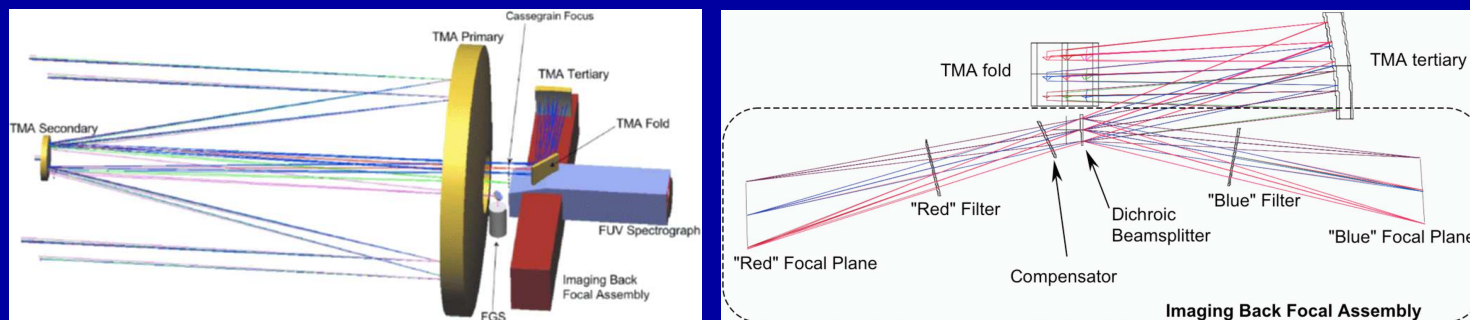


The *Star Formation Observatory (SFO)*

From Cosmic Dawn to Our Solar System: A Next-Generation
UV–Optical Space Facility for the Study of Star Formation

Rolf Jansen (ASU/SESE), for the *SFO* science team



Star Formation Observatory – Science



- **What?** Conduct a *comprehensive* and *systematic* study of the astrophysical processes and environments relevant for the births and life cycles of stars and their planetary systems, and to investigate and understand the range of environments, feedback mechanisms, and other factors that most affect the outcome of the star and planet formation process.

Star Formation Observatory – Science



- **How?** Via a 4-Tier program, step out from the nearest star-forming regions within our Galaxy (**Tier 1**), via the Magellanic Clouds and Local Group galaxies (**Tier 2**), to other nearby galaxies out to the Virgo Cluster (**Tier 3**), and on to the early cosmic epochs of galaxy assembly (**Tier 4**). Interpretation of the panchromatic imaging is intimately tied to far-UV $R \gtrsim 30,000$ spectroscopic observations. Each step will build on the detailed knowledge gained at the previous one.

Star Formation Observatory – Science



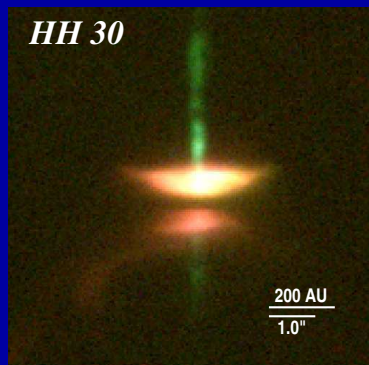
- **Why?** This program addresses the origins and evolution of stars, galaxies, and cosmic structure and has direct relevance for the **formation** and **survival** of planetary systems like our Solar System and planets such as Earth.

Star Formation Observatory – Science



- **How?** *SFO* would be a medium-class 1.65 m UV–optical space telescope in L2. TMA feeds two instruments: a mid-UV–near-IR (190–1100 nm) wide-field ($17' \times 17'$) dichroic camera (two FPA's of 3×3 3500×3500 -CCDs with $0''.06 \times 0''.06$ pixels), and a far-UV (100–175 nm) high-resolution ($R \lesssim 40,000$) spectrograph (additional 175–320 nm low-res mode considered). Optics are Al+LiF coated to provide access to $\lambda \lesssim 115$ nm; $100 \times$ greater imaging and $>10 \times$ greater spectroscopic efficiency than previous missions.

