STScI | SPACE TELESCOPE SCIENCE INSTITUTE

EXPANDING THE FRONTIERS OF SPACE ASTRONOMY

The ULLYSES Director's Discretionary Program

Charting Young Stars' Ultraviolet Light with Hubble

Julia Roman-Duval, TalaWanda Monroe, Jo Taylor, Travis Fischer, Charles Proffitt,

Alex Fullerton, Will Fischer & the ULLYSES implementation team

STUC Meeting – October 8, 2021

Outline

- Program status and miscellaneous updates
- Update on observing:
  - LMC/SMC massive stars
  - Low-metallicity imaging and spectroscopy
  - Survey T Tauri stars
  - T Tauri star monitoring
- Update on data products and releases
- Status of coordinated programs


Program Status and Misc. Updates

Recent Timeline and Milestones

- March 2021: DR2 (LMC/SMC HST and FUSE; Orion CTTS HST data)
- March-April 2021: HST monitoring of TW Hya
- April 2021: Beginning of HST observations of T Tauri stars in Lupus, Cha I, Eta Cha with TESS
- August 2021: DR3 (LMC/SMC, survey CTTS and TW Hya, time-series, NGC 3109 spectroscopy)
- August-September 2021: monitoring of RU Lup and BP Tau
- October 2021: monitoring of GM Aur
- November 2021: COS spectroscopy of NGC3109 (3 stars)
- December 2021: DR4

Program Status

- As of September 2021, ULLYSES observing is about 50% complete
- 3 data releases (latest DR3 on August 31, 2021) – see ullyses.stsci.edu
- 1 press release (https://hubblesite.org/contents/news-releases/2020/news-2020-50)
- 2 peer-reviewed publications by the community (Manara et al. 2021, Vink et al. 2021)

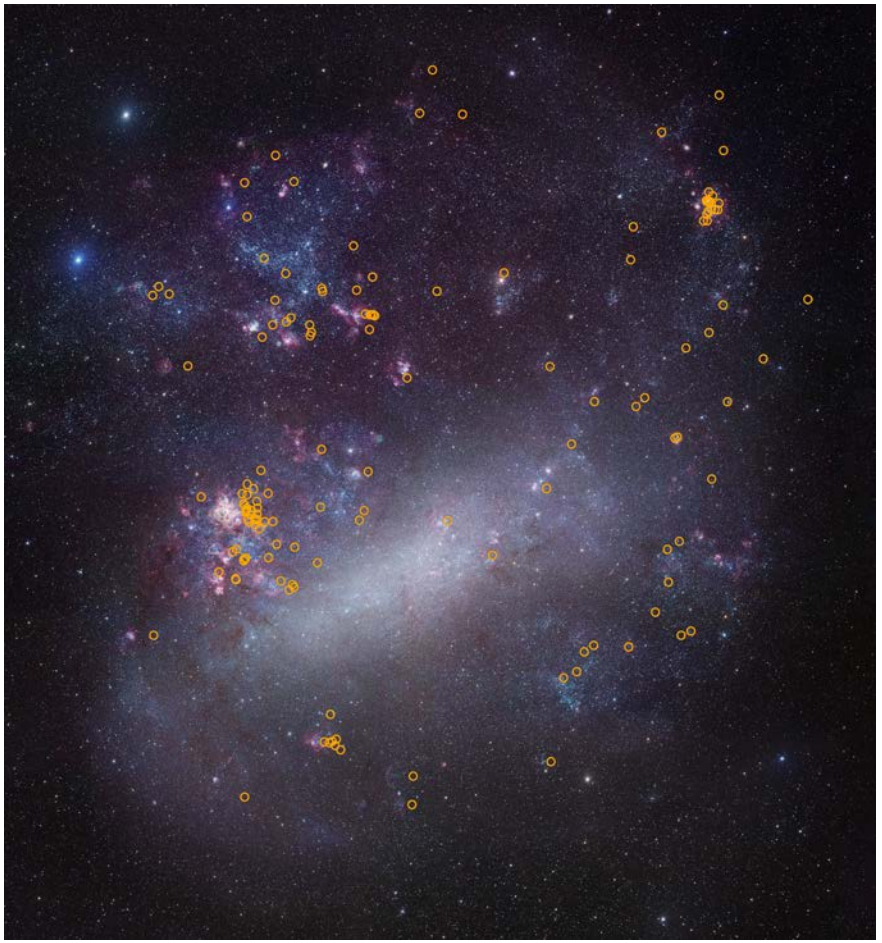
ULLYSES special session at AAS #239

- Special Session for ULLYSES accepted at the Winter AAS (#239) to be held in Salt Lake City (Utah) in January 2022
  - 90 min on January 11 (2-3:30 pm)
  - 6 invited speakers confirmed
  - Poster session (contributed)


Technical Observing Updates

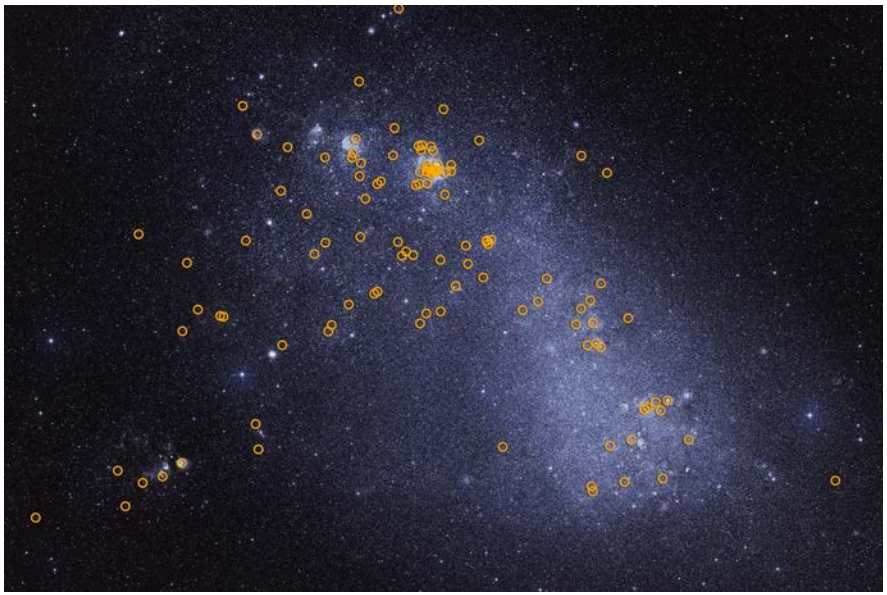
Observing: Massive Stars in the LMC

- LMC (98 targets to be observed)
  - 41 targets/100 orbits successfully observed in the LMC
  - 11 visits requiring HOPRs
  - 9 targets/25 orbits scheduled or scheduling
  - 4 objects being implemented before the end of 2021
  - 43 objects will be submitted through 2022



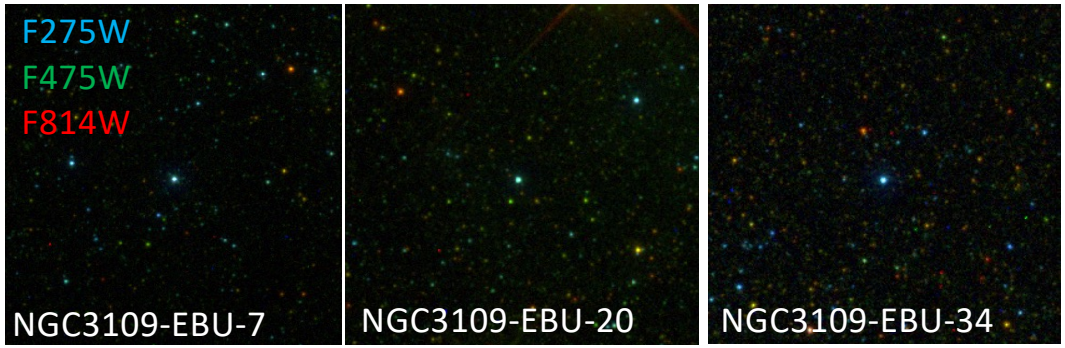
Observing: Massive Stars in the SMC

- SMC (64 targets to be observed)
  - 94 orbits/34 targets successfully observed
  - 9 visits requiring HOPRs
  - 14 targets/59 orbits scheduling or scheduled
  - 14 objects being implemented before the end of 2021
  - 2 objects will be submitted through the first half of 2022



Observing: Massive Stars in Low-Metallicity Galaxies

- WFC3 F225W, F275W, F336W, F475W, F814W pre-imaging in **NGC 3109 complete**
- **Sextans-A** pre-imaging will execute in **December 2021-January 2022** due to ORIENT constraints and guide star availability (original window occurred during March 2021 safing event)
- 11 orbits of follow-up **spectroscopic observations with COS/G140L/800** for 3 of stars in **NGC3109** will execute in **November 2021** (postponed due to July 2021 safing event)
- Spectroscopy of Sextans A will occur in 2022 (Cycle 29)



