

Number \_\_\_\_\_  
Priority \_\_\_\_\_

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I 1) Principal Investigator:

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2) Collaborators (state institution and country)

Scott Schnee [Ph.D. Thesis] CfA USA  
and several others from many countries, see justification

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II **TITLE AND CATEGORY OF INVESTIGATION** *Star Formation/Molecular Clouds*  
**The COMPLETE Survey: FCRAO Observations, Part 1**

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III **ABSTRACT OF PROPOSED OBSERVATIONS**

We request a total of 9 days of observing time this season as an FCRAO contribution to our ongoing "COMPLETE" Survey of 3 star-forming regions. COMPLETE is comprised of COordinated Molecular Probe Line Extinction Thermal Emission observations of (3 out of the 5) star-forming complexes to be mapped in the upcoming Evans et al. SIRTf Legacy Survey. The SIRTf data, along with HHT mapping to be carried out under COMPLETE, will give unbiased maps of thermal dust *emission*. Dust *extinction* maps are being constructed under COMPLETE using 2MASS (and ultimately SIRTf Legacy) near-IR data. We plan to use FCRAO to provide all of the fully-sampled large-scale *molecular-line emission* maps of the 3 SIRTf Legacy regions visible from the North (Per, Ser, and  $\rho$ -Oph). This proposal represents approximately the first half of the time we will ultimately request.

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IV System Configuration:  SEQUOIA  FAAS  QEF  Other

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V **BREAKDOWN OF TIME REQUESTED**

Molecule (Transition)	Frequency (GHz)	Days Requested	LST Coverage	Total Hours
1) $^{12}\text{CO}$ (1-0)	115 GHz	8	0-24h	192
2) $^{13}\text{CO}$ (1-0)	110 GHz	same 8	0-24h	same192
3) CS (2-1)	98 GHz	1	0-24h	24
4) $\text{N}_2\text{H}^+$ (1-0)	93 GHz	same 1	0-24h	same24

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VI **SPECIAL SCHEDULING REQUIREMENTS:**

Since our time request is large, we are amenable to breaking it into chunks within the winter/spring season.

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## THE COMPLETE SURVEY: FCRAO OBSERVATIONS, PART 1

This proposal is the first of a series planned for the next 18 months that will request time at FCRAO to carry out molecular spectral-line observations needed for the COMPLETE Survey of Star-Forming Regions, whose goals are described below. We request that you consider FCRAO's participation in the COMPLETE Survey as you would a "Key Project," in that it requests, in total, an unusually large time allocation, but serves the needs of a community much larger than just its proposers.

The COMPLETE Survey is being carried out by a large international collaboration, formed in 2001. The investigators listed on the recently-submitted COMPLETE proposal to NSF are: Alyssa **Goodman** (P.I., Harvard/CfA); Joao **Alves** (ESO, Germany); Paola **Caselli** (Arcetri, Italy); James **diFrancesco** (UC Berkeley); Doug **Johnstone** (HIA, Canada); Mario **Tafalla** (OAN, Spain); and Tom **Wilson** (MPI/HHT)<sup>1</sup>. In addition, the NSF proposal seeks funding for a postdoctoral fellow to join the collaboration. Harvard graduate student Scott Schnee, listed as a co-I on this proposal, will carry out his Ph.D. research using results from the COMPLETE Survey. Although only Goodman and Schnee are explicitly listed as proposers on the cover page here, we anticipate that several other COMPLETE co-I's will participate in acquiring, reducing, and publishing the FCRAO data.

In this proposal, we only briefly explain the goals of the COMPLETE Survey—hoping their worth is readily apparent—and then we describe our plans for a first round of SEQUOIA observations.

### Summary of the COMPLETE Survey

The COMPLETE Survey will produce an unbiased database that will serve the star-formation research community for many years to come. COMPLETE is comprised of COordinated Molecular Probe Line Extinction and Thermal Emission observations of a small set of large star-forming regions scheduled to be extensively observed by SIRTf. What is unique about COMPLETE is its coordinated approach. Prior observations of the types included in COMPLETE abound, but they only rarely fully-sample any region, and *no survey has ever covered a single (~10 pc) region fully with molecular line, extinction, and dust emission observations. The lack of an unbiased survey like COMPLETE has left star formation theories without statistical constraints on the temporal and spatial frequency of: inward motions, outflow motions, star-formation; cloud disruption; core formation and several other key parameters.* All of the COMPLETE data will be made publicly available on the Internet within one year of its acquisition, and we expect the statistical constraints offered by the COMPLETE Survey to be of great interest to the Milky Way, nearby-galaxy, and high-redshift star formation communities.

