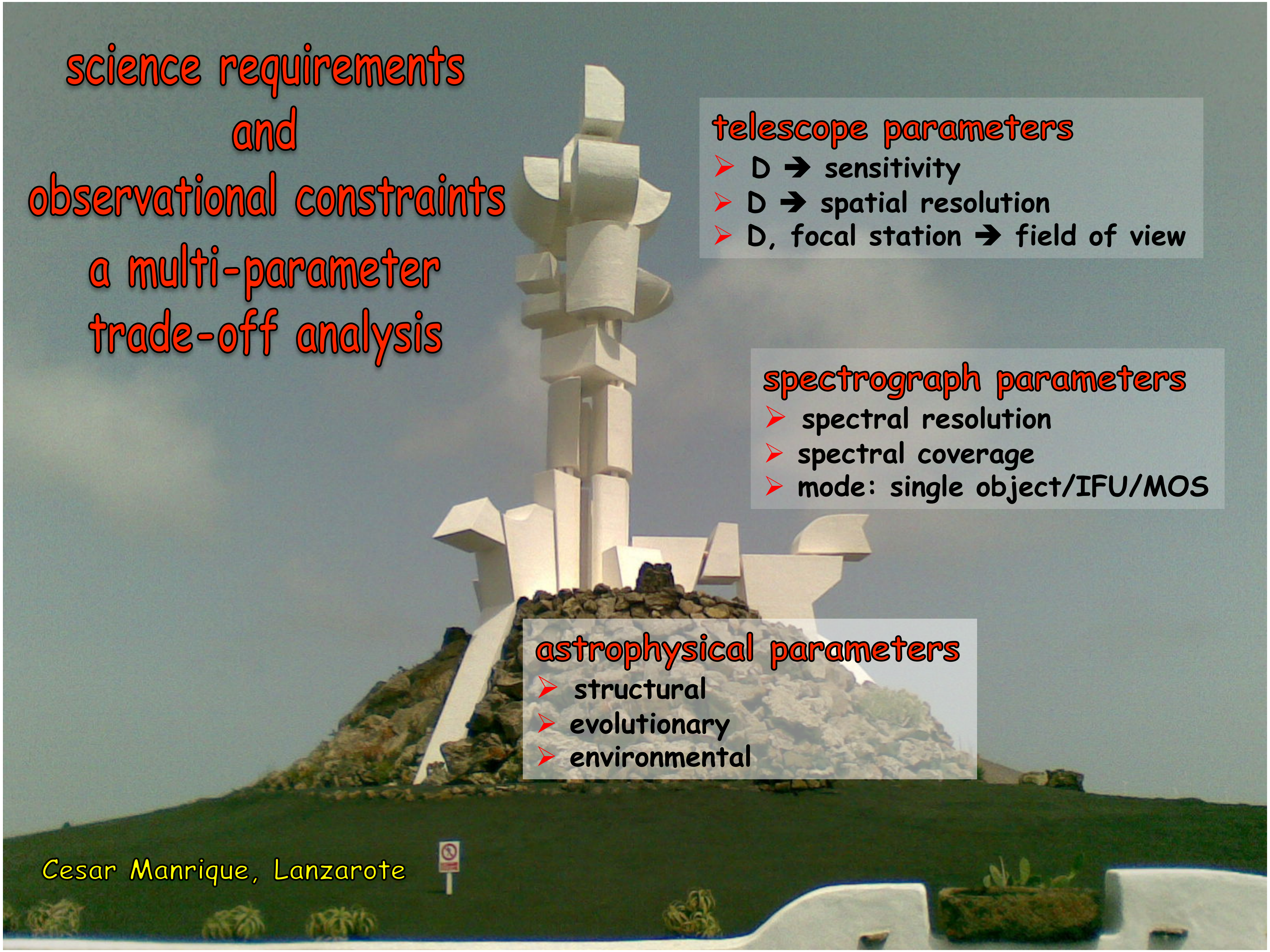
RASPUTIN ESO Workshop
October 13-17, 2014, Garching bei Muenchen, Germany

NIR spectroscopy of stellar populations in the E-ELT era

Livia Origlia

INAF - Osservatorio Astronomico di Bologna
livia.origlia@oabo.inaf.it

Aalsmeer, Amsterdam



science requirements and observational constraints

a multi-parameter trade-off analysis

telescope parameters

- D ➔ sensitivity
- D ➔ spatial resolution
- D, focal station ➔ field of view

spectrograph parameters

- spectral resolution
- spectral coverage
- mode: single object/IFU/MOS

astrophysical parameters

- structural
- evolutionary
- environmental

Cesar Manrique, Lanzarote

spectroscopy: general

- chemical abundances & abundance patterns

  nucleo-synthesis, SF & evolutionary timescales, SF rates, primordial *vs* self-enrichment etc.

- velocities, rotation, Zeeman splitting, asteroseismology

  distances, masses, m.f, 3D structure, winds, mass loss etc.

spectro-photometry ➔ spectral classification, thermal properties

spectro-polarimetry ➔ magnetic fields

spectro-astrometry ➔ sub-structures on spatial scales smaller than the DL

<u>other [challanging] science top level requirements</u>:
large/full spectral coverage, ifu/mos capabilities, various spec/spat resolutions … possibly simultaneously…

practically impossible ➔ <u>finite</u> number of pixels for cross-dispersion or IFU or MOS

spectroscopy: spectral coverage

in extra-gal (z>1) science, the most suited spectral range is first driven by the redshift

in stellar science, the most suited spectral range depends on several factors:

- reddening
- stellar temperature
- some line diagnostics
- …

NIR spectroscopy: stellar populations

cool star physics and chemistry

surface chemical abundances, magnetic fields, activity, rotation, 3D structure, winds

observing mode: high resolution echelle spectroscopy

cool stellar populations census

metallicity and radial velocities of large samples of stars to trace galactic structure & archaelogy in the MW, in the LG and beyond

observing mode: medium resolution multi-object (either slit/fibers MOS and/or IFUs) spectroscopy

young stars and star-forming regions

proto-stars & star-disk interactions ➔ planet formation

observing mode: medium/high resolution spectroscopy, IFU

NIR spectra & spectrographs: a taste of the state-of-the-art

existing IR spectrometers on 4-10m telescopes

long slit, low-medium resolution ➔ common facility

cross dispersed echelle, IFUs, MOS ➔ a few, only

spectrograph	telescope	spectral range	max res	f.o.v.	multiplex
cross-dispersed, high-resolution					
NIRSPEC	Keck	Y,J,H,K	37,000	single obj, cross-dispersed	
GIANO	TNG3.6m	YJHK single exp	50,000	single obj, cross-dispersed	
IGRINS	McDonald2.7m	HK single exp	40,000	single obj, cross-dispersed	
IRCS	Subaru	zY,J,H,K	20,000	single obj, cross dispersed	
XShooter	VLT	JHK	8,000	single obj, cross dispersed	
CRIRES+	VLT	YJ,H,K	100,000	single obj, cross-dispersed	
SPIRou	CFHT	YJHK	70,000	single obj, cross-dispersed	
Carmenes	CalarAlto3.5m	YJH	82,000	single obj, cross-dispersed	
IFU – diffraction limited					
SINFONI	VLT	YJ,H,K	4,000	8”x8”	
OSIRIS	Keck	YJ,H,K	4,000	3”x6”	
NIRSPEC	JWST	YJ,H,K,L,M	2,700	3”x3”	IFU

NIR spectra & spectrographs: a taste of the state-of-the-art

existing IR spectrometers on 4-10m telescopes

long slit, low-medium resolution ➔ common facility

cross dispersed echelle, IFUs, MOS ➔ a few, only

spectrograph	telescope	spectral range	max res	f.o.v	multiplex
MOS - seeing limited					
MOIRCS	Subaru	zYJ,H,K	3,000	4'x7'	40 slits
Flamingos-2	Gem-S	YJ,H,K	3,000	2'x6'	80 slits
LUCIFER	LBT	zYJ,H,K	8,000	4'x2.8'	40 slits
MOSFIRE	Keck	zYJ,H,K	4,000	6'x3'	46 slits
KMOS	VLT	YJ,H,K	4,000	7.2'x7.2'	24 IFUs
FMOS	Subaru	zY,J,H	2,000	30' diam	400 fibers
APOGEE ➔	APT 2.5m	H	22,000	1.7°x1.7°	300 fibers
MOONS	VLT	IzYJH	6,000/20,000(J,H)	25' diam	1000 fibers
NIRSPEC	JWST	YJ,H,K,L,M	2,700	3'x3'	100 slits

NIR stellar spectroscopy: sensitivity

4-10m-class telescopes: H≅15-16 (Vega mag)

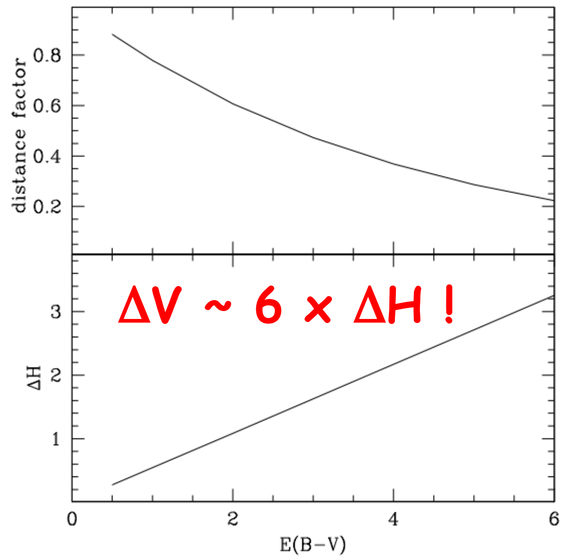
RGB@Red Clump: M_H≅-1 RGB@Tip: M_H≅-5 ➔ within ~100 kpc

old giants at 8 kpc (bulge)

