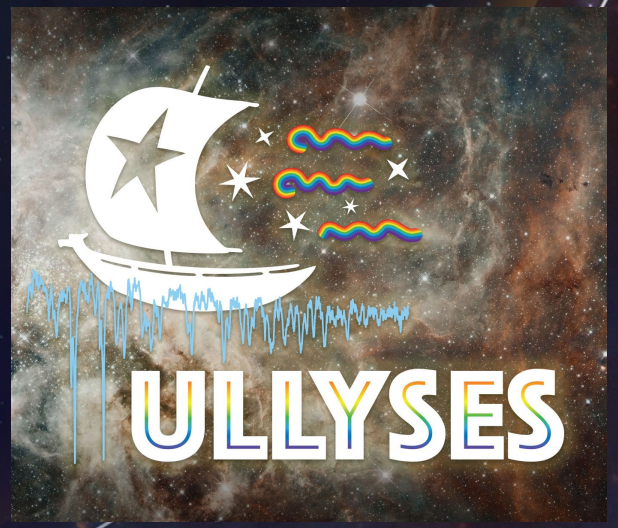
STScI | SPACE TELESCOPE SCIENCE INSTITUTE

EXPANDING THE FRONTIERS OF SPACE ASTRONOMY



Overview and Status of the ULLYSES Director's Discretionary Program

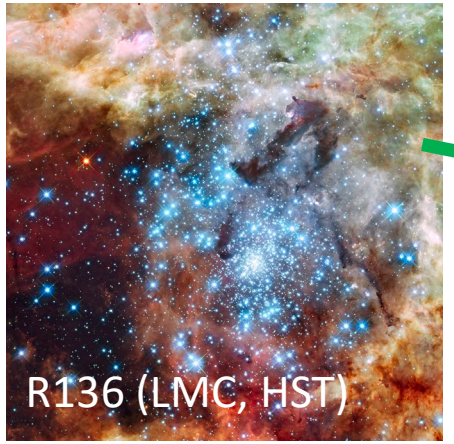
Charting Young Stars' Ultraviolet Light with Hubble

Julia Roman-Duval

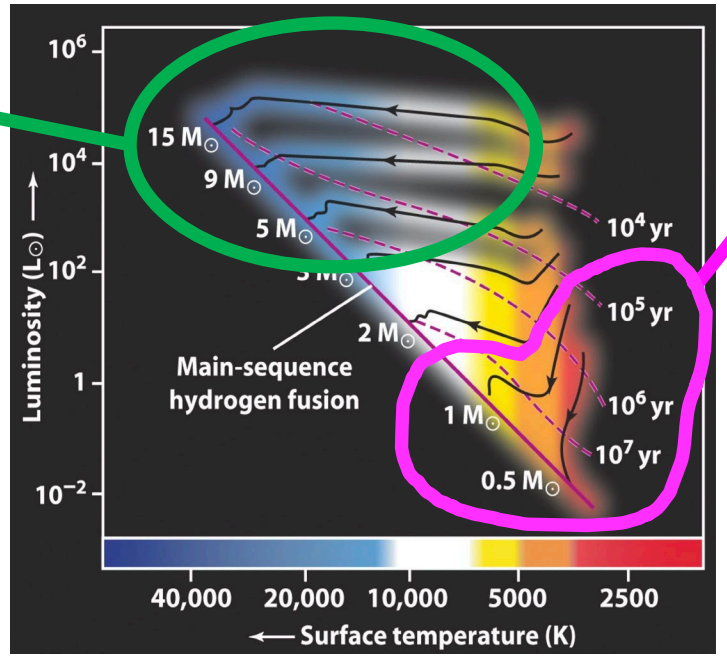
ULLYSES Implementation Team Lead

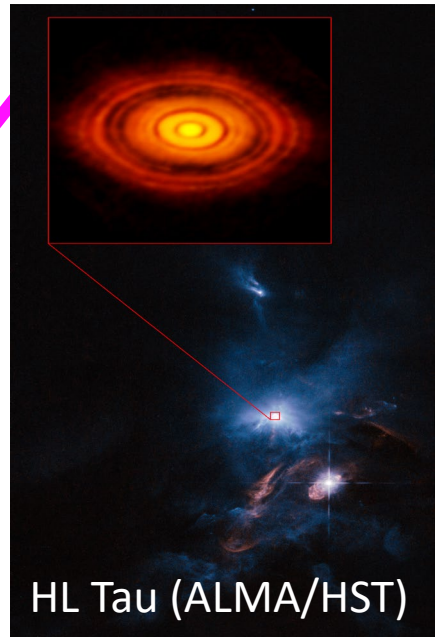
ULLYSES at a glance

- ULLYSES = **Ultraviolet Legacy Library of Young Stars as Essential Standards**
- **Director's Discretionary** Hubble program to obtain a **spectroscopic reference sample of young low and high mass stars – Largest HST program ever executed (~1000 orbits)**
- The scientific framework of the program was designed by the community, via a UV Legacy Working Group and the program is being implemented by a dedicated team at STScI



~500 orbits to extend the spectroscopic library of O and B stars to low metallicity (8% - 50% solar)

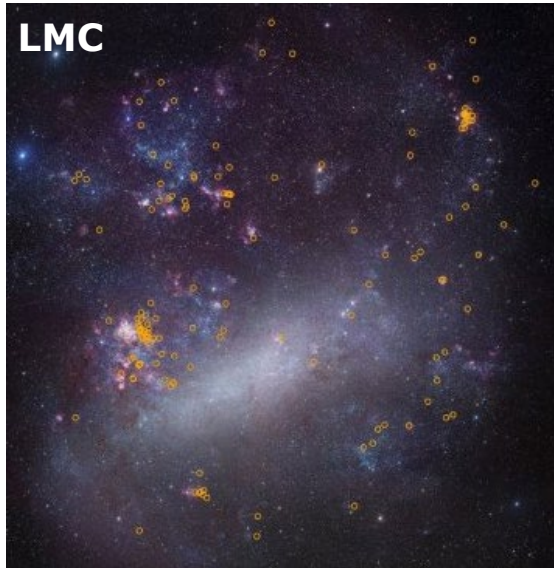


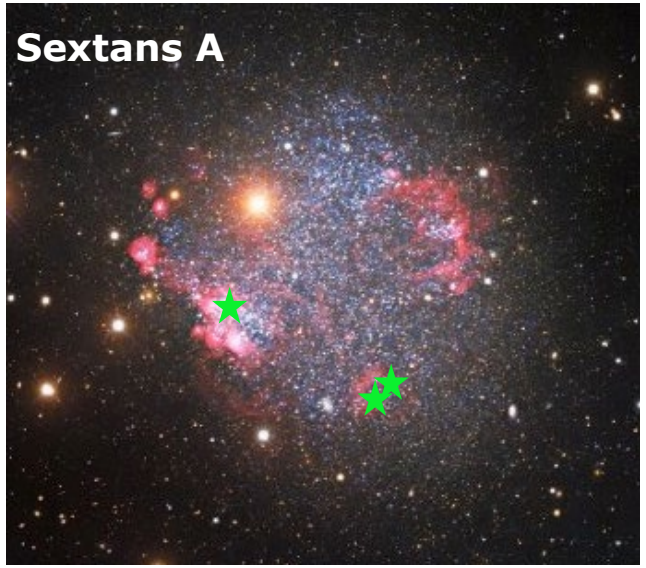


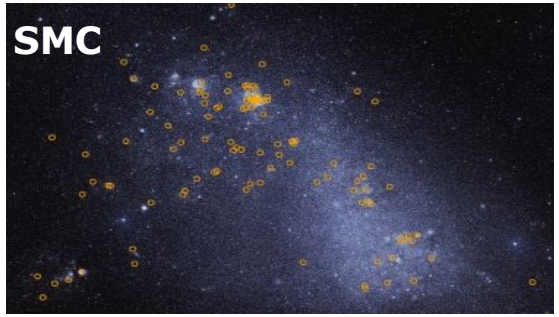
~500 orbits to obtain a spectroscopic library and time monitoring of T Tauri stars (younger than 10 Myr, mass < 1 M_o)

ULLYSES Massive Stars (~500 orbits)

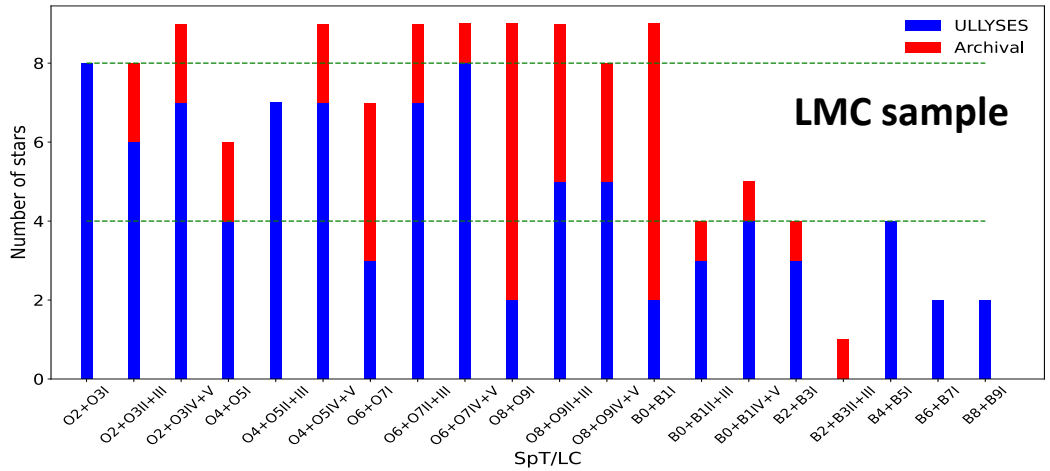
- ULLYSES targets **~170 OB stars** in **4 galaxies** spanning a range of **metallicities (8%-50% solar)**
- Also includes **~140 OB stars** with **archival** spectra in the same galaxies
- Statistical sample covering **metallicity, temperature class, and luminosity class** uniformly







Galaxy	Distance	Metallicity	# targets Obs (AR)
LMC	50 kpc	0.5 Z_o	94 (54)
SMC	62 kpc	0.2 Z_o	60 (63)
NGC 3109	1.3 Mpc	0.15 Z_o	3 (0)
Sextans A	1.6 Mpc	0.08 Z_o	3 (9)



