Origins Space Telescope
の情報整理


ORIGINS
Space Telescope
From
first light
to life

National Aeronautics and
Space Administration

NASA

Mission Concept
Study Report

August 2019

www.nasa.gov

Learn more at
origins.ipac.caltech.edu

橋本拓也 (筑波大学)

- 資料URL
https://asd.gsfc.nasa.gov/firs/docs/OriginsVolume1MissionConceptStudyReport25Aug2020.pdf

- 376ページ (ここでは、銀河形成に関わる内容を抜粋)

Origins Space Telescope 概要

Origins Space Telescope とは

- 複数ある次世代大型宇宙計画の一つ (LUVOIR, Habex, **OST**, Rynx)

- 2035 年打ち上げを目標とする、**冷却宇宙望遠鏡 (口径 5.9 m; 波長 20-600 μm)**
    - SPICA (口径 2.5 m; 波長 30-300 μm)　OST は SPICA よりも高感度かつ広波長
    - ATT10 (地上 10 m; 波長 230-750 μm)　OSTはATT10と波長オーバーラップあり

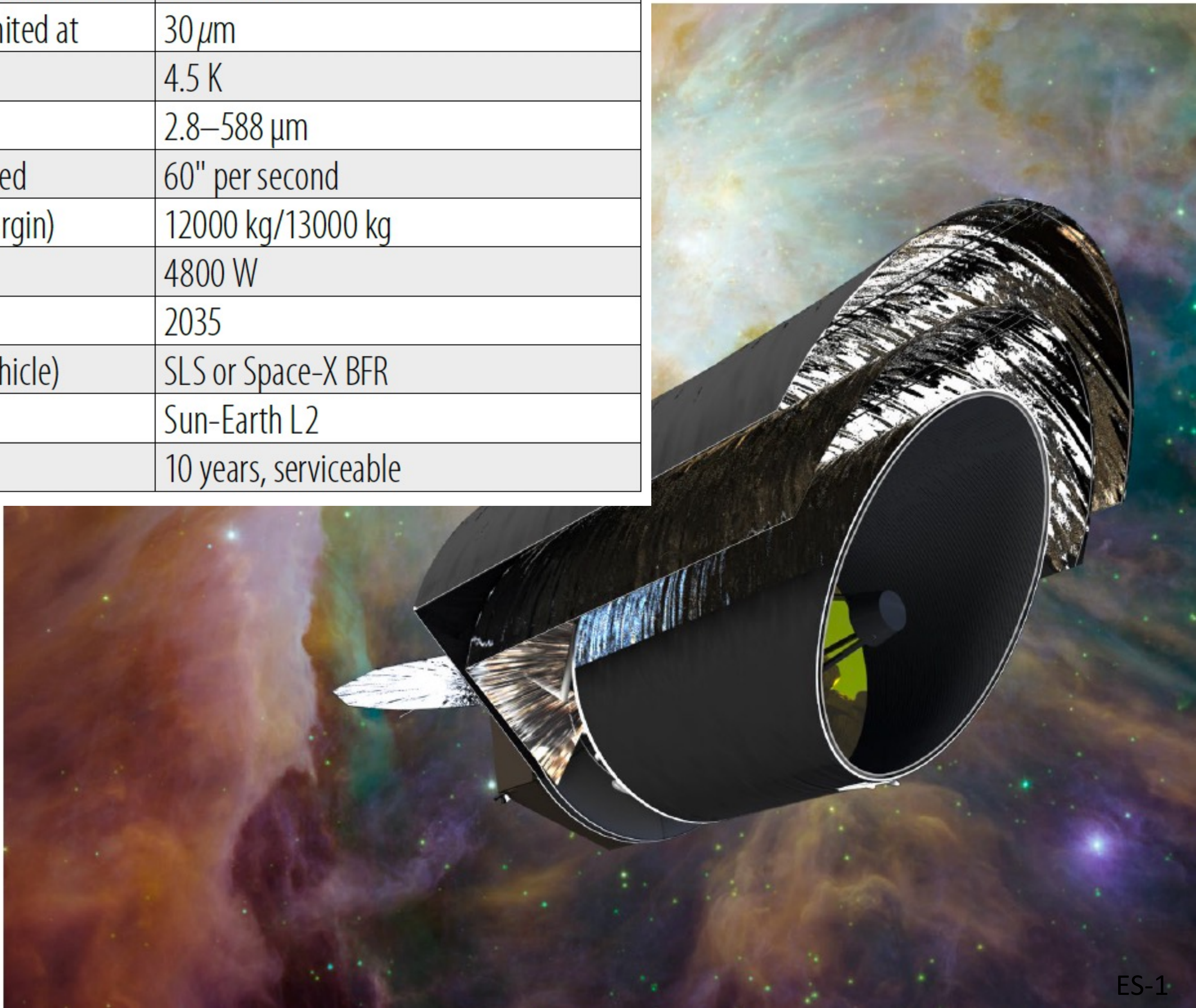
- 費用 ~7BUSD (~7,000億円)　(参考:JWST ＞ 10 BUSD ~ 1兆円)

- 日本の窓口 = 左近樹さん (東大天文学教室)
    - MP2023 大型計画へ提案済 (問い合わせ先 = 左近さん)

- OST 最大の特徴 = 桁違いに高感度 (ハーシェルの 1,000倍!!)

Origins Observatory Level Parameters

	Mission Parameter	Value
✔	Telescope: Aperture Diameter/Area	5.9 m/25 m^2
	Telescope Diffraction Limited at	30 μm
✔	Telescope Temperature	4.5 K
✔	Wavelength Coverage	2.8–588 µm
	Maximum Scanning Speed	60" per second
	Mass: Dry/Wet (with margin)	12000 kg/13000 kg
	Power (with margin)	4800 W
✔	Launch Year	2035
	Launch Vehicle (large vehicle)	SLS or Space-X BFR
	Orbit	Sun-Earth L2
✔	Propellant lifetime	10 years, serviceable



HOW DOES THE UNIVERSE WORK?

How do galaxies form stars, make metals, and grow their central supermassive black holes from reionization to today?

Using sensitive spectroscopic capabilities of a cold telescope in the infrared, Origins will measure properties of star-formation and growing black holes in galaxies across all epochs in the Universe.

HOW DID WE GET HERE?

How do the conditions for habitability develop during the process of planet formation?

With sensitive and high-resolution far-IR spectroscopy Origins will illuminate the path of water and its abundance to determine the availability of water for habitable planets.

ARE WE ALONE?

Do planets orbiting M-dwarf stars support life?

By obtaining precise mid-infrared transmission and emission spectra,
habitability of nearby exoplanets and search for signs of life.

Discovery science

- 銀河/BH進化
- 星/惑星の水探査
- 系外惑星とbiosignature

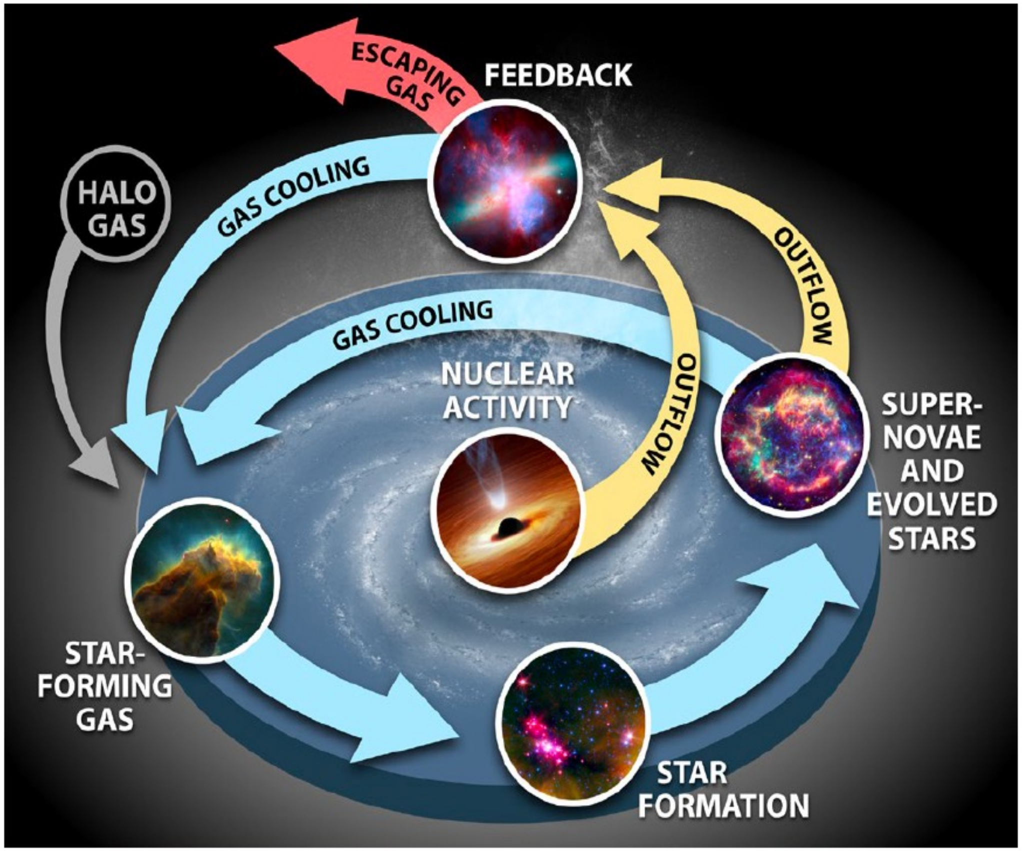


Figure ES-3: *Origins* studies the baryon cycle in galactic ecosystems. Energetic processes that shape galaxies and the circumgalactic medium together define this ecosystem. Through its ability to measure the energetics and dynamics of the atomic and molecular gas and dust in and around galaxies, *Origins* can probe nearly all aspects of the galactic ecosystem: star formation and AGN growth; stellar death; AGN- and starburst-driven outflows; and gas cooling and accretion. These measurements provide a complete picture of the lifecycle of galaxies.

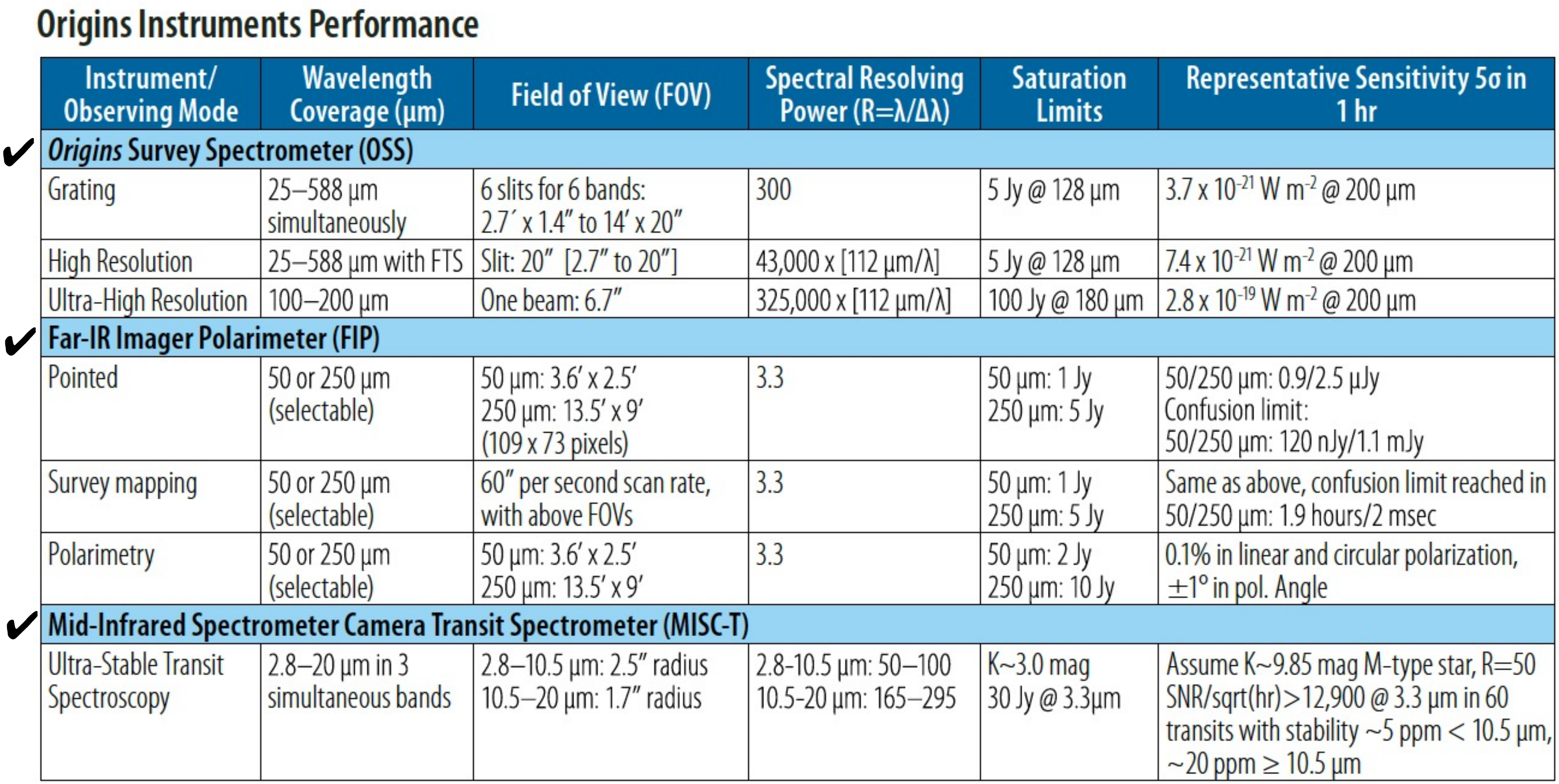
① z=0-8にわたる星形成史とBH降着率史
(ATT10 とサイエンスは重複する箇所あり)

