Advanced Calibration and Imaging

Software Development

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Atacama Large Millimeter/submillimeter Array

Expanded Very Large Array

Robert C. Byrd Green Bank Telescope

Very Long Baseline Array

Caveat

I am not advocating any particular set of software development projects for ALMA.
My intention is to highlight what I see as potential opportunities.

Opportunities for Software Development

- VLA upgrades post construction:
  - Hardware (Feeds, correlator electronics,)
  - Online System
    - Improved observing modes
    - Efficiencies
  - Postprocessing System
    - New Algorithms

It is reasonable to expect that we will find similar opportunities for improvement in ALMA.

Software Support for Hardware Development Programs

- ALMA is different from the initial VLA (not EVLA): it is supported by a suite of end-to-end software systems.
  - Most hardware development programs will need to have a software component.
  - Some projects may fit easily within the efforts of the operations software group.

Very Long Baseline Interferometery

- Requires significant software development in addition to hardware.
  - Phasing Algorithms
  - Translation of .vex files to online system
  - Support of correlator protocol for application of phasing commands
  - Various bits of hardware control

NRAO ALMA

Online System: Observing Modes

- The ALMA construction project will deliver a substantial set of observing modes:
  - Standard Interferometery (both the BL Array and the ACA)
    - "Continuum" and Spectral Line Modes
  - Pointed Mosaics
  - Total Power Observing modes
    - OTF Mapping, nutating subreflectors, …
  - OTF Interferometery

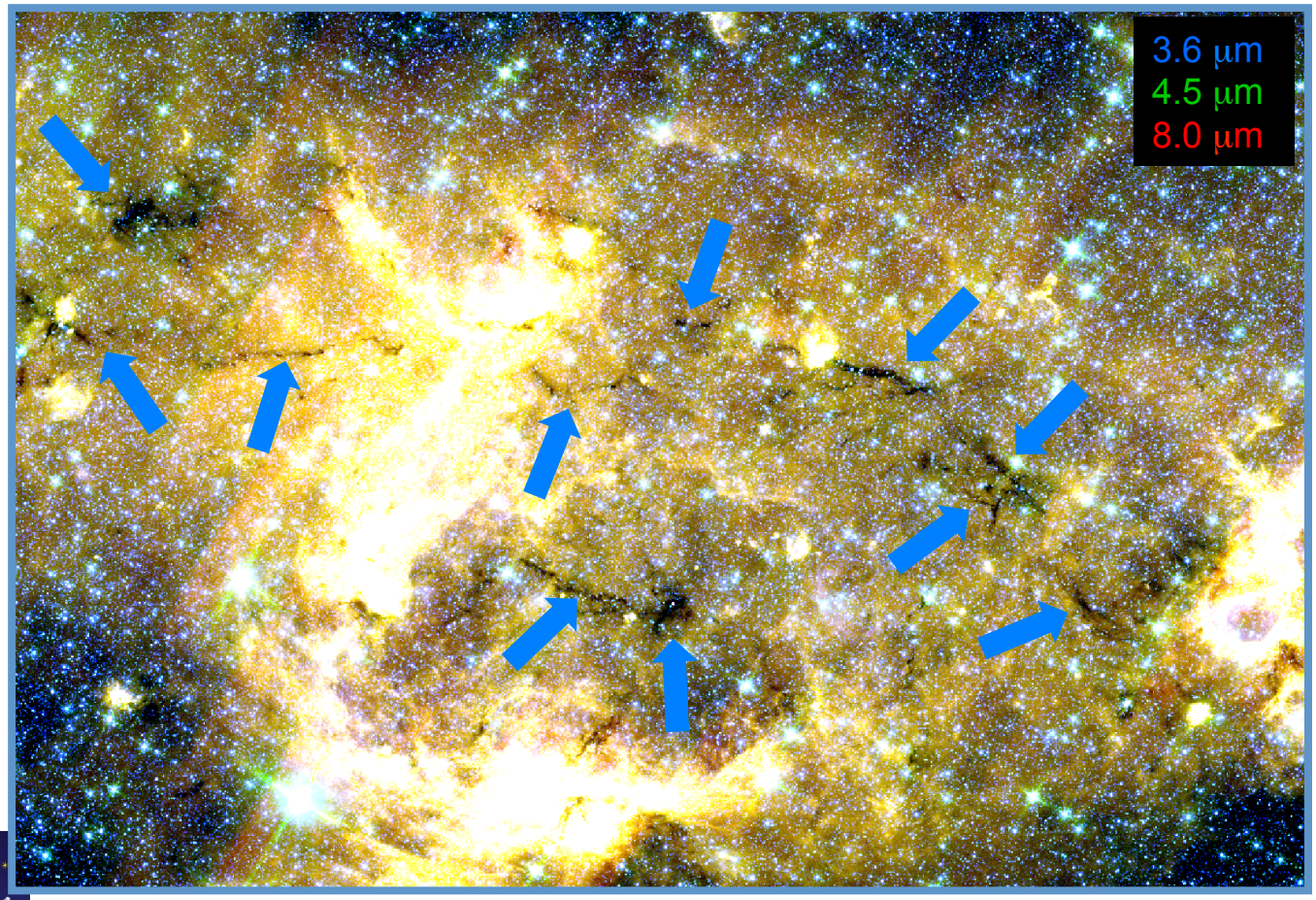
ALMA has spectacular instantaneous UV coverage, wide bandwidth, low slew times, and multi-array support.

