Astronomy with Laser Guide Star Adaptive Optics

Ringberg Castle Conference, Germany
October 29 - November 2, 2007

Scientific Organising Committee

- Wolfgang Brandner (chair)
- Ric Davies
- Reinhard Genzel
- Andrea Ghez
- Thomas Henning
- Norbert Hubin
- Masanori Iye
- Claire Max
- François Rigaut
- Hans-Walter Rix

More Information and registration form available at: www.mpia.de/ring2007
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Astronomy with Laser Guide Star Adaptive Optics

*Ringberg Workshop 2007 - **Notes***

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SALZBURG, AUSTRIA - EXCURSION, WED, OCT 31, 11:00-18:30H

The earliest settlements can be traced back about 6500 years. 2000 years ago, various Celtic villages in the area became the Roman town of **Juvavum**. The name **Salzburg** ("Salt Castle") goes back to the year 696, when missionary (Saint) Rubert arrived in the area and founded the Benedictine Monastery of St. Peters. The town evolved into an independent church state, ruled by the Archbishop. The sovereign was not only the spiritual leader but also possessed many worldly powers. The organisation of the city was in a Vatican-like style and is was not without a reason that **Salzburg** was referred to as the "Rome of the North".

The city of **Salzburg** is nestled between the two mountains **Kapuzinerberg** and **Mönchsberg** and the river **Salzach**. It is a picturesque city with **small alleyways, quaint colourful town houses, rich castles** and **palaces,** with styled gardens and a large number of churches and monasteries.

The Fortress of **Hohensalzburg**, a 900 year old building, is considered to be the most well-maintained Medieval Fortress in Europe. **St. Sebastian** is the city's most impressive church, built in the Gothic style, with a well-tended cemetery. The city of Salzburg still displays the wealth and power of the former Archbishops, and is today home to approximately 150.000 inhabitants.

Salzburg is a **city of music**. It was the home and birthplace of Wolfgang Amadeus **Mozart** and the memorial to him at the Salzburg **Mozart Square** honours the city's most famous son. Salzburg has a long history of being a popular destination for musicians, harboured by the many Archbishops' fondness for music. This city has retained its charm and character through the centuries. Today Salzburg is known for its annual cultural Festival (**Salzburger Festspiele**), which offers a variety of operas, concerts and theatrical plays, ranging from classical to contemporary styles. The city is also a very popular place for musical or theatrical studies, and as a result, many students from around the world enrol at one of the many different schools in Salzburg every year. (source: http://www.aboutaustria.org/capitals/salzburg.htm)

Main sights (from Wikipedia)

Salzburg is a tourist favorite. In addition to Mozart's birthplace, other notable places include:

- The whole Old Town of Salzburg was nominated as a World Heritage Site in 1996.
- The baroque architecture including the many churches are world famous.
- The Salzburg Cathedral
- The fortress Hohensalzburg on a hill dominating the old town is one of the largest castles in Europe, with views over Salzburg.
- The Franziskanerchurch
- The St.Peter cemetery
- The Nonnberg Abbey a Benedictine monastery
- The "Residenz" Palace (the magnificent former Prince-Archbishop's residence)
- Mozart's Birthplace
- Mozart's Residence
- The University Church
- The Siegmundstor (or Neutor)
- The Getreidegasse (where you can find Mozart's birthplace)

Astronomy with Laser Guide Star Adaptive Optics

Scope of the workshop:

The field of Adaptive Optics (AO) for astronomy has matured in recent years, and diffraction-limited image resolution in the near-infrared spectral range is now routinely achieved by most 8-10m class tele-scopes. In order to work, adaptive optics needs a nearby reference star that has to be relatively bright, thereby limiting the area of the sky that can be surveyed. To overcome this limitation, astronomers use a powerful laser that creates an artificial star – a so called laser guide star (LGS) – where and when they need it. The combination of both techniques, LGS and AO, has opened new research windows to galactic and extragalactic astronomy. Research topics range from the study of binary brown dwarf systems, search for exoplanets, observations of young, massive stars, starburst clusters, galactic black holes and active galactic nuclei, galaxy clusters as well as high redshift galaxies, including those magnified by gravitational lensing effects.
This workshop is intended to bring together scientists and engineers working in the field of Laser Guide Star Adaptive Optics.

The aims of this meeting can be summarised in the following points:
The purpose of LGS-AO is to widen the range and increase the impact of astrophysics that is possible with adaptive optics. Therefore, we ask: for what science are LGS-AO systems being used?
•Evaluation and discussion of the first science results obtained from LGS-AO systems. In particular: Galactic center and AGN, galactic and extra-galactic star formation, solar system objects, brown dwarfs, galaxies and cosmology.

• LGS-AO systems are designed to produce high Strehl ratios and diffraction limited observations over most of the sky. Are the systems living up to these expectations?

• The first generation of LGS systems on 3-m class telescopes (at the Lick Observatory, and at Calar Alto, the MPIA/MPE system) were difficult to use; the new generation on 8- to 10-m class telescopes are significantly better. Are we now confident that LGS-AO could become part of the standard observing procedure, as is envisaged for the next generation of extremely large telescopes?

• Have LGS-AO systems been employed in novel methods of observing (e.g. if there is no natural star for tip-tilt compensation)? Have these been successful?

• Knowledge of the Point Spread Function is of crucial importance for extracting the most information from the data. What progress has been made in determining this for LGS-AO (either empirically through additional observations or via modelling)?

• What lessons have been learned either in the design or operation of the LGS-AO systems that should be borne in mind when designing future systems for ELTs?

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Astronomy with Laser Guide Star Adaptive Optics

*Ringberg Workshop 2007 - **Programme** (v071025)*

Sunday, Oct 28

16:00 to 22:00 Arrival
18:30 **Welcome reception**. Italian Buffet.