E(B-V)~0 H_{tip}~8 H_{RC} ~13

E(B-V)~1 ΔH~-0.5 factor of 25 % in distance

E(B-V)~3 ΔH~-1.6 factor of 2 in distance



RSG,AGB: M_H≅-9 ➔ within ~1 Mpc

star clusters in integrated light: M_H>-13 ➔ within a few Mpc

NIR spectroscopy: spectral resolution

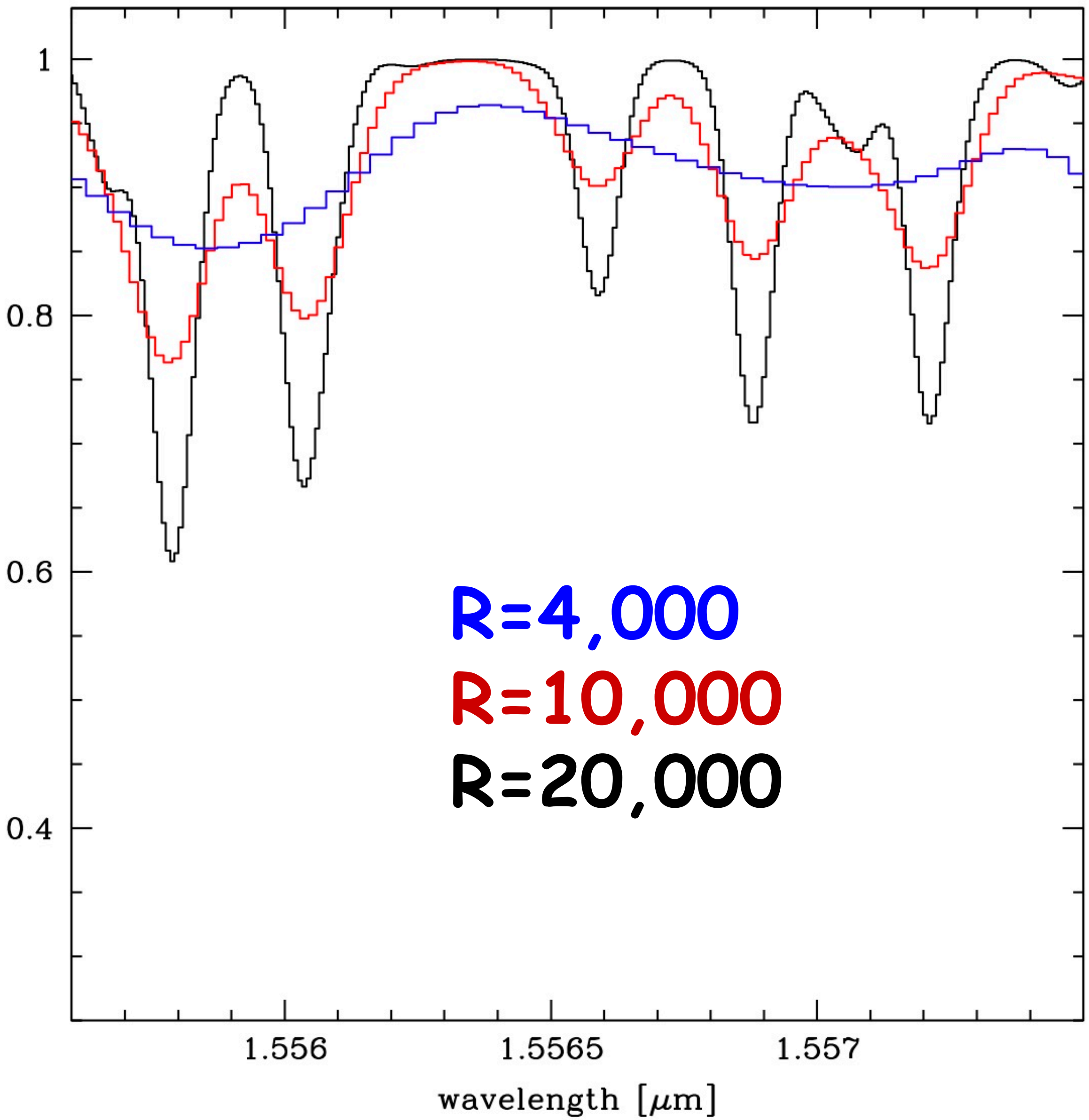
spec resolution plays a major role in chemical studies
see also M. Bergemann's talk

R~1,000	**FWHM~300 km/s**	broad lines, spec classification, global metallicity
R~10,000	**FWHM~30 km/s**	molec blends, a few atomic lines/species
R~30,000	**FWHM~10 km/s**	OH,CN lines, CO bandheads several atomic lines/species
R~100,000	**FWHM~3 km/s**	many individual molec+atomic lines/species, isotopes

higher the resolution → more [and fainter] lines

broader metallicity range, higher accuracy, full set of iron-peak, CNO, alpha, other light, neutron-capture element abundances

NIR stellar spectroscopy: OH lines at different resolutions

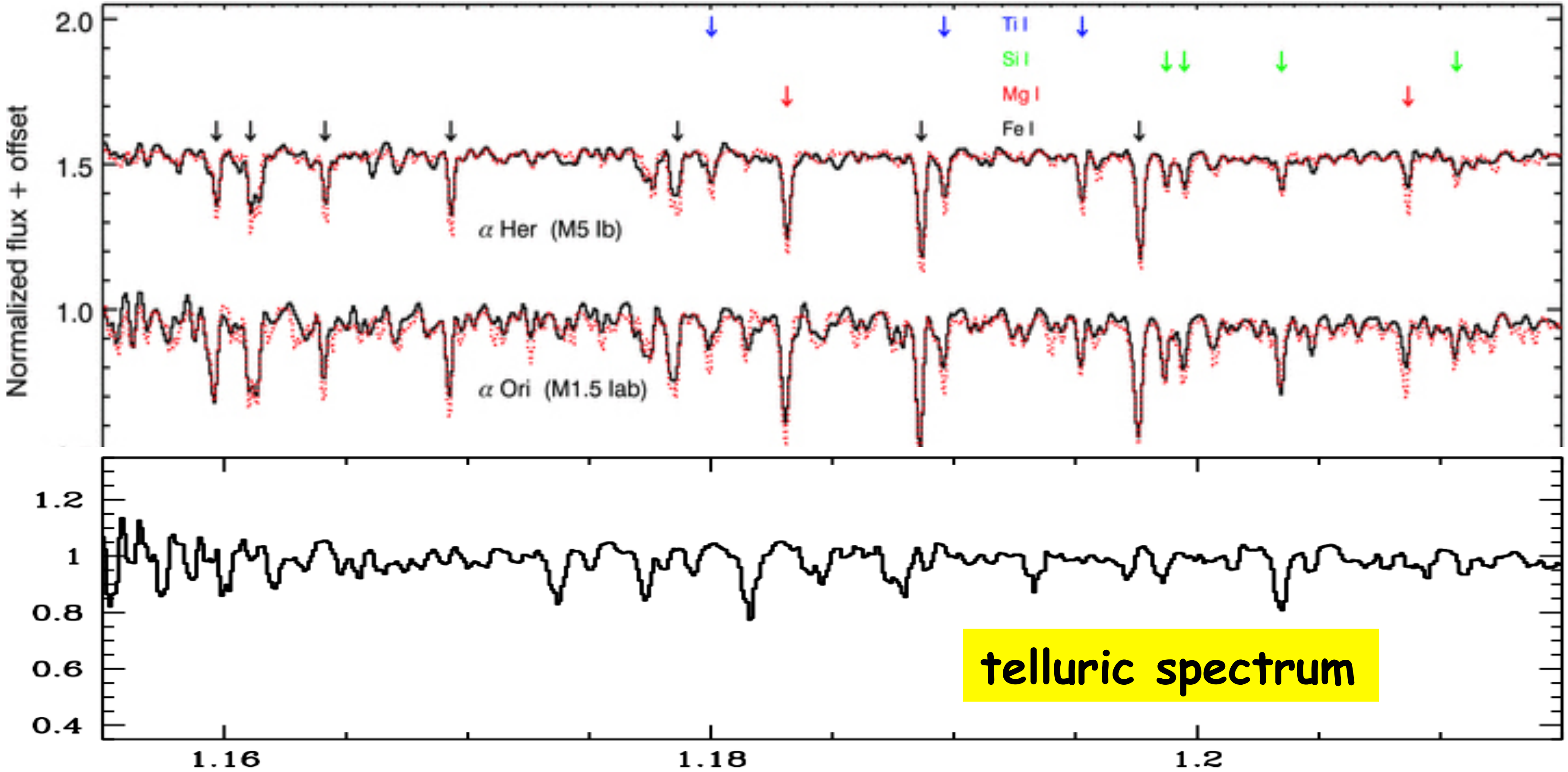


NIR spectra & spectrographs: a taste of the state-of-the-art

young RSG stars in the Galactic disk

see also B. Davies' talk

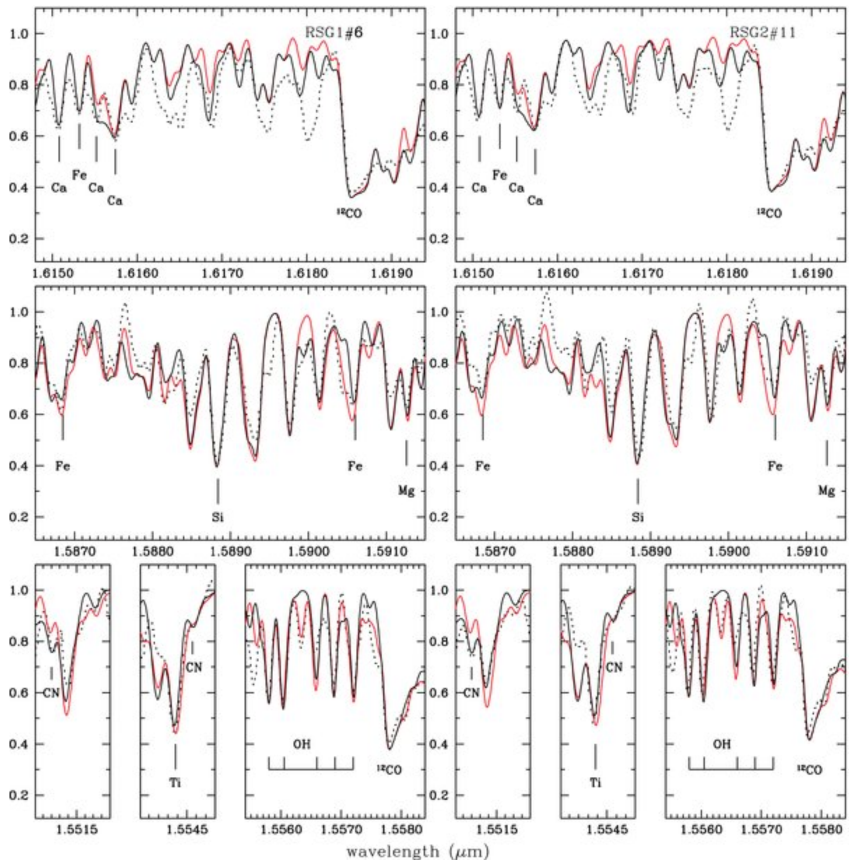
Low resolution J-band spectroscopy of metal-rich red supergiants



