Dust-obscured Galaxies in the Early Universe

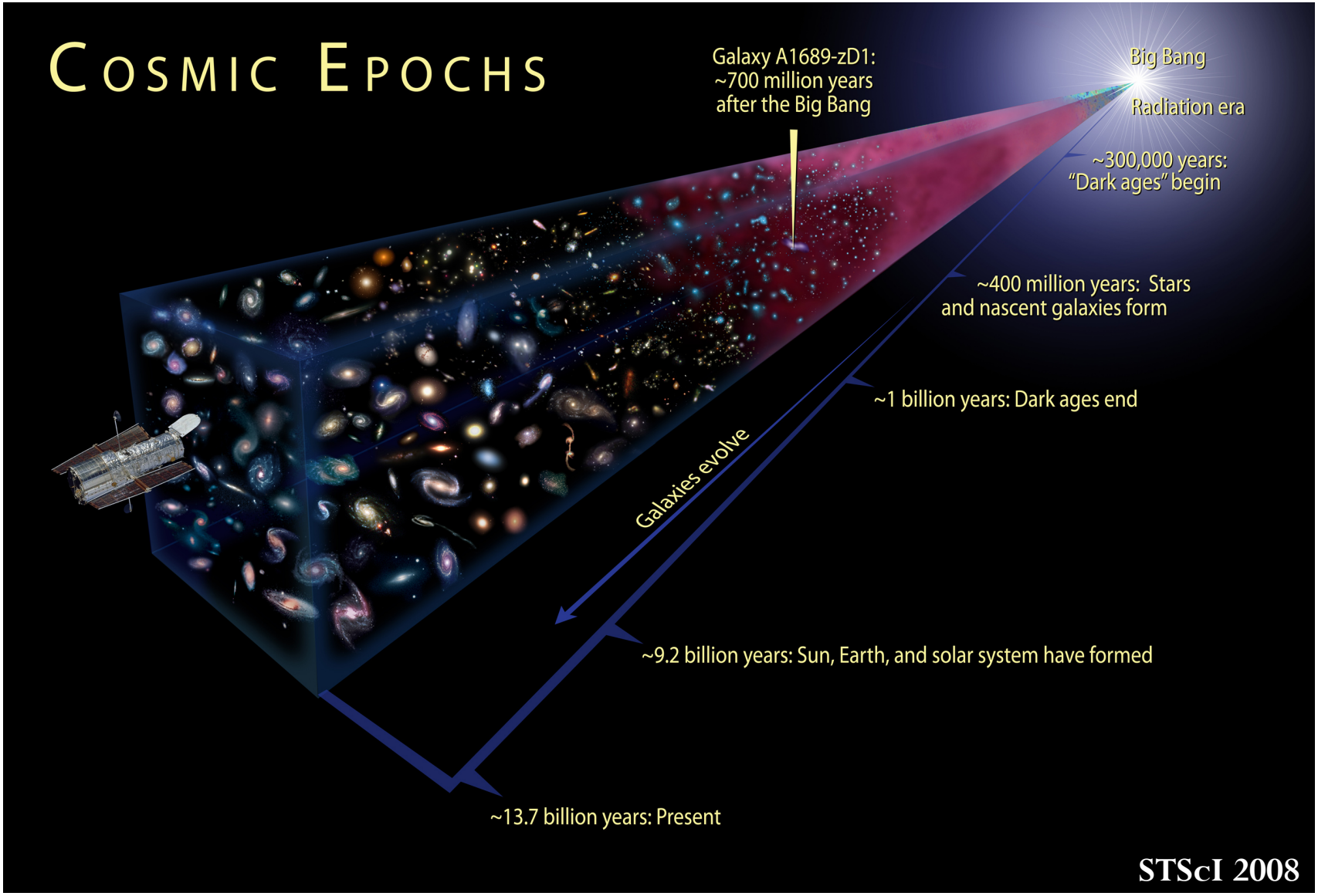
Alexandra Pope

University of Massachusetts Amherst

AAAS Annual Meeting 2014 – Chicago

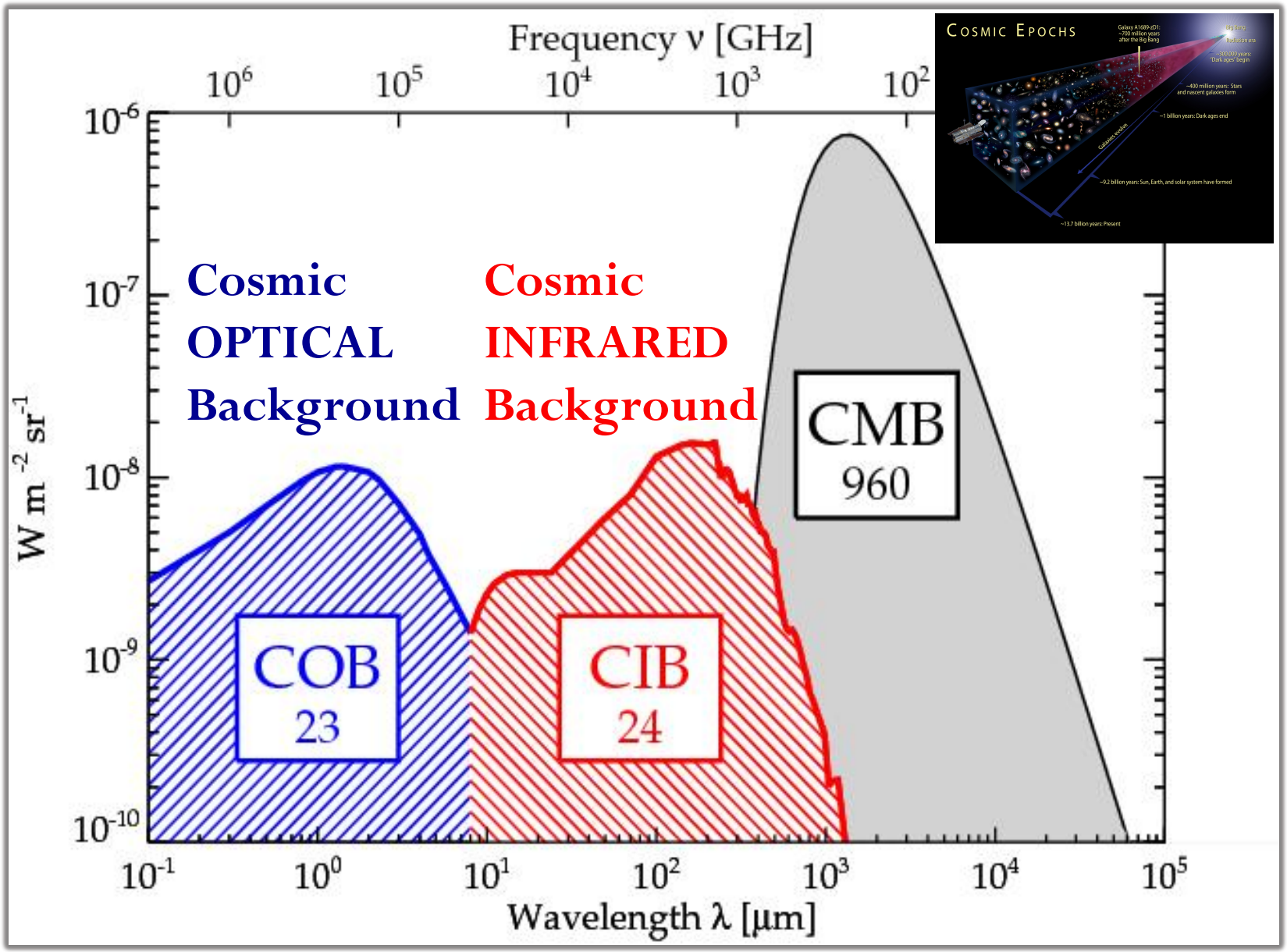
Symposium: New Millimeter-Wavelength Insights into Galaxy Evolution in the Early Universe

The cosmic history of galaxies: The optical light perspective

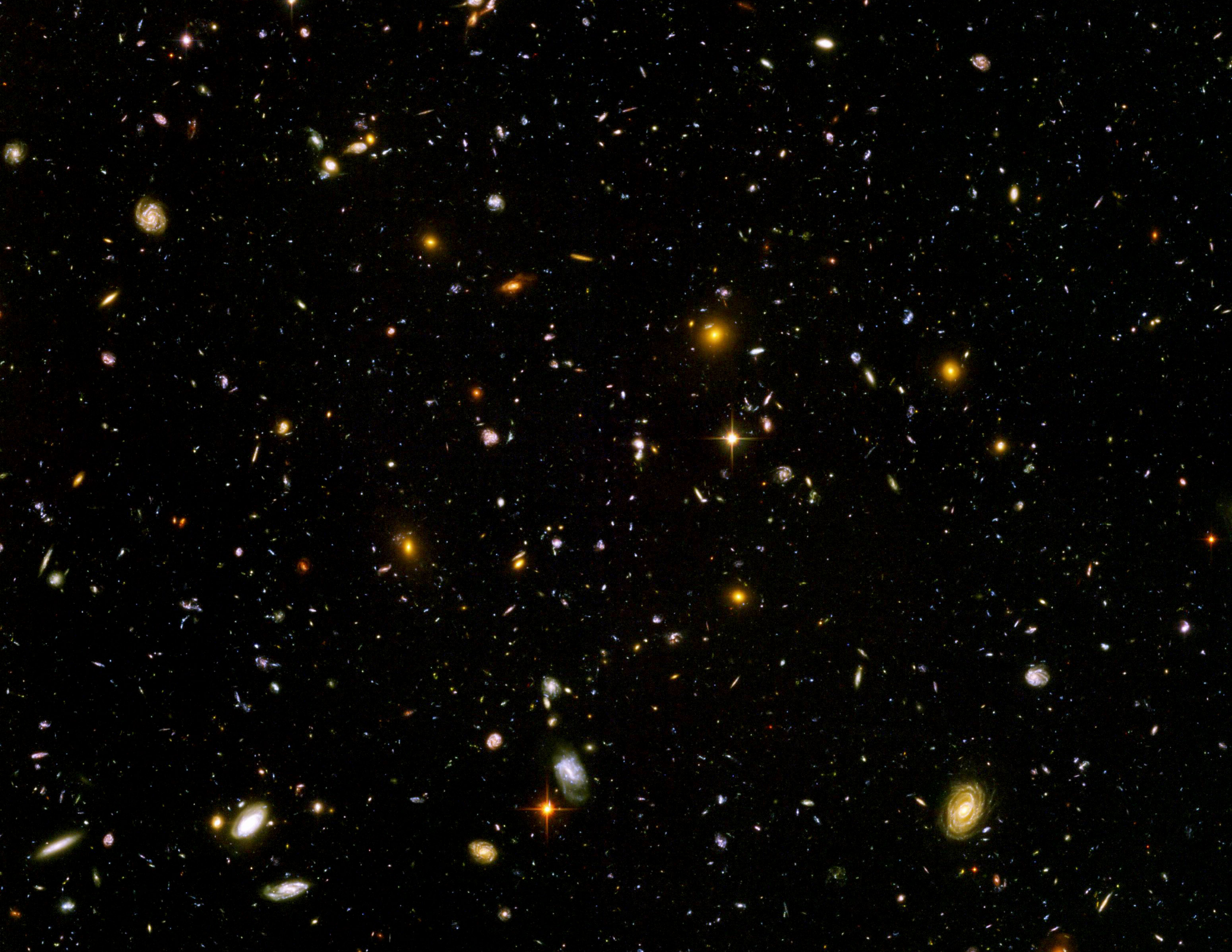


Light takes time to travel so we observe distant galaxies as they were in the past

Much of galaxy formation and evolution occurs behind dust



Dole et al. 2006



3 reasons to study distant galaxies in the infrared:

1. Dust-obscured activity dominates the build-up of stellar mass and black holes in galaxies

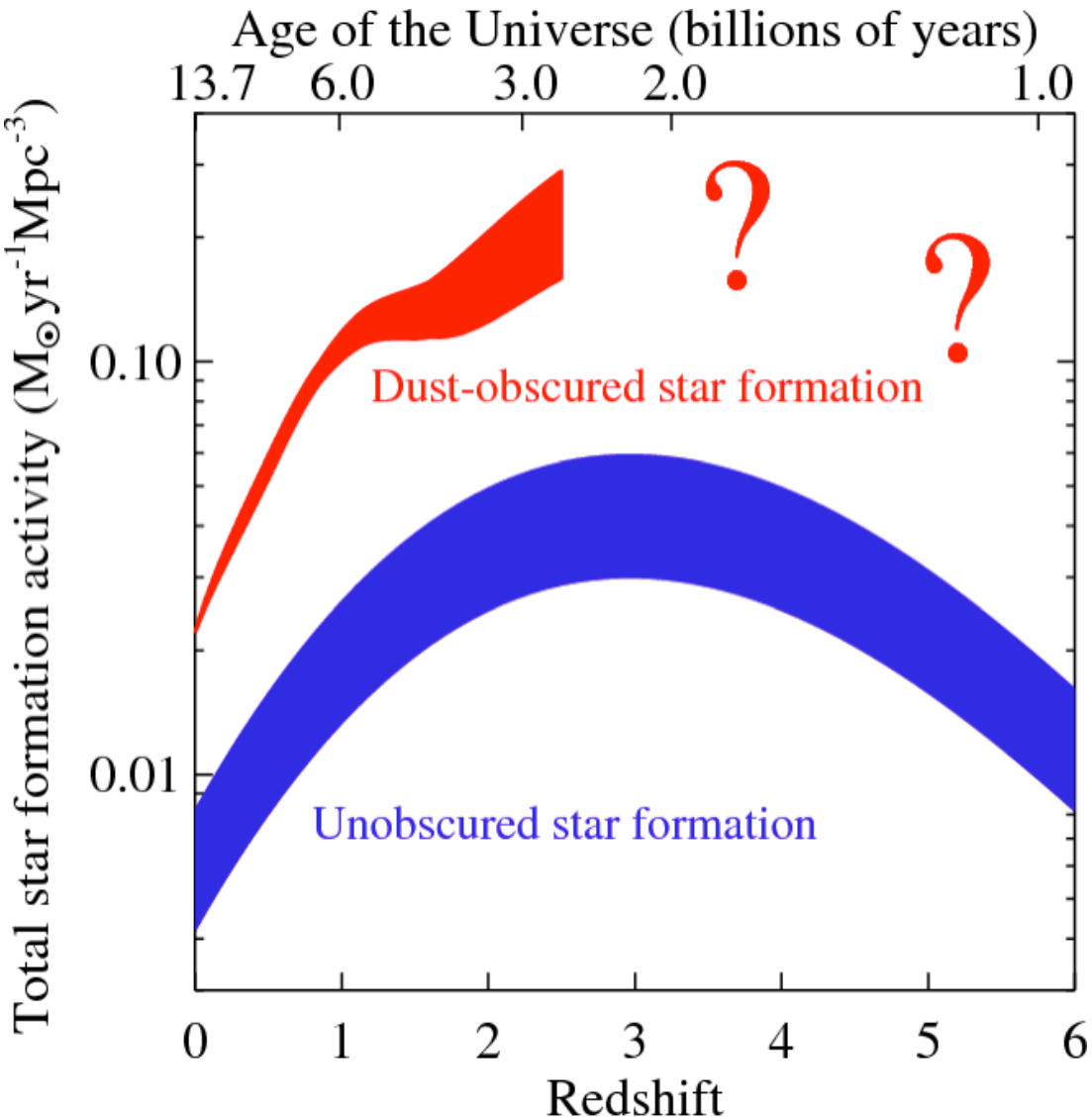
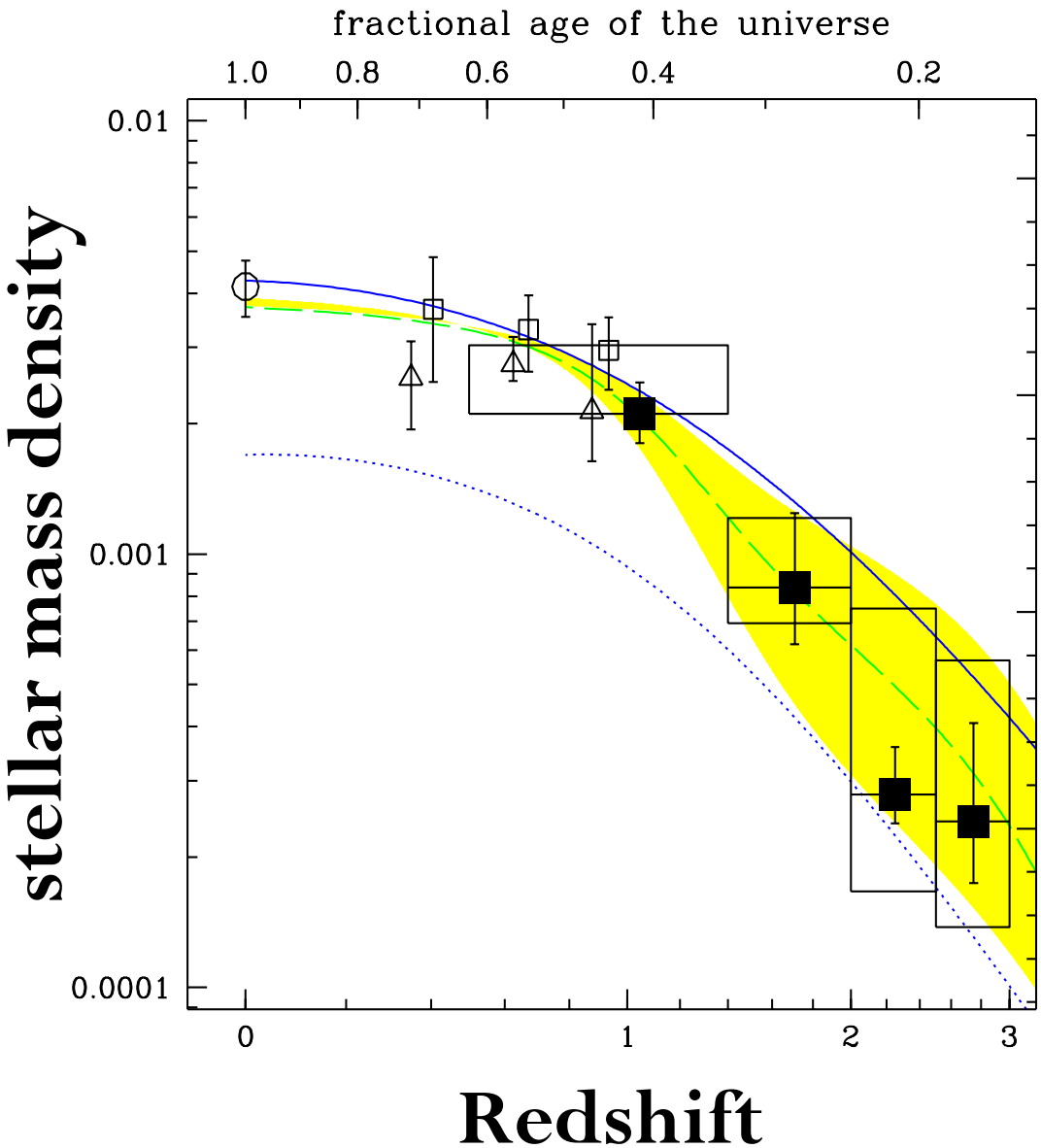


