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SIRIUS: Stellar and ISM research via in-orbit (E)UV spectroscopy

Martin Barstow & Jianrong Shi

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- Instrument Working Team
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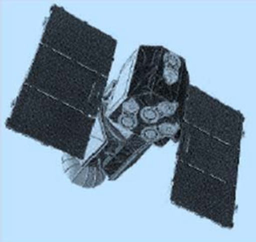
Introduction

- Importance of the EUV (~100 – 900 Å)
- Science goals – stellar and galactic environment
- Requirements for a new mission
- SIRIUS, a high resolution EUV spectroscopic mission
- Key systems and readiness levels
- Conclusions

Extreme Ultraviolet Astronomy

- Once called the "unobservable ultraviolet"
  - Erroneous assumptions about interstellar densities
- Cruddace et al. (1974) predicted feasibility
  - Patchy ISM, lower density
- Demonstrated by sounding rockets & Apollo-Soyuz
- All-sky surveys by ROSAT WFC & EUVE
- Low resolution spectroscopy (R~100), EUVE
- High resolution spectroscopy (R~5000), J-PEX



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Importance of the EUV

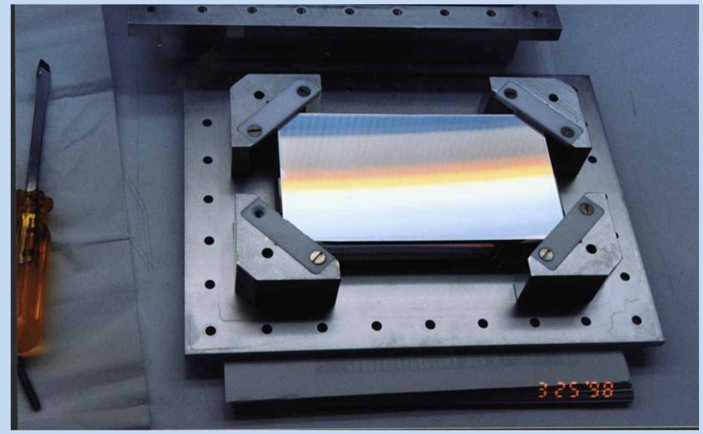
Important processes traced by hot gas (10^5-10^7K)

- Formation and evolution of stars
  - Their interaction with the ISM
  - Effect on planetary atmospheres & habitability
- Activity levels
  - Stellar winds.. control flow of material & cosmic rays from galactic environment
- Recycling of material into ISM
  - Enriching galactic metal content
  - Production of white dwarfs and supernovae

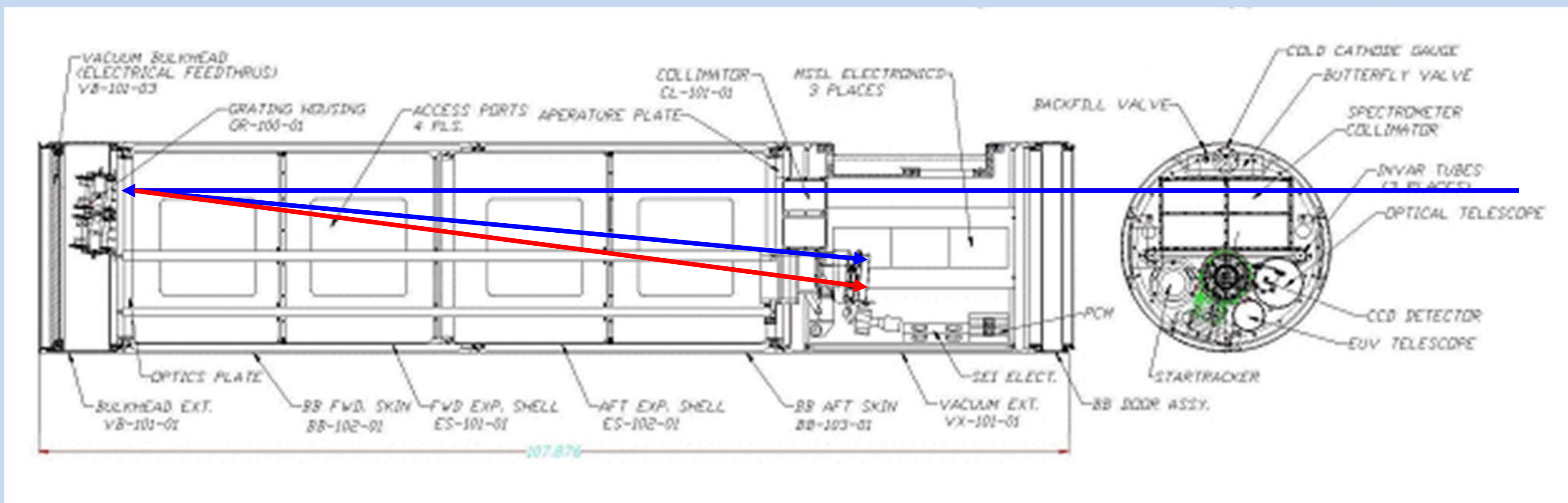
Importance of the EUV

- Region with a high density of spectral lines
  - Stellar atmospheres
  - Stellar transition regions and coronae
- Unique coverage of He II Lyman series
  - Probe of density and ionization in ISM
- No planned missions by any agency…

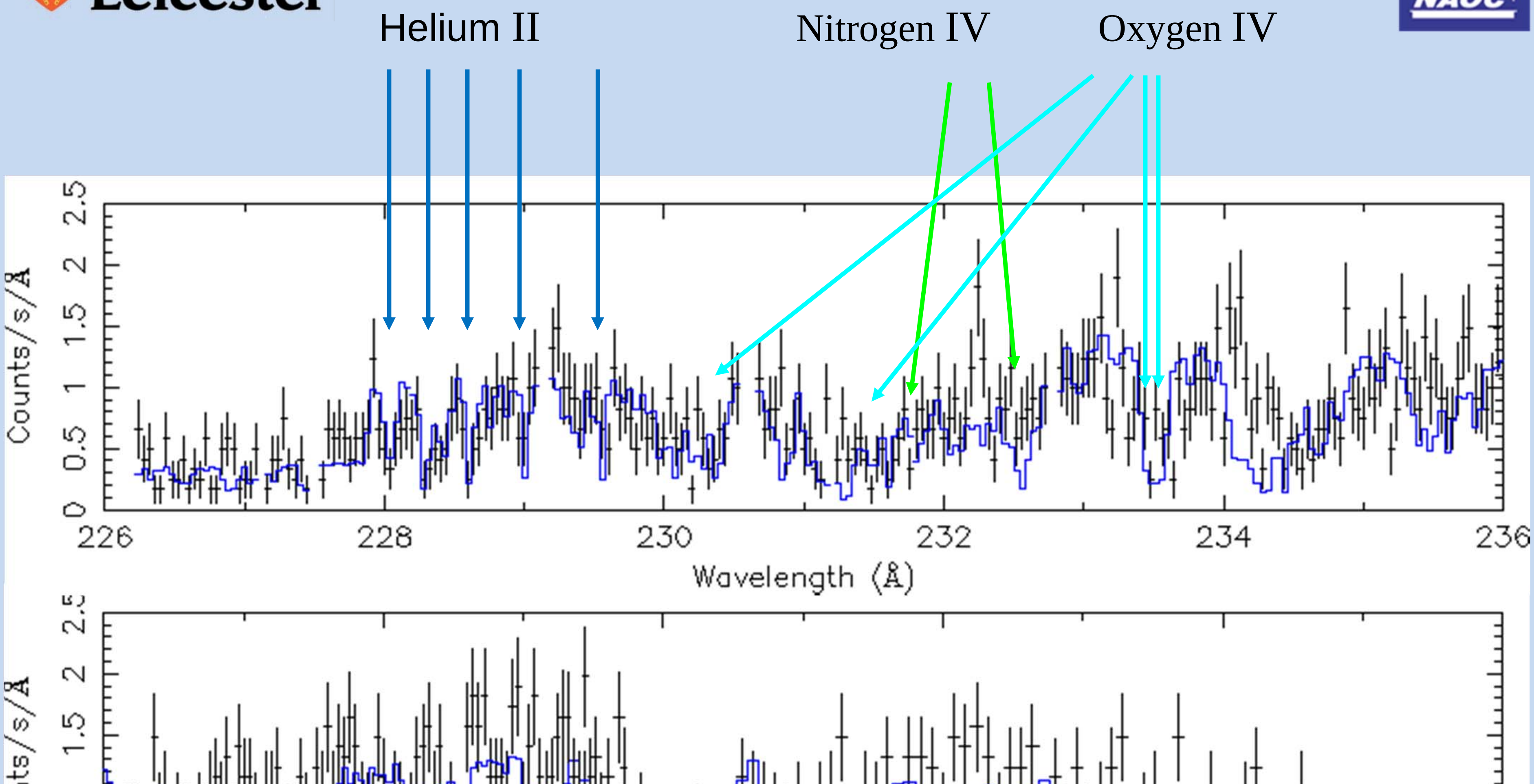
The J-PEX Spectrometer

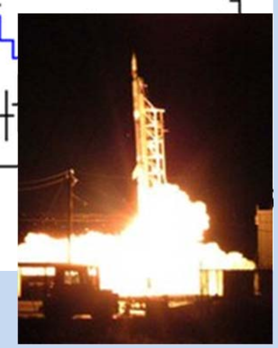


Ion etched, blazed grating.
MoSi multilayers for high reflection
Spherical figure, 2.2m focal length



