T. Gull 680

SPACE TELESCOPE IMAGING SPECTROGRAPH
CO-INVESTIGATOR SUPPORT

FINAL REPORT

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Final Report STIS GTO Support Contract

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Summary

The purpose of this contract has been to support investigation of astronomical problems primarily using data from the Space Telescope Imaging Spectrograph (STIS) on the Hubble Space Telescope (HST). As a Co-investigator on STIS, I participated in several projects, which will be described below. The research resulted in 19 papers in refereed journals, 8 papers published in conference proceedings, and 27 papers presented at meetings. There are still at least four papers submitted or in press, as well as some additional research yet to be written up for publication. The research has also produced one master's thesis and two PhD dissertations currently underway, with one to be completed Spring 2003. Undergraduates have participated in the analysis of supporting observations. One student has published some of his results in a web-based refereed publication for undergraduate research (www.jyi.org). I have given several talks to the general public describing results from the HST as well as the results of my research. I have been named the UNLV Regents' Outstanding Faculty Member for 1995 and received the 2002 College of Science Distinguished Researcher's Award as a result of these activities.

Star Formation in Interacting Galaxies

Star formation and its role in galaxy evolution is one of the major problems in modern astronomy. Recent work has indicated galaxy interactions and mergers play a big role in star formation and galaxy morphology. To study the impact of mergers and interactions on star formation, we chose four galaxy pairs or mergers in which to investigate recent star formation. These targets are in various stages of interaction. NGC 3994/3995 are gravitationally interacting, NGC 3395/3396 are predicted to merge in about 100 million years, and NGC 4194 is an advanced merger. The forth target, IRAS15179+3956 is a peculiar galaxy with two nuclei, apparently undergoing a merger, and located in the low density environment of the Bootes Void. The three other targets are relatively nearby in more populated parts of the universe. Groundbased imaging and spectroscopy were obtained to identify the strongest starforming regions in the galaxies.

STIS ultraviolet and visible imaging was obtained for the nearby galaxies. IRAS15179+3956 is faint, because of its distance, and was observed only in visible wavelengths. The absence of suitable filters to use with the STIS imager made WFPC2 a better choice for these observations. The most active star forming regions in the nearby galaxies were selected for follow-up spectroscopy with STIS.

Our results have proven to be quite interesting. We have identified several star forming regions bright in the ultraviolet in galaxies NGC 3395, NGC 3396, NGC 3994, NGC 3995 and NGC 4194. Most of the ultraviolet knot luminosity distributions were fit by power laws, as expected from the results on other galaxies, but the distribution for NGC 4194 can be fit by a

gaussian distribution. This result is interesting in relation to the expectation that some of the knots are the precursors of globular clusters, which has been suggested by others. Older globular cluster systems around the Milky Way and other galaxies have gaussian luminosity distributions and one question has been how and when the power law knot luminosity distributions become gaussian. Our results suggest this change may occur late in the merger process itself, and early in the life of the clusters. There are not enough knots in NGC 3994 to reliably determine the luminosity distribution. This galaxy is not undergoing a starburst. Star formation is taking place in the spiral arms and appears to be part of normal spiral galaxy evolution.

We compared our data with Starburst99 evolutionary models to estimate the ages and masses of the knots. Most of the ultraviolet knots are younger than 10 - 20 million years (Myrs), not surprising since the massive young stars which produce most of the ultraviolet emission only live about 10 Myrs. The sizes of the knots were determined by fitting their profiles on the ultraviolet images. Masses were estimated by comparison with the Starburst99 models with correction for the lower mass cut-off of one solar mass for the models. Masses and radii were used to estimate which knots are likely to be gravitationally bound and thus possible protoclusters. While some of the knots are most probably bound, others are not.
The most luminous, massive protoclusters are found in the most mature merger, NGC 4194. Whether that is due to the maturity of the merger or the nature of the original galaxies and the amount of interstellar gas they contained is a subject for further investigation.