Are there novel ways to utilize these resources to open new windows on the millimeter and submillimeter sky?

Large Area Surveys - I

- Large area surveys can answer fundamental questions about the distribution of gas in galaxy clusters, how gas cycles in and out of individual galaxies, how molecular clouds form, and how stars form

Infrared Dark Clouds:
A Galactic web of star formation



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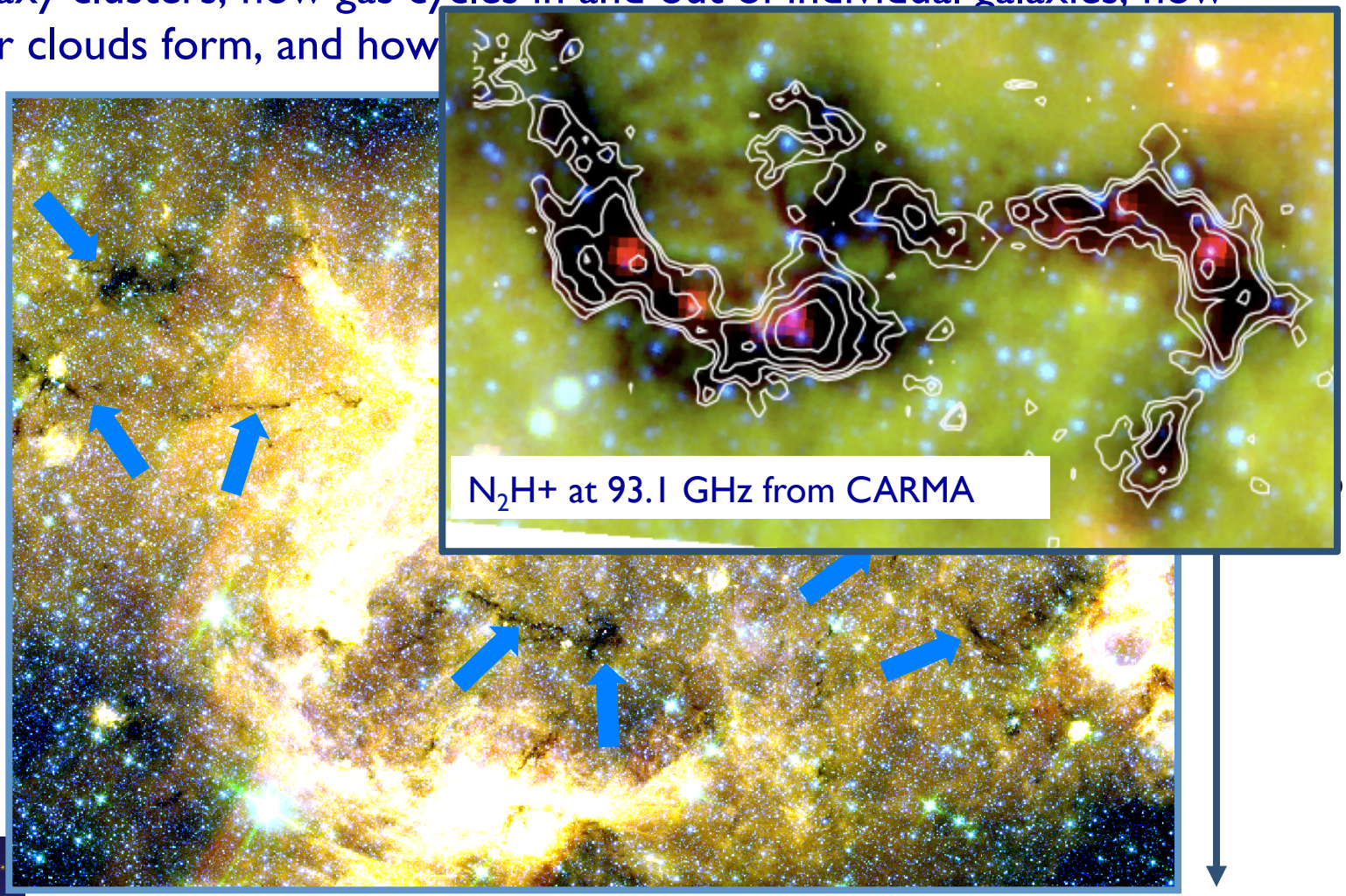