300s exposure of G191-B2B



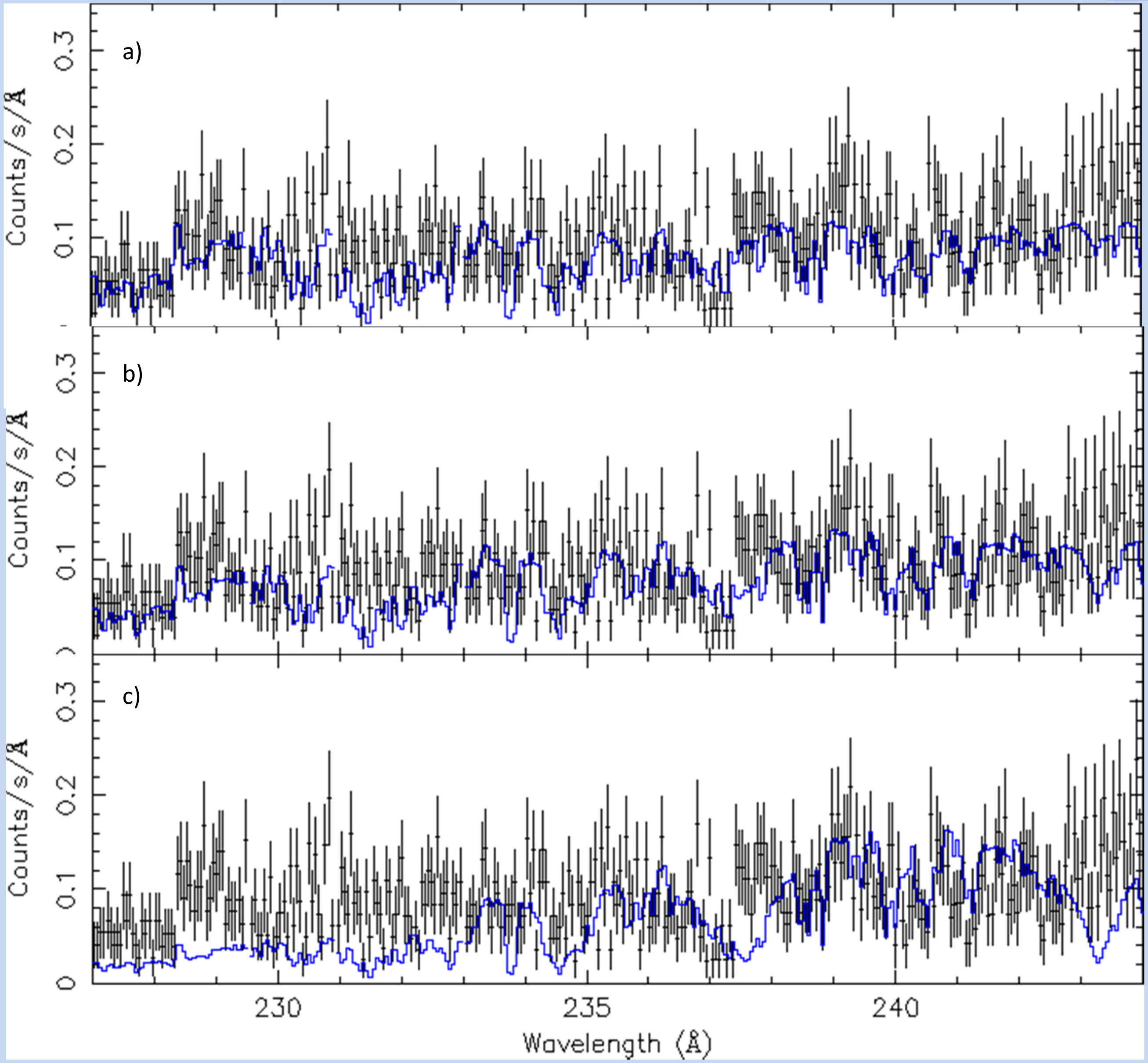


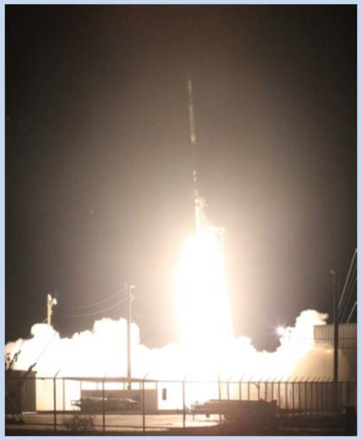
Feige 24; DA+dM

a) H-layer mass = $10^{-12.92}M_\odot$

b) H-layer mass = $10^{-13.5}M_\odot$

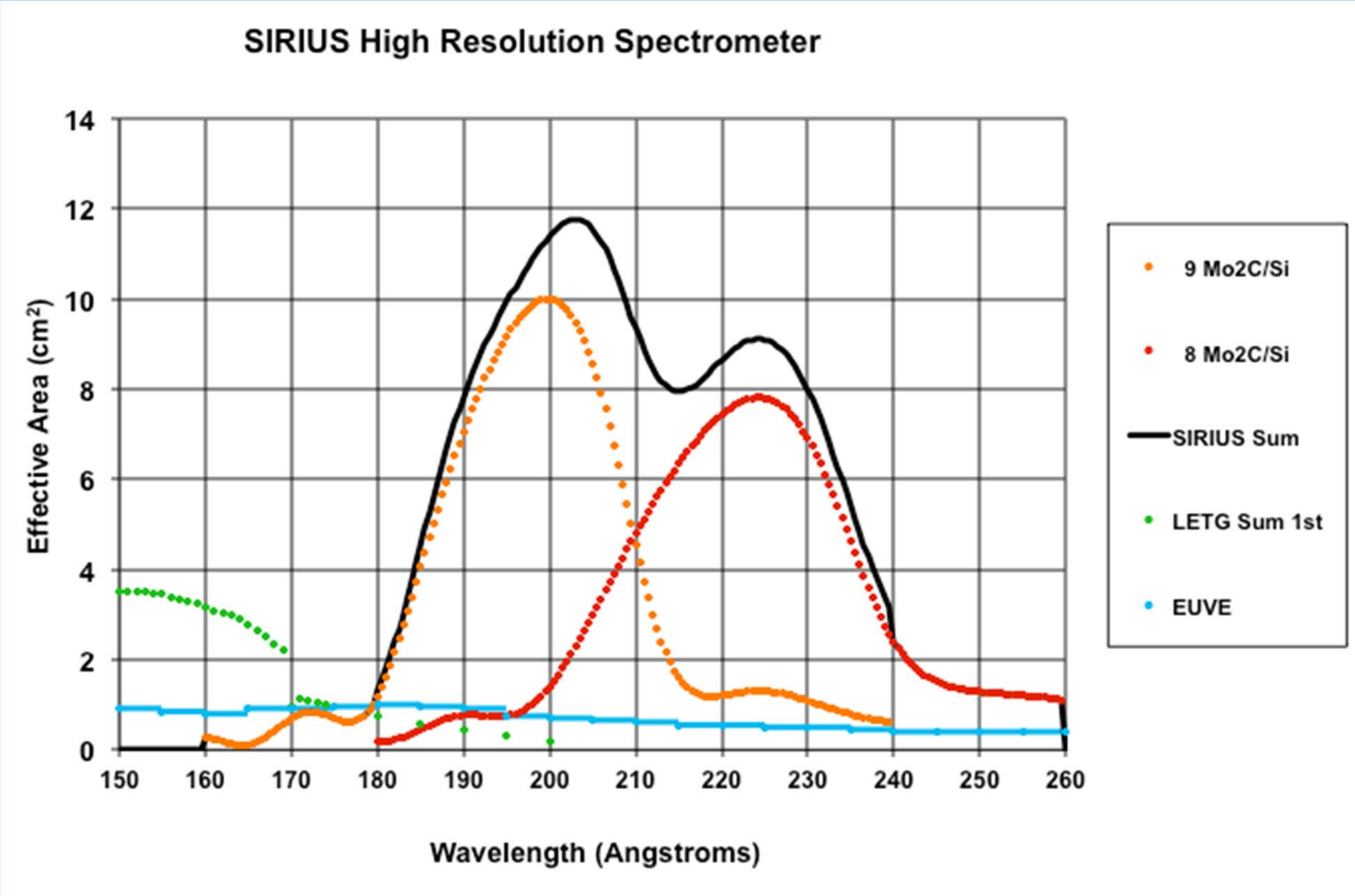
c) H-layer mass = $10^{-14}M_\odot$.





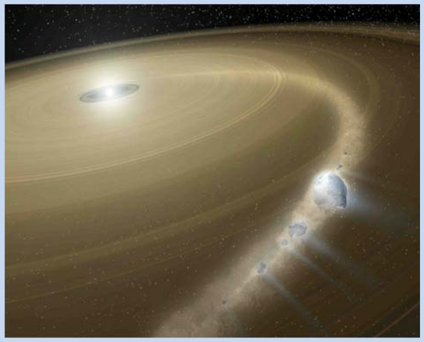
Evolution into an orbital instrument

- The J-PEX design is scalable
- Multiple units can be constructed
  - Tuned to different wavebands by multilayer thickness
- Gratings in a single unit can be divided for broader wavelength coverage
  - Recent, shortlisted, ESA S-mission proposal
  - Four gratings tuned in pairs to two bands: 180 - 220 Å and 200 - 240 Å

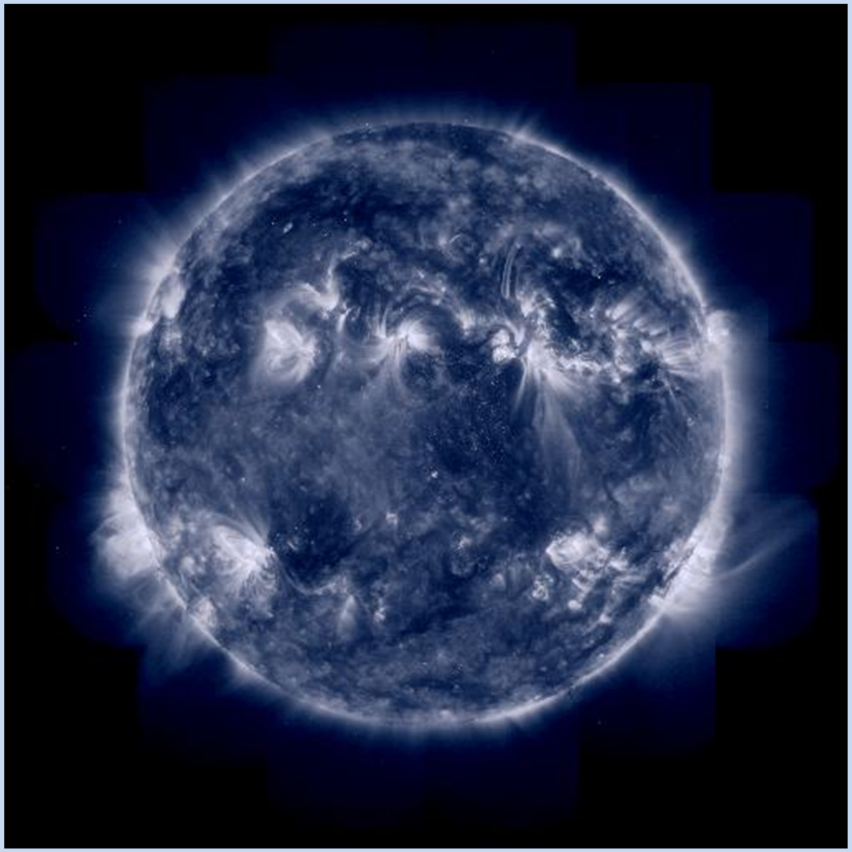

SIRIUS High Resolution Spectrometer
Effective Area (cm²)
Wavelength (Angstroms)
0
2
4
6
8
10
12
14
150
160
170
180
190
200
210
220
230
240
250
260
9 Mo2C/Si
8 Mo2C/Si
SIRIUS Sum
LETG Sum 1st
EUVE

Stellar & Galactic Environment

- Structure & Dynamics of Stellar Coronae
  - Coronal heating, activity and flares – Solar quality data for nearby stars
  - Exoplanet environments
- Evolution of White Dwarfs
  - Atmospheric composition & structure
  - Extrasolar planetary debris (arXiv – 1402.2164)
- Structure & Ionization of the Local Interstellar Gas
  - Can only be directly measured in the EUV
- Extra-galactic observations in low density regions

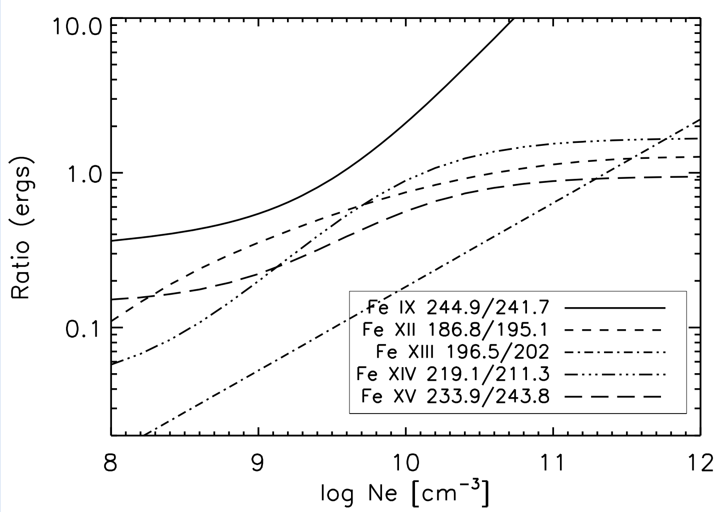


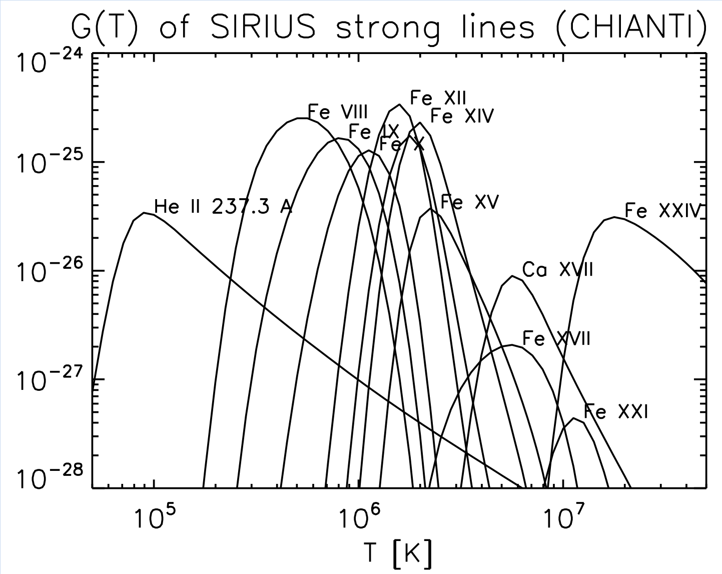
Stellar activity in Solar-like stars



Stellar coronae

- Solar-like stars emit mainly in EUV, 170 - 600 Å
  - virtually invisible to XMM-Newton and Chandra HEG
- Measure T_e and N_e from chromospheric temperatures (He II) to 15 MK (Fe XXIII, Fe XXIV)
- Range well studied in Sun
  - Hinode EIS R~3000 solar spectra (170 - 210 and 245 - 290 Å)





