Comparison of Gaia BP/RP spectra with LDS (Low Dispersion Spectroscopy) photographic sky surveys

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Motivation/Why historical LDS

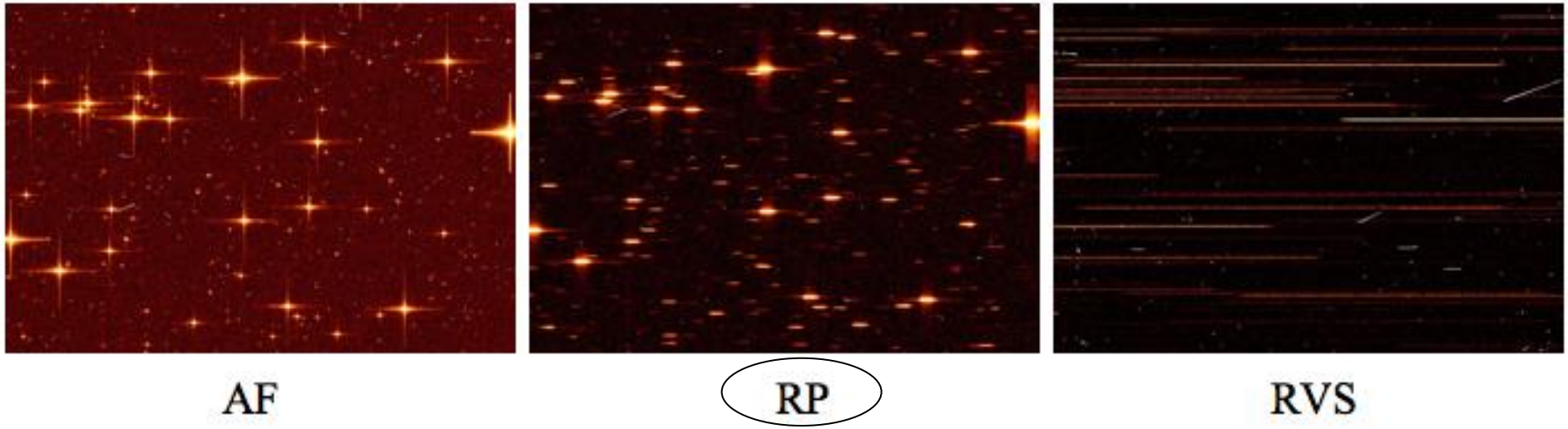
- Adding historical epochs
- (Large) Spectral variations with time … so far little exploited
- Astrophysics e.g searches for high z objects and optical counterparts of GRBs

The Three Modes of Gaia

astrometry

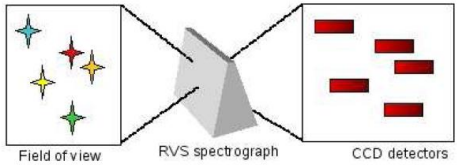
"photometry"

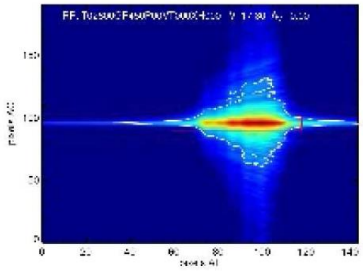
spectroscopy



In this talk we focus of the „photometric mode" RP/BP. In reality this mode generates ultra low-dispersion prism spectra

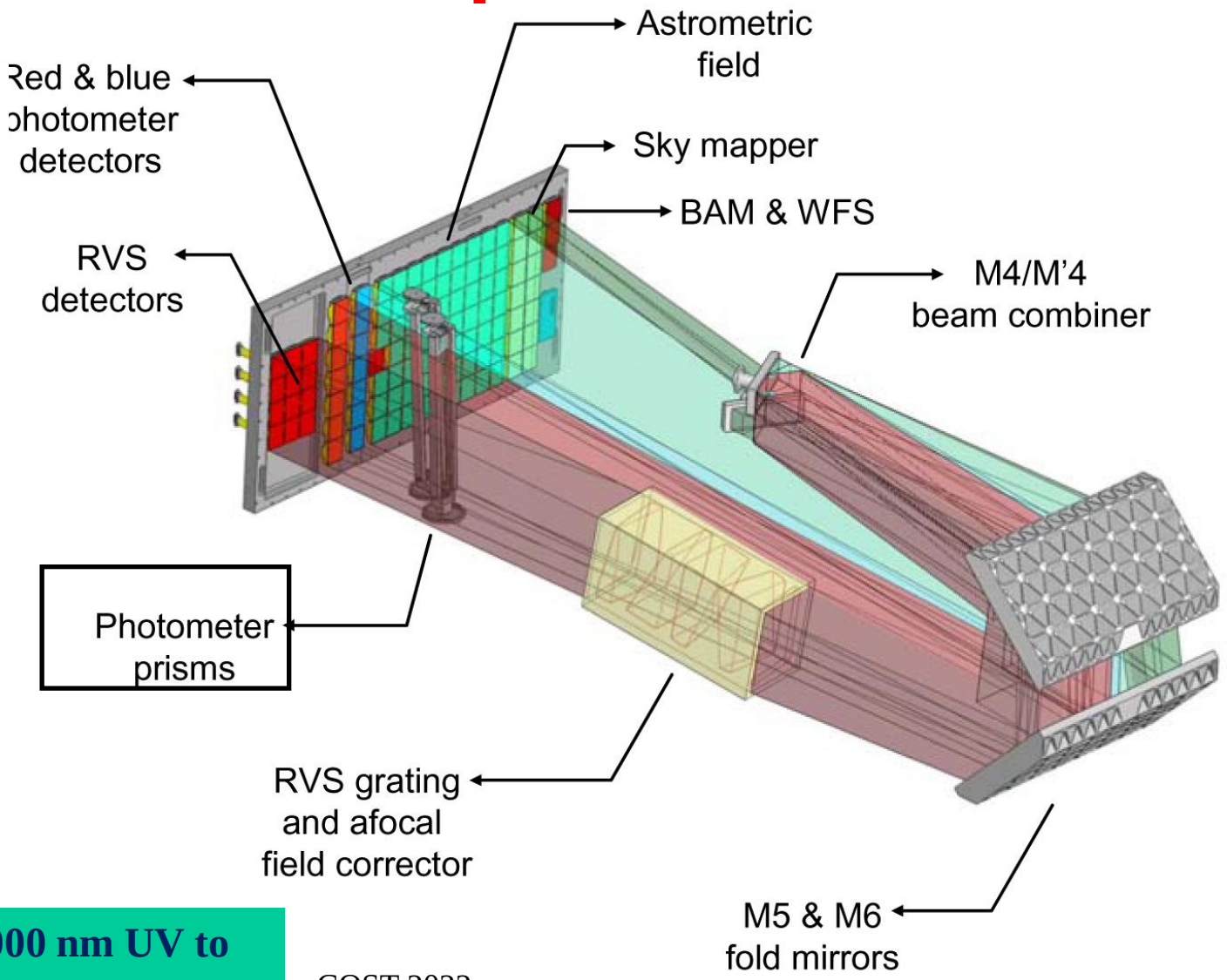
Gaia Photometry Measurement Concept





Blue photometer: 330–680 nm

Red photometer: 640–1000 nm



LDS from 330 to 1000 nm UV to near IR

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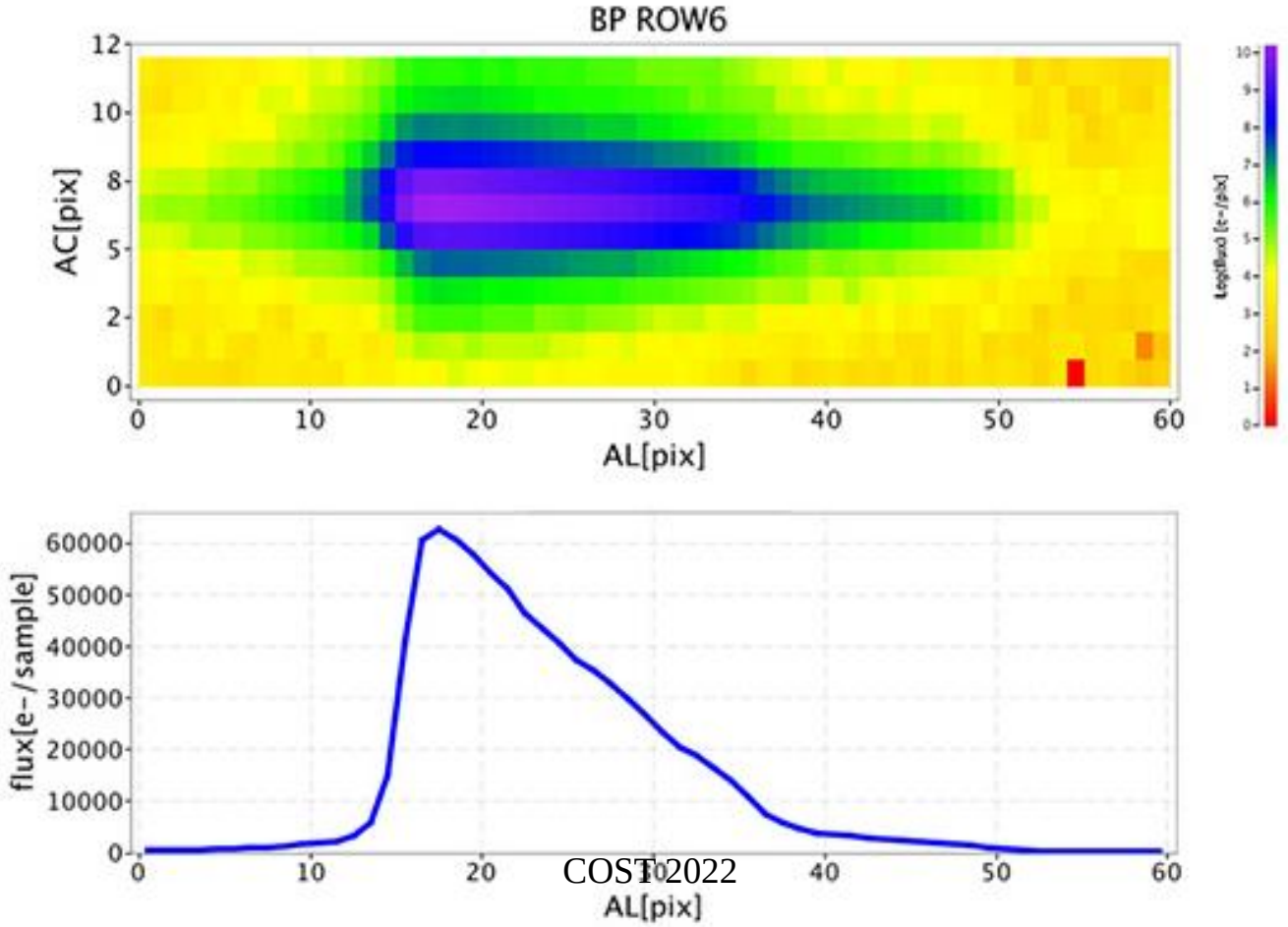
Figures courtesy EADS Astrium

Motivation

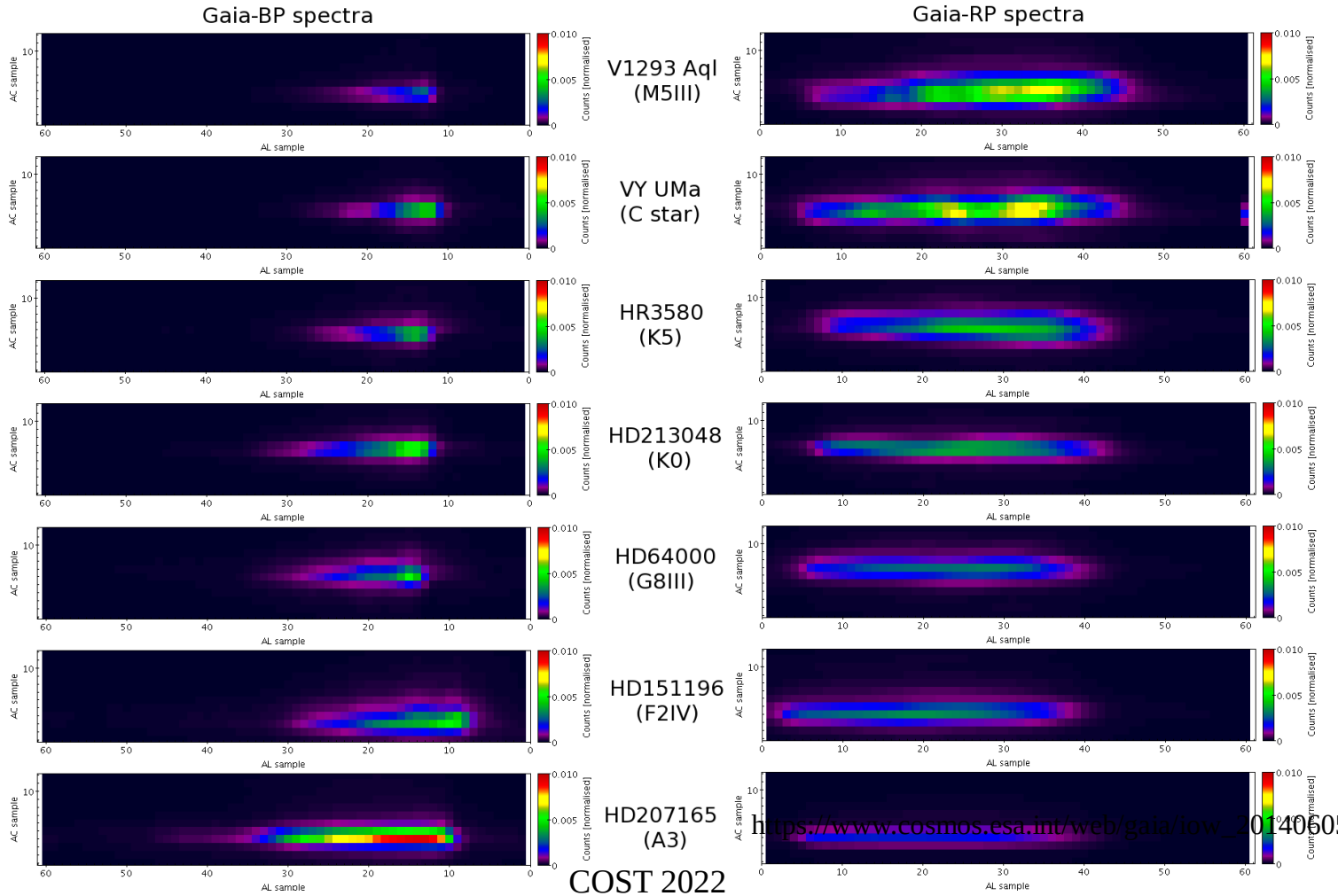
- Blue (BP) and Red (RP) Photometer low-resolution spectral data is one of the exciting new products in Gaia Data Release 3 (Gaia DR3)
- https://gaia.aip.de/cms/services/spectra-access/
- LDS data also in numerous historical photographic sky surveys (access after digitization)
- My estimate is > 100 mil LDS star spectra in these databases