Star Formation Observatory – Tier 1

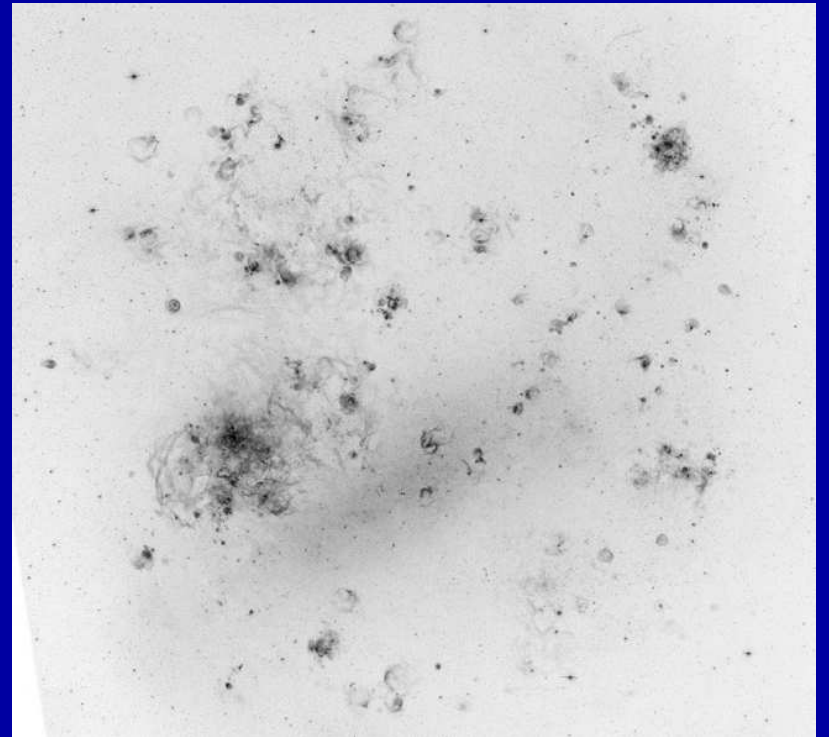


(NASA / ESA / STScI)

Star Formation Observatory – Tier 1

- **Star Formation within our Galaxy** Assemble a complete census of **all** high-mass star formation sites within 2.5 kpc of the Sun. Conduct (1) a comprehensive, pan-chromatic, wide-area imaging survey and (2) a far-UV spectroscopic survey of Young Stellar Objects (YSOs), protoplanetary disks, and their outflows. Probe **all** aspects of the star formation process in different star formation environments.
 - interaction of detailed physical processes that operate on small scales (accretion, jets, shocks, photo-evaporation, bubbles and bulk flows, SNRs) with those active on galactic scales;
 - characterize their imprint on lower resolution measurements;
 - foundation for interpreting observations in more distant galaxies;
 - resolve billions of individual stars within, and along sightlines toward these Galactic SF-regions;
 - learn if/how the Initial Mass Function (IMF) varies with the mode of star formation and metallicity.

Star Formation Observatory – Tier 2



(Courtesy: W. Keel, U. Alabama; Henize 1956)

Star Formation Observatory – Tier 2

- **Star Formation within the Local Group** Conduct a panchromatic imaging survey of both Magellanic Clouds and other star-forming Local Group galaxies in broad-band and nebular emission-line filters. Secure far-UV spectroscopy of up to ~ 2000 OB-stars in the Clouds.
 - obtain a complete census of the richly varied stellar populations within the Clouds;
 - investigate feedback from massive stars, both in H II-region environments and in the diffuse, warm ISM, with access to O VI and to H₂ and HD at $30 < T < 300,000$ K;
 - quantitatively parametrize stellar clustering and star formation propagation;
 - determine how giant, starbursting H II-regions like 30 Doradus differ from more modest H II-regions within the Milky Way;
 - determine the impact of metallicity by comparing broadly similar H II-regions within the Magellanic Clouds, our Galaxy, and other Local Group galaxies.

