# Extragalactic Distance Scale lect. III

Grzegorz Pietrzyński CAMK
pietrzyn@camk.edu.pl


ŚMIGUS DYNGUS
2020
MEMISKO.PL

# Photometry Resume

CCD technology invented in 1959, in 1970s in astronomy

Huge upgrade: from very small (100x100 pixels) and noisy CCDs (1980s) to:

- very efficient very low noise 4kx4 chips.

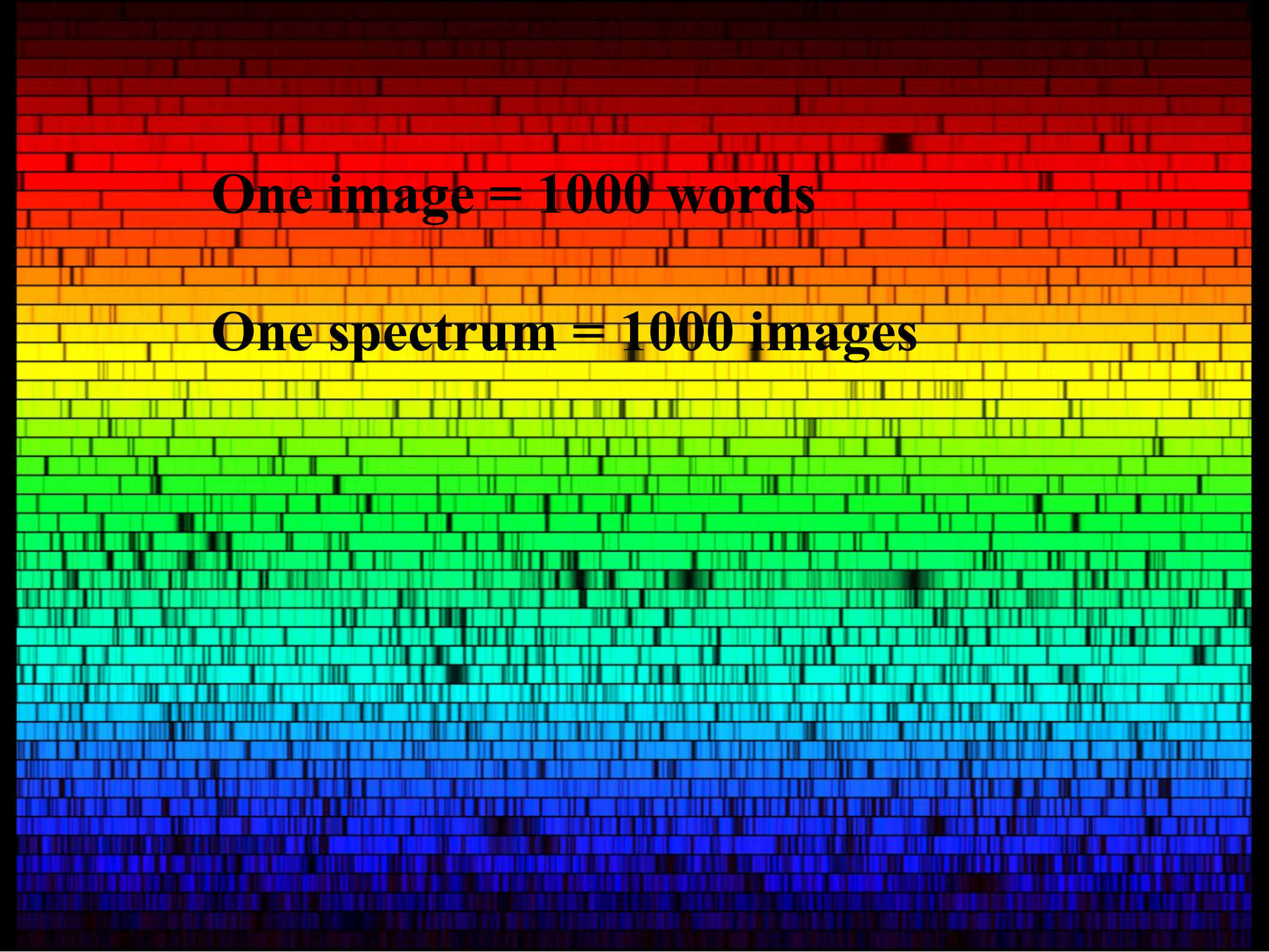
- precision photometry, calibration < 1%

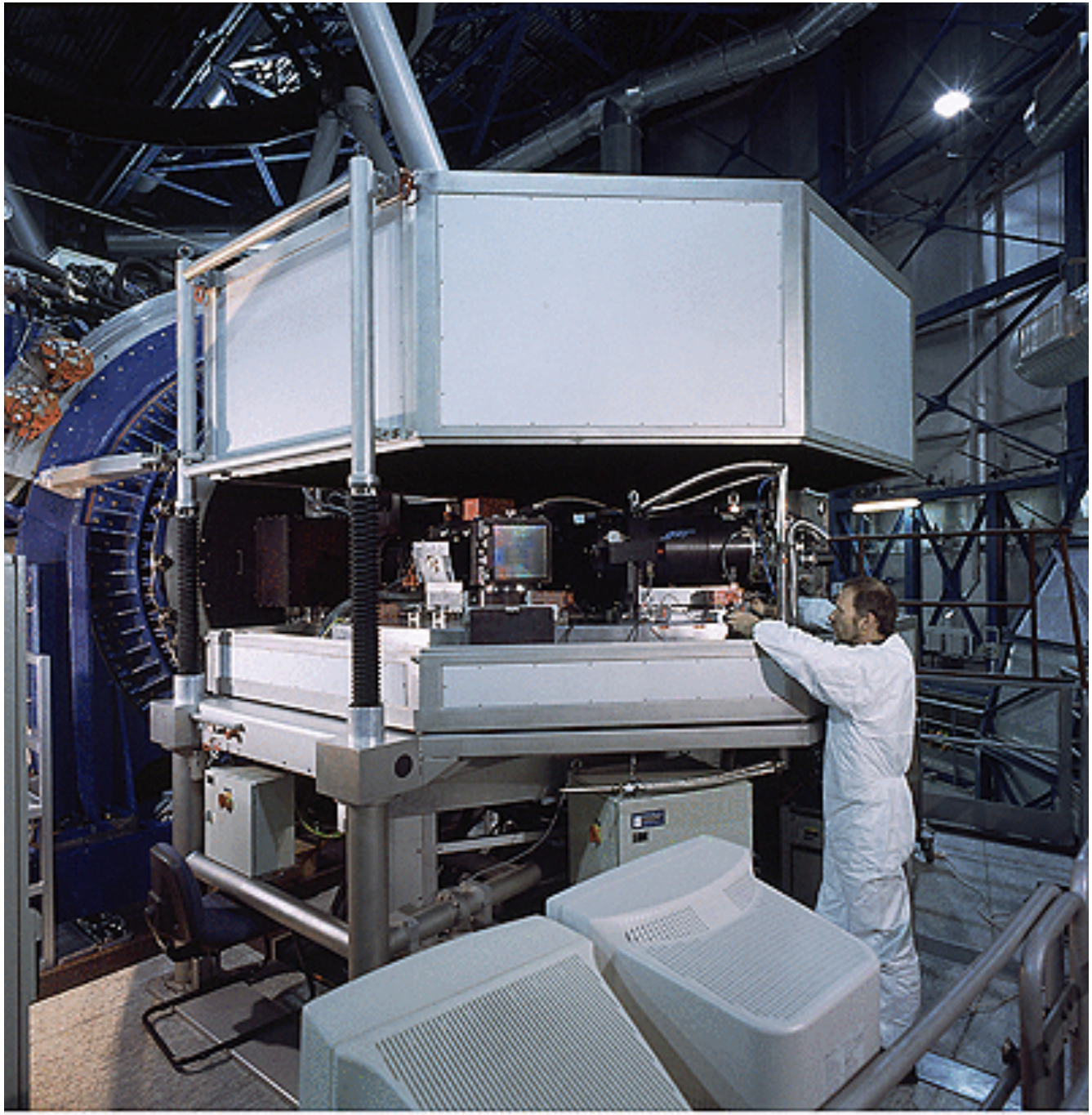
- huge surveys (SLOAN, PANSTARS, LSST, etc)

  both millions of objects (deep) and whole sky surveys.

Similar for NIR photometry (UKIRT, VMC, 2MASS)

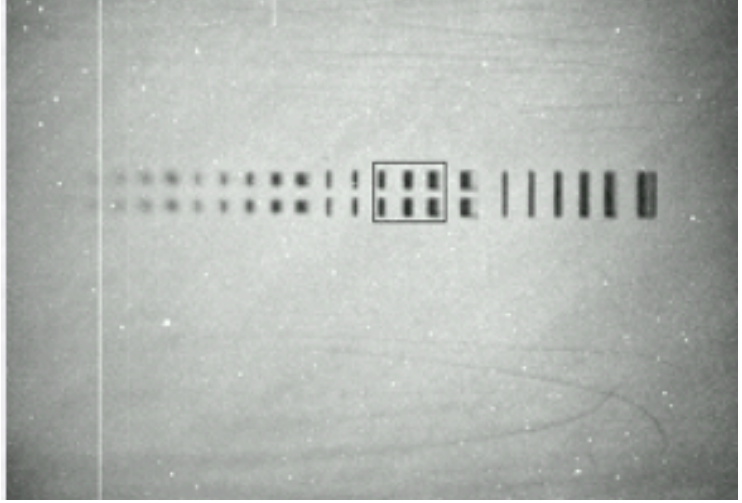
# Spectroscopy

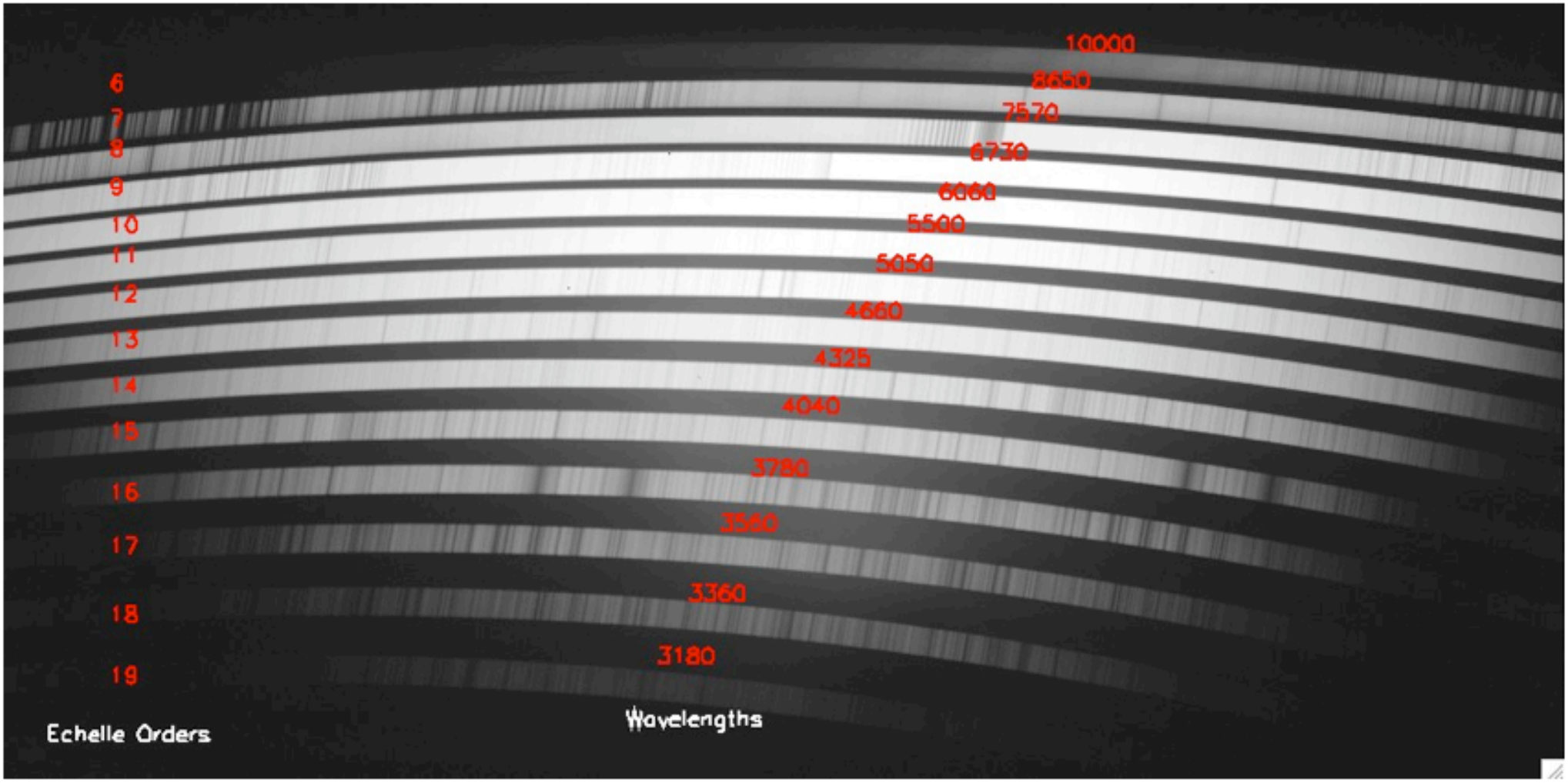

One image = 1000 words
One spectrum = 1000 images



UVES at Kueyen

ESO PR Photo 43c/99 (8 December 1999)




10000
8650
7570
6730
6060
5500
5050
4660
4325
4040
3780
3560
3360
3180
6
7
8
9
10
11
12
13
14
15
16
17
18
19
Echelle Orders
Wavelengths

