The main scientific tasks of the 'Millimetron' mission and the preliminary structure of the scientific program

Dmitry Novikov on behalf of 'Millimetron' team,
Astro Space Center, Moscow

Millimetron workshop, 9-12 September 2019

The main scientific tasks of Millimetron:

Supermassive Relativistic Objects	Origin of life in the Universe	CMB Spectral Distortions

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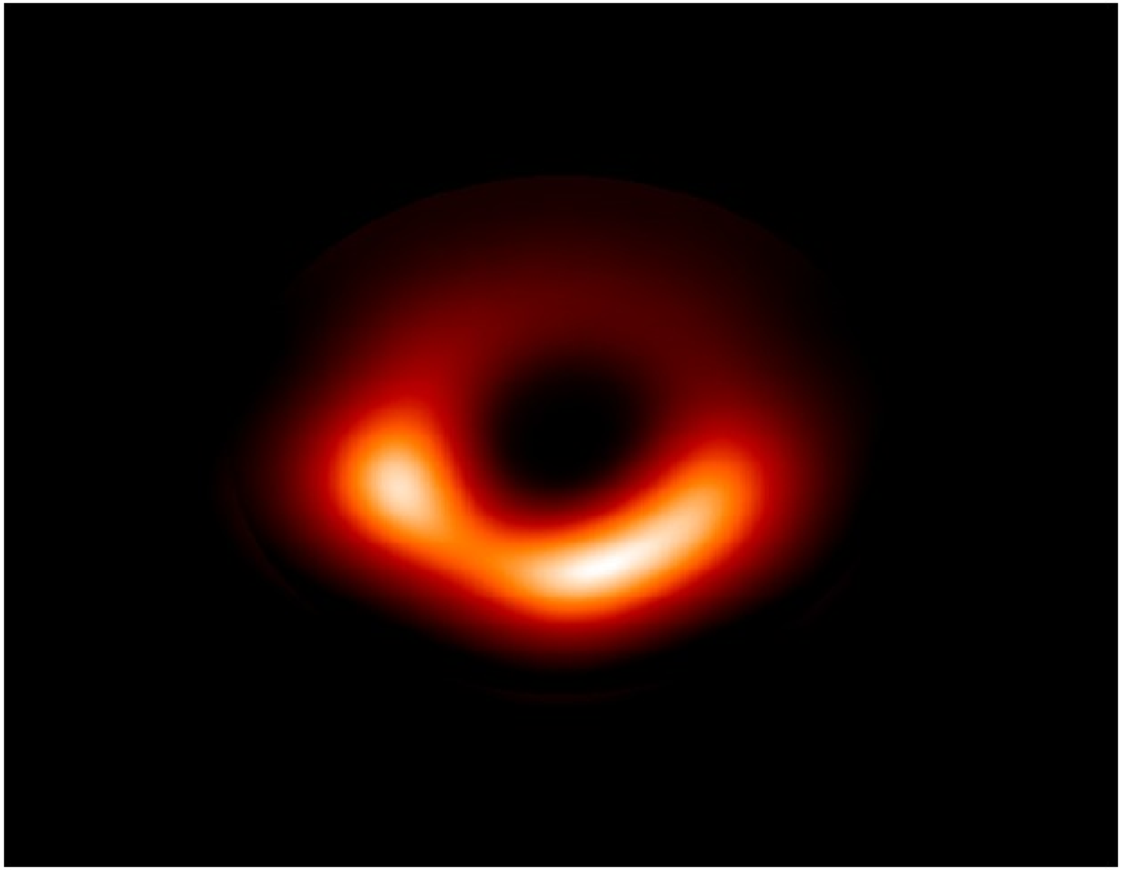
Additional scientific challenges:

The main scientific tasks of Millimetron:

Supermassive Relativistic Objects	Origin of life in the Universe	CMB Spectral Distortions
Yuri Shchekinov	Paola Caselli	Jens Chluba, Joe Silk

Supermassive Relativistic Objects



EHT, April 2019, M87

Supermassive Relativistic Objects.

Scientific goals:

- To understand the physics of processes in the surroundings of supermassive black holes;
- To determine whether supermassive black holes or wormholes are in the centers of some galaxies;
- To test the General Relativity under condition of strong gravity.

Observations:

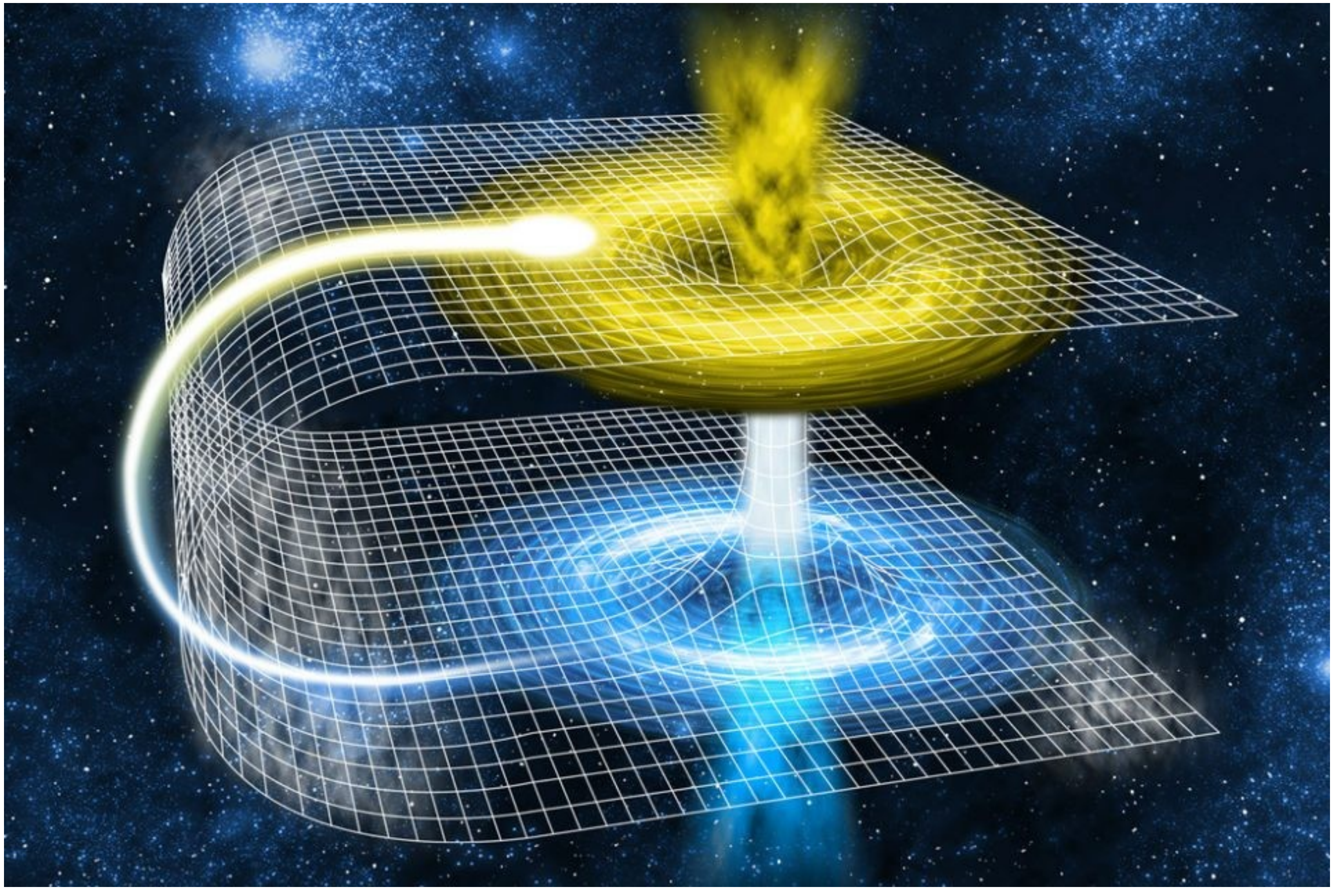
Centers of galaxies M87, Sgr A*

and others.

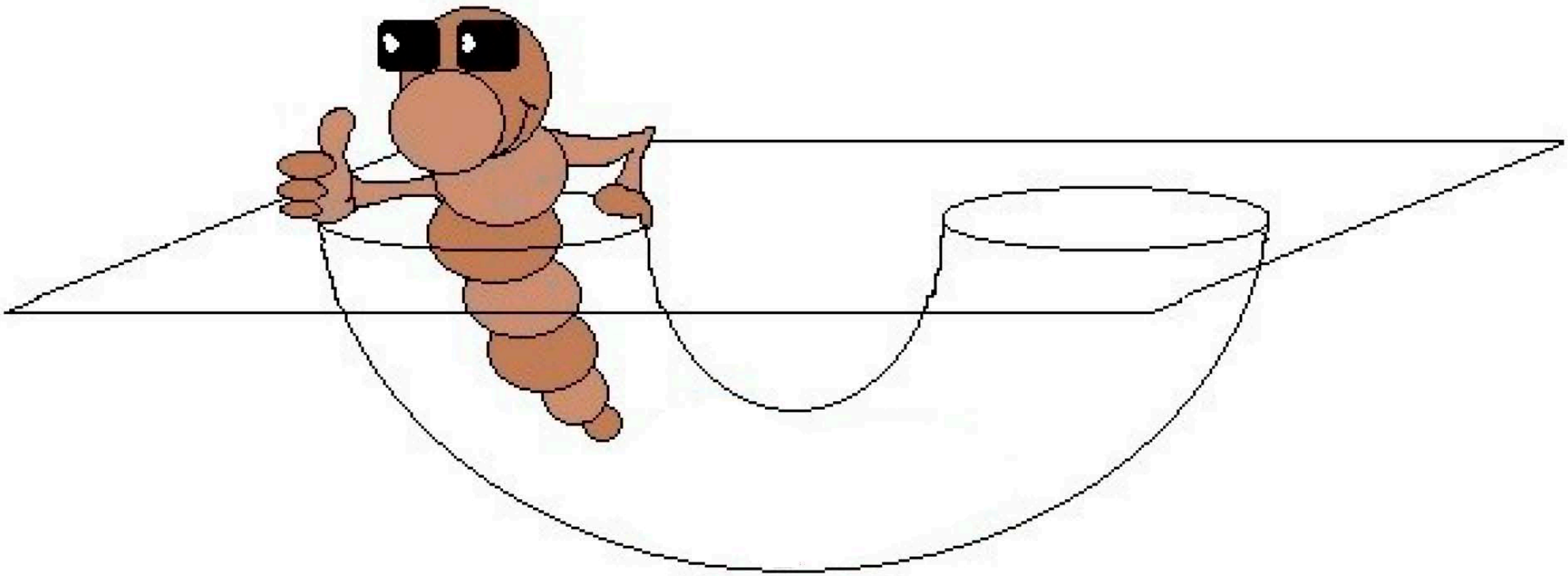
Surroundings of supermassive black holes:

- To determine SMBH parameters;
- To understand the physics of processes occurring in the closest vicinity of a black hole;
- To determine main characteristics of accretion discs and jets.

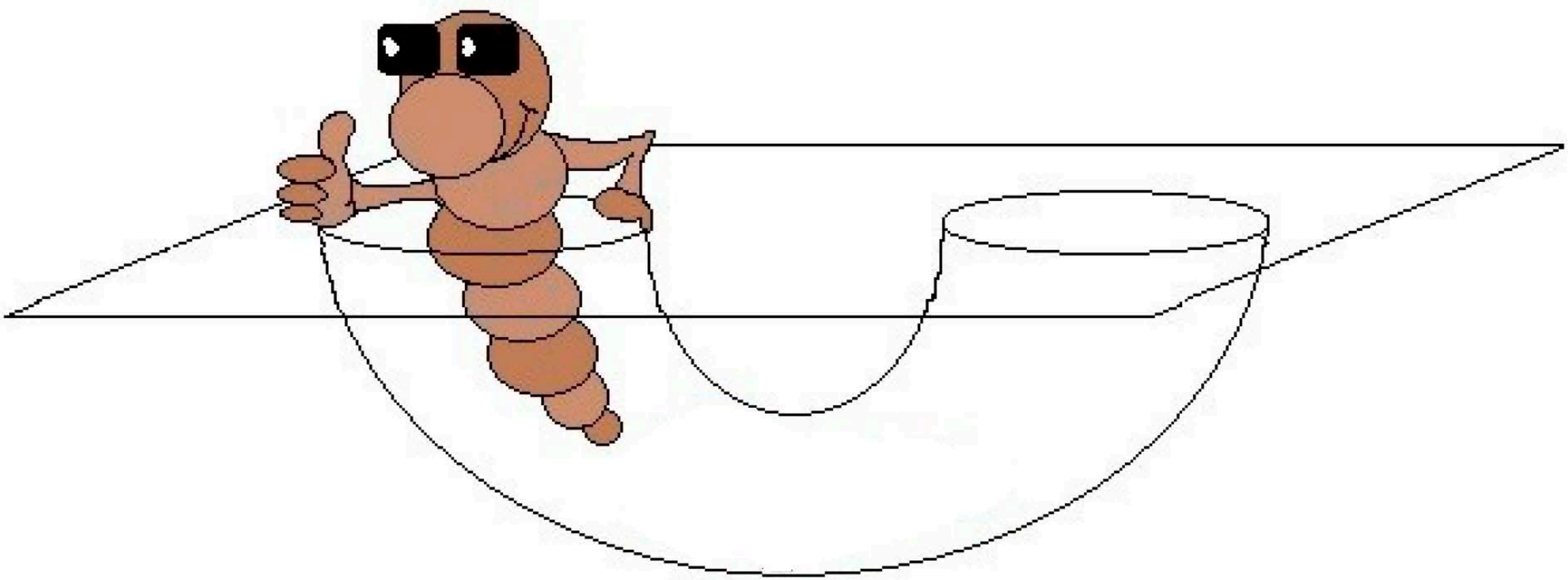
Supermassive black holes or wormholes?



I. Flamm, Phys. Z. 17, 448 (1916), J.A. Wheeler Phys Rev 97, 511 (1955).



Another Universe?



