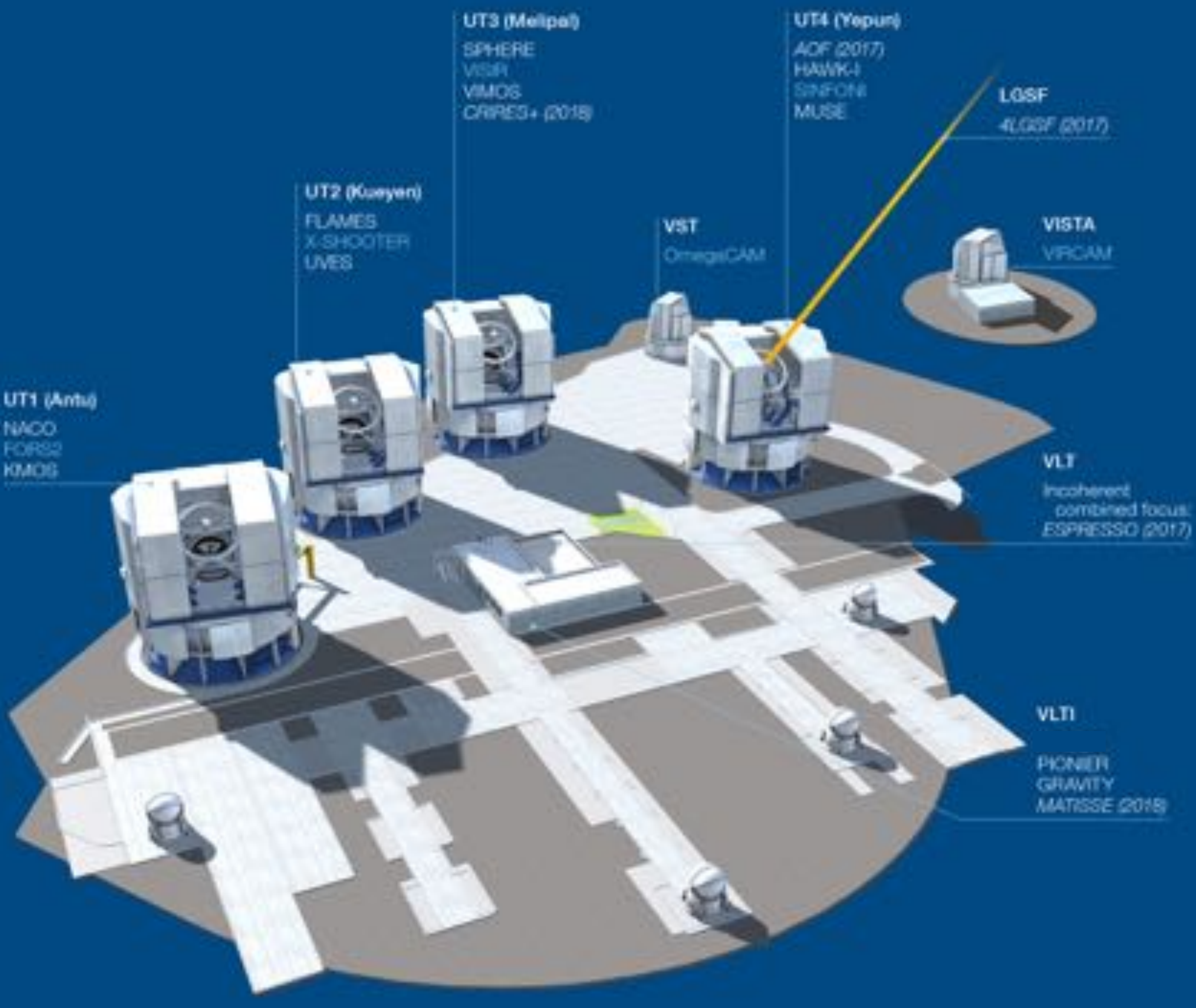
The Right Instrument for your Science Case

Henri Boffin

ESO

Karen Humby, The Messenger



UT3 (Melipal)
SPHERE
VISIR
VIMOS
CRIRES+ (2018)
UT4 (Yepun)
AOF (2017)
HAWK-I
SINFONI
MUSE
LGSF
4LGSF (2017)
UT2 (Kueyen)
FLAMES
X-SHOOTER
UVES
VST
OmegaCAM
VISTA
VIRCAM
UT1 (Antu)
NACO
FORS2
KMOS
VLT
Incoherent
combined focus:
ESPRESSO (2017)
VLTI
PIONIER
GRAVITY
MATISSE (2018)

An amazing suite

Imagers

EFOSC2	visible
SOFI	IR
FORS2	visible
HAWK-I	NB, JHKs
VISIR	M
NACO	AO JHK, Lp
SPHERE	AO visible, JHK

Multiplex

FORS2 MXU
KMOS IFU (24 arms)
MUSE IFU 1’x1’
SINFONI IFU
FLAMES 130 fibers

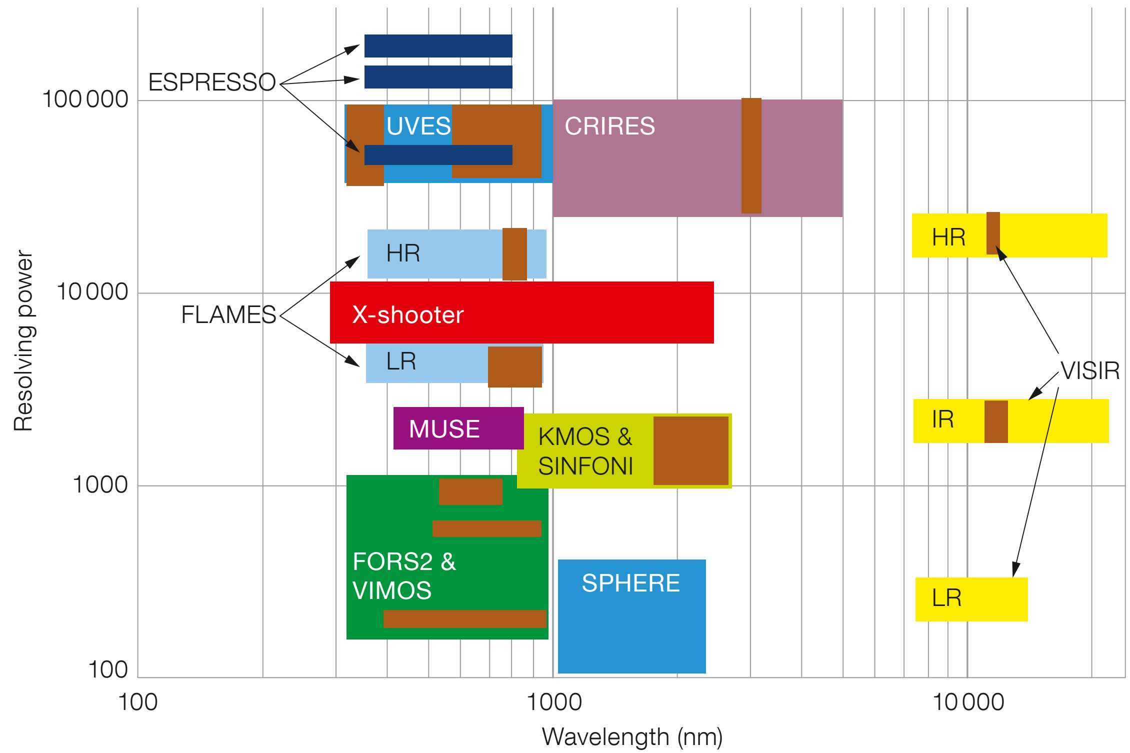
Polarimeters

FORS2
EFOSC2
SOFI
SPHERE
NACO

Interferometry

PIONIER
GRAVITY

Spectrographs: Resolving Power versus λ



VIRCAM

Attached to VISTA,
a 4m telescope

Wide-field infrared imager

0.9–2.5 μm

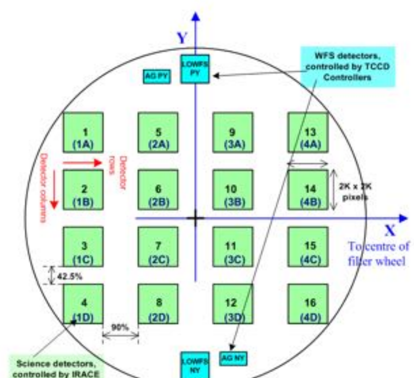
Pixel: 0.34”

BB and NB filters

FoV: 1. 5 deg^2

in 6 pawprints

16 CCDs



OMEGACAM

Attached to the 2.6-metre VLT Survey Telescope (VST)

Visible: 350 to 1000 nm

BB and NB filters

32 individual CCDs

Pixel size: 0.21”

FoV: 1 x 1 degree

Orion in full VISTA

FORS2

FOcal Reducer

low dispersion Spectrograph

FORS2

FOcal Reducer

low dispersion Spectrograph

A wonderful German understatement!

It should be called

FOcal Reducer Fast Imager and low dispersion Single and Multi-Object Spectropolarimeter

FORFISMOS

The Workhorse instrument in Paranal!

FORS2 observing modes:		
IMA	imaging	fast
OCC	imaging with occulting bars	FIMS
LSS	longslit spectroscopy	fast
MOS	multi-object spectroscopy (movable slits)	FIMS - SR collimator only
MXU	multi-object spectroscopy (masks)	FIMS - SR collimator only
HIT-I	high time resolution imaging	fast - SR collimator only
HIT-S	high time resolution spectroscopy	fast - SR collimator only - visitor mode only
HIT-MS	high time resolution multiple shift mode	fast - SR collimator only - visitor mode only
IPOL	imaging polarimetry	fast
PMOS	multi-object spectropolarimetry	FIMS & fast** - SR collimator only
** fast mode PMOS observations are only possible for a single target on 1 slit		

FORS Iconic Images

FOV: 7'x7'

Pixel scale: 0.125"

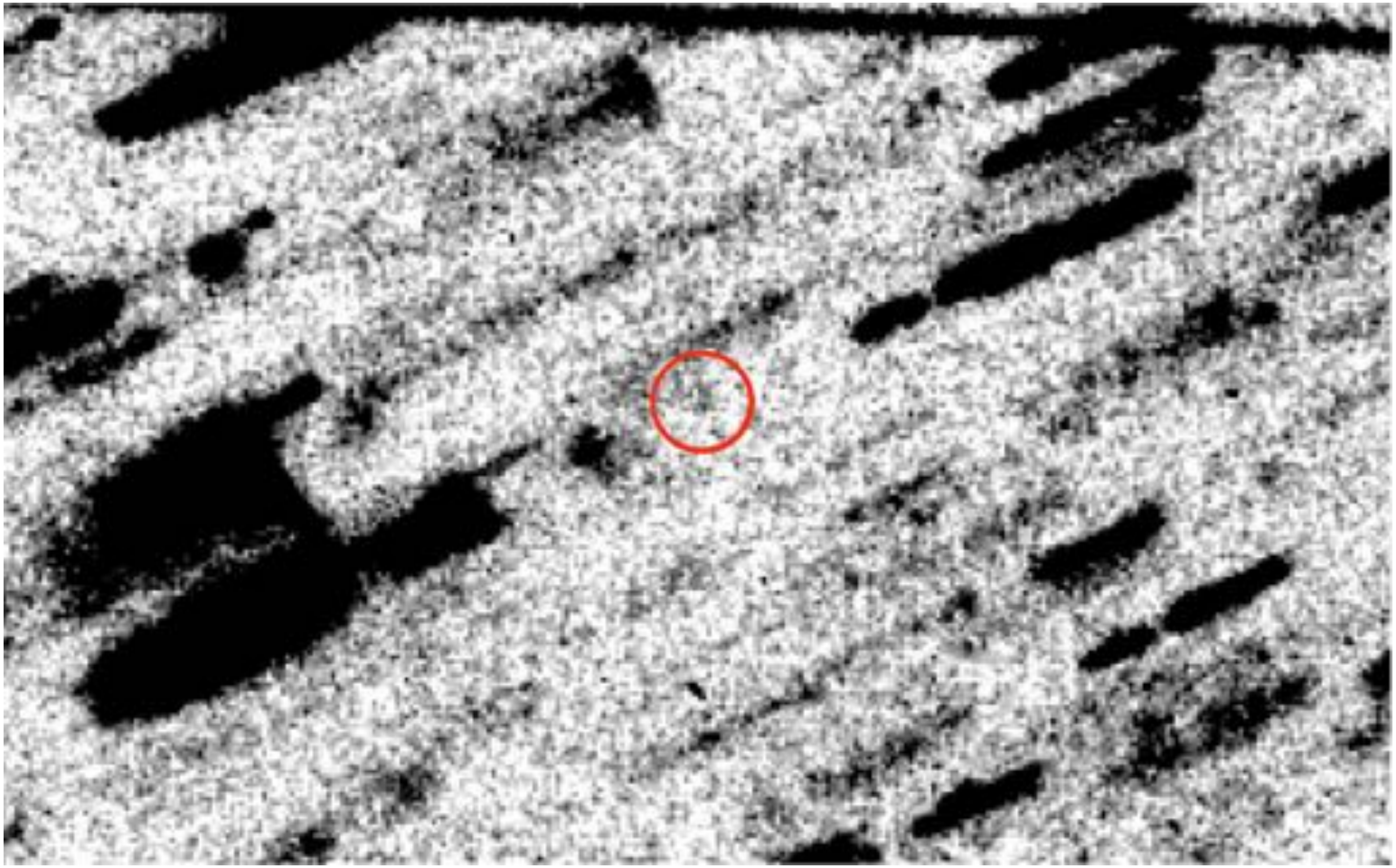
Imaging

The direct imaging "Mag-limit" is the broad band magnitude calculated for a point source of zero colour (A0V star) which would give a S/N of 5 in one hour with dark sky, clear conditions, a seeing FWHM of 0.8'' and an airmass of 1.2. The U, B, V magnitudes are calculated using the broadband filters of the standard instrument configuration.

Instrument mode	Magnitude limit
FORS2 E2V	U=25.9 B=27.6 V=27.3 R=26.6 I=25.8
FORS2 MIT	U=24.5 B=27.1 V=27.0 R=26.7 I=25.7 z=24.7
VIMOS E2V	U=26.1 B=27.4 V=26.9 R=26.6 I=25.9 z=25.1

Remember: FORS2 has a LADC and narrow band filters

IMAGING



Halley
V = 28.2

FORS1+
FORS2+
VIMOS

3 nights

81 images

32284 s

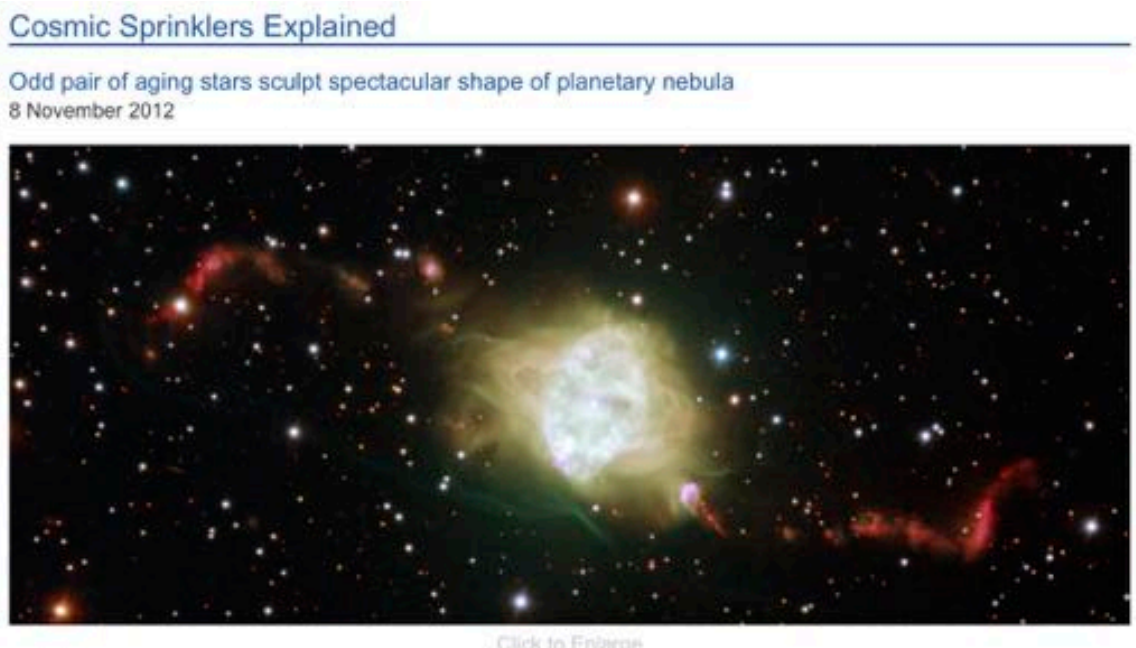
Long-slit spectroscopy

330 – 1100 nm

Slits: 0.3” to 2.5”

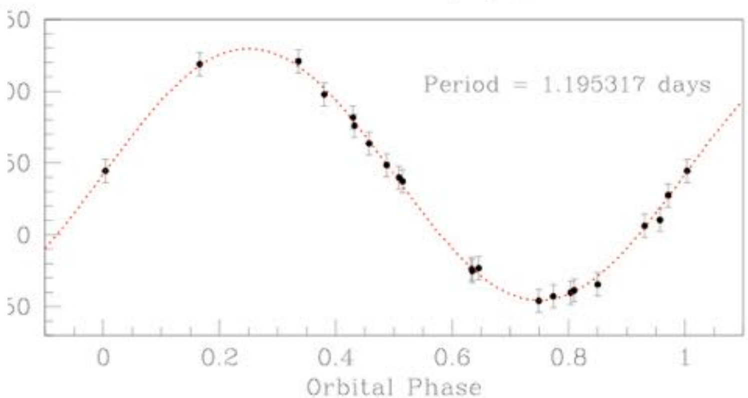
R ~ 150 – 2600

Mag limit ~ 23 – 24

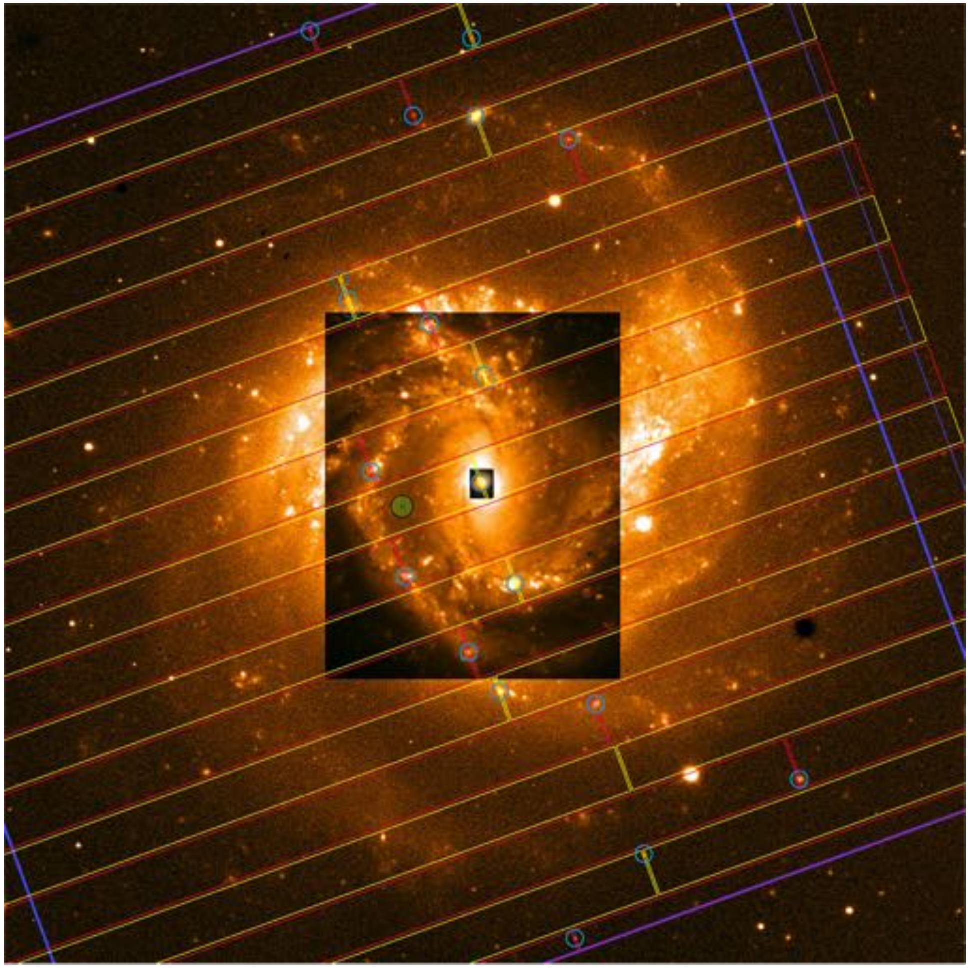


Fleming 1 PN: host of a post-CE binary

Boffin+ 12, Science



MXU



- Up to ~100 slits
- Slit width: 0.1” →30”
- Slit length < 30”
- slit shapes: rectangular, circular, and curved
- Wavelength range depends on position on CCD (x-axis)

VLT Rediscovers Life on Earth

By looking at the Moon

29 February 2012

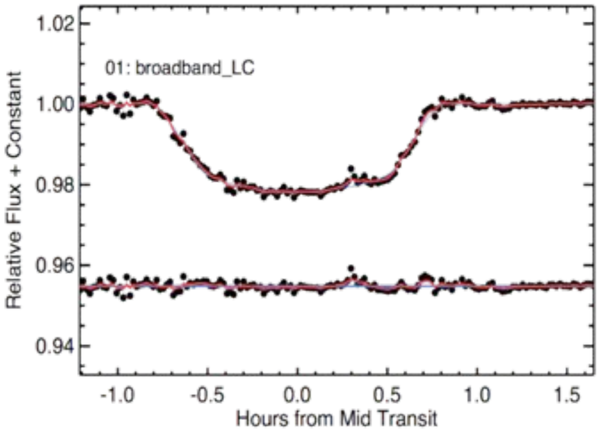
Click to Enlarge

By observing the Moon using ESO's Very Large Telescope, astronomers have found evidence of life in the Universe — on Earth. Finding life on our home planet may sound like a trivial observation, but the novel approach of an international team may lead to future discoveries of life elsewhere in the Universe. The work is described in a paper to appear in the 1 March 2012 issue of the journal Nature.