Analysis of the spectroscopy of NGC 3395 and NGC 3396 indicates the metallicity of the star forming regions is about half the solar value. This agrees with our lower resolution groundbased spectra of extended regions of the galaxies. There is also evidence of Wolf-Rayet stars in several of the knots. In one of the more massive star forming regions, there is a large 'bubble', a region of space cleared of interstellar matter by strong stellar winds. There is also evidence of a large number of Wolf-Rayet stars, known to have strong stellar winds, in this region.

The analysis of IRAS15179+3956 confirms groundbased data suggesting this object is an interacting pair. Comparison with Starburst99 models indicates enhanced star formation within the last 10 Myrs. Low resolution N-body simulations reproduce the large, observed tidal tail and suggest a mass ratio for the original galaxies of at least 2:1.

Participants in the analysis of these STIS results and supporting ground based data included STIS co-investigator Dr. M.E. Kaiser, Dr. Charles Nelson, Prof. Shawn Cruzen, Research Assistant Diane Eggers, graduate students Mark Hancock, Kenneth Plaks, and Alessandra Stone, and undergraduates Robert Bachilla and Jennifer Yates. This work has been and continues to be supported in part by a grant from the Nevada Space Grant Consortium.

Nuclear Dynamics in Galaxies

Our group also participated in the STIS team's key project concerning nuclear dynamics in galaxies. This effort was led by Dr. Charles H. Nelson, who used the CaII triplet absorption lines at ~ 8600 Å to investigate the existence and mass of a black hole at the center of the nearby

S0 galaxy NGC 7332. Though the best fit three-integral model to the data indicated a small black hole, the fit is also consistent with no black hole in this galaxy.
Nelson and Weistrop also participated in analyses of the mass of black holes in other galaxies in the team's sample.

A Detailed Analysis of the Activity in NGC 4151

We also took part in the STIS team's extensive study of the nearby Seyfert galaxy NGC 4151. While we participated in several investigations, we took the lead on the analysis of the kinematics and emission lines of the narrow-line region of NGC 4151. The kinematics shows evidence for three components, a low-velocity system in normal disk rotation, a high-velocity system in radial outflow at a few hundred kilometers per second relative to the systemic velocity, and an additional high-velocity system also in outflow with velocities up to 1400 km s^{-1}, in agreement with results from STIS slitless spectroscopy. We explored two kinematic models which suggest that radial outflow in the form of a wind is the most likely explanation. Our data also indicate that the wind may be decelerating with distance from the nucleus. The emission-line ratios along the slits are all entirely consistent with photoionization from the nuclear continuum source. There is no strong evidence for interaction between the radio jet and the NLR gas in either the kinematics or the emission-line ratios, in agreement with the recent results of Kaiser et al., who found no spatial coincidence of NLR clouds and knots in the radio jet. These results are in contrast to other recent studies of nearby active galactic nuclei that find evidence for significant interaction between the radio source and the NLR gas.

Public Outreach

During the course of this contract, I presented the following public talks describing the results of my research and/or recent results from the Hubble Space Telescope.

August 1, 2002, Las Vegas Astronomical Society: Hubble Observations of Young Globular Clusters and What's Next: The Next Generation Space Telescope

June 27, 2002, Westminster Woods Senior Center (Pennsylvania) : The Hubble Space Telescope

May 24, 2001, Las Vegas Senior Center: Recent Results from the Hubble Space Telescope

February 7, 2000, University Forum Lecture (UNLV): Recent Observations with the Hubble Space Telescope, Colliding Galaxies and Active Galactic Nuclei

January 15, 2000, Space Science Center, Columbus State University (Columbus, GA): Star Formation, Active Galaxies, and Black Holes: Recent Observations with the Hubble Space Telescope

July 1, 1999, Las Vegas Astronomical Society, Recent Results from the Hubble Space Telescope.

I was also interviewed by the local press several times concerning Hubble Space Telescope and

other NASA issues.