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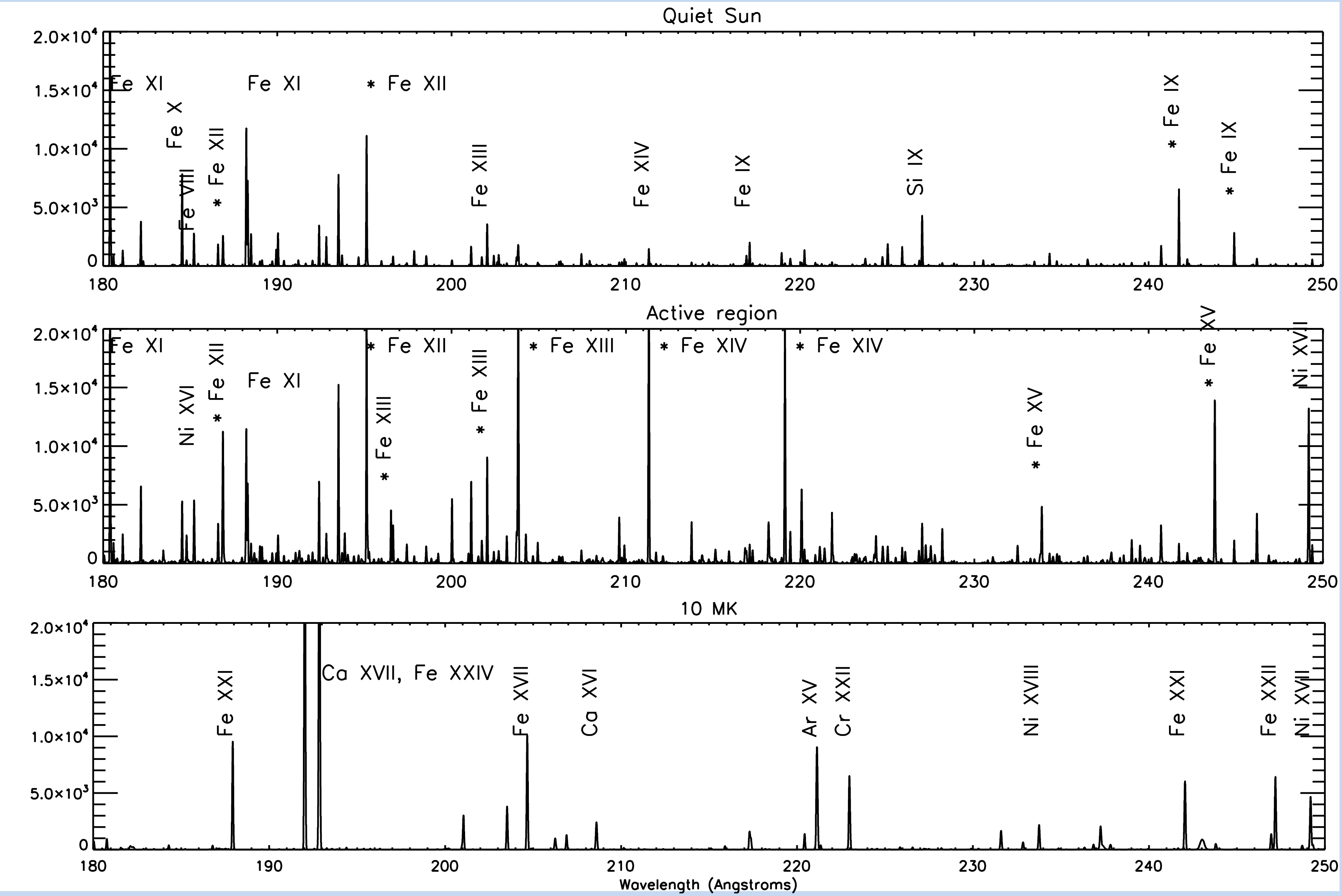
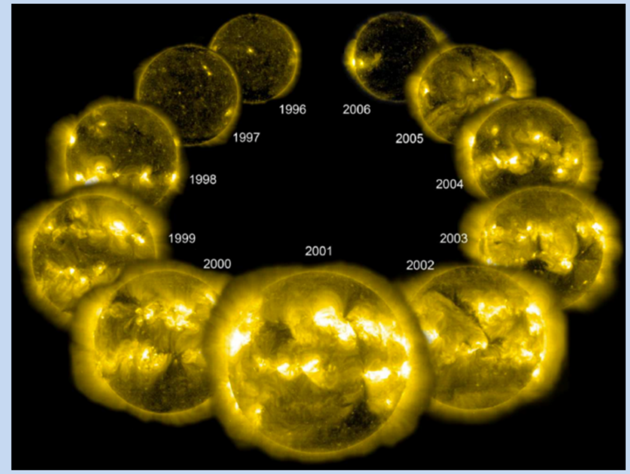
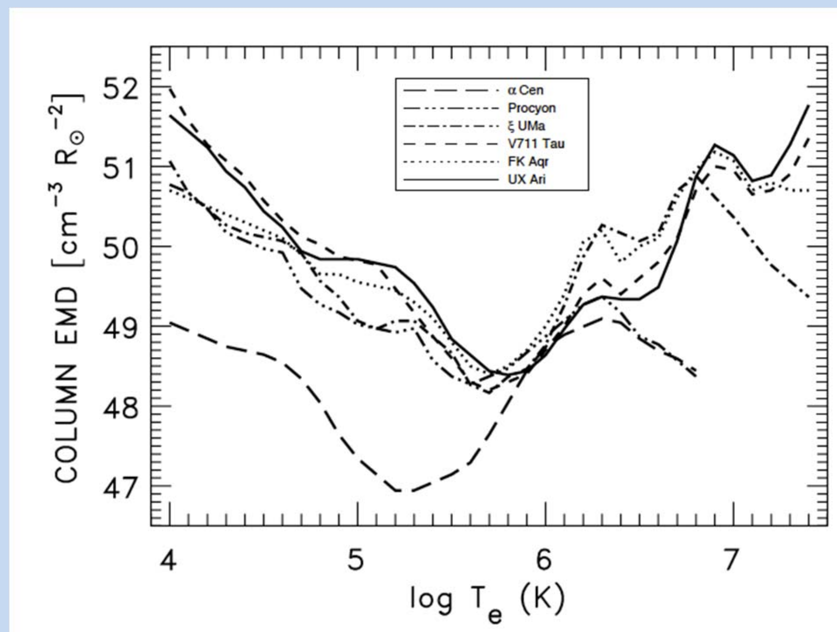


Important questions

- Magnitude of the fluxes
  - Knowledge of extremes, but what is "normal"?
- Time variability of activity
  - Age/rotation rate
  - Ranges of short timescale changes?

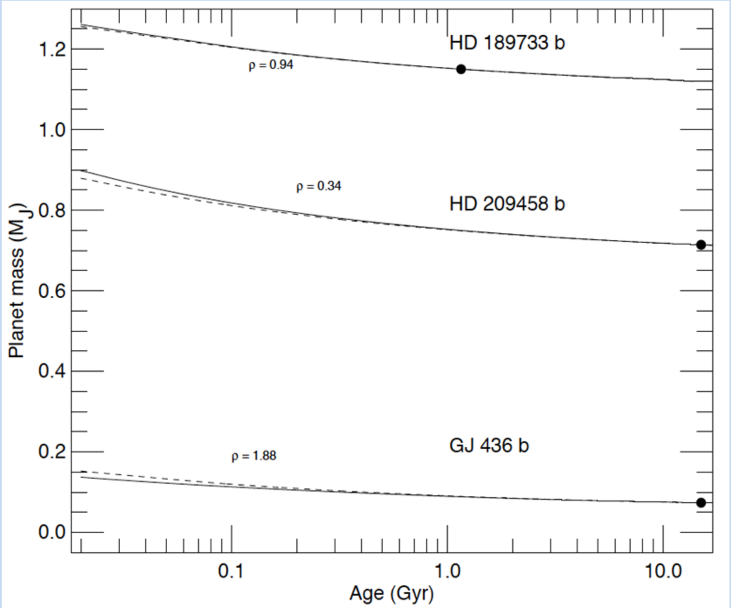




Exoplanets in stellar environment

- The XUV (X-ray+EUV) irradiance from the parent star affects:
  - Volatile loss from planetary atmosphere… condition for habitability
  - Planetary mass evolution, via evaporation by EUV/X-ray radiation & losses through Roche Lobe

Sanz-Forcada et al. 2011, A&A, 532, 6

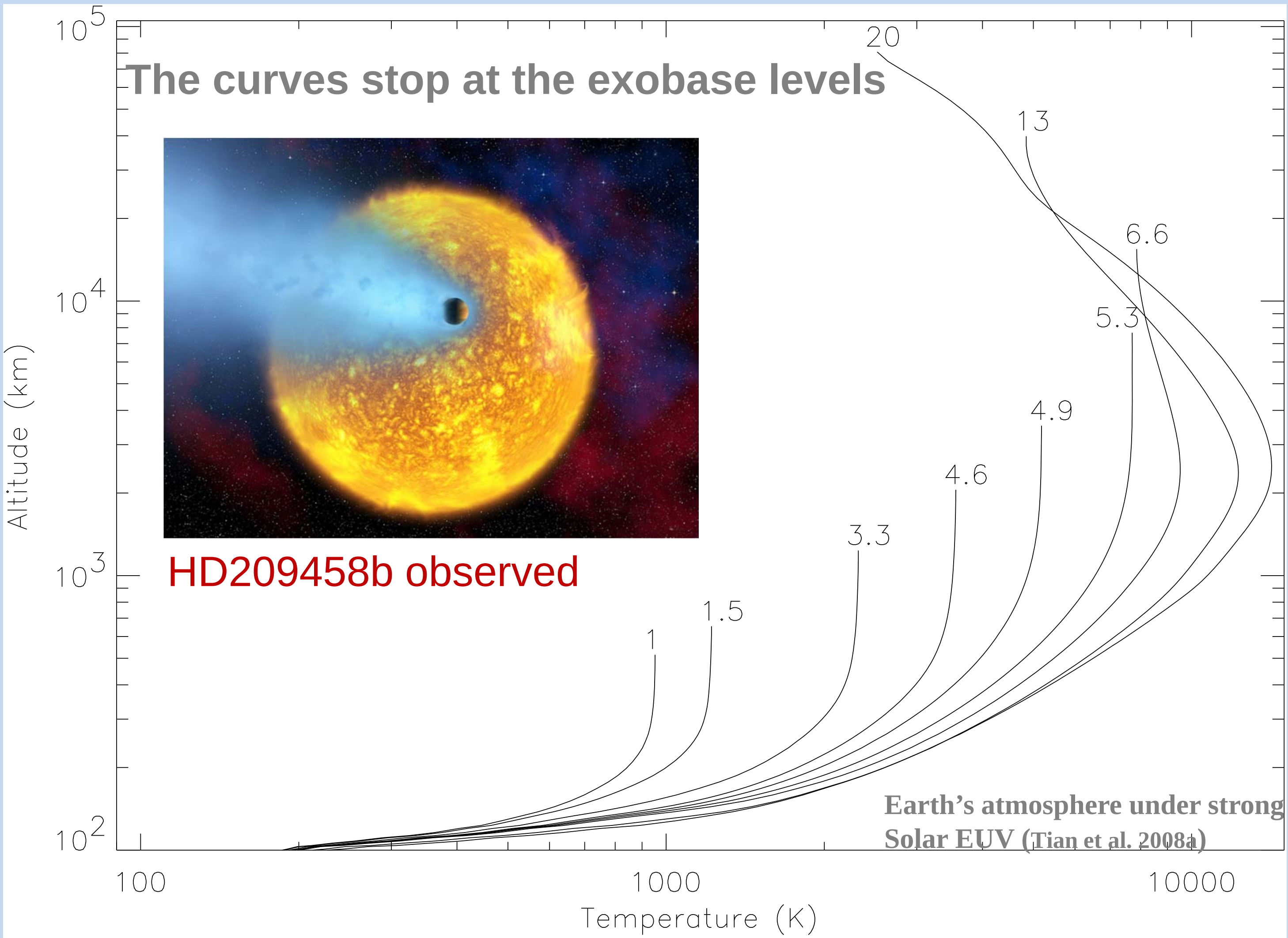


Exoplanets in stellar environment

- Models use EUV fluxes extrapolated from X-ray measurements, but…
  - Real EUV data required as EUV flux comes mainly from the stellar transition region
  - For low activity stars EUV main contribution to the XUV
- Need to study EUV properties of exoplanet systems
  - Specifically those to be investigated by JWST (2018, cf. 2021) and habitable planet hosting stars identified by PLATO 2.0, TESS, STEP, etc.