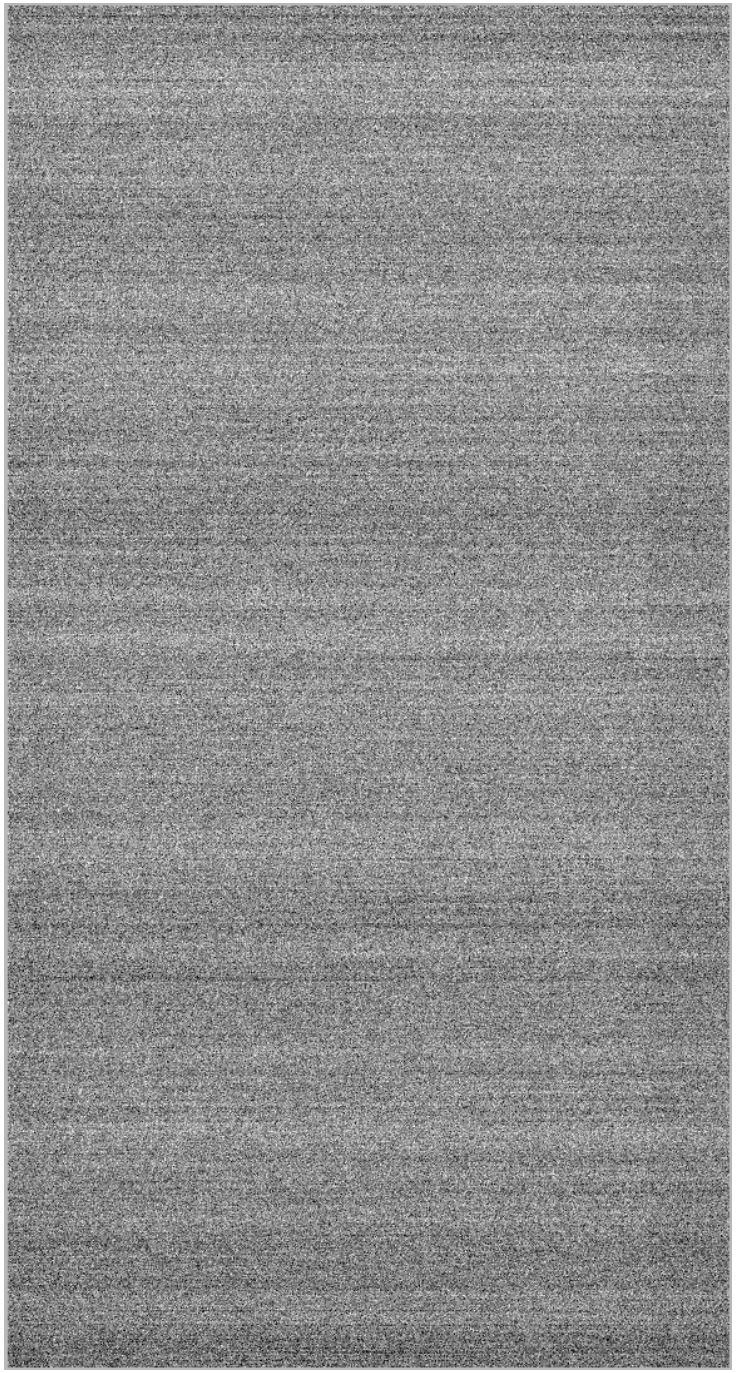
# Calibrations

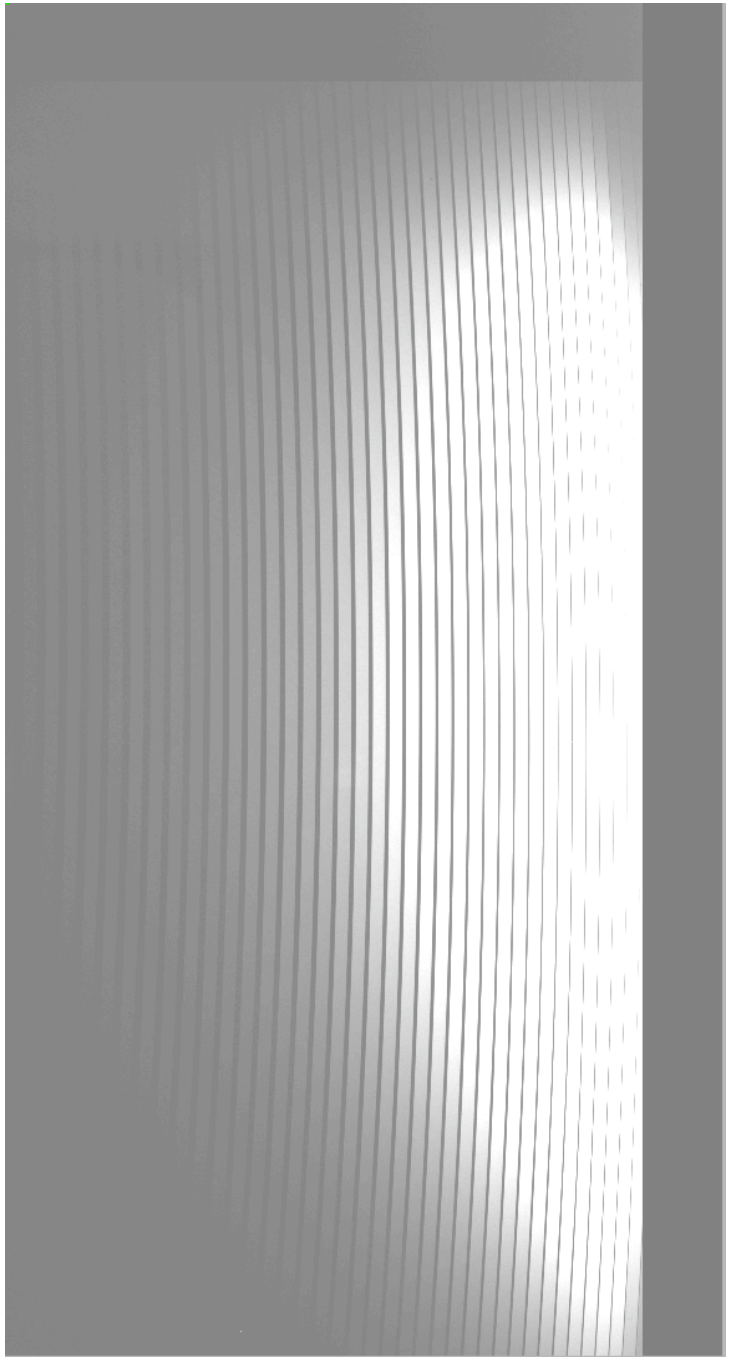
Bias

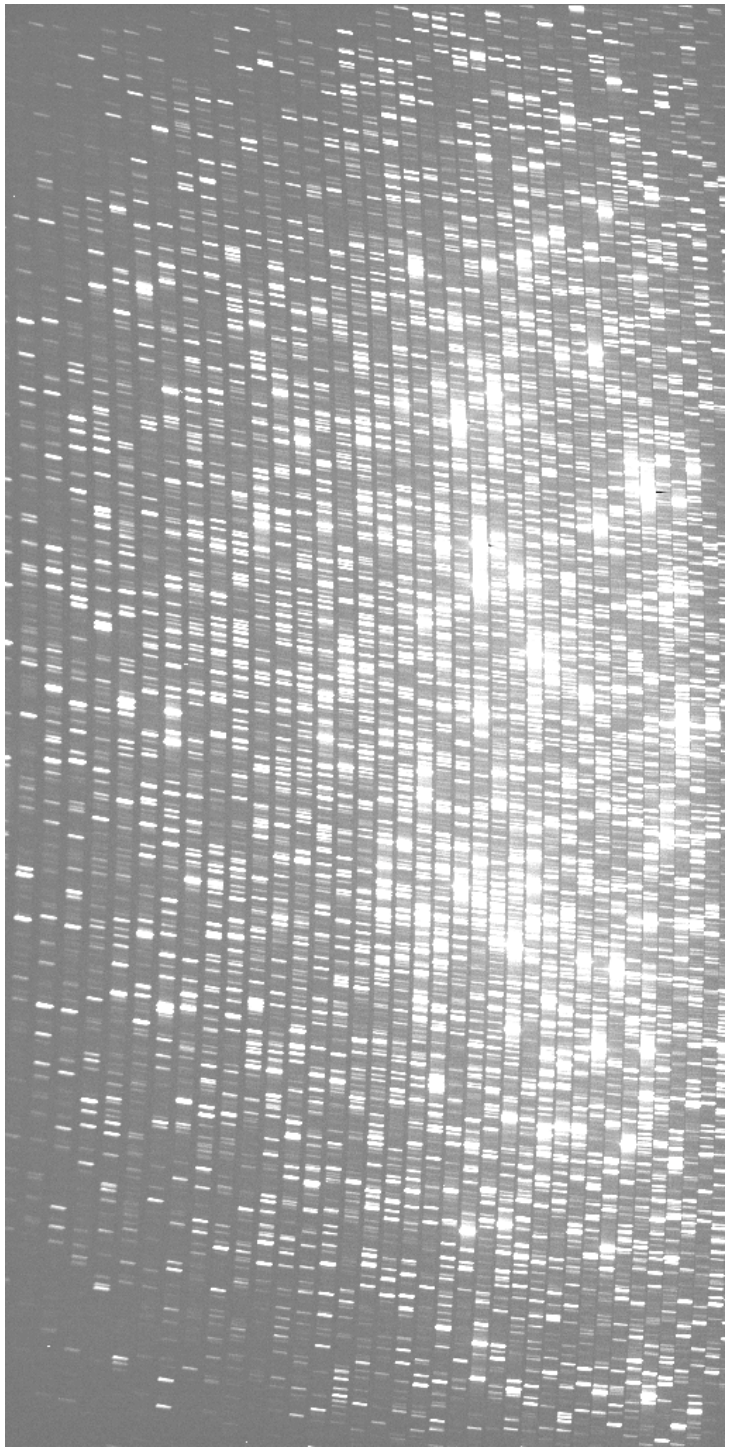
Flat Field (difficult)

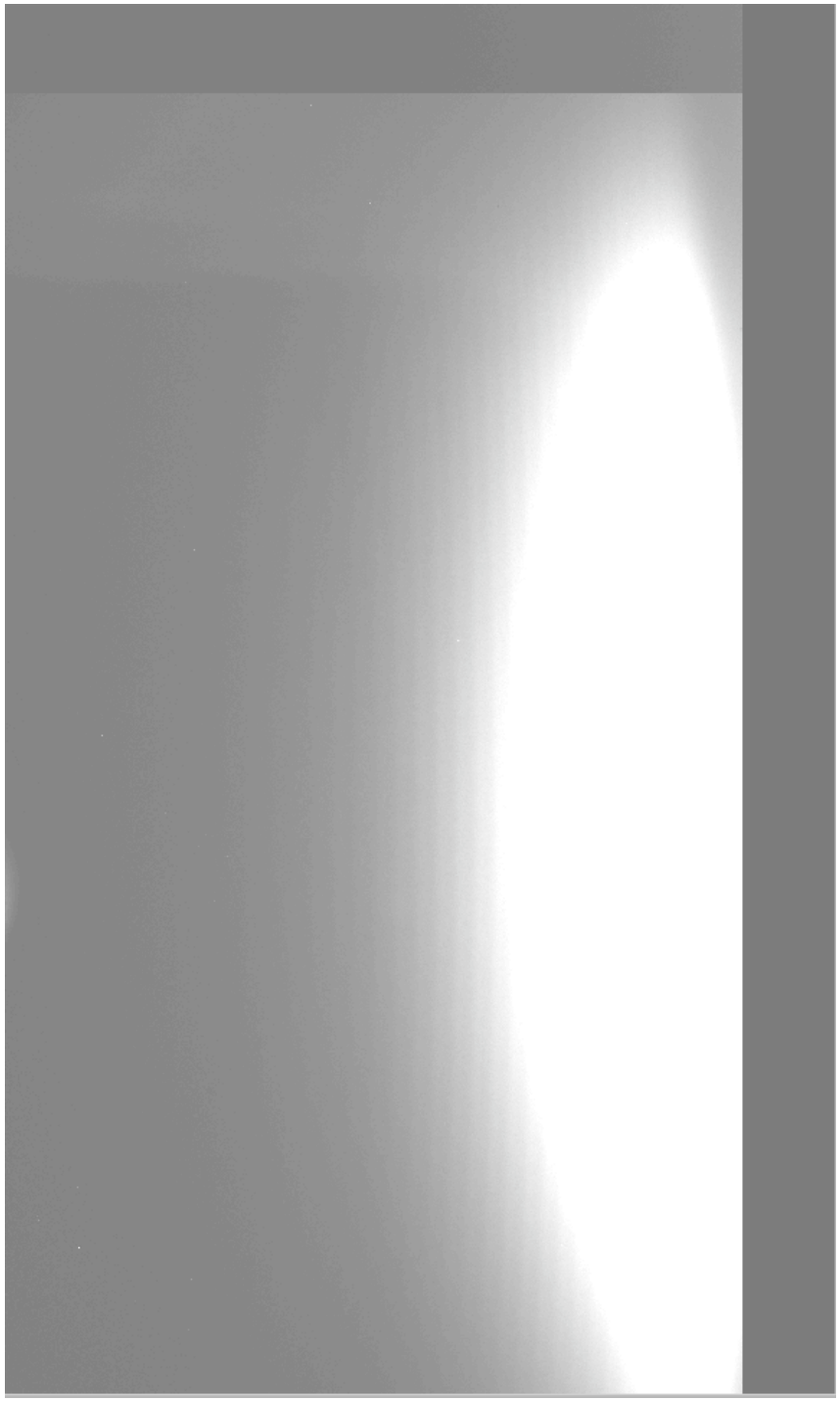
Order definition

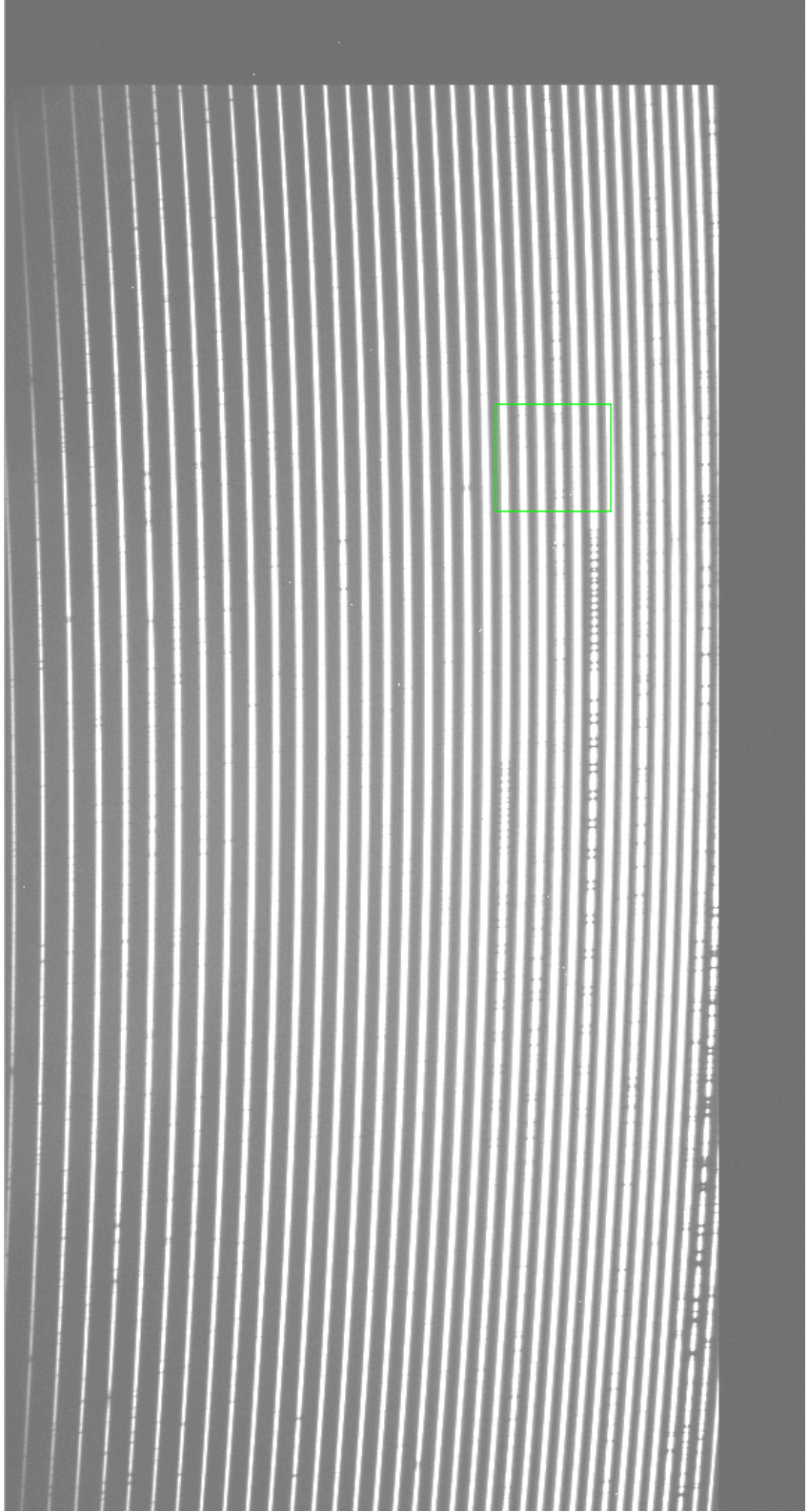
Internal lamps (wavelength calibration)