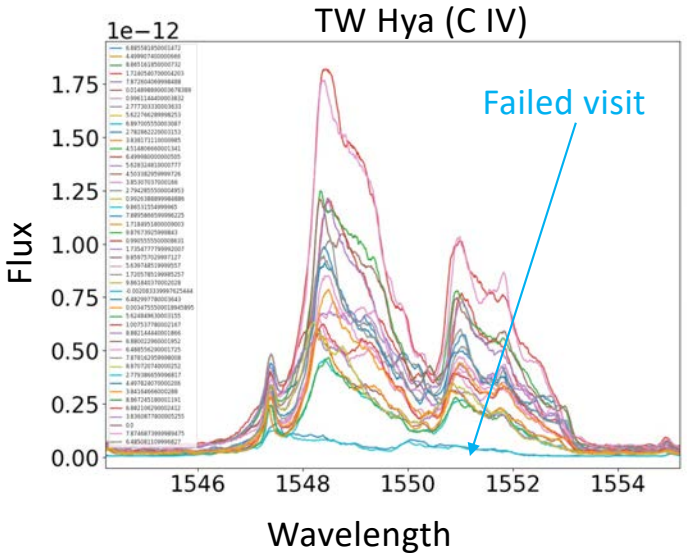
Galaxy	Star	MAST Star Name	RA(J2000)	DEC(J2000)	SpType	V	E(B-V)	F225W	F275W	F336W	F475W	F814W
NGC3109	NGC-3109 EBU 07	NGC-3109-EBU-07	10h 02m 54.69s	-26d 08m 59.64s	B0-1Ia[1]	18.69[1]	0.09[1]	16.25	16.62	17.23	18.27	20.12
NGC3109	NGC-3109 EBU 20	NGC-3109-EBU-20	10h 03m 03.22s	-26d 09m 21.41s	O8I[1]	19.33[1]	0.17[1]	17.04	17.35	17.90	18.91	20.67
NGC3109	NGC 3109 EBU 34	NGC-3109-EBU-34	10h 03m 14.24s	-26d 09m 16.96s	O8I(f)[1]	19.61[1]	0.1[1]	16.99	17.40	18.03	19.16	21.07
Sextans A	Sextans A GHF s4	SEXTANS-A-GHF-S4	10h 10m 57.89s	-04d 43m 10.2s	O6z[2]	20.9[2]	0.05[2]					
Sextans A	Sextans A GHF s2	SEXTANS-A-GHF-S2	10h 10m 58.59s	-04d 43m 28.9s	O3-5Vz[2]	20.8[2]	0.22[2]					
Sextans A	Sextans A GHF s8	SEXTANS-A-GHF-S8	10h 11m 05.69s	-04d 42m 13.6s	B0 I[3]	19.7[3]	0.05[3]					

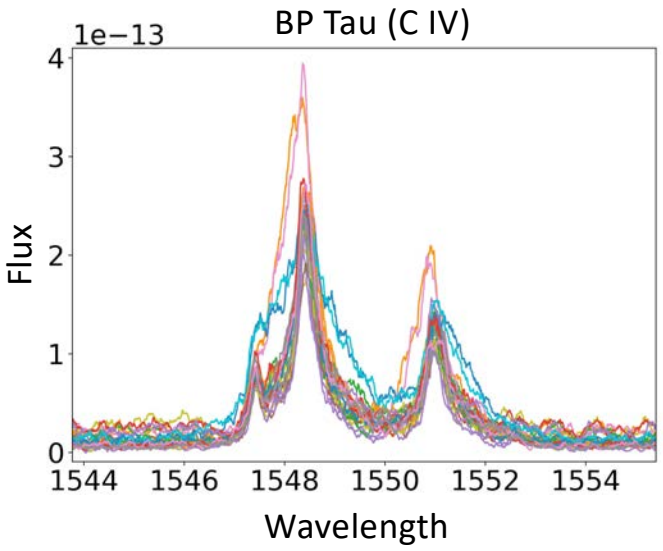
Observing: Survey T Tauri stars (59 targets)

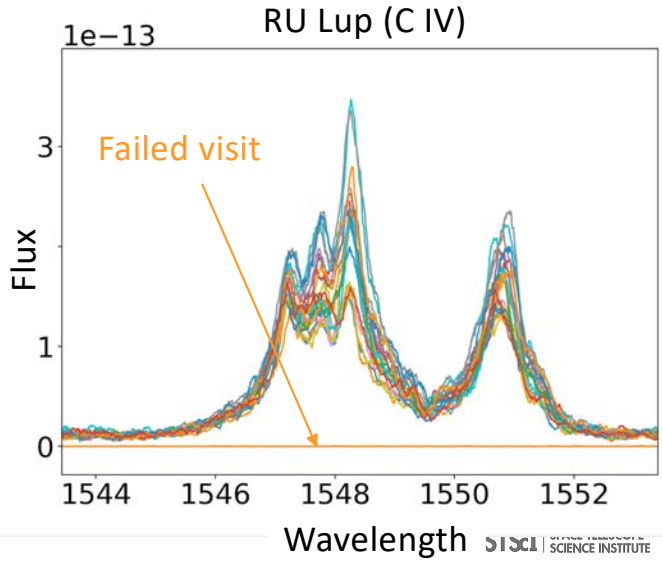
- 13 T Tauri stars in Orion observed with 59 orbits in November-December 2020 during period when covered by TESS
- 19 T Tauri stars in Lupus, Cha I, Eta Cha observed with 127 orbits in March-August 2021, in coordination with TESS
- Phase IIs submitted for 10 survey T Tauri stars (56 orbits), mostly in Eta Cha and Cha I
  - Observations will execute January-May 2022
  - Includes second epoch of observations for V505-Ori, a dipper in Orion observed in a low state during the first epoch
- 16 Lupus stars will be implemented before the end of 2021
- 2 stars in CrA will be implemented in early 2022

Observing: Monitoring of 4 T Tauri stars

- 12 observations (4/period over 3 rotational periods) executed:
  - For TW Hya (March-April 2021) – 1 failed visit (the second one)
  - BP Tau (August-September 2021) – 0 failed visits
  - RU Lup (August 2021) – 2 failed visits (repeat of first failed visit also failed)
- GM Aur monitoring will execute in October 2021







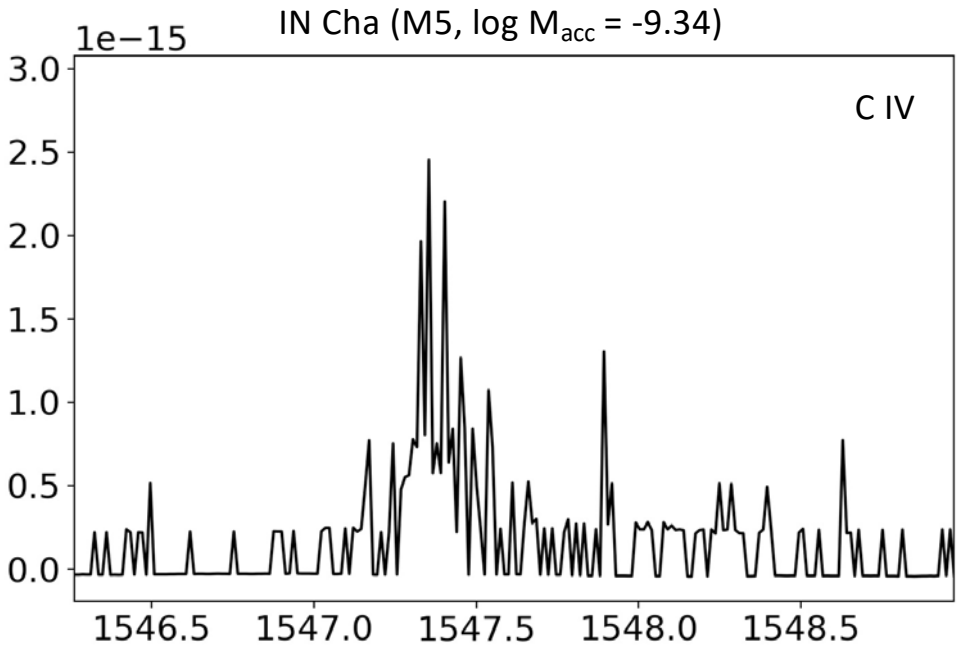
Scheduling updates

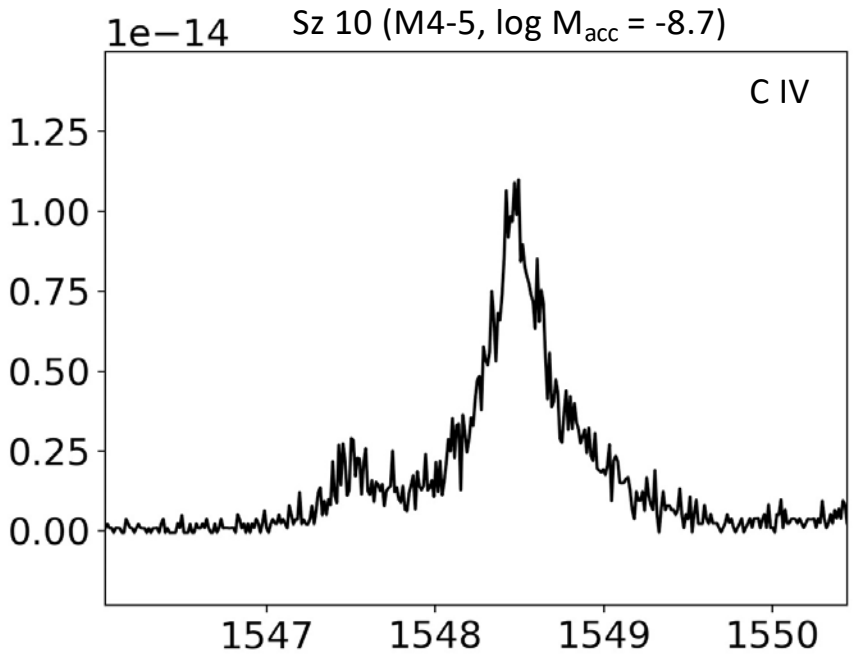
- Scheduling information is included on the ULLYSES website (https://ullyses.stsci.edu/ullyses-targets-ttauri.html)
- Scheduling updates are forwarded to a specific email distribution that includes PIs of coordinated observations (ullyses_ctts_scheduling@maillist.stsci.edu)

Observation outcomes for the Spring 2021 batch of CTTS

Observing outcomes for late M stars

- Some M3-5 stars were observed to be much fainter in the FUV than expected given their published accretion rates (from X-Shooter)