A complete bibliography follows, as well as selected reprints of our published results.

Bibliography

Publications in Refereed Journals

Weistrop, D., Eggers, D., Hancock, M., Nelson, C.H., Bachilla, R., Kaiser, M.E. 2002, 'Looking Closely at Medusa: Star Formation at the Center of NGC 4194', (submitted)

Eggers, D., Weistrop, D., Stone, A., Nelson, C.H., Hancock, M. 2002, 'Hubble Space Telescope Observations of Star Forming Regions in NGC 3994/3995', (submitted)

Ishibashi, K., Gull, T.R., Davidson, K., Smith, N., Lanz, T., Lindler, D., Feggans, K., Verner, E., Woodgate, B.E., Kimble, R.A., Bowers, C.W., Kraemer, S., Heap, S.R., Danks, A. C., Maran, S. P., Boggess, A., Green, R. F., Hutchings, J.B., Jenkins, E. B., Joseph, C. L., Kaiser, M.E., Linsky, J.L., Moos, H. W., Roesler, F., Timothy, J. G., Weistrop, D. 2002, Astronomical Journal, 'Discovery of a Little Homunculus within the Homunculus Nebula' (submitted)

Hancock, M., Weistrop, D., Eggers, D., Nelson, C.H. (2003) 'Star Forming Knots in the UV Bright Interacting Galaxies NGC 3395 and NGC 3396', Astron.J., (in press)

Hutchings, J.B., Crenshaw, D.M., Kraemer, S.B., Gabel, J.R., Kaiser, M.E., Weistrop, D., Gull, T.R. (2002) 'Balmer and HeI Absorption in the Nuclear Spectrum of NGC 4151', Astron.J., 124, 2543.

Grady, C. A., Polomski, E. F.,Henning, Th.,Stecklum, B.,Woodgate, B. E.,Telesco, C. M., Pina, R. K.,Gull, T. R.,Boggess, A.,Bowers, C. W.,Bruhweiler, F. C.,Clampin, M.,Danks, A. C.,Green, R. F.,Heap, S. R.,Hutchings, J. B.,Jenkins, E. B.,Joseph, C.,Kaiser, M. E.,Kimble, R. A.,Kraemer, S.,Lindler, D.,Linsky, J. L.,Maran, S. P.,Moos, H. W.,Plait, P.,Roesler, F.,Timothy, J. G.,Weistrop, D. (2001) 'The Disk and Environment of the Herbig Be Star HD 100546', Astron.J., 122,3396.

Ruiz, J.R., Crenshaw, D. M., Kraemer, S. B., Bower, G. A.,Gull, T. R., Hutchings, J. B., Kaiser, M. E., Weistrop, D. (2001) 'Kinematics of the Narrow-Line Region in the Seyfert 2 Galaxy Markarian 3' Astron.J., 122, 2961.

Gebhardt, K., Lauer, T. R., Kormendy, J., Pinkney, J., Bower, G. A., Green, R., Gull, T., Hutchings, J. B., Kaiser, M. E., Nelson, C. H., Richstone, D., Weistrop, D. (2001) ' M33: A Galaxy with No Supermassive Black Hole' Astron.J. 122, 2469

Kraemer, S.B., Crenshaw, D.M., Hutchings, J.B., George, I.M., Danks, A.C., Gull, T.R., Kaiser, M.E., Nelson, C.H., Weistrop, D., Vieira, G.L. (2001) 'Space Telescope Imaging Spectrograph Echelle Observations of the Seyfert Galaxy NGC 4151: Physical Conditions in the Ultraviolet Absorbers', ApJ, 551, 671.

Bower, G.A., Green,R.F., Bender,R., Gebhardt, K., Lauer, T.R., Magorrian, J., Richstone, D.O., Danks,A., Gull, T., Hutchings, J., Joseph,C., Kaiser, M.E., Weistrop, D.,

Woodgate, B., Nelson, C., and Malumuth, E.M. (2001) 'Evidence of a Supermassive Black Hole in the Galaxy NGC 1023 from the Nuclear Stellar Dynamics' Ap.J. 550, 75.