Star Formation Observatory – Tier 3



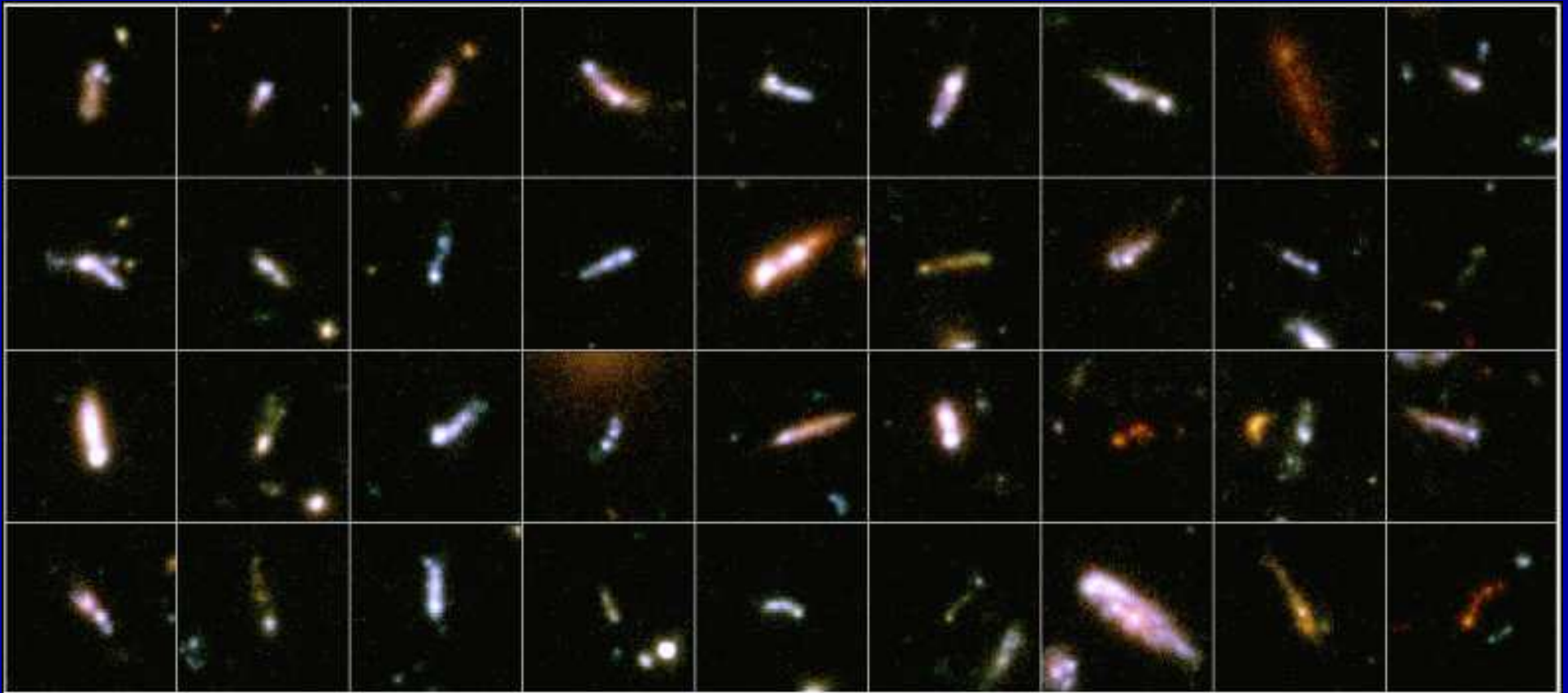
(Jansen 2004)

Star Formation Observatory – Tier 3

- **Star Formation out to the Virgo Cluster** Next, image a sample of ~ 600 nearby galaxies out to the Virgo Cluster and study their resolved, partially resolved, and unresolved stellar populations and ISM, and their immediate environments. Via far-UV spectroscopy of background QSOs along sightlines through galaxies at $z < 0.2$, we will study the interface between galaxies and the Intergalactic Medium (IGM), and look for missing baryons.
 - how do spatially resolved star formation histories and ISM features depend on galaxy mass (from dwarf to giant), structural type (E, S0, Sa–Sm, Im/Irr, and pathological morphologies that are rare today but common at high- z), metallicity, satellite systems, and larger cosmic environments.
 - how do disk/spheroid properties relate to the galactic centers;
 - are disks growing and if so how.

We aim to sample the *full* parameter space of physical conditions and environments in which stars form.