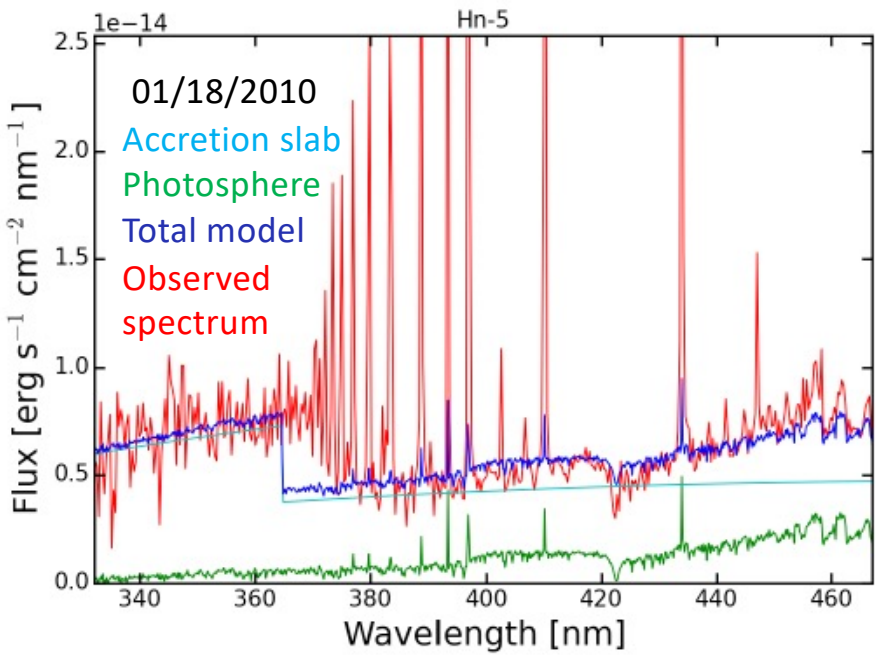


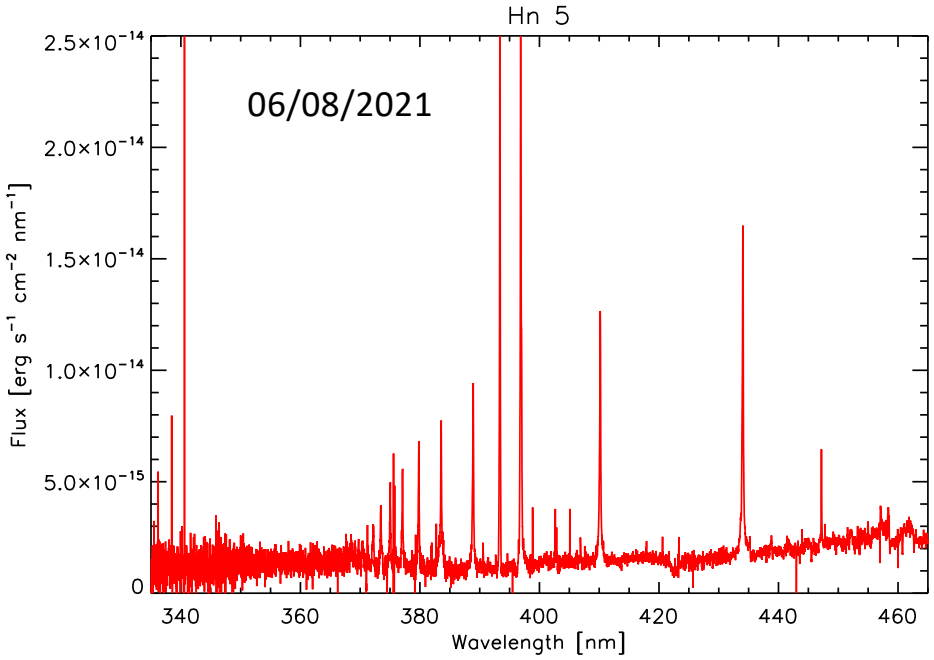
Signal-to-noise outcome

Target	SpT	Log dm/dt	S/N NV	S/N CIV	S/N Mg II
CHX18N	K2	-8.09	8	16	44
Sz75	K6	-7.67	11	22	88
Sz77	K7	-8.79	5	14	34
Sz45	M0.5	-8.09	8	22	75
Sz111	M1	-9.12	5	20	30
Sz71	M1.5	-9.06	5	17	21
Sz72	M2	-8.65	7	24	88
Sz130	M2	-9.19	4	11	30
Sz66	M3	-8.54	0	0	20
XX Cha	M3.5	-7.41	9	30	30
Sz76	M4	-9.26	4	5	20
Sz10	M4-5	-8.7	5	17	20
Sz69	M4.5	-9.51	0	2	30
SSTc2dJ1600	M4.5	-9.81	2	3	12
Hn5	M5	-9.28	0	0	8
IN Cha	M5	-9.34	0	0	8
2MASS J1143-78044	M5.5	-8.71	3	10	10
ECHA-J0844.2-7833	M6	-10.18	4	10	13

Variable accretion

- Carlo Manara shared X-Shooter data taken concurrently with the HST observations
- Accretion rate in IN Cha and Hn5 appears to have decreased dramatically, explaining the faint FUV flux





Plan forward

- All remaining M stars left to implement show prominent Balmer jump, indicative of significant accretion
- We will discuss how to proceed with observations of remaining M stars with the SAC

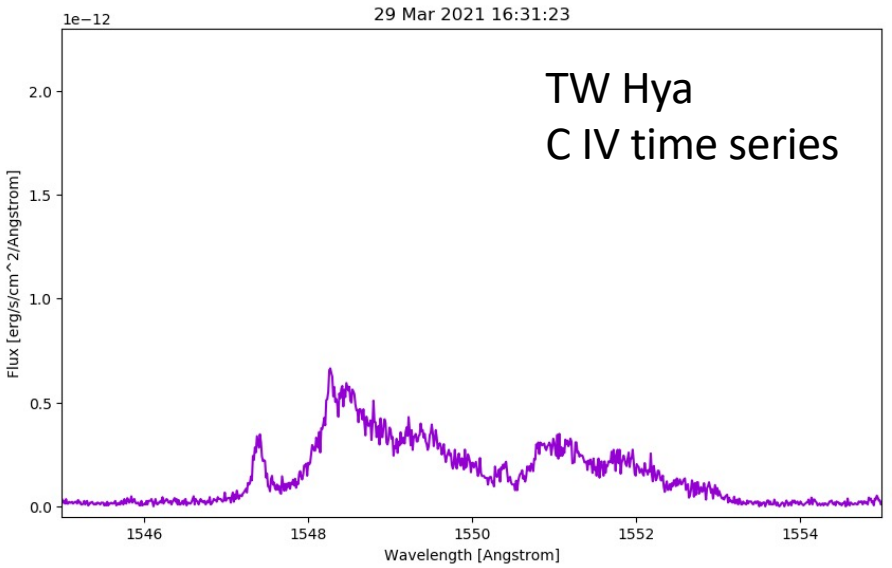

ULLYSES Data Products

Data Release 3 (August 2021)

- Massive stars and products in Data Release 3 (DR3)
  - HST COS/STIS spectra for 179 massive stars in the LMC/SMC
    - Calibrated spectra and different levels of co-added and spliced spectra
  - FUSE spectra for 99 LMC/SMC stars
  - WFC3 drizzled images for low-metallicity galaxy NGC3109
  - Database of LMC/SMC star metadata, thoroughly vetted by STScI and community members expert on massive stars

Data Release 3 (August 2021)

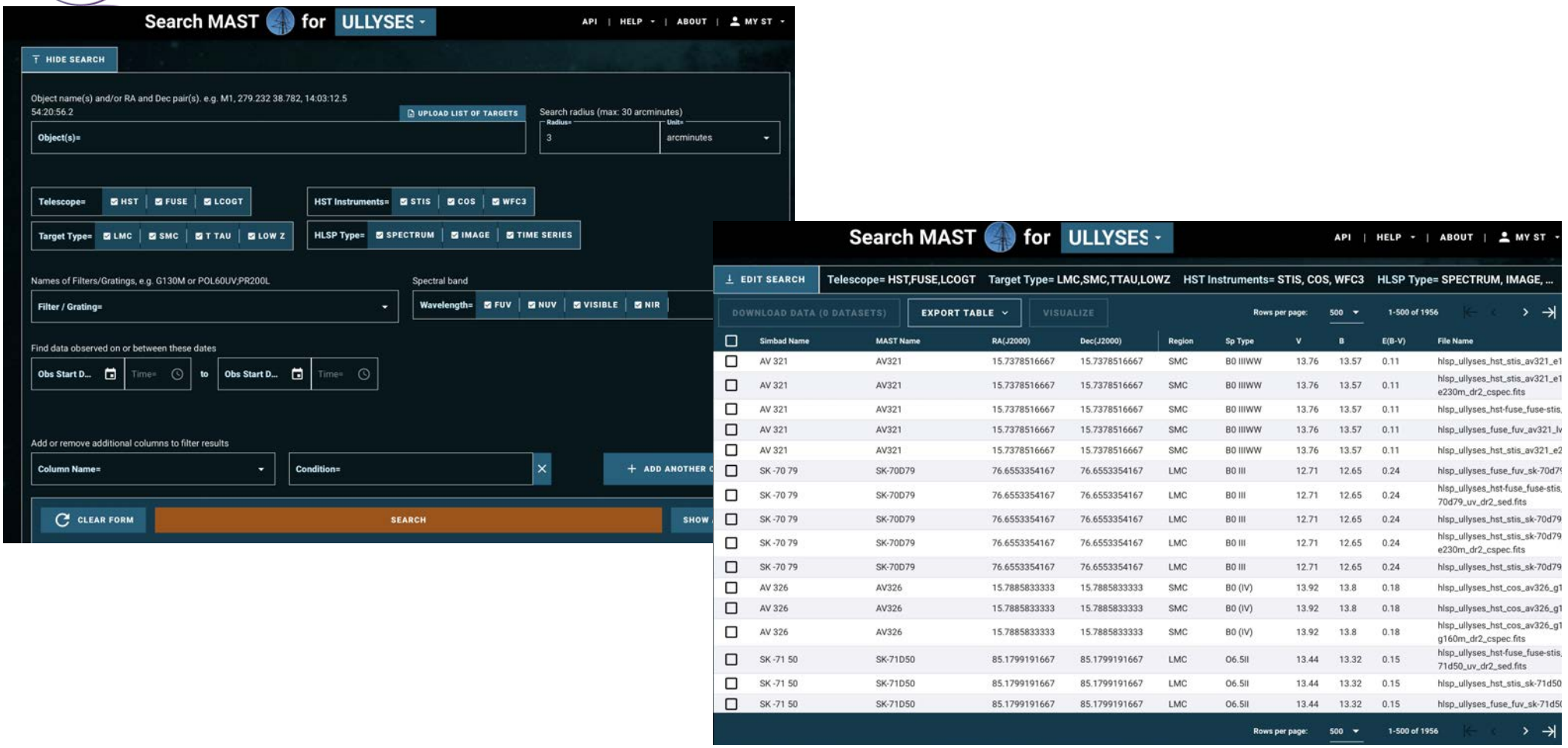
- T Tauri stars and products in DR3
  - COS FUV and NUV spectroscopic time-series for TW Hya (monitoring target)
    - Includes custom calibration for NUV vignetting and custom wavelength-alignment
    - Time-series spectra sampled at exposure duration and sub-exposure duration
  - COS spectra for 47 T Tauri stars (27 of which also have STIS NUV-optical-NIR)
    - STIS NUV and CCD data manually calibrated
  - LCOGT photometric time-series for 13 Orion T Tauri stars
- Announcements:
  - By email sent to 5000+ HST users
  - Posted on Twitter by OPO
  - Posted to the STScI homepage



