RevMexAA (Serie de Conferencias), **3**, 275–278 (1995)

STELLAR JETS AND STAR FORMATION WITH A 6.5-m TELESCOPE

Patrick Hartigan
Department of Space Physics and Astronomy
Rice University, PO Box 1892, Houston, TX 77251-1892, USA

RESUMEN

Un telescopio de 6.5-m, optimizado para estudios espectroscópicos del medio interestelar, tendría impacto inmediato y a largo plazo en el estudio de estrellas jóvenes, sus discos de acreción y chorros. Considero algunos de los avances que esta facilidad podría aportar al tema y presento una lista de los instrumentos que proporcionarían el máximo de aportes científicos.

ABSTRACT

A 6.5-m telescope optimized for spectroscopic studies of the interstellar medium would have an immediate and long term impact upon the study of young stars, their accretion disks, and jets. I consider some of the advances that such a facility might bring to the field, and present a list of instruments that could provide the maximum scientific return.

Key words: **LINE: PROFILES — STARS: MASS LOSS — STARS: PRE-MAIN SEQUENCE**

1. INTRODUCTION

Just about everyone who has gone observing has at one time or another yearned for a larger telescope with better instrumentation to do their projects. It often seems that the really interesting objects are always just a bit too faint to observe with the desired spatial or spectral resolution. This panel discussion shows that the supporters of the proposed 6.5-m UNAM telescope are considering instrumentation early in the development of the new facility. I think this discussion is an excellent idea, because the quality of the instrumentation will determine to what extent the new facility will be able to address the fundamental questions concerning star formation and the interstellar medium that have been raised by the speakers at this conference.

There are two schools of thought as to how to equip observatories with instrumentation. Most national facilities tend to have what one might refer to as a "standard" suite of instruments, which include optical and near-infrared imagers with various plate scales, low and medium resolution long slit spectrographs, an echelle spectrograph, and perhaps a polarimeter and a multi-object spectrograph. These instruments are sufficient to satisfy the needs of a diverse group of astronomers with widely varying specialties, but the instrument budget and personnel are often fully committed to the standard instruments, so there is little room for technologies that are best suited for specific applications. Sometimes visitor instruments satisfy the need for a specialized applications, but these are often poorly documented and difficult to use.

Another possibility is to identify a specific set of problems to be addressed and to design the instrumentation accordingly. A successful example of this approach within the last decade has been the "Z-machine", an instrument optimized for redshift survey work on the 1.5-m SAO telescope on Mt. Hopkins. Having a few specialized instruments that run well usually means that the observatory operates fairly smoothly, and that the data acquisition and reduction procedures are well-understood. The disadvantage of this approach is that some astronomers will not be able to use the telescope easily for their research.

I would argue that UNAM should try to optimize its instrumentation for a specific set of problems. By the time the proposed 6.5-m telescope sees first light, there will already be several larger telescopes (Gemini N and S, VLT, Keck I and II, Subaru) in existence, and many of these will be equipped with a standard suite of instruments. If the instrumentation for the UNAM telescope complements, rather than competes with, the instruments on these larger telescopes then the 6.5-m could become a unique facility, and a world leader for research in a particular area. Given the large amount of interest by UNAM astronomers in the study of star formation and emission line objects, these areas would seem to be natural choices for specialization, but there are many other possibilities.

In what follows I summarize what I believe to be the most promising areas of research for the study of young stars (§2) and stellar jets (§3) with a large ground-based optical/near-infrared telescope. My selection of instruments in §4 does not consider any of the technical issues, such as beam sizes, image quality, reflective ghosts, etc. that must be addressed when the instruments are actually designed.

2. T TAURI STARS

T Tauri stars are young ($\lesssim 10^7$yr), low mass stars ($\lesssim 1.5M_\odot$) located near molecular clouds. About half of all young stars show evidence for circumstellar disks by way of their near-infrared excess emission or accretion signatures, while the other half are identified as young stars only by their strong X-ray radiation and absorption lines of lithium. Much of the current research in this field focuses on how accretion disks evolve and interact with young stars and their environments (Beckwith & Sargent 1993).

There are two numbers that are useful to keep in mind when considering how a large telescope will affect the direction of research for young stars. The first is the spatial scale of disks around T Tauri stars, which is typically 100 AU. The closest molecular clouds to the Sun lie at a distance of about 150 pc (e.g., Taurus, Cha I, Lupus, R CrA, ρOph), so that a circumstellar disk around a young star typically subtends somewhat less than an arcsecond for the closest objects. Adaptive optics will undoubtedly enable astronomers to obtain remarkable new images of disks around young stars, especially in the near-infrared, but it may be difficult for the 6.5-m to compete with the *Hubble Space Telescope* and the larger ground-based systems in this regard. Nevertheless, some sort of optical/IR camera with subarcsecond pixels is probably a good investment.