Examples of Gaia BP/RP LDS

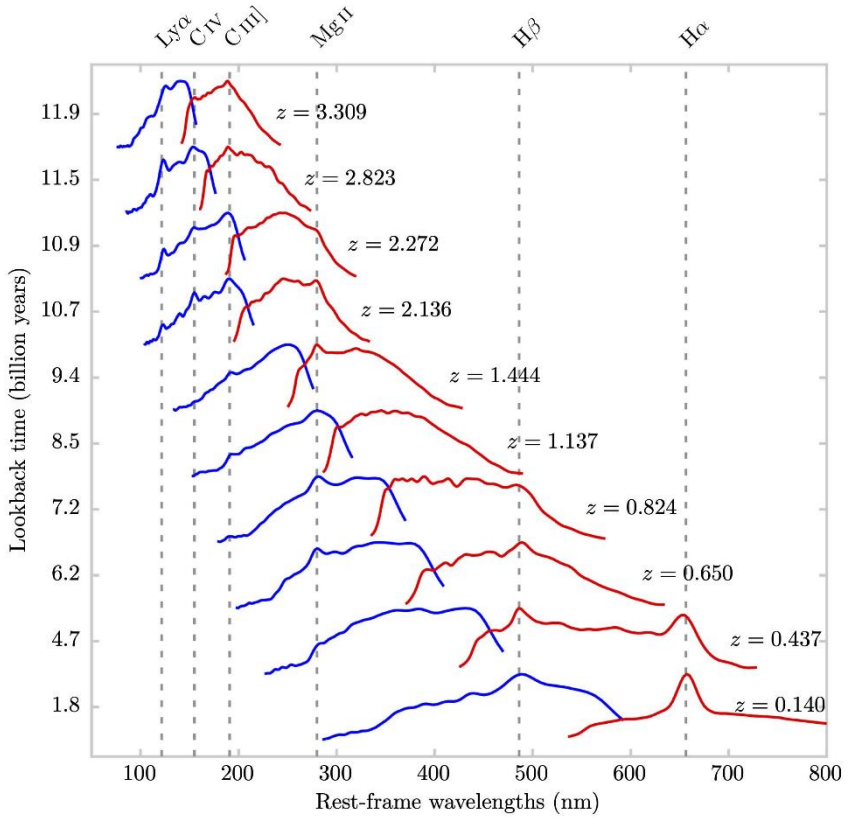
https://www.gaia.ac.uk/sites/default/files/media/images/bp_spec.jpeg



Examples of Gaia BP/RP LDS

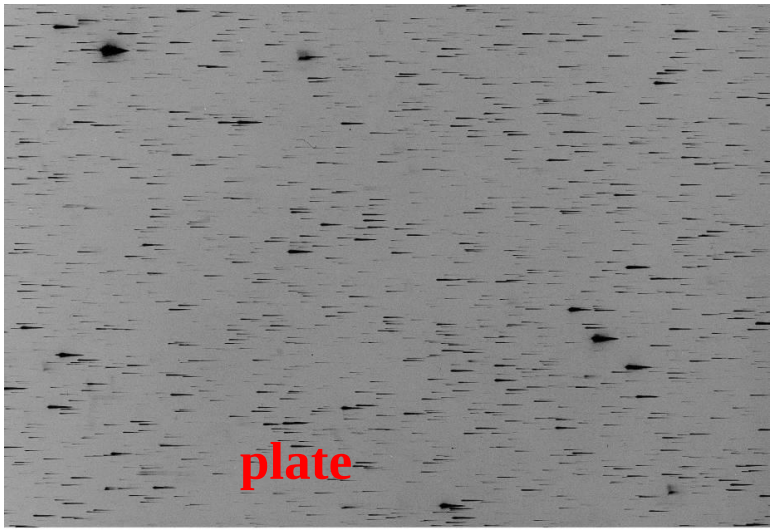


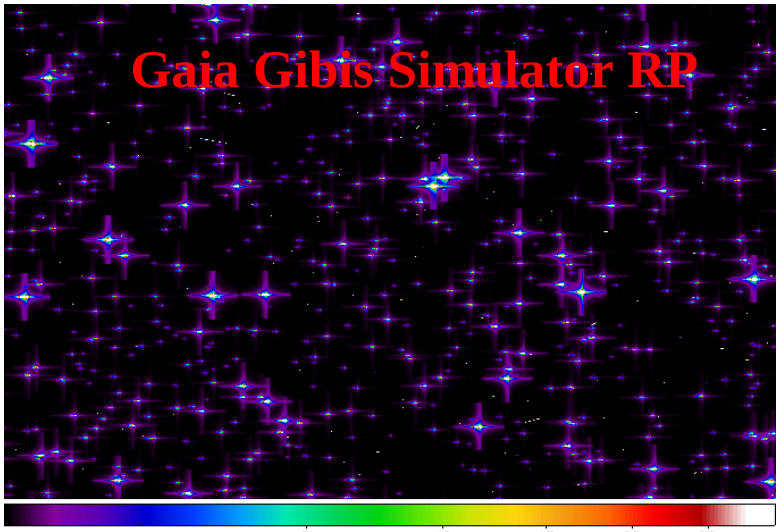
Examples of Gaia BP/RP LDS



Gaia low-resolution BP and RP spectra (blue and red, respectively) of ten known quasars selected with apparent G magnitudes between 17 and 18. The QSO spectra are plotted in their rest-frame https://www.cosmos.esa.int/web/gaia/iow_20201222

Comparison of Gaia BP/RP Low Dispersion Spectra Versus Spectral Low Dispersion Plates





	Wavel range, nm	Limiting magn	Dispersion at Hg nm/mm	Spectr resol at Hg nm
Gaia	330-660, 650-1000	~19	900	~18
Sonneberg Schmidt	340-650	18	10 , 23	~3/6
Bolivia Expedition	340-650	14	9	~3/6-10
Hamburg	340-540	19	139	4.5/10
Byurakan	340-690	17.5	180	5/10-15
PARI	330-535	18	45-340	~5/10-15

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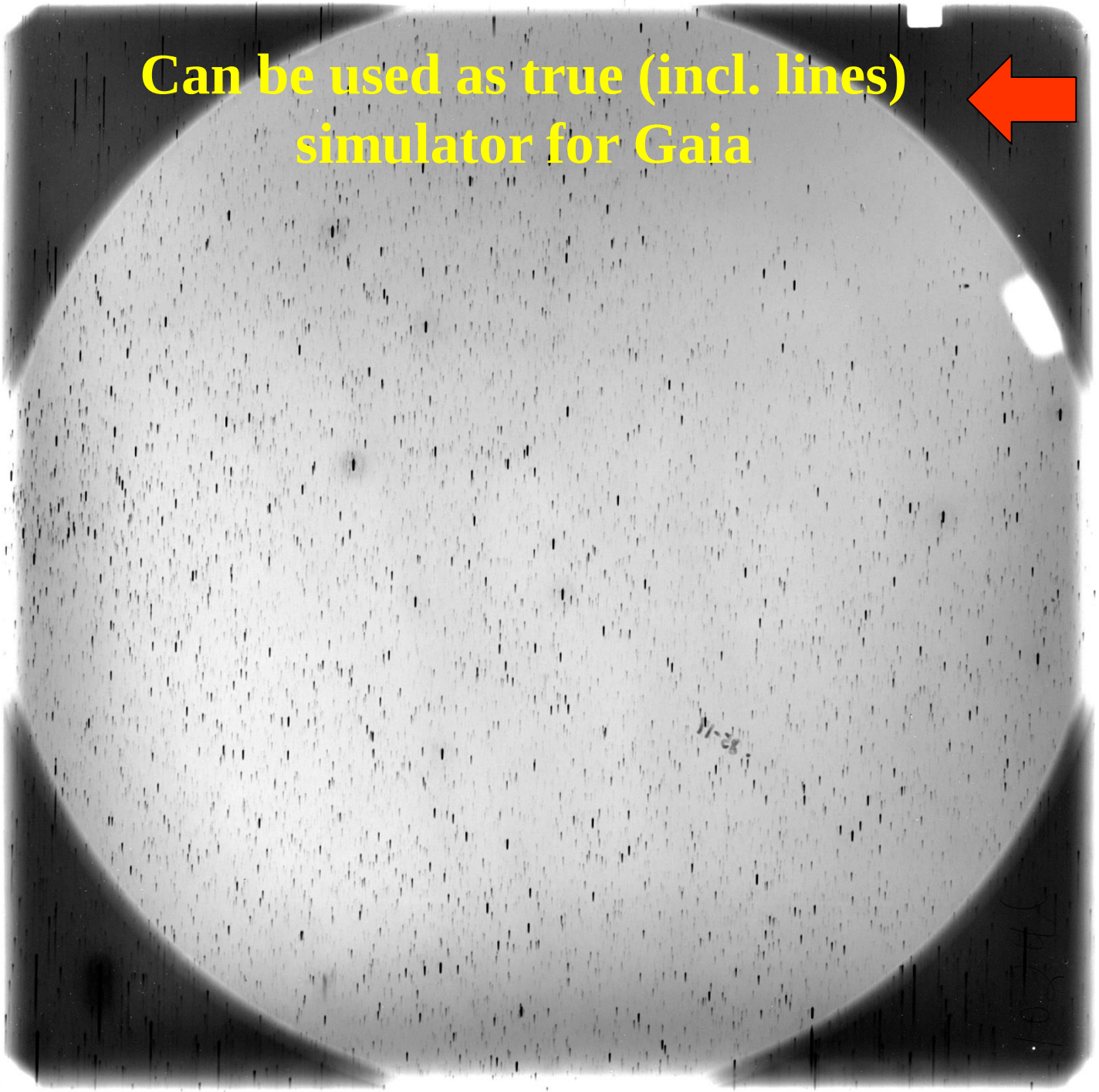
Spectral resolution for plates theoretical/real



Can be used as true (incl. lines) simulator for Gaia

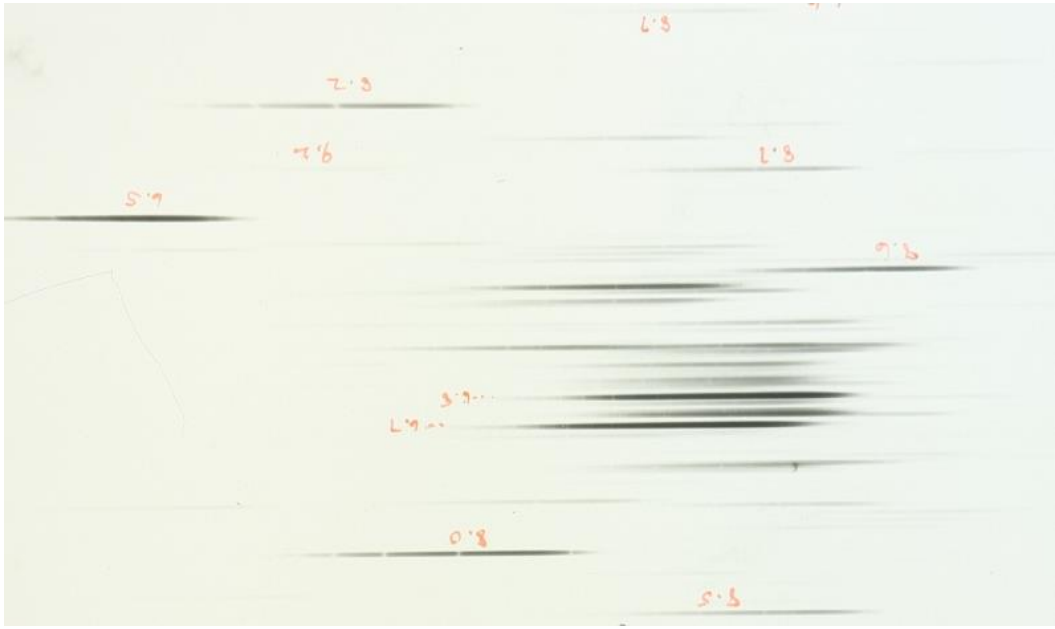
PARI USA

Scan of a plate from the PARI Case Western Reserve Univ. collection. This plate (#10246) was taken on November 17, 1974 (dec= +23.5, RA= 4h50m) and is part of the Tau Cloud Survey. The exposure is 72min, Emulsion 103aE, Filter = OG2, 1.8 deg prisma

1983ApJS,51,117 (Pesch & Sanduleak)

LDS can go > 110 years back

LDS from 1909 at Carnegie Observatories, Pasadena, CA, USA



Astrophysics with LDS in the past

Terminology! Objective prism spectra = Slit less spectra

- **The LDS (Low-Dispersion Spectroscopy) astrophysics was evolved and performed at numerous observatories (many in US) between ca 1909 and ~1980.**
- **Mostly LDS with Schmidt telescopes (plates with objective prism)**
- **Used for various projects e.g. QSO, emission line and Halpha surveys, star classifications, etc.**
- **Little used after ~1980**
- **Today knowledge in astronomical community very limited**

Most Important LDS Plate Surveys/Databases for Gaia

- **German La Paz Bolivia Expedition, 1926--1929: Southern Sky Coverage D**
- **Hamburg Quasar Spectral Survey D**
- **Byurakan Spectral Survey D**
- **Northern Halpha MtWilson-Michigan Sky Survey PD**
- **Southern Halpha MtWilson-Michigan Sky Survey PD**
- **D = Digitised, PD=Partly Digitised**