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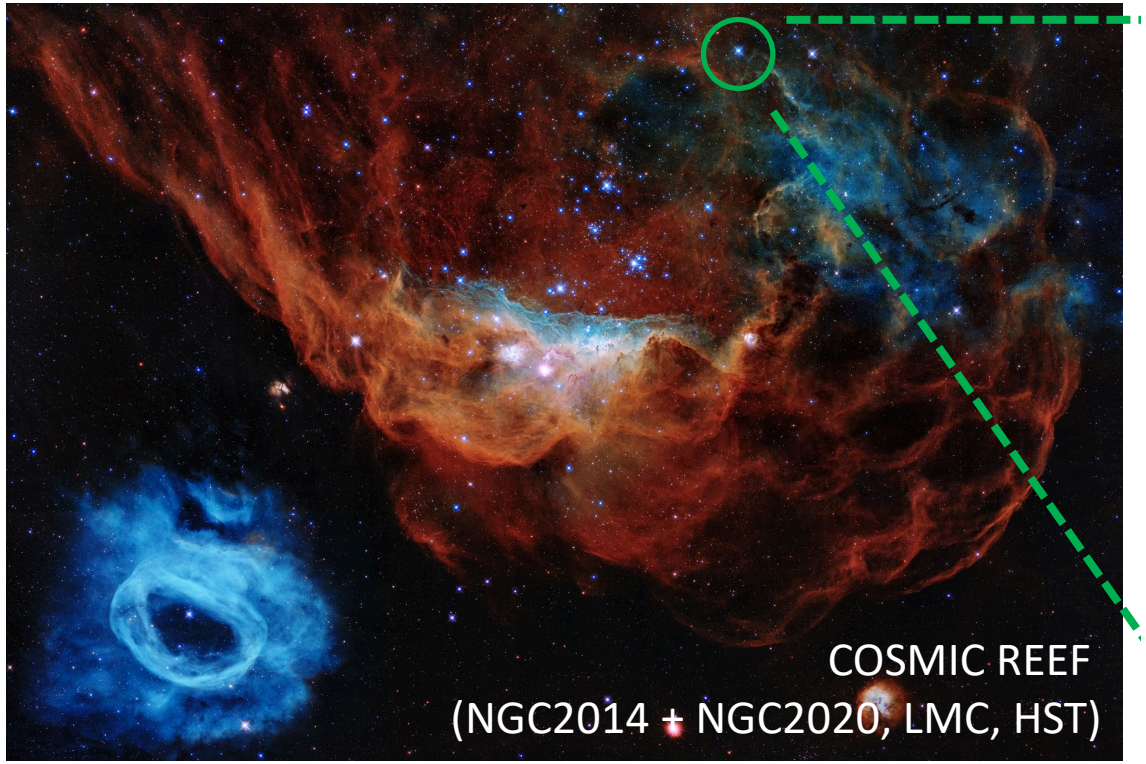
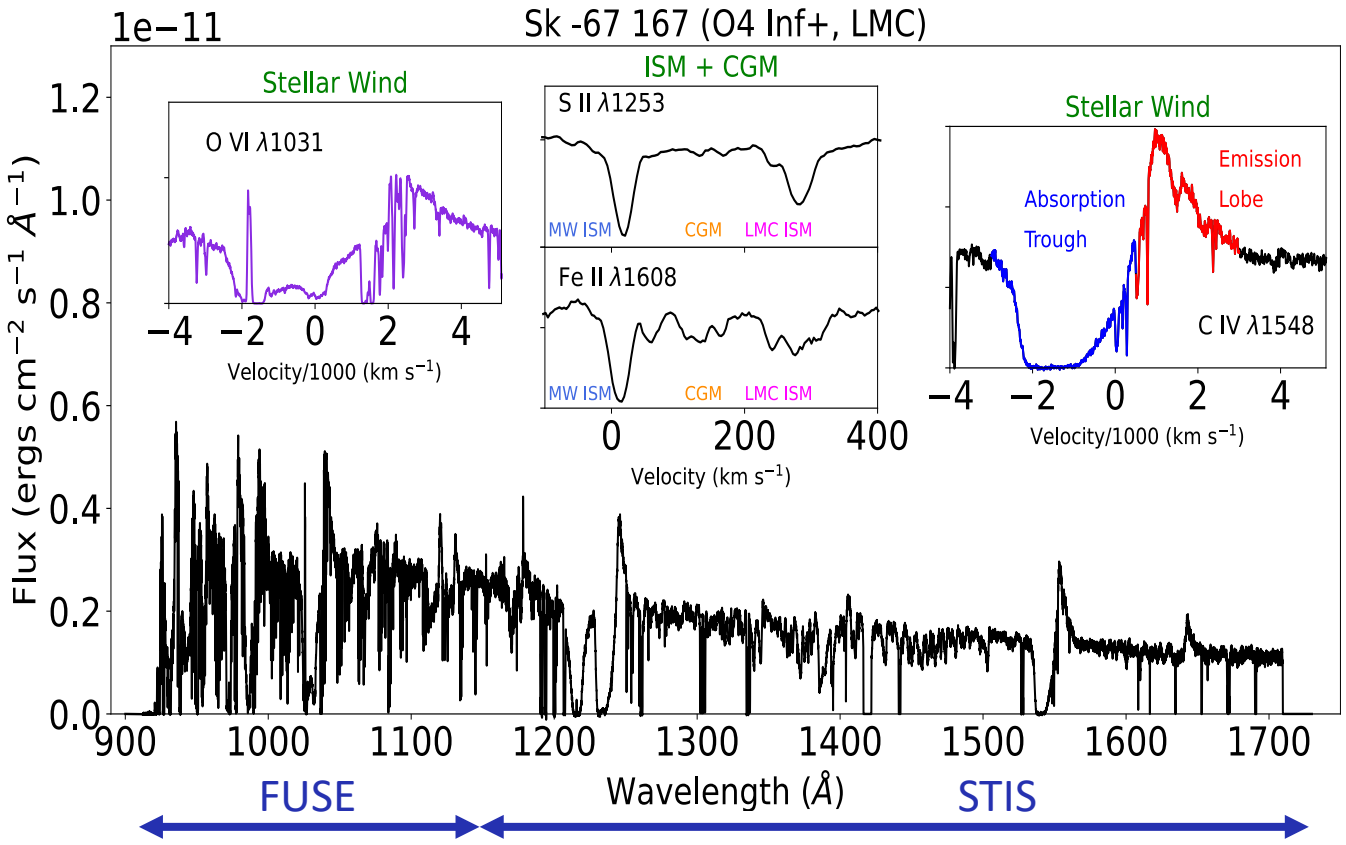
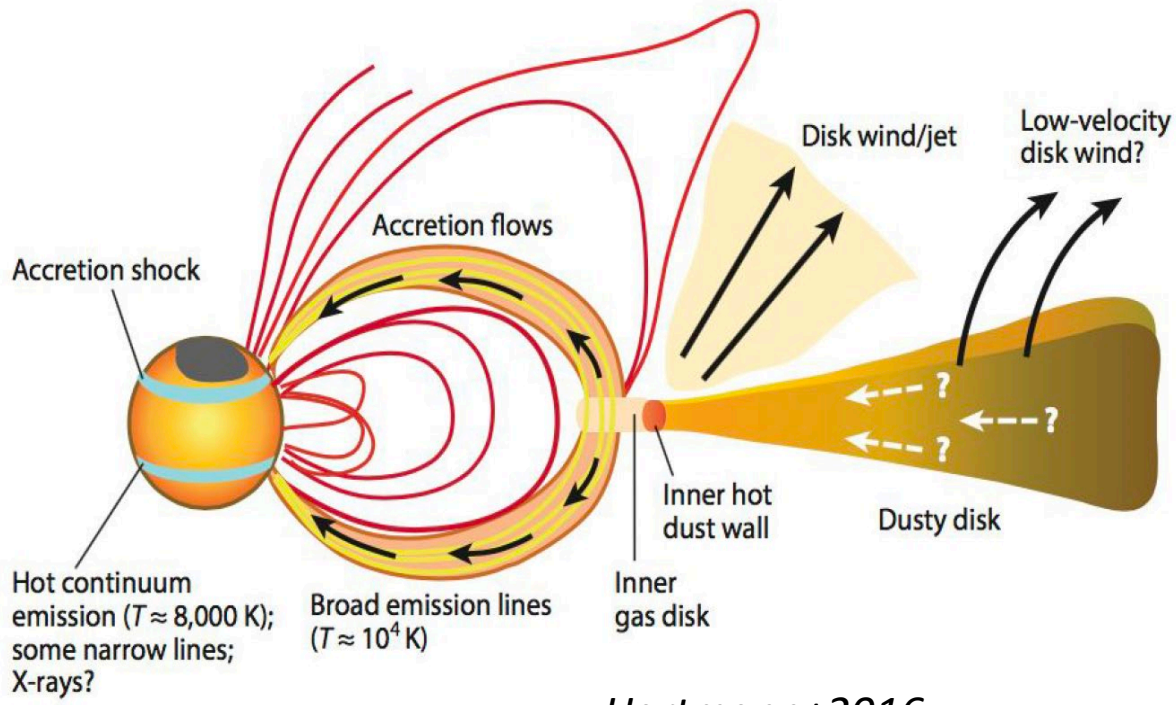
A Spectroscopic Survey of High Mass Stars



