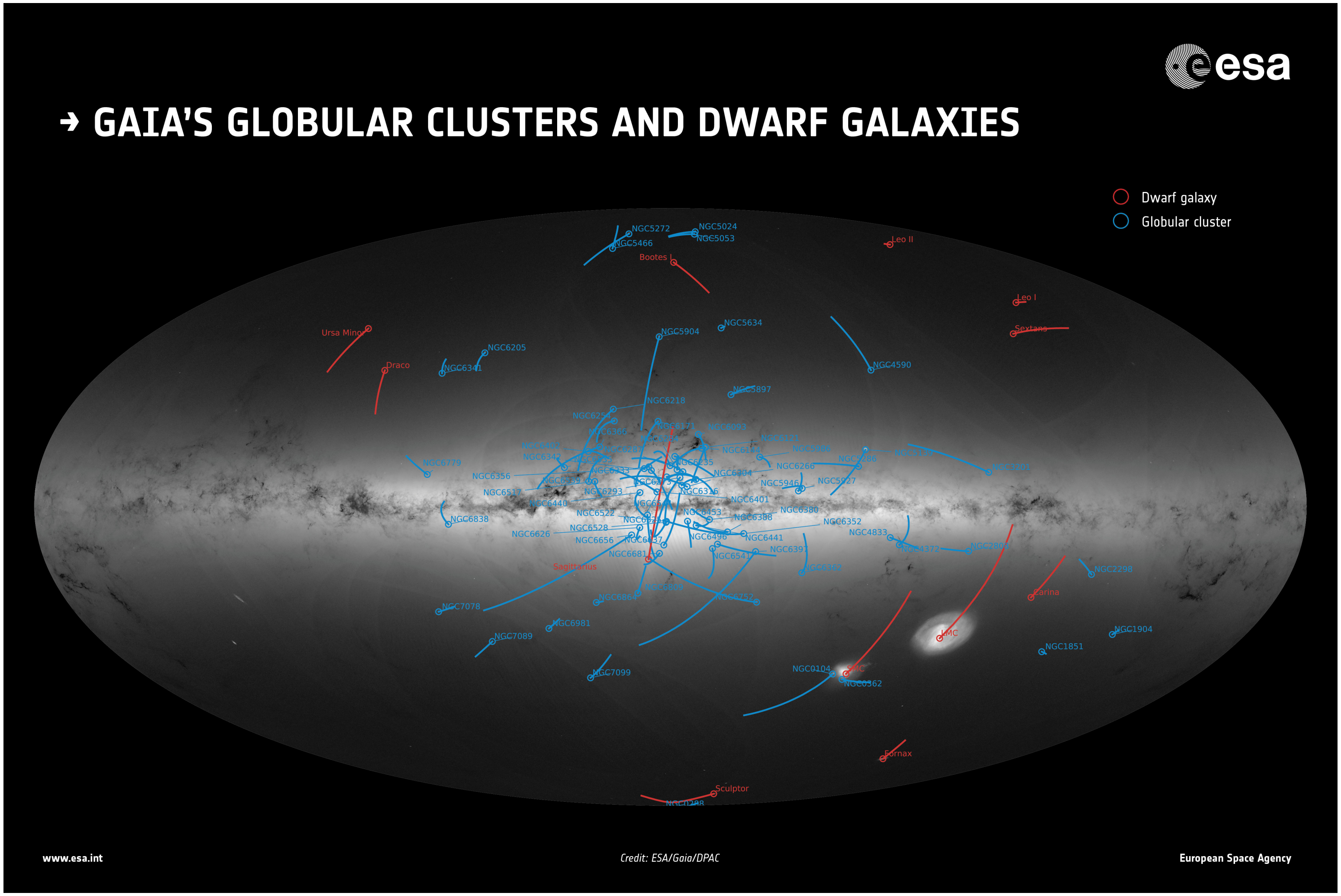
Treasury & Legacy Proposals

Treasury GO Programs

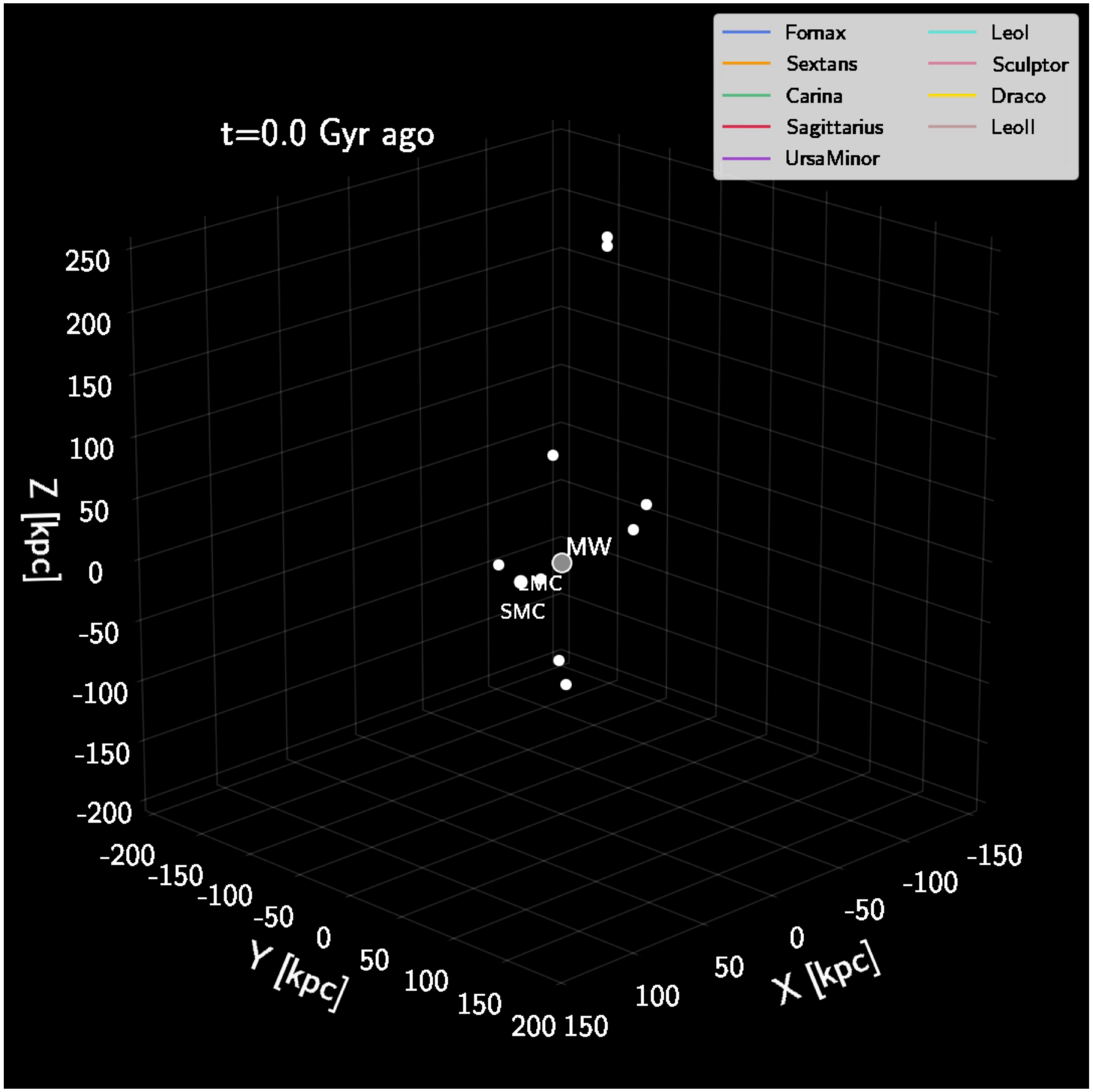
- Increase the science impact of HST
- Provide enhanced data products for the community that can used to address **multiple** scientific topics
- 28 Treasury programs submitted in Cycle 24 (9073 orbits)
- 2 accepted (662 orbits allocated)

- Example Programs:
  - The Great Observatories Origins Deep Survey (GOODS) (PI Giavalisco)
  - NICMOS imaging of UDF (PI Thompson)
  - The COSMOS 2-Degree ACS Survey (PI Scoville) (590 orbits)
  - ACS Nearby Galaxy Survey (ANGST) (PI Dalcanton)
  - Cluster Lensing Supernova Survey (CLASH) (PI Postman) (474 orbits)
  - 3D-HST: A Spectroscopic Galaxy Evolution Treasury (PI van Dokkum)
  - LEGUS: Legacy ExtraGalactic UV Survey (PI Calzetti)
  - The Goods UV Legacy Fields: A Full Census of Faint Star-Forming Galaxies at z~0.5-2 (PI Oesch) (Cycle 22)