Plan for Data Release 4

- Plan for DR4 (in addition to data/products already delivered in previous DRs)
  - Mid-December 2021
  - COS spectral time series for RU Lup, BP Tau, GM Aur
  - COS and STIS spectra for T Tauri stars observed after 8/15/2021
  - COS spectra and target metadata for additional archival T Tauri stars (in Taurus in particular)
  - Time permitting - LCOGT time-series for T Tauri stars included in DR3 (observed in Spring-Summer 2021)
  - Observation date permitting - COS spectroscopy of NGC 3109
  - FUSE spectra for massive stars observed in 8/15/2021
  - Time permitting - catalogs and user-interfaces for querying ULLYSES data/targets based on astrophysical and observation metadata

ULLYSES Search and Download Form



Future DRs

- DR5 will occur around May 2022 (TBD)
  - Public release of HLSP code
  - HST data for T Tauri stars observed in Spring 2022
  - HST spectral time-series for TW Hya (second epoch)
  - LCOGT photometric time-series for first epoch of monitoring T Tauri stars
  - More LMC/SMC massive stars
  - Pre-imaging of Sextans-A
- Future DRs every few (~ 5) months until completion of project close-out (expected in 2023)
- ULLYSES HLSPs, catalogs, and user interfaces integrated in MAST for long-term maintainability and impact

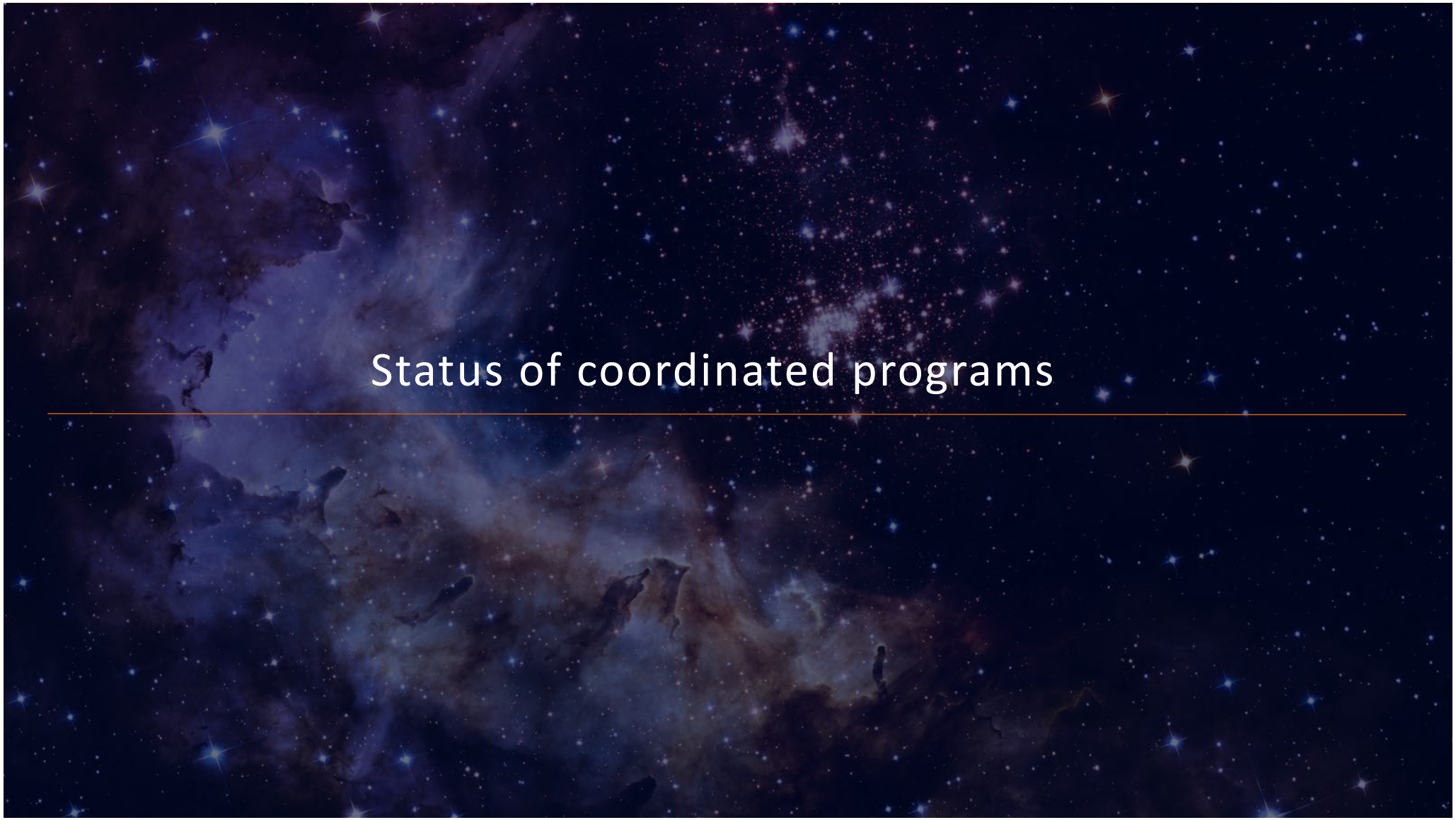
ULLYSES Data Accessibility

Data can be downloaded from:

- ULLYSES website: https://ullyses.stsci.edu/ullyses-download.html
- ULLYSES search & download web application: https://ullyses.stsci.edu/search/
- MAST Portal: https://mast.stsci.edu/portal/Mashup/Clients/Mast/Portal.html
- Astroquery

Coming soon:

- ULLYSES search and download form using new Missions-MAST application

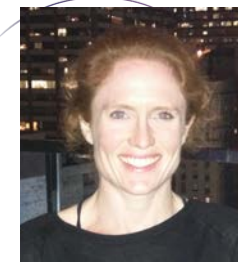

Status of coordinated programs

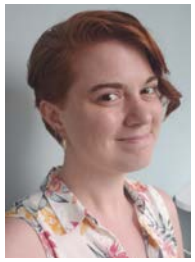
Coordinated programs for T Tauri stars

- 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 (variability context)
  - TESS (high cadence variability context)
- All programs executing successfully
  - Some coordination with TESS and LCOGT lost when programs got bumped due to July safing

Acknowledgements

ULLYSES Core Implementation Team (CIT)


Julia Roman-Duval
(CIT Lead)


Jo Taylor
(DP Lead)


Travis Fischer
(DP Deputy Lead)


TalaWanda Monroe
(Observing Lead)


Charles Proffitt
(Observing)


Will Fischer
(T Tauri star Lead Expert)


Alex Fullerton
(Massive Star Lead Expert)


Alessandra Aloisi
(Pre-imaging)


Chris Britt
(Public Outreach)


Ivo Busko
(DP/software)


Svea Hernandez
(DP)


Alec Hirschauer
(Oberving)


Robert Jedrzejewski
(DP, software)


Sean Lockwood
(ETC, Obs)


Elaine Frazer
(DP)


Rachel Plesha
(Targets, Obs, DP)


Adric Riedel
(Targets, DP)


David Sahnow
(Observing)


Richard Shaw
(DP)


Ravi Sankrit
(Observing)


Linda Smith
(Targets)


Debopam Som
(Observing)


Leonardo Ubeda
(Website)


Dan Welty
(Targets, Obs, DP)


Brian York
(DP)

Other STScI staff involved

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

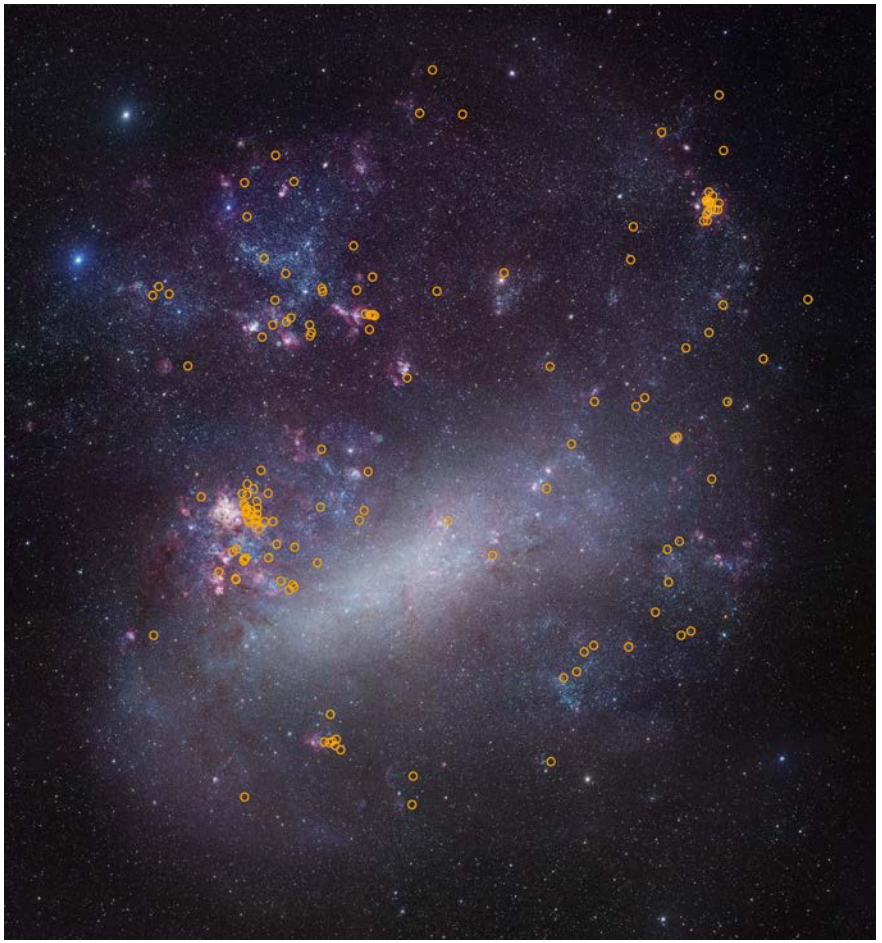
- Carlo Manara (ESO) for providing updated accretion rates and extinction values
- Jesus Hernandez and Javier Serna (UNAM) for providing TESS-based rotational periods
- ODYSSEUS team (led by Greg Herczeg) for interesting discussions about targets and coordination
- IAU G2 (massive stars) for useful feedback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