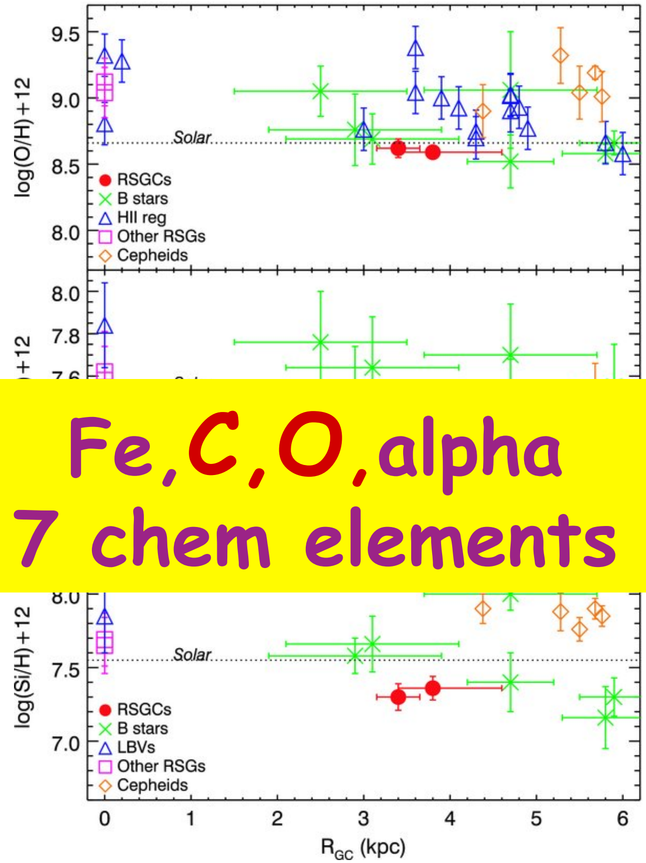
NIR spectra & spectrographs: a taste of the state-of-the-art

young RSG stars in the Galactic disk

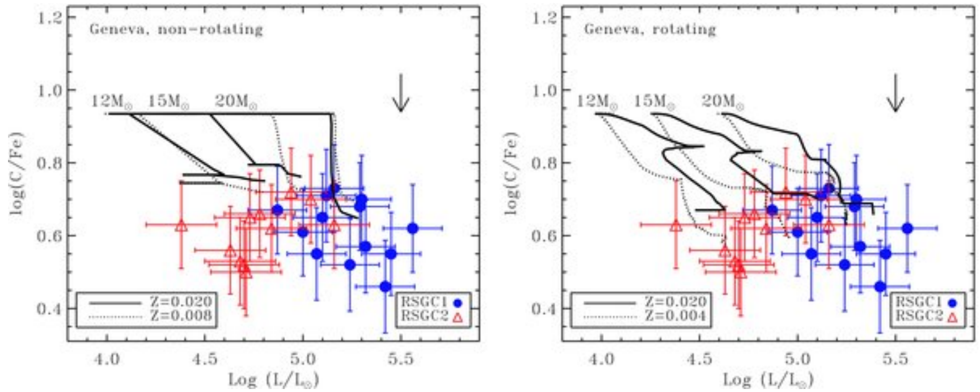
NIRSPEC-Keck R=17,000
H-band spectra of RSGs
in Scutum clusters (A_V>10 !)



Davies+ 2009, ApJ 696, 2014



Fe,C,O,alpha
7 chem elements

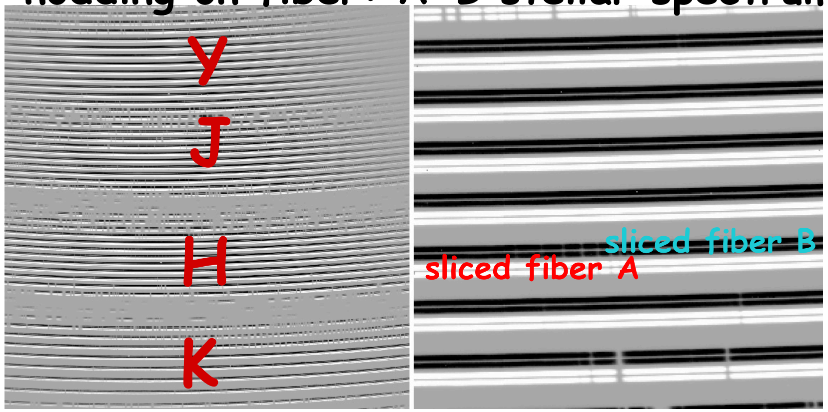


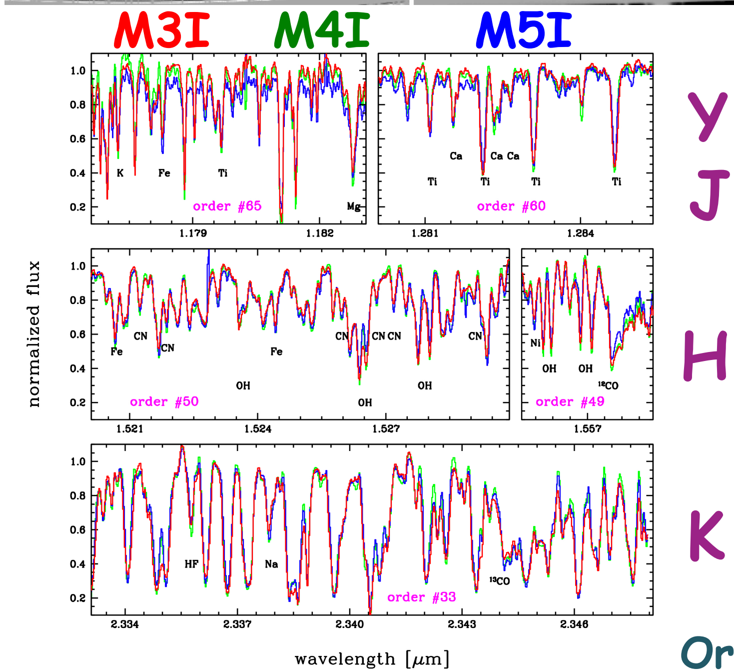
NIR spectra & spectrographs: a taste of the state-of-the-art

young RSG stars in the Galactic disk

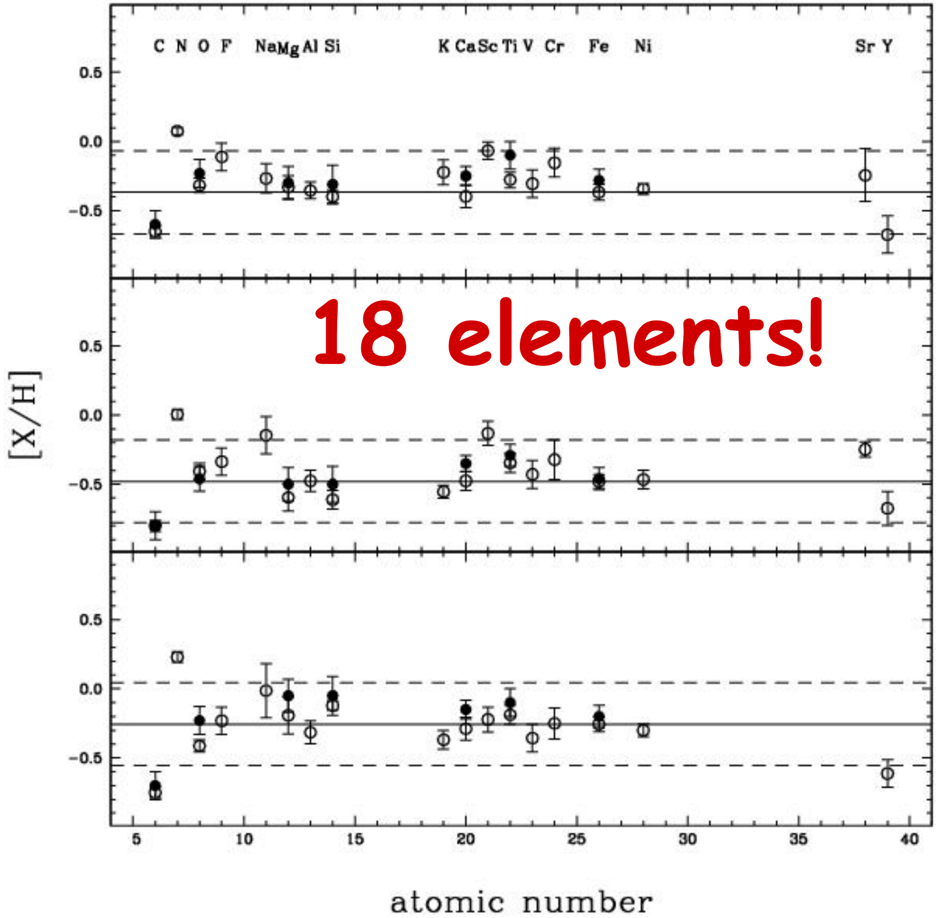
3 RSGs in Scutum-RSGC2 GIANO-TNG R=50,000 0.95-2.45 μm

nodding on fiber: A-B stellar spectrum





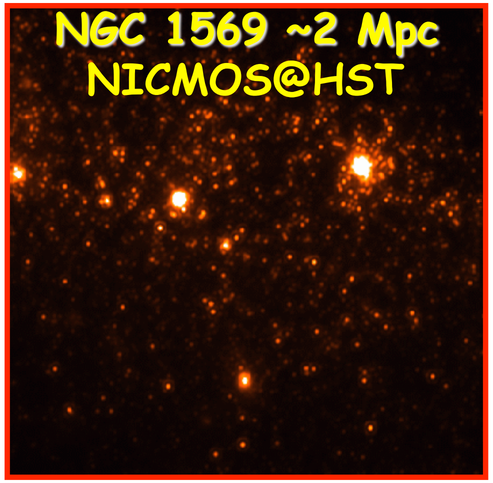
CNO, alpha, other light, iron-peak, neutron-capture elements