Or

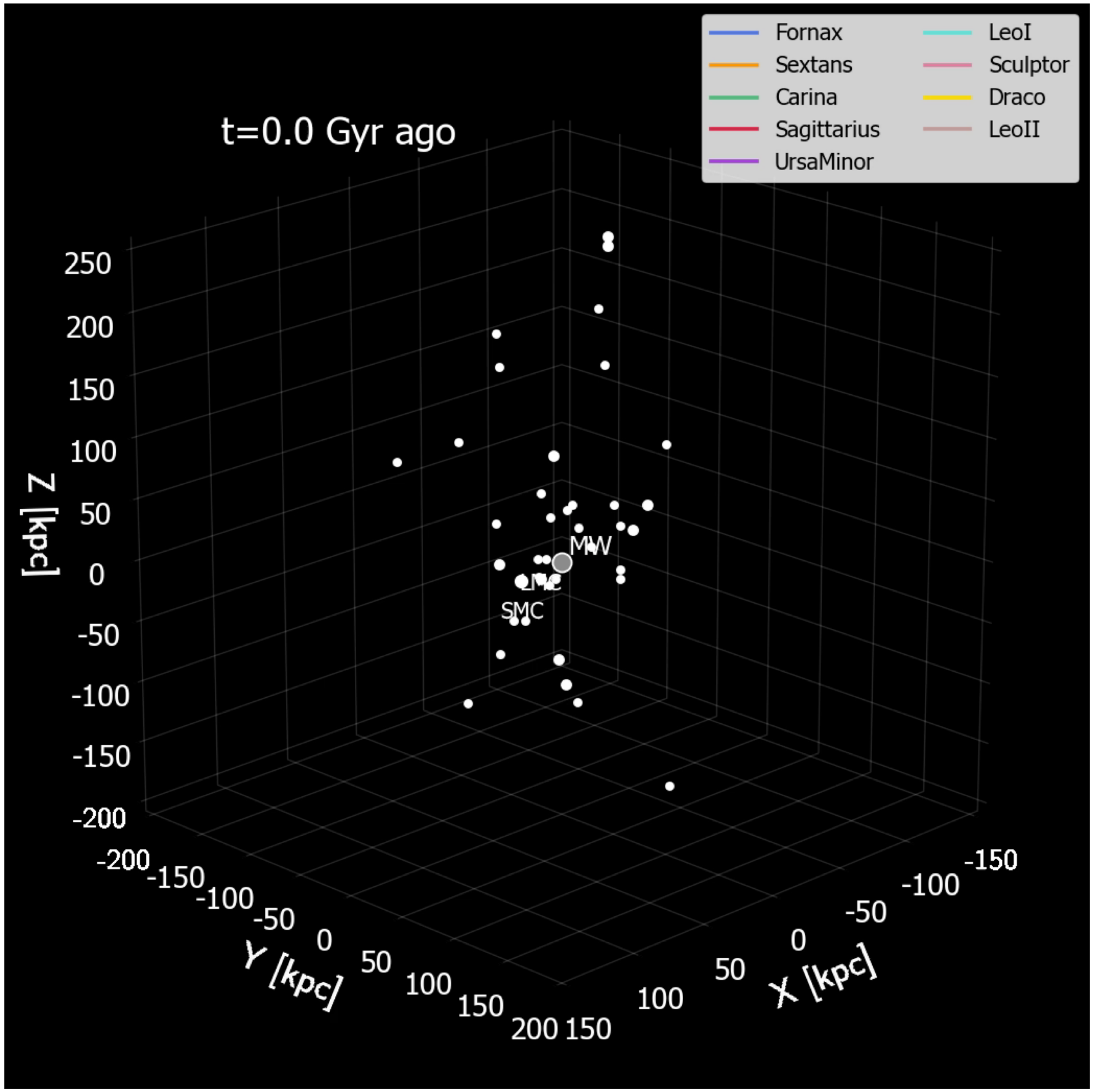


Gaia Collaboration, Helmi+2018 ; Watkins+2018 Simon 2018
Fritz+2018; Kallivayalil+2018; Massari & Helmi 2018



Ekta Patel, GB +2017b,2018a

Constraining the DM mass of the MW (statistical comparisons to CDM; satellite energetics; HVSs; GCs)



Ekta Patel, GB +2017b,2018a

Constraining the DM mass of the MW (statistical comparisons to CDM; satellite energetics; HVSs; GCs)

The Need for HST:

Both Gaia & HST in concert are needed to develop a model for the dynamics of our Local Group.

	ΔPM (km/s)	
Galaxy	HST	Gaia (2017)/2018
Horologium I	23	45
Pictoris II	24	119
Phoenix II	25	125
Hydra II	27	138
Grus I	26	138
Eridanus III	23	151
Tucana II	24	59

< 30 kpc: Gaia

30-80 kpc: Gaia & HST

> 80 kpc: HST

HSTPROMO

HST Cycle 23 Large
PI Kallivayalil

GO Abstract Recipe

Set the stage & be concise !!!!

- Start with one or two facts
- Explain why these facts are important
- Introduce the problem
- State your goal
- Explain why HST obs. will solve it (strategy/instrument)
- State why the solution is important
- Explain the broader implications/data products generated by your results

Kallivayalil Cycle 24 Treasury
164 Orbits

High-precision astrometry throughout the Milky Way halo is a unique capability of HST, with potential for transformative science, including constraining the nature of dark matter, probing the epoch of reionization, and understanding key physics of galaxy formation. While Gaia will provide unparalleled astrometric precision for bright stars in the inner halo of the Milky Way, HST is the only current mission capable of measuring (1) accurate orbital proper motions for systems at greater distances (> 80 kpc), in order to measure the total mass profile of the Milky Way, or (2) internal kinematics of stars in dwarf galaxies, to test the cusp versus core nature of their inner density profiles. We propose to initiate the next-generation, high-precision, proper-motion survey of all known dwarf galaxies within the Milky Way halo, thus laying the foundation to dynamically map the nearby Universe in full 6-D orbital phase space. Specifically, we propose to use ACS/WFC3 to establish a first-epoch baseline for proper-motion measurements for the 32 known dwarf galaxies within 420 kpc that currently lack sufficient first-epoch imaging. These observations will provide the critical anchor point for forefront scientific results within the next 4 years of HST's life, which can be extended with future missions, including JWST, over 10+ years to obtain unprecedented astrometric accuracy, ensuring that HST leaves a unique and lasting legacy for decades to come.

Facts | Importance | Why HST/Need | Goal | HST Strategy | Broader. Impacts

Urgency, JWST Precursor, HST only one to do this, Big picture topics,

SCOPE is large – building a large data base – not really trying to solve a “problem”

Science Justification: Section 1
The Big Picture

- Use descriptive headings (not “intro”/ “backgrd”)
- 1-3 paragraphs:
  - Explain/Justify “the Facts” stated in abstract
  - Role of HST in establishing facts.
  - Explain the importance of “the Facts”
  - Introduce the “Problem” (to be expanded on)
- Last paragraph (1-2): (to be expanded upon in the remainder of the proposal)
  - State the GOAL & the observation
  - State that they will fix “the problem” by doing *blah*
  - Big picture statement to end it off

Kallivayalil GO Treasury, first para.

Introduction: The field of astrometry is poised to produce fundamental advances in our understanding of the local Universe in the coming decade. The remarkable stability and resolution of ACS and WFC3 position HST to play a leading role, enabling precise measurements of proper motions (PMs) that complete the full 6-dimensional orbital phase space of nearby galaxies. HST astrometry measured by our collaboration already has led to breakthroughs such as (1) determining the orbit of the Large and Small Magellanic Clouds (LMC and SMC) (Kallivayalil et al., 2013), (2) detecting internal rotation in the LMC (van der Marel & Kallivayalil, 2014), (3) measuring the tangential motion of the distant satellite Leo I, as well as M31 (Sohn et al., 2012, 2013), and (4) constraining the presence of intermediate-mass black holes in globular clusters (Anderson & van der Marel, 2010). Simultaneously, the satellite dwarf galaxies around the MW have emerged as key testbeds for ΛCDM, the epoch of reionization, and the physics of galaxy formation. However, progress in all of these areas is significantly limited by the lack of comprehensive, unbiased, and robust PM measurements. Of the 51 known dwarf galaxies within ≈ 400 kpc, only 10 (20%) have well-measured PMs, and these form a biased sample, being relatively nearby and/or massive ("classical") dwarfs (Figure 2). Furthermore, 32 (two-thirds) do not have good ACS/WFC3 imaging for even the first epoch of a PM measurement, even though HST can readily measure them.

Facts/Info – indisputable.

Team Expertise & Role of HST in establishing facts

Significance of facts – bigger picture

Problem – to be expanded on

Kallivayalil GO Treasury Last Par.

