EXPANDING THE FRONTIERS OF SPACE ASTRONOMY

ULLYSES Status Update

Julia Roman-Duval for the implementation team

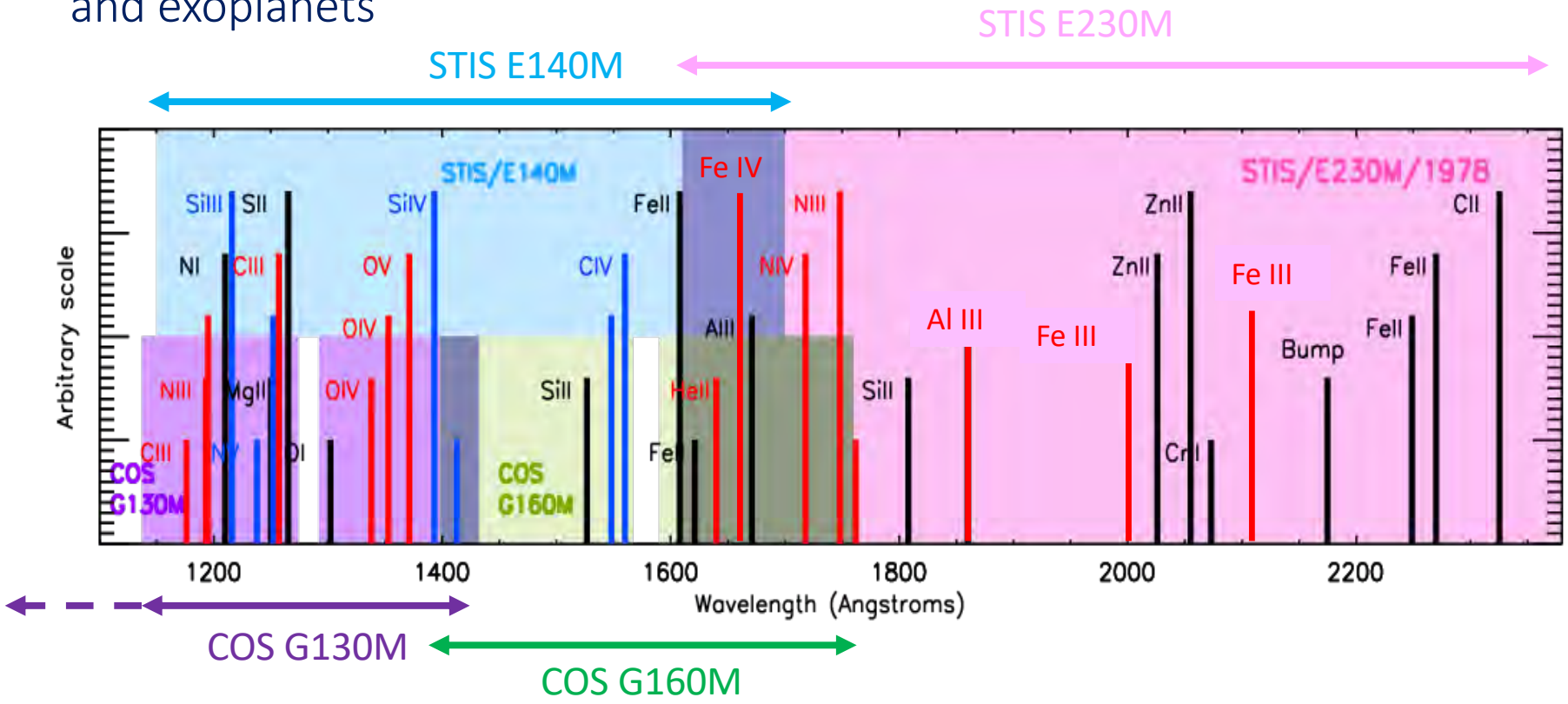
Recommendations from the Science Definition Working Group

ULLYSES: Scientific Goal

- The goal of the Hubble UV Legacy Library of Young Stars as Essential Standards (ULLYSES) is to provide a UV spectroscopic reference sample of high mass and low mass young stars
  - ULLYSES will extend the massive star parameter space to low metallicity (< 50% solar)
  - ULLYSES will extend the low mass star parameter space to lower mass (< 0.5 M_o)
- ULLYSES will invest ~1,000 HST orbits with COS and STIS to observe ~200 high and low mass young stars

ULLYSES: Scientific Goal

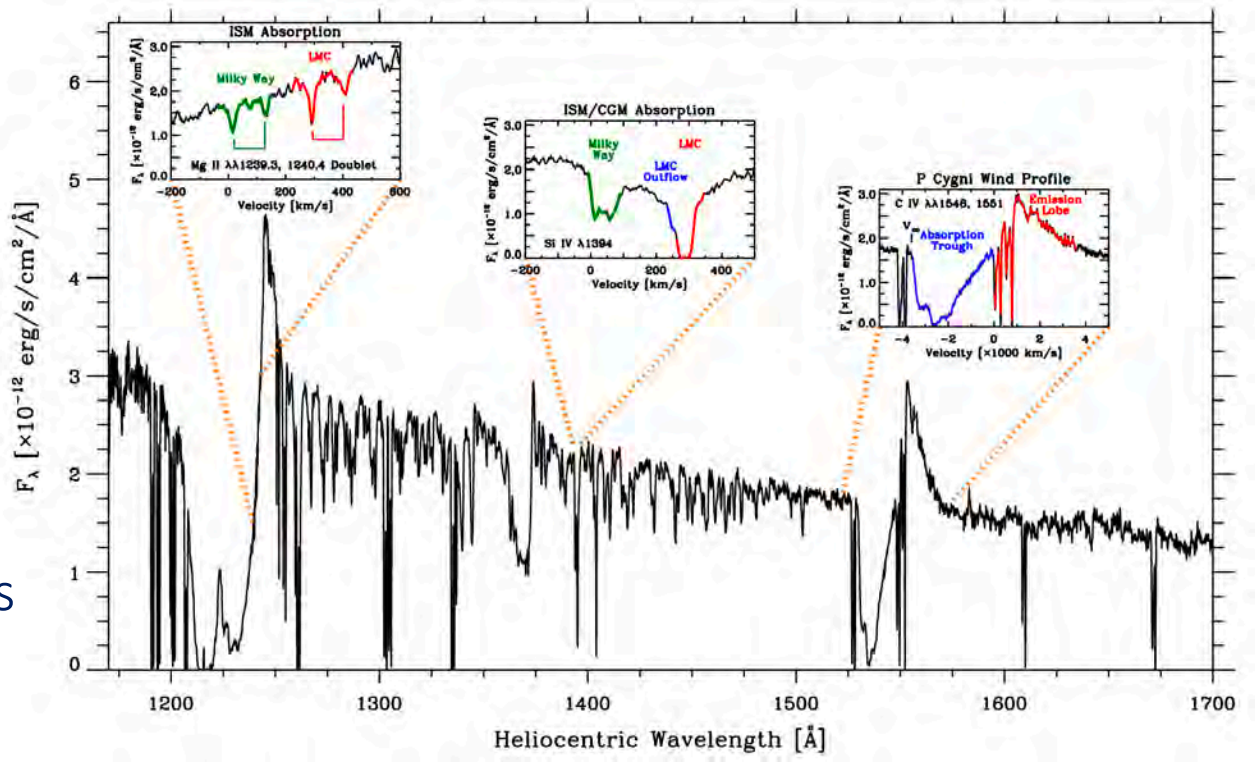
ULLYSES will enable legacy studies of the ISM (abundances, chemical evolution, dust depletions), CGM (galactic scale inflow and outflow), jets, and exoplanets



ULLYSES: Massive Stars

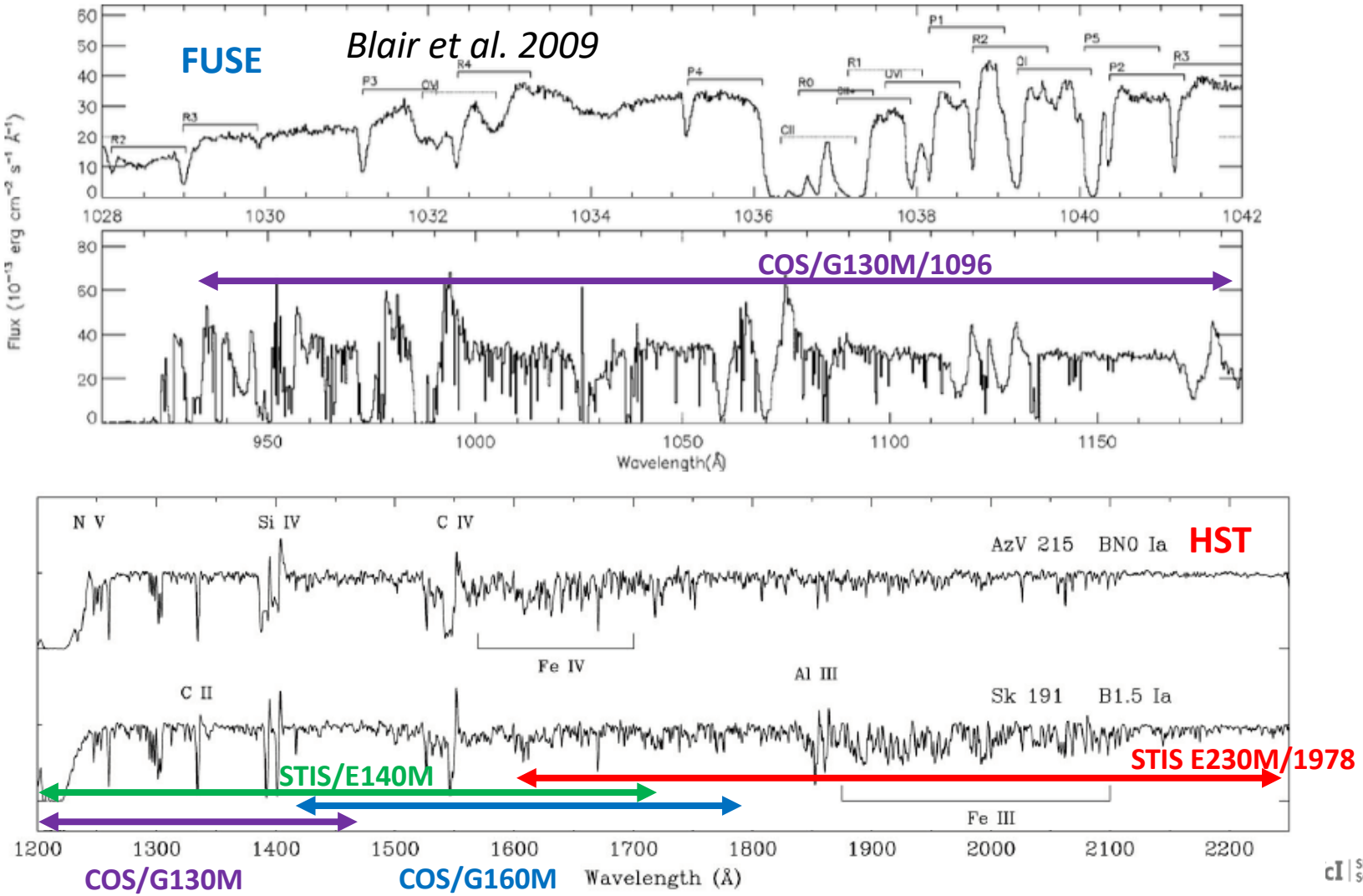
- ULLYSES will target massive stars:
  - ~140 massive stars in the Large and Small Magellanic Clouds
  - 5-10 massive stars in a few Local Group low-metallicity (<10% solar) galaxies (e.g., Sextans A and B with 12 + log O/H = 7.5, Sagittarius Dwarf SagDIG with 12 + log O/H = 7.4)

- Stellar wind properties, LyC luminosities, low metallicity stellar spectral templates for population synthesis
- ISM (abundances, depletions) and CGM (inflow/outflow) studies



