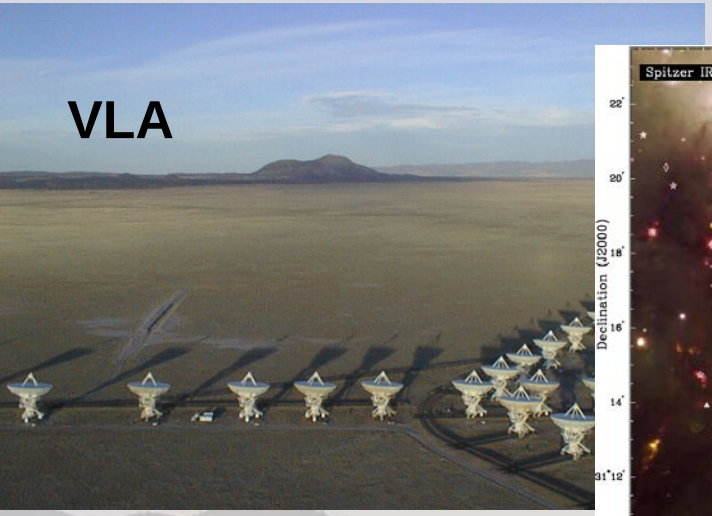
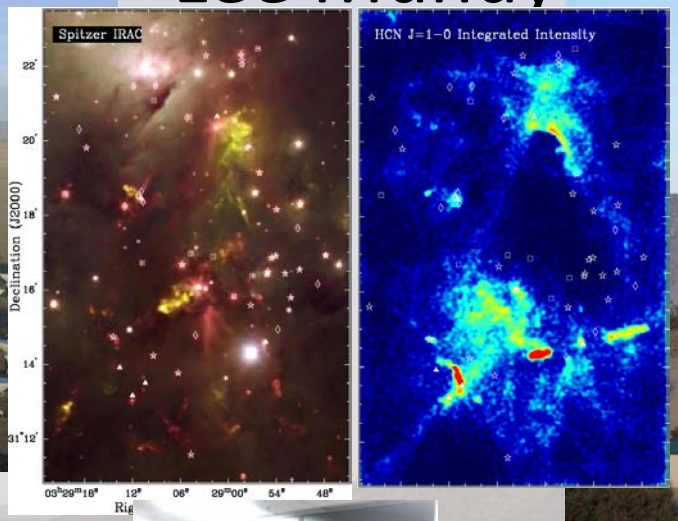
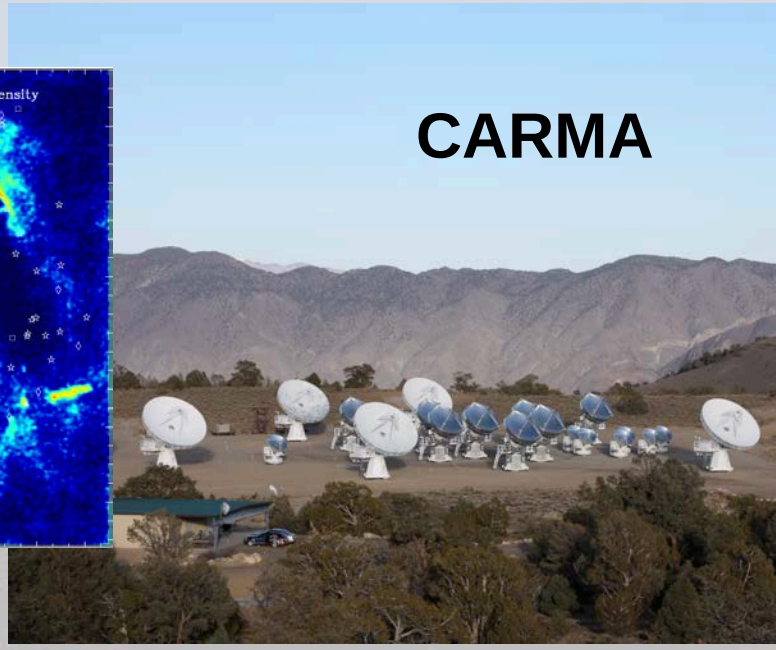
Understanding Star Formation in our Backyard: Observations, Modeling, and Science Mining

Lee Mundy







Visualization

Science Mining for Large Datasets

Combined Array for Research in Millimeter-wave Astronomy (CARMA) and the Laboratory for Millimeter-wave Astronomy

CARMA: Current Status

- Heterogeneous array of 10.4, 6.1, and 3.5 m antennas
  - 23 antennas in total (six 10.4-m, nine 6.1-m, and eight 3.5-m)
  - correlators with capability to measure spectral lines and continuum
- Operating as two arrays and 1-array
  - 6/10 m antennas: 3mm and 1 mm bands (80-115 GHz and 215-250 GHz)
  - 3.5 m antennas: 3mm and 1 cm bands (80-110 GHz and 26-34 GHz)
  - 23 elements at 3mm; 23 elements at 1 cm being commissioned
- Maryland gets about 9% of the time.