Through this Treasury program, we propose a comprehensive survey to provide robust imaging for optimal first-epoch proper-motion measurements for all known dwarf galaxies out to 420 kpc, encompassing the MW's full halo profile out to its virial radius. Specifically, we will target the 32 known dwarf galaxies that currently do not have adequate ACS/WFC3 imaging. Here, we propose for exclusively first-epoch imaging, to provide a solid foundation to be followed up with second-epoch baselines by HST and JWST over the next 4 - 11+ years, to enable unprecedented proper-motion measurements.

Because we do not know how long HST will last beyond 2020, it is "now or never" to start such a PM survey that can be realized by HST. Even more excitingly, JWST will have similar resolution and capabilities for PM measurements as HST, so it can be used to leverage HST first-epoch data over an 11+ year baseline. Given the relatively short proposed lifetime of JWST, it is critical that HST establishes first-epoch baselines now, to leverage JWST's full lifetime for optimal PM measurements. As we argue below, this will allow HST to do transformative science on many fronts, uniquely addressing critical issues related to galaxy formation, cosmic reionization, and the nature of dark matter.

GOAL/the proposal – TO BE EXPANDED UPON

The Plan to use HST to solve the problem – TO BE EXPANDED UPON

Urgency – Importance of doing this science now

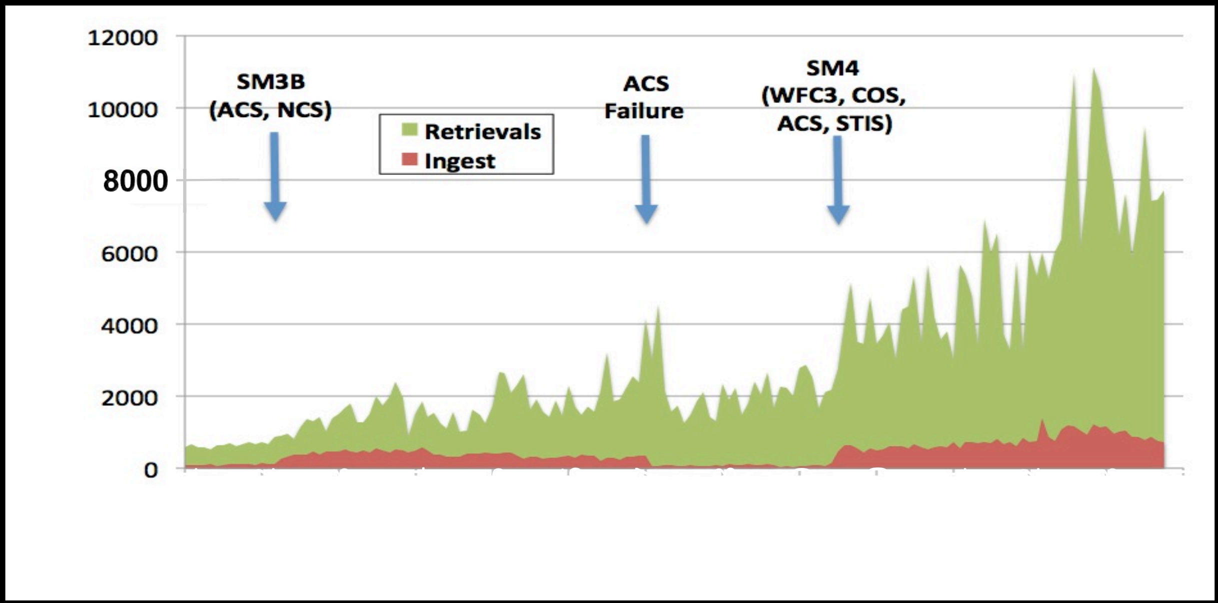
Broader Impact – significance of the proposal – TO BE EXPANDED UPON

Archival Program (AR) (~17% of total)

- Carry out investigations using a subset of the HST Archive and are awarded a dollar amount (US institutions only)
- Must improve upon previous usage of the data or address different science questions
- 167 submitted in Cycle 24; 42 accepted (25%)
- Median funding ~50K (< 120K)

The Archive

- HST archive size is >100 TB
- HST archive retrievals doubled after Servicing Mission 4 in May 2009
- >12,000 registered archive users (85 countries, 50 states)
- HST archive now online cache for rapid retrieval & improved/scripted queries



Legacy AR Programs

The main difference between a Large, Regular and a Legacy AR Proposal is that the former aims at performing a specific scientific investigation, while the latter will also create data products and/or tools for the benefit of the community.

- Legacy AR Proposals are larger in scope and requested funds than most Regular AR Proposals (>$120,000 & can be multi-year projects)
- 3 AR Legacy Proposals were approved in Cycle 24, 2 in 25, 5 in 26

  - The project should perform a homogeneous analysis of a well-defined subset of data in the HST Archive.
  - The main goal should be to provide a homogeneous set of calibrated data and/or ancillary data products to the scientific community.
  - The results of the project should enable a variety of new and important types of scientific investigations.
  - We also encourage the development of software tools for dissemination to the community.

Theory Program (AR)
(~6% = 63 proposals)

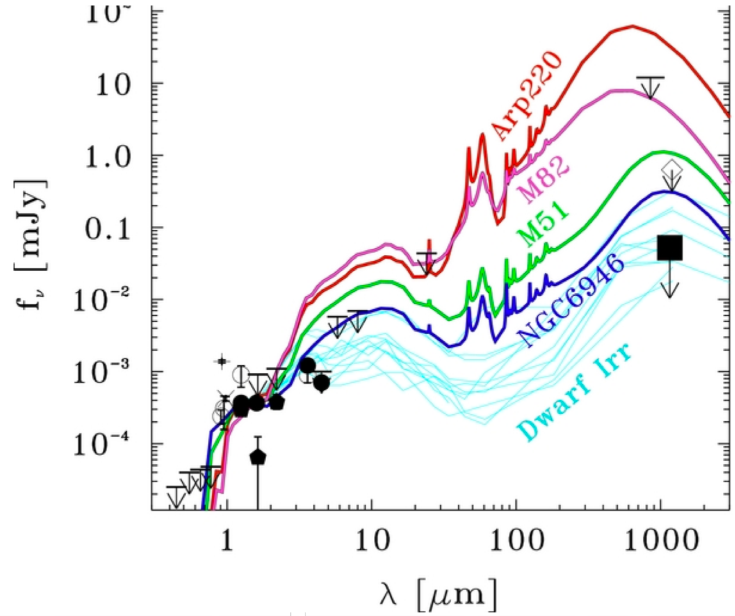
- Financial support for theoretical research
- Science must be of direct relevance to HST observational programs
- Some analysis of archival data is allowed, but primary program should be theory
- The primary criterion for a Theory Proposal is that the results should enhance the value of HST observational programs through their broad interpretation (in the context of new models or theories) or by refining the knowledge needed to interpret specific observational results.

Examples: Legacy Program

- Cloudy as a Shock Modeling Code: Utility for HST, & Looking out to JWST: Chatzikos)

(code development – usually asking for 3 yr salary, hence legacy.)

