5 \times 10^{12}\, L_\odot$), RDJ 030117+002025 is the most distant optically faint ($M_B > -26$ mag) quasar known. MAMBO continuum observations at $\lambda = 1.2$ mm (185μm rest-frame) showed that this quasar has a far-IR luminosity comparable to its optical luminosity. We present near-infrared J- and K-band photometry obtained with NIRC on the Keck I telescope, tracing the slope of the rest frame UV spectrum of this quasar. The observed spectral index is close to the value of $\alpha_\nu \sim -0.44$ measured in composite spectra of optically-bright SDSS quasars. It thus appears that the quasar does not suffer from strong dust extinction, which further implies that its low rest-frame UV luminosity is due to an intrinsically-faint AGN. The FIR to optical luminosity ratio is then much larger than that observed for the more luminous quasars, supporting the suggestion that the FIR emission is not powered by the AGN but by a massive starburst.

(20)
CONNECTING DENSE GAS TRACERS OF STAR FORMATION IN OUR GALAXY TO HIGH-z STAR FORMATION

Jingwen Wu (University of Texas at Austin), Neal J. Evans II, Philip M. Solomon, Yu Gao, Yancy L. Shirley, & Paul A. Vanden Bout

Observations have revealed prodigious amounts of star formation in starburst galaxies as traced by dust and molecular emission, even at large redshifts. Recent work shows that for both nearby spiral galaxies and distant starbursts, the global star formation rate, as indicated by the infrared luminosity, has a tight and almost linear correlation with the amount of dense gas as traced by the luminosity of HCN. Our surveys of Galactic dense cores in HCN 1−0 and 3−2 emission show that this correlation continues to a much smaller scale, with nearly the same ratio of infrared luminosity to HCN luminosity found over 7 orders of magnitude in $L_{\rm FIR}$, with a lower cutoff around $10^{4.5}\, L_\odot$ of infrared luminosity. The linear correlation suggests that we may understand distant star formation in terms of the known properties of local star-forming regions. We propose a model in which the basic unit of star formation is a dense core, similar to those studied in our Galaxy; this model may explain both the correlation and the luminosity cutoff.

(21)
MOLECULAR COLUMN DENSITIES NEAR THE CENTER OF THE MILKY WAY

Kecheng Xiao (CWRU), Christopher L. Martin (Oberlin), Dan Hemberger(Oberlin), Wilfred M. Walsh (UNSW), Adair P. Lane (CfA), Christopher K. Walker (Steward), & Antony A. Stark (CfA)

We use submillimeter-wave survey data to estimate molecular column densities throughout the Galactic Center Region. Fully-sampled maps of 461 GHz CO J=4-3, 807 GHz CO J=7-6, and 492 GHz [C I] emission from the AST/RO survey of the Galactic Center Region (Martin et al. 2004 ApJS 150:239, Martin et al. 2005 this conference), together with 115 GHz CO J=1-0 and 110 GHz

13CO J=1-0 data from the Bell Labs Survey (Bally et al. 1988 ApJS 65:13) are used in a Large Velocity Gradient model to estimate the radiative transfer properties of CO and thereby determine the column densities of molecular material in the inner few degrees of the Milky Way. These data are presented in the form of a map.

(22)
Analysis of wideband spectra for line detection

Stephanie G. Zonak (University of Maryland), Andrew J. Baker, & Andrew I. Harris

We present methods and model results for determining the probability that a spectral line is present within a set of data. In wideband spectroscopy the noise across a spectrum varies significantly with frequency and complicates the usual methods for calculating noise. As an alternative to determining the noise across frequency bins in an averaged spectrum, it is possible to analyze the time sequence of signals to estimate the mean and uncertainty in the mean for each bin. A detection is then defined as a channel or set of channels whose mean is statistically significantly higher than those of its neighboring channels, making it possible to construct a plot of the confidence that a line is detected versus frequency. Calculating amplitude uncertainties for each channel also establishes error bounds on line intensities regardless of gain and noise variation with frequency. This method of spectral analysis is useful for wideband spectrometers such as the Zpectrometer, which will be placed on the Green Bank Telescope next year.

FROM Z–MACHINES TO ALMA: SUPPLEMENTAL MATERIAL

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PRACTICAL INFORMATION

0.1 Workshop Location

The Workshop will be held at the NRAO Edgemount Road Facility on the grounds of the University of Virginia. This newly renovated building is the site of the North American ALMA Science Center (NAASC).

Charlottesville is a city of about 45,000 located in Albemarle county in the eastern half of the state of Virginia. It is 70 miles west of the state capital in Richmond, 110 miles southwest of the nations capital in Washington D.C., 20 miles east of Staunton, and 70 miles north of Lynchburg. The NRAO has two facilities in Charlottesville: our Headquarters, located on the Grounds of the historic and picturesque University of Virginia (UVa), and the NRAO Technology Center (NTC), located about 1.5 miles west of UVa's Central Grounds. Charlottesville, at the heart of Jefferson Country, is a quaint historic city, and we cannot extol all of its virtues here. Instead, we point you to many local websites. Pertinent information is weather: early January is unpredictable. Recently we've had everything from weeks of 60 F temperatures, to weeks of rain, to about a foot of snow.