Figure adapted from Bouwens et al. 2009 and Murphy et al. 2009

3 reasons to study distant galaxies in the infrared:

2. Most stellar mass (and black hole) growth occurs between redshifts z~1-3



Dickinson et al. 2003

3 reasons to study distant galaxies in the infrared:

3. Much of the stellar mass growth occurs in dusty high star formation galaxies

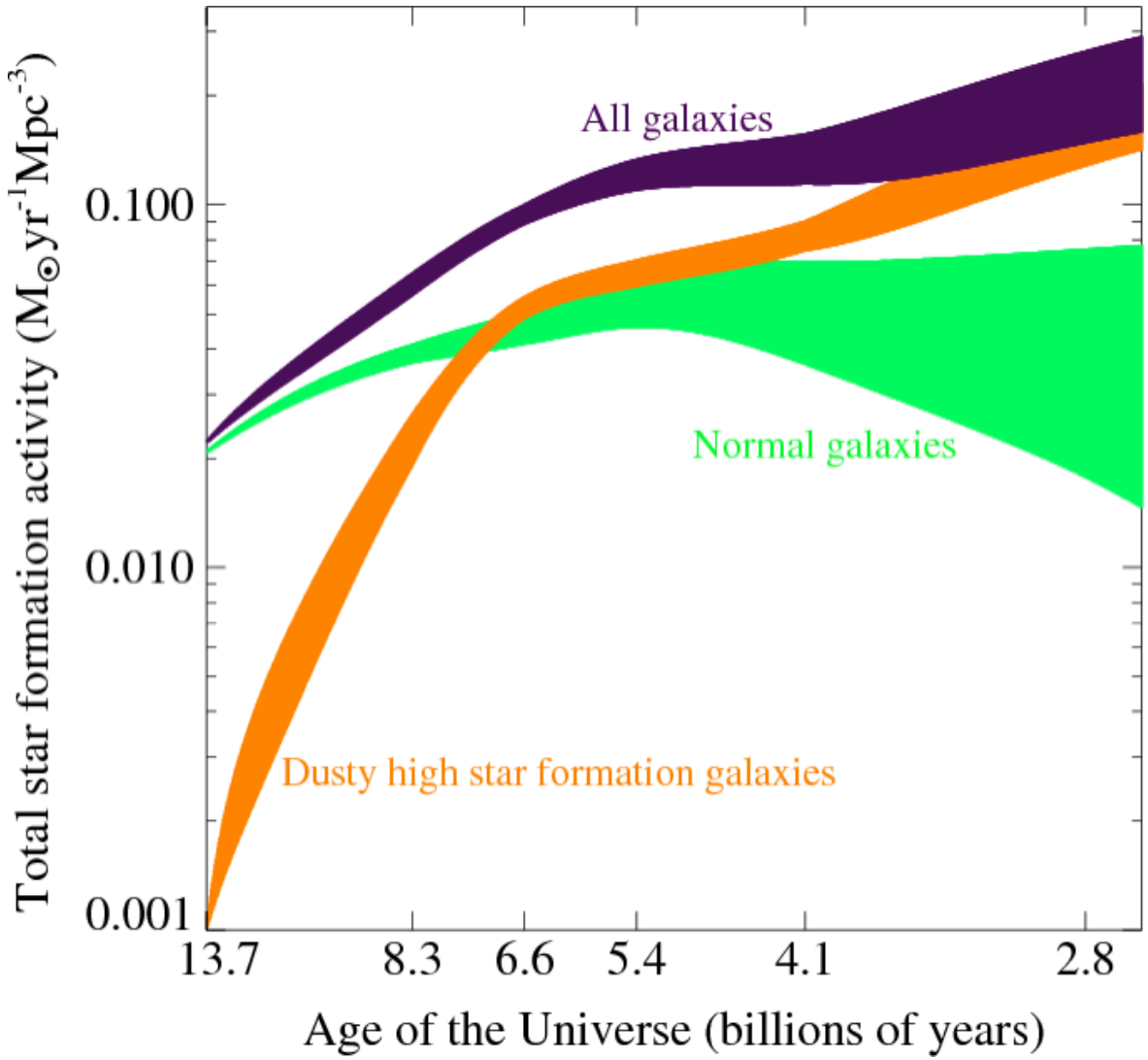
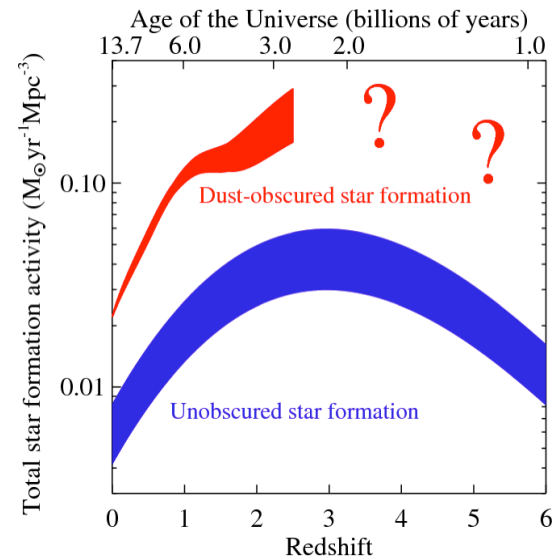


Figure adapted from Murphy et al. 2009

Outstanding Question(s)



- **What is driving the peak period of dusty star formation?**
  - **Are the mechanisms of triggering and fueling star formation different in the distant Universe?**
    - **How do the galaxies differ during the peak period from those in the local Universe?**

What fuels dusty high star formation galaxies?

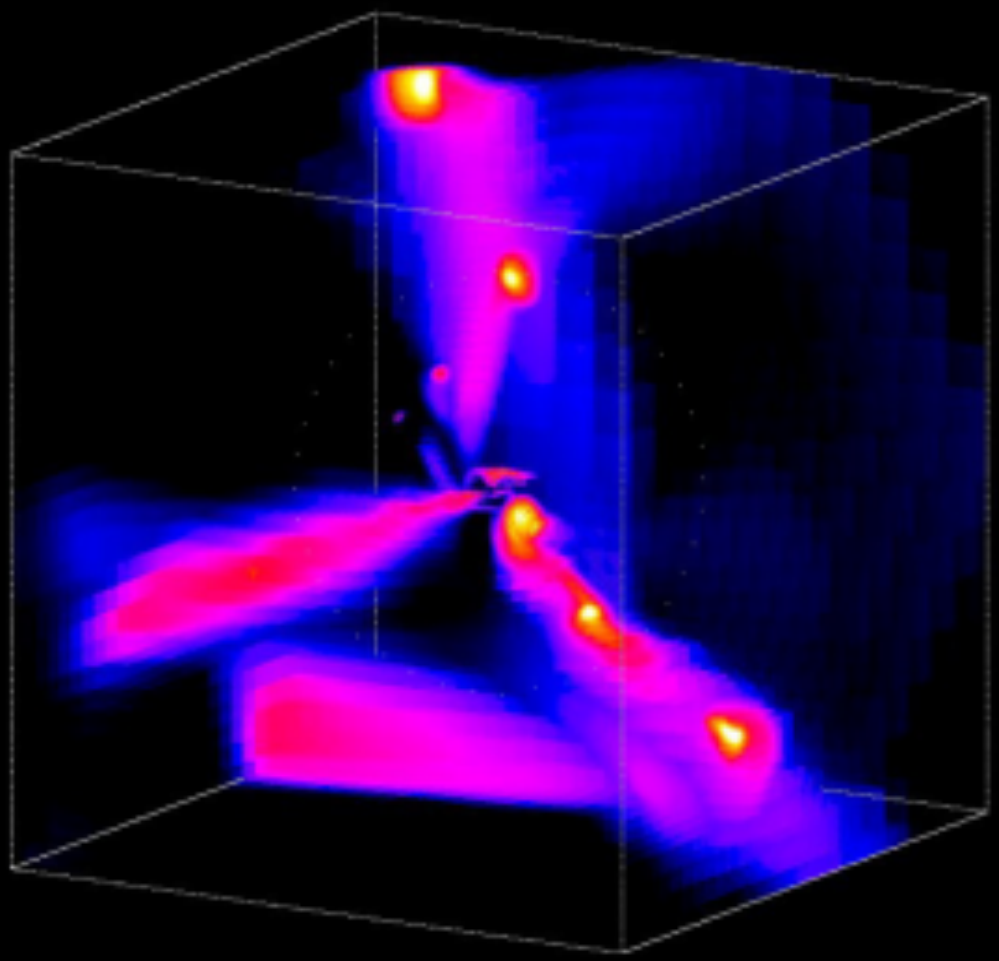
Cold Gas Flows

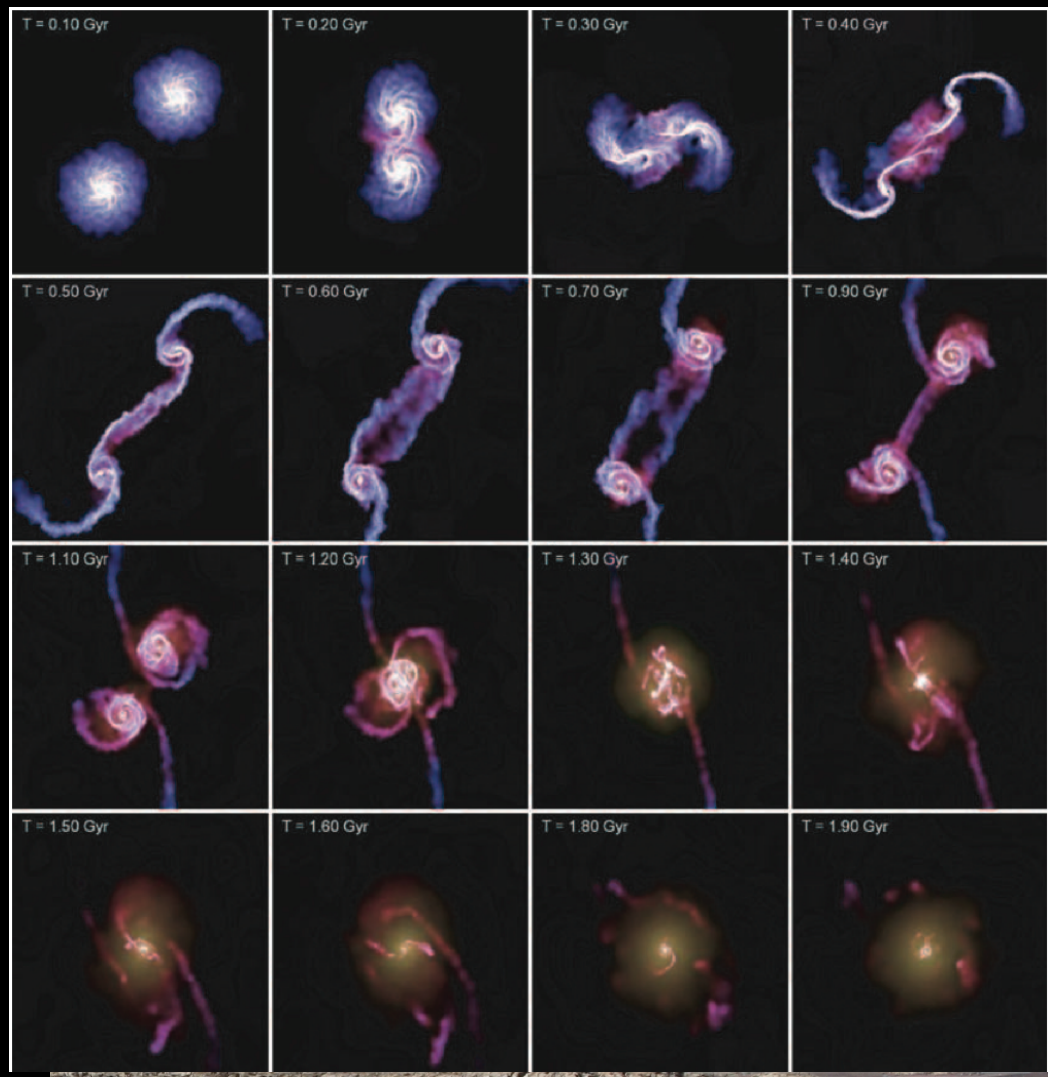
e.g. Dekel et al. 2009, Dave et al. 2010, Katz et al. 1992