Spectral Energy Distribution - SED



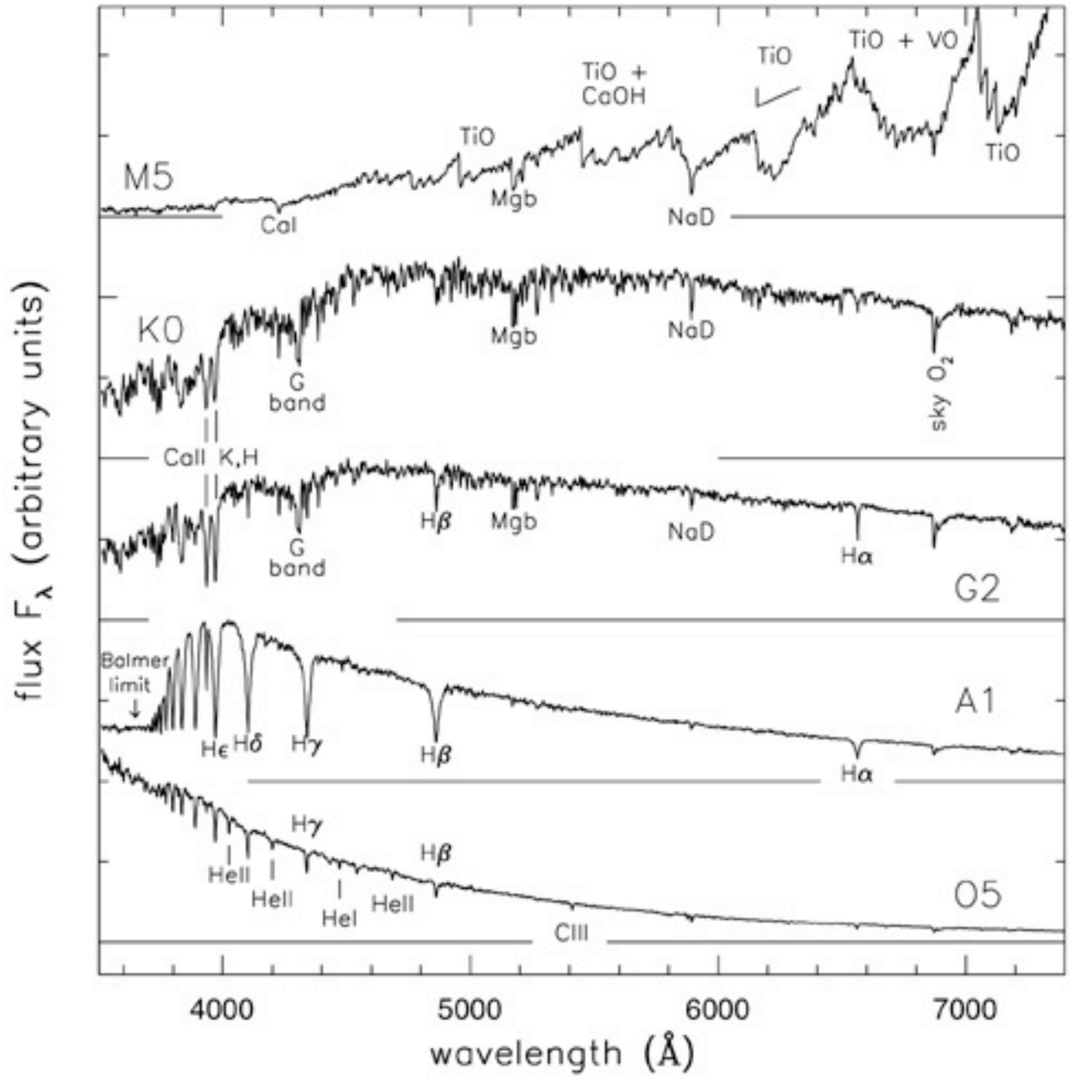


Fig 1.1 'Galaxies in the Universe' Sparke/Gallagher CUP 2007

Spectra of galaxies from ultraviolet to near-infrared wavelengths; incompletely removed emission lines from the night sky are marked. From bottom to top:

1) a red S0 galaxy;

2) a bluer Sb galaxy;

3)an Sc spectrum showing blue and near UV light from hot young stars and gas emission lines;

4) a blue starburst galaxy, that has made many of its stars in the past 100 Myr.