CARMA Partners:

Caltech
University of California, Berkeley
University of Illinois
University of Maryland
University of Chicago
National Science Foundation

Science and Opportunities

Continuum emission from dust, gas, and non-thermal sources:

- dust emission to trace star formation locally and in external galaxies
- free-free emission to trace embedded HII regions and recombination lines
- non-thermal emission from quasars, AGN, and our galactic center
- cosmic background radiation and the creation and evolution of structure

Molecular line emission from dense gas

- the details of star formation in our galaxy
- the chemistry of dense gas
- the late stages of evolution of stars
- the global properties of star formation and the gas kinematics in galaxies
- the evolution of galaxies and the structure of galaxies in the early universe

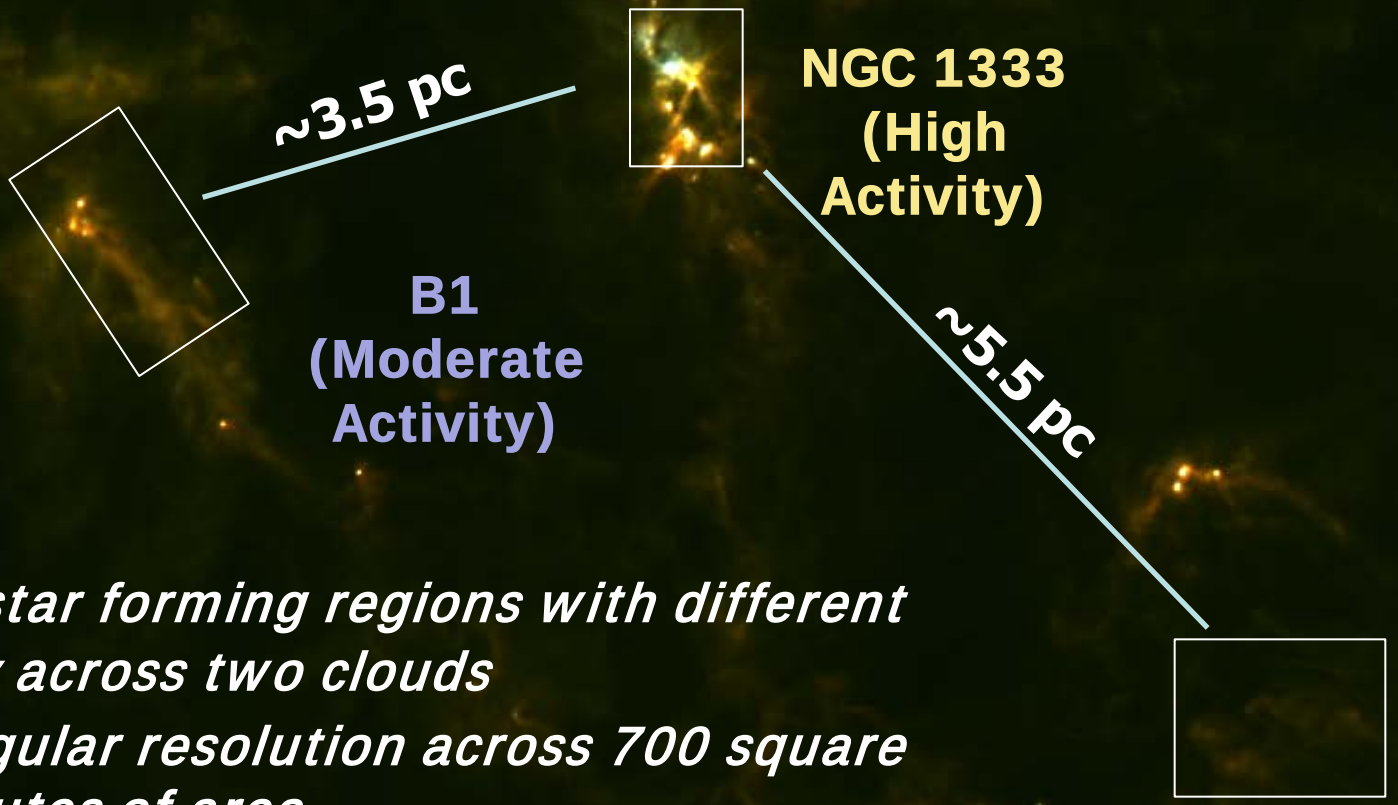
Unique Opportunity for hands-on experiences

- summer school and site observer
- participate in commissioning new capabilities of the instrument
- participate in development of hardware and/or software

Science interests of: Bolatto, Harris, Vogel, and myself

CLASSy Key Project

Perseus CLASSy Regions as seen by Herschel (160-350 μm)



- *Five star forming regions with different activity across two clouds*
- *5'' angular resolution across 700 square arcminutes of area*
- *Three molecules: J=1-0 N_2H^+, HCN, HCO^+ ($n>10^5$ cm^{-3})*