"*We used a trick called earthshine observation to look at the Earth as if it were an exoplanet,*" says Michael Sterzik (ESO), lead author of the paper [1]. "*The Sun shines on the Earth and this light is reflected back to the surface of the Moon. The lunar surface acts as a giant mirror and reflects the Earth's light back to us — and this is what we have observed with the VLT.*"

Sterzik+ 12

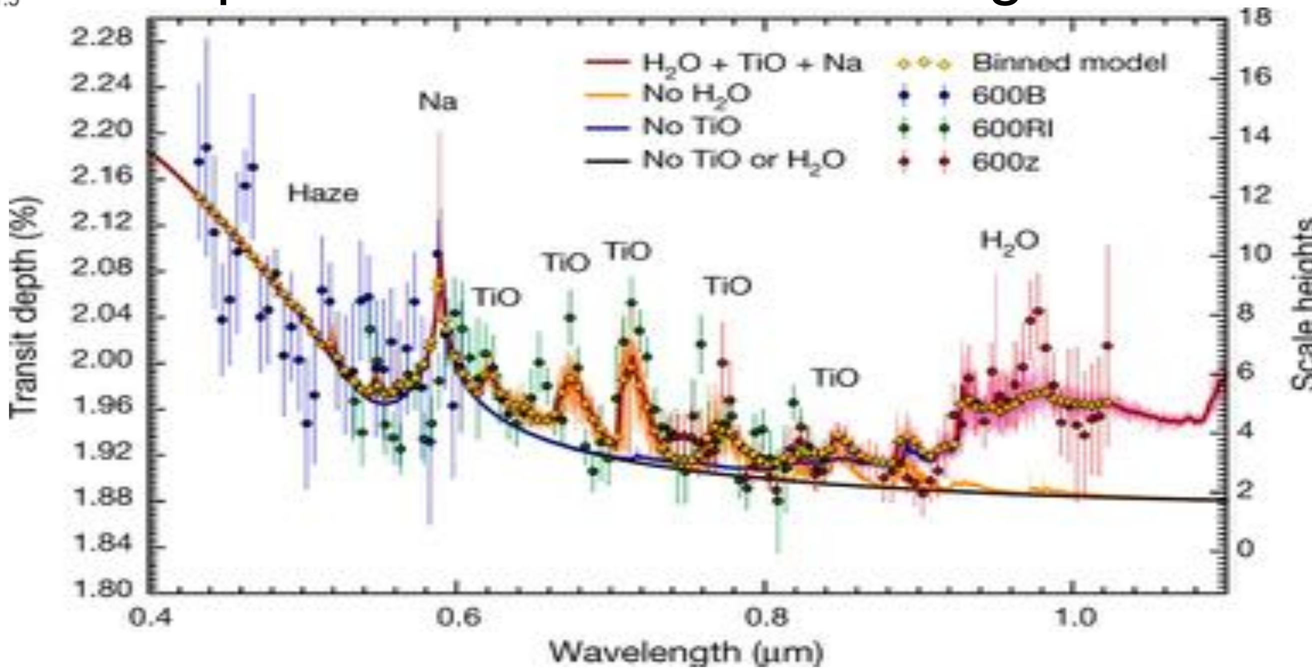
Transmission Spectroscopy



Transiting exoplanets

Tens of ppm precision

Use MXU and measure transit depths as function of wavelength

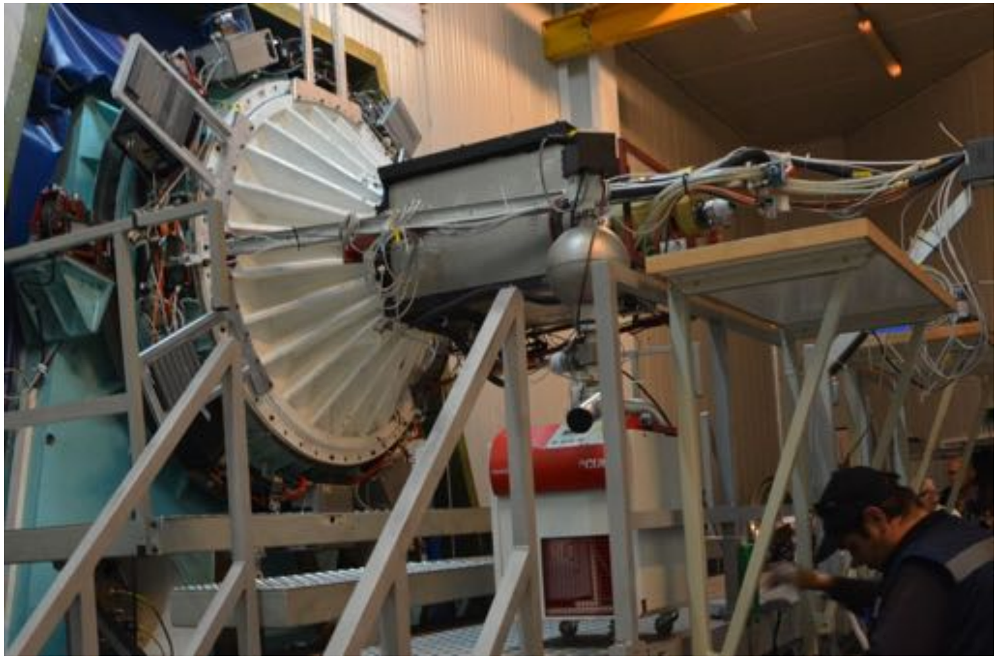


Sedaghati+ 17

The little but older brother: EFOSC2

ESO Faint Object Spectrograph and Camera 2

FOV: 4.1’x4.1’
Pixel scale: 0.12"



The little but older brother: EFOSC2

Imaging (BB, NB)

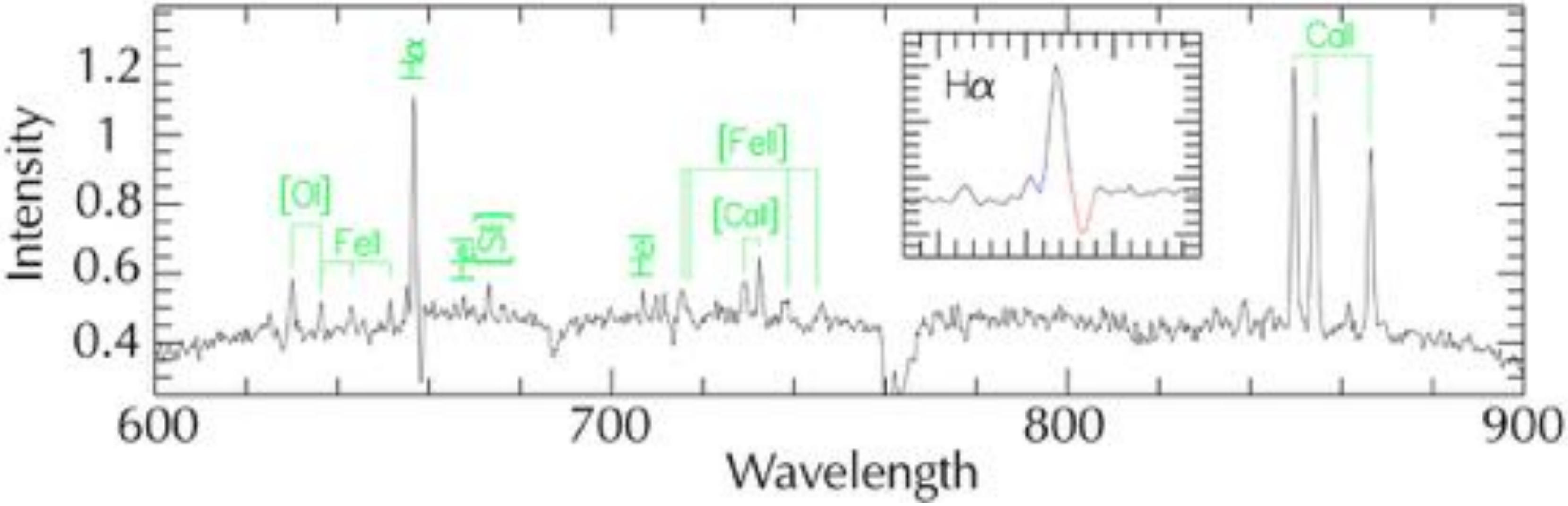
Arp 271

The little but older brother: EFOSC2

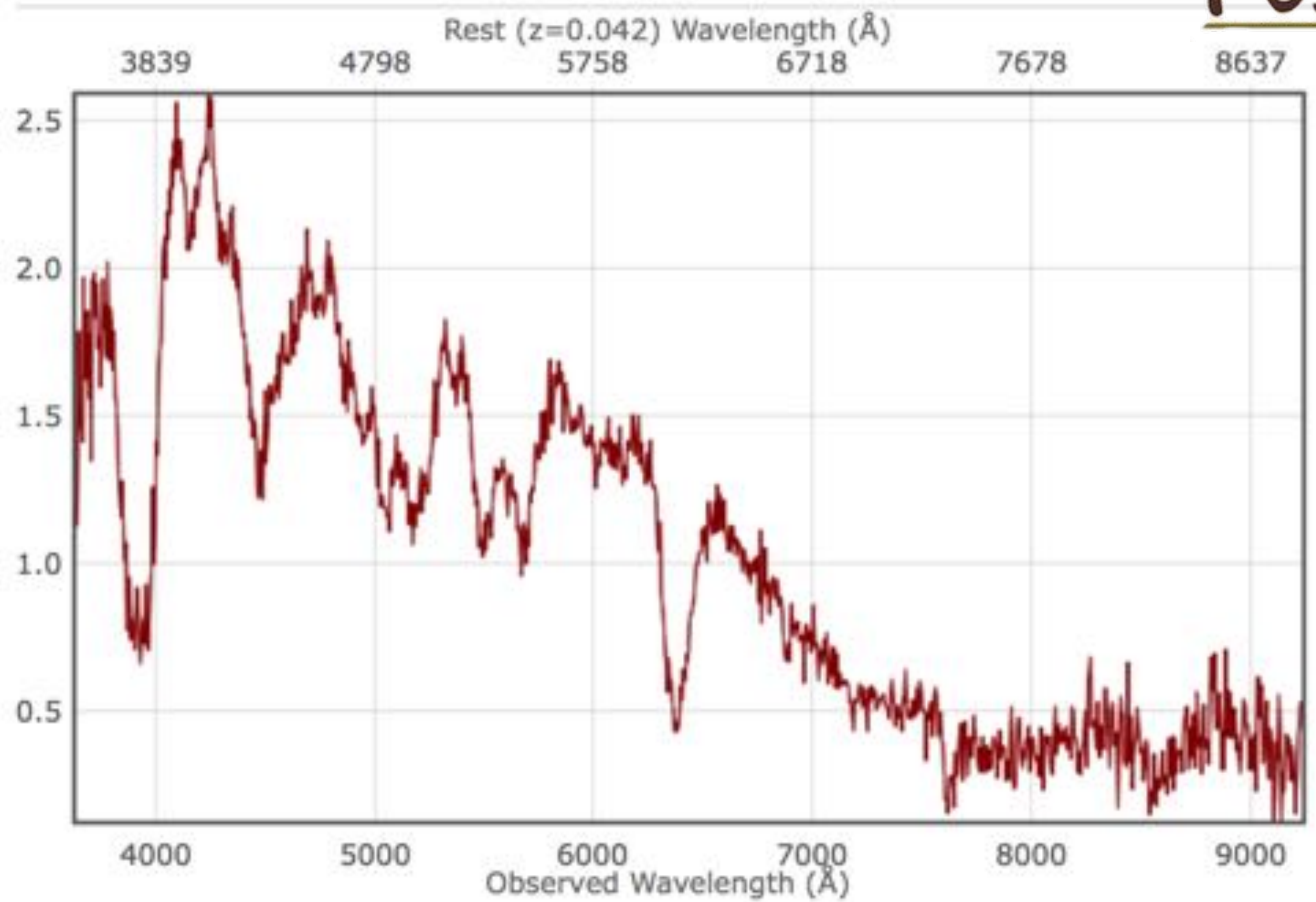
Imaging (BB, NB)
Spectroscopy
MXU
Polarimetry

Arp 271

Spectrum of a
Young Star in M17



The little but older brother: EFOSC2



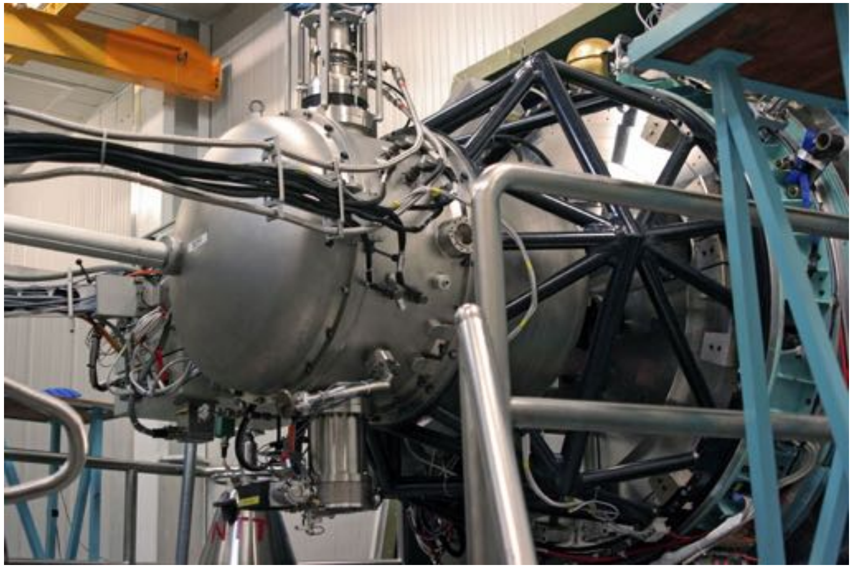
SN 2018aca
Type IA

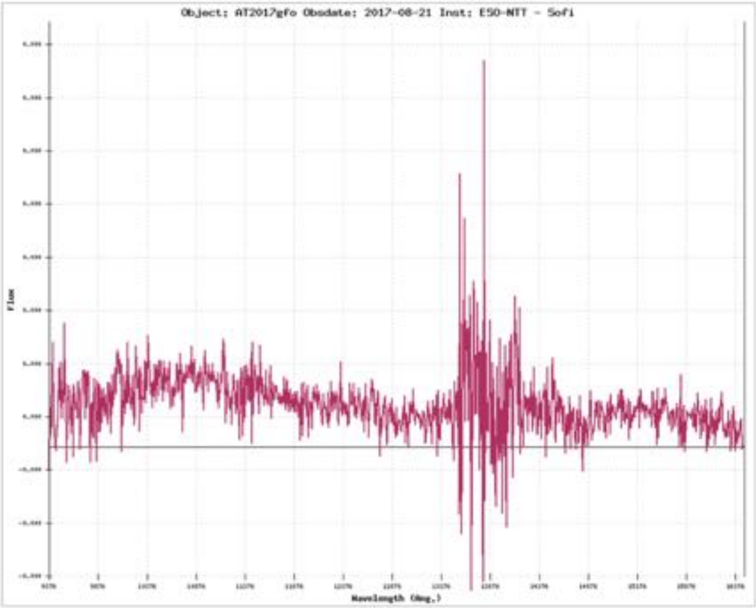
SoFI: Son of ISAAC

0.9-2.5 μm range

Imaging (0.28”/pix) - BB and NB filters.

Spectroscopy: low resolution (R=600) and medium resolution (R=1200-1500), with fixed width slits of 0.6“, 1“ and 2”.





Kilonova
AT2017gfo
Smartt+ 2017

SoFI: Son of ISAAC

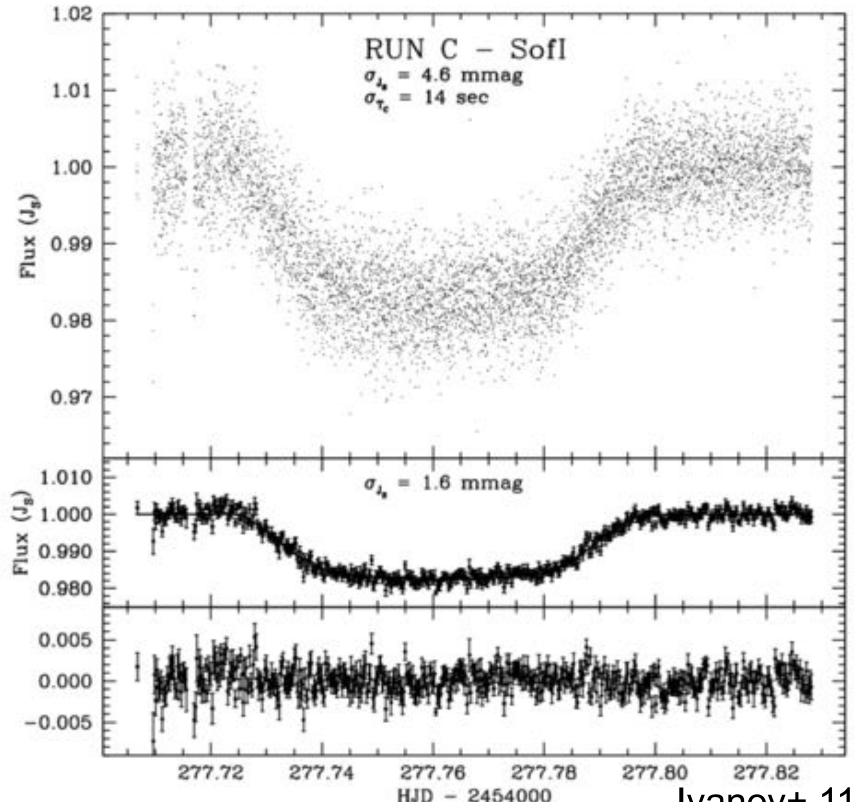
0.9-2.5 μm range

Imaging (0.28”/pix) BB and NB filters.

Spectroscopy: low resolution (R=600) and medium resolution (R=1200-1500), with fixed width slits of 0.6“, 1“ and 2”.

Imaging polarimetry

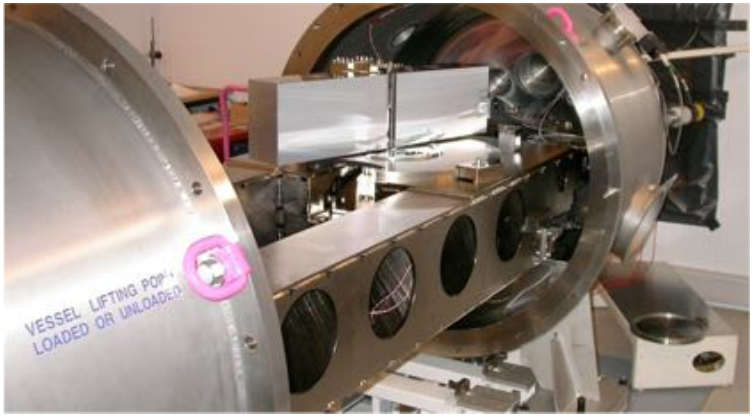
High time-resolution imaging in burst and fast photometry mode with integration times of the order of a few tens of milliseconds via hardware windowing of the detector array.