Thank you

Back-up Slides

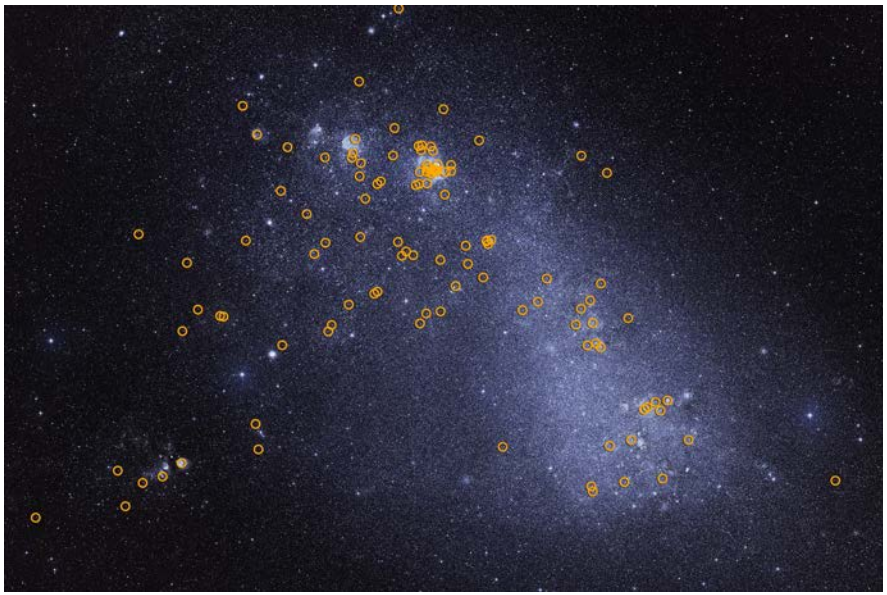
Observing: Massive Stars in the LMC (TALA CHECK NUMBERS)

- LMC (98 targets to be observed)
  - 105 orbits successfully completed for 42 targets observed to date in the LMC
  - 10 HOPRs
  - 11 targets/26 orbits scheduled or scheduling
  - ??? objects being implemented before the end of 2021
  - 45 objects will be submitted through 2022



Observing: Massive Stars in the SMC (TALA CHECK NUMBERS)

- SMC (65 targets to be observed)
  - 110 orbits/38 targets successfully completed
  - 8 HOPRs
  - 13 targets/55 orbits scheduling or scheduled
  - 14 objects being implemented before the end of 2021
  - 0 objects will be submitted through the first half of 2022



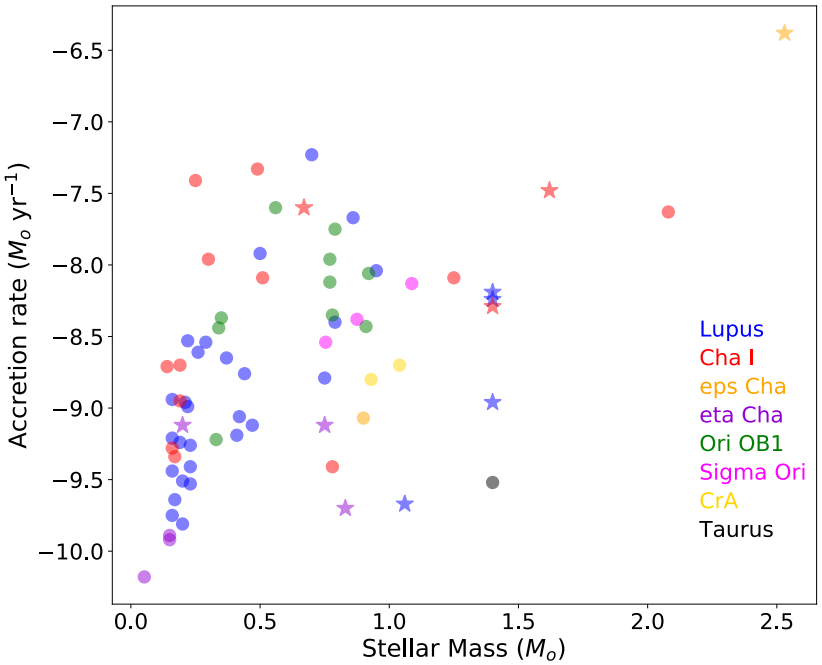
Extinction and exposure times for CTTS

- Flux level of Orion CTTS was fainter than expected from from published accretion rates and extinction
- All T Tauri star models were scaled with an extra 0.5 of A_V before ETC calculation for the sample observed in Spring 2021
  - Except for T Tauri stars in Eta Cha, for which we robustly know there is very low extinction
  - Goal S/N was decreased to S/N = 10 for N V and 20 for C IV (instead of 15 and 30 respectively)

RXJ0438.6+1546

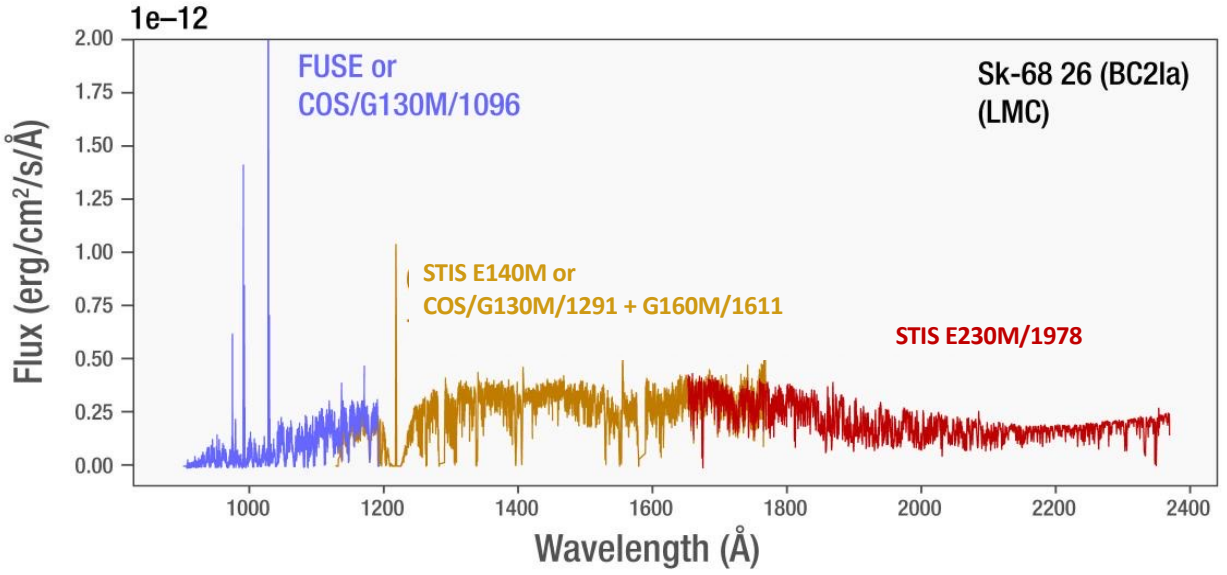
Recent T Tauri star sample updates

- To accommodate extra exposure time, 6 expensive stars were removed from the sample
  - There is redundancy in M*, log(dm/dt) for all those stars, so sample is still covering parameter space
- 1 star (2MASSJ11183572-7935548) was found to be very weakly accreting and also removed from sample
- 3 stars (RECX 7, RECX 12, TWA 8A) did not clear the M dwarf flare BOP rules and were removed from the sample
- 2 stars (RECX 6, RXJ0438.6+1546) was added to the sample as M3 and K2 WTTS templates
- CTTS sample now includes 59 targets (instead of 67 targets in the original sample)