Many surveys represent the almost full sky hemisphere coverage

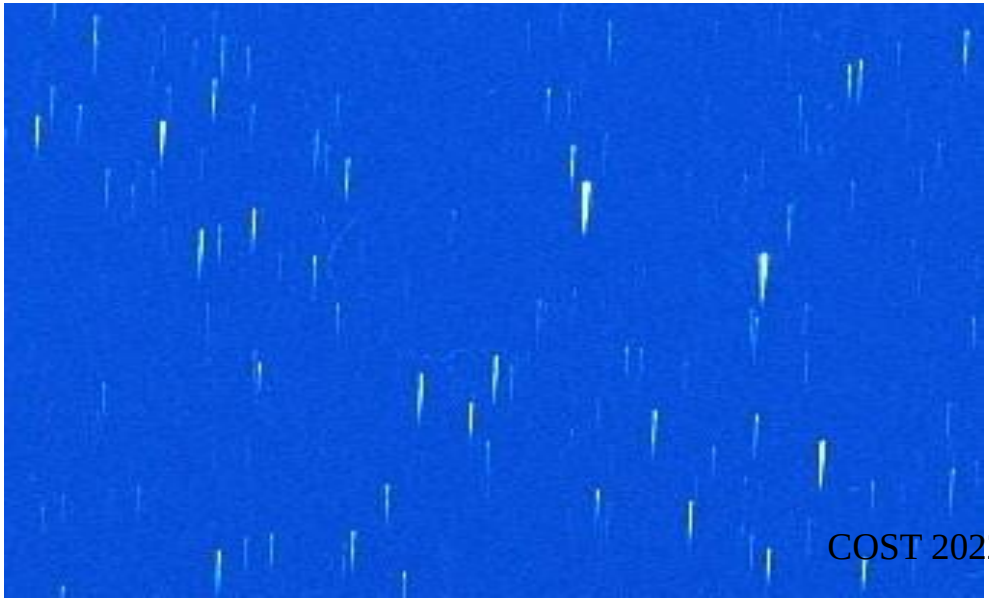
Byurakan Survey

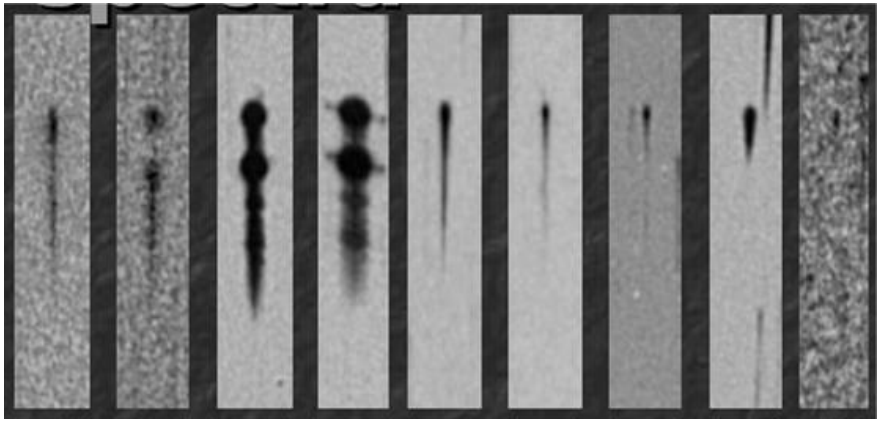
The Digitized First Byurakan Survey (DFBS) is the digitized version of the First Byurakan Survey (FBS). It is the largest spectroscopic database in the world, providing low-dispersion spectra for 20,000,000 objects on 1139 FBS fields = 17,056 deg^2 Online access. Sky coverage: DEC>-15°, all RA (except the Milky Way). Prisma spectral plates by 1 m Schmidt telescope.

Limiting magnitude: 17.5 in V

Spectral range: 340 – 690 nm, spectral resolution 5 nm

Dispersion: 180 nm/mm near H-gamma

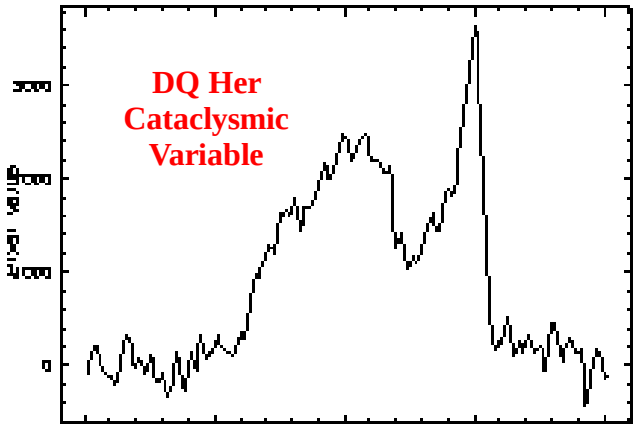


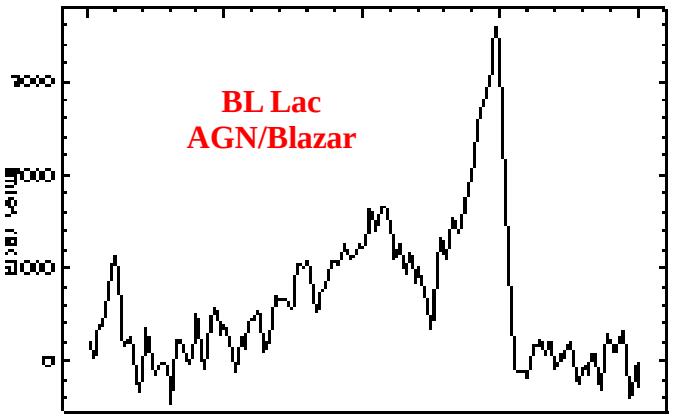


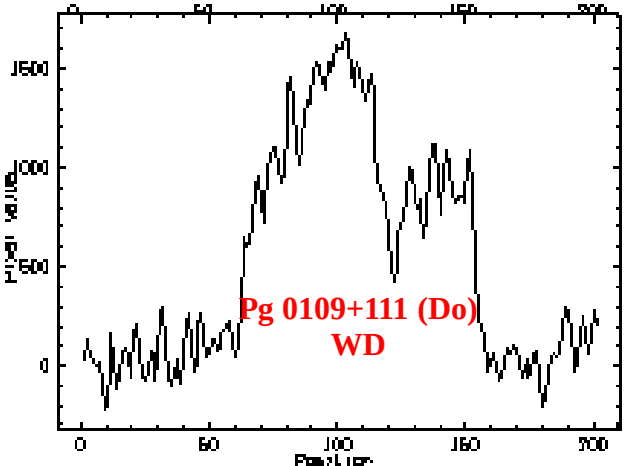
Complete northern sky coverage for dec >15
Online access

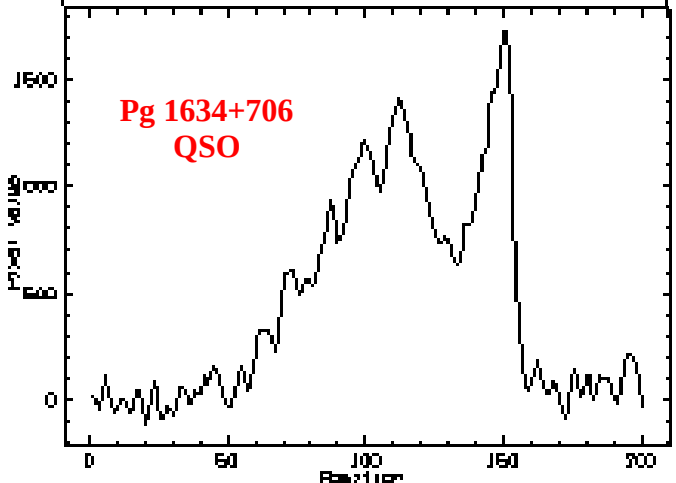
Examples of prominent spectral features from Byurakan Survey

These objects will be also probably visible in Gaia BP (Optical) and RP (Near IR)





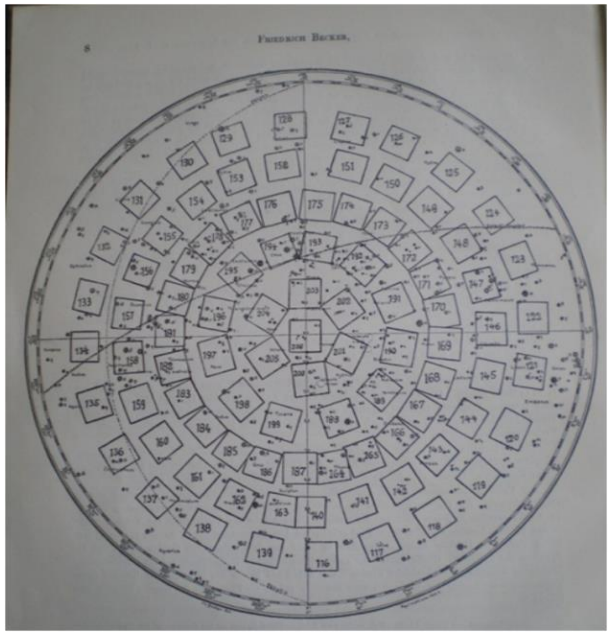


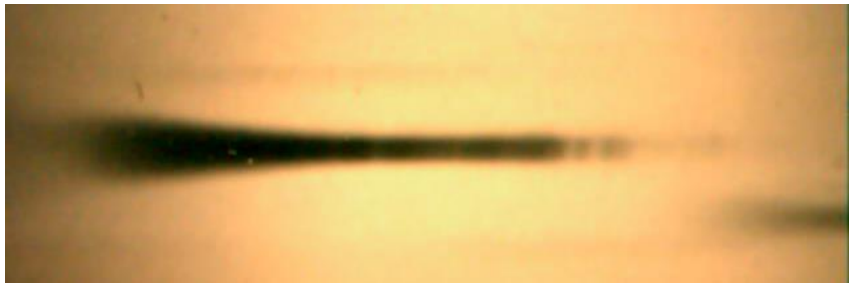


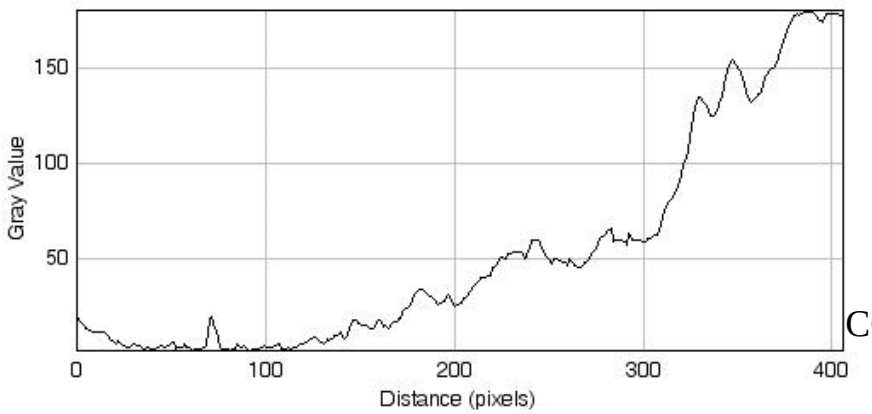
There are categories of HE sources included

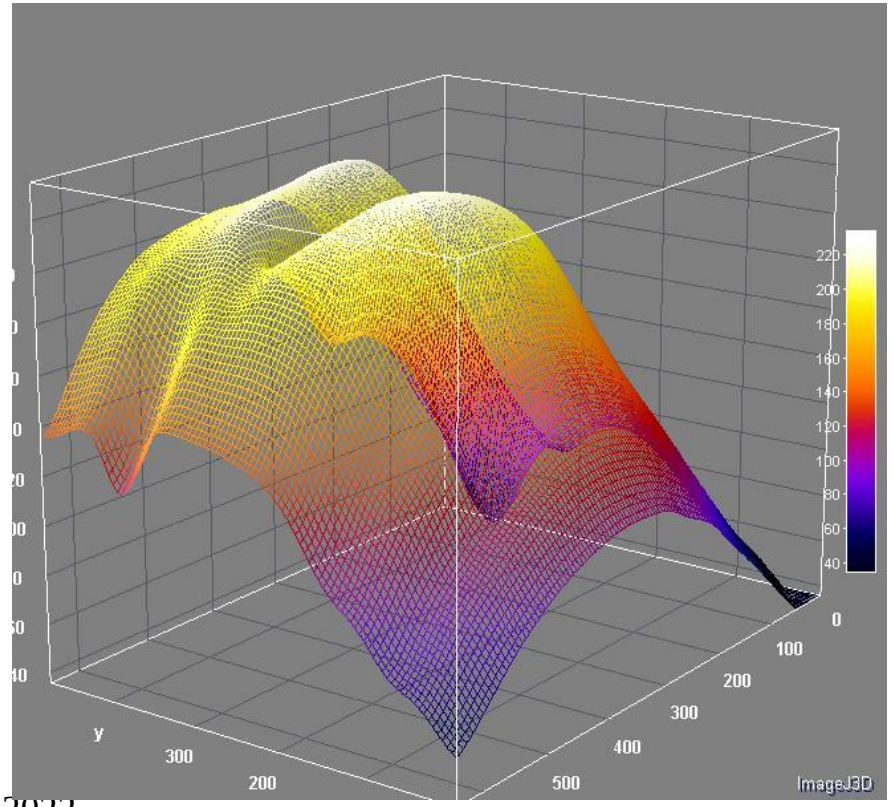
LDS from Las Paz Southern Sky Survey

scanned spectrum, profile, 3D plot
almost complete southern sky coverage
plates stored at Sonneberg Observatory
and completely digitised









Karl Henize MtWilson-Michigan Southern Sky Hα Survey

MICHIGAN-MT. WILSON SOUTHERN Hα SURVEY
LAMONT-HUSSEY OBSERVATORY
BLOEMFONTEIN, SOUTH AFRICA

NO. L Hα 440
DATE 11 June 51
R. A. 1740
DEC. -55.0
EXPOSURE 6 x 40
EMULSION 103a E
OBSERVER HENIZE

Professor of Astronomy, later NASA Astronaut

290 high quality plates 15 x 15 inches taken in 1950-1952 in South Africa by dedicated telescope by Karl Henize (for his Dissertation)