② 重元素、ダスト、有機物 (PAH) の物質進化史

③ SN および QSO によるフィードバック効果とISMへの影響

→ 銀河および周辺領域のバリオンサイクルの解明

Origins Space Telescope
具体的な装置や感度

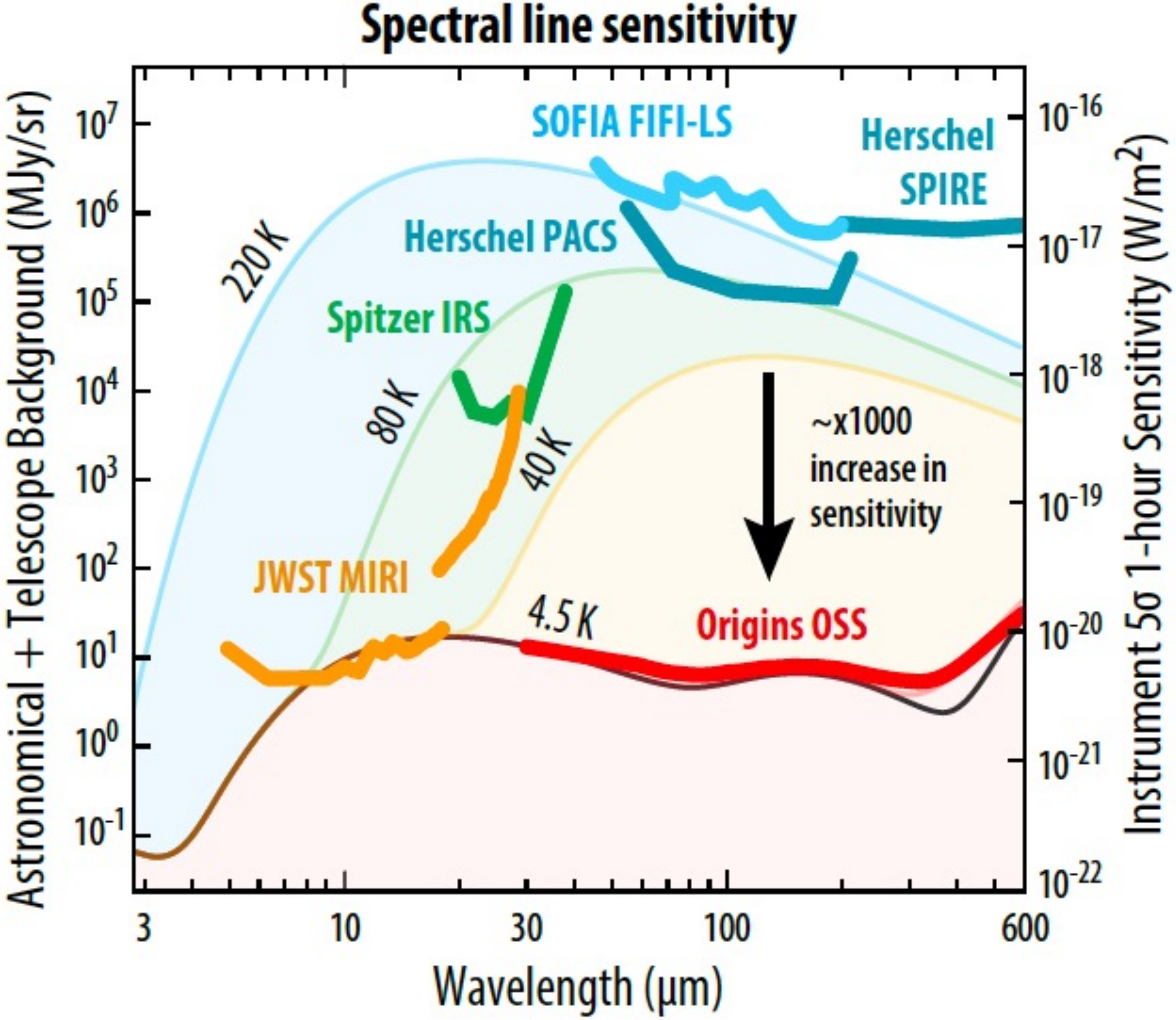


Origins Instruments Performance

Instrument/ Observing Mode	Wavelength Coverage (μm)	Field of View (FOV)	Spectral Resolving Power (R=λ/Δλ)	Saturation Limits	Representative Sensitivity 5σ in 1 hr
✔ ***Origins* Survey Spectrometer (OSS)**					
Grating	25–588 μm simultaneously	6 slits for 6 bands: 2.7´ x 1.4″ to 14′ x 20″	300	5 Jy @ 128 μm	3.7 x 10^{-21} W m^{-2} @ 200 μm
High Resolution	25–588 μm with FTS	Slit: 20″ [2.7″ to 20″]	43,000 x [112 μm/λ]	5 Jy @ 128 μm	7.4 x 10^{-21} W m^{-2} @ 200 μm
Ultra-High Resolution	100–200 μm	One beam: 6.7″	325,000 x [112 μm/λ]	100 Jy @ 180 μm	2.8 x 10^{-19} W m^{-2} @ 200 μm
✔ **Far-IR Imager Polarimeter (FIP)**					
Pointed	50 or 250 μm (selectable)	50 μm: 3.6′ x 2.5′ 250 μm: 13.5′ x 9′ (109 x 73 pixels)	3.3	50 μm: 1 Jy 250 μm: 5 Jy	50/250 μm: 0.9/2.5 μJy Confusion limit: 50/250 μm: 120 nJy/1.1 mJy
Survey mapping	50 or 250 μm (selectable)	60″ per second scan rate, with above FOVs	3.3	50 μm: 1 Jy 250 μm: 5 Jy	Same as above, confusion limit reached in 50/250 μm: 1.9 hours/2 msec
Polarimetry	50 or 250 μm (selectable)	50 μm: 3.6′ x 2.5′ 250 μm: 13.5′ x 9′	3.3	50 μm: 2 Jy 250 μm: 10 Jy	0.1% in linear and circular polarization, ±1° in pol. Angle
✔ **Mid-Infrared Spectrometer Camera Transit Spectrometer (MISC-T)**					
Ultra-Stable Transit Spectroscopy	2.8–20 μm in 3 simultaneous bands	2.8–10.5 μm: 2.5″ radius 10.5–20 μm: 1.7″ radius	2.8-10.5 μm: 50–100 10.5-20 μm: 165–295	K~3.0 mag 30 Jy @ 3.3μm	Assume K~9.85 mag M-type star, R=50 SNR/sqrt(hr)>12,900 @ 3.3 μm in 60 transits with stability ~5 ppm < 10.5 μm, ~20 ppm ≥ 10.5 μm

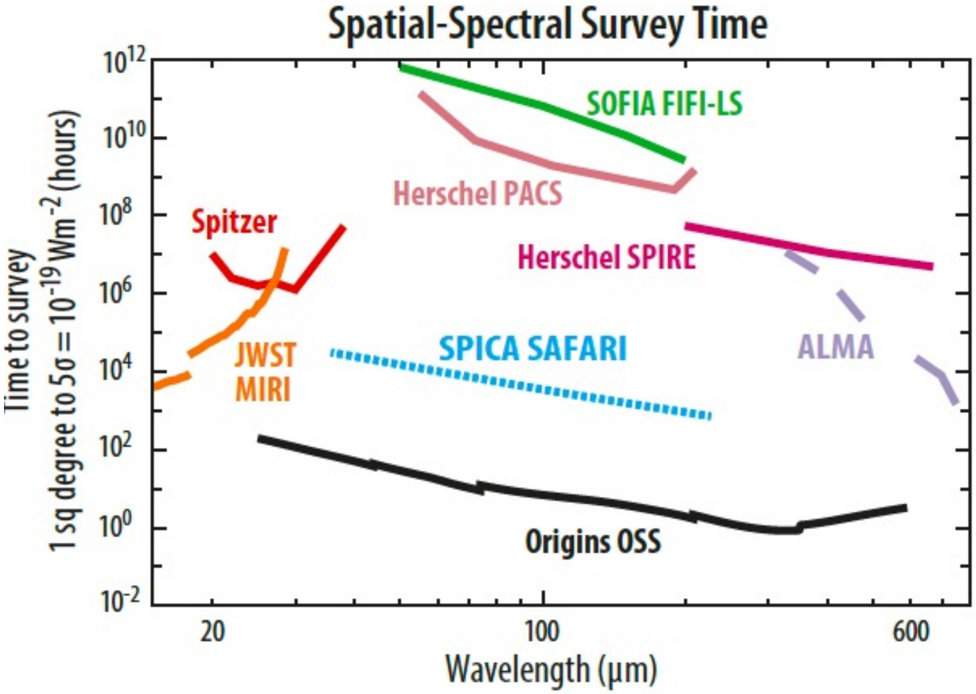
- □ 銀河形成進化の観点では、OSS および FIP が主戦場
- □ OSS の強みは、桁違いの感度 (ハーシェルに比べ 1,000倍向上)による 3D 無バイアス探査
- □ FIP の強みは、中程度のFoV + マッピング速度による広視野サーベイ (10,000平方度@250um)

~1.2 THz



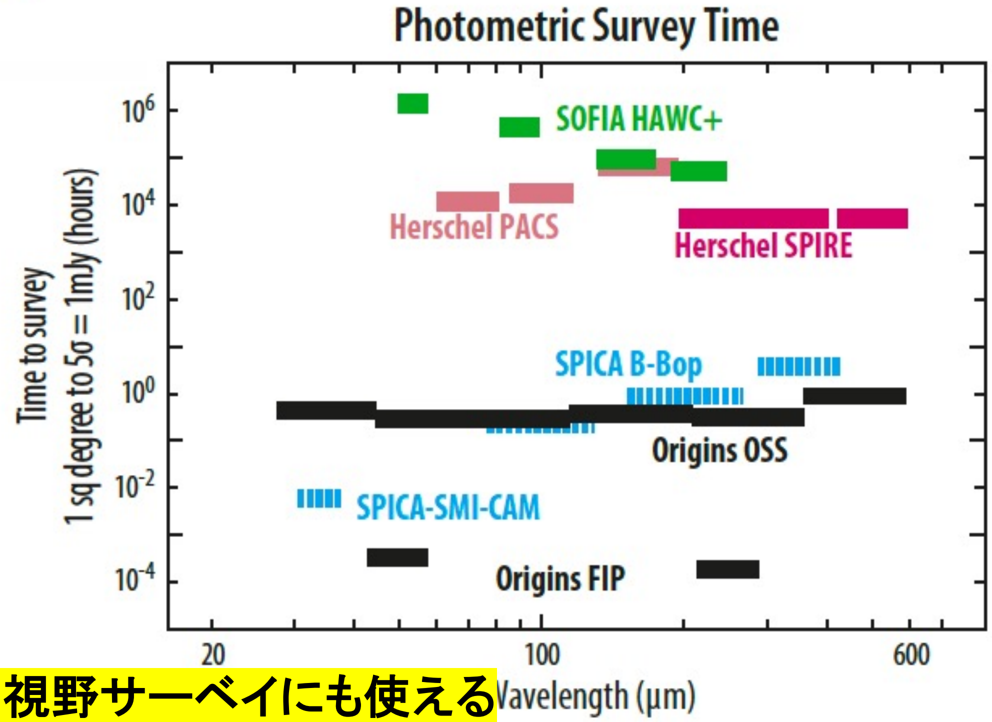
□ 同じ波長帯では、ハーシェルと比べ 1,000倍程度の感度向上

□ 5-20 um における JWST/MIRI 程度の感度を、30-600 um で実現



- 3D サーベイ (cf., SDSS in optical)

