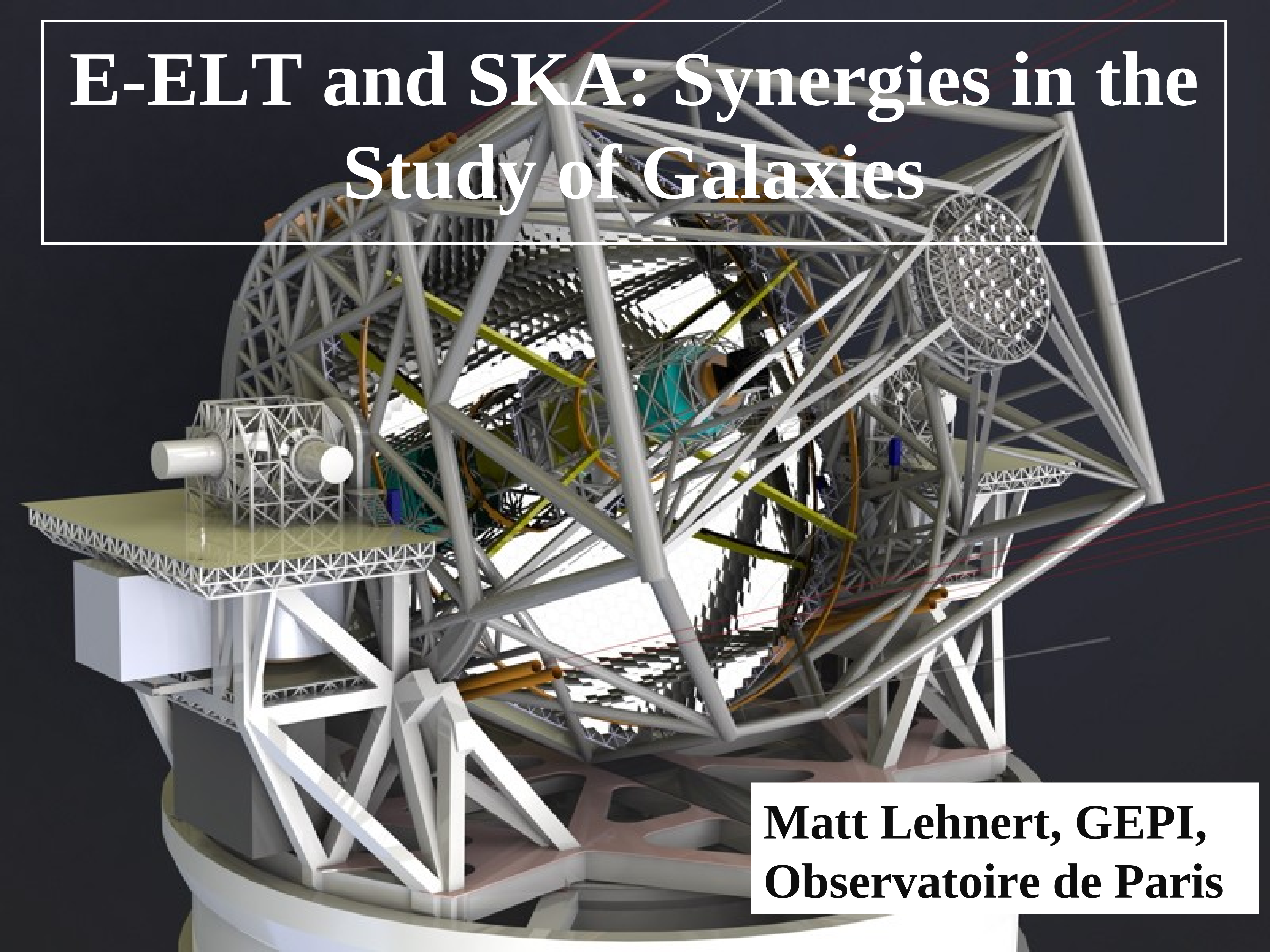
E-ELT and SKA: Synergies in the Study of Galaxies