VS

Major Mergers

e.g. Sanders et al. 1988, Narayanan et al. 2010





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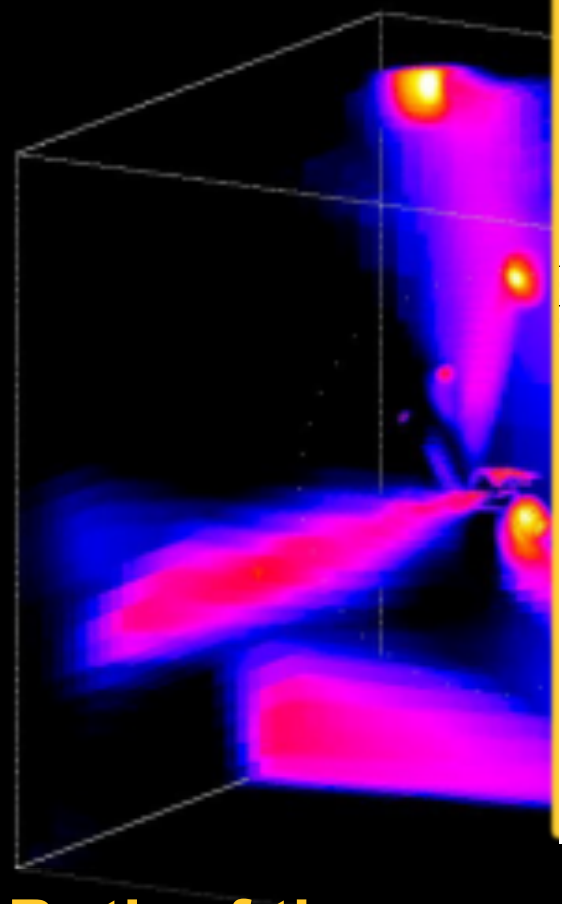
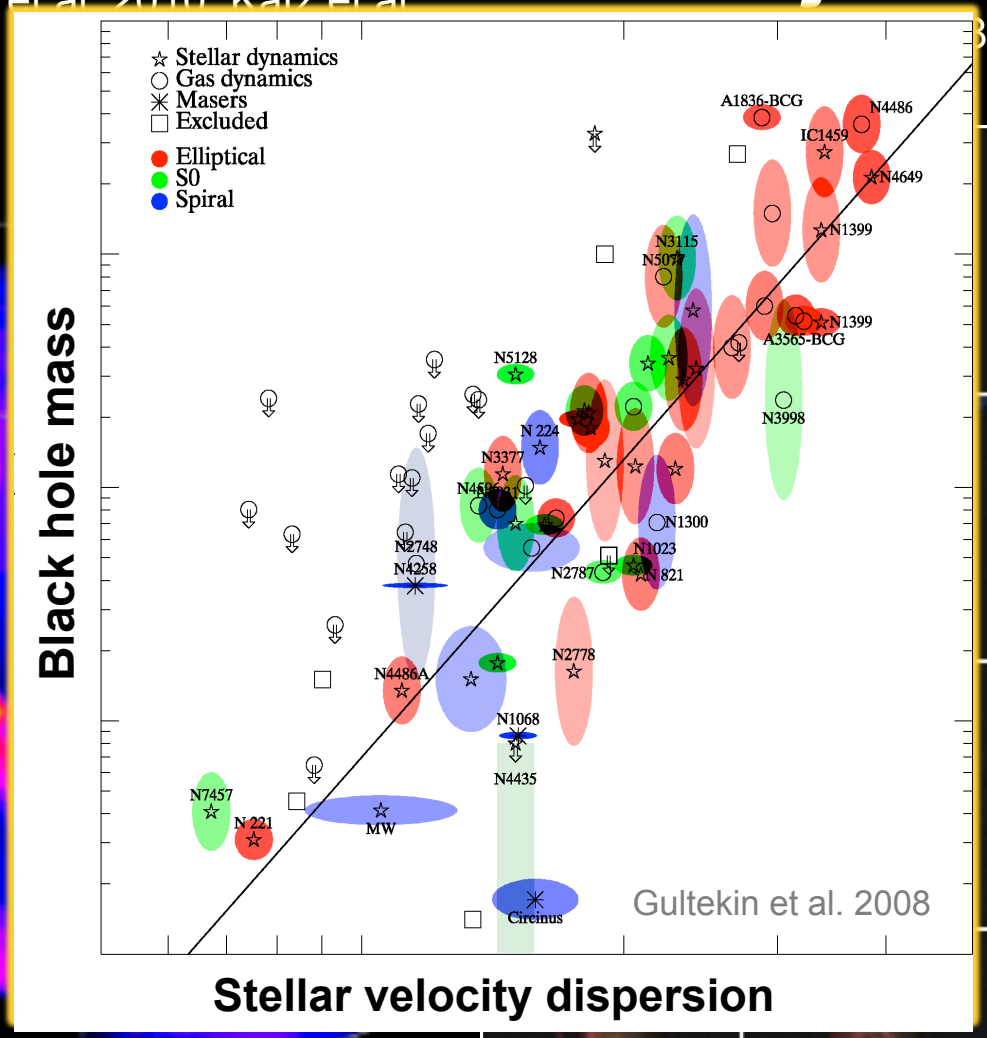
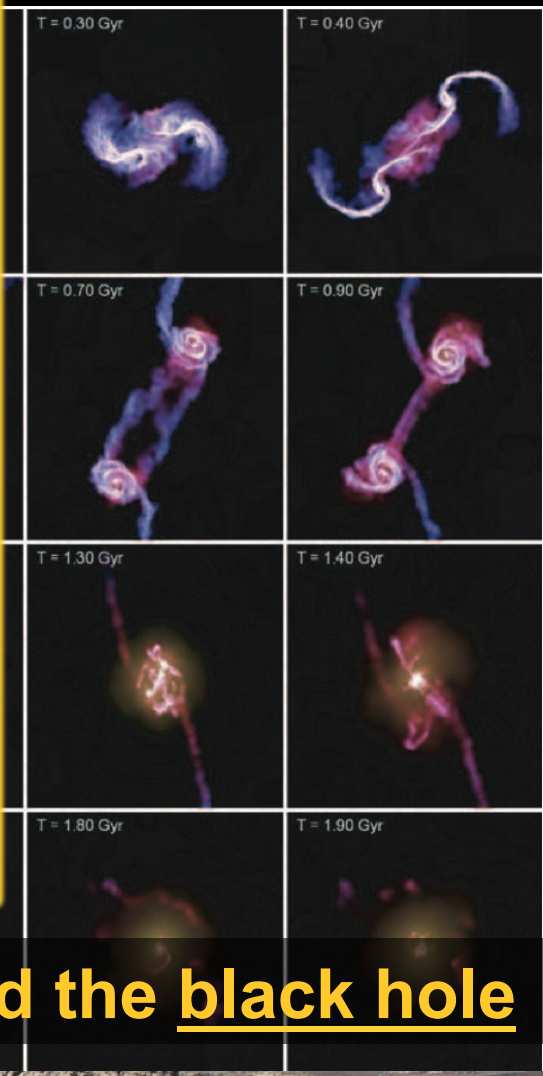




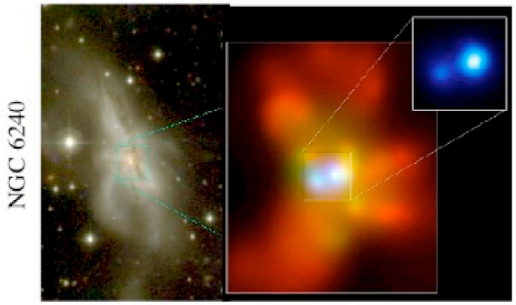


Both of these processes will feed the stars and the black hole

(c) Interaction/"Merger"

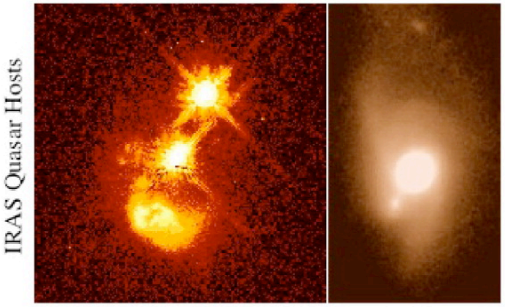
- now within one halo, galaxies interact & lose angular momentum
- SFR starts to increase
- stellar winds dominate feedback
- rarely excite QSOs (only special orbits)

(d) Coalescence/(U)LIRG



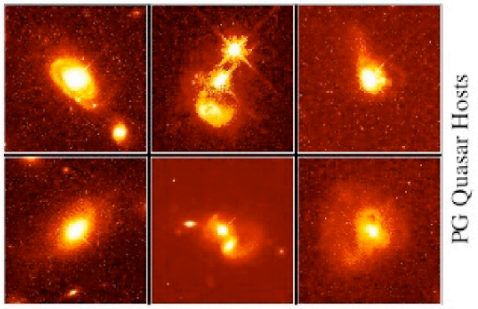
- galaxies coalesce: violent relaxation in core
- gas inflows to center: starburst & buried (X-ray) AGN
- starburst dominates luminosity/feedback, but, total stellar mass formed is small

(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

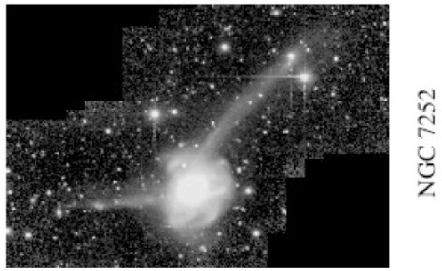


- dust removed: now a "traditional" QSO
- host morphology difficult to observe: tidal features fade rapidly
- characteristically blue/young spheroid

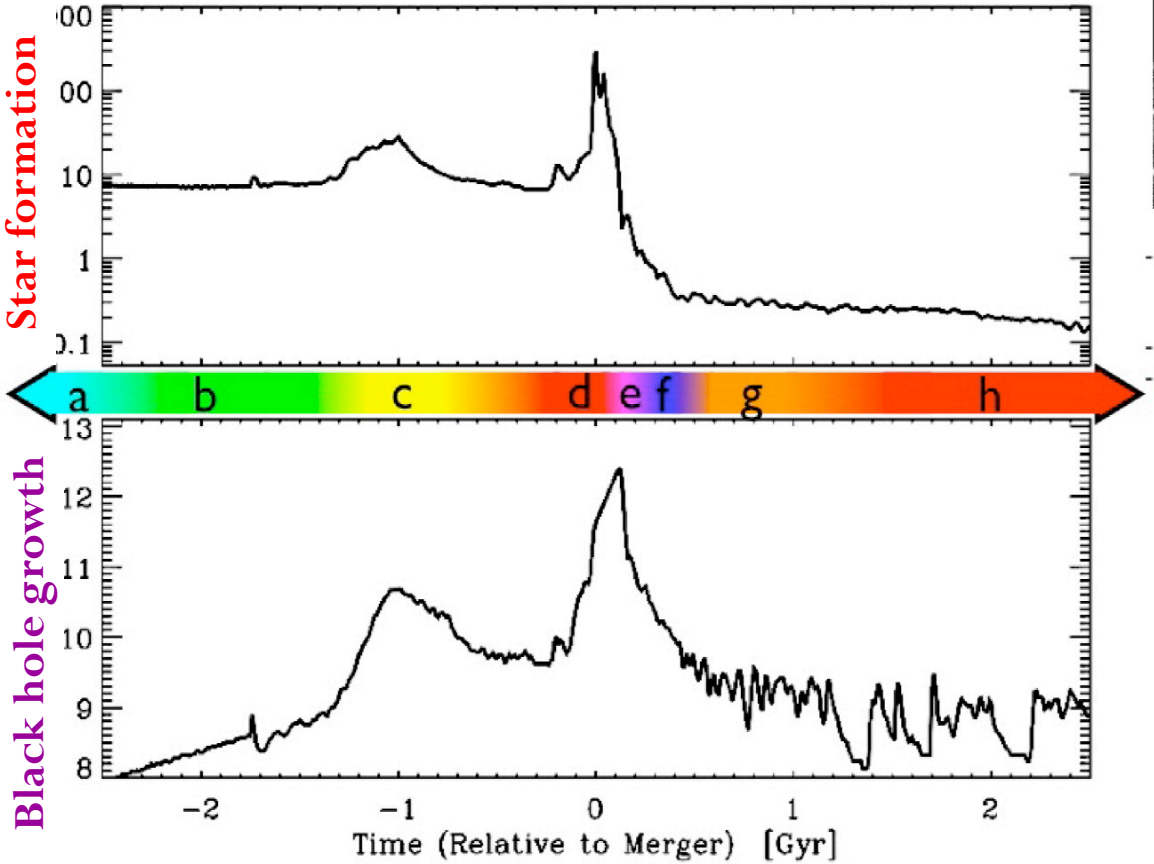
(b) "Small Group"

- 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

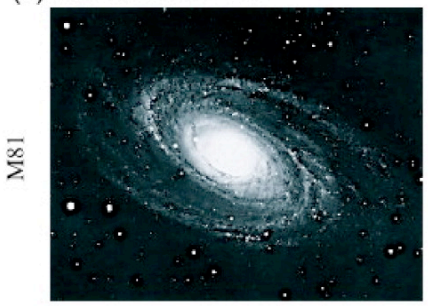
(g) Decay/K+A



- 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

Hopkins et al. 2008

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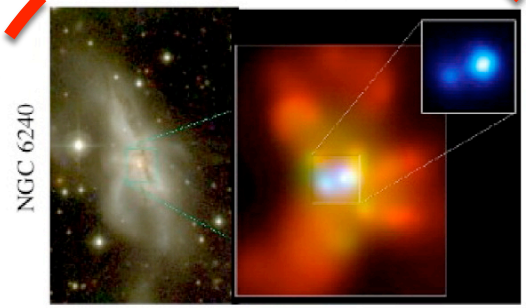

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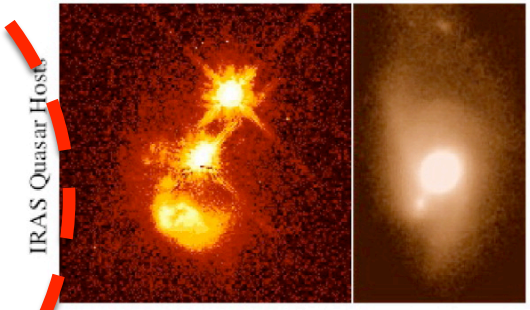

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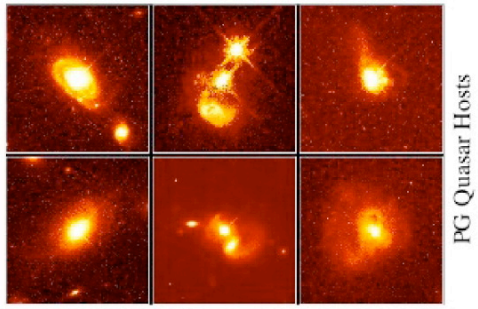

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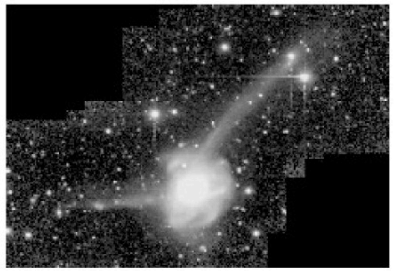

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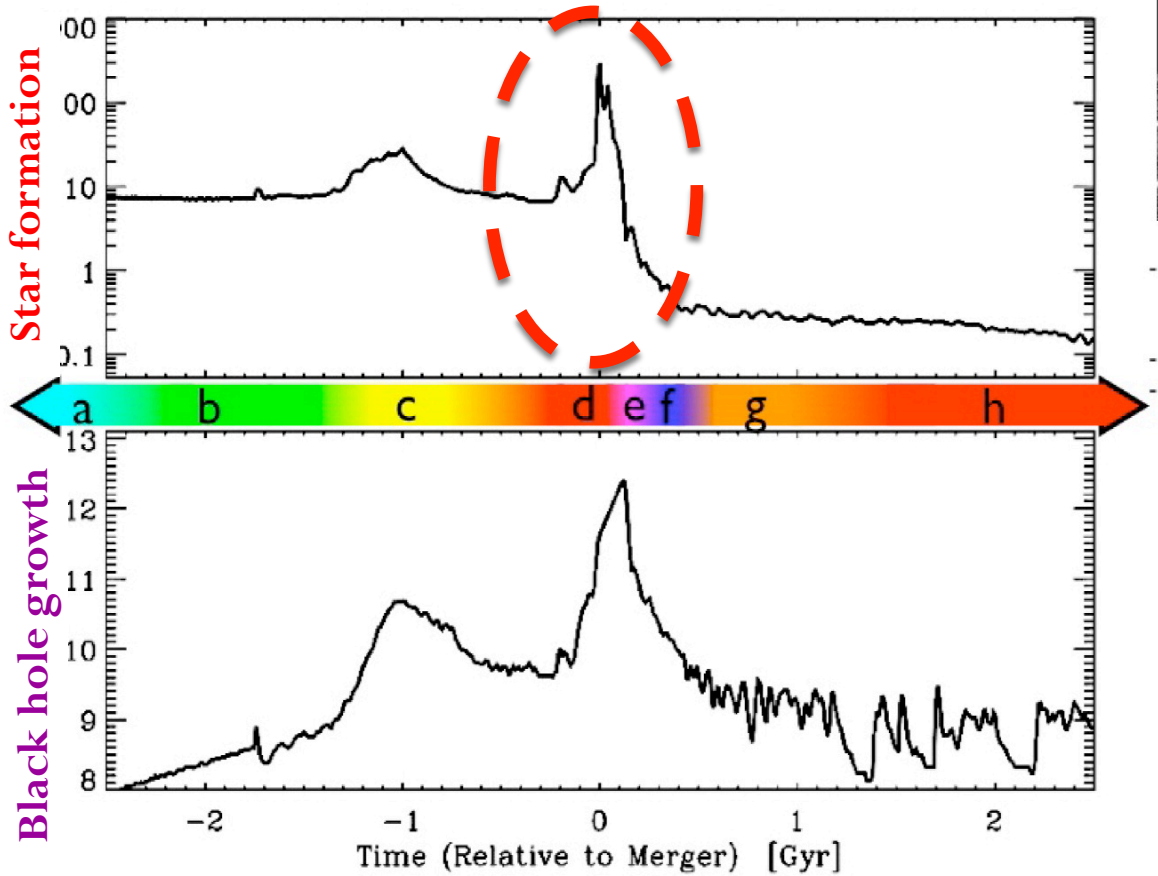