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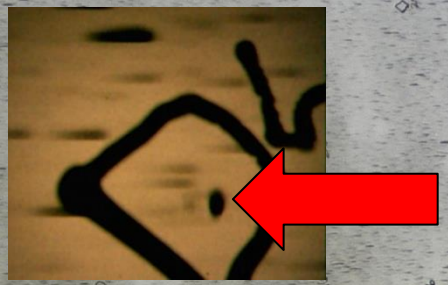
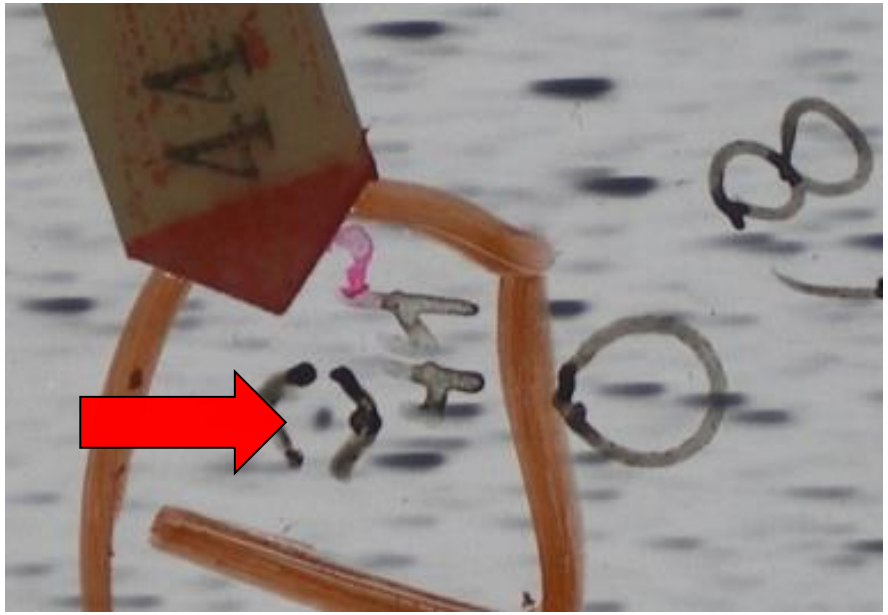
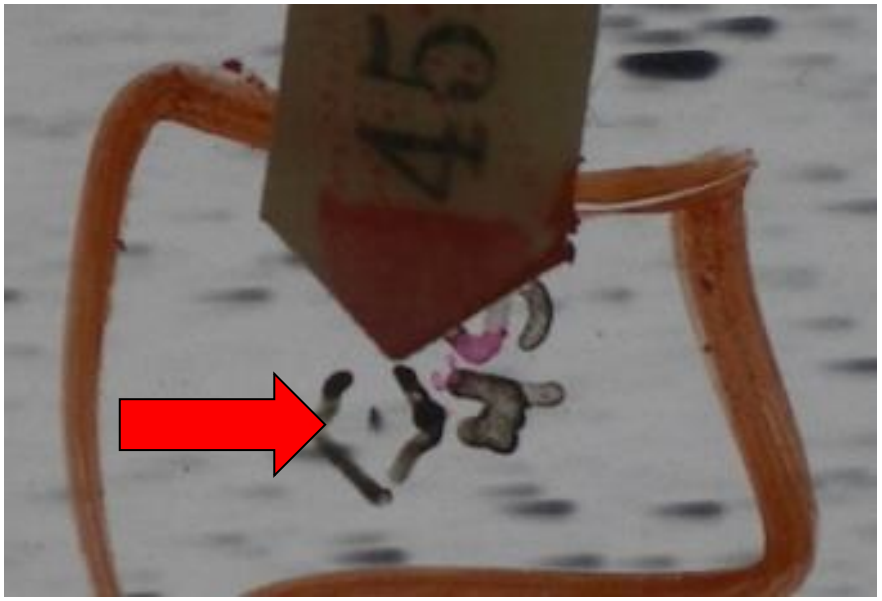
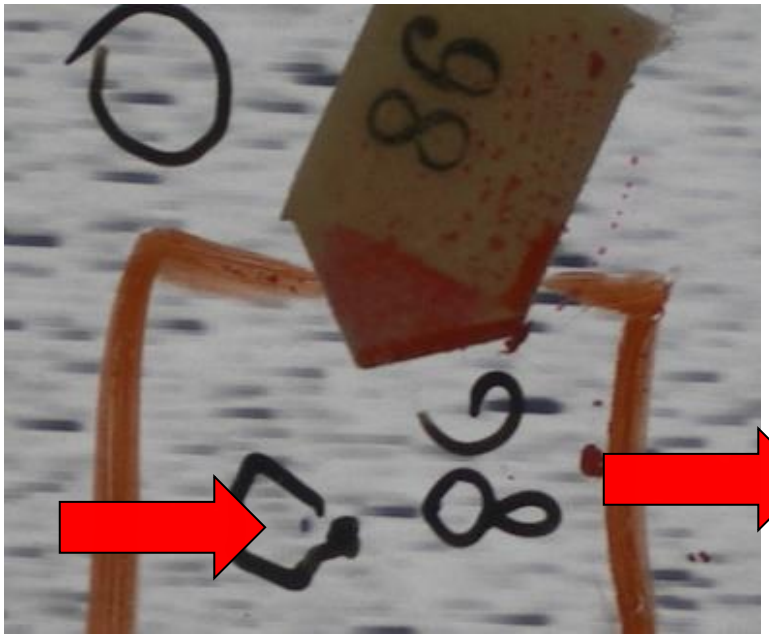
Example of emission object found



Southern Ha Mt Wilson Michigan Survey Plate
Plate extensively analysed by K. Henize
20 000 spectra investigated by eye
on every plate







Few examples of prominent emission spectral features found by K. Henize

In objective spectrum sky survey
Rate ~1: 10 000

Michigan-Mt Wilson Southern Hα Survey

There are hints that at least some these strong emissions are variable

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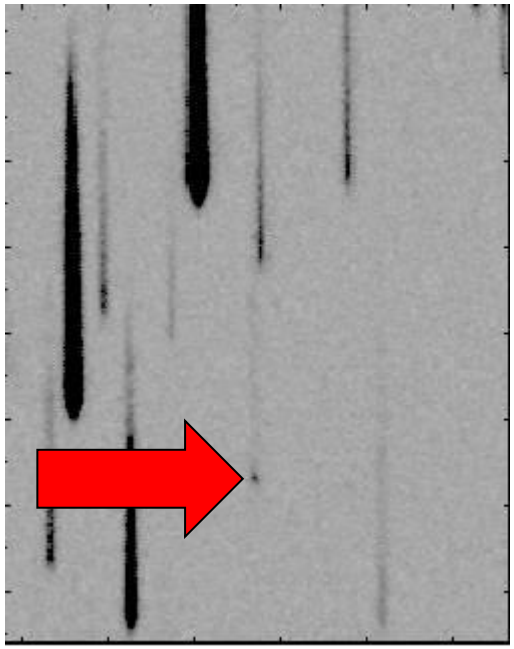
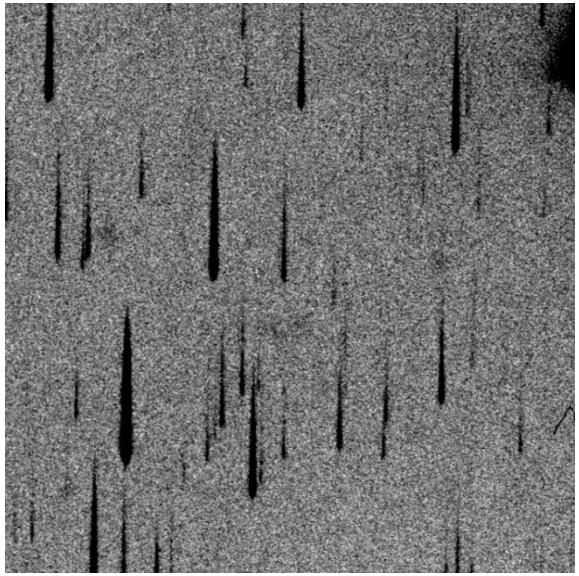
D25 cm, 45 nm/mm at Hα

Hamburg Quasar Survey

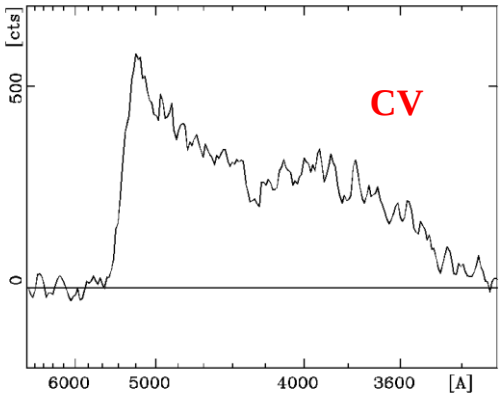
A wide-angle objective prism survey searching for quasars with B<17.5 on the northern sky. The survey plates have been taken with the former Hamburg Schmidt telescope , which is located at Calar Alto/Spain since 1980. For the survey the 1.7° prism was used providing unwidened objective prism spectra with a dispersion of 139 nm/mm at Hgamma. Under conditions of good seeing the FWHM of the images is 30 µm (plate resolution) giving a spectral resolution of 4.5 nm at Hgamma on the objective-prism plates. Online access.

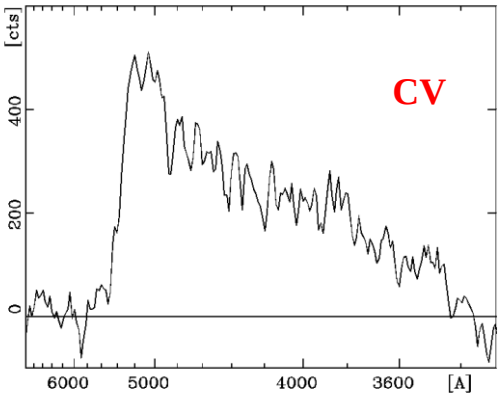


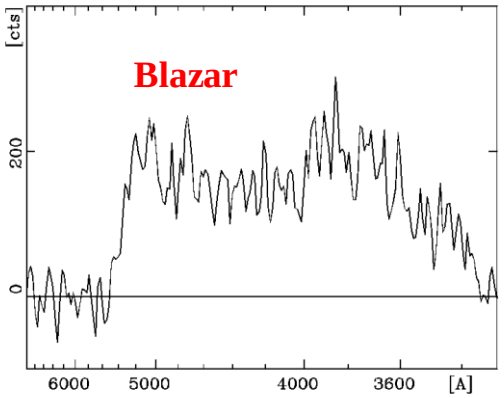


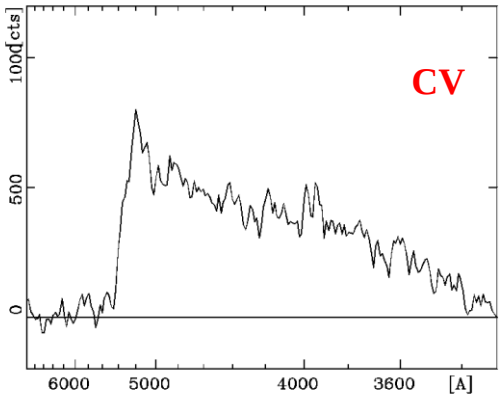
Discovery objective prism spectrum of HS 0822+3542, emision line galaxy. The wavelength coverage is 3200Å (upper end) to 5400Å (lower end). HS 0822+3542 shows almost nothing but the O[III] 5007Å emission line (the black dot) is seen, while the continuum is barely visible.

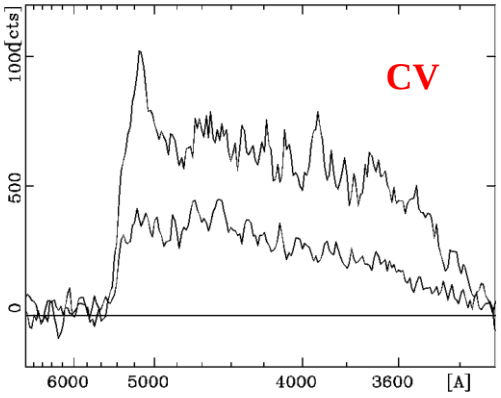
Example spectra of cataclysmic variables & blazars (digitised Hamburg Survey)

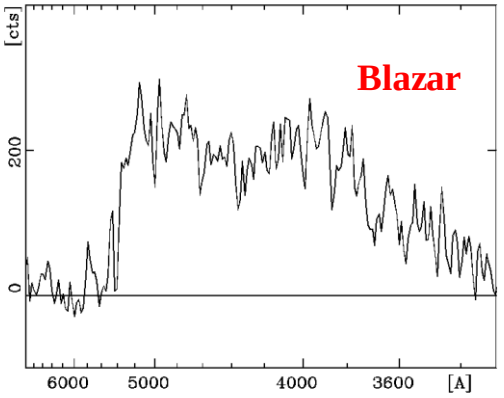












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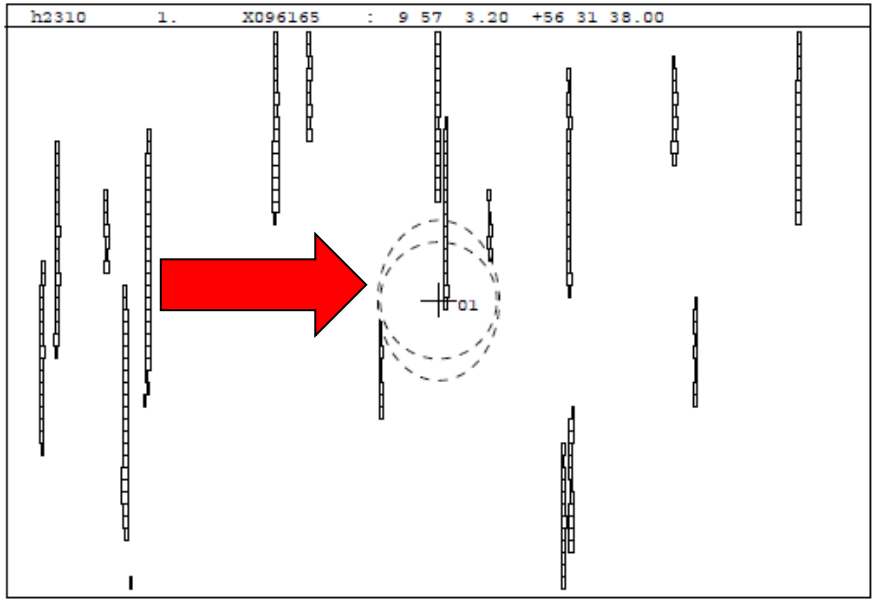


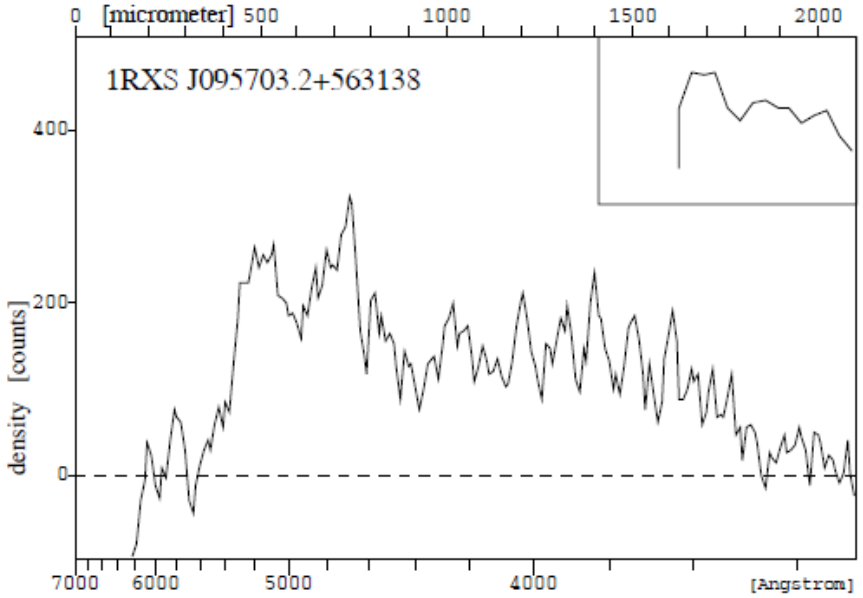


Fig. 1. Digitized objective prism spectrum of 1RXS J095703.2+563138. The left image shows a part of the digitized objective prism plate (low resolution scan) around the X-ray position. The right image displays the spectrum from the high-resolution and low-resolution (inset) scan