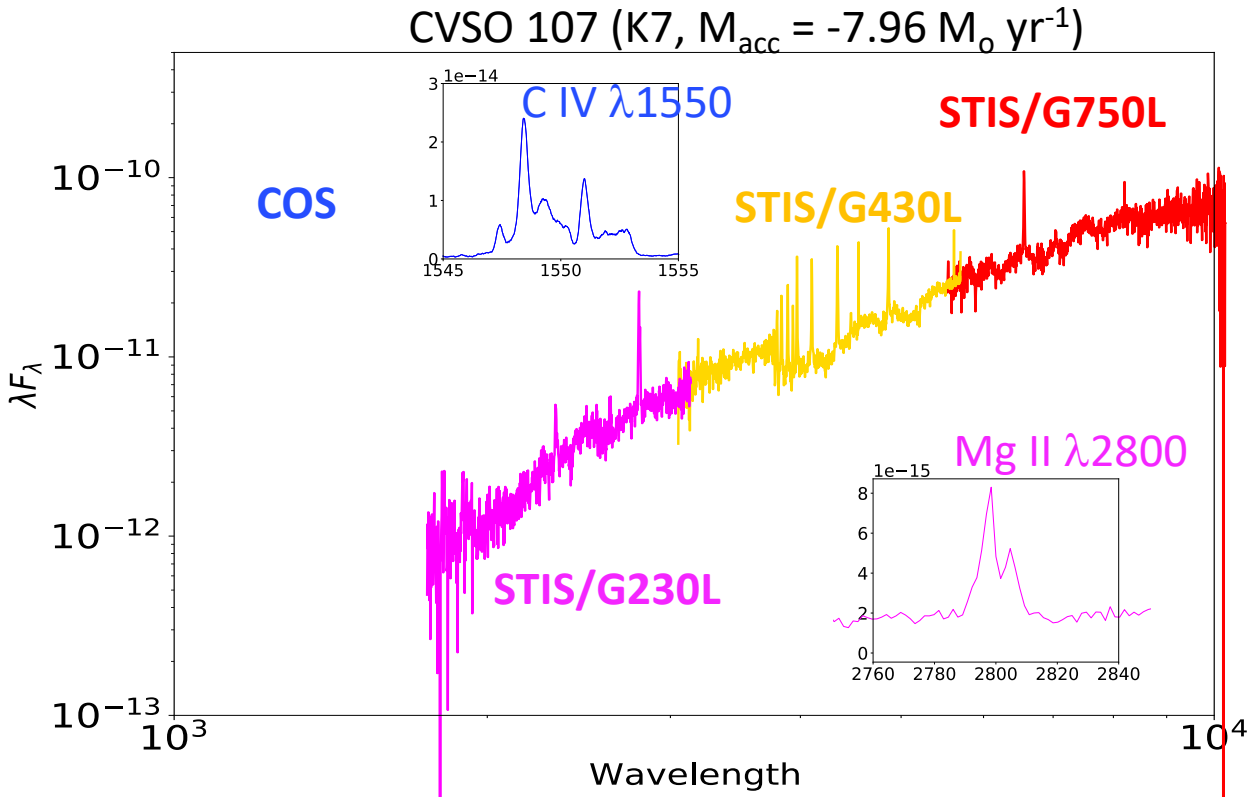


- ✓ **Massive Stars**
  - Stellar winds and abundances
  - Ionizing radiation
  - Spectral templates for population synthesis
- ✓ **CGM**
  - Kinematics
  - Metallicity
  - Disk-halo interface/feedback
- ✓ **ISM**
  - Chemical abundances
  - Depletions on dust

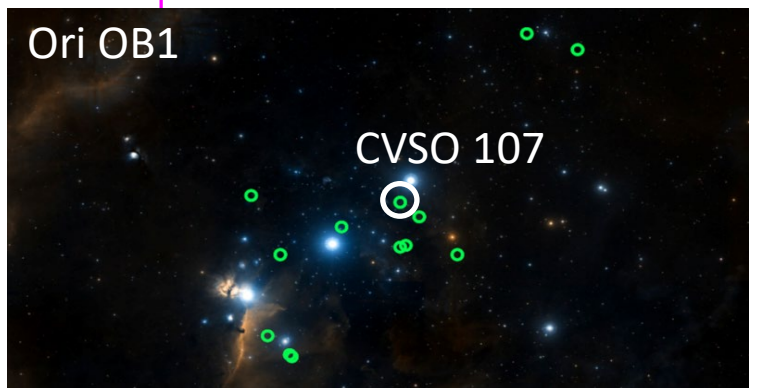
Strategy and Science goals of the low-mass star observations



Hartmann+2016



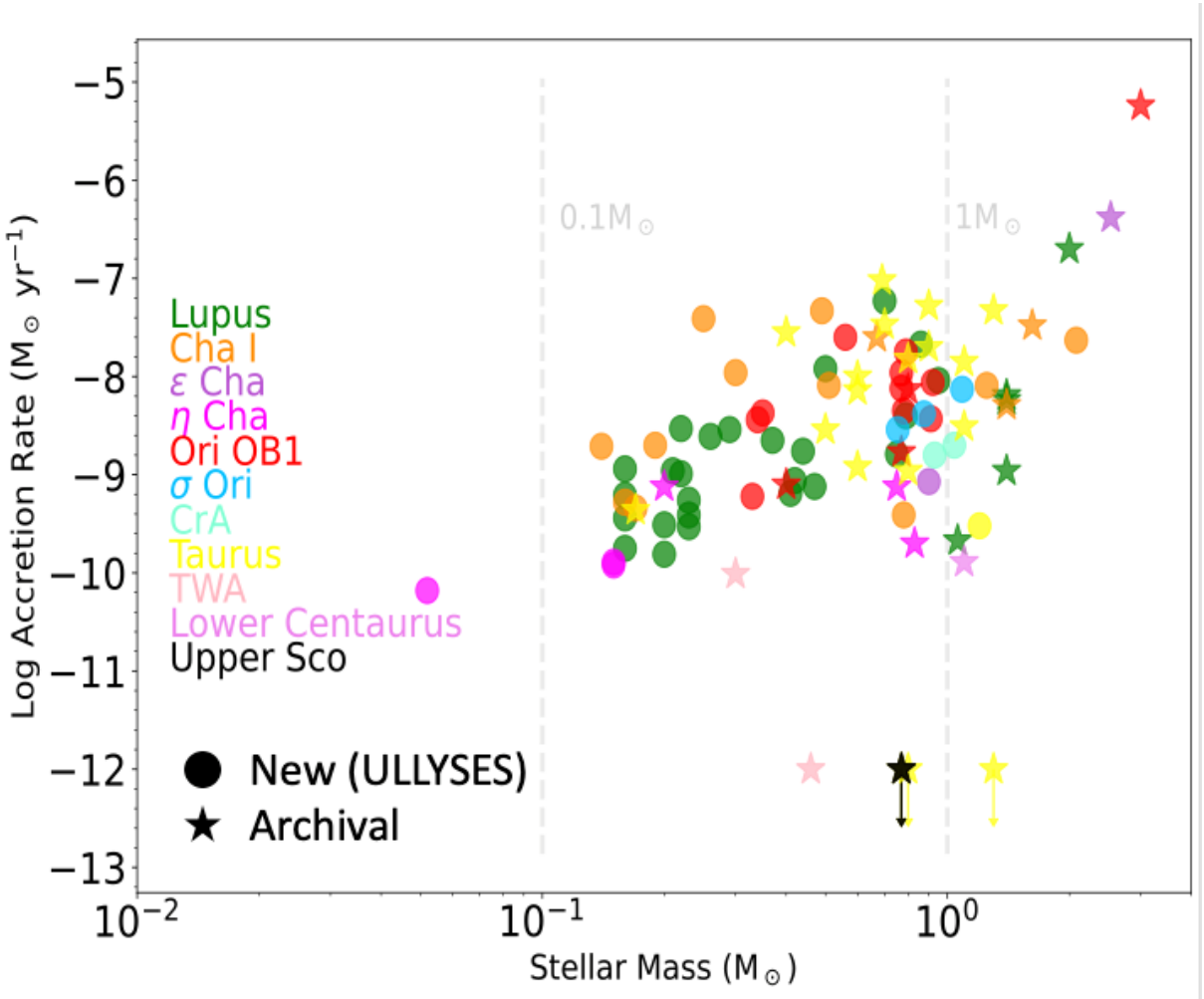
- ✓ T Tauri Stars
  - Accretion physics
  - UV radiation and impact on disk evolution, chemistry, planet habitability, atmospheric escape
  - Time monitoring component for 4 targets (100 orbits) to study accretion variability



ULLYSES "survey" T Tauri stars (single-epoch observations)

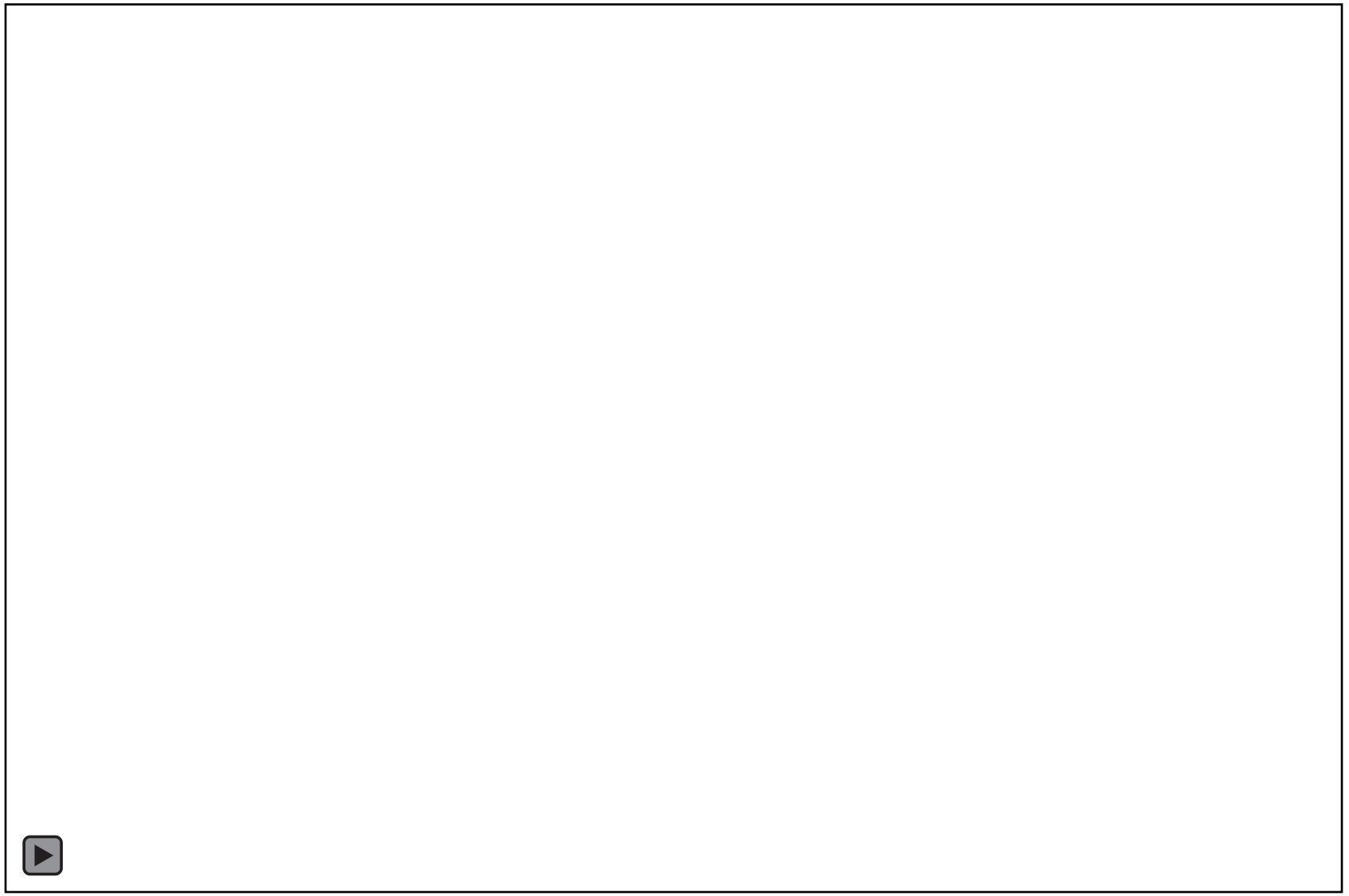
- ULLYSES is targeting 58 stars in 8 star-forming regions in the Milky Way (~ 400 orbits)
- Also includes ~40 T Tauri stars with archival data in Taurus and other SF regions
- Uniform coverage of stellar mass and accretion rate