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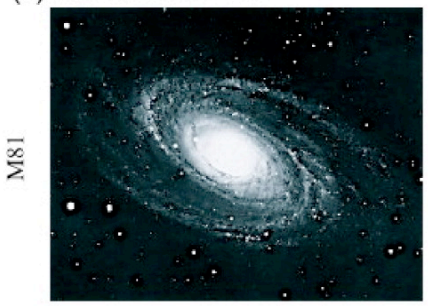

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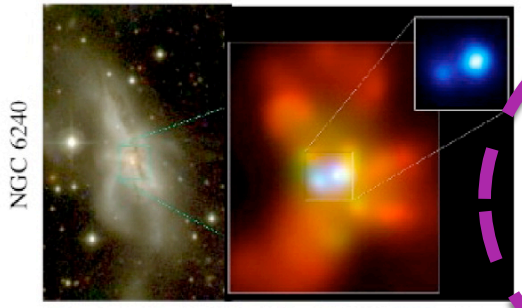

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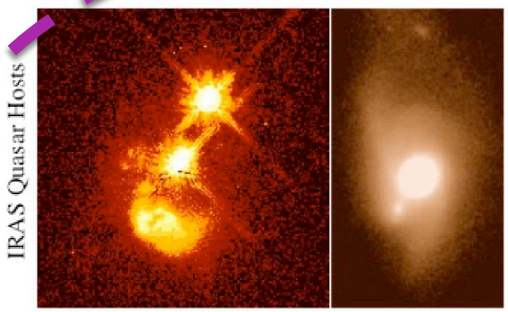

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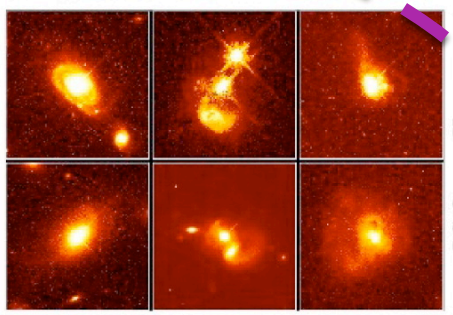

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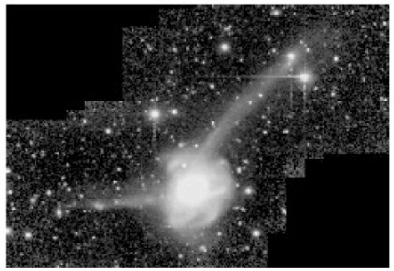

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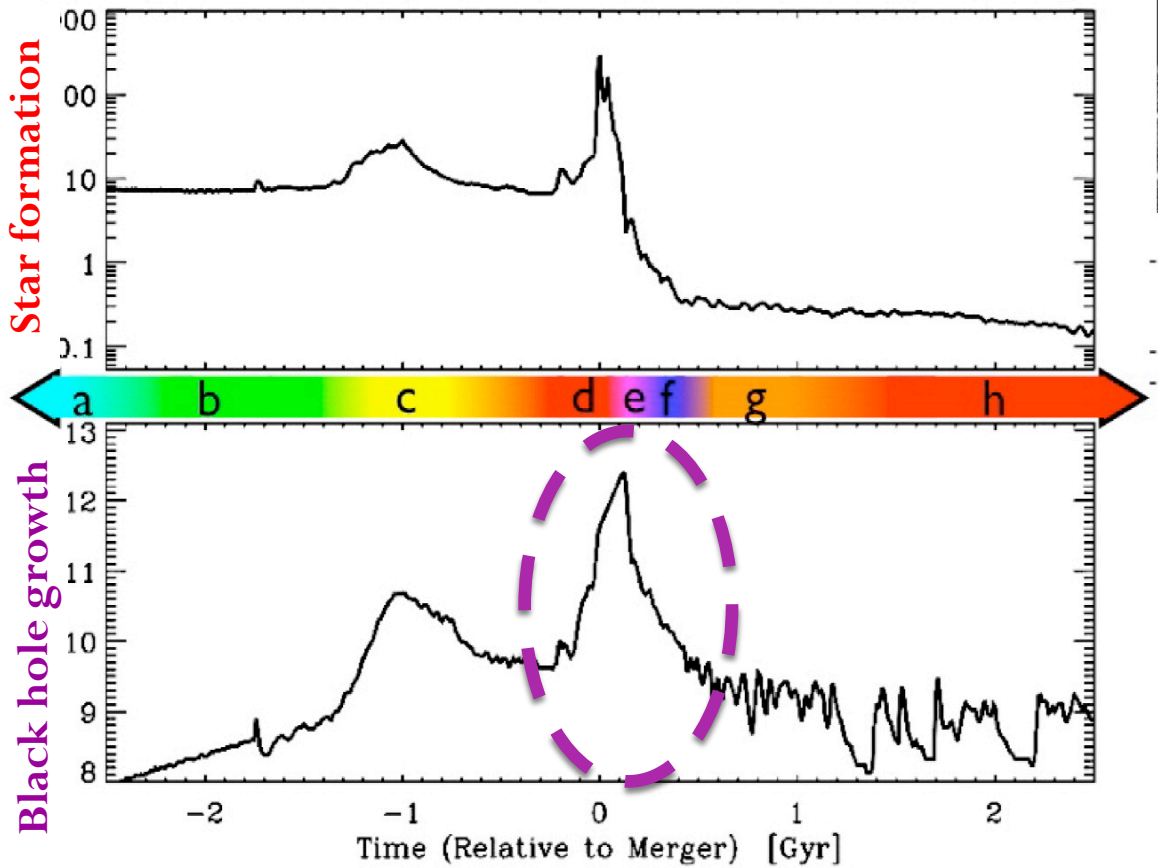

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Hopkins et al. 2008

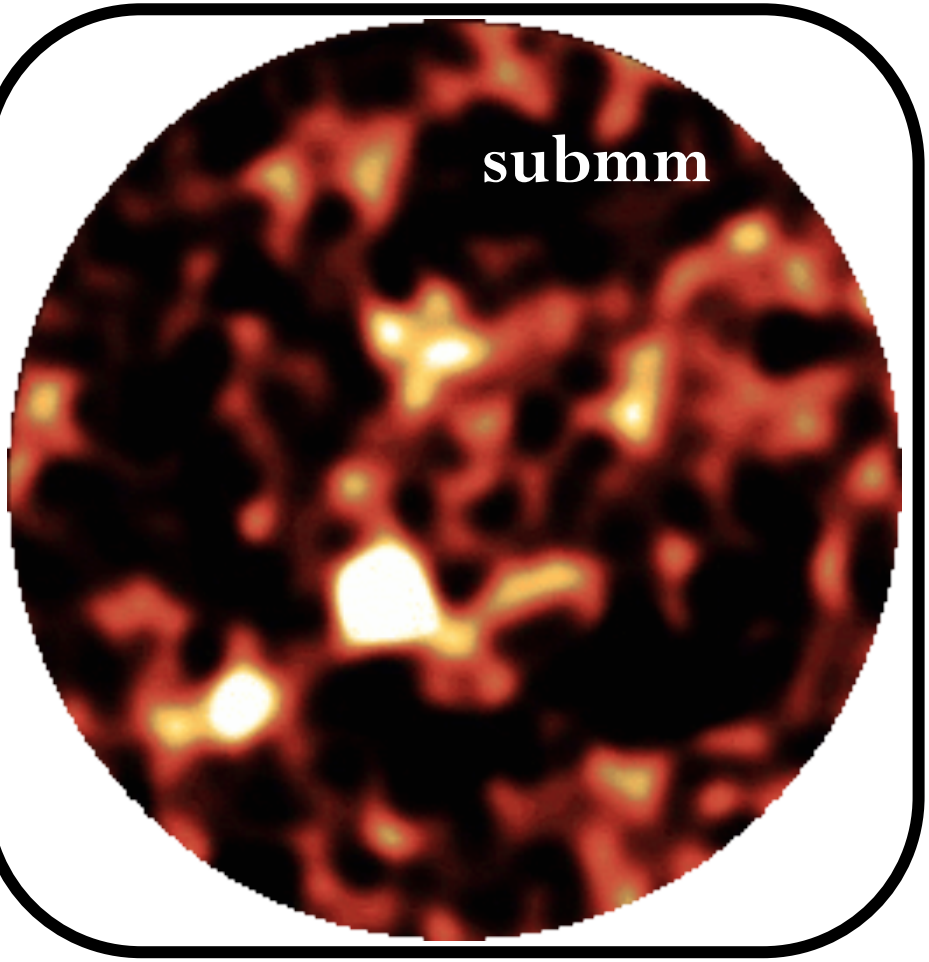
Ultra-luminous infrared galaxies (ULIRGs)

Star formation rates > 100 M_{sun}/year

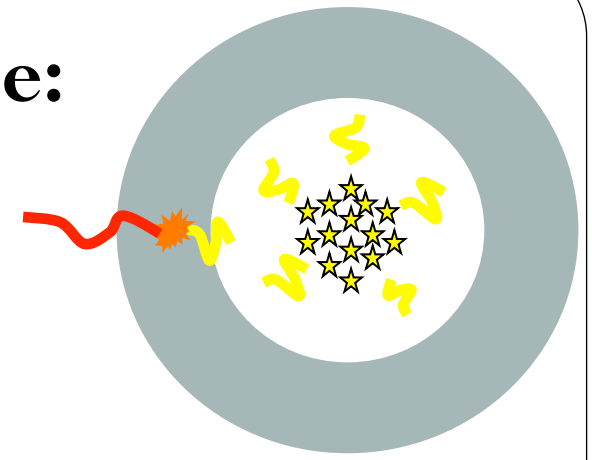
Local

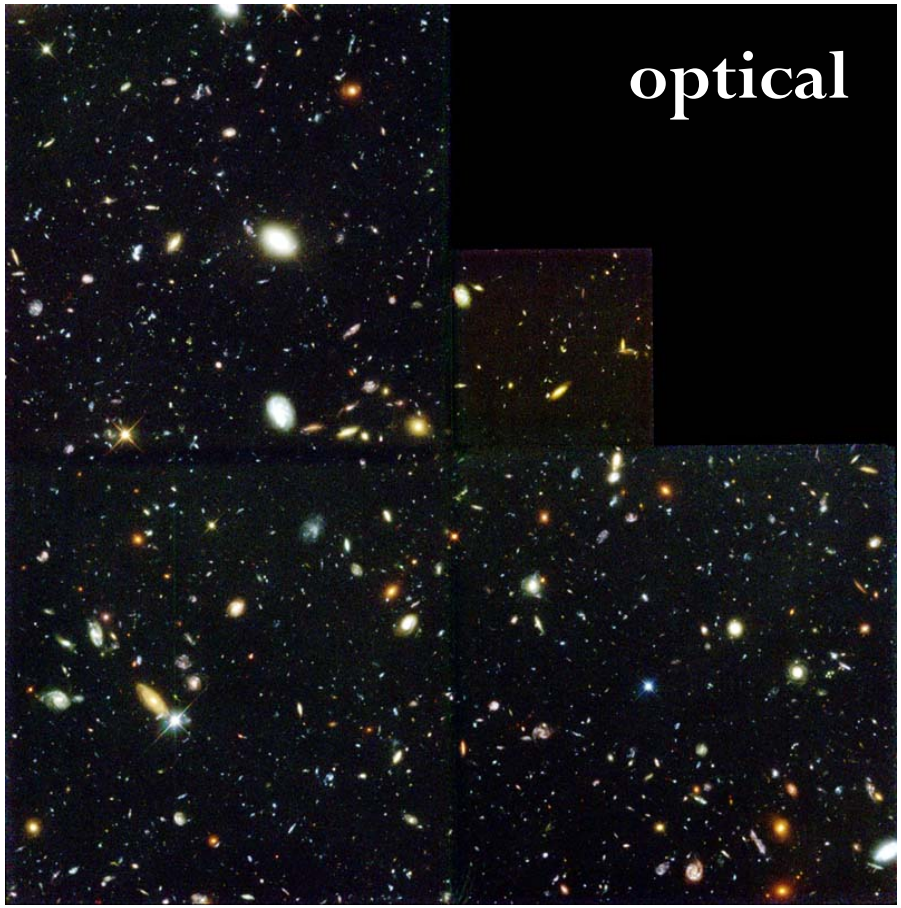
- **Complete samples of galaxies**
- **Show signs of star formation and rapid black hole growth: active galactic nuclei (AGN)**
- **Mostly major mergers**