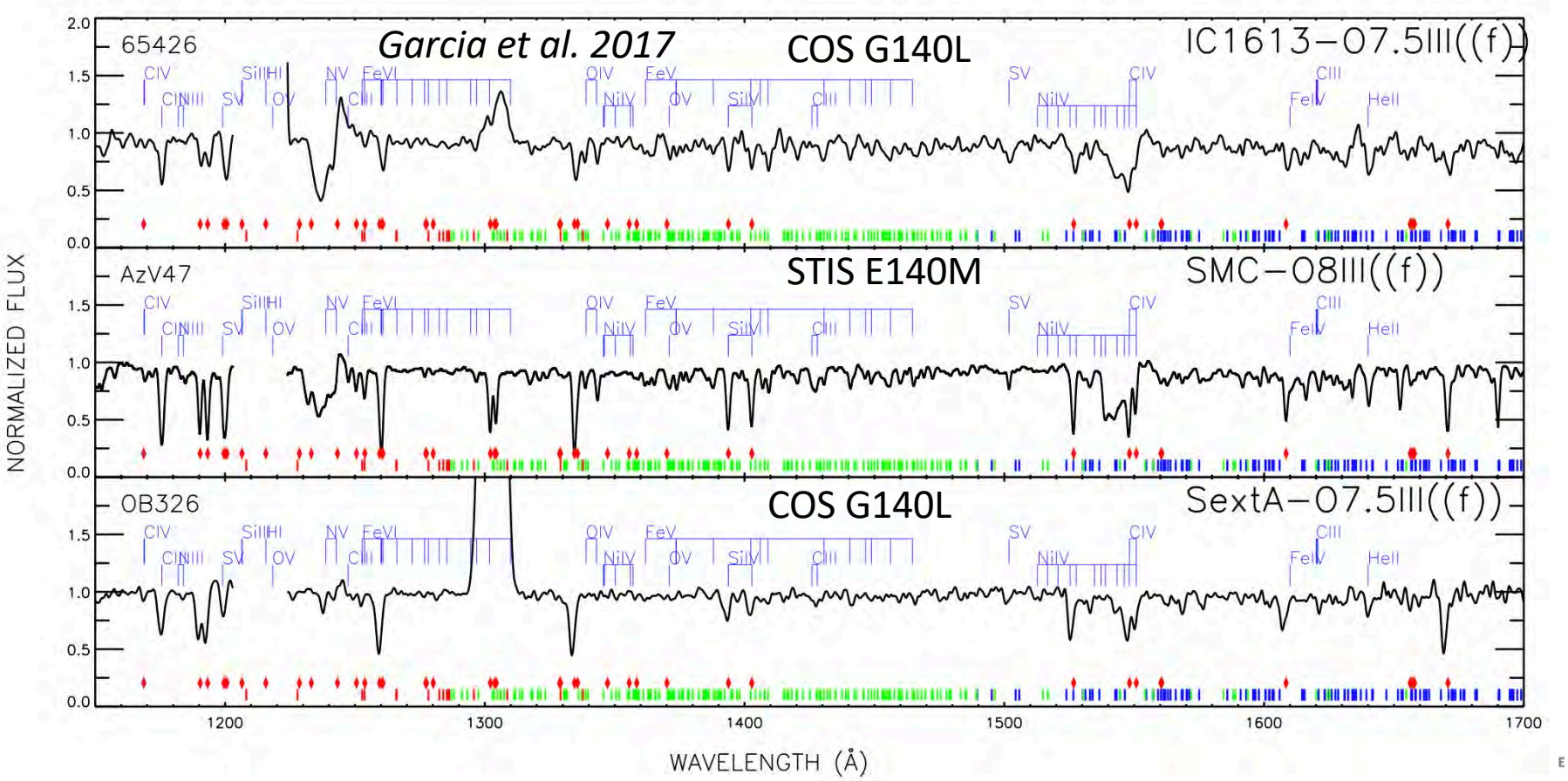
ULLYSES Scientific Motivation – High Mass Stars

- Stellar wind diagnostics in the FUSE/COS and COS/STIS spectral range



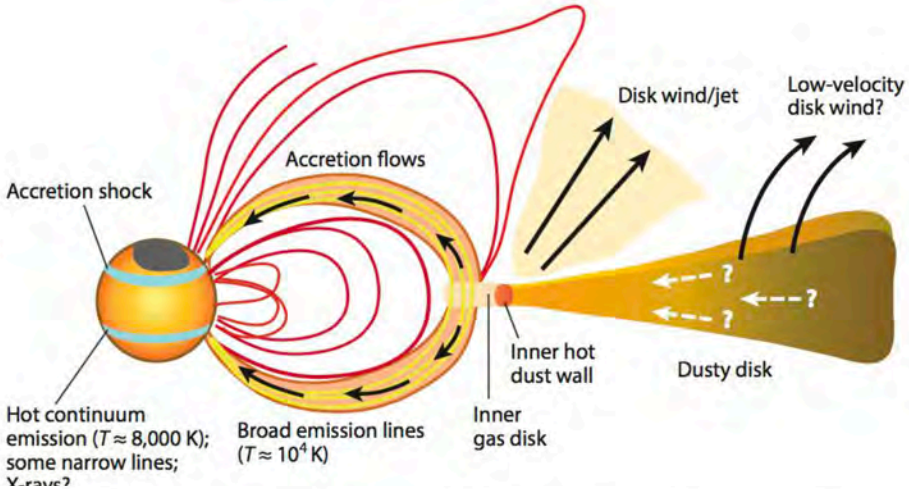
ULLYSES Scientific Motivation – Low Metallicity High Mass Stars

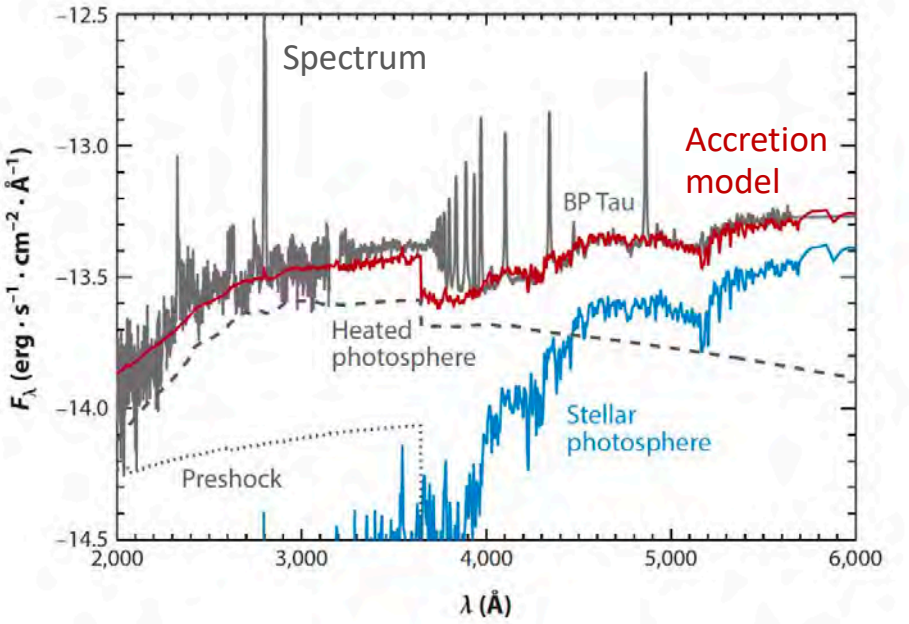
- Stellar wind properties vary significantly with metallicity
- Local group galaxies Sextans A, Sextans B, and SagDIG, possibly Leo-P with metallicities <10% solar are accessible to HST and can extend the stellar wind characterization to low metallicity



ULLYSES: Low Mass Targets

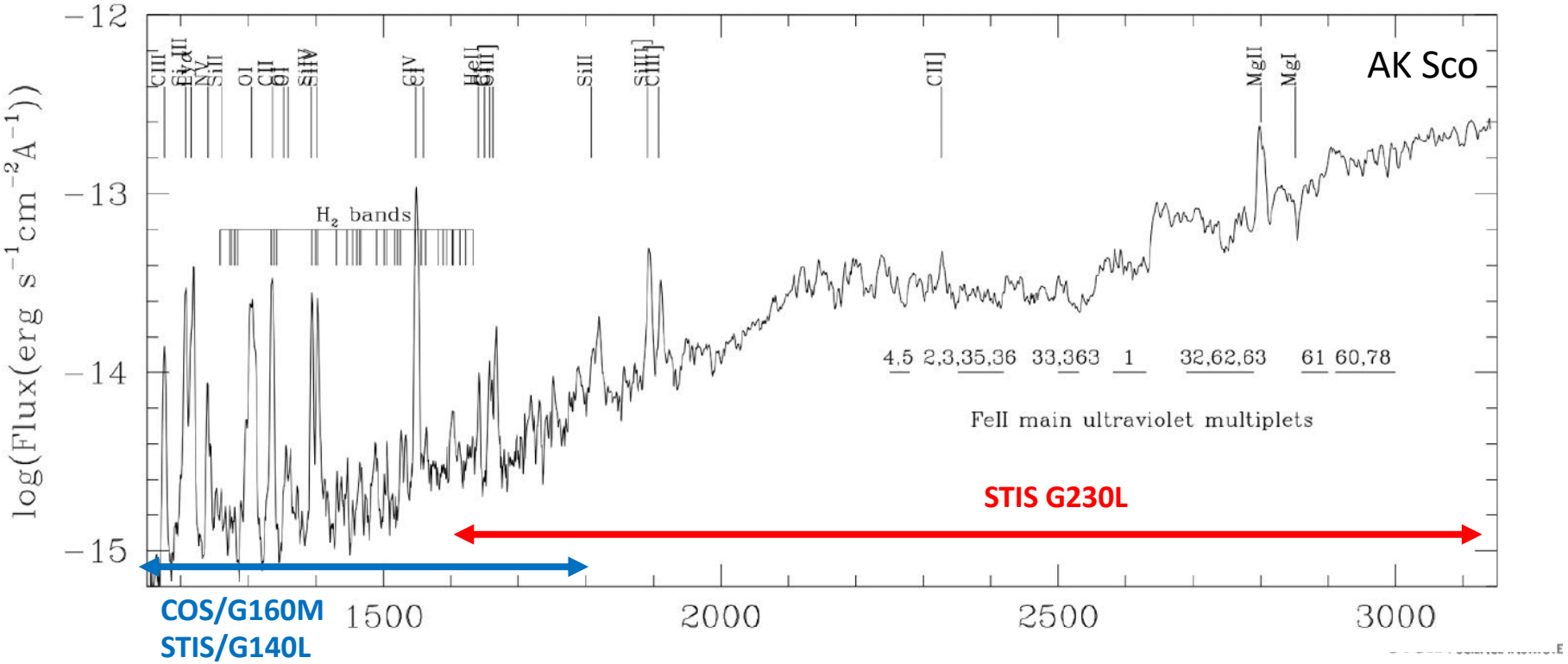
- ULLYSES will target low mass stars:
  - ~50 low mass young stars (<10 Myr, 0.05-1 M_o) in Chamaeleon I, Lupus, Ori OB, Upper Sco star forming regions
  - 4 typical T-Tauri stars, each observed 25 times (time monitoring)
  - Accretion and jet physics, disk evolution and dispersal, chemistry and planet formation





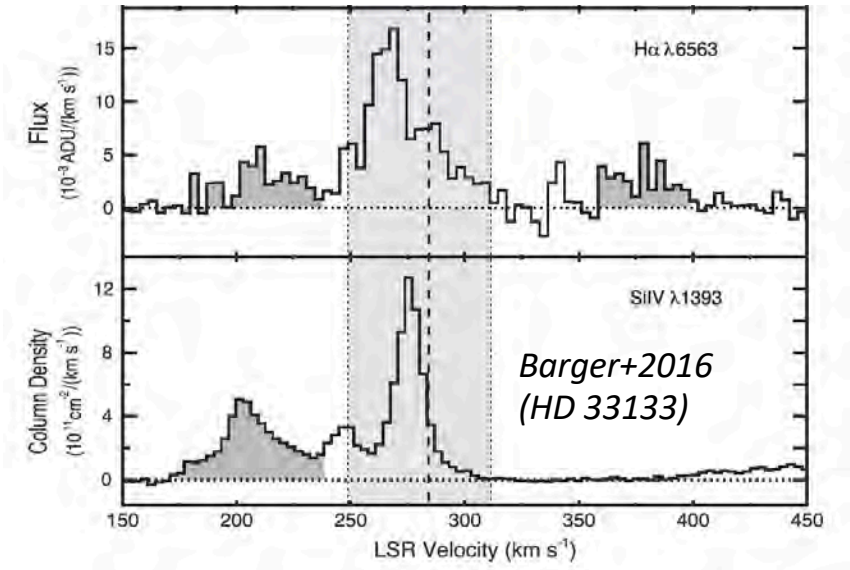
ULLYSES Scientific Motivation – Low Mass Stars

- Line diagnostics in the COS/STIS range (UV-optical)
- Accretion shocks: continuum, N V, He II, C IV, Si IV, Mg II, Fe II, C II)
- Jets: Si III], C III], O III], Fe II], C II]
- Disks: H_2