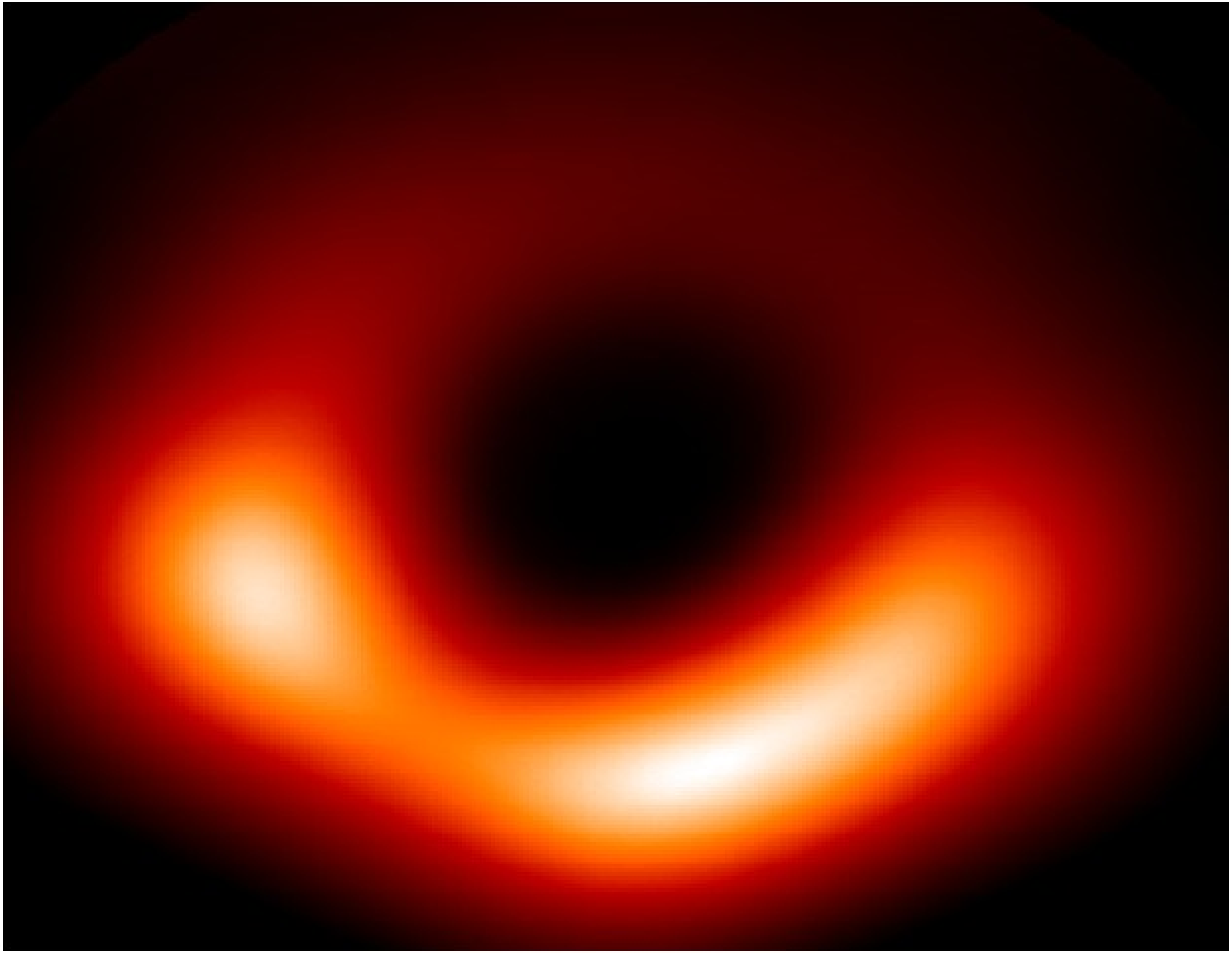
Observational manifestations of wormholes:

1. Radiation may come out of a wormhole;

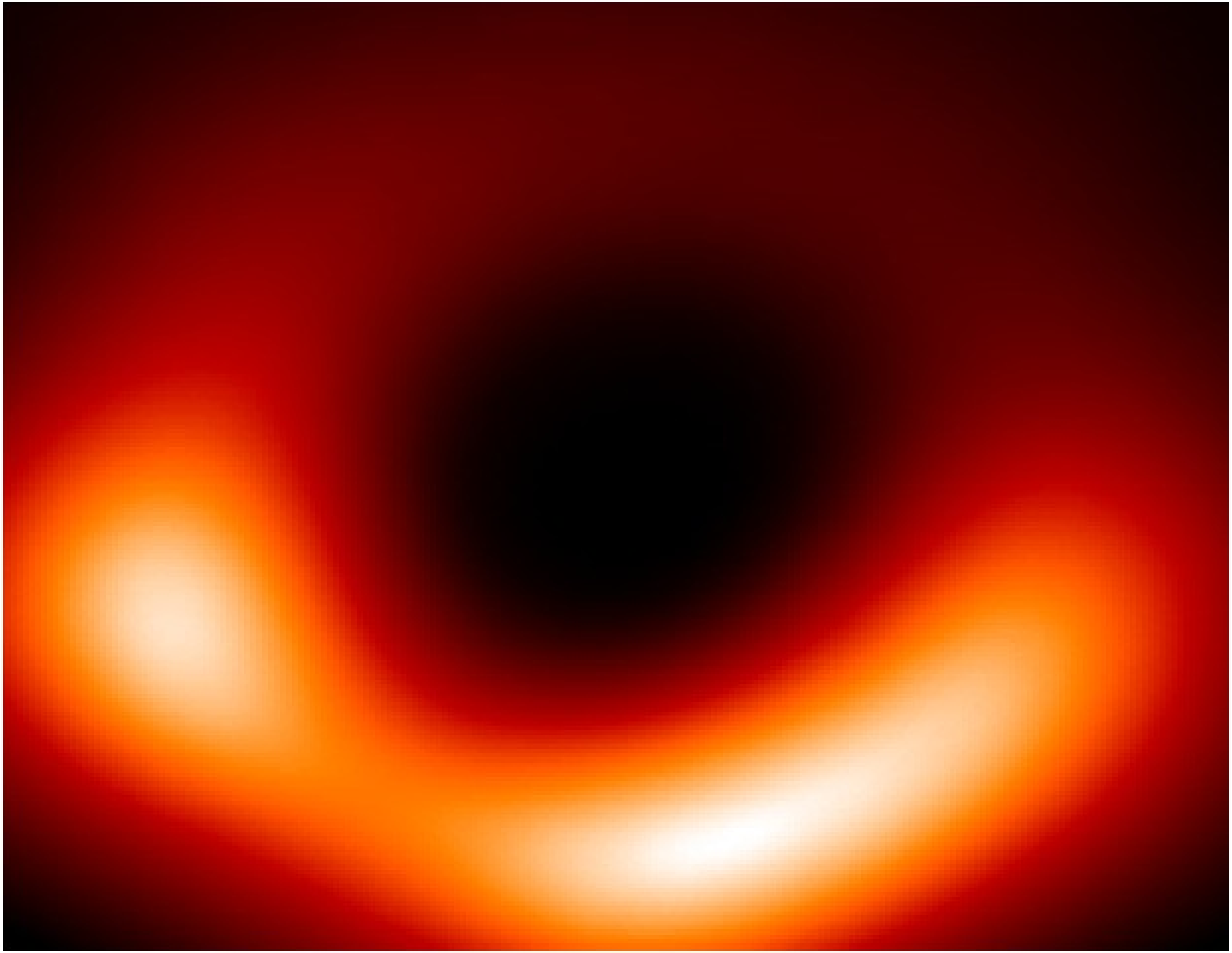
Black hole

Black hole

Black hole



Black hole



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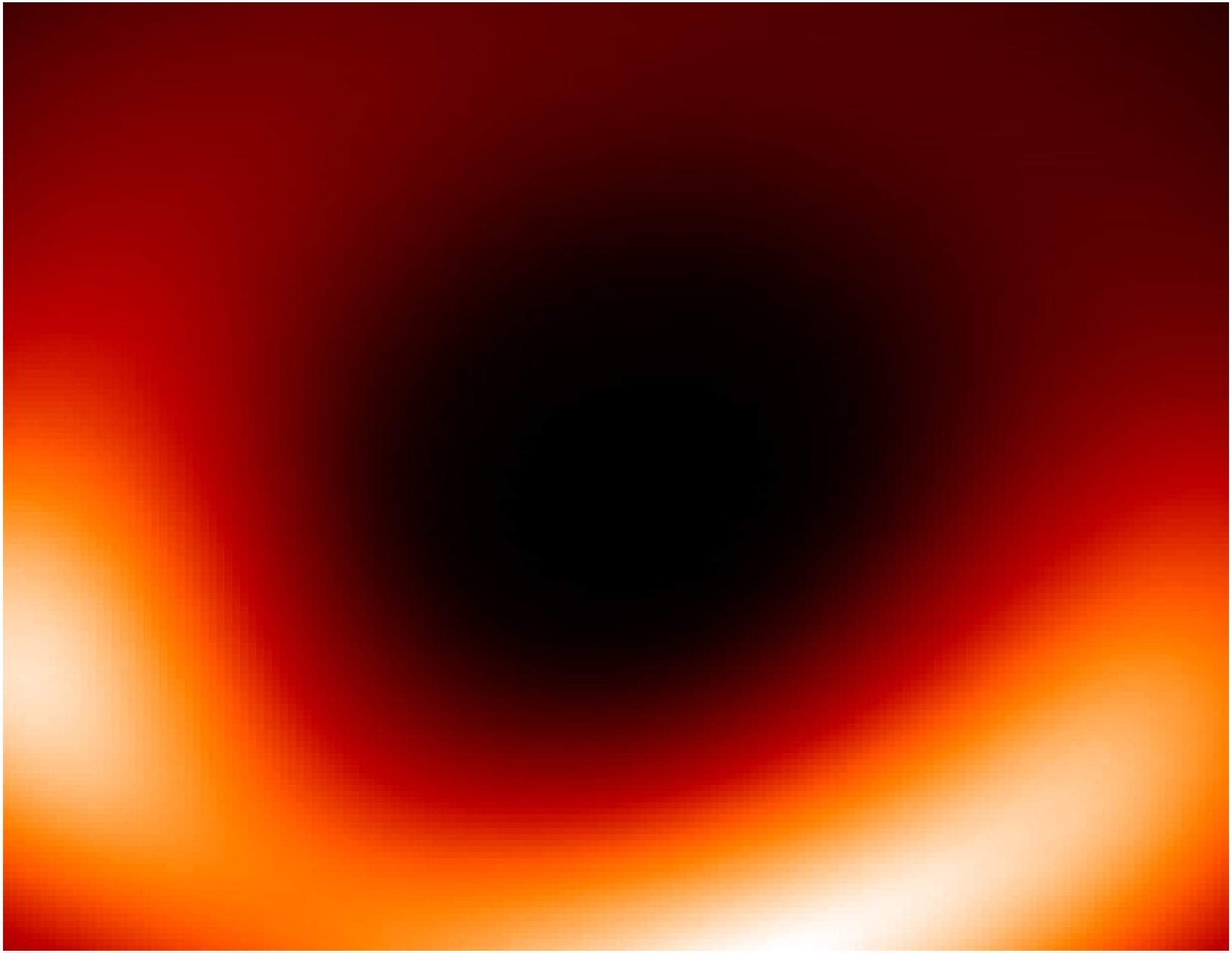

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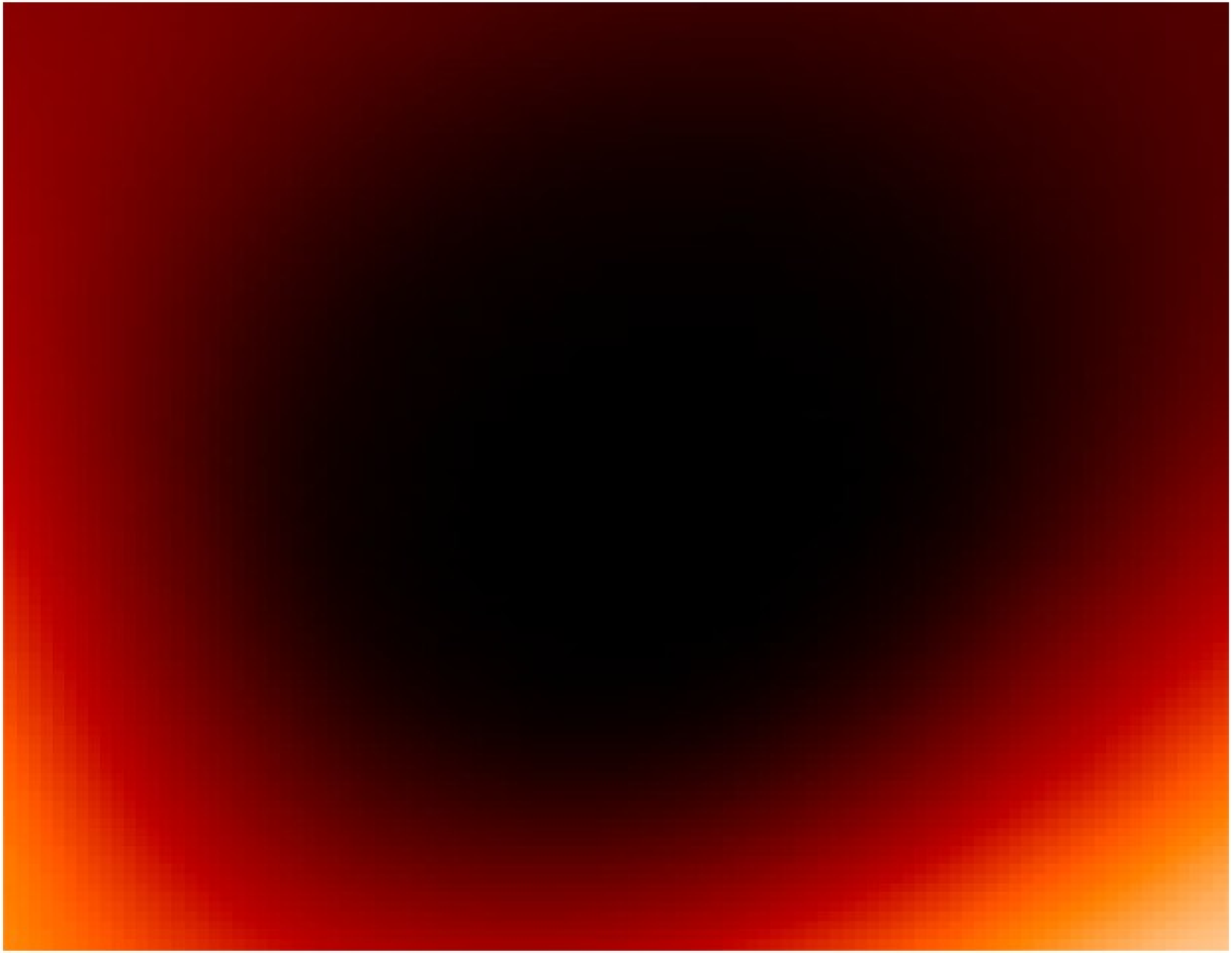

