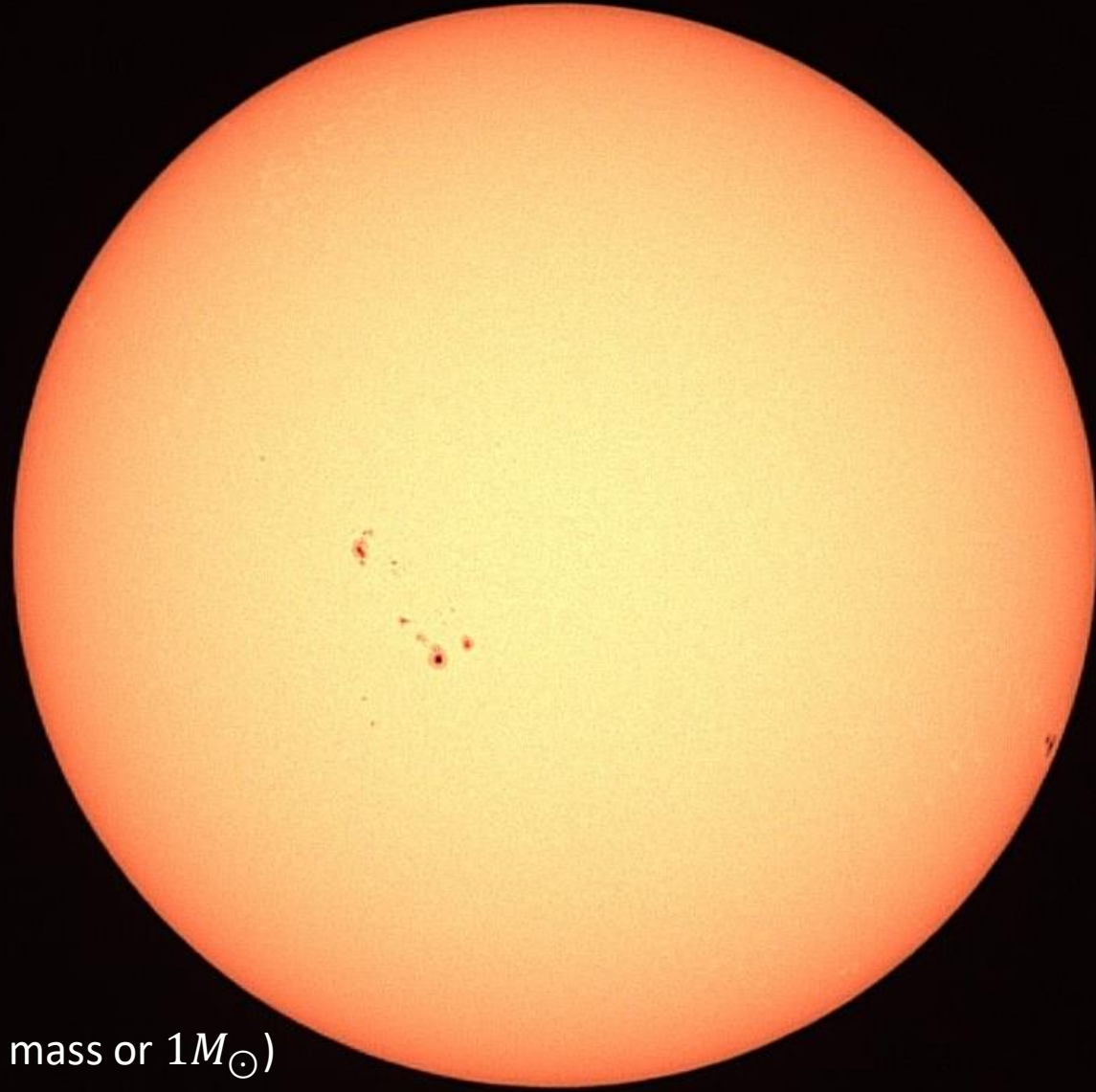


# Stellar Evolution

The background of the slide is a photograph of a bright, glowing sun in the center, partially obscured by dark, billowing clouds at the bottom. The sky is a deep golden-yellow color, and the sun's light creates a strong lens flare effect.

The birth, life and death of stars



## Sol (our Sun)

Distance 8.3 light minutes

Mass  $1.989 \times 10^{30}$  kg (1 solar mass or  $1M_{\odot}$ )

Age 4.6 billion years

Dwarf 3 Digital Telescope

|          |          |           |           |           |           |           |           |           |           |           |           |           |           |           |           |           |           |
|----------|----------|-----------|-----------|-----------|-----------|-----------|-----------|-----------|-----------|-----------|-----------|-----------|-----------|-----------|-----------|-----------|-----------|
| 1<br>H   |          |           |           |           |           |           |           |           |           |           |           |           |           |           |           |           | 2<br>He   |
| 3<br>Li  | 4<br>Be  |           |           |           |           |           |           |           |           |           |           | 5<br>B    | 6<br>C    | 7<br>N    | 8<br>O    | 9<br>F    | 10<br>Ne  |
| 11<br>Na | 12<br>Mg |           |           |           |           |           |           |           |           |           |           | 13<br>Al  | 14<br>Si  | 15<br>P   | 16<br>S   | 17<br>Cl  | 18<br>Ar  |
| 19<br>K  | 20<br>Ca | 21<br>Sc  | 22<br>Ti  | 23<br>V   | 24<br>Cr  | 25<br>Mn  | 26<br>Fe  | 27<br>Co  | 28<br>Ni  | 29<br>Cu  | 30<br>Zn  | 31<br>Ga  | 32<br>Ge  | 33<br>As  | 34<br>Se  | 35<br>Br  | 36<br>Kr  |
| 37<br>Rb | 38<br>Sr | 39<br>Y   | 40<br>Zr  | 41<br>Nb  | 42<br>Mo  | 43<br>Tc  | 44<br>Ru  | 45<br>Rh  | 46<br>Pd  | 47<br>Ag  | 48<br>Cd  | 49<br>In  | 50<br>Sn  | 51<br>Sb  | 52<br>Te  | 53<br>I   | 54<br>Xe  |
| 55<br>Cs | 56<br>Ba | 71<br>Lu  | 72<br>Hf  | 73<br>Ta  | 74<br>W   | 75<br>Re  | 76<br>Os  | 77<br>Ir  | 78<br>Pt  | 79<br>Au  | 80<br>Hg  | 81<br>Tl  | 82<br>Pb  | 83<br>Bi  | 84<br>Po  | 85<br>At  | 86<br>Rn  |
| 87<br>Fr | 88<br>Ra | 103<br>Lr | 104<br>Rf | 105<br>Db | 106<br>Sg | 107<br>Bh | 108<br>Hs | 109<br>Mt | 110<br>Ds | 111<br>Rg | 112<br>Cn | 113<br>Nh | 114<br>Fl | 115<br>Mc | 116<br>Lv | 117<br>Ts | 118<br>Og |
|          |          | 57<br>La  | 58<br>Ce  | 59<br>Pr  | 60<br>Nd  | 61<br>Pm  | 62<br>Sm  | 63<br>Eu  | 64<br>Gd  | 65<br>Tb  | 66<br>Dy  | 67<br>Ho  | 68<br>Er  | 69<br>Tm  | 70<br>Yb  |           |           |
|          |          | 89<br>Ac  | 90<br>Th  | 91<br>Pa  | 92<br>U   | 93<br>Np  | 94<br>Pu  | 95<br>Am  | 96<br>Cm  | 97<br>Bk  | 98<br>Cf  | 99<br>Es  | 100<br>Fm | 101<br>Md | 102<br>No |           |           |