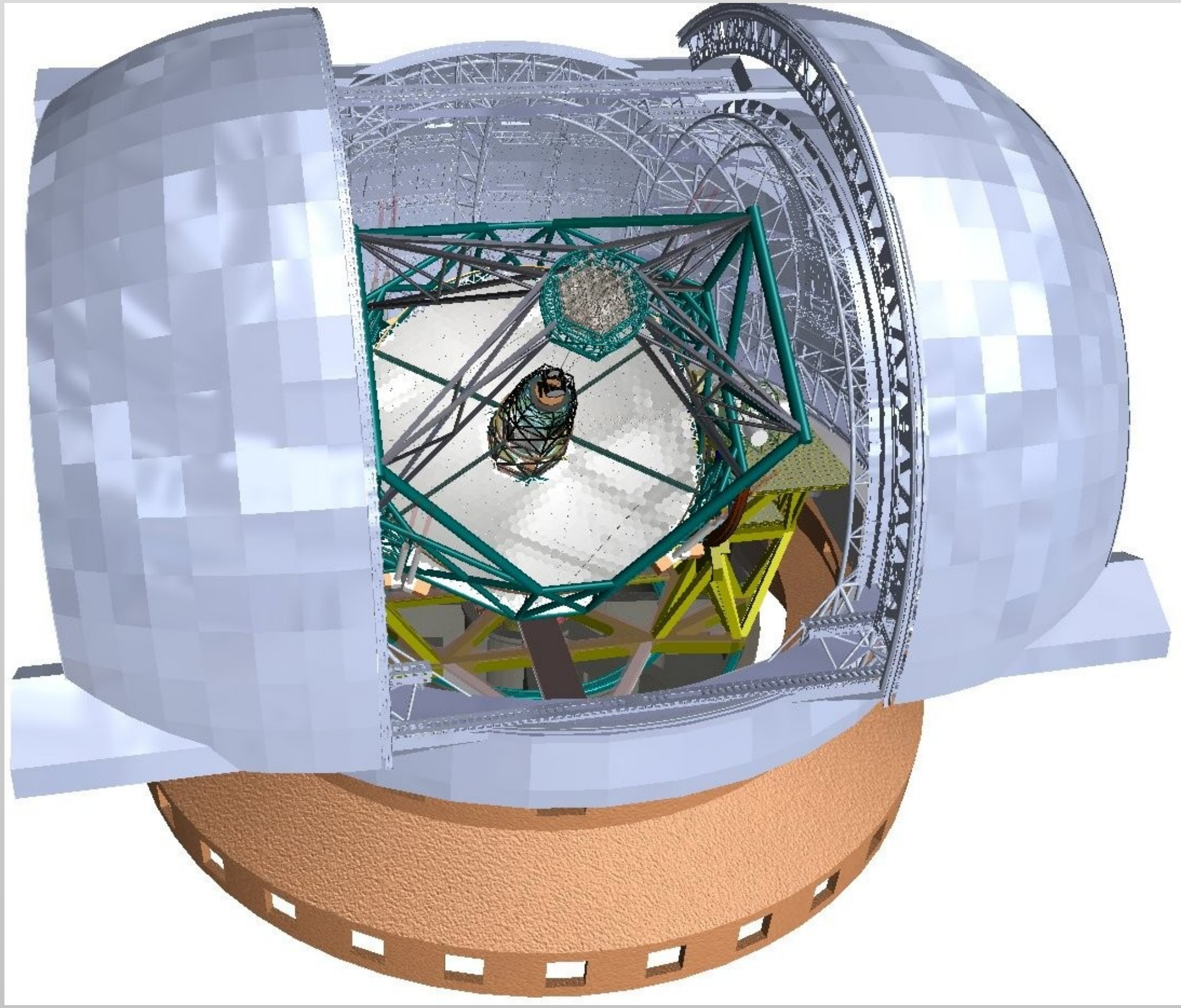
Matt Lehnert, GEPI, Observatoire de Paris

Baseline 5 Mirror Design

42m aperture
- 984 hexagonal segments
- 1.45m in size each
- f/1

3 powered mirrors
- 6m 2nd-ary
- M4 adaptive, 2.5m in diameter
- M5 at 2.7m provides tip-tilt

10' FOV
- Flat – GLAO fed – 6 LGS
- lowers instrument complexity
- can raise throughput
- novel correction schemes possible



… but is complex … 85000 elements, 27000 nodes … scheduled for completion in ~2018 …

“Prominent” E-ELT Science Drivers

1) Planets and Stars:
Extrasolar Planets (S3)
Circumstellar disks (S9)
Young stellar clusters and the IMF (S5)

2) Stars and Galaxies:
Imaging and spectroscopy of resolved stellar populations in galaxies (G4)
Black Holes and AGN (G9)

3) Galaxies and Cosmology
Physics of high redshift galaxies (C10)
First light-the highest redshift galaxies (C4)
Dynamical measurement of universal expansion (C2)
Is the low-density intergalactic medium metal enriched? (C7)