Ivanov+ 11

HARPS: The exoplanet hunter!

HARPS is an exceptionally STABLE spectrograph



380 to 690 nm

Resolving power: 115,000

- **RV accuracy:**
  - ~ 0.5 m/s on the short term (instrument, guiding, ThAr, atmosphere);
  - ~ 1 m/s on the medium term (2 years);

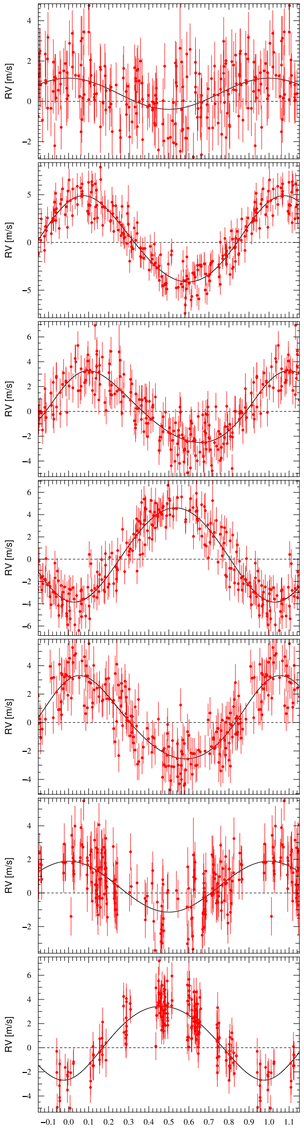
- **Limiting magnitude:** 17 (T_{exp}~ 1h, RV ~ 100m/s).

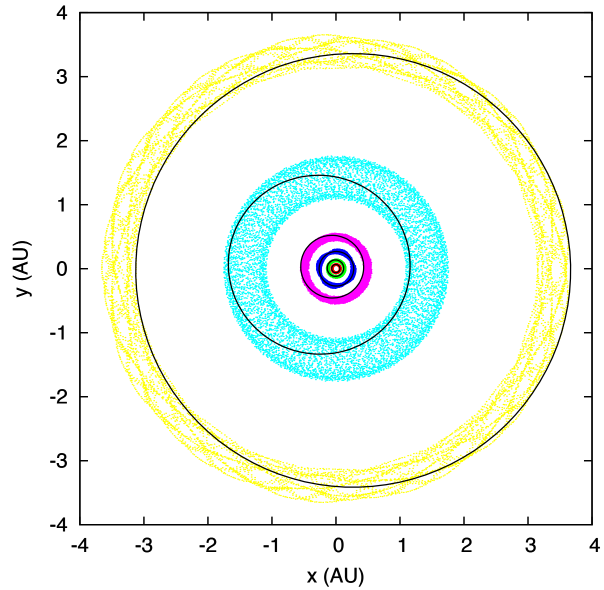
HD 10380

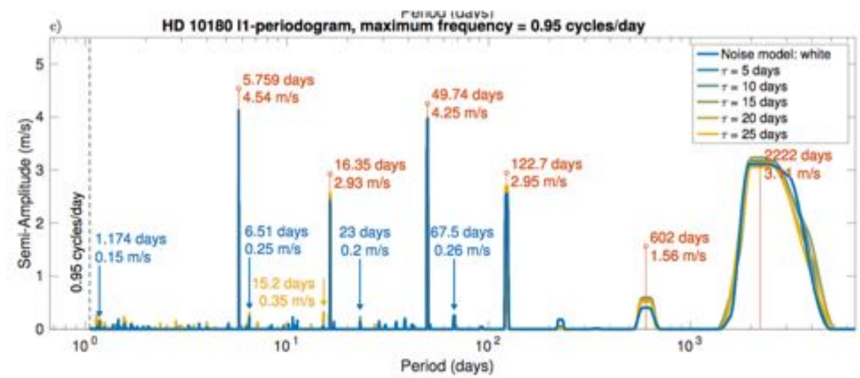
5 to 7 planets in one system:

- (1 Super-Earth, with 1.4 Earth masses, orbital period of 1.18 days)
- 5 Neptune-like planets, with masses between 13 and 25 Earth masses, orbital periods from 6 to 600 days
- 1 Saturn-like planet, with 65 Earth masses, orbital period of 2200 days

Lovis+ 2011

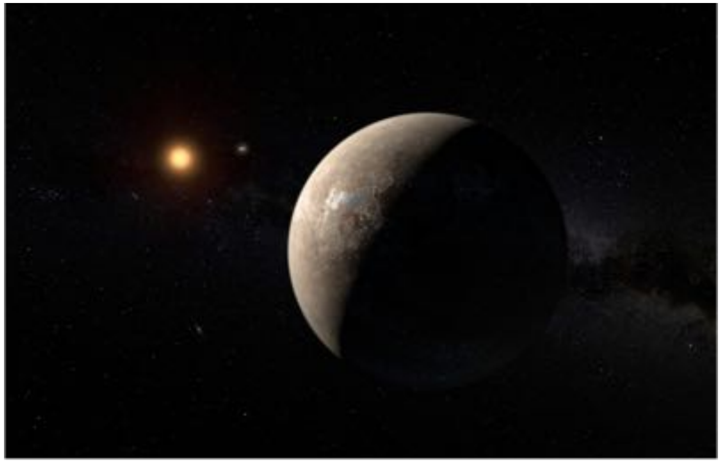






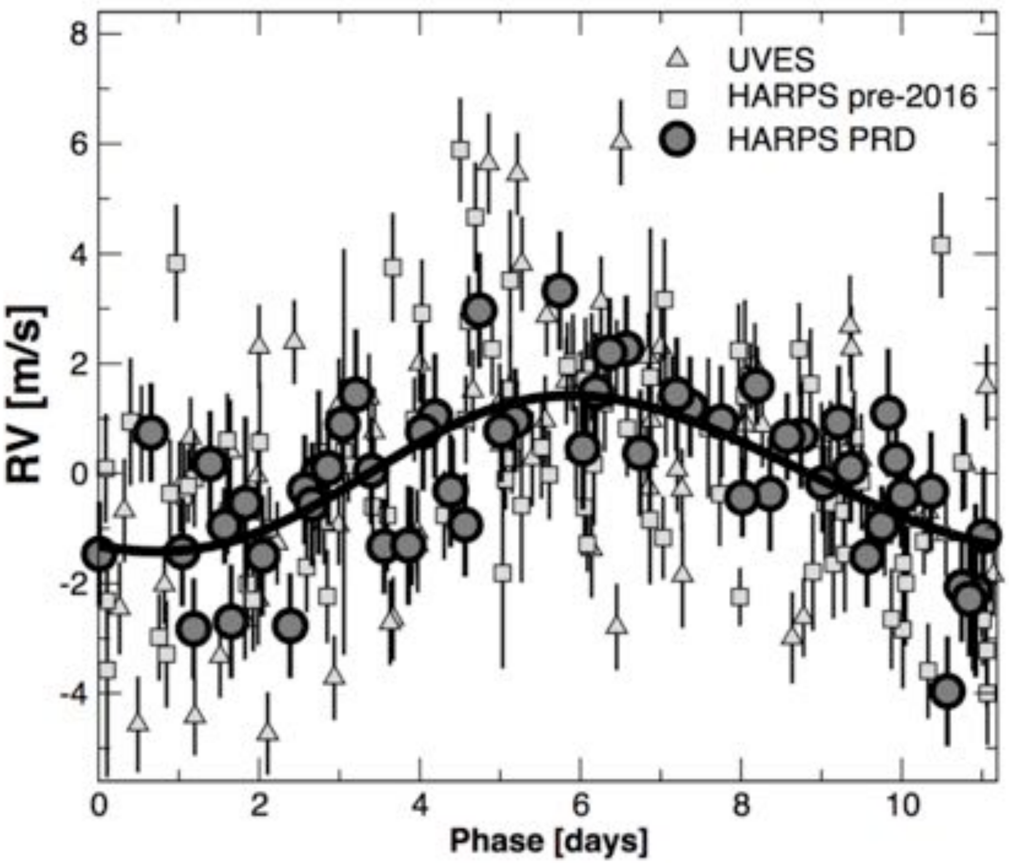
Hara+ 16 → 6 planets secure

Proxima b

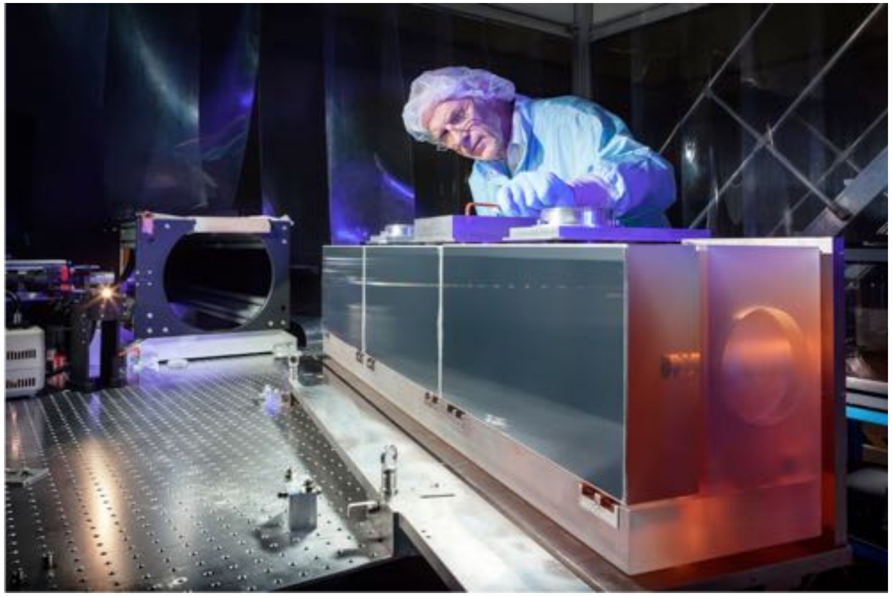


$K \approx 1.4$ m/s
$M \sin i \approx 1.3\ M_E$
$P = 11.2$ d

Anglada-Escudé + 16



Big Brother: ESPRESSO



380-686 nm

R= 120,000 – up to 220,000 (1 UT) or 30,000 (4UTs)

RV precision < 10 cm/s (1 UT)
< 1-5 m/s (4 UTs)

S/N=260 in one hour on a V=12 star (1 UT)

S/N = 20 on a V = 20 object in one hour (4 UTs)

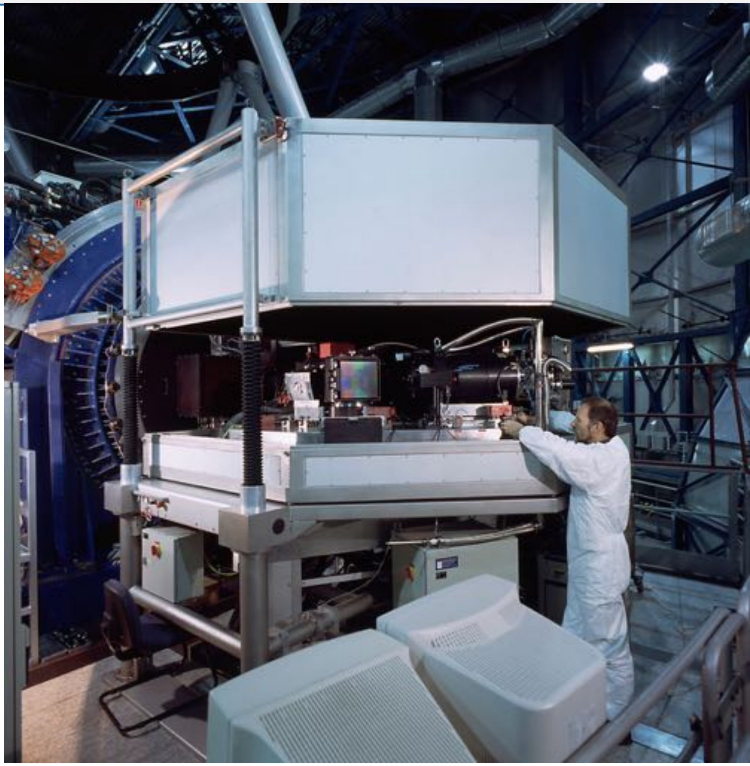
To be offered soon!

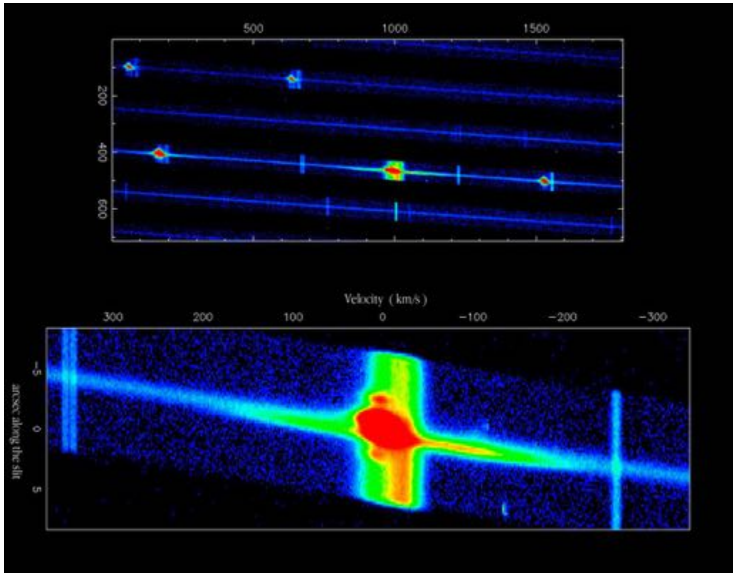
UVES

Echelle Spectrograph

300–500 nm (blue arm)
420–1100 nm (red arm)

Spectral resolution ~ 40,000
up to 80 000 (blue arm) – 110 000 (red arm)

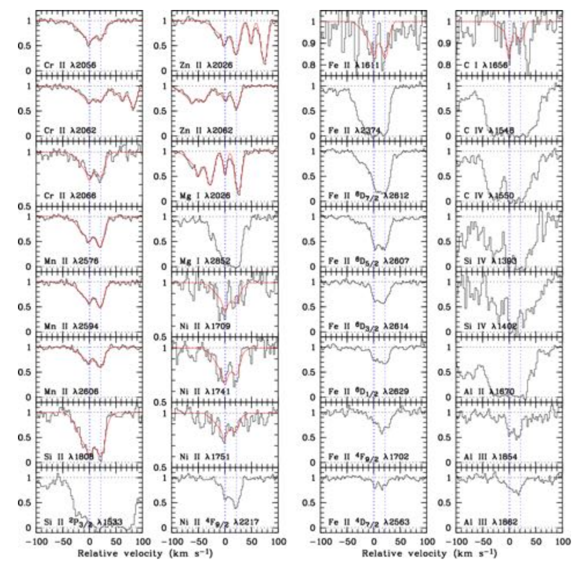




SN 1987A in 1999

Rapid Response Mode

Observe within minutes of discovery

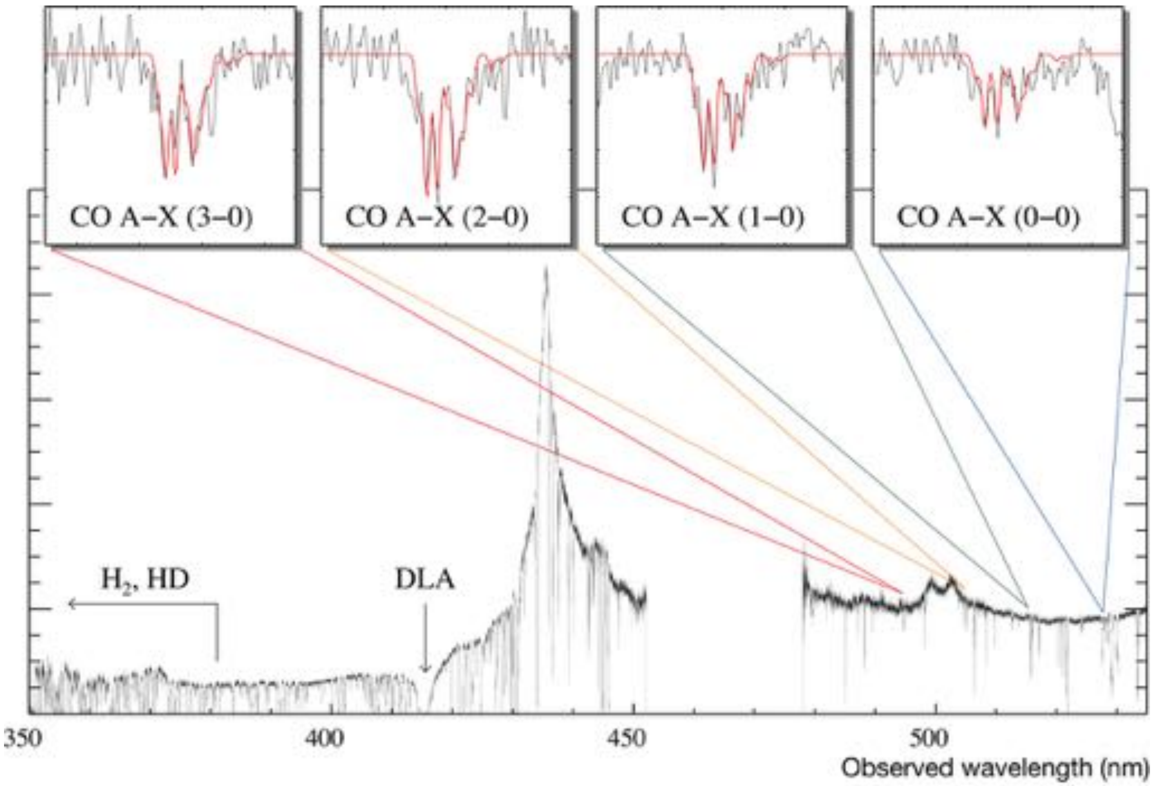


GRB 060418

Vreeswijk+ 107

Also for kilonovae, GW

Detecting CO molecules



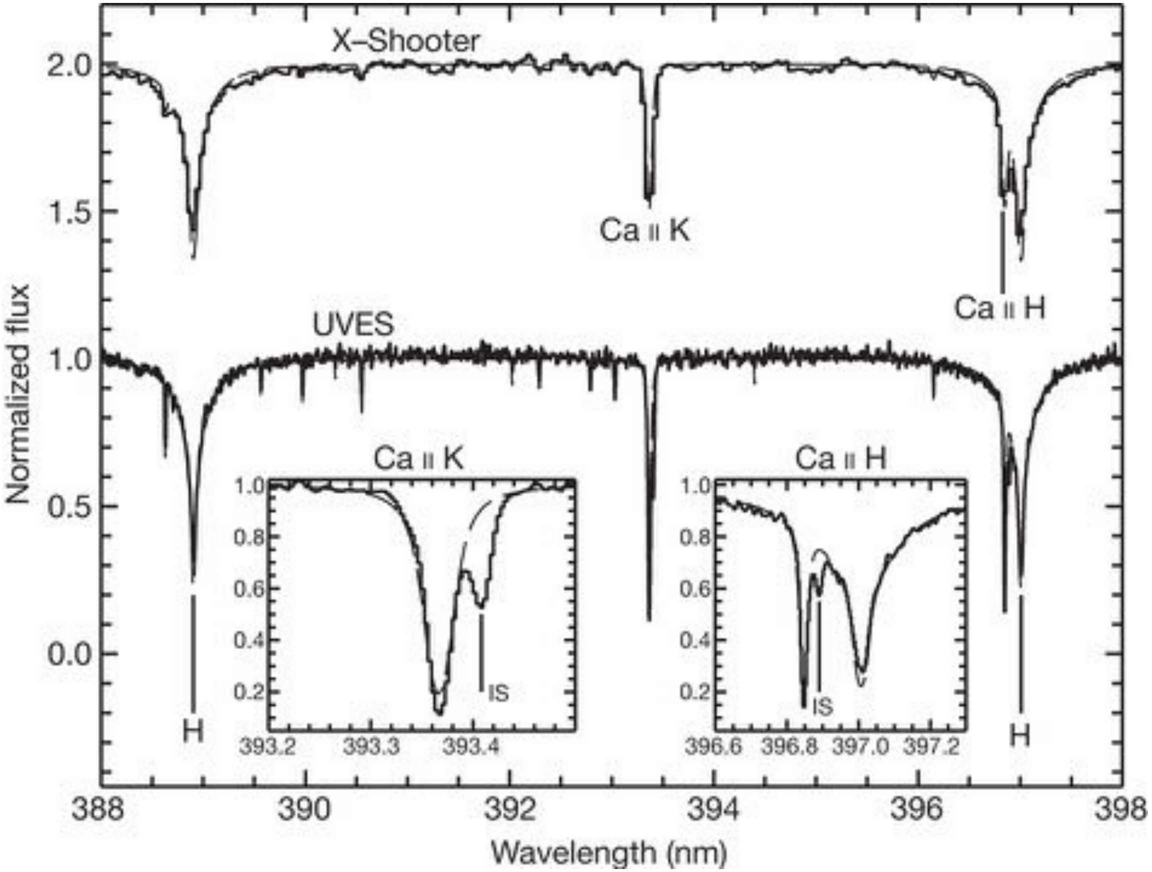
Srianand+ 08

8h spectrum of a distant quasar

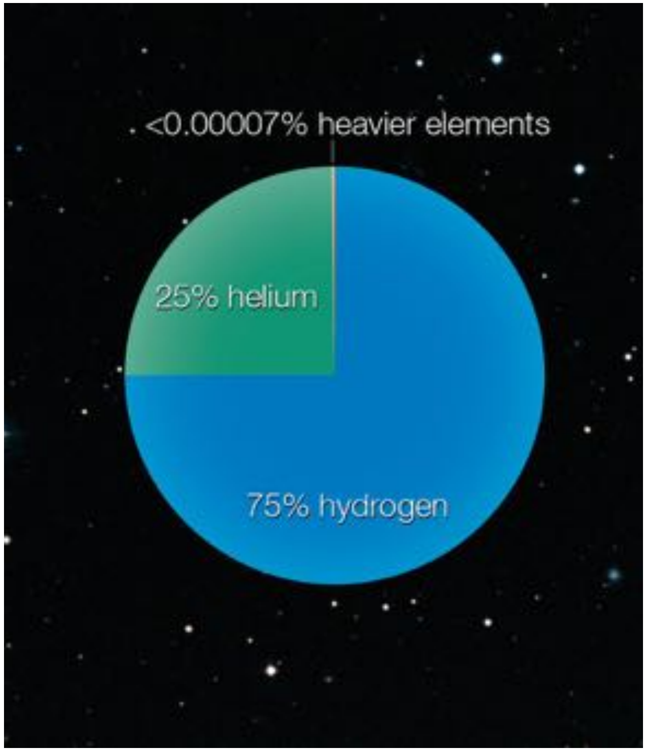
Detect CO molecules 11 billion ly away

Measure Temperature of Universe at this epoch: 9.15 K
(in excellent agreement with Big Bang)