Monday, Oct 29

9:00 Arrival and Registration
10:30 *Coffee*
10:50 Welcome, Opening
11:00 **LGS-AO Intro** (1a - chair: **François Rigaut**)
- ESO adaptive optics roadmap and plan for ELT - *Norbert Hubin*
- Common-user and Experimental Laser Guide Star AO at the William Herschel Telescope - *Tim Morris*
- Overview of the current ESO activities on Laser Guide Stars for Adaptive Optics - *Ronald Holzlöhner*

12:30 *Lunch*
14:00 **Galactic Nucleii** (1b - chair **Claire Max**)
- Bringing our Galaxy's Supermassive Black Hole and its Environs into Focus with LGS AO - *Andrea Ghez*
- High angular resolution observations of the Galactic Center at the VLT with LGS-AO - *Thomas Ott*
- Detecting supermassive black holes in pseudobulges and low-mass bulges with LGS-AO - *Nina Novak*

15:30 *Coffee*
16:00 **LGS Techniques and Optimizations** (1c - chair **Norbert Hubin**)
- Can laser beacons be used as guide stars? - *Erez Ribak*
- Compensation of ELT LGS WFSs for variations of sodium layer - *Glen Herriot*
- Increasing the return flux from sodium guide star lasers- *Ed Kibblewhite*
- Optimization of a LGS support wavefront corrector - *Diethard Peter*

18:30 *Dinner*

Tuesday, Oct 30

9:00 **High-z Universe** (2a - chair **Andrea Ghez**)
- OSIRIS: Early Science from the Keck LGSAO Integral Field Spectrograph - *James Larkin*
- Modeling the dynamics of high redshift galaxies with SINFONI and LGS - *Giovanni Cresci*
- High redshift science with Adaptive Optics: Highlights from the SINS survey - *Natasha Förster-Schreiber*

10:30 *Coffee*
11:00 **AO-PSF** (2b - chair **Ed Kibblewhite**)
- The Point Spread Function of a Laser Guide Star Adaptive Optics System - *Matthew Britton*
- Getting Lucky with (LGS) AO: 2X HST resolution in the visible - *Nicholas Law*
- LGS-AO without tip-tilt - *Ric Davies*

12:30 *Lunch*
14:00 **PSF Fitting Discussion + Poster Talks** (2c - chair **Wolfgang Brandner**) - Andersen, Rajagopal, ... (5min)
15:30 **Poster Viewing** + *Coffee*
16:00 **High-z Universe** - cont'd (2d - chair **Masanori Iye**)
- Mass-Metallicity Relation and Dynamical Mass of Galaxies at z>3 - *Filippo Mannucci*
- Star Forming Galaxies in the Early Universe: Spatially Resolved Spectroscopy with Keck LGS AO - *Shelley Wright*
- CATS observations of 11 Chandra sources in GOODS-S at z~1 using Keck LGSAO - *Mark Ammons*

18:30 *Dinner*

Astronomy with Laser Guide Star Adaptive Optics

Lodging (25 October 2007)

During the workshop week all participants will have rooms either in the castle itself or in one of the neighbouring hotels. All participants who cannot stay overnight at the castle will be informed until September 21, 2007 in order to make their own reservation in the hotel Parkresidenz or a hotel of their choice.

A block reservation of 20 double rooms (category "Deluxe") has been arranged for workshop participants in the hotel Parkresidenz (www.parkresidenz.com, email: info@parkresidenz.com). The block reservation is valild until September 26, 2007.

Price per room and day including a "Vital" breakfast buffet is 135,00 Euro (one person) or 163,00 Euro (two persons).

A shuttle service to the castle (conference location) will be available in the morning at 8:45am and in the evening after dinner. Participants lodging outside the castle can have lunch (10,00 Euro) and dinner (13,00 Euro) at the conference site.

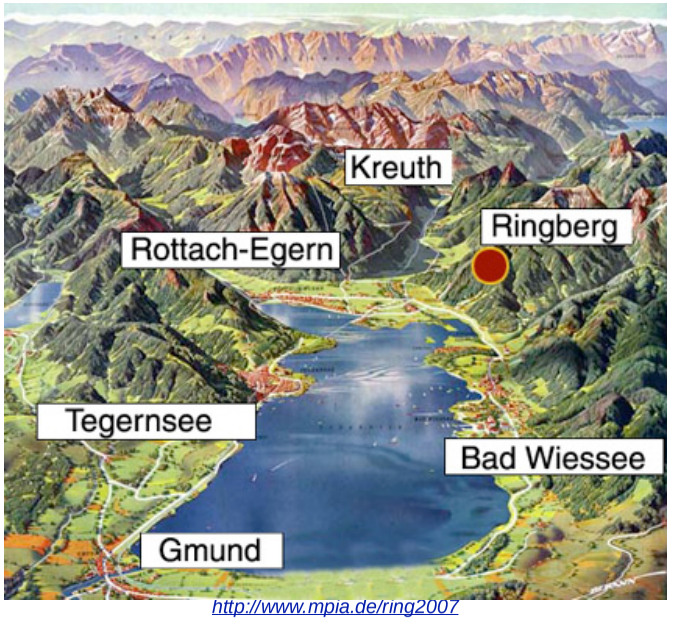
The earliest check-in at the Ringberg castle hotel is on Sunday, Oct 28, at 16:00 hours (4pm).

You have to leave your room at the latest until 9:00 hours (9am) on Friday, Nov 2. This allows the castle management to prepare for the next conference.

The conference will end at 14:00 hours (2pm) after Lunch.

Please note that Europe will switch from summer to winter time on Oct 28 at 3am.

If you need further information or help please contact the LOC via email to ring2007@mpia.de



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Travel Information (24 October 2007)

Coming to Germany is usually very easy, from most countries no visa is required, just a passport will do. Nevertheless please double check.

All participants arriving via airplane should travel to Munich airport. From the airport, Munich and Ringberg Castle can be reached via public transportation (~100 km). For the city of Munich transportation services (commuter trains, underground trains, busses) are provided by the MVV.