Joseph, C.L., Merritt, D., Olling, R., Valluri, M., Bender, R., Bower, G., Danks, A., Gull, T., Hutchings, J., Kaiser, M.E., Maran, S., Weistrop, D., Woodgate, B., Malumuth, E., Nelson, C., Plait, P., Lindler, D. (2001) 'The Nuclear Dynamics of M32.I. Data and Stellar Kinematics', ApJ 550, 668.

Crenshaw, D.M., Kraemer, S.B., Hutchings, J.B., Danks, A., Gull, T., Kaiser, M.E., Nelson, C.H., Weistrop, D. (2000), 'Space Telescope Imaging Spectrograph Echelle Observations of NGC 4151: Variable Ionization of the Intrinsic UV Absorbers', Astrophys.J 545, L27.

Crenshaw, D.M.,Kraemer, S.B., Hutchings, J.B.,Bradley, L.D.,II, Gull, T.R., Kaiser, M.E., Nelson, C.H., Ruiz, J.R,Weistrop, D.(2000) 'A Kinematic Model for the Narrow Line Region in NGC 4151', AJ,120,1731.

Bower, G.A., Green, R.F., Quillen, A.C., Danks, A., Gull, T., Hutchings, J., Joseph, C., Kaiser, M.E., Weistrop, D., Woodgate, B., Malumuth, E. M., Nelson, C.(2000) 'The Ionization Source in the Nucleus of M84', ApJ,534,189.

Nelson, C.H., Weistrop, D., Hutchings, J.B., Crenshaw, D.M., Gull, T.R., Kaiser, M.E., Kraemer, S.B., Lindler, D. (2000) 'STIS Longslit Spectroscopy of the Narrow Line Region of NGC 4151. I. Kinematics and Emission Line Ratios', ApJ, 531,257.

Kraemer, S.B., Crenshaw, D.M., Hutchings, J.B., Gull, T.R., Kaiser, M.E., Nelson, C.H., Weistrop, D.(2000) STIS Longslit Spectroscopy of the Narrow Line Region of NGC 4151. II. Physical Conditions along Position Angle 221°', ApJ, 531,278.

Kaiser, M.E., L. D. Bradley II, J. B. Hutchings, D. M. Crenshaw, T. R. Gull, S. B. Kraemer, C. H. Nelson, J. Ruiz, and D. Weistrop (2000) `The Resolved Narrow Line Region in NGC 4151', Ap.J., 528, 260.

Hutchings, J.B., Crenshaw, D.M., Danks, A.C., Gull, T.R., Kraemer, S.B., Nelson, C.H., Weistrop, D., Kaiser, M.E., Joseph, C.J. (1999) 'High Velocity Line Emission in the NLR of NGC 4151', Astronomical Journal, 118, 2101.

Woodgate, B. E., et al. (1998) `The Space Telescope Imaging Spectrograph Design', PASP, 110, 1183.

Hutchings, J.B., et al. (1998) `Spatially Resolved Spectra of 3C Galaxy Nuclei', AJ, 116, 634.

Hutchings, J.B., et al. (1998) `Gas Cloud Dynamics near the nucleus of NGC 4151', ApJ, 492, L115-L120.

Bower, G. et al. (1998) `Kinematics of the Nuclear Ionized Gas in the Radio Galaxy M84 (NGC 4374)', ApJ, 492, L111-L114.

Kimble, R.A., et al. (1998) `The On-Orbit Performance of the Space Telescope Imaging Spectrograph', ApJ, 492, L83-L94.