A Pristine Star



Caffau+ 11



Extremely metal-poor star
~13 billion year old

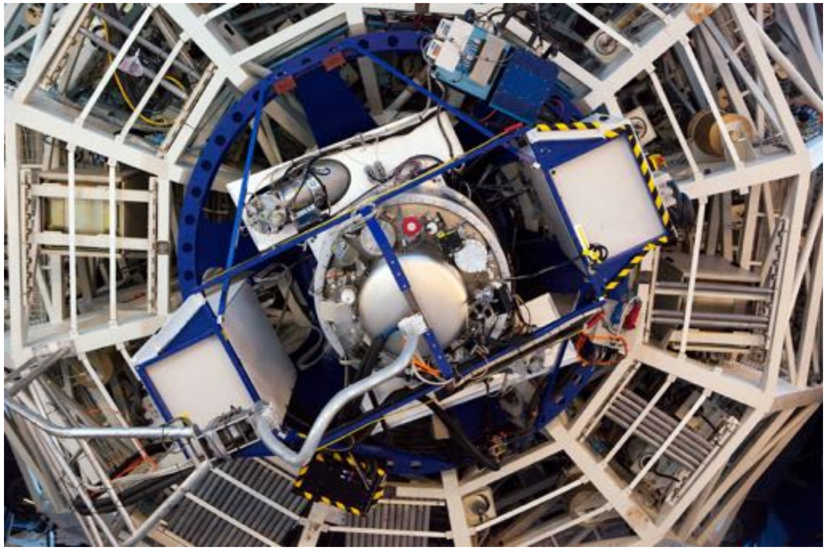
X-SHOOTER

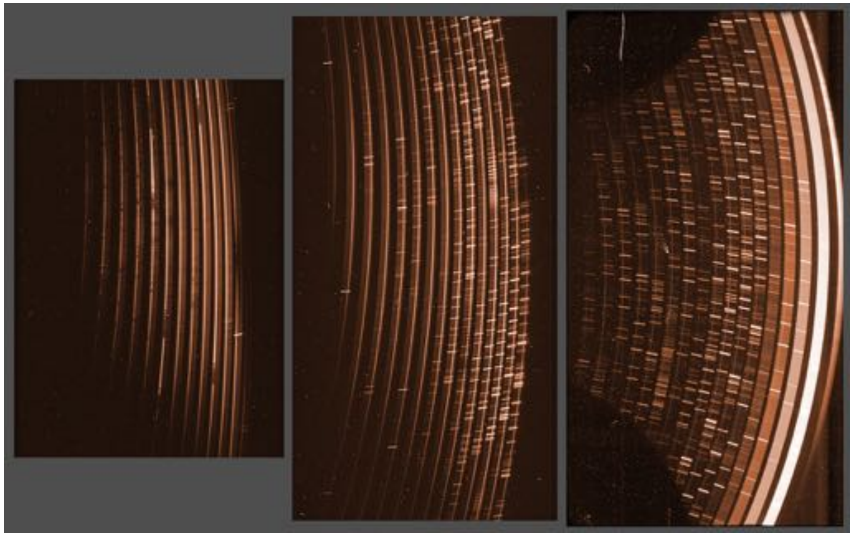
Echelle spectrograph

300–2500 nm

R ~ 4000–17 000
(various slit widths)

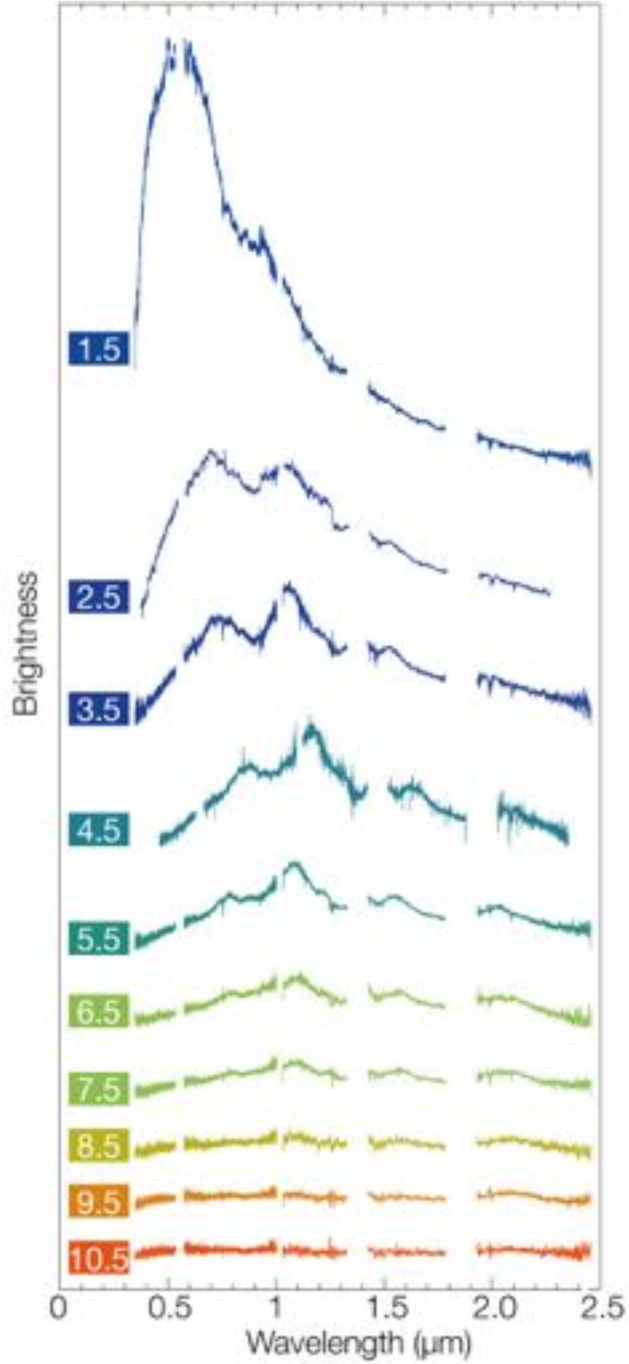
Mag limit ~ 21

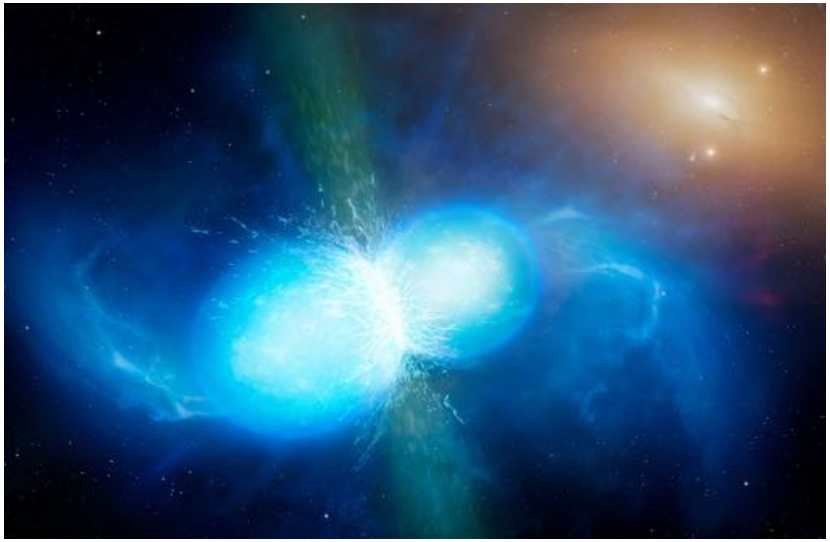




Three arms:
UVB
VIS
Near-IR

X-SHOOTER

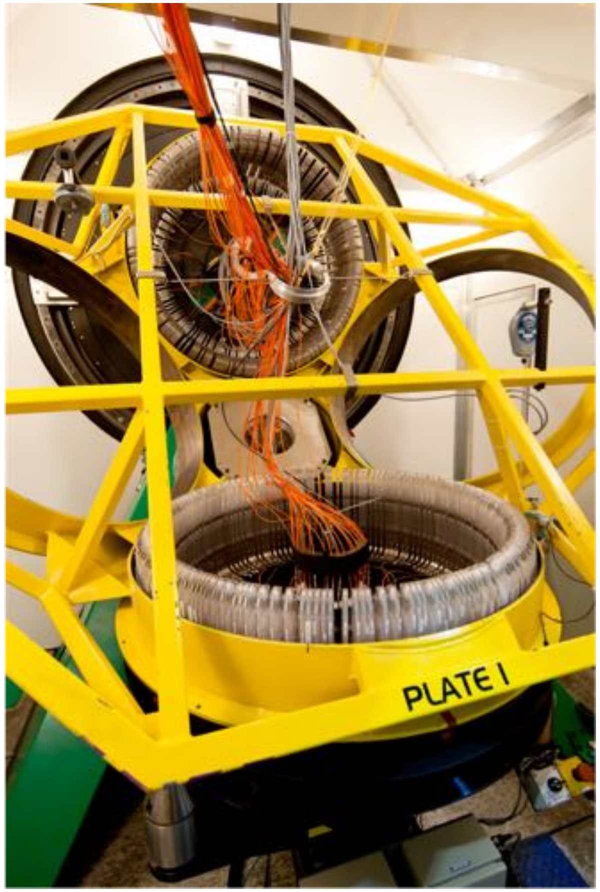




Colliding Neutron Stars

ESO/E. Pian et al./S. Smartt & ePESSTO

FLAMES: multi-fibre robot



370–950 nm

R=7000–24 000 with GIRAFFE (up to 130 fibres)

R=47 000 with UVES (up to 8 objects)

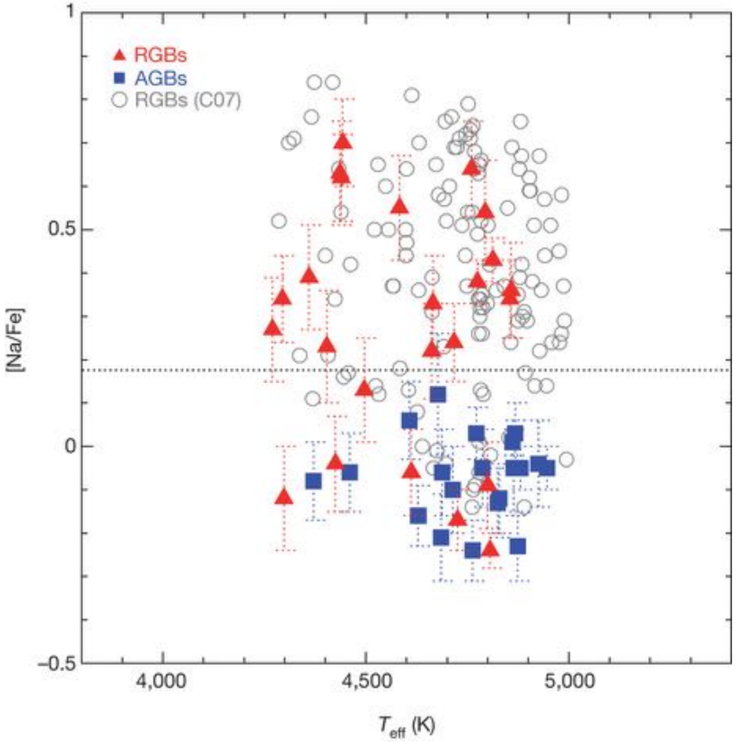
FoV: 25’ diam.

Fibre fed: 1”or 1.2” diam
IFU also possible (2” x 3”)

FLAMES

Campbell+ 13

NGC 6752
Second generation of stars fail to enter AGB phase



MUSE

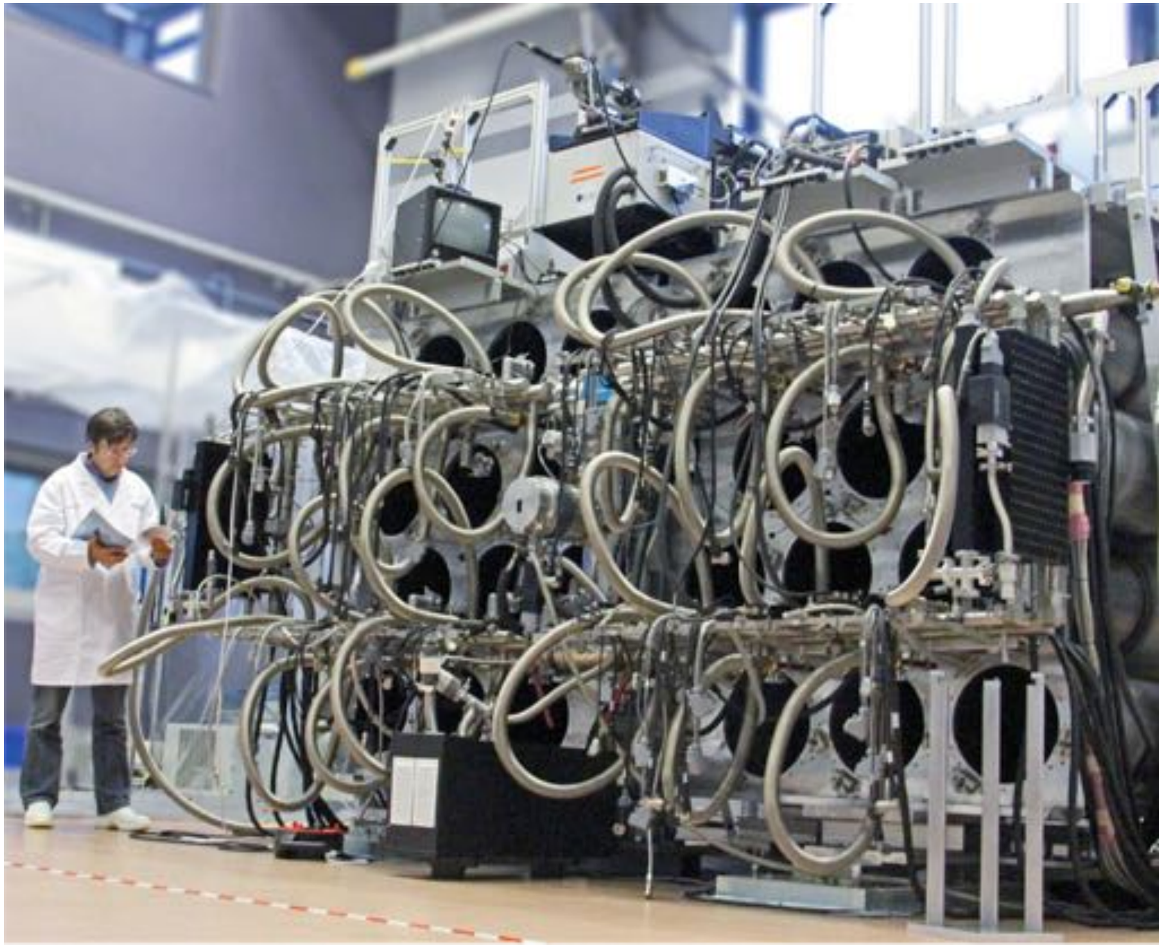
Integral Field
Spectrograph
24 spectrographs

24 x 48 = 1152 mini-slits

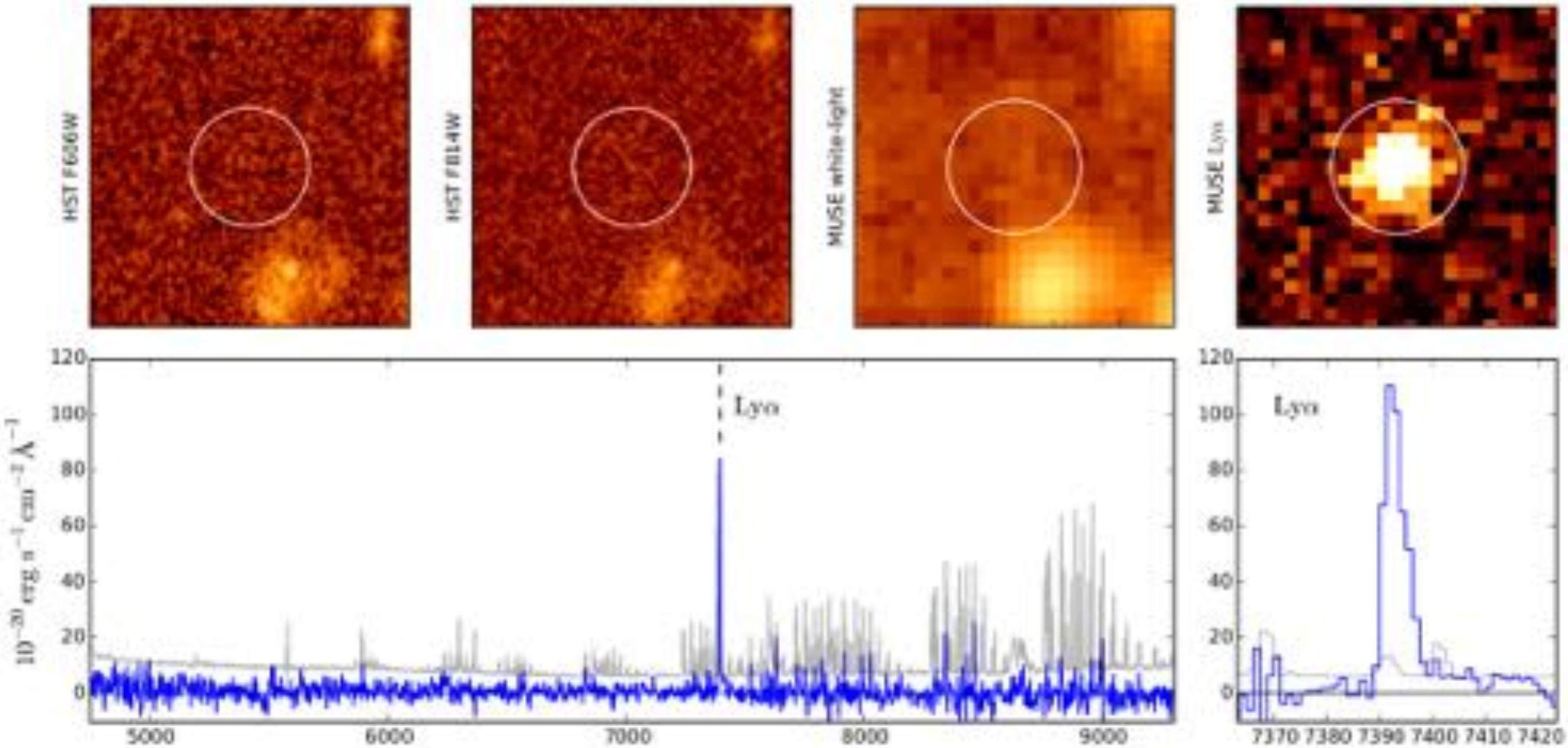
365–930 nm

R ~ 4000

Pixel scale: 0.2”
FoV: 1’ x 1’
With or without AO
(AOF)