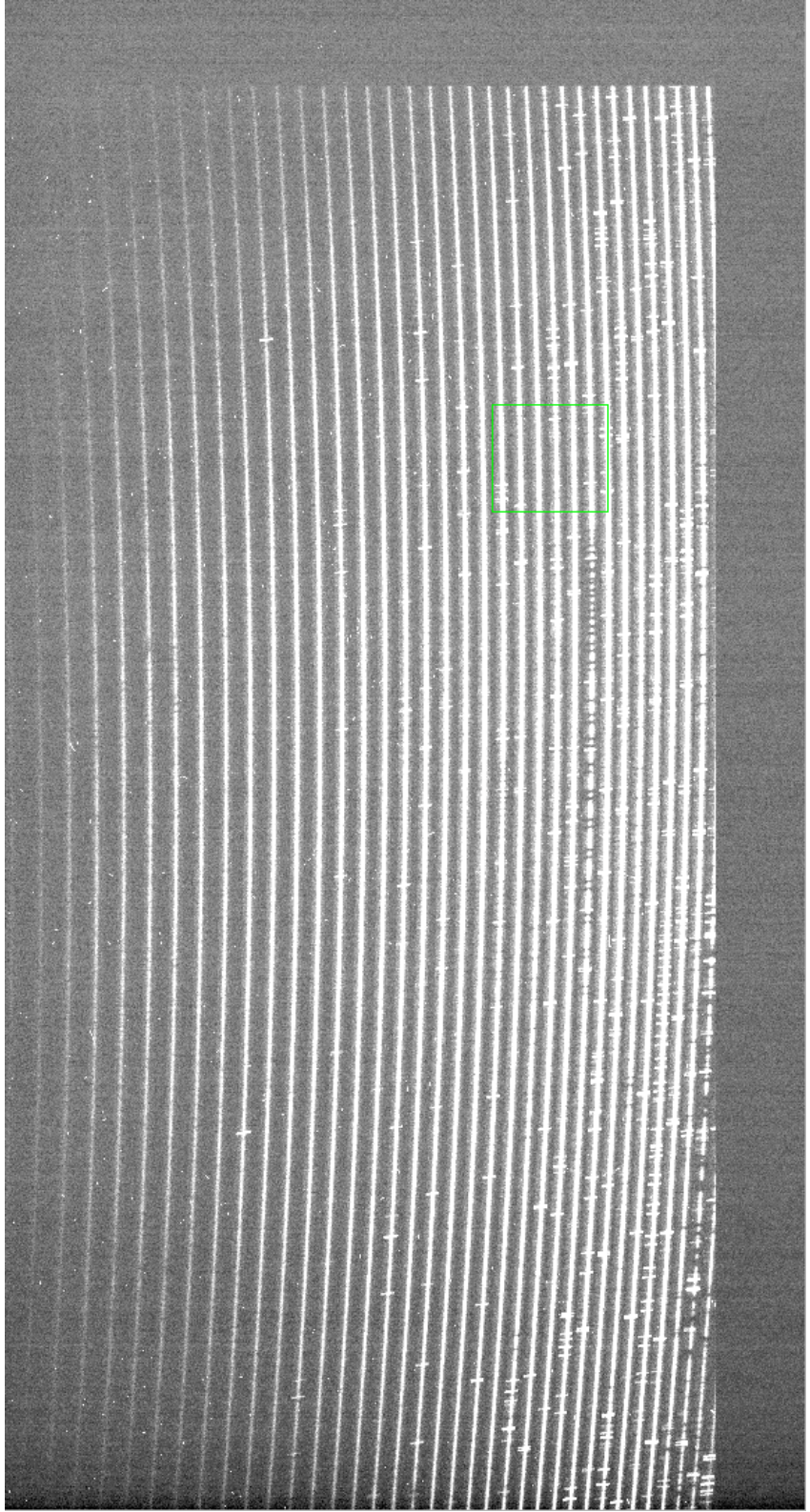










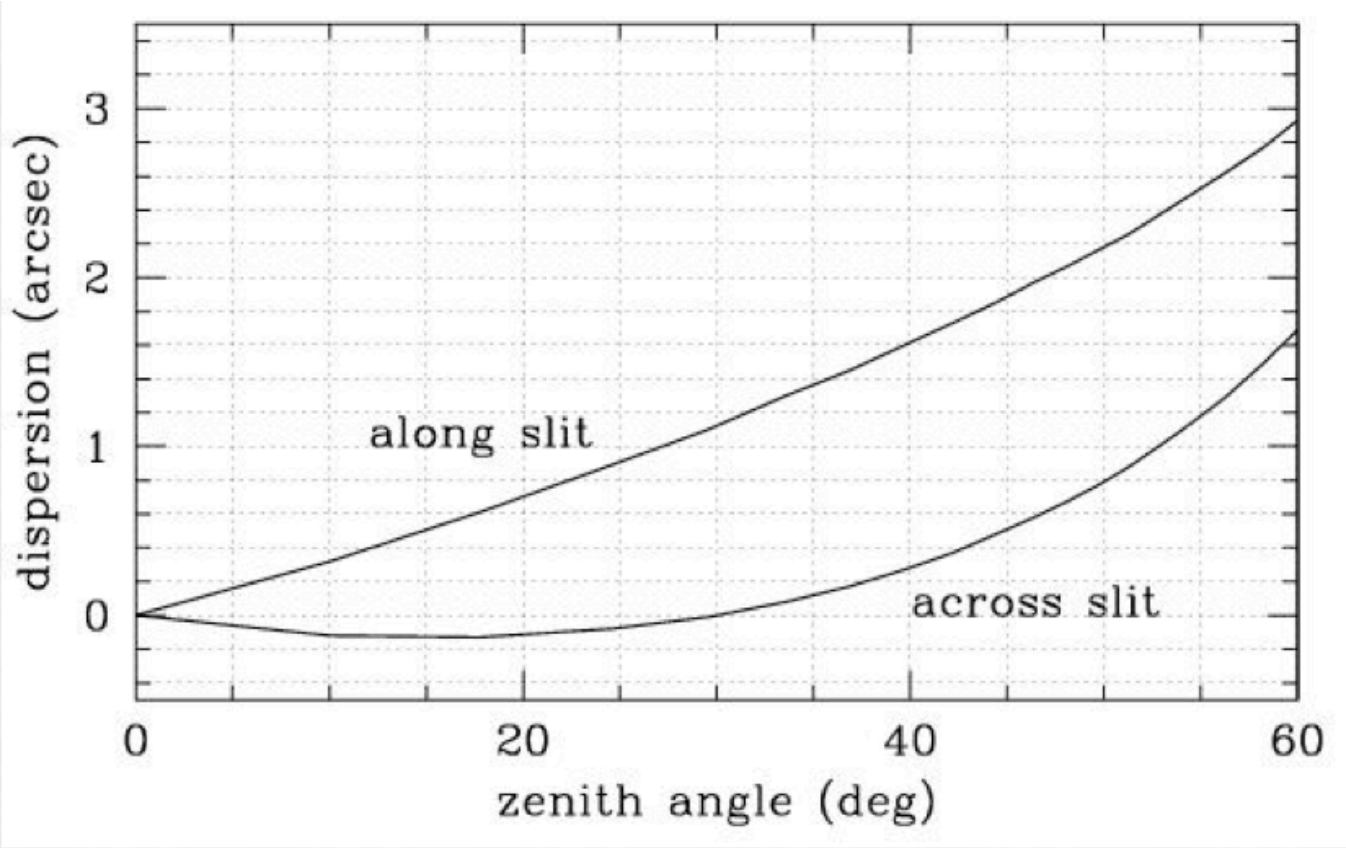


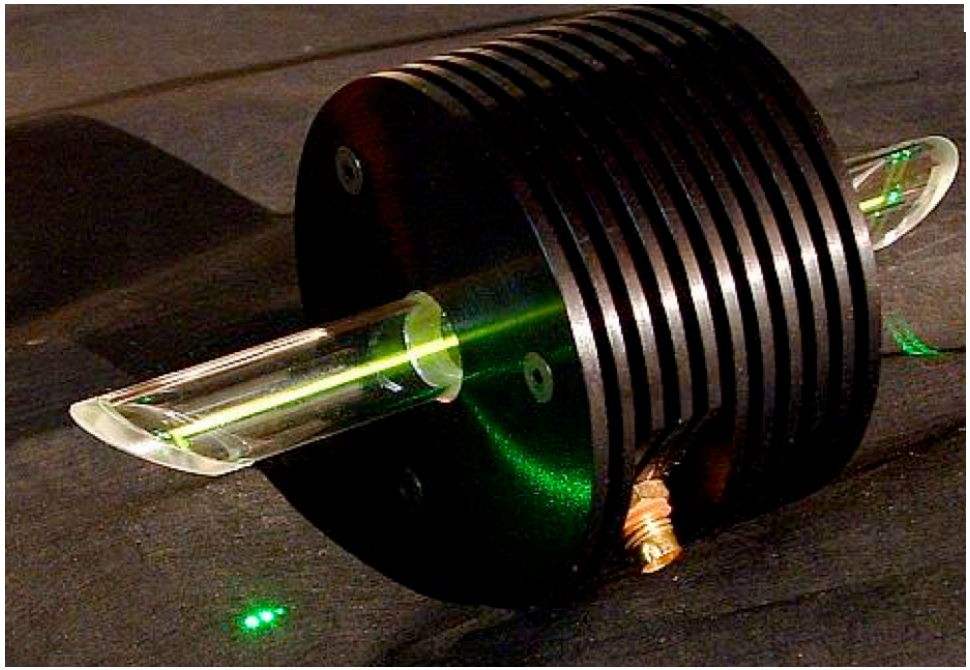
# Precision RVs

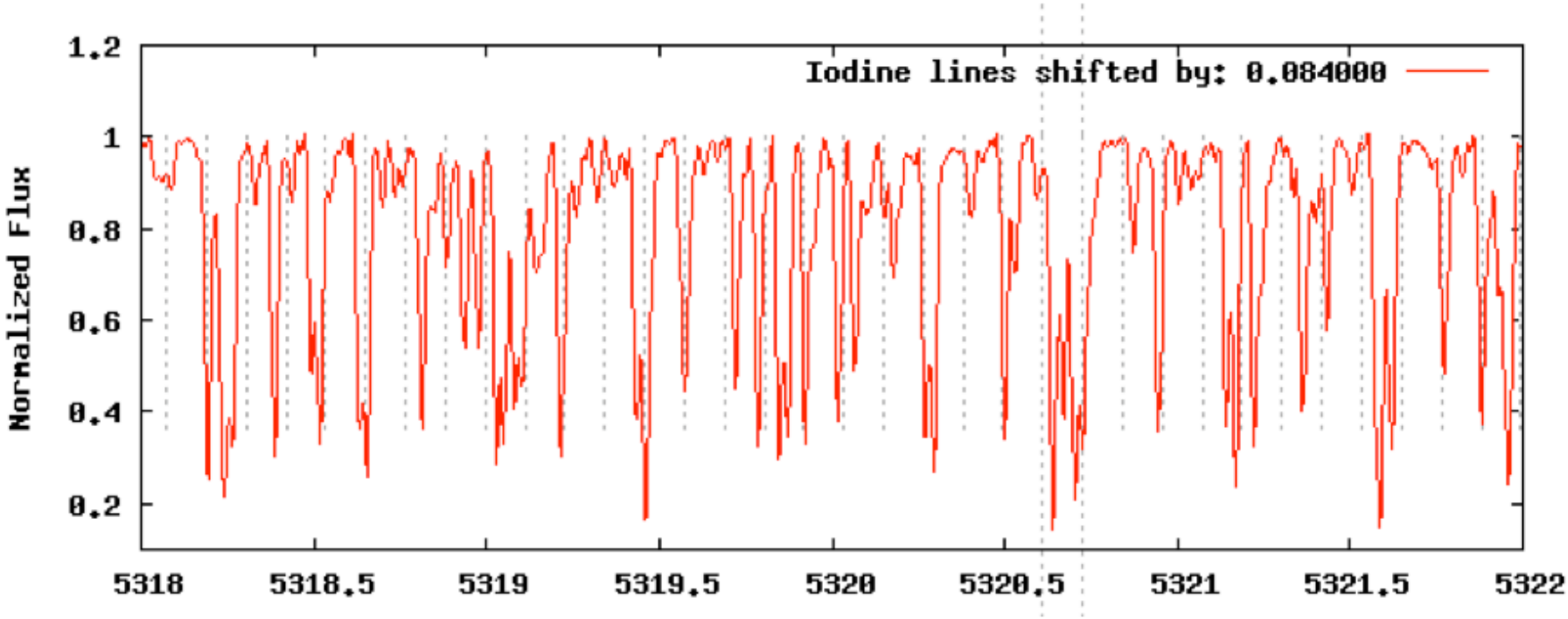
1 deg T => 100 m/s change

100 hpa => 100 m/s change

Positioning on slit => 100-200 m/s difference






Iodine lines shifted by: 0.084000
Normalized Flux
1.2
1
0.8
0.6
0.4
0.2
5318
5318.5
5319
5319.5
5320
5320.5
5321
5321.5
5322

# Iodine cell

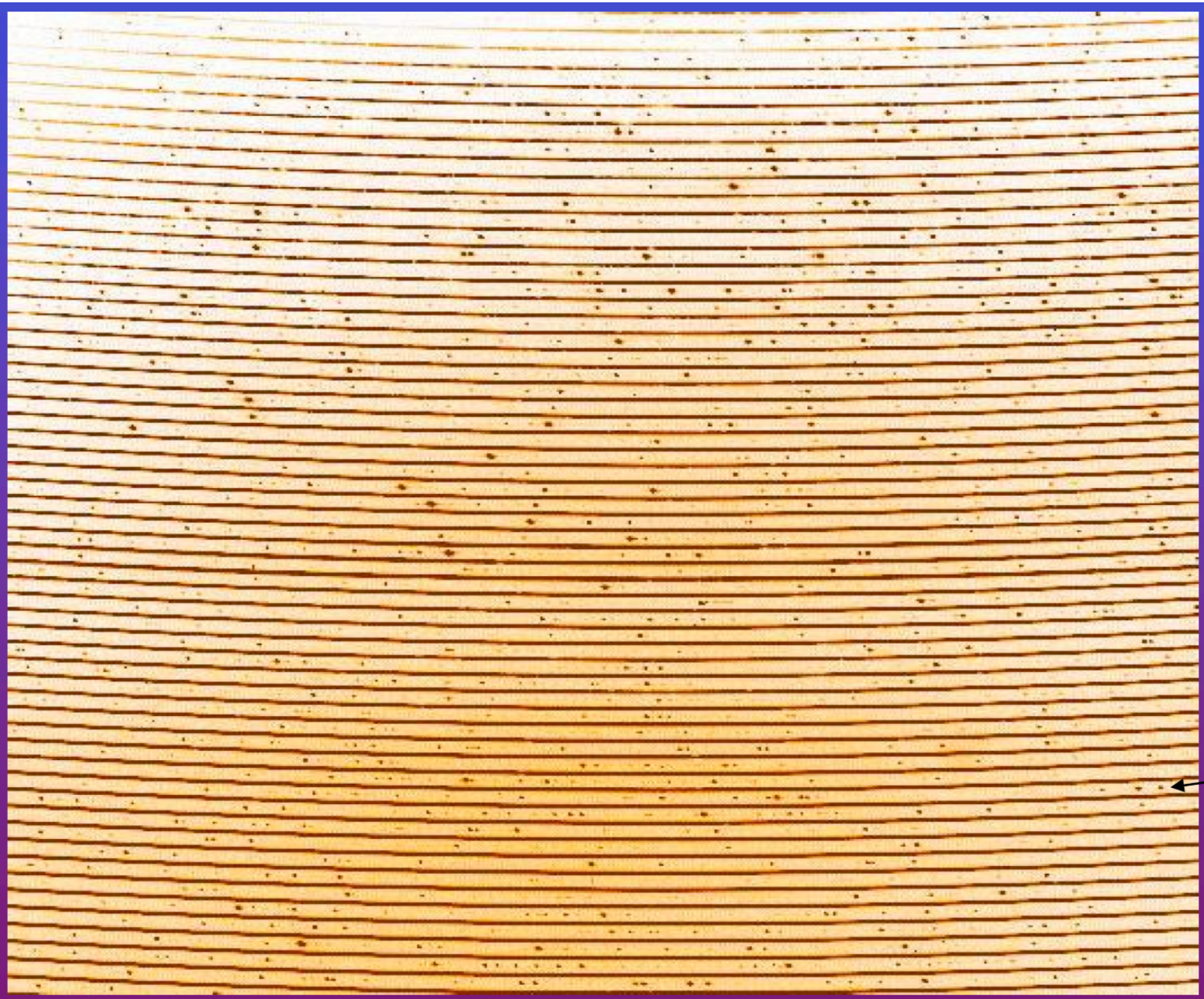
High temperature long time needed to heat (1 day)

50 % of the flux eaten by Iodine (big telescopes needed)

Narrow range of spectrum

Deconvolution S/N > 150 required

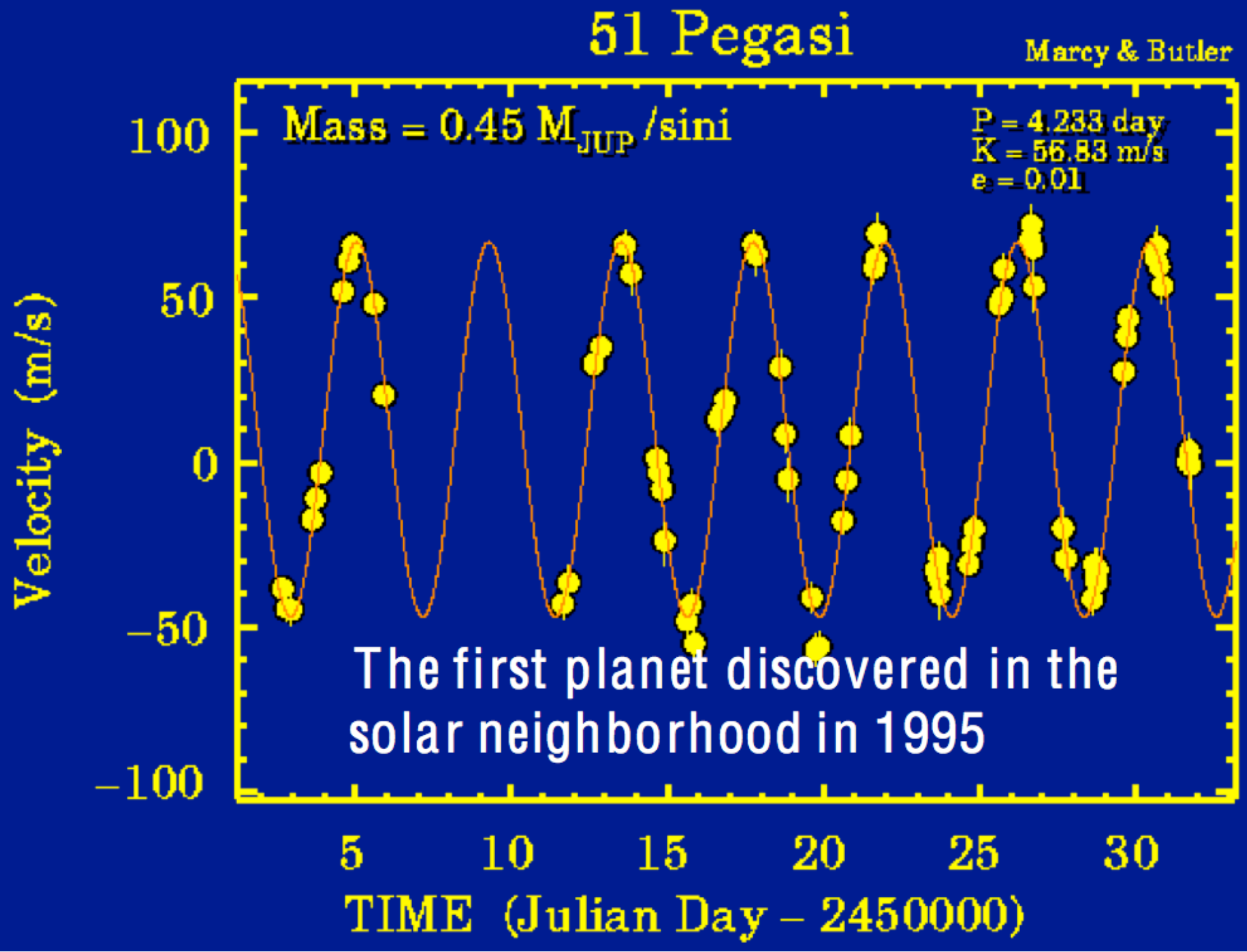
BUT easy to implement and relatively “cheap”

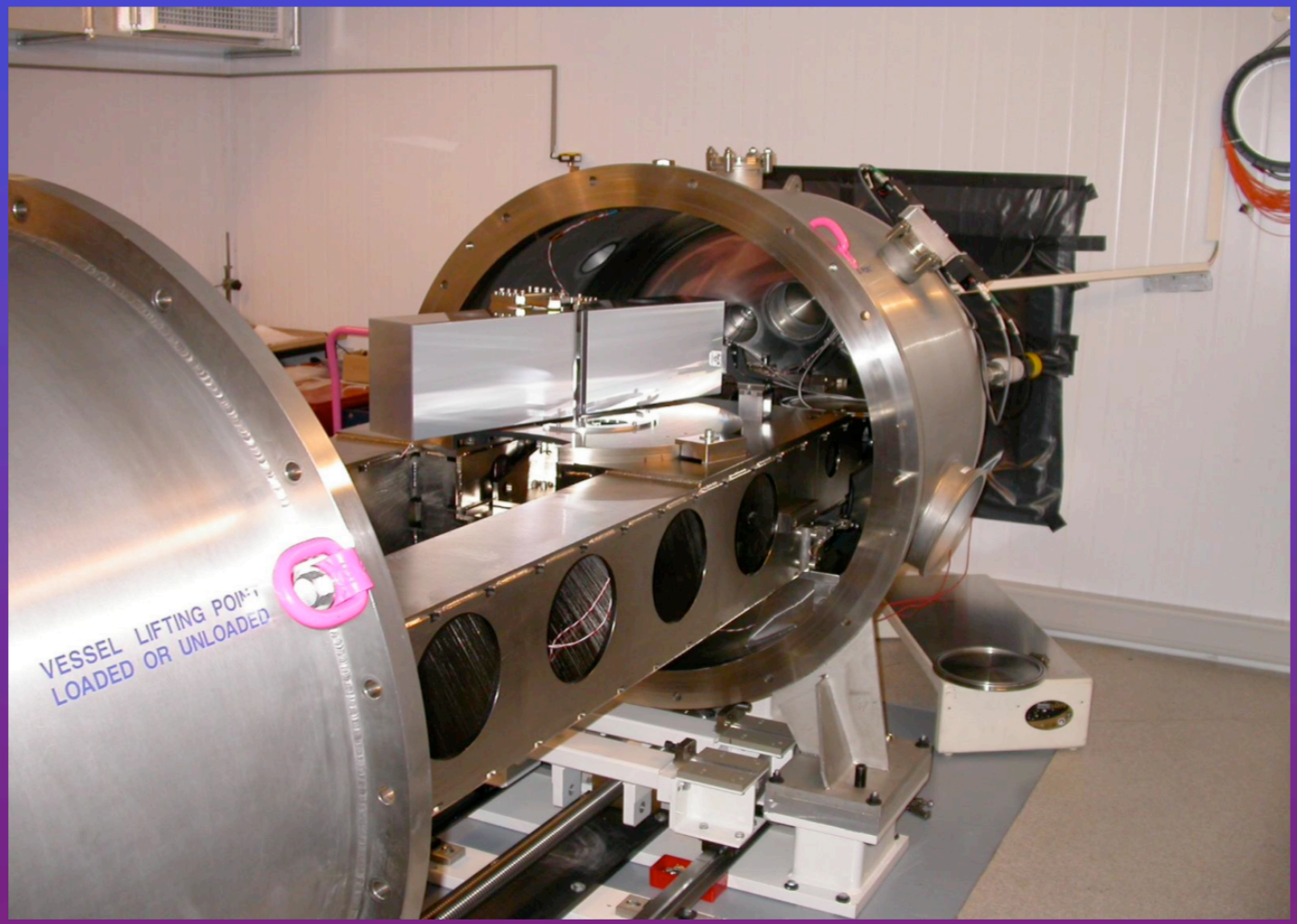


Thorium lines



From Mayor 2005


51 Pegasi
Marcy & Butler
Mass = 0.45 M_JUP /sini
P = 4.233 day
K = 56.83 m/s
e = 0.01
100
50
0
−50
−100
Velocity (m/s)
5
10
15
20
25
30
TIME (Julian Day – 2450000)
The first planet discovered in the solar neighborhood in 1995