Phase A E-ELT Instruments

Instrument concepts

Instrument parameters	CODEX	EAGLE	EPICS		HARMONI	METIS			MICADO		OPTIMOS				SIMPLE
											EVE		DIORAMAS		
Mode	SOS (fibre)	Multi-IFS	IFS-L/M/H resolution	EPOL	IFS	Imaging (coronograph, polarimeter)	SOS (long slit)	IFS	Imaging	SOS (long slit)	MOS (fibres) L/M/H resolution	Multi-IFS	Imaging	MOS (slits) L/H resolution	SOS (long slit)
Wavelength range (μm)	0.368 – 0.723	0.8 – 2.45	0.95–1.70 (LM) 0.95 – 1.15 (H) 1.15 – 1.40	0.6 – 0.9	0.82 – 2.4	2.9 – 13.8	One of L,M,N bands	2.9 – 5.3 (LM) 7.6 – 13.8 (N)	0.8 – 2.4	One band within 0.8 – 2.4?	0.37 – 1.7	0.37 – 1.7	0.37 – 1.4	0.37 – 0.8 (L) 0.4 – 1.4 (H)	0.84 – 2.5
Size of FoV (arcsec)	0.82 ∅ fibre	438 ∅ patrol field 1.65 × 1.65 pick-off	0.8 × 0.8	3 × 3	0.51 × 1.02 1.28 × 2.56 2.56 × 5.12 5.12 × 10.24	18 × 18	18 slit length	0.4 × 1.6	53 × 53	6 16 slit length	420 ∅ patrol field 0.9 ∅ fibre	420 ∅ patrol field 2 × 3 pick-off	420 × 420	420 ∅ patrol field 5 slit length	0.45 4 slit length
Pixel/spaxel size (mas)	n/a	75	2.33	1.5	4 10 20 40	17.2 (LM) 34.4 (N)	17.2 (LM) 34.4 (N) in spatial direction	18 (LM) 44 (N)	1.5 4	1.5 4 in spatial direction	n/a	0.3	50	500 in spatial direction	9 in spatial direction
Spectral resolution	115300	4000 10000	125 (L) 1500 (M) 21000 (H)	n/a	4000 10000 20000	n/a	1700 (LM) 1000 (N) 2300	100000 (LM) 50000 (N)	n/a	3000 5000	5000 (L) 20000 (M) 40000 (H)	5000	n/a	>300 (L) >3000 (H)	100000 – 150000
Multiplexity		20									>300 (L) >80 (M) >25 (H)	25		500 (L) 170 (H)	

Summary provided by J. Liske

Wide range of scientific capability (atm cut-off to thermal IR):

- Diffraction limited imaging/spectroscopy (few mas)
- Light bucket optical spectroscopy w/fibres or slits
- Optical and near-infrared IFS w/multiplex 1-20 and good AO correction for the near-IR instruments
- Spectral resolutions from ~200 to ~150000

<u>Will be a call for 2 1st light instrument studies … early 2011?</u>

Galaxy Formation: Why so Difficult?

Developing a coherent model for the growth of baryons in galaxies is inherently difficult. Why?

- Highly non-linear problem
- Wide range of physical scales (LSS to Galaxies to Stars)
- Lots of marginally constrained physics like AGN- and starburst-driven feedback, star-formation efficiency, gas accretion/infall, merging, etc. − all highly stochastic.