## M42

Distance 1,344 light years

Radius 25 light years

SeeStar S50 Digital Telescope



# Orion Constellation

Apple iPhone

# Betelgeuse

Distance 650 light years

Mass 14  $M_{\odot}$

Would extend to asteroid belt



## Orion Constellation

Apple iPhone

# Bellatrix

Distance 250 light years

Mass  $9 M_{\odot}$



## Orion Constellation

Apple iPhone

# Rigel

Distance 850 light years

Mass  $21 M_{\odot}$

## Orion Constellation

Apple iPhone



# Saiph

Distance 650 light years

Mass  $15 M_{\odot}$

## Orion Constellation

Apple iPhone

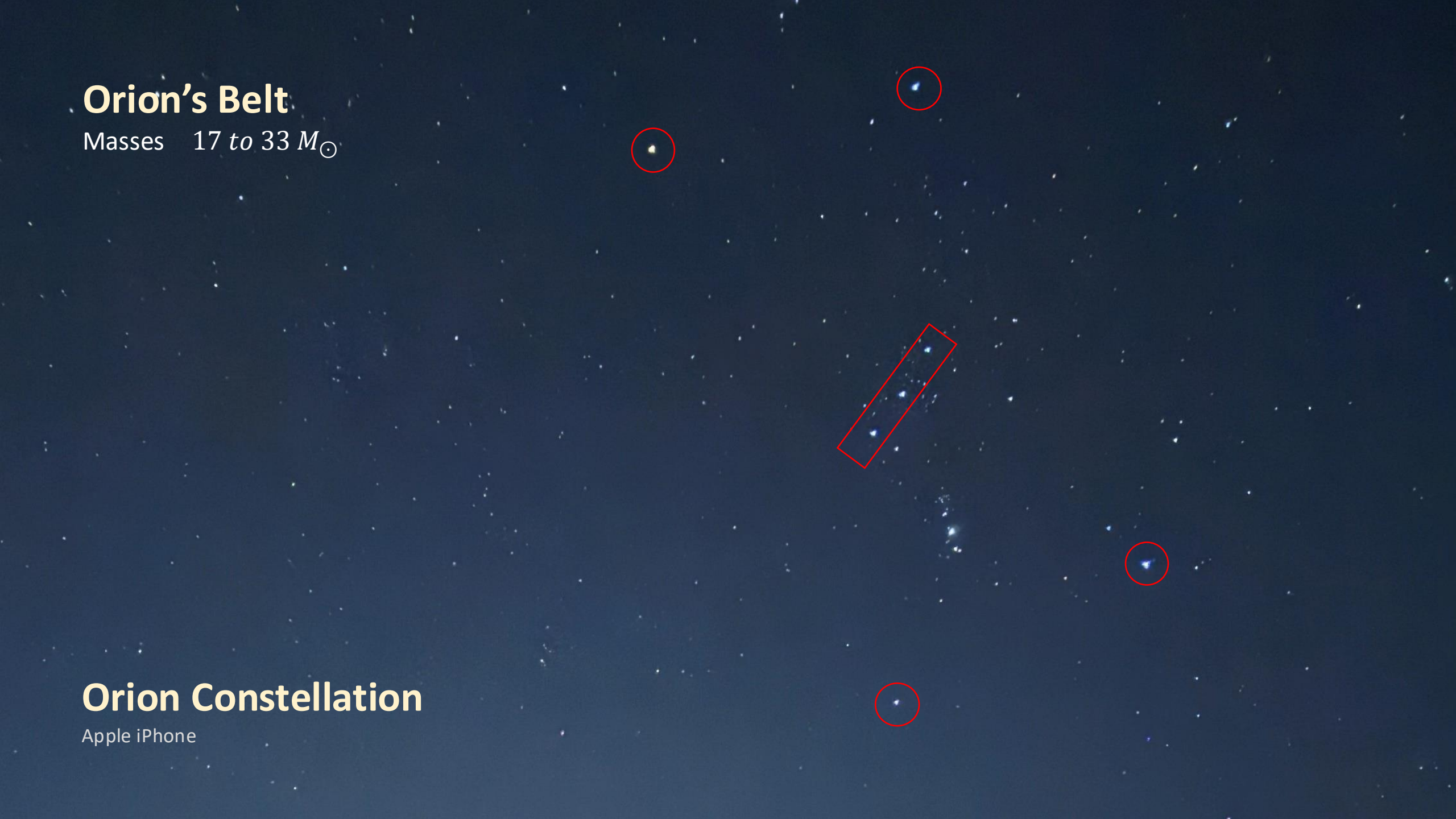


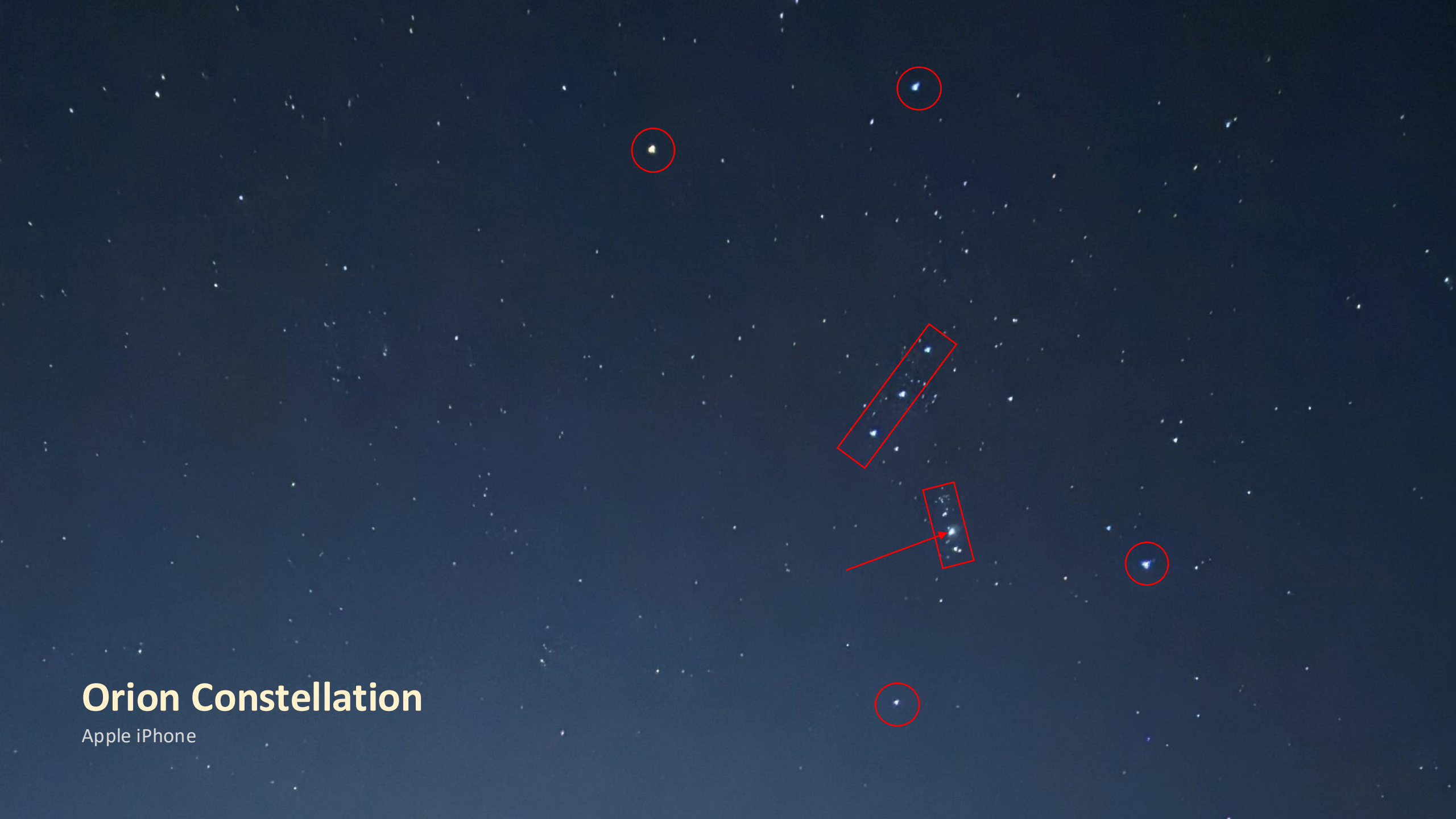
# Orion's Belt

Masses 17 to 33  $M_{\odot}$

# Orion Constellation

Apple iPhone





# Orion Constellation

Apple iPhone



## M42

Distance 1,344 light years

Radius 25 light years

SeeStar S50 Digital Telescope



# Orion Molecular Cloud

Rogelio Bernai Andreo in October 2010



## M42

Distance 1,344 light years

Radius 25 light years

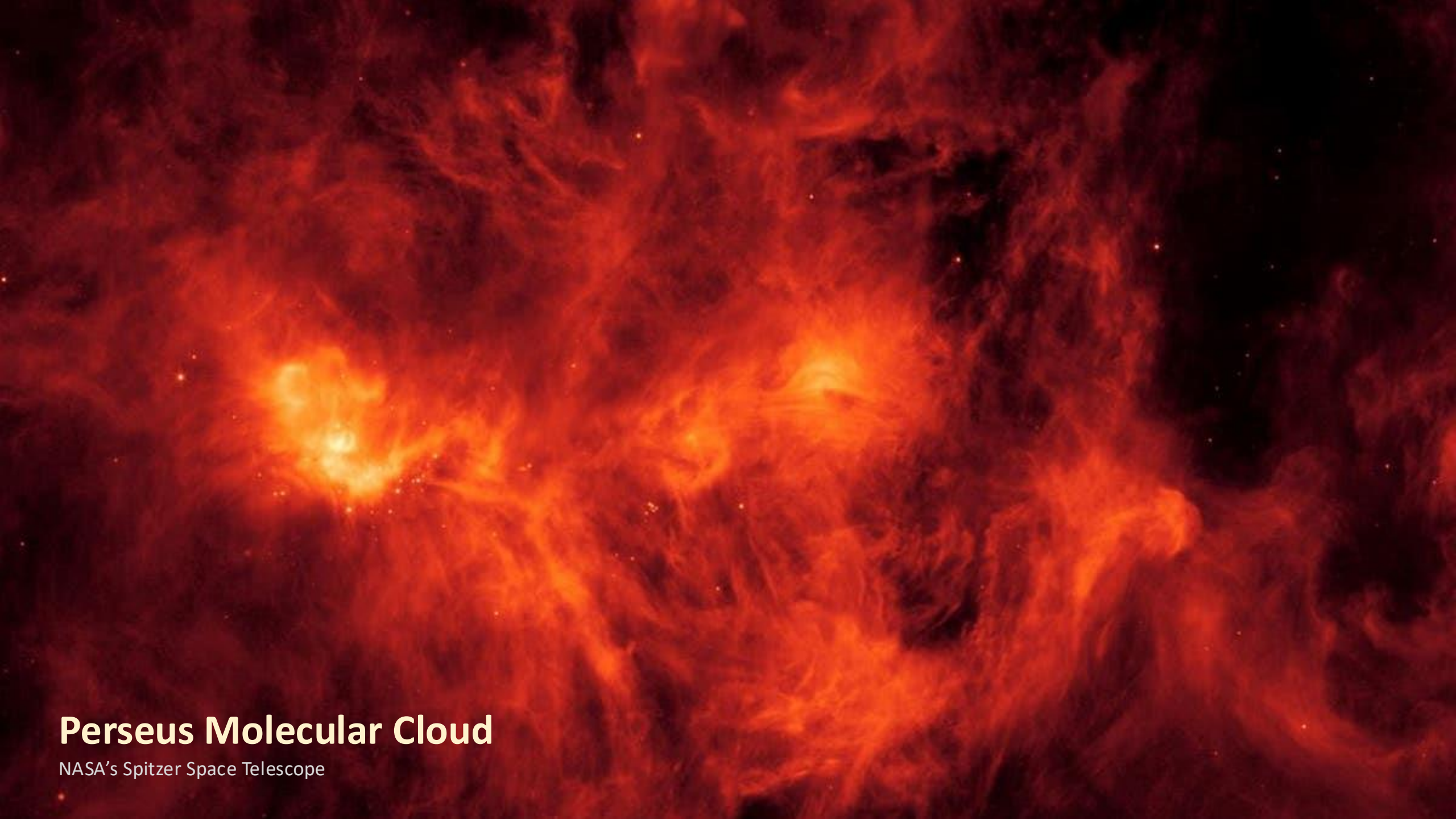
SeeStar S50 Digital Telescope

|          |          |           |           |           |           |           |           |           |           |           |           |           |           |           |           |           |           |
|----------|----------|-----------|-----------|-----------|-----------|-----------|-----------|-----------|-----------|-----------|-----------|-----------|-----------|-----------|-----------|-----------|-----------|
| 1<br>H   |          |           |           |           |           |           |           |           |           |           |           |           |           |           |           |           | 2<br>He   |
| 3<br>Li  | 4<br>Be  |           |           |           |           |           |           |           |           |           |           | 5<br>B    | 6<br>C    | 7<br>N    | 8<br>O    | 9<br>F    | 10<br>Ne  |
| 11<br>Na | 12<br>Mg |           |           |           |           |           |           |           |           |           |           | 13<br>Al  | 14<br>Si  | 15<br>P   | 16<br>S   | 17<br>Cl  | 18<br>Ar  |
| 19<br>K  | 20<br>Ca | 21<br>Sc  | 22<br>Ti  | 23<br>V   | 24<br>Cr  | 25<br>Mn  | 26<br>Fe  | 27<br>Co  | 28<br>Ni  | 29<br>Cu  | 30<br>Zn  | 31<br>Ga  | 32<br>Ge  | 33<br>As  | 34<br>Se  | 35<br>Br  | 36<br>Kr  |
| 37<br>Rb | 38<br>Sr | 39<br>Y   | 40<br>Zr  | 41<br>Nb  | 42<br>Mo  | 43<br>Tc  | 44<br>Ru  | 45<br>Rh  | 46<br>Pd  | 47<br>Ag  | 48<br>Cd  | 49<br>In  | 50<br>Sn  | 51<br>Sb  | 52<br>Te  | 53<br>I   | 54<br>Xe  |
| 55<br>Cs | 56<br>Ba | 71<br>Lu  | 72<br>Hf  | 73<br>Ta  | 74<br>W   | 75<br>Re  | 76<br>Os  | 77<br>Ir  | 78<br>Pt  | 79<br>Au  | 80<br>Hg  | 81<br>Tl  | 82<br>Pb  | 83<br>Bi  | 84<br>Po  | 85<br>At  | 86<br>Rn  |
| 87<br>Fr | 88<br>Ra | 103<br>Lr | 104<br>Rf | 105<br>Db | 106<br>Sg | 107<br>Bh | 108<br>Hs | 109<br>Mt | 110<br>Ds | 111<br>Rg | 112<br>Cn | 113<br>Nh | 114<br>Fl | 115<br>Mc | 116<br>Lv | 117<br>Ts | 118<br>Og |
|          |          | 57<br>La  | 58<br>Ce  | 59<br>Pr  | 60<br>Nd  | 61<br>Pm  | 62<br>Sm  | 63<br>Eu  | 64<br>Gd  | 65<br>Tb  | 66<br>Dy  | 67<br>Ho  | 68<br>Er  | 69<br>Tm  | 70<br>Yb  |           |           |
|          |          | 89<br>Ac  | 90<br>Th  | 91<br>Pa  | 92<br>U   | 93<br>Np  | 94<br>Pu  | 95<br>Am  | 96<br>Cm  | 97<br>Bk  | 98<br>Cf  | 99<br>Es  | 100<br>Fm | 101<br>Md | 102<br>No |           |           |