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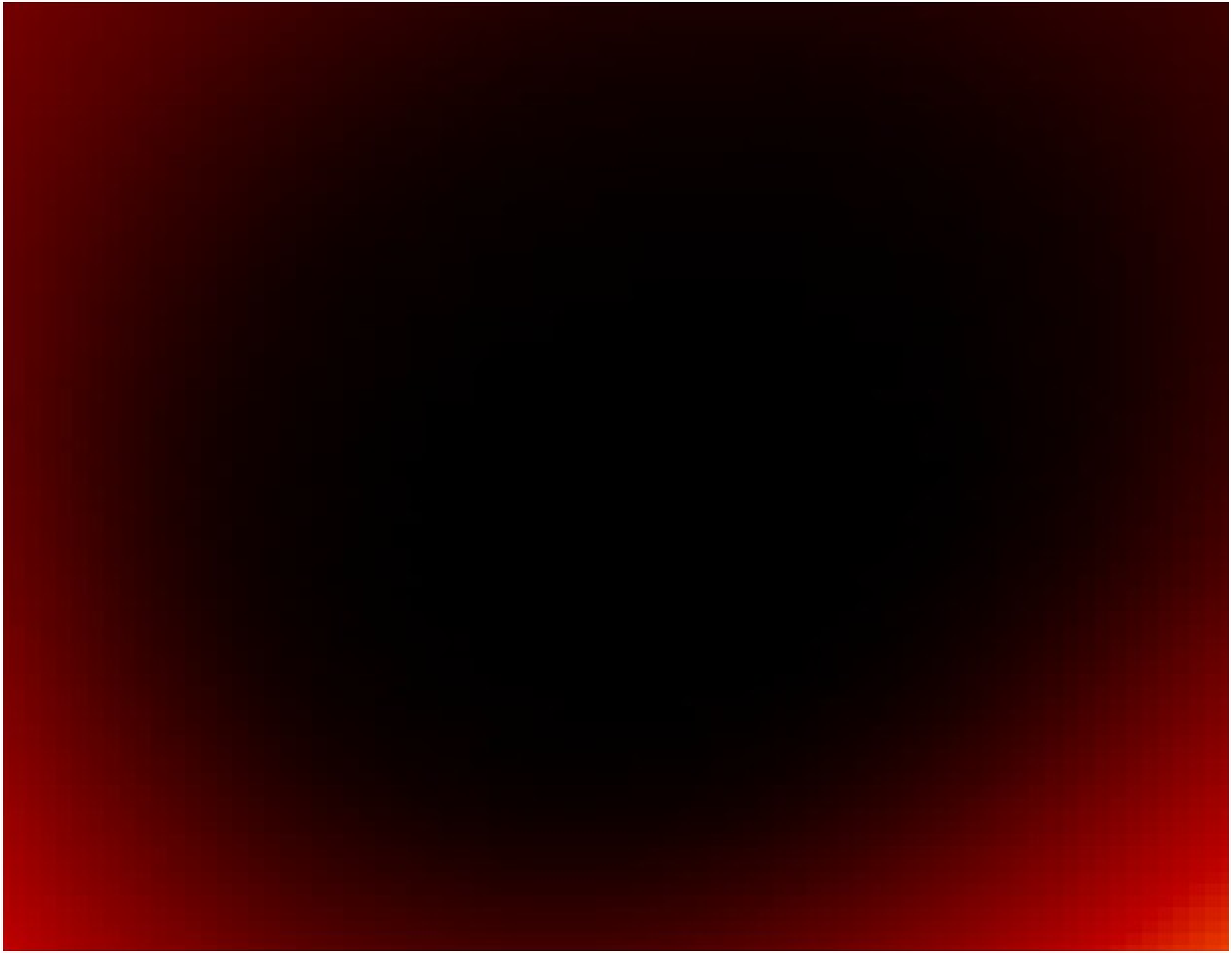
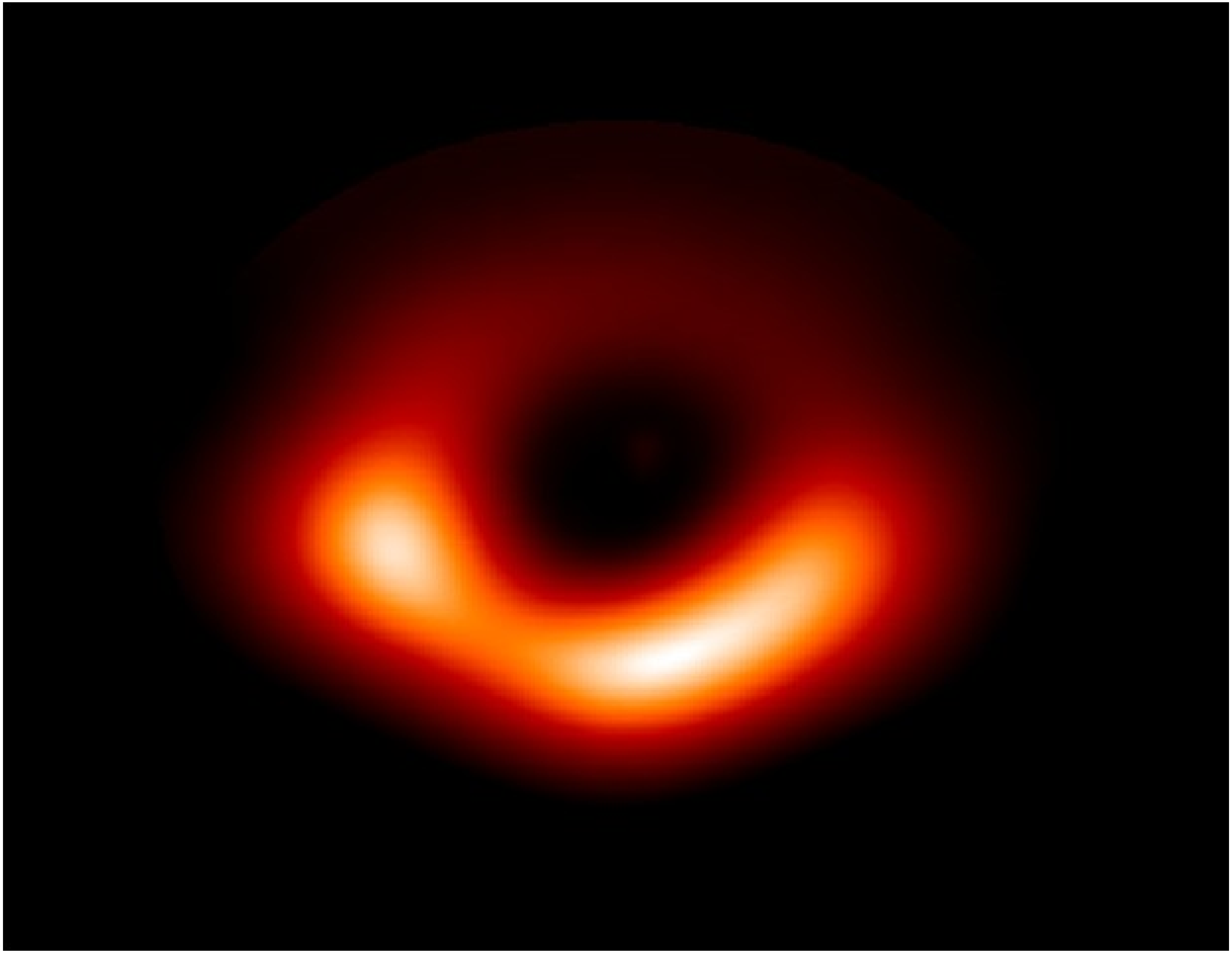


Black hole

Wormhole



Wormhole

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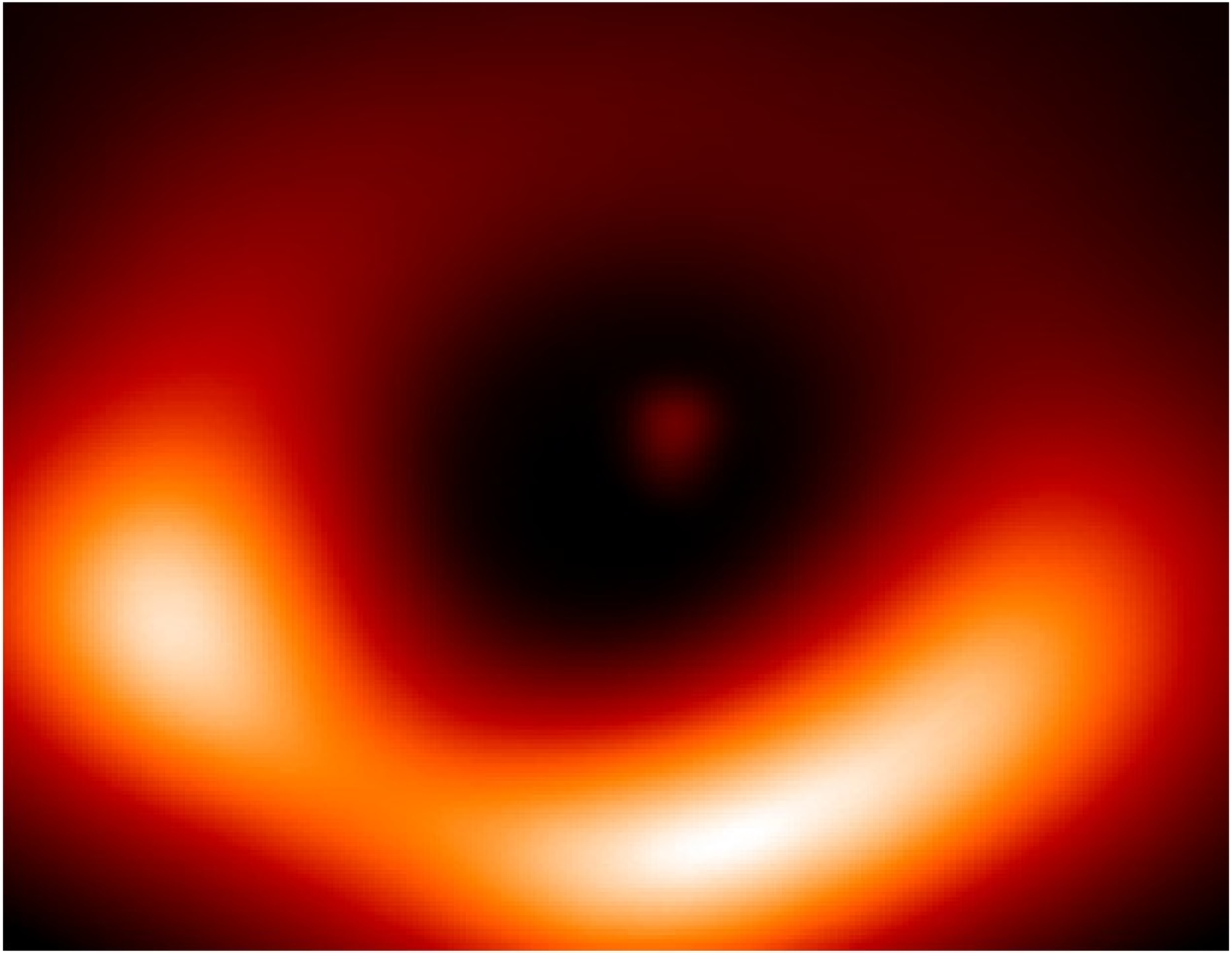
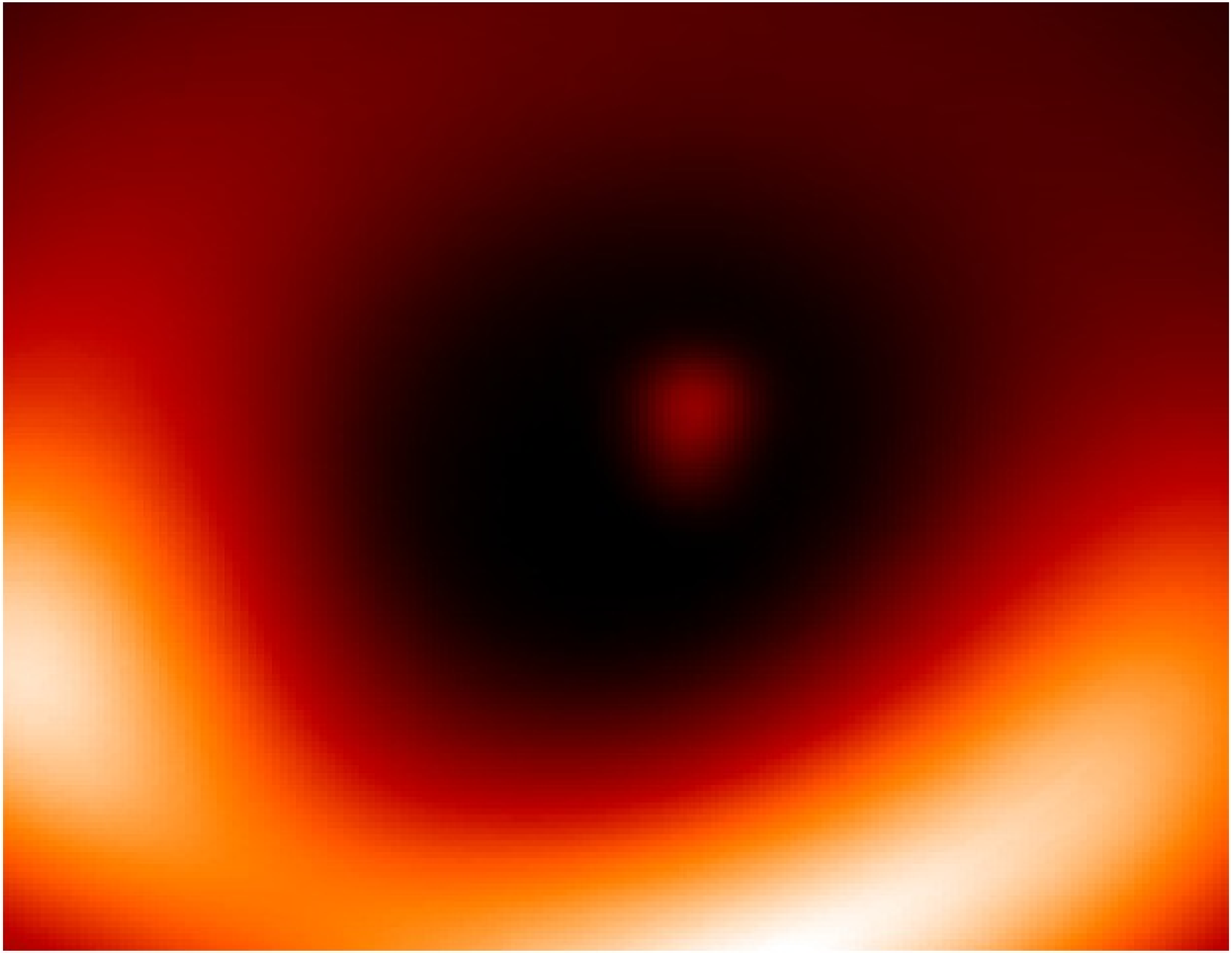
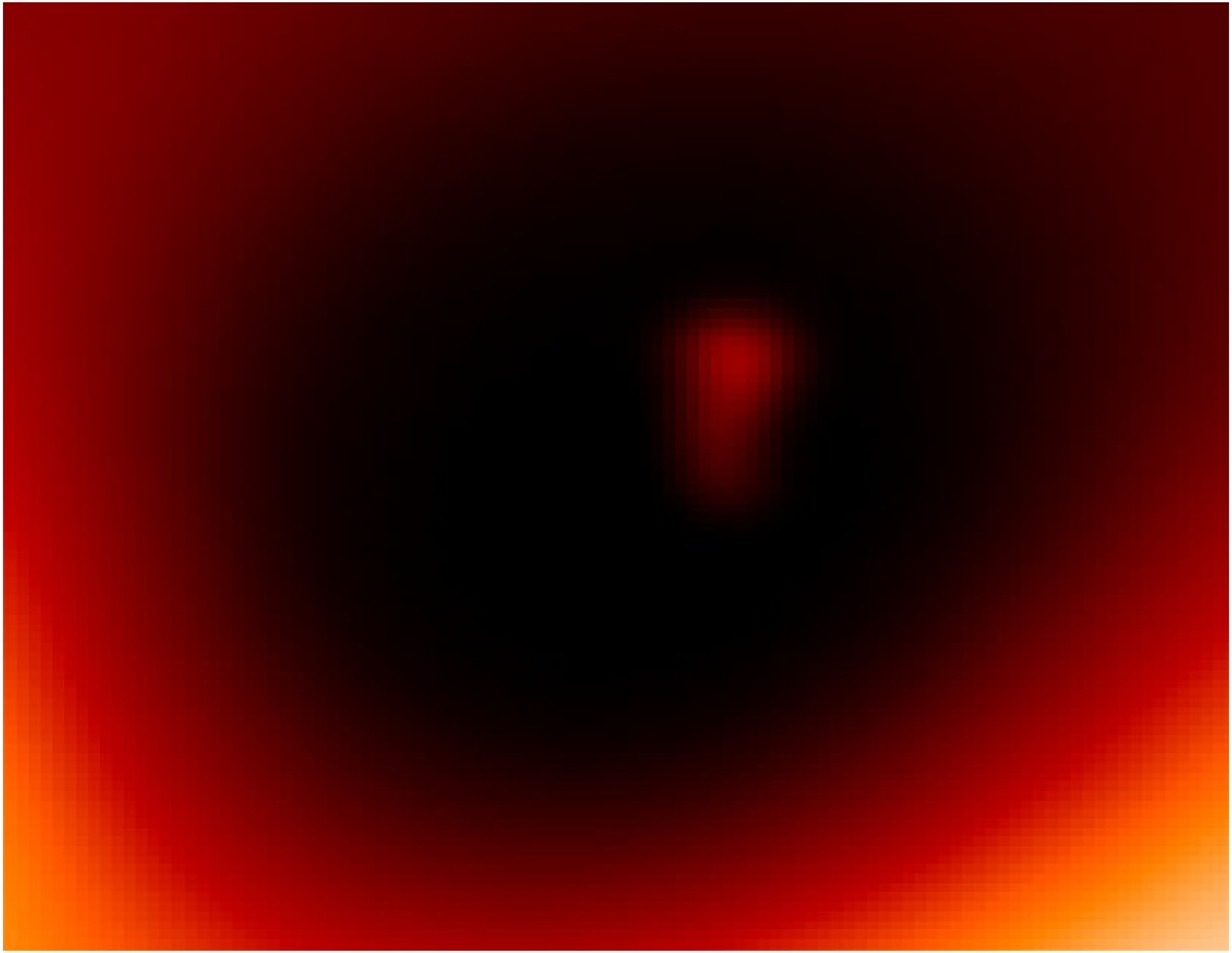
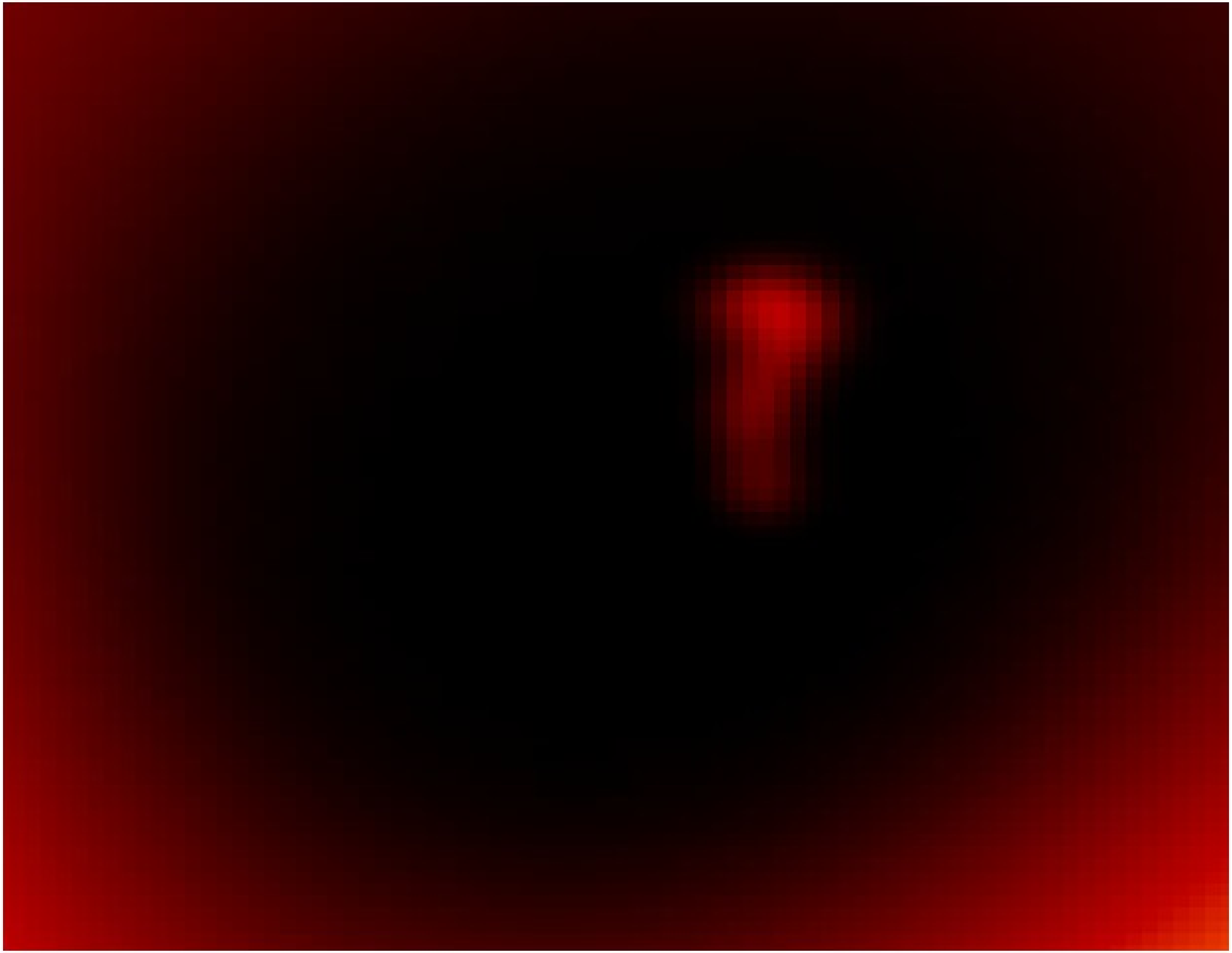