1平方度で 10^{-19} W m^{-2} (5σ)の感度を達成する時間効率はハーシェル (SPICA) の 10^{7} (10^{3}) 倍



- 測光サーベイ (連続光)

1平方度で 1 mJy (5σ) の感度を達成する時間効率はハーシェルよりも 10^{4} 倍高い。

→ 超高感度&マッピング速度のおかげで広視野サーベイにも使える

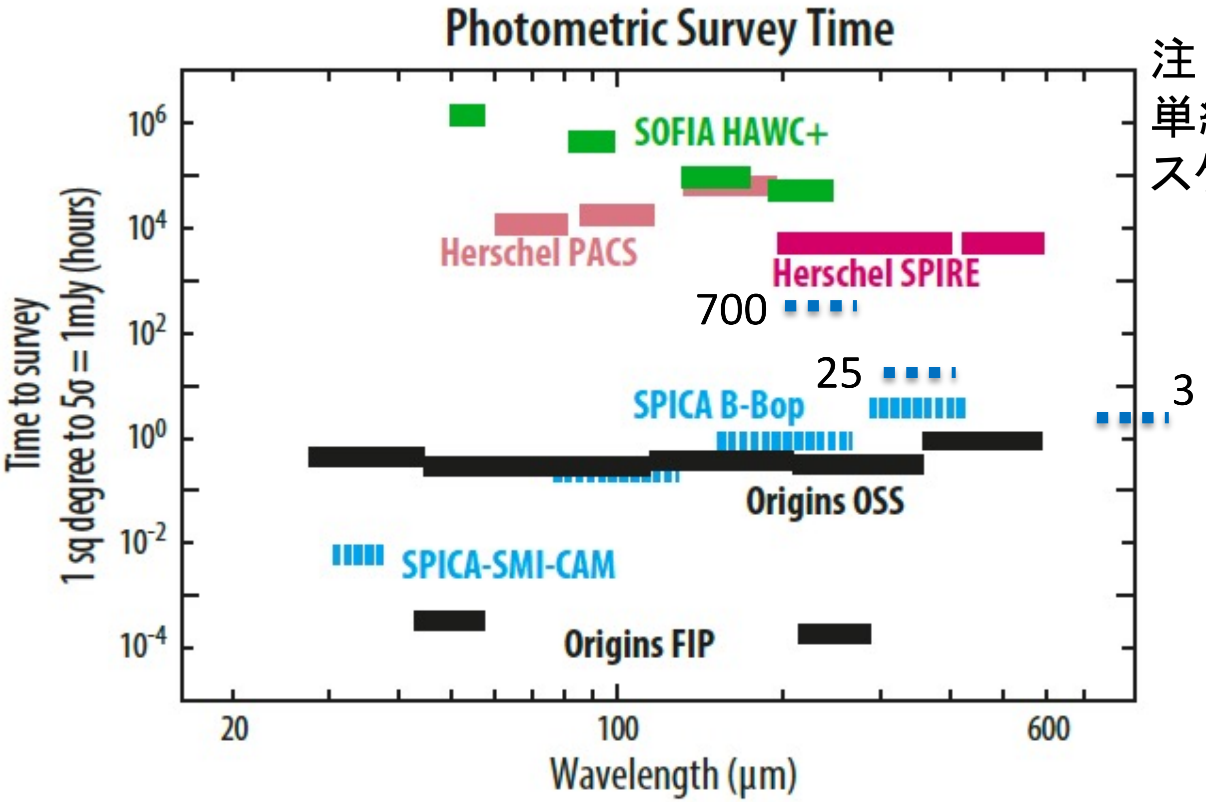
○感度等

(1) 連続波観測（注 1）

ATT10のFoV = 1 sq deg

（冬季 50%レベル＠ドームC）

	周波数帯 （注 2）	感　度 (5 σ rms)				角分解能	素子数
		τ =60sec	1 hour	10 hours	Confusion		
750 um	400 GHz	13 mJy	1.7 mJy	0.55 mJy	2.1 mJy	18.6”	700×2
350 um	850	39	5.1	1.6	1.5	8.7”	3000×2
230 um	1300	215	27.7	8.8	0.26	5.7”	1200×3(注 4)

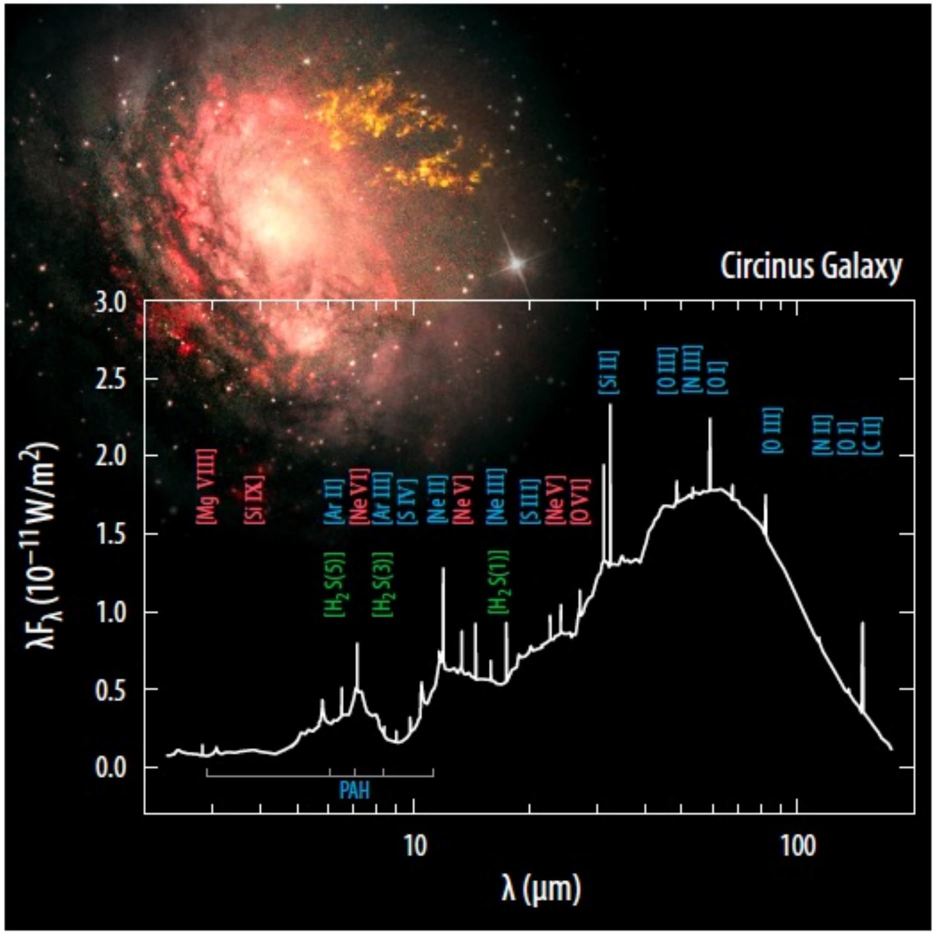


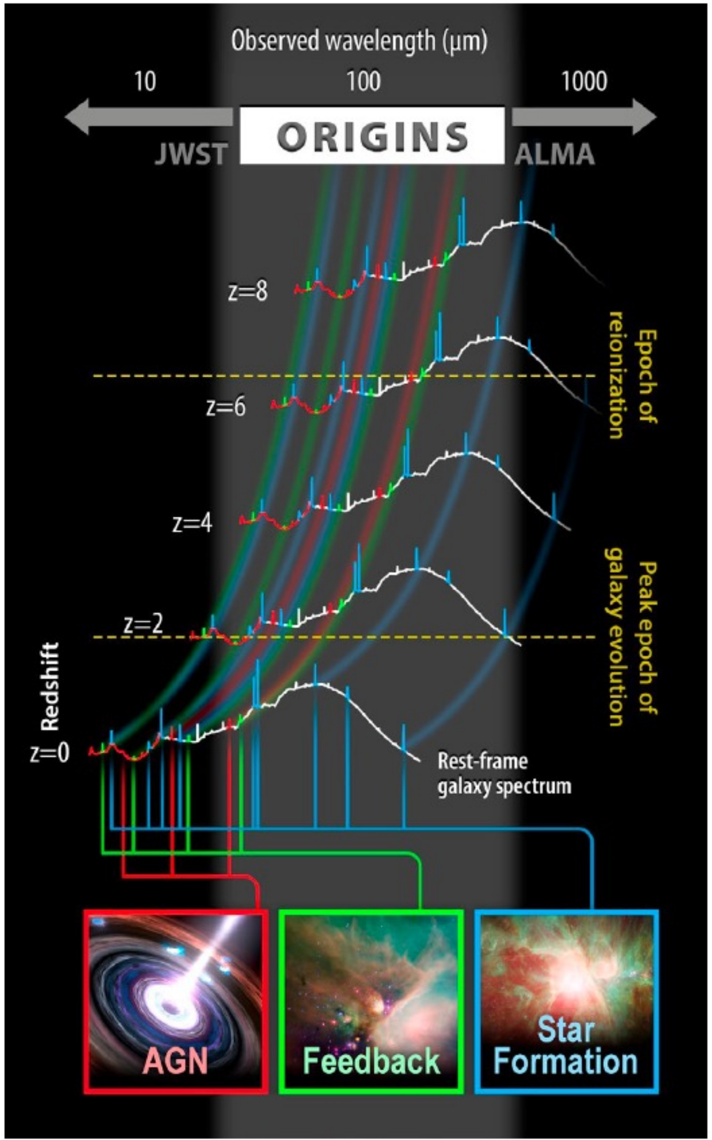
注
単純にsqrt(時間)で
スケールしたもの

Origins Space Telescope
サーベイデザインと予想されるデータ

1.1.1 The Infrared Toolbox and Origins in the 2030s Context

Origins is designed to detect spectral features that fully characterize star formation, black hole accretion, and the state of the ISM in an unbiased sample of galaxies across cosmic time—something no other telescope can do.





若い星により励起される輝線

AGNによる高励起線

分子ガス輝線 (フィードバック効果を調べるのに有効)