Another number that relates to this discussion is the rotational velocity of T Tauri stars, which are typically ~ 10 km s^{-1}. Studies of the rotational velocities of T Tauri stars in the last few years (Edwards et al. 1993; Bouvier et al. 1993) have shown that stars with accretion disks rotate *more slowly* than do their counterparts that lack accretion disks. This unexpected result has far-reaching implications for the transfer of angular momentum in all astronomical objects with accretion disks. These studies can only be done using a high resolution (R $>$ 30000) spectrograph. Moreover, only a high resolution spectrograph will allow astronomers to measure the optical excess emission, mass accretion rates, and kinematics of infalling and outflowing gas in young stars. Analysis of photospheric lines, abundances, and magnetic fields in these objects would all benefit from an efficient high resolution spectrograph on a large telescope.

Not all studies of young stars are best done in the nearest molecular clouds. For example, if we wish to measure the current initial mass function in the galaxy, study massive star formation, or determine how parameters such as the mass, rotation, temperature, and magnetic fields in molecular clouds influence the masses of the stars formed within the clouds we must observe young stars in giant molecular clouds. About 95% of all stars form within giant molecular clouds, most within clusters. The closest giant molecular cloud to the Sun is in Orion (460 pc), which is also the nearest site of massive star formation. The best way to estimate the masses and ages of a large sample of young stars is to use a multi-object spectrograph with medium spectral resolution to measure the spectral types of the objects. Such projects would benefit considerably from the large aperture of a 6.5-m telescope.

3. STELLAR JETS

Young stars redirect a fraction of the mass they accrete from their circumstellar disks into highly collimated supersonic outflows known as stellar jets. Shock waves form in the jets as the velocity fluctuates, and also when the jet encounters the ambient medium (e.g., Hartigan et al. 1993). Because stellar jets are resolved spatially and are dense enough to cool radiatively, one can measure radial velocities, electron densities, and line excitations in the flow, which is usually not possible for other astronomical objects with accretion and outflow, like active galactic nuclei and compact binaries.

As in the case of T Tauri stars, there are important spatial scales $\lesssim 100$ AU, such as the cooling distance behind shock waves in the flow and the size scale for the collimation of the jet. Velocities in stellar jets are usually several hundred km s^{-1}, but the most interesting kinematics appear when the velocities are resolved to within the thermal speed, ~ 10 km s^{-1}. Although *HST* has returned some remarkable images of stellar jets