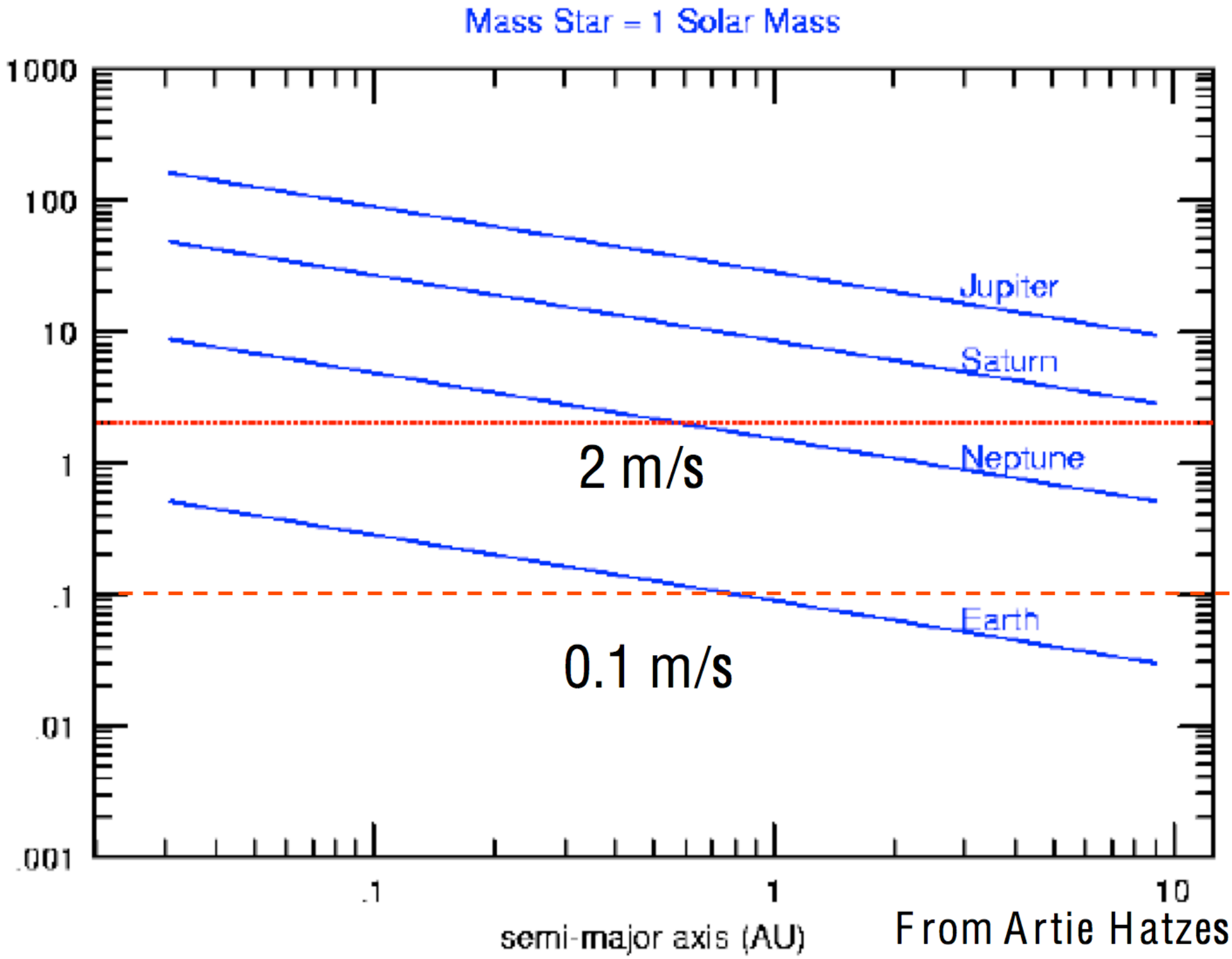



Instrument long term stability:

$\Delta T = 0.01$ K

$\Delta P = 0.01$ mbar

From Mayor 2005




From Artie Hatzes

# 3. ESPRESSO – A NEW-GENERATION SPECTROGRAPH

## 3.1 Instrument concept

ESPRESSO is a fiber-fed, cross-dispersed, high-resolution, echelle spectrograph. The telescope light is fed to the instrument via a Coudé-Train optical system and fibers. ESPRESSO is located in the Combined-Coudé Laboratory (incoherent focus) where a front-end unit can combine the light from up to 4 Unit Telescopes (UT) of the VLT. The target and sky light enter the instrument through two distinct optical fibers which form the 'slit' of the spectrograph.

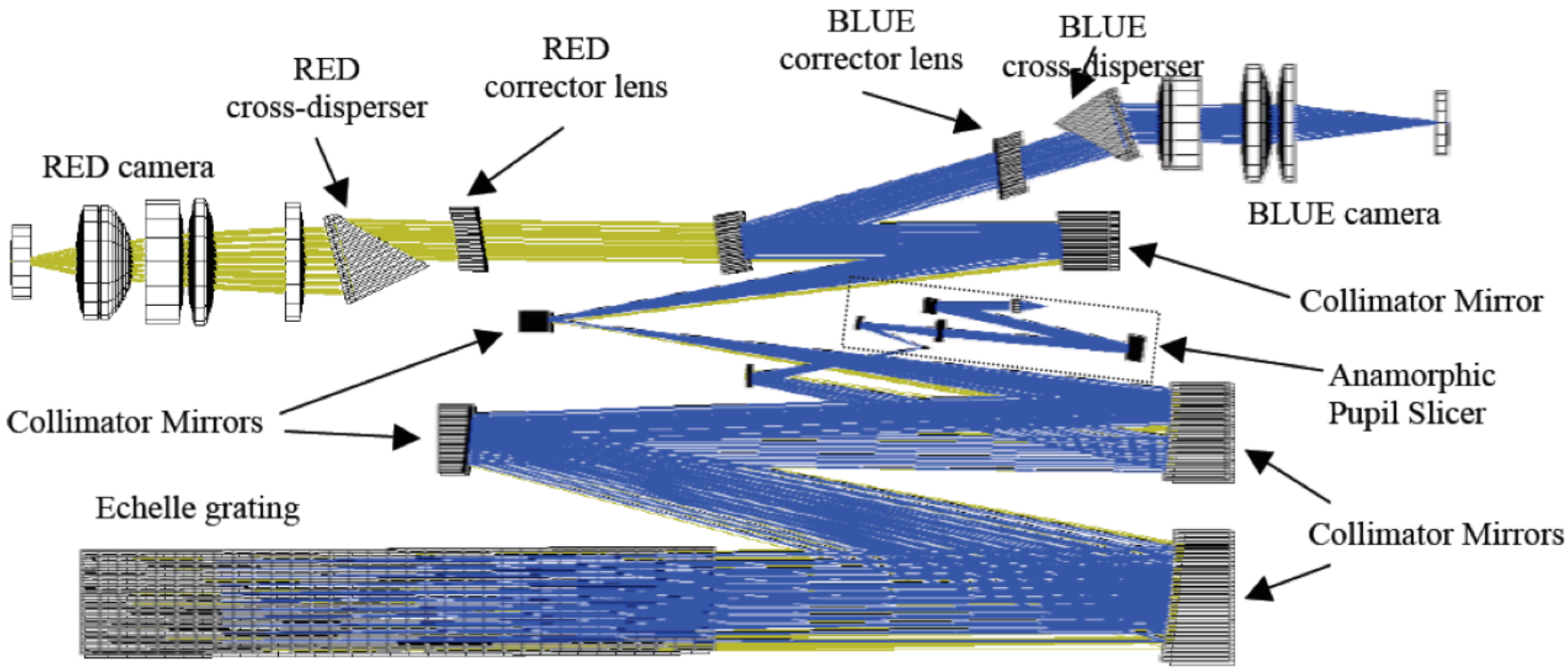
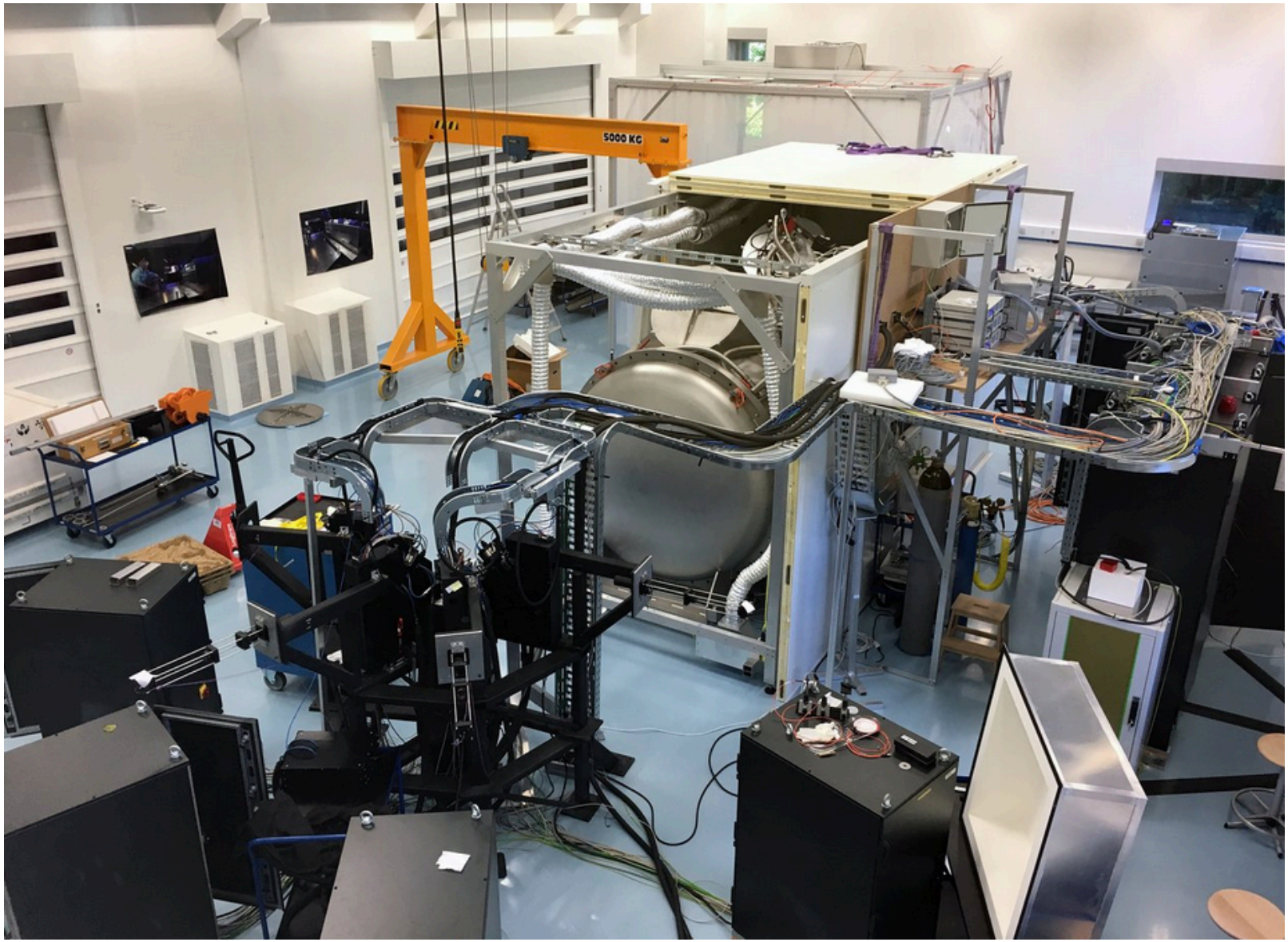
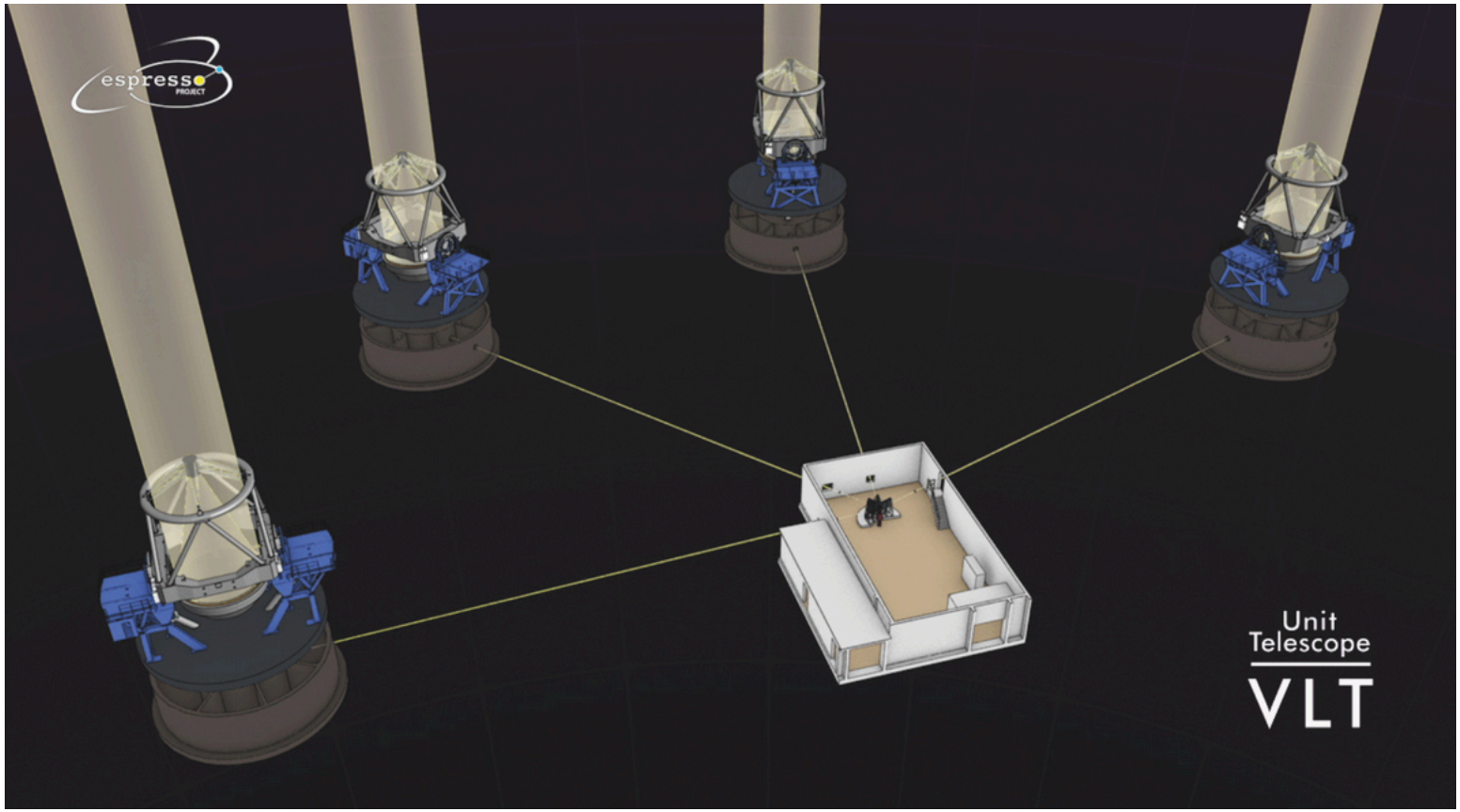



Figure 1. Optical layout of the ESPRESSO spectrograph


5000 KG


espresso
PROJECT
Unit
Telescope
VLT

| | HR (1-UT) | UHR (1-UT) | MR (4-UT) |
|---|---|---|---|
| Wavelength range | 380–788 nm | 380–788 nm | 380–788 nm |
| Resolving power (median) | 140,000 | 190,000 | 70,000 |
| Aperture on sky | 1".0 | 0".5 | 4x1".0 |
| Total efficiency | 11% | 5% | 11% |
| RV precision (requirement) | < 10 cm/s | < 5 m/s | < 5 m/s |
| Limiting V-band magnitude* | ~17 | ~16 | ~20 |
| Binning | 1x1, 2x1 | 1x1 | 4x2, 8x4 |
| Spectral sampling (average) | 4.5 px | 2.5 px | 5.5 px (binned x2) |
| Spatial sampling per slice | 9.0 (4.5) px | 5.0 px | 5.5 px (binned x4) |
| Number of slices | 2 | 2 | 1 |

Rocky planets: How to find such stable stars ?

Stability of physical constants: fine-structure constant ($\alpha$) and the proton-to-electron mass ratio ($\mu$). A relative variation in $\alpha$ or $\mu$ of 1 ppm leads to velocity shifts of about 20 m/s between typical combinations of transitions.