SF region	# of targets
Lupus	26
Chamaeleon I	11
ε Cha	1
η Cha	4
Ori OB1a, b	10
σ Ori	3
Corona Australis (CrA)	2
Taurus	1



ULLYSES T Tauri stars monitored with HST

- 4 stars monitored over time with COS/FUV + NUV:
  - ✓ TW Hya
  - ✓ BP Tau
  - ✓ RU Lup
  - ✓ GM Aur
- 12 observations over 3 rotational periods
  - ➢ Repeated over 2 epochs separated by 1 year
  - ➢ COS/G160M + COS/G230L
  - ➢ 1 orbit per observation
  - ➢ 100 orbits



Program Status

- As of January 2023, ULLYSES observing is **96% complete**
- **6 data releases** (latest DR5b on November 15, 2022)
  - **DR6 planned for early March 2023**
- **1 press release**

NASA

Hubblesite

- **8 peer-reviewed publications** by the community (and counting)
- **Completion of the program expected by the end of 2023** (this is a working goal)
- All data products will have their final delivery as part of **DR7 in the fall/winter 2023**
- ULLYSES workshop at STScI penciled in for late 2023

ULLYSES Deliverables

WEBSITE
ullyses.stsci.edu

Program information
Observing status and schedule
Data product description
List of coordinated programs
Data release (DR) notes

PUBLIC CODEBASE
github.com/spacetelescope/ullyses

Custom calibration routines and config files Photometry
Spectral coaddition and splicing
Spectral time-series
COS vignetting correction
Target metadata, alias information
Automatic webpage generation
Product data quality checks

INTERNAL DATABASE

Target metadata
Observational metadata

ULLYSES SEARCH FORM
mast.stsci.edu/search/ui/#/ullyses

Built on Missions MAST framework
Uses database and custom API

ULLYSES HLSPs

High level science data products
See next slide

Description of data products

- **Flux-weighted co-added spectra** obtained with the same grating
  - E.g., different exposures with the same or different cenwaves and FP-POS
- **Spliced (abutted) spectra** between different gratings and instruments
  - E.g., FUSE + HST, COS + STIS
- Vetted **FUSE spectra** for LMC/SMC massive stars
- **Custom calibrated STIS G230L and CCD spectra** of T Tauri stars
  - In particular, **de-fringing of G750L** spectra, improved hot pixel flagging, and re-extraction of targets (as needed) and companions
- Photometric (LCOGT) and spectroscopic (HST) **time-series**
  - Spectroscopic time-series from HST only for T Tauri stars monitored over time
- **Drizzled WFC3 images** of NGC 3109 and Sextans A

Data Dissemination Platforms

Data can be downloaded from 3 different platforms

NEW!

ULLYSES SEARCH FORM (HLSPs only)

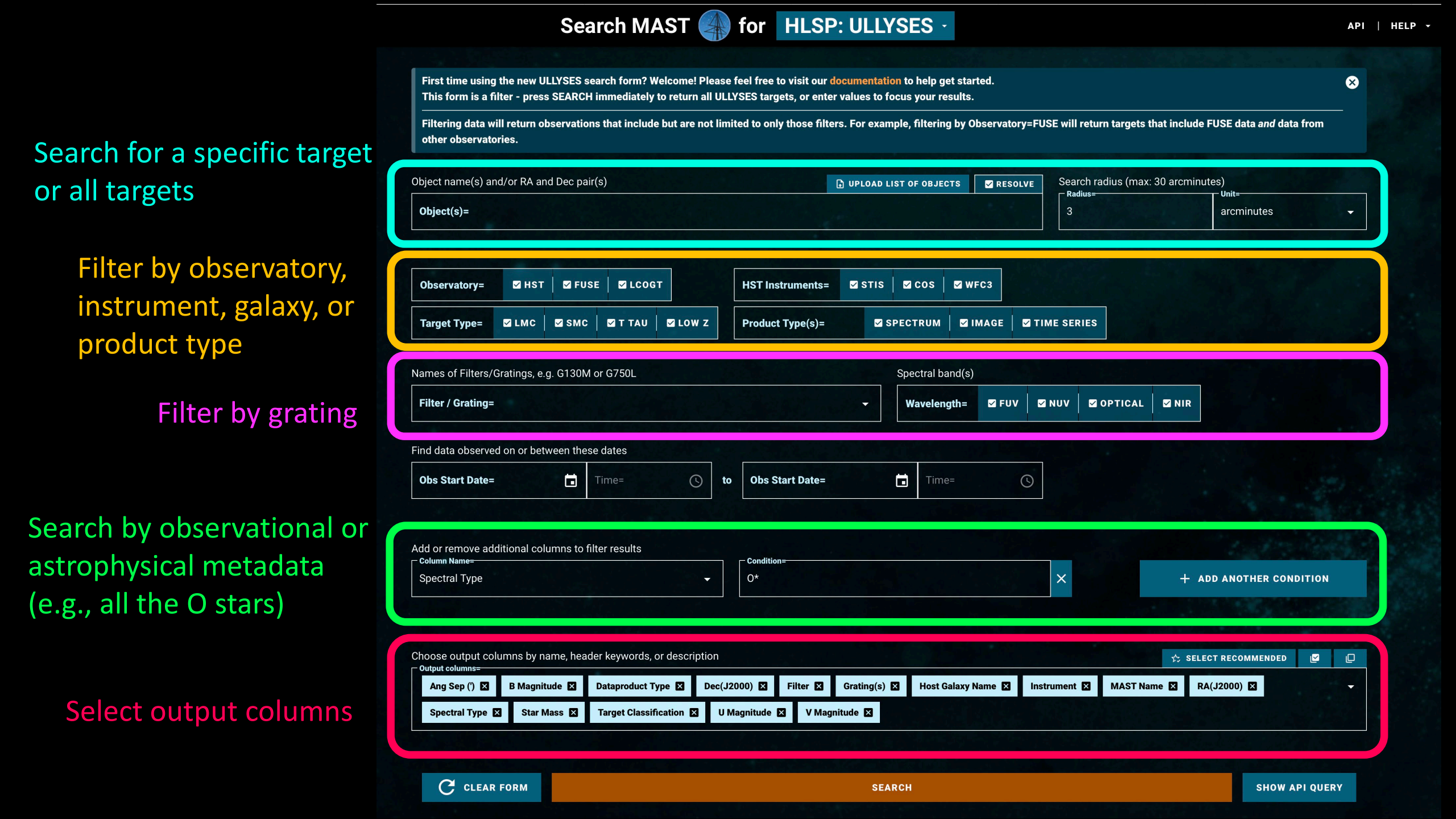
Built on Missions MAST framework
Uses database and custom API

MAST DISCOVERY PORTAL (HLSPs and contributing data)

See instructions at the MAST HLSP collection

MAST ULLYSES HLSP COLLECTION (HLSPs only)

Uses MAST portal interface


Search for a specific target or all targets
Filter by observatory, instrument, galaxy, or product type
Filter by grating
Search by observational or astrophysical metadata (e.g., all the O stars)
Select output columns
Search MAST for HLSP: ULLYSES
API | HELP
First time using the new ULLYSES search form? Welcome! Please feel free to visit our documentation to help get started.
This form is a filter - press SEARCH immediately to return all ULLYSES targets, or enter values to focus your results.
Filtering data will return observations that include but are not limited to only those filters. For example, filtering by Observatory=FUSE will return targets that include FUSE data and data from other observatories.
Object name(s) and/or RA and Dec pair(s)
UPLOAD LIST OF OBJECTS
RESOLVE
Object(s)=
Search radius (max: 30 arcminutes)
Radius=
3
Unit=
arcminutes
Observatory=
HST
FUSE
LCOGT
HST Instruments=
STIS
COS
WFC3
Target Type=
LMC
SMC
T TAU
LOW Z
Product Type(s)=
SPECTRUM
IMAGE
TIME SERIES
Names of Filters/Gratings, e.g. G130M or G750L
Filter / Grating=
Spectral band(s)
Wavelength=
FUV
NUV
OPTICAL
NIR
Find data observed on or between these dates
Obs Start Date=
Time=
to
Obs Start Date=
Time=
Add or remove additional columns to filter results
Column Name=
Spectral Type
Condition=
O*
ADD ANOTHER CONDITION
Choose output columns by name, header keywords, or description
SELECT RECOMMENDED
Output columns=
Ang Sep (')
B Magnitude
Dataproduct Type
Dec(J2000)
Filter
Grating(s)
Host Galaxy Name
Instrument
MAST Name
RA(J2000)
Spectral Type
Star Mass
Target Classification
U Magnitude
V Magnitude
CLEAR FORM
SEARCH
SHOW API QUERY

EDIT SEARCH | Telescope= HST, FUSE, LCOGT | Target Type= LMC, SMC, TTAU, LOWZ | HST Instruments= STIS, COS, WFC3 | HLSP Type= SPECTRUM, IMAGE, TS | Wavelength= FUV, NUV, VIS, NIR | Spectral Type= O* | Columns= Ang Sep ...