ε Eri	K2V
47 Uma	G1V
51 Peg	G2.5IV
Gleise 581	M3
Gleise 876	M4
Pollux	K0III
υ And	F8V
γ Cephei	K1IV
55 Cancri	G8V
GJ1214	M4.5

Stability of planetary atmospheres



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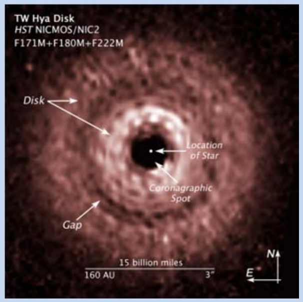
TW HYA



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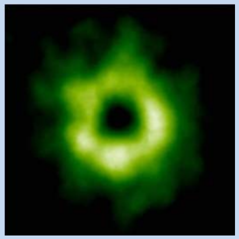
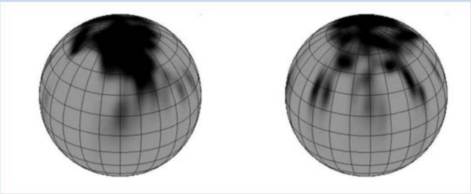
Evolution of disks

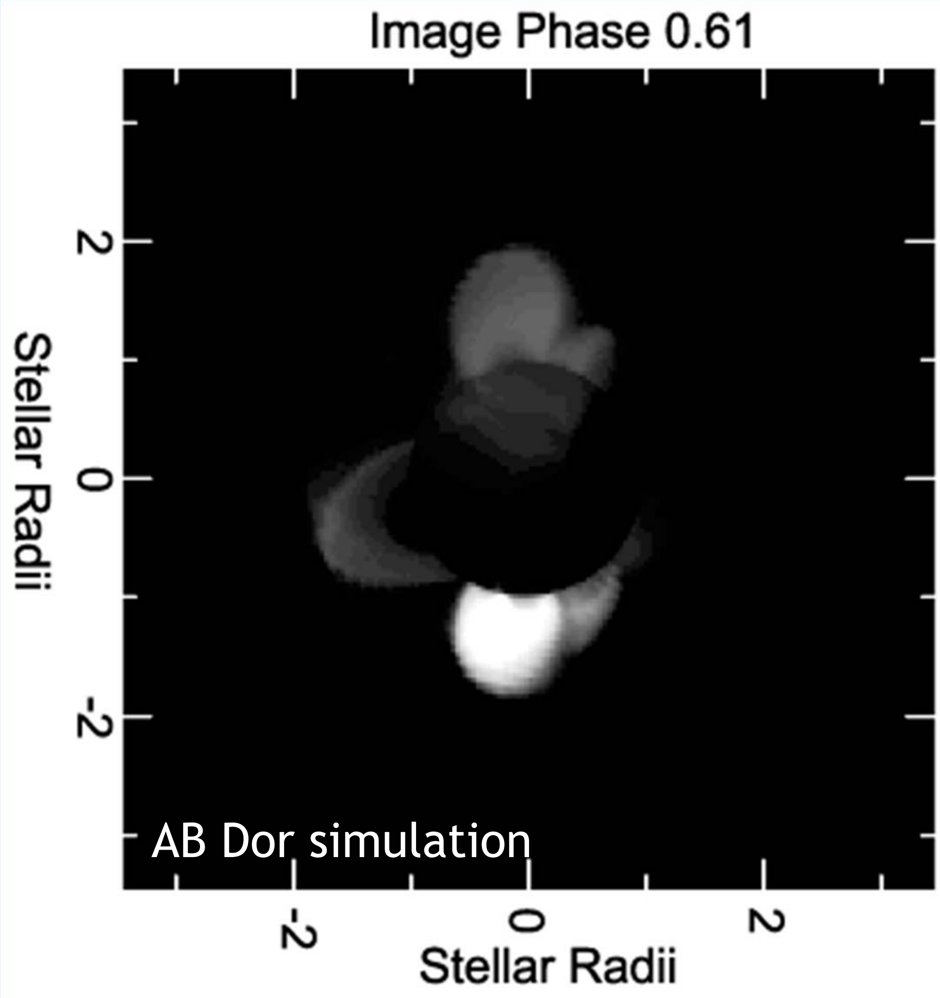


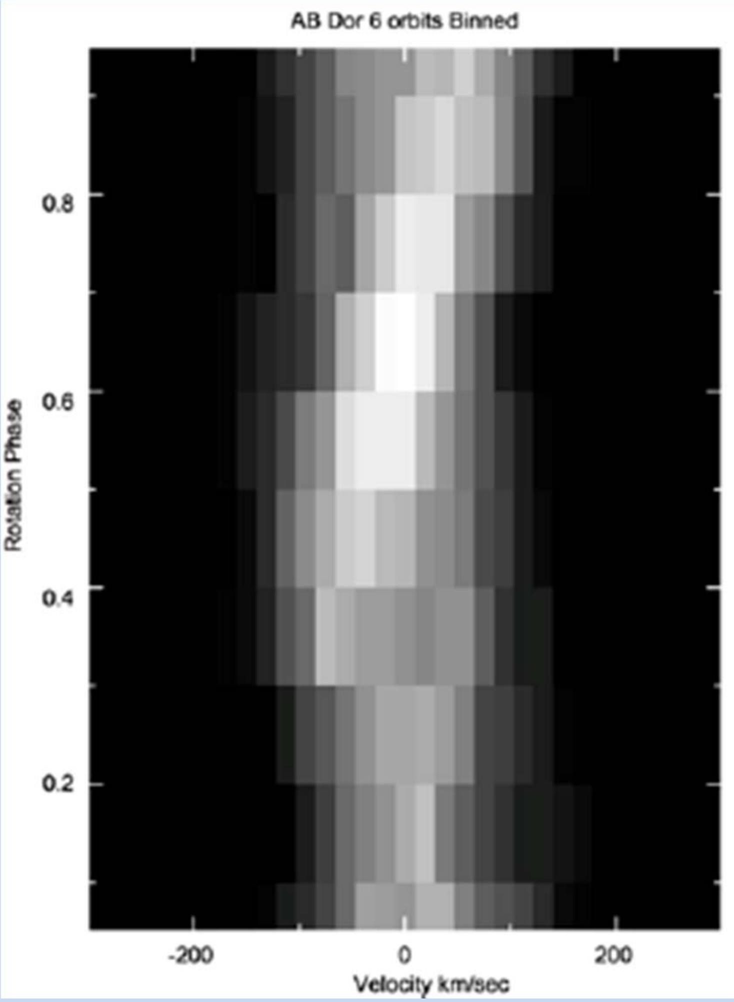
- Gap in SED between X-ray and UV
- Variability time scales
- Thermal properties of flares
- Impact of EUV flux on nearby components and disks
- Main targets TW Hya and AB Dor

