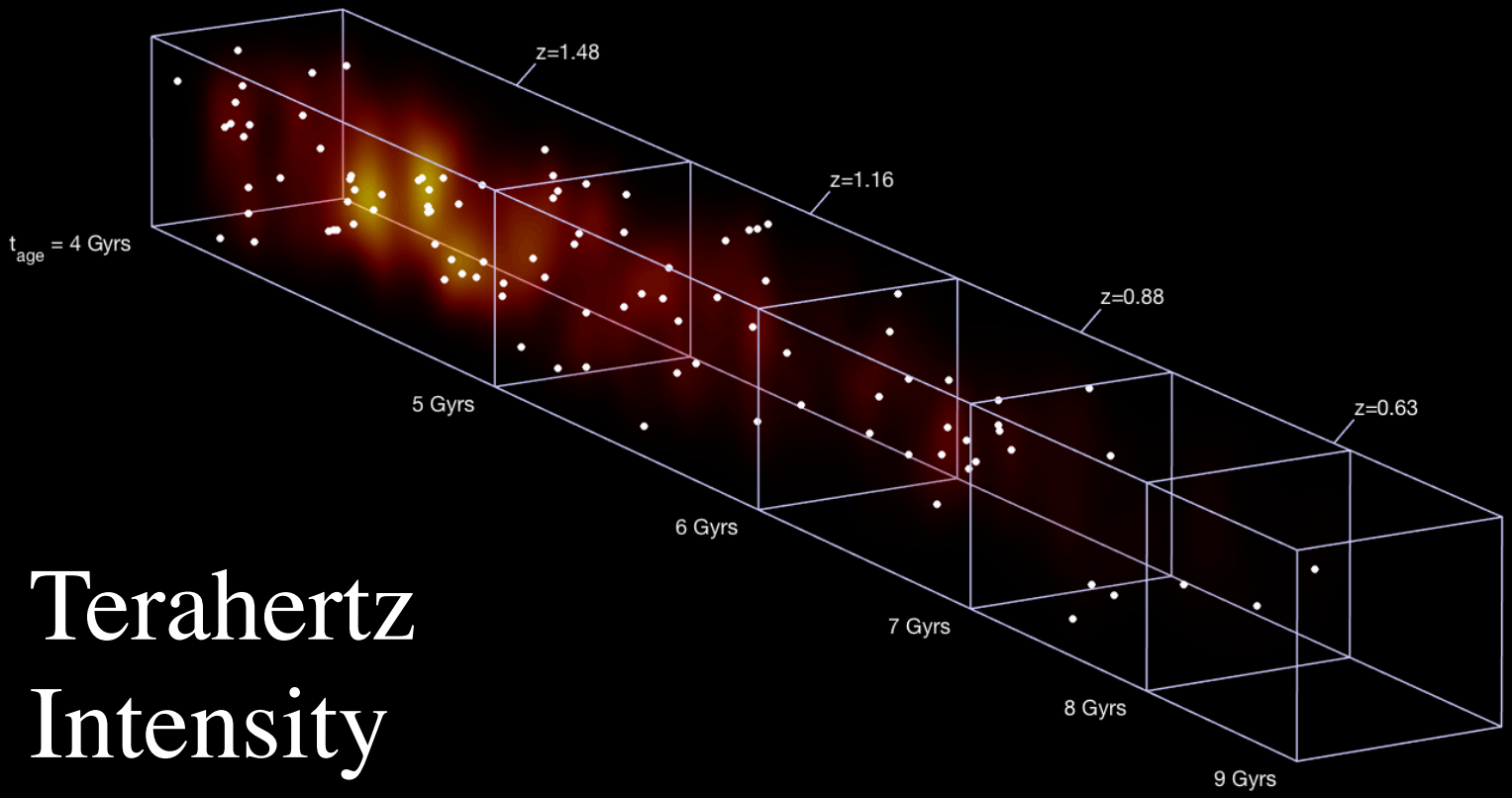


Terahertz Intensity Mapper (TIM)

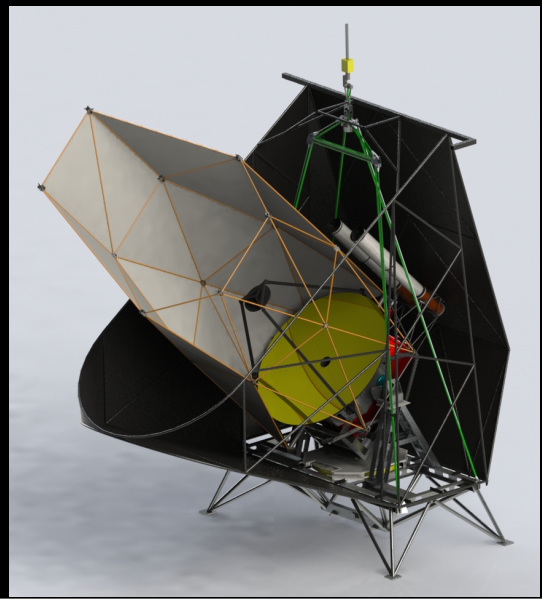
James Aguirre

University of Pennsylvania

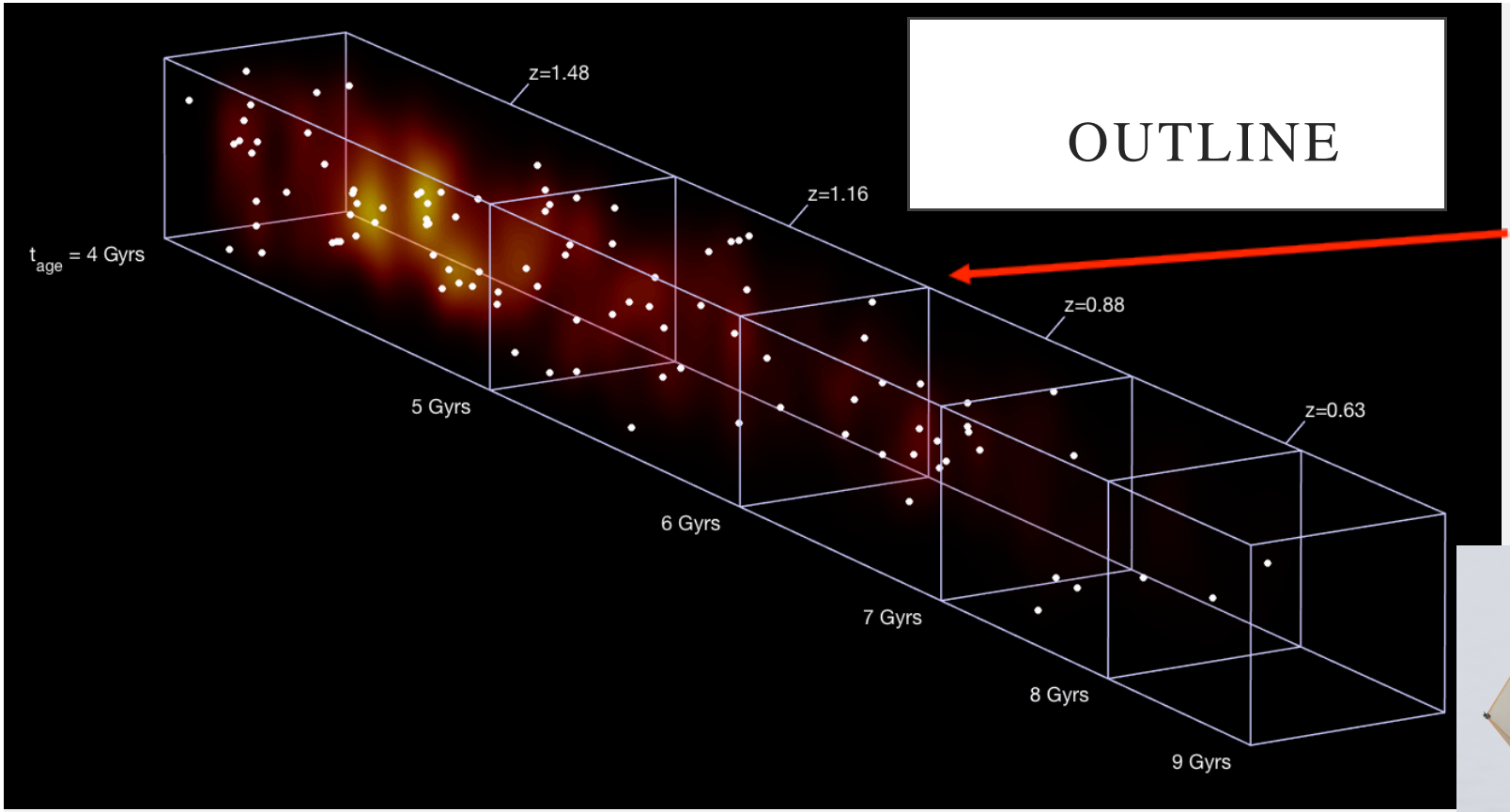
and the TIM Collaboration

CCA

18 February 2019

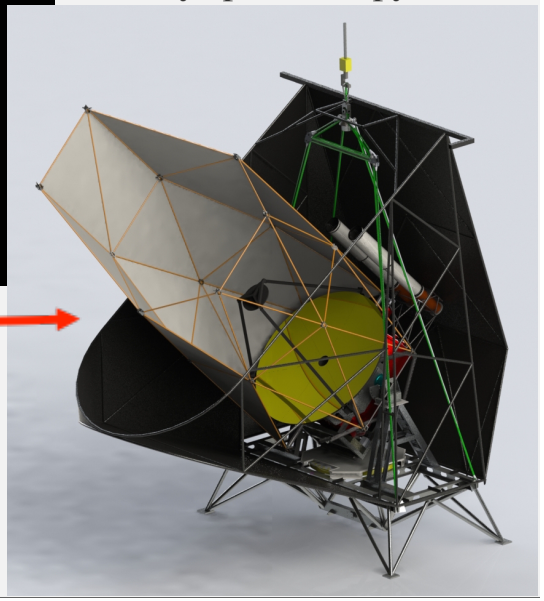


OUTLINE



The Science

- The evolution of galaxies
- Why look the far-infrared?
- Why spectroscopy?