Wormhole



Wormhole





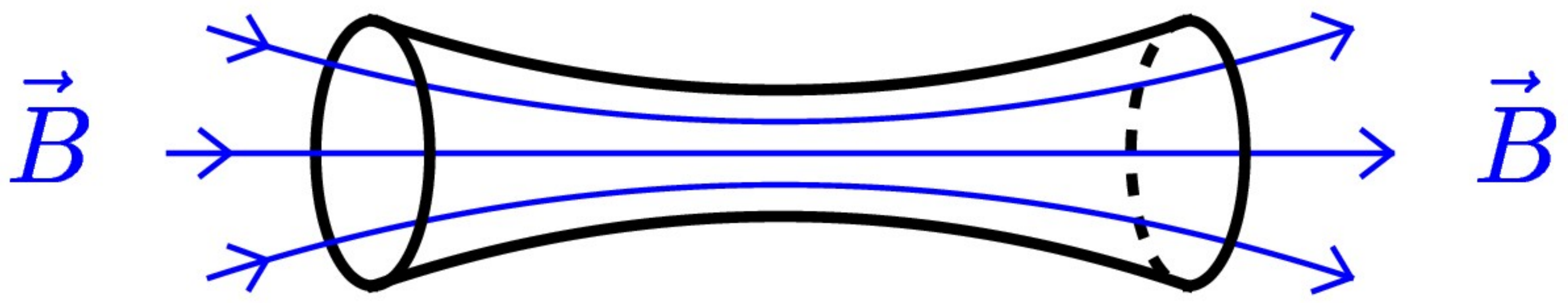
Wormhole

Observational manifestations of wormholes:

1. Radiation may come out of a wormhole;

2. Wormhole can be a source of radial magnetic field;

V. Frolov, I.Novikov, Phys. Rev. D 42, 1057 (1990)



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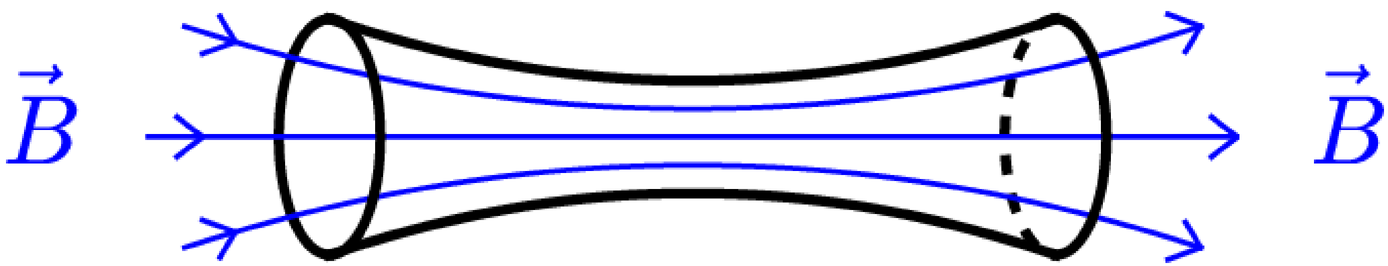
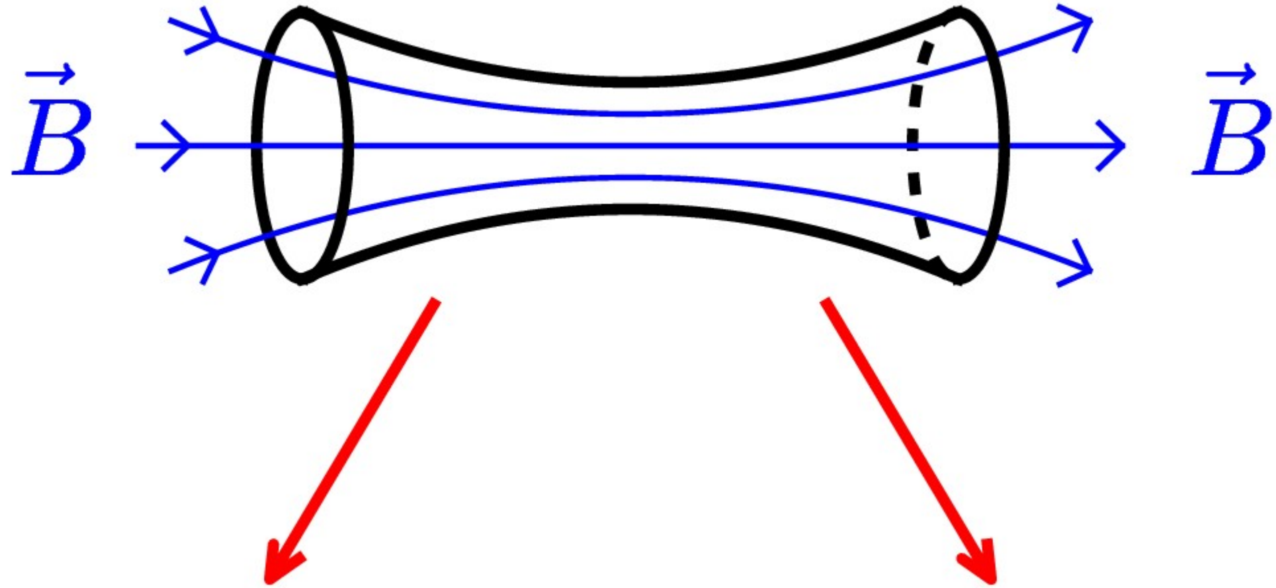


$$B \sim 3 \times 10^{10} G \times \left(\frac{10^9 M_\odot}{M} \right)$$



$\vec{B}$
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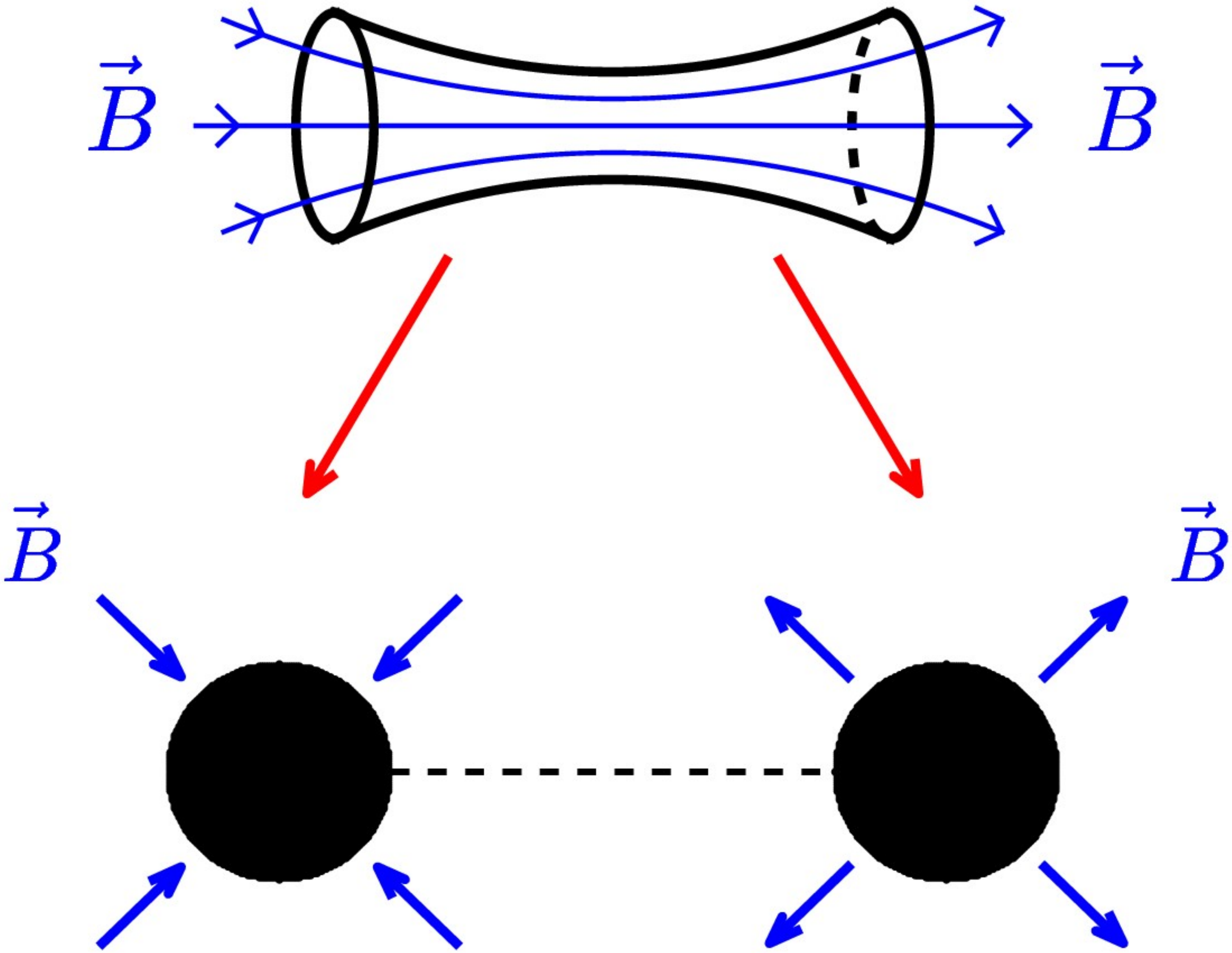

Igor Novikov, 2019

Observational manifestations of wormholes:

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3. Blueshift.