AB DOR

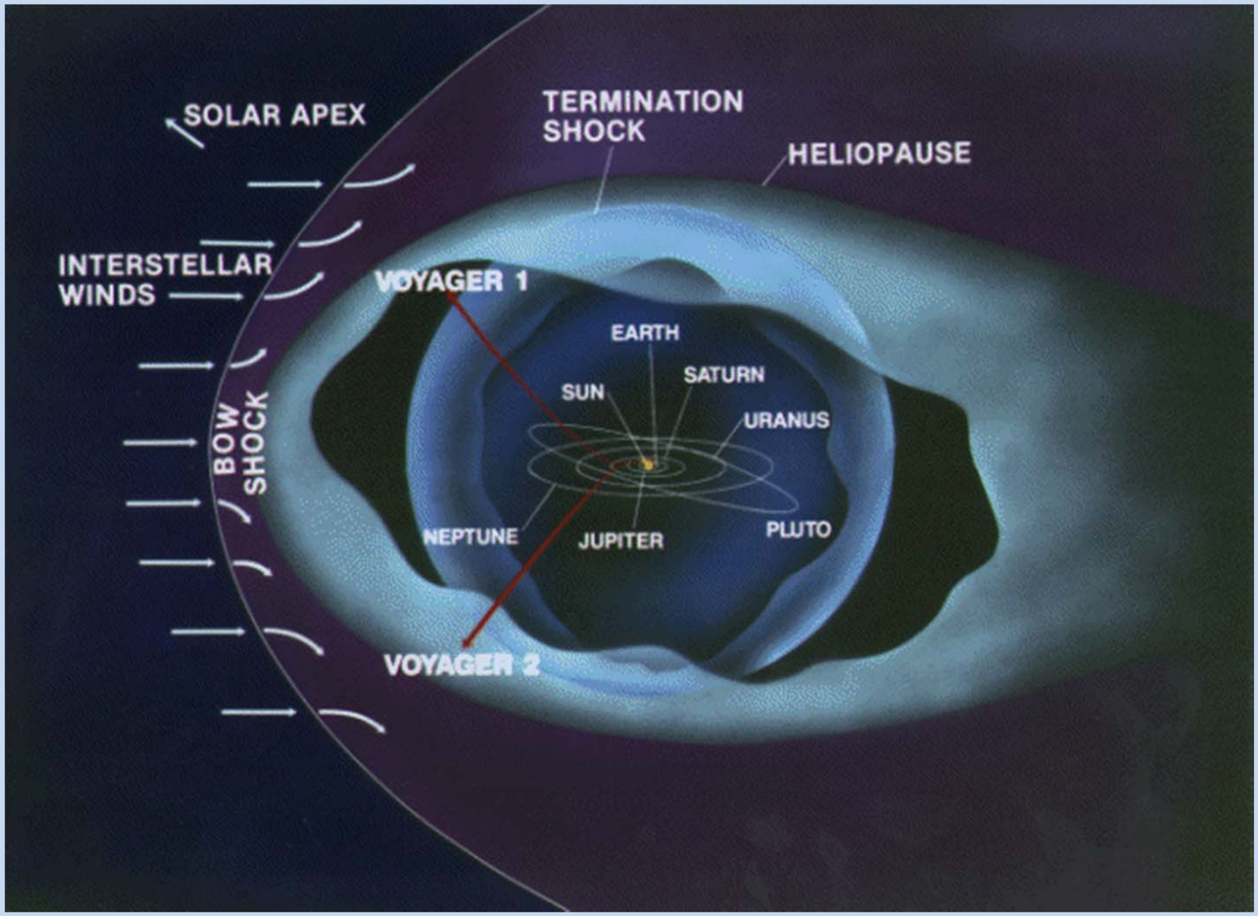


Coronal Dynamics – Doppler Imaging

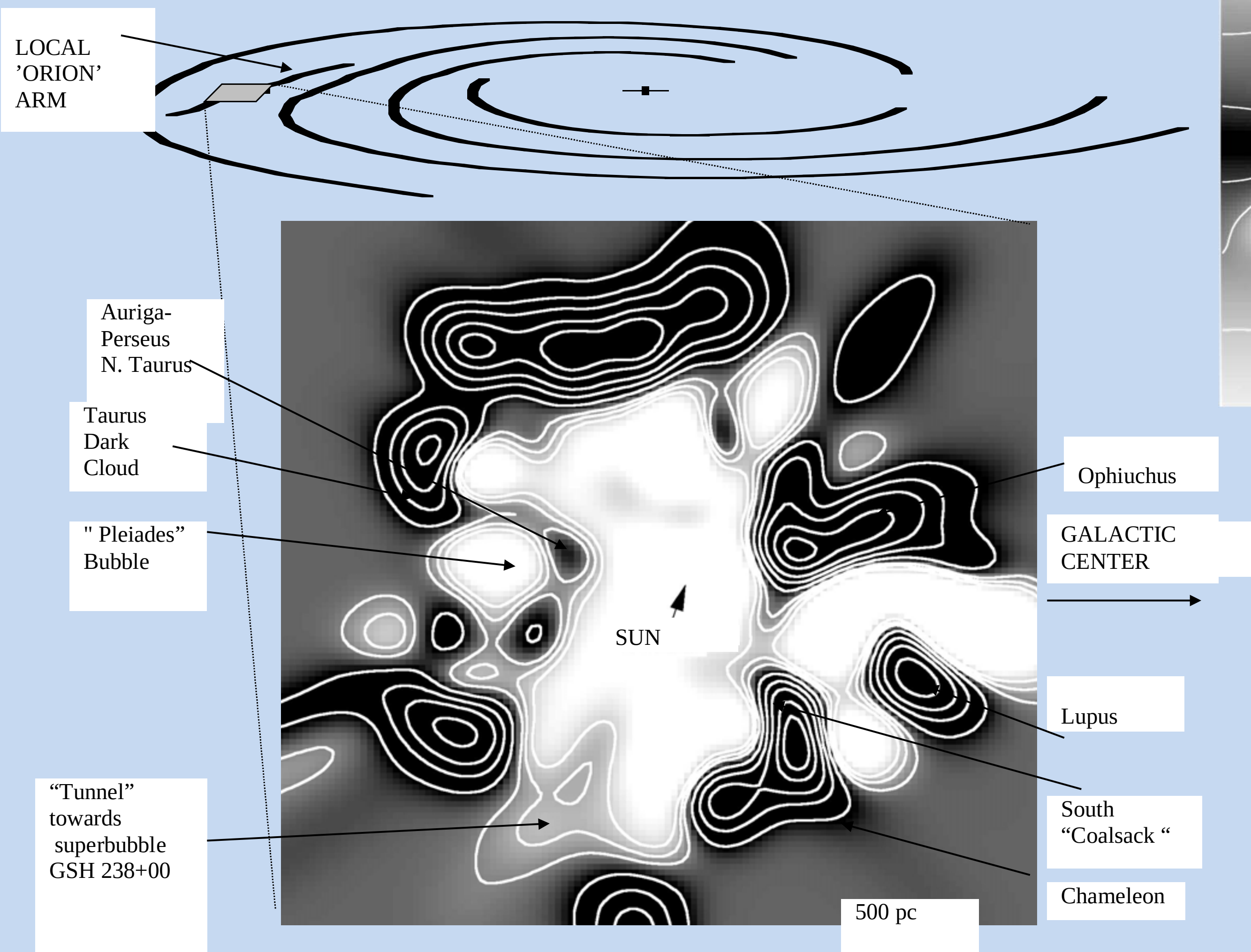


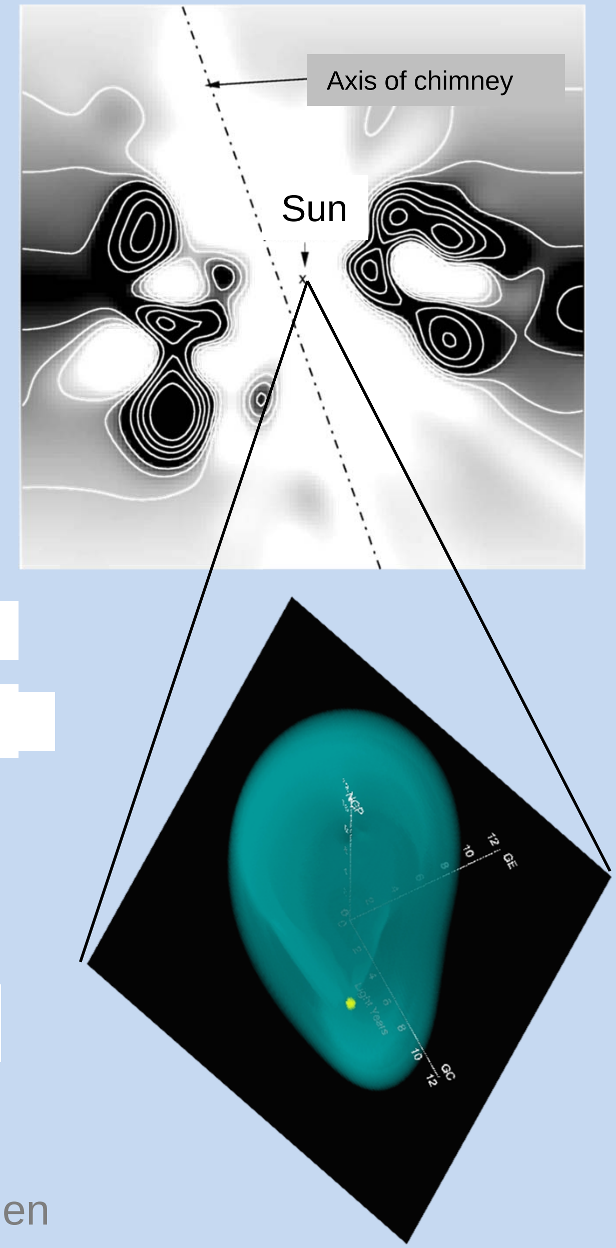


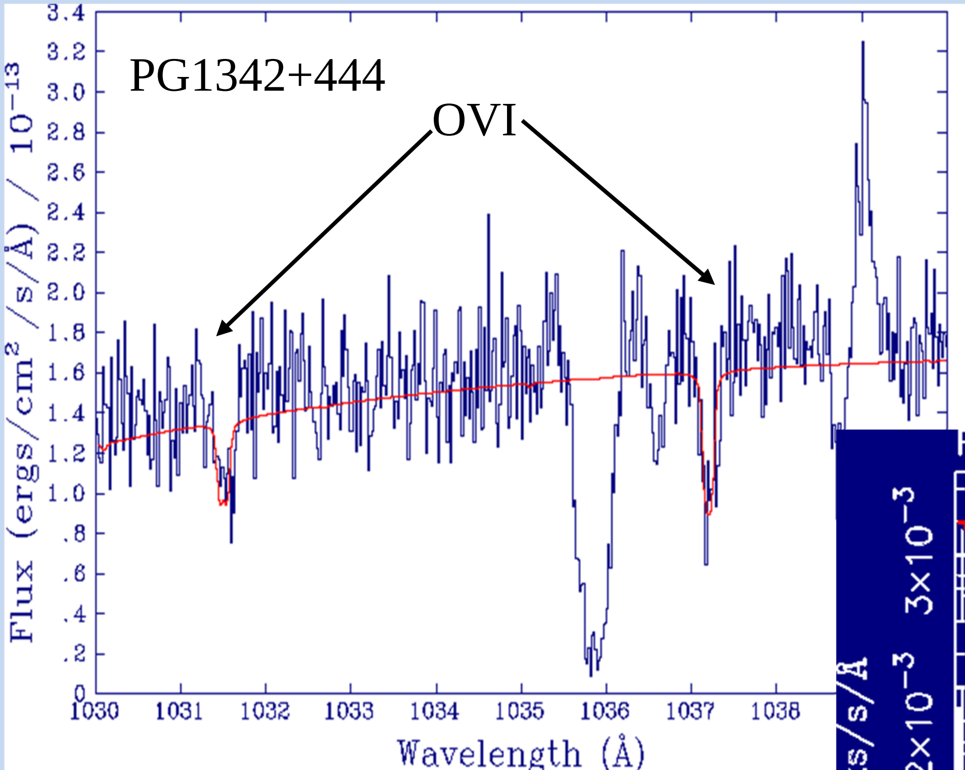
Heliosphere

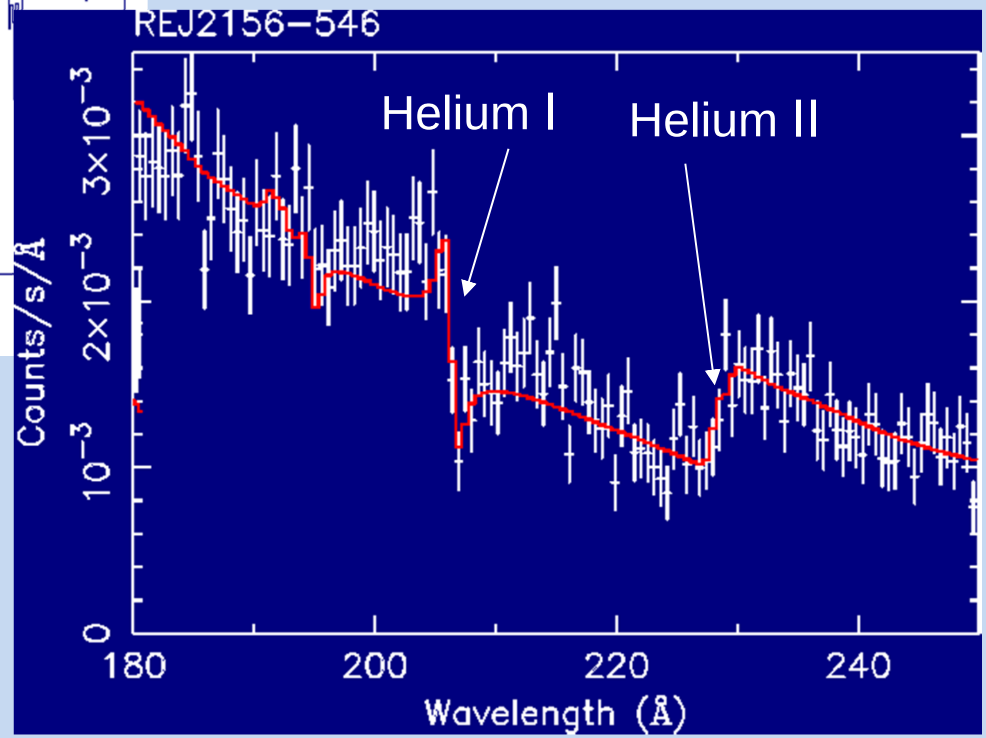


The Local ISM






PG1342+444
OVI
Flux (ergs/cm^2 /s/Å) / 10^{-13}
Wavelength (Å)
1030
1031
1032
1033
1034
1035
1036
1037
1038


REJ2156−546
Helium I
Helium II
Counts/s/Å
Wavelength (Å)
180
200
220
240

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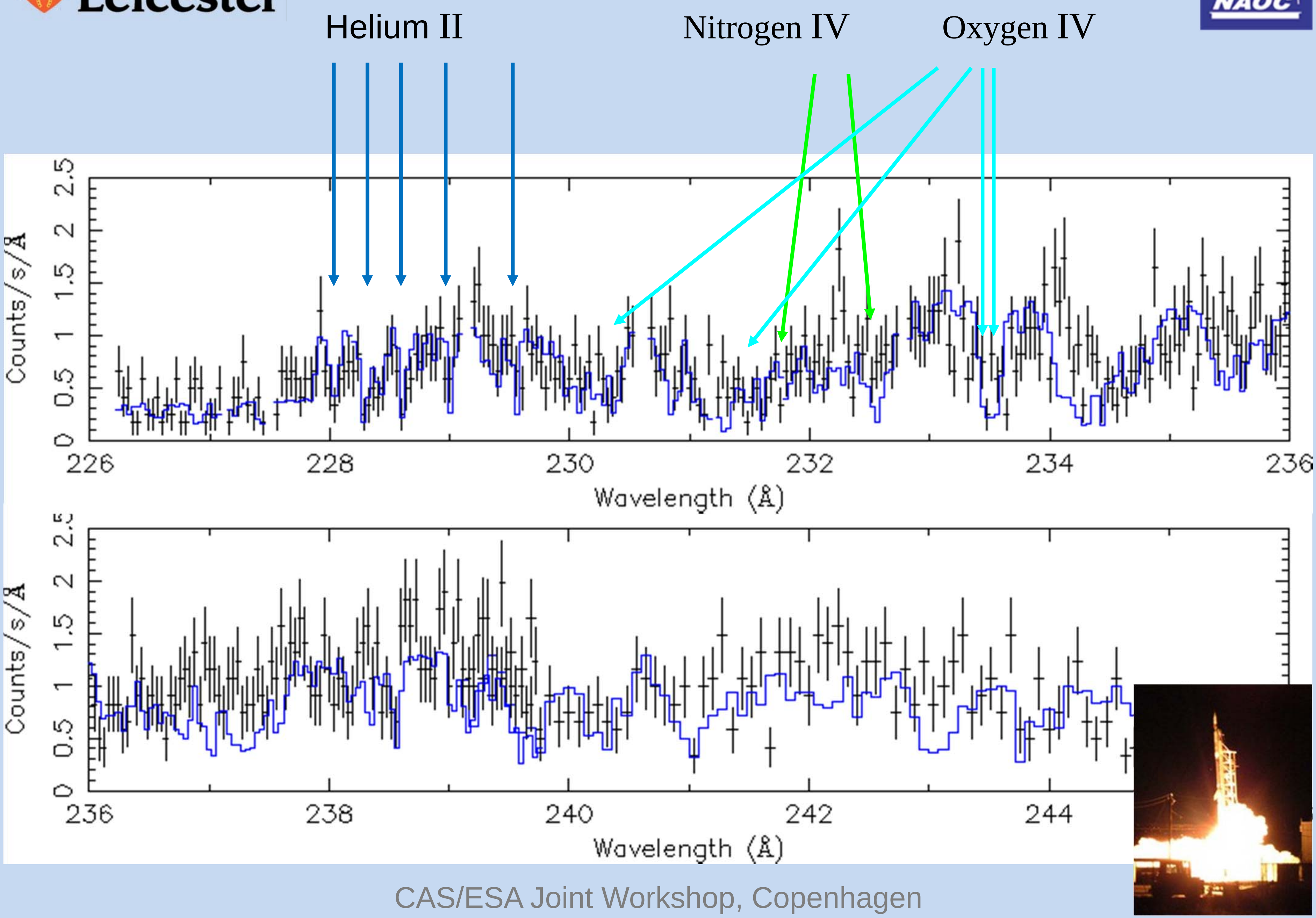
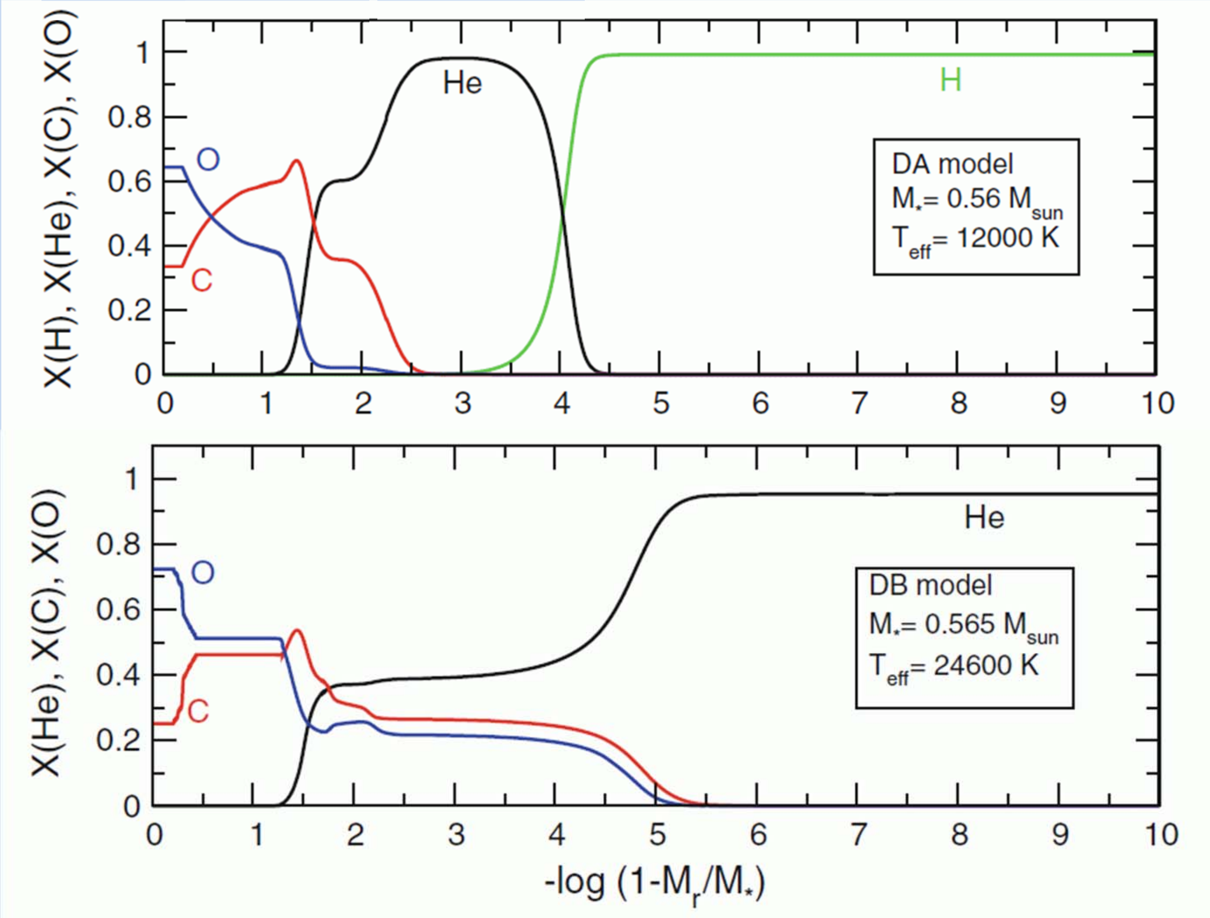
300s exposure of G191-B2B