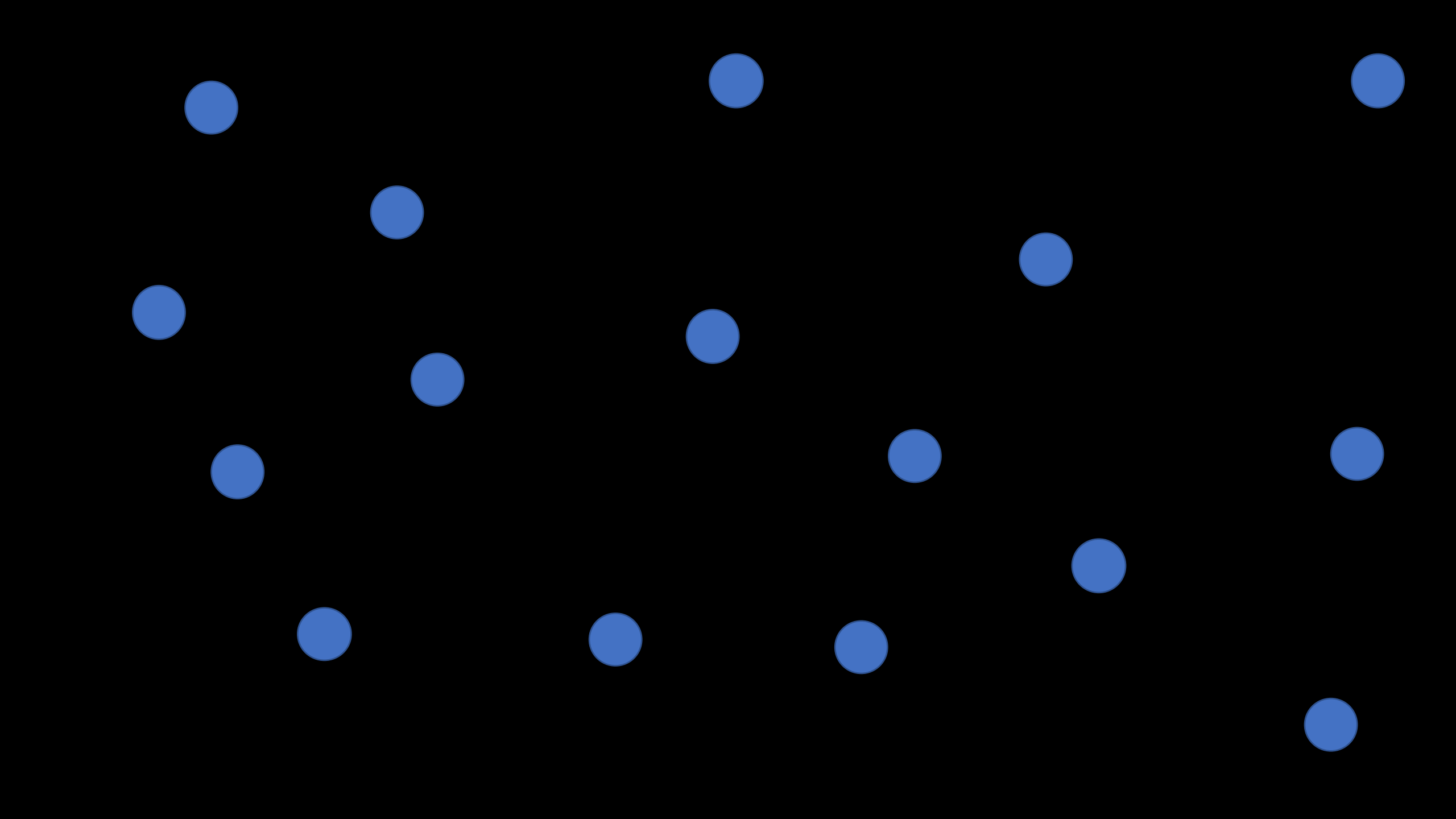
# Orion Molecular Cloud

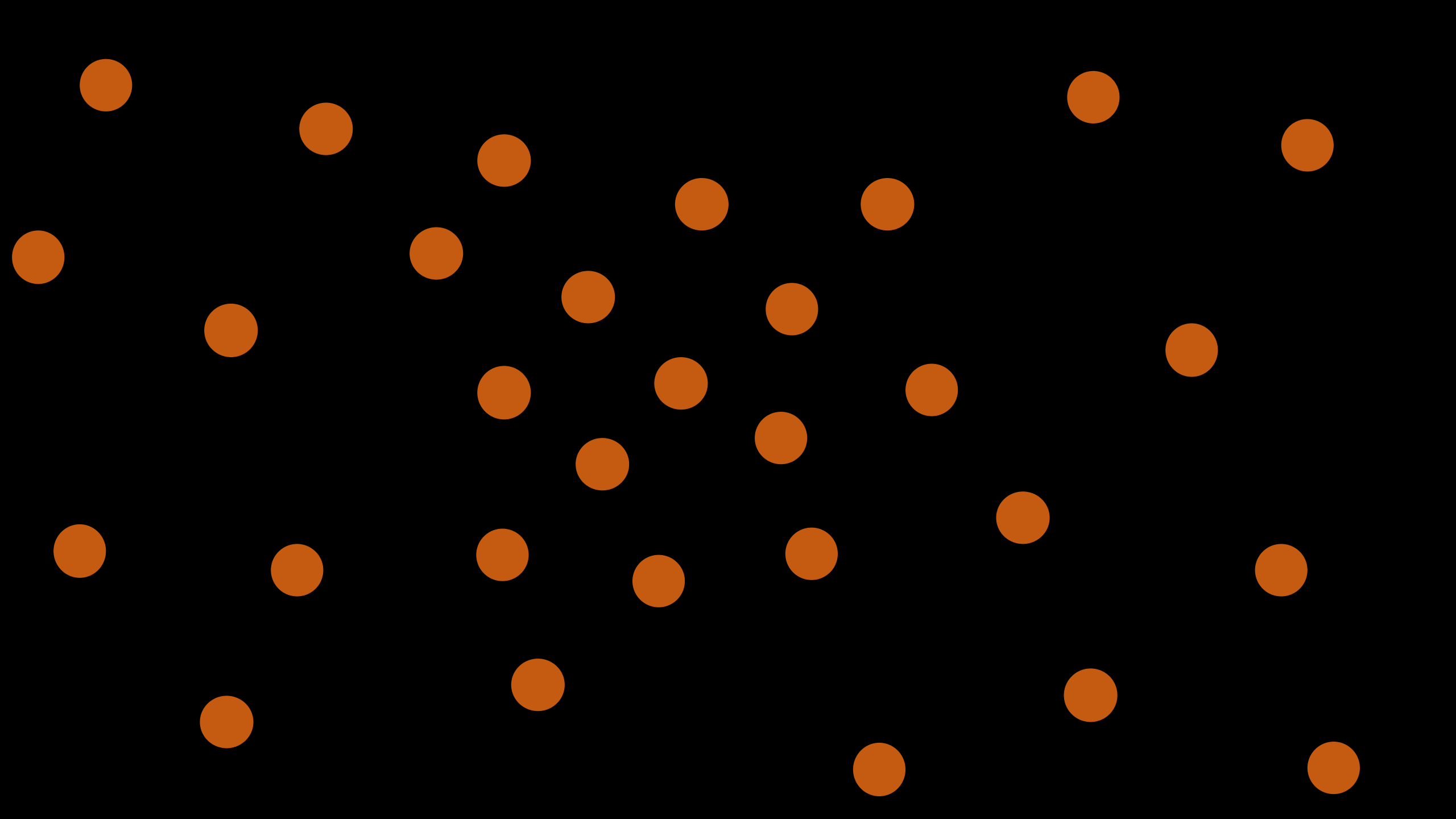
Rogelio Bernai Andreo in October 2010

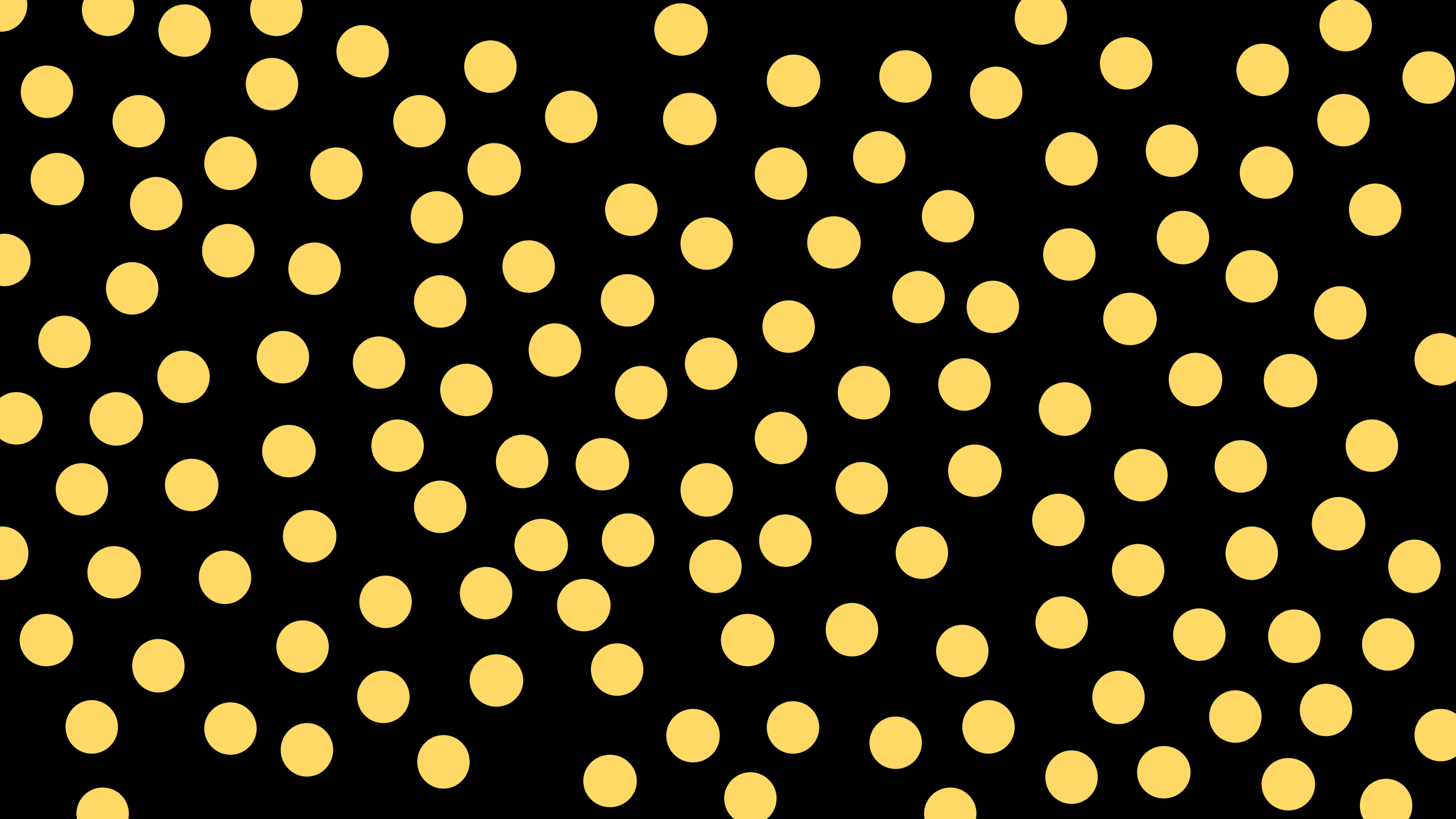


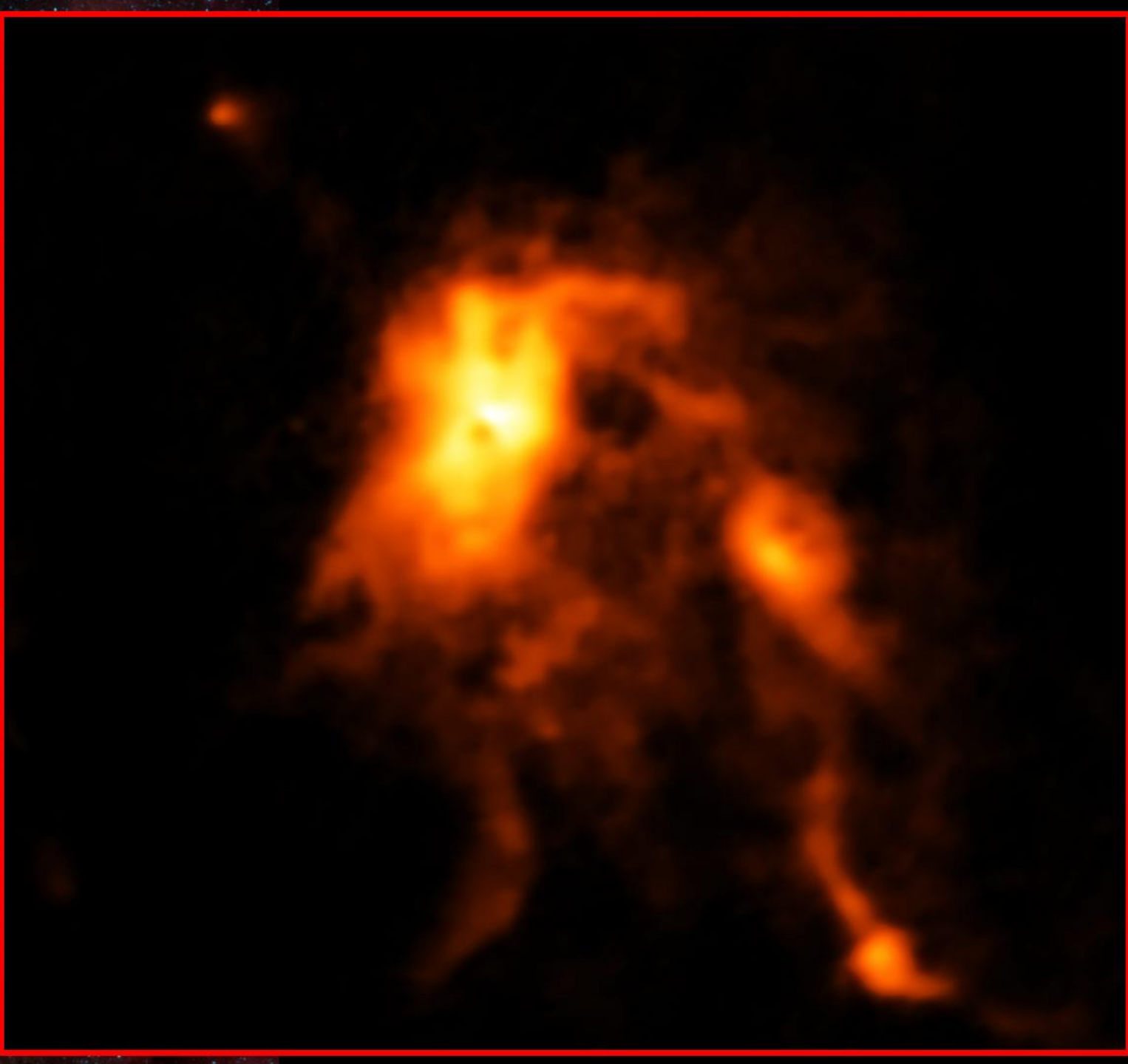
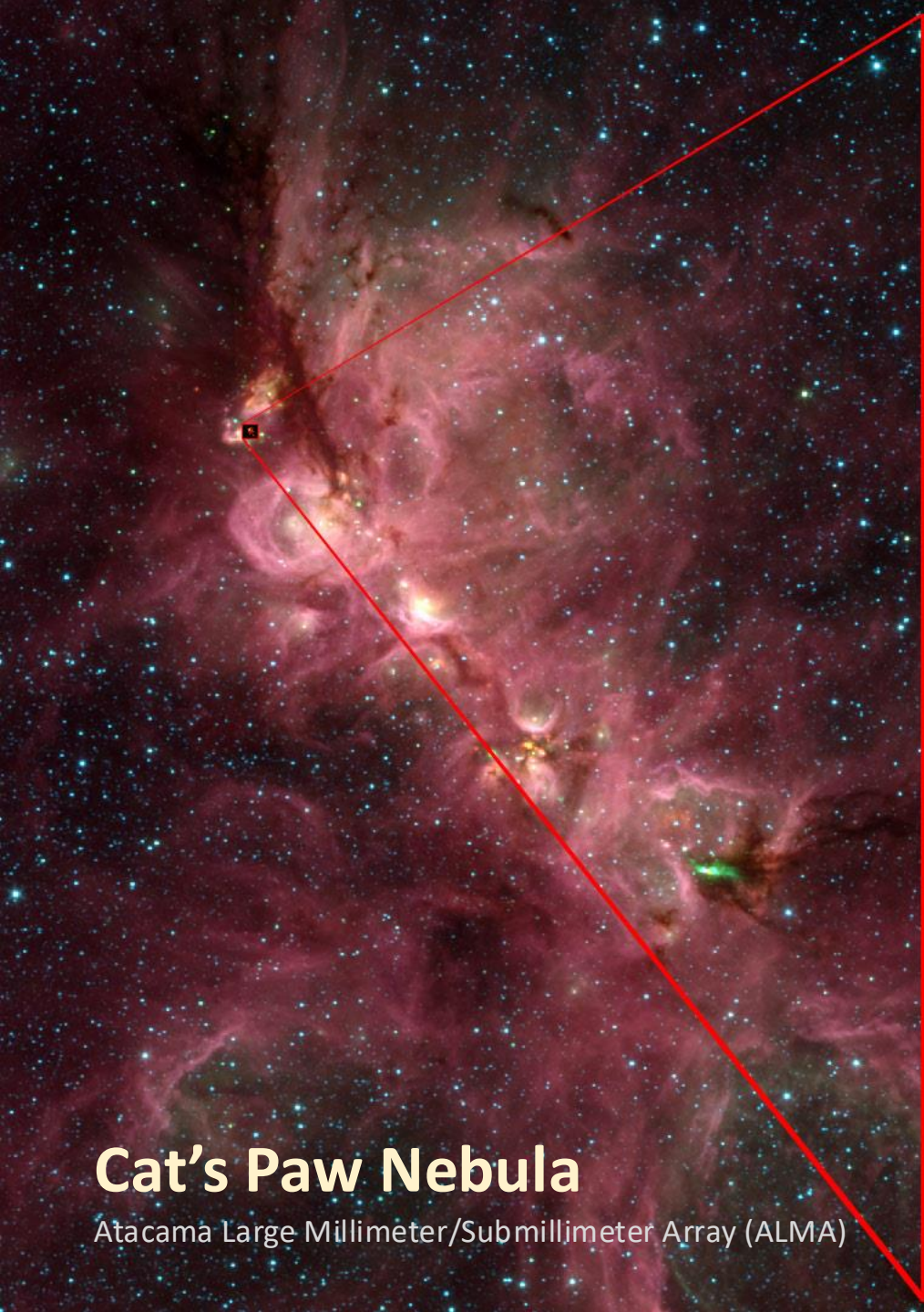
# Perseus Molecular Cloud

NASA's Spitzer Space Telescope









# Cat's Paw Nebula

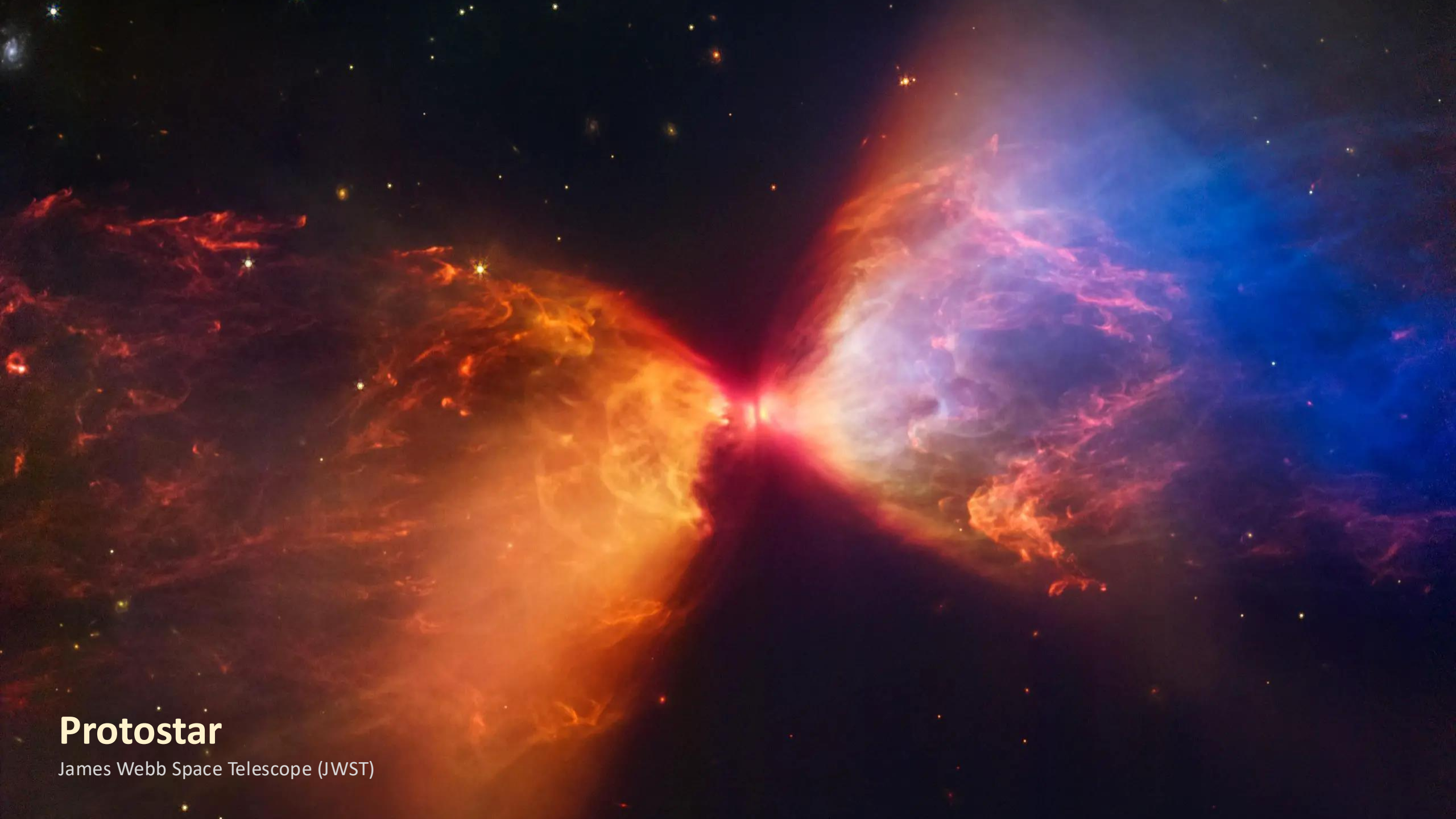
Atacama Large Millimeter/Submillimeter Array (ALMA)