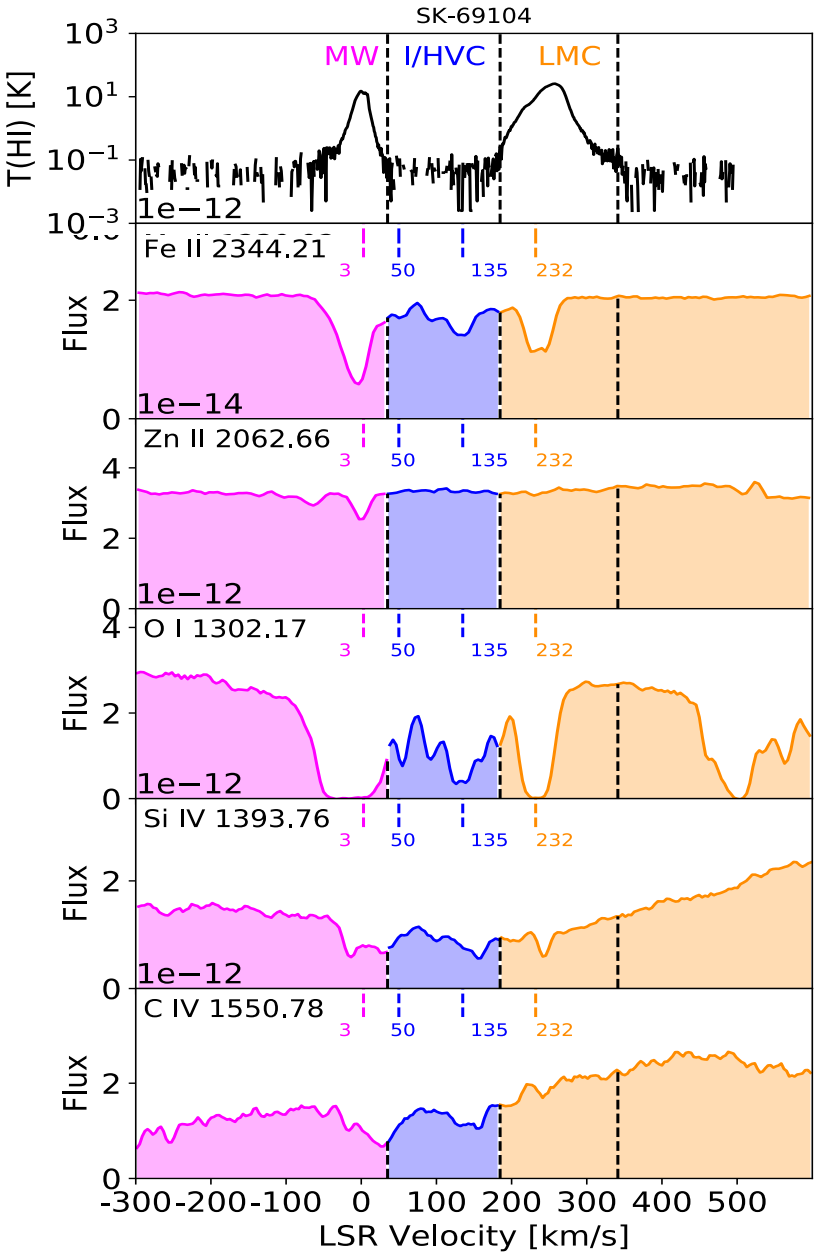


ULLYSES Scientific Motivation – ISM and CGM

- Interstellar abundances in neutral gas
- Dust and depletions (Fe, Si, Mg, Zn, Ni, S), baryon cycle of metals between the gas and dust phases, as a function of metallicity
- Dust extinction properties
- Inflow and outflow in/out of the CGM – kinematics and metallicity (C IV, Si IV), also combined with GASKAP surveys (21 cm)



Roman-Duval+2019



Implementation

ULLYSES – Implementation Team

Implementation Team Lead:

Julia Roman-Duval

Observing Technical Lead:

Charles Proffitt

Data Technical Lead:

Gisella De Rosa

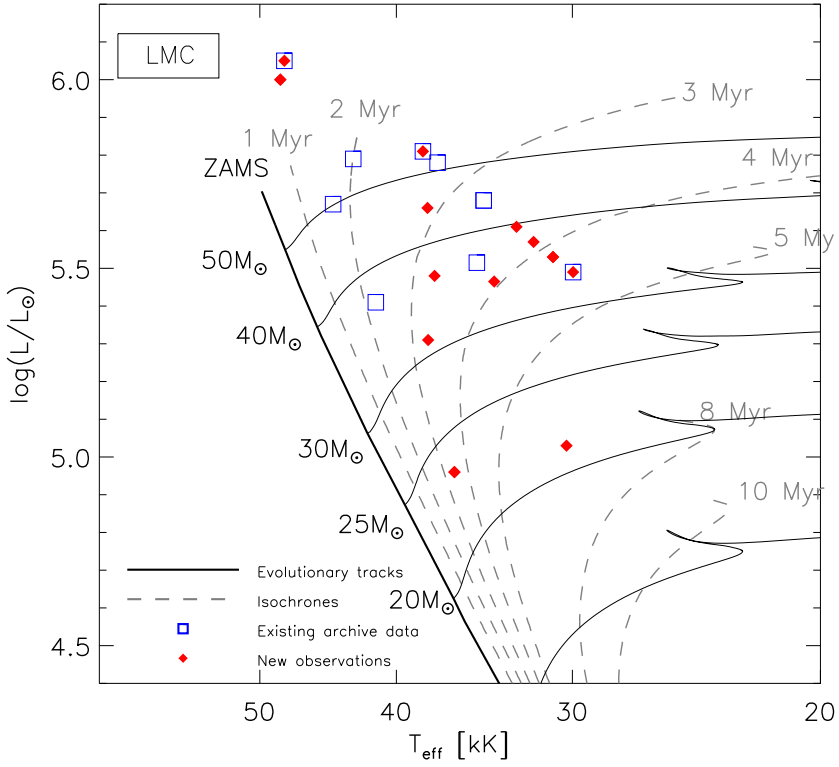
- The Core Implementation Team (CIT), composed of STScI staff, is being assembled by the three leads
- A Science Advisory Committee (SAC), composed of STScI and community experts, is being assembled by the CIT leads, HSTMO, and the Associate Director for Science
- The CIT lead has identified a set of critical skills for the implementation of ULLYSES
- The CIT lead has reached out to the STScI staff for volunteers with the relevant expertise and availability to commit time

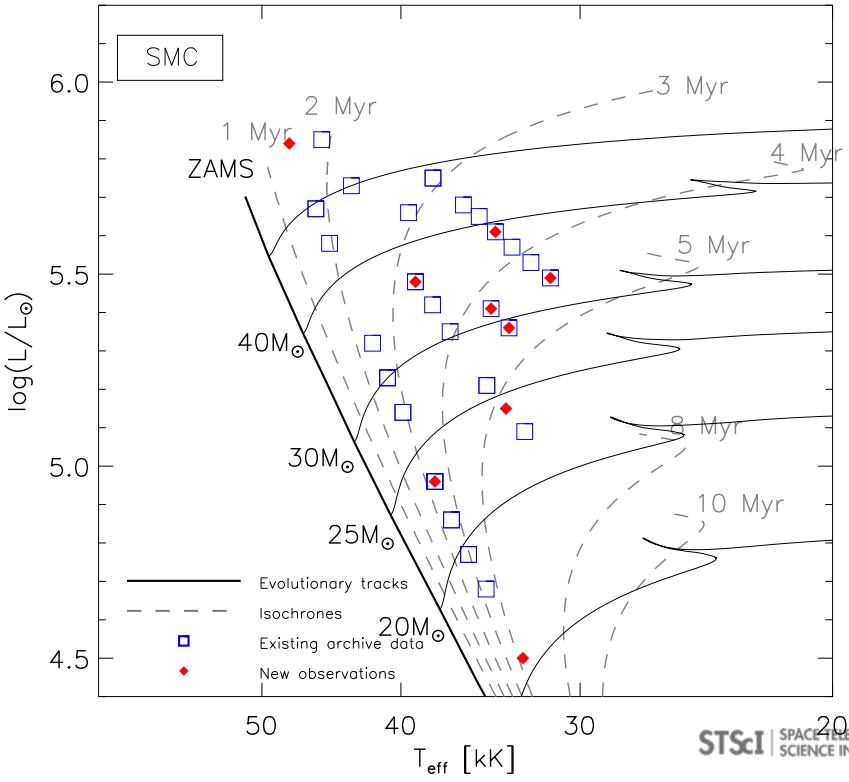
Near-term planning

- Finalize recruitment of CIT and SAC team members
- Prepare a detailed 3 year plan for:
  - Target selection
  - Search for archival and catalog data
  - Computation of exposure times
  - Phase II proposal preparation
  - Monitoring of execution and data quality
  - Generation of high-level science products
  - Development of analysis tools
  - Development of database and webpages
  - Public outreach
  - Communication with community

Target Sample: Massive Stars in the Magellanic Clouds

- Probe the first 10 Myr of stellar evolution
- Sample SpT uniformly (4/2 stars per Spt bin for SMC/LMC)
- ULLYSES will add 63/71 new targets to the existing 60/68 OB stars observed with HST, and add coverage below 1150 A for O stars, above 1800 A for B stars
- Also add spectroscopy of a few WN stars (1 in the SMC, 5 in the LMC)





Target Sample: Massive Stars in the Magellanic Clouds

- Verify tables provided by SDWG
- Check availability of FUSE and VLT spectra
- Explore back-up targets with more optimal archival coverage
- Compile IUE and other archival UV spectra, and catalog information (V, E(B-V) for scripted pysynphot calculations

LMC O stars

SpT/Lum Cl	?	IV-V	II-III	Iab
O2-2.5		AzV476#		
O3-3.5	AzV493# [M2002] 3173#	Sk183# (Lin 178#)		
O4	[M2002] 59319# (AzV80#)	AzV435# (AzV388#) (NGC346 MPG368#)		
O5-5.5		AzV14=Sk9# AzV377# NGC346 MPG342 [M2002] 25912#	(AzV296#)	
O6-6.5		[M2002] 14324# AzV133# [M2002]77368# [M2002] 51500#	[M2002] 69460 [M2002] 15271#	(AzV26=Sk18#)
O7-7.5	(Sk190#)	AzV114 [M2002] 9732 [M2002] 17240 [M2002] 67269 [M2002] 40380	AzV226# AzV15=Sk10# AzV491 (AzV77#) (AzV207#)	AzV26=Sk18# AzV232=Sk80
O8-8.5		NGC330 ELS 52 [M2002] 7782 [M2002] 5313 [M2002] 11045 [M2002] 35491	Az135# AzV186 AzV469=Sk148 AzV454=Sk142# SMC 2dF 1618	(AzV261#)
O9-9.7		SMC 2dF 2815 SMC 2dF 5040 NGC346 MPG213 (AzV326#)	NGC346 MPG217 (AzV307#) (AzV43#) (AzV454=Sk142#)	AzV372=Sk116* AzV70=Sk35* Sk101#* AzV490=Sk160#* Dachs SMC 1-14#*

SMC O stars

SpT/Lum Cl	?	IV-V	II-III	Iab
O2-2.5	(CPD=69 471#)	VFTS506# VFTS169 (BI237#) (BI253#)	Sk-70 91 (Sk-67 211#) (VFTS16#)	Mk42 (O2If) Mk39# (O2.5If*WN6) (Mk35# O2If*WN5) (Mk30# O2If*WN5)
O3-3.5		VFTS755 VFTS404# PGWM 3058#	(W61 7-7#)	TSWR3# (O3If) Mk51# (O3.5If*WN7)
O4	(Sk-67 105#)	VFTS586	Sk-67 69 (VFTS 603#)	Sk-67 167 (O4If) Sk-67 166 (O4If) R136b (O4If*WN8) (Sk-65 47#)
O5-5.5	(FWM 82#) (ST92 2-53#)	Sk-70 69 (Sk-70 79#) (PGWM 3120#)	PGWM 3100#	(N11-020#)
O6-6.5	(UCAC3 42-3081#) (BI214#)	Sk-66 18# PGWM 3204# (VFTS 96#)	N11-018# Sk-66 100 Sk-66 20# (VFTS 440#) (Sk-71 50#)	(Sk-70 115#)
O7-7.5	(Sk-69 50#) (Sk-68 112#)	Sk-67 118#	Sk-68 18# PGWM 3168# Sk-70 57#	W61 7-19#
O8-8.5		VFTS 168 (BI42#) (Sk-67 191#)		Sk-66 25# (Sk-67 168#) (Sk-68 155#) (Sk-71 41#)
O9-9.7		N11-061	N11-045#	Sk-69 124* BI170* Sk-66 16#* Sk-65 21* Sk-66 169* (Sk-69 279#)

LMC B stars

SpT/Lum Cl	?	IV-V	II-III	Iab
B0-0.7		NGC346 MPG310 NGC346 MPG304 NGC346 MPG64 NGC346 ELS27 NGC346 ELS39 AzV259	AzV349 AzV403 AzV192 [M2002] 30018 [M2002] 80412 = Sk167=AzV505 [M2002] 24213 = AzV 130	AzV235=Sk82* AzV356* AzV488* AzV420=Sk131* [M2002] 77609* = Sk161 = AzV492
B1-1.5		NGC330 ELS27 NGC346 ELS38 [M2002] 82711 [M2002] 80573 [M2002] 69769	NGC346 ELS21 [M2002] 28841 [M2002] 34315 = AzV 169 [M2002] 35474 [M2002] 83232	AzV86=Sk42* AzV264=Sk94* AzV242=Sk85* [M2002] 19728* = Sk46 = AzV96 [M2002] 50609* = Sk95 = AzV266
B2-2.5			AzV178	AzV472=Sk150* AzV56=Sk31* AzV443=Sk137*
B3-4			NGC330 ELS 18	AzV23=Sk17*
B5-6				
B7-8				AzV200=Sk69* AzV2=Sk3*
B9				AzV76=Sk39* AzV101=Sk47*
WR	AzV2a# (WN3ha)			