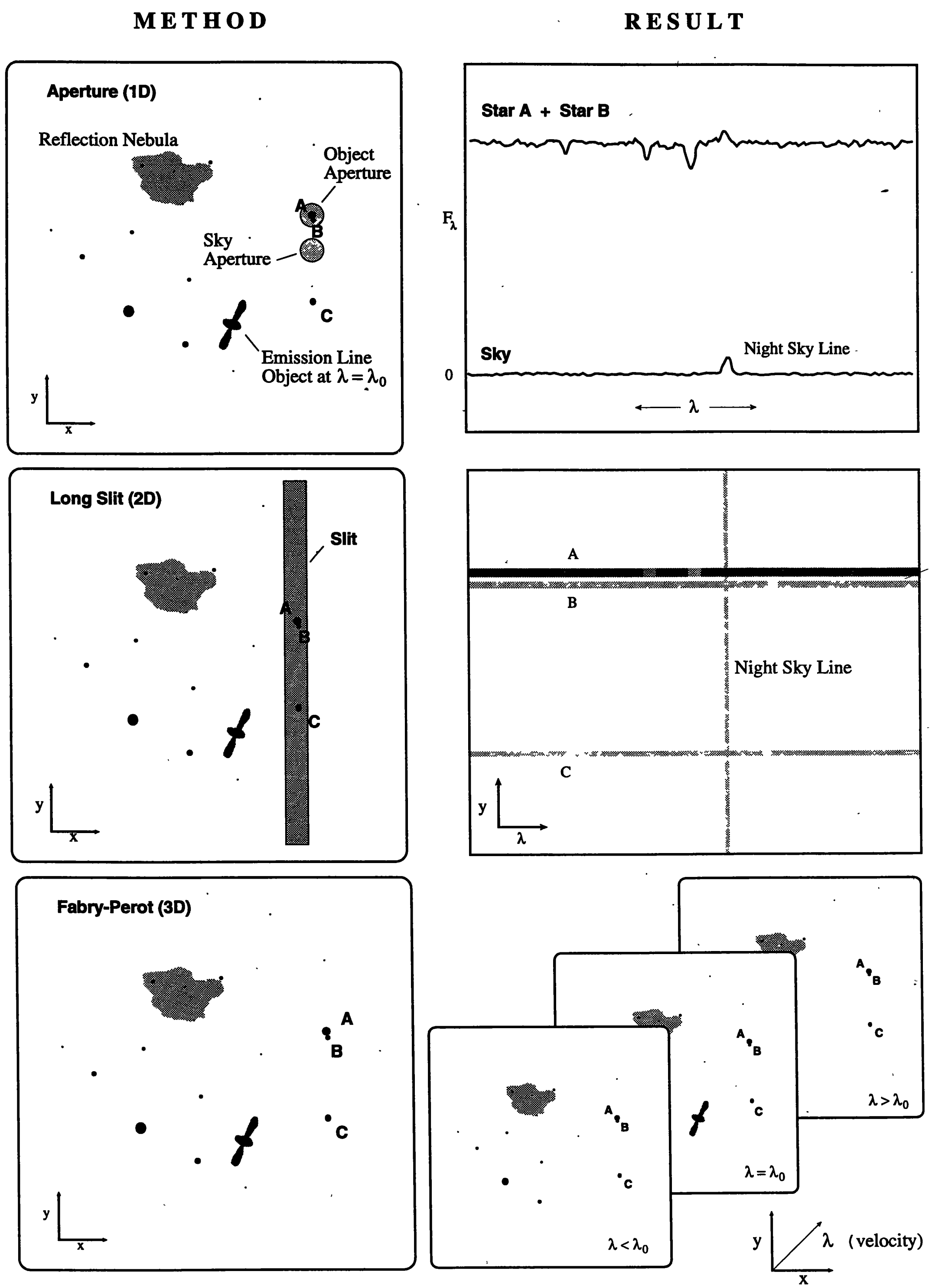

Fig. 1. An illustration of the differences between aperture spectroscopy (top), long slit spectroscopy (middle), and Fabry-Perot imagery (bottom). In this example the aperture includes light from both star A and star B, and the background emission line is removed by observing a blank patch of sky near the object. In the middle frames, a long slit records a spectrum at each point along the slit. This technique resolves the binary but still only records objects positioned within the slit. The Fabry-Perot produces a 3D data cube of position and velocity, and can distinguish continuum sources (stars and reflection nebulae) from emission line objects.

(Reipurth et al. 1995; Hester et al. 1995), the kinematics of these objects are easier to study from the ground, where the exposure times are longer and the aperture sizes larger.

To obtain a comprehensive picture of the kinematics in an extended emission nebulae such as a stellar jet, a planetary nebulae, or an H II region, we must measure the strength of each emission line of interest at each velocity and spatial position. The data are therefore 3-dimensional, where two of the dimensions are spatial directions on the sky, and the third "dimension" is radial velocity. The best instrument to use in these cases is a Fabry-Perot spectrometer, which gives an image of the source at each velocity (Figure 1).

Recently, several investigators (Raga & Cabrit 1993; Masson & Chernin 1993; Stahler 1994) have tried to relate what we know about stellar jets to the less collimated molecular outflows often observed around young stars. The means by which jets transfer momentum to their surroundings is a subject of much active research, and to address this issue we will have to combine the kinematics of optical and radio lines with those of infrared transitions such as the molecular hydrogen lines at 2 μm. Hence, a Fabry-Perot that operates at near-infrared wavelengths must also be a top priority for any new telescope.

4. INSTRUMENTATION FOR A 6.5-M TELESCOPE

The following is a list, ordered according to priority, of the five instruments I believe would be the most useful for studies of T Tauri stars and stellar jets. Remarkably, membership in this list did not seem to differ significantly among the various members of the panel, even though we considered our respective areas independently of one another. I hope that astronomers at UNAM will give serious consideration to optimizing the proposed 6.5-m telescope for spectroscopic studies of the interstellar medium. The result should be a unique facility that is at the forefront of research in this discipline.

INSTRUMENT	AREA OF STUDY
1. High Resolution Optical Fabry Perot ($\sim$ 10 km s^{-1})	Dynamics of Stellar Jets Physics of Radiative Shock Waves
2. High Resolution IR Fabry Perot ($<$ 30 km s^{-1})	Interaction of Jets and Molecular Flows
3. High Resolution Optical Spectrograph (R $\gtrsim$ 50,000)	Angular Momentum (Vsin $i <$ 10 km s^{-1}) Photospheric Magnetic Fields Accretion Studies
4. Hi-Res IR/Optical Imager w/Adaptive Optics	Resolve Disks, Go Deeper than HST Study Close Binaries Shock Structures in Jets
5. Multiple Object Spectrograph (red limit $\gtrsim$ 1 μm)	Deeper Studies of Young Clusters Better Census of Clouds

The author would like to thank P. Ghavamian for his help in drafting Figure 1.

REFERENCES

Beckwith, S. & Sargent, A. 1993, Protostars and Planets III, ed. E. H. Levy & J. I. Lunine (Tucson: University of Arizona Press), 521
Bouvier, J., Cabrit, S., Fernández, M., Martín, M., & Matthews, J. M. 1993, A&ASS, 101, 495
Edwards, S., Strom, S. E., Hartigan, P., Strom, K. M., Hillenbrand, L. A., Herbst, W., Attridge, J., Merrill, K. M., Probst, R., & Galley, I. 1993, AJ, 106, 372
Hartigan, P., Morse, J. A., Heathcote, S., & Cecil, G. 1993, ApJ, 414, L121
Hester, J. et al. 1995, in preparation
Masson, C. & Chernin, L. 1993, ApJ, 414, 230
Raga, A. & Cabrit, S. 1993, A&A, 278, 267
Reipurth, B. et al. 1995, AJ, in preparation
Stahler, S. 1994, ApJ, 422, 616