We have included Appendix A, taken from our NSF proposal, to give just a taste of the kind of questions our Survey will be able to address. We expect to tackle some of these questions within our collaboration, but we also expect that many will be the subject of future research by others, using the on-line COMPLETE database.

### Large-scale COMPLETE Observations, and their Status

The COMPLETE collaboration was formed in November 2001. Our goal is to "COMPLETE-ly" observe three of the five star-forming regions to be included in the Evans et al. SIRTf Legacy Survey<sup>2</sup> (Perseus,  $\rho$ -Ophiuchus, and Serpens), and our "baseline" specification is two regions (Perseus and Ophiuchus). Figure 1, on the next page, shows how a COMPLETE Survey is quite human(e)ly possible today, even though it was completely unfeasible just five years ago.

Our NSF proposal lays out a detailed three-year plan for executing the COMPLETE Survey. We begin with "fully-sampled" observations of each of the three ~10-pc size star-forming regions. After those large-scale observations are completed (and in a few cases concurrently) higher-resolution observations of a "representative" sample of dense peaks are to be carried out. We focus in this first FCRAO proposal, though, primarily on the large-scale initial observations.

The observations needed to collect the large-scale data we require are as follows:

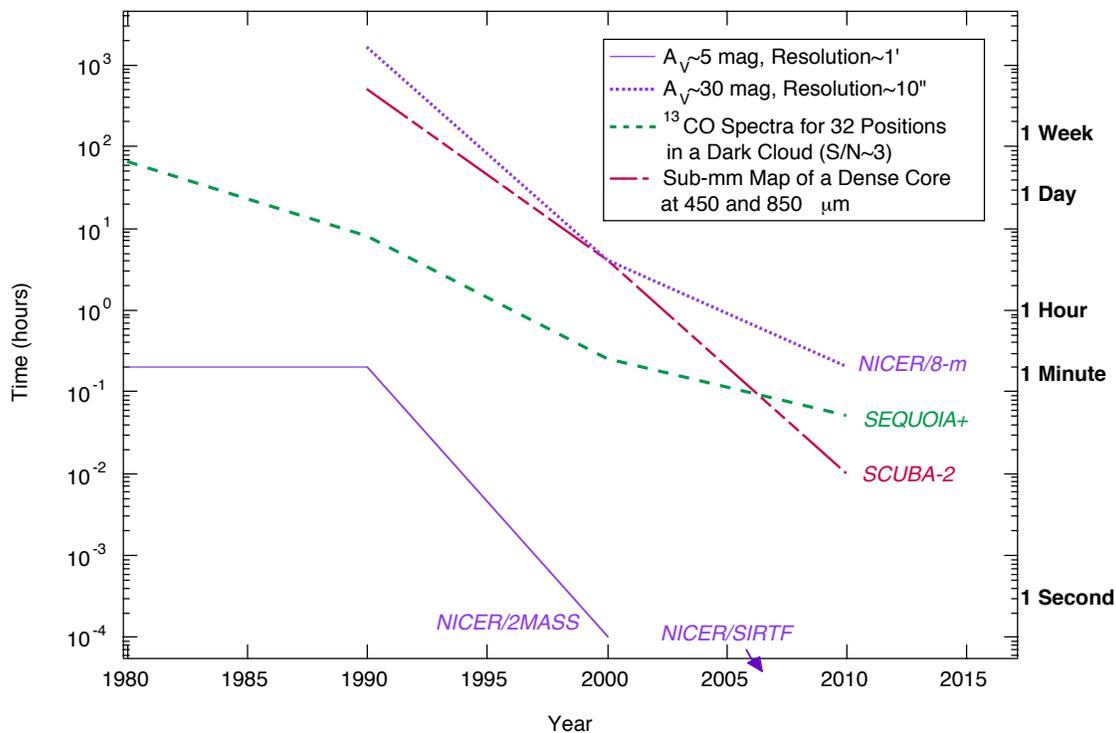
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<sup>1</sup> More information on the COMPLETE Survey, and the full NSF proposal, are available at: <http://cfa-www.harvard.edu/~agoodman/research8.html>

<sup>2</sup> More information on the Evans et al. SIRTf Legacy program is available at <http://peggysue.as.utexas.edu/SIRTf/>.