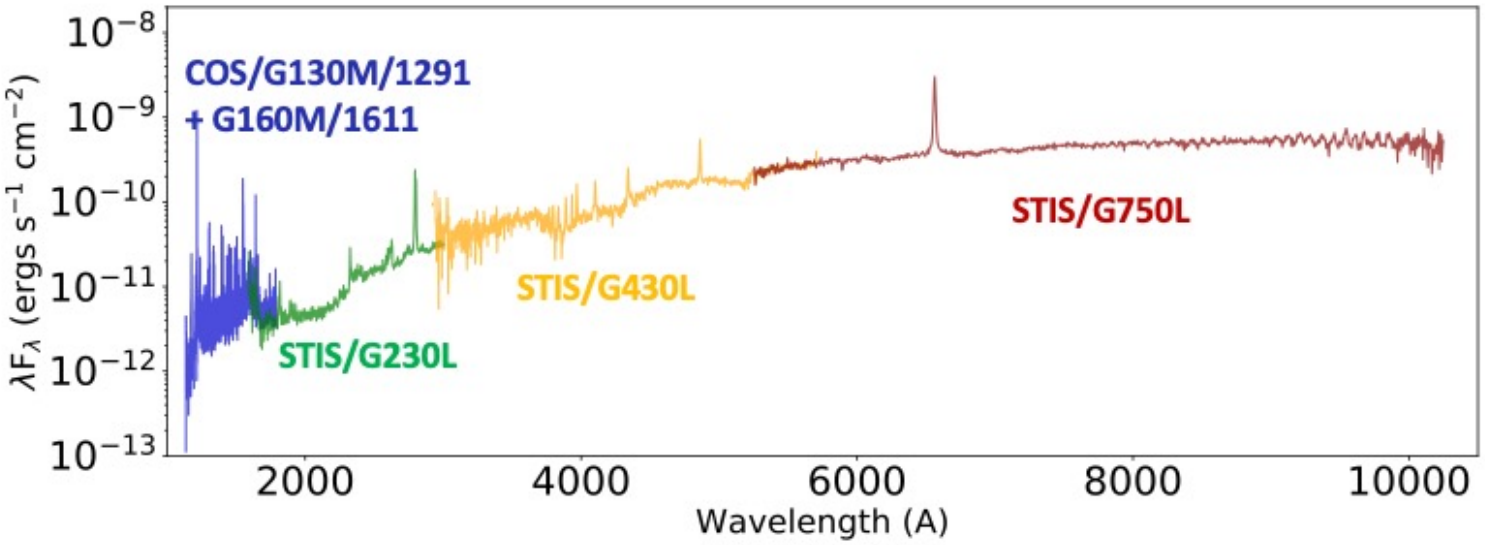
Observing Strategy – LMC/SMC Massive stars

- **FUV coverage from 1140 Å to 1800 Å** with COS/G130M/1291 + COS/G160M/1611, or STIS/E140M for brighter stars
  - Coverage includes Ly-α
- Coverage below 1150 Å with archival **FUSE** data, or COS/G130M/1096 if cost is reasonable
- O9-B9 I stars will also be observed with the E230M/1978, extending coverage to 2400 Å (Al III, Fe III)
- B5-B9 I stars will be observed with STIS/E230M/2707 or COS/G185M/1953+1986 (Mg II)
- FUSE or COS/G130M/1096 for:
  - 70/92 O stars in LMC
  - 54/54 O stars in SMC
- Stars observable in < ~8000s with E140M offloaded to STIS (longer COS lifetime, better spectral resolution)



Observing Strategy – T Tauri Stars

- Survey stars:
  - Medium-resolution UV coverage 1140-1780 Å with COS/G130M/1291 + COS/G160M/1589+1623
  - NUV coverage at low resolution with STIS/G230L
  - Optical-NIR with STIS G430L and G750L
- Monitoring stars:
  - COS/G160M/1589+1623 + COS/G230L/2950

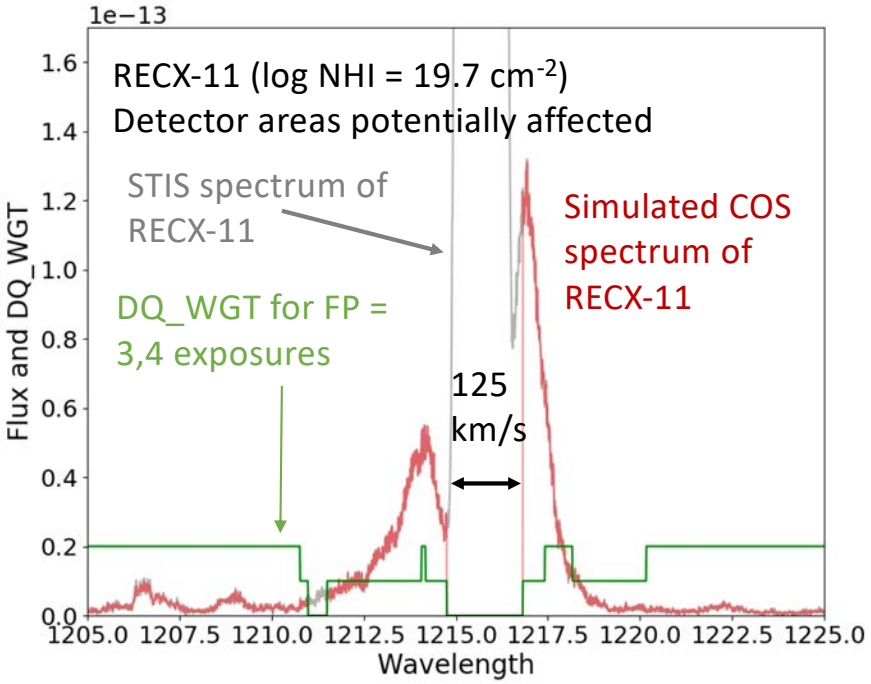


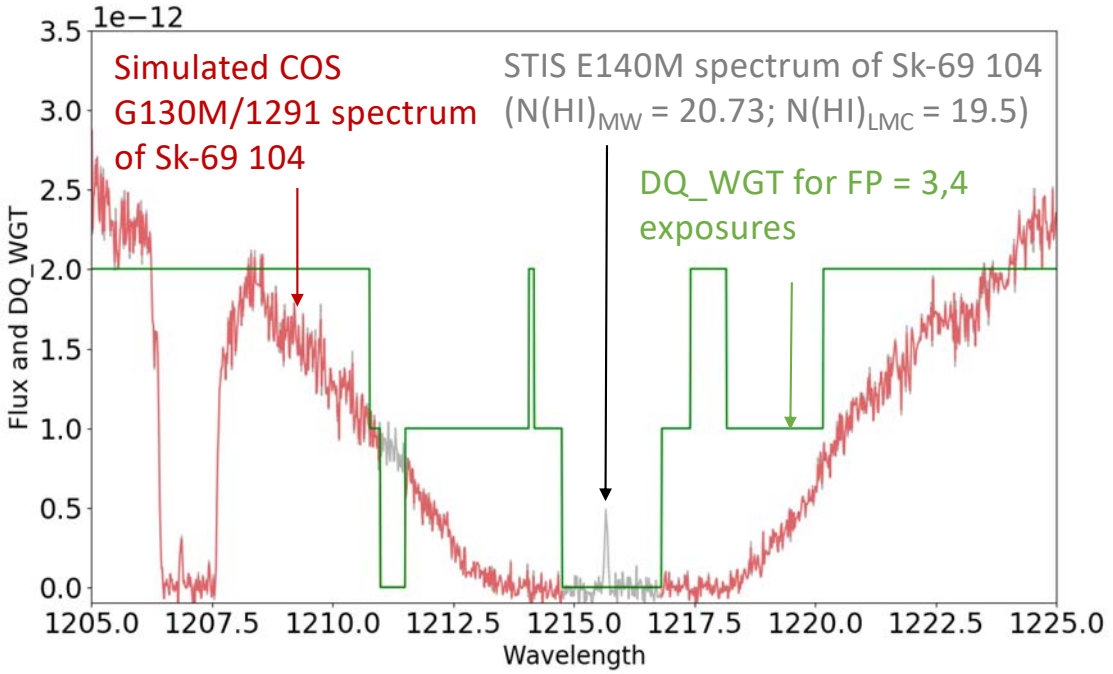
ULLYSES S/N Requirements

- 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

Observing Strategy – Lyman-α

- Two gain-sag holes at LP4 make Ly-α unobservable with COS/G130M/1291 within +/- 65 km/s
- The wings of an interstellar Ly-α absorption line in the LMC or SMC, and of the emission profile of an accreting star fall outside the gain-sag holes and can be observed at LP4.