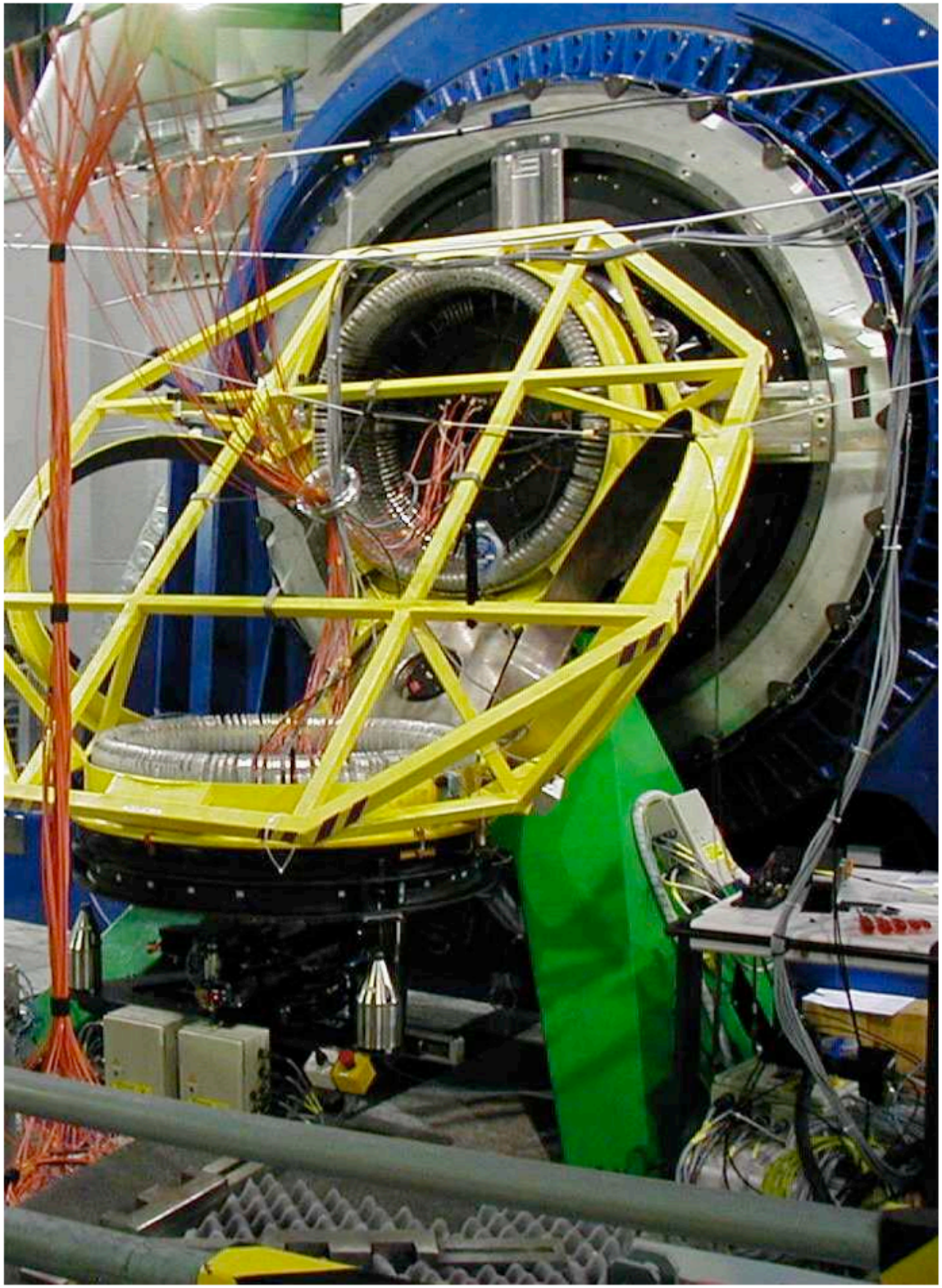
Abundances, blending, rotation

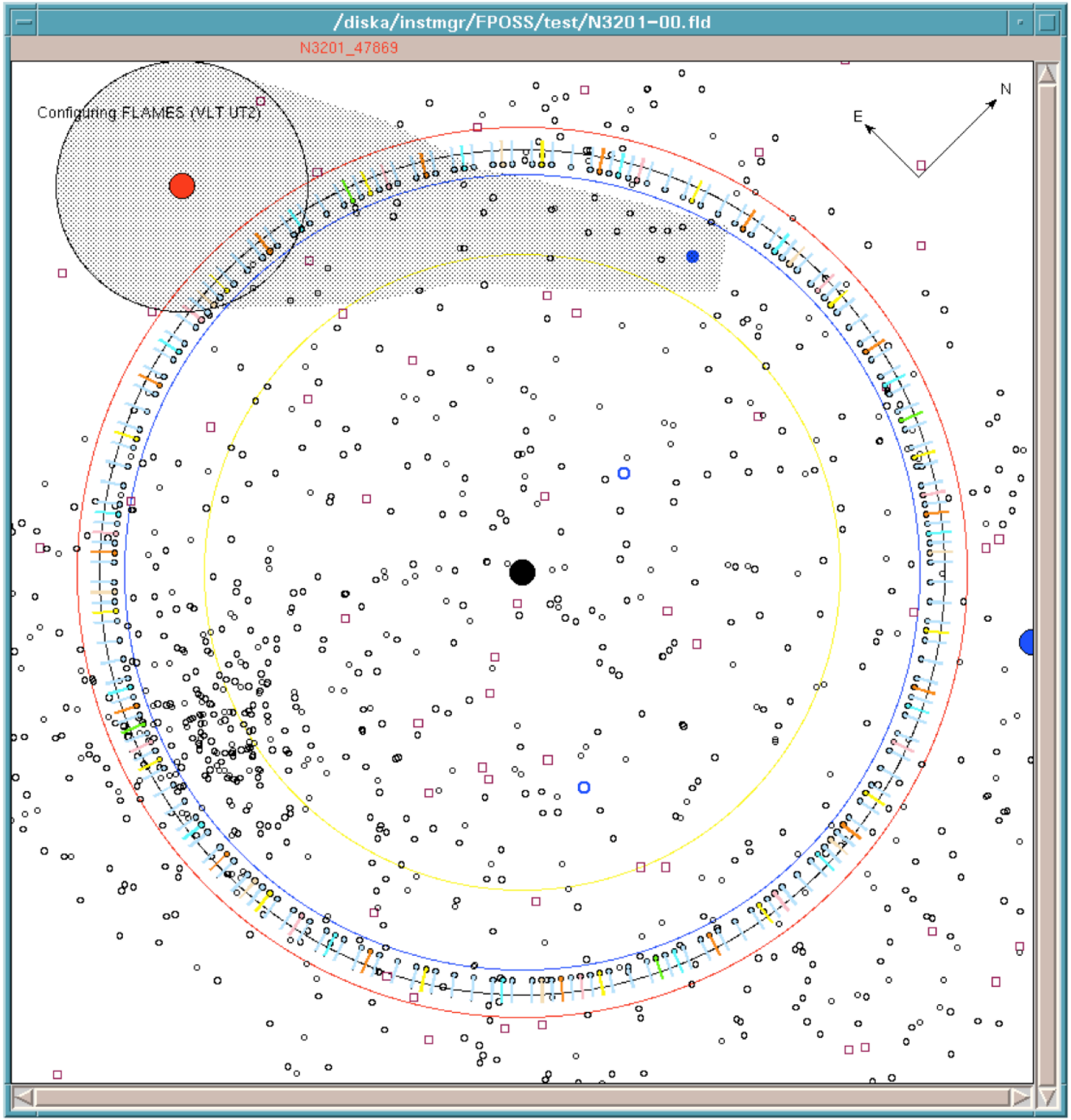
# Multi fiber spectrographs

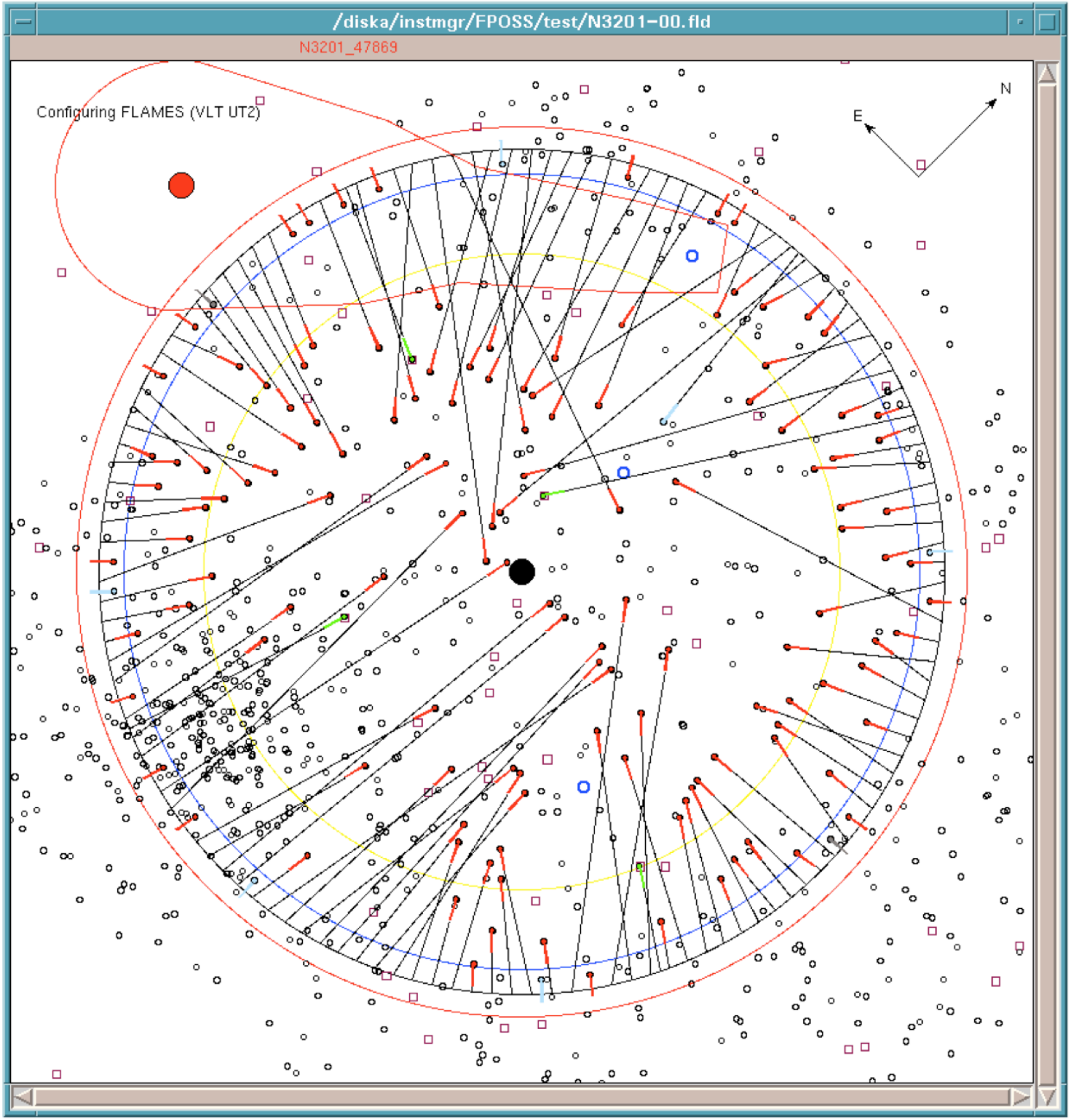
## Full list of instrument setups in the FLAMES User manual

| Spectrograph | Mode | N. Of Objects | Aperture (") | Resolving Power (*) | Spectral Band [nm] (**) |
|---|---|---|---|---|---|
| **UVES** | Red Arm | 8 | 1.0 | 47000 | 200 |
| **UVES** | Red Arm | 7 + 1 calibration | 1.0 | 47000 | 200 |
| **GIRAFFE** | MEDUSA buttons | 130 (w. sky fibres) | 1.2 | 12000 - 24000 | λ/12 to λ/24 |
| **GIRAFFE** | MEDUSA buttons | 130 (w. sky fibres) | 1.2 | 7000 | λ/9.5 |
| **GIRAFFE** | IFU | 15 (+15 sky fibres) | 2 x 3 | 19000 - 39000 | λ/12 to λ/24 |
| **GIRAFFE** | IFU | 15 (+15 sky fibres) | 2 x 3 | 11000 | λ/9.5 |
| **GIRAFFE** | ARGUS | 1 | 11.5 x 7.3 or 6.6 x 4.2 | 19000 - 39000 | λ/12 to λ/24 |
| **GIRAFFE** | ARGUS | 1 | 11.5 x 7.3 or 6.6 x 4.2 | 11000 | λ/9.5 |

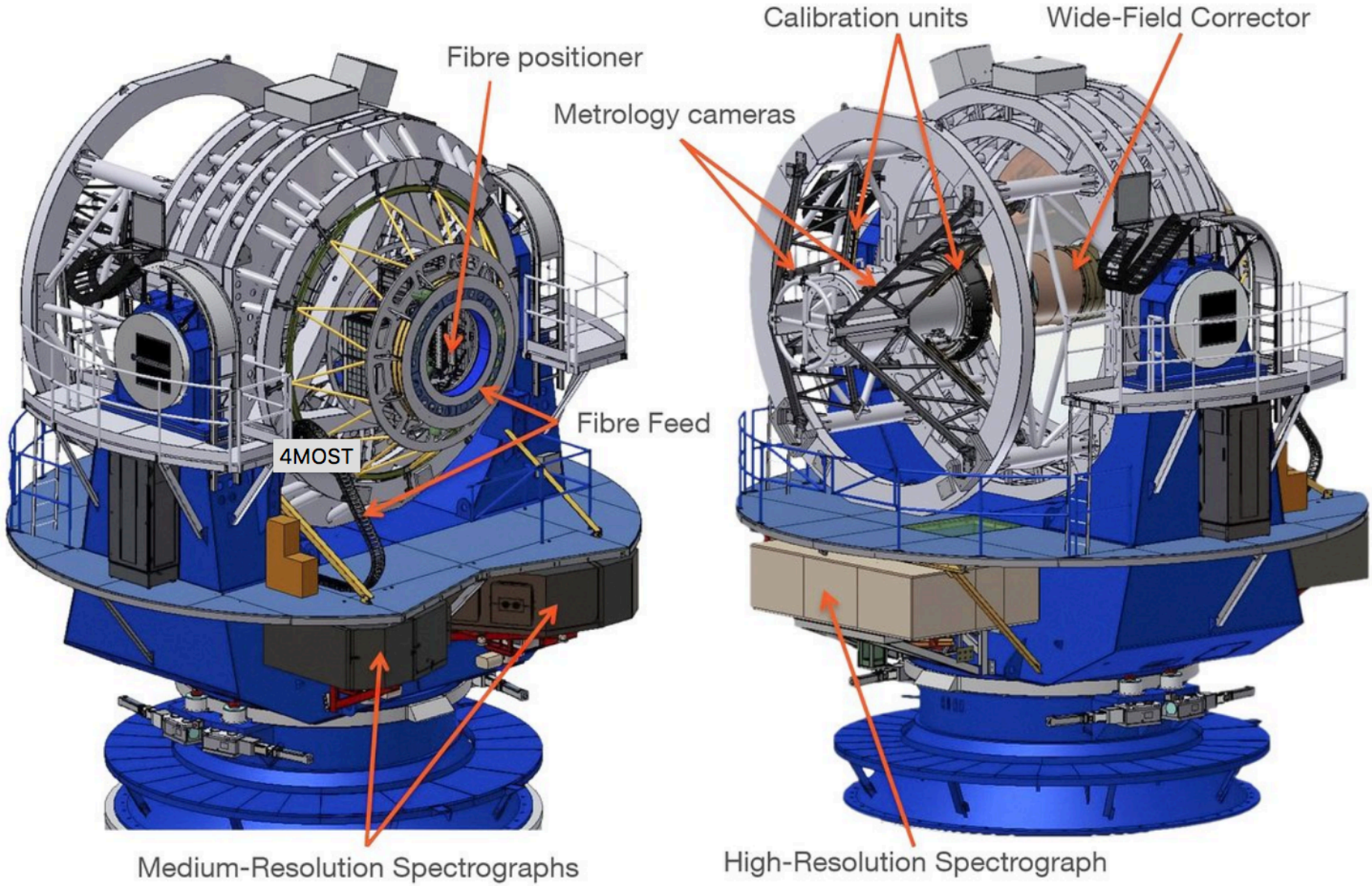
- Medusa
- Medusa + UVES (8 fibres) [580,860nm]
- Medusa + UVES (7 fibres + 1 calibration) [580nm]
- Medusa + UVES (6 fibres) [520nm]
- IFU
- IFU + UVES (8 fibres) [580,860nm]
- IFU + UVES (7 fibres + 1 calibration) [580nm]
- IFU + UVES (6 fibres) [520nm]
- ARGUS sky
- ARGUS sky + UVES (8 fibres) [580,860nm]
- ARGUS sky + UVES (7 fibres + 1 calibration) [580nm]
- ARGUS sky + UVES (6 fibres) [520nm]
- UVES (8 fibres) [580,860nm]
- UVES (7 fibres + 1 calibration) [580nm]
- UVES (6 fibres) [520nm]




/diska/instmgr/FPOSS/test/N3201-00.fld
N3201_47869
Configuring FLAMES (VLT UT2)
N
E


/diska/instmgr/FPOSS/test/N3201-00.fld
N3201_47869
Configuring FLAMES (VLT UT2)
N
E