Large collaboration and thesis work of Shaye Storm

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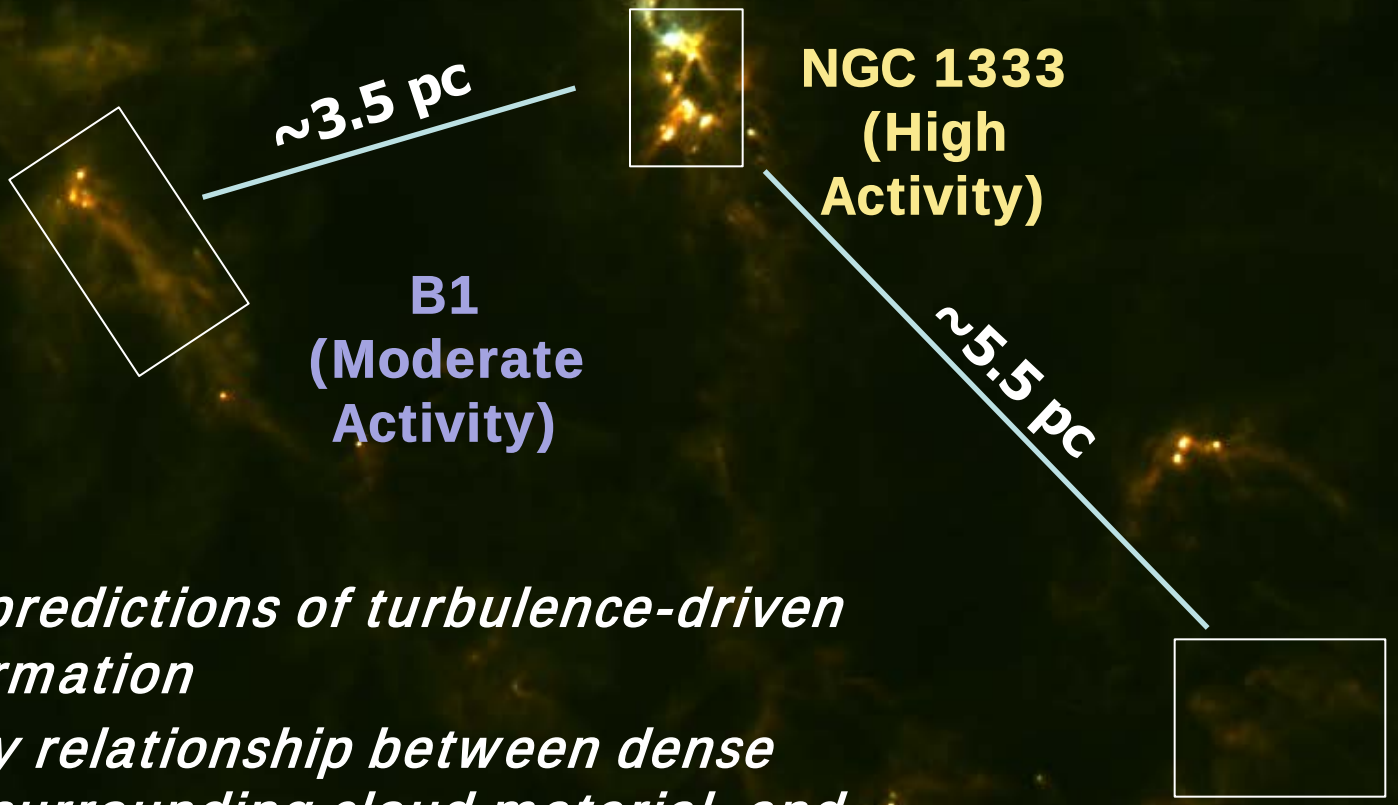
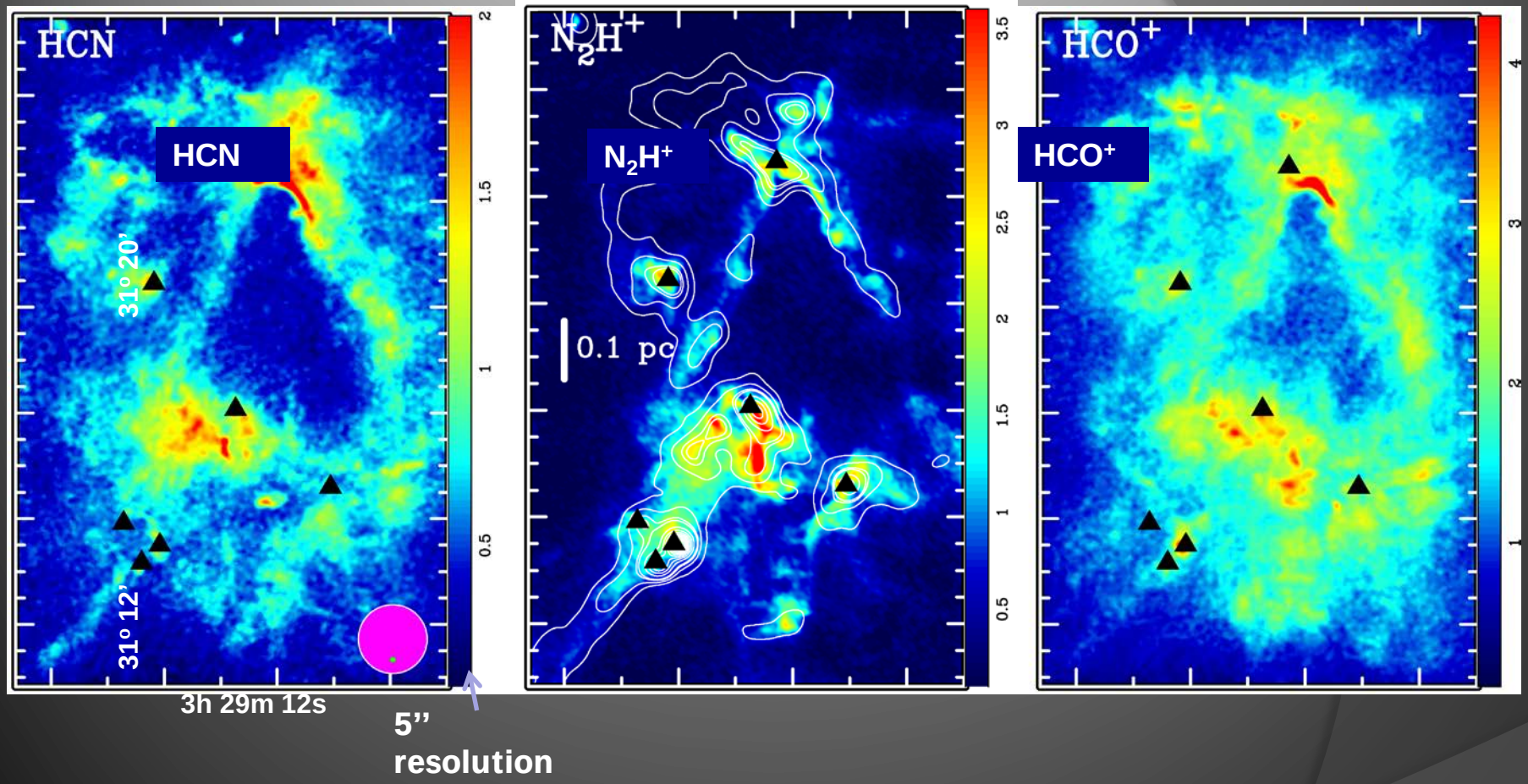