Gas Cloud  
H-II



Protostar



# Protostar

James Webb Space Telescope (JWST)



## Eagle Nebula

Distance 6,000 light years

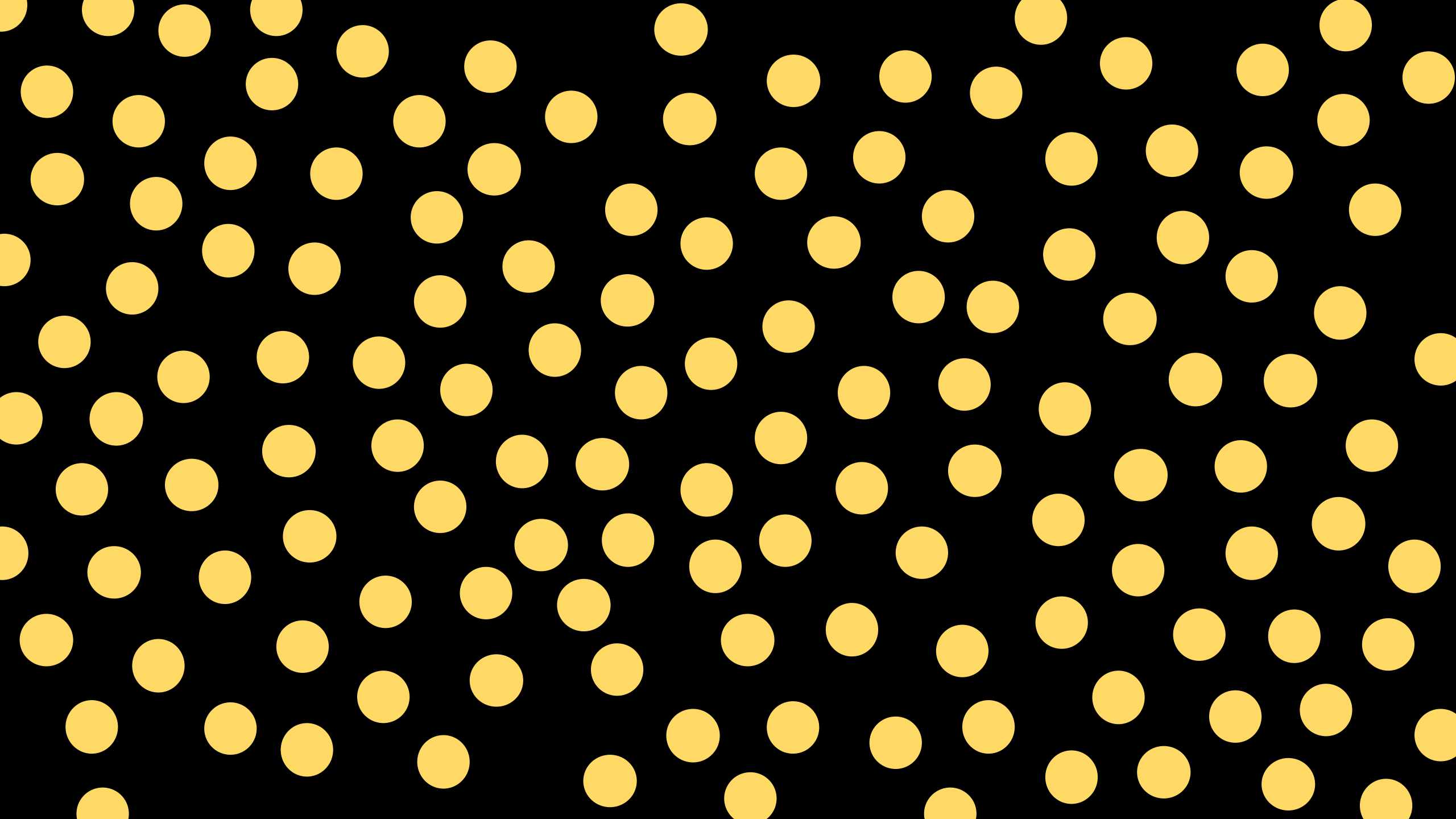
Radius 75 light years

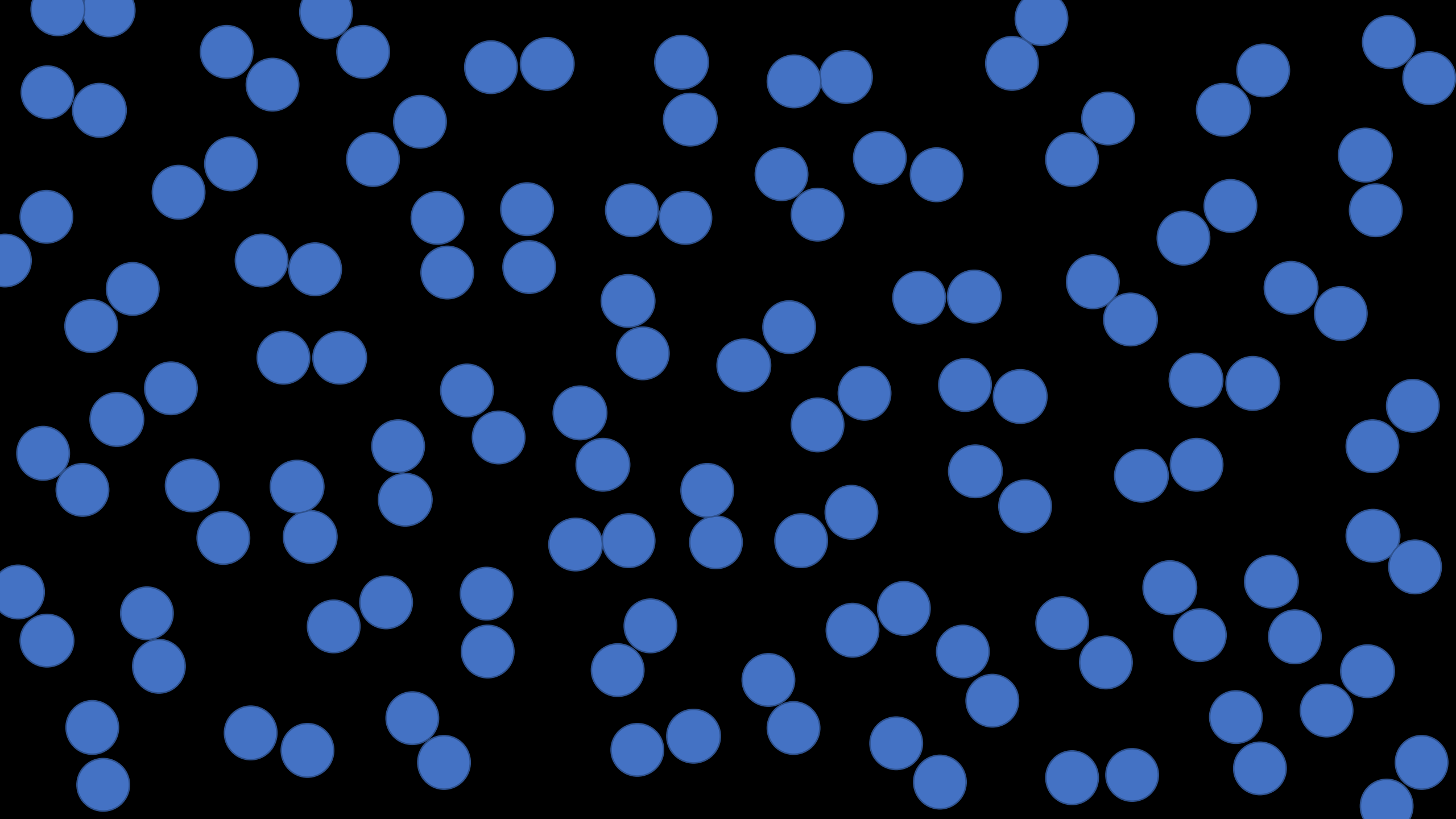
Dwarf 3 Digital Telescope

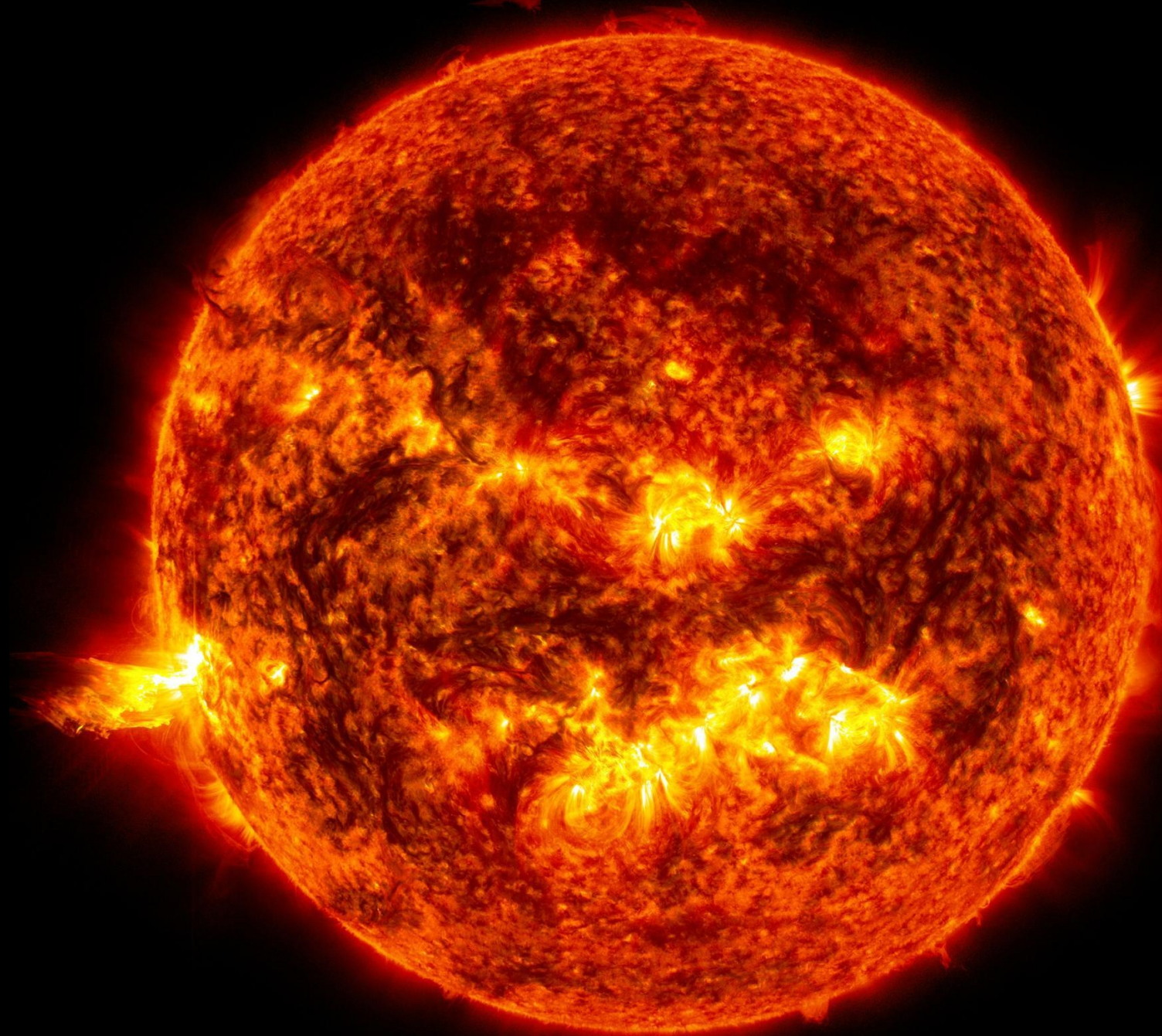
A stunning image of the Pillars of Creation nebula, showing three massive, towering columns of interstellar dust and gas. The columns are illuminated from within, glowing with a mix of blue, green, and yellow light. The background is a deep blue space filled with numerous stars, some of which are bright and prominent, while others are faint and distant. The overall scene conveys a sense of vastness and the ongoing process of star formation.