How to reach Ringberg Castle by public transportation

From Munich airport take either the "S-Bahn" or the Lufthansa Airport Shuttle bus and go to the main station in Munich ("Hauptbahnhof"). Both options will take around 40 minutes. If you go with the S-Bahn try to get a "Bayern Ticket Single" (19 Euros), which is valid for one person for the whole day in Bavaria - it will thus be valid also in the train from Munich to Ringberg. You need to validate the ticket using the small blue machines as you enter the S-bahn station. Going with the shuttle bus will cost you 10 Euro (payable to the driver), and you will need another ticket for the train from Munich to Ringberg. A taxi costs around 60 Euro from the airport to the central station.

From Munich central station to Ringberg you have to take the Bayrische Oberlandbahn, nicknamed "BOB". It leaves from tracks 27 to 36, at the northern side of the station. The very last train leaves shortly before midnight. The ticket office is located close to these tracks and not in the main hall of the station. If you already have a "Bayern Ticket Single" you do not need to go to the ticket office and can go directly to the train. The "BOB" trains are composed out of several cars. Not all will go to "**Tegernsee**" since the trains are split on their way south. So watch out that you get on the right car. Go with the "BOB" to the final station "**Tegernsee**". Travel time: Roughly one hour. BOB timetable: Saturdays/Sundays/Holidays, working days.

If no special arrangement was made, you should take a taxi at Tegernsee main station to "Schloss Ringberg". The price for the taxi to Ringberg Castle should be less than 20 Euros. Phone numbers to call a cab at Tegernsee main station are:

Taxi Tag und Nacht: Telefon: +498022 2011
Taxi Thelen: Telefon: +498022 3030 oder +49171 3862004
Taxi Company: Telefon: +498022 99445
Taxi Siefert: Telefon: +498022 271818
Taxi-Stand Bad Wiessee: Telefon: +498022 81031
Taxi Seidler: Telefon: +49171 4520420
Taxivereinigung Tegernseer Tal: Telefon: +498022 2011
Taxi Seidl: Telefon: +498029 1249
Taxi Eckert: Telefon: +49171 7757386
Taxi Wolfger: Telefon: +498022 65800

Phone number of Ringberg Castle: +498022/2790

For those who stay overnight in the hotel Parkresidenz leave BOB at the station "**Gmund**" and take a taxi (~15 Euro) to the hotel. You can also ask the hotel for a shuttle taxi.

You also might want to check the respective section of the Ringberg Castle webpage.

Contact phone numbers:
Stefan Hippler (cell phone): +49 (0) 176 233 97516
Wolfgang Brandner (cell phone):+49 (0) 151 107 13266

Astronomy with Laser Guide Star Adaptive Optics

*Ringberg Workshop 2007 - **Programme** (v071025)*

Wednesday, Oct 31

9:00 **Brown Dwarfs** (3a - chair **Imke de Pater**)
- A Keck Laser Guide Star Adaptive Optics Study of Very Low Mass Binaries: Constraining Evolutionary Models with New Dynamical Masses - *Quinn Konopacky*
- Astrometric monitoring of binary brown dwarfs with PARSEC - *Micaela Stumpf*
- Binary Brown Dwarfs from Keck LGS AO - *Mike Liu*

10:30 *Coffee*
11:00 to 18:30 **Excursion to Salzburg**
18:45 **Conference Dinner** - Bavarian Buffet

Thursday, Nov 1

9:00 **Resolved Stellar Populations** (4a - chair **Hans-Walter Rix**)
- Proper Motions of Galactic Compact Objects - *Brian Cameron*
- The orbital motion of the Arches cluster from Keck LGS- and VLT NGS-AO observations - *Andrea Stolte*
- Bulge and disk fields in M31 with the ALTAIR AO system and NIRI on Gemini North - *Knut Olsen*

10:30 *Coffee*
11:00 **LGS Upgrades and Operations** (4b - chair **Andreas Glindemann**)
- Upgrades to the pulsed sum frequency laser operated on the 5m at Palomar - *Ed Kibblewhite*
- SuPy: science cases for the infrared tip-tilt sensor for the Subaru laser system - *Miwa Goto*
- The Paranal/VLT AO Facility - *Sylvain Oberti*

12:30 *Lunch*
14:00 **LGS Operations** (cont'd) **+ Discussion** (4c - chair **Erez Ribak**)
- LGS-AO at the VLT, commissioning report - *Markus Kasper*
- SINFONI and LGS at the VLT, commissioning report - *Stefan Ströbele* (10 min)
- Keck LGS AO experience - *Randy Campbell*
- Gemini LGS AO experience - *François Rigaut* (5min)
- Improving the Sky Coverage of the Gemini LGS AO system - *David Andersen* (5min)

15:30 **Poster Viewing** + *Coffee*
16:00 **Milky Way & Beyond** (4d - chair **Miwa Goto**)
- Keck / OSIRIS LGSAO Observations of the Ejecta from the Classical Nova, V723 Cas - *Randy Campbell*
- Using LGS AO to Study Stellar and Gas Kinematics in the Central 100 pc of AGN - *Erin Hicks*
- AO Imaging and Spectroscopy of NGC 6240 - *Claire Max*
- Deep view of the Arp 299 interacting system with Altair-LGS - *Damien Gratadour*

18:30 *Dinner*

Friday, Nov 2

9:00 **Solar System** (5a - chair **Markus Kasper**)
- Applications of LGS-AO to Solar System Sciences - *Christophe Dumas*
- AO Imaging of Giant Planets using LGS - *Imke de Pater*
- Searching and Characterizing Multiple Trojan Asteroids With LGS AO Systems - *Franck Marchis*