The Technology

- Why the far-infrared again?
- Balloons
- Detectors

COLLABORATION

Current Funding (APRA16):

Detector Development

- James Aguirre (PI, Penn)
- Alyssa Barlis (Penn, NSTRF)
- Matt Bradford
- Steve Hailey-Dunsheath
- Joseph Redford
- H. G. LeDuc
- C. M. McKenney
- M. I. Hollister

Fully –funded APRA18:

Full instrument

Executive:

- Joaquin Vieira (PI, UIUC)
- James Aguirre
- Dan Marrone
- Christopher Groppi
- C. Matt Bradford
- Jeffrey Filippini

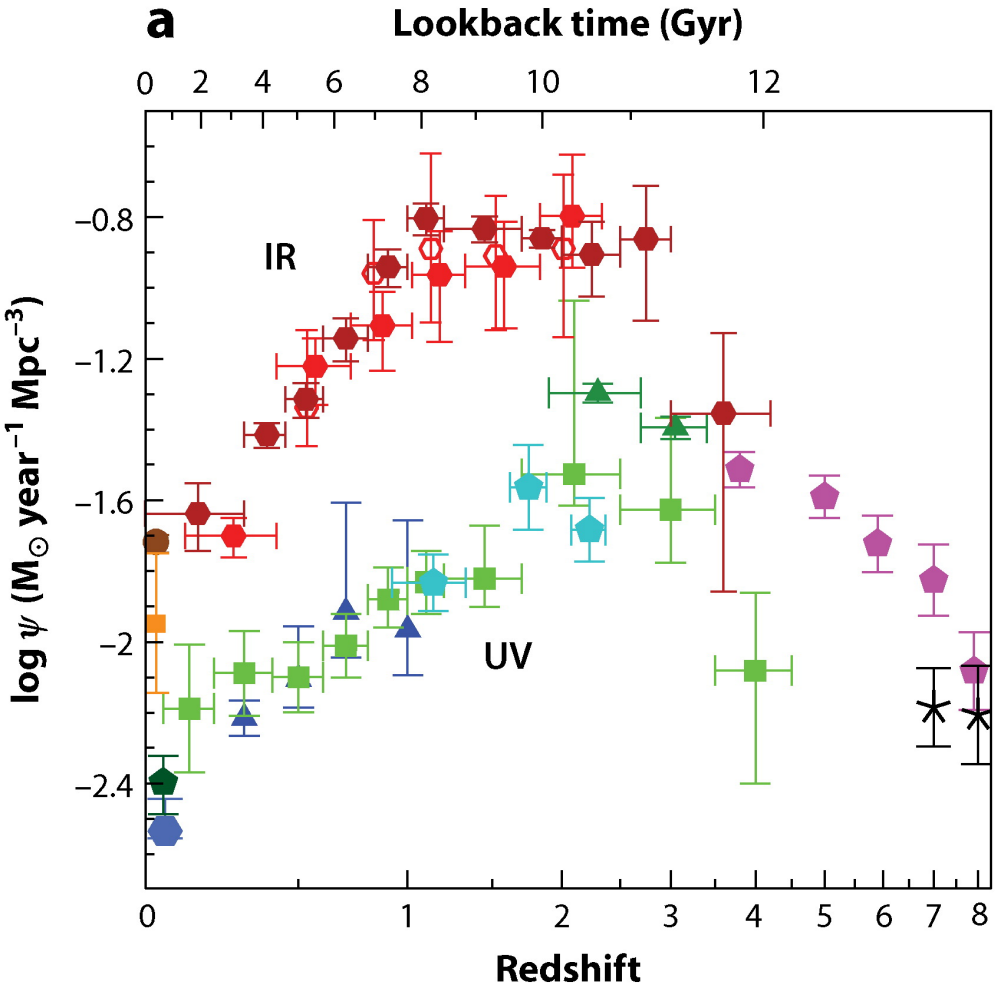
Collaborators:

- Mark Devlin
- Gilbert Holder
- Philip Mauskopf

THE SCIENCE

GALAXY EVOLUTION IS THE HISTORY OF STAR FORMATION

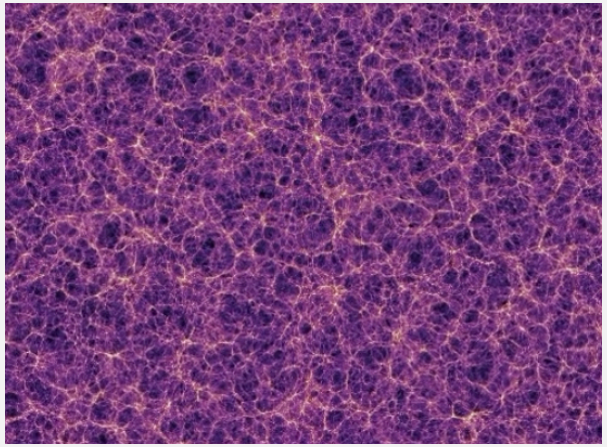
At its most basic, galaxy evolution means accounting for the build-up of stars in galaxies: the cosmic star formation history

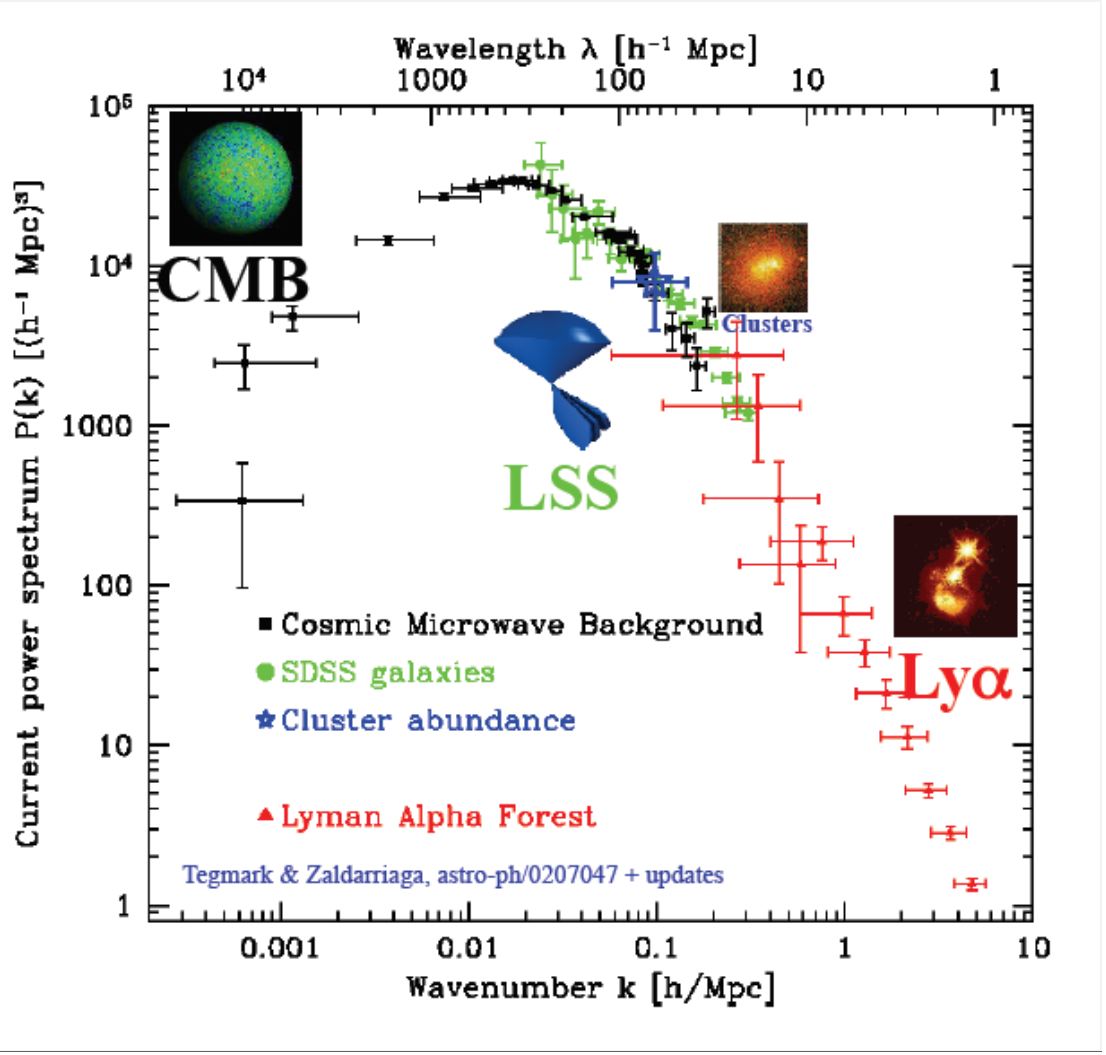


Madau P, Dickinson M. 2014.
Annu. Rev. Astron. Astrophys. 52:415–86

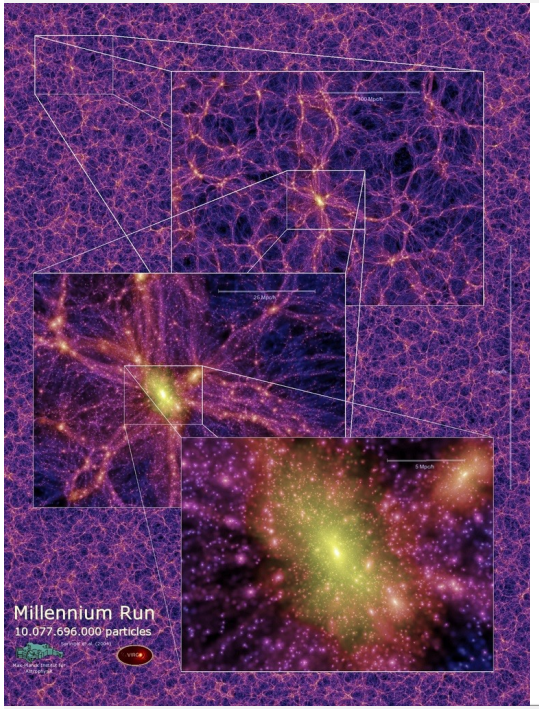
CONNEC

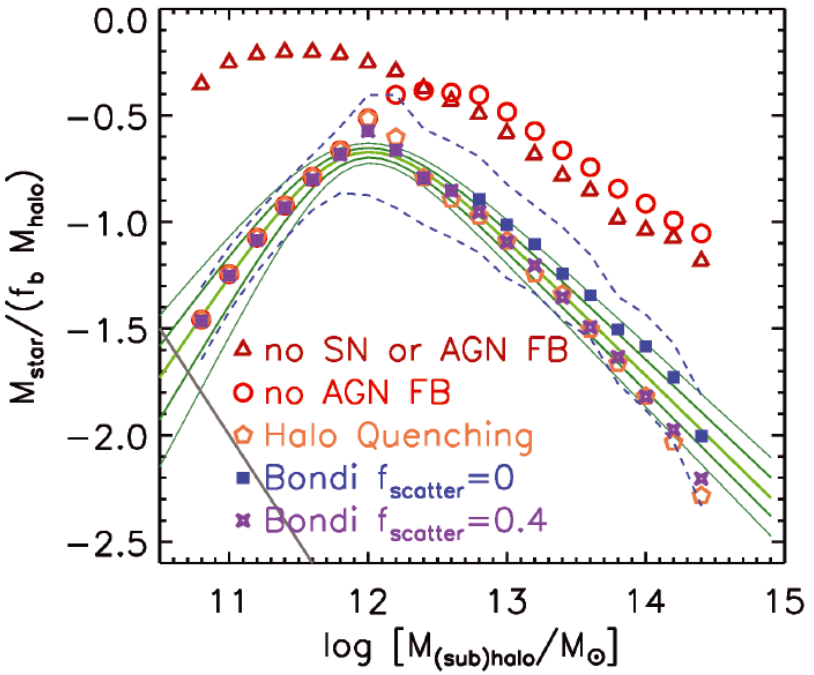
Galaxy clustering, as measured through the angular spectra or 3-D power spectra of their positions, are related to the underlying dark matter density, including linear and nonlinear regimes