DOWNLOAD DATA (2 DATASETS) | EXPORT TABLE

- Choose Files
- Quick API Script
  - Recommended Files
  - All Files

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		Classification	RA(J2000)	Dec(J2000)	Host Galaxy Name	Spectral Type	Star Mass	U Magnitude	B Magnitude	V Magnitude	Instrument	Grating(s)
		Dwarf	21.1166061	-73.2374879	SMC	O9.7 V	35	12.78	13.77	13.97	COS	G130M; G160M
		upergiant	84.9612208	-69.4076306	LMC	O5 If		12.63	13.64	13.66	COS	G130M; G160M
		Dwarf	84.8064943	-69.5013906	LMC	O3 V((f))		13.48	14.48	14.58	COS	G130M; G160M
		Supergiant	9.2426668	-73.3925519	SMC	O8 Ib(f)		13.84	14.95	15.11	COS	G130M; G160M
		right Giant	16.8094759	-72.2298699	SMC	OC7 II(f)		13.83	14.91	15.16	COS	G130M; G160M
	2dFS 3954	Mid O Dwarf	22.6796167	-73.4178175	SMC	O6 V((f))z	19	13.93	15.01	15.27	COS	G130M; G160M
	2dFS 3966	Mid O Dwarf	13.3035651	-72.6166619	SMC	O6V((f))			14	14.14	COS	G160M
☐	AV 14	Early O Dwarf	11.6359778	-73.1015508	SMC	O5 V	74	12.38	13.38	13.55	COS, FUSE, STIS	E140M; FUSE/LWRS; G185M
☑	AV 148	Late O Dwarf	13.4259785	-72.7098053	SMC	O8.5 V	19	12.92	13.92	14.12	COS	G130M; G160M
☑	AV 15	Mid O Bright Giant	11.6756704	-73.4154202	SMC		47.2	11.9	12.93	13.12	FUSE, STIS	E140M; FUSE/LWRS
☐	AV 170	Late O Supergiant	13.9268014	-73.2918177	SMC	O9.7I			13.82	14.11	FUSE, STIS	E140M; FUSE/LWRS
☐	AV 177	Early O Dwarf	14.1837744	-72.0588053	SMC	O4 V((f))	38.8	13.27	14.32	14.53	COS, FUSE	FUSE/LWRS; G130M; G160M
☐	AV 186	Late O Giant	14.3622539	-72.5537720	SMC	O8.5 III((f))	32.2	12.75	13.77	13.98	COS	G130M; G160M
☐		Early B Subgiant	14.3854865	-72.4808760	SMC	O9 V	18.8	13.32	14.26	14.37	COS	G130M; G160M
☐	AV 207	Mid O Giant	14.6382993	-71.9296494	SMC	O7 III((f))	22	12.99	14.05	14.25	COS, FUSE, STIS	E230M; FUSE/LWRS; G130M; G160M
☐	AV 220	Mid O Supergiant	14.7915474	-72.0967497	SMC	O7If			14.24	14.51	FUSE, STIS	E140M; FUSE/LWRS
☐	AV 232	Mid O Supergiant	14.8832439	-72.1794800	SMC	O7 Iaf+	35.3	11.15	12.15	12.35	FUSE, STIS	E140M; FUSE/LWRS
☐	AV 243	Mid O Dwarf	15.0280329	-72.7886511	SMC	O6 V	41	12.63	13.67	13.84	COS, FUSE	FUSE/LWRS; G130M; G160M
☐	AV 251	Mid O Dwarf	15.0923184	-72.5135422	SMC	O7.5 V		13.32	14.34	14.52	COS	G130M; G160M
☐	AV 258	Late O	15.1855103	-72.4973207	SMC	O9			13.7	13.69	STIS	E140M
☐	AV 26	Mid O Supergiant	11.9585471	-73.1391871	SMC	O6I(f)			12.29	12.46	FUSE, STIS	E140H; E140M; E230M; FUSE/LWRS
☐	AV 267	Late O Dwarf	15.3153942	-72.1098302	SMC	O8 V	21.5	13.53	14.58	14.84	COS	G130M; G160M
☐	AV 287	Late O Supergiant	15.4884399	-72.2117332	SMC	O9.5I			12.77	12.54	STIS	E140M
☐	AV 307	Late O Giant	15.6340989	-72.6618302	SMC	O9 III	22.5	12.82	13.8	13.96	COS	G130M; G160M
☐	AV 321	Early B Giant	15.7378517	-72.1358703	SMC	O9 IInp		12.54	13.57	13.76	FUSE, STIS	E140M; E230M; FUSE/LWRS
☐	AV 326	Early B Subgiant	15.7886326	-72.4325390	SMC	O9 V	18.8	12.84	13.8	13.92	COS	G130M; G160M
☐	AV 327	Late O Bright Giant	15.7939600	-72.0373207	SMC	O9.5 II-Ibw	22.8	11.83	12.87	13.03	FUSE, STIS	E140M; FUSE/LWRS
☐	AV 372	Late O Supergiant	16.2322616	-72.7800457	SMC	O9.5 Iabw		11.41	12.44	12.59	FUSE, STIS	E140M; E230M; FUSE/LWRS

2 datasets selected

Rows per page: 500 | 1-134 of 134

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Rachel Plesha
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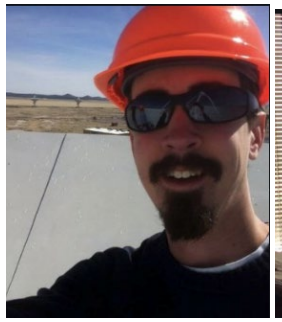
TTS Observing Lead


Alex Fullerton
(OB star Observing Lead)


Alessandra Aloisi
(Pre-imaging)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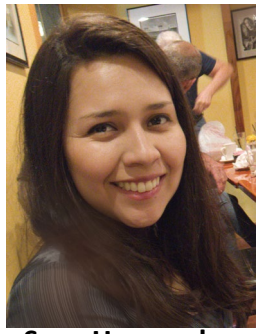
Ivo Busko
(DP/software)


Van Dixon
(Observing, DP)


Travis Fischer
(DP)


Elaine Frazer
(DP)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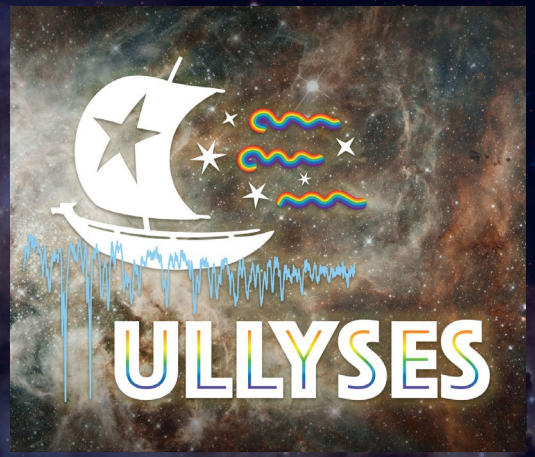
Debopam Som
(Observing)


Leonardo Ubeda
(Website)


Dan Welty
(Targets, Obs, DP)


Brian York
(DP)

Thank you for your attention



Acknowledgements

Other STScI staff involved

- Tricia Royle (Program Coordinator)
- Dave Adler and scheduling team
- Scott Fleming, Peter Forshay, David Rodriguez and Brian Erickson (MAST)
- OPO team

Science Advisory Committee (SAC)

- SAC composition (Massive stars/T Tauri stars)
  - Jean-Claude Bouret (Laboratoire d'Astrophysique de Marseille)
  - Catherine Espaillat (Boston University)
  - Chris Evans (ESA@STScI, formerly UK Astronomy Technology Centre)
  - Kevin France (University of Colorado Boulder)
  - Miriam García (Instituto Nacional de Técnica Aeroespacial)
  - Chris Johns-Krull (Rice University)
  - Derck Massa (Space Science Institute)
  - Joan Najita (National Optical Astronomy Observatory)

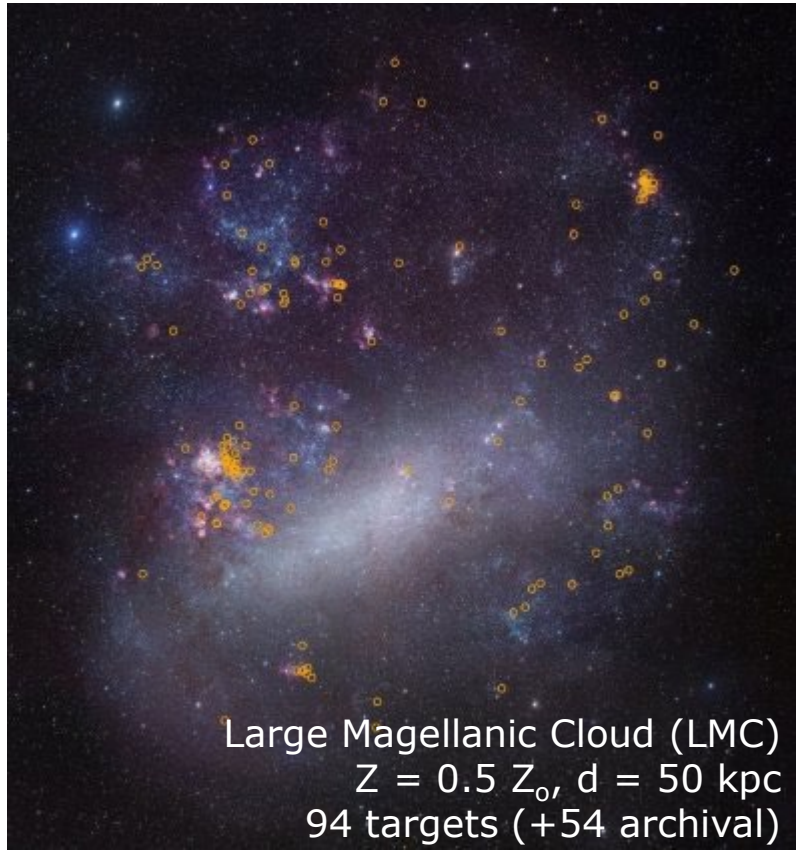
Other community members

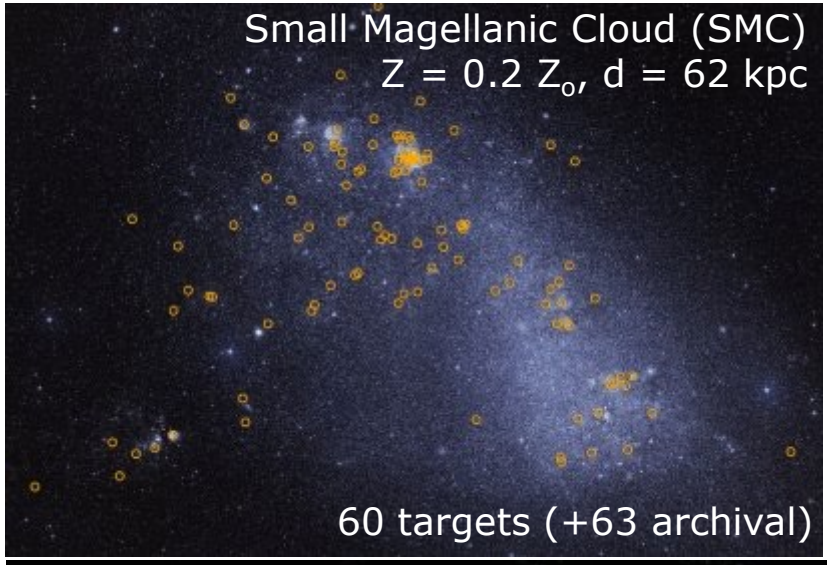
- Carlo Manara (ESO) for providing updated accretion rates and extinction values
- Jesus Hernandez and Javier Serna (UNAM) for providing TESS-based rotational periods
- ODYSSEUS team (led by Greg Herczeg) for interesting discussions about targets and coordination
- IAU G2 (massive stars) for useful feedback on implementation