- *Test predictions of turbulence-driven star formation*
- *Clarify relationship between dense cores, surrounding cloud material, and existing stellar content*
- *Study core evolution*

Large collaboration and thesis work of Shaye Storm

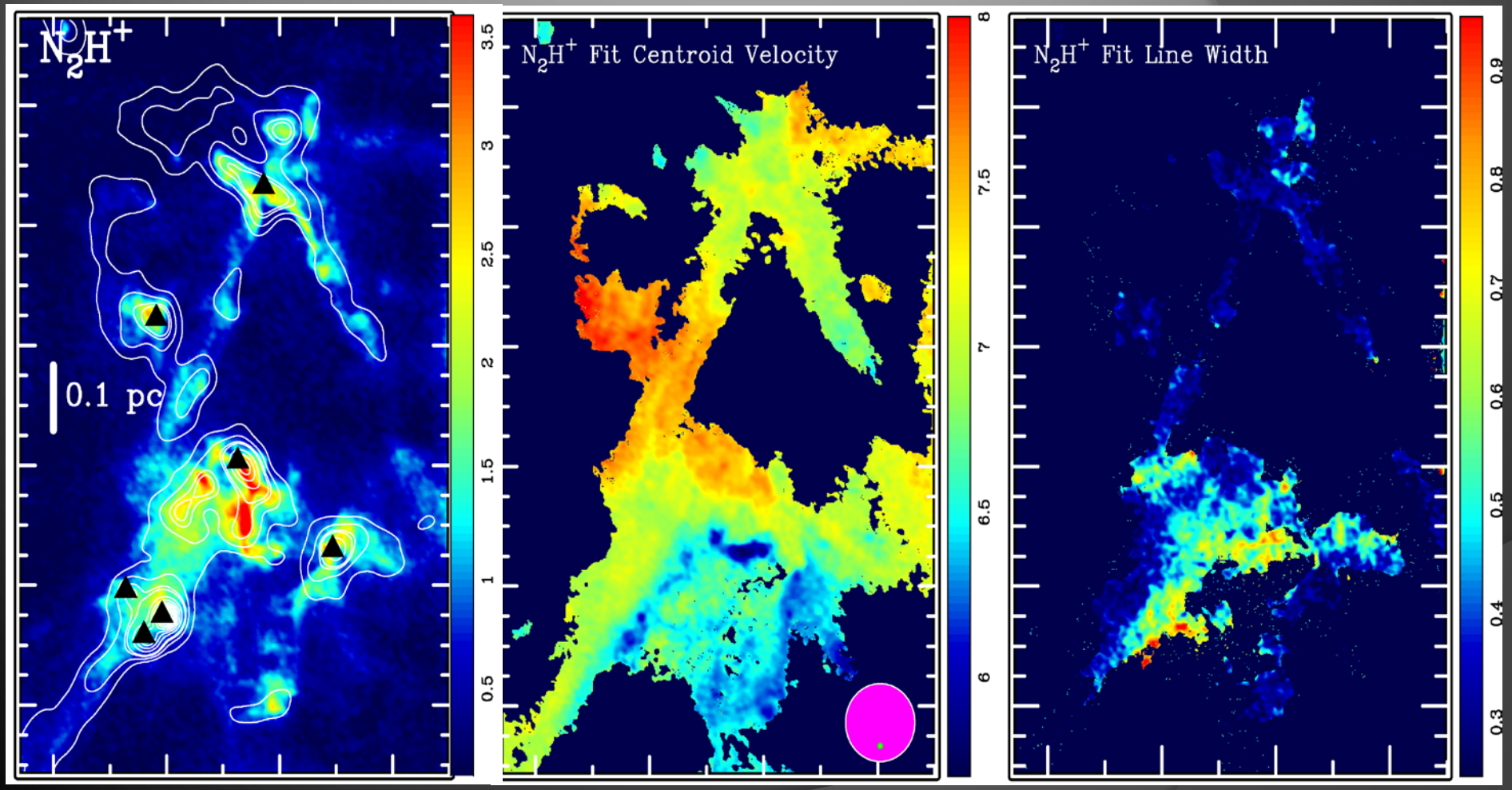
CLASSy View of NGC 1333



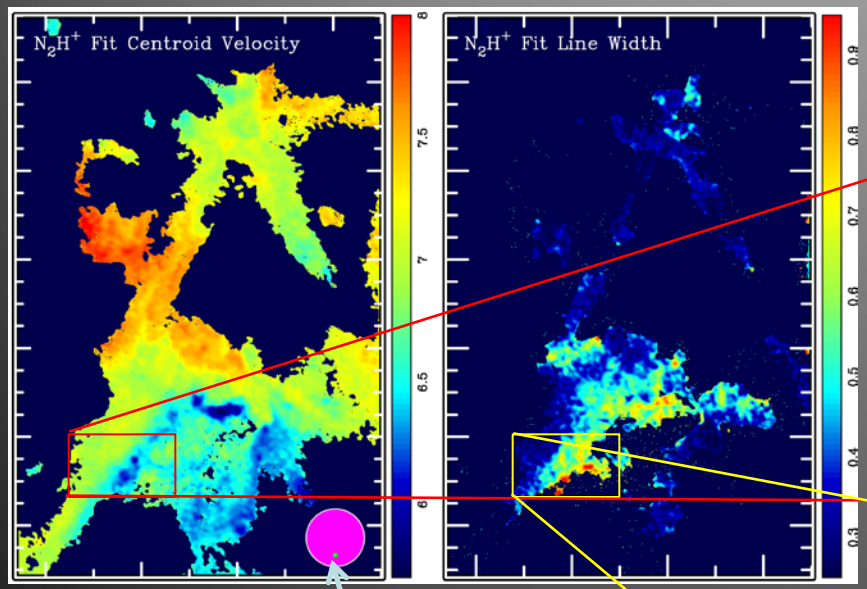
Field contains:

- **72 *Spitzer* identified YSOs**
- **Multiple sub-mm cores (black triangles)**

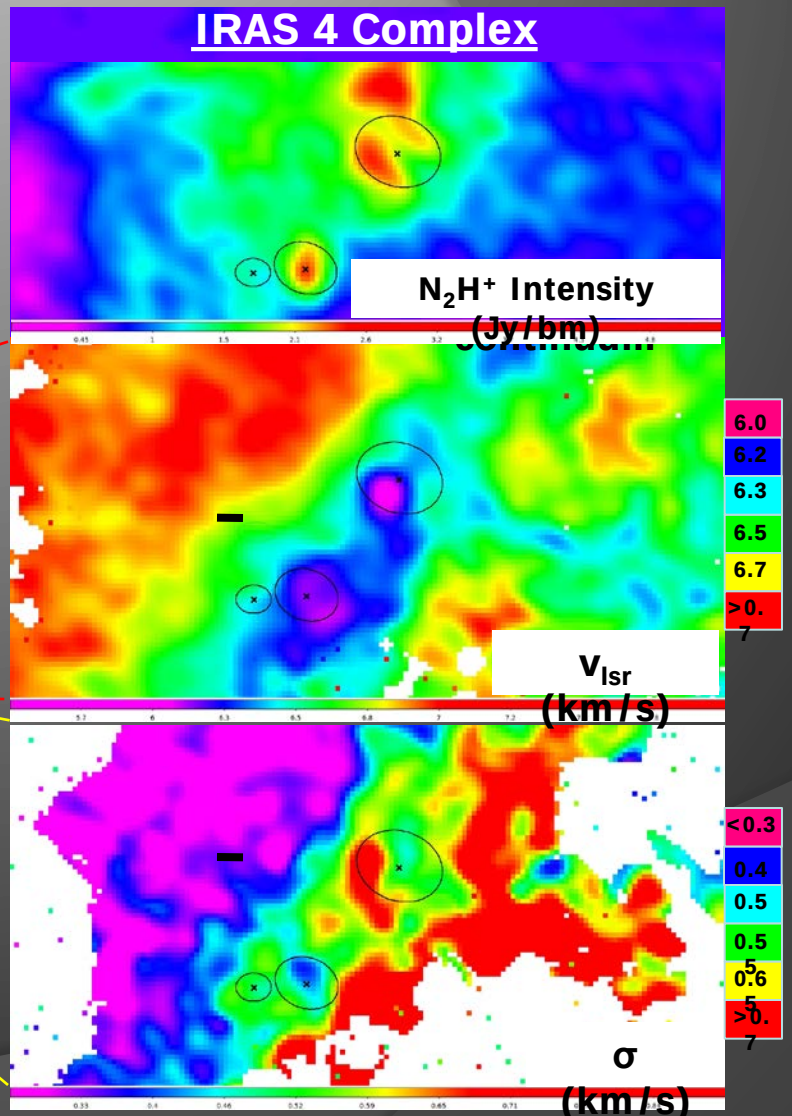
Structure and Kinematics of NGC 1333 N_2H^+ 1-0