✓ **25-588 um を一度に観測できる**

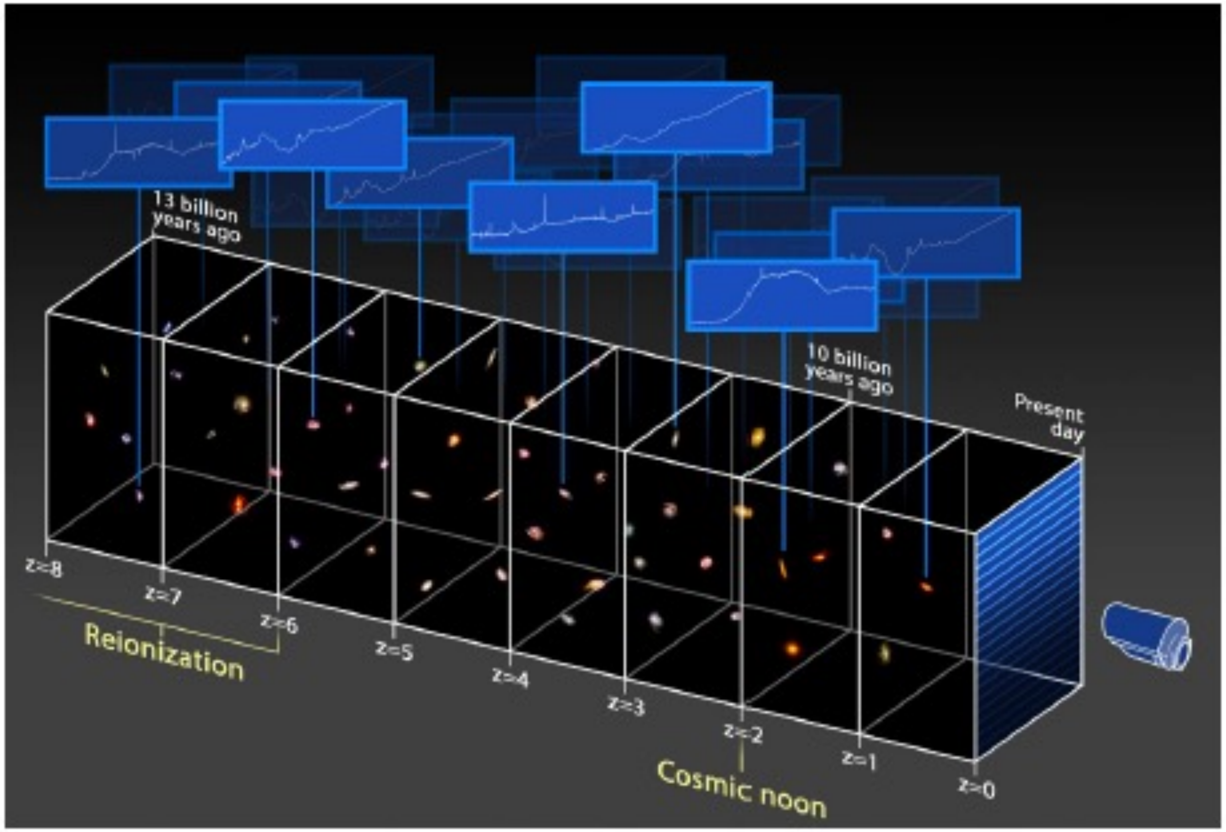
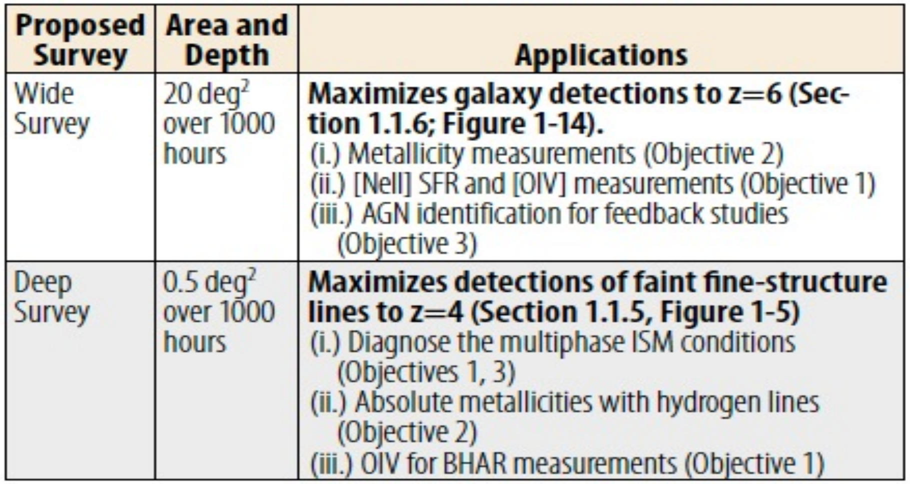


Figure 1-16: *Origins* enables three-dimensional (3D) spectroscopic surveys of the Universe of galaxies. The extragalactic science program is based on *Origins*' ability to conduct wide-area spectral surveys at a resolving power R=λ/Δλ of 300 over the full 25-588 μm spectral range. *Origins* can conduct spectroscopic surveys of order 20 deg^2 in less than 1000 hours, leading to spectra for at least a million galaxies out to $z > 8$.

Table 1-4: Extragalactic Surveys for Scientific Objectives



Proposed Survey	Area and Depth	Applications
Wide Survey	20 deg^2 over 1000 hours	**Maximizes galaxy detections to z=6 (Section 1.1.6; Figure 1-14).** (i.) Metallicity measurements (Objective 2) (ii.) [NeII] SFR and [OIV] measurements (Objective 1) (iii.) AGN identification for feedback studies (Objective 3)
Deep Survey	0.5 deg^2 over 1000 hours	**Maximizes detections of faint fine-structure lines to z=4 (Section 1.1.5, Figure 1-5)** (i.) Diagnose the multiphase ISM conditions (Objectives 1, 3) (ii.) Absolute metallicities with hydrogen lines (Objective 2) (iii.) OIV for BHAR measurements (Objective 1)

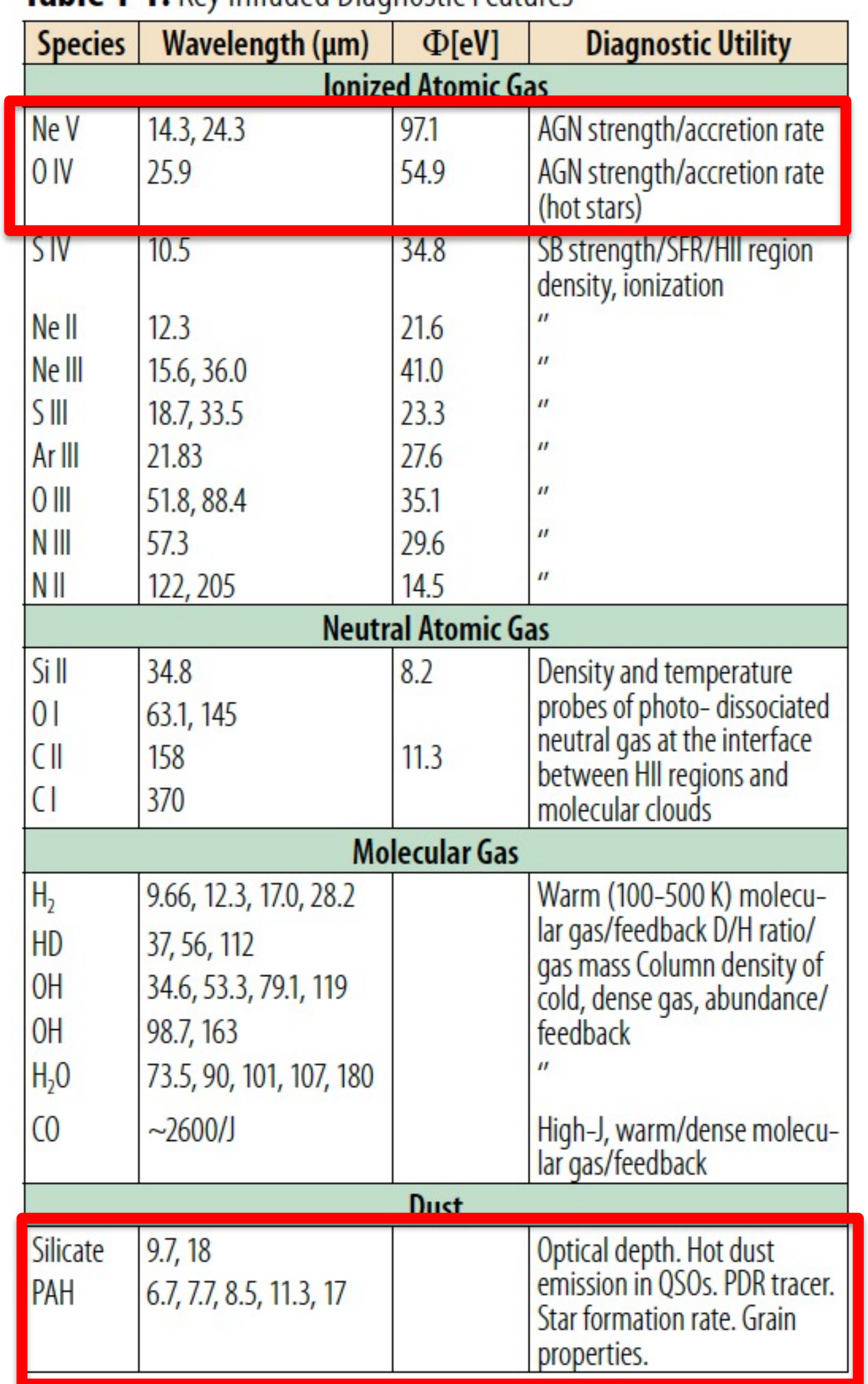
Z=0-8 にわたる、
N > 100万天体
の3D スペクトル

可視光の SDSS, MUSE
のようなデータを赤外で
得られる

- ☐ 電離ガス (AGN による高励起輝線、星による輝線)、中性ガス、分子ガス、ダスト放射および有機物 (PAH)など ISM の多相にわたる情報を得る。

- ☐ SFR、BHARなどの量や、ISM パラメータ (Z, Ne, PDR density, grain etc) を得る

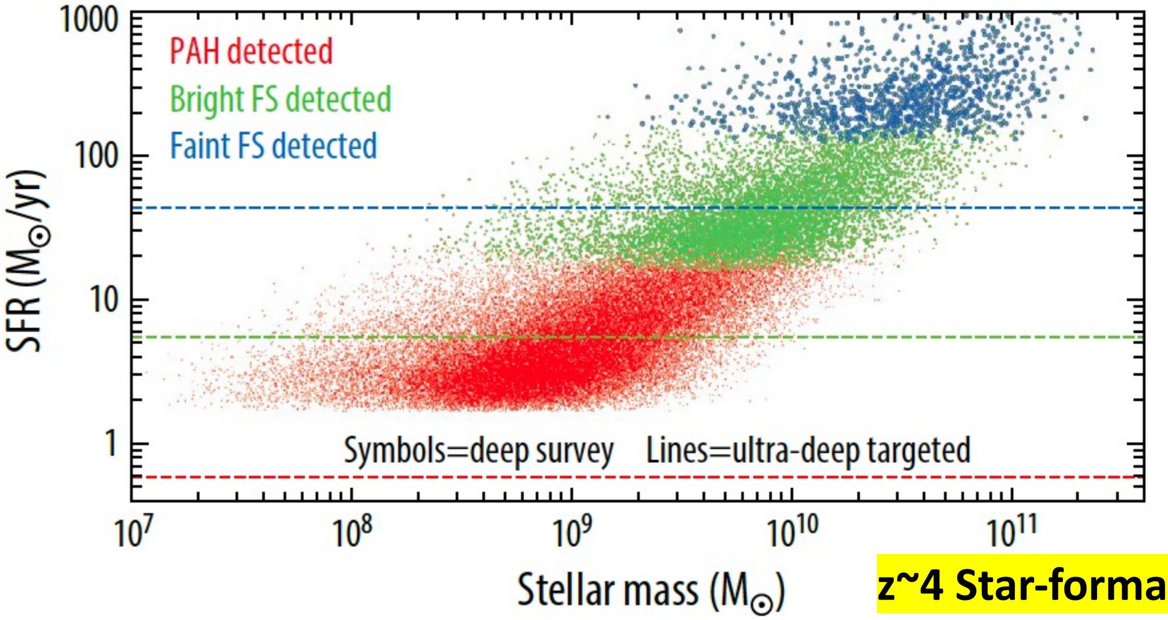
AGN tracer



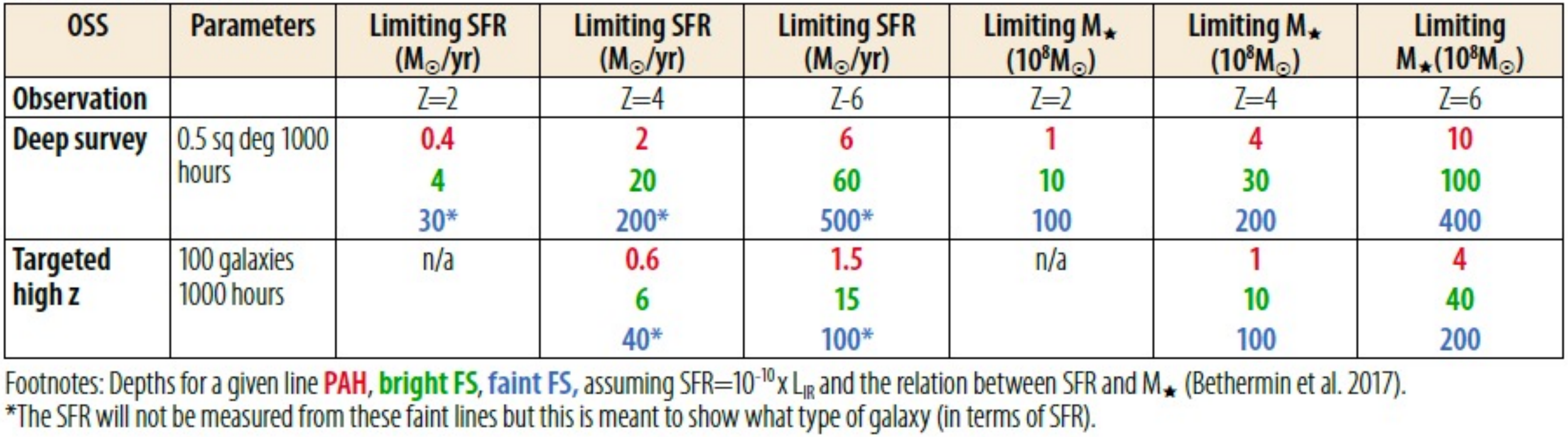
Species	Wavelength (μm)	Φ[eV]	Diagnostic Utility
Ionized Atomic Gas			
Ne V	14.3, 24.3	97.1	AGN strength/accretion rate
O IV	25.9	54.9	AGN strength/accretion rate (hot stars)
S IV	10.5	34.8	SB strength/SFR/HII region density, ionization
Ne II	12.3	21.6	"
Ne III	15.6, 36.0	41.0	"
S III	18.7, 33.5	23.3	"
Ar III	21.83	27.6	"
O III	51.8, 88.4	35.1	"
N III	57.3	29.6	"
N II	122, 205	14.5	"
Neutral Atomic Gas			
Si II	34.8	8.2	Density and temperature probes of photo- dissociated neutral gas at the interface between HII regions and molecular clouds
O I	63.1, 145		
C II	158	11.3	
C I	370		
Molecular Gas			
H_2	9.66, 12.3, 17.0, 28.2		Warm (100-500 K) molecular gas/feedback D/H ratio/ gas mass Column density of cold, dense gas, abundance/ feedback
HD	37, 56, 112		
OH	34.6, 53.3, 79.1, 119		
OH	98.7, 163		
H_2O	73.5, 90, 101, 107, 180		"
CO	~2600/J		High-J, warm/dense molecular gas/feedback
Dust			
Silicate	9.7, 18		Optical depth. Hot dust emission in QSOs. PDR tracer. Star formation rate. Grain properties.
PAH	6.7, 7.7, 8.5, 11.3, 17		