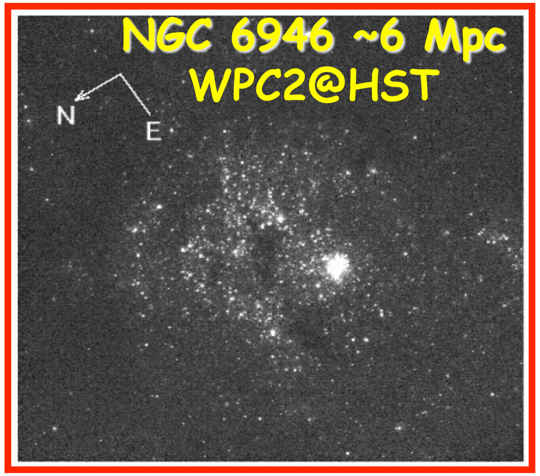


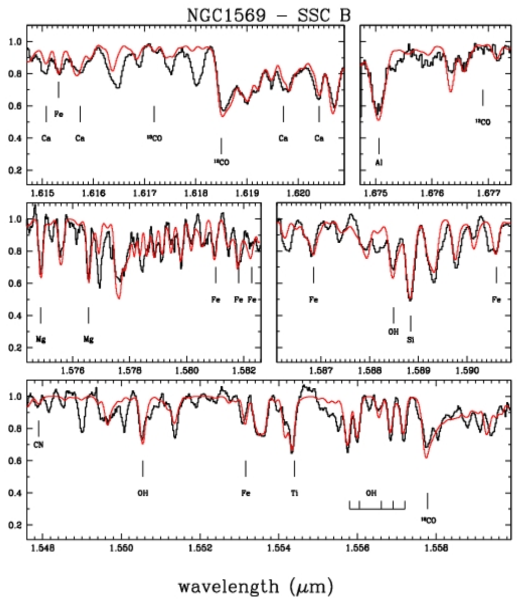
Origlia+ 2013, A&A 560, 46

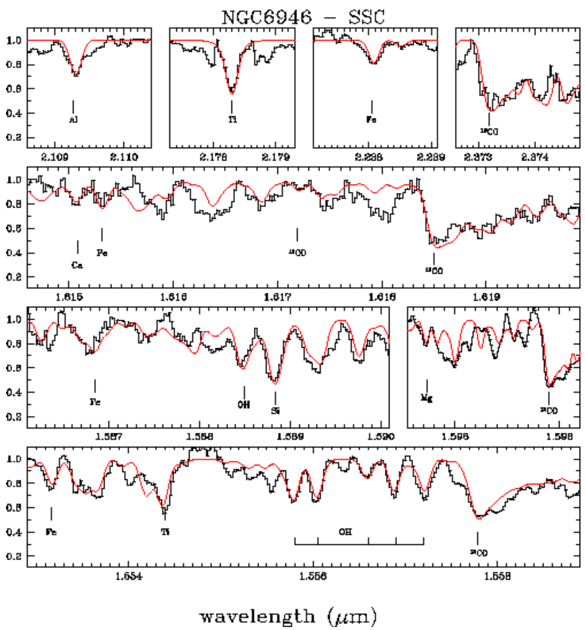
NIR spectra & spectrographs: a taste of the state-of-the-art

young SSCs in nearby SB galaxies









unique tracers of the IMF in SB galaxies

KeckII-NIRSPEC R=25,000
integrated light spectra
dominated by RSGs

chemical abundances

sub-solar iron
some alpha enhancement
and carbon depletion

dynamical masses

σ~10 km/s, M_{dyn}~5x10^5 M_o

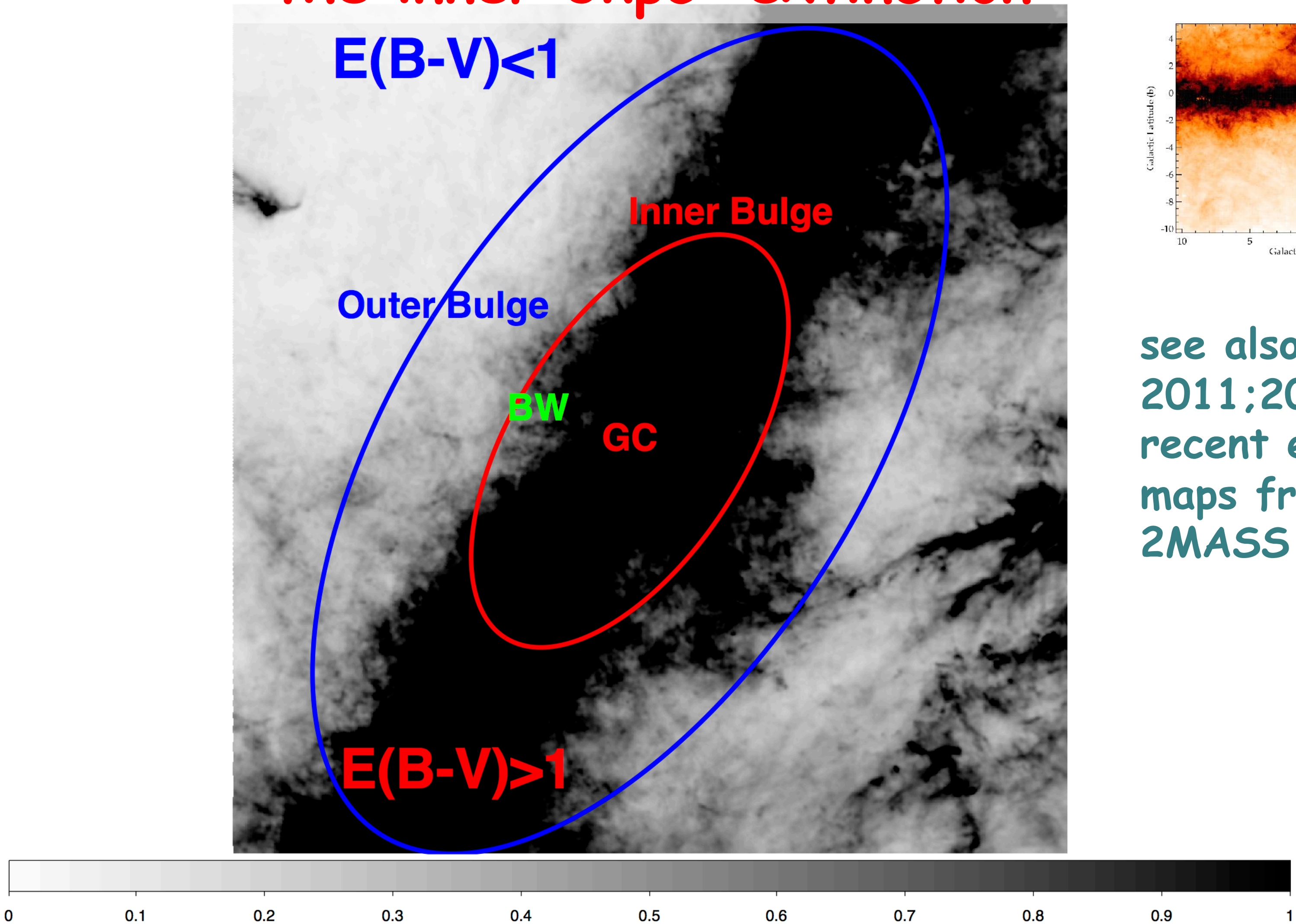
Larsen, Origlia, Brodie & Gallagher, 2006, 2008

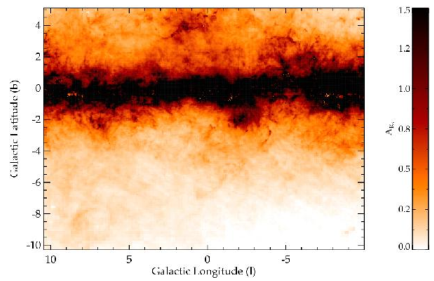
NIR spectra & spectrographs: a taste of the state-of-the-art

old giants in high reddening environments

the inner Galaxy: disk, bulge, Galactic center

the inner 3kpc: extinction





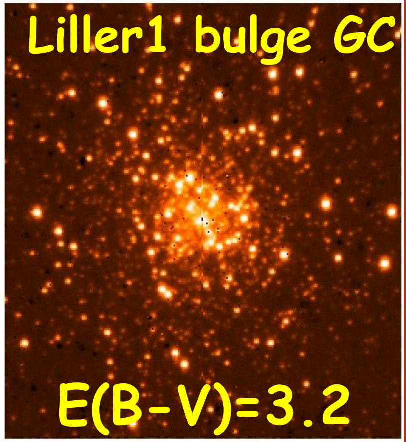
see also Gonzalez+ 2011;2012 for recent extinction maps from VVV & 2MASS