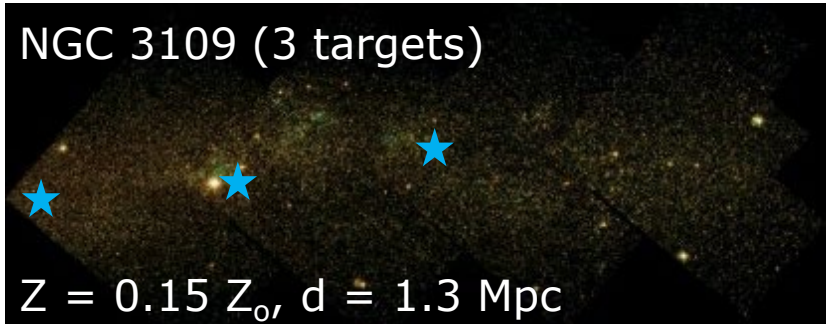
Back-up Slides

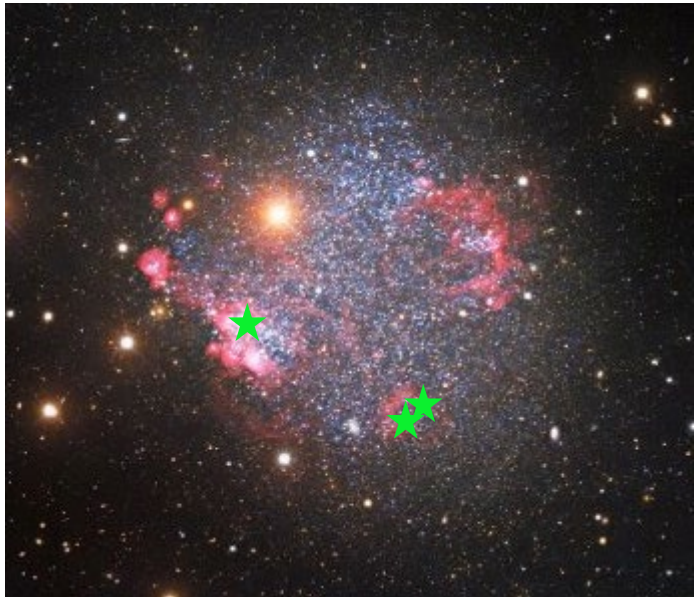
ULLYSES Massive Stars (~500 orbits)

- ULLYSES targets ~170 OB stars in 4 galaxies spanning a range of metallicities (8%-50% solar)
- Also includes ~140 OB stars with archival spectra in the same galaxies
- Statistical sample covering metallicity, temperature class, and luminosity class uniformly









Sextans A
Z = 0.1 Z$_o$, d = 1.6 Mpc
3 targets (+9 archival)

Observing Status

LMC	Number	Complete	%
Targets	94	76	81%
Orbits	244	206	84%
Programs	33	26	79%
HOPRs	14	24 orbits repeated (14%)	

Survey TTS	Number	Complete	%
Targets	58	56	97*
Orbits	390	390	100
Programs	24	24	100
HOPRs	9	50 orbits repeated (13%)	

*2 targets dropped after failure

SMC	Number	Complete	%
Targets	60	59	98%
Orbits	205	204	99.5%
Programs	19	18	95%
HOPRs	19	42 orbits repeated (22%)	

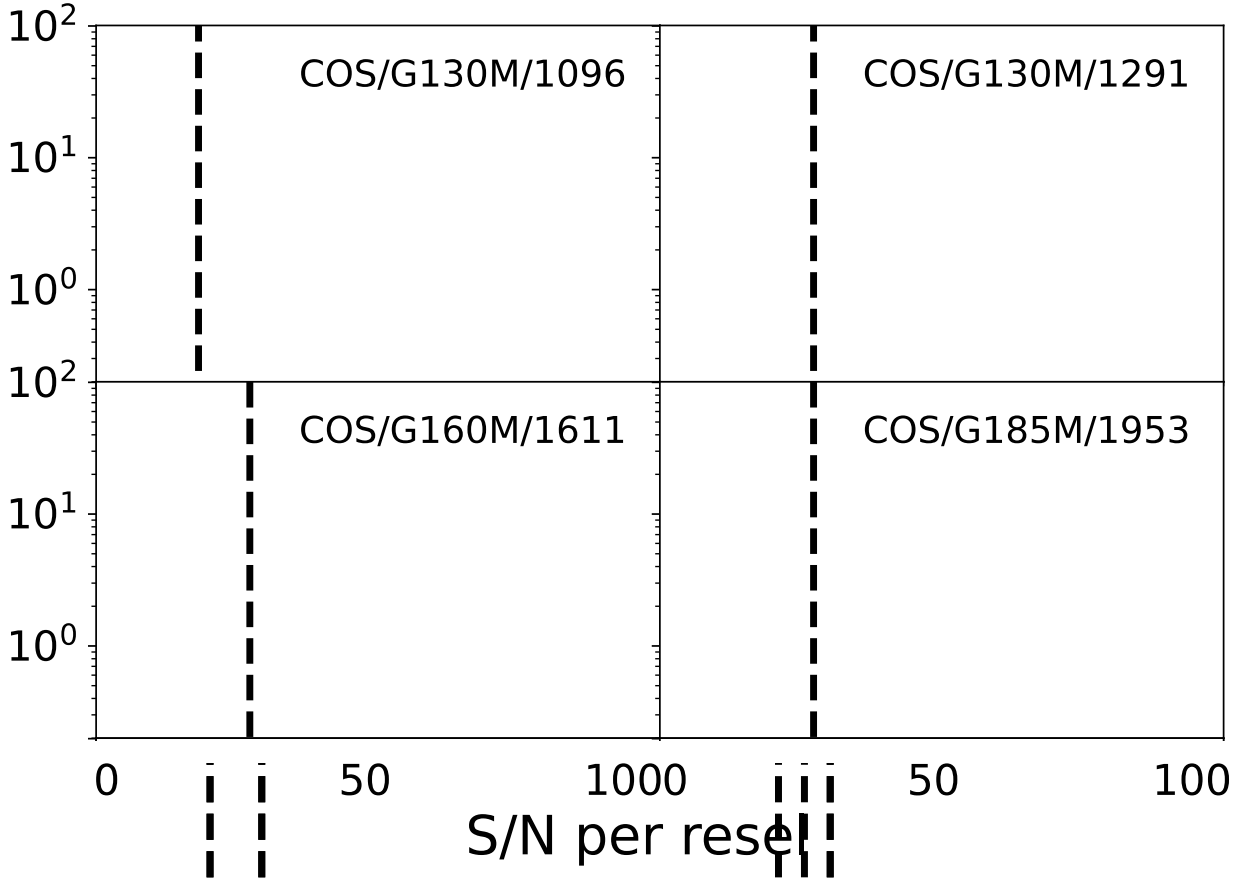
Monitor TTS	Number	Complete	%
Targets	4x2	6	100
Orbits	96	96	100
Programs	8	8	100
HOPRs	6	6 orbits repeated (8%)	

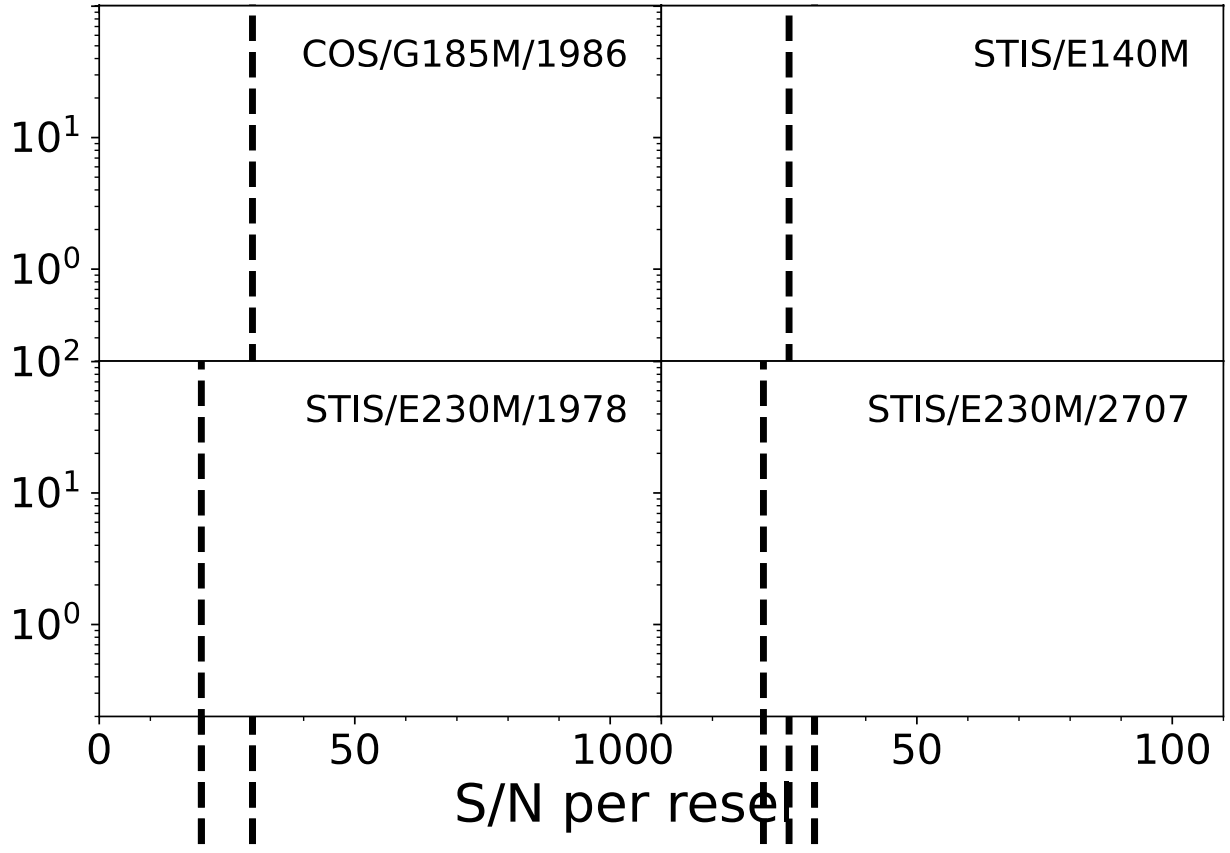
Galaxy	Metallicity	WFC3 Pre-Imaging *		COS G140L/800 Spectroscopy		
		Orbits	Status	Targets	Orbits	Status
NGC 3109	0.1 – 0.2 $Z_\odot$	4	Complete	3	9	Complete
Sextans A	< 0.1 $Z_\odot$	2	Complete	3	20	Complete

