*RevMexAA (Serie de Conferencias)*, **29**, 110–113 (2007)

# THE FLAMINGOS-2 EARLY SCIENCE SURVEYS AND THE GTC

S. S. Eikenberry[1]

RESUMEN

Al iniciar las operaciones en Gemini Sur, FLAMINGOS-2 será uno de los instrumentos más poderosos de campo amplio en el infrarrojo cercano para imágenes y espectrógrafo multiobjetos que haya sido construido para usarse en un telescopio de clase 8-m. Para aprovechar mejor las fortalezas de FLAMINGOS-2 desde que inicie su ciclo de vida, el equipo instrumental ha propuesto usar 21 noches de su tiempo garantizado en 3 inspecciones – los Mapeos Científicos tempranos de FLAMINGOS-2 (F2ESS). Éstos corresponden a 3 temas científicos – el Centro Galáctico, la evolución galáctica, y la formación estelar. La inspección extragaláctica juega un papel importante en la planeación de las observaciones EMIR/GTC para el proyecto GOYA, y la inspección del Centro Galáctico es un precursor de las observaciones clave que se planean con FRIDA/GTCAO. Haré una reseña de la situación de FLAMINGOS-2, de las inspecciones F2ESS, y de la Inspección Gemini Genesis, así como su relación e impacto en la ciencia con el GTC.

ABSTRACT

Upon commissioning on Gemini South, FLAMINGOS-2 will be one of the most powerful wide-field near-infrared imagers and multi-object spectrographs ever built for use on 8-meter-class telescopes. In order to take best advantage of the strengths of FLAMINGOS-2 early in its life cycle, the instrument team has proposed to use 21 nights of Gemini guaranteed time in 3 surveys – the FLAMINGOS-2 Early Science Surveys (F2ESS). The F2ESS will encompass 3 corresponding science themes – the Galactic Center, galaxy evolution, and star formation. The extragalactic survey plays an important role in the planning of EMIR/GTC observations for the GOYA project, and the Galactic Center survey is a precursor for key planned scientific observations with FRIDA/GTCAO. I will review the status of FLAMINGOS-2, the F2ESS surveys, the additional Gemini Genesis Survey, and their relationship to and impact on GTC science.

*Key Words:* **GALAXIES: EVOLUTION — GALAXY: CENTER — INFRARED: GENERAL — INSTRUMENTATION: SPECTROGRAPHS — STARS: FORMATION — X-RAYS: BINARIES**



## 1. INTRODUCTION

Multi-object spectroscopy (MOS) is revolutionizing optical astronomy, in fields as far ranging as abundance studies of globular clusters to the large-scale structure of the Universe. While MOS instruments often have somewhat lower throughput than their single-object counterparts, they overcome this loss by observing tens to hundreds of objects at a single time. This has enabled large increases in sample sizes for many studies - often as much as 2 or more orders of magnitude.

Near-infrared spectroscopy has lagged significantly behind optical spectroscopy, with the first instruments featuring large-format (1024x1024-pixel or larger) detector arrays appearing on telescopes in just the past few years. In particular, near-infrared MOS have only begun to appear very recently. The first fully-cryogenic IR MOS, FLAMINGOS, was developed at the University of Florida, and has seen successful use at the Gemini South 8-m and MMT 6.5-m telescopes, and is currently in service as a facility instrument of the Kitt Peak 4-meter telescope (Elston et al. 2002).

FLAMINGOS-2 (Eikenberry et al. 2006) is a fully cryogenic near-infrared (0.9-2.5 $\mu m$) wide-field imager and multi-object spectrograph which is being built by the University of Florida Department of Astronomy for the Gemini 8-m telescopes on Mauna Kea, Hawaii and Cerro Pachon, Chile. FLAMINGOS-2 shares much of the instrument heritage of FLAMINGOS (Elston et al. 2002), as both a wide-field imager and MOS. FLAMINGOS-2 differs from FLAMINOGS primarily in having optics and opto-mechanical systems optimized for the Gemini telescopes, providing 0.18-arcsec pixels and a 6.2-arcmin field of view - covering approximately 6 times the solid angle of FLAMINGOS on the same tele-

[1]Department of Astronomy, University of Florida, 211 Bryant Space Science Building, Gainesville, Fl 32608, USA (eiken@astro.ufl.edu).

scopes. When commissioned on Gemini in late 2007, FLAMINGOS-2 will be an instrument of similar capabilities to the EMIR facility instrument for the Gran Telescopio Canarias and, due to its delivery date several years prior to EMIR, provide advanced access to this type of science on large telescopes.