SMC B stars

SpT/Lum Cl	?	IV-V	II-III	Iab
B0-0.7		PGWM 3128 VFTS 469 VFTS 707	PGWM 1005 PGWM 1332	Sk-68 41* Sk-68 59*
B1-1.5		N11-086 N11-105	N11-110 N11-088	Sk-68 111* Sk-67 169* Sk-69 228*
B2-2.5				Sk-69 221* Sk-70 116* Sk-69 89* Sk-69 274*
B3-4				Sk-69 244* Sk-70 50*
B5-6				Sk-67 58* Sk-68 8*
B7-8				Sk-67 122* Sk-67 143* Sk-67 145* Sk-66 50*
B9				Sk-69 82* Sk-67 204*
WR	Sk-70 64 (WN3h#), HDE269015 (WN4o#), HD38344 (WN5h#), BE381 (WN9#*), HDE269582 (WN10#*)			

Target sample: Massive Stars in Low Metallicity Local Group Galaxies

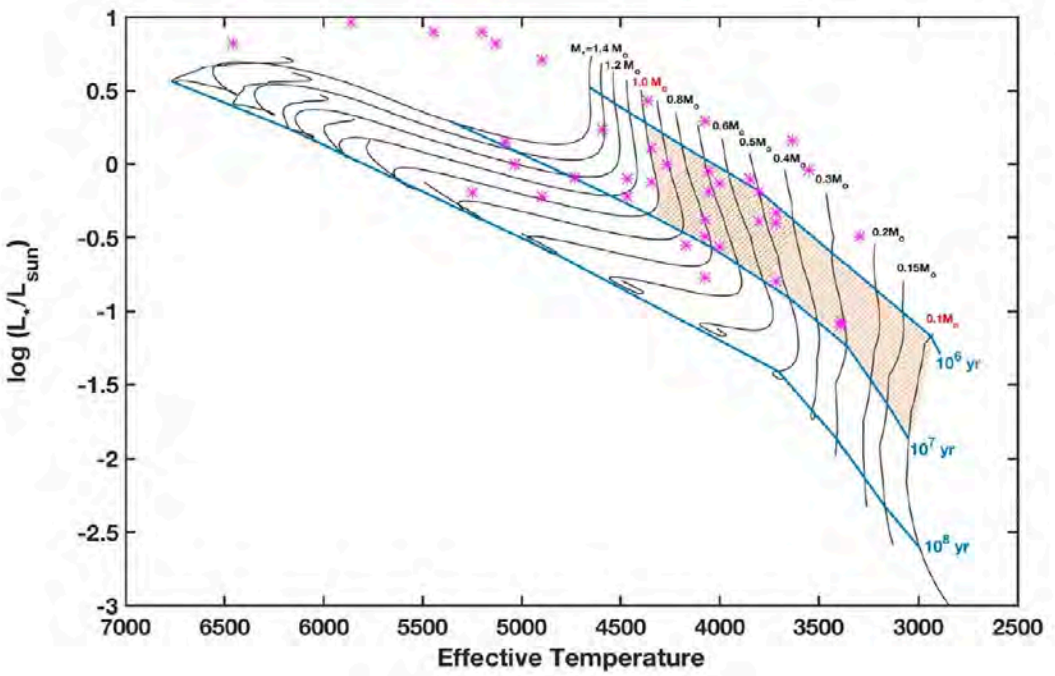
Sextans A, Sextans B and SagDIG are the only Local Group (d ~ 1 Mpc) galaxies with metallicities below 10% solar catalogued massive stars and SpT (based on optical spectroscopy with VLT and GTC)

Leo-P (d = 1.6 Mpc, 12 + log O/H = 7.2, McQuinn et al. 2015, Evans et al. 2019) has an O star that is bright enough for COS G140L observations

Galaxy	Star	SpT/Lum Class
SexA	s2	O3-5Vz
SexA	s4	O6Vz
SexA	s3	O9V
SexA	s1	O9.5I
Sag DIR	SD1	Late OI
Sag DIR	SD3	OBV

Target Sample: Low Mass Stars

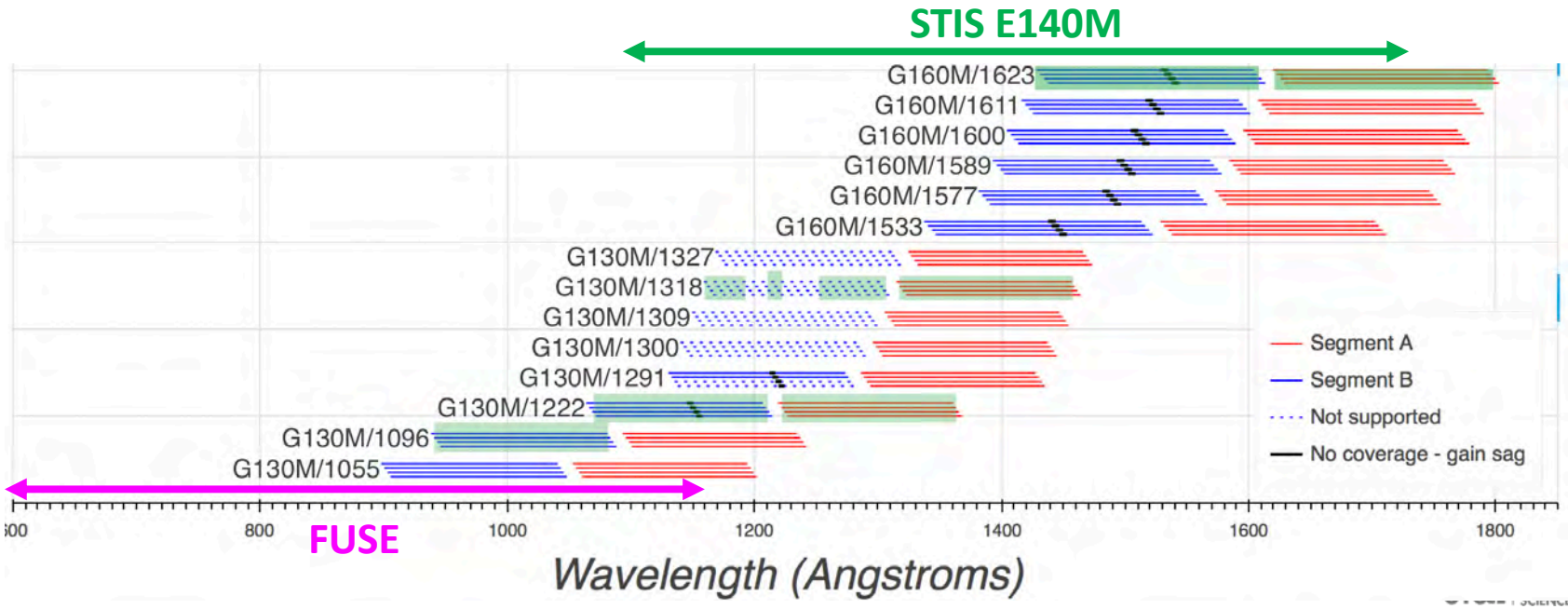
- Archive biased toward stars with M>0.5Mo in Taurus (1-2 Myr old)
- ULLYSES will expand the sample to lower mass (0.05-1 Mo) and in different star forming regions: Lupus, Chamaeleon I, Upper Sco, Ori OB1
- The CIT will select 4 typical T-Tauri stars sampling different magnetic field strengths and disk inclination for monitoring



Age (Myr)	Region	Spectral types	Mass Accretion Rates (log M_{SUN}/yr)	Possible # of targets
1-2	Chamaeleon I	K2-M5.5	-10 to -7.5	18
1-2	Lupus	K2-M4	-10 to -7.5	17
5 and 10	Ori OB1a,b	K5-M4	-10 to -8.5	14
7	Upper Sco	K4, M4	-10 to -9.5	2

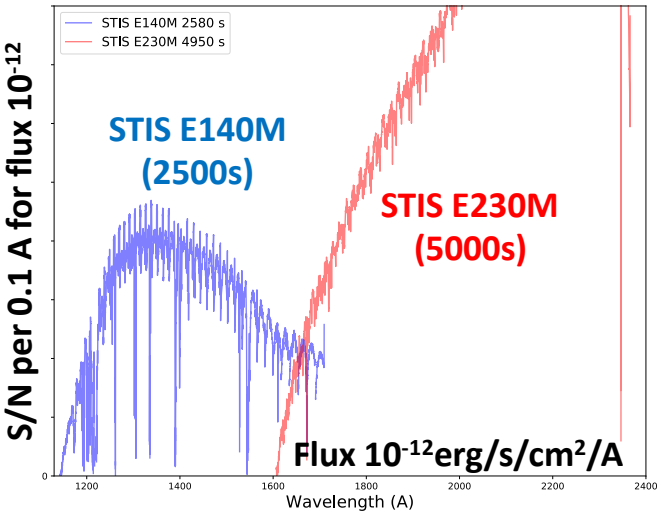
Observing Strategy for LMC/SMC Massive Stars

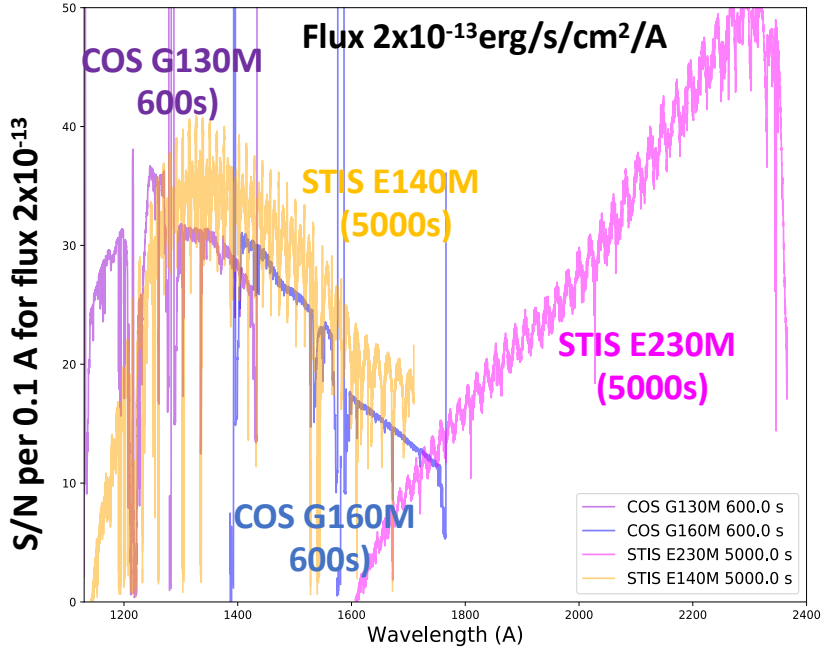
- The report recommends observing the massive stars across the full UV range with COS and STIS (250/200 orbits for the SMC/LMC)
- CIT leads envision the following modes:
  - COS G130M 1096 (bright O stars only), 1222, 1318 (LP3, for Lyman-α), G160M 1623; or COS G130M 1096, 1222 and STIS E140M
  - For late OB supergiants: add STIS E230M 1978
  - S/N = 30/resel for COS (R = 18,000), S/N = 20/resel for STIS (R = 30,000-45,000)



Observing Strategy for LMC/SMC Massive Stars

- STIS might be more advantageous than COS, even for relatively faint stars:
  - For stars with FUSE spectra, only λ>1150 A is required
  - Later OB stars must be observed with STIS E230M, so with overhead COS<->STIS, a star with flux $2x10^{-13}$ takes 4 orbits with COS (FUV)+STIS (NUV) and 5 orbits with STIS (FUV) +STIS (NUV)
  - Bright OB stars (>10^{-12}) can and should be observed with 1 orbit of STIS/E140M
  - Better resolution for ISM/CGM
  - Lyman-α covered by STIS/E140M (NOT COS at LP4)
  - Preserves limited COS lifetime