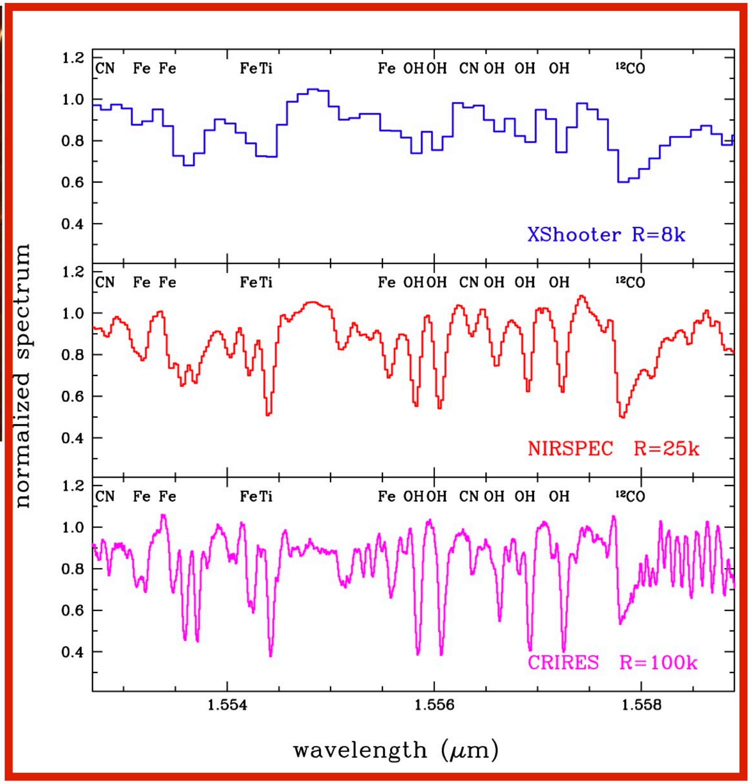
NIR spectra & spectrographs: a taste of the state-of-the-art

old giants in high reddening environments
the inner Galaxy: disk, bulge, Galactic center

a rich bibliography on chem & kinematic studies of their SPs in the last 10 yrs

spectral resolution *vs* coverage in one exposure





Xshooter: R=8k full
10-12 chem el a few lines/el
[Fe/H]>-1.0

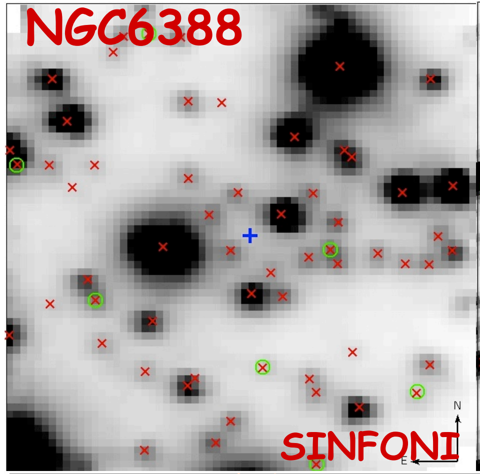
NIRSPEC: R~25k ½ band
5-10 chem el a few lines/el
[Fe/H]>-1.5

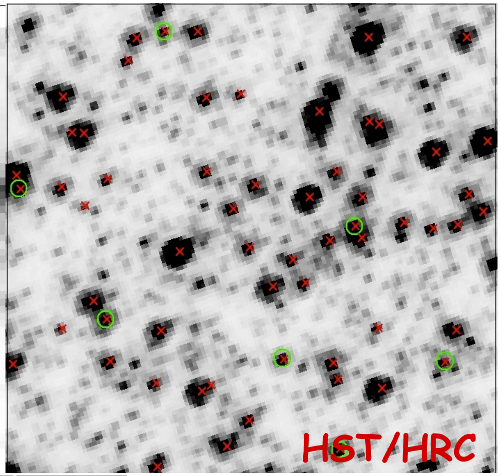
CRIRES R~100k single ord
a few chem el several lines/el

GIANO: R=50k full >20 chem elements, several lines/el
CRIRES+: R=100k 1 band 10-15 chem elements, several lines/el

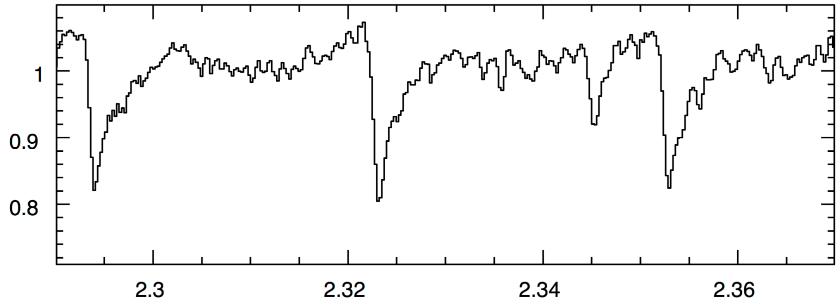
NIR spectra & spectrographs: a taste of the state-of-the-art

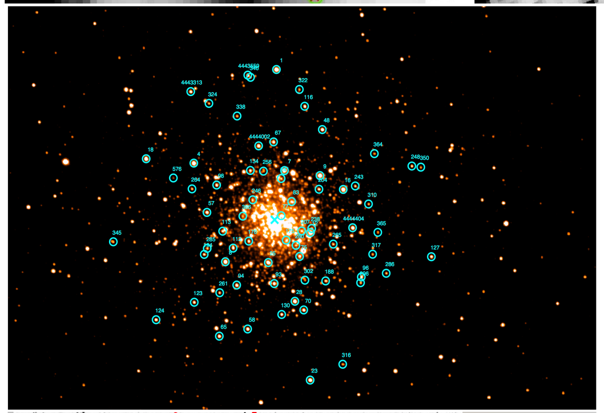
RVs of individual giant stars in GCs: from the core out to the tidal radius

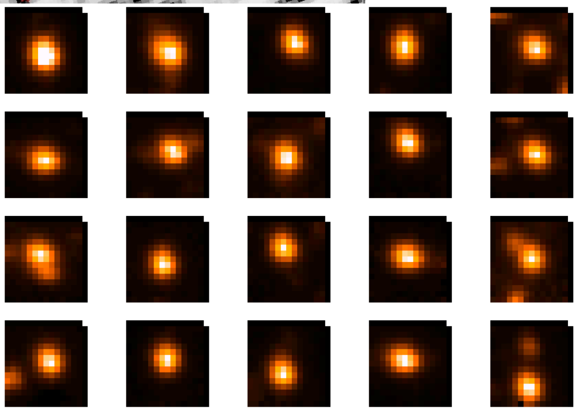


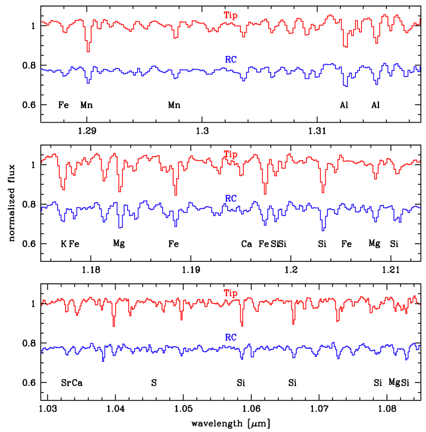


SINFONI+AO K band spectra
R~4000 ~60 stars at r<2"

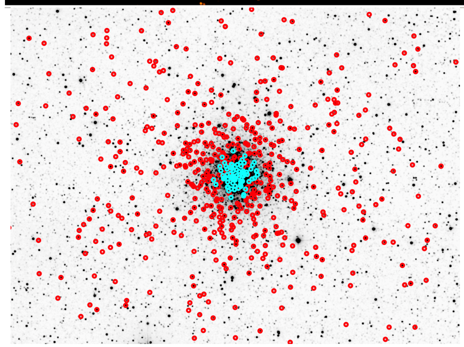








KMOS YJ spectra
R~3,400
4 pointings
~90 stars
at r<70"