10:30 *Coffee*
11:00 **LBT LGS** (5b - chair **Ric Davies**)
- Laser Guide Stars for the LBT - *Sebastian Rabien*
- What's the best LGS upgrade for LINC-NIRVANA? - *Wolfgang Gässler*
- LBT LGS system: first simulation results and sensor optical design - *Lorenzo Busoni / Enrico Pinna*
- Science Perspectives for Lucifer and LGSAO at LBT - *Andreas Quirrenbach*

12:30 *Lunch*
14:00 **End of Workshop**

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Poster Sessions: Tu, Th 15:30-16:00h

✱ Improving the Sky Coverage of the Gemini LGS AO system - *David Andersen*

A Laser Guide Star has been successfully deployed on Gemini-North for use with the Altair Adaptive Optics (AO) system. The sky coverage of the Gemini AO system is limited, however, by the relatively small patrol field available for the Natural Guide Star (NGS) tip-tilt (T/T) wavefront sensor (WFS). At the request of the Gemini director and the Gemini Adaptive Optics Science Working Group (GAOSWG), we have explored the possibility of re-configuring the NIRI on-instrument WFS to operate as a near-infrared T/T probe over a larger FOV (up to 60 arcsec in diameter), finding that substantial improvements in sky coverage are possible, up to almost 60% at the North Galactic Pole.

✱ First PARSEC/LIDAR mesospheric Sodium profiles above Paranal - *Stefan Hippler et al.*

We report on first measurements of the mesospheric Sodium layer using PARSEC/LIDAR at the ESO VLT.

✱ Physical Optics Simulation of LGS Propagation - *Ronald Holzlöhner*

We report on physical optics simulations of LGS propagation and imaging in the planned GRAAL wavefront sensor (WFS). We model different launch telescopes (LTS) with realistic aberrations, the turbulent atmosphere, a sodium layer of finite thickness, the downlink propagation of the return light, the VLT, and finally the 7x7 NACO or 40x40 GRAAL WFS. We study both long-exposure and instantaneous images and compute spot size statistics. The results agree with observation and enable us to optimize the LTS diameter and devise design rules.

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Liu Michael IfA Honolulu
Mannucci Filippo INAF-IRA Arcetri
Marchis Franck UC Berkeley / SETI
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Myers Richard University of Durham
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Ridgway Susan CTIO/NOAO La Serena
Rigaut François Gemini Observatory Hilo
Rix Hans-Walter MPIA Heidelberg
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Salinari Piero INAF Firenze
Schwab Christian ZAH/LSW Heidelberg
Simard Luc NRC-HIA Victoria
Stolte Andrea UC Los Angeles
Ströbele Stefan ESO Garching
Stumpf Micaela MPIA Heidelberg
Tacconi-Garman Lowell ESO Garching
Wright Shelley UC Los Angeles
Zinnecker Hans AIP Potsdam

Matthias Tecza/Tim Goodsall: The Oxford SWIFT integral field spectrograph

We present the design and laboratory test results of the Oxford SWIFT integral field spectrograph, a dedicated I and z band instrument (0.65 micron - 1.0 micron at R~4000), designed to be used in conjunction with the Palomar laser guide star adaptive optics system (PALAO, and its planned upgrade PALM3k). SWIFT simultaneously provides spectra of ~4000 spatial elements, arranged in a rectangular field-of-view of 44 ◊ 89 pixels. It has three on-the-fly selectable pixel scales of 0.235", 0.16" and 0.08". It builds on two recent developments (i) the improved ability of second generation adaptive optics systems to correct for atmospheric turbulence at wavelengths less than or equal to 1 micron, and (ii) the availability of CCD array detectors with high quantum efficiency at very red wavelengths (close to the silicon band edge). Combining these with a state-of-the-art integral field unit design using an all-glass image slicer, SWIFT's design provides very high throughput and low scattered light. The image slicer and most of the optics are finished while the mechanics is currently in its manufacturing phase. Integration will start in September 2007 with test starting in January 2008 and commissioning and first light in spring 2008.

Shelley Wright: Star Forming Galaxies in the Early Universe: Spatially Resolved Spectroscopy with Keck LGS AO

will present results of an on-going study of the dynamics of high-redshift star forming galaxies at sub-kiloparsec scales. Observations were made using the integral field spectrograph (IFS) OSIRIS and the Keck Laser Guide Star Adaptive Optics (LGSAO) system. For six z~1.5 galaxies I will present resolved H-alpha kinematics within the central arcsecond at 0.1" resolution. Kinematics, disk modeling, merger scenarios, mass distributions, star formation rates, and metallicity for each galaxy will be discussed. In addition, I will discuss our experience using an LGSAO system coupled with an IFS on faint extragalactic targets. Highlighted shall be issues of LGSAO acquisition of faint tip-tilt stars with a small IFS field of view, PSF estimation for an IFS, beam smearing effects on morphology and kinematics, and future directions.

Poster Sessions: Tu, Th 15:30-16:00h

✱ A LGS WFS test bench demonstrator for TMT - *Olivier Lardiere, Glenn Herriot*

Laser Guide Stars (LGS) allow, in theory, a full sky coverage. However LGS have their own limitations. In particular, for the Na LGSs, the artificial star is elongated due to the Na layer thickness, and the temporal and spatial variability of the Na atom density induces changing wavefront measurement errors. In the framework of the Thirty-Meter-Telescope project (TMT), the AO-Lab of the University of Victoria is building a LGS-simulator test bed in order to assess the performance of wavefront sensing algorithms when using Na LGSs. The design of this bench is presented, as well as first laboratory images obtained for a 30x30 SH-WFS in the TMT case. This bench is not limited to SH-WFS, but can serve as a LGS-simulator test bed to any other LGS-AO projects for which Na layer fluctuations can be an issue.

✱ A lunar scintillometer to measure ground-layer seeing - *Jayadev Rajagopal*

New techniques like LGS-AO require a detailed knowledge of the turbulence profile. The intensity of Ground Layer (GL) turbulence determines the gain expected from ground-layer AO, while its thickness defines the size of the compensated field. The extent of the turbulence in the first few metres is also important in determining the optimum height of future domes, especially for Antarctic sites where the GL is strong. A simple and accurate way for determining the GL turbulence is by measuring solar and lunar scintillation. We present a new lunar scintillometer, "LuSci". Robust methods for profile restoration, incorporating effects of lunar phases, are developed and first tests of the technique are described.