↓

Yet little direct predictive power – need observational constraints

Need to trace the physical nature of all components of the gas

Galactic and Extra-Galactic Cycles

Big bang cooling to nucleosynthesis

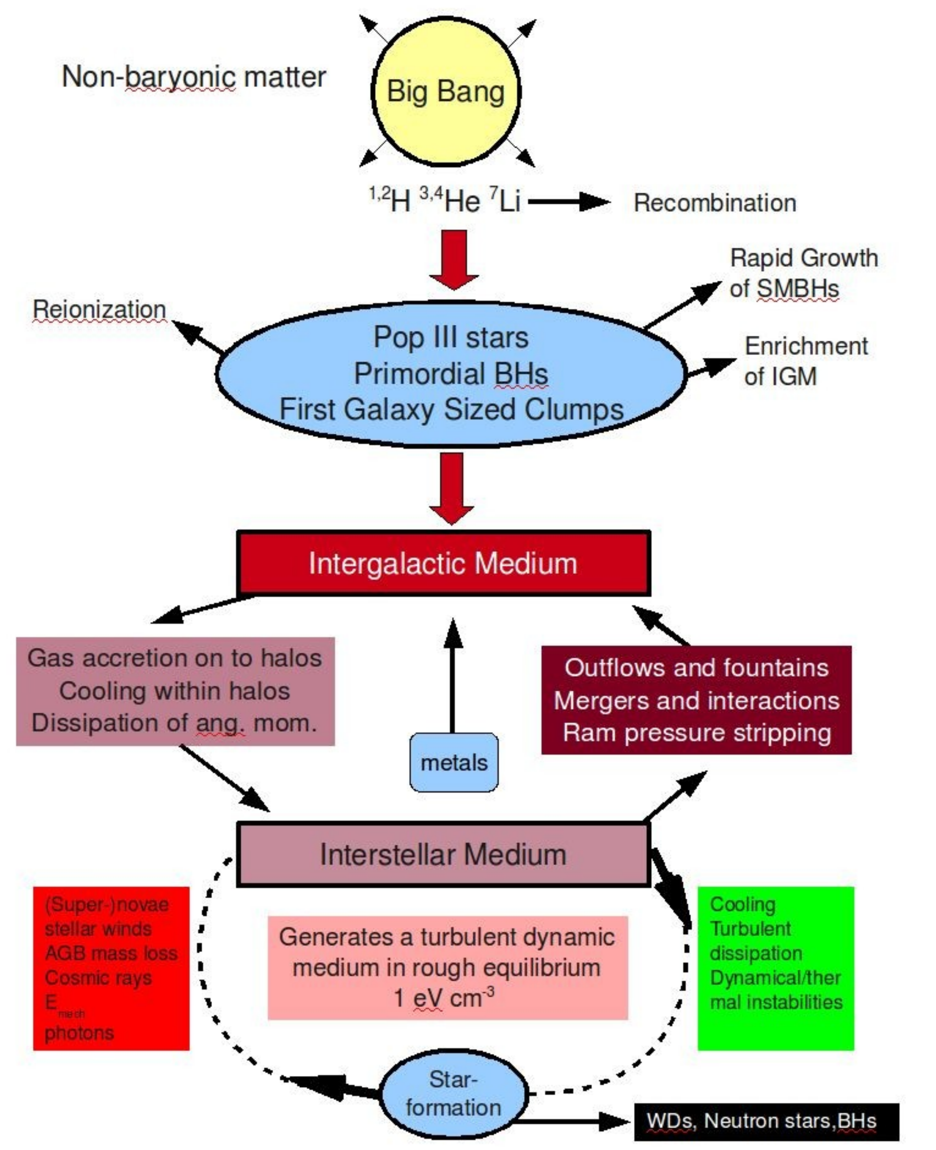
First objects and galaxies form
Reionization

Cosmic web forms through gravitational infall

Infall and outflow into and out of halos

Complex cycle of cooling and heating controls the ISM

Galaxies become stellar dominated



Constituent	Observable	Diagnostic
Relativistic Plasma	Radio continuum X-ray continuum	Magnetic field, aging of electrons, relativistic or thermal pressure, jet collimation star-formation rate, number of X-ray binaries
Hot ionized gas $T \sim 10^7$ to 10^8 K log $n_e \sim -3$ to -1 cm^{-3}	X-ray continuum, emission and absorption lines Radio depolarization	Thermal pressures, metal abundances, density, mass, cooling rate, viscosity, turbulence, outflow rate
Warm ionized gas $T \sim 10^4$ to 10^6 K log $n_e \sim -1$ to 3 cm^{-3}	UV absorption lines Optical emission lines Radio recombination lines Far-IR emission lines	Temperature, shock heating or photoionization rate, density, mass, turbulence, dynamics, metallicity, filling factor, pressure, outflow rate, cooling rate
Warm neutral gas $T \sim 4\text{-}8 \times 10^3$ K log $n_e \sim 0$ to 2 cm^{-3}	Optical em/abs lines HI emission and absorption Mid-IR H-H lines Far-IR lines of neutral species	Filling factor, temperature, column densities, cooling rate, pressures,masses, etc.
Cold neutral gas $T \sim 10^2$ K log $n_e \sim -1$ to 0 cm^{-3}	HI emission and absorption	Filling factor, temperatures, column densities, cooling rate, pressure, masses, etc.
Warm molecular gas $T \sim 0.5\text{-}2 \times 10^3$ K log $n_e \sim 1$ to 4 cm^{-3}	Mid-IR H-H lines High order molecular lines of neutral and ionized species	Filling factor, temperatures, column densities, cooling rate, pressure, masses, etc.
Cold molecular gas/dust $T < 10^2$ K log $n_e > 4$ cm^{-3}	Molecular lines Infrared dust continuum Mid-infrared features	Heating and cooling rates, dynamics, turbulence, masses, densities, temperature, pressure, cosmic ray heating rate, interstellar chemistry, etc
Stars	UV/optical/near-infrared continuum	Mass, dynamics, star-formation history, metallicity, energy injection rate, mass return rate, etc.