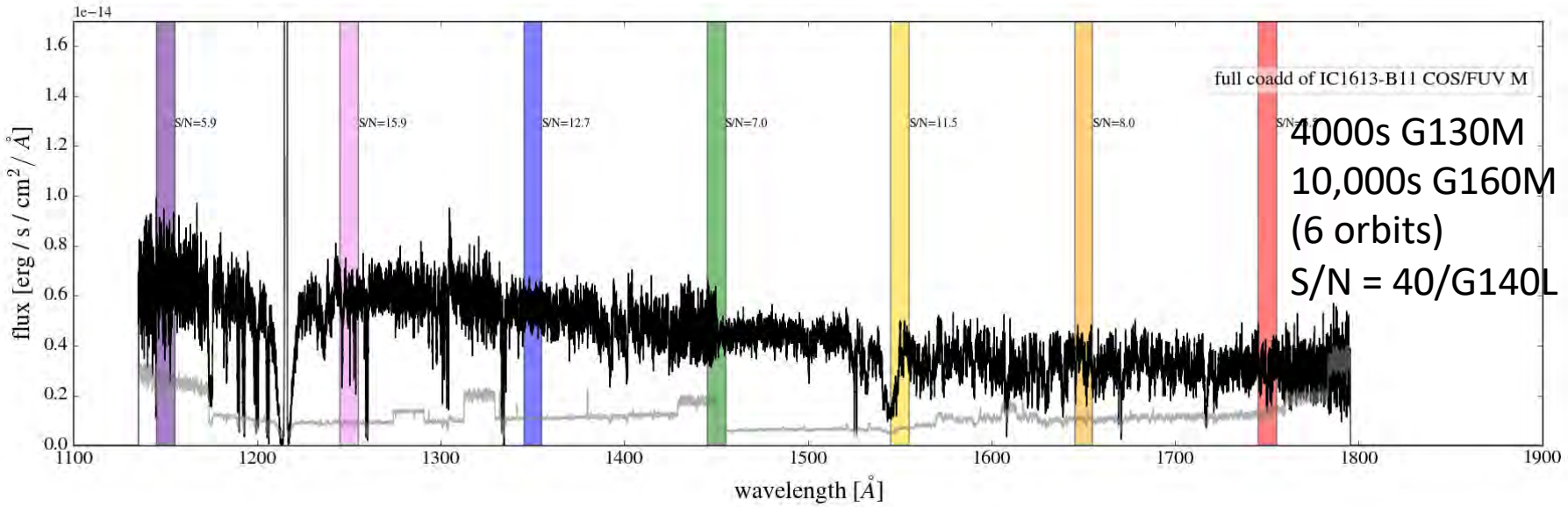




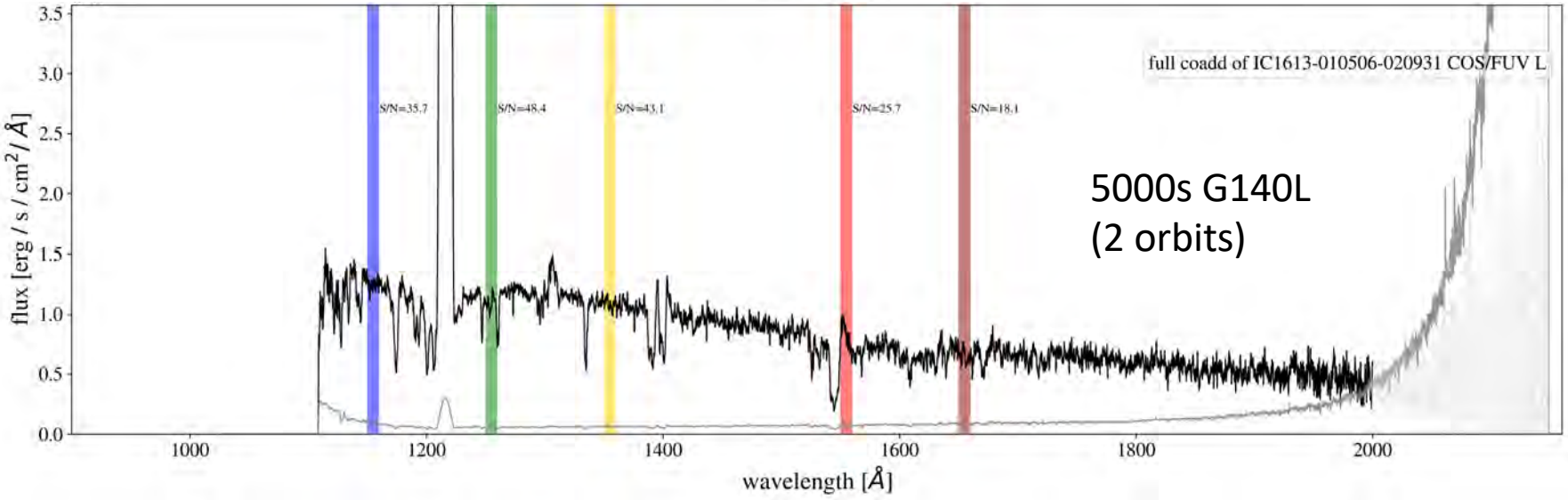
Observing Strategy for High Mass Stars in Low-Metallicity Local Group Galaxies

- 50 orbits available for 5-10 massive stars in Sextans A, Sextans B, SagDIG, possibly Leo-P
- The brighter O stars might be observable in 10 orbits with COS G130M + G160M (see, e.g., GO-15156)
  - Will enhance legacy value for ISM/CGM if doable
- Most of the stars will need G140L 800 to maximize wavelength coverage (900-1800 A)
- Some stellar field might require pre-imaging with WFC3 (F275W) to verify that the objects are individual stars and estimate their UV fluxes
  - Some imaging available from GO-15275, but some stars lie outside spatial coverage

Observing Strategy for High Sass Stars in Low-Metallicity Local Group Galaxies



4000s G130M
10,000s G160M
(6 orbits)
S/N = 40/G140L rese



5000s G140L
(2 orbits)

SCOPE
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Observing Strategy for Low-mass Star Survey

- 400 orbits will be allocated to observe ~50 young low mass stars
- FUV is critical to trace the accretion shock: COS G130M + G160M for the FUV, and the CIT will investigate whether some targets are observable with STIS/E140M
- Co-eval NUV-optical-NIR spectroscopy with STIS G230L, G430L, G750L (Balmer continuum emission)
- NUV-optical-NIR STIS long slit should be aligned with the jets
- The process for CS reviews and BOP clearing will be agreed upon with the instrument team, streamlined, and scripted to the extent possible (M-dwarfs are difficult to clear)

Observing Strategy for Low-Mass Star Monitoring

- Monitoring for 4 typical T-Tauri stars (25 observations each)
- Cover different phases of the orbital period, across three rotational periods
- Long-term changes tracked by observations on month-year timescales
- COS G160M to cover C IV, He II, H_2 with S/N = 30
- Short COS G230L exposures with S/N = 20 to measure NUV continuum
- The CIT will investigate whether STIS G230L are preferred in some cases, thanks to wider wavelength coverage and similar throughput

First thoughts on Data Products and Dissemination

- Co-added spectra within a grating, spliced spectra within an instrument (i.e., COS G130M and G160M coadds will be spliced, STIS E140M and E230M will be spliced)
- Zoomable quick-looks with S/N estimates (see, e.g., HSLA quick-looks) and metadata (target, SpT, R.A., DEC, V mag)
- The spectra will be searchable and accessible in a database, and from clickable/zoomable images
- Spectral images for low mass stars observed with STIS long slit
- Time-series for low mass stars monitored over time
- Acquisition images
- Ancillary data (VLT, FUSE, archival HST, X-ray, radio, optical etc.) will be available on the ULLYSES page, along with the ULLYSES data products
- Some overlap between the development of ULLYSES code infrastructure and tools and HSLA re-write and will coordinate with the relevant teams to avoid redundancy

Expected Role of the Science Advisory Committee

- Help prepare and review the target samples and observing modes to ensure optimal design
  - Large number of targets and variety of archival data will make this process somewhat complex
  - Many grating/cenwave combinations – SAC input/review will ensure that we have all the important diagnostics covered
- Provide input for which coordinated observations to perform, particularly for the low mass stars
  - Some members of the SAC may even have better access to facilities of interest (e.g., VLT for the Europeans) and may help coordinate those
- Review the CIT's definition and design of data products and methods for disseminating them (webpage, databases)

ULLYSES – Coordination of Target Selection with the Community

- Target samples listed here are recommendations from SDWG
- The CIT will coordinate final target selection with the SAC and the community, after the HST TAC results
  - **Step 1:** CIT will first prepare target samples that satisfy set of criteria (sampling requirements in SpT, luminosity class, A_V for massive stars; age, mass, accretion rate for low mass stars) and maximizes availability of archival data (e.g., FUSE for massive stars)
    - ➢ Start from the tables given by the SDWG and iterate using up-to-date catalog information and archives (HST, FUSE, ground-based facilities)
  - **Step 2:** In parallel, the CIT will release a call to the community to provide targets of interest given the science goals described in the SDWG
  - **Step 3:** The final target samples will be prepared using the initial targets from step 1, the target lists from the community (step 2), in coordination with the SAC through telecons and email communications
  - **Step 4:** The target samples will be released to the community so that they can start planning coordinated and related observations

Coordinated Observations for LMC/SMC Massive Stars

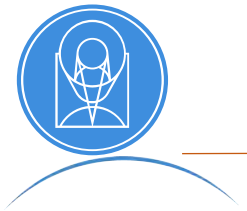
- Maximize overlap between ULLYSES samples and archival samples with VLT and FUSE
- Some targets required for the HR diagram sampling that do not have archival optical spectroscopy will need coordinated VLT/UVES observations (but co-eval scheduling is not required)
- The SAC will include stellar astrophysics experts with deep knowledge of optical spectroscopy to help coordinate these observations
- The target samples and observing schedules will be released to the community early on to allow preparation of independent coordinated and supplemental observations

Coordinated Observations for Low-Mass Stars

- The target samples and observing schedules will be released to the community early on to allow preparation of independent coordinated and supplemental observations
- Co-eval observations are more critical for low mass stars than massive stars, so we will front-load massive stars observations to allow for more time to prepare coordinated observations of low mass stars
- Very preliminary thoughts on coordinated low mass star observations:
  - Chandra
  - XMM
  - SWIFT
  - Spitzer
  - mm/radio (ALMA, VLA)
  - Spectro-polarimetric observations (magnetic field)
- Updates on data execution will be provided to the community routinely (email, website, social media)

Preliminary Schedule

- End of May 2019:
  - CIT assembled
  - SAC assembled
  - Call to the community for targets of interest
- September 2019: Final target selection and release to the community
- November 2019: Cycle 27 Phase II for the massive stars and provide instrument teams with photometry, SpT, relevant fluxes, archival spectra, Excel spreadsheets for BOP reviews (particularly M dwarves)
- December 2019: Cycle 27 Phase II for low mass stars
- ULLYSES will execute over 3 years
- Quaterly updates to the community (via social media, website, email)



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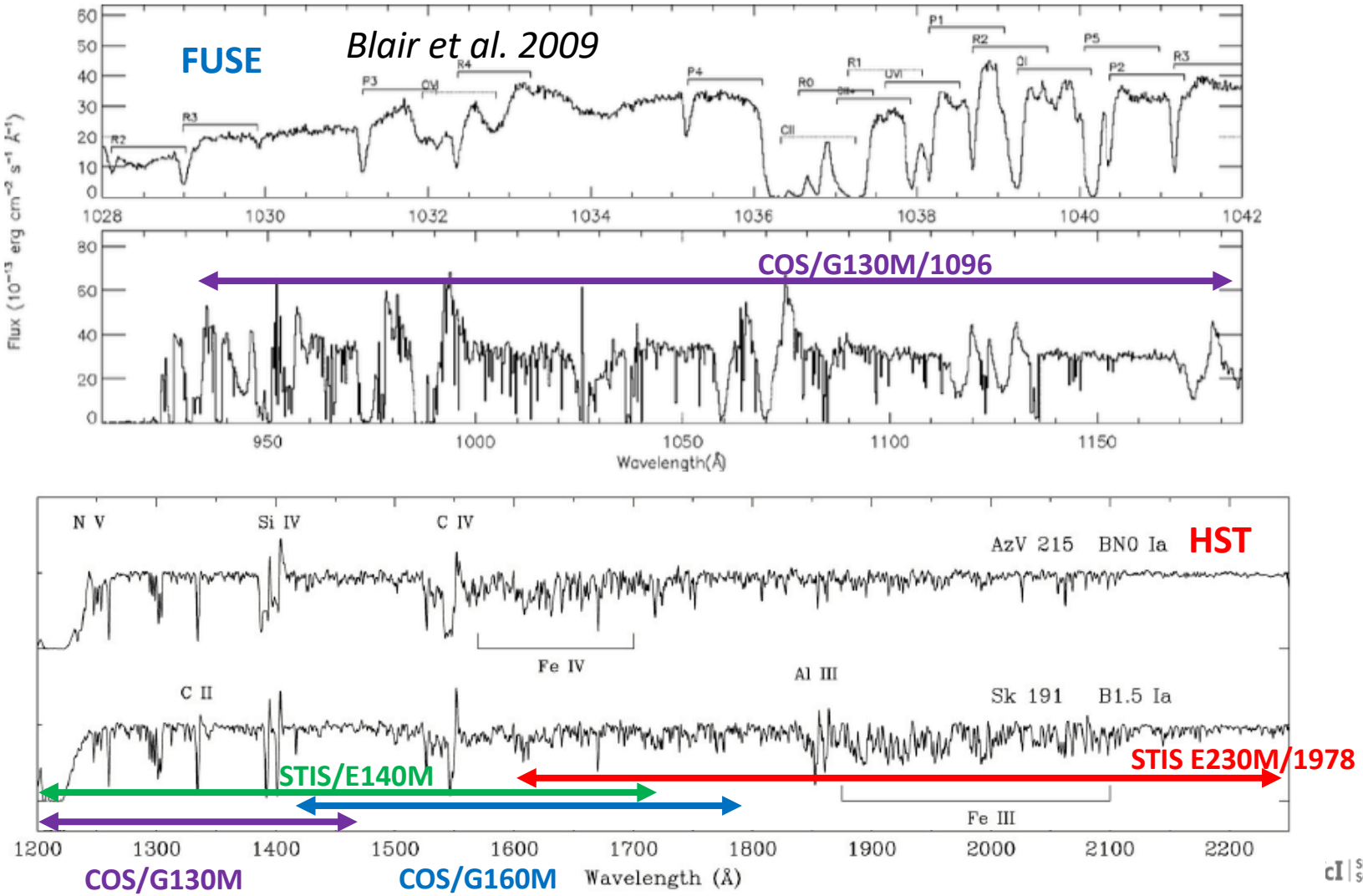
- Stellar wind diagnostics in the FUSE/COS and COS/STIS spectral range