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3. Blueshift.

Detecting any of these three properties will mean that we are observing a wormhole, not a black hole !

Will be continued by Yuri Shchekinov

Origin of life in the Universe

Scientific goals:

- To trace the chemical evolution from pre-stellar phase to planet formation;

- To understand to what extent the conditions for the emergence of life on Earth are unique.

Origin of life in the Universe

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Paola Caselli

Observations:

- Solar like Star Forming Regions;
- Protoplanetary discs;
- Objects in our Solar system.

Seeds Of Life In Space (SOLIS)

List of the iCOMs Detected in Solar-like Star-forming Regions

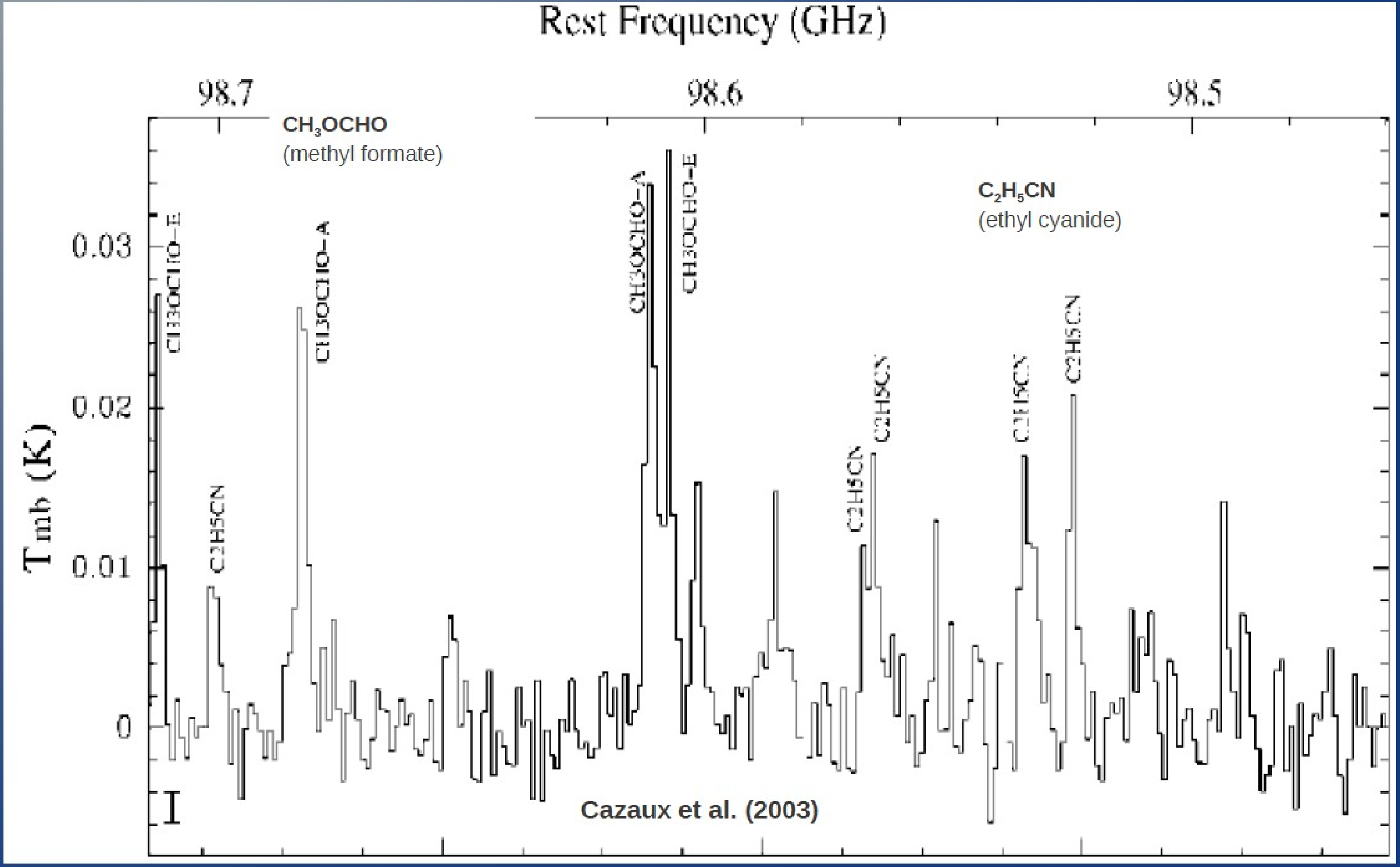
Molecule Name	Formula	References
Methanol	CH_3OH	1, 2
Methanethiol	CH_3SH	3
Methyl cyanide	CH_3CN	4
Formamide	NH_2CHO	5
Propyne	CH_3CCH	6, 7
Ethylene oxide	$c\text{-}C_2H_4O$	8
Acetaldehyde	CH_3CHO	6, 9, 10
Methyl isocyanate	CH_3NCO	11, 12
Cyanoacetylene	HC_5N	13
Methyl formate	$HCOOCH_3$	14, 15, 16
Glycol aldehyde	$HCO(CH_2)OH$	17, 18, 19
Acetic acid	CH_3COOH	20
Dimethyl ether	CH_3OCH_3	14, 13, 16
Ethanol	CH_3CH_2OH	21, 18, 16
Ethyl cyanide	CH_3CH_2CN	14, 15, 22
Acetone	CH_3COCH_3	8
Propanal	CH_3CH_2CHO	8
Ethylene glycol	$(CH_2OH)_2$	17

Ceccarelli etal 2017

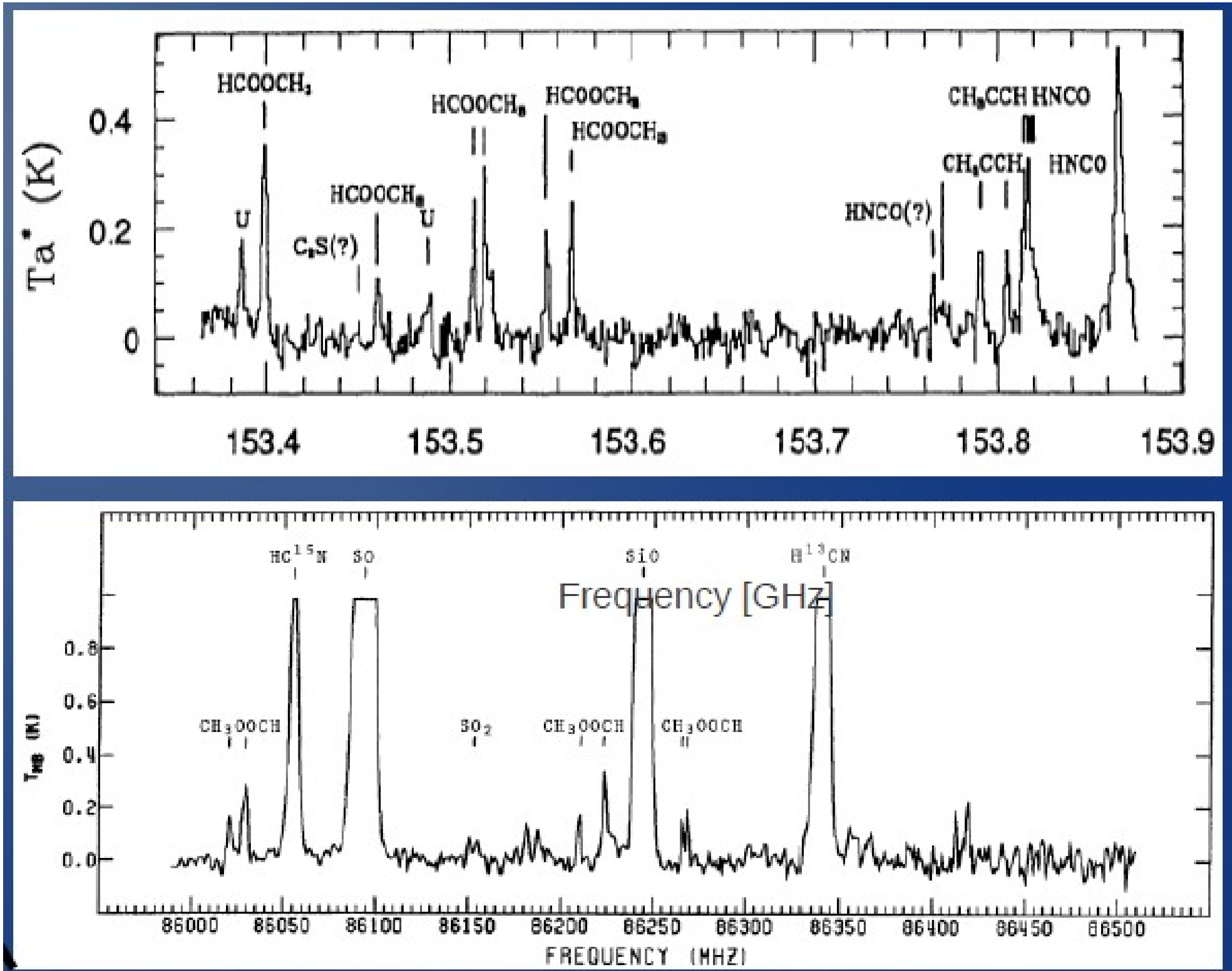
Formation of star and planetary system:

1. Pre-stellar (formation of simple molecules);
2. Protostellar (formation of complex molecules);
3. Protoplanetary disc (simple & complex molecules);
4. Planetesimal formation;
5. Planet formation and the comet/asteroid rain.

The combination of atoms into molecules leads to the creation of unique types of energetic states and therefore unique spectra of the transitions between these states: we can recognize the molecules from their lines!



From presentation by Bernardo Ercoli



Spectral line surveys:
Schilke et al. (2001); Ziurys & McGonagle (1993) Johansson et al. (1984)

From presentation by Bernardo Ercoli

Known maser lines:

Species	Frequency (GHz)
OH	1.612, 1.665, 1.667, 1.720, 6.035
H_2O	22.235, 187, 233, 658
NH_3	20.719, 21.071, 23.870, 24.533, 25.056
SiO	42.820, 43.122, 85.640, 86.243
CH_3OH	(many)

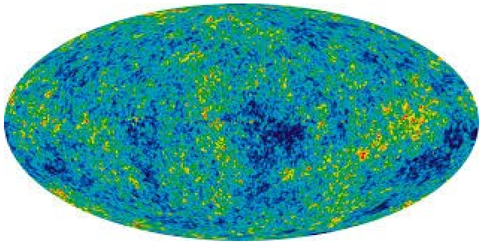
From presentation by Bernardo Ercoli

Some of opened questions:

- More observations are needed to trace the formation, storage and delivery of water;
- The chemical composition of the envelopes of solar-type protostars has not so far been studied, due to the sensitivity of the available instrumentation;
- We will need to measure the HDO/H2O in different stages of the protostellar evolution.