Identification/classification of HE sources with LDS

Table 1. Classification codes with contents

Code	Objects	Number	Fraction	Comments
1	AGN/QSO	1574	40.9%	
2	Galaxies	138	3.6%	extended optical image, contain some AGN
3	Galaxy clusters	113	2.9%	
5	M-dwarfs	155	4.0%	
6	White Dwarfs	31	0.8%	
7_1	K Stars	136	3.5%	can also contain some stars of early M type
7_2	F or G Stars	4	0.1%	Classification needs further support from high resolution spectra
7_3	CVs	16	0.4%	
7_4	Bright Stars	956	24.9%	
8	Unidentified	619	16.1%	Majority consists probably of optically weak AGN and clusters
0	Empty	105	2.7%	empty on objective prism and direct HQS IIIa-J plates

Identification of ROSAT X-ray Sources with Hamburg LDS QSO Survey Plates

The Hamburg/RASS Catalogue of optical identifications

Northern high-galactic latitude ROSAT Bright Source Catalogue X-ray sources

F.-J. Zickgraf[1], D. Engels[1], H.-J. Hagen[1], D. Reimers[1], and W. Voges[2]

A&A 406, 535–553 (2003)

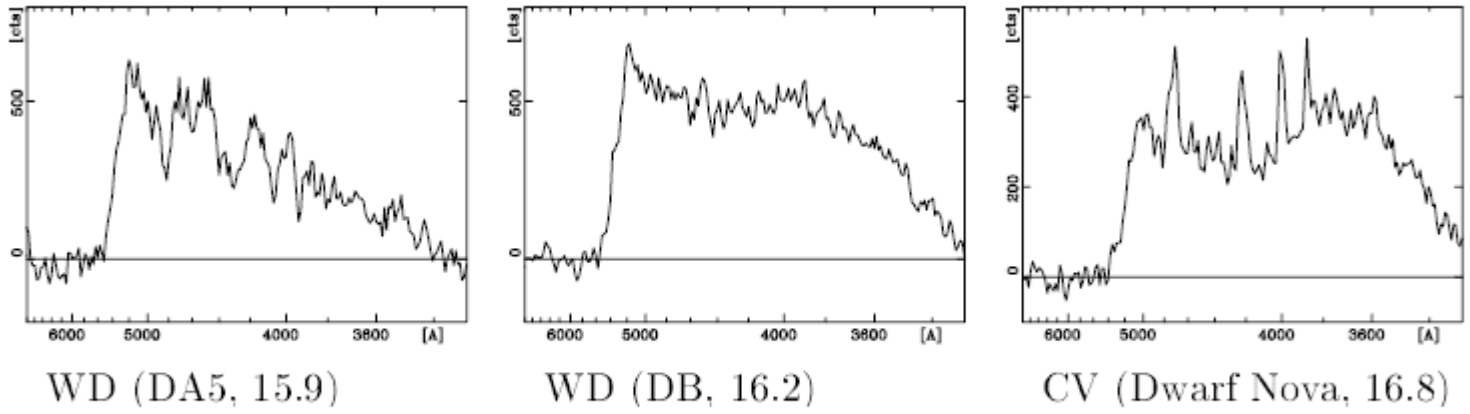


Fig. A.5. Sample spectra of white dwarfs and cataclysmic variables.

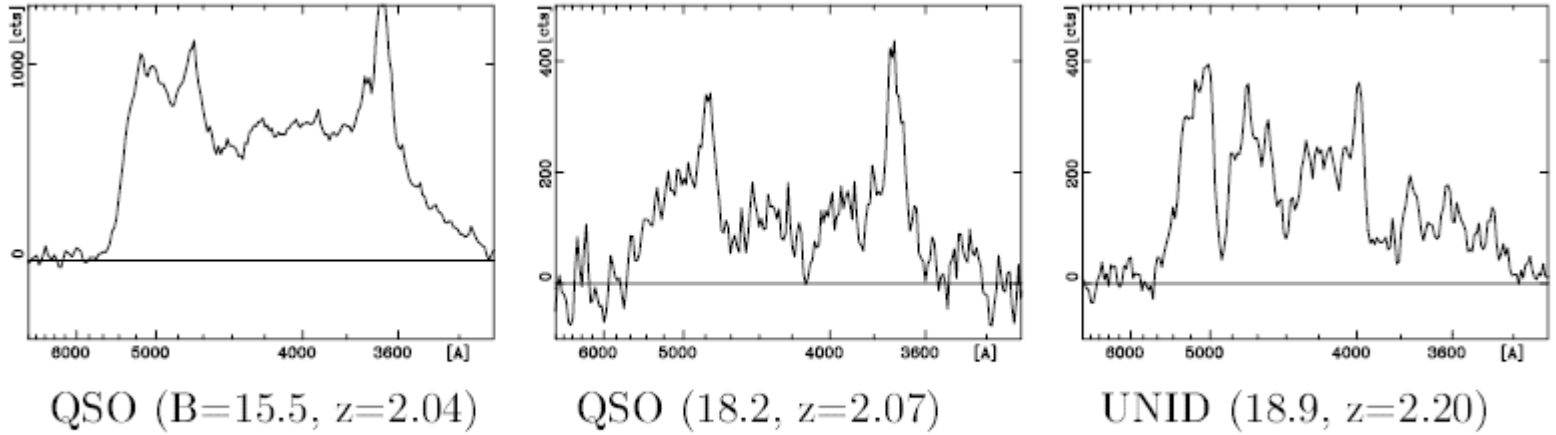
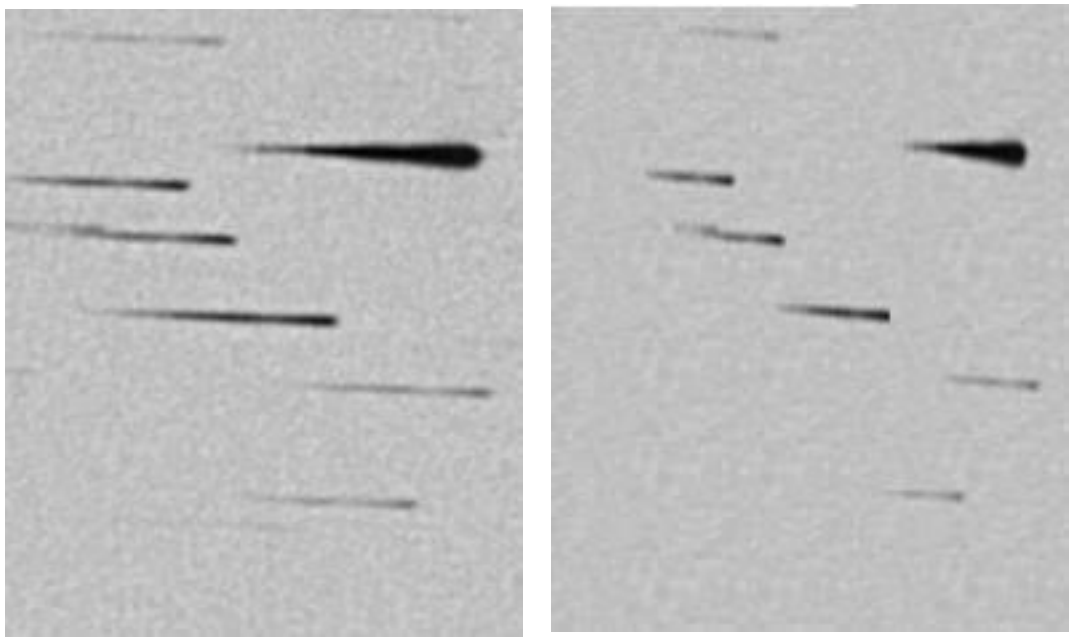
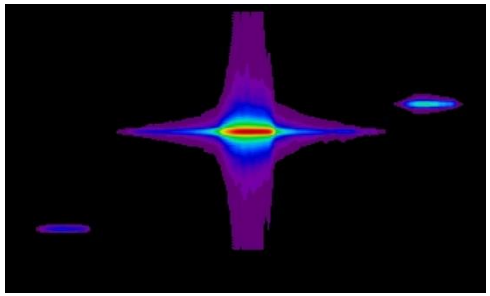


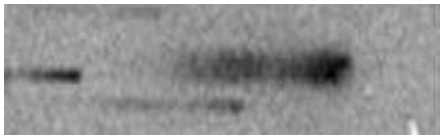
Fig. A.1. Sample spectra of QSOs with various redshifts and brightnesses.

Re-scaling of plate LDS to Gaia BP/RP resolution





Gaia RP simulated spectrum



Left: part of digitized Byurakan Sky Survey (spectral resolution 10 nm/mm at Hgamma), Right: Re-scaling to simulate the Gaia BR/RP resolution (18 nm/mm at Hgamma)
This is a part of efforts to develop an alternative and real Gaia BP/RP simulator

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Emission lines, planetary nebula and UV excess galaxy seen at spectral resolution analogous to Gaia RP/BP

Spectral Type Variability with Gaia?

- **It is known that certain types of variable stars (VS) such as Miras, Cepheids, and peculiar VS exhibit large variations in their spectral types**
- **This fields is however little exploited, as before were these studies very laborious (plates were mostly visually inspected) and limited. No review on spectral variability among VS exists (Samus, personal comm. 2008)**
- **The evaluation by computers and dedicated s/w will allow to search and investigate spectral variability in Gaia data and in digitized Spectral plates**
- **Gaia well suited for this work**

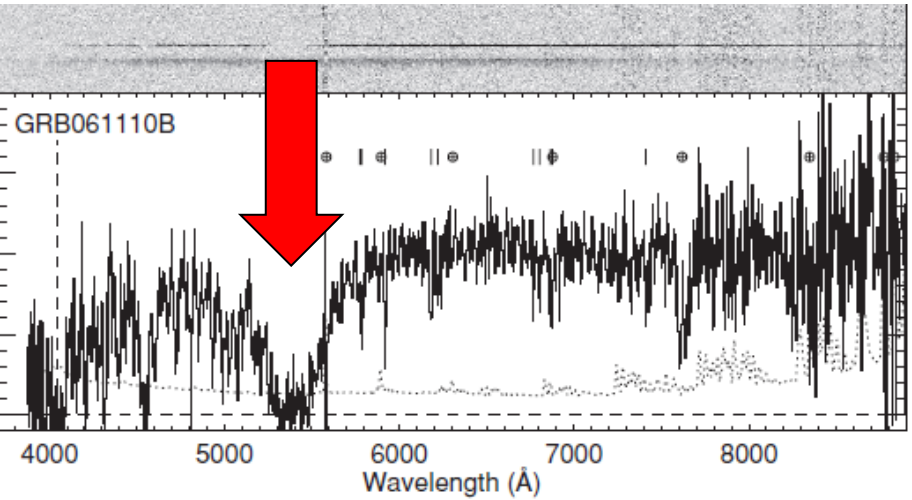
LDS and Redshift Estimation (High z Universe)

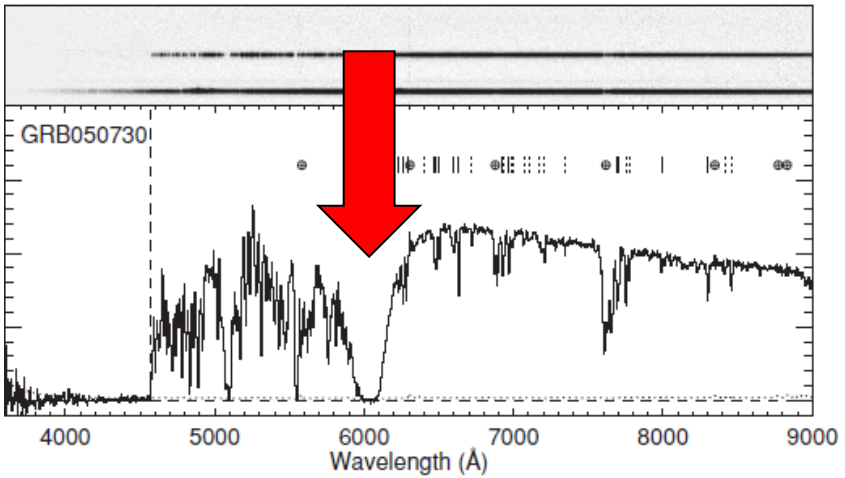
- **The Lyman alpha line can be used to measure the redshift**
- **Idea of JANUS Space Mission: 0.7 – 1.7 microns**
- **Gaia RP 0.65 – 1.0 microns …. z to ~ 7**
- **The digitized plate surveys can be used too**

LDS of OAs of GRBs with Strong Intervening Absorbers

Are the absorbers strong and wide i.e. observable by Gaia BP/RP?