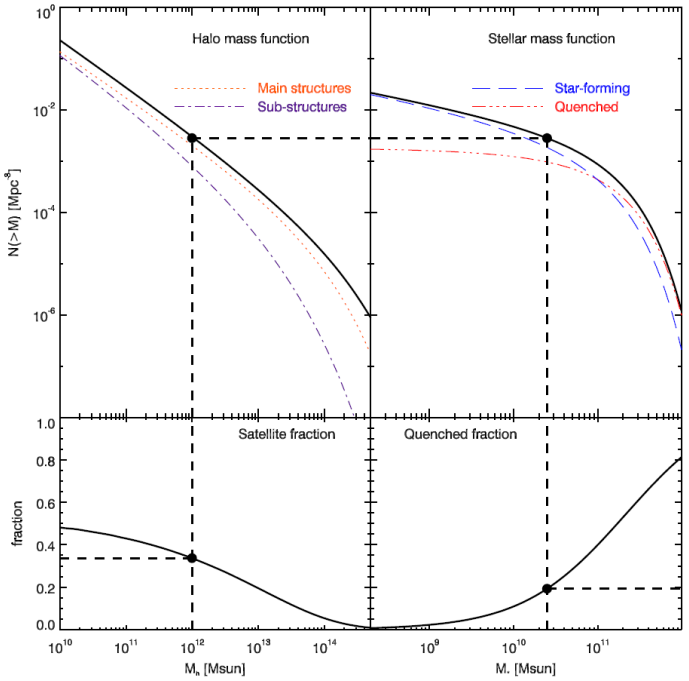




STAR FORMATION IN THE UNIVERSE IS INTIMATELY TIED TO THE COLLAPSE OF DARK MATTER HALOS, BUT THE RELATION IS COMPLICATED



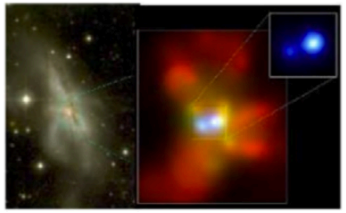




(c) Interaction/"Merger"

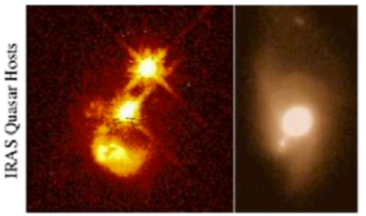
- now within one halo, galaxies interact & lose angular momentum
- SFR starts to increase
- stellar winds dominate feedback
- rarely excite QSOs (only special orbits)

(d) Coalescence/(U)LIRG



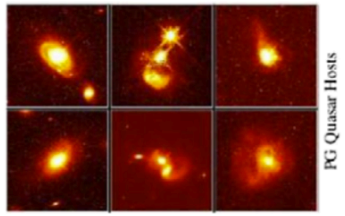
- galaxies coalesce: violent relaxation in core
- gas inflows to center: starburst & buried (X-ray) AGN
- starburst dominates luminosity/feedback, but, total stellar mass formed is small

(e) "Blowout"



- BH grows rapidly: briefly dominates luminosity/feedback
- remaining dust/gas expelled
- get reddened (but not Type II) QSO: recent/ongoing SF in host high Eddington ratios merger signatures still visible

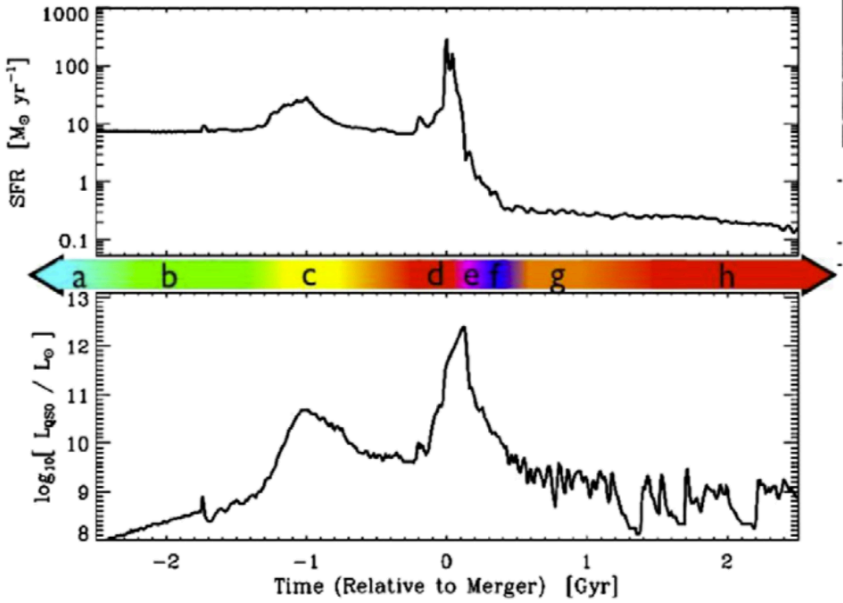
(f) Quasar



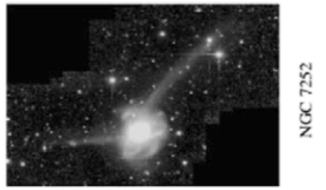
- dust removed: now a "traditional" QSO
- host morphology difficult to observe: tidal features fade rapidly
- characteristically blue/young spheroid

(b) "Small Group"

- halo accretes similar-mass companion(s)
- can occur over a wide mass range
- M_{halo} still similar to before: dynamical friction merges the subhalos efficiently



(g) Decay/K+A

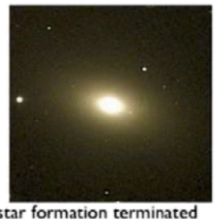


- QSO luminosity fades rapidly
  - tidal features visible only with very deep observations
- remnant reddens rapidly (E+A/K+A)
- "hot halo" from feedback
  - sets up quasi-static cooling

(a) Isolated Disk

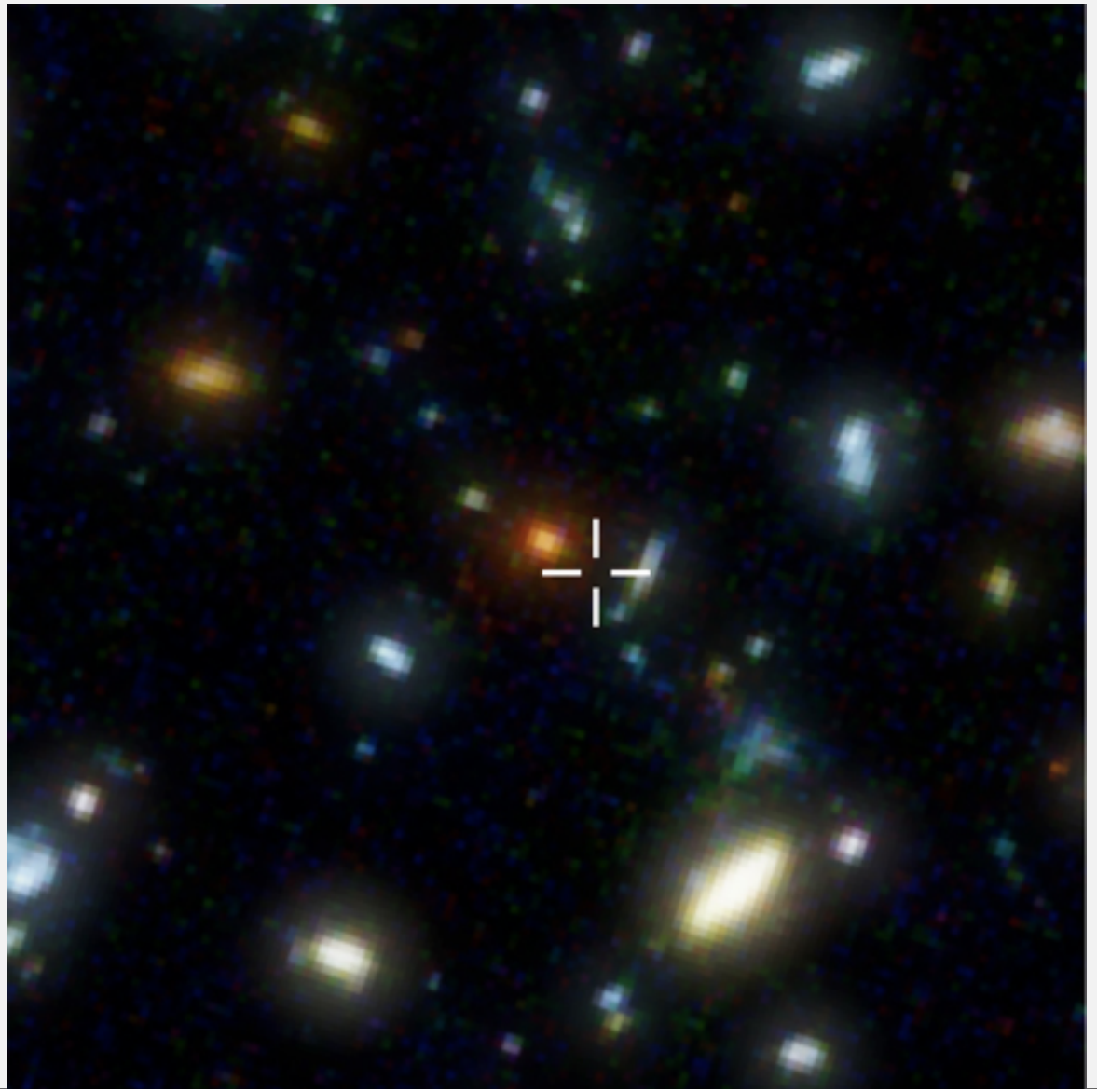
- halo & disk grow, most stars formed
- secular growth builds bars & pseudobulges
- "Seyfert" fueling (AGN with M_B>-23)
- cannot redden to the red sequence