AGN tracer
PAH破壊される

- Bethermin+17の銀河進化モデルに、輝線光度/赤外光度比の情報 (Spitzer/Herschel) を入れた。z > 4 は不定性が大きいことに注意は必要 (どの赤外プロジェクトも同じ問題あり)。
- Bright FS = [NeII] 12 um ; Faint FS = [NeV] 14, 23 um



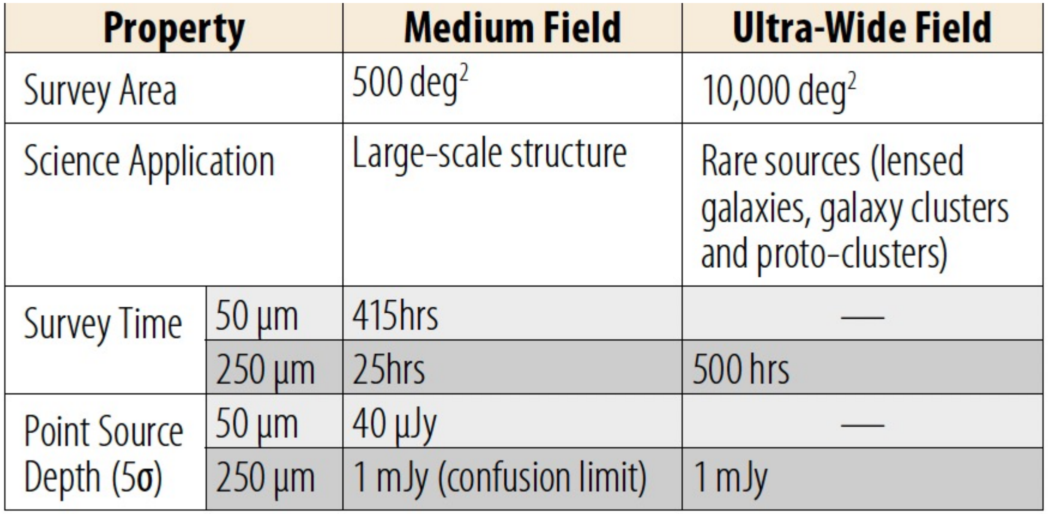
z~4 Star-formation main sequence



OSS	Parameters	Limiting SFR ($M_\odot$/yr)	Limiting SFR ($M_\odot$/yr)	Limiting SFR ($M_\odot$/yr)	Limiting $M_\star$ ($10^8 M_\odot$)	Limiting $M_\star$ ($10^8 M_\odot$)	Limiting $M_\star$($10^8 M_\odot$)
Observation		Z=2	Z=4	Z-6	Z=2	Z=4	Z=6
Deep survey	0.5 sq deg 1000 hours	0.4 4 30*	2 20 200*	6 60 500*	1 10 100	4 30 200	10 100 400
Targeted high z	100 galaxies 1000 hours	n/a	0.6 6 40*	1.5 15 100*	n/a	1 10 100	4 40 200

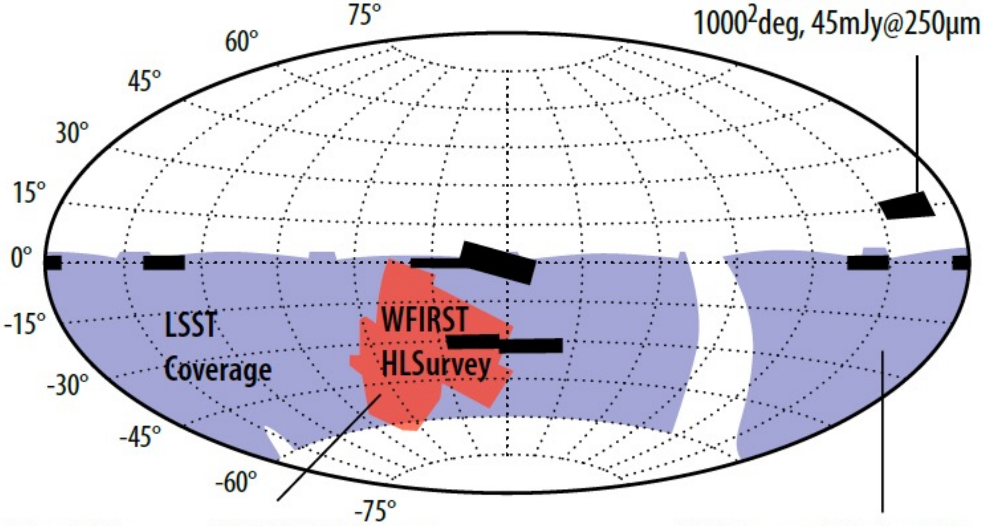
Footnotes: Depths for a given line **PAH**, **bright FS**, **faint FS**, assuming SFR=10^{-10}x L_{IR} and the relation between SFR and $M_\star$ (Bethermin et al. 2017).
*The SFR will not be measured from these faint lines but this is meant to show what type of galaxy (in terms of SFR).

FIP continuum survey



Property		Medium Field	Ultra-Wide Field
Survey Area		500 deg^2	10,000 deg^2
Science Application		Large-scale structure	Rare sources (lensed galaxies, galaxy clusters and proto-clusters)
Survey Time	50 µm	415hrs	—
	250 µm	25hrs	500 hrs
Point Source Depth (5σ)	50 µm	40 µJy	—
	250 µm	1 mJy (confusion limit)	1 mJy

Herschel (black areas)
1000^{2}deg, 45mJy@250µm



Origins FIP = WFIRST HLSurvey
1600hrs. 11,000hrs
2200^{2}deg, 40µJy@50µm

LSST = Origins FIP
~10 years 1000hrs.
18,000^{2}deg, 1mJy@250µm

Origins Space Telescope
具体的なサイエンスの内容

銀河形成分野におけるメインサイエンス

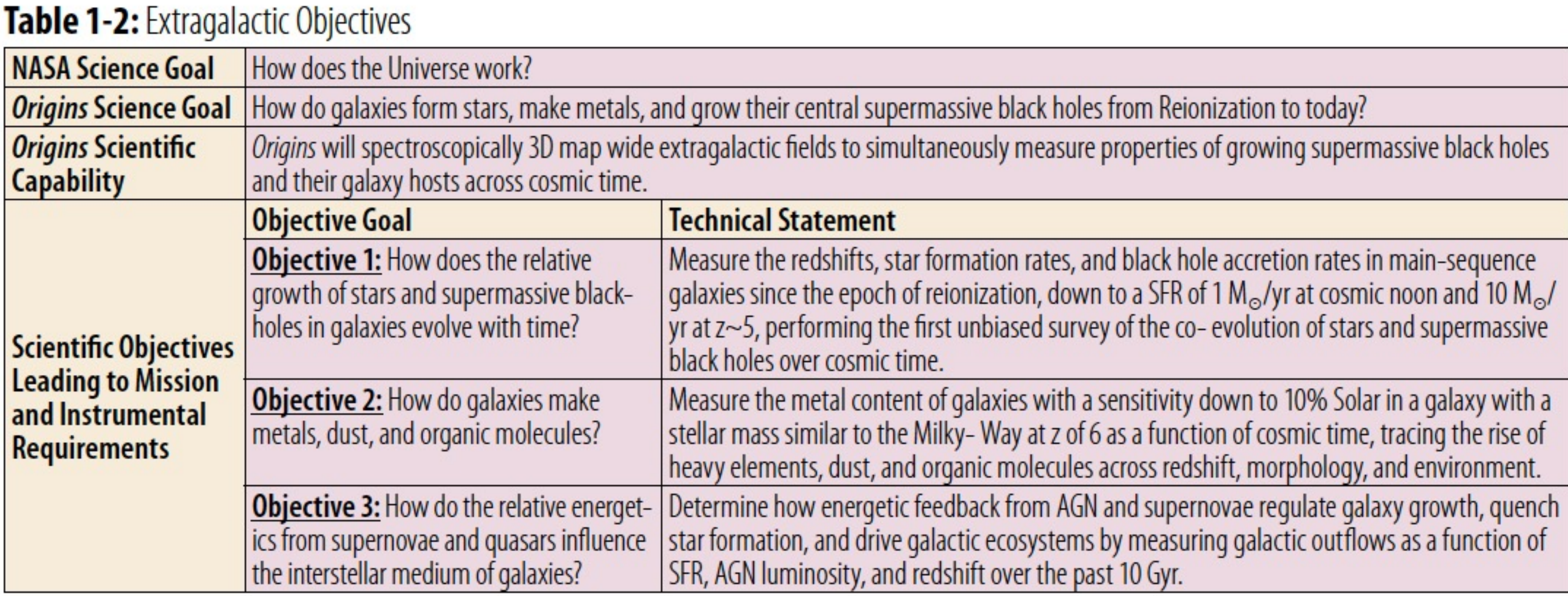


Table 1-2: Extragalactic Objectives

NASA Science Goal	How does the Universe work?	
***Origins* Science Goal**	How do galaxies form stars, make metals, and grow their central supermassive black holes from Reionization to today?	
***Origins* Scientific Capability**	*Origins* will spectroscopically 3D map wide extragalactic fields to simultaneously measure properties of growing supermassive black holes and their galaxy hosts across cosmic time.	
Scientific Objectives Leading to Mission and Instrumental Requirements	**Objective Goal**	**Technical Statement**
	Objective 1: How does the relative growth of stars and supermassive black-holes in galaxies evolve with time?	Measure the redshifts, star formation rates, and black hole accretion rates in main-sequence galaxies since the epoch of reionization, down to a SFR of 1 $M_\odot$/yr at cosmic noon and 10 $M_\odot$/yr at z~5, performing the first unbiased survey of the co- evolution of stars and supermassive black holes over cosmic time.
	Objective 2: How do galaxies make metals, dust, and organic molecules?	Measure the metal content of galaxies with a sensitivity down to 10% Solar in a galaxy with a stellar mass similar to the Milky- Way at z of 6 as a function of cosmic time, tracing the rise of heavy elements, dust, and organic molecules across redshift, morphology, and environment.
	Objective 3: How do the relative energetics from supernovae and quasars influence the interstellar medium of galaxies?	Determine how energetic feedback from AGN and supernovae regulate galaxy growth, quench star formation, and drive galactic ecosystems by measuring galactic outflows as a function of SFR, AGN luminosity, and redshift over the past 10 Gyr.

1.1.2 Science Objective 1: The Co-evolution of Stars and Black Holes

> With deep and wide spectroscopic surveys, *Origins* reveals how galaxies and black holes grow together over cosmic time.