Star Formation Observatory – Tier 4



(Straughn et al. 2006)

Star Formation Observatory – Tier 4

- **Star Formation at Cosmic Dawn** Lastly, we aim to understand in detail how galaxies formed from perturbations in the primordial density field, the original metal enrichment of the IGM, and final stages of its reionization through Ly α -emitters.
 - sample faint-end of the galaxy LF at high significance from $z \sim 8$ to 5 — the “cosmic dawn” of Pop II star formation and dwarf galaxy assembly — over a sufficiently large area for the results to be unaffected by cosmic variance. These dwarfs likely completed reionization of H in the universe.
 - track the mass- and environment-dependent galaxy assembly from $z \sim 5$ to 1 through early-stage mergers (“*tadpole*” galaxies) and constrain how Λ affected galaxy assembly.
 - by studying faint variable objects — feeding weak AGN — study how growth of SMBHs and galaxy spheroids kept pace through feedback processes.


Star Formation Observatory – Requirements

Table 1 — Overview of science-driven technical requirements for SFO

Imaging requirements: FOV cannot be substantially smaller than 17' × 17' (total area vs. depth requirement)	
<i>Focal plane geometry:</i>	stable to $\lesssim 0''.001$ (0.017 pixel) stable for $\gtrsim 4$ hrs
<i>Point spread function:</i>	diffraction limited at $\gtrsim 200$ nm and round to $\lesssim 10\%$ stable to $\lesssim 10\%$ for $\gtrsim 4$ hrs
<i>Pointing jitter:</i>	$\lesssim 0''.006$ (0.1 pixel) stable for $\gtrsim 4$ hrs
<i>Photometricity:</i>	amplifier gain, A/D conversion, QE, stable to $\sim 10^{-5}$ stable for $\gtrsim 4$ hrs
<i>Wavelength agility:</i>	peak response 99%; $\gtrsim 40\%$ over 205–1050 nm range access to full 190–1100nm range
Filter requirements: wheels must hold at least 10 blue and 12 red filters (goal: 2 × 12 filters)	
<i>Broadband:</i>	F262W F278X* F330W F432W F612W F775W F885W UV2 UVW u B r i z
<i>Mediumband:</i>	F218M F547M F980M F990M F1020M F1050M UV1 y Ly $\alpha_{z\sim 7.1}$ Y/Ly $\alpha_{z\sim 7.2}$ Ly $\alpha_{z\sim 7.4}$ Ly $\alpha_{z\sim 7.6}$
<i>Narrowband[†]:</i>	F280N F373N F470N F487N F502N F632N F659N F674N F956N Mg II [O II] He II H β [O III] [O I] H α + [N II] [S II] [S III]
Far-UV spectroscopy: must be able to access O VI at 103.2 nm and discriminate sources on scales of $\sim 0''.05$	
<i>Resolving power:</i>	$R \sim 40,000$ over 100–175 nm range (2 gratings) lower-resolution covering full bandpass (1 grating)
<i>Wavelength agility:</i>	optimized for 100–115 nm response access to full 100–175 nm range


*Ultra-wide UV filter with $\lambda_c \sim 278$ nm and FWHM ~ 125 nm; [†]narrow-band filters must capture emission redshifted to ~ 2500 km s⁻¹.

Star Formation Observatory – Fact sheet



Star Formation Observatory

Mission Fact Sheet



Overview:
 The Star Formation Observatory (SFO) Astrophysics Science Mission Concept is a 1.65m UV-visual observatory orbiting at Earth-Sun L2 to address:

- How frequently do solar systems form and survive?
- How do stars and galaxies form and evolve?
- How were the heavy elements necessary for life created and distributed through cosmic time?

Measurements:

1. Pan-chromatic (200–1100 nm) broad- and key narrow-band emission-line imaging of all high-mass starforming sites within 2.5 kpc will provide the basic data required to understand star formation as a fundamental astrophysical process that controls the evolution of the baryonic content of the universe.
2. Conduct a complete-area imaging survey of both Magellanic Clouds in 8 broad-band and 4 key nebular emission-line filters that span the full 200–1100 nm wavelength range. In less than 1 year, SFO will be able to map both Clouds in their entirety to $m_{AB} > 26$ mag and $\sim 10^{-16}$ erg cm⁻² s⁻¹ arcsec⁻².
3. Far-UV spectroscopic survey of ~500 sight-lines toward massive young OB-stars within stellar nurseries in the Magellanic Clouds, M33 and M31. The powerful suite of diagnostic transitions from molecular, atomic, and ionic species (e.g., H₂, Ly α and Ly γ , "low ions" like O I, Ar I, C II, Si II, Fe II, Fe III and P II, as well as "high ions" like CIV, Si IV, SV, NV and OVI) allow quantitative analysis of temperatures, densities, compositions, and kinematics of different components of the gas, as well as properties of the OB stars themselves.
4. Image and analyze as part of the Hundred Galaxies Survey (HuGS) the resolved and unresolved stellar populations of ~100 archetypical nearby galaxies through color-magnitude and color-color diagram fitting and population synthesis modeling of multi-band (200–1100 nm) colors. Derive spatially resolved star formation histories as a function of galaxy type, luminosity/mass, and environment.
5. A tiered imaging survey with SFO using 8 filters spanning 200–1100 nm, including near-IR medium-band filters optimized for the search for Ly α -Emitters at $z \sim 7.2, 7.4, 7.6, \text{ and } 7.8$. The survey covers $\sim 1 \text{ deg}^2$ to AB $\sim < 27$ mag (at 10 σ point source sensitivity; DEEP), $\sim 3 \text{ deg}^2$ to AB $\sim < 26$ mag (MEDIUM), and $\sim 9 \text{ deg}^2$ to AB $\sim < 25$ mag (WIDE). Each tier combines pan-chromatic data from at least two separate epochs.

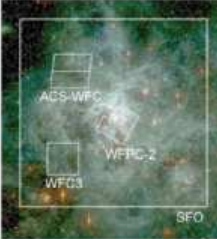
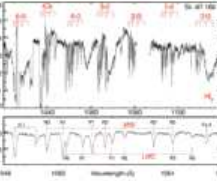








Table 1 — Overview of science-driven technical requirements

Far-UV spectroscopy:	must be able to access O VI and discriminate sources on scales of $\sim 0''.05$								
Resolving power:	$R \sim 40,000$ over 100–175 nm range	(2 gratings)							
	lower-resolution covering full bandpass	(1 grating)							
Wavelength agility:	optimized for 100–115 nm response	access to full 100–175 nm range							
Imaging requirements:	FOV cannot be substantially smaller than $16.9' \times 16.9'$ (total area vs. depth requirement)								
Focal plane geometry:	stable to $\lesssim 0''.001$ (0.017 pixel)	stable for ≥ 4 hrs							
Point spread function:	diffraction limited at ≥ 200 nm and round to $\lesssim 10\%$	stable to $\lesssim 10\%$ for ≥ 4 hrs							
Pointing jitter:	$\lesssim 0''.006$ (0.1 pixel)	stable for ≥ 4 hrs							
Photometricity:	amplifier gain, A/D conversion, Q/E, stable to $\sim 10^{-3}$	stable for ≥ 4 hrs							
Wavelength agility:	peak response 99%; $\geq 40\%$ over 210–1050 nm range	access to full 200–1100 nm range							
Filter requirements:	wheels must hold at least 10 blue and 12 red filters (goal: 2×12 filters)								
Broadband:	F250W UV2	F275X* UVW	F336W u	F438W B	F625W r	F775W i	F850W z		
Mediumband:	F218M UV1			F547M y	F960M Ly $\alpha_{z \sim 7.2}$	F1020M Ly $\alpha_{z \sim 7.4}$	F1050M Ly $\alpha_{z \sim 7.6}$	F1080M Ly $\alpha_{z \sim 7.8}$	
Narrowband¹:	F280N Mg II	F373N [O II]	F469N He II	F487N H β	F502N [O III]	F631N [O I]	F656N H α	F673N [S II]	F953N [S III]

^{*} Ultra-wide UV filter with $\lambda_c \sim 275$ nm and FWHM ~ 100 nm; ¹ narrow-band filters must capture emission redshifted to ~ 3000 km s⁻¹.