# Pillars of Creation

Hubble Space Telescope







# Our Sun

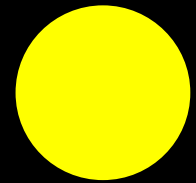
NASA



Gas Cloud



Protostar

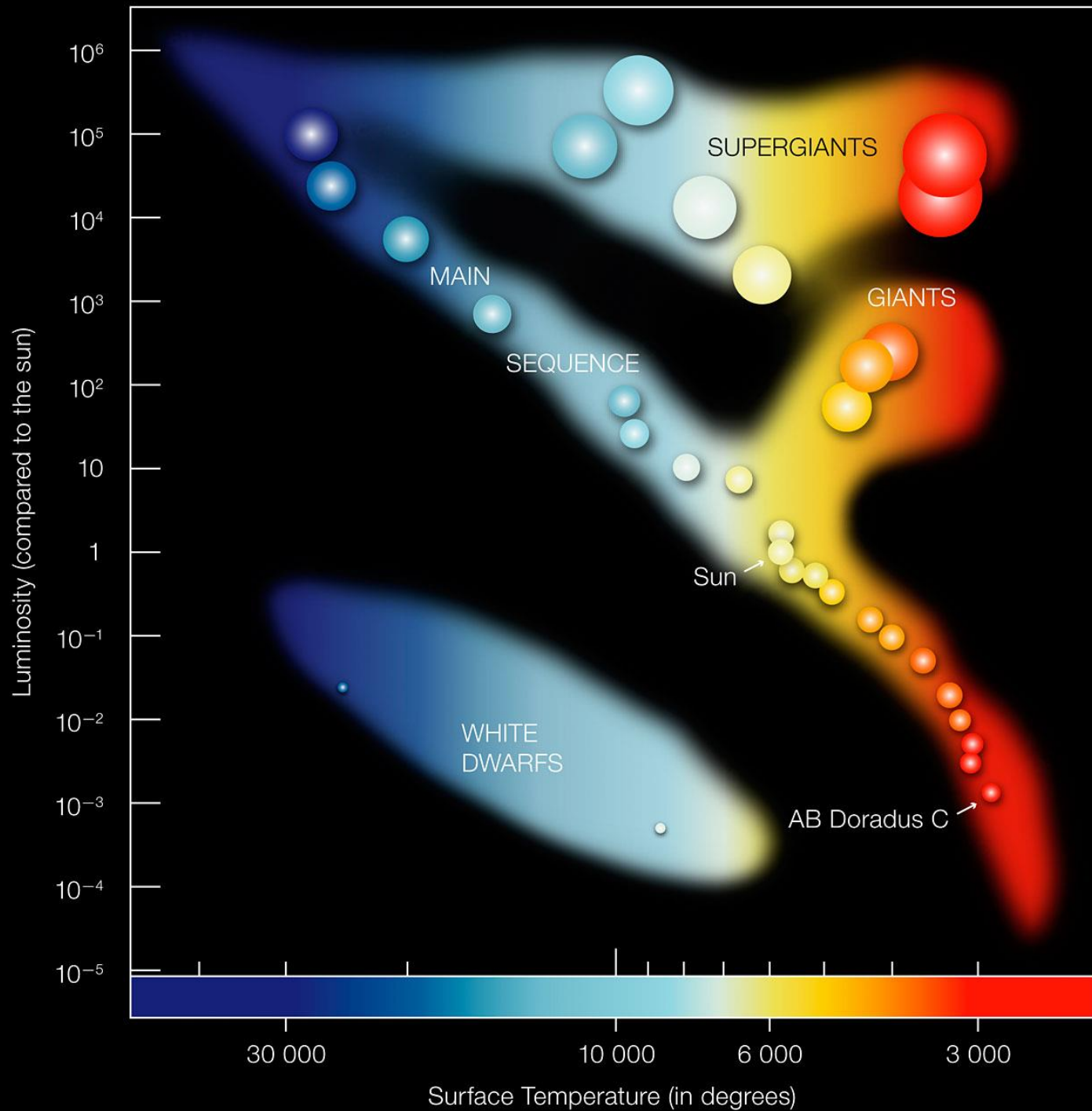


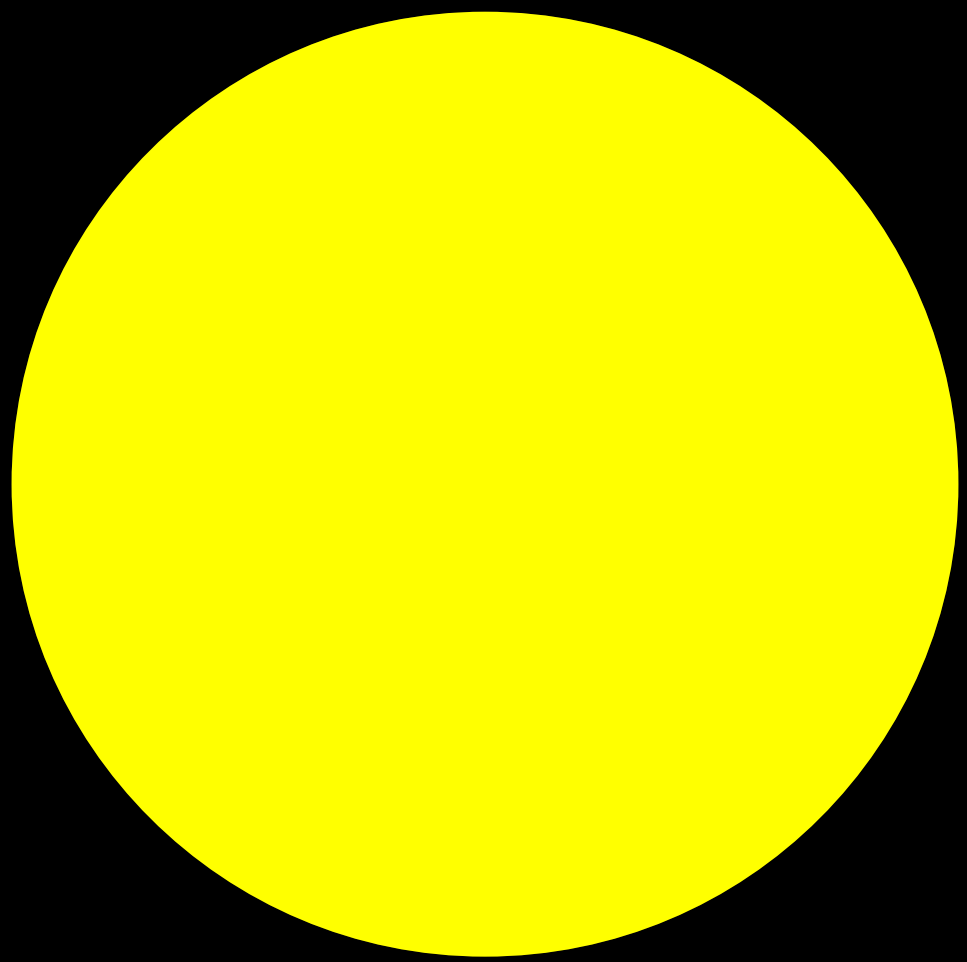
Main Sequence Star

|          |          |           |           |           |           |           |           |           |           |           |           |           |           |           |           |           |           |
|----------|----------|-----------|-----------|-----------|-----------|-----------|-----------|-----------|-----------|-----------|-----------|-----------|-----------|-----------|-----------|-----------|-----------|
| 1<br>H   |          |           |           |           |           |           |           |           |           |           |           |           |           |           |           |           | 2<br>He   |
| 3<br>Li  | 4<br>Be  |           |           |           |           |           |           |           |           |           |           | 5<br>B    | 6<br>C    | 7<br>N    | 8<br>O    | 9<br>F    | 10<br>Ne  |
| 11<br>Na | 12<br>Mg |           |           |           |           |           |           |           |           |           |           | 13<br>Al  | 14<br>Si  | 15<br>P   | 16<br>S   | 17<br>Cl  | 18<br>Ar  |
| 19<br>K  | 20<br>Ca | 21<br>Sc  | 22<br>Ti  | 23<br>V   | 24<br>Cr  | 25<br>Mn  | 26<br>Fe  | 27<br>Co  | 28<br>Ni  | 29<br>Cu  | 30<br>Zn  | 31<br>Ga  | 32<br>Ge  | 33<br>As  | 34<br>Se  | 35<br>Br  | 36<br>Kr  |
| 37<br>Rb | 38<br>Sr | 39<br>Y   | 40<br>Zr  | 41<br>Nb  | 42<br>Mo  | 43<br>Tc  | 44<br>Ru  | 45<br>Rh  | 46<br>Pd  | 47<br>Ag  | 48<br>Cd  | 49<br>In  | 50<br>Sn  | 51<br>Sb  | 52<br>Te  | 53<br>I   | 54<br>Xe  |
| 55<br>Cs | 56<br>Ba | 71<br>Lu  | 72<br>Hf  | 73<br>Ta  | 74<br>W   | 75<br>Re  | 76<br>Os  | 77<br>Ir  | 78<br>Pt  | 79<br>Au  | 80<br>Hg  | 81<br>Tl  | 82<br>Pb  | 83<br>Bi  | 84<br>Po  | 85<br>At  | 86<br>Rn  |
| 87<br>Fr | 88<br>Ra | 103<br>Lr | 104<br>Rf | 105<br>Db | 106<br>Sg | 107<br>Bh | 108<br>Hs | 109<br>Mt | 110<br>Ds | 111<br>Rg | 112<br>Cn | 113<br>Nh | 114<br>Fl | 115<br>Mc | 116<br>Lv | 117<br>Ts | 118<br>Og |
|          |          | 57<br>La  | 58<br>Ce  | 59<br>Pr  | 60<br>Nd  | 61<br>Pm  | 62<br>Sm  | 63<br>Eu  | 64<br>Gd  | 65<br>Tb  | 66<br>Dy  | 67<br>Ho  | 68<br>Er  | 69<br>Tm  | 70<br>Yb  |           |           |
|          |          | 89<br>Ac  | 90<br>Th  | 91<br>Pa  | 92<br>U   | 93<br>Np  | 94<br>Pu  | 95<br>Am  | 96<br>Cm  | 97<br>Bk  | 98<br>Cf  | 99<br>Es  | 100<br>Fm | 101<br>Md | 102<br>No |           |           |