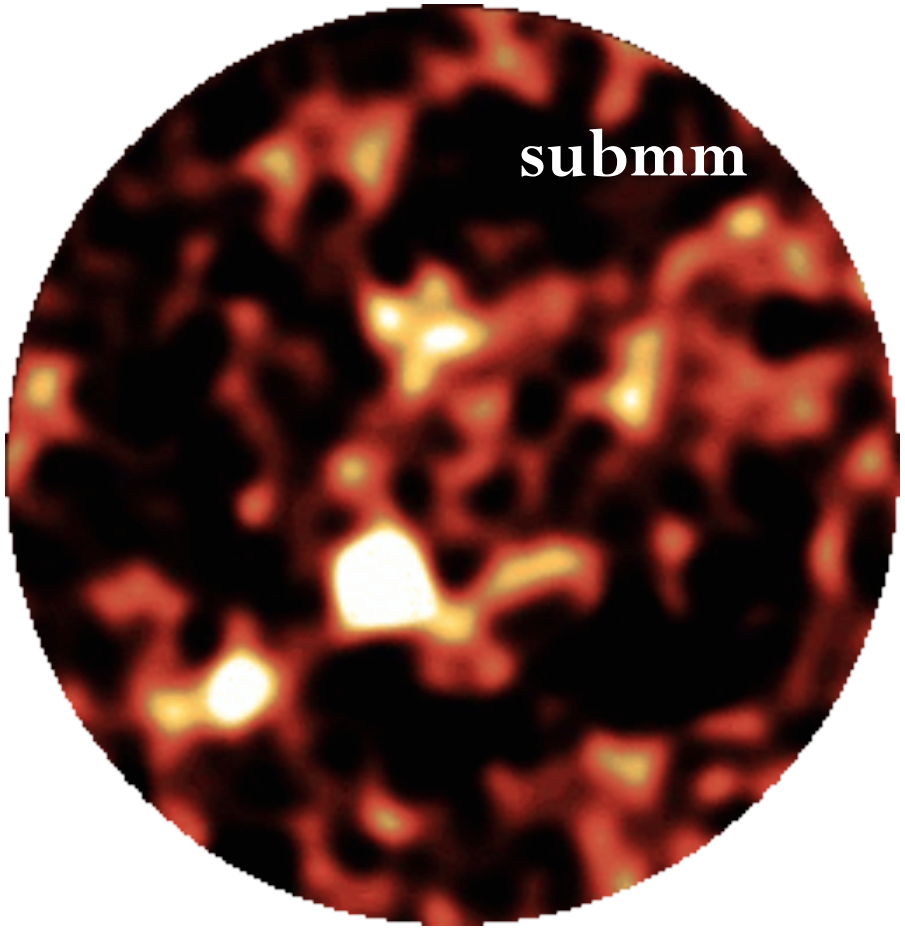
Distant Universe



The unobscured and obscured Universe: Optical and submillimeter images



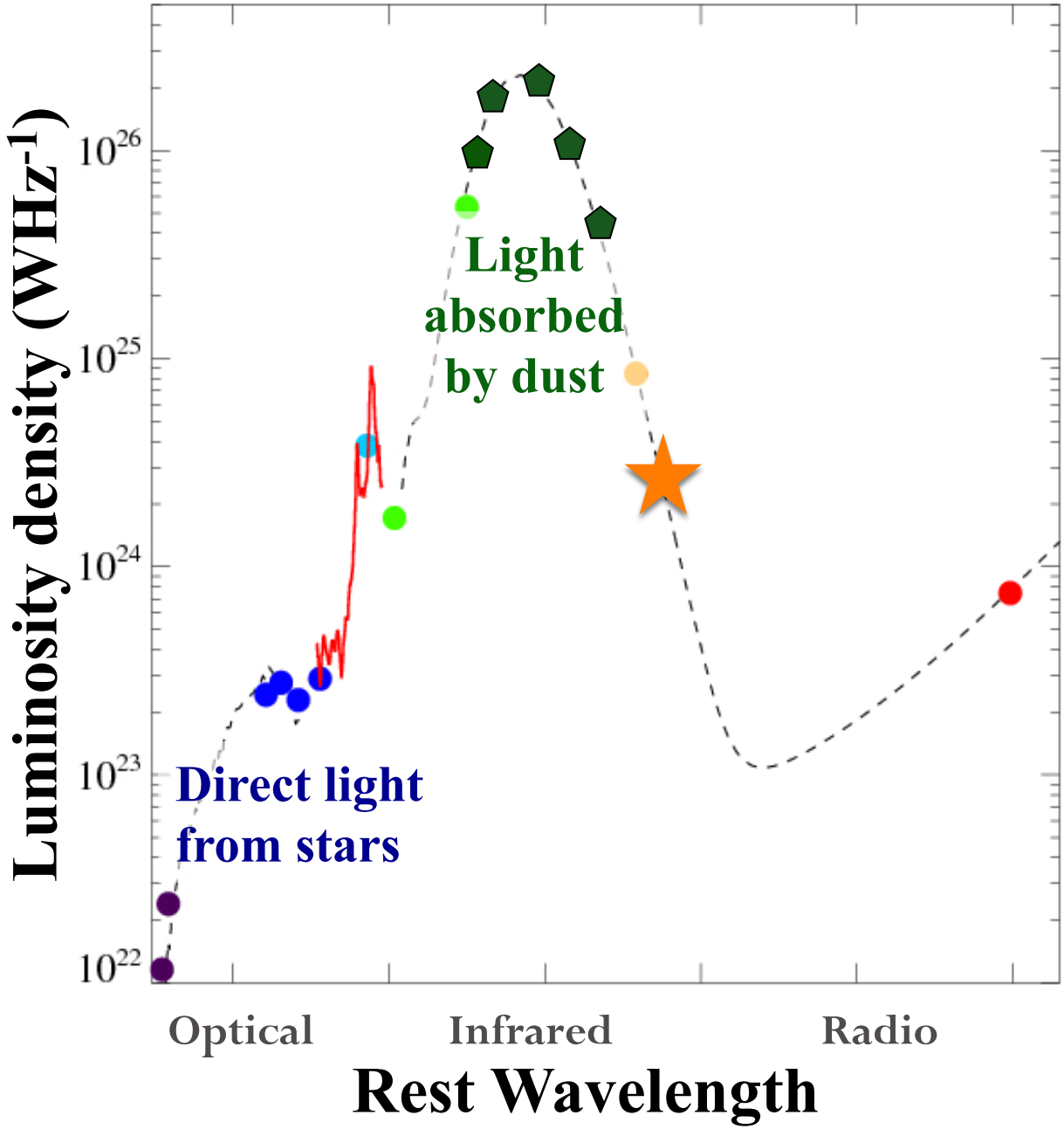




The Hubble Deep Field

Multi-wavelength Observations of Dusty Galaxies

Spectral energy distribution (SED) of high redshift ULIRGs [circa 2014]



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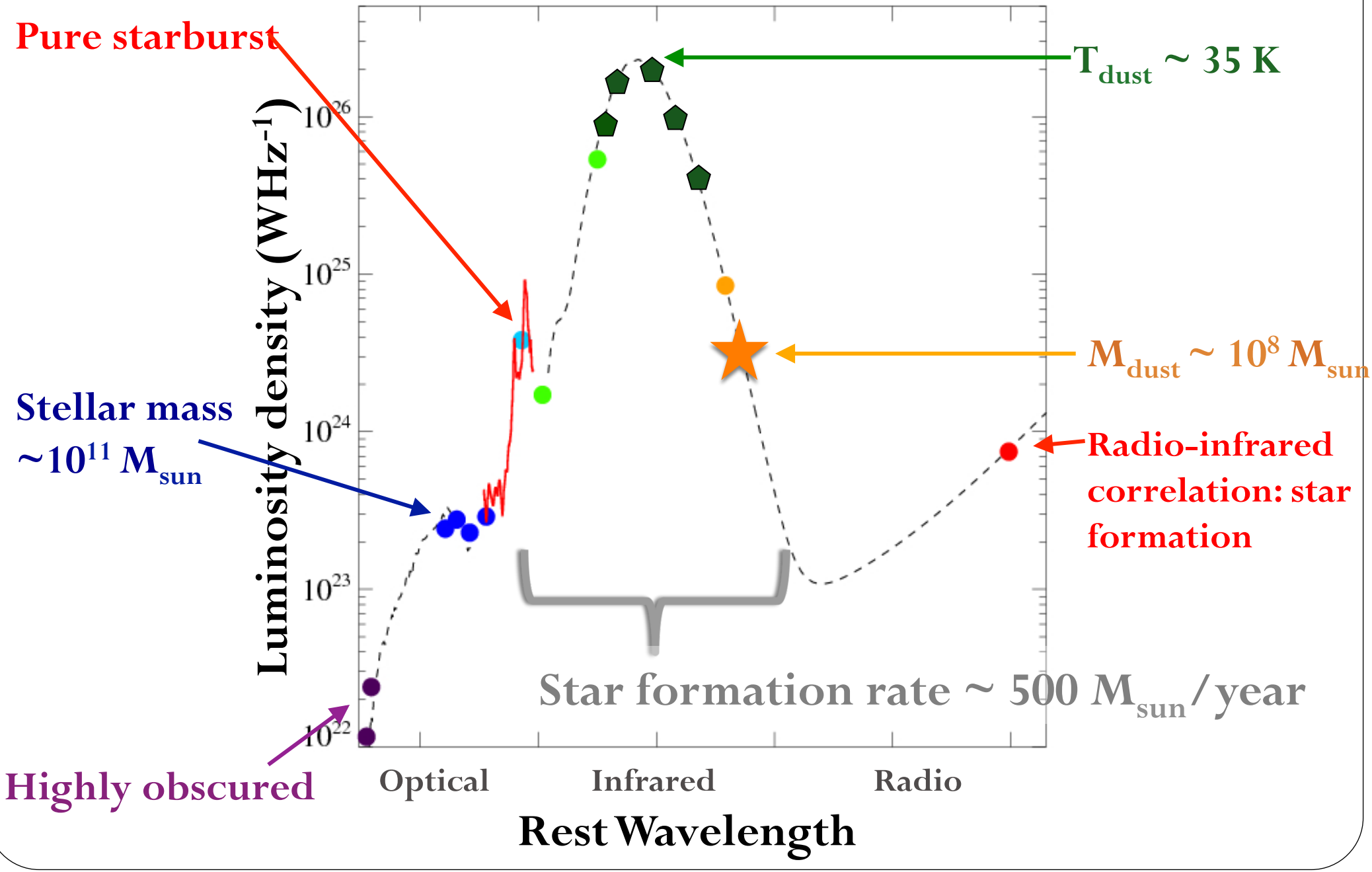

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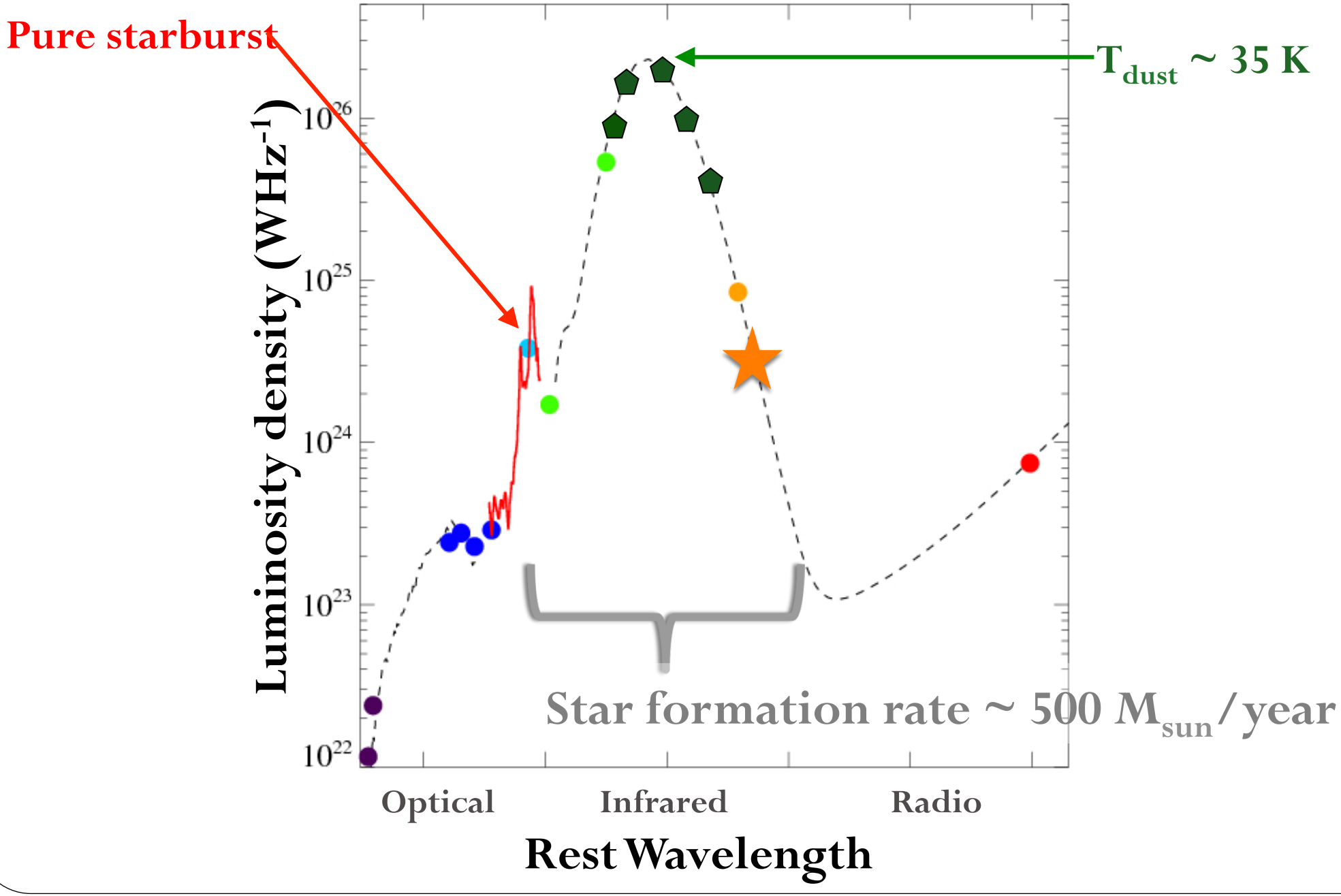
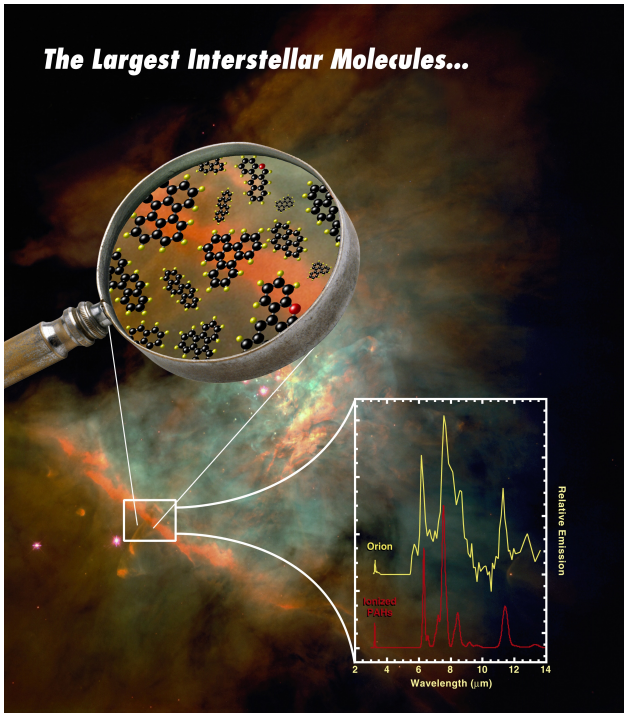
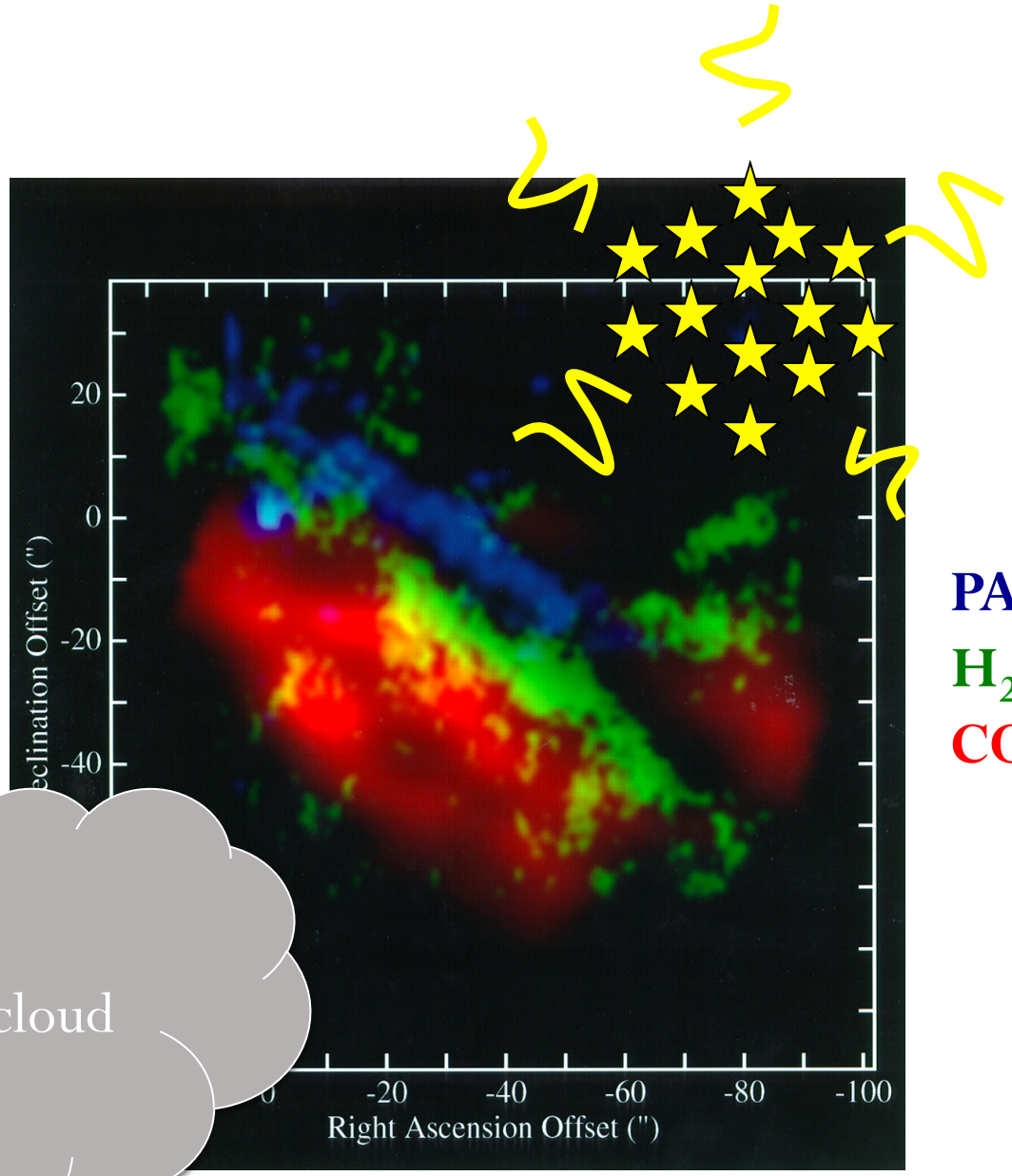