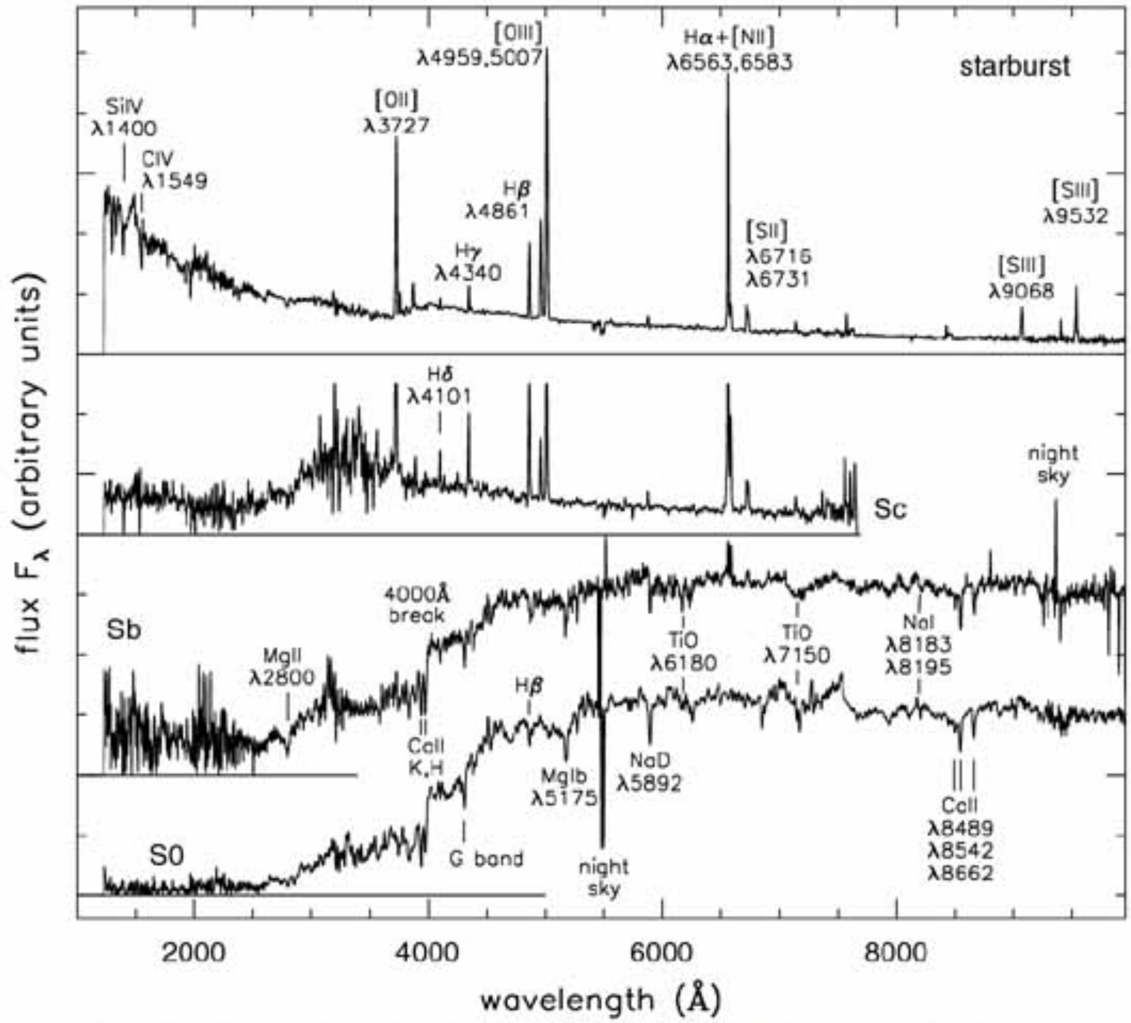


Fig 5.24 (A. Kinney) 'Galaxies in the Universe' Sparke/Gallagher CUP 2007

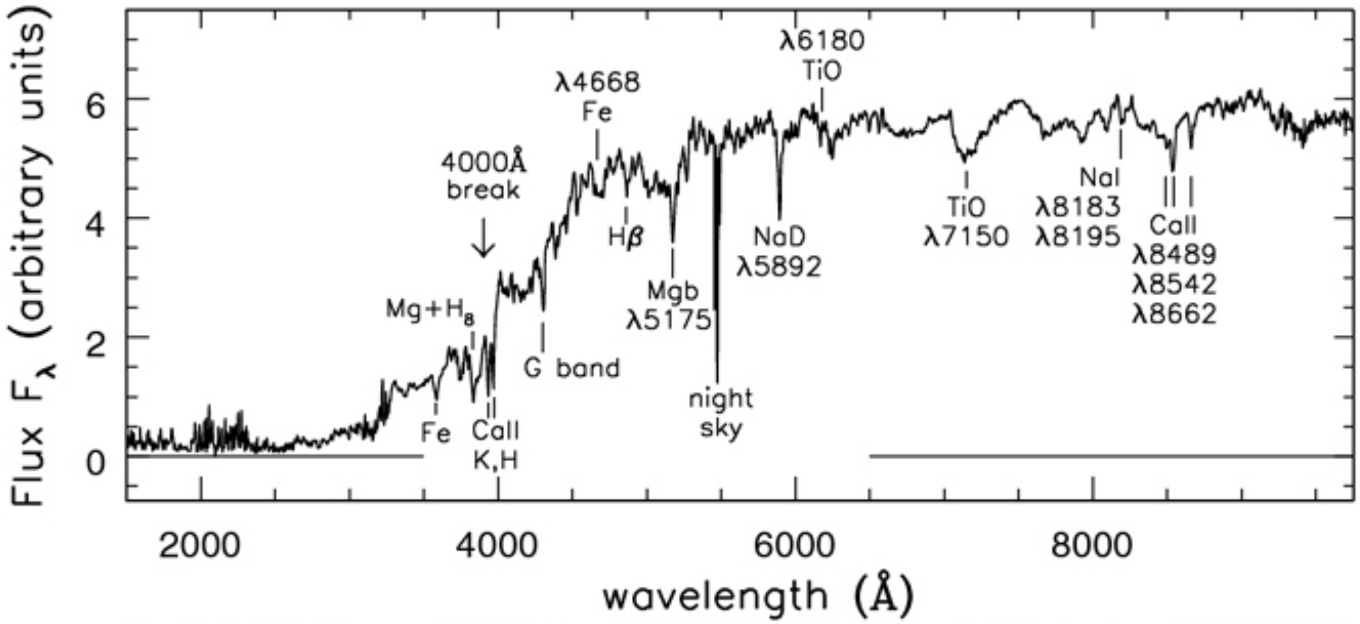
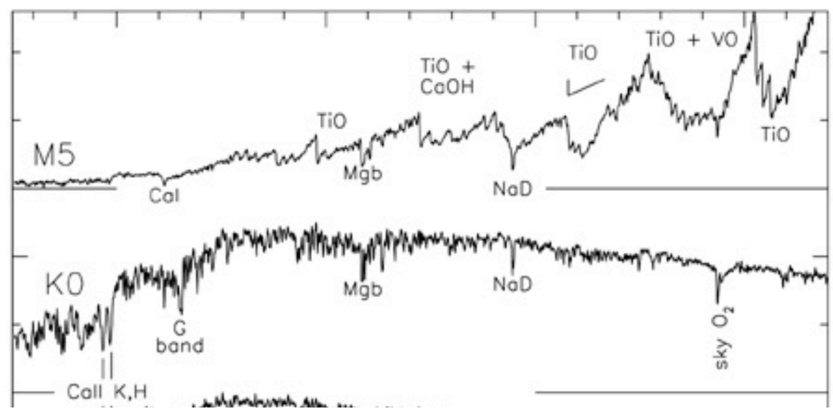
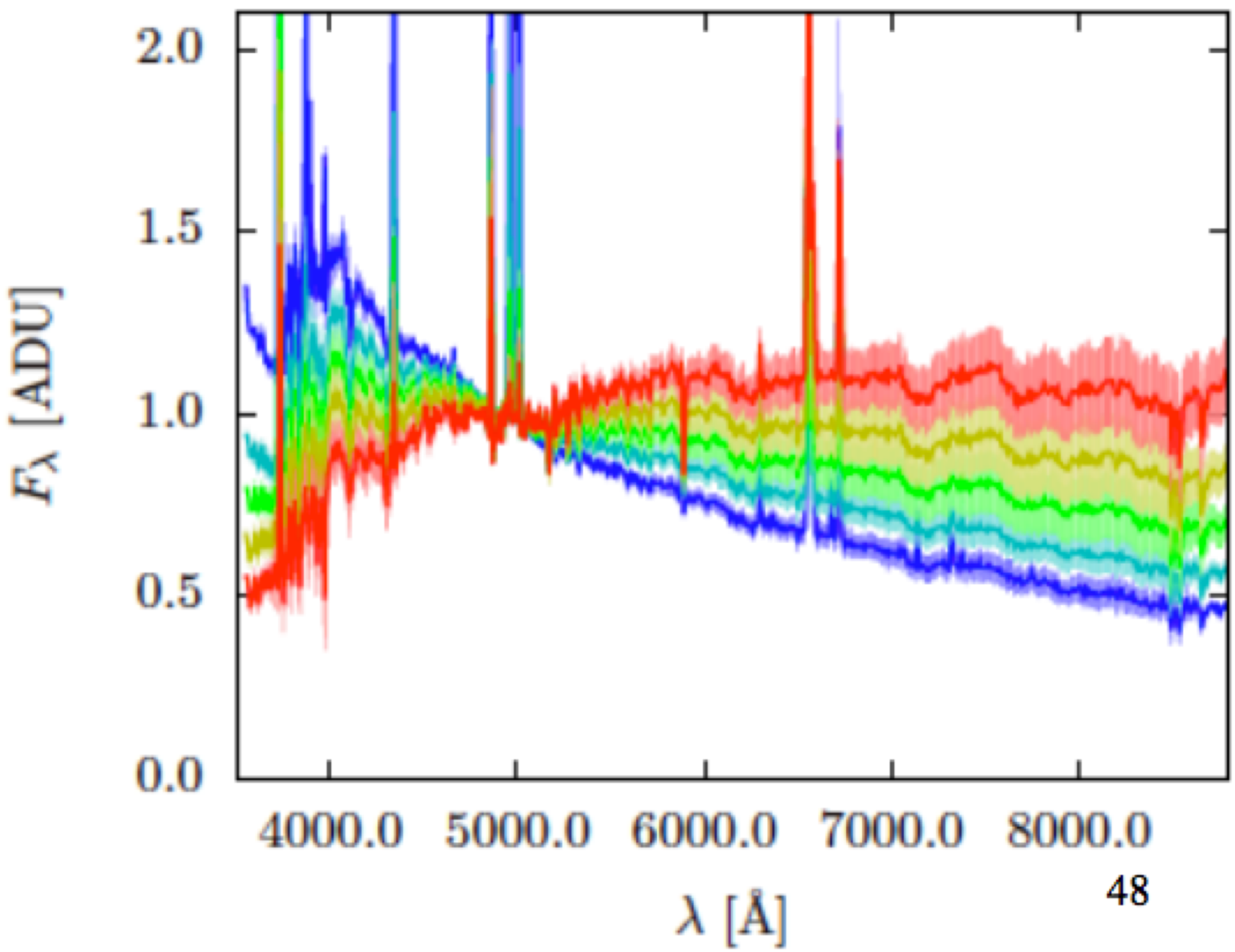


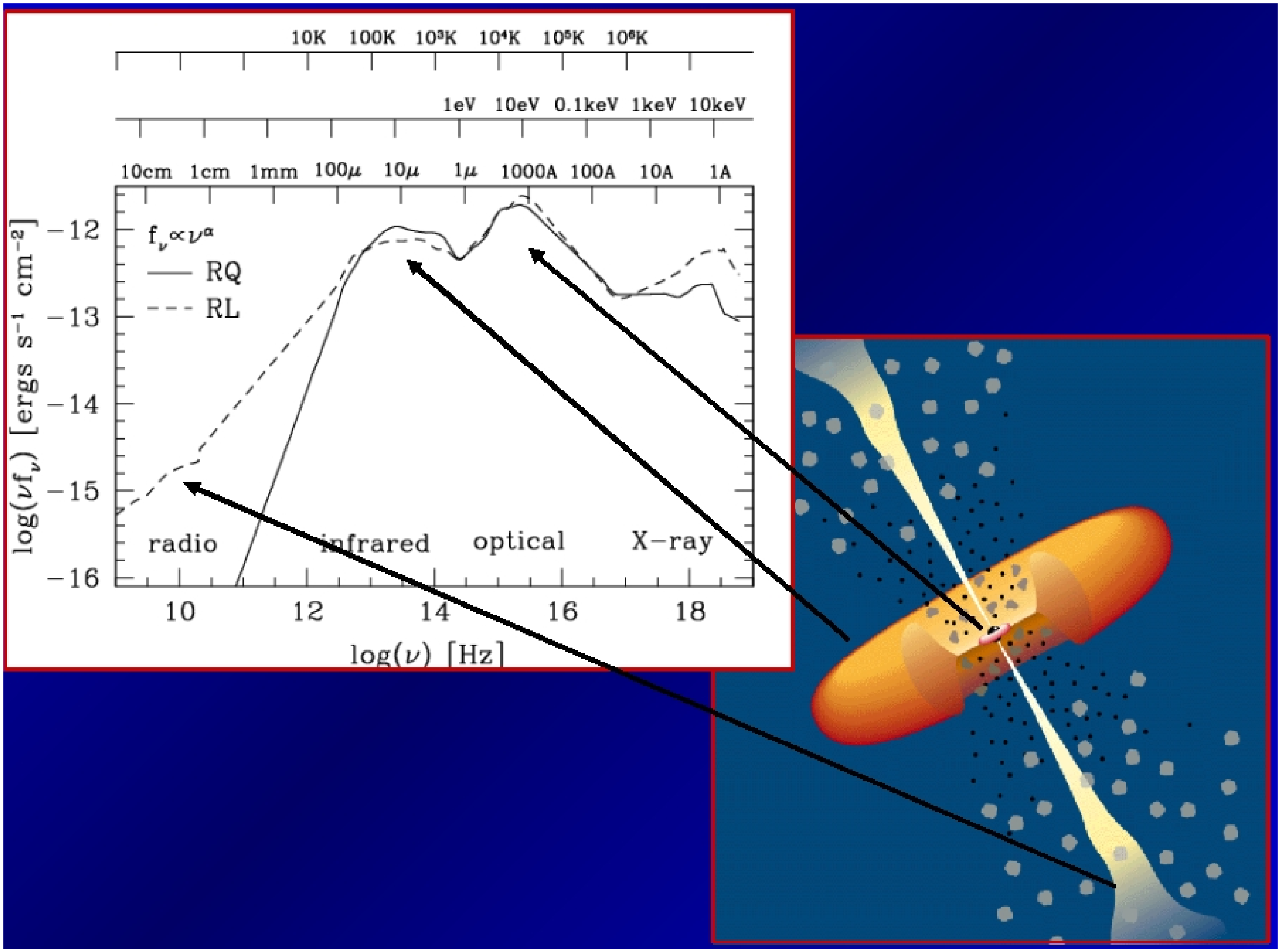
Fig 6.17 (A. Kinney) 'Galaxies in the Universe' Sparke/Gallagher CUP 2007