Large Area Surveys - II

- Requires: Increasing the field of view or increasing the mapping speed (or both)
  - Increasing field of view = Focal Plane Arrays (FPAs)
  - Increasing mapping speed = on-the-fly (OTF) mapping. Requires short integration times = high impact on data rate and compute power

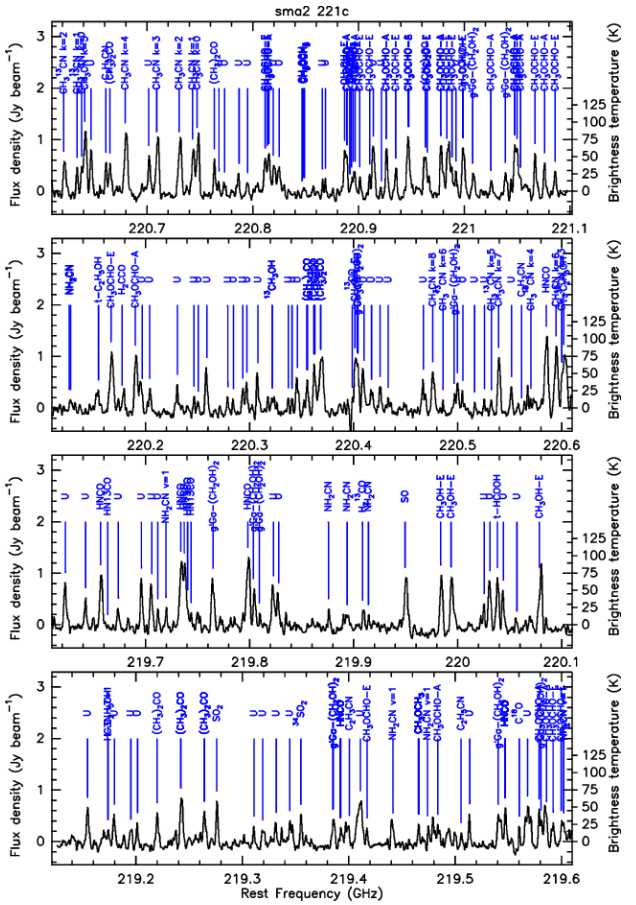
Examples:

- ALMA – OTF map of 1 square degree in CO(3-2) in 50 hours would require ~2x the current maximum data rate (64 MB/s). Raw data ~ 20 TB. Image would have 100 Mpixels per channel!

Biggest Challenges: Archiving, Data analysis, and Visualization

Spectral Line Surveys

- Spectral lines are critical tools for probing physical conditions, understanding astrochemistry, and discerning the chemical building blocks of life
  - Requires: wide bandwidths plus high spectral and angular resolution and data rates of ~1 GB/s
    - ALMA – Wide bandwidth (8 GHz/pol), but baseline peak data rate (64 MB/s) utilizes ~6% of correlator capability (1 GB/s). Restricted by network hardware, ability to process and archive.
      - ➢ Processing 1 GB/s will require ~1000 CPUs



2 GHz of bandwidth toward a massive star forming region (Brogan et al. in prep.)

Transient Phenomena

- In Astro2010 identified as key discovery space
  - Requires: High time resolution of a few 10s of ms, and data rates of 1 GB/s for spectral resolution and RFI mitigation plus long-term archiving
    - ALMA – 16 ms dump time – good for transient science, but with current data rate constraint must average to ~ 1 second or use a small number (~100) of channels. Field of view is also small = FPAs