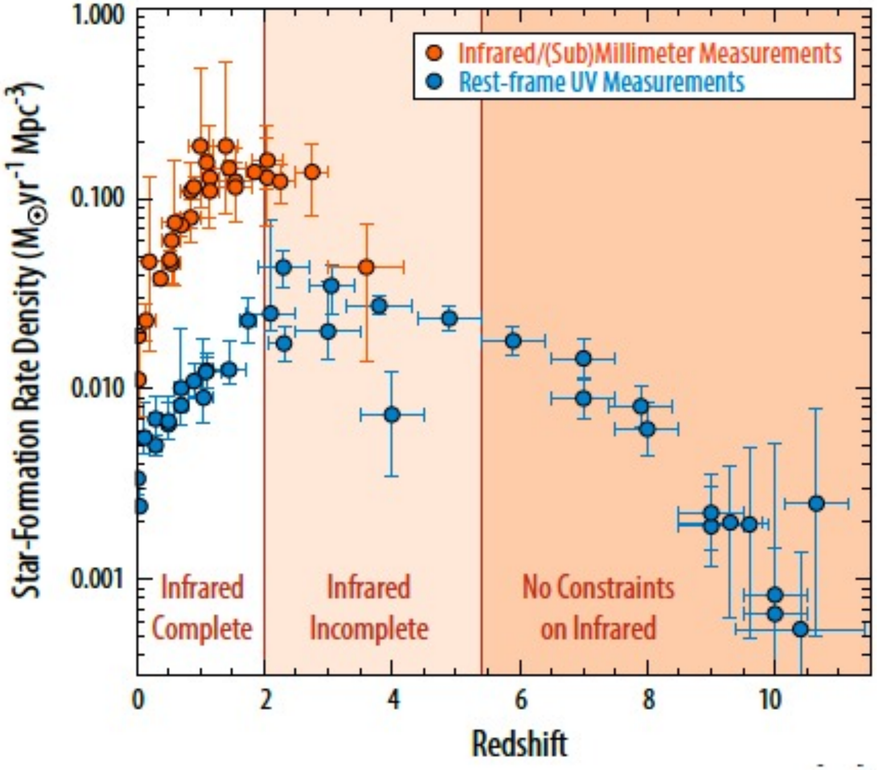
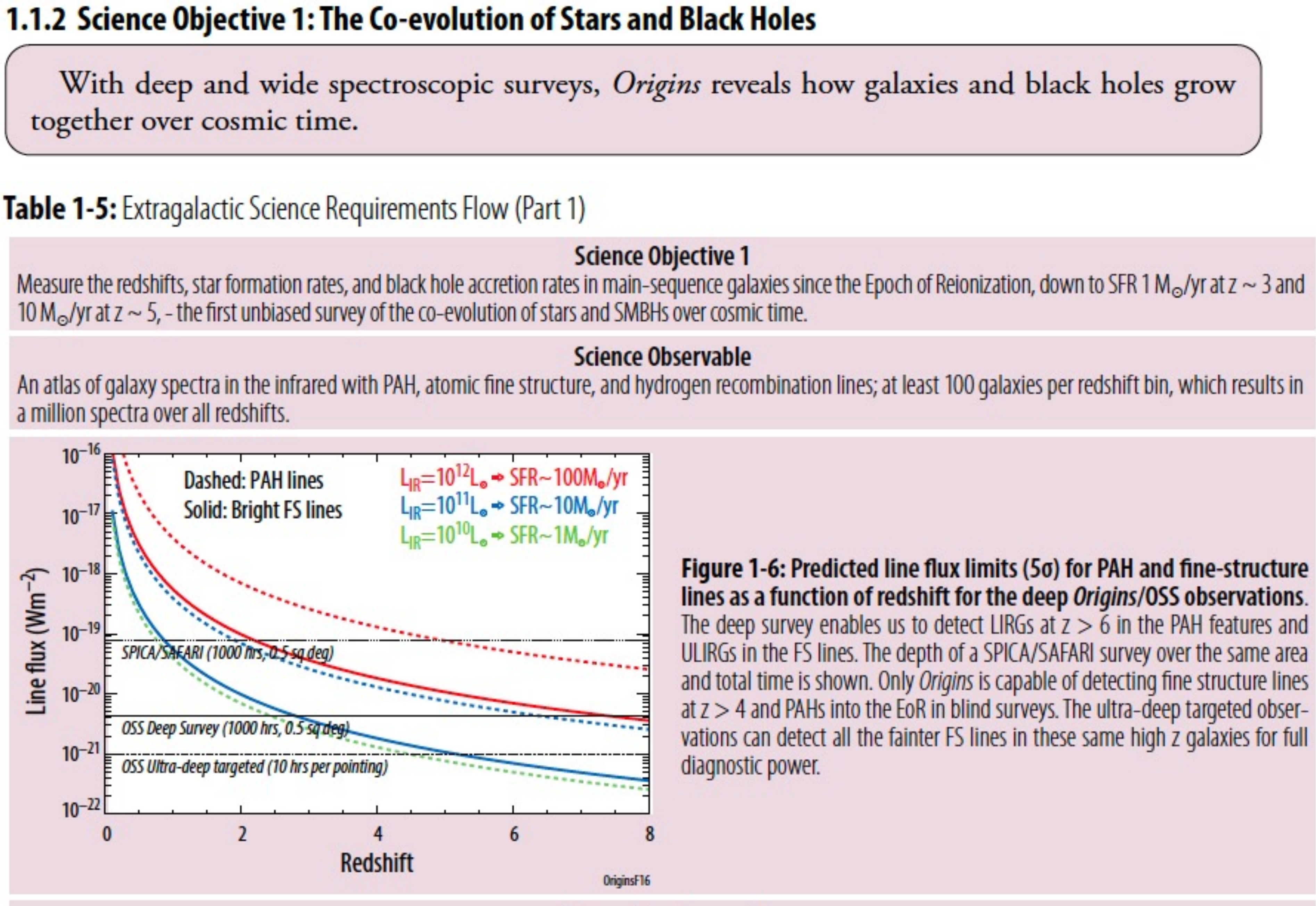


Figure 1-3: Star Formation over Cosmic Time. *Origins* provides the first accurate measure of the star formation rate in galaxies at $z > 3$ in the infrared, with sufficient large samples to determine the effects of environment, AGN power, and other physical variables. This figure, adapted from Casey et al. (2018), shows the current state of the art – the lack of infrared data for $z > 2$, and the vast discovery space that can be filled in with *Origins*.

Table 1-4: Extragalactic Surveys for Scientific Objectives

Proposed Survey	Area and Depth	Applications
Wide Survey	20 deg^2 over 1000 hours	**Maximizes galaxy detections to z=6 (Section 1.1.6; Figure 1-14).** (i.) Metallicity measurements (Objective 2) (ii.) [NeII] SFR and [OIV] measurements (Objective 1) (iii.) AGN identification for feedback studies (Objective 3)
Deep Survey	0.5 deg^2 over 1000 hours	**Maximizes detections of faint fine-structure lines to z=4 (Section 1.1.5, Figure 1-5)** (i.) Diagnose the multiphase ISM conditions (Objectives 1, 3) (ii.) Absolute metallicities with hydrogen lines (Objective 2) (iii.) OIV for BHAR measurements (Objective 1)

AGN 由来の FS lines ([OIV] 26 um) 光度
→ Black hole accretion rate の計算
→ SFRD 進化vs. BHAR 進化は、z ~3 まで似てる。
Z > 3 で両者の違いが見えてくるか? (共進化のメカニズム解明)



1.1.2 Science Objective 1: The Co-evolution of Stars and Black Holes

With deep and wide spectroscopic surveys, *Origins* reveals how galaxies and black holes grow together over cosmic time.

Table 1-5: Extragalactic Science Requirements Flow (Part 1)

Science Objective 1

Measure the redshifts, star formation rates, and black hole accretion rates in main-sequence galaxies since the Epoch of Reionization, down to SFR 1 $M_\odot$/yr at z ~ 3 and 10 $M_\odot$/yr at z ~ 5, - the first unbiased survey of the co-evolution of stars and SMBHs over cosmic time.

Science Observable

An atlas of galaxy spectra in the infrared with PAH, atomic fine structure, and hydrogen recombination lines; at least 100 galaxies per redshift bin, which results in a million spectra over all redshifts.

Figure 1-6: Predicted line flux limits (5σ) for PAH and fine-structure lines as a function of redshift for the deep *Origins*/OSS observations. The deep survey enables us to detect LIRGs at z > 6 in the PAH features and ULIRGs in the FS lines. The depth of a SPICA/SAFARI survey over the same area and total time is shown. Only *Origins* is capable of detecting fine structure lines at z > 4 and PAHs into the EoR in blind surveys. The ultra-deep targeted observations can detect all the fainter FS lines in these same high z galaxies for full diagnostic power.

ダスト連続光 → MIR + FIR をテンプレートfitして AGN vs. SF
FS lines, PAH lines と組み合わせて総合的に調べる。

Table 1-6: Extragalactic Science Requirements Flow (Part 2)

Science Objective 2

Measure the metal content of galaxies with a sensitivity down to 10% Solar in a galaxy with a stellar mass similar to the Milky-Way at $z=6$, as a function of cosmic time, tracing the rise of heavy elements, dust and organic molecules across redshift, morphology and environment.

Science Observable

A catalog of oxygen and nitrogen fine-structure line fluxes from galaxies spanning the luminosity range $10^{11} < L_{IR} < 10^{13}\,L_{\odot}$ to measure relative metallicities in nearly 10^5 galaxies over the redshift range $1 < z < 9$.

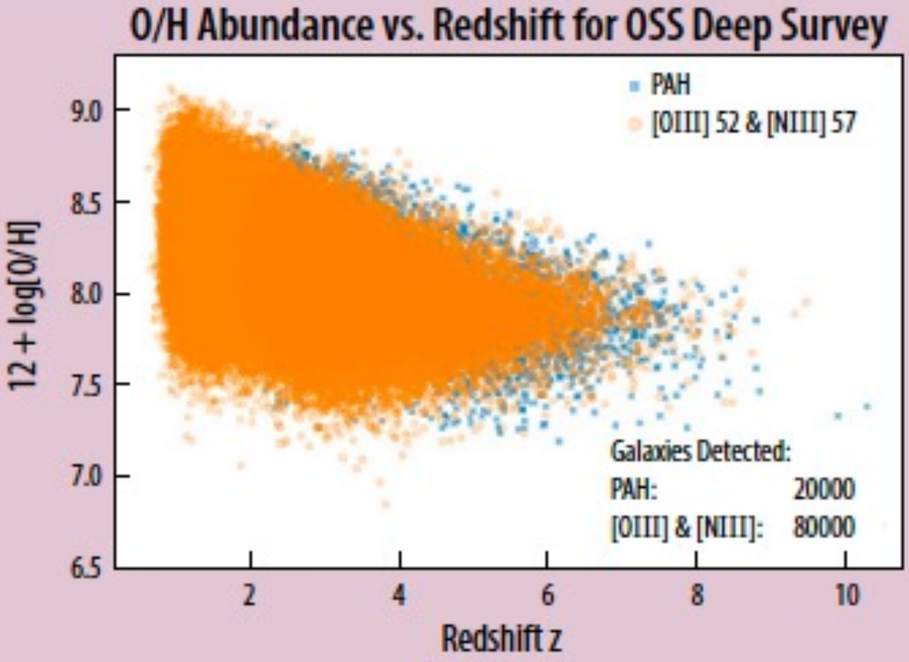


Figure 1-9: O/H abundance vs redshift detected with *Origins*. O/H abundance versus redshift for galaxies detected in the OSS Deep Survey. Shown are galaxies detected in either the PAH or [OIII] and [NIII] metallicity probes. PAH detections are based on the detections of the 7.7-µm feature, which enters the OSS band at $z=2.2$. [OIII] and [NIII] galaxies are simultaneously detected in the [OIII] 52 and [NIII] 57-µm lines.

Science Requirements

A line sensitivity of 4×10^{-21} W m^{-2} (5σ) in 1 hr at 100 µm and sufficient beams on the sky to give mapping speeds of ~ 10^{-4} deg^2 (10^{-19} W m^{-2})$^{-2}$ sec^{-1}. Wavelength coverage from: 25 to 500 µm.