Polycyclic Aromatic Hydrocarbon (PAH) emission as a tracer of star formation





Molecular cloud

PAH

H_2

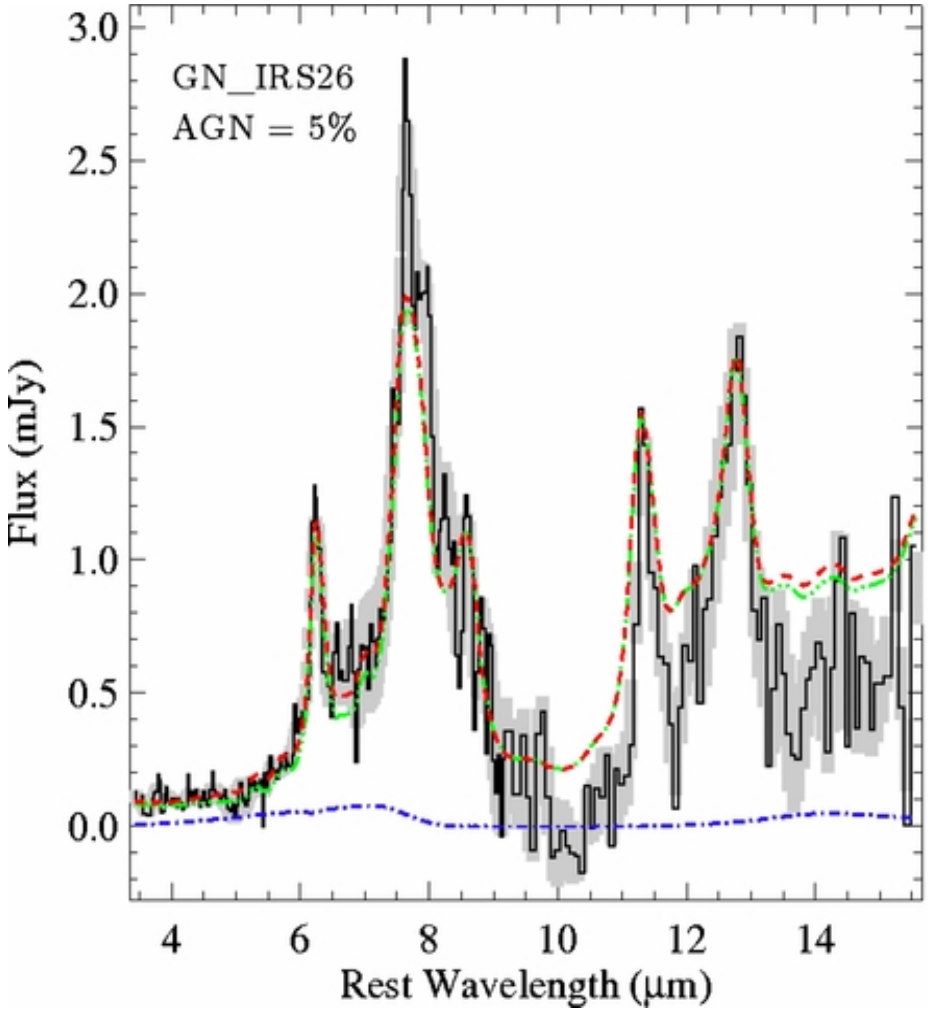
CO

Hollenbach & Tielens 1997

The mid-IR spectrum consists of two main components:

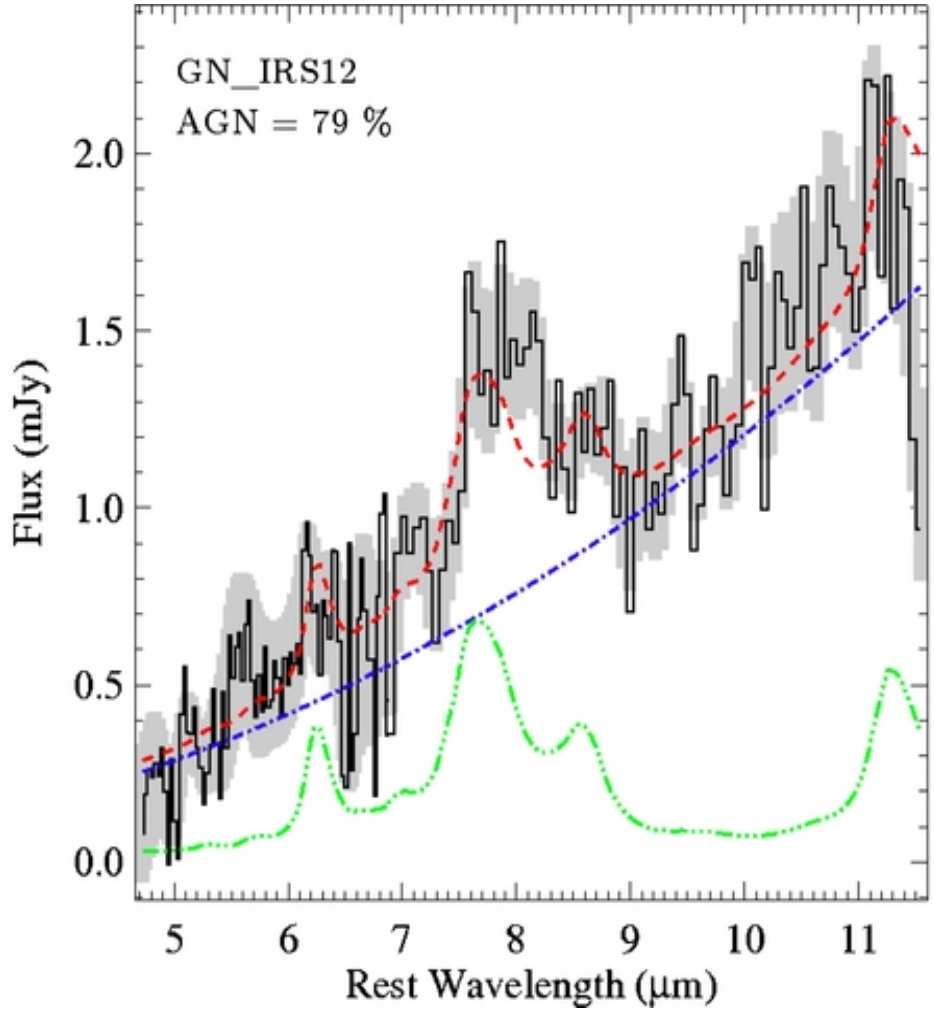
1. Starburst:

Polycyclic aromatic hydrocarbons (PAH) emission lines + extinction



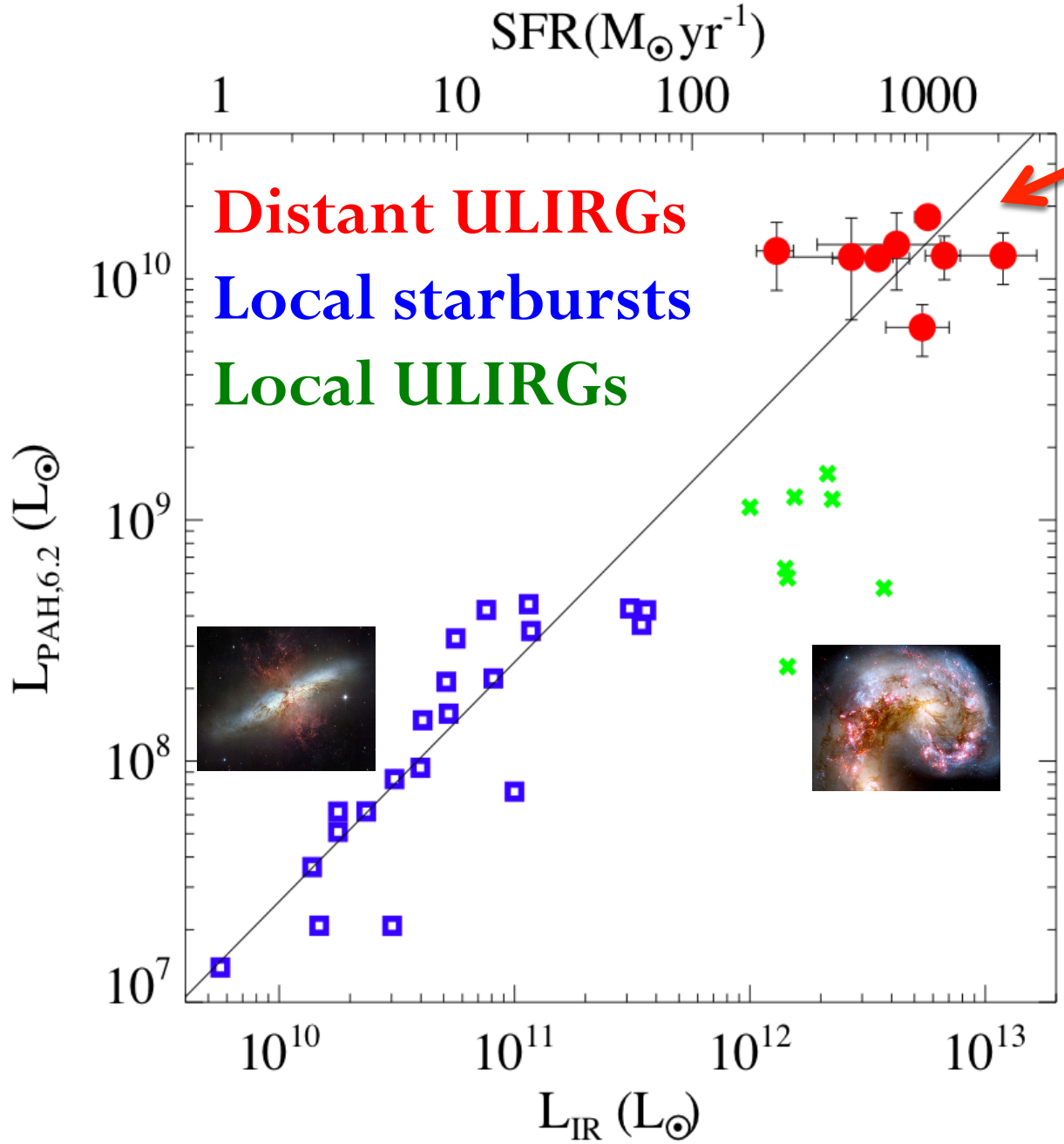
2. Active Galactic Nuclei:

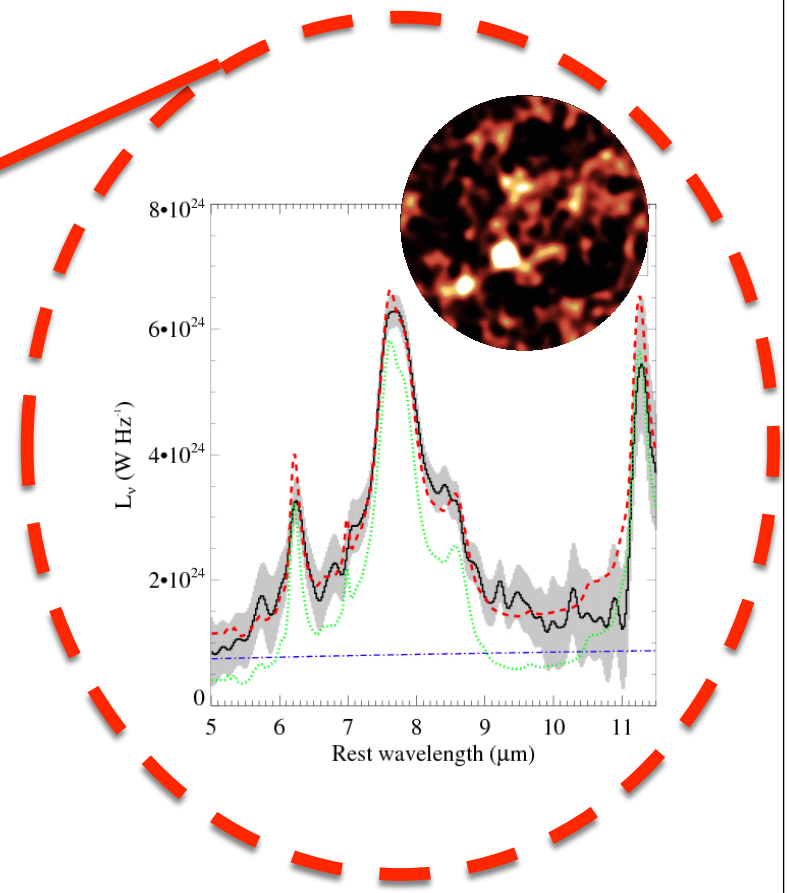
Power-law + extinction



Kirkpatrick, Pope, et al. 2012

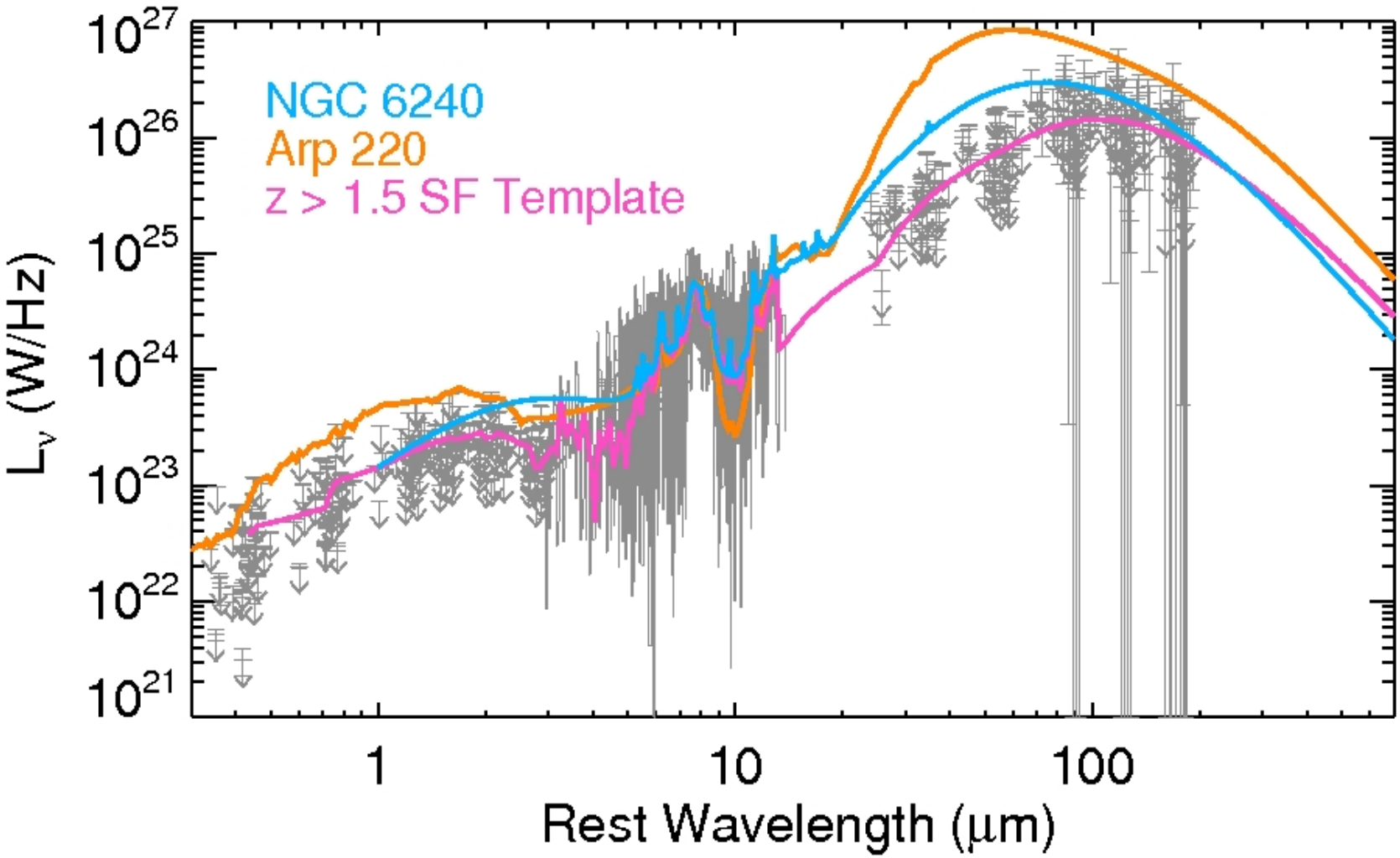
Distant dusty galaxies are scaled up local starbursts