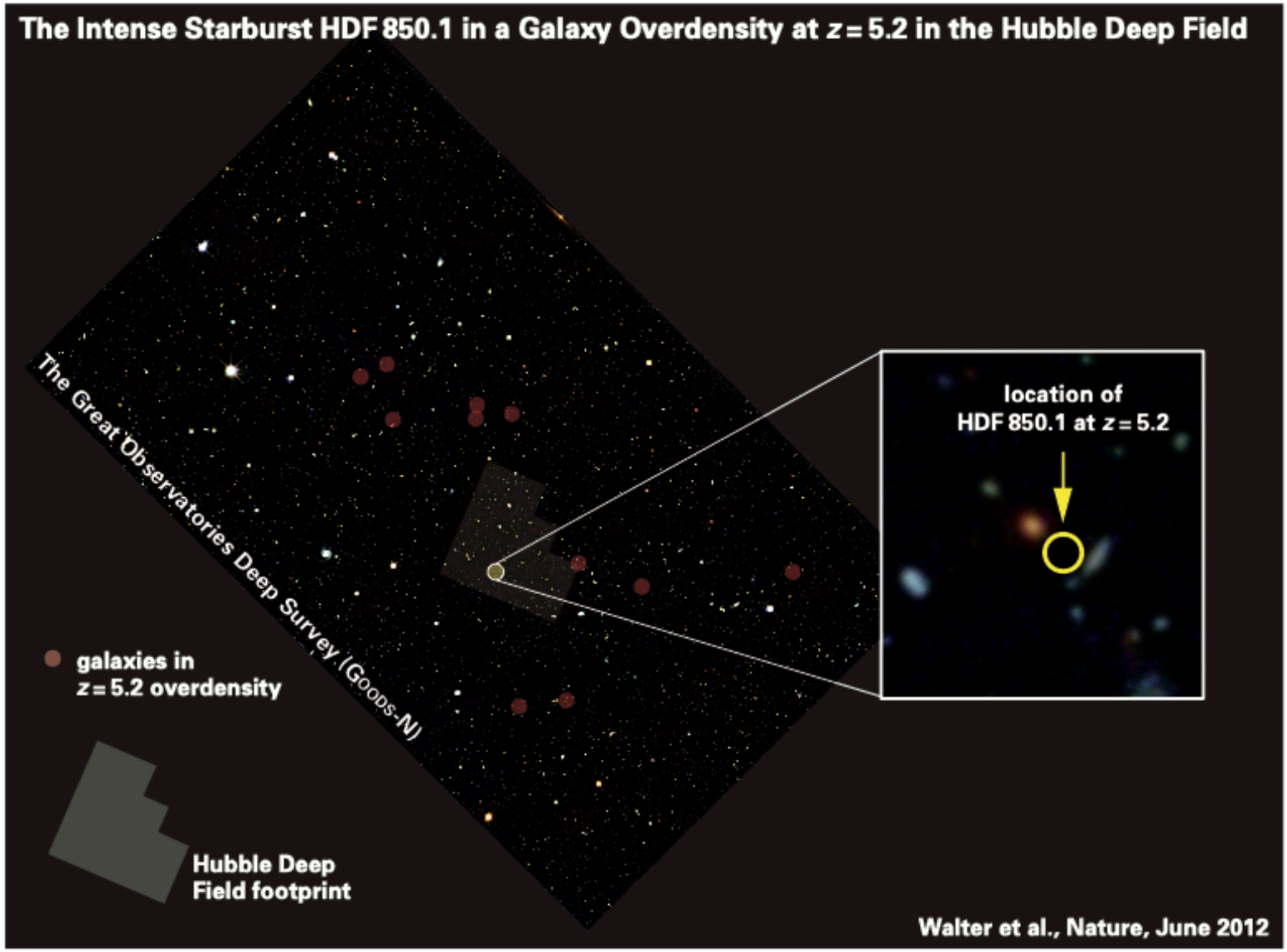
(h) " Dead" Elliptical

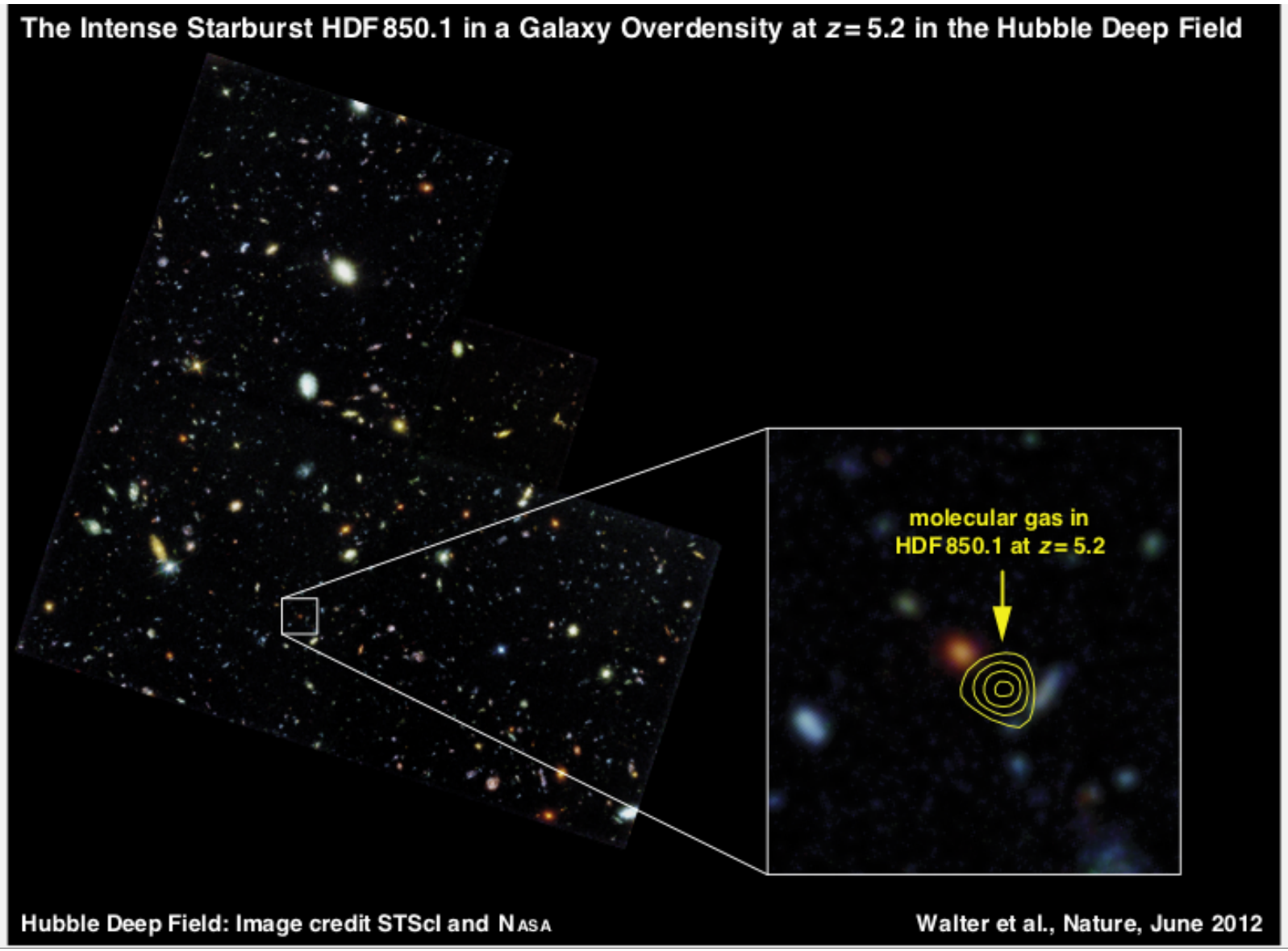


- star formation terminated
- large BH/spheroid - efficient feedback
- halo grows to "large group" scales: mergers become inefficient
- growth by "dry" mergers

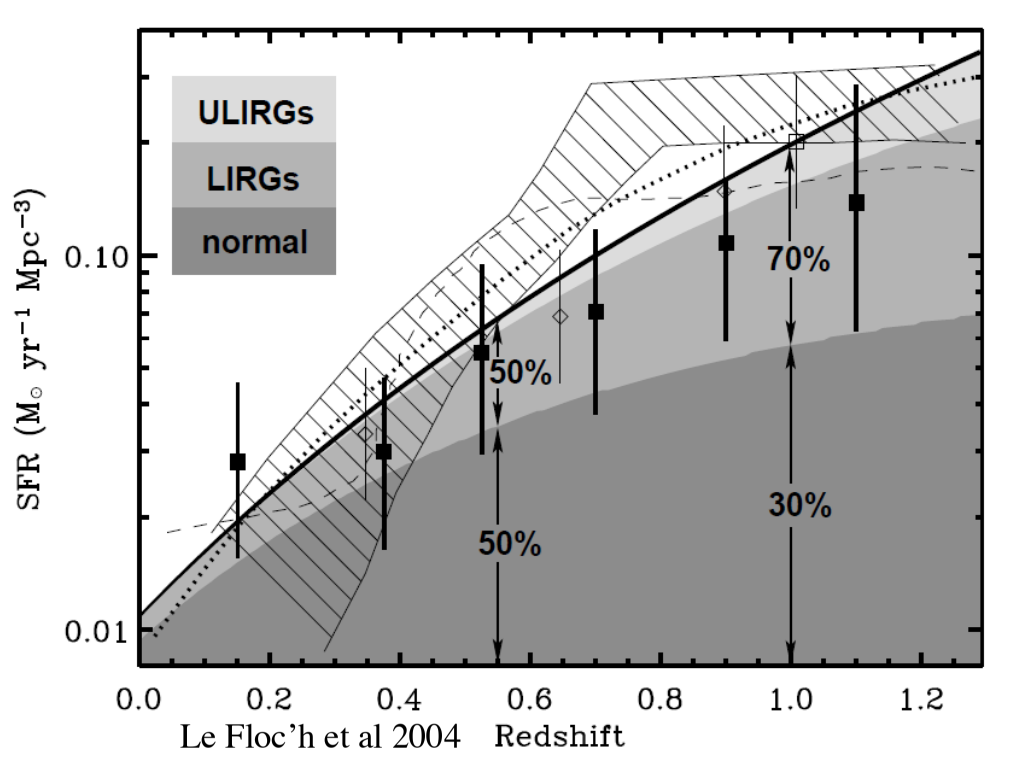
AN IMPORTANT CLASS OF GALAXIES ARE NEARLY INVISIBLE



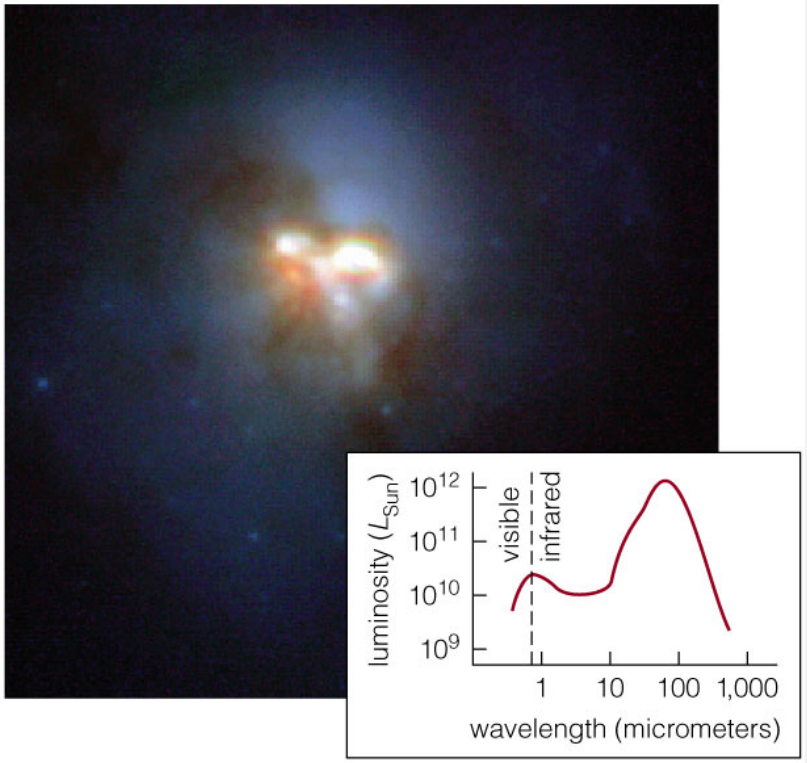

The Intense Starburst HDF 850.1 in a Galaxy Overdensity at z = 5.2 in the Hubble Deep Field
The Great Observatories Deep Survey (GOODS-N)
location of
HDF 850.1 at z = 5.2
galaxies in
z = 5.2 overdensity
Hubble Deep
Field footprint
Walter et al., Nature, June 2012


The Intense Starburst HDF 850.1 in a Galaxy Overdensity at z = 5.2 in the Hubble Deep Field
molecular gas in
HDF 850.1 at z = 5.2
Hubble Deep Field: Image credit STScI and NASA
Walter et al., Nature, June 2012