Discovery Efficiency: Imaging: 100x HST-WFPC2, WFC3, or ACS capabilities; Spectroscopic: >10x HST-COS

Star Formation Observatory/Camera – Poster

Astrophysics Strategic Mission Concept Studies

From Cosmic Dawn to Our Solar System: A Next-Generation UV-Optical Space Facility for the Study of Star Formation

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Abstract

We propose a new observatory for the study of star formation in the UV-optical range. The observatory will consist of a 10-m diameter primary mirror and a 4.5-m secondary mirror, providing a collecting area of 70 m². The observatory will be designed to observe the star formation process in the UV-optical range, from the formation of the first stars to the formation of the first galaxies. The observatory will be designed to observe the star formation process in the UV-optical range, from the formation of the first stars to the formation of the first galaxies. The observatory will be designed to observe the star formation process in the UV-optical range, from the formation of the first stars to the formation of the first galaxies.

Star Formation as a Path from the Big Bang to People

Star formation is the process by which stars are born. It is a process that has shaped the universe since the beginning of time. The observatory will be designed to observe the star formation process in the UV-optical range, from the formation of the first stars to the formation of the first galaxies. The observatory will be designed to observe the star formation process in the UV-optical range, from the formation of the first stars to the formation of the first galaxies.

The Star Formation Observatory (SFO)

The SFO is a multi-mission observatory for the study of star formation in the UV-optical range. The observatory will be designed to observe the star formation process in the UV-optical range, from the formation of the first stars to the formation of the first galaxies. The observatory will be designed to observe the star formation process in the UV-optical range, from the formation of the first stars to the formation of the first galaxies.

The Star Formation Camera (SFC)

The SFC is a camera for the study of star formation in the UV-optical range. The camera will be designed to observe the star formation process in the UV-optical range, from the formation of the first stars to the formation of the first galaxies. The camera will be designed to observe the star formation process in the UV-optical range, from the formation of the first stars to the formation of the first galaxies.

Table 1: Technical specifications for the SFO and SFC

Parameter	SFO	SFC
Primary Mirror Diameter	10 m	4.5 m
Secondary Mirror Diameter	4.5 m	1.5 m
Collecting Area	70 m ²	16 m ²
Resolution	0.1 arcsec	0.2 arcsec
Field of View	1.5 deg	0.5 deg
Wavelength Range	100-1000 nm	100-1000 nm
Throughput	0.1	0.1
Stability	10 ⁻⁸ arcsec	10 ⁻⁸ arcsec
Pointing Accuracy	0.1 arcsec	0.1 arcsec
Tracking Accuracy	0.1 arcsec	0.1 arcsec
Integration Time	1000 s	1000 s
Dynamic Range	10 ⁵	10 ⁵
Detector	CCD	CCD
Readout Rate	1000 Hz	1000 Hz
Power Consumption	1000 W	1000 W
Mass	10000 kg	10000 kg
Launch Vehicle	Orion	Orion
Launch Cost	\$100M	\$100M
Operational Cost	\$10M/yr	\$10M/yr
Science Return	High	High