Upon completion of the FLAMINGOS-2 (F2) commissioning work, the F2 instrument team at the University of Florida (UF) will have access to approximately 27 nights of guaranteed observing time with F2 on Gemini. This team consists primarily of the Principal Investigator, Stephen Eikenberry, and two Instrument Scientists, S. Nicholas Raines and Reba Bandyopadhyay, as well as Anthony Gonzalez. In order to take best advantage of the strengths of F2 early in its life cycle, the instrument team has proposed that the majority of this guaranteed time be used in 3 surveys - the FLAMINGOS-2 Early Science Surveys (F2ESS). The F2ESS surveys will encompass 3 corresponding scientific themes - the Galactic Center, extragalactic astronomy, and star formation. Each of these surveys will be carried out by the F2 instrument team in collaboration with groups of scientists drawn from the Gemini community and elsewhere, with the goal of maximizing the early scientific return from F2.

In this paper, I will briefly review the designed performance characteristics of FLAMINGOS-2 as well as the current instrument status. I will then move on to a brief discussion of each of the F2ESS projects as well as the Gemini Genesis Survey, but paying particular attention to the FLAMINGOS-2 Galactic Center Survey (F2GCS).



## 2. FLAMINGOS-2 OVERVIEW & STATUS

### 2.1. *Instrument Overview*

FLAMINGOS-2 is an imaging spectrometer for use at the f/16 telescope focal surface of either Gemini 8-m telescope. It consists of a collimator providing a pupil image of high quality, and a camera following the collimator to produce a reimaged focal surface on the detector array with 2048x2048 18$\mu m$ pixels. A combination of filters and grisms are placed near the pupil for broad- and narrow-band imaging and moderate-resolution spectroscopy. A pupil mask reduces excess thermal emission from the telescope. The imaging mode field will form an inscribed circle on the detector. FLAMINGOS-2 may also be fed with a slower (f/30) beam provided by the Gemini Multi-Conjugate Adaptive Optics (MCAO) system. In spectroscopic mode, a selection of 9 MOS plates and 3 long slits mask off-target locations in the focal plane, passing target light through the collimator to a selectable grism inserted into the beam after the pupil. The grism disperses the incident light, which is reimaged as a spectrum on the detector array by the camera optics. We present the basic optical performance requirements for FLAMINGOS-2 in Table 1.

TABLE 1

FLAMINGOS-2 PERFORMANCE REQUIREMENTS

| Parameter | Value |
|---|---|
| Wavelength Range | $0.9 - 2.5\mu$m |
| Imaging field of view | 6.2-arcmin circular |
| Pixel scale | $0.180 \pm 0.002$ arcsec |
| Detector | HAWAII-2 ($2048 \times 2048$) pix |
| MOS field of view | $6 \times 2$-arcmin |
| MOS multiplex gain | up to $\sim 100$ targets |
| Low-res spectroscopy | $R \sim 1300$ JH or HK bands |
| High-res spectroscopy | $R \sim 3300$ J, H, or K band |
| MCAO field of view | $3 \times 1$-arcmin |
| MCAO pixel scale | 90-mas/pixel |

### 2.2. *FLAMINGOS-2 Status*

FLAMINGOS-2 is currently undergoing final full-system testing at the University of Florida. The FLAMINGOS-2 instrument team at the University of Florida includes Steve Eikenberry (PI), Reba Bandyopadhyay, Greg Bennett, Richard Corley, Skip Frommeyer, Anthony Gonzalez, Kevin Hanna, Rick Herlevich, David Hon, Jeff Julian, Roger Julian, Toni Marin, Charlie Murphey, Nick Raines, William Rambold, David Rashkind, Craig Warner, and the late Richard Elston. The FLAMINGOS-2 On-Instrument Wavefront Sensor was developed at the Herzberg Institute of Astrophysics in Canada by a team including Brian Leckie, Rusty Gardhouse, Jennifer Dunn, Murray Fletcher, Bob Wooff, and Tim Hardy.

As of this writing, FLAMINGOS-2 has been fully integrated in the laboratory at the University of Florida, and has successfully demonstrated high-performance operation in all of its major modes. It will be shipped to Gemini South in late 2007 for on-telescope commissioning. In addition to the instrument hardware and control software, the UF team has developed a data pipeline tool for FLAMINGOS-2 called the Florida Analysis Tool Born Of Yearning for high quality scientific data (FATBOY). FATBOY combines Python scripting and code with PyRAF calls to provide imaging, long-slit spectroscopy, and MOS spectroscopy data reduction capabilities in a rapid, automated manner. It has been extensively tested with FLAMINGOS data, and is currently in scientific use at UF.