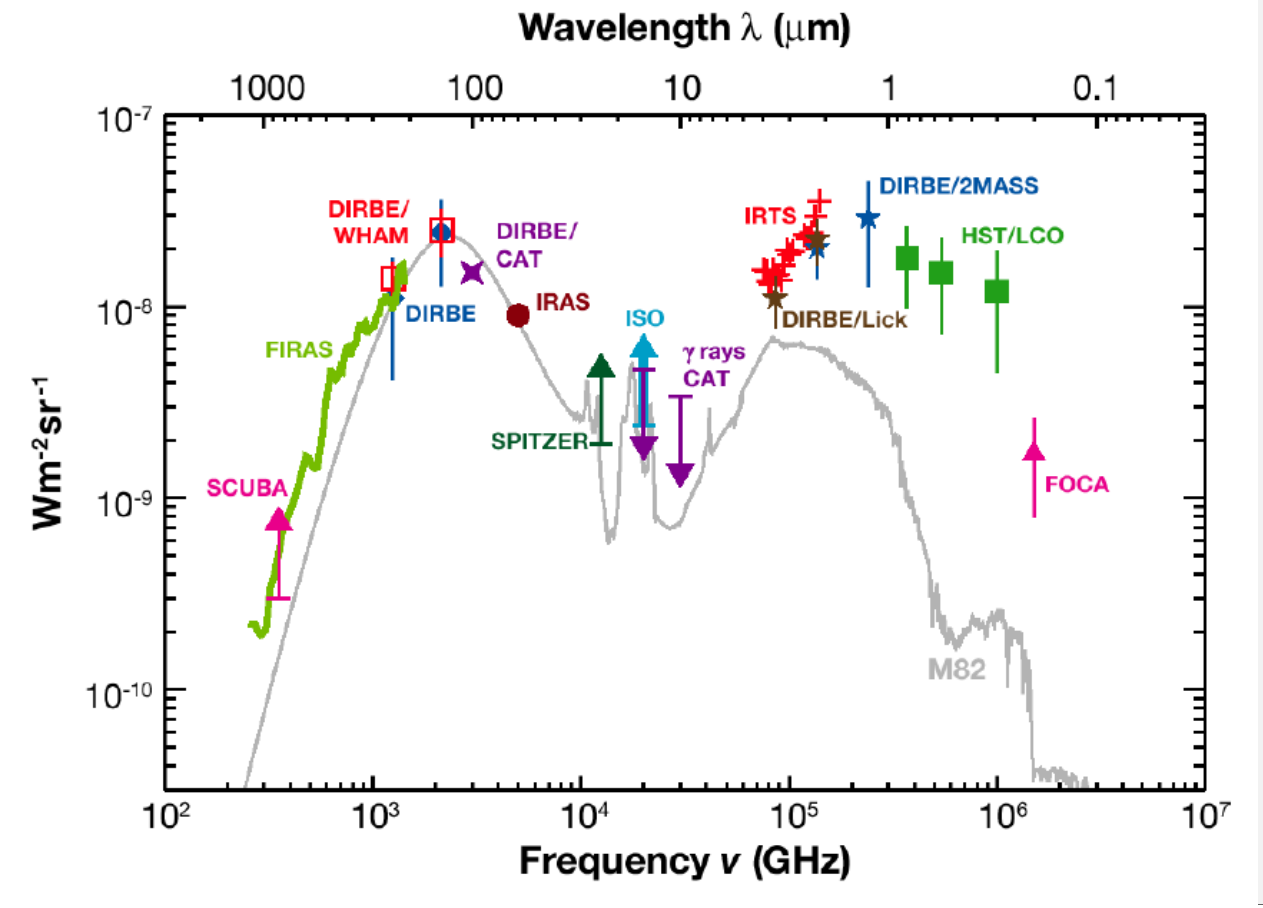
THE CONTRIBUTION OF DUSTY GALAXIES AND (U)LIRGS TO THE COSMIC SFR CHANGES OVER TIME



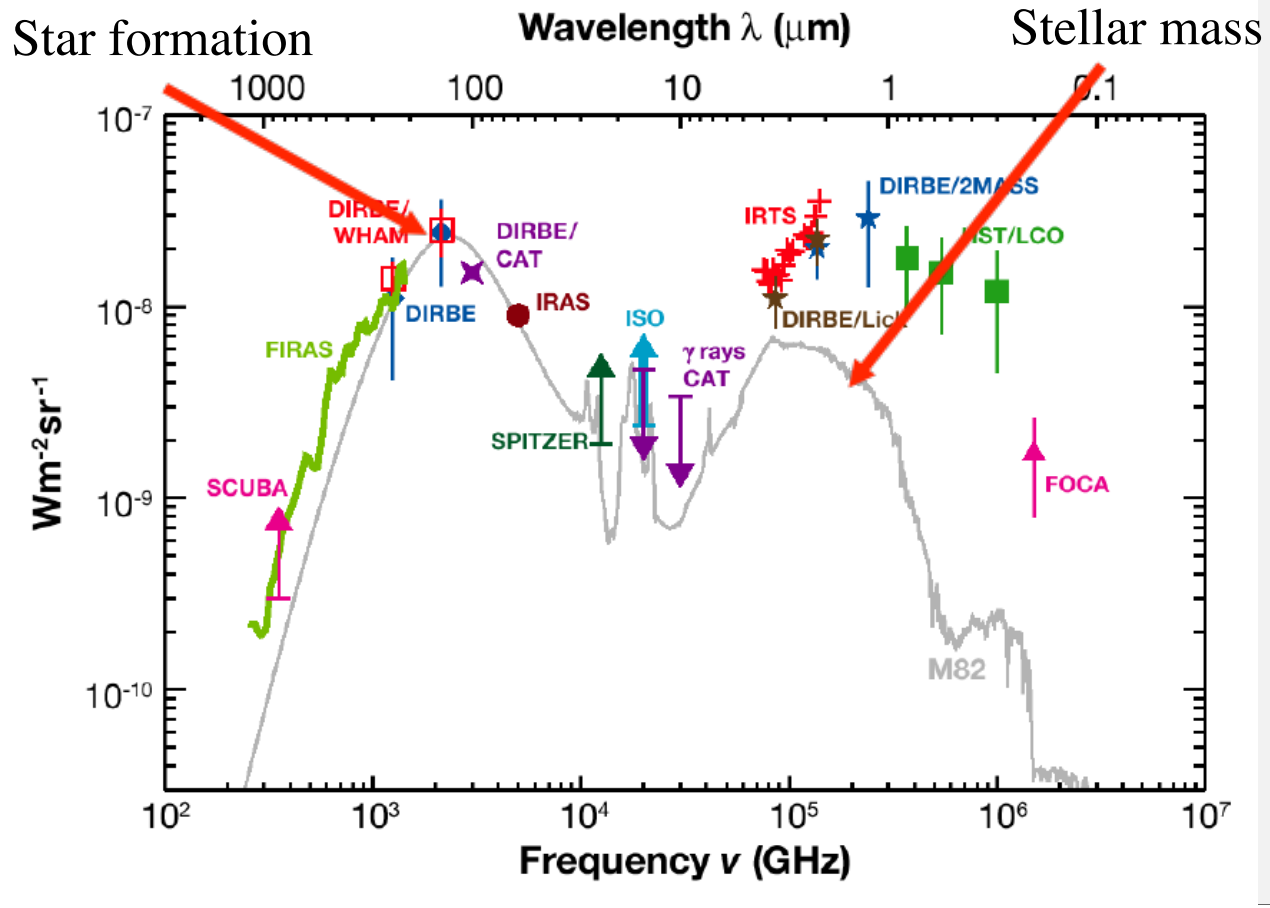
Le Floc'h et al 2004



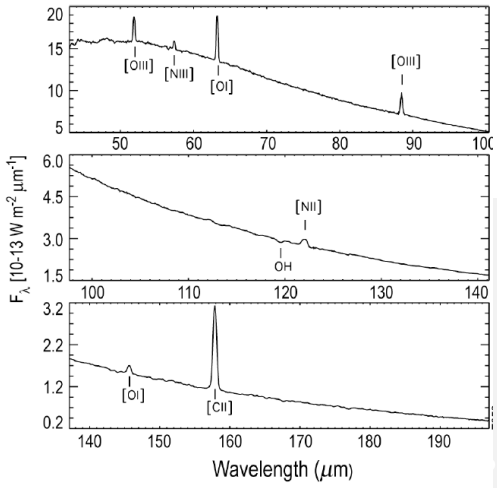
DUST HIDES ABOUT HALF THE POWER RELEASED BY STAR FORMATION AND ACCRETION ONTO BLACK HOLES