# HR Diagram

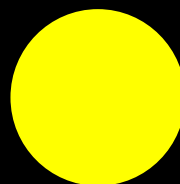
ESO







Gas Cloud



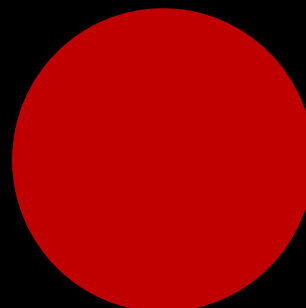
Main Sequence Star



White Dwarf



Protostar



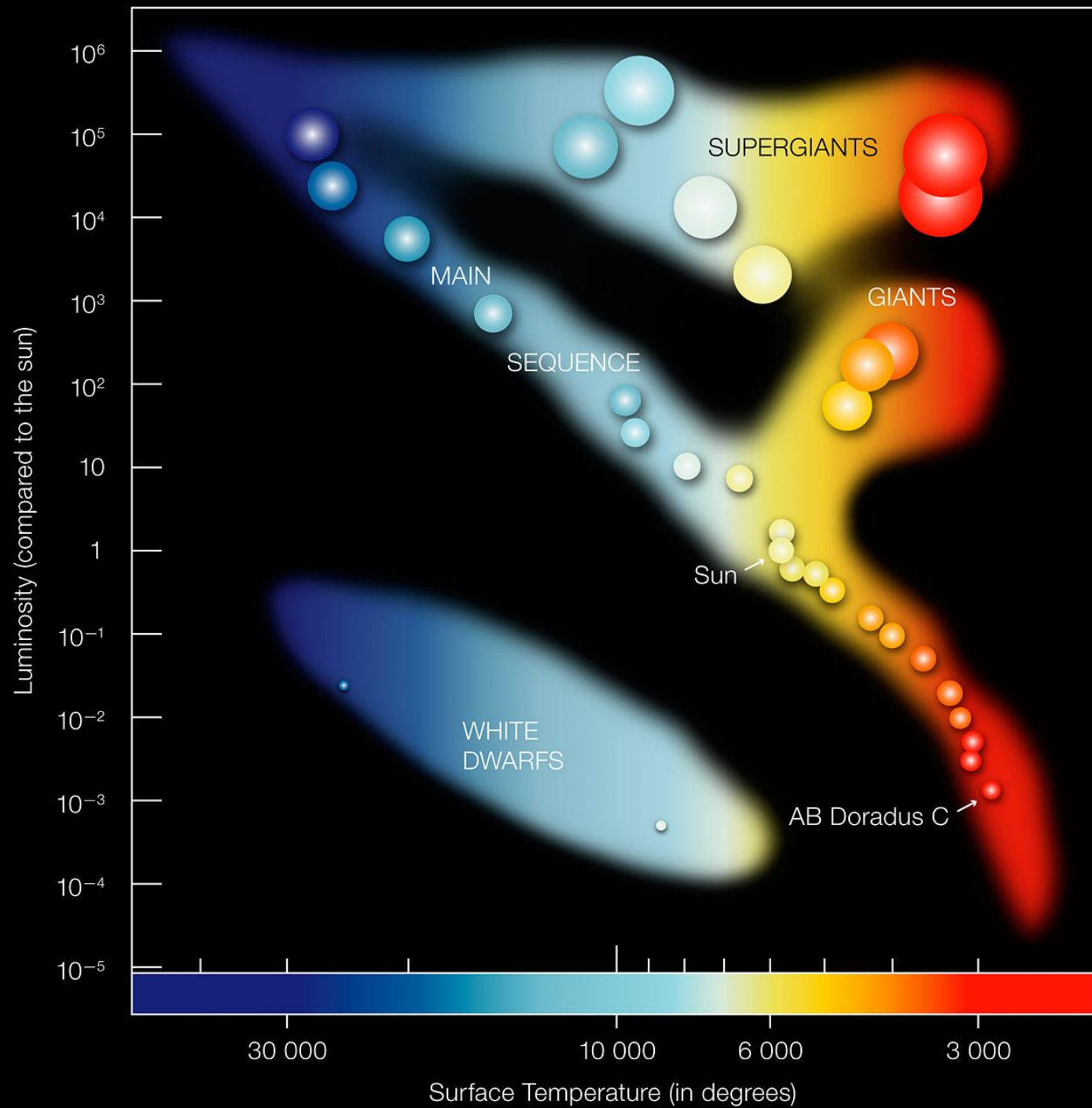
Red Giant



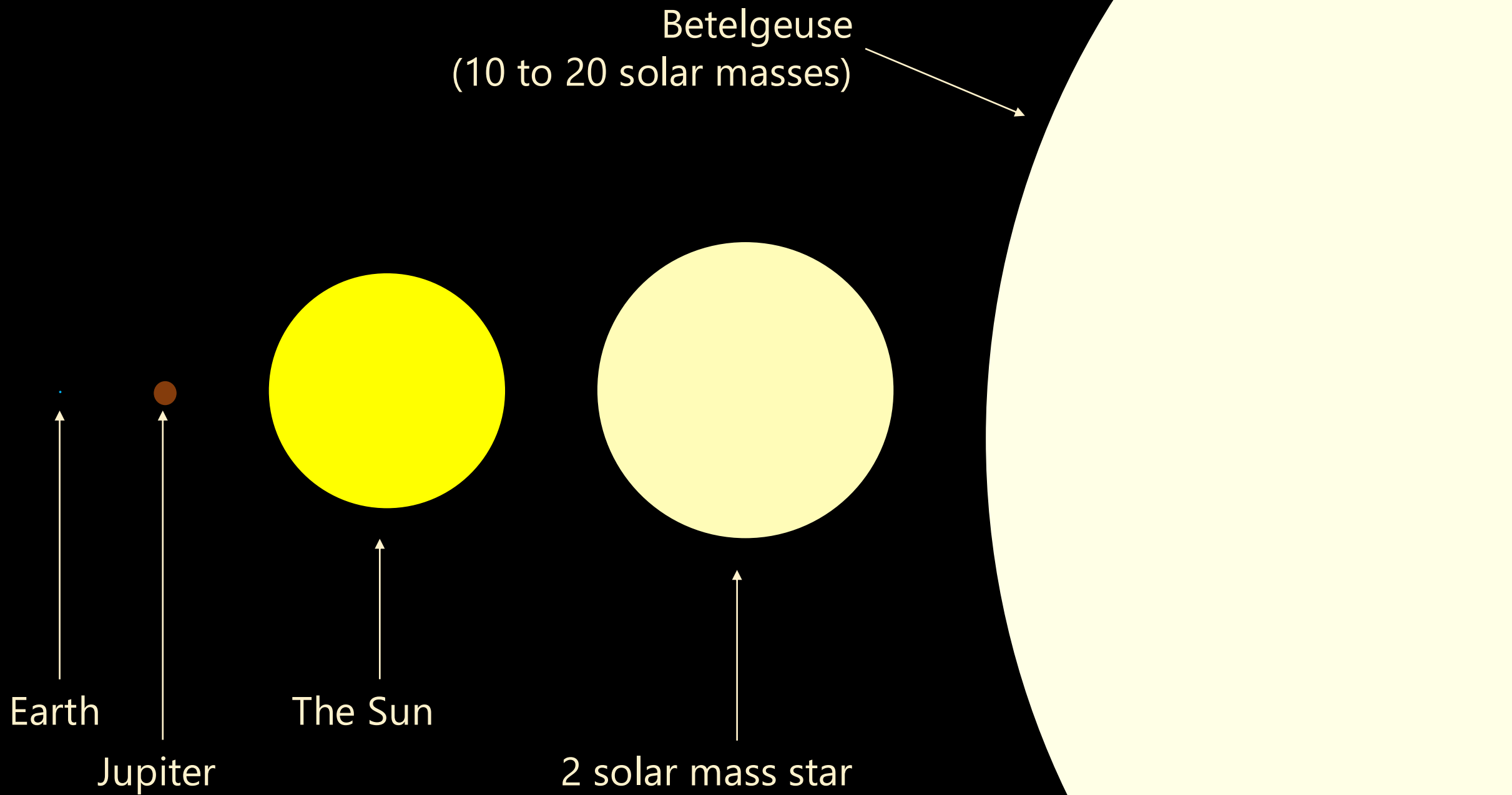
Black Dwarf

# HR Diagram

ESO



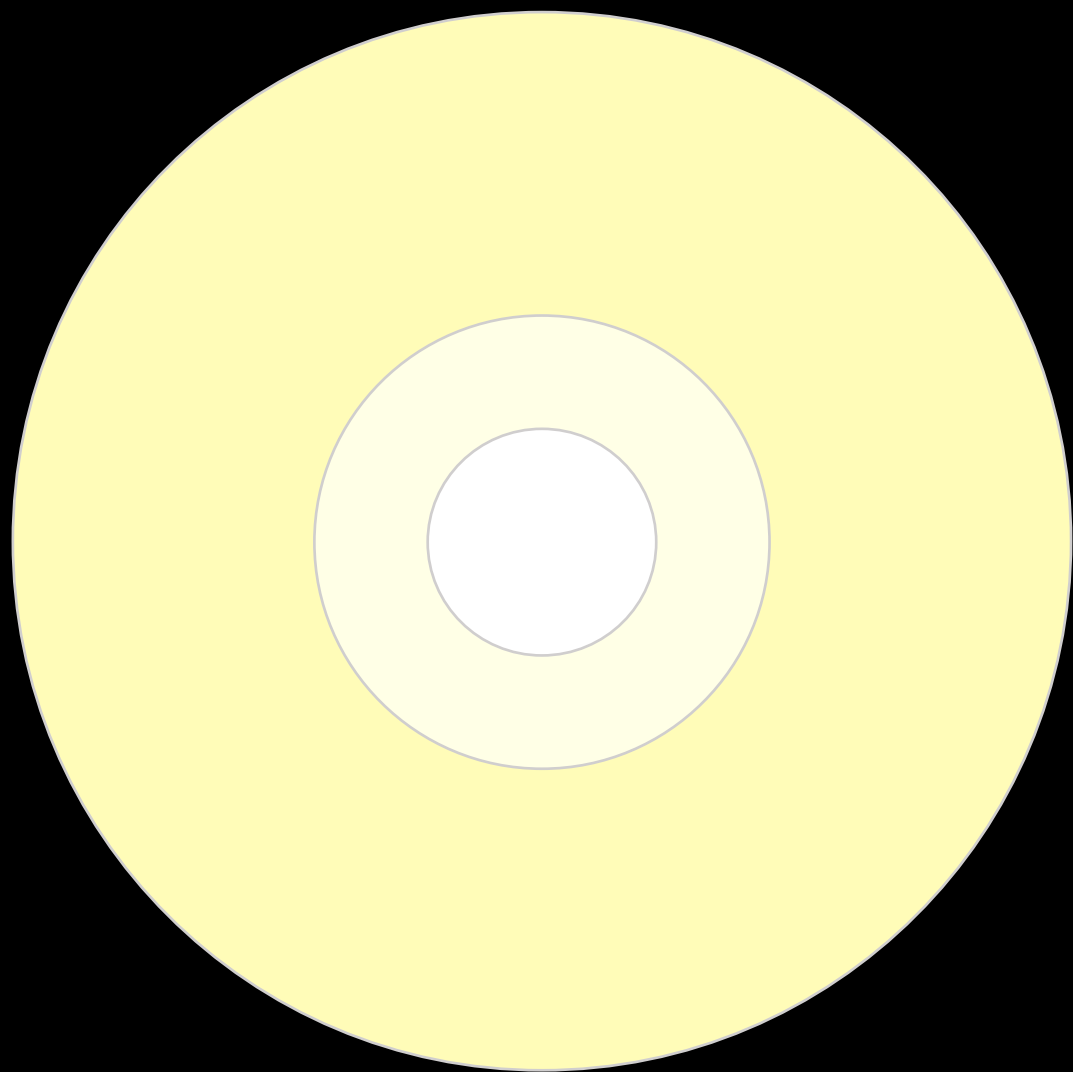
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|----------|----------|-----------|-----------|-----------|-----------|-----------|-----------|-----------|-----------|-----------|-----------|-----------|-----------|-----------|-----------|-----------|-----------|
| 1<br>H   |          |           |           |           |           |           |           |           |           |           |           |           |           |           |           |           | 2<br>He   |
| 3<br>Li  | 4<br>Be  |           |           |           |           |           |           |           |           |           |           | 5<br>B    | 6<br>C    | 7<br>N    | 8<br>O    | 9<br>F    | 10<br>Ne  |
| 11<br>Na | 12<br>Mg |           |           |           |           |           |           |           |           |           |           | 13<br>Al  | 14<br>Si  | 15<br>P   | 16<br>S   | 17<br>Cl  | 18<br>Ar  |
| 19<br>K  | 20<br>Ca | 21<br>Sc  | 22<br>Ti  | 23<br>V   | 24<br>Cr  | 25<br>Mn  | 26<br>Fe  | 27<br>Co  | 28<br>Ni  | 29<br>Cu  | 30<br>Zn  | 31<br>Ga  | 32<br>Ge  | 33<br>As  | 34<br>Se  | 35<br>Br  | 36<br>Kr  |
| 37<br>Rb | 38<br>Sr | 39<br>Y   | 40<br>Zr  | 41<br>Nb  | 42<br>Mo  | 43<br>Tc  | 44<br>Ru  | 45<br>Rh  | 46<br>Pd  | 47<br>Ag  | 48<br>Cd  | 49<br>In  | 50<br>Sn  | 51<br>Sb  | 52<br>Te  | 53<br>I   | 54<br>Xe  |
| 55<br>Cs | 56<br>Ba | 71<br>Lu  | 72<br>Hf  | 73<br>Ta  | 74<br>W   | 75<br>Re  | 76<br>Os  | 77<br>Ir  | 78<br>Pt  | 79<br>Au  | 80<br>Hg  | 81<br>Tl  | 82<br>Pb  | 83<br>Bi  | 84<br>Po  | 85<br>At  | 86<br>Rn  |
| 87<br>Fr | 88<br>Ra | 103<br>Lr | 104<br>Rf | 105<br>Db | 106<br>Sg | 107<br>Bh | 108<br>Hs | 109<br>Mt | 110<br>Ds | 111<br>Rg | 112<br>Cn | 113<br>Nh | 114<br>Fl | 115<br>Mc | 116<br>Lv | 117<br>Ts | 118<br>Og |
|          |          | 57<br>La  | 58<br>Ce  | 59<br>Pr  | 60<br>Nd  | 61<br>Pm  | 62<br>Sm  | 63<br>Eu  | 64<br>Gd  | 65<br>Tb  | 66<br>Dy  | 67<br>Ho  | 68<br>Er  | 69<br>Tm  | 70<br>Yb  |           |           |
|          |          | 89<br>Ac  | 90<br>Th  | 91<br>Pa  | 92<br>U   | 93<br>Np  | 94<br>Pu  | 95<br>Am  | 96<br>Cm  | 97<br>Bk  | 98<br>Cf  | 99<br>Es  | 100<br>Fm | 101<br>Md | 102<br>No |           |           |



When is a star a massive star?

Sun = 1 solar mass ( $1 M_{\odot}$ )

Massive star  $\geq 8$  solar masses ( $8 M_{\odot}$ )



Hydrogen

Helium

Lithium

Beryllium

Boron

Carbon

Nitrogen

Oxygen

Fluorine

Neon

Sodium

Magnesium

Aluminium

Silicon

Phosphorus

Sulphur

Chlorine

Argon

Potassium

Calcium

Scandium

Titanium

Vanadium

Chromium

Manganese

Iron

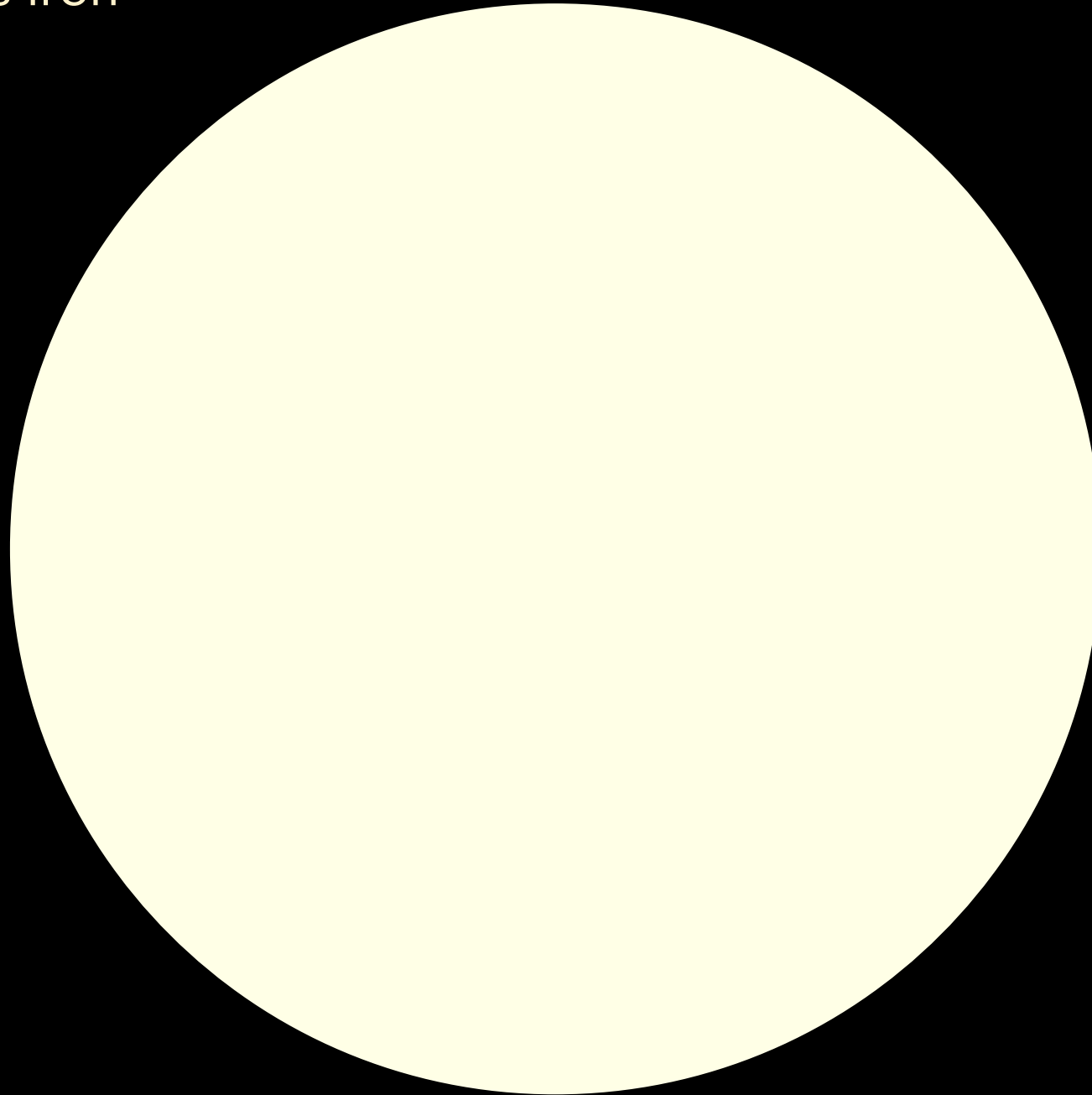
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|----------|----------|-----------|-----------|-----------|-----------|-----------|-----------|-----------|-----------|-----------|-----------|-----------|-----------|-----------|-----------|-----------|-----------|
| 1<br>H   |          |           |           |           |           |           |           |           |           |           |           |           |           |           |           |           | 2<br>He   |
| 3<br>Li  | 4<br>Be  |           |           |           |           |           |           |           |           |           |           | 5<br>B    | 6<br>C    | 7<br>N    | 8<br>O    | 9<br>F    | 10<br>Ne  |
| 11<br>Na | 12<br>Mg |           |           |           |           |           |           |           |           |           |           | 13<br>Al  | 14<br>Si  | 15<br>P   | 16<br>S   | 17<br>Cl  | 18<br>Ar  |
| 19<br>K  | 20<br>Ca | 21<br>Sc  | 22<br>Ti  | 23<br>V   | 24<br>Cr  | 25<br>Mn  | 26<br>Fe  | 27<br>Co  | 28<br>Ni  | 29<br>Cu  | 30<br>Zn  | 31<br>Ga  | 32<br>Ge  | 33<br>As  | 34<br>Se  | 35<br>Br  | 36<br>Kr  |
| 37<br>Rb | 38<br>Sr | 39<br>Y   | 40<br>Zr  | 41<br>Nb  | 42<br>Mo  | 43<br>Tc  | 44<br>Ru  | 45<br>Rh  | 46<br>Pd  | 47<br>Ag  | 48<br>Cd  | 49<br>In  | 50<br>Sn  | 51<br>Sb  | 52<br>Te  | 53<br>I   | 54<br>Xe  |
| 55<br>Cs | 56<br>Ba | 71<br>Lu  | 72<br>Hf  | 73<br>Ta  | 74<br>W   | 75<br>Re  | 76<br>Os  | 77<br>Ir  | 78<br>Pt  | 79<br>Au  | 80<br>Hg  | 81<br>Tl  | 82<br>Pb  | 83<br>Bi  | 84<br>Po  | 85<br>At  | 86<br>Rn  |
| 87<br>Fr | 88<br>Ra | 103<br>Lr | 104<br>Rf | 105<br>Db | 106<br>Sg | 107<br>Bh | 108<br>Hs | 109<br>Mt | 110<br>Ds | 111<br>Rg | 112<br>Cn | 113<br>Nh | 114<br>Fl | 115<br>Mc | 116<br>Lv | 117<br>Ts | 118<br>Og |
|          |          | 57<br>La  | 58<br>Ce  | 59<br>Pr  | 60<br>Nd  | 61<br>Pm  | 62<br>Sm  | 63<br>Eu  | 64<br>Gd  | 65<br>Tb  | 66<br>Dy  | 67<br>Ho  | 68<br>Er  | 69<br>Tm  | 70<br>Yb  |           |           |
|          |          | 89<br>Ac  | 90<br>Th  | 91<br>Pa  | 92<br>U   | 93<br>Np  | 94<br>Pu  | 95<br>Am  | 96<br>Cm  | 97<br>Bk  | 98<br>Cf  | 99<br>Es  | 100<br>Fm | 101<br>Md | 102<br>No |           |           |

Iron is where fusion ends.

Unlike lighter elements, fusing iron doesn't release energy  
- it requires energy.