Will be continued by Paola Caselli

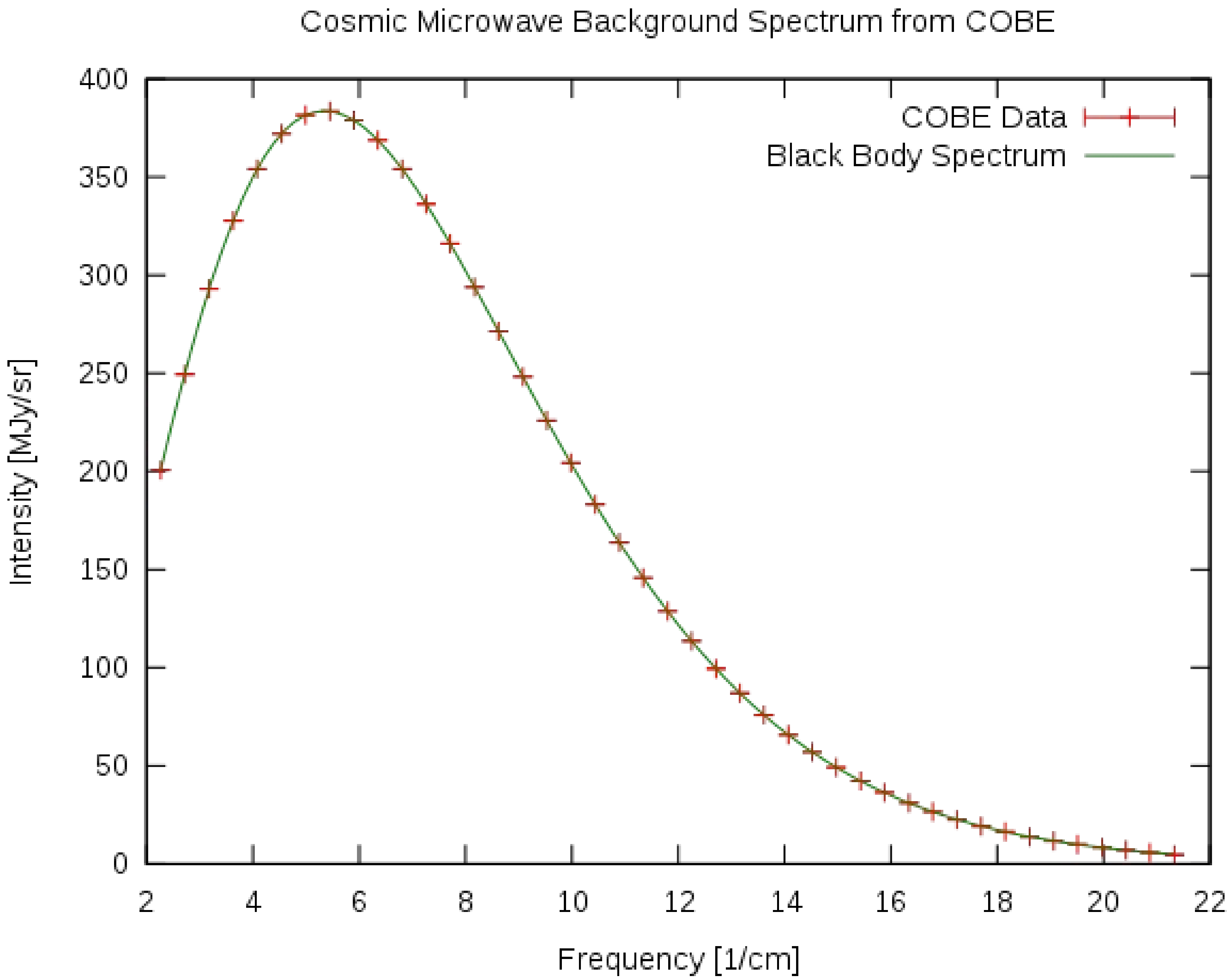
CMB spectral distortions:



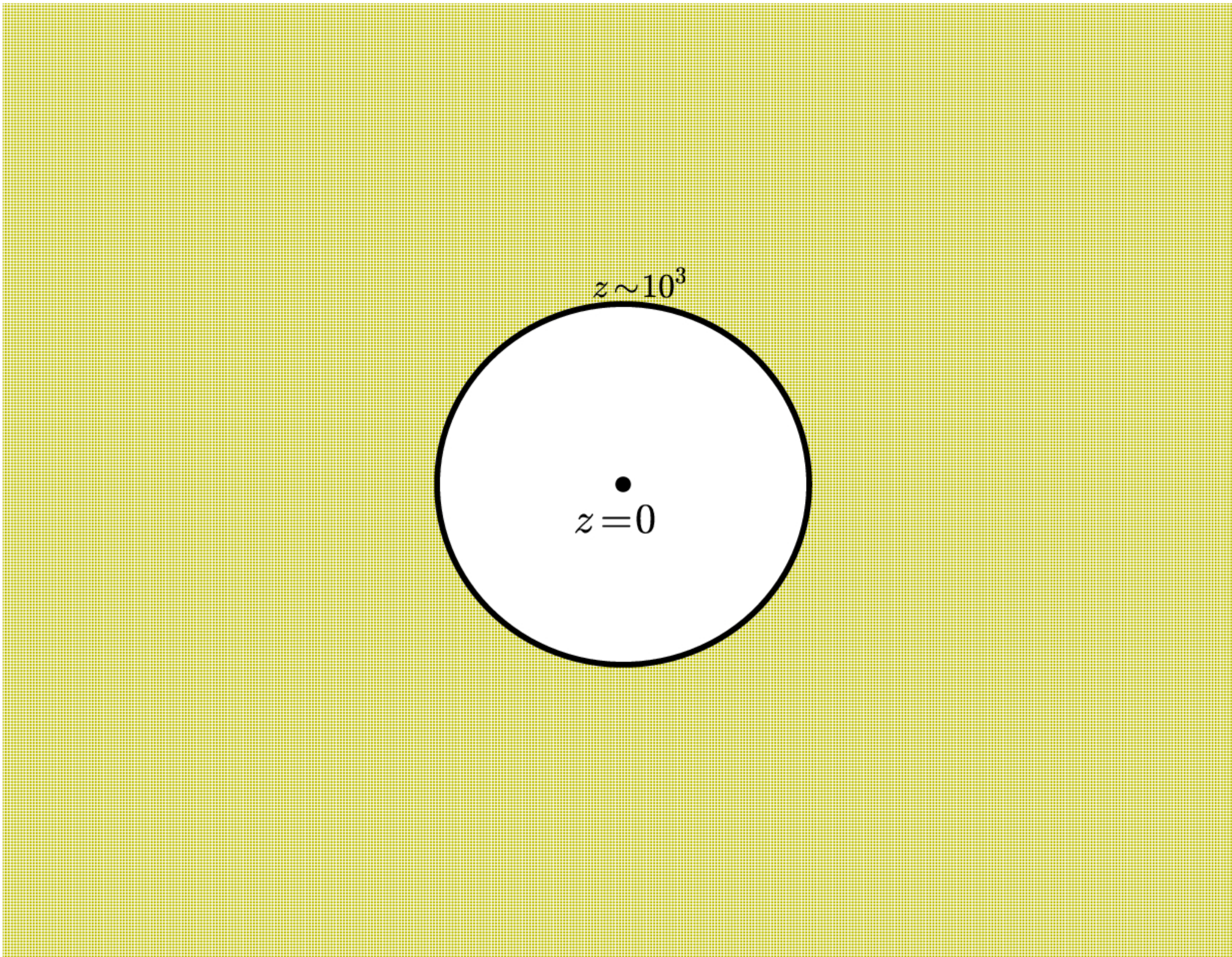
Scientific goals:

- To open a completely new channel of information about the evolution of the Universe in the pre-recombination era;

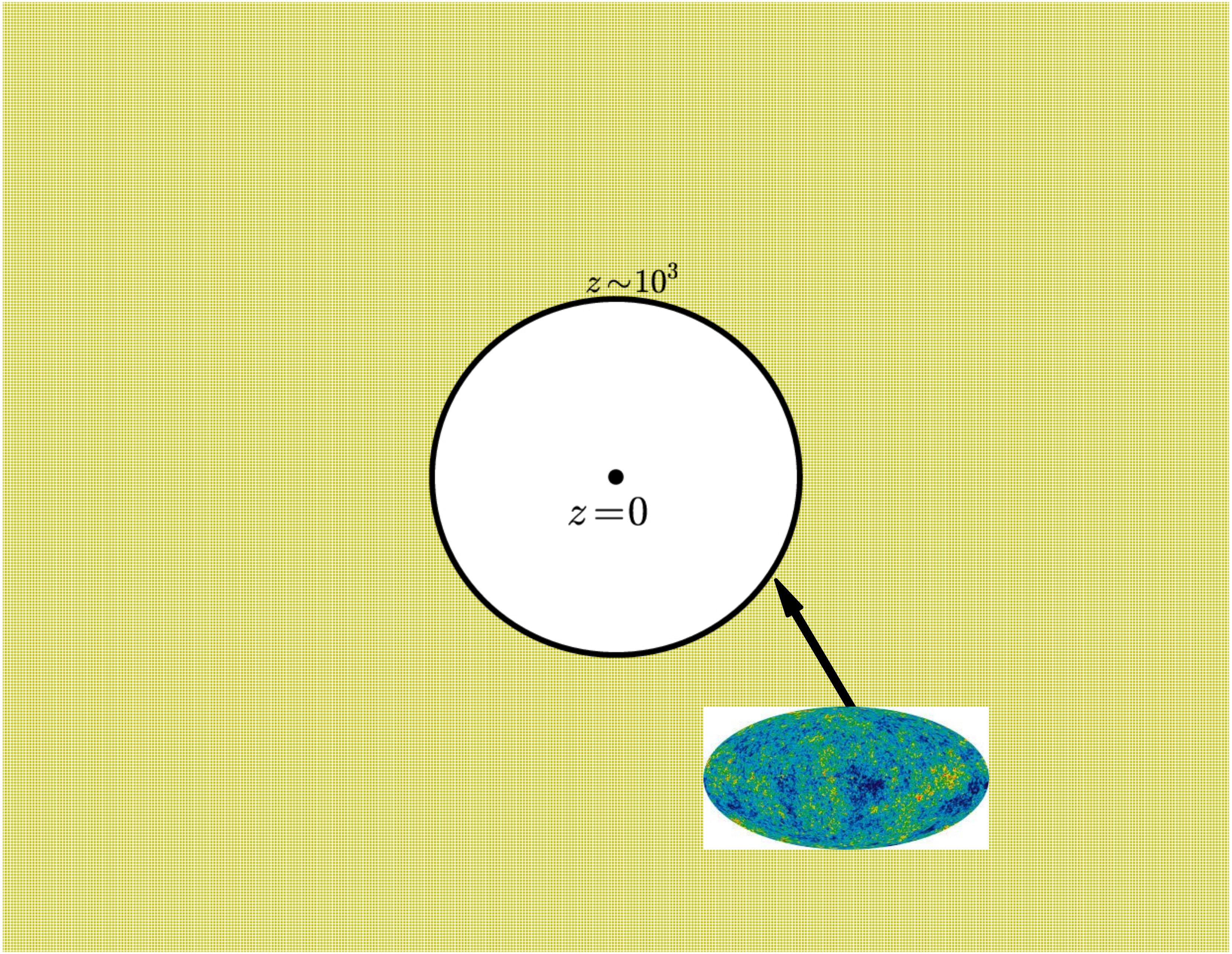
- To find manifestations of fundamental physical processes occurring in the Universe at redshifts $z = 10^3 – 10^6$



Cosmic Microwave Background Spectrum from COBE
COBE Data
Black Body Spectrum
Intensity [MJy/sr]
Frequency [1/cm]
0
50
100
150
200
250
300
350
400
2
4
6
8
10
12
14
16
18
20
22



$z \sim 10^3$
$z = 0$



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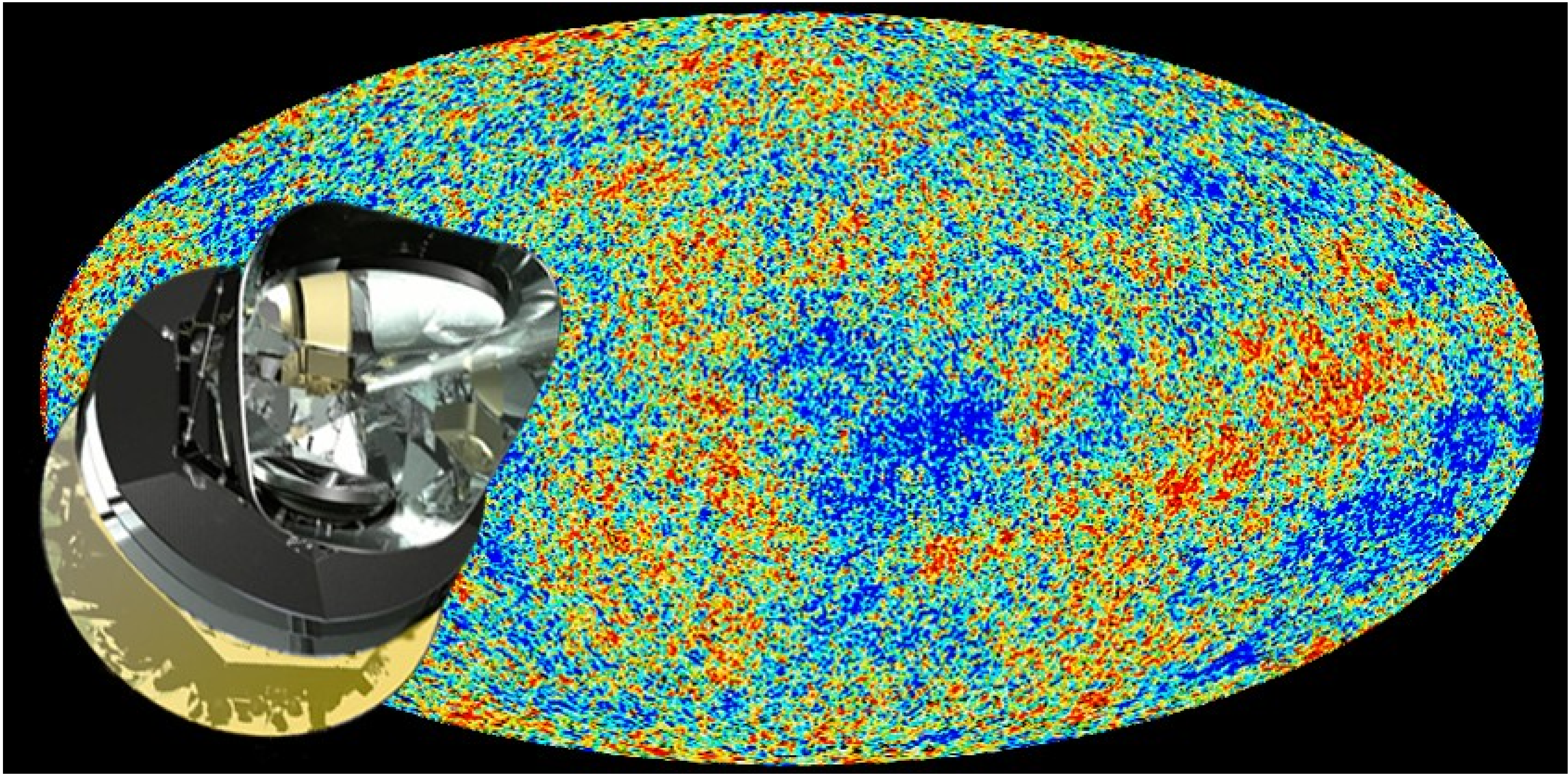
CMB by Planck:



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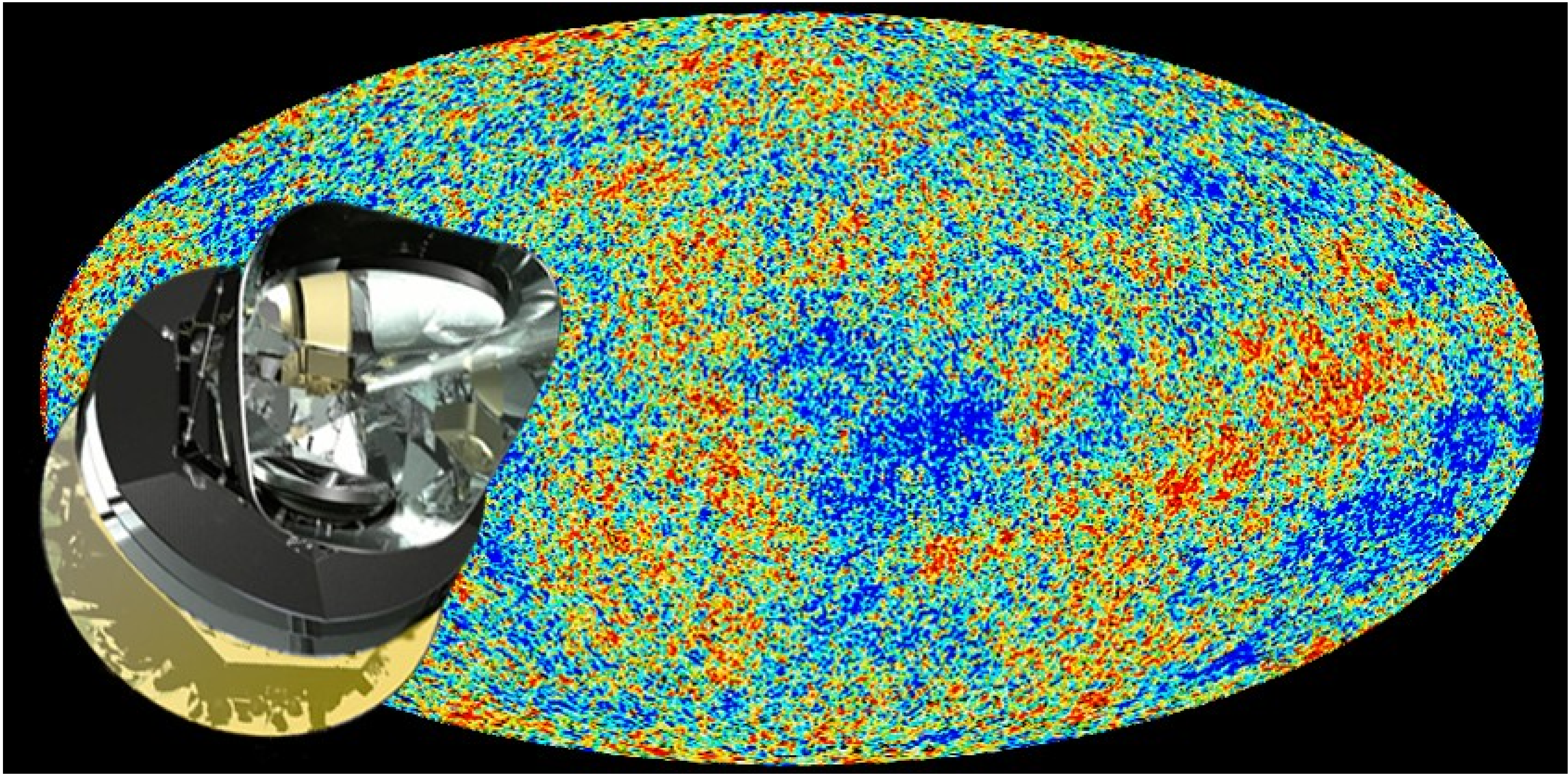
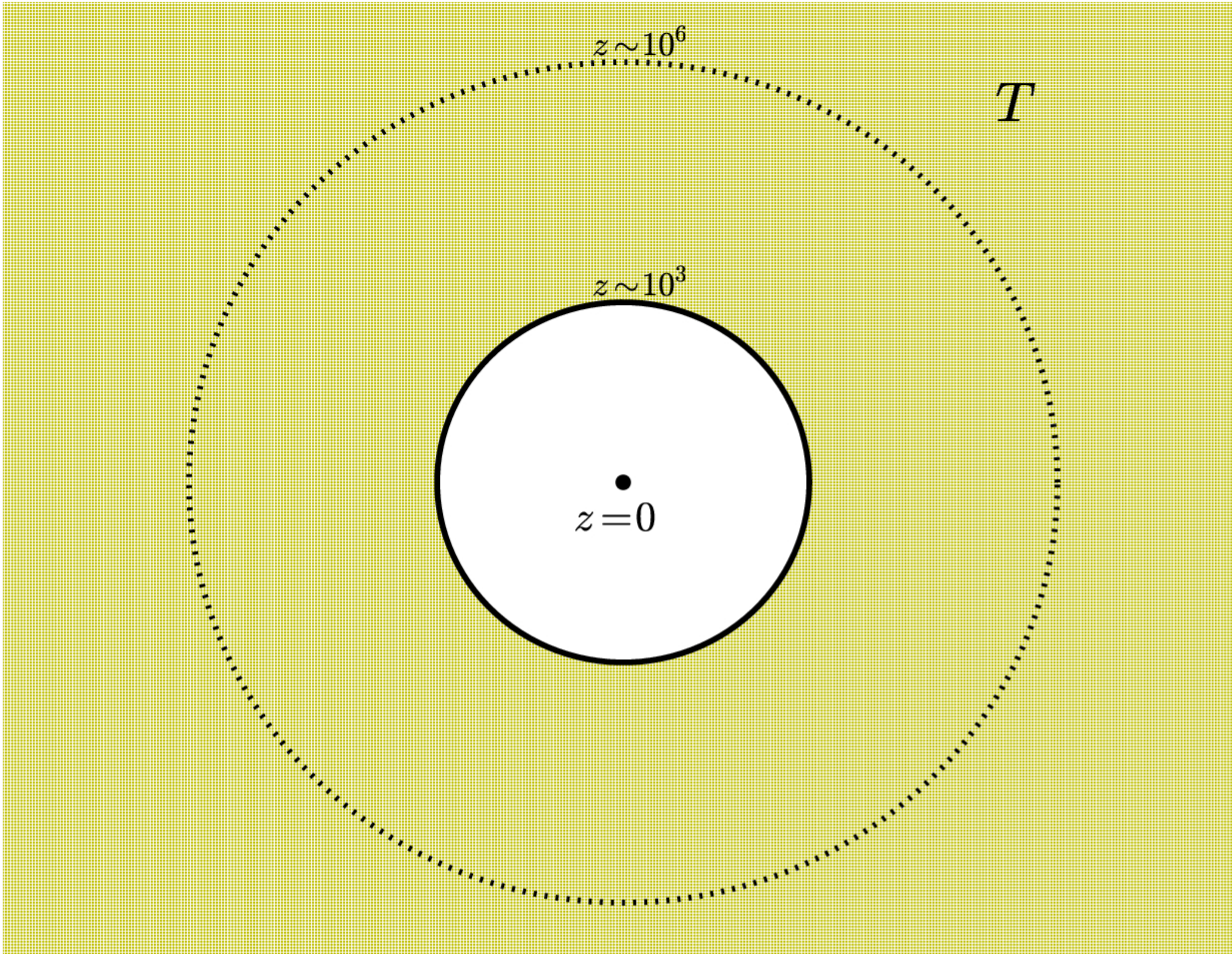


François Bouchet: Future of CMB observations


$z \sim 10^6$
T
$z \sim 10^3$
$z = 0$

Kompaneets equation:

$$\frac{\partial n}{\partial t} = \frac{\sigma_T N_e h}{m_e c}\frac{1}{\nu^2}\frac{\partial}{\partial \nu}\left[\nu^4\left(n + n^2 + \frac{kT_e}{h}\frac{\partial n}{\partial \nu}\right)\right],$$

$$h\nu, kT_e << m_e c^2,$$

$n(\nu, t)$: photon concentration in phase space (photon number density).

Properties of the Kompaneets equation:

$$\frac{\partial}{\partial t}\int_0^\infty \nu^2 n d\nu = \frac{\sigma_T N_e h}{m_e c}\int_0^\infty \frac{\partial}{\partial \nu}\left[\nu^4\left(n+n^2+\frac{kT_e}{h}\frac{\partial n}{\partial \nu}\right)\right]d\nu,$$

1. $N=\int_0^\infty \nu^2 n d\nu$ - total number of photons

$\frac{\partial N}{\partial t}=0,$ => N=const

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1. $N = \int\limits_0^\infty \nu^2 n d\nu$ - total number of photons

$\frac{\partial N}{\partial t} = 0,$ => N=const

2. Stationary solution: $n = \frac{1}{e^{x+\mu}-1},$

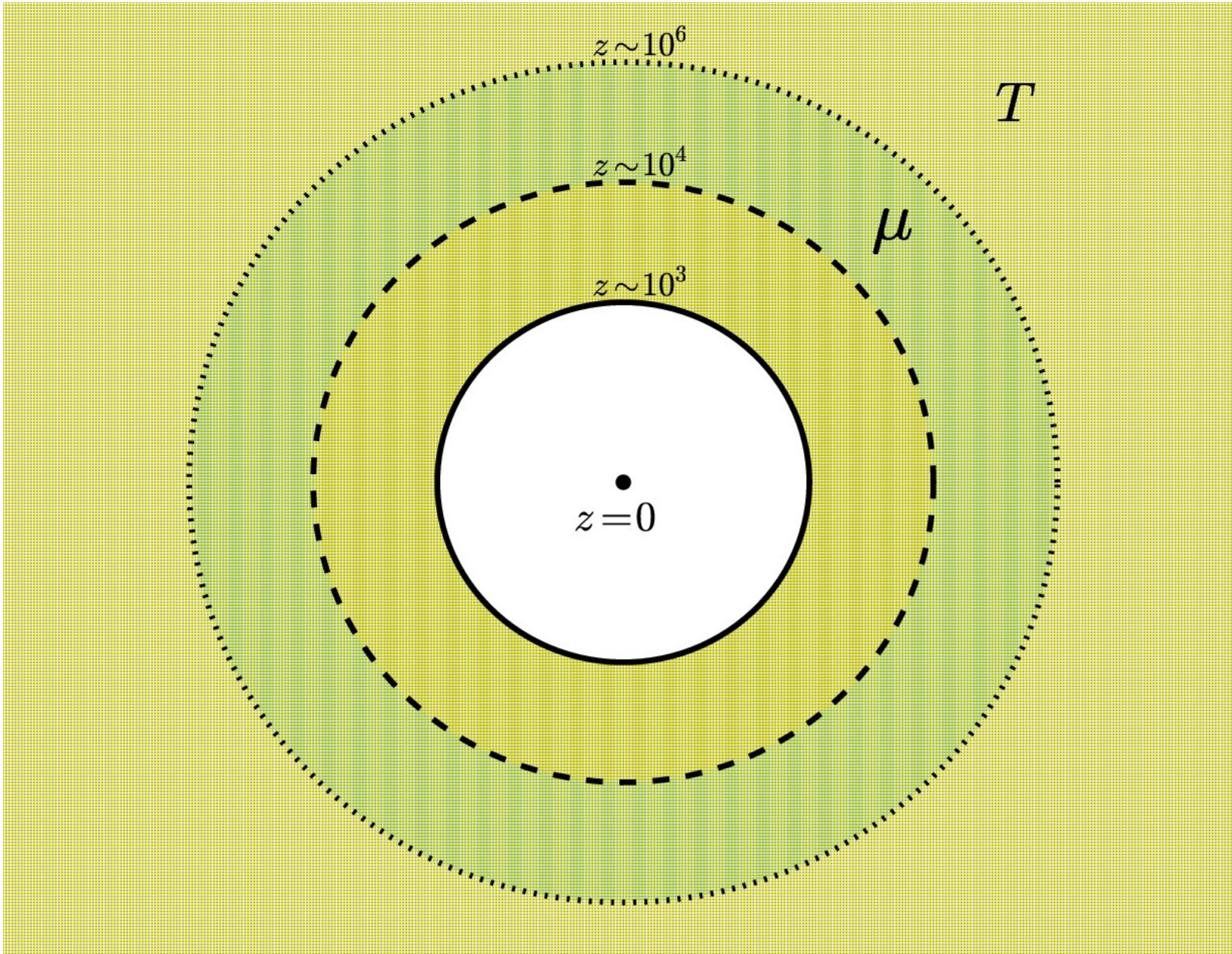
$x = h\nu/kT_e,$ μ - chemical potential.

Possible solutions of Kompaneets equation:

$$\frac{\partial n}{\partial t} = \frac{\sigma_T N_e h}{m_e c} \frac{1}{\nu^2} \frac{\partial}{\partial \nu} \left[\nu^4 \left(n + n^2 + \frac{kT_e}{h} \frac{\partial n}{\partial \nu} \right) \right],$$

1. If optical depth $\gg 1$, then $n = \frac{1}{e^{x+\mu} - 1}$, $x = h\nu / kT_e$,

μ-distortions.



$z \sim 10^6$
T
$z \sim 10^4$
μ
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$z = 0$

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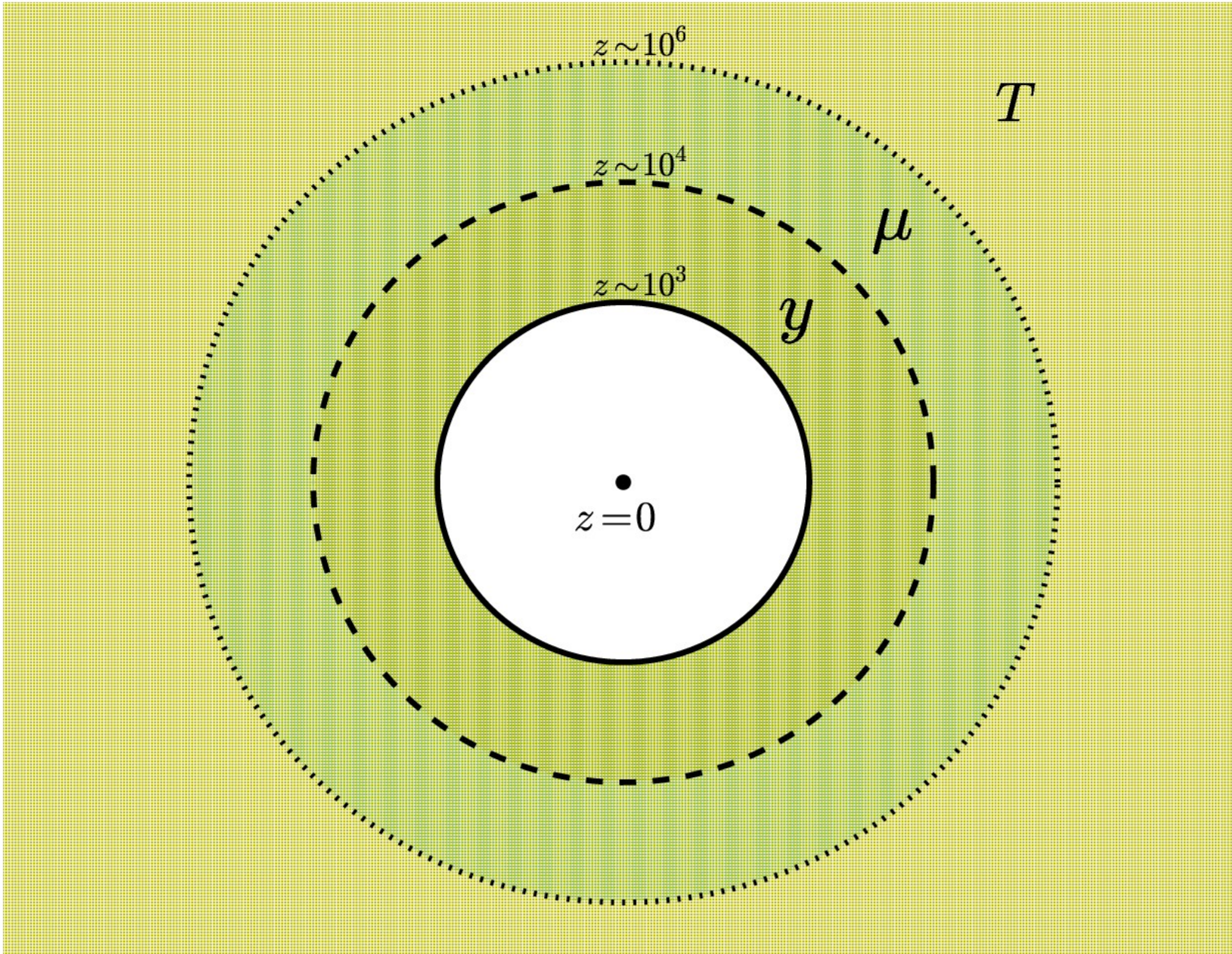
1. If optical depth $\gg 1$, then $n = \frac{1}{e^{x+\mu}-1}$, $x = h\nu/kT_e$,

μ-distortions.