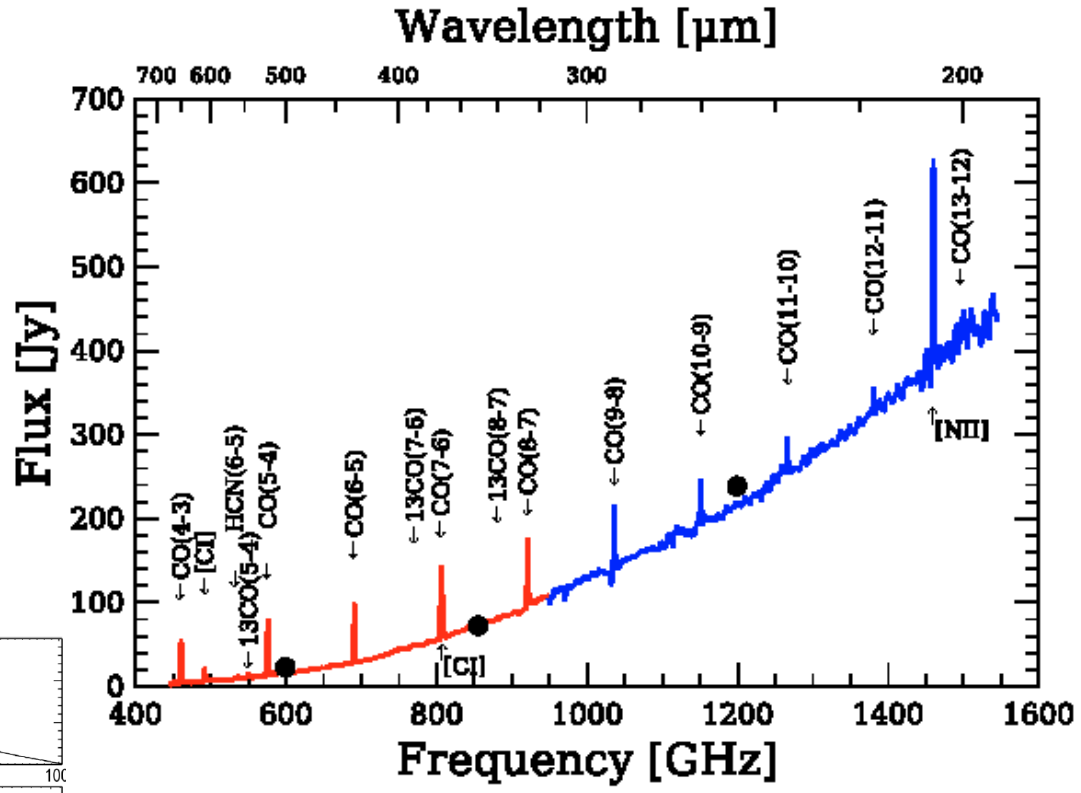


DUST HIDES ABOUT HALF THE POWER RELEASED BY STAR FORMATION AND ACCRETION ONTO BLACK HOLES

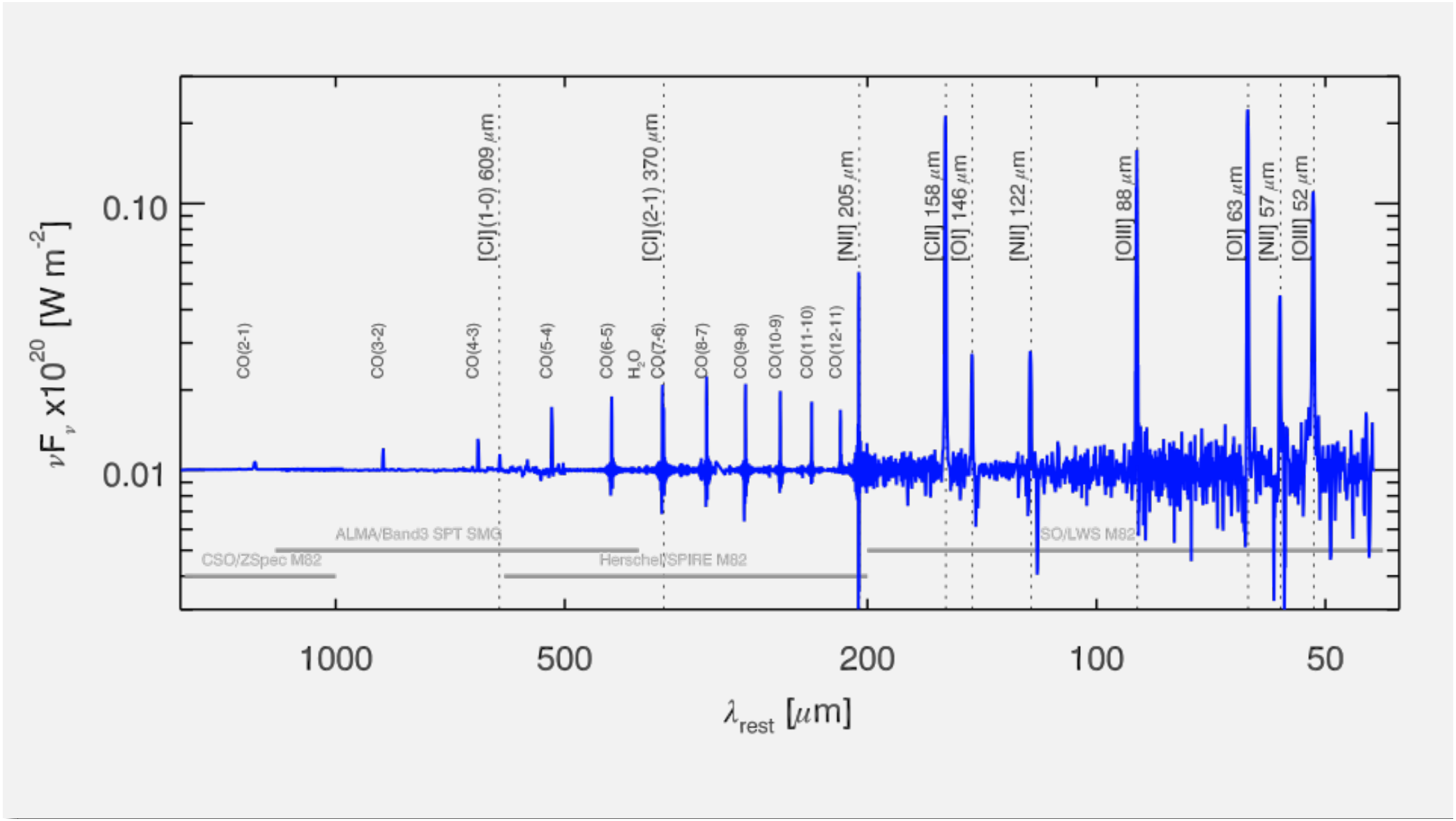


The fine-structure transitions in this spectrum are the primary coolants of the interstellar gas, and are among the most powerful spectral lines emitted by the galaxy. The suite of lines probes the conditions of the starburst, including the masses of the most massive stars.



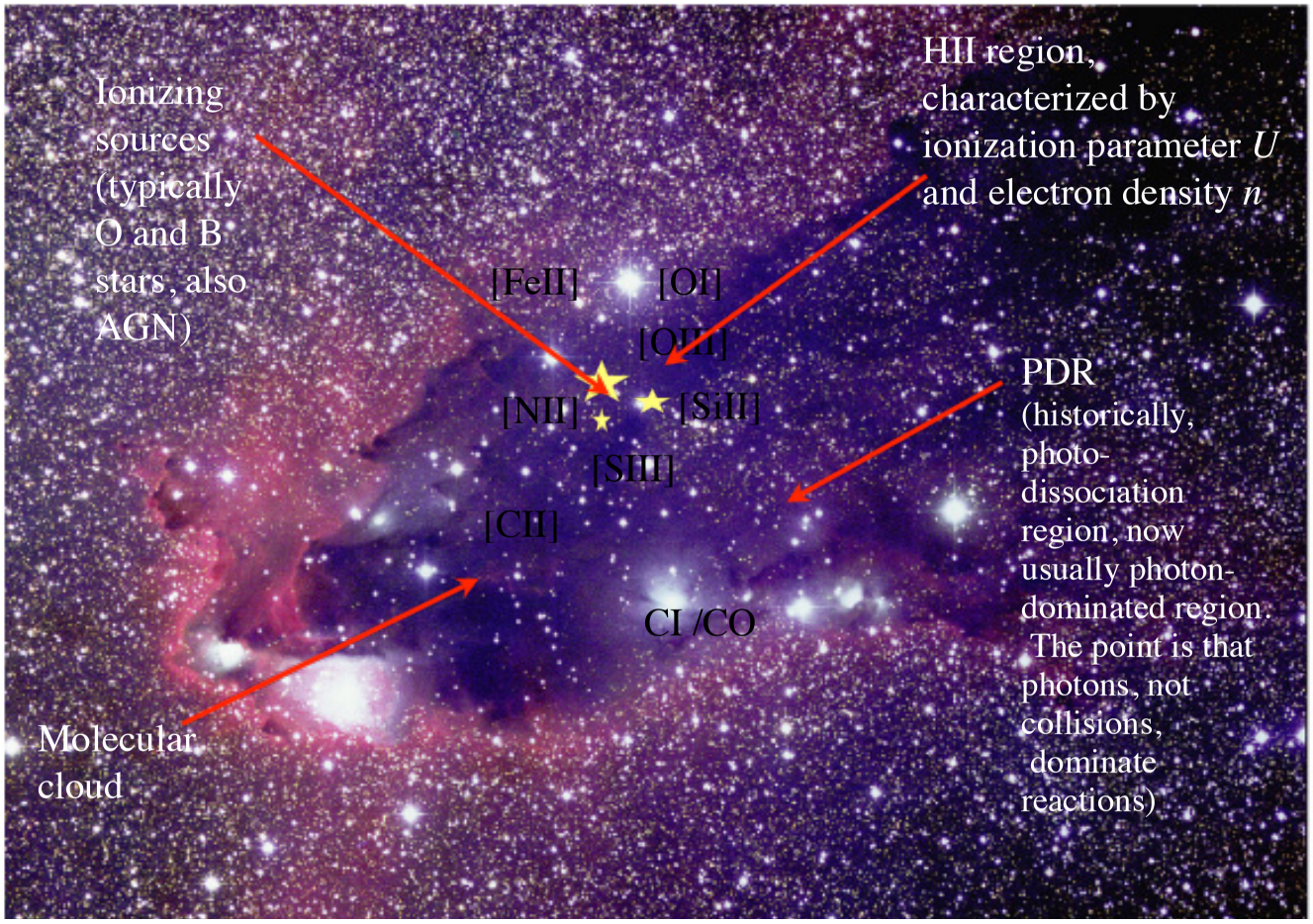


et al 2010

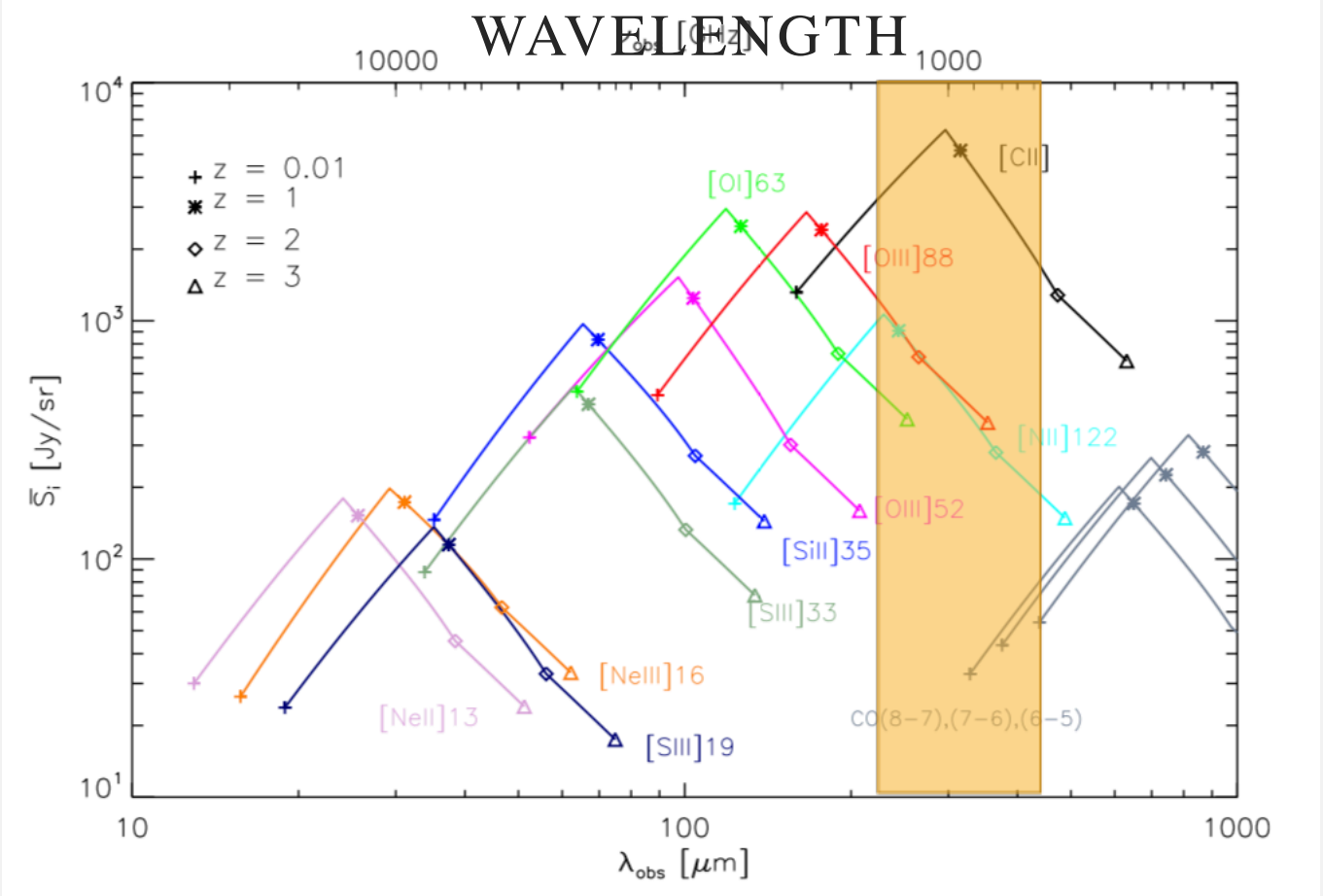

0.10
0.01
νF_ν x10^{20} [W m^{-2}]
CO(2-1)
CO(3-2)
CO(4-3)
[CI](1-0) 609 μm
CO(5-4)
CO(6-5)
H_2O
CO(7-6)
[CI](2-1) 370 μm
CO(8-7)
CO(9-8)
CO(10-9)
CO(11-10)
CO(12-11)
[NII] 205 μm
[CII] 158 μm
[OI] 146 μm
[NII] 122 μm
[OIII] 88 μm
[OI] 63 μm
[NII] 57 μm
[OIII] 52 μm
ALMA/Band3 SPT SMG
CSO/ZSpec M82
Herschel/SPIRE M82
SO/LWS M82
1000
500
200
100
50
λ_{rest} [μm]