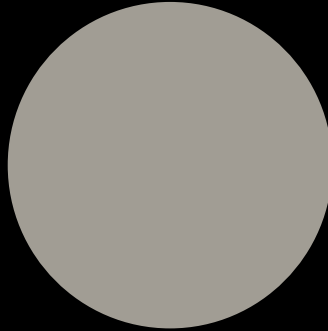
When a massive star's core turns to iron, it's doomed

Central core becomes iron



Core collapses





Collapse leads to explosion

Supernova explosion

|          |          |           |           |           |           |           |           |           |           |           |           |           |           |           |           |           |           |
|----------|----------|-----------|-----------|-----------|-----------|-----------|-----------|-----------|-----------|-----------|-----------|-----------|-----------|-----------|-----------|-----------|-----------|
| 1<br>H   |          |           |           |           |           |           |           |           |           |           |           |           |           |           |           |           | 2<br>He   |
| 3<br>Li  | 4<br>Be  |           |           |           |           |           |           |           |           |           |           | 5<br>B    | 6<br>C    | 7<br>N    | 8<br>O    | 9<br>F    | 10<br>Ne  |
| 11<br>Na | 12<br>Mg |           |           |           |           |           |           |           |           |           |           | 13<br>Al  | 14<br>Si  | 15<br>P   | 16<br>S   | 17<br>Cl  | 18<br>Ar  |
| 19<br>K  | 20<br>Ca | 21<br>Sc  | 22<br>Ti  | 23<br>V   | 24<br>Cr  | 25<br>Mn  | 26<br>Fe  | 27<br>Co  | 28<br>Ni  | 29<br>Cu  | 30<br>Zn  | 31<br>Ga  | 32<br>Ge  | 33<br>As  | 34<br>Se  | 35<br>Br  | 36<br>Kr  |
| 37<br>Rb | 38<br>Sr | 39<br>Y   | 40<br>Zr  | 41<br>Nb  | 42<br>Mo  | 43<br>Tc  | 44<br>Ru  | 45<br>Rh  | 46<br>Pd  | 47<br>Ag  | 48<br>Cd  | 49<br>In  | 50<br>Sn  | 51<br>Sb  | 52<br>Te  | 53<br>I   | 54<br>Xe  |
| 55<br>Cs | 56<br>Ba | 71<br>Lu  | 72<br>Hf  | 73<br>Ta  | 74<br>W   | 75<br>Re  | 76<br>Os  | 77<br>Ir  | 78<br>Pt  | 79<br>Au  | 80<br>Hg  | 81<br>Tl  | 82<br>Pb  | 83<br>Bi  | 84<br>Po  | 85<br>At  | 86<br>Rn  |
| 87<br>Fr | 88<br>Ra | 103<br>Lr | 104<br>Rf | 105<br>Db | 106<br>Sg | 107<br>Bh | 108<br>Hs | 109<br>Mt | 110<br>Ds | 111<br>Rg | 112<br>Cn | 113<br>Nh | 114<br>Fl | 115<br>Mc | 116<br>Lv | 117<br>Ts | 118<br>Og |
|          |          | 57<br>La  | 58<br>Ce  | 59<br>Pr  | 60<br>Nd  | 61<br>Pm  | 62<br>Sm  | 63<br>Eu  | 64<br>Gd  | 65<br>Tb  | 66<br>Dy  | 67<br>Ho  | 68<br>Er  | 69<br>Tm  | 70<br>Yb  |           |           |
|          |          | 89<br>Ac  | 90<br>Th  | 91<br>Pa  | 92<br>U   | 93<br>Np  | 94<br>Pu  | 95<br>Am  | 96<br>Cm  | 97<br>Bk  | 98<br>Cf  | 99<br>Es  | 100<br>Fm | 101<br>Md | 102<br>No |           |           |

# Core collapses

|          |          |           |           |           |           |           |           |           |           |           |           |           |           |           |           |           |           |
|----------|----------|-----------|-----------|-----------|-----------|-----------|-----------|-----------|-----------|-----------|-----------|-----------|-----------|-----------|-----------|-----------|-----------|
| 1<br>H   |          |           |           |           |           |           |           |           |           |           |           |           |           |           |           |           | 2<br>He   |
| 3<br>Li  | 4<br>Be  |           |           |           |           |           |           |           |           |           |           | 5<br>B    | 6<br>C    | 7<br>N    | 8<br>O    | 9<br>F    | 10<br>Ne  |
| 11<br>Na | 12<br>Mg |           |           |           |           |           |           |           |           |           |           | 13<br>Al  | 14<br>Si  | 15<br>P   | 16<br>S   | 17<br>Cl  | 18<br>Ar  |
| 19<br>K  | 20<br>Ca | 21<br>Sc  | 22<br>Ti  | 23<br>V   | 24<br>Cr  | 25<br>Mn  | 26<br>Fe  | 27<br>Co  | 28<br>Ni  | 29<br>Cu  | 30<br>Zn  | 31<br>Ga  | 32<br>Ge  | 33<br>As  | 34<br>Se  | 35<br>Br  | 36<br>Kr  |
| 37<br>Rb | 38<br>Sr | 39<br>Y   | 40<br>Zr  | 41<br>Nb  | 42<br>Mo  | 43<br>Tc  | 44<br>Ru  | 45<br>Rh  | 46<br>Pd  | 47<br>Ag  | 48<br>Cd  | 49<br>In  | 50<br>Sn  | 51<br>Sb  | 52<br>Te  | 53<br>I   | 54<br>Xe  |
| 55<br>Cs | 56<br>Ba | 71<br>Lu  | 72<br>Hf  | 73<br>Ta  | 74<br>W   | 75<br>Re  | 76<br>Os  | 77<br>Ir  | 78<br>Pt  | 79<br>Au  | 80<br>Hg  | 81<br>Tl  | 82<br>Pb  | 83<br>Bi  | 84<br>Po  | 85<br>At  | 86<br>Rn  |
| 87<br>Fr | 88<br>Ra | 103<br>Lr | 104<br>Rf | 105<br>Db | 106<br>Sg | 107<br>Bh | 108<br>Hs | 109<br>Mt | 110<br>Ds | 111<br>Rg | 112<br>Cn | 113<br>Nh | 114<br>Fl | 115<br>Mc | 116<br>Lv | 117<br>Ts | 118<br>Og |
|          |          | 57<br>La  | 58<br>Ce  | 59<br>Pr  | 60<br>Nd  | 61<br>Pm  | 62<br>Sm  | 63<br>Eu  | 64<br>Gd  | 65<br>Tb  | 66<br>Dy  | 67<br>Ho  | 68<br>Er  | 69<br>Tm  | 70<br>Yb  |           |           |
|          |          | 89<br>Ac  | 90<br>Th  | 91<br>Pa  | 92<br>U   | 93<br>Np  | 94<br>Pu  | 95<br>Am  | 96<br>Cm  | 97<br>Bk  | 98<br>Cf  | 99<br>Es  | 100<br>Fm | 101<br>Md | 102<br>No |           |           |

# Collapse leads to explosion

|          |          |           |           |           |           |           |           |           |           |           |           |           |           |           |           |           |           |
|----------|----------|-----------|-----------|-----------|-----------|-----------|-----------|-----------|-----------|-----------|-----------|-----------|-----------|-----------|-----------|-----------|-----------|
| 1<br>H   |          |           |           |           |           |           |           |           |           |           |           |           |           |           |           |           | 2<br>He   |
| 3<br>Li  | 4<br>Be  |           |           |           |           |           |           |           |           |           |           | 5<br>B    | 6<br>C    | 7<br>N    | 8<br>O    | 9<br>F    | 10<br>Ne  |
| 11<br>Na | 12<br>Mg |           |           |           |           |           |           |           |           |           |           | 13<br>Al  | 14<br>Si  | 15<br>P   | 16<br>S   | 17<br>Cl  | 18<br>Ar  |
| 19<br>K  | 20<br>Ca | 21<br>Sc  | 22<br>Ti  | 23<br>V   | 24<br>Cr  | 25<br>Mn  | 26<br>Fe  | 27<br>Co  | 28<br>Ni  | 29<br>Cu  | 30<br>Zn  | 31<br>Ga  | 32<br>Ge  | 33<br>As  | 34<br>Se  | 35<br>Br  | 36<br>Kr  |
| 37<br>Rb | 38<br>Sr | 39<br>Y   | 40<br>Zr  | 41<br>Nb  | 42<br>Mo  | 43<br>Tc  | 44<br>Ru  | 45<br>Rh  | 46<br>Pd  | 47<br>Ag  | 48<br>Cd  | 49<br>In  | 50<br>Sn  | 51<br>Sb  | 52<br>Te  | 53<br>I   | 54<br>Xe  |
| 55<br>Cs | 56<br>Ba | 71<br>Lu  | 72<br>Hf  | 73<br>Ta  | 74<br>W   | 75<br>Re  | 76<br>Os  | 77<br>Ir  | 78<br>Pt  | 79<br>Au  | 80<br>Hg  | 81<br>Tl  | 82<br>Pb  | 83<br>Bi  | 84<br>Po  | 85<br>At  | 86<br>Rn  |
| 87<br>Fr | 88<br>Ra | 103<br>Lr | 104<br>Rf | 105<br>Db | 106<br>Sg | 107<br>Bh | 108<br>Hs | 109<br>Mt | 110<br>Ds | 111<br>Rg | 112<br>Cn | 113<br>Nh | 114<br>Fl | 115<br>Mc | 116<br>Lv | 117<br>Ts | 118<br>Og |
|          |          | 57<br>La  | 58<br>Ce  | 59<br>Pr  | 60<br>Nd  | 61<br>Pm  | 62<br>Sm  | 63<br>Eu  | 64<br>Gd  | 65<br>Tb  | 66<br>Dy  | 67<br>Ho  | 68<br>Er  | 69<br>Tm  | 70<br>Yb  |           |           |
|          |          | 89<br>Ac  | 90<br>Th  | 91<br>Pa  | 92<br>U   | 93<br>Np  | 94<br>Pu  | 95<br>Am  | 96<br>Cm  | 97<br>Bk  | 98<br>Cf  | 99<br>Es  | 100<br>Fm | 101<br>Md | 102<br>No |           |           |



**Feb 1994**

What does this all mean?

All elements beyond the most basic are produced by stars

Elements heavier than iron will be generated in supernova explosions

Some of the gold or silver you have with you today  
possibly originated from the explosion of a massive star

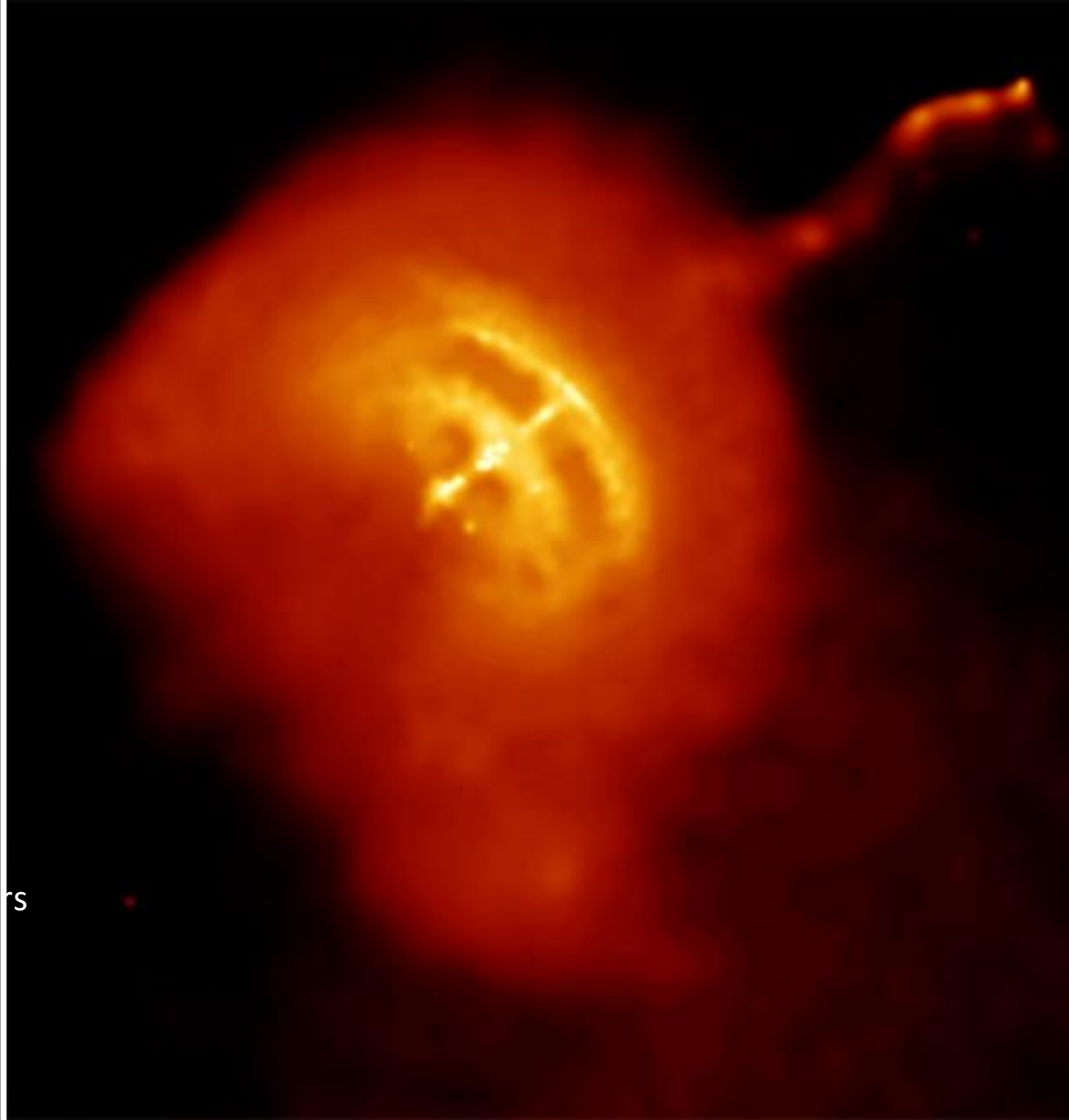
Almost all the elements that make up YOU are from an extinct star

## Vela Pulsar

Distance 1,000 light years

Age 11,000 years

Chandra X-Ray Observatory





## **M87 Black Hole**

Distance 55 million light years

Event Horizon Telescope Collaboration



## M87

Distance 55 million light years

FORS2 (FOcal Reducer/low dispersion Spectrograph 2) on ESO's Very Large Telescope