Evidently the wide redshifted Lyman alpha break will be observable by Gaia



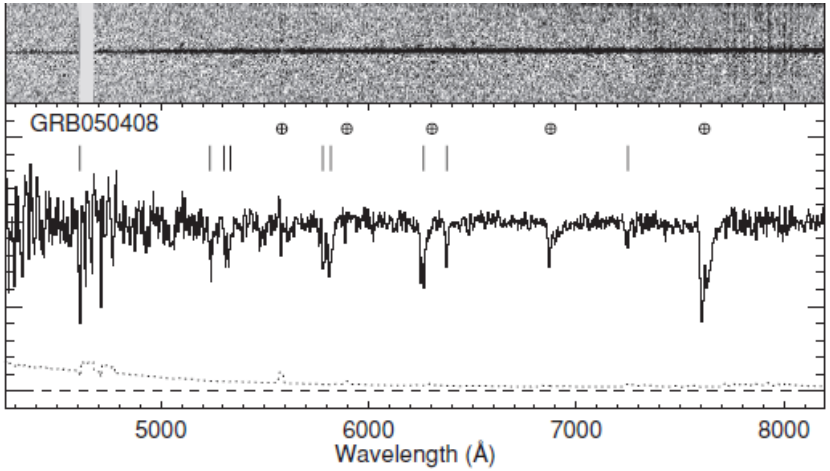


Fynbo et al., 2009, ApJSS 285, 526

Continuum profile studies

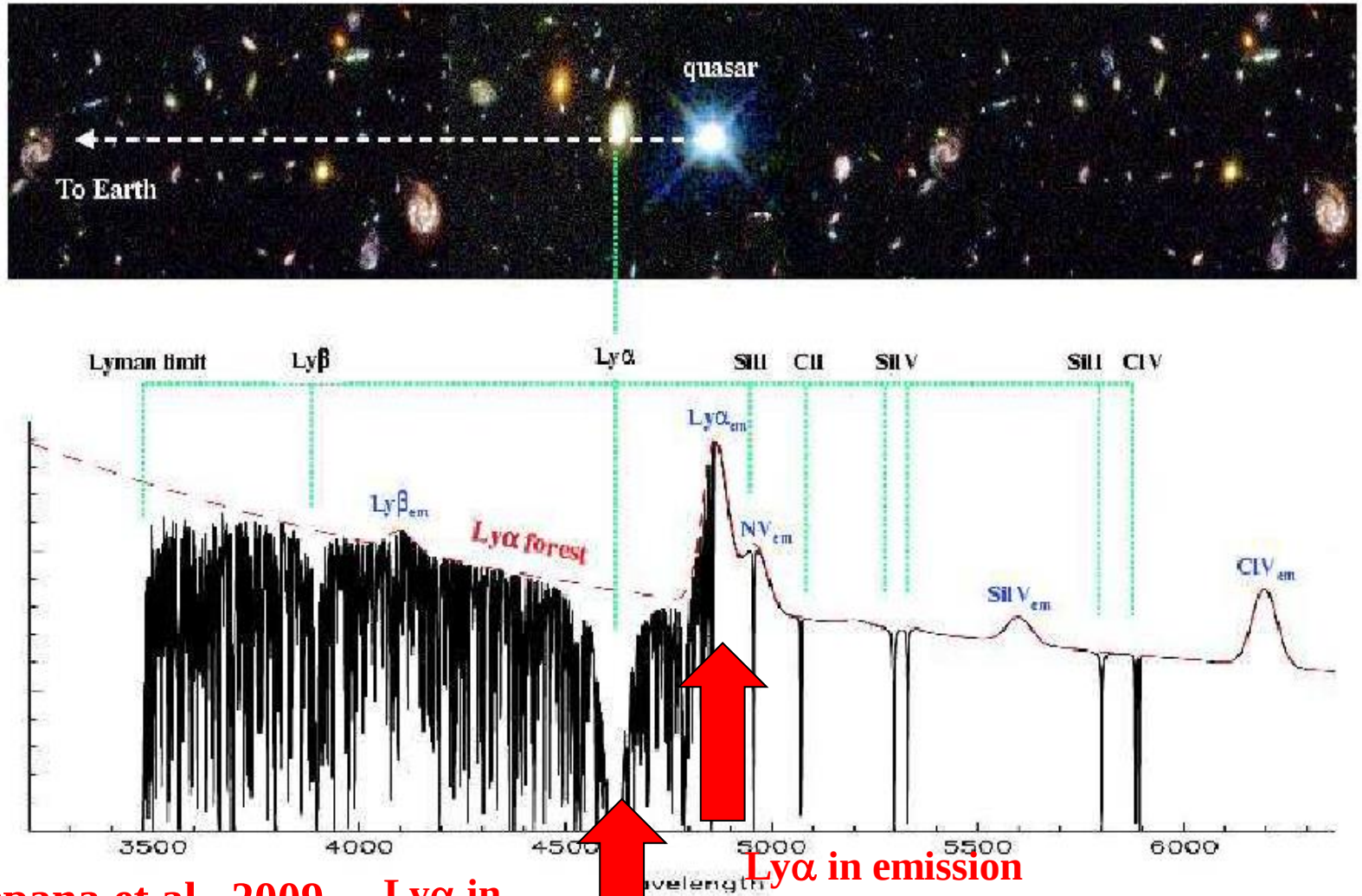
Very flat continuum. No strong lines – possibility to distinguish the spectral continuum profile from stars

Explanation: synchrotron emission



Gaia, LDS and Highly Redshifted Universe - LDS of distant GRBs (adopted from QSOs)

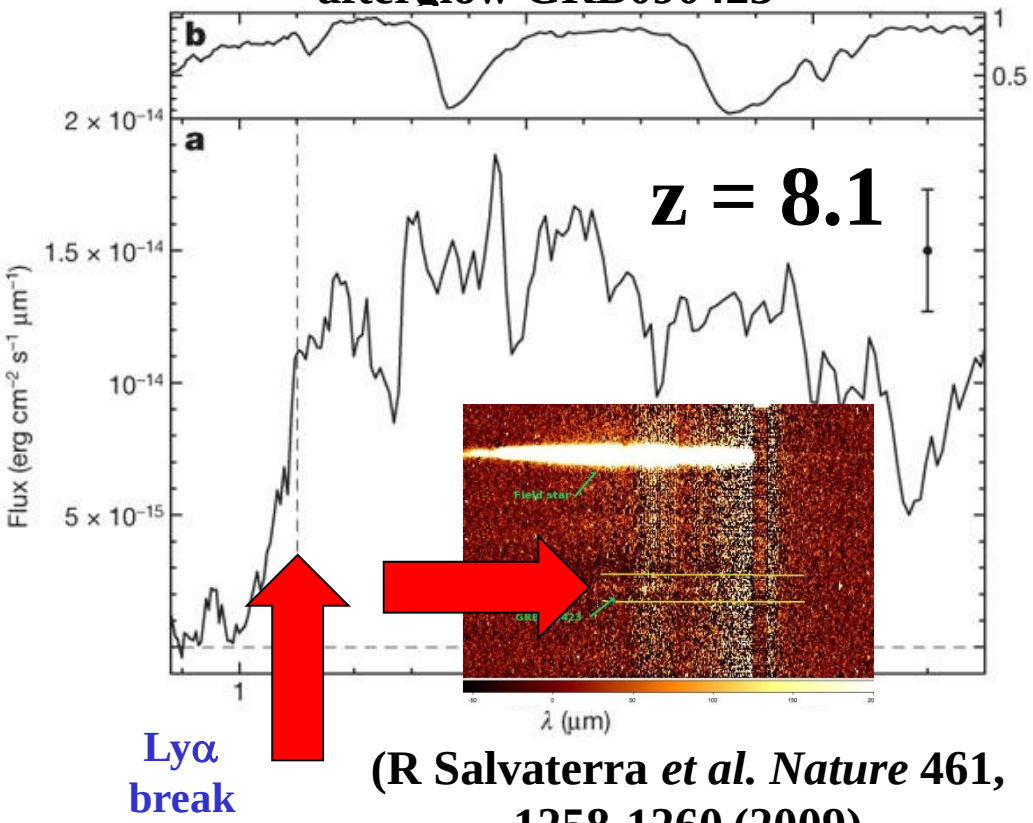
The redshifted Lyman alpha line/break can be used to measure the redshift



Campana et al., 2009

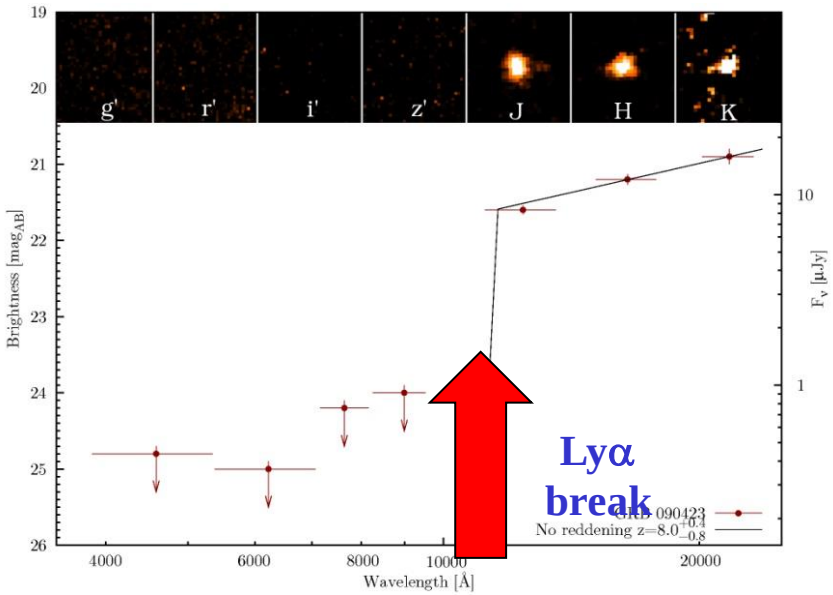
LDS of OAs of GRBs: determination of redshifts using redshifted Lα

TNG LDS spectrum of the near-infrared GRB afterglow GRB090423



14.36 hr after GRB

(R Salvaterra *et al.* *Nature* 461, 1258-1260 (2009) doi:10.1038/nature08445)



GROND

(http://www.mpe.mpg.de/~jcg/GROND/grb090423.html)

Analogous results can be expected from Gaia BP

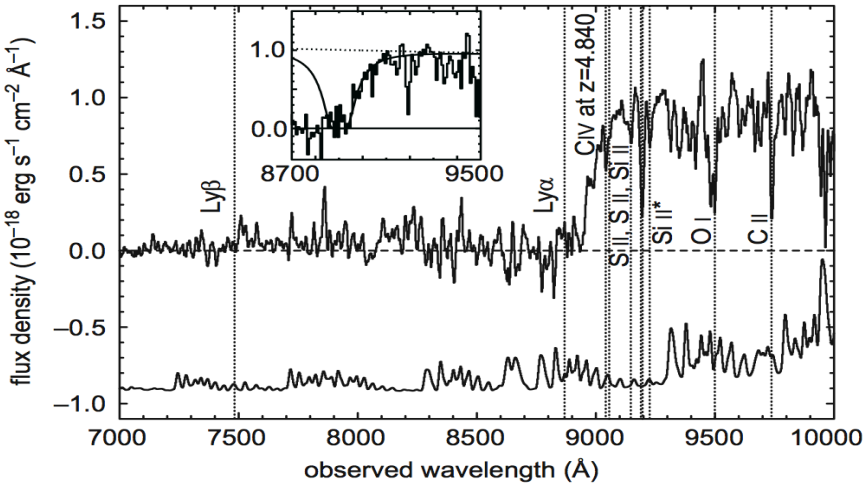
But the limit will be 1 micron
Redshifts up to 7 feasible

Confirmation that even very low resolution spectrum can provide valuable results for GRBs science

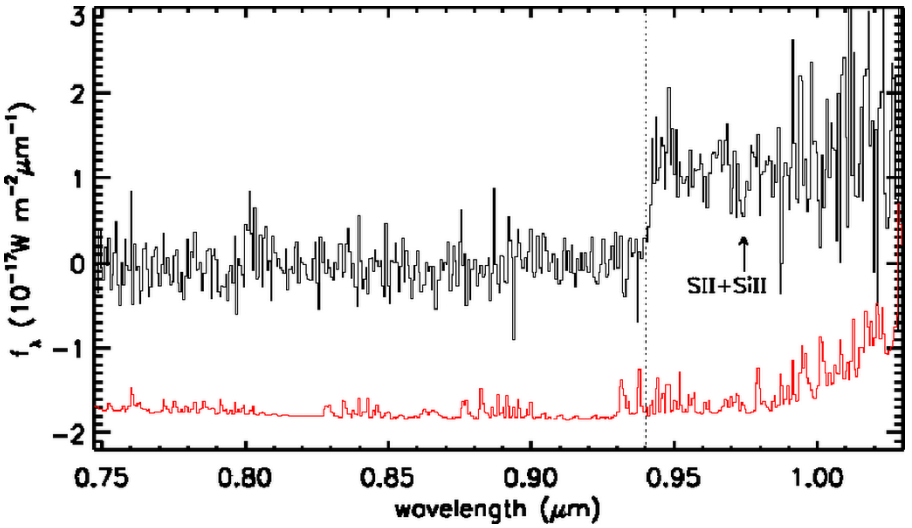
nature

GRB 050904 at z=6.29

Kawai et al. 2005; Totani et al. 2006 $x_{HI}<0.17$



GRB 080913 at z=6.7



Gallerani et al. 2008

Red arrows: Gaia RP coverage

R Salvaterra, 2011

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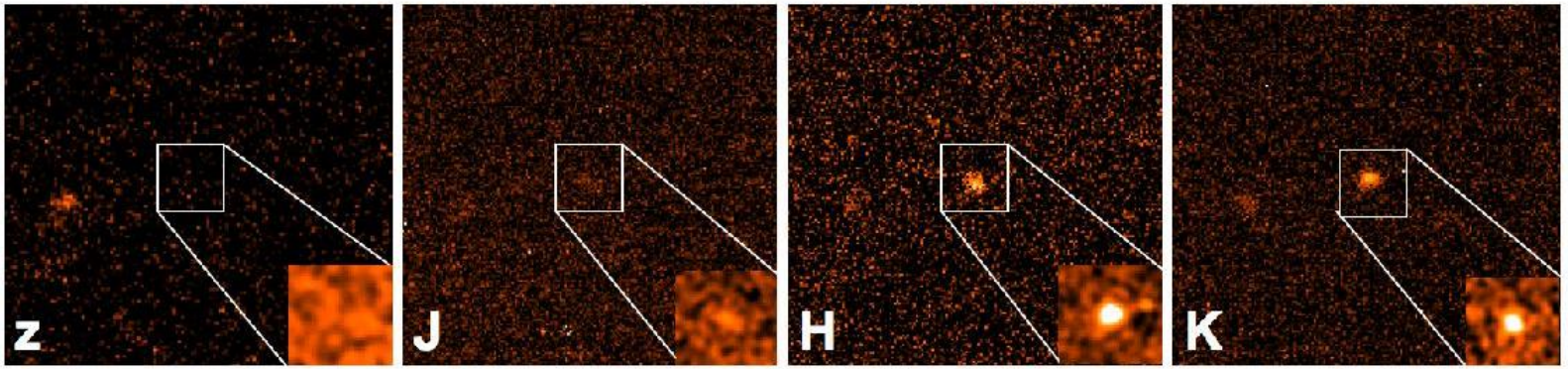
GRB 090429B at z = 9.4



1220 nm 1630 nm 2190 nm

Photometric redshift of z=9.4

Cucchiara et al. 2011

R Salvaterra, 2011

Gaia RP ends at 1000 nm – z larger than 7 cannot be accessed

How fast are the recent LDS of GRBs?

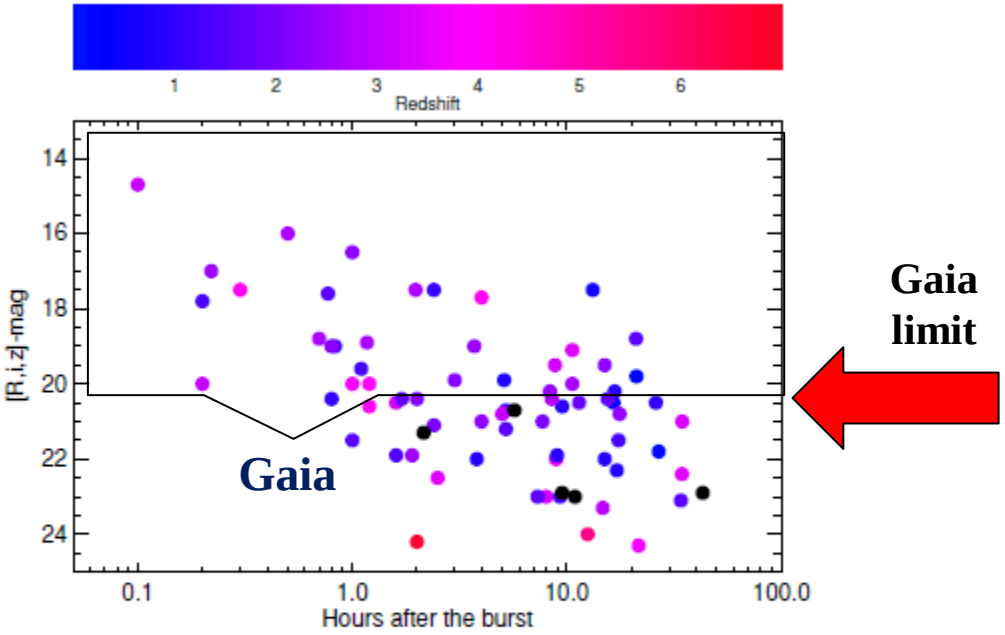


Figure 2. *R*-, *i*-, or *z*-band magnitude of the OAs in the acquisition image for the spectroscopy as a function of the time when the spectroscopic observations were started. The color bar in the top indicates the color code for the measured redshifts. Black points represent spectra for which we were not able to determine the redshift.