# 4MOST

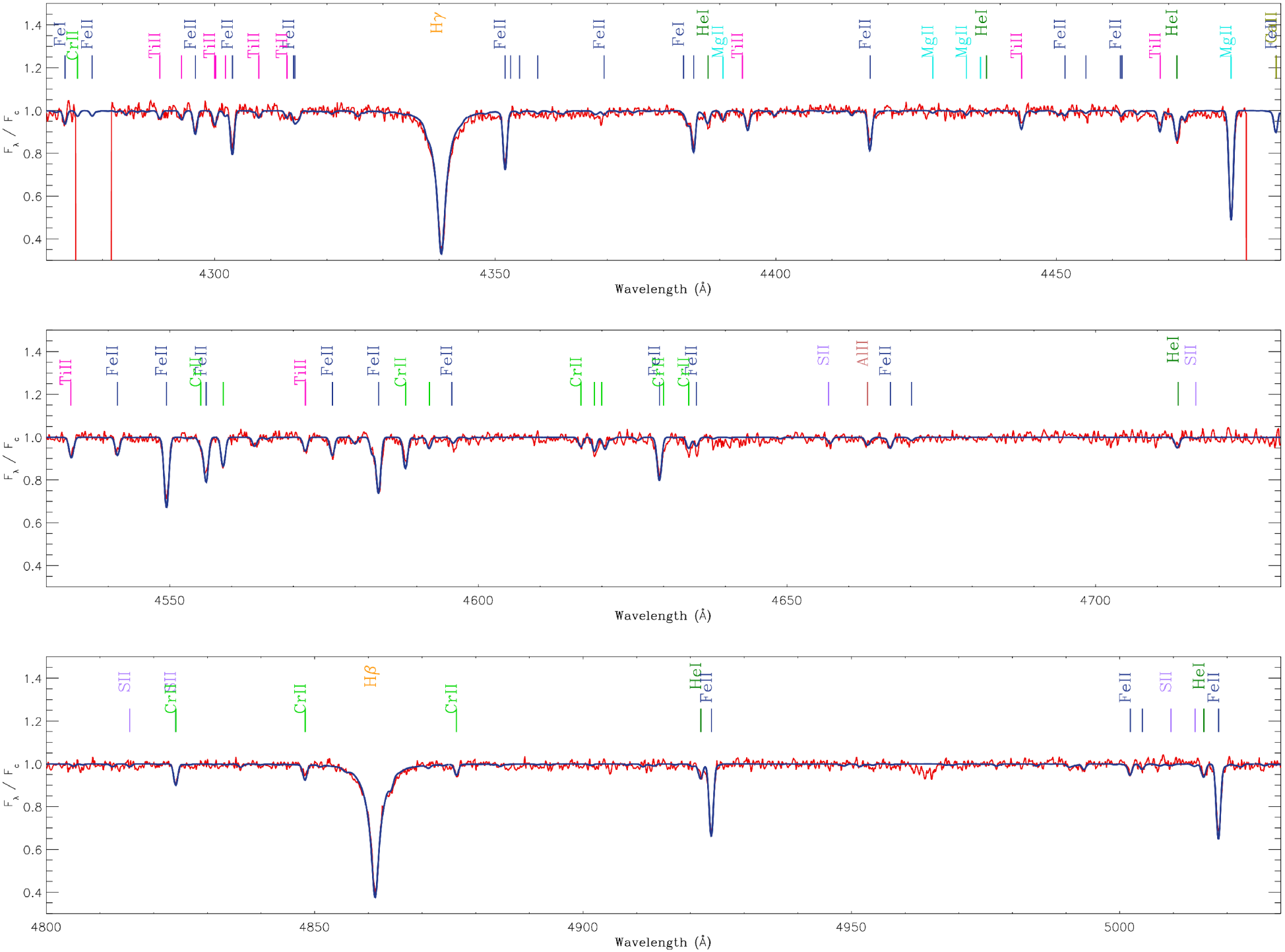



2400 fibers 390-950 nm expected in 2022

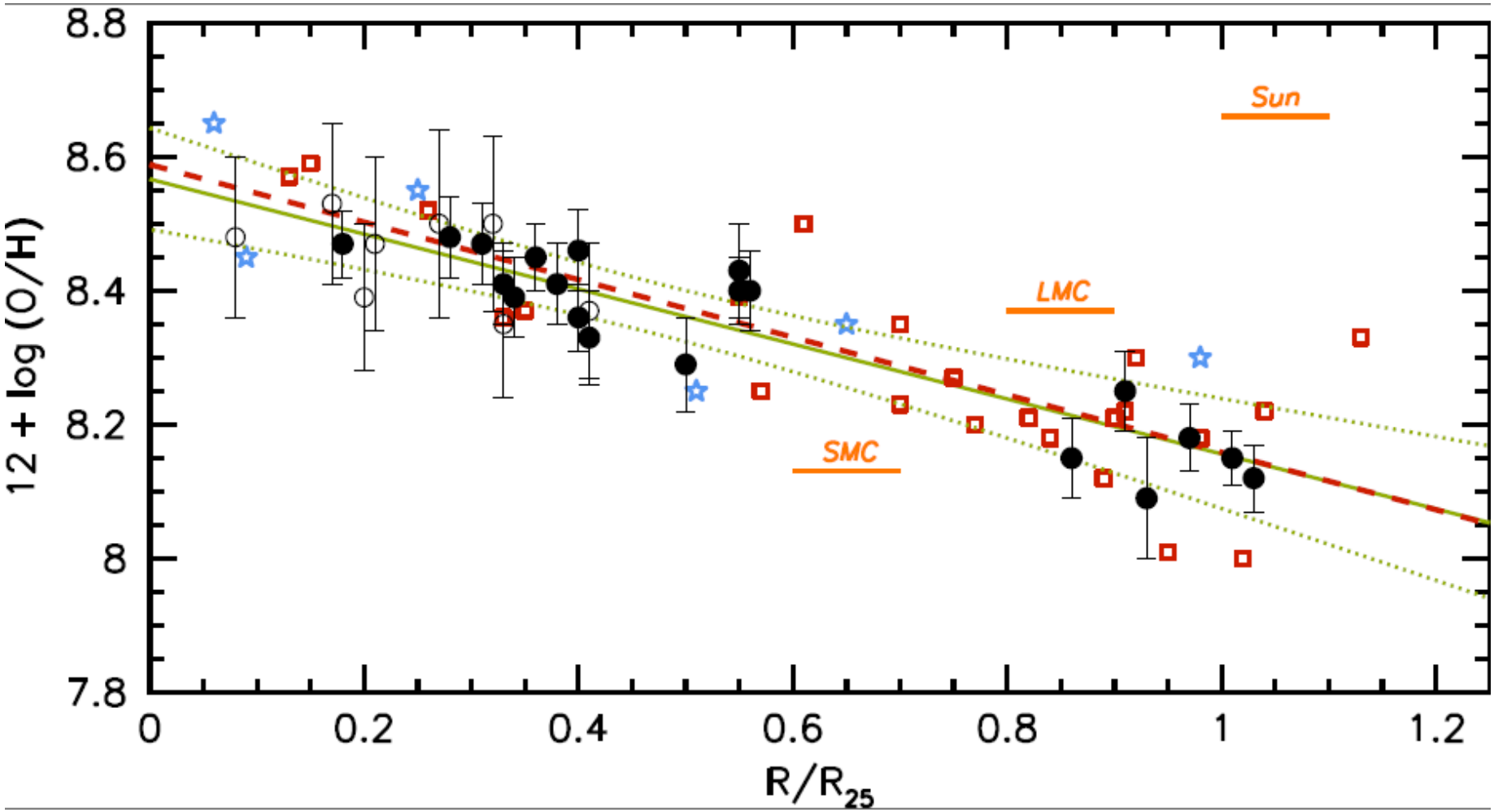
# Distance scale

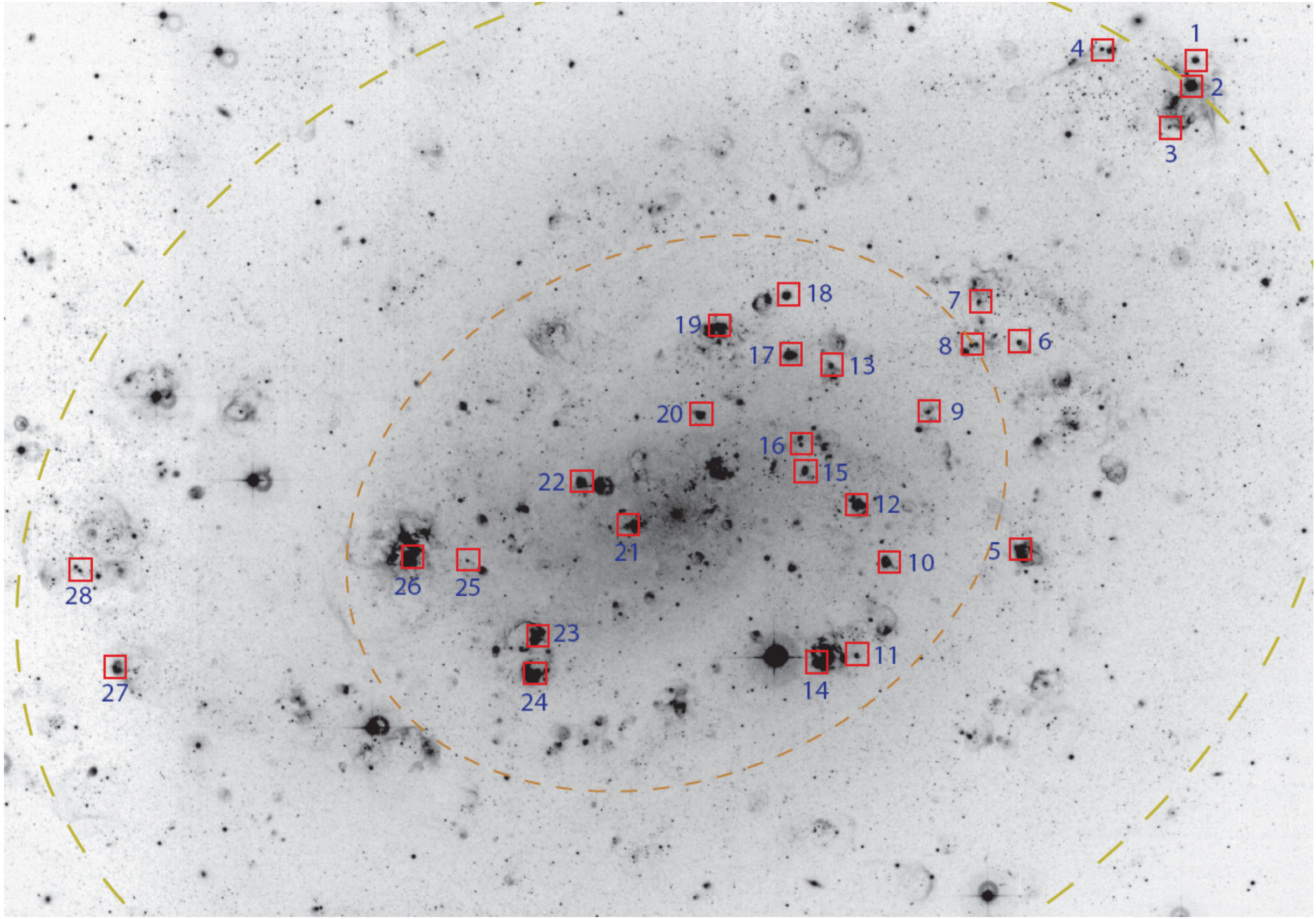
LR - determination of z, AGN reverberation, metallicity estimates, etc

HR − metallicity, abundaces, $T_{eff}$ and other parameters, precision RVs (binary stars, Cepheids)

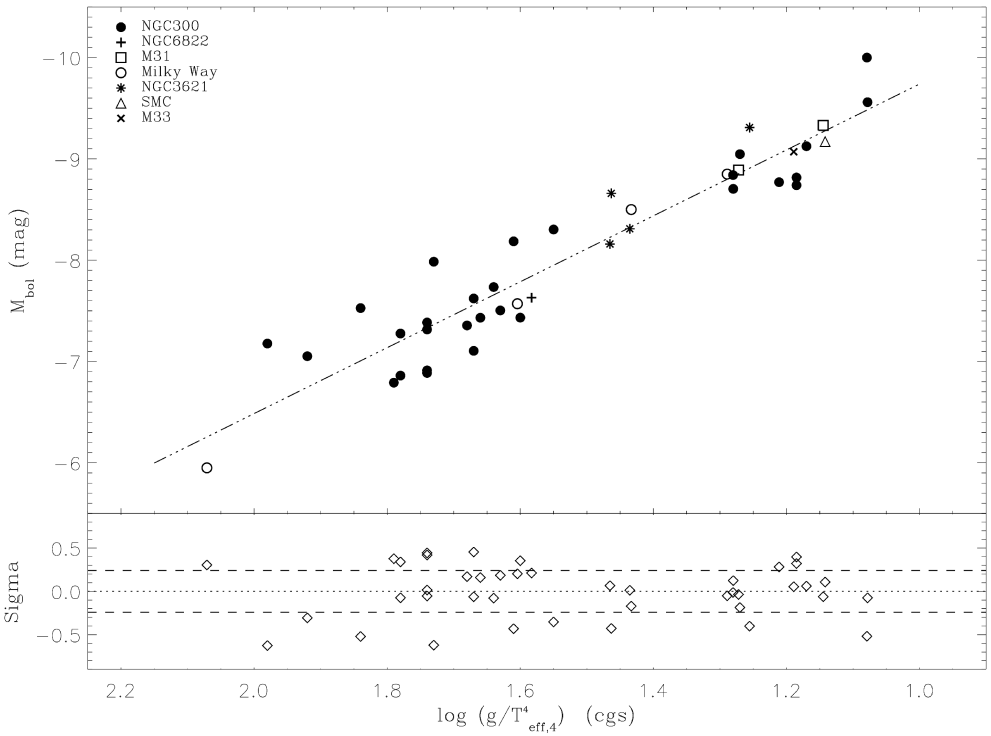

FeI
CrII
FeII
TiII
FeII
TiII
FeII
TiII
TiII
FeII
Hγ
FeII
FeII
FeI
HeI
MgII
TiII
FeII
MgII
MgII
HeI
TiII
FeII
FeII
TiII
HeI
MgII
FeII
TiII
FeII
CrII
FeII
TiII
FeII
FeII
CrII
FeII
CrII
FeII
CrII
FeII
CrII
FeII
SII
AlII
FeII
HeI
SII
SII
CrII
CrII
CrII
Hβ
CrII
HeI
FeII
FeII
SII
HeI
FeII
$F_\lambda / F_c$
Wavelength (Å)

# Metallicity gradients in spiral galaxies




1
2
3
4
5
6
7
8
9
10
11
12
13
14
15
16
17
18
19
20
21
22
23
24
25
26
27
28

# Flux weighted Gravity – Luminosity Reationship (FGLR)




**L,M ~ const.**

$$M \sim g \times R^2 \sim L \times (g/T^4) = \text{const.}$$

const.

$$\rightarrow L \sim M^x \sim L^x (g/T^4)^x,\ x \sim 3$$

$$\rightarrow L^{1-x} \sim (g/T^4)^x$$

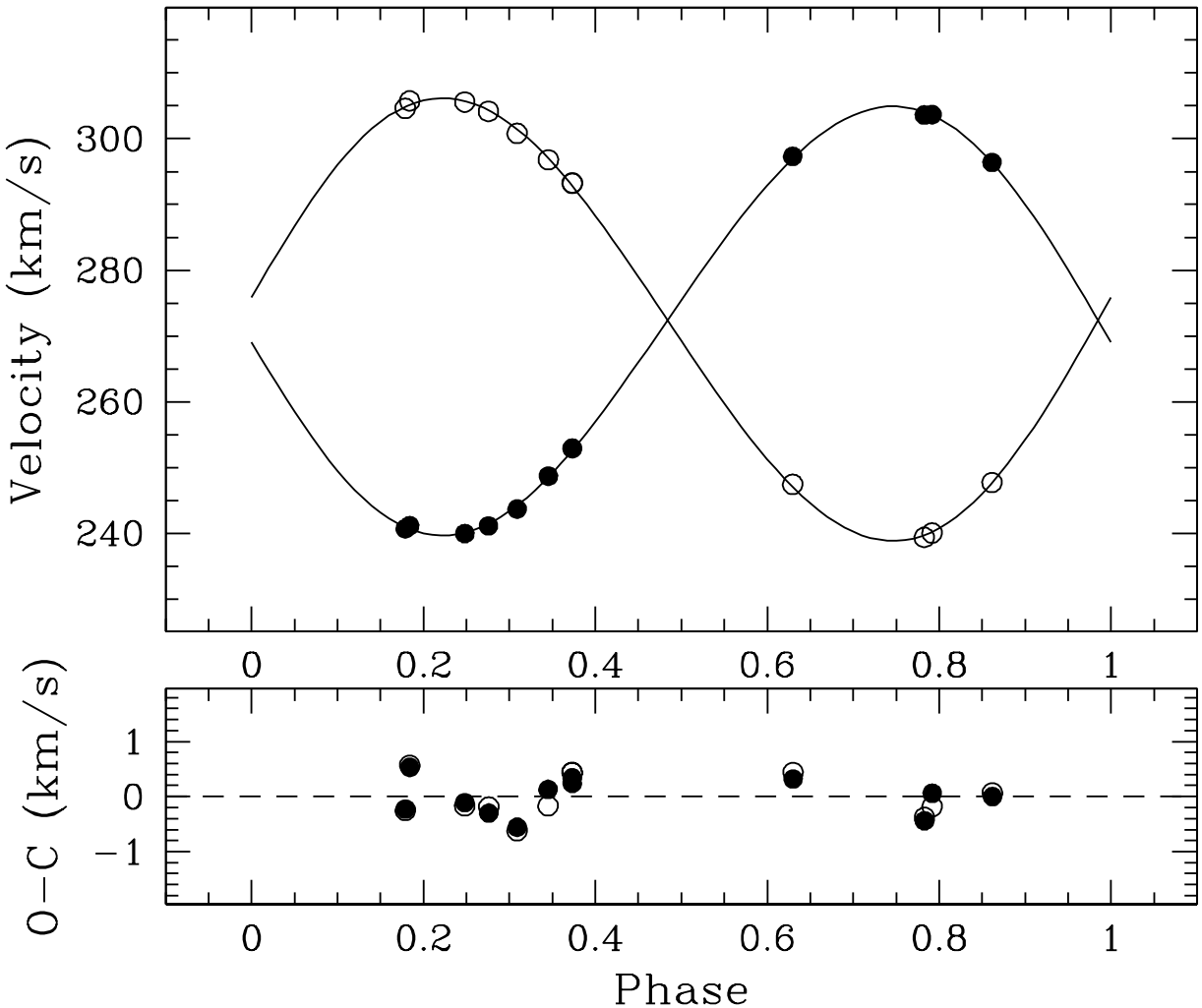
or with $M_{bol} \sim -2.5 \log L$

$$M_{bol} = a \log(g/T^4) + b \qquad \text{(FGLR)}$$

$$a = 2.5\, x/(1-x) \sim 3.75$$

# OGLE-051019.64-685812.3

(Pietrzynski et al. 2009, ApJ, 697, 862)



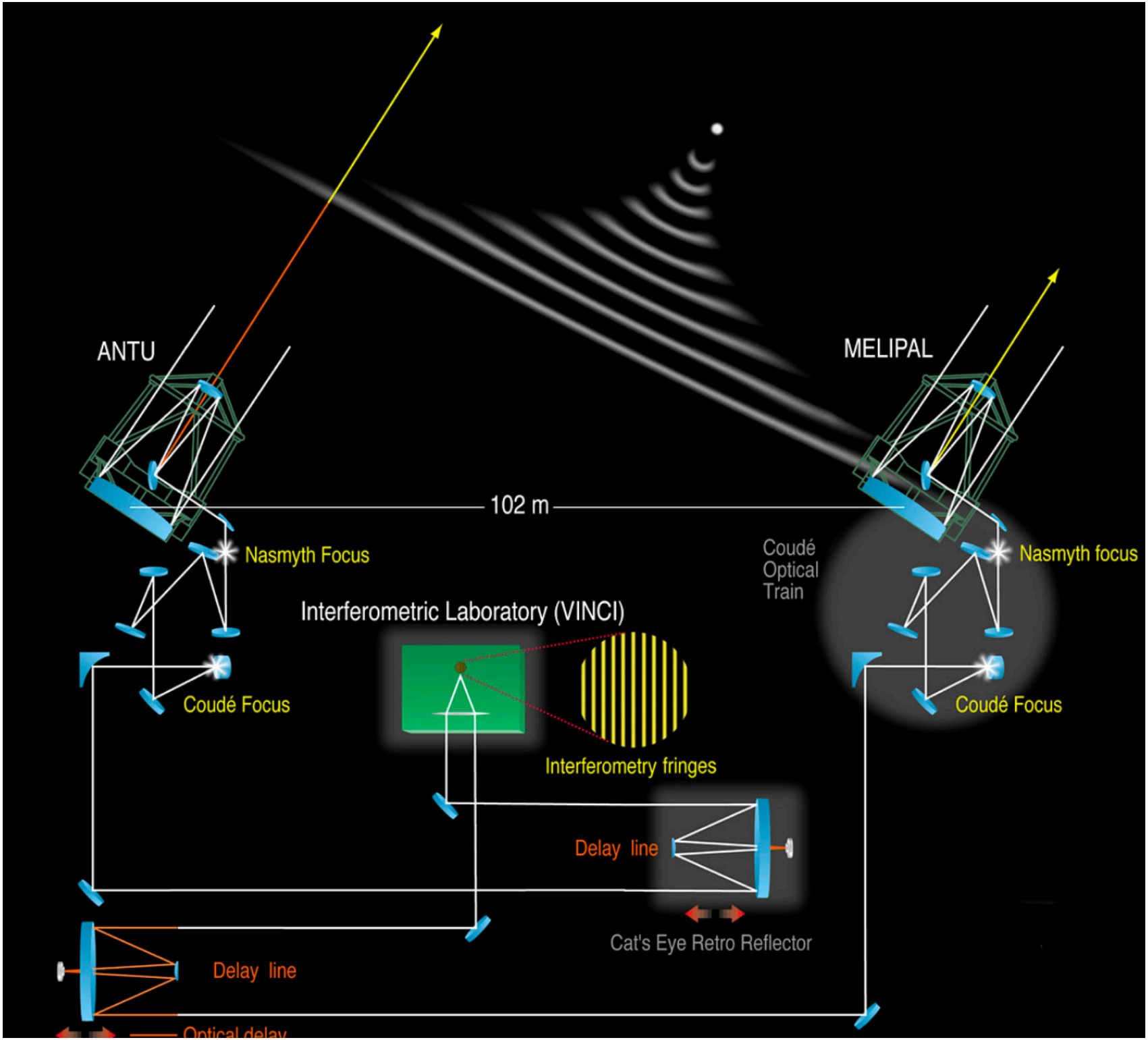
# Interferometry − ultra high resolution (frequency, baseline)