## 3. THE FLAMINGOS-2 EARLY SCIENCE SURVEYS

In May of 2004, as the FLAMINGOS-2 PI, I initiated discussions with the Gemini Observatory administration to develop 3 surveys to make use of the FLAMINGOS-2 guaranteed payback time. Given the broad scientific range and tremendous power for large-scale surveys of FLAMINGOS-2, I deemed that this approach would make the most effective use of the instrument's scientific potential in its early phases. Based on the scientific interests of the FLAMINGOS-2 instrument team, we selected surveys to be focused in the areas of the Galactic Center, galaxy evolution, and star formation. The plan is for each survey to be allocated 7 nights of FLAMINGOS-2 guaranteed time to carry out its work. I briefly review two of the surveys below, and spend some more time on the FLAMINGOS-2 Galactic Center Survey (F2GCS). I also briefly touch on a related survey planned for early in the life of FLAMINGOS-2, which is of interest to the GTC community – the Gemini Genesis Survey.

### 3.1. *The F2 Galaxy Evolution Survey and F2 Star Formation Survey*

The FLAMINGOS-2 Galaxy Evolution Survey (F2GES) portion of the three F2ESS surveys is focused on the evolution of galaxies, particularly at moderate to high redshifts ($z > 1$). The fields being studied for targeting in this F2ESS will include those already deeply imaged in existing multi-wavelength surveys (i.e. the Chandra Deep Field South, or CDFS). Particular areas of interest include star-forming galaxies, the $H\alpha$ luminosity function at high redshift, AGN, and others. This portion of the F2ESS has team co-leads Anthony Gonzalez and Rafael Guzman. Other team members at this time include R. Bandyopadhyay, S. Eikenberry, F. Hamann, N. Raines, V. Sarajedini (all of UF), and Luc Simard (HIA). Of particular interest to the GTC community is that we plan to carry out this F2ESS in collaboration with the GOYA project for GTC. In particular, the FLAMINGOS-2 survey will serve as a pathfinder survey for the larger EMIR-based GOYA survey on the GTC.

The FLAMINGOS-2 Star Formation Survey (F2SFS) portion of the three F2ESS surveys is focused on the formation of stars in the Milky Way Galaxy. Detailed planning for the F2SFS is currently underway, and is being led at UF by team co-leads Nick Raines and Elizabeth Lada.

### 3.2. *The F2 Galactic Center Survey*

The FLAMINGOS-2 Galactic Center Survey (F2GCS) portion of the three F2ESS surveys is focused on the unusual properties of stars, gas, and black holes at the center of the Milky Way. The key goals of the F2GCS are to study and identify the unusual population of Chandra-identified X-ray sources at the Galactic Center, and to use the star formation history of this region to probe the physics of the "bulge/black-hole connection" in galaxies. This survey is being led by team co-leads Steve Eikenberry (UF) and Bob Blum (NOAO). Other team members include F. Baganoff (MIT), F. Bauer (Columbia), R. Bandyopadhyay (UF), D. Crampton (HIA), C. Dewitt (UF), A. Gonzalez (UF), M. Muno (Caltech), K. Olsen (NOAO), N. Raines (UF), and K. Sellgren (Ohio State).

#### 3.2.1. *X-ray sources in the F2GCS*

The Galactic Center is a wonderful and mysterious place in our local Universe. It contains a supermassive black hole in Sgr A*, loads of massive stars and clusters and, importantly, more than 2000 identifiable X-ray point sources in its central region (Muno et al. 2006). These X-ray sources are unusual in their properties, being both faint (typical luminosities $L_x < 10^{34}$ ergs s$^{-1}$) and spectrally hard. These properties and their number density at the Galactic Center are not compatible with other known source populations in the Galaxy.

Historically, much of the information on X-ray binary source populations in the Galaxy has come from studies of optically- and infrared-identified counterparts. From them, one can determine the donor star type and thus a rough mass estimate. Furthermore, optical/IR studies can frequently reveal variations in brightness and/or wavelength to determine the binary period and mass function of the system – two critical parameters for assessing the nature of the underlying sources. However, this is a non-trivial task in the Galactic Center region. First of all, the high reddening ($A_V \sim 20 - 40$ mag) makes optical observations highly impractical, so that only infrared techniques are efficient for these studies. Secondly, the fields are highly crowded. Virtually every Chandra X-ray source has an IR counterpart candidate within ∼ 1-arcsec at $K < 16$ mag – but our statistical analyses indicate that ∼ 85% of these candidates are spurious chance superpositions. Thus, we need to sort the "wheat" from the "chaff".