Table 2: Comparison of the SFO and SFC to other observatories

Observatory	Primary Mirror Diameter	Secondary Mirror Diameter	Collecting Area	Resolution	Field of View	Wavelength Range	Throughput	Stability	Pointing Accuracy	Tracking Accuracy	Integration Time	Dynamic Range	Detector	Readout Rate	Power Consumption	Mass	Launch Vehicle	Launch Cost	Operational Cost	Science Return
SFO	10 m	4.5 m	70 m ²	0.1 arcsec	1.5 deg	100-1000 nm	0.1	10 ⁻⁸ arcsec	0.1 arcsec	0.1 arcsec	1000 s	10 ⁵	CCD	1000 Hz	1000 W	10000 kg	Orion	\$100M	\$10M/yr	High
SFC	4.5 m	1.5 m	16 m ²	0.2 arcsec	0.5 deg	100-1000 nm	0.1	10 ⁻⁸ arcsec	0.1 arcsec	0.1 arcsec	1000 s	10 ⁵	CCD	1000 Hz	1000 W	10000 kg	Orion	\$100M	\$10M/yr	High
Hubble Space Telescope	2.4 m	0	36 m ²	0.05 arcsec	0.5 deg	400-1000 nm	0.1	10 ⁻⁸ arcsec	0.1 arcsec	0.1 arcsec	1000 s	10 ⁵	CCD	1000 Hz	1000 W	10000 kg	Columbia	\$100M	\$10M/yr	High
James Webb Space Telescope	6.5 m	0	270 m ²	0.07 arcsec	10 deg	0.6-2.2 micrometers	0.1	10 ⁻⁸ arcsec	0.1 arcsec	0.1 arcsec	1000 s	10 ⁵	CCD	1000 Hz	1000 W	10000 kg	Orion	\$100M	\$10M/yr	High
Keck II	10 m	0	78 m ²	0.02 arcsec	10 deg	0.4-2.2 micrometers	0.1	10 ⁻⁸ arcsec	0.1 arcsec	0.1 arcsec	1000 s	10 ⁵	CCD	1000 Hz	1000 W	10000 kg	Orion	\$100M	\$10M/yr	High
Large Binocular Telescope	2.2 m	2.2 m	9.7 m ²	0.04 arcsec	10 deg	0.4-2.2 micrometers	0.1	10 ⁻⁸ arcsec	0.1 arcsec	0.1 arcsec	1000 s	10 ⁵	CCD	1000 Hz	1000 W	10000 kg	Orion	\$100M	\$10M/yr	High
Very Large Telescope	8.2 m	0	53 m ²	0.015 arcsec	10 deg	0.4-2.2 micrometers	0.1	10 ⁻⁸ arcsec	0.1 arcsec	0.1 arcsec	1000 s	10 ⁵	CCD	1000 Hz	1000 W	10000 kg	Orion	\$100M	\$10M/yr	High
European Southern Observatory	3.6 m	0	13 m ²	0.03 arcsec	10 deg	0.4-2.2 micrometers	0.1	10 ⁻⁸ arcsec	0.1 arcsec	0.1 arcsec	1000 s	10 ⁵	CCD	1000 Hz	1000 W	10000 kg	Orion	\$100M	\$10M/yr	High
Keck I	3.8 m	0	14 m ²	0.02 arcsec	10 deg	0.4-2.2 micrometers	0.1	10 ⁻⁸ arcsec	0.1 arcsec	0.1 arcsec	1000 s	10 ⁵	CCD	1000 Hz	1000 W	10000 kg	Orion	\$100M	\$10M/yr	High
Large Millimeter Telescope	50 m	0	1960 m ²	0.0005 arcsec	10 deg	1-2 mm	0.1	10 ⁻⁸ arcsec	0.1 arcsec	0.1 arcsec	1000 s	10 ⁵	CCD	1000 Hz	1000 W	10000 kg	Orion	\$100M	\$10M/yr	High
ALMA	12 m	0	113 m ²	0.001 arcsec	10 deg	0.3-9 mm	0.1	10 ⁻⁸ arcsec	0.1 arcsec	0.1 arcsec	1000 s	10 ⁵	CCD	1000 Hz	1000 W	10000 kg	Orion	\$100M	\$10M/yr	High
SKA	35 m	0	1225 m ²	0.0007 arcsec	10 deg	0.07-1.35 m	0.1	10 ⁻⁸ arcsec	0.1 arcsec	0.1 arcsec	1000 s	10 ⁵	CCD	1000 Hz	1000 W	10000 kg	Orion	\$100M	\$10M/yr	High
FAST	300 m	0	70685 m ²	0.0001 arcsec	10 deg	0.3-3.0 m	0.1	10 ⁻⁸ arcsec	0.1 arcsec	0.1 arcsec	1000 s	10 ⁵	CCD	1000 Hz	1000 W	10000 kg	Orion	\$100M	\$10M/yr	High