Characterizing Core Material and Kinematics Using 5” resolution

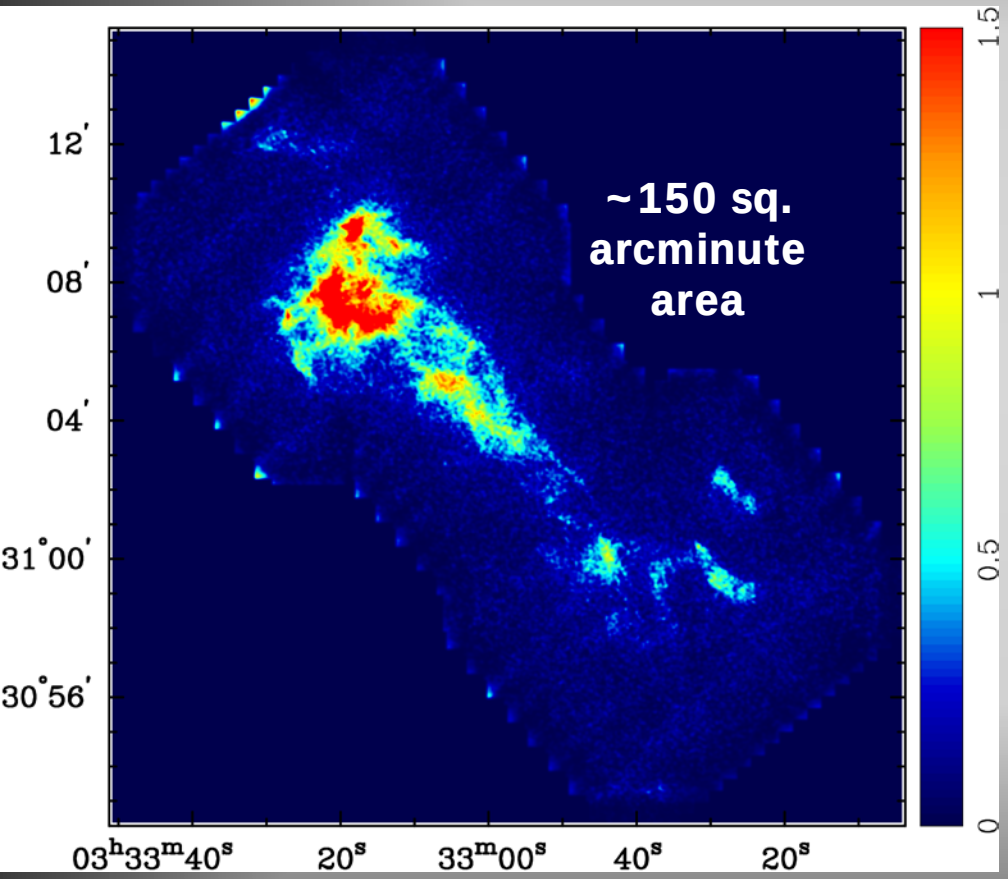


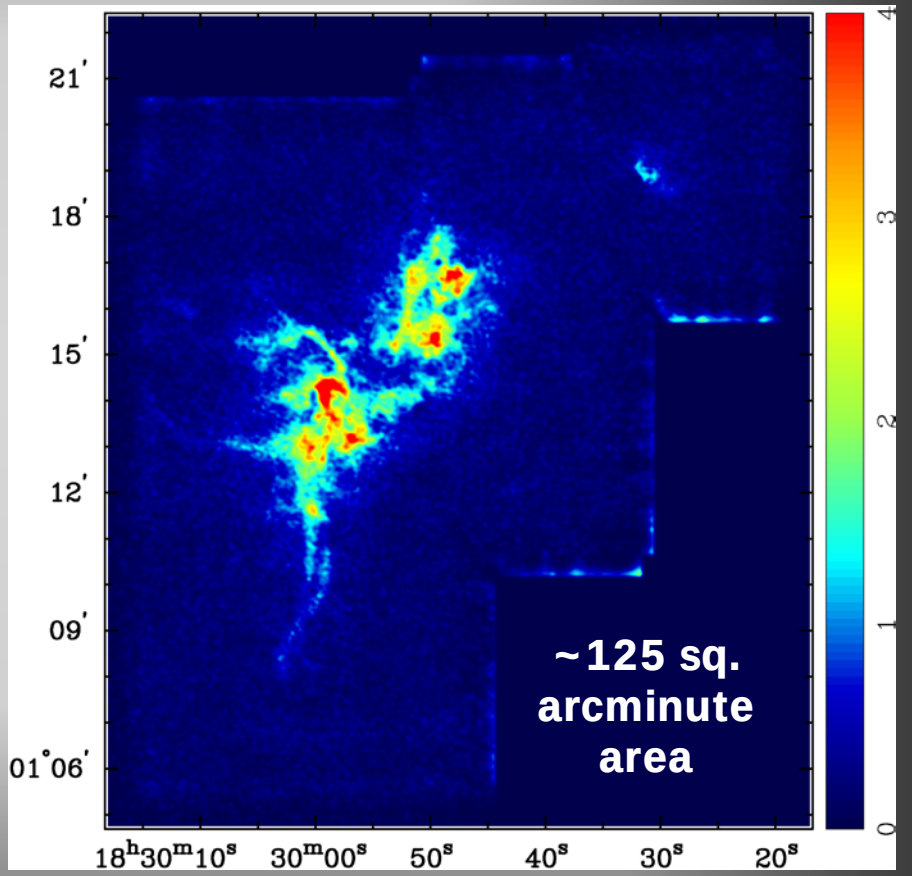
5” resolution



- *Correlation between column density and line width as predicted by turbulence theories?*
- *Dependent on evolutionary state of region?*