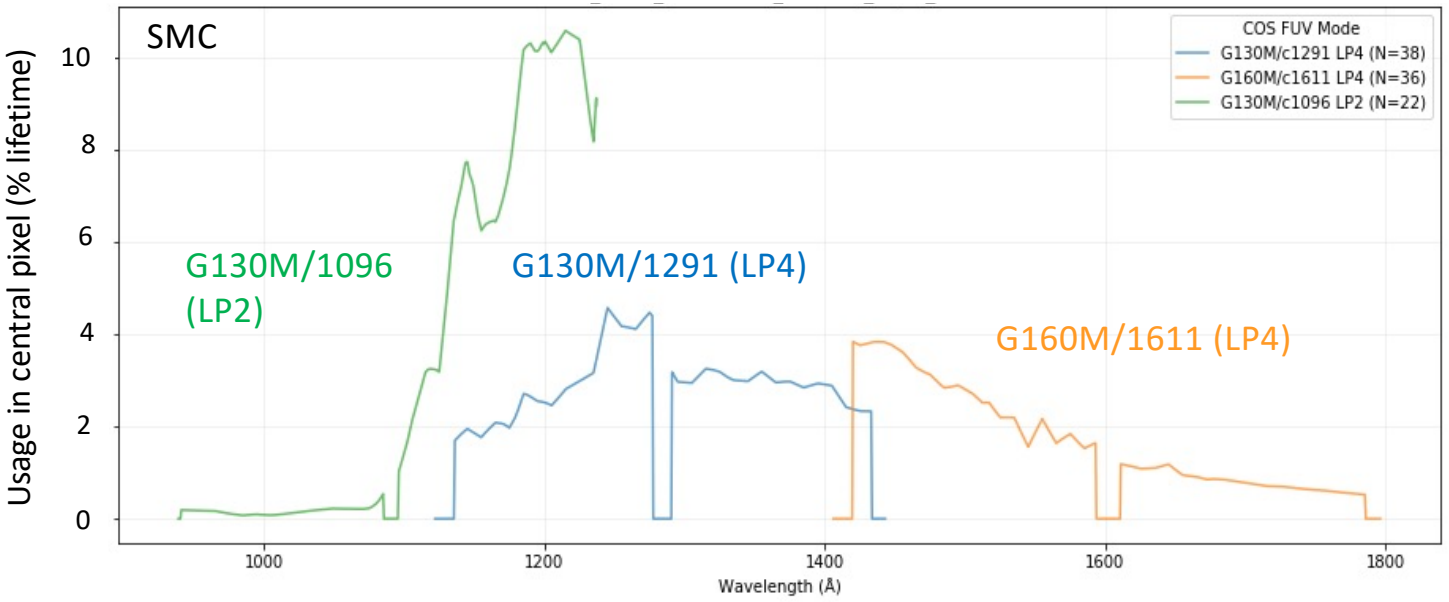




Gain-sag impact on COS – SMC

New

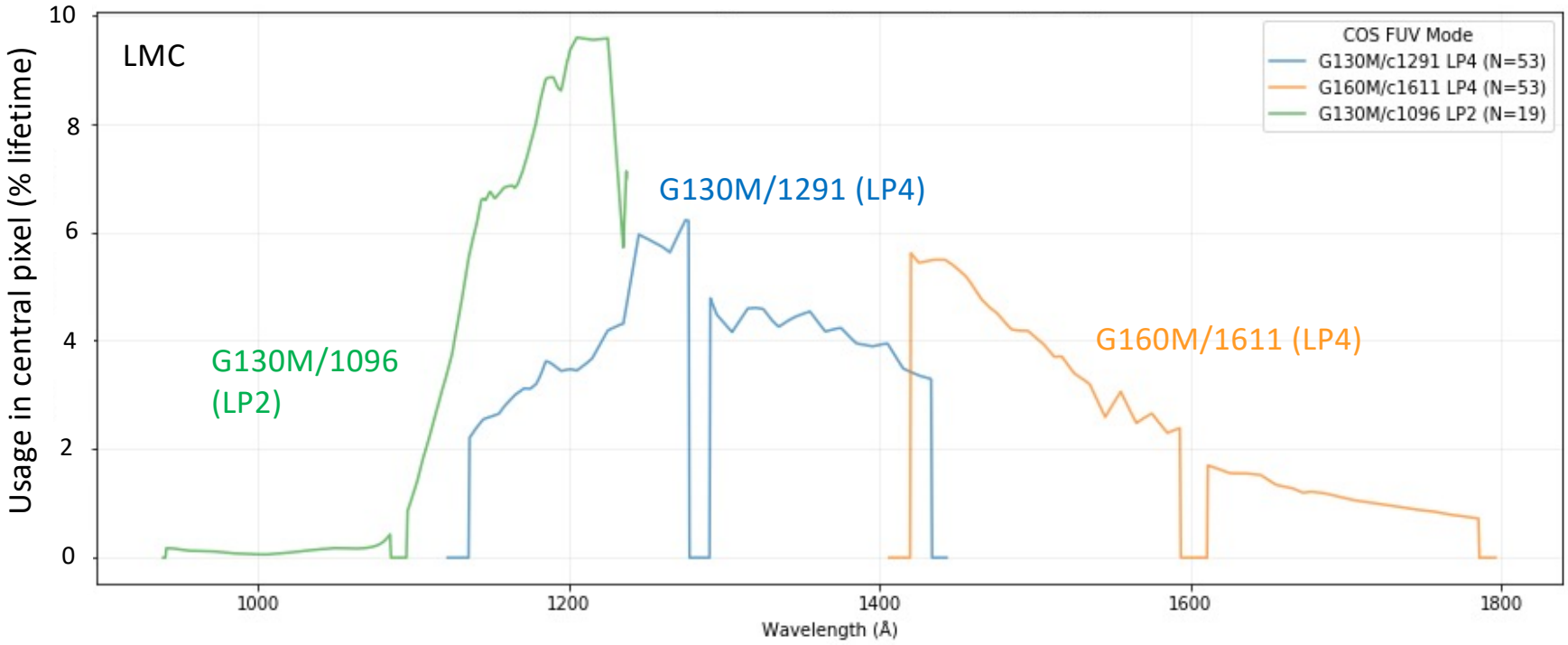
- Model SEDs and scriptable ETC used to estimate counts in the brightest pixel as a function of wavelength for each mode of observation
- Fraction of lifetime is counts/50,000
- Note: COS/G130M/1096 is operated at LP2 with high counts on FUVA



Gain-sag impact on COS - LMC

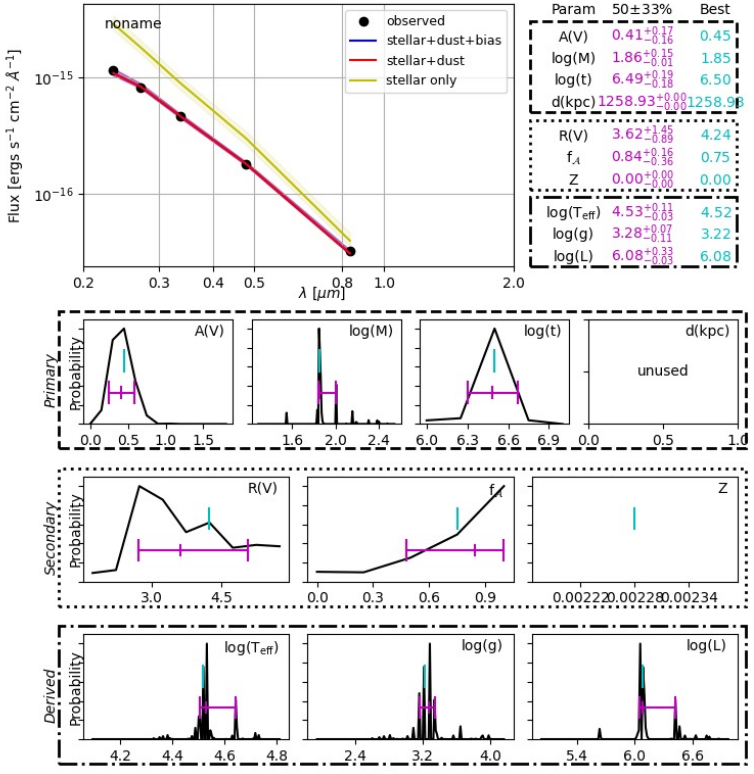
New

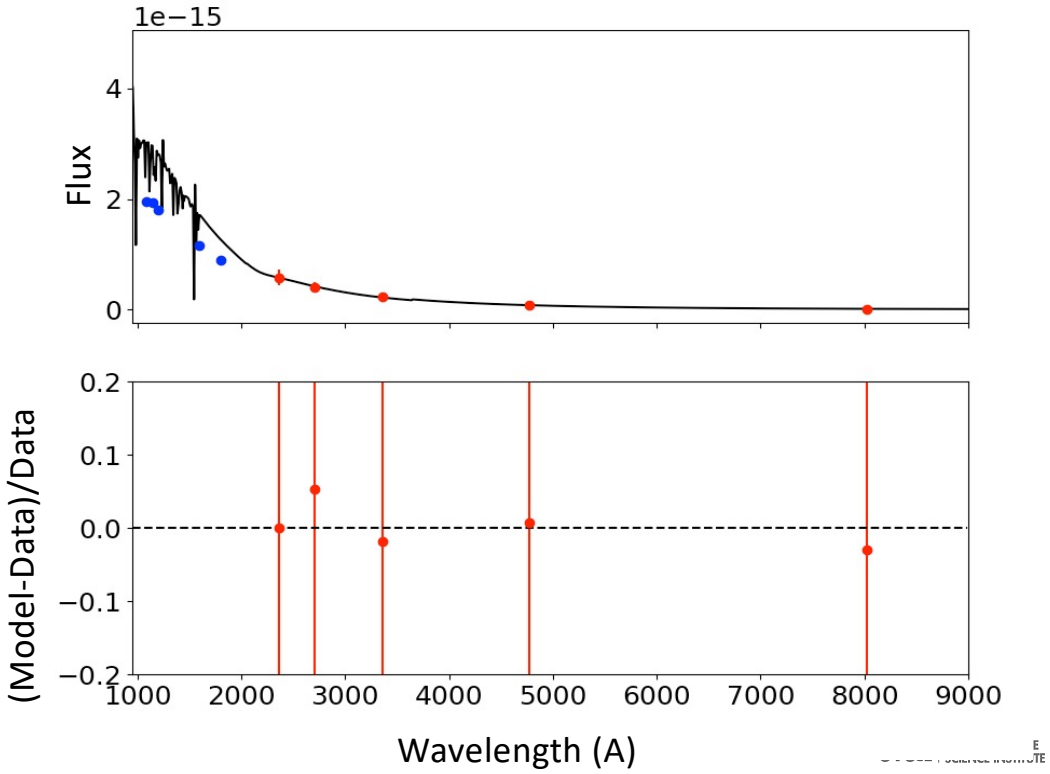
- Combined LMC/SMC observations will use up about 15% (10%) of the COS LP4 FUB (FUVA) lifetime and 20% of the COS LP2 FUVA lifetime



SED fitting for low-Z galaxies

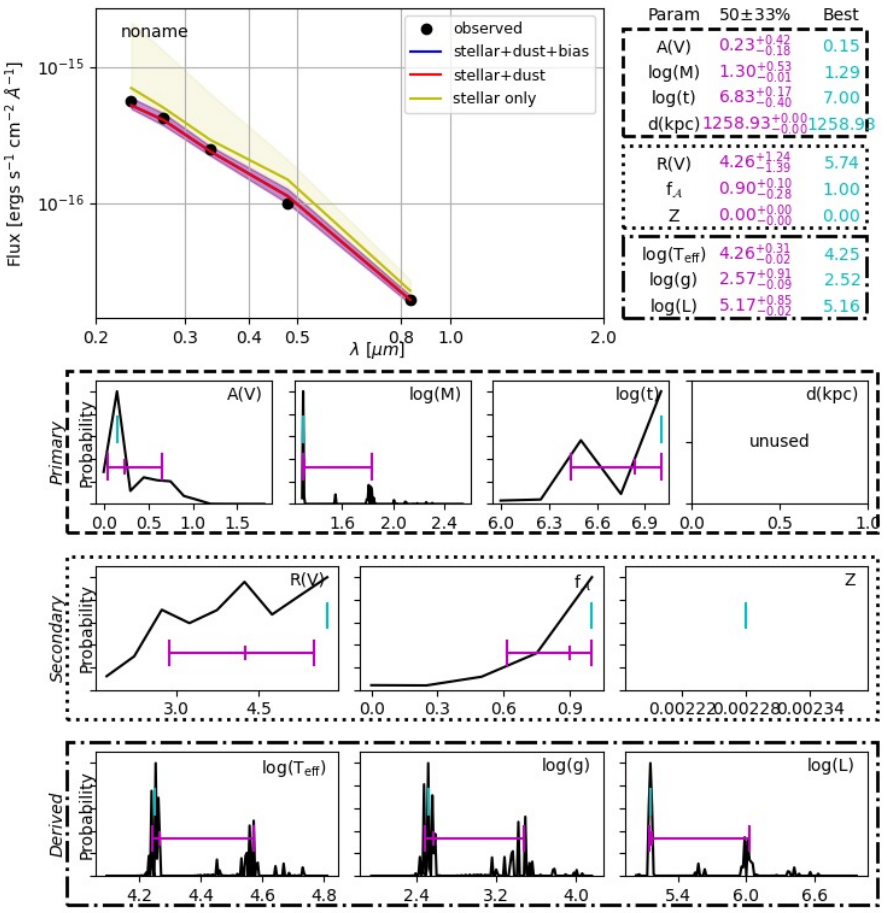
- Karl Gordon ran the photometry through the BEAST SED fitting code (Gordon+2016)
- Provided probability density functions for SpT/LC, A_V