GBT	30 m	0	706 m ²	0.0004 arcsec	10 deg	0.3-3.0 m	0.1	10 ⁻⁸ arcsec	0.1 arcsec	0.1 arcsec	1000 s	10 ⁵	CCD	1000 Hz	1000 W	10000 kg	Orion	\$100M	\$10M/yr	High
Arecibo	305 m	0	72600 m ²	0.0001 arcsec	10 deg	0.3-3.0 m	0.1	10 ⁻⁸ arcsec	0.1 arcsec	0.1 arcsec	1000 s	10 ⁵	CCD	1000 Hz	1000 W	10000 kg	Orion	\$100M	\$10M/yr	High
Green Bank Telescope	100 m	0	7850 m ²	0.0002 arcsec	10 deg	0.3-3.0 m	0.1	10 ⁻⁸ arcsec	0.1 arcsec	0.1 arcsec	1000 s	10 ⁵	CCD	1000 Hz	1000 W	10000 kg	Orion	\$100M	\$10M/yr	High
Effelsberg	100 m	0	7850 m ²	0.0002 arcsec	10 deg	0.3-3.0 m	0.1	10 ⁻⁸ arcsec	0.1 arcsec	0.1 arcsec	1000 s	10 ⁵	CCD	1000 Hz	1000 W	10000 kg	Orion	\$100M	\$10M/yr	High
IRAM 30m	30 m	0	706 m ²	0.0004 arcsec	10 deg	0.3-3.0 m	0.1	10 ⁻⁸ arcsec	0.1 arcsec	0.1 arcsec	1000 s	10 ⁵	CCD	1000 Hz	1000 W	10000 kg	Orion	\$100M	\$10M/yr	High
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IRAM 30m	30 m	0	706 m ²	0.0004 arcsec	10 deg	0.3-3.0 m	0.1	10 ⁻⁸ arcsec	0.1 arcsec	0.1 arcsec	1000 s	10 ⁵	CCD	1000 Hz	1000 W	10000 kg	Orion	\$100M	\$10M/yr	High
IRAM 30m	30 m	0	706 m ²	0.0004 arcsec	10 deg	0.3-3.0 m	0.1	10 ⁻⁸ arcsec	0.1 arcsec	0.1 arcsec	1000 s	10 ⁵	CCD	1000 Hz	1000 W	10000 kg	Orion	\$100M	\$10M/yr	High
IRAM 30m	30 m	0	706 m ²	0.0004 arcsec	10 deg	0.3-3.0 m	0.1	10 ⁻⁸ arcsec	0.1 arcsec	0.1 arcsec	1000 s	10 ⁵	CCD	1000 Hz	1000 W	10000 kg	Orion	\$100M	\$10M/yr	High
IRAM 30m	30 m	0	706 m ²	0.0004 arcsec	10 deg	0.3-3.0 m	0.1	10 ⁻⁸ arcsec	0.1 arcsec	0.1 arcsec	1000 s	10 ⁵	CCD	1000 Hz	1000 W	10000 kg	Orion	\$100M	\$10M/yr	High
IRAM 30m	30 m	0	706 m ²	0.0004 arcsec	10 deg	0.3-3.0 m	0.1	10 ⁻⁸ arcsec	0.1 arcsec	0.1 arcsec	1000 s	10 ⁵	CCD	1000 Hz	1000 W	10000 kg	Orion	\$100M	\$10M/yr	High
IRAM 30m	30 m	0	706 m ²	0.0004 arcsec	10 deg	0.3-3.0 m	0.1	10 ⁻⁸ arcsec	0.1 arcsec	0.1 arcsec	1000 s	10 ⁵	CCD	1000 Hz	1000 W	10000 kg	Orion	\$100M	\$10M/yr	High
IRAM 30m	30 m	0	706 m ²	0.0004 arcsec	10 deg	0.3-3.0 m	0.1	10 ⁻⁸ arcsec	0.1 arcsec	0.1 arcsec	1000 s	10 ⁵	CCD	1000 Hz	1000 W	10000 kg	Orion	\$100M	\$10M/yr	High
IRAM 30m	30 m	0	706 m ²	0.0004 arcsec	10 deg	0.3-3.0 m	0.1	10 ⁻⁸ arcsec	0.1 arcsec	0.1 arcsec	1000 s	10 ⁵	CCD	1000 Hz	1000 W	10000 kg	Orion	\$100M	\$10M/yr	High
IRAM 30m	30 m	0	706 m ²	0.0004 arcsec	10 deg	0.3-3.0 m	0.1	10 ⁻⁸ arcsec	0.1 arcsec	0.1 arcsec	1000 s	10 ⁵	CCD	1000 Hz	1000 W	10000 kg	Orion	\$100M	\$10M/yr	High
IRAM 30m	30 m	0	706 m ²	0.0004 arcsec	10 deg	0.3-3.0 m	0.1	10 ⁻⁸ arcsec	0.1 arcsec	0.1 arcsec	1000 s	10 ⁵	CCD	1000 Hz	1000 W	10000 kg	Orion	\$100M	\$10M/yr	High
IRAM 30m	30 m	0	706 m ²	0.0004 arcsec	10 deg	0.3-3.0 m	0													