Optical Chara, NPOI

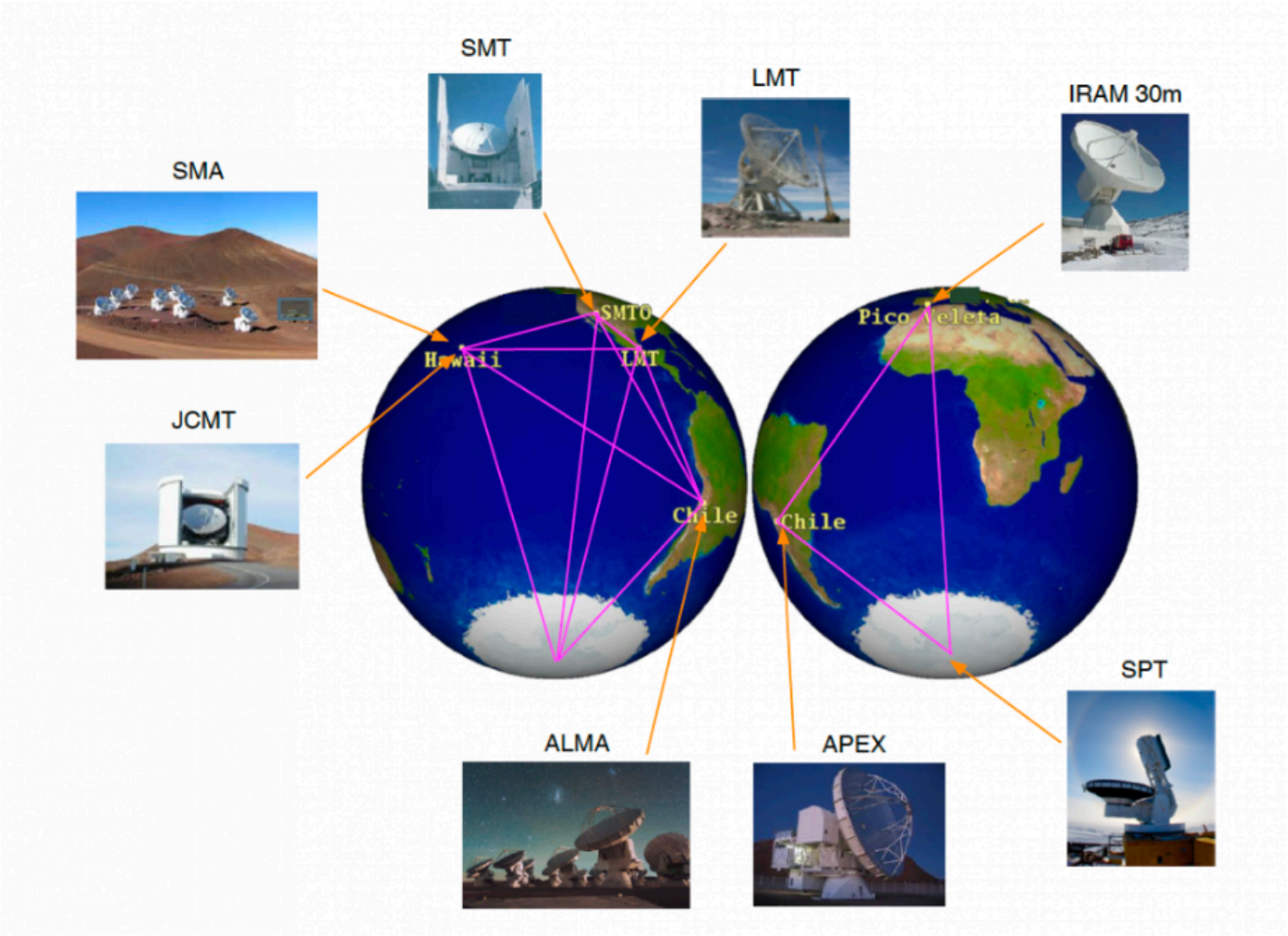
NIR VLTI

mm/ sub-mm ALMA

Radio VLBI array


ANTU
MELIPAL
102 m
Nasmyth Focus
Nasmyth focus
Coudé
Optical
Train
Interferometric Laboratory (VINCI)
Coudé Focus
Coudé Focus
Interferometry fringes
Delay line
Cat's Eye Retro Reflector
Delay line
Optical delay

# VLBI


SMT
LMT
IRAM 30m
SMA
JCMT
SMTO
Hawaii
LMT
Chile
Pico Veleta
Chile
SPT
ALMA
APEX

# VLBI

Distances via masers:

Miras

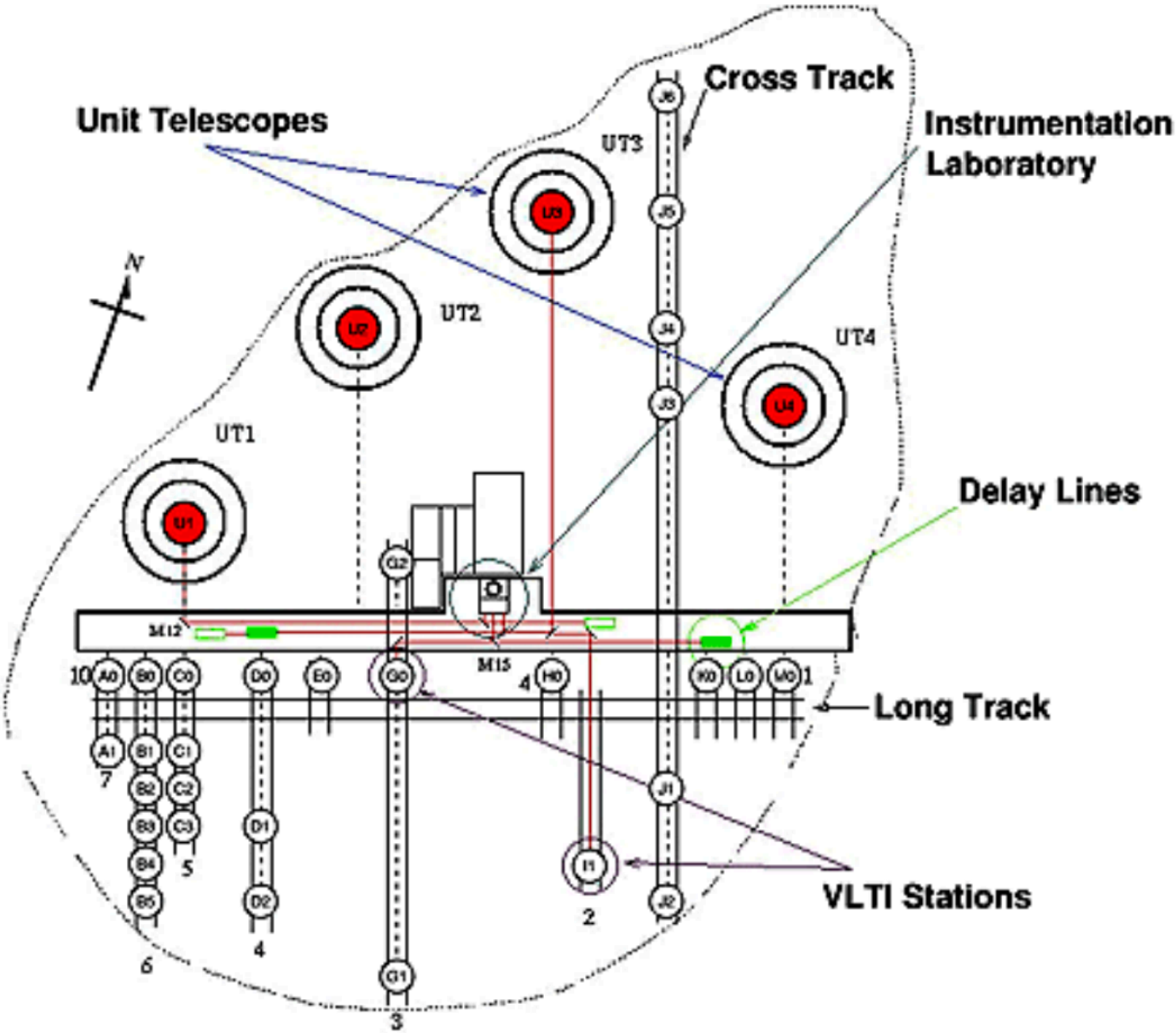
Star forming regions

NGC 4852  1% distance ?

Distances to very distant galaxies => one step $H_0$

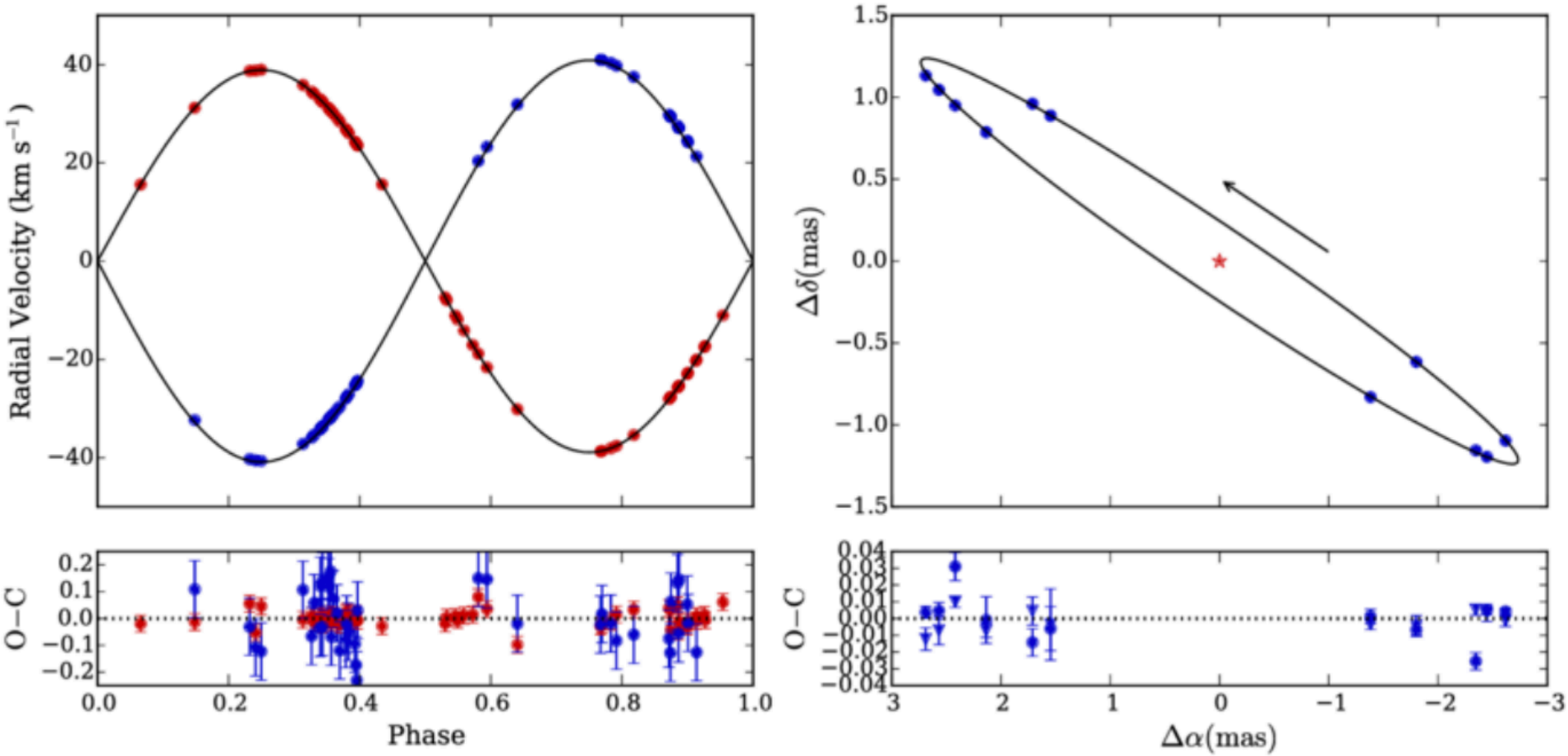
ALMA interferometer
tracing structure of the universe

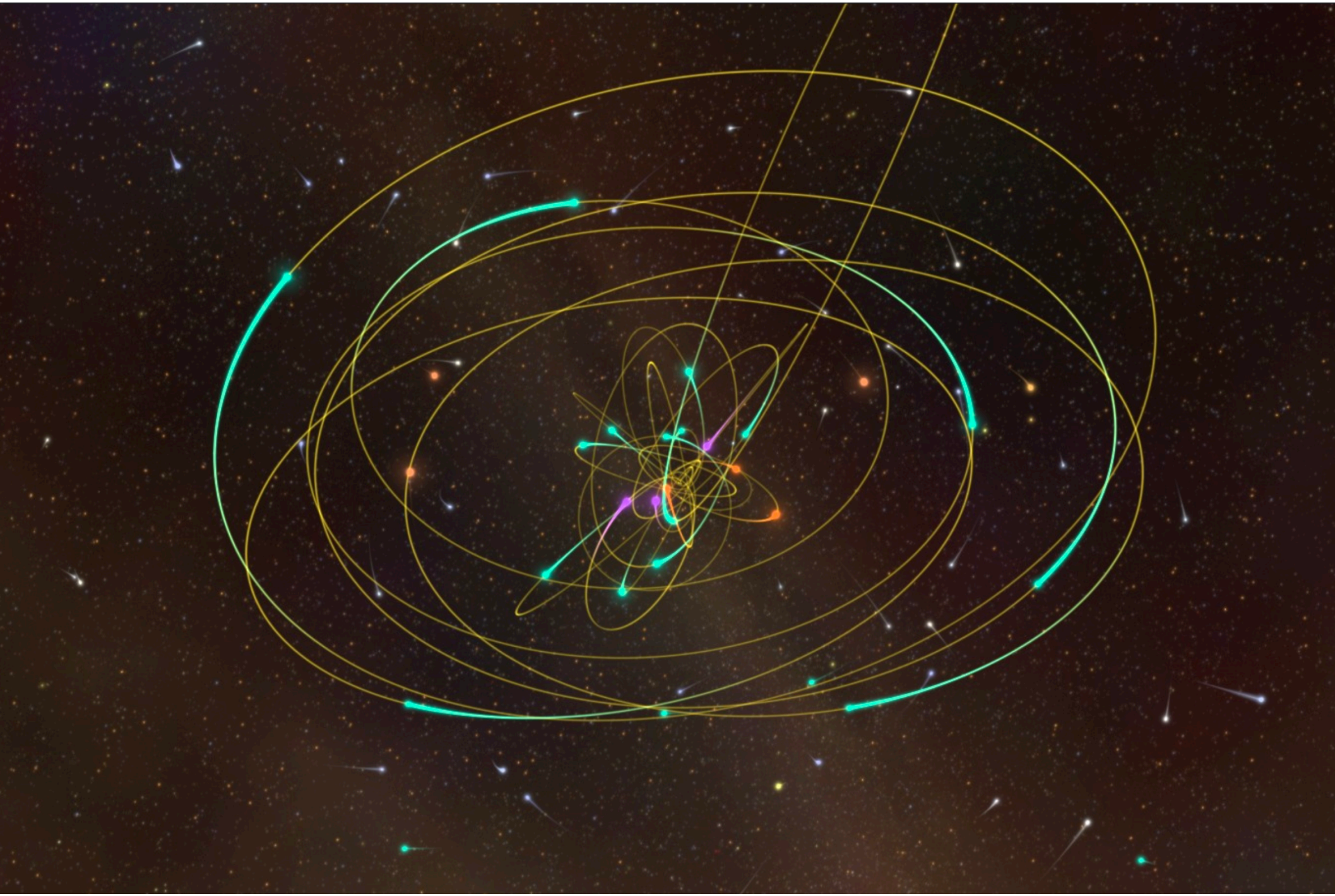
# NIR VLTI

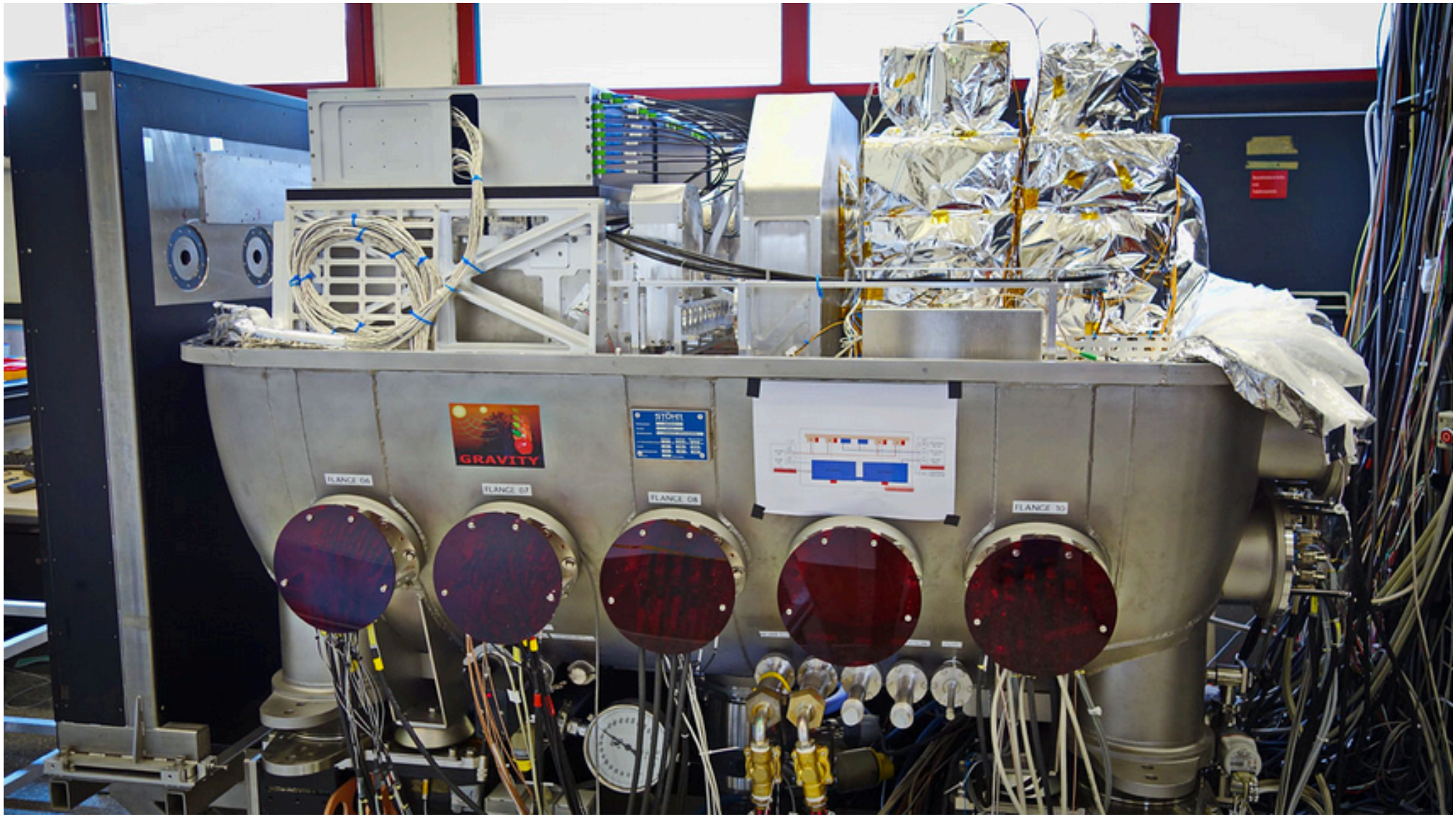

Unit Telescopes
Cross Track
Instrumentation Laboratory
UT1
UT2
UT3
UT4
N
Delay Lines
Long Track
VLTI Stations