Recently the typical LDS response times for OAs of GRBs are of order of 1-10 hrs

Gaia BP/RP will go down to 0 in some cases, lim mag 19-20

Fynbo et al., 2009, ApJSS 285, 526

LDS Plate Surveys in the IR

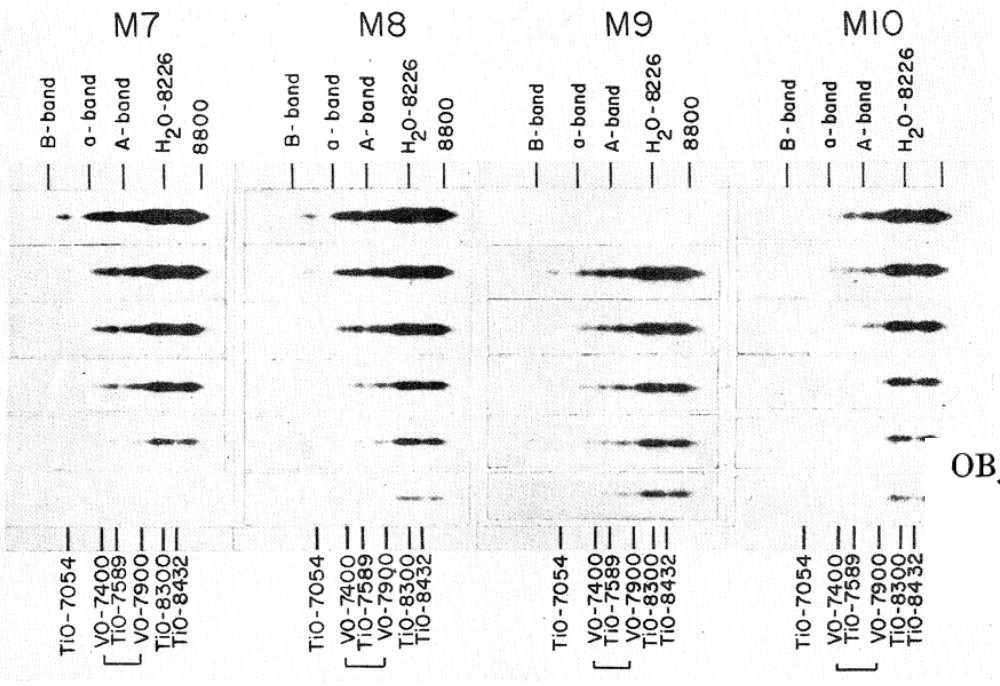


FIG. 3.—With M7 and later classes, the VO bands at λ 7400 and λ 7900 appear and the TiO bands continue to increase in strength

OBJECTIVE PRISM SPECTRA IN THE NEAR INFRARED

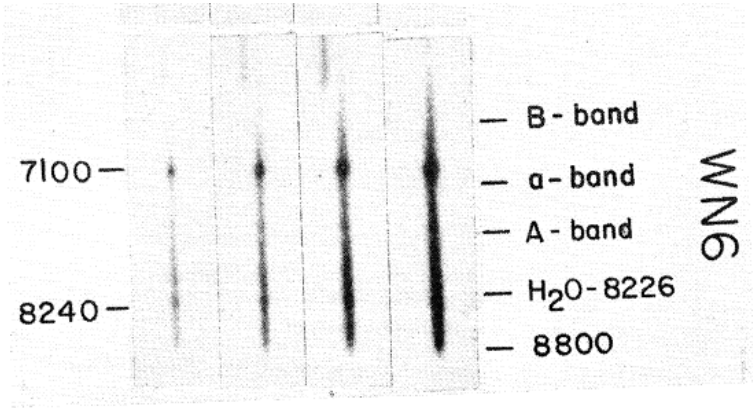
J. J. NASSAU AND A. G. VELGHE
Warner and Swasey Observatory and Royal Observatory of Belgium

Received August 16, 1963

All spectra were taken with a 4° prism attached to the 24-inch Schmidt-type telescope of the Warner and Swasey Observatory, utilizing 1N emulsion and a Wratten No. 89 filter or its near-equivalent, RG8 Schott filter. This yields a dispersion at the A-band of 1700 Å/mm. The wavelength range is from λ 6800 to λ 8800.

The LDS in IR can be used to study highly redshifted features in high z objects

These surveys can be used for independent searches for high z OAs (historical)



WR Star

COST

Astrophysics with Ultra LDS provided by Gaia RP/BP

- **Continuum profiles – including high z objects**
- **Strong emission lines**
- **Strong variable emission lines**
- **Prominent spectral variability**
- **Possibility of spectroscopic Gaia alerts**
- **Follow-Up by ground based RTs with LDS**
- **Plate Sky Surveys can add long-term coverage and historical epochs**

Conclusion: Prospects of LDS with Gaia RP/BP

- **Unique chance to provide early or simultaneous LDS for GRBs (so far LDS mostly late)**
- **Chance to recognize/classify OAs and OTs of GRBs using LDS and/or color information**
- **Chance to detect/study orphan OAs of GRBs**
- **Study possible spectral time changes/evolution**
- **Chance of redshift estimation up to z~7 – Study of high z Universe**

The End

Tests of Simulated Gaia BP/RP Spectra with LDS (Low Dispersion Spectroscopy) Photographic Sky Surveys

René Hudec, Vojtěch Šimon, Lukáš Hudec, Thurburn Barker, Michael Castelaz & Collaborators

Group of High Energy Astrophysics, Stellar Department
Astronomical Institute of Academy of Sciences of the Czech Republic, Ondřejov, Czech Republic
Czech Technical University in Prague, Faculty of Electrical Engineering, Czech Republic
PARI, Pisgah Astronomical Research Institute
Rosman, NC, USA

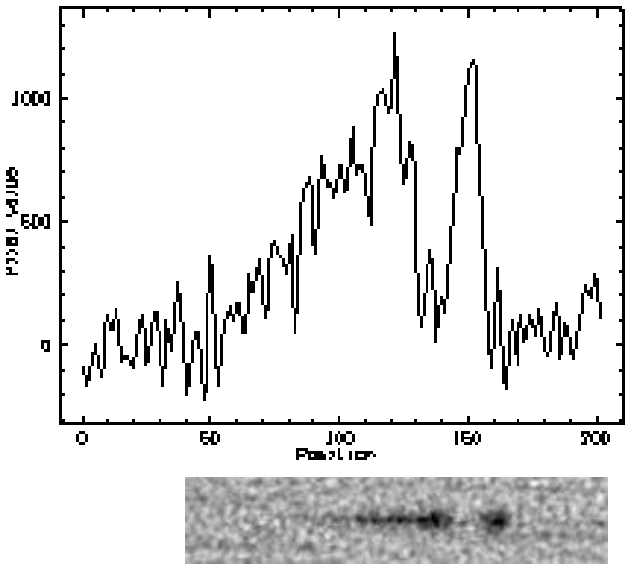
COST 2022
Reference: http://sci.esa.int/gaia/

Examples of prominent spectra from Byurakan Survey

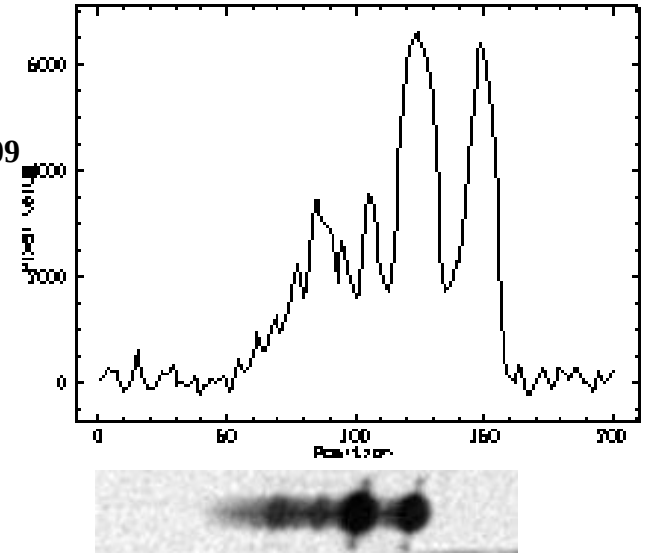
These objects will be also probably visible in Gaia BP and RP

Planetary Nebulae

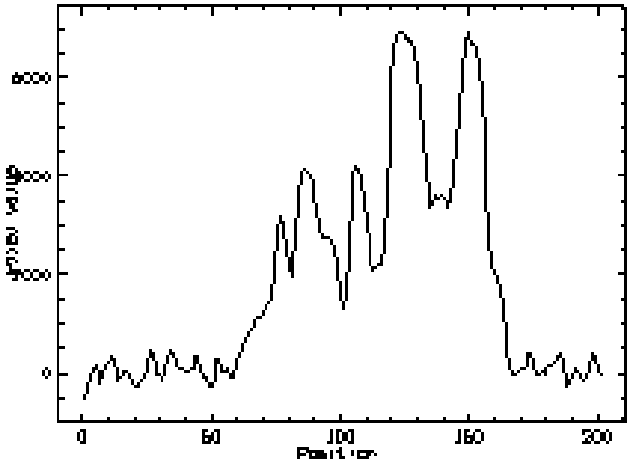
NGC 2242



NGC 7009

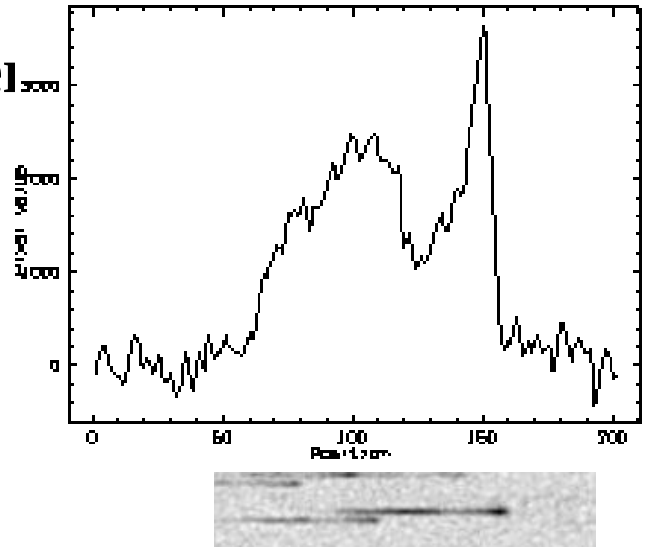


NGC 6210

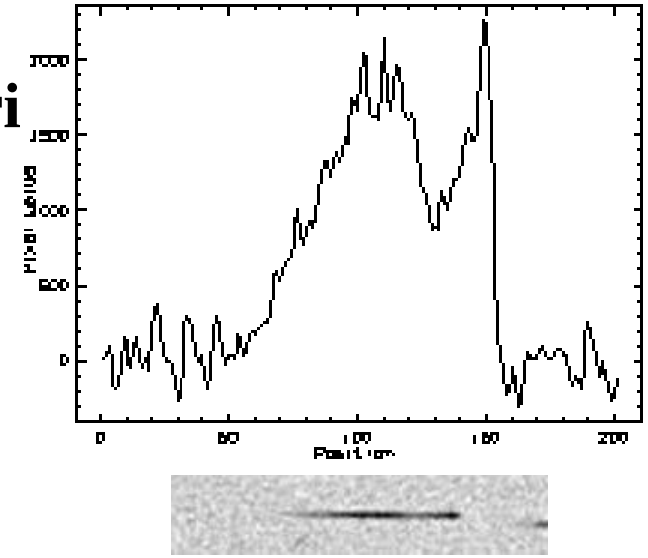


Cataclysmic variables

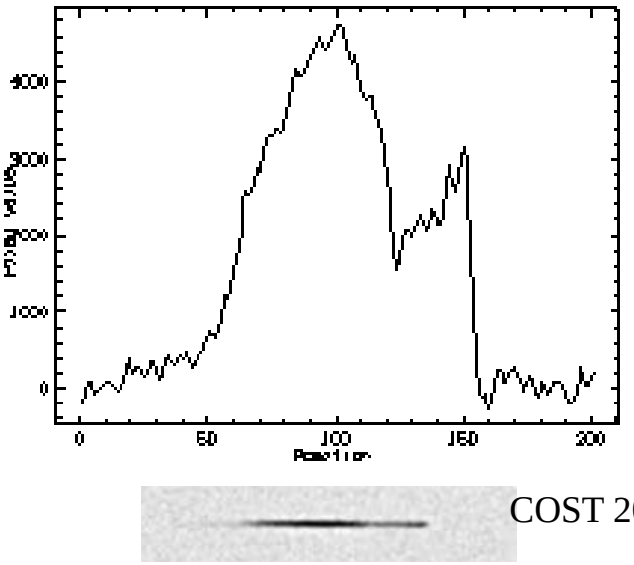
DQ Her



V1193 Ori

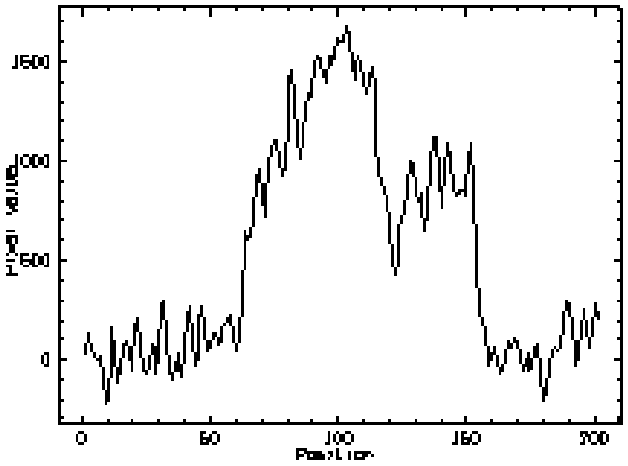


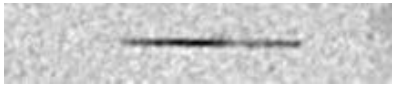
Ux CVn



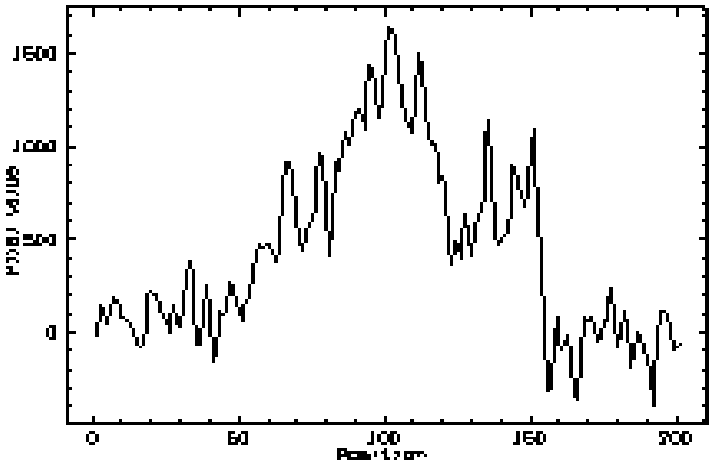
White dwarfs

- Pg 0109+111 (Do)