Biggest Challenges: Data rate, Processing, Analysis and Visualization

Data Rate Improvements

- ALMA (and EVLA) are fundamentally limited by the amount of data that we can transport and afford to store.
- ALMA– Data rate of 1 GB/s needed for increasing mapping speed, spectral line surveys, and transient phenomena.
- Physical Transport Solution:
  - Hardware Upgrade: 1 GB/s to10 Gb/s (Swithes, NICs)
  - Improvements to operational computers and software
  - Data transmission speed to the local "spool" archive
- Software / Analysis Solution:
  - What types of pre-archival data analysis could be done to allow higher effective data rates from the instrument without increasing the volume of data to store:

Algorithm Development

- Producing thermal noise limited images from ALMA requires new techniques and algorithms.
- Pointing self cal (in development by ARDG) is likely to be required for sources which fill the primary beam.
- A-Projection will likely be required for mosaics
- OTF Interferometery is still in early days
  - Data rate limitations will have a large effect here.

To some extent this effort will be driven by the data, but it is likely that to optimize ALMA science new imaging and calibration algorithms will need to be designed and implemented.

Analysis Challenges

The complexity of ALMA spectra present new challenges in analysis.

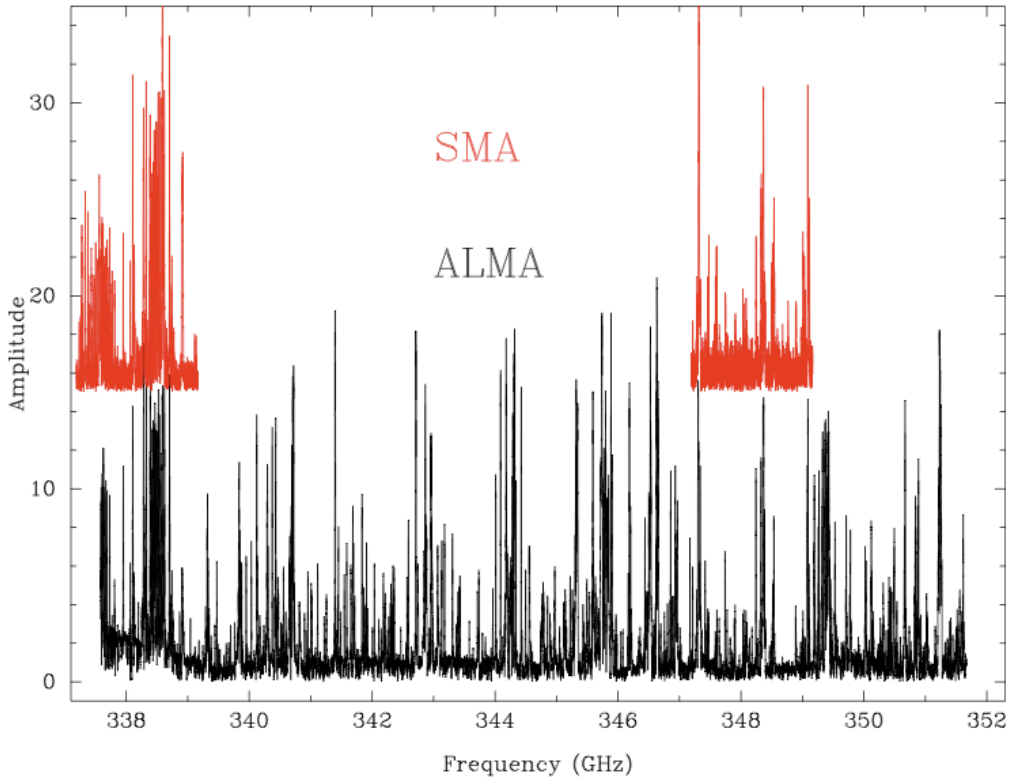
We need to to develop new analysis methods and algorithms.

"Embrace the Complexity"

-Ted Bergin

Extending the Limits of Astrophysical Spectroscopy

Orion Band 7



Visualization

- Medical imaging confronts many of the same issues that we see in astronomical imaging
  - Large 3-D images
  - Distillation of numerical parameters
  - Joint analysis of between imaging techniques and resolutions
- Commercial medical imaging packages are focused
  - Optimized for a particular type of diagnosis
- CASA is currently working to deliver the fundamental building blocks which more sophisticated techniques can be built from.

Identification of tools and techniques will be useful in the analysis of data from ALMA and development of those tools