ULLYSES Scientific Motivation – Low Metallicity High Mass Stars

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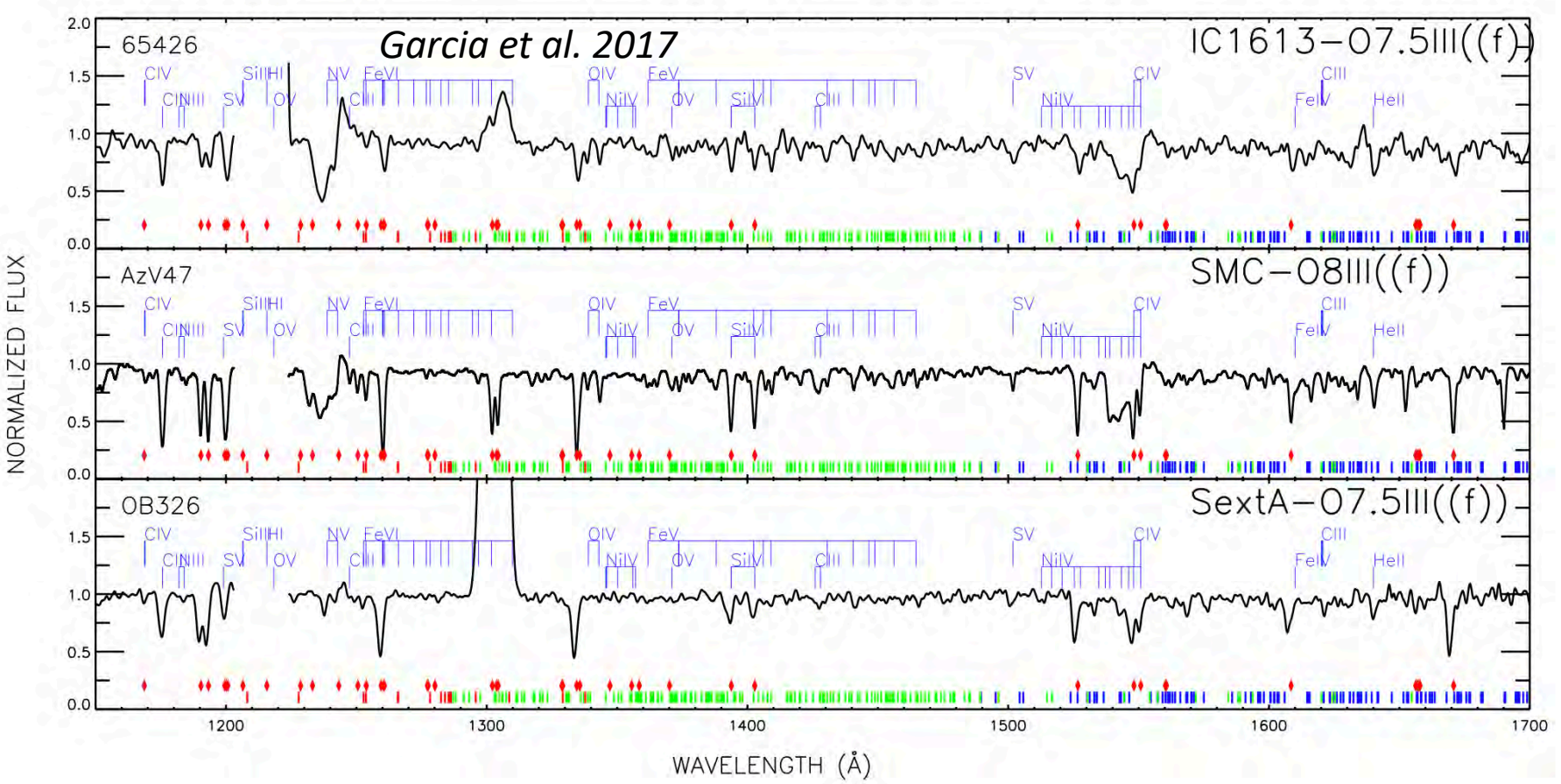
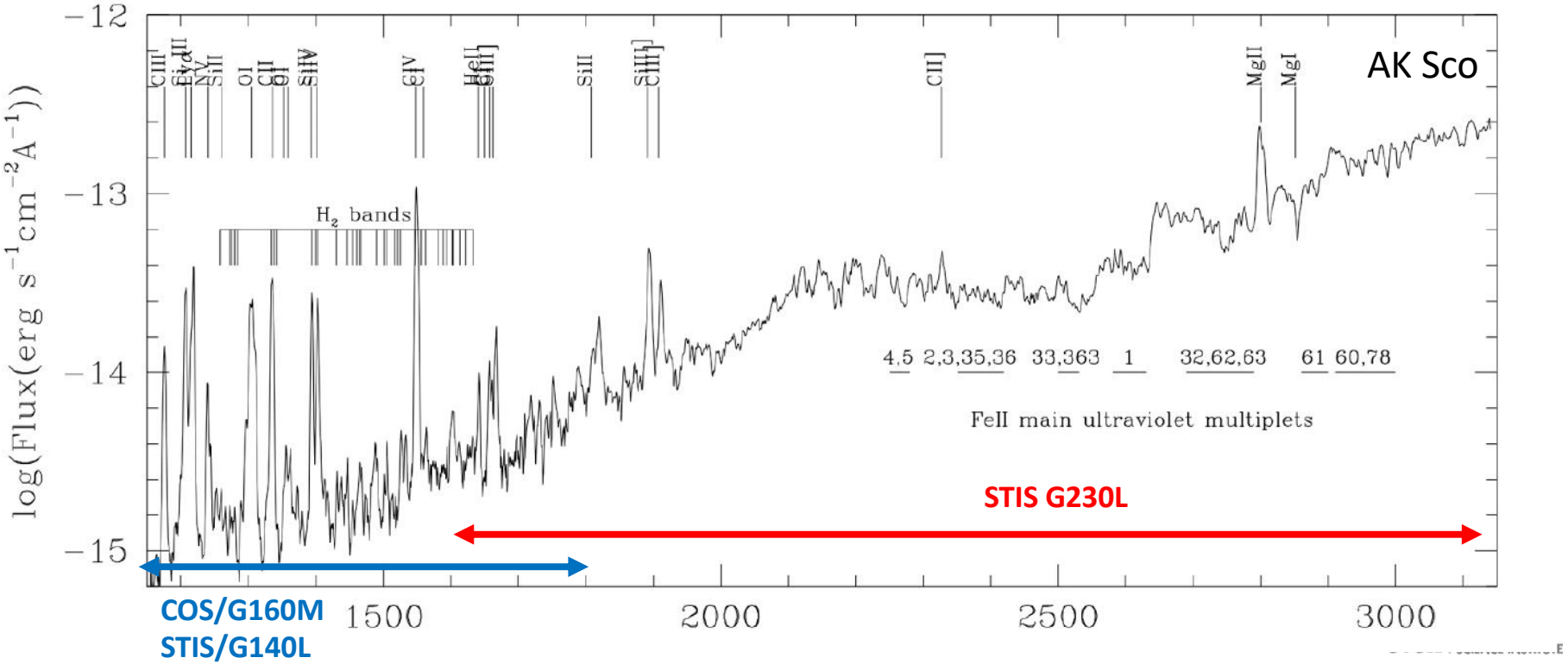
- Local group galaxies Sextans A, Sextans B, and SagDIG, possibly Leo-P with metallicities <10% solar are accessible to HST and can extend the stellar wind characterization to low metallicity



ULLYSES Scientific Motivation – Low Mass Stars

- Line diagnostics in the COS/STIS range (UV-optical)
- Accretion shocks: continuum, N V, He II, C IV, Si IV, Mg II, Fe II, C II)
- Jets: Si III], C III], O III], Fe II], C II]
- Disks: H_2

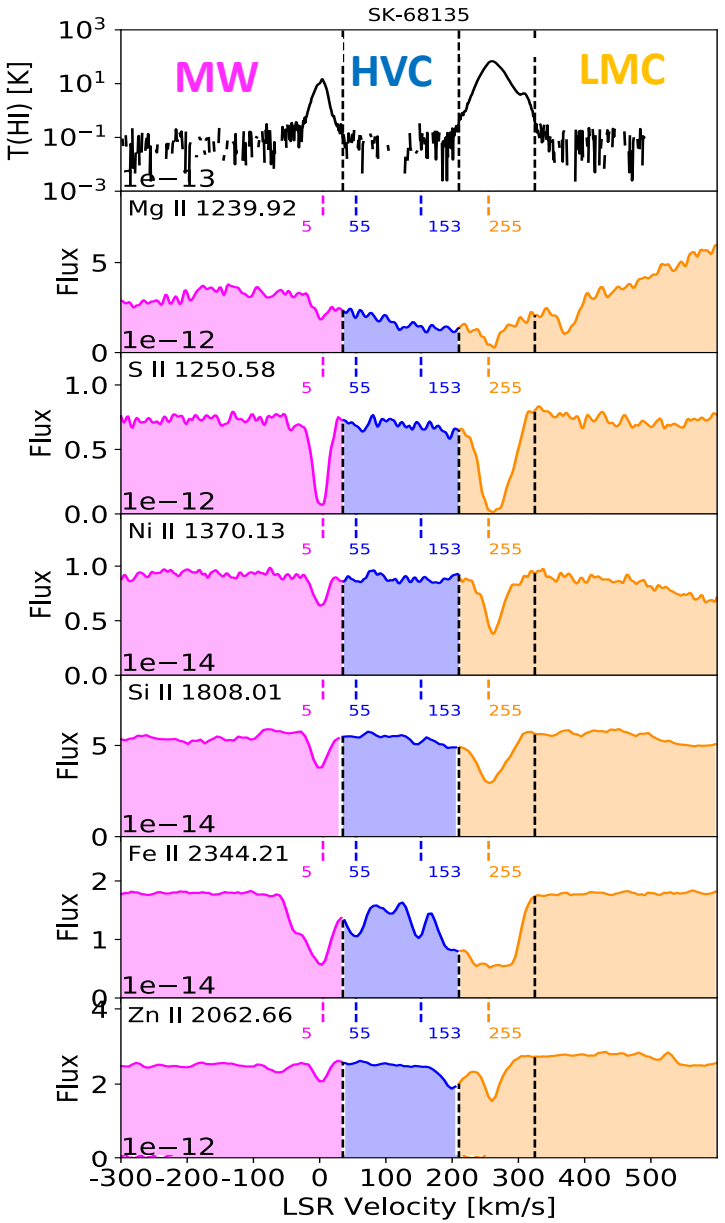


ULLYSES Scientific Motivation – ISM

- Interstellar abundances and chemical evolution: UV medium-resolution spectra of massive stars will provide hydrogen column densities and abundances for many elements (Fe, Si, Mg, Ni, Cu, Zn, S, P, etc.) and many (~150) sight-lines, which can be compared to those in stars of various age

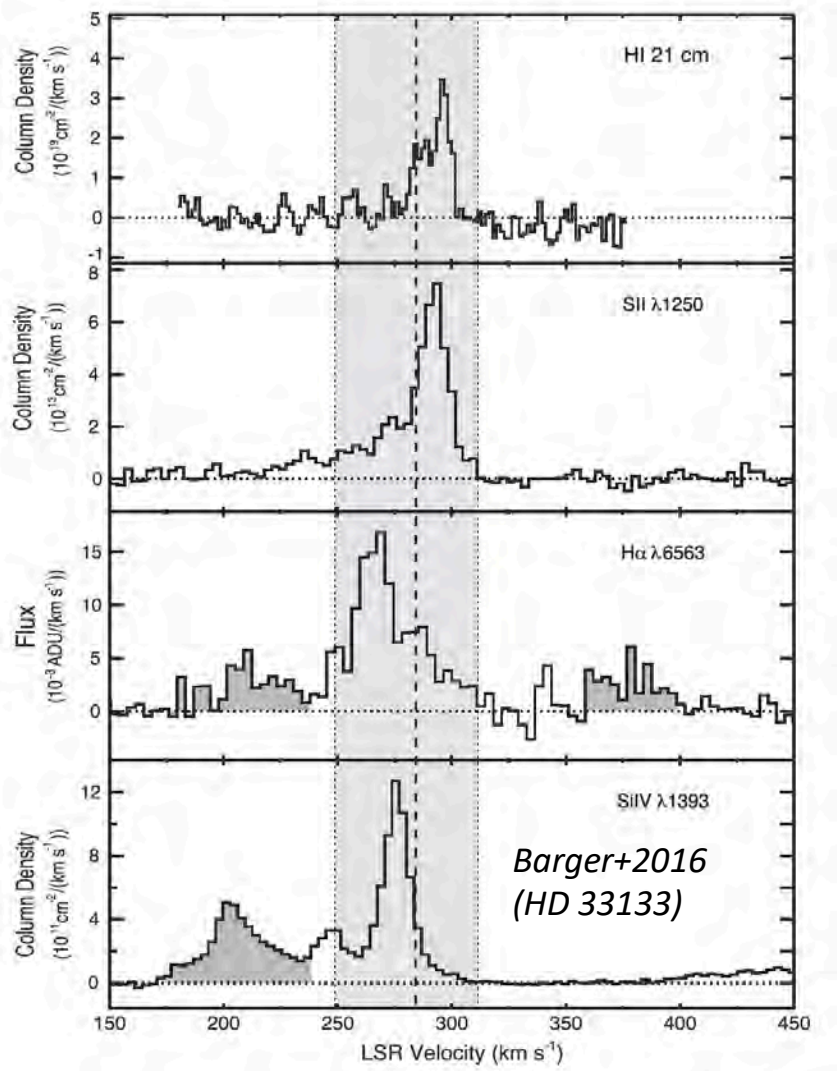
- Dust and depletions: Combined with known stellar abundances of young stars and HII regions the ISM abundances can be used to study the baryon cycle of metals between the gas and dust phases, as a function of metallicity