*F225W, F275W, F336W, F475W, F814W

Data Quality of COS and STIS observations of LMC/SMC stars

- Generally, the distribution of S/N is centered on the goal
- Exception of COS/G130M/1096, presumably due to estimation of exposure times based on SpT, E(B-V), and optical photometry



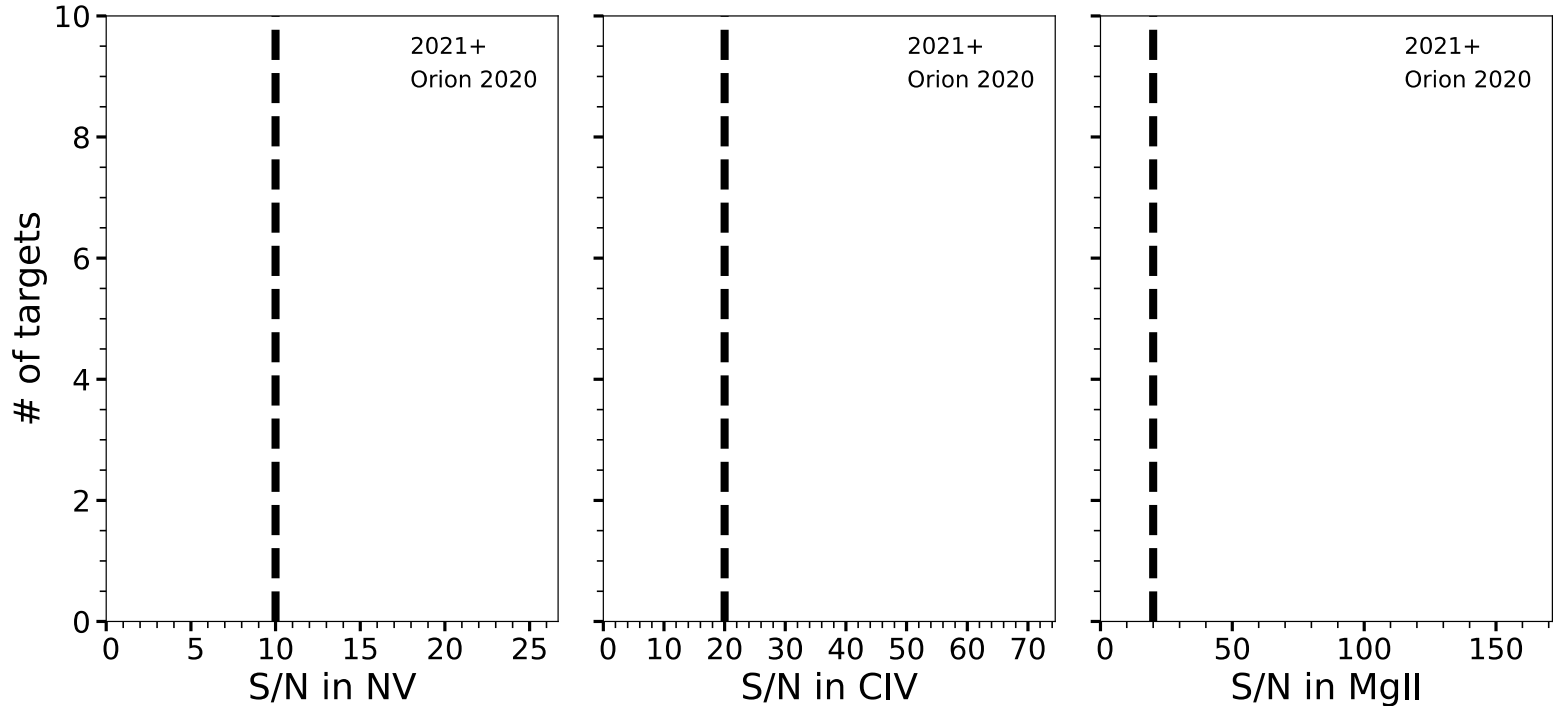


Observing: Survey T Tauri stars (58 targets/400 orbits)

	Number	Complete	%
Targets	58	56	97
Orbits	390	390	100
Programs	24	24	100
HOPRs	9	50 orbits repeated (13%)	

- ✓ Observations for all single epoch ("survey") T Tauri stars are complete!

- ✓ The distribution of S/N is about on target
  - ➢ Some objects have low S/N due to accretion severely decreasing over time



DR5 and DR5b contents

- Latest data release (DR5, June 28 2022) includes:
  - COS spectra for 85 Tauri stars (41 with STIS NUV-optical-NIR)
  - COS spectroscopic time series for 4 T Tauri stars monitored with HST
    - Both epochs completed for TW Hydra!
  - LCOGT photometric time series for 40 T Tauri stars
  - HST UV spectra of **233 stars in the LMC and SMC**, plus **FUSE spectra** of 122 of those stars
  - COS/FUV/G140L/800 spectra of 3 massive stars in low metallicity galaxy NGC 3109 NEW!
  - Drizzled WFC3 imaging of NGC 3109 and Sextans A
  - STIS spectra of 9 non-ULLYSES targets present in STIS long-slit observations
  - **Publication of the HLSP-making code (including co-addition and time-series)** NEW!
- DR5b includes HST products for **17 T Tauri stars observed since DR5**
  - ➢ Custom calibrated STIS G230L, G430L, G750L spectra
  - ➢ Co-added COS/FUV G130M + G160M spectra

13 AR, parallel, or complementary GO programs related to ULLYSES

Cycle	PID	Orbits	Title	Topic
27	GO-15967 PI Chisholm	49	Constraining the Stellar Astrophysics Powering Cosmic Reionization: Spectral Templates of Extremely Low-metallicity Main-sequence O-stars	Low-Z massive stars
27	Multiple PIDs PI C Murray	500	Scylla (PI C. Murray, multiple PIDs) – Scylla: A pure-parallel, multi-headed attack on dust evolution and star formation in ULLYSES galaxies	Parallel to LMC/SMC
28	GO-16233 PI Schneider	17	Jets and disk scattering – Spatially resolved optical and FUV observations of AA Tau	CTTS
28	SNAP-16239 PI Massa	200	A NUV SNAP program to supplement and enhance the value of the ULLYSES OB star legacy data	LMC/SMC STIS CCD spectra
28	AR-16148 PI Senchyna		Painting the first empirical picture of massive stars below the metallicity of the SMC with ULLYSES	Low-Z stars
28	AR-16129 PI Herczeg		Outflows and Disks around Young Stars: Synergies for the Exploration of ULLYSES Spectra (ODYSSEUS)	CTTS
28	AR-16131 PI Hillier		CMFGEN: A key spectroscopic tool for astrophysics	LMC/SMC/low-Z
28	AR-16133 PI Jenkins		A comprehensive investigation of Gas-phase element abundances and extinction by dust in the LMC and SMC	ISM LMC/SMC

13 AR, parallel, or complementary GO programs related to ULLYSES

Cycle	PID	Title	Topic
29	AR-16616 PI Howk	Interstellar tomography of highly ionized gas in the MW thick disk with ULLYSES	CGM
29	AR-16623 PI Leitherer	Feasting on the Riches of Odysseus' voyage	Population synthesis
29	AR-16640 PI Zheng	Braving the storm, quantifying the effects of Ram Pressure and Stellar Feedback in the LMC	ISM/CGM
29	AR-16602 PI Barger	The LMC's Galactic Wind through the eye of ULLYSES	ISM/CGM
29	AR-16635 PI Tchernyshyov	The first direct measurement of CO/H2 in subsolar environments using ULLYSES data	ISM