Pope et al. 2008

Significant evolution in SEDs between local and distant dusty galaxies



Kirkpatrick, Pope, et al. 2012

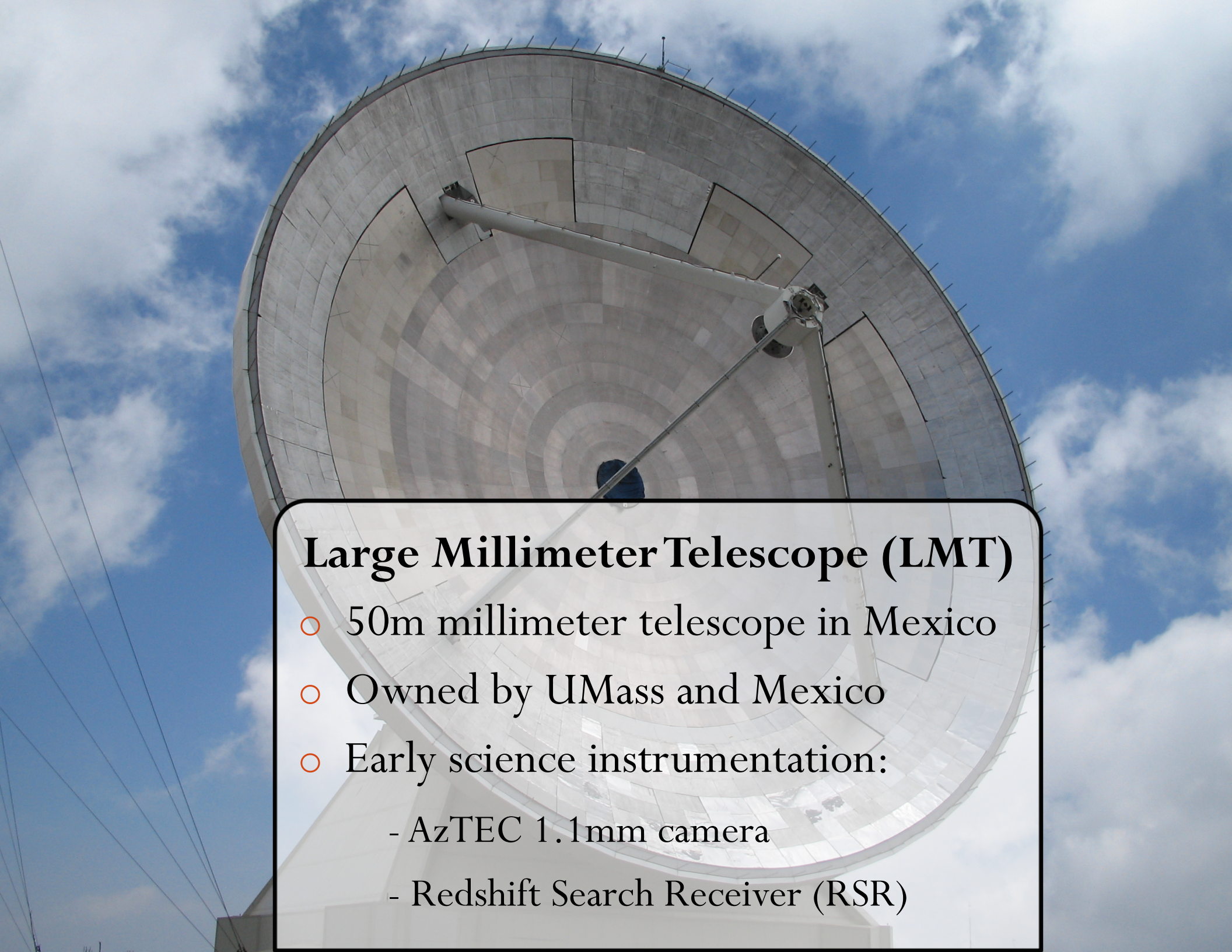
Distant dusty galaxies look different from their local counterparts – WHY?

- **Dust emission spectrum of galaxies is changing with cosmic time:** distant galaxies have less warm dust (more cold dust) and more PAH emission indicating a stronger starburst

- This is consistent with there being different triggering/fueling mechanisms (continuous gas accretion vs mergers) and more gas available at high redshift


ULIRGS

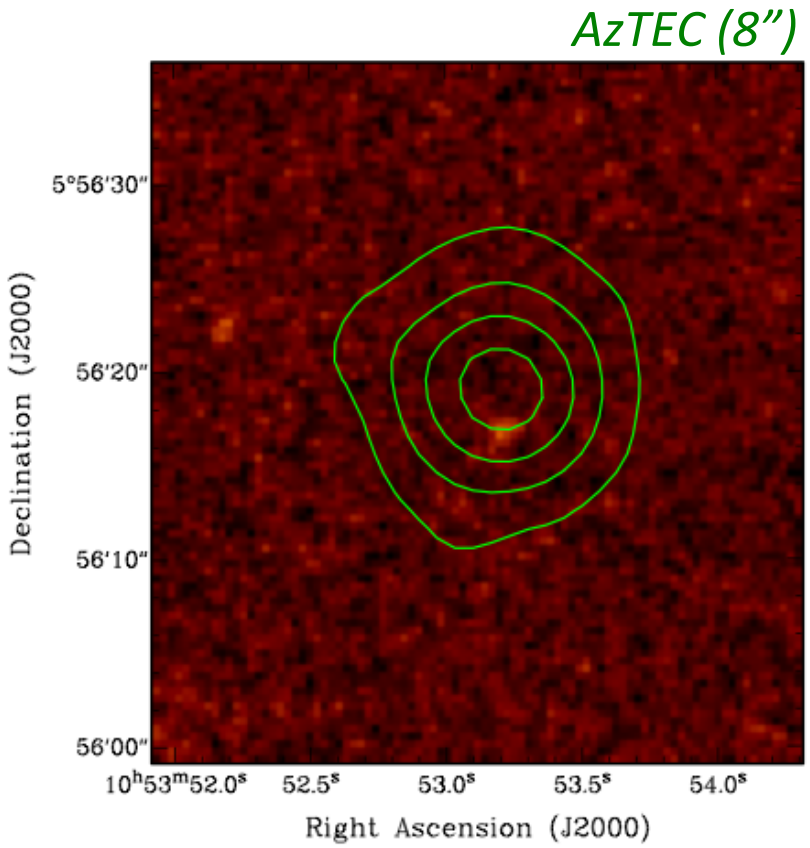
The Atacama Large Millimeter Array (ALMA)

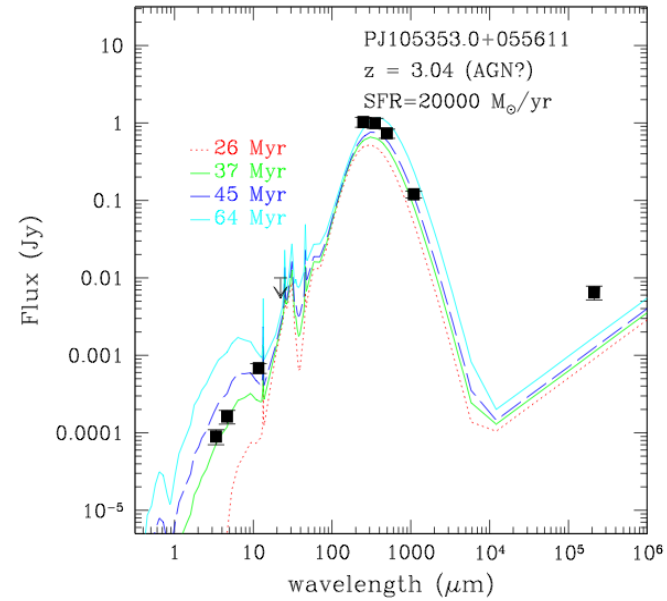


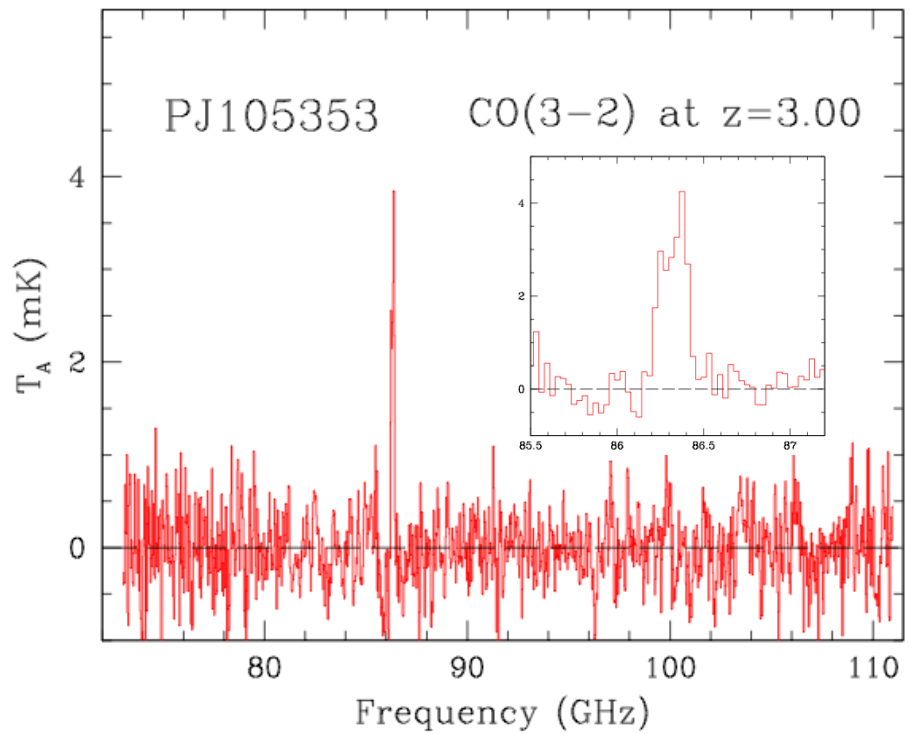
Large Millimeter Telescope (LMT)

- 50m millimeter telescope in Mexico
- Owned by UMass and Mexico
- Early science instrumentation:
  - AzTEC 1.1mm camera
  - Redshift Search Receiver (RSR)

LMT Early Science 2013/2014
(with 32.5m LMT surface)

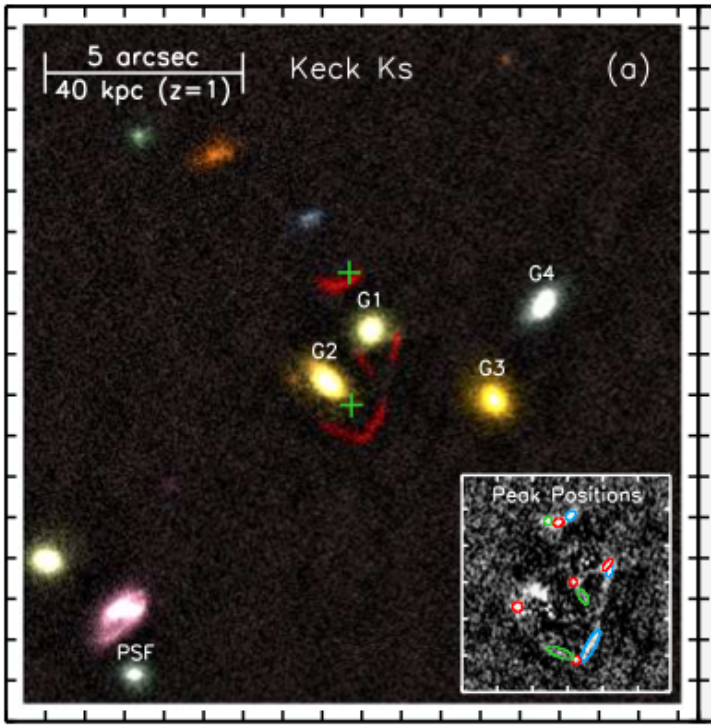






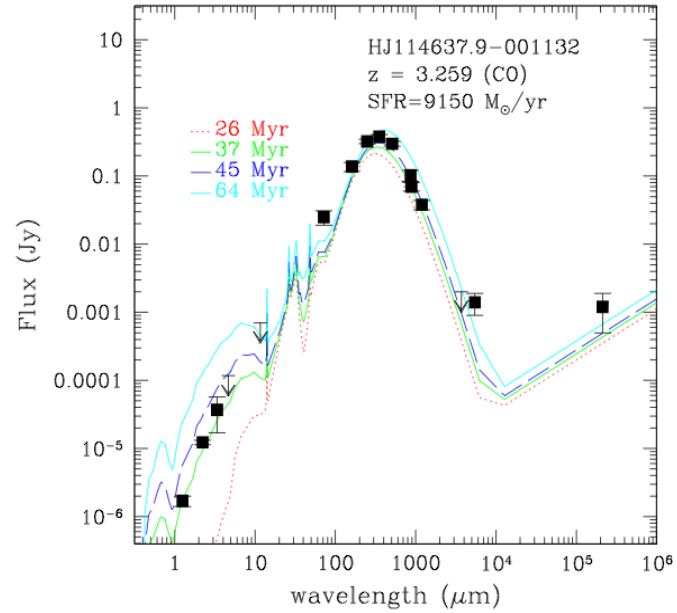
High redshift lensed galaxy: PJ105353 (z=3.00)

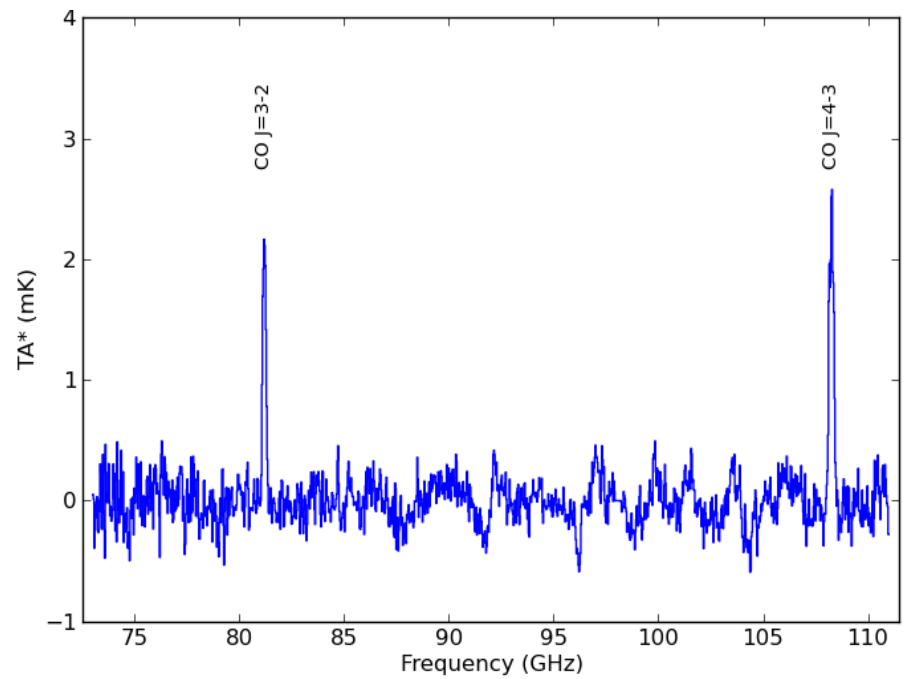
LMT Early Science 2013/2014
(with 32.5m LMT surface)



Fu et al. (2012)

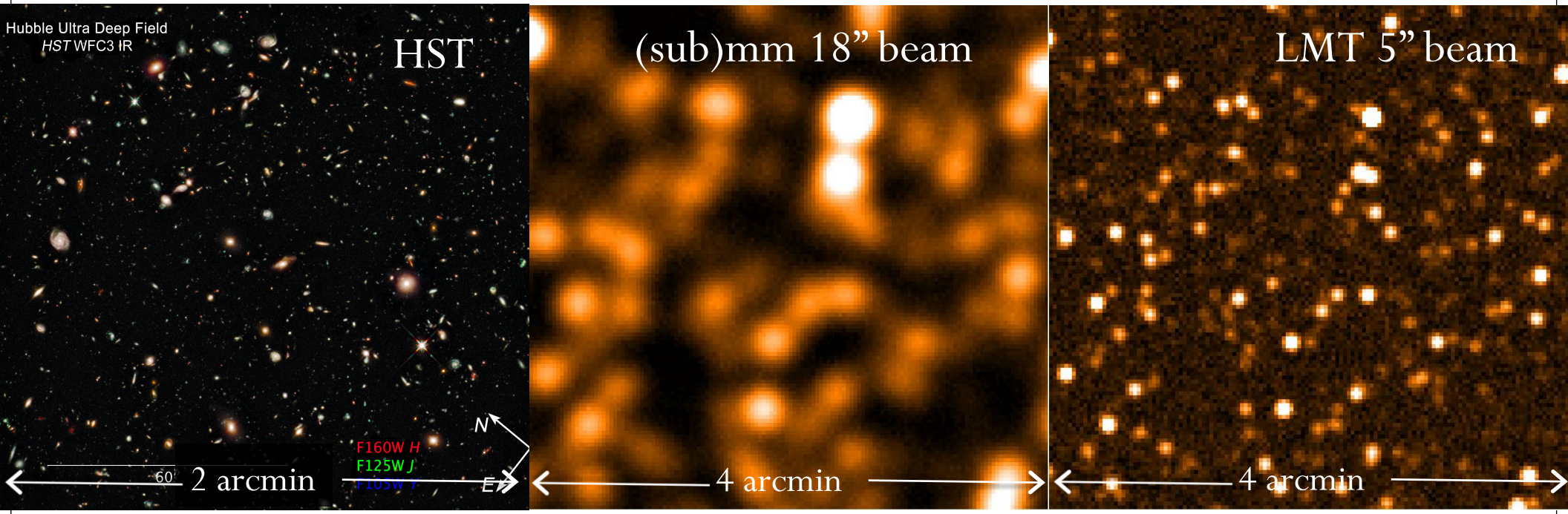
Red "arcs" are lensed images of the z=3.26 galaxy