FLAMINGOS-2 presents the perfect tool for carrying this out. IR spectroscopy of potential targets can separate out many false positives, in that X-ray binaries often carry spectral signatures of accretion – particularly emission lines such as Br$\gamma$, HeI, and HeII (e.g. Mikles et al. 2006). Observing all 2000 IR candidates should yield ∼ 300 newly-identified X-ray binaries in the Galactic Center region – increasing the number of such optical/IR identifications in this region by 2 orders of magnitude and effectively doubling the entire Galactic sample of optical/IR X-ray binary counterparts. With previous instruments, such observations would take about 1 hour per target on an 8-meter-class telescope – or roughly 250 nights of Gemini time (!!). However, the massive multiplex gain of FLAMINGOS-2 will allow us to accomplish this task in $\sim 5 - 7$ nights of observation – an eminently feasible task.

#### 3.2.2. *Star Formation History and the F2GCS*

While the F2GCS will find many X-ray source counterparts in a relatively short amount of time, the fundamental efficiency of searching will only be ∼ 15%, as set by the expected "false coincidence" rate (see above). However, we will not simply "waste" the resulting ∼ 1700 IR spectra. Rather, these HK $R \sim 1300$ spectra will be combined with another ∼ 3000 stars selected from our pre-imaging survey to provide nearly 5000 spectra of stars in this field – primarily Red Giant Branch (RGB) stars. This will produce a master catalog of many such stars in this field, and the spectra will cover both the $H/K$ "steam" bands and the CO obserorption bands. Combining measurements of these features will allow us to measure the luminosity class and extinction for each individual star. Combining these with photometry (already obtained from the CTIO 4-meter telescope and ISPI instrument) will provide $M_{bol}$ and $T_{eff}$ for each star. This in turn places them on a Hertzsprung-Russell diagram.

Blum et al. (2003) used a similar approach based on 75 stars to constrain the star formation history of the Galactic Center region. The F2GCS will increase the sample size for this work by nearly 2 orders of magnitude (!). Just as importantly, the F2GCS will reach much ($\Delta K \sim 5$ mag) fainter than the previous work, and thus be dominated by stars for which systematic errors due to atmospheric spectral variations are minimized. In this way, we can constrain the star formation history of the Galactic Center over the past 4 billion years. Since these stars are effectively "fossil tracers" of the motion of star-forming gas through the region over this long time, we should be able to link this flow to the mass evolution history of the super-massive black hole in Sgr A*. Future work will include high-resolution IR spectroscopy of F2GCS-selected stars to also determine the abundances and kinematics of these stars over time, using instruments such as the FRIDA adaptive optics imager and high-resolution spectrograph on the GTC.

### 3.3. *Gemini Genesis Survey*

Another survey for early science with FLAMINGOS-2 (though not part of the formal F2ESS projects) is the Gemini Genesis Survey. This survey makes use of a cryogenic tunable filter for FLAMINGOS-2 which images a ∼ 1-arcmin field of view with the Gemini MCAO system at ultra-narrow bandpasses of $R \sim 1000$. The survey will use the gravitational lensing boost to image the first stars formed after the Big Bang – so-called "First Light" or "Cosmic Dawn" science. The tunable filter (F2T2) is nearing completion now and will be integrated shortly after FLAMINGOS-2 commissioning. The Gemini Genesis Survey is the brainchild of Bob Abraham (U. Toronto), and is co-led by Abraham (Canadian PI), Joss Bland-Hawthorn (Australian PI), and Steve Eikenberry (USA PI). Other team members from across the Gemini consortium include: Betsy Barton, Matt Bershady, David Crampton, Rene Doyon, Mike Gladders, Joe Jensen, Jeff Julian, Jean-Paul Kneib, Dave Loop, Erin Mentuch, Nick Raines, Al Scott, and JD Smith. The Gemini Genesis Survey with FLAMINGOS-2 may provide very complementary capabilities to the shorter-wavelength tunable filters provided by OSIRIS on the GTC.

## REFERENCES

Blum, R. D., Ramírez Solange V., Sellgren, K., Olsen, K. 2003, ApJ, 597, 323

Eikenberry, S., et al. 2006, Proc. SPIE, 6269, 39

Elston, R. 2002, Proc. SPIE, 4841, 1611

Mikles, V. J., Eikenberry, S. S., Muno, M. P., Bandyopadhyay, R. M., & Patel, S. 2006, ApJ, 651, 408

Muno, M. P., Bauer, F. E., Bandyopadhyay, R. M., & Wang, Q. D. 2006, ApJS, 165, 173