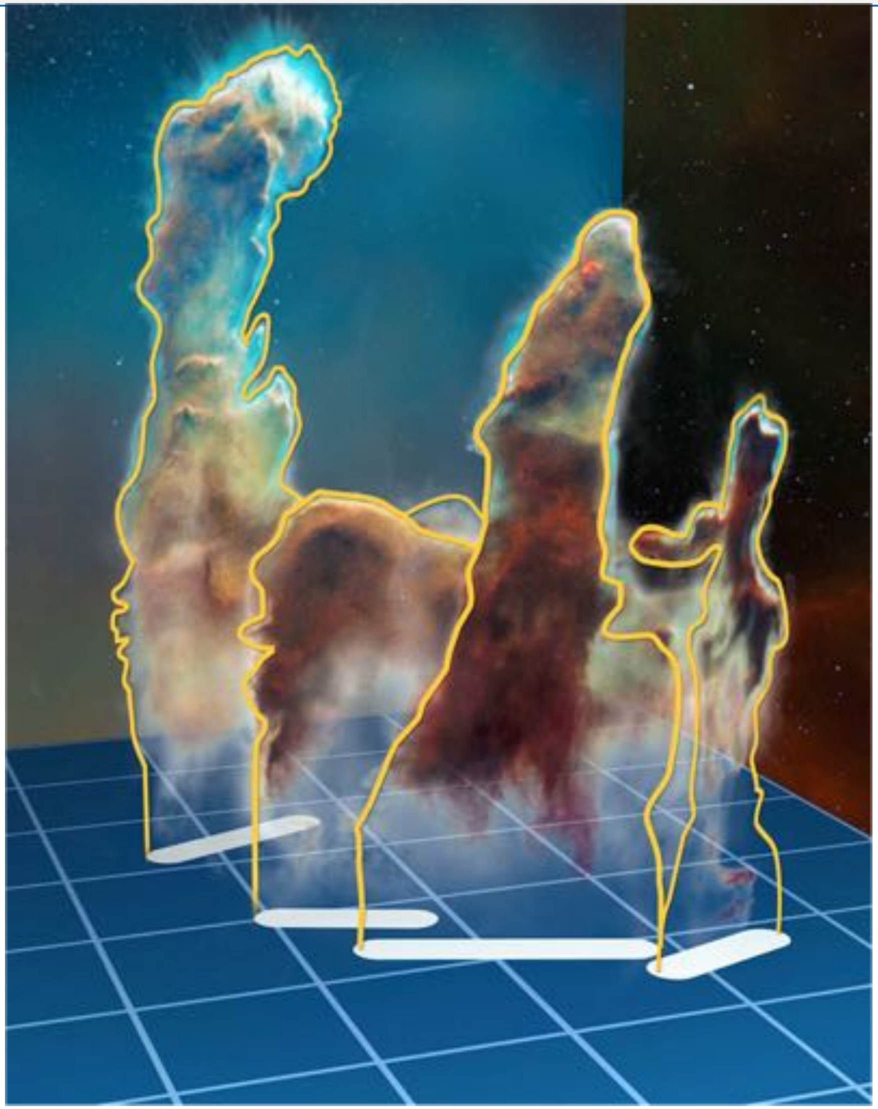


MUSE: Redshift 5 Galaxy



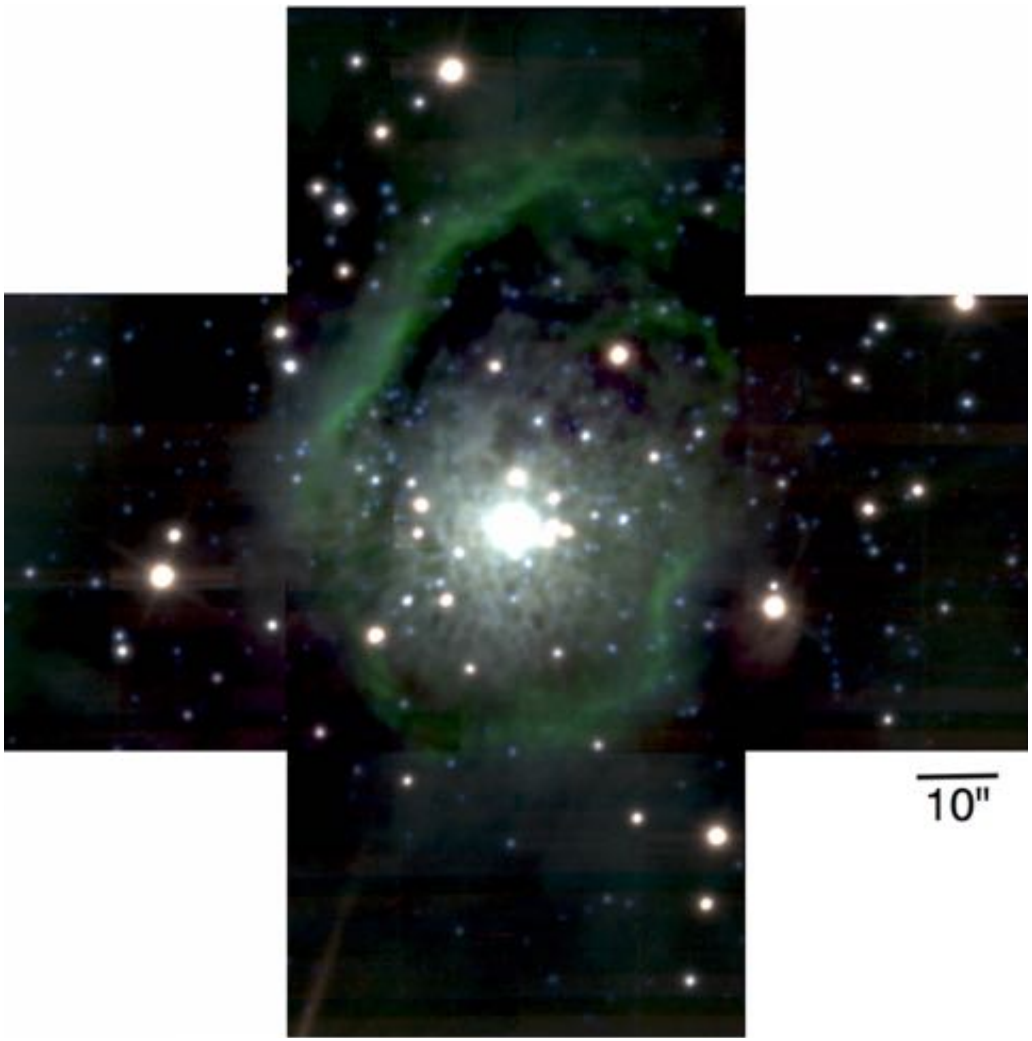
Pillars of Creation (M16)

McLeod+ 15

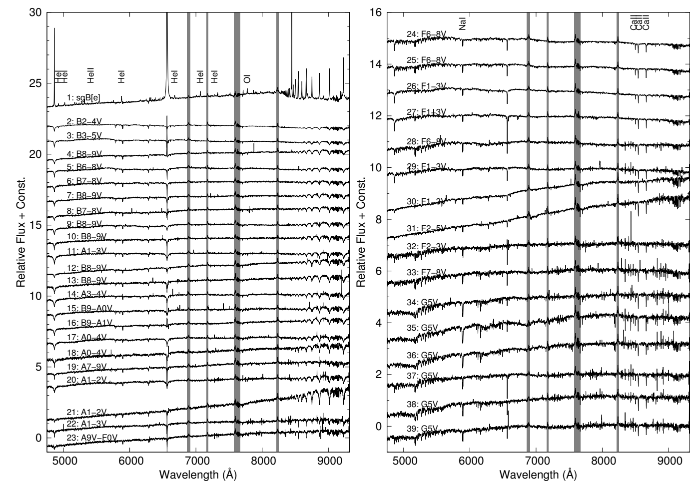


3D Structure
Lifetime: 3 Myrs

Cluster SH 2-266

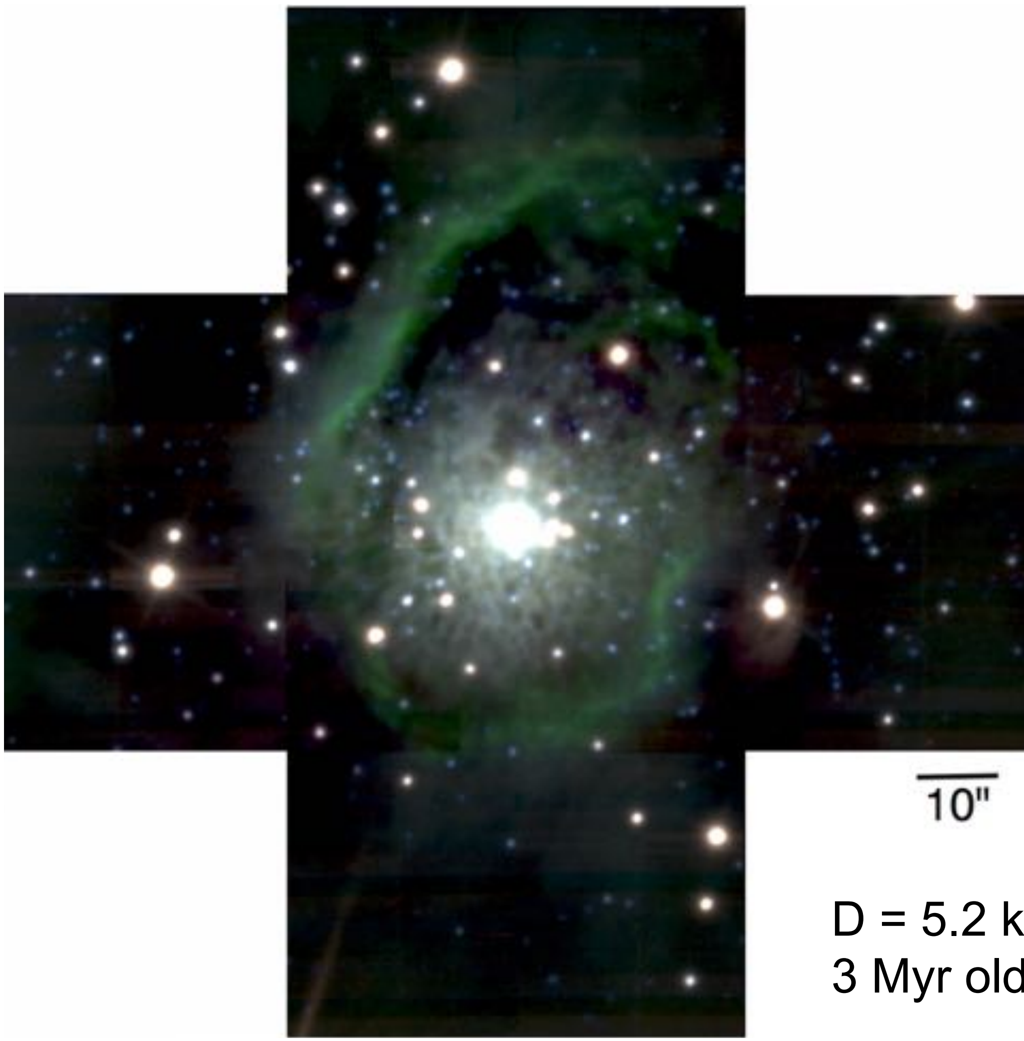


Mehner+ 15

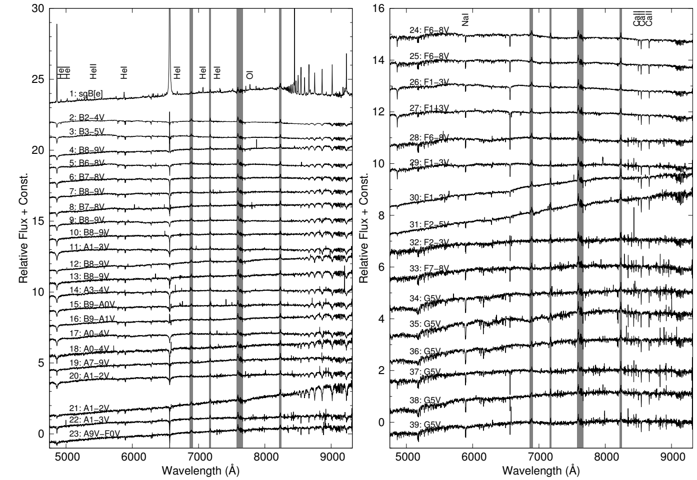


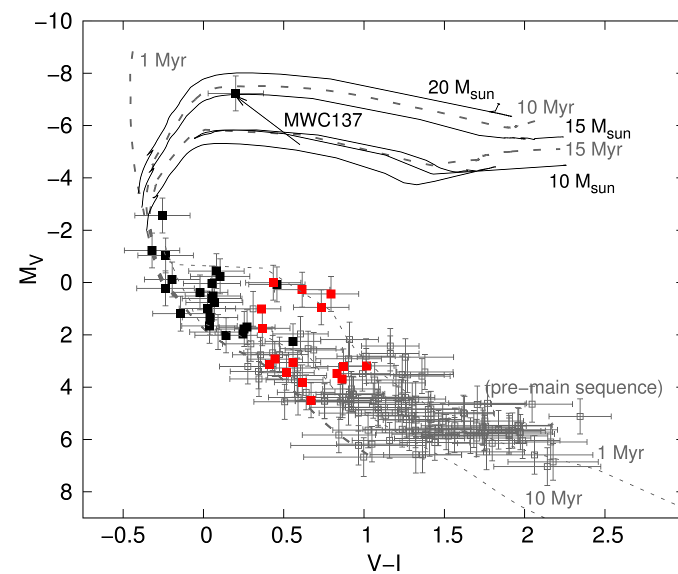
For each star in the cluster, we have a spectrum → spectral classification → extinction → magnitude → isochrones → age of cluster

Cluster SH 2-266



D = 5.2 kpc
3 Myr old



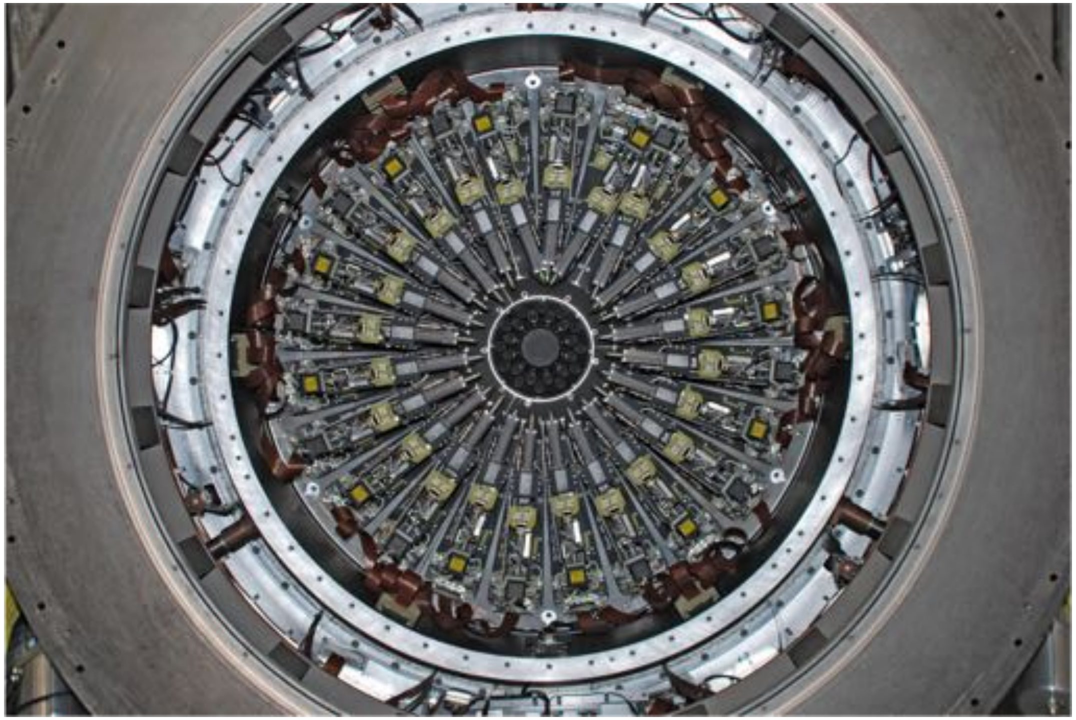


Mehner+ 15

KMOS

The octopus of Paranal…
But with 24 cryogenic arms…
and each is an IFU

KMOS



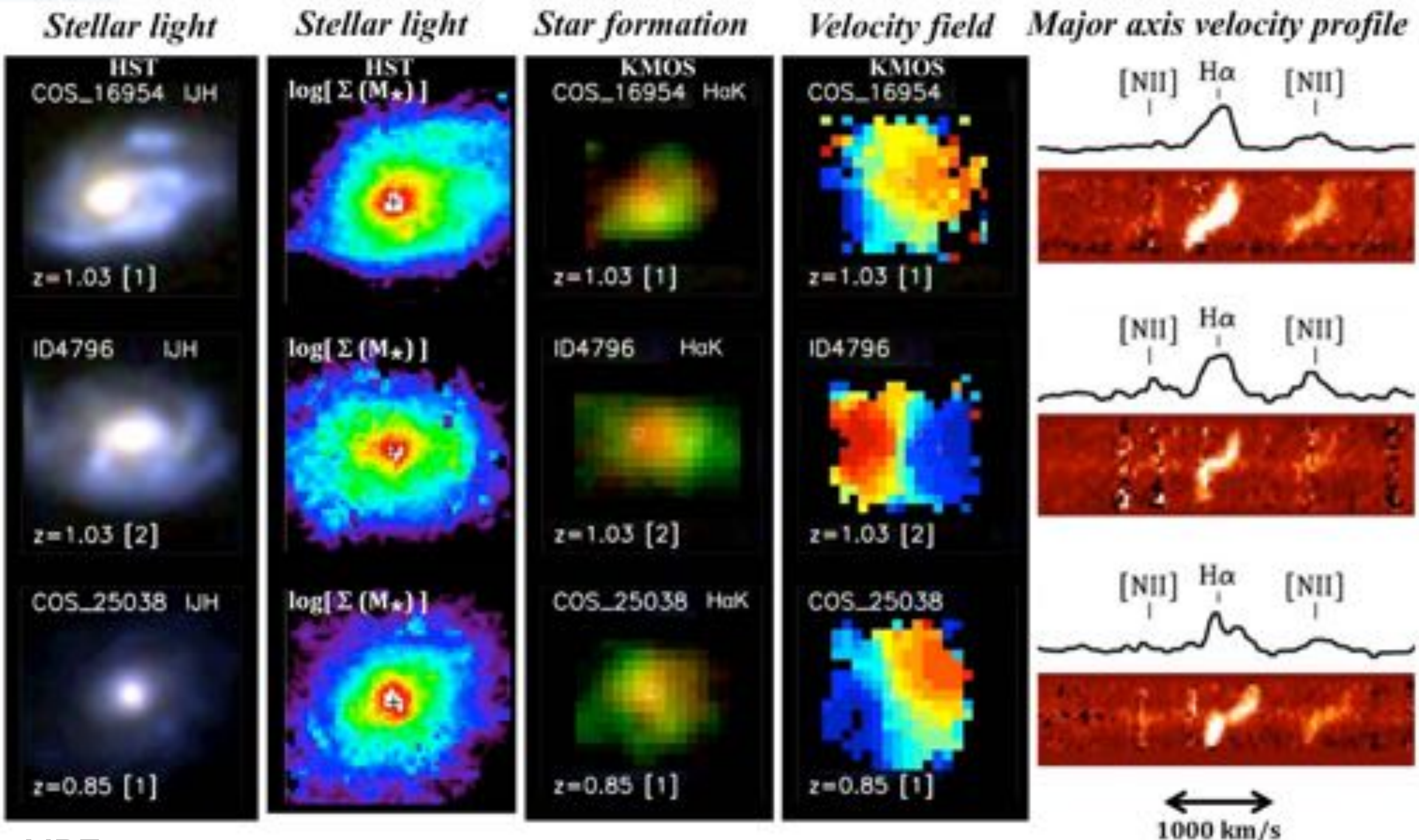
0.8µm to 2.5µm
IZ, YJ, H, K, H+K

R = 2000–4200

24 IFUs
in 7.2 arcmin diameter circle
Each IFU: 2.8" x 2.8”
0.2" x 0.2” pixels

to understand how galaxies grew and evolved in the early cosmos

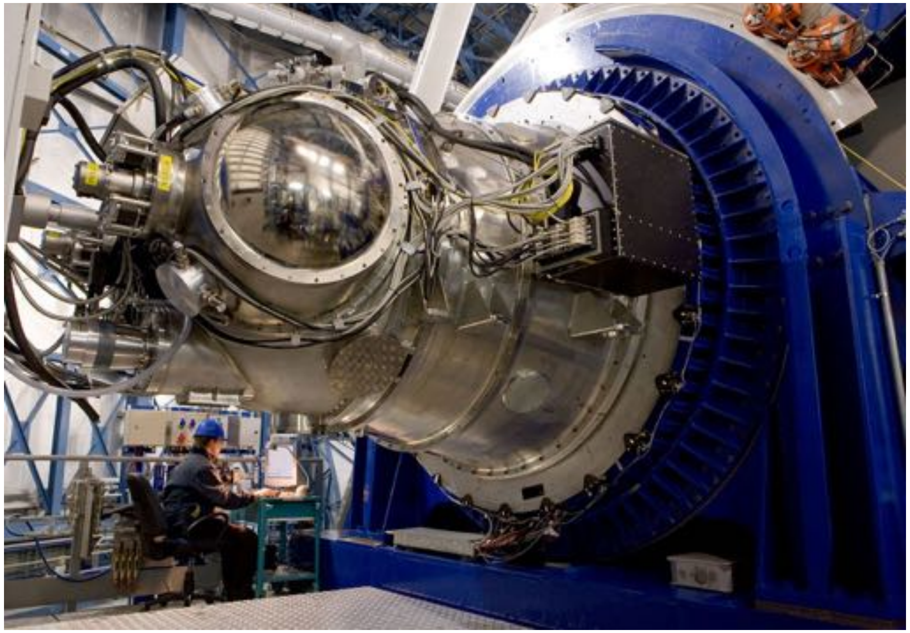
KMOS^{3D}

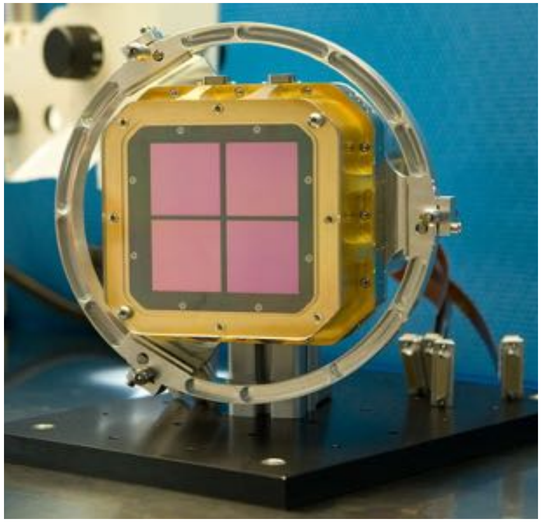


MPE

3D HST and CANDELS

HAWK-I: High Acuity Wide field K-band Imager





near-infrared 0.85-2.5 μm

wide-field imager 7.5' x 7.5'