The spectrum of an elliptical galaxy. Dominated by K and M stars (see right)



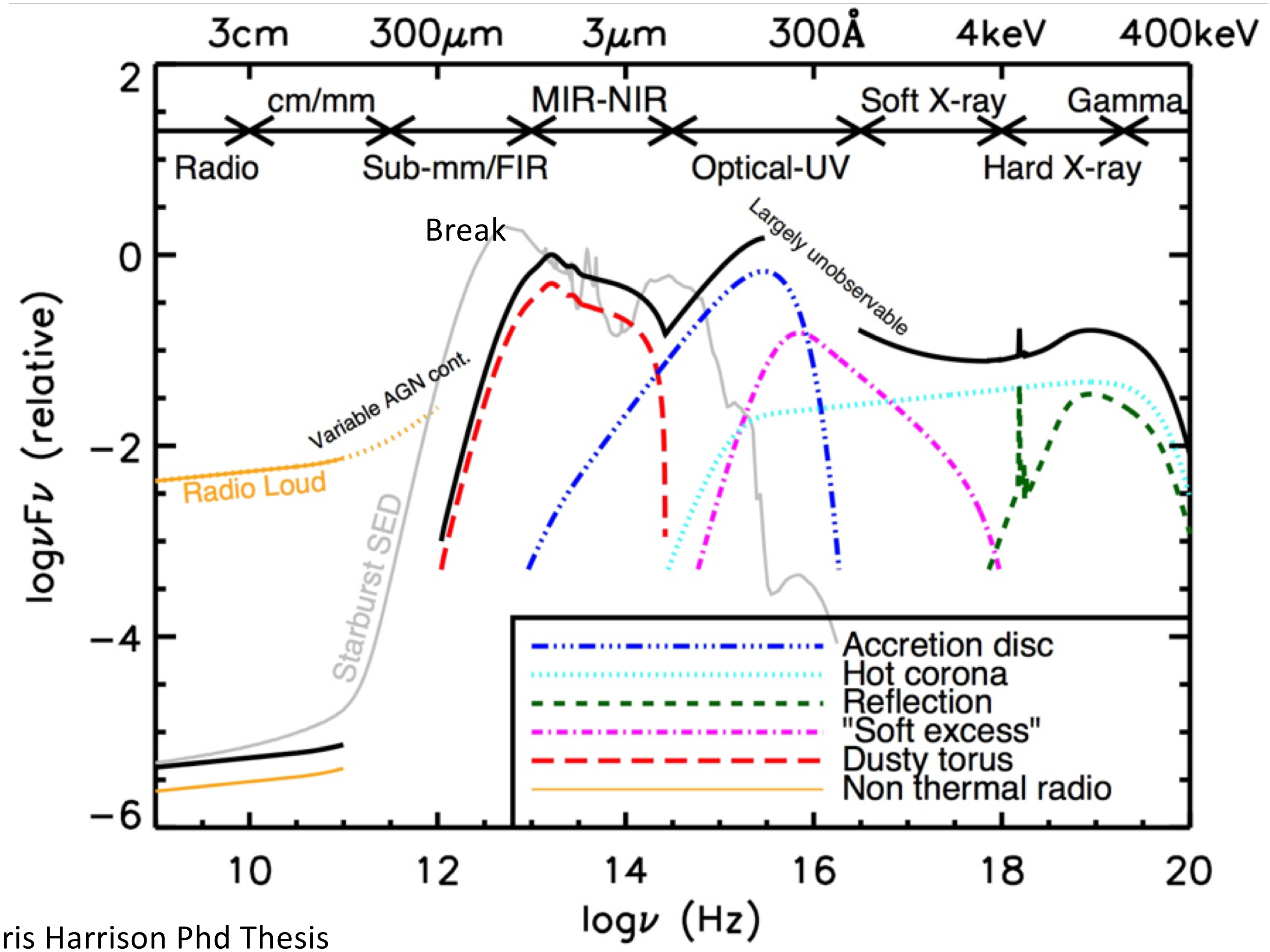


2.0
1.5
1.0
0.5
0.0
F_λ [ADU]
4000.0
5000.0
6000.0
7000.0
8000.0
48
λ [Å]



10K
100K
10³K
10⁴K
10⁵K
10⁶K
1eV
10eV
0.1keV
1keV
10keV
10cm
1cm
1mm
100μ
10μ
1μ
1000A
100A
10A
1A
$f_\nu \propto \nu^\alpha$
RQ
RL
radio
infrared
optical
X-ray
$\log(\nu f_\nu)$ [ergs s⁻¹ cm⁻²]
$\log(\nu)$ [Hz]