Typical White Dwarf Chemical Profile

centre 10% 1% 0.1%



Expect a pure hydrogen or helium atmosphere

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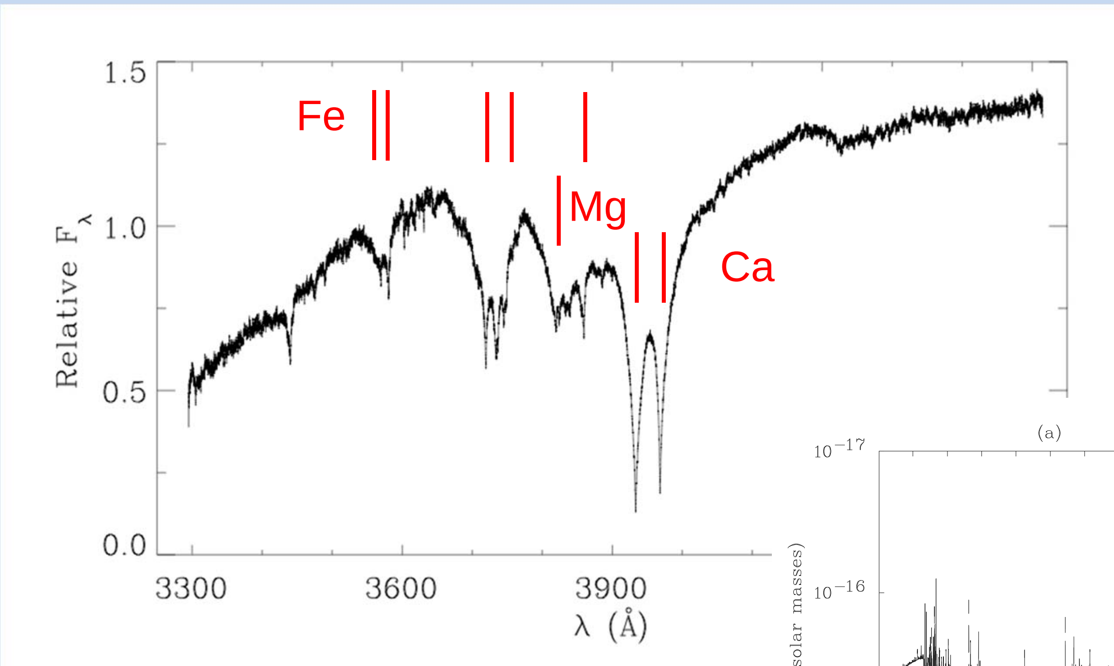
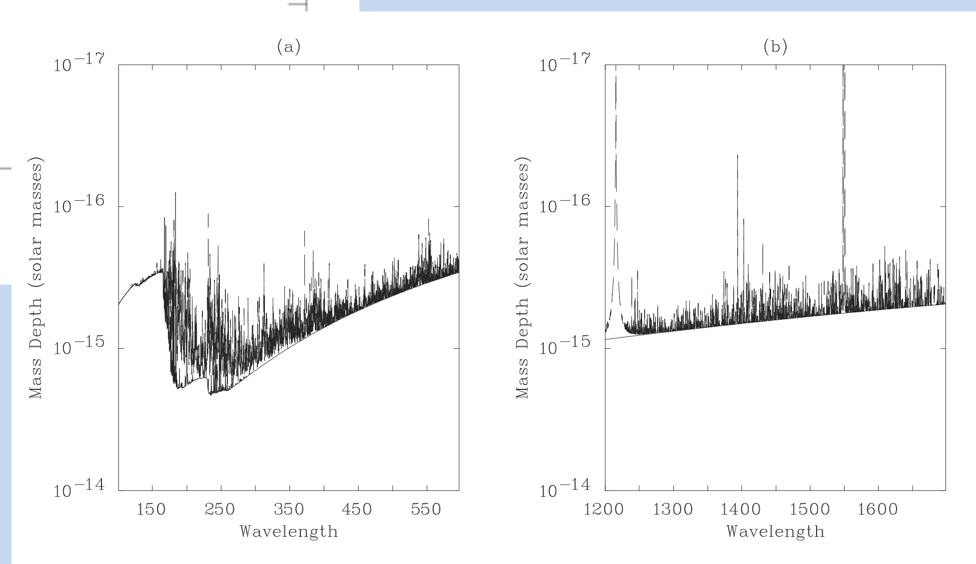
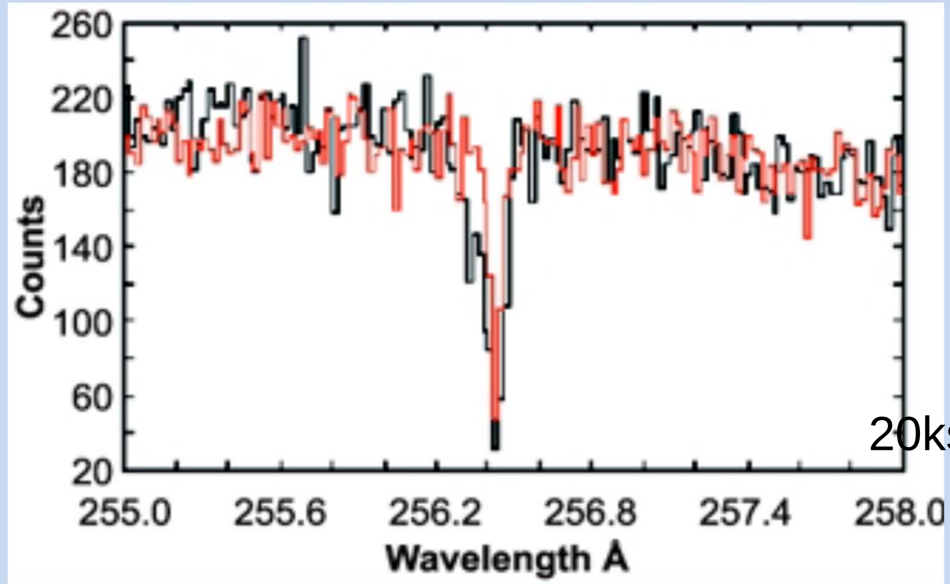
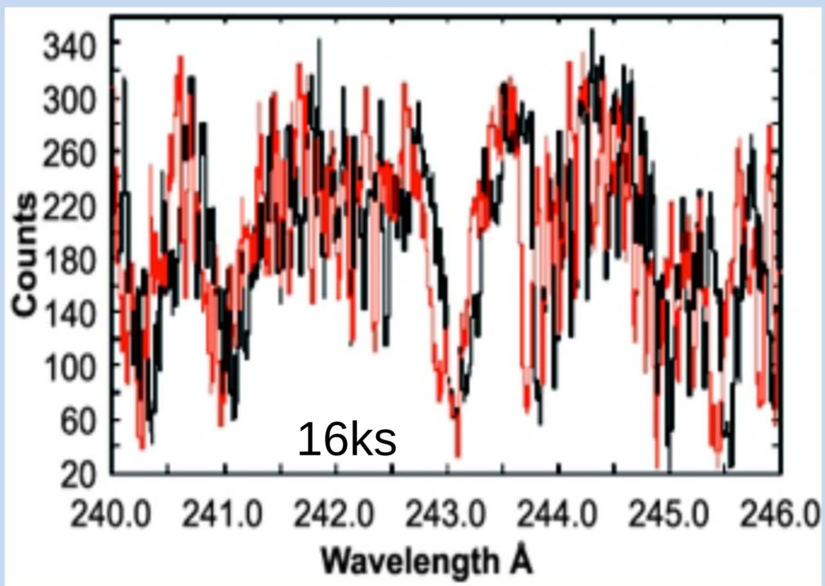
Van Maanen's star (1917)

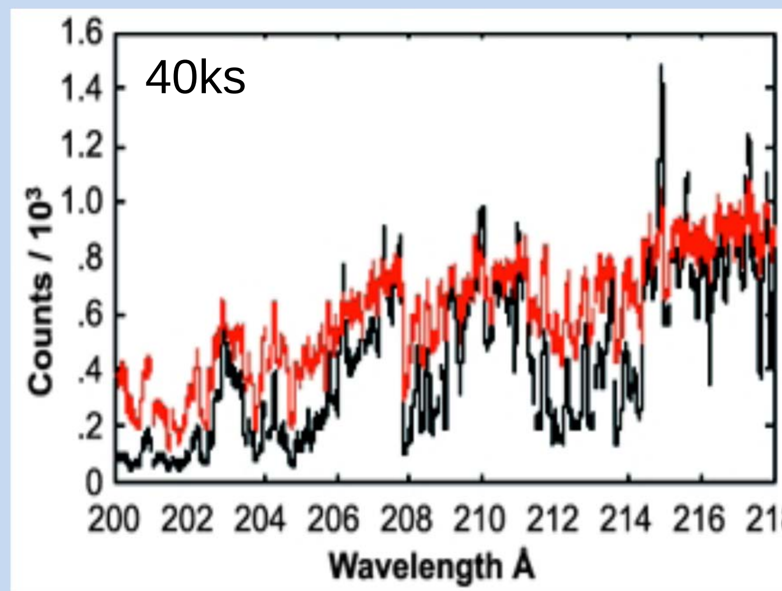




Capability


Counts
260
220
180
140
100
60
20
255.0
255.6
256.2
256.8
257.4
258.0
Wavelength Å
20ks