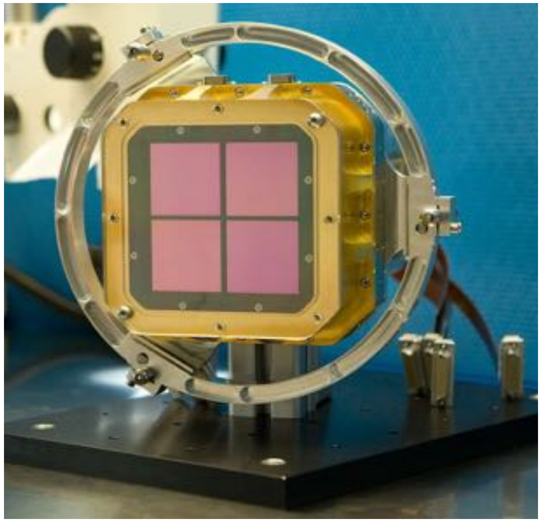
Pixel scale 0.1064"

HAWK-I: High Acuity Wide field K-band Imager

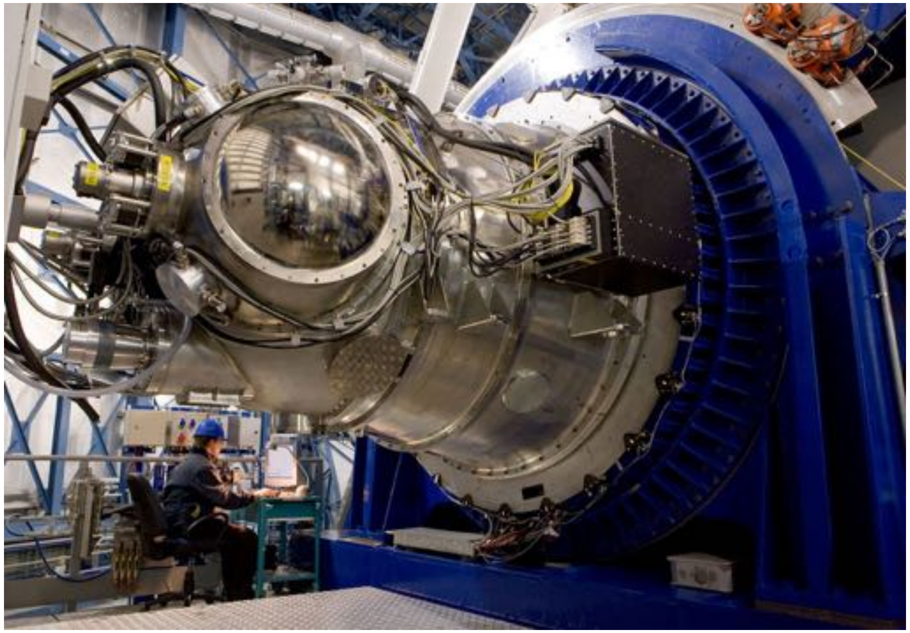
HAWK-I limiting magnitude examples

Filter	Limiting mag [Vega]	Limiting mag [AB]
J	23.9	24.8
H	22.5	23.9
K	22.3	24.2

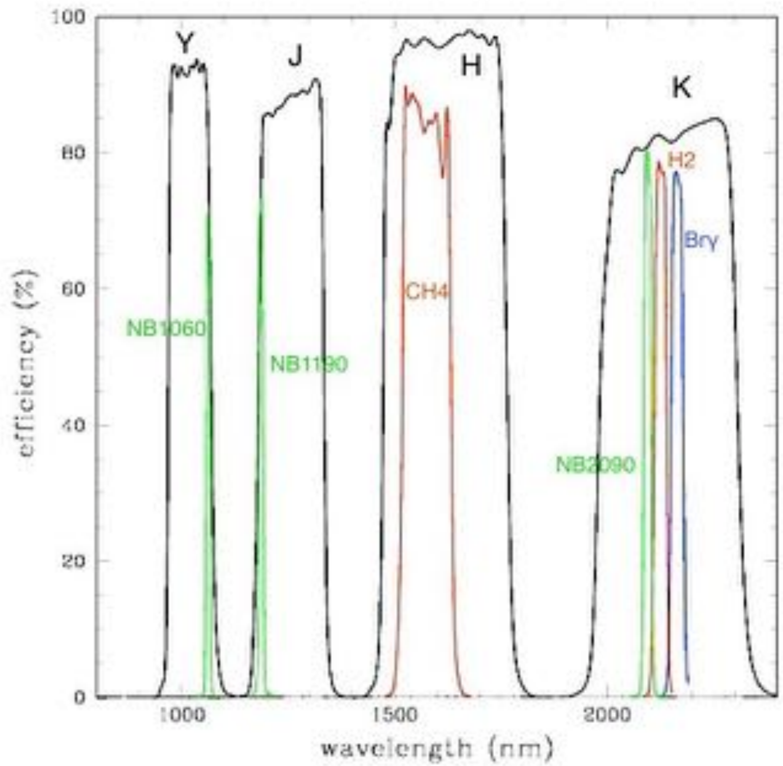
1 hour integration



HAWK-I: High Acuity Wide field K-band Imager



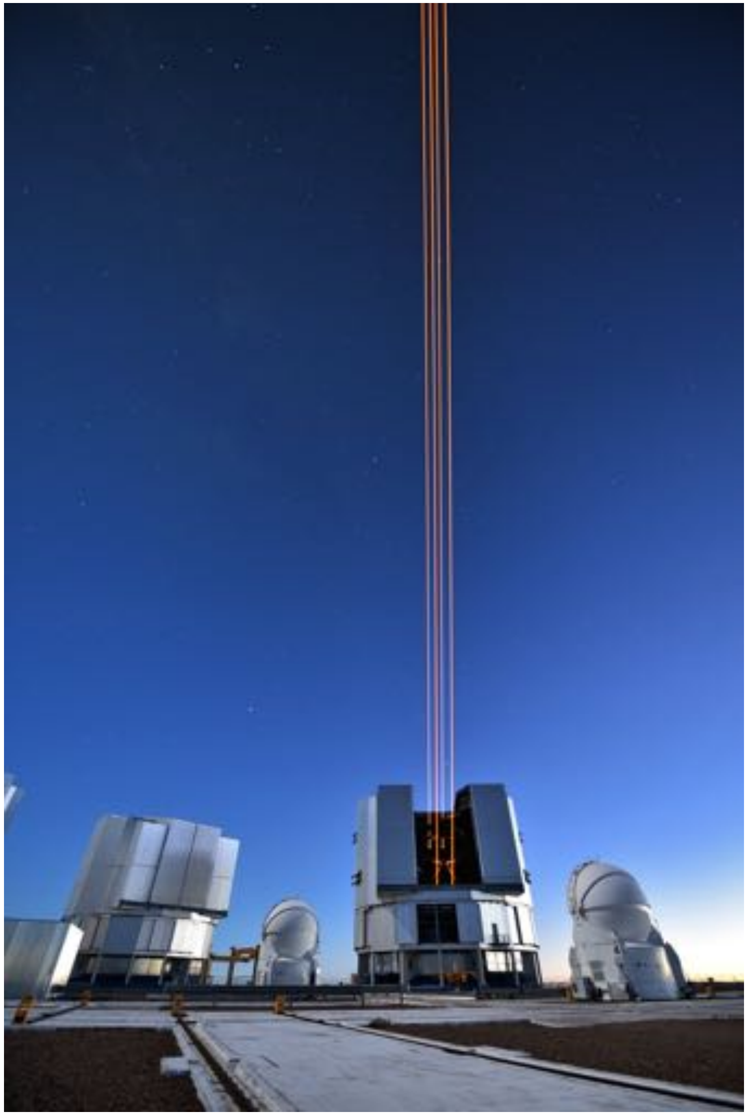
Y, J, H, K and 6 NB filters available

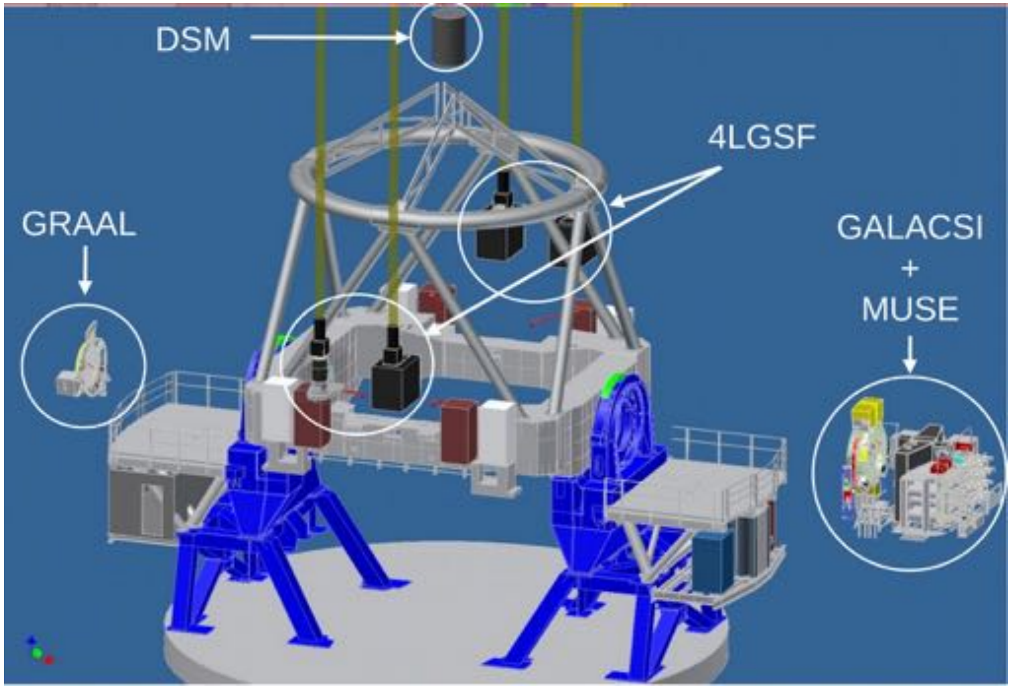


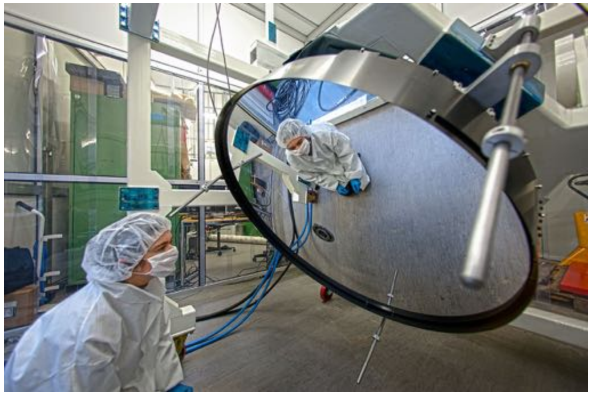
A gallery of Spiral Galaxies

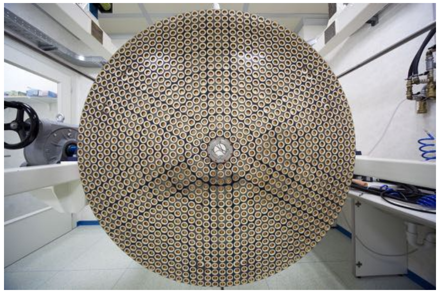
ESO/P. Grosbøl

AO Facility on UT4 (AOF)









Tarentula without/with AOF

Down to 0.2” resolution
→ Better resolved
→ Deeper

VISIR: VLT Imager and Spectrometer for mid-Infrared

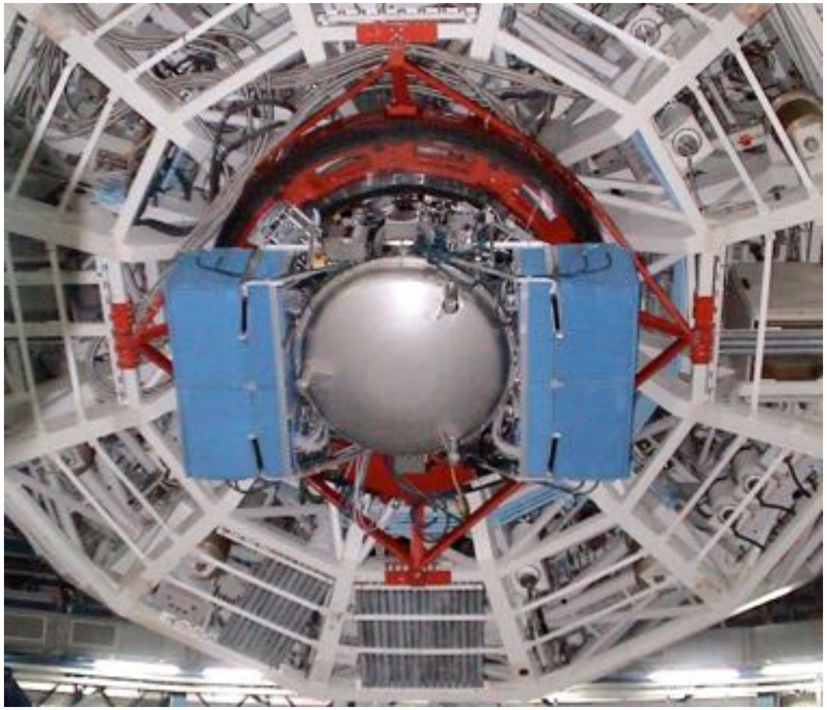
Mid-Infrared
imager, spectrograph

N-band 8–13μm
Q-band 16.5–24.5 μm

Pixel scale: 45-76 mas

FoV: 36x38” or 60x60”

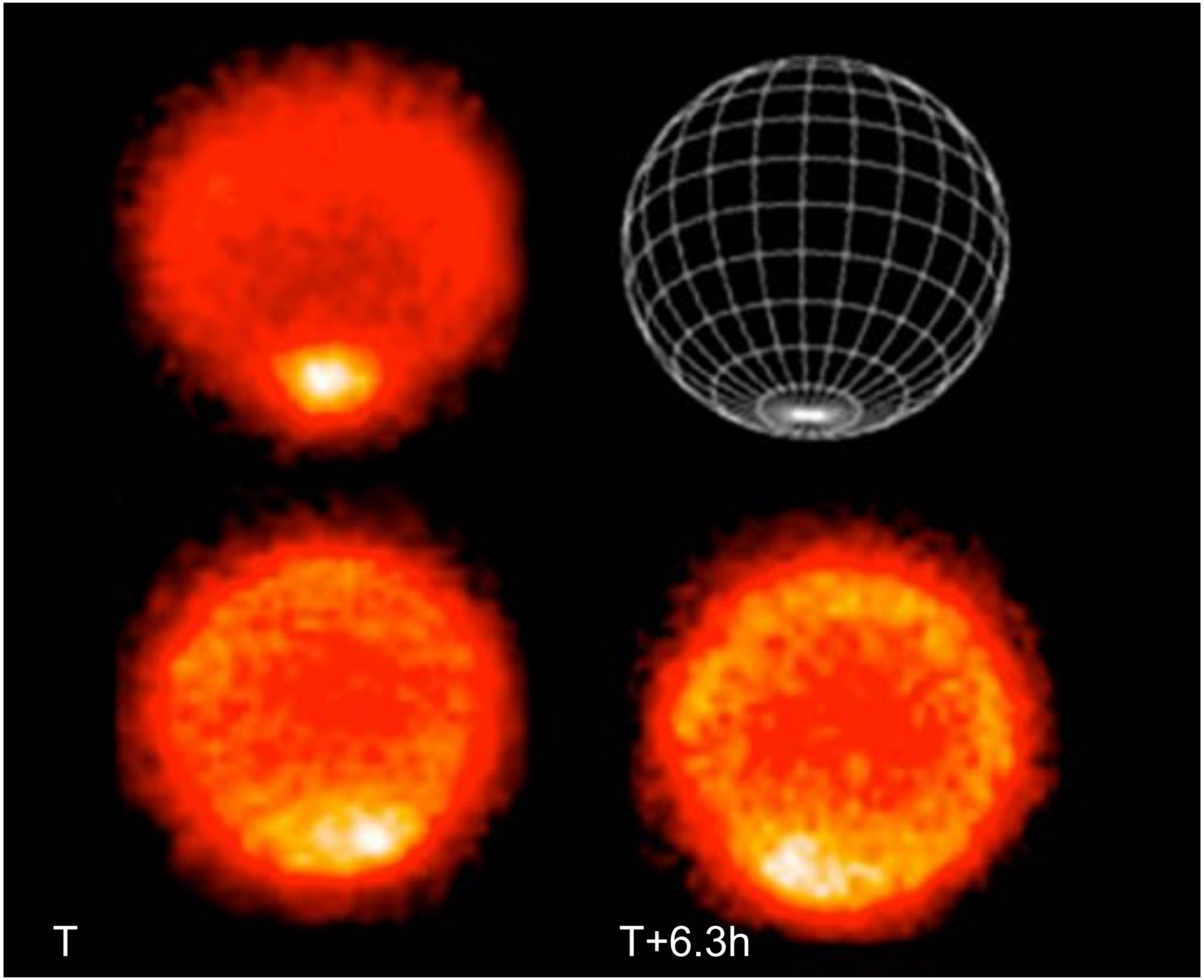
Spectroscopy: 350 to 25,000



'Hot' South Pole of Neptune

Troposphere

Stratosphere



The Fried Egg Nebula

Yellow hypergiant

Huge dusty double shell

ESO/E. Lagadec

NAOS-CONICA (NACO)

0.8–5 μm

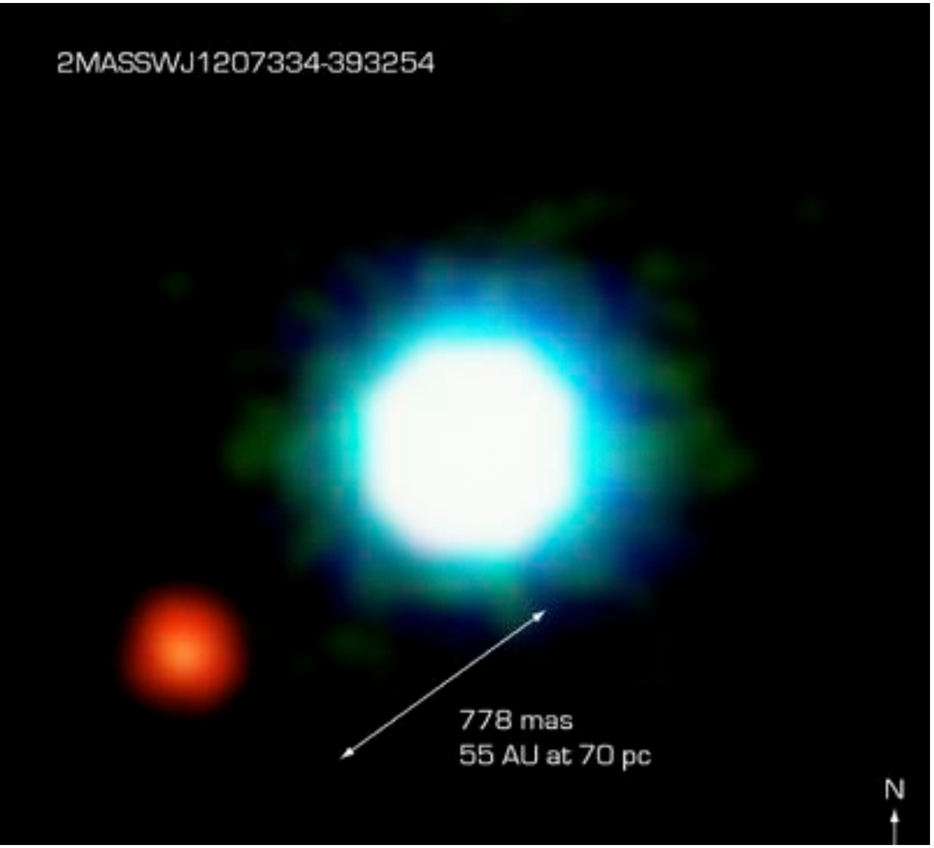
Adaptive-optics-assisted imaging
imaging polarimetry, and
coronagraphy

Pixel scale: 13, 27 or 54 mas

Equipped with one infrared (0.8-2.5 μm) and one visual wavefront sensor (0.45-1.0 μm). Reference star can be off-axis!