We had an unusually cold Fall, but the outlook for the week of the conference is for mild temperatures (50 F or 10 C) with the possibility of rain.

See the map section of this book for maps and directions from the conference hotel to the four nearest airports: Charlottesville (CHO), Washington Dulles (IAD), Reagan National (DCA), and Richmond (RIC).

0.2 Accommodations

Room blocks for the workshop were reserved in the Courtyard by Marriott on Main Street:

Courtyard by Marriott Hotel
1201 W Main St
Charlottesville, VA 22903
(434) 977-1700
(800) 321-2211
(434) 977-2600 (Fax)
http://www.courtyardcharlottesville.com/
(see enclosed map to NRAO from Courtyard)

The Courtyard is conveniety located a few blocks from "The Corner", a popular site of restaurants and bars just off of the grounds of the University of Virginia (see enclosed maps and dinning guide). The Courtyard provides a free courtesy shuttle service to and from the Charlottesville Airport. Call (434) 973-7100 to schedule a pickup.

NRAO will provide a free morning and evening shuttle from the Courtyard Marriott to transport meeting participants to and from NRAO. The morning shuttle departs from Courtyard by Marriott

at 8:00am and 8:30am. On Friday, buses will depart NRAO for the hotel at 6:00pm and 6:30pm, and on Saturday they will depart at 5:45pm and 6:15pm.

If you reserved your room in The Courtyard before December 22nd 2005, but did not get the conference rate of $82/night plus tax, please mention that you are with the NRAO ALMA workshop when you check in. They should be able to get you the correct rate. If there are problems, ask to talk to Victoria at 977-1700 ext 6005. If you have problems reaching her, contact a member of the LOC.

0.3 Reception and Registration

There will be a reception at the Courtyard by Marriott Rivanna-Albemarle Room on Thursday, January 12 from 6:30pm - 8:30pm. There will be a bar and Hors d'oeuvres served, and your registration material will include one drink ticket for the bar.

Your abstract book and other registration materials will be available at the reception. Laurie Clark from NRAO will be there with these materials and to answer any questions you may have. You can also talk to any LOC member (look for the blue nametags) for help.

0.4 Transportation to the Workshop

Transportation has been arranged through the University of Virginia Transit Service to transport participants to and from the hotel to the workshop. Buses will depart the hotel at 8:00am and 8:30am both mornings. On Friday, buses will depart NRAO for the hotel at 6:00pm and 6:30pm, and on Saturday they will depart at 5:45pm and 6:15pm. If you would like to participate in this free service, please board the bus on 12th Street (adjacent to the hotel) shortly before 8:00 a.m. and 8:30 a.m. on Friday, January 13, and Saturday, January 14. To board the bus, exit hotel through front door, turn left onto Main Street, turn left onto 12th Street.

0.5 Refreshments & Lunch

The meeting will run from 9am-5:15pm each day. There will be morning and afternoon breaks and catored box lunches provided each day. A lunch ticket for each day will be in your registration packet.

You are invited to a Reception with the NRAO Director, Fred K. Y. Lo, after the Friday program (5:15–6:30pm Friday). Free drinks and light fare will be served in the NRAO lobby. Buses will depart from here to the Courtyard hotel at 6pm and 6:30pm.

There are a plethora of great restaurants within walking distance from the Courtyard Marriott on Main street. To find a restaurant see our Restaurant Recommendation List in the following section. You may also want to ride the free Trolley to the downtown mall (about 1 mile from the Courtyard by Marriott; see enclosed map) where there are a variety of restaurants within close proximity to each other.

0.6 Oral Presentations

There will be a Machintosh and a PC computer for use for the oral presentations. We may also provide a linux box if needed. Please have your talk available via a transportable medium (CD,

DVD, memory stick) or an internet-viewable computer (via ftp, wget, scp) and look for the AV tech in the NRAO auditorium during one of the breaks before your talk. If you talk in the morning, please have your talk transferred to an NRAO computer the day before.

0.7 Poster Presentations

You are encouraged to present a poster for viewing throughout the meeting. Posters will be set up in room 230 which is adjacent to the lecture room (see enclosed map of NRAO 2nd floor). Refreshments will also be provided here during the breaks.

Poster should be placed according to the number given in this abstract book (i.e., alphabetically). The poster dimensions should be no larger than 35" by 42". Posters may be put up starting at 8:00am and will be left up for the duration of the workshop. Please use the NRAO-provided "T-pins" when putting up your poster.

0.8 Computer Access

Wireless connections are availible within the NRAO building. A few machines will be set up in a nearby room for web browsing and email access.

0.9 Contact Information

If you have problems and need to contact someone, call the NRAO main line at 434-296-0211 and ask to get in contact with Laurie Clark or John Hibbard. If that doesn't work, you can contact John Hibbard at 434-962-6501.

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DINNING GUIDE

FROM Z–MACHINES TO ALMA:

MAPS TO AREA AIRPORTS