CARTOON MODEL OF THE INTERSTELLAR MEDIUM

CARTOON MODEL OF THE INTERSTELLAR MEDIUM

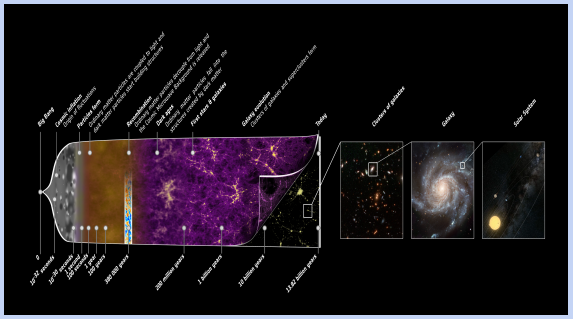


[CII] DOMINATES THE OTHER LINES OVER AN INTERESTING RANGE OF REDSHIFT AND OBSERVING WAVELENGTH

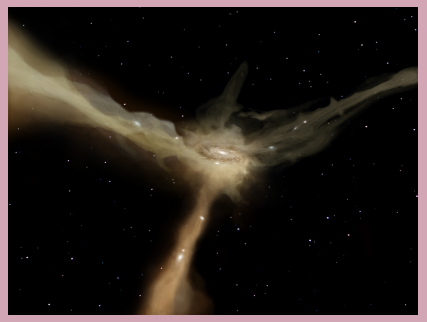


MOTIVATION FOR FAR-IR GALAXY INTENSITY MAPPING

Cosmology



- Evolution of Large Scale Structure
- Clustering
  - Intrahalo correlations
  - Halo-halo correlations



Astrophysics

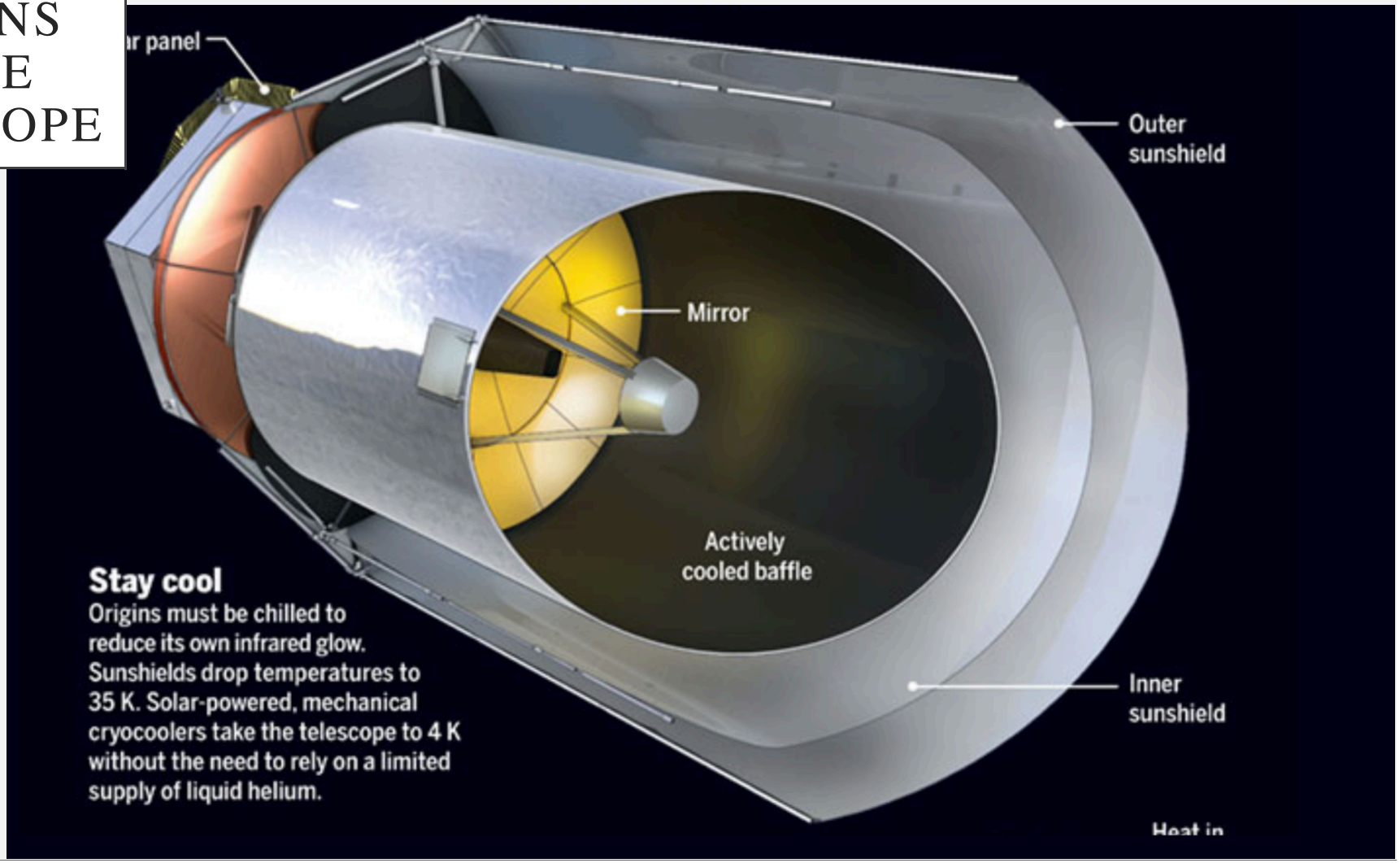
- Evolution of total luminosity of ISM coolants
- Evolution of metal abundance, ISM properties via line ratios
- Evolution of SFRD
- Evolution of the cosmic mean of LX/LFIR

THE TECHNOLOGY

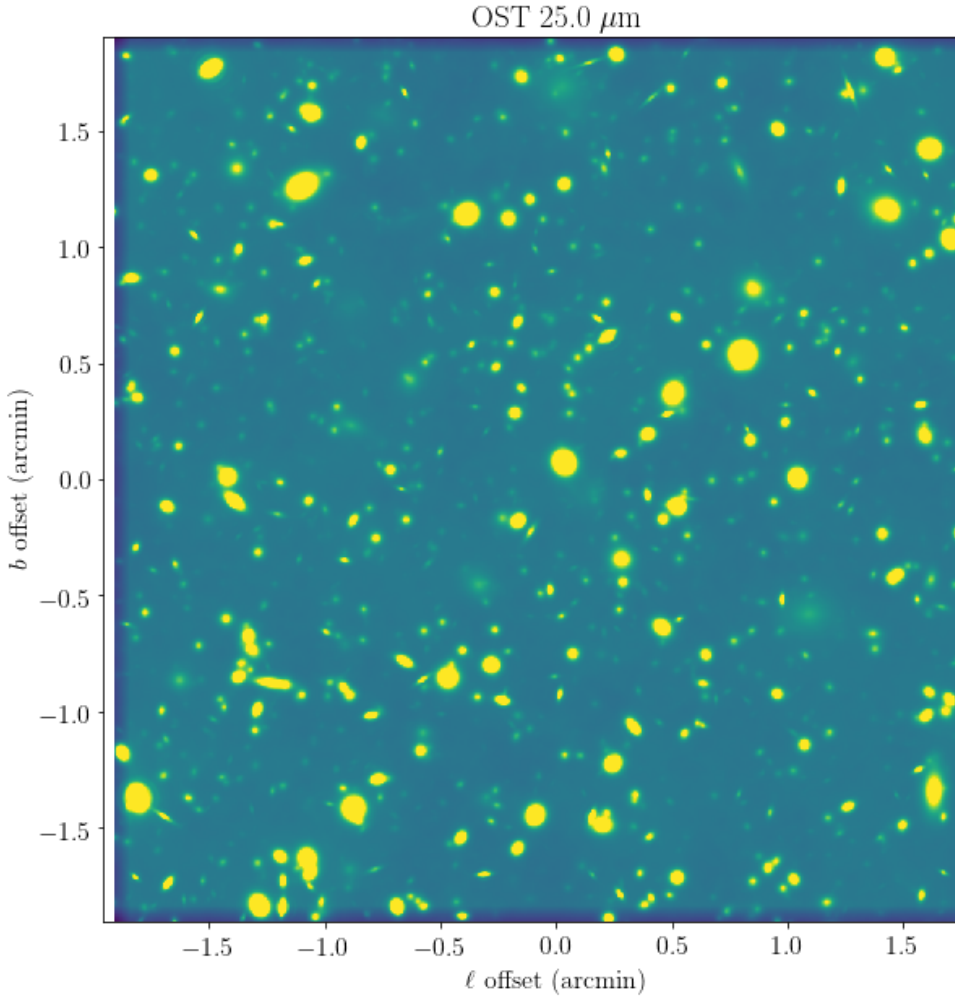
SOME FACTS ABOUT SUBMILLIMETER ASTRONOMY

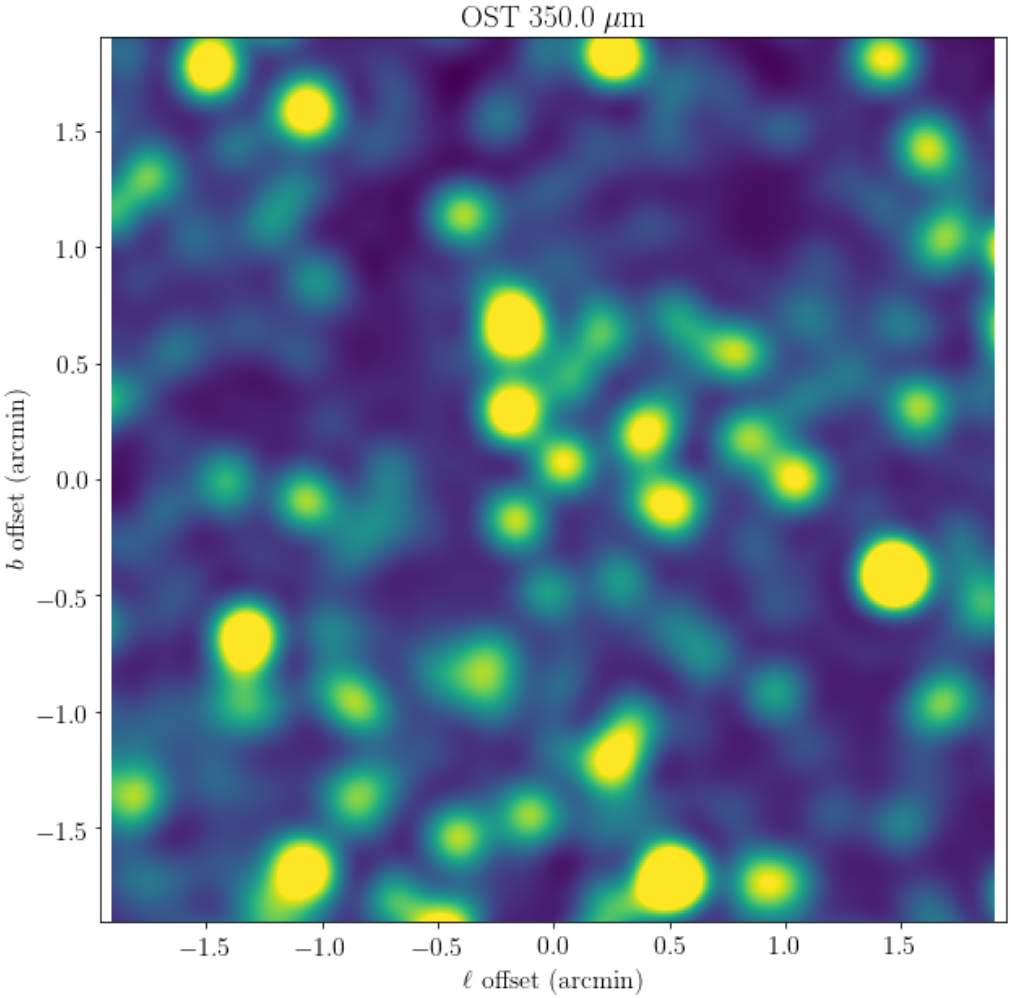
- The wave nature of light … is
  - Resolution at a wavelength
    telescope mirror with diam
- Thermodynamics … is also n