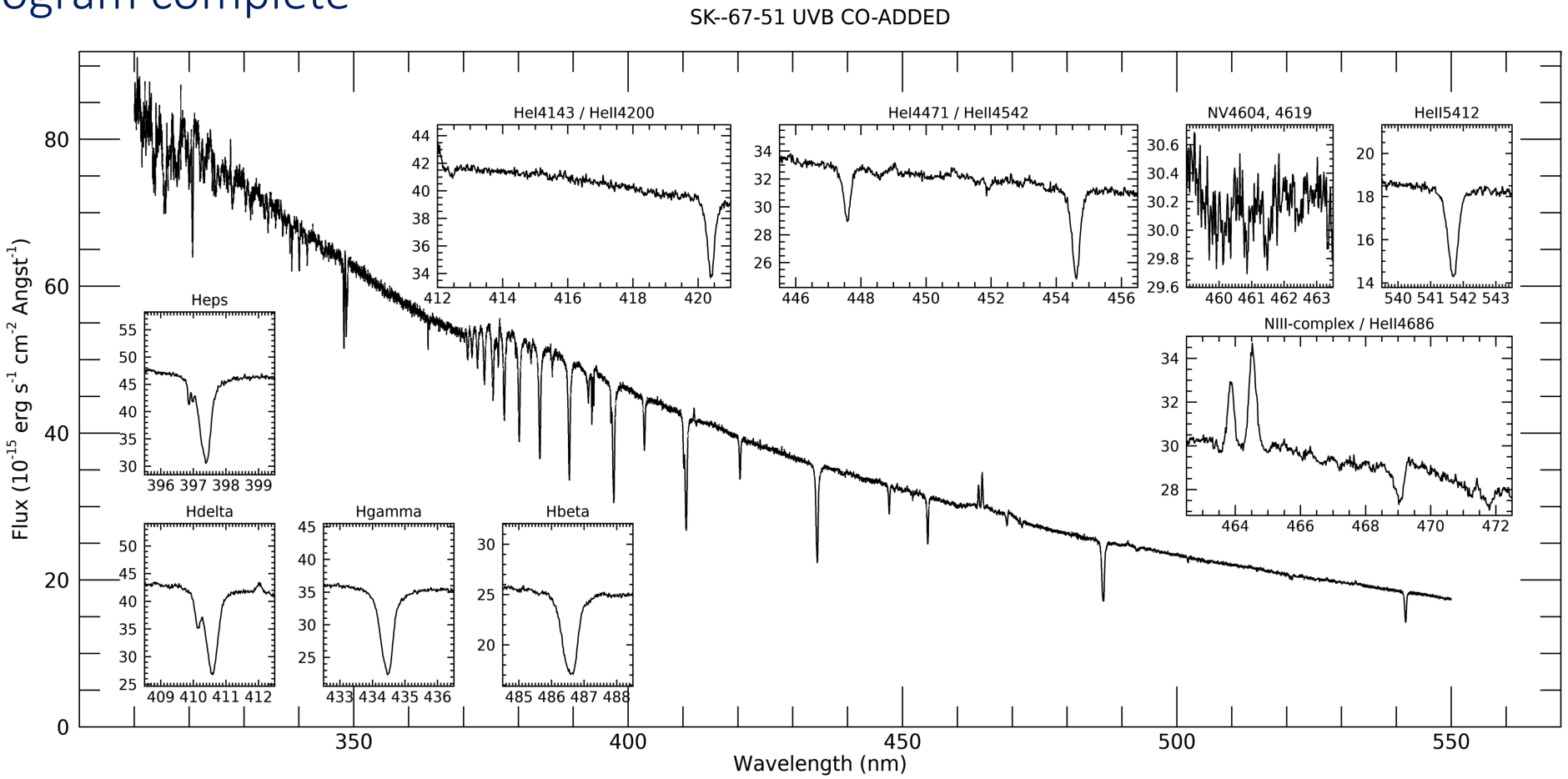
ULLYSES S/N Requirements

- Massive SMC/LMC Stars
  - COS/G130M/c1096: S/N = 20 / nine-pixel resel at 1080 Å continuum
  - COS/G130M/c1291: S/N = 30 / six-pixel resel at 1150 Å continuum
  - COS/G160M/c1589+1623: S/N = 30 / six-pixel resel at 1590 Å continuum
  - COS/G185M/c1953: S/N = 30 / three-pixel resel at 1860 Å continuum
  - COS/G185M/c1986: S/N = 30 / three-pixel resel at 1980 Å continuum
  - STIS/E140M/c1425: S/N = 20 / two-pixel resel at 1200 Å continuum
  - STIS/E230M/c1978: S/N = 20 / two-pixel resel at 1800 Å continuum
  - STIS/E230M/c2707: S/N = 20 / two-pixel resel at 2800 Å continuum
- Massive Low Z Stars in Sextans A and NGC 3109
  - COS/G140L/c800: S/N = 15 / six-pixel resel at 1600 Å continuum
- T Tauri Stars
  - COS G130M/c1291 S/N = 15 / six-pixel resel in peak of N V 1239 Å
  - COS G160M/c1611 S/N = 20 / six-pixel resel in peak of CIV 1549 Å
  - STIS G230L/c2376 S/N = 20 / six-pixel resel in peak of Mg II 2800 Å
  - STIS/G430L S/N=20 / two-pixel resel in continuum at 4000 Å
  - STIS/G750L S/N= / two-pixel resel in continuum at 5700 Å

Coordinated observations

Coordinated programs for massive stars

- X-ShootU program led by IAU-G2
  - VLT X-Shooter for all ULLYSES targets
  - Program complete

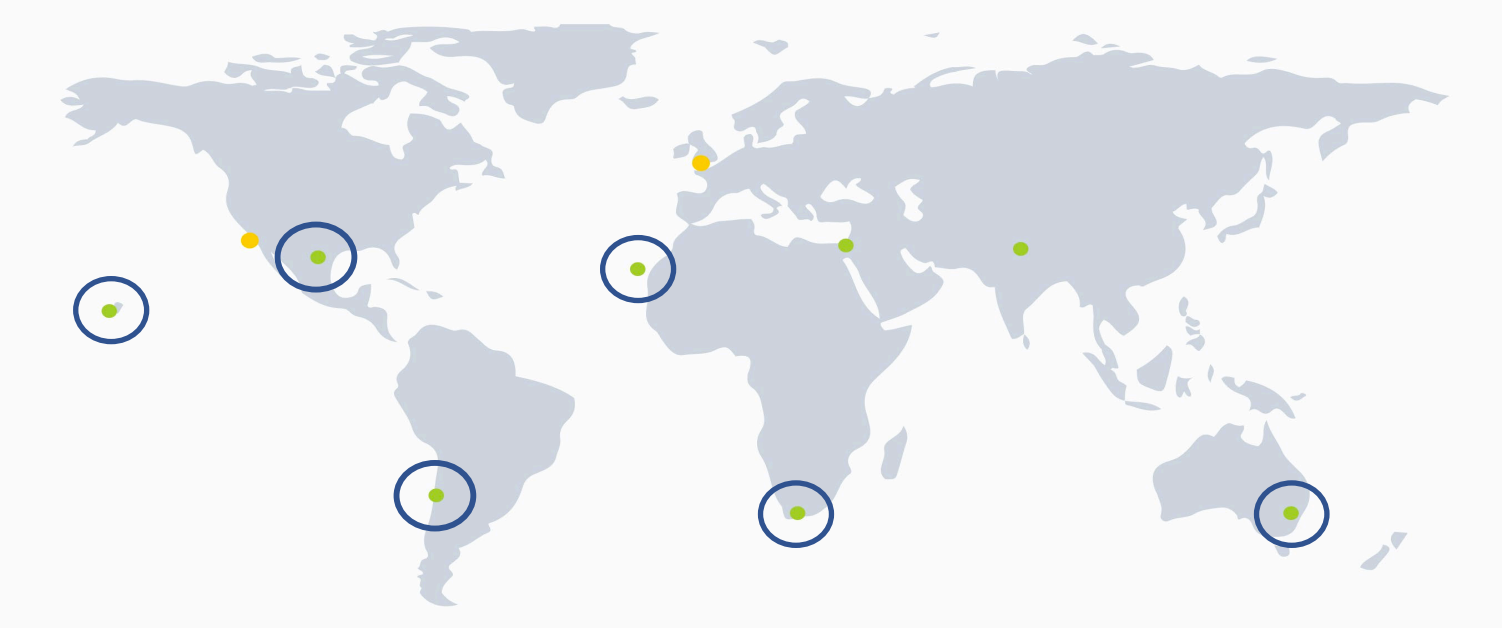


Coordinated programs for T Tauri stars

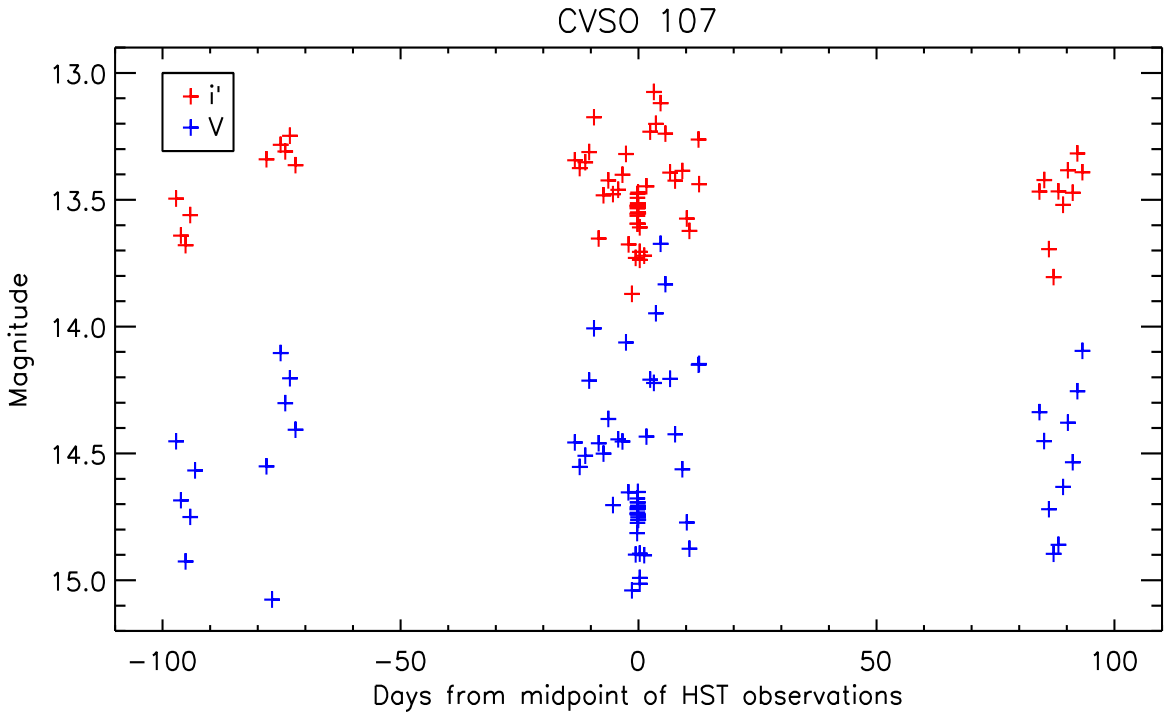
- Monitored stars only
  - Chandra/XMM-Newton (X-ray; accretion)
  - CFHT/SPIRou spectro-polarimetry (magnetic field mapping)
- Survey and monitored stars
  - VLT X-Shooter, ESPRESSO, UVES (accretion, extinction, stellar properties, kinematics)
  - IRTF (calibration of MIR accretion diagnostics in preparation for JWST observations of deeply embedded protostars)
  - LCOGT photometric monitoring led by our team (variability context + detector safety)
  - TESS (high cadence variability context, March-June 2021 only)
- All programs executing successfully
  - Some coordination with TESS and LCOGT lost when programs got bumped due to July 2021 safing

LCOGT Photometric Monitoring

- STScI implementation team designed a large LCOGT program to perform photometric monitoring in V, i' for survey and u', V and i' for monitoring T Tauri stars
  - Program was accepted and started late August 2020
  - 545h approved in 2020B, 2021A, B, 2022A so far
- LCOGT has 0.4m robotic telescope network around the World (almost continuous longitudinal coverage)



LCOGT Photometric Monitoring



- Cadence:
  - 1x/day 3 months before/after HST epoch
  - 1x/day 10 days before/after HST epoch
  - 10x/period of the 1 (3) periods centered on the HST observations for the survey (monitoring) stars
  - 15 min cadence during the HST observations
- S/N > 10 for all targets/bands
- Flux calibration field (1x/night) for 3 targets (51 fields per target) – Use SkyMapper for other fields/targets
- u' exposure times predicted by LCOGT ETC are underestimated by a factor ~100 → u' monitoring is not feasible for the survey stars
  - We perform u' monitoring only for the brighter 4 CTTS monitored with HST