## Messier 110

Distance 2.7 million light years

Stars few billion

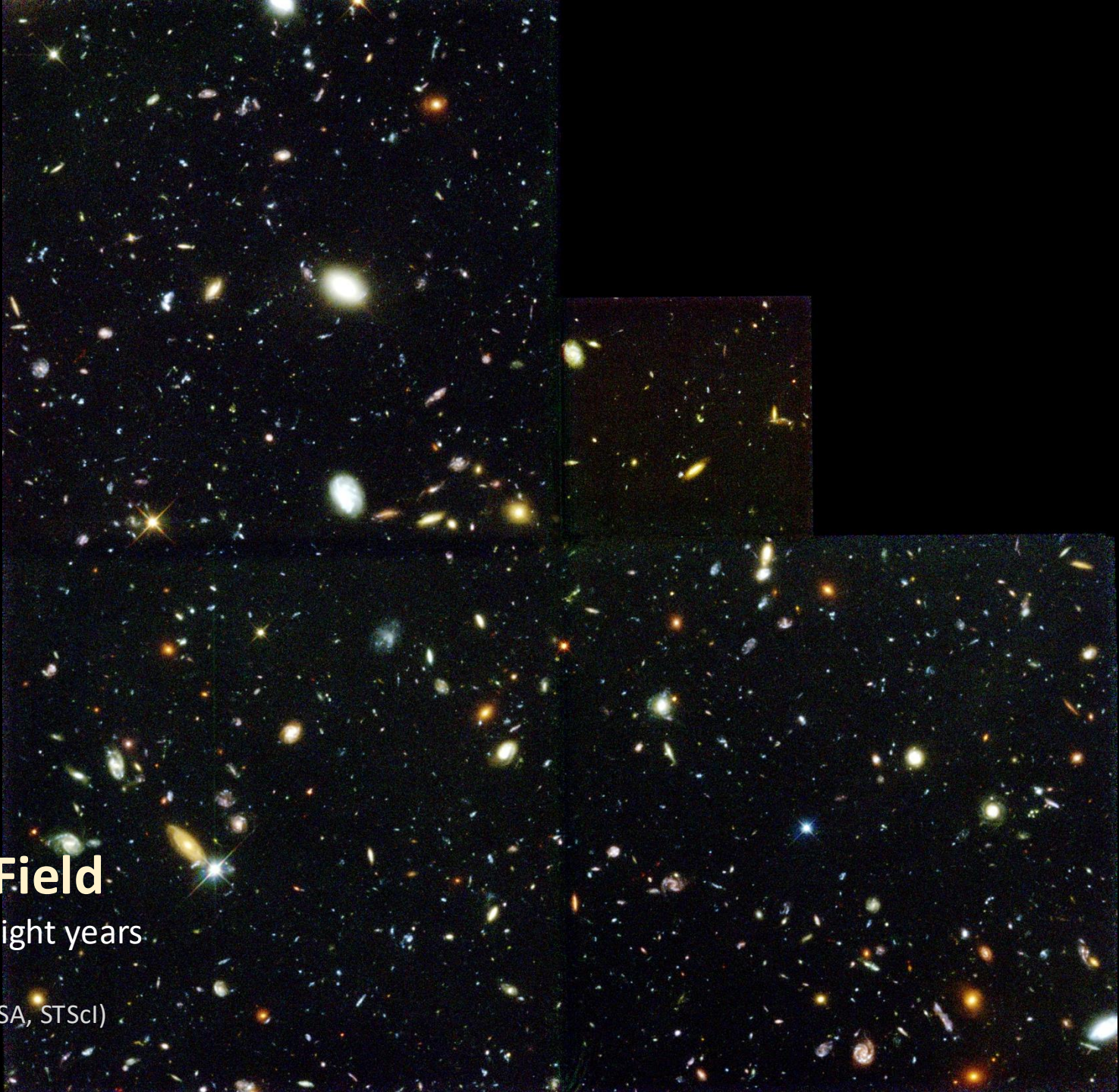
Dwarf 3 digital telescope

## Andromeda Galaxy

Distance 2.5 million light years

Stars 1 trillion

Dwarf 3 digital telescope

A mosaic of numerous small images of galaxies, showing a vast field of distant galaxies. The galaxies are of various shapes and sizes, including spiral, elliptical, and irregular forms. They are scattered across a dark background, with some appearing as bright, distinct objects and others as faint, distant points of light. The colors range from yellow and orange to blue and purple, indicating different types of galaxies and their distances.

## Hubble Deep Field

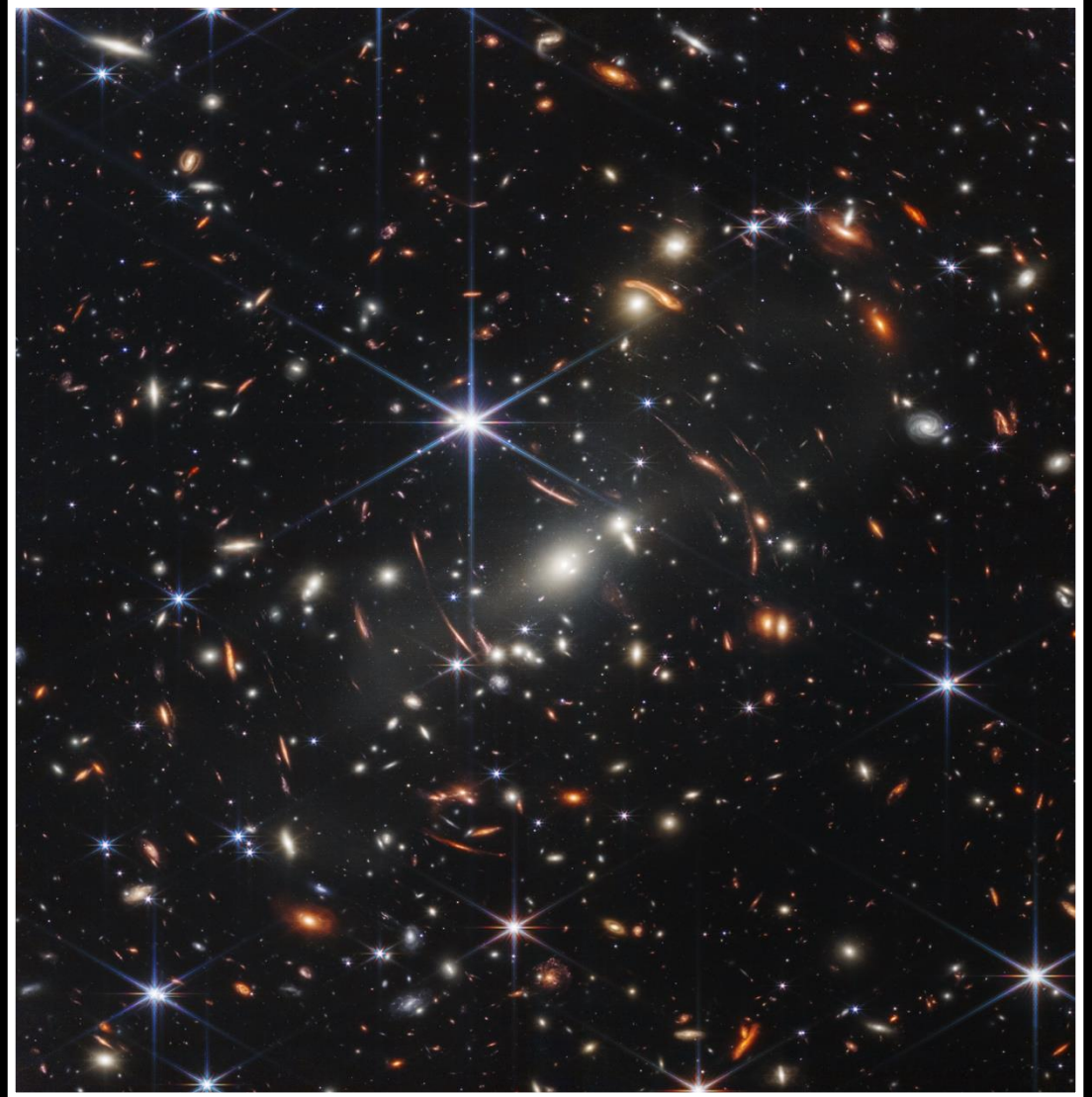
Distance 12.7 billion light years

Galaxies 3,000

By Robert Williams (NASA, ESA, STScI)



100 hours  
over 10 days  
342 exposures



12.5 hours

*Where did it all begin ...?*



# The first 3 minutes

A sea of elementary particles and energy

3 to 20 minutes

First atomic nuclei

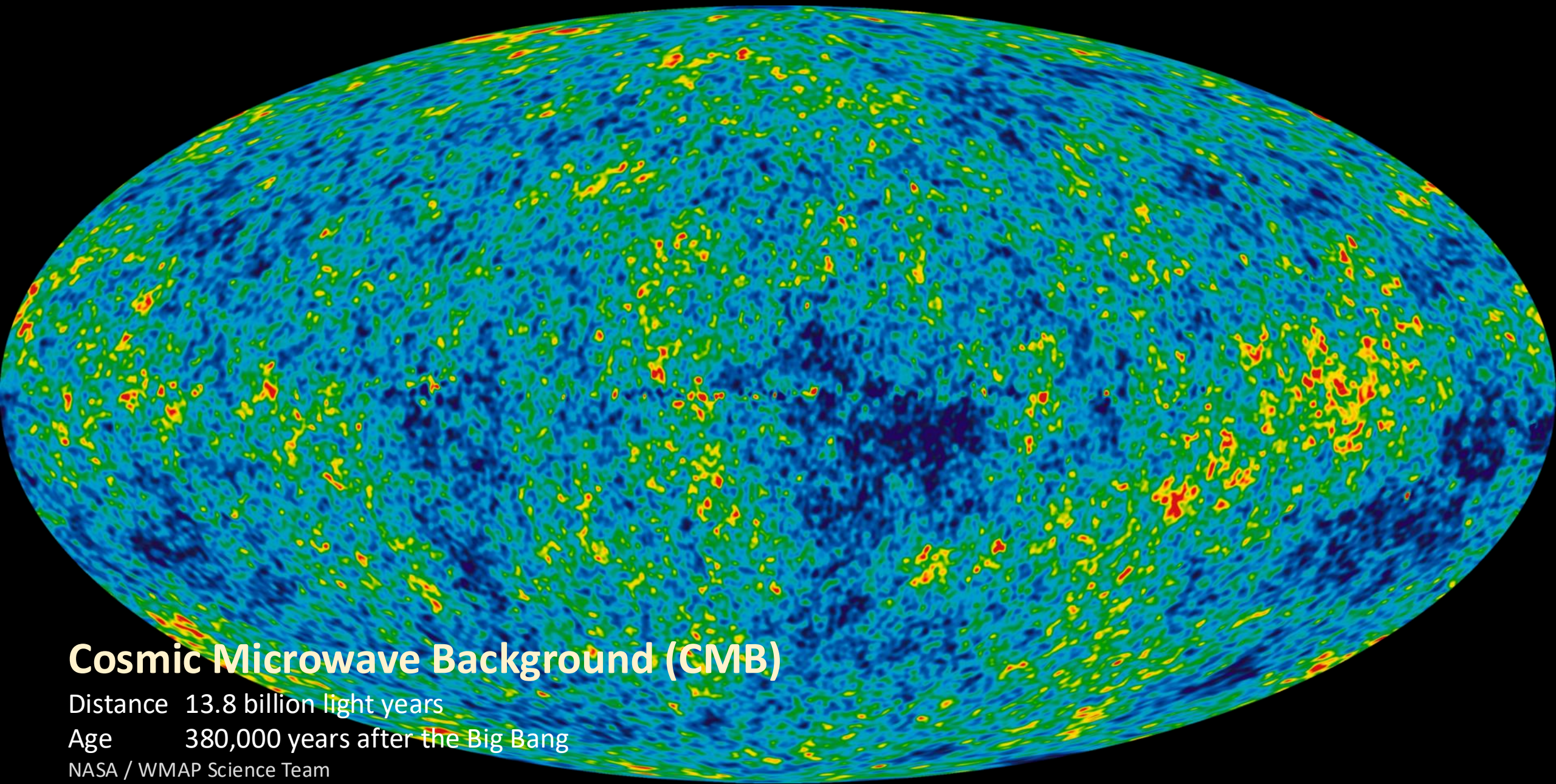
380,000 years

First atoms – space ceases to be opaque

*~ 75% Hydrogen*

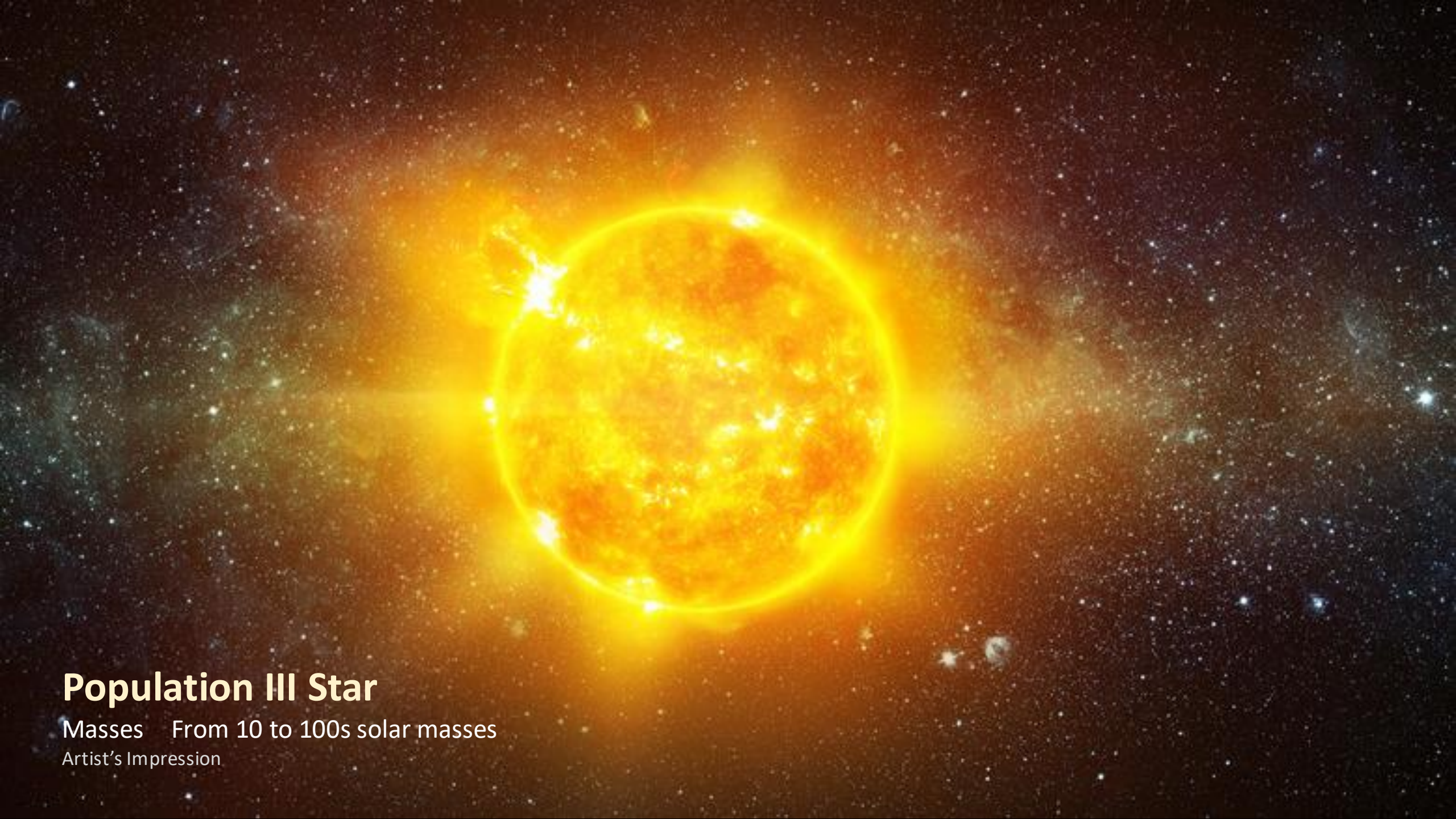
*~25% Helium*

*traces of Lithium*



# Cosmic Microwave Background (CMB)

Distance 13.8 billion light years  
Age 380,000 years after the Big Bang  
NASA / WMAP Science Team



## Population III Star

Masses From 10 to 100s solar masses

Artist's Impression



## Westerlund 2

Blue/White stars are young stars  
Pillars and globules are star forming regions  
Surrounding clouds are ionized Hydrogen  
20,000 light years away  
Hubble Space telescope (25<sup>th</sup> Anniversary image)

A detailed rendering of the James Webb Space Telescope (JWST) in space. The telescope is shown from a low angle, highlighting its large, gold-colored hexagonal primary mirror and the complex support structure. The Earth's horizon is visible in the background, with a bright blue glow from the sun. The text "Thank you" is centered over the telescope's mirror.

Thank you