Mark Ammons: CATS observations of 11 Chandra sources in GOODS-S at z~1 using Keck LGSAO

The Center for Adaptive Optics (CfAO) Treasury Survey (CATS) is collecting near-IR imaging and spectroscopy of AGN and high-redshift galaxies in several regions of the sky, including GOODS, EGS, and COSMOS, to take advantage of the presence of other deep datasets in these regions. Recently, CATS has observed 11 Chandra sources (10 AGN) at z ~ 1 in the GOODS-South field with the laser guide star adaptive optics (LGSAO) system at Keck Observatory. We combine this K, band imaging with ACS imaging in the B, V, I, and z bands to obtain multi-color imaging at a spatial resolution better than 80 mas in all bands. We attempt to remove central optical point sources from the optical AGN using the GALFIT (Peng et al. 2002) routine. We fit Bruzual & Charlot (2003) tau-models to the residuals and find young, dusty stellar populations in the central 1-2 kpc (the mean central optical depth at rest-frame 500 nm is 4-5). We compare the age gradients in these AGN to a field sample. I will also highlight other recent results from the CATS survey, including measurements of the H-band flux of a z = 1.3 supernova and OSIRIS observations of z~1 AGN and LIRGS. I will specifically concentrate on results that are unobtainable with any other instrumentation to display the power of the new suite of laser guide star adaptive optics systems.

Matthew Britton: The Point Spread Function of a Laser Guide Star Adaptive Optics System

The point spread function (PSF) of a single conjugate adaptive optics system varies in field location due to anisoplanatism. Temporal variability in the PSF arises as the atmospheric turbulence profile evolves in time. This evolution of the PSF in both time and field location complicates the interpretation of observations acquired with adaptive optics systems. Recently, measurements from turbulence monitoring equipment have been used in successfully predicting the PSF evolution of a natural guide star adaptive optics systems. This presentation will discuss prospects for applying this technique to laser guide star adaptive optics systems.

Lorenzo Busoni: LBT LGS system: first simulations results and sensor optical design

Astronomy with Laser Guide Star Adaptive Optics
Ringberg Workshop 2007 - ***Abstracts***

Andrea Stolte: The orbital motion of the Arches cluster from Keck LGS-AO and VLT NGS-AO observations

The excellent astrometric accuracy of ~1 milliarcsecond provided by adaptive optics (AO) observations allowed us to measure the proper motion of the Galactic center Arches cluster. Combining Keck/NIRC2 LGS-AO and VLT NAOS/CONICA NGS-AO observations, we have measured the proper motion of the Arches with respect to the surrounding field population to 212 +/- 20 km/s. The proper motion measurement, when combined with the known radial velocity of the cluster, yields a first estimate of 232 +/- 22 km/s for the 3D space motion of the Arches in the Galactic center potential. I will discuss the implications of the large velocity of the cluster in view of possible formation scenarios of young, massive clusters in a dense environment such as the center of our Galaxy.

Stefan Ströbele: SINFONI & LGSF commissioning

Micaela Stumpf: Astrometric monitoring of binary brown dwarfs with PARSEC

Since their detection Brown Dwarfs have always been of special interest, but the absence of a clear mass-luminosity relation makes it hard to determine their physical properties and to test theories of formation processes, inner structure and atmospheres. Spatially resolved brown dwarf binaries provide the unique opportunity to determine the dynamical masses of the binary components independently from theoretical models. We now present high-resolution multi-epoch ESO/VLT NGS and LGS AO observations of the orbital motion of the benchmark brown dwarf binary Kelu 1 AB. The observations are part of our astrometric monitoring program of binary brown dwarfs with relatively short orbital periods. We carry out fitting of the orbital parameters for Kelu 1 and derive a first dynamical mass estimate of the binary. In addition we present the first spatially resolved H +K-band spectra for the binary EpsIndi BC achieved with PARSEC which provide the most reliable way for spectral classification in the NIR, as well as comparing them with the existing resolved H-band spectra from NACO. These results will help to improve the understanding of the physical parameters of brown dwarfs and to adjust the theory of their evolution and improve the interpretation of the observations of brown dwarfs.

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Andreas Quirrenbach: Science Perspectives for Lucifer and LGSAO at LBT

Sebastian Rabien: Laser Guide Stars for the LBT

Erez Ribak: Can laser beacons be used as guide stars?

We have adopted LIDARs as beacons for adaptive optics, and indeed they function quite well. However, when the telescope grows bigger and the beam return too weak, we do wish for something better, something without spot elongation, a guide star that does not require fast shutters and complex detectors. The price to pay, it seems, is in complex optics, some of it at the transmitting and some at the receiving end. Using ideas from other fields of optics, it might be possible to overcome some of the limitations posed by the pure, narrow laser beams now employed. If successful, we will achieve a wide artificial asterism which will allow us to separate atmospheric layers using simple wave front sensors.

Astronomy with Laser Guide Star Adaptive Optics
Ringberg Workshop 2007 - ***Abstracts***

Brian Cameron: Proper Motions of Galactic Compact Objects

It is now generally appreciated that the space velocities of compact objects (pulsars, magnetars, LMXBs and HMXBs) directly inform us as to their origins and constrain their lifetimes. Here, we will report on a program to measure the proper motions of Galactic compact objects using the LGS-AO system on the Keck II telescope. We will also discuss the limits of ground-based astrometry with adaptive optics and consider the implications of this work for the design of future adaptive optics systems.