Papers in Non-refereed Publications

Kraemer, S.B., Crenshaw, D.M., Hutchings, J.B., George, I.M., Gull, T.R., Kaiser, M.E., Nelson, C.H., Weistrop, D. (2002) 'Physical Conditions in the UV Absorbers in NGC 4151', in Mass Outflow in Active Galactic Nuclei: New Perspectives, ASP Conf. Proc., vol. 255, edited by D.M. Crenshaw, S.B. Kraemer, & I.M. George (San Francisco, ASP) p. 93.

Weistrop, D., Eggers, D., Nelson, C. H., Kaiser, M. E. (2001) 'HST Observations of Star Formation in Interacting Galaxies: NGC 4194, the``Medusa"', in Gas and Galaxy Evolution, ed. by J.E. Hibbard, M.P. Rupen, J.H. van Gorkom, ASP Conf. Series 240, 210.

Green, R. F., Richstone, D., Boroson, T., Bower, G., Gebhardt, K., Kormendy, J., Magorrian, J., Nelson, C., Weistrop, D. (2001) ' AGN and the Demographics of Supermassive Black Holes', in AGN Surveys, Proc. of IAU Colloq. 184, ed. by R.F. Green, E. Ye. Khachikian, D.B.Sanders, p. 8.

Kaiser, M.E., Bradley II, L.D.,Hutchings, J.B.,Crenshaw, D.M., Kraemer, S.B., Ruiz, J., Gull, T.R. Nelson, C., Weistrop, D. (1999) `Kinematics and Morphology of the Resolved Narrow Line Region in NGC4151', Astrophysics and Space Science, 269/270, p. 431-434.

Kaiser, M.E., Bradley II, L.D., Hutchings, J.B.Kraemer, S.B., Crenshaw, D.M., Ruiz, J., Weistrop, D., Nelson, C., Gull, T.R.(1999) 'Kinematic Mapping of the Narrow Line Region of NGC 4151', in Active Galactic Nuclei and Related Phenomena, Proc. of IAU Symp. 194, eds. Y. Terzian, E. Khachikian, & D. Weedman (San Francisco: ASP), 194, p. 79.

Kaiser,M.E., Bradley II, L.D.,Hutchings, J.B. Weistrop, D., Nelson, C., .Kraemer, S.B., Crenshaw, D.M., Ruiz ,J., Gull, T.R.(1999) `Kinematics and Dynamics of the Narrow Line Region of NGC4151', in Galaxy Dynamics, eds. D. Merritt, J.A.Sellwood, & M. Valluri (San Francisco: ASP) 182, p. 51.

Weistrop, D., & Nelson, C. (1999) `Kinematics in the Interacting, Star-forming Galaxies NGC 3395/3396 and NGC 3991/3994/3995', in Galaxy Dynamics eds. D. Merritt, J.A.Sellwood, & M. Valluri (San Francisco: ASP) 182, p.455.

Woodgate, B.E., et al. (1997) `First Results from the Space Telescope Imaging Spectrograph', Proc. SPIE, 3118, 2-12.

Papers Presented at Meetings

Weistrop, D., Eggers, D., Nelson, C.H., Hancock, M., Bachilla, R., Kaiser, M.E.(2002), 'Proto-Globular Clusters in NGC 4194', AAS, 200.1003W.

Hancock, M., Weistrop, D., Eggers, D., Nelson, C.H. (2002), 'Star Forming Knots in the UV Bright Interacting Galaxies NGC 3395 and NGC 3396', AAS, 200.4307H.

Weistrop, D., Eggers, D., Stone, A., Nelson, C.H., Bachilla, R. (2000), 'Young, Star Forming Regions in NGC 3994 and NGC 3995', AAS, 197.7913W.

Cruzen, S., Wehr, T., Weistrop, D., Nelson, C., Angione, R. (2000), 'HST Observations of IRAS 15179+3956, an Interacting Galaxy Pair in the Bootes Void', AAS, 197.7904.

Plaks, K., Weistrop, D., Nelson, C.H. (2000), 'A Spectroscopic Analysis of the Starburst Galaxies NGC 3395/3396', AAS, 197.13404P.