Can provide Strehl of 50% with V=12 reference star
Magnitude limit ~ 23.5-24 in J, H, K

Image of an "Exoplanet"



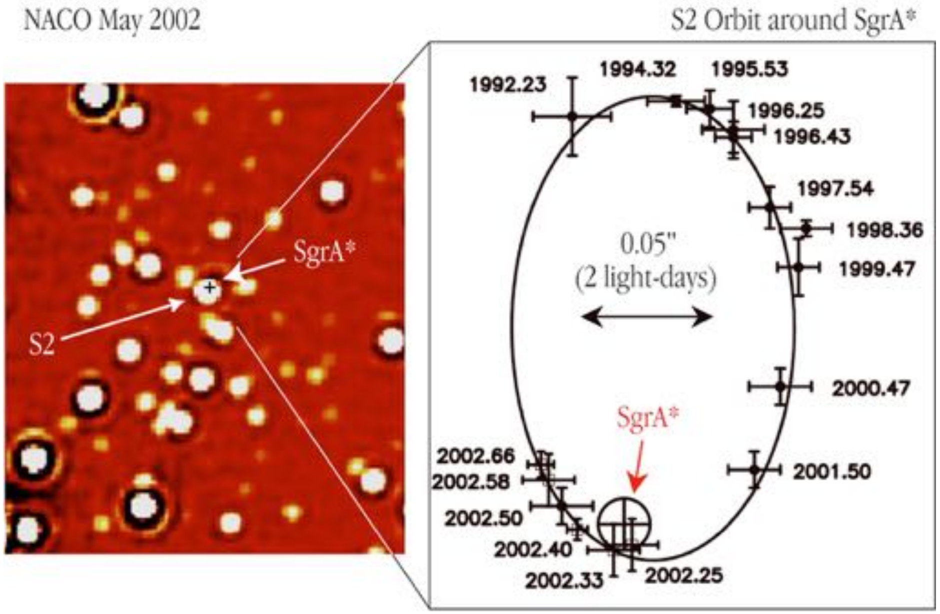
Chauvin et al., 2005

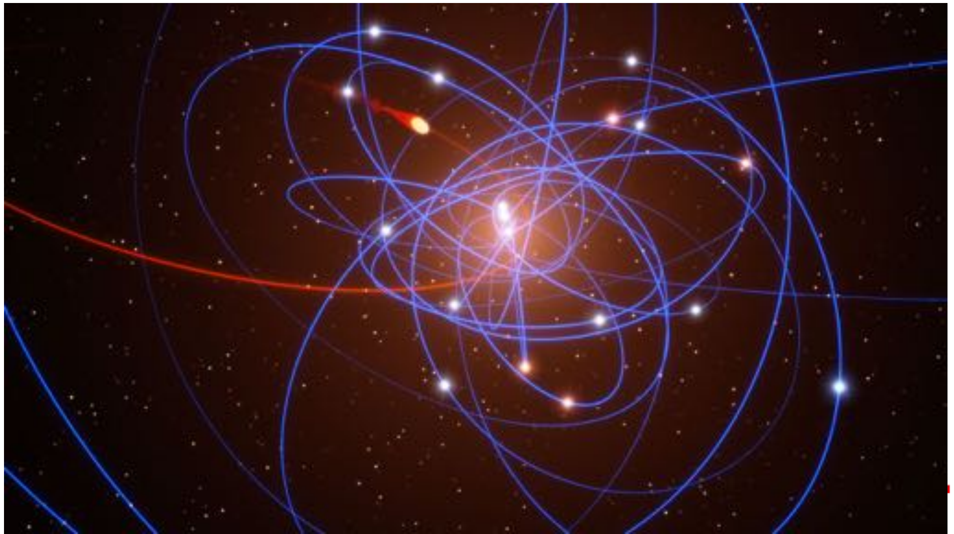
Brown Dwarf "2M1207"
- 25 Jupiter-masses
- 8 million years old

"Giant Planet Candidate Companion (GPCC)"
- 100 x fainter
- 1000 ºC
- 55 AU distance
- 5 Jupiter-masses

TW Hydrae Association
- 230 light-years
- Water molecules

Galactic Centre





SINFONI

Near-infrared integral field spectrograph with adaptive optics capabilities

1–2.5 μm

R ~ 1500–4000

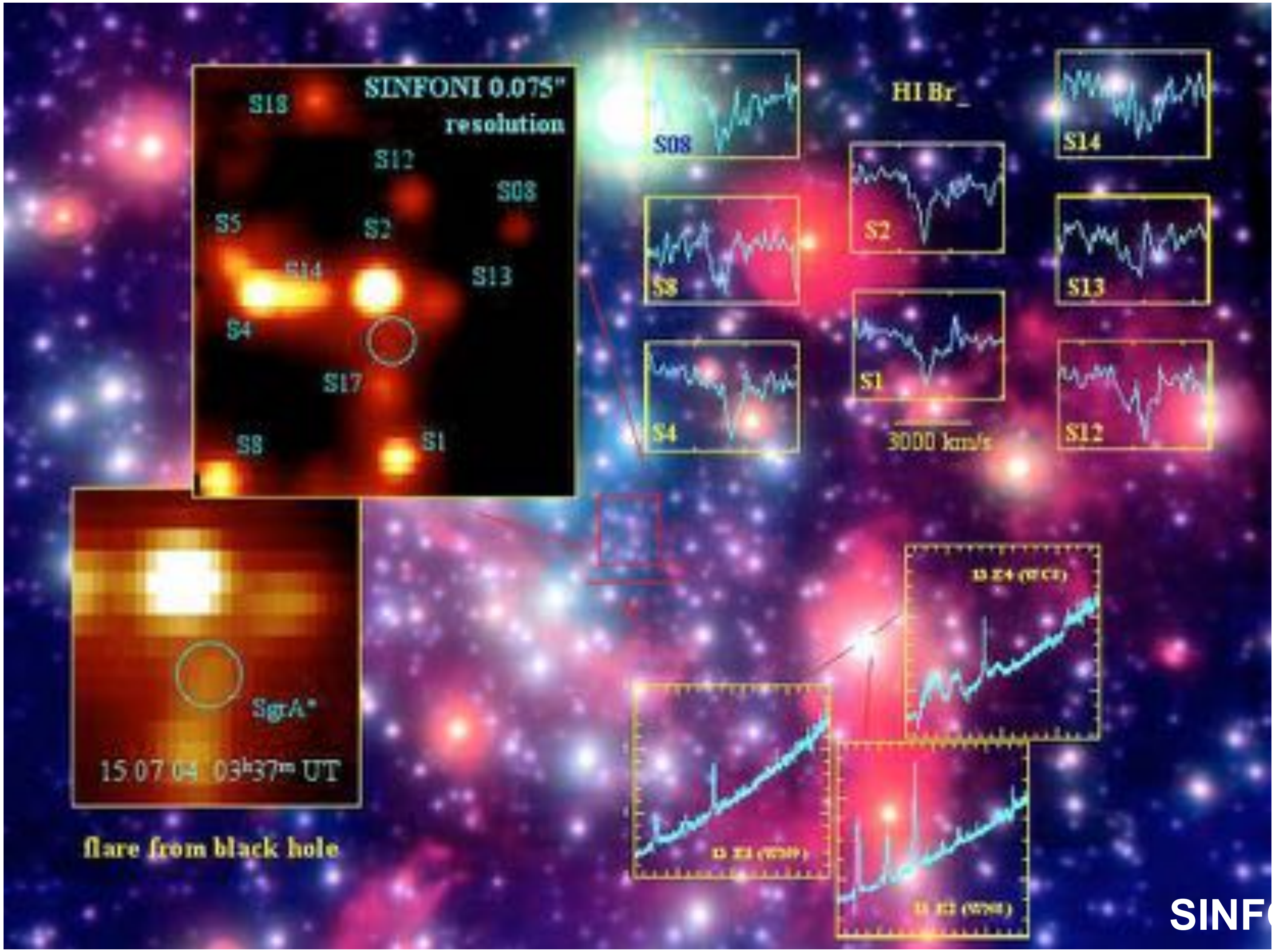
Pixel scale: 25 to 250 mas

FoV: 0.8”x0.8” to 8”x8”

Mag limit ~ 18-20

Can use a Laser Guide Star

Galactic Centre



SPHERE

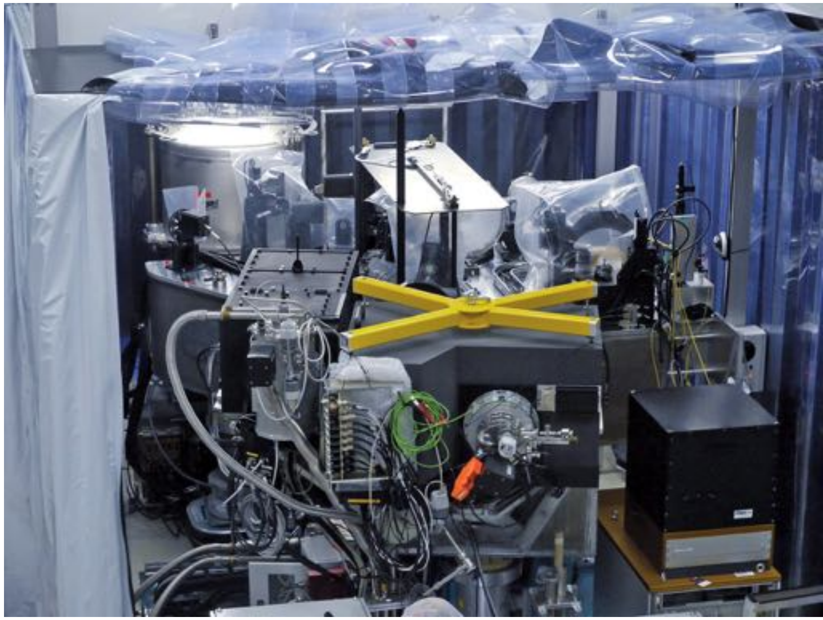
High-contrast Imaging (coronagraph), low-resolution spectroscopy (R~30-350), polarimetry

Extreme AO: Strehl ratio of ~75% in H-band

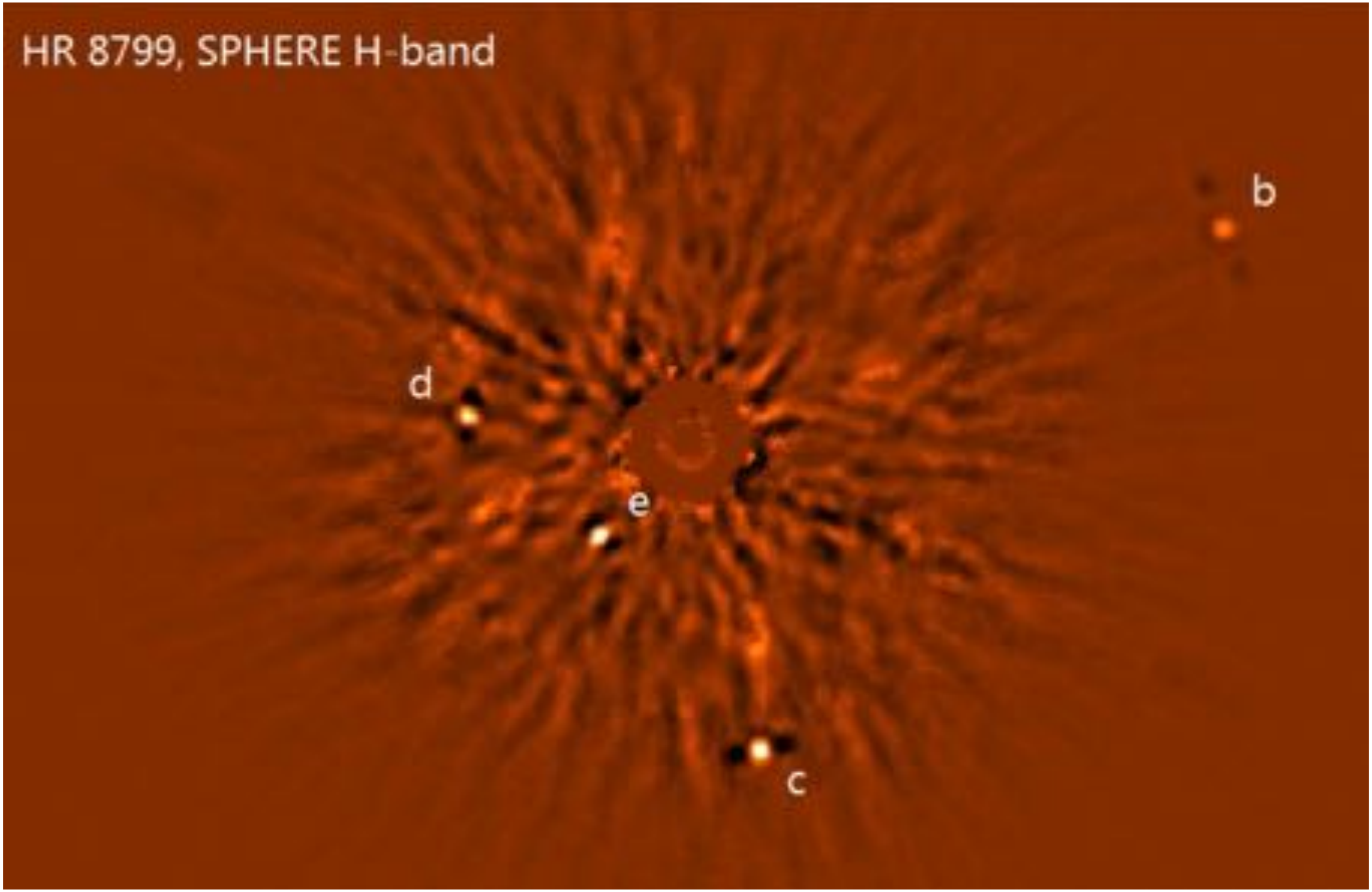
On-axis reference star (R < 13 mag)

In visible and in near-IR: 0.5–2.32 µm

FoV: 1.73"x1.73“ (IFU),
3.5”x3.5” (optical) to 11’’ x 11” (IR)