<b>Molecular Probe Line</b>	<b>This FCRAO proposal</b> requests time to begin fully-sampled OTF $^{12}\text{CO}$ and $^{13}\text{CO}$ maps of Perseus, $\rho$ -Ophiuchus, and Serpens. Note that Figure 1 illustrates that the needed observations will take $\sim 1$ minute per SEQUOIA footprint, as contrasted with $\sim 1$ hour for the same areal coverage with QUARRY, c. 1995.
<b>Extinction</b>	Alves and collaborators will complete the large-scale <b>NICER extinction maps using 2MASS</b> data by the <b>Summer of 2002</b> . This work has already begun, and all needed data are in-hand. "NICER" is the algorithm used to extract extinction maps from near-IR images, and NICER applied to 2MASS data yields a resolution of about $1'$ at $A_V$ of 5 mag for our targets.
<b>Thermal Emission</b>	<b>Extended mapping, sub-mm:</b> <b>Pilot HHT observations</b> to optimize sub-mm dust mapping technique with newly-installed $19\text{-element } 850\ \mu\text{m}$ bolometer are already scheduled for <b>February 2002</b> , and the remainder will be completed by 2003. Johnstone will take the lead on this project. <b>Extended mapping, far-IR; and Point Source Census, near-IR:</b> The <b>SIRTF</b> launch is currently scheduled for December 2002. With that launch date, the Legacy maps and near-IR censuses of Perseus, $\rho$ -Ophiuchus, and Serpens should be available before the <b>end of 2003</b> . Note that our NICER extinction maps will be updated and improved using the SIRTF point source data in lieu of the 2MASS data (see Figure 1).

Next Fall, we will begin proposing the COMPLETE observations that will sample the finer-scale higher-density structures within the extended maps we focus on here. At that time, we will request time on several telescopes to which our team members have special access, including the VLT, Magellan, the JCMT, and the IRAM 30-m. As explained below, we request one day of high-density-tracer ( $\text{N}_2\text{H}^+$  and CS) observing under this proposal as "pilot" observations aimed at refining our 2<sup>nd</sup> FCRAO COMPLETE proposal.

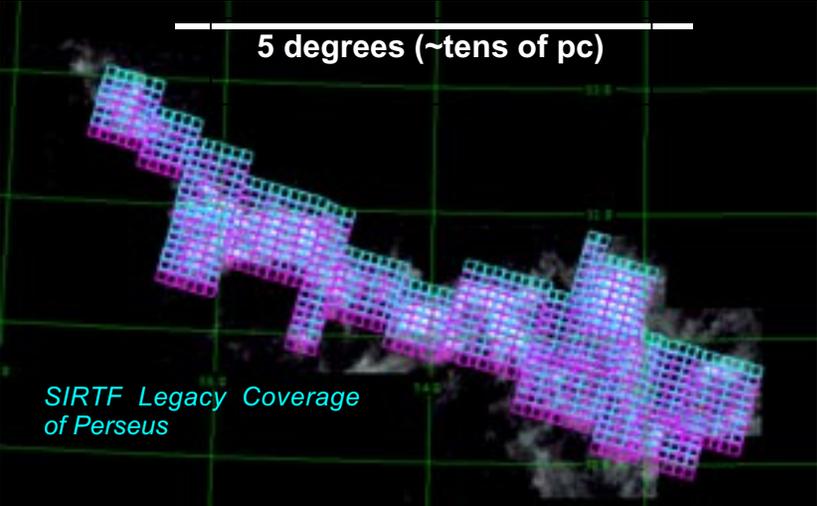
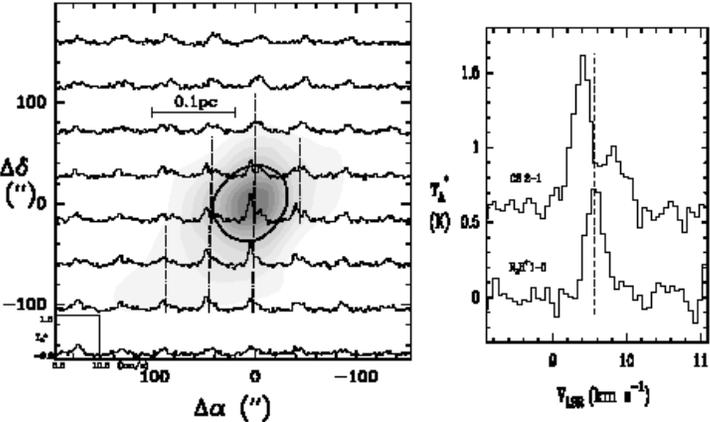


**Figure 1: Dramatic improvements in sensitivity that make a COMPLETE Survey feasible.** (Labels for sample instruments are shown near "2010" for graphical clarity, but these instruments will each be ready between now and  $\sim 2006$ . Note that "SEQUOIA+" refers to a SEQUOIA-like array on the LMT.)

We fully appreciate that even though we have violated the usual "page count" for FCRAO proposals, the scope and aim of COMPLETE may still be hard for those outside our field to appreciate based just upon what is written here. We ask that the TAC consult with Mark Heyer, who has read the full COMPLETE plan, for additional information. The molecular-line observations proposed in COMPLETE are its soul source of kinematic information. Since FCRAO is currently the **only** facility capable of providing these observations, we hope you can consider granting us the kind of "Key Project" time we request with this proposal.