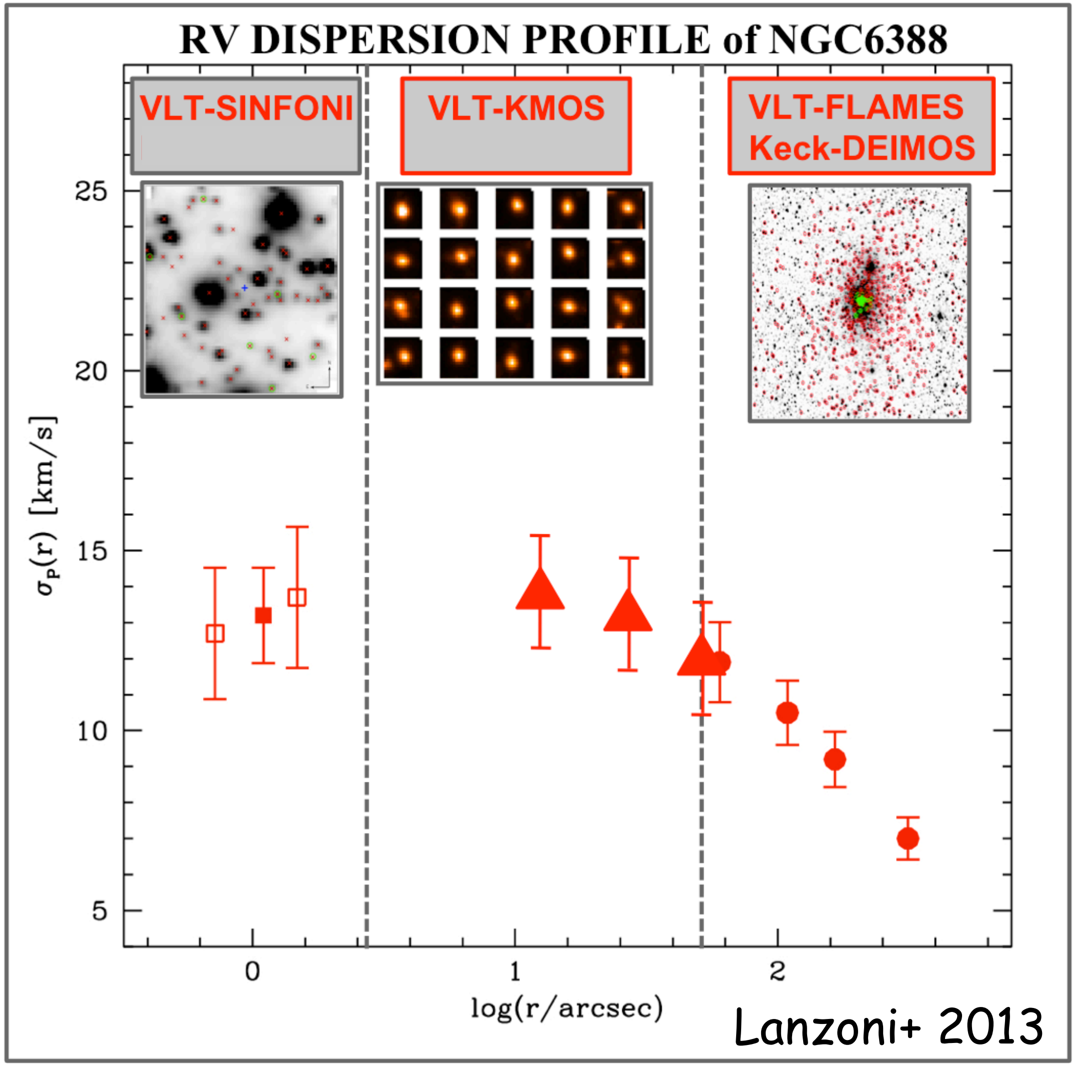


FLAMES GIRAFFE/MEDUSA CaT spectra at r>1'

velocity dispersion and rotational profiles of 30 GCs
VLT-KMOS+FLAMES LP 193-0232 194hrs PI: Ferraro

NIR spectra & spectrographs: a taste of the state-of-the-art

RVs of individual giant stars in GCs: from the core out to the tidal radius

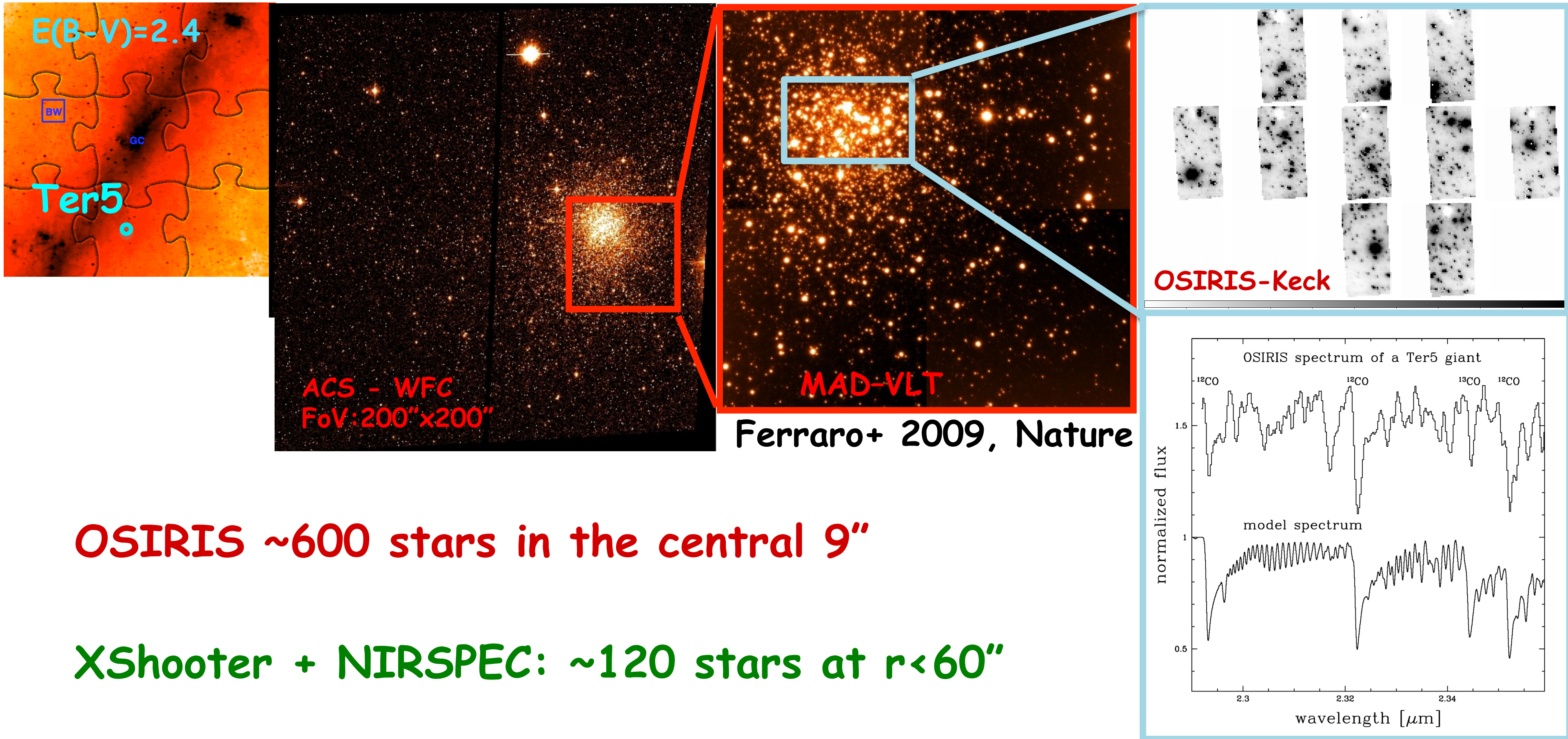


velocity dispersion and rotational profiles of 30 GCs

VLT-KMOS+FLAMES LP 193-0232 194hrs PI: Ferraro

NIR spectra & spectrographs: a taste of the state-of-the-art

Terzan 5: internal kinematics



OSIRIS ~600 stars in the central 9"

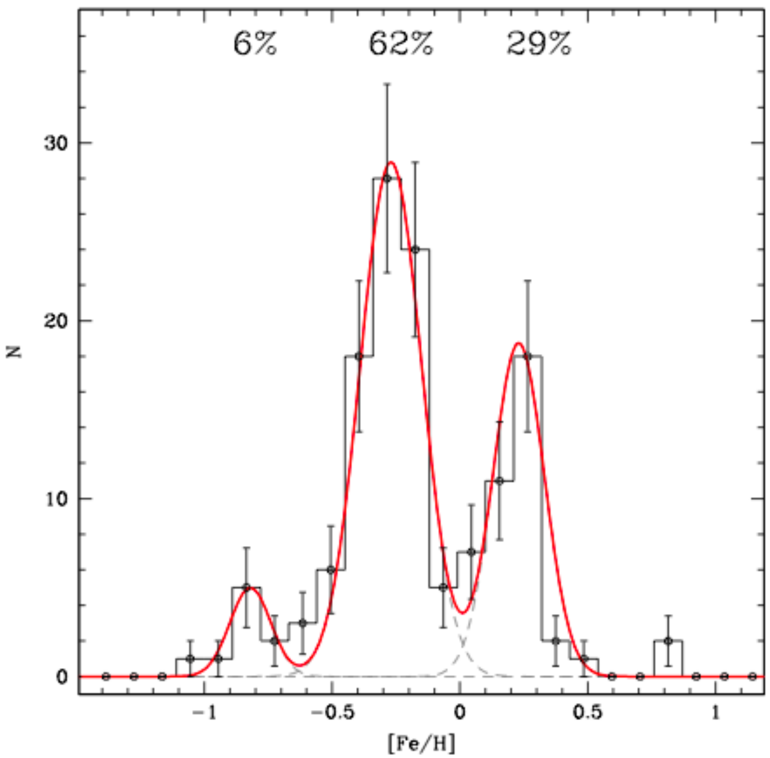
XShooter + NIRSPEC: ~120 stars at r<60"

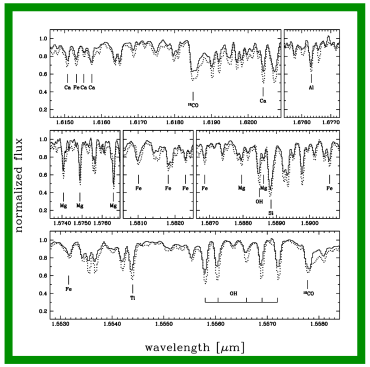
FLAMES + DEIMOS: ~1500 stars in the outer regions

NIR spectra & spectrographs: a taste of the state-of-the-art

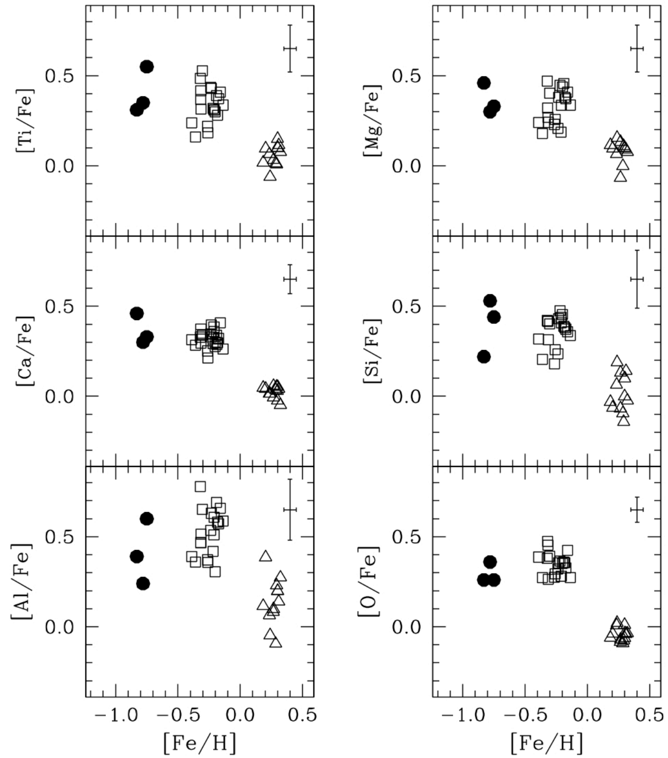
Terzan 5: chemistry - only medium-high res spectra

metallicity distribution
NIRSPEC, XSOOTER, FLAMES, DEIMOS
Massari+ 2014





[X/Fe] distribution
NIRSPEC - Origlia+2013



overall Δ[Fe/H] ~ 1dex !
not a genuine GC!