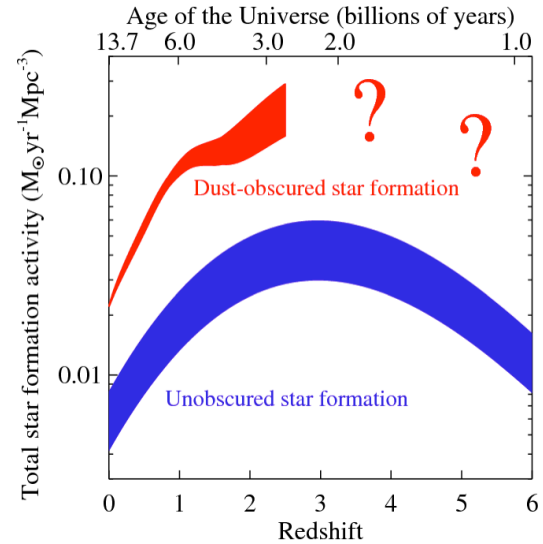
High redshift lensed galaxy: HJ114637 (z=3.26)

The Future: Synergy between **ALMA** and large single-dish telescopes like the **LMT**

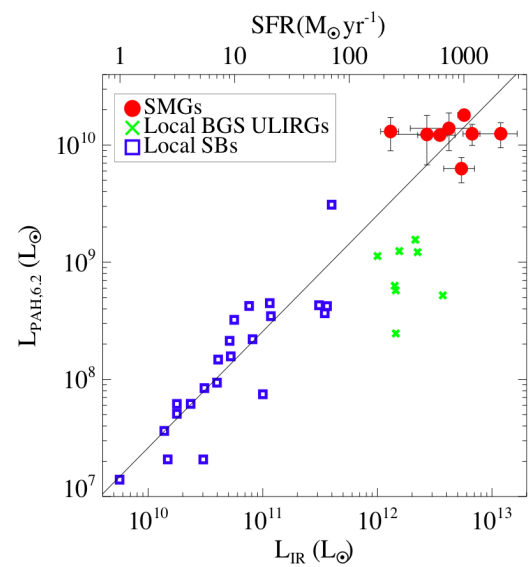


[Simulation]

SUMMARY



1. **Dusty galaxies are important for growing stars and black holes over cosmic time**



2. **Extremely dusty galaxies are different in the distant Universe: different dust emission spectrum indicating different fueling/triggering of the star formation**

3. **With upcoming facilities we will study dust emission in typical galaxies that dominate the build-up of stars in the Universe**

Thank you

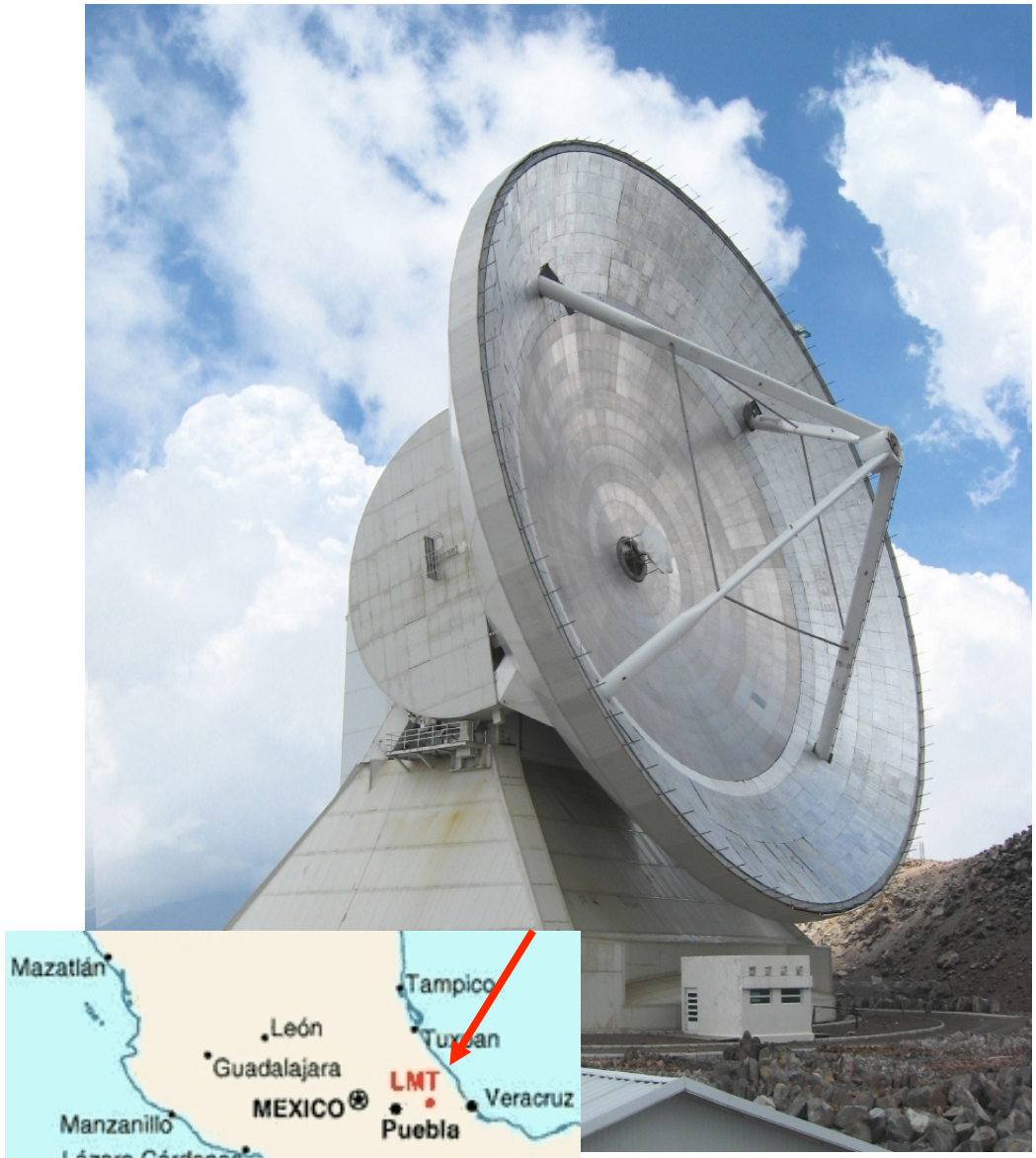
Large Millimeter Telescope (LMT)

- 50m Antenna
  - Operation: 4mm-0.85mm
  - Active Primary Surface

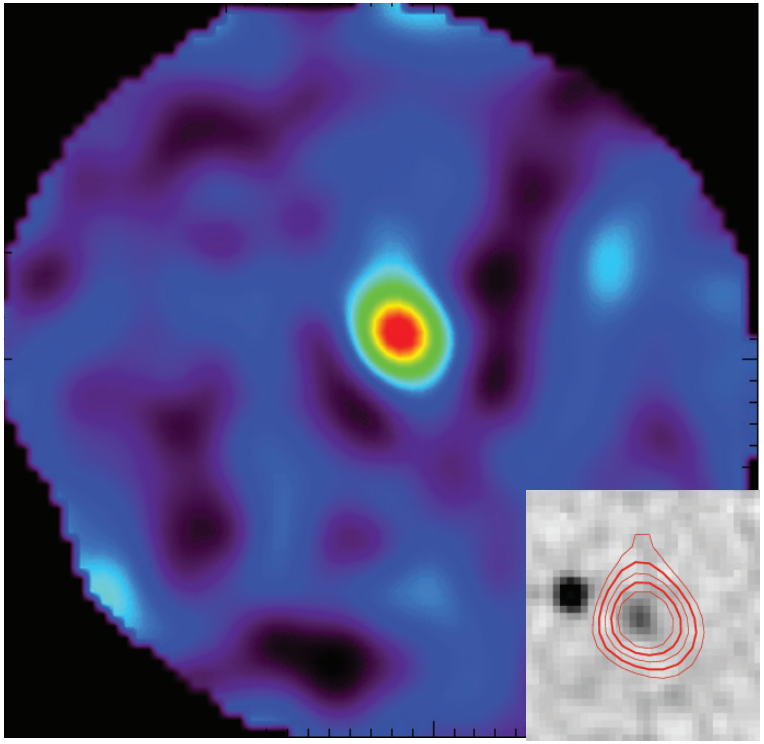
    75 microns rms.
- Located in Mexico
  - Excellent mm-wave site
  - High Altitude (15,000 ft)
  - +19 deg. Latitude
- Early science instrumentation:

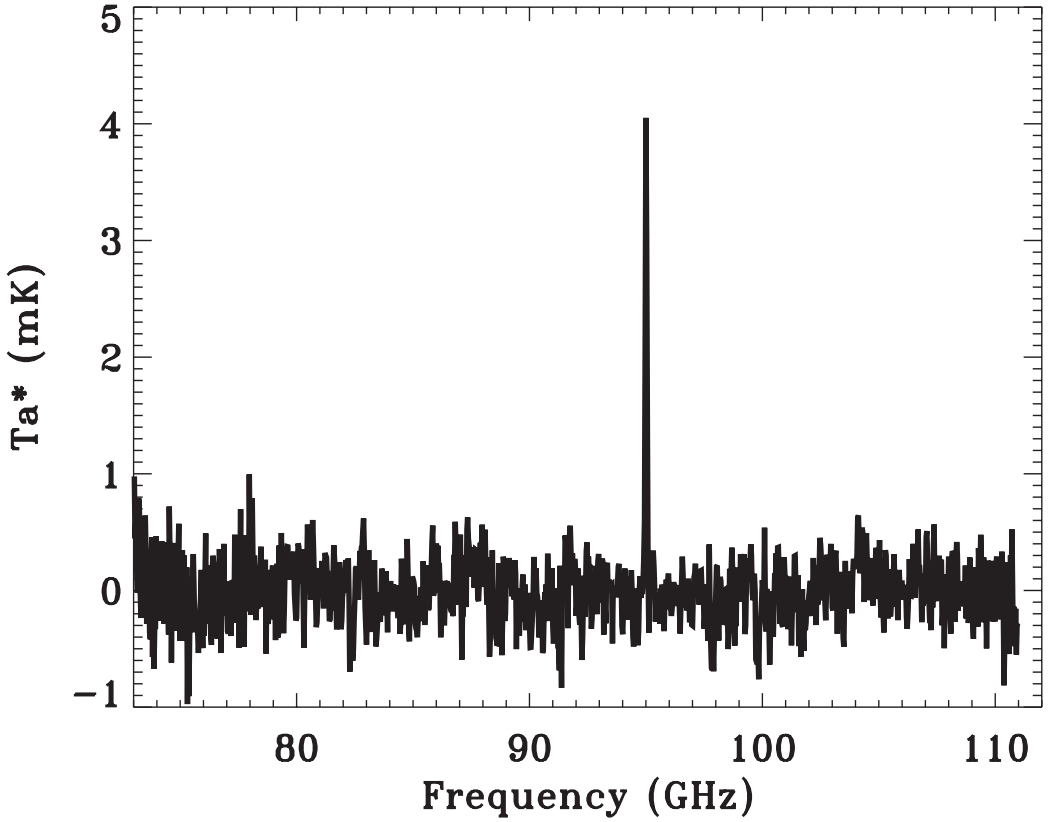
  AzTEC 1.1mm camera

  Redshift Search Receiver (RSR)



LMT Early Science 2013/2014
(with 32.5m LMT surface)

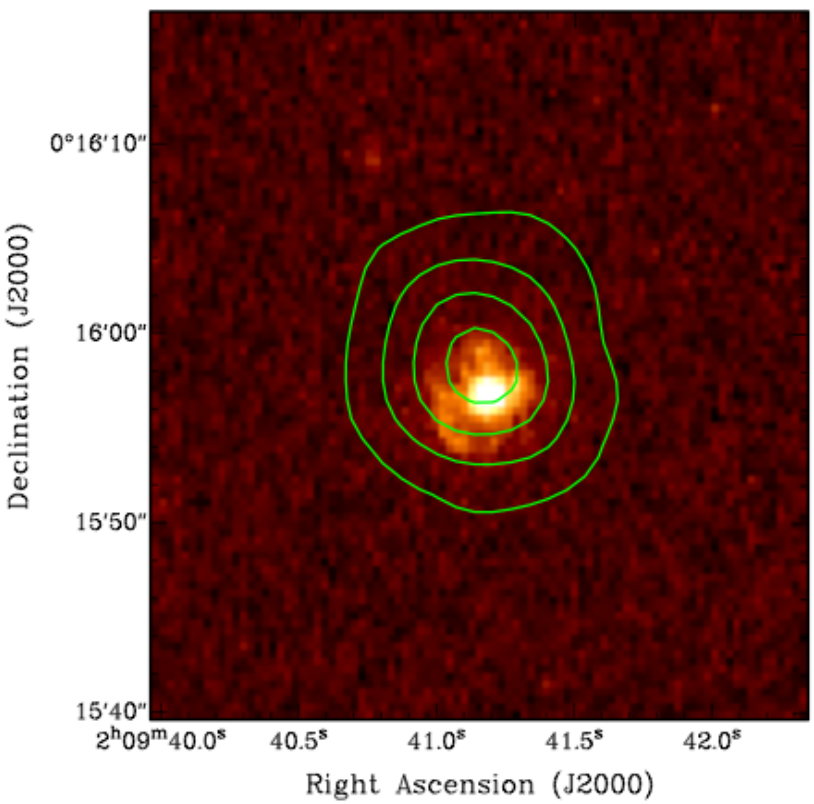


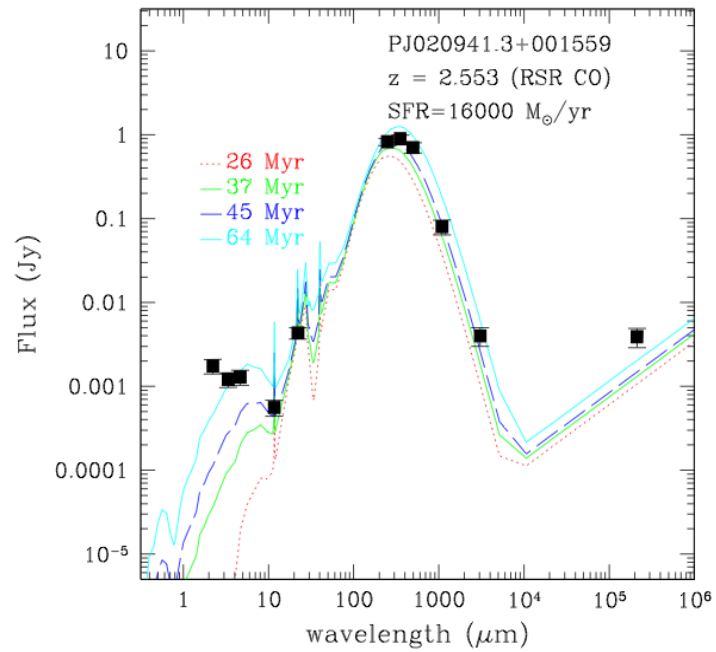


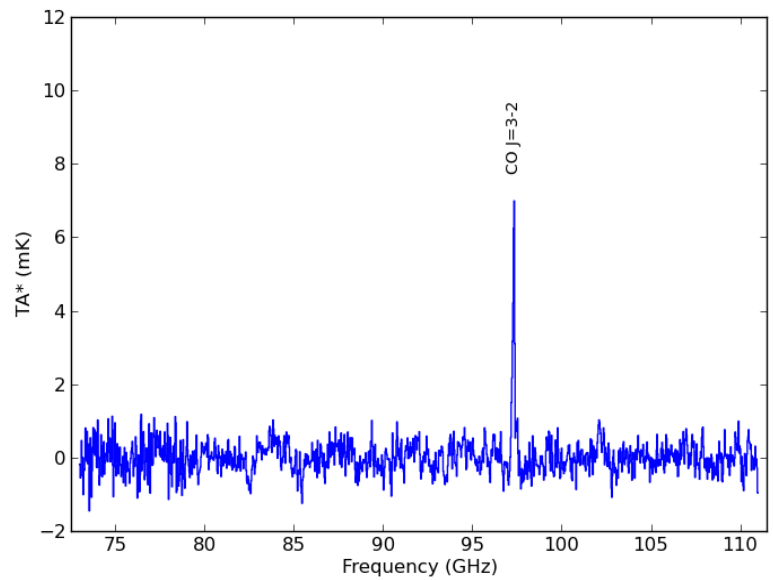
High redshift lensed submillimeter galaxy from ACT

LMT Early Science 2013/2014
(with 32.5m LMT surface)

AzTEC (8")







High redshift lensed galaxy: 9io9 (z=2.54)