Grady, C. A., et al. (2000), 'The Disk and Environment of HD 100546', AAS, 197.4702G.

Danks, A.C., et al. (2000), 'STIS Echelle Observations of NGC 4151. III. Interstellar Medium', AAS, 197.3801D.

Crenshaw, D.M., et al. (2000) ,'STIS Echelle Observations of NGC 4151.I. Measurements of the Intrinsic Absorption', AAS, 197.11009C.

Kraemer, S.B., et al. (2000), 'STIS Echelle Observations of NGC 4151.II. Modeling and Analysis', AAS, 197.11008K.

Weistrop, D., Eggers, D., Nelson, C.H., Kaiser, M.E. (2000),'Looking Closely at Medusa:Star Forming Regions in NGC 4194', AAS, 196.5019W.

Hancock, M., Weistrop, D., Nelson, C.H. (2000),'Star Bursts in the UV Bright Interacting Galaxies NGC 3395 & 3396',AAS, 196.2913H.

Nelson, C.H., et al. (2000) 'The Nuclear Stellar Dynamics of the S0 Galaxy NGC 7332', AAS, 196.2114N.

Weistrop, D., Eggers, D., Nelson, C.H., Kaiser, M.E., (2000), HST Observations of Star Formation in Interacting Galaxies:NGC 4194, the 'Medusa', presented at 'Gas and Galaxy Evolution' May 21-24, 2000, Socorro, NM.

Nelson, C.H., et al. (1999) 'The Nuclear Stellar Dynamics of the S0 Galaxy NGC 7332', AAS, 195.11804N.

Nelson, C.H., et al. (1999) 'STIS UV and Optical Longslit Spectroscopy of the Narrow Line Region of NGC 4151', AAS, 194.4906N.

Nelson, C.H., Weistrop, D., Hancock, M. (1998) 'STIS Ultraviolet Images of Interacting Galaxies', AAS, 193.7608N

Kaiser, M.E., et al. (1998) STIS Kinematic Mapping of the Narrow Line Region of NGC 4151', AAS, 193.0701K

Kaiser, et al. (1998) `Kinematic Mapping of the Narrow Line Region of NGC4151', IAU 194, August 1998

Kaiser, et al. (1998) `Kinematics and Dynamics of the Narrow Line Region of NGC4151', Galaxy Dynamics, Rutgers University, August 1998

Weistrop, D., & Nelson, C. (1998) `Kinematics in the Interacting, Star-forming Galaxies NGC 3395/3396 and NGC 3991/3994/3995', Galaxy Dynamics, Rutgers University, August 1998

Bower, G.A., et al. (1998) `Long-slit Spectroscopy of the Nuclear Point Source in M84: Further Evidence of a Supermassive Black Hole', Galaxy Dynamics, Rutgers University, August 1998

Nelson, C., Weistrop,D., & Angione, R. (1998) `Long-Slit Spectroscopy of the Star-Forming Regions in the Interacting Galaxies NGC 3991, NGC 3994, and NGC 3995', AAS, 192.6912N

Weistrop, D., Nelson, C., & Angione, R. (1998) `Long-Slit Spectroscopy of the Star-Forming Regions in the Interacting Galaxies NGC 3395/3396', AAS, 192.6911W.

Weistrop, D., Kraemer, S.B., Crenshaw, D.M., Kaiser, M.E., Hutchings, J.B., Gull, T.R. (1997) `NGC 4151 Slitless Spectroscopy with STIS', AAS, 191.7808W

Nelson, C.H., Weistrop, D., Angione, R., Cruzen, S., Kaiser, M.E. (1997) `UBVR Imaging of UV Bright Interacting Galaxies', AAS, 191.7604N

Bower, G.A., et al. (1997) `The Stellar Dynamics in the Center of the Galaxy NGC 1023', AAS, 191.4910B

Woodgate, B., et al. (1997) 'Overview of the Space Telescope Imaging Spectrograph (STIS)', AAS, 190.4205W