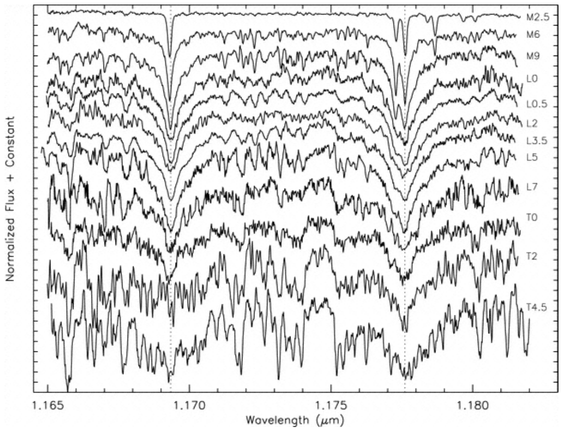
[Fe/H] & [a/Fe] similar to the bulge distributions

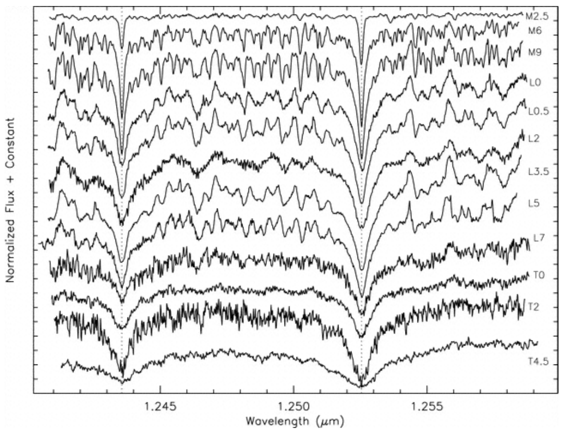
NIR spectra & spectrographs: a taste of the state-of-the-art

late-M and brown dwarfs

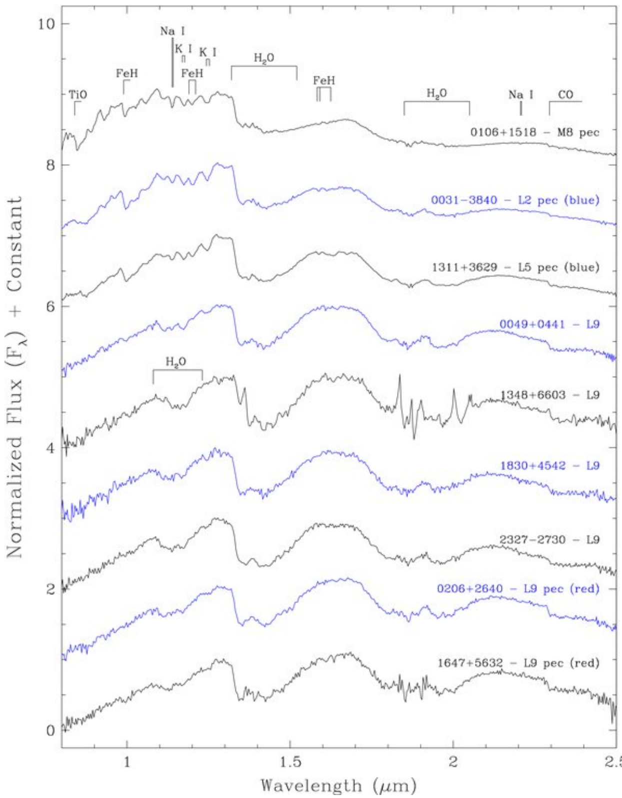
with the current 4-10m class telescopes low-to-medium R spec in the Solar neighborhood, mostly for spectral classification using molecular (FeH,H_2O,CH_4,CO) and atomic (Al,K,Fe,etc.)

The NIRSPEC BDSS
McLean+ 2003; 2007
http://bdssarchive.org/

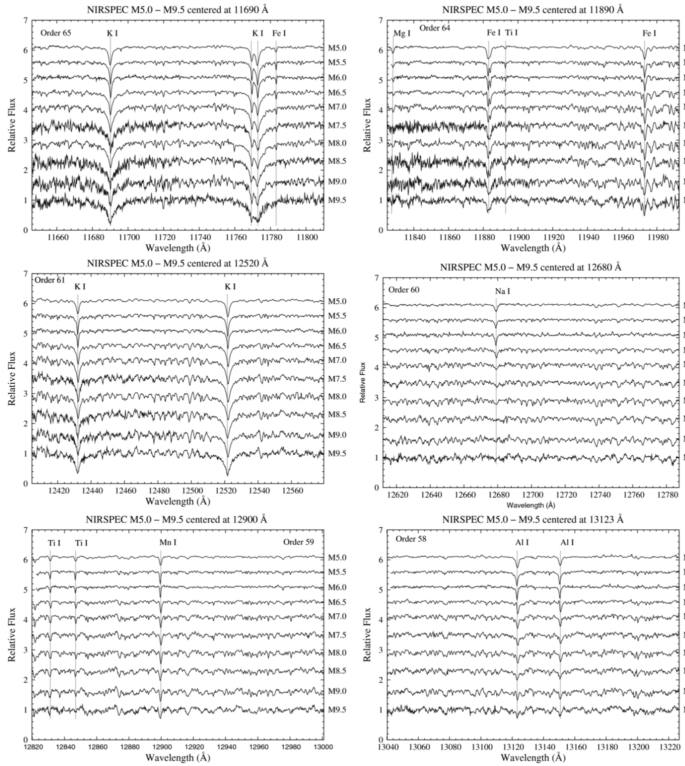




The first 100 BDs discovered by WISE
Kirkpatrick+ 2011



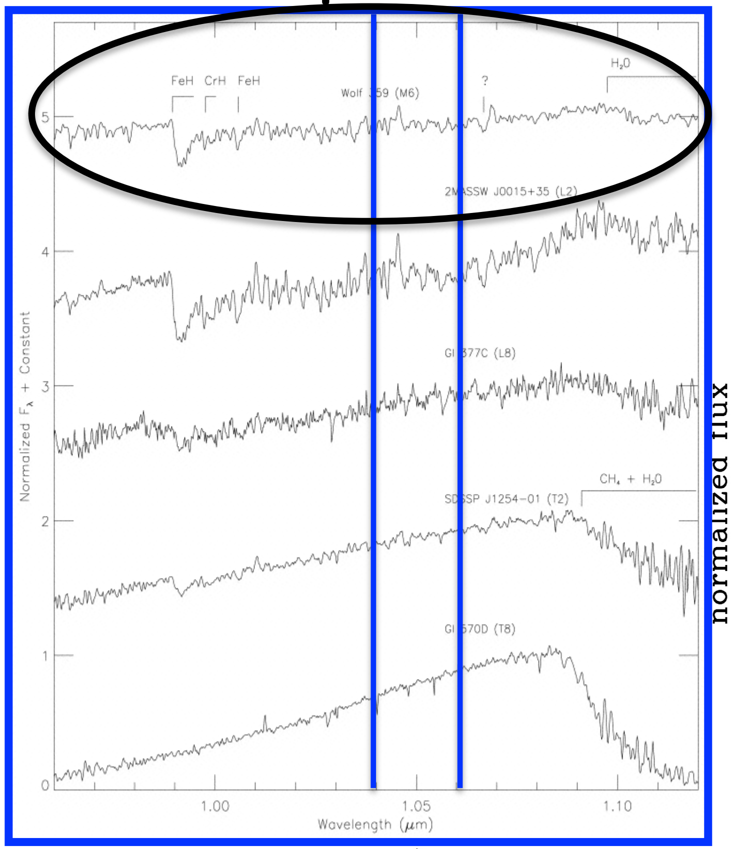
intermediate resolution NIR spectra of 36 late-M dwarfs
Deshpande+ 2012