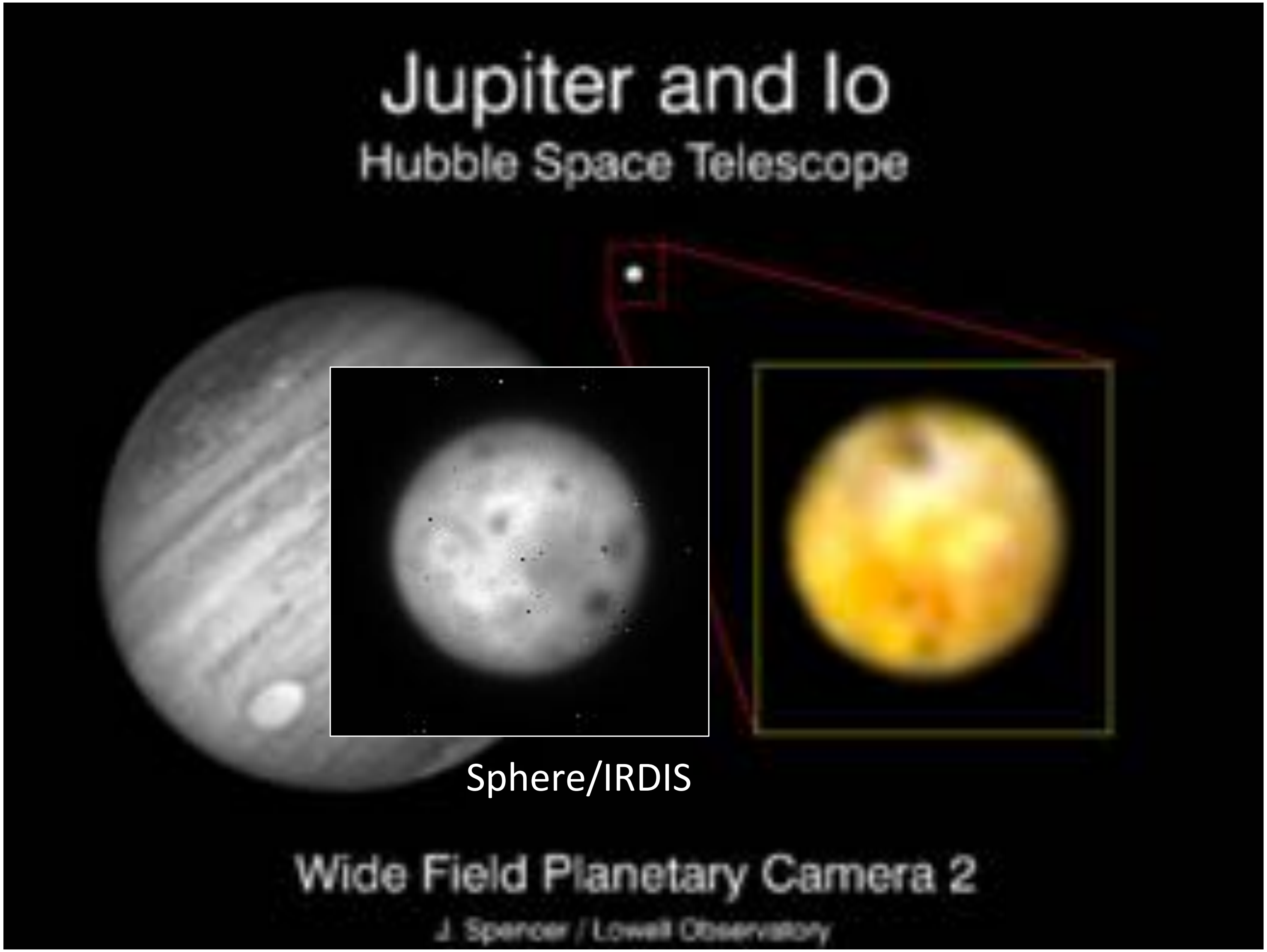


Four planets around HR 8799

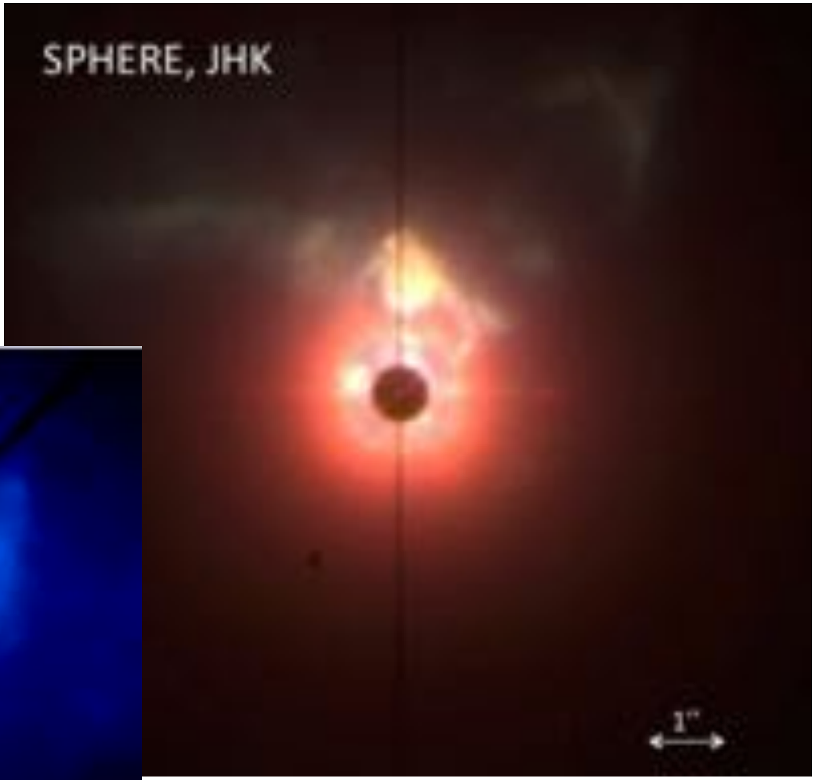


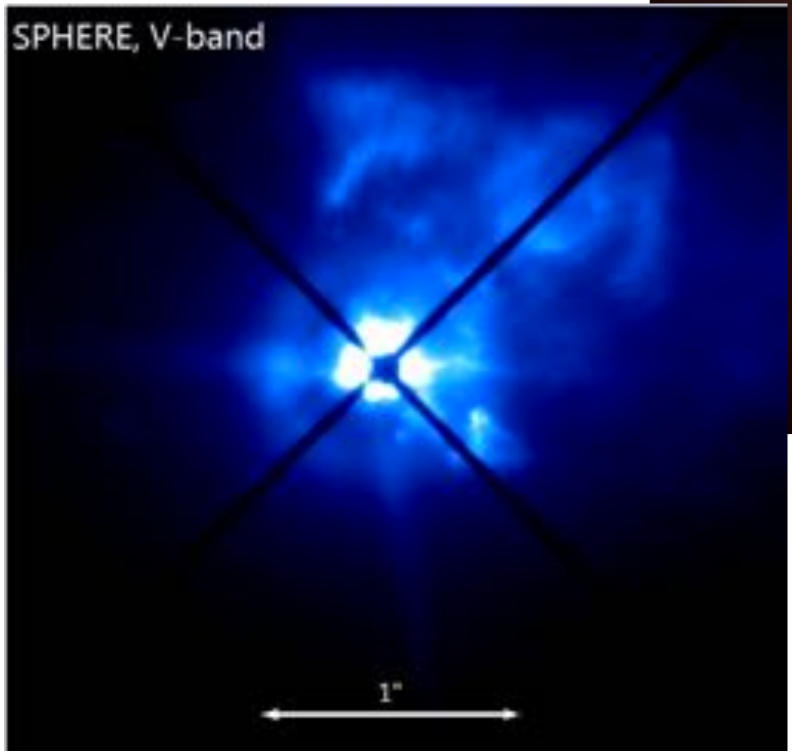
Protoplanetary discs

Better than Hubble



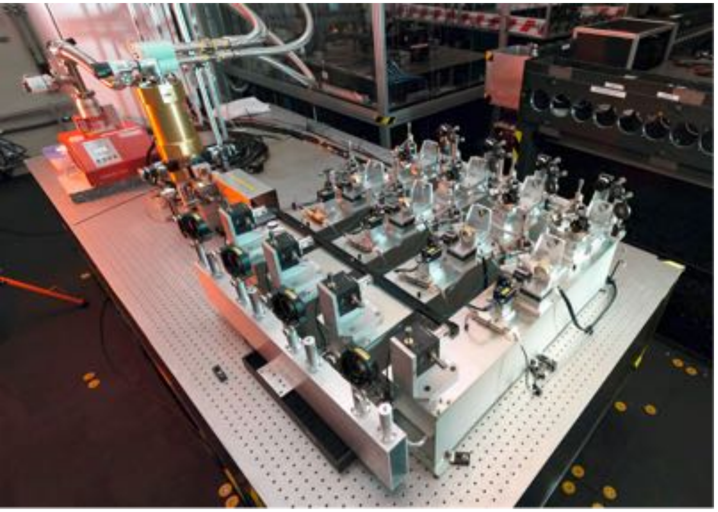
VY CMa, a red hyper-giant





PIONIER at the VLTI

4 telescopes



Visibilities on 6 baselines and 4 closure phases simultaneously

Highly efficient (1 point ~ 5-7 min)
A typical calibrated sequence is 45 min

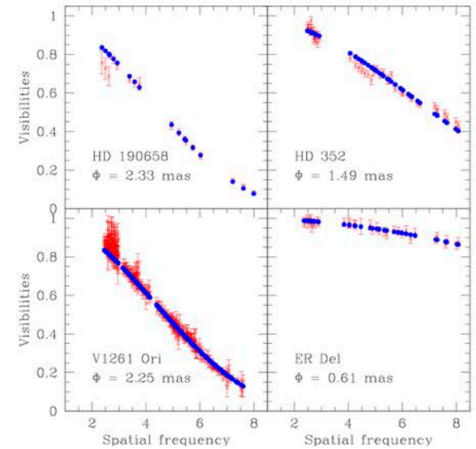
PIONIER: Measuring Stars

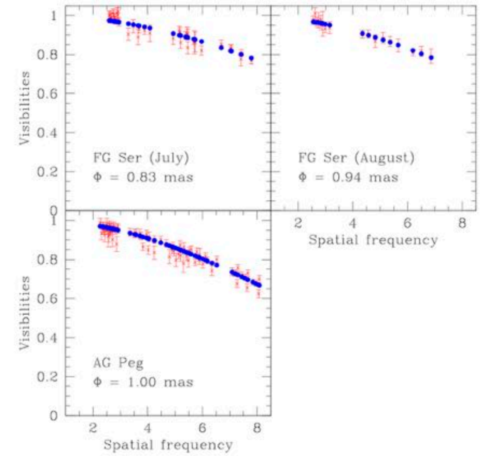
Studied 6 symbiotic or related stars

Star designation		Date	Diameter (mas)	Error (mas)	χ^2_{red}
V1472 Aql	HD 190658	2012-07-03	2.33	0.03	0.82
AP Psc	HD 352	2012-08-13	1.49	0.02	2.48
V1261 Ori	HD 35155	2012-03-03	2.25	0.08	0.87
ER Del	–	2012-08-13	0.61	0.04	0.80
FG Ser	–	2012-07-03	0.83	0.03	0.69
	–	2012-08-13	0.94	0.05	0.26
AG Peg	HD 207757	2012-08-13	1.00	0.04	1.31

Boffin+ 2014

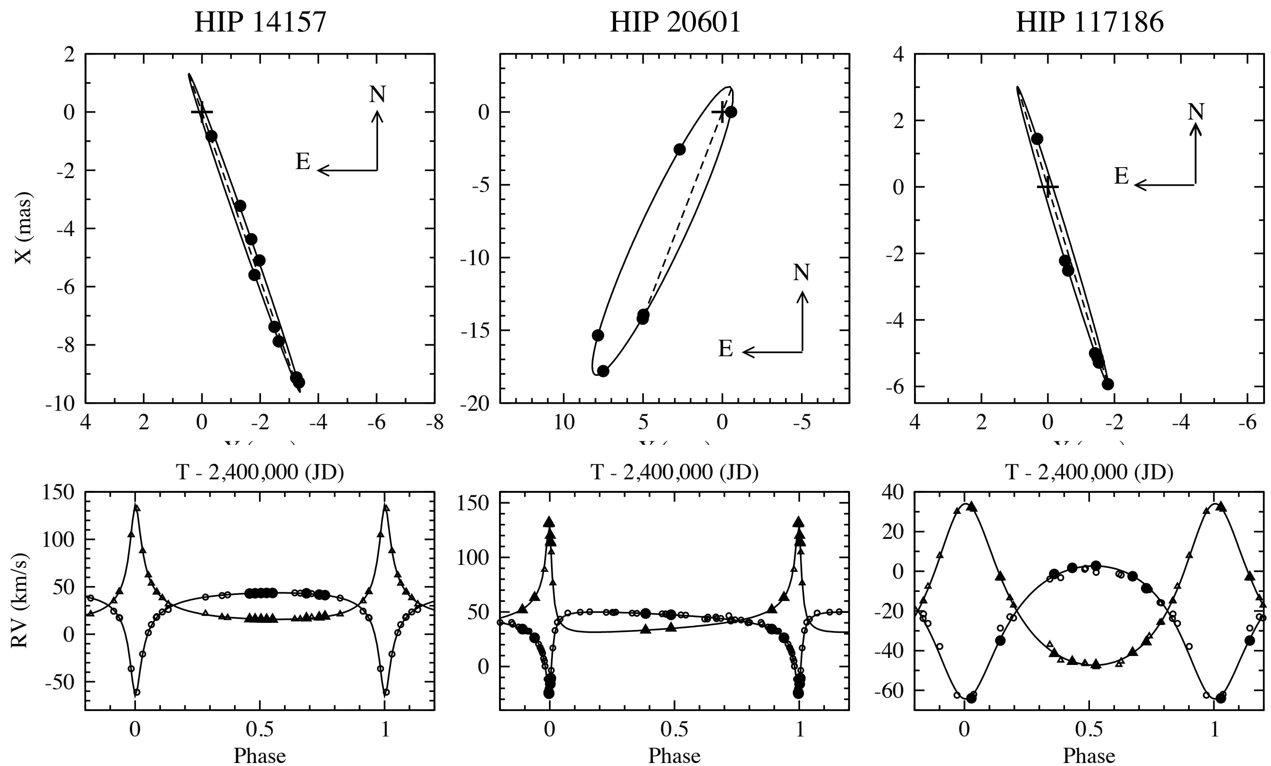
Visibilities





Application to Binaries

Halbwachs+ 15



	HIP 14157	HIP 20601	HIP 117186
$\mathcal{M}_1$ $(\mathcal{M}_\odot)$	0.982 $\pm$ 0.010	0.9808 $\pm$ 0.0040	1.686 $\pm$ 0.021
$\mathcal{M}_2$ $(\mathcal{M}_\odot)$	0.8819 $\pm$ 0.0089	0.7269 $\pm$ 0.0019	1.390 $\pm$ 0.034

Achieve 1% or better precision on stellar mass!

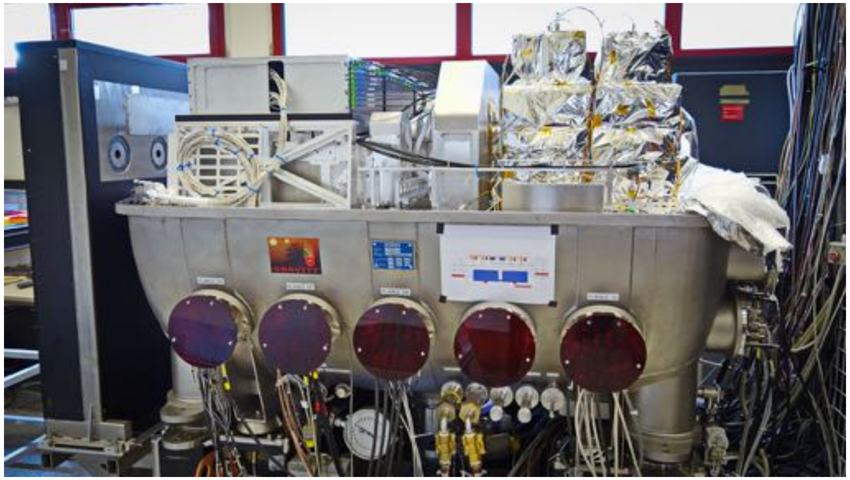
GRAVITY

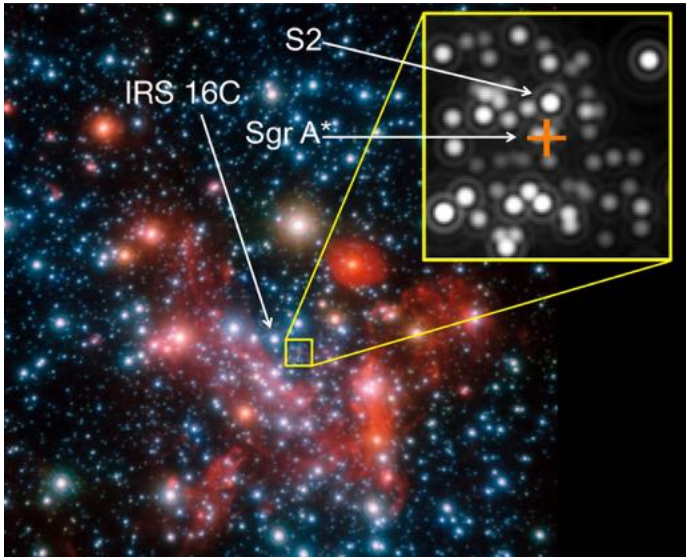
Four-beam combiner

2.0–2.4 μm (K-band)

3-mas resolution

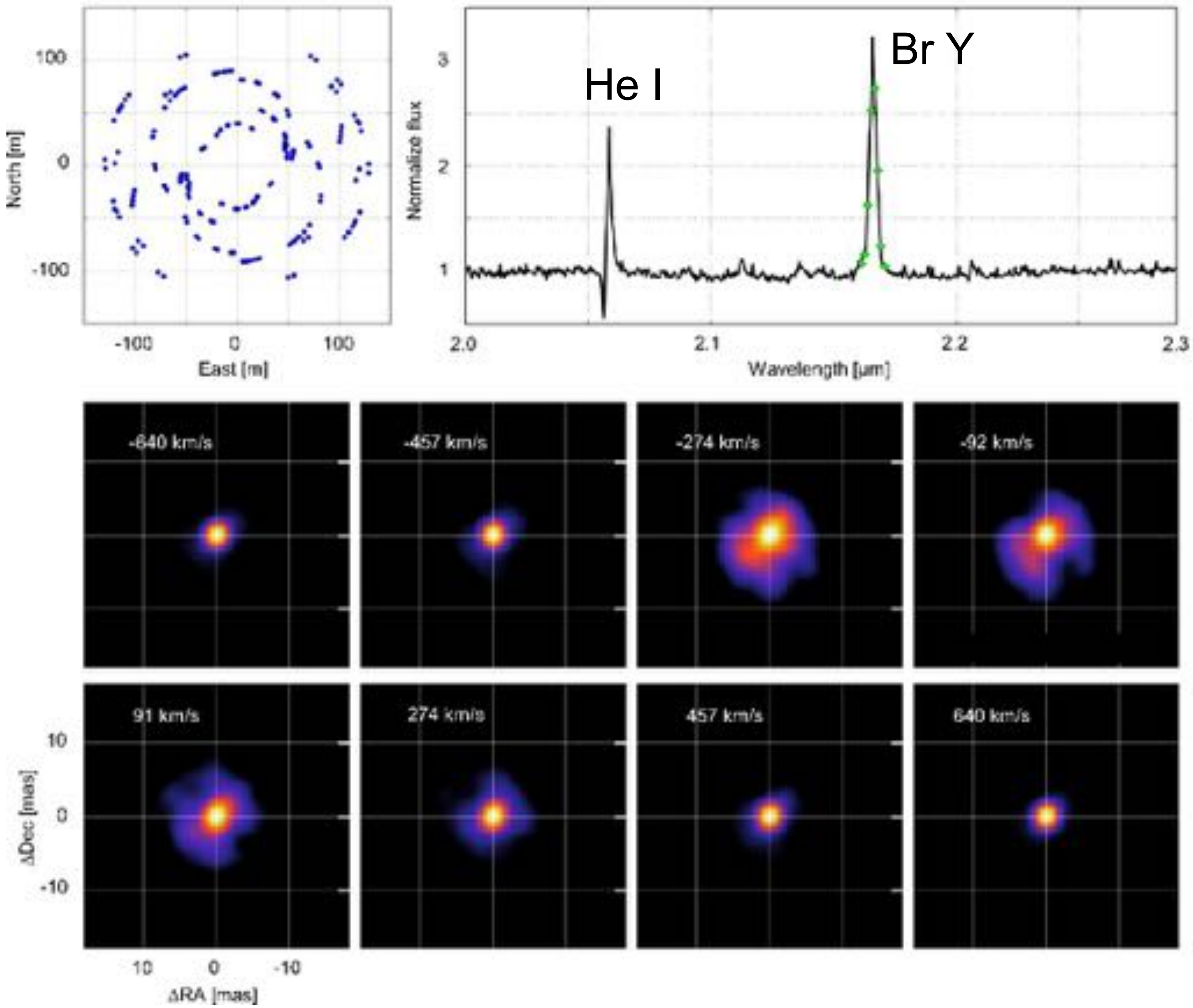
Spectroscopy
R ~ 22, 500, and 4500





Main science: Study of stars in Galactic Centre

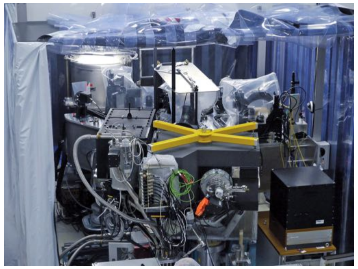
The wind of Eta Carinae



complex morphology of the wind

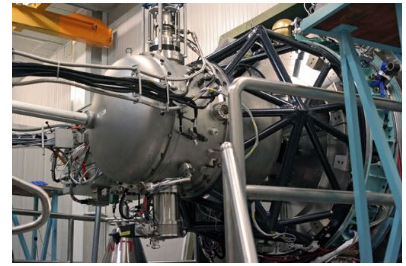
Gravity Collaboration 17

La Silla Paranal instruments


SPHERE


FORS

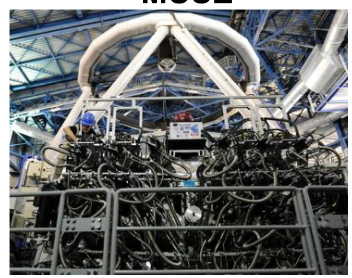

KMOS

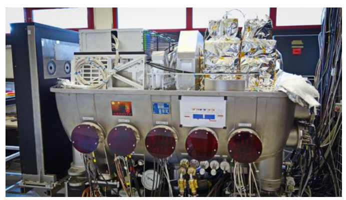

SOFI

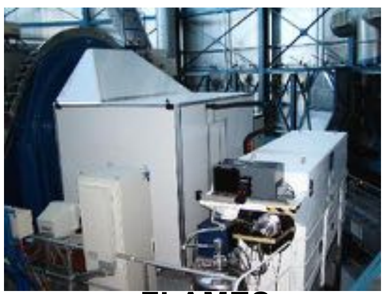

UVES

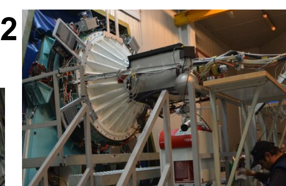

SINFONI

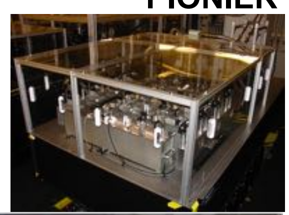

VISIR


MUSE

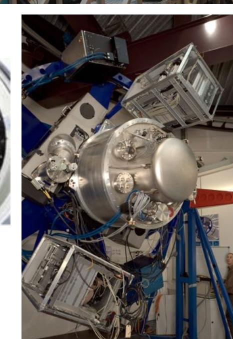

GRAVITY


FLAMES

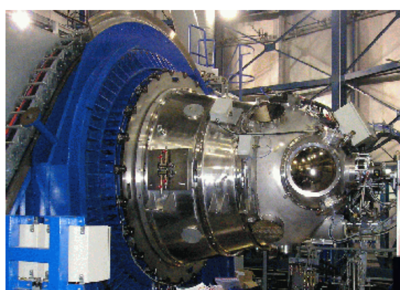

EFOSC2


PIONIER


VIRCAM + OMEGACAM


XSHOOTER


NACO


HAWKI


ESPRESSO


HARPS


Happy
Observing!