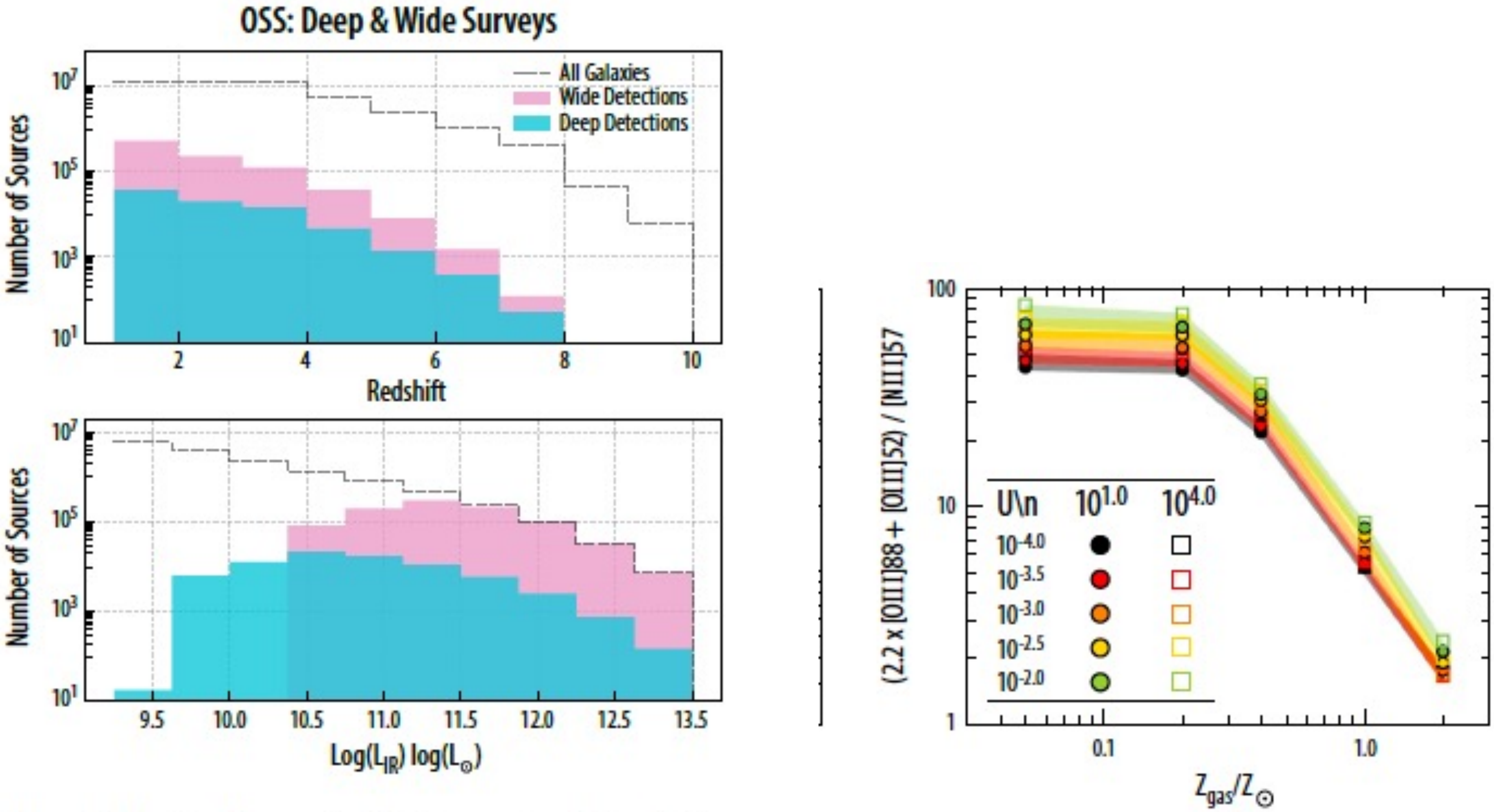


Figure 1-10: Metal Content in Galaxies seen by *Origins*. *Origins* will determine the metallicities for an unbiased sample of nearly a million galaxies. These plots show the expected numbers of unique galaxies detected as a function of redshift and IR luminosity in the OSS Deep and Wide Surveys. These galaxies are all detected in the [OIII] 52 and [NIII] 57-μm lines.

Table 1-7: Extragalactic Science Requirements Flow (Part 3)

Science Objective 3

Determine how energetic feedback from AGN and supernovae regulate galaxy growth, quench star formation, and drive galactic ecosystems, by measuring galactic outflows as a function of SFR, AGN luminosity and redshift over the past 10 Gyr.

Science Observable

A catalog of warm and cold molecular gas velocity and mass outflow rates via mid-IR H_2 emission and far-IR OH absorption lines in 10^3 galaxies.

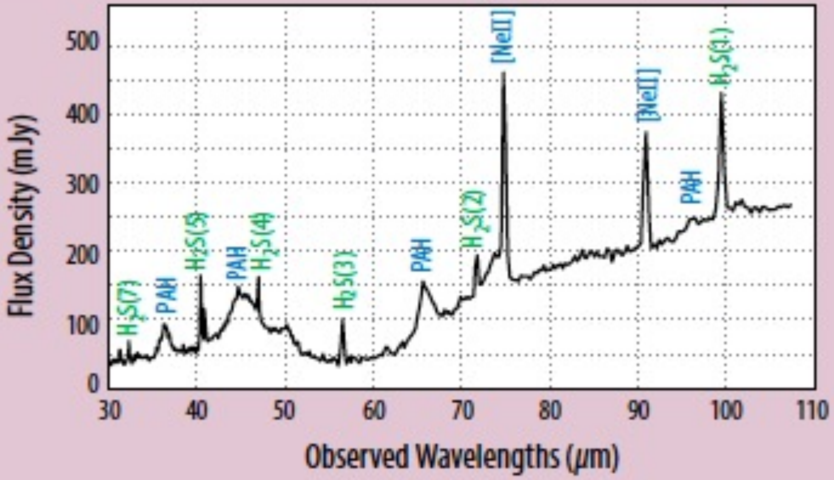


Figure 1-14: Simulated rest-frame mid-IR spectrum of the local ULIRG NGC 6240 scaled to LIR=5×10^{12} $L_\odot$ and placed at z=5, as seen with *Origins*/OSS in a 1hr integration. Extremely strong H_2 lines from warm molecular gas shock heated by the outflowing galactic wind are seen. Also seen are strong, broad PAH features and the [NeII] and [NeIII] fine structure lines.

Science Requirements

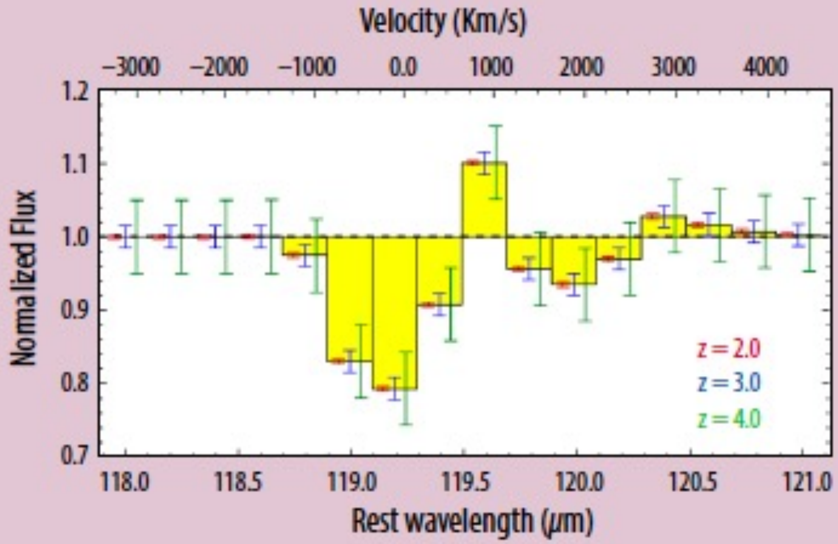


Figure 1-15: To measure the velocity and mass outflow rates in the molecular gas in an L* galaxy at z=3, *Origins*/OSS shall be capable of resolving an emission line of 1000 km/s (R=300) in low-resolution mode and 100 km/s (R=3000) in high-resolution FTS mode, with a 5σ, 1hr line flux sensitivity of 10^{-20} W m^{-2}. *Origins* also must have a long wavelength cutoff of no less than 476 μm (to detect OH 119 μm at z=3).

Figure 1-11: Galactic Outflows. *Origins* detects and measures galactic outflows in galaxies over the past 10 Gyr of cosmic time. In this image of the nearby starburst galaxy M82, the warm ionized gas (red) traces a familiar hourglass shape extending along the minor axis (stellar disk in blue), driven by the collective effect of young stars and supernovae. Starbursts and AGN can eject energy and metal-enriched gas into the inter-galactic medium, where they can sometimes be seen in emission against dark space, and in absorption against the light of background QSOs.

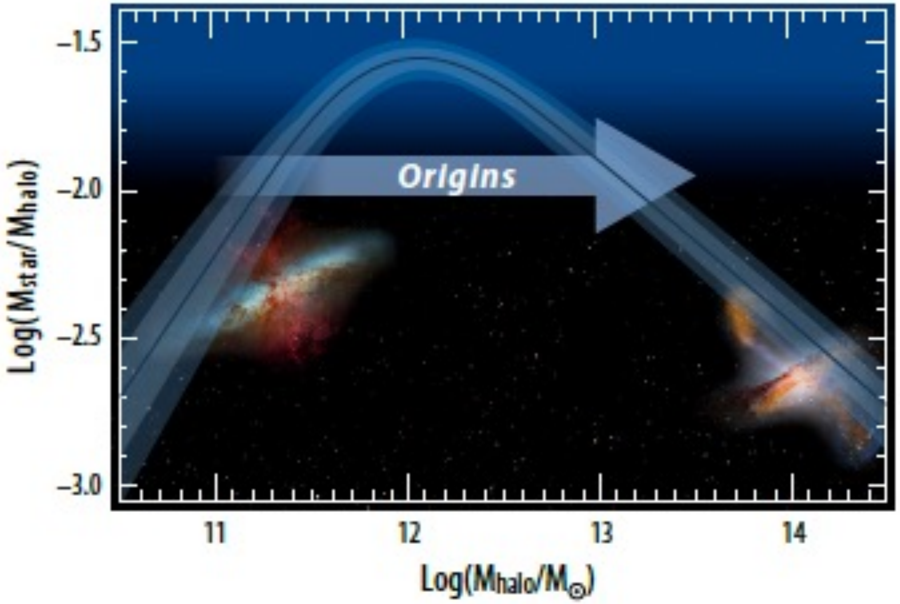


Figure 1-12: The inefficiency of star formation. *Origins* measures feedback over a huge range in galaxy mass, when galaxies were rapidly evolving. The plot shows the ratio of stellar to halo mass as a function of halo mass in galaxies (Moster et al., 2010; Erb, 2015). The ratio drops off precipitously above and below a halo mass of about 10^{12} $M_{\odot}$, suggesting extremely inefficient star formation in both low and high mass galaxies. It is believed that stellar feedback dominates at the low-mass end, while AGN dominate at the high-mass end. *Origins* probes both kinds of feedback over at least three orders of magnitude in galaxy mass.

OSTで提案された個別ミッション例 – 銀河に関わるもの

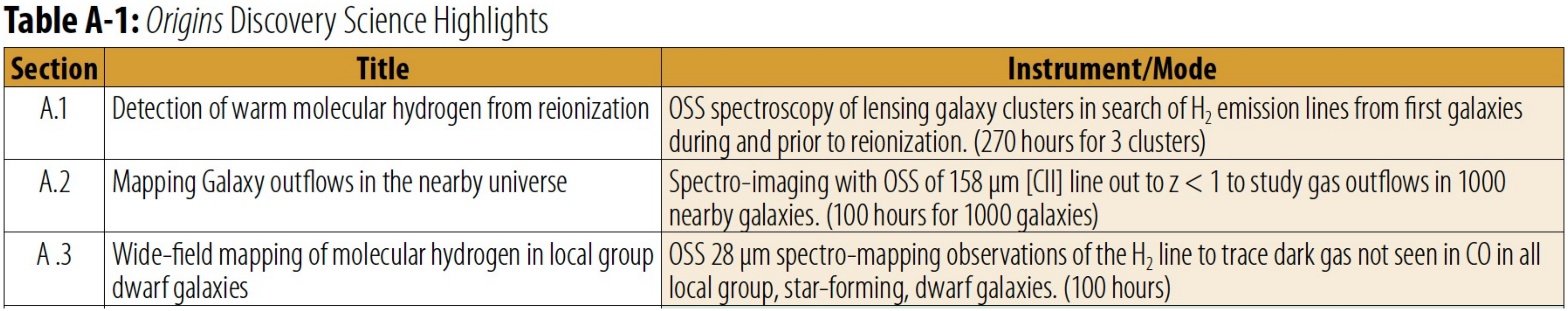


Table A-1: *Origins* Discovery Science Highlights

Section	Title	Instrument/Mode
A.1	Detection of warm molecular hydrogen from reionization	OSS spectroscopy of lensing galaxy clusters in search of H_2 emission lines from first galaxies during and prior to reionization. (270 hours for 3 clusters)
A.2	Mapping Galaxy outflows in the nearby universe	Spectro-imaging with OSS of 158 μm [CII] line out to $z < 1$ to study gas outflows in 1000 nearby galaxies. (100 hours for 1000 galaxies)
A .3	Wide-field mapping of molecular hydrogen in local group dwarf galaxies	OSS 28 μm spectro-mapping observations of the H_2 line to trace dark gas not seen in CO in all local group, star-forming, dwarf galaxies. (100 hours)

A.1 Detection of Warm Molecular Hydrogen in the Dark Era of Galaxy Formation

Deep spectroscopic observations used to search for warm molecular hydrogen and other key fine-structure cooling lines in gas heated as it collapses inside massive dark matter halos at $7.5 < z < 8.5$ provides a direct measure of the mechanical heating of molecular gas as the first galaxies form. The observations, aimed toward rich clusters, make use of gravitational lensing amplification to search for faint molecular hydrogen line emission from distant galaxies. *Author: Phil Appleton (IPAC)*

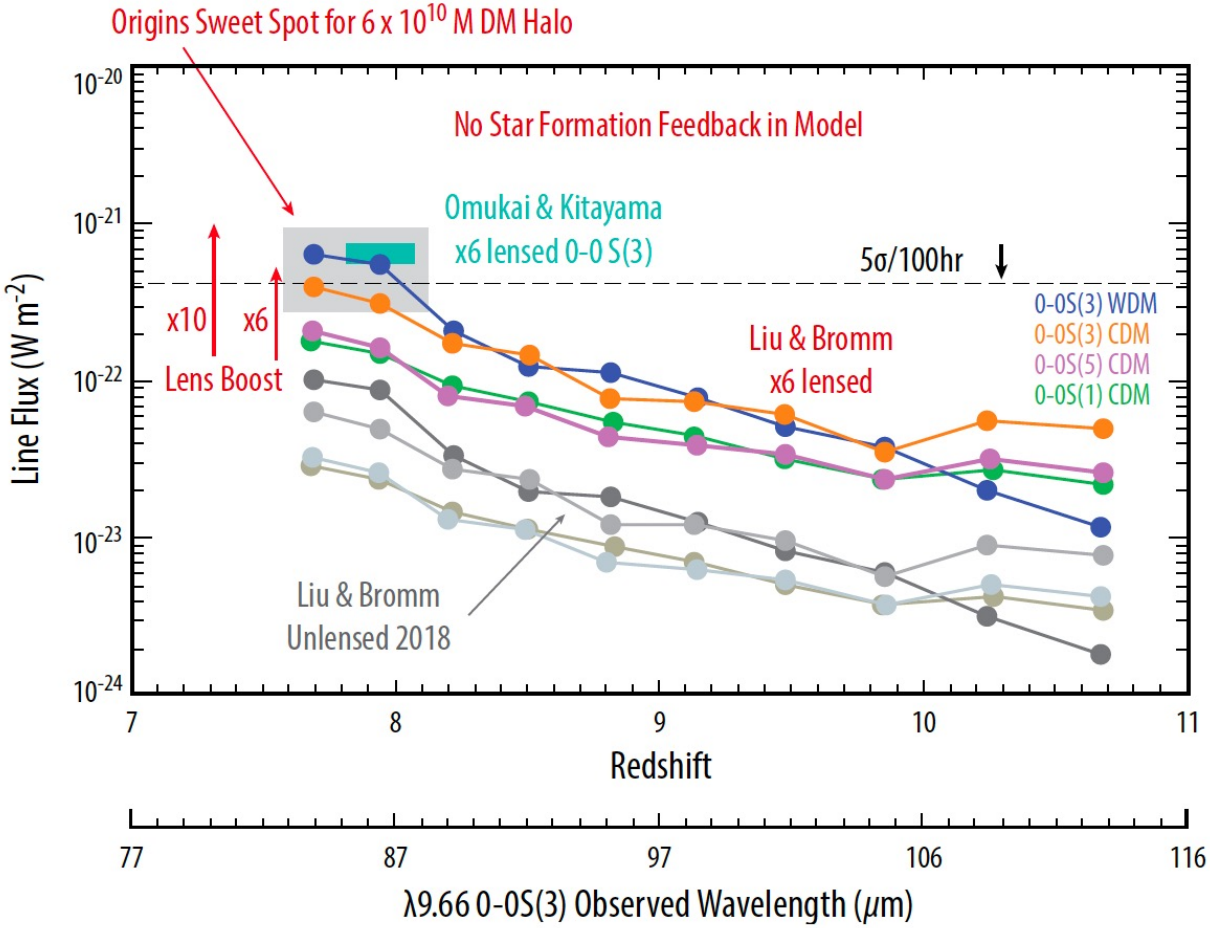


Figure A-1: *Origins*/OSS is capable of detecting the molecular hydrogen emission related to primordial gas cooling to form first galaxies. Predictions for 6x lensed (colored lines) and un-lensed (grey lines) for H_2 line emission as a function of redshift for a DM halo of mass 6.9×10^{10} $M_\odot$, extrapolated from the models by Lui & Bromm et al. (in prepration) and the models of Omukai & Kitayama (2003) (pale blue horizontal line). It also shows the 5σ/100hr sensitivity threshold for OSS for the 80–120 µm (Band 3) detectors (black horizontal line). Detection is only possible in the lower-z range. *Origins* adopts a fiducial observation time of 30 hours per pointing, which includes many beams across the target cluster.

A.2 Mapping Galaxy Outflows in the Nearby Universe

An *Origins*/OSS spectroscopic mapping program to observe the dust continuum and far-IR cooling line emission (particularly [*CII*] 158 μm) from outflowing material around nearby galaxies provides a comprehensive view of outflow characteristics across a statistically-meaningful sample of nearby galaxies and provides critical constraints on models of star formation and galaxy evolution. *Author: Alberto Bolatto (Maryland)*

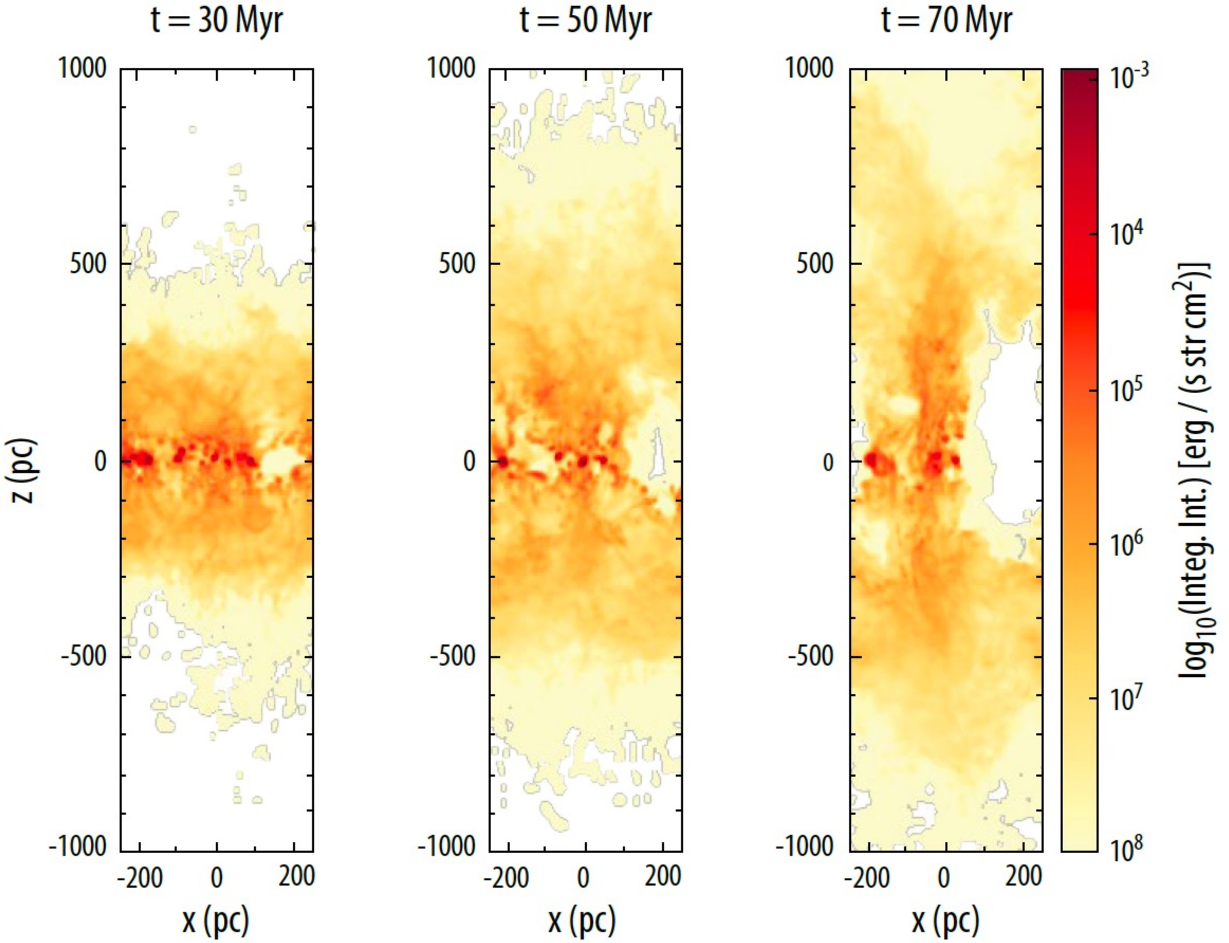


Figure A-2: Extraplanar [CII] 158 μm emission as a probe of outflow activity. Simulations of stellar feedback in a galaxy disk, showing star formation driving galactic outflows visible in [CII] emission. The calculations use the SILCC simulations and include radiative transfer to compute [CII] emission (Franeck et al., in prep; Walch et al., 2015). The *Origins*/OSS instrument can efficiently map the areas around nearby galaxies to the depth needed to detect this faint extraplanar [CII] emission.

A.3 Wide-field Mapping of Molecular Hydrogen Emission in Local Group Dwarf Galaxies

With *Origins*/OSS spectral mapping, it is possible to observe the 28 μm rotational line of H_2 across all star forming dwarf galaxies of the Local Group (excluding the Magellanic Clouds). These observations provide critical insight into the properties of molecular gas in conditions where most of the H_2 is not traced by carbon monoxide. *Origins*/OSS surpasses JWST's mapping speed at 28 μm by many orders of magnitude, making large area maps of H_2 emission feasible for the first time. *Author Karin Sandstrom (UCSD)*

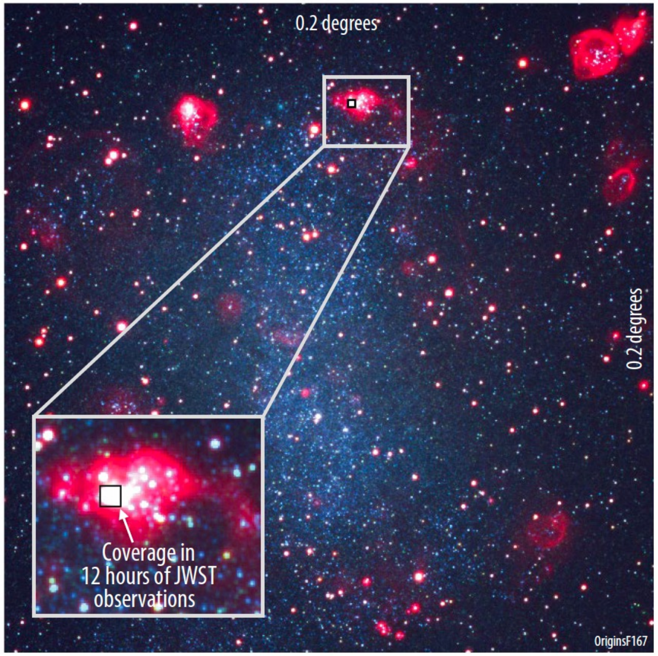


Figure A-3: The unprecedented sensitivity and mapping speed of *Origins*/OSS enables wide-field maps of H_2 28 μm rotational emission for the first time. This figure shows the coverage of an 0.04 deg^2 map of the Local Group dwarf NGC 6822 (color is U, V, and R band imaging from Hunter et al., 2012), which would require 12 hours of OSS observations to obtain the required sensitivity. The area JWST could observe to the same depth in 12 hours is shown in the inset.

require 5σ line sensitivity of $\sim 2\times10^{-20}$ W/m^2. In 100 hours, *Origins*/OSS could map 0.3 deg^2 to this depth, which would be sufficient to cover the full star-forming extent of all Local Group dwarf galaxies (*e.g.*, NGC 6822, WLM, Sextans A, Sextans B, IC 10, and IC 1613, ~0.26 deg^2 total), excluding the Magellanic Clouds. These *Origins*/OSS observations, in combination with ground-based CO mapping, would enable unprecedented characterization of the state of the warm and cold H_2 gas in low metallicity environments dominated by CO-dark molecular phases.

JWST MIRI でも不可能なサイエンスを、2030年代に
初めて OST/OSS で実現する