Randy Campbell: Keck / OSIRIS LGSAO Observations of the Ejecta from the Classical Nova, V723 Cas

We present the spatially resolved velocity structure of the V723 Cas nova shell observed at three epochs: 13 Sep 2005, 31 Aug 2006, and 3 Sep 2007. Strong coronal emission lines of [Si VI], [Al IX], and [CaVIII] are present in the expanding shell. The continuum-subtracted data cubes reveal the morphology of the nova shell in 3 dimensions. The different species of emission lines are inhomogeneous and arise from distinct regions of the ejecta. The emission has an ellipsoidal shape in the case of the [Al IX] feature and has radially symmetric torus shape with polar knots in the case of [Si VI] and [CaVIII] lines. We measure a near-constant expansion velocity with the multi-epoch observations and determine a distance to the system using expansion parallax. Our data show that recent novae are ideal subjects for the unprecedented spatial resolution in the infrared provided by OSIRIS with LGSAO on Keck II.

Giovanni Cresci: Modeling the dynamics of high redshift galaxies with SINFONI and LGS

In the framework of the SINS survey we have observed ~35 high-z star-forming galaxies, selected in a variety of ways. Our SINFONI integral field data provide spatially-resolved information on the dynamics, stellar populations, metallicities, and ionization state of the gas on typical resolved scales of 1.5-4 kpc from rest-frame optical spectral diagnostics. These unique data provide the possibility to study the relation between the dynamical and stellar mass, that is of fundamental importance to our understanding of the dimensions of the halo and the evolutionary stage of the galaxies, and it is directly linked to cosmological simulations. We present the first results in this direction from a robust dynamical χ^2 fitting of the observed velocity and velocity dispersion fields with suitable rotating disks models, and discuss the implications on the baryonic content and on the dynamical evolutionary state of the galaxies.

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Ric Davies: LGS-AO without tip-tilt

Imke de Pater: AO Imaging of Giant Planets using LGS

The giant planets Jupiter and Saturn have been imaged in detail by various spacecraft, and by HST. These images, as well as numerous amateur images, show that the atmospheres are very dynamic. However, in order to quantify such dynamics, one needs to determine the velocity fields in these atmospheres to a high precision. This can only be done via images at high spatial resolution, which historically could only be done with spacecraft and HST. With AO being available at large telescopes, in principle such projects can be done from the ground. In July 2006 the new Red Oval on Jupiter was passing Great Red Spot, an event we tried to image with the W.M. Keck observatory using LGSAO. Although the LGS part did not work, we will show some results and hope to stimulate discussions of how best to do this. Other projects which would be enabled using LGSAO on Jupiter/Saturn is imaging of their ring systems and aurora.

Christophe Dumas: Applications of LGS-AO to Solar System Sciences

I will present an overview of LGS-AO applications to the study of solar system bodies, with a particular emphasis towards the capabilities offered by the newly commissioned LGS system at the VLT-Yepun. SINFONI-LGS observational results of the transneptunian object 2003 EL61 and its system of satellites will be discussed.

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Knut Olsen: H and K observations of the bulge and disk of M31 with the ALTAIR adaptive optics system and NIRI on Gemini North

These are the highest resolution and deepest near-infrared observations obtained to date of the inner regions of M31 and demonstrate the promise of ground-based adaptive optics for studying the crowded regions of nearby galaxies. We have combined our observations with previously published Hubble Space Telescope Near-Infrared Camera and Multi-Object Spectrometer observations of nine M31 fields and have derived the coarse star formation histories of M31's bulge and inner disk. From fits to the M_K luminosity functions, we find the stellar population mix of the bulge and inner disk to be dominated by old, nearly solar-metallicity stars. The old populations, which we define as having age >~6 Gyr, indeed dominate the star formation histories at all radii independent of the relative contributions of bulge and disk stars. In our least crowded disk field, we see the clear signature of the 10-kpc ring, with ~30% of the stellar mass having formed ~250 Myr ago, superposed on an old metal-poor population. Our results suggest that M31 acquired a stable disk a long time ago.

Thomas Ott: High angular resolution observations of the Galactic Center at the VLT with LGS-AO

Imaging observations of the Galactic Center at the diffraction limit of the VLT are done regularly. Thanks to the infrared wavefront sensor of the NAOS adaptive optics system, these observations don't need the assistance of a laser guide star, since using the bright infrared source IRS7 for wavefront sensing is straightforward. The integral field spectrometer SINFONI, however, is only equipped with an optical wavefront sensor. Here we present first observations with LGS-AO and compare them with previous results.

Diethard Peter: Optimization of a LGS support wavefront corrector

Based on measurements performed with the pyramid infrared wavefront sensor PYRAMIR on the 3.5 m telescope on Calar Alto we discuss the design of a supporting low order wavefront corrector for LGS-AO observation. The question of the sensor type (SHS or pyramid) is addressed as well as the number of mode subject to the correction of the supporting system.

Tim Morris: Common-user and Experimental Laser Guide Star AO at the William Herschel Telescope

The William Herschel Telescope (WHT) has been used in several laser guide star experiments over the years, and has recently been equipped with a common-user Rayleigh LGS AO system, GLAS. An overview of the GLAS system is presented followed by results from on-sky commissioning. The second section of the talk deals with experimental LGS AO system developments being designed for the WHT, including an on-sky NGS/LGS MOAO demonstrator and a proposed European Union LGS test facility.

Nina Nowak: Detecting supermassive black holes in pseudobulges and low-mass bulges with LGS-AO

Over the past decade we have learned that probably all ellipticals and bulges contain a central supermassive black hole (SMBH). The mass of the SMBH correlates both with the mass of the bulge component and with the velocity dispersion \sigma of the bulge. In order to understand the link between bulge evolution and the growth of the SMBH we are investigating, whether these relations remain valid or how they change when galaxies with pseudobulges or very low-mass bulges are considered. As the nuclei of those galaxies are often faint, not or only weakly active, and enshrouded in dust, they cannot be used as a natural guide star for AO. Only with LGS-AO it is possible to observe these galaxies with the required spatial resolution. First results on NGC3368, a pseudobulge galaxy observed with SINFONI LGS-AO, are presented.