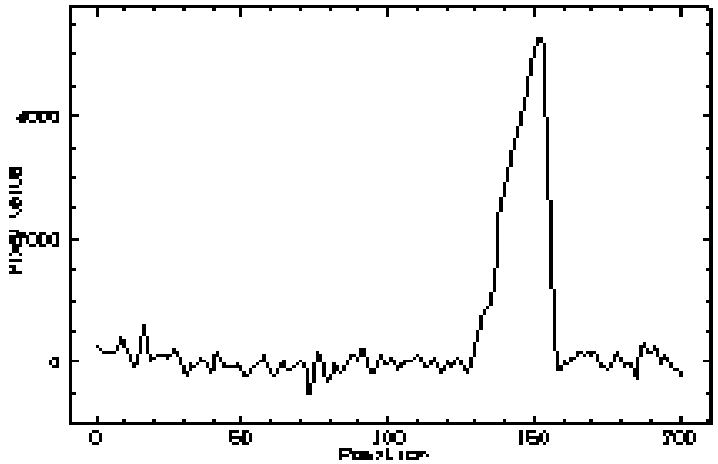


- Pg 1449+168 (Da3)

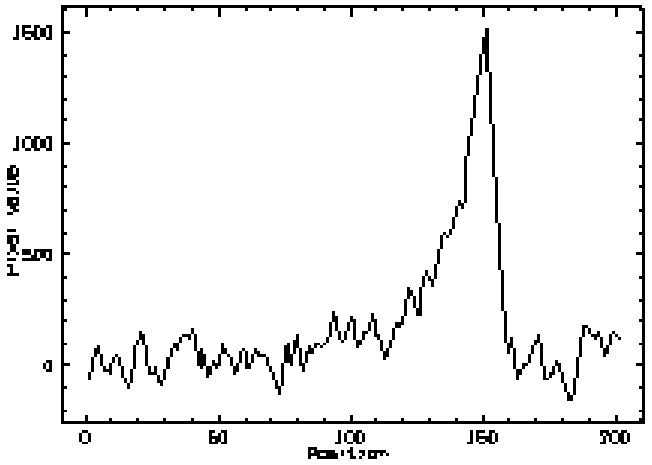


Carbon (C) Stars

- BIS 184

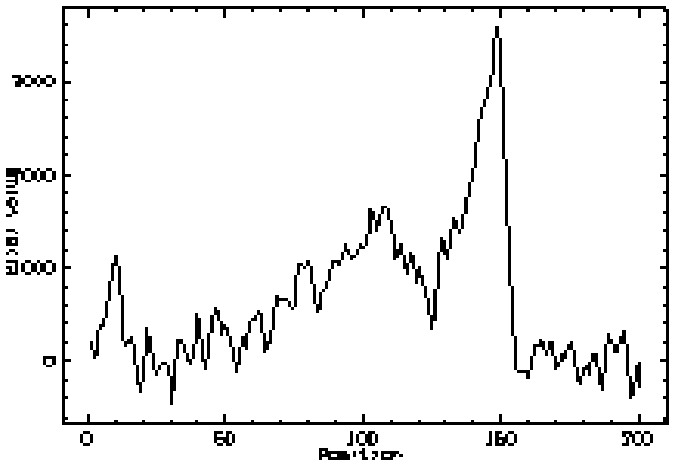


- BIS 001



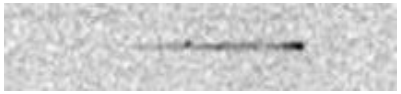
AGN and peculiar galaxies

- BL Lac



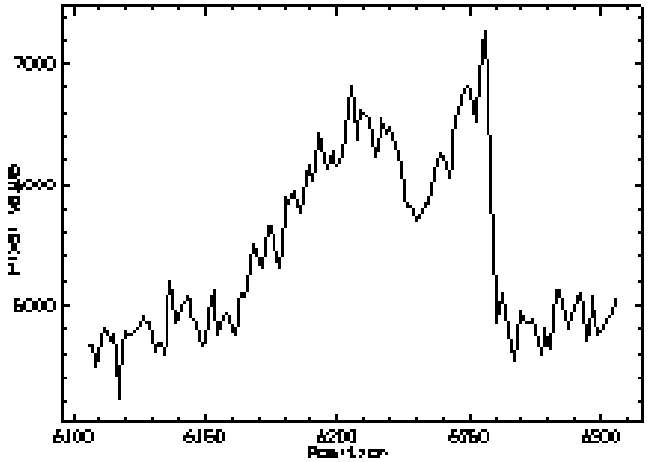
- I Zw 1

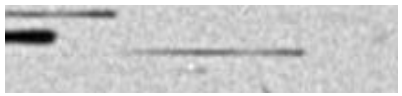
- 3c 120



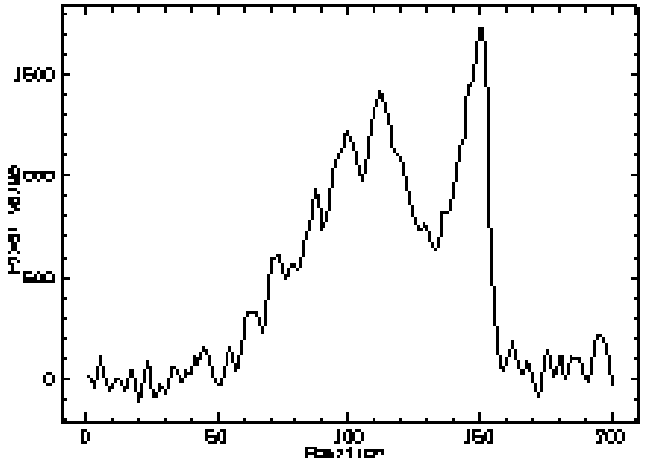
Quasars

- CSO 409

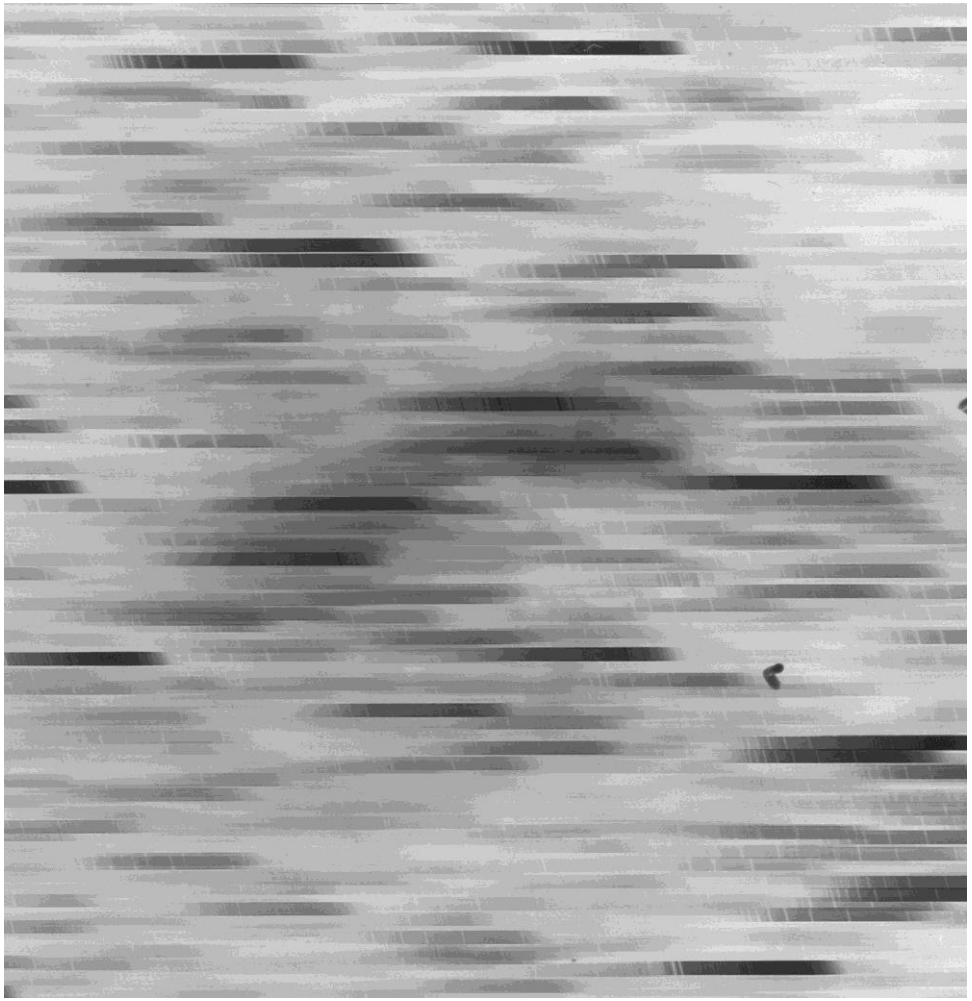




- Pg 1634+706



With larger dispersion one can easily see lines



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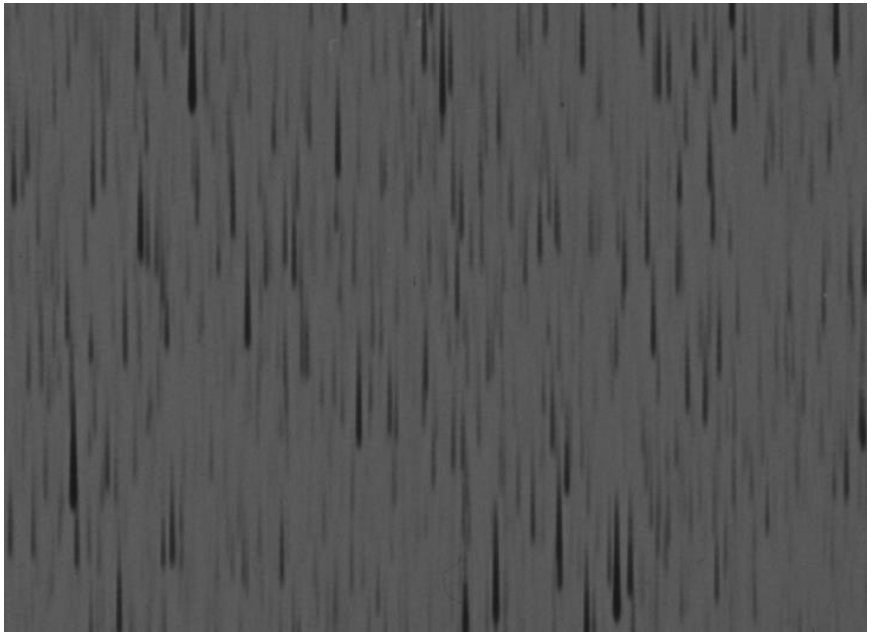
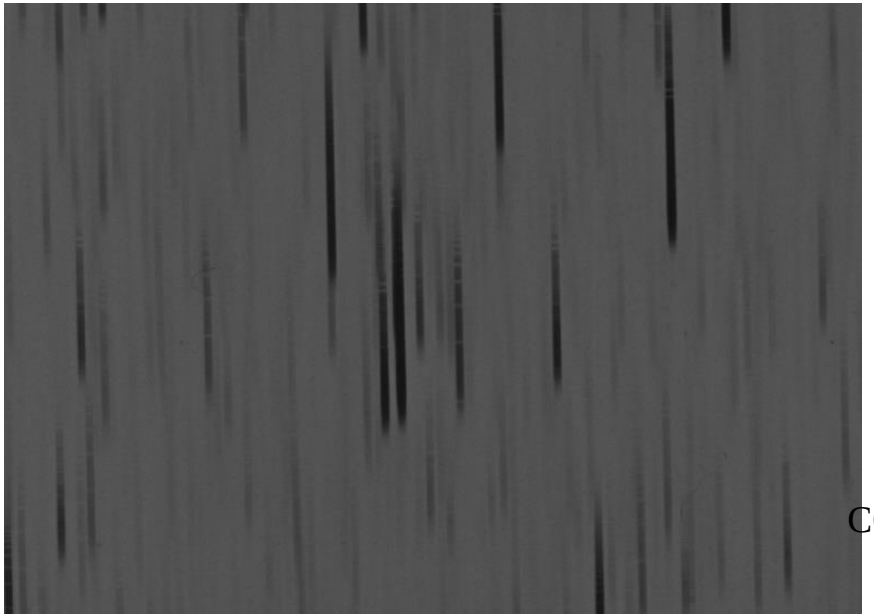
The Eta Car region from PARI CTIO Curtis-Schmidt plate 10464, March 11, 1972 using IIaO emulsion, with 10-degree prism. (The 2-deg is the approximate size of the field cropped).

(1) Reference: 1971BAAS....3..401H (N. Houk)
(2) Limiting magnitude: ~9.5
Telescope: Curtis-Schmidt 61/91 cm (twin to the Case Western Schmidt) f/3.5
Prism: 10-degree
Prism Dispersion: 108 Angstroms per mm at H-gamma
Prism resolution: 2-Angstroms; widened to 0.8mm
Emulsion: IIaO
Exposure time: 20-minutes
Program: Systematic Reclassification in the MK system of the entire Henry Draper Catalogue (HD).
Investigator: N. Hock, University of Michigan

Schmidt Camera Sonneberg



The dispersion ~ 23 nm/mm at Hg for the 3 deg prisma The scan resolution is 0.05 mm/px, thus about 0.5 nm/px.



The dispersion ~ 10 nm/mm at Hg for the 7 deg prisma. The scan resolution is 0.02 mm/px, thus about 0.2 nm/px.