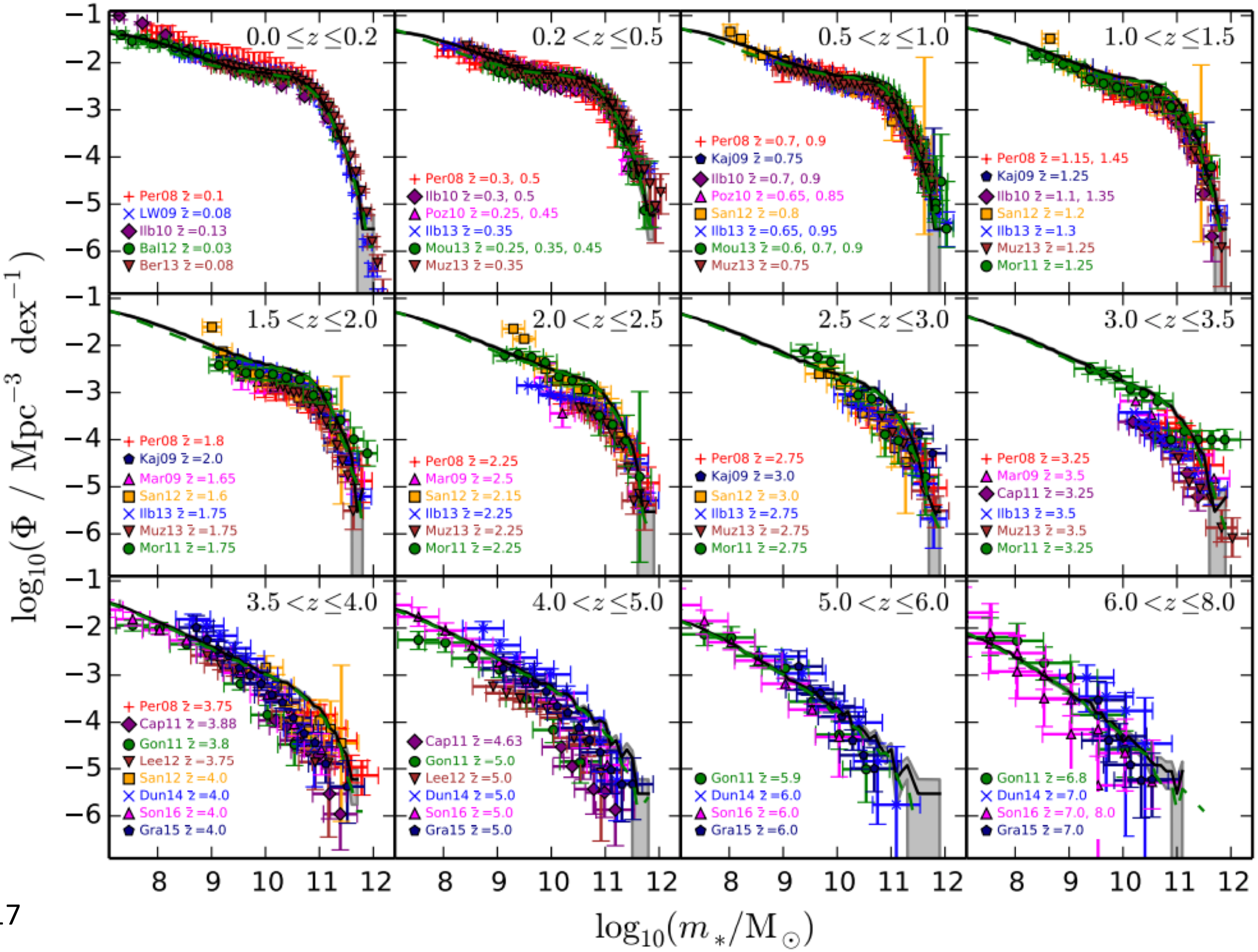
SED



Chris Harrison Phd Thesis

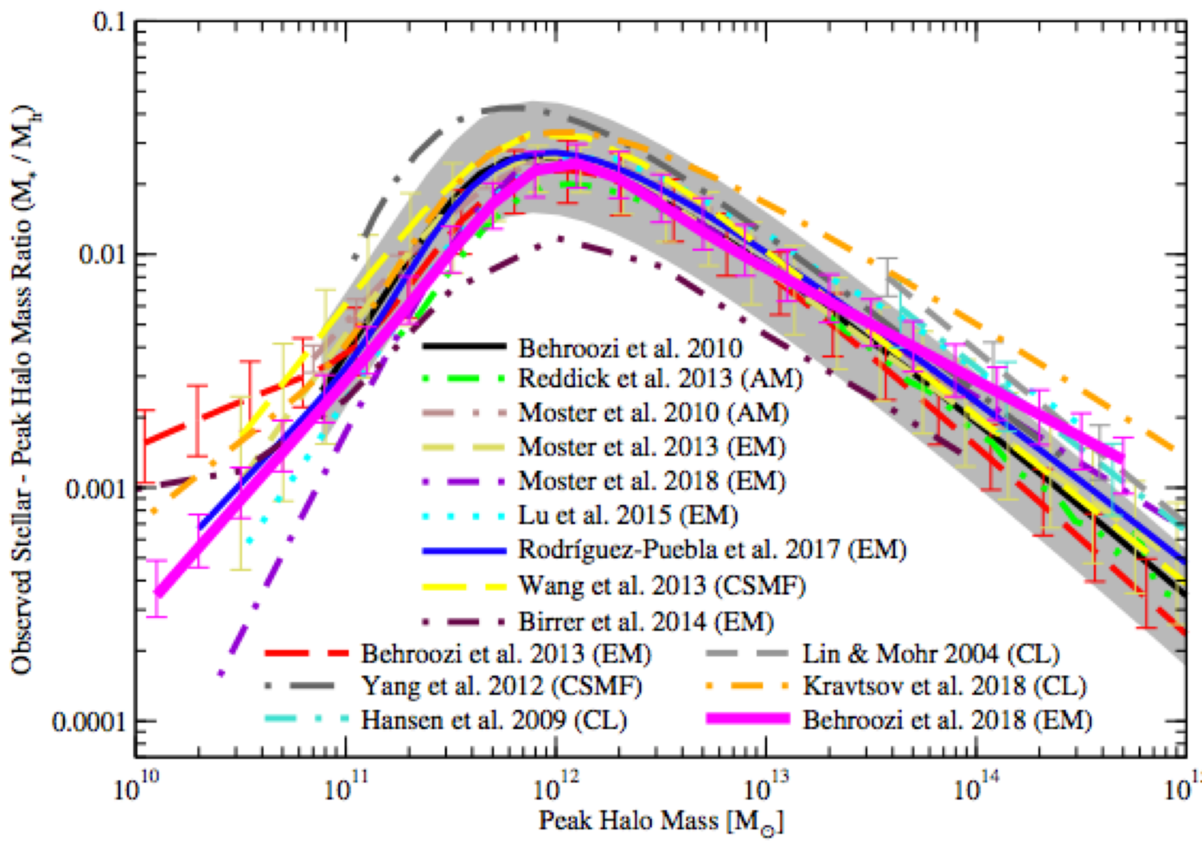
Lost of codes!

- http://www.sedfitting.org/Fitting.html
- http://www.iap.fr/magphys/



$\log_{10}(\Phi\ /\ \mathrm{Mpc}^{-3}\ \mathrm{dex}^{-1})$
$\log_{10}(m_*/\mathrm{M}_\odot)$
$0.0 \leq z \leq 0.2$
Per08 z̄ =0.1
LW09 z̄ =0.08
Ilb10 z̄ =0.13
Bal12 z̄ =0.03
Ber13 z̄ =0.08
$0.2 < z \leq 0.5$
Per08 z̄ =0.3, 0.5
Ilb10 z̄ =0.3, 0.5
Poz10 z̄ =0.25, 0.45
Ilb13 z̄ =0.35
Mou13 z̄ =0.25, 0.35, 0.45
Muz13 z̄ =0.35
$0.5 < z \leq 1.0$
Per08 z̄ =0.7, 0.9
Kaj09 z̄ =0.75
Ilb10 z̄ =0.7, 0.9
Poz10 z̄ =0.65, 0.85
San12 z̄ =0.8
Ilb13 z̄ =0.65, 0.95
Mou13 z̄ =0.6, 0.7, 0.9
Muz13 z̄ =0.75
$1.0 < z \leq 1.5$
Per08 z̄ =1.15, 1.45
Kaj09 z̄ =1.25
Ilb10 z̄ =1.1, 1.35
San12 z̄ =1.2
Ilb13 z̄ =1.3
Muz13 z̄ =1.25
Mor11 z̄ =1.25
$1.5 < z \leq 2.0$
Per08 z̄ =1.8
Kaj09 z̄ =2.0
Mar09 z̄ =1.65
San12 z̄ =1.6
Ilb13 z̄ =1.75
Muz13 z̄ =1.75
Mor11 z̄ =1.75
$2.0 < z \leq 2.5$
Per08 z̄ =2.25
Mar09 z̄ =2.5
San12 z̄ =2.15
Ilb13 z̄ =2.25
Muz13 z̄ =2.25
Mor11 z̄ =2.25
$2.5 < z \leq 3.0$
Per08 z̄ =2.75
Kaj09 z̄ =3.0
San12 z̄ =3.0
Ilb13 z̄ =2.75
Muz13 z̄ =2.75
Mor11 z̄ =2.75
$3.0 < z \leq 3.5$
Per08 z̄ =3.25
Mar09 z̄ =3.5
Cap11 z̄ =3.25
Ilb13 z̄ =3.5
Muz13 z̄ =3.5
Mor11 z̄ =3.25
$3.5 < z \leq 4.0$
Per08 z̄ =3.75
Cap11 z̄ =3.88
Gon11 z̄ =3.8
Lee12 z̄ =3.75
San12 z̄ =4.0
Dun14 z̄ =4.0
Son16 z̄ =4.0
Gra15 z̄ =4.0
$4.0 < z \leq 5.0$
Cap11 z̄ =4.63
Gon11 z̄ =5.0
Lee12 z̄ =5.0
Dun14 z̄ =5.0
Son16 z̄ =5.0
Gra15 z̄ =5.0
$5.0 < z \leq 6.0$
Gon11 z̄ =5.9
Dun14 z̄ =6.0
Son16 z̄ =6.0
Gra15 z̄ =6.0
$6.0 < z \leq 8.0$
Gon11 z̄ =6.8
Dun14 z̄ =7.0
Son16 z̄ =7.0, 8.0
Gra15 z̄ =7.0

Moster+2017



Behroozi+2018

- Unknowns – IMF, SFHs (continuous? bursty?), total stellar mass, total dust mass --- attenuation, metallicity, redshifts