Sylvain Oberti: The Paranal/VLT AO Facility

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Natascha Förster-Schreiber: High redshift science with Adaptive Optics: Highlights from the SINS survey

I will discuss applications and benefits of Adaptive Optics in studies of high redshift galaxies. This will be illustrated with results from our SINS survey on the dynamics and morphologies of z~1.5-3 star-forming galaxies, from both high resolution near-IR integral field spectroscopy and imaging with the SINFONI and NACO instruments at the ESO VLT. I will emphasize results obtained with Laser Guide Star AO and compare with those from AO observations using a Natural Guide Star.

Wolfgang Gässler: What's the best LGS upgrade for LINC-NIRVANA?

LINC-NIRVANA is a Fizeau-Imager for the LBT. Currently it is designed to use MCAO with natural guide Stars to increase the field of view for fringe tracking. The system uses the layer-oriented approach with optical co-adding. Simulations show that a sky coverage up to 17% could still be reached at the Galactic poles. We discuss advantages and drawbacks of an LN upgrade with LGS in comparison to the existing system design as well as to the current LBT LGS upgrade plans.

Andrea Ghez: Bringing our Galaxy's Supermassive Black Hole and its Environs into Focus with Laser Guide Star Adaptive Optics

In 2004, laser guide star adaptive optics (LGS-AO) came on-line at the Keck Observatory and was the first such system on a 8-10 meter class telescope. This facility has revolutionized what can be done in high angular resolution astronomy. In this talk, I will focus on new LGS-AO studies of the black hole at the Galactic center and its environs. Specifically, I will discuss

(1) our current understanding of the galaxy's central gravitational potential,
(2) the possibility of future measurements of relativistic effects in the strong gravity regime,
(3) the characteristics and origin of young stars that have been discovered in the vicinity of the central black hole, a region of space that is inhospitable to star formation ("the paradox of youth"), and
(4) the characteristics of the emission associated with the central black hole (otherwise known as SgrA*).

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Tim Goodsall: Dynamics of high-z galaxies

We discuss results of NGS-AO SINFONI observations of a sample of z~3 LBGs. We determined dynamical masses for our targets, selected using K-band rest-frame fluxes from Spitzer. We describe our findings and discuss the possibilities, and limitations, that LGS-AO observations present when studying these high redshift, and small angular scale, objects.

Miwa Goto: SuPy: science cases for the infrared tip-tilt sensor for the Subaru laser system

We will give a review on a program to build an infrared tip-tilt sensor for the Subaru laser system with the emphasis on the scientific field where the combination has particular advantages.

Glenn Herriot: Compensation of ELT LGS WFSs for variations of sodium layer

Both the altitude and internal structure of the sodium layer varies on short time scales, which cause problems that become significant for ELTs. However, this internal structure can be exploited to construct matched filters that can determine SH WFS image positions of elongated spots using undersampled detectors. Undersampling permits lower laser power or faster read times or lower read noise, providing new matched filters are constructed in a timely fashion. We present background algorithms to determine LGS WFSs offsets and gains as inputs to the creation of new filters to suit the changing sodium layer structure and altitude.

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Franck Marchis: Searching and Characterizing Multiple Trojan Asteroids With LGS AO Systems

Over the past 2 years, we have conducted various observational programs with the Keck LGS AO systems to search and characterize multiple asteroid systems in the Jupiter-Trojan population. This work gives us the possibility to estimate, for the first time, the bulk density of a similarly-sized (100 km in diameter each) binary asteroid systems (L5-Trojan 617 Patroclus, see Marchis et al., Nature, 439, 565-567, 2006) which seems to be extremely low (~0.8 g/cc) suggesting an icy and porous composition. More recently we discovered the presence of a 15km-diameter moonlet companion around 624 Hektor, the largest L4-Trojan (Marchis et al., IAU, 8732, 2006) using the Keck LGS AO. Preliminary analysis of a few observations indicates that the bulk density of this trojan is significantly higher (2.4 g/cc). Additional observations with VLT/NACO LGS should be recorded soon. The characteristics of both binary systems are fundamentally different (size ratio, separation, size of primary, bulk density) suggesting a different origin and evolution. We will discuss how we could expand our program to other minor planet populations, in particularly Trans-Neptunian Objects, and how combining LGS with spectroscopic capabilities (SPIFFI, OSIRIS), we will better constrain the formation of these multiple asteroid systems.

Claire Max: AO Imaging and Spectroscopy of NGC 6240

We discuss Keck imaging and spectroscopy of NGC 6240, a pair of disk galaxies in the midst of a starbursting merger. In particular we shall focus on determining the age of the young nuclear star clusters, the positions of the two black holes (each galaxy in the merger contains one of them), and OSIRIS integral field spectroscopy showing the kinematics of the complex inner kpc. Along the way we shall highlight AO-specific issues such as PSF uncertainties, showing how they affect population synthesis of the young star clusters.

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Michael Liu: Binary Brown Dwarfs from Keck LGS AO

We present results from our ongoing LGS imaging survey of field brown dwarfs. Keck LGS AO provides a powerful new capability for identifying and characterizing ultracool binaries, achieving 3-4 times better angular resolution in the near-IR than Hubble Space Telescope over most of the sky. With Keck LGS, we are measuring the substellar binary frequency and searching for exceptionally cool objects using the largest sample to date of ultracool (late-L and T-type) dwarfs imaged at high resolution. Resolved studies of ultracool binaries also provide valuable laboratories for testing models of substellar evolution and atmospheres, given the common age and metallicity of the individual components. We present results on understanding the L/T transition, using binaries whose components bridge this interesting spectral transition regime. Finally, drawing on a set of ~100 observations of different science targets and/or filters, we assess the current performance of the Keck LGS system over a wide range of off-axis tiptilt reference sources.