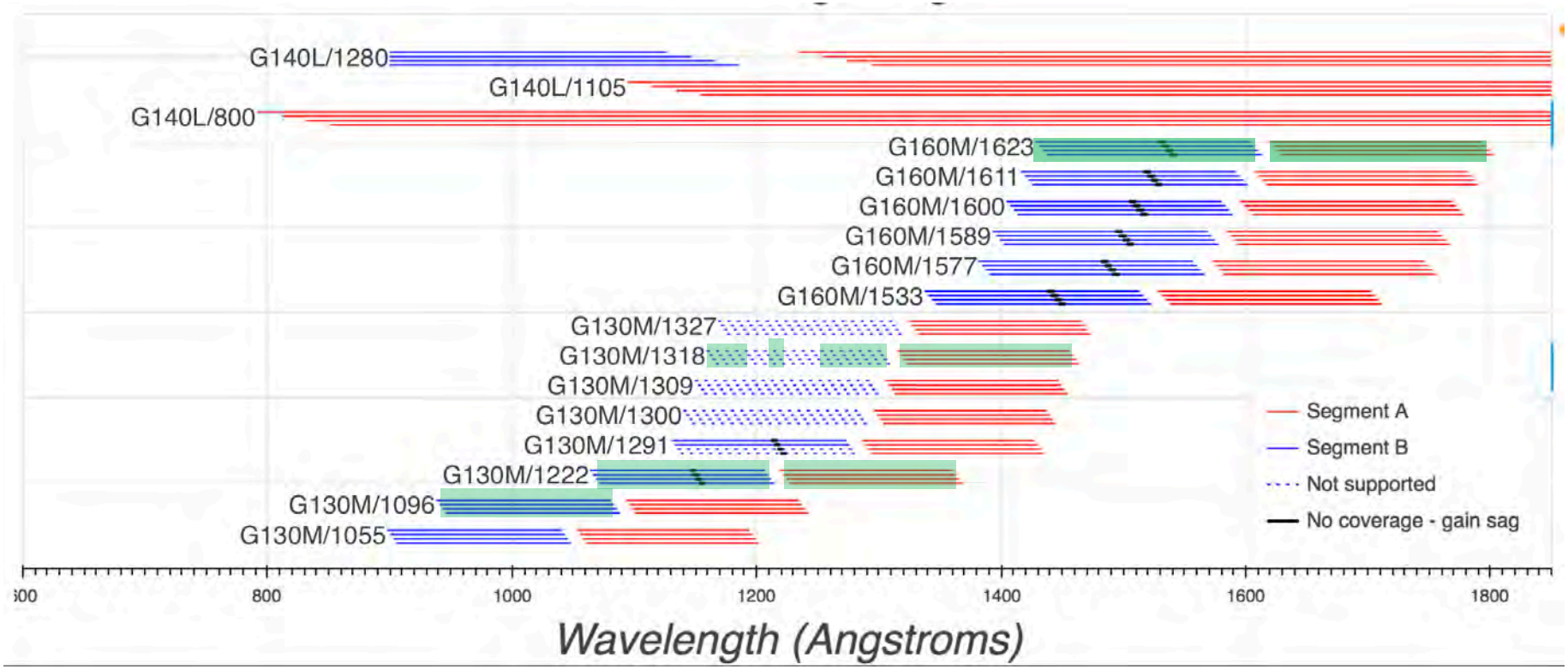
- Dust extinction properties: The spectra of sight-lines with a range of A_V can be used to constrain how the UV dust extinction curve varies with environment (density, radiation field, metallicity)

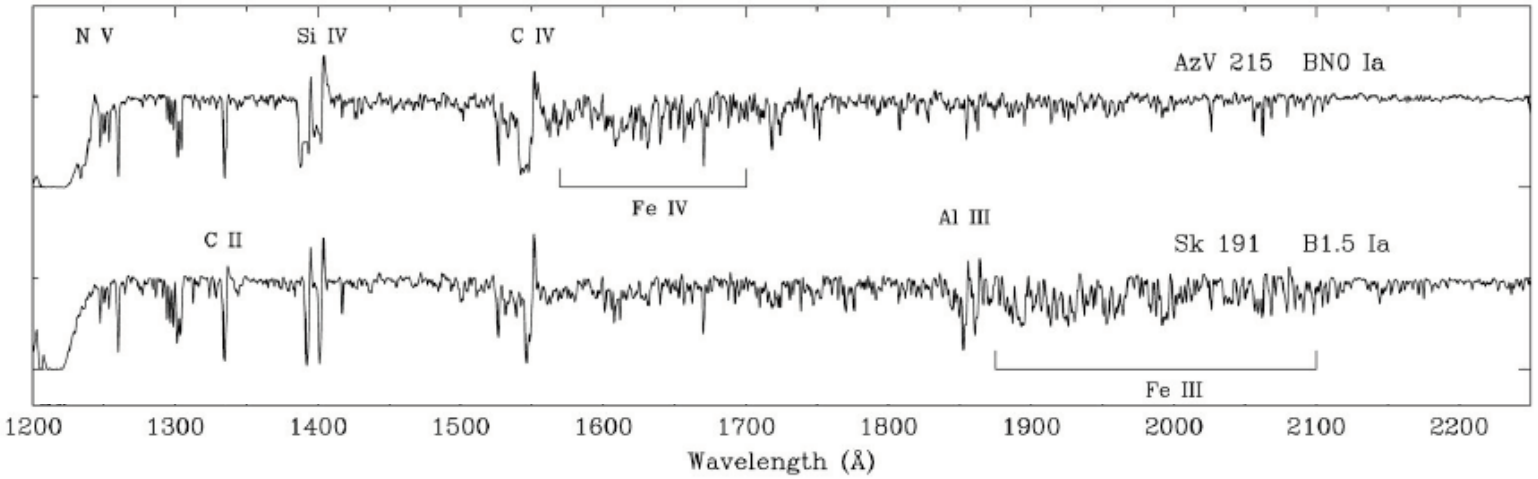


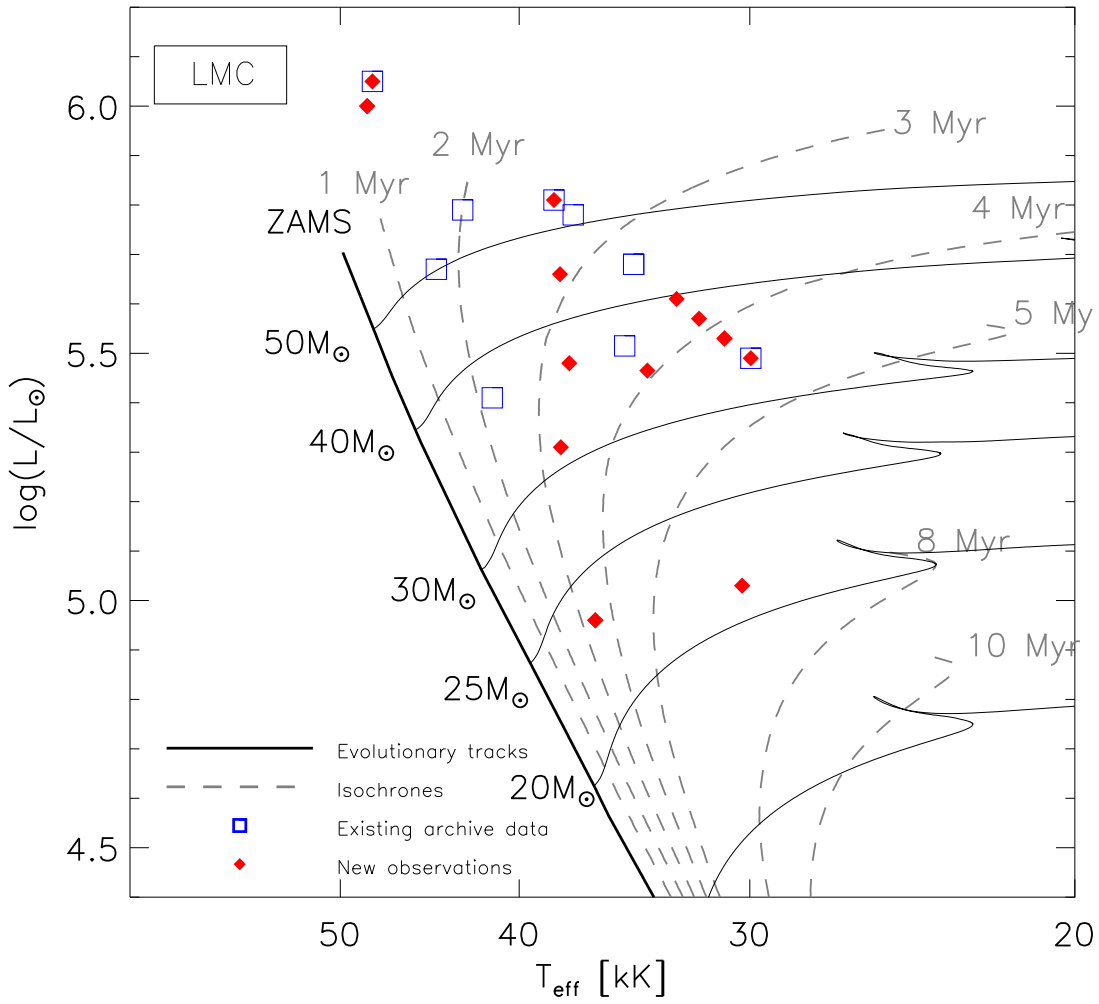
ULLYSES Scientific Motivation – CGM

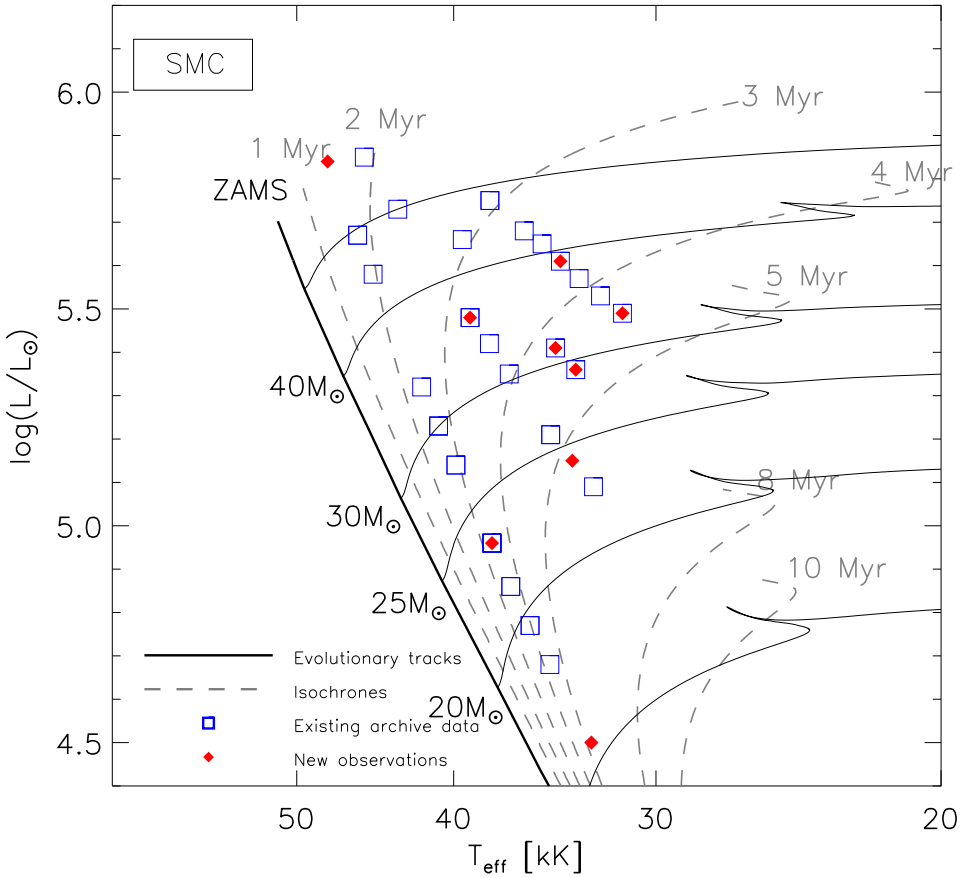
- Galactic-scale inflow and outflow: The medium—resolution UV spectra will reveal inflowing and outflowing gas out/into the CGM
- With the upcoming ASKAP surveys of the LMC and SMC, the metallicity of the inflows/outflows will be measured
- ULLYSES can enable studies of the physical conditions in the CGM, and the properties and origin of inflows/outflows