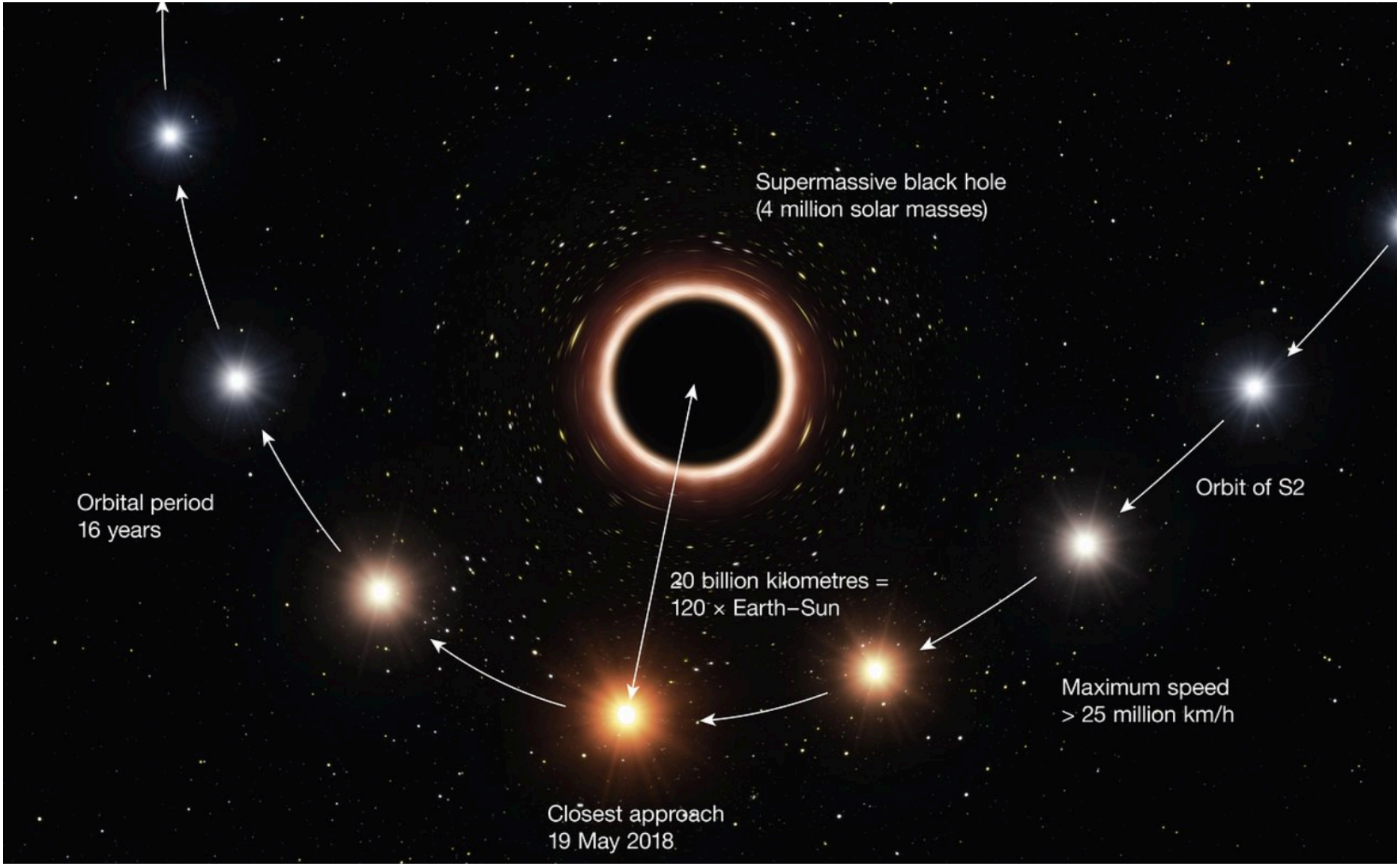
Site Layout

# VLTI Astrometry
# Astrometric systems 0.5% distances up to 200 pc





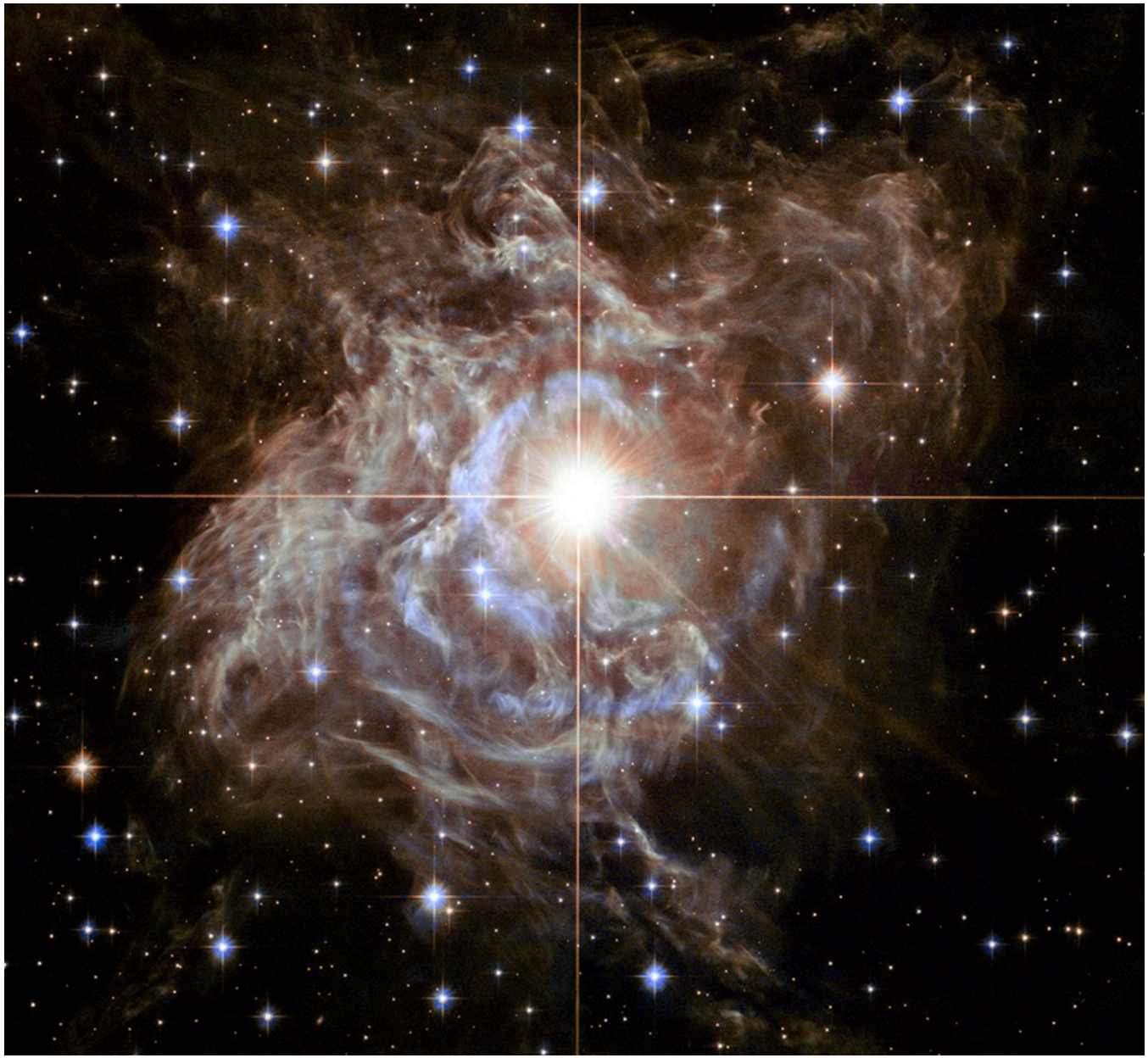

GRAVITY
FLANGE 06
FLANGE 07
FLANGE 08
FLANGE 10

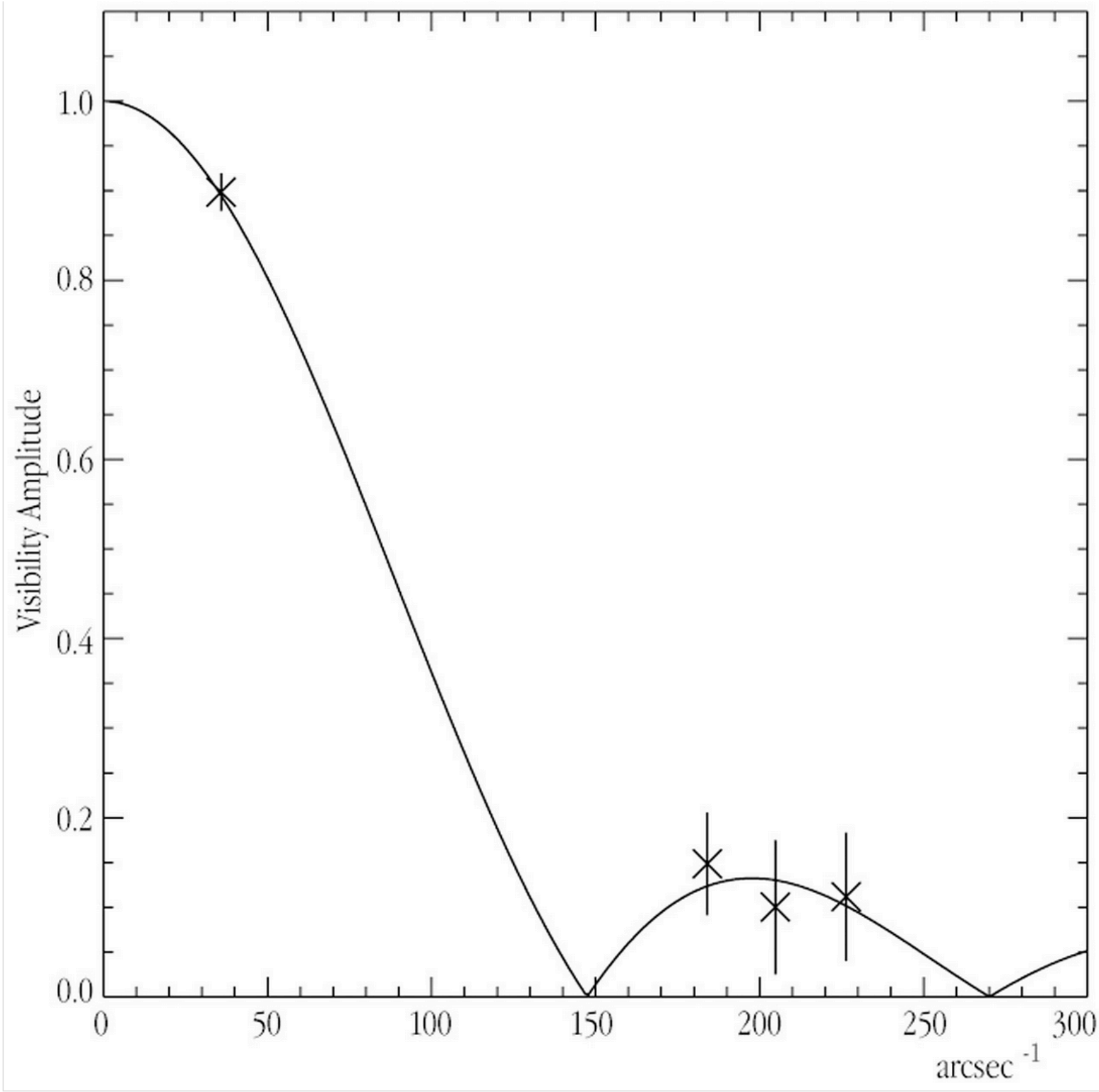



Testing general theory of relativity

Distance to Galactic center at 0.3% uncertainty !!

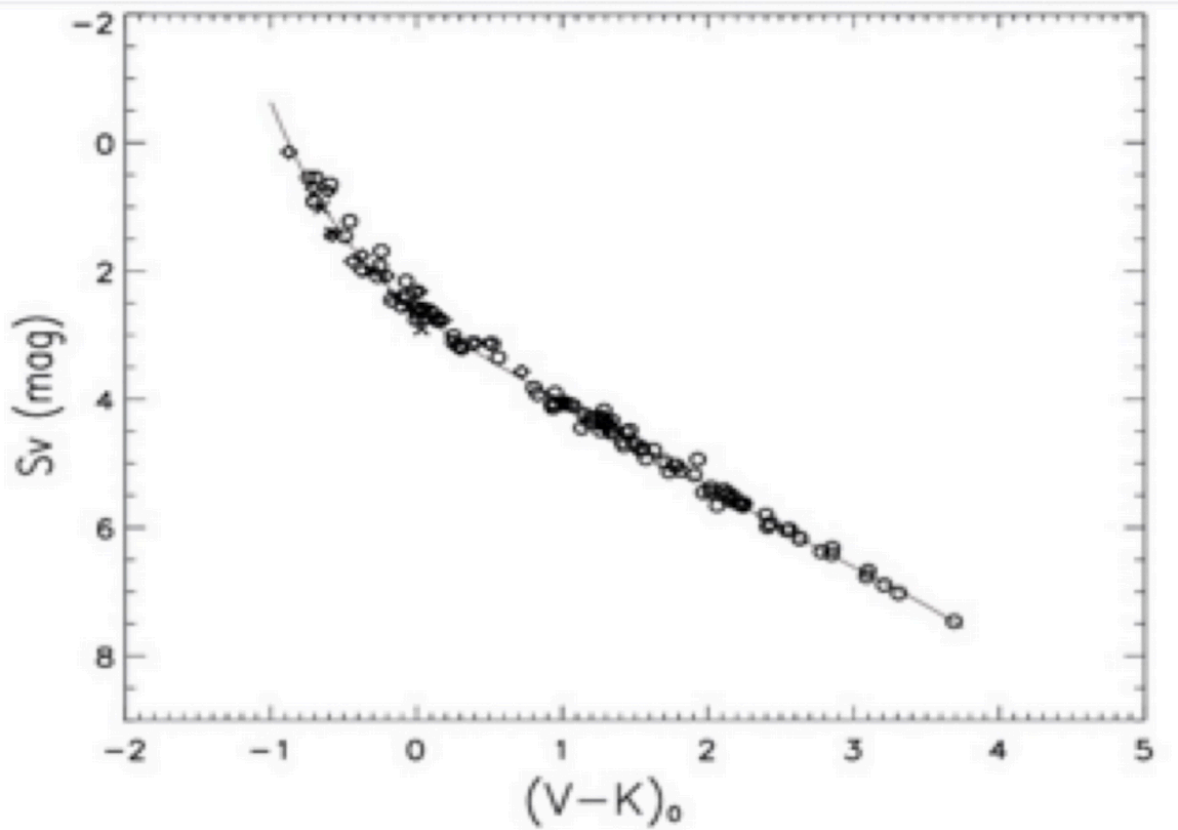
# RS Pup long period Cepheid



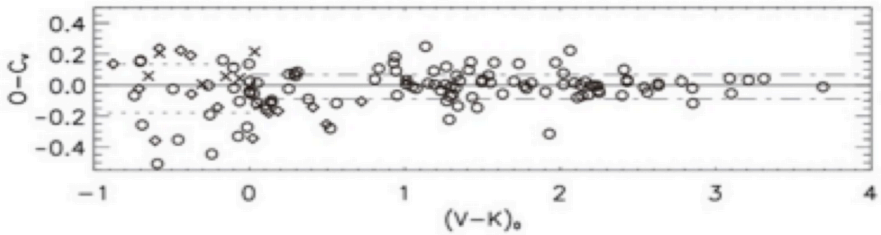

Visibility Amplitude
1.0
0.8
0.6
0.4
0.2
0.0
0
50
100
150
200
250
300
arcsec -1

# SBCR

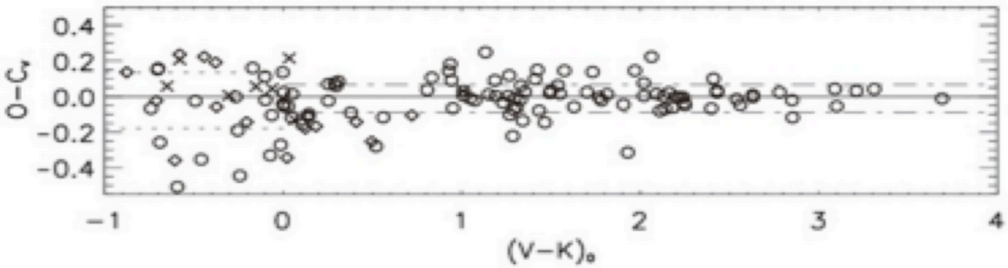
$$S_V = 2.656 + 1.483 \times (V-K)_0 - 0.044 \times (V-K)_0^2$$




$$\phi\ [\mathrm{mas}] = 10^{0.2\cdot(S-m_0)}$$




10% 2%




Data from 1960s

# Combinations

Optical + NIR photometry + spectroscopy + interferometry: Eclipsing binaries, BW method (Cepheids)

Optical + NIR photometry + spectroscopy: SN Ia, AGNs

Optical + NIR photometry:  P-L relations Cepheids

# Growth of Optical Telescopes