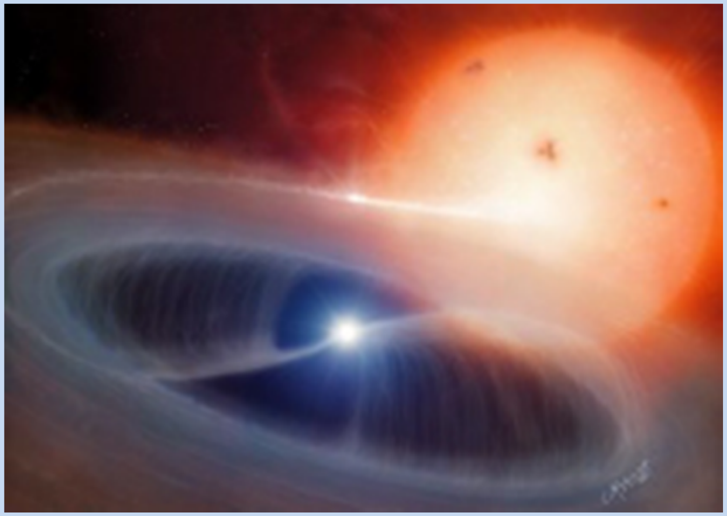

Counts
340
300
260
220
180
140
100
60
20
240.0
241.0
242.0
243.0
244.0
245.0
246.0
Wavelength Å
16ks

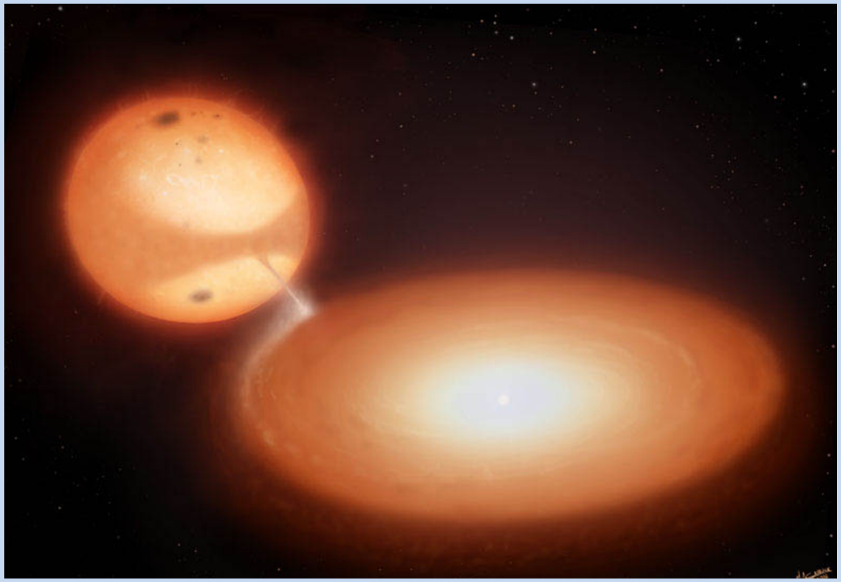

Counts / 10³
1.6
1.4
1.2
1.0
.8
.6
.4
.2
0
200
202
204
206
208
210
212
214
216
218
Wavelength Å
40ks

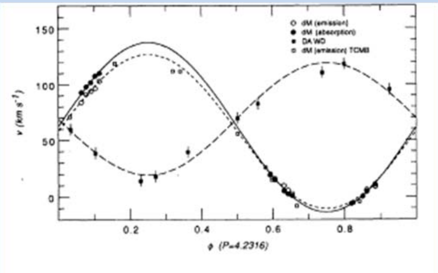
Interacting Binaries

E.g. Pre-CV Feige 24

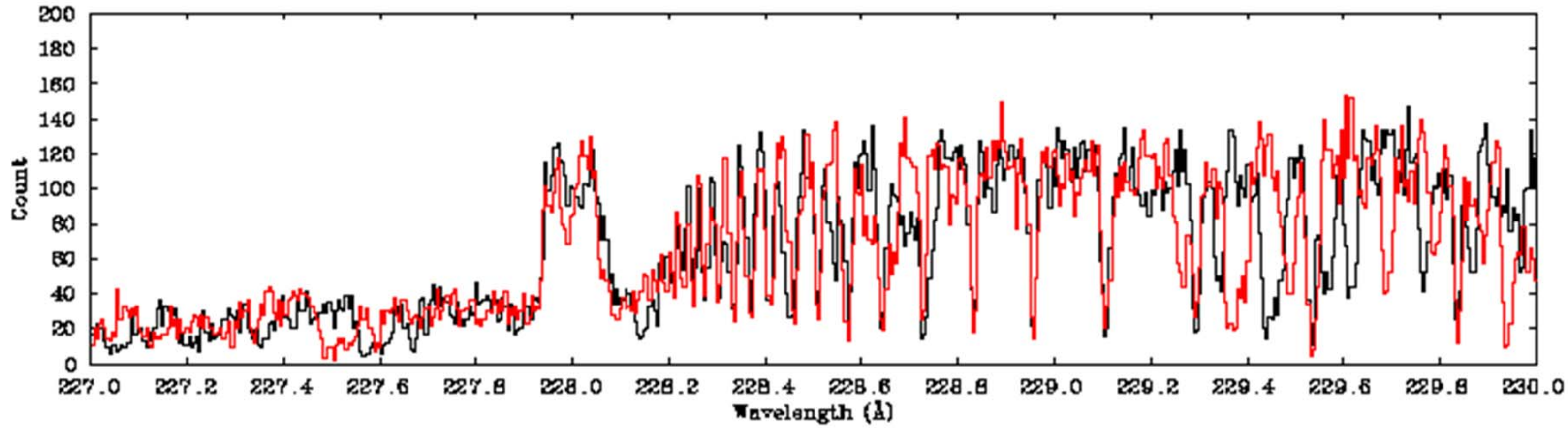
- Period = 4.23d
- $T_{eff}(wd)$ = 60,000K
- K_{wd} ~ 50 km s^{-1}
- γ_{total} ~ 70 km s^{-1}
- v_{ISM} ~ -10 km s^{-1}

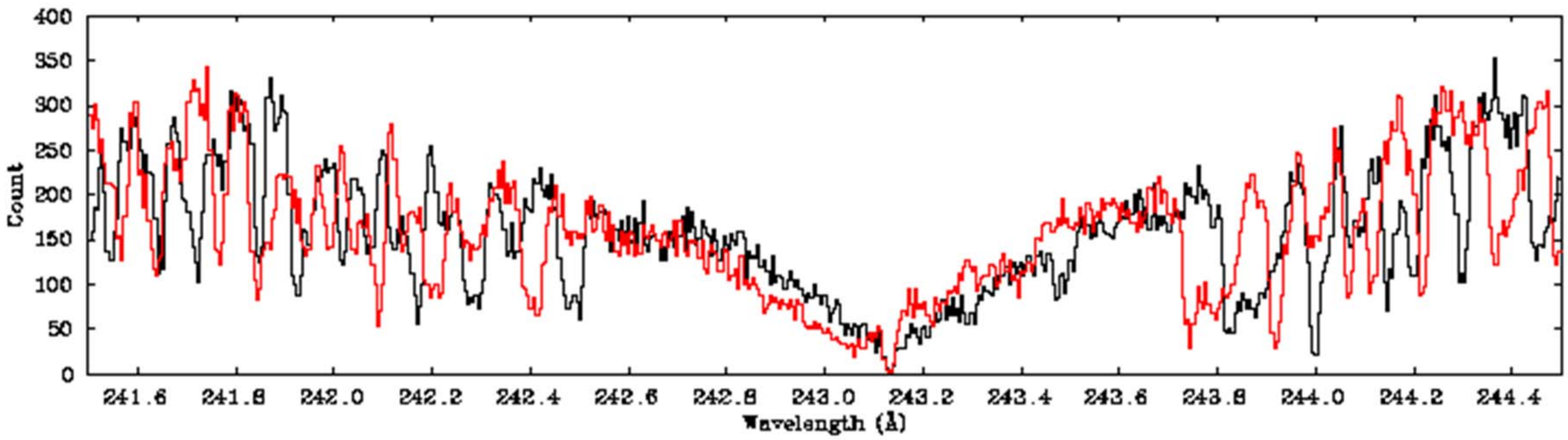






Feige 24 simulation, exposure = 4000s





SIRIUS – mission implementation

- Instrument – slitless, normal incidence off-axis EUV spectrograph
  - R~5000, peak $A_{eff} > 10\ cm^2$, λλ 180 - 240 Å
- Science goal – survey of stellar and galactic environments
- Programme – observations of ~100 stellar sources in 3 years, including long term monitoring of a subsample

Primary Scientific Objectives	Targets	Scientific Products
Examine the structure of Stellar Coronae	19 main sequence stars and giants	Shape of spectral line wings; constraints on heating models
Determine the effects of coronae on Planets	10 Planet hosting stars	EUV radiation levels and planetary irradiance
Observations of young stars	9 stars belonging to young associations	Distinguish between coronal emission/accretion stream
Investigate abundance anomalies	19 main sequence stars and giants	Determine the FIP effect; Ne/Fe abundance for dwarfs
Monitoring observations of Flaring stars	16 G-M stars	Measure flows and line widths of flares
Study the evolution of white dwarfs and surrounding material	40 white dwarfs	Abundances for hot white dwarfs; radiative levitation/diffusion balance; determine composition of planetary debris
Probe the structure of local interstellar gas	40 white dwarfs (same observations as for white dwarf evolution)	Determine He ionization fraction; measure He I abundance
Examine hot plasma effects	4 flaring stars	Doppler imaging
Further investigation of abundance anomalies in selected objects	19 main sequence stars and giants	Determine Fe/O abundance for distant dwarfs S/N permitting

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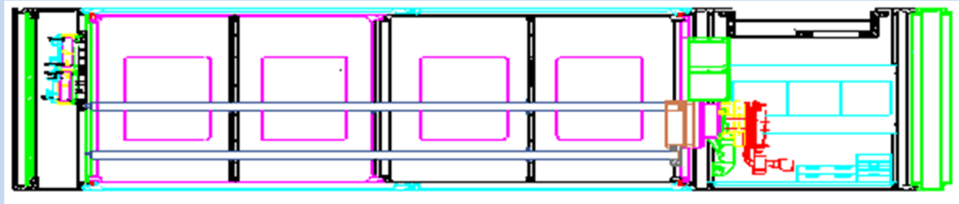

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Spectrometer subsystems & heritage

Subsystem	Heritage	TRL
Gratings	Hinode, J-PEX	7/8
MCP detectors	ROSAT HRI/WFC, Chandra HRI, J-PEX	7/8
Background filter	ROSAT, J-PEX	7/8
Collimator	Ginga, J-PEX	7/8
Optical tracking camera	J-PEX	7/8
Invar spectrograph structure	J-PEX	7/8
Detector vacuum door	SSULI, J-PEX	7/8
Front end electronics	ROSAT, J-PEX	7/8
Data processing electronics	ROSAT, J-PEX	7/8
High voltage supply (MCP)	ROSAT, J-PEX	7/8