Filippo Mannucci: Mass-Metallicity Relation and Dynamical Mass of Galaxies at z>3

We present the first results of two projects, LSD (Lyman-break galaxies Stellar populations and Dynamics) and AMAZE (Assessing the Mass Abundance redshift Evolution), aimed at studying the chemical, dynamical and morphological evolution of galaxies at z>3. These projects are based on deep near-infrared spectroscopic observations of a sample of ~40 LBGs with the integral-field unit SINFONI on ESO/VLT. These deep spectra are used to obtain informations on two related subjects:
1- metallicity is estimated from emission lines, and stellar mass from the multiwavelength (from 0.3 to 8 mic) photometry. This allows us to study the evolution of the mass-metallicity relation at z>3 and compare it with the same relation at lower redshift. Early results show a strong evolution from z=2 to z=3, and this can be compared with the expectations of recent models of galaxy evolution involving stellar winds, AGN feedback and galaxy merging.
2- the VLT adaptive-optics module was used to obtained deep, spatially resolved, IFU spectra of 10 of these LBGs. Optical line widths and velocity maps are used to obtain both virial and dynamical mass for these objects. In this case the mass of the dark halo can also be measured and compared with both stellar mass and cosmological expectations. We discuss how the use of LGS is able to revolutionize this field allowing for the observations of larger and more complete samples of galaxies.

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Erin Hicks: Using LGS AO to Study Stellar and Gas Kinematics in the Central 100 pc of AGN

With adaptive optics it is now possible to measure stellar and gas kinematics in the central 100 parsecs of local active galactic nuclei (AGN) down to a spatial resolution of a few parsecs. The availability of LGS AO has increased the number of AGN accessible for study at this resolution to a sample of statistical significance. With this sample, not only can general AGN nuclear properties be characterized (molecular and ionized gas distribution, star formation, etc.), but with direct measurements of the black hole masses from stellar and gas kinematics it is also possible to calibrate the commonly used indirect methods, such as reverberation mapping. We have undertaken a survey of local AGN using LGS AO with both the integral field spectrometer SINFONI on the VLT and OSIRIS on Keck. Results from the survey will be presented, including modeling of both the stellar and gas kinematics and an assessment of how well the gas traces the gravitational potential. In addition, the merits of using LGS AO with AGN for which natural guide star AO is feasible will be discussed, comparing the observing overheads associated with the LGS to the scientific gains.

Ronald Holzlöhner: Activities of the ESO LGS Group

We give an overview of the current ESO activities on Laser Guide Stars for Adaptive Optics. Four projects will be highlighted:
- The existing LGSF on UT4 of the VLT
- Physical optics simulations of LGS spot size on wavefront sensors
- Fiber laser developments and
- The VLT AOF LGSF upgrade, to produce 4+1 LGS

Norbert Hubin: ESO adaptive optics roadmap and plan for ELT

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Markus Kasper: LGS-AO at the VLT, commissioning report

Laser guide star AO is now offered to observers at the VLT and produces first scientific results. I'll present analysis, results and conclusions from the commissioning runs of the AO systems NACO and SINFONI together with the laser guide star carried out early 2007.

Edward Kibblewhite: Increasing the return flux from sodium guide star lasers

Significant increases in the return flux should be possible by suitable tailoring of the spectral and temporal structure of the laser. I will review the physics of the sodium atom and discuss the hardware required to increase the return from sum frequency lasers by a factor of two.

Edward Kibblewhite: Upgrades to the pulsed sum frequency laser operated on the 5m at Palomar

A pulsed frequency laser, originally built at Chicago, has been upgraded at Palomar mountain and is now used as a shared risk common facility. Its design and performance will be discussed and a review of the operating experience presented.

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Quinn Konopacky: A Keck Laser Guide Star Adaptive Optics Study of Very Low Mass Binaries: Constraining Evolutionary Models with New Dynamical Masses

We present new results from our ongoing monitoring of very low mass (VLM) binary stars with laser guide star adaptive optics (LGSAO) on the 10 m Keck II telescope. Our survey, which targets 22 sources between spectral types M8 and T5, is aimed at obtaining dynamical mass estimates with an accuracy of 10% or better over the course of the study. Utilizing the near-infrared imaging camera NIRC2, we have obtained new epochs of high precision (~ 1 mas) astrometry on nearby VLM binaries, allowing us to determine the astrometric orbital solutions for a number of these sources. These solutions provide the total system mass of the VLM binaries. In addition, we are using the high resolution infrared spectrometer NIRSPEC in conjunction with the LGSAO system to obtain the first spatially resolved radial velocity measurements for these sources, yielding not only improved total system masses, but also individual masses of the components. We have a radial velocity precision of less than 1 km/s. In the best case, we have constrained the dynamical mass of a VLM binary to better than 2%, allowing us to conclude that the DUSTY evolutionary models make the best predictions for the mass of this system.

James Larkin: OSIRIS: Early Science from the Keck LGSAO Integral Field Spectrograph

OSIRIS is the newest instrument at Keck and is designed to dissect small patches of the sky in unprecedented detail. It has now been used with the Keck LGS AO system for almost two years and has made ground breaking observations of the Jovian moons, young stellar objects, non-stellar companions, the black hole at the center of our Galaxy, active galactic nuclei, super star clusters, and some of the most distant galaxies. We,ll briefly present how the instrument works and why a lenslet based design was selected. Then we ,ll focus on the LGS AO science with the instrument.

Nicholas Law: Getting Lucky with (LGS) AO: 2X HST resolution in the visible

We present the first results from the LAMP instrument, a L3CCD-based Lucky Imaging camera operating behind the AO system on the Palomar 200" telescope. In a 6-night science run in July 2007 the system regularly achieved 710nm Strehl ratios approaching 20% with the full 5m telescope aperture. The PSFs show clearly diffraction limited cores at twice HST resolution. Science and engineering results will be discussed, along with applicability to future LGS-AO observations.

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