G140L/1280
G140L/1105
G140L/800
G160M/1623
G160M/1611
G160M/1600
G160M/1589
G160M/1577
G160M/1533
G130M/1327
G130M/1318
G130M/1309
G130M/1300
G130M/1291
G130M/1222
G130M/1096
G130M/1055
Segment A
Segment B
Not supported
No coverage - gain sag
800
1000
1200
1400
1600
1800
Wavelength (Angstroms)


N V
Si IV
C IV
AzV 215 BN0 Ia
Fe IV
C II
Al III
Sk 191 B1.5 Ia
Fe III
1200
1300
1400
1500
1600
1700
1800
1900
2000
2100
2200
Wavelength (Å)

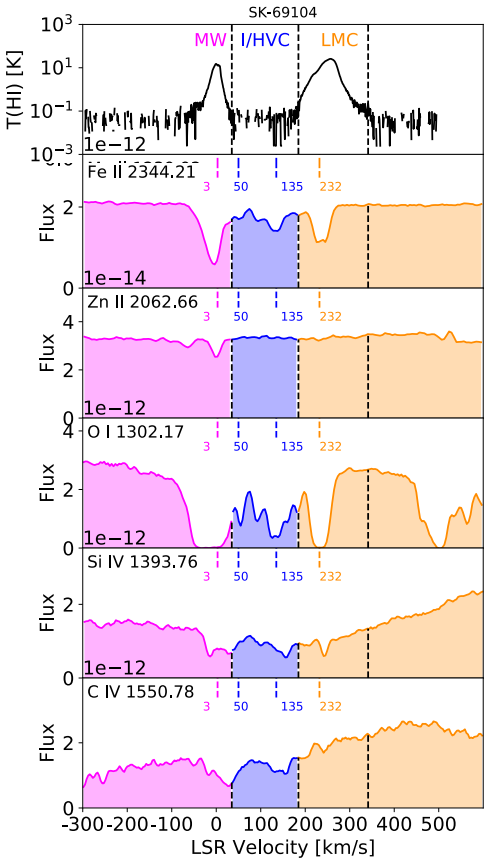

LMC
6.0
5.5
5.0
4.5
log(L/L⊙)
50
40
30
20
T_eff [kK]
ZAMS
1 Myr
2 Myr
3 Myr
4 Myr
5 My
8 Myr
10 Myr
50M⊙
40M⊙
30M⊙
25M⊙
20M⊙
Evolutionary tracks
Isochrones
Existing archive data
New observations

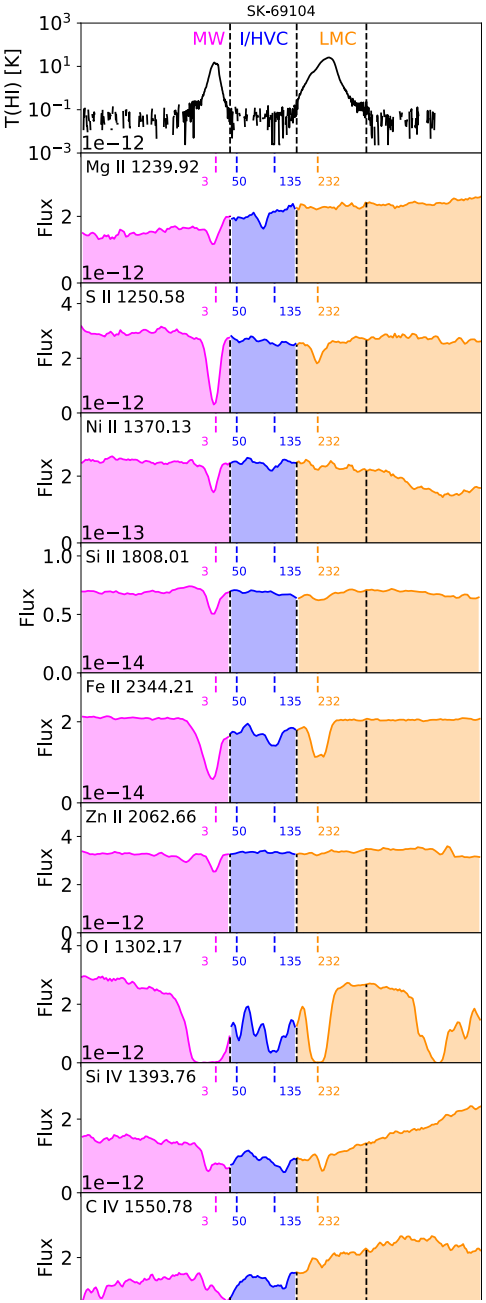

SMC
6.0
5.5
5.0
4.5
log(L/L⊙)
50
40
30
20
T_eff [kK]
ZAMS
1 Myr
2 Myr
3 Myr
4 Myr
5 Myr
8 Myr
10 Myr
40M⊙
30M⊙
25M⊙
20M⊙
Evolutionary tracks
Isochrones
Existing archive data
New observations

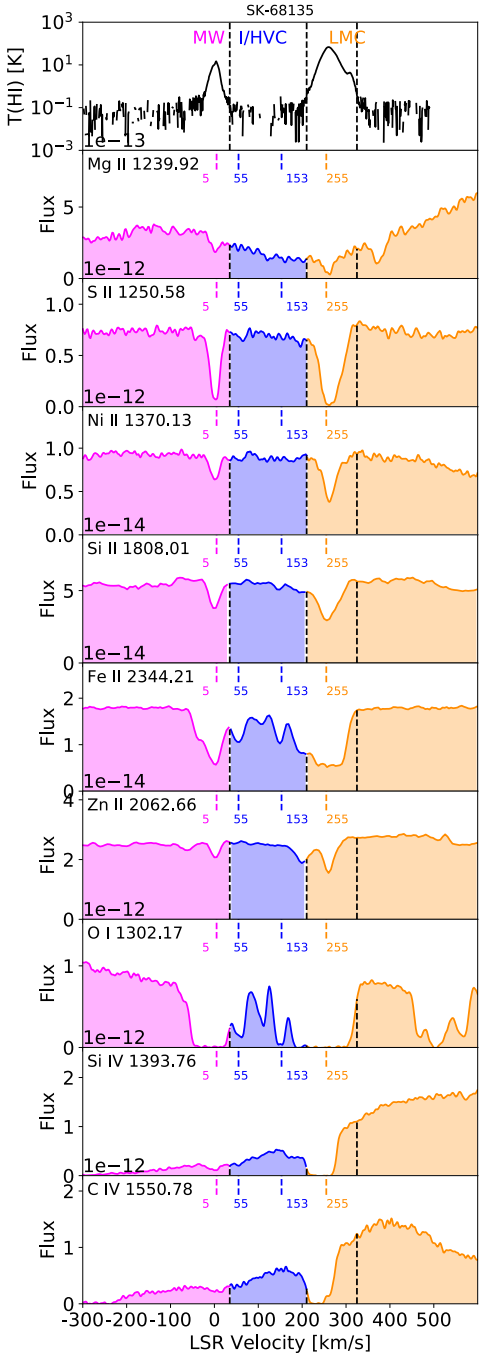
Target sample: Massive Stars in Low Metallicity Local Group Galaxies

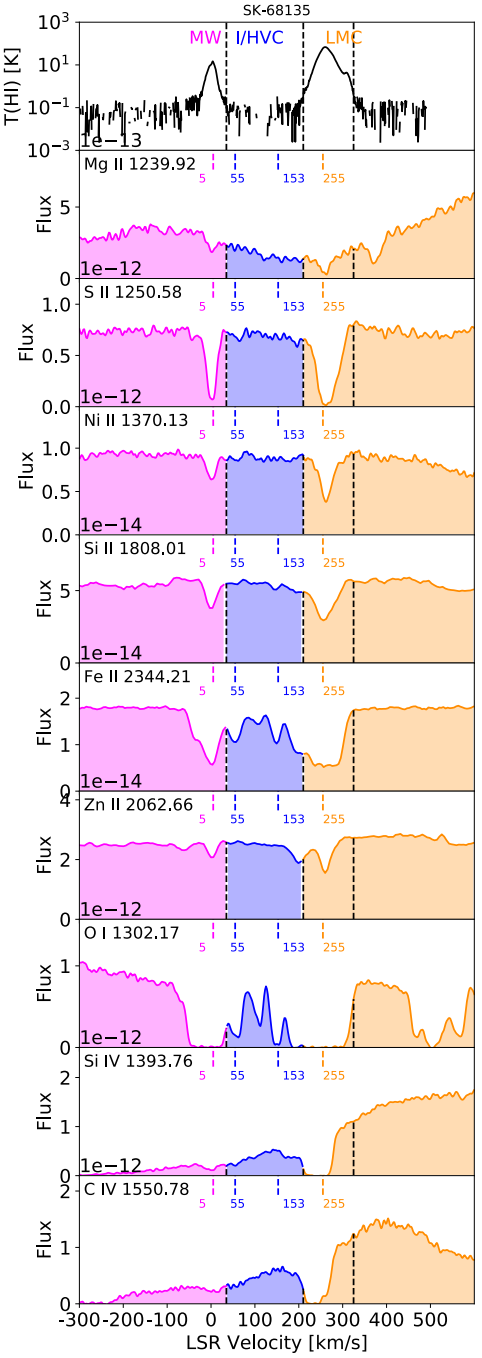
- Only a few Local Group galaxies (d ~ 1 Mpc) have catalogued massive stars and SpT (based on optical spectroscopy with VLT and GTC (Venn et al. 2003, Bresolin et al. 2006, 2007,Evans et al. 2007, Kaufer et al. 2004, Camacho et al. 2017, Garcia et al. 2009, 2013, 2019)
- Of those, only Sextans A, Sextans B and SagDIG have metallicities below 10% solar and will be the focus of ULLYSES

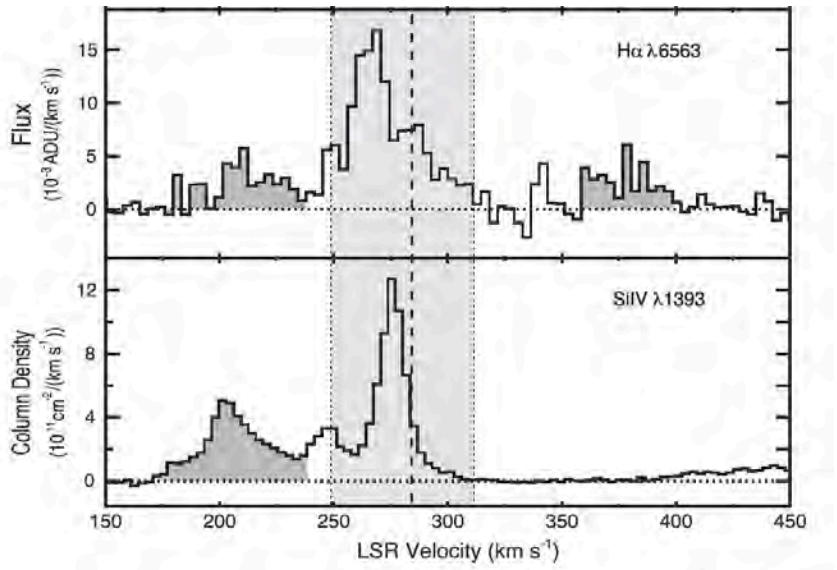
SexA	s1	O9.5I
Sag DIR	SD1	Late OI
Sag DIR	SD3	OBV


SK-69104
MW
I/HVC
LMC
T(HI) [K]
1e−12
Fe II 2344.21
Zn II 2062.66
O I 1302.17
Si IV 1393.76
C IV 1550.78
Flux
1e−14
1e−12
3
50
135
232
-300 -200 -100 0 100 200 300 400 500
LSR Velocity [km/s]


SK-69104
MW
I/HVC
LMC
T(HI) [K]
1e−12
Mg II 1239.92
S II 1250.58
Ni II 1370.13
Si II 1808.01
Fe II 2344.21
Zn II 2062.66
O I 1302.17
Si IV 1393.76
C IV 1550.78
Flux
1e−13
1e−14
3
50
135
232


SK-68135
MW
I/HVC
LMC
T(HI) [K]
Mg II 1239.92
S II 1250.58
Ni II 1370.13
Si II 1808.01
Fe II 2344.21
Zn II 2062.66
O I 1302.17
Si IV 1393.76
C IV 1550.78
Flux
LSR Velocity [km/s]


SK-68135
MW
I/HVC
LMC
T(HI) [K]
Mg II 1239.92
S II 1250.58
Ni II 1370.13
Si II 1808.01
Fe II 2344.21
Zn II 2062.66
O I 1302.17
Si IV 1393.76
C IV 1550.78
Flux
LSR Velocity [km/s]


Hα λ6563
SiIV λ1393
Flux
(10⁻³ ADU/(km s⁻¹))
Column Density
(10¹¹ cm⁻²/(km s⁻¹))
LSR Velocity (km s⁻¹)
15
10
5
0
12
8
4
0
150
200
250
300
350
400
450