2. If optical depth $\ll 1$ and $n(\nu,0) = \frac{1}{e^x-1}$, $x = h\nu/kT_r$, then

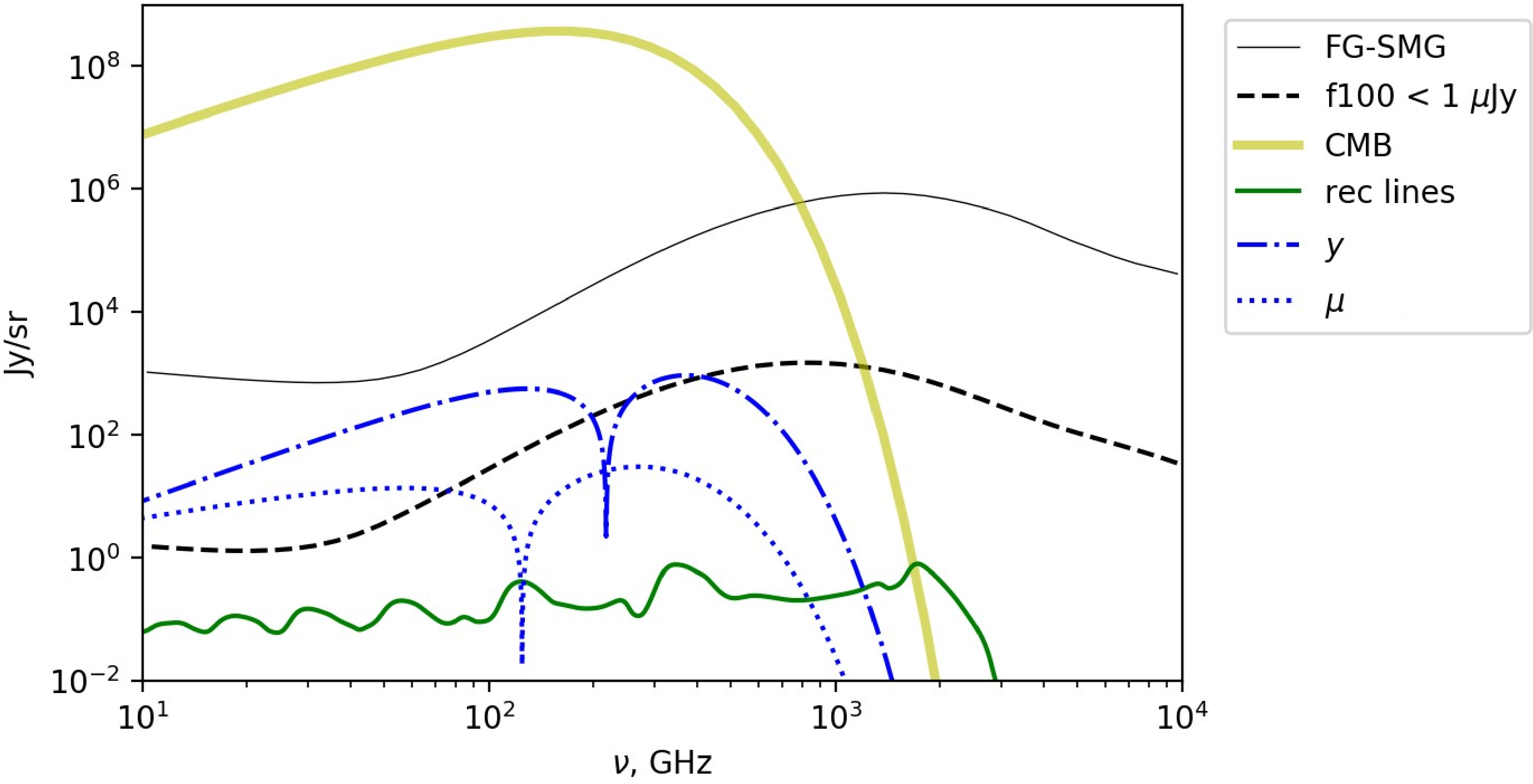
$$\Delta n = \Delta t \times k(T_e - T_r) \frac{\sigma_T N_e}{m_e c} \frac{xe^x}{(e^x-1)^2} \left[x\frac{e^x+1}{e^x-1} - 4 \right],$$
$$x = h\nu/kT_r, \quad T_r \neq T_e$$

y-distortions.



$z \sim 10^6$
T
$z \sim 10^4$
μ
$z \sim 10^3$
y
$z = 0$

CMB spectral distortions:



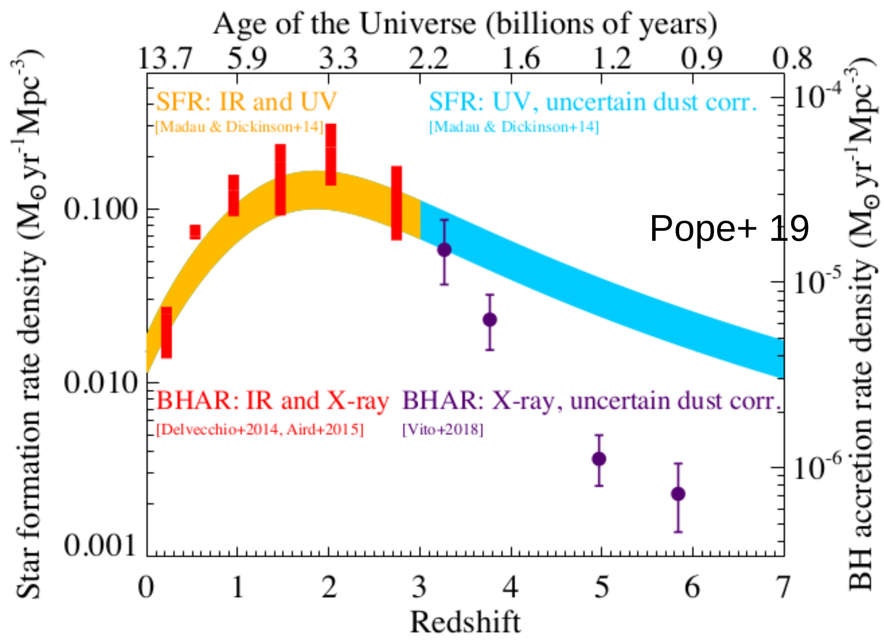
Chluba, Rubiño-Martin & Sunyaev (2007),
Rubiño-Martin, Chluba & Sunyaev (2008)

Will be continued by Jens Chluba and Joe Silk

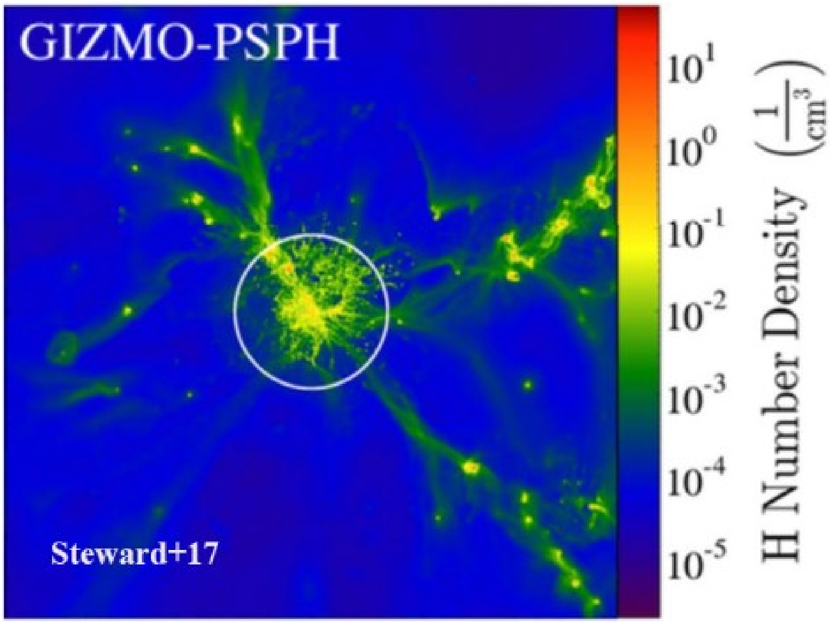
Additional scientific challenges:

Studies of high redshift galaxies

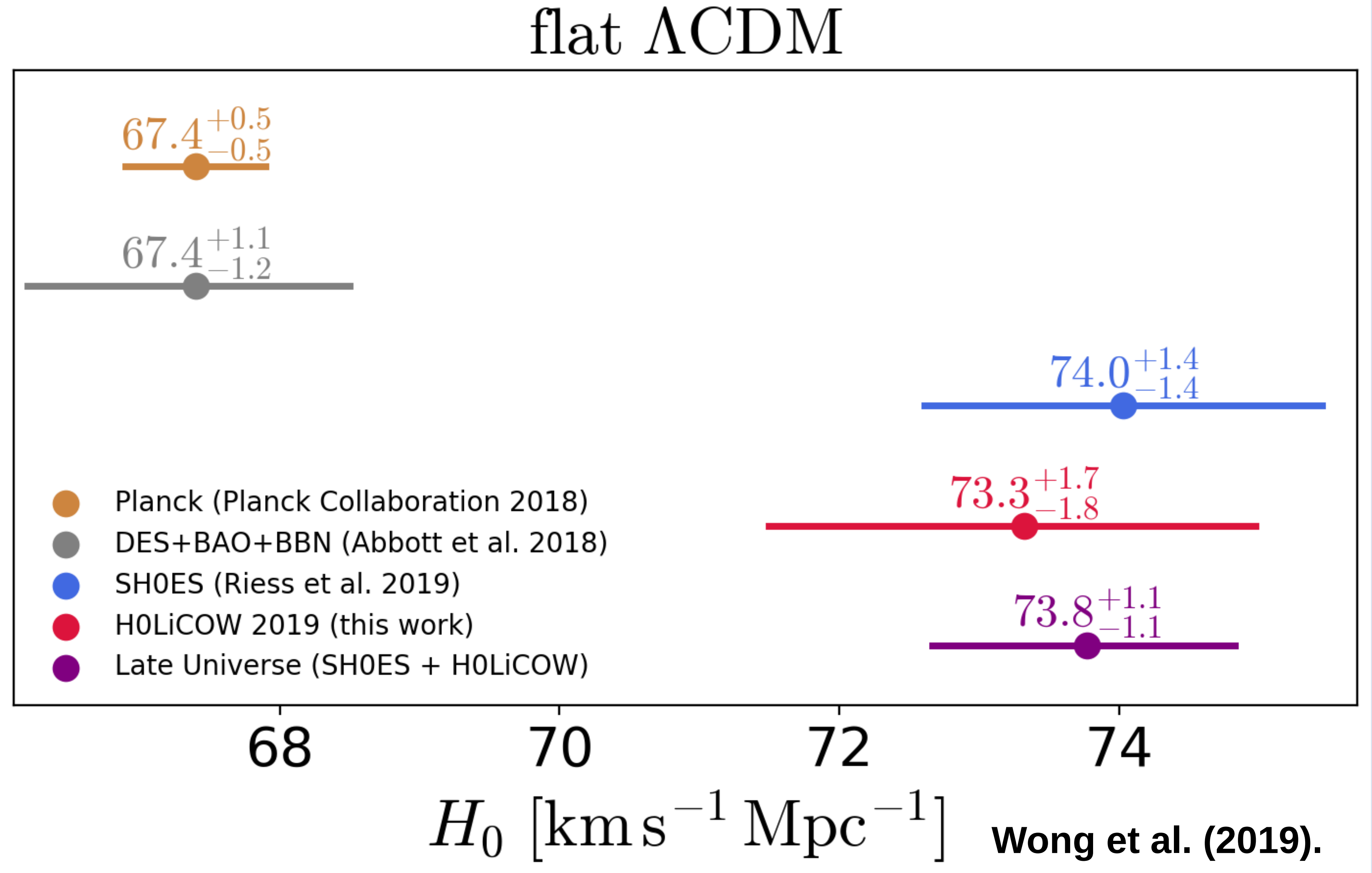
- What:
  - Gas accretion modes
  - Feedback
  - SMBH - bulge coevolution
- How:
  - H_2 rotational lines (28, 17, 12, 9.
  - HD, [CII], [OI] emission
  - PAH emission



S. Pilipenko



Gravitational lensing



Wong et al. (2019).

SZ effect:

Paolo de Bernardis, Jens Chluba.

Observations of galaxy clusters to measure the following effects:

SZ effect:

Paolo de Bernardis, Jens Chluba.

Observations of galaxy clusters to measure the following effects:

- Kinematic SZ effect;
- Relativistic corrections to Thermal SZ effect;
- Multiple scattering;
- Anisotropic SZ effect.

SZ scientific goals:

- Galaxy clusters structure, optical depth, temperature, peculiar velocities;
- Independent measurement of CMB quadrupole and octupole;
- Separation of ISW effect from SW effect;
- Better understanding of LSS formation;
- CMB dipole determination.

Preliminary scientific program

Main projects:

1. Supermassive Relativistic Objects;
2. Origin of life in the Universe;
3. CMB spectral distortions.

Additional projects:

1. Studies of high redshift galaxies;
2. SZ effect;
3. Gravitational lensing;
4. Star and planet formation;
6. Stellar evolution / late type stars;
7. Exoplanets;
8. Solar system studies.

Conclusions:

1. 'Millimetron' mission can provide us with unique observational data in the millimeter and submillimeter wavelength ranges;

2. These data are needed to give answers for some of the most important questions of modern astrophysics, astrochemistry and cosmology;

3. 'Millimetron' implies wide international cooperation involving research by a large scientific community.

Thank you !