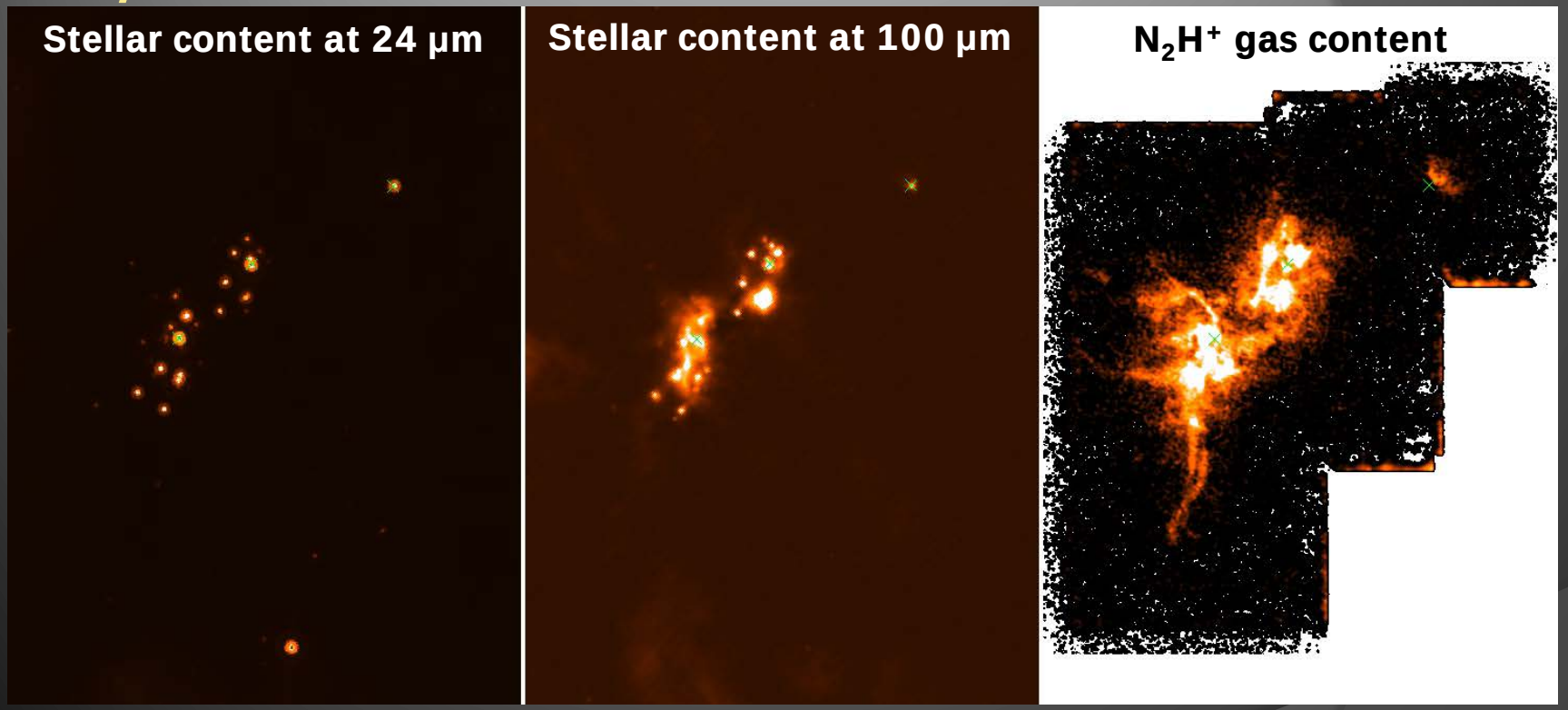
B1 and Serpens Main (preliminary) N_2H^+ Integrated Intensity Maps





Connecting Stellar and Gas Content within Serpens Main

Spitzer MIPS | *Herschel* PACS | CARMA



Serpens Main CLASSy field

Spitzer and Herschel Space Telescope

- Cores to Disks and Gould Belt Spitzer Legacy Projects
  (Tracy Huard)
  - mapped major molecular clouds in 3.1 – 70 micron bands
  - catalogs of 1000's of YSO's and possible low luminosity YSO candidates
  - maps of cloud extinction and correlation of star formation and material
- Herschel Dust, Ice, and Gas in Time (DIGIT) Large Project
  (Demerese Salter and DIGIT team international)
  - studying dust and gas properties of embedded sources with Herschel spectra
- SpitzerTime variable emission from YSO's
  (Tracy Huard, and Shaye Storm)
  - studying accretion behavior of YSO's time variable accretion!

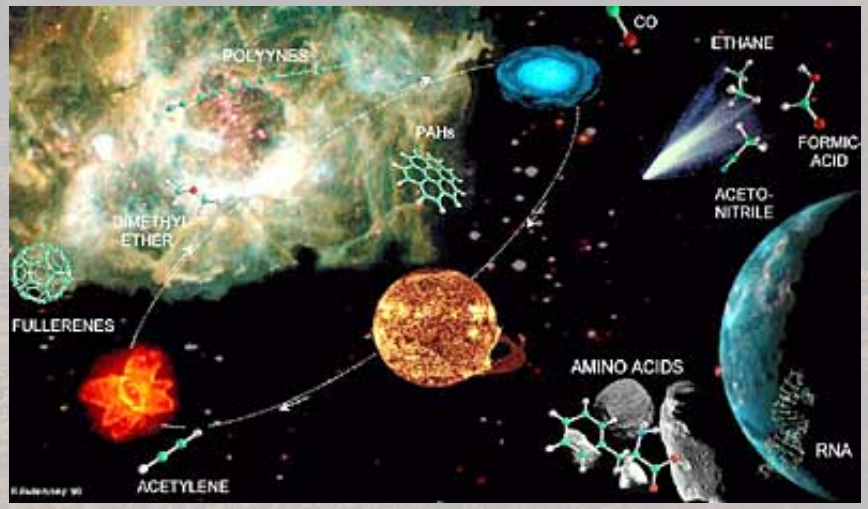
Goddard Astrobiology Node

• Overall goal is to study the delivery and evolution of complex organic molecules from the ISM into forming planetary systems and onto the surface of planets.

- PI: Mike Mumma at Goddard; large consortium of co-I's including A'Hearn, Derek Richardson, and myself in the astronomy department
- Many opportunities for research on observations, theory, lab work….

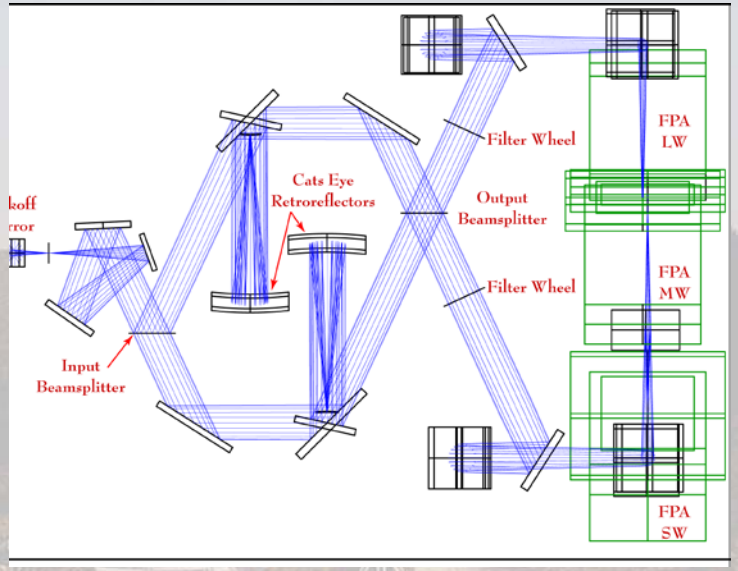
• My interests are in structure and chemistry of the star forming environment from molecular cores to the disk around optical T Tauri –type stars