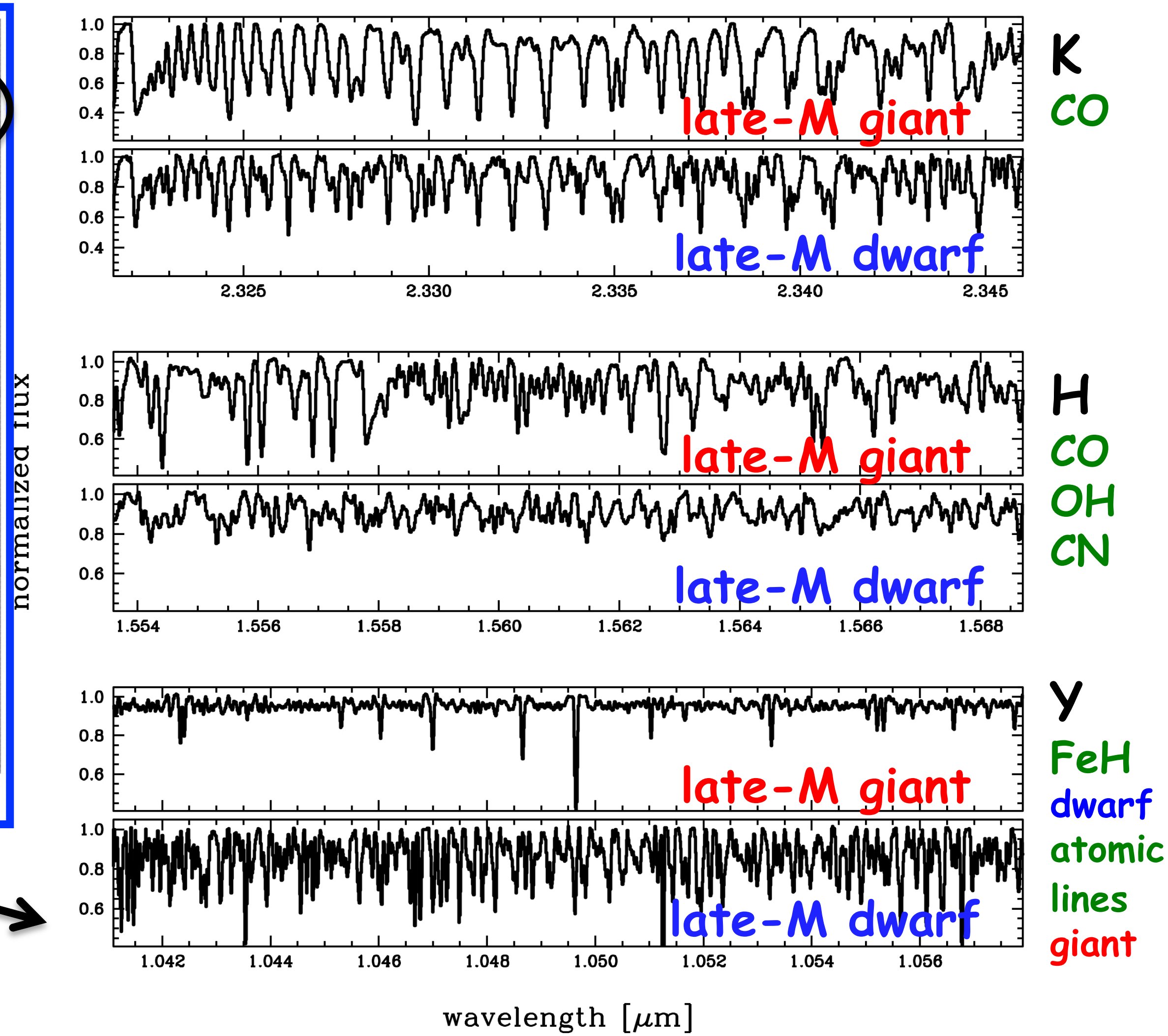
NIR spectra & spectrographs: a taste of the state-of-the-art

late-M stars in the Solar neigh: observable at high spec res

NIRSPEC spectra R~2,000



GIANO-TNG spectra at R~50,000

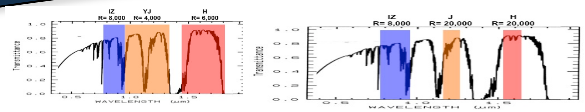


see also Wende+ 2010, line-by-line identification from CRIRES spectra

NIR spectra & spectrographs: the future

Multi-Object Optical and Near-infrared Spectrograph for the VLT

1000 fibers



webpage: http://www.roe.ac.uk/~ciras/MOONS.html

APOGEE a crucial precursor…

Galactic Surveys design

Inner Galaxy survey to obtain **complete kinematic and chemical screening** of the old stellar populations of the inner disc and bulge regions. 1-2 hrs per pointing **at R=20,000** in the [J]- and H-bands (i.e. down to H<15.5 mag) + **CaT**:

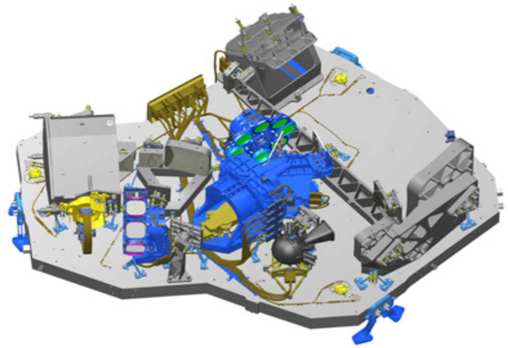
- **50 nights programme, spectra for ~250,000 stars.**
- **200 nights programme spectra for more than 1 million stars.**

Wide-area Gaia survey to follow-up stars observed with Gaia in Thin and Thick disc, tidal streams, the field populations around halo and clusters. 0.5-1hr integration:
***CaT** and simultaneously near-IR low-resolution spectra in J & H-band (i.e. I<21)* :

- **50 nights, spectra for ~500,000 stars**
- **150 nights, spectra for ~1.5 million stars**

NIR spectra & spectrographs: the future

NIRSPEC onboard JWST: R_{max}=2700



MOS 3'x3' FoV multiplexing~100
IFU 3"x3" FoV spaxel~100mas

NIRSPEC-JWST *vs* MOONS-VLT in the low-res mode

performances in the 1.0-1.8 micron spectral range

- about the same overall sensitivity → JH~17 Vega mag (s/n~30 texp~1hr)

- 2x less spectral resolution
- 5x more spatial resolution
- 60x less FoV
- 10x less multiplexing

NIRSPEC to sample highly crowded regions (e.g. star clusters)
MOONS to sample the field stellar populations (e.g. disks, bulge(s))

NIR spectra & spectrographs: the future

from 8-10m to 30-40m telescopes…

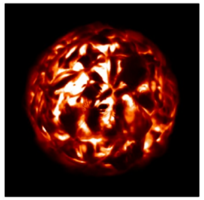
because of the larger aperture

- a few mag deeper
- several times more distant
- tens to hundreds times larger searching volume
- 5x more spatial resolution if AO-assisted
- higher spectral R for a given limiting mag

- smaller FoV
- lower multiplexing

NIR spectra & spectrographs: the future

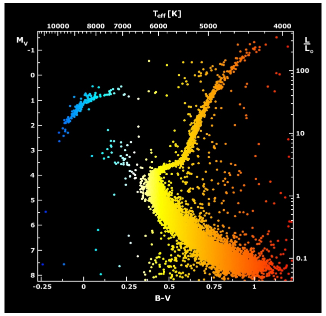
from 8-10m to 30-40m ELTs: a new parameter space



stellar physics/structure

in stars <u>other than</u> suns and <u>outside</u> the Solar neigh

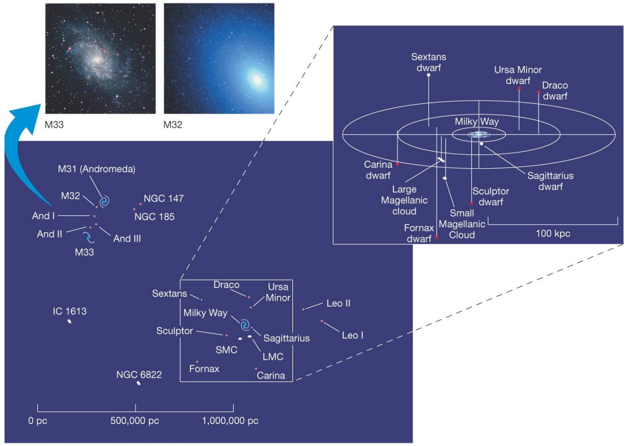
high (R>=100k) spectral resolution, high s/n



detailed chemistry of the pristine gas

- old, unevolved MS stars in the MW/MCs
- BDs in the Galactic disk

medium-high (R~20k→100k) spectral resolution



kinematics and chemistry of giant stars in the LG and beyond

medium (R~10k→20k) spectral resolution

with some MOS/IFU capabilities

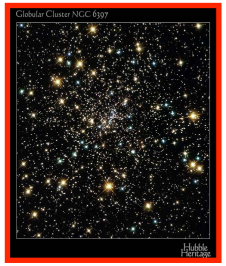
low resolution → only metal-rich objects

NIR spectra & spectrographs: the future

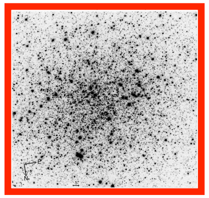
from 8-10m to 30-40m ELTs: resolving the unresolved

internal kinematics of star clusters in the MW/MCs

NGC 6397



SMC-121



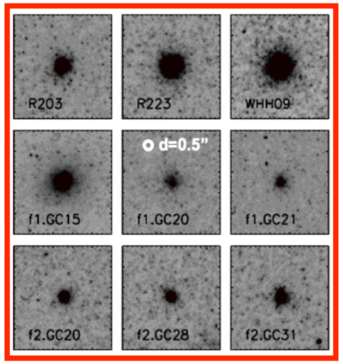
AO-assisted integral field spectroscopy down to the MS

velocity dispersion and rotation profiles from RVs of individual stars within 1" in bins of 100mas ➔

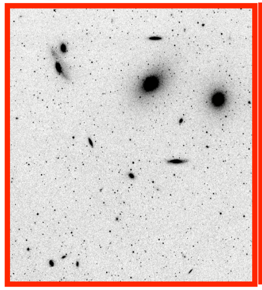
sampling the sphere of influence of a potential IMBH

SPs outside the LG: extragal star clusters/UCDs

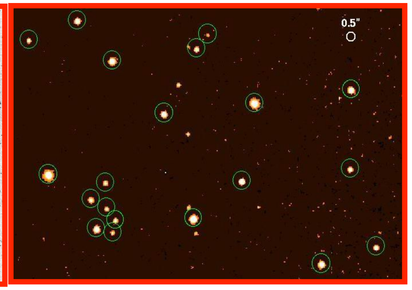
Centaurus



Virgo Cluster



M87



medium-high (R>=20k) spectral resolution

chemistry and dynamical mass

AO-assisted IFU

velocity profiles in the outer regions to check for possible DM halos