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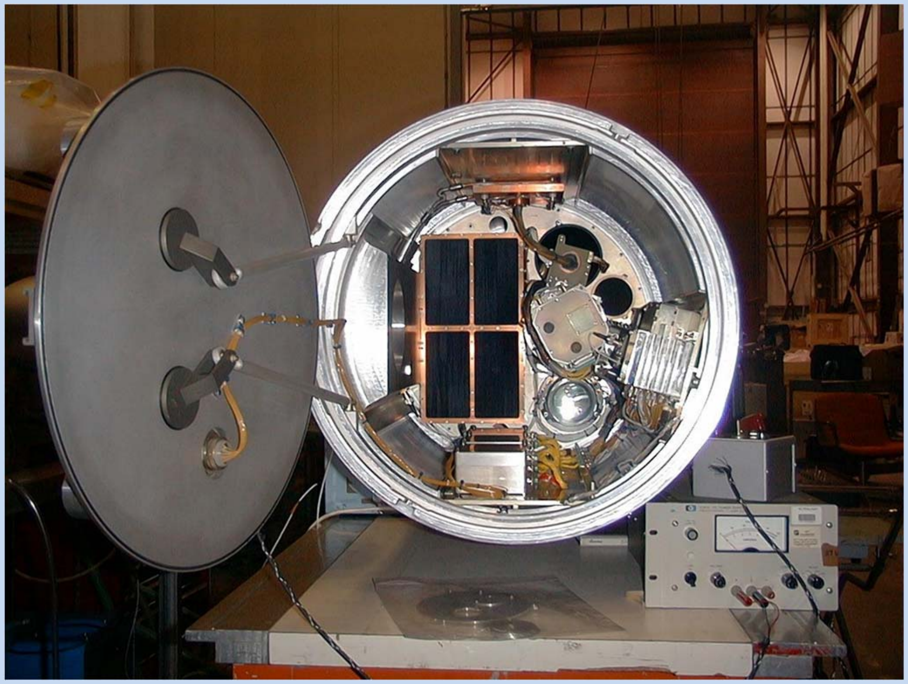
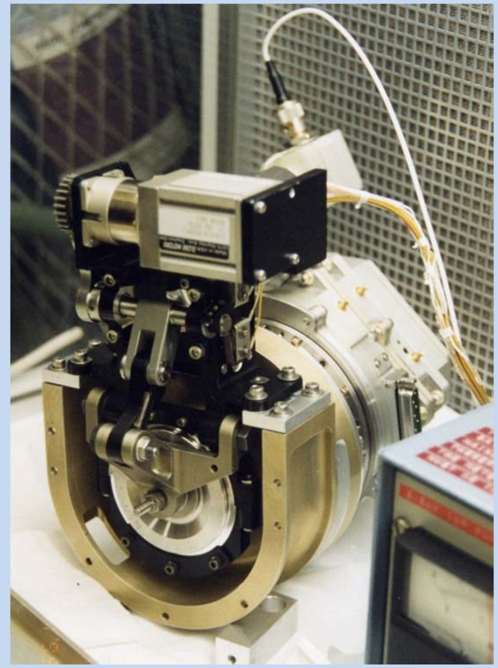
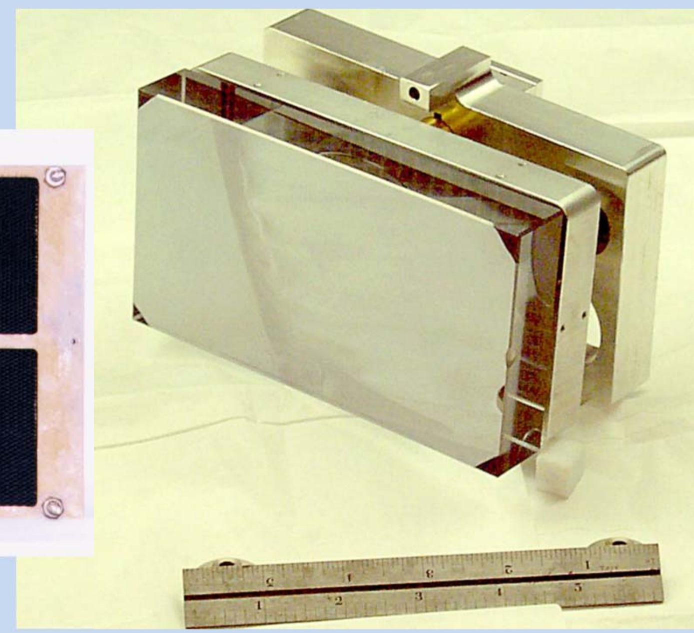
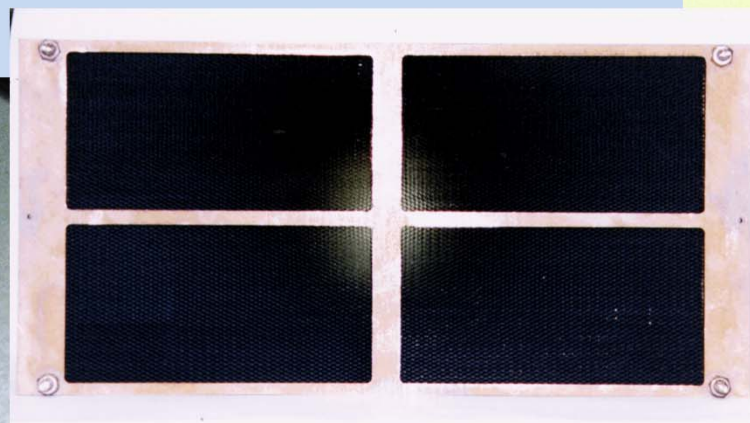


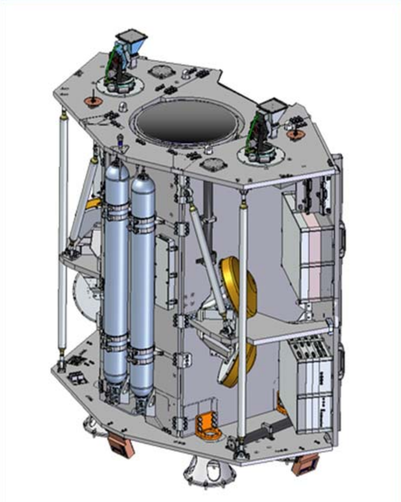


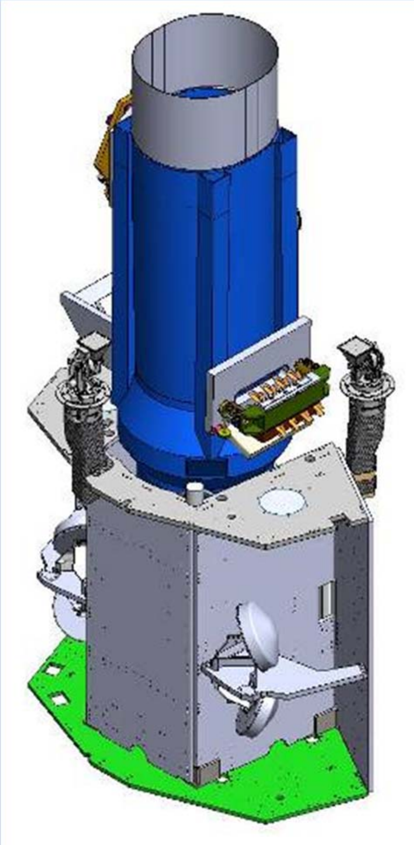


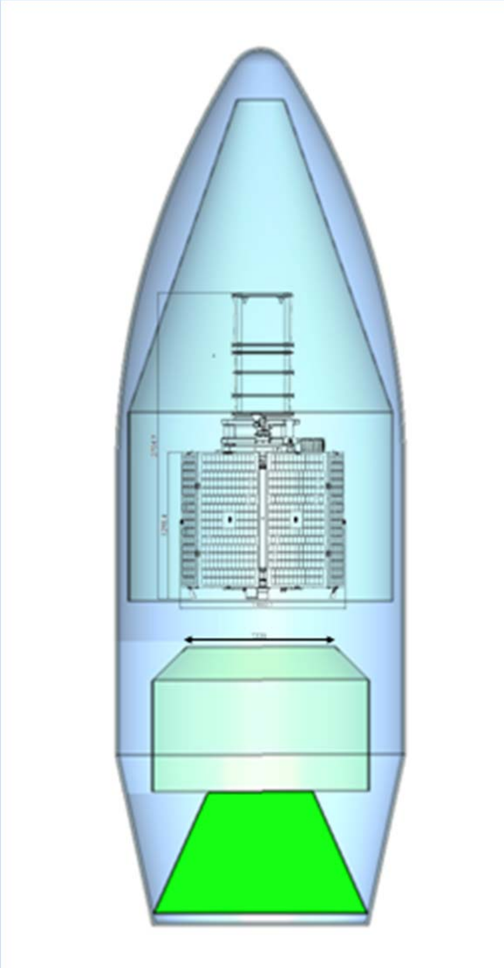


Assembled Satellite

SSTL 300







Vega Launch

Mission Summary

Category	Requirements
Launch Vehicle	Shared launch on Vega or Long March 2C/2D
Trajectory Design	Science Orbit: LEO, above 300km
Flight System	Design Lifetime: 5 years, nominal mission 3 years Payload: Mass 55 kg, Power 13.5 W Pointing: 3-axis,1 arcmin,1 arcsec/s stability Average Science Data Acquisition Rate: 20kb/s
Spacecraft Bus	SSTL-300 or Chinese
Data Return Strategy	Downlink Volume <1.2Gb per day, X-band
Telecommunications	ESA, China or UKSA
Ground Systems	2 contacts per day
Solar Array	1.66 m^2 Emcore BTJM triple junction GaAs cells
Propulsion (ACS)	24kg Xe, 32m/s delta-v at an Isp of 48s

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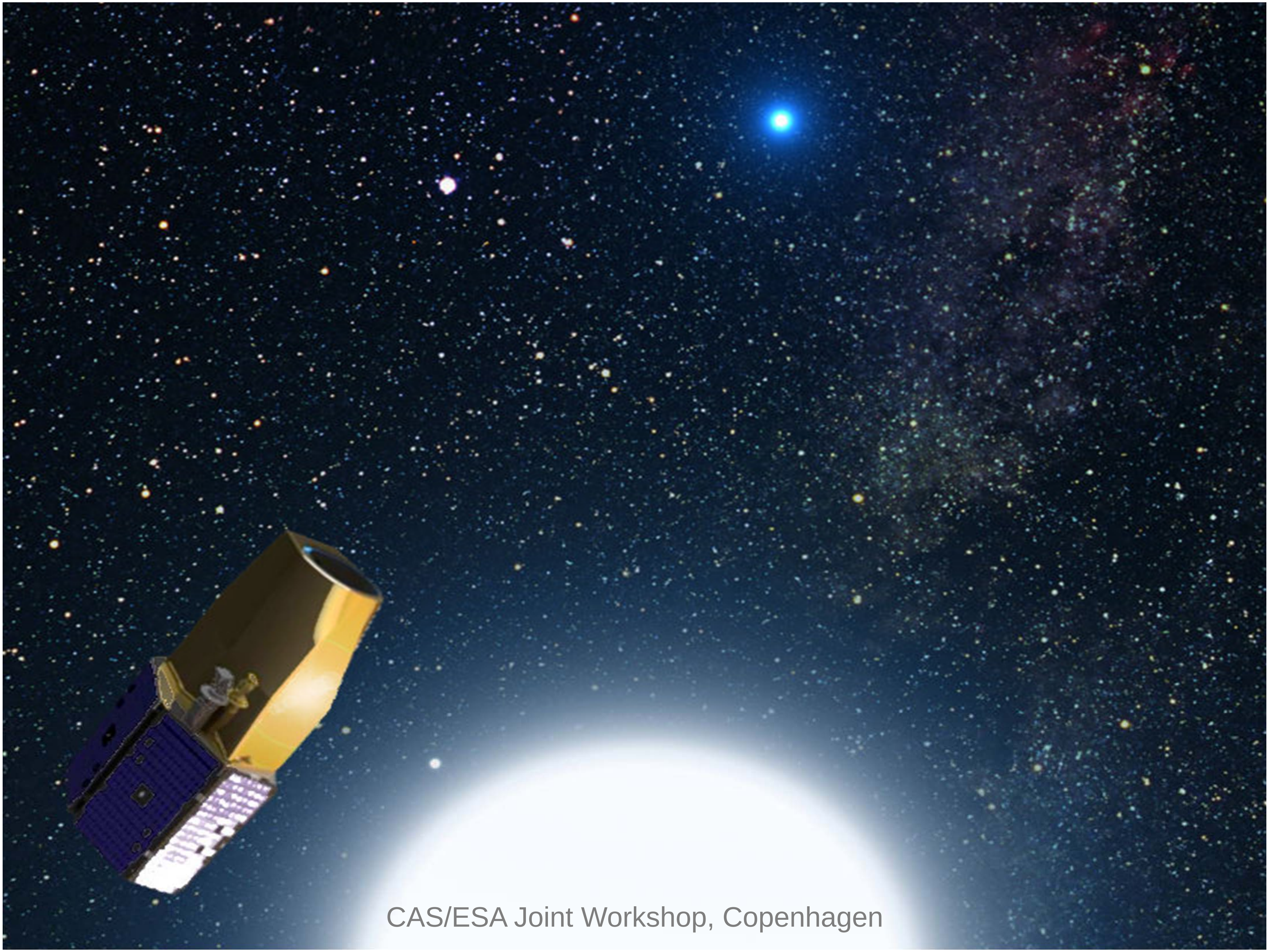
Possible responsibilities

- Opportunities for the EU
  - Gratings – Carl Zeiss, Horiba
  - Detectors – EU institutes, e2v, Photonis
  - Spacecraft – SSTL, Airbus
  - Launch, ground segment & operations
- Opportunities for China
  - Optical tracking telescope
  - Structure, collimator
  - Detector contribution, processing electronics
  - Spacecraft – TBD
  - Launch, ground segment & operations

Conclusion

- New technology & innovative design yield high sensitivity instrumentation… ITAR free
- New, unique science from a unique instrument
- Observatory-class science at low cost
- Study indicates our proposed SIRIUS EUV spectrograph feasible (within the defined parameters) for this joint opportunity
- Continuing discussions defining mission roles


CAS/ESA Joint Workshop, Copenhagen