Topic	SKA	E-ELT
Reionization	HI emission/absorption First Radio Sources for absorption lines	Mid-infrared H_2 H and He emission UV absorption lines (galaxies, GRBs)
Galaxy Dynamics	HI profiles and rotation curves HI absorption	Stellar absorption lines Optical emission lines
AGN Feedback	Mechanical power of AGN Pressure of relativistic fluid HI emission and absorption for the HI content and dynamics Radio recombination lines	UV/optical absorption lines UV cooling lines for warm to hot gas (OVI) Optical/near-IR emission lines Mid-infrared H_2
Gas Accretion	HI distribution in halos from both absorption and emission	QSO metal and Ly-alpha "forest" lines in UV and optical UV cooling lines for warm to hot gas (e.g., OVI) Optical emission lines
Outflows	Radio recombination lines, radio continuum, supernova rate, pressures, compton heating, HI absorption and emission	UV/optical absorption lines QSO absorption lines UV cooling lines for warm to hot gas (OVI) Optical/near-IR emission lines Mid-infrared H_2
Redshift surveys and Large scale structure	HI velocity centroids – large field of view, wide z	UV/optical emission lines Stellar absorption lines

Conclusions

To understand galaxy formation and evolution, we must:

• Understand the heating and cooling of gas on scales from individual stars (star-formation), compact star clusters, HII regions, HII region complexes, bulges, disks, galaxy halos, groups, clusters and filaments. Challenging to say the least.

• This understanding will only come by probing gas over a range of temperatures, 10^1 to 10^8 K, densities, log n~-4 to 9 cm^{-3}, ionization parameters, log U~-5 to 1, and shock speeds, v_{shock}=3 to 30000 km s^{-1}.

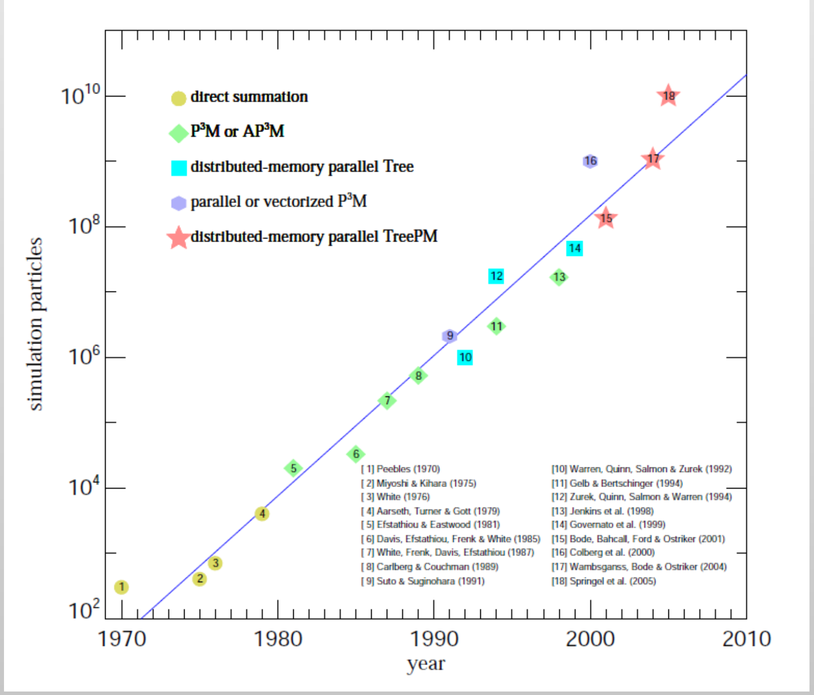
• Because of the scale of the problem and the variety of scales, astrophysics is still an empirical science. The better our observations, the more physical understanding we have to put into the models.

The combination of SKA and E-ELT will allow us to investigate many problem related to galaxy formation and evolution.

Conclusions

To understand galaxy formation and evolution, we must:

• By mid-2020s, simulations will be able to model every star in the MW or particle masses in cosmological scale simulations to the size of globular clusters with faster computers and better algorithms. But will our understanding of the physics be any better???



E-ELT and SKA may play a key role in our developing understanding of the physics behind the formation and evolution of galaxies and the IGM.