- Study distribution of complex molecules using CARMA and ALMA
- Study evolution of dust grains and the structure of protoplanetary disks



Far Infrared Interferometer

- BETTII: Balloon Experiment Twin Telescope Imagine Interferometer
  - PI: Stephen Rinehart at Goddard; Maryland role in software, data reduction and data analysis. 5 year project – in year 1.5
  - 40-100 micron wavelength interferometer flown on a balloon
  - Imaging star forming regions with 0.5” resolution



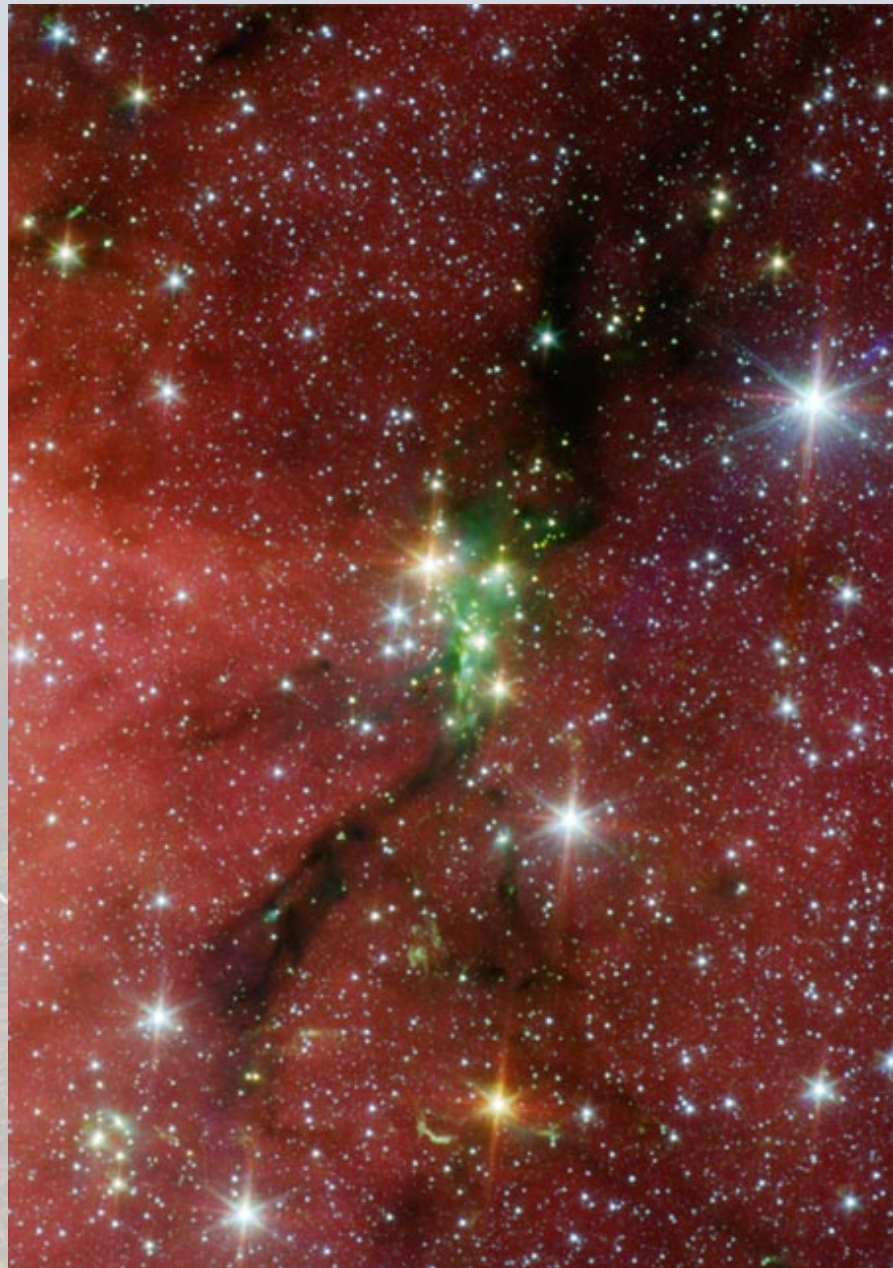
- Funded now with opportunities for graduate students
  - engineering of interferometer system
  - development of detector system
  - development of software system for analysis
  - ALL leading to unique science

BETTII: Dense Young Star Clusters

Forming star clusters are embedded in gas and dust. The embedded young stars emit much of their radiation at mid-to-far infrared wavelengths where current instruments provide poor resolution.

BETTII provides 0.5” to 1” spatial resolution at 40 to 90 microns wavelength.

Key Question: How does star formation proceed in the dense environment of a star cluster?



Science Mining of Large Datasets

New and upgraded instruments such as ALMA and the VLA at radio wavelengths – and LSST, JWST, and others at optical and infrared wavelengths will produce enormous datasets… which contain a wealth of science information – both intended and unintended by the original proposers.

Collaborating with Amitabh Varshney (Computer Science Professor and Director of UMIAC) to apply characterization and descripter techniques from his work to astronomical datasets.

Goal: Science mining of large spatial-spectral datacubes:

- user-driven automated discovery of “features of interest”
- creation of meta-data descriptions of data to compress information
- creative and efficient visualization of large datasets