ORIGINS SPACE TELESCOPE



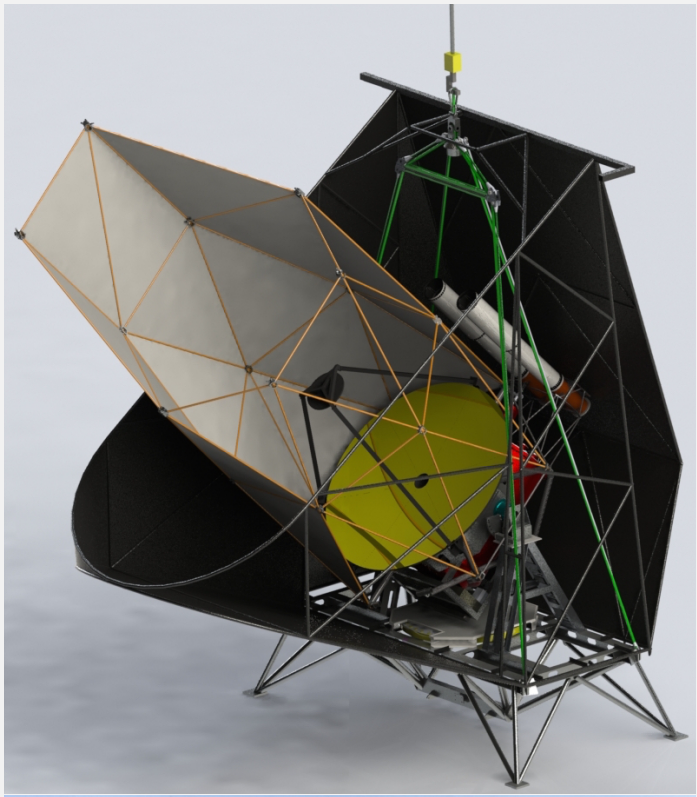
OST SIMULATION
COURTESY OF DAVID LEISAWITZ

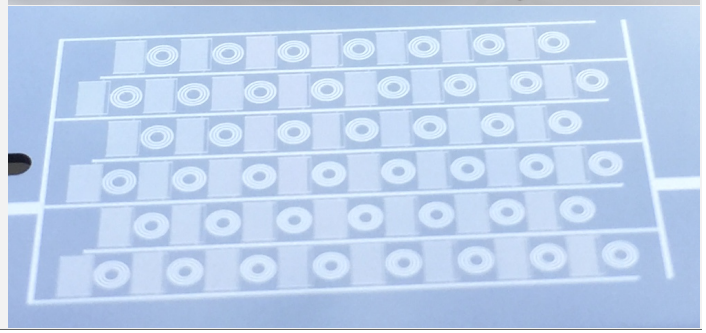


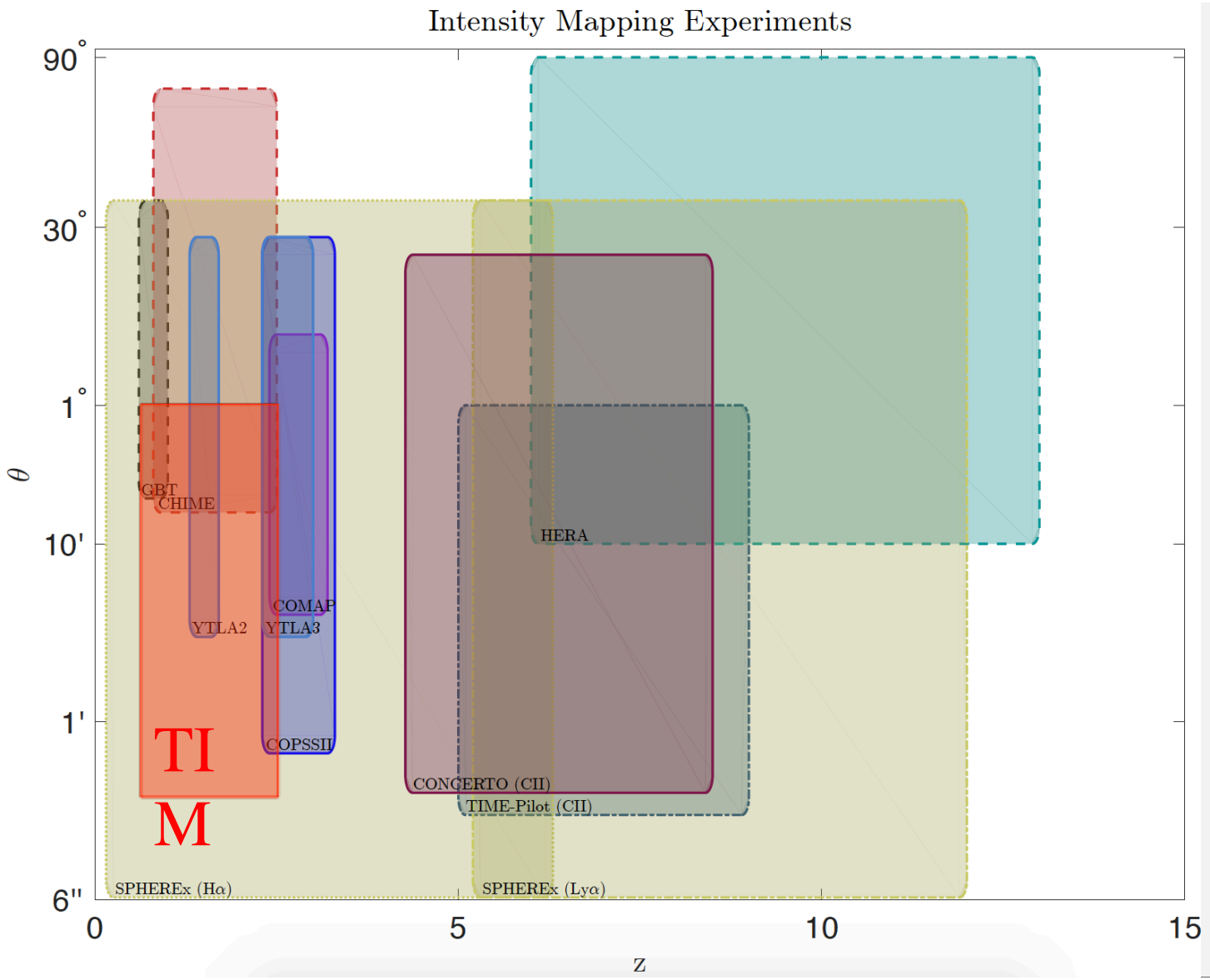


TIM
TERAHERTZ INTENSITY MAPPER

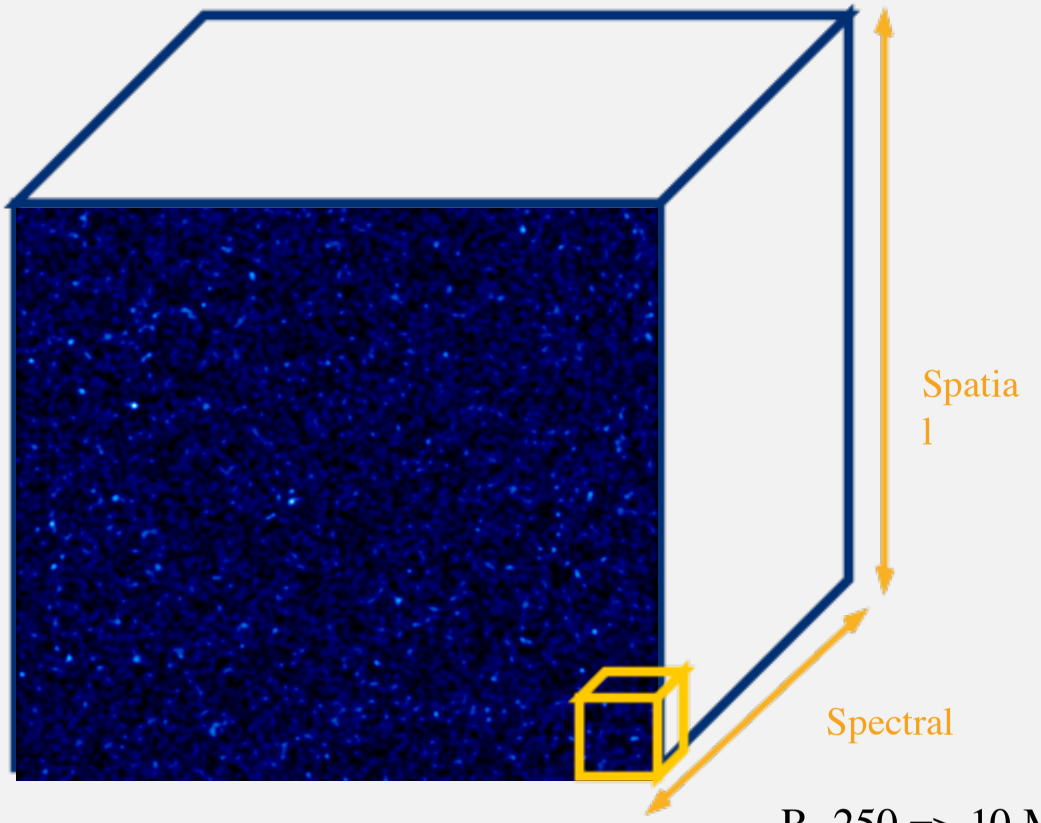
- Designed to study the ISM of galaxies for $0.5 < z < 1.5$, primarily in the [CII](158 μm) line, and also in cross-correlation with [NII]
- Offers a view of the star-forming medium with minimal impact from dust extinction throughout the period of peak cosmic star formation and into the epoch where feedback begins to lower the cosmic star formation rate
- 2.0 meter low-emissivity carbon-fiber balloon-borne telescope; diffraction limited resolution between ~30”
- Two long slit spectrometer modules, $R \sim 250$ from 240 - 420 μm, feeding arrays of kinetic inductance detectors (prototype shown lower right)
- With dispersive spectroscopy and the stratospheric platform, TIM can achieve better performance than SOFIA or Herschel-SPIRE






Intensity Mapping Experiments
90°
30°
1°
10'
1'
6"
θ
0
5
10
15
z
GBT
CHIME
YTLA2
COMAP
YTLA3
COPSSII
TI
M
HERA
CONCERTO (CII)
TIME-Pilot (CII)
SPHEREx (Hα)
SPHEREx (Lyα)

Intensity mapping creates a data cube



R~250 => 10 Mpc h-1 @ z=1

30” FWHM => 0.5 Mpc h-1 @ z=1

PROJECTED TIM PERFORMANCE