Results

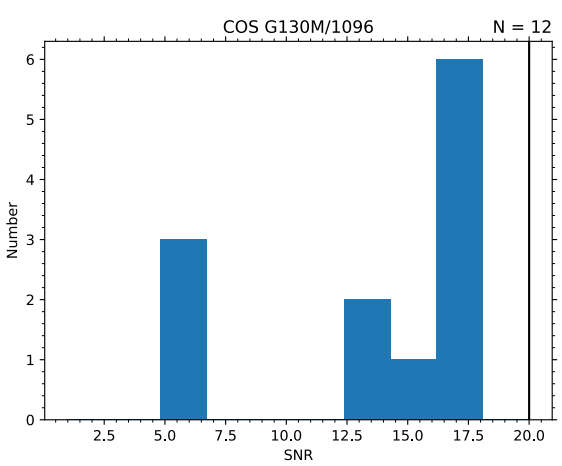
Star	SpT (BEAST)	SpT (JRD)	SpT (Evans+2007)	A_V
NGC3109-7	O9 I	B0 I	B0-1 I	0.2
NGC3109-20	B3 I	B1 I	O8 I	0.26
NGC3109-34	O9 I	O8 I	O8 I	0.2

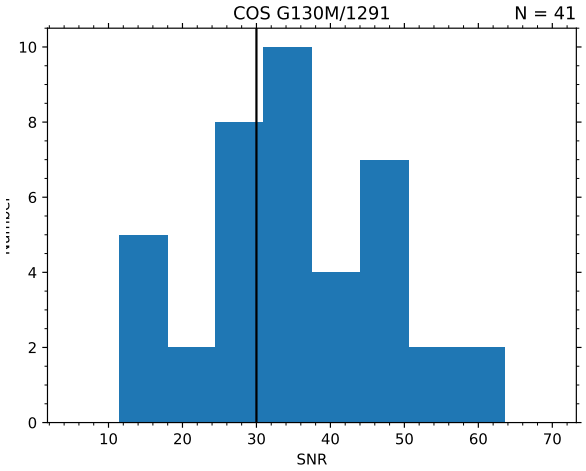


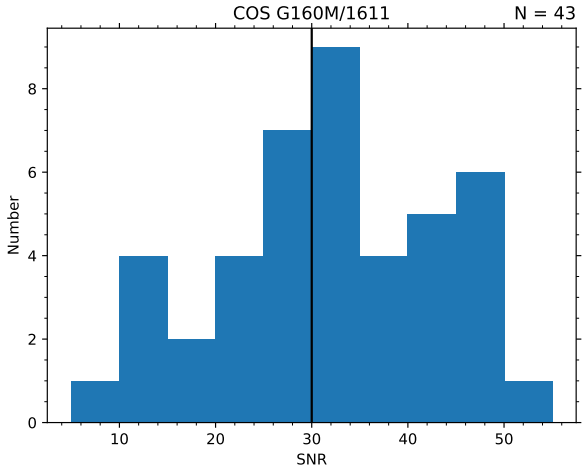
Technical Implementation: BOP procedures for T Tauri stars

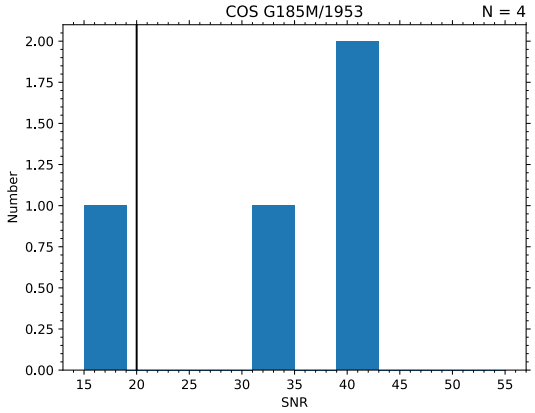
- Estimates for UV accretion flux based on published relations scaling emission line and continuum flux with accretion rate.
  - For Bright Object Protection (BOP) screening allow for 4X variability above baseline accretion scaling
  - Bright object magnetic flare rules for M dwarfs will also be applied to M-type T Tauri stars
    - Comparison of active T Tauri stars and main-sequence stars shows magnetic activity and flares scale with bolometric luminosity, and not with accretion. It is the nature of the underlying star that matters.
    - To apply existing flare rules, which depend on U magnitude of target, we use a U value inferred from the spectral type and V magnitude rather than the observed U flux, which is typically dominated by the accretion rather than the spectrum of the underlying star
    - Extinction is applied to the modeled flare spectrum

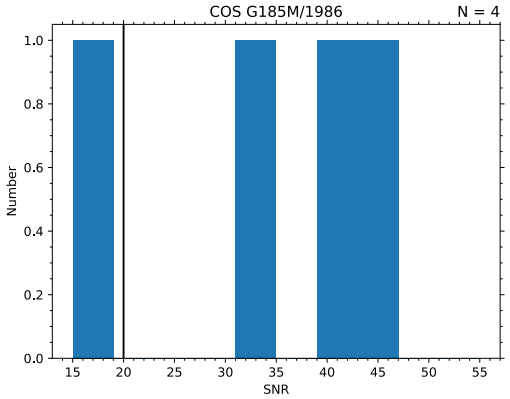
S/N outcomes for massive stars












Coordinated observations and community engagement

LCOGT Photometric Monitoring

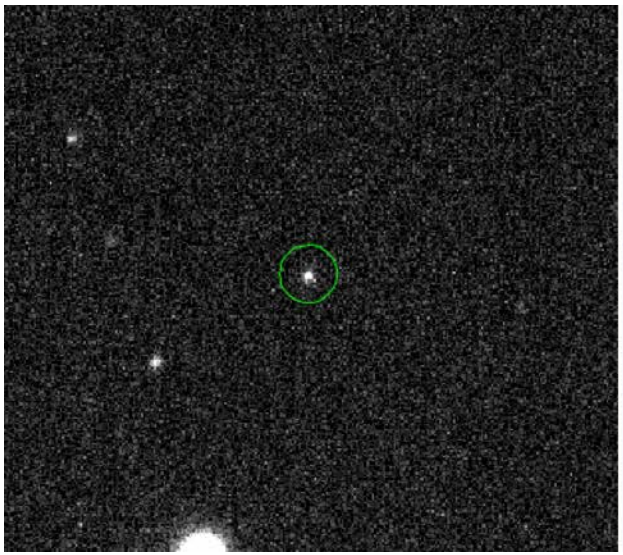
- Cadence:
  - 1x/day 3 months before/after HST epoch
  - 1x/day 10 days before/after HST epoch
  - 10x/period of the 1 (3) periods centered on the HST observations for the survey (monitoring) stars
  - 15 min cadence during the HST observations
- S/N > 10 for all targets/bands
- Flux calibration field (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 will perform u' monitoring only for the brighter 4 CTTS monitored with HST

LCOGT Optical Photometry

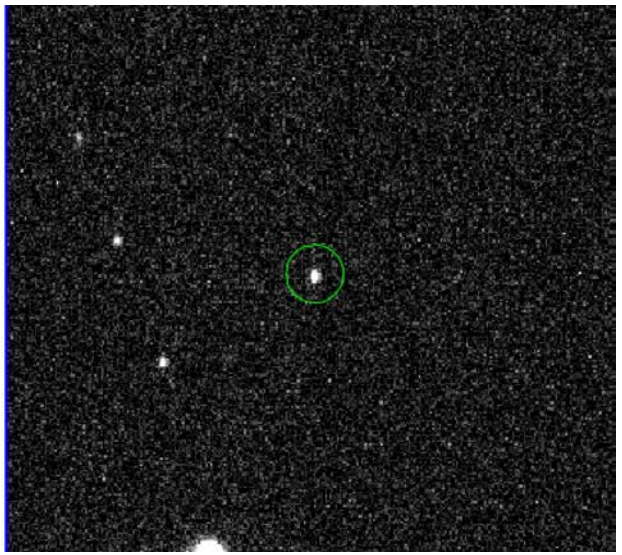
- Near-simultaneous V & i' images are obtained for each star
- Exposure times typically 30 sec at V, 15 sec at i'
- Including overheads, takes about 2 min to obtain the two images
- Automated data reduction by LCOGT's BANZAI pipeline

Zoom in on CVSO 146
observed at Haleakala on 2020 Sep 19

V



i'



LCOGT Optical Photometry

- Use `aper.pro` and related routines from IDL Astronomy Users' Library (Landsman 1993) to measure counts in a 5 px (2.9") aperture, subtract sky measured in a 10–20 px annulus
- Convert counts to magnitudes by calibrating with field stars in NOMAD (V band; Zacharias et al. 2005) or SkyMapper (i' band; Australian National University)
- None of the targets observed so far are in a FU Ori burst state