## Appendix A: COMPLETE SUMMARY

Sample Region	Planned Observations	COMPLETE Results
 <p style="text-align: center; font-weight: bold;">5 degrees (~tens of pc)</p> <p style="color: cyan;">SIRTFLegacy Coverage of Perseus</p>	<ul style="list-style-type: none"> <li>• <b>SIRTFLegacy Observations</b> give dust temperature and column density maps and information on point sources <i>~5 degrees mapped with ~15" resolution (at 70 μm)</i></li> <li>• <b>NICER/2MASS Extinction Mapping</b> gives dust column density maps, used as target list in HHT &amp; FCRAO observations + reddening information <i>~5 degrees mapped with ~5' resolution</i></li> <li>• <b>HHT Observations</b> give dust column density maps, finds all "cold" sources <i>~20" resolution on all <math>A_V &gt; 2</math>"</i></li> <li>• <b>FCRAO/SEQUOIA <math>^{13}\text{CO}</math> and <math>^{12}\text{CO}</math> Observations</b> give gas temperature, density and velocity information <i>~40" resolution on all <math>A_V &gt; 1</math></i></li> </ul>	<ul style="list-style-type: none"> <li>• <b>Combined Thermal Emission (SIRTFL/HHT) data</b> will yield dust spectral-energy distributions, giving emissivity, <math>T_{\text{dust}}</math> and <math>N_{\text{dust}}</math></li> <li>• <b>Extinction/Thermal Emission inter-comparison</b> will give unprecedented constraints on dust properties and cloud distances, in addition to high-dynamic range <math>N_{\text{dust}}</math> map.</li> <li>• <b>Spectral-line/<math>N_{\text{dust}}</math> Comparisons</b> Systematic censuses of inflow, outflow &amp; turbulent motions will be enabled—for regions with <i>independent</i> constraints on their density.</li> <li>• <b>CO maps in conjunction with SIRTFL point sources</b> will comprise outflow census</li> </ul>
<p style="text-align: center; font-weight: bold;">L894-2</p>  <p style="text-align: center;"><math>\Delta\alpha</math> (")</p>	<p><i>Using target list generated from above column-density-limited surveys:</i></p> <ul style="list-style-type: none"> <li>• <b>NICER/8-m/IR camera Observations</b> give best density profiles for dust associated with "cores". <i>~10" resolution</i></li> <li>• <b>SCUBA Observations</b> give density and temperature profiles for dust associated with "cores" <i>~10" resolution</i></li> <li>• <b>FCRAO+ IRAM <math>\text{N}_2\text{H}^+</math> Observations</b> give gas temperature, density and velocity information for "cores" <i>~15" resolution</i></li> </ul>	<p><i>All of the above combinations &amp; inter-comparisons will be possible, plus:</i></p> <ul style="list-style-type: none"> <li>• <b>Multiplicity/fragmentation studies</b></li> <li>• Detailed modeling of <b>pressure structure</b> on <math>&lt; 0.3</math> pc scales</li> <li>• Searches for the "loss" of turbulent energy (<b>coherence</b>)</li> </ul> <p><i>Image at left shows an FCRAO <math>\text{N}_2\text{H}^+</math> map with CS spectra superimposed. The two spectra shown in detail are for the central position. Notice how the (thick) CS shows self-absorption, while the (thin) <math>\text{N}_2\text{H}^+</math> does not (Lee, Myers &amp; Tafalla 2001).</i></p>

## References Cited

- Arce, H.G. & Goodman, A.A. 2001a, *Molecular Bow Shocks, Jets & Wide-angle Winds: A High-Resolution Study of the PV Ceph Outflow*, ApJ, submitted Fall 2001.
- Arce, H.G. & Goodman, A.A. 2001b, *The Episodic, Precessing Giant Molecular Outflow from IRAS 04239+2436 (HH 300)*, ApJ, 554, 132.
- Arce, H.G. & Goodman, A.A. 2001c, *The Great PV Ceph Outflow: A Case Study in Outflow-Cloud Interaction*, ApJ, submitted Fall 2001.
- Goodman, A.A., Barranco, J.A., Wilner, D.J. & Heyer, M.H. 1998, *Coherence in Dense Cores. II. The Transition to Coherence*, ApJ, 504, 223.
- Simon, R., Jackson, J.M., Clemens, D.P., Bania, T.M. & Heyer, M.H. 2001, *The Structure of Four Molecular Cloud Complexes in the BU-FCRAO Milky Way Galactic Ring Survey*, ApJ, 551, 747.