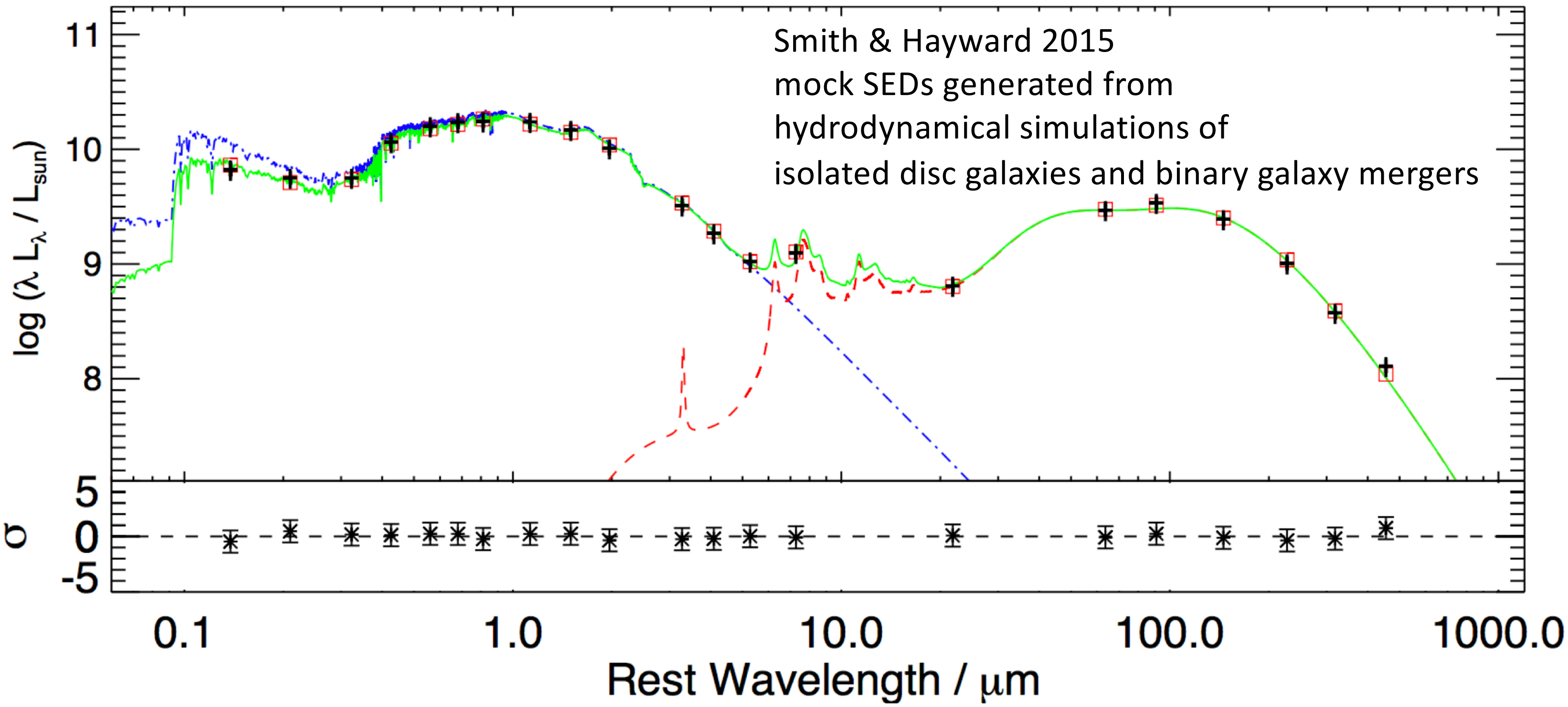


Figure 1. An example best-fit UV-mm SED (green solid line). Also overlaid are the best-fit unattenuated stellar SED (dot-dashed blue line) and the best-fit dust SED component (red dashed line). The model photometry associated with the best-fit SED is shown as the red squares, while the synthetic photometry derived from the simulations is shown as the black error bars (assuming a signal-to-noise ratio of 5 in every band). The lower panel shows the residuals of the synthetic photometry about the best-fit SED for each photometric band; we do not add noise to the photometry, and the uncertainties are included solely for the purposes of enabling us to use MAGPHYS.

Physically Consistent Galaxy Stellar Masses and Star Formation Rates From z=0 to z=10
HST Proposal 15631

Peter Behroozi
University of Arizona

Proposal Abstract

We propose a forward modeling approach that will self-consistently combine multi-epoch and multi-waveband data and reduce uncertainties in recovering galaxy stellar masses and star formation rates from current ~0.35 dex levels to the 0.15 dex level or less, benefiting both observers and theorists. Key outcomes include: a fully physical, self-consistent picture of galaxy stellar masses and star formation histories from z=0 to 10; significantly reduced uncertainties on the evolution of galaxies in dark matter halos; mock catalogs for arbitrary current and future surveys that simultaneously match currently observed galaxy number densities, colors, and clustering; and public code to enable easy incorporation of future datasets as they become available.;

Goal, problem, importance/benefits

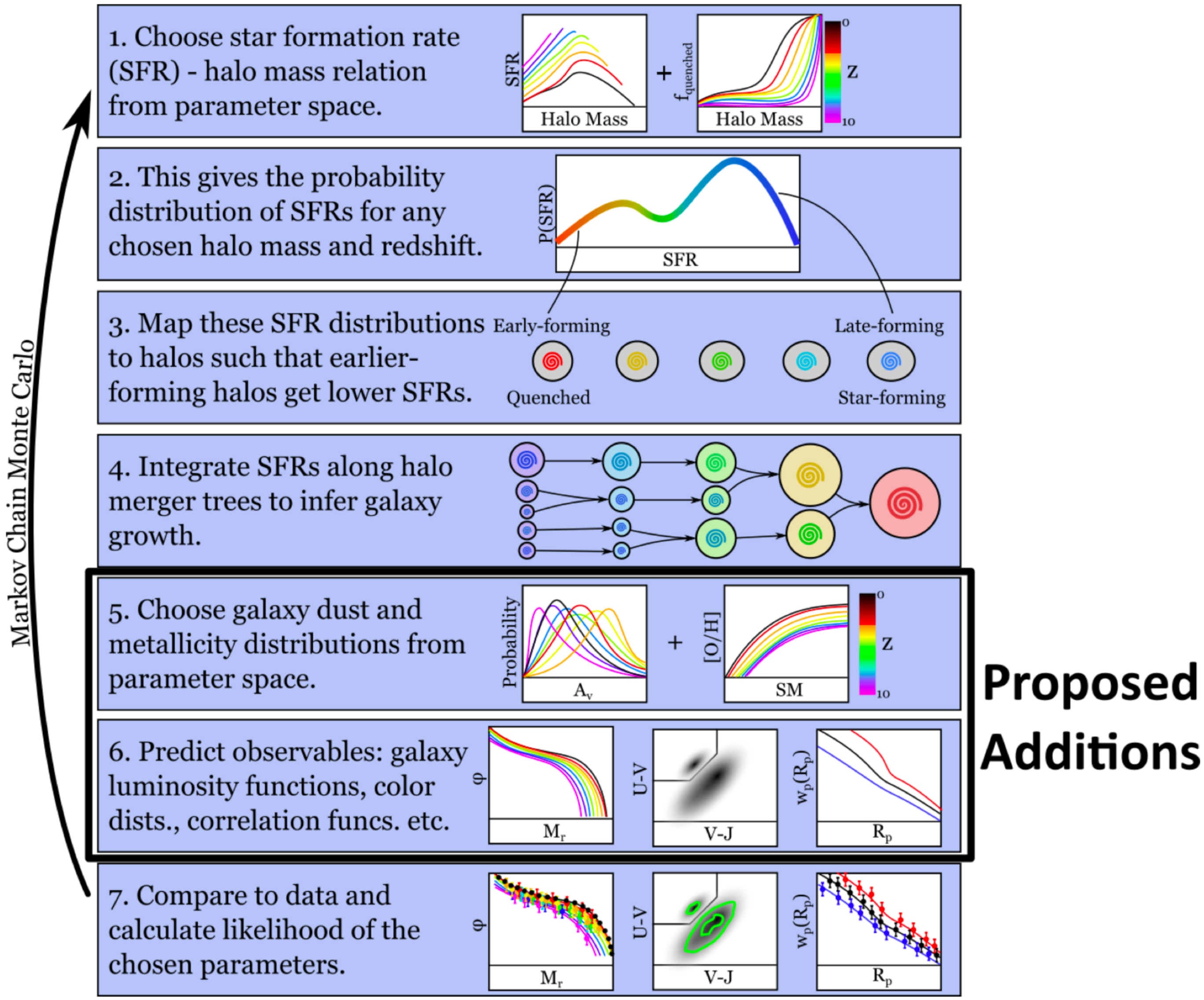
Strategy (products)/Broader Impacts

Scientific Justification

Large HST surveys including CANDELS, BORG, XDF, and HDUV have given an exquisite view of galaxy colors and luminosities from $z \sim 0$ to $z \sim 10$ (Grogin et al. 2011; Koekemoer et al. 2011; Bradley et al. 2012; Illingworth et al. 2013; Oesch et al. 2018). Yet, major systematic uncertainties ($\sim$0.35 dex) remain in how these colors and luminosities map to physical galaxy properties (including stellar masses and star formation rates) even down to $z = 0$ (see Conroy et al., 2013; Mobasher et al., 2015, for reviews). Accurate measurements of these physical properties are crucial for both interpreting observations and comparing with theory (e.g., Behroozi et al., 2018; Moster et al., 2018). **We propose an empirical forward modeling approach that will self-consistently combine multi-epoch and multi-waveband data and reduce these uncertainties to the 0.15 dex level or less, benefiting both observers and theorists.** Key outcomes include:

1. A fully physical, self-consistent picture of galaxy stellar masses and star formation histories from $z = 0$ to 10, enabling robust comparisons between observations and theory.
2. Public mock catalogs for arbitrary current and future surveys that simultaneously match currently observed galaxy number densities, colors, and clustering.
3. Significantly reduced systematic uncertainties in the galaxy–dark matter halo relation.
4. Public code to enable easy incorporation of future datasets as they become available.

Facts/ HST Connection | Problem | Importance | Goal | Products and Impacts



Markov Chain Monte Carlo
1. Choose star formation rate (SFR) - halo mass relation from parameter space.
SFR
Halo Mass
+
f_quenched
Halo Mass
0
Z
10
2. This gives the probability distribution of SFRs for any chosen halo mass and redshift.
P(SFR)
SFR
3. Map these SFR distributions to halos such that earlier-forming halos get lower SFRs.
Early-forming
Late-forming
Quenched
Star-forming
4. Integrate SFRs along halo merger trees to infer galaxy growth.
5. Choose galaxy dust and metallicity distributions from parameter space.
Probability
A_v
+
[O/H]
SM
0
Z
10
6. Predict observables: galaxy luminosity functions, color dists., correlation funcs. etc.
φ
M_r
U-V
V-J
w_p(R_p)
R_p
7. Compare to data and calculate likelihood of the chosen parameters.
φ
M_r
U-V
V